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Charge exchange $dp \to (pp)n$ reaction study at 1.75 A GeV/c by the STRELA spectrometer

S. N. Basilev[1], **Yu. P. Bushuev**[1], **S. A. Dolgiy**[1], **V. V. Glagolev**[1], **D. A. Kirillov**[1], **N. V. Kostyaeva**[1], **A. D. Kovalenko**[1], **A. N. Livanov**[1], **P. K. Manyakov**[1], **G. Martinská**[2], **J. Musinsky**[3,a], **N. M. Piskunov**[1], **A. A. Povtoreiko**[1], **P. A. Rukoyatkin**[1], **R. A. Shindin**[1], **I. M. Sitnik**[1], **V. M. Slepnev**[1], **I. V. Slepnev**[1], **J. Urbán**[2]

[1] Joint Institute for Nuclear Research, Joliot Curie 6, 141980 Dubna, Moscow region, Russia
[2] University of P. J. Šafárik, Jesenná 5, 04001 Košice, Slovak Republic
[3] Institute of Experimental Physics, Watsonova 47, 04001 Košice, Slovak Republic

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Abstract The differential cross sections of the charge exchange reaction $dp \to (pp)n$ has been measured at 1.75 GeV/c per nucleon for small transferred momenta using the one arm magnetic spectrometer STRELA at the Nuclotron accelerator in JINR Dubna. The ratio of the differential cross section of the charge exchange reaction $dp \to (pp)n$ to that of the $np \to pn$ elementary process is discussed in order to estimate the spin-dependent part of the $np \to pn$ charge exchange amplitude. The $np \to pn$ amplitude turned out to be predominantly spin-dependent.

1 Introduction

In the theory of nucleon-nucleon scattering extracting complex amplitudes of the scattering matrix is a matter of fundamental importance. For all amplitudes to be obtained, a complete experiment must be performed, *i.e.*, an experiment with a set of observed quantities providing a full and exhaustive description of this process. Such an experiment comprises measurements with polarized both projectile and target what is large and laborious task.

However, under certain experimental conditions, there is a possibility to determine some amplitudes of the scattering matrix or a set of them. One of the chances is the charge exchange reaction on the deuteron $dp \to (pp)n$ with the use of unpolarized protons and unpolarized deuterons, which under certain conditions is determined only by the spin-dependent amplitude of the elementary $np \to pn$ scattering. When studying the differential cross section of this reaction at small four-momentum transfer squared, it is possible to estimate the spin-dependent term of the $np \to pn$ scattering amplitude in the context of the impulse approximation. The effect can be understood qualitatively in the following way. Two nucleons, bound in the deuteron may be in $^3S_1$ and $^3D_1$ $(T = 0)$ spatial and spin symmetric states; their isospin is antisymmetric. In the $dp \to (pp)n$ charge exchange on the proton target the transition from $^3S_1$ or $^3D_1$ to a charge symmetric $^1S_0$ or $^1D_2$ state of the two protons requires spin flip, in order to satisfy the Pauli principle and ensure an antisymmetric total wave function. The two secondary protons are produced at angles close to 0° w.r.t. the incoming deuteron. In this way, the spin-dependent part of the elementary charge exchange amplitude will be reflected through the probability of the charge exchange process on the deuteron.

[a] e-mail: musinsky@saske.sk

The original idea to take use of the charge exchange reaction on the unpolarized deuteron to determine the spin-dependent part of the $np \to pn$ charge exchange was proposed by Pomeranchuk [1] and Chew [2]. Later this possibility was emphasized in a series of works [3–10]. The mathematical description was developed later by Dean [6,7]. These formulas were obtained under certain assumptions, namely relying on the validity of the impulse and closure approximations. In the work by Lednicky and Lyuboshitz [11] it was shown that at relativistic energies these two assumptions are also justified.

In the general case the nucleon-nucleon (NN) amplitude in the centre of mass system can be presented as [12]

$$M = a + b(\sigma_1 \mathbf{n})(\sigma_2 \mathbf{n}) + c\left[(\sigma_1 \mathbf{n}) + (\sigma_2 \mathbf{n})\right] + \\ + e(\sigma_1 \mathbf{m})(\sigma_2 \mathbf{m}) + f(\sigma_1 \mathbf{l})(\sigma_2 \mathbf{l}), \tag{1}$$

where the orthonormal basis

$$\mathbf{l} = \frac{\mathbf{k} + \mathbf{k}'}{|\mathbf{k} + \mathbf{k}'|}, \quad \mathbf{m} = \frac{\mathbf{k} - \mathbf{k}'}{|\mathbf{k} - \mathbf{k}'|}, \quad \mathbf{n} = \frac{\mathbf{k} \times \mathbf{k}'}{|\mathbf{k} \times \mathbf{k}'|}, \tag{2}$$

introduced in [13] is used. The unit vectors $\mathbf{k}$ and $\mathbf{k}'$ are in the direction of the incoming and scattered particles, respectively. The spin operators σ_1 and σ_2 are the Pauli 2×2 matrices for the beam and target nucleons, respectively.

