DECAY ANGULAR DISTRIBUTIONS IN DIFFRACTIVE ONE-PION PRODUCTION
AT ISR ENERGY

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ABSTRACT

New experimental results are reported on decay angular distributions in
diffractive dissociation of protons into \((n\pi^+)\) in proton-proton collisions
at a centre-of-mass energy of \(\sqrt{s} = 45\) GeV. There is strong evidence for
two distinct components of diffraction dissociation which have different
decay angular distributions in the Gottfried-Jackson frame; the resonant
and the non-resonant component with \((n\pi^+)\) invariant mass in the interval
\(1.6 < m < 1.7\) GeV are separated by their different \(t\) dependence. We
find strong violation of \(s\)-channel and \(t\)-channel helicity conservation
for both the resonant and the non-resonant component.

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In the preceding letter\textsuperscript{1}, we have reported on diffractive one-pion production in the reaction

\begin{equation}
pp \rightarrow p(n\pi^+) \tag{1}
\end{equation}

at a centre-of-mass energy of $\sqrt{s} = 45$ GeV. The aim of this letter is to describe the decay angular distributions of the ($n\pi^+$) system and to discuss questions concerning the helicity structure of the diffractive process.

While for $\rho^0$ photo-production and elastic pion proton scattering helicity conservation in the s-channel is fairly well established\textsuperscript{2}, s-channel helicity conservation (SCHC) has been disproved for diffraction dissociation\textsuperscript{3}. On the other hand, extensive studies\textsuperscript{4} of t-channel helicity conservation in the two-body dissociation $N + N\pi$ have not lead to a clear answer.

In the present investigation of diffraction dissociation at very high energy where non-diffractive exchange contributions to reaction (1) have been shown experimentally to be negligible\textsuperscript{5}, we find strong violation of both SCHC and TCHC for the resonant and for the non-resonant part of the reaction.

If helicity is conserved in a particular reference frame, the total helicity of the ($n\pi^+$) system is the same as that of the dissociating proton. We consider the two cases of s-channel and t-channel helicity conservation which are thought to be singled out by dominant dynamical mechanisms, e.g. the latter by Pomeron exchange. In the Gottfried-Jackson system\textsuperscript{6}, the polar angle $\theta_J$ of the neutron in the ($n\pi^+$) rest frame is measured against the direction of the dissociating proton, and the azimuthal angle $\phi_J$ against the production plane. These angles can be reconstructed with a probable experimental error of $\Delta \cos \theta_J \sim 0.017$ and $\Delta \phi_J \sim 1.8^\circ$, on average.

The observed angular distributions for different intervals of the invariant mass of the ($n\pi^+$) system are shown in figure 1. We note a
forward and a backward peaking of \( d\sigma/d\cos\theta_J \), and an asymmetry, favoring the forward direction, which is increasing with increasing mass. The distributions in \( \phi_J \) are peaking in the production plane, at \( \phi_J = 0^\circ \), for all mass intervals. There appear to be two distinct components\(^1\) of diffraction dissociation, resonance production and non-resonant pion production. We expect these components to have different polar and azimuthal angular distributions in the Gottfried-Jackson system; production of a single resonance will be reflected by forward-backward symmetry in \( d\sigma/d\cos\theta_J \) and by symmetry in \( d\sigma/d\phi_J \) with respect to the normal to the production plane, whereas in non-resonant pion production, if it is assumed to be dominated by a double-peripheral mechanism, the neutron will be produced predominantly forward and in the production plane\(^7\). There is qualitative evidence in the data for both components. To help demonstrating this we also show results of a model calculation in figure 1. Non-resonant pion production has been described by a simple Deck model\(^8\); assuming a reggeized pion exchange leads to the following double-peripheral matrix element squared\(^7\):

\[
|M|^2 = s_2^{1/2} \frac{4(t_2-m_\pi^2)}{(t_2-m_\pi^2)^2} \cdot \frac{2\alpha'_\pi(t_2-m_\pi^2)}{s_1^{1/2}} \cdot e^{8t_1} \tag{2}
\]

where \( t_1 \) and \( t_2 \) designate the momentum transfers between incoming and outgoing proton and dissociating proton and outgoing neutron, respectively; \( s_1 \) and \( s_2 \) are the subenergies squared of the outgoing proton and the pion and the outgoing neutron and the pion, respectively; the differential cross section for \( \pi p \) elastic scattering is taken proportional to \( e^{8t_1} \), and an empirical form factor, \( e^{4(t_2-m_\pi^2)} \), is used to obtain a better description of the data in the variable \( t_2 \). \( \alpha'_\pi \) is the slope of the pion Regge trajectory.

