CERN-EP/79-02
10 January 1979

FEATURES OF COHERENT NEUTRON DIFFRACTION ON DEUTERONS AT THE ISR

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ABSTRACT

We present preliminary results from a study of two-body coherent neutron diffraction dissociation on deuterons at $\sqrt{s} = 37.2$ GeV. The data were obtained at the CERN Intersecting Storage Rings with colliding deuteron beams, using the Split Field Magnet detector. We observe a large structureless low-mass enhancement centred at 1.4 GeV with resonant $N(1688)$ production. The decay angular correlations can be interpreted in terms of Deck amplitudes with both pion and baryon exchange, the latter giving significant contributions for $(N\pi)$ invariant masses above 1.35 GeV.

(Submitted to Physics Letters)

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One of the peculiar features of coherent dissociation of nucleons on nuclear targets is the suppression of non-zero isospin-exchange amplitudes which might still be contributing to the analogous process on free nucleons; the suppression is complete for an isoscalar target. In addition to this, coherent processes may be particularly sensitive to the details of the production mechanisms of an inelastic state through its secondary interactions in the multiple-scattering approximation. A deuteron target, besides providing a pure isoscalar analyser of the diffracted system, allows an exact description of the diffraction process to all orders.

High-energy coherent diffraction of protons on deuterons has been recently studied inclusively [1] at Fermilab in the reaction $pd \rightarrow Xd$; neutron coherent diffraction in $(p\pi^-)$ systems has been measured only on medium and heavy nuclei [2]. As part of a detailed study of high-energy nucleon diffraction on nucleons [3] and on deuterons [4] we have measured the exclusive coherent reactions

$$nd \rightarrow (p\pi^-)d \quad (1)$$

$$pd \rightarrow (p\pi^+\pi^-)d, \quad (2)$$

at the CERN Intersecting Storage Rings (ISR). The purpose of the experiment was: i) to study diffraction dissociation in reactions free of possible background from normal Reggeon exchange, for further comparison with the corresponding incoherent processes of single and double diffraction [3]; ii) to investigate the characteristics of the interaction of the diffractively produced systems with the nucleon. This last experimental information complements what has been obtained on inelastic propagation within the deuteron in pd and dd elastic scattering [4].

We report in this letter results on reaction (1) at $\sqrt{s} = 37.2$ GeV and for $0.05 < -t < 1.3$ GeV². In this region both single- and double-scattering terms contribute substantially, the latter involving the rescattering of the excited $(N\pi)$ system with the second nucleon in the deuteron. The following letter reports on point (ii) with an analysis of the relevance of helicity-flip amplitudes in the rescattering process.

The data for this experiment were obtained with 26.6 GeV deuteron-deuteron [reaction (1)] and proton-deuteron [reaction (2)] colliding beams using the Split Field Magnet (SFM) detector system. A detailed description of the spectrometer and of the detector has been published [5]. For details on the experimental procedure and data analysis we refer to previous papers [3,4].

The SFM detector consists of two symmetric magnetic spectrometers in the forward direction, each one equipped with ten planes of multiwire proportional chambers (MWPC); four additional chambers in the downstream compensator magnets allow tracking at very small angles to the beams. These small compensator spectrometers allow an efficient detection of the spectator protons associated with neutron diffraction in one arm and of the quasi-elastically scattered deuteron in the other.

The trigger logic for reaction (1), operating at a fast and a slower level, was symmetric in the two arms and included a special hardware processor. It required an elastic-like track in one arm pointing to the vertex within a narrow angular aperture; in the opposite arm a spectator proton in a specific angular interval and two additional charged tracks in a wider acceptance region were also required. Detector information for calibration and monitoring was collected during data taking, together with monitor counts from two scintillation hodoscopes for absolute cross-section normalization. The recorded events were analysed through a sequence of standard reconstruction programs performing pattern recognition and geometrical track reconstruction.

Since the deuteron break-up products peak, in our case, at half the beam momentum and the momentum resolution for elastically scattered deuterons is $\Delta p/p \approx \pm 7\%$ at 26.6 GeV/c, a simple momentum cut was applied to select the event configuration [1] in the two spectrometer arms. Finally, a four-constraint kinematical fit was performed and events corresponding to a confidence level larger than 1% were retained in the final sample. Owing to the presence of the beam tubes in the forward telescopes, deuterons with momentum transfer $-t < 0.04 \text{ GeV}^2$ remained undetected.

