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

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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 charge exchange at 0° w.r.t. laboratory frame (proton rest frame), $dp \to (pp)n$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.

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 partly [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]

$$\begin{aligned} M = \; & a + b(\boldsymbol{\sigma}_1\mathbf{n})(\boldsymbol{\sigma}_2\mathbf{n}) \; + \; c\big[(\boldsymbol{\sigma}_1\mathbf{n}) + (\boldsymbol{\sigma}_2\mathbf{n})\big] \; + \\ & + e(\boldsymbol{\sigma}_1\mathbf{m})(\boldsymbol{\sigma}_2\mathbf{m}) \; + \; f(\boldsymbol{\sigma}_1\mathbf{l})(\boldsymbol{\sigma}_2\mathbf{l}) \,, \end{aligned} \qquad (1)$$

where the orthonormal basis

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

introduced in [13] is used. The unit vectors $\mathbf{k}$ and $\mathbf{k}'$ are the initial and final nucleons momentain the direction of the incoming and scattered particles, respectively. σ and σ_i The spin operators $\boldsymbol{\sigma}_1$ and $\boldsymbol{\sigma}_2$ are the Pauli 2×2 matrices corresponding to

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the fast particle and the struck nucleon from the deuteronfor 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

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

where $F_d(t)$ denotes the deuteron form factor, t is the 4-momentum transfer squared , $t = (P_d - P_1 - P_2)^2$, $t = (P_d - P_1 - P_2)^2$ 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 w. r.t. laboratory frame, and P_d is the incoming deuteron four-momentum.

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

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 θ (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

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

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, studying the 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 ratio of the elementary spin-independent to spin-dependent elastic 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 cross sections $R^{ID}_{np\to pn} = 0.21 \pm 0.17$ has been obtained [14]. This result testifies data led to a conclusion, although with great statistical uncertainties, about the prevailing contribution of the spin-dependent part to the the into the $np \to pn$ amplitude [12,14].

The study of the charge exchange reaction using the chamber based technique 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 a layout of an electronic the layout of a counter experiment for studying the charge exchange reaction with a deuteron in the energy range 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 , named STRELA , have been 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.

The aim of the present study is to extract information on the elementary charge exchange channel using the charge exchange reaction at 3.5 deuteron momenta by the STRELA spectrometer [15]. The existing data on that reaction are still very scanty and concern mainly the $d\sigma/dt$ distribution. During the past few years, interest in obtaining In the meantime the interest to obtain information on the cross section of the spin-dependent part of the $np \to pn$ scattering renewed. This is partly connected with the appearance of accelerated deuteron beams at the JINR VBLHEP Nuclotron with energies over 1 . Before our investigations, no experiments with a fast deuteron beam have been carried out. In the region above 1 GeV the only results results on the $nd \to p(nn)$ reaction in a neutron beam of the JINR Delta-Sigma group [16–18] are known, where the $R_{dp}(0) = (d\sigma/dt)_{nd}/(d\sigma/dt)_{np}$ ratios have been successfully measured. Seven data points at the energies $T_n = 0.5 - 2.0$ at seven values of beam kinetic energies from 0.5 to 2.0 GeV have been obtained using liquid D_2 / H_2 and solid CD_2 / CH_2 / C targets. The contribution of non flip to flip ratio in the charge exchange process have been estimated via $R_{dp}(0)$ values. The experiment with monochromatic fast deuterons is more rational in respect to appeared [16–18]. Experiment ANKE at COSY Juelich storage ring carried out an extensive study of the analysis of experimental data: the two secondary protons, products of the charge exchange on deuteron , are fast moving in $dp \to (pp)n$charge exchange reaction in vector and tensor polarized deuteron beams at four energies from 0.6 to 1.135 GeVper nucleon [19, 20].

The aim of the present study is to determine the differential cross section of the forward direction at small angles, and so they are easily detectable$dp \to (pp)n$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 one meter 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 spectrometercomposed , consisting of scintillator detectors (S1 , S2 – S3) used to trigger the setupand , blocks of drift chambers (DC1 – DC4) used as coordinate detectorand , analyzing magnet M . The recent version of the experimental setup is shown in Fig.and targets (C and CH_2), see Fig. 1.

