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$NN(^1S_0)$ PAIRS IN ^{3}He AND IN p^3He BACKWARD ELASTIC SCATTERING

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1 Introduction

Over the past few years p^3He backward elastic scattering has been investiged [1, 2, 3] on the basis of the DWBA method using a trinucleon bound-state wave function [4] obtained from solving the Faddeev equations for the RSC nucleon-nucleon (NN) potential. Those studies suggest that this process at beam energies $T_p = 1-2$ GeV can give unique information about the high momentum component of the ^{3}He wave function $\varphi^{23}(\mathbf{q}_{23}, \mathbf{p}_1)$, and specifically for high relative momenta, $q_{23} > 0.6$ GeV/c, of the nucleon pair $\{23\}$ in the $^1S_0$ state and low momenta of the nucleon "spectator" $p_1 < 0.1$ GeV/c. Here φ^{23} is the first Faddeev component of the full wave function of ^{3}He, $\Psi(1,2,3) = \varphi^{23}+\varphi^{31}+\varphi^{12}$. The calculations presented in Refs. [1, 2, 3] demonstrate a dominance of the mechanism of sequential transfer (ST) of the proton-neutron pair (Fig.1a) in this process over a wide range of initial energies $T_p = 0.1-2$ GeV, except for the region of the ST dip at around 0.3 GeV. Other mechanisms of two-nucleon transfer, such as the deuteron exchange [5], non-sequential np transfer [2], and direct pN scattering [6, 7] involve very high internal momenta in the ^{3}He wave function in q_{23} as well as in p_1 and, in sum, give much smaller contributions. However, in analogy to pd backward elastic scattering [8] one should expect also a significant contribution from mechanisms related to excitation of nucleon isobars in the intermediate state followed by emission of virtual pions. Such mechanisms were discussed in Refs. [3, 9] on the basis of the triangle diagram of the one pion exchange (OPE) with the subprocess $pd \to {}^3\mathrm{He}\,\pi^0$ (Fig. 1b) and in Ref. [10, 11] for the two-loop diagram with the subprocess $\pi d \to \pi d$. The energy dependence of the cross section for $p^3\mathrm{He} \to {}^3\mathrm{He}p$ and also its absolute value were explained to some extent in Refs. [10, 11]. However, a common drawback of the models [9, 10, 11] is the neglect of both (i) the contribution of the singlet deuteron d^* (i.e. where the pn pair is in the spin-singlet ($^1S_0$) state) in ^{3}He and (ii) distortions coming from rescattering in the initial and final states. In the present paper we consider both these effects and show that each of them is very important, though there is an effective cancellation between them in the unpolarized cross section.

2 The One Pion Exchange model

To account for the OPE mechanism (Fig. 1b-d), we proceed here from the formalism of Ref. [3] which takes into account the two-body $d+p$ configuration of ^{3}He. The $d+p$ configuration of ^{3}He gives a reasonable approximation to the ^{3}He charge form factor $F(Q)$ [7] up to rather high transferred momenta $Q \approx 1.5$ GeV/c. Furthermore, by neglecting off-shell effects in the subprocess $pd \to {}^3\text{He}\,\pi^0$ one can express the cross section of p^3He scattering through the experimental cross section of the reaction $pd \to {}^3\text{He}\,\pi^0$ without elaboration of its concrete mechanism.

2.1 The mechanism of the $pd^* \to {}^3\text{He}\,\pi^0$ reaction

In the calculation of Ref. [3] the d^*+p configuration was not taken into account explicitly but via normalization of the form factor to $F(0) = 1$. In order to calculate the contribution of the meson production on the virtual singlet deuteron d^* and on the diproton, i.e. on the pp $^1S_0$ state in ^{3}He, one has to use the $d^* + p$ and $(pp) + n$ configurations of ^{3}He explicitly and also one needs the cross sections of the reactions $pd^* \to {}^3\text{He}\,\pi^0$ and $p(pp) \to {}^3\text{He}\,\pi^0$.

