TRISTAN EXPERIMENT

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This talk is intended to be a brief introduction to experiments at the TRISTAN e^+e^- collider for very young theorists. In most part of this written version, individual publication will not be referred to. Instead, a list of publication is provided in APPENDIX for convenience.

1. Choice of Energy

Electron-positron colliders had played critical roles in the progress of particle physics in the 1970's and were expected to do so in coming years. Accordingly, any successor of PETRA and PEP colliders was expected to extend the energy reach to the region where the weak interaction effects would become sizable in annihilation processes. The aim was to reach the level where an all-round study of the Standard Model could be performed in a clean system of e^+e^- collisions. It was also aimed to explore the energy region where the top quark pair production would be very likely. As far as the top mass is concerned, a reasonable guide to its estimate had been the observed hierarchy in quarkonium mass ;

$$M(\phi) \approx 3^0,\ M(\Psi) \approx 3^1,\ M(\Upsilon) \approx 3^2\ \text{GeV}.$$

Lacking any reason that the top be special in its status, a naive expectation had held for topponium to be roughly 3^3 GeV. After initial search at PETRA, theoretical speculations on the top mass widely ranged from 20 to 40 GeV.

Considering the available site for accelerator construction and the expected size of the electroweak interference effects, the target energy was set to 60 GeV at the lowest. On the other hand, machine physicists knew that, because of radiation energy loss, the optimized bending radius of a collider ring should increase in proportion to the beam energy squared. Optimized TRISTAN ring would have been 3 km in diameter. Instead, the largest possible in the site was 1/3 of it. A hard decision was thus made to equip the ring with unusually many accerelating RF cavities and to apply superconducting technology to a significant part of them. The world accelerator community was understandably skeptical about this.

2. Long-Range Physics Program

The experiment, TRISTAN-I, has first made an exploratory study over the new energy region up to 64 GeV and is now carrying out deeper and broader studies with as high lumunosity as possible[1]. Aiming to accumulate at least 300 pb^{-1} of high-quality data, the experiment will continue for about two more years. Note that the total cross section for quark-pair production at 58 GeV is 140 pb and a numerical factor corresponding to the procuct (detector acceptance)x (radiative correction) happens to be colse to unity, convenient for a quick conversion.

TRISTAN-I experiment is a big initial step in our long-range physics program. The Laboratory has established the plan to move on to TRISTAN-II (B-Factory) Project [2] after the scheduled completion of the current experiment. It will be a natural extention of the present accelerator complex. Recall that Japanese theorists have made pioneering contributions to the physics related to CP violation[3]. At the 12-GeV Proton Synchrotron, three large-scale experiments are in preparation for CP and related researches in K-meson system[4]. Forthcoming experiment at the B-factory will make a systematic and decisive study of CP violation in B-meson system. Thus, the 30-year long puzzle is going to be attacked from every aspect.

Central to the future plan is the construction of a high energy e^+e^- linear collider, the JLC in short. R&D for this major project had to start from scratch, but it has progressed remarkably well in the past 5 years. The second-stage plan for the next 3 to 4 years is to construct and study with a large-scale accelerator test facility aiming to establish key technologies and to prepare a conceptual design of JLC-I, a 300-500 GeV linear collider. A series of studies on physics and experimentation has already shown that JLC-I will be a crucial machine for particle physics[5].

3. TRISTAN Accelerator

The TRISTAN Main Ring (the storage ring) is illustrated in Fig.1. It has a 3 km circumference and is located approximately 12 m underground. Two e^- bunches and two e^+ bunches injected at equal intervals are accelerated to the final energy and are kept circulating in opposite directions. Due to the relatively small size of bending radius, energy loss of a 30 GeV e^-/e^+ is as large as 290 MeV per turn. It has to be compensated for by a constant acceleration even during circulation, *ie* in the storage mode. Opposite-going bunches, each containing about $2\cdot10^{11}$ particles, cross each other at 4 points (the collision points) at every turn. At this instant, the bunches are tightly squeezed by a superconducting magnetic lens system to about a 10μm · 300μm cross section, thereby significantly increasing the chance of e^+e^- collisions. The intrinsic spread in collision energy is about 100 MeV around $\sqrt{s}$ = 60 GeV.

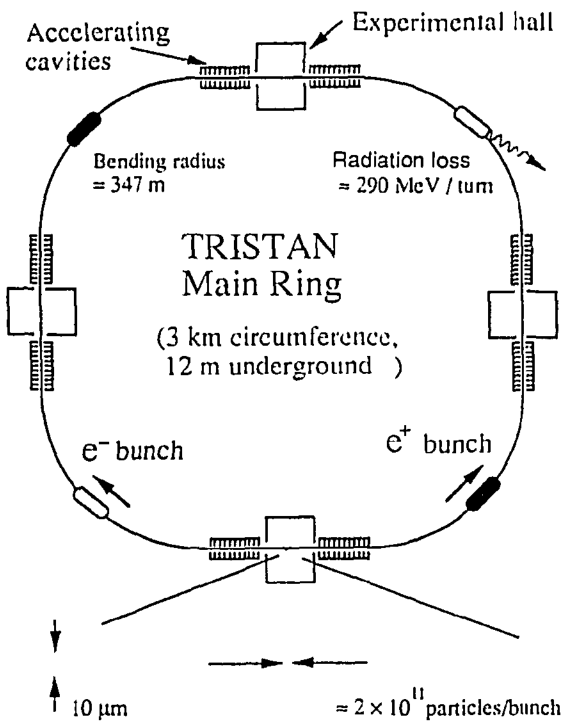

Fig.1 TRISTAN Min Ring.

Fig. 2 illustrates the time sequence of storage ring operation for experiment. Beam bunches of 8 GeV are injected one by one from a pre-acceleration system (the 2.5 GeV Linac and the Accumulation Ring not shown in Fig.1), two for each Main Ring bunch. After a further acceleration, the operation is automatically switched to a beam collision mode for experiment. The circulating beam particles are gradually lost due both to beam-beam Bremsstrahlung and beam-gas interactions. Since the chance of