Layout of the experimental setup for determining the spin-dependent part of scattering: scintillator counters S1 and S2, drift chambers (DC1 – DC4), analyzing magnet M and target T.

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. All Drift chambers contain an (Ar_2 + CH_4) gas mixture and have alternating, orthogonal x and y coordinate planes. Chambers DC1, DC3, DC4 are equiped 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 analyzing magnet M of field intensity $B = 0.85$ T is used to separate deuterons and two protons, respectively.

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].

The experimental setup was started by the two polystyrene based coincidence of two scintillation counters S1 (dimensions 10 7.5 × 10 7.5 × 0.5 cm^3) and S2 (dimensions 7 diameter 3.0 × 7 × 0.5 0.2 cm^3). The light guides are made of plexiglass. For light readout XP 2020 photomultipliers were used. The signals from the XP 2020 photomultipliers are connected to the shaper inputs. The use of these shapers allows shapers with constant fraction timing in order to compensate the time spread of the signals caused by the leading edge of the amplitude of the photomultiplier 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 trigger system of the setup must ensure selection of events of the deuteron breakup reaction at zero angle (or close to zero) between the incoming deuteron and scattering protons. The acceptance of the experimental facility for the studied process of charge exchange reaction is close to 100 %.

The dipole electromagnet 2SP-40, with transverse dimensions 100 × 30 cm^2 , was used as an analyzing magnet. The magnet and length 150 cm, creates the required magnetic field in the range of 0.7 – 1.0 T at a distance of 150 cm along the path of the particles. The spreads in space of the non interacting deuteron beam and that of the recorded protons from the examined reaction are bended to the blocks of large drift chambers for detection. The radius of the curvature of the stripping protons trajectory in the magnet is about 7 m at the value of the magnetic field 0.83 T.

The STRELA setup is irradiated with a deuteron beam of an incident momentum of 3.5 . The detected events are supposed to contain either two protons with close momenta (equal to the 0.85 T and serves as an analyzing magnet. The recorded protons of about the half of the incident deuteron beam momenta), from the charge exchange reaction of a deuteron with a proton or a single proton from the charge retention deuteron breakup . The extracted beam intensity from the accelerator is not lower then ∼ 10^7 particles per spill. Since the drift chambers are operable at intensities lower than ∼ 10^6 particles/spill, a steel collimator with a rectangular aperture of 4 × 4 mm^2 and a length of 1.2 m has to be

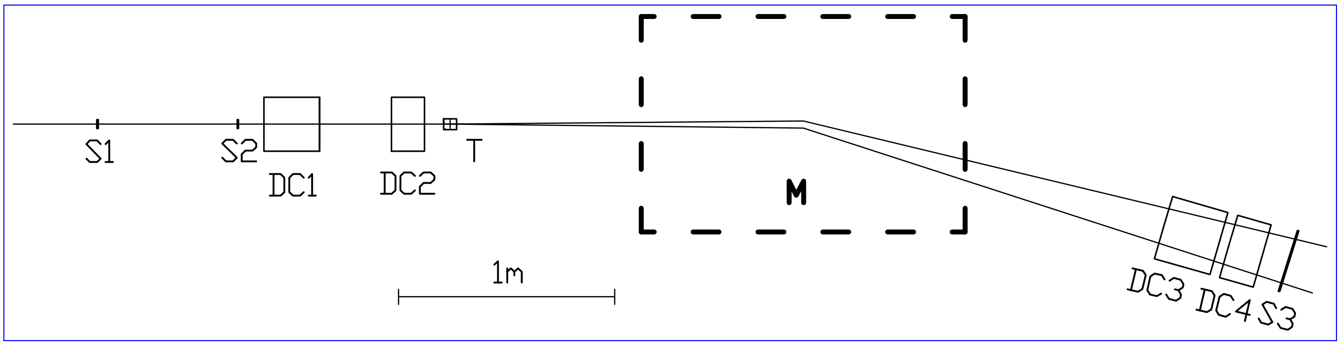

Fig. 1 Schematic layout of the experimental setup to study the $dp \to (pp)n$charge exchange channel, consisting of scintillator counters (S1 – S3), drift chambers (DC1 – DC4), analyzing magnet M and target T.

