Probing the Deuteron short-range Spin Structure in the (d,p) reactions using polarized deuteron beam at Nuclotron

Prolongation for 2022-2024 yy

M. Janek on behalf of DSS collaboration

55-th meeting of the PAC for Particle Physics, 21-22.06.2021

Collaboration

V.A.Baskov[2], E.V.Chernykh[1] , I.Dobrin[3] , V.A.Dronov[2], D.Enache[3], S.G.Genchev[4], Yu.V.Gurchin[1] , A.Yu.Isupov[1] , F.Chernobila[5], M.Janek[5], J.-T.Karachuk[3], A.N.Khrenov[1], V.P.Ladygin[1], N.B.Ladygina[1], A.N.Livanov[1], A.I.Lvov[2] , Y.Maeda[7], G.Martinska[8] , O.Mezhenska[8] , K.Miki[9], S.Nakai[9], S.Ohta[10] , S.M.Piyadin[1], V.V.Polansky[2], S.G.Reznikov[1] , D.Sakai [9], K.Sekiguchi [9] , S.Shibuya[9] , S.S.Sidorin[2] , V.V.Syschenko[11], G.Tarjanyiova [5], A.A.Terekhin[1] , A.V.Tishevsky[1] , T.Uesaka[12], J.Urban [8], M.Veverichek [5], A.Watanabe [9] , I.E.Vnukov[11], I.S.Volkov [1]

~40 participants (8.3 FTE from JINR)

Collaboration: Bulgaria-JINR-Japan(4)-Romania-Russia(2)-Slovakia(2)

11 Institutes, Universities and Research Centers

12 scientists from JINR

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

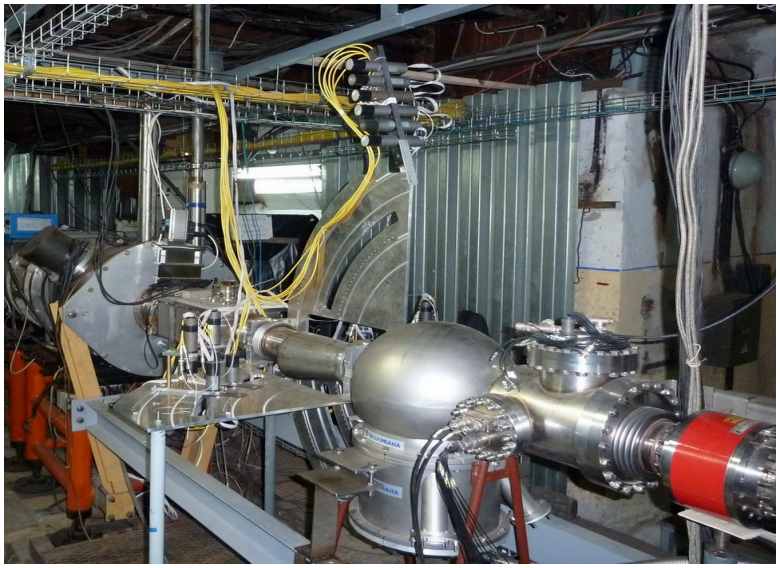
Studies at ITS at Nuclotron

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

1.dp-elastic scattering at the energies between 300 - 2000 MeV;

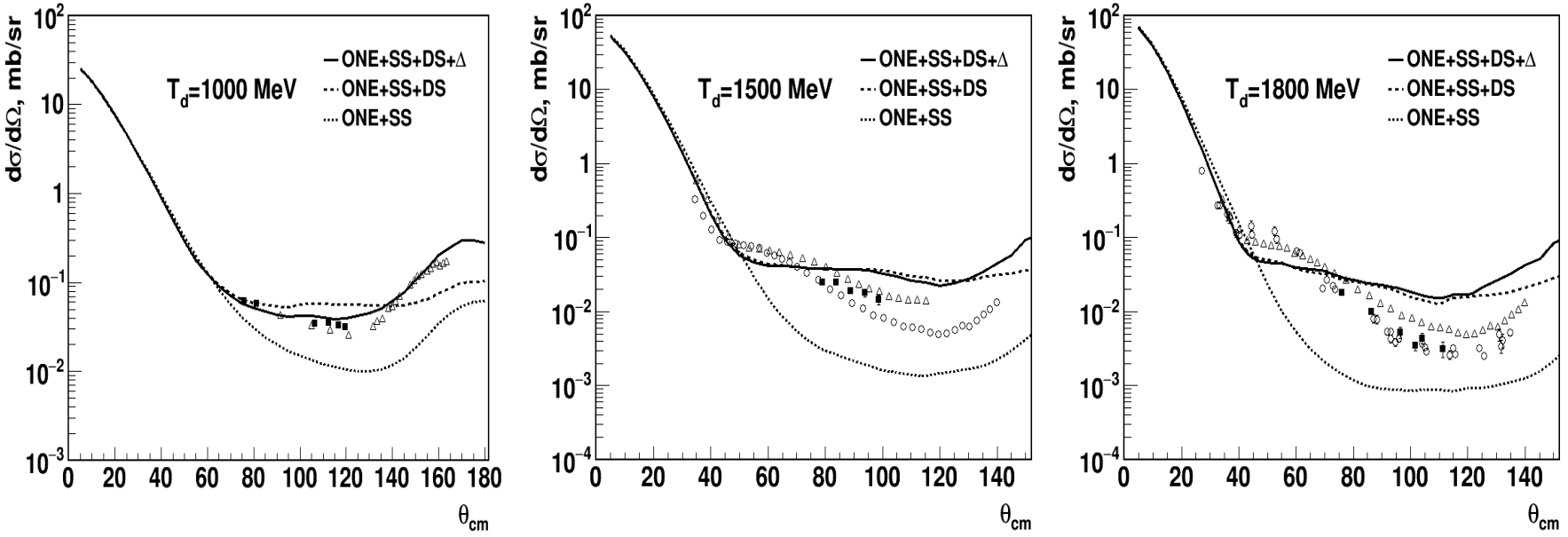
2.dp-breakup with registration of two protons at deuteron energies of 300 - 500 MeV.

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



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

dp- elastic scattering cross section energy scan at 1000-1800 MeV

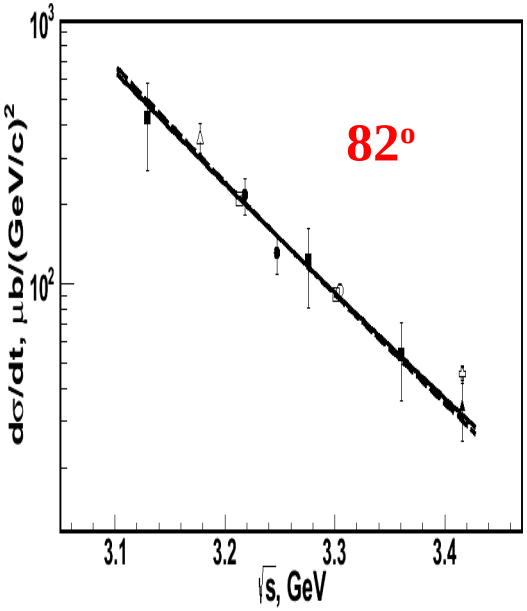


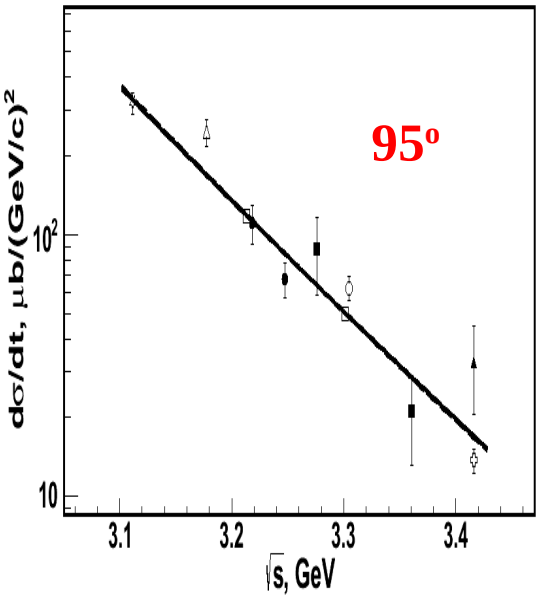
A.A.Terekhin et al., Eur.Phys.J., A55 (2019) 129

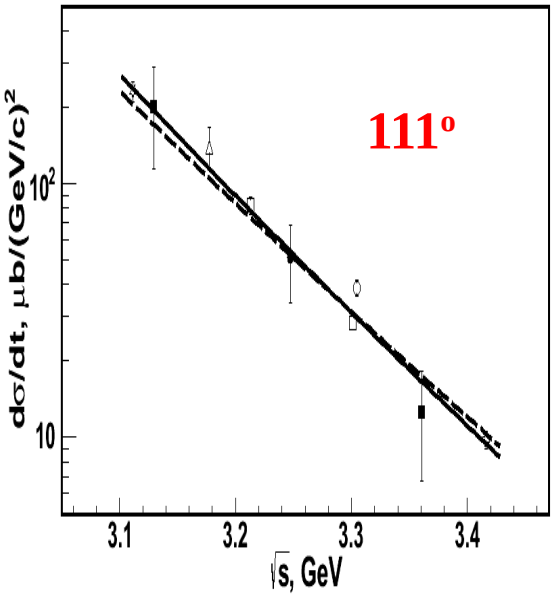
Relativistic multiple scattering model calculation:
N.B.Ladygina, Eur.Phys.J, A56 (2020) 5, 133

