The 7th Asia-Pacific Conference on Few-Body Problems in Physics

Dp breakup reaction investigation using polarized and unpolarized deuteron beam

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

Guilin, China, 25-30 August 2017

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**
- **Physics Department, University of Zilina, Slovakia**

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 Ay, Ayy and Axx at 400 MeV
- **dp** breakup reaction at deuteron energy (300 – 500) MeV
  - Unpolarized data
  - Polarized data at 270 and 400 MeV

Fundamental degrees of freedom

- **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 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

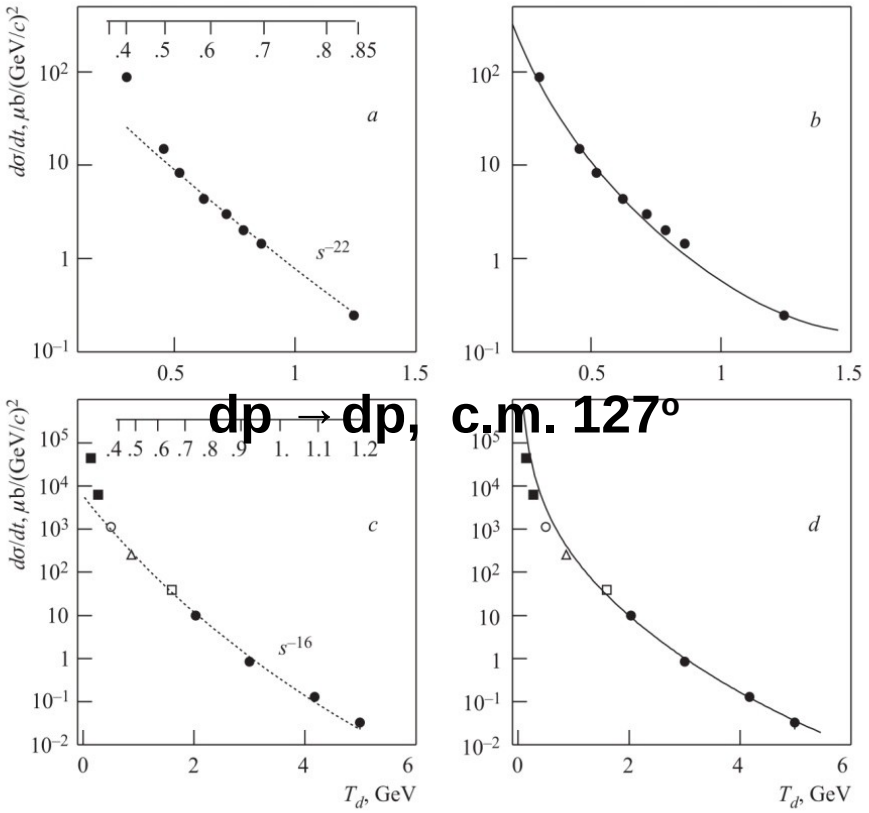
One needs to be very careful: according to the theorem of W.N.Polyzou and W.Gloeckle, Few Body Syst. 9 (1990) 97, off-shell behaviour of 2NF can imitate 3NF effect.

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.)

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

dd → ^{3}He n, c.m. 60°



dp → dp, c.m. 127°

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**

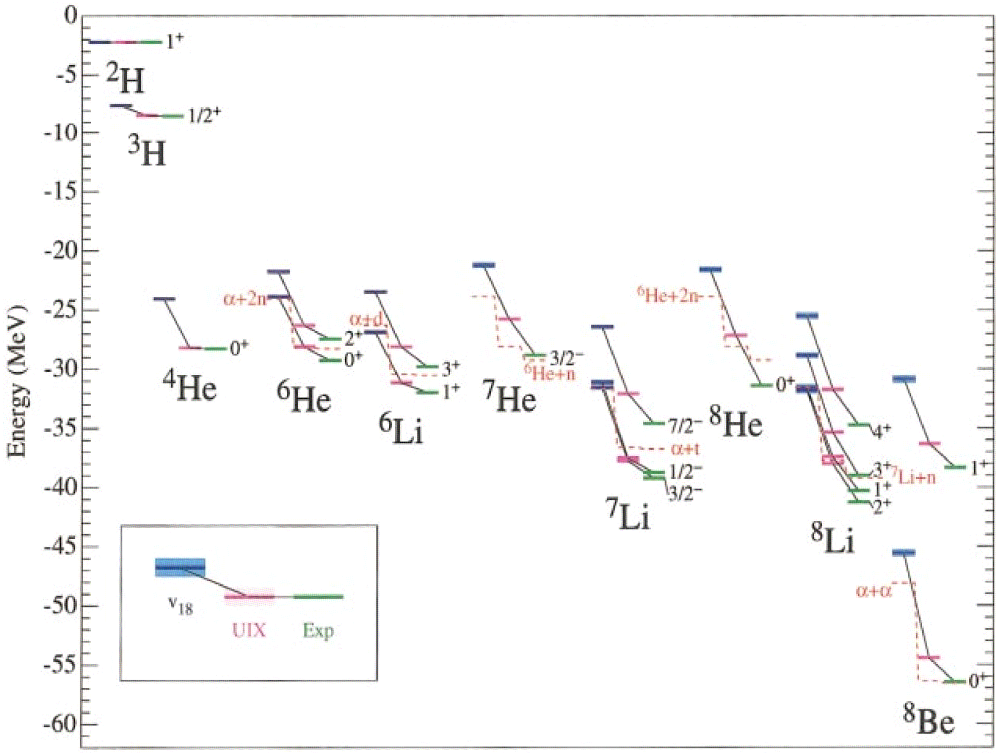
$$N_A + N_B + N_C + N_D - 2 = 16$$

The regime corresponding to CCR can occur already at T_d ~500 MeV for dd → ^{3}He n (^{3}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.

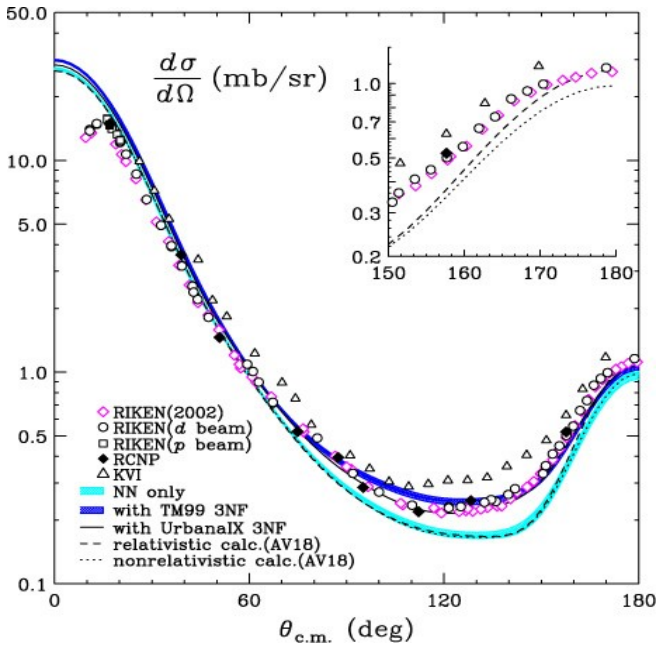
[1] K. Hatanaka et al., Phys. Rev. C66, 044002, (2002)
[2] K. Sekiguchi et al., Phys. Rev. C65, 034003, (2002)
[3] S. Kistryn, et al., Phys. Rev. C68, 054004, (2003)

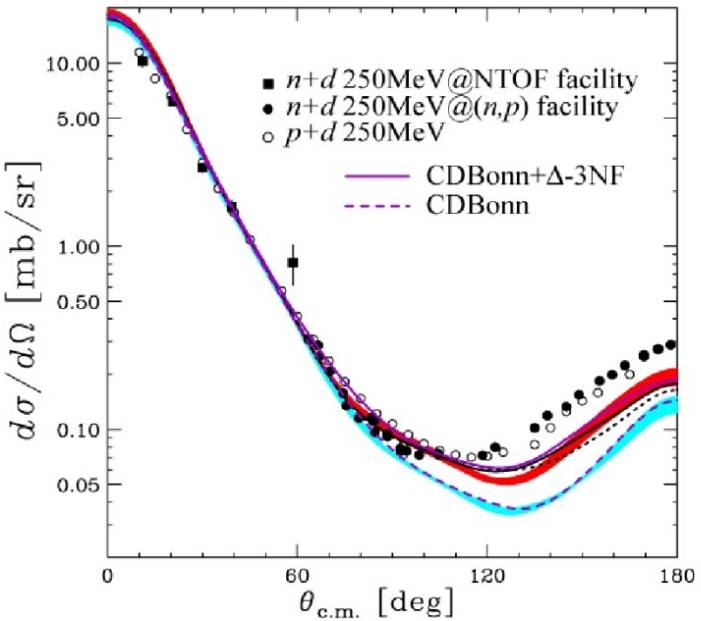


Spin parts of the 2N and 3N correlations are important to describe the light nuclei structure.

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

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.

