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[2]S. L. Adler, unpublished.

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[4]Instead of the time-ordered product, the retarded commutator could be used. This is advantageous for the energy averaging problem (see references 2 and 3).

[5]This approximation can be avoided by accepting the existence of short-range integral operators M and M^{-1} such that $MG_0M = G_{00}$. Then $G' = MGM$ satisfies

$$G' = G_{00} - iG_{00}V'G',$$

with $V' = M^{-1}VM^{-1}$. The subsequent development proceeds with G' and V' replacing G and V. Equations (9), (10), and (11) finally contain V' instead of V and their right-hand sides are multiplied by $M^{-2}(q^2)$, a factor which for $q^2 = -m_\pi^2$ is unity and for $q^2 > -m_\pi^2$ is real, positive, nonzero, nonsingular, and independent of nuclear size.

[6]To prove this "off-the-mass-shell optical theorem" write $\chi = \Psi - \exp(i\vec{q}\cdot\vec{x})$ so that Eq. (12) becomes

$$(\nabla^2 - m_\pi^2 + q_0^2)\chi = V\Psi,$$

whence

$$2\int d\vec{s}\, \mathrm{Im}\chi^*\nabla\chi = 2\,\mathrm{Im}\int d\vec{x}(\Psi^*V\Psi - e^{-i\vec{q}\cdot\vec{x}}V\Psi)$$

where the first integral is over a distant surface and the second over the enclosed volume. The last term is Γ of Eq. (9); the other term on the right is $-\Gamma_a$ of Eq. (11); on using the asymptotic form of χ the right-hand side is seen to equal Γ_e of Eq. (10).

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DIFFERENTIAL AND TOTAL CROSS SECTION FOR THE REACTION $p+p \to d+\pi^+$*

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The differential cross section for the reaction $p+p \to d+\pi^+$ has been measured with scintillation counters for incident proton kinetic energies of 1.3, 1.5, 1.7, 2.0, 2.5, and 2.8 BeV, using the external proton beam of the Cosmotron of the Brookhaven National Laboratory. Values of $d\sigma/d\Omega$ with a total uncertainty of ±11% are given for barycentric deuteron angles, θ, for $0 \leq \cos\theta \leq -0.97$ in small intervals of $\cos\theta$. The primary interest of the authors in this reaction is that it is one of the few two-body reactions in high-energy particle physics, and therefore might provide both a stimulus and a test for dynamical theories of particle interactions. Perl, Jones, and Ting[1] have pointed out that the simplest Feynman diagram for this reaction is a one-nucleon exchange, while Chahoud, Russo, and Selleri[2] and Yao[3] have studied the reaction in terms of a one-pion-exchange model. A further interest stems from the results of Turkot, Collins, and Fujii[4] and Cocconi et al.[5] who measured a single point in the differential cross section near 0° at various energies. Their combined results when plotted versus energy[5] show a peak in the forward differential cross section at 2.5-BeV incident kinetic energy.

The reaction occurred in a three-inch-long liquid hydrogen target. The detection apparatus consisted of two scintillation-counter telescopes, one consisting of two counters to detect the pion, and the other of six counters (two parallel channels of three each) to detect the deuteron. The solid angle subtended from the target was determined by the first counter in the pion telescope. Depending on this counter size and its distance from the target, the solid angle varied from 0.035 to 0.87 millisteradians. The deuteron telescope channel included a magnet providing a 10° deflection of the emergent deuterons, and a flight path of 53 feet from the target to the last counter. Both counter telescopes and the magnet were movable to allow them to be set for any desired pion and deuteron angle. In the deuteron channel the magnetic momentum selection combined with the time-of-flight selection separated the deuterons from pions and protons up to 2.4 BeV/c. This selection, combined with the required pion channel coincidence, identified the desired events which comprise 0.05% to 0.5% of the total pp cross section in this energy interval.

Numerous checks to verify that the events detected indeed corresponded to the π^+d final state included deuteron time-of-flight delay curves, magnet current curves, and measurement of the angular correlations of the pion and deuteron angles. For lower incident energies it was also possible to measure $d\sigma/d\Omega$ for backward pion angles and verify the symmetry of the reaction about 90° c.m. The beam rate was set by the requirement that accidental events be less than 10% of the good events. Nuclear interactions of the deuterons and pions, beam attenuation in the target, multiple Coulomb scattering, counter efficiencies, counter dead time, and background from the empty target resulted in a net correction of 1.16 to 1.18 ± 0.05. The normalization, using the reaction $C^{12}(p,pn)C^{11}$, had an uncertainty of ±7%, leading to an overall nonstatistical uncertainty of ±9%.

