$\pi^- p$ ELASTIC SCATTERING NEAR 180° AT 8 AND 16 GeV/c*

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We report differential cross sections for $\pi^- p$ elastic scattering near 180° at incident pion momenta of 8 and 16 GeV/c. For $|u| < 0.5$ (GeV/c)^2 the formula $d\sigma/du = A\exp(Bu)$ fits the data very well. At 8 GeV/c, $A = 3.75 \pm 0.35$ μb/(GeV/c)^2 and $B = 3.16 \pm 0.24$ (GeV/c)$^{-2}$. At 16 GeV/c, $A = 0.91 \pm 0.13$ μb/(GeV/c)^2 and $B = 4.23 \pm 0.40$ (GeV/c)$^{-2}$. A Regge-pole model fit to these data gives for the Δ_δ trajectory $\alpha(u) = (-0.06 \pm 0.12) + (0.8 \pm 0.3)u$.

Several years ago the importance of precise measurements of backward $\pi^- p$ elastic scattering at high energy was stressed as a test of the Regge model.[1] Since a doubly charged baryon must be exchanged in this model, only the Δ_δ trajectory contributes and the characteristic Regge "shrinkage" was predicted. Experiments at that time and more recently[2] have shown a "backward peak" in high-energy (5- to 16-GeV) $\pi^- p$ elastic scattering at pion scattering angles near 180°. Recent attempts to fit these data in terms of Regge-pole[3] and quark models,[4] and to systematize the energy dependence of two-body reaction cross sections,[5] have emphasized the need for more accurate data at the highest available pion energies. We have, therefore, measured the differential cross section for backward elastic scattering, viz.,

$$\pi_{(1)}^- + p_{(2)} \to p_{(3)} + \pi_{(4)}^-,$$

at incident pion momenta of 8.0 and 16.0 GeV/c with improved precision. (The subscripts are assigned for the purpose of labeling dynamical parameters hereafter.) This experiment, performed at the Brookhaven alternating-gradient synchrotron (AGS), covers a range of the four-momentum transfer squared (u) given by

$$-0.40 \leq u \leq +0.12 \text{ (GeV/}c)^2 \text{ at 8.0 GeV/}c$$

and

$$-0.73 \leq u \leq -0.10 \text{ (GeV/}c)^2 \text{ at 16.0 GeV/}c,$$

where $u = (p_1 - p_3)^2$ and p_i is the four momentum of particle i.

The method employed was the missing-mass technique. By measuring p_1 and p_3 with high precision, it was not necessary to measure p_4 as in previous experiments.[2] Elastic events are those for which the square of the missing mass, $W^2 = [\vec{p}_1 + \vec{p}_2 - \vec{p}_3]^2$, lies in the peak at $W^2 = m_\pi^2$ as seen in a typical missing-mass spectrum such as shown in Fig. 2(a).

The apparatus is shown schematically in Fig. 1. The negative pions were produced at the F-9 target (beryllium) of the AGS near 0° to the 28-GeV/c internal proton beam. The beam transport sys-

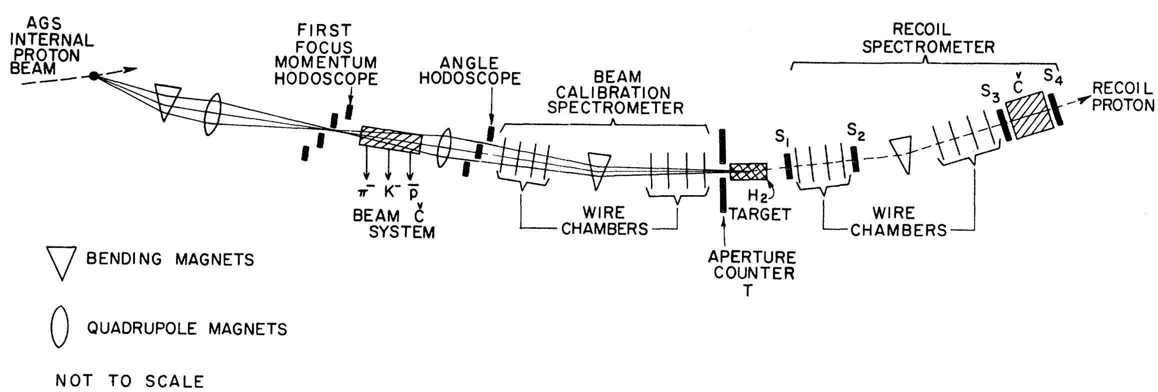

FIG. 1. Schematic layout of experiment. A valid trigger was defined by $P\pi A\bar{T}S_1S_2S_3\bar{C}S_4$, where P = signal from momentum hodoscope, π = signal from beam Cherenkov system indicating that the beam particle was a pion, A = signal from angle hodoscope, $\bar{T}$ = veto by aperture counter, and $S_1S_2S_3\bar{C}S_4$ = signal indicating a scattered proton in the spectrometer.