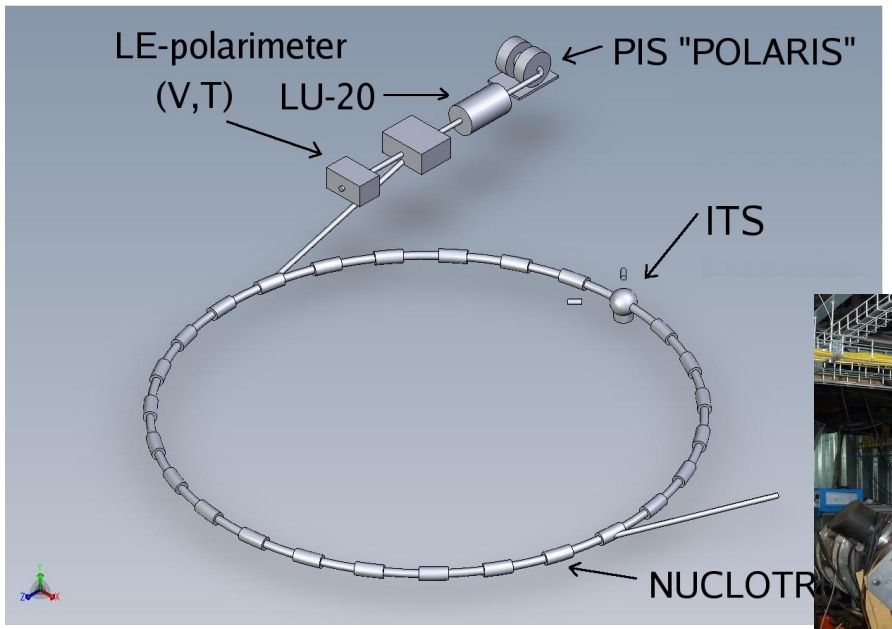
- Inclusion of modern **3NFs** allows to describe cross section and deuteron vector analyzing power of dp- elastic scattering up to **135** MeV/nucleon, while the tensor observables are not described.
- The data at higher energies (up to **300** MeV/nucleon) are not described even taking into account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

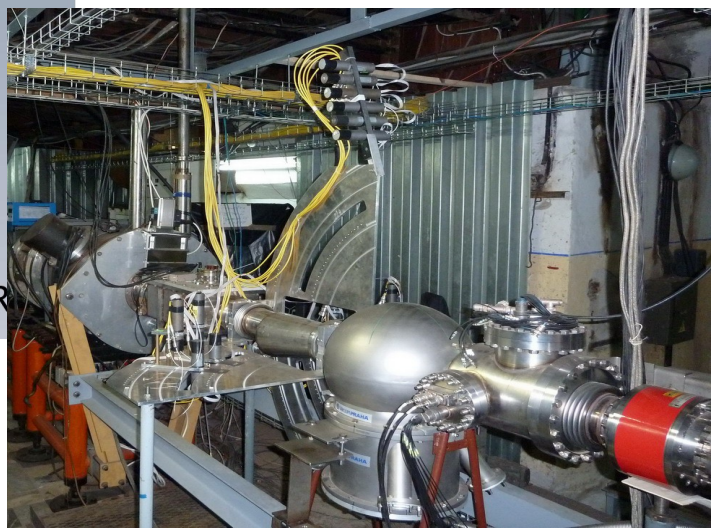
Experiments at Internal Target Station at Nuclotron (DSS-project)

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

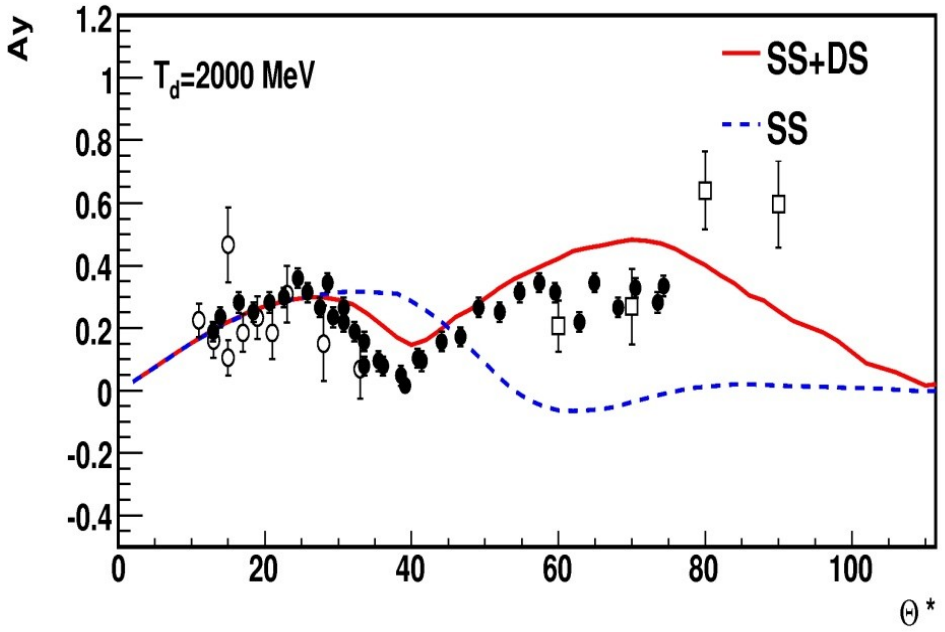
- dp-elastic scattering at the energies between 300 - 2000 MeV;
- dp-breakup with registration of two protons at deuteron energies of 300 - 500 MeV.

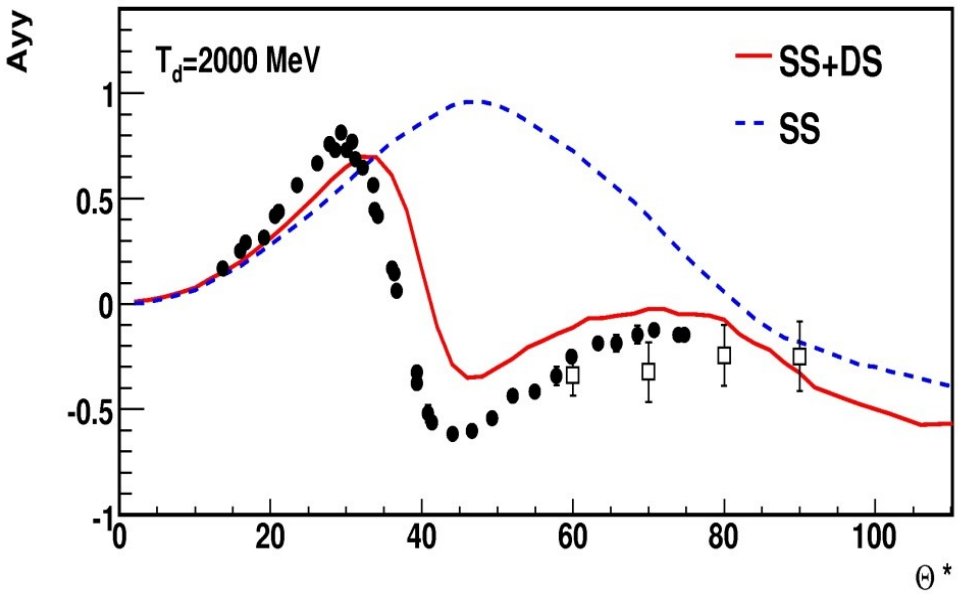


Internal Target Station is very well suited for the measurements of the deuteron- induced reactions observables at large scattering angles.



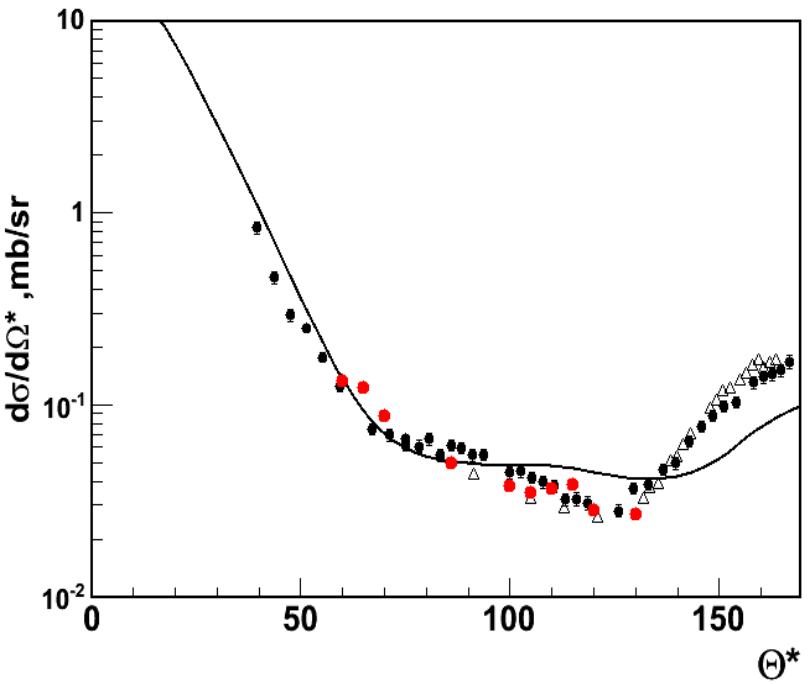
A_y and A_{yy} in dp- elastic scattering at 2000 MeV





- 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:

