

The light nuclei spin structure from the hadronic interactions at intermediate energies



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- Institute for Nuclear Research, Moscow, Russia
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- CYRIC, Tohoku University, Sendai, Japan

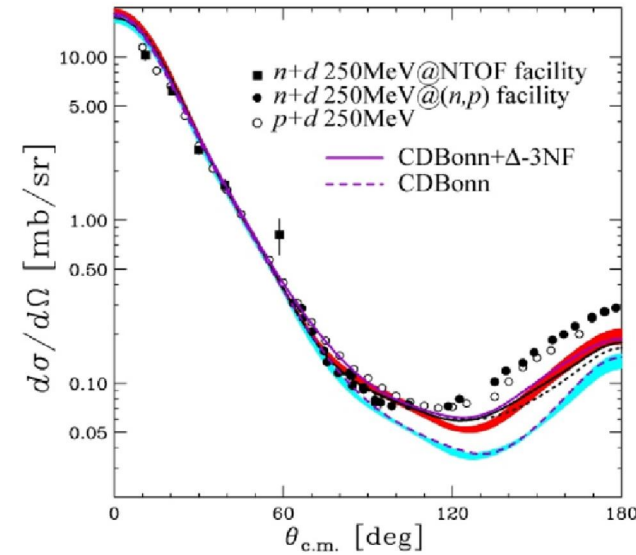
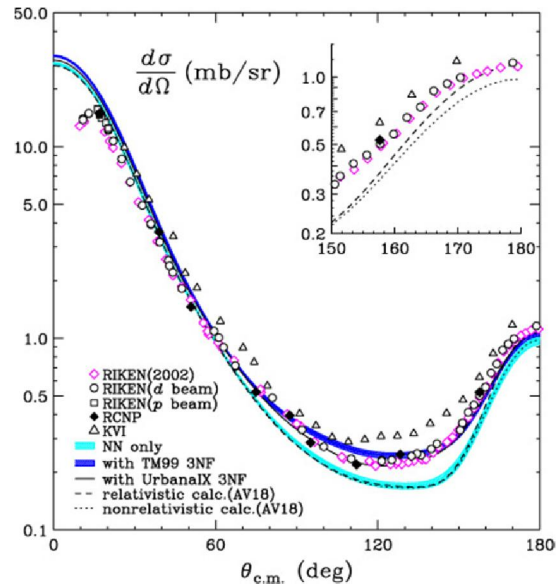
Outline

- Introduction
- Recent LHEP-JINR(Dubna) results on spin studies for few-body systems
- Results of the ^3He , ^3H and deuteron spin structure investigations at RIKEN
- High energy deuteron beam polarimetry at Internal Target Station @ Nuclotron-M
- Plans for Nuclotron-M
- Conclusion

Motivation

- Modern NN potentials (CD-Bonn, AV-18, Nijmegen etc.) accurately reproduce the NN data set up to about 350 MeV. However they fail in the description of the binding energy and data on unpolarized dp-elastic scattering and breakup reactions
- Incorporation of three nucleon forces (3NF), when interaction depends on the quantum numbers of the all three nucleon, allows to reproduce the binding energy of the three-nucleon bound systems and the data on unpolarized dp- interaction.
- Polarization data for the reaction with participation of three and more nucleons aren't described even with the 3NF inclusion.
- The cross section data for dp- elastic scattering are reproduced well up to 150 MeV taking into account 3NF. Manifestation of three-nucleon forces effect in the cross-section of **dp**-elastic scattering at this energy: up to **30%** in the vicinity of Sagara discrepancy.

Cross section in dp- elastic scattering at intermediate energies



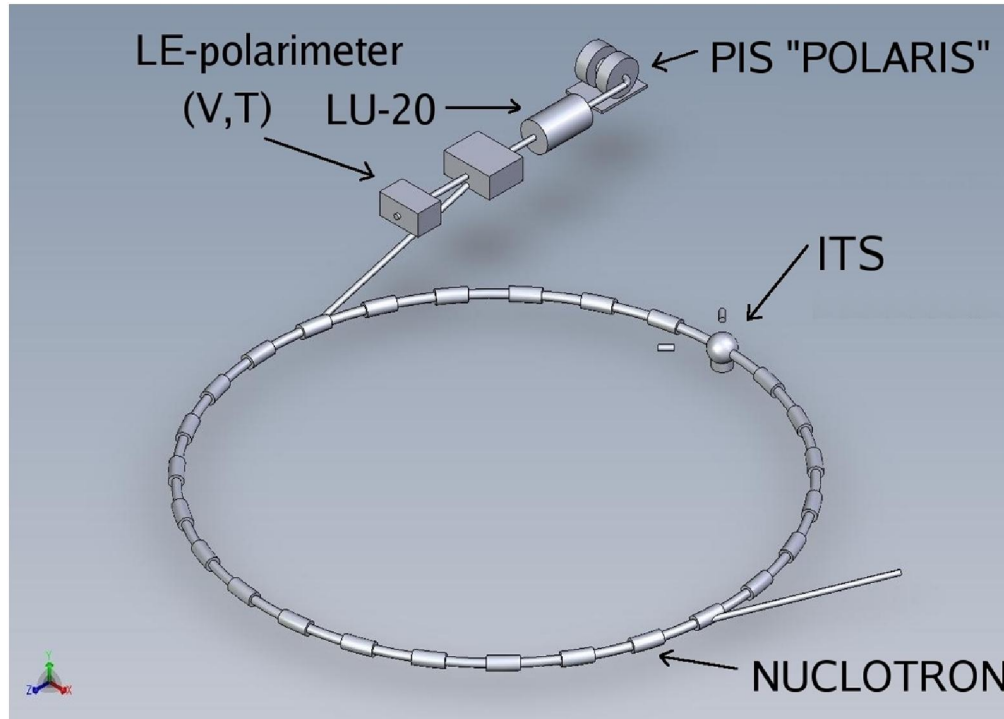
The differential cross section in elastic Nd scattering at the energy of 135 (left figure) and 250 (right figure) MeV/u.

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

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

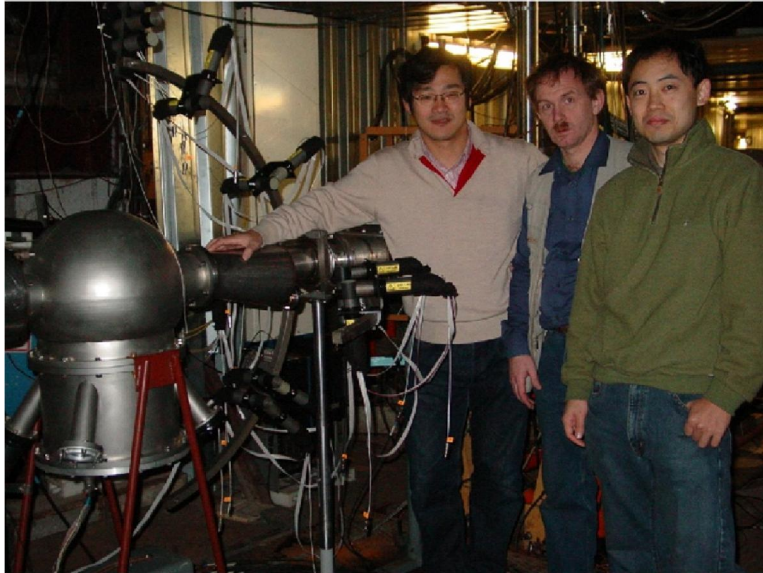
The study of hadronic reactions induced by polarized deuterons at Nuclotron-M will allow to study the spin structure of 2N and 3N SRC.

