

STRUCTURE IN 5-GeV/c π^+p ELASTIC SCATTERING AT LARGE ANGLES*D. R. Rust, P. N. Kirk, R. A. Lundy, C. E. W. Ward, and D. D. Yovanovitch
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Data from a high-resolution experiment on the reaction $\pi^+ + p \rightarrow \pi^+ + p$ at 5 GeV/c show a very deep, sharp dip in $d\sigma/dt$ at $t = -2.8$ (GeV/c)² and a gentle exponential decrease in $d\sigma/du$ between $u = -1.5$ and -3.5 (GeV/c)².

During a recent experiment to study the reaction $\pi^+ + p \rightarrow K^+ + \Sigma^+$, high-statistics, high-resolution data were also taken on the elastic-scattering reaction $\pi^+ + p \rightarrow \pi^+ + p$. Nearly the whole angular range was covered at an incident momentum of 5 GeV/c, with approximately 1600 events being accumulated in the region where $d\sigma/dt < 10$ $\mu\text{b}/(\text{GeV}/c)^2$, plus a great many events in the region of larger cross section. Less extensive data were also collected at 3.0, 3.25, 4.0, and 7.0 GeV/c, but these will be reserved for a later publication.

This experiment was performed at the Argonne National Laboratory zero-gradient synchrotron in two parts separated in time by about one year. The results of the first experiment on $\pi^+ + p \rightarrow K^+ + \Sigma^+$, where the K^+ meson was observed between laboratory angles of 3° and 17° , have already been reported.¹ The small-angle elastic-scattering data reported here, with the outgoing π^+ meson observed in the same angular range, were taken at the same time with the same apparatus. The rest of the data were taken recently with a similar apparatus which accepted outgoing particles, either π^+ mesons or protons, between 13° and 27° in the laboratory.

Figure 1 shows the arrangement of the wire spark-chamber spectrometer and other detectors for the recent large-angle part of the experiment. π^+ mesons in the beam were identified by coincident counts in three beam scintillation counters (BM1 [not shown], BM2, BM3), and three gas threshold Cherenkov counters (CPI [not shown], CK1, CK2; CK3 was not used for the identification of pions). A beam halo veto counter (BM4) and a no-interaction veto (BM5) were used in anticoincidence. Scattered particles on one side of

the beam were selected to have approximately the correct momentum for a given scattering angle by a pairwise coincidence between elements of hodoscope A and hodoscope B. A large gas threshold Cherenkov counter (C1) counted pions going through the spectrometer with momentum greater than about 2.0 GeV/c. On the other side of the beam, a large scintillation counter (SIG) detected recoil particles.

The groups of wire spark chambers are designated in Fig. 1 as K1, K2, K3, and Σ . There were four gaps in each group. These chambers determined the momentum and angle of the forward scattered particle and the angle of the recoil particle precisely enough to make a very clean separation of elastic events from background events. A complete kinematic analysis was performed on-line by the EMR 6050 computer which received the wire spark-chamber information.

The results are shown in Fig. 2 and Table I. The data for $|t| < 1.1$ (GeV/c)² were taken in the earlier part of the experiment, in which the recoil proton was not detected. In this region a

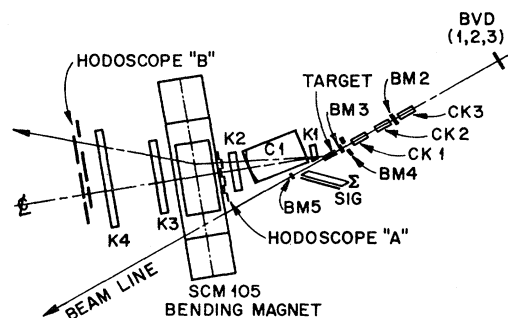


FIG. 1. Layout of experimental apparatus.