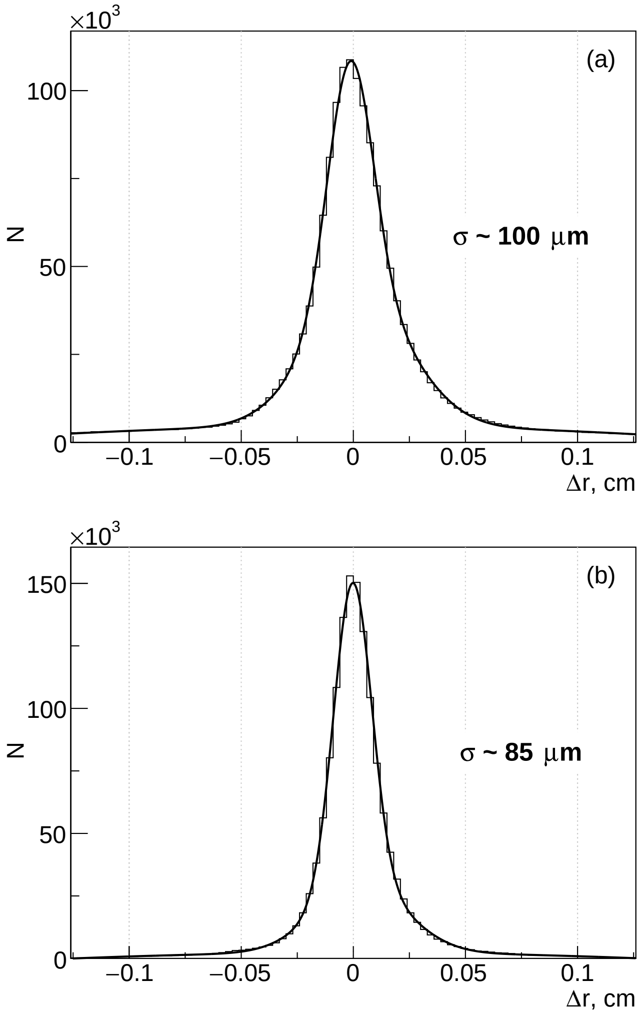

Fig. 2 Example of distribution of track residuals Δr in the xz plane of drift chambers: (a) small and (b) large. The solid curve is a double Gaussian approximation [15].

used to reduce the intensity. After applying the collimator the deuteron beam intensity of $\sim 5 \times 10^5$ particles per spill or below is reached at the target. The deuteron flux (number of triggers) has been determined using S1 and S2 scintillation counters (monitored numbers) in coincidence. This is corrected for momentum from the examined reaction are bended at 0.289 mrad to the efficiency of the drift chambersand admixture in the beam using a direct deuteron beam. The track of deuteron beam in drift chambers DC1, DC2 before magnet and behind DC3, DC4 are reconstructed using the track reconstruction algorithm [15]. The value of the correction is different from run to run and is in the interval 0.85 – 0.89blocks 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/cis about 1 %.

Carbon (C) and polyethylene (CH_2) targets have been are used to extract the dp interaction . Carbon target was used to account for the background events. The final distributions of the dp interactions are obtained by subtracting CH_2 and C distributions. The size volume of the targets have been is determined by carbon nuclei equivalent. The shape of targets CH_2 and C 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 $(4.74 \pm 0.05) \times 10^{23}$ cm^{-2}. The background from other channels of the dp reactionand the influence of carbon nuclei have been

The measurement was done at the intensities of beam of $2 - 3 \times 10^5$ 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 simulation package for transporting the reaction products (taken from the corresponding events of the one meter bubble chamber at the momenta 3.35) through the dp interaction products from the 1m HBC events through the STRELA experimental setup. More details about the chamber experiment can be found in [12, 14]. There is also shown that the reaction proceeding predominantly as a quasi free nucleon interaction and intermediate isobaric states does not influence the differential cross section at $t = 0$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 $dp \to ppn$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.

3 Data analysis and experimental results

The experimental facility has been irradiated in the beam of deuterons with 3.5 GeV/c momenta and one billion triggers were receivedapproximately 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 tracks 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.

