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PERIPHERALITY OF NUCLEON DIFFRACTION DISSOCIATION
FROM COHERENT AND INTERACTIONS AT THE ISR

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ABSTRACT

We present differential cross-sections for coherent neutron diffraction 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. The analysis of the low-mass differential cross-sections with the Glauber model clearly favours a peripheral description of the elementary nucleon diffraction dissociation process. Only in this case a strong constructive interference between single- and double-scattering amplitudes is able to reproduce the pronounced structure observed in the experimental data.

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In the preceding letter [1] we have reported on coherent diffractive one-pion production on neutrons in the reaction

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

at $\sqrt{s} = 37$ GeV. This process has been studied with 26.6 GeV/c colliding deuteron beams in the CERN Intersecting Storage Rings using the Split Field Magnet detector. In Ref. 1 we have analysed the mass spectrum of the $(p\pi^-)$ system and its decay angular correlations in terms of simple Deck amplitudes. Here we show results on differential cross-sections for reaction (1), and discuss the detailed features of its t -dependence in terms of the Glauber model [2,3] for coherent production on deuterons. The differential cross-section for low $(p\pi^-)$ masses displays complex structures, which reflect in part similar features observed [4] in nucleon-nucleon inelastic diffraction and in part can be attributed to a peculiar mechanism of *constructive* interference between the single- and double-scattering terms. This, in turn, is shown to be due to the zeros of the peripheral helicity amplitudes [5], which describe the process of NN diffraction. The diffraction dissociation of the nucleon on a deuteron target can thus provide, by means of the interference between single and double scattering, a unique tool to discriminate between different models describing the elementary NN diffraction.

In this letter we first discuss single-pion production in NN diffraction in terms of peripheral helicity amplitudes; these are then used as input to our Glauber calculation to obtain a zero-parameter description of our coherent production data for reaction (1). The differential cross-section for NN one-pion diffractive production in different mass bins was parametrized with the form

$$\frac{d\sigma}{dt dM} = \sum_{\Delta\lambda} |T_{\Delta\lambda}(t, M)|^2 \quad (2)$$

where the s -channel helicity amplitudes of order $\Delta\lambda$ are given by

$$T_{\Delta\lambda}(t, M) = C_{\Delta\lambda}(M) e^{at} J_{\Delta\lambda}(b_0 \sqrt{-t}) \quad (3)$$

These describe an impact parameter distribution peaked at $b \sim b_0$ and with a finite width controlled by the parameter a .

We do not make a hypothesis of strict b -universality, $a(s,M) = a_\infty$ and $b_0(s,M) = b_{0\infty}$, nor do we assume a specific mass-spin correlation in the functional form of the coefficients $C_{\Delta\lambda}(M)$, as made in Ref. 5. Rather a free parameter fit to the form (2) was performed on different mass bins of the reaction $pp \rightarrow p(\pi\pi^+)$ recently measured at the ISR by the CHOV Collaboration [4]. The results yield values of a and b_0 , which are essentially mass independent at typical values of 3 GeV^{-2} and 1 fm , respectively. These values correspond to a peripheral impact parameter profile of the type assumed in Ref. 5 and expected on the grounds of absorption at small values of b . While at low masses the zero helicity-flip amplitude dominates, higher values of $\Delta\lambda$ become important with increasing mass; the contributions of the helicity amplitudes to the differential cross-section for all masses was found to be strongly damped as a function of $\Delta\lambda$. We found a practical upper limit at $\Delta\lambda = 4$, higher contributions being negligible.

We also consider a central description of the inelastic amplitude, with $\Delta\lambda = 0$; indeed there are no strong arguments to exclude such a representation for a partial cross-section. Only the total inelastic diffraction is required to be more peripheral than elastic diffraction by the existence of upper bounds in the impact parameter space [6].

The NN data were fitted to a central form given by two interfering exponentials. Very good fits were obtained, similarly to the peripheral case, with essentially Gaussian overlap functions with r.m.s. values of the impact parameter varying between 0.4 and 0.6 fm .

Both the central and the peripheral amplitudes were used in the Glauber calculation for the coherent pion production on deuterons. A similar analysis has been performed with helicity-flip amplitudes to describe coherent production on heavy nuclei [7]. For the deuteron the production amplitude is simply the sum of the single-scattering and the double-scattering terms; the latter is composed of

two parts, one corresponding to a nucleon propagator and the other to the propagation of an excited state. In spite of the fact that several experimental results indicate anomalously small values of the N^*N cross-section obtained by this model, this approach is at present the only one [8] capable of providing detailed predictions for reaction (1). The individual helicity amplitude reads in this case

$$F_{\Delta\lambda} = 2\hat{S}\left(\frac{\vec{q}_T}{2}, \frac{q_L}{2}\right) T_{\Delta\lambda}(\vec{q}_T, M) + \frac{i}{2\pi p_\ell} \int d^2 q'_T \hat{S}\left(\frac{\vec{q}_T}{2} - \vec{q}'_T, q_L\right) T_{\Delta\lambda}(\vec{q}'_T, M) \times \\ \times [f(\vec{q}_T - \vec{q}'_T) + f^*(\vec{q}_T - \vec{q}'_T)], \quad (4)$$

where $\hat{S} = \langle \psi | e^{i\vec{q} \cdot \vec{r}} | \psi \rangle$ is the deuteron form factor operator, which includes scalar and quadrupole terms [9]; q is the momentum transfer with transverse and longitudinal components $\vec{q}_T$ and $q_L = (M^2 - m^2)/2p_\ell$, p_ℓ being the equivalent laboratory momentum of the incident neutron. f and f^* are the elastic-scattering amplitudes for nucleon and excited states on nucleons, respectively; $\vec{q}'_T$ is the internal momentum transfer in the plane normal to the beam.

