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

49th meeting of the PAC for Particle Physics, 18.6. 2018

Collaboration

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Collaboration: Bulgaria-JINR-Japan(4)-Romania-Russia(3)-Slovakia(2)
12 Institutes and Research Centers
13 scientists from JINR
DSS FTE (JINR) = 9.33

Leaders: **Janek M., Ladygin V.P., Sekiguchi K.**.

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
- **dp breakup reaction** at deuteron energy (300 – 500) MeV

- 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

- The regime corresponding to constituent counting rules can occur already at T_d ~500 MeV for dd $\rightarrow$ ^{3}He n (^{3}Hp)

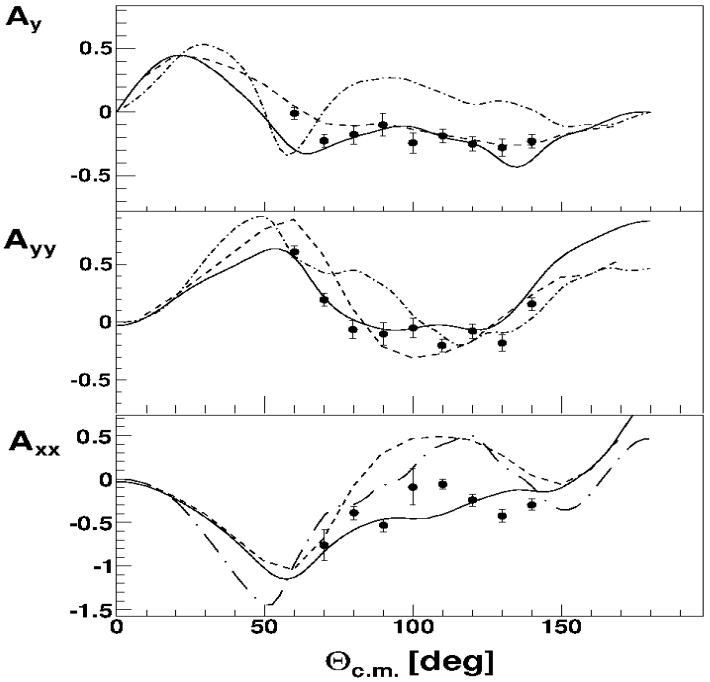
  (Yu. N. Uzikov JETP Lett, 81 (2005) 303-306)

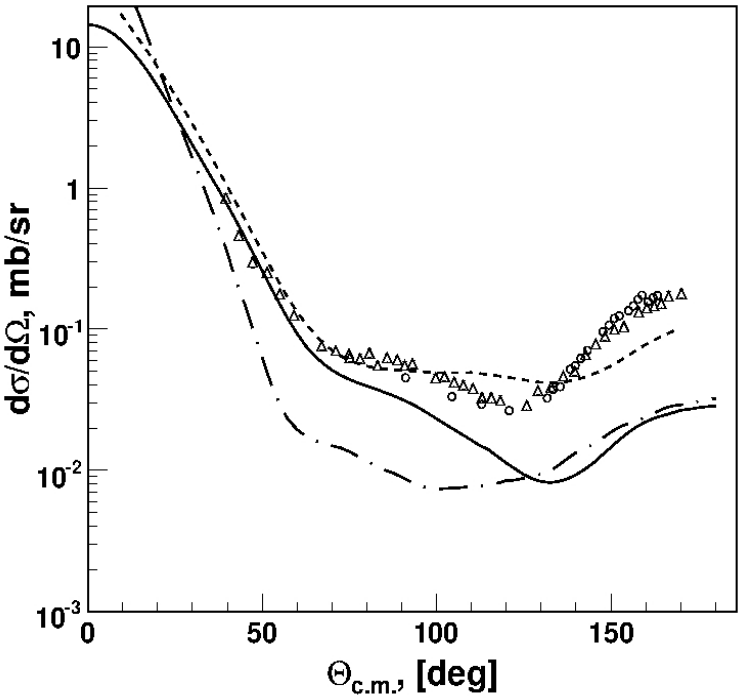
- The dp elastic data at ~300 MeV/nucleon are not described even taking into account relativistic effects. The reason of the discrepancy is nowadays called the importance of the short range 3NFs which are still not included.

- 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)

The systematic study of hadronic reactions induced by deuterons at Nuclotron allows to study the structure of 2N and 3N forces.

Analyzing powers in dp- elastic scattering at 880 MeV





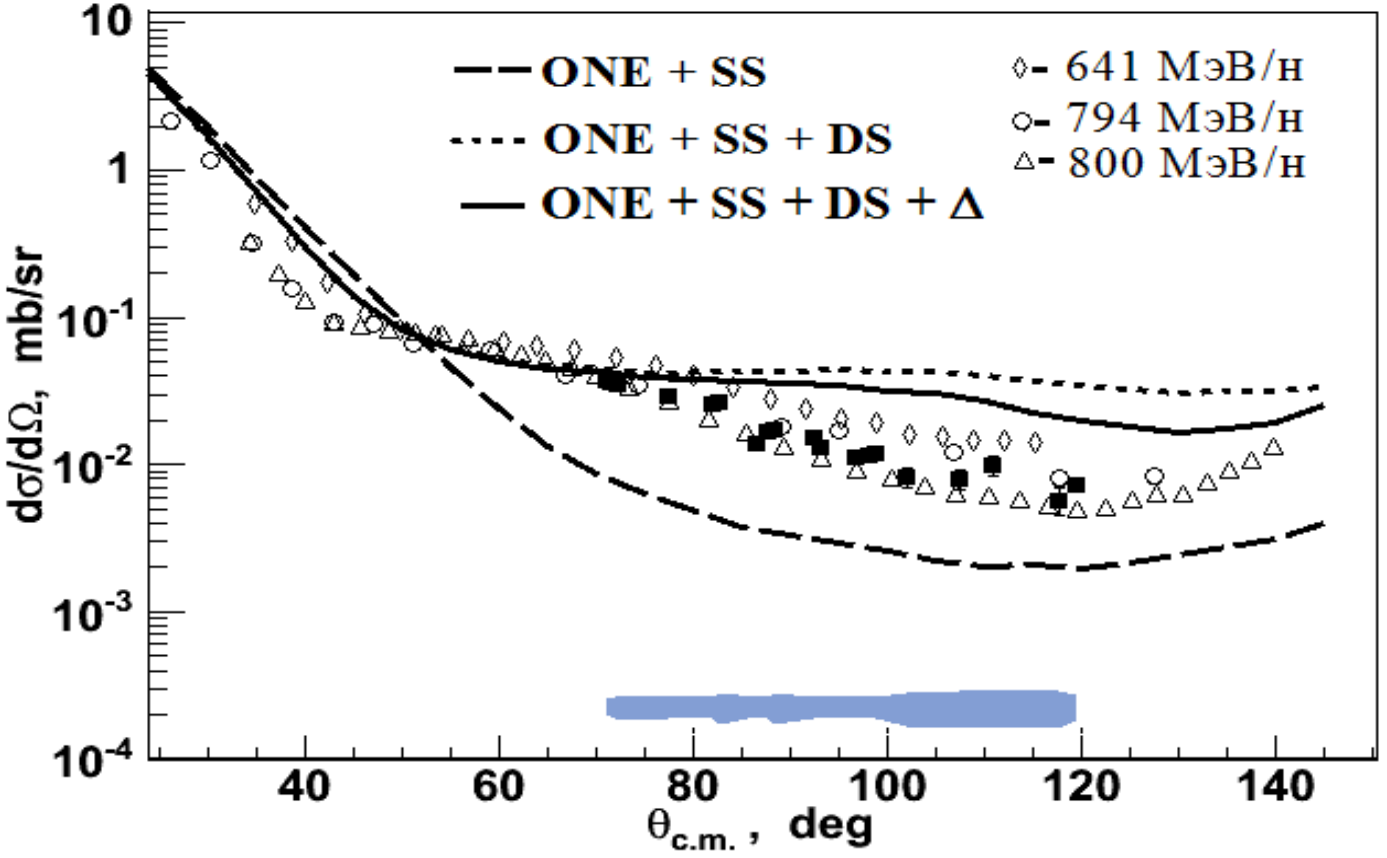
Dashed lines are the multiple scattering model calculations using CD - Bonn DWF (N.B.Ladygina, Phys.Atom.Nucl.71 (2008), 2039)

Solid lines are the Faddeev calculations using CD-Bonn potential (H.Witala, private communication)

Dott-dashed lines are the optical-potential calculations using Dibaryon DWF (M.Shikhalev, Phys.Atom.Nucl.72 (2009), 588)

Published in P.K.Kurilkin et al., Phys.Lett.B715 (2012) 61.

dp- elastic scattering cross section at 1400 MeV



A.A.Terekhin et al., Phys.Atom.Nucl. 80(2017) 1061.

