(1967); S. M. Berman, Phys. Rev. Letters 18, 1081 (1967).

[12]R. J. Abrams et al., Phys. Rev. Letters 19, 259 (1967).

[13]The paraquark and three-triplet models give the same results for 1" resonances in the three-triplet model, so that the classification of such resonances in the paraquark model can be maintained.

[14]We will give a complete list of predictions in a later publication.

$\pi^{\pm}p$ BACKWARD SCATTERING BETWEEN 1.5 AND 3.0 BeV/c †

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We report here on measurements of elastic scattering of π^+ and π^- mesons from protons in the backward direction ($-0.7 \gtrsim \cos\theta_{\text{c.m.}} \geqslant -0.995$). The momentum range covered was from 1.48 to 2.93 BeV/c. The G 10°-17° (test) beam of the Brookhaven alternating-gradient synchrotron was used which yielded typically fluxes of $(0.5 \text{ to } 2.0)\times 10^4$ pions per pulse into our detectors with a nominal $\Delta p/p = \pm 0.01$. The absolute value of the beam momentum was known to ± 30 MeV/c.

The experimental apparatus[1] consisted of two arrays of four magnetostrictive wire spark chambers each; both x and y coordinates were determined in each chamber. One array was positioned at 45° to the beam line and detected the incoming and scattered pion tracks up to 90° in the laboratory; the other array was normal to the beam line and detected the forward-going proton. Pions were selected by a threshold gas Čerenkov counter and appropriate scintillators provided the trigger.[1] The hydrogen target was 2 in. in diameter and $3\frac{1}{2}$ in. long. The wire plane information was controlled and stored on magnetic tape by a PDP 8 computer connected on line.[2] Preliminary checks and diagnostics were performed on line but the final processing was performed off line on Brookhaven's CDC 6600 computer.

After geometrical reconstruction[3] elastic events were selected by coplanarity and kinematical angles of scattered and recoil particles. The selection limits were ± 0.010 for the normalized coplanarity and ± 15 mrad for the difference in the observed and calculated proton scattering angle; the signal-to-noise ratio was typically better than 10.

The over-all efficiency of the spark-chamber system[4] was approximately 98%, and the ratio of elastic events to triggers varied with the incoming energy between 1 and 25%. The solid angle was determined by the fiducial region of the chambers and corrections were applied for the following: (a) lepton contamination (~5%) and absorption in the apparatus (~3%) of the beam, (b) losses in reconstruction due to extra tracks[5] (~10 to 20%), (c) no requirement for empty target correction, and (d) inelastic background, which was calculated from the number of events outside the previously mentioned selection criteria, typically of the order of 2-5 μb/sr. Our over-all absolute normalization error is estimated to be ~10-15%.[6]

Our data are presented in Fig. 1(a) for π^+p scattering and in Fig. 1(b) for the π^-p scattering; there are between 500 and 1000 events in each distribution. We note a rapid variation of the angular distribution at each momentum, and furthermore, a drastic change of the angular distribution with momentum. Indeed, the rapid variation of the 180° cross section for π^-p scattering in this energy region was first observed by Kormanyos et al.[7] Barger and Cline[8] showed that one can reproduce the data by assuming that the scattering amplitude is given by a sum of contributions from a Reggeized baryon exchange and the known pion-nucleon resonances in the direct channel. On the other hand, Dikmen[9] and other authors have pointed out that the data can be reproduced by considering only the resonances in the direct channel. In any case, it is true that when only the 180° cross sections are considered, small variations of the masses, elasticities, and

Table I. Input parameters used in the resonance model which produced the solid-line fits shown in Figs. 1 and 2.

J^P	E	Width (Γ)	Elasticity (x)
		$T=\frac{1}{2}$	
$\frac{3}{2}^-$	1.512	0.12	0.55
$\frac{5}{2}^+$	1.688	0.10	0.70
$\frac{7}{2}^-$	2.19	0.24	0.15
$\frac{9}{2}^+$	2.20	0.24	0.083
$11/2^-$	2.64	0.35	0.10
$13/2^+$	2.61	0.32	0.10
$15/2^-$	3.02	0.40	0.06
		$T=\frac{3}{2}$	
$\frac{1}{2}^-$	1.677	0.25	0.40[a]
$\frac{3}{2}^+$	1.236	0.12	1.0
$\frac{5}{2}^-$	2.25	0.15	0.10[b]
$\frac{7}{2}^+$	1.929	0.11	0.40
$11/2^+$	2.41	0.35	0.13
$15/2^+$	2.84	0.40	0.061
$19/2^+$	3.22	0.44	0.025

[a]Width increased. [b]New resonance.

widths of the known resonances[10] suffice in order to fit the data.

