NAL PROPOSAL No. 241

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ENERGY DEPENDENCE OF BACKWARD $\pi^- p$ ELASTIC SCATTERING

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Abstract

We propose to measure the cross section for $\pi^- p$ elastic scattering at 180°. The experiment will be performed for incident π^- momenta from 15 GeV/c to the 100 GeV/c region, corresponding to an s range of 30 to ~200 GeV^2. We will obtain ~350 backward events at each momentum. The focusing spectrometer facility will be utilized for these measurements.

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Physics Interest

In a simple billiard ball picture of $\pi^- p$ backward elastic scattering, the π^- will strike the proton "head-on," thereby undergoing a large acceleration with, in general, the attendant radiation of hadronic matter. In a statistical analysis of this interaction, elastic scattering (no radiation) has to compete with other final states, resulting in a backward elastic cross section that will drop as a power law of s.[1] In this picture of the interaction, a knowledge of the value of the power would be very interesting.[2]

If hadronic matter contains parton seeds, backward πp scattering at high energies could be dominated by parton-parton scattering. This could lead to a break in the s-dependence of $d\sigma/du$, the break occurring where the dominate mechanism for the reaction changes. For example, Regge exchange might be primarily responsible for the reaction at lower s, $s \sim 50$ or $100\ GeV^2$, and parton-parton interactions, which presumably would fall more slowly with s, would then take over primary responsibility for backward $\pi^- p$ scattering.

The Regge-pole theory is about ten years old. There has been, as yet, no definitive test of the s-dependence prediction of the Regge model in a simple situation in which just one leading trajectory is exchanged. In $\pi^- p$ backward elastic scattering, only $I = 3/2$ trajectories can be exchanged, and the Δ_δ trajectory is expected to dominate.[3,4] This leads to a definite prediction of

$$\frac{d\sigma}{du} = A(u)\ s^{2\alpha(u)-2}$$

for the s-dependence of backward $\pi^- p$ scattering, where $\alpha(u) = .15 + .9u(\mathrm{GeV}/c)^2$ is the Δ_δ trajectory. At 180° ($u \approx 0$), the model predicts

$$\frac{d\sigma}{du} = A(0)s^{-1.7}.$$

We will test this prediction from s = 30 to ~200 GeV^2. There is one aspect of existing low energy $\pi^- p$ backward data that appears inconsistent with this simple Regge picture. There is apparently no "shrinkage" of the angular distribution near 180° as s increases.[5] Also the differential cross section flattens out or turns over slightly as θ approaches 180°. (This latter feature can be accommodated by the A(u) term in the Regge pole model, although this is a little unnatural.)

There is sentiment that the naive Regge pole model should be embellished with Regge cuts. These cuts affect the 180° cross section, but a power law dependence,

$$\frac{d\sigma}{du} \propto s^{2\alpha_{eff}-2},$$

is still expected.[4] A measurement of the effective α, α_{eff}, could help distinguish between the Regge pole and the various Regge cut models.

The optical model, although usually associated with forward scattering, is intimately concerned with scattering at all angles - in particular, backward scattering. For example, Chu and Hendry[6] show how the dip in backward $\pi^+ p$ scattering at $u \approx -.2(\mathrm{GeV}/c)^2$ can be associated with a peripheral interaction whose contribution in the backward direction goes essentially as $J_0(R\sqrt{-u})$, where J_0 is the usual Bessel function. In a large-angle pp → pp polarization experiment currently in progress at the Argonne ZGS, the Indiana spark chamber group has preliminary evidence for "double zeros" in the pp scattering amplitudes.[7] These double zeros would appear naturally in an optical model. The major drawback to the optical model has been its lack of built-in energy dependence. However, instead of summing contributions from different impact parameters one can use a closed form for an s-channel Regge pole, resulting in an optical model containing energy dependence. Work on this modified optical model is in progress,[8] and our proposed experiment should provide a stringent test of the model, assuming it is different from the u-channel Regge pole prediction.