tem accepted a 3% momentum bite, focusing the beam onto a scintillation-counter hodoscope (momentum hodoscope), where each hodoscope counter had a momentum resolution of ±0.25%. The beam was refocused further downstream onto a liquid-hydrogen target 36 in. long and 6 in. in diameter. An angle hodoscope in the incident beam measured θ_1 to ±0.8 mrad. The beam Cherenkov system (three threshold counters) identified π^-'s, K^-'s, and $\bar{p}$'s in the incident beam. The pion beam thus defined was 99.8% pure and had an intensity of 6×10^5 pions/pulse at 8 GeV/c and 10^6 pions/pulse at 16 GeV/c within a 1.0×1.5-in.^{2} spot at the hydrogen target. The digitized wire spark-chamber spectrometer situated before the hydrogen target was used to calibrate the momentum and angle hodoscopes.

The scattered particle spectrometer located after the hydrogen target subtended a laboratory solid angle of 0.4 msr and had a momentum acceptance, $\Delta p/p$, of 50%. This spectrometer was a new version of the one used in a previous experiment.[6,7] It used wire chambers (with ferrite core readout) as large as 1×3 ft^2 having a spatial resolution of ±1/80 in. in x (horizontal) and ±1/40 in. in y (vertical). These chambers had both x and y coordinates read out from the same gap resulting in fewer planes and a higher overall system efficiency.[8] This spectrometer determined p_3 and θ_3 with a resolution of ±0.25% and ±0.2 mrad, respectively. A threshold Cherenkov counter 70 ft downstream from the hydrogen target separated π^+'s and K^+'s from the protons.

These spark chambers had resolving times of 1 μsec and the whole system had a dead time of 2 msec. Events were stored sequentially in a buffer memory which was read out at the end of each AGS pulse into a PDP-6 computer for a partial on-line analysis, and in parallel onto magnetic tape for a permanent record to be completely analyzed off line at the Brookhaven National Laboratory (BNL) CDC 6600 computer. For each event p_1, θ_1, p_3, θ_3, and W^2 were calculated on line. During data taking the system performance was monitored on a display scope. At about 1-h intervals a summary was printed out which included histograms of differential cross sections, beam characteristics, and information on the performance of the wire chambers. In this experiment event rates ranged from 1 to 60 per AGS pulse and the recoil spectrometer efficiency was 80%. The overall resolution in W^2 at 8 and 16 GeV/c for $W^2=m_\pi^2$ was ±0.059 and ±0.075 $(\mathrm{GeV}/c^2)^2$, respectively.

The number of elastic events recorded at 8 GeV/c was 1840 and at 16 GeV/c 950. Differential cross sections obtained by integrating the peak in the missing-mass spectrum [see Fig. 2(a)] in each angle bin are listed in Table I and shown in Fig. 2(b) along with the results of Brody et al. and Ashmore et al.[2] The lines through our data are the result of a least-squares fit of the form $d\sigma/du=A\exp(Bu)$ to data with $u\geq-0.420$. The values of A, B, and the total backward cross section, defined as $\sigma=(A/B)\exp(Bu_{180°})$, are also listed in Table I.

