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FULL DETERMINATION OF THE *dp* BACKWARD ELASTIC SCATTERING MATRIX ELEMENT

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Полное определение матричного элемента
в упругом *dp*-рассеянии назад

Проведен модельно-независимый анализ упругого *dp*-рассеяния назад. Показано, что измерение 10 поляризационных наблюдаемых первого и второго порядка позволяет реализовать полную экспериментальную программу по определению амплитуд реакции упругого *dp*-рассеяния назад.

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Full Determination of the *dp* Backward
Elastic Scattering Matrix Element

The model-independent analysis of the *dp* elastic scattering in the collinear geometry has been performed. It is shown that the measurements of 10 polarization observables of the first and second order realize the complete experimental program on the determination of the amplitudes of the *dp* backward elastic scattering reaction.

The investigation has been performed at the Laboratory of High Energies, JINR.

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1 Introduction

The structure of the deuteron is extensively studied at last decades using both electromagnetic and hadron probes. This interest is related with the hope to explore the internal deuteron structure over a wide range of distances between constituents. The backward elastic scattering $dp \to pd$ at medium and high energies is one of the simplest processes with the large momentum transfer and, therefore, can be used to study the high-momentum tail of the deuteron wave function (DWF). Another interesting feature of this process is that within framework of the one nucleon exchange (ONE) the cross section is proportional to the fourth degree of the DWF, $|\Phi(q)|^4$, and polarization observables are also simply related with the S- and D-components of the DWF.

The experimental data on the differential cross section of the $dp \to pd$ reaction [1] show a sharp peak at 180^o in the center of mass. On the other hand, the differential cross section at $\theta \sim 180^o$ demonstrates the strong energy dependence and an enhancement in vinicity of the Δ-isobar excitation. This resonant-like energy dependence of the cross section could not be explained by the pole mechanism only. In the model of Kerman and Kisslinger [2] the dp backward elastic peak is interpreted as due to the admixture of $NN^*(1688)$ state in the standard deuteron wave function. The cross section of the $dp \to pd$ process was calculated in the framework of the two-step model in which the cross section of the dp backward elastic scattering is expressed in terms of the $pp \to d\pi^+$ cross section. Such mechanism, considered firstly by Craigie and Wilkin [3] and later by Barry [4] leads to a resonant behaviour of the cross section at energies near $T_p \sim 600\ MeV$. Calculations of Kolybasov and Smorodinskaya [5] taking into account D- state and relativistic corrections are in the satisfactory agreement with the cross section data.

In the model developed by Kondratyuk and Lev [6], the $dp \to pd$ reaction amplitude is expressed directly in terms of the $NN \to N\Delta$ amplitudes. It is shown that the interference of the Δ excitation with the pole mechanism could provide a satisfactory description of the energy dependence of the dp backward elastic scattering cross section.

The description of the cross section data improves significantly when the contribution from the three-baryon resonances obtained in the bag model as the nine-quark states with hidden color are added [7].

However, description of the polarization observables is related with the numerous difficulties. The two-step model predicts the simple relations between polarization observables of the dp backward elastic scattering and the $pp \to d\pi^+$ process, which should coincide. Moreover, the measurements of analyzing power due to the polarization of incident proton have shown that these relations do not hold even in vinicity of the Δ resonance. Measurements of the vector analyzing power A_y for $\vec{p}d \to dp$ at large angles at 316 and 516 MeV and comparison with the $pp \to d\pi^+$ data have shown that this analyzing power is higher than that for the corresponding $\vec{p}p \to d\pi^+$ reaction [8].

Measurements of the tensor analyzing power T_{20} performed at Saturne [9] at $T_d \sim 0.3 \div 2.3$ GeV shown the large negative value for T_{20}. Calculations of Boudard and Dillig [10] taking into account ONE and rescattering mechanisms from the Δ resonance fails to reproduce the behavior of T_{20}. The better agreement with the experimental data was obtained by Nakamura and Satta [11] in the framework of the two-step model by imposing of T-invariance on the triangle amplitudes. The results have shown the strong sensitivity to the results of the $pp \to d\pi^+$ phase shift analysis and possible existing of dibaryon resonances at $\sqrt{s} \sim 2.1 \div 2.2$ GeV. Recent measurements of T_{20} and spin transfer coefficient from vectorially polarized deuteron to the proton, κ_o, performed at Saclay [12] have confirm the deviation from ONE model. Measurements of T_{20} at Dubna up to $T_d \sim 5$ GeV have demonstrated the new unexplained to date structure at $T_d \sim 3 \div 3.2$ GeV [13].