N.E.Booth et al., Phys.Rev.D4 (1971) 1261

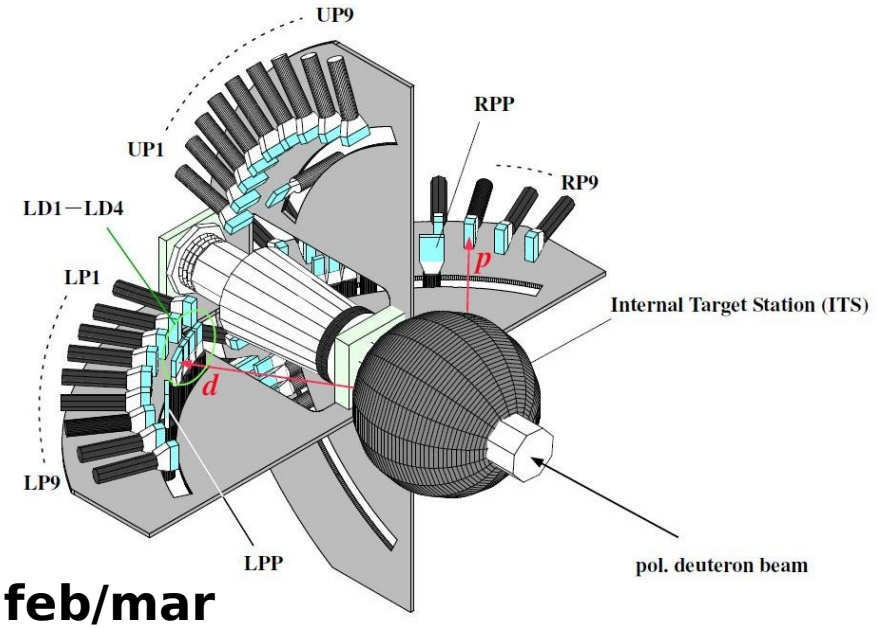
J.C.Alder et al., Phys.Rev.C6 (1972) 2010

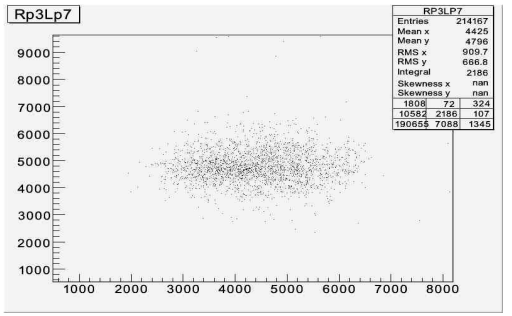
Relativistic multiple scattering model calculation:
N.B.Ladygina, Eur.Phys.J, A42 (2009) 91

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

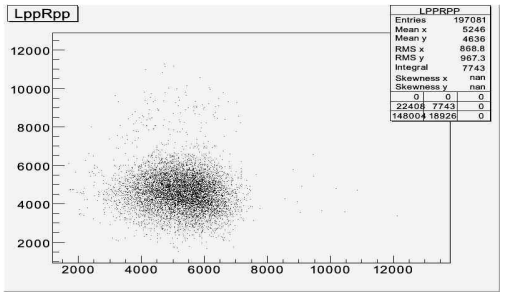
Results from the commissioning run at Nuclotron at 270 MeV (June 2016)

- **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 pz,pzz = (+1/2,-1/2), while only tensor polarization for 3-4 transition pz,pzz = (-1/2,-1/2).**





DP



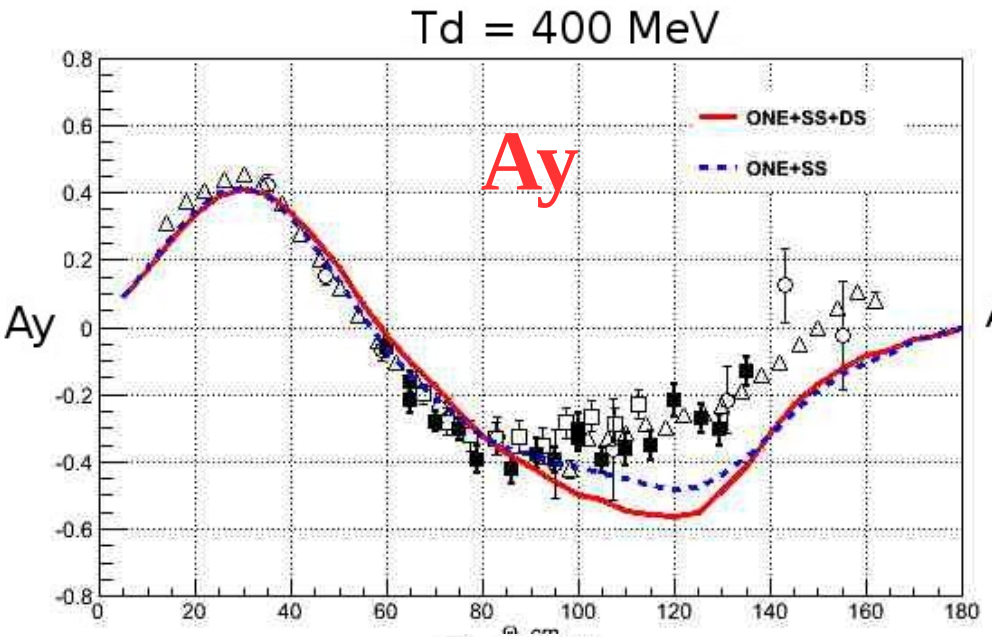
PP

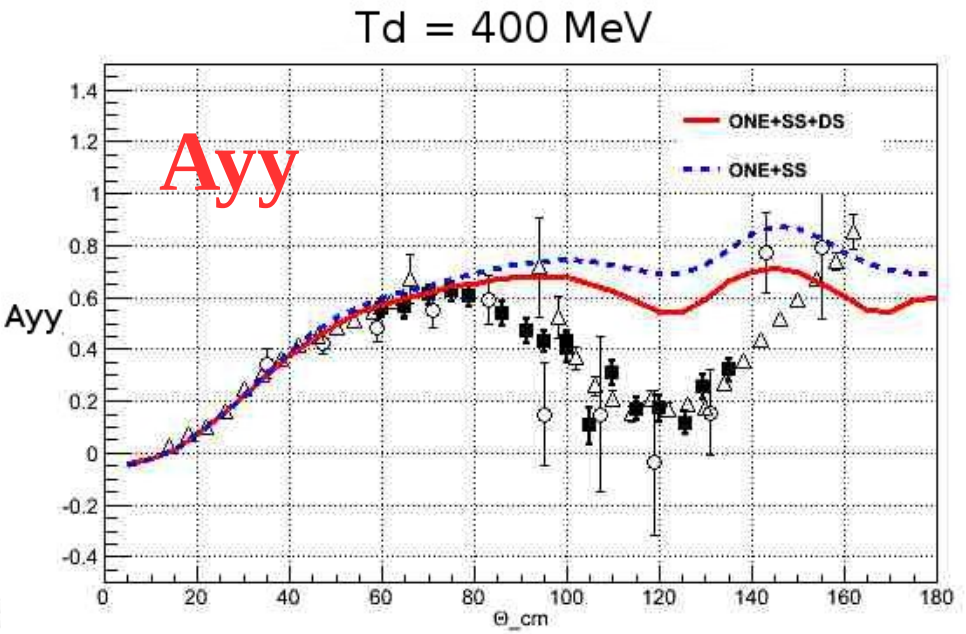
2017 feb/mar

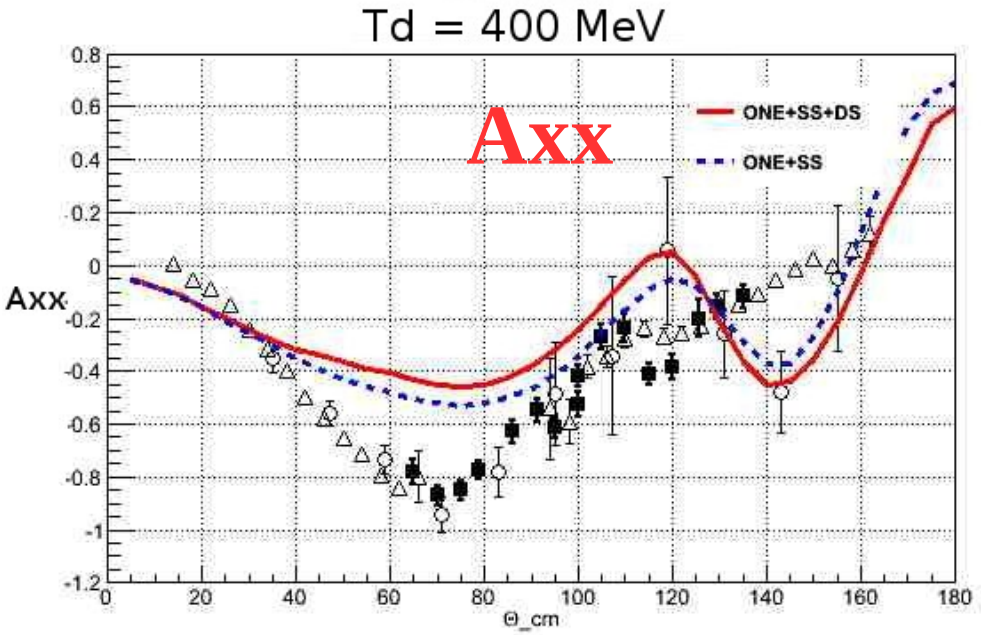
dp elastic scattering has been investigated with using polarized deuteron beam at Internal Target Station at various kinematic configurations at deuteron energies:

400, 700, 800, 1000, 1100, 1300, 1500 and **1800** MeV.

