good agreement with experiment for $\Lambda = -1.5 \pm 0.5$ (allowing for the uncertainty in the phase shifts). Other π^+ photoproduction experiments[12] have also indicated the need for inclusion of multipion effects, in that the experimental cross sections at large angles were smaller than predicted by CGLN amplitudes with any choice of phase shifts.

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PRODUCTION OF ANTI-ISOBAR, ISOBAR PAIRS IN $\bar{p}$-p COLLISIONS*

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The production of $\bar{N}_1{}^*$, the "anti" of the familiar $T=\frac{3}{2}$, $J=\frac{3}{2}$ pion-nucleon isobar,[1,3] has been observed in a hydrogen bubble chamber study of $\bar{p}$-p interactions.[4] The $\bar{N}_1{}^*$ is produced in association with the $N_1{}^*$, and within our limited statistics, the production process is consistent with single pion exchange. The evidence comes from a study of 304 four-prong events of the type

$$\bar{p}+p\rightarrow\bar{p}+p+\pi^{+}+\pi^{-}. \qquad (1)$$

The momentum of the incident antiproton beam[5] was 3.25 BeV/c, corresponding to a total center-of-mass energy of 2850 MeV. The 304 events were identified by a kinematic fitting procedure[6] applied to a group of four-prong events selected in the following way: A larger group of four-prong events had been analyzed for annihilation studies,[4] but not fitted to Reaction (1). All those four-prong events in the larger group which were not identified as four-pion final states (four-constraint fits), and for which the momentum imbalance of the observed tracks was less than 300 MeV/c, were selected for fitting to Reaction (1). Kinematic identification was confirmed by visual ionization estimates, which usually allowed positive identification of the proton.

Reaction (1) appears to occur primarily via production of a pair of $T=\frac{3}{2}$, $J=\frac{3}{2}$ pion-nucleon isobars:

$$\bar{p}+p \to N_1^{*++} + \bar{N}_1^{*--},$$
$$N_1^{*++} \to \pi^+ + p,\ \bar{N}_1^{*--} \to \pi^- + \bar{p}. \tag{2}$$

This reaction was first predicted by Sternheimer and Lindenbaum.[2]

The mass spectra of the $\pi^+ p$ and the $\pi^- \bar{p}$ combinations are shown in Figs. 1(a) and 1(b). The invariant mass M of a group of particles is defined here by

$$M^2 = (\Sigma_i E_i)^2 - (\Sigma_i \vec{P}_i)^2,$$

where ΣE_i is the total energy and $\Sigma \vec{P}_i$ the resultant momentum of the group. Both spectra are shown, even though charge conjugation invariance predicts that they must be identical, because the appearance of the N_1^* is quite different from that of the $\bar{N}_1^*$ in the laboratory system. Because of the predominance of low-momentum-transfer events, the N_1^* is produced with a wider range of directions than the $\bar{N}_1^*$, which is emitted primarily in the forward direction. In spite of this difference, the agreement between the two spectra is good. Furthermore the spectra are in satisfactory agreement with the accepted values of mass and width of the N_1^* resonance, 1.22 BeV and 0.09 BeV, respectively.[3]

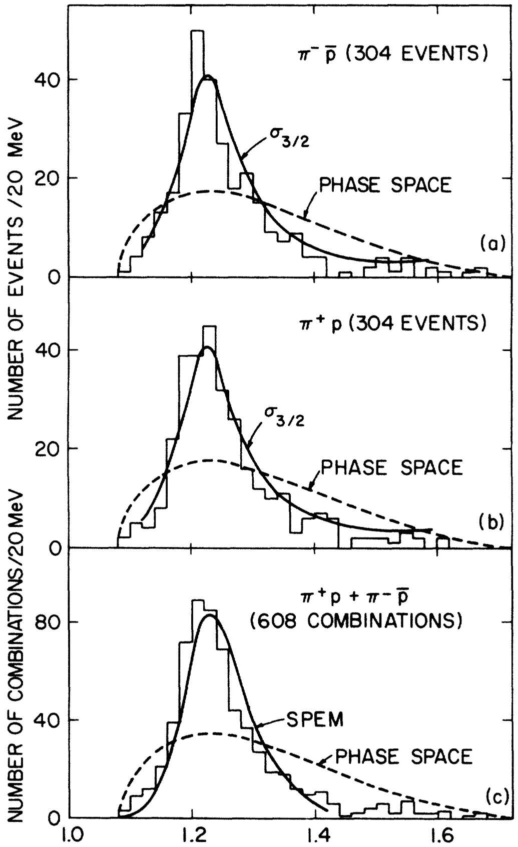

FIG. 1. Spectra of the invariant masses of (a) $\pi^-\bar{p}$, (b) $\pi^+ p$, and (c) the sum of (a) and (b) for the reaction $\bar{p}+p \to \bar{p}+p+\pi^+ +\pi^-$. The phase-space curve is the Lorentz-invariant phase space not assuming production of isobar pairs, and normalized to the total number of events. The $\sigma_{3/2}$ curves represent the $T=\frac{3}{2}$ pion-nucleon cross section normalized to the peak events (1120 to 1380 MeV). The SPEM curve is the spectrum predicted by the single-pion exchange model normalized to the number of peak events.

