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[12] For pd interactions we convolute the averaged $\pi^\pm p$ distribution (πN) at $p_h/2$ with pp at $p_h/2$, and for πd interactions we convolute πN with itself. The data used are as follows: (i) $\pi^- p$, 50 GeV, A. Akopdjanov *et al.*, Nucl. Phys. B75, 401 (1974); 100 GeV, E. L. Berger *et al.*, Nucl. Phys. B77, 365 (1974); 147 GeV, D. Fong *et al.*, Nucl. Phys. B102, 386 (1976); 205 GeV, D. Ljung *et al.*, Fermilab Report No. FERMILAB-PUB-76/92-EXP (unpublished). (ii) $\pi^+ p$, 50 GeV, A. Akopdjanov *et al.*, Nucl. Phys. B75, 401 (1974); W. M. Morse *et al.*, Phys. Rev. D 15, 66 (1977). (iii) pp, 50 GeV, V. V. Ammosov *et al.*, Phys. Lett. 42B, 519 (1972); 100 GeV, W. M. Morse *et al.*, Phys. Rev. D 15, 66 (1977); 200 GeV, G. Charlton *et al.*, Phys. Rev. Lett. 29, 515 (1972), 300 GeV, A. Firestone *et al.*, Phys. Rev. D 10, 2080 (1974).

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Comparison of the Line-Reversed Channels $\bar{p}p \to \pi^-\pi^+$ and $\pi^+p \to p\pi^+$ at 6 GeV/c

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Differential cross sections have been measured for $\bar{p}p \to \pi^-\pi^+$ (1) and its line-reversed partner $\pi^+p \to p\pi^+$ (2) in the range $t_{\min} > t > -1.5$ (GeV/c)^2 at 6 GeV/c. Clear structure is seen in the differential cross section for Reaction (1) at $t \sim -0.4$ (GeV/c)^2. However, this feature is quite different from the striking dip seen in (2) at $t \sim -0.15$ (GeV/c)^2, indicating a failure of line reversal and disagreement with simple Regge models.

The line-reversed reactions $\bar{p}p \to \pi^-\pi^+$ (1) and $\pi^+p \to p\pi^+$ (2) proceed via nucleon and Δ exchange in the t channel.[1] Simple models predict that if the scattering is dominated by a single amplitude, then the differential cross sections for the two reactions will have the same shape and that at asymptotic energies backward elastic scattering will be twice the annihilation reaction.

In recent years, workers have employed Regge models[2] and absorption models[3] to explain the detailed structure of baryon-exchange reactions. These models, with large numbers of free parameters, have successfully explained the t structure in related processes.[4] However, in order to limit such models, new high-quality data with small and/or canceling systematic errors are needed. Reactions (1) and (2) are especially interesting to study since π^+p backward elastic scattering[5] displays one of the most striking dips in high energy physics at $t' \equiv t - t_{\min} \sim -0.2$ (GeV/

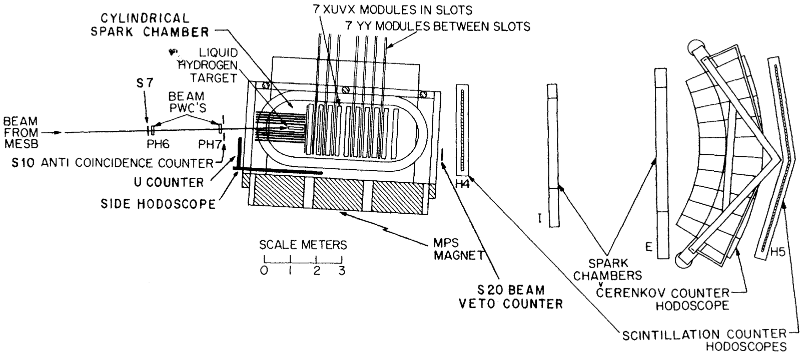

FIG. 1. Layout of the experimental apparatus.

$c)^2$. Hence, measurement of the annihilation reaction $\bar{p}p \to \pi^-\pi^+$ should prove highly useful.