Dp-elastic @ 400 MeV, Ay, Ayy and Axx







Relativistic multi-scattering model

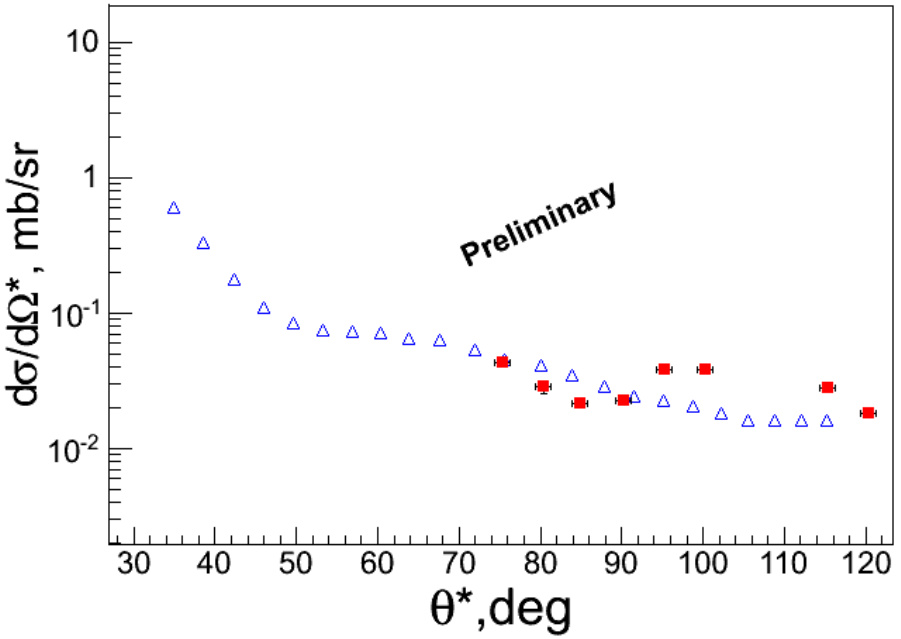
ONE+SS+DS

ONE+SS

Preliminary results (feb./mar. 2017 run)

dp-elastic differential cross section

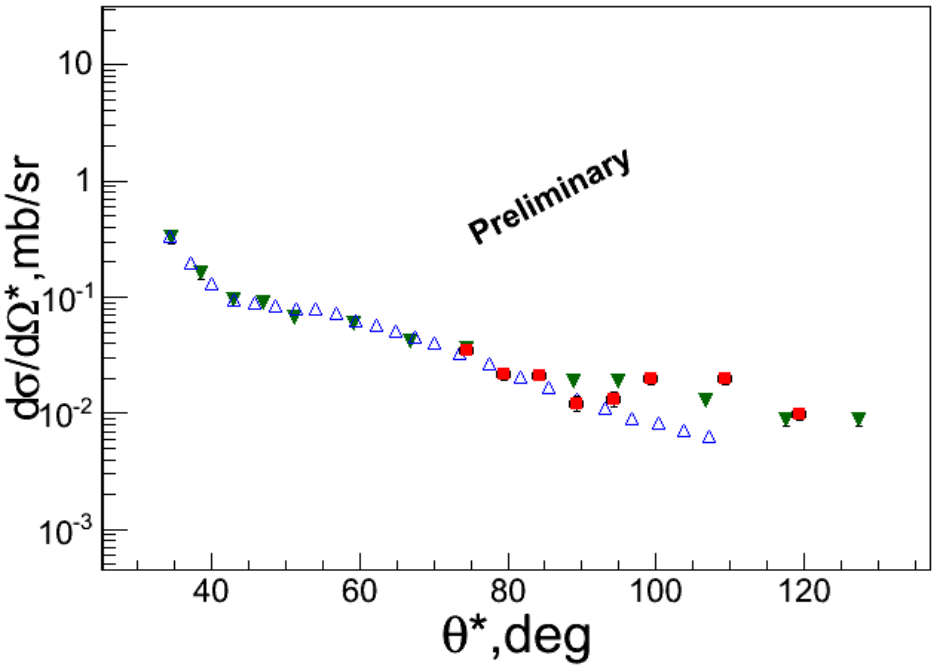
1300 MeV



Triangles – data at 641.3 MeV/n (Culmez E. Phys.Rev.C, V43, №5, 1991)

red symbols - Nuclotron's data

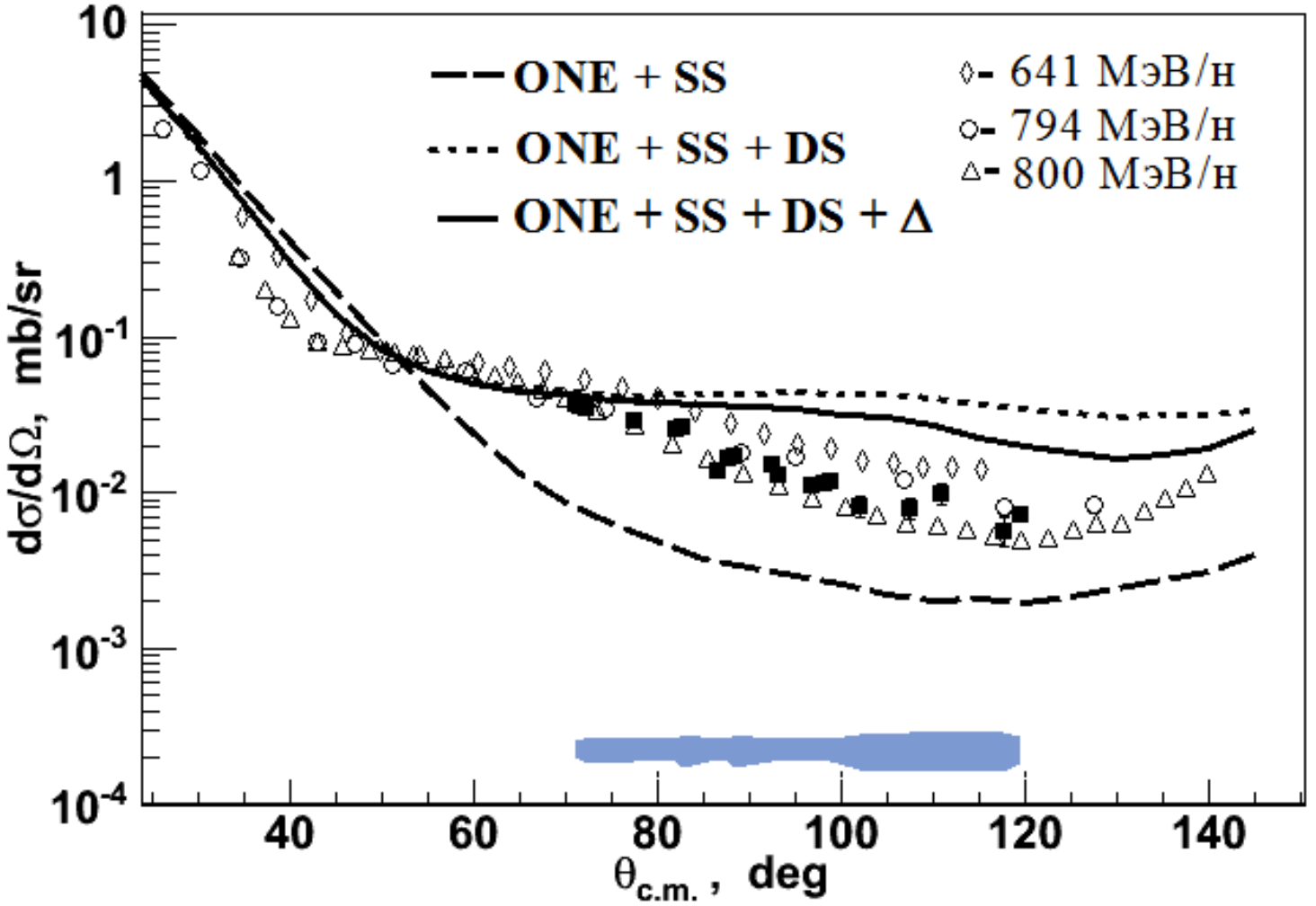
1500 MeV



Blue triangles – data at 792.7 MeV/n (Culmez E. Phys.Rev.C, V43, №5, 1991)

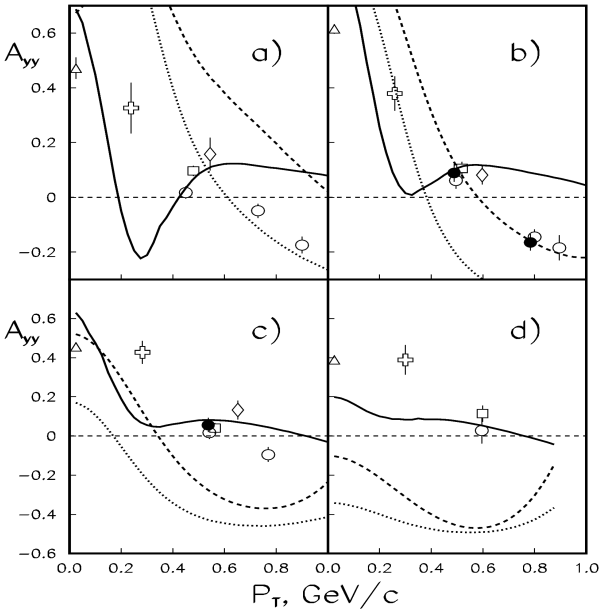
Green triangles – data from 800 MeV/n (Winkelmann E. Phys.Rev.C, V21, №6, 1980)

Dp-elastic @ 1400 MeV

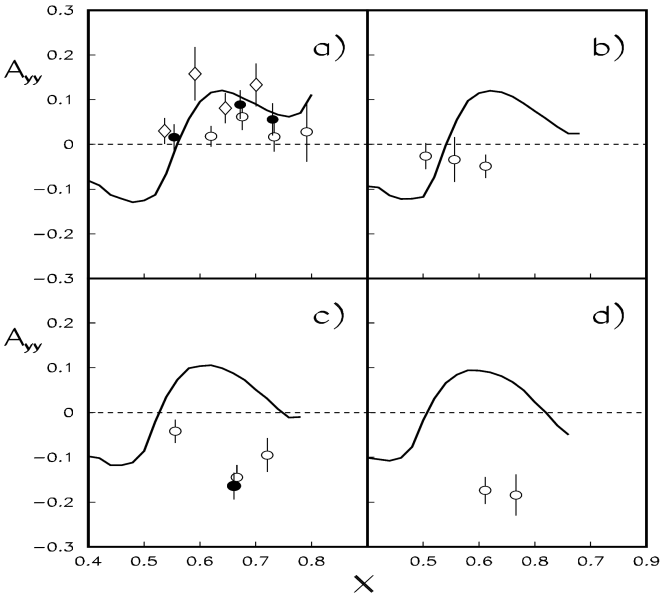


full squares - 700 MeV/N, Internal Target Station (ITS) of Nuclotron, 2017y
other symbols - world data at 3 energies: 641, 794 and 800 MeV/N
Data accumulated also at:
400, 500, 600, 700, 880, 1000, 1300, 1500, 1600, 1700, 1900, 2000 MeV.

