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RESEARCH IN HIGH ENERGY PHYSICS

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Proposal for Research in High Energy Physics

Abstract

The high energy physics research program at the University of Hawaii is directed toward the study of the properties of the elementary particles and the application of the results of these studies to the understanding of the physical world. Experiments using high energy accelerators are aimed at searching for new particles, testing current theories, and measuring properties of the known particles. Experiments using cosmic rays address particle physics and astrophysical issues. Theoretical physics research evaluates experimental results in the context of existing theories and projects the experimental consequences of proposed new theories.

Chapter 1

Introduction

1.1 Overview

The primary purpose the research being supported by this Grant is the understanding of the properties of the elementary constituents of matter and the nature of the fundamental forces between them. The currently accepted theory for these processes, the so-called Standard Model, has been so successful that it can be applied with some confidence to fundamental cosmological questions such as the origin of the universe, and has been used to develop a detailed picture for what went on in the earliest moments of the big bang. This has led to considerable overlap in the research interests of particle and astrophysicists.

The experimental component of our group has a strong involvement in particle-astrophysics. Members of our group identified neutrinos from the SN1987a supernova in the IMB underground water Čerenkov counter. They pioneered the field of high energy neutrino astrophysics with the DUMAND proposal effort to construct a large volume Čerenkov detector on the deep ocean floor. Although the DUMAND project itself has been discontinued, there are a number of detectors inspired by the DUMAND idea in operation or in the planning stages. The theoretical research program addresses the relation of neutrino properties to results of various neutrino experiments, including observations of solar neutrinos.

Accelerator-based research, using the D0 detector at Fermilab, the AMY detector at KEK in Japan, the CLEO detector at Cornell, and the BES detector at IHEP in Beijing, China, searches for new particles, tests aspects of the Standard Model, and measures various particle properties. Theoretical research in particle spectroscopy and experimental consequences of Supersymmetry complement this experimental work.

The high energy communities in Japan and China are expanding high energy physics facilities that closely match our group's scientific interests. This, together with Hawaii's proximity to Asia, makes experiments in these countries a natural future direction for our group. We are collaborating on the Super-Kamiokande experiment in Japan and the BES experiment at IHEP in Beijing.

The long-range plan for our accelerator-based research program is to concentrate on the study of CP violation at the asymmetric $B-$factory being constructed at KEK in Japan, named KEK-B. An elucidation of the CP violation is essential for completing our understanding of the evolution of the Universe. Our group is playing a leading role in the BELLE experiment at the KEKB facility. This matches well interests of the theoretical group, which has done some of the pioneering work in the area of Standard Model CP-violations that will be tested at a B-factory, and has always had close collaborations with theory groups in Japan.

1.1.1 Background

Experimental particle physics at the University of Hawaii started in the 1960's with experiments using the Bevatron at LBL. Subsequently, the Hawaii group played a central role in the construction of the external muon identifier (EMI) for the 15-foot bubble chamber and participated in a number of the neutrino experiments that were the main focus of the early experimental program at Fermilab. This experience with neutrinos led to the DUMAND proposal. As the neutrino program at Fermilab reached its conclusion, M. Peters, M. Jones and R. Cence joined the D0 experiment, which was then preparing to run at the Fermilab collider. The Hawaii D0 involvement has been concentrated on the measurement of the $t-$quark mass and studies of $b-$quark decays. Decay channels involving muons are a particular interest of our group.

S. Parker initiated and led the development of the silicon strip detector for the Mark-II experiment at the SLC, the first application of this technology in a colliding beam environment. The successful Mark-II device has served as the paradigm for vertex devices in numerous other experiments, including those at LEP, CDF, CLEO, and ARGUS. This effort has evolved into the development of a unique monolithic silicon pixel device that appears to have widespread applicability. The primary current focus of this research is the preparation of $\sim$ cm^2 devices for use in the E781 (Charmed Baryon) experiment at Fermilab.

In 1992, V. Peterson, the principal investigator for the group since its inception, retired and S. Olsen moved to Hawaii as his replacement. Cence retired in 1993, and T. Browder was recruited as his replacement. Browder has a strong interest in heavy quark physics and is participating in the CLEO-II experiment and helping with the planning of the BELLE $B-$factory experiment. The group currently consists of three theoretical faculty (Professors Pakvasa, Tata, and Tuan) and nine experimental faculty (Browder, Gorham, Harris, Learned, Olsen, Peters and Stenger are University supported;* Jones and Parker are supported by the Grant), four Research Associates, and twelve graduate students. In addition, the theory

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*Gorham and Learned have 11-month University appointments and receive no summer salary from the Grant.

group has an affiliate faculty member (Simmons) and has just hired a postdoctoral researcher to come on board in September. The University has assigned another faculty slot to our experimental group, to be filled in the near future.

The group has permanent laboratory facilities in Watanabe Hall and the Physical Sciences Building on the University of Hawaii Manoa Campus. An assortment of mostly University-provided computers and work-stations are networked via Ethernet, and linked to the mainland via the University's fiber-optic T1 line. The computer system is managed by a University-supported system manager. Our group is the main user of the Physics Department machine-shop, which has two full-time University-supported machinists and one engineer. The Physics Department is located near the University's School of Ocean and Earth Science and Technology (SOEST), which has electronics and mechanical engineering and shop facilities that are available for our use on a costed basis. We were frequently given use of SOEST's research vessel, the RV Moana Wave, for preliminary tests of DUMAND concepts and surveys of the site. In addition, we have many formal and informal contacts with the astronomers and astrophysicists at the University's Institute for Astronomy.

1.1.2 Recent Accomplishments

A recent highlight was the discovery of the top quark announced by the CDF and D0 groups in March. The HEPG-D0 group had an important impact on this discovery: the D0 t-quark event sample was selected using criteria devised using a technique developed by Hawaii student Yoshikawa, and relied heavily on the excellent calibration of the muon system, which was Cummings' responsibility. Jones was asked by the D0 collaboration to present results of the top-quark mass determination in an invited talk at the Spring APS meeting in Indianapolis.

Other activities of HEPG members in the past year include:

CLEO: Browder's study inclusive of η' and K_s production in B decays appears to be a promising method for detecting $\mathcal{B}(B \rightarrow s \text{ gluon})$, an important channel for searching for physics beyond the Standard Model. Rodriguez has done a systematic study of hadronic B-meson decays, including a measurement of the relative strength of color suppressed contributions. These results are reported in CLEO papers submitted to the Warsaw conference and DPF Minneapolis meeting.

BES: The HEPG-BES group has completed the laser/fiber-optic calibration system for the BES-upgrade time-of-flight system and the front-end electronics for the new vertex chamber. Both systems work reliably and with the desired performance level. Results from Hawaii analyses of $\psi' \rightarrow$ baryon pairs, $\psi' \rightarrow$

Axialvector Pseudoscalar mesons, and $\psi' \to \pi^+\pi^- J/\psi$ will be reported at Warsaw and Minneapolis.

BELLE: We have started building the time-of-flight scintillation counters for the BELLE detector. Beam tests of the first module demonstrated a tof resolution of better than 80 picoseconds—a new state-of-the art for counters of this size. We have designed and prototyped novel front-end electronics for the tof counters.

AMY: Although the AMY experiment ceased data taking in 1994, analysis of data continues. During the past year new limits on the SUSY selectron mass, the asymmetry in $b\bar{b}$ production and the cross-section for two-photon charm production have been published.

Pixel R& D: The production of the E781 pixels is now complete and they are being implemented into the experiment. A new idea for "3-D" pixel detectors is being investigated. This latter holds promise for coping with the severe radiation environment expected for the inner-most LHC detector components.

DUMAND: Support for the DUMAND experiment was terminated during the past year. We have started closing down DUMAND activities at Hawaii.

Superkamiokande: The SuperKamiokande experiment has been in operation since April 1996 and data analysis at Hawaii has started. The Hawaii-provided pulsed-laser calibration system for the outer detector is operating well. Matsuno is a co-convener of the Superkamiokande muon analysis group, and Flanagan is measuring the high energy ν_μ flux for his Ph.D. thesis.

Theory: Search strategies for SUSY particles developed by Tata and collaborators are now routinely used by CDF and D0; their SUSY-ISAJET simulation package is also in general use. Experiments suggested by Pakvasa and collaborators to search for CP violating effects in hyperon decays are about to be performed at Fermilab. CTF, a mini-Borexino, has started taking data in the Gran Sasso and found impurity levels acceptably low.

1.1.3 Personnel Changes

During the past year, we recruited S. Sahu from KEK to replace M. Cummings, who will leave HEPG in November. D0 students J. Balderston and C. Yoshikawa graduated: Balderston is now with Hughes Aerospace and Yoshikawa is with Lucent Software. The Theory Group has recruited Dr. Tonnis ter Veldhuis from Vanderbilt University to fill the newly established postdoc position.

Chapter 2

Accelerator-Based Experiments

2.1 The BELLE Experiment

Drs. T. Browder, F. Harris, M. Jones, S. Olsen, M. Peters, J. Rodriguez, S. Sahu, and Messers G. Varner and Y. Zheng

The Hawaii group is participating in the BELLE experiment at KEKB, the asymmetric e^+e^- $B-$factory being constructed at KEK in the TRISTAN tunnel. The purpose of BELLE is to search for CP violations in the decays of $B-$mesons predicted by the Kobayashi Maskawa model [1]. Harris and Peters have been concentrating on software-related issues; Olsen, Rodriguez, Varner and Zheng have been working together with a KEK group on construction of a time-of-flight system. Browder and Sahu are studying backgrounds at the machine detector interface for KEKB with the goal of developing plans for including a layer of monolithic pixel detectors in an upgrade to the BELLE vertex detection system. This is an extension of Browder's previous work on detector backgrounds and masking schemes for the CESR upgrade.

2.1.1 Physics Motivation

If the KM model is a correct description of nature, there should be sizable CP-violating effects in several B-meson decay channels. The magnitude of observable effects can be estimated from experimentally established constraints on the KM matrix elements. The largest observable effects are expected to show up in differences of the decay rates between B^0 and $\bar{B}^0$ mesons decaying to the same CP eigenstate. In these "CP asymmetries," theoretical ambiguities arising from strong interaction effects tend to cancel, thus allowing the clean extraction of the relevant KM matrix elements from the measured quantity. The KM model provides definitive predictions for three CP angles, ϕ_1, ϕ_2, ϕ_3, which can be extracted from measurements of different CP asymmetries in the decays of B-mesons: ϕ_1 from $B \to J/\psi K^0$; ϕ_2 from $B \to \pi^+\pi^-$; and ϕ_3 from $B \to D^0 K$ (for example).

Most of our present knowledge about B-meson decays comes from measurements from e^+e^- colliders operating at the $\Upsilon(4S)$ resonance [2], which has the nice characteristic of decaying into $B\bar{B}$ pairs with no other accompanying particles. This resonance has a 1.2 *nb* cross section above a 3.7 *nb* continuum level and, thus, an excellent signal-to-background ratio. However, measurements of the CP angles using $B^0\bar{B}^0$ pairs from $\Upsilon(4S)$ decays must be derived from comparisons of the time evolution of the B^0 and $\bar{B}^0$ decays, rather than from time-integrated asymmetries. Oddone suggested that these studies could be done at an asymmetric e^+e^- collider operating at the center-of-mass energy of the $\Upsilon(4S)$ [3]. This is the motivation for the two-ring asymmetric character of KEKB, where collisions of 8 GeV electrons and 3.5 GeV positrons produce B mesons that travel an average 150 μm before decaying. By using a small-radius beam pipe surrounded by high resolution position-measuring devices in a carefully designed interaction region, the time pattern of B-meson decays can be measured.

In two body modes such as $B^- \to K^{(*)-}\pi^0$, $B^- \to K^{(*)-}\rho^0$, or $B^- \to K^{(*)-}a_1$, there are contributions from $b \to s\ g$ and Cabibbo suppressed $b \to u$ amplitudes which interfere and have a relative phase. If one can isolate inclusive signals in channels such as $B \to K^{(*)-}X$, where the sign of the energetic $K^{(*)-}$ meson tags the flavor of the parent B meson, it is possible to search for direct CP violation in addition to measuring the size of the gluonic penguin amplitude.

The experimental feasibility of this approach is being examined with CLEO II data and is discussed in detail in the CLEO section of the report. We are using Monte Carlo simulations of the BELLE detector to evaluate the feasibility of this approach at the KEKB. By boosting to the $\Upsilon(4S)$ center of mass frame, we recover the quasi-monochromatic peak which is characteristic of two body decays. To reduce continuum background, vertexing and high momentum particle identification will be required. The theoretical feasibility and associated issues are being investigated by Browder and Pakvasa in collaboration with A. Datta and X-G. He.

2.1.2 The BELLE Detector

An overview of the BELLE detector is shown in Fig. 2.1 In designing BELLE, CP violating decay modes that are sensitive to the three CP violating angles in the KM formalism are considered. The implications for the detector design are summarized as follows:

Vertex detection. An adequate proper-time resolution in the rest frame of the decaying B-mesons for measuring CP-violating asymmetries translates into a minimum vertex resolution requirement of $\sim 80\mu$m. Initially, this will be accomplished with a silicon μ-strip detectors. Later, we expect to upgrade this with the addition of an inner layer comprised of monolithic pixels at a smaller beampipe radius.

Momentum resolution. Good momentum resolution is needed to identify specific B meson decay modes and separate them from background. For example, in order to reduce the contamination of the $B \longrightarrow \pi^+\pi^-$ event sample from misidentified $B \longrightarrow K^+\pi^-$ decays to the 10% level using kinematical considerations alone, a momentum resolution of $\delta p/p \simeq 0.3\%$ is needed. This will be accomplished with a 52-layer drift-chamber tracking system of radius $r = 100$cm in a magnetic field of $B = 1.5$T using a helium-dominated gas.

Particle identification. Clean K/π separation is needed to isolate various B meson decay modes and is also essential to flavor-tag B-mesons using identified $K^{\pm}$ tracks. Identification of lower momentum particles will be accomplished with a sub-100 ps resolution scintillation counter time-of-flight system and 6% dE/dx measurements in the central drift chamber. This will be supplemented with an aerogel Čerenkov counter system for high momentum K/π separation.

Photon detection. A primary goal for photon detection is the efficient reconstruction of π^0's for the reconstruction of B mesons. This will be provided by a 9000 element CsI crystal calorimeter with resolution of $\sigma_E/E \simeq 2\%$ at $E = 1$ GeV.

Lepton identification. The clean identification of electrons and muons is essential both for b-flavor tagging and for detecting decays into CP-eigenstates that contain J/ψ's. Electrons will be identified by dE/dx, E/p, and by the Čerenkov counter system. Muons will be identified by their penetration through the instrumented material of the magnet's iron return yoke, which also serves as a K_L catcher in order to identify the decay $B \longrightarrow J/\psi K_L$. This CP-eigenstate decay mode, which is expected to have a CP-violating asymmetry that is opposite to that of the commonly discussed $B \longrightarrow J/\psi K_S$ decay, could provide a valuable confirmation of an observation of a CP violation.

Data acquisition and trigger. The high event rate for real physics events (~100 Hz) and the high frequency of beam crossings (500 MHz) requires the use of signal pipelining for all detector elements. All of the detector subsystems of BELLE, with the exception of the silicon vertex detector, will use a novel readout scheme based on multihit time-to-digital converters.

Data handling software. The high event rate for real physics events and the large amount of information associated with each event will require advancements in the capabilities of on- and off-line analysis systems.

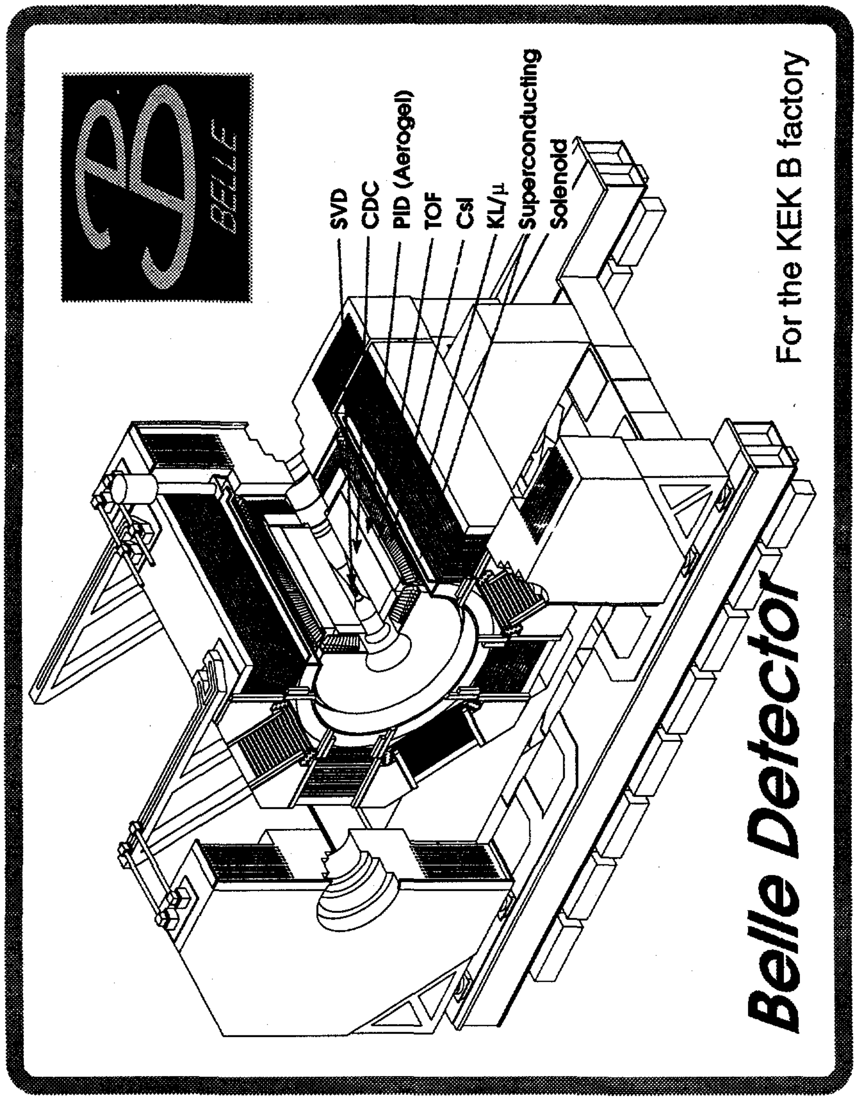


Figure 2.1: A cutaway isometric view of the BELLE detector.

2.1.3 Hawaii Participation in BELLE

Time of Flight

Our work on the BES and CLEO time-of-flight (TOF) systems naturally led us to participate in the development of this system for the BELLE detector. In BELLE, the TOF system will also provide a fast timing pulse for the first-level trigger system.

Time-of-flight using plastic scintillation counters is a very powerful method for particle identification in e^+e^- collider detectors. In BELLE there is a 1.2 m flight path, and we are assembling a system of counters with sub-100 ps time resolution that will give $\sim 4\sigma$ K/π separation effective for particle momenta below about 1.1 GeV/c, which covers most of the particles produced from $\Upsilon(4S)$ decays. This TOF system will identify 90% of the charged Ks from B meson decays that are incident on it, providing clean and efficient B-flavor tagging.

In addition to particle identification, thin trigger scintillation counters (TSC) in coincidence the the TOF counters will provide fast signals to the online farm for the trigger decision, gate signals for the ADCs, and stop signals for the TDCs. This additional level of coincidence will insure that the rate of fast trigger signals will be kept below 70 kHz, which is the level needed to avoid pileup.

TOF and TSC configuration To achieve the 100 ps design goal, the following design strategies are adopted:

(1) use of fast timing scintillator with an attenuation length longer than 2 m;

(2) elimination of light guides to minimize the time dispersion of scintillation photons propagating in the counter; and

(3) use of phototubes with large-area photocathodes that cover a large portion of the counter end to maximize photon collection.

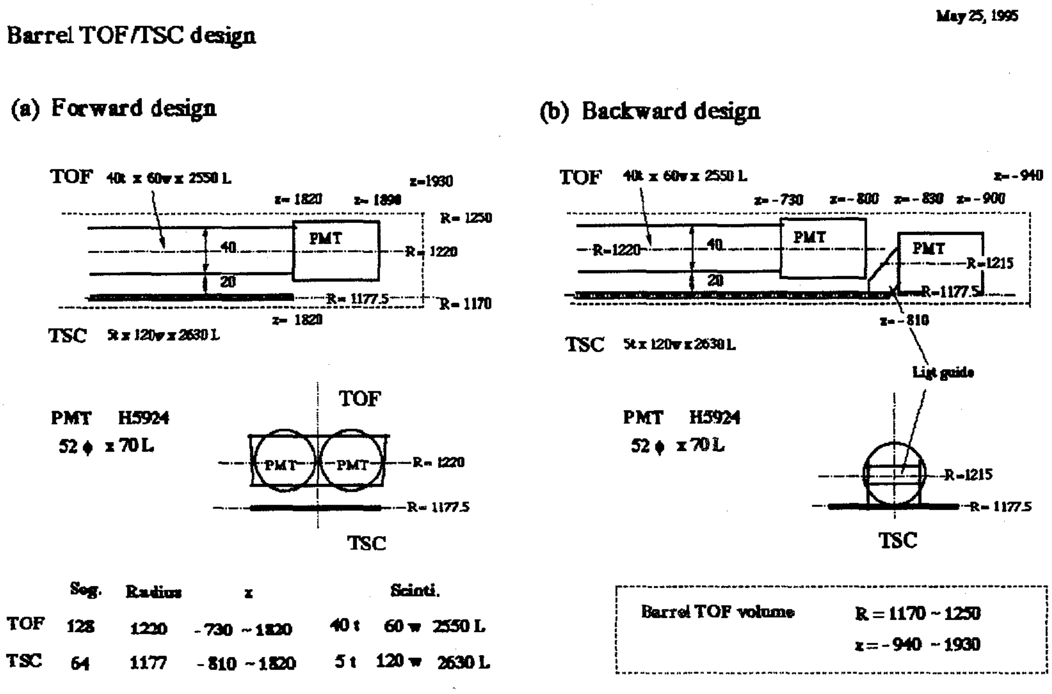
These considerations led us to a configuration with a 24-stage fine-mesh-dynode photomultiplier tubes (FM-PMT) mounted directly to the TOF and TSC scintillation counters and situated in the 1.5 Tesla field.

Table 2.1 describes the TOF counter configuration. The barrel TOF consists of 128 plastic scintillation counters forming a cylindrical structure located at a radius of 120cm. Each barrel TOF scintillator is 4 cm thick, 6 cm wide and 2.6 m long with phototubes mounted directly on each end. The barrel TSC consists of 64, 5 mm thick scintillators, which are attached to the front surfaces of adjacent pairs

Table 2.1: Configuration of the Barrel TOF counters.

TOF Counter	thickness cm	Z cm	R cm	Polar angle	Seg.	PMT
Barrel TOF	4	-120∼180	120∼124.0	36°-130°	128	2
Barrel TSC	0.5	-120∼180	117.5∼118.0	36°-130°	64	1

of TOF counters. Figure 2.2 shows the individual barrel-TOF and TSC counter designs. A Monte Carlo study with full detector simulation including the effects of the material of the aerogel Čerenkov counters and back-splash from the CsI calorimeter indicates that the single hit probability is about 90% for particles from $B\bar{B}$ events in the solid angle of the barrel TOF array.



	Seg.	Radius	z	Scinti.		
TOF	128	1220	-730 ~ 1820	40 t	60 w	2550 L
TSC	64	1177	-810 ~ 1820	5 t	120 w	2630 L

Barrel TOF volume R = 1170 ~ 1250
z = -940 ~ 1930

Figure 2.2: The TOF/TSC module design. Each module consists of one TSC and two TOF counters. The TOF counters are readout by PMTs at each end, the TSC is readout by a single PMT. A total of 64 such modules comprise the barrel TOF/TSC system.

Scintillator assembly and testing. The Hawaii group is currently involved in the assembly, quality control assessment, and testing of the BELLE TOF and trigger TSC counters. The assembly phase consists of wrapping each TOF and TSC counter with a 0.045 mm thick PVF film (Tedlar), to isolate each counter and shield it from extraneous light. After each counter is wrapped, careful measurements are made of its physical dimensions to insure that each counter falls within the allowed design tolerances. These measurements will be part of the general detector database used to establish the TOF system geometry for the Monte Carlo simulator and event reconstruction algorithms.

Because of the large number of measurements, approximately 4000, and the desire to reduce the possibility of operator errors in transcribing the measurements we employ a computerized method of data recording. The computerized system is based on digital measuring instruments, a digital caliper and a digital protractor, connected through serial lines to a personal computer. A BASIC program interprets the signals from the measuring devices and writes them to disk.

To evaluate the measurements we have set up a database using a commercial database management system also running on a personal computer. On three pieces of scintillator the measuring process has been repeated a number of times to provide estimates of the measurement uncertainties. We find that the angle of the sloped side of the scintillator is typically measured to better than 0.02 degree, well within the 0.5 degree tolerance in the specification. The distance between the cast surfaces, specified to a tolerance of 0.75 mm, is measured with an accuracy of .08 mm and the larger of the two distances between diamond milled surfaces is measured to within 0.02 mm compared with a tolerance of 0.2 mm. We conclude that our measuring process is sufficiently accurate to verify compliance with the design tolerances.

We have completed measurements on 125 pieces of scintillator. To give an overview of the differences between pieces we have computed the RMS deviations of the measured dimensions of the separate pieces. The results are summarized in Table 2.2.

We find that the scintillator pieces are, on average, very close to the specification, but that there are piece-to-piece variations. Some individual pieces appear to be outside the specification, but using our measurements we should be able to match scintillators to give a good fit to the design dimensions of the TOF system.

In addition to the assembly and measurements described above the UH group is responsible for testing the light collection and timing resolution performance of each individual scintillator. To perform these tests we have constructed a cosmic-ray test bed which will provide us with a suitable beam of particles to measure the performance of the counters. The test bed consists of two arrays of 16 drift-tubes, each arranged so that particle tracks can be reconstructed as cosmic ray events

Table 2.2: Results of BELLE scintillator measurements. The quantities measured are the length of the scintillator (L), the angle of the sloped side (A), the distance between milled surfaces (H) and the distance between cast surfaces (W). The measured lengths are corrected for the thickness of two layers of Tedlar wrapping (0.09 mm).

	L (mm)	A (deg)	H (mm)	W (mm)
Tolerance	.75	.5	.2	.75
Measurement Error	.018	.026	.020	.082
Scint RMS	.434	.159	.128	.240
Specification	2550	2.8	59.8	40.0
Measured (mean)	2550.4	2.68	59.92	39.95

traverse the detector. To trigger on the cosmic-ray events we employ two of the prototype BES scintillators used last year for laser calibration tests. The drift chamber system cosmic test stand we have designed should provide us with 3 mm resolution along the axis of the detector and better than .5 mm perpendicular to the axis. In addition, the design will allow the recording of data along the complete length of the TOF counter simultaneously.

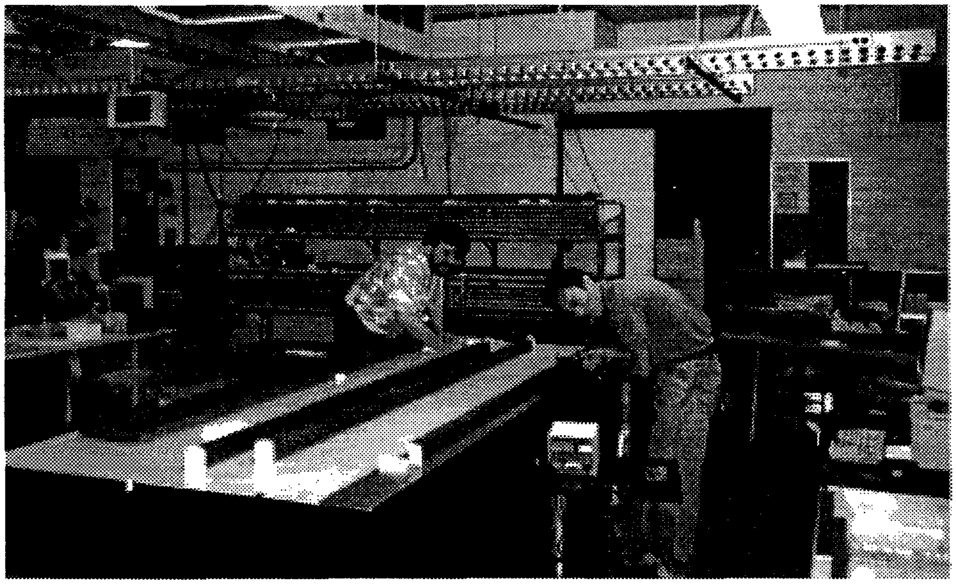


Figure 2.3: J. Rodriguez and Y. Zheng measuring a TOF scintillation counter. The cosmic-ray test station can be seen in the background.

Laser monitor The timing and gain of the individual phototubes as well as long-term aging effects of the scintillators will be monitored by a pulsed-laser calibration system similar to the one we prepared for the BES experiment. This will be essential for minimizing systematical errors, for monitoring the performance of each counter module, and debugging the entire system, especially at the time of installation.

Our plan is to build a dye-laser-based system that is functionally similar to the one successfully implemented in BES except with the additional facility of a remotely controlled variable attenuator. This will allow us to automatically monitor of the trigger threshold levels, a subject that is not of much concern in BES, but an important part of the BELLE trigger logic.

Beam tests of TOF counters The first production versions of the TOF counters were tested in a 2 GeV/c pion beam. Figure 2.4 shows the time resolution as a function of the beam position along the counter. Here time walk corrections have been applied at each beam position independently and the time jitter of the start counter (35 ps) is subtracted quadratically. Time resolutions of between 70 and 80 ps are obtained. Figure 2.5 shows the π^+/p separation over a 1.4 m flight path in a 2 GeV/c unseparated beam. The π^+ and proton peaks are separated by about 6 σ, corresponding to what could be expected for 1 GeV/c π/K separation.

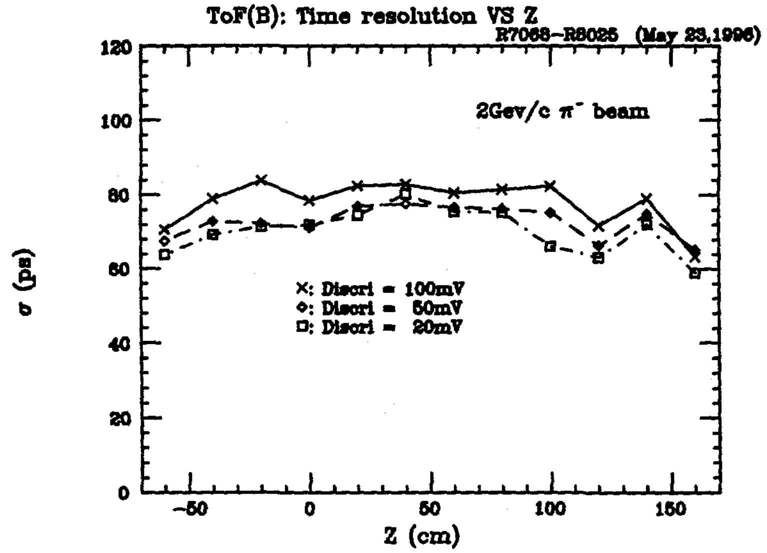


Figure 2.4: Beam test results for time resolution *vs* beam position.

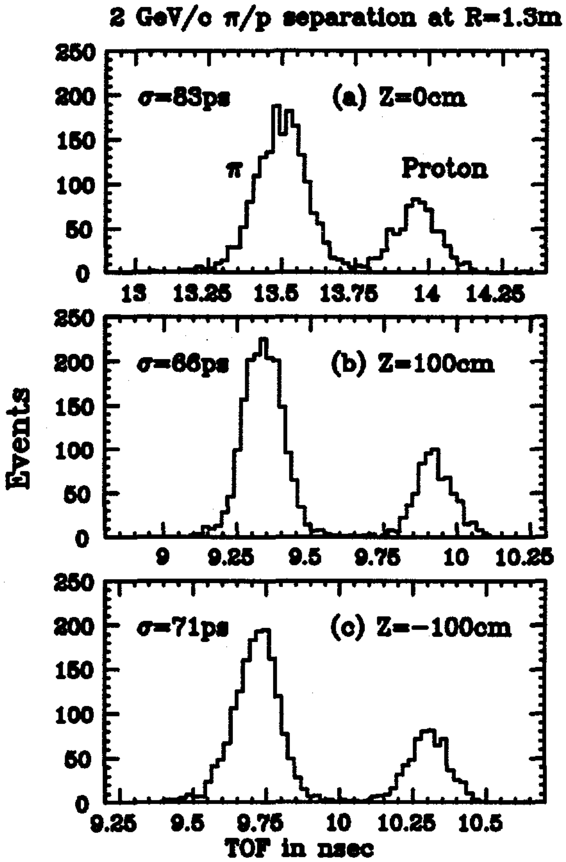


Figure 2.5: The tof distribution for a 2 GeV/c π^+ and proton beam over a 1.4 m flight path for different positions on the counter. The π^+/p separation seen here is equivalent to what could be expected for 1.0 GeV/c π^+/K^+ separation in BELLE.

Fine-mesh PMTs exhibit a substantial loss of gain when operating in a high magnetic field. In order to compensate, the PMT high voltage is raised to keep the output signal nearly constant (about 800 ADC counts x 0.25 pC) as the field strength increased. For the commercially available 19-stage PMT this corresponds to increasing the operating voltage from about 1.5 kV to nearly 3.5 kV, beyond the safe margin of operation of the tube. We have worked with Hamamatsu to develop a 24-stage FM phototube with improved photon collection and reduced material thickness. This tube, which has a wider photocathode diameter (43.5 mm ϕ) and a shorter length (6 cm), requires an operating voltage in a 1.5 T field of about 2.6 kV, which is in the region of safe operation of the tube.

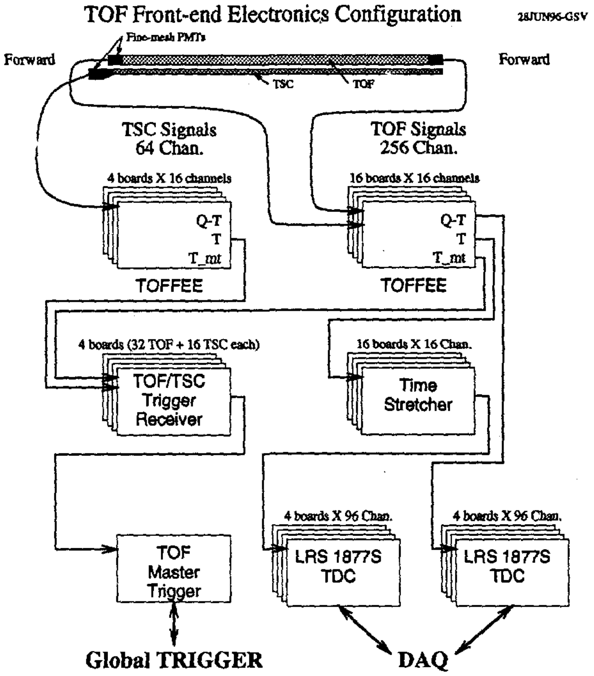


Figure 2.6: Schematic diagram for the TSC and TOF readouts

Readout electronics and related items Figure 2.6 shows schematic diagrams for (a) TSC fast trigger and (b) TOF readout. Here we briefly describe each component:

TOFFEE The TOF TSC signals are input into custom-made TOFFEE (TOF Front End Electronics) modules that provide information in a format suitable for readout in multihit TDCs. Each TOFFEE channel encodes three pieces of information:

- **Time.** A high threshold crossing is used to qualify a low threshold discriminator signal that is input to a "time stretching module." The output of this module is a digital pulse whose start time *and* width stores the information associated with the low-threshold crossing time.
- **Amplitude.** The TOFFEE module encodes the integrated charge of each PMT pulse to a digital signal with width proportional to the charge. This Q-to-T method is the standard technique used in BELLE for digitizing analog signals.
- **Mean Time.** The mean time of the two PMT pulses for each struck tof counter is determined and output to the BELLE trigger system, which uses the information to determine the correct beam-crossing time, and the TOF/TSC trigger receiver module.

Time Stretcher. The time stretcher module, jointly developed by LeCroy Research System and BELLE, creates an output pulse whose width serves as a vernier measurement of the start time. In this way, the 500 ps least-count precision of the multi-hit TDC is improved by a factor of 20 to give an effective least count of 25 ps.

TOF/TSC Trigger Receiver. This module combines the mean-timed TOF outputs to provide "sector hit" signals for the TOF Master trigger logic.

Multihit TDC. All of the BELLE subsystems, with the exception of the silicon vertex detector, use LRS1877S Fastbus multihit TDCs as the data collection module. The multihit memory provides a convenient buffer that holds data prior to a trigger decision. The commonality among the various subsystems allows for a simplified data acquisition system.

TOF Master Trigger. This module will categorize the patterns of hit TOF/TSC modules for use in global trigger decesions. It will be a Fastbus unit based on FPFA for maximum flexibility.

The Hawaii group has the responsibility for the design, fabrication and implementation of the TOFFEE modules, the TOF/TSC Trigger receiver cards and the TOF Master Trigger units.

B-factory Computing

At a luminosity of $10^{34} cm^{-2} s{-}1$, BELLE will accumulate over 10^8 events per year, most of them interesting. Storing this much data and analyzing it in a reasonable amount of time presents a considerable challenge; the computing power required will be 20,000 VAX 780 equivalents! Fortunately, computer and magnetic storage technology continue to advance at an ever increasing rate, making the hardware part of this problem solvable at a reasonable cost. However, the software problem will also be extremely large and will also provide a considerable challenge.

Two informal BELLE computing meetings have been held in Hawaii. R. Itoh (KEK) visited for the first to discuss computing issues with the Hawaii Group. N. Katayama (Cornell) visited for the second meeting on object oriented programming. Katayama, who wrote the CABS system, which uses a scripting language on top of C++ to do analysis in CLEO, is now a leader of the BELLE computing effort. We will continue to study the use of object oriented programming for BELLE.

Another difficult topic for the future is databases. With the tremendous amount of data, a good database system will be required to keep track of all of the detector conditions and calibration constants. Rodriguez has taken over the responsibility for framework of the BELLE calibration software and will implement an database program for this task. In addition, he will be responsible for the TOF-specific part of the calibration software.

Other BELLE-related R&D topics.

Browder, Sahu and Varner are also pursuing R&D on the applications of pixel detectors for B-factory experiments.

Pixel Detectors for a B Factory Pixel detector development has advanced to the stage where these detectors may be realistically considered for use at a B factory. Their fine grain intrinsic resolution which remains constant as a function of the track angle of incidence as well as their insensitivity to beam related backgrounds will prove useful at a B factory. Browder, Sahu, and Varner, in collaboration with S. Parker, are investigating the physics gains from the use of such detectors at a B factory. Examples of physics processes where these detectors will prove useful include CP violating modes with large backgrounds, $B_s - \bar{B}_s$ mixing, and searches for $D^0 - \bar{D}^0$ mixing. The practical feasibility and constraints imposed by the B factory interaction region and detector will also be studied.

2.1.4 BELLE Equipment Budget

KEK has already purchased the scintillator for the BELLE TOF barrel. In FY 96 our group is measuring, wrapping, and testing the individual counters using a

Table 2.3: Budget Request.

	FY 96	FY 97	FY 98	FY 99
TOF Counter Assembly	15	20		
Front End Electronics	10	20	43	20
Calibration System		10	20	32
Integration Engineer	25	60	60	60
Total	50	110	123	112

cosmic ray test station in Hawaii and start assembling this in the support structure that is currently under construction in Japan. In addition we are evaluating prototypes and finalizing the design of the TOFFEE electronics. We request FY 97 funds to support the assembly and alignment of the counters in the barrel configuration, complete the electronics prototyping, and start work on the remotely controlled variable attenuator for the pulsed-laser calibration system. These funds were the subject of a multiyear request for equipment funds that was submitted to the DOE by the Hawaii, Princeton and VPI collaborators on BELLE in April 1995.

2.1.5 Detector Integration

We also request funds to support an engineer/technical physicist to be resident at KEK to oversee the integration of all of the U.S.-provided equipment into BELLE. This include Princeton and VPI-supplied components of the KLM detector. The normal KEK style is to have companies construct detector elements and then provide the integration engineering. As such, there are no KEK engineers available for this task. We propose to recruit a person to do this work at KEK this summer and suppport him/her throughout the detector assembly/commissioning via a consulting contract.

2.1.6 Budget

In Table 2.3 we provide a budget for FY 97. For context we provide the FY 96 BELLE equipment award and tentative budgets for FYs 98 and 99.

2.1.7 Publications

1. H. Kichimi et al., *The Cherenkov correlated timing detector: beam test results with quartz and acrylic bars*, Nucl. Instr. and Meth. **A371**, 91 (1996).

2. G. Varner et al., *Performance Results of the BELLE TOF System and Progress Toward 50 ps Resolution*, proceedings of the Beijing Tau-Charm Workshop (February 1996).
3. G. Varner et al., *Electronics for a High Resolution TOF System*, proceedings of the Beijing Tau-Charm Workshop (February 1996).

References

1. M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973).
2. D. Andrews *et al.* (CLEO), Phys. Rev. Lett. **45**, 219 (1980).
3. P. Oddone, *Proceedings of the UCLA Workshop: Linear Collider $B\overline{B}$ Factory Conceptual Design*, D. Stork, editor, page 243, World Scientific (1987).

2.2 The BES Experiment

Drs. F.A. Harris, S.L. Olsen, Ms. D. Paluselli, Ms. L.J. Pan, and Mr. D. Kong

The BES detector is a large solid angle multi-particle spectrometer based on a 4.5 kilogauss solenoid magnet operating at the BEPC e^+e^- storage ring in Beijing. The BEPC energy range spans the charm- and τ-pair thresholds. After an initial run at the J/ψ resonance in 1990, BEPC/BES did a scan around the τ-pair threshold, making a τ mass measurement with an order of magnitude improvement over previous work. From 1992 to 1994, BEPC operated just above $D_s\overline{D_s}$ threshold. Since 1994, BEPC has been operated almost exclusively at the ψ' resonance at $\sqrt{s}$ = 3.686 GeV. In Spring 1995, after BES had accumulated in excess of 3 million ψ' events, BEPC and BES stopped for major hardware upgrades. The upgrades are now complete and results from preliminary test runs have been encouraging.

The Hawaii group joined the BES collaboration in 1993 and since then has had an increasingly larger impact on the BES program. Our group has been focusing its physics analysis efforts on the ψ' data sample, the largest ever collected. All of the US reconstruction of the raw ψ' data was done on our computing system. For the detector upgrade, we have prepared a laser/fiber-optic calibration system for the new time-of-flight detector and are responsible for the front-end electronics for the new BES vertex detector, which was built around the old Mark III beryllium beampipe by our collaborators at Colorado State University.

2.2.1 ψ' Physics

In the quarkonium model, the ψ' is the first radial excitation of the ^3S $c\bar{c}$ bound state. As such, its properties are expected to be relatively straight-forward to understand, at least in terms of those of the J/ψ ground state. Somewhat surprisingly, these expectations do not always hold. In particular, there are two rather dramatic anomalies associated with the ψ':

1. The $\rho\pi$-puzzle. One major puzzle in hadronic ψ decays is the large discrepancy between the decay widths for $J/\psi(1s) \rightarrow \rho\pi$ and K^*K and the corresponding widths for $\psi(2s)$ decays. These modes are expected to proceed via $\psi \rightarrow ggg$, with widths that are proportional to the square of the $c\bar{c}$ wave function at the origin, which is well determined from dilepton decays. The prediction, known as *"the 15% rule,"* is

$$\frac{Br(\psi' \rightarrow X_{had})}{Br(J/\psi \rightarrow X_{had})} = \frac{Br(\psi' \rightarrow e^+e^-)}{Br(J/\psi \rightarrow e^+e^-)} = 0.147 \pm 0.023,$$

where X_{had} designates any exclusive hadronic decay channel. Experimentally, the $\psi(2s) \to \rho\pi$ and K^*K are reduced by nearly two orders of magnitude from these naive expectations.[1]

2. The ψ' anomaly. The CDF group has reported a large anomaly in the charmonium production rate in high energy $\overline{p}p$ collisions.[2] It is expected that the J/ψs are mainly decay products of χ states, which are expected to be copiously produced by gluon-gluon fusion. This channel is not expected to be available for ψ' production, and these are expected to be primarily produced via B meson decays. Experimentally, the J/ψ production rate is a factor of two or three above expectations, while that for ψ's exceeds expectations by as much as a factor of thirty.

These anomalies call into question the underlying assumption behind the theoretical predictions, namely that the ψ' is a pure $c\overline{c}$ state.

$\psi' \to B_8\overline{B_8}$

In the context of flavor $SU(3)$, a pure $c\overline{c}$ state is a flavor singlet and, in the limit of $SU(3)$ flavour symmetry, the phase-space-corrected reduced branching ratios to any baryon octet pair, $|M_i|^2$, where

$$|M_i|^2 = \frac{Br(\psi' \to B_i\overline{B_i})}{\pi p^*/\sqrt{s}}$$

(p^* is the momentum of the baryon in the ψ' rest frame), should be the same for every octet baryon, B_i. Deviations from this rule would indicate a non-$c\overline{c}$ component of the charmonium wave function. This relation has not been previously tested for the ψ', where the only relevant branching ratio that has been measured is $\psi' \to p\overline{p}$, and that with rather poor precision,[3].[4]

We plot our results for the branching fractions in Fig. 2.7, along with previous limits and results. Our measured value for the $Br(\psi' \to p\overline{p})$ is about one standard deviation higher than the previous DASP measurements, which was based on 4 events[3] and a Mark I measurement with similar statistics.[4] The results for $\Lambda\overline{\Lambda}$ and $\Xi^-\overline{\Xi^-}$ are below the PDG upper limit values. There are no previous experimental results for $\Sigma^0\overline{\Sigma^0}$.

