

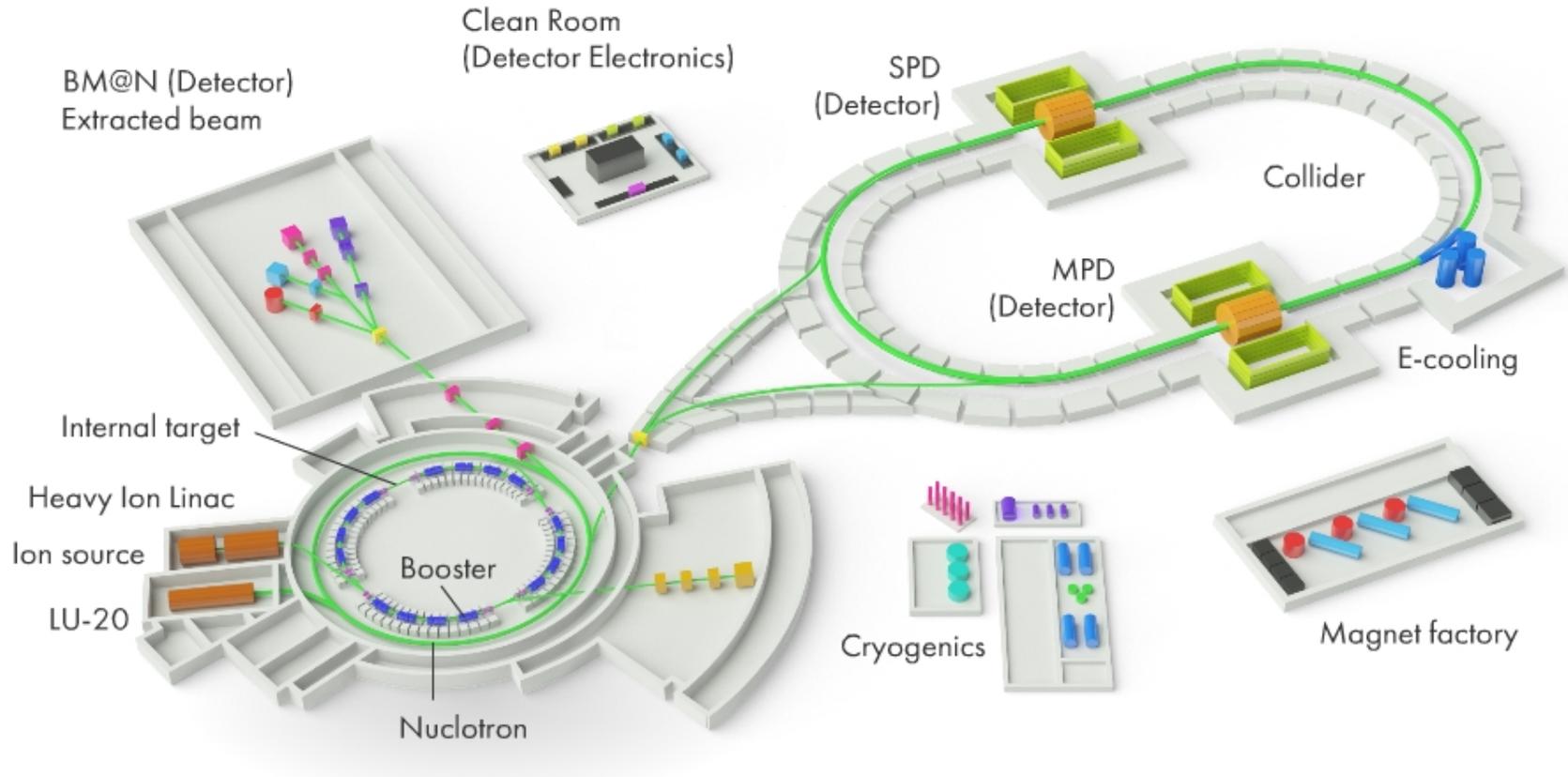
Spin studies of the short-range correlations at Nuclotron

DSS spin **structure**
deuteron

V.P. Ladygin on behalf of DSS collaboration

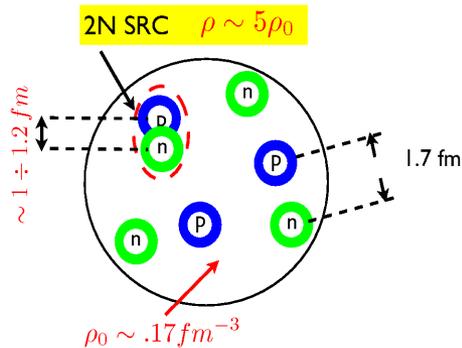
SPIN2018, Ferrara, 10-14 September 2018

NICA complex



Fixed target **DSS experiment is devoted to study of the short range correlations using polarized deuteron and proton beams**

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

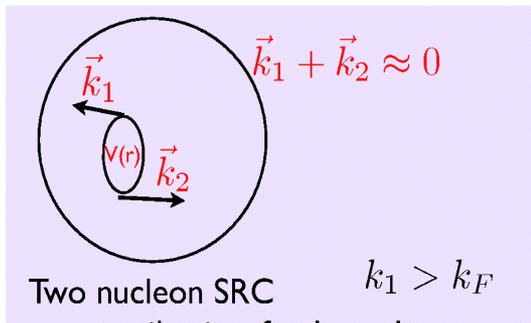
More than ~90% all nucleons with momenta $k \geq 300 \text{ MeV}/c$ belong to two nucleon SRC correlations BNL + Jlab + SLAC

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

Probability for a nucleon to have momentum $> 300 \text{ MeV}/c$ 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 $6q, \Delta\Delta, \dots$ 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 $p_T \sim 1 \text{ GeV}/c$

Studies at ITS at Nuclotron

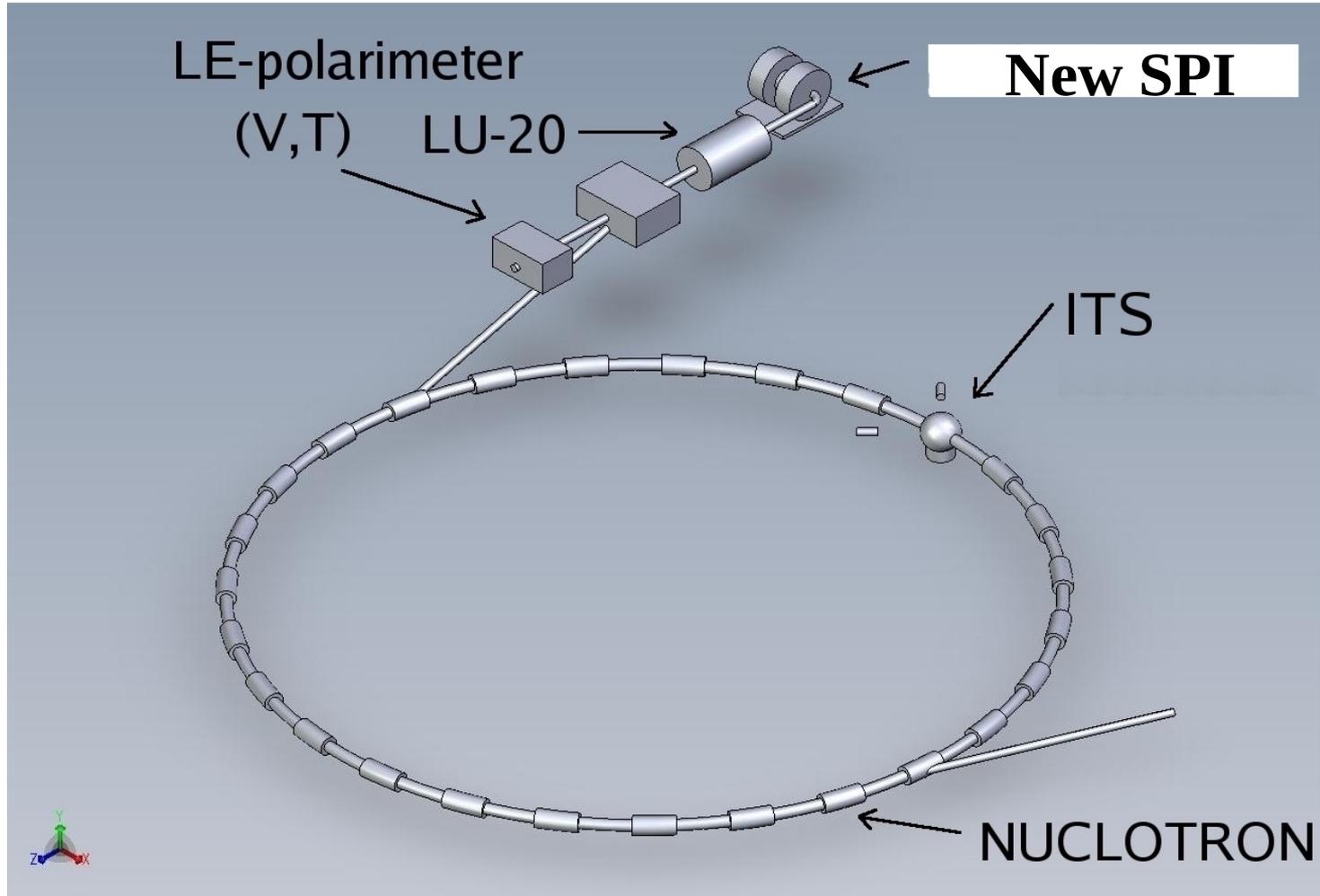


The purpose of the **DSS** experimental program is to obtain the information about **2N** and **3N SRCs** (including their spin – dependent parts) from the processes:

dp(pd) -elastic scattering at the energies between **300 - 2000 MeV**;

dp(pd) -breakup with registration of two protons at deuteron energies of **300 - 500 MeV**.