Relativistic effects in 2N SRCs (deuteron)



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 ~550 MeV/c, ~700 MeV/c, ~800 MeV/c and ~900 MeV/c are presented in the a), b), c) and d).

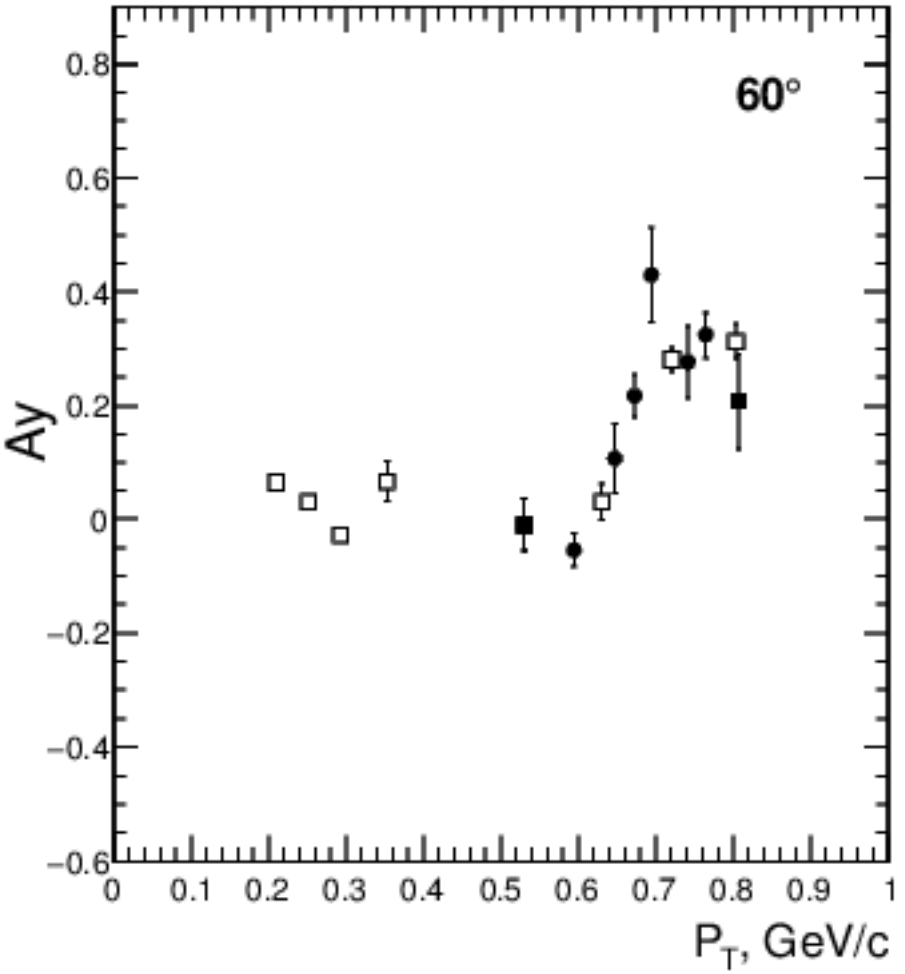
A_{yy} in deuteron inclusive breakup demonstrates the dependence on 2 internal variables: p_T and x_F.

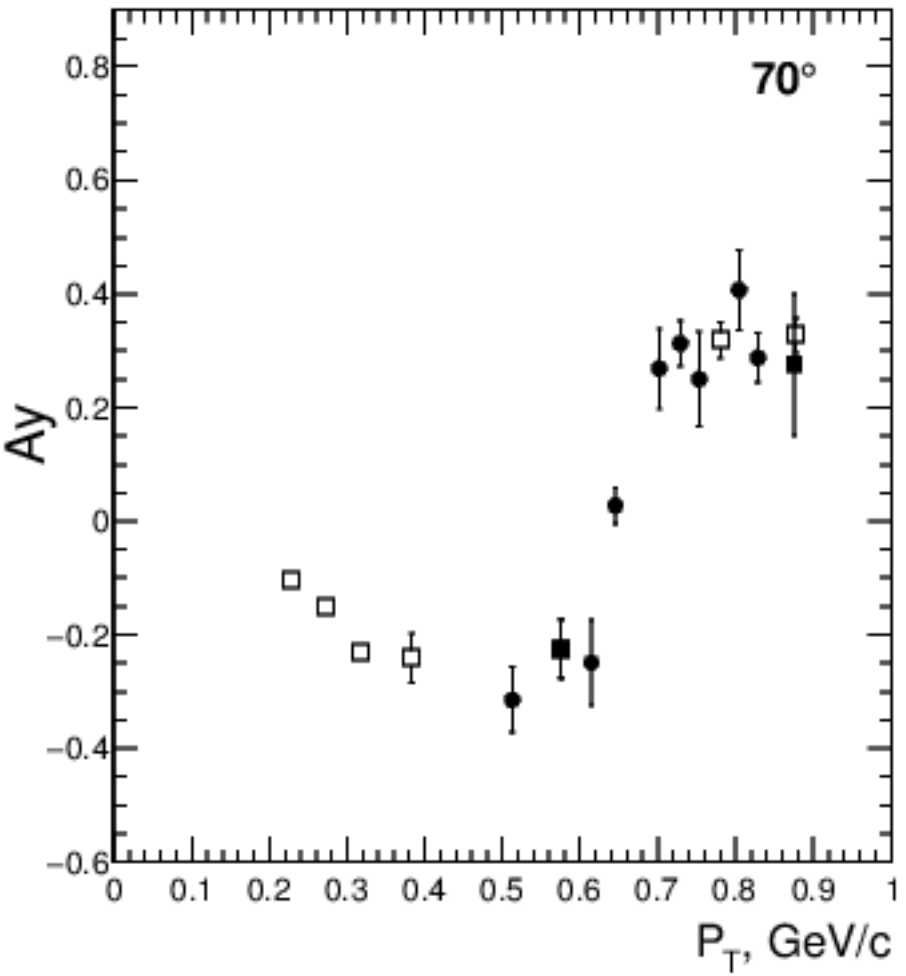
A_{yy} changes the sign at p_T of about 600 MeV/c independently on x_F.

A_{yy} demonstrates negative asymptotic at large p_T .

