Helicity Nonconservation in the Reaction $dp \to dp\pi^+\pi^-$ at 25 GeV/c*

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We observe the reaction $dp \to d(p\pi^+\pi^-)$ which allows no exchange of isospin between beam and target particles and therefore may approximate pure diffractive dissociation at this energy. The decay of the $p\pi^+\pi^-$ system is not azimuthally isotropic around its direction in the overall c.m. frame, vitiating its interpretation as a fireball. Both s- and t-channel helicity conservation fail for the process.

In spite of its long history, the concept of diffraction dissociation in strong interactions is still rather poorly defined and even less well understood. Two supposed characteristics of diffraction dissociation are no quantum-number exchange (except angular momentum) and small momentum transfer between beam and target particles. In an effort to isolate such a process we have investigated the reaction

$$dp \to dp\pi^+\pi^- \qquad (1)$$

using a 25-GeV/c deuteron beam in the Brookhaven National Laboratory 80-in. hydrogen bubble chamber. The reaction is characterized by very small t values (four-momentum transfer from d to d) and allows no exchange of charge, baryon number, strangeness, or isospin. These features make it a good candidate for a reaction which has already approached an energy-independent limit at our energy.

We chose to use a deuteron beam on a hydrogen target rather than vice versa because of the ease with which high-momentum final-state deuterons can be identified in the bubble chamber. The deuterons from Reaction (1) retain nearly all of the 25-GeV/c beam momentum whereas protons from the much more copious reactions in which the deuteron breaks up are centered around 12.5 GeV/c. This technique allows us to positively identify deuterons at all t values without resorting to kinematic fitting.

The deuterons were produced off an internal target at the alternating-gradient synchrotron and were separated magnetically by making use of the fact that they can have a *higher* momentum than the internal beam.[1] In this way a beam of >99% purity was achieved.

The exposure consisted of 250 000 pictures which produced a sensitivity of ~4.5 events/μb. All four-prong events with a positive track of ≥8 GeV/c and a proton of ≤1 GeV/c were measured. The measurers imposed these cuts using an on-line three-point curvature measurement. The distribution in (unfitted) momentum "P_d" of the fast positive track for a sample of such events is shown in Fig. 1(a). It shows a clear deuteron peak centered near the beam momentum and a much larger proton peak from breakup reactions. This shows that very few breakup protons have true momentum >20 GeV/c. As an independent check on the event identification we show in Fig. 1(b) the distribution in missing mass above the $p\pi^+\pi^-$ for all events with "P_d" ≥ 20 GeV/c. Such

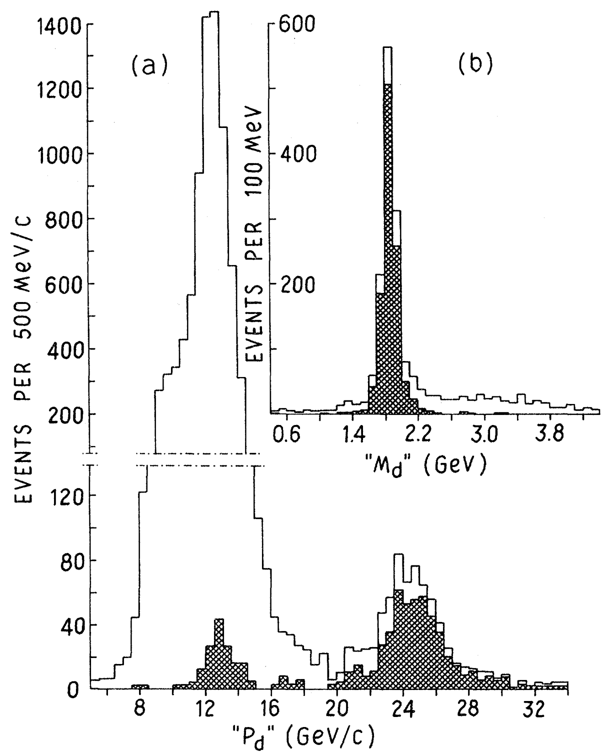

FIG. 1. (a) Distribution of momentum "P_d" of the highest-momentum positive track from a sample of events where the length of the "P_d" track is >75 cm. (b) Distribution of missing mass for all events with "P_d" >20 GeV/c. Shaded events fit Reaction (1).

plots give us confidence that we can select an essentially complete sample of Reaction (1) with negligible contamination by requiring a four-constraint fit with (1) and "P_d" > 20 GeV/c.