In Fig. 2.8, we plot the reduced branching fractions derived from our measurements. The results show a trend to smaller values for the higher massses and is only marginally consistent with expectations from flavor-$SU(3)$ symmetry. Fitting the data with a simple symmetry breaking model requires an SU(3)-octet amplitude that is $\sim 22\%$ of the singlet term.

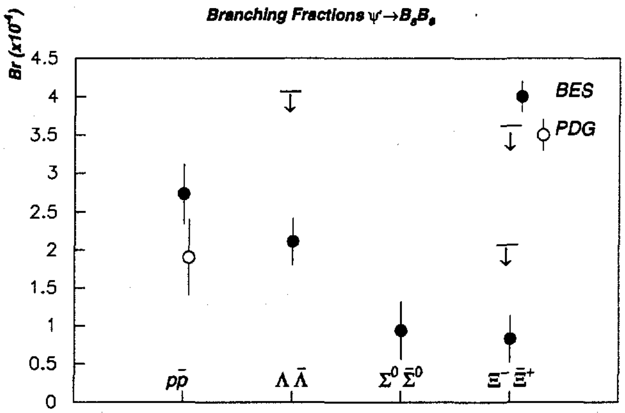


Figure 2.7: The measured branching fractions for $\psi' \to B_i\overline{B_i}$ decays, $B_i = p$, Λ, Σ^0 and Ξ^-. Previous measurements are indicated for comparison.

Our measured ψ' branching fractions agree with expectations derived from the application of the 15% rule to the PDG values for the corresponding J/ψ decays:

Decay Mode	Br	0.147×Br
$J/\psi \to p\overline{p}$	$(2.14 \pm 0.10) \times 10^{-3}$	$(3.15 \pm 0.15) \times 10^{-4}$
$\to \Lambda\overline{\Lambda}$	$(1.35 \pm 0.14) \times 10^{-3}$	$(1.98 \pm 0.21) \times 10^{-4}$
$\to \Sigma^0\overline{\Sigma}^0$	$(1.3 \pm 0.2) \times 10^{-3}$	$(1.9 \pm 0.3) \times 10^{-4}$
$\to \Xi^-\overline{\Xi}^+$	$(0.9 \pm 0.2) \times 10^{-3}$	$(1.3 \pm 0.3) \times 10^{-4}$.

$\psi' \to B_{10}\overline{B}_{10}$

We make the same comparison for ψ' to decuplet pairs: $\Delta^{++}\overline{\Delta}^{--}$, $\Sigma^+(1385)\overline{\Sigma}^-(1385)$, $\Xi^0(1530)\overline{\Xi}^0(1530)$, and $\Omega^-\overline{\Omega}^+$. There are no previous experimental results for those modes. Currently we only give upper limits for $\Xi^0\overline{\Xi}^0$ and $\Omega^-\overline{\Omega}^+$. We need more ψ' data to study these two modes. In Fig. 2.9, we plot the reduced branching fractions derived from our measurements.

Our measured ψ' branching fractions agree within errors with expectations derived from the application of the 15% rule to the PDG values for the corresponding J/ψ decays for $\Delta^{++}\overline{\Delta}^{--}$ and $\Sigma^-\overline{\Sigma}^+$. There is no PDG entry for J/ψ to $\Xi^0(1530)\overline{\Xi}^0(1530)$ and the $\Omega^-\overline{\Omega}^+$ mode is not kinematically accessible. This work has been done by Hawaii student Pan.

The preliminary branching ratio values are:

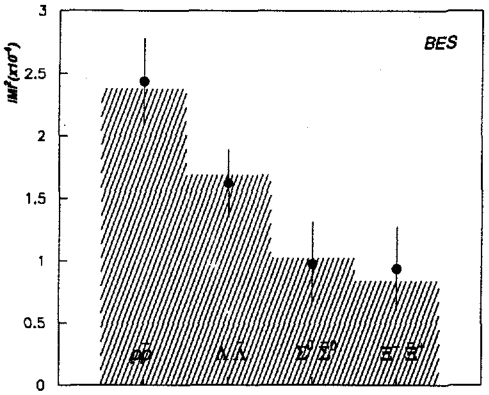


Figure 2.8: The reduced branching fractions $|M_i|^2$ for $\psi' \rightarrow B_i\overline{B_i}$ decays. The shaded bars indicate results of a fit to an SU(3)-symmetry breaking model with an SU(3)-violating octet amplitude that is ~ 22% of the SU(3)-conserving singlet term.

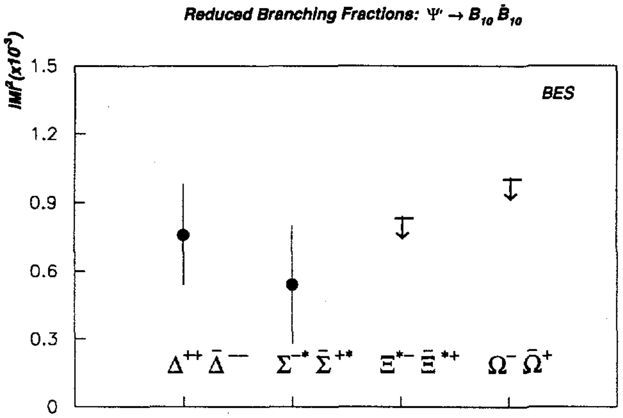


Figure 2.9: The reduced branching fractions $|M_i|^2$ for $\psi' \rightarrow B_i\overline{B_i}$ decuplet decays.

	Decay Mode	Branching fraction
$\psi' \rightarrow$	$p\bar{p}$	$(2.73 \pm 0.21 \pm 0.33) \times 10^{-4}$
$\rightarrow$	$\Lambda\bar{\Lambda}$	$(2.11 \pm 0.23 \pm 0.26) \times 10^{-4}$
$\rightarrow$	$\Sigma^0\overline{\Sigma}^0$	$(0.94 \pm 0.30 \pm 0.38) \times 10^{-4}$
$\rightarrow$	$\Xi^-\overline{\Xi}^+$	$(0.83 \pm 0.28 \pm 0.12) \times 10^{-4}$
$\rightarrow$	$\Delta^{++}\overline{\Delta}^{--}$	$(0.89 \pm 0.10 \pm 0.24) \times 10^{-4}$
$\rightarrow$	$\Sigma^-(1385)\overline{\Sigma}^+(1385)$	$(0.56 \pm 0.25 \pm 0.10) \times 10^{-4}$
$\rightarrow$	$\Xi^0(1530)\overline{\Xi}^0(1530)$	$< 0.75 \times 10^{-4}$
$\rightarrow$	$\Omega^-\overline{\Omega}^+$	$< 0.83 \times 10^{-4}$

Charmonium decays to axialvector plus pseudoscalar mesons: determination of $Br(\psi(2S) \to b_1\pi)$

There are two lowest-lying axialvector-meson octets. These correspond to the singlet ($^1P_1$) and triplet ($^3P_1$) spin states of two quarks in a p-wave orbital angular momentum state. The non-strange $I = 1$ members of the two octets have opposite G-parity: the $b_1(1235)$ is in the $^1P_1$ octet and has $G = +1$, while the $a_1(1260)$ is in the $^3P_1$ octet and has $G = -1$. The strong decays of the J/ψ and $\psi(2S)$ conserve G-parity: decays to the axialvector pseudoscalar (AP) pair $b_1\pi$ are G-parity allowed and seen in J/ψ decays; decays to $a_1\pi$ final states are G-parity forbidden and not seen in J/ψ decays.

Since the decay $b_1 \to \omega\pi$ is dominant we apply a five constraint kinematic fit to events of the type

$$\psi(2S) \to \pi^+\pi^-\pi^+\pi^-\gamma\gamma, \tag{2.1}$$

where the the invariant mass of the two $\gamma's$ is constrained to $M_{\pi 0}$.The resulting $\omega(780)\pi^\pm$ mass distribution, shown in Fig. 2.10, is well fit with a s-wave Breit Wigner function with the resonance mass and width fixed at the PDG values for the b_1, of $M_0 = 1.232$ and $\Gamma_0 = 0.155$ GeV.

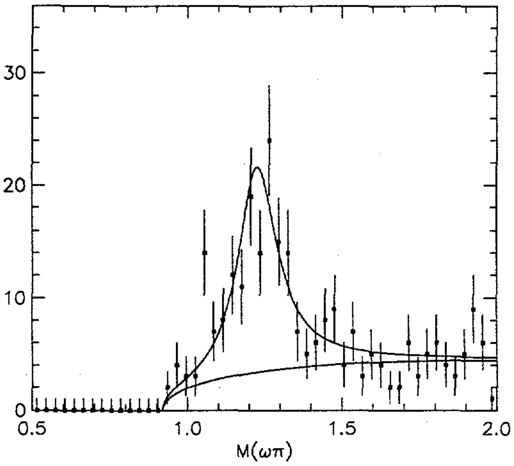


Figure 2.10: The $\omega\pi^\pm$ mass distribution showing a fit using to a b_1 resonance and a smooth background function.

Using an acceptance determined from from a Monte Carlo simulation of the experiment and the total number of $\psi(2S)$ decays in our event sample, we determine a $\psi(2S) \to b_1\pi$ branching fraction of

$$Br(\psi(2S) \to b_1^+\pi^- \ + \ cc) = (7.3 \pm 1.9) \times 10^{-4}, \tag{2.2}$$

where the error includes uncertainties associated with the shape of the background under the b_1 peak. This is $\sim 2\sigma$ above the 15% rule expectation applied to the PDG result for the J/ψ.[7]

Charmonium decays to strange axialvector plus pseudoscalar mesons:

The strange members of the two ${}^3P_1$ and ${}^1P_1$ octets, called the K_A and K_B, are mixtures of the observed physical states, the $K_1(1270)$ and the $K_1(1400)$.

$$\begin{aligned} K_A &= \cos\theta K_1(1270) + \sin\theta K_1(1400) && (2.3) \\ K_B &= \cos\theta K_1(1400) - \sin\theta K_1(1270), && (2.4) \end{aligned}$$

where the mixing angle is near $\theta = 45^0$.[5] The dominant $K_1(1270)$ decay modes are to $K\rho$ (Br = 42%) and $K_2^*(1430)\pi$ (Br=28%). The $K_1(1400)$ decays almost always to $K^*\pi$ (Br = 92%).

Flavor-SU(3) symmetry says that the amplitude for two body decays to conjugate mesons in the same pair of octets should be equal. Thus, since decays to $a_1\pi$ are forbidden by G-parity, decays to $K_A\overline{K}$ are disallowed by SU(3) and one expects relatively pure $K_B\overline{K}$ final states in J/ψ and $\psi(2S)$ decays. Since $\theta \simeq 45^0$, there should be roughly equal amounts of $K_1(1270)$ and $K_1(1400)$.

Results for $\psi(2S) \to K_1(1270)K$ and $K_1(1400)K$

For the K_1K decays, we select events of the type $\psi(2S) \to K^+K^-\pi^+\pi^-$ on the basis of the quality of a four-constraint kinematic fit. This final state includes the dominant $K_1(1270)$ and $K_1(1400)$ decay channels.

Using events with $\pi^+\pi^-$ pairs that have an invariant mass within ±150 MeV of the nominal $\rho(770)$, we find a $K^\pm\rho^0$ mass distribution with a strong enhancement near $M_{K\rho} = 1.27$ GeV, as shown in Fig. 2.11. Since the restricted phase space for the $K_1(1270) \to K\rho$ decay distorts the resonance shape for this mode, we fit the $K^\pm\rho$ mass distribution of with a specially devised function $f_{K\rho}$ that takes these effects into account.[8] This function and a smooth background provides an adequate fit the data for masses below 2.0 GeV, as can be seen in the figure.

Using events with $K^\pm\pi^\mp$ pairs that are within ±50 MeV of the $K^*(890)$, we find the $K^{*0}\pi^\pm$ mass distribution shown in Fig. 2.12. Here there is no strong evidence for a $K_1(1400)$ signal. We use this to derive a 90% CL upper limit on the $K_1(1400)$ yield.

The resulting $K_1(1270)K$ branching ratio is

$$Br(\psi(2S) \to K_1^+(1270)K^- \ + \ cc) = (7.6 \pm 1.7) \times 10^{-4}, \qquad (2.5)$$

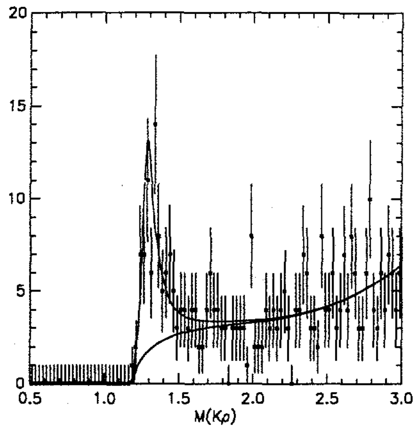


Figure 2.11: Fit to the $K^+\rho^0$ mass distribution using the function $f_{K\rho}$ for the K_1(1270 line shape and a smooth curve to parameterize the background.

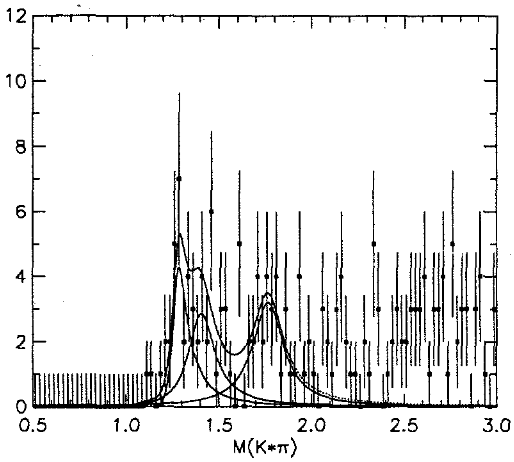


Figure 2.12: Fit to the $K^{*0}\pi^{\pm}$ mass distribution. Here we using a Breit Wigner at higher mass as a background shape in order to maximize any possible $K_1(1400)$ contribution.

where the error includes uncertainties in the shape of the background under the K_1 peak. The 90% CL upper limit for $K_1(1400)K$ mode is

$$Br(\psi(2S) \rightarrow K_1^+(1400)K^- \; + \; cc) < 2.7 \times 10^{-4} \quad 90\% \text{ CL.} \qquad (2.6)$$

Contrary to flavor-SU(3) expectation of roughly equal amounts, the $K_1(1400)K$

branching ratio is smaller than the $K_1(1270)K$ mode by at least a factor of three. To accommodate with the mixing angle, a value $\theta < 30^0$ is required.

Results for $J/\psi \to K_1(1270)K$ and $K_1(1400)K$

In the absence of any published results on J/ψ decays to these channels, we used the $\psi(2S) \to \pi^+\pi^- J/\psi$ cascade events in our $\psi(2S)$ data sample to make a first measurement of these branching ratios for $J/\psi \to K_1(1270)\overline{K}$ and $K_1(1400)\overline{K}$.

We select events that fit a five-constraint fit to the hypothesis $\psi(2S) \to \pi^+\pi^- J/\psi; J/\psi \to K + K^-\pi^+\pi^-$. hypothesis. We use the particle species assignment that gives the best χ^2 value, and reject events where the BES particle identification system unambiguously identifies as a pion a particle that the fit assigned as a kaon. We use the same $K\rho$ and $K^*\pi$ event selection criteria as are used for direct $\psi(2S)$ decays.

In contrast to the $\psi(2S)$, the $K\rho$ mass spectrum, shown in Fig. 2.13 shows little evidence for the $K_1(1270)$. We can find adequate fits to the spectrum with no $K_1(1270)$. The fit shown in the figure is used to determine a 90% CL upper limit on the number of $K_1(1270)$ events.

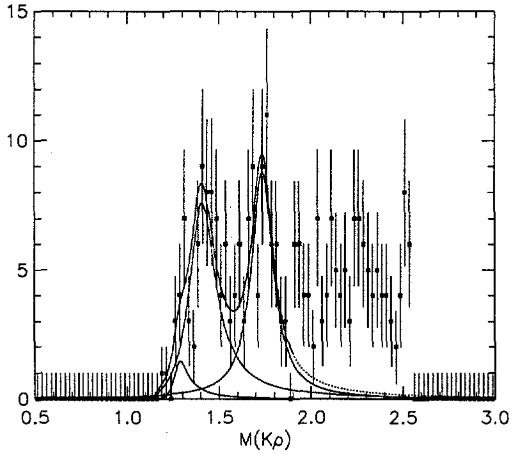


Figure 2.13: Fit to the $K^+\rho^0$ mass distribution from J/ψ decays using $f_{K\rho}$, an s-wave Breit Wigner with mass and width fixed at the PDG values for the $K_1(1400)$ and a background parameterized by a Breit Wigner resonance at higher masses.

In contrast, the $K^*\pi$ mass distribution for the J/ψ decays, shown in Fig. 2.14, exhibits a clear $K_1(1400)$ signal. We determine the number of $K_1(1400)$ events from fits to the $K^*\pi$ mass spectrum shown in Fig. 2.14.

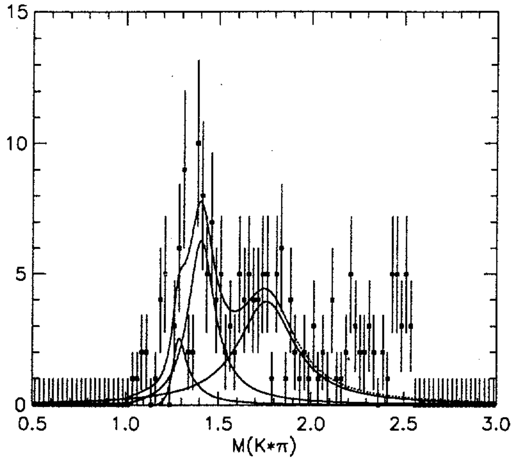


Figure 2.14: Fit to the $K^*\pi$ mass distribution from J/ψ decays using $f_{K\rho}$, an s-wave Breit Wigner with mass and width fixed at the PDG values for the $K_1(1400)$ and a background parameterized as a Breit Wigner resonance at higher masses.

We determine a 90% CL upper limit for the $J/\psi \to K_1(1270)K$ of

$$Br(J/\psi \to K_1^+(1270)K^- \ + \ cc) < 1.8 \times 10^{-3} \ \ 90\% \text{ CL}, \qquad (2.7)$$

which is more than a factor of two below the result expected from applying the 15% rule to our result for $\psi(2S)$ decays to this channel. The $J/\psi \to K_1(1400)K$ result

$$Br(J/\psi \to K_1^+(1400)K^- \ + \ cc) = (5.0 \pm 1.3) \times 10^{-3}, \qquad (2.8)$$

is well above our upper limit for the $K_1(1270)\overline{K}$ mode, indicating a flavor-SU(3) violation in J/ψ decays that is opposite to that seen in $\psi(2S)$ decays. Accommodating this effect in J/ψ decays by adjusting the mixing angle requires a value of $\theta > 60^0$, in contradiction to the $\theta < 30^0$ result from $\psi(2S)$ decays. This work is being done by Olsen and Hawaii student Paluselli.

Determining the number of ψ's in the data sample.

Branching ratio measurements require a precise knowledge of the number of ψ's in each data sample. This number is obtained from the analysis of the distribution of the mass recoiling against the π π system in the process $\psi' \to \pi\pi J/\psi$ with the $J/\psi \to$ anything, which is shown in Fig. 2.15a. As can be seen, the distribution contains signal and background; the signal shape is obtained from the process $\psi' \to \pi\pi J/\psi$, $J/\psi \to l^+l^-$, which is very clean and is shown in Fig. 2.15b.

Currently Hawaii obtains:

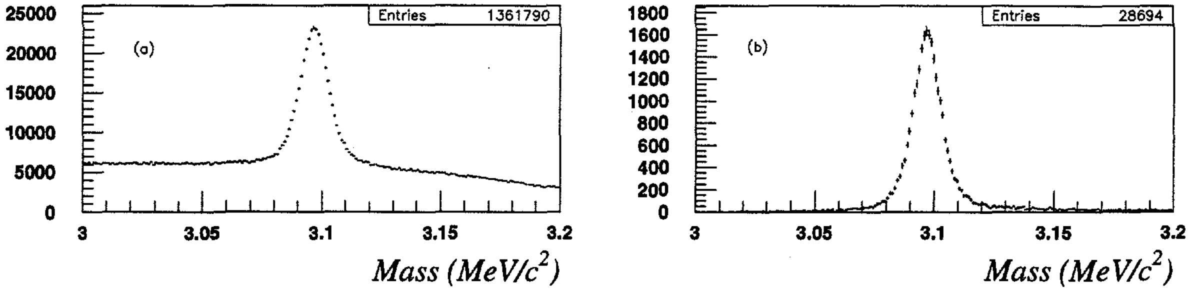


Figure 2.15: **a)** Mass recoiling against $\pi^+\pi^-$ pairs in '95 data. **b)** Mass recoiling against $\pi^+\pi^-$ pairs in $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ events in the '95 data.

$$N_{\psi'}(\text{'93 data}) = 1.26 \times 10^6$$

$$N_{\psi'}(\text{'95 data}) = 2.28 \times 10^6$$

These results agree closely but not exactly with those at IHEP so work is proceeding to understand the differences. The limiting error in this determination is the branching ratio $B(\psi' \to \pi^+\pi^- J/\psi)$, which is only known to 8%. This work is being done by Harris

Study of $\psi' \to \pi^+\pi^- J/\psi, J/\psi \to l^+l^-$.

This process can be used to determine the branching ratio $B(J/\psi \to l^+l^-)$ with high precision, as well as study details of the non-perturbative decay of the ψ'. IHEP has determined the leptonic branching ratios for the '93 ψ' data:

$$B(J/\psi \to e^+e^-) = (5.90 \pm 0.07 \pm 0.16)\%$$

$$B(J/\psi \to \mu^+\mu^-) = (5.96 \pm 0.08 \pm 0.16)\%.$$

Hawaii has analyzed both the '93 and '95 data and finds some disagreement between them. Work is proceeding with IHEP to try to understand the differences. A draft of a paper has already been prepared.

The large data sample allows a detailed study of the $\psi' \to \pi^+\pi^- J/\psi$ decay process. Data distributions are compared with Monte Carlo distributions, where the Monte Carlo program assumes:

1. The orbital angular momentum between the $\pi\pi$ system and the J/ψ and between the π's in the $\pi\pi$ system is 0.

2. The mass of the $\pi\pi$ system is weighted towards high mass.

$$\frac{d\sigma}{dm_{\pi\pi}} \propto \text{phasespace} \times (M_{\pi\pi}^2 - 4m_\pi^2)^2$$

3. The process occurs via sequential 2-body decays: $\psi' \to X + J/\psi$, $X \to \pi^+\pi^-$, and $J/\psi \to l^+l^-$.

4. X and J/ψ are uniformly distributed.

5. π's are uniformly distributed in the X rest frame.

6. Leptons have a $1 + \cos^2\theta$ distribution in the J/ψ rest frame.

The comparison between the corrrected data distributions and Monte Carlo distributions are shown in Fig. 2.16. All distributions agree well with the Monte Carlo model, except for Fig. 2.16d, where the fit is very poor, indicating a significant D-wave contribution in the decay of the dipion system. The high statistics will enable us to make detailed tests of non-perturbative models for this process. This work is being done by Harris.

2.2.2 χ_c Physics.

The large ψ' data sample allows us to make studies with unprecented precision of the properties of the χ_c states. Our first results in this area are measurements of the χ_{c0} width and two-body branching fractions for the χ_c states, including the first measurement of $Br(\chi_{c0} \to p\overline{p})$.

The total width of the χ_{c0}.

The E760 gas-jet experiment in the Fermilab $\overline{p}$ accumulator ring has reported precision measurements of the total widths and $p\overline{p}$ partial widths for χ_{c1} and χ_{c2}, but not for the χ_{c0}.[9] The PDG value of χ_{c0} decay width, $\Gamma_{\chi c0} = 13.5 \pm 3.3 \pm 4.2 MeV$, is derived from two apparently discrepant Crystal Ball results[10]: 13-21 Mev from $\psi' \to \gamma X$ study and $8.8 \pm 1.3 \pm 1.5 MeV$ from $\psi' \to \gamma\pi^0\pi^0$.

We use events of the type $\psi' \to \gamma\chi_c$; $\chi_c \to \pi^+\pi^-$ and K^+K^- to measure the width of the χ_{c0}. Figure 2.17 shows the $\pi^+\pi^-$ invariant mass spectra where clear peaks corresponding to χ_{c0} and χ_{c2} are evident. (The K^+K^- mass spectrum looks similar.) Since parity conservation forbids χ_{c1} and $\eta_c(2s)$ decays to these

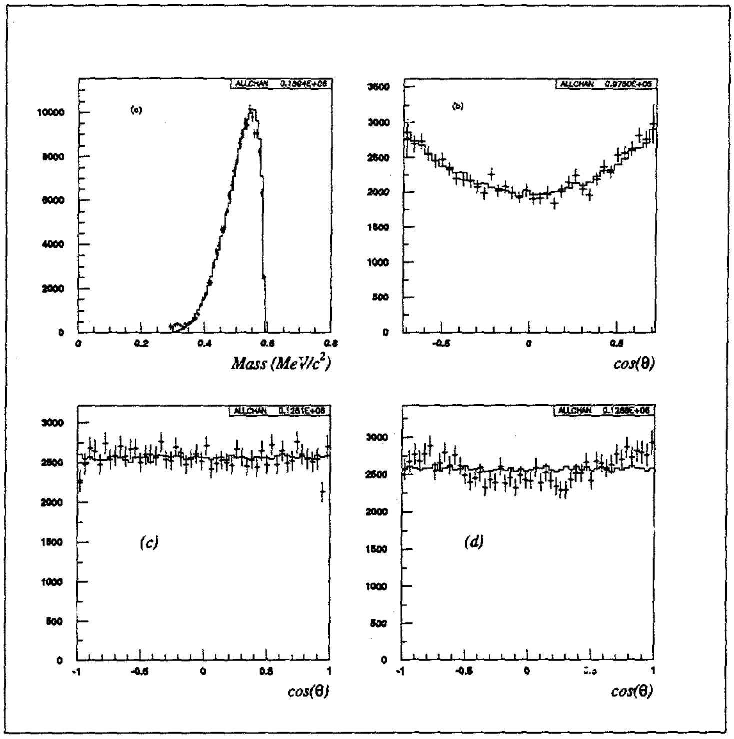


Figure 2.16: Distributions of $\psi' \rightarrow \pi^+\pi^- J/\psi, J/\psi \rightarrow l^+l^-$ events. Points with error bars correspond to data; histogram corresponds to Monte Carlo data. **a)** Invariant mass of the dipion system. **b)** Cosine of the l^+ with respect to the beam direction in the J/ψ rest frame. **c)** Cosine of the dipion system in the lab. **d)** Cosine of the angle between the π^+ and the J/ψ in the dipion rest frame.

final states, there is no distortion of the χ_{c0} and χ_{c2} spectra due to contaminations from these resonances.

Our experimental mass resolution is calibrated by fitting the χ_{c2} to a convolution of a gaussian reslolution function and a Breit-Wigner resonance line with the PDG value for the χ_{c2} total width, which has been precisely determined to be $\Gamma(\chi_{c2}) = 2.00 \pm 0.18$ MeV by the E760 experiment. In this way we can infer the mass resolution at χ_{c0} mass region that only relies on Monte Carlo simulations to indciate how the resolution changes from the χ_{c2} to the χ_{c0}. After this correction, fits to the $\chi_{c0} \rightarrow \pi^+\pi^-$ and K^+K^- invariant mass spectra yield the following results:

$$\Gamma_{\chi_{c0}} = 15.0 \pm^{3.2}_{2.8} MeV,$$

where the error includes both statistical and systematic uncertainties.

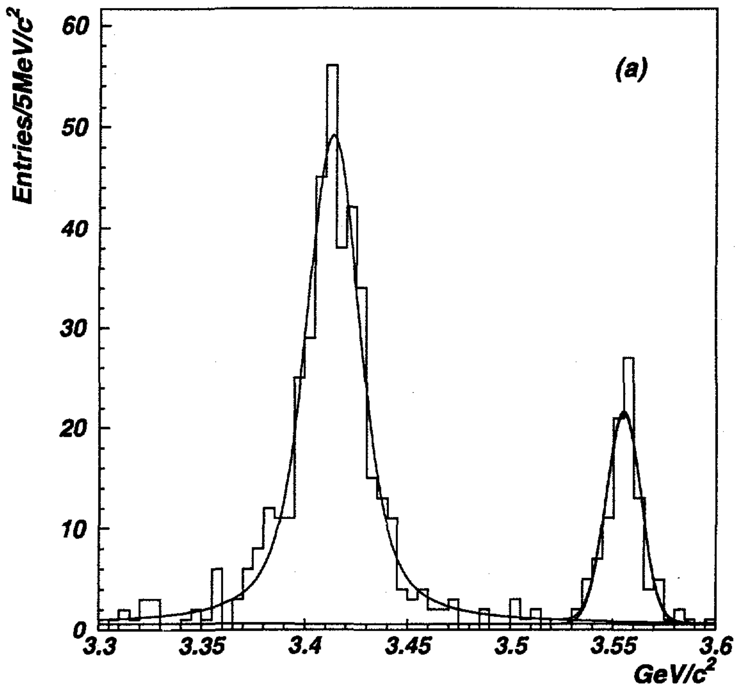


Figure 2.17: The $\pi^+\pi^-$ and mass spectrum from $\psi' \to \gamma\pi^+\pi^-$ events.

$Br(\chi_c \to p\bar{p},\ \pi^+\pi^-$ and $K^+K^-)$.

We have determined branching fractions for χ_{c0} and χ_{c2} decays to $\pi^+\pi^-$, K^+K^- and $p\bar{p}$. For the $\pi^+\pi^-$ and K^+K^- modes we use the data shown in Fig. 2.17. The $p\bar{p}$ mass distribution from selected $\psi' \to \gamma p\bar{p}$ events, shown in Fig. 2.18, has clear signals for all three χ_c states. The results are:

Branching Fractions ($\times 10^{-4}$)

		$\pi^+\pi^-$	K^+K^-	$p\bar{p}$
χ_{c0}	BES	42.7 ± 6.4	34.4 ± 5.1	1.45 ± 0.50
	PDG	75 ± 21	71 ± 24	< 9.0
χ_{c1}	BES			0.83 ± 0.40
	PDG			0.86 ± 0.12
χ_{c2}	BES	15.2 ± 3.4	5.2 ± 2.1	0.96 ± 0.54
	PDG	19 ± 10	15 ± 11	1.00 ± 0.10

Our measurement for $\chi_{c0} \to p\bar{p}$ is the first measurement for this mode and will be useful for planning the program for future gas-jet experiments in the Fermilab $\bar{p}$ accumulator ring. Our results for $Br(\chi_{c0,2} \to \pi^+\pi^-$ and $K^+K^-)$ represent a large improvement in precision over previous measurements. We see a significant difference between $Br(\chi_{c2} \rightarrow \pi^+\pi^-$ and $Br(\chi_{c2} \rightarrow K^+K^-$, a deviation from flavor symmetry that was not apparent in the previous measurements. This work is primarily being done in Beijing by IHEP student C.Z. Yuan. Olsen is doing various checks on these results in Hawaii.

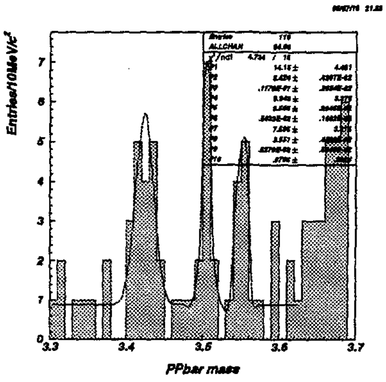


Figure 2.18: The $p\bar{p}$ mass spectra from $\psi' \rightarrow \gamma p\bar{p}$ events.

2.2.3 Charm Physics: measurement of f_{D_s} and f_D.

The 1992-94 run at $\sqrt{s} = 4.03$ GeV focussed on the study of decays of D_s mesons produced via the process $e^+e^- \rightarrow D_s\overline{D}_s$. At this energy, $D^*\bar{D}^*$, $D^*\bar{D}$, and $D\bar{D}$, as well as $D_s\bar{D}_s$ are produced.

A major goal of this run was the direct measurements of the pseudoscalar decay constants f_{D_s} and f_D. In 1995, we published the result $f_{D_s} = 430^{+150+40}_{-130-40}$ MeV, based on the observation of one tagged $D_s \rightarrow \mu\nu$ and two tagged $D_s \rightarrow \tau\nu$ events. Although this result has less precision than other extant measurements, it is a direct measurement and not dependent on any theoretical input other than lepton universality. During the past year we expanded the number of tagging and τ-lepton decay channels, thus increasing our acceptance and adding three more events to our $D_s \rightarrow \tau\nu$ sample. Including these events in the analysis results in a new preliminary value for the decay constant of $f_{D_s} = 296^{+88+19}_{-81-21}$ MeV. The precision of our direct measurement is now approaching that of the other, model dependent, results. This work is done by our Cal Tech and Beijing collaborators.

Events of the type $e^+e^- \rightarrow D^{*+}D^-$ at a center of mass energy 4.03 GeV have been searched for $D^- \rightarrow \mu^-\nu$ recoiling against a D^o or D^+, which were reconstructed from their hadronic decays. A single candidate was found where $D^o \rightarrow K^-\pi^+$ with the recoiling D^- decaying via $D^- \rightarrow \mu^-\nu$. This yields a branching ratio $B(D \rightarrow \mu\nu) = 0.08^{+0.16+0.05}_{-0.05-0.02}\%$, and a corresponding value of the pseudoscalar decay constant $f_D = 300^{+180+80}_{-150-40}$ MeV. This is the first observation of this Cabbibo suppressed decay. A paper on this result has been submitted to Phys. Rev. D. This work is done by our CSU collaborators.

2.2.4 CODEMAN

Software updates of BES software to all BES sites are handled by CODEMAN (the Code Manager). The primary code server had been SLACVM. However SLACVM is being phased out, so it was necessary to shift the code server function to UNIX. Hawaii student Kong took the leading role in developing a UNIX CODEMAN primary, using the PERL scripting language. The primary is currently running on the SLAC UNIX farm. The development of the CODEMAN primary has been an important software contribution to the BES experiment. Students at Caltech and UT Dallas have been responsible for the CODEMAN secondary software, which runs on the various computers used by all the BES collaborators.

2.2.5 The BES upgrade.

During the past year, BES and BEPC have been undergoing upgrades. In BES, a new vertex chamber, a new drift chamber, a new TOF system, and a new luminosity monitor were added. A new online system, using a DEC AXP 3000/600 with a VME front end, will reduce the deadtime to less than 10 ms and allow a much higher trigger rate. In addition, many other hardware problems were fixed.

In BEPC, work was done to improve the beam impedance of the vacuum pipe, and the IR quadrupoles were moved closer to the interaction point to facilitate lower beta operation. Improvements were made in the beam diagnostic and control systems. The goal is a factor of two increase in luminosity. Next year, collisions will be avoided at the other, unused, crossing point and additional RF cavities will be installed. These improvements are expected to provide an additional factor of two improvement in luminosity.

Our group provided the front-end electronics for the new vertex chamber, which was the Mark-III vertex chamber rebuilt at Colorado State University. A picture of the vertex chamber is shown in Fig. 2.19. In addition, we built a pulse-laser/fiber-optic calibration system for the new BES TOF system.

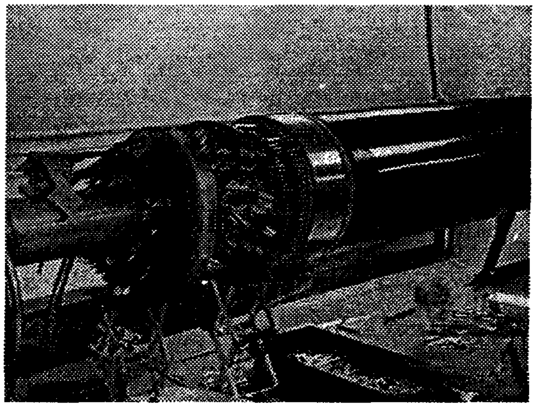


Figure 2.19: Picure of the open vertex chamber during reconstruction at Colorado State University.

Vertex chamber electronics

We developed a modified version of the front-end electronics that was used for the AMY central drift chamber for use with the BES-upgrade vertex detector. The system consists of a hybrid preamplifier mounted very near the chamber, just outside the magnetic volume of the detector, and a post-amplifier/discriminator card located further away, but still in the detector hall. The discriminated signals are sent to TDCs in the counting room. This system was installed in BES and commissioned in February 1996 by Hawaii student Pan.

Time-of-Flight

The TOF system is of extreme importance to the BES experiment. At BEPC energies, all final-state particles have momenta less than 2 GeV/c and can be identified with a state-of-the-art, sub-200 ps resolution, TOF system. In BES, a new TOF system styled after the system developed for the BELLE detector and using a counter design based on prototype work done at Hawaii was provided by our IHEP collaborators. It consists of 48, 5x15x284 cm^3 scintillators with light pipes at each end readout by fine mesh phototubes located inside the magnetic field volume.

The Hawaii group, exploiting our fiber-optic expertise developed for the DUMAND experiment, constructed a pulsed-laser system that will provide light signals with well defined relative times to both ends of each of the 48 TOF scintillators, providing a simple and robust means for adjusting and monitoring the channel-to-channel calibration constants. This was installed in BES in January 1996 by Hawaii student Paluselli.

Preliminary Results from BESII

The reassembly of BESII was completed in March, and machine studies occupied all of April. In May, a small amount of time was made available to BES to debug the new online system and the new detector elements. Although there has been only a very small amount of data taken with the upgraded BESII detector, we can begin to check how well it is working. More meaningful results will require further data and careful calibrations.

The new vertex chamber appears to be a success. The preliminary spatial resolution obtained from a first-pass study of triplet hits (see Fig. 2.20) is approximately 80 μm. (The intrinsic resolution, found earlier using cosmic ray triplet hits, is 50 μm.) In addition, the events look very clean. An event display showing vertex chamber hits is shown in Fig. 2.21. At present there are about 17 dead channels out of 640, but most of these are probably due to bad cables or electronics channels and will be recovered before the next run.

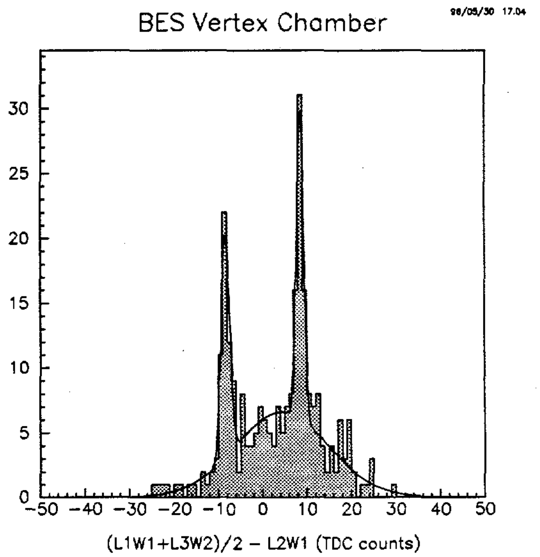


Figure 2.20: Representative Triplet From Layers 1, 2, and 3.

The initial look at the new TOF system also looks very promising. Although full calibration corrections have not yet been made, we already have acheived better than 200 ps resolution. To date, the Hawaii laser calibration system has only been

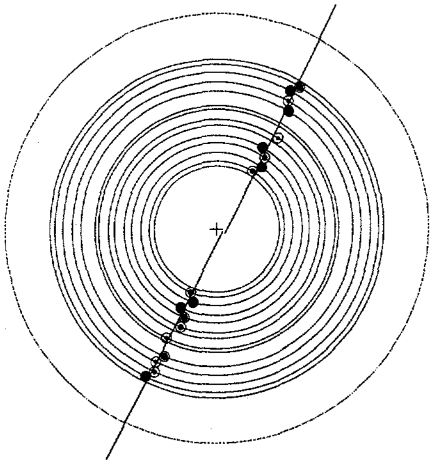


Figure 2.21: One event display of the vertex chamber.

used as a diagnostic tool. The calibration aspects of the system will be put into operation this summer. Hawaii student Kong is writing offline software for this.

Although data has been obtained with the new main drift chamber and the spatial resolution looks very good, the chamber has trouble holding high voltage on humid days, and there appears to be a noise problem which requires that the thresholds be set too high. These problems will be worked on this summer after the run is completed.

Initial Results from the Upgraded BEPC Storage Ring

In the beginning of June, the accelerator physicists at IHEP obtained their initial goals: a luminosity of 4×10^{30} $cm^{-2}s^{-1}$ for a peak current of 40 ma. This was 50% higher than previous luminosities obtained before the upgrade. Although more work remains to be done, time was to be made available for a few days of data taking for further checkout and testing of BESII. The future is very promising.

2.2.6 Recent BES publications:

In print

1. J.Z. Bai, et al. (BES), *A Direct Measurement of the Pseudoscalar Decay Constant, f_{D_s}*, Phys. Rev. Lett. 74, 4599 (1995).
2. J.Z. Bai, et al. (BES), *A Direct Measurement of the D_s Branching Fraction to the $\phi\pi$*, Phys. Rev. D52, 3781 (1995).

3. J.Z. Bai, et al. (BES), *Measurement of the Mass of the τ Lepton*, Phys. Rev. D53, 20 (1996).

Submitted for publication

1. J.Z. Bai, et al. (BES), *Search for a Vector Glueball by a Scan of the J/ψ Resonance*, submitted to Phys. Rev. D.
2. J.Z. Bai, et al. (BES), *Measurement of the Branching Ratio $D^+ \to \mu^+\nu_\mu$*, submitted to Phys. Rev. D.

In preparation

1. J.Z. Bai, et al. (BES), *A Measurement of the Branching Ratio for $\psi' \to \tau\tau$*, to be submitted to Phys. Rev. Lett.
2. J.Z. Bai, et al. (BES), *A Measurement of the Branching Fraction of D_s Inclusive Semileptonic Decay $D_s^+ \to e^+X$*, to be submitted to Phys. Rev. D.
3. J.Z. Bai, et al. (BES), *Direct Measurement of $B(D_s^+ \to \phi X$*, to be submitted to Phys. Rev. D.

Summer 1996 conference reports

1. L.J. Pan, et al. (BES), *A Measurement of the $\psi' \to$ Baryon-Antibaryon Pairs*, contributed paper to the Minneapolis DPF meeting (August 1996).
2. D. Paluselli, et al. (BES), *A Study of ψ' Decays to Axialvector plus Pseudoscalar Mesons*, contributed paper to the Minneapolis DPF meeting (August 1996).
3. Y.F. Gu, et al. (BES), *Results on Hadronic $\psi(2S)$ Decays into VP and VT Final States*, contributed paper to the Minneapolis DPF meeting (August 1996).
4. X.H. Li, ei al. (BES), *Study of Charmonium ${}^3P_J$ States Produced in e^+e^- Annihilations*, contributed paper to the Minneapolis DPF meeting (August 1996).
5. I. Blum, ei al. (BES), *Measurement of the Observed Inclusive Charm Cross Section at 4.03 GeV*, contributed paper to the Minneapolis DPF meeting (August 1996).

References

[1] M.E.B. Franklin et al. (Mark II Collaboration), Phys. Rev. Lett. **51**, 963 (1983). 20

[2] M. Mangano (CDF collaboration), proceedings of the XXIX Rencontres de Moriond on QCD and High Energy Hadronic Interactions, Meribel, March 1994; and the XVIIth International Conference on High Energy Physics, Glasgow, July, 1994.

[3] R. Brandelick et al. (DASP Collaboration), Z. Phys. **C1**, 233 (1979).

[4] G. Feldman and M. Perl (Mark I Collaboration), Phys. Rep. **C33**, 285 (1977).

[5] See, for example, H.G. Blundell, S. Godfrey, and B. Phelps, Phys. Rev. **53**, 3712 (1996), M. Suzuki, Phys. Rev. **D47**, 1252 (1993), and references cited therein.

[6] J.Z. Bai *et al.* (BES Collaboration), *Branching Fractions for ψ' Decays to Octet-Baryon Pairs*, paper submitted to the 1995 International Symposium on Lepton and Photon Interactions at High Energies, Beijing, China.

[7] The PDG value for $Br(J/\psi \to b_1^{\pm}\pi^{\mp})$ is $(3.20 \pm 0.25) \times 10^{-3}$. As a check of our $\psi(2S)$ measurement, we applied the same procedures to J/ψ's from $\psi(2S) \to \pi^+\pi^- J/\psi$ cascade decays. Our result, $(3.4 \pm 0.7) \times 10^{-3}$ agrees well with the PDG value.

[8] The function used to fit the $K_1(1270)$ is a convolution of an s-wave Breit Wigner function with mass and width fixed at the PDG values for the $K_1(1270)$ ($M_{K1} = 1.270$ GeV and $\Gamma_{K1} = 0.090$ GeV) with a p-wave ρ meson Breit Wigner with $M_\rho = 0.77$ GeV and $\Gamma_\rho = 0.150$ GeV.

[9] T.A. Armstrong et al. (E760), Phys. Rev. Lett. **68**, 1468 (1992).

[10] J.E. Gaiser et al. (Crystal Ball), Phys. Rev. **D34**, 711 (1986).