VBLHEP-JINR award in 2019
A.A.Terekhin PhD Thesis 2020

dp- elastic scattering cross section scaling properties at the fixed angles in cms







A.A.Terekhin et al., Eur.Phys.J., A55 (2019) 129

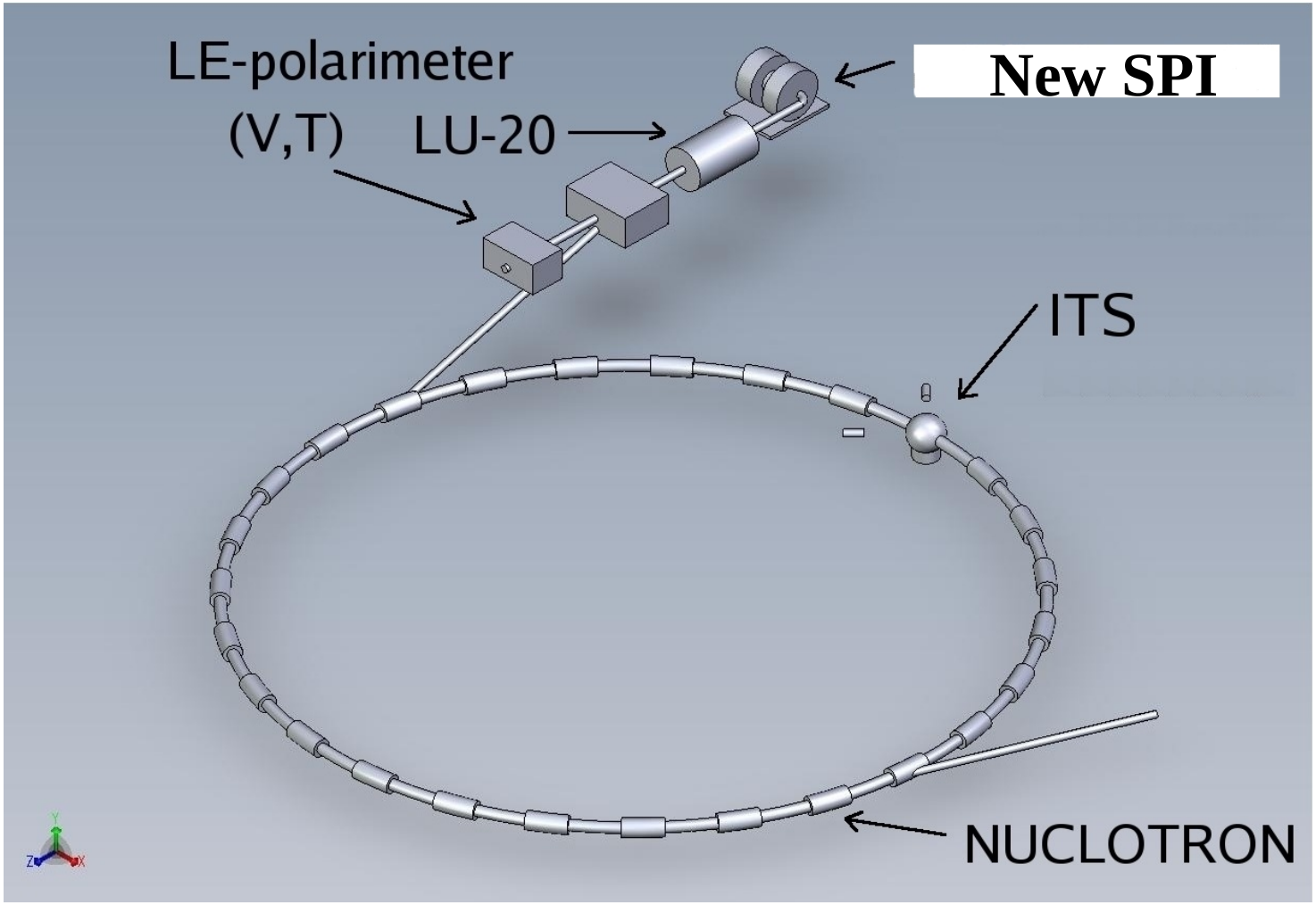
Constituent Counting Rules predictions:

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

1. self-similarity,
2. pQCD,
3. AdS/QCD correspondence

S^{-16}

Nuclotron-M accelerator complex



General View of SPI

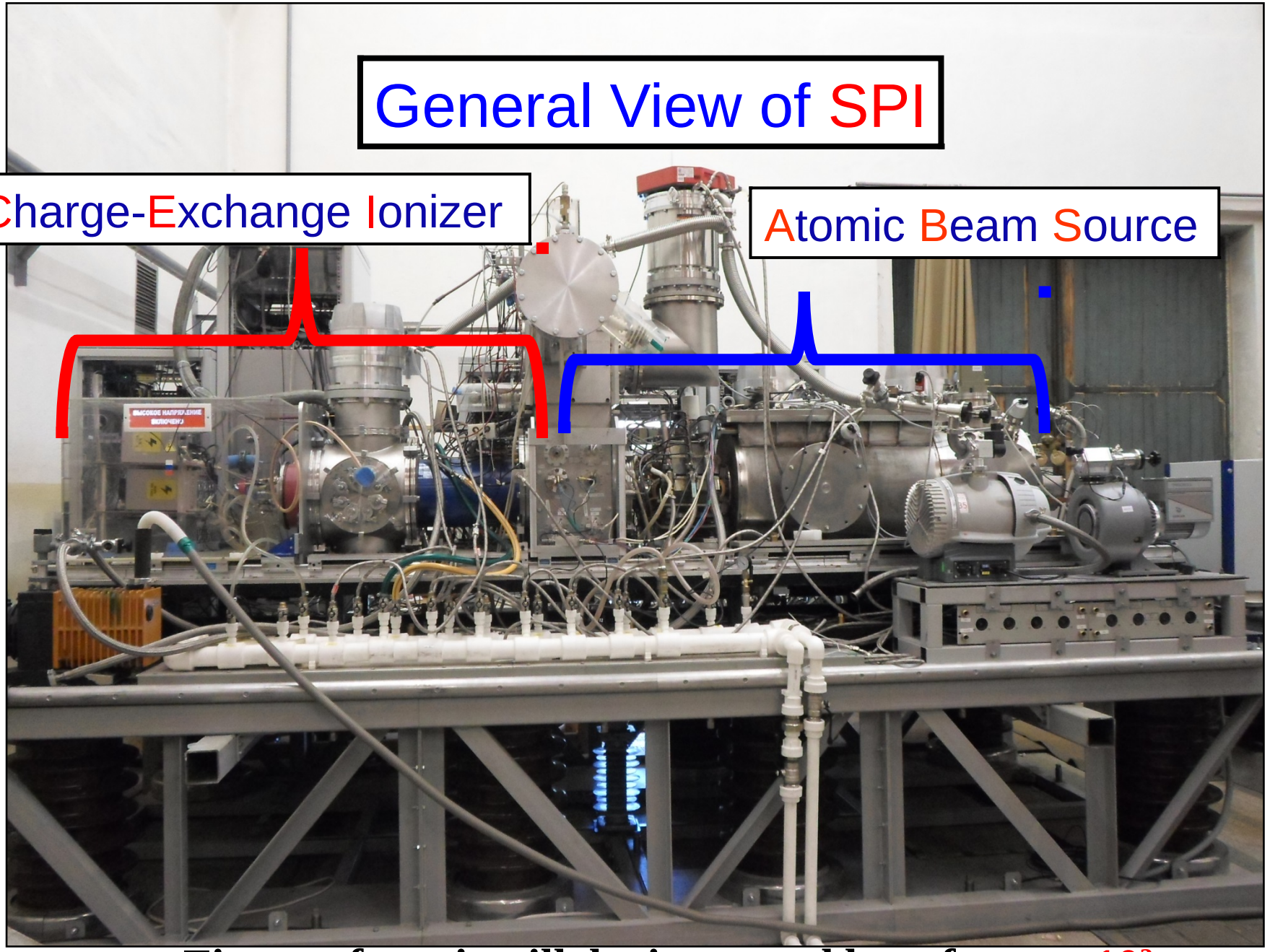
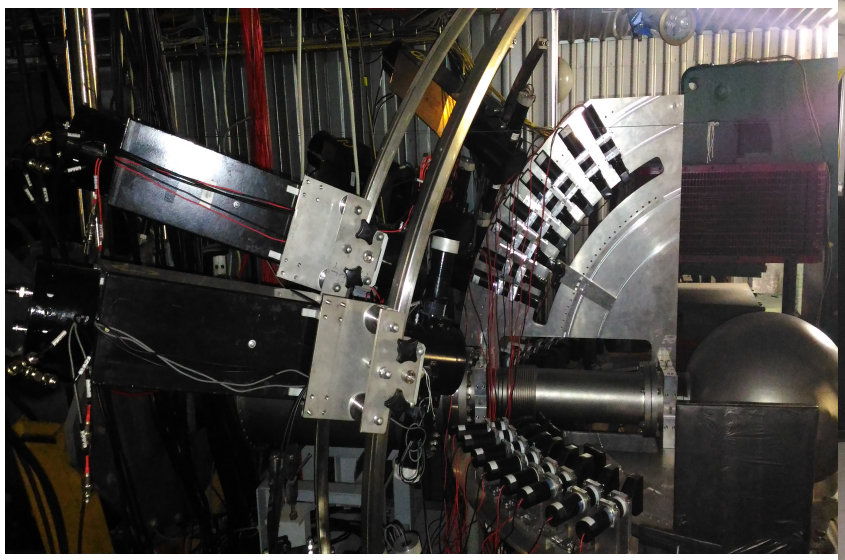
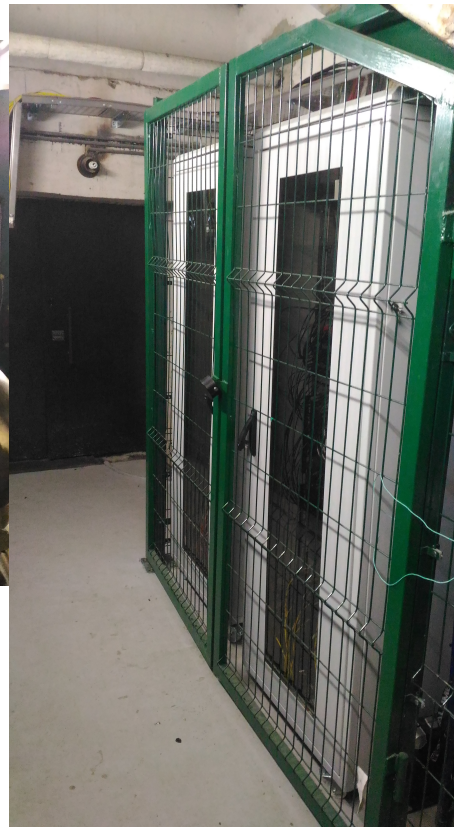