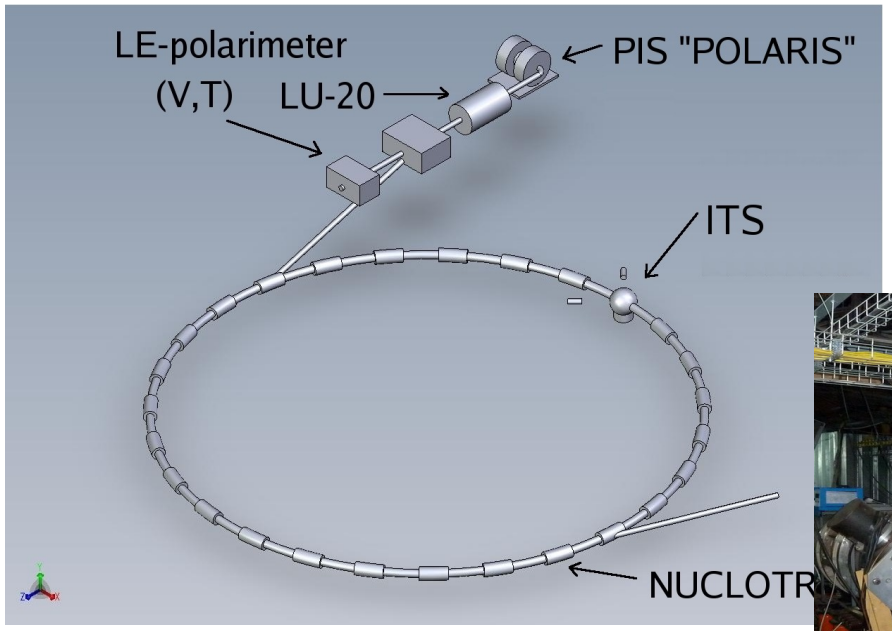
Relativistic multiple scattering model calculation:
N.B.Ladygina, Eur.Phys.J, A52 (2016) 199

Final cross section data at 1000, 1300 and 1800 MeV

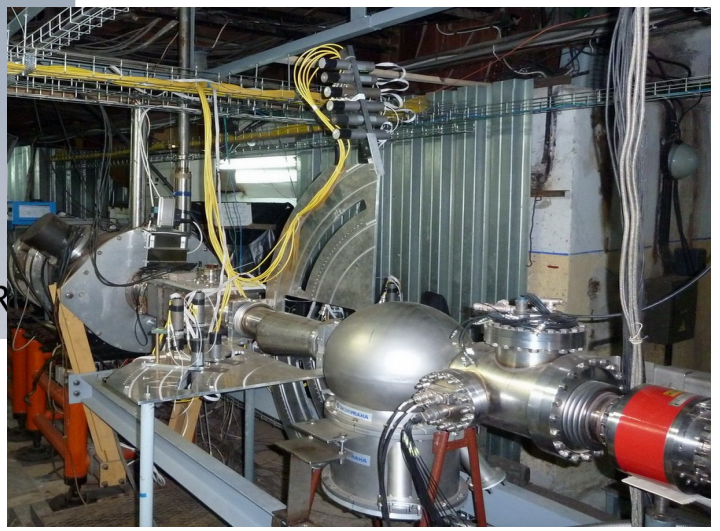
Experiments at Internal Target Station at Nuclotron (DSS-project)

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

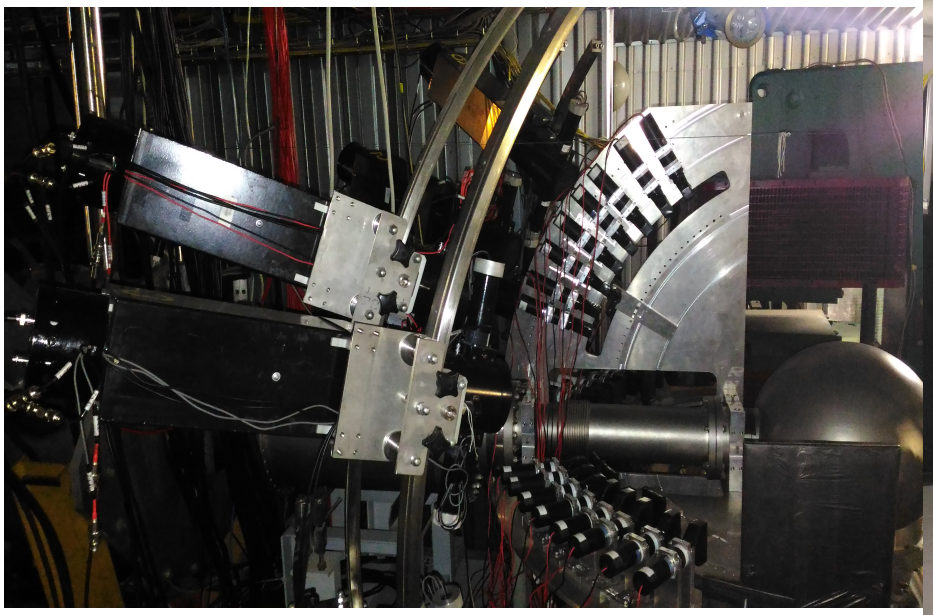
- dp-elastic scattering at the energies between 300 - 2000 MeV;
- dp-breakup with registration of two protons at deuteron energies of 300 - 500 MeV.

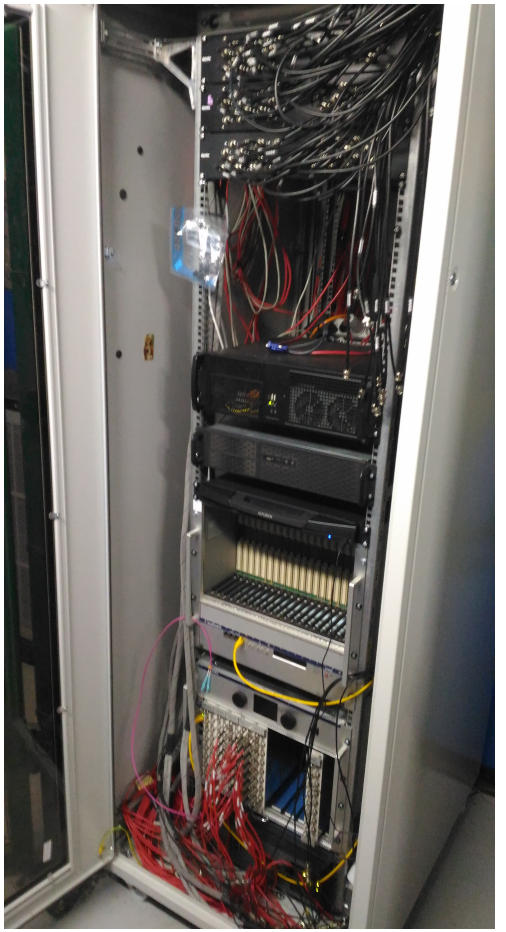


Internal Target Station is very well suited for the measurements of the deuteron- induced reactions observables at large scattering angles.



