# PION PRODUCTION IN *pd* INTERACTIONS* **

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Recent experimental data for the reaction $pd \to pd\pi^0$ in the pion momentum range $\eta = p^{\pi^0}_{\mathrm{c.m.max}}/m_{\pi^0}c \leq 0.96$ is discussed. The excitation function $\sigma_{pd\pi^0}(T_p)$ roughly follows a $\eta^4$ power law for Ss wave interaction; close to threshold it is compatible with that for $pd \to {}^3\mathrm{He}\pi^0$, *i.e.* a strong spin-dublett interaction. The model of a quasi-free elementary process $np \to d\pi^0$ with a spectator proton describes $\sigma_{pd\pi^0}(T_p)$, too, but does not exhaust the observed spectator energy spectra. Comparison to isospin related $pd \to nd\pi^+$ data indicates another reaction mechanism contributing with a strength comparable to that of the quasi-free process.

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## 1. Introduction

Light ion accelerators with cooled beams and internal targets allow to address the questions of meson production in few nucleon systems close to threshold with unprecedented precision in projectile energy and background suppression. The first generation of such precision experiments was devoted to pion production in two nucleon systems, e.g. $pp \to pp\pi^0$ or $pp \to pn\pi^+$. Based on these results meson production in the nuclear environment can be approached as a fundamental nucleon-nucleon (NN) process with a quasifree NN interaction in a multinuclear environment as reaction model. The most natural first step in this direction leads to the pd system with our detailed knowledge about the structure of the deuteron.

Rohdjeß *et al.* [1] succeeded in measuring the total cross section for $pd \to pd\pi^0$ for proton energies from 1.0 MeV above threshold up to 295

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MeV. This corresponds to maximum pion momenta $\eta$ ranging from 0.10 to 0.96. The experiment was performed with a detector system allowing a kinematically complete measurement of p and d and a reconstruction of the missing mass $m_{\pi^0}$.The resulting excitation function extends over almost four orders of magnitude, *c.f.* Fig. 1.

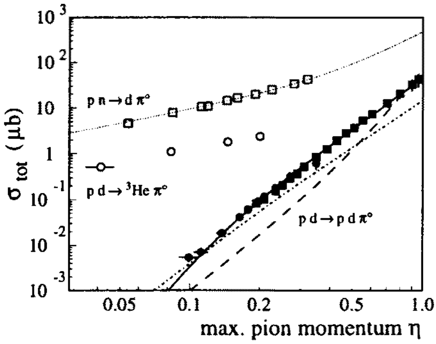


Fig. 1. Experimental $pd \to pd\pi^0$ cross sections compared to predictions derived [2] from the results of [3] for $pd \to {}^3\text{He}\pi^0$ (dot-dashed line), and to a quasi-free $pn \to d\pi^0$ mechanism without (dashed line) and with (solid line) inclusion of final-state interaction. Also shown are the $pn \to d\pi^0$ cross sections (open squares, dashed line) of [4].

## 2. Discussion of the reaction mechanism

Close to threshold, the $L_{pd}l_\pi$ = Ss term of the partial wave expansion dominates. From phase space arguments $\sigma_{pd\pi^0}(\eta)$ is expected to follow a $\eta^4$ power law, which is approximately observed. A similar dependence on $\eta$ results from the work of Fäldt *et al.* [2] that relates cross sections for $pd \to {}^3\text{He}\pi^0$ to those for the unbound final $pd$ spin–dublett pair and accounts for most of the experimentally observed cross section (Fig. 1).

