24th European Conference on Few-Body Problems in Physics

Latest results concerning short range correlations obtained in the dp elastic and dp breakup processes at Nuclotron, JINR.

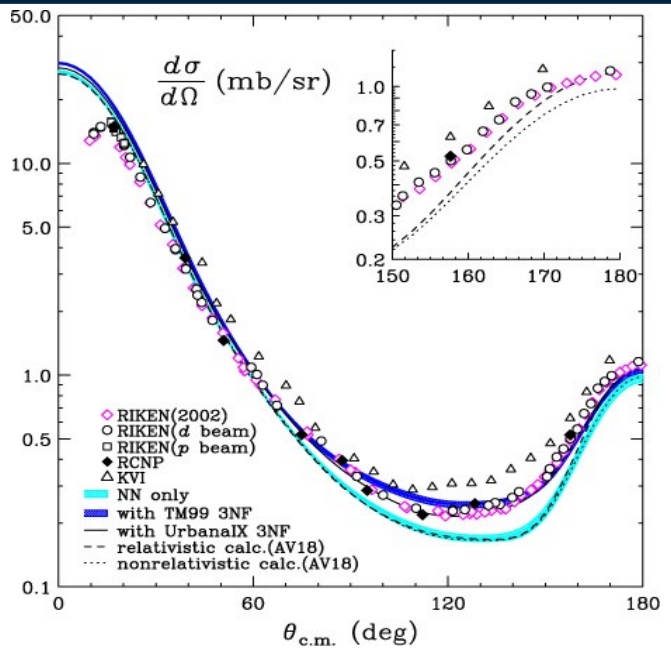
M. Janek on behalf of **DSS** collaboration
(Russia-Japan-JINR-Romania-Bulgaria-Slovakia)

24th European Conference on Few-Body Problems in Physics, Guildford, England

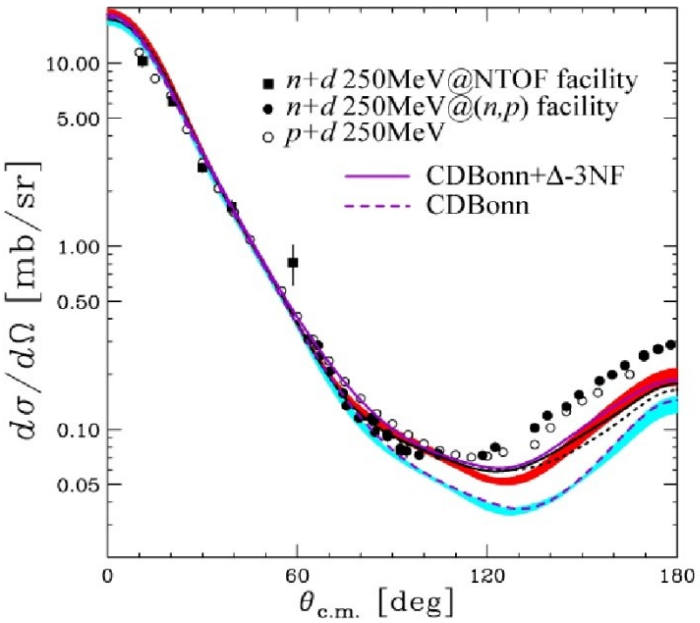
Collaboration

- **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**

Motivation to study of dp elastic scattering



K. Sekiguchi et al., Phys. Rev. Lett. 95, 162301 (2005)



K. Hatanaka et al., Phys. Rev. C 66, 044002 (2002)

The differential cross section in elastic Nd scattering at the energy of 135 (left) and 250 (right figure) MeV/u.

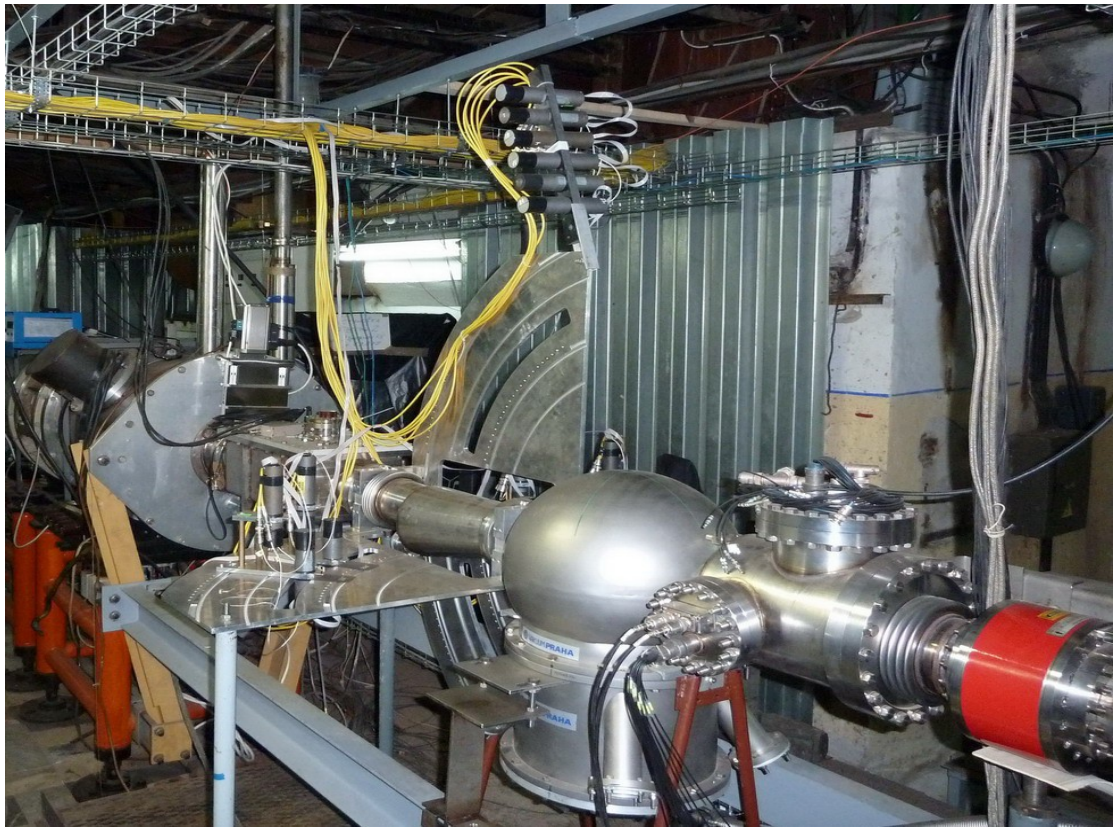
- Inclusion of modern **3NFs** allows to describe cross section and deuteron vector analyzing power of dp- elastic scattering up to **135** MeV/nucleon, while the tensor observables are not described.
- The data at higher energies (up to **300** MeV/nucleon) are not described even taking into account 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.

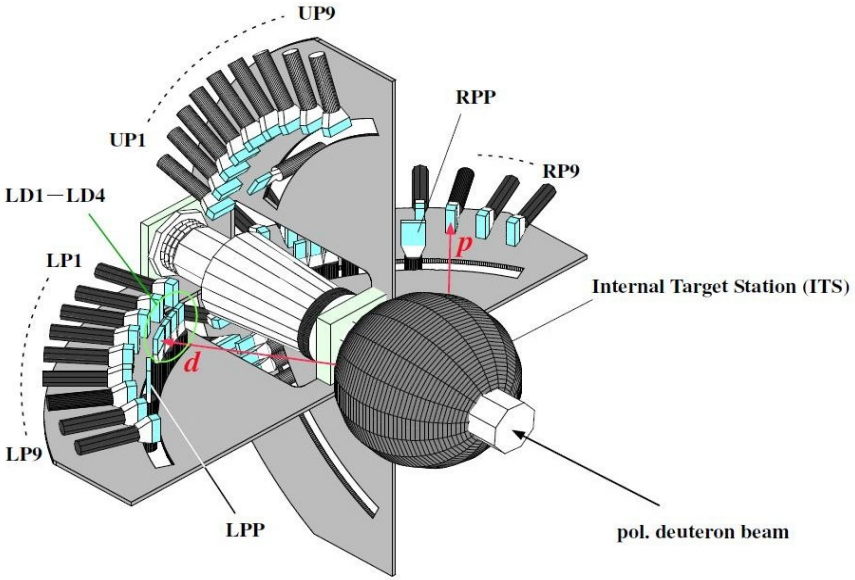
Experiments at Internal Target Station at Nuclotron (DSS-project)

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

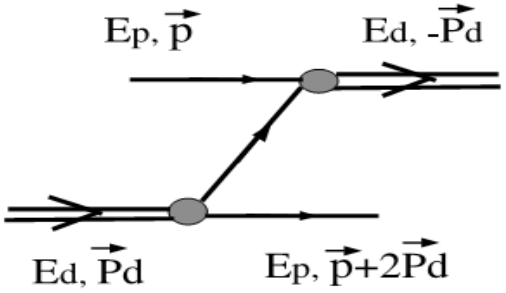
- dp-elastic scattering at the energies between 300 - 2000 MeV;
- dp-breakup with registration of two protons at deuteron energies of 300 - 500 MeV.



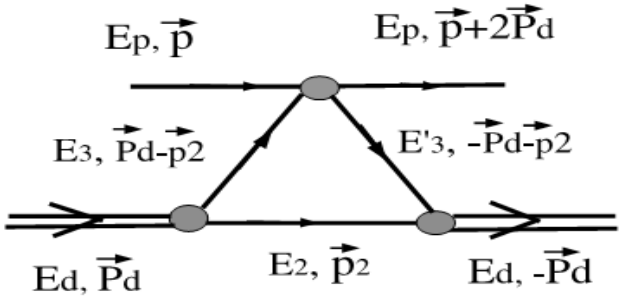
Internal Target Station is very well suited for the measurements of the deuteron- induced reactions observables at large scattering angles.