Figure of merit will be increased by a factor ~10^3

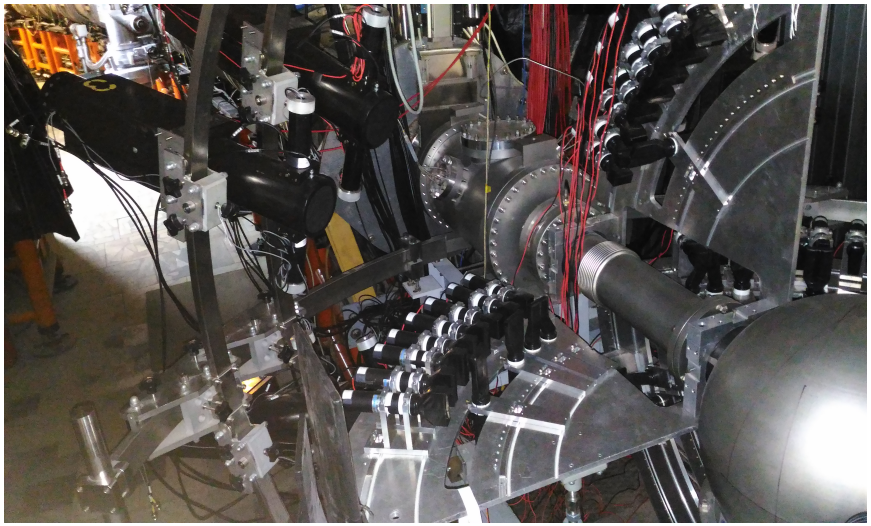
Upgrade of the Delta-LNS (DSS) setup at ITS at Nuclotron

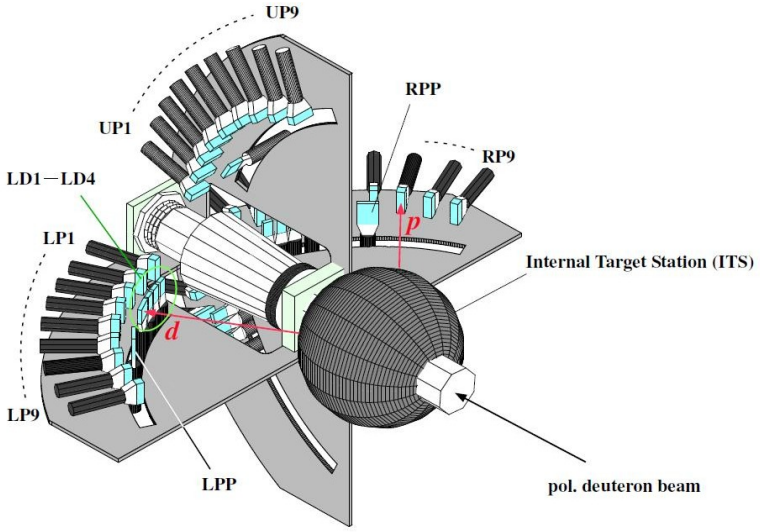




New infrastructure, cabling
New HV system (Mpod)
New VME DAQ
40 counters for dp-elastic scattering studies
8 dE-E detectors for dp -breakup studies

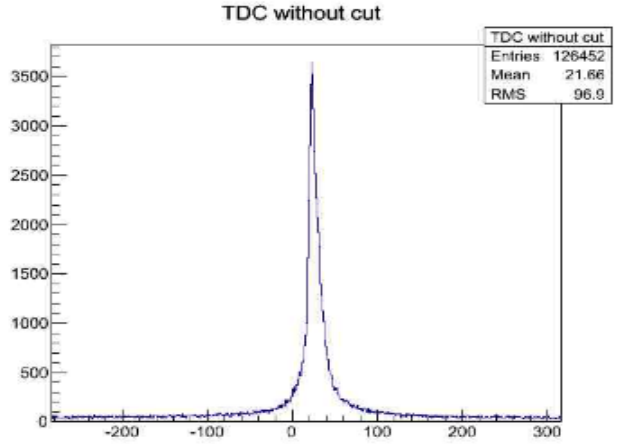
Setup to study dp- elastic scattering at ITS at Nuclotron

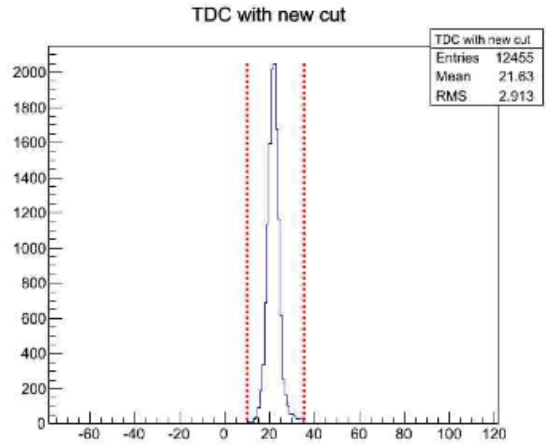


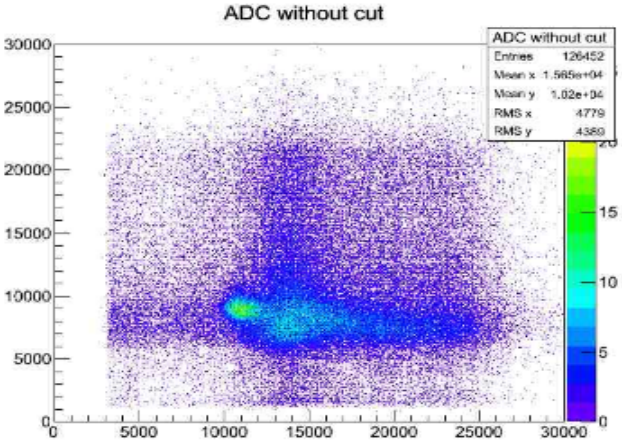


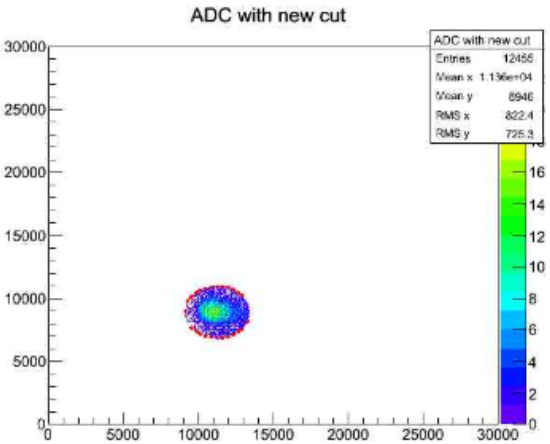
Deuterons and protons in coincidences using scintillation counters
Internal beam and thin CH_2 target (C for background estimation)
Permanent polarization measurement at 270 MeV (between each energy).
Analyzing powers measurement at 400-1800 MeV
The data were taken for three spin modes of SPI: unpolarized, “2-6” and “3-5” (p_z,p_{zz}) = (0,0), (1/3,1) and (1/3,-1).
Typical values of the polarization was 70-75% from the ideal values.