Concerning the latter two, there are no direct measurements of this reactions though there are experimental data on the inverse reactions of pion capture, i.e. $\pi^+\,{}^3\text{He} \to ppp$ from Ref. [14] and $\pi^-\,{}^3\text{He} \to pnn$ [15], both being kinematically complete experiments which cover the final state NN interaction regions. Unfortunately, these data are restricted to pion energies close to the threshold and contain only total cross sections. Moreover, the π^+ and π^- data [14, 15] are not sufficient to deduce the matrix element of the reaction $pd^* \to {}^3\text{He}\,\pi^0$. Nevertheless, these data [15] show that the formation of the pn and nn pairs in the final state interaction region is dominated by the spectator mechanism of pion absorption on the isosinglet NN pair in ^{3}He (Fig. 2). This mechanism is used here to calculate the cross section of the subprocesses $p(NN)_{s,t} \to {}^3\text{He}\,\pi$ on the spin-triplet (t) and singlet (s) NN pairs. According to Ref. [12], this two-body mechanism explains reasonably well the cross section of the reaction $pd \to {}^3\text{He}\,\pi^0$ in the forward ($\theta_\pi = 0°$) and backward ($\theta_\pi = 180°$) directions in the energy range $T_p \sim 0.3 - 1.0$ GeV. Within a similar model, the tensor analyzing power T_{20} (at $\theta_\pi = 180^o$) could be reasonably explained in Ref. [13], but using the pure deuteron and singlet deuteron in the intermediate state of the diagram in Fig. 2 instead of the NN loop. At higher energies, $T_p > 1$ GeV, the spectator mechanism fails to reproduce the second peak in the excitation function of the reaction $pd \to {}^3\mathrm{He}\,\pi^0$. In this region the 3-body mechanism [12] is expected to be more important, since all three nucleons are active in the ^{3}He at high transfer of momentum. Nevertheless the latter mechanism also underestimates considerably the experimental cross section at $\theta_\pi = 180^\circ$ [12].

Since the mechanism of the reaction $pd^* \to {}^3\mathrm{He}\,\pi^0$ is not established at higher energies, a completely microscopic description of the reaction $p^3\mathrm{He} \to {}^3\mathrm{He}p$ within the OPE model cannot be achieved at present at $T_p > 1$ GeV. In the present analysis of the contribution of the singlet $(NN)_s$ pairs we concentrate mainly on the energy region $T_p = 0.3 - 1$ GeV, where the spectator diagram in Fig. 2 dominates.

2.2 Formalism

The reaction amplitude is given by the coherent sum of the OPE amplitudes $M_d + M_{d^*} + M_{pp}$, with contributions from the deuteron M_d (Fig. 1b), singlet deuteron M_{d^*} (Fig. 1c) and diproton M_{pp} (Fig. 1d). For the evaluation of the individual amplitudes, we use the overlap integrals $^3\mathrm{He}-d$ and $^3\mathrm{He}-d^*$ from Ref. [16]. The $^3\mathrm{He}-d$ overlap wave function contains the S-wave and D-wave components. As was shown in Ref. [3], the D-wave component of the $^3\mathrm{He}-d$ overlap integral is negligible in the OPE amplitude. Keeping the S-wave in the $^3\mathrm{He} - d$ overlap wave function, one can find for the OPE amplitude of the reaction $p^3He \to {}^3\mathrm{He}p$ with the subprocess $pd \to^3 He\,\pi^0$ the following form [3]

$$M_d^{\mu_h',\mu_p';\,\mu_h,\mu_p} = -\sqrt{3}\,KG_d\,(10\frac{1}{2}\mu_p'|\frac{1}{2}\mu_p')\sum_\lambda(1\lambda\frac{1}{2}\mu_p'|\frac{1}{2}\mu_h)T_d^{\mu_h';\,\mu_p,\lambda}. \quad (1)$$