Upgrade of the Delta-LNS (DSS) setup at ITS at Nuclotron

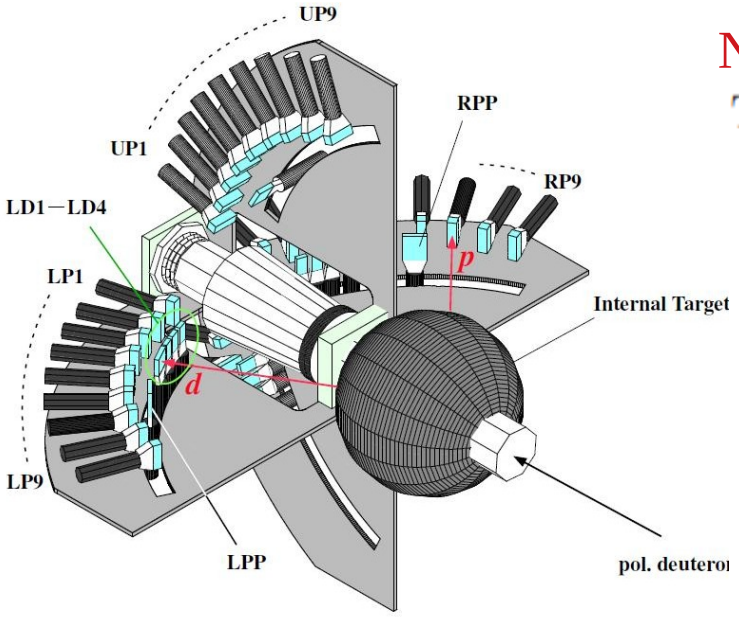




New infrastructure, cabling
New HV system (Mpod)
New VME DAQ
40 counters for dp-elastic scattering studies
8 dE-E detectors for dp -breakup studies

Results from the run in 2016 & 2017 years at Nuclotron at 270 MeV

- Deuterons and protons in coincidences using scintillation counters thin CH_2 target (C for background estimation)
- Measurement performed 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) – **June 2016**.



Nov. / Dec. 2016 and Feb. 2017 polarization measurement.

The vector and tensor polarization for different spin modes of SPI

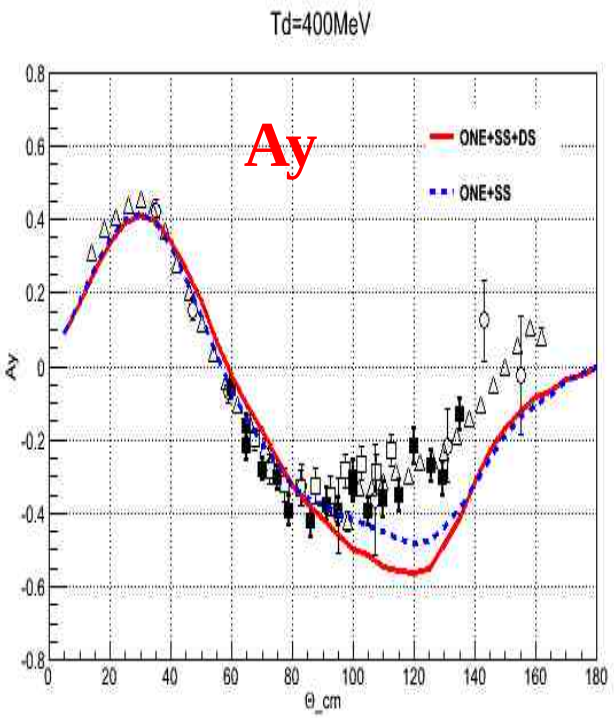
Spin mode(P_z, P_{zz})	P_z	dP_z	P_{zz}	dP_{zz}
(-1/3,+1)	-0.254	0.022	0.637	0.039
(-1/3,-1)	-0.223	0.017	-0.621	0.030
(-2/3,+1)	-0.489	0.026	0.631	0.045
(+2/3,0)	0.427	0.021	0.061	0.037
(0,+1)	0.030	0.027	0.880	0.049
(0,-2)	0.046	0.015	-1.469	0.031

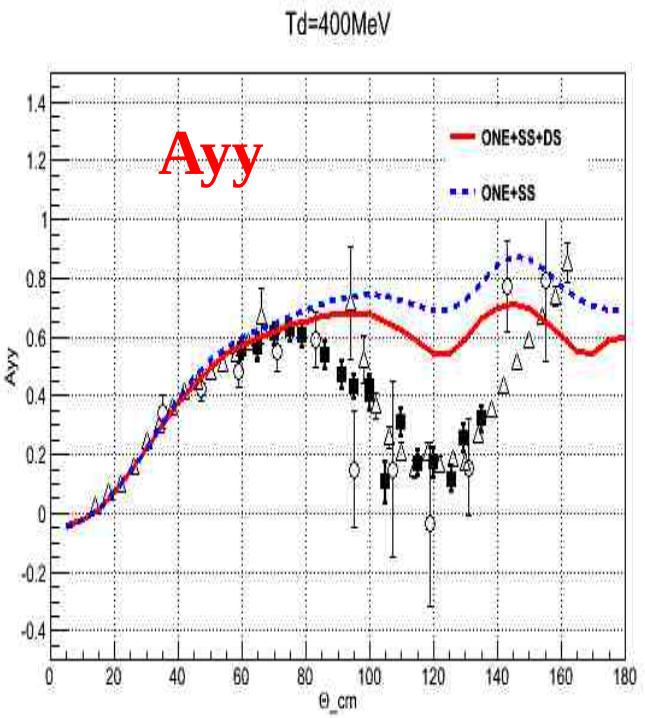
2017 feb/mar

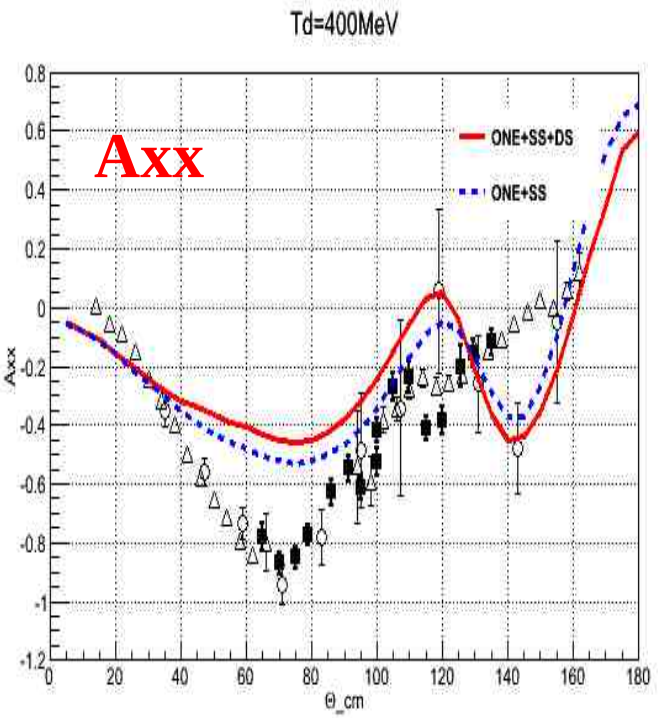
dp elastic scattering has been investigated with using polarized deuteron beam at Internal Target Station at various kinematic configurations at deuteron energies:

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

Angular dependence of the vector and tensor analyzing powers in dp-elastic scattering at 400 MeV



