

## Search for Backward $A_1$ and $A_2$ Production in $\pi^- p \rightarrow p \pi^- \pi^+ \pi^-$ at 8 GeV/c\*

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Backward meson production in the reaction  $\pi^- p \rightarrow p \pi^- \pi^+ \pi^-$  has been studied with use of a streamer chamber triggered by the detection of a fast forward proton. For  $\cos\theta^* < -0.98$  we find no evidence of  $A_1$  or  $A_2$  production, and we determine total backward cross-section upper limits (95% confidence) of 0.93 and 0.72  $\mu\text{b}$ , respectively. At  $m_{3\pi} = 1.9 \text{ GeV}/c^2$  we observe a broad enhancement of about 3-standard-deviation significance. Evidence for backward quasi-two-body production is seen in the  $\rho^0 p \pi^-$  and  $f^0 p \pi^-$  channels.

We have studied various channels in the reaction  $\pi^- p \rightarrow p \pi^+ \pi^- \pi^-$  where the event trigger required a fast forward proton. The data were obtained in the University of Illinois-Argonne National Laboratory streamer chamber exposed to an 8-GeV/c pion beam at the zero-gradient synchrotron. We discuss here 799  $p \pi^+ \pi^- \pi^-$  events with  $\cos\theta^* < -0.98$ , where  $\theta^*$  is the angle between the incident  $\pi^-$  and the outgoing three-pion system in the overall center-of-mass system. Events in this kinematic region are expected to have baryon exchange as the dominant production mechanism. We find no evidence for  $A_1$  or  $A_2$  production. We do observe production of the  $\rho^0$  and  $f^0$  in quasi-two-body reactions.

The apparatus, consisting primarily of a streamer chamber<sup>1</sup> and a hodoscope-Cherenkov-count-

er system for selecting fast forward protons, is shown schematically in Fig. 1. The usable volume of the streamer chamber is  $1.5 \text{ m} \times 1.0 \text{ m} \times 0.6 \text{ m}$ . It was placed in a 14.5-kG magnet and photographed in 18° stereo by three cameras. A 3.8-cm-diam  $\times$  30.5-cm-long liquid-hydrogen target enclosed in a foam vacuum box was positioned in the chamber so that about 20 cm of entering beam track and 80 cm of outgoing proton track remained visible.<sup>2</sup>

The event trigger required a beam interaction and a fast forward proton. A beam interaction,  $B_0 H_1 B_1 B_2 B_3 \bar{B}_4 \bar{B}_5$ , was defined by counters  $B_0$  and  $H_1$  at the momentum slit,  $B_1$ ,  $B_2$ , and  $B_3$  in the region of the last beam line magnets, a 3.2-cm-i.d. annular counter  $B_4$  just in front of the target, and  $B_5$  downstream of the streamer cham-

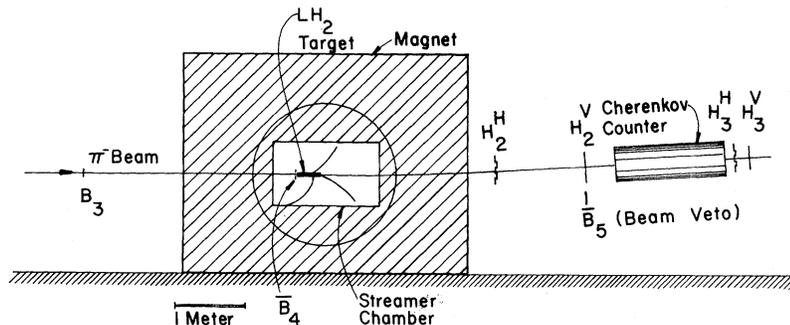


FIG. 1. Schematic elevation view of streamer-chamber spectrometer.  $B_3$ ,  $B_4$ , and  $B_5$  denote scintillation counters.  $H_2^H$ ,  $H_2^V$ ,  $H_3^H$ , and  $H_3^V$  are scintillation hodoscopes at each end of the proton-trigger Cherenkov counter.

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The 44.5-cm-diam threshold Cherenkov counter was located 5 m downstream of the target. Hodoscopes with three vertical ( $H_2^V, H_3^V$ ) and five horizontal ( $H_2^H, H_3^H$ ) elements registered the direction of the trigger particle. A logic matrix selected particles whose directions, had they originated at the center of the target, would have corresponded to a momentum  $\geq 4$  GeV/c. The Cherenkov counter was used as a veto and its pressure was set to reject pions of momentum  $> 1.23$  GeV/c and kaons of momentum  $> 4.4$  GeV/c, while accepting protons up to 8.3 GeV/c.

