BNL 18524

CRISP/74-3

BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York

ACCELERATOR DEPARTMENT
Informal Report

95,823

REPORT on the MEASUREMENT of the TOTAL CROSS SECTION and LUMINOSITY at ISABELLE - a of existing CRISP reports.

Jay N. Marx
Yale University

January 1974

10/12/73

Report On The Measurement Of The Total Cross Section And Luminosity At Isabelle - a summary of existing CRISP reports.

Jay N. Marx
Yale University

I. Introduction

The measurement of the proton-proton total cross section (σ_T) and its dependence on the energy in the center of mass ($\sqrt{s}$) constitutes a critical test of our ideas of the asymptotic behavior of the strong interactions. The recent observations of a rising σ_T at ISR energies makes it important that we further investigate this phenomena at Isabelle energies. Some representative models and their predictions are listed below:

1. Simple Regge Pole models with Pomeron dominance in the high energy region predict $\sigma_T = A$ where A is a constant.
2. Regge Pole and cut models predict that

$\sigma_T = \sigma_0 \left(1 - \frac{a}{b + \ln (s/S_0)} \right)$ so that, for example, $\sigma_T = 50.6$mb at 80Tev lab equivalent energy.[1]

3. Complex Regge Pole models predict for the S dependence at very high energies: $\sigma_T = A - B \cos (\ln S + D)$ where S, B, C, D are constants.
4. Field Theoretical Models which saturate the Frorssart bound predict $\sigma_T = A + B (\ln s/s_0)^2$. A fit to the ISR results[2] gives $\sigma_T = 52.2$mb at 80Tev.

There are, of course, many other models which predict a different energy dependence for σ_T and which begin from vastly different points of view as to the fundamental dynamics of the strong interactions. A measurement of σ_T to 1% accuracy and its S dependence would be a significant step in limiting the range of acceptable models.

II Measurements of the Total Cross Section

Basically there are three methods for measuring the total cross section with colliding beams. The first requires the detection of all interactions occuring in an intersection region; the second involves a measurement of the attenuation of the beams due to their mutual interactions; the third determines the total cross section from the elastic scattering cross section and the optical theorm. In each case one measures a rate and normalizes to the luminosity. Thus, in order to measure σ_T to better than 1% one needs to measure the luminosity to at least this accuracy. Methods and limitations for determining the luminosity will be discussed later in this report. In the following we assume that the intersection regions have calibrated luminosity monitors.

a. Measurement of σ_T from the Total Interaction Rate:

The total cross section can be determined from the total interaction rate (R) and the luminosity (L): $\sigma_T = \frac{R}{L}$ where R is determined by surrounding intersection region as nearly as is possible with detectors.

The general layout for such an experiment and details of a possible detector and beam pipe[3] is shown in Figures 1 and 2. In order to have high efficiency, good time resolution and low deadtime, all detectors should be scintillation counters. There would be two sets of concentric ring counters (A) at small angles (0.5 to 5.0 mrad) and two more sets (B) at moderate angles (5.0 to 50.0 mrad). These counter rings are in two sets in order to be able to cover the wide angular region required by the large energy range of the machine (20 - 200GeV/c) with reasonably sized counters. The remaining solid angle is covered by two additional layers of counters (C).

The minimum angle detected by A is dictated by the requirement that not too many small angle elastic scatters by lost. If the forward elastic cross section is given by $\frac{d\sigma}{dt} = 100\ e^{10t}$ then all but 1mb of σ_T is detected if counters A cover angles corresponding to $t \leq -0.01\text{GeV/c}^2$. At 200GeV/c this corresponds to $\theta_{min} = 0.5$mrad. Thus the inner ring would circle the 5cm beam pipe at a distance of 50m. This requirement determines the length of the free space needed in the intersection region.

An extrapolation error of 20% to $t > -0.01\text{GeV/c}^2$ corresponds to an error of 0.5% in determining σ_T.Counter arrays A and B are made of concentric rings in order to simplify such an extrapolation. This correction can also be made with results from the small angle scattering experiment.

The requirements of Isabelle for such an experiment follow:

1. Variable beam momentum from the injection energy to the maximum.

2. Beams colliding at the maximum angle to keep the length of the intersection region small. This is required so that reasonably sized detectors could be used to surround the interaction region.

3. A moderate β so that the beam divergence is small enough to allow a free space of 50m on either side of the intersection region and so that the luminosity is limited to avoid rate problems in the detectors.