Previous measurements of the annihilation reaction above the resonance region include those at 3 and 4,[6] 5,[7] and 6.2 GeV/c.[8] The 5- and 6.2-GeV/c data do not cover the region of possible structure $|t| < 0.4$ (GeV/$c)^2$. The 4-GeV/c data give some indication of structure in the form of a leveling of the cross section for $|t| \gtrsim 0.3$ (GeV/$c)^2$. However, because of the limited range covered, $|t| < 0.5$ (GeV/$c)^2$, the precise nature of this structure is not clear. In addition, line-reversal comparisons have been difficult in the past because of the need to compare different experiments with different systematic biases.

We have performed an experiment designed to measure the differential cross sections for a number of two-body and quasi-two-body baryon-exchange scattering reactions at 4, 6, and 8 GeV/c and at the 1000-events/μb level, from which we shall make a comprehensive study of baryon-exchange process. A sample (~40%) of the 6-GeV/c data for $\bar{p}p \to \pi^-\pi^+$ and $\pi^+p \to p\pi^+$ is presented here.[9]

The experiment was performed using the Brookhaven National Laboratory multiparticle spectrometer (MPS) in a partially separated beam (see Fig. 1). During annihilation runs the $\bar{p}$ to π^- ratio in the beam was 2:1 and the beam delivered ~35 000 $\bar{p}$'s per alternating-gradient synchrotron (AGS) spill. Two gas threshold Cherenkov counters tagged π's, K's, and $\bar{p}$'s in the beam. Six proportional wire chambers (PWC's) and an 18D72 magnet were used to determine the incident momentum, position, and angle to ±0.25%, ±1 mm, and ±0.75 mrad, respectively. The liquid hydrogen target was a 10-cm-diam × 60-cm-long cylinder placed inside the 10-kG field of the MPS magnet. 42 magnetostrictive spark chamber planes downstream of the target were used to momentum analyze forward-going tracks with an accuracy of ±1.5%. The scattering angle was measured to ±0.75 mrad. Five low-mass cylindrical spark chambers concentric with the target were used to measure the recoil track angle to an accuracy of ±15 mrad.

The trigger had four major components: (1) a good incident beam coincidence, (2) a momentum/angle/charge selection of forward tracks by use of the $H4$ and $H5$ hodoscopes in a matrix coincidence. Acceptance for this requirement was $-0.5 \lesssim M_{\text{recoil}}^2 \lesssim 4.0$ (GeV/$c^2)^2$ and $-t \lesssim 1.5$ (GeV/$c)^2$, (3) proper forward-particle identification in the segmented Cherenkov counter, and (4) only one counter hit in $H4$ and one in $H5$. For the annihilation reaction a hit was also required in either the side hodoscope or U counter in order to enhance the separation of annihilation events ($\sigma_{\bar{p}p \to \pi^-\pi^+} \sim 1$ μb) from events of the type $\bar{p}p \to \bar{p}X$ ($\sigma_{\bar{p}p \to \bar{p}X} \sim 25$ mb).

An event was reconstructed by first fitting individual tracks in the spark chambers. The recoil mass was then computed from the forward- and recoil-track angles. The momentum transfer was computed from the forward-track angle and kinematic considerations. Coplanarity and recoil-mass distributions for $\bar{p}p \to \pi^-\pi^+$ are presented in Fig. 2. Target-empty data indicated negligible background.

The geometric acceptance of the apparatus was computed using a Monte Carlo simulation of the experiment. In addition the $\bar{p}p \to \pi^-\pi^+$ [$\pi^+p \to p\pi^+$] data were corrected for absorption in the target (12.5 ± 0.5%) [9.5 ± 0.5%], absorption in the apparatus (6.0 ± 1.0%) [6.0 ± 1.0%], inefficiency introduced by trigger requirement (4) (12.0 ± 2.0%) [12.0 ± 2.0%], $C6$ inefficiency (4.0 ± 1.0%) [1.0 ± 0.5%], beam-reconstruction efficiency (78.0

