OBSERVATIONS OF A BACKWARD PEAK IN $\pi^- p \to p\rho^-$ AT 8 AND 16 GeV/c*

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We report differential cross sections for ρ^- production near 180° in the reaction $\pi^- p \to p\rho^-$ at 8 and 16 GeV/c. These cross sections, which cover a range of $|u| \leq 0.6$ (GeV/c)^2, are well represented by the formula $d\sigma/du = A\exp(Bu)$ and are comparable in magnitude to backward $\pi^- p$ elastic cross sections. Results are compared to Regge model calculations.

We report here the first measurements of the differential cross section for backward ρ production in the reaction

$$\pi_{(1)}^- p_{(2)} \to p_{(3)} \rho_{(4)}^- \quad (1)$$

at high energy.[1] (The subscripts are assigned for the purpose of labeling kinematic variables hereafter.) This experiment, performed at the Brookhaven National Laboratory (BNL) alternating-gradient synchrotron (AGS), measured cross sections at incident-pion momenta of 8.0 and 16.0 GeV/c and covered ranges in the squared four-momentum transfer (u) given by $-0.37 \leq u \leq -0.01$ (GeV/c)^2 at 8.0 GeV/c, and $-0.64 \leq u \leq -0.10$ (GeV/c)^2 at 16.0 GeV/c, where $u = (p_1 - p_3)^2$ and p_i is the four-momentum of particle i.

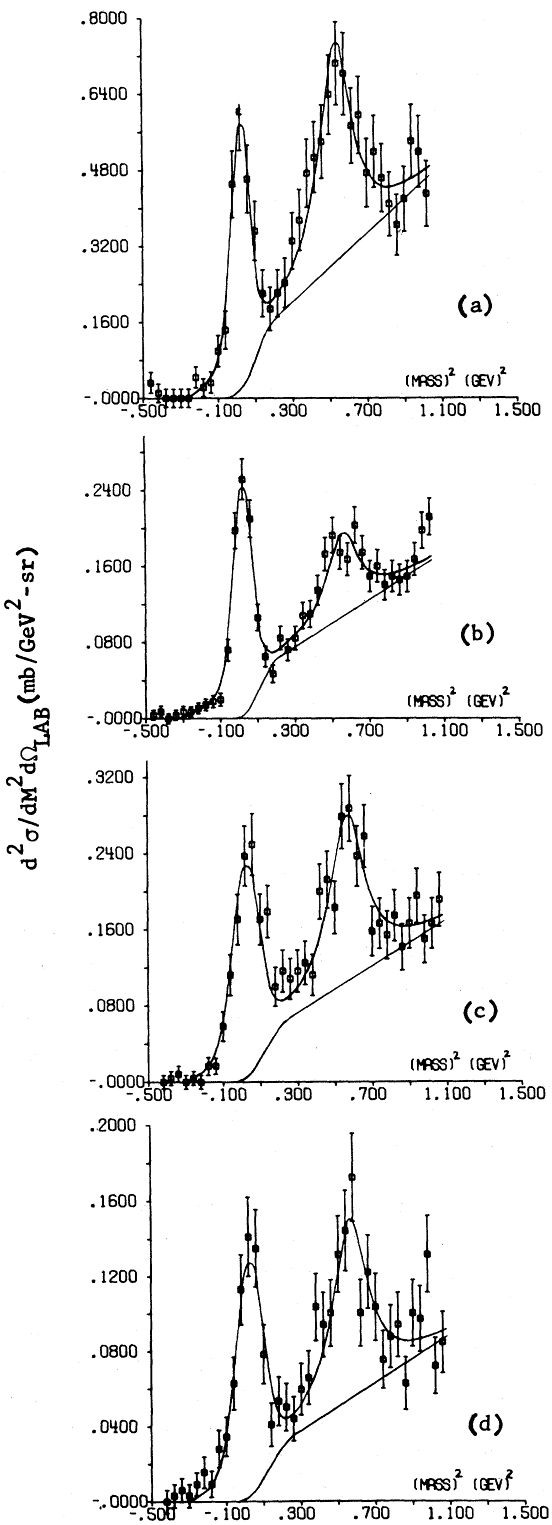
In this experiment the missing-mass method was used to identify backward ρ^- events. For each event only the momenta and angles of the incident π^- and outgoing proton were measured. Some typical spectra which are plotted as a function of missing mass squared, $M^2 = (p_1 + p_2 - p_3)^2$, are shown in Fig. 1, where both the π^- and ρ^- peaks are clearly evident.