Nuclotron-M accelerator complex



General View of SPI

Charge-Exchange Ionizer

Atomic Beam Source

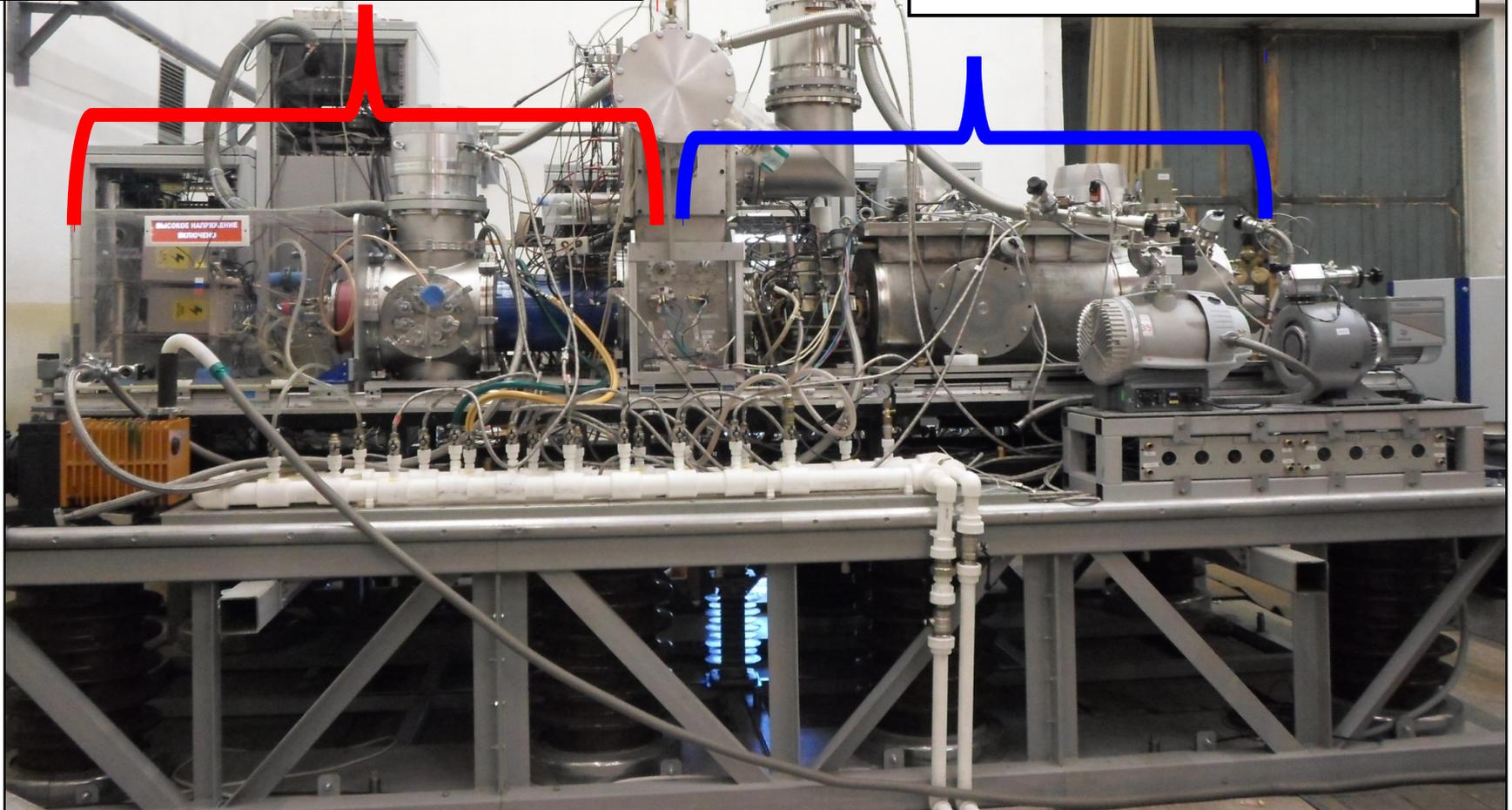


Figure of merit will be increased in future by a factor $\sim 10^3$

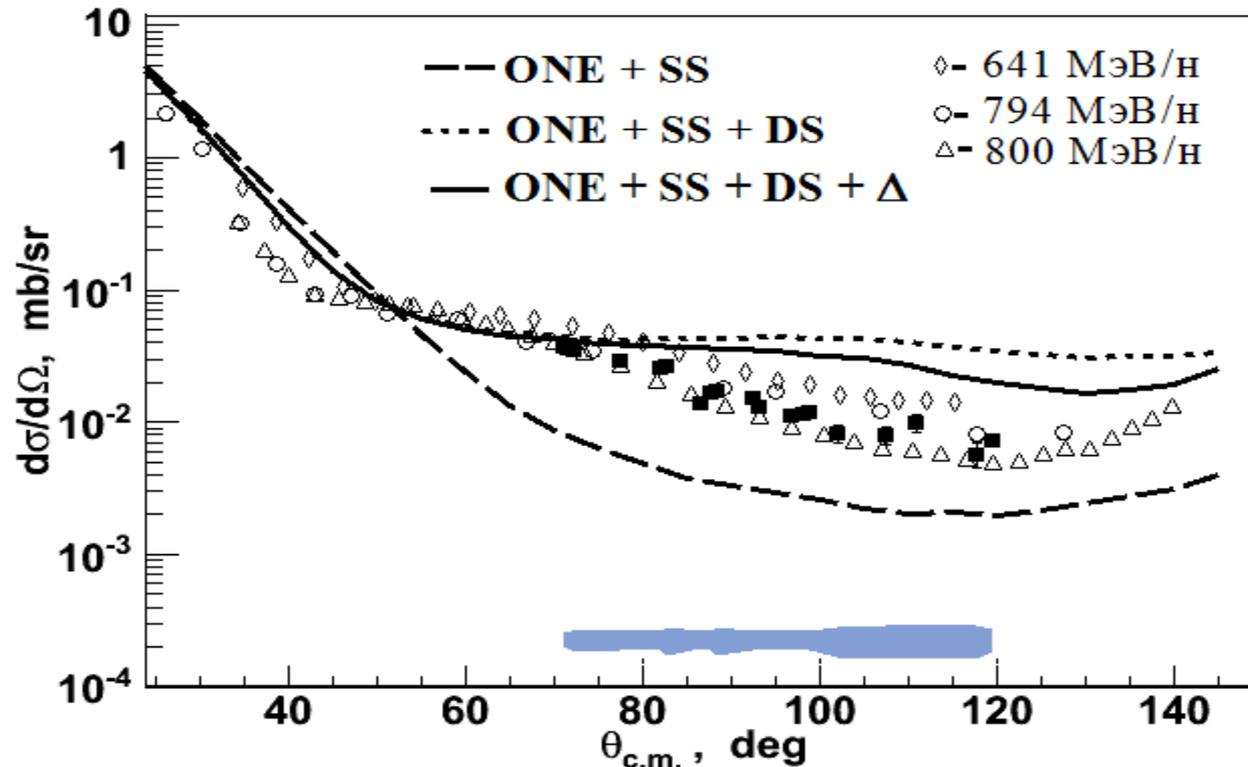
Experiments at Internal Target Station at Nuclotron