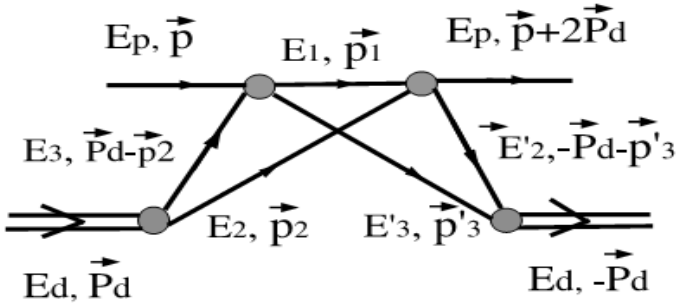
Relativistic multiple scattering model for dp- elastic scattering at moderate energies



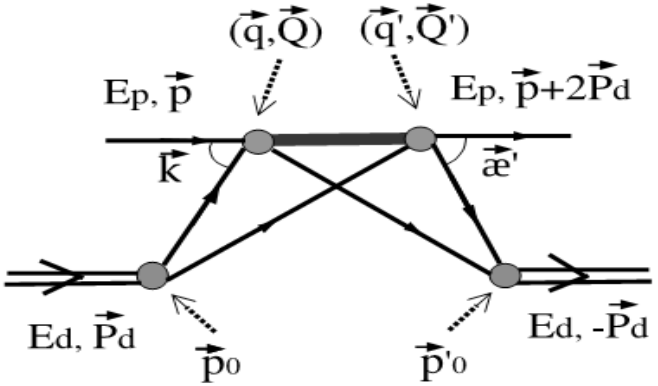
(a) **ONE**



(b) **SS**



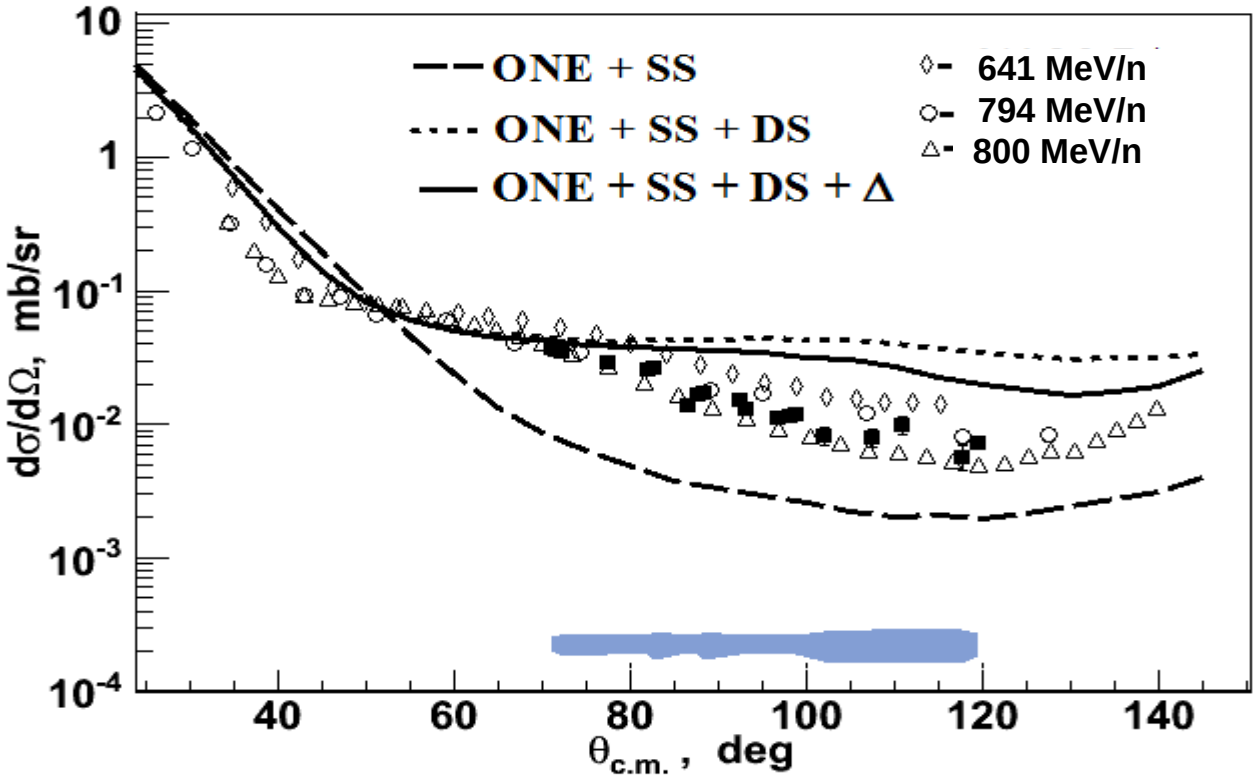
(c) **DS**



(d) **Δ**

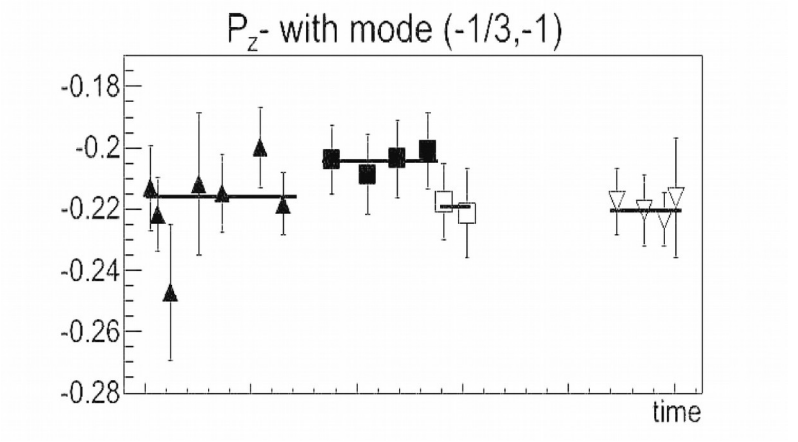
ONE+SS+DS - **N.B.Ladygina, Phys.Atom.Nucl.71 (2008) 2039**
N.B.Ladygina, Eur.Phys.J, A42 (2009) 91
ONE+SS+DS +Δ- **N.B.Ladygina, Eur.Phys.J, A52 (2016) 199**

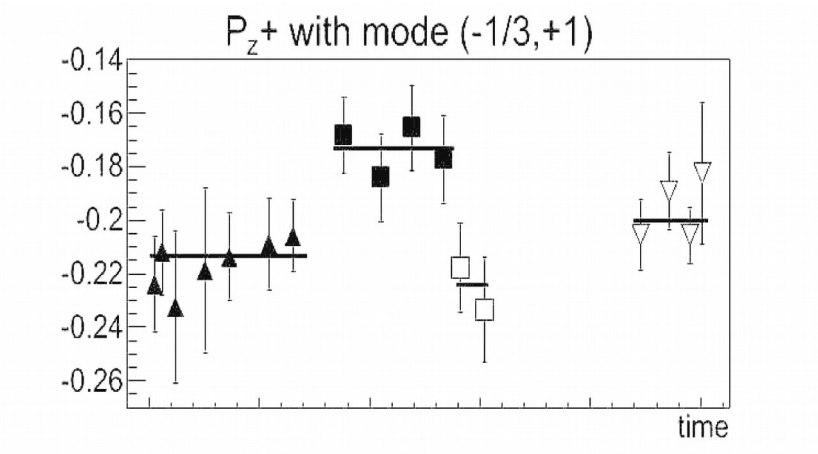
dp- elastic scattering cross section at 1400 MeV

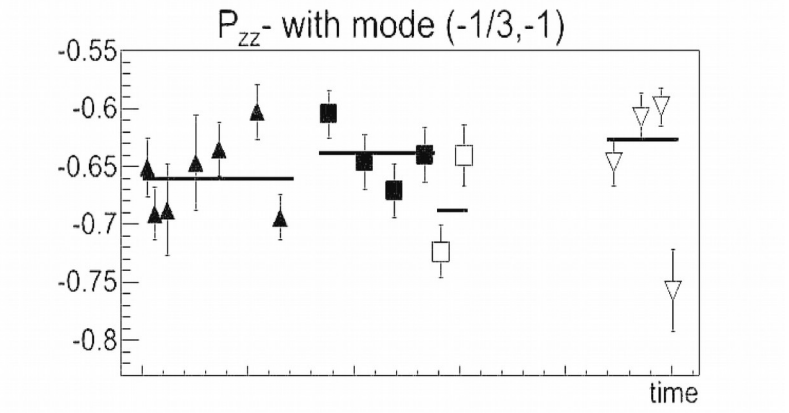


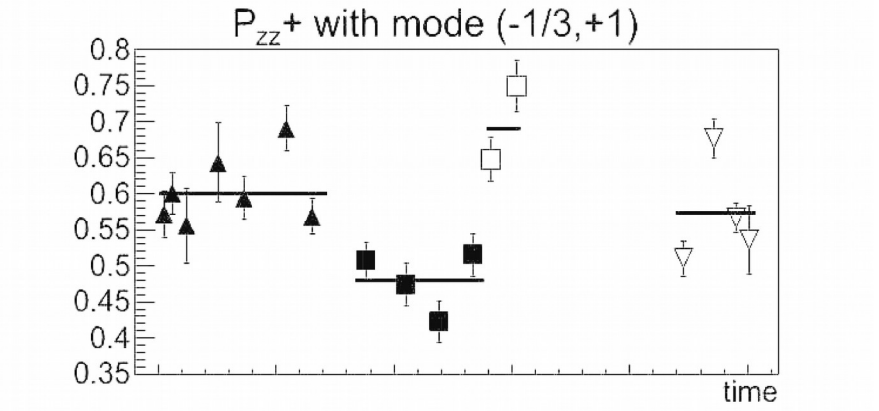
A.A.Terekhin et al., Phys.Atom.Nucl. 80(2017) 1061.
Relativistic multiple scattering model calculation:
N.B.Ladygina, Eur.Phys.J, A52 (2016) 199
Final cross section data at 1000, 1300 and 1800 MeV