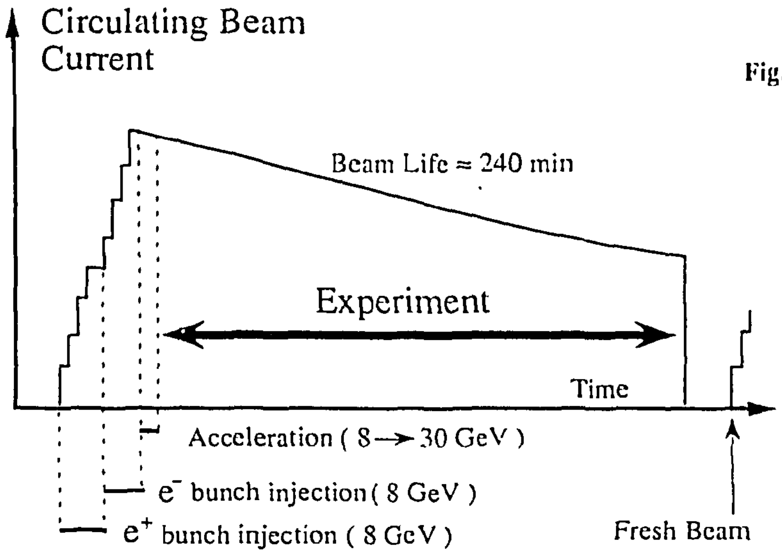

Fig.2 Time sequence of TRISTAN Main Ring operation.

e^+e^- collisions decreases in proportion to the product of the numbers of crossing particles, it is a usual practice at TRISTAN to dump a beam after about 90 min of data taking and then to inject fresh bunches. All of these, the system and its operation, might sound simple, but are in fact an art of accelerator science.

The TRISTAN currently provides the peak luminosity of about $5 \cdot 10^{31}$ $cm^{-2}sec^{-1}$. The integrated luminosity of 1 pb^{-1} / day / experiment was reached in the end of 1991 and 100 pb^{-1} / year / experiment in FY1992. The history is shown in Fig.3 where a rapid increase in luminosity is clearly seen after a few years of exploratory experiment.

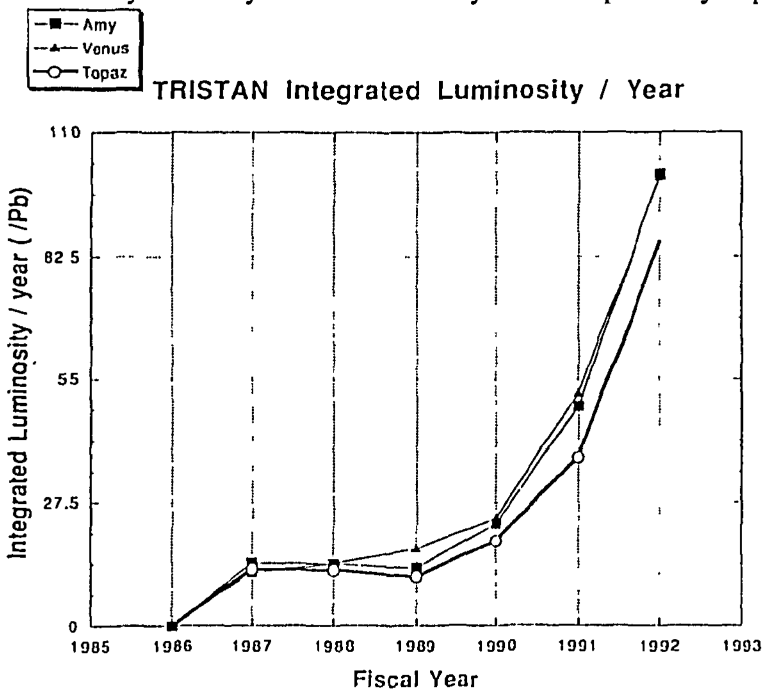

Fig.3 Record of yearly luminosities accumulated by each group. Efforts continue to equalyze them at the highest level.

4. Experiment

4.1. Basic Annihilation Processes

Three experimental groups (the AMY, TOPAZ and VENUS Collaborations) have been collecting data with their own general-purpose detectors and continue to improve event statistics for basic annihilation processes. Efforts are also being made to significantly reduce systematic uncertainties dominating the final precision. The role to be played by TRISTAN can be seen from such basic data shown in Figs. 4 to 6.

One of the distinctive features of the covered energy is that the total annihilation cross sections (Fig.4) are nearly at the minima in the region below Z^0. It implies that

1) large integrated luminosities are required for high precision measurements,
2) the Standard Model background is smallest for search of new physics, and
3) studies of t-channel exchange and two-photon processes are easiest.

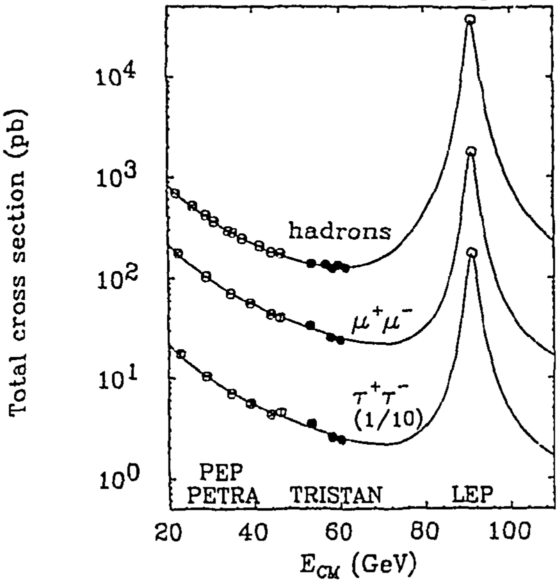

Fig.4 Total cross sections of typical annihilation processes.

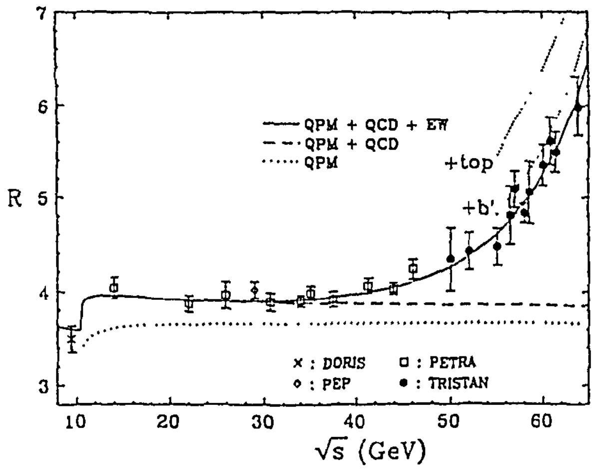

Fig.5 Hadronic total cross section normalized to QED lepton pair production.

The quark-pair production receives a considerable contribution from Z^0. It is clearly seen (Fig.5) when plotted relative to the QED pair-production cross section for point-like fermions like μ's. One consequence was that the initial cross section data correctly predicted the Z^0 mass to 1.7 % before SLC / LEP came on, though totally insensitive to the width. Note that the total cross sections for lepton-pair production are much less affected by Z^0 due to the smallness of the vector coupling constants.