The dp-elastic scattering events selection



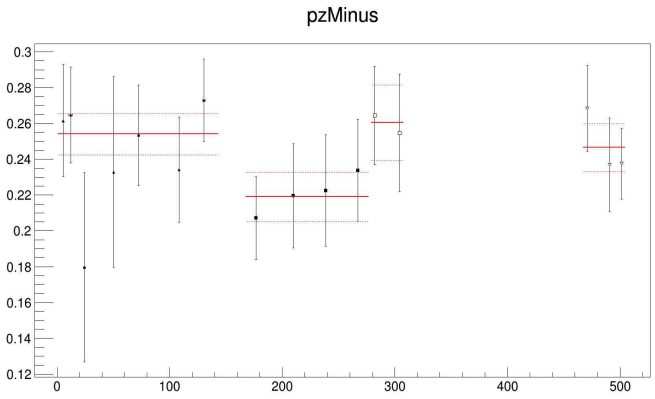


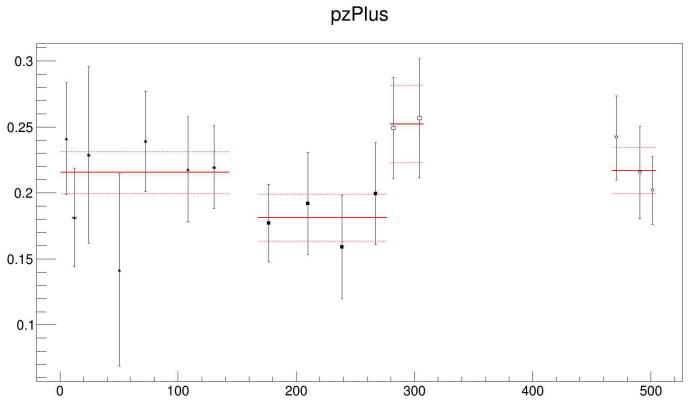


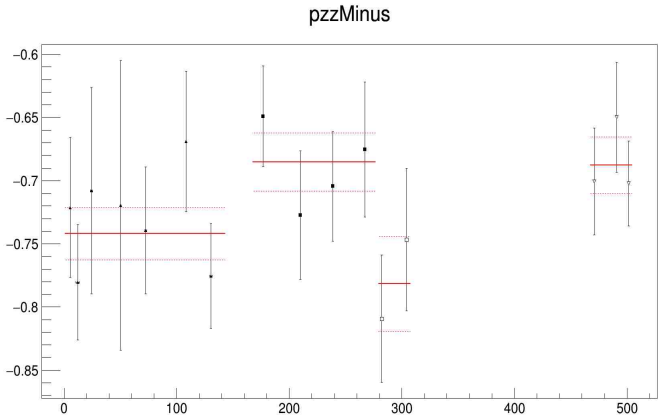


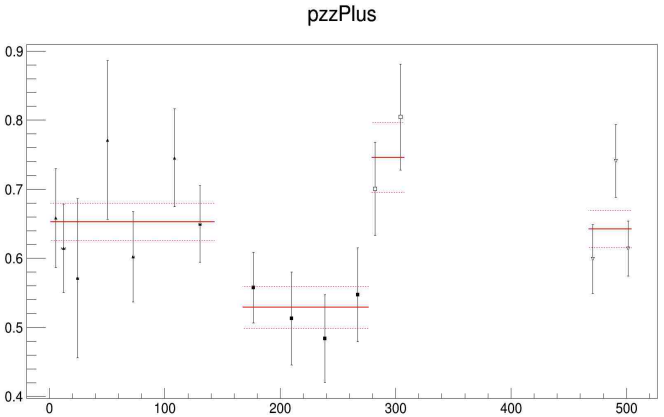
Selection of the dp elastic events by the time difference between the signal appearance from deuteron and proton detectors with the criteria on the amplitude signal correlation.

Polarization measurements using dp- elastic scattering at 270 MeV





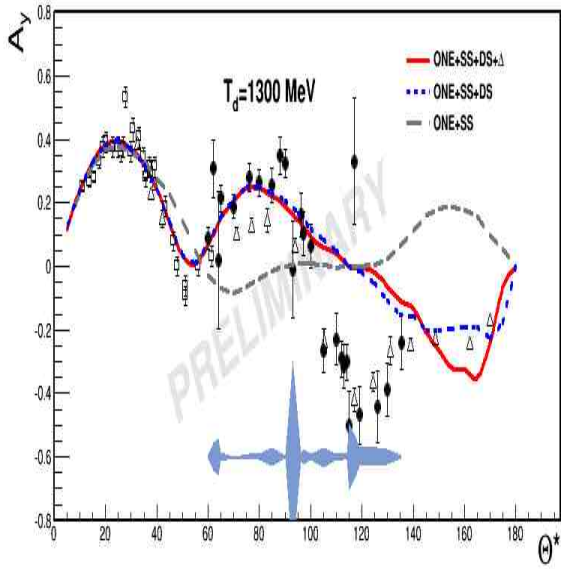


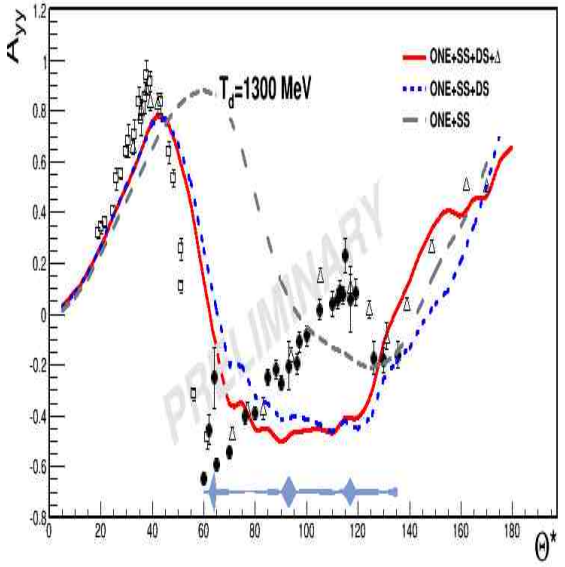


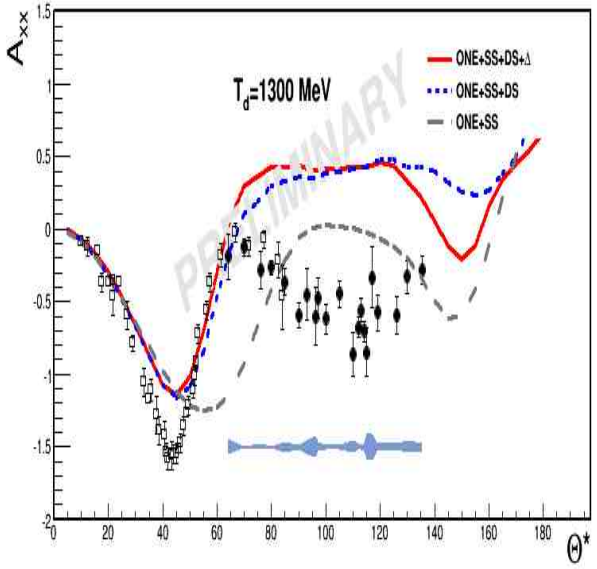
SPI was tuned for 6 spin modes (p_z,p_{zz}) = (1/3,1), (1/3,-1), (0,+1), (0,-2), (-2/3,0),(+1,0).

Angular dependence of the vector and tensor analyzing powers in dp-elastic scattering at 1300 MeV

Ay **Ayy** **Axx**





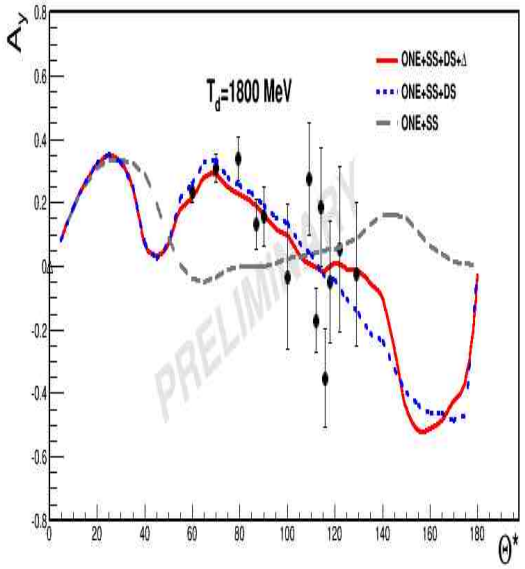


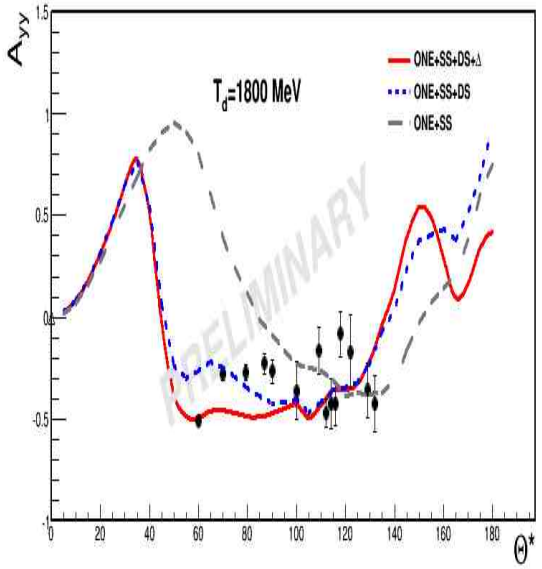
Data shown by the open symbols are obtained at 1200 MeV at Saclay

