The charge-exchange reaction $dp \to \{pp\}_s N\pi$ in the Δ-isobar region

Yu.N. Uzikov,[1] J. Haidenbauer,[2] and C. Wilkin[3]

[1]*Laboratory of Nuclear Problems, Joint Institute for Nuclear Research, 141980 Dubna, Russia*
[2]*Institute for Advanced Simulation and Jülich Center for Hadron Physics, Forschungszentrum Jülich, D-52425 Jülich, Germany*
[3]*Physics and Astronomy Department, UCL, London, WC1E 6BT, UK*

(Dated: November 9, 2012)

Mechanisms for the charge exchange reaction $dp \to \{pp\}_s N\pi$, where $\{pp\}_s$ is the two-proton system at low excitation energy $E_{pp} < 3$ MeV, are studied at beam energies 1 – 2 GeV, with focus on the invariant mass M_x of the final $N\pi$ system corresponding to the formation of the $\Delta(1232)$-isobar. We show that the direct mechanism for this reaction, with the initial proton being excited to the $\Delta(1232)$, dominates and can explain qualitatively the existing data on the unpolarized differential cross section at $M_x > 1.2$ GeV/c^2. The contribution of the exchange mechanism, where the Δ-excitation takes place on one of the nucleons inside the deuteron, is an order of magnitude smaller and cannot explain the data at low M_x. The tensor analyzing powers A_{xx} and A_{yy} are estimated within the direct mechanism and found to be in strong disagreement with the preliminary ANKE-COSY data at $M_x > 1.2$ GeV/c^2.

PACS numbers: 25.10.+s, 25.40.Qa, 25.45.-z
Keywords: proton–deuteron collisions, Δ-isobar, spin observables

I. INTRODUCTION

The $dp \to \{pp\}_s n$ reaction at very low transferred momenta from the incident deuteron to the final di-proton $\{pp\}_s$ allows one to study the spin-flip part of the nucleon-nucleon (NN) charge-exchange forces [1, 2]. Here $\{pp\}_s$ is a pp pair at low excitation energy, typically $E_{pp} < 3$ MeV, being predominantly in the $^1S_0$ state. A recent review can be found in Ref. [3]. A systematic experimental study of this reaction is underway at ANKE@COSY in both single- [4] and double-polarized [5] experiments. The main goal of these experiments is to extend the existing data set on proton-neutron scattering, which has been much less well studied than proton-proton scattering.

In addition to data where there is a single missing neutron in the reaction, there are variants where a pion is also produced. The $dp \to \{pp\}_s n\pi^0$ or $dp \to \{pp\}_s p\pi^-$ allow one to study the spin-flip part of the Δ-excitation amplitude in the $pn \to \Delta^+ n$ transition, which is difficult to measure directly. The reaction $\vec{d}p \to \{pp\}\Delta^0$ was studied at SATURNE with a polarized deuteron beam at the energy of 2 GeV [6, 7]. In addition to the differential cross section, a linear combination of the tensor analyzing powers A_{xx} and A_{yy} was also measured and found to be quite large.

A phenomenological impulse approximation analysis of the SATURNE data was performed in order to determine the ratio of the strengths of the spin-transverse to spin-longitudinal transitions [6]. The results obtained for the analyzing powers suggest that there is a large transverse component in the elementary Δ production. On the other hand, the spin-averaged cross section is well described by one-pion exchange (OPE) [8] but this leads to a purely longitudinal transition.

New data on the unpolarized cross sections for the reaction $\vec{d}p \to \{pp\}N\pi$ and also for tensor analyzing powers were recently obtained at ANKE@COSY at incident deuteron energies from 1.6 to 2.3 GeV [9, 13]. It is important to note that in the ANKE experiment the tensor analyzing powers A_{xx} and A_{yy} were determined separately. An interesting point is that the measured A_{xx} and A_{yy} differ from the corresponding observables in the ordinary $dp \to \{pp\}_s n$ charge-exchange reaction in absolute value as well as in sign.