Polarization measurements using dp- elastic scattering at 270 MeV



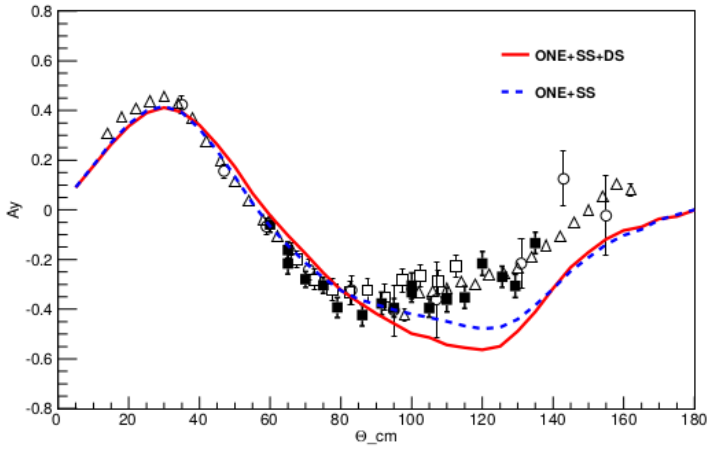


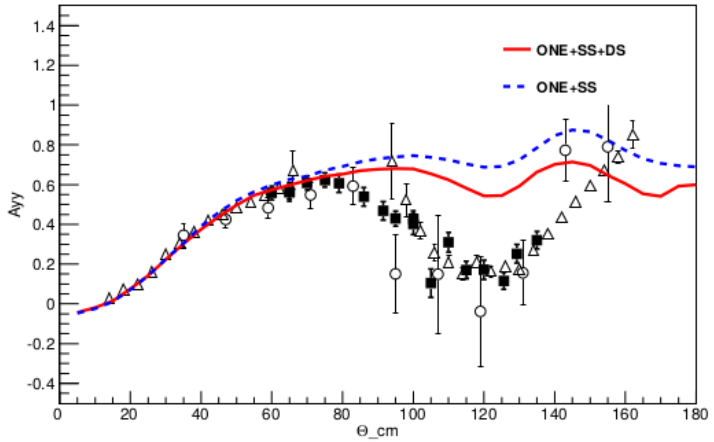


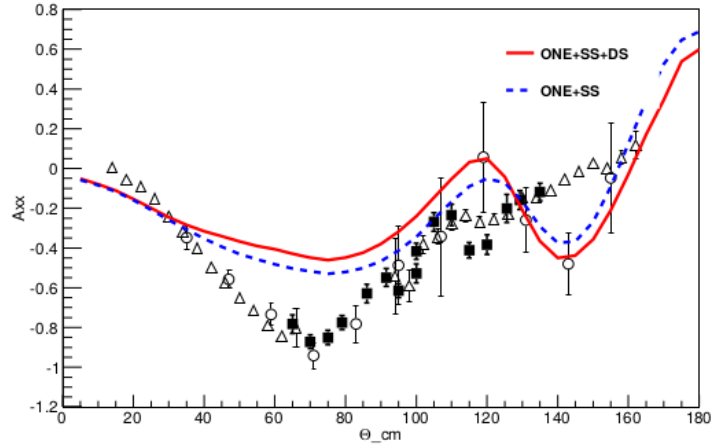


SPI was tuned for 6 spin modes (p_z,p_{zz}) = (-1/3,1), (-1/3,-1), (0,+1), (0,-2), (-2/3,0),(+1,0).

Dp elastic scattering, T_d = 400 MeV





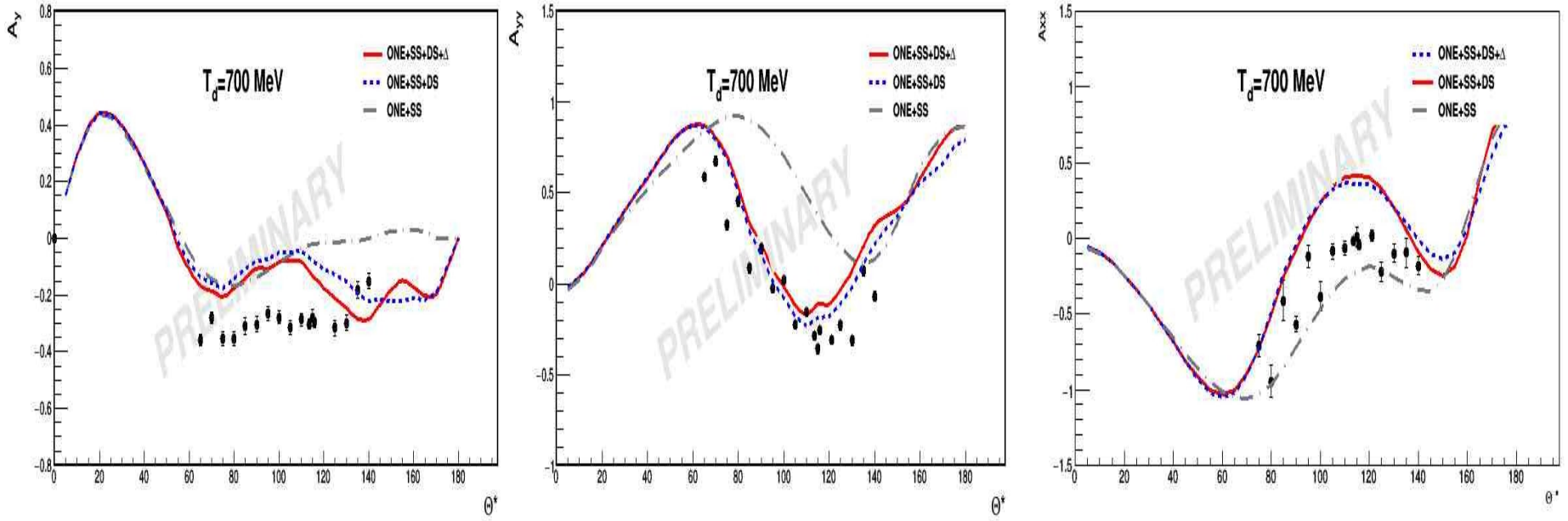


The angular dependence of the vector analyzing power A_y at the deuteron kinetic energy T_d of 400 MeV. The full squares are the preliminary results of the DSS experiment at ITS at Nuclotron. Open symbols are the world data.

Curves are the relativistic multiple scattering model calculations
N.B.Ladygina, Eur.Phys.J, A42 (2009) 91

Dp elastic scattering, T_d = 700 MeV

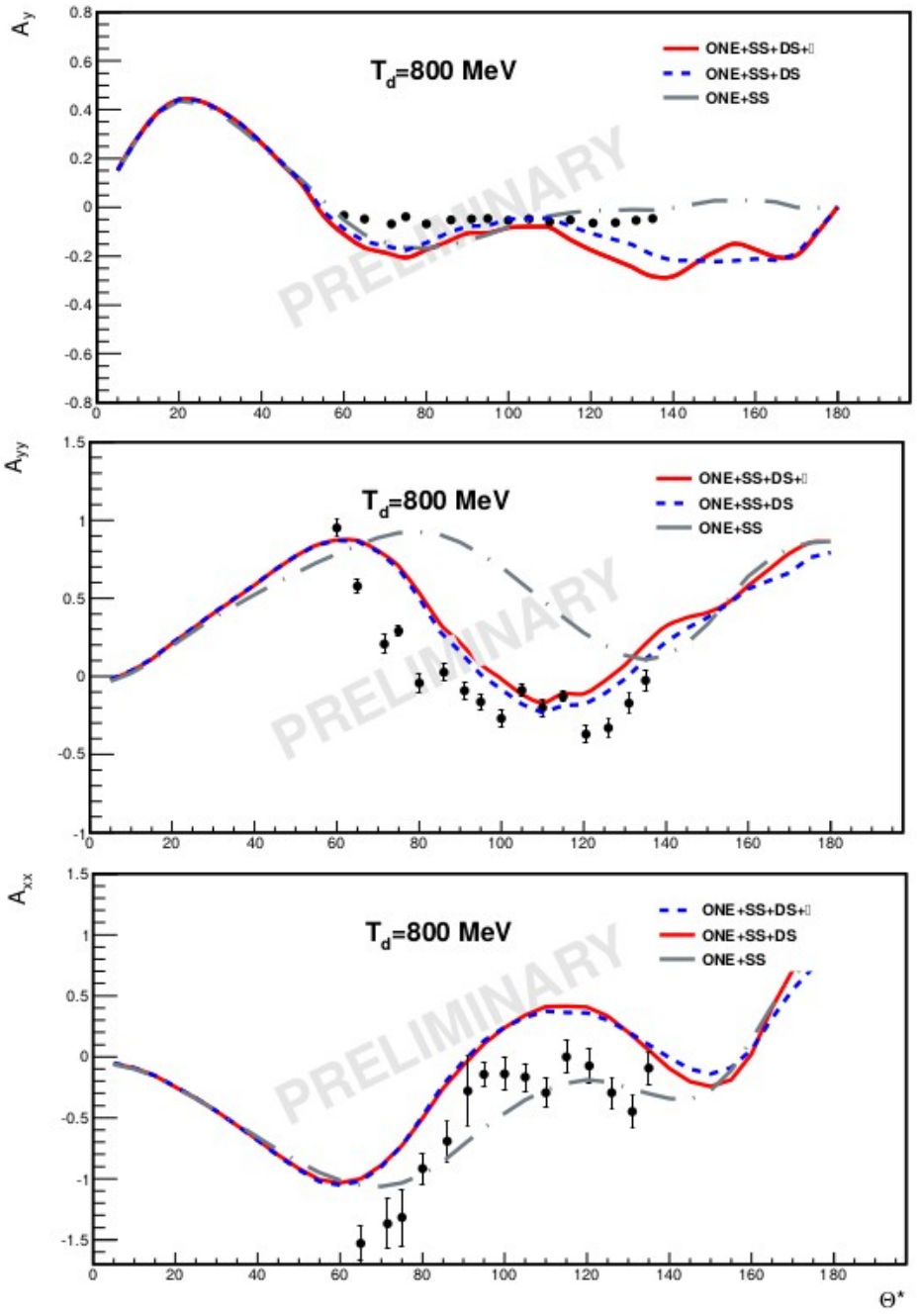
Ay **Ayy** **Axx**



Angular dependence of the vector and tensor analyzing powers in dp-elastic scattering at 700 MeV