Another distinctive feature appears in the differential cross sections as in Fig.6. Angular distributions exhibit substantial asymmetries indicating the presence of a large electroweak interference. It is clear that TRISTAN sits where the electromegnetic and the weak interaction maximally cross over.

4. 2. New Particle Search

Needless to say, one of the urgent initial tasks of TRISTAN was a search for every conceivable new particle, even unthinkable ones. Here, a few out of many cases will be mentioned. New heavy quarks including the top were searched for by

1) looking for quarkonium peaks, the triplet 1S-state in particular,
2) measuring multihadronic cross section in continuum, and

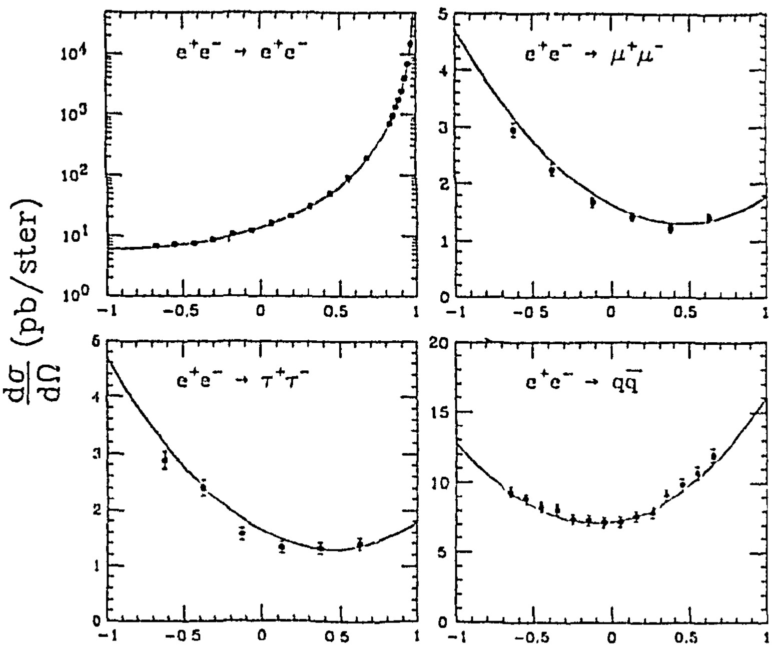

Fig.6 Differential cross sections for fermion-pair productions exhibiting large asymmetries.

3) studying event shapes of multihadronic events with or without high energy leptons. The first two methods, 1) and 2), rely on expected effects[6] on the cross section shown, for example, in Fig.7. As already shown in Fig.5, the pair production of a new charge 2/3 quark was easily ruled out, but uncertainties remained for a charge -1/3 quark.

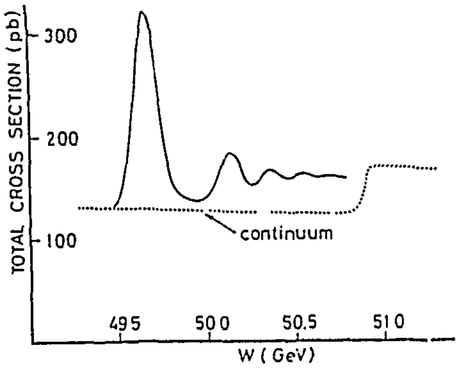

Fig.7 Calculated topponium spectrum for 25 GeV top. Important effects of initial-state radiation and intrinsic beam energy spread are taken into account.

The third method uses the simple kinematics that quarks produced near threshold will fragments into many undirectional hadrons leading to a spherical distribution in momentum space. Such a shape analysis was in fact very effective as seen in Fig. 8.

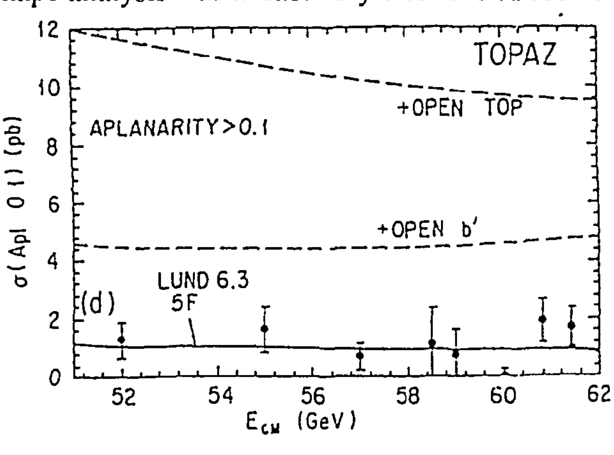

Fig.8 Hadronic cross section after a strong cuts on aplanarity of multiparticle final states. Light quark events are considerably supressed relative to heavy quarks produced near threshold.

Since the top turned out to be too heavy to produce, a new possibility was pointed out[7] that the 4th-generation down-type quark b', if not that heavy, would prefer to decay as b'→bγ, b+gluon by effective flavor-changing neutral current interactions rather than decaying to the c-quark by the charged-current interaction. A thorough search was thus made to give the last words regarding the number of quark (lepton, too) generations in the covered mass region.

It should be mentioned that, through a series of searches at PETRA / TRISTAN / SLC / LEP / SppS / Tevatron, the current upper bound of the top mass has already reached about 110 GeV (for Standard Model decay modes), well above the W-mass. Clearly the top can not be regarded as a mere 6th quark any more. Its exceptionally large mass among fermions is a completely new feature in the electroweak sector and plays a role to discriminate among various scenarios of next physics.

Fig.9 summarizes the results of search. A most part of them has naturally been superseded by later results from larger accelerators. It should be stressed that these are solid bounds not depending on theoretical assumptions.

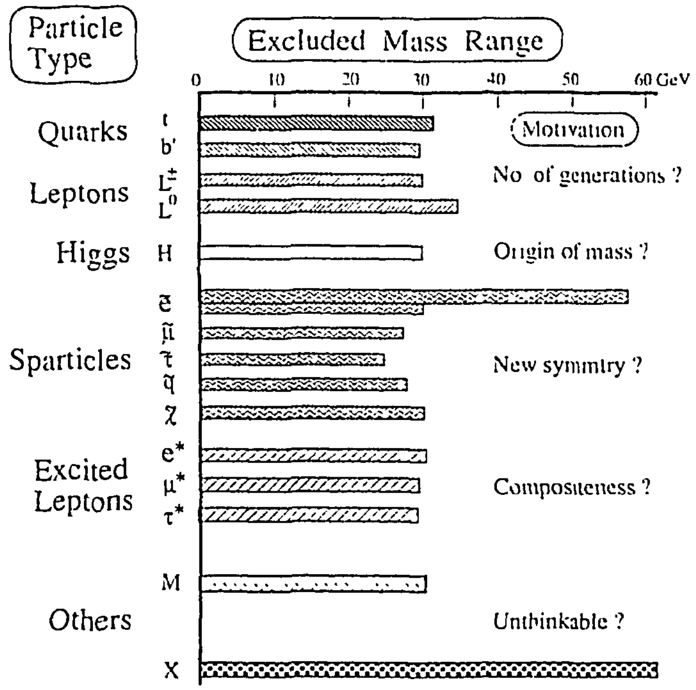

Fig.9 Summary of new particle search at TRISTAN.