The over-all acceptance of the detector and of the reconstruction chain is almost uniform up to t -values in excess of 2 GeV^2 , where it starts to be affected by the aperture of the small compensator telescopes of the SFM^{*)}. The dissociated system is detected without acceptance distortions up to masses in excess of 3 GeV , with a resolution of about 15 MeV on the average.

The final sample consists of 14053 events, corresponding to an integrated luminosity of $12455 \mu\text{b}^{-1}$.

The invariant mass distribution of the $p\pi^-$ system for coherent neutron diffraction is shown in Fig. 1. The distribution integrated over momentum transfer (Fig. 1a) is dominated by a low-mass peak centred at 1.4 GeV . No significant structures appear unambiguously in this region. A clear signal of coherent isobar production is present at the $N(1688)$ mass. A local Breit-Wigner fit with a smooth polynomial background in the region $1.5 < M_{p\pi^-} < 2.0 \text{ GeV}$ yields for the resonant signal $M_0 = 1684 \pm 4 \text{ MeV}$ and $\Gamma_0 = 100 \pm 19 \text{ MeV}$.

The shape of the mass spectrum is considerably different from the corresponding distribution of incoherent two-body nucleon diffraction [3,6], which shows a much less pronounced and more structured enhancement at masses below 1.6 GeV . This can be qualitatively understood in terms of the slope-mass correlation for small produced masses and of the heavy weighting of low- t events in reaction (1) due to the deuteron form factor. This effect is also evident in Fig. 1b, which shows the mass spectrum for $-t > 0.2 \text{ GeV}^2$; this value lies in the interference region between single and double scattering. One can observe that, contrary to the incoherent diffraction case [6], the low-mass enhancement, although somewhat depressed, still dominates the threshold behaviour of the mass spectrum.

The features of non-resonant pion production in nucleon diffraction dissociation are usually interpreted in the framework of Deck-like models [7].

*) Given the steep form factor at the coherent deuteron vertex, we have selected events in the interval of four-momentum transfer $0.05 < -t < 1.5 \text{ GeV}^2$, which covers the single- and most of the double-scattering regions.

In this paper we compare our results with the predictions of simple Deck production amplitudes modified to take into account the structure at the deuteron vertex.

Assuming a Reggeized pion exchange, we set for the dominant double-peripheral matrix element squared

$$|M|_{\pi}^2 \approx \frac{[0.5(s_{\pi p} - u_1)]^{2\alpha_{\pi}}}{(t_1 - m_{\pi}^2)^2} s_{\pi d}^2 e^{b_{\pi d} t}, \quad (3)$$

where $\alpha_{\pi} = 0.9(t_1 - m_{\pi}^2)$ is the pion Regge trajectory; t is the momentum transfer to the deuteron; t_1 and u_1 are the momentum transfers between the dissociating neutron and the outgoing proton and pion, respectively; $s_{\pi p}$ and $s_{\pi d}$ are squares of the πp and πd invariant masses; the πd elastic differential cross-section is parametrized with an exponential of slope $b_{\pi d} = 38.4 \text{ GeV}^{-2}$.

The solid curve in Fig. 1a, normalized to the data sample, shows the mass distribution predicted with the matrix element (3). If one ignores the intrinsic difficulty of the Deck models in predicting absolute cross-sections [8], it is remarkable how the features of the entire low-mass peak are well reproduced.

It is well known [8,9] that exchange contributions other than that of the pion have to be incorporated in the model in order to describe the detailed features of the final state, such as the decay angular correlations as a function of four-momentum transfer. However, these additional contributions do not appear to modify appreciably the mass distribution as generated by the simple π -exchange term (3). This is shown in Fig. 1a, where the dashed curve has been obtained using a three-component dual Deck model developed in Ref. 9. In this approach both the baryon and the direct pole terms are added coherently to the pion amplitude, giving rise to substantial interference effects.

This model has also been extended to take into account resonance production in the $N\pi$ final state by means of a simple parametrization of the direct pole

amplitude. This parametrization appears though to be too rigid to account in detail for the observed structures of the mass distribution.

Figure 2a shows the contour plot in the $(\cos \theta - \phi)$ plane of the Jackson decay angles of the $(p\pi^-)$ system. A fiducial cut at $|\cos \theta_J| = 0.9$ has been applied to the data sample, in order to avoid decay angular regions in which the acceptance for a two-body system is more critically affected by the presence of the beam vacuum chamber. We observe distinct azimuthal distributions in the forward and backward hemispheres with a remarkable symmetry around the $\phi_J = 0$ plane. Evidence for these structures is shown in Figs. 2b and c, where the azimuthal distributions for $\cos \theta_J < 0.8$ and $\cos \theta_J > 0.8$ are separately shown^{*)}.

