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BACKWARD SCATTERING IN THE REACTION $\pi^+ n \to \Delta^{++}(1238)\pi^-$ FROM 1.9 TO 2.5 GeV/c*

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ABSTRACT

We have measured differential cross sections and decay distributions for the reaction $\pi^+ n \to \Delta^{++}(1238)\pi^-$ over a center of mass energy range 2.1 to 2.4 GeV. We have observed backward peaking in the differential cross section with a dip in the extreme backward direction. We observe decay distributions inconsistent with simple unmodified $J = 1/2$ baryon exchange in the u-channel. The dip is caused by strong helicity 3/2 amplitudes which must vanish in the extreme backward direction.

Backward peaking has been observed in the charge symmetric reaction $\pi^- p \to \Delta^- \pi^+$ by Anthony et al. [1]) at 2.15 GeV/c who examine the c.m. production angle cosine interval $-0.999 < \text{cospro}(\pi^-_{in}, \pi^+_{out}) < -0.950$. This group observes a dip in the production distribution in the backward direction $-0.999 < \text{cospro}(\pi^-_{in}, \pi^+_{out}) < -0.990$. Since this was a spark-chamber missing-mass experiment, this group does not have the extra constraint of the decay distributions available for analysis.

We report here on a sample of 13 766 events of the reaction $\pi^+ D \to pp\pi^+\pi^-$ obtained from the Alvarez Group 72-inch deuterium-filled bubble chamber with c.m. energy of all outgoing particles except the lower momentum proton between 2.1 and 2.4 GeV and with the lower momentum proton < 300 MeV/c in the laboratory system (impulse approximation). A clear enhancement in the recoil proton-π^+ mass spectrum corresponding to the known mass and width of $\Delta(1238)$ is observed in both the forward and backward directions. The production differential cross section has been presented previously in fig. 2(c) of ref. 2. We note a clear dip in the backward direction $-1.0 < \text{cospro} < -0.90$ with a peak of 55μb/sr in the bin $-0.9 < \text{cospro} < -0.8$. Background under the $\Delta^{++}(1238)$ peak typically averages 15% for the cospro bins that include the backward enhancement ($-1.0 < \text{cospro} < -0.5$). We have used Monte Carlo programs[3]) to investigate the possibility that the enhancements observed are kinematical reflections of resonances produced in other channels, e.g., backward-produced $\rho^0(765)$ such as seen in ref. 4; however, these reflections fail to give peaks with the mass and width of the $\Delta(1238)$.

We also measure differential cross sections for the reaction $\pi^+ n \rightarrow \Delta^0(1238)\pi^+$ and find differential cross sections in the backward direction $[-1.0 < \text{cospro}(\pi^+_{in}, \pi^+_{out}) < -0.5]$ with an upper limit of 7 μb/sr and statistically consistent with zero. Since only I = 3/2 exchange amplitudes can mediate backward peaking in this reaction and since by Clebsch-Gordan arguments I = 3/2 exchange contributes only 1/3 as much to backward peaking in $\pi^+ n \rightarrow \Delta^{++}(1238)\pi^-$, we infer that the only significant backward production mechanisms for $\pi^+ n \rightarrow \Delta^{++}(1238)\pi^-$ involve I = 1/2 exchange. An interpretation of the data (particularly the dip in the backward direction) on the basis of s-channel resonances as in ref. 1 is unlikely, since our data exhibit no rapid variation in c.m. energy(ECM) commonly associated with s-channel mechanisms over an ECM range of 300 MeV. The differential cross section retains the same shape throughout this ECM interval.

In order to test production mechanisms it is of considerable help to know the decay distributions of a resonance. This report represents, to the best of the author's knowledge, the first experiment in which enough events exist in backward-produced inelastic resonance peaks to permit reliable measurement of the decay distributions. In a coordinate system with z-axis in the production plane (in the resonance rest frame) the normalized decay distribution of Δ(1238) can be described by the formula[5])

$$D(\theta, \phi) = (1/4\pi)[\rho_{11}(1+3\cos^2\theta) + 3\rho_{33}\sin^2\theta - 4\sqrt{3}\,\text{Re}(\rho_{31})\sin\theta\cos\theta\cos\phi - 2\sqrt{3}\,\text{Re}(\rho_{3-1})\sin^2\theta\cos 2\phi],$$

