Dp breakup reaction investigation using polarized and unpolarized deuteron beam

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Collaboration

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- Advanced Research Institute for Electrical Engineering, Bucharest, Romania
- Institute of Physics Slovak Academy of Sciences, Bratislava, Slovakia
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- Institute for Physical and Chemical Research (RIKEN), Saitama, Japan
- Department of Physics, University of Tokyo
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Motivation

The main goal of the DSS collaboration is to investigate the spin structure of nucleon-nucleon and three nucleon short-range correlations through the measurements of the polarization observables in the deuteron induced reactions at intermediate energies at Nuclotron.

- \( dp \) elastic scattering at deuteron energy (300 – 2000) MeV
- Polarized data: analyzing powers \( A_y, A_{yy} \) and \( A_{xx} \) at 400 MeV
- \( dp \) breakup reaction at deuteron energy (300 – 500) MeV
  - Unpolarized data
  - Polarized data at 270 and 400 MeV
When the distances between the nucleons are comparable with the size of the nucleon, the nucleon-nucleon interaction is a non-local.

The fundamental degrees of freedom, quark and gluons in the frame of QCD, begin also to play a role at the internucleonic distances comparable with the size of the nucleon. They can manifest as $\Delta\Delta$, NN*, N*N*, 6q etc. components.


One needs to be very careful: according to the theorem of W. N. Polyzou and W. Gloeckle, Few Body Syst. 9 (1990) 97, off-shell behaviour of 2NF can imitate 3NF effect.
Fundamental degrees of freedom

At high energy $s$ and large transverse momenta $p_t$, the constituent counting rules (CCR) predict the following behaviour of the differential cross section for the binary reactions: (Matveev, Muradyan, Tavkhelidze, Brodsky, Farrar et al.)

$$\frac{d\sigma}{dt}(ab \rightarrow cd) = \frac{f(t/s)}{s^{n-2}}; \quad n = N_a + N_b + N_c + N_d$$

$dd \rightarrow ^3\text{He} n$, c.m. 60°

$dp \rightarrow dp$, c.m. 127°

Yu. N. Uzikov


For the reaction $dd \rightarrow ^3\text{He} n$

$$N_A + N_B + N_C + N_D - 2 = 22$$

For the reaction $dp \rightarrow dp$

$$N_A + N_B + N_C + N_D - 2 = 16$$

The regime corresponding to CCR can occur already at $T_d \sim 500$ MeV for $dd \rightarrow ^3\text{He} n$ ($^3\text{Hp}$)
Three Nucleon Forces

Experiments (e.g. [1], [2], [3]) performed during last two decades clearly indicate the importance of the three nucleon forces in description of binding energies of light nuclei, polarisation observables and scattering experiments with at least three nucleons involved in the reaction.


Spin parts of the 2N and 3N correlations are important to describe the light nuclei structure.
Inclusion of modern 3NFs allows to describe cross section and deuteron vector analyzing power of dp- elastic scattering up to 135 MeV/nucleon, while the tensor observables are not described. The data at higher energies (up to 300 MeV/nucleon) are not described even taking into account relativistic effects. The reason of the discrepancy is nowadays called the importance of the short range 3NFs which are still not included.

The systematic study of hadronic reactions induced by deuterons at Nuclotron will allow to study the structure of 2N and 3N forces.
The purpose of the **DSS** experimental program is to obtain the information about \(2\text{NF}\) and \(3\text{NF}\) (including their spin – dependent parts) from two processes:

- dp-elastic scattering at the energies between \(300 - 2000\ \text{MeV}\);
- dp-breakup with registration of two protons at deuteron energies of \(300 - 500\ \text{MeV}\).