The cross sections are a factor of $10^2$ to $10^3$ lower than those for an elementary quasifree $np \to d\pi^0$ process. This reduction can result [5] from the constraint of momentum conservation within the known momentum distribution in the deuteron, because the internal motion of the target neutron has to account for the energy difference to the threshold of the $np \to d\pi^0$ process. The quasifree interaction makes the proton of the deuteron a spectator with momentum $\vec{p_s} = \vec{k_p}$ in the laboratory frame. At threshold it is $p_s \approx 200$ MeV/c, and it must be $\vec{k_n} = -\vec{k_p}$ because the deuteron is at rest in the laboratory frame. At this value the momentum density distribution $|\Phi_d|^2$ in the deuteron is a factor $10^3$ lower than for a neutron at rest and this cuts the cross section down as compared to that $\frac{d\sigma_{pn\to d\pi^0}}{d\Omega_{q^*}}$ of the elementary NN process, viz.

$$|M_{spect}|^2 \propto |\Phi_d(\frac{\vec{k}_n - \vec{k}_p}{2})|^2 \frac{d\sigma_{pn\to d\pi^0}}{d\Omega_{q^*}}(\eta^*)\,, \tag{1}$$

where $q^\star$ is the pion momentum in the $pn \to d\pi^0$ center of mass frame, respectively and $\eta^* = \frac{q^*}{m_\pi}$. The dashed line in Fig. 1 gives the *absolute* cross section if the quasi free $np \to d\pi^\circ$ mechanism were the only one contributing. It represents the correct order of magnitude but fails to describe the shape of the experimental excitation function. This discrepancy was removed in [5] by introducing a pd final state interaction in Watson-Migdal approximation with an arbitrary overall normalization (see Fig. 1).

Now, the dominance of the quasifree NN reaction mechanism cannot be deduced from the excitation function alone; observables more sensitive to the matrix element Eq. (1) are angular and energy distributions of the outgoing particles p and d. A careful Monte Carlo (MC) based analysis of the data [1] yielded [6] that distributions calculated from Eq. (1) do NOT agree with the experimental results. In particular the energy distributions of the outgoing protons are at variance with the quasifree expectation, see Fig. 2.

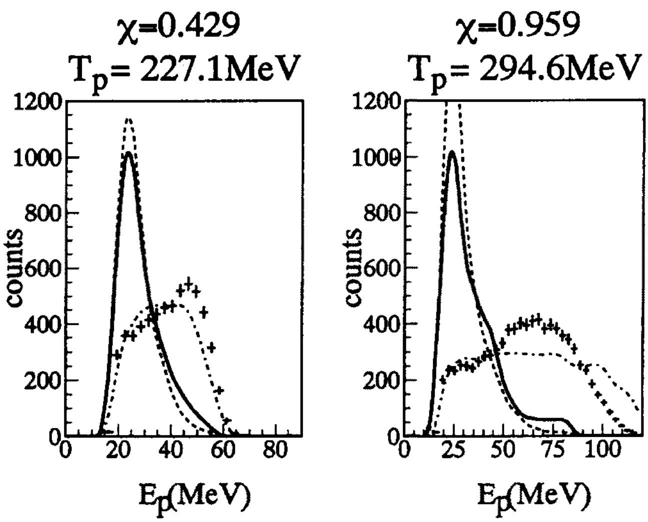


Fig. 2. Comparison of experimental proton energy distributions from $pd \to pd\pi^\circ$ (crosses) with MC predictions for the spectator model without (solid line) and with pd–FSI (dashed) for $T_p$ = 227 MeV ($\eta$ = 0.429, left) and $T_p$ = 294.6 MeV ($\eta$ = 0.959). The pure phase space result is shown as dot–dashed line.

- Close to threshold they rather follow a phase space distribution, *i.e.* a constant $|M|^2$ corresponding to a relative angular momentum L=0 of the pd subsystem and l=0 of the pion with respect to the pd pair.This can be considered the Ss term in the partial wave expansion of the pd$\pi^\circ$ final state wave function.
- For pion momenta $\eta \geq 0.3$, however, partial waves of higher order, in particular Ps, Pp and Pd, contribute and give rise to a dependence of $|M|^2$ both on the proton angle $\Theta_p$ in the pd subsystem and the pion angle $\Theta_{\pi^\circ}$ in the c.m. system.