The results are shown in Fig. 1, where the error bars indicate the standard deviation from counting statistics. The points of reference 4 are also indicated. The resulting total cross

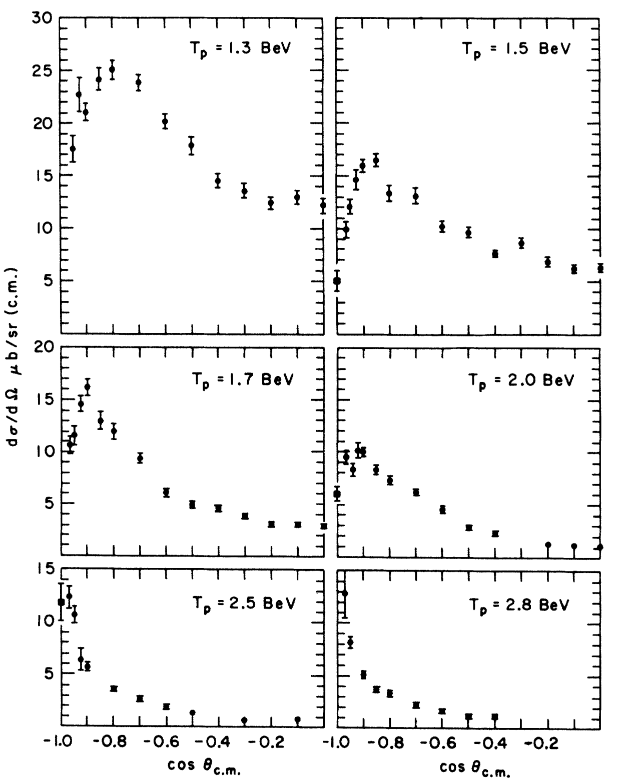

FIG. 1. Differential cross sections for the reaction $p+p\rightarrow d+\pi^+$ in microbarns per steradian (center of mass) plotted vs cosine θ of the deuteron (center of mass). The data from this experiment are shown as circles, where the errors are standard deviations from counting statistics. The zero-degree data from reference 4 are indicated by squares.

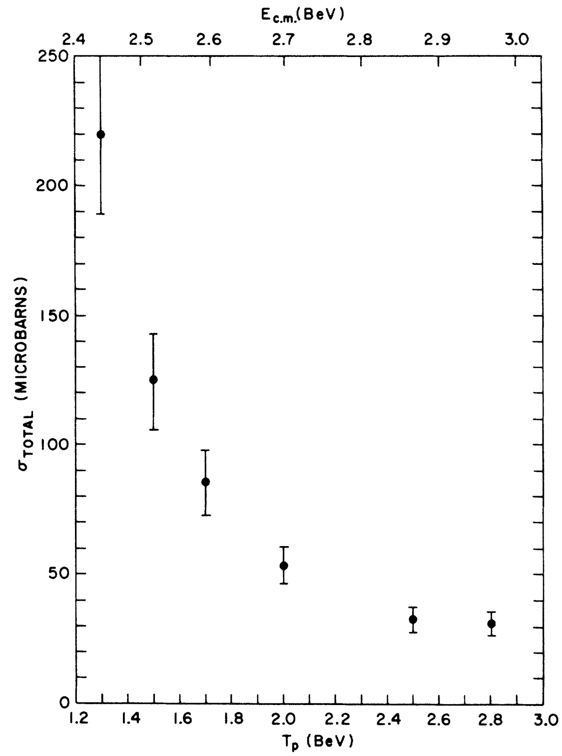

FIG. 2. Total cross sections for the reaction $p+p\rightarrow d+\pi^+$ derived from the differential cross sections measured in this experiment. The error flags include the uncertainty in the shape of the differential cross section and the 11% uncertainty in the normalization (see text). The abscissa is given as incident proton kinetic energy (bottom) and total center-of-mass energy (top).

sections are shown in Fig. 2. The value at 2.0 BeV is in agreement with a bubble chamber determination by Sechi-Zorn.[6]