The full set of data on the $dp \to \{pp\}_s n$ reaction can be well explained by the single-scattering mechanism with the $pn \to np$ amplitude as input provided that one includes the pp final-state interaction in the $^1S_0$ channel. It is important to check whether the tensor analyzing powers of the $dp \to \{pp\}_s N\pi$ reaction can be explained within the same mechanism which allowed one to describe the unpolarized differential cross section. It is expected that at low transferred momenta this reaction should be dominated by the direct (D) one-pion exchange mechanism, as depicted in Fig. 1a). The shape of the differential cross section of the $dp \to \{pp\}_s N\pi$ reaction was calculated utilizing this mechanism [13]. These estimates were based on a modified formalism that was originally developed for the $p(^3\mathrm{He}, t)\Delta^{++}$ reaction [6]. It was found that this mechanism explains well the shape of the measured spectra at high missing masses, $M_x \sim 1.2 - 1.35$ GeV/c^2, but fails at lower ones, $M_x \sim 1.1 - 1.2$ GeV/c^2. It was suggested that this deficiency might be due to a missing contribution, called here the exchange (E) contribution, where the nucleon in the deuteron is excited into the Δ-isobar (see Fig.1b). This mechanism was not considered in Ref. [13]. However, it is taken into account in the present work in addition to the D-mechanism. Furthermore, the $pp\,(^1S_0)$ final-state interaction is also included. For the elementary amplitudes $pN \to \Delta N$ we use, not only one-pion exchange, but also ρ-meson exchange and the $\pi + \rho$ interference.

The expected results could also shed light on the long-standing problem, the so-called T_{20} puzzle, in backward pd elastic scattering and $dp \to pX$ break up in the Δ-isobar region (see Ref. [10] and references therein).

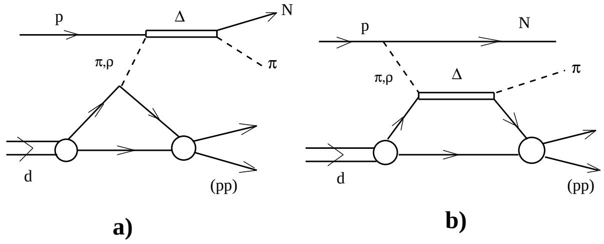

FIG. 1: Direct (a) and exchange (b) mechanisms with Δ-isobar excitation for the reaction $dp \to \{pp\}_s N\pi$.

II. UNPOLARIZED CROSS SECTION

We use the Feynmann diagram techniques for the mechanisms depicted in Fig. 1. For the meson-baryon vertices, we apply the formalism used in Ref. [11], where exclusive data on the reaction $pp \to pn\pi^+$ [12] were analyzed in the Δ-isobar region and the cut-off parameters at the $\pi(\rho)NN$- and $\pi(\rho)N\Delta$ vertices were determined through fits to data. Using phenomenological Lagrangians $\mathcal{L}_{\pi NN}$, $\mathcal{L}_{\rho NN}$, $\mathcal{L}_{\pi N\Delta}$, $\mathcal{L}_{\rho N\Delta}$ [14] for the meson-baryon vertices one has

$$
\begin{aligned}
<\pi N_2|N_1> &= \frac{f_{\pi NN}}{m_\pi}\varphi_1^+(\boldsymbol{\sigma}\mathbf{Q})(\boldsymbol{\tau}\boldsymbol{\Phi}_\pi)\varphi_2 2m_N, \qquad (1)\\
<\rho N_2|N_1> &= \frac{f_{\rho NN}}{m_\rho}\varphi_1^+([\boldsymbol{\sigma}\times\mathbf{Q}]\epsilon_\rho)(\boldsymbol{\tau}\boldsymbol{\Phi}_\rho)\varphi_2 2m_N,\\
<\pi N|\Delta> &= \frac{f_{\pi N\Delta}}{m_\pi}(\boldsymbol{\Psi}_\Delta^+\mathbf{Q}'_\pi)(\mathbf{T}\boldsymbol{\Phi}_\pi)\varphi\sqrt{2m_N 2m_\Delta},\\
<\rho N|\Delta> &= \frac{f_{\rho N\Delta}}{m_\rho}([\boldsymbol{\Psi}_\Delta^+\times\mathbf{Q}'_\rho]\boldsymbol{\epsilon}_\rho)(\mathbf{T}\boldsymbol{\Phi}_\rho)\varphi\sqrt{2m_N 2m_\Delta},
\end{aligned}
$$

where

$$
\begin{aligned}
f_{\pi NN} &= 1.00, f_{\pi N\Delta} = 2.15,\\
f_{\rho NN} &= 6.20, f_{\rho N\Delta} = 13.33. \qquad (2)
\end{aligned}
$$