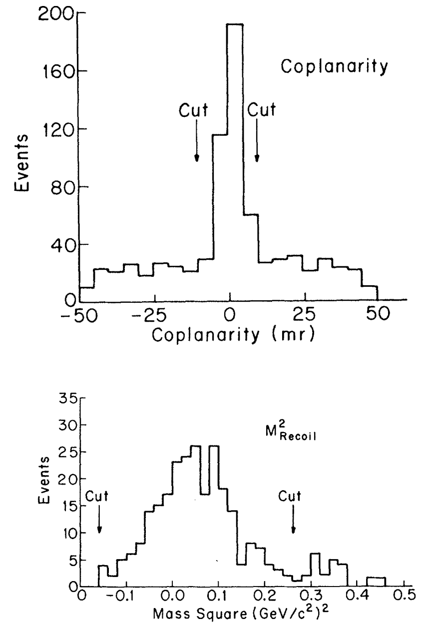

FIG. 2. The $M_{\text{recoil}}^2(\theta_{\text{fast}}, \theta_{\text{recoil}})$ and coplanarity distributions measured for $\bar{p}p \rightarrow \pi^-\pi^+$.

$\pm 0.5\%$) [$80.0 \pm 0.5\%$], recoil-track-reconstruction efficiency ($90.0 \pm 10.0\%$) [$90.0 \pm 10.0\%$], pion decay ($1.0^{+0.5}_{-0.25}\%$) [$0.5^{+0.25}_{-0.10}\%$], losses due to cuts ($2.5 \pm 1.0\%$) [$4.0 \pm 1.0\%$] and lepton contamination in the beam ($0 \pm 0\%$) [$4.0 \pm 2.0\%$]. We conservatively estimate the overall normalization uncertainty for each reaction to be $\pm 20\%$.

Differential cross sections for $\pi^+p \rightarrow p\pi^+$ are presented in Fig. 3(a) along with the data of Owen *et al.*[5] Note the sharp dip at $t' \sim -0.2$ (GeV/c)^2 [$t \sim -0.15$ (GeV/c)^2]. The accurate reproduction in our data of the striking features of this reaction indicate that our t resolution is good [uncertainty $\lesssim 0.01$ (GeV/c)^2], that our t scale is correct, and that the normalization is accurate to within the assigned error. Further corroboration of our results comes from the excellent agreement with earlier data[11] of $\bar{p}p$, π^-p, and π^+p forward elastic scattering measurements, taken simultaneously with baryon-exchange data in order to check the systematics of our apparatus and event reconstruction.

Differential cross sections for $\bar{p}p \rightarrow \pi^-\pi^+$ are shown in Fig. 3(b). Also shown are data from Refs. 6–8 scaled by s^{-2} and from Owen *et al.*[5] scaled by the line-reversal factor.[10] For the first time, our data provide full coverage of the small $|t|$ region. We observe a break in the peripheral slope at $t' \sim -0.35$ (GeV/c)^2 [$t \sim -0.40$ (GeV/c)^2] and perhaps a shallow dip at that point followed by essentially flat cross sections[12] out to $t = -1.3$ (GeV/c)^2. In addition we note the following three points: (1) Where data overlap, agreement with Buran *et al.* is excellent. (2) These several experiments are inconsistent with a simple energy dependence. As an example, in the region $t > -0.3$ (GeV/c)^2 ours and the 4-GeV/c data behave roughly like s^{-4}. (3) The line-reversal test fails dramatically. The forward slope for $\bar{p}p \rightarrow \pi^-\pi^+$ is shallower than for $\pi^+p \rightarrow p\pi^+$, the