Nuclotron accelerator complex



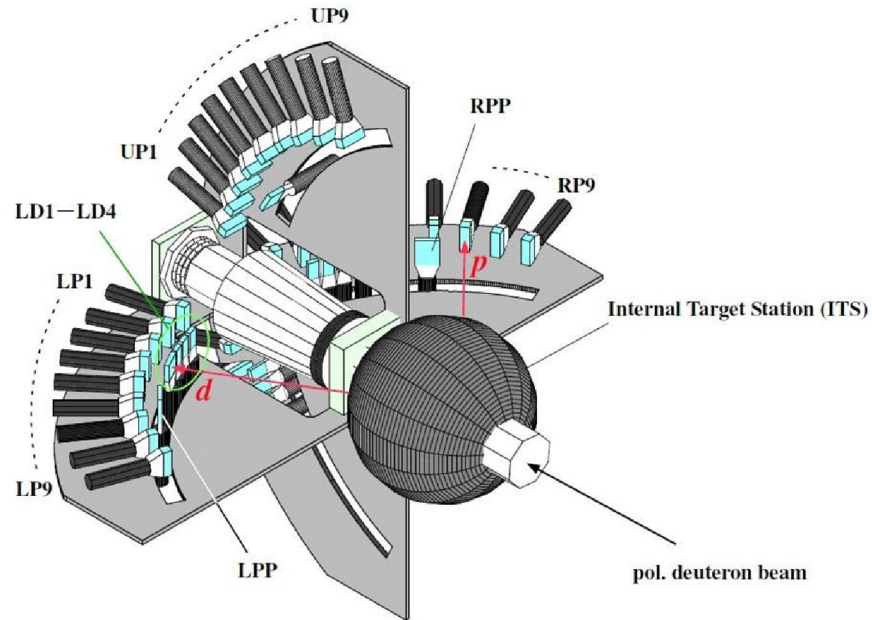
- PIS **POLARIS** on 360 kV terminal
- 5 MeV/A (20 MeV protons) LINAC **LU20**
- Tensor and vector **LEPs** based on the $d^3\text{He} \rightarrow p(0^\circ)^4\text{He}$ and $d^4\text{He} \rightarrow d^4\text{He}$ reactions, respectively
- Nuclotron Ring: 6 GeV/A deuterons.

Joint **CNS-JINR** experiment at Internal Target Station at Nuclotron
(**DSS-proect**)



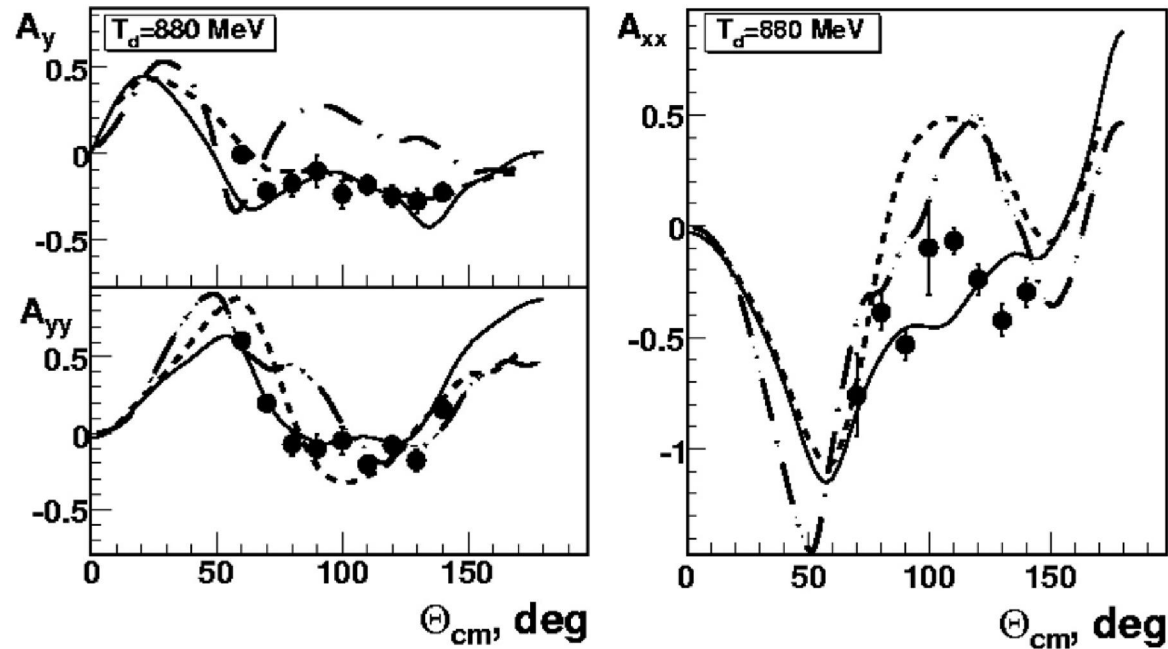
New Internal Target Station is very well suited for the measurements of the dp - elastic scattering observables at large angles in the c.m.s. due to a large opening angle.

CNS-JINR setup to study dp - elastic scattering



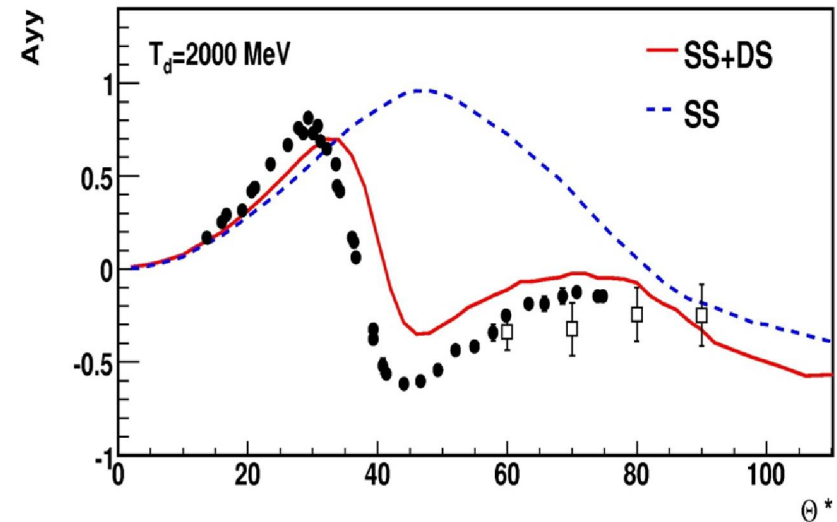
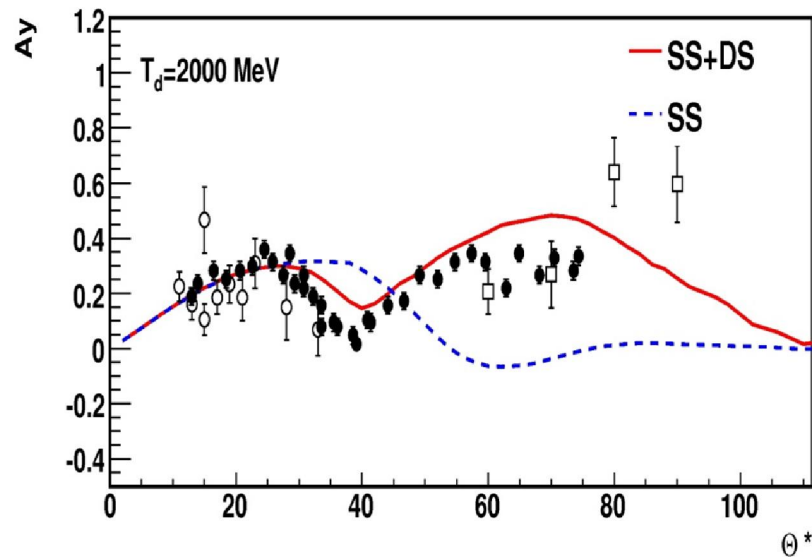
- Deuterons and protons in coincidences using scintillation counters
- Internal beam and thin CH_2 target (C for background estimation)
- Polarization measurement at 270 MeV
- Analyzing powers measurement at 880 and 2000 MeV
- The data were taken for three spin modes of PIS: unpolarized, “2-6” and “3-5”
(p_z, p_{zz}) = (0,0), (1/3,1) and (1/3,-1)