Here μ_j (μ_j') is the spin projection of the initial (final) particle $j = p, h$ (p denotes the proton and h - the ^{3}He) and λ is the spin projection of the deuteron. $T_d^{\mu_h';\,\mu_p,\lambda}$ is the amplitude of the reaction $pd \to^3 He\,\pi^0$. The Clebsch-Gordan coefficients are written in Eq. (1) in standard notations. The dynamical and structure factors K and G_d will be defined below. For the singlet deuteron there is only the S-wave component in the overlap integral ^{3}He$-d^*$. Therefore, the OPE amplitude for the d^* can be written as

$$M_{d^*}^{\mu_h',\mu_p';\mu_h,\mu_p} = KG_{d^*}\,(10\tfrac{1}{2}\mu_p'|\tfrac{1}{2}\mu_p')\delta_{\mu_p',\mu_h}T_{d^*}^{\mu_h';\mu_p}, \tag{2}$$

and similarly for the intermediate diproton (pp)

$$M_{pp}^{\mu_h',\mu_p';\mu_h,\mu_p} = 2\,KG_{d^*}(10\tfrac{1}{2}\mu_p'|\tfrac{1}{2}\mu_p')\delta_{\mu_p',\mu_h}T_{pp}^{\mu_h';\mu_p} \tag{3}$$

where $T_{d^*}^{\mu_h';\mu_p}$ and $T_{pp}^{\mu_h';\mu_p}$, are the amplitudes of the subprocesses $pd^* \to {}^3\mathrm{He}\,\pi^0$ and $p(pp)_s \to {}^3\mathrm{He}\,\pi^+$, respectively. As compared to Eq. (2), an additional isospin factor of 2 arises in Eq. (3) and there is also an isospin factor of $\sqrt{3}$ in Eq. (1). Both these factors are related only to the isospin structure of the lower vertices $^3He \to (NN)_{s,t} + N$ and $\pi N \to N$ of the triangular diagram for the OPE amplitude of the process $p^3He \to {}^3\mathrm{He}p$ and do not depend on the mechanism of the process $p(NN)_{s,t} \to {}^3\mathrm{He}\,\pi$. The dynamical factor K is defined as

$$K = \frac{\sqrt{m\,M(E_{p'}+m)}}{\sqrt{2\pi}\,E_{p'}}\,\frac{f_{\pi NN}}{m_\pi}\,D(T_p)F_{\pi NN}(k^2). \tag{4}$$

Here m, M and m_π are the masses of the proton, ^{3}He and the pion, respectively. $E_{p'} = \sqrt{m^2+\mathbf{p}_{p'}^2}$ and $\mathbf{p}_{p'}$ are the total energy and momentum of the secondary proton in the laboratory system, and $f_{\pi NN}$ and $F_{\pi NN}(k^2)$ are the coupling constant and the (monopole) form factor at the πNN vertex. The distortion factor $D(T_p)$ is given in Ref. [3] in eikonal approximation in terms of an analytical parametrization of the forward pN and p^3He scattering amplitudes.

The nuclear form factors for the triplet (G_d) and singlet (G_{d^*}) channels are given by

$$G_{d,d^*} = \sqrt{S_{d,d^*}^h}\left(i\kappa F_0^{d,d^*}(\tilde p) + W_{10}^{d,d^*}(\tilde p,\tilde\delta)\right). \tag{5}$$

where

$$\begin{aligned} F_0^{d,d^*}(\tilde p) &= \int_0^\infty U_0^{d,d^*}(r)\,j_0(\tilde p r)\,r dr,\\ W_{10}^{d,d^*}(\tilde p,\tilde\delta) &= \int_0^\infty j_1(\tilde p r)U_0^{d,d^*}(r)(i\tilde\delta+1)\exp(-i\tilde\delta r)dr. \end{aligned} \tag{6}$$

Here $U_0^d(r)$ ($U_0^{d^*}(r)$) is the S-wave component of the $^3\mathrm{He}-d$ ($^3\mathrm{He}-d^*$) overlap integral and j_l is the spherical Bessel function. The kinematical variables κ, $\tilde{\mathbf{p}}$ and $\tilde{\delta}$ are determined by the proton momentum $\mathbf{p}'$ [3]: $\tilde{\mathbf{p}} = 2m/E_{p'}\mathbf{p}'$, $\kappa = \tilde{p}(2E_{p'}+m)/(2E_{p'}+m)$, $\tilde{\delta}^2 = 2m/E_{p'}(m_\pi^2 - k^2) + |\tilde{\mathbf{p}}|^2$, where k^2 is the square of 4-momentum of the virtual π-meson. The spectroscopic factors for the deuteron, S_{pd}^h, and the singlet deuteron, including diproton, $S_{pd^*}^h$, are taken here to be $S_{pd}^h = S_{pd^*}^h = 1.5$, in accordance with Refs. [13, 16].