We have 1096 such events that fit Reaction (1) with a confidence level >0.5%. We find a cross section of 360 ± 30 μb for the process at our energy (equivalent to 12.5-GeV/c protons on deuterons). This cross section can be compared to 250 ± 25 μb found at 7 GeV/c (p on d) for the same reaction.[2] The difference between these two values can be accounted for by the kinematic $t_{\min}$ suppression factor,[3] indicating that the cross section may be close to its maximum value at our energy. If we are seeing pure diffraction dissociation at our energy then the cross section should remain approximately the same at very high energies.

There is a portion of cross section (~ 35% in our case) which *is* expected to decrease with energy and that is the so-called d^* phenomenon. The d^* can be described by one of the final-state pions trying to make a Δ(1238) with one of the nucleons in the deuteron.[4] Although estimating the d^* cross section is subject to some uncertainty, particularly for the low-momentum data, it has roughly the same value at 7 GeV/c and at our energy. By use of a $t_{\min}$ correction factor[3] one then concludes that the corrected cross section for d^* production is definitely falling over this energy range. At our energy the d^* produces a sharp peak at the bottom of the $\pi^- d$ invariant mass plot [Fig. 2(a)] so that these events can be removed by a simple mass cut with little effect on the sample of diffractive events. The remainder of the paper will deal with 708 diffractive (non-d^*) events which we select by requiring $M(d\pi^-) > 2.5$ GeV. Making a cut on cosθ of the π^- gives essentially equivalent results [Fig. 2(b)].

The invariant mass spectrum[3] of the $p\pi^+\pi^-$ system is shown in Fig. 3(a). It shows a low-mass peak in the 1350–1500-MeV region but very little evidence for another peak around the 1700-MeV N^* region that has been seen in several high-energy pp, πp, and Kp experiments[5,6] and also in lower-energy pd[2] and $\bar{p}d$[7] experiments.

The differential production cross section $d\sigma/dt'$ (where $t' = t - t_{\min}$) for our data is well described by a simple exponential in t' with a slope of 34.5 ± 1.5 GeV^{-2}. Experiments which use a deuteron target have problems identifying events with $-t'$ < 0.05 GeV^2. There is no such loss in our case,