When considering the central amplitudes, for which $\Delta\lambda = 0$, formula (4) is unchanged but for the form of the elementary amplitude T . For the peripheral case the coherent production cross-section is given by the incoherent sum over $\Delta\lambda$ of $|F_{\Delta\lambda}|^2$.

In the central case for Gaussian elastic amplitudes f and f^* , the rescattering integral in Eq. (4) can be carried out analytically. The same is true for the peripheral amplitudes, for which we get explicitly,

$$F_{\Delta\lambda} = C_{\Delta\lambda}(M) \left\{ 2J_{\Delta\lambda}(q_T b_0) e^{-Aq_T^2} \hat{S}\left(\frac{q_T}{2}, \frac{q_L}{2}\right) + \right. \\ \left. + \frac{i}{2p_\ell} [f(0) + f^*(0)] \sum_i \frac{A_i e^{-\alpha_i q_L^2} e^{-(\alpha_i + 4B)q_T^2/4}}{(\alpha_i + B + A)} \exp \left[\frac{(\alpha_i + 2B)^2 q_T^2 - b_0^2}{4(\alpha_i + B + A)} \right] \times \right. \\ \left. \times J_{\Delta\lambda} \left[\frac{(\alpha_i + 2B)q_T b_0}{2(\alpha_i + B + A)} \right] \right\} \quad (5)$$

where B is the slope of the NN and N^*N elastic amplitudes. The quantities A_i , α_i are the parameters of a Gaussian parametrization of the deuteron charge form

factor^{*)}. The NN total cross-section, entering in the definition of $f(0)$ is determined using the parametrization of Amaldi et al. [10]. The N^*N total cross-section is taken to be 20 mb, from the data of coherent production on heavy nuclei [11]; the ratio of the real-to-imaginary part is taken to be equal to zero in both cases [10,12].

The results of this model are compared with the experimental data for reaction (1), in Figs. 1a and b. The differential cross-sections refer to the two lowest mass bins, where greater structure appears because of the dominance of the small helicity-flip contributions. The solid curves are generated by the peripheral NN amplitudes $T_{\Delta\lambda}$, whereas the dotted curves correspond to central amplitudes. It is clear how this latter case is unable to describe the complex behaviour of the differential cross-sections; on the contrary, the peripheral approach shows a very good agreement with the data. We stress that the calculation does not contain free parameters; we have only adjusted the normalizations within the relative uncertainties of proton-proton and neutron-deuteron data.

The structures appearing in Fig. 1 can be interpreted as the effect of a subtle interference between the first and the second terms in formula (5). The structure for the first mass bin is more in evidence in Fig. 2a, where both the data and the prediction of the peripheral calculation are shown normalized to the result of the Glauber model with central amplitudes. Examining both the cross-sections in Fig. 1 and the pronounced structure of Fig. 2a, one is led to conclude that the source of the effect is a strong constructive interference in the region $0.1 < -t < 0.5 \text{ GeV}^2$. This, in fact, appears to be the case if one plots separately the single- and double-scattering amplitudes for the dominating $\Delta\lambda = 0$ term, as shown in Fig. 2b. The signs of both amplitudes alternate through each zero and are indicated on the curves. It is clear from the figure that the two amplitudes interfere constructively in a substantial way in the t -range where the structure appears. The essential reason for this is due to the first zero of the double-scattering amplitude being shifted to higher t -values than the corresponding zero of the single-scattering term. This peculiar relationship between the two amplitudes is

*) We neglect small corrections due to the deuteron quadrupole form factor.

determined by different effects of the deuteron form factor, with the elementary amplitudes being computed at q_T and $q_T/2$ in the single- and double-scattering terms, respectively.

Similar results are obtained for higher mass bins for which, however, the effect appears to be smaller, owing to the greater importance of higher helicity-flip contributions in the elementary process.

In conclusion, we have measured the differential cross-section for the coherent neutron dissociation on deuterons for different mass intervals of the $p\pi^-$ diffractive system. For low produced masses, structures develop in the interference region between single and double scattering. We interpret these results using the Glauber model, with no free parameters. Input to the model comes from NN diffraction data, using both a central and a peripheral approach. The experimental results for coherent diffraction clearly favour a peripheral description in terms of helicity-flip amplitudes of the elementary NN diffraction process. The deuteron target, with its simple and rather loose structure, shows an optimal balance between single- and multiple-scattering terms and therefore provides an excellent analyser of the elementary diffraction amplitude.

Our results represent therefore an additional severe constraint on any model for diffraction dissociation of the nucleon.

Further analysis of both neutron and proton coherent diffraction will be the subject of a forthcoming paper.

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Figure captions

Fig. 1 : a) Differential cross-section for coherent neutron diffraction on deuterons at $\sqrt{s} = 37$ GeV for $(p\pi^-)$ masses smaller than 1.3 GeV. The continuous curve is the result of the model of Eq. (5) with peripheral amplitudes for elementary nucleon diffraction. The dashed curve is the result of the Glauber formula [Eq. (4)], with central amplitudes.

b) The same as in (a) for the $(p\pi^-)$ mass interval 1.3-1.44 GeV.

Fig. 2 : a) Ratio of data points and results of the peripheral model to the predictions of the Glauber model with central amplitudes as a function of the four-momentum transfer squared.

b) The t -dependence of the imaginary part of the coherent production amplitudes for $\Delta\lambda = 0$. The continuous curve is the single-scattering term, the dashed curve the double-scattering one. The sign of each part of the amplitude is also shown on the curves.

Fig. 1

Fig. 2