Sternheimer and Lindenbaum[2] have pointed out that the N_1^* and $\bar{N}_1^*$ effective-mass spectra should be approximately proportional to the $T=\frac{3}{2}$ pion-nucleon scattering cross section, $\sigma_{3/2}$. In Figs. 1(a) and 1(b) the $\sigma_{3/2}$ curves have been normalized to the number of events in the "peak" region, 1120 MeV to 1380 MeV. The experimental distributions are in good agreement with the shape of the $\sigma_{3/2}$ curve and clearly show the influence of N_1^* and $\bar{N}_1^*$ production. The $\pi^+ p$ and $\pi^-\bar{p}$ effective masses are both in the peak region for ~80% of the events. No resonance structure is observed in the effective-mass spectra of the $\pi^+\bar{p}$ and $\pi^- p$ combinations. The cross section for Reaction (1) has been determined to be 3.2 ± 0.3 mb.

It is interesting to compare these results with similar reactions which have been observed in p-p collisions[7] with 2.85-BeV incident protons (2970-MeV total center-of-mass energy). The cross section for the process

$$p+p \to p+p+\pi^+ +\pi^- \tag{3}$$

was found to be 2.67 ± 0.13 mb. Reaction (3) has been shown[7] to involve peripheral collisions and production of both N_1^* and the higher $T=\frac{1}{2}$ pion-nucleon resonances.

Figure 2 shows the dependence of the cross section on the square of the four-momentum transfer Δ^2. Here Δ is defined as the four-momentum transfer to the $\pi^+ p$ system. The boundary of the physical region for Δ^2 for the case of a pair of isobars of mass 1220 MeV is 0.11 $(\mathrm{BeV}/c)^2$. This limit is indicated by an arrow in Fig. 2. The Δ^2 spectrum of the events is in qualitative agreement with a curve of the form $(\Delta^2 + M_\pi^{\,2})^{-2}$. The curve has been normalized to the number of events with $\Delta^2 > 0.11$ $(\mathrm{BeV}/c)^2$. In the physical region Δ^2 is much larger than $M_\pi^{\,2}$, so the curve is not very sensitive to the choice of $M_\pi^{\,2}$ [as compared with $(2M_\pi)^2$, for example].

In the following the experimental results are

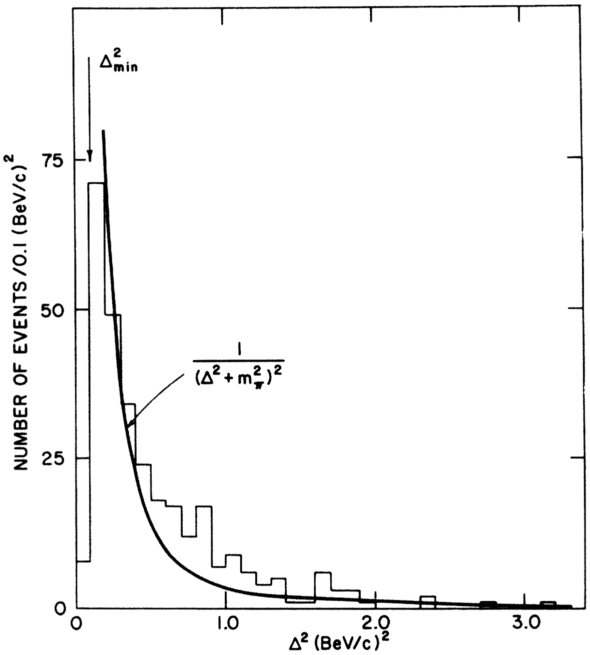

FIG. 2. The distribution of the square of the four-momentum transfer to the π^+p system. A comparison curve $(\Delta^2+M_\pi^2)^{-2}$ is shown normalized to the number of events having $\Delta^2 > 0.11$ (BeV/c)^2.

compared with some of the consequences of the single-pion exchange model (SPEM) for isobar pair production. The dominant diagram is expected to be that illustrated in Fig. 3.

Salzman and Salzman[8] have studied the single-pion exchange model with the assumption that the cross section for the interaction of the virtual pion with the nucleon is equal to that for a real pion, at the same total energy of the pion-nucleon system. The shape of the mass spectrum of the π^+p and $\pi^-\bar{p}$ combinations has been calculated according to the theory of reference 8. The resulting SPEM curve, shown in Fig. 1(c), has been normalized to the number of events in the peak region. The SPEM prediction is very similar to the $\sigma_{3/2}$ curve, and like $\sigma_{3/2}$, is an adequate representation of the experimental spectrum.

