p-p and p-d Elastic and Inelastic Scattering in the
High t -Region in the New Internal Target Laboratory

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ABSTRACT

We propose an experiment to measure p-p and p-d elastic and inelastic scattering in the high t -region in the new B-0 Internal Target Laboratory. These measurements will continuously cover incident beam energies from 30 to 500 GeV. We will cover the t -region from 0.2 up to at least 10 (GeV/c)² for p-p elastic scattering and up to 5 (GeV/c)² for p-d elastic scattering; we can go higher with future modifications. Magnetic spectrometers will be used to measure the angles and momenta of the recoil particle and the forward scattered particle.

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1. Introduction

Small angle p-p elastic scattering up to 0.2 (GeV/c)^2 has been measured at the C-0 straight section by Experiment 36. The slope parameter and the real part of the scattering amplitude for p-p elastic scattering and the total cross section were measured.¹ Some of the same parameters for p-d elastic scattering were also measured² and will be measured in much more detail in the near future by Experiment 186.

In these measurements solid state detectors are used to define the scattering angle and the energy of the recoil particles for determination of elastic events. These measurements are limited to the very small t-range due to thickness of the solid state detector which defines the maximum detectable energy of the recoil particles.

We propose to measure elastic scattering from where the above experiment stops, up to about 10 (GeV/c)^2 , and possibly into higher t-regions. The energy range covered will be from about 30 GeV up to 500 GeV. In the internal target area we have the added advantage that all incident energies are readily available up to the maximum machine energy. The s-dependence of the reactions can be determined easily. At low-t where only the recoil particle is measured, different energy data will be taken within the same main ring cycle. At high-t, where both recoil and forward scattered protons are measured, data will be taken by moving the magnets remotely within a short time.

Most of the equipment which we propose can be used for many future experiments, including these same experiments extended to 1000 GeV with the proposed energy doubler. Likewise, when the new internal target area

is built, it will be used by many other experiments, and will be the first experimental area for the beam from the energy doubler.

2. Physics

Elastic scattering may be divided into regions according to the t -range covered as shown in Table 1 for p-p elastic scattering and Table 2 for p-d elastic scattering. The data are divided according to their phenomenological behavior. Regions 1 and 2, for p-p and p-d, will be measured in Experiment 36 and 186. We will extend these measurements in the new internal target laboratory to higher t and higher s -regions.

2.1 p-p Scattering

Elastic p-p scattering at very high energy and at high- t up to 5 (GeV/c)² has been measured at the ISR and reported³ as shown in Fig. 1. There is extensive data below 30 GeV, but there is not enough data between 30 GeV and ISR energies. We can measure elastic scattering in the NAL energy range and thereby provide this fundamental data in the gap between 30 GeV and ISR energies.

The most prominent feature of the ISR data may be the dip around 1.3 (GeV/c)² as shown in Fig. 1. This had not been observed at lower energies, although a kink in the cross sections exists there. This dip was predicted by many models for the asymptotic limit.⁴ According to theory, this dip is partially filled in at low energy where the real part of the scattering amplitude is large. Preliminary data from Experiment 36 finds the ratio of the real to the imaginary part of the scattering amplitude to be less than 10% around 200 GeV and up (Fig. 2). Therefore,

we should be able to observe this dip and its s -dependence at NAL energies. Its relation to the real part of the scattering amplitude will be studied.

The theory also predicts another dip around $|t| = 5 \sim 8 \text{ (GeV/c)}^2$. If this dip exists, our counting rate is high enough to find it. The internal target has an advantage over the ISR as far as counting rate is concerned. As is described in a memo by E. Malamud,⁵ the interaction rate per second for $\sigma = 40 \text{ mb}$ is 10^4 for the ISR with a 10 ampere current, while that of a jet target is 7×10^8 with a proton density of $5 \times 10^{-7} \text{ g/cm}^2$ and a beam intensity of 10^{13} ppp. Thus, our rate is about 10^5 higher than that of the ISR. We will have better statistics and will be able to measure into the higher t -region where the cross section is smaller. The data of Fig. 1 ends around $|t| = 5 \text{ (GeV/c)}^2$, and we will be able to extend these results to $|t| \approx 10 \text{ (GeV/c)}^2$. With future improvements in the jet target it may be possible to go to even higher momentum transfers.