2.3 The CLEO-II Experiment

Dr. T. Browder, Dr. J. Rodriguez, Ms. F. Li., and Mr. Y. Li.

Browder's physics program is a continuation of the CLEO-II experimental program and active participation in the Hawaii effort on the KEK B factory. Rodriguez will construct and calibrate TOF counters for the KEK B factory detector and work on analysis of exclusive hadronic B decays in the CLEO II data sample. Fang Li is a second year graduate student who has recently completed course work and the qualifier exam. She is spending the 1996-1997 academic year at Cornell working on TOF counter hardware and rewriting the TOF detector Monte Carlo simulation. This summer she began work on an analysis of inclusive B decays to K_s mesons. Yong Li is a first year graduate student who is working on preparing high level calibration constants for the TOF system and physics analyses of inclusive $B \to \eta^{'}$ transitions.

The Hawaii group is involved in several CLEO research efforts that are currently in progress:

2.3.1 Studies of inclusive B Meson decays

There are two related anomalies in hadronic B meson decay. These are the low value of the B semileptonic branching ratio and the small average number of c quarks observed in inclusive b decay. Experimentally, the semileptonic B branching ratio has been measured precisely ($\mathcal{B}(B \to Xl^{-}\nu) = 10.65 \pm 0.05 \pm 0.33\%$) by CLEO II using the inclusive lepton spectrum. This result has been confirmed by two other methods: using dileptons and using leptons opposite reconstructed B mesons. On the other hand, quark level calculations based on QCD give branching ratios above 12.5%. This indicates the hadronic width of the B meson predicted by theory is too small. Most of the efforts to adjust theory to be consistent with the semileptonic branching fraction enhance the $b \to c\bar{c}s$ channel and increase the number of c quarks produced per B decay.

Experimentally, one can combine measurements of inclusive B decay rates to determine the number of charm quarks produced per B decay, n_c. Using existing data from the CLEO 1.5, CLEO II, and ARGUS experiments, one finds the world average $n_c = 1.13 \pm 0.05$. This is consistent with the usual parton model expectation of 1.15. However, if the low value of the B semileptonic branching ratio is due to an enhancement of the $b \to c\bar{c}s$ portion of the width, then the number of charm quarks produced per B decay should be 1.3. This indicates that the hadronic width predicted by theory is too large. These two problems are probably related and may be either experimental or theoretical in origin. By measuring the inclusive properties of B meson decay, (i.e. $B \to D^0 X, B \to D^+ X$,

$B \to D_s X, B \to \Lambda_c X, B \to \Xi_c X, B \to \psi X$....) it may be possible to understand the origin of these unexplained features of hadronic B meson decay. The University of Hawaii group is systematically measuring inclusive B decays to light mesons as part of this effort. Browder has also been a participant on the committee reviewing the work on inclusive $B \to D^{(*)}X$ transitions, which is one ingredient in the determination of n_c.

Last year, Browder carried out one component of this large program of studying inclusive B meson decay: a study of inclusive ϕ production from $b \to c$ transitions. This work led to the conference paper CLEO CONF-95-3 which is now being prepared for publication. A search for high momentum ϕ production can be used to constrain the $b \to s$ gluon mechanism. In particular, a large enhancement of $b \to s$ gluon processes (a branching fraction of order 10% rather than 1%) that has been suggested by Kagan and by Ciuchini, Gabrielli, and Giudice does not appear to be the explanation of the semileptonic branching fraction problem. Browder with students Fang Li and Yong Li has now extended this program of study to cover inclusive B decays to $B \to K_s$ and $B \to \eta'$. Upper limits on $b \to s$ gluon processes from these analyses and the first observation of inclusive $B \to \eta'$ transitions with $p_{\eta'} < 2.0$ GeV are among the CLEO II results reported at this year's International Conference in Warsaw and at the DPF conference in Minnesota. Ongoing work on $B \to \eta' X_s$ and $B \to K_s X$ may improve the sensitivity of the analyses to the level at which a signal can be observed.

2.3.2 Search for the process $b \to s$ gluon

Browder initiated work on $b \to s$ gluon decays using an inclusive technique. In this case, the experimental signature is the production of ϕ mesons with momenta between $2.0 - 2.6$ GeV, in the kinematic range beyond the endpoint for most ϕ from $b \to c$ processes. This work is described in a CLEO paper, CLEO CONF-95-8, submitted to the Brussels Europhysics Conference and the Lepton-Photon conferences in Beijing. This study has already stimulated theoretical work on predicting the ϕ momentum spectrum from $b \to s$ gluon by the group of Deshpande, Eilam, He, and Trampetic at the University of Oregon and by the group of Ciuchini, Gabrielli and Giudice. The limits on $\mathcal{B}(B \to X_s \phi)$ may also be used to rule out some extensions of the Standard Model with large rates for $b \to s$ gluon which do not modify $\mathcal{B}(b \to s\gamma)$, the rate for the radiative penguin decay.

The current model dependent limit of $\mathcal{B}(B \to X_s \phi) < 1.3 \times 10^{-4}$ at the 90% confidence level rules out the high end of the SM range $(0.6 - 2.0) \times 10^{-4}$ and suggests that inclusive studies do have sufficient sensitivity to observe $b \to s\ g$ signals. The analyses in progress on inclusive $B \to \eta'$, $B \to \eta$, and $B \to K_s$ will also give constraints or measurements of $b \to s\ g$. Additional theoretical work will also be needed before they become useful constraints.

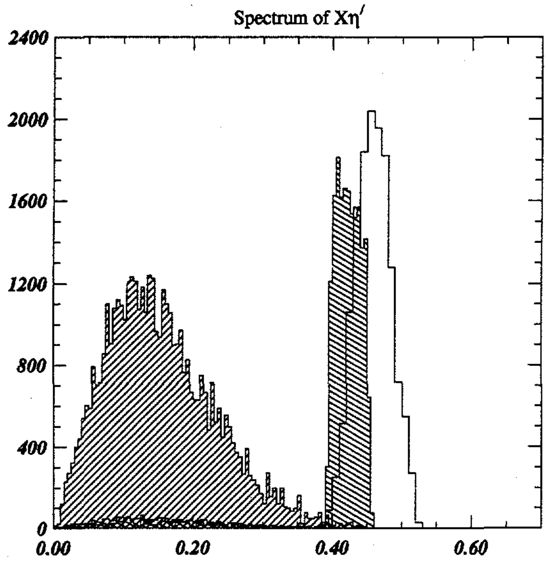


Figure 2.22: The number of η' mesons from B decay as a function of the scaled η' momentum in Monte Carlo simulation. The η' mesons in the histogram (cross-hatched to the righ) originate from $b \rightarrow c$ transitions such as $B \rightarrow D_s, D_s \rightarrow \eta'$. Note that this contribution is small above $x > 0.39$. Above this kinematic limit two contributions are present. The histogram (cross-hatched to the left) shows the shape of the contribution from internal spectator $b \rightarrow c\bar{u}d$ transitions such as $\bar{B}^0 \rightarrow D^{0(*)}\eta'$. The open histogram shows the shape of the contribution of quasi two-body $b \rightarrow s\ g$ modes.

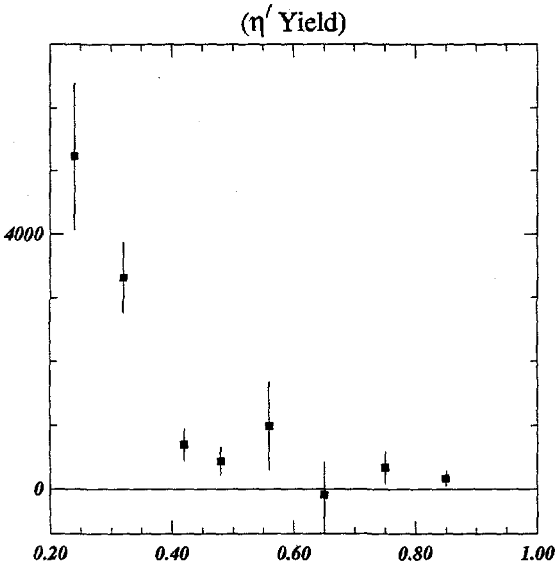


Figure 2.23: The number of η' mesons from B decay as a function of the scaled η' momentum in CLEO II data. The kinematic range $0.39 < x < 0.52$ $(2.0 < p_{\eta'} < 2.7$ GeV) corresponds to the range where $b \rightarrow s\ g$ decays are expected.

The ultimate goal of this work is to isolate an inclusive signal in a channel such as high momentum $B \to K^{*-}X$, where the sign of the energetic K^{*-} meson tags the flavor of the parent B. In two body modes such as $B^- \to K^{*-}\pi^0$, $B^- \to K^{*-}\rho^0$, or $B^- \to K^{*-}a_1$, there are contributions from $b \to s\ g$ and Cabibbo suppressed $b \to u$ amplitudes that interfere and have a relative phase. In principle, such an inclusive signal could be then used to observe direct CP violation. The experimental feasibility of this approach can be examined with CLEO II data. The theoretical feasibility and issues are being investigated by Browder and Pakvasa in collaboration with A. Datta and X-G. He. In Monte Carlo studies with the BELLE detector, we are evaluating the feasibility of this approach at an asymmetric B-factory. If all the experimental and theoretical difficulties of this approach can be resolved, the ultimate application will require the large data samples available at the KEK B factory.

2.3.3 Exclusive hadronic B decays

Rodriguez has built on his expertise in the study of exclusive hadronic B decays and has become a major contributor to this area on CLEO. He will continue his work on precise measurements of exclusive hadronic decays and his search for color suppressed (internal spectator) B decays to a final state with a $D^{0(*)}$ and a light neutral meson.

With a data sample three times larger than that used for the original CLEO II publication, Rodriguez has remeasured the branching fractions for 12 hadronic B modes. Using these results and comparing to measurements of semileptonic B decay, one can test factorization for B decay. At the current 20% level of precision of the measurements, factorization appears to be a valid assumption.

By comparing B^- and $\bar{B}^0$ decays e.g. $B^- \to D^0\pi^-$ and $\bar{B}^0 \to D^+\pi^-$ one can determine the magnitude and the sign of the internal spectator amplitude relative to the external spectator amplitude. The original result that the sign of the internal spectator amplitude is positive in B decay is confirmed with higher statistics. This differs from the usual theoretical extrapolation from charm decay by Bauer, Stech, and Wirbel and others.

It is also puzzling that the sign of the internal spectator amplitude is the same for all the decay modes studied so far. If the spectator amplitude is positive for all hadronic B decay modes, this would lead to a large difference (O(15-20%)) in the lifetimes of charged and neutral B mesons. Such a difference is not observed. This suggests that either (1) the sign of the amplitude is negative for the unobserved modes or (2) there is a large unanticipated contribution to B^0 decays which compenstates for the increase in the B^- hadronic width or (3) the remaining unobserved modes have no contribution from the internal spectator amplitude. This

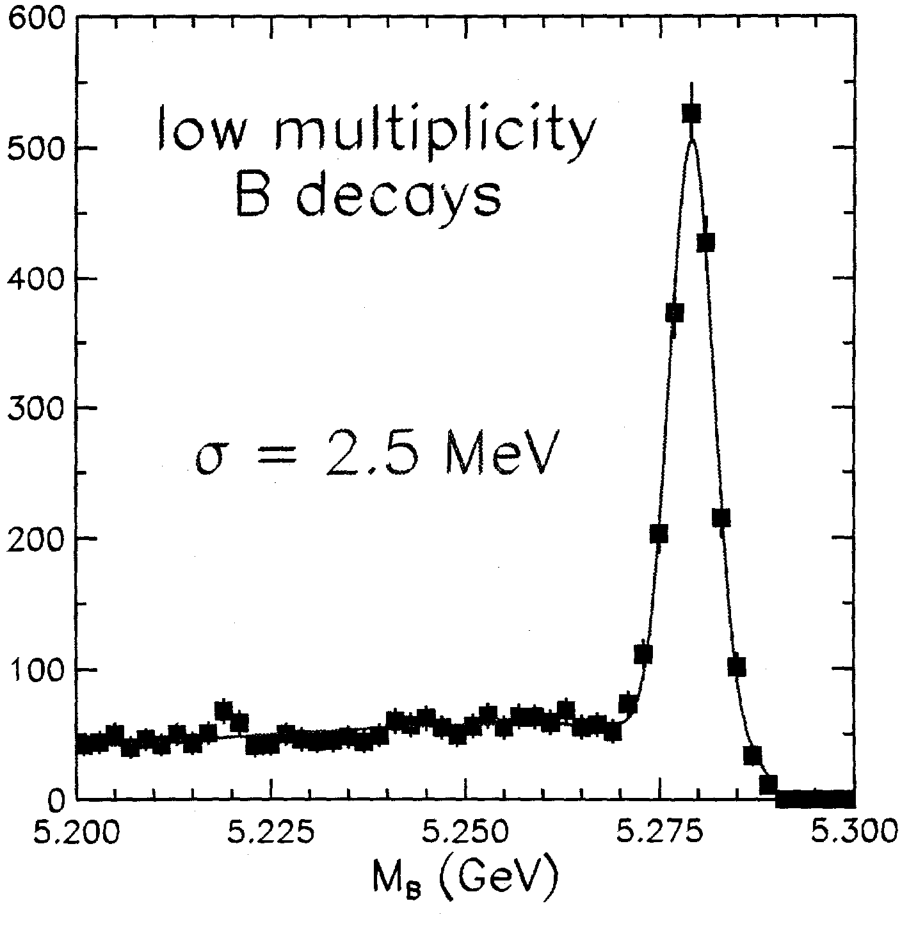


Figure 2.24: The beam constrained mass distribution for low-multiplicity B decays.

issue is also directly relevant to the semileptonic branching fraction problem discussed above, since an increase in the $b \to c\bar{u}d$ component of the hadronic width could reduce the semileptonic branching fraction. In the next year, Rodriguez will investigate experimentally which of these explanations is correct.

2.3.4 Determination of CKM matrix elements.

An investigation of the decay $B \to D^* l\nu$ has now been completed. In CLEO-II this decay can be observed using the D^* mode $D^{*+} \to D^0\pi^+$ or using the mode $D^{*0} \to D^0\pi^0$. The latter mode is of special interest since the momentum cutoff for π^0 detection is much lower than that for π^+ detection. This implies that semileptonic decays can be observed in the kinematic domain (high Q^2) where the Isgur-Wise heavy quark effective theory is most reliable. Detailed measurements of $B \to D^{*0} l\ \nu$ allow the extraction of V_{cb} in a model independent way. Use of the mode $B \to D^{*+}\ l\ \nu$, $D^{*+} \to D^0\pi^+$ requires a major effort to understand the response of the detector to low momentum tracks in the momentum range 50 to 200 MeV. The work on these decay modes is described in a recent Physical Review D paper and in a contribution by Browder to the ICHEP 94 conference in Glasgow.

The next major effort on CKM matrix elements will focus on improving the knowledge of $|V_{ub}|$. This year CLEO announced the observation of $B \to \pi\ell\nu$ and $B \to \rho\ell\nu$ decays the first exclusive charmless semileptonic B decays. This is one important step in the program. In addition, work is in progress on reducing model dependence, the dominant error, in inclusive determinations of $|V_{ub}|$. One approach is to extend the endpoint analysis to lower lepton momenta and observe a larger portion of the spectrum. Browder is the chairman of the committee to oversee the work on inclusive measurements of $|V_{ub}|$.

2.3.5 $B_s - \bar{B}_s$ Mixing.

Browder and Pakvasa collaborated on a paper entitled "A Comment on the Experimental Determination of $|V_{ts}/V_{td}|^2$". In it, we propose a method to extract the ratio $|V_{ts}/V_{td}|^2$ from a measurement of $\Delta\Gamma/\Gamma$ for the B_s meson. This method is experimentally more sensitive than the conventional method for large values of $|V_{ts}|$ but depends on the accuracy of parton level calculations.

As is well known, the measurement of the mixing parameter $x_s = \Delta m/\Gamma$ for the B_s meson is one of the goals of high energy collider experiments and experiments planned for the facilities of the future. Since time integrated measurements of B_s mixing are insensitive to x_s when mixing is maximal, one must make time dependent measurements in order to extract this parameter. A severe experimental difficulty is the rapid oscillation rate of the B_s meson, as recent experimental limits indicate that $x_s > 8.5$ and theoretical fits to the Standard Model parameters suggest that x_s lies in the range $10 - 40$.

It should be noted that there is another parameter of the B_s meson that can also be measured, this is $\Delta\Gamma/\Gamma$, the difference between the widths of the two B_s eigenstates. For $|V_{ts}| \sim 0.043$ this could lead to a value of $\Delta\Gamma/\Gamma$ of order $10 - 20\%$ which is measurable at high energy experiments or asymmetric B factories. In parton calculations

$$\Delta\Gamma = \frac{-G_F^2 f_B^2 m_B m_b^2 \lambda_t^2}{4\pi} \, [1 + \frac{4}{3}\frac{\lambda_c}{\lambda_t}\frac{m_c^2}{m_b^2} + O(m_c^4/m_b^4)]. \tag{2.9}$$

Comparing to the dispersive term, this gives

$$\frac{\Delta\Gamma_{B_s}}{\Delta m_{B_s}} \approx \frac{-3}{2}\pi \, \frac{m_b^2}{m_t^2} \times \frac{\eta_{QCD}^{\Delta\Gamma(B_s)})}{\eta_{QCD}^{\Delta M(B_s)}}, \tag{2.10}$$

where m_b, m_t are the masses of the b and t quark respectively and terms of order m_c^2/m_b^2, m_b^2/m_t^2 are neglected. From equations (1) and (3), the ratio x_s/x_d is given by,

$$\frac{\Delta\Gamma_{B_s}}{\Delta m_{B_d}} = \frac{-3}{2}\pi \, \frac{m_b^2}{m_t^2} \, \frac{(m_{B_s}\eta_{QCD}^{\Delta\Gamma(B_s)} \; B f_{B_s}^2)}{(m_{B_d}\eta_{QCD}^{\Delta M(B_d)} \; B f_{B_d}^2)} \frac{|V_{ts}|^2}{|V_{td}|^2}. \tag{2.11}$$

This method circumvents the difficult experimental problem of determining Δm_{B_s} if x_s is large. This paper has stimulated groups on CDF and DELPHI to perform Monte Carlo simulations to determine the resolution on $\Delta\Gamma$ in $B_s \to D_s \ell \nu$ and $B_s \to \phi\pi$. The sensitivity that can be reached during the next CDF data run should allow a first measurement of $\Delta\Gamma$.

2.3.6 Doubly Cabibbo-suppressed D^0 meson decay and $D^0 - \bar{D}^0$ mixing.

A search was made for the doubly Cabbibo-suppressed decay modes $D^0 \to K^+\pi^-$, $D^0 \to K^+\pi^-\pi^0$ and $D^0 \to K^+\pi^-\pi^-\pi^+$. The analysis requires a thorough understanding of the particle identification systems: 51 layers of tracking chambers instrumented for dE/dx measurements and the TOF system. The $D^0 \to K^+\pi^-$ search resulted in the first observation of a doubly suppressed decay mode and is described in a Physical Review Letter.

The analysis of the $D^0 \to K^+\pi^-\pi^0$ channel showed no evidence for the enhancement of doubly Cabibbo suppressed decays (DCSD). The mode $D^0 \to K^+ l^- \nu$ is currently being examined in order to search for $D^0 - \bar{D}^0$ mixing without the complication of interference from DCSD. In addition, after the installation and calibration of the CLEO II silicon vertex detector, time dependent studies of mixing will also be attempted.

In collaboration with Pakvasa, Browder has attempted to address some issues that are at the interface between theory and experiment in the search for $D^0 - \bar{D}^0$ mixing at fixed target and e^+e^- experiments.

A recent paper by Blaylock, Seiden, and Nir notes that due to final state interaction (FSI) a term proportional to $\Delta M\ t\ e^{-\Gamma t}$ may appear in the rate of wrong sign D decays even in the absence of CP violation. Moreover, in some extensions of the Standard Model that have a large value of ΔM and a significant CP violation, a similar term may arise. Blaylock et al. have suggested that a value of ΔM larger than the present experimental limit can be accommodated if one of these previously neglected terms destructively interferes with the other time dependent terms which arise from mixing (proportional to $t^2\ e^{-\Gamma t}$) and from doubly Cabibbo suppressed decays (DCSD) (proportional to $e^{-\Gamma t}$). They suggest that this may invalidate the use of existing limits from time dependent mixing studies at fixed target experiments (E691, E791, E687) to constrain extensions of the Standard Model.

Browder and Pakvasa also collaborated on a paper entitled "Experimental Implications of Large CP Violation and Final State Interactions in the Search for $D^0 - \bar{D}^0$ Mixing" which will appear shortly in Physics Letters B. This paper discusses the implications of CP violation as well as final state interaction phases in the experimental search for $D^0 - \bar{D}^0$ mixing. At the present level of sensitivity and with reasonable (though model dependent) values for the phase difference δ, we find that the $\Delta M\ t$ term which arises from FSI could change the observed event yield for experiments which study the time dependence of mixing by at most 10%. This is not yet a significant systematic experimental limitation.

Browder is chairman of the committee reviewing the work of D. Kim and H. Yamamoto (Harvard University) on isospin analysis of singly Cabibbo suppressed decays. Rodriguez is also a member of this review committee.

2.3.7 CLEO II particle ID

Rodriguez, Fang Li, Yong Li and Browder have been important participants in the calibration of the existing CLEO II particle ID systems with particular emphasis on the TOF system. This year, the entire TOF calibration code was rationalized and rewritten by Rodriguez. In particular, the efforts this year were focused on calibrating the endcap counters and improving the barrel calibration. Completion of the endcap calibration will effectively increase the luminosity by 20% for those physics analyses that depend on TOF input.

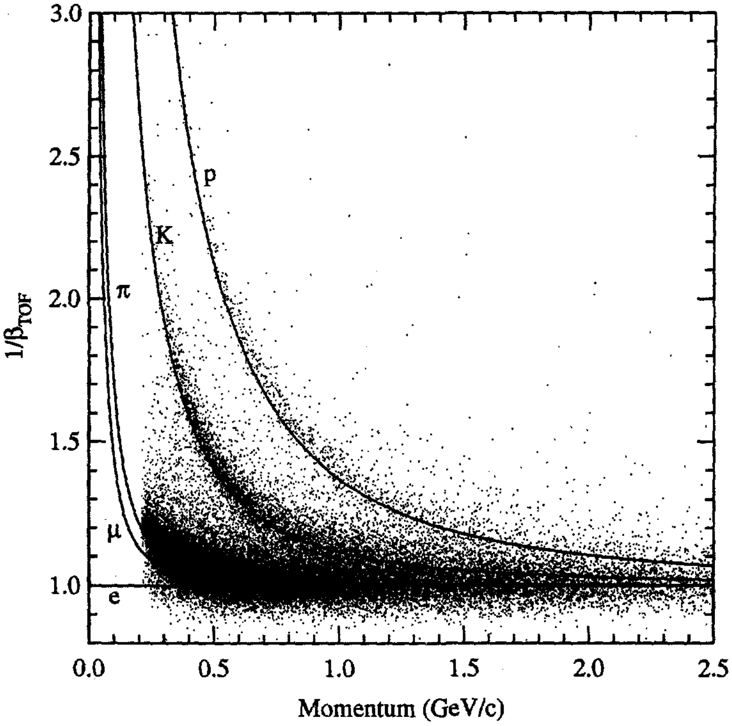


Figure 2.25: The distribution of $1/\beta$ versus momentum for charged tracks in the CLEO II barrel TOF counters. Note that the existing system separates charged pions and kaons up to 1.0 GeV and achieves a resolution of 154 ps.

Last year, Fang Li prepared the TOF counters for running with the helium in the CLEO drift chamber in collaboration with P. Pomianowski of the VPI group. This work involved sealing and packaging the phototubes of the barrel and endcap in order to avoid poisoning by helium from the main drift chamber. The use of helium based gas for the drift chamber will improve the chamber's momentum resolution, reduce backgrounds from synchrotron radiation, and maintain the same dE/dx resolution. This year she will work on rewritting the CLEO TOF counter Monte Carlo simulation code which is poorly understood and does not currently agree with data. Yong Li is currently preparing high level calibration constants and is studying the response and resolution of the re-calibrated endcap TOF counters.

The University of Hawaii's work on CLEO TOF counters will be beneficial and is directly related to the on-going work of the group in construction and calibration of the TOF system at the KEK B factory.

2.3.8 Reviews of B Physics

A review of the entire field of B Meson Physics has recently appeared in Volume 35 of Progress in Nuclear and Particle Physics edited by K. Faessler. This work was carried out in collaboration with K. Honscheid of Ohio State University. Browder has recently finished a contribution on B and D Meson Hadronic Decay for the 1996 edition of Annual Review of Nuclear and Particle Science in collaboration with Honscheid and D. Pedrini of Milan. Browder will also review results on hadronic B decays at the Warsaw (Rochester) Conference and at the Cracow Conference on Radiative Corrections.

Publications

1. Inclusive B Decays and Search for $b \to s$ gluon.
   T.E. Browder, F. Li, Y. Li *et al.*, CLEO CONF 96-18, submitted to the Warsaw and DPF Conferences.

2. Factorization and Color Suppression in Hadronic B Decays.
   J.L. Rodriguez, UH 511-842-96, hep-ex/9604011, to appear in the Proceedings of the Rencontres de Vietnam, World Scientific, edited by K. Faessler.

3. Measurement of $B \to \phi X$.
   J. Alexander *et al.*, CLEO CONF 95-3, submitted to the EPS and Lepton-Photon Conferences. Publication in preparation.

4. Search for Color Suppressed B Decays.
   G. Brandenburg *et al.*, CLEO CONF 95-4, submitted to the EPS and Lepton-Photon Conferences.

5. Search for $B \to \phi X_s$ from $b \to s$ gluon transitions.
   K. Edwards *et al.*, CLEO CONF 95-8, submitted to the EPS and Lepton-Photon Conferences. Publication in preparation.

6. Lifetimes and Hadronic Decays of b-quark and c-quark Hadrons.
   T.E. Browder, K. Honscheid, and D. Pedrini, UH 511-848-96, To appear in Annual Review of Nuclear and Particle Science.

7. B Mesons.
   T.E. Browder and K. Honscheid, UH 511-816-95, and Progress in Nuclear and Particle Physics, Volume 35 edited by K. Faessler.

8. A Comment on the Experimental Determination of $|V_{td}/V_{ts}|^2$.
   T. E. Browder and S. Pakvasa, Physical Review D **52**, 3123 (1995)

9. Experimental Implications of Large CP Violation and Final State Interactions in the Search for $D^0 - \bar{D}^0$ Mixing.
   T. E. Browder and S. Pakvasa, UH-511-828-95, to appear in Physics Letters B.

10. Exclusive Hadronic B Decays to Charm and Charmonium Final States
    M.S. Alam *et al.*, Physical Review D **50**, 43 (1994)

11. Measurement of the $\bar{B} \to D^* \ell \bar{\nu}$ Branching Fractions and $|V_{cb}|$
    T. E. Browder, Contribution to the Proceedings of the ICHEP 94 Conference, Glasgow, Scotland, IOP Publishing, 1995.

12. Measurement of the $\bar{B} \to D^* \ell \bar{\nu}$ Branching Fractions and $|V_{cb}|$
    B. Barish *et al.*, Physical Review D **51**, 1014 (1995)

2.4 The D0 Experiment

Drs. J. Balderston, M.A. Cummings, M. Jones, M. Peters, C. Yoshikawa

2.4.1 Top Mass Fitting

Status of top quark mass determination

The main D0 analysis activity in Hawaii over the past year has been the determination of the top quark mass using kinematic fitting of top event candidates in the lepton + jets final state. Lepton + jets events have a high transverse momentum electron or muon, large missing transverse energy, and at least four jets. These events were used both by D0 and CDF in the top mass determination for the papers that reported the discovery of the top quark last March. Several techniques are being analyzed within D0 both to determine masses for individual top candidates and to extract the top mass from the ensemble of candidates. Hawaii is the only D0 group actively using SQUAW to fit lepton + jets events; we are also doing the only analyses to extract the top mass using the χ^2 values for a series of kinematic fits with fixed top masses.

There have been several important changes in the D0 top mass analysis in the past year. The integrated luminosity for the current analysis is about twice that for the paper that reported discovery of the top quark. The cuts used to select top candidates have been re-optimized. Jet energy reconstruction has been improved and we now use jets with cone size R=0.5 with newly-determined corrections for out-of-cone gluon radiation. This is the same cone size used to calculate quantities on which the selection of top candidates is based. The improved jet reconstruction and more data have led to a reduction in the contribution to the systematic error due to the jet energy scale from 10% a year ago to 4% now.

The changes in the past year required refitting data and Monte Carlo samples and extensive checking of the results. Refitting using SQUAW was done in Hawaii and comparisons were done again with results from other kinematic fitters used in D0. Some problems were found and corrected. The major resulting change is that the top Monte Carlo fitted mass distributions now have smaller mass shifts – for example, the average SQUAW fitted mass for HERWIG-generated 180 GeV top events is 181 GeV now compared to 172 GeV a year ago. These distributions are used in the likelihood analysis that extracts a top mass; a smaller mass shift implies that the extracted top mass is closer to the average mass value for the data. The slope of the average fitted mass versus input mass curve has also increased resulting in a smaller statistical error on the extracted top mass. The current preliminary D0 top mass value of $170 \pm 15 \pm 10$ GeV is smaller than, but consistent with, the published value of 199 GeV.

The current CDF and D0 top mass results were reviewed by Jones in a talk at the May APS/AAPT Meeting in Indianapolis. A summary of the results is given in Table 2.4. Current results which have been reported by CDF and D0 are plotted in Figure 2.26; for comparison the indirect top mass determinations from Standard Model fits to electroweak data by the Particle Data Group (PDG) are also plotted.

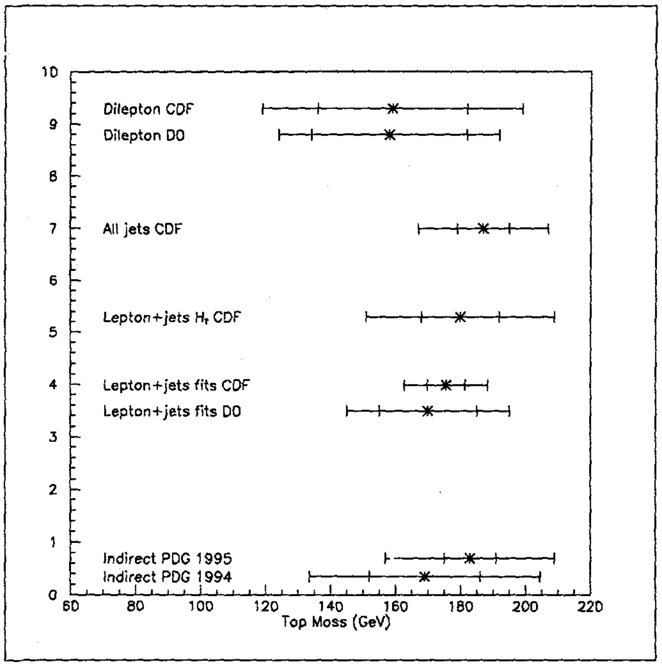


Figure 2.26: Top quark mass determinations by CDF and D0.

Overall there is good agreement between CDF and D0 and among the top mass values determined from the lepton + jets, dilepton, and all jets final states. However, the statistical errors are comparable to the systematic errors so it is worthwhile examining whether the statistical errors could be reduced. If the likelihood analysis effectively separates top and background events, the optimal statistical error is approximately

$$\text{optimal top mass error} = \frac{\text{width of fitted mass dist}}{\text{slope} \cdot \sqrt{n}},$$

where 'slope' is the slope of average fitted mass versus input top mass and 'n' is the number of top events.

Table 2.4: Summary of top quark mass determinations by CDF and D0 as of May 1996

	CDF		D0	
	Loose	Tight	Loose	Tight
2-C kinematic fits				
e/μ + jets events	PRL **74**, 2626 (1995)		PRL **74**, 2632 (1995)	
Events	99		29	14
Background				3.1
Ev with good fits	88	19	24	11
Background	62	6.9	11.6	2.1
M$_{top}$		176^{+8}_{-8}	199^{+19}_{-21}	199^{+31}_{-25}
Systematic error		$^{+10}_{-10}$	$^{+22}_{-22}$	
Current samples				
Ev with good fits	153	34	30	21
Background	98	6.4	17.4	9.0
M$_{top}$		$175.6^{+5.7}_{-5.7}$	170^{+15}_{-15}	172^{+20}_{-20}
Systematic error		$^{+7.1}_{-7.1}$	$^{+10}_{-10}$	
H$_T$ distribution				
e/μ + jets events	PRL **75**, 3997 (1995)			
Events	267	99	34	
Background		54	20	
M$_{top}$		180^{+12}_{-12}	178^{+21}_{-21}	
Systematic error		$^{+19}_{-15}$	$^{+10}_{-10}$	
3-C kinematic fits				
6-jet events				
Events	142			
Background	113			
M$_{top}$	187^{+8}_{-8}			
Systematic error	$^{+12}_{-12}$			
Dilepton events				
Events for mass/total	8/10		3/5	
Background	1.1/2.0		.36/1.7	
M$_{top}$	159^{+24}_{-22}		158^{+24}_{-24}	
Systematic error	$^{+17}_{-17}$		$^{+10}_{-10}$	

For both the CDF and D0 lepton + jets event samples, this expression reduces to 37 GeV divided by the square root of the number of top events in these samples. Using the estimated numbers of top events – 27.6 for CDF and 12.6 for D0 – predicts optimal errors of 7 GeV and 10 GeV respectively. CDF's quoted statistical error of 5.7 GeV is determined directly from the likelihood fit to the data. This error is slightly smaller than the 6.6 GeV value that CDF obtains from simulations of 34-event ensembles containing 27.6 top events on average. So the CDF analysis has achieved an error comparable to the optimal value. D0's quoted statistical error of 15 GeV is taken from simulations of 30-event ensembles containing 12.6 top events on average. Several changes to improve the D0 analysis and thus achieve a statistical error closer to the optimal value are being studied.

There are also differences between CDF and D0 in some contributions to the systematic error. One of the largest differences is in the contribution due to dependence on Monte Carlo generators for top events. Both CDF and D0 estimate this contribution from the difference in extracted top mass values obtained using HERWIG and ISAJET generators to model top events. This contribution is estimated to be 0.9 GeV by CDF and 5.0 GeV by D0. It was only by detailed comparisons in preparation for the APS talk that the size of this difference became apparent. It was also observed that the difference between the HERWIG and ISAJET fitted mass distributions is greater for D0 samples than for CDF samples. These differences are now being studied in detail by Jones.

2.4.2 Hawaii analyses to extract the top mass

For the lepton + jets analyses that have been presented so far by CDF and D0, the top mass is extracted from a likelihood fit to the masses of the top candidates (each of which has a fitted mass obtained from a kinematic fit with a variable top mass) to a sum of signal and background functional forms. The function describing the top signal is obtained from the fitted mass distribution for Monte Carlo top events. Unfortunately, the overall shape of the Monte Carlo distribution is affected significantly by fits with incorrect jet assignments. The width of the peak in the Monte Carlo distribution is 25-30 GeV compared to a width of 15 GeV in the distribution for fits with the correct jet assignment. We have developed two different methods to extract the top mass that seem to be more sensitive to fits with the correct jet assignment and thus achieve a smaller statistical error on the top mass. Both methods use the χ^2 values from SQUAW fits of the top candidates at a series of fixed top masses between 100 and 250 GeV. A function based on the χ^2 values is calculated for each mass value; the top mass is then extracted by a fit to this function as for a maximum likelihood analysis.

The method developed by Jones uses a pseudo-likelihood function defined at each mass value as the product of the fit probabilities for each event, where the fit probability is determined by the fit with the lowest χ^2 value at that mass. This function would be a Gaussian likelihood for a sample of pure top events where the best fits were all for the correct jet assignment. For simplicity, the analysis actually uses the negative of the natural log of the pseudo-likelihood, which corresponds to the sum of the $\chi^2/2$ values for the best fits for each event. Because the real event samples are a mixture of top and background events, one subtracts the expected contribution from the background to obtain the contribution from top events. The shape of the background contribution is determined by fitting event samples that simulate the expected backgrounds – i.e. VECBOS Monte Carlo events for the W + jets background and multi-jet events in the data for the QCD background. The background level is taken as the calculated number of events expected in the top candidates used for the mass analysis. The background-subtracted distribution is then fit with a parabola in the region near the minimum to get the top mass and error.

This pseudo-likelihood method has some important differences from the standard likelihood analysis. It uses the fit χ^2 values in a way that effectively weights events with good fits more than those with poor fits whereas the standard analysis effectively gives all events with acceptable fits equal weight. This weighting has the potential to provide more sensitivity to fits with the correct jet assignment. Another important difference is that the fit which determines the top mass assumes only that the shape of the distribution near the minimum is roughly parabolic whereas the standard analysis depends on the shape over the entire mass range as derived from top Monte Carlo events. This should make the results of the pseudo-likelihood analysis less sensitive to top Monte Carlo generators.

The pseudo-likelihood method can be compared quantitatively to the standard likelihood analysis by comparing the results from simulations of 30-event ensembles containing 12.6 top events on average. The distribution of top mass values from the pseudo-likelihood method is somewhat narrower than that for the standard analysis; the corresponding average statistical mass error is 12 GeV compared to 15 GeV for the standard analysis. The contribution to the systematic error from Monte Carlo dependence (obtained from the HERWIG-ISAJET difference) is 2.4 GeV compared to 5.0 GeV for the standard analysis. Work is in progress to try to improve both methods and it seems likely that both statistical and systematic errors on the D0 top mass value can be reduced.

Future work on top mass analysis

There are three main areas in which we are working:

1. understanding the differences between the CDF and D0 fitted mass distributions for Monte Carlo top events;
2. reducing the contribution to the systematic error on the top mass from dependence on top Monte Carlo generators; and
3. reducing the statistical error on the top mass by doing analyses based upon SQUAW fits at a series of fixed top masses.

We expect this work to continue for several months and that the results will be incorporated into papers reporting the final D0 top mass value for the entire data sample.

2.4.3 Another pseudolikelihood fit

Peters has evaluated a variant of Jones' top mass determination method. The variant incorporates *all* fixed mass fits to an event rather than just the best fit as in the Jones technique. This method is motivated by the observation that only 50% of Herwig Monte Carlo events have the correct jet combination as the best fit. The alternate likelihood function is

$$\ln \mathcal{L} = \sum_{i=1}^{N_e} \ln \left[\sum_{j=1}^{N_c} \frac{\alpha}{N_c} e^{-\frac{1}{2}\chi^2_{ij}} + (1-\alpha)\,\epsilon \right].$$

In this expression, N_e is the number of events, N_c is the number of jet combinations in a particular event, α is the signal fraction of the event sample, ϵ is a parameter representing an average background probability density and χ^2_{ij} is the SQUAW fit χ^2 for the j^{th} jet combination in the i^{th} event. The value of ϵ is chosen to optimize the mass determination on a set of 1000 Monte Carlo ensembles of signal and background events in the (mean) proportions believed to best agree with the data. Note that in the case that $N_c = 1$ and $\epsilon = 0$ this likelihood would reduce to $-\frac{1}{2}\chi^2$, which is the value used in Jones' technique. In this method we also subtract from the data $\ln \mathcal{L}$ curve the estimated background shape and fit the resulting points with a parabola. The results of applying this method to Monte Carlo ensembles of 1000 events at each of 3 input masses are given in Table 2.5.

A least squares fit to these three points yields the relationship

$$M_{fit} = .925 M_{in} + 6.83\ GeV.$$

The nearly unit slope means that the statistical errors are only slightly inflated upon correcting from the fitted mass to the true mass. The bias of 6.83 *GeV* reflects

Table 2.5: Top mass results on Monte Carlo ensembles of 1000 events

Input Mass	μ	σ
160	154.7	8.73
180	173.6	8.74
200	191.7	9.67

the effect of wrong jet combinations. In the standard D0 and CDF analyses, the wrong combination effects are "swept under the rug" by using Monte Carlo curves that include the wrong combinations. In the Hawaii analyses the effect is explicit and its size can be directly determined.

2.4.4 Optimal cuts

Hawaii student Yoshikawa has spent the last year writing his dissertation and finalizing the analyses that went into it. The dissertation contained two analyses pertaining to the $t\bar{t} \rightarrow \mu +$jets physical process: 1) an optimization for separating the top quark signal events from its backgrounds and 2) a mass determination of the top quark. (This optimal discrimination technique is the method used by the DØ collaboration[1] in its discovery of the top quark.)

The optimization in separating the top quark from its backgrounds was accomplished by ascertaining the set of one–sided cut values which minimize the overlap of the two hypotheses: 1) only background processes exist and 2) background and signal processes exist. A probability is calculated for the expected number of background events ($\langle n_b \rangle$), with its uncertainty (σ_b), to equal or exceed the sum of the expected number of background ($\langle n_b \rangle$) and signal ($\langle n_s \rangle$) events. Quantitatively, the probability is:

$$\begin{aligned} P(\langle n_b \rangle \pm \sigma_b \rightarrow \langle n_b \rangle + \langle n_s \rangle) \quad = \quad & \int_0^\infty dn_b \frac{1}{\sqrt{2\pi}\sigma_b} \cdot \exp^{-\frac{(n_b - \langle n_b \rangle)^2}{2\sigma_b^2}} \\ & \left\{ \sum_{N'_{TOT}=0}^{\infty} \frac{\exp^{-(n_b + \langle n_s \rangle)} (n_b + \langle n_s \rangle)^{N'_{TOT}}}{N'_{TOT}!} \right. \\ & \left. \left[\sum_{n'_b = N'_{TOT}}^{\infty} \frac{\exp^{-\langle n_b \rangle} (\langle n_b \rangle)^{n'_b}}{n'_b!} \right] \right\}, \qquad (2.12) \end{aligned}$$

where

$$\langle n_b \rangle = \sum_j \langle n_b^j \rangle$$

and

$$\sigma_b = \sqrt{\sum_j \left(\sigma_b^j\right)^2}.$$

The index j runs over the various sources of backgrounds. The sensitivity of this decision–making probability with respect to two variables (of the seven used) around the globally optimal set of cuts is shown in Figure 2.27.

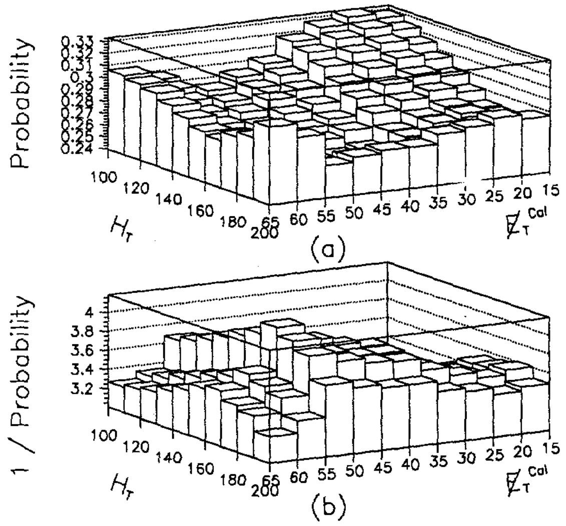


Figure 2.27: Cumulative probability lego plots in H_T(GeV) and $\not\!\!E_T^{cal}$(GeV).
(a) Probability defined in Equation 2.12.
(b) Reciprocal of the probability is plotted to visualize the optimal location which is hidden in the probability plot.

Application of the derived set of optimal cuts to the real data sample yields four candidate events over an expected background of 1.40 ± 0.71 events. A consistency calculation between the expected number of background events and that actually observed is carried out using a Poisson probability and results in a 1.7 σ effect in the gaussian approximation. The top quark mass dependence of the overall efficiency $\epsilon(m_{top})$ of $t\bar{t} \rightarrow \mu + \text{jets}$ events to survive the optimal selection criteria creates a mass dependence in the top production cross section, as illustrated in Figure 2.28.

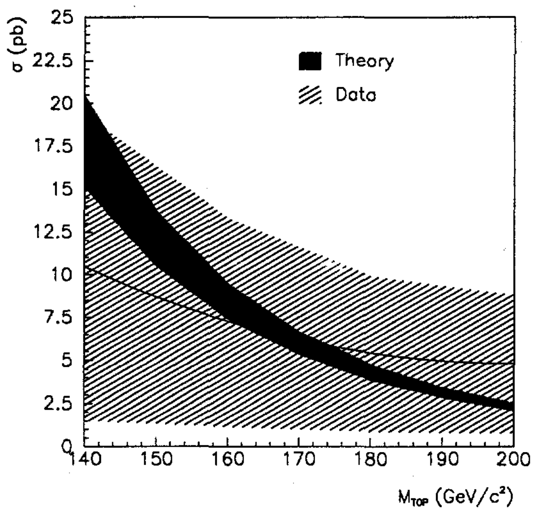


Figure 2.28: Cross section of excess events as a function of top quark mass. The central value of the cross section and its one standard deviation error are shown by the solid line and the borders of the lighter band. The theoretical estimate[2] for $t\bar{t}$ production is shown by the darker band.