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 at 1400 MeV

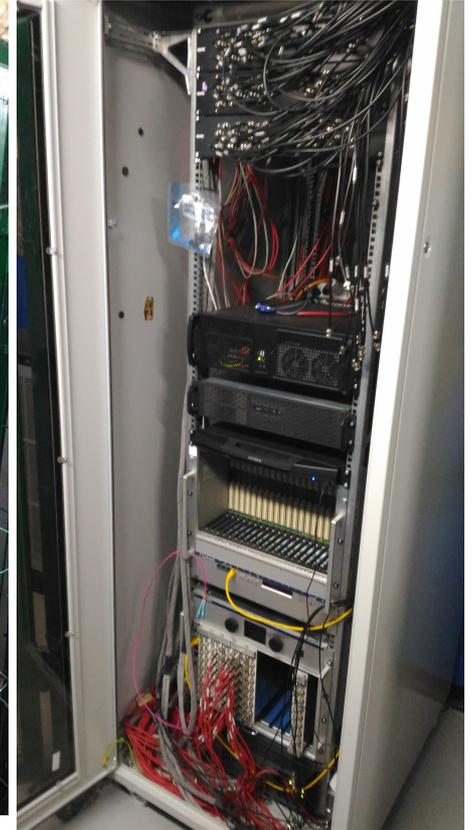
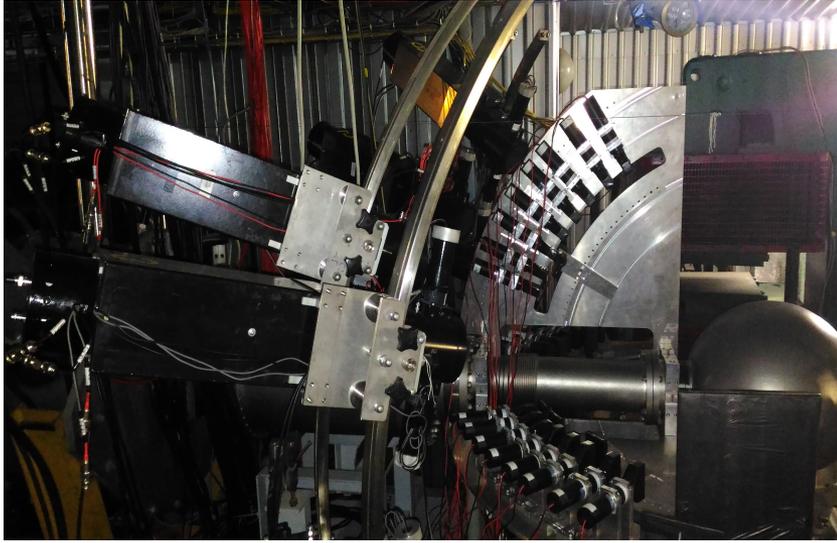


A.A.Terekhin et al., Phys.Atom.Nucl. 80(2017) 1061.

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

Final cross section data at 1000, 1300 and 1800 MeV

Upgrade of the **DSS** setup at ITS at Nuclotron



New infrastructure, cabling

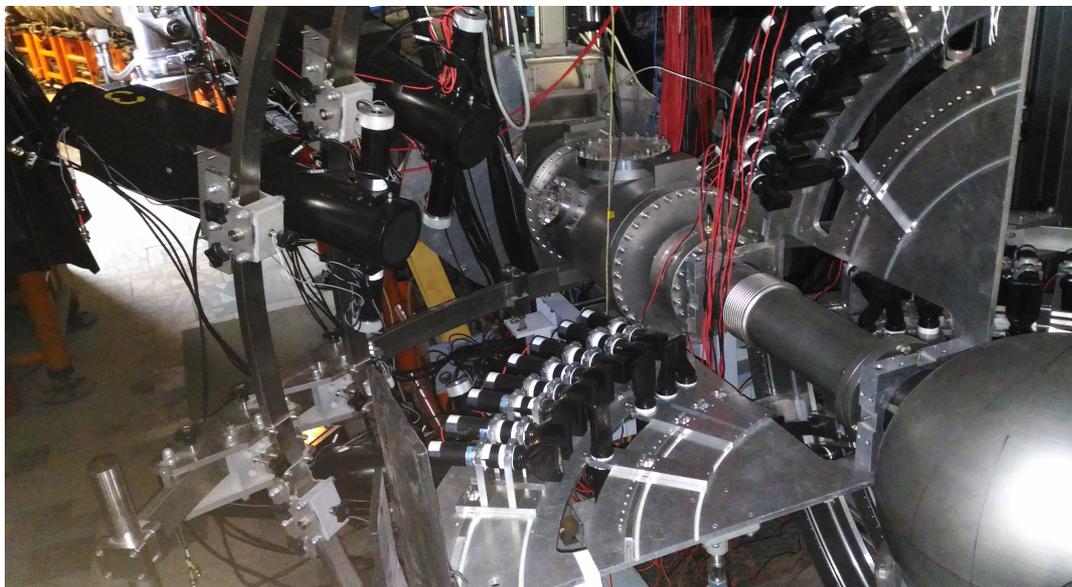
New HV system (Mpod)

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 in 2016-2017.



Deuterons and protons in coincidences using scintillation counters

Internal beam and thin **CH₂ target (**C** for background estimation)**

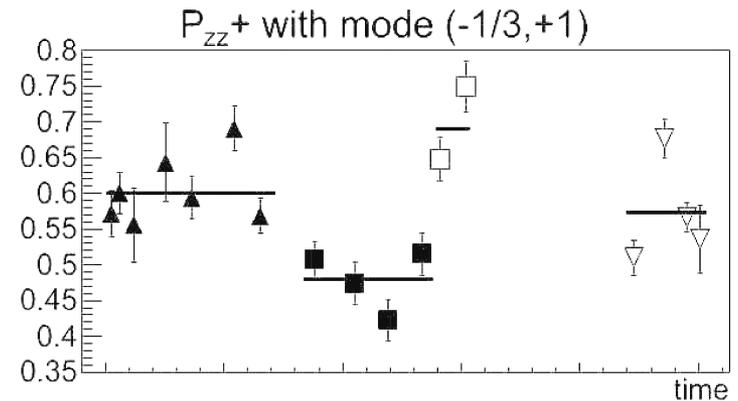
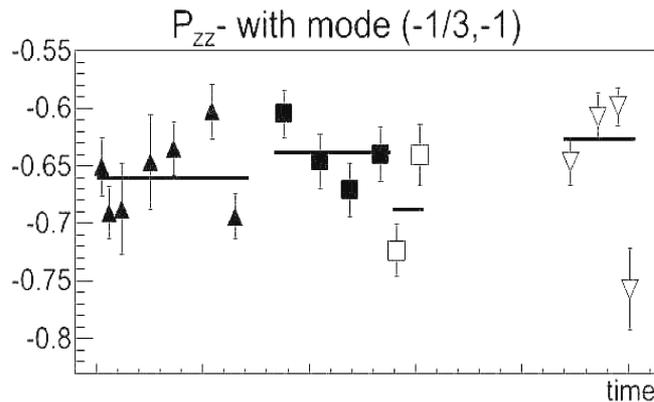
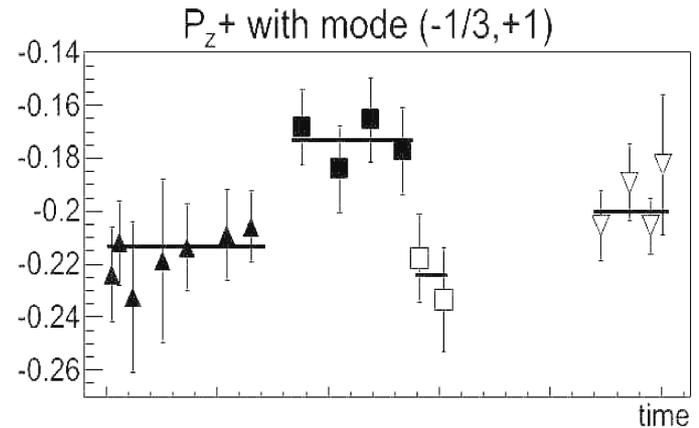
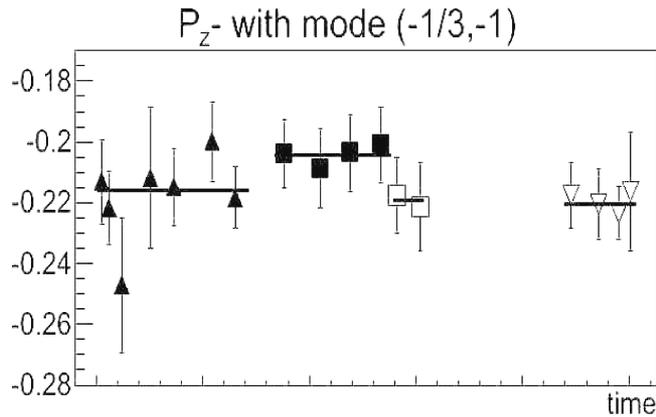
Permanent polarization measurement at **270 MeV (between each energy).**

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).