Analyzing powers in dp - elastic scattering at 880 MeV



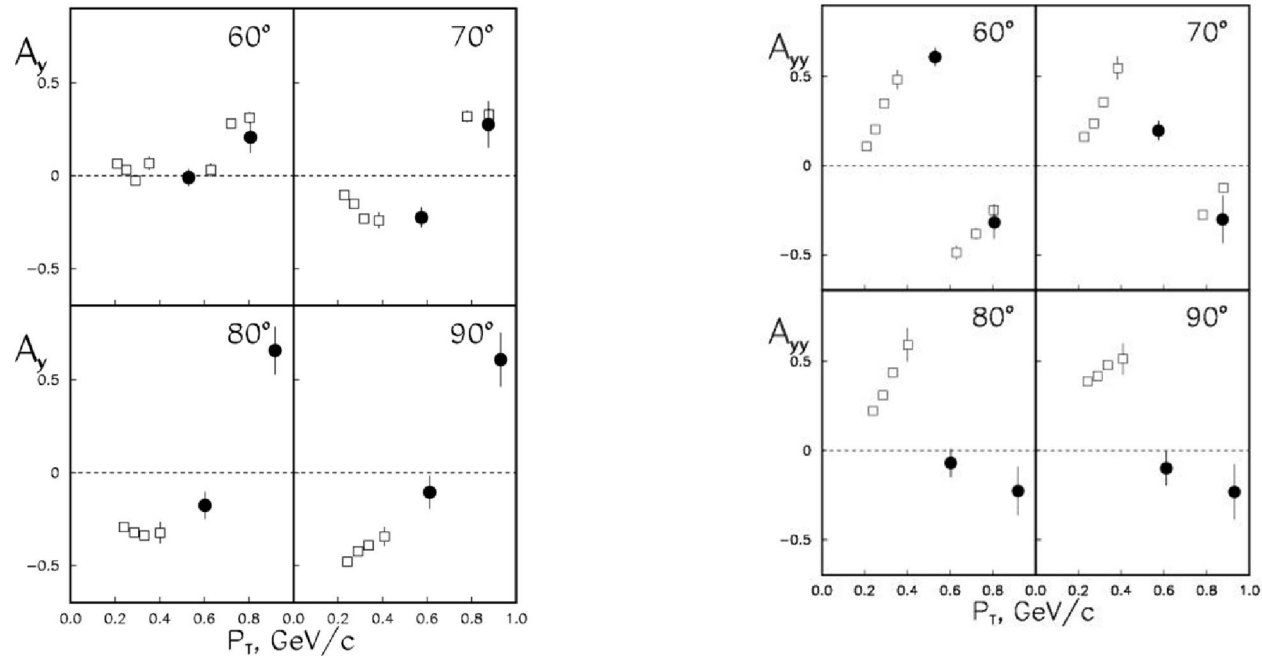
- Dashed lines are the multiple scattering model calculations using [CD-Bonn DWF](#) (N.B.Ladygina, *Phys.Atom.Nucl.*71 (2008), 2039)
- Solid lines are the Faddeev calculations using [CD-Bonn potential](#) (H.Witala, private communication)
- Dott-dashed lines are the optical-potential calculations using [Dibarion DWF](#) (M.Shikhalev, *Phys.Atom.Nucl.*72 (2009), 588)

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



- Open symbols are the data obtained at **JINR**.
- 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 (**in the talk of N.B.Ladygina**).

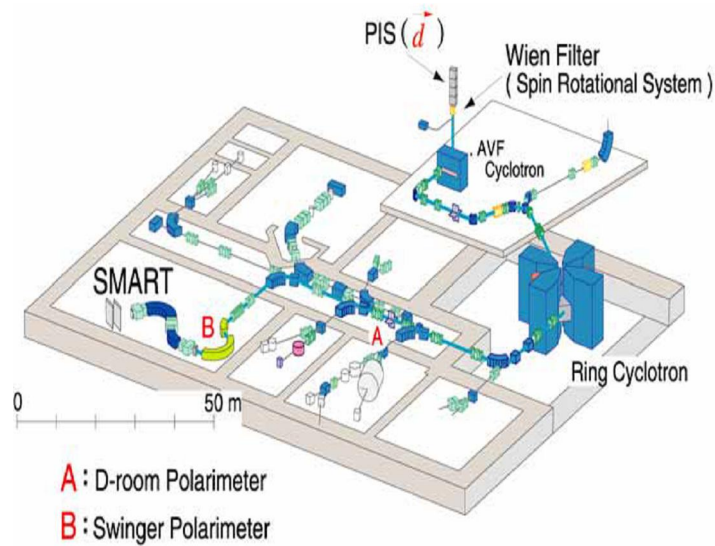
Energy dependence of the dp -elastic scattering analyzing powers at fixed scattering angles in the c.m.s.



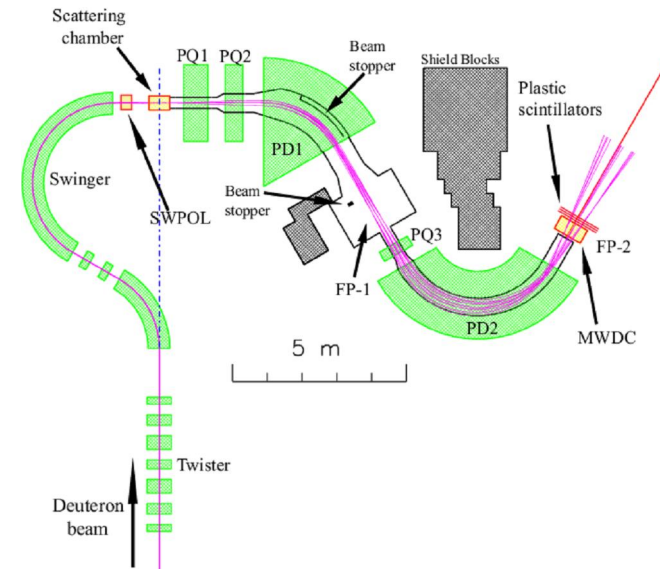
- Full symbols are the data obtained at **JINR**
- Open symbols are the data obtained at RIKEN, Saclay and ANL.
- The study of the energy dependence of the analyzing powers in dp - elastic scattering at large p_T is one of the tools to study **cold dense matter**

R308 experiment at RIKEN

- Investigation of the ^3H , ^3He and **deuteron** spin structure at short distances at the energies 140, 200, 270 MeV.
- Polarization observables comparison from mirror channels: $^3\text{H}_p$ and $^3\text{H}_n$.