The differential cross section of the elementary $np \to pn$ charge exchange can be represented as a sum of the spin-independent (superscript SI) and spin-dependent (superscript SD) parts

$$(d\sigma/dt)_{np\to pn} = (d\sigma/dt)^{SI}_{np\to pn} + (d\sigma/dt)^{SD}_{np\to pn} \,. \qquad (3)$$

The mathematical formalism developed in [6,7,10] allows to connect the differential cross sections of the deuteron charge exchange and the elementary $np \to pn$ reactions. In the impulse approximation the dp charge exchange differential cross section at small momentum transfer $|t|$ is related to the NN-amplitudes via

$$\begin{aligned}(d\sigma/dt)_{dp\to(pp)n} = {} & \left[1 - F_d(t)\right] (d\sigma/dt)^{SI}_{np\to pn} \;+ \\ & \left[1 - 1/3\, F_d(t)\right] (d\sigma/dt)^{SD}_{np\to pn}\,,\end{aligned} \qquad (4)$$

where $F_d(t)$ denotes the deuteron form factor, $t = (P_d - P_1 - P_2)^2$ is the four-momentum transfer squared from the incoming deuteron to the two fast protons. P_1, P_2 are the final fast protons four-momenta and P_d is the incoming deuteron four-momentum.

$$\begin{aligned}(d\sigma/dt)^{SI}_{np\to pn} &= |a|^2 + |c|^2\,, \\ (d\sigma/dt)^{SD}_{np\to pn} &= |b|^2 + |c|^2 + |e|^2 + |f|^2\,,\end{aligned} \qquad (5)$$

and the coefficients a, b, c, e and f refer to spin invariants of the elementary charge exchange amplitude in Eq. (1) [6,9].

In this paper we consider the case, when the scattering angle (between the incoming and scattered particles) is very small, close to zero. Under such kinematical conditions one obtains $b = e$ and $c = 0$ and for the elementary cross sections simple expressions can be written

$$(d\sigma/dt)^{SI}_{np\to pn} = |a|^2\,, (d\sigma/dt)^{SD}_{np\to pn} = 2\,|b|^2 + |f|^2\,, \qquad (6)$$

where the amplitude a is spin-independent, and b and f are spin-dependent. Equation (4) implies that at zero transfer $|t| = 0$, *i.e.*, at the neutron CMS scattering angle 180°, when $F_d(0) = 1$, the differential cross section reduces to

$$(d\sigma/dt)_{dp\to(pp)n} = 2/3\,(d\sigma/dt)^{SD}_{np\to pn}\,. \qquad (7)$$

So, the charge exchange breakup reaction of the unpolarized deuteron on the unpolarized proton target at zero transfer ($t = 0$) is completely determined by the spin-dependent part of the elementary $np \to pn$ backward scattering in CMS, so the deuteron acts as a spin filter. It should be noted that this result also remains valid when the deuteron D-state is taken into account [11]. Thus, the study of $dp \to (pp)n$ process at small transferred momenta allows to estimate the spin-dependent part of the elementary $np \to pn$ reaction.

The first experiment of such type has been realized at the JINR Synchrophasotron, irradiating the one meter hydrogen bubble chamber (1m HBC) with deuteron beams of 3.35 GeV/c momenta. The differential cross section $d\sigma/dt$ of the $dp \to (pp)n$ reaction was measured and the extrapolated value of $(d\sigma/dt)|_{t=0} = (30.2 \pm 4.1)$ mb/(GeV/c)^2 obtained. Comparison with the elementary $np \to pn$ charge exchange data led to a conclusion, although with great statistical uncertainties, about the prevailing contribution of the spin-dependent part into the $np \to pn$ amplitude [12,14].

Before our investigations, no experiments with fast deuteron beams have been carried out in the energy range above 1 GeV. Experiments with monochromatic fast deuterons are reasonable in respect to the analysis of experimental data: the two secondary protons, products of the charge exchange on the deuteron $dp \to (pp)n$, are fast moving in the forward direction at small angles, and so they are easily detectable.

These studies made it possible to propose the layout of a counter experiment for studying the charge exchange reaction with sufficient statistical accuracy in unpolarized deuteron beams at energies above 1 GeV. For the observation of the proton pairs in a narrow cone coming from the $dp \to (pp)n$ reaction several variants of experimental setup for the prepared experiment STRELA were suggested and realized [15]. For the optimization of the experiment geometry the above dp events from 1m HBC were used as input the GEANT3 tracking simulations.

In the meantime the interest to obtain information on the cross section of the spin-dependent part of the $np \to pn$ scattering renewed. In the region above 1 GeV results on the $nd \to p(nn)$ reaction in a neutron beam of the JINR Delta-Sigma group at seven values of beam kinetic energies from 0.5 to 2.0 GeV appeared [16–18]. Experiment ANKE at COSY Juelich storage ring carried out an extensive study of the $dp \to (pp)n$ charge exchange reaction in vector and tensor polarized deuteron beams at four energies from 0.6 to 1.135 GeV per nucleon [19,20].

The aim of the present study is to determine the differential cross section of the $dp \to (pp)n$ charge exchange channel at $t = 0$ in unpolarized deuteron beam by the STRELA spectrometer, extract information on the elementary $np \to pn$ charge exchange amplitude and compare with the existing experimental results.