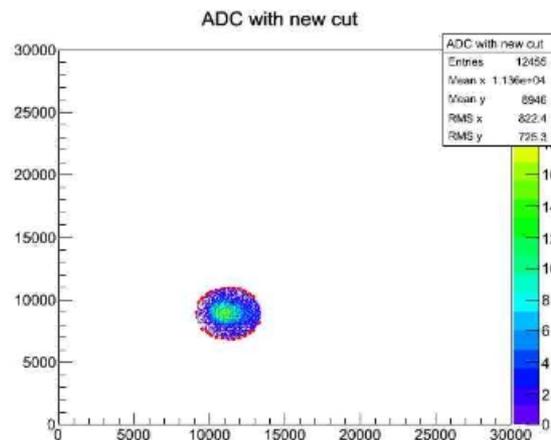
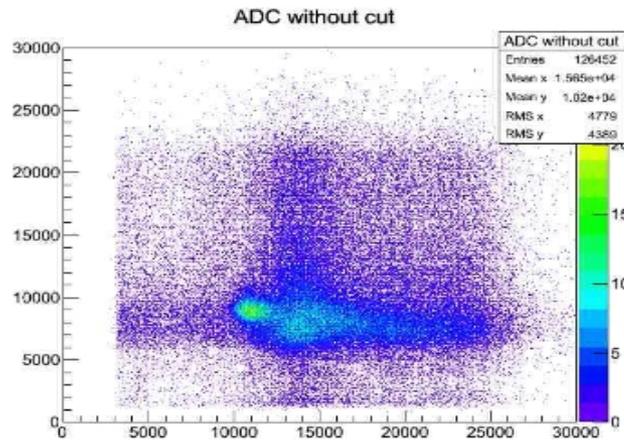
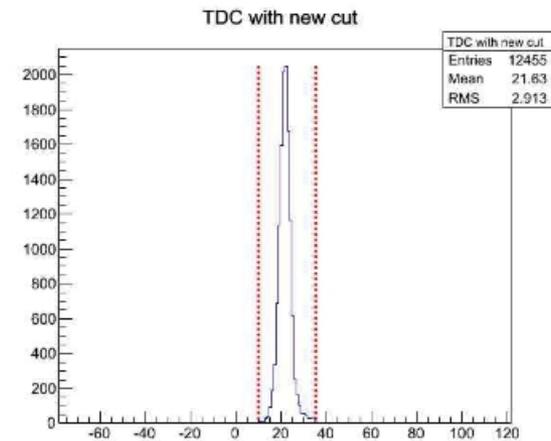
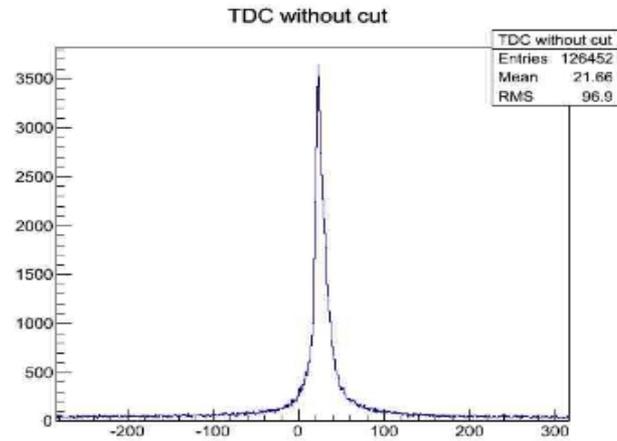
Typical values of the polarization was 70-75% from the ideal values.

Polarization measurements using **dp**- elastic scattering at **270 MeV**



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

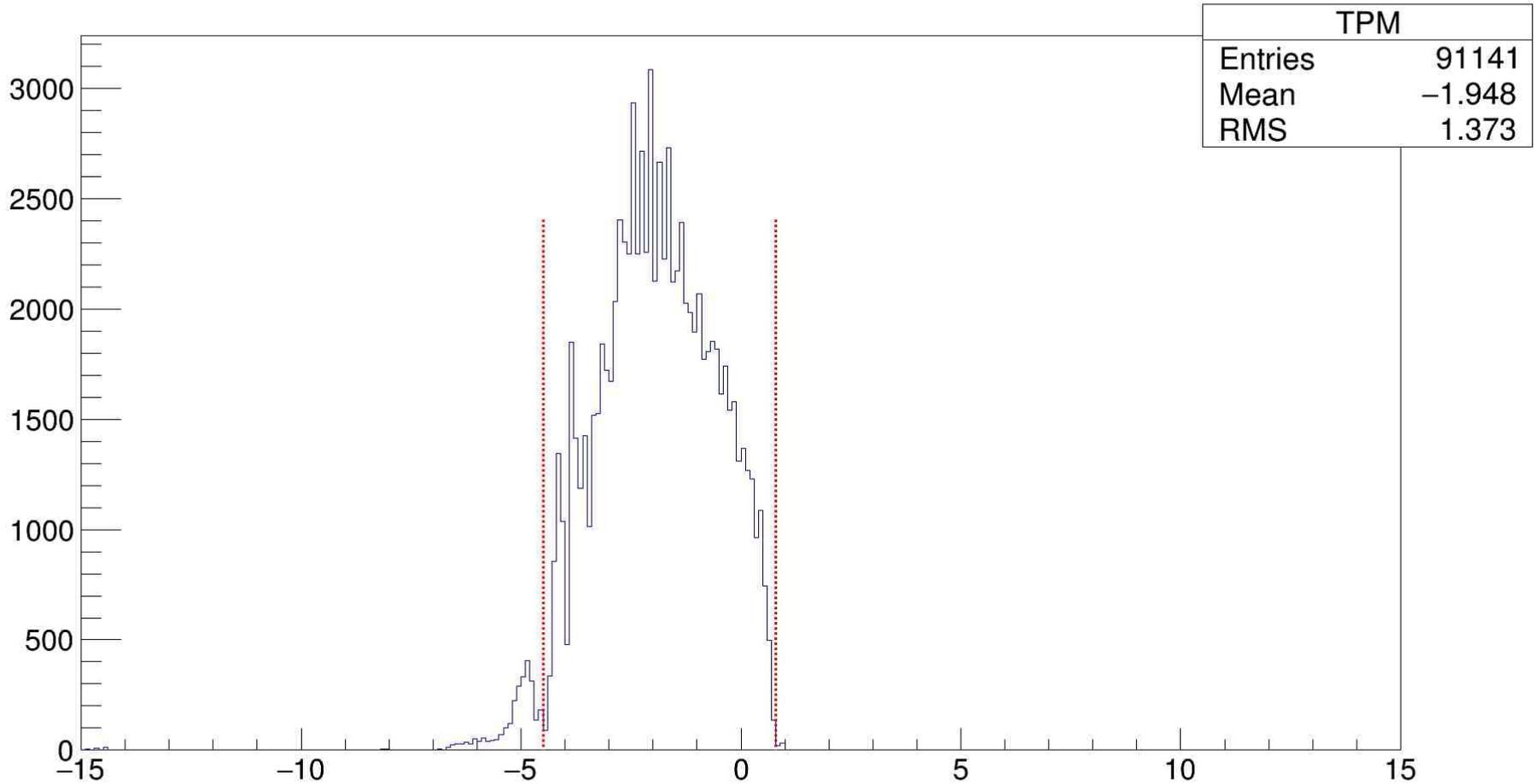
The dp-elastic scattering events selection



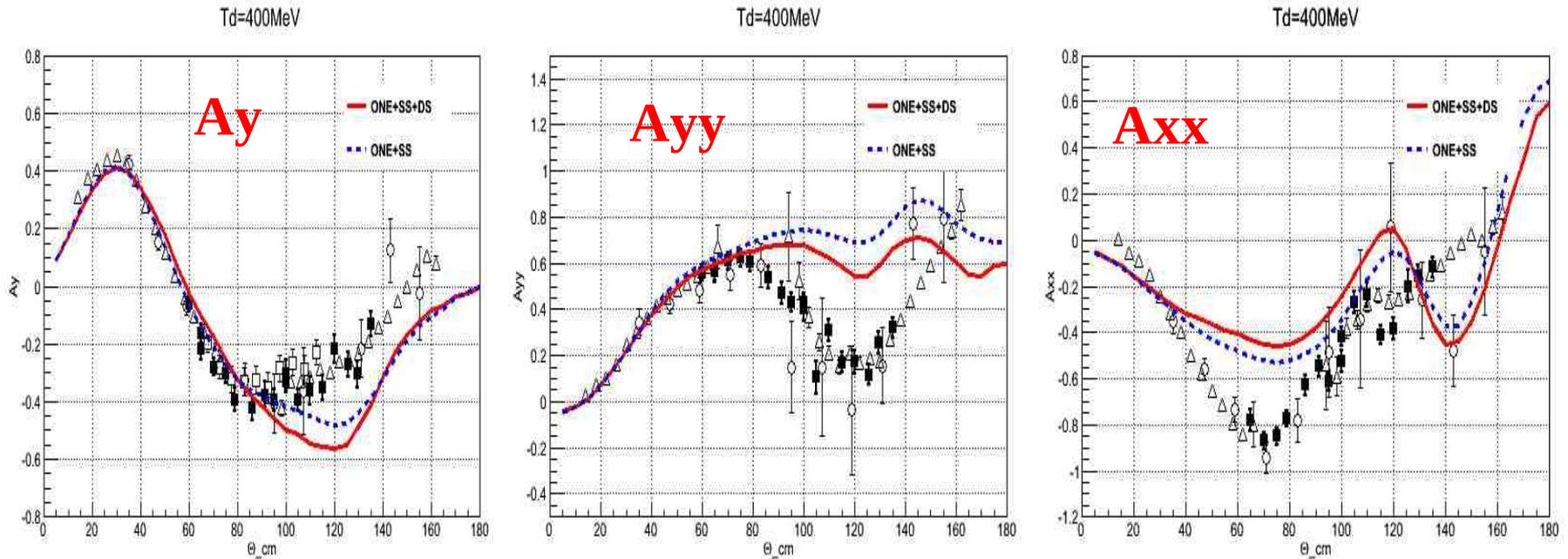
Selection of the dp elastic events by the time difference between the signal appearance from deuteron and proton detectors with the criteria on the amplitude signal correlation.