Not included is an indirect search of an additional Z-boson. Theoretical possibility of an additional U(1) symmetry implies the existence of the second Z, denoted Z', though its mass or mixing with Z is not predictable. Though small, the fermion-pair production cross sections at TRISTAN will be affected due to a long-range interference effect by an amount depending on the Z' mass and other properties. The TRISTAN results have so far been competitive with a direct search at Tevatron for specific types of Z'. To improve the limits, it is imperative to reduce systematic uncertainties in the measurement. The same data set has also served to set bounds on quark / lepton compositeness scale to a few TeV or higher. A theoretical assumption, however plausible, is inevitable in deriving such bounds. However, it is clear that high precision measurements of annihilation cross sections are very important in many respects.

The latest particle search was triggered by an observation[8] at LEP of apparent excess of $e^+e^- \to l^+l^-\gamma\gamma$ (l = e or μ) events in which the invariant mass of the photon pair sharply clustered around 59 GeV. One of the possibilities was the production of an unexpected neutral boson X, predominantly decaying into two photons. Since its interpretation as a Higgs boson was not possible when combined with informations on other final-states, the possibility of X having a sizable coupling to electrons remained. Previous data on $e^+e^- \to e^+e^-$, $\gamma\gamma$, $\gamma\gamma\gamma$ at TRISTAN did not show any anomaly, but a narrow resonance could have been hidden. In addition, the rate of such cluster of events was only a few per million and a decisive result could be hardly expected from LEP.

An energy scan was thus quickly conducted at TRISTAN over the suspected mass range. The energy interval was chosen such that there would be no hole left in sensitivity, taking into account of the existing data points and the intrinsic beam energy spread. In any final states, no deviation from the Standard Model was found as shown in Fig.10. The conclusion was the stringent bounds on $\Gamma_{ee} \cdot BR(X \to \text{each decay mode})$ [9].

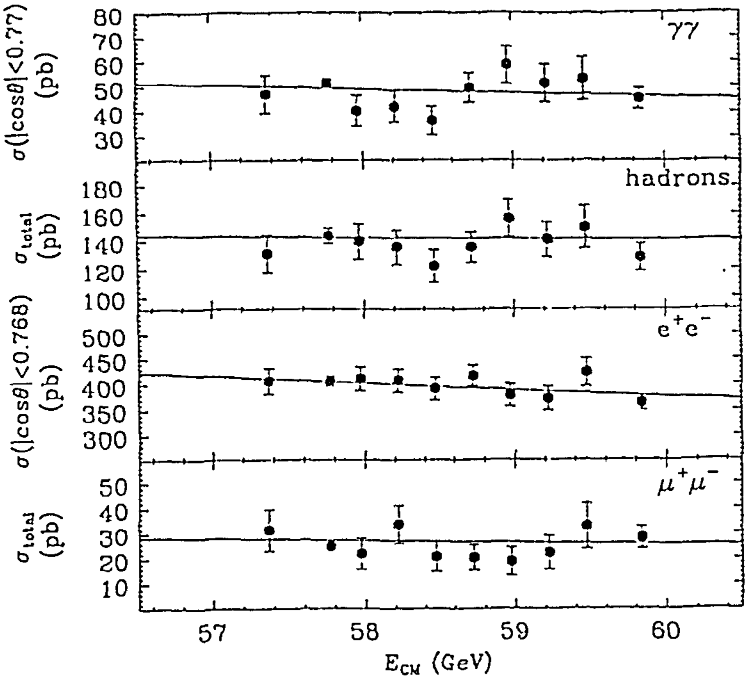

Fig.10 Observed cross sections for four final states in a search of a new massive boson.

4.3. Electroweak Interactions

Beside the direct search of new heavy fermions, the number of fermion generations can be experimentally studied through neutrino counting. The neutrinos being practically invisible in detectors, only viable way to do this at TRISTAN energies was a cross section measurement for the radiative neutrino-pair production : $e^+e^- \to \gamma\nu\nu$. Here the emission of a single photon signals that a collision has taken place. This is a well-known, very difficult technique since many QED reactions can mimic it and, furthermore, the reaction cross section would be as small as 0.1pb at 60 GeV for a typical detector configuration (Fig.11). Having the best solid-angle coverage, VENUS challenged it and came to conclusion that $N_\nu < 3.9$ (90% confidence level) when the initial data was combined with existing upper bounds from PEP/PETRA. Therefore

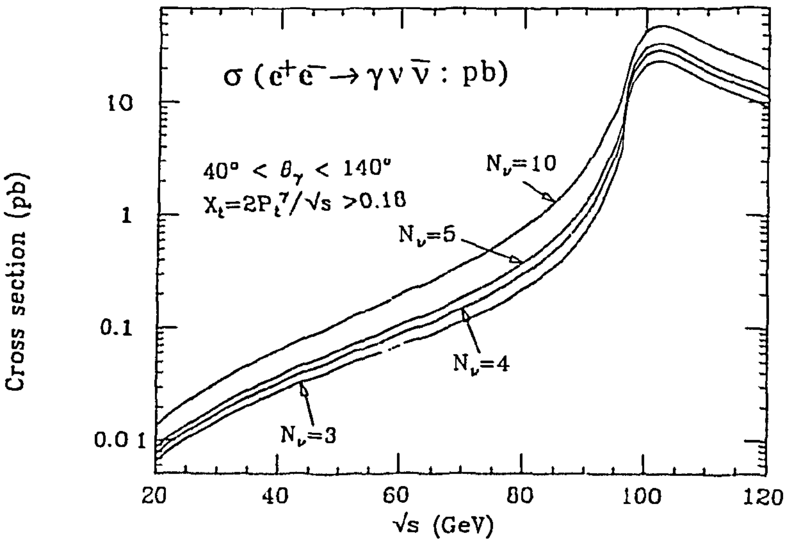

Fig.11 Crosssection of radiative ν-pair production, calculated for actual single-photon acceptance set to avoid a large background from QED reactions.

the later LEP result deduced from invisible width and peak cross section of Z^0 did not come as a surprise, but its precision was admirable[10].