2 Experimental facility STRELA

Based on the above mentioned ideas and experimental results, obtained using the 1m HBC [12,14], the experiment STRELA has been designed and constructed in the Veksler Baldin Laboratory for High Energy Physics (VBLHEP) of the Joint Institute for Nuclear Research (JINR) in Dubna with the aim to select and detect charge exchange events in deuteron proton collisions. The experiment demands registration of two final state protons with momenta approximately equal to the half of the primary deuteron beam momenta. STRELA is a typical one arm magnetic spectrometer,

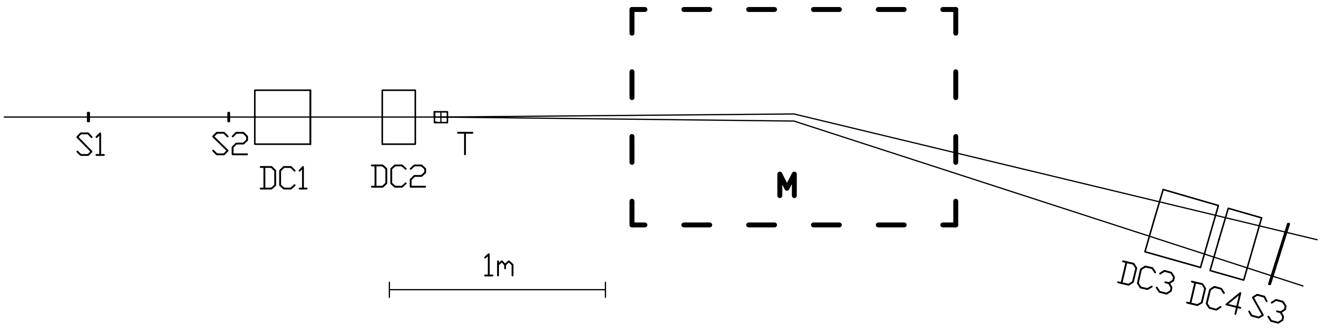

Fig. 1 Schematic layout of the experimental setup to study the $dp \to (pp)n$ charge exchange channel, consisting of scintillator counters (S1 – S3), drift chambers (DC1 – DC4), analyzing magnet M and target T.

consisting of scintillator detectors (S1 – S3) used to trigger the setup, blocks of drift chambers (DC1 – DC4) used as coordinate detector, analyzing magnet M and targets (C and CH_2), see Fig. 1.

The sensitive areas of the drift chambers are the following: 12.5 × 12.5 cm^2 for DC1, DC2 (small chambers) and 25 × 25 cm^2 for DC3, DC4 (large chambers). The right handed coordinate system has been used, where the z axis is in the beam direction and x and y axis lie in the plane of the chambers. Drift chambers contain an $(Ar + CH_4)$ gas mixture and have alternating, orthogonal x and y coordinate planes. Chambers DC1, DC3, DC4 are equipped with xy wires and DC2 only with x wires. DC1 and DC3 are composed of 8 sensitive planes ($4y$, $4x$), DC4 is composed of 4 sensitive planes ($2y$, $2x$) while the DC2 contains 4 sensitive planes ($4x$).

The drift length for all chambers is r_{max} = 21 mm. The basic characteristics of the drift chambers have been established from irradiation of a polyethylene target with a deuteron beam of 3.5 GeV/c momentum. For each wire the minimal t_{min} and maximal t_{max} drift times have been determined. The average total drift time was found to be ~ 450 ns. In the track finding procedure the relation between the measured drift time and the minimal distance from the anode wire to the track plays an important role. To find the function, transforming the drift time t to radius r, also referred to as $r(t)$ relation, is the central task. This transformation function may depend on many parameters like: the electric field strength, the gas mixture, the pressure, the temperature and the drift chamber geometry. For determination of the transformation function two methods are applied: the linear or quick one, mainly used for the preliminary results and online monitoring, the second method, called cumulative or integral one suitable for offline purposes, which gives the final results. The spatial resolution of the drift chambers used in the STRELA setup is in the range of ~ 80 – 120 μm (Fig. 2). The minimal time between consecutive signals is ~ 50 ns, which corresponds to a minimum distance of ~ 2 mm between the tracks in the drift chamber, which fully satisfies the requirement of the STRELA experiment. Moreover, the analyzing magnet enhances the space separation of the recorded protons from the examined reaction. More technical details and the algorithm of the track reconstruction can be found in [15].