2.2 p-d Scattering

The differential cross section for p-d elastic scattering was measured up to 2 (GeV/c)^2 at CERN using the PS up to 24 GeV/c .⁶ This result is shown in Fig. 3. The dip around $|t| = 0.3$ has been investigated at lower energies extensively in other laboratories. Recently, Glauber has suggested that it may be due to the strong dependence on polarization of the deuteron spin and the d-state admixture⁷. Beyond 2 (GeV/c)^2 no data exists even at low energy. Only the NAL machine has the capability to investigate this region.

From the p-d elastic scattering we can also deduce information about p-n scattering.⁸

2.3 Isobar Production

In the previously mentioned measurements of p-p and p-d elastic scattering, we will measure the momentum spectrum of the recoil protons. With sufficient resolution we can measure the cross sections for isobar production.

The production of isobars having masses of 1236, 1400, 1520, 1688, and 2190 MeV in p-p reactions has been investigated quite extensively up to $|t| = 6 \text{ (GeV/c)}^2$ and $P = 24 \text{ GeV/c}$.⁹ These results show that the differential cross sections for the 1520, 1688, and 2190 isobars have relatively small slope parameters ($b = 3 \sim 5$) and that they are comparable to that for elastic scattering around $|t| = 1 \text{ (GeV/c)}^2$ as shown in Fig. 4. Moreover, the cross sections for producing these isobars are roughly s-independent up to 24 GeV/c.

As shown in Fig. 9, our mass resolution on the recoil particle using only the recoil arm is good enough to separate the isobars at 100 GeV beam energy for $0.2 \lesssim |t| \lesssim 6 \text{ (GeV/c)}^2$. At higher beam energies the separation of isobars becomes more difficult, especially between the 1520 and 1688 isobars. Thus, we expect to measure isobar production cross sections certainly at 100 GeV and perhaps up to 300 GeV in incident energy.

3. Experimental Setup

The proposed experimental setup is shown in Fig. 5. A magnetic spectrometer is used to define the angle and momentum of the recoil particle and a

forward spectrometer is similarly employed for forward scattered particles. A set of monitors will also be provided in the tunnel.

For the low $|t|$ region as shown in Fig. 9, only the recoil spectrometer need be used. Its resolution is sufficient to define elastic events, especially at lower energies. For the higher $|t|$ region, both spectrometers are used. Scintillation counter hodoscopes are used in the forward spectrometer; the angle information and the momentum of the forward particle are used together with the information from the recoil spectrometer to define the coplanarity and elasticity of the event. Four parameters are measured and the elasticity of the event is therefore over-defined (the momentum and the angle of a recoil particle, and of a forward scattered particle are measured).

3.1 Recoil Particle Spectrometer

At large fixed angles momentum and t -value of elastic recoil particles change very little when the incident beam energy increases. The angle and the momentum of the recoil particle is shown in Fig. 6 for 300 GeV/c incident momentum. As was suggested in a note by R. Carrigan,¹⁰ it is reasonable to use a magnetic spectrometer where high t -values are studied. We propose to make a magnetic spectrometer with two bending magnets and a proportional chamber system for recoil particles in the B-O section as shown in Fig. 7. We will be able to use this spectrometer up to $|t| = 15 \text{ (GeV/c)}^2$ in steps of 5 degrees.

The spectrometer consists of two magnets, four vertical and two horizontal proportional chamber planes and trigger counters. The relative position of these components to the target and beam line is

shown in Fig. 7. The whole system is mounted on a carriage and will be remotely rotated around the center of the target. The carriage supports two magnets, proportional chambers, trigger counters and some electronic circuits. There will be some provision to change the relative angle of the two magnets on the carriage for different deflection angles.

The first two wire planes define the incident angle of the recoil particle using only vertical wires. They will be placed about 0.5 and 2.5 meters from the target. The vertical wires will have 1 mm spacing. The polar angle will be defined with an accuracy of $\sim \pm .4$ mrad. The recoil particle line will be extrapolated back to the target to check that it originated in the target.

There is a set of vertical and horizontal chambers between the two magnets, and another similar set two meters downstream from the second magnet. These also have one millimeter wire spacing vertically and two millimeters spacing horizontally. The 6.3 and 2.9 GeV/c protons, corresponding to $|t| = 10$ and 4 (GeV/c)², will be bent by 14.7 and 32.1° at 18 kG respectively. The momentum resolution ($\Delta p/p$) will be about .15 and .08% respectively.