4. 100 meters of magnet free straight section.

5. Negligible beam tails to minimize rate problems in the small angle detectors.

These requirements result in a 64cm long intersection region and a beam size of 6.3 x 3mm for a intersection angle of 20mr. The beam divergence is 250μr and the counting rate is 3×10^5 per second assuming 10 amps in each beam.

We note that in such an intersection region, the beam-gas background is less than 1% of the beam-beam rate for a luminosity of 10^{30} cm^{-2} sec^{-1} with a vacuum of 10^{-11} mm Hg. From the point of view of counting rate, the experiment could tolerate lower luminosity, but a serious reduction of the luminosity below this value without a comparable improvement in the vacuum would soon limit the accuracy due to beam-gas background. A luminosity substantially higher than 10^{31} cm^{-2} sec^{-1} could begin to result in accidental and deadtime problems due to the large collision rate and multiplicity. Since the experiment is set up to measure only the total interaction rate, there are no obvious advantages to horizontal or vertical crossing. The momentum spread of the beams has no effect on the measurement beyond the constraint of an intersection region with the specified characteristics. Bunching of the beams can only increase rate problems with no benefit since this measurement has luminosity to spare.

It is difficult to estimate the dwell time of an experiment in a new facility but this experiment should probably tie up a crossing region only for several months. The detectors are simple and the rate is high. In addition the requirements of Isabelle should be fairly straight forward. Most probably the most time consuming and difficult part of the determination of σ_T will be the determination of the luminosity in the .5% - 1.0% range.

b. Measurement of σ_T from the Forward Elastic Cross Section

σ_T is measured as a by-product of the small angle scattering experiment.[4] If one measures the rate of elastic scatters as a function of t, the optical theorm can be used to determine σ_T.

$$\sigma_T = \left[\frac{1}{L} \frac{dR}{dt} \frac{1}{(1 + \alpha^2)} \right]^{1/2}$$

where L is the luminosity, R the rate of elastic scatters and α the ratio of the real to imaginary parts of the forward scattering amplitude. This formula assumes spin independence of the elastic cross sections at small angles. Measurements at conventional accelerators[5] seem to bear out this assumption, but this low energy result must be taken over to Isabelle energies. The ratio of real to imaginary parts, α, will also be determined from the small angle scattering experiment from an observation of the interference of the nuclear scattering amplitude with the essentially real coulomb amplitude. It should be noted, however, that spin dependent and real part contibutions can only increase the apparent σ_T so that this method determines an absolute upper limit to σ_T.. In addition, this method depends on the luminosity in a weaker fashion than the other methods to determine σ_T, and for a fixed number of events one obtains a statistical error which is 50% of that for the direct methods of measuring σ_T. The detector and beam requirements for this experiment are both severeand specialized. They are discussed in detail in another report.

c. Measurement of σ_T from the Beam Attenuation Rate

The highest luminosities to be achieved at Isabelle ($10^{34}cm^{-2}$ sec^{-1}) result in an attenuation of the protons beams by ~8% per day for a total cross section of 50mb. In order to measure σ_T from this attenuation a subtraction must be made for losses other than beam-beam interactions (eg. beam-gas and beam-wall loss). For a pressure of 10^{-10}mm Hg, for example, the beam-gas loss is about 25% of the beam-beam rate. Thus it seems rather difficult to measure σ_T to the order of 1% from a measurement of the beam attenuation over long periods of time.

An alternative approach has been suggested[6] which allows the measurement of short term beam attenuation due to beam-beam interactions with a signal to noise ratio of >99% and which clearly separates beam-beam from other sources of attenuation. If one beam is caused to sinusoidally sweep across the other beam by a magnetic deflection system, the beam attenuation due to beam-beam interactions is periodic with the driving frequency of the deflection system while other losses are approximately constant in time. By use of a high permeability toroid around the stationary beam, the sinusoidal beam loss can be detected as an AC component in the induced EMF in the toroid (Fig. 3) By phase locking techniques the beam-beam loss of $1/10^6$ per second can be detected and a signal to noise ratio of better than 99% can be achieved in only a few seconds sampling time. These conclusions are based on a detection system which is not optimized, a driving frequency of 5KC, and a noise level of 1mV in the system. As with other methods of measuring σ_T, the luminosity must be measured. Collective beam loss effects may be understood and corrected for by a series of measurements at different luminosities since such effects vary with the luminosity.