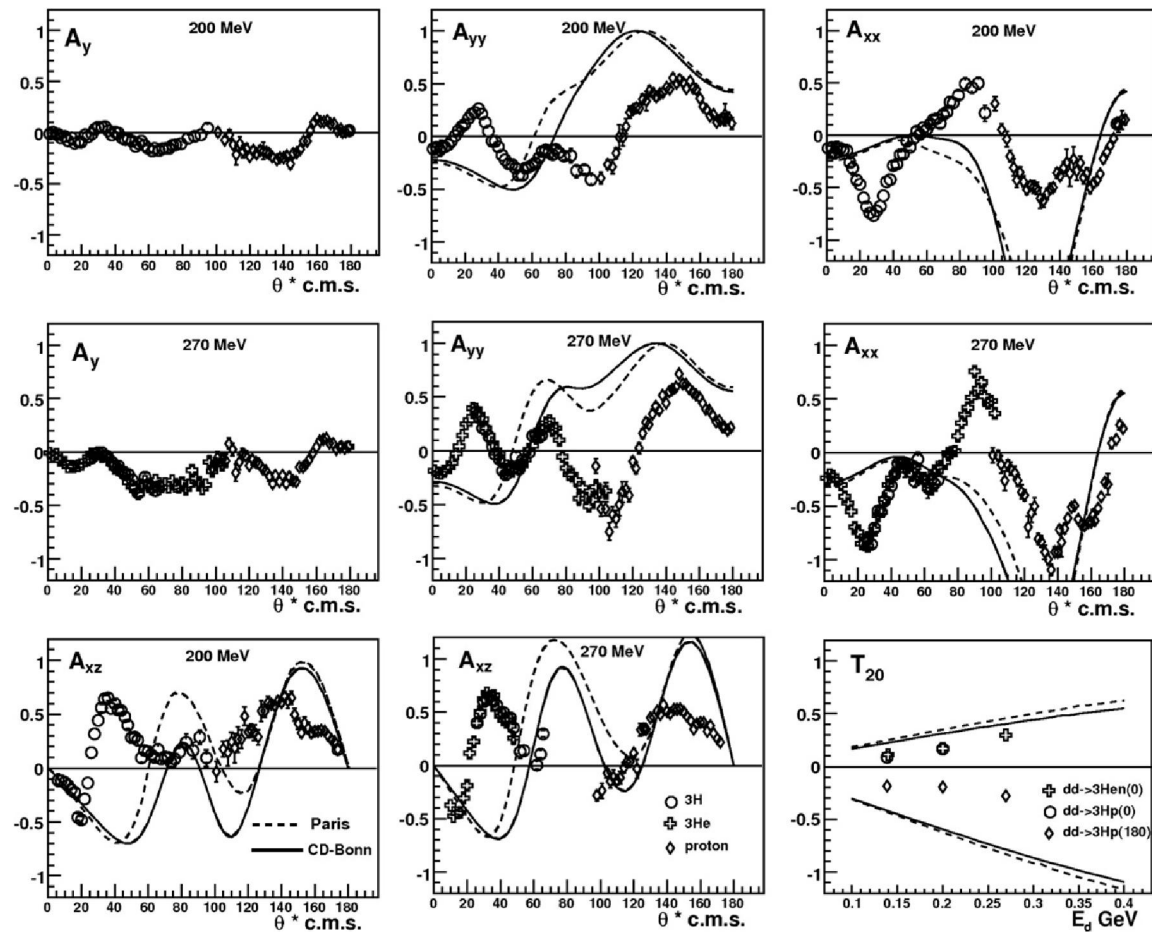


RIKEN Accelerator Research Facility.



SMART spectrometer.

Polarization observables from the $dd \rightarrow {}^3\text{He}n({}^3\text{Hp})$ reactions (CNS-JINR)



The solid curve is the result of the ONE calculations using **CD-Bonn** ${}^3\text{He}$ and deuteron wave functions. The dotted curve is the result of the ONE calculations using ${}^3\text{He}$ and deuteron wave functions derived from **Paris** potential. The ${}^3\text{He}$ wave function were taken from the work (V.Baru *Eur.Phys.J.A*16:437-446,2003).

Deuteron beam polarimetry at the ITS at Nuclotron-M

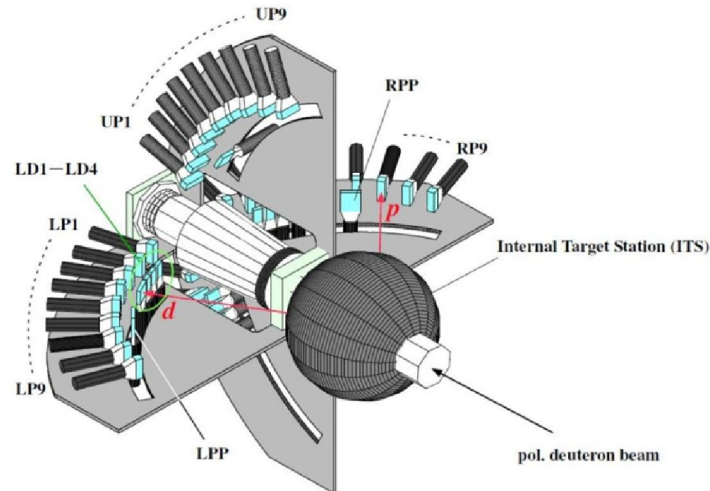
Measurement of the beam polarization is an important element in different physical experiments.

dp elastic scattering at large angles ($\Theta_{\text{cm}} > 60^\circ$) – the deuteron beam polarimetry at RIKEN ($E_d \sim 100 \text{ MeV}$).

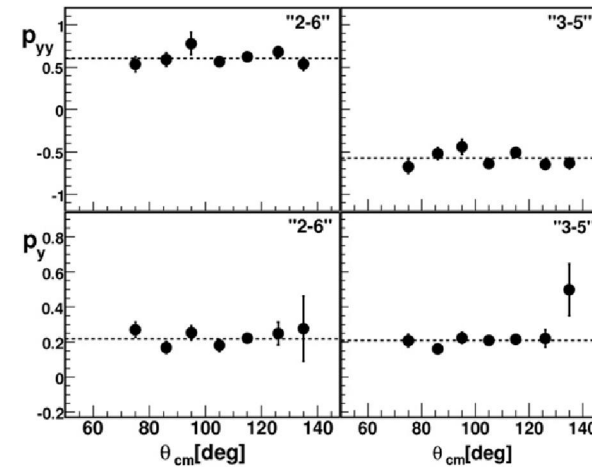
The advantages of the use of the **dp**- elastic scattering at large angles ($\Theta_{\text{cm}} > 60^\circ$) at the **270 – 2000 MeV** energy range:

- Analyzing powers of this reaction have large values.
- The kinematical coincidence measurement of the deuteron and proton with plastic scintillation counters sufficient for event identification.