The solid angle is defined by the scintillation counter S1, which subtends about 2.2 msr in the lab system and covers five degrees in the polar angle. The aperture at the entrance of the first bending magnet must be 21.9 cm wide and 6.3 cm high to cover the solid angle. The apertures of the bending magnets are larger than these dimensions (5 inches high and 20 inches wide). The magnets bend the recoil particle in horizontal plane as indicated in Fig. 7. The proposed shape of the magnet is shown in Fig. 8A. It is almost a C-shaped magnet having only

a thin yoke on the beam side which acts as a magnetic shield for the main ring and gives structural strength. Although we are describing conventional magnets, we should like to use super-conducting magnets whenever they become feasible.

The solid angle defining counter S1 is at the end of the spectrometer as is a second scintillation counter, S2. An absorber and a Cherenkov counter are placed between them. A signal derived from the coincidence of S1 and S2 will be used to register events into the computer. In addition, a coincidence is required with the RF structure of the main ring beam to avoid events not originating in the target. Pulse height in the Cherenkov counter will be recorded and used to help eliminate background due to pions.

Time of flight will be used at low t -values only. The time of flight difference between a 2.9 GeV/c pion and a proton of the same momentum ($|t| = 4 \text{ (GeV/c)}^2$) is about 1 ns.

3.2 Mass Resolutions

Measuring only the recoil proton, the missing mass squared of the forward scattered particle is given by

$$M^2 = m_o^2 + 2m_r^2 + 2m_r (E_o - E_r) - 2 (E_o E_r - p_o p_r \cos \theta_r).$$

Here the subscripts o and r refer to the incident and recoil particles respectively. Thus, the missing mass resolution can be estimated by taking

$$\Delta M^2 = \left[\left(\frac{\partial M^2}{\partial p_o} \right)^2 (\Delta p_o)^2 + \left(\frac{\partial M^2}{\partial p_r} \right)^2 (\Delta p_r)^2 + \left(\frac{\partial M^2}{\partial \theta_r} \right)^2 (\Delta \theta_r)^2 \right]^{1/2}.$$

~) The results of our calculations are shown in Fig. 9. We have taken into account multiple scattering in the vacuum chamber windows and proportional chambers and also the position measurement error in the chambers.

If we insist on having resolution better than the separation between the elastics and the $N^*(1520)$, say $\Delta M^2 \approx .7 \text{ (GeV/c)}^2$ or $\Delta M \approx 370 \text{ MeV}$ then, as may be observed in Fig. 9, we can measure from $|t| = .2$ to $|t| = 10 \text{ (GeV/c)}^2$ at 100 GeV/c. At 300 GeV/c we can measure from $|t| = .3$ up to $|t| \approx 9.0 \text{ (GeV/c)}^2$ with only the recoil spectrometer. At the higher energies and momentum transfer values both spectrometers are required to separate elastics from the N^* 's. For example, at 300 and 400 GeV/c the forward spectrometer acceptance begins at $|t| = 1.0$ and $|t| = 1.8 \text{ (GeV/c)}^2$ respectively. Thus, for energies below 300 GeV we will measure the angular distribution starting at $|t| = .2$ and continue on up to about $|t| = 10 \text{ (GeV/c)}^2$. At energies above 300 GeV our measurements will begin at some lower cut-off (e.g., $|t| = 1.8 \text{ (GeV/c)}^2$ at 400 GeV) and continue to the higher t -values.

3.3 Forward Particle Spectrometer

As is shown in Fig. 10, the forward scattered particles at fixed angle have increasing momentum and t -values as the circulating beam energy increases. Therefore, the system at a fixed position with a fixed current measures elastic scattering for one energy only. The laboratory angle for the forward scattered particle at $|t| = 4 \text{ (GeV/c)}^2$ is 6.9, 5.2, and 4 mr for 300, 400, and 500 GeV beams respectively.

The system consists of three bending magnets and four sets of scintillation counter hodoscopes as indicated in Fig. 6. At 300 GeV the front end of the first magnet is placed 19.1 meters downstream from the jet target in order to cover the t -region from 4 to 10 $(\text{GeV}/c)^2$. The current in the magnets as well as the position and angles of the magnets will be adjusted to accept only the elastically scattered protons. The momentum acceptance, which should be about 0.5%, can be easily achieved and the necessary horizontal acceptance is 2 mr. The solid angle is defined by the recoil spectrometer.