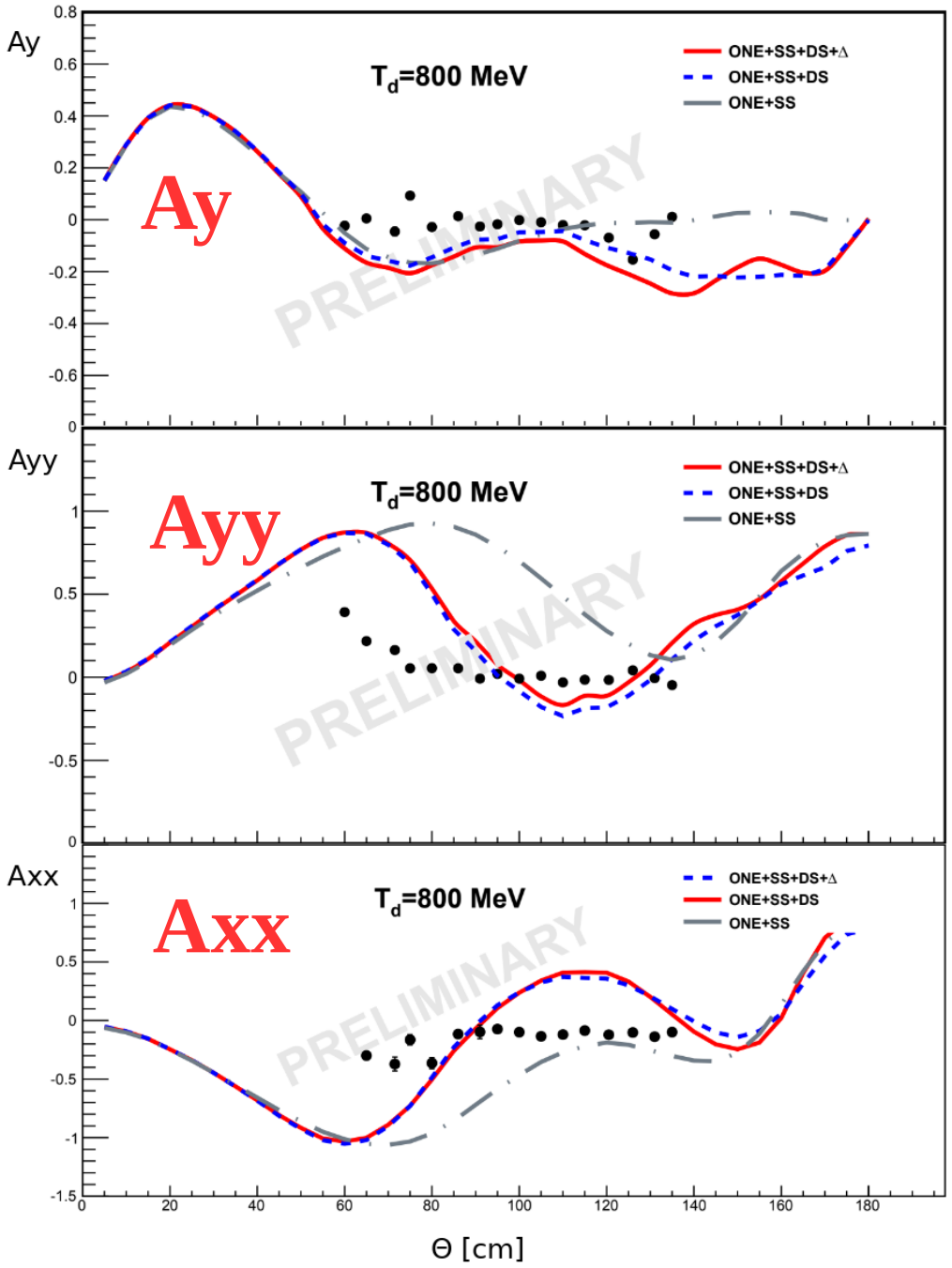




Full squares are the data fom Nuclotron (December 2016)

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

Dp-elastic @ 800 MeV, Ay, Ayy and Axx

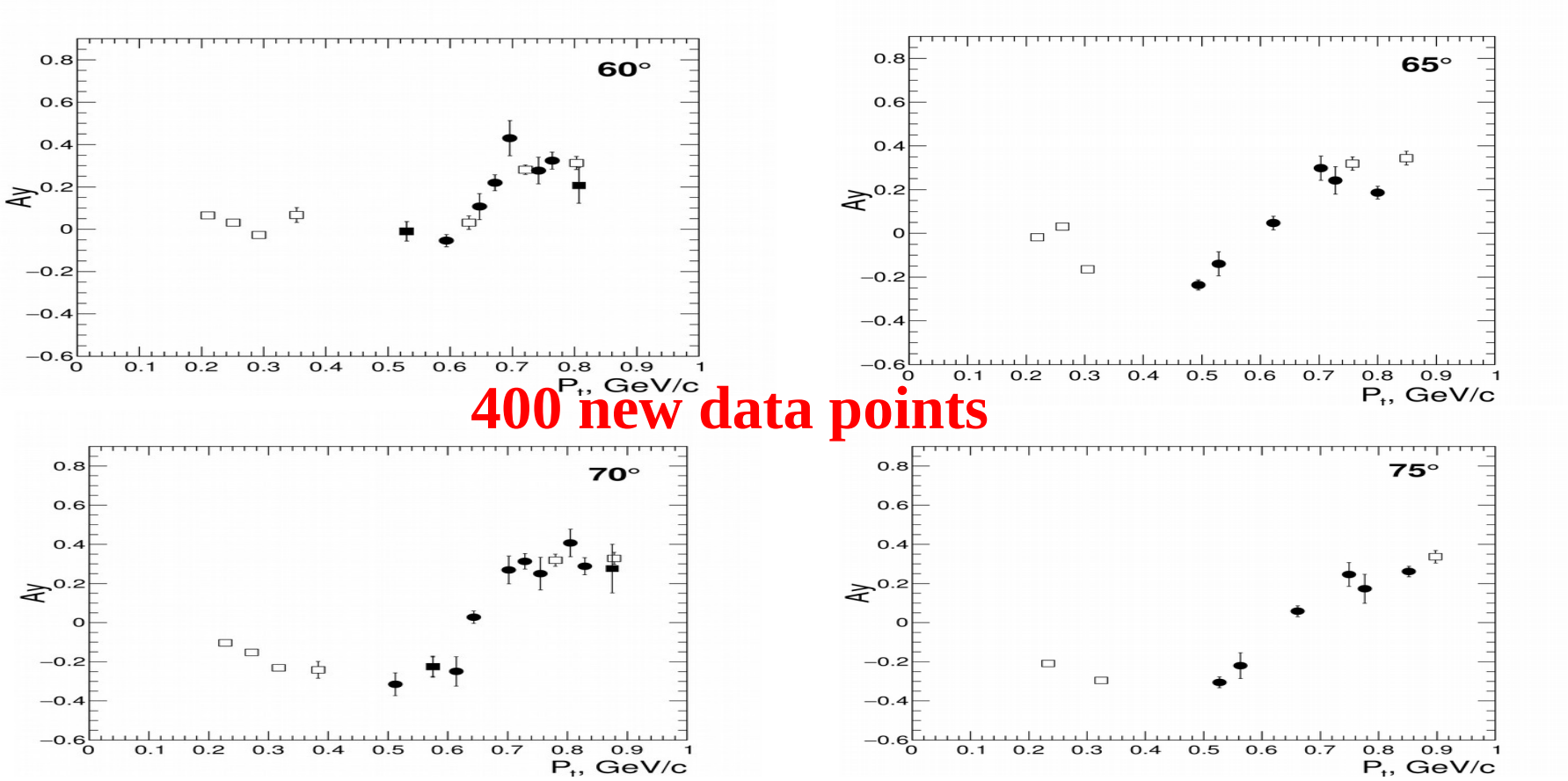


Relativistic multi-scattering model

Preliminary results

(E. Mezhenska, UPJS - Slovakia)