In present article we perform the model-independent analysis of the dp backward elastic scattering reaction in the collinear geometry. The purpose of this analysis is to find the minimal and optimal set of the experiments for the direct reconstruction of the reaction amplitudes. In the next section we derive the matrix element of the dp elastic scattering. In section 3 we give the expressions for the number of polarization observables. In section 4 we find the set of observables to reconstruct the amplitudes of the reaction. In the last section we discuss the experimental possibilities to perform this set of measurements.

2 dp elastic scattering in the collinear geometry

In the general case the $1 + \frac{1}{2} \to 1 + \frac{1}{2}$ process can be described in terms of 18 independent complex amplitudes:

$$\mathcal{M} = \chi_f^\dagger \mathcal{F} \chi_i,$$

$$\mathcal{F} = f_1(\vec{\xi_1}\vec{l})(\vec{\xi_2}^+\vec{l}) + f_2(\vec{\xi_1}\vec{m})(\vec{\xi_2}^+\vec{m}) + f_3(\vec{\xi_1}\vec{n})(\vec{\xi_2}^+\vec{n}) + f_4(\vec{n}\,\vec{\xi_1}\times\vec{\xi_2}^+)$$
$$+f_5((\vec{\xi_1}\vec{l})(\vec{\xi_2}^+\vec{m}) + (\vec{\xi_1}\vec{m})(\vec{\xi_2}^+\vec{l})) + (f_6(\vec{\xi_1}\vec{l})(\vec{\xi_2}^+\vec{l}) + f_7(\vec{\xi_1}\vec{m})(\vec{\xi_2}^+\vec{m}) \qquad (1)$$

$$+f_8(\vec{\xi_1}\vec{n})(\vec{\xi_2}^+\vec{n}))(\vec{\sigma}\vec{n}) + (f_9(\vec{m}\,\vec{\xi_1}\times\vec{\xi_2}^+) + f_{10}(\vec{l}\,\vec{\xi_1}\times\vec{\xi_2}^+))(\vec{\sigma}\vec{l}) + (f_{11}(\vec{m}\,\vec{\xi_1}\times\vec{\xi_2}^+)$$
$$+f_{12}(\vec{l}\,\vec{\xi_1}\times\vec{\xi_2}^+))(\vec{\sigma}\vec{m}) + f_{13}(\vec{n}\,\vec{\xi_1}\times\vec{\xi_2}^+)(\vec{\sigma}\vec{n}) + f_{14}((\vec{\xi_1}\vec{l})(\vec{\xi_2}^+\vec{n}) + (\vec{\xi_1}\vec{n})(\vec{\xi_2}^+\vec{l}))(\vec{\sigma}\vec{l})$$
$$+f_{15}((\vec{\xi_1}\vec{m})(\vec{\xi_2}^+\vec{n}) + (\vec{\xi_1}\vec{n})(\vec{\xi_2}^+\vec{m}))(\vec{\sigma}\vec{l}) + f_{16}((\vec{\xi_1}\vec{l})(\vec{\xi_2}^+\vec{n}) + (\vec{\xi_1}\vec{n})(\vec{\xi_2}^+\vec{l}))(\vec{\sigma}\vec{m})$$
$$+f_{17}((\vec{\xi_1}\vec{m})(\vec{\xi_2}^+\vec{n})(\vec{\xi_1}\vec{n})(\vec{\xi_2}^+\vec{m}))(\vec{\sigma}\vec{m}) + f_{18}((\vec{\xi_1}\vec{l})(\vec{\xi_2}^+\vec{m}) + (\vec{\xi_1}\vec{m})(\vec{\xi_2}^+\vec{l}))(\vec{\sigma}\vec{n}),$$

where χ_f and χ_i are the spinors of the final and initial fermions, $\vec{\xi_1}$ and $\vec{\xi_2}$ are the polarization vectors of the initial and final spin 1 particles; f_i are scalar amplitudes, depending in the general case on the energy and scattering angle θ. The three mutually orthogonal unit vectors $\vec{l}$, $\vec{m}$ and $\vec{n}$ are defined as:

$$\vec{l} = \frac{\vec{k_i} + \vec{k_f}}{|\vec{k_i} + \vec{k_f}|}, \qquad \vec{m} = \frac{\vec{k_i} - \vec{k_f}}{|\vec{k_i} - \vec{k_f}|}, \qquad \vec{n} = \frac{\vec{k_i} \times \vec{k_f}}{|\vec{k_i} \times \vec{k_f}|}, \qquad (2)$$

where $\vec{k_i}$ and $\vec{k_f}$ are the relative momenta of the initial and final states, respectively.

