

# Recent results with polarized deuterons and future plans for Nuclotron-NICA



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