Curves are the relativistic multiple scattering model calculations
N.B.Ladygina, Eur.Phys.J, A52 (2016) 199

Dp elastic scattering, T_d = 800 MeV

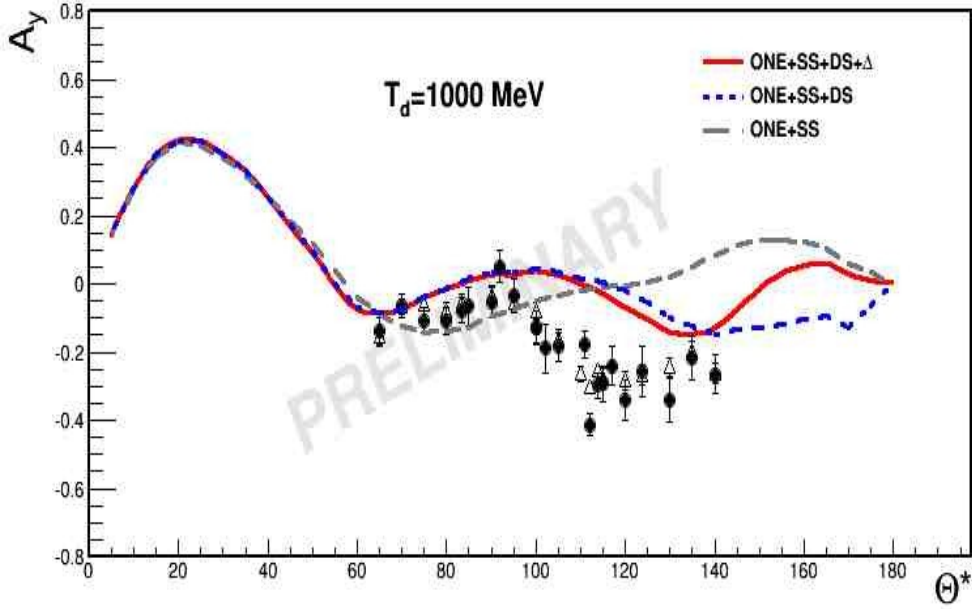


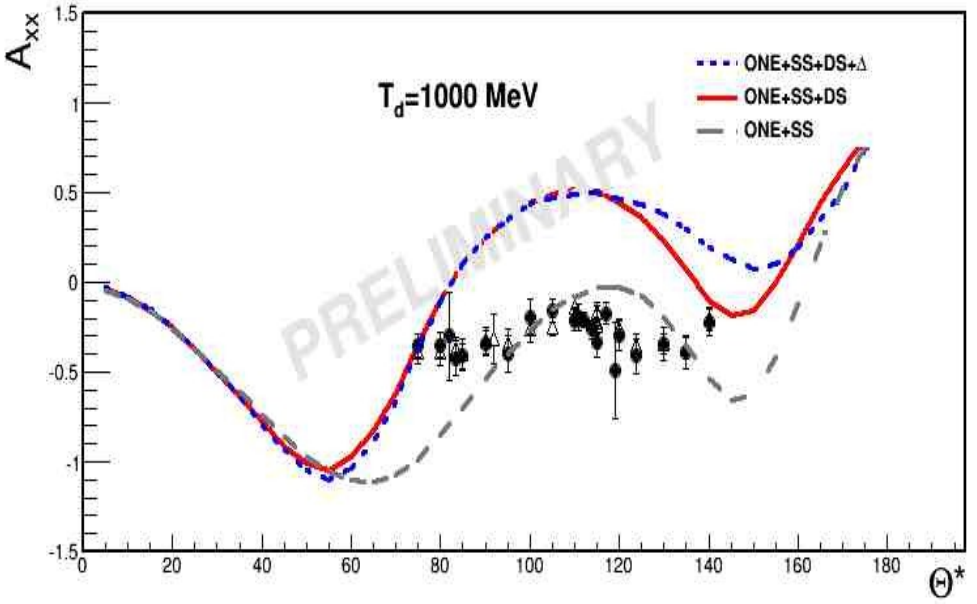
The angular dependence of the vector analyzing power A_y at the deuteron kinetic energy T_d of 800 MeV. The full symbols are the preliminary results of the DSS experiment at ITS at Nuclotron.

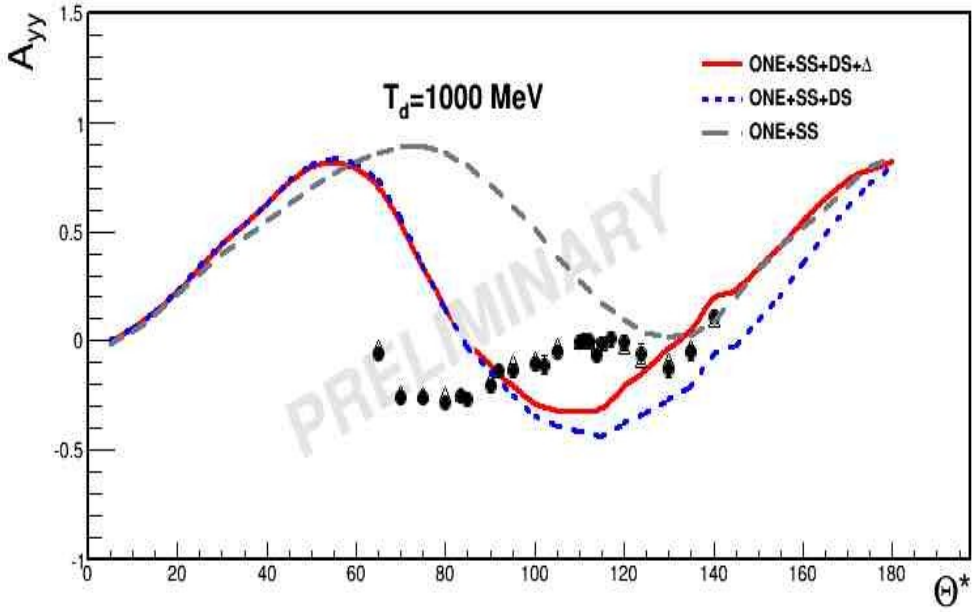
Curves are the relativistic multiple scattering model calculations
N.B.Ladygina, Eur.Phys.J, A52 (2016) 199

Dp elastic reaction, T_d = 1000 MeV

Curves are the relativistic multiple scattering model calculations N.B.Ladygina, Eur.Phys.J, A52 (2016) 199



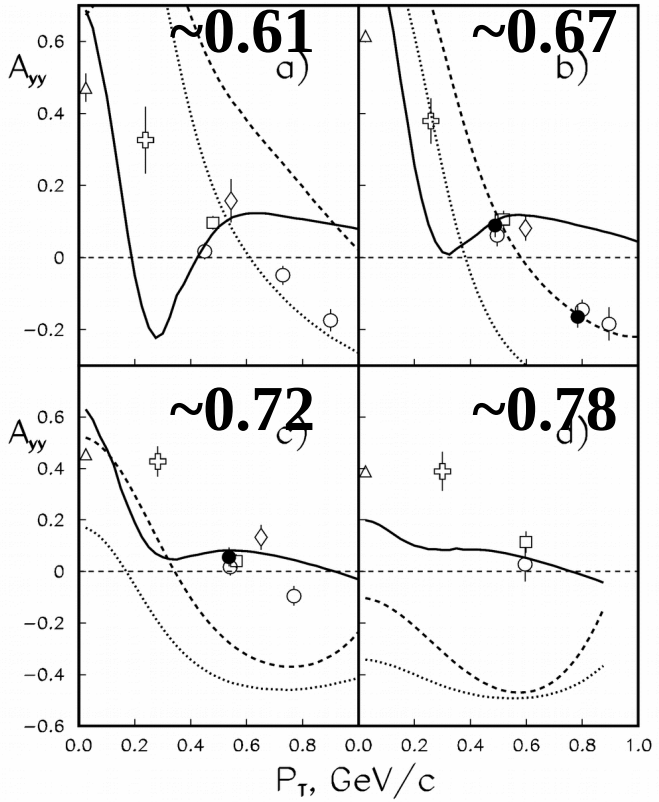


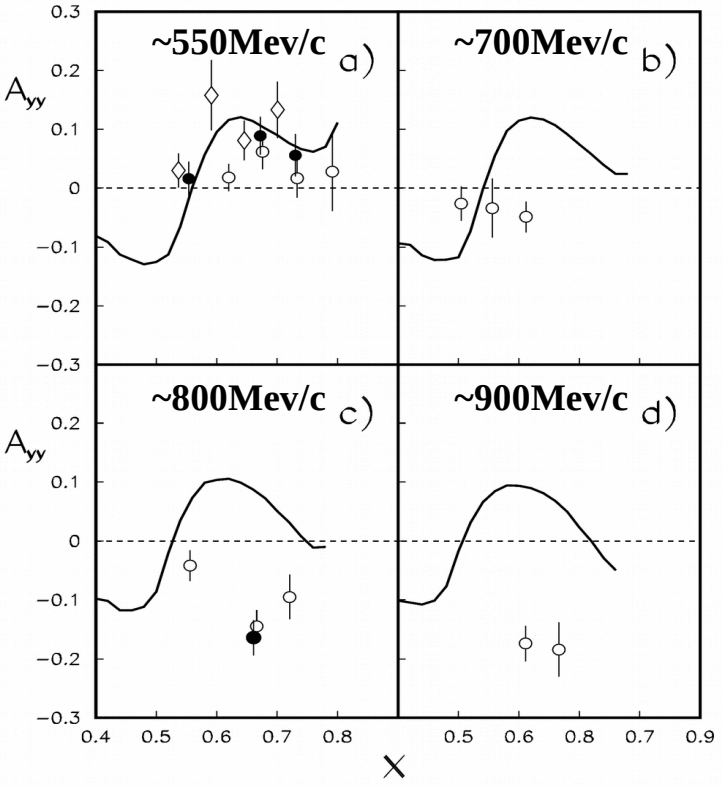


The angular dependence of the vector and tensors analyzing powers at the deuteron energy of 1000 MeV.