where $\rho_{11} = 1/2 - \rho_{33}$ by the trace condition on the density matrix elements. This formula can be rewritten in terms of the spherical harmonics $Y_\ell^m(\theta,\phi)$ as

$$D(\theta,\phi) = (1/4\pi)\{1 + \sqrt{4\pi/5}\,(1-4\rho_{33})Y_2^0(\theta,\phi) + 8\sqrt{2\pi/5}\,\mathrm{Re}(\rho_{31})\mathrm{Re}[Y_2^1(\theta,\phi)] - 8\sqrt{2\pi/5}\,\mathrm{Re}(\rho_{3-1})\mathrm{Re}[Y_2^2(\theta,\phi)]\},$$

from which arises the following relations between the density matrix elements and the moments $\langle Y_\ell^m\rangle$:

$$\langle Y_2^0\rangle = 1/\sqrt{20\pi}\,(1-4\rho_{33}),$$

$$\langle \mathrm{Re}(Y_2^1)\rangle = 8\sqrt{1/40\pi}\,\mathrm{Re}(\rho_{31}),$$

and

$$\langle \mathrm{Re}(Y_2^2)\rangle = -8\sqrt{1/40\pi}\,\mathrm{Re}(\rho_{3-1}).$$

In the Jackson coordinate system with z-axis along the incident π^+ direction (in the resonance rest frame) and y-axis along the normal to the production plane, we have evaluated the moments of the decay distribution for three intervals in cospro(π^+_{in}, π^-_{out}). These are partially listed in table 1. All other moments are statistically consistent with zero. If the reaction is mediated by simple J = 1/2 nucleon exchange in the u-channel, we expect $\rho_{33} = \mathrm{Re}(\rho_{31}) = \mathrm{Re}(\rho_{3-1}) = 0.0$ and $\langle Y_2^0\rangle$ =0.126(corresponding to $\rho_{11} = 1/2$) as the only non-vanishing $\ell = 2$ moment. We see from table 1, however, that for all intervals in cospro the $\langle Y_2^0\rangle$ moments are inconsistent with the value 0.126 and there exist $\langle Y_2^2\rangle$ moments inconsistent with zero. Therefore, explanation of the production mechanism in terms of simple unmodified nucleon exchange is ruled out. An interpretation based on the single Regge exchange amplitude N_α is ruled out, since there exists no dip in the differential cross section $d\sigma/du$ at the value $-u = 0.15$ GeV^2/c^2 where the N_α exchange amplitude goes to zero as a result of α passing through the wrong signature nonsense point $\alpha = -1/2$.[6]

In order to discuss reasons for the dip in the backward production direction it is convenient to use the helicity frame with z-axis along $-\underset{\sim}{P}_{\pi^-}$ (in the resonance rest frame). Here the density matrix elements $\rho_{\mu\mu'}$ are directly proportional to the products of helicity amplitudes, i.e., $\rho_{\mu\mu'} \sim \langle \mu | +1/2 \rangle \langle \mu' | +1/2 \rangle^*$, where $\langle \mu | +1/2 \rangle$ is the helicity amplitude with initial nucleon of helicity $+1/2$ and final $\Delta(1238)$ of helicity μ. (There are four independent helicity amplitudes for this reaction: two with final $\Delta(1238)$ |helicity| = 3/2 and two more with |helicity| = 1/2.) In fig. 1 we plot the polar decay angle in the helicity frame with superposed curves calculated from the measured moment $\langle Y_2^0 \rangle$ for each interval in cospro. The relevant one-dimensional formula for the decay polar angle distribution is

$$D(\cos\theta) = D(\theta, \phi)\, d\phi = 1/2 + \sqrt{5\pi/4}\, \langle Y_2^0 \rangle (3\cos^2\theta - 1).$$

We note strongly dominant production of the $\Delta^{++}(1238)$ in |helicity| = 3/2 states which must vanish along the extreme backward direction (cospro = -1.0). This explains the dip in the differential cross section in the backward direction. However, the dynamical mechanism responsible for the dominant |helicity| = 3/2 production of the $\Delta^{++}(1238)$ (for cospro < -0.5) is still open to conjecture.

FOOTNOTES AND REFERENCES

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Table 1. Decay moments for backward-produced $\Delta^{++}(1238)$ $2.1 < ECM < 2.4$ GeV, $1.35 < M^2_{p\pi^+} < 1.69$ GeV^2 in Jackson coordinate system.