Close to the $pn \to pn\pi^\circ$ threshold $T_p^{thr,NN} = 275$MeV or $\eta \approx 0.86$, the quasifree contribution according to Eq. 1 should be observable at the maximum of $|\Phi_d|^2$ where the spectator proton is at rest: $\vec{p_s} = 0$. At this velocity, however, its energy distribution escapes direct detection. In summary shows the $pd \to pd\pi^\circ$ reaction for proton projectiles up to the 2N threshold evidence for more than one reaction mechanism. Therefore it is interesting to study the reaction mechanism in the isospin related channel $pd \to nd\pi^+$ by detection of the charged particles $\pi^+, d$ and missing mass reconstruction for the spectator *neutron.* This has been done in [6] based on the experimental data [1], however with low detection efficiency for the outgoing $\pi^+$. The results for $\eta \geq 0.6$ point to a second mechanism with phase space distribution. As an example we show in Fig. 3 deuteron energy spectra compared

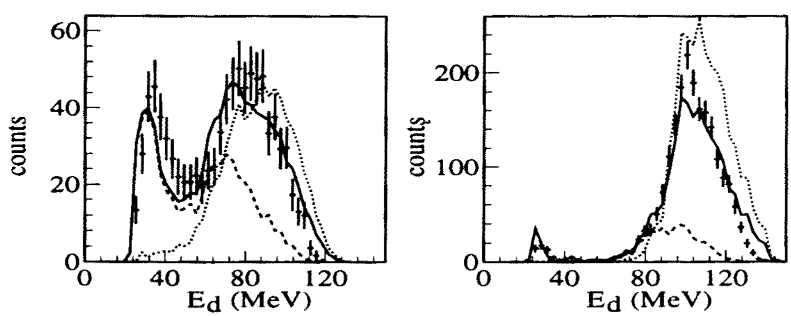


Fig. 3. Comparison of experimental deuteron energy distributions from $pd \to nd\pi^+$ (crosses) with MC predictions based on a best fitting phase space approach to the $pd \to pd\pi^\circ$ data (dashed line), the spectator model (dotted) and an incoherent superposition (solid) for $T_p = 270.5$ MeV ($\eta = 0.718$, left) and $T_p = 294.6$ MeV ($\eta = 0.881$).

to calculations within the the spectator model (*i.e.* the quasi free $pp \to d\pi^+$ process) and the same phase space calculation as before for $pd \to pd\pi^\circ$; it is indicative of comparable contributions from *both* mechanisms. It is, however, not possible to extrapolate this result into the threshold region $\eta < 0.6$. The disadvantage of this indirect approach is that it samples the spectator model without observing the (presumed) spectator itself.

This shortcoming is avoided by having *deuteron* projectiles interact with target *protons* from the three nucleon threshold at 414.5 MeV on in order to study the reaction mechanisms in $pd \rightarrow pd\pi^\circ$ with the energy and angular distributions of the particles in the exit channel. For deuteron energies close to the two nucleon threshold $T_d^{thr,NN} = 550$ MeV of the $np \rightarrow d\pi^\circ$ subprocess the spectator proton will thus be sampled at the velocity of the deuteron projectile in the forward direction and with the momentum density $|\Phi_d|^2$ of the deuteron at its maximum [7]. It is hoped to disentangle this way the contributions to $\pi^\circ$ production in dp interactions from the quasi free $pn \rightarrow d\pi^\circ$ process in this 3N environment and from the mechanism characterized by a phase space distribution.

## REFERENCES

[1] H. Rohdjeß *et al.*, *Phys. Rev. Lett.* **70**, 2864 (1993).
[2] G.Fäldt, C. Wilkin, preprint TSL/ISV-96-0131, subm. to *Phys. Lett.* (1996).
[3] M.A. Pickar *et al.*, *Phys. Rev.* **C46**, 397 (1992).
[4] D.A. Hutcheon *et al.*, *Nucl. Phys.* **A535**, 618 (1991).
[5] H.O. Meyer, J.A. Niskanen, *Phys. Rev.* **C47**, 2474 (1993).
[6] H. Rohdjeß, PhD Thesis, Hamburg 1994.
[7] Experiment CA40 at CELSIUS, Uppsala 1996.