Target Position Monitor cut

TPM



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



Full squares are the data from Nuclotron (December 2016)

Curves are the relativistic multiple scattering model calculations

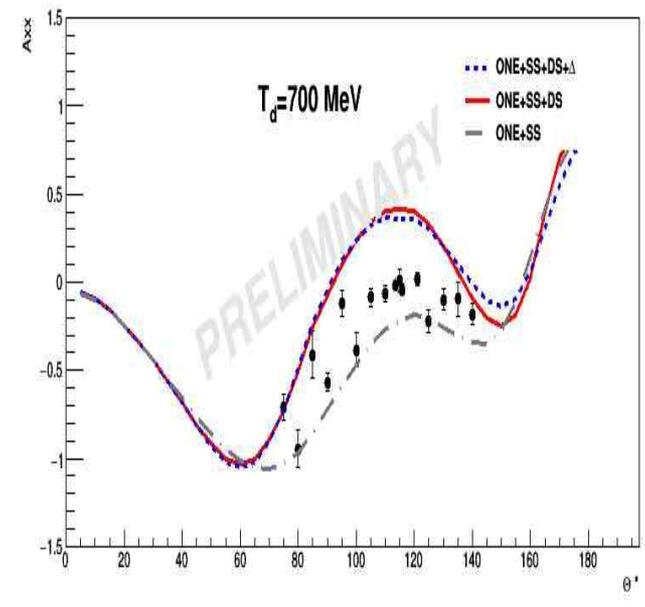
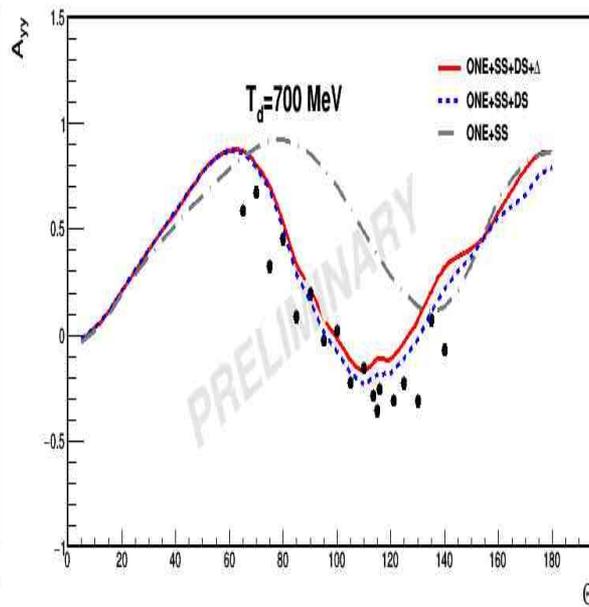
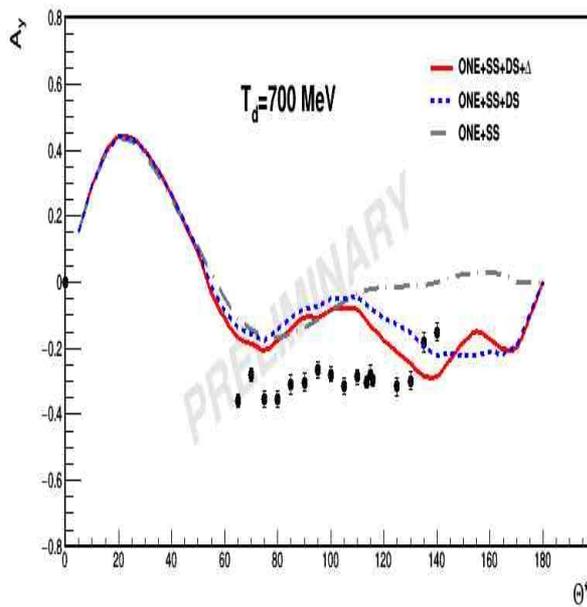
N.B.Ladygina, Eur.Phys.J, A42 (2009) 91

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

A_y

A_{yy}

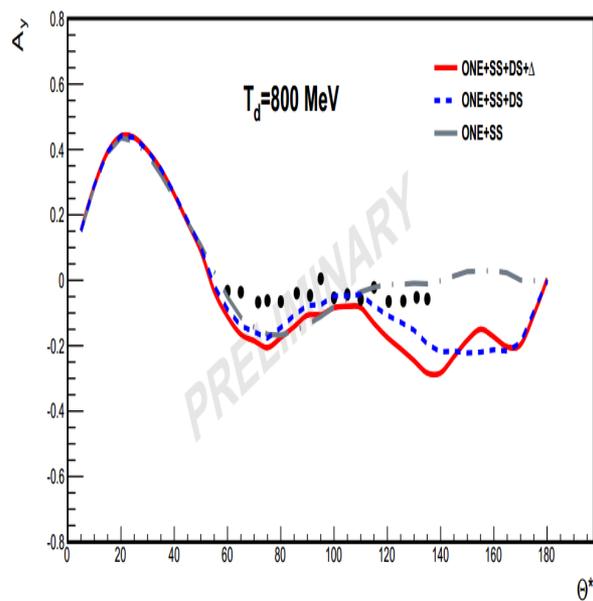
A_{xx}



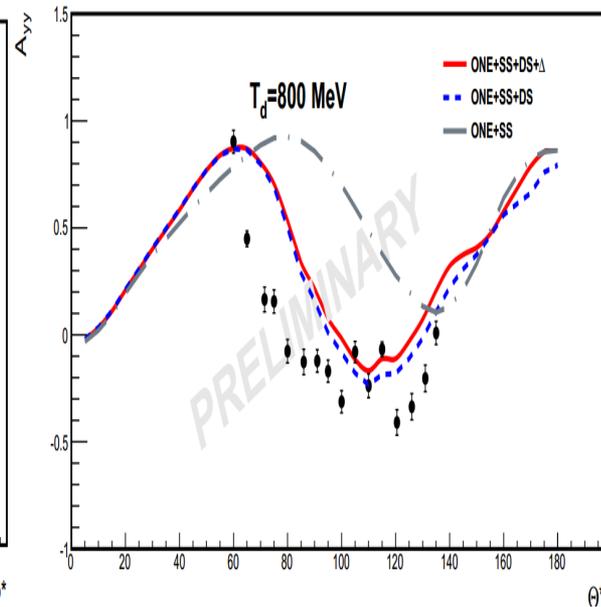
Curves are the relativistic multiple scattering model calculations
N.B.Ladygina, Eur.Phys.J, A52 (2016) 199

Angular dependence of the vector and tensor analyzing powers in **dp**-elastic scattering at **800 MeV**

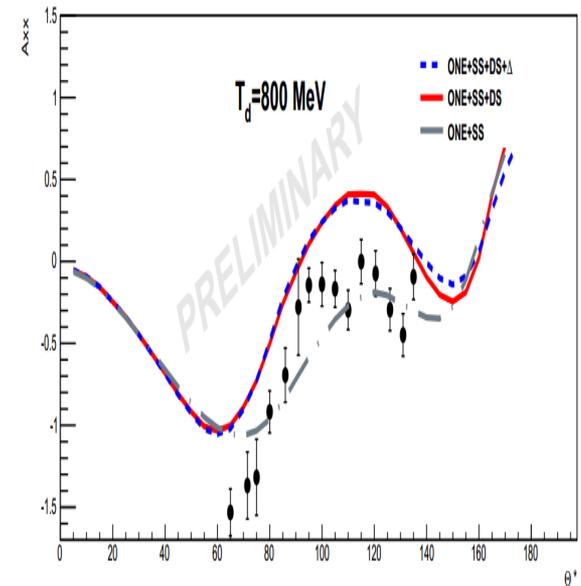
A_y



A_{yy}



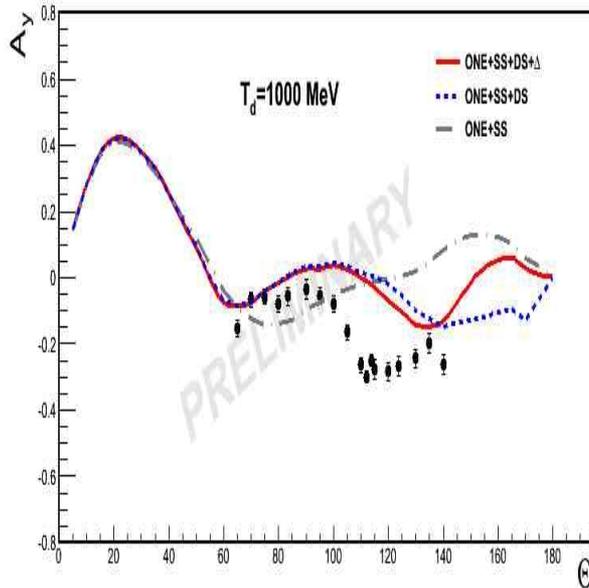
A_{xx}



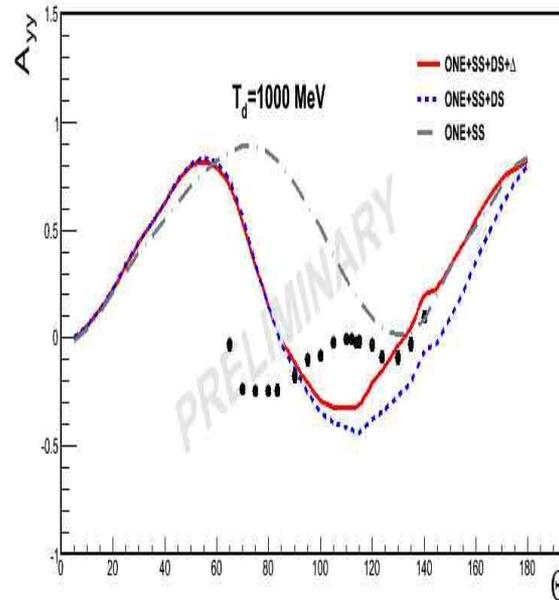
Curves are the relativistic multiple scattering model calculations
N.B.Ladygina, Eur.Phys.J, A52 (2016) 199