The obtained distribution of the sum of the two charged particles (two protons) momenta for both targets are obtained. The background from C and CH_2 targets can be neglected. The dependences of the sum of the two proton momenta from dp reaction are presented and C targets are displayed in Fig. 5for CH_2 and C targets (a) and their difference $CH_2 - C$ (b) , 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 (Fig.6) shown in Fig. 6 include all channels of the dp reaction interaction (a) and channel $dp \to ppn$ channel only (b). Note that for the simulation real events from the one meter bubble chamber (with relatively small statistics) from the 1m HBC at the momenta 3.35 GeV/c (with relatively small statistics) 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(b)). The contribution from the

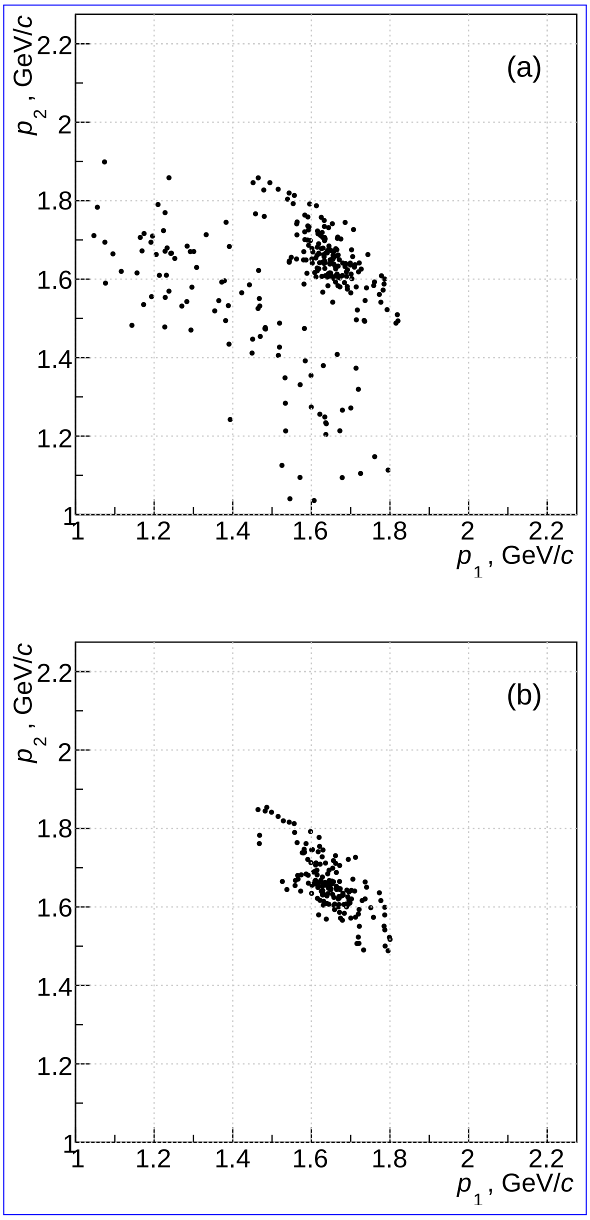

Fig. 3 Plot of the GEANT3 tracked 1m HBC two charged particles momenta p_1 vs. p_2 from dp: all channels (a) and $dp \to ppn$only (b).

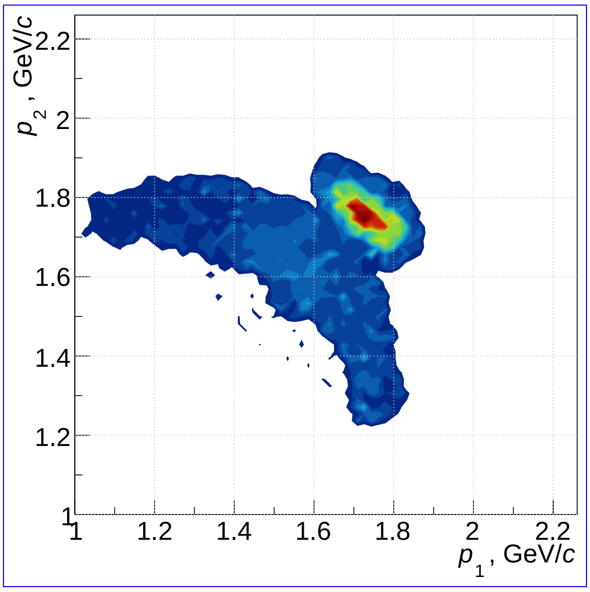

Fig. 4 Distributions Plot of the sum measured momenta p_1 vs. p_2 of the two protons momenta tracks from dp reaction, experimental results: (a) target d + CH_2 full line$_2$ interaction, target C dashed line, (b) difference between $CH_2 - C$ targetsexperimental result.