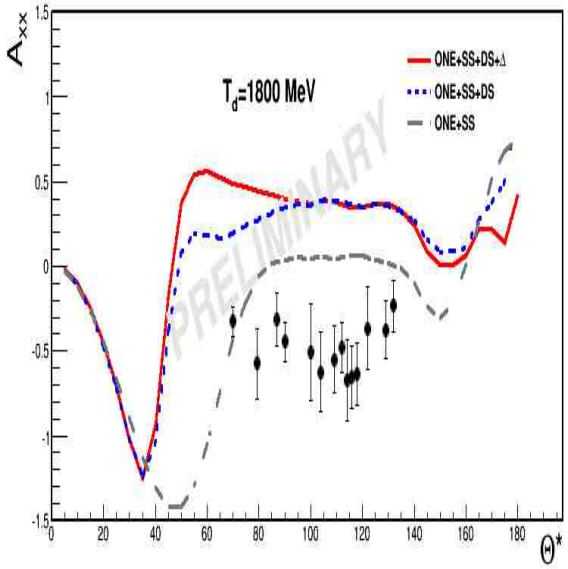
Curves are the relativistic multiple scattering model calculations
N.B.Ladygina, Eur.Phys.J, A52 (2016) 199, ibid A56 (2020) 133.
+ additional ρ-meson exchange

Angular dependence of the vector and tensor analyzing powers in dp-elastic scattering at 1800 MeV

Ay **Ayy** **Axx**

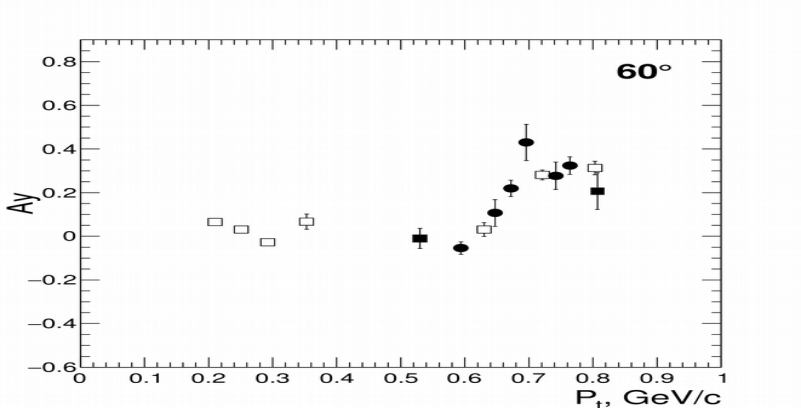


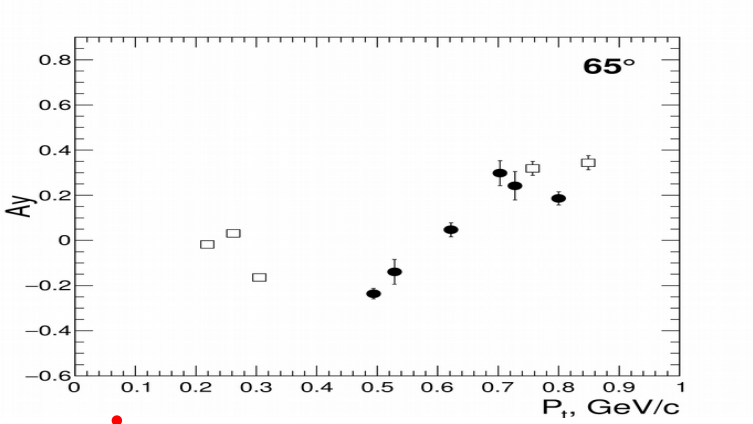




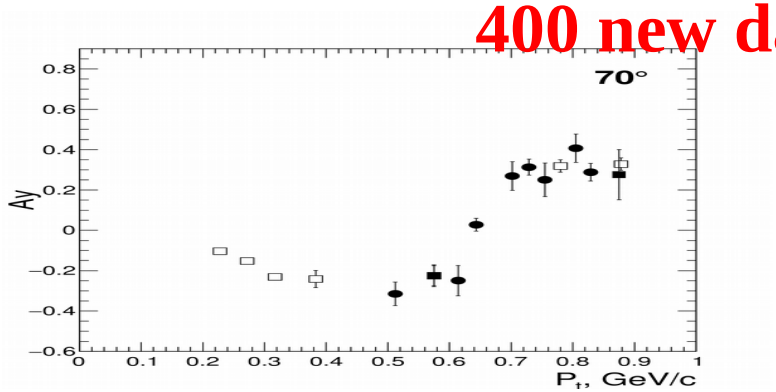
Curves are the relativistic multiple scattering model calculations
N.B.Ladygina, Eur.Phys.J, A52 (2016) 199, ibid A56 (2020) 133.

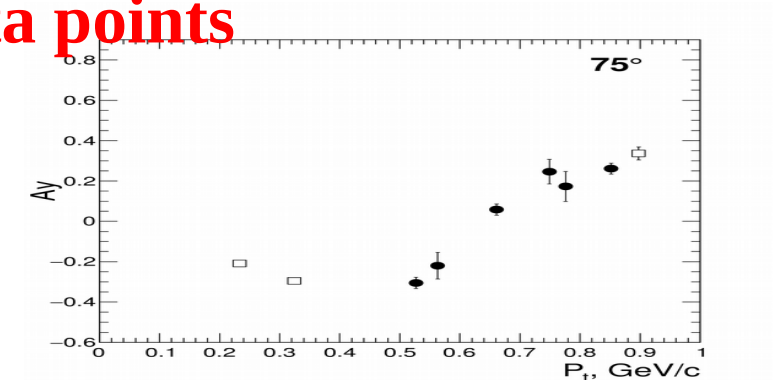
Energy dependence of the vector analyzing power Ay in dp-elastic scattering at 700-1800 MeV





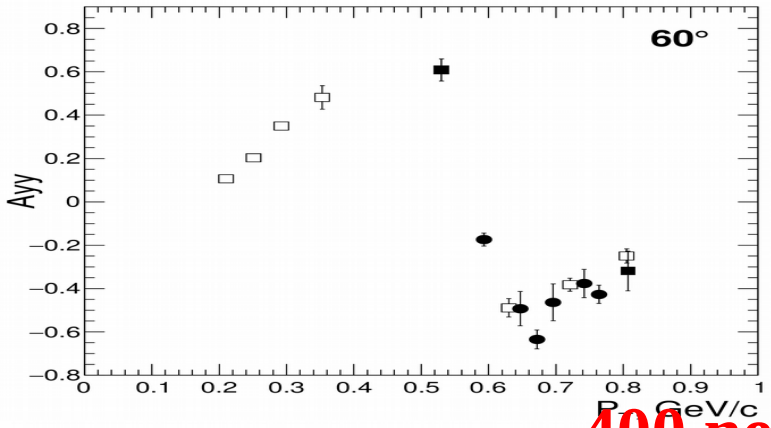
400 new data points

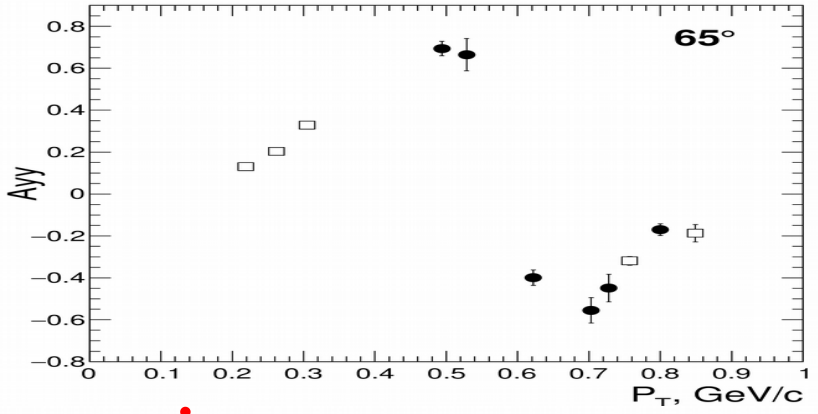




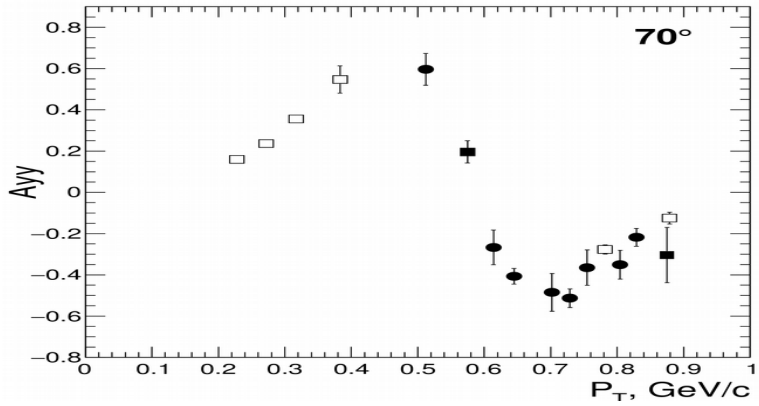
Full circles are the new preliminary data fom Nuclotron (2016-2017).
Full squares are the data fom Nuclotron (2005).
Open symbols are the world data.