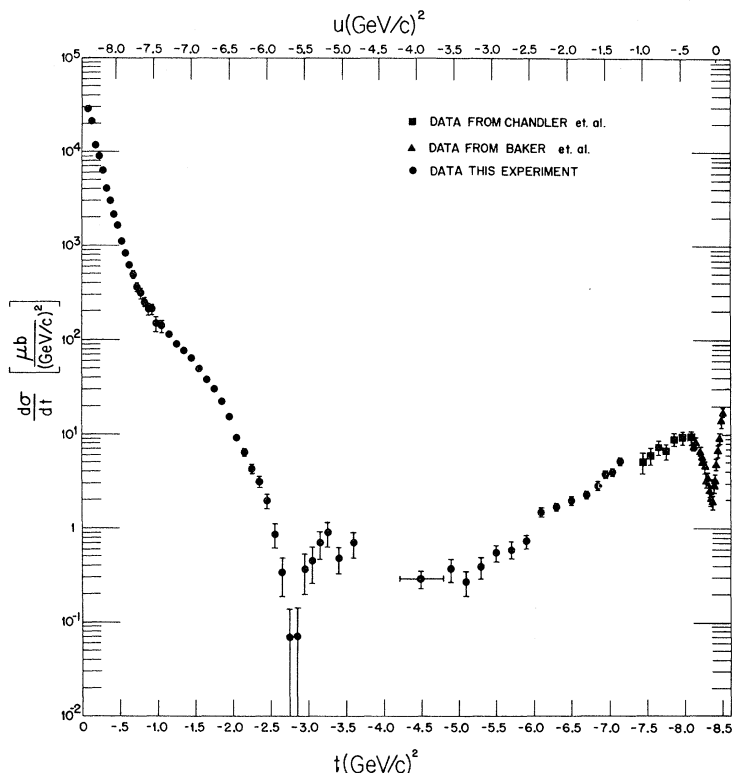


FIG. 2. Differential elastic-scattering cross section for π^+p at 5.0 GeV/c. Solid points are data from this experiment.

background which amounted to between 5 and 15% was subtracted to obtain the correct cross section. The background was determined by fitting the missing-mass distribution in the region of the elastic peak with a Gaussian plus a linear background.

The remainder of the data from the more recent experiment were obtained from a three-constraint fit using the measured missing mass, opening angle, and coplanarity angle. This procedure virtually eliminated inelastic background events. To estimate the background in the data, a two-constraint fit with constraints only on opening angle and coplanarity was performed, and the fraction of events in the linear background under the elastic peak was determined. We estimate the background near $t = -1.3$ (GeV/c)² to be about $1 \mu\text{b}/(\text{GeV}/c)^2$, about one-half of the statistical error of the data, while at $t = -2.8$ (GeV/c)² the background cross section is less than $0.02 \mu\text{b}/(\text{GeV}/c)^2$, again much less than the statistical error at this value of t . In the backward hemisphere, $|t| > 4.3$ (GeV/c)², an upper limit of $0.05 \mu\text{b}/(\text{GeV}/c)^2$ is estimated even though no evidence of any background is observed in our data. Because the estimated background was small

compared with statistical errors for all values of t , the data in Fig. 2 for $|t| > 1.1$ (GeV/c)² are presented with no background subtracted. Nevertheless, the cross section at the bottom of the dip at $t = -2.8$ (GeV/c)² is less than $0.1 \mu\text{b}/(\text{GeV}/c)^2$ and consistent with zero. The presence of such a deep dip demonstrates (a) the success of the fitting procedure in eliminating nonelastic events, and (b) the absence of any significant contamination from pp elastic scattering, which was achieved by the use of four Cherenkov counters. Since the sides of the dip at $t = -2.8$ (GeV/c)² appear so steep, it is necessary to quote a t resolution of the apparatus. It is $\Delta t = \pm 0.07$ (GeV/c)², mainly due to the incident beam divergence. Therefore, the true cross section could have an even deeper and narrower dip.