As with the other methods of measuring σ_T the attenuation method requires a correction for scatters which do not result in protons leaving the beam phase space. In this case, this correction can be determined in a way analogous to classical σ_T measurements by the transmission method. For a given set of β functions there is a minimum scattering angle above which a scattered proton leaves the beam before reaching the toroid.

In principle the determination of this angle is a straight forward calculation in beam dynamics since one need not consider machine resonances which take more than a fraction of a turn in order to remove a scattered particle from the beam. By varying the functions one could perform the equivalent of the classical total cross section measurement where the limit of $\beta \rightarrow \infty$ is analogous to the extrapolation to zero solid angle.

The correction for small angle scatters remaining in the beam can be made with data from the experiment on elastic scattering so that, this attenuation measurement can be performed using the highest luminosity. Thus, for example, a quassi colliniear region with $\beta_V, \beta_H < .7$m could give a luminosity of $10^{34} cm^{-2} sec^{-1}$. Beam shapes, divergence, and momentum spread should be such as to maximize the luminosity. There is no preference for vertical or horizontal crossing. Bunching of the beams to increase luminosity is probably not a good idea in this case as it results in an additional periodic signal being injected into the system. If, however, it is found desireable to measure the attenuation for different functions and luminosities to be able to correct for small angle and collective effects the requirement of the machine are more varied. However, one could consider the toroidal detector as a permanent facility since it does not tie up an intersection region. Then, whenever the machine runs with a particular luminosity or β of interest, the attenuation can be measured so that eventually the data for making the connections can be accumulated. In fact, even if this were not necessary the dwell time of this detector should be indefinite as it can provide a measurement of the luminosity once σ_T has been measured. This point will be elaborated later in this report.

d. Measurement of the Nucleon-Nucleon Total Cross Section Ratio

For completeness we mention a suggestion[7] for measuring nucleon-nucleon total cross section ratios with colliding deuteron beams by looking at spectator nucleon coincidences with scintillation counters. A coincidence between two counters where two spectator protons are expected would signify the occurrence of an n-n interaction. Similarly a coincidence between two neutrons along the beam directions would signify a pp collision while pn (np) collisions would be monitored by np (pn) spectator coincidences. Typically spectators would have 1/2 the deuteron momentum with an angle $\theta \leq .2/P_d$ GeV/c which is 1mr for p_d = 200GeV deuterons. A schematic detec- arrangement is shown in Figure 4.

III. Determination of the Luminosity

Many experiments with colliding beams require rather precise measurements of the luminosity. These experiments are of two general classes, those which measure absolute reaction rates (eg., total cross sections) and those which require relative luminosity measurements in order to normalize a series of runs (eg. studies of the S dependence in a particular reaction.) The problem of luminosity measurement is a serious one in that such a measurement way limit the accuracy of a particular experiment.

The luminosity of the intersecting beams is defined by the expression for the interaction rate for a particular channel with cross section σ_i; $N_i = L\sigma_i$ where N_i is the rate and L the luminosity. The luminosity can also be expressed in terms of the properties of the intersecting beams; thus the luminosity for a horizontal crossing at angle α is given by

$$L = \frac{I_1 I_2}{e^2 c \tan^{\alpha/2}} \frac{1}{H}$$ where H is the vertical overlap integral of the two beams whose currents are I_1 and I_2.

$$\frac{1}{H} = \int \rho_1 (x) \rho_2 (x) dx \quad \text{where} \int \rho_{1,2} (x) dx = 1$$

For 0° crossing the luminosity per unit length is given by

$$\frac{dL}{dZ} = \frac{2I_1 I_2}{e^2 c A} \quad \text{where} \quad \frac{1}{A} = \int \rho_1 (x,y) \rho_2 (x,y) d x dy$$

$\int \rho_{1,2} (x,y) d x dy = 1.\frac{1}{A}$ is the two dimension normalized beam density overlap integral.

Thus we see that the luminosity can be determined by two general methods: first by measuring the reaction rate in a channel whose cross section can be calculated or independantly measured to the desired accuracy; second by determining the beam characteristics, specifically the currents and overlap integrals. As will be discussed below, luminosity measurements may require rather severe or unusual conditions in an intersection region in order to optimize the results, but this is not, in turn, a constraint on the types of intersection regions which can be used for experiments whose results depend on the luminosity. If the luminosity of any special intersection region is know and the rate for any arbitrary, convenent reaction is measured in that region, then the luminosity at any other region can be established by a measurement of that same rate. In this way one constructs calibrated luminosity monitors.