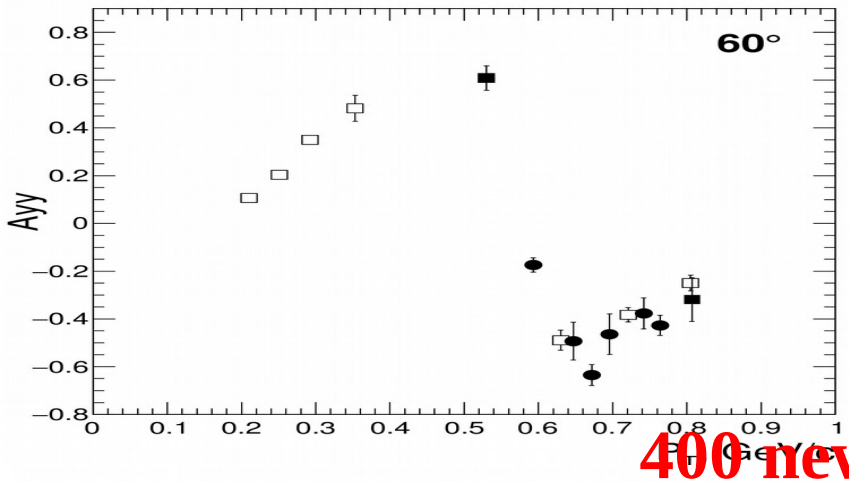
Energy dependence of the vector analyzing power Ay in dp-elastic scattering at 700-1800 MeV

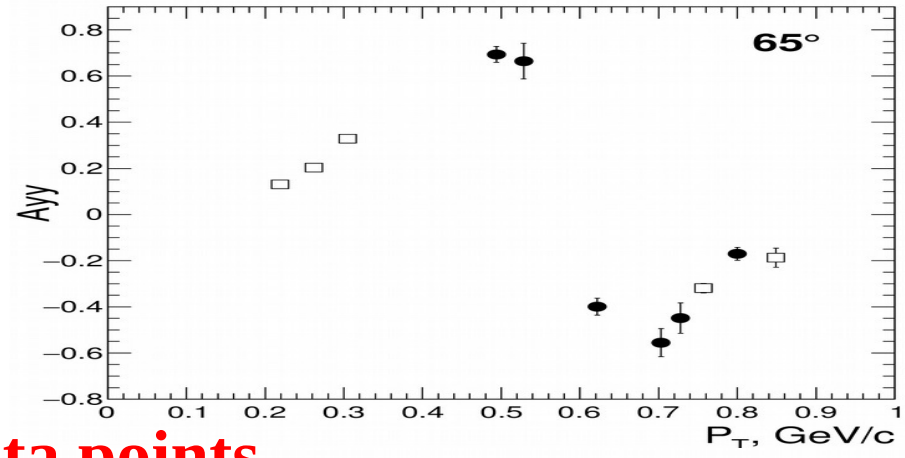


400 new data points

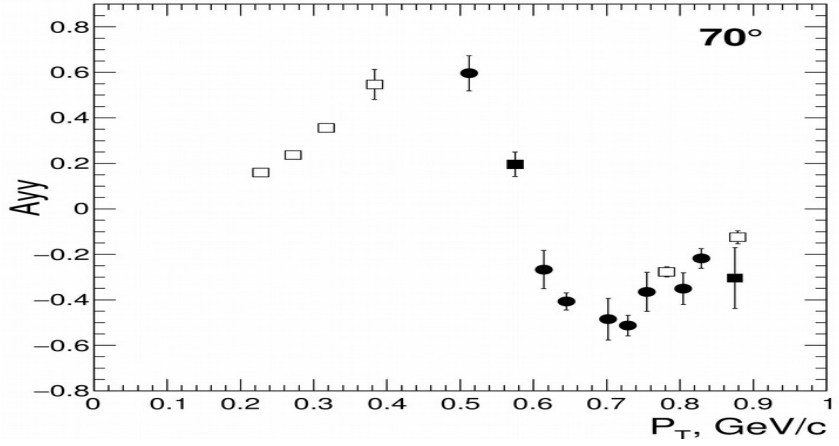
Full circles are the new preliminary data fom Nuclotron (2016-2017).
Full squares are the data fom Nuclotron (2005).
Open symbols are the world data.

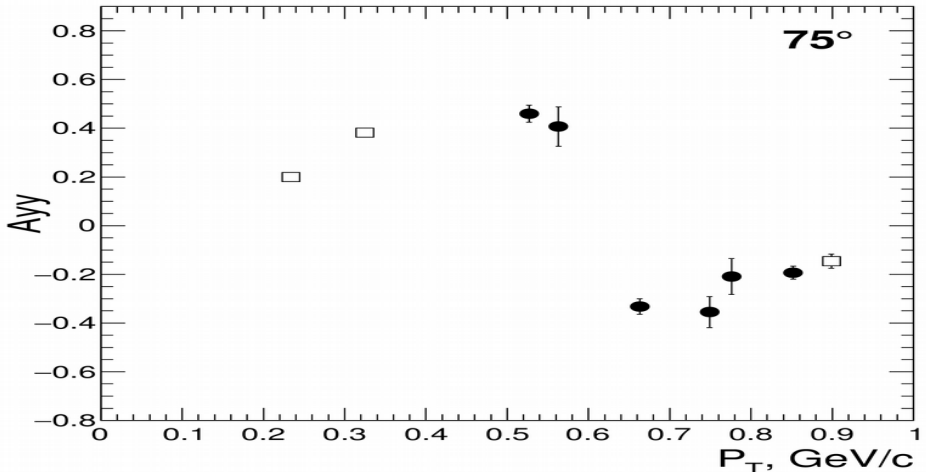
Energy dependence of the tensor analyzing power Ayy in dp-elastic scattering at 700-1800 MeV





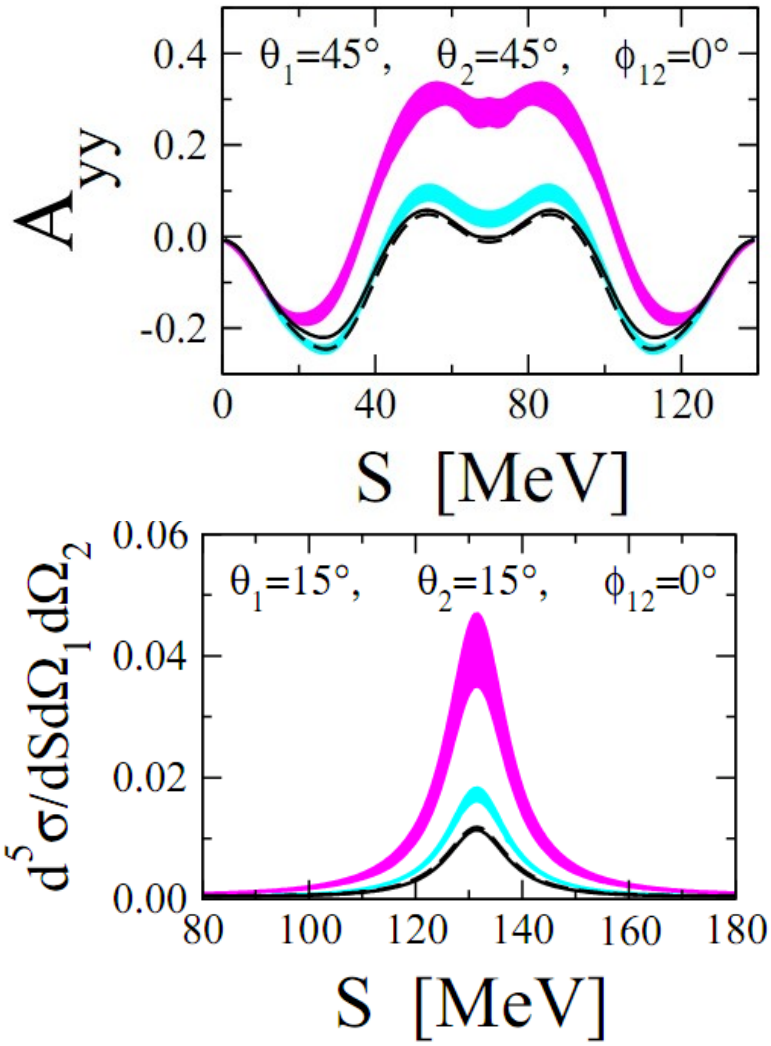
400 new data points





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

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.