The acceptance of the proton trigger fixes the range of  $m_{3\pi}$  and  $\cos\theta^*$  which can be investigated. The Cherenkov counter was positioned so that a proton produced in the center of the target at  $\cos\theta^* = -1$  and with a recoil mass of  $1.6$  GeV/c<sup>2</sup> would traverse the central axis of the Cherenkov counter. The resulting proton acceptance is near unity for recoil masses below  $2$  GeV/c<sup>2</sup> when  $\cos\theta^* = -1$ . For constant recoil mass the acceptance falls off smoothly as a function of  $\cos\theta^*$ , and limits our study to  $\cos\theta^* < -0.98$ . Towards higher masses (slower protons) the acceptance changes, and production at  $\cos\theta^* = -1$  can be observed only out to a mass of  $2.5$  GeV/c<sup>2</sup>.

The streamer chamber also has an associated acceptance, which is in general a much more slowly varying function of  $m_{3\pi}$  and  $\cos\theta^*$ . Losses include 13% of events with a secondary track obscured from view by the target box, 13% of events with a secondary going towards the cameras (dip  $> 57^\circ$ ) which flares,<sup>3</sup> and 6% of events with a secondary interaction in the target. The percentages are averages for fitted events with  $\cos\theta^* < -0.98$ .

The 250 000-picture exposure was double scanned and measured on DOLLY, a cathode-ray-tube measuring device.<sup>4</sup> Standard reconstruction and kinematic fitting techniques were used. Because the vertex is not observed, it was determined by extrapolating tracks into the target. In the fits the vector momentum of the beam, and associated errors, were defined by central values of averaged measurements together with the known  $\pm 1.25\%$  momentum bite and  $3$  mrad  $\times 10$  mrad divergences. A  $350\text{-}\mu\text{m}$  setting error in space was consistent with both  $\chi^2$  distributions for four-constraint fits and residuals of the reconstructed helices. The fits also yield a  $3\pi$  mass resolution of  $\pm 15$  MeV/c<sup>2</sup> in the  $A_1$  and  $A_2$  region.<sup>5</sup>

Because of variations in streamer brightness 33% of the four-prong events were unmeasurable.

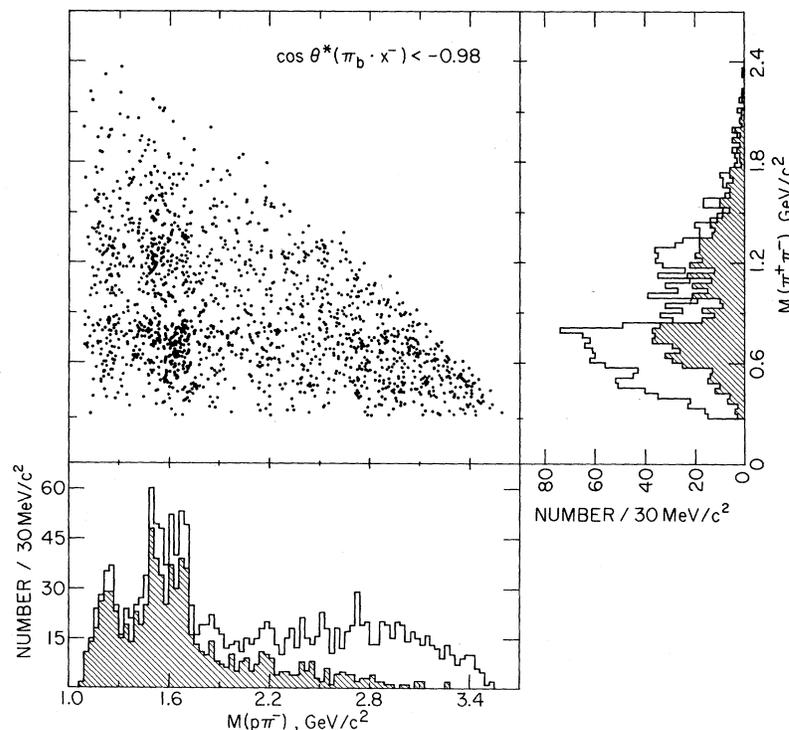


FIG. 2. Scatter plot of the  $\pi^+\pi^-$  invariant mass versus the recoiling- $p\pi^-$  invariant mass (two combinations per event). The shaded projection shows these masses for the more backward  $\pi^+\pi^-$  combination.  $x^-$  represents the  $\pi^+\pi^-\pi^-$  system.