We should note that due to the presence of the Kronecker-δ in Eqs. (2) and (3), the singlet amplitudes M_{d^*} and M_{pp} contribute only to the spin-independent part of the OPE amplitude of the reaction $p^3\mathrm{He} \to {}^3\mathrm{He}p$. At the same time the spin-dependent part is given by the spin-triplet amplitude M_d alone. Because of this specific structure there is no interference between the triplet and singlet amplitudes in the spin-averaged sum $\overline{|M_d + M_{d^*} + M_{pp}|^2}$. This feature simplifies the theoretical analysis of the unpolarized cross section significantly. Thus, we find that the total spin averaged OPE amplitude of the $p^3\mathrm{He}$ backward elastic scattering has the form

$$\overline{|M^{\mu_h',\mu_p';\mu_h,\mu_p}|^2} = |K|^2 \left\{ \overline{|G_d T_d^{\mu_h';\mu_p,\lambda}|^2} + \frac{1}{3}\overline{|G_{d^*}(T_{d^*}^{\mu_h';\mu_p} + 2\,T_{pp}^{\mu_h';\mu_p})|^2} \right\}. \tag{7}$$

Since there is no interference term between singlet and triplet NN pairs, it is convenient to introduce the following relation for the squared singlet and triplet amplitudes of the processes $p(NN)_{s,t} \to {}^3\mathrm{He}\,\pi$,

$$\frac{1}{3}\overline{|T_{d^*}^{\mu_h';\mu_p} + 2T_{pp}^{\mu_h';\mu_p}|^2} = C_I\overline{|T_d^{\mu_h';\mu_p\,\lambda}|^2}. \tag{8}$$

Of course, in general, the factor C_I is a complicated function depending on the energy and the transferred momentum. However, for the spectator model (Fig. 2) we can obtain a reasonable estimate of this factor on the basis of isospin relations only. We can then use Eq. (8) in order to express the singlet contribution in terms of the experimental cross section of the reaction $pd \to {}^3\mathrm{He}\,\pi^0$. After that the c.m.s. cross section of $p^3\mathrm{He}$ backward elastic scattering can be written as

$$\frac{d\sigma}{d\Omega_{cm}} = \frac{m\,M(E_{p'}+m_p)}{2\pi\,E_{p'}^2}\left(\frac{f_{\pi NN}}{m_\pi}\right)^2 \frac{s_{pd}\,q_{pd}}{s_{ph}\,q_{\pi h}} F_{\pi NN}^2(k^2)\,|D(T_p)|^2 \times$$

$$\times\{|G_d|^2 + C_I\,|G_{d^*}|^2\}\frac{d\sigma}{d\Omega_{cm}}(pd \to {}^3\mathrm{He}\,\pi^0)\ , \qquad (9)$$

where s_{ij} is the square of the invariant mass of the system $i+j$, and q_{ij} is the relative momentum in this system.

2.3 Approximated evaluation of C_I

In the evaluation of the factor C_I in Eq. (8) for the spectator model of the process $p(NN)_{s,t} \to {}^3\mathrm{He}\,\pi$ we assume that the spatial parts of the vertices $d \to p+n$, $d^* \to p+n$, and $(pp)_s \to p+p$ in Fig. 2 are approximately the same in ^{3}He. Furthermore, we assume that the subprocess $pN \to (NN)_t\,\pi$ dominates in the upper vertex of the diagram in Fig. 2 and that the amplitude $pN \to (NN)_s\,\pi$ is negligible. This is true in the Δ-region, as was shown recently [17]. With this approximation the following relation between the amplitudes of the processes $pd^* \to {}^3\mathrm{He}\,\pi^0$ and $p(pp)_s \to {}^3\mathrm{He}\,\pi^+$ follows from isospin invariance