To perform a sensitive test of TCHC we have tried to separate the two components on the basis of these expectations. A mass region including the peak at 1650 MeV was selected as the most prominent resonant contribution\(^1\), and another region, \( 1.30 < m < 1.40 \) GeV which is dominated by non-resonant pion production. Owing to the large statistics of this experiment we can investigate \( d\sigma/d\phi_J \) in these mass regions for different intervals of \( \cos \theta_J \).
A necessary condition for TCHC is isotropy in the azimuthal angle $\phi_j$. The observed angular distributions are shown in figure 2a and 2b. We note strong deviations from isotropy for both the predominantly non-resonant mass interval $1.3 < m < 1.4$ GeV and for the resonant mass region $1.6 < m < 1.7$ GeV. A tendency for an increase of $d\sigma/d\phi_j$ at $\phi_j \approx 180^\circ$ for backward produced neutrons can be attributed to a baryon exchange contribution $^{10}$ in a double-peripheral mechanism.

One may argue that the resonant contribution in figure 2b may interfere with the non-resonant background and that a test of TCHC is not meaningful. We have therefore attempted to separate resonant and non-resonant events occurring in the same mass interval, $1.6 < m < 1.7$ GeV. In the preceding letter $^1$ we have studied the variation of the slope of $d\sigma/dt$ as a function of the $(n\pi^\pm)$ mass for various regions of $\cos \Theta_j$; we find that for the region $-0.3 < \cos \Theta_j < +0.3$ there is a minimum of the slope in the resonance region. Hence, selecting events in this region of $\cos \Theta_j$ with $|t| < 0.2$ GeV$^2$ and $0.2 < |t| < 0.5$ GeV$^2$, respectively, we expect an enrichment in non-resonant and resonant events. An enrichment of each component is indeed observed in the mass spectra of figure 3. Investigating again the distributions in $\phi_j$ of these samples we observe in figure 3 a strong peaking in the production plane for non-resonant events and approximate symmetry with respect to the normal to the production plane for resonant events, as expected for a single resonance. However, we do not observe isotropy. In the s-channel we observe even stronger deviations from isotropy.

Hence, we conclude that helicity conservation is strongly violated in the t-channel and in the s-channel for both components of diffraction dissociation. Violation of TCHC may be reconciled with Pomeron exchange by assuming that the Pomeron is transferring spin.
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FIGURE CAPTIONS

Figure 1 - (a) Decay angular distribution of the neutron in polar angle $\Theta_j$ in the Gottfried-Jackson system for various mass regions of the (nπ⁺) system.

(b) Azimuthal angular distribution $d\sigma/d\phi_j$ in the Gottfried-Jackson system. $\phi_j = 0$ corresponds to the production plane. The solid curves represent the results of a model calculation of a non-resonant diffractive process.

Due to phase-space limitations in the experiment the distributions are shown for $|t| > 0.1$ GeV$^2$ and $\cos \Theta_j > -0.9$. The cut at $\cos \Theta_j = -0.3$ in the first mass bin is also due to these limitations.

Figure 2 - $d\sigma/d\phi_j$ in the Gottfried-Jackson system for two mass regions, (a) of predominantly non-resonant processes, $1.3 < m < 1.4$ GeV, and (b) containing resonant processes, $1.6 < m < 1.7$ GeV, in three intervals of $\cos \Theta_j$ with the cut $|t| > 0.1$ GeV$^2$.

Figure 3 - Enrichment of the mass spectra in (a) non-resonant and (b) resonant events by cuts on $|t|$. Selecting the mass interval $1.6 < m < 1.7$ GeV (the cross-hatched regions) $d\sigma/d\phi_j$ is plotted with the same $|t|$ cuts. The distributions are distinctly different; both are non-isotropic and hence do not support TCHC.
FIG. 3

-0.3 < \cos \Theta_j < 0.3
0.05 < |t| < 0.2 \text{ GeV}^2

(a) $\mu_b/0.025 \text{ GeV}$ vs. $m(n\pi^+) \text{ (GeV)}$

-0.3 < \cos \Theta_j < 0.3
0.2 < |t| < 0.5 \text{ GeV}^2

(b) $d\sigma/dm$ vs. $m(n\pi) \text{ (GeV)}$

$-0.3 < \cos \Theta_j < 0.3$
$0.05 < |t| < 0.2 \text{ GeV}^2$
$1.6 < m < 1.7 \text{ GeV}$

-0.3 < \cos \Theta_j < 0.3
0.2 < |t| < 0.5 \text{ GeV}^2
$1.6 < m < 1.7 \text{ GeV}$

$\varphi_j$ (degrees)

-0.3 < \cos \Theta_j < 0.3
0.05 < |t| < 0.2 \text{ GeV}^2

$\mu_b/18^\circ$ vs. $\varphi_j$ (degrees)

$\varphi_j$ (degrees)