The apparatus, which has been described in detail elsewhere, consisted primarily of an incident-beam transport system and a scattered-particle spectrometer.[2] The incident beam contained Čerenkov counters for particle identification and scintillation hodoscopes for precise momentum ($\Delta p/p = \pm 0.25\,\%$) and angle ($\Delta\theta = \pm 0.8$ mrad) determination at high intensities ($10^6\ \pi^-$/AGS pulse). The scattered-particle spectrometer subtended a laboratory solid angle of 0.4 msr and had a momentum acceptance $\Delta p/p = \pm 25\,\%$. A threshold Čerenkov counter at the end of the spectrometer identified the outgoing proton. This spectrometer determined the proton angle and momentum to an accuracy of ±0.2 mrad and ±0.25 %, respectively. The large acceptance, high data rate, and excellent resolution of this spectrometer were achieved by using large digitized spark chambers as detectors. The large momentum acceptance allowed us to record in a single setting entire spectra such as those in Fig. 1. The overall resolution in missing-mass squared δM^2 was ±0.059 (GeV)^2 for an incident beam momentum of 8 GeV/c and ±0.075 (GeV)^2 at 16 GeV/c. For fixed beam momentum this resolution is independent of M^2.

Corrections to the raw data were the following: target empty background (3 %), muon contamination in the beam (3 %), nuclear absorption in the target (13 %) and in the spectrometer (5 %), and detection inefficiency (20 %).

From spectra such as those in Figs. 1(a)-1(d), π^- elastic and ρ^- cross sections were extracted. The analysis of the π^- elastic data is described in detail in Ref. 2. The ρ^- cross sections were determined by a least-squares fitting procedure which assumed that the spectra in the region of the ρ mass could be represented by the sum of a simple Breit-Wigner shape for the ρ and an incoherent background. The ρ parameters which gave the best fit to all the data were $M_\rho = 750 \pm 15$ MeV and $\Gamma_\rho = 124 \pm 15$ MeV. We have assumed the simplest form of the background, namely $a(u)(M^2 - M_0^2)$, where M_0^2 was fixed at its best value -0.29 (GeV)^2 and $a(u)$ was a free parameter in the fit.[3] The background behavior under and in the vicinity of the elastic peak was constrained by the elastic cross section and the known shape of the experimental resolution function. Typical fits to the mass spectra for $M^2 \leq 1.05$ (GeV)^2 are shown in Fig. 1.

In Fig. 2 we plot the ρ^- differential cross sections and the coefficients $a(u)$. The solid lines are fits of the form $A\exp(Bu)$ to the π^- elastic and ρ^- differential cross sections $d\sigma/du$ and to the background coefficients $a(u)$. The values for the parameters A and B are listed in Table I along with an estimate of the total backward cross section $\sigma_{tot} = (A/B)\exp(Bu_{180°})$.



The errors on the data points in Fig. 2 are given by the least-squares fits to the spectra. The quoted errors for A, B, and σ include, in addition to the errors given by the fits, a ±7% uncertainty in the relative normalization of the 8- and 16-GeV/c data. There is an additional uncertainty of ±20% in the overall normalization of our π data and ±30% for our ρ data which is not included in the errors quoted in Table I and Fig. 2. This normalization uncertainty is mainly due to the uncertainty in the exact shape of the background in the vicinity of the peaks. As discussed below, no uncertainty has been included to account for possible changes in the functional form of the background with angle. The errors in the energy dependences of the cross sections due to uncertainties in M_ρ, Γ_ρ, and the background parameter M_0^2 are negligible.