The expression (1) have been obtained using the parity conservation only. Therefore, it keeps the terms violating the T-invariance in the dp elastic scattering. The requirement of time reversal invariance implies that:

$$f_5 = f_9 = f_{12} = f_{15} = f_{16} = f_{18} = 0, \qquad (3)$$

what reduces the number of independent amplitudes for dp - elastic scattering to 12.

In this paper we consider the dp elastic scattering in the collinear geometry. The condition of the total spin projection conservation for the collinear processes restricts the number of independent amplitudes of the matrix element (1) in such a way that:

$$f_2 = f_3, \quad f_{11} = f_{13},$$
$$f_4 = f_6 = f_7 = f_8 = f_{14} = f_{17} = 0 \qquad (4)$$

for the forward elastic scattering ($\theta_{cm} = 0^o$) and

$$f_1 = f_3, \quad f_{10} = f_{13},$$
$$f_4 = f_6 = f_7 = f_8 = f_{14} = f_{17} = 0 \qquad (5)$$

for the backward elastic scattering ($\theta_{cm} = 180^o$), respectively.

Finally, the amplitude of the dp elastic scattering in the collinear geometry can be written as:

$$\mathcal{F} = \quad A(\vec{\xi_1}\vec{\xi_2}^+) + B(\vec{\xi_1}\vec{k})(\vec{\xi_2}^+\vec{k}) + iC(\vec{\sigma}\vec{\xi_1}\times\vec{\xi_2}^+) + iD(\vec{\sigma}\vec{k})(\vec{k}\vec{\xi_1}\times\vec{\xi_2}^+), \qquad (6)$$

where $\vec{k}$ is the unit vector in the direction of the relative momentum of the initial state, A, B, C and D are the amplitudes of the dp elastic scattering depending on the energy.

3 Polarization observables

In this section we give the definition of the general polarization observable and results of our calculations for the number of polarization observables of the dp elastic scattering in the collinear kinematics.

We define the general spin observable in terms of the Pauli 2×2 spin matrices σ for protons and a set of spin operators S for deuterons as in refs[14, 15, 16]:

$$C_{\alpha,\lambda,\beta,\gamma} = \frac{Tr(\mathcal{F}\sigma_\alpha S_\lambda \mathcal{F}^+ \sigma_\beta S_\gamma)}{Tr(\mathcal{F}\mathcal{F}^+)}, \tag{7}$$

where indices α and λ refer to the initial proton and deuteron polarization, indices β and γ refer to the final proton and deuteron, respectively; σ_0 and S_0 corresponding to the non-polarized particles are the unit matrices of two and tree dimensions in these notations. We use a righthand coordinate system, defined in accordance with Madison convention [17]. This system is specified by a set of three ortogonal vectors $\vec{L}$, $\vec{N}$ and $\vec{S}$, where $\vec{N} = \vec{n}$, $\vec{L} = \vec{l}$ and $\vec{S} = [\vec{N}\vec{L}]$.

Below we shall show that the direct reconstruction of the amplitudes can be provided by the measurements of the first and second order polarization observables only, therefore, we derive the expressions only for them.

The squared matrix element (6) is expressed as:

$$Tr\mathcal{F}\mathcal{F}^+ = 2(3A^2 + 2\mathcal{R}eAB^* + B^2 + 6C^2 + 4\mathcal{R}eCD^* + 2D^2) \tag{8}$$

The only non-vanishing polarization observable of the first order is the tensor analyzing power due to the polarization of the initial deuteron (or the induced tensor polarization of the final deuteron) can be written as:

$$Tr\mathcal{F}\mathcal{F}^+ C_{0,NN,0,0} = 2(2\mathcal{R}eAB^* + B^2 - 2\mathcal{R}eCD^* - D^2) \tag{9}$$

This observable $T_{20} = -\sqrt{2} \cdot C_{0,NN,0,0}$ was measured up to 5 GeV of the initial deuteron kinetic energy at Saclay and Dubna [9, 12, 13].