The scintillation counter hodoscopes are before the first magnet, between magnets, and after the last magnet in the forward spectrometer. There are also some anticoincidence counters to veto particles scattered from the steel surface and from the outside. Each hodoscope consists of twelve horizontal and six vertical scintillation counters. With the information from the forward spectrometer the coplanarity and elasticity of the events will be determined, and we can select the elastically scattered protons from the background. If necessary, proportional chambers will be installed near the end of the forward spectrometer to improve resolution. For completeness we show the layout of the forward spectrometer for a different energy in Fig. 11.

The magnets are similar to the main ring magnets as far as aperture and length are concerned. The steel core is shaped like the recoil spectrometer, as shown in Fig. 8B. The outside dimensions will be about 28 inches high and 27 inches wide.

The first magnet has an aperture 1.5 inches high and 9.75 inches wide with a 16 turn coil. The inside yoke is 1/4 inch thick and the coil is 2.39 inches wide. Therefore, the particle can go through the magnet at a minimum distance of 2.64 inches from the outside surface. The second and third magnets have an aperture 2.0 inches high and 8.73 inches wide and 24 turn coils.

These magnets are connected in series and are excited by the same power supply to a magnetic field of about 18 kG with 3500 Amp. The resistance of the first and second magnets will be about 17 and 26 m Ω . The maximum total power consumption for these three magnets will be about 850 kW.

The main ring vacuum pipe at B0 will be shifted inward by one inch relative to the center line connecting the upstream and downstream quadrupole magnets. The injected beam will be centered in this pipe with local low field correction magnets. However, the high energy beam will be set to run 2 inches from the outer surface of the 6 inch pipe as shown in Fig. 9B. As the extraction septum in A0 is set at 3 cm outside the center line and the abort target in D0 is set at 1.5 inches, this would not seem to be a problem.

The use of a local magnetic field beam bump at high energy will be considered. With this modification the beam will be shifted outward to make a lower t-region accessible in the coincidence experiment.

3.3 Monitor

We will install a vacuum guide at right angles to the main ring beam line, which is about 4 meters long and covers laboratory angles

roughly from 90 to 80 degrees. At the end of it will be installed several fixed solid state detectors which will be used to monitor small angle elastic events as was done in Experiment 36. These will be used as a relative luminosity monitor.

We will also develop and install an absolute luminosity monitor, utilizing either light emission due to the beam hydrogen gas interaction or Coulomb scattering.

4. Counting Rates

The density of the hydrogen jet is about 5×10^{-7} g/cm³. As the present beam interaction region is about 1 cm³, we can assume $N_t = 3 \times 10^{17}$ proton/cm³ is available as our target. The jet duration time is about 200 ms, and 3 or 4 jet pulses in a main ring cycle are now possible. Also, the jet may be pulsed for one second continuously. We will operate the jet during the ramp for lower t-values. For higher t-values we may use the flat-top or front porches of the main ring ramp.

The presently available beam intensity in the main ring is about 4×10^{12} proton/pulse; this will be increased eventually to 5×10^{13} proton/pulse. For these calculations we assume 1×10^{13} proton/pulse which may be a conservative value in the latter part of 1973. During a jet duration of 200 ms, the main ring beam circulates 10^4 turns around the ring. So effectively, the available beam during a jet pulse is $N_b = 10^4 \times 10^{13} = 10^{17}$ proton/pulse. We will operate one jet at low energy and another at higher energy where the forward spectrometer is adjusted. We will operate 2 or 3 jets during flat-top when it is feasible.

The counting rate, N, per jet pulse is given by the following equation:

$$N = N_b N_t \frac{d\sigma}{dt} \Delta t \frac{\Delta\phi}{2\pi} = 3 \times 10^{34} \frac{d\sigma}{dt} \Delta t \frac{\Delta\phi}{2\pi} / \text{jet pulse}$$

N is given in Table 3, with the estimated $d\sigma/dt$ values from the presently available data. $\Delta\phi$ is given by $6.3 \text{ cm} / (250 \text{ cm} \times \sin \theta)$. The counting rate is defined by the solid angle of the recoil particle spectrometer since the forward particle hodoscope is made large enough to accommodate all the corresponding elastic events.

The Russian members of our collaboration are presently exploring the possibility of increasing the density of the jet for use at the highest t-values. One possibility is to reduce the velocity of the jet and another is to develop a solid hydrogen target. With such modifications the jet density may be increased by a factor of 10 or more. On the other hand the beam intensity may be raised to 5×10^{13} proton/pulse. With both these modifications the counting rate may be increased by a factor of 50 in the near future. Thus, the highest accessible t-value may be higher than discussed in this proposal.