**Internal Target Station** is very well suited for the measurements of the deuteron- induced reactions observables at large scattering angles.
A_y and A_{yy} in dp- elastic scattering at 2000 MeV

- Open squares are the data obtained at Nuclotron JINR.
- Open circles are the Synchrophasotron data (V.V.Glagolev, Eur. Phys. J. A48 (2012) 182)
- Solid symbols are the data obtained by ANL group (Haji-Saied et al., Phys.Rev.C.36 (1987) 2010).
- Dashed and solid lines are the relativistic multiple scattering model calculations using CD- Bonn DWF taking into account single scattering and single+double scattering, respectively.
Cross section in $dp$- elastic scattering at 880 MeV

- The results of the multiple scattering model are in agreement with the cross section data in the range 30 - 130º.
- Double scattering dominates over single scattering at the angles larger than 70º.
- Deviation of the data on the calculations at backward angles are related with the s-type of the FM 3NF.
- Is the deviation on the data from the calculations around 90º manifestation of 3N short range forces?

World data:

Red circles are the LHEP-JINR results: DSS-project at Nuclotron.

Relativistic multiple scattering model calculation:
Results from the commissioning run at Nuclotron at 270 MeV (June 2016)

- Deuterons and protons in coincidences using scintillation counters thin CH$_2$ target (C for background estimation)
- measurement at 270 MeV
- New PIS demonstrated good vector and tensor polarization values for 1-4 transition $p_z,p_{zz} = (+1/2,-1/2)$, while only tensor polarization for 3-4 transition $p_z,p_{zz} = (-1/2,-1/2)$.

2017 feb/mar

dp elastic scattering has been investigated with using polarized deuteron beam at Internal Target Station at various kinematic configurations at deuteron energies: 400, 700, 800, 1000, 1100, 1300, 1500 and 1800 MeV.
Dp-elastic @ 400 MeV, Ay, Ayy and Axx

T_d = 400 MeV

Relativistic multi-scattering model

- **ONE+SS+DS**
- **ONE+SS**

Preliminary results (feb./mar. 2017 run)
dp-elastic differential cross section

1300 MeV


1500 MeV


Red symbols - Nuclotron's data
Dp-elastic @ 1400 MeV

- full squares - 700 MeV/N, Internal Target Station (ITS) of Nuclotron, 2017y
- other symbols - world data at 3 energies: 641, 794 and 800 MeV/N

Data accumulated also at:
400, 500, 600, 700, 880, 1000, 1300, 1500, 1600, 1700, 1900, 2000 MeV.
Transverse momentum $p_T$ at four different fixed values of $x_F \sim 0.61$, 0.67, 0.72 and 0.78, are shown in the a), b), c) and d).

Fraction $x_F$ obtained at fixed $p_T$ values of $\sim 550$ MeV/c, $\sim 700$ MeV/c, $\sim 800$ MeV/c and $\sim 900$ MeV/c are presented in the a), b), c) and d).

$A_{yy}$ in deuteron inclusive breakup demonstrates the dependence on 2 internal variables: $p_T$ and $x_F$.

$A_{yy}$ changes the sign at $p_T$ of about 600 MeV/c independently on $x_F$.

$A_{yy}$ demonstrates negative asymptotic at large $p_T$.

Dp-elastic, Nuclotron - recent results

open symbols - world data obtained at RIKEN, Saclay, ANL
full squares - 880 and 2000 MeV, Internal Target Station (ITS) of Nuclotron, 2005y
full circles - preliminary data obtained during 2016 and 2017 years at the ITS (Nuclotron), (Polarized deuterons were provided by the new polarized ions sources)
Dp-elastic, Nuclotron - recent results

open symbols - world data obtained at RIKEN, Saclay, ANL
full squares - 880 and 2000 MeV, Internal Target Station (ITS) of Nuclotron, 2005y
full circles - preliminary data obtained during 2016 and 2017 years at the ITS
(Polarized deuterons were provided by the new polarized ions sources)
The importance of relativistic effects under specific phase space configurations has been observed.

Internal Target Station is very well suited for the experiment on the measurement of the \( dp \)- breakup reaction.

\[ \Theta (12^\circ, 45^\circ) \]
\[ \Phi (0^\circ, 360^\circ) \]

Space angle of the detector 4.6°.