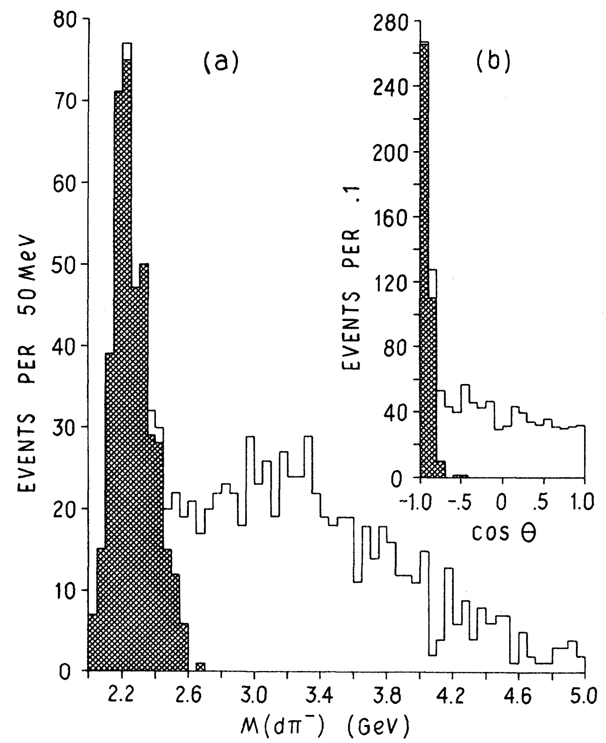

FIG. 2. (a) Distribution of $d\pi^-$ invariant mass, showing the d^* effect. Shaded events have cos $\theta < -0.85$, where θ is the π^- polar angle in the helicity frame. (b) Distribution of cos θ showing events with $M(d\pi^-) < 2.5$ GeV shaded.

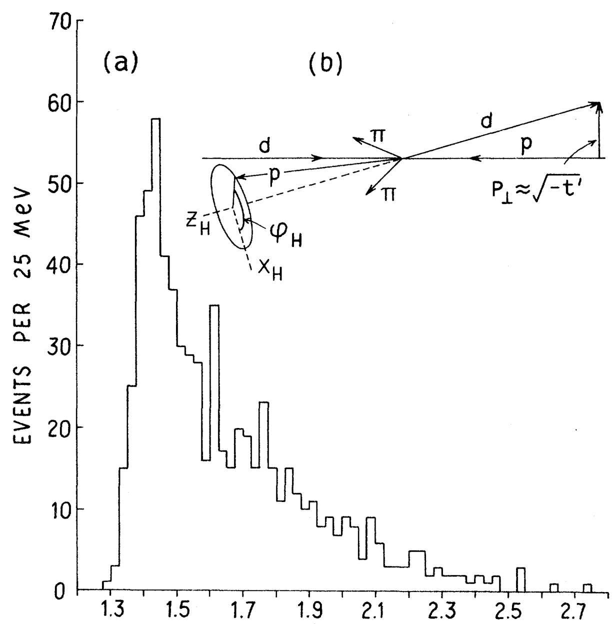

FIG. 3. (a) Distribution of $p\pi^+\pi^-$ invariant mass for non-d^* events [$M(d\pi^-) > 2.5$ GeV]. (b) Momentum vector diagram of a typical event in the overall c.m. frame showing the helicity-frame x and z axes and the φ_H angle of the proton.

and since 77% of our events have $-t' < 0.05$ GeV^2, our events have much smaller average $|t'|$ than other pd data.

We now turn to the question of helicity conservation. In spite of much theoretical and experimental effort on this question, no clear picture seems to emerge.[8] s-channel helicity conservation (SCHC) appears to hold for π-N elastic scattering and ρ^0 photoproduction whereas $\pi \to A_1$ and $K \to Q$ diffractive production favors t-channel helicity conservation (TCHC). In $pp \to pp\pi^+\pi^-$ at 16 GeV/c it was concluded that SCHC fails but that TCHC might be satisfied for $p\pi^+\pi^-$ masses above 1.6 GeV.[5] A similar conclusion was reached for $\pi^\pm p \to \pi^\pm p\pi^+\pi^-$.[9] Since our reaction does not allow isospin exchange, which can significantly affect angular distributions at these energies, it is important to make an independent test of SCHC and TCHC with our data. The simplest test for *failure* of TCHC or SCHC is to look for anisotropy of the outgoing particles in azimuthal angle φ_J or φ_H about the Gottfried-Jackson– or the helicity-frame z axes. These axes are defined in the $p\pi^+\pi^-$ c.m. system along the incoming proton and negative outgoing deuteron directions, respectively. The y axes are given by $\vec{d}_{in} \times \vec{d}_{out}$ in both cases. The two coordinate systems coincide at $t' = 0$. The distributions in φ_H and φ_J for both the proton and π^- are shown in Fig. 4. It is apparent that both SCHC and TCHC are violated by both particles. These conclusions are not weakened by uncertainties about the d^* cut. The d^* events can be cleanly removed by making cuts on the polar angle of the π^- in the helicity or Gottfried-Jackson frames [see Fig. 2(b)] and then the φ distributions of the π^- should still be symmetric for the remaining polar angles, which they clearly are not (not shown).