In the following we describe several methods for determining the luminosity in order to illustrate the range of machine requirements that are needed for these approaches. In some cases we will see that the machine requirements are so severeas to rule out the feasibility of a particular approach.

a. The Van der Meer Method[8]

For two beams of current I_1 and I_2 crossing at an average angle of θ, the luminosity can be written

$$L = \frac{I_1 \ I_2}{e^2 c \tan (\theta/2)} \cdot \frac{1}{H}$$

If one measures the beam currents by either induction or by observing gas scattering at a point away from the interaction region, then a determination of H constitutes a measure of the luminosity. H is the vertical overlap integral of the two beams

$$\frac{1}{H} = \int \rho_A (X) \ \rho_B (X) \ dx; \text{where} \int \rho_{AB} (X) \ dx = 1$$

Van der Meer considers a relative measurement of the interaction rate as a function of δ, the vertical separation of the two beams

$$R (\delta) = c \ . \int \rho_A (X) \ \rho_B (X + \delta) \ dx \qquad R (0) = C/H$$

To determine C we measure the area of the curve R (δ)

$$\int R(\delta)\, d\delta = c \int d\delta \int \rho_A(X)\, \rho_B(X+\delta)\, dx = C \cdot \int d X\, \rho_A(X) \cdot$$

$\int d X\, \rho_B(X+\delta)$ since $\rho_A(X)$, $\rho_B(X)$ are normalized to unit area $\int R(\delta)\, d\delta = C$. Thus $1/H = R(0)/\int R(\delta)\, d\delta$

This calculation assumes the independence of beam shape and detection efficiency on the displacement δ. The shape changes only if the betatron function is locally modified by a beam displacement. The Van der Meer method has been used at the ISR with an accuracy of 2% where the uncertainty is due to the uncertainty in δ[9]. This method may be pushed to the level of 1% accuracy but one must be careful to worry about changes in the beam characteristics (shape, emittance) during the displacement. In addition it is inconvenient to measure the luminosity continually in this way because of the duty cycle factor introduced.

b. Using the Intersection of a High β and Low β Beams[10]

This method for determining the luminosity requires the intersection of two beams, one with low β and the other with high β, at a finite crossing angle. Consider, for instance, the intersection of a beam with $\beta_1 = 1$ meter (diameter $d_1 \approx 0.5$mm) with a beam of $\beta = 1000$m ($d_2 = 1.5$cm) at the crossing angle θ of .03 radians. The intersection will look as in Figure 5. The intersection region is $\approx$ 50cm long which is reasonable. In the approximation $\beta_1 \ll \beta_2$ the luminosity will be given by

$$L \approx \frac{1}{e^2 c} \cdot I_1 \frac{\partial I_2}{\partial y} \frac{1}{\sin\theta}$$

$$\approx 1.3 \times 10^{27} I_1 I_2 \frac{1}{d_2 \sin\theta}$$

which for $I_1 = I_2 = 15$ amps gives

$$L \approx 6.5 \times 10^{30}.$$

From the equation above we note that L is not dependent (to first order) on the size or shape of the low β beam. It is dependent only on the currents (which can be accurately determined) and on the $\partial I_2/\partial y$ of the high β beam. Now this $\partial I_2/\partial y$ can be determined by displacing the low β beam vertically and noting the counting rate R(y) as a function of this displacement (y)

$$\frac{\partial I_2}{\partial y} \text{ (at } y = 0) = \frac{I_2 R(0)}{\int R(y)dy}$$

$$\text{Thus } L = \frac{1}{e^2 c} \frac{I_1 I_2}{\sin\theta} \cdot \frac{R(0)}{\int R(y)dy}$$

This, of course, is the old Van der Meer method the two beams have approximately the same diameter. The trouble arises when one beam is displaced vertically to obtain R(y). There is no way of assuring that the vertical distribution of the displaced beam does not change as a function of its displacement. When the two beams are of similar size such variations have only a second-order effect. A change in mean diameter of the low β beam by a factor ε of 10% will only cause a change in $\int R(y)\,dy$ of $(d_1/d_2)\varepsilon$ or 0.3%. Ten percent seems a conservative estimate for c since larger changes could be observed and measured. Errors in current measurement could be made negligible and thus this method could give luminosities to the order of 0.3% accuracy.