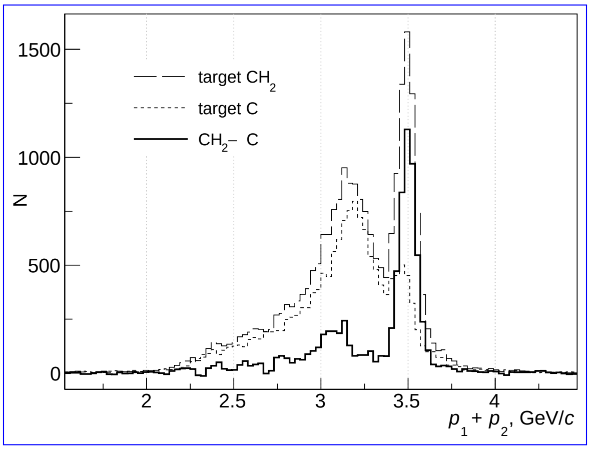

Fig. 5 Distributions of the sum of the two protons momenta from dp reaction$d + CH_2$ and d + C interactions, simulation experimental results: (a) include all channels dp reaction CH_2 target long dashed line, C target dashed line and (b) channel onlytheir difference full line.

background reactions, other than the studied reaction, which could also produce the two positively charged track in the forward direction, is negligible (Fig. 6 (b)). Into the differential cross section $d\sigma/dt$). Into the further analysis only those events have been included, where the sum of the two charged particle protons momenta is in the interval (3.5 ± 0.2) GeV/c (Fig. 5 (b)). .

The plot of momenta p_1 *vs.* p_2 of the two charged particles (two protons) from dp reaction is shown in Fig. ??. From the comparison of the simulation results (a) and (c) with the experimental results (b), it can be seen that the background from other channels of the dp reaction may be eliminated.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

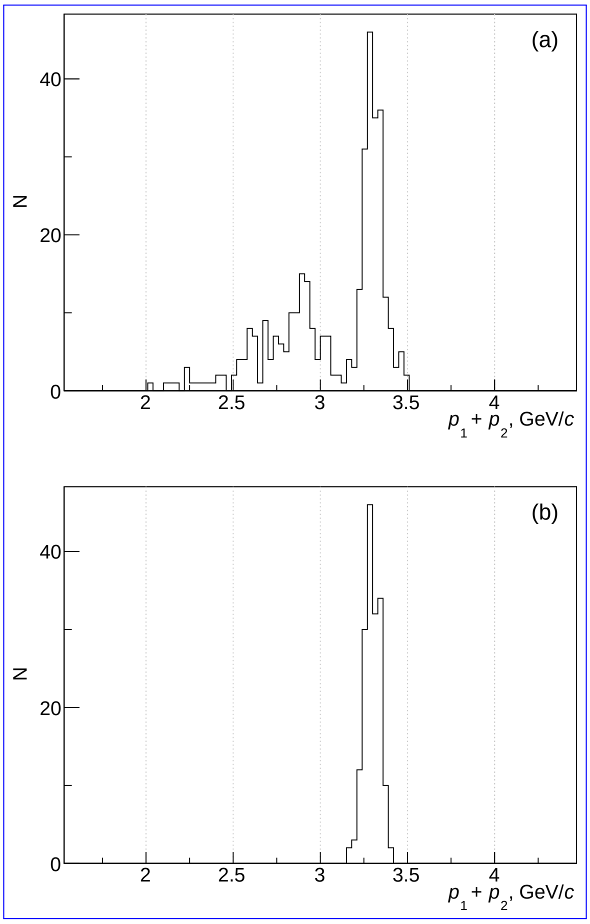

Fig. 6 Distributions of the sum of the two protons momenta from GEANT3 tracked 1m HBC: dp all channels (a) and $dp \to ppn$channel only (b).