2.4.5 H_T analysis

The analysis for the top quark mass is based on the amount of jet activity transverse to the $p\bar{p}$ beam direction. The quantity used to track the mass behavior is the scalar sum of all central jets, H_T. The mass extraction procedure uses a likelihood function defined with a gaussian constraint on the expected number of background events ($\langle n_b \rangle \pm \sigma_b$), a Poisson weight for the total number of observed events (N_{obs}) to have come from the sum of the best fit number of background and signal events ($n_b + n_s$), and a weighted mixture of background and signal using the probability density functions (f_b and f_s) in the mass sensitive H_T variable. The likelihood function is:

$$\begin{aligned} L &= \frac{1}{\sqrt{2\pi}\sigma_b} \exp^{-\frac{(n_b - \langle n_b \rangle)^2}{2\sigma_b^2}} \cdot \frac{\exp^{-(n_s+n_b)} \cdot (n_s + n_b)^{N_{obs}}}{N_{obs}!} \\ &\cdot \prod_{i=1}^{N_{obs}} \frac{n_b f_b(H_T(i)) + n_s f_s(H_T(i), M_{top})}{(n_s + n_b)}, \end{aligned} \tag{2.13}$$

where n_s, n_b, and M_{top} are the fitted parameters which maximize the likelihood. The probability density functions (f_b and f_s) are shown in Figure 2.29. Application

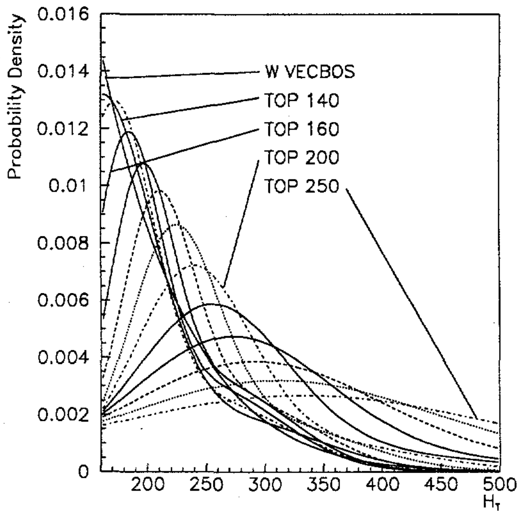


Figure 2.29: H_T(GeV) probability density curves for background (modeled by W VECBOS) and top of several mass values. The H_T curves are in 10 GeV/c^2 increments of top mass.

of the likelihood function defined in Equation 2.13 to the four candidate events results in the best fits with respect to M_{top}, n_s, and n_b, as shown in Figure 2.30.

Table 2.6 summarizes the significance of the signal over background and values of M_{top} and σ in this analysis as well as the discoveries by D0[1] and CDF.[3]

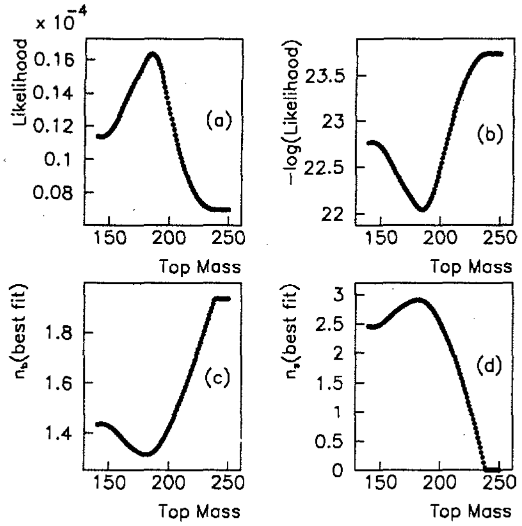


Figure 2.30: Result of fit for candidate events to the mass likelihood function. (a) Likelihood value. (b) -Log(likelihood). (c) Number of background events in best fit. (d) Number of signal events in best fit.

Table 2.6: Summary of discoveries of the top quark by D0[1] and CDF,[3] with supporting evidence from this analysis.
D0$_{\mu+jets}$ refers to the analysis presented here.
* The cross section is calculated by interpolating the results to $m_{top} = 185$ GeV/c^2.

	Background Fluctuation Confidence Level (σ)	m_{top} (GeV/c^2)	Cross Section (pb)
D0[1]	4.6	199^{+19}_{-21}(stat.) $\pm$ 22(syst.)	6.4 ± 2.2
CDF[3]	4.8	176 ± 8(stat.) $\pm$ 10(syst.)	$6.8^{+3.6}_{-2.4}$
D0$_{\mu+jets}$	1.7	185^{+16}_{-26}(stat.)$^{+6}_{-8}$(syst.)	$5.3 \pm 4.4^*$

2.4.6 Personnel

Upon completion of his dissertation reporting the work discussed above, Yoshikawa carried out a brief study of the use of D0 data to set limits on the KM matrix element V_{tb}. This study was terminated when he took up a new position in industry.

2.4.7 Other Activities

Balderston completed and submitted his dissertation on heavy quark production. He is now employed in industry.

Cummings has continued her studies of b-quark production. She has particularly examined $b\bar{b}$ production in dijet events from Z decay as a background to possible detection/limits on production of a light Higgs at the upgraded D0 detector in Tevatron Run 2. Note, however, that the Hawaii group will not be involved in Run 2. Cummings has also carried out studies of signal to noise ratios in the $t \to jets$ channel. She has been interested in the improvements that might be achieved if one could statistically separate quark and gluon jets.

Cummings also continued to be one of the D0 data acquisition system experts through the end of Run 1. Besides day-to-day operation of the data acquisition system she was responsible for the maintenance of the D0 hardware database.

2.4.8 Future Plans

As discussed above, the graduate students involved in the Hawaii group participation in the D0 experiment have both completed their PhD degrees and taken jobs in industry. Cummings will complete her service with our group at the end of the current fiscal year. Jones and Peters will continue their analysis of Run 1 data as they increase their involvement with the Belle experiment. As much as possible, they will use video conferencing to participate in top mass group meetings, but an occasional trip to Fermilab will be necessary. Peters has started Belle activities. (See that section for details.) We do not plan for the Hawaii group to take part in any Run 2 activities at the Tevatron.

2.4.9 Publications

- The D0 Detector Nucl. Instr. and Methods, **A338**, 185 (1994), FERMILAB-PUB-93/179-E.
- First Generation Leptoquark Search in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV. Phys. Rev. Letters **72** 965 (1994), FERMILAB PUB-93/340-E.

- Search for the Top Quark in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV. Phys. Rev. Letters **72** 2138 (1994), FERMILAB PUB-94/004-E.

- Rapidity Gaps between Jets in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV. Phys. Rev. Letters **72** 2332 (1994), FERMILAB PUB-94/005-E

- Search for High Mass Top Quark Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV. Phys. Rev. Letters **74** 2422 (1995), FERMILAB PUB-94/354-E.

- Inclusive mu and b-Quark Production Cross Sections in $p\bar{p}$ Collisions at $\sqrt{s} =$ 1.8 TeV. Phys. Rev. Letters **74** 3548 (1995), FERMILAB PUB-94/409-E.

- Observation of the Top Quark Phys. Rev. Letters **74** 2632 (1995), FERMILAB PUB-95/028-E.

- Limits on the $ZZ\gamma$ and $Z\gamma\gamma$ Couplings in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV. Phys. Rev. Letters **75** 1028 (1995) , FERMILAB PUB-95/042-E.

- Search for W Boson Pair Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV. Phys. Rev. Letters **75** 1023 (1995) , FERMILAB PUB-95/044-E.

- Search for Squarks and Gluinos at $\sqrt{s} = 1.8$ TeV. Phys. Rev. Letters **75** 618 (1995) , FERMILAB PUB-95/057-E.

- Transverse Energy Distributions within Jets in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV. Phys. Letters **B357** 500 (1995) , FERMILAB PUB-95/203-E.

- A Study of the Strong Coupling Constant Using W - Jets Processes Phys. Rev. Letters **75** 3226 (1995) , FERMILAB PUB-95/085-E.

- Second Generation Leptoquark Search in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV. Phys. Rev. Letters **75** 3618 (1995), FERMILAB PUB-95/185-E.

- Measurement of the WWgamma Gauge Boson Coupling in $p\bar{p}$ Collisions at $\sqrt{s} =$ 1.8 TeV. Phys. Rev. Letters **75** 1034 (1995), FERMILAB PUB-95/101-E.

- W and Z Boson Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV. Phys. Rev. Letters **75** 1456 (1995), FERMILAB PUB-95/130-E.

- Top Quark Search with the D0 1992-1993 Data Sample Phys. Rev. **D52** 4877 (1995), FERMILAB PUB-95/020-E.

- Search for Wino1 Zino2 via Trilepton Final States in $p\bar{p}$ Collisions at $\sqrt{s} =$ 1.8 TeV. Phys. Rev. Letters **76**, 2228 (1996), FERMILAB-PUB-95/385-E.

- Jet Production via Strongly-Interacting Color-Singlet Exchange in $p\bar{p}$ Collisions. Phys. Rev. Lett. **76** 734 (1996), FERMILAB PUB-95/302-E.

- Search for Right-Handed W Bosons and Heavy W' in $p\bar{p}$ Collisions at $\sqrt{s} =$ 1.8 TeV. Phys. Rev. Letters **76**, 3271 (1996), FERMILAB PUB-95/412-E.
- Search for Heavy W Bosons in 1.8 TeV $p\bar{p}$ Collisions. Phys. Letters **B358** 405 (1995), FERMILAB PUB-95/283-E.
- J/Ψ Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV. Phys. Lett. **B370**, 239 (1996), FERMILAB-PUB-96/003-E.
- Search for Light Top Squarks in $p\bar{p}$ Collisions at $\sqrt{s} = 1.8$ TeV. Phys. Rev. Letters **76**, 2222 (1996), FERMILAB-PUB-95/380-E.
- M. Adams et al., A Detailed Study of Plastic Scintillating Strips with Axial Wavelength Shifting Fiber and VLPC Readout. Nucl. Instrum. and Meth. **A366** 263 (1995), FERMILAB PUB-95/027-E.

References

[1] S. Abachi *et al.* (DØ). Phys. Rev. Lett., 74:2632, April 1995.

[2] E. Laenen, J. Smith, and W. van Neerven, Phys. Lett. 321B, 254 (1994)

[3] F. Abe. *et al.* (CDF). Phys. Rev. Lett., 74:2626, April 1995.

2.5 The AMY Experiment

Drs. S. Olsen and S. Sahu

The AMY experiment, which started operating at the beginning of TRISTAN running in November 1986, stopped running in June 1994 with a total data sample corresponding to ~300 pb^{-1} Although experimental operations have terminated, a considerable amount of data analysis continued during the past year and a number of publications were produced.

Since the operation of SLC and LEP, AMY has concentrated on tests of the electroweak theory and on inclusive two-photon physics, using both single-tagged and untagged events. We have established a new limit on the mass of the SUSY scalar electron, measured the charm production rate in untagged two-photon collisions and the forward-backward asymmetry for b-quarks produced via the $e^+e^- \rightarrow b\bar{b}$. In the following we briefly describe some of the highlights of these analyses.

2.5.1 Search for the SUSY scalar electron

A study of e^+e^- annihilations into final states containing a single energetic photon with no accompanying particles is made at a center of mass energy of 57.8 GeV. The process $e^+e^- \rightarrow \tilde{\gamma}\tilde{\gamma}\gamma$ would provide evidence for the photino ($\tilde{\gamma}$) and the scalar electron ($\tilde{e}$), the SUSY partners of the photon and the electron. In this reaction, the scalar electron is exchanged in the t-channel and the cross section is a function of its mass as well as that of the photino. Since the photinos are not detected, this process will produce events with a single photon with unbalanced momentum.

In the standard model, events with this single-photon signature can be produced by the radiative production of neutrino pairs, $e^+e^- \rightarrow \nu\bar{\nu}\gamma$. The cross section for this process depends on the number of neutrino generation N_ν, which has been measured by LEP experiments by the direct counting of radiative decays and inferred from the invisible Z^0 width. Both methods strongly support $N_\nu = 3$. The existence of SUSY particles would produce an excess in the number of single-photon events over the expectation from the standard model with $N_\nu = 3$.

The search reported here was performed using data collected with the AMY detector at TRISTAN at $\sqrt{s} = 57.8$ GeV. Of particular importance for this measurement is the near hermetic coverage provided by the "beam pipe calorimeter" (BPC), which extends down to $\theta = 1.9°$. Sahu, the newest member of HEPG, played a leading role in the construction and implementation of this detector.

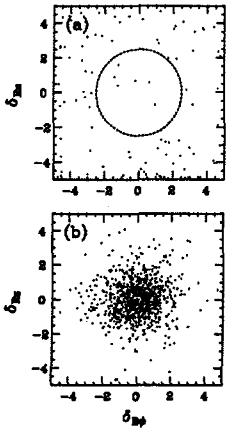


Figure 2.31: Two dimensional distributions of the normalized distance of closest approach to the interaction point for **a)** single photon event candidates and **b)** photons from $e^+e^-\gamma$ events. The dashed circle indicates the selected region.

Backgrounds from cosmic rays make showers that do not point to the interaction point. We use the ability of the AMY shower counter to determine shower directions to effective for rejecting this background. The two-dimensional distribution of the distance of closest approach to the interaction point (normalized to the experimental resolution) for candidate single-photon events is shown in Fig. 2.31a; the same distribution for photons from $e^+e^-\gamma$ events is shown in Fig. 2.31b. Six events survive the acceptance cut, indicated by the dashed circle in Fig. 2.31a, consistent with the standard model expectation of 8.9 events.

In Fig. 2.32 we show the 90% CL limits on the selectron and photino mass both for the AMY results alone and for the combined results of all similar measurements. In the latter case, for a massless photino, we derive a the 90% CL lower limit for the scalar electron mass of $m_{\tilde{e}} > 79.3$ GeV.

2.5.2 Charm production in photon photon collisions.

While LEP and the SLC have redefined the energy frontier for e^+e^- annihilation physics, the TRISTAN data sample remains the world's premier source of high energy $\gamma\gamma$ interactions. In the past year we have published two papers on the subject of charm production via two photon collisions.

Open charm production in two-photon processes has been inferred from a measurement of the rate of production of inclusive electrons and muons, and from inclusive $D^{*\pm}$ production. The D^* measurement was based on detecting the soft $\pi^\pm$ from the $D^* \to \pi D$ decay. These show up as an excess of particles with small transverse momentum relative to the Trust axis of the event, as can be seen in Fig. 2.33.

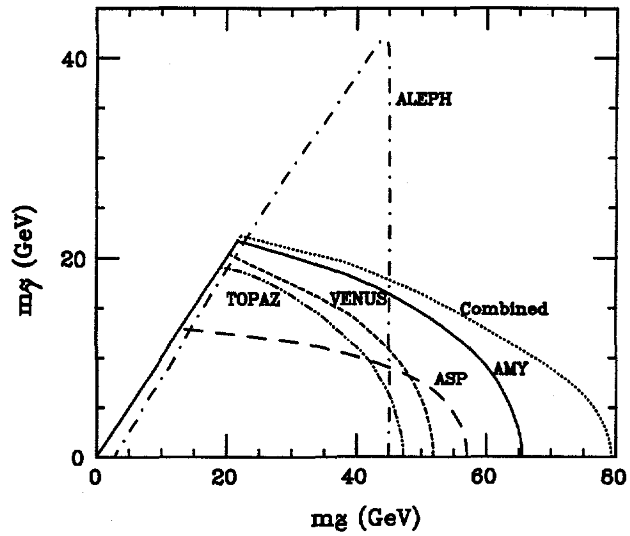


Figure 2.32: The 90% CL lower limits for the masses of the selectron and photino.

No large excess of charm production, as had been indicated by a TOPAZ measurement, is seen; the measured rate is 1.8 standard deviations above QCD expectation.

2.5.3 The $b\bar{b}$ forward-backward asymmetry

At the TRISTAN energy, because the $b\bar{b}$ asymmetry is nearly maximal, it can, in principle, be measured relatively precisely. In previous results, all three TRISTAN experiments favor a value of the asymmetry $A_b = -0.583$ as opposed to the standard model prediction, including the effects of $B\overline{B}$ mixing of $A_b = -0.437$. In an analysis started while he was a member of the Hawaii group, Ueno determined the forward-backward asymmetry using a neural network technique to identify b-quark jets. Unlike previous methods where the estimated background from c-quark decays and other sources are subtracted, we categorized events as being either b-quark or non b-quark by neural networks focused on event-by-event characteristics. One network was trained using mostly hadron-related information. Results from this network were input into a second network that was trained to recognize b-events from the muon-detector-related information.

The resulting $e^+e^- \to b\bar{b}$ differential cross section, shown in Fig.2.34, was fit to the formula:

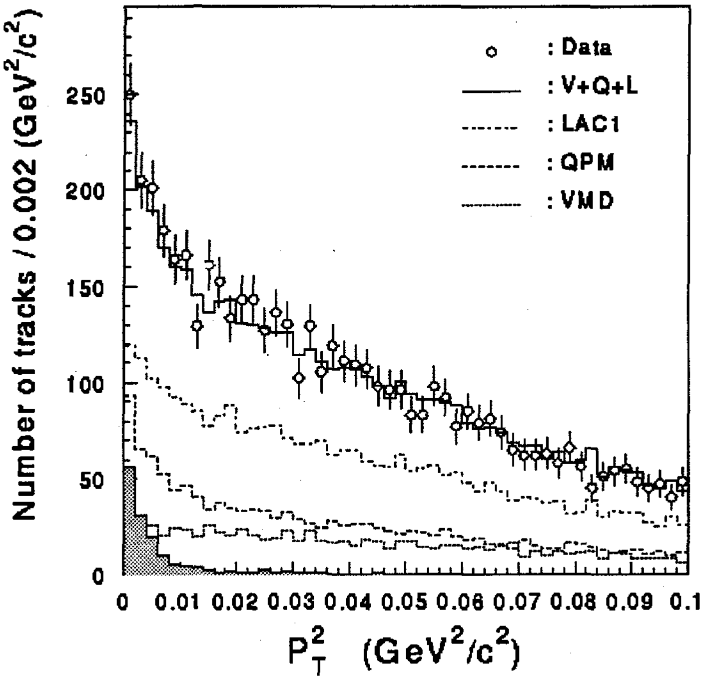


Figure 2.33: The distribution of charged particle transverse momentum relative to the Thrust axis for untagged two-photon events. The excess at small p_t is from $D^* \to \pi D$ decays..

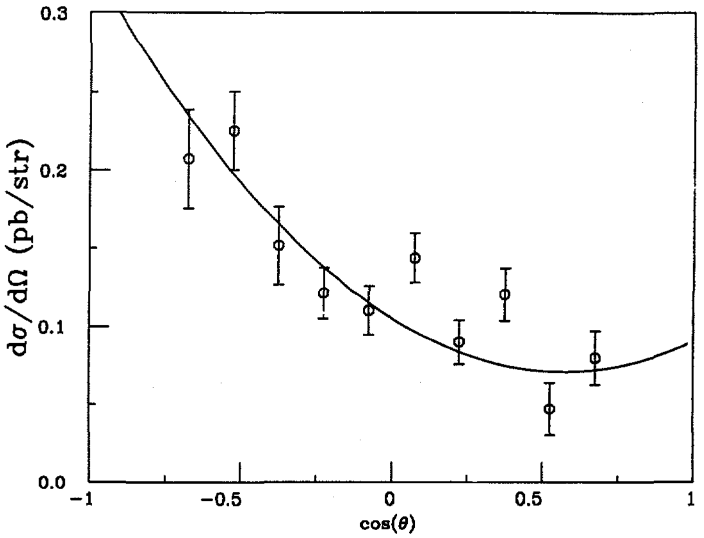


Fig. 4

Figure 2.34: The $e^+e^- \to b\bar{b}$ differential cross section.

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4s} R_b (1 + \cos^2\theta + \frac{8}{3} A_b \cos\theta), \tag{2.14}$$

where α is the fine structure constant; s the square of the c.m. energy; R_b and A_b free parameters. The determined asymmetry is $-0.406 \pm 0.048(sta) \pm 0.049(sys)$ and is consistent with the prediction of the standard model. A fit to this plus results from other experiments and energies, shown in Fig. 2.35, gives the $b\bar{b}$ mixing parameter of $0.134 \pm 0.028(sta + sys) \pm 0.020(model)$.

2.5.4 Conclusion

The AMY group will continue to analyze data and publish results. We expect to continue to produce publications and theses for a number of years. Although Olsen and Sahu will continue a small level of involvement in this activity, no funds specifically aimed at AMY are included in the budget requested for 1996.

AMY publications since August 1995.

1. S.K. Choi et al. (AMY), *A measurement of Bose-Einstein Correlations in* e^+e^- *annihilation at Tristan*, Phys. Lett. **B 355**, 406 (1995).

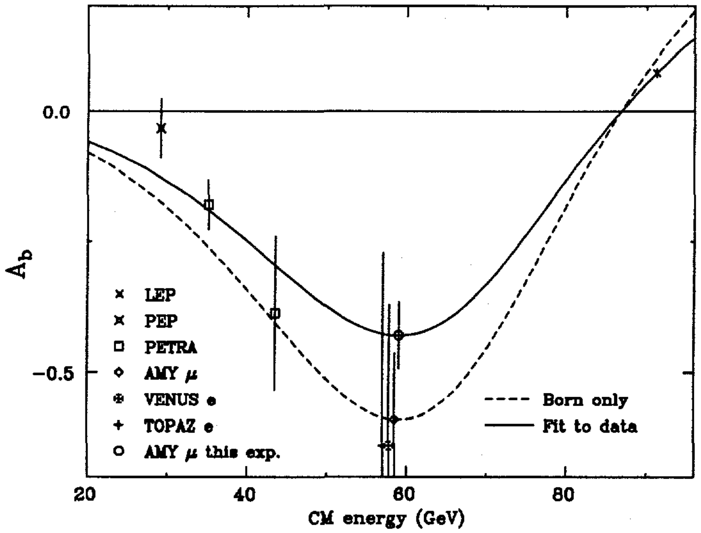


Fig. 5

Figure 2.35: The forward-backward asymmetry for $e^+e^- \rightarrow b\bar{b}$.

2. T. Aso et al. (AMY), *Measurement of charm production in two-photon processes using inclusive lepton events at TRISTAN*, Phys. Lett. **B 363**, 249 (1995).

3. Y. Sugimoto et al. (AMY), *New Limits on the Masses of the Selectron and Photino*, Phys. Lett. **B 369**, 86 (1996).

4. S. Behari et al. (AMY), *Observation of Color Coherence Effects in the Subjet Multiplicity in Thre- and Four-jet Events in e^+e^- Annihilation*, Phys. Lett. **B 374**, 304 (1996).

5. N. Takashimizu et al. (AMY), *Measurement of $D^{*\pm}$ production in two-photon processes at TRISTAN*, accepted for publication to Physics Letters B (1996).

6. K. Ueno et al. (AMY), *Measurement of the Forward-Backward asymmetry in $e^+e^- \rightarrow b\bar{b}$ and the b-quark Branching Ratio to muons at TRISTAN using Neural Networks*, accepted for publication in Physics Letters B (1996).

2.6 Monolithic Pixel Development

Drs. C.J. Kenney, S.I. Parker and V.Z. Peterson

Last year, we published results of the first-generation monolithic detectors (with 34 × 125 micron pixels) demonstrating: (1) greater than 99.995% charge collection of infra-red generated charge; (2) no misses in 5889 traversals of 500 GeV muons; (3) spatial resolution from 1.3 to 2.3 microns depending on deposited energy for perpendicular tracks; and (4) angular resolution of about 1.5 - 3 degrees from a single traversal for tracks tilted to the normal (19 - 56 degrees) using the pulse height in adjacent hit pixels, demonstrating the capability of pixel detectors to provide space points with correlated track directional information [1]. Last year's report can be consulted for further details, as well as a comparison of the advantages and disadvantages of pixels vs strips and monolithic pixels vs bump-bonded ones.

Larger, second-generation detectors with sparse-field readout had been fabricated for possible use in Fermilab experiment E781. They use a more robust back side and require fewer fabrication steps–23 fewer photoresist protection steps and using only 13 mask steps (14 when a scratch mask is added), 3 less than our earlier detectors. (For comparison, VLSI chips often take 15 - 20 or more mask steps; double-sided Hamamatsu silicon strip detectors take 12.) Their fabrication had been done in a manner similar to that used for the original Microplex chips–the first VLSI chip ever to be used for silicon-strip readout–and the first generation pixel detectors: by staff and students of the Center for Integrated Systems at Stanford University.

The circuit design was done by an electrical engineering graduate student under the supervision of a faculty member specializing in circuitry, rather than by an engineer or student working with the physicists who were going to use the chips. The resulting design had many clever elements that provided elegant solutions to the great demands of a rapid readout capable of preserving good analog information [2]. However, it did not have the same level of double-checking as did the earlier versions and there was only limited checking of the circuit and layout details by the faculty member. While the new process, on the first try, produced detectors that worked as well or better than those of the successful first generation devices, with all 1024 pixels working on the packaged chip used for gamma tests (compared with at least one or two bad pixels per 300 in the first generation) and individual circuit elements such as the analog pulse height output and the non-sparse field readout control that also were fine, vital components of the new sparse-field readout were not satisfactory.

This report covers work finished this year and that planned to follow on the E781 detectors:

(1) test results on the sources of the circuit problems;

(2) fabrication of detectors with circuit corrections;

(3) revised design–test results;

(4) additional tests;

(5) fabrication of detectors for installation in E781;

(6) testing of the radiation hardness of the existing circuitry; and

(7) a start on the development of radiation hardened circuitry.

It not certain that we will have the resources to complete a significant amount of work on (6) and (7) during the next year, despite their importance.

This report also describes a new development just now making the transition from planning, calculation, and design to fabrication of test structures, of a new 3-D architecture for solid state detectors that may produce ones with one order of magnitude greater speed and with two orders of magnitude greater hardness against the effects of bulk radiation damage than current detectors. During the coming year we plan to fabricate prototype versions of 3-D architecture detectors and test structures. Assuming the new architecture works, the tests of the hardness against bulk damage of the p-type silicon used in our monolithic detectors, mentioned in last year's report, will no longer be of much interest.

2.6.1 The E781 detectors

Sources of circuit problems

The initial E781 chips had:

(a) large pedestal variations in the analog pulse height readout due to the row-read logic signal making the transition off before the entire row is read out, with the edge altering the pixel reset value needed for a double sampling subtraction. (The pixel signal value, stored elsewhere, was still valid.) This timing error could be fixed with changes to the metal 1 and metal 1 to poly contact masks.

(b) oscillation in the column scanning logic for the 96 x 128, but not for the 32 x 32 array. A signal needed for proper operation was too slow due to capacitive loading. This can also be fixed with changes to the metal 1 and metal 1 to poly contact masks.

(c) large row threshold spread and offset in the sparse-field readout. This was due to another logic timing error that allowed the turning off of the transistors that isolated the pixel collection electrode from the pixel signal transistor during readout, rather than before. The rerouting of the control logic requires the addition of a second metal layer.

(d) large column threshold spread and offset in the sparse-field readout. This was due to an inadequate number of well contacts to the low impedance well busses. The resultant well currents have larger IR drops that couple unequally to the pixel signal and reference nodes once they have been isolated for readout. The well currents would not affect properly timed row readouts, as their discriminators should be set while data is coming in, prior to readout. The solution here is to use the metal 2 layer to provide the necessary well contacts.

Fabrication of detectors with circuit corrections

To test the revised design, four wafers that had been partially processed in the first E781 fabrication run were carried through the remainder of the fabrication steps including deposition of polysilicon and two layers of metal. Performing only a partial fabrication run instead of starting an entirely new run with more wafers, allowed us to check the circuit modifications sooner. Three masks had to be modified and two additional masks added to provide a second metal layer. Several mishaps occurred during fabrication of the repaired chips: two wafers suffered uplifting of their polysilicon/tungsten, one wafer broke in a resist-strip bath, and there was scattered peeling and flaking off of the first metal layer. These problems combined to result in only one of the original four wafers being usable.

One useful lesson learned from this refabrication run: when a machine you were about to use goes down, don't try to make up lost time by being the first to use it after it is fixed—at least not with your good wafers. Both the polysilicon and metal problems occurred under those circumstances. Even one trial run with several test wafers proved insufficient this time.

Of the 28 smaller (32 rows by 32 columns) pixel chips on the one surviving wafer, only three chips clocked out and just one chip was fully functional; the rest had fatal short circuits. All results for the repaired chips are from tests performed with this chip. All of the 17 large (128 rows by 96 columns) pixel chips appear to have metal shorts that prevent them from operating properly. Given the large fraction of small chips with shorts, it's not surprising that the large detector arrays all had fatal shorts. This high number of metal shorting problems may result from the peeling problems observed during fabrication. The bulk PIN diodes seem to function reasonably well with leakage currents similar to those seen in the first set of E781 detectors and depletion voltages of around 45 volts.

Revised design: test results

(a) The pedestal variations have been reduced from a full width of about 3 times to less than 0.5 times the signal expected for a minimum-ionizing particle (MIP). As a result the dynamic range of the system is limited by the signal expected in the actual experiment and the saturation point of the output amplifiers, not by the pedestals.

(b) Even though all the large chips had short circuits, some large detectors could be made to clock out. The observed output possessed the correct time structure at both the row and individual pixel level. This, combined with the fact that the small chips had the same control logic and functioned well, leads to the conclusion that this problem is fixed.

(c) The row threshold offset has been reduced from -1.0 MIPs to +0.25 MIPs, and the row threshold spread reduced from 1.0 MIPs to 0.25 MIPs. These improved values are close to the expected performance and are probably satisfactory for use in E781. Regretfully, this performance only holds while the detector's PIN diode is undepleted. The effects of depletion will be discussed later.

(d) The column threshold offset has been reduced from +1.0 MIPs to +0.1 MIPs, and the column threshold spread reduced from 0.7 MIPs to 0.25 MIPs. These improved values are still a bit higher than expected, but may suffice for use in E781. Here too, this performance only holds while the detector'ss PIN diode is undepleted.

Thus, all four problems with the initial, E781 pixel detectors were corrected by the circuitry modifications.

Infrared light was used to illuminate the chip, because it can penetrate into the bulk to create electron-hole pairs, using both the sparse read out mode and the readout of the entire array. Reasonable changes in the analog pulse heights and in the number of pixels and rows of pixels being read out indicate that the detector is reacting properly to the infrared signal. The noise associated with the analog signal from each cell is 6 mV—the same level as for the initial chip, which had a most-probable signal for a minimum-ionizing particle of 50 times the single-channel, root-mean-square noise. Event displays depicting the signals from Am-241, 60 KeV gamma rays were shown in last year's proposal (Figure 2.22). Gamma rays have not yet been observed with the repaired chip, so its signal-to-noise is not yet known.

There is one remaining problem: both the row and column threshold widths and offsets increase significantly when the detector's PIN diode is depleted. The column threshold width increases from 0.2 MIPs to 0.55 MIPs and the offset from +0.1 MIPs to 0.6 MIPs. The row threshold width increases from 0.2 MIPs to 1.5 MIPS and the offset from +0.25 MIPs to 2.0 MIPs. The analog pedestal levels also increase when the device is depleted. This behavior is not understood, although some type of leakage current is suspected.

Further testing has revealed that the effects of depletion on the column threshold are independent of the signal integration time, but depend quite sensitively on temperature. The temperature dependence is compatible with leakage current from the depleted bulk, but the lack of dependence on integration time is not. On the other hand, the row threshold's behavior depends sensitively on the integration time, but only slightly on the temperature. Behavior of the row thresholds is complicated by the fact that the row amplifiers may be operating in a non-linear regime. It appears that this detector can be operated at low temperatures—about zero degrees Celsius—and with integration times of up to 3 microseconds in a way that would meet the needs of E781. Additional work is needed to verify this.

Additional Tests

The question of whether the large chip functions as well as the small chip is unanswered because of the short circuits affecting all the large chips. An attempt to locate the shorts will be made using a technique involving liquid crystals with a transition point that is temperature sensitive. This involves coating the large pixel chip with liquid crystals, powering up the chip, and visually observing over what areas of the device the liquid undergoes a phase change. This is a technique commonly used in the semiconductor industry, and will be performed by a local company. If a large chip can be found with a small number of well localized shorts, we would attempt to fix the shorts using a focused-ion-beam machine as was done with the first generation of monolithic pixel chips.

Fabrication of detectors for installation in E781

Producing a complete set of functioning large detectors for E781 will require another complete fabrication run. This would start with twenty or more wafers with about 30 large chips on each wafer. With a reasonable yield this would provide an ample number of large chips. This full run would use the existing repaired mask set. The fabrication run will start soon, but may wait for results with the large chips.

2.6.2 3D–A new architecture for solid state detectors

Problems with using silicon detectors at future colliders: The technology that made silicon strip detectors practical and brought them into common use in the last decade is described in three papers that were presented at the Third European Symposium on Semiconductor Detectors in 1983. Two were on the first custom VLSI readout chip—one already in fabrication at that time [3] and one that was in design [4]—and one on the planar fabrication technology that could be used to make reliable detectors [5]. Planar technology, in which all the fabricated elements are within a few microns of the surface of the silicon wafer, continues to totally dominate both VLSI and detector fabrication. In future colliders such as the LHC, these detectors will be exposed to high radiation fluences and face serious problems that have no immediately clear solution: radiation damage to the bulk silicon that causes it to become increasingly p type, eventually requiring a depletion voltage so large that the detector breaks down [6]. The inner layers with pixel readout have a particularly severe problem and the innermost layer is not even expected to last much beyond the initial low intensity running (for B physics).

Proposed partial solutions: Several partial solutions have been proposed, including:

(a) the use of thinner detectors which decreases the available signal and increases the probability of wafers breaking in fabrication;

(b) the use of partially depleted detectors which precludes the use of double sided readout; and

(c) the use of operating temperatures around -10 C, with only about one day per year allowed at room temperature for damaged detectors[6].

Other research indicates that the electrical activation of boron impurities (interstitial boron combining with a vacancy) may be responsible for the temperature dependent long term annealing which increases the p-type impurities and the depletion voltage [7]. Should this be the case, low boron content could help. However, boron is the most difficult of all elements to separate from silicon in float zone refining.

A second problem arises from silicon strip detector charge collection times of about 30 ns, a bit longer than desirable with a beam crossing interval of 25 ns [8].

The 3-D solution: We propose a radically new approach that uses 3D collection electrodes that penetrate the bulk material of the detector. (This idea was triggered by a third problem that effects ongoing GaAs detector work, that of short lifetime and collection distances.) Figure 2.36 shows a view of one possible arrangement.

The key elements that make this technology possible are:

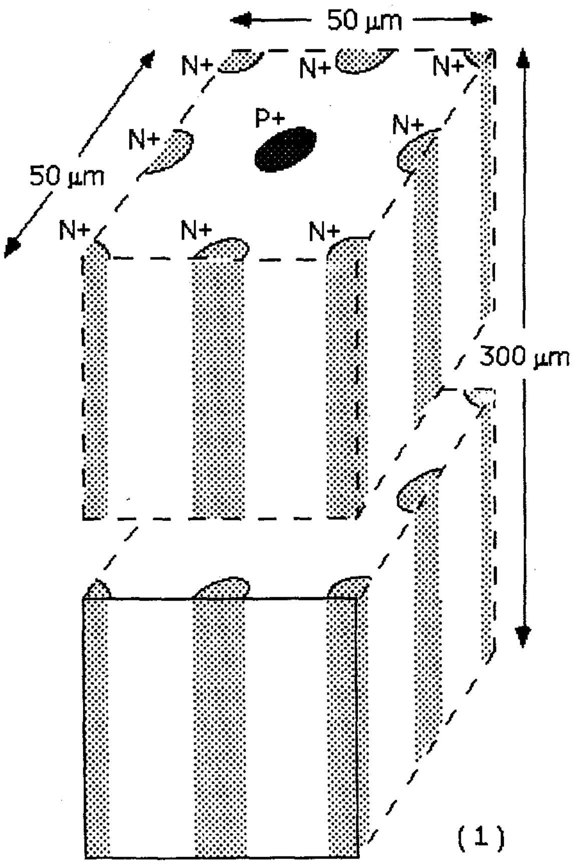


Figure 2.36: A three dimensional view of a typical cell for a detector based on the proposed 3-D architecture.

(a) Deep, reactive-ion etching now permits holes to be made with depth-to-width ratios of over 15:1 and with silicon-to-oxide-mask etch rate selectivity of greater than 300:1 or silicon-to-photoresist selectivity of greater than 50:1 [9]. The absolute etch rates (about 5 microns/min) are also high.

(b) The holes can then be filled with silicon made by the surface reaction of silane, which will bounce off the silicon surfaces thousands of times before reacting, thus depositing silicon as readily near the bottom as the top.

(c) Similar behavior by dopant gases such as diborane and phosphine, when added to the silane, allows the fabrication of n+ and p+ electrodes. All of the three gases will form conformal coatings without clogging the top of the hole before the bottom can be covered.

(d) The silicon layers deposited simultaneously on the wafer surfaces will have a thickness somewhat greater than the hole radius, and can be readily removed by etching.

The fabrication steps following electrode formation can be varied to produce monolithic pixel detectors, bump-bonded pixel detectors, and strip detectors with or without on-chip driving electronics associated with the bulk electrodes. Proposed devices of each type will be described, with the most detail for the simplest ones, which we plan to fabricate first: diodes for DC and capacitance tests and for bump-bonded pixel detectors. Although we are concentrating here on a silicon device, it is possible that GaAs ones could benefit even more, as large thicknesses could provide good x-ray and gamma-ray detection efficiencies but for their drift-length limitations. Here it could be possible to provide electrode spacings that are less than those drift length limitations. The short maximum drift distances combined with the high electron mobility of GaAs will also produce an extremely fast detector.

Additional details are given in a paper presented at the Third International Workshop on Semiconductor Pixel Detectors for Particles and X-rays in Bari, Italy, March 1996, and submitted to Nuclear Instruments and Methods [10]. One development since that paper is the realization that CMOS electronics can, in all probability, be placed directly over the pixel array, as well as along the borders. With current, monolithic detector technology, that would require a relatively difficult well within a well (a P well entirely within an N well). In 3D devices with alternating columns of P and N collection electrodes, a column of P and N collection electrodes could be separated by columnar N and P wells making sequences: P(collection) - N(well) - P(well) -N(collection) - P(well), etc. Detailed simulations of these structures, however, have yet to be done.

Fabrication of 3D-architecture detectors and test structures

A set of masks for simple detectors and test structures has been under design for several months and should be finished soon. It is hoped their fabrication can be done together with that for the E781 detectors, since a substantial fraction of the time in the clean room is spent waiting for specific processes to complete. A second project could utilize this time. Also, Stanford student Segal, having largely completed the work needed for her thesis, is interested in 3D technology, and plans to help in this first fabrication run. Having her help would be extremely valuable as she had considerable experience in designing fabrication processes in industry before coming to Stanford. The longer of the two projects, taking many more masks steps, is one for E781. It may be possible, but will be difficult, to finish it in time for the next major shutdown at Fermilab in December, 1996.

Kenney has started to learn fabrication technology, and Parker plans to learn to use several plasma etching machines that will be key to the 3D technology. Nevertheless, when Segal completes her Ph.D., the only experienced person will be C. Storment, who specializes in micromachining, and is interested in collaborating with us for one key part of the initial fabrication run. Starting with a new graduate student of Stanford EE professor Plummer may be possible although that always involves a delay of a year or more, while the student spends most of the time on courses. So a major question on our ability to proceed expeditiously and still be involved in physics experiments is currently unanswered.

2.6.3 Testing of the radiation hardness of the existing circuitry

Understanding the effects of changed structures and fabrication steps for radiation hardening requires the determination of the baseline hardness of the current devices. It would also be desirable to know, in advance, how any detectors installed in Fermilab would fare.

A start on the development of radiation hardened circuitry

It is planned initially to make use of the extreme bulk hardness inherent in 3D devices by bump-bonding them to already designed radiation hard readout chips. However, minimal input capacity and optimum performance would come from monolithic devices, such as the CMOS structure mentioned above. In addition, with the decrease in military budgets, several companies, both here and in Europe, that had indicated interest in providing readout chips for pixels have now left the field. Sandia engineer W. Dawes, who invented their key rad hard field oxide process, has expressed interest in helping us, and has already made a trip here for that purpose. He has expressed a continued interest in working with us, and it could be quite important for high energy physics to have some independence from the uncertainties of that particular marketplace.

Nevertheless, given our limited time and resources, it is clear that these latter items must be lower in priority than the other items.

References

1. C. Kenney, S. Parker, V. Peterson, W. Snoeys, J. Plummer, and C. Aw, "A prototype monolithic pixel detector", Nucl. Instr. and Meth. **A 342**, (1994) 59-77.
2. Chye Huat Aw, "CMOS circuits for integrated particle detection and imaging arrays", July 1996, thesis, Integrated Circuits Laboratory, Stanford University, Stanford, CA.
3. J. Walker, S. Parker, B. Hyams, and S. Shapiro, "Development of high density readout for silicon strip detectors", Nucl. Instr. and Meth. **226**, (1984) 200-203.
4. R. Hofmann, G. Lutz, D. Hosticka, M.Wrede, G. Zimmer and J. Kemmer, "Development of readout electronics for monolithic integration with diode strip detectors", Nucl. Instr. and Meth. **226**, (1984) 196-199.
5. J. Kemmer, "Improvement of detector fabrication by the planar process", Nucl. Instr. and Meth. **226**, (1984) 89-93.
6. J. Matthews, P. Berdusis, J. Schuler, H. Sadrozinski, K. O'Shaughnessy, A. Palounek, and H. Ziock, "Bulk radiation damage in silicon detectors and implications for ATLAS SCT", ATLAS internal note INDET-NO-118, 12 Dec. 1995.
7. R. Wunstorf, W. Bugg, J. Walter, F. Garber, and D. Larson, "Investigations of donor and acceptor removal and long term annealing in silicon with different boron/phosphorus ratios", presented at the 7th European symposium on semiconductor detectors, Schloss Elmau, Germany, 7-10 May 1995.
8. AR. Sonnenblick, et al., "Electrostatic simulations for the disign of silicon strip detectors and front-end electronics", Nucl. Instr. and Meth. **A310**, (1991) 1889- 191.
9. K. Petersen, D. Gee, F. Pourahmadi, R. Craddock, J. Brown, and L. Christel, "Surface micromachined structures fabricated with silicon fusion bonding" Proc. Transducers **91**, (1991) 397; C. Hsu and M. Schmidt, "Micromachined structures fabricated using a wafer bonded sealed cavity process", Tech. Digest, IEEE S.S. Sensors Workshop, Hilton Head, SC, 1994, p 151; E. Klaassen, K. Petersen, J. Noworolski, J. Logan, N. Maluf, J. Brown, C. Storment, W. McCulley

and G. Kovacs, "Silicon fusion bonding and deep reactive ion etching–a new technology for microstructures", Transducers, **95**, (1995) 556; K. Murakami, Y. Wakabayashi, K. Minami, and M. Esashi, "Cryogenic dry etching for high aspect ratio microstructures", Proc. IEEE Microelectromechanical Systems Conference, Fort Lauderdale, FL, (1993) 65; A. Furuya, F. Shimokawa, T. Matsuura, and R. Sawada, "Micro- grid fabrication of fluorinated polyimide by using magnetically controlled reactive ion etching", Proc. IEEE Microelectromechanical Systems Conference, Fort Lauderdale, FL, (1993) 59; V. Lehmann, W. Hnlein, H. Reisinger, A. Spitzer, H. Wendt, and J. Willer, "A new capacitor technology based on porous silicon", Solid State Technology, 38 (1995) 99.

10. S. Parker, C. Kenney, and J. Segal, "3D–A new architecture for solid-state radiation detectors", submitted to Nucl. Instr. and Meth.

Chapter 3

Non-Accelerator Experiments

3.1 SuperKamiokande/KEK, Neutrino Oscillations Experiment

Drs. J. Learned, S. Matsuno, V. Stenger, and Messers J. Flanagan and D. Takemori

The SuperKamiokande experiment is now operating and acquiring excellent quality data in the Mozumi Mine in Western Japan. The Collaboration is a descendant of the old IMB Project, active from 1980 until 1993 in a salt mine beneath Freeport, Ohio. With the end of the very successful IMB project the Collaboration, along with new members, joined with the Japanese Kamioka group in the SuperKamiokande Project, building a detector ten times larger and substantially more sensitive than IMB.

With the observation of an anomaly in the muon neutrino to electron neutrino ratio in IMB and then in Kamioka, with one interpretation being that the effect is the result of neutrino oscillations, the group has studied the efficacy of an accelerator-produced beam being transmitted from KEK to Kamioka, some 300 km distant. This program is moving ahead.

3.1.1 Overview of SuperKamiokande

SuperKamiokande (SK) started taking data on 1 April 1996, as scheduled several years previously. The already accumulated data on solar neutrinos, contained neutrino interactions, and throughgoing muons from cosmic rays and neutrinos are probably of publication quality; below we show some pictures of the first events. A major (and happy) problem is dealing with the volume of data, which amounts to some 20 gigabytes of raw data per day.

The Detector

The SuperKamiokande instrument is a 50,000 ton water Čerenkov detector contained in a cylindrical tank of 34 m diameter by 36 m high. It is located in a former zinc mine in the Southern Alps of western Japan, and is accessible via road tunnel. The construction was completed in December 1995 and filling began on 26 December. The tank has an inner structure, rather like a "jungle jim," on which 11,146 Hamamatsu 20" diameter photomultipliers are mounted facing inwards, comprising the inner detector (ID); 1,827 of the old IMB 8" tubes, with 60 cm wavelength shifter plates, are mounted facing outwards into a two meter thick annular veto region called the outer detector (OD).