The tensor polarization of the final deuteron is equal to the tensor analyzing power due to polarization of the initial deuteron according to the T-invariance:

$$C_{0,0,0,NN} = C_{0,NN,0,0} \tag{10}$$

The spin transfer coefficients from deuteron to deuteron due to the vector polarization of both particles can be expressed as:

$$Tr\mathcal{F}\mathcal{F}^+ C_{0,L,0,L} = 4 \cdot (A^2 + C^2 + 2\mathcal{R}eCD^* + D^2) \tag{11}$$
$$Tr\mathcal{F}\mathcal{F}^+ C_{0,N,0,N} = 4 \cdot (A^2 + \mathcal{R}eAB^* + C^2) \tag{12}$$

Since the deuteron is a spin 1 particle, there are the number of tensor-tensor and vector-tensor (tensor-vector) spin transfer coefficients apart from the usual vector-vector ones. The tensor-tensor non-vanishing spin transfer coefficients are defined as:

$$Tr\mathcal{F}\mathcal{F}^+ C_{0,LL,0,LL} = 4(3A^2 + 4\mathcal{R}eAB^* + 2B^2 - 3C^2 + 2\mathcal{R}eCD^* + D^2) \tag{13}$$
$$Tr\mathcal{F}\mathcal{F}^+ C_{0,NN,0,NN} = 2(6A^2 + 2\mathcal{R}eAB^* + B^2 - 6C^2 - 8\mathcal{R}eCD^* - 4D^2) \tag{14}$$
$$Tr\mathcal{F}\mathcal{F}^+ C_{0,NN,0,SS} = 2(-3A^2 + 2\mathcal{R}eAB^* + B^2 + 3C^2 + 10\mathcal{R}eCD^* + 5D^2) \tag{15}$$
$$Tr\mathcal{F}\mathcal{F}^+ C_{0,LN,0,LN} = 9 \cdot (A^2 + \mathcal{R}eAB^* - C^2) \tag{16}$$
$$Tr\mathcal{F}\mathcal{F}^+ C_{0,SN,0,SN} = 9 \cdot (A^2 - C^2 - 2\mathcal{R}eCD^* - D^2) \tag{17}$$

Note that tensor-tensor spin transfer coefficients $C_{0,NN,0,NN}$, $C_{0,NN,0,SS}$, $C_{0,NN,0,LL}$, $C_{0,LL,0,LL}$, and $C_{0,SN,0,SN}$ are not independent and related as the following:

$$\begin{aligned} C_{0,NN,0,LL} &= -\frac{1}{2}C_{0,LL,0,LL} \\ C_{0,SN,0,SN} &= \frac{1}{2}(C_{0,NN,0,NN} - C_{0,NN,0,SS}) \\ C_{0,LL,0,LL} &= 2(C_{0,NN,0,NN} + C_{0,NN,0,SS}) \end{aligned} \tag{18}$$

The existence of these relationships allows to perform the measurements of $C_{0,NN,0,NN}$ and $C_{0,NN,0,SS}$ instead $C_{0,SN,0,SN}$ and $C_{0,LL,0,LL}$, being more difficult to be realized from the experimental point of view.

The spin transfer coefficient from the vectorially polarized deuteron to the tensorially polarized final deuteron depends on the A and B amplitudes only:

$$Tr\mathcal{F}\mathcal{F}^+ C_{0,N,0,LS} = 6 \cdot \mathcal{I}mAB^* \tag{19}$$

There are the simple relations between the tensor-vector and vector-tensor spin transfer coefficients due to the T-invariance and rotation symmetry:

$$C_{0,LS,0,N} = -C_{0,LN,0,S} = -C_{0,N,0,LS} = C_{0,S,0,LN} \tag{20}$$

The availability of the polarized proton target and polarized beam gives the opportunity to measure the different spin correlations. As in case of the spin transfer coefficients from the deuteron to deuteron, there are the spin correlations due to the vector polarization of the deuteron:

$$
\begin{aligned}
Tr\mathcal{F}\mathcal{F}^{+}C_{L,L,0,0} &= 4\cdot(2\mathcal{R}eAC^{*}+2\mathcal{R}eAD^{*}-C^{2}) &(21)\\
Tr\mathcal{F}\mathcal{F}^{+}C_{N,N,0,0} &= 4\cdot(2\mathcal{R}eAC^{*}+\mathcal{R}eBC^{*}-\mathcal{R}eCD^{*}-C^{2}), &(22)
\end{aligned}
$$

as well as due to tensor polarization:

$$
Tr\mathcal{F}\mathcal{F}^{+}C_{N,LS,0,0}=6\cdot(\mathcal{I}m(B+D)C^{*}) \qquad (23)
$$