The electroweak interference effect manifests itself as a contribution odd in cosϑ to the differential cross section for fermion-pair production. At energies well below Z^0, this is predominantly due to an interference between the axial vector coupling to Z^0 and the vector coupling to γ that provides the best means of determining the sign and the magnitude of the axial vector coupling a_f. It is a common practice to express it as the forward-backward (or charge) asymmetry. Fig.12 shows such data for leptons and heavy quarks.

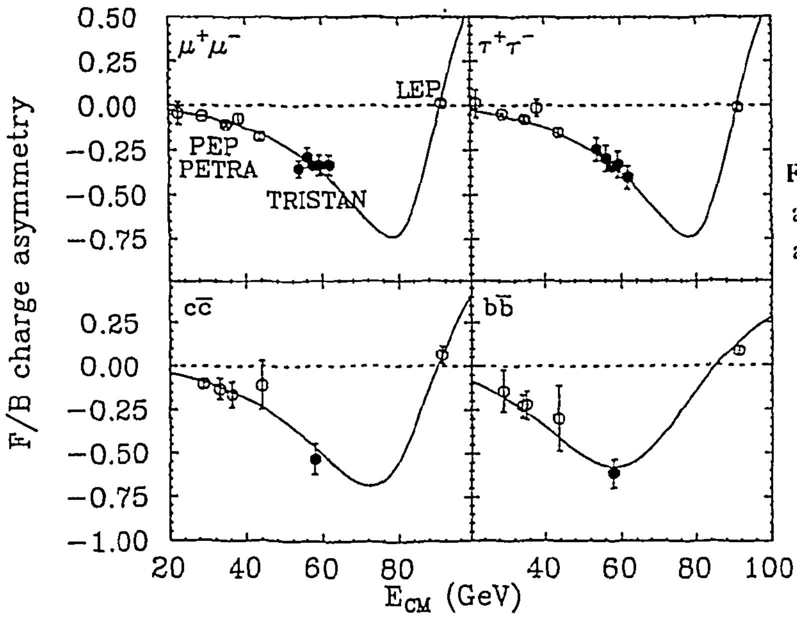

Fig.12 Forward-backward asymmetries measured for lepton and heavy-quark pair productions.

The observed large asymmetries immediately show that the Standard Model picture is essentially valid. In particular, the data on b-quarks firmly established $a_b = T_{3L} - T_{3R} = -1/2$ that had been suggested by PETRA experiment, ruling out any multiplet structures other than a left-handed (t-b) doublet with right-handed singlets. This is an independent measurement from the later, more precise LEP experiments and is unique in that the negative sign was unambiguously determined. The same asymmetry data was also used to estimate the lower bound on B_s mixing, but now the LEP data are more precise on this subtle effect.

The asymmetry data on leptons gave a_μ, a_τ=-1/2 within 10% in a single experiment at TRISTAN, *supporting the lepton universality.* The analysis in the same context has not been updated with added data because more accurate values are supplied from LEP.

The weak interaction is practically negligible in the "QED reaction", $e^+e^- \to \gamma\gamma(\gamma)$. The data exhibited good agreement with QED calculation and were used to study electron compositeness by introducing a hypothetical chirality conserving $ee\gamma\gamma$ contact interactions. The best limits were obtained, but were less significant than from $e^+e^- \to e^+e^-$ data. On the other hand, they can be translated to traditional QED cut-off parameters and then to a lower limit on the excited electron mass that is about 170 GeV for a unit $e^*e\gamma$ coupling. QED was also examined to higher orders with the reactions $e^+e^- \to e^+e^-\gamma$, $\mu^+\mu^-\gamma$, $e^+e^-e^+e^-$ and $e^+e^-\mu^+\mu^-$.

4. 4. Studies of QCD

Partons produced in high energy interactions appear as jets of hadrons. Studies of such jets occupied an important position in the physics program at PETRA, establishing basic analysis techniques. The parton-jet association is relatively easier at TRISTAN because of stronger collimation of the hadrons, although it can never be perfect. However complex in final states (*e.g.*,the mean charged-particle multiplicity is about 16 at 60 GeV), the quark-gluon dynamics is best studied in jet production from e^+e^- annihilation.

Only fundamental parameter of QCD is the effective coupling strength α_s (or the scale parameter Λ_{QCD}), once its flavour independence is acknowledged that has been strongly supported by the flavor independent quarkonium potential and a recent comparison of α_s(b) and α_s(other quarks)[11]. The quark-pair production followed by a non-colinear hard gluon emission is controlled by α_s, and the scale involved in the process increases in proportion to the annihilation energy. Accordingly, the probability of 3-jet formation is expected to directly reflect the energy evolution of α_s. Note that the parton fragmentation is not a clean process and the number of recognized jets in each final state significantly depends on the jet algorithm. Fig.13 shows the measured jet multiplicity as a function of the jet resolution parameter. Here, a scaled pair mass of any two resolvable jets were required to exceed a threshold value[12].

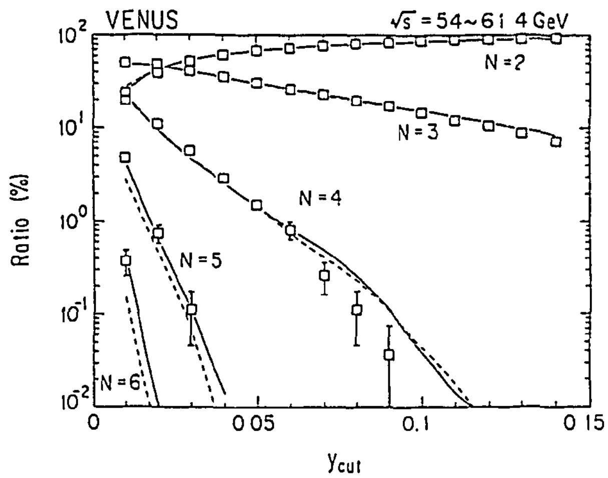

Fig.13 Measured jet multiplisity. JADE algorithm was used for jet finding.

The resulting 3-jet fraction is plotted in Fig.14 against energy. This was the first convincing evidence for the running (decreasing) α_s and therefore the asymptotic freedom.

