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

ACCELERATOR DEPARTMENT
Informal Report

Proton-Proton Elastic Scattering at Large
Momentum Transfer

J. Russ
Carnegie-Mellon University
March 1974

ABSTRACT

The physics interests in pp elastic scattering at ISABELLE energies is considered in light of ISR results. An experimental configuration for studying pp elastic scattering at $s = 160000 \text{ (GeV)}^2$ and $1 < -t < 25 \text{ (GeV)}^2$ is described.

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Proton-Proton Elastic Scattering at Large

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J. Russ, Carnegie-Mellon University

The intimate relationship of elastic scattering and absorptive processes makes large t elastic scattering a very interesting process to study at ISAbelle energies. The Chou-Yang⁽¹⁾ picture of the interaction of Lorentz-contracted composite protons has recently been revitalized and discussed in a parton picture by Kac⁽²⁾ and Byers⁽³⁾, and they obtain quite reasonable fits to ISR data. A less fundamentally motivated model of Phillips and Barger⁽⁴⁾ gives good fits to all pp elastic data for $0.15 < -t < 2(\text{GeV}/c)^2$ and shows characteristic dip structure persisting to the highest ISAbelle energies, along with prediction of an s -independent component dominating behavior for $-t > 1.5(\text{GeV}/c)^2$. Fits for ISAbelle energies of 100×100 and $200 \times 200 \text{ GeV}^2$ are shown in Fig. 1. If such an s -independent term with a small t -slope is real, it may indicate discrete parton behavior within the proton. In any event there is clear physics interest in the high energy, small impact parameter region of pp elastic scattering, and some new aspects of hadronic matter may be elucidated.

Experimental Requirements

Because the elastic cross sections are likely to be less than $100 \text{ nb}/(\text{GeV}/c)^2$ for $-t > 1$, high luminosity beams and good signal/noise rejection are required. The momentum requirement on each particle is not nearly as effective a discriminant against low mass isobar production as is the colinearity requirement of two-body scattering. Consequently, the apparatus must measure the two outgoing protons' vector directions with angular error of order $50 \text{ } \mu\text{rad}$. For example, production of a low-mass $p\pi^0$ state will lead to one proton having a momentum change of $\sim .02\%$, but an angular change of order 1 mrad . Hence, measuring angles to better than $100 \text{ } \mu\text{rad}$ should produce excellent background rejection even for these low cross sections.

In the Phillips and Barger parameterization, there will be movement of the dip near $-t=1$ by roughly $.07(\text{GeV}/c)^2$ in going from $s=40,000$ to $s=160,000$. To follow this implies t resolution of $.03$ at worst. Hence both the beam divergence and the apparatus angular error must be small, for at $-t=1$, $\Delta t \approx \frac{2\sqrt{(\Delta\theta_{\text{Beam}})^2 + (\Delta\theta_{\text{scatt}})^2}}{\theta_{\text{Beam}} - \theta_{\text{scatt}}}$. At $-t=1$ for $200 \text{ GeV}/c$

proton CM momentum, $\theta_{\text{Beam}} - \theta_{\text{scatt}}$ is 5 mrad . We've already set out to make $\Delta\theta_{\text{scatt}} \sim 0.1 \text{ mrad}$ for background suppression. For experimental insertion III (grey book, p.82) $\Delta\theta_{\text{Beam}}$ for the horizontal plane is $\sim 0.1 \text{ mrad}$. This would give (at $L=10^{33}$) $\Delta t = \frac{0.2\sqrt{2}}{5} = .057$. This is too large. One can immediately gain $\sqrt{2}$ by improving the scattered particle detector resolution, as we shall do later. Even that step is barely adequate, leading to $\Delta t \sim \pm .04$ at $-t=1$. Hence, to study details of the dip's energy dependence, one may have to reduce the emittance (and hence luminosity) by trimming the beam size. This would be a

special run once the general features had been mapped out. In most circumstances a resolution of $.04(\text{GeV}/c)^2$ is completely adequate.

Apparatus

As described above, the primary apparatus requirement is angular resolution $<50 \mu\text{rad}$. This implies that a non-focussing two-arm system is a reasonable choice. Because of the high angular resolution desired, parallel to point optics with small angles, high gradients, and a line source ($\sim 3\text{m}$ interaction region) does not offer any advantage, especially since a two-arm system is required. The layout in Fig. 2 shows one side of a high resolution spectrometer capable of projected angle resolution of $20 \mu\text{rad}$, given detector resolution of 0.25 mm . This precision and high data rate capabilities are presently available from drift chambers or pressurized MWPC. One may be able to do 0.1 mm in a year or so. In any event, detector angular resolution of $\pm 50 \mu\text{rad}$ seems quite feasible, even in high rate environments.

The sweep magnets M1 and M1' bend the primary beams by 4 mrad . Their function is to protect the detectors from the flood of mesons produced at small x for which $P_{\perp}/P_{\parallel}$ happens to lie between $.004$ and $.025$, the acceptance range for elastic events. The field integral of each must be sufficiently well known ($\sim 0.1\%$) that tracking a $200 \text{ GeV}/c$ particle through them can be done with angular error $<10 \mu\text{rad}$.

For data collection, one needs to impose a momentum requirement to avoid small x triggers. Hence one side will use a magnetic spectrometer to ensure that only positive particles trigger, while the other will use a calorimeter requiring an energy deposition, say, greater than 160 GeV .

