XXIV International Baldin Seminar
on High Energy Physics Problems
Relativistic Nuclear Physics & Quantum Chromodynamics
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DP BREAKUP REACTION INVESTIGATION UNDER SPECIFIC KINEMATIC CONFIGURATIONS AT ITS OF NUCLOTRON

M. Janek on behalf of DSS collaboration
(Bulgaria-Japan-JINR-Romania-Russia-Slovakia)

XXIV International Baldin Seminar on High Energy Physics Problems "Relativistic Nuclear Physics and Quantum Chromodynamics"

Collaboration

- Joint Institute for Nuclear Research (LHE & LNP & LNR)
- Center for Nuclear Study, University of Tokio, Tokio, Japan
- P.J. Safarik University, Kosice, Slovakia
- Advanced Research Institute for Electrical Engineering, Bucharest, Romania
- Institute of Physics Slovak Academy of Sciences, Bratislava, Slovakia
- Saitama University, Saitama, Japan
- Institute for Physical and Chemical Research (RIKEN), Saitama, Japan
- Department of Physics, University of Tokyo
- Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland
- Physics Department, University of Zilina, Slovakia

Short range correlations (SRCs)

Summary of the theoretical analysis of the experimental findings
practically all of which were predicted well before the data were obtained

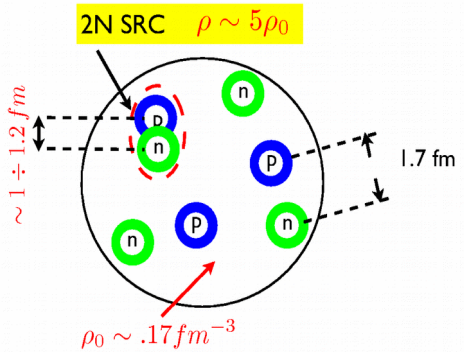
More than ~90% all nucleons with momenta k≥300 MeV/c belong to two nucleon SRC correlations BNL + Jlab +SLAC

Probability for a given proton with momenta 600> k > 300 MeV/c to belong to **pn** correlation is ~ 18 times larger than for **pp** correlation BNL + Jlab

Probability for a nucleon to have momentum > 300 MeV/c in medium nuclei is ~25% BNL + Jlab 04 +SLAC 93

Probability of non-nucleonic components within SRC is small - < 20% - 2N SRC mostly build of two nucleons not 6q, ΔΔ,... BNL + Jlab +SLAC

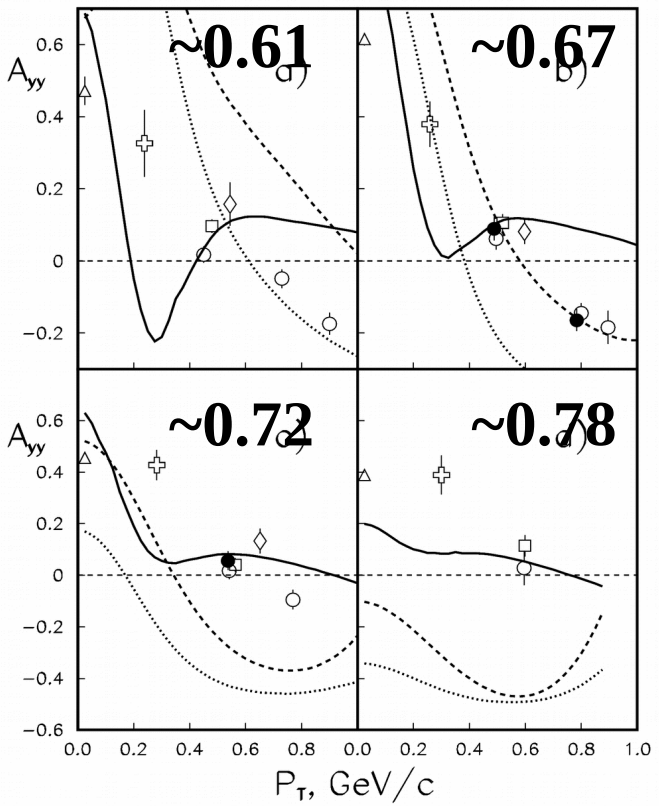
Three nucleon SRC are present in nuclei with a significant probability Jlab 05

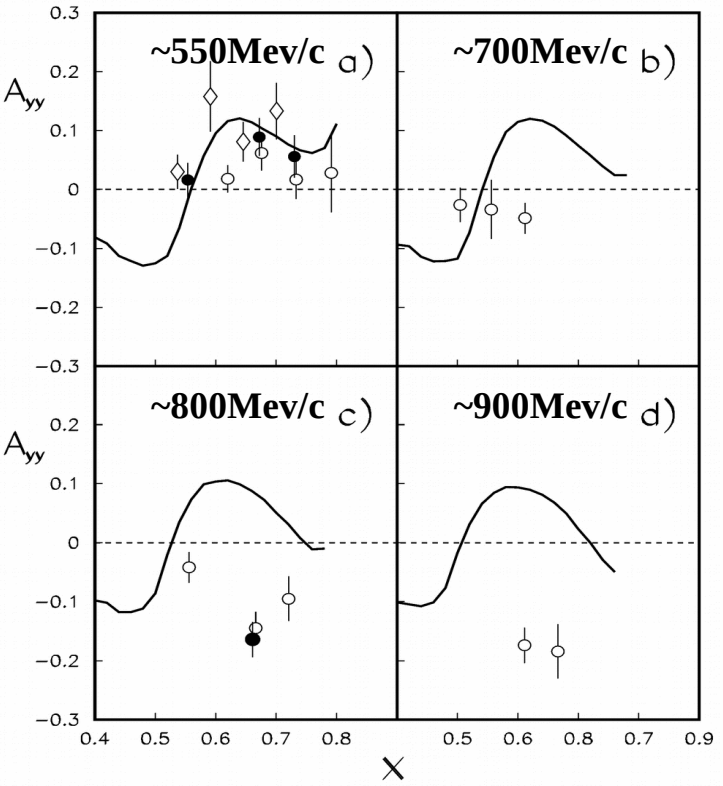


Poor data base on the spin parts of the 2N and 3N short-range correlations. This motivates the necessity to study light nuclei structure at short distances.

Experiments at Nuclotron allow to reach $p_T \sim$ 1 GeV

Relativistic effects in 2N SRCs (deuteron)





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 .

V.P.Ladygin et al., Phys.Lett. B629 (2005) 60

Fundamental degrees of freedom

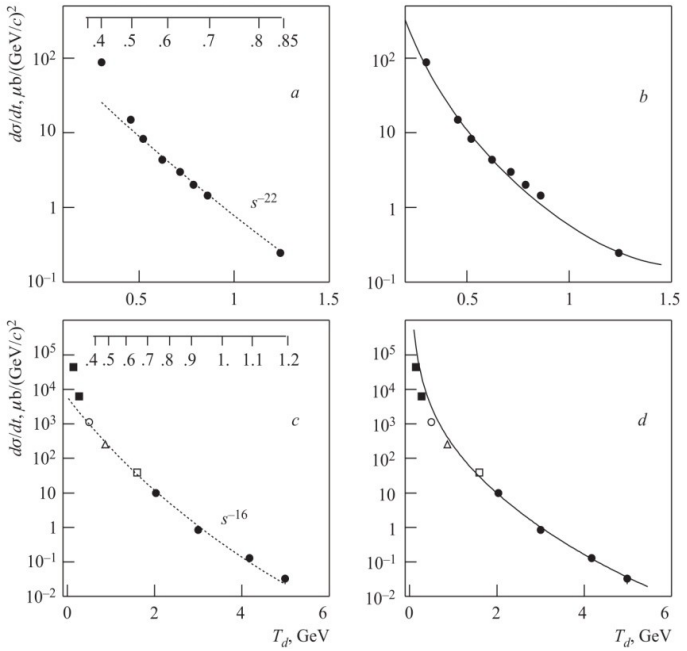
At high energy s and large transverse momenta p_t the constituent counting roles (CCR) predict the following behavior of the differential cross section for the binary reactions:

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

- **WFDF**
- **ΔΔ, NN*, N*N*, 6q etc.components.**

V.Punjabi et al., Phys.Lett.B350 (1995) 178
L.S.Azhgirey et al., Phys.Lett.B391 (1997) 22
L.S.Azhgirey et al., Phys.Lett.B387 (1996) 37

(Matveev, Muradyan, Tavkhelidze, Brodsky, Farrar et al.)