The bulk of the existing 180° π^-p scattering data come from an Argonne experiment which covered beam momenta, p_b, from 1.6 to 5.3 GeV/c.[9] These data showed s-channel resonance bumps superimposed on a cross section falling as

$$\frac{d\sigma}{d\Omega} = 420\ p_b^{-2.58}\ \mu b/sr,$$

or

$$\frac{d\sigma}{du} \sim p_b^{-3.58}\ \mu b/(GeV/c)^2.$$

Ashmore *et al.*[10] found at 5.9, 9.9, 13.7, and 16.3 GeV/c that

$$\frac{d\sigma}{d\Omega} = 27\ p_b^{-1.02}\ \mu b/sr,$$

or

$$\frac{d\sigma}{du} \sim p_b^{-2.1}\ \mu b/(GeV/c)^2.$$

Obviously, for $p_b \leq 16$ GeV/c the backward π^-p cross section has not yet settled down to a predictable behavior, such as a single power law. Finally, there are backward data from Anderson et al.[11] that are in approximate agreement with Ashmore et al. However, these two experiments disagree as to whether the cross section peaks or dips as θ approaches 180°.

Experimental Apparatus

The ultimate layout of the experiment is shown in Figure 1. The M6 π beam will strike a 16" long H_2 target. (The length of this target can be adjusted in order to achieve compatibility with other users of the focusing spectrometer.) The focusing spectrometer will analyze the fast, forward proton.[12] Backward π^-'s will be detected in an array of proportional chambers and scintillators. An anti counter array for γ's and charged particles will cover the solid angle not subtended by the detectors.

Beam M6 will be used with an intensity of 8×10^6 π^-/burst. In order to obtain this yield with $\sim 10^{13}$ primary 300 GeV protons/pulse and a standard tungsten production target, we will take a momentum bite of about ±1/2 percent.[13] We will operate the beam in a momentum-dispersed mode in order to achieve a beam momentum resolution of ~.1 percent. The beam size at the H_2 target will be 1 inch wide and ~.05 or .1 inch high. The beam divergence will be $\leq$1mr.

The beam will pass through two detector stations separated by .5m before striking the H_2 target. Each detector station will consist of two horizontal and two vertical proportional chambers (PC), each with a 2 inch wide x 1/4 inch high central insensitive region through which the incident beam will pass. There will be a scintillation counter hodoscope B to cover the PC dead region. The counter-PC combination is used to match the detector time resolution with the expected counting rates. (Depending on the time structure of the NAL beam spill and depending on the beam halo in beam M6 we may replace the proportional chambers with scintillation hodoscopes, trading off spacial resolution for time resolution.) Beam Cerenkov counters will be set just below the π and electron thresholds. The beam detectors, along with counter telescopes pointed toward the H_2 target, will measure and monitor the incident π^- flux.

Recoil pions in a backward cone of half-angle 15° will be detected in the beam detector stations (see Figure 1). A scintillator BH, containing a rectangular hole for the beam, will be used to strobe the PC's. We plan to operate the beam and recoil pion detectors in a tagged or gated latch mode. Independent of beam momentum, about 5 percent of the recoil π's will decay before reaching BH. For most of the π decays, the μ will satisfy our event conditions.

In an early phase of the experiment, say Phase 1, we plan to tune without the proportional chambers, replacing them with scintillators having small holes for the beam. After observing backward pions from the time sequence of pulses in these two scintillators, we would then correlate this information with the focusing spectrometer and beam monitor information so that cross sections for $\pi^- p \to \pi^- p$ at 180° can be measured. Initial results would be used to determine the exciting physics s regions to explore. The observed background would dictate the design of a more sophisticated detector system, as in Fig. 1.

Anticounter A will detect charged particles and γ's (~70 percent efficiency) that leave the H_2 target at angles not subtended by the desired final-state particles.

The entire detector assembly for π^-'s and γ's will be designed to be easily installed and removed so that our apparatus would not interfere with other users of the spectrometer during periods in which we are not running. However, it could well be that our detectors would be desirable to other users of the spectrometer. Our equipment would then augment the spectrometer by providing information about final state particles having large lab angles.