The measurement of the spin correlations of the final particles is not realistic due to the small cross section of the considered process. Moreover, since they are equal to the corresponding spin correlations of the initial particles according to the T-invariance:

$$
\begin{aligned}
C_{0,0,L,L} &= C_{L,L,0,0} \qquad C_{0,0,N,N}=C_{N,N,0,0}\\
C_{0,0,S,S} &= C_{0,0,N,N} \qquad C_{0,0,N,LS}=C_{N,LS,0,0}, \qquad (24)
\end{aligned}
$$

these experiments are not necessary.

The deuteron-proton spin transfer coefficients can be written as:

$$
\begin{aligned}
Tr\mathcal{F}\mathcal{F}^{+}C_{0,L,L,0} &= 4\cdot(2\mathcal{R}eAC^{*}+2\mathcal{R}eAD^{*}+C^{2}) &(25)\\
Tr\mathcal{F}\mathcal{F}^{+}C_{0,N,N,0} &= 4\cdot(\mathcal{R}e(2A^{*}+B^{*}+D^{*})C+C^{2}) &(26)\\
Tr\mathcal{F}\mathcal{F}^{+}C_{0,LS,N,0} &= 6\cdot(\mathcal{I}m(-B^{*}+D^{*})C) &(27)
\end{aligned}
$$

kappa

Only $C_{0,N,N,0}=\frac{2}{3}\kappa_0$ was measured at Saturne to date [12].

Finally, we give the expressions for the spin transfer coefficients from polarized proton target to the final proton:

$$
\begin{aligned}
Tr\mathcal{F}\mathcal{F}^{+}C_{L,0,L,0} &= 2(3A^{2}+2\mathcal{R}eAB^{*}+B^{2}-2C^{2}) &(28)\\
Tr\mathcal{F}\mathcal{F}^{+}C_{N,0,N,0} &= 2(3A^{2}+2\mathcal{R}eAB^{*}+B^{2}-2C^{2}-4\mathcal{R}eCD^{*}-2D^{2}) &(29)\\
C_{S,0,S,0} &= C_{N,0,N,0} &(30)
\end{aligned}
$$

In this section we have derived the expressions for all non-vanishing observables of the first and second order, which can be used to determine the matrix element of the process. Some of these observables are not independent due to the symmetries properties. As the consequence of the T-invariance one can write the relationships between the different observables:

$$
\begin{aligned}
C_{0,0,0,NN} &= C_{0,NN,0,0} \qquad C_{0,NN,0,SS}=C_{0,SS,0,NN} \qquad C_{0,LL,0,NN}=C_{0,NN,0,LL}\\
C_{L,0,0,L} &= C_{0,L,L,0} \qquad C_{N,0,0,N}=C_{0,N,N,0} \qquad C_{N,0,0,LS}=C_{0,LS,N,0} \qquad (31)
\end{aligned}
$$

There are also the following relations due to the collinear geometry of the considered process:

$$
\begin{aligned}
C_{S,S,0,0} &= C_{N,N,0,0} \qquad C_{0,S,0,S}=C_{0,N,0,N} \qquad C_{S,0,S,0}=C_{N,0,N,0}\\
C_{0,0,S,S} &= C_{0,0,N,N} \qquad C_{0,LN,0,LN}=C_{0,LS,0,LS} \qquad (32)
\end{aligned}
$$

4 Direct reconstruction of the amplitudes

Since the $dp\rightarrow pd$ process is described by 4 complex amplitudes, one needs to measure at least 7 observables to determine the matrix element. On the other hand, all polarization observables are expressed through the bilinear combinations of the amplitudes, therefore, the number of experiments to be performed at given energy increases. Another restriction comes from small cross section of the process at high energies and low efficiency of the polarimeters or limited possible flux on the polarized target. Therefore, one needs to find the set of observables satisfying to the experimental possibility to be measure also.

Below we assume that the axis of the primary deuteron beam polarization at the exit of the ion source is vertical.