Yu. N. Uzikov

JETP Lett, 81 (2005) 303-306

For the reaction **dd → ^{3}Hen**

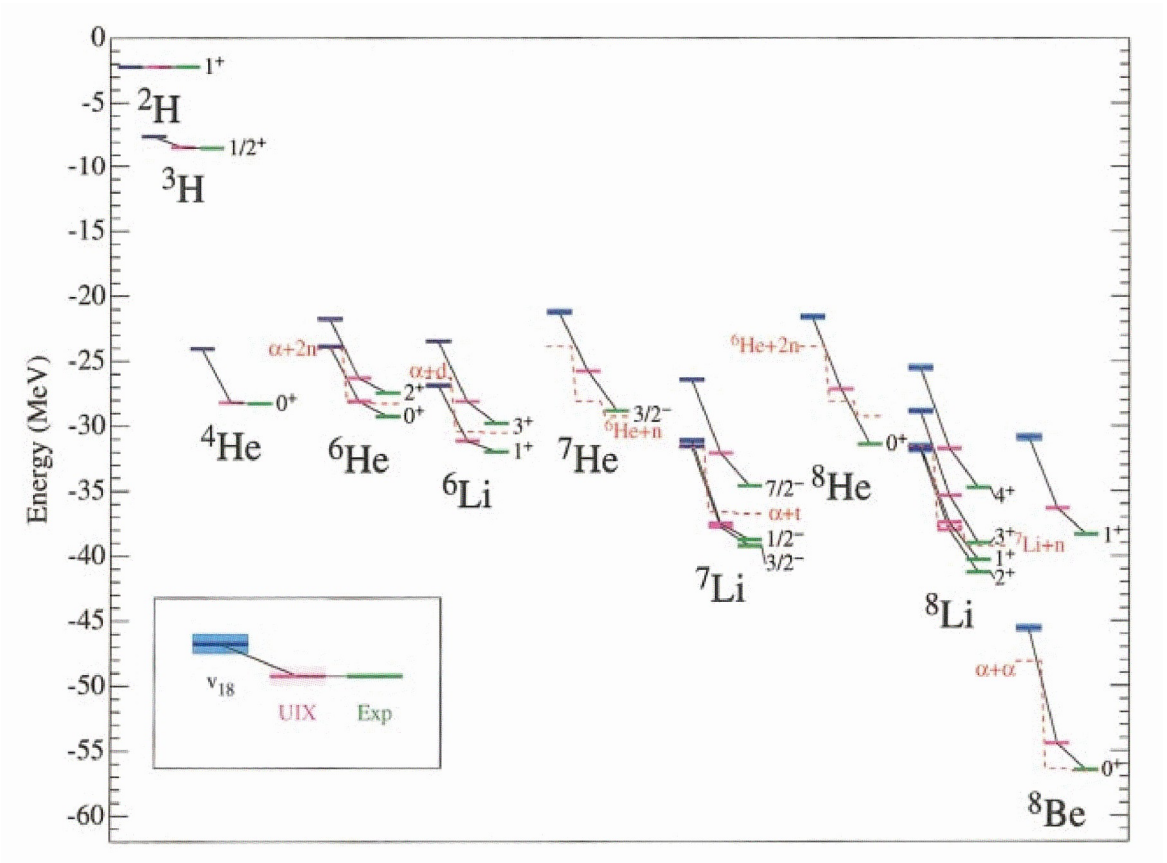
$$N_A + N_B + N_C + N_D - 2 = 22$$

For the reaction **dp → dp**

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

The regime corresponding to CCR can occur already at T_d ~ 500 MeV

Importance of the spin part of 3NF for the light nuclei binding energies

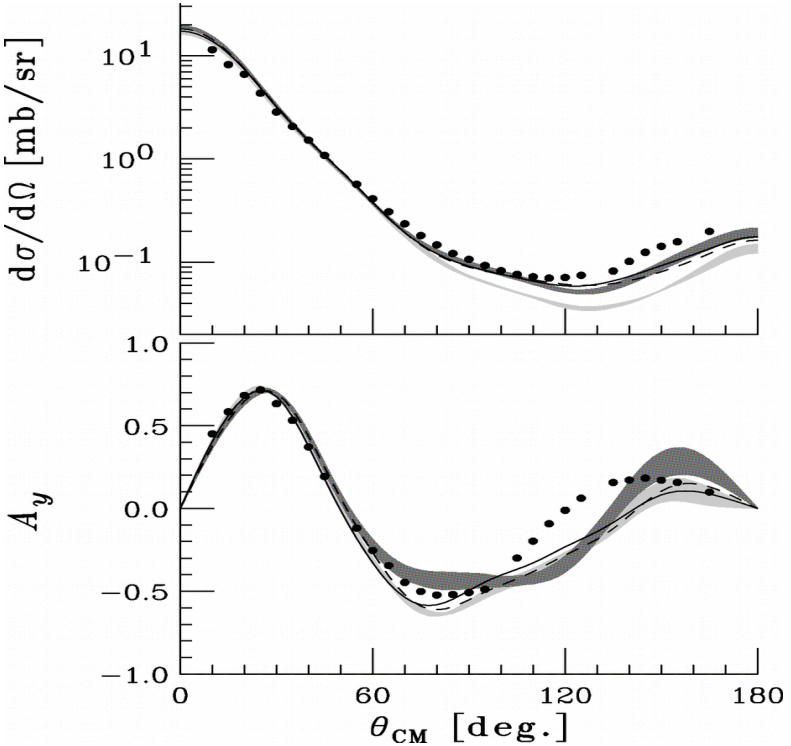


- **Modern NN potentials**
- **Incorporation of 3NFs**
- **theorem of W.N.Polyzou and W.Gloeckle, Few Body Syst. 9 (1990) 97, off-shell behaviour of 2NF can imitate 3NF effect.**

Spin parts of the 2N and 3N correlations are important to describe the light nuclei structure.

(S.C.Pieper et al., Phys.Rev.C64 (2001) 014001)

Cross section and proton analyzing power Ay in pd- elastic scattering at 250 MeV



NNLO allows to describe the data up to 65 MeV/n

Problems in description at backward angles. Relativistic effects become large, short range 3NFs manifestation.

dp- elastic scattering

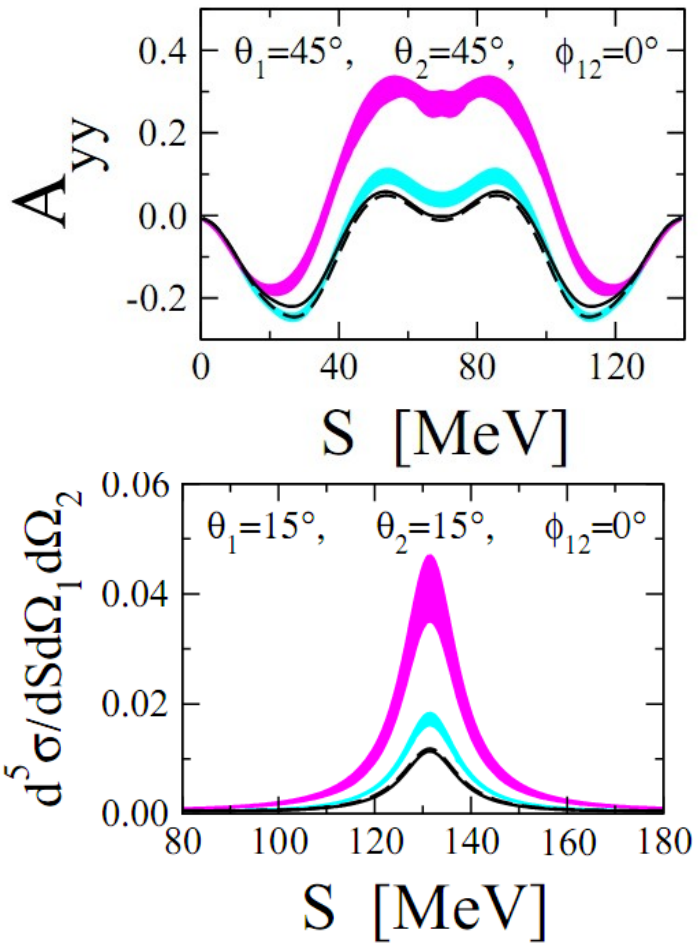
- Inclusion of modern **3NFs** allows to describe cross section and deuteron vector analyzing power of dp- elastic scattering up to **135** MeV/nucleon, while the tensor observables are not described.