Initial Performance

Although we had anticipated that the water transparency might be poor at first and that Radon levels might be too high to allow detection of solar neutrinos in the early days of data-taking, that has proven not to be the case. As illustrated in Fig. 3.1, the SK Radon levels are already below those of Kamioka III, and are decreasing with time. Some things about the rate are not yet understood: the effects of the mixing of the filtered water, decay of Radon, and the dissolving of residual dirt that was in the detector all add complications. A small, few gallon per minute, leak requires makeup water, but the Japanese collaborators have the situation under control, and divers have reduced the leak (around a weld on the bottom) to minimal levels (few gallons per hour). Also a new radon system is being installed to clean the makeup water.

Similarly the water transparency has been good since turn-on, and continues to improve. As expected, the water near the top (the tank is filled from the bottom and water is recycled from the top) is less transparent. As happened in IMB, the water is becoming so transparent that measurements of that transparency are difficult; in any case, the characteristic attenuation length is greater than about 40 m, presenting no problem for the data. Plans are in motion (in which Hawaii will be an active participant) to measure both the spectral transmissivity and scattering functions better than was done in IMB and Kamioka, but this is at the level of fine tuning our understanding of the detector performance, mainly in terms of energy reconstruction as relating to the solar neutrino spectrum.

Phototube performance is excellent, with failures now at the level of less than 1% in the inner detector, six months after installation. The flasher problem, familiar from IMB, persists and measures are being instituted to identify and disable these tubes. At first we saw what appeared to be a high rate of outer detector PMT failures, but this may be stabilizing (the current total of dead PMTs is less than 100).

Some annoyances with electrical crosstalk between inner and outer detector have been found, mainly with outer detector hits being picked up on inner detector channels. These events have a characteristic and non-physical behavior and can

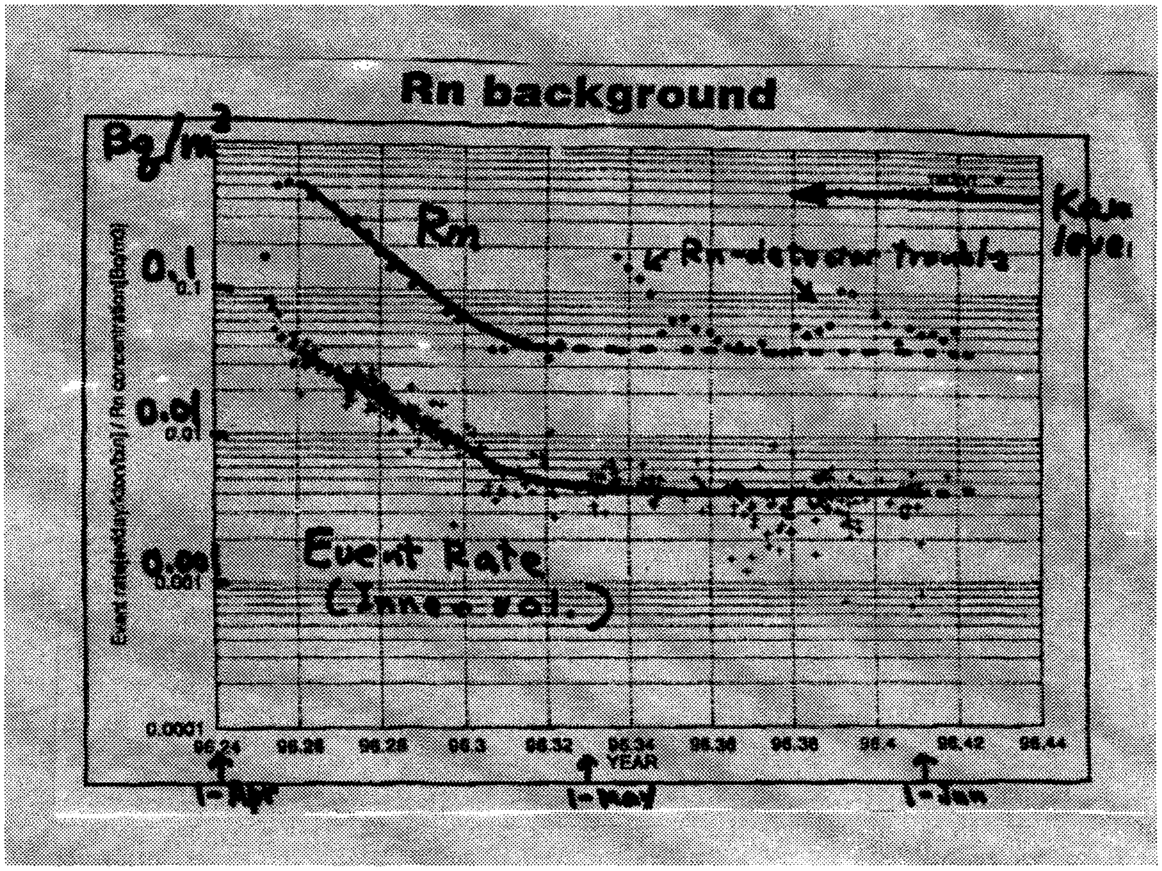


Figure 3.1: Radon level and inner detector event rate as a function of time since turn-on.

be easily eliminated. However, concern for its possible implications for energy resolution has made us pursue the issue, and at present we are testing reduction of the OD PMT voltages and discriminator thresholds. This would have the added advantage of reducing the OD noise rate, and the amount of data to be stored.

There are a number of small problems with the OD electronics. Studies are preceding of the precise setting of acceptance time windows around events (in order to minimize trash data recording), precise systematics of the energy calibration, etc. Plans are underway to reduce the OD data window from 32 μsec to 16 μsec. All of these are of secondary priority to collecting useful data, and are issues on which we can back-calibrate.

The trigger can be adjusted to almost any value by changing the energy threshold. We currently run with a trigger rate of 10 Hertz with a 5-6 MeV threshold. The conversion constant is roughly 6 photoelectrons/MeV. The noise rate in the inner detector is about 10kcs per PMT. Tests have been made of the data recording system up to rates of 50 Hertz. Note that the volume of data does not increase as much as one might think with lower threshold, since the newly-included events are relatively small (typically 50 PMTs in the ID). The first throughgoing muon, seen on turn-on day April 1, is shown in Figure 3.2. It illuminates approximately 7000 PMTs, and since these occur at about 3 Hertz, these muons dominate the data collection volume.

The high data rate makes it necessary to filter the data on-line. Simply identifying muons and fitting them in real time will get rid of the bulk of the data. The philosophy being taken is to fit the events we understand and do not wish to save (downgoing muons, corner clippers, caterpiller events where the muon goes through the PMT structure behind the PMTs, entering stopping downgoing muons) and save only summary information. This way events we do not understand will be kept, along with all neutrino interactions and any candidates for this includes nucleon decay. Reliable, fast, and accurate single muon fitting is thus a high priority, and several US collaborators are working upon various strategies for such a fitter, Hawaii being one such group; our preliminary results are described below.

The first neutrino event seen on April 1 is shown in Figure 3.3. We expect about 10 per day in the inner detector (ID) with energy between 100 MeV and 2 GeV. Solar neutrinos already have been culled, and we have an apparent signal from the Sun, as shown in Fig. 3.4, where the angular distribution of low energy events relative to the Sun's direction is shown. The peak, containing about 20 events, is not of scientific significance as yet, but illustrates that the signal is present in SuperKamiokande, and at a similar rate as was found in Kamioka (the solar deficit has not gone away). Indeed data now reduced from the first 29 live days has roughly the same statistical weight as the sum of all previous solar neutrino data. Refinements will, however, wait until we have more data collected, and more careful analyses of energy thresholds and efficiencies. We expect a first publication

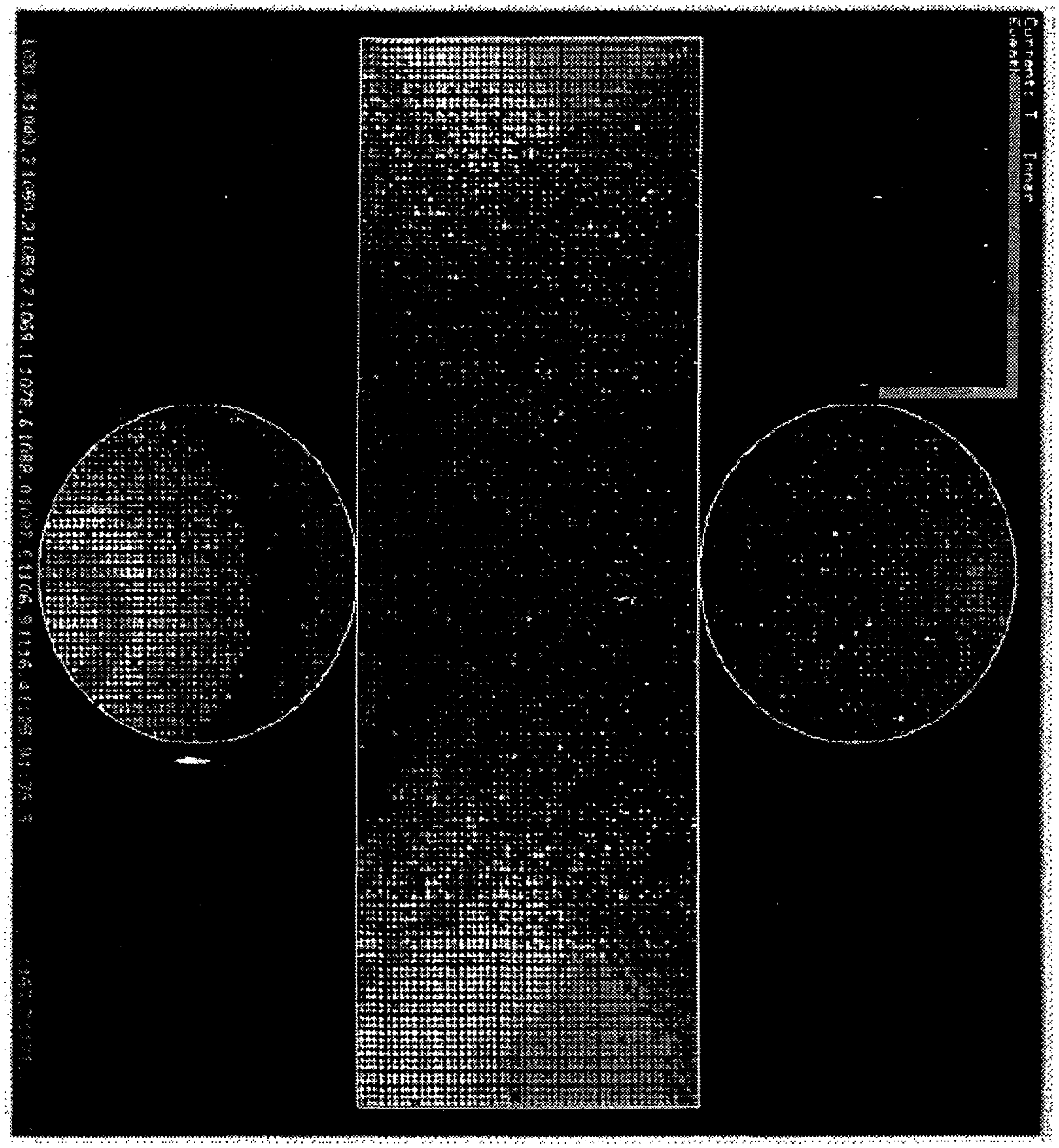


Figure 3.2: A throughgoing muon seen on April 1, 1996, the first day of data taking in SuperKamiokande.

in this area around the end of 1996 when the statistics will have well surpassed previous work and the systematics are understood quantitatively.

Figure 3.3: A neutrino-event candidate seen on April 1, 1996, the first day of data taking in SuperKamiokande.

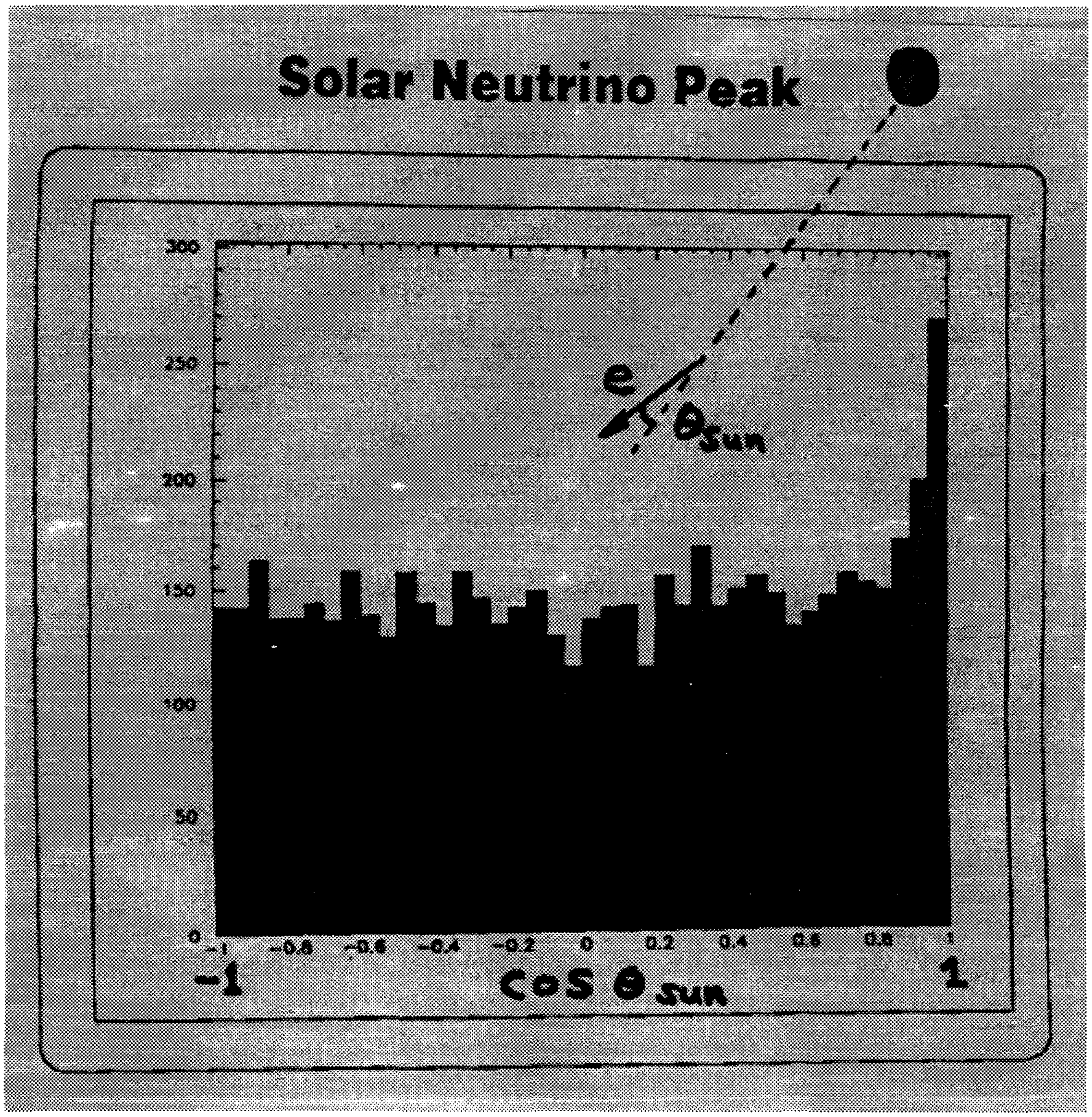


Figure 3.4: A plot of the angular distribution neutrino events over a 27 day period showing a peak in the direction of the sun.

The data analysis tasks are divided into three groups: low energy (solar and supernova), high energy (contained and semi-contained neutrino interactions), and muon (upcoming muons, stopping muon, entering events, cosmic ray muons). We discuss the Hawaii role in these below.

3.1.2 Hawaii Role in SK

Calibration Responsibilities

The UH group was initially in charge of the US calibration efforts in SK. As such we organized contributing efforts from other institutions, in particular for the laser light diffusing balls and the radioactive sources from Maryland, and the purchase of fiber optic equipment from BU and some other related equipment from UCI.

Hawaii student Flanagan has been resident in Japan for the last two years, and has made major, recognized contributions in several areas. His ability with the language makes him invaluable and often results in his being deflected from his assigned tasks to help solve general problems. Co-spokesperson H. Sobel, of UCI, has described Flanagan as "more like a post-doc than a graduate student," and several others have reported to us that in their view he is the best of all the graduate students on the project, in the Japan and U.S. groups.

The calibration equipment was installed in time for the start of filling, and initial OD calibrations were made and installed in the on-line program this Spring. Flanagan has worked daily with the resident calibration team at Kamioka and in particular with the laser ID calibrations, which are employed for the precise time calibrations.

As of now, calibrations are settling in to be a regular maintenance item, but one which of course requires constant vigilance, lest there be drift in the detector sensitivity. For some time in the future (a year?) calibrations will be taken monthly until the drift pattern (if any) is tabulated and stabilizes. We propose that Hawaii student Takemori move to SK, to be resident in Japan for most of the year. He will be the UH responsible individual for calibrations, with help from Flanagan.

UH is also involved in designing a device for track calibration, and another device for trapping photons after injection of a collimated laser beam. The light trap is nontrivial as it must not backscatter more than one in a million entering photons.

Hawaii Role in Muon Analysis

Matsuno has been appointed co-convener of the US Muon Working Group that will be developing fitters and other techniques for the analysis of muon data. All Hawaii SK personnel are part of this group.

As mentioned above, rapid filtering of through-going muons is highly desirable in order to collect these events efficiently. In the course of his DUMAND Monte Carlo simulations, Stenger developed a muon fitter that appears to be useful for this purpose. The fitter gives an approximate solution to the muon position and direction directly, without carrying on the usual time-consuming iterative search for the best chisquare. He is currently testing this out for SK using Monte Carlo data and preliminary results are promising. In particular, he has reconstructed 1 GeV muons going straight up the center of the tank with a mean point error of 0.6 degree, a level good enough for physics analysis.

Flanagan and Learned are also developing a fitter employing vectors fit to the light arrival direction in neighborhoods of groups of 12 PMTs. These vectors are then used to calculate the direction cosines of the muon or muons that have a dot product with these vectors which is the cosine of the Čerenkov angle. This trick thus yields a direction of particle travel without having fit for track location, and, in principle, should work for multiple muons as well as single muons. This method also has the virtue of being fast, since it can be solved in closed form.

Multiple muons have become somewhat of a problem in occupying a large fraction of the bulk of data after the first reduction pass, and a multi-muon fitter is needed by the low-energy analysis group to identify locations for possible spallation events (a limiting background for solar neutrinos). So, both fitting routines will be tried for this purpose, as well as extracting physics. While muon fitters are being written at other collaborating institutions, Hawaii's experience with this problem and general interest in throughgoing muons guarantees us a strong role in their development and implementation as collaboration tools.

General Analysis Techniques

During the IMB experiment, UH collaborators specialized in the analysis of throughgoing muons. Many programs and techniques were developed for this, some of which are documented in the dissertations of Svoboda, Dye, Becker-Szendy and McGrath, and in internal notes by Learned. We will bring these up to date, as appropriate for SK. Neutrino astronomy will be a continuing subject, although we now think the detection of point sources unlikely with a 1600 m^2 effective area underground instrument. A long shot with high payoff will be to monitor for coincidences with gamma ray bursts.

One area where we can surely make significant progress is in searching for high energy through-going muons, as might be due to UHE neutrino production from active galactic nuclei (AGNs). The recent TeV gamma ray observations of Markarian 421 and 501 (both blazars) by the Whipple gamma ray observatory (and now confirmed by others) give credence to UHE neutrino production, as was confirmed by the gathered astrophysicists at the High Energy Neutrino Astronomy Workshop at the Aspen Center for Physics last month (27 May - 9 June).

Data from SK will permit significant limits to be placed upon greater than 10 TeV neutrino fluxes from AGNs, if none are seen. The more optimistic models (Szabo and Protheroe 1995) predict events at about the rate of one per month in SK, although new models presented at Aspen suggest lower fluxes at low energies.

An experimental question remains as to whether the detector will respond well enough to permit identification and reconstruction to events as bright as these (indeed in IMB we never could extract this possible signal from the light blasts due to downgoing muons making electromagnetic cascades due to bremsstrahlung or pair production). With the employment of the veto layer and the excellent ID electronics it may now be possible, though not yet guaranteed. However, scanning online events gives encouragement that the US-built veto layer will prove decisive in this application: that is to say we have seen huge events where the inner detector was near saturation, but the entry and exit spots were clearly discernible with the use of the outer detector.

KEK Neutrino Oscillations Experiment

The Collaboration is in the process of preparing a proposal to DOE for participation in a long baseline neutrino oscillation experiment between KEK and SK, with one or more intermediate detectors. The proposal will be submitted in a few months to the DOE.

SuperKamiokande Project Management

The SK Council member from UH is Learned, with Stenger as Alternate. We participate in decision making at the senior level when needed, though most decisions within the US group are taken in the IMB traditional collegial style of consensus management. Matsuno is also assuming more of a leadership role, consistent with his experience on IMB and familiarity with the Japanese system.

In general it should be said that things are going well in SK communications and personnel relations, despite some interesting sociological differences between the Japanese and US contingents. The good will and excitement has carried us along so far, and we hope to keep smooth relationships working for the long haul. There is friction among some who feel that the US bought into the SK project with a large group at an unreasonably low price (less than 5 percent of the construction cost, yet an almost equal numbers of signators for papers). Much of this will be tempered by efficient and timely data analysis by US groups, which is an enormous task in which there is no surplus of manpower on either side. We are attempting to employ the double analysis plan which worked so well in IMB (East and West Coasts), between US and Japanese analysis groups. There is significant crossover between groups, mostly with US scientists working with the Japanese, which we hope will make for keeping the natural competition between teams at a healthy level and yet not becoming too great.

SAGENAP on SuperKamiokanda

In this regard, we quote from the summary of the reviews of Super-Kamiokande by the SAGENAP panel: "Some concern was expressed that the US groups lack strength and resources in the data analysis effort to maintain a highly visible US participation. A continued strong support by DHEP for the US groups is recommended . . ." We believe that the demise of DUMAND makes this an opportune time for Hawaii to make a significant impact on the US SuperKamiokande effort.

3.1.3 Personnel and Budget

We propose to substantially increase our participation in SK by moving over most of the effort previously devoted to DUMAND. A budget of $227K is shown. Personal costs include Stenger's summer salary and Matsuno's full salary. Graduate student Takemori is also moved over from DUMAND. His and Flanagan's salaries are listed as off-campus on the assumption that they will both spend most of the year in Japan.

We request $1,500 for communication costs, which include a monthly video conference of one hour duration.

Other than $5K for miscellaneous materials and supplies in Japan, the remainder of the budget request is for travel and maintenance in Japan. Maintenance costs of $20K are requested. This will cover only minimal living expenses and one trip back to Hawaii for each student. For example, if both students spend 11 months at Kamioka, $20 per diem, which assumes free lodging in the UCI apartment and free transportation, comes to $13,200. These funds will also be considered off-campus for overhead purposes.

Each collaborating group is obligated to staff a minimum of 32 shifts per year per physicist, which comes to 160 total shifts for Hawaii. The bulk of these will be covered by the two Hawaii students stationed in Japan. Additionally, each collaborator is expected to put in a minimum of 2.5 weeks of shifts per year to earn his or her place on the author list. Minimal funds for four trips totaling 8 weeks for three faculty (Learned, Matsuno, and Stenger) are requested, for a total of $10K. In addition, $5K and $4K are also included for foreign and domestic trips, mostly to collaboration meetings.

3.2 The DUMAND Project

3.2.1 Search for UHE Cascades in DUMAND SPS data

Drs. P. Gorham, J. Learned, S. Matsuno, V. Stenger, and Mr. J. Bolesta

We are in the processs of performing a reanalysis of the DUMAND I (Short Prototype String, or SPS) data to search for evidence of events which might be attributable to ultra-high-energy cascades, presumably due to neutrinos from active galactic nuclei (AGN). At the time of the SPS experiment, the possibility of a cascade-type signature of UHE neutrinos had not been realized, and the data have not yet been analyzed with this possibility in mind. In fact, only a relatively small fraction of the 30 hrs of livetime has been analyzed to date, because the earlier efforts concentrated only on the cleanest data to demonstrate the functionality of the system as a proof-test for further phases of DUMAND.

Initial Monte Carlo studies of the SPS sensitivity to UHE cascades indicate that even under conservative assumptions, the effective volume of the 7-OM string is at least $\sim 10^7 m^3$ at 10^{15} eV. Thus, the 30 hrs of data now being analyzed can yield an interesting limit on the presence of such events that is below any presently available result, including those of UHE air showers and other Čerenkov detectors. This is due to the fact that the ocean water clarity is much higher than a lake such as Baikal, and the effective scattering length is a factor of 20-30 larger than that of Antarctic ice. Moreover, an ocean-based detector sees a much greater number of nucleons than do air-shower arrays; thus the neutrino target volume is significantly higher at these high energies than an EAS array that scans a much larger area.

New ocean optical attenuation results

Initial results of the reanalysis have already yielded a much improved measure of the diffuse attenuation length of the water at the DUMAND site. This is shown in Fig. 3.5. The plot shows the apparent intensity seen at the five different distances of the 7 SPS optical modules from the calibration module, corrected for the r^{-2} decrease. The remaining exponential slope corresponds to an attenuation length of ${33.8_{-6.0}}^{+9.1}$ m at 410 nm. This is an improvement of more than a factor of two in the uncertainty of the previous analysis (Clem 1990).

In the deep ocean, the wavelength of minimum attenuation is about 480 nm. Extrapolating these data to 480 nm using previous measurements of spectral variation (cf. Zaneveld 1980), gives an effective diffuse attenuation length is ${68_{-12}}^{+18}$ m at 480 nm, consistent with other sites of extreme clarity in the deep ocean.

These data have also allowed us to set lower limits on the mean free path for molecular and particle scattering, which is important for cascades that originate

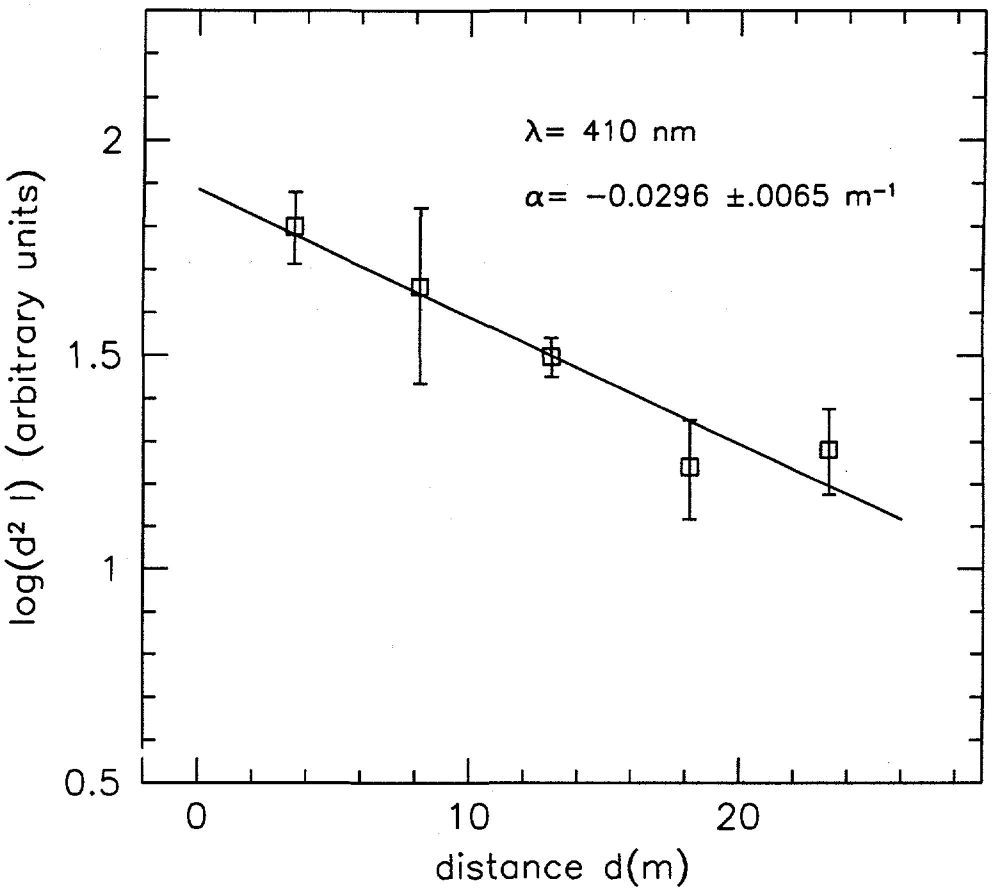


Figure 3.5: New diffuse attenuation length measurement with DUMAND SPS data. The coefficient α is the inverse attenuation length.

hundreds of meters from the string. At present, we find a mean free path of $\lambda_{mfp} > 90$ m, which is consistent with estimates made from measuring particulate concentrations at the DUMAND site (Zaneveld 1980). The expected mean cosine of the scattering angle of about 0.80. Since most of the scattering is forward, the light from a distant event may scatter a number of times and still arrive at the detector in adequate proximity in angle and time to the unscattered path; one defines an effective scattering length:

$$\lambda_{eff} = \frac{\lambda_{mfp}}{1 - < \cos(\theta) >}, \tag{3.1}$$

where θ is the scattering angle. For the DUMAND site this gives $\lambda_{eff} = 400$ m, about six times the absorption length.

Plans & schedule

Initial efforts have concentrated on adapting improved Monte Carlo routines to simulate the SPS data accurately, in order to provide reliable background estimates. A cascade event is expected to produce a bright "plane wave" that triggers all seven OMs at levels greater than 5 photoelectrons per module. In contrast muon events on average only trigger 5 OMs at the 1-2 photoelectron level. Thus, the background for cascade-type events is expected to be very small, coming primarily from muons passing close to the string with some timing fluctuations causing them to be misfit as a plane wave. Some effort will be required to make software fitting routines that can consistently distinguish the cascade events. Hawaii student Bolesta is focussing his efforts on this program for his doctoral dissertation. We expect to complete the final analysis of these data later this year, when Bolesta will then concentrate on producing publications and completing his dissertation.

3.2.2 DUMAND Closeout

On 21 June 1996 we received the official word that DOE will no longer fund the DUMAND Project. This followed the recommendations of the SAGENAP report (P.K. Williams of DOE, Chairman), the results from the DOE-hosted 20 February 1996 review of DUMAND and other non-accelerator projects. For purposes of this renewal proposal we propose a closeout budget of $50K assuming a full shutdown of DUMAND. This budget includes the salary of one graduate student for a terminal one year to finish his Ph.D thesis. It also includes requested funds for student help to clean out the facilities used and scrap or salvage the hardware, travel to NELH for cleanup at that site, and some storage and shipping costs.

Personnel

Currently two graduate students have their salaries charged to DUMAND, Bolesta and Takemori. We propose to move Takemori to the SuperKamiokande effort and retain Bolesta as part of the DUMAND close-out budget so he may finish up his Ph. D. thesis on DUMAND subjects, including the documentation of the many calibrations and tests that have been performed. Additionally, as discussed above, he and Gorham are reanalyzing the data from the SPS runs of a few years ago. This shows promise of yielding better ocean optical data that earlier and limits on neutrinos from AGNs. We anticipate at least one publication on this subject.

At the faculty level, Matsuno has been a long term veteran of both DUMAND and IMB (he was resident manager for the IMB experiment for several years in the late 80's). He is currently participating full time in the SuperKamiokande project, where he has already made contributions and been elected as a leader of one of the three analysis groups. Likewise, Stenger is devoting all of his research time to SK. See the SK sections of this request for further discussion.

Equipment Ownership

Previously we have assumed that all DUMAND apparatus purchased by Hawaii under this grant was State of Hawaii property. However, we have learned that significant portions of DUMAND equipment are listed in our inventory as Federal property. One item that is potentially troublesome is the disposal of the DUMAND fiber optic cable and equipment attached to its end, 30 km offshore from Keahole Point and at 4.8 km depth. We are still investigating the requirements of the environmental regulations, which nowadays mandate cleanup of even items left in the deep ocean. We have a rough preliminary cost estimate from AT&T for removing the cable and junction box, of $600K. For purposes of this budget we exclude this cost. We propose to submit a supplementary proposal for the environmental cleanup once the legal situation is clarified. We have already been assured verbally that cleanup of at least the first 2 miles offshore is mandated.

Negotiations are in progress to see if we can convince the Natural Energy Laboratory of Hawaii to assume ownership of the cable and equipment at its terminus. They have little interest in assuming a liability that is not functional, so at issue is how much would it cost them to repair the short in the junction box, and then to identify possible users. These discussions are in progress, but it is too soon to make a detailed plan.

For the rest of the DUMAND hardware, we request that DOE proceed with handing over title to the University of Hawaii so that we can dispose of the equipment in a reasonable and timely manner.

Cleanup and Storage

The DUMAND project has accumulated quite a bit of hardware over the years, which gear is located at NELH at Keahole Point, the UH Marine Facility at Snug

Harbor, the Hale DUMAND assembly area on campus (Crouse Hall Annex D), and in several lab spaces in the Physics Department in Watanabe Hall.

NELHA A special laboratory building was built by the State of Hawaii for DUMAND and other potentials users. The space rented by DUMAND will be occupied by other projects at NELH. There is a large power supply, belonging to Kiel University, that will be returned to Kiel (at Kiel expense). There are cable trays and some racks that will need to be removed. The furniture (which was state surplus) can remain. A few boxes of equipment need to be packed and returned to UH. We estimate one man week to clean up and pack, plus shipping.

As stated above, we do not include the cable and junction box removal cost in this closeout budget, pending resolution of legal environmental requirements. Associated with the cable are the entry conduit into the laboratory, the two wells containing the ground return electrodes, the central cable pit, and the slant drilled pipe for the entry into the ocean through the surf zone. If the cable is to be removed, we can pull the cable from the conduit between slant cable pit and the laboratory, and likewise the ground cables from the electrode wells. It is unclear whether the wells would have to be filled or possibly even removed, since they are within the shore Conservation District and rather strict regulations apply. This seems not to pose a large expense in any case.

The cable removal could be done with a ship, starting just off shore with divers attaching tag lines to the cable and cutting it. The shore end could then be pulled back through the slant drilled pipe, while the ship proceeds to haul in the fiber optic cable. If the cable becomes entangled on rocks on the steep offshore slope it may break during this process. The cable ship then will drag for the cable (a well practiced procedure) and continue. If we go all the way to the junction box we can pull it up as well. This would have some benefit in recovering the equipment attached to the junction box (TV cameras and lights, hydrophones, pinger, ctd) as well as being able to understand what caused the short. A forensic effort and report documenting the state of the JB would be worthwhile for all future similar efforts.

UH Marine Facility The greatest mass of DUMAND hardware is presently located at Snug Harbor. We have the following major items there:

- three modified strings, vans, refrigerated, containing strings;
- electronics van, seagoing, with computers, special electronics and tools;
- cable storage container with 3km of good E-O cable (DUMAND shore cable); and

- three storage containers with cables, lead weights, floats, anchor packs, umbilical cable payout packs and much sundry hardware associated with deployment.

We have been assured of being allowed to keep the vans at the Marine Facility for at least several years (there is a plan to move that facility, but it now seems to be delayed beyond the turn of the century). This facility is not altogether ideal, and we will need to either operate air conditioners in the vans, which seems worthwhile for the high value optical modules, or install a double roof that keeps the solar heating to a more reasonable level for storage.

We are in the process of making an inventory, and developing a plan as to what is worth saving, what to give away, and what to return to other owners.

Hale DUMAND This is the building on campus (Crouse Hall) were we tested optical modules and assembled much of the strings. The OM tests were carried out in a 15 m long test tank, filled with RO filtered water. The triggering was mainly provided by three MACRO counters loaned to us by CalTech. We have asked if they want 10 m long counters returned. We would have to assume the shipping cost.

Campus space limitations being what they are, we assume that we will have to move out of Hale DUMAND within the next year. We can recover some of the structure (Unistrut) but most will have to be scrapped. The rest of the contents of this building can be brought back to HEP labs in Watanabe Hall and Physical Sciences, or put in storage at Snug Harbor (ocean hardware). Our agreement of use for this structure was to return it to previous condition, which is a little ambiguous as it was full of junk when we got it and we have greatly improved it with cleanout, painting and new wiring (mainly done by the DUMAND team on a weekend). Thus there seems to be little expense beyond some undergraduate student labor supervised by UHHEPG personnel.

DUMAND Laboratory in 109 Watanabe Hall We have two substantial laboratory spaces in Watanabe Hall. In Room 109 we have the fiber optics facilities and associated gear. We will keep this as a generally useful HEP facility. The cost for packing away DUMAND material is included.

DUMAND Laboratory in 322 Watanabe Hall The third floor DUMAND laboratory has been the major optical module work area, dark room for testing, electronics work area, computer preparation location, connector pressure test facility location, and high value storage area, amongst other uses. Many optical modules of various generations and a variety of equipment are stored here and in the hallway behind the laboratory. This laboratory will be used for SuperKamiokande staging and tests, and much of the equipment reapplied to that purpose. The specifically ocean related gear will be inventoried, packed, and stored at Snug Harbor.

DUMAND Pressure Test Facility With funds from the Japan-US agreement and the UH, construction is in progress of a large pressure test facility on campus, near Watanabe Hall. This pressure tank has internal dimensions of 10 feet long by 2 feet in diameter, and was designed to accommodate optical modules (including the ability to withstand housing collapse) and string controller housings for full ocean pressure testing. The SOEST (oceanography school) gave matching funds to make the $250K tank generally useful to other ocean researchers. It is a unique facility in the mid-Pacific.

3.3 Non-Accelerator Publications

1. Walter Simmons, John Learned, Sandip Pakvasa, Xerxes Tata, SONOLUMINESCENCE IN NEUTRON STARS, UH-511-844-96, Feb 1996.
2. R.S. Miller et al. (IMB Collaboration), A SEARCH FOR ASTROPHYSICAL SOURCES OF LOW-ENERGY NEUTRINOS USING THE IMB DETECTOR, Astrophys. J. **428** 629 (1995).
3. John N. Bahcall, Kenneth Lande, Robert E. Lanou, Jr., John G. Learned, R.G. Hamish Robertson, Lincoln Wolfenstein. PROGRESS AND PROSPECTS IN NEUTRINO ASTROPHYSICS, Nature **375**, 29 (1995).
4. T.J. Weiler, W.A. Simmons, S. Pakvasa, J.G. Learned, GAMMA RAY BURSTERS, NEUTRINOS, AND COSMOLOGY, VAND-TH-94-20, revised 1996.
5. R. Becker-Szendy, et al. (IMB Collaboration), NEW MAGNETIC MONOPOLE FLUX LIMITS FROM THE IMB PROTON DECAY DETECTOR, Phys. Rev. **D49**, 2169 (1994).
6. John G. Learned, Sandip Pakvasa, DETECTING TAU-NEUTRINO OSCILLATIONS AT PEV ENERGIES, Astropart. Phys. **3**, 267 (1995).
7. John G. Learned and Michael Riordan, NEUTRINO ASTRONOMY, SLAC Beamline, Fall 1995
8. R. Becker-Szendy, et al. (IMB Collaboration), Calibration of the IMB Detector, N.I.M. **A253**, 629 (1995).
9. John G. Learned, PHYSICS AND ASTRONOMY WITH HIGH ENERGY NEUTRINOS, Nucl. Phys. B, in press (1996).
10. John G. Learned, CHALLENGES FOR A KM3 NEUTRINO DETECTOR, Proceedings of the 1996 Neutrino Telescope Workshop, Venice 2/96, in press.
11. John G. Learned and Igor Zheleznykh, ACOUSTIC DETECTION IN THE OCEAN OF UHE NEUTRINOS USING EXISTING SONAR ARRAYS, in preparation from Aspen Institute for Physics Workshop on High Energy Neutrinos, 6/96.
12. J. George et al., "Estimate flux limit for UHE neutrino via acoustical detection techniques", 24th ICRC, Rome, HE (1995) p. 812.
13. H. Crawford et al, "Mapping of the earth interior with astrophysical neutrino", 24th ICRC, Rome, HE (1995) p. 804.

14. A. Okada et al, "Monte Carlo study of DUMAND three string array", 24th ICRC, Rome, HE (1995) p. 718.

DUMAND EXTERNAL REPORTS

1. DUMAND-1-95 V. J, Stenger. "Detecting AGN Neutrinos with a Single DUMAND String". November 1995.
2. DUMAND-1-96. V. J. Stenger. " Detecting nu ebar + e → W with a Single DUMAND String" Feb. 1996.

Chapter 4

Theoretical Physics

Drs. S. Pakvasa, W. Simmons, X. Tata, S-F.Tuan, and Mr. J. Sender

4.1 Overview

The Theory group currently consists of three tenured faculty members (Pakvasa, Tata and Tuan), an affiliate faculty member (Simmons) and graduate student (John Sender). The research activities of the group are largely phenomenological in nature and revolve around strategies to confront the Standard Model and extensions thereof to experimental tests, both at high energy colliders as well as at non-accelerator experimental facilities. This leads to a healthy interaction with experimentalists in Hawaii as well as at other laboratories and universities.

We have stressed in several of our recent proposals that it is rather anomalous that a group of our size and visibility does not include a post-doctoral research associate. Our request for a post-doctoral position has been endorsed by the several external referees who reviewed our proposal during the last major DOE review. To quote some from these reviews,

Reviewer No. 1 wrote: *The group makes the addition of a postdoc a high priority. This referee agrees that the isolation of Hawaii is no longer a real obstacle with the advent of cheap travel and E-mail. This referee agrees that the quality of the group justifies the addition of a postdoc. This addition should not happen, however, at the expense of funding for travel which the group has successfully used to further its program by collaboration.*

Reviewer No. 2 wrote: *The theory group at Hawaii is a small one. They have helped themselves greatly by hiring X. Tata whose work on phenomenology is widely respected. This group should certainly be supported and encouraged to expand.*

Reviewer No. 4 wrote: *The researchers make a strong case for one postdoctoral fellow and I strongly endorse their request.*

The DOE also recognized the importance of establishing a postdoc position in the group and granted us the flexibility to convert one of our GRA positions toward partial support of a post-doctoral fellow (PDF). For an appointment in this category, the University would waive the overhead. Since, in addition, the position carries no fringe benefits, the cost to DOE of such an appointment is significantly reduced relative to an appointment in the Researcher Category.

This year, we had made use the flexibility granted to us by the DOE to appoint Dr. Tonnis ter Veldhuis (Vanderbilt University) to this position. Tonnis comes highly recommended. His research interests, which include dynamical supersymmetry breaking, supersymmetry and Higgs boson physics, mesh extremely well with those of Pakvasa and Tata. He has also been working on the recently constructed models where supersymmetry is broken at low energies, and should therefore inspire new research directions within the group. We are excited about the prospects of having Tonnis on board and have no doubt that the creation of this position will have a positive impact on the entire Hawaii HEPG program.

Unfortunately, after we made the appointment, we were informed of a change in Immigration Law which precluded Tonnis from coming to Hawaii on a J-1 (exchange visitor) visa as had been anticipated. We were advised that he should instead be brought in on an H-1 visa, but that would require that he be appointed as a Jr. Researcher instead of a PDF. Since such an appointment entails regular fringe benefits and overhead costs which had not been anticipated, we approached the administration in this regard. We have been informed that if we absorbed the fringe benefit costs into the rest of the program, the University would absorb the costs of the overhead. Our request for the Overhead Waiver is still pending with the administration, but we have been given to understand that because of the unusual circumstances, the bulk of these costs will somehow be covered for the first 12 months of Tonnis's appointment. However, since the waiver has not yet been approved, we have included the Overhead expense in our current budget request which is about $30K higher than last year. Of this almost $20K is due to the additional overhead discussed above, while the other $10K is the unexpected expense of the fringe benefits for the Jr. Researcher.

We stress though that despite the further cutting that we have had to do in the GRA category to accommodate the unexpected increase due to the change in INS Law, we are excited about establishing a postdoc position in the Theory Group and appreciate the flexibility that the DOE granted us to enable us to bring this about. We view the unexpected Overhead and fringe benefit expense as a temporary phenomenon caused by unforeseeable circumstances, and anticipate being able to support a full GRA in the near future.

We review the research activities along with research plans for the upcoming year. This report is organized by subject. A list of last year's scientific publications by the members of the group appears separately.

4.2 Research in Neutrino Physics

The properties of neutrinos such as their masses, mixings, magnetic moments etc. are extremely important in two ways. They are fundamental parameters, and furthermore, they will teach us about what may be beyond the Standard Model (SM). Apart from direct laboratory measurements of masses, etc. from beta decay end point measurements, the other technique for getting information on neutrino properties is the study of neutrino propagation and flavor conversion over long distances via neutrino mixing and oscillations.

It continues to be the aim of the Hawaii Theory group to devise means to deduce neutrinos properties from various neutrino experiments, to propose new experiments and to speculate on and build models for neutrino masses and mixings.

Solar Neutrinos

During 1987 Pakvasa and Raghavan proposed a new Solar Neutrino Detector "Borex" with neutral current capability and which can hence provide a real test to distinguish neutrino properties from astrophysical uncertainties (Phys. Rev. **D37**, 849 (1988)). It was shown that a "modest" kiloton detector containing 100T Boron-11 can, in one year of running, distinguish between almost all the scenarios for explaining the solar neutrino conundrum: flavor oscillations (either vacuum or MSW), decay, magnetic moment, astrophysical uncertainties etc. Eventually a collaboration consisting of additional members from Drexel, MIT and Milano was formed and evolved into the proposal for a smaller detector "Borexino". Although with this smaller size the neutral current rates are too small, the threshold can be lowered to 250 KeV enabling the 0.86 MeV line $\nu_e's$ from ^7Be to be seen via $\nu_e e \rightarrow \nu_e e$ at a rate of about 50 events per day. In 1993 a group from Princeton (F. Calaprice et. al) joined the collaboration and a proposal for support of the U.S. effort was submitted to the NSF. The Princeton proposal to NSF for the support of the U.S effort in the construction of the CTF (Counting Test Facility) was reviewed and approved.