Here φ_i $(i = 1, 2)$ is the Pauli spinor, Ψ_Δ is the Rarita-Schwinger spinor of the $\Delta-$isobar in the static approximation. These spinors describe the spin and isospin states of the nucleon and Δ-isobar, respectively. $\boldsymbol{\Phi}_\pi$ and $\boldsymbol{\Phi}_\rho$ are the isospin vectors of the π- and ρ-mesons, $\boldsymbol{\epsilon}_\rho$ is the polarization vector of the ρ-meson, $\boldsymbol{\tau}$ is the Pauli isospin matrix. The isospin operator $\mathbf{T}$ is defined in Ref. [15].

The momentum $\mathbf{Q}$ in Eq. (1) has the form

$$
\mathbf{Q} = \left[\frac{E_1 + m_N}{E_2 + m_N}\right]^{1/2}\mathbf{p}_2 - \left[\frac{E_2 + m_N}{E_1 + m_N}\right]^{1/2}\mathbf{p}_1 \ , \qquad (3)
$$

where $E_i = \sqrt{p_i^2 + m_N^2}$ $(i = 1, 2)$. The quantity $\mathbf{Q}'_\pi$ ($\mathbf{Q}'_\rho$) is the 3-momentum of the π (ρ) meson in the Δ rest frame.

The form factors at the $\pi(\rho)NN$, $\pi(\rho)N\Delta$ vertices are assumed to be of monopole type,

$$
F_{\pi(\rho)}(k^2) = \frac{\Lambda^2 - m_{\pi(\rho)}^2}{\Lambda^2 - k^2} \ , \qquad (4)
$$

where m_π (m_ρ) is the π (ρ) mass, k is the π (ρ) 4-momentum, and Λ is the cut-off parameter. The q^3-dependence of the total width of the Δ-isobar on the relative momentum q in the $\pi+N$ system is taken into account. The transition form factor $d \to \{pp\}_s$ is calculated using the CD Bonn potential [16]. Appropriate isospin factors were introduced for the two final $\pi^0 n$ and $\pi^- p$ channels for each mechanism. Preliminary results for the unpolarized cross section were presented in Ref. [17].

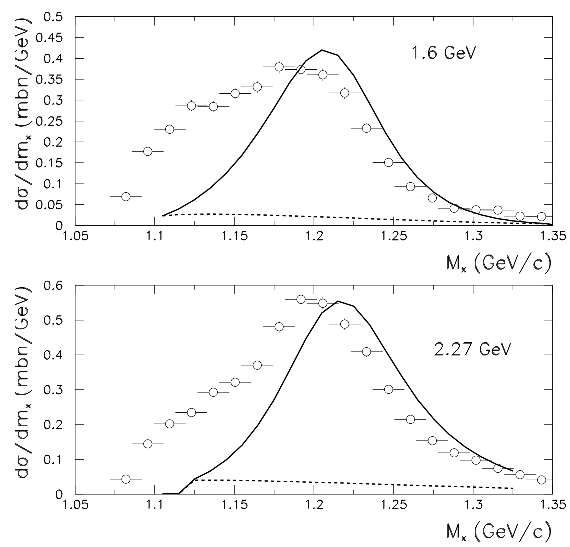

FIG. 2: Differential cross section for the $dp \to \{pp\}_s N\pi$ reaction versus the invariant mass of the $\pi + N$ system, M_x, at the beam energies $T_d = 1.6$ GeV (upper panel) and $T_d = 2.27$ GeV (lower panel). Preliminary ANKE@COSY missing-mass data [13] ($\circ$) are compared with the results of calculations based on the D-mechanism (solid line) and the E-mechanism (dashed line) in the impulse approximation. At 2.27 GeV the results of the calculation are multiplied by the factor 1/1.56.