$$T_{pp}^{\mu_h';\mu_p} = 2\,T_{d^*}^{\mu_h';\mu_p}. \qquad (10)$$

After that the factor C_I is basically given by the Clebsch-Gordan coefficients at the vertices of the spectator diagram in Fig. 2 and in the OPE diagrams in Fig. 1b-d. We find that there is a constructive interference between the singlet amplitudes M_{d^*} and M_{pp} and that the factor C_I in Eqs. (8,9) equals to $\frac{25}{3}$. Thus, the contributions of the singlet deuteron and the diproton are significantly larger than those of the deuteron. Since the singlet and triplet form factors are related numerically by $G^{d^*} \approx 1.5\ G^d$ in the kinematical region under discussion (cf. Ref. [13]), we get a total enhancement of about 12 in the $p^3\mathrm{He} \to {}^3\mathrm{He}p$ cross section due to the contribution of the singlet NN pairs. Note that we use Eq. (8) with the factor $C_I = 25/3$ also at energies above 1 GeV. Due to the poor knowledge of the mechanism of the reaction $pd \to {}^3\mathrm{He}\,\pi$ at these energies, however, this has to be considered as a purely phenomenological prescription.

In order to explore the reliability of the assumptions and approximations discussed above, we performed also a direct calculation of the term $\overline{|T_{d^*} + 2T_{pp}|^2}$ in the left hand side of Eq. (8). It was done in collinear kinematics in the region of $T_p = 0.3 - 0.8$ GeV on the basis of the spectator diagram (Fig. 2) with the intermediate deuteron, taking into account the S- and D-wave components of the ^{3}He-d overlap integral. For the $pp \to d\pi^+$ amplitude we employed the parametrization given in Ref. [18]. As an estimation, for the internal wave function of the d^*, we used the separable term $\varphi_1(r)$ of the $^1S_0$ component of the RSC trinucleon wave function from Ref. [19] and, for comparison, the S-wave component of the RSC deuteron wave function. In both these cases the obtained results for the cross section at 0.3-0.8 GeV coincide with the present estimation based on Eqs.(8,9) within $\approx$30%. At last, the total cross section of the reaction $\pi^+\,{}^3\mathrm{He} \to (pp)p$ in the final state interaction region measured in Ref. [14] at kinetic energy of pion 37 MeV, $\sigma = 2.4 \pm 0.7$ mb, is comparable with that for the reaction $\pi^0\,{}^3\mathrm{He} \to dp$, $\sigma = 1.3$ mb, recalculated here from the $pd \to ^3\mathrm{He}\,\pi^0$ data [20] for the corresponding proton beam energy $T_p = 262$ MeV. The ratio of these cross sections $\sigma(\pi^+\,{}^3\mathrm{He} \to (pp)p)/\sigma(\pi^0\,{}^3\mathrm{He} \to dp)$ is in agreement with the value $\frac{2^2}{2J_d+1} = \frac{4}{3}$, expected within the spectator mechanism, where the factor 4 in the numerator is the squared isospin factor 2 from Eq. (10), and the factor 3 in the denominator is the spin-statistical factor for the final deuteron.

The result above implies that, within this approximation, the total contribution of the triplet and singlet NN pairs can be taken into account by variation of the effective spectroscopic factor of the deuteron in ^{3}He, $S^h_{pd} \rightsquigarrow S^h_{pd}(1+1.5C_I)$. In the numerical calculation we use the parametrizations from Ref. [13] for the $^3\mathrm{He} - d$ and $^3\mathrm{He} - d^*$ overlap integrals [16] obtained for the Urbana NN potential. We have found that the final result is almost the same when the RSC parametrization from Ref. [3] is used. The experimental cross section of the reaction $pd \to {}^3\mathrm{He}\,\pi^0$ for the backward scattered pions ($\theta_{cm} = 180°$) is taken from [20]. For the cut-off parameter Λ_π in the monopole form factor of the πNN vertex we consider values in the range of $\Lambda_\pi = 0.65 - 1.3$ GeV/c. The lower case, $\Lambda_\pi = 0.65$ GeV/c, corresponds to the value obtained in an analysis of the reaction $pp \to pn\pi^+$ at 0.8 GeV performed in the $\pi + \rho$ exchange model [21]. The upper case, $\Lambda_\pi = 1.3$ GeV/c, is the value used in the full Bonn NN model [22].