The fits to the spectra described above yield both π^- and ρ^- differential cross sections which are consistent with an exponential behavior in the region of u studied. That the cross sections, as well as the background coefficients $a(u)$, vary smoothly with u shows that the assumed shape for the background is not an unreasonable one. In addition, Monte Carlo studies of reactions of the type

$$\pi^- p \to \pi N^*, \quad N^* \to \pi p, \qquad (2)$$

where the N^* is produced near 0° in the c.m. system (i.e., at small u), indicate that backgrounds of this type do not produce peaks such as those appearing in Fig. 1.[4] Possible π^+ misidentification in the threshold Čerenkov counter at the end of the recoil spectrometer makes no contribution to the background.

Two features of the total cross sections are noteworthy. First, the total backward ρ^- and π^- elastic cross sections are comparable in magnitude. Second, a comparison of our results at $u \sim 0$ (backward processes) with those obtained at

FIG. 1. (a) Missing-mass spectrum in the reaction $\pi^- p \to pX^-$ for $M_{X^-} \leq 1.0$ GeV at 8 GeV/c. The laboratory proton angle $\theta_p = 20$–26 mrad and $\langle u_\rho \rangle = -0.02$ (GeV/c)^2. (b) Same spectrum as (a) but $\theta_p = 58$–76 mrad and $\langle u_\rho \rangle = -0.29$ (GeV/c)^2. (c) Same spectrum as (a) except at 16 GeV/c, $\theta_p = 20$–26 mrad, and $\langle u_\rho \rangle = -0.13$ (GeV/c)^2. (d) Same spectrum as (c) but $\theta_p = 30$–38 mrad and $\langle u_\rho \rangle = -0.30$ (GeV/c)^2. In these figures the solid lines are the results of the least-squares fits described in the text.

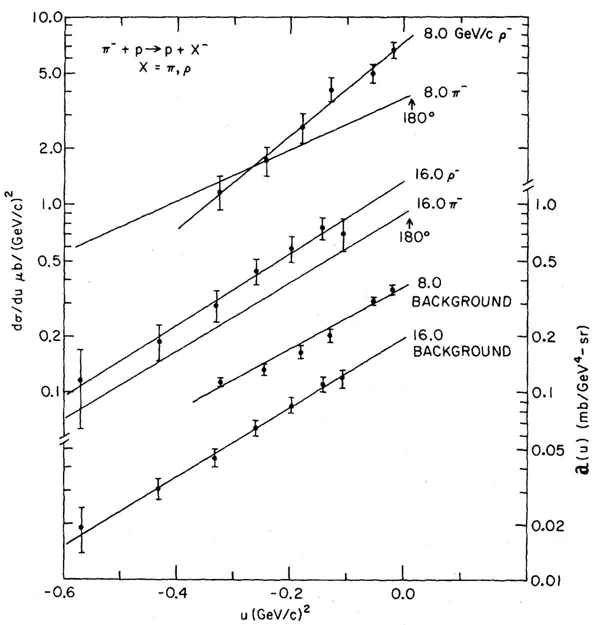


FIG. 2. $d\sigma/du$ for ρ^- production near 180°. For comparison the least-squares fit to the π^- elastic data of Ref. 2 are indicated as 8.0 π^- and 16.0 π^-. The ρ^- data points and fitted lines are indicated as 8.0 ρ^- and 16.0 ρ^-. Data points and fitted lines for $a(u)$, the background parameter described in the text, are indicated as 8.0 and 16.0 BACKGROUND. The values of the parameters used in these fits are given in Table I. The units for $d\sigma/du$ are μb/(GeV/c)^2 (left-hand scale) and for $a(u)$ are mb/GeV^4 sr (right-hand scale).