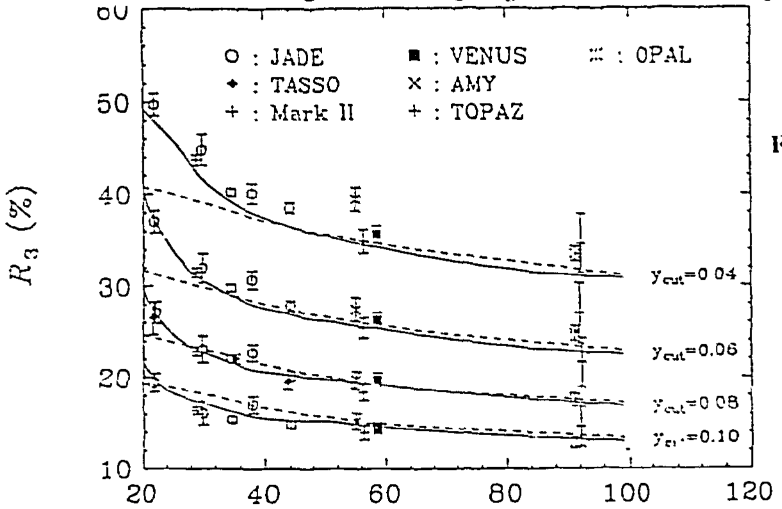

Fig.14 Measured 3-jet fraction in multiparticle production.

Precise determination of α_s itself is still a formidable task because of uncertainties in hadronization and renormalization scale. The total hadronic cross section for e^+e^- annihilation is a totally inclusive quantity, free from ambiguities inherent to hadronization, and is the best place to determine α_s. Unfortunately, as seen in Fig.5, a portion sensitive to α_s is only a small fraction that is not sufficiently larger than typical systematic errors in measurement. Therefore, various event shapes, energy correlations and scaling violations have been the primary source of information. Progress is not as fast as one hopes, but analysis methods have been gradually improved. With improved event ststistics at TRISTAN, a variety of methods have been applied (Fig.15). It is stressed that the limiting factor in α_s determination is of theoretical nature and that the accuracies achieved are similar at TRISTAN and LEP. Systematic uncertainty differs depending on the analysis method, so that it is desirable to analyze data at sufficiently different energies (at PEP/PETRA, TRISTAN and LEP) with the same and as many methods as possible. Such efforts are going on.

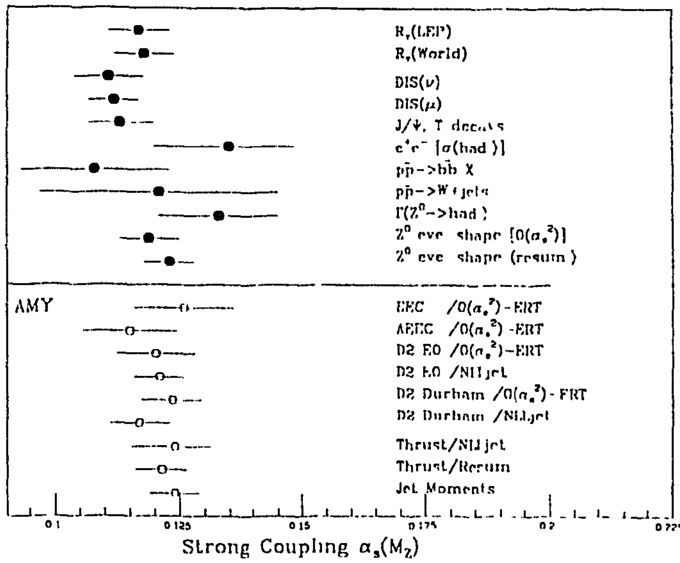

Fig.15 α_s values derived from various analyses. All are compared at $Q^2 = M_Z^2$.

As a local non-abelian gauge theory, QCD requires the gluon to be color charged. A key phenomenon arising from this basic property is the existence of the gluon self-coupling (or the triple gluon coupling) at tree level. In e^+e^- interactions, it should first appear in 4-parton final states as shown in Fig.16.

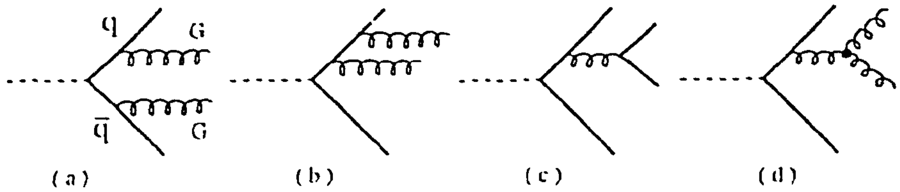

Fig.16 4-parton production processes.

As can be seen from Fig.13, the 4-jet rate is only about 1% of total. To be sensitive to the diagram d), TRISTAN experiments made use of the difference in spin structure of GGG and Gqq vertices that leads to different angular correlations among jet axes. The result of such study proved QCD prediction to $O(\alpha_s^2)$ and gave the first evidence for the gluon self-coupling. Behind the asymptotic freedom experimentally verified as in Fig.14 lies this colored gluon. Effective antiscreening of color charge implies a limited number (16 or less) of the quark flavors.

It is mentioned here that these studies on the fundamental laws of QCD would have been easier if the topponium had been in the present e^+e^- collider's reach. In the planning stage of experiment at TRISTAN, the triplet 1S-state of the topponium had been expected to act as the most efficient gluon factory ; in contrast to the case with quark-pair production, the triple gluon coupling would dominate the final state of the topponium decay in the next to leading order, and the 3-gluon decay would allow a clean measurement of α_s. But, the top would have ended up being just one of many.

The gluon was shown to be color charged as predicted by QCD. With a larger color factor expected for gluons than quarks, results of their fragmentation should be different, such that the gluon fragments into more particles. Stusies in the past were not conclusive, but recent results support the expectation that the gluon jet is softer[13]. At TRISTAN, comparisons were made of energy concentration near a jet core, rapidity of leading particles and more recently particle momentum spectrum. The latest case selected three-fold symmetric 3-jet events (qqG) and 2-jet plus a hard photon events (qqγ) in the same three-fold symmetry at the same collision energy (Fig.17).

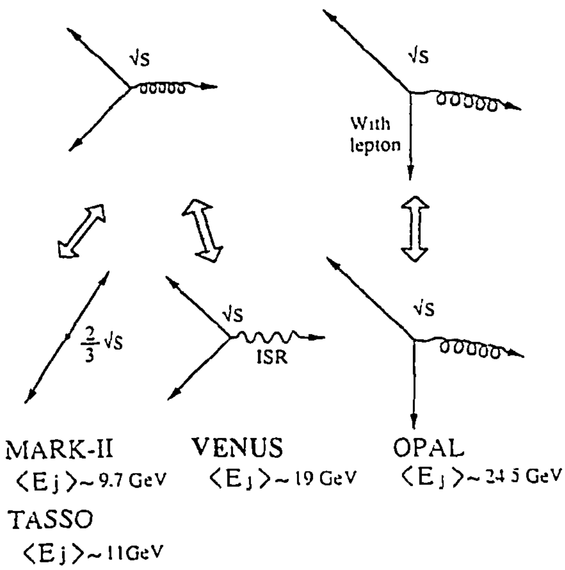

Fig.17 Methods of studying differences in quark and gluon jets.