c. Luminosity Determination by Beam Attenuation

As discussed earlier in the report, the total beam-beam interaction rate can be measured by sinusoidally sweeping one beam across the other and by using phase locking techniques to extract the AC component of the voltage induced in a toroidal beam monitor. It was suggested that such a measurement when combined with an independent luminosity measurement could be used to determine σ_T. Of course, we can turn this arguement on its head. Once σ_T is known this method can be used to measure the luminosity. In fact, even without a knowledge of σ_T, this approach can give use useful method for monitoring the relative luminosities at different times for the same machine energy or in an energy range where σ_T varies by less than the accuracy needed in the luminosity. The nice feature about this approach is that it requires no special apparatus in the intersection region to constrain experiments. It can be used to periodically recalibrate luminosity monitors.

d. Measurement of the Coulomb Region in P-P Collisions:

As is well known, at sufficiently low values of t ($t <$ .002 GeV/c$)^2$) the differential cross section for P-P is dominated by coulomb scattering

$$\frac{d\sigma}{d\sigma}\Big|_{coulomb} = \frac{2.6 \times 10^{-4}}{t^2} \quad mb/GeV^2$$

where $t = E_1 E_2 (1-\cos\theta)$

If one could study the small t region with sufficient resolution, this calculable cross section can be used to calibrate the luminosity. Unfortunately, as will be shown, this idea imposes prohibitive constraints on the angular divergence of the colliding beams. Let us assume that one wishes a 1% measure of the luminosity.

$\Delta\, d\sigma/dt/d\sigma/dt = 2\Delta\, t/t = 1\%$

thus one must determine $\Delta\, t/t$ to 0.5%. From the relation between t, E_1, E_2, and θ

$$\Delta\, t/t = 2\left[\left(\frac{\Delta E}{E}\right)^2 + \left(\frac{\Delta\theta}{\theta}\right)^2\right]^{1/2} = 2.5 \times 10^{-3}$$

$E_1 = E_2$ 200 GeV and $t = .001\ (GeV/c)^2$, for example, correspond to $\theta = 0.15$ mr. Thus the largest tolerable beam divergence is $\Delta\theta < .4\ \mu r$. This requirement is prohibitive. In fact a great deal of beam gyrations are required to limit the divergence to the 25 μr required for the study of the low t nuclear elastic scattering[4] at ISABELLE.

e. Coulomb Dissociation of N^* (1236)[11]

In the reaction $p+p \to p+p\,\Delta \to N\,\pi^+$ where the Δ is producted in the coulomb field of one of the protons, the momentum impulse required is $q_L = \frac{M_\Delta^2 - M_p^2}{2p} = 3$ KeV/c. In terms of an impact parameter $b = \hbar/q_L \sim 0.7A^\circ$ so we see that the interaction occurs so far from the proton that we may regard it as a point particle and neglect both the strong interactions and the contribution of the proton magnetic moment to the electromagnetic interaction. Since the coulomb photons are quite near the mass shell, the cross section for the coulomb production of deltas can be determined by measuring low energy delta photoproduction. Gobbi and Rosen estimate a cross section for coulomb production of the $\Delta(1236)$ of about 0.1 μb which gives 100 events/sec for a luminosity of 10^{31} cm^{-2} sec^{-1}. This reaction produces a forward going neutron of average energy 150 GeV and a π^+ at about 4 mr with 40 Gev of energy. One could measure the π^+ with a classic spectrometer and the neutron direction and energy in a calorimeter with a matrix of detection elements. This method is limited by the accuracy of the low energy photoproduction experiment and by background. It is proposed to suppress the 40 mb of strong interaction backgrounds with veto counters and kinematic constraints. Out of this cross section there is 100 μb of N π^+ diffractive production by Pomeron exchange. This background is eliminated by kinematics. Exchanges of trajectories other than the Pomeron are expected to be greatly suppressed at Isabelle energies.

e. <u>Electron Pair Production in P-P Collisions</u>

Budnev, et al.[12] have suggested the use of the reaction $P+P \rightarrow P+P+e^{+}+e^{-}$ in the appropriate kinematic region in order to measure luminosity. In the region of small lepton four-momentum the protons in the final state do not leave the beam. Here, the cross section is dominated by diagrams of the sort studied by Brodsky and which can be calculated from pure QED to accuracies of $1/10^3$ (Fig. 6). Diagrams involving strong vertices contribute only at the level of $1/10^4$. Radiative corrections, which depend on the details of the method of detection, can be ignored at the 1% level. At the level of 0.1% they must only be calculated to 10%.