5. Background Rate

There are two types of background: one target associated and the other not. The background which does not come from the target was measured in May 1973 at 300 GeV to be about 16 minimum ionizing particles/cm²/sec/ 10^{10} circulating protons at 3.5 feet from the beam line.¹¹ Thus, at 13 cm from the beam line and with 10^{13} circulating protons, the corresponding number is 10^6 particles/cm²/sec. Although this rate is tolerable for the forward hodoscope, it will be reduced by at least an order of magnitude. First of

all, the experimental area at B-0 will be designed more carefully so as not to restrict the circulating beam. Secondly a beam scraper at A17 and beam collimators at D-0 will be used.

The effect of the accidental rate due to particles coming from the target can be estimated for the forward spectrometer including the first forward hodoscope as follows. This hodoscope is more seriously affected than the recoil spectrometer. We estimate the background rate at the $|t| = 4 \text{ (GeV/c)}^2$ setting at 300 GeV. As there is a maximum of 1113 beam bunches in the main ring, we have $N_b = 10^{10}$ proton/bunch for a beam intensity of 10^{13} ppp. The interval between beam bunches is about 20 ns and the total number of reactions during a bunch is estimated from a total cross section of 40 mb as follows:

$$N_b N_t \sigma_{\text{tot}} = 10^{10} \times 3 \times 10^{17} \times 40 \times 10^{-27} = 120$$

The multiplicity measured by the bubble chamber is about 8.9 at 303 GeV, and the projected distribution in one dimension is shown in Fig. 12, where the events are grouped in 0.5 mr bins.¹² Therefore, we have about 1000 charged particles coming from a jet target associated with a single beam bunch. The maximum number of particles going through the aperture of the first useful magnet opening (which is 4 mr horizontally and 1.5 inches high) is estimated to be less than 0.6%. Thus, on the average, 6 particles may go through this opening; we can easily select the elastic scattered proton from the information given by the following counter hodoscopes. As these 1000 charged particles may produce many low energy daughter particles when they finally hit vacuum chambers and magnets, it is preferable to use a thin vacuum tube and also to place the counter hodoscope so that the back

scattered particles reach the hodoscope out of phase with the scattered particles of interest, e.g., 10 ns later. The number of muons was measured in the CO area by Experiment 120.¹³ They observed 500 μ /jet (≈ 200 ns) / 10^{12} proton at 250 GeV with a counter of 2/3" x 2/3" placed at 16 msr and at 32 feet downstream from the jet. This gives 2.5×10^{-3} /bunch (≈ 20 ns) / 10^{13} proton/2 msr at 16 msr. This number will not cause difficulty for this experiment.

6. Comparisons with Other Experiments

In the future, elastic scattering will be measured at NAL using the external beam. However, we can measure the elastic scattering of p-p and p-d in the main ring in a very flexible and efficient way. There are several advantages of the internal target experiment over external target experiments for these reactions:

- A. It is possible to select the incident beam energy freely from the injection energy to the highest extraction energy. Thus the s-dependence measurement can be done easily and in a bias free way.
- B. The internal target has the first access to the highest machine energy (500 GeV/c or even 1000 GeV/c because no slow extraction is involved).
- C. The target is thin, so that the multiple scattering of the recoil particle is small compared to that of a liquid hydrogen target. Therefore, elastic scattering may be measured using only the recoil spectrometer over a large range of t (Fig. 9).

- D. The luminosity for the internal target is comparable to that of the external beam. For the internal target with 3 pulses of 200 ms width and a beam intensity of 10^{13} ppp, $L = N_b N_t = 10^{13} \times 3 \times 10^4 \times 5 \times 10^{-7} \times 6 \times 10^{23} = 0.9 \times 10^{35}$. For the external beam with 4×10^{11} ppp and 4" long liquid hydrogen target we have:

$$L = N_b N_t = 4 \times 10^{11} \times 4 \times 2.54 \times 0.071 \times 6 \times 10^{23} = 1.7 \times 10^{35}$$

- E. At the internal target the incident beam has no pion contamination; identification of incident particles using Cherenkov counter is therefore not necessary.

7. Apparatus

We are assuming the construction of the B0 internal target area will be started sometime in 1973. Allowing six months for construction of this area, we expect the experimental area will be ready for occupation in early 1974. While the experimental area of the B0 straight section and the service building are under construction, we will work on preparations for the experiment.