Only assumptions are that one of the 3 jets be of a gluon origin and that the qq-system behave similarly both in qqG and qqγ environments. The second assumption was checked with Monte Carlo method. The particle momentum spectrum derived from a statistical comparison of the two types of events clearly verified the prediction that the gluon jet is softer than the quark jet of the same energy. As a result, a consistent result has been obtained for the average jet energies of 10, 20 and 25 GeV.

The two-photon physics has recently become one of the important issues at TRISTAN, in that the QCD aspects of interacting photons can be studied beyond the tree level. While single-tag events mostly probe quark content of the photon, no-tag events significantly include hard interactions of partons from low-Q^2 photons and tend to result in multiple jets[14]. This process is depicted in Fig.18.

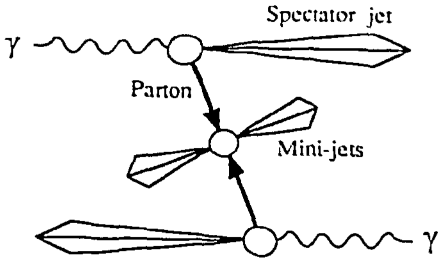

Fig.18 Multiple-jet production by hard parton interactions in low-Q^2 two-photon processes

The first clear experimental evidence for this "resolved photon process" was obtained at TRISTAN. Recent experiments at the HERA ep collider also begin to see it[15]. The study of jet production in two-photon process thus serves to elucidate low-x parton distribution in the photon. One of such data is shown in Fig. 19.

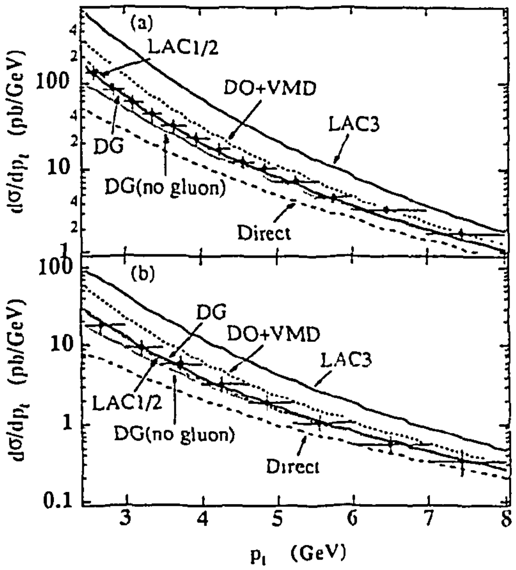

Fig.19 Inclusive P_t distributions of single and double jets in two photon process. Symbols for individual curves represent specific photon structure functions.

The resolved photon process in Fig.18 is a new source of high P_t jets in high energy e^+e^- interactions. These jets (called the mini-jets) were suspected to give huge background at future linear collider. Fortunately, the TRISTAN data such as shown in Fig.19 ruled out the possibility of large gluon content at moderate x and thus the mini-jets do not seem to jeopardize experiment at the next linear collider.

Charmed quark production in two photon process (Fig.20) is also under intensive study at TRISTAN. It is being studied with two methods ; one is to reconstruct D* mesons through their Dπ decays and the other is through inclusive electron production. The second method will allow higher event statistics, but requires very good electron identification. Invariant masses of hadronic states of accepted events are large enough to avoid complicated threshold effects. A first glimpse of preliminary results shown in Fig.21 showed consistency of two analyses and, at the same time, found the cross sections larger than theoretically expected. See R. Enomoto[16] for discussion.

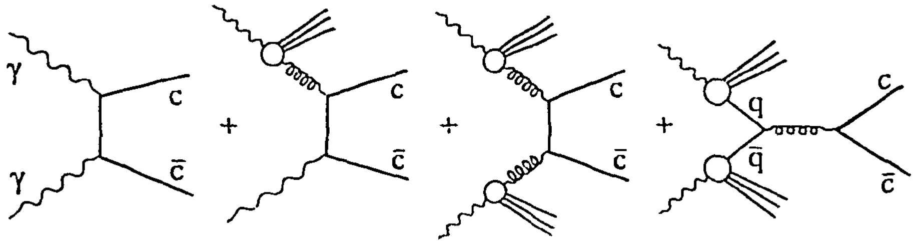

Fig.20 Charmed quark production prosesses.

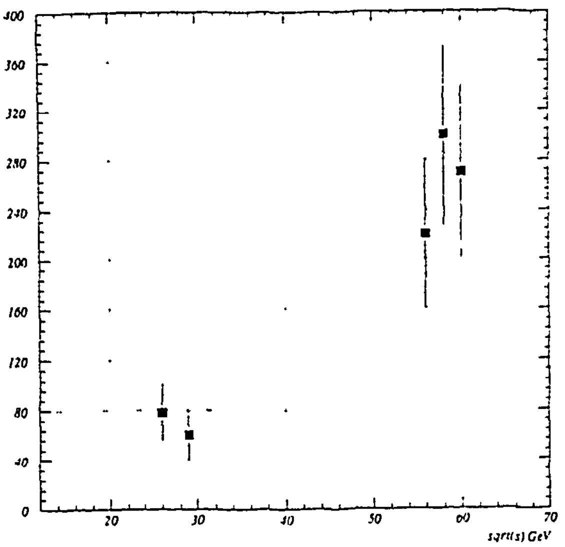

Fig.21 Very preliminary data on D* total cross section. The analyses are being considerably refined.

5. Conclusion

Next "Workshop on TRISTAN Physics" will be held on Nov. 25 and 26, 1993.