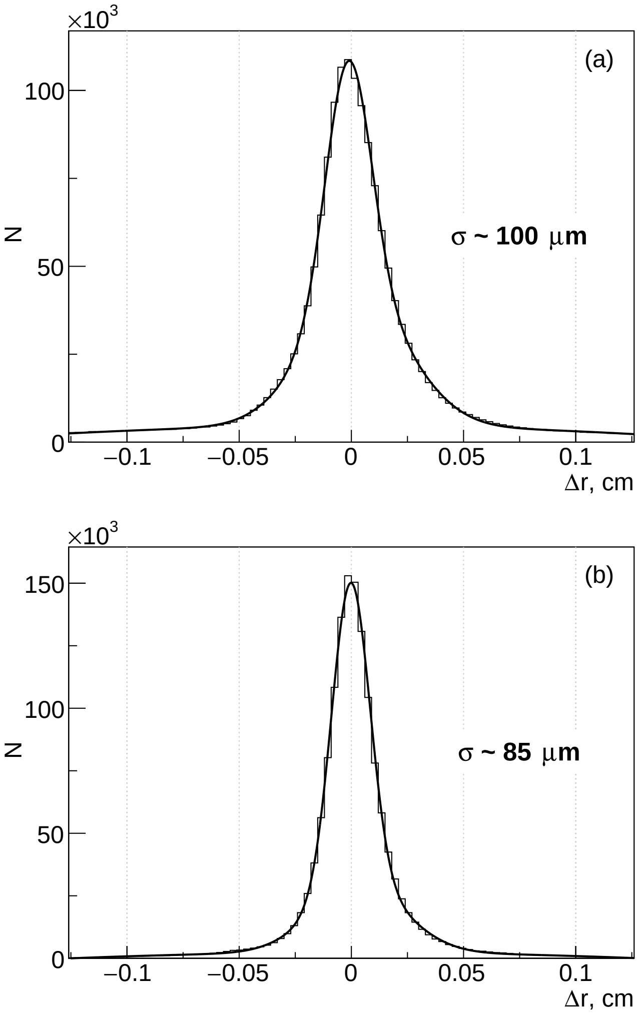

Fig. 2 Example of distribution of track residuals Δr in the xz plane of drift chambers: (a) small and (b) large. The solid curve is a double Gaussian approximation [15].

The experimental setup was started by coincidence of two scintillation counters S1 (dimensions 7.5 × 7.5 × 0.5 cm^3) and S2 (dimensions diameter 3.0 × 0.2 cm^3). The signals from the XP 2020 photomultipliers are connected to the shapers with constant fraction timing in order to compensate the time jitter of the amplitude signal. The time and amplitude information from the counters is digitized and recorded in each event for the subsequent monitoring of the counters and the entire trigger system functionality.

The dipole electromagnet 2SP-40, with transverse dimensions 100 × 30 cm^2 and length 150 cm, creates the required magnetic field 0.85 T and serves as an analyzing magnet. The recorded protons of about the half of the incident deuteron beam momentum from the examined reaction are bended at 0.289 mrad to the blocks of large drift chambers (DC3 and DC4) for detection; unscattered primary deuteron beam does not enter the sensitive areas of these chambers. The momentum resolution measured with the primary deuteron beam of 3.5 GeV/c is about 1 %.

Carbon (C) and polyethylene (CH_2) targets are used to extract the *dp* interaction by subtracting CH_2 and C distributions. The volume of the targets is determined by carbon nuclei equivalent. Their shapes are cylindrical, both with diameters of 60 mm. The length of targets CH_2 and C are 48 mm and 54 mm, respectively. The density of H nuclei per cm^2 for CH_2 target is $(4.74 \pm 0.05)\times10^{23}$ cm^{-2}.

The measurement was done at the intensities of beam of 2 – 3 × 10^5 deuterons per second, duration of the spill was 4 seconds. The deuteron flux (number of triggers) has been determined by S1 and S2 scintillation counters in coincidence. This is corrected for the inefficiency of the drift chambers and admixture of protons in the primary deuteron beam using the empty target measurements. The value of the correction is different from run to run and is in the interval 0.85 – 0.89.

The trigger system selects events of the deuteron breakup reaction, where at least one charged track inclined by magnet reaches the drift chambers DC3 and DC4. The momenta of the tracks in the event are reconstructed using information from the magnet and from the drift chambers. Into the analysis only the events containing two reconstructed tracks are involved.

The detector performance for two-track events was estimated by the use of the GEANT3 package for transporting the *dp* interaction products from the 1m HBC events through the STRELA experimental setup. The plots of momenta p_1 *vs.* p_2 of the two charged particles reaching the DC3 and DC4 chambers are shown in Fig. 3. Simulation including all *dp* interaction channels (a) and $dp \rightarrow ppn$ channel only (b). From this comparison and the fact that 1m HBC is full solid angle detector one can judge that the two protons of the charge exchange reaction are fully in the detector acceptance.