The moduli of the amplitudes A, B and C can be extracted from the information on the cross section, tensor analyzing power $C_{0,NN,0,0}$ (or $C_{0,0,0,NN}$) and 3 different tensor-tensor spin transfer coefficients: $C_{0,NN,0,LL}$, $C_{0,SN,0,SN}$ (see relations (18)) and $C_{0,LN,0,LN}$ as:

$$
\begin{aligned}
A^{2} &= \frac{1}{18}Tr\mathcal{F}\mathcal{F}^{+}(1-\frac{1}{2}C_{0,NN,0,LL}-2\,C_{0,NN,0,0}+C_{0,SN,0,SN}) &(33)\\
B^{2} &= -\frac{1}{4}Tr\mathcal{F}\mathcal{F}^{+}(C_{0,NN,0,LL}+\frac{2}{9}(4C_{0,LN,0,LN}-C_{0,SN,0,SN})) &(34)\\
C^{2} &= \frac{1}{18}Tr\mathcal{F}\mathcal{F}^{+}(1+C_{0,NN,0,LL}+C_{0,NN,0,0}) &(35)
\end{aligned}
$$

Note, that C^2 can be also reconstructed from the vector-vector, $C_{0,N,0,N}$, and tensor-tensor, $C_{0,LN,0,LN}$, spin transfer coefficients from the deuteron to deuteron:

$$
C^{2}=\frac{1}{8}Tr\mathcal{F}\mathcal{F}^{+}(C_{0,N,0,N}-\frac{4}{9}C_{0,LN,0,LN}). \qquad (36)
$$

In such a way $C_{0,N,0,N}$ is not independent and can be expressed through the discussed above observables as:

$$
C_{0,N,0,N}=\frac{4}{9}(1+C_{0,NN,0,LL}+C_{0,NN,0,0}+C_{0,LN,0,LN}) \qquad (37)
$$

The reconstruction of the D^2 requires the measurement of the additional observables because the D^2 appears always together with the $2\mathcal{R}eCD^*$ in the expressions for the cross section, tensor analyzing power and tensor-tensor spin transfer coefficients, and therefore, can not be extracted. One can easy to show that the D^2 can be obtained from the 3 polarization observables: spin transfer coefficient from deuteron to proton, $C_{0,N,N,0}$ [12], spin correlation parameter, $C_{N,N,0,0}$ [18], and spin transfer coefficient from the proton to proton, $C_{N,0,N,0}$:

$$D^2 = \frac{1}{4}Tr\mathcal{F}\mathcal{F}^+(\frac{1}{2}(1 - C_{N,0,N,0}) + C_{N,N,0,0} - C_{0,N,N,0})) \tag{38}$$

On the other hand, the spin transfer coefficient $C_{N,0,N,0}$ is not independent observable and related with the tensor analyzing power $C_{0,NN,0,0}$ and tensor-tensor spin transfer coefficient $C_{0,NN,0,NN}$ by:

$$C_{N,0,N,0} = \frac{1}{9}(1 + 4\ C_{0,NN,0,0} + 4\ C_{0,NN,0,NN}) \tag{39}$$

Therefore, D^2 can be obtained by the measuring of the spin correlation $C_{N,N,0,0}$ and spin transfer coefficient from the deuteron to proton, $C_{0,N,N,0}$ [12], in addition to the cross section, tensor analyzing power and tensor-tensor spin transfer coefficient:

$$D^2 = \frac{1}{9}Tr\mathcal{F}\mathcal{F}^+(1 - \frac{1}{2}(C_{0,NN,0,0} + C_{0,NN,0,NN}) + \frac{9}{4}(C_{N,N,0,0} - C_{0,N,N,0})) \tag{40}$$

The reconstruction of the phases of the amplitudes can be performed using an additional information apart from the discussed above observables. Since the observables are expressed through the bilinear combinations of the amplitudes, the reconstruction of the common phase is impossible. We put the phase of the amplitude A equal to zero, $\Phi_A = 0$. Therefore A amplitude is real:

$$\mathcal{I}mA = 0 \qquad \mathcal{R}eA = \sqrt{A^2} = |A| \tag{41}$$

Imaginary part of the B amplitude can be easy reconstructed from the measurement of the spin transfer coefficient from the vectorially polarized initial deuteron to the tensorially polarized final deuteron $C_{0,N,0,LS}$. Therefore, the phase Φ_B can be reconstructed as:

$$\begin{aligned} \mathcal{I}mB &= |B|\ \sin\Phi_B = \frac{1}{6\ |A|}Tr\mathcal{F}\mathcal{F}^+C_{0,N,0,LS} \\ \mathcal{R}eB &= |B|\ \cos\Phi_B = \frac{1}{|A|}(\frac{1}{9}Tr\mathcal{F}\mathcal{F}^+C_{0,LN,0,LN} - A^2 + C^2) \end{aligned} \tag{42}$$