If, however, one attempts to fit all the angular distributions shown in Fig. 1 (both π^+p and π^-p), much more severe constraints are placed on the input data.[11] Starting with the known values for the resonances,[9,10] we have attempted to fit our data by allowing variations about the known values using only the direct-channel (s) resonances.[12] The best fits so obtained are given by the solid lines in Fig. 1; the resonance parameters for these calculations are given in Table I. Whereas the order of magnitude and general agreement is reasonable, the detailed fitting is not satisfactory,[11] particularly in the region of the minima.

For comparison of our data we have included in Fig. 1 the results of Duke et al.[13] and Coffin et al.[14] whenever available in the same energy region.

In Fig. 2 we show the π^+p 180° cross section as a function of momentum. This was obtained by extrapolating[15] the data of Fig. 1(b) to 180°; data points from other relevant experiments are also included.[13,16,17] The solid curve is again that calculated from the resonance model with the same resonance parameters as given in Table I. In order to reproduce the sharp minimum in the 180° cross section it was necessary to introduce an additional negative-par-

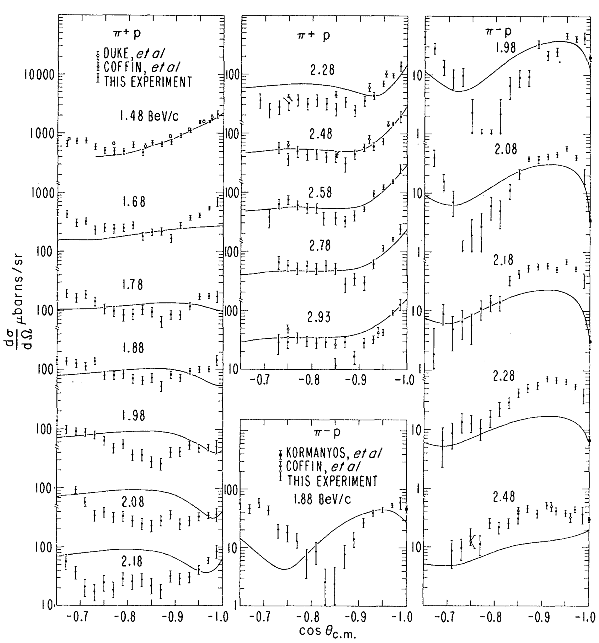

FIG. 1. Cross sections for the elastic scattering of (a) π^+ mesons and (b) π^- mesons from protons in the backward direction. The solid lines are fits obtained from a resonance model discussed in the text. Data from Ref. 7 (squares), Ref. 13 (open circles), and Ref. 14 (triangles) are also included.

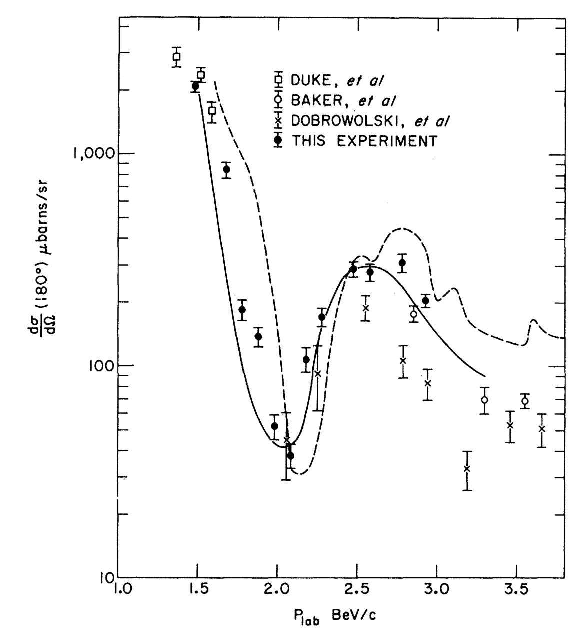

FIG. 2. The π^+p elastic scattering cross section at 180° as a function of incident pion momentum. The solid line is the prediction of the resonance model discussed in the text. Data from Ref. 13 (squares), Ref. 16 (crosses), and Ref. 17 (circles) are also included. The dashed curve indicates the π^-p elastic cross section at 180° multiplied by a factor 10 from Ref. 7.

ity resonance with a mass near 2 BeV. This is not to be interpreted as meaning that a new resonance of this mass necessarily exists but only that some negative-parity amplitude is required. The width of the S_{31} resonance at 1677 MeV had to be increased in order to improve the fit to the angular distributions.

It is interesting to note that the behavior of the 180° π^+p cross section follows very closely the shape of the π^-p cross section but differs by a factor of 10 in magnitude (see the dashed curve in Fig. 2). Since the contribution of the $T=\frac{3}{2}$ resonances in the direct channel to π^+p and π^-p scattering is obviously in the ratio 9:1, it is tempting to conclude that there is a near cancellation of the $T=\frac{1}{2}$ state at 180° throughout this momentum interval; this would be due to the MacDowell symmetry of the N_α and N_γ trajectories.[18]

We are indebted to the staff and personnel of the alternating-gradient synchrotron who made this experiment feasible, in particular to Dr. G. K. Green, Dr. J. R. Sanford, and Mr. W. Walker, Mr. L. Cimenti, Mr. G. E. Tangnay, and Mr. R. Gibbs for their cooperation under unusual circumstances. The efforts of Mr. H. Pate and of the Instrumentation Division as well as of the technical staffs both at Brookhaven and Rochester are greatly appreciated. Dr. R. L. Cool provided continuous support and Dr. B. D. McDaniel participated in the initial stages of this experiment.