Numerical results are presented in Fig. 2. These indicate that the D-mechanism allows one to describe the measured shapes of the $d\sigma/dM_x$ distribution for $M_x > 1.2$ GeV/c^2 at all the beam energies T_d studied in Ref. [13], i.e. at 1.6, 1.8, and 2.27 GeV. With a cut-off parameter $\Lambda = 0.5$ GeV the absolute values of the cross section are also reasonably well described at $M_x > 1.2$ GeV/c^2 for $T_d = 1.6$ and 1.8 GeV, while for 2.27 GeV a normalization factor $\approx 1/1.56$ is required. The discrepancy at the highest energy might be connected with the non-relativistic treatment of the $\pi N \to \Delta \to \pi N$ process, here one has to evaluate the scalar product of the 3-momenta of the initial ($\mathbf{k}$) and final ($\mathbf{k}'$) pions in the cms of the Δ-isobar, $(\mathbf{k}\cdot\mathbf{k}')$. Another possible origin of the normalisation factor is that the fitting procedure in Ref. [11] was done at 0.8 GeV (which is equivalent to a deuteron beam energy of 1.6 GeV) but not at 1.15 GeV.

At lower masses, $M_x < 1.2$ GeV, the D-mechanism fails to explain the measured cross section, as already reported in Ref. [13]. The lack of strength at low M_x in this case is associated with the p-wave nature of the $\Delta(1232)$ isobar. The E-mechanism is calculated in a similar way. Due to the spin-flip in the $d \to \{pp\}_s$ transition, the vector product $[\mathbf{k}\times\mathbf{k}']$ of the pion momenta survives in the reaction amplitude. We found that the E-contribution has a maximum at low masses, $M_x \approx 1.1$ GeV, but that its magnitude is much smaller than that of the D-contribution (see the dashed line in Fig. 2). It therefore does not allow one to explain the observed shape of the cross section $d\sigma/dM_x$. The reasons for this small size are (i) the smallness of the Δ propagator for the E-mechanism as compared to the D-mechanism and (ii) the smallness of the vector product $[\mathbf{k}\times\mathbf{k}']$ for the kinematics of the E-mechanism as compared to the scalar product $(\mathbf{k}\cdot\mathbf{k}')$ for the one of the D-mechanism.

In order to check our calculation we evaluated, using the same techniques and within almost the same kinematics, the cross section of the reaction $dp \to dX$. In this case the D-mechanism is forbidden by isospin though the E-mechanism is allowed. We obtained reasonable agreement with the data [18] for this reaction and also with the model calculations given in that paper.

III. TENSOR ANALYZING POWERS

In the impulse approximation, the transition matrix element for the direct mechanism of the $dp \to \{pp\}_s\Delta^0$ reaction can be written as

$$M_{fi} = \Psi^+_j(\lambda_\Delta)(D_\pi k_j T_i + D_\rho M_{ji}) e_i(\lambda_d)\varphi_p(\sigma_p). \quad (5)$$

Here Ψ^+_j is the vector-spinor of the Δ-isobar, φ_p is the spinor of the initial proton, e_i is the polarization vector of the deuteron, λ_Δ, λ_d and σ_p are the spin projections of the Δ, the deuteron, and the proton, respectively. Furthermore, k_j is the 3-momentum of the pion in the Δ-isobar rest frame ($j = x, y, z$). The vector operator for the pion exchange, T_i, has the form

$$T_i = (S_S + \frac{1}{2}S_D)Q_i - \frac{3}{\sqrt{2}}S_D(\mathbf{Q}\cdot\mathbf{n})n_i \ , \quad (6)$$

where $S_S(q)$ and $S_D(q)$ are the S- and D-wave transition form factors $d \to \{pp\}_s$ at the 3-momentum transfer $\mathbf{q}$, with $\mathbf{n}$ being the unit vector along $\mathbf{q}$. The momentum $\mathbf{Q}$ in Eq. (6) is given by Eq. (3), where $\mathbf{p}_1$ ($\mathbf{p}_2$) is the 3-momentum of the virtual proton (neutron) in the diagram of Fig. 1a.