Full symbols are preliminary data obtained from DSS experiment at ITS of Nuclotron.

Relativistic effects in 2N SRCs (deuteron)





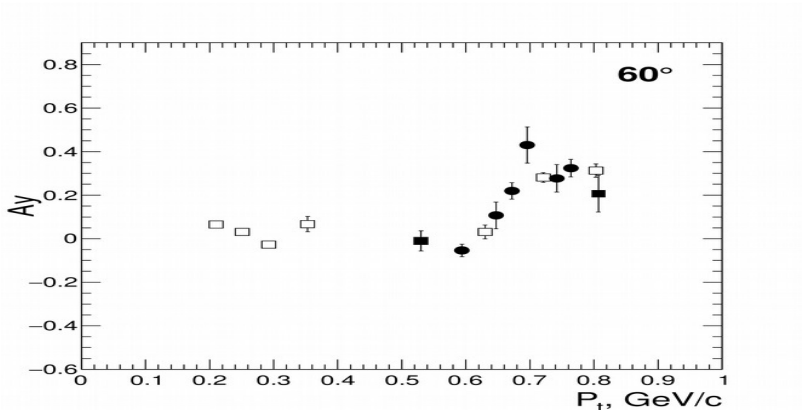
A_{yy} in deuteron inclusive breakup demonstrates the dependence on 2 internal variables: p_T and x_F.

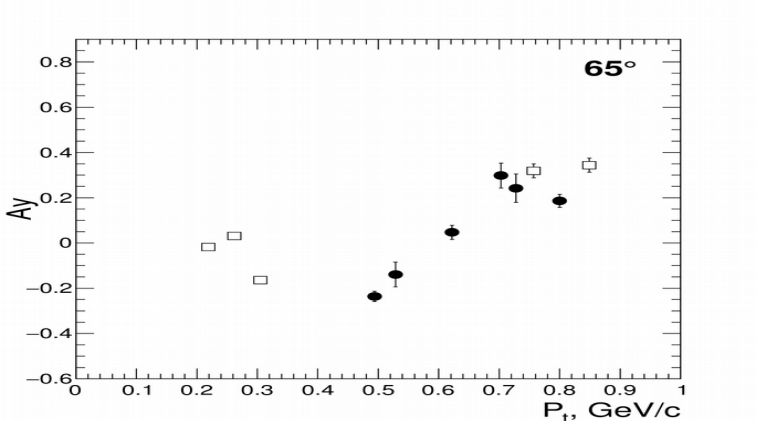
A_{yy} changes the sign at p_T of about 600 MeV/c independently on x_F.

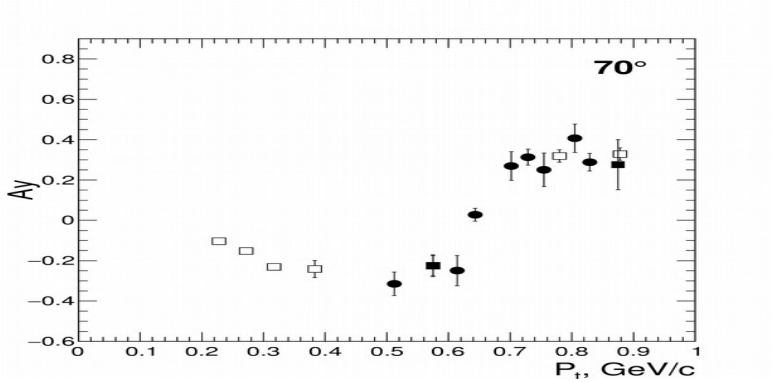
A_{yy} demonstrates negative asymptotic at large p_T .

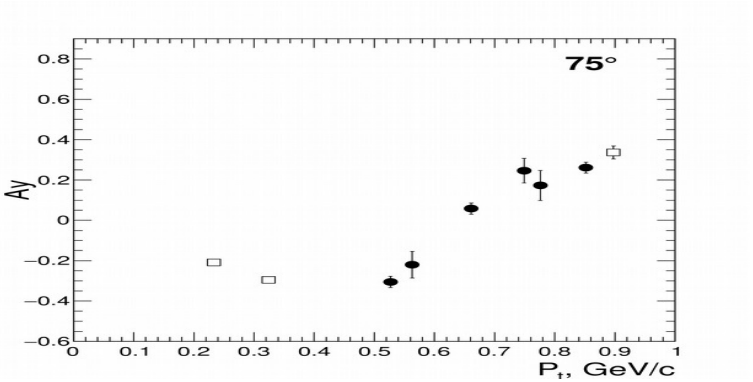
V.P.Ladygin et al., Phys.Lett. B629 (2005) 60

Energy dependence of the vector analyzing power Ay in dp-elastic scattering at 700-1800 MeV



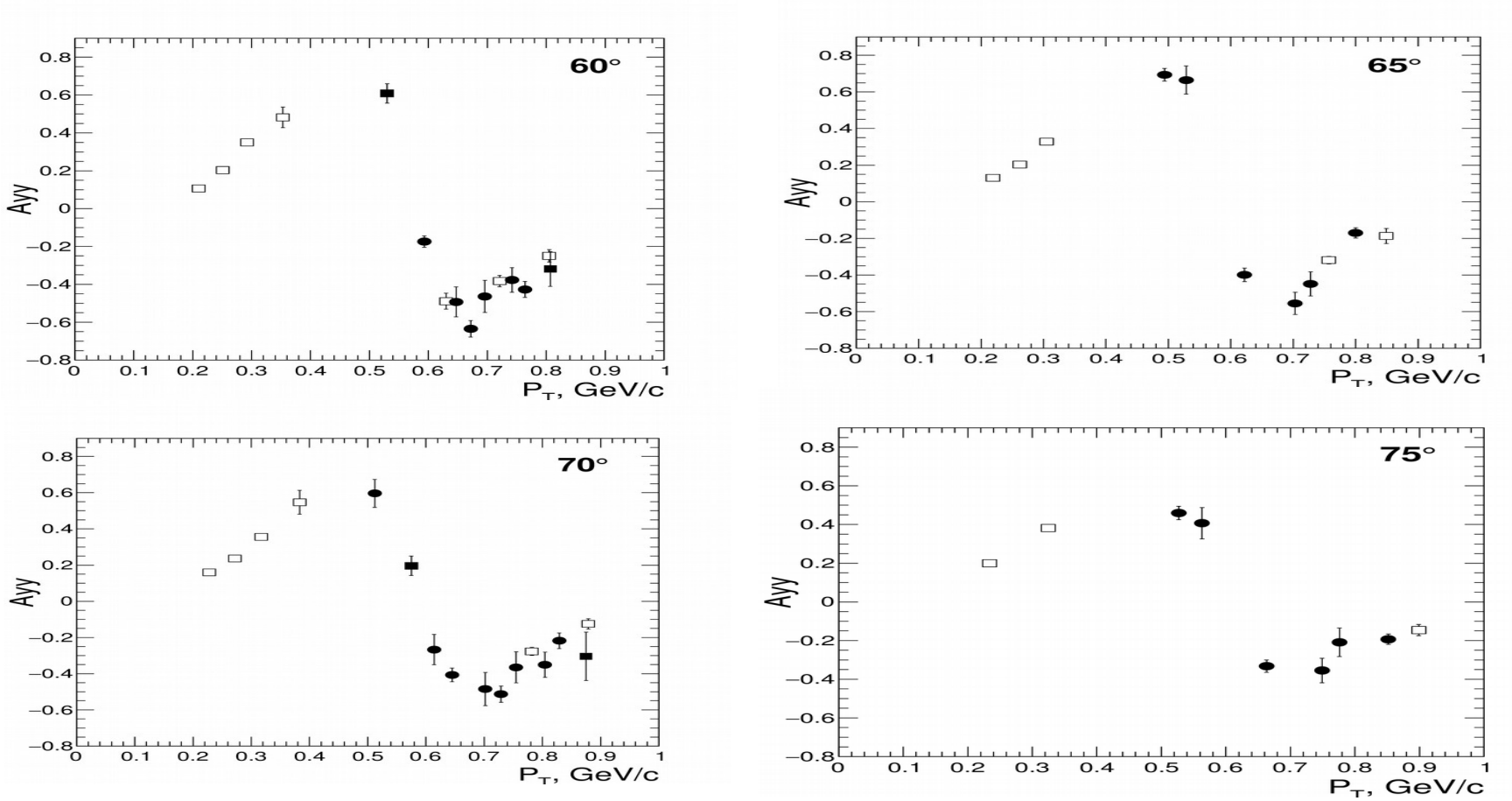






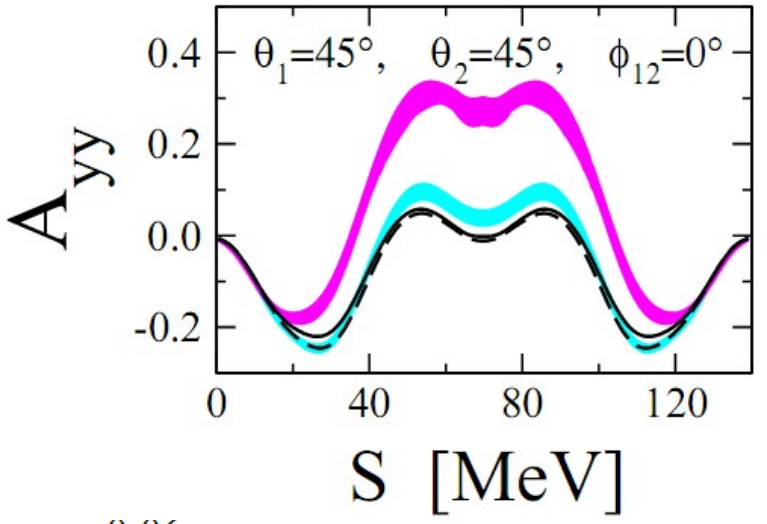
Full circles are preliminary data fom Nuclotron (2016-2017).
Full squares are the data fom Nuclotron (2005).
Open symbols are the world data.