Measurement of the deuteron beam polarization at ITS using CNS detection system at 270 MeV



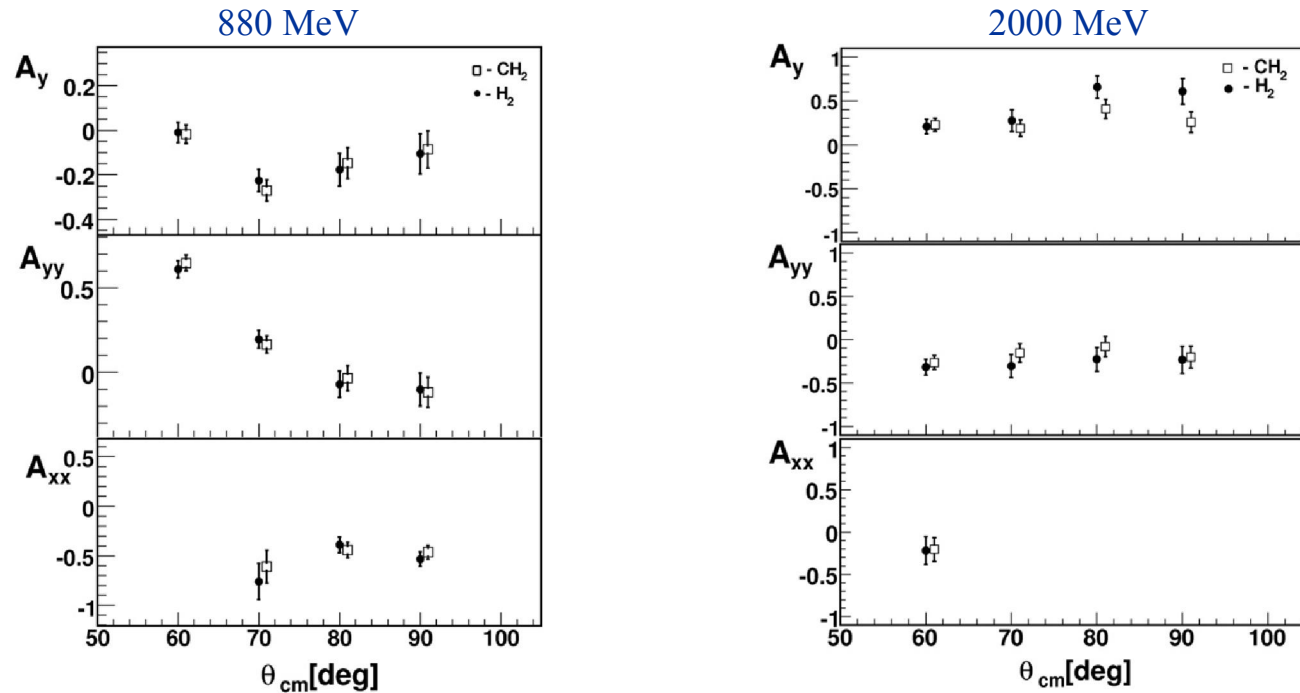
A schematic view of the polarimeter setup installed downstream the ITS spherical chamber.



Tensor p_{yy} and vector p_y polarization of the beam for "2-6" and "3-5" spin modes of PIS POLARIS as a function of the deuteron scattering angle in the c.m.s.

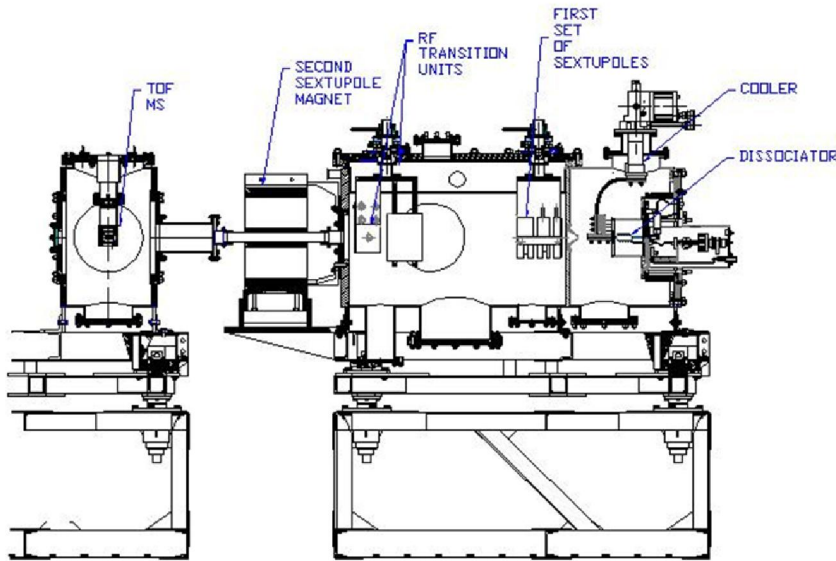
- Main deuteron beam polarimeter at Nuclotron-M.
- **dp**- elastic scattering at large scattering angles in the center of mass system.
- The detectors cover the angular range 60-140° in the c.m.s.
(P.K. Kurilkin et al., Nucl. Instr. and Meth. A 642 (2011) 45)

A_y , A_{yy} and A_{xx} in dp - elastic and quasielastic scattering at 880 and 2000 MeV



- The analyzing powers in dp -elastic scattering are large enough to provide both the vector and tensor polarimetry at high energies.
- The analyzing powers values for elastic and quasielastic deuteron scattering are comparable. Therefore, polarimeter can be used in the counting mode (without event-by-event analysis).