The construction CTF, which is essentially a mini-Borexino (8T of LS), was completed during mid 1995. The CTF took data during 1995 and 1996 and determined the levels of radioactive impurities such as ^{14}C, U and Th which are responsible for background to the low energy signal. It was found that the levels of concentration are below 10^{-18} for ^{14}C and below 10^{-15} for U and Th. Thus the requisite levels of radio-purity were shown to have been achieved. Currently the properties of a new scintillator (PXE) are being tested for possible use in the full size Borexino detector and the design is being finalized. The final proposals to the three main funding agencies (INFN in Italy, DFG in Germany and NSF in U.S.A.) are being prepared and will be submitted soon.

The current status of the data on solar neutrino observations from the four on-going experiments is summarized in the Table below.

Table
The solar neutrino data compared to the SSM

Experiment	Data/SSM
Kamiokande	0.51 ± 0.07
Gallex	0.66 ± 0.12
Sage	$0.44\pm^{0.17}_{0.21}$
Homestake	0.28 ± 0.04

The Kamiokande detector is sensitive only to ^8B neutrinos; and the Homestake detector is sensitive to ^8B (77%) as well as ^7Be(14%), pep (2%) and CNO (6%) neutrinos. If the observations need no new neutrino properties, then the $^8B\ \nu's$ are not distorted in their spectrum and the flux seen by Kamiokande (over a limited energy range), can be assumed uniform and hence applicable to Homestate as well. In that case a minimum of $(38 \pm 8)\%$ of SSM counting rate is contributed by ^8B neutrinos alone and adding pep neutrinos it is $(40 \pm 8)\%$ to be compared to the observed $(28 \pm 4)\%$. It is obvious that something must reduce the ^7Be neutrino flux drastically to obtain agreement. Since the effective temperature dependence of $^7Be\ \nu$ flux is much weaker than for ^8B flux, it is difficult to arrange for a stronger suppression for ^7Be than for the ^8B flux. This is borne out in calculations where the core temperature is allowed to be a free parameter and it is found that a good fit to all the data cannot be obtained. Furthermore, no solar model has been found which can reproduce the Chlorine rates even with the reduced ^8B flux, or even come close. It has become clear in the last year that the reduction in the $^7Be\nu$ flux can be deduced from just the neutrino data and the observed solar luminosity. Even if the remaining uncertainties in the solar modeling (or very low energy nuclear cross-sections) and difficulties inherent in pioneering experiments may cloud the interpretation of solar neutrino data in terms of neutrino properties; it is important to keep in mind that there is no question that neutrinos from the sun have been detected: both at high energies - 10 MeV (Kamiokande, Homestake) and at low energies - 1 MeV (Gallex, SAGE). Hence a powerful neutrino beam with sensitivity to $\delta m^2 \geq 10^{-10} eV^2$ and $\sin^2 2\theta \geq 0.1$ is available, free of charge. It behooves us to utilize this beam maximally; and future upcoming experiments will do just that. They have rates of order 10^4 per year; in real time, spectrum measurement (SNO and Superkamiokande), flux monitoring (via NC/CC in SNO) and low threshold (in Borexino) with capability to detect the ^7Be line. If the neutrino parameters lie in this region we will definitely know the answer by 1998.

Assuming that neutrino properties are the culprits, the solutions to the solar neu-

trino deficit are summarized below:
MSW: This is the case in which δm^2 and $\sin^2 2\theta$ lie in the range in which the solar matter effects are very important. A fit to all four experiments leaves three allowed regions. One is the small angle ($\sin^2 2\theta \sim 4.10^{-3}, \delta m^2 \sim 10^{-5} eV^2$) region; in this region the rate for ^7Be νe scattering in Borexino varies rapidly between 0.2 and 0.5 of SSM and ^8B spectrum seen in SNO or Superkamiokande will show distortion. Another is the large angle large δm^2 region ($\sin^2 2\theta \sim 1; \delta m^2 \tilde{>} 10^{-5} eV^2$); in this region ^7Be is suppressed between 0.35 and 0.7 and there is no distortion of ^8B spectrum. Finally there is a small region at large angle small $\delta m^2 (\sin^2 2\theta \sim 1, \delta m^2 \tilde{<} 10^{-6} eV^2)$; here there is a strong day-night variation in ^7Be line that can be seen in Borexino.
Large Angle Long Wavelength: The large angle long wavelength ("just so") continues to fit all the data with $\delta m^2 \sim 10^{-10} eV^2$ and $\sin^2 2\theta \tilde{>} 0.8$. Matter effects are negligible. This has striking predictions testable with future detectors: (i) suppression of ^7Be in Borexino between 0.2 and 0.5, (ii)sharp distortion of ^8B spectrum and most importantly, (iii) visible oscillations of ^7Be line with time of the year with upto factor of 2 variations. This maybe the only chance to see true quantum mechanical neutrino oscillations and can be easily seen in Borexino and distinguished from the $1/r^2$ variation.

Atmospheric Neutrinos

The atmospheric neutrino anomaly in the ratio of ν_μ to ν_e fluxes at low energies continues to hint at neutrino oscillations. Kamiokande finds (based on 6.1 Kton yr) for the ratio of ratios:

$$R_{obs}/R_{MC} = 0.60 \pm 0.07, \tag{4.1}$$

while IMB finds (based on 7.7 Kton yr)

$$R_{obs}/R_{MC} = 0.54 \pm 0.07. \tag{4.2}$$

The results of Frejus (for contained events) and Nusex are, respectively, 0.87 ± 0.21 (based on 1.56 Kton yr) and 0.99 ± 0.40(based on 0.4 Kton yr). Finally, SOUDAN II has recently reported a result of 0.69 ± 0.19 based on a 1 Kton yr- exposure.

The ratio $N(\nu_\mu)/N(\nu_e)$ is considered more reliably calculated than the individual fluxes: the ratio is stable to about 5% amongst different calculations whereas the absolute fluxes vary by as much as 20 to 30%.

The most important question is whether there is a "mundane" explanation for the deficit or is a new physics explanation called for? Let us consider the mundane explanations.

(i) Perhaps the e/μ identification in the water Cerenkov detectors is simply wrong. In response to this, Kamiokande has made a very convincing case for the correctness of their e/μ identification by showing how it works very well in finding the expected number of $\mu \rightarrow e$ decays in their contained events. Also, the fact that Soudan-II sees the same deficit (in a non-water-Cerenkov detector) is encouraging. Finally, beam tests performed last year at KEK have settled the issue once and for all.

(ii) There is the question of low energy ν-nuclear cross-sections and lepton energy distributions in the region $E_\nu \sim 200$ MeV to 1 GeV. Ideally we would like to have these ($\nu^{16}0 \rightarrow \ell^{16}F$) measured experimentally. Even though e/μ universality is not expected to be violated except kinematically (and hence in a known manner) the difference between ν and $\bar{\nu}$ cross sections is important. This is unlikely to be the explanation.

(iii) It has been pointed out by Volkova that if π^+ at low energies dominates over π^-, then (because $\sigma_{\bar{\nu}_e} < \sigma_{\nu_e}$) the effect is to enhance e/μ signal. She finds that with a $\pi^+/\pi^- \sim 2.5$ (compared to values in the range 1.1-1.3 used to by others) the effect is only about 10% of the observed.

(iv) The possibility of background due to neutrals such as n or K^0_L faking extra shower events have been ruled out by the spatial distribution of the events in the Kamiokande tank.

The flux independent explanation in terms of neutrino oscillations: The deviation of R_{obs}/R_{MC} from 1 is fairly uniform over zenith angle and is most pronounced in the charged lepton energy range 200-700 MeV which corresponds to neutrino energies from 300 MeV to 1.2 GeV. If we are to interpret this deficit of $\nu_\mu' s$ (and/or excess of $\nu_e' s$) as being due to neutrino oscillations, the relevant parameters are determined rather easily to be $\delta m^2 \gtrsim 4 \times 10^{-3}$ and $\sin^2\theta \gtrsim 0.4$ for either ν_μ-ν_τ or ν_μ- ν_e oscillations. The recent observation by Kamiokande of a zenith angle dependence for higher energy $\nu' s$ (arguably) favors the neutrino oscillation explanation over others.

Simultaneous Explanations for Solar Atmospheric and Dark Matter Neutrinos.

Simultaneous solutions of the solar, atmospheric and hot dark matter problems with only three neutrinos require an almost degenerate spectrum for the neutrinos. With the common mass around a few eV this scenario is constrained by the neutrinoless $\beta\beta$ decay. This constraint would force the mixing among neutrino states to be large. The idea is to determine possible ranges of the mixing parameters that would satisfy the $\beta\beta$ constraints and also explain the solar and atmospheric neutrino data.

It may become necessary to allow the possibility of CP violation for proper cancellation in $\beta\beta$ decay. Choose the following parameterization for the mixing matrix U:

$$U = \begin{pmatrix} c_{13}c_{12} & c_{13}s_{12}e^{i\delta_1} & s_{13}e^{i\delta_2} \\ U_{21} & U_{22} & s_{23}c_{13} \\ U_{31} & U_{32} & c_{13}c_{23} \end{pmatrix} \tag{4.3}$$

This parameterization differs from the KM due to the fact that one cannot redefine neutrino mass eigenstates to absorb some of the phases for Majorana neutrinos). The charged lepton mass eigenstate have been redefined so as to make the elements U_{11}, U_{23}, U_{33} real. The unspecified elements of (1) are complex. They contain in addition to $\delta_{1,2}$, an additional KM-like phase. But the expressions of these elements $U_{21}, U_{22}, U_{31}, U_{32}$ are not needed. The phases $\delta_{1,2}$ do not appear in the conventional vacuum oscillations probabilities but they do appear in the $\beta\beta$ decay amplitude. The latter is given by:

$$\bar{m} = m_0 \sum_i \mid U_{ei} \mid^2 = m_0 \mid c_{13}^2 c_{12}^2 + c_{13}^2 s_{12}^2 e^{2i\delta_1} + s_{13}^2 e^{2e\delta_2} \mid \tag{4.4}$$

The cases with $\delta_{1,2} = 0, \frac{\pi}{2}$ correspond to the CP conserving situations. This may still be consistent with all observations. One has the following possibilities if CP is conserved.

$$\begin{array}{cccc} & \delta_1 & \delta_2 & \frac{<m>}{m_0} \\ (A) & 0 & 0 & 1 \\ (B) & 0 & \frac{\pi}{2} & \mid \cos 2\theta_{13} \mid \\ (C) & \frac{\pi}{2} & 0 & \mid c_{13}^2 \cos 2\theta_{12} + s_{13}^2 \mid \\ (C) & \frac{\pi}{2} & \frac{\pi}{2} & \mid c_{13}^2 \cos 2\theta_{12} - s_{13}^2 \mid \end{array} \tag{4.5}$$

The mixing angles appearing above are constrained by laboratory limits on $\nu-$ oscillations solar and atmospheric data. If the solar neutrino problem is solved with "just so" or through MSW, Δ_{12} $(= m_1^2 - m_2^2)$ can be neglected while considering laboratory limits and all the vacuum probabilities can be expressed in terms of the elements in the third column of eq. (4.3). Specifically,

$$\begin{aligned} P_{\alpha\beta} &= 4U_{\alpha 3}^2 U_{\beta 3}^2 S \ (\alpha \neq \beta) \\ P_{\alpha\alpha} &= 1 - 4U_{\alpha 3}^2 (1 - U_{\alpha 3}^2) S \end{aligned} \tag{4.6}$$

where $S = \sin^2(1.27\frac{\Delta L}{E})$ and $\Delta = \Delta_{31} \sim \Delta_{32}$ is in the atmospheric range. Thus, we need to determine the ranges of $\theta_{12,13,23}$ and Δ allowed by eq. (4.4) with $\bar{m} \leq 1\ eV$, the laboratory oscillation results and eqs. (4.6), atmospheric neutrino data and solar ν data with different possibilities, i.e. long and short wavelength vacuum oscillations, or MSW. Pakvasa, Acker and Joshipura are working on this problem. Pakvasa and Joshipura are also working on models for near generate neutrinos.

4.3 Research in Collider Physics

Research Objectives.

The search for the mechanism of electroweak symmetry breakdown is the driving force behind the construction of colliders to study particle collisions at high energy. Within the Standard Model (SM) framework, the scalar Higgs boson is the anticipated relic of spontaneous symmetry breaking. As is well known, the instability of elementary scalar masses to radiative corrections leads to the so-called fine-tuning problem; *i.e.* the parameters of the theory have to be adjusted to an uncanny precision order by order in perturbation theory, unless (i) electroweak symmetry breaking interactions become strong so that perturbative arguments are inapplicable, or (ii) there are new degrees of freedom not present in the SM that must manifest themselves in high energy collisions at a scale smaller than $O(1\ \mathrm{TeV})$. In either case, new phenomena, not described by the SM, are expected to manifest themselves by the time the TeV energy scale is explored at supercolliders such as the Large Hadron Collider (LHC) at CERN. Possibilities include a strongly interacting symmetry breaking sector (strong $W_L W_L$ scattering), composite quarks, leptons and leptoquarks, composite "Higgs bosons" (technicolour models), supersymmetry, or even something totally unanticipated.

During the last few years, Tata and his collaborators have mainly been working on strategies for the detection of supersymmetric particles and Higgs bosons, both at present colliders as well as at the LHC which is expected to become operational in about a decade.

Simulation of Supersymmetry.

During the last two to three years, H. Baer (FSU) and Tata, in collaboration with F. Paige (Brookhaven) and S. Protopopescu (Brookhaven), the authors of ISAJET, have incorporated supersymmetry processes into the ISAJET simulation of high energy hadron collisions. They have constructed a program, ISASUSY, (a subroutine of ISAJET) which, for any input set of the Minimal Supersymmetric Model (MSSM) parameters, computes the branching ratios for the decays of various sparticles. In the computation of chargino and neutralino decay patterns, splitting between slepton and squark masses which, as we have seen, can significantly enhance their leptonic decays has also been incorporated. ISASUSY interfaces with ISAJET where sparticle pair production is calculated. ISAJET provides experimentalists a powerful new tool for their analyses, and is used extensively in the supersymmetry analyses by the CDF and D0 collaborations at Fermilab.

ISAJET is constantly evolving. The supersymmetric processes included in the most recent versions of ISAJET are, production of gluinos and squarks, the production of a squark or gluino in association with a chargino or neutralino, the production of chargino and neutralino pairs, associated chargino-neutralino production, slepton pair production, and finally, the production of top squarks at pp and $\bar{p}p$ colliders. All 2 → 2 sparticle pair production processes that can occur at e^+e^- colliders have also been incorporated into ISAJET 7.13. ISAJET 7.14 includes the production of SUSY Higgs bosons (with radiative corrections to their masses and couplings, as given by the effective potential method, included) at hadron colliders. ISAJET 7.16 incorporates sparticle production at e^+e^- colliders, allowing for longitudinal polarization of the electron and/or positron beams. This will facilitate the inclusion of cascade decays for physicists studying the prospects for supersymmetry at future linear colliders. We have just completed one such detailed study described below. Up to now, most detailed e^+e^- studies assume that the parent particle directly decays to the LSP. In ISAJET 7.20, which has just been released, we have incorporated the possibility of independently inputting the three gaugino masses: this was motivated by a recent analysis of LEP and Fermilab data that suggest that the gaugino masses might not be unified as in the simplest GUT model.

The SUSY simulation in ISAJET is still incomplete in several respects:

- Isajet is currently valid only when $\tan\beta \leq 10$, primarily because the mixing and mass splitting between bottom squarks and stau leptons due to their Yukawa interactions is not yet included. Such splittings can be very important if they result in new two body decay channels of the gluinos, charginos and neutralinos. Yukawa interaction contributions to three body decays of charginos, neutralinos and gluinos have also to be included.
- Spin correlations are not included. These may be important for detailed simulations, particularly at e^+e^- colliders. These are difficult to include in a general purpose generator.
- The D-term splitting in the masses of the first two generations of squarks has been neglected.
- There has been much recent interest in a new class of models where SUSY breaking is communicated by gauge interactions rather than by ultra weak interactions as *e.g.* in supergravity models. The sparticle masses and phenomenology can be quite distinct in these scenarios, and needs to be included in ISAJET.
- Initial state photon radiation is not included in ISAJET simulations of SUSY at e^+e^- colliders.

Baer and Tata anticipate remedying several of these deficiencies in the near future. The major effort would be expended in the first of these items, since it requires recomputation of the three body decay rates of charginos, neutralinos and gluinos to include effects of Yukawa couplings and squark mixing.

Searching for Supersymmetry at the Tevatron and its Upgrades.

Experimental searches for supersymmetry at the Tevatron collider have rightly focused most of their attention on the $\not\!\!E_T$ signal for squarks and gluinos. Recently, however, the CDF and D0 collaborations, motivated by work of Tata and his collaborators (among others), have also begun to look for multilepton signals from cascade decays of gluinos and squarks. In addition, the CDF and D0 experiments have also searched for multilepton events from chargino/neutralino production, and also for signals from the top squarks. These signals, it had been pointed out in several papers discussed in our 1994-95 DOE proposal/progress report, should begin to be viable as the experiments accumulate an integrated luminosity of 20-100 pb^{-1}, as is now the case. Very recently, the D0 collaboration has reported an analysis of SUSY signals within the so-called supergravity framework which allows for a unified analysis of signals in several channels. This is also based on the work of Baer, Chen, Paige, R. Munroe (FSU) and Tata described in last year's proposal.

In recent years, several authors (including ourselves) have performed detailed studies of the reaction $p\bar{p} \to \widetilde{W}_1\widetilde{Z}_2 \to \ell\nu\widetilde{Z}_1 + \ell'\bar{\ell}'\widetilde{Z}_1$, which leads to the essentially background-free signal with three hard isolated leptons plus $\not\!\!E_T$, and free from hadronic activity except from QCD radiation. In models where the gaugino masses become unified at the GUT scale, $m_{\widetilde{W}_1} \simeq m_{\widetilde{Z}_2} \simeq 2m_{\widetilde{Z}_1} = m_{\tilde{g}}/3$, so that this reaction can potentially probe gluino masses that are kinematically inaccessible at the Tevatron. Motivated by the considerable recent interest in the possibility of a luminosity upgrade of the Tevatron beyond the Main Injector (referred to as TeV2000 or TeV33), Tata in collaboration with Baer, C-H. Chen (UC Davis) and Paige has investigated how the SUSY reach of the current Tevatron compares with that of the Main Injector and the proposed TeV33. While they find that these upgrades will indeed substantially increase the SUSY reach of the Tevatron, it is concluded that experiments at supercolliders that directly probe the TeV scale are essential for a definitive search for SUSY: in other words, while SUSY may indeed be discovered at TeV33 or even the Main Injector, there are substantial regions of parameter space where sparticles could evade detection at these facilities. Their findings are reported in UH-511-847-96 submitted for publication to Physical Review **D**.

Hawaii student Sender has examined the implications of the recent discovery of the top quark for the physics of its supersymmetric partner, the top squark. In particular, he finds that if $\tilde{t}_1 \to b\widetilde{W}_1$, there are many scenarios that are not excluded by Tevatron counting experiments even if $\Gamma(t \to \tilde{t}_1)$ is comparable to $\Gamma(t \to bW)$. Especially, most supergravity models remain viable even in light of the Tevatron data. Finally, he concludes that by the time a sufficiently large data sample is accumulated to improve the branching fraction limit on non-standard top decays, Tevatron experiments should directly be able to search for top squarks. This work (UH-511-843-96) has been submitted for publication to Physical Review **D**.

Tata and Sender are also following up on earlier work with Baer on top squark signals at the Tevatron where it was shown that, with a data sample of 100 pb^{-1}, Tevatron experiments ought to be able to probe masses of 80-100 GeV. They are currently exploring the reach of the Main Injector and the TeV* upgrades for discovering t-squarks, regardless of how these decay. They have only obtained preliminary results up to now.

If the chargino is too heavy to be accessible in stop decays, it is generally believed that the loop decay $\tilde{t}_1 \to c\tilde{Z}_1$ will dominate. This conclusion is based upon the comparison of the loop decay width to the width for the tree-level four-body decay of the stop. If, however, $\tilde{t}_1$ is heavy enough, the decay $\tilde{t}_1 \to bW\tilde{Z}_1$ may be kinematically allowed. Tata, in collaboration with T. Wöhrmann (Vienna) who was a visitor at Hawaii a year ago and others is investigating the importance of this decay for t-squark phenomenology.

Supersymmetry at the Large Hadron Collider.

During the past year, Tata and Baer have continued their on-going program for the identification of strategies for identifying sparticles at hadron supercolliders. In a paper described in last year's proposal (Phys. Rev. **D52**, 2746 (1995)), Baer, Paige, Chen and Tata had used ISAJET to perform a detailed study of the $\not{E}_T$ signal at the LHC within the minimal supergravity framework. Aside from delineating the region of parameter space where the signal was observable, they had proposed a new strategy for gluino mass measurement as well as for trying to identify whether squark production was a significant contributor to the $\not{E}_T$ sample. Since then, these authors have done a follow-up of this study by investigating multilepton signals from gluinos and squarks. They find that the greatest reach of the LHC is obtained via the $1\ell+\not{E}_T$ channel: gluinos as heavy as 1.5 TeV (2.3 TeV if squarks and gluinos are degenerate) should be readily detectable. Confirming signals should be present in several channels if gluinos are lighter than about 1 TeV. They have made the first attempt to see whether it is possible to test the correlations expected in the minimal SUGRA framework as well as to determine the underlying model parameters at the LHC, by combining results for rates in various $n - lepton + m - jets + \not{E}_T$ channels, jet and B-hadron multiplicities, and charge and lepton flavour asymmetries. Their preliminary conclusion is that it may be possible to get at the values of m_0 and $m_{1/2}$, but that $\tan\beta$ and A_0 are much harder to obtain. This paper (UH-511-837-95) is to appear in Physical Review **D**.

Baer, Chen, Paige and Tata propose to follow up on this study to investigate new strategies to see how well the underlying model parameters can be determined at the LHC. Current belief is that the Linear Collider is essential for this purpose. They propose to generate Monte Carlo samples for about 10^3 randomly chosen points in parameter space, and use these as "reference samples" for comparing with the "data". They would draw upon the variables identified in their earlier study (and presumably find other variables) to see how well the "data" can be matched up with one of the reference samples to get at the model parameters.

Supersymmetry at e^+e^- Colliders.

As already noted above, Baer and Tata have incorporated sparticle production at e^+e^- colliders into ISAJET. This now enables the simulation of supersymmetry, including cascade decays, for linear collider studies. Baer, M. Bhrlik (FSU), Munroe and Tata have studied the reach of LEP II within the supergravity framework where the masses and coupling of sparticles are strongly correlated. For some regions in parameter space, these correlations are important since the cause kinematic effects that significantly alter the detection efficiency. In this study, the authors have also identified a strategy to directly look for the neutralino signal from $\tilde{Z}_1\tilde{Z}_2$ and $\tilde{Z}_2\tilde{Z}_2$ production: for limited ranges of parameters, these channels afford the only hope for the detection of SUSY. Finally, they have examined how the reach changes as a function of the machine energy. This study (UH-511-829-95) has already been published in Phys. Rev. **D**.

Baer, Munroe and Tata have used the recent upgrade of ISAJET to study the prospects for supersymmetry at a 500 GeV Linear Collider. They work within the framework of the minimal SUGRA model and map out the parameter region where it should be possible to detect supersymmetry. Furthermore, they perform four detailed case studies to examine the prospects for precision mass measurements in the presence of several SUSY reactions occurring simultaneously and with the cascade decays of sparticles incorporated. They confirm that selectron and chargino masses can indeed be measured to within a few percent, and demonstrate for the first time that precision mass measurements of neutralinos, sneutrinos and even top squarks might be possible at these facilities. This paper (UH-511-850-96) has been submitted for publication to Physical Review **D**.

It would be interesting to ask whether a reanalysis of hadron supercollider data, in light of information from linear colliders, could facilitate the untangling of hadron collider cascade decay events. For instance, it is possible that the chargino and the second lightest neutralino are discovered and their masses measured at an electron-positron collider. A study of strategies to see how a re-analysis of hadron collider squark and gluino events could help disentangle the complicated decay chains would be of considerable interest.

Higgs Boson Searches.

All supersymmetric models necessarily contain at least two Higgs doublets so that the spectrum of physical Higgs particles is richer than in the SM. Even within the MSSM framework, there are five physical spin zero bosons associated with the Higgs sector: these are the light and heavy neutral scalars H_l and H_h, a pseudoscalar, H_p (the terms scalar and pseudoscalar refer to their couplings to matter fermions) and a pair of charged scalars $H^{\pm}$. Tata in collaboration with Baer, C. Kao (Rochester), S. Abdullin (Moscow) and N. Stephanov (Moscow) have recently investigated the feasibility of the simultaneous detection of H_p and H_l via the process $pp \to H_p + X$, $H_p \to ZH_l \to l^+l^-b\bar{b}$ at the LHC. This study is a followup on their earlier study where they studied the same reaction but focused on the tau decays of H_l. They find that the signal detection appears to be possible if $M_Z + m_{H_l} < m_{H_p} < 2m_t$ and $\tan\beta < 3$. They also show that this discovery channel may allow for measurement of the masses of the Higgs bosons. This study (UH-511-845-96) has been submitted for publication to Physical Review D.

During the last two years, Tata in collaboration with former Hawaii student M. Bisset (now at TIFR, Bombay), Baer and Kao has been investigating novel strategies for their detection at hadron supercolliders. These analyses were done within the MSSM framework. Bisset is currently working with Tata and others to see how their earlier results alter if they restrict their focus to the more constrained supergravity models. They also propose to study whether signals for charged Higgs bosons might be accessible at the LHC when $H^{\pm}$ is too heavy to be produced in top quark decays.

Signals of R-parity Violation.

Although most phenomenological analyses are carried out assuming that R-parity is conserved, it is possible to construct perfectly viable models where this is no longer the case. In this case, the lightest SUSY particle (LSP) is unstable and decays via lepton or baryon number violating interactions. In the former case, the decay products of the LSP necessarily contain additional leptons, while in the latter case, the LSP decays hadronically. New R-violating decays of other sparticles are generally assumed to be negligible. The decays of the LSP lead to (1) an increase in the multilepton signal when R-parity is broken by lepton number violating interactions, and (2) a reduction in $\not{E}_T$ along with the reduction of lepton isolation due to the hadronic decays of the LSP if R-violation is due to the non-conservation of baryon number. In the second case it is natural to ask whether it is just possible that SUSY signals may remain hidden even at the LHC even if sparticles are light because baryon-number and R-parity violating operators dominate sparticle decays, thereby vitiating both the $\not{E}_T$ as well as the multilepton signals. Baer, Chen and Tata are currently examining the impact of LSP decays on the usual SUSY search strategies at the LHC; *i.e.* is the SUSY signal detectable in R-violating scenarios if the search is carried out as in the MSSM framework? At the next level, it may be interesting to ask whether SUSY might remain hidden at the LHC if R-violating decays of sparticles other than the LHC are important, since then the multilepton signals from their gauge-mediated decays would also be suppressed. Tata proposes to investigate this in collaboration with R. Godbole (Bangalore).

Participation in Study Groups for Future Collider Studies

Tata has also been actively involved in various study groups investigating the detection of SUSY at future colliders. He was a co-convenor for the SUSY subgroup of the DPF study which was concluded about a year ago. Their report is to be published in *Electroweak Symmetry Breaking and New Physics at the TeV Scale* (World Scientific). He was also a member of the Event Generators and the Search for New Physics groups organized for LEP studies. The reports of these groups have already appeared as preprints (UH-511-840-95, UH-511-841-95). He has also participated in the SUSY working group for NLC study. The detailed report of this study, which is in preparation for Snowmass 96, is due to appear shortly. He was also an active participant in the TeV2000 study but has declined to be an author on this document. Finally, Tata is serving as a co-convenor for the Supersymmetry subgroup at Snowmass 96.

A Proposal for a Text Book on Weak Scale Supersymmetry

Baer and Tata have for some time been considering writing a textbook on supersymmetry. Although they thought of this project two or three years ago, they shelved it because they felt that the text might become dated in light of the new data from LEP II and the Main Injector. Since LEP II will commence operations soon, and since the Main Injector data will become available before the completion of the project, they felt that the time is appropriate to begin consideration of such a text. The book they envision is different from the available texts, and their intended audience is phenomenologically inclined graduate students with a background in the basics of quantum field theory and the Standard Model, as well as experimentalists working on the search for supersymmetry.

They have already approached David Pines, Editor, Frontiers in Physics Series and their proposal is currently under review. Two referees have favourably reviewed their proposal, while the review from the third has not yet been received at the time of this writing.

Needless to say, both Baer and Tata expect to continue their research actively during the period that this book is being prepared.

4.4 Heavy Quarkonium Physics

Introduction

Much of S.F. Tuan's work since June 1995 remains concentrated in the area of heavy quarkonium physics with an eye on the experimental programs at BES, Fermilab, and CLEO. Let us first review the publication status of manuscripts listed in last year's renewal proposal. The Ms. "On Trigluonia in Charmonium Physics" in collaboration with Y.F. Gu of IHEP-Beijing and K.T. Chao of Peking University [BIHEP-TH-93-45, PUTP-93-24, and UH-511-790-94] has been proof read by one of us (K.T.Chao) and has appeared in Commun. Theor. Phys. in Beijing, Vol. 25, No. 4, pp. 471-478, June 15 (1996). The Ms. "Some Theoretical Considerations on Heavy Quarkonium Systems" [UH-511-791-94] has been accepted by Commun. Theor. Phys. (Beijing). The Ms. "Isospin Violating Pion Emission from Heavy Quarkonium" in collaboration with H.J. Lipkin has appeared in Phys. Lett. B368, 148 (1996). The Ms. "New Challenges in Charmonium Physics" in collaboration with Y.F. Gu of IHEP-Beijing [BIHEP-EP1-95-04, UH-511-819-95] is published in Mod. Phys. Lett. A, Vol. 10, 615 (1995). Finally the Ms "Search for the χ_c' Charmonium States as Solution to the CDF ψ' Puzzle" has now appeared in Pramana, Vol. 45, No.2, August 1995, pp. 209-214.

Work in Progress and Planning

The trip to the NATO Summer School in June and July at London/Swansea, followed by the Hadron '95 Conference in Manchester last year (supported in part by our DOE grant) was highly productive in terms of both interaction and in defining some half a dozen projects for further study. First at Hadron '95 [July 10-14, 1995] I was asked to Chair Plenary Session PY2 on July 10 (1995) right after PY1 the opening Plenary Session Chaired by the Conference Chairman Sandy Donnachie himself. Second I was given Rapporteur length time (30 minutes) to give a talk on "Aspects of Charmonium". Here I summarized three separate topics of charmonium. (a) The Omicron O as 1^{--} tri-gluonia, and the charmonium puzzle; the $\eta_c'(3600)$ search. (b) The decay $\psi(1P_1) \to \pi^0 + J/\psi$ and isospin violating charmonium decays. (c) How to search for $\chi_c' = \chi_c(2P)$ charmonium states. This Review Talk has appeared in the Proceedings of Hadron '95, p. 361 (World Scientific Publishing Co.). At the end of the talk on July 10, Dr. Sergei Sadovsky of Protvino asked whether the two photon production of $\chi_c(2P)$ charmonium states I discussed under (c) can be extended to include the search for the η_c' state itself. I did not have an immediate answer, but upon further thought this developed into the first completed project of the many mentioned below. I list it as:-

(1) In collaboration with Ted Barnes of Oak Ridge/University of Tennessee and

my experimental colleague Tom Browder here in Hawaii, we completed a Ms. on "Prospects for detecting an η_c' in two photon processes" [ORNL-CTP-96-04, UH 511-849-96, hep-ph/9605278] where we argue that an experimental search for an η_c', the first radial excitation of the $\eta_c(2980)$, may be carried out using the two photon process $e^+e^- \to e^+e^-\gamma\gamma \to e^+e^-\eta_c'$. We estimate the partial width $\Gamma_{\gamma\gamma}(\eta_c')$ and the branching fraction $B(\eta_c' \to h)$, where h is an exclusive hadronic channel, and find that for $h = K_s^0 K^\pm \pi^\mp$ it may be possible to observe this state in two photon collisions at CLEO-II. This manuscript was submitted to Phys. Lett. B for publication at the beginning of May 1996.

(2) A second project is the extensive dialogue with Dr. Philip R. Page of Oxford/Manchester and later with Professor J.M. Cornwall of UCLA. They were the crystallization of thoughts discussed with Page during my trip to England. I asked whether there is a synthesis between the selection rules obtained by Dalitz, Ferbel, and Tuan [Phys. Lett. B213, 537 (1988)] and H.J. Lipkin [Phys. Lett. B219, 99 (1989)] particularly with reference to C-exotic hybrid states and the selection rules (A), (B), (C), (D) developed by Page in his paper in the Advanced Study Institute ASI at London/Swansea on "Decay and Production of Flux-Tube Excitations in Mesons" and also in his Oxford Ph.D thesis on "Gluonic Excitations in Mesons" completed in Trinity Term 1995. Philip has clarified these issues and he accepted my encouragement to have these findings published in a review Journal in due course. I also asked both Page and Cornwall to clarify why both the flux tube approach [references above] and my earlier work with Mike Cornwall [Phys. Lett. B136, 110 (1984)] both predicted that the C-exotic $J^{PC} = 1^{-+}$ hybrid should be found around 2.1 GeV for which some experimental support is found from the recent Brookhaven experiment of J.H. Lee *et al.* [Phys. Lett. B323, 227 (1994)]. Mike then explained in detail why the vortex picture of Cornwall is the correct one, while the strong coupling flux tube approach of Isgur-Paton is at best an approximation. However approximations are needed to compute mass spectrum (e.g. the WKB approximation used for the L=1 $q\bar{q}g$ work of Cornwall-Tuan), and they probably won't be good enough to distinguish between the vortex picture and the strong-coupling flux tube picture. However I expect that dialogue will now occur between proponents of the two approaches via these extensive e-mail/fax correspondence. I look forward to reading Mike Cornwall's paper on why the strong-coupling picture is incorrect (hep-ph/9605116) but he has not found a better way of calculating with the correct force laws in his paper on quark forces in a baryon. Hence as of 5/31/96 it remains hard to distinguish Mike's correct monopole vortex confinement picture from the claimed faulty flux tube model. I particularly enjoyed Page's views on the Color Octet craze; see Cho and Leibovich on "Color Octet Quarkonia Production" (hep-ph-9505329). Page writes that in his mind the pre-eminence of the color-octet picture has to do with a need for people with a perturbative QCD background to meaningfully describe experiment in a way they can conceptualize it. What they are saying is trivially true, in the sense

that non-perturbative ψ' state must have a color octet component if expanded in perturbative Fock space. What is not trivial is the size of the coefficient in front of the color octet component. When they fit the coefficient from the data they are already making the assumption that there is no other mechanism, like the one proposed by Roy and Sridhar, Close, Wise, Trivedi, and Cho earlier which is at work. Hence my PRAMANA paper based on Sridhar et al. may still be relevant, provided that Page's estimate of the width of the $\chi_c(2P)$ for J=2 of about 1 MeV [c.f. his Ph.D thesis] is correct and the Godfrey/Isgur (Phys. Rev. D32, 189 (1985)) estimate of its mass is also in the right ballpark.

(3) In the course of doing the first project above, it became increasingly clear that the data from E760 at Fermilab are at variance with conventional theoretical wisdom and/or other experiments. A Ms. was drafted at the end of May between the three collaborators of (1) on "Experiment E760 and Conventional Wisdom" where the preliminary abstract reads:- We examine the experimental results of E760 at Fermilab and compare them with conventional theoretical wisdom and/or competing experimental studies e.g. CLEO II in three areas. (a) The measurement of the ratio $R = \Gamma(\chi_{c0} \to \gamma\gamma)/\Gamma(\chi_{c2} \to \gamma\gamma)$, (b) the η_c and η_c' results, and (c) measurements associated with the claimed discovery by E760 of the $\psi(1P_1)$ state of charmonium. It is hoped that such a final version will evolve in time for the DPF Meeting in Minneapolis from August 10-15, 1996 where I wish to discuss with M. Voloshin that E760 is not the appropriate basis for choosing between his theory and that of Kuang-Tuan-Yan.

(4). At the NATO Summer Institute last year, I questioned Russian physicists Volodya Anisovich and Andrei Sarantsev of St. Petersburg about their paper [Phys. Rev. D51, R4619 (1995)] with David Bugg and Bingsong Zou. I pointed out that Sheldon Stone of CLEO II in an e-mail message of October 5 (1994) said "I am sure we can generate distributions to compare with theoretical predictions...and we will endeavor to find new people to do this. The data are easily accessible". Hence it is up to my Russian colleagues to present CLEO II with a more sharply focused program of experimental tests to push their interest further about experimental discovery of a four-quark state proposed by Anisovich et al. in the context of triangle singularity. Volodya and Andrei became very enthusiastic about a collaboration in which they will do the computer modeling for comparison with experiment. However e-mail connection between Hawaii and St. Petersburg in Russia proved surprisingly inadequate during the fall and winter of 1995-1996, and I kept getting repetitions of their modeling endeavors which were largely unintelligible. The final message from Anisovich arrived on February 25 (1996). Excerpt reads:- "Please excuse me for delay in work with the upsilon-decay topic: we have hard times here, so, to survive, we need to do the job which is more-or-less quickly paid. Nevertheless we, Andrei and me, have not lost optimism and hope that the upsilon-decay consideration will be completed, if not immediately but in the nearest future...". Clearly there is no point in pressing this work until they are ready, though the physics remains a very good one to resolve in due time.

(5). Study of the nature of the eta-baryon octet [Phys. Rev. D46, 4095 (1992)] received additional impetus at the ASI NATO Summer School in Swansea. I was impressed with Ted Barnes' work on photonic decays of mesons. For instance he finds that for $f_0(975)$, the molecular interpretation as $K\bar{K} \rightarrow \gamma + \gamma$ would give a width of 0.6 KeV, while the $q\bar{q} \rightarrow \gamma + \gamma$ interpretation would predict 3 KeV. I understand that the Crystal Ball experiment gives for $f_0(975) \rightarrow \gamma + \gamma$ of order 0.3 KeV - a full one order of magnitude smaller than the $q\bar{q}$ interpretation. Ted however stressed that in "molecular" $(q\bar{q})(q\bar{q})$ we need to be able to calculate $S_{fi}(2 \rightarrow 2)$ amplitudes for convincing confirmation. However Eric Swanson has already set up this formalism for annihilation in the meson system. Hence I have been trying to persuade Barnes and Eric Swanson to look into the following topics (i) set up the $S_{fi}(2 \rightarrow 2)$ amplitudes for the S-wave baryon system of the η octet [not yet done as of end of May (1996)], (ii) adapt the method of Darewych, Koniuk, and Isgur [Phys. Rev. D32, 1765 (1985)] on $\Lambda(1405)$ and its transition to $\gamma + (\Lambda, \Sigma)$ to study the photonic transitions of the eta-baryon octet [N(1535), $\Lambda(1670)$, $\Sigma(1750)$,....], and (iii) assess whether the η- baryon S-wave octet of $1/2^-$ states can be given a molecular interpretation. Ted Barnes gave strong support to this type of study at the NATO ASI in Swansea, and I look forward to his continued enthusiasm.

(6). At Swansea, I tried to interest Simon Capstick to look into the η- baryon octet mentioned under (5) above to see if this octet can be classified under the Isgur et al. (almost standard) model of qqq L-excitation baryons. His reply on May 15 (1996) is that he will look at the references and try and understand this, that it sounds interesting (as it did last summer!) and that I should please bear with him, since he does have a lot of frying pans in the fire right now! However Capstick pointed out an important point relative to the $\Lambda(1405)$ or L(1405). Its classification as a predominantly qqq in the [70, L=1^-] require essential degeneracy with the $J^P = 3/2^-$ member L(1520) even with the inclusion of spin-orbit terms. However this classification of L(1405) with $J^P = 1/2^-$ can be maintained with the recognition that some sizeable mass shift (in this case 115 MeV!) is occurring due to the neglect of (virtual) decay channel couplings on its mass. Whenever we have a state close to a threshold [$\bar{K}N$ at 1433 MeV] like this one, it is inconceivable that the narrow resonance approximation used in the Isgur-Karl type quark model calculation of its mass will give the correct answer, unless by chance. Isgur [Baryons '95 Conference contribution] adds to this interpretation with the observation that even the quantitative properties of the spectra of heavy quark systems persist as the mass of the heavy quark drops, and that in particular for many purposes the s quark may be treated as a heavy quark (like c,b). The splitting between $L_s(1405)$ and $L_s(1520)$ is in quite good accord with the splitting between $L_c(2595)$ and

$L_c(2625)$ according to the expected m_c/m_s ratio. Since in the Heavy Quark Limit the spin structure of the $L_s(1405)$ is totally prescribed, and is incompatible with the $\bar{K}N$ picture, Isgur feels that this latter interpretation is ruled out, and a 25 year old controversy settled. Note also that the work of Darewych, Koniuk, and Isgur [Phys. Rev. D32, 1765 (1985)] on photonic decays of $L_s(1405)$ also favor the uds interpretation for this state. Balanced against this is the very strong interpretation of Dalitz in PDG (1994) and Veit et al. [Phys. Rev. D31, 1033 (1985)] using the most serious candidate theory (the chiral cloudy bag model) as finding that the $L_s(1405)$ is overwhelmingly $\bar{K}N$ "molecule" (or virtual bound state). I believe Sandip Pakvasa's suggestion that we have here a duality between qqq and $\bar{K}N$ interpretations at one (resonant) energy point deserves further study.

Tom Browder of our HEPG group has kindly introduced me to Rob Kutschke of UC - Santa Barbara who has broad interest in baryon spectroscopy (and was also a Lecturer on Heavy Flavor Spectroscopy at the NATO Advanced Study Institute at Swansea last summer). Together with Sandip we are in the process of summarizing Isgur's latest idea on $L_s(1405)$, $L_c(2595)$, and by extension to $L_b(\sim 5910)$ in HQET by examining mass relations treating s as a heavy quark. Status of $L_s(1405)$ as qqq vs. $\bar{K}N$ and Sandip's duality idea. Kutschke's ideas about no mixing in negative parity baryon states; extension of Capstick's suggestion about mass shifts due to opening of thresholds (e.g. $\bar{K}N$) to the η-octet of baryons; status of the Jaffe speculation that $L_s(1405)$ is actually an *udsg* hybrid baryon etc.

4.5 Topics in Heavy Quark Physics and CP Violation

CP Non Conservation in Hyperon decays

In the standard model, the observed CP violation in K_L is supposed to arise from the single phase in the Kobayashi-Maskawa matrix. It is obviously of fundamental significance to test whether (i) this is true, (ii) are there any other sources of CP non-conservation, (iii) if this source of CP violation plays any role in the cosmological baryon asymmetry. The mechanism for CP violation can be and has to be tested in many places e.g. (i) neutron electric dipole moment, (ii) ϵ'/ϵ in K_L decay, (iii) hyperon decays, (iv) CP violating lepton-nucleon interactions (v) B decays, etc.

So far CP violation has been seen in only one place : the mass matrix of the $K_L - K_S$ system. The results for search for a CP violating amplitude ("direct") in K_L decay, that is a non-zero value for ϵ'/ϵ, are ambiguous. In the Standard Model, with a top quark mass of about 175 GeV, the expected value for ϵ'/ϵ can be as small as 10^{-4}. CP violation in B decays will be a prime target for B factories and can serve as a test of Standard Model as well as an example of CP violation in systems other than the $K_L - K_S$ complex. One can also observe CP violation in the hyperon decays and although it involves $\Delta S = 1$ transition like ϵ'/ϵ, it is sensitive to a somewhat different combination of operators and different uncertainties in the hadronic matrix elements. Deshpande, He and Pakvasa recently considered two of the operators (the gluon and photon electric dipole couplings) that were neglected in previous analyses and found that they can contribute up to 25 percent in the asymmetry A (defined as $A = (\alpha + \bar{\alpha})/(\alpha - \bar{\alpha})$) for Λ and Ξ decays. At the same time they found that the claim made in the literature (Bertolini et al) that the effect of these operators is large in ϵ'/ϵ to be false (N.G.Deshpande, X-G. He and S.Pakvasa, Phys. Lett. **B326**, 307 (1994)). As a by-product they found that the sum of the two asymmetries $A = A(\Lambda) + A(\Xi)$ lies in the range 10^{-5} to 10^{-4}. The proposal P-871 at Fermilab by an LBL group intends to measure A in the decay $\Xi^- \to \Lambda\pi^- \to p\pi^-\pi^-$ with the goal of eventually reaching a sensitivity of 10^{-5}. This is a test of Standard Model as well as search for possible new physics. Datta and Pakvasa estimated the S-wave phase shift in $\Lambda\pi$ scattering and found it to be small ($\sim 0.2^0$) at m_Ξ, combined with the P-wave result of Wise et al. the expectation for A (Ξ) becomes rather small.