From 27 000 successful measurements, 1227 four-constraint fits<sup>6</sup> were obtained to the final state  $p\pi^+\pi^-\pi^-$ , of which 799 had  $\cos\theta^* < -0.98$ . From the monitoring of the incident pion flux, we obtain a cross-section sensitivity of  $0.85 \pm 0.11$  nb/event for these  $p\pi^+\pi^-\pi^-$  events, not including corrections for the proton-trigger and streamer-chamber acceptances.<sup>7</sup>

Figure 2 shows the  $p\pi^-$ -versus-recoiling- $\pi^+\pi^-$  invariant-mass scatter plot. Several quasi-two-body backward reactions are evident involving  $\rho^0$  or  $f^0$  in conjunction with baryons of mass 1236, 1520, or 1670 MeV/ $c^2$ .

Figure 3(a) shows the  $3\pi$  invariant-mass distribution for the data before and after weighting for the detection efficiency, while Figs. 3(b) and 3(c) show the  $\rho^0\pi^-$  and  $f^0\pi^-$  unweighted mass distributions. The most prominent feature in the  $3\pi$  mass is a 3-standard-deviation departure from a smooth background at  $m_{3\pi} = 1895 \pm 19$  MeV/ $c^2$  with a full width at half-maximum of  $\Gamma = 123 \pm 66$  MeV/ $c^2$ . No corresponding enhancement is prominent in the  $\rho\pi$  or  $f\pi$  channels, nor is there strong overlap of events in this mass region with the quasi-two-body  $N^*\rho$  and  $N^*f$  events. After correction for the acceptance, there remains no significant evidence of peaking in the  $d\sigma/du'$  for any  $3\pi$  mass region, although it should be noted that

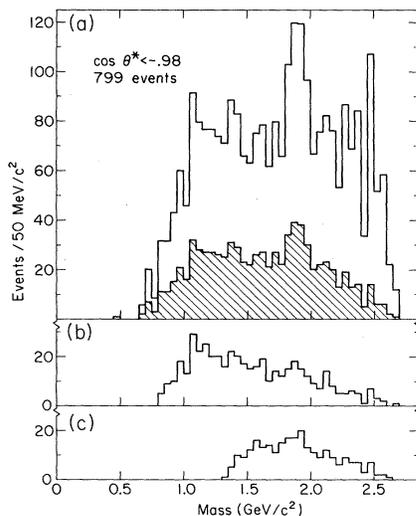


FIG. 3. (a) Histogram of the  $\pi^+\pi^-\pi^-$  invariant mass. The shaded histogram is unweighted and the unshaded histogram is weighted to correct for the proton-trigger and streamer-chamber acceptance losses. (b) Histogram of the  $\pi^+\pi^-\pi^-$  invariant mass if either of the  $\pi^+\pi^-$  invariant-mass combination is a  $\rho$  [ $0.6 < M(\pi^+\pi^-) < 0.9$  GeV/ $c^2$ ]. (c) Histogram of the  $\pi^+\pi^-\pi^-$  invariant mass if either of the  $\pi^+\pi^-$  invariant-mass combinations is an  $f^0$  [ $1.1 < M(\pi^+\pi^-) < 1.4$  GeV/ $c^2$ ].

the value of  $u'$  for  $\cos\theta^* < -0.98$  never exceeds 0.14. This is in contrast with the results of interpreting the events as  $\rho$  or  $f$  plus  $N^*$ , where the corresponding momentum-transfer range is larger and backward peaking is evident.

There is some suggestion, particularly in the  $\rho\pi$  mass plot, of an enhancement in the  $A_1$  region. This observation is weakened in significance by the fact that the  $\rho\pi$  mass distribution of the observed  $N^*\rho$  events shows a broad peak near 1100 MeV/ $c^2$ . We have nevertheless fitted the low-mass part of the  $3\pi$  spectrum with a smooth background plus 100-MeV/ $c^2$ -wide Breit-Wigner resonances at 1100 MeV/ $c^2$  ( $A_1$ ) and 1300 MeV/ $c^2$  ( $A_2$ ). For  $\cos\theta^* < -0.98$  we obtain, after correcting for detection efficiency,  $\sigma(A_1) < 0.157$   $\mu\text{b}$  and  $\sigma(A_2) < 0.082$   $\mu\text{b}$ , both at a 95% confidence level.