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.

Two dimensional distribution of the measured momenta p_1 *vs.* p_2 of the two protons from dp reaction: (a) simulation includes all channels dp reaction, (c) simulation only channel and (b) experimental distribution.

The measured differential distribution dN/dt The measured dN/dt distribution of the $dp \to (pp)n$ reaction is displayed in Fig. 7 together with the curve corresponding to fit by expression 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)$$a = (435.6 \pm 6.8)$ and $b = (-440.9 \pm 9.1)$. The value $(dN/dt)|_{t=0}$ was transformed to cross section

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

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.

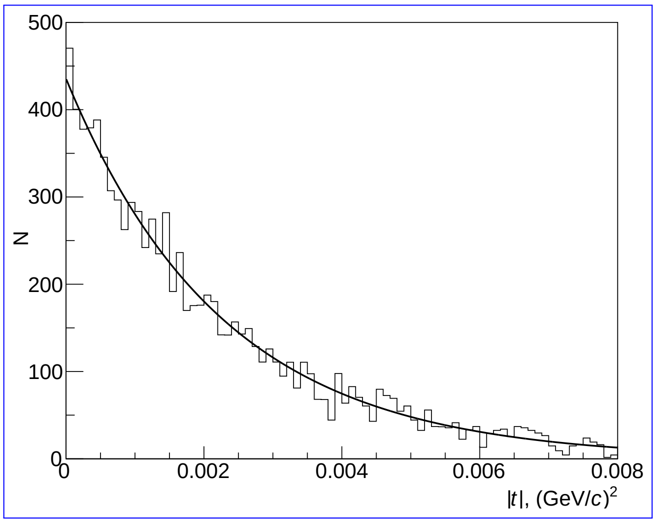

Fig. 7 Differential distribution dN/dt of the $dp \to (pp)n$reaction. The solid line is approximation by Eq. (8).

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 comparably relatively small.

Differential distribution dN/dt of the reaction. The solid line is approximation by Eq. , see details in the text.

The cross section was calculated using the relation

$$\sigma = \frac{1}{n\, l b_w} \ln \left(1 / \left(1 - \frac{N_{int}}{N_0}\right)\right),$$

where n is the concentration of H nuclei in cm^{-3} in target, l is the target length, b_w is the histogram bin width, N_{int} is the number of interactions and N_0 is the number of beam triggers. The number of triggers is corrected for the efficiency of chambers.

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].

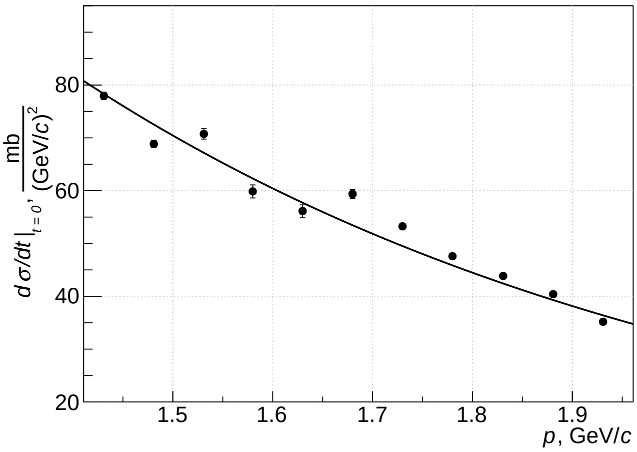

Fig. 8 The dependence of the $(d\sigma/dt)|_{t=0}$ for the $np \to pn$ reaction on the beam momentum. The data points are computed from the experimental results [21]. The solid curve is a simple exponential fit to the data points.

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

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

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

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

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

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

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 has been developed on the basis of the STRELA setup STRELA has been proposed and realized to study the charge exchange reaction in unpolarized 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 obtained established at 1.75 A 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/cper nucleon. The obtained ratio of the charge exchange differential cross sections at at $t = 0$ for $dp \to (pp)n$ and that of $np \to pn$ reactions 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 $np \to pn$ cross section scattering. The obtained ratio depends on the $(d\sigma/dt)|_{t=0}$ the reaction extracted from published data scattering. Continuation of these researches at 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 GeVDelta-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 GeVper 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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