Rates

The signal rate for $-t > 0.8(\text{GeV}/c)^2$ will not be high. One can expect luminosity $L \sim 10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$, and the apparatus proposed has acceptance $\Delta\phi/2\pi \sim \frac{1}{3}$ at $-t=2$. The cross section there will be roughly $10 \text{ nb}/(\text{GeV}/c)^2$, extrapolating the ISR results, and the event rate will be $10^{33} \times 10^{-32} \times \frac{1}{3} \times \frac{1}{4}$ events/sec/ $0.25(\text{GeV}/c)^2$ Δt bin. This will produce very good statistics in the dip and secondary maximum region. If the cross section falls as $e^{-1.8|t|}$ for $-t > 2$ as suggested by the model of Phillips and Barger, then the cross section sensitivity per $(\text{GeV}/c)^2$ [i.e., $\Delta t = 1$] per 100 hours running time is $10^{-11} \text{ mb}/(\text{GeV}/c)^2$ for 1 event, and one should see events out to $-t \sim 10$. Note that if a power law behavior $P_{\perp}^{-10}$ prevails instead of $e^{-1.8|t|}$ there may be significantly more events at $-t = 10$. In the Chou-Yang formulation of Kac and Byers, there will be another diffraction minimum near $-t = 5$ and another peak, but at the level of $10^{-9} \text{ mb}/(\text{GeV}/c)^2$. Nevertheless, in a run of 400 hours, one should be able to use t bins of 0.1 and see the effects of such structure, if it exists.

Backgrounds

At the highest luminosity one must worry about the overall detector rates, to avoid confusion in event reconstruction. The background sources, of course, are particle production via beam-beam collisions, and beam-gas collisions. For the beam-beam collisions, one knows from the ISR experiments that there is at least approximate scaling in the central region with a plateau-like distribution out to $x \sim 0.1$ followed by a power-law falloff as $x \rightarrow 1$. If one computes π^+ production, Giacomelli's compilation ⁽⁵⁾ of the CHLM results at the ISR suggests approximate factorization; for

$p + p \rightarrow \pi^+ + x$, $E \frac{d^3\sigma}{dp^3} \sim Af(x)g(p_T)$, with $g(p_T) \sim e^{-5p_T}$. The quantity $Af(x)$ agrees roughly with a form $Af(x) = 130[0(.075-x) + 0(x-.075)(.075/x)^{3.85}]$ $\text{mb}(\text{GeV})^{-2}c^3$. This is computationally convenient. It gives a total π^+ production cross section for one hemisphere of 10 mb at $s=160000$. Including the sweep magnet effects, which serve to keep all particles from the plateau region out of the first detector, the net cross section feeding π^+ into the first detector at any angle is $<200 \text{ } \mu\text{b}$, or a rate of $\sim 40 \text{ KHz}$ in D_1 .

Despite a high mean multiplicity, the forward compression of inelastic proton distributions makes $p + p \rightarrow p + x$ the most intense background source. The choice of 4 mrad sweep angle in fact is a compromise between accepting more π^+ as the sweep angle is lowered and getting more protons as it is raised. Again using Giacomelli's compilation, we have parametrized the inelastic proton yield in m_{11} and y :

$$E \frac{d^3\sigma}{dp^3} = 17.5 e^{-6.8\sqrt{p_\perp^2 + m^2}} e^{-1.5(y_{\text{max}} - y)}$$

Because this favors forward protons and has little falloff for $P_\perp < 1 \text{ GeV}/c$, a substantial contribution to detector rate is unavoidable. The cross section that populates D_1 is $\sim 3.5 \text{ mb}$, or a detector rate of 700 KHz from protons. Hence, detector rates of 1-2 Mhz may be expected, chiefly in the small angle region. Because the event rate is quite high in this vicinity, one may wish to taper the ϕ acceptance to reduce the rates in this region. However, for 1-2 Mhz rates that should be unnecessary.

References

1. T. T. Chou and C. N. Yang, Phys. Rev. 170, 1591 (1968).
2. Maxwell Kac, Oxford preprint 33/73.
3. Nina Byers, Oxford preprint 35/73.
4. R. J. N. Phillips and V. Barger, RHEL preprint.
5. G. Giacomelli, NAL-Pub-73/74.

Figure Captions

- Figure 1. Differential cross section for pp elastic scattering for beam energies of 100 GeV x 100 GeV and 200 GeV x 200 GeV from the model of Ref. 4.
- Figure 2. Proposed high $|t|$ elastic scattering geometry. The arm shown uses magnetic analysis to trigger only on "nearly"-elastic protons. The arm not shown will use a calorimeter to require a "full energy" proton. One can use fast arithmetic units to produce a fast θ, ϕ correlation between the two arms before accepting an event for storage on tape. This should reduce enormously the data load from this experiment.

FIG. 1

PHILLIPS & BAERGER MUEL

X S = 40000

. S = 160000

$\frac{d\sigma}{dt} \text{ (nb/GeV}^2\text{)}$

K&E SEMI-LOGARITHMIC 45 6010
4 CYCLES x 70 DIVISIONS
MADE IN U.S.A.
KEUFFEL & ESSER CO.

100

10

1.0 -t (GeV/c)² 2.0

3.0

FIG. 2