Cospro interval	No. events	$\langle Y_2^0 \rangle$	$\langle Re(Y_2^2) \rangle$
-1.0 to -0.85	110	-0.050±0.025	-0.072±0.019
-0.85 to -0.70	135	0.027±0.023	-0.062±0.016
-0.70 to -0.50	106	-0.034±0.026	-0.082±0.019

FIGURE CAPTION

Fig. 1. Polar decay angle helicity frame $\cos(-\hat{\pi}^-, \hat{\pi}^+)$ distributions and corresponding values of $\langle Y_2^0 \rangle$ for (a) $-1.0 < \text{cospro} < -0.85$, (b) $-0.85 < \text{cospro} < -0.70$, and (c) $-0.70 < \text{cospro} < -0.50$ for $\Delta^{++}(1238)$ events with ECM intervals and $M^2_{p\pi^+}$ cuts as in table 1.

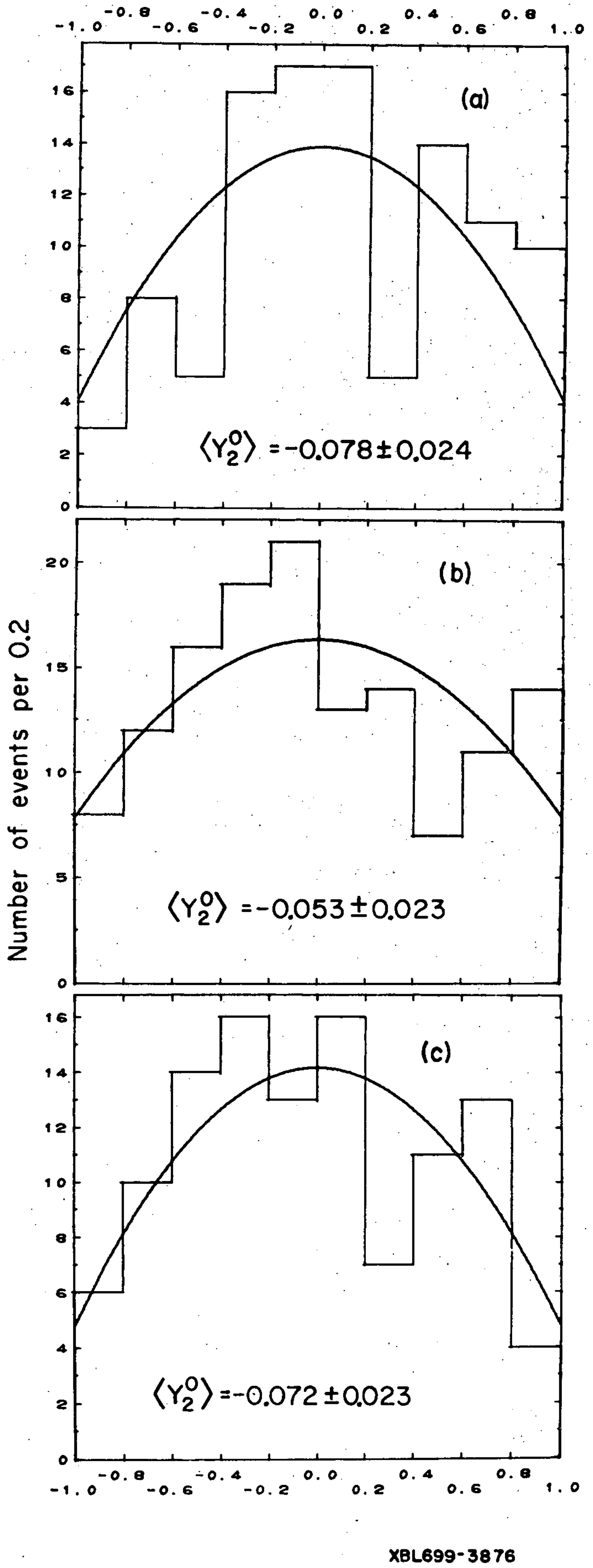
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
(a)
⟨Y20⟩ = -0.078 ± 0.024
(b)
⟨Y20⟩ = -0.053 ± 0.023
(c)
⟨Y20⟩ = -0.072 ± 0.023
Number of events per 0.2
XBL699-3876

Fig. 1

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