- 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.

Dp breakup reaction



Tensor analyzing power Ayy (top) and differential cross section in selected breakup configurations at 200 MeV (bottom).

- The light shaded band (blue) contains the theoretical predictions based on CD-Bonn, AV18, Nijm I, II and Nijm 93.
- The darker band (magenta) represents predictions when these NN forces are combined with the TM 3NF.
- The solid line is for AV18+Urbana IX and the dashed line for CD Bonn+TM

The inclusion of 3NF have great impact on the values of analyzing power and cross section.

Θ_1 – polar angle of the 1-st proton.

Θ_2 – polar angle of the 2-nd proton.

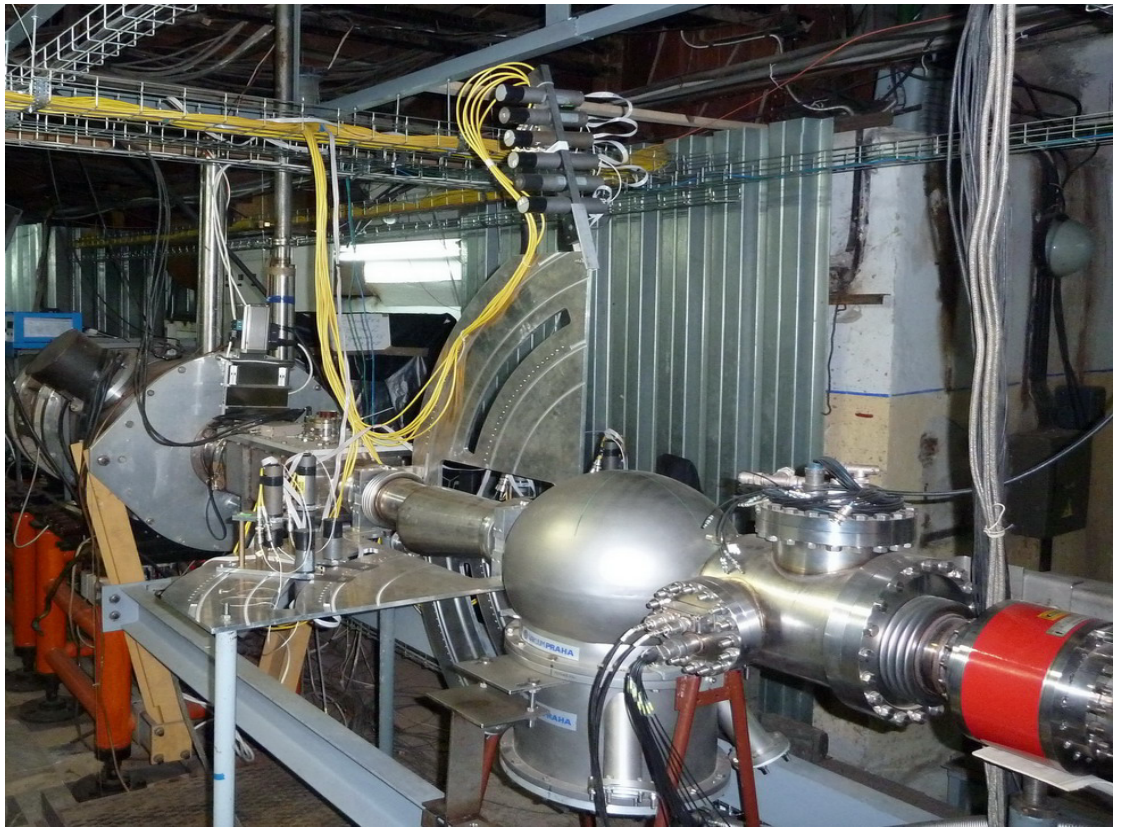
S – arc length along the kinematical curve.

Φ_{12} – azimuth angle with respect to the horizontal plane.

Experiments at Internal Target Station at Nuclotron (DSS-project)

The purpose of the **DSS** experimental program is to obtain the information about 2NF and 3NF (*including their spin – dependent parts*) from two processes:

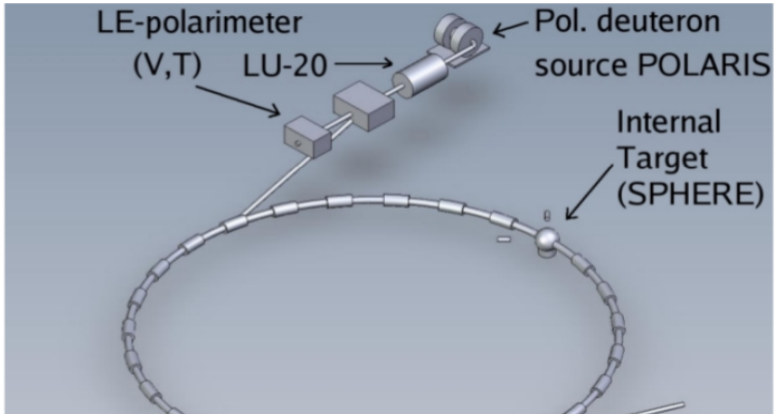
1. dp-elastic scattering at the energies between 300 - 2000 MeV;
2. dp-breakup with registration of two protons at deuteron energies of 300 - 500 MeV.

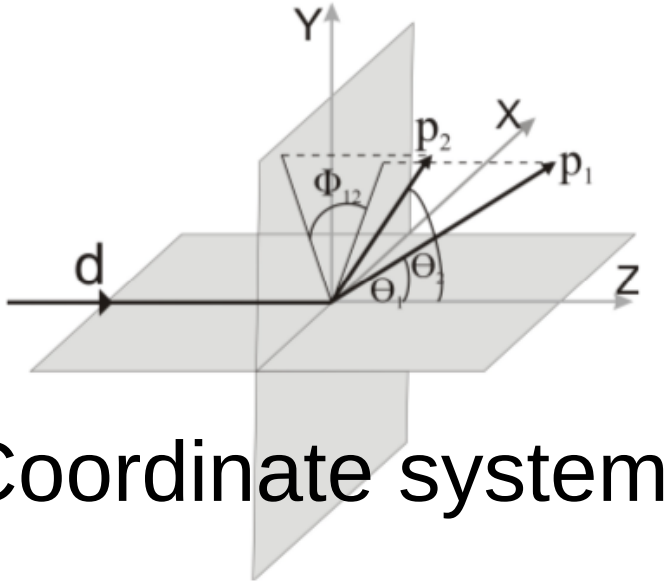


Internal Target Station is very well suited for the measurements of the deuteron- induced reactions observables at large scattering angles.