3 Numerical results and discussion

The result of our calculation are shown in Fig. 3. One can see that the OPE model with the deuteron yields a reasonable description of the energy dependence of the cross section for $T_p = 0.4 - 1.5$ GeV, although it underestimates the magnitude. The calculated cross section is smaller than the experiment by a factor of around 3–3.5 for $\Lambda_\pi = 0.65$ GeV/c, and by about 1.5–2.5 for $\Lambda_\pi = 1.3$ GeV/c depending on the beam energy. After the contributions of the singlet deuteron d^* and of the pp pair are taken into account, the cross section for $p^3\mathrm{He} \to {}^3\mathrm{He}\,p$ is overestimated at $T_p > 0.3$ GeV by a factor of 2.5–4 (for $\Lambda_\pi = 0.65$ GeV/c) and 5–10 (for $\Lambda_\pi = 1.3$ GeV/c), respectively. The distortion factor $D(T_p)$ reduces the OPE cross section of the reaction $p^3\mathrm{He} \to {}^3\mathrm{He}\,p$ by one order of magnitude (thick solid line) and brings it in qualitative agreement with the data. The discrepancy with the data in the region of the first shoulder, $T_p = 0.3 - 0.6$ GeV, can be attributed to others terms in the $pd^* \to {}^3\mathrm{He}\,\pi^0$ amplitude, like the two-step mechanism [23]. It can be shown that for the two-step mechanism there is also an enhancement of the $d^* + p$ contribution in the Δ-isobar region but, in contrast to the spectator mechanism, its energy dependence is strongly affected by the off-shell behaviour of the πN scattering amplitude and not considered here.

Turning back to the pure two nucleon transfer mechanism [1, 2, 3] we should note that the three-nucleon bound-state wave function [4] based on the Reid RSC potential most likely contains too large high momentum components as compared to modern NN potentials. In order to corroborate that we show here, in the framework of the S-wave formalism of Ref. [3], that for the trinucleon wave function [24] based on the CD Bonn NN interaction [25] the ST cross section at $T_p > 0.5$ GeV is by a factor of 30 smaller than for the RSC. Nevertheless the predicted cross section is still comparable with the experimental data at $T_p > 0.9$ GeV (Fig.4).[1] One can see from Fig. 3, that the ST mechanism is very important at beam energies $T_p = 0.9 - 1.5$ GeV and it definitely dominates at low ($T_p < 0.3$ GeV) and high ($T_p > 1.5$ GeV) energies. A dominant role of the singlet $NN(^1S_0)$ pairs in ^{3}He, as

[1] Inclusion of the D-waves will lead to an additional increase of the calculated cross section (see Ref. [2]).

reflected in the ST and OPE mechanisms of the p^3He backward elastic scattering, probably, can be connected to the pp-correlations in the reaction ^{3}He$(e, e'pp)n$ reaction recently observed in Ref. [31].

Summarizing our results, we can conclude the following: (i) The OPE mechanism in the plane wave approximation with the subprocess $pd \to {}^3\text{He}\pi^0$ describes well the energy dependence of the $p^3\text{He} \to {}^3\text{He}p$ cross section, but underestimates its absolute value by a factor of 2–3.5, depending on the cut-off mass used in the form factor at the πNN vertex. (ii) The contribution of the singlet deuteron for the spectator mechanism of the reaction $pd^* \to {}^3\text{He}\pi^0$ is by one order of magnitude larger than the one of the deuteron. (iii) The enhancement of the OPE cross section after inclusion of the contribution of the singlet deuteron is, however, almost completely counterbalanced by the reduction caused by distortions in the initial and final states.