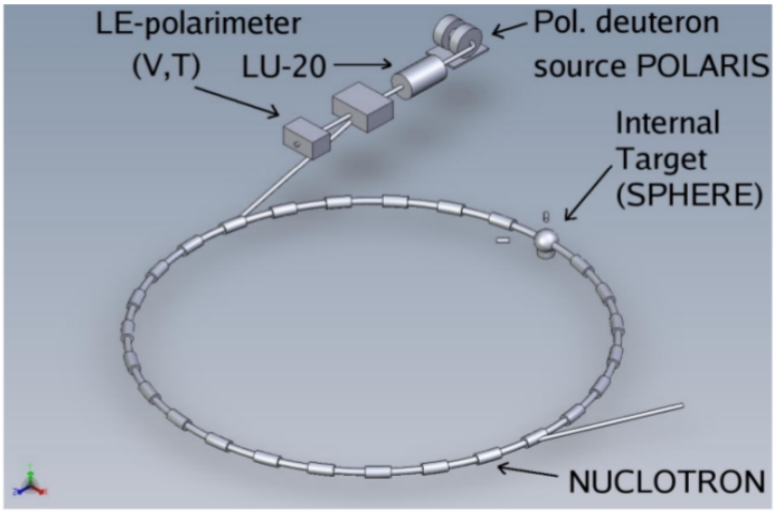
Θ_2 – polar angle of the 2-nd proton.

S – arc length along the kinematical curve.

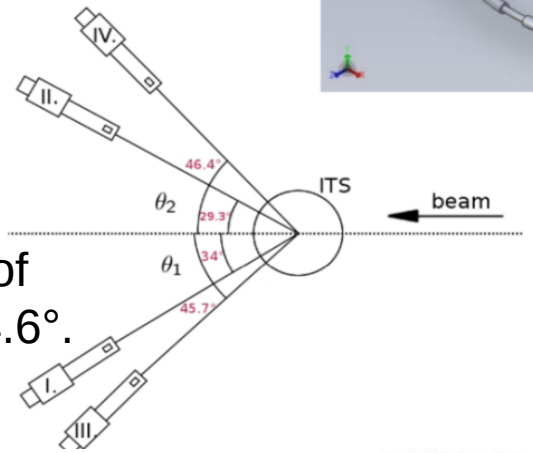
Φ_{12} – azimuthal angle with respect to the horizontal plane.

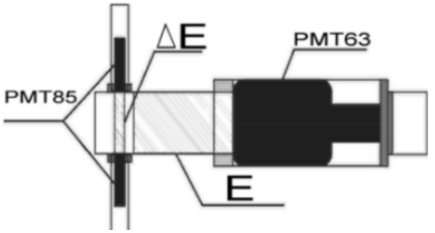
dp breakup reaction, Nuclotron

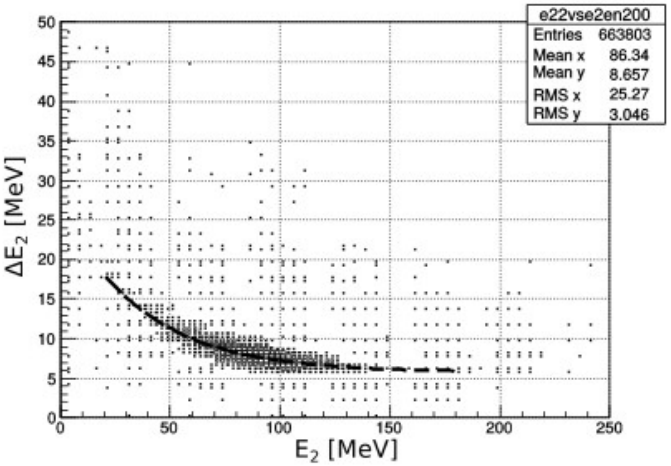
Internal Target Station is very well suited for the experiment on the measurement of the *dp*- breakup reaction.

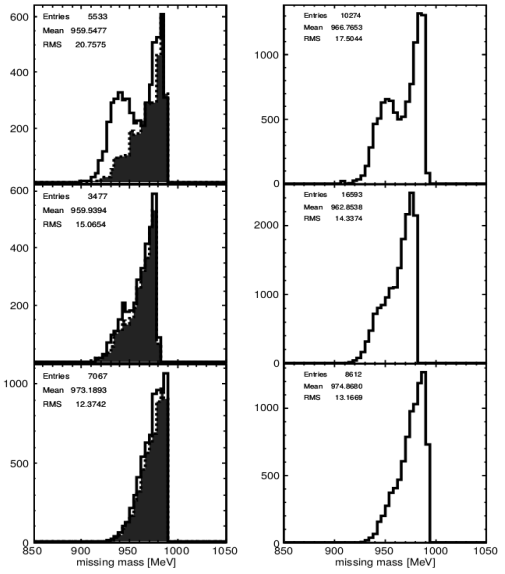


Θ (12°, 45°)
Φ (0°, 360°)
Space angle of the detector 4.6°.









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:

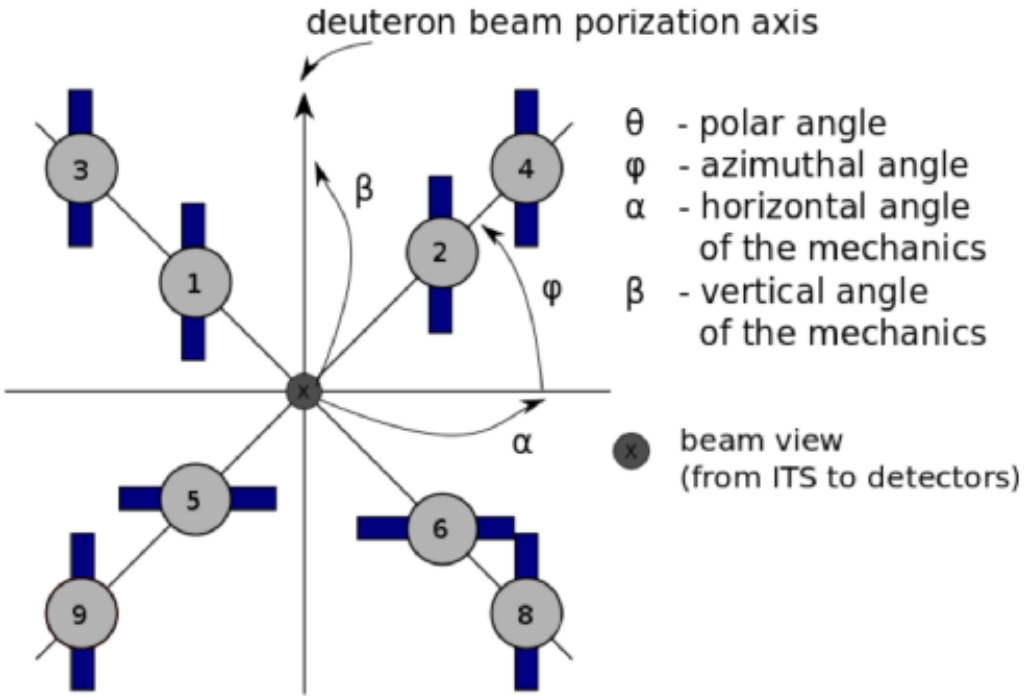
27°-43° (first row),
31°-43° (second row)
32°-38° (third row)