The kinematic region of interest is the region of proton scattering angles $< \frac{Me}{E} \sim 2\ \mu r$. For this region the cross section for $p+p \rightarrow p+p\ e^+ + e^-$ from QED is calculated to be

$$\sigma(\delta) = \frac{28}{27\pi} \frac{\alpha^4}{M_e^2} \left[\left(\ln \frac{4E\delta}{M_p^2} - 1 \right)^3 + \frac{3}{2} \ln \frac{4E^2\delta}{M_p^2} - 2 \right]$$

where δ is a parameter which defines the region of phase space to be considered: $|q_1^2| < \omega^2\delta$ where $\omega^2 = 4\omega_1\omega_2$; $\omega_1\omega_2$ = energy loss by protons. For $\delta = .1$, for example, the cross section is $\sigma >$ 1mb. The kinematics of the electron pairs is as follows: if Σ is the sum of the electron energies

$$\frac{dN}{d\Sigma} \sim \frac{1}{\Sigma} \quad \text{if } \Sigma \leq \frac{m_e}{M_p} E \qquad E = 200 \text{ Gev}$$

$$\frac{dN}{d\Sigma} \sim \frac{m_e}{M_p} \frac{E}{\Sigma^2} \quad \text{if } \Sigma >> \frac{m_e}{M_p} E$$

The transverse momenta are both of order $E\,m_e$ and their sum is near zero, i.e. e^+ and e^- are emitted symmetrically around the beam. Thus we must detect electron pairs of typical momenta of 50 Mev and emission angles of 10 mr with respect to the beams. Since the cross section is > 1 mb we can avoid being swamped by strong interaction background. In fact, such a luminosity measurement could be made with two small shower counters and vetos to eliminate events with large angle hadrons. One could work with luminosities of 10^{30} $cm^{-2}sec^{-1}$ and see 1000 events/sec and a background counting rate from hadrons of only 10^4 - 10^5/sec.

We must also consider various contributions to the backgrounds. Lepton pair production on residual gas with charge Ze can be calculated by the substitution of 2E/M for $4E^2/M^2$ and a factor Z^2 in the formula for the beam-beam pair production cross section. For a vacuum of 10^{-10} torr, beam currents of 10 amps, a luminosity of 10^{33} $cm^{-2}sec^{-1}$ and Z=7 this background is 0.02%. Pair production in inelastic pp scattering can contribute a cross section 10% of the signal, however, the final state hadrons have a wide angular distribution ($< \theta > \sim$ lmr $< p_\perp > \sim$ 300 Mev/c) as compared to the final state protons in the signal reaction. One can kill this background by detecting lepton pairs in anticoincidence with hadrons. The contribution of $p + p \to \pi^0 + \ldots,\ \pi^0 \to \gamma\ e^+e^-$ is small in this kinematic region ($\sigma \sim \sigma_{pp}^{inel}\ K_\perp{}^2/m_\pi{}^2$). If, however, it should be that the electron pair production in the appropriate kinematic region suffers from some residual background problem one can reduce the kinematic region. This does not substantially decrease the elastic pair production cross section and the accuracy. For example, decreasing δ by a factor of 3 decreases the cross section by only 25% while the background should scale down as δ.

IV. Conclusion:

In this report we have discussed several methods for the measurement of σ_T and of the luminosity of colliding beams. Certainly, in time, better methods will be suggested. The point that must be emphasized, however, is that some of these methods could give accuracies to the 1% level or better under carefully controlled circumstances.

One can measure absolute luminosities under such controlled circumstances in order to calibrate one or more 90° telescopes. These telescopes would then provide the luminosity monitor in that interaction region when the physics program proceeds. During this time the method for measuring beam attenuation with a toroidal detector far from the interaction region could be used to periodically monitor the relative luminosity and thus the stability of the calibrated 90° telescopes. The advantage of this approach is that an extensive effort with optimal equipment could be mounted to measure the absolute luminosity at convenient beam currents and for all beam energies of interest. In fact, one could employ several of the methods suggested above to serve as a cross check. One could then have 90° telescopes calibrated for all beam currents. These telescopes could then be used for all experiments (some experiments may calibrate a still more convenient monitor with respect to the 90° telescope).