The reconstruction of the $\mathcal{R}eC$ and $\mathcal{I}mC$ can be obtained from the spin correlation $C_{N,LS,0,0}$ and spin transfer coefficient $C_{0,LS,N,0}$ due to the tensor polarization

of the initial deuteron and polarization of the initial and final proton, respectively. Using the following combinations of the polarization observables

$$\begin{aligned} X &= \frac{1}{12}Tr\mathcal{F}\mathcal{F}^+(C_{N,LS,0,0} + C_{0,LS,N,0}) = \mathcal{I}mBC^* \\ Y &= \frac{1}{8}Tr\mathcal{F}\mathcal{F}^+(C_{N,N,0,0} + C_{0,N,N,0}) = 2\ \mathcal{R}eAC^* + \mathcal{R}eBC^*, \end{aligned}$$

one can reconstruct the phase Φ_C:

$$\begin{aligned} \mathcal{I}mC &= |C|\ \sin\Phi_C = \frac{Y\ \mathcal{I}mB - X\ (2\ |A| + \mathcal{R}eB)}{2\ |A|\mathcal{R}eB + B^2} \\ \mathcal{R}eC &= |C|\ \cos\Phi_C = \frac{X\ \mathcal{I}mB + Y\ \mathcal{R}eB}{2\ |A|\mathcal{R}eB + B^2} \end{aligned} \tag{43}$$

The reconstruction of the real and imaginary parts of the D amplitude can be performed without measurements of the additional observables. Using the following relations:

$$\begin{aligned} U &= -\frac{1}{12}Tr\mathcal{F}\mathcal{F}^+(C_{N,LS,0,0} + C_{0,LS,N,0}) = \mathcal{I}mCD^* \\ V &= \frac{1}{8}Tr\mathcal{F}\mathcal{F}^+(C_{N,N,0,0} - C_{0,N,N,0}) - C^2 = \mathcal{R}eCD^*, \end{aligned}$$

one can easy obtain Φ_D:

$$\begin{aligned} \mathcal{I}mD &= |D|\ \sin\Phi_D = \frac{1}{C^2}(V\mathcal{I}mC - U\mathcal{R}eC) \\ \mathcal{R}eD &= |D|\ \cos\Phi_D = \frac{1}{C^2}(V\mathcal{R}eC + U\mathcal{I}mC) \end{aligned} \tag{44}$$

It should be noted, that the matrix element can be expressed in terms of different sets of amplitudes which are simply related (see Appendix 1). The minimal number of different experiments (seven) does not depend on the used set of amplitudes. The expressions of the amplitudes $A - D$ calculated within One Nucleon Exchange are given in Appendix 2.

5 Conclusions and discussions

To conclude we have found that the measurement of 10 observables of the first and second order only, i.e. cross section, tensor analyzing power $C_{0,NN,0,0}$ ($C_{0,0,0,NN}$) and 8 second order spin observables $C_{0,NN,0,NN}$, $C_{0,NN,0,SS}$, $C_{0,LN,0,LN}$, $C_{0,N,0,LS}$, $C_{0,N,N,0}$, $C_{N,N,0,0}$, $C_{LS,N,0,0}$ and $C_{0,LS,N,0}$ could provide the direct reconstruction of the amplitudes of the dp backward elastic process. The choosen observables are mostly realistic to be measured at the moment with the existing experimental techniques.

Using of purely tensor polarimeter POLDER [19] based on the $(d, 2p)$ charge exchange reaction [20] could provide the measurements of $C_{0,NN,0,NN}$, $C_{0,NN,0,SS}$ and $C_{0,LN,0,LN}$ (which could be easy obtained by the rotation of the initial deuteron spin) and $C_{0,N,0,LS}$ in addition to the measured cross section [1] and $C_{0,NN,0,0}$ [9, 12, 13]. The cross section and tensor analyzing power could be measured simultaneously with the spin transfer coefficients allowed by the triggering system of POLDER [19]. Note, that as a by-product the tensor polarization of the final deuteron $C_{0,0,0,NN}$ also would be obtained. Two additional observables: spin transfer coefficients $C_{0,N,N,0}$ [12] and $C_{0,LS,N,0}$ could be obtained from the measurement of the proton polarization by the polarimeter POMME [22]. The spin correlations $C_{N,N,0,0}$ [18] and $C_{LS,N,0,0}$ could be measured using polarized deuteron beam and polarized proton target installed now at LHE of JINR [23]. The rotation of the primary deuteron spin could be provided by the magnetic field of the beam line upstream the target [2] or by the special spin-flip magnet, what is necessary for the measurement of T-odd observables like $C_{N,LS,0,0}$ and $C_{0,LS,N,0,0}$ or tensor-tensor spin transfer coefficient $C_{0,LN,0,LN}$.