The ρ-meson exchange is described by the tensor M_{ji}:

$$\begin{aligned} M_{ji} &= (S_S + \frac{1}{2}S_D)(\mathbf{Q}\cdot\mathbf{Q}')\left[\delta_{ji} - Q_jQ'_i\right] \\ &-\frac{3}{\sqrt{2}}S_D\left[(\mathbf{Q}\cdot\mathbf{Q}')n_j - (\mathbf{Q}'\cdot\mathbf{n})Q_j\right] \ . \end{aligned} \quad (7)$$

Here $\mathbf{Q}'$ is the momentum of the ρ-meson in the Δ-isobar rest frame and $\mathbf{Q}$ is given by Eq. (3). The factors D_π and D_ρ in Eq. (5) have the following forms

$$\begin{aligned} D_\pi &= 4\sqrt{\pi}\frac{f_{\pi NN}}{m_\pi}\frac{f_{\pi N\Delta}}{m_\pi}\frac{F_{\pi NN}(k^2)F_{\pi N\Delta}(k^2)}{k^2 - m_\pi^2 + i\epsilon} \\ &\times N_{pp}C_T\,2m_p\sqrt{m_p}\sqrt{2M_\Delta} \ , \end{aligned} \quad (8)$$

$$\begin{aligned} D_\rho &= 4\sqrt{\pi}\frac{f_{\rho NN}}{m_\rho}\frac{f_{\rho N\Delta}}{m_\rho}\frac{F_{\rho NN}(k^2)F_{\rho N\Delta}(k^2)}{k^2 - m_\rho^2 + i\epsilon} \\ &\times N_{pp}C_T\,2m_p\sqrt{m_p}\sqrt{2M_\Delta} \ . \end{aligned} \quad (9)$$

Here $C_T = \sqrt{2/3}$ is an isospin factor, $N_{pp} = 2$ is a combinatorial factor appearing due to identity of two final protons, and M_Δ is the mass of the Δ-isobar.

The tensor analyzing power A_{ij} is determined by

$$A_{ij} = Tr\{M\hat{\mathcal{P}}_{ij}M^+\}/Tr\{MM^+\} \ , \quad (10)$$

where M is the transition operator given by Eq. (5), $\hat{\mathcal{P}}_{ij} = \frac{3}{2}(\hat{S}_i\hat{S}_j + \hat{S}_j\hat{S}_i) - \delta_{ij}$ and S_l is the spin-one operator ($i, j, l = x, y, z$). To compare with the ANKE@COSY experiment [13], we consider A_{xx} and A_{yy} as functions of the transverse component of the momentum transfer q_t. The OZ-axis is chosen along the deuteron beam momentum $\mathbf{p}_d$, OY along $\mathbf{p}_d\times\mathbf{p}_{pp}$, and OX is taken so that a right-handed coordinate system is formed. At a given q_t the experimental data are integrated over the invariant mass of the undetected $\pi + N$ system in the interval $M_x = 1.19 - 1.35$ GeV [13], To simulate this we evaluate, for example,

$$A_{xx} = 1 - 3\frac{\int_{M_x^{min}}^{M_x^{max}} M_{\alpha x}M^+_{\alpha x}dM_x}{\int_{M_x^{min}}^{M_x^{max}} M_{\alpha i}M^+_{\alpha i}dM_x} \ . \quad (11)$$

It is assumed here that repeated indices α and i ($\alpha, i = x, y, z$) are summed over. The analyzing powers A_{yy} and A_{zz} can be obtained from Eq. (11) by the replacements $x \to y$ and $x \to z$, respectively.

In the non-relativistic approximation $\mathbf{Q} = \mathbf{p}_p - \mathbf{p}_n = \mathbf{q}$. Within this approximation one can find from Eq. (11) for the one-pion exchange (ignoring the integration over M_x)

$$A^\pi_{xx} = 1 - 3\frac{q_x^2}{\mathbf{q}^2},\ A^\pi_{yy} = 1 - 3\frac{q_y^2}{\mathbf{q}^2} \ . \quad (12)$$

Similarly, for pure ρ-meson exchange one has

$$A^\rho_{xx} = -\frac{1}{2} + 3\frac{q_x^2}{2\mathbf{q}^2},\ A^\rho_{yy} = -\frac{1}{2} + 3\frac{q_y^2}{2\mathbf{q}^2} \ . \quad (13)$$