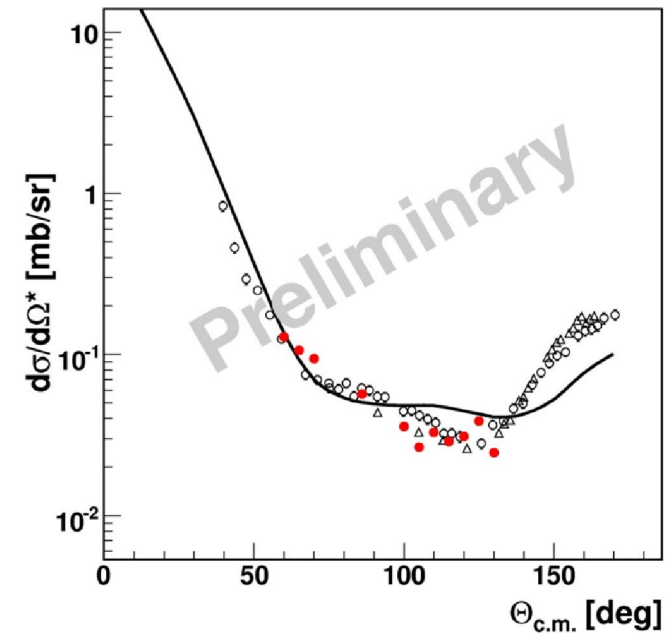
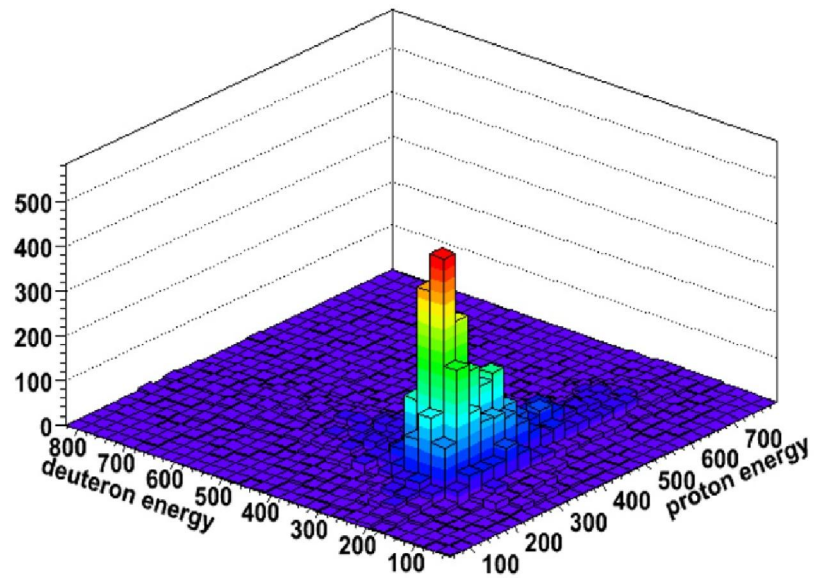
New Polarized Deuteron Source for LHEP



- New source will provide up to $2 \cdot 10^{10}$ ppp and higher values of polarization than **POLARIS**.
- Part of the **IUCF** source can be used for the construction. **400k\$** is required to put into operation new PIS.
- Large variety of the spin modes. **DSS** project will use the spin modes with the following ideal values of (p_z, p_{zz}) : $(0,0)$, $(0,-2)$, $(2/3,0)$ and $(-1/3,+1)$

Figure of merit increasing by a factor $\sim 10^3$

The **dp**- elastic scattering investigation at the ITS at Nuclotron-M

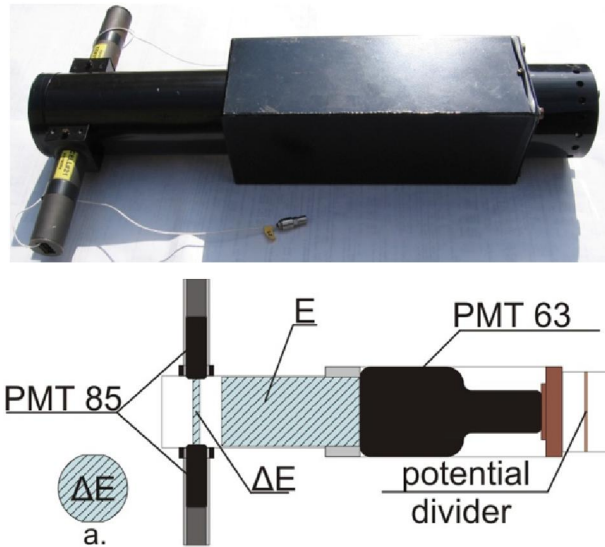


Left figure: The correlation of the amplitude signals for one pair of the deuteron and proton detectors at 880 MeV.

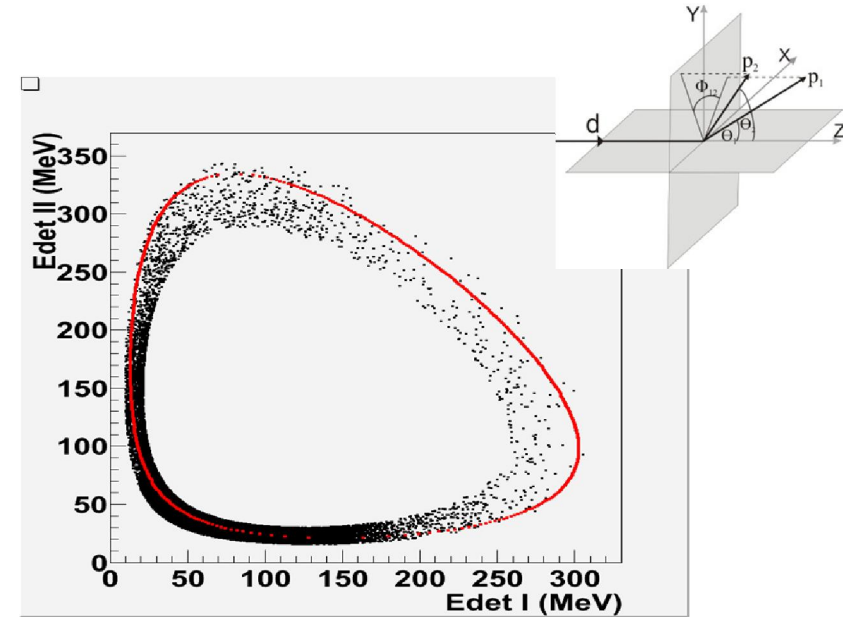
Right figure: The angular dependences of the **dp**- elastic cross section at ~880 MeV. The red solid and open symbols are the world data (N.E.Booth et al., *Phys.Rev.D4* (1971) 1261; J.C.Alder et al., *Phys.Rev.C6* (1972) 2010) and data obtained at the Nuclotron-M, respectively. Solid curve is the result of the multiple scattering model(N.B.Ladygina, *Eur.Phys.J, A42* (2009) 91).

- Commissioning experiment with the upgraded setup has been performed in March 2011 at the energy of 500 and 880 MeV.
- Systematic studies of **dp**- elastic scattering (cross section and deuteron analyzing powers) at **ITS** at **Nuclotron-M** at 300-2000 MeV.

dp- breakup study at the ITS at Nuclotron-M



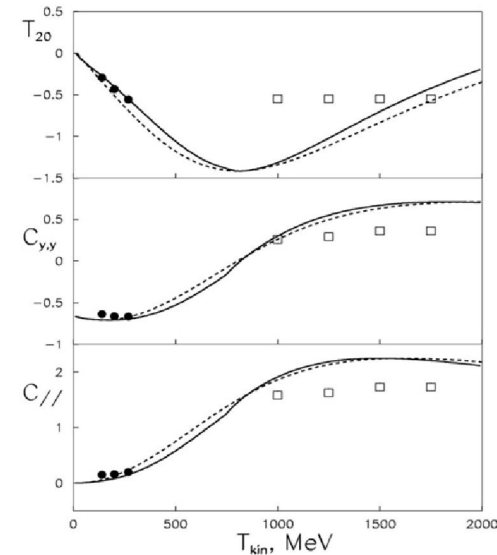
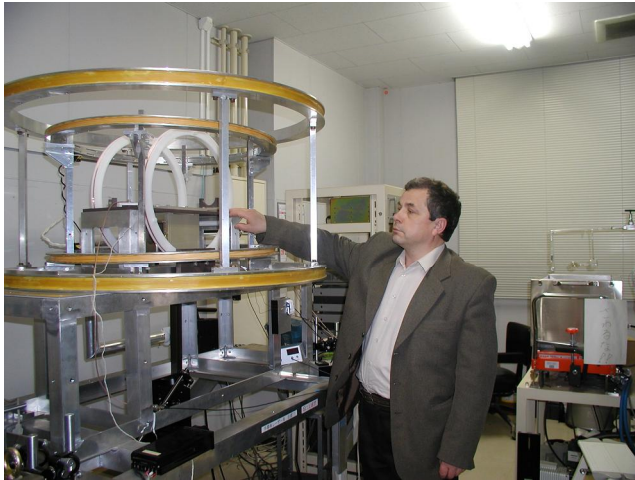
The photo and layout of the ΔE -E detector for the dp-breakup study at the ITS@Nuclotron-M