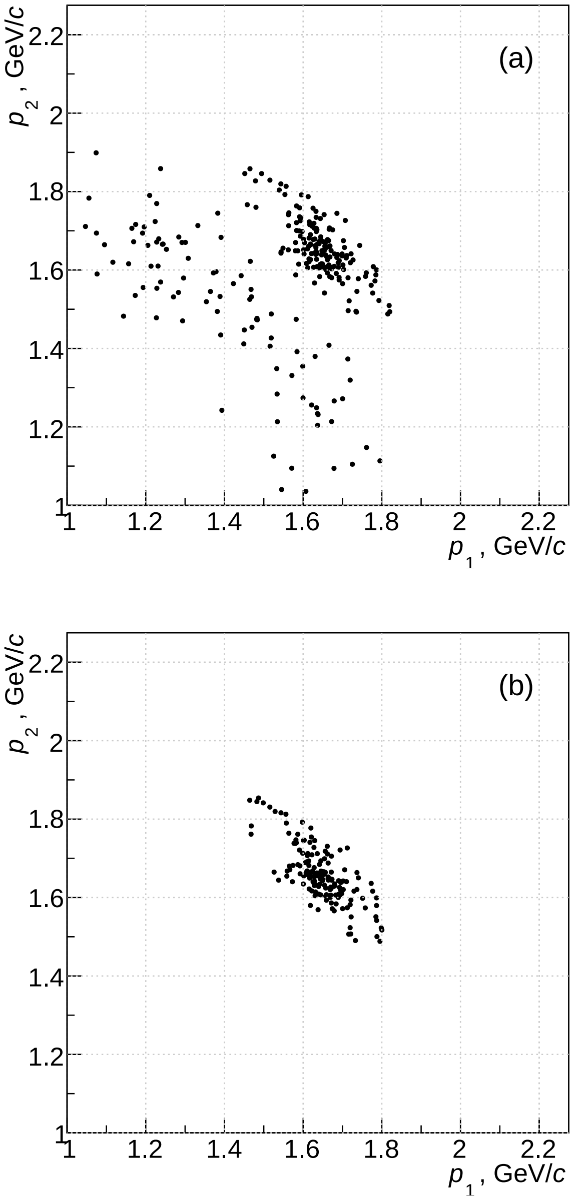

Fig. 3 Plot of the GEANT3 tracked 1m HBC two charged particles momenta p_1 *vs.* p_2 from dp: all channels (a) and $dp \rightarrow ppn$ only (b).

3 Data analysis and experimental results

The experimental facility has been irradiated in the beam of deuterons with 3.5 GeV/c momenta and approximately milliard triggers were taken. The first step in the analysis was to decode events. Calibration procedure and the track reconstruction in the drift chambers transformed the raw data into physical quantities. For the further processing and physical analysis three track segments in the *xz* plane drift chambers were selected: one before the target and two behind it. The topology of this events is shown in Fig. 1. The momentum of the particles (protons) was determined from the angle of deflection of the charged particle after passing through the magnet M.

The $dp \to ppn$ events reaching the drift chambers DC3 and DC4 are supposed to contain: two fast protons from the charge exchange reaction $dp \to (pp)n$ with momenta approximately equal to the half of the beam momenta, or a single fast proton from the charge retention $dp \to (pn)p$ channel, where the recoil slow proton is filtered out by the magnet.

In the presented data (Fig. 4) two well-separated areas can be distinguished as well as in the simulated ones (Fig. 3 (a)). The more populated ellipse like area in Fig. 3 (a) can be ascribed to the charge exchange events if one compares with the results of simulation in Fig. 3 (b). This crosschecks the statements made about the detector acceptance above. The arch like areas in Fig. 3 (a) and Fig. 4 correspond to background two-track events. A simple cut on the sum of the two reconstructed momenta can remove the events from the arch like area.

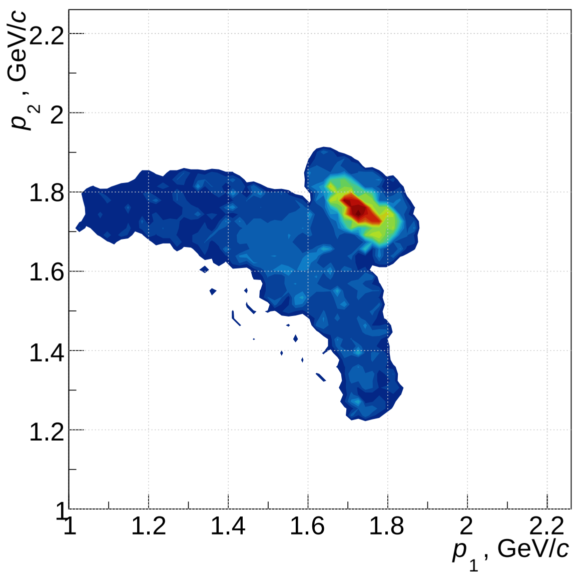

Fig. 4 Plot of the measured momenta p_1 *vs.* p_2 of the two tracks from $d + CH_2$ interaction, experimental result.

The obtained distribution of the sum of the two charged particles (two protons) momenta for both CH_2 and C targets are displayed in Fig. 5, distinguished by long dashed and dashed lines, respectively. The difference of the two distributions (full line) shows that the background from C target can be reduced. The results of simulation shown in Fig. 6 include all channels of the dp interaction (a) and $dp \to ppn$ channel only (b). Note that for the simulation real events (with relatively small statistics) from the 1m HBC at the momenta 3.35 GeV/c were used. As one can see, the distribution has a characteristic peak near the incoming deuteron momentum kinematically associated with the pair of protons from the $dp \to ppn$ reaction (Fig. 5). Into the further analysis only