Analyzing powers of dp breakup reaction at 400 MeV

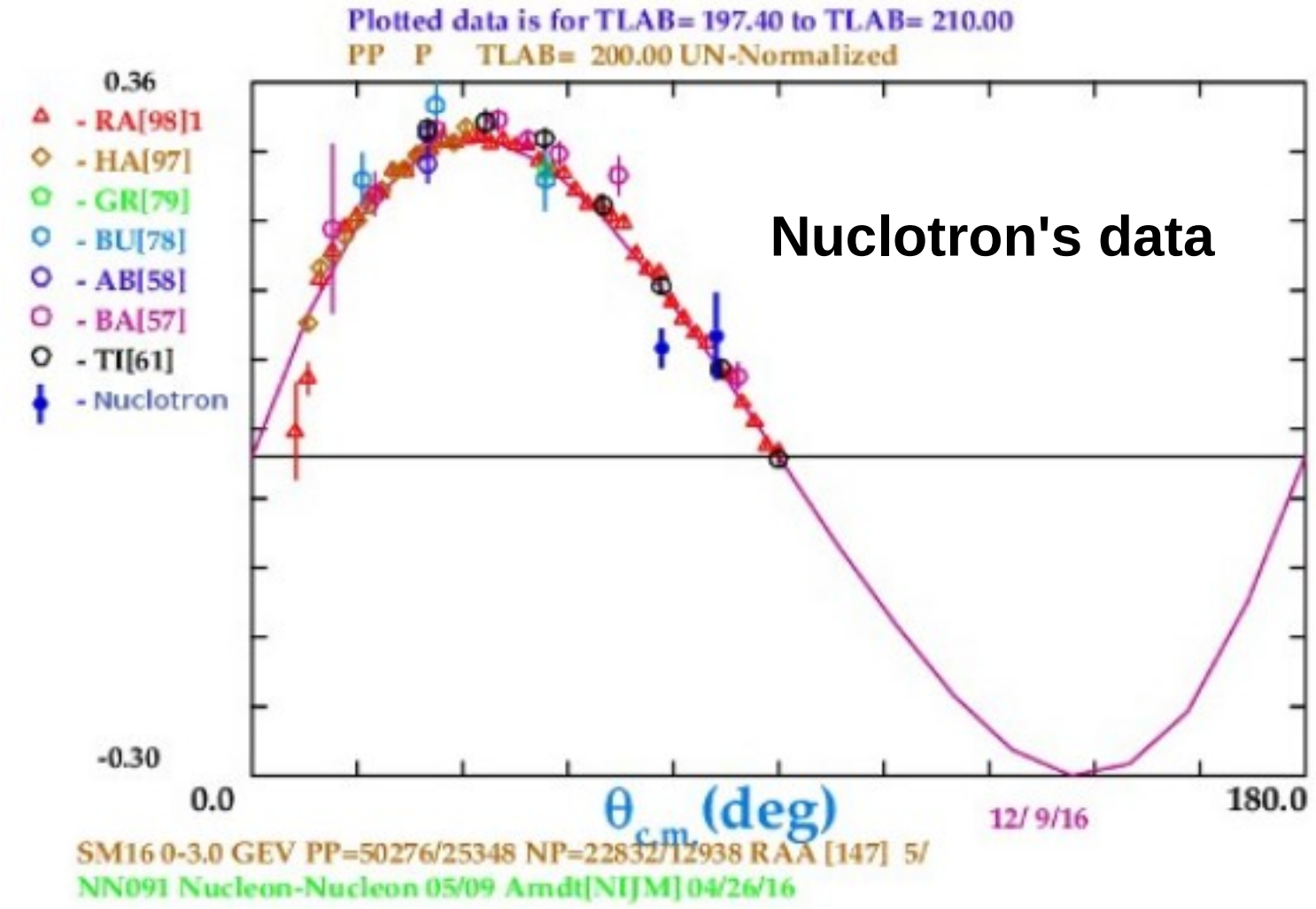
Detector No.	θ [°]	φ [°]	α[°]	β[°]
1	34.8	45.0	24.1	24.1
2	36.8	315.0	-25.0	25.0
3	50.4	45.0	38.6	38.6
4	52.5	315.0	-39.6	39.6
5	34.8	135.0	24.1	-24.1
6	36.8	225.0	-25.0	-25.0
8	52.5	225.0	-39.6	-39.6
9	50.4	135.0	38.6	-38.6

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

Azimuthal angle **φ** have anticlockwise direction.



iT_{11} analyzing powers of dp breakup reaction at 400 MeV, pp-quasielastic 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 -quasielastic
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.

Polarized protons at ITS.

Injection of 5 MeV protons into Nuclotron ring.
Acceleration up to 500 MeV- no serious depolarization resonances (Yu.Filatov).

Unpolarized protons: I∼1.5·10^8 ppp
Polarized protons: I∼2-3·10^7 ppp

IPol=1 P=-1 (WFT 1→3)
IPol=2 P=0 (unpolarized)
IPol=3 P=-1 (WFT 1→3)

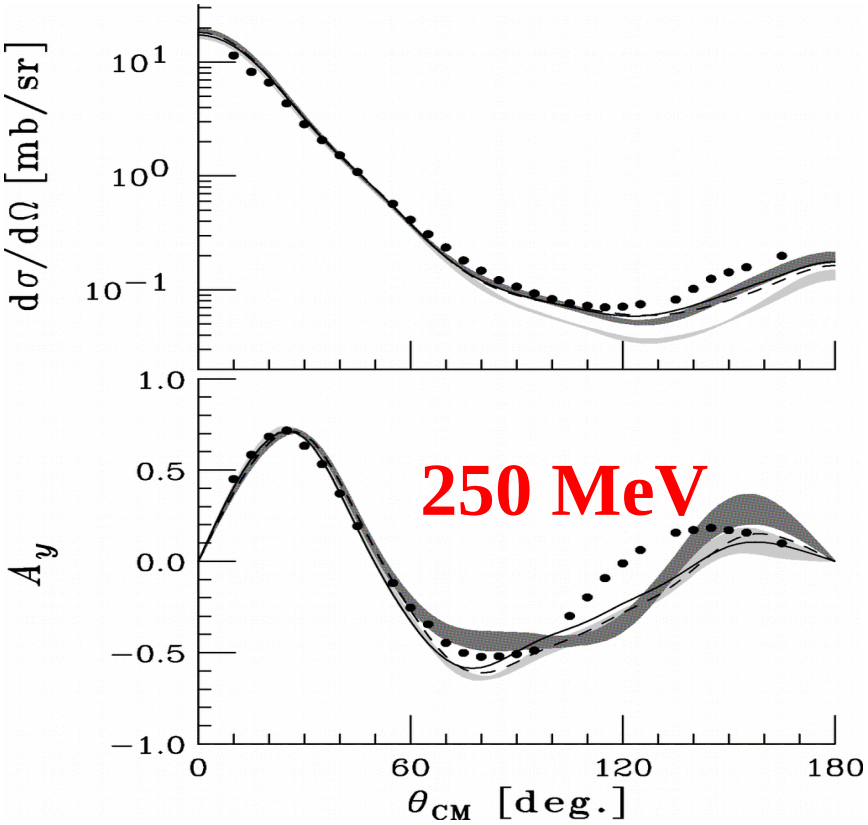
beam 2/3 of time.

Having the asymmetries for 8 angles (55^0-125^0 in the cms) we obtained the averaged value of the proton beam polarization

Unpolarized protons: P= 0.017 ±0.021
Polarized protons: P=-0.354 ±0.022

Need to produce new detection system for protons.

Energy scan of the proton analyzing power Ay in pd-elastic scattering at large angles



Problems in description at backward angles.

Relativistic effects become large ?

Short range 3NFs manifestation ?

Answers can be obtained from the energy scan at 100-1000 MeV (simultaneously with the polarimetry using pp-quasielastic scattering).

Publications, talks, thesis

- **The results are published or accepted in 2015-2018 in 10 regular papers (FBS, EPJA, PTE, 2*PAN, 4*PPNL, Z.Comm.).**

- **The results were reported in more than 20 talks at DSPIN-2015, HS-2015, IBSHEPP-XXIII, EFB23, MESON2016, DSPIN-2017 Conferences.**

- **2 Master + 1 Bachelor Thesis (2017).**

Beam-time request in 2019-2021 yy.

The total beam time request with new PIS in **2019-2021** is **700 hours** for the measurements at ITS. It includes **300** hours with ions for the tests and commissioning and **400** hours with polarized beams (protons and deuterons).