The correlation of the ΔE +E information from I and II proton detectors. $\theta_1 = 34^\circ$, $\theta_2 = 29.3^\circ$, $\phi_{12} = 180^\circ$

- Study of dp-breakup in different parts of the phase space allows to separate contribution of $2N$ and $3N$ correlations.
- These investigation will be done at ITS at Nuclotron-M at 300-500 MeV.
- Commissioning experiment with upgraded setup has been performed in March 2010 (4 ΔE -E detectors) at 500 MeV.

Polarization observables in the ${}^3\text{He}(d,p){}^4\text{He}$ and $dd \rightarrow {}^3\text{He}n({}^3\text{He}p)$ reactions (DSS-project)



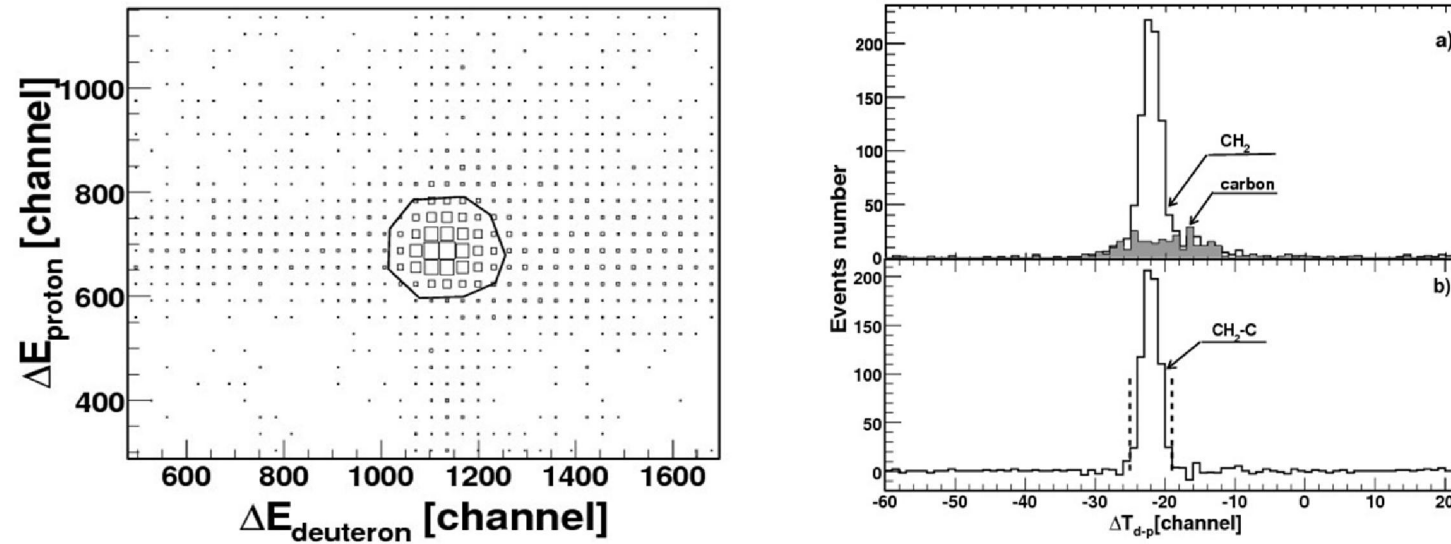
- The main goal of the project is the measurements of the tensor analyzing power T_{20} and spin correlation $C_{y,y}$ in the ${}^3\text{He}(d,p){}^4\text{He}$ reaction in the kinetic energy range between 1.0 and 1.75 GeV.
- The study of T_{20} in the $dd \rightarrow {}^3\text{He}n({}^3\text{He}p)$ reactions in a GeV region at the Nuclotron-M.

Conclusion

- The data on the analyzing powers A_y , A_{yy} and A_{xx} in **dp**- elastic scattering **have been measured** at ITS at the Nuclotron at the energies of **880** and **2000 MeV**. The experimental results are compared with the different theoretical predictions based on the use the NN forces only. All the calculations can't simultaneously reproduce the behavior of the measured analyzing powers and differential cross section obtained earlier.
- The results on the vector and tensor analyzing powers in the **dd**->**³Hp(³He)** reactions at the initial deuteron beam energy of **200** and **270 MeV** have been obtained. The data demonstrate large values of the analyzing powers. The deviation between the data and theoretical calculations indicate to the possibility other mechanism than ONE in these reactions. Also, the problem may be in inadequate description of the ³He, ³H and deuteron spin structure.
- It is planned to continue the **study** of the binary **reactions** like **dp**→**pd**, **dd** →**³Hp(³He)** and **d³He** → **p⁴He** at **Nuclotron-M** at LHEP-JINR. The new experimental data and further development in theoretical approaches are important for adequate description of the short-range light nuclei spin structure.

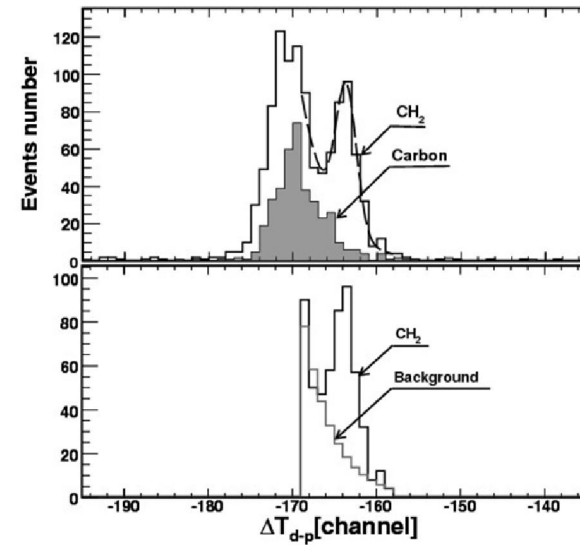
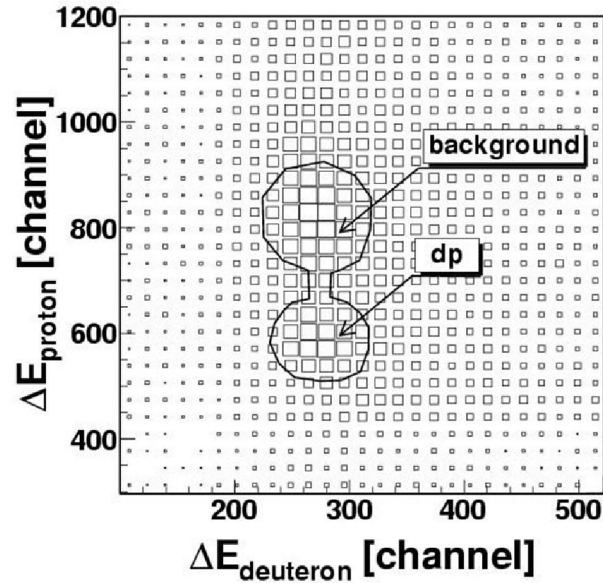
Thank you for the attention!!!