Missing mass spectra on \( \text{CH}_2 \) and C at 400 MeV

Experimental and simulated missing mass spectra are shown in first and second column, respectively.

Solid and dashed (shaded) spectra represent results obtained on \textbf{Polyethylene} and \textbf{Carbon} targets for detector arms angles:

- 27°-43° (first row)
- 31°-43° (second row)
- 32°-38° (third row)
The energy correlation between two protons in coincidence for the three-body deuteron break-up reaction is shown as S-curves for several kinematical configurations.

Space star configuration is interesting from the point of 3N correlations and non nucleonic degrees of freedom investigation.
Dp breakup reaction at 400 MeV,
\[ \theta_{p1} = 39^\circ (\pm 2.3^\circ), \theta_{p2} = 43^\circ (\pm 2.3^\circ) \]

dp → ppn, two protons registered at angles:
\[ \theta_{p1} = 39^\circ (\pm 2.3^\circ), \theta_{p2} = 43^\circ (\pm 2.3^\circ) \]

1\textsuperscript{st} Arm fixed at 43\textdegree, 2\textsuperscript{nd} moving \((27^\circ, 31^\circ, 35^\circ, 39^\circ, 43^\circ)\)
Analyzing powers of dp breakup reaction at 400 MeV

Detector placement is determined by polar $\theta$ and azimuthal $\varphi$ angles.

Azimuthal angle $\varphi$ have anticlockwise direction.
Angular dependence of the vector analyzing power at energy of 200 MeV/n. Data obtained at Nuclotron JINR are represented by full blue symbols (72.3° and 76.5° in cm). Other symbols - world data.
Analyzing powers of dp breakup reaction at 400 MeV, physics data

Spherical analyzing powers $iT_{11}$ and $T_{20}$. Detector configuration is determined by polar $\theta_1$ and $\theta_2$, and azimuthal angles $\phi$. Azimuthal angle is related to the angle of the detector which is closest to beam direction.

<table>
<thead>
<tr>
<th>Conf.</th>
<th>$\theta_1$ [°]</th>
<th>$\theta_2$ [°]</th>
<th>$\phi$ [°]</th>
<th>$iT_{11}$</th>
<th>$T_{20}$</th>
<th>$iT_{11}$ combined</th>
<th>$T_{20}$ combined</th>
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<tr>
<td>detectors – 5, 4</td>
<td>34.8</td>
<td>52.5</td>
<td>135</td>
<td>0.10 ± 0.02</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>detectors – 6, 3</td>
<td>36.8</td>
<td>50.4</td>
<td>45</td>
<td>0.11 ± 0.06</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>detectors – 1, 6</td>
<td>34.8</td>
<td>36.8</td>
<td>135</td>
<td>0.55 ± 0.15</td>
<td>0.13 ± 0.30</td>
<td>0.47 ± 0.10</td>
<td>0.02 ± 0.20</td>
</tr>
<tr>
<td>detectors – 5, 2</td>
<td>34.8</td>
<td>36.8</td>
<td>135</td>
<td>0.39 ± 0.13</td>
<td>-0.09 ± 0.27</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

pp -quasi 72.3° and 76.5°

Results combined
Conclusion

- Ay, Ayy and Axx analyzing powers data (2017) of dp elastic scattering at 400 MeV along with theoretical calculations including single and double scattering term were discussed.

- dp elastic data at 1400 MeV are compared with relativistic multi-scattering calculations including single, double scattering term and delta isobar excitation.

- Dp breakup reaction were investigated at internal target station of Nuclotron in energy range from 300 – 500 MeV using unpolarized and polarized deuteron beam in various detector configurations.

- Presented energy and S spectra of unpolarized dp breakup for particular configuration.

- Analyzing powers of dp → ppn at 400 MeV were also presented.
Thank you for the attention!