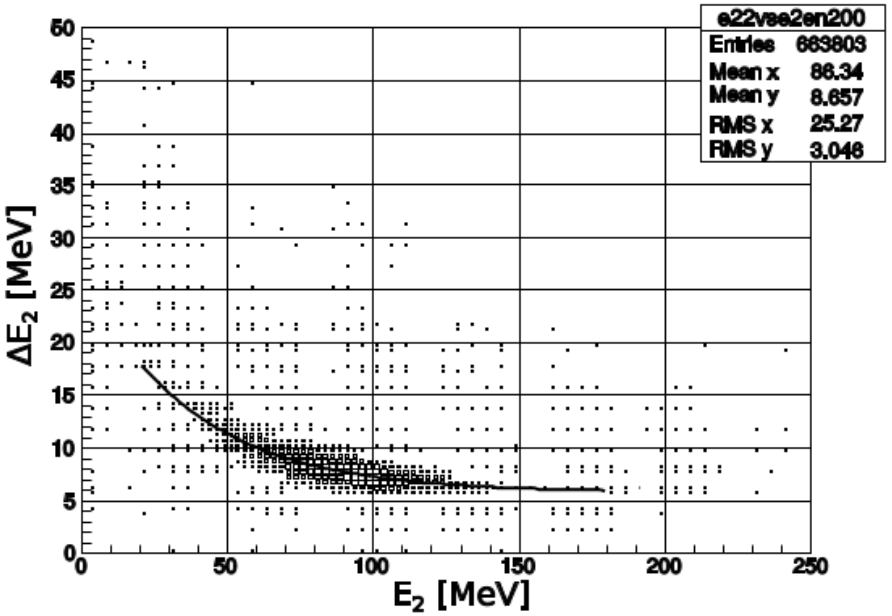
Dp breakup reaction

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



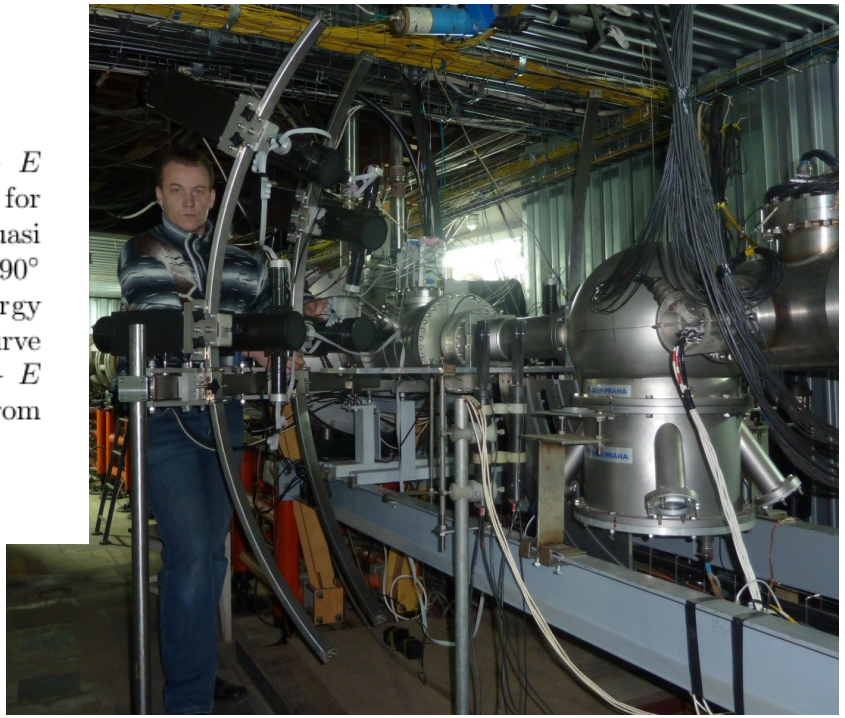


Coordinate system

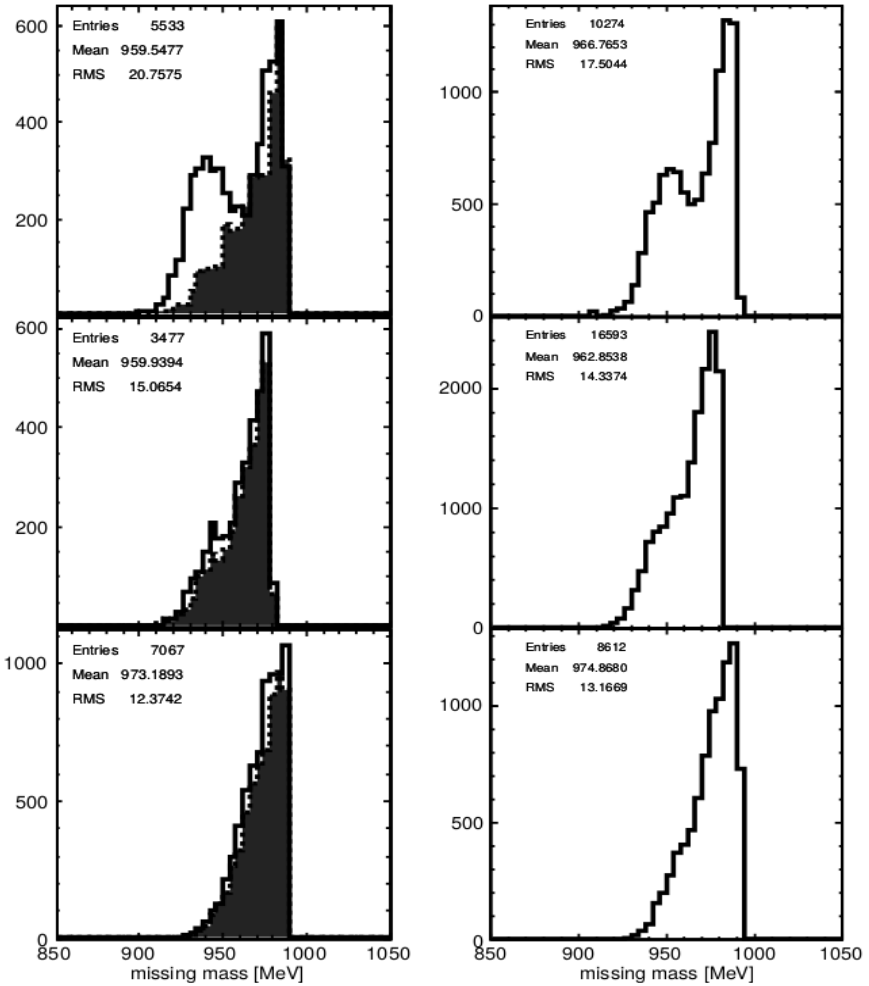


Space angle of the detector 4.6°.

$\Delta E - E$ correlation obtained for one of arm in the *pp* quasi elastic kinematics at 90° cm and deuteron energy of 200 MeV/n. Curve represents the $\Delta E - E$ correlation obtained from GEANT4 simulation