Darwin Chang, X-G. He and Pakvasa studied CP violation due to left-right mixing in a class of Left-Right symmetric models and in particular observable effects in hyperon decays (Phys. Rev. Lett. 74, 3927 (1995)). For S-wave, the contribution to CP violating asymmetry A of the polarization in hyperon and anti-hyperon decays is proportional to ϵ'/ϵ. While the tree level $L-R$ operators contribution is constrained to be less than 10^{-5}, the gluon penguin operator contribution can be as large as 10^{-4}. For P-wave, the contribution is not directly related to ϵ'/ϵ. This is much larger than the value expected for A in the Standard Model. They are also looking at a variety of new physics scenarios and working on a review article on the subject

There has been some scepticism about the reliability of the new calculations of $\Lambda - \pi$ phase-shifts yielding small numbers and hence a small value for $A(\Xi)$. To settle this issue Datta and Pakvasa decided to use the same technique (heavy baryon chiral perturbation theory with the parameters of nearest resonances (such as Δ (1232) and N(1440)) as input), to calculate $N - \pi$ phase shifts where a direct comparison to data is possible. They found that the agreement with data is good for S_{31} and P_{33} phase shifts, and only fair for S_{11}, P_{11}, P_{13}, and P_{31}. Based on these results, the results for $\Lambda - \pi$ phase shifts are probably correct to at least a factor of two and the smallness of $A(\Xi)$ (in S.M.) is confirmed. A paper describing this work is being submitted for publication (A. Datta and S. Pakvasa, UH-511-852-96, submitted to Phys. Rev. D).

Flavor Mixing and CP Violation in Heavy Quark Systems.

The issues of interest are somewhat different in b-quarks and c-quarks. In the b-system, it is worthwhile to search for the CP violation and "rare" decay modes as predicted by the Standard Model (SM) since the effects are sizable and a measurable at CLEO or the B-factories. For the charmed particles all such effects, such as $D^0 - \bar{D}^0$ mixing, CP Violation, rare flavor changing decays ($c \to u\gamma$ etc) are predicted to be too small to be observable in SM and hence the search is for new physics.

In B physics the problems under study are: (i) Long Distance effects in $B \to K^*\gamma$ and $B \to \rho\gamma$, (S. Pakvasa and E. Golowich), (ii) direct CP violation in B-decay modes with a single isospin final state, such as $\psi K, \eta K$ etc (S. Pakvasa, N. G. Deshpande and X-G. He), (iii) predictions for and experimental search for direct CP violation in inclusive modes such as $B \to KX, K^*X$ etc. (T.E, Browder, X-G. He and S. Pakvasa).

The decay mode $B \to K^* + \gamma$ and the inclusive mode $B \to \gamma + X$ receive large contribution from the penguin graph in the SM. It has been suggested as a diagnostic for the mass of the t-quark as well as for non SM contributions. It was pointed out by Golowich (Massachusetts) and Pakvasa in 1988 that long-distance contributions are non-negligible and must be taken into account before any strong conclusions can be drawn.

Golowich and Pakvasa wrote a new and updated paper (Phys. Rev. D 51, 1215 (1995)) estimating carefully the long distance contribution to the decay $B \to K^* + \gamma$ which they found to be of the order of 10% in rate. They are continuing to study similar effects in $B \to \rho\gamma, \omega\gamma$. This is an important question in the efforts to determine the KM parameter ratio $\mid U_{td}/U_{ts} \mid^2$ from these decay modes.

It is now well-known that for non-zero CP violating particle-antiparticle rate asymmetry the following conditions must be satisfied: at least two distinct final states with (i) different CP phases and (ii) different final state strong-interaction phases. (These were first delineated carefully in the 1983 paper of T. Brown, S. Pakvasa and S.F. Tuan, Phys. Rev. Lett. 51, 1823 (1983)). For example, one expects no rate difference between $K^+ \to \pi^+\pi^0$ and $\bar{K} \to \pi^-\pi^0$ even if CP is not conserved, because the final state is pure $I = 2$. For decays of a particle as massive as B, the situation in quite different. For example, consider the decay mode $B^\pm \to \pi^\pm\eta$. Again, although the final state isospin is fixed to be 1, there can still be rate difference between B^- and B^+ modes. The reason is that $(\pi\eta, I = 1)$ is no longer a strong interaction eigenstate. There are many inelastic channels open including ones with different CP phases e.g. $D\bar{D}$ etc. As illustration of this effect Deshpande, He and Pakvasa calculated the expected CP asymmetries for decay modes $B \to \psi K, B \to \eta\pi, B \to \eta K$ (including inclusive modes $B \to \psi + s, B \to \phi + s$). It is found that interestingly large asymmetries can obtain in $B^\pm \to \eta\pi^\pm, \eta K^\pm$. This work has been submitted for publication: N.G. Deshpande, X-G. He and S. Pakvasa, UH-511-851-96, submitted to Phy. Rev. D.

The possibility of detecting sizable CP violating rate asymmetries in inclusive or semi-inclusive B-decay modes is being considered by Browder, X-G. He and Pakvasa. To this end, the first task is to estimate rate asymmetries in $B^\pm \to K^*X, B^\pm \to \rho X$, etc; with cuts on M_X to reduce charm contamination. Another process of interest is $B^- \to \rho^0 X$ where one can use $\rho^0\omega^0$ interference to enhance the effect (Enomoto-Tanabashi).

In case of charm, if one it to search for new physics effects, the first task is to have at hand careful SM estimates. Thus, in the work of Burdman et al. (G. Burdman, E. Golowich, J. Hewett and S. Pakvasa, Phys. Rev. D52, 6383 ((1995)) on weak radiative decays of charm mesons, careful estimates of both short distance and long distance contributions are made. A full analysis of the short distance $c \to u + \gamma$ electromagnetic Penguin amplitude with QCD radiative corrections was carried out. The QCD corrections enhance the B.R. from 10^{-17} to 10^{-11}; but even so the long distance contributions dominate by many orders of magnitude and overwhelm the short distance Penguin contribution. For example $D^+ \to \rho^+\gamma$(or $D_s \to K^*\gamma$) predicted to have B.R. of about 10^{-5} and $D^0 \to \rho^0\gamma$ of about 10^{-6} etc. This also means that these radiative decays, while very useful probes to learn about long distance strong interaction effects, are not of use in probing new beyond SM physics.

Other, rarer decays might be more useful for probing new physics. Examples are $D^0 \to \mu\bar{\mu}, D^0 \to \gamma\gamma, D \to \pi\ell\bar{\ell}, D \to K\ell\bar{\ell}, D \to K\nu\bar{\nu}, D \to \pi\nu\bar{\nu}$ etc. Calculations of these modes in the SM are in progress. Another interesting topic is direct CP violation in D decays. In the SM, direct CP violating rate asymmetries can only arise in CKM suppressed modes such as $D \to \pi\pi, D \to K\bar{K}$ etc. Careful estimates of these SM asymmetries as well as possible signatures of new physics in CP violating asymmetries in CKM allowed as well as double CKM suppressed decay modes are under investigation.

Another very interesting phenomenon is mixing and CP violation in $D^0 - \bar{D}^0$ mixing. In SM, the short distance contribution to δm_D is known to be extremely small, of order of 10^{-17} GeV. At one time, it was thought that the long distance enhancement could be several orders of magnitudes. Now, there is some rethinking about this. The CP violating phase is also expected to be very small. In a careful and detailed paper (Burdman, Golowich, Hewett and Pakvasa), the following program is carried out: an up-to-date analysis of both short distance and long distance contributions to δm_D and the lifetime difference $\delta\Gamma_D$ between D^0_L and D^0_H; also the CPV effects; many proposed extensions of SM are also investigated and their predictions will be compared. The phenomenology of $D^0 - \bar{D}^0$ mixing (with possible large CPV effects) is discussed here as well as in the work of Browder and Pakvasa. (T.E. Browder and S. Pakvasa, Phys. Lett. B (in press)).

4.6 Sonoluminescence in Neutron Stars.

In the Standard Model the electro-weak phase transition, is expected to take place when the characteristic temperature exceeds the Higgs vacuum expectation value of about 250 GeV where G_F is the Fermi constant. For temperatures in this range and above, baryon and lepton number non-conservation become important. At still higher temperature, above the sphalleron energy, which is, between 8 and 15 TeV. The Standard Model predicts that baryon and lepton number violation is completely unsuppressed.

These processes are experimentally inaccessible because they are expected to occur only at temperature or fermion densities inaccessible at laboratory scales.Nor are these processes thought to be available for study in any contemporary astrophysical situations.

In view of the potential importance of finding an experimental system in which the electroweak phase transition might be observed today; Simmons, Learned, Pakvasa and Tata considered a speculative possibility. Sonoluminescence in water is an acoustical process which focuses mechanical energy from macroscopic dimensions down to nearly atomic dimensions. If sonoluminescence should somehow occur in a neutron star as a result, say, of a star quake or supernova core bounce, we could have focusing of energy over a stellar volume, down, perhaps, to nearly nuclear dimensions; a volume scale factor of the order of 10^{30} over the laboratory scale sonoluminescence. We calculate the minimum energy needed to overcome lepton cooling and to compress matter to the electroweak scale and find that the energy required is small compared to that available in a star quake.

This implies that the electroweak phase transition may be reached by way of high temperature or high fermion density (which is to say, high Fermi level) but the characteristic energy of the transition and the rate of baryon and lepton violation can only be determined by means of detailed modeling. Several authors report that the characteristic energy, either temperature or Fermi level, is in the range 100 to 200 GeV. Based upon those results, we assume that baryon number and lepton number violation is important above 100 GeV.

We have shown that in the normal course of gravitational collapse, the electroweak density will not be reached. However, we have suggested a mechanism, sonoluminescence in a neutron star, which might achieve the electroweak phase transition. While this mechanism is only a speculation on our part, it is of some interest since this may well be the only contemporary process where the electroweak phase transition would be of relevance. We have also presented a very simple hydrodynamic scenario to support the plausibility of our speculation of sonoluminescence. Should the sonoluminescence process occur during star quake or supernova, (with nor without attainment of the electroweak threshold), the result is a pulse of low energy neutrinos ($E \sim MeV$) of all flavors which diffuse from the star. The neutrino flux from such a process at 10 kpc would not register any events with even the low-threshold solar neutrino detectors such as Borexino under construction at Grand Sasso and Hellaz in the design state at present. If such an event occurs as close as 1 kiloparsec, then it may be possible to see 10 to 20 neutrino events of a time scale 10^{-3} sec due to sonoluminescence in a detector such as Borexino. The events would stand out above backgrounds (due to solar neutrinos) and be distinguished from the neutronization burst events by being lower in energy (average energy being close to 1 MeV rather than 10 MeV for neutronization $\nu's$) and being later in time. The secondary thermal neutrinos are expected to be emitted as usual; these were observed from SN1987A but due to the high thresholds of the detectors no conclusion can be drawn about possible low energy neutrinos from sonoluminescence. Future low threshold ($E_{th} <$ 1MeV) high volume detectors would be able to study this question in detail. This work is reported and submitted for publication (W.A. Simmons, J. G. Learned, S. Pakvasa and X. Tata, UH-511-846-96, submitted to Phys. Rev. Lett.)

4.7 Publications

We list publications since the last DOE Report. We also list the published reference for papers reported as preprints or "in press" in last year's Report.

4.7.1 Journal Publications

A. Datta, S. Pakvasa and U. Sarkar, Gravitational Uncertainties from dimension six operators in SUSY-GUT Predictions, Phys. Rev. **D52**, 550 (1995).

J. G. Learned and S. Pakvasa, Detecting tau-neutrino oscillations at PeV Energies, Astroparticle Physics Journal **3**, 267 (1995).

T.E. Browder and S. Pakvasa, A Comment on Experimental Determination of $| V_{ts}/V_{td} |^2$, Phys. Rev. **D52**, 3123 (1995).

G. Burdman, E. Golowich, J. Hewett and S. Pakvasa, Radiative Weak Decays of Charm Mesons, Phys. Rev. **D52**, 6383 (1995).

J. Feng, M. Peskin, H. Murayama and X. Tata, Testing Supersymmetry at the Next Linear Collider, Phys. Rev. **D52**, 2746 (1995).

T. Wöhrmann and H. Fraas, Associated Slepton-Neutralino/Chargino Production at LEP$\otimes$LHC, Phys. Rev. **D52**, 78 (1995).

H.J. Lipkin and S.F. Tuan, Isospin Violating Pion Emission from Heavy Quarkonium, Phys. Lett. **B368**, 148 (1996).

Y.F. Gu and S.F. Tuan, New Challenges in Charmonium Physics, Mod. Phys. Lett. **A10**, 615 (1995).

S.F. Tuan, Search for the χ_c' Charmonium States as Solution to the CDF ψ' Puzzle, Pramana, **45**, 209 (1995).

T.E. Browder and S. Pakvasa, Experimental Implications of Large CP Violation and Final State Interactions in the Search for $D^0 - \bar{D}^0$ Mixing, (Revised), Phys. Lett. B (in press).

N.G. Deshpande, X-G. He and S. Pakvasa, Single Isospin Decay Amplitude and CP Violation, UH-511-851-96. (submitted to Phys. Rev. **D**).

A. Datta and S. Pakvasa, Pion-Nucleon Phase Shifts in Heavy Baryon Chiral Perturbation Theory, UH-511-852-96 (submitted to Phys. Rev. **D**).

Y.F. Gu, K.T. Chao, and S.F.Tuan, On Trigluonia in Charmonium Physics, Commun. Theor. Phys. V. 25, No. 4, pp. 471-478, June 15 (1996).

S.F. Tuan, Some Theoretical Considerations on Heavy Quarkonium Systems, Commun. Theor. Phys. (in press).

T. Barnes, T.E. Browder, and S.F. Tuan, Prospects for detecting an η_c' in two photon processes, UH 511-849-96 (1996) (submitted to Phys. Lett. **B**).

H. Baer, C-H. Chen, F. Paige and X. Tata, Signals for Minimal Supergravity at the CERN Large Hadron Collider: Multijet plus Missing Energy Channel, Phys. Rev. **D52**, 2746 (1995).

F. Franke and T. Wöhrmann, Production of Supersymmetric Higgs Bosons at LEP$\otimes$LHC, UH-511-823-95 (1995) (Submitted to Phys. Lett. **B358**, 281 (1995).

H. Baer, C-H. Chen, C. Kao and X. Tata, Supersymmetry Reach of an Upgraded Tevatron Collider, (submitted to Phys. Rev. **D52**, 1565 (1995).

H. Baer, M. Brhlik, R. Munroe and X. Tata, Prospects for Supersymmetry at LEP 2, Phys. Rev. **D52**, 5031 (1995).

H. Baer, C-H. Chen, F. Paige and X. Tata, Signals for Minimal Supergravity at the CERN Large Hadron Collider II: Multilepton Channels, Phys. Rev. **D53**, 6241 (1993).

W. Simmons, J. Learned, S. Pakvasa and X. Tata, Sonoluminescence in Neutron Stars, UH-511-844-96 (1996) (submitted to Phys. Rev. Lett).

S. Abdullin, H. Baer, C. Kao, N. Stephanov and X. Tata, Simultaneous Search for Two Higgs Bosons of Supersymmetry at the LHC, UH-511-845-96 (1996) (submitted to Phys. Rev. **D**).

H. Baer, C-H. Chen, F. Paige and X. Tata, Supersymmetry Reach of Tevatron Upgrades: A Comparative Study, UH-511-847-96 (1996) (submitted to Phys. Rev.

D).

H. Baer, R. Munroe and X. Tata, Supersymmetry Studies at Future Linear Colliders, UH-511-850-96 (1996) (submitted to Phys. Rev. D).

4.7.2 Conference Publications.

S.F. Tuan, Aspects of Charmonium, UH-511-832-95 (1995), Proceedings of Hadron '95, p. 361 [World Scientific Publishing Co. Pte. Ltd., 1996].

X. Tata, Supersymmetry: Where it is and How to find it, UH-511-833-95 (1995) (to be published in Proceedings of TASI 95, World Scientific).

X. Tata, Supersymmetry Phenomenology: A Microreview, UH-511-834-95 (1995) (to be published in the Proceedings of the 1995 EPS meeting, Brussels, Belgium, July 1995).

E. Accomando *et. al.* Event Generators for Discovery Physics, UH-511-840-96 (1996) (to appear as a LEP II Report, CERN (1996)).

S. Ambrosanio *et. al.* Searches for New Physics, UH-511-841-96 (1996) (to appear as a LEP II Report, CERN (1996)).

S. Pakvasa, Neutrino Physics: Phenomenology, Proc. of the International Conference on Astrophysics and Cosmology, Calcutta, Dec. 19-23, 1993. Ed. B. Sinha and R.K. Moitra, Narosa Press (N. Delhi, India) 1995, p. 88.

S. Pakvasa, Phenomenology of Solar and Atmospheric Neutrinos, Proceedings of International Conference on Non Accelerator particle Physics, Bangalore, India, Jan. 2-9, 1994. Ed. R. Cowsik (World Scientific) 1995, p. 188.

S. Pakvasa, First International Conference on Symmetries in Subatomic Physics, Taipei, May 1994, Ed. W-Y Pauchy Hwang and L.S. Kisslinger; Chin. J. Phys. 32, 1163 (1994).

S. Pakvasa, Neutrino Oscillations with Beams from AGN's and GRB's, Proceedings of International Conference on Physics Beyond the Standard Model, Lake

Tahoe, Dec. 13-18, (1994), Ed. J. Gunion, T. Han and J. Ohnemus, (World Scientific) 1995, p. 570.

S. Pakvasa, Topics in Neutrino Physics, Fourth Workshop in High Energy Physics Phenomenology, Calcutta, Jan. 3-11, 1996 (to be published).

4.7.3 Other Publications

H. Baer, H. Murayama, X. Tata *et. al.* Low energy Supersymmetry Phenomenology, (to be published in *Electroweak Symmetry Breaking and New Physics at the TeV Scale*, T. Barklow, S. Dawson, H. Haber and J. Seigrist, Editors (World Scientific)).

S. Pakvasa, CP Violation: the Standard Model, "A Gift of Prophecy", Ed. E.C.G. Sudarshan, (World Scientific) 1995, p. 387.

Chapter 5

Relation to Other Projects

As described above, our research is highly collaborative. Consequently, we maintain many close ties with groups at other Universities and Laboratories. Members of our group frequently play leadership roles in these collaborations: Olsen is the Spokesman for AMY and a Co-spokesman for BELLE, Parker is the leader of the monolithic pixel development collaboration and Learned is on the collaboration council of the Superkamiokande experiment. Pakvasa and Tata are the US Principal Investigators for an NSF-India Cooperative Research Program between Hawaii and Bombay University/ Indian Institute of Science, Bangalore, and a similar program between Hawaii and CINVESTAV in Mexico.

5.1 Other Activities

A brief summary of some of the activities of members of our research group follows.

Browder gave contributed talks on B physics and QCD at the Warsaw meeting (July 1996) and invited talks on B meson physics at the Brussels Europhysics meeting (July 1995), the Calcutta Workshop on High Energy Physics Phenomemology (January 1996), and is invited to talk at the Conference on Radiative Corrections in Cracow (August 1996). He also gave a seminar at SLAC (January 1996) and participated in the Beijing Tau-Charm Factory Workshop, where he presented results on calculations of synchrotron radiation backgrounds for the proposed Beijing Tau-Charm Factory (February 1996).

Cummings gave invited talks on B physics with the D0 detector at the Rencontres du Viet Nam (October 1995) and the Beauty 96 meeting in Rome (June 1996).

Learned gave talks on high energy neutrino astronomy with a km^3 detector at the Rome Cosmic Ray conference, where he also chaired a session (August 1995). He gave a talk on physics and astronomy with high energy neutrinos at the Florence Cosmic Ray and Astrophysics meeting (September 1995). He gave talks on high energy neutrino telescopes at the Venice Neutrino Telescope Workshop (February 1996) and the KM3 Workshop in Arcadia CA (April 1996). He attended the Aspen Institute's High Energy Neutrino Workshop where he discussed the possibility of detecting $E > 10^{20}$ eV neutrinos using existing sonar arrays (June 1996).

Jones gave an invited talk on the determination of the top-quark mass at the Indianapolis APS meeting (May 1996).

Kenney gave two talks at the UCLA Conference on Imaging Detectors in High Energy Physics and Astroparticle Physics (September 1995): one on monolithic silicon pixel detectors and the other on digital quantum mammography. He gave a talk on 3D architecture for silicon detectors at the Indianapolis APS meeting (May 1996) and will give a talk on the same subject at the Minneapolis DPF meeting (August 1996). He will give talks on simulating charge cloud evolution in silicon drift detectors and energy deposition of minimum-ionizing particles in thin silicon layers at the Anaheim IEEE Nuclear Science Symposium (November 1996).

Olsen presented results on detector R&D at the annual meeting of the U.S.-Japan Committee for Cooperation in High Energy Physics at Brookhaven (May 1996), gave an invited talk on ψ' results from BES at the Quarkonium Workshop in Chicago (June 1996), is invited to give a plenary talk on B-factories at the Minneapolis DPF meeting (August 1996), and gave a seminar on ψ' physics at the University of Rochester (June 1996). In addition, he reported on the status of the BELLE experiment to the Lepton Collider Advisory Panel at KEK (February 1996). He is a member of the International Advisory Committee for the Minneapolis DPF meeting, a member of the KEK B-factory Steering Committee, and has served on the Lehman reviews for the BaBar experiment at PEP-II.

Pakvasa gave an invited talks at the Calcutta Workshop on High Energy Physics Phenomemology (January 1996), and the Gleb Wataghin School on High Energy Physics Phenomenology in Campinas, Brazil (July 1996). He presented a series of lectures on neutrino physics and CP violation as the McMinn Lecturer at Vanderbilt University (March-April 1996). He was a member of the International Advisory Committee for the Linear Collider Physics Workshop in Morioka, Japan (September 1995), where he chaired the final plenary session, and is a member of the International Organizing Committee for the Fourth KEK Topical Conference on Flavor Physics (October 1996). He attended PHENO 96: Recent Developments in Phenomenology meeting in Madison (April 1996) and chaired the closing plenary session. He is a co-convenor for Non-accelerator Physics and Neutrinos at the Minneapolis DPF meeting (August 1996).

Parker gave talks on pixel detectors with a 3D architecture at the Third International Workshop on Semiconductor Pixel Detectors in Bari (March 1996) and the ICHEP Warsaw Meeting (July 1996). He is a co-convenor for the parallel session on instrumentation at the Minneapolis DPF meeting (August 1996).

Peterson serves on the State of Hawaii's Department of Health's advisory committee on health effects of electromagnetic fields from overhead power lines. He advised the National Weather Service and Federal Aviation Authority on the possible adverse health effects of pulsed radar systems.

Rodriguez gave an invited talks on factorization and color suppression in B-meson decays at the Rencontres du Viet Nam (October 1995).

Stenger attended the Irvine meeting of the Superkamiokande group (September 1995) and gave a talk on "The Pevascope" at the Arcadia KM3 Workshop (April 1996) and on optimizing underwater detectors at the Aspen High Energy Neutrino Workshop (May 1996). He gave a colloquim entitled "Quantum Quackery" at the Aspen Institute of Physics (June 1996) and similar talks at the World Skeptics Congress in Buffalo (June 1996) and at Skeptic Society meetings in Berkeley and Pasadena (May 1996).

Tata was a lecturer at the 1995 Theoretical Advanced Study Institute at Boulder. He spent the Fall 1995 semester on sabbatical leave at Wisconsin and Florida State. He gave an invited talk on SUSY phenomenology at the Brussels Europhysics meeting (July 1995) and gave the SUSY summary talk at the SLAC meeting on Linear Collider Physics (March 1996). He served as a co-convenor of the Supersymmetry subgroup at the Linear Collider Physics Workshop at Morioka (September 1995) and Snowmass 96. He is active in the SUSY working groups for LEP II and the NLC and was co-leader of the SUSY subgroup for the 1994-95 DPF Long Term Planning study,

Tuan chaired a session and gave an invited talk on Aspects of Charmonium at the Hadron '95 meeting in London (July 1995).

5.2 Visitors

Sept. 1995 :	J. Kühn (Karlsruhe), J. Duboseq (Ohio State)
Oct. 1995 :	T. Rizzo (SLAC), J. Hewett (SLAC)
Nov. 1995 :	D. Dikeman (Minnesota), Z.P. Zheng (IHEP – Beijing)
Dec. 1995 :	S. Parke (Fermilab), P. Greider (Bern)
Jan. 1996 :	E. Golowich (Massachusetts), W.S.Hou (Taiwan)
Feb. 1996 :	P. Kim (Cornell), Y. Ohashi (Tokyo)
Mar. 1996 :	A. Maki(KEK), T. Shintake (KEK)
Apr. 1996 :	K. Hikasa (Tohoku), A. Wolf (OhioState)

In addition, the BES, DUMAND, and U.S.-SuperKamiokande Collaborations have had group meetings in Hawaii. This provides for additional interactions with the members of HEPG. Most visitors provided their own support. University funds was the prime source of support for theory visitors when it was needed.

With the Dean of Natural Science's assistance, we have acquired a Pictel videoconference system that we use to have meetings with collaborators on the mainland and in Japan. We also make frequent use of PC-based internet conferencing systems such as CUseeMe and Mbone.

Chapter 6

Conference on B Physics and CP Violation

We will host a conference on B Physics and CP Violation, which will be held in Honolulu, Hawaii, during March 24-27, 1997. The conference will concentrate on physics and detector issues relevant to experiments on B Physics and CP Violation which are in progress and planned for the near future. This is the second in a series of international workshops begun in Nagoya, Japan by Professor A.I. Sanda in October 1994. We ask for partial support for this conference from the DOE in this request. We are also asking for funds from SLAC, KEK, the NSF, and the University of Hawaii.

6.1 Introduction

Although readily accommodated in the Standard Model by a complex phase in the CKM matrix, CP violation remains one of the least understood phenomena in physics. So far it has only been observed in the decays of kaons. While the results from the kaon sector are consistent with the Standard Model, the complications introduced by strong interaction effects make it nearly impossible to ascertain whether the complex CKM phase is the sole source for the observed asymmetries. If the Standard Model is correct, large CP asymmetries are expected in hadronic B decays to CP eigenstates. Efforts are now underway at every major high energy physics laboratory to observe these CP violating effects in the B sector.

Data samples at least one order of magnitude larger than those available at present are required to observe CP asymmetries in the B meson system and to provide fundamental consistency checks of the Standard Model. This is the justification for the construction of high luminosity e^+e^- storage rings in the US at SLAC(PEP II/BABAR), at Cornell (CESR PHASE III/CLEO III), and in Japan(KEK-B/BELLE), as well as a dedicated fixed target experiment at the HERA ring at DESY. Hadron collider experiments dedicated to the study of CP violation have also been proposed at Fermilab and at CERN.

The physics that can be addressed at these machines and the development of necessary detectors will obviously depend on (and hence, should influence) the design of the collider, making it essential to consider machine, detector, and physics issues in parallel. For instance, there is at present enormous theoretical activity on the development of strategies for measuring the CP angles. The experimental and theoretical issues involved in studying direct CP or measuring the 2nd and 3rd CP angles are not yet in hand. The large number of new measurements which are emerging from CLEO, LEP, Fermilab will also impact these plans. Since the strategies for the BELLE and BaBar experiments depend on all this the dates for our meeting are quite timely.

We note that the two volumes of Proceedings for the last major conference organized by the University of Hawaii High Energy Physics Group at Waikoloa, Hawaii on Linear Collider Physics has become a benchmark reference for workers in the field.

6.1.1 Program of the last B Physics and CP Violation Conference

The program of the last B physics and CP Violation Conference held in Nagoya, Japan had the following talks during the three day period of the conference in October 1994.

1. Opening Address by N. Kato
2. Time Reversal and CP Violation by T.D. Lee
3. CP Violation in the Standard Model by C. Jarlskog
4. Exploring New Physics with B Mesons by L. Wolfenstein
5. B-Factory Accelerators for Theorists- A Primer by M. Tigner
6. Status of the SLAC/LBL/LLNL B-Factory and the BABAR Detector by P. Oddone
7. Progress of the B Factory at KEK by S. Suzuki
8. Recent Results from CLEO by R. A. Poling
9. Top Physics at CDF by B. L. Winer
10. Results from Solar Neutrino Experiments by M. Nakahata
11. Testing the Standard Model of CP Violation in the B system by M.Gronau
12. New Physics and Rare B Decays by A. Ali
13. Towards a Unified Origin of Forces, Families, and Mass Scales by J.C. Pati

14. S0(10) SUSY GUTS by S. Raby
15. Silicon Vertex Detectors at e^+e^- B Factories by A.S. Schwarz
16. Particle Identification with Silica Aerogel Threshold Cerenkov Counters at an Asymmetric B Factory by G. Eigen
17. Interaction Region Issues at KEKB by N. Toge
18. KEKB Accelerator Design by K. Satoh
19. The PEP-II Design by M.K. Sullivan
20. Measuring $|V_{ub}|$ at the LEP/SLC by C. S. Kim
21. Model-Independent Determination of $|V_{ub}|$ in Heavy Meson Effective Theory by N. Kitazawa
22. The Fermi Motion Parameter p_F of the B Meson from a Relativistic Quark Model by D. S. Hwang.
23. New Approach for Measuring $|V_{ub}|$ at Future B-Factories by P. Ko
24. Effect of the Flavor Changing Neutral Current on Rare B Decays by T. Morozumi.
25. Probing New Physics in B Penguins by J.L. Hewett
26. Constraints on the Left-Right Symmetric Model from $b \to s\gamma$ by T.G. Rizzo
27. B Physics at CDF and D0 Present and Future by N.S. Lockyer
28. Review of CP Violation Studies with B-Mesons at LHC by T. Nakada
29. Weak Matrix Elements Efforts on the Lattice: Status and Prospects by A. Soni
30. SUSY and CP Violation by Y. Okada
31. A QCD Treatment of the Weak Decays of Heavy Flavor Hadrons without Voodoo and Undue Incantations by I. I. Bigi
32. Spontaneous CP Violation by G. C. Branco
33. The Pattern of Quark Masses and CP Violation by H. Fritzsch
34. Conference Summary by D. G. Hitlin

6.1.2 Preliminary Conference Program

The workshop will run from March 24 to 27, 1997. On Monday morning there will be welcoming talks followed by overview talks on B factory machines and experiments. The conference will have alternating sessions which cover theoretical and experimental work on B decay. Thursday will be devoted to review talks and the conference summary.

1. Sunday Afternoon, March 23, 1997
2. Registration 3:00 - 5:00 PM

- Monday Morning, March 24, 1997 – Plenary Session
    1. Registration 8:00 AM
    2. Welcome 9:00 AM
    3. Physics Overview
    4. Break
    5. Future e+e- B Factories: Accelerators
- Monday Afternoon, March 24, 1997 – Plenary Session
    1. Future Hadron B Factories: Accelerators
    2. Break
    3. Future e^+e^- B Factories: Detectors
    4. Future Hadron B Factories: Detectors
- Monday Evening, March 24, 1997 – Reception
- Tuesday Morning, March 25, 1997 – Plenary Sessions
    1. Experimental Results on B Physics
    2. Break
    3. Experimental Results on B Physics
- Tuesday Afternoon, March 25, 1997 – Plenary Sessions
    1. Theoretical Aspects of CP Violation
    2. Break
    3. Theoretical Aspects of CP Violation
- Wednesday Morning, March 26, 1997 – Plenary Session
    1. Theoretical Aspects of Rare B Decay

2. Break
3. Experimental Results on Rare B Decay

- Wednesday Afternoon, March 26, 1997 – Plenary Session

1. Experimental Results on CP Violation and Rare Decays of Charm
2. Break
3. Theoretical Work on CP Violation and Rare Charm Decay

- Wednesday Evening, March 26, 1997 – Banquet Luau
- Thursday Morning, March 27, 1997 — Plenary Session

1. Experimental Results on CKM Matrix Elements
2. Break
3. Theoretical Work on CKM Matrix Elements

- Thursday Afternoon, March 27, 1997 — Plenary Session

1. Summary Talks
2. Break
3. Summary Talks
4. Conference Summary

6.1.3 Conference Organization

The Conference on B Physics and CP Violation is being organized by the High Energy Physics Group at the University of Hawaii at Manoa. This group has organized many conferences, including ten Hawaii Conferences in High Energy Physics between 1965 and 1985, the International Conference on Neutrino Physics and Astrophysics at Wailea, Maui (1981), the High Energy Neutrino Astronomy Workshop, April 1992 and most recently the successful Workshop on Physics and Experiments with Linear e^+e^- Colliders at Waikoloa in 1993. This conference will have published proceedings. The proceedings of the last conference organized by the University of Hawaii on linear colliders is now of the one standard references in the field.

Local Organizing Committee

The members of the Local Organizing Committee are listed below:

1. J. Bolosan

2. **T. E. Browder, Co-Chair**

3. J. Bruce
4. F. Harris
5. D. Ibaraki
6. M. Jones
7. S. Olsen
8. **S. Pakvasa, Co-Chair**
9. M. W. Peters
10. J. Rodriguez
11. S. Sahu
12. X. Tata
13. T. Ter Veldhuis

The members of the International Advisory Committee are listed below:

1. **A.I. Sanda (Nagoya) Chair**
2. A. Ali (DESY)
3. R. Aleksan (Orsay)
4. G. Eigen (Bergen)
5. N.G. Deshpande (Oregon)
6. J. Dorfan (SLAC)
7. D. Green (FNAL)
8. M. Gronau (Weizmann)
9. D. Hitlin (Caltech)
10. K. Honscheid (OSU)
11. W.S. Hou (Taiwan)
12. K. Kinoshita (VPI)
13. T. Nakada (PSI)

14. R. Poling (Minnesota)
15. H. Quinn (SLAC)
16. B. Richter (SLAC)
17. W. Schmidt-Parzefall(DESY)
18. M. Shapiro (Berkeley)
19. A. Schwarz (DESY)
20. H. Sugawara (KEK)
21. S. Suzuki (Nagoya)
22. F. Takasaki (KEK)
23. B. Wicklund (Argonne)
24. M. Witherell (Santa Barbara)
25. S.-L. Wu (Wisconsin)

6.1.4 Location and Meeting Dates

The Second Conference on B Physics and CP Violation will be held in Honolulu, Hawaii March 24-27, 1997. The proximity of Waikiki and the presence of well equipped hotels with experience in conference organization and excellent conference facilities and infrastructure should minimize the overhead required for this conference. The University of Hawaii has previously held successful International conferences at Wailea, Maui on Neutrino Physics, at the University of Hawaii campus on High Energy Neutrino Astrophysics, and at Waikoloa, Hawaii on Linear Collider Physics.

6.1.5 Announcements and Invitations

The conference dates have been announced in SPIRES and notices of the dates been sent to the APS Division of Particles and Fields, and Physics Today. We have also printed a preliminary announcement which will be mailed out from Hawaii in June 1996. It will be sent to over 550 individuals and institutions throughout the world. A larger color poster with more complete information will be mailed soon after from the University of Hawaii to the same list. The first bulletin will also be mailed out to the same list as well as to all individuals who have inquired about the workshop because of the announcements or posters. The bulletin will include a registration form, the preliminary program, and an interest form for further mailings for the conference. A second mailing will be sent in early 1997 to those who register or express interest in the workshop. Both mailings will include details about the conference program, lodging, and social events.

6.2 Funding

A budget estimate has been made for the Conference on B Physics and CP Violation. Much of the work before and during the conference will be done by members of the High Energy Physics Group at the University of Hawaii. They will serve as local hosts for the meeting, check on audio visual equipment, insure that conference activities are successful, and work on last minute changes to the conference program. We plan to use commercial duplicating services during the workshop to make copies of transparencies for attendees. However, it will be necessary to rent a copier during the conference to make a master copy of the transparencies and to do other duplicating necessary during the workshop. Also listed are the funding sources for the Conference. We have included a contingency because many of the cost estimates are preliminary and incomplete.

6.2.1 Overall B Physics and CP Violation Workshop Budget

Non Registration Items

- Subsistence/Travel
  1. Foreign $ 1,750
  2. USA $ 1,750
- Waikiki/UHM Operations
  1. Photo copies: (brochures, programs, etc.) $ 1500
  2. Printing: (mini-poster, poster, name tags) $ 2500
  3. Copier rental, paper, supplies $ 1,000
  4. Computer Link, modems, phone $ 1000
  5. Audio visual equipment rental (overhead projectors, slide projector, microphones) $ 2000
  6. Van Rental $ 1000
- Communications/Supplies
  1. Phone/FAX/Telex $ 1,000
  2. Postage $ 2,000
  3. Stationary/Other Supplies $ 2,500
- Other Costs
  1. Registration Fee for local participants (20) $ 7,000
- Subtotal nonregistration items $ 25,000
- Contingency (10%) $ 2,500
- Total nonregistration items $ 27,500

Registration Items

- Proceedings $ 11,500 (World Scientific Quote for 200 copies of a 500 page Proceedings)
- Rental of conference rooms and 2 additional rooms $ 7,600
- Conference Events

1. Reception for 200 persons $ 8,000
2. Banquet for 200 persons $ 11,000
3. Session breaks for 200 persons $ 12,000

- Miscellaneous $ 700
- Registration packet (bags and tags) $ 3,000
- CCECS (Conference center) $ 9,800

- Subtotal Registration Items $ 63,600
- Contingency Registration (10%) $ 6,400
- Total Registration Items $ 70,000

Grand Total (Registration and nonregistation) $ 97,500

The expected funding sources for this conference are listed below.

Overall Funding Sources

- Registration Fees ($ 350 per person - early registration for 200 persons) $ 70,000
- KEK (requested)$ 10,000
- DOE (requested) $ 10,000
- NSF(requested) $ 5,000
- University of Hawaii (requested) $ 2,500
- Total $ 97,500

Chapter 7

Computing Facility

7.1 HEPG Computer/Network System and Video Conferencing

Dr. F. Harris and Ms. D. Ibaraki

During the past year, the most important change was the addition of a Macintosh 8500/120 and a PictureTel system to enable the High Energy Physics Group to participate in meetings via video conferencing. Video conferencing is extremely important for us in Hawaii because of the long distance and high expense involved in commuting to collaboration meetings. University money was used to buy the PictureTel system.

7.1.1 Computing

We increased our CPU power substantially with the addition of three DEC AlphaStation 3000/700's purchased during a three-for-one sale on these systems. Currently we have four AXP 3000/300's, one AXP 3000/600, one AlphaStation 200 4/166 and the three AXP 3000/700's. One AXP 3000/300 runs OpenVMS, all the other systems run UNIX. The total computing power of these computers is approximately 1000 Specmarks (or approximately 1000 times the computing power of a VAX 11/780). This computing power has been very important for BES reconstruction, BELLE, BES, CLEO, DUMAND and SK analysis, and Monte Carlo event generation.

Also important was the addition of five 9 Gbyte disk drives and a Digital Linear Tape (DLT) drive which can hold 40MB of data per tape in compressed mode. Both CLEO and SUPERK use DLT's for data storage.

We have purchased two Uninterruptible Power Supplies (UPS) and received one from the SSC. These will help maintain smooth functioning of our system and protect our substantial investment in it. Lately there have been frequent glitches in the Oahu power grid, some of which resulted in disk failures or required personnel to fix file systems in order to reboot. The UPS' will be attached to our main servers. We plan to add more in the future if these work out well. Additional Xterminals were purchased to support new CLEO and BELLE personnel. The arrangement of our computer systems and network are shown in Fig. 7.1.

We are continuing to purchase software under the DEC Education Software Initiative. This program, which drastically reduces the cost of DEC software, supports both VMS and UNIX computers. Software support for our VAX VMS cluster, OpenVMS, and our UNIX systems is handled by D. Ibaraki and student helpers. Duties include answering questions for faculty and students, adding users, fixing stopped printers, installing upgrades and new software, ordering documentation and software, etc.

7.1.2 Networking

Figure 7.1 also provides detail on our network, PHYSNET. Our computers, terminals, X-terminals, and PC's are distributed throughout the Physical Science Building (PSB) and Watanabe Hall. We are connected to the UH Network (UHNET) by the Wellfleet Router in the UH Computing Center via a fiber optic cable. UHNET is connected to NASA Ames via a T1 (1.5 Mbits/s) fiber optic link which provides DECNET and Internet communication with the mainland and HEPNET. The cost of this link is borne by NASA, NSF, and the University of Hawaii. Although this connection has been adequate in the past, it is becoming increasingly busy, and its performance is deteriorating.

7.1.3 Video conferencing

During the past year, we have increased our use of different video conferencing systems. Last year, the US-BES group instituted weekly analysis meetings via the CuSeeMe program on Macintosh computers. CuSeeMe has the advantage that it can be used on a reasonably modern Macintosh with only the addition of a $99 video camera. The internet is used for the conference. During these meetings, which usually involve Hawaii, UT Dallas, Colorado State, and UC Irvine, status reports on various aspects of the experiment are discussed, with results accessed via World Wide Web using Netscape. Most monthly collaboration meetings have also been broadcast using CuSeeMe, allowing those who have stayed at home to "attend" the meetings. CuSeeMe meetings with China have also been attempted with varying success. We find these meetings very useful ways to exchange information. Also, it enables all the Hawaii BES group members to participate in these meetings and present results.

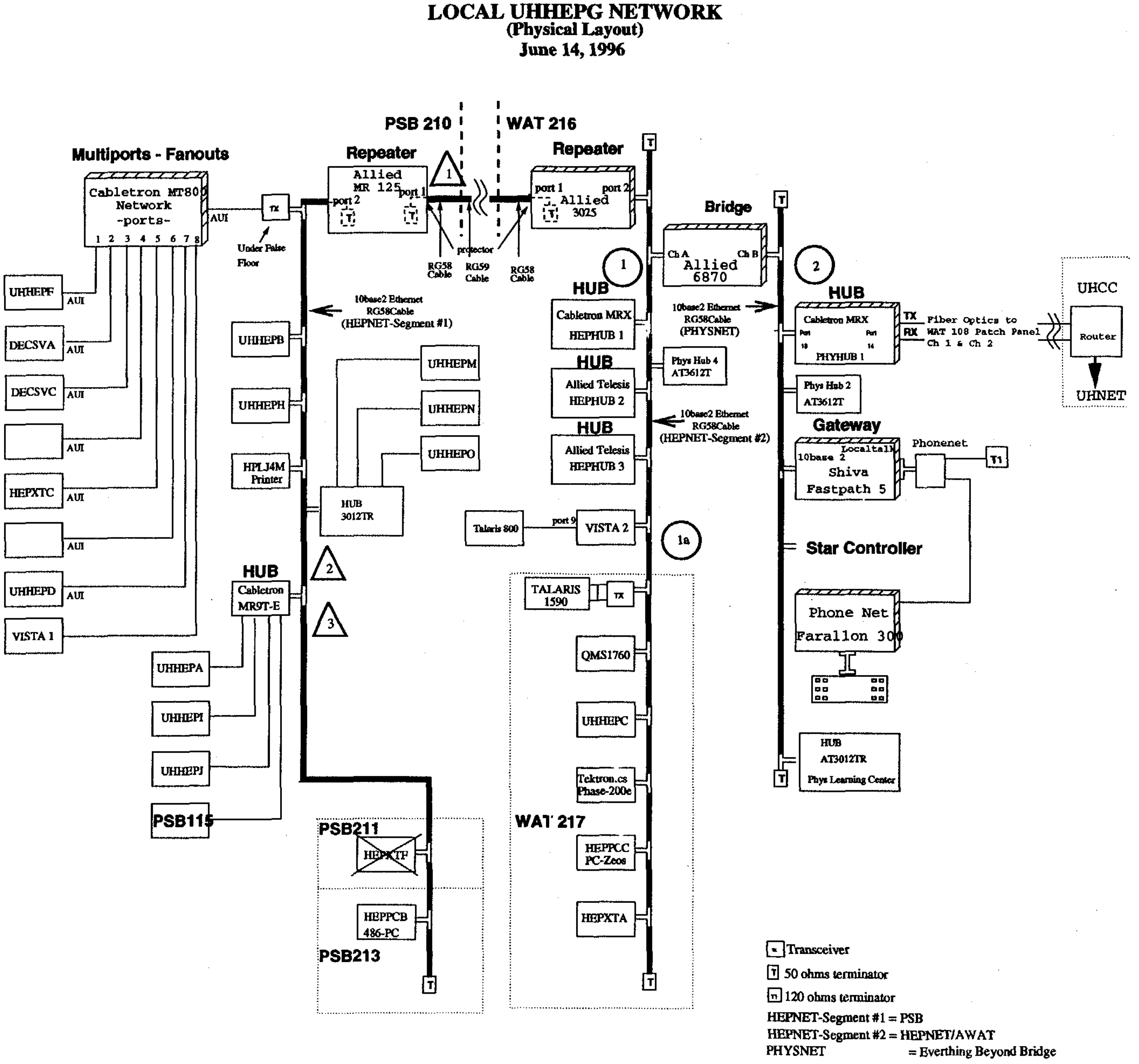


Figure 7.1: High Energy Group Computing Systems and Network.

In order to participate conveniently in the CuSeeMe meetings, we purchased a Macintosh 8500. Unfortunately with our network connection being poor, we still often have trouble with the video conference connection and the sound.

During the past year, we also tested, with help from experts at Fermilab, another video conferencing system which uses dialup ISDN (Integrated Services Digital Network) telephone lines. The PictureTel 2000 system, which is much superior to CuSeeMe, features a large screen TV; a full duplex audio system with echo cancellation, noise suppression, and automatic gain control; a video camera with power zoom and pan; and a wireless keypad control. It supports all the current Video Conferencing standards and can video conference with equipment from other vendors. D0 and CLEO have both standardized on the PictureTel system. After successfully testing the system, we were able to obtain support from the College of Natural Sciences for its purchase. The D0 and CLEO groups routinely use this system for meetings with mainland colleagues. The BELLE group is using it for weekly meetings with our collaborators on the TOF system at KEK.