Table I. Values of the parameters A and B from fits to the cross sections of $d\sigma/du = A\exp(Bu)$ in the reaction $\pi^-p \to pX^-$ near 180°, where $X^- = \pi^-$ and ρ^-. At 8.0 GeV/c, $-0.37 \leq u \leq -0.01$ (GeV/c)^2 and at 16.0 GeV/c, $-0.64 \leq u \leq -0.10$ (GeV/c)^2. The total backward cross sections are estimated as $\sigma = (A/B)\exp(Bu_{180°})$. The errors quoted below are defined in the text. The values for $X^- = \pi^-$ are taken from Ref. 2. The fits to the background parameter $a(u)$ evaluated in the laboratory system are also given.

X^-	(Incident Momentum)	A μb/GeV/c^2	B (GeV/c)$^{-2}$	σ (μb)
π^-	8.0	3.75±0.35	3.16±0.24	1.38±0.14
π^-	16.0	0.91±0.13	4.23±0.40	0.24±0.03
ρ^-	8.0	7.57±0.83	5.79±0.58	1.86±0.2
ρ^-	16.0	1.36±0.23	4.44±0.60	0.32±0.04
		mb/GeV^4-sr	(GeV/c)$^{-2}$	
Back-ground	8.0	0.37±0.03	3.89±0.21	-
"	16.0	0.20±0.02	4.32±0.37	-

$t \sim 0$ (forward processes) indicates the small probability for backward processes. At 8 GeV/c the ratio of the total cross sections [σ(forward)/σ(backward)] is 3.3×10^3 and about 75 for the π^- elastic and ρ^- production, respectively.[5]

Differences in the differential cross sections are readily apparent. At 8.0 GeV/c [where $-0.37 \leq u \leq -0.01$ (GeV/c)^2] the exponential slope of the ρ^- cross section is larger than the slope of the π^- cross section, whereas at 16 GeV/c [where $-0.64 \leq u \leq -0.10$ (GeV/c)^2] the slopes, within experimental errors, are equal. This effect is apparent in Figs. 1(a)-1(d) where the 8-GeV/c ρ^- peak falls more rapidly with u than the 8-GeV/c π^- peak. However, at 16 GeV/c the two peaks appear to decrease at approximately the same rate.

The energy dependence of the π^- and the ρ^- cross sections is most apparent when the results listed Table I are expressed in the following form:

$$R_\rho \equiv A_\rho(8\ \text{GeV}/c)/A_\rho(16\ \text{GeV}/c) = 5.56 \pm 1.13,$$

$$\Delta B_\rho \equiv B_\rho(16\ \text{GeV}/c) - B_\rho(8\ \text{GeV}/c) = -1.35 \pm 0.84\ (\text{GeV}/c)^{-2},$$

$$R_\pi \equiv A_\pi(8\ \text{GeV}/c)/A_\pi(16\ \text{GeV}/c) = 4.12 \pm 0.50,$$

and

$$\Delta B_\pi \equiv B_\pi(16\ \text{GeV}/c) - B_\pi(8\ \text{GeV}/c) = 1.05 \pm 0.42\ (\text{GeV}/c)^{-2}.$$

Assuming that $d\sigma/du$ at $u = 0$ is proportional to P_{lab}^{-n}, then our ρ^- data at 8 and 16 GeV/c give $n = 2.5 \pm 0.3$, while our elastic data give $n = 2.0 \pm 0.2$. A recent survey[6] of previous data on the energy dependence of two-body reactions indicated $n = 4$ for baryon exchange in the range $1 \leq P_{\text{lab}} \leq 8$ GeV/c. Thus, our data suggest a less rapid decrease in baryon-exchange cross sections above 8 GeV/c.