Angular dependence of the vector and tensor analyzing powers in **dp**-elastic scattering at **1000 MeV**

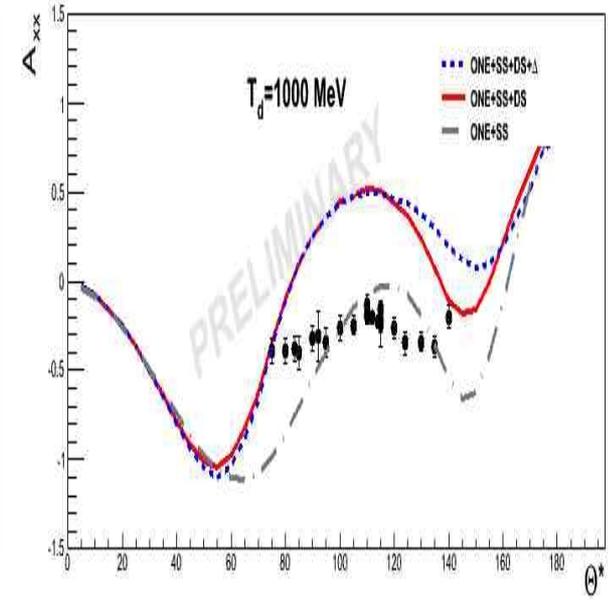
A_y



A_{yy}

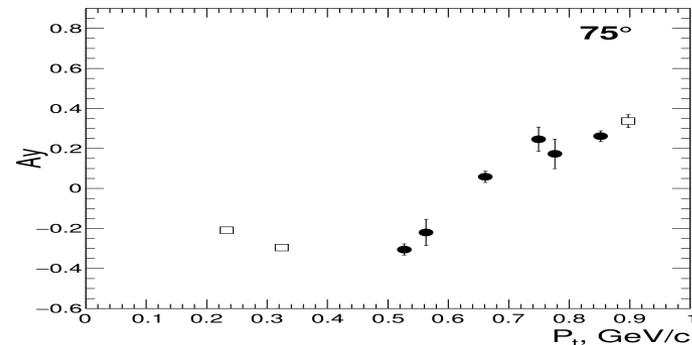
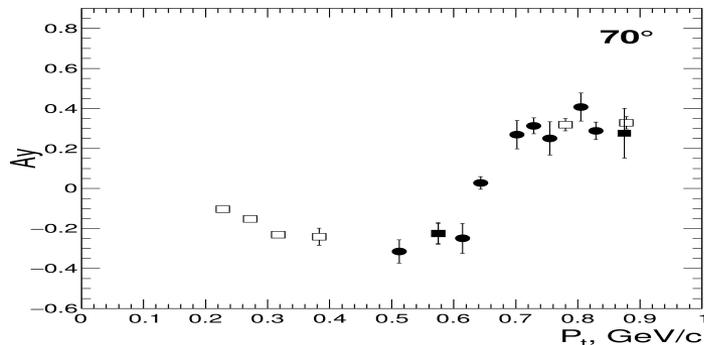
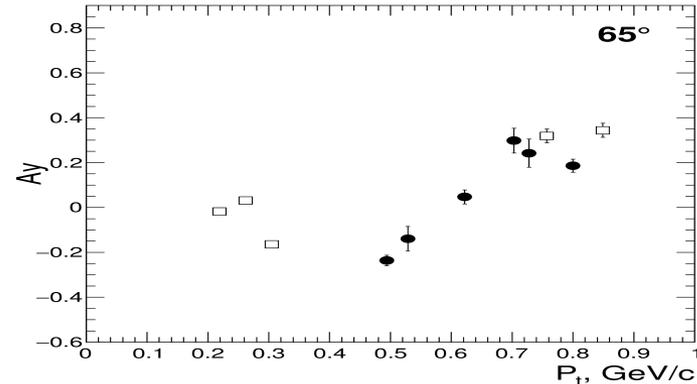
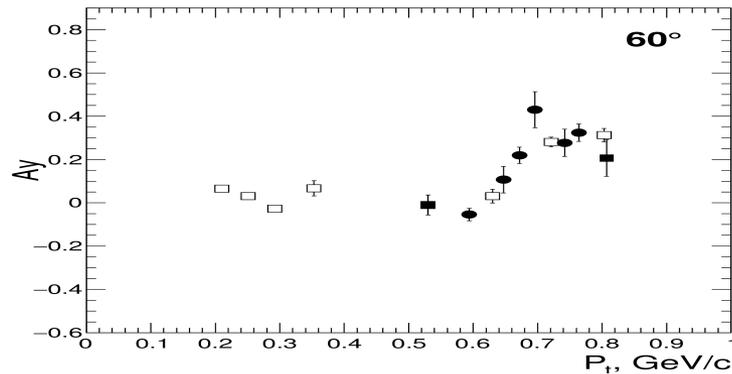


A_{xx}



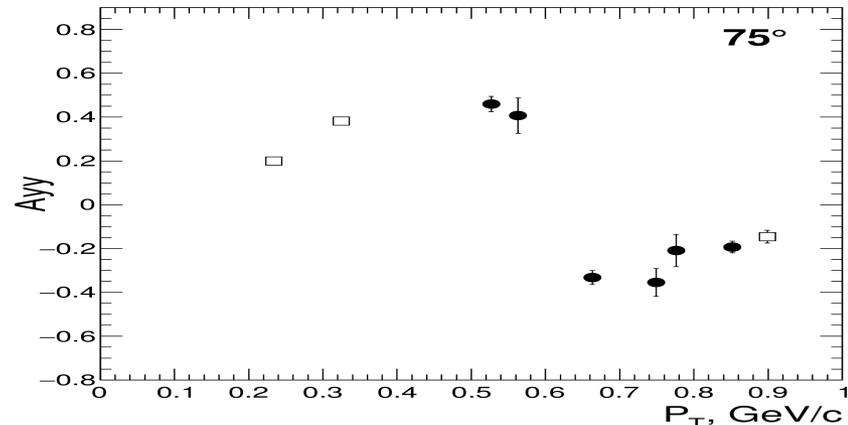
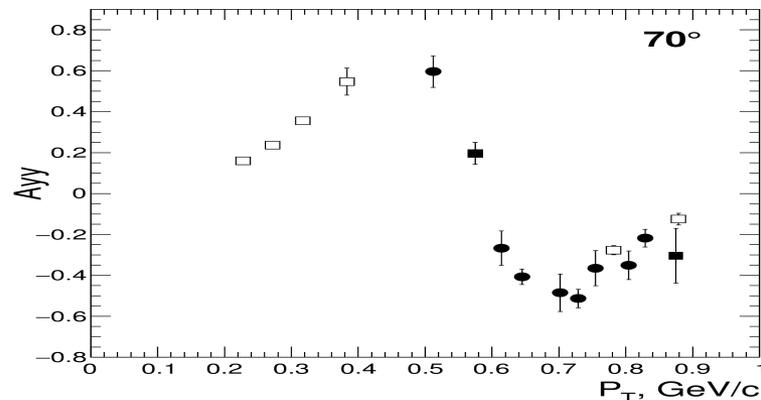
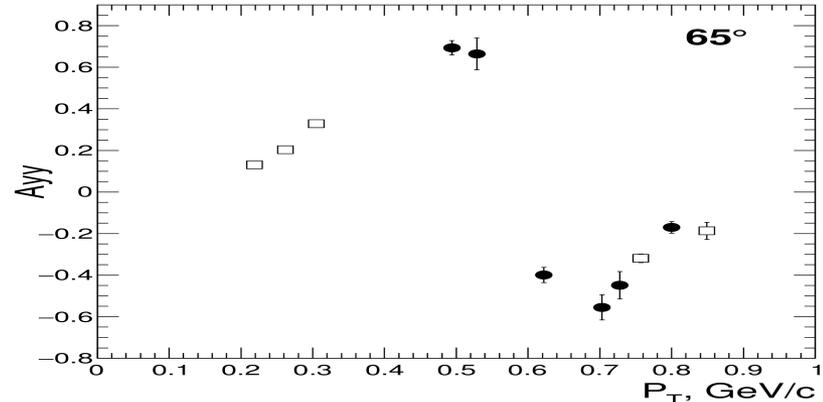
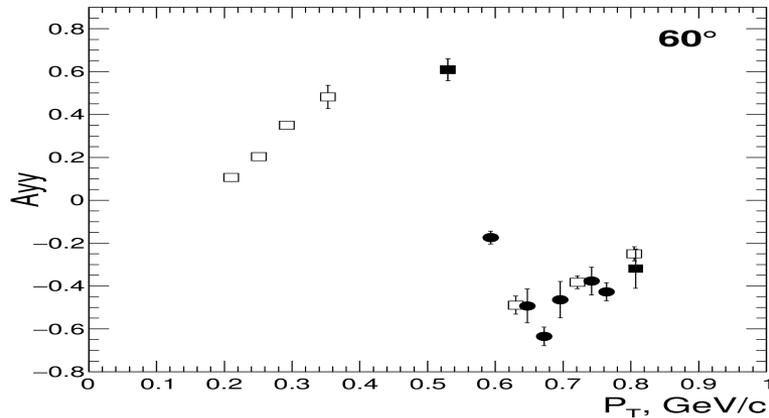
Curves are the relativistic multiple scattering model calculations
N.B.Ladygina, Eur.Phys.J, A52 (2016) 199

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



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

Energy dependence of the tensor analyzing power A_{yy} in dp -elastic scattering at 700-1800 MeV



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

Conclusion

Upgraded Nuclotron with new **SPI** provides quite unique opportunity for the studies of the spin effects and polarization phenomena in few body systems.