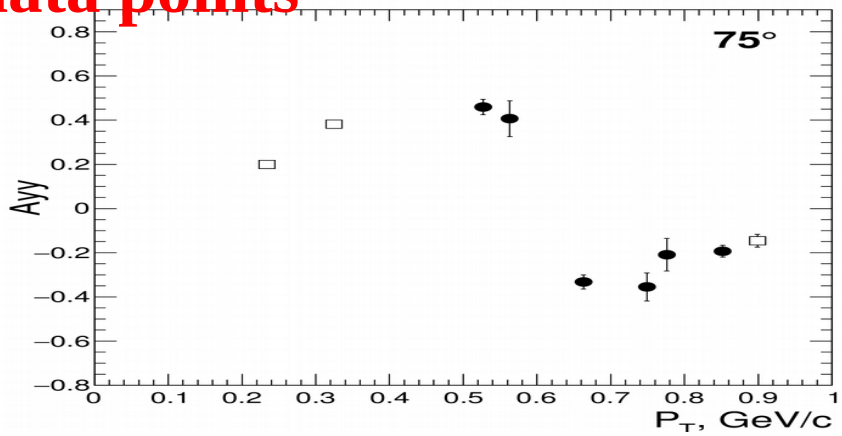
Energy dependence of the tensor analyzing power Ayy in dp-elastic scattering at 700-1800 MeV





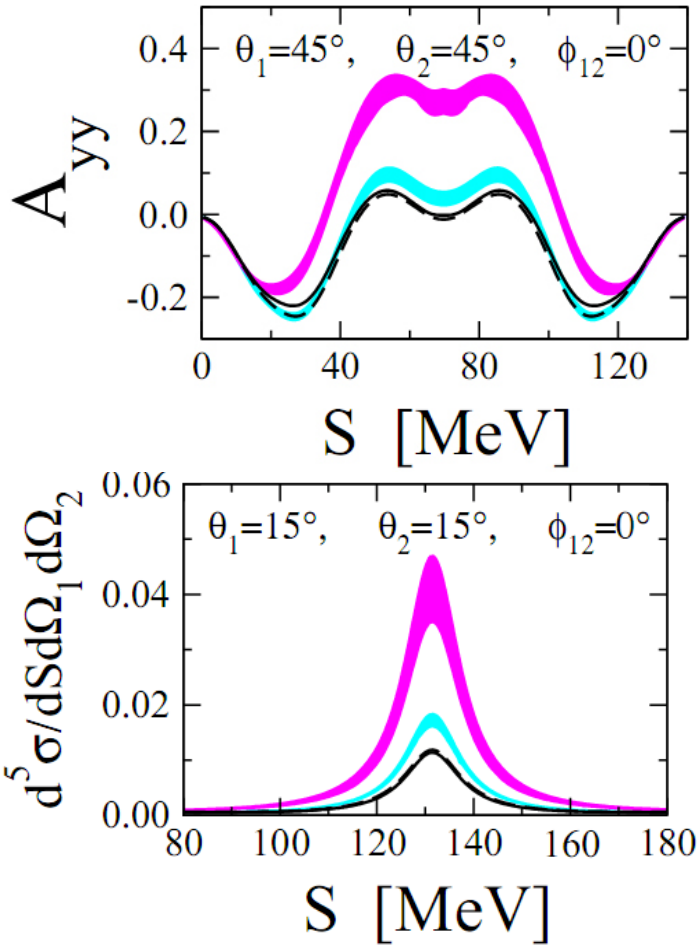
400 new data points





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.

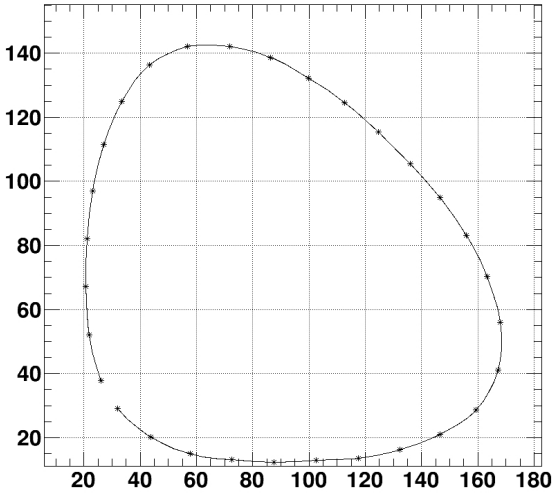
Θ_2 – polar angle of the 2-nd proton.

S – arc length along the kinematical curve.

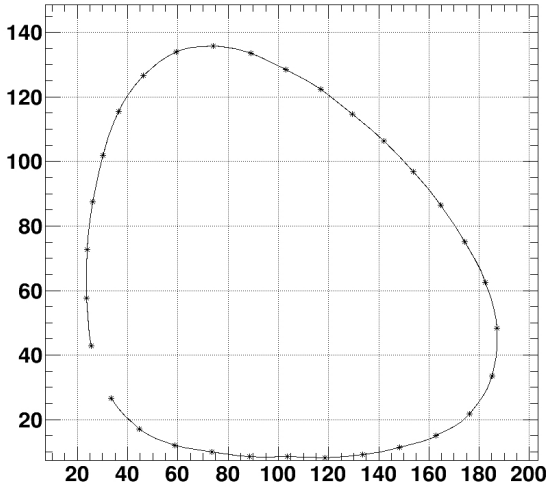
Φ_{12} – azimuthal angle with respect to the horizontal plane.

Dp breakup – S (kinematical) curve

a)



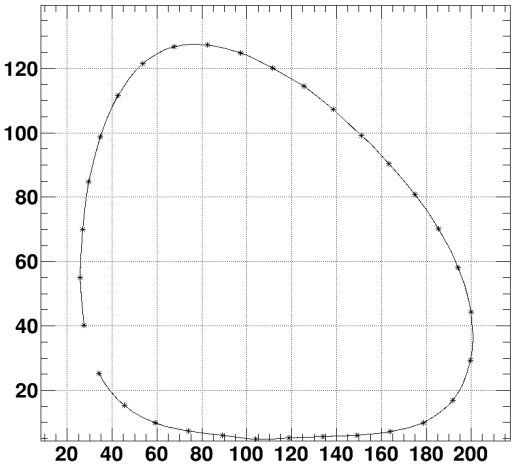
b)



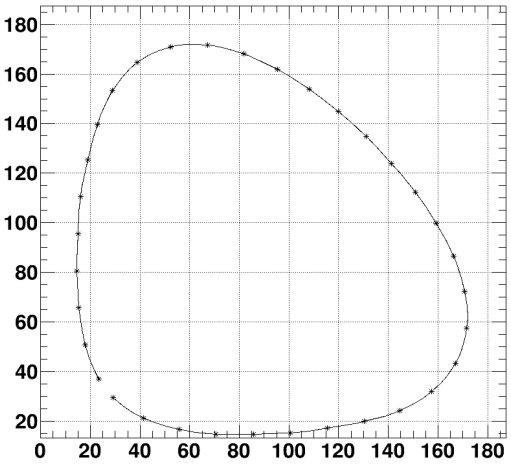
Step = 10 MeV

S- curve:
Anticlockwise
Orientation

c)



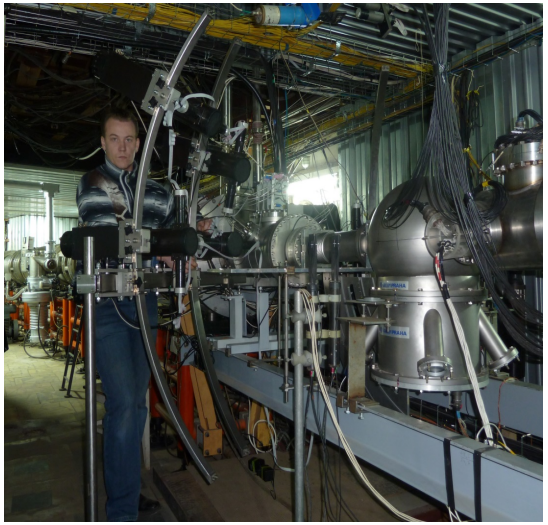
d)



Exp. data are projected into kinematical curve obtained by phase space simulation for the case of 300 MeV of deuteron energy and angles (polar angle1 / polar angle 2 and difference in azimuthal angles):

a) 37.1° / 30.5° / 145°; b) 40.1° / 26.9° / 150.8°; c) 42.1° / 23.3° / 152.1°; d) 34.0° /34.0° / 180°