We have previously pointed out[2] that the backward π^- elastic cross sections measured at 8 and 16 GeV/c agree with Regge-model calculations which assume that the scattering amplitude is dominated by the exchange of a linear Δ_δ trajectory. Since the reaction $\pi^-p \to p\rho^-$ near 180° is also believed to take place via the exchange of a doubly charged baryon, the simplest assumption is that this reaction and backward elastic scattering are due only to the exchange of the Δ_δ trajectory. The s dependence of the cross sections at high energy for both reactions is then of the form $(s)^{2\alpha(u)-2}$, where $\alpha(u)$ is the real part of the Δ_δ trajectory. This simple model leads to the predictions that $R_\pi = R_\rho$ and $\Delta B_\pi = \Delta B_\rho$.

Our results and these predictions differ by 1.2 standard deviations for the R's and by 2.5 standard deviations for the ΔB's. This discrepancy could be due to the following: (1) An incorrect description of the background. However, the discrepancy remains the same even when we fit the data with more complicated backgrounds. (2) Inadequacies in the simple Regge model outlined above.[7] It should be pointed out that more detailed Regge calculations for backward ρ^- production are in reasonable agreement with our data.[8]

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, 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. We also wish to acknowledge useful discussions with Dr. C. C. Shih and Dr. E. Paschos.

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[1]Some evidence for backward ρ production has been reported in the Aachen-Berlin-Birmingham-Bonn-Hamburg-London (Imperial College)-Munchen Collaboration, Phys. Rev. 138, B897 (1965); Aachen-Berlin-CERN Collaboration, Phys. Letters 12, 356 (1964).

[2]E. W. Anderson, E. J. Bleser, H. R. Blieden, G. B. Collins, D. Garelick, J. Menes, F. Turkot, D. Birnbaum, R. M. Edelstein, N. C. Hien, T. J. McMahon, J. Mucci, and J. Russ, Phys. Rev. Letters 20, 1529 (1968).

[3]We label the background coefficients $a(u)$ with the values of u calculated from the beam energy, the average laboratory angle of the data being fit, and the ρ mass.

[4]Data on Reaction (2) at small u and low energy have been reported by R. Anthony, C. Coffin, E. Meanley, J. Rise, N. Stanton, and K. Terwilliger, in the Proceedings of the Fourteenth International Conference on High Energy Physics, Vienna, Austria, 1968 (to be published).

[5]In these comparisons we have used our forward $\pi^- p$ elastic cross section data at 8 GeV/c (to be published) and the forward ρ^+ cross section data at 8 GeV/c of the Aachen-Berlin-CERN Collaboration, to be published.

[6]D. R. O. Morrison, Phys. Letters 22, 528 (1966).

[7]There are ways to modify the model outlined above. For example, it is not necessary to assume a simple exponential behavior of the cross section. Detailed studies by E. Paschos (to be published) of u-channel processes based on Regge-pole model have suggested deviations from the "usual" Regge behavior at small values of u. Also, the possibility of another low-lying $I=\frac{3}{2}$ baryon trajectory contributing to Reaction (1) cannot be ruled out. [Particle Data Group, University of California Radiation Laboratory Report No. UCRL 8030 Revised, 1968 (unpublished)].

[8]C. Shih, following Letter [Phys. Rev. Letters 22, 105 (1969)].

REGGE-POLE ANALYSIS FOR π^- PRODUCTION OF ρ^- MESON NEAR THE BACKWARD DIRECTION*

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ρ^- production near backward direction has been analyzed in a Regge-pole model with the emphasis on kinematic structures and constraint relations. We obtain results which agree well with experimental data and are consistent with backward elastic scattering.

Recently many attempts have been made in Regge-pole models to understand the connections between high-energy backward meson-baryon scattering and baryon trajectories.[1] Theoretically, unequal-mass kinematics,[2] conspiracy,[3] MacDowell symmetry,[4] and Gribov's theorem[5] complicate the problem. With the success for backward elastic scattering, it is natural to investigate whether the same kind of analysis can be achieved for the more complicated production proceses.[6] Because of the data available, and the more complicated spin structure, we shall restrict our-