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

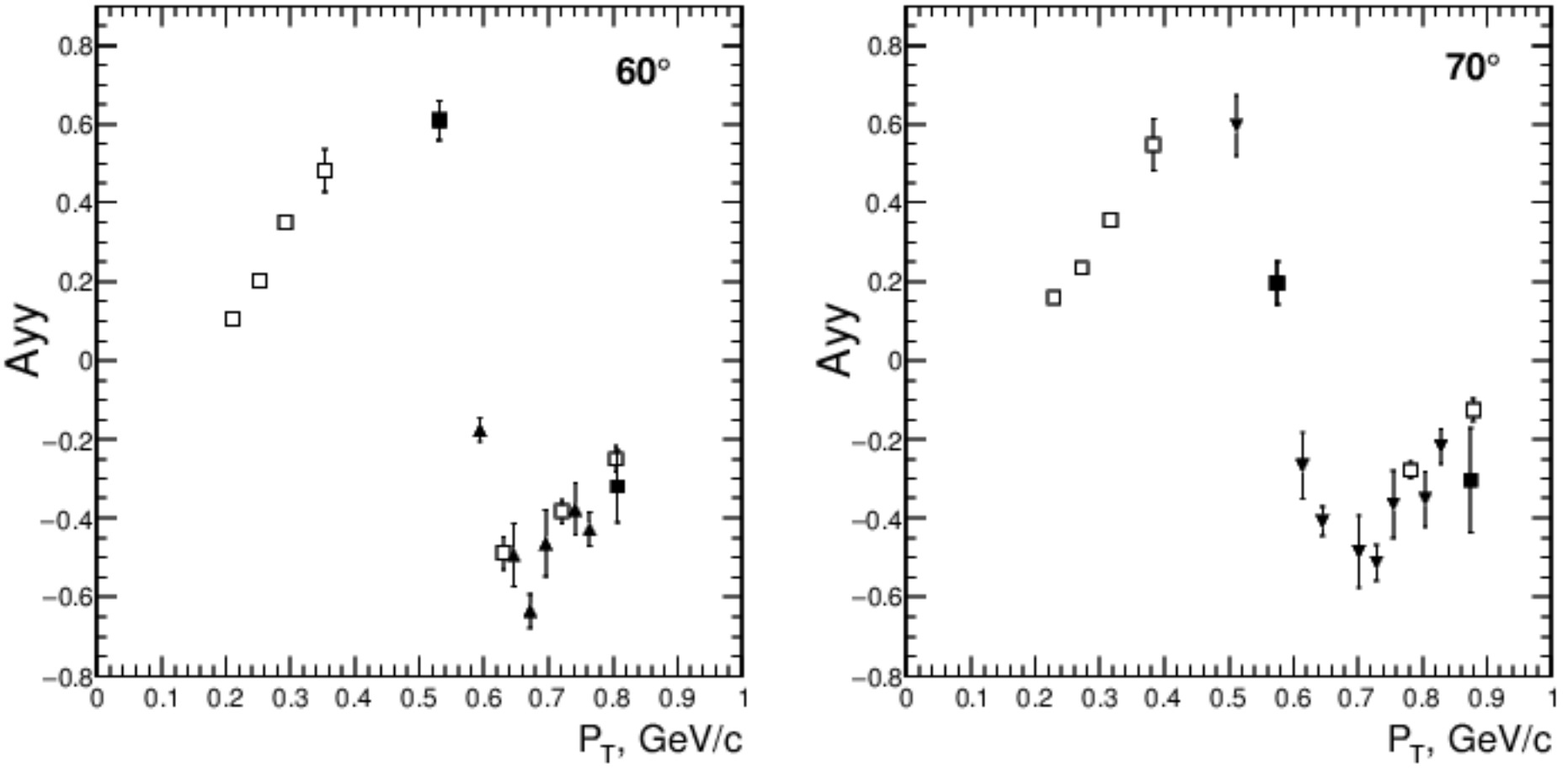
Dp-elastic, Nuclotron - recent results





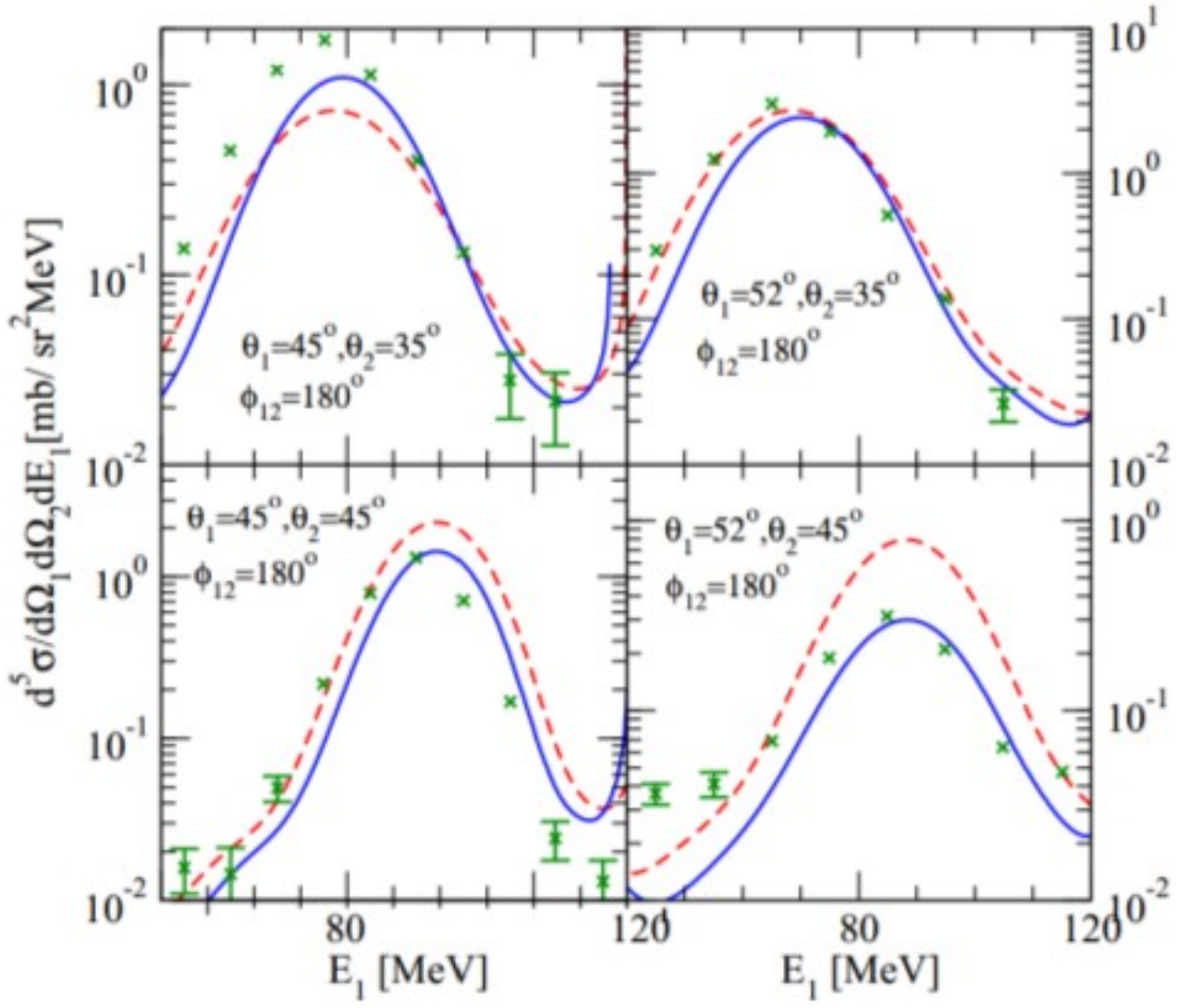
open symbols - world data obtained at RIKEN, Saclay, ANL
full squares - 880 and 2000 MeV, Internal Target Station (ITS) of Nuclotron, 2005y
full circles - preliminary data obtained during **2016** and **2017** years at the ITS (Nuclotron), (Polarized deuterons were provided by the new polarized ions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

Relativistic effects in neutron-deuteron breakup at 200 MeV



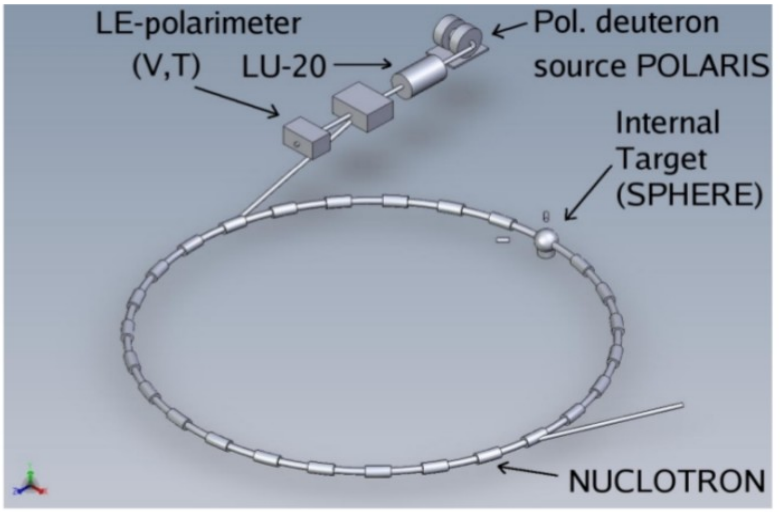
The five-fold cross section $d^5\sigma/d\Omega_1 d\Omega_2 dE_1^{lab}$ for the breakup reaction d(n,np)n at E_{lab} = 200 MeV and fixed angles of outgoing nucleons 1 and 2 The dashed (red) line is the nonrelativistic CD Bonn potential prediction and the solid (blue) line is the corresponding relativistic result.

- **The importance of relativistic effects under specific phase space configurations has been observed.**

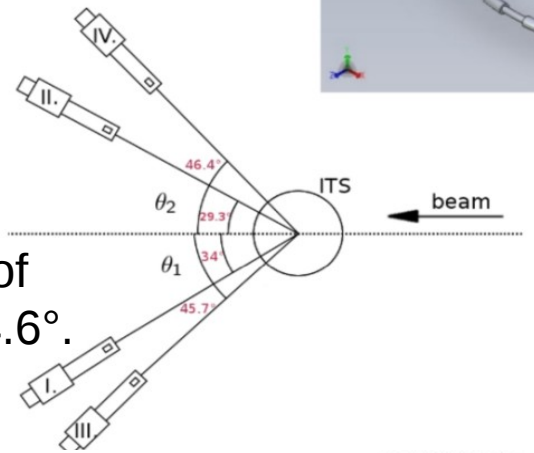
H. Witala, Few Body Syst. (2011) 49, 61.

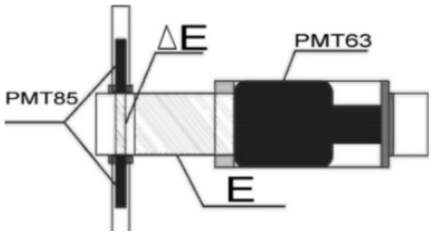
dp breakup reaction, Nuclotron

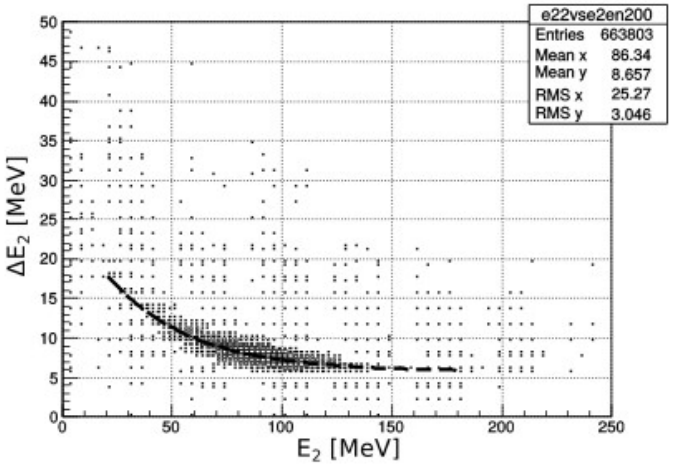
Internal Target Station is very well suited for the experiment on the measurement of the *dp*- breakup reaction.