The realization of the **DSS** program at **ITS** will allow to obtain the crucial data on the spin structure of 2-nucleon and 3- nucleon short range correlations.

The first natural step in these studies, namely, the energy scan of the deuteron analyzing powers in **dp**- elastic scattering has been performed in 2016-2017.

Next experiments using polarized deuterons and protons at **ITS** are in preparation.

The extention of the studies to the high energies is possible with the extracted polarized deuteron and **proton** beams.

Further DSS plans

Final analysis of the systematic data on the cross section and analyzing powers A_y , A_{yy} and A_{xx} in **dp**- elastic scattering between **270** MeV and **2000** MeV at ITS.

Preparation of the experiments on the systematic studies of the analyzing powers A_y , A_{yy} and A_{xx} in **dp**- elastic scattering between **270** MeV and **500** MeV using new SPI at Nuclotron to study the manifestation of the short-range 3NFs.

Preparation for the taking of new polarized data for the **dp (pd)**- nonmesonic breakup at the energies between **300** and **500** MeV for different kinematic configurations at ITS with polarized beams.

Preparation of the experiment on the energy scan of the nucleon analyzing power A_y^p in **pd**- elastic scattering between **135** MeV and **1000** MeV at ITS.

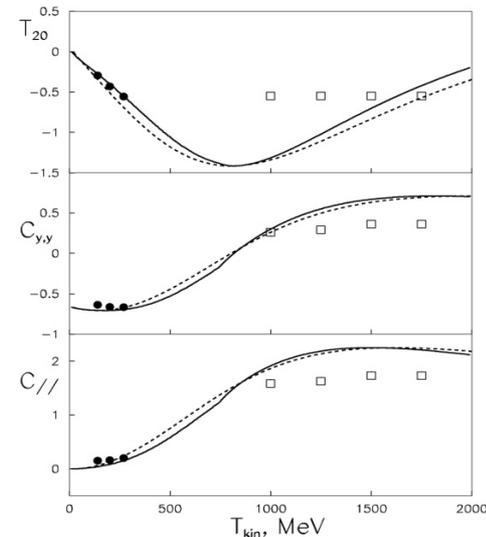
Thank you for the attention!

Polarization observables for polarized deuteron induced reactions

Target position is in F5

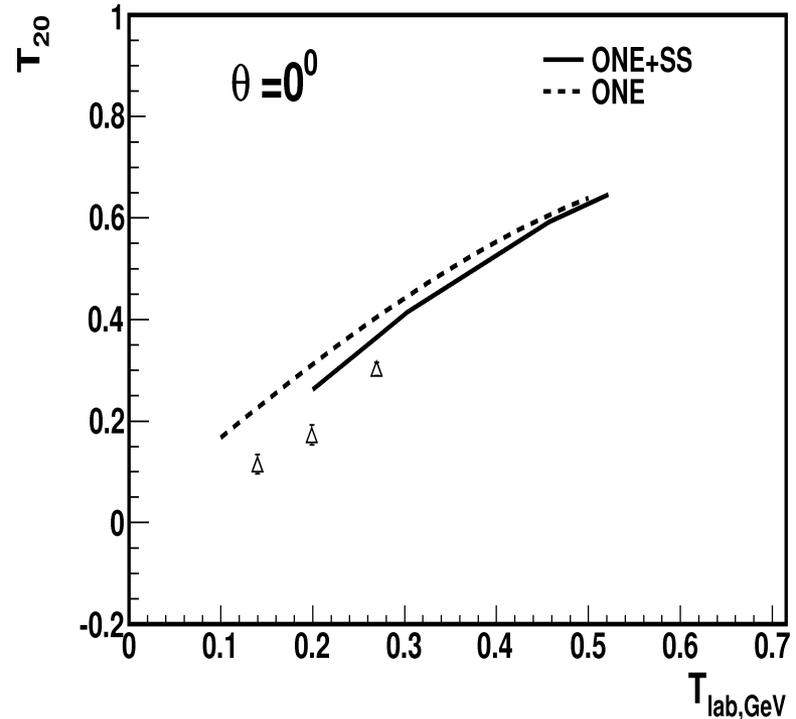
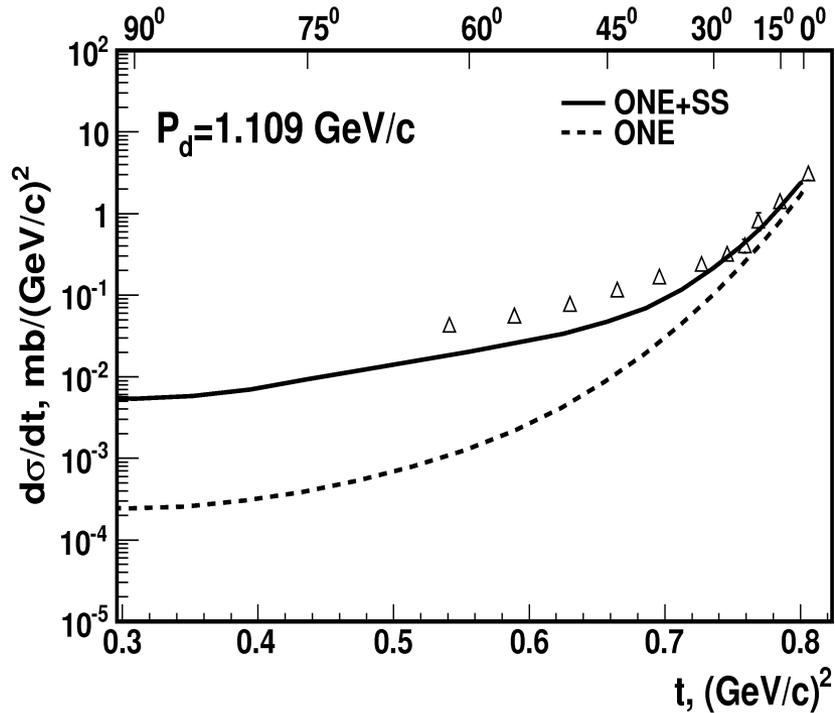


${}^3\text{He}(d,p){}^4\text{He}$



- The measurements of the tensor analyzing power T_{20} and spin correlation $C_{y,y}$ in the ${}^3\text{He}(d,p){}^4\text{He}$ reaction in the kinetic energy range between 1.0 and 1.75 GeV can be performed at the BM@N area.
- The polarization observables for the $p(d,p)d$, $d(d,p)t$ and $d(A,p(0^\circ))X$ at intermediate and high energies also can be studied.
- Non-nucleonic degrees of freedom and baryonic resonances properties can be studied in the $d(A,d(0^\circ))X$ and $d(A,\pi^-(0^\circ))X$ reactions at different energies.
- The tensor analyzing power T_{20} can be studied for the meson production in the $d(A,{}^3\text{He}(0^\circ))X$ reactions.