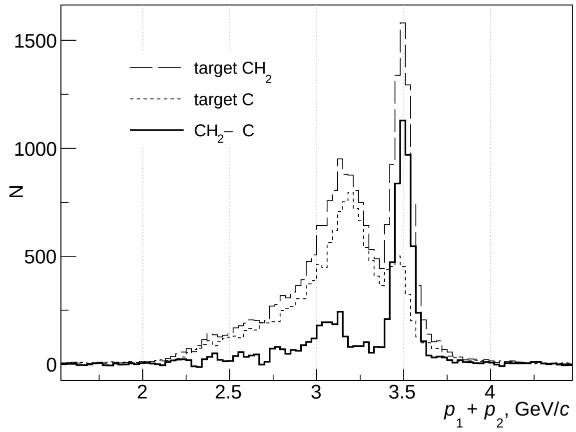

Fig. 5 Distributions of the sum of the two protons momenta from $d + CH_2$ and $d + C$ interactions, experimental results: CH_2 target long dashed line, C target dashed line and their difference full line.

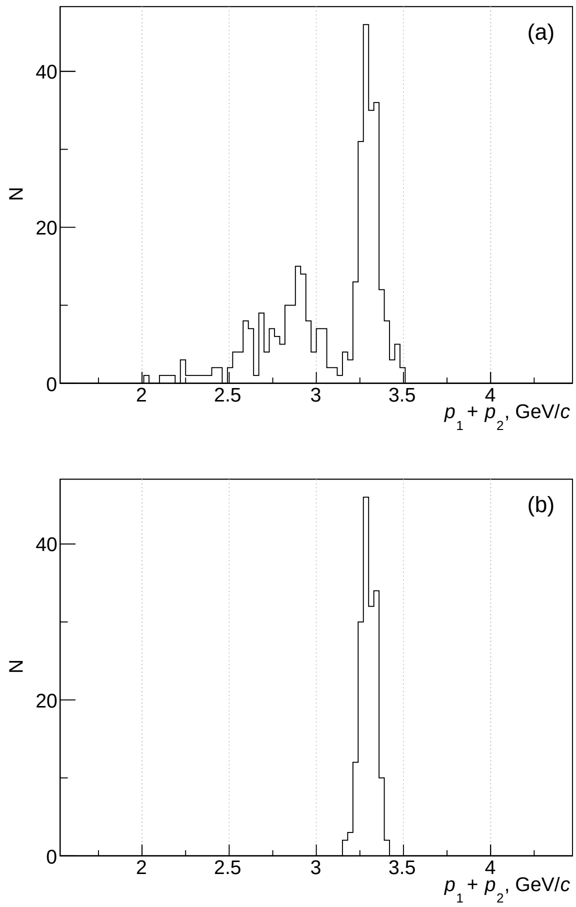

Fig. 6 Distributions of the sum of the two protons momenta from GEANT3 tracked 1m HBC: dp all channels (a) and $dp \to ppn$ channel only (b).

those events have been included, where the sum of the two protons momenta is in the interval (3.5 ± 0.2) GeV/c.

The main goal of present experiment is to determine the differential cross section $(d\sigma/dt)|_{t=0}$ of $dp \to (pp)n$, which can only be done as an extrapolation of the measured data to $|t| \mapsto 0$. This can be connected according to Eq. (7) with the spin-dependent part of the $np \to pn$ process.

The measured dN/dt distribution of the $dp \to (pp)n$ reaction is displayed in Fig. 7 together with the curve corresponding to a fit by empirically well established expression

$$dN/dt = a\,\exp(b\,t)\,, \tag{8}$$

with parameters $a = (435.6 \pm 6.8)$ and $b = (-440.9 \pm 9.1)$. The value $(dN/dt)|_{t=0}$ was transformed to cross section

$$\left.\frac{d\sigma}{dt}\right|_{t=0} = \frac{a}{n\,l\,b_w}\ln\left(\frac{N_0}{N_0 - N_{rec}}\right), \tag{9}$$

where n is the number of H nuclei in cm^{-3} in target, l is the target length in cm, b_w is the histogram bin width. The number of reconstructed two proton events N_{rec} and the number of incoming deuterons N_0 were corrected for the efficiency of chambers.

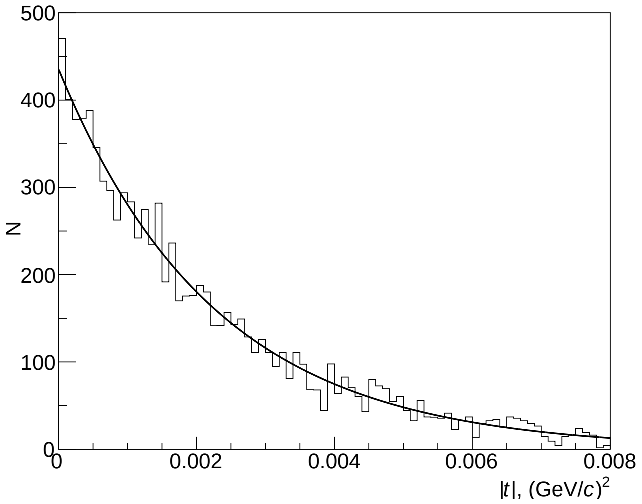

Fig. 7 Differential distribution dN/dt of the $dp \to (pp)n$ reaction. The solid line is approximation by Eq. (8).