The major items which should be made or purchased during that time are:

- A. B0 general facility
1. Jet target
 2. Control system for jet target
 3. Helium liquifier, including dewars
 4. Transfer line for helium
 5. Recovery system of gases
 6. Beam bumping, possibly using local bump magnets

7. Monitors (beam intensity, beam position, elastic monitor, etc.)
8. Communication system (TV, utility crate)

We assume NAL will supply all of these except for the jet target, which will be built by the Soviet collaborators. All of these are similar to the equipment presently in CO, and we expect all of it to be duplicated and completed in nine months.

B. Experimental equipment

1. Recoil spectrometer magnets
2. Forward spectrometer magnets
3. Power supplies for spectrometers
4. Cooling system for spectrometers
5. Fast logic circuits
6. Proportional chamber system including Camac and its interface
7. Scintillation counter hodoscopes
8. On-line PDP-11 system

We request NAL to supply the spectrometer magnets and power supplies as well as the cooling system. Purdue University will build the proportional chambers and all scintillation counters. NAL will supply the readout electronics for the chambers, the PDP-11, Camac and its interface.

8. Experimental Procedure

We will first study p-p and p-d elastic and inelastic scattering in the lower t-region up to 4 (GeV/c)² with continuous incident energies using only the recoil arm. For this phase of the experiment we need about 400 hours of running time.

Next, using both the forward and recoil spectrometers, we will measure p-p elastic scattering in the high t -region with 200, 300, 400 and possibly 500 GeV beams. This experiment needs about 600 hours of running.

Thus, we are requesting a total of 1,000 hours of running time for all experiments. Within one month after we move into the new service building, we will be able to start the experiments. Members of our collaboration started the CO Internal Target Area and also helped carry out other experiments. This has provided a driving force in CO and we expect to provide a similar driving force in the new BO Internal Target Area.

9. Possible Future Experiments

The elastic scattering experiment we propose to do should be the first experiment in the new Internal Target Area; it will provide data essential to understanding the apparatus for further experiments. Using the same equipment and with some modifications the apparatus can also do the following experiments.

9.1 $p+p \rightarrow p + \text{anything}$

9.2 $p+p \rightarrow n^{\pm} + \text{anything}$

These two reactions will be very interesting to study over the entire s -range. We can do these experiments by adding suitable Cherenkov counters to the recoil arm.

9.3 Elastic scattering from some nuclei

Elastic scattering from some nuclei can be measured using the same equipment by observing the recoil nuclei with the low momentum spectrometer.

9.4 Polarization measurement

A carbon polarizer can be placed after the first magnet of the recoil spectrometer in order to measure the left-right asymmetry with use of an extra set of wire chambers. A polarization measurement in the region around the dip at $|t| = 1.3 \text{ (GeV/c)}^2$ should help provide an understanding of the mechanism responsible for the dip.

9.5 $p+p \rightarrow \pi^+ + d$

10. Manpower

In addition to the physicists listed on the title page, we expect one or more people from NAL and at least one graduate student from Purdue University to join the experiment when it is approved.

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Table 1 - pp Elastic Scattering (at 300 GeV/c)

t range	Recoil Proton P (GeV/c)	E (GeV)	Angle (°)	Scattered Proton P (GeV/c)	Angle (°)	Physics
1. $0 < t < 0.01$	$P < 0.1$	$E < 0.005$	$\theta > 87$	≈ 300	< 0.02	Coulomb Interference Real Part
2. $0.01 < t < 0.2$	$P < 0.46$	$E < 0.11$	$\theta > 76.5$	≈ 300	< 0.09	Break in b
3. $0.2 < t < 1$	$P < 1.2$	$E < 0.55$	$\theta > 61.5$	> 299.5	< 0.19	
4. $1 < t < 10$	$P < 6.2$	$E < 5.4$	$\theta > 42$	> 294.6	< 0.61	Dips
5. $10 < t < 100$	$P < 54.3$	$E < 53.3$	$\theta > 9.6$	> 246.5	< 2.1	
6. $100 < t$						