Missing mass spectra on CH_2 and C at 400 MeV

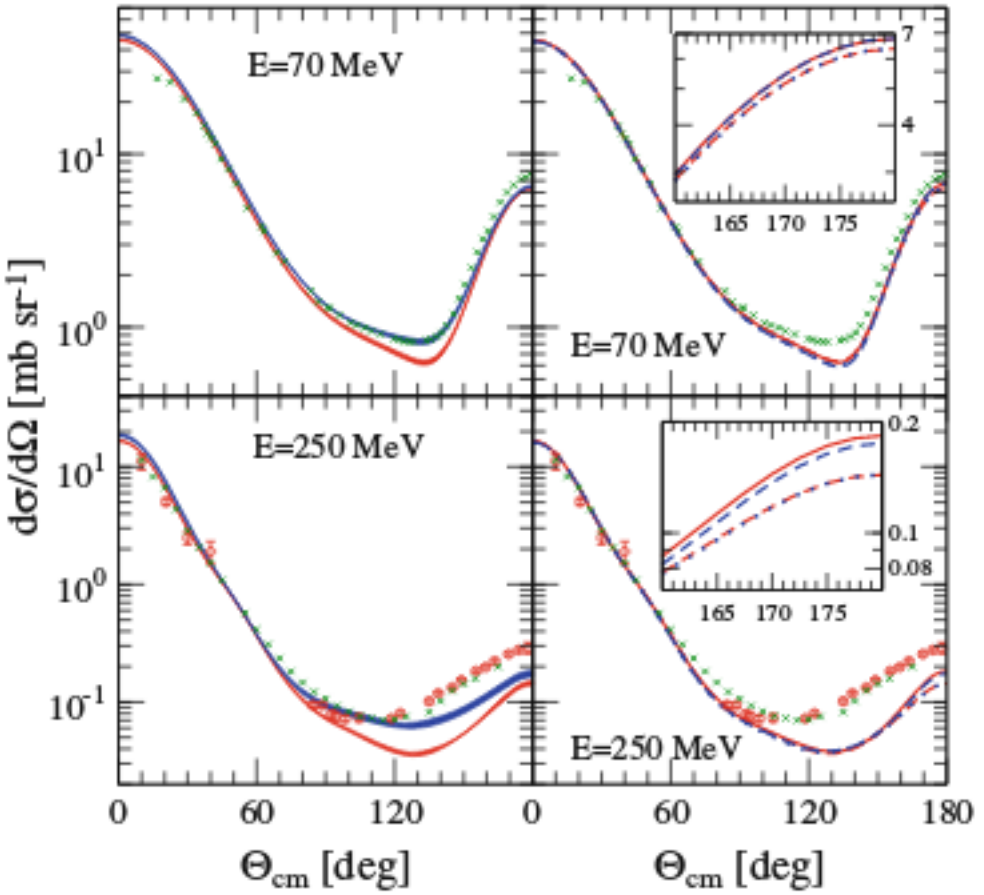


Experimental and simulated missing mass spectra are shown in first and second column, respectively.

Solid and dashed (shaded) spectra represent results obtained on **Polyethylene** and **Carbon** targets for detector arms angles:

27°-43° (first row),
31°-43° (second row)
32°-38° (third row)

Nd breakup reaction

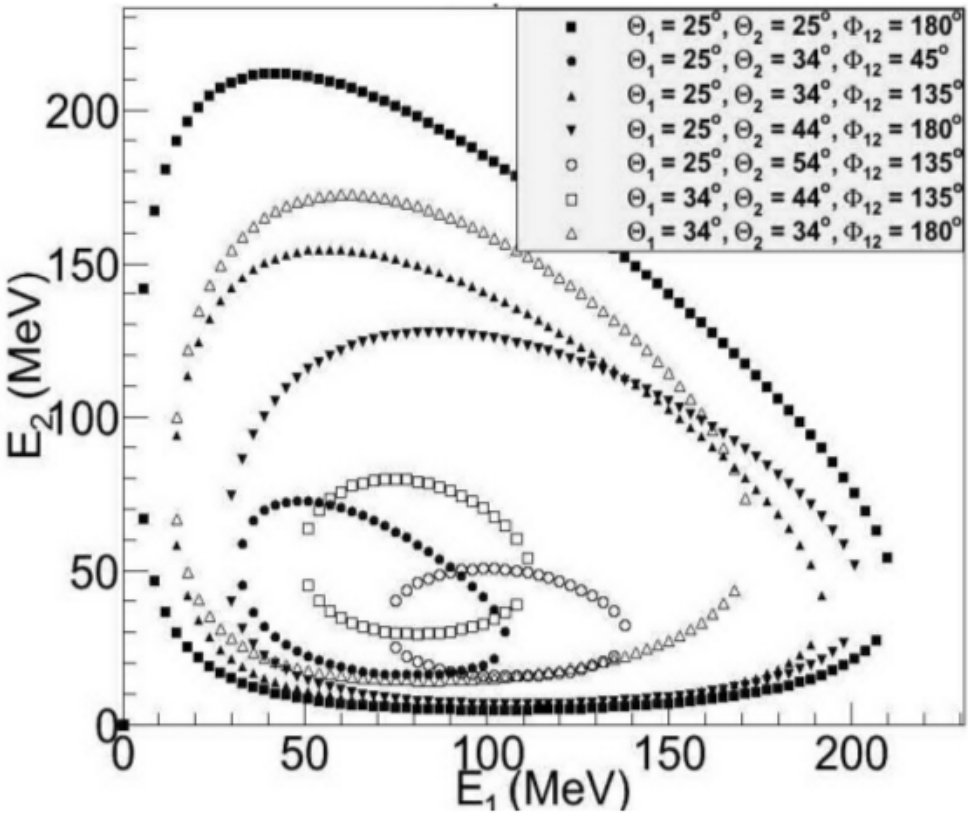


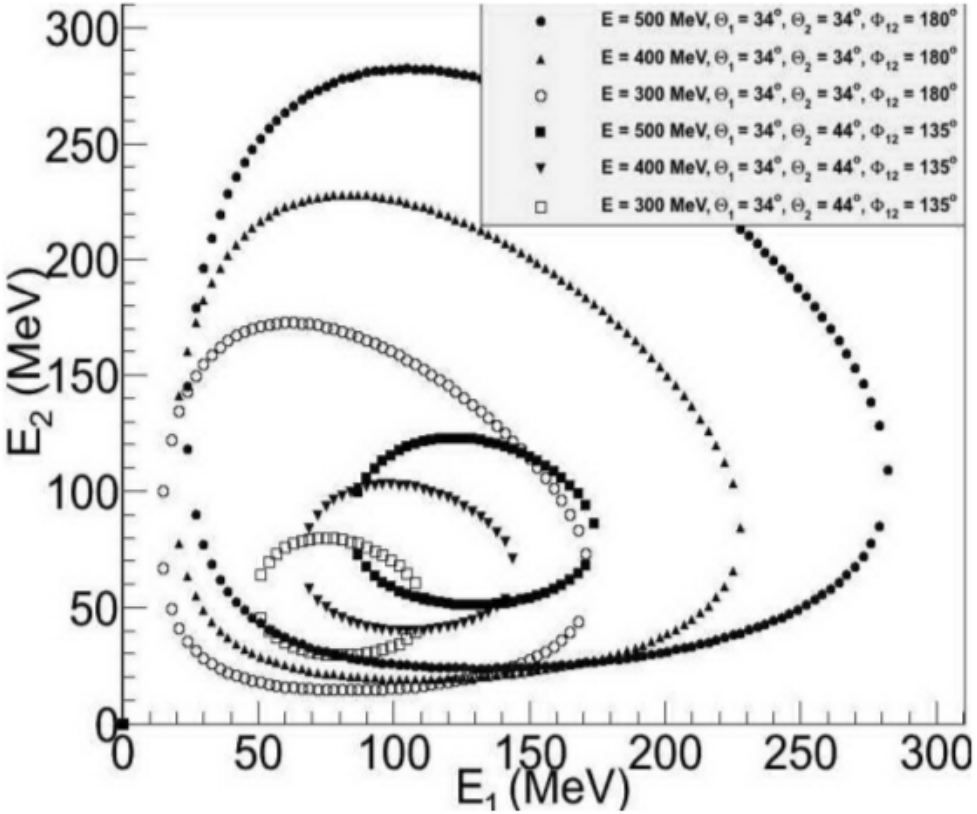
H. Witala,
Few Body Syst.
(2011) 49, 61.

Fig. 1 (Color online) The Nd elastic scattering cross sections at 70 and 250 MeV lab. energy of the incoming nucleon. In the *left column* predictions based on AV18 [13], CD Bonn [14], NijmI and Nijm II [15] NN potentials alone and on their combinations with the TM99 3NF [16] are shown by the *light shaded* (*red*) and *dark shaded* (*blue*) band, respectively. In the *right column* the relativistic predictions based on the boosted CD Bonn ((*red*) *solid line*) and AV18 ((*blue*) *dashed line*) potentials are compared with the nonrelativistic CD Bonn ((*red*) *dashed line*) and AV18 ((*blue*) *dotted line*) predictions. The 70 MeV pd data (x-es) are from [17]. The 250 nd (x-es) and pd (*open circles*) data are from [18] and [19], respectively