The pion-exchange contribution described by the matrix element (3) is expected to be dominant in the forward direction and the corresponding prediction for the ϕ_J distribution is shown in Fig. 2c. On the other hand, for decay angles in the backward hemisphere, the baryon-exchange amplitude is essential in describing the data. The curve in Fig. 2b is obtained with a matrix element squared analogous to expression (3)

$$|M|_p^2 \approx \frac{[0.5(s_{p\pi} - t_1)]^{2\alpha_p}}{(u_1 - m_p^2)^2} s_{pd}^2 e^{b_{pd}t} \quad (4)$$

where $\alpha_p = (-0.35 + 0.9 u_1)$ is the proton Regge trajectory: s_{pd} is the square of the pd subenergy and $b_{pd} = 30 \text{ GeV}^{-2}$ the slope of the pd elastic cross-section measured in our previous experiment [4].

It is clear from Fig. 2 that the ϕ_J decay angular distributions of coherent neutron diffraction can be well described in the single-scattering region by single appropriate Deck amplitudes in the limiting forward and backward polar regions.

*) Only events with $-t < 0.2 \text{ GeV}^2$ were used in this analysis, which does not appreciably degrade the statistical accuracy of the sample and isolates the single-scattering term in reaction (1). This allows a direct comparison between coherent and incoherent processes without complications arising from multiple-scattering terms.

In studying the transition from pion- to baryon-dominated exchanges in reaction (1) we observe a strong correlation between azimuthal decay angle and mass of the produced ($p\pi^-$) system. This is shown in Fig. 3, where the azimuthal angle distribution is displayed in different mass intervals together with the predictions from the matrix element (3). We observe that pion exchange gives a good description of the data only near mass threshold, whereas strong discrepancies appear already in the region of the 1.4 GeV mass peak. Figures 3b, c, and d show clearly that this is due to a rapid onset with mass of a peak in the ϕ_J angular distribution at $\phi_J = 0$, typical of baryon exchange.

To summarize, we measured the coherent neutron diffraction dissociation on deuterons in ($p\pi^-$) final states. The mass distribution of the ($p\pi^-$) system is dominated by a large low-mass enhancement with an appreciable resonant signal only at the N(1688) mass. This distribution is well described by a simple pion-exchange Deck mechanism, as well as by a more complete model incorporating also baryon exchange and the direct baryon pole, together with all interference terms. The decay angular correlations display also a simple Deck interpretation in the single-scattering region. When integrating over the polar decay angle the azimuthal distributions appear dominated by pion-exchange only near mass threshold, with a rapid onset of a baryon-exchange peak with increasing ($p\pi^-$) mass above 1.35 GeV.

Further experimental results and a more detailed analysis of coherent nucleon diffraction from reactions (1) and (2) will be the subject of a forthcoming paper.

We wish to thank G. Cohen-Tannoudji and D. Lévy for very useful discussions.

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Figure captions

Fig. 1 : a) Invariant mass distribution of the $(p\pi^-)$ system in reaction (1) for $-t > 0.05 \text{ GeV}^2$. The solid curve is the distribution predicted by a pion-exchange Deck amplitude normalized to the data sample. The dashed curve is the distribution obtained with a three-component dual Deck model described in Ref. 9.

b) Invariant mass distribution of the $(p\pi^-)$ system for $-t > 0.2 \text{ GeV}^2$.

Fig. 2 : a) Contour plot in the $(\cos \theta - \phi)$ plane of the Jackson decay angles for the $(p\pi^-)$ system, after local smoothing of the data.

b) Azimuthal angular distribution for backward decay angles. Owing to the azimuthal symmetry, also displayed by the data, the distribution has been folded around $\phi_J = 0$. The curve is the prediction of the baryon-exchange term [Eq. (4)], normalized to the data.

c) The same as in (b) for forward decay angles. The curve is obtained from the pion-exchange term, Eq. (3).

Fig. 3 : Azimuthal angular distributions in different mass intervals of the $(p\pi^-)$ system. The curves, normalized to the data, are obtained from the pure pion-exchange term, Eq. (3).

Fig. 1

Fig. 2

Fig. 3