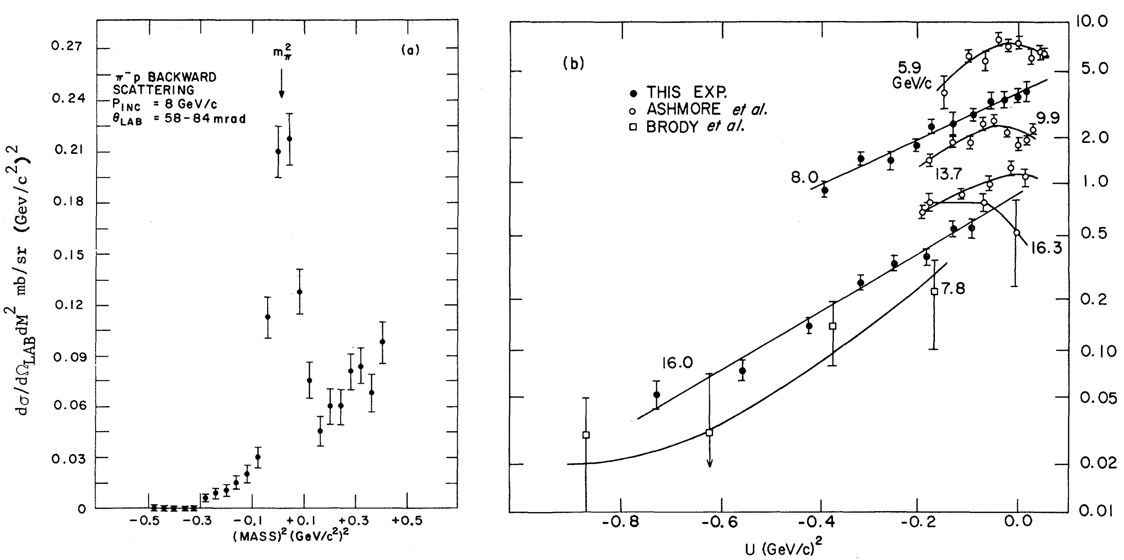

FIG. 2. (a) Typical missing-mass spectrum at 8 GeV/c showing $d\sigma/d\Omega_{\mathrm{LAB}}dM^2$ vs M^2. (b) $d\sigma/du$ for backward elastic π^-p scattering.

Table I. $d\sigma/du$ [μb/(GeV/c)^2] vs u (GeV/c^2) for π^-p backward elastic scattering. The values of the least-squares fit to $d\sigma/du = A\exp(Bu)$ are also given. The total backward elastic cross section is defined as $\sigma = (A/B)\exp(Bu_{180°})$. See text for an explanation of errors quoted here.

u	$d\sigma/du$
Incident momentum 8.0 GeV/c[a]	
+0.012	3.83 ± 0.48
−0.005	3.56 ± 0.32
−0.031	3.44 ± 0.39
−0.061	3.37 ± 0.43
−0.096	2.75 ± 0.20
−0.136	2.46 ± 0.37
−0.181	2.32 ± 0.24
−0.214	1.80 ± 0.18
−0.267	1.49 ± 0.19
−0.324	1.51 ± 0.12
−0.396	0.97 ± 0.10
Incident momentum 16.0 GeV/c[b]	
−0.095	0.557 ± 0.071
−0.131	0.547 ± 0.054
−0.186	0.376 ± 0.046
−0.250	0.340 ± 0.033
−0.322	0.256 ± 0.023
−0.420	0.138 ± 0.015
−0.556	0.075 ± 0.011
−0.730	0.053 ± 0.011

[a] $A = 3.75 \pm 0.35$ μb/(GeV/c)^2, $B = 3.16 \pm 0.24$ (GeV/c)^2, $\sigma = 1.38 \pm 0.14$ μb.

[b] $A = 0.91 \pm 0.13$ μb/(GeV/c)^2, $B = 4.23 \pm 0.40$ (GeV/c)^2, $\sigma = 0.24 \pm 0.03$ μb.

The errors on the data points in Fig. 2(b) and Table I include statistics and angular-dependent uncertainties in the background subtraction. The quoted errors for A, B, and σ include, in addition, a 10% uncertainty in the relative normalization of the 8- and 16-GeV/c data. The data have been corrected for target-empty background (3%), muon contamination in the beam (3%), nuclear absorption in the target (13%) and in the spectrometer (5%), and inelastic background (10%). There is an additional uncertainty of ±20% in the overall absolute normalization of our data which is not included in the errors quoted in the abstract, Table I, and Fig. 2(b).

An independent check of our system, which demonstrated the absence of biases, was obtained by reversing the polarity of the scattered-particle spectrometer magnets and measuring forward elastic π^-p cross sections with the same geometry. Our forward differential cross sections are in good agreement with published values.[9]

Our data are consistent with a simple exponential behavior of the cross section in the region of u studied and they confirm the previously observed rapid energy dependence of the total backward elastic π^-p cross section. In addition, our results are consistent with an energy dependence in the slope of the differential cross section ("shrinkage"). Finally, our data do not show the decrease of the cross section near $u = 0$ suggested by Ashmore et al.[10] and are in disagreement with the absolute normalization of Brody et al.[2] by a factor of 10.