Dp breakup reaction

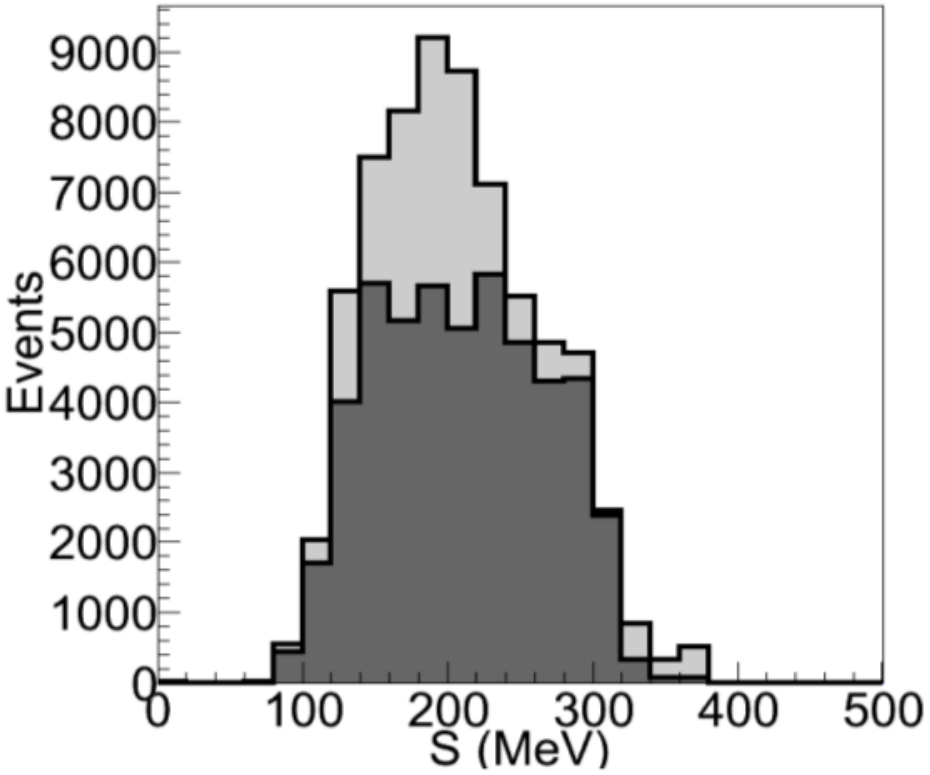
Space star configuration is interesting from the point of 3N correlations and non nucleonic degrees of freedom investigation.



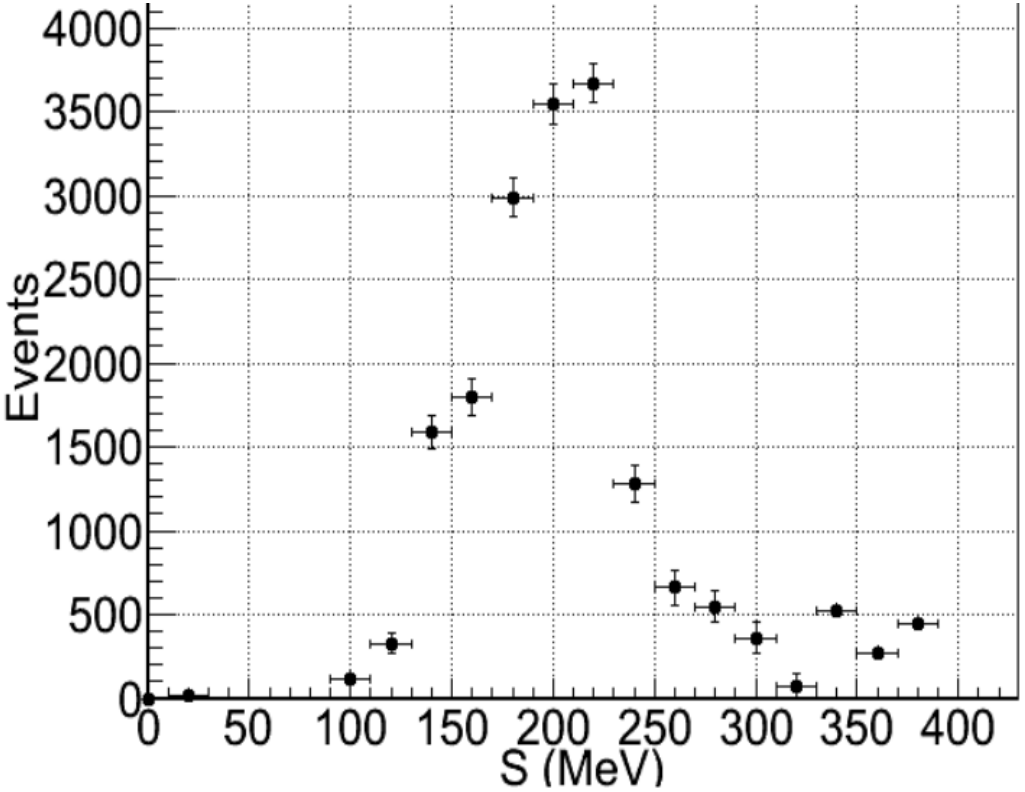


The energy correlation between two protons in coincidence for the three-body deuteron break-up reaction is shown as S-curves for several kinematical configurations

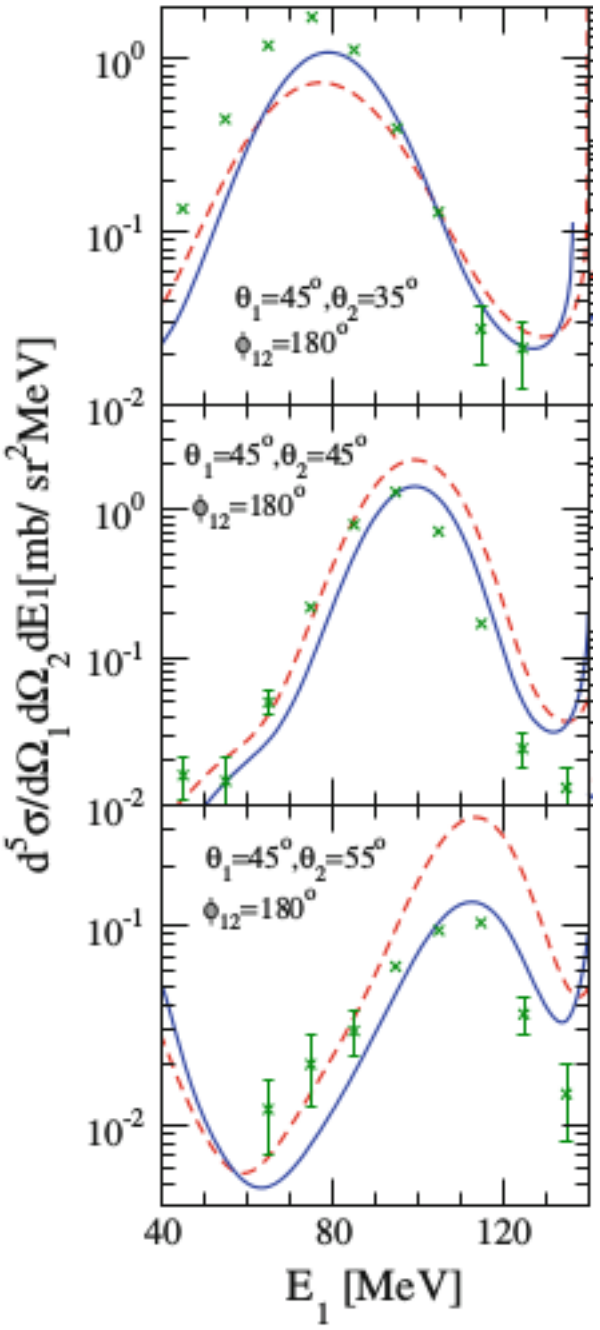
Dp breakup reaction investigation



Preliminary result:
S-curve (MeV) obtained on CH_2 (light grey) and Carbon (dark grey) at 300 MeV for $\Theta_1 = 25^o$, $\Theta_2 = 34^o$, $\Phi_{12} = 135^o$ detector configuration.



Preliminary result:
S-curve (MeV) is obtained after background subtraction at 300 MeV for $\Theta_1 = 25^o$, $\Theta_2 = 34^o$, $\Phi_{12} = 135^o$ detector configuration.