The value $(dN/dt)|_{t=0} = (435.6 \pm 6.8)$ N/(GeV/c)^2 corresponds to the charge exchange reaction differential cross section $(d\sigma/dt)|_{t=0} = (30.56 \pm 0.48)$ mb/(GeV/c)^2. The quoted error is statistical only. Systematic uncertainties which affect the overall normalization of the cross sections have been estimated to be about 5 %. This uncertainty stems mainly from the deuteron flux determination. The uncertainty from the target thickness and the histogram bin width are relatively small.

The obtained charge exchange differential cross section on the deuteron at $t = 0$ was compared with the available data from $np \to pn$ reaction at the same interpolated energy from published data. The closest energy data comes from measurements made at the SATURN accelerator [21, 22]. Unlike to the other similar experiments, Bizard et al. [21] used quasi monochromatic neutrons from accelerated deuteron stripping with a momentum spread of 5 %. New data about $np \to pn$ scattering at the momenta of incident quasi monochromatic neutrons at 1.43, 2.23 and 5.20 GeV/c have been obtained in [23].

The values of $(d\sigma/dt)|_{t=0}$ of $np \to pn$ reaction as a function of the incident momenta is shown in Fig. 8. Each individual differential cross sections from Bizard et al. [21] are transformed into $d\sigma/dt$ versus t in the region of momenta 1.4 – 2.0 GeV/c and extrapolated at each momentum to $t = 0$ by fitting the expression $d\sigma/dt = a\,\exp(b\,t + c\,t^2)$. This reference dependence has already been used in [14].

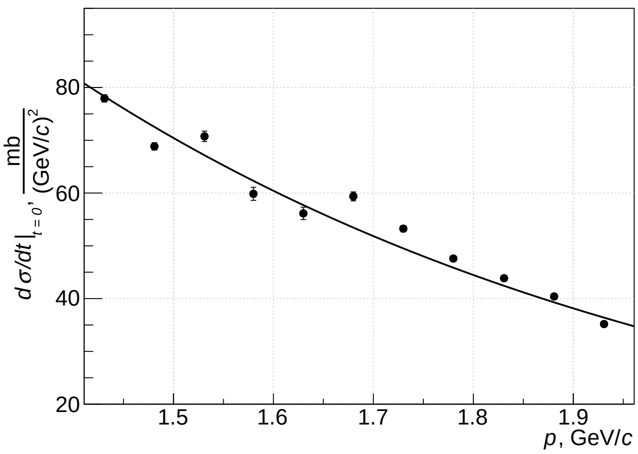

Fig. 8 The dependence of the $(d\sigma/dt)|_{t=0}$ for the $np \to pn$ reaction on the beam momentum. The data points are computed from the experimental results [21]. The solid curve is a simple exponential fit to the data points.

To determine the $(d\sigma/dt)|_{t=0}$ of the $np \to pn$ reaction at "our incident" proton momentum of 1.75 GeV/c per nucleon, an exponential fit is made to the results of Fig. 8, which gives the following value of $(d\sigma/dt)|_{t=0} = (48.0 \pm 0.2)$ mb/(GeV/c)^2. The systematical error due to fit procedure is approximately 5 %. The obtained value will be related to the estimated differential cross section of the quasi elastic $dp \to (pp)n$ charge exchange at $t = 0$ from our experiment.

One can introduce the ratio of the differential cross sections for the forward scattering (charge exchange) on the deuteron and proton

$$\begin{aligned} R_{np\to pn} &= \frac{(d\sigma/dt)_{dp\to(pp)n}}{(d\sigma/dt)_{np\to pn}} \\ &= 0.64 \pm 0.01\,(\text{stat.}) \pm 0.04\,(\text{syst.}). \end{aligned} \tag{10}$$

Under the assumption Eq. (7) and Eq. (3) stated above this, $R_{np\to pn}$ can be related to

$$R_{np\to pn} = \frac{2}{3}\,\frac{(d\sigma/dt)^{SD}_{np\to pn}}{(d\sigma/dt)_{np\to pn}} \tag{11}$$

and accordingly the contribution of the spin-independent part, as a ratio of the two parts of the elastic $np \to pn$ charge exchange cross section, has been obtained as

$$R^{ID}_{np\to pn} = \frac{(d\sigma/dt)^{SI}_{np\to pn}}{(d\sigma/dt)^{SD}_{np\to pn}} = \frac{2}{3\,R_{np\to pn}} - 1 \qquad (12)$$
$$= 0.05 \pm 0.02\,(\text{stat.}) \pm 0.07\,(\text{syst.}).$$

It should be emphasized that the obtained contribution, of course, depends on the elementary $np \to pn$ charge exchange cross section which is taken from another experiment and on the systematical errors of approximately 5 % which is due to the fit procedure. Preliminary data published in [24, 25] are not contradicting the presented results.