We have investigated separately the φ distributions for the low-mass region $M(p\pi^+\pi^-) < 1.6$ GeV and the high-mass region $1.6 < M(p\pi^+\pi^-) < 2.0$ GeV and find no significant dependence of the shape of the distributions on mass. *Thus TCHC and SCHC fail for all masses up to at least 2.0 GeV.* It is not clear at this point how one might translate these φ anisotropies into a measure of the nonconserving amplitudes.

The nonflat φ_H distributions would seem to bode ill for some currently popular models[10] which describe high-energy multiparticle production in terms of one or two "fireballs." In the context of such models our reaction would be a clear example of the deuteron exciting a single fireball which then decays into $p\pi^+\pi^-$. Our φ_H angles are the

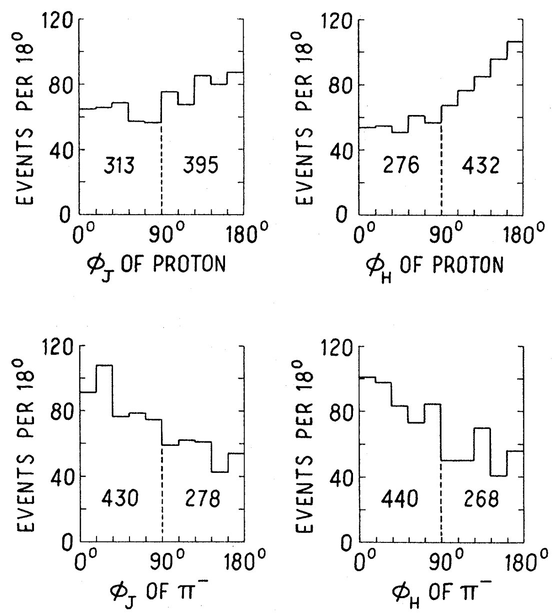

FIG. 4. Distributions in azimuthal angles of the proton and π^- in the Gottfried-Jackson (φ_J) and helicity frames (φ_H) for non-d^* events. Numbers indicate the events in each half of each distribution. The flattest distribution (upper left) is 3 standard deviations from having equally populated halves.

azimuthal angles of the fireball decay products around the z axis chosen along the fireball's direction in the overall c.m. [see Fig. 3(b)]. Figure 4 proves that the fireball decays nonisotropically and nonflat azimuthally about the helicity-frame z axis. We of course have no proof that the process has reached its asymptotic limit of our energy but if the reaction scales with energy (i.e., if $d\sigma/dp_\perp^2 dx$ for the p, π^+, and π^- are functions only of $p_\perp$ and x) *then this azimuthal anisotropy will be the same at higher energies*, and the fireball models will have to accomodate it somehow.

Referring to Fig. 3(b) one sees that the tendency of the protons to peak toward $\varphi_H = 180°$ means the outgoing proton has a preference to stay close to the incoming proton's direction in the overall c.m. This effect has been noted before[11] and we speculate that similar φ_H peaking is a general property of leading particles or any particles with large $|x|$ in the overall c.m., making life difficult for fireball models.

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[1]J. C. Vander Velde and H. Foelsche, "Proposal to Extract a Deuteron Beam from the AGS" (unpublished).

[2]U. Karshon *et al.*, Nucl. Phys. B37, 371 (1972).

[3]The $p\pi^+\pi^-$ mass spectrum is undoubtedly suppressed at the high end by the effect of the increase of t_{min} with M. At $M=2.0$ GeV, for example, the suppression factor would be of the order $\exp(35t_{min})=0.58$. Our observed mass spectrum falls off much faster than this suppression factor, indicating that for $M<2.0$ GeV the cross section may have approximately reached its limiting value at our energy. If we integrate the reciprocal of the suppression factor over our observed mass spectrum up to 1.8 GeV we find an average correction factor of 1.13 at our energy and 1.58 for the 7-GeV/c pd experiment of Ref. 2. We have not included a correction for this suppression factor in our quoted cross section. We have included a 2.3% correction due to our slow proton cut of 1.0 GeV/c.