The forward proton will be detected and analyzed by the focusing spectrometer. Proposal #96 contains the details of the spectrometer design. To have an ideal match of final-state π^- and p acceptances, the spectrometer solid angle acceptance would vary from 178 μsr at 15 GeV/c to less than 10 μsr at 100 GeV/c. Assuming that the spectrometer acceptance is fixed at 40 μsr, it will limit the yield at low momenta; however, this is where cross sections and yields are high. The momentum acceptance of the spectrometer will be ±1 percent, and the momentum resolution will be ~.05 percent.

The experimenters will provide the π^- and A detectors. With the cooperation and assistance of NAL, the experimenters will provide a data link between the H_2 target area and the downstream end of the spectrometer. NAL will provide fast electronics logic and a liquid H_2 target with appropriate windows. NAL will provide beam line M6 and the focusing spectrometer, including the standard technical support for these items.

Scope of Experiment

During Phase I of the experiment, in which we utilize scintillators to supplement the focusing spectrometer, we would tune parasitically. Then we would implement a means of correlating the data from the target region and the spectrometer. This would require a modest interaction between us and primary spectrometer users, but could be done when the accelerator is not running. For example, we might pass one word of information from the H_2 target region to the spectrometer on-line computer. We would then be in a position to start running, perhaps compatibly with another spectrometer user. In a minimal number of eight-hour shifts (~15), we could collect ~50 events at five or six momenta from 15 to 100 GeV/c. This statistical accuracy is already comparable to that of Kormanyos et al.[9], who did $\pi^- p \to \pi^- p(180^\circ)$ at 1.6 to 5.3 GeV/c.

As mentioned above, the knowledge that we gain from this early running would determine the future course of the experiment. In order to specifically discuss the ultimate scope of the experiment, we can make assumptions about the foreground and background that we will find. In Table I we list three predictions for the $\pi^- p \to \pi^- p(180^\circ)$ cross section under "$d\sigma/d\Omega$." As shown in Table I, we require 110 shifts to accumulate 350 events at each of eight momenta. This yield calculation, based on the most reasonable of the three extrapolations, includes a safety factor of two and assumes 720 beam pulses/hour. The c.m. scattering angle θ ranges from the minimum shown in Table I to 180°. The minimum is determined by the focusing spectrometer at low momenta (assuming a 40 μsr acceptance) and the recoil π^- detector at high momenta. The corresponding u range is also listed in Table I.

Because of the scarcity of high-momentum forward protons in π^-p interactions, it is possible to have a very loose trigger which requires only that this proton is detected by the focusing spectrometer. All other detectors can be interrogated subsequently to determine if the forward proton was accompanied by a backward π in the appropriate region of space and time and was not accompanied by particles in A. At 15 GeV/c, the trigger rate will be the rate for producing backward $S = B = 0$ systems with a mass $\leq .7$ GeV. From reference 14 on backward ρ^- production, we see that this rate will be about three times the elastic trigger rate. Thus at 15 GeV, we expect a trigger rate of 1/(8 pulses). At higher momenta we make the plausible assumption that the missing mass spectrum recoiling from the forward proton will have the same shape as at 15 GeV/c. Thus for the same backward missing mass bite, the trigger rate will be the same as at 15 GeV/c, when expressed as a fraction of the elastic trigger rate. We find at 75 GeV/c, for example, that after allowing for the increased mass bite (1.2 GeV vs. .7 GeV at 15 GeV/c) and using data on backward A_1 and A_2 production,[15] we expect a trigger rate of seven times the elastic trigger rate, or 1/(30 pulses). If the trigger rate is an order of magnitude higher than we estimate, it still would not begin to become a burden.

As a first order attempt at eliminating background from the final sample, the missing mass recoiling from the forward proton is calculated.