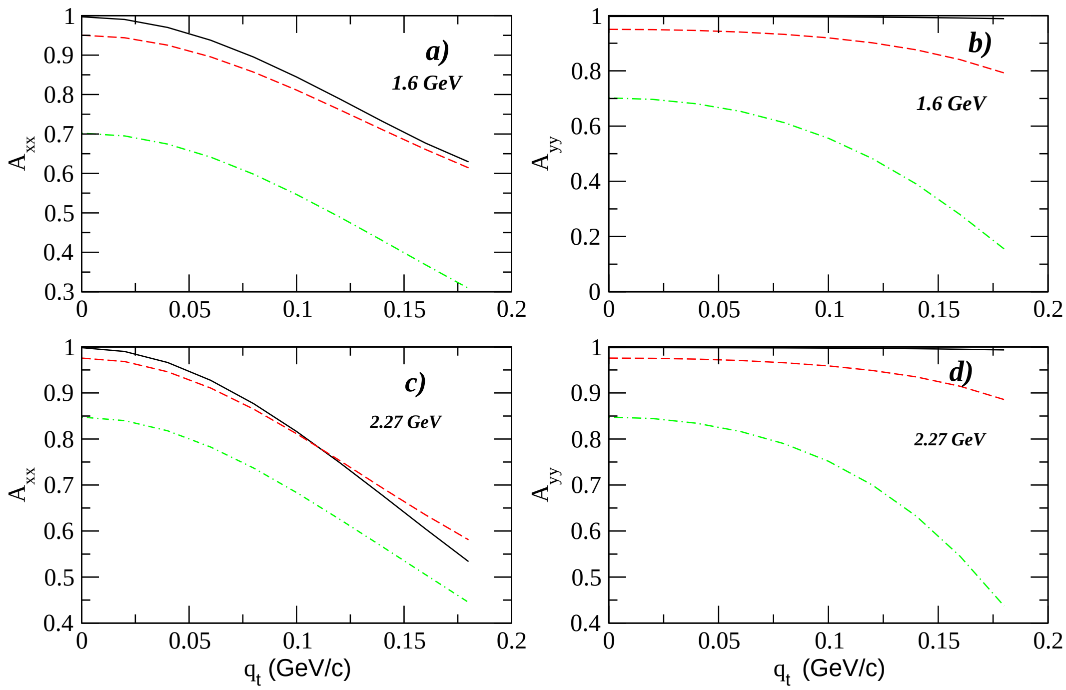

FIG. 3: Tensor analyzing powers A_{xx} and A_{yy} versus the transverse component q_t of the momentum transfer calculated for the direct mechanism with $\pi + \rho$ exchange at the deuteron beam energy 1.6 GeV (a,b) and 2.27 GeV (c,d). The integration over the invariant mass M_x (cf. Eq. (11)) is performed for the interval $1.19 < M_x < 1.35$ GeV$/c^2$. The cut-off parameters used at the vertices are: $\Lambda_\pi = 0.5$ GeV, $\Lambda_\rho = 0.7$ GeV (solid line); $\Lambda_\rho = 1.0$ GeV (dashed line), $\Lambda_\rho = 1.3$ (dash-dotted line).

Both these limits are in contradiction with the results of the measurement [13], which yields $A_{xx}(q_t = 0) = A_{yy}(q_t = 0) \approx 0$. Furthermore, for $q_y = 0$ the calculated A_{yy} does not depend on q_t, for the OPE and for the ρ-meson exchange mechanisms, whereas the experimental data [13] exhibit a smooth q_t dependence of A_{yy}.

The results of our numerical calculations for the $\pi + \rho$ exchange are displayed in Fig. 3. For the cut-off parameters $\Lambda_{\pi NN} = \Lambda_{\pi N\Delta} = 0.5$ GeV and $\Lambda_{\rho NN} = \Lambda_{\rho N\Delta} = 0.7$ GeV [11] the ρ-meson exchange gives negligible contribution. One can see from Fig. 3 that for these parameters A_{xx} decreases with increasing q_t from $A_{xx} = 1$ at $q_t = 0$ to $A_{xx} \approx 0.5$ at $q_t = 0.2$ MeV$/c$, whereas A_{yy} is almost independent of q_t and close to unity. This behaviour is only similar to the measurement [13] in so far as the shape is concerned; it differs strongly in absolute value. If the contribution of the $\rho-$meson exchange is increased by raising the value of the cut-off parameter $\Lambda_{\rho NN} = \Lambda_{\rho N\Delta}$ from 0.7 GeV to 1.3 GeV, A_{xx} and A_{yy} decrease but stay far away from the experimental data $A_{xx}(0) = A_{yy}(0) \approx 0$.