Therefore, the first shoulder in the $p^3\text{He} \to {}^3\text{He}p$ cross section at 0.4–0.6 GeV is caused mainly by the OPE mechanism with the singlet $NN(^1S_0)$ pairs. A measurement of spin observables, planned at the RCNP in Osaka [30], can give additional information here because, in contrast to the d term, the d^* and pp terms contribute only to the spin-independent part of the OPE amplitude of the reaction $p^3\text{He} \to {}^3\text{He}p$ and, consequently, could have a strong influence on the spin-spin correlation parameter $C_{y,y}$. The origin of the second shoulder at 0.9–1.3 GeV is less clear. A significant part of this cross section is produced by the ST mechanism [1, 2, 3]. Using the CD Bonn wave function for ^{3}He instead of the one based on the RSC potential decreases the contribution of the ST mechanism. Nevertheless, this does not change the main conclusion of Ref. [3], namely that the significance of the contribution from this mechanism for energies $T_p > 1$ GeV allows one to probe specifically the high momentum components of the ^{3}He wave function. However, the connection between the observables and the high-momentum structure of the ^{3}He wave function becomes much less transparent because of the large contribution of the OPE mechanism and the uncertainties connected to its d^* contribution in this region. Future progress in the analysis of the role of intermediate pions in the reaction $p^3\text{He} \to {}^3\text{He}\,p$ requires the clarification of the mechanism for the subprocess $pd \to {}^3\text{He}\,\pi^0$, in particular at energies $T_p > 1$ GeV.

In addition it is desirable to take into account that this subprocess is off-shell in $p^3\mathrm{He} \to {}^3\mathrm{He}\,p$ and also to consider the NN continuum in the virtual subprocesses $p(NN)_{s,t} \to {}^3\mathrm{He}\,\pi^0$.

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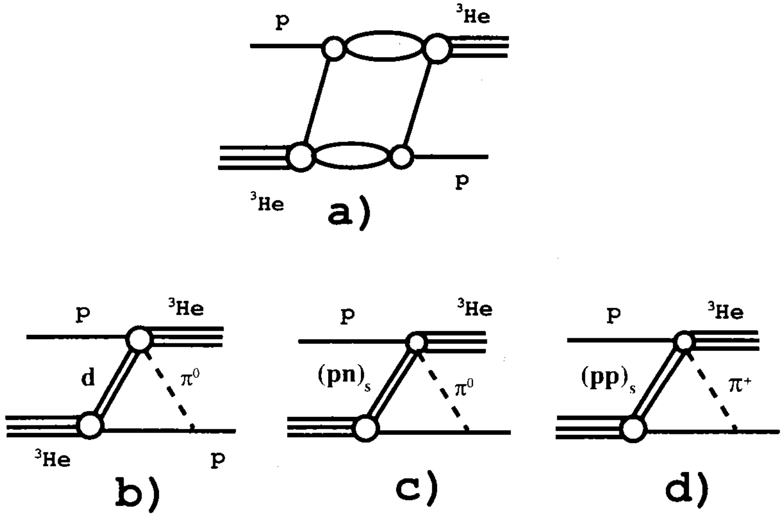

Figure 1: The sequential transfer (ST) (a) and one pion exchange (OPE) (b-d) mechanisms of p^3He backward elastic scattering with intermediate deuteron (b), singlet pn pair (d^*) (c), and singlet pp pair (diproton) (d).

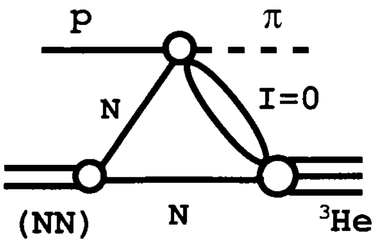

Figure 2: The spectator model of the reaction $p(NN)_{s,t} \rightleftharpoons {}^3\mathrm{He}\pi$.