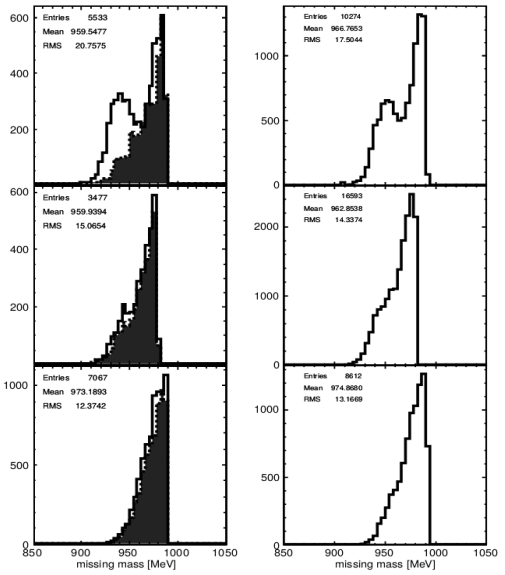


Θ (12°, 45°)
Φ (0°, 360°)
Space angle of the detector 4.6°.









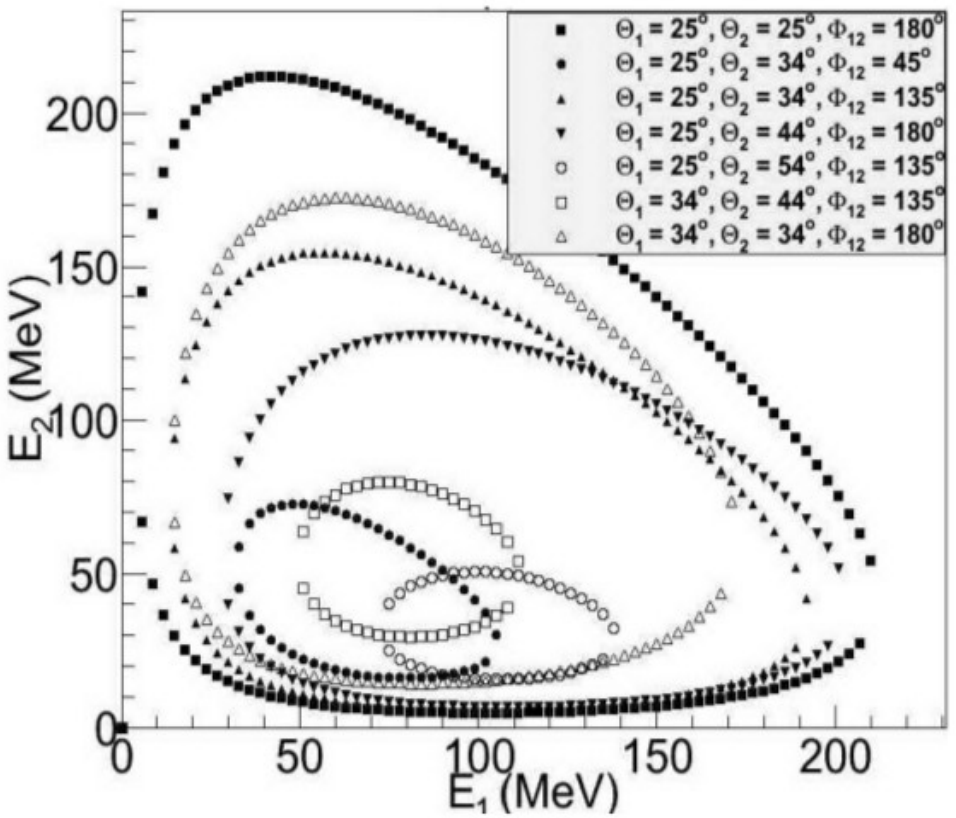
Missing mass spectra on CH_2 and C at 400 MeV

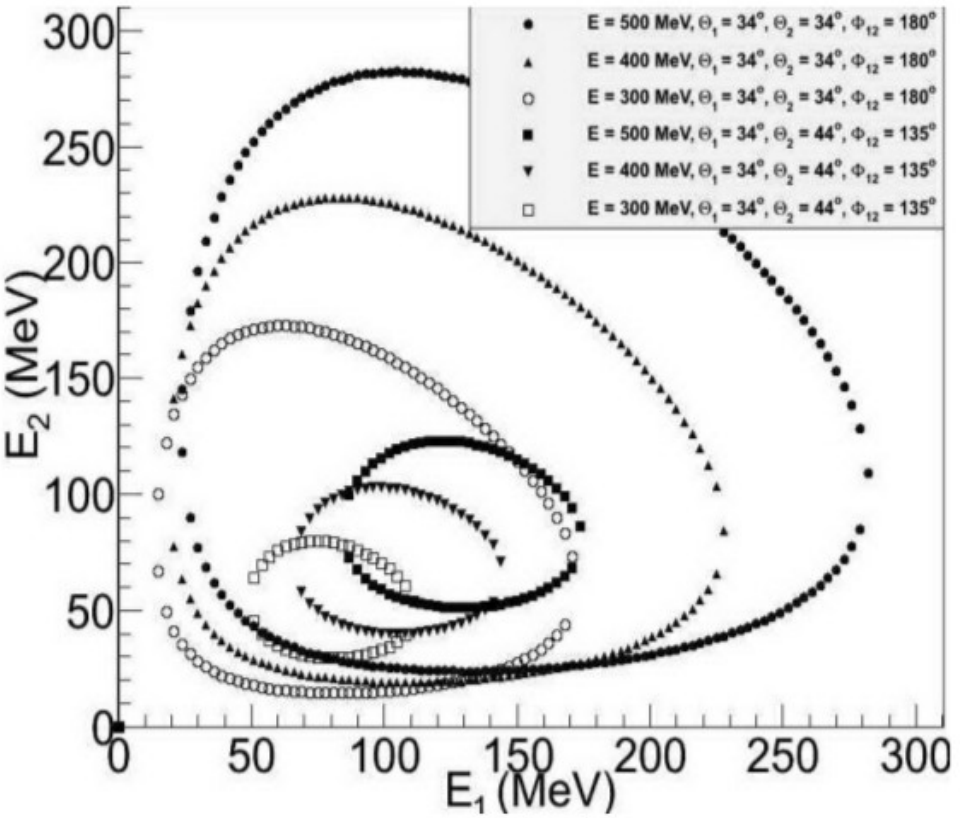
Experimental and simulated missing mass spectra are shown in first and second column, respectively.

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)