IV. CONCLUSION

The direct mechanism of the $dp \to \{pp\}_s N\pi$ reaction mediated by one-pion exchange and with cut-off parameters at the πNN and $\pi N\Delta$ vertices fixed from the fit to the $pp \to pn\pi^+$ data at 0.8 GeV [12] allows us to describe reasonably well the unpolarized differential cross section of the deuteron charge-exchange reaction at beam energies $1.6 - 2.3$ GeV (which is equivalent to proton beam energies of $0.8 - 1.15$ GeV) at high missing masses $M_x = 1.2 - 1.35$ GeV. At lower masses $M_x = 1.1 - 1.2$ GeV this mechanism underestimates considerably the cross section measured at ANKE [13]. We find that the inclusion of the exchange mechanism does not remedy the disagreement because its contribution is an order of magnitude smaller than that of the direct mechanism.

Regarding the tensor analyzing powers A_{xx} and A_{yy}, the direct mechanism fails completely to explain the data of the ANKE collaboration [13], even in the region $M_x = 1.2 - 1.35$ GeV$/c^2$. This disagreement persists for the OPE and for $\rho-$meson exchange, and also for their coherent sum. One should emphasize that a very similar problem, still unresolved, appears in the study of the more complicated process of backward elastic pd scattering in the Δ-isobar region (see Ref. [10] and reference therein).

It is possible that the interference of the direct and exchange mechanisms might modify the behaviour of the tensor analyzing powers A_{xx} and A_{yy} while leaving the unpolarized cross section unchanged. A proper treatment of this interference requires one to consider the three-body final states $\pi^0 n\{pp\}_s$ and $\pi^- p\{pp\}_s$ explicitly instead of the quasi-two-body state $\Delta^0\{pp\}_s$. However, in any case, this will not improve the situation at lower masses $M_x < 1.2$ GeV. Here the results obtained suggest that new features have to be introduced into the model in order to explain the experimental data on A_{xx} and A_{yy} together with the unpolarized cross section. One might, for example, have to use the $NN \to N\Delta$ amplitude beyond the Born approximation for the $\pi + \rho$ exchange.

The authors are grateful to A. Kacharava and D. Mchedlishvili for useful discussions. Yu. U. would like to recognize the hospitality of the Institut für Kernphysik of the Forschungszentrum Jülich, where part of this work was carried out. This work was supported in part by the Heisenberg–Landau program.

[1] I. Ya. Pomeranchuk, Doklady Akad. Nauk S.S.S.R. **78** (1951) 249.
[2] D. V. Bugg, C Wilkin, Nucl. Phys. A **467** (1987) 575.
[3] F. Lehar, C. Wilkin, Phys. Part. Nuclei Lett. **7** (2010) 235.
[4] D. Chiladze et al., Eur.Phys. J. A **40** (2009) 23.
[5] A. Kacharava et al., *Measurement of the* $\vec{d}\vec{p} \to \{pp\}n$ *charge exchange reaction with polarized beam and target*, COSY Proposal **172** (2007).
[6] C. Ellegaard et al., Phys. Lett. B **154** (1985) 110.
[7] C. Ellegaard et al., Phys. Lett. B **231** (1989) 365.
[8] V. Dmitriev, O. Sushkov, C. Gaarde, Nucl. Phys. A **459** (1986) 503.
[9] D. Mchedlishvili, D. Chiladze, J. Phys. G: Conf. series **295** (2011) 012099.
[10] Yu. N. Uzikov, J. Haidenbauer, C. Wilkin, Phys. Rev. C **75** (2007) 014008.
[11] O. Imambekov, Yu. N. Uzikov, Yad. Fiz. **44** (1988) 1089.
[12] J. Hudomalj-Gabitzsch et al., Phys. Rev. C **18** (1978) 2666.
[13] D. Mchedlishvili, PoS (STORI'11), **040** (2011). `http://pos.sissa.it/`
[14] B. J. Verwest, Phys. Lett. B **83** (1979) 161.
[15] E. Oset, H. Toki, W. Weise, Phys. Rep. **83C** (1982) 281
[16] R. Machleidt, Phys. Rev. C **63** (2001) 024001.
[17] Yu. N. Uzikov, IKP Jülich Annual Report, `www2.fz-juelich.de/ikp/anke/en/Annual-Report-11.shtml/`.
[18] R. Baldini Celio et al., Nucl. Phys. A **379** (1982) 477.