The absence of data near 90° in the center-of-mass system is due to the fact that our angular acceptance unfortunately did not extend far enough.

Major corrections which have been applied to the raw t distribution to convert it to the one presented here are solid angle and spark-chamber efficiency corrections. The overall event recognition efficiency was 45%, due primarily to non-ideal chamber performance, the presence of

Table I. Differential cross section for 5-GeV/c π^+p elastic scattering. Only statistical errors are given. In addition, there is a $\pm 10\%$ normalization uncertainty.

$-t$ (GeV/c) ²	$\frac{d\sigma}{dt}$ mb/(GeV/c) ²	$-t$ (GeV/c) ²	$\frac{d\sigma}{dt}$ $\mu\text{b}/(\text{GeV}/c)^2$
0.075	28.5 \pm 0.5	1.85	22.0 \pm 1.1
0.125	20.9 \pm 0.3	1.95	15.3 \pm 0.9
0.175	11.7 \pm 0.2	2.05	9.20 \pm 0.7
0.225	8.9 \pm 0.2	2.15	6.45 \pm 0.6
0.275	6.3 \pm 0.2	2.25	4.28 \pm 0.50
0.325	4.01 \pm 0.12	2.35	3.12 \pm 0.45
0.375	2.97 \pm 0.11	2.45	1.95 \pm 0.35
0.425	2.14 \pm 0.09	2.55	0.86 \pm 0.25
0.475	1.63 \pm 0.08	2.65	0.34 \pm 0.15
0.525	1.11 \pm 0.07	2.75	0.07 \pm 0.07
0.575	0.82 \pm 0.06	2.85	0.07 \pm 0.07
0.625	0.62 \pm 0.05	2.95	0.37 \pm 0.17
0.675	0.49 \pm 0.05	3.05	0.45 \pm 0.19
0.725	0.36 \pm 0.04	3.15	0.70 \pm 0.23
0.775	0.31 \pm 0.04	3.25	0.90 \pm 0.27
0.825	0.25 \pm 0.03	3.4	0.48 \pm 0.15
0.875	0.21 \pm 0.03	3.6	0.70 \pm 0.22
0.925	0.21 \pm 0.03	4.5	0.29 \pm 0.06
0.975	0.147 \pm 0.028	4.9	0.37 \pm 0.10
1.05	0.138 \pm 0.020	5.1	0.27 \pm 0.08
1.15	0.112 \pm 0.002	5.3	0.39 \pm 0.10
1.25	0.090 \pm 0.002	5.5	0.55 \pm 0.11
		5.7	0.59 \pm 0.12
		5.9	0.73 \pm 0.12
		6.1	1.47 \pm 0.17
	$\mu\text{b}/(\text{GeV}/c)^2$	6.3	1.69 \pm 0.18
		6.5	1.96 \pm 0.19
1.35	77.0 \pm 1.9	6.7	2.28 \pm 0.20
1.45	64.6 \pm 1.7	6.85	2.82 \pm 0.30
1.55	49.5 \pm 1.6	6.95	3.74 \pm 0.34
1.65	38.0 \pm 1.4	7.05	3.97 \pm 0.35
1.75	30.0 \pm 1.3	7.15	5.18 \pm 0.50

background tracks, and the simplicity of the track fitting routine. In order to check the normalization of the data at large angles, pp elastic-scattering runs were interspersed with pion scattering runs. The pp cross section at large $|t|$ is considerably larger than that for πp elastic scattering and has been measured accurately in counter experiments.² The cross section at small angles measured in the earlier part of the experiment was checked against the optical point and other π^+p elastic scattering data.³ Because of these checks on the normalization, we are able to quote a $\pm 10\%$ systematic error in addition to statistical uncertainty.

In the large- $|t|$ region, there have been extensive experiments on high-energy π^-p elastic scattering³⁻⁵ but data on π^+p elastic scattering^{3,5} above 3 GeV/c have been rather sparse.⁶ With the present measurements, 5 GeV/c is now the highest momentum for which a nearly complete

angular distribution exists. In Fig. 2 the data from this experiment are supplemented by data from Baker *et al.*⁷ and Chandler *et al.*⁸ at very backward angles.