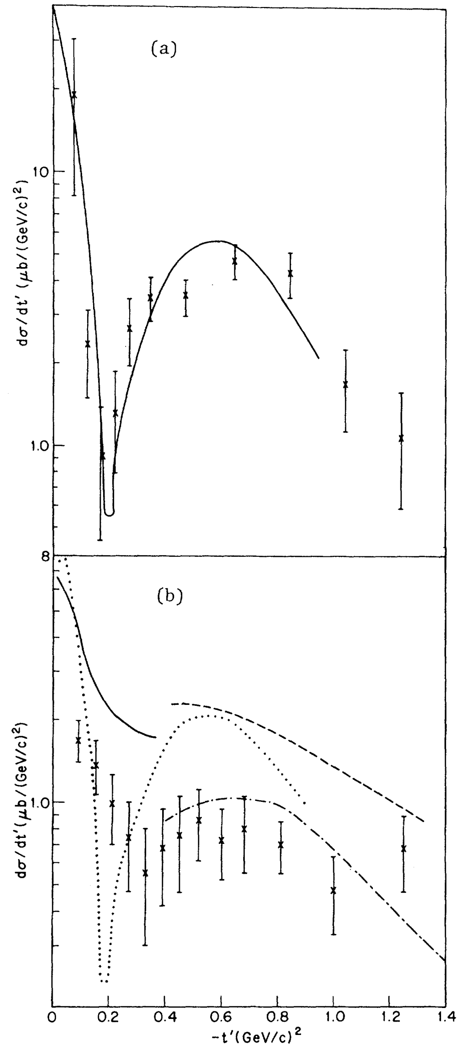

FIG. 3. (a) The measured differential cross section, $d\sigma/dt'$, for $\pi^+p \rightarrow p\pi^+$. The solid line represents the data of Owen *et al.* (Ref. 5). (b) The differential cross section for $\bar{p}p \rightarrow \pi^-\pi^+$. The curves ——, ----, — — — —, and · · · · are for 4-, 5-, and 6.2-GeV/c data (Refs. 6–8) scaled by s^{-2} and for $\pi^+p \rightarrow p\pi^+$ scaled by the line-reversal factor (Refs. 5 and 10).

TABLE I. Results of fits to the $\bar{p}p \to \pi^-\pi^+$ data from this experiment and the $\pi^+p \to p\pi^+$ data from Ref. 5 using $d\sigma/dt' = AJ_0^2(B\sqrt{-t'}) + CJ_1^2(D\sqrt{-t'})$.

Data	A [μb/(GeV/c)^2]	B [(GeV/c)$^{-1}$]	C [μb/(GeV/c)^2]	D [(GeV/c)$^{-1}$]	χ^2 per degree of freedom
$\bar{p}p \to \pi^-\pi^+$	6.6 ± 0.6	8.1 ± 0.3	6.15 ± 0.10	7.8 ± 0.2	0.6
$\pi^+p \to p\pi^+$	38.4 ± 0.9	5.10 ± 0.03	3.2 ± 0.5	5.1 ± 0.2	2.6

intercept at $t'=0$ is much lower, the structure is much less pronounced, and it occurs at a different value of t' (or of t).

Barger and Cline[2] have used isospin arguments and $\pi^\pm p$ backward elastic scattering data to predict the dominance of the N_α trajectory in $\pi^+p \to p\pi^+$. In the absence of absorption, one would expect a dip in the annihilation reaction at the same t as the dip in $\pi^+p \to p\pi^+$ and the normalization for the annihilation to be a factor of ~3 below that for the backward elastic scattering.[10] The absorption model of Harari[13] predicts a dip in $\bar{p}p \to \pi^-\pi^+$ at the same value of t' as the $\pi^+p \to p\pi^+$ dip. Neither of these predictions is borne out by our data. It is difficult to reconcile these data with weak-absorption models where the dips are due to the basic single-exchange amplitude, since very large differences in s-channel absorption would be necessary.

We have fitted the data to the form $d\sigma/dt' = AJ_0^2(B\sqrt{-t'}) + CJ_1^2(D\sqrt{-t'})$. This form contains strongly absorbed nonflip (J_0) and flip (J_1) amplitudes with no interference. The results are presented in Table I. Note that the radii (B and D) are approximately equal for each reaction and that the radii for $\bar{p}p \to \pi^-\pi^+$ are ~1.5 times larger than for $\pi^+p \to p\pi^+$. This is indicative of stronger absorption in the annihilation reaction. Also, the ratio of the nonflip to flip contribution is 12:1 for $\pi^+p \to p\pi^+$ but only 1:1 for $\bar{p}p \to \pi^-\pi^+$.

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