Most of the other US-BES groups have available to them systems that allow participation in a multi-point conference with our PictureTel system. The last monthly collaboration meeting was conducted very successfully in this fashion. Everyone in Hawaii was able to "attend" and talks were presented by the two faculty members involved and by two graduate students. The sound and picture quality were far superior to earlier conferences using CuSeeMe. We expect that, in the future, this system will be used in place of CuSeeMe.

7.1.4 Future Upgrades

Of the system upgrades we propose for FY97, the most important is increased disk space. CLEO and SuperK are currently taking data; BES will be taking data with higher luminosity in the fall; and we anticipate greater BELLE disk space needs as the turn-on approaches. The increasingly lower for disk storage makes it feasible to keep more and more data on disk, allowing for much faster analysis turn around. We now anticipate that 23GB disks will be available in the 3rd quarter of FY'96 at a cost of about $5K.

We also want to improve our networking in PSB 210, where most of the workstations and disks are located. At present, we find that we overload our network when we analyze data on one workstation with data located on a disk mounted on another workstation. By adding a fiber channel ring in PSB, we will be able to solve this problem. In order to do this, we need FDDI cards for each PSB 210 workstations and a FDDI concentrator. We estimate that this will cost approximately $10K.

Table 7.1: Computer Upgrade Items for FY97

ITEM	Price
2 Elite 23 Gbyte Disk Drives	$10,000
6 Fiber Channel Ethernet Cards and Fast Ethernet Hub	10,000
1 Digital Linear Tape (20 Gbyte)	5,200
1 Helical Scan, 8mm Tape Drive	3,500
1 CDRom Drive	500
2 Uninterruptible Power Supply	1,000
2 1Gbyte disk for pcs	500
2 8MB memory for pcs	400
1 Jazz Removable Hard Drive & 5 Cartridges	1,300
5 4MB memory for Xterminals	1,000
TOTAL	$33,400

As we become more reliant on the DLT, we foresee a need for an additional drive as a backup should our first drive develop problems and to enable more than one person or more than one project to do analysis of data at a time.

We also need a new 8mm tape drive to replace one of the older tape drives, another CD ROM drive and a more uninterruptible power supplies. We also propose to add more memory and disk space to our PCs.

The upgrade items are given in Table 7.1, and our complete budget for computing including supplies and maintenance is given in Chapter 8.7.

Chapter 8

Budget Request

We present a detailed, task-by-task, budget request for FY'97, together with comparisons with funding levels for the previous two fiscal years. The amount of funds requested for FY'97 is approximately 3 percent higher than the FY'96 award. (The FY'96 award was 5 percent below the previous year's base level.) The small requested increase primarily reflects a small increment in the amount requested for theoretical physics to support a new Junior Researcher, and funds to support activities related to the conference on B Physics and CP Violation that we will host in March 1997. With the cancellation of DUMAND, we have scaled back the funds for this task to the bare minimum needed to close out the project. However, this decrease is compensated by an increase in funds requested for operation expenses associated with the Superkamiokande in Japan, which is now in full operation.

In past requests, we have listed the D0 experiment as a major budget category and lumped our three activities at e^+e^- machines, i.e. BES, CLEO, and BELLE, in another single category. With the termination of D0 running, Jones' and Peters' participation in the experiment is now limited to data analysis activities centered primarily on campus in Hawaii. Moreover, our activities on the BELLE experiment have increased substantially. In this request we no longer list D0 as a separate activity, but list the three e^+e^- activities separately. This gives a more accurate breakdown of the actual levels of activity in our accelerator-based research program. Residual D0-related expenses are contained in the budget associated with BELLE.

In the following, we present the budget request for each activity together with a brief explanation. (Detailed justifications are presented in the preceding sections of this report.)

8.1 EA-I The BELLE Experiment

Our activities in the BELLE experiment were described in a comprehensive proposal that was submitted to the DOE by the Hawaii, Princeton, and VPI groups in April 1995 and sent out for external review. We were informed that the referee comments were favorable and a four-year budget plan for equipment funds for BELLE was developed. Encouraged by the favorable reviews and the positive action by the DOE, we have continued the increasing emphasis of our group's efforts on the BELLE experiment.

The requested budget for BELLE is summarized in Table 8.1. Support for Hawaii-based D0 personnel has been shifted to this category. Balderston and Yoshikawa completed their PhD theses on D0 data and have graduated. They are replaced by BELLE students Varner and Zheng. Cummings, a Hawaii research associate based at Fermilab, completed her second three-year term and will leave our group in December 1996. She will be replaced by Dr. Saroj Sahu, who will work on BELLE full-time and will initially be stationed at KEK. Summer support for Olsen, who also participates in the BES experiment, is included here.

Aside from salaries, the biggest single item is travel to KEK. This includes travel to the three general group meetings, each is usually attended by two Hawaii staff, and extended visits for TOF-related beam tests and the assembly and tests of the barrel TOF detector.

Included in the budget are modest amounts for travel and videoconferencing to Fermilab that will be associated with the continuing analysis of D0 data. The equipment request is itemized above in subsection 2.1.4 (BELLE).

Table 8.1: EA–I; The BELLE Experiment

Overhead Status	On	Off	Exempt	Eqmnt
Personnel				
Faculty Overload	15,300	22,700		
Physicists	62,500			
Junior Physicists		39,000		
Graduate Students (2)	38,500			
Hourly Student Help	5,000			
Fringe Benefits	24,700	13,300		
Personnel Costs	146,000	75,000		
Instrumentation				
Equipment Fabrication BELLE				110,000
Materials & Supplies (UH)	1,200			
Materials & Supplies (KEK)			6,500	
Instrumentation Subtotal	1,200		6,500	110,000
Computing Services				
Telecom/Network BELLE	3000			
Telecom/Network w/Fermilab	2000			
Computing Services Subtotal	5,000			
BELLE Travel (Domestic)	2,800			
BELLE Travel (Foreign)	8,000	12,000		
Meetings & Conferences (Foreign)	2,000	2,000		
Travel to Fermilab (Domestic)	3,500			
Travel Subtotal	16,300	14,000		
Other				
Publications	1,000			
Phone/FAX, Mail	1,500			
Freight/Delivery	2,000			
Other Subtotal	4,500			
Total Direct Costs	173,000	89,000	6,500	110,000
Indirect (45%/10.83%)	77,900	9,600		
Total BELLE Budget	250,900	98,600	6,500	110,000

Summary	Opers: 356,000	Eqmnt: 110,000	Total: 466,000

8.2 EA-II The BES Experiment

This item contains support for Harris, who participates in both BES and BELLE. One of the three students associated with this experiment, is supported by the University as a part-time teaching assistant.

After salaries, travel to IHEP-Beijing is the biggest expense. It is expected that each participant in the BES experiment be on-site in Beijing for about one month per year for shift taking, maintenance of the Hawaii provided detector hardware and software, and for consultation on data analysis, papers, etc. We try to limit this to one trip per participant per year and combine BELLE- and BES-related trips when possible. In addition, the US contingent of BES has monthly meetings, usually at one of the mainland institutions. Although we normally participate in parts of these meetings via videoconferencing, we anticipate the need for occasional on-hand participation at times when those times when we submit papers for the group's approval.

We use the Hawaii computer system to perform a number of group-wide services, such as data reconstruction, tape copying and distribution, and code management. We use some hourly undergraduate help to carry out many of these tasks and need a small amount of materials and supplies for tapes.

The hardware that we provided for the BES upgrade appears to be working reliably. We have supplied IHEP with enough spare parts for day-to-day maintenance. The accumulated defective components will be occasionally taken back to Hawaii for repair. We need a modest amount of materials and supplies funds to support this.

Table 8.2: EA–II; The BES Experiment

Overhead Status	On	Off	Exempt	Eqmnt
Personnel				
Faculty Overload	15,300			
Physicists				
Graduate Students (2)	39,800			
Hourly Student Help	5,000			
Fringe Benefits	4,300			
Personnel Costs	64,400			
Instrumentation				
Equipment Fabrication (BES)				
Materials & Supplies (UH)	3,000			
Instrumentation Subtotal	3,000			
Computing Services				
Telecommunications/Network	3,500			
Computing Services Subtotal	3,500			
Travel & Consultants				
BES Travel (Foreign)	14,000			
BES Travel (Domestic)	2,800			
Meetings & Conferences (Foreign)	2,000			
Travel Subtotal	18,800			
Other				
Publications				
Phone/FAX, Mail	1,000			
Freight/Delivery	2,500			
Other Subtotal	3,500			
Total Direct Costs	93,200			
Indirect (45%/10.83%)	41,900			
Total BES Budget	135,100			

Summary	Opers: 135,100	Total: 135,100

8.3 EA-III The CLEO-II Experiment

This item contains support for Rodriguez and Browder, who participate in both CLEO-II and BELLE, and two graduate students.

Although Browder makes effective use of videoconferencing while he is in Hawaii during the school year, he have to travel to Ithaca with some regularity, and spend most of the summer there, to take shifts, execute various collaboration responsibilities, and to defend his analysis results at major group meetings. One student will be in Ithaca full time to help with the operation and calibration of the detector; the other will remain in Hawaii during the school year and spend the summer in residence at Ithaca to take shifts and contribute to the normal detector maintenance activities.

We have a subcontract with Wilson Laboratory to cover the materials and supplies needed by Hawaii personnel while they are resident in Ithaca.

Table 8.3: EA–III The CLEO-II Experiment

Overhead Status	On	Off	Exempt	Eqmnt
Personnel				
Faculty Overload		10,700		
Physicists		39,000		
Graduate Students (2)	19,200	19,200		
Hourly Student Help				
Fringe Benefits	1,500	16,500		
Personnel Costs	20,700	85,400		
Instrumentation				
Materials & Supplies (CLEO)			4,000	
Instrumentation Subtotal			4,000	
Computing Services				
Telecommunications/Network	3,000			
Computing Services Subtotal	3,000			
Travel & Consultants				
CLEO Travel (Domestic)	8,000	11,000		
Maintenance @ Cornel - (1 student)		8,100		
Meetings & Conferences	2,000			
Travel Subtotal	10,000	19,100		
Other				
Publications	1,000			
Phone/FAX, Mail	1,000			
Freight/Delivery	1,000			
Other Subtotal	3,000			
Total Direct Costs	36,700	104,500	4,000	
Indirect (45%/10.83%)	16,500	11,300		
Total CLEO Budget	53,200	115,800	4,000	

Summary	Opers: 173,000	Total: 173,000

8.4 EA-IV Pixel Detector Development

This activity involved technologies from high energy physics and material science. Parker's home base is at LBL where he has good access to mechanical and electronics shops and high energy physics directed engineering expertise. In particular, the circuitry needed for the sparse field readout is a problem common to the Hawaii monolithic design and the LBL-group's bump-bonding approach. Parker has very close interactions with this group that has been mutually beneficial. Many of the circuitry concepts have emerged from these interactions. The *implemention* of these ideas in the environment of the monolithic silicon wafer depends on very different technologies; these are available at the Stanford Center for Integrated Systems, most notably in the person of the Stanford electrical engineering students that have been attracted to these research problems. This requires commuting between LBL and Stanford. Expenses at LBL and CIS are covered by subcontracts. Travel to Fermilab is for E781.

The budget request covers these subcontracts, salaries for Parker and Kenney, their travel and the costs associated with the fabrication of a radiation-hard prototype device, the next step in the development program described in the supplemental request that was submitted and reviewed in Fall 1994.

Table 8.4: EA–IV; Pixel Detector Development

Overhead Status	On	Off	Exempt	Eqmnt
Personnel				
Faculty Overload				
Physicists		88,800		
Junior Physicists		42,200		
Graduate Students				
Hourly Student Help				
Fringe Benefits		25,800		
Personnel Costs		156,800		
Instrumentation				
Lithography masks (RADHARD)			16,000	
Microchip Packaging			1,200	
Materials & Supplies (SLAC)			1,200	
Materials & Supplies (FNAL)			1,200	
Materials & Supplies (LBL)			4,600	
Instrumentation Subtotal			24,200	
Travel & Consultants				
LBL-SLAC Commuting		2,000		
LBL-FNAL Commuting		2,000		
LBL-UH Commuting		2,000		
UH-SLAC Commuting	1,500			
Meetings (Domestic)		2,000		
Meetings (Foreign)		6,000		
Travel Subtotal	1,500	14,000		
Subcontracts to CIS		27,000		
Other				
Phone/FAX, Mail	100	300		
Freight/Delivery		500		
Misc. supplies		500		
Other Subtotal	100	1,300		
Total Direct Costs	1,600	199,100	24,200	
Indirect (45%/10.83%)	700	21,600		
Total Pixel Budget	2,300	220,700	24,200	

Summary	Opers: 247,200	Eqmnt: 0	Total: 247,200

8.5 EN-I The Kamioka Neutrino Observatory

In last year's request, personnel costs for the Superkamiokande experiment were limited to one graduate student, Flanigan, who has been on-site in Japan, initially at KEK for the beam tests and currently at Kamioka working on the installation of the veto array and constructing the pulsed-laser calibration system. With the termination of DUMAND, we have concentrated the personnel involved in nonaccelerator physics on the Superkamiokande experiment, including Stenger, Matsuno and former DUMAND student Takemori. The level of activity has been high, since the experiment has been operating in a data-taking mode since April 1, 1996.

This year, with the experiment in full operation, we request funds for our staff to visit the site for shifts, etc. (All Superkamiokande collaborators are expected to be on-site for a minimum of two weeks.) In addition, we propose to station a second student at Kamioka for a long term to become a resident expert on the US-supplied components of the detector. Until now, our one student in Kamioka has been able to use housing and transportation provided by other US groups. With two students in residence and with more frequent visits by Hawaii staff, this mode of operation will cease being viable. Moreover, housing and transportation costs in Kamioka are quite high, much higher than at KEK. Subsistence costs at Kamioka are estimated at $1.2K/month, assuming three people sharing an apartment and a car. We request subsistence two long-term residents at Kamioka. The additional funds requested for this task (above that requested for FY96) is what we estimate to be the minimum amount needed to cover these expenses.

Table 8.5: EN–I; Kamioka Neutrino Observatory

Overhead Status	On	Off	Exempt	Eqmnt
Personnel				
Faculty Overload	17,900			
Physicists	51,300			
Graduate Students (2)		35,200		
Fringe Benefits	18,000	3,000		
Personnel Costs	87,200	38,200		
Instrumentation				
Materials & Supplies		5,000		
Equipment				
Instrumentation Subtotal		5,000		
Travel				
Travel & Maintenance @ Kamioka		20,000		
Travel to Kamioka	10,000			
Meetings & Conferences (Foreign)	4,000			
Meetings & Conferences (Domestic)	5,000			
Travel Subtotal	19,000	20,000		
Other				
phone, fax/mail	1,500			
shipping/delivery	500			
Other Subtotal	2,000			
Total Direct Costs	108,200	63,200		
Indirect (45%/10.83%)	48,700	6,800		
Total SuperK Budget	156,900	70,000		

Summary	Opers: 226,900	Total: 226,900

8.6 EN-II DUMAND

For DUMAND we request funds to continue support for Bolesta, the most senior student. He will complete a PhD thesis on the instrumentation and tests of the DUMAND strings that will serve as the documentation to facilitate future us of this equipment. The DUMAND equipment will be inventoried and stored in a way to preserve it for future use. Most of this work will be done with hourly undergraduate labor supervised by Rosen, who is 100% University-supported. Some travel to the NELH laboratory at Kona will be necessary in order to clean out the DUMAND and ship the equipment there back to campus for storage. The $3K equipment request is for a storage van suitable for keeping equipment at Snug Harbor.

Table 8.6: EN–II; The DUMAND Experiment

Overhead Status	On	Off	Exempt	Eqmnt
Personnel				
Graduate Student (1)	20,000			
Hourly Student Help	8,000			
Fringe Benefits	1,700			
Personnel Costs	29,700			
Storage Containers				3,000
Materials & Supplies	1,000			
Travel & Consultants				
Travel to NELH	1,000			
Travel Subtotal	1,000			
Other				
Freight/Delivery	500			
Other Subtotal	500			
Total Direct Costs	32,200			3,000
Indirect (45%/10.83%)	14,500			
Total DUMAND Budget	46,700			3,000

Summary	Opers: 46,700	Eqmnt: 3,000	Total: 49,700

8.7 EG Experimental Facilities

The support required for our experimental facilities (primarily the computer system) is specified in Table 8.7. This category provides partial support for our system manager (the remainder comes from the University), student engineering help, and the costs associated with maintaining the large network of computers that is essential to our research. The University waives the indirect costs on the maintenace contracts to compensate for the usage of the system by teaching faculty for instructional purposes. This category also includes the bulk of the videoconferencing costs.

We have not replaced our fulltime engineer and, instead, purchase engineering services as they are needed from the Engineering Support Facility of the Oceanography school (SOEST).

Here travel reflects the costs associated with D.O.E.-requested travel such as that associated with Olsen's participation in reviews of the BaBar experiment and the meeting of the US-Japan Committee for Cooperation in High Energy Physics.

The equipment request is discussed above in subsection 7.1.4.

Table 8.7: EG; Experimental Support

Overhead Status	On	Off	Exempt	Eqmnt
Personnel				
Faculty Overload				
Technical Specialists	30,000			
Hourly Student Help	14,000			
Fringe Benefits	9,200			
Personnel Costs	53,200			
Computing System Support				
Equipment				32,000
Hardware Maintenance Contracts			3,000	
Software Maintenance Contracts			19,500	
Telecommunications/Network	13,200			
Computing Supplies	11,000			
Computing Subtotal	24,200		22,500	32,000
Electronic Support				
Electronic Maintenance & Repair	8,000			
Engineering Support (SOEST)	10,000			
Materials & Supplies (general)	6,000			
Electronic Subtotal	24,000			
Travel				
DOE-related Travel	5,000			
Travel Subtotal	5,000			
Other				
Phones, faxes	1,000			
Freight/delivery/misc.	2,000			
Other Subtotal	3,000			
Total Direct Costs	109,400		22,500	32,000
Indirect (45%/10.83%)	49,200			
Total EG Budget	158,600		22,500	32,000

Summary	Opers: 181,100	Eqmnt: 32,000	Total: 213,100

8.8 Theory

The budget reflects the increase in graduate student salaries effective this calendar year, and includes a projected 4% increase in faculty salaries. As discussed above in the subsection 4.1 in the narrative on Theoretical Physics, we request funds for a Junior Researcher, including indirect costs on his salary and fringe benefits as required by the University. A request for a waiver of these overhead costs is still pending. If, as anticipated, the overhead costs are waived or absorbed by the University, the net increase in our budget is about $10K — corresponding to the unexpected costs of the postdoc's fringe benefits. We reiterate that this was made necessary by the unforeseeable change in federal rules for J-1 visas, which precluded identifying the appointment as a postdoctoral fellow, in which case it could have been made without overhead and fringe benefit costs and would have been possible without any increase in the budget. We have temporarily reduced the GRA appointment to 0.6 FTE. This should have no impact on the program, because after Sender graduates during the 1996-97 academic year, a new student can come on board no earlier than Summer 1996. In spite of the addition of the Junior Researcher position, the amount requested for travel is the same as last year. As in the past, we plan to use University funds as the primary source of support for visitors and consultants, and have only included a nominal sum for this purpose in the budget. Other expenses for communications and publications have been increased only nominally from last year's level.

Table 8.8: Theoretical Physics

Overhead Status	On	Off	Exempt	Eqmnt
Personnel				
Faculty Overload	35,100	20,900		
Post-Doctoral Fellow	33,300			
Graduate Students (1)	11,800			
Fringe Benefits	13,500	600		
Personnel Costs	93,700	21,500		
Travel & Consultants				
Domestic	13,000	3,000		
Foreign	8,000	5,000		
Consultants/Collaborators	1,000			
Travel Subtotal	22,000	8,000		
Other				
Publications	2,500			
Phone/FAX, Mail	3,500			
Other Subtotal	6,000			
Total Direct Costs	121,700	29,500		
Indirect (45%/10.83%)	54,800	3,200		
Theory Total	176,500	32,700		
20% of Administration	22,400			
Theory Summary	231,600			

Summary	Opers: 231,600	Total: 231,600

8.9 Administration

We request funds to support our administrative staff at the same level as last year. As the lead group in BELLE, and as the host institution for the upcoming conference on B Physics and CP violation, our staff is required to provide services that extend beyond the specific needs of our group itself. In the past, the University has recognized that by providing much of our own administrative support, we place reduced demands on the University's administrative infrastructure, and has granted us a waiver on indirect charges for these costs.

Table 8.9: Administrative Support

Overhead Status	On	Off	Exempt	Eqmnt
Personnel				
Admin. Specialist			36,400	
Clrk-Typst & Acct Clrk			42,200	
Hourly Student Help			5,000	
Fringe Benefits			19,000	
Personnel Costs			102,600	
Other				
Office Supplies			3,300	
Repairs and Maintenance			1,800	
Copying/Graphics/etc.			4,500	
Other Subtotal			9,600	
Total Direct Costs			112,200	
Indirect (45%/10.83%)				
Total Admin.			112,200	

8.10 Conference on B Physics and CP Violation

Most of the expenses of the conference will be covered by registration fees and support that we anticipate receiving from KEK and the University of Hawaii. From the DOE, we only request funds to support registration fees for the local participants in the conference, stationary and rental of audio visual equipment.

Table 8.10: Conference on B Physics and CP Violation

Overhead Status	On	Off	Exempt	Eqmnt
Non-Registration Items				
Other Costs:				
Registration Fee/Local Participants (20	7,000			
Other Costs Subtotal	7,000			
Waikiki/UHM Operations				
Audio Visual Equipment Rental	500			
Waikiki/UHM Operations Subtotal	500			
Communications/Supplies				
Stationary/Other Supplies	2,500			
Communications/Supplies Subtotal	2,500			
Total Direct Costs	10,000			
Indirect (45%/10.83%)	4,500			
Conference Total	14,500			

Summary	Opers: 14,500

8.11 Budget Summary

We list in Table 8.11 the actual funding levels for FY95 and 96 and the requested funds for FY97. The reorganization of our tasks precludes a direct comparison of the budgeted amounts for the individual accelerator-based activities. The new task names are in italics. The current five-year Grant started in FY94.

Table 8.11: Three year budget summary

		FY95	FY96	FY97(req)
D0	Operations	293,300	198,200	356,000
(FY97 - BELLE)	Equipment	0	0	110,000
e+e-	Operations	385,300	404,500	135,100
(FY97 - BES)	Equipment	50,000	10,000	0
e+e-	Operations	————	————	173,000
(FY97 - CLEO)	Equipment	————	————	0
Pixel	Operations	171,700	240,00	247,200
	Equipment	0	0	0
DUMAND	Operations	275,300	227,100	46,700
	Equipment	0	0	3,000
	Construction	218,000	0	0
SuperK	Operations	35,200	52,300	226,900
	Equipment	0	0	0
EG Exptl Spprt	Operations	238,000	238,000	181,100
	Equipment	0	20,000	32,000
Theory	Operations	175,700	180,300	209,200
Admin. Spprt	Operations	109,300	109,500	112,200
B-physics Conference	Operations			14,500

With the administrative support budget split 80% experiment, 20% theory the totals are:

		FY95	FY96	FY97 (req)
Experiment	Operations	1,507,400	1,447,800	1,470,400
	Equipment	50,000	30,000	145,000
	Construction	218,000	0	0
Theory		197,600	202,200	231,600
Totals	Operation	1,705,000	1,650,000	1,702,000
	Equipment	50,000	30,000	145,000
	Construction	218,000	0	0

8.12 University Support

Here we briefly summarize University support for our program. The University provides full nine-month salaries to the eight teaching faculty with the understanding that a 0.54 fraction of their time during the academic year is spent on research-related activities. In addition, the University funds a number of positions expressly in support of our research:

Two faculty, i.e., Learned and Gorham, get full (11-month) salary support from the University. Gorham has had no teaching responsibilities.

Rosen, a full time engineer for group, is fully supported by University funds.

The College of Natural Science provides salary support for Ibaraki, who manages our computing system.

Mitiguy's (part time) work for high energy physics, has been supported by University funds.

Our group is the primary user of the Physics Department's machine shop, which has two full-time machinists and is totally supported by University funds. Our group receives technical support from the Engineering Support Facility of the Hawaii Institute for Geophysics, where State subsidies keep the hourly rate well below actual costs. We are provided with approximately 10,000 square feet of permanent quality laboratory space in Watanabe Hall and the Physical Sciences Building. We have been given the use of additional temporary laboratory space as needed.

The bulk of the equipment in our computer network and our copy machine were purchased with University funds. The College of Natural Sciences provided funds for the purchase of our Pictel videoconference system. In addition, University start-up funds provided to Browder and Olsen were used for alpha workstations and to outfit the TOF lab for the BES/BELLE R&D work. University funds are used to provide partial support to a number of visitors. The University waives indirect costs on administrative costs, computer maintenance contracts, and subcontracts at off-campus laboratories.

Appendix A

Curriculum Vita of the Principal Investigators

A.1 Stephen L. Olsen

Curriculum Vitae

Stephen Lars Olsen
Born: March 22, 1942, Brooklyn, New York (U.S. citizen)

Education:

B.S. (Physics)	City College of New York, 1963	(Phi Beta Kappa, Magna cum Laude)
M.S. (Physics)	University of Wisconsin, 1965	
Ph.D.(Physics)	University of Wisconsin, 1970	

Employment:

1/70 - 11/70	Research Associate	University of Wisconsin
11/70 - 9/72	Research Associate	Rockefeller University
9/72 - 7/75	Assistant Professor	University of Rochester
7/75 - 1/77	Associate Professor (untenured)	University of Rochester
1/77 - 6/82	Associate Professor (tenured)	University of Rochester
6/82 - 8/92	Professor	University of Rochester
8/92 - present	Professor	University of Hawaii

Visiting Positions:

8/82 - 8/83	Visiting Researcher	High Energy Physics Laboratory (KEK), Japan
9/87 - 9/89	Foreign Scholar	Tsukuba University, Japan

Fellowships:

1973 - 1977	Fellow, Alfred P. Sloan Foundation
1984	Fellow, American Physical Society
1986 - 1987	Fellow, John Simon Guggenheim Foundation
1987 - 1988	Fellow, Japan Society for the Promotion of Science

Professional Activities:

1975 - 1978	Program Advisory Committee, Fermilab
1989 - 1992	URA Visiting Committee, Fermilab
1989 - 1993	Program Advisory Committee, SSC Laboratory
1989 - 1994	Scientific Policy Committee, SLAC
1990 - 1992	Spokesman for the Rochester High Energy Physics DOE Contract
1990	HEPAP Subpanel on Research for the 1990's
1990	Panel to Review the KEK Proton Synchrotron Program
1990	DOE Panel to Review the SDC Experiment
1992 - present	Principal Investigator, University of Hawaii High Energy Physics Group
1993	Chair, DOE Panel to Review US-Japan Cooperation Program
1994 - 1996	B-Factory Steering Committee, KEK Japan
1995 - present	DOE Panel to Review the BaBar Experiment

Major Research Activities:

1974 - 1977	Fermilab Experiment 198 (Spokesman)
1978 - 1984	CLEO Experiment at the Cornell Electron Storage Ring
1983 - present	AMY Experiment at KEK, Japan (Spokesman)
1987 - 1989	Heavy Stable Matter Search, Rochester Nuclear Physics Laboratory
1989 - 1992	CDF Experiment, Fermilab
1991 - present	BELLE Experiment at KEK, Japan (Co-spokesman)
1992 - present	Studies of the Charm quark at IHEP, Beijing China

Professional Associations:

American Physical Society
American Association for the Advancement of Science
Japan Association of High Energy Physicists

Current Addresses:

Home: 2333 Kapiolani Blvd.
Apartment 2816
Honolulu, HI 96826
(808) 946-8004

Work: Department of Physics and Astronomy
University of Hawaii
2505 Correa Road
Honolulu, HI 96822
(808) 956-2929
SOLSEN@UHHEPG.PHYS.HAWAII.EDU

Some Recent Publications:

1. T.K. Hemmick, D. Elmore, T. Gentile, P.W. Kubik, S.L. Olsen, D. Ciampa, D. Nitz, H. Kagan, P. Haas, P.F. Smith, B.B. McInteer, J. Bigeleisen,
   Search for Low-Z Nuclei Containing Massive Stable Particles,
   Phys. Rev. **D41**, 2074 (1990).

2. G.N. Kim et al., (AMY)
   Search for Charged Heavy Leptons with Arbitrary Neutrino Mass in e^+e^- Annihilations at $\sqrt{s} = 50$ - 60.8 GeV,
   Int. J. Mod. Phys. **A6**, 2583 (1991).

3. R. Tanaka et al., (AMY)
   Evidence for Hard Scattering of Hadronic Constituents of Photons in Photon-Photon Collisions at TRISTAN,
   Phys. Lett. **B273**, 181 (1992).

4. M. Franklin, A. Fry, K.K. Gan, S. Han, H. Kagan, S. Kanda, D. Kania, R. Kass, S.K. Kim, R. Malchow, F. Morrow, S.L. Olsen, W.F. Palmer, L.S. Pan, F. Sannes,S. Schnetzer, R. Stone, Y. Sugimoto, G.B. Thompson, C. White, and S. Zhao
   Development of Diamond Radiation Detectors for the SSC and LHC,
   Nucl. Inst. and Meth. **A315**, 39 (1992).

5. K. Ueno, H.W. Zheng, C. Back, D. Blanis, S. Eno, T. Haelen, Y.H. Ho, Y.K. Kim, T. Mori, S.L. Olsen, N.M. Shaw, E.H. Thorndike, J. Edwards, C. Rosenfeld, Y. Higashi, and Y. Kobayashi
   The Design of the AMY Central Drift Chamber and Performance in a 3 Tesla Magnetic Field,
   Nucl. Inst. and Meth. **A323**, 601 (1992).

6. K.B. Lee et al., (AMY)
   Measurement of α_s from the Moment of Particle Momenta within Jets from e^+e^- annihilation,
   Phys. Lett. **B313**, 469 (1993).

7. M. Franklin, A. Fry, K.K. Gan, S. Han, H. Kagan, S. Kanda, D. Kania, R. Kass, S.K. Kim, R. Malchow, F. Morrow, S.L. Olsen, W.F. Palmer, L.S. Pan, F. Sannes,S. Schnetzer, R. Stone, Y. Sugimoto, G.B. Thompson, C. White, and S. Zhao
   Particle- and Photoinduced Conductivity in Type-IIa Diamonds,
   J. Appl. Phys. **74**, 1086 (1993).

8. B.J. Kim et al., (AMY)
   Measurements of the inclusive jet cross section in photon-photon

interactions at TRISTAN,
Phys. Lett. **B325**, 248 (1994).

9. F. Liu et al., (AMY)
Measurements of Cross Section and Asymmetry for $e^+e^- \rightarrow b\bar{b}$ and Heavy Quark Fragmentation at TRISTAN,
Phys. Rev. **D49**, 4339 (1994).

10. C. Velissaris et al., (AMY)
Measurement of Cross Section and Charge Asymmetry for $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow \tau^+\tau^-$ at $\sqrt{s} = 57.8$ GeV,
Phys. Lett. **B331**, 227 (1994).

11. S.K. Sahu et al., (AMY)
A High-Q^2 Measurement of the Photon Structure Function F_2^γ,
Phys. Lett. **B 346**, 208 (1995).

12. J.Z. Bai et al., (BES)
A Direct Measurement of the Psuedoscalar Decay Constant f_{D_s},
Phys. Rev. Lett. **74**, 4599 (1995).

13. S.K. Choi et al. (AMY)
A measurement of Bose-Einstein Correlations in e^+e^- annihilation at Tristan,
Phys. Lett. **B 355**, 406 (1995).

14. T. Aso et al. (AMY)
Measurement of charm production in two-photon processes using inclusive lepton events at TRISTAN,
Phys. Lett. **B 363**, 249 (1995).

15. Y. Sugimoto et al. (AMY)
New Limits on the Masses of the Selectron and Photino,
Phys. Lett. **B 369**, 86 (1996).

16. S. Behari et al. (AMY)
Observation of Color Coherence Effects in the Subjet Multiplicity in Thre- and Four-jet Events in e^+e^- Annihilation,
Phys. Lett. **B 374**, 304 (1996).

17. J.Z. Bai, et al. (BES)
A Direct Measurement of the D_s Branching Fraction to the $\phi\pi$,
Phys. Rev. **D52**, 3781 (1995).

18. J.Z. Bai, et al. (BES)
Measurement of the Mass of the τ Lepton,
Phys. Rev. **D53**, 20 (1996).

A.2 Xerxes Tata

VITA

Xerxes Ramyar TATA

PERSONAL DATA

Date of Birth: April 27, 1954

Place of Birth: Bombay, India

Marital Status: Married

EDUCATION

Bachelor of Science	Bombay University, India	1974
Master of Science	Indian Institute of Technology Bombay, India	1976
Ph.D.	University of Texas at Austin	1981

EXPERIENCE

Professor	University of Hawaii at Manoa	1994-present
Associate Professor	University of Hawaii at Manoa	1988-1994
Visiting Scientist	KEK, Japan	Sept. 1987-Feb. 1988
Assistant Scientist	University of Wisconsin at Madison	1986-1988
Research Associate	University of Oregon at Eugene	1985-1986
Scientific Associate	CERN, Geneva, Switzerland	1984-1985
Research Scientist	University of Texas at Austin	1984
Research Associate	University of Oregon at Eugene	1983-1984
Lecturer in Physics	University of Texas at Austin	1981-1982
Research Associate	University of Texas at Austin	1981-1983

RECENT SCIENTIFIC SERVICE ACTIVITIES

1. Co-leader of Supersymmetry Subgroup for 1994-95 DPF Long Term Planning Study.
2. Lecturer at 1995 Theoretical Advanced Study Institute, Boulder, Colarado.
3. Co-convenor of SUSY Session at International Workshop on Physics and Experiment at Linear Colliders, Morioka-Appi, 1995.
4. Co-convenor of SUSY Working Group at Snowmass 1996.

RECENT PUBLICATIONS

1. H. Baer, R. Munroe and X. Tata, Supersymmetry Studies at Future Linear Colliders, UH-511-850-96 (1996) (submitted to Phys. Rev. **D**).
2. H. Baer, C-H. Chen, F. Paige and X. Tata, Supersymmetry Reach of Tevatron Upgrades: A Comparative Study, UH-511-847-96 (1996) (submitted to Phys. Rev. **D**).
3. H. Baer, C-H. Chen, F. Paige and X. Tata, Signals for Minimal Supergravity at the CERN Large Hadron Collider II: Multilepton Channels, Phys. Rev. **D53**, 6241 (1996).
4. H. Baer, C-H. Chen, F. Paige and X. Tata, Signals for Minimal Supergravity at the CERN Large Hadron Collider: Multijet plus Missing Energy Channel, Phys. Rev. **D52**, 2746 (1995).
5. The search for top squarks at the Fermilab Tevatron Collider, H. Baer, J. Sender and X. Tata, Phys. Rev. **D50**, 4517 (1994).
6. Detecting Sleptons at Hadron Colliders and Supercolliders, H. Baer, C. Chen, F. Paige and X. Tata, Phys. Rev. **D49**, 3283 (1994).
7. New Signals for gluinos and squarks of supergravity at the Tevatron Collider, H. Baer, C. Kao and X. Tata, Phys. Rev. **D48**, R2978 (1993).
8. Probing Charginos and Neutralinos Beyond the Reach of LEP at the Tevatron Collider, H. Baer and X. Tata, Phys.Rev. **D47**, 2739 (1993).
9. Observability of $\gamma\gamma$ Decays of Higgs Bosons from Supersymmetry at Hadron Supercolliders, H. Baer, M. Bisset, C. Kao and X. Tata, Phys.Rev. **D46**, 1067 (1992).
10. Multi-lepton Signals from Supersymmetry at Hadron Super Colliders, H. Baer, X. Tata and J. Woodside, Phys. Rev. **D45**, 142 (1992).

11. Searching for Supersymmetry at e^+e^- Supercolliders, H. Baer, A. Bartl, D. Karatas, W. Majerotto and X. Tata, Int. J. Mod. Phys. **A4**, 4111 (1989).

12. Detecting Gluinos at Hadron Super Colliders, H. Baer, V. Barger, D. Karatas and X. Tata, Phys. Rev. **D36**, 96 (1987).

Appendix B

Budget Explanations & Forms

B.1 Budget Explanation

The materials provided for individual activities for FY'96 are summarized in the Grant Application Budget Summary Form 4620.1.

Personnel The personnel are summarized in the appended table, where the University and requested DOE support are itemized.

Senior Personnel This includes the teaching faculty and senior physicists. Gorham and Learned, whose 11-month salaries are completely paid by the University, are not included in this tally. Teaching faculty on this grant are allowed a 0.54 fraction of the academic year for research activities supported by this grant. The senior physicists receive full fringe benefit packages (typically 24% of the salary). The bulk of the teaching faculty's fringe benefits for the summer are provided by the University; only Workman's Compensation and Medicare are included in this request.

Post-Doctoral Associates This includes existing personnel and a new Junior Researcher (T. ter Veldhuis) in theoretical physics. (S. Sahu replaces M. Cummings.) They receive full fringe benefit packages.

Other Professionals These funds are for partial support of our computer system manager. The rest of her support is expected to be provided by the College of Natural Science. Here full fringe benefit packages are included in this request.

Graduate Students The University considers graduate students as being half-time on research (6 months) with additional support allowed for the summer. This varies from case-to-case but averages 1.12 months extra support per student. Fringe benefits vary from student-to-student, and range up to a full package.

Undergraduate Students Undergraduate students are hired on an hourly basis to help various tasks and with clerical duties. The only fringe benefit they receive is Workman's Compensation.

Secretarial-Clerical The typist, and clerk receive full fringe benefit packages.

Other The corresponds to the administrator, who receives a full fringe benefit package.

Equipment Here we list the items and the sections where they are discussed.

Equipment	Request	Sections
BELLE Equipment	110,000	2.1.4
DUMAND Closeout	3,000	3.2.2
Computer Upgrade	32,000	7.1.4

Travel Domestic The primary need for domestic travel is commuting to the laboratories where the research activities are carried out; e.g. Ithaca for the CLEO experiment and Fermilab for the D0 experiment. In addition there are BES and Superkamiokande group meetings at various collaborating U.S. institutions, and scientific meetings where results are reported.

Foreign The primary need for foreign travel is travel to Japan: KEK for the BELLE and Kamioka for the SK experiment, travel to IHEP in Beijing for the BES experiment (approximately twice per year per participant), and theoretical collaborations. In addition, there is travel to international meetings to present papers.

Other Direct Costs

Materials & Supplies These include incidental items needed to support the individuals activities, such as computer tapes, hand tools, solvents, etc. Estimated costs are based on previous experience. Also included in materials and supplies are masks needed by the pixel R&D group for intgrated circuit fabrication.

Publications Estimated costs are based on previous experience.

Consultant Services These include technical consultants for research projects and seminar speakers. The standard rate is $100 per day, with a maximum of $130 per day without special approval.

Computer Services This includes hardware maintenance contracts and software licenses, as listed in Section 7.1. This also includes networking and telecommunications costs.

Subcontracts We maintain subcontracts at KEK, LBL, Fermilab, SLAC, and CIS(Stanford) (see Section 2.6).

Other This include office supplies, communication costs, shipping, etc. Estimated costs are based on previous experience.

Indirect Costs The University rates for indirect costs are 45% for on-campus and 10.83% for off-campus activities. Indirect costs on administrative costs, computer maintenance and licenses, and the subcontracts at other laboratories have been waived by the University.

Cost Sharing The University supports these activities with $568,300 in direct salary support, as is documented in the appended table. In addition, some indirect charges are waived, as described above. The amounts listed in Form 4620.1 have already been reduced by these amounts.

DOE F 4620.1
(04-93)
All Other Editions Are Obsolete

U.S. Department of Energy

Budget Page

(See reverse for Instructions)

OMB Control No.
1910-1400
OMB Burden Disclosure
Statement on Reverse

ORGANIZATION University of Hawaii at Manoa				Budget Page No:	
PRINCIPAL INVESTIGATOR (PI)/PROJECT DIRECTOR (PD) Stephen L. Olsen				Requested Duration: 12 (Months)	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in bracket(s))	DOE Funded Person - mos			Funds Requested	Funds Granted
	CAL	ACAD	SUMR	by Applicant	by DOE
1. Faculty: (8) T. Browder, S. Olsen,			16	137,900	
2. F. Harris, M. Peters, V. Stenger, X. Tata					
3. S. Pakvasa, SF Tuan					
4.					
5. (SRA) M. Jones, S. Parker				151,300	
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)					
7. ( ) TOTAL SENIOR PERSONNEL (1-6)				289,200	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)				534,100	
1. ( ) POST DOCTORAL ASSOCIATES (5)				204,800	
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)				30,000	
3. ( ) GRADUATE STUDENTS (10)				183,700	
4. ( ) UNDERGRADUATE STUDENTS (7)				37,000	
5. ( ) SECRETARIAL - CLERICAL (2)				42,200	
6. ( ) OTHER				36,400	
TOTAL SALARIES AND WAGES (A + B)				823,300	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				151,100	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				974,400	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM)					
BELLE equipment fabrication $110,000				110,000	
Computer support upgrade & instrument support $ 32,000				32,000	
Storage containers $ 3,000				3,000	
TOTAL PERMANENT EQUIPMENT				145,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				74,700	
2. FOREIGN				93,000	
TOTAL TRAVEL				167,700	
F. TRAINEE/PARTICIPANT COSTS					
1. STIPENDS (itemize levels, types + totals on budget justification page)					
2. TUITION & FEES					
3. TRAINEE TRAVEL					
4. OTHER (fully explain on justification page)					
TOTAL PARTICIPANTS ( ) TOTAL COST					
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				65,200	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				4,500	
3. CONSULTANT SERVICES				1,000	
4. COMPUTER (ADP) SERVICES				65,200	
5. SUBCONTRACTS				27,000	
6. OTHER				35,700	
TOTAL OTHER DIRECT COSTS				198,600	
H. TOTAL DIRECT COSTS (A THROUGH G)				1,485,700	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)				308,700 52,600	
TOTAL INDIRECT COSTS				361,300	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				1,847,000	
K. AMOUNT OF ANY REQUIRED COST-SHARING FROM NON-FEDERAL SOURCES					
L. TOTAL COST OF PROJECT (J + K)				1,847,000	

Appendix C

Salary Details (Confidential)

C.1 Details of Salaries Listed in Proposal

FY-97 (12 months): December 1, 1996 - November 30, 1997

Personnel presently on the payroll, plus those whose employ is contemplated and described in the proposal, are included and listed by position (function) and by name (if current).

Teaching faculty involved in DOE-supported research nominally are expected to devote 50% of their time to this research during the 9-month academic year, but their salaries are paid by the University from State funds. (Exceptions to this rule, higher or lower, are listed.) Graduate Research Assistants, all DOE-funded, also are expected to assist on research half-time (for 11 months) is permitted. The 50% 9-month academic year research effort, plus 2.00 months 100% summer work equates to 0.54 FTE for a full year.

The FTE equivalent time devoted to High Energy Physics research is indicated below, together with the associated research salary expected to accompany this research.

RP-96 (CONFIDENTIAL)

Details On Salaries Listed in Proposal

FY-97 (12 month, December 1, 1996 - November 30, 1997)

Position	Name	Research Time (FTE)	Research Salary UH	Research Salary DOE
(A) Experimental				
Professor	F.A. Harris	0.54	$ 34,400	$ 15,300
Professor	J.G. Learned	1.00	88,800	0
Professor	S.L. Olsen	0.54	50,900	22,700
Professor	M.W. Peters	0.54	34,400	15,300
Professor	V.J. Stenger	0.54	40,200	17,900
Assistant Professor	T.E. Browder	0.50	24,100	10,700
Physicist	S.I. Parker	1.00	0	88,800
Associate Physicist	M.D. Jones	1.00	0	62,500
Jr. Physicist (Pixel)	C.J. Kenney	1.00	0	42,200
Jr. Physicist (BELLE)	S. Sahu	1.00	0	39,000
Jr. Physicist (CLEO)	J.L. Rodriguez	1.00	0	39,000
Project Manager	P.W. Gorham	1.00	64,900	0
Assistant Physicist (SuperK)	S. Matsuno	1.00	0	51,300
Assoc. Specialist/Mech.	R.C. Mitiguy	0.50	26,800	0
Assoc. Specialist/Mech.	M.M. Mignard	0.50	28,800	0
Asst. Specialist/Mech. (BES/BELLE)	M.D. Rosen	1.00	43,800	0
Computer Specialist IV	Diane Ibaraki	1.00	12,200	30,000
Graduate Assistants	nine (9)	5.37	0	171,900
Undergraduates	eight (8)	4.26	0	32,000
Subtotals:		23.29	449,300	638,600

(B) Theoretical:

Professor	S. Pakvasa	0.54	45,300	20,900
Professor	S.F. Tuan	0.54	41,900	19,800
Professor	X. Tata	0.54	31,800	15,300
Graduate Assistants	One (1)	0.324	0	11,800
Jr. Physicist	T.A. ter Veldhuis	1.00	0	33,300
Subtotals:		1.944	119,000	101,100

(C) Combined Support:

Administrative Specialist	J.D. Bruce	1.00	0	36,400
Clerk-Typist III	J.N. Bolosan	1.00	0	22,200
Account Clerk II	P.B. Huang	1.00	0	20,000
Undergraduates		0.34	0	5,000
Subtotals:		3.34	0	83,600

	PROJECT TOTAL:	28.57	$568,300	$823,300

Note: Research salary does not include overhead or fringe benefit costs.