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

ACCELERATOR DEPARTMENT
Informal Report

MEASUREMENT OF PP TOTAL CROSS SECTIONS IN ISABELLE

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CRISP 71-53
ISABELLE PROJECT

INTERSECTING STORAGE ACCELERATOR NOTES

MEASUREMENT OF pp TOTAL CROSS SECTIONS

IN ISABELLE

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One of the most obvious and important measurements to be made with ISABELLE is the pp total cross section over the full energy range of the machine. Since the measurements of the total cross sections at Serpukhov there have been several theoretical predictions as to the asymptotic behavior of these cross sections.¹ In particular there is considerable expectation that all cross sections may rise at high energies. For the pp total cross section differences are only 1 or 2 mb out of 40 mb are expected, so that accuracies of $\approx 1\%$ are very desirable.

Unlike conventional accelerators where measuring total cross section to better than 1% is a relatively straightforward task by the transmission method, for a colliding beam facility this accuracy is very difficult to achieve. The principal difficulty is the measurement of the luminosity for the intersection region.

There appear to be three possible methods for measurement of the pp total cross section.

1. Measurement of the attenuation of the circulating beams due to beam-beam collisions.
2. Use of the optical theorem and extrapolation of the elastic differential cross section to 0° .
3. Detection of all interactions from beam-beam collisions.

- 2 -

For a luminosity of $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$ for 6×10^{14} stacked protons in each beam, the attenuation per day is $\sim 10^{-2}$, and is approximately equal to the loss from beam-gas collisions for a vacuum of 10^{-10} mmHg^2 (At the CERN ISR the cross rate is as low as 10^{-2} per day³). So with present design parameters for ISABELLE this method is very marginal and lengthy. However, if the luminosity for a given number of protons could be increased by a factor of 5 or 10 (e.g. by electron cooling) this method would become feasible.

As mentioned by Foley and Ozaki, the second method would be a by-product of the proposed small angle elastic scattering experiment⁴. The limitations on this method are that one must assume spin independence of the elastic cross section at small angles and the collinear collision region necessary for this measurement is a difficult one in which to make an absolute determination of the luminosity. From measurements made at the AGS the spin dependence of the cross section seems to be small, but this is subject to uncertainties⁵. It should be noted that the spin dependent and real part contributions can only increase the apparent total cross section so that this method does determine an absolute upper limit. Finally it would be very useful to have independent measurements of the total cross section and real part for checks on dispersion relations.

The third method demands a reasonably small interaction region of easily determined luminosity. This region is then as nearly surrounded by detectors as physically possible and the total cross section is determined from the simple equation,

$$\sigma_{\text{tot}} = \frac{R}{L}$$

where L is the luminosity and R the rate in the detectors.

- 3 -

A 20 mrad intersection region similar to that described by Ramanauskas for his multiplicity experiment appears to meet most of the requirements for the total cross section⁵. The difference would be that a longer straight section would be desirable.

The general layout of the experiment is shown in Fig. 1a and more details of the detectors and vacuum pipe are shown in Fig. 1b. In order to have high efficiency, good time resolution and low dead time it seems best to use scintillation counters for all the detectors. There are two sets of concentric ring counters at small angles (0.5 to 5.0 mrad) labelled SAD and two more sets at moderate angles (5.0 to 50.0 mrad) labelled MAD. These are split up into two portions in order to be able to cover the wide angular region required by the large energy span of the machine (20 to 200 GeV/c) with reasonably sized counters. Covering the remaining solid angle are two layers of counters labelled LAD. The logic requirement would be a coincidence between the concentric ring detectors on one side with the concentric ring detectors on the other side or the LAD around the interaction region. A proper time relationship would insure that the interaction had occurred in the proper region. Also a coincidence between two elements in LAD would be allowed if the counter telescope indicated that the event had come from the interaction region.

These requirements should make the beam-gas background $\lesssim 10\%$ of the beam-beam rate for luminosities as low as $10^{30} \text{ cm}^{-2} \text{ sec}^{-1}$ and vacuums as poor as 10^{-10} mm Hg .

The minimum angle detected by SAD is dictated by the requirement that not too many small angle elastic scatters be lost. If the forward elastic scattering cross section is given by

$$\frac{d\sigma}{dt} = 100 e^{10t}$$

- 4 -

then if SAD covers angles corresponding to $t = -0.01 \text{ (GeV/c)}^2$, then all but 1 mb of the total cross section will be covered. At 200 GeV/c this corresponds to a $\theta \text{ min} = 0.5 \text{ mrad}$ or the expected beam pipe size of 5.0 cm diameter at 50 m from the interaction region. Assuming an extrapolation error of less than 20%, this gives an error of less than 0.5% to the total cross sections. The SAD and MAD are made of concentric rings in order to be able to perform the extrapolation.

The monitor telescopes are used to measure the effective height, h_{eff} , of the beam-beam interaction, which along with the beam currents determines the luminosity,

$$L = \frac{I_1 I_2}{e^2 c h_{\text{eff}} \tan \frac{1}{2} \alpha}$$

Two CERN experiments quote errors of 5% on the h_{eff} measurement by the Van der Meer method^{3,7}. Statistically there certainly is no reason for not improving this accuracy and if subsidiary measurements of beam-gas scattering are made to check that the beam shapes are not affected by the few millimeter displacements the systematic effects can be made small. In addition the monitor telescopes would insure that the luminosity remained constant during the data taking period.

Since measurement of the luminosity will be a recurring problem, particularly in the collinear interaction regions, a special effort should be made in this experiment to calibrate the absolute pp elastic scattering cross sections at convenient angles with the monitor telescopes for use in other experiments. It is also very important to measure the total cross section at least down to 30 + 30 GeV center of mass energy to tie on with existing data. There appear to be no fundamental limitations as to the lower energy limit of ISABELLE other than loss of luminosity.⁸ Therefore, one could consider joining with measurements to be made at NAL.

- 5 -

In conclusion it appears reasonable to measure the pp total cross section to a precision of $\sim 1\%$ in ISABELLE as it is presently designed. Since this experiment requires very precise knowledge of the luminosity it appears that the experiment should also be used to obtain absolute measurements of the elastic differential cross section for use in other experiments.

- 6 -

References

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Fig 1a. General Layout for Test Experiment.
Top View

Fig 1b. Detail of Detectors and Vacuum Pipes - Side View