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[1]A detailed description of the apparatus will be given in a forthcoming publication. See, however, A. S. Carroll, J. Fischer, A. Lundby, B. D. McDaniel, R. H. Phillips, C. L. Wang, F. Lobkowicz, A. C. Melissinos, and S. Tewksbury, Brookhaven National Laboratory Report No. 11359 (unpublished).

[2]Developed by the Instrumentation Division of Brookhaven National Laboratory.

[3]The special program was developed in cooperation with M. Frantz Hind, Applied Mathematics Department, Brookhaven National Laboratory.

[4]This was obtained automatically by counting the cases when only three chambers gave the correct coordinates in comparison with the cases where all four chambers gave the correct coordinates.

[5]These are accidental tracks (either beam or background) which occur during the sensitive time of the chambers (approximately 450 nsec). The computer program found and eliminated these accidental tracks. The correction obtained was checked by reconstructing a sample fraction of the digital information onto film and scanning it with human operators.

[6]The following uncertainties contribute to our estimate for the over-all normalization error: (a) extra track correction uncertainty ±7%, (b) lepton contamination uncertainty ±1%, (c) chamber and detection efficiency uncertainty ±1%, and (d) solid-angle-evaluation uncertainty ±3%.

[7]S. W. Kormanyos, A. D. Krisch, J. R. O'Fallon, K. Ruddick, and L. G. Ratner, Phys. Rev. Letters 16, 709 (1966).

[8]V. Barger and D. Cline, Phys. Rev. Letters 16, 913 (1966), and Phys. Rev. 155, 1792 (1967).

[9]F. N. Dikmen, Phys. Rev. Letters 18, 798 (1966).

[10]These variations are within the accepted error of the resonance parameters; see, for example A. H. Rosenfeld et al., University of California Radiation Laboratory Report No. 8030 (revised), 1967 (unpublished).

[11]One could even adopt the attitude that simple models such as presented in Refs. 8 and 9 cannot predict the behavior of the cross section for angles substantially removed from 180° due to the presence of nonresonating partial waves. The 180° cross section will also be influenced by deviation of the resonance amplitudes from the simple Breit-Wigner form.

[12]We used the expressions

$$d\sigma(S,\theta)/d\Omega=|f|^2+\sin^2\theta|g|^2,$$

with f and g given by

$$f^I=\frac{1}{k}\frac{X_I(J+\frac{1}{2})}{\epsilon-i}P_l(\cos\theta);\quad g^I=\frac{1}{k}\frac{X_I(-1)^{J-l+\frac{1}{2}}}{\epsilon-i}P_l'(\cos\theta),$$

$$\epsilon=(M_R^2-S)/M_R\Gamma;$$

X_I is the elasticity.

[13]P. J. Duke, D. P. Jones, M. A. R. Kemp, P. G. Murphy, J. D. Prentice, and J. J. Thresher, Phys. Rev. 149, 1077 (1966).

[14]C. T. Coffin, F. N. Dikmen, L. Ettlinger, D. Meyer, A. Saulys, K. Terwilliger, and D. Williams, Phys. Rev. 159, 1169 (1967).

[15]A similar extrapolation for the π^-p data would be unreliable because of the extremely rapid variation of the angular distribution at 180°. This effect is most pronounced around 2.1 BeV/c and is attributed to the cancellation of the partial waves arising from the $T=\frac{1}{2}$ resonances with approximately the same mass but opposite parity [see, for example, V. Singh, Phys. Rev. 129, 1889 (1963)]. See also Table I.

[16]T. Dobrowlski, B. N. Gus'kov, M. F. Likhashev, A. L. Lubimov, Yu. A. Matulenko, V. S. Stravinsky, and A. S. Vorenko, Phys. Letters 24B, 203 (1967). Their data were obtained at $\cos\theta_{\text{c.m.}}\approx 0.995$.

[17]W. F. Baker, P. J. Carlson, V. Chabaud, A. Lundby, J. Banaigs, J. Berger, C. Bonnel, J. Duflo, L. Goldzahl, and F. Plouin, Phys. Letters 25B, 361 (1967); W. F. Baker, P. J. Carlsen, V. Chabaud, A. Lundby, E. G. Michaelis, J. Banaigs, J. Berger, C. Bonnel, J. Duflo, L. Goldzahl, and F. Plouin, Phys. Letters 23, 605 (1966).

[18]See, for example, Singh, Ref. 15.