Given a sufficiently accurate calibration of the luminosity, the total cross section and its energy dependence can be measured to the 1% level by several different methods (beam attenuation, total rate, and $d\sigma/dt$ + optical theorem) which have different background, systematic problems and dependence on the luminosity. A comparison of results among these methods would be useful if such accurate cross section measurements are to be taken at face value.

Figure Captions

Fig. 1) General layout for measurement of σ_T by detecting all interactions.

Fig. 2) Details of detectors and vacuum pipe for detecting all interactions.

Fig. 3) Detector for measuring beam attenuation by phase locking techniques.

Fig. 4) Layout for measuring ratio of nucleon-nucleon total cross section with stored deuterons.

Fig. 5) Configuration of beams for measuring luminosity using high and low β intersecting beams.

Fig. 6) Diagrams of contributions to $p + p \rightarrow p + p + e^{+} + e^{-}$: a) Calculable reaction; b) Strong interaction background which contributes at level of 10^{-4} of a).

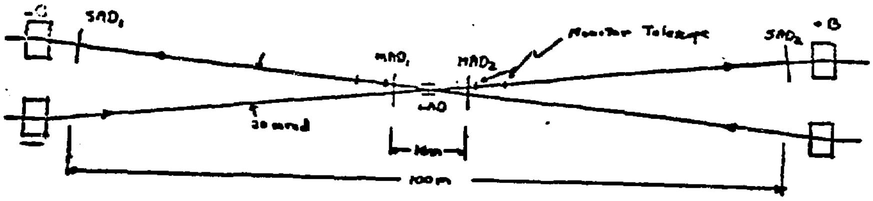

Fig 1. General Layout for σ_{tot} Experiment. Top View

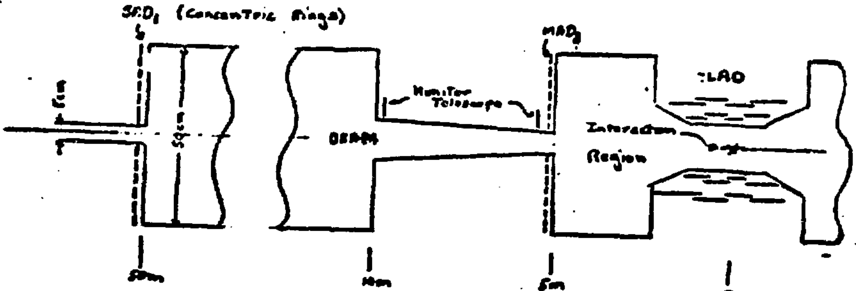

Fig 2 Detail of Detectors and Vacuum Pipes – Side View

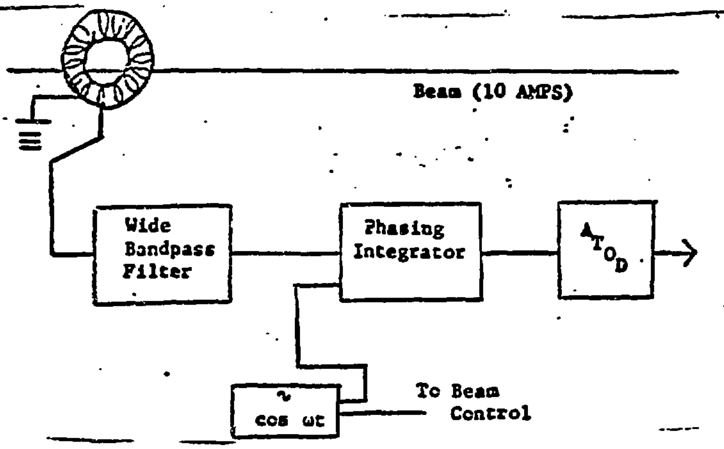

Fig 3.