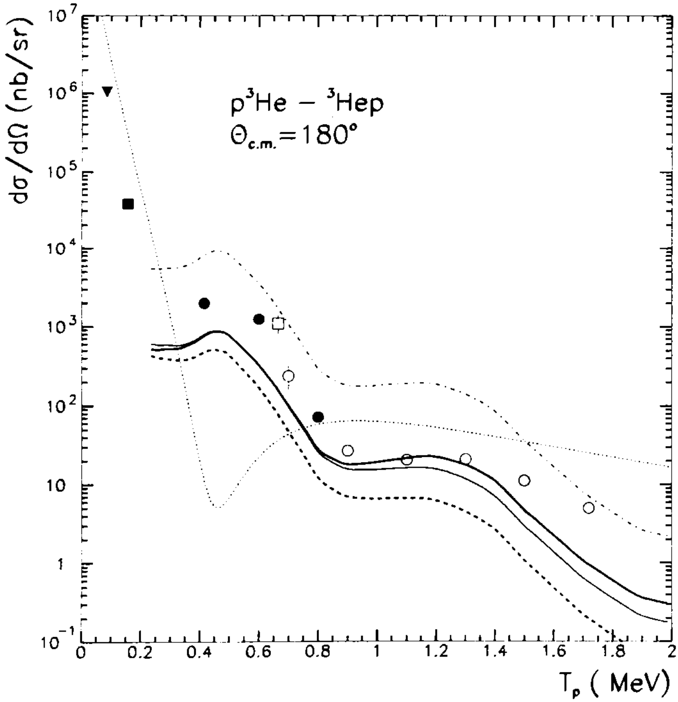

Figure 3: C.m.s. cross section of elastic p^3He scattering at the scattering angle $\theta_{cm} = 180°$ as a function of the kinetic energy of the proton beam. Calculations on the basis of the OPE model for the deuteron in the intermediate state and without distortions are shown by thin solid line (for $\Lambda_\pi = 1.3$ GeV/c) and dashed line ($\Lambda_\pi = 0.65$ GeV/c). OPE cross section for $d+d^*+pp$ with $\Lambda_\pi = 1.3$ GeV/c is shown by dashed-dotted (without distortions) and thick solid line (including distortions). The result for the non-distorted ST cross section with CD Bonn is given by the dotted line. Experimental data are from Refs. [10] (o), [26] (filled square), [27] (open square), [28] (•), and [29] (filled triangle).

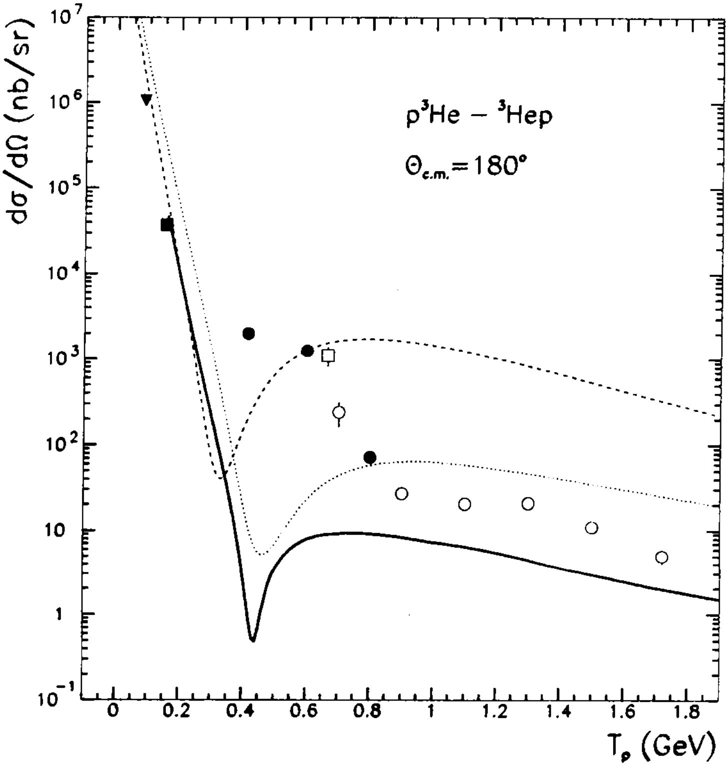

Figure 4: C.m.s. cross section of elastic p^3He scattering at the scattering angle $\theta_{cm} = 180°$ as a function of the kinetic energy of the proton beam. The theoretical curves show results of calculations for the ST mechanism in the Born approximation and with different ^{3}He wave functions: Reid RSC (dashed line); CD Bonn (dotted). The ST cross section for the CD Bonn wave function with distortions taken into account is shown by thick solid line. Note that the distortion factor for the ST mechanism differs from the one for OPE. Same description of data as in Fig. 3.

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