dp breakup reaction

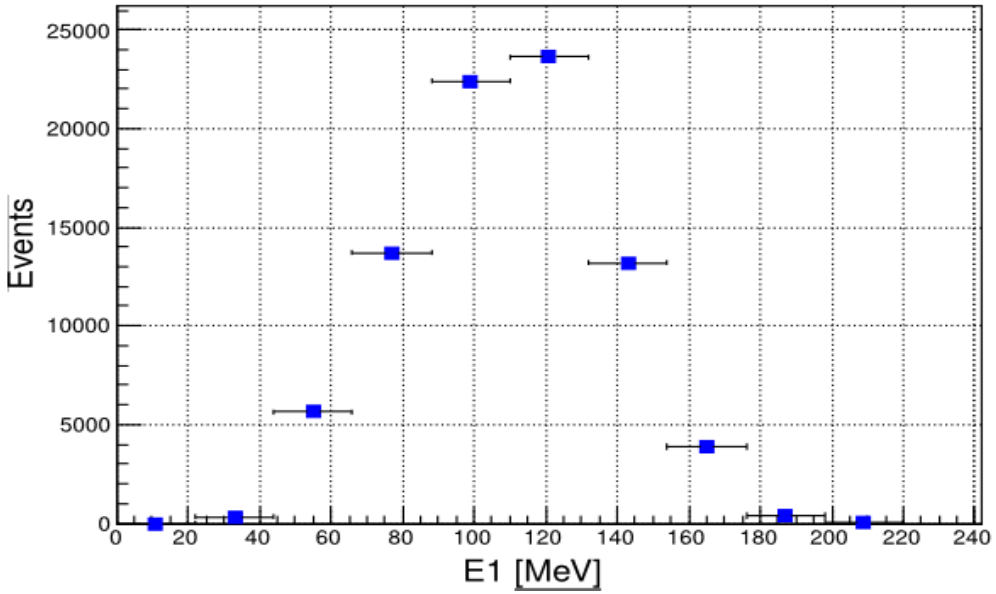


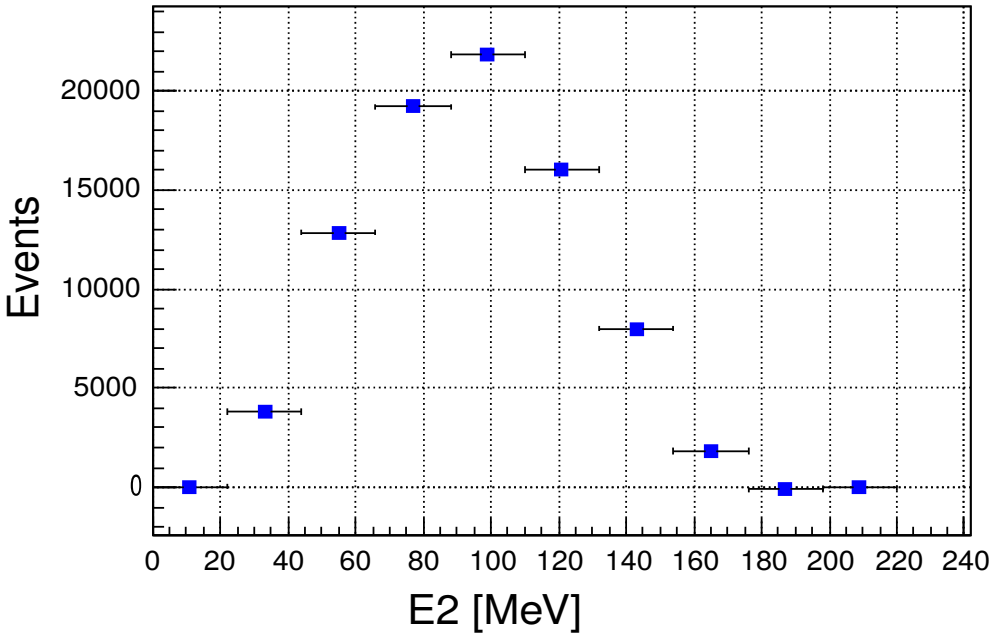


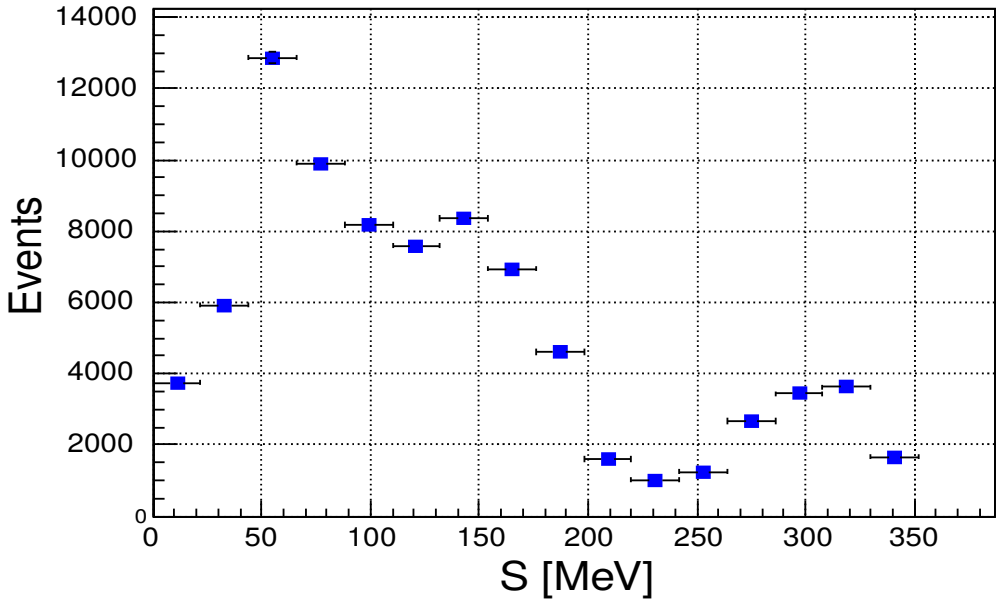
The energy correlation between two protons in coincidence for the three-body deuteron break-up reaction is shown as S-curves for several kinematical configurations

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

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





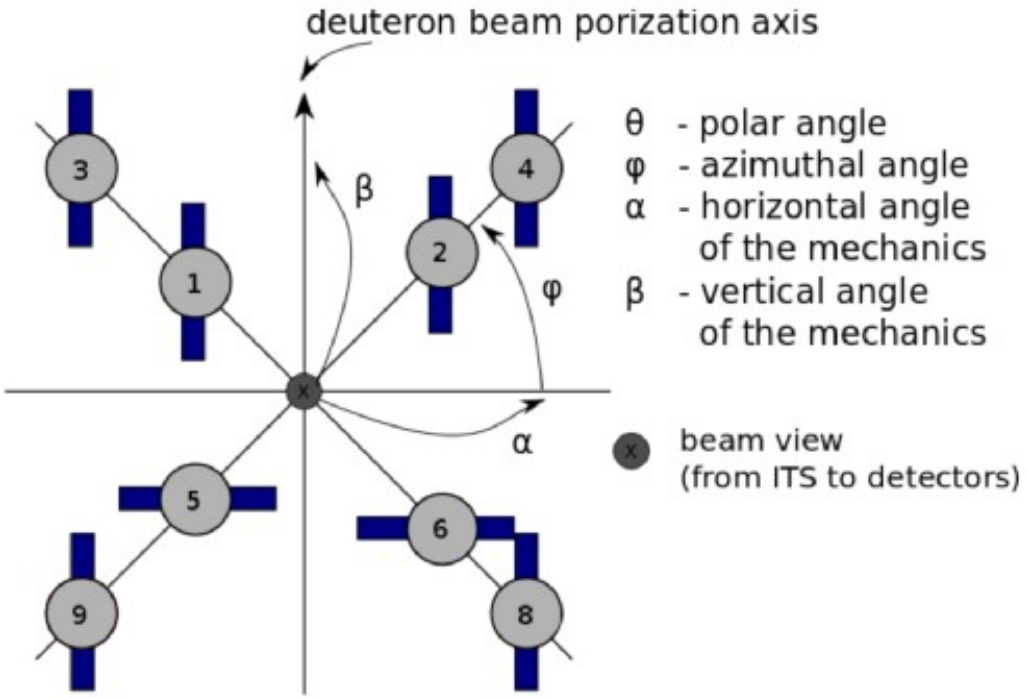


dp → ppn, two protons registered at angles:
θ_{p1}= 39º (±2.3º), θ_{p2}=43º (±2.3º)

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

Analyzing powers of dp breakup reaction at 400 MeV

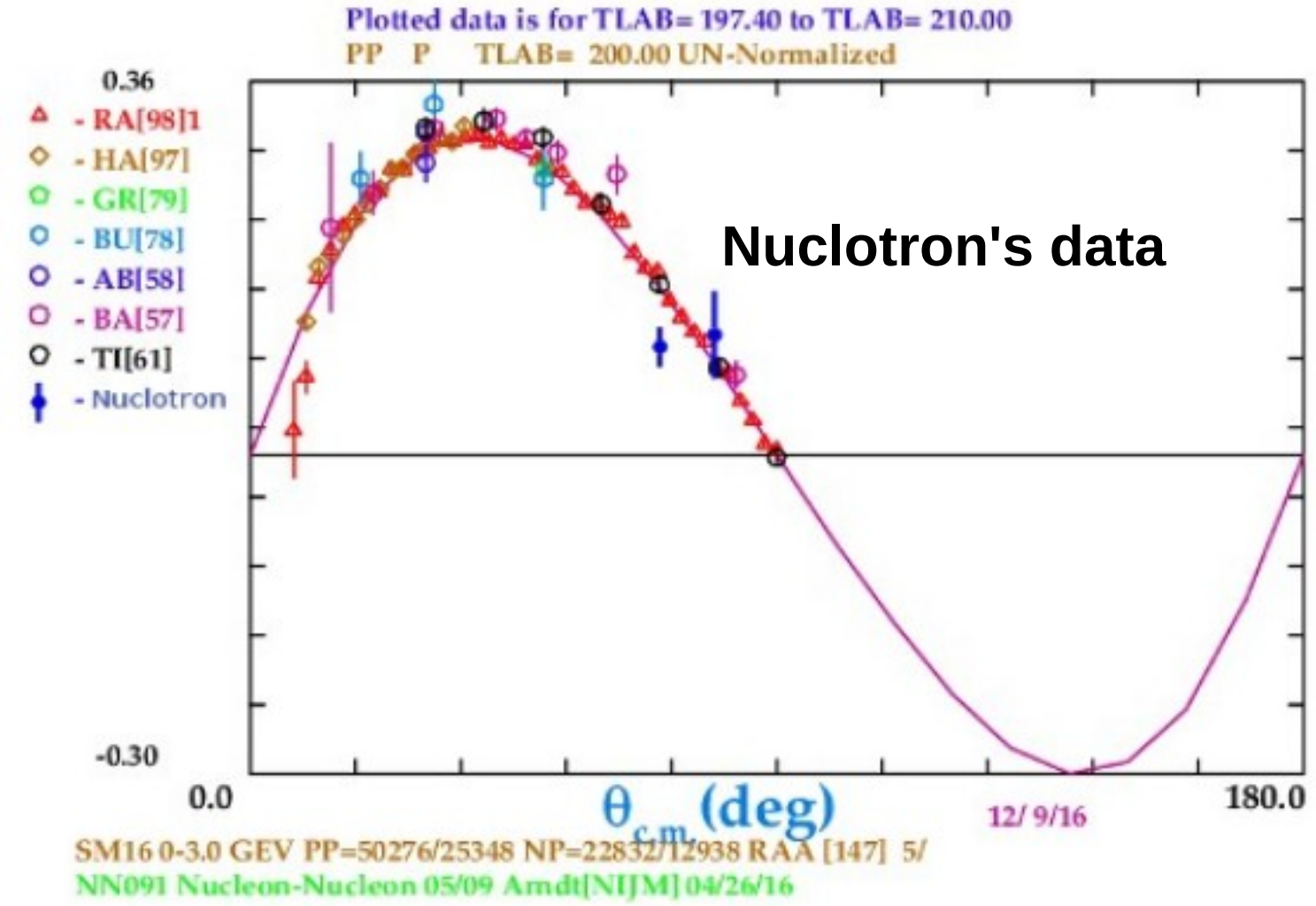
Detector No.	θ [°]	φ [°]	α[°]	β[°]
1	34.8	45.0	24.1	24.1
2	36.8	315.0	-25.0	25.0
3	50.4	45.0	38.6	38.6
4	52.5	315.0	-39.6	39.6
5	34.8	135.0	24.1	-24.1
6	36.8	225.0		
8	52.5	225.0		
9	50.4	135.0		



Detector placement is determined by polar **θ** and azimuthal **φ** angles.

Azimuthal angle **φ** have anticlockwise direction.

IT_{11} analyzing powers of dp breakup reaction at 400 MeV, pp-quasi kinematics



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

pp -quasi
72.3° and 76.5°

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		

Results combined

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

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!