Table 2 - pd Elastic Scattering (at 300 GeV/c)

t range	Recoil Deuteron P (GeV/c)	E (GeV)	Angle (°)	Scattered Proton P (GeV/c)	Angle (°)	Physics
1. $0 < t < 0.01$	$P < 0.1$	$E < 0.003$	$\theta > 88.5$	≈ 300	< 0.02	Coulomb Interference Real Part
2. $0.01 < t < 0.2$	$P < 0.45$	$E < 0.053$	$\theta > 83.2$	≈ 300	< 0.09	Single Scattering
3. $0.2 < t < 1$	$P < 1.0$	$E < 0.27$	$\theta > 75$	> 299.7	< 0.19	Interference between single and double scattering
4. $1 < t < 10$	$P < 4.2$	$E < 2.7$	$\theta > 50$	> 297.3	< 0.61	Double scattering
5. $10 < t < 100$	$P < 28.4$	$E < 26.6$	$\theta > 19.6$	> 293.4	< 2.0	
6. $100 < t$						

Table 3 Counting Rate

$$N = 3 \times 10^{17} \times 10^4 \times 10^{13} \times \frac{d\sigma}{dt} \Delta t \frac{\Delta\phi}{2\pi} / \text{jet pulse}$$

pp Elastic Scattering

t	dσ/dt	Δt	θ	sinθ	Δφ	N / jet pulse	N / day**
1	1.5x10 ⁻³⁰	0.5	62°	0.88	0.028	102	3.3x10 ⁶
2	4x10 ⁻³²	0.8	52.5°	0.79	0.032	4.8	1.6x10 ⁵
4	3x10 ⁻³³	1.7	43.5°	0.69	0.036	0.88	3.0x10 ⁴
10	~1x10 ⁻³⁶	4	30.3°	0.50	0.050	0.001	33

pd Elastic Scattering

1	6x10 ⁻³⁰	0.8	75.5°	0.97	0.026	590	2.0x10 ⁸
2	1x10 ⁻³¹	1.0	69.3°	0.94	0.027	12	3.9x10 ⁵
4	~5x10 ⁻³⁵	1.7	61.5°	0.88	0.028	0.01	3.9x10 ²

**

Note 1 These counting rates will be increased by a factor of 50 in the future, as mentioned in the text due to the improvement of the main ring beam and the jet target.

Note 2 For this calculation we assume 5 sec for a main ring cycle and three jets per pulse. Also we assume only two thirds of the total main ring pulses are available due to the sublimation of jet and other miscellaneous things.

Fig. 1 Proton-Proton Elastic Scattering

Fig. 2 Ratio of Real Part to Imaginary Part of Scattering Amplitude

The results of elastic $p-d$ scattering at 24.0 GeV/c are shown versus four-momentum transfer squared, $|t|$. The curves are Glauber-model calculations of elastic $p-d$ scattering for two values of the ratio α of the real to the imaginary part of the $p-p$ and $p-n$ scattering amplitude.

The pd elastic differential cross-section at 9.7 (□), 12.8 (○), and 15.9 (△) GeV/c.

Fig. 3 $p-d$ Elastic Scattering

55288

Fig. 4 Isobar Production at 24 GeV/c

TUNNEL PLAN VIEW

FIG.5 GENERAL LAYOUT OF PROPOSED EXPERIMENT IN BO STRAIGHT SECTION

FIG.6 KINEMATICS OF RECOIL PARTICLES

Figure 9A. Missing Mass Squared Resolution as a Function of $|t|$ for p-p Elastic Scattering.

The dashed line represents the geometric boundary of the forward spectrometer. Points below $\Delta M^2 = 0.7$ (GeV)² (broken line) are accessible with the recoil spectrometer only. Hence, only the crosshatched region is inaccessible to this experiment.

Figure 9B. Missing Mass Squared Resolution as a Function $|t|$ for p-d Elastic Scattering.

The dashed line represents the geometric boundary of the forward spectrometer. Points below $\Delta M^2 = 0.7$ (GeV^2) (broken line) are accessible with the recoil spectrometer only. Hence, only the crosshatched region is inaccessible to this experiment.

FIG. 10 KINEMATICS OF FORWARD SCATTERED PROTON

Fig. 11 Position of Forward Spectrometer

FALL PROJECTED ANGLE

_____E_____

SCALE 1,0000

5151

counting

[illegible]

CONTENTS ALL CHLV.= 5439.20 NOT INCLUDING UNDERFLOW= 3568.00 NOR OVERFLOW= 3383.00 12390 ENTRIES IN ALL.

Fig. 12 Projected Angular Distribution of p-p reaction at 303 GeV/d in units of 5 mr