Dp breakup – cross section



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

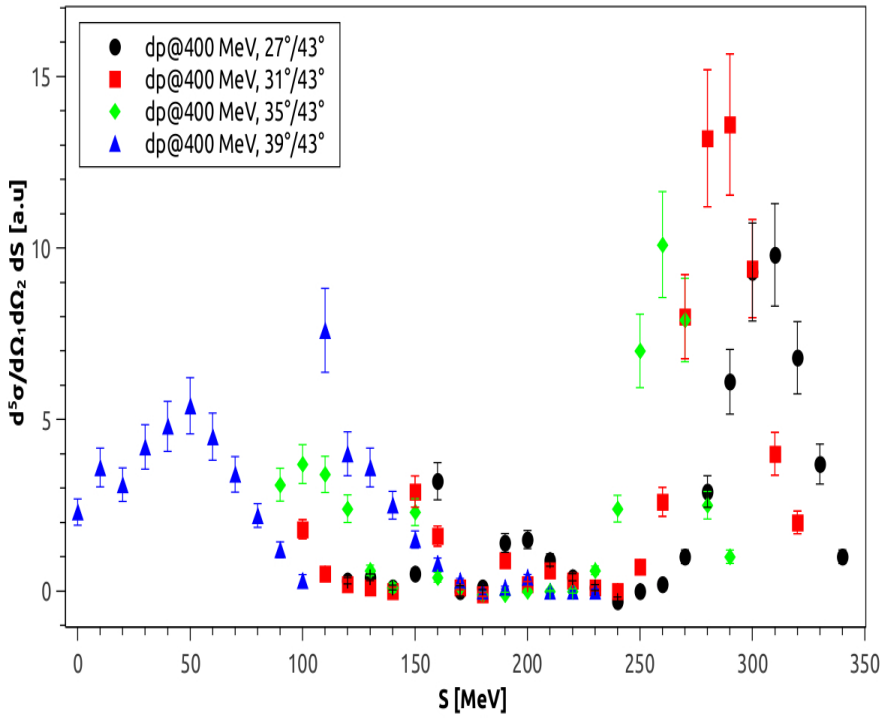
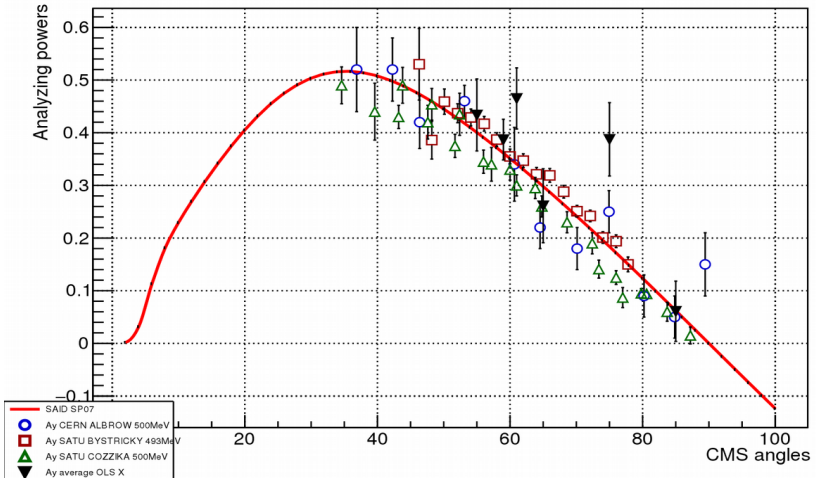
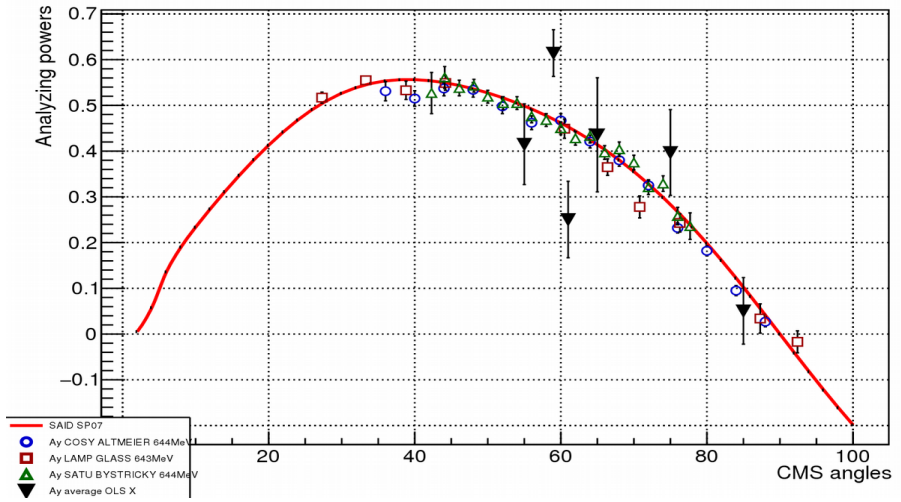


Figure 2: Preliminary results of the five fold differential cross section of *dp* breakup reaction investigated at 400 MeV for the case of detector arms placed at the angles of 27° and 43° (black symbols), 31° and 43° (red symbols), 35° and 43° (green symbols), 39° and 43° (blue symbols), respectively. Only statistical errors are shown.

Polarized protons at ITS.





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

IPol=1 P=1 (WFT 1→3)
IPol=2 P=0 (unpolarized) **2/3 of time - polarized beam**
IPol=3 P=1 (WFT 1→3)

Having the asymmetries for 10 angles (50^0-130^0 in the cms) we obtained the averaged value of the proton beam polarization

Unpolarized protons: I∼$1.5\cdot10^8$ ppp Py=0.056 ±0.021
Polarized protons: I∼$2\text{-}3\cdot10^7$ ppp Py=0.367 ±0.015

Publications, talks, thesis

• **The results are published or accepted in 2019-2021 in 4 regular papers (2*EPJA, PAN, PPN).**

• **The results were reported in 25 talks at DSPIN-2019, AYSS2019, LC2019, EFB24, NUCLEUS2019, AYSS2020, LXX2020, ELEKTRO-2020, KCzSF-2020 Conferences.**

Talks in 2021: AFB2020, MESON2020, SPIN2020(?)

• **2 Master (2019, 2020) + 1 PhD Theses (2020)**
1 PhD Theses (planned in August 2021, Slovak Republic).

A chapter with the proposal on the study of the analyzing powers in dp- elastic scattering at SPD has been prepared

Beam-time request in 2022-2024 yy.

The total beam time request with new PIS in 2022-2024 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 ~ $5 \cdot 10^9$.
2. Ay, Ayy and Axx for dp-nonmesonic breakup at 400 MeV with averaged beam intensity ~ $5 \cdot 10^9$.
3. Energy scan of the nucleon analyzing power Ay in pd-elastic scattering at 100-1000 MeV with polarized protons.
4. Proton beam polarimetry using pp- and pd-elastic scattering.

***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 ~ $5 \cdot 10^9$.**

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

Expected results in 2022-2024 yy.

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 final results will be 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.

JINR expenses in 2022-2024 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*	200	200
2. Computers	-	-	-	-
3. Computer connection	-	-	-	-
4. Design bureau	300	100	100	100
5. Experimental Workshop	500	200	200	100
6. Materials	60	22	22	16
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	21	7	7	7
b) rouble zone countries	15	5	5	5
c) protocol-based				
Total direct expenses	140	50	50	40

*- partly in parasitic beam mode

PROJECT LEADER

LHEP DIRECTOR

LHEP CHIEF ENGINEER-ECONOMIST

New detectors, new mechanics, electronics

JINR staff FTE = 8.3

V.P.Ladygin	0.5
E.V.Chernykh	0.9
Yu.V.Gurchin	1.0
A.Yu.Isupov	0.7
A.N.Khrenov	0.5
N.B.Ladygina	0.9
A.N.Livanov	0.1
S.M.Piyadin	-
S.G.Reznikov	0.7
A.A.Terekhin	1.0
A.V.Tishevsky	1.0
I.S.Volkov	1.0

Overlap with SPD (proton beam and Local polarimetry)

SWOT analysis for DSS project

Strengths: The strong points of the DSS- project are the unique physics related with the studies of the short-range correlations spin structure, development of the efficient polarimetry for the deuteron and proton beams, contribution to the first stage physics program at SPD. The project is an inevitable step for spin program at NICA.

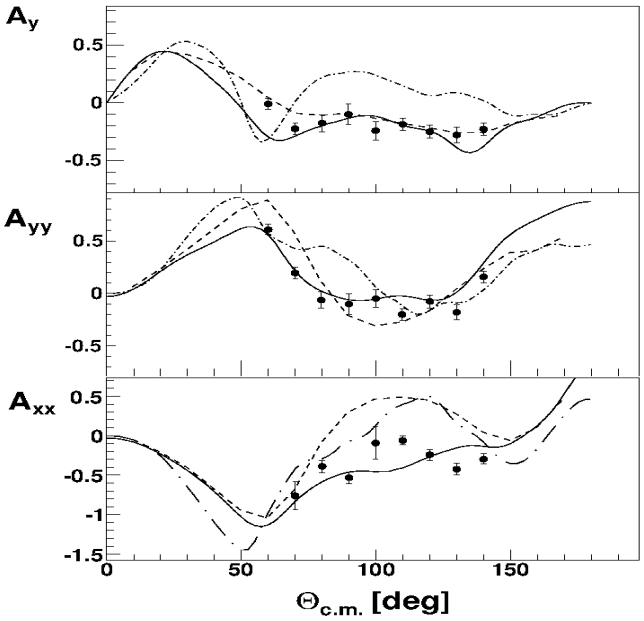
Weaknesses: Very high competition for the beam at Nuclotron due to higher priority of the heavy ion program.

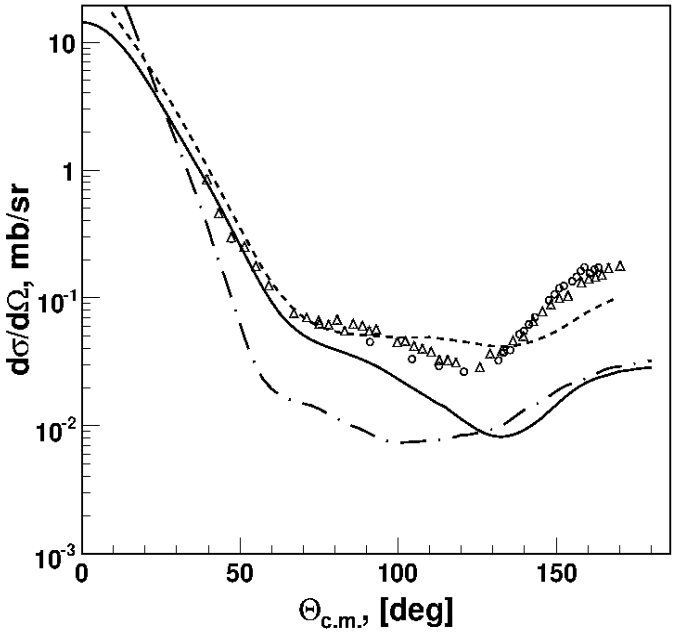
Opportunities: Project provides visible role for young scientists, real possibility to defense the thesis (5 PhD thesis and ∼15 Master thesis).