Nd breakup reaction

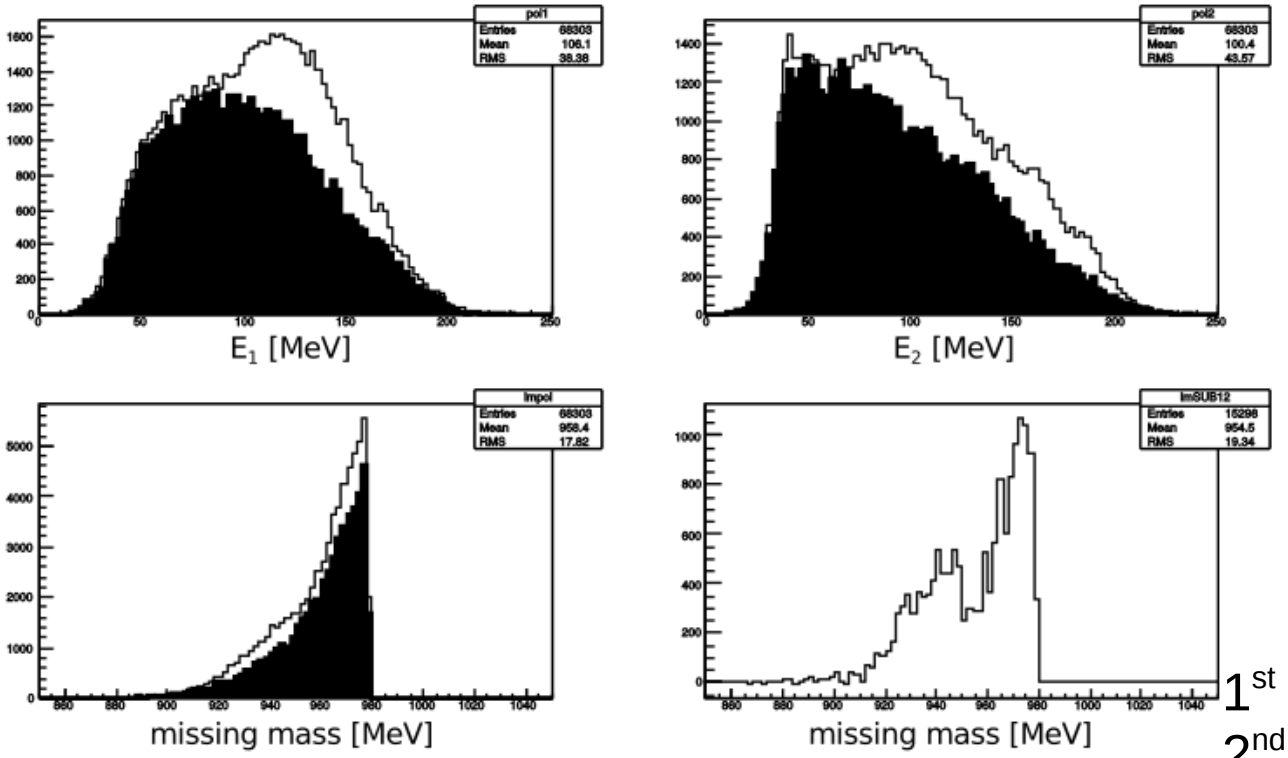
Relativistic effects in neutron-deuteron breakup at 200 MeV.

One arm is fixed, second arm scans angular range.

Important contribution comes from relativistic effects.

H. Witala, Few Body Syst. (2011) 49, 61.

Dp Breakup

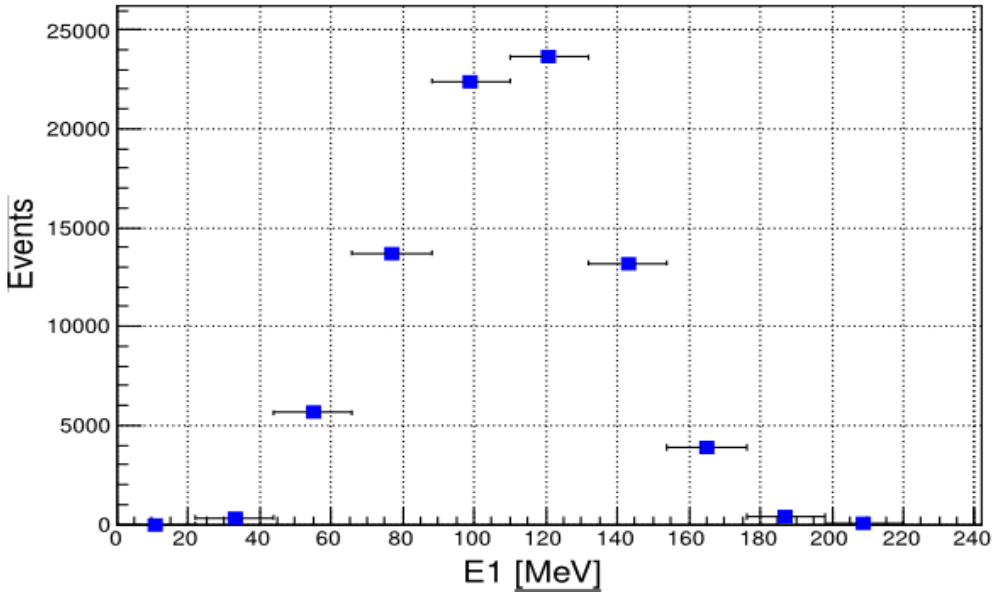


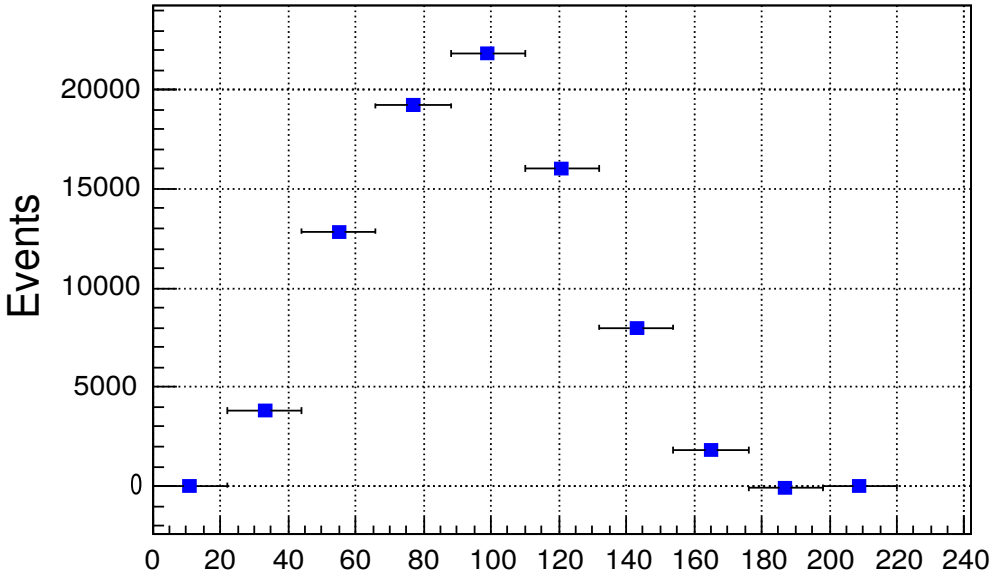
conf. No.	$\theta_1[^\circ]$	$\theta_2[^\circ]$
01	27	32
02	27	43
03	29	29
04	31	43
05	32	38
06	35	43
07	39	43
08	43	43
09	46	43

1st arm fixed at 43º,
2nd moving (27º,31º,35º,39º,43º)

E_1, E_2 energies and missing mass spectra obtained at angles of 31° and 43° and deuteron energy of 200 MeV/n. Polyethylene and Carbon spectra (third panel) are represented by non-shaded and shaded histograms. Last panel - missing mass spectra obtained by subtracting of Carbon content from Polyethylene one.

