Two-pion decay modes of the $N^*(1440)$ in $np \to d\pi\pi$

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A simple model for the $np \to d\pi\pi$ reaction has been developed. It is shown that the deuteron momentum spectra measured at $T_n = 795$ MeV can be understood in terms of the Roper excitation and its $N\pi\pi$ decay modes. A similar pattern, recently observed in $pp \to pp\pi^+\pi^-$, can be explained in the same way.

Double-pion production in nucleon-nucleon (NN) collisions is a source of interesting information about the properties of baryonic resonances and the NN interaction in the inelastic region. It has actually become an active field of experimental research at CELSIUS and COSY, where the reactions $pp \to NN\pi\pi$, $d\pi\pi$, $pd \to {}^3He\,\pi\pi$ and $dd \to {}^4He\,\pi\pi$ are being studied near threshold.

The $np \to d\pi\pi$ reaction was studied in the past in connection with the ABC effect. Here, I focus the attention on the deuteron spectrum measured using a neutron beam with $T_n = 795$ MeV [1]. In contrast to the experiments performed at higher energies (~ 1 GeV), the ABC peaks are not present in the data; they rather show a well defined bump at high $\pi\pi$ missing masses, in disagreement with the models available in the literature [1].

My aim is to show that this behavior can be understood as a consequence of the interference of two mechanisms involving the excitation of the Roper resonance $N^*(1440)$ and its subsequent decay into $N(\pi\pi)^{T=0}_{S-wave}$ and $\Delta\pi$ respectively [2]. The present model is a reduced version of the one of Ref. [3] for the $NN \to NN\pi\pi$ reaction. With these ingredients, and using the Paris deuteron wave function, one can calculate the deuteron momentum

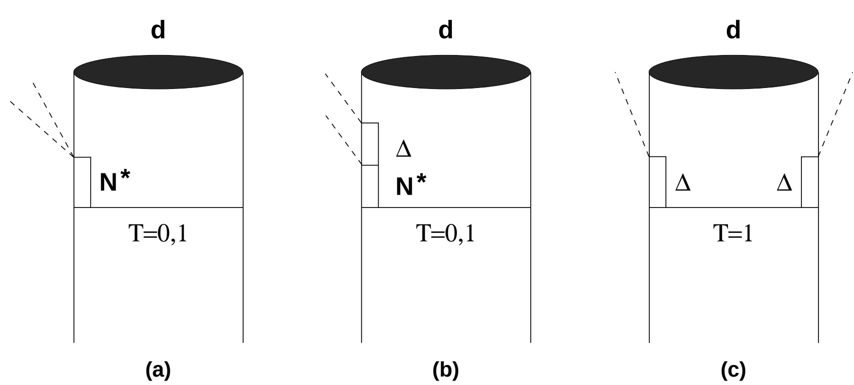

Figure 1. Set of diagrams of the model.

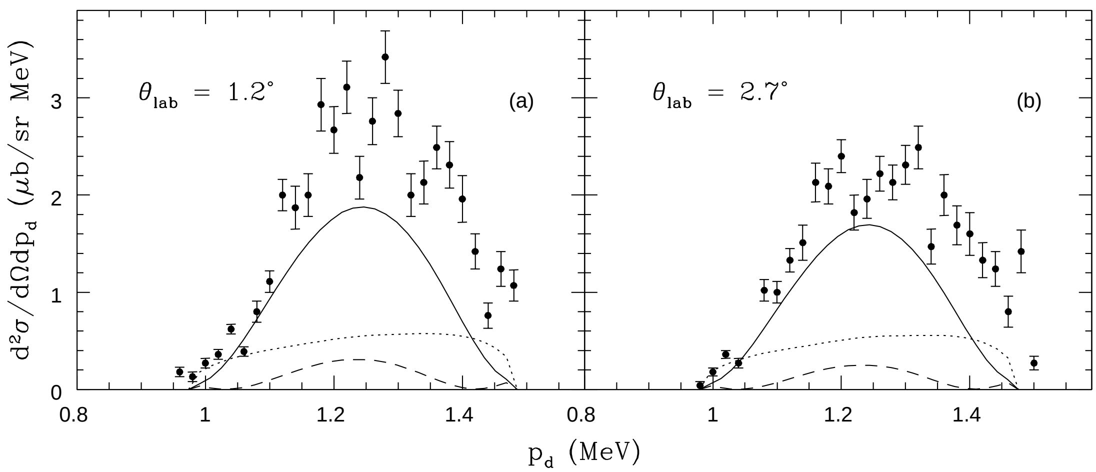

Figure 2. Calculated deuteron momentum spectra at $T_n = 795$ MeV/c (solid lines) compared to the measured data [1]. The dotted line corresponds to the $N^* \to N(\pi\pi)^{T=0}_{S-wave}$ mechanism (Fig. 1 a); the short-dashed line stands for the $N^* \to \Delta\pi$ (Fig. 1 b).