In order to obtain limits for the cross sections for  $A_1$  and  $A_2$  production integrated over all  $u$ , we assume that  $d\sigma/du = Ae^{Bu}$ , where  $B$  is taken as<sup>8</sup>  $3.2$  (GeV/ $c$ )<sup>-2</sup> and  $A$  is then calculated from the cross sections with  $\cos\theta^* < -0.98$ .<sup>9</sup> After correcting for the unobserved decay modes, we find that  $\sigma_{A_1}^{\text{tot}} < 0.928$   $\mu\text{b}$  and  $\sigma_{A_2}^{\text{tot}} < 0.715$   $\mu\text{b}$ .<sup>10</sup> These limits are lower than the 95%-confidence-level limits corresponding to the missing-mass experiment of Anderson *et al.*,<sup>11</sup> where the cross sections were both given as  $0.5_{-0.3}^{+0.5}$   $\mu\text{b}$ . Had we removed the events which correspond to the simultaneous production of  $\rho$  and  $N^*$  ( $600$  MeV/ $c^2$   $< m_{\pi^+\pi^-} < 900$  MeV/ $c^2$ ,  $1450$  MeV/ $c^2$   $< m_{p\pi^-} < 1750$  MeV/ $c^2$ ) the  $A_1$  production-cross-section limit would have been  $0.500$   $\mu\text{b}$ .

The backward production of  $A_1$  or  $A_2$  would require the  $u$ -channel exchange of  $I = \frac{3}{2}$  trajectories, while the observed  $N^*\rho$  and  $N^*f$  final states can occur via the exchange of  $I = \frac{1}{2}$  trajectories as well. Thus, our results suggest that  $\Delta$  exchange is suppressed relative to nucleon exchange near  $180^\circ$  in the center-of-mass system at 8-GeV/ $c$  incident momentum.

The construction of the 1.5-m streamer-chamber facility required the enthusiastic contribution of many people. We would like to express our appreciation to B. Cork for his endorsement at a very early stage of development. F. Davenport, J. Sarracino, and C. Dean Wheeler contributed to many areas of development. Technicians D. Dupius, F. Paulis, and C. Smock were invaluable in the development and operation of the hardware. Many developments were possible only because of the contributions of the Argonne National Laboratory engineering staff, in particular J. Dawson, R. Fuja, T. Kovarik, J. Peerson,

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<sup>1</sup>The streamer-chamber system is described in detail by A. Abashian *et al.*, Nucl. Instrum. Methods **115**, 445 (1974).

<sup>2</sup>The streamer chamber had a 3- $\mu$ sec memory time and a 200-msec system dead time. About 1.2 events were recorded during each 600-msec zero-gradient-synchrotron spill with  $2 \times 10^4$  pions incident.

<sup>3</sup>Target obstruction and flaring reduce the solid-angle acceptance of the streamer chamber by 18% from  $4\pi$

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<sup>4</sup>R. M. Brown and R. W. Downing, in Proceedings of the International Conference on Advanced Data Processing for Bubble and Spark Chambers, Argonne, Illinois, 1968, ANL Report No. ANL-7515, 1968 (unpublished), p. 40.

<sup>5</sup>To check the error evaluation, we studied the effective-mass distribution obtained by measuring a sample of  $K^0$  decays and observed a half width at half-maximum of 8 MeV/ $c^2$  consistent with the calculated resolution.

<sup>6</sup>These events remained after cuts on kinematic  $\chi^2$ , vertex  $\chi^2$ , fiducial volume, and measurement quality. The cross-section sensitivity has been adjusted to reflect the ensuing loss of real events.

<sup>7</sup>As a check of cross-section corrections a 12 000-picture exposure taken with a trigger requiring only an interacting beam track was scanned and measured. The corrected four-prong topological cross section was determined and agreed within 10% with bubble-chamber data.

<sup>8</sup>We assume the same slope as for backward  $\pi^-p$  elastic scattering at 8 GeV/ $c$ . See E. W. Anderson *et al.*, Phys. Rev. Lett. **22**, 102 (1969).

<sup>9</sup>The  $\cos\theta^*$  cut restricts  $u$  to the range  $-0.15$  to  $-0.02$  (GeV/ $c$ )<sup>2</sup> for  $m_{3\pi} = 1100$  MeV/ $c^2$  and  $-0.18$  to  $-0.05$  (GeV/ $c$ )<sup>2</sup> for  $m_{3\pi} = 1300$  MeV/ $c^2$ .

<sup>10</sup>The fit gives  $0.466 \pm 0.231 \mu\text{b}$  for the  $A_1$  and  $-0.147 \pm 0.357 \mu\text{b}$  for the  $A_2$ .

<sup>11</sup>E. W. Anderson *et al.*, Phys. Rev. Lett. **22**, 1390 (1969).