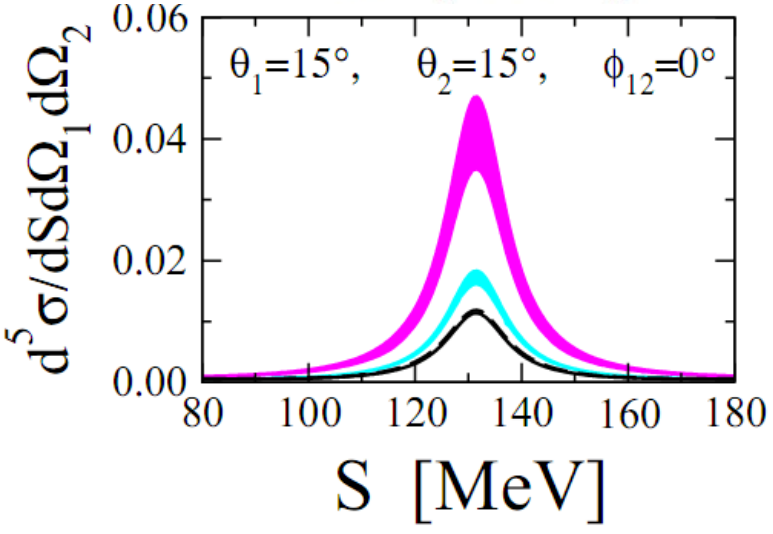
Energy dependence of the tensor analyzing power Ayy in dp-elastic scattering at 700-1800 MeV



Full circles are preliminary data fom Nuclotron (2016-2017).
Full squares are the data fom Nuclotron (2005).
Open symbols are the world data.

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

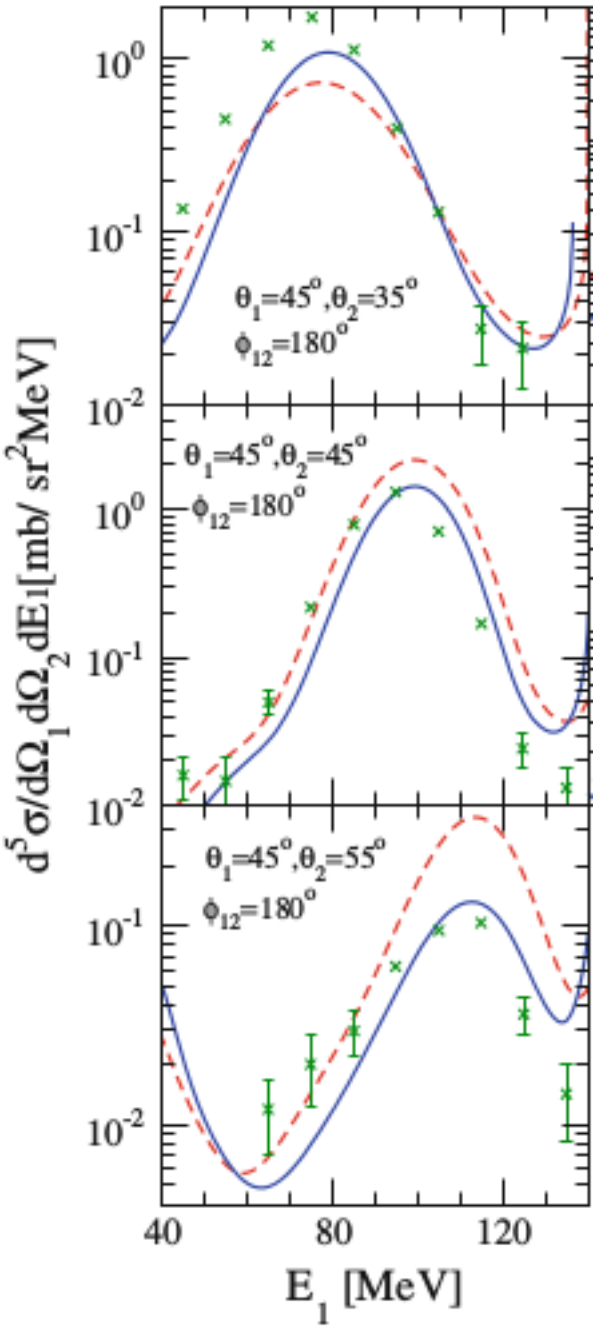
One can see that the inclusion of 3NF have great impact on the values of analyzing power and cross section.

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.



nd breakup reaction

Relativistic effects in neutron-deuteron breakup at 200 MeV.

One arm is fixed, second arm scans angular range.

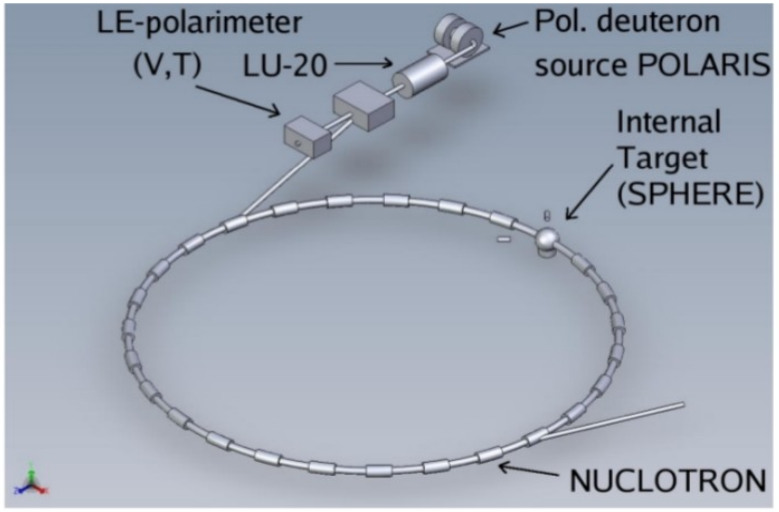
Important contribution comes from relativistic effects.

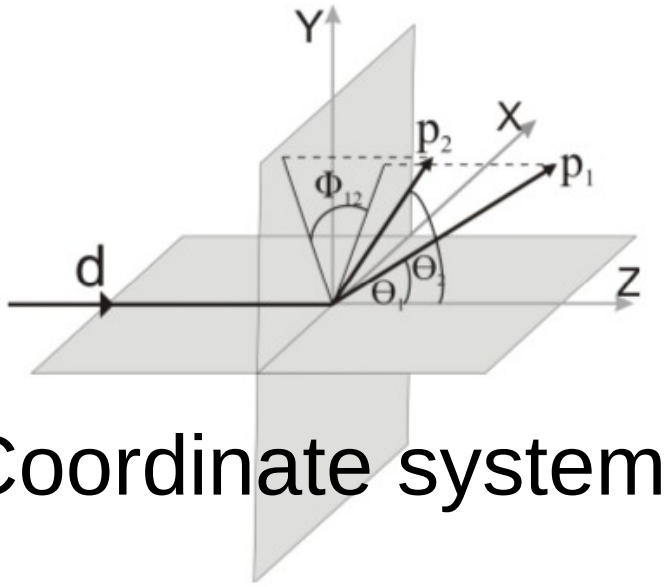
Red curve – nonrelativistic CD Bonn
Blue curve – relativistic CD Bonn

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

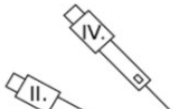
Dp breakup reaction

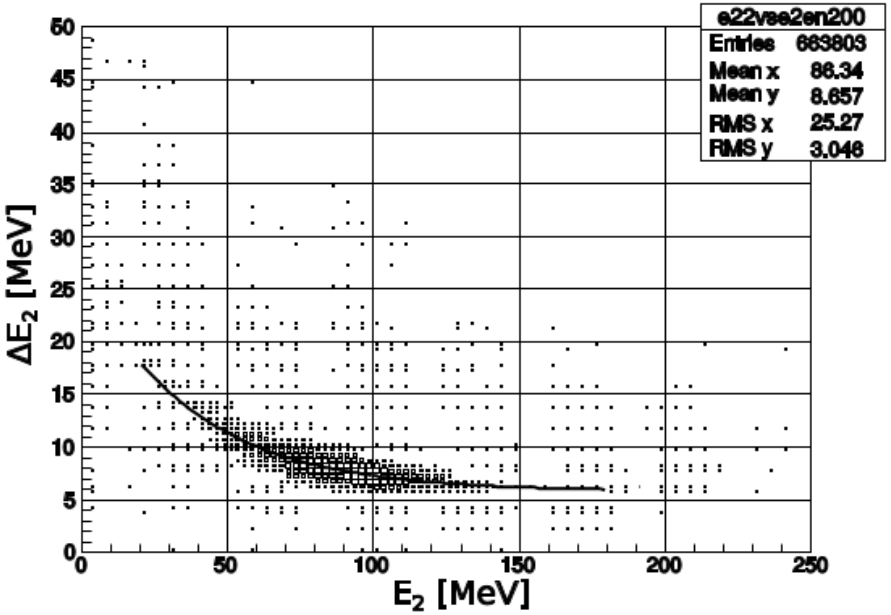
Internal Target Station is very well suited for the experiment on the measurement of the *dp*- breakup reaction.