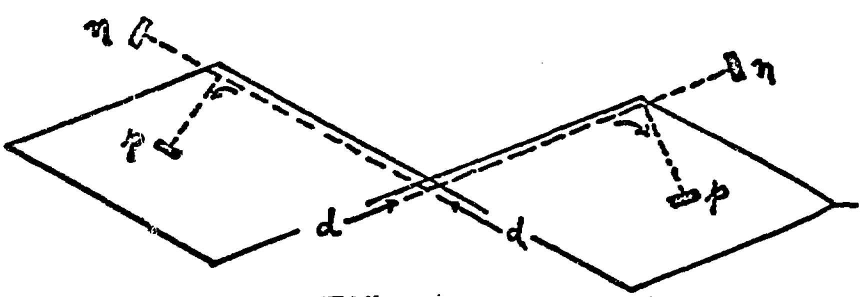

Fig 4

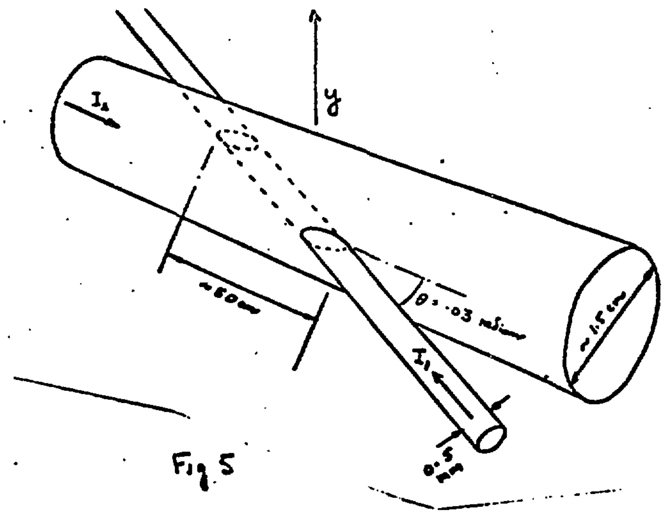
y
I_2
I_1
~60cm
θ = ·03 radians
~1.5 cm
0·5 mm

Fig 5

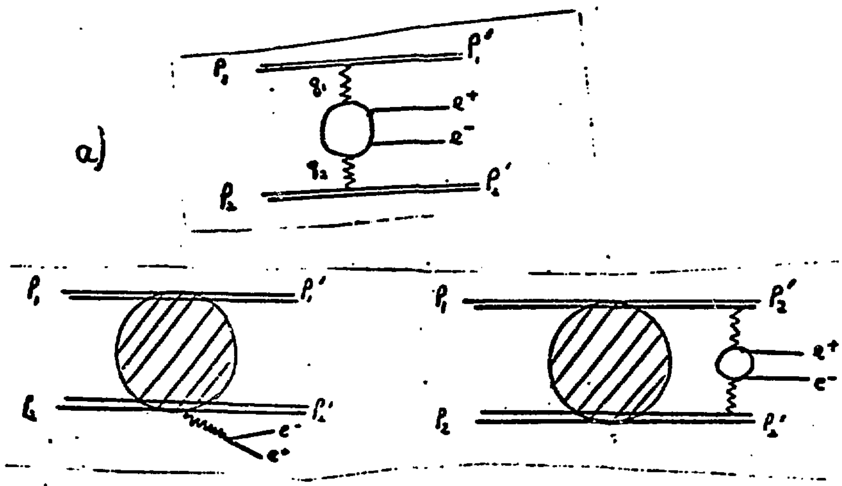
a)
p_1
p_1'
q_1
e^+
e^-
q_2
p_2
p_2'
b)
p_1
p_1'
p_2
p_2'
e^-
e^+
p_1
p_2'
e^+
e^-
p_2
p_2'

Fig 6

<u>References</u>

1) A fit due to Arbarbenal gives $\sigma_\tau = \sigma_0 \left(1 - \frac{a}{b + \ln P_{lab}}\right)$ where a=b=3, $\sigma_0 = 60\,mb$ and P_{lab} is the equivalent laboratory momentum.

2) ISR data can be fit to a form $\sigma_\tau = 38.8 + 0.7$ ~~(ln p_{lab}/1000)~~^{2} $\times [\ln s/s_0]^2$ $s_0 = 200\,GeV^2$.

3) A.S. Carroll, CRISP 71-53.

4) K.J. Foley and S. Ozaki, CRISP 71-22.

5) E.F. Parker et al, Phys. Rev. Lett. <u>31</u>,783(1973).

6) J.N. Marx and J. Sandweiss, CRISP 72-57.

7) K. Goulianos, CRISP 71-56.

8) M. Holder et al, Phys. Lett. <u>35B</u>, 361(1971).

9) U. Amaldi, Talk at 2nd Aix-en-Provence International Conference on Elementary Particles, 1973.

10) R. Palmer, CRISP 72-35.

11) B. Gobbi and J.L. Rosen, CRISP 72-41.

12) V. Budnev et al, Phys. Lett. <u>39B</u>, 526(1972).