The most striking feature of the angular distribution appears in the energy range between 1.3 and 2.0 BeV. As $\cos\theta$ varies from -0.5 to -1.0 the differential cross section rises, passes through a pronounced maximum, and then decreases rapidly. This maximum in $d\sigma/d\Omega$ appears to migrate from $\cos\theta = -0.80$ at 1.3 BeV to almost -1.0 at 2.0 BeV. At 2.5 and 2.8 BeV there is no indication of this turnover; the cross section simply rises rapidly as $\cos\theta$ approaches -1.0. At considerably lower energies this turnover is also not seen. For example, at 660 MeV, Mescheryakov et al.[7] find the differential cross section for this reaction rises to a broad maximum at $\cos\theta = -1.0$. The cross section near 90°, however, decreases rapidly and monotonically with energy from 12 μb/sr at 1.3 BeV to less than 1 μb/sr at 2.8 BeV. Finally, the total cross section (Fig. 2) decreases monotonically with energy. Thus, the maximum in the forward differential cross section seen from combining the data of Turkot, Collins, and Fujii and Cocconi et al. is caused by the energy dependence of the angular distribution and is not indicative of any maximum in the total cross section.

The narrow width of the peak at $\cos\theta = -1$ above 2.0 BeV suggests a peripheral interaction such as a one-nucleon exchange.[1] The energy dependence of $d\sigma/d\Omega$ near 90°, coupled with the smoothly varying angular distribution near 90°, is similar to the behavior observed in high-energy pp elastic scattering,[8] and thus is suggestive of a statistical interpretation.[9]

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STUDY OF $S = -2$ BARYON SYSTEMS UP TO 2 BeV*

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In this Letter we present evidence for existence of an 1810-MeV, $S = -2$ baryon state. During an extensive exposure of the 72-in. hydrogen bubble chamber to a separated beam of K^- at incident momenta of 2.45, 2.64, and 2.70 BeV/c, approximately 380 000 pictures have been taken, with 6 to 7 K^-'s and 1 to 2 π^-'s per picture. The 2.64- and 2.70-BeV/c momenta comprise 75% of the total K^- path length. The reactions of interest in this discussion are these:

$$K^- + p \to \Xi^- + K^{+,0} + \pi^{0,+} \quad (1)$$

$$\to \Xi^0 + K^+ + \pi^- \quad (2)$$

$$\to \Lambda^0 + K^0 + \bar{K}^0 \quad (3)$$

$$\to \Lambda^0 + K^+ + K^- \quad (4)$$

$$\to \Sigma^+ + K^0 + K^- \quad (5)$$

$$\to \Sigma^- + K^+ + \bar{K}^0 \quad (6)$$

$$\to \Xi^- + K^{0,+} + \pi^{0,-} + \pi^+ \quad (7)$$

$$\to \Xi^0 + K^0 + \pi^+ + \pi^- \quad (8)$$

$$\to \Xi^- + K^+ + \text{neutrals } (>\pi^0) \quad (9)$$

$$\to \Xi^0 + K^0 + \text{neutrals} \quad (10)$$

$$\to \Lambda^0 + \bar{K}^0 + K^{0,+} + \pi^{0,-} \quad (11)$$

$$\to \Lambda^0 + K^- + K^{0,+} + \pi^{+,0}. \quad (12)$$

We first consider the three kinematically fitted four-body final states of (7) and (8), $\Xi^-K^+\pi^-\pi^+$, $\Xi^-K^0\pi^0\pi^+$, and $\Xi^0K^0\pi^+\pi^-$.[1] Figure 1(a) shows a Dalitz plot of $M^2(\Xi^{-,0}\pi^{\pm})$ versus $M^2(\Xi^{-,0}\pi^{\mp})$ for the $\Xi^-K^+\pi^-\pi^+$ and $\Xi^0K^0\pi^+\pi^-$ final states. These two have been grouped together, since each reaction has only one $\Xi\pi$ pair in the $t_z = \pm\frac{1}{2}$ state. We see that both final states are dominated by the $\Xi_{1/2}$*(1530 MeV).[2] The pure $T = \frac{3}{2}$ system ($\Xi^-\pi^- + \Xi^0\pi^+$) shows no particular structure.[3] In Fig. 1(b) we have plotted $M^2(\Xi^-\pi^+)$ versus $M^2(\Xi^-\pi^0)$ for $\Xi^-K^0\pi^0\pi^+$. In this case, both $\Xi\pi$ systems have $t_z = \pm\frac{1}{2}$; two orthogonal bands centered at 1530 MeV are evident on this plot. We conclude that the combined three final states involve the production of Ξ*(1530) in approximately