A more rigorous test of the single-pion exchange theory has been proposed by Treiman and Yang.[9] Following their procedure, the angle α_I for the π^+p combination (isobar decay) is defined by

$$\cos\alpha_I = (\vec{k}_{\rm inc} \times \vec{k}_{\bar{I}}) \cdot (\vec{k}_p \times \vec{k}_{\pi^+}) / |(\vec{k}_{\rm inc} \times \vec{k}_{\bar{I}})| \cdot |(\vec{k}_p \times \vec{k}_{\pi^+})|, \tag{4}$$

where $\vec{k}_{\rm inc}$, $\vec{k}_{\bar{I}}$, $\vec{k}_p$, and $\vec{k}_{\pi^+}$ are unit vectors in the directions of the incident $\bar{p}$, the outgoing $\pi^-\bar{p}$ resultant momentum, the outgoing proton, and π^+ meson, respectively. All of these vectors are defined in the laboratory system. Because the exchanged pion is a spinless particle, all experimental distributions must be independent of α_I. In an exactly analogous way we define $\cos\alpha_{\bar{I}}$ for the $\pi^-\bar{p}$ combination (anti-isobar decay). In so doing, the vectors occurring in the analog of (4) are defined in the frame of reference in which the incident antiproton is at rest. Because of parity

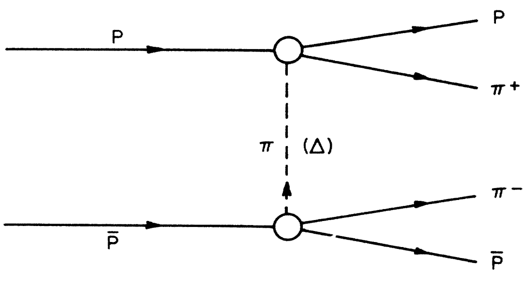

FIG. 3. Diagram for single-pion exchange.

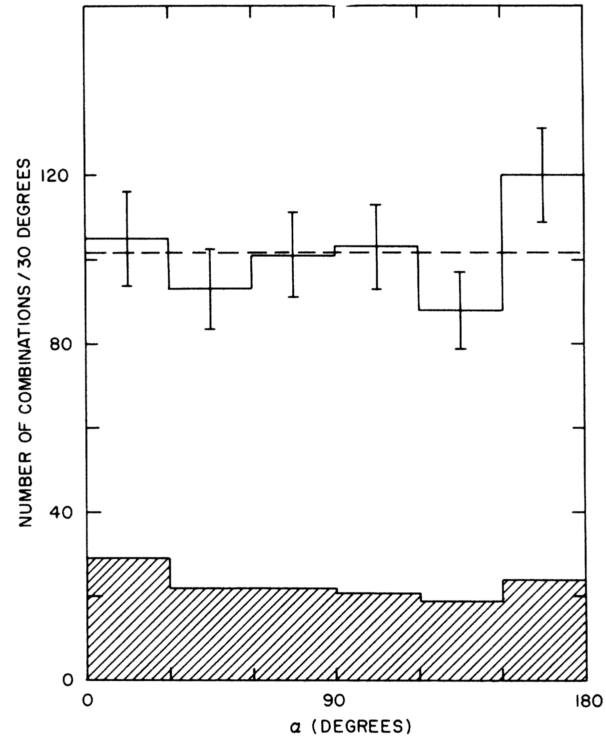

FIG. 4. The distribution of the angle of rotation about the direction of the momentum transfer (Treiman-Yang angle) folded about 0°. The shaded area corresponds to the events in which either the π^+p or $\pi^-\bar{p}$ mass lies outside the peak region (1120 to 1380 MeV). The mean number of events per interval is indicated by the dashed line.

conservation in the strong production reaction (1), α can be defined meaningfully only for a range of 180°. At present the number of events is sufficient only for the study of the distribution in α rather than the study of the dependence of other distributions on α. The distributions in α_I and $\alpha_{\bar{I}}$ must be the same because of charge-conjugation invariance of (1), but they are statistically independent so they may be added together. The results are shown in Fig. 4 for the peak and nonpeak events. Both distributions are consistent with isotropy. This result is a necessary but not sufficient condition for the validity of the single-pion exchange model.

Further studies of Reaction (1) with increased statistics are in progress including more detailed studies of decay angular distributions and correlations and more detailed comparison with the single-pion exchange theory.

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DETECTION OF NUCLEAR DISINTEGRATIONS PRODUCED BY 1.55-BeV PROTONS IN SILVER CHLORIDE SINGLE CRYSTALS*

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A new technique which makes the tracks of heavy primary cosmic rays visible in transparent silver chloride single crystals has recently been developed.[1] The purpose of this note is to point out that it is possible to apply this method to the study of nuclear disintegrations produced by particles accelerated in high-energy machines. After exposure, each crystal is subjected to a synchronous pulsed electric field and ultraviolet light for two hours. Photoelectrons are swept into the interior and are trapped at the imperfections formed in the paths of energetic particles. These electrons in turn trap interstitial silver ions, forming metallic silver and thereby delineating the path of the particle.

Silver chloride single crystals were prepared as previously described and at room temperature were exposed to the Brookhaven Cosmotron 1.55-BeV proton beam, to an integrated flux of about 10^8 protons/cm^2. Several days later the crystals