1. **Ay**, **Ayy** and **Axx** for intermediate energy **dp**-elastic scattering (below 700 MeV) with the precision of ±0.02 with averaged beam intensity $\sim 5 \cdot 10^9$.
2. **Ay**, **Ayy** and **Axx** for **dp**-nonmesonic breakup at 400 MeV with averaged beam intensity $\sim 5 \cdot 10^9$.
3. Simultaneous calibration of the ITS and external beam polarimeters at 1600 MeV. The expected error bars are ±0.02 for the analyzing powers with averaged beam intensity $\sim 5 \cdot 10^9$.
4. Energy scan of the nucleon analyzing power **Ay** in **pd**-elastic scattering at 100-1000 MeV with polarized protons

Risks:

peak intensity was $\sim 8 \cdot 10^8$ and $\sim 2 \cdot 10^7$ for deuterons and protons, respectively.

JINR expenses in 2019-2021 yy.

Estimated expenditures for the Project Probing the Deuteron short-range Spin Structure in the (d,p) reactions using polarized deuteron beam at Nuclotron-M (DSS)

	Expenditure items	Full cost	1st year	2nd year	3rd year…
	Direct expenses for the Project				
1.	Accelerator, Nuclotron-M	700	-	300	400
2.	Computers	-	-	-	-
3.	Computer connection	-	-	-	-
4.	Design bureau	300	100	100	100
5.	Experimental Workshop	500	200	200	100
6.	Materials	40	17	17	6
7.	Equipment	44	16	16	12
8.	Construction/repair of premises	-	-	-	-
9.	Payments for agreement-based research	-	-	-	-
10.	Travel allowance, including:	36	12	12	12
	a) non-rouble zone countries	20	7	7	6
	b) rouble zone countries	16	5	5	6
	c) protocol-based				
	Total direct expenses	120	45	45	30

PROJECT LEADER
LHEP DIRECTOR
LHEP CHIEF ENGINEER-ECONOMIST

New counters for proton beam, new mechanics, CAEN electronics

Expected results in 2019-2021

The systematic data on the cross section and analyzing powers A_y, A_{yy} and A_{xx} in dp-elastic scattering at between 700 MeV and 1800 MeV will be analyzed and submitted to regular journals.

New systematic data on the analyzing powers A_y, A_{yy} and A_{xx} in dp- elastic scattering at between 270 MeV and 700 MeV will be obtained at ITS.

New polarized data for the dp- nonmesonic breakup at the energies between 300 and 500 MeV for complanar geometry will be obtained at ITS.

The proton beam polarimeter for the energy range of 0.1-3.5 GeV will be developed and calibrated with the error bars for analyzing powers ±0.02.

The nucleon vector analyzing power A_y in pd- elastic scattering at between 100 MeV and 1000 MeV will be obtained at ITS.

The theoretical analysis of the observables in hadronic reactions with the participation of light nuclei will be continued.

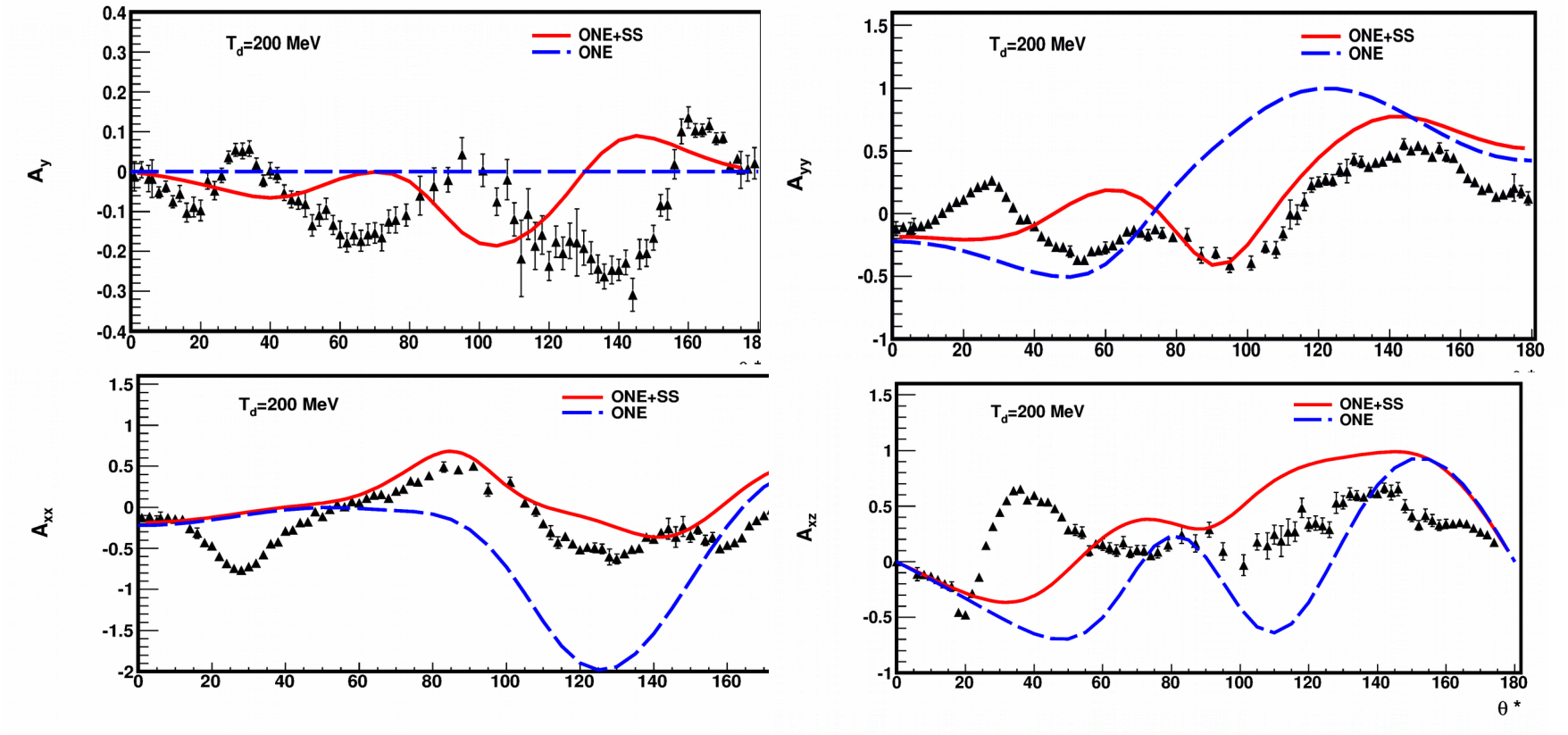
Request

Prolongate the DSS- project for 3 years (2019-2021) with the 1-st priority.

The realization of the project in 2019-2021 will allow to obtain the crucial data on the spin structure of 2-nucleon and 3-nucleon short range correlations (2N and 3N SRC) and to develop the efficient polarimetry for Nuclotron and NICA.

Thank you for the attention!!!

Polarization effects in the dd → ^{3}Hen(^{3}Hp) reactions at Nuclotron energies



The relativistic multiple scattering model was successfully used to describe the dd → ^{3}Hen (^{3}Hp) reactions in a GeV region at the Nuclotron.

The calculations require a large amount of CPUs.

The results were published in FBS, PRC, PPN, Phys.Atom.Nucl.

DSS FTE = 9.33

V.P.Ladygin	0.5
E.V.Chernykh	0.9
Yu.V.Gurchin	1.0
A.Yu.Isupov	1.0
A.N.Khrenov	0.5
N.B.Ladygina	1.0
A.N.Livanov	0.1
S.M.Piyadin	-
S.G.Reznikov	1.0
Yu.T.Skhomenko	1.0
A.A.Terekhin	1.0
A.V.Tishevsky	1.0
I.S.Volkov	0.33
NEOAFI	0.15

2018 – start at SPD (proton beam and Local polarimetry)