distribution for different laboratory angles. The mechanism $N^* \to N(\pi\pi)^{T=0}_{S-wave}$ produces spectra very similar to phase space, while the $N^* \to \Delta\pi$ mechanism plays a crucial role in providing the right shape to the distributions through its interference with the larger $N^* \to N(\pi\pi)^{T=0}_{S-wave}$ contribution. This interference is constructive at high $\pi\pi$ masses and destructive at low ones. Such a pattern can be understood by realizing that the $N^* \to \Delta\pi$ amplitude is dominated by terms proportional to the scalar product of the outgoing pions three momenta; this scalar product has different signs in the center of the spectra, where the pions go back to back, and at the edges, where they travel together. In order to further illustrate the effect of the interference, Fig. 3 shows the effect of changing the relative sign of the two amplitudes. The data clearly favor a choice of the sign of $g_{N^*\Delta\pi}$

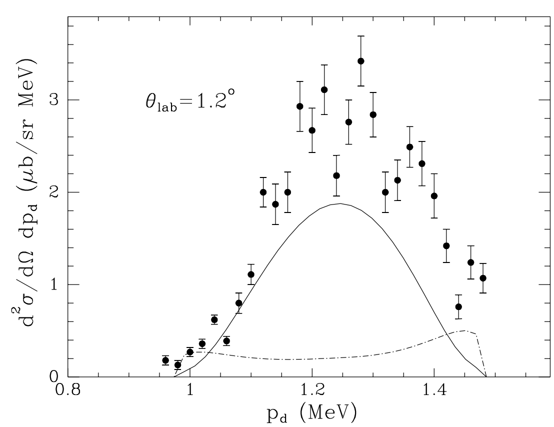

Figure 3. Calculated spectra for two different choices of the $g_{N^*\Delta\pi}$ sign

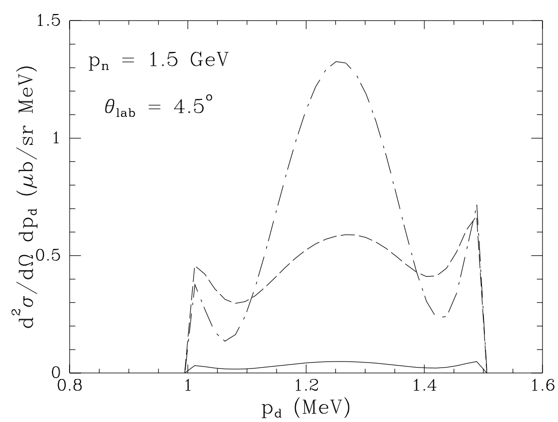

Figure 4. The double-Δ mechanism in the case of π exchange alone (dashed line), $\pi + \rho$ (dash-dotted) and $\pi + \rho +$ short range correlations (solid line).

in agreement with earlier works [4].

The double-Δ mechanism is too small to be represented in Fig. 2. In Fig. 4, its contribution is shown for $T_n = 830$ MeV, $\theta_{lab} = 4.5°$ and using the Hulthen wave function, in order to compare with the calculation of Ref. [5] (Fig. 4 b). The differential cross section obtained in the case of only pion exchange is very similar to the one given by the relativistic model of Ref. [5] but the inclusion of the rho exchange modifies the result, and the short range correlations cause a strong reduction of the strength of this mechanism.

The presented spectra are equivalent to a $\pi^+\pi^-$ invariant mass distribution shifted to higher masses with respect to phase space; a similar behavior has been recently observed in $pp \to pp\pi^+\pi^-$ at a lower energy $T_p = 750$ MeV (see Fig. 2 of Ref. [6]). I have calculated this observable including only the dominant isoscalar excitation of the $N^*(1440)$ decaying into $N(\pi\pi)^{T=0}_{S-wave}$ and $\Delta\pi$. I have also included pp final state interaction (strong plus Coulomb) via effective range approximation [7] and the experimental kinematical constrain $3° \leq \theta_{lab} \leq 24°$ for the detected particles (protons and π^+). Also here, the interference between the two mechanisms allows to explain the observed shift.

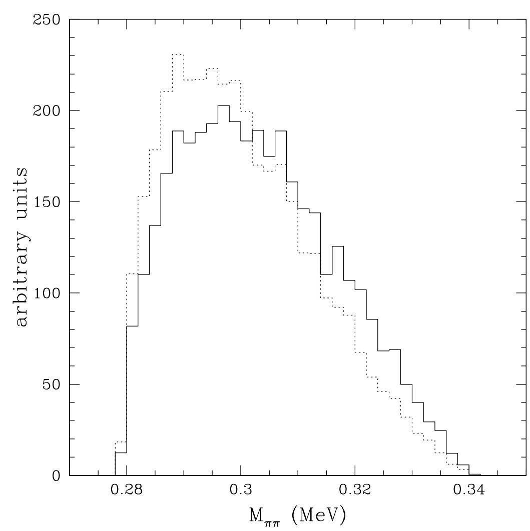

Figure 5. $\pi^+\pi^-$ invariant mass spectrum for $pp \to pp\pi^+\pi^-$ at $T_p = 750$ MeV. The dotted line stands for $N^* \to N(\pi\pi)^{T=0}_{S-wave}$ alone; the solid line includes also $N^* \to \Delta\pi$.

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