$dd \rightarrow {}^3\text{He}n({}^3\text{H}p)$ reactions at Nuclotron energies

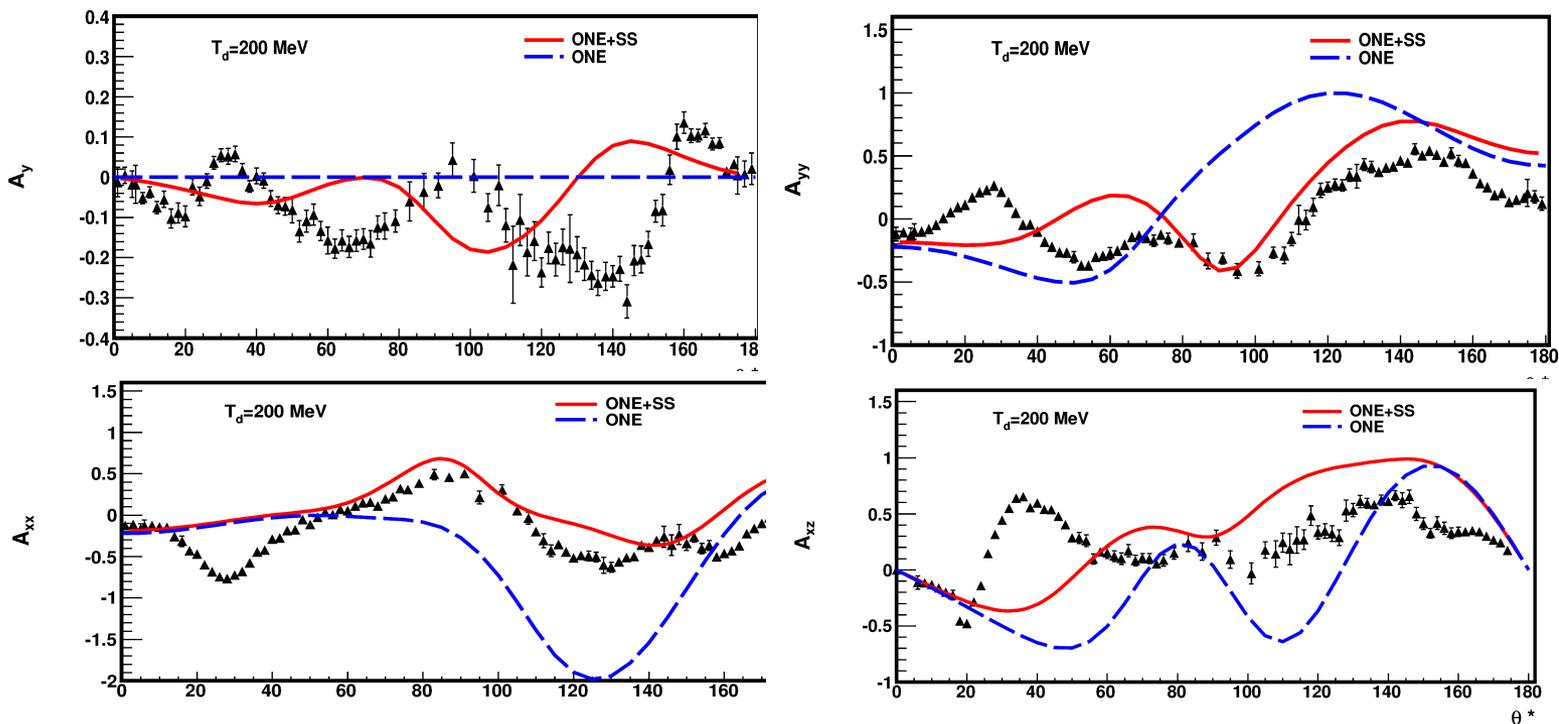


The relativistic multiple scattering model can be successfully used to describe the $dd \rightarrow {}^3\text{He}n({}^3\text{H}p)$ reactions in a GeV region at the Nuclotron.

The calculations require a large amount of CPUs.

The results are published in [N.B.Ladygina, Few Body Systems 53 \(2012\) 253](#).

Polarization effects in the $dd \rightarrow {}^3\text{He}({}^3\text{He})$ reactions at Nuclotron energies



The relativistic multiple scattering model was successfully used to describe the $dd \rightarrow {}^3\text{He}({}^3\text{He})$ reactions in a GeV region at the Nuclotron.

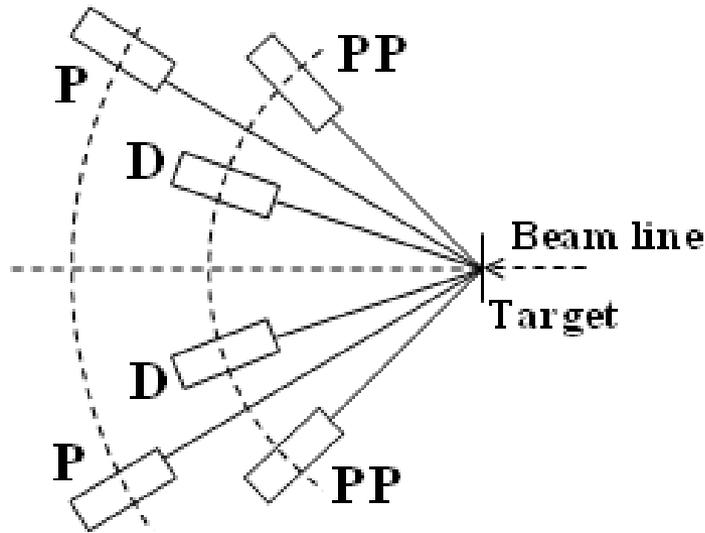
The calculations require a large amount of CPUs.

The results were published in FBS, PRC, PPN.

N.Ladygina - theory

A.Kurilkin - experiment

Scheme of the HE-dp- experiment

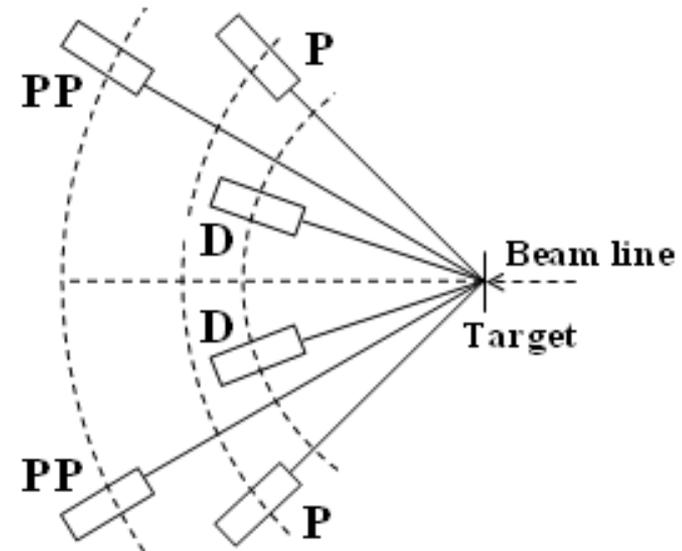


$P = 20 \times 60 \times 20 \text{ mm}^3$

$D = 10 \times 40 \times 24 \text{ mm}^3$

$PP = 50 \times 50 \times 20 \text{ mm}^3$

March 2013-2015



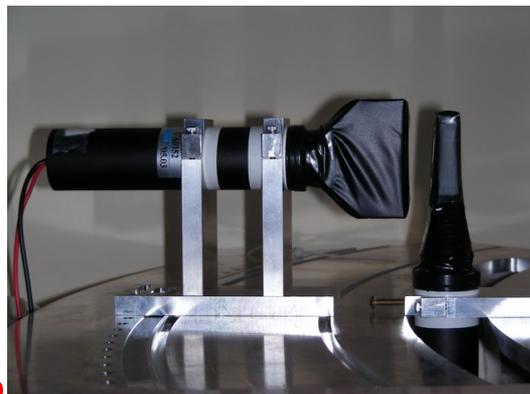
$P = 20 \times 60 \times 20 \text{ mm}^3$

$D = 50 \times 50 \times 20 \text{ mm}^3$

$PP = \phi 100 \times 200 \text{ mm}^3$

December 2012

LE-dp- experiment has been performed with PMT-85 in 2011-2012

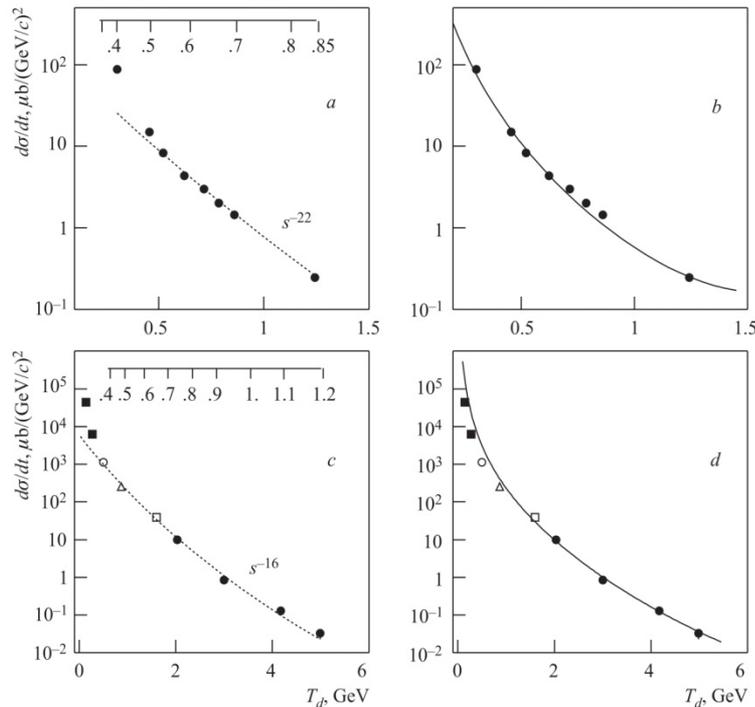


Fundamental (quark) degrees of freedom

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

$$\frac{d\sigma}{dt}(ab \rightarrow cd) = \frac{f(t/s)}{s^{n-2}} \quad ; \quad \mathbf{n} = \mathbf{N}_a + \mathbf{N}_b + \mathbf{N}_c + \mathbf{N}_d$$

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



Yu. N. Uzikov

JETP Lett, 81 (2005) 303-306

For the reaction $dd \rightarrow {}^3\text{He}n$

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

For the reaction $dp \rightarrow dp$

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

The regime corresponding to CCR can occur already at $T_d \sim 500$ MeV