Threats: COVID-19 pandemy impact is related with the absence of the exchanges which reflects on the speed of the data analysis and publishing and possible cancellation of the european and japaneze phycisists participation in data taking at Nuclotron.

Thank you for the attention!!!

Analyzing powers in dp- elastic scattering at 880 MeV





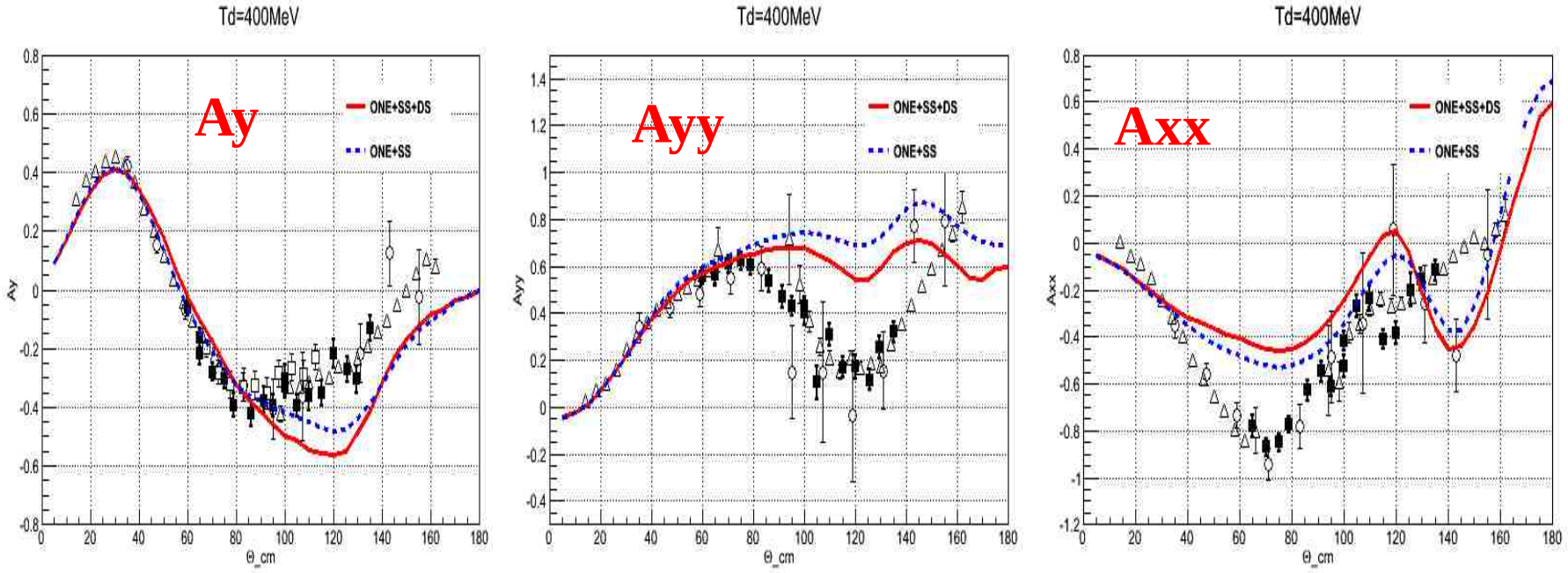
Dashed lines are the multiple scattering model calculations using CD -Bonn DWF (N.B.Ladygina, Phys.Atom.Nucl.71 (2008), 2039)

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.

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

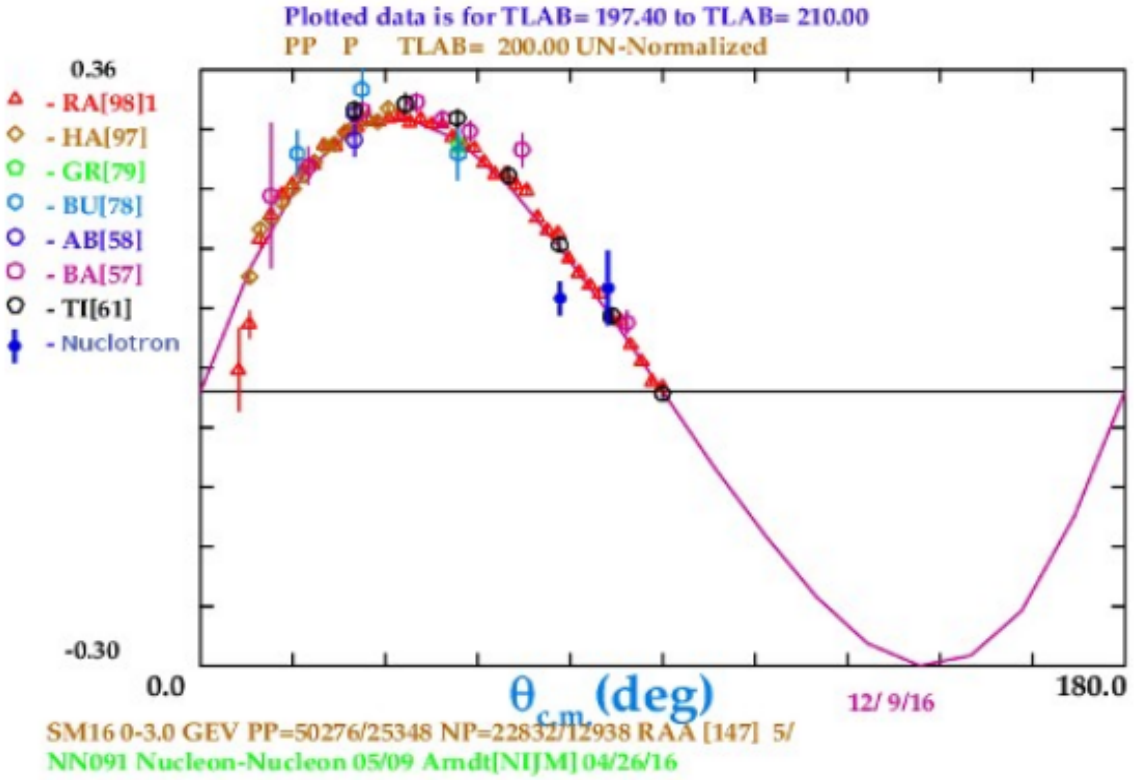


Full squares are the data fom Nuclotron (December 2016)

Curves are the relativistic multiple sacttering model calculations

N.B.Ladygina, Eur.Phys.J, A42 (2009) 91

Ay in dp breakup reaction at 400 MeV, pp-quasielastic data



(pz, pzz)
=
(-1/3, 1)
(-1/3, -1)

Angular dependence of the vector analyzing power **Ay** 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.

dp breakup reaction at 400 MeV, analyzing power data

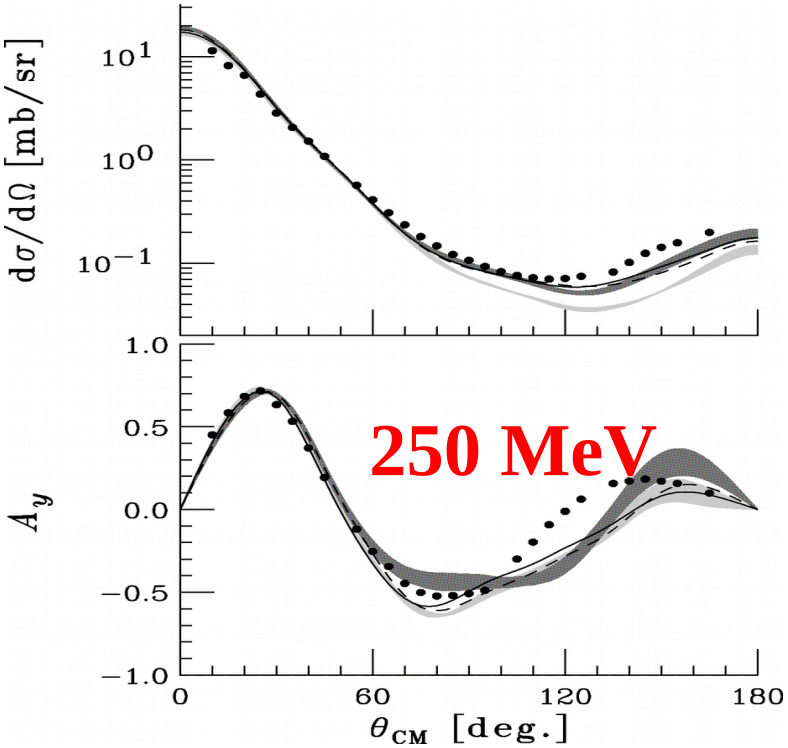
Spherical analyzing powers iT_{11} and T_{20}. Detector configuration is determined by polar θ_1 and θ_2, and azimuthal angles φ. Azimuthal angle is related to the angle of the detector which is closest to beam direction.

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

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).

Request

Prolongate the DSS- project for 3 years (2022-2024) with the 1-st priority.

The realization of the project in 2022-2024 will allow to obtain the crucial data on the spin structure of 2-nucleon and 3-nucleon short range correlations (2N and 3N SRC);
to develop the efficient polarimetry for Nuclotron/NICA and to make a visible contribution to physics program at SPD.