4 Conclusion and outlook

The spectrometric complex STRELA has been proposed and realized to study the charge exchange reaction in unpolarized deuteron beam. The value of the charge exchange reaction $dp \to (pp)n$ differential cross section $(d\sigma/dt)|_{t=0} = (30.56 \pm 0.48)$ mb/(GeV/c)^2 has been established at 1.75 GeV/c per nucleon. This value agrees with the differential cross section $(d\sigma/dt)|_{t=0} = (30.2 \pm 4.1)$ mb/(GeV/c)^2 determined by means of the one meter hydrogen bubble chamber at 1.675 GeV/c per nucleon. The obtained ratio of the charge exchange differential cross sections at $t = 0$ for $dp \to (pp)n$ and that of $np \to pn$ reaction $R_{np\to pn} = 0.64 \pm 0.01$ (stat.) $\pm$ 0.04 (syst.) testifies the prevailing contribution of the spin-dependent part to the $np \to pn$ scattering. This conclusion is in accordance with [14], where the quantities are published with considerably large errors. For illustration of the improvement in this experiment one can quote, *e.g.*, the $R^{ID}_{np\to pn} = 0.21 \pm 0.17$ [14] and the present ratio $R^{ID}_{np\to pn} = 0.05 \pm 0.02$ (stat.) $\pm$ 0.07 (syst.).

In the region above 1 GeV Delta-Sigma group published the $R_{dp}(0) = (d\sigma/dt)_{nd}/(d\sigma/dt)_{np}$ ratios [16–18] at seven values of the neutron energies $T_n = 0.5 - 2.0$ GeV. Both $nd \to p(nn)$ and $np \to pn$ reactions were detected in the same experiment. The reported contributions of the non-flip to flip ratio in the $np \to pn$ charge exchange are estimated between 0.551 and 0.589 depending on energy. The value of $R_{dp}(0) = 0.553 \pm 0.026$ at 1.0 GeV [16] is within the experimental uncertainties consistent with our result. The experiment with monochromatic fast deuterons is more rational in respect to the analysis of experimental data, *e.g.* STRELA, because the two secondary protons, products of the $dp \to (pp)n$ channel, are fast moving in the forward direction at small angles, and so they are easily detectable.

In the works [19, 20] the $dp \to ppn$ reaction as was used to study neutron proton charge exchange amplitudes on the ANKE spectrometer at the COSY storage ring at deuteron energies of 0.6, 0.8, 0.9 and 1.135 GeV per nucleon. A rich set of data has been obtained on the differential cross section, vector and tensor analyzing powers as well as on the spin correlations of the charge exchange reaction. The whole set of data allowed to draw a conclusion on the individual amplitudes of the $dp \to (pp)n$ scattering. On the other hand, the spin-independent amplitude α, whose magnitude can only be estimated by comparing the deuteron data with the free $np \to pn$ differential cross section, is absent.

So, to extend the studies to higher energies on STRELA setup is acceptable and the preparation is in progress.

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References

1. I. Pomeranchuk, Sov. JETF **21**, 1113 (1951)
2. G.F. Chew, Phys. Rev. **84**, 710 (1951)
3. A.B. Migdal, J. Exp. Theor. Phys. (in Russian) **28**, 3 (1955)
4. I. Pomeranchuk, Dokl. Akad. Nauk (in Russian) LXXVIII, 249 (1951)
5. L.I. Lapidus, J. Exp. Theor. Phys. (in Russian) **32**, 1437 (1957)
6. N.W. Dean, Phys. Rev. D **5**, 1661 (1972)
7. N.W. Dean, Phys. Rev. D **5**, 2832 (1972)
8. B.S. Aladashvili et al., Nucl. Phys. B **92**, 189 (1975)
9. B.S. Aladashvili et al., Nucl. Phys. B **86**, 461 (1975)
10. D.V. Bugg, C. Wilkin, Nucl. Phys. A **167**, 575 (1987)
11. R. Lednicky, V.L. Lyuboshitz, V.V. Lyuboshitz, Proc. ISHEPP XVI, 199, Dubna (2004)
12. V.V. Glagolev et al., Eur. Phys. J. A **15**, 471 (2002)
13. M. Goldberger, K. Watson, Collision Theory, Wiley, New York (1966)
14. V.V. Glagolev et al., Cent. Eur. J. Phys. **6**, 781 (2008)
15. V.V. Glagolev et al., Instrum. Exp. Tech. **56**, 387 (2013)
16. V.I. Sharov et al., Eur. Phys. J. A **39**, 267 (2009)
17. V.I. Sharov et al., Phys. At. Nucl. **72**, 1007 (2009)
18. R.A. Shindin et al., Phys. Part. Nucl. Lett. **8**, 90 (2011)
19. D. Chiladze et al., Eur. Phys. J. A **40**, 23 (2009)
20. D. Mchedlishvili et al., Eur. Phys. J. A **49** (2013)
21. G. Bizard et al., Nucl. Phys B **85**, 14 (1975)
22. J. Bystricky, F. Lehar, Nucleon-Nucleon Scattering data, Karlsruhe: Fachinformationszentrum, 521, (1978)
23. Yu.A. Troyan et al., Phys. Part. Nucl. Lett. **11**, 101 (2014)
24. S.N. Basilev et al., PoS (Baldin ISHEPP XXII), 137, 2014
25. S.N. Basilev et al., J. Phys. Conf. Ser. **678**, 012040, 2016