Elastic events selection at 880 MeV



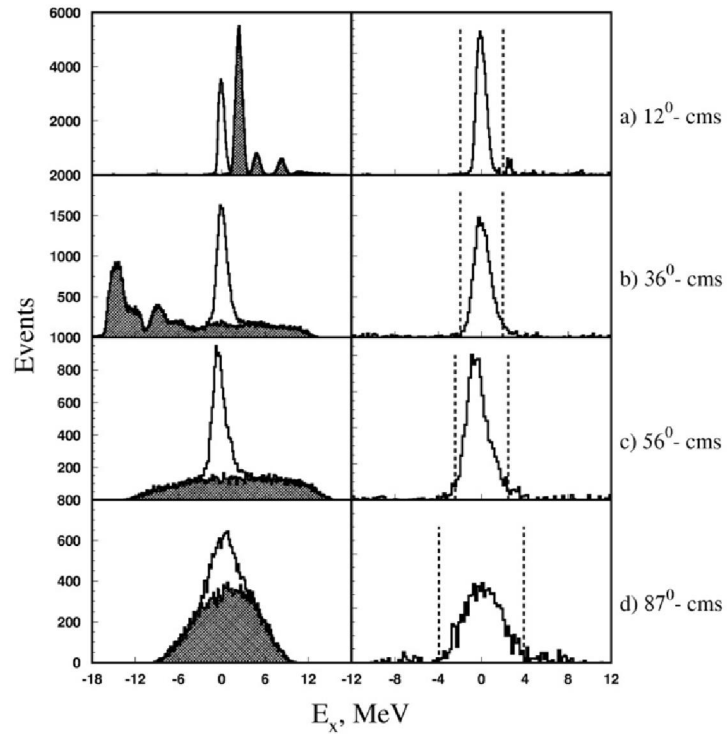
Event selection using signal amplitude correlations, time-of-flight difference, target position and $\text{CH}_2\text{-C}$ subtraction for each spin state of PIS

Elastic events selection at 2000 MeV

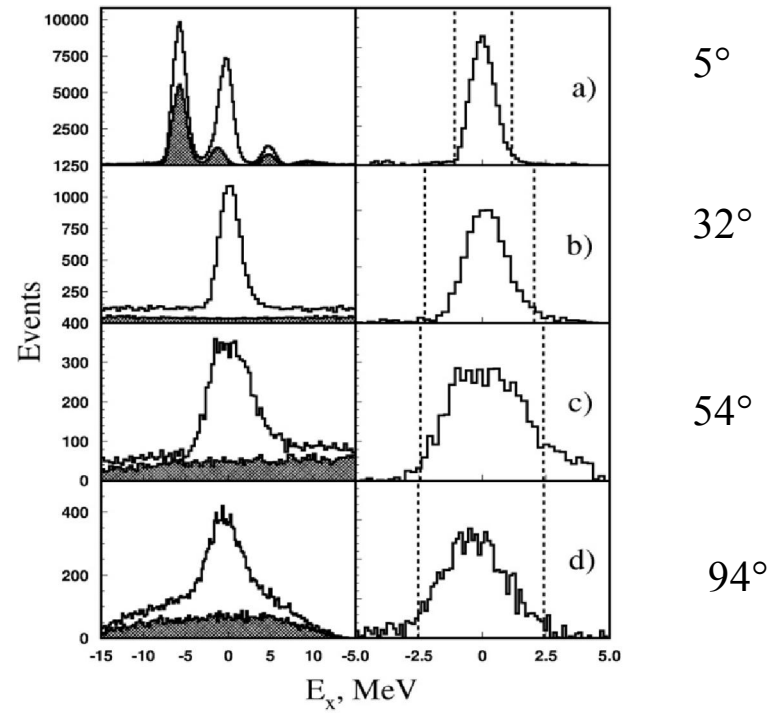


Event selection using signal amplitude correlations, time-of-flight difference, target position and **CH₂-C** subtraction for each spin state of **PIS**

Subtraction of carbon contribution

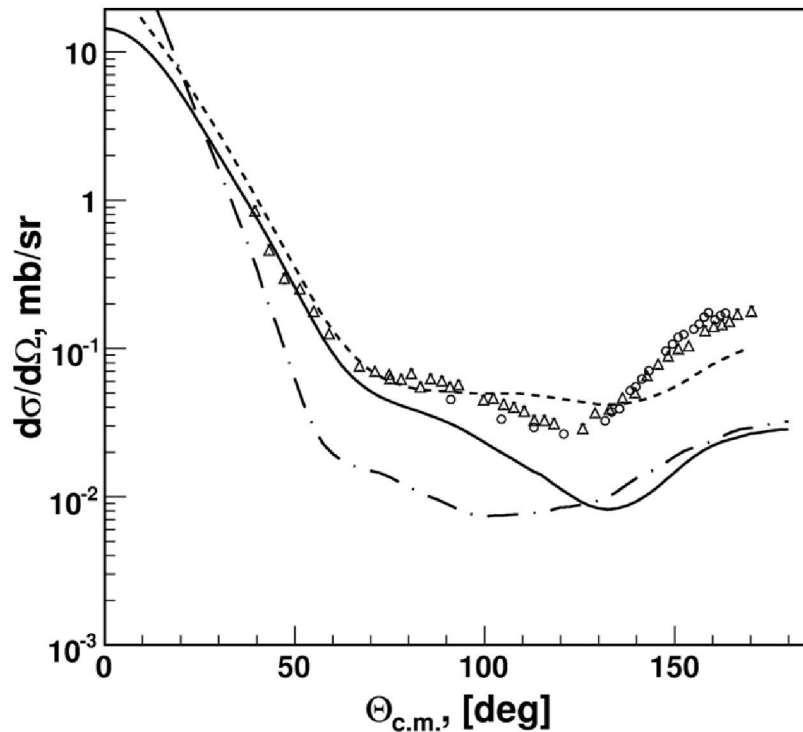


The quality of the carbon contribution subtraction for $dd \rightarrow {}^3\text{He}$ at 200 MeV at several scattering angles in c.m.s.



The quality of the carbon contribution subtraction for $dd \rightarrow {}^3\text{He}$ at 270 MeV at several scattering angles in c.m.s.

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 **30-130°**.
- Double scattering dominates over single scattering at the angles larger than **70°**.
- The deviation of the data on the calculation at backward angles are related with the **s-type** of **FM 3NF**.
- Is the deviation of the data on the calculations around **90°** manifestation of **3N SRC**?