[4]The d^* effect has been treated theoretically, for example, by D. Evrard, A. Fridman, and C. C. Hirshfeld, Nucl. Phys. B14, 699 (1969). See also Ref. 2 and P. Antich *et al.*, Nucl. Phys. B29, 327 (1971); H. Braun *et al.*, Phys. Rev. D 2, 1212 (1970).

[5]J. G. Rushbrooke *et al.*, Nucl. Phys. B35, 1 (1971).

[6]R. Morse *et al.*, Phys. Rev. D 4, 133 (1971); Aachen-Berlin-CERN-London-Vienna Collaboration, Nucl. Phys. B33, 445 (1971), and B35, 61 (1971).

[7]Antich *et al.*, Ref. 4; Braun *et al.*, Ref. 4.

[8]For a recent discussion of helicity conservation, see D. Leith, in Proceedings of the Sixteenth International Conference on High Energy Physics, National Accelerator Laboratory, Batavia, Illinois, 1972 (to be published).

[9]J. W. Lamsa *et al.*, Nucl. Phys. B37, 364 (1972).

[10]G. Cocconi, Phys. Rev. 111, 1699 (1958); R. K. Adair, Phys. Rev. 172, 1370 (1968), and to be published; R. C. Hwa and C. S. Lam, Phys. Rev. Lett. 27, 1098 (1971); M. Jacob and R. Slansky, Phys. Rev. D 5, 1847 (1972).

[11]See Ref. 2 and also H. Satz and K. Schilling, Lett. Nuovo Cimento, 1, 351 (1971).

n-Particle Cross Sections in Diffraction-Production Models

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We show how a simple t_{min} effect can significantly alter the $\sigma_n \sim 1/n^2$ rule found in most diffractive models of particle production. Data on pp, π^-p, and K^-p collisions appear consistent with $n^2\sigma_n \sim \exp(-n^4/s)$, which implies that (1) double diffraction dissociation is the dominant feature, and (2) $\langle n\rangle \sim \ln s$, but correlation functions rise much more slowly than in earlier treatments. Critical comments on diffractive models are given.

In this short note we would like to comment on the relationship between the observed cross sections $\sigma_n(s)$ for production of n charged particles at incident energy $s \approx 2P_{lab}$ and the variety of diffractive production[1] or nova[2] models. These models have as one of their simple common features a large-n behavior of $\sigma_n(s)$ at fixed s which is

$$\sigma_n(s) \underset{\text{fixed } s}{\sim} \frac{1}{n^2}. \tag{1}$$

This is built in so that the average multiplicity is

$$\langle n\rangle = \sum^{\sqrt{s}} n\sigma_n \sim \ln s. \tag{2}$$

Naively, the experimental results[3] for σ_n at $P_{lab}=50$, 69, 100, 200, and 300 GeV/c incident momenta for charged particles produced in pp collisions would appear to reduce considerably the credibility of such models. In Fig. 1 we have plotted the observed $n^2\sigma_n$ versus n^4 at each of the mentioned energies. If $\sigma_n \sim 1/n^2$, one should see a *horizontal line;* one does not.

This effect is not restricted to charged-particle distributions from pp collisions. In Fig. 2 we show[4] σ_n for π^-p collisions at a π^- lab momentum of 50 GeV/c and σ_n for K^-p interactions at 33.8 GeV/c. Each of these is presented as $n^2\sigma_n$ plotted against n^4; once again exponential deviations from the simplest expectation are observed.

As has also been noted by Hwa,[5] there is at least one piece of the physics, even within the diffractive models, which has been omitted from a straightforward $\sigma_n \sim 1/n^2$. Namely, when one