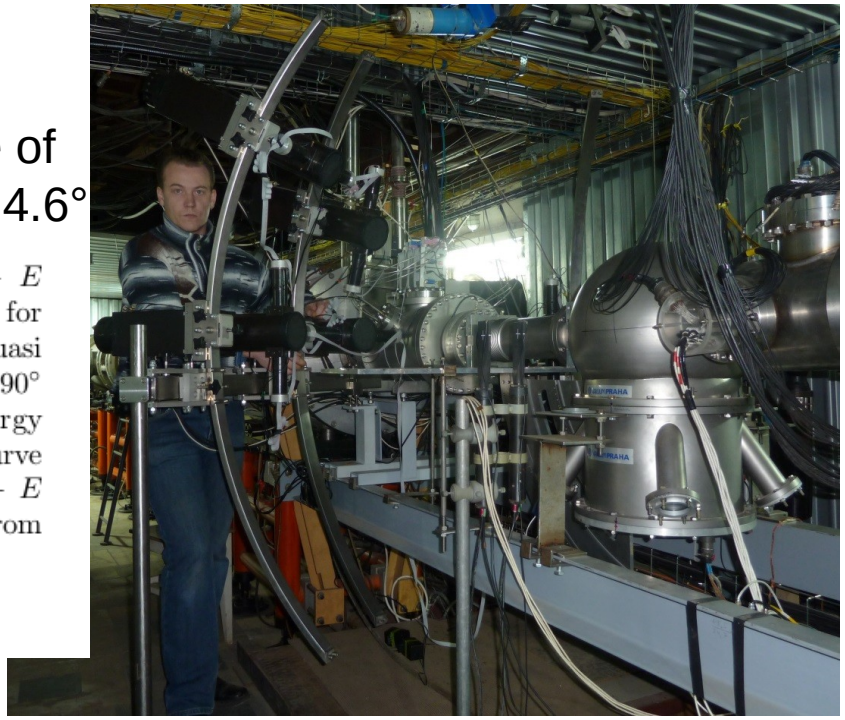
Coordinate system



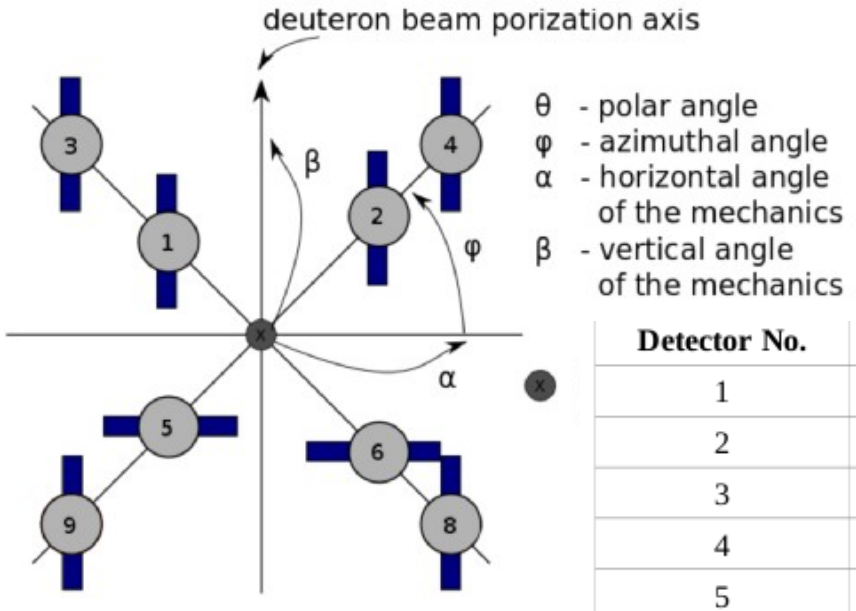


Θ (12°, 45°)
Φ (0°, 360°)
Space angle of the detector 4.6°

$\Delta E - E$ 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



Dp breakup reaction, polarized beam

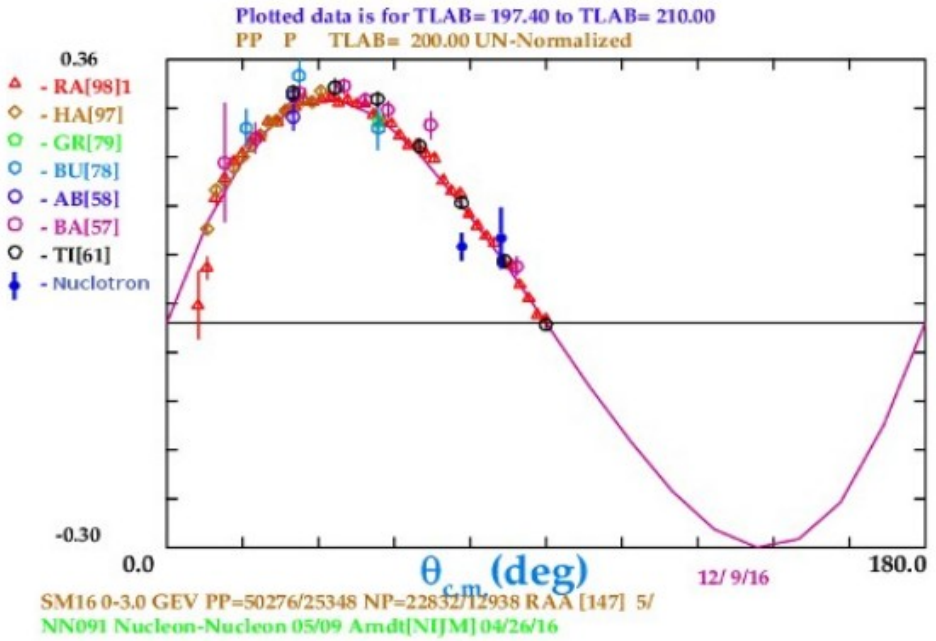


Placement of eight ΔE-E detectors at deuteron energy of 400 MeV.

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



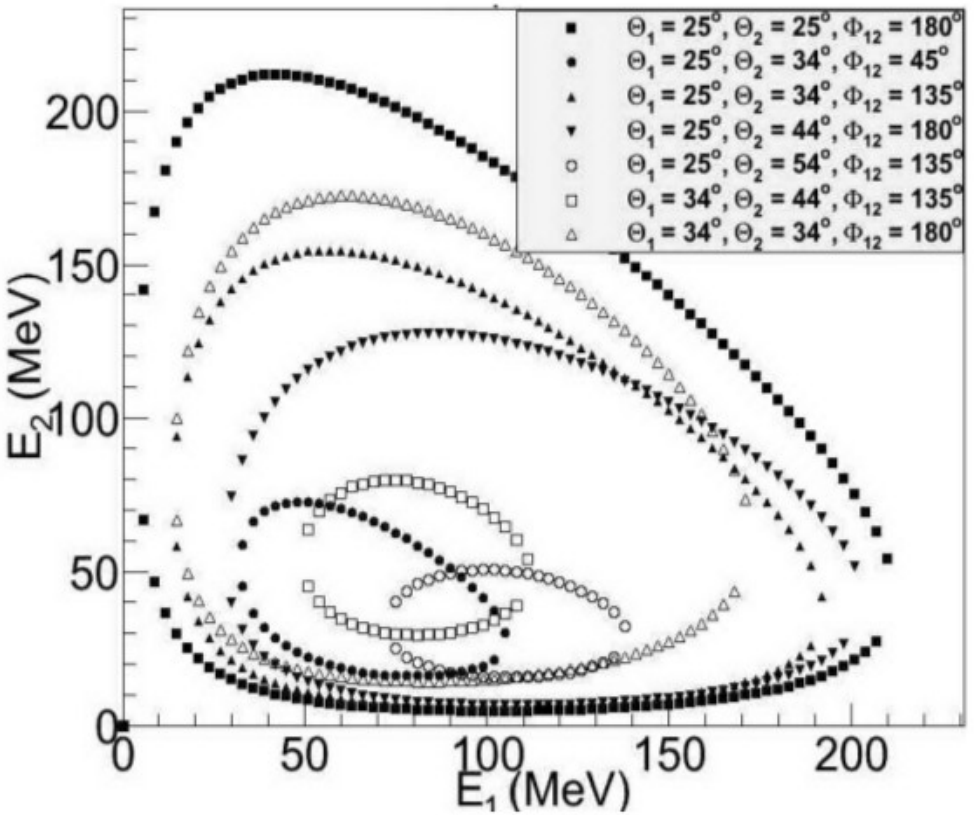
Angular dependence of the vector analyzing $\mathbf{iT_{11}}$ power at energy of 200 MeV/n. Data obtained at Nuclotron JINR are represented by full blue symbols (72.3° and 76.5° in cm). Other symbols - world data.