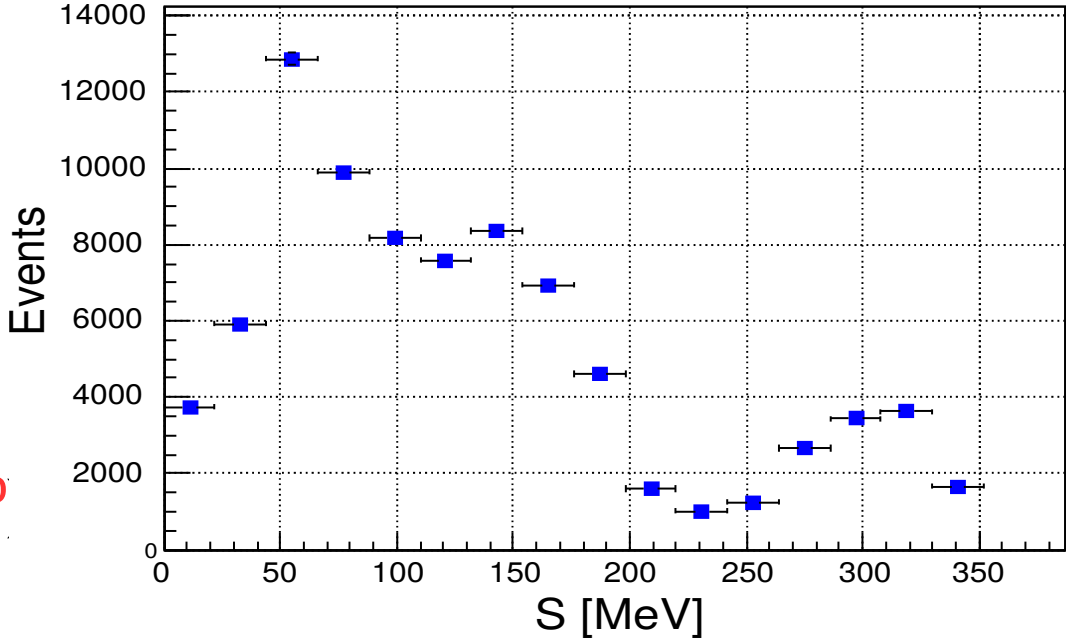
Dp breakup reaction at 400 MeV, θ_{p1}= 39º(±2.3º), θ_{p2}=43º(±2.3º)



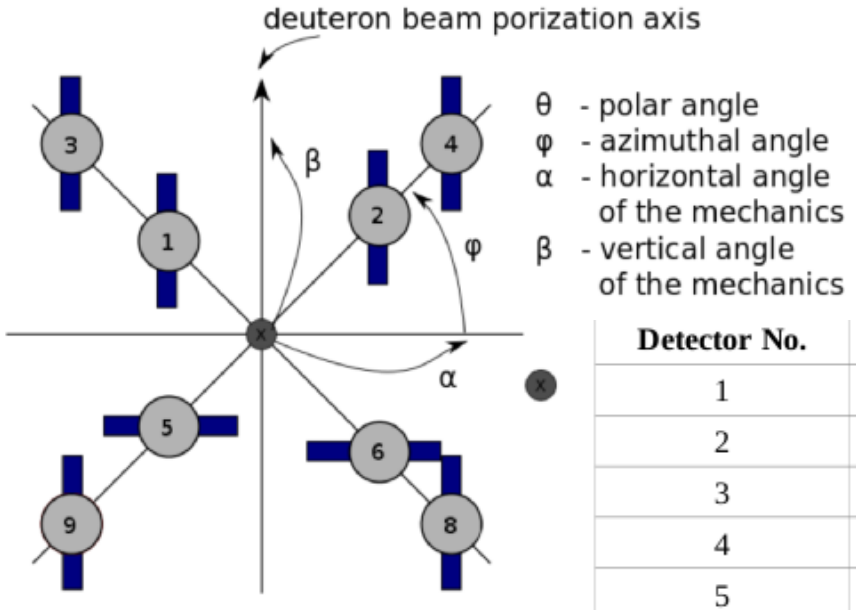


dp → ppn, two protons registered at angles:
θ_{p1}= 39º (±2.3º), θ_{p2}=43º (±2.3º)

1st arm is fixed at 43º,
2nd moving (27º,31º,35º,39º,43º



dp breakup reaction, polarized beam

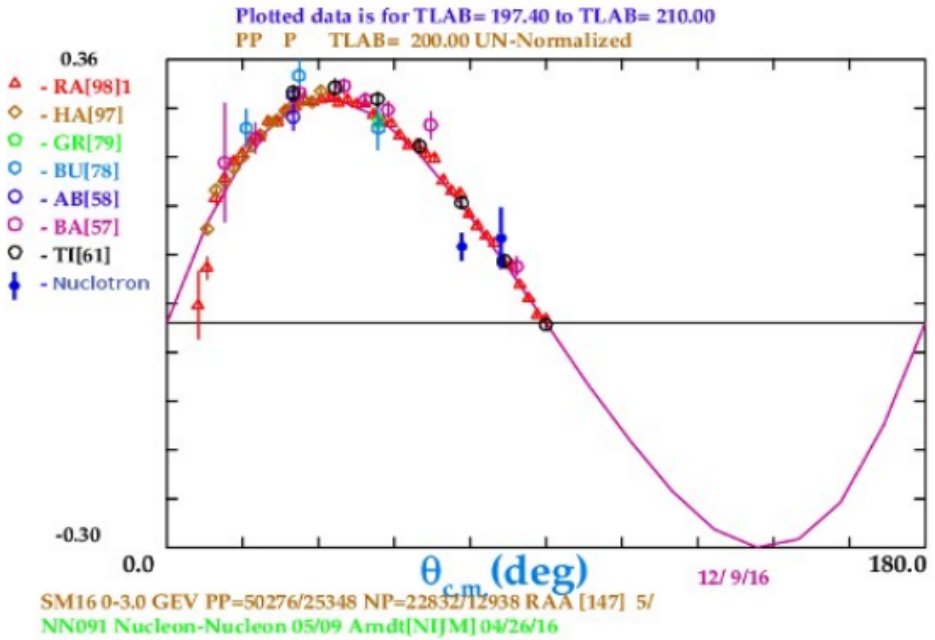


Placement of eight ΔE-E detectors at deuteron energy of 400 MeV.

Detector No.	θ [°]	φ [°]	α[°]	β[°]
1	34.8	45.0	24.1	24.1
2	36.8	315.0	-25.0	25.0
3	50.4	45.0	38.6	38.6
4	52.5	315.0	-39.6	39.6
5	34.8	135.0	24.1	-24.1
6	36.8	225.0	-25.0	-25.0
8	52.5	225.0	-39.6	-39.6
9	50.4	135.0	38.6	-38.6

Detector placement is determined by polar **θ** and azimuthal **φ** angles.
Azimuthal angle **φ** have anticlockwise direction.
Detector setup for the case of analyzing power investigation.

APs of dp breakup reaction at 400 MeV, pp-quasi data



Angular dependence of the vector analyzing $\mathbf{iT_{11}}$ 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.

- pp -quasi at 72.3° and 76.5°.
- combined results

Conf.	θ_1 [°]	θ_2 [°]	φ [°]	iT_{11}	T_{20}	iT_{11} combined	T_{20} combined
detectors – 5, 4	34.8	52.5	135	0.10 ± 0.02	0	-	-
detectors – 6, 3	36.8	50.4	45	0.11 ± 0.06	0	-	-
detectors – 1, 6	34.8	36.8	135	0.55 ± 0.15	0.13 ± 0.30	0.47 ± 0.10	0.02 ± 0.20
detectors – 5, 2	34.8	36.8	135	0.39 ± 0.13	-0.09 ± 0.27		

Conclusion

- Dp breakup reaction is investigated at Internal Target Station of Nuclotron in energy range (300 MeV – 500 MeV), where possible manifestation of 3NFs and relativistic effects can be investigated using polarized and unpolarized deuteron beams.

- Part of the exp. data were obtained under specific kinematic configurations in which relativistic effects can occur according theory (H. Witala).

- Preliminary data of energy spectra of protons at particular detector setup is presented.

- Analyzing powers of dp → ppn using polarized deuteron beam at 400 MeV were obtained for certain detector configurations.