If a beam momentum resolution of .1 percent can be achieved, the missing mass resolution for backward π's, δM_x, will be ~150 MeV at 15 GeV/c and ~700 MeV at 100 GeV/c. Thus the single forward arm will not be able to cleanly separate elastic scattering from ρ and other 2π and 3π low effective mass backward production at the higher beam momenta. At the lowest momentum, 15 GeV/c, a single forward arm experiment is feasible. The experimenters in reference 12 used this technique at 16 GeV/c, with $\delta M_x = 270$ MeV, and encountered a background of ~10 percent. However, the background subtraction is complicated by its inherent nonlinearity due to threshold effects.[14] Based on this Brookhaven work at 8 and 16 GeV/c,[11,14] and allowing for the deteriorating mass resolution as the beam mementum increases, we would estimate a background of ~100 percent of the overall elastic missing mass signal at 100 GeV/c. We have investigated the effect of detecting the non-proton final state particles by performing a Monte Carlo calculation which pessimistically assumes that the background system recoiling from the proton is a $(\pi^-\pi^0)$. This calculation was done for a beam momentum of 75 GeV/c. Requiring a π^- in a 15° backward cone, as we would do in Phase I, reduces the background by a factor of five. Detecting the γ's from π^0 decay attenuates the background by another factor of six. If proportional chambers are used to detect the π^-, the elastic scattering constraints will reduce the background by an additional factor of two to four, depending on the beam angular divergence. Thus we expect background at the several percent level.

We do not use the anticounters and backward pion counters in the trigger, but rather in a tag, so that real background events can be collected and used to help in understanding any necessary correction for background that might exist in the elastic data sample. If the background in the final missing mass sample is an order of magnitude worse than we expect, in which case we would use proportional chambers, our background subtraction problem will be similar to that of reference 11, and we would expect to be able to do the subtraction with a systemic error of approximately several percent.

We will run for short periods with the target empty in order to study background due to non-hydrogen interactions. Based on reference 11, we expect a 5-10 percent effect if only the proton information is used. There will be a significant reduction in this target empty effect when we require a backward π^- and an absence of γ's.

We are interested in exploring other backward meson - forward proton reactions, with or without extra π^o's. Backward $\pi^+ p \rightarrow \pi^+ p$ cross sections, which can have both I = 1/2 and I = 3/2 u-channel exchanges, complement and supplement the $\pi^- p$ results. $K^+ p$ backward scattering bears directly on hyperon exchange, while the "mysterious" $K^- p$ backward peak is still thought to be due to exotic Z exchange in the u channel. In the "background" for the backward meson-proton experiments we would expect to obtain interesting results on inclusive and two-particle correlation processes in a kinematical region unaccessable to most experiments.

We can be ready to start tuning Phase I on February 1, 1974.

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8. S-Y Chu and A. Hendry, to be published.

9. S. Kormanyos et al., Phys. Rev. 164, 1661 (1967).

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12. We assume that the focusing spectrometer will soon become an NAL facility. We appreciate the cooperation and assistance that we have received from Dr. Jim Sanford (NAL) and Prof. D. Ritson (SLAC) regarding the spectrometer.