The new data show the following features: (a) The sharp, deep dip at $t = -2.8 \pm 0.1$ (GeV/c)². A similar dip was previously seen⁴ in π^-p elastic scattering but it did not appear so deep and narrow there. Possibly there is better background rejection and angular resolution in the present experiment. (b) A slow variation of the cross section in the backward hemisphere. The present data vary roughly as $\exp(1.3u)$ for values of u between -1.5 and -3.5 (GeV/c)², and appear to join smoothly to the backward data.

The dip at $t = -2.8$ (GeV/c)² has been interpreted⁹ as the effect of the P' trajectory passing through $\alpha_{P'} = -2$, but this interpretation requires a particular assumption for the form of the residue function. The cyclic residue function of Bar-ger and Phillips⁹ is not consistent with the usual assumption of nearly constant values for the reduced residue but at the present time this is the only published attempt to account for the dip. The effects of absorption and multiple scattering, which can be identified with Regge cuts, are thought to be important at high momentum transfers. These effects, however, tend to fill in dips and the presence of as sharp a dip as is seen at $t = -2.8$ (GeV/c)² is rather unexpected from this point of view.

Both pure Regge-pole fits^{10,11} and a strong Regge-cut-model fit¹² to the backward data give a steeper slope in the large- $|u|$ region than we observe. Regge-pole fits using linear trajectories predict a fairly deep dip near $u = -2.6$ (GeV/c)², where the N_α trajectory passes through $\alpha = -\frac{5}{2}$. We do not observe such a dip; however, we cannot rule out the existence of a small structure near this point.

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STUDY OF $\gamma p \rightarrow p \omega$ WITH LINEARLY POLARIZED PHOTONS AT 2.8 AND 4.7 GeV*

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The reaction $\gamma p \rightarrow p \omega$ was studied in a hydrogen bubble chamber using a linearly polarized photon beam. The total cross section was found to be $5.8 \pm 0.5 \mu\text{b}$ at 2.8 GeV and $3.2 \pm 0.3 \mu\text{b}$ at 4.7 GeV. From the decay angular distributions these cross sections have been separated into contributions from natural- and unnatural-parity exchange σ^N , σ^U in the t channel. For $|t| < 1 \text{ GeV}^2$ $\sigma^N = 2.5 \pm 0.4 \mu\text{b}$, $\sigma^U = 2.7 \pm 0.4 \mu\text{b}$ at 2.8 GeV and $\sigma^N = 1.8 \pm 0.3 \mu\text{b}$, $\sigma^U = 1.3 \pm 0.3 \mu\text{b}$ at 4.7 GeV. The contributions from unnatural-parity exchange are consistent with the predictions of the one-pion-exchange model.

The energy dependence and the magnitude of the cross section for ω production by unpolarized photons measured^{1,2} in the reaction

$$\gamma p \rightarrow p \pi^+ \pi^- \pi^0 \quad (1)$$

suggests that ω production proceeds partly via one-pion exchange (OPE) and partly via diffraction scattering, with the dominant contribution at low energies (~ 2 -4 GeV) coming from OPE. Using polarized photons, the contributions from natural parity [$P = (-1)^J$] and unnatural parity

[$P = -(-1)^J$] exchange in the t channel can be separated, and the above conjecture can be tested.

We have analyzed ω production in Reaction (1) at 2.8 and 4.7 GeV exposing the 82-in. hydrogen bubble chamber at Stanford Linear Accelerator Center to the linearly polarized Compton-back-scattered laser beam. Table I summarizes the details of the beam and of the exposure.³⁻⁶

In Table I we list the number of events which gave a zero-constraint "fit" to Reaction (1) (the photon energy E_γ not being constrained) and