If direct-channel contributions to backward scattering are assumed negligible, the Regge-pole model predicts backward π^-p cross sections of the form $d\sigma/du = K(u)s^{2\alpha(u)-2}$, where s is the total center-of-mass energy squared, and $\alpha(u)$ is the real part of the Δ_δ Regge trajectory associated with the doubly charged baryon exchanged. Assuming a trajectory of the form $\alpha(u) = a + bu$, a fit to our data gives $\alpha(u) = (-0.06 \pm 0.12) + (0.8 \pm 0.3)u$. The Chew-Frautschi plot[11] of the known $I = \frac{3}{2}$ isobars gives $\alpha(u) = 0.1 + 0.9u$, in reasonable agreement with our results.

Assuming that $(d\sigma/du)(u = 0)$ is proportional to p_{lab}^{-n}, then our data at 8 and 16 GeV/c give $n = 2.0 \pm 0.2$. A recent survey[5] of previous data on the energy dependence of two-body reactions indicated $n = 4$ for this reaction in the range $1 \leq p_{\text{lab}} \leq 8$ GeV/c. Thus, our data suggest a less rapid decrease in the cross section above 8 GeV/c.

It is a pleasure to acknowledge the generous cooperation and valuable assistance of the AGS staff in the setting up and running of this experiment. We also wish to acknowledge the important contributions made to this experiment by the staffs of the BNL On-Line Data Facility, the BNL Instrumentation Division (especially J. Fischer for design and construction of the wire chambers), and the Physics Design Groups at BNL and Carnegie-Mellon University. We are particularly grateful to A. Abrahamson, E. Bihn, R. Rothe, and J. Smith for their invaluable assistance throughout the experiment.

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VECTOR-DOMINANCE MODEL COMPARISON OF π^+ PHOTOPRODUCTION WITH ρ^0 PRODUCTION BY PIONS

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A comparison of the reactions $\gamma p\to\pi^+n$ and $\pi^-p\to\rho^0n$ at 4 and 8 GeV/c has been made using the vector-dominance model. Although the ρ^0 data are insufficient to show the very narrow forward peak observed in the photoproduction data, agreement is obtained to within errors for $|t|\lesssim 0.1$ (GeV/c)^2. Taking interference effects into account, this agreement can be extended to $|t|\approx 1.5$ (GeV/c)^2 at 4 GeV/c, but only to 0.3 (GeV/c)^2 at 8 GeV/c.

The reactions

$$\gamma p\to\pi^+n \tag{1}$$

and

$$\pi^-p\to V^0n \tag{2}$$

(where V^0 is a mixture of ρ^0, ω, and φ) can be directly related to one another in the vector-dominance model[1] by time-reversal and isospin invariance as shown schematically in Fig. 1. The γ-ray–vector-meson couplings γ_v can in principle be obtained from the leptonic decays $V^0\to l^+l^-$; up to now only the decays $\rho^0\to e^+e^-$ and $\rho^0\to\mu^+\mu^-$ have been well measured, giving[2]

$$\gamma_\rho^{\ 2}/4_\pi\approx 0.45 \tag{3}$$

with perhaps a 20% uncertainty.[3] The couplings γ_ω and γ_φ can be estimated using SU(3) with the usual $\omega\varphi$ mixing angle[4] ($\cos\theta=\sqrt{\tfrac{2}{3}}$):

$$\gamma_\rho^{\ -2}:\gamma_\omega^{\ -2}:\gamma_\varphi^{\ -2}=9:1:2. \tag{4}$$

Various modifications to the ratios have been proposed[5] but the $V^0=\rho^0$ amplitude of Fig. 1(a) is expected to be dominant, in which case the relation between processes (1) and (2) becomes[1,6]

$$\frac{d\sigma}{dt}(\gamma p\to\pi^+n)\approx\frac{\pi\alpha}{\gamma_\rho^{\ 2}}\rho_{11}^{\ \mathrm{hel}}(t)\frac{d\sigma}{dt}(\pi^-p\to p^0n), \tag{5}$$

where we will take $\pi\alpha/\gamma_\rho^{\ 2}=1/250$ and $\rho_{11}^{\ \mathrm{hel}}(t)$ is the helicity density matrix[7] giving the fraction of ρ mesons with helicity +1 at momentum transfer

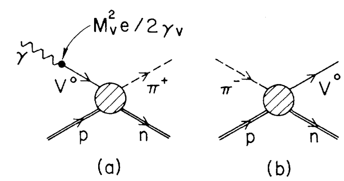

FIG. 1. Feynman diagrams showing the relationship between Reactions (1) and (2) in the vector-dominance model.