13. Meson Laboratory Preliminary Design Report, March 1971, J. R. Orr and A. L. Read, NAL, p. 22 and Fig. 28.

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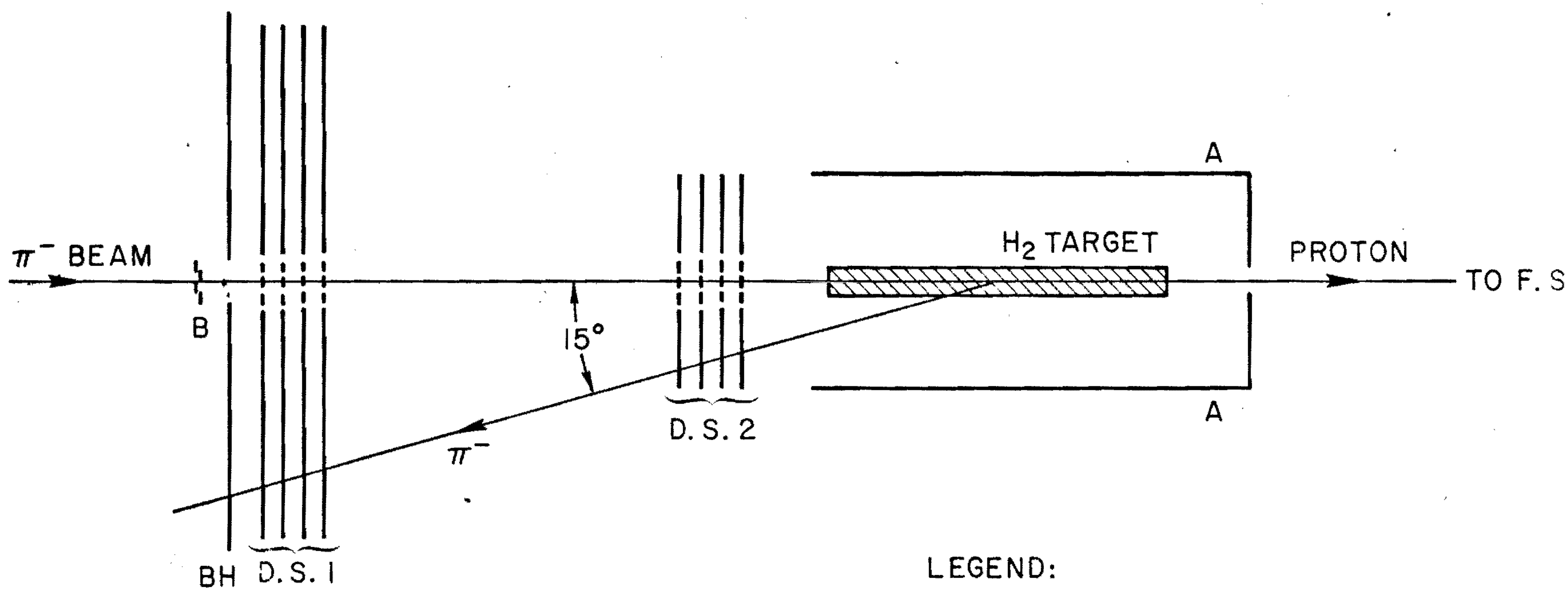
TABLE I

YIELD

Beam Momentum (GeV/c)	s (GeV^2)	Minimum θ angle (degrees)	u range $(GeV/c)^2$	dσ/dΩ nb/sr (1)	dσ/dΩ nb/sr (2)	dσ/dΩ nb/sr (3)	Time of Run (hours)	# Events (3)
15	29.05	178.80	.023 to .026	390	3200	1700	32	350
25	47.82	178.45	.007 to .015	100	2300	1000	32	350
35	66.59	178.30	-.003 to .011	44	1900	720	38	350
45	85.34	178.50	-.006 to .009	23	1600	550	56	350
55	104.1	178.65	-.007 to .007	14	1400	450	95	350
65	122.9	178.75	-.008 to .006	9	1200	380	132	350
75	141.6	178.85	-.009 to .005	6	1100	330	181	350
100	188.5	179.00	-.010 to .004	3	900	250	315	350
							881, or 110 shifts	

Notes

1. This is based on an extrapolation of a formula from reference 9: $d\sigma/d\Omega = 420\ (p_b)^{-2.58}$ μb/sr, where p_b = beam momentum in GeV/c.
2. This is calculated from a Regge exchange model and assumes $d\sigma/d\Omega = A\ s^{2\alpha(u)-1}$, where $\alpha = .15 + .9u$ is the Δ_δ Regge trajectory and $u \simeq 0\ GeV/c^2$. (See reference 3) From the reference 9 data, A = 33.7 μb/sr.
3. This calculation assumes $d\sigma/d\Omega = 27\ (p_b^{-1.02})$ μb/sr, a fit to Ashmore et al., reference 10, at p_b = 5.9, 9.9, 13.7, and 16.3 GeV/c.



LEGEND:

D.S. PROPORTIONAL CHAMBER DETECTOR STATION

F.S. FOCUSING SPECTROMETER

SCALE:

10 inches

2363A1

Figure 1. PLAN VIEW OF LAYOUT