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13. AMY Collab., Y. K. Kim et al., *Phys. Rev. Lett.* 63 (1989) 1772,
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APPENDIX : Publication List

AMY Collaboration

1. Measurements of R and a Search for Heavy-Quark Production in e^+e^- Annihilation.
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2. Search for Isolated Leptons in Low Thrust e^+e^- Annihilation Events at $\sqrt{s}$ = 50 and 52 GeV.
   Physical Review Letters 60 (1988) 2359.
   S. Igarashi et al.
3. Experimental Mass Limit for a Fourth Generation Sequential Lepton from e^+e^- Annihilation at $\sqrt{s}$ = 56 GeV.
   Physical Review Letters 61 (1988) 911.
   G. N. Kim et al.
4. Measurements of Cross Sections and Charge Asymmetries for $e^+e^- \to \tau^+\tau^-$ and $e^+e^- \to \mu^+\mu^-$ for $\sqrt{s}$ from 52 to 57 GeV.
   Physics Letters B218 (1989) 112.
   A. Bacala et al.
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8. Search for Unstable Heavy Neutral Leptons in e^+e^- Annihilations at $\sqrt{s}$ from 50 to 60.8 GeV.
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   N. M. Shaw et al.
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10. Comparison of Quark and Gluon Jets Produced in High Energy e^+e^- Annihilations.
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11. Search for a Fourth-Generation Charge $-1/3$ Quark.
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12. Measurement of $e^+e^- \to$ bb Forward-Backward Charge Asymmetry between $\sqrt{s}$ = 52 and 57 GeV.
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13. A Search for SUSY Particles in e^+e^- Annihilations at $\sqrt{s}$ = 50 to 60.8 GeV.
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14. Multihadronic Event Properties in e^+e^- Annihilations at $\sqrt{s}$ = 52 to 57 GeV.
    Physical Review D41 (1990) 2675.
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15. Forward-Backward Charge Asymmetry in $e^+e^- \to$ Hadron Jets.
    Physical Review Letters 64 (1990) 983.
    D. Stuart et al.
16. A Search for Leptoquark and Colored Lepton Pair Production in e^+e^- Annihilation at TRISTAN.
    Physics Letters B240 (1990) 243.
    G. N. Kim et al.
17. Measurements of R for e^+e^- Annihilation at the KEK Collider TRISTAN.
    Physical Review D42 (1990) 1339.
    T. Kumita et al.

18. Observation of Anomalous Production of Muon Pairs in e^+e^- Annihilation into Four-Lepton Final States.
Physics Letters B244 (1990) 573.
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19. Charged Hadron Multiplicities in e^+e^- Annihilations at $\sqrt{s}$ = 50 to 61.4 GeV.
Physical Review D42 (1990) 737.
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20. Mass Limits of Charged Higgs at Large tanβ from e^+e^- Annihilations at $\sqrt{s}$ = 50 – 60.8 GeV.
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21. A Measurement of the Photon Structure Function F_2.
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23. Evidence for Hard Scattering of Hadronic Constituents of Photons in Photon–Photon Collisions at TRISTAN.
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24. Search for Anomalous $\gamma\gamma$ Production at TRISTAN.
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K. L. Sterner et al.
25. Measurement of α_s from the Moment of Particle Momenta within Jets from e^+e^- Annihilation.
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K. B. Lee et al.

SHIP Collaboration

1. Search for Highly Ionizing Particles in e^+e^- Annihilations at $\sqrt{s}$ = 50 - 52 GeV.
Physical Review Letters 60 (1988) 1610.
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2. Search for Highly Ionizing Particles in e^+e^- Annihilations at $\sqrt{s}$ = 50 - 60.8 GeV.
Physics Letters B228 (1989) 543.
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TOPAZ Collaboration

1. Search for Top Quark in e^+e^- Collisions at $\sqrt{s}$ = 52 GeV.
Physical Review Letters 60 (1988) 97.
I. Adachi et al.
2. Search for Sequential Heavy Leptons in e^+e^- Collisions at $\sqrt{s}$ = 52 GeV.
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3. Measurement of the Processes $e^+e^- \to e^+e^-$ and $e^+e^- \to \gamma\gamma$ at $\sqrt{s}$ = 52 GeV.
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5. Search for SUSY Particles in e^+e^- Annihilation at TRISTAN.
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6. Measurement of α_s in e^+e^- Annihilation at $\sqrt{s}$ = 53.3 and 59.5 GeV.
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7. A Search for Excited Leptons in the Energy Region $\sqrt{s}$ = 52-60.8 GeV.
Physics Letters B228 (1989) 553.
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8. Search for a Fourth-Generation Charge -1/3 (b') Quark Using Inclusive Muons in e^+e^- Annihilation at $\sqrt{s}$ = 56.5 to 60.8 GeV.
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9. Measurement of Total Hadronic Cross Sections in e^+e^- Annihilation and Determination of the Standard Model Parameters.
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10. A Study of Pion Pair Production in Two Photon Process.
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12. A Search for Charged Higgs Bosons at TRISTAN.
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13. Search for Pair Production of Heavy Stable Particles at TRISTAN.
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14. A Search for Inclusive Production of Heavy Stable Particles by the TOPAZ Detector at TRISTAN.
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15. Charge Asymmetry of Hadronic Events in e^+e^- Annihilation at $\sqrt{s}$ = 57.9 GeV.
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16. Measurement of b-Quark Forward-Backward Charge Asymmetry and Axial-Vector Coupling using Inclusive Muons in e^+e^- Annihilation at $\sqrt{s}$ = 52 - 61.4 GeV.
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K. Nagai et al.

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Physics Letters B284 (1992) 144.
K. Shimozawa et al.

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B. Howell et al.

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K. Abe et al.

22. Measurement of the Inclusive Cross Section of Jets in $\gamma\gamma$ Interactions at TRISTAN.
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8. Search for a Fourth Generation Quark with Q = e / 3 in e^+e^- Collisions at $\sqrt{s}$ = 56 - 57 GeV.
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15. Measurement of R and Search for New Quark Flavours Decaying into Multi–Jet Final States in e^+e^- Collisions between 54 and 61.4 GeV C. M. Energies.
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21. Search for Charged Scalars in e^+e^- Annihilation up to 64 GeV C.M. Energy.
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23. Measurement of the Forward-Backward Asymmetry of Charm Quark Production in e^+e^- Annihilations at $\sqrt{s}$ = 58.4 GeV.
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A. Okamoto et al.

24. Measurement of Forward–Backward Charge Asymmetry in the Process of b-Quark Production in e^+e^- Annihilation around $\sqrt{s}$ = 60 GeV.
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25. Search for Heavy Neutral Spinless Particles Using $e^+e^- \to e^+e^-$ and $e^+e^- \to \gamma\gamma$ Reactions in the CM Energy Range between 54 and 64 GeV.
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    K. Hikasa and M. Kobayashi
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    M. Igarashi
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15. Automatic Generation of Feynman Graphs and Amplitudes in QED.
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16. Radiative Correction to Jet Production in e^+e^- Annihilation.
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V. Berger and K. Hagiwara

25. Double Cascade Scheme for QCD Jets in e^+e^- Annihilation.
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M. Drees and K. Hikasa

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28. Higgs Associated Production in e^+e^- Annihilation at TRISTAN.
Physics Letters B252 (1990) 127.
M. Drees and K. Hikasa

29. Limits on Lepton–Quark Contact Interactions from the Quark Forward-Backward Asymmetry in e^+e^- Annihilation.
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