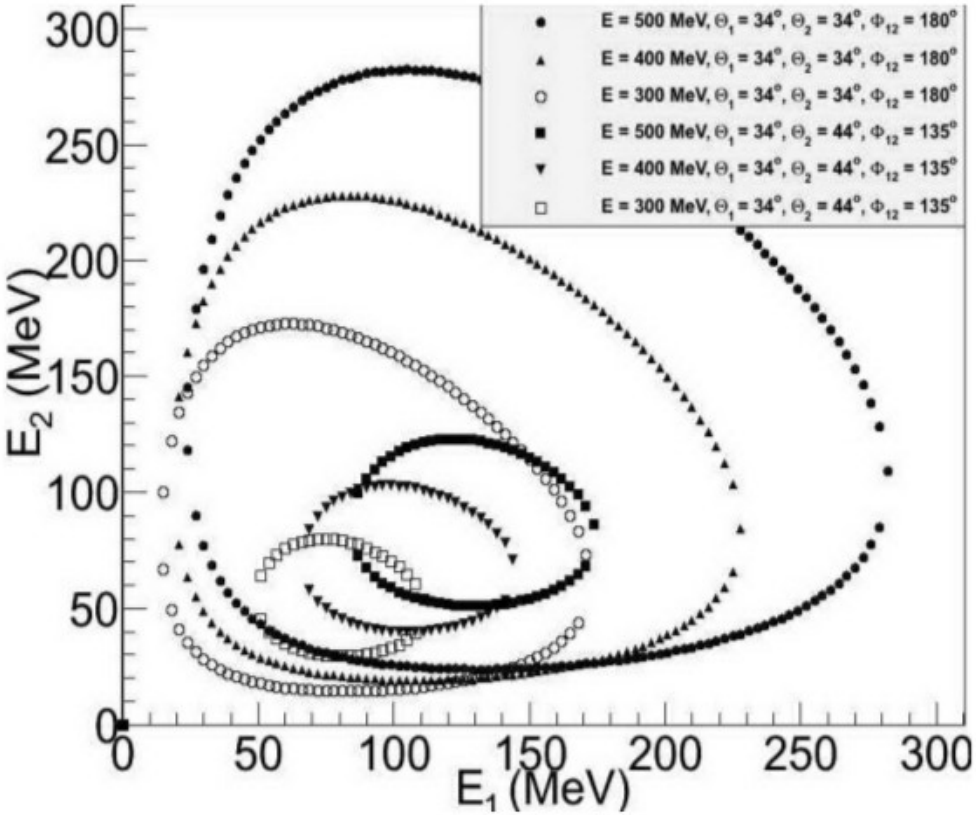
- pp -quasi at 72.3° and 76.5°.
- combined results

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		

Dp breakup reaction

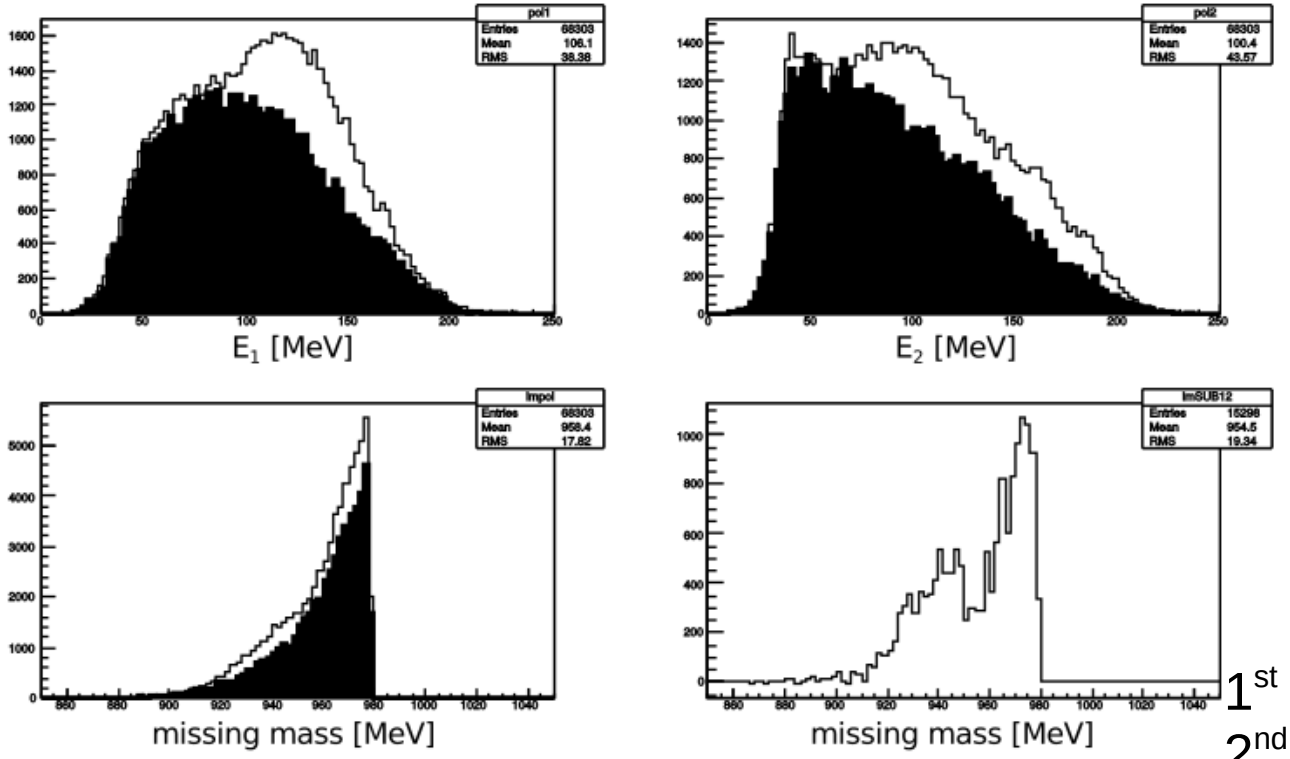
Space star configuration is interesting from the point of 3N correlations and non nucleonic degrees of freedom investigation.





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



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 - Cross section evaluation

Monitor counts can be obtained from experiment - from selected events. Proper detector's square is obtained by Monte Carlo simulation in ROOT package. Cross section can be obtained from:

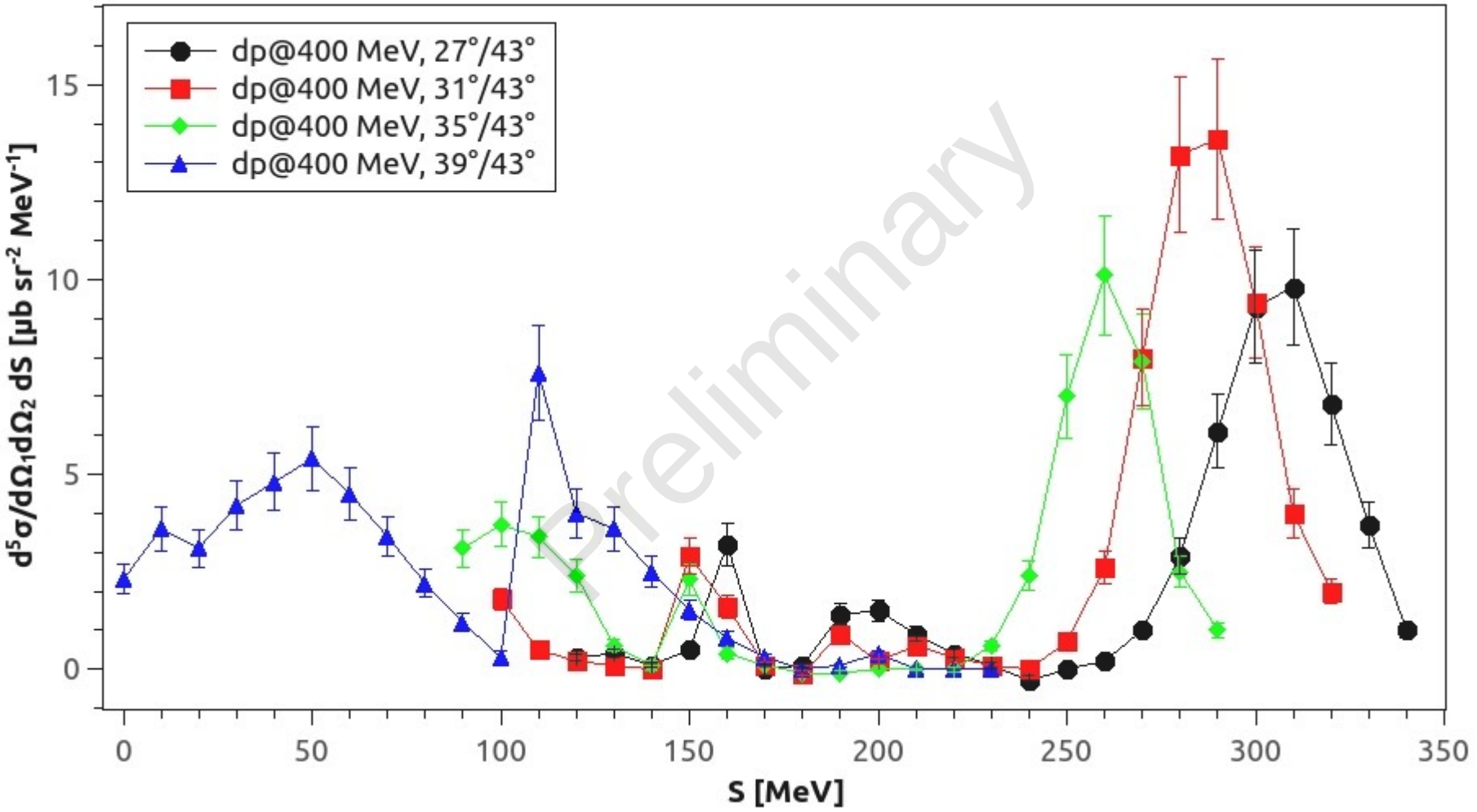
$$C_n = \frac{XS * M}{N_s * d\Omega}$$

- dp elastic reaction at 135 MeV/n **Complete set of deuteron analyzing powers from dp elastic scattering at 190 MeV/nucleon, K. Sekiguchi et al. Phys. Rev. C 96, 064001**
- pp quasi reaction at 150 MeV/n **SAID**
- pp quasi reaction at 200 MeV/n **SAID**
- pp quasi reaction at 250 MeV/n **SAID**

- C_n – normalization coefficient
- N_s – number of selected events
- M – monitor counts
- Solid angle

Selected events N_s are corrected using detector efficiency which depends on particle's energy.

Dp breakup - Cross section evaluation



Conclusion

- **New polarized ion source of Nuclotron provides quite unique opportunity for the studies of the spin effects and polarization phenomena in few body systems.**
- **The energy scan of the deuteron analyzing powers in dp- elastic scattering has been performed in 2016-2017. Data have been partially processes and presented.**
- **Unpolarized and polarized dp breakup data are partially processed at 300, 400 and 500 MeV.**
- **Preliminary differential cross section for 4 configurations at 400 MeV of deuteron energy are presented.In order to obtain final cross section additional possible sources of errors have to be taken into account (beam and target position, C_n coef. fixation …).**
- **The extension of the studies to the high energies is possible with the extracted polarized deuteron and proton beams including pd breakup process investigation.**