The measurements of the tensor-tensor spin transfer coefficients is the most difficult task from the experimental point of view because of two reasons: unfavourable jacobian in the laboratory for the final deuteron and small figures of merit F_{20}, F_{22} and F_{21} of POLDER [19] which are about 1%. These factors could be compensated by the using of the full intensity of the deuteron beam reaching $2 \cdot 10^{11}$ per beam burst and a large solid angle. The measurement of the proton polarization can be performed with the better precision because of the figure of merit of POMME as a proton polarimeter at high energies is about $4 \div 5\%$ and favourable jacobian for the final proton, on the other hand. But an additional problem due to the large yield of the background breakup process near the backward elastic peak arises [13]. The precision of the measurement of the observables requiring the using of the polarized target is also limited by the maximal possible flux of the charged particles as 10^8 per second.

Therefore, to realize the program of the full experiment, it is necessary to use 2 different setups: high resolution spectrometer with the proton polarimeter and proton polarized target for the fast final proton and a large solid angle spectrometer and low energy deuteron polarimeter like POLDER [19] or AHEAD [21] to measure the

[2] We thank I.M.Sitnik for the estimation of the deuteron spin rotation angle due to the beam line upstream polarized proton target installed at LHE JINR

polarization of the final deuteron. The first setup can be used to measure $C_{N,N,0,0}$, $C_{N,LS,0,0}$, $C_{0,N,N,0}$ and $C_{0,LS,N,0}$, the second one to measure deuteron-deuteron spin transfer coefficients. Both setups can be used to measure cross section, tensor analyzing power and spin correlations.

It has been shown in the previous section that, for instance, the measurement of the vector-vector spin transfer coefficient from deuteron to deuteron, $C_{0,N,0,N}$, or from proton to proton, $C_{N,0,N,0}$, do not provide an additional information in comparison with the tensor-tensor spin transfer coefficients. But the using of low energy deuteron AHEAD-like polarimeter [21] which has a non-negligiable vector figure of merit instead purely tensor polarimeter POLDER could provide the simultaneous measurement of $C_{0,N,0,N}$ or $C_{0,LN,0,S}$. Some of additional observables (for instance, $C_{0,S,S,0}$) could be measured as a by-product during the experiments requiring the rotation of the polarization axis of tensorially polarized beam which has an admixture of the vector polarization. This additional information could be used in order to reduce the systematic errors of the amplitudes reconstruction.

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Appendix 1

We give here the relations between different sets of amplitudes.

The helicity amplitudes, $\underline{H_{\frac{1}{2}1\to\frac{1}{2}1}}$, can be expressed as following:

more helicity, spin amplitudes

$$
\begin{aligned}
H_{++\to++} &= A+C+D \\
H_{+0\to+0} &= A+B \\
H_{+-\to+-} &= A-C-D \\
H_{+0\to-+} &= \sqrt{2}C
\end{aligned}
$$

The ukrainian amplitudes [18] are simply related with the amplitudes used in this work as:

$$
\begin{aligned}
g_1 &= A \\
g_2 &= A+B \\
g_3 &= C \\
g_4 &= C+D
\end{aligned}
$$

Appendix 2

Here we derive the expressions for $A-D$ amplitudes calculated in the framework of the pole mechanism:

$$
\begin{aligned}
A &= \left(u+\frac{w}{\sqrt{2}}\right)^2 \\
B &= -\frac{3}{2}w\left(2\sqrt{2}u-w\right) \\
C &= \left(u+\frac{w}{\sqrt{2}}\right)\left(u-\sqrt{2}w\right) \\
D &= \frac{3}{\sqrt{2}}w\left(u+\frac{w}{\sqrt{2}}\right),
\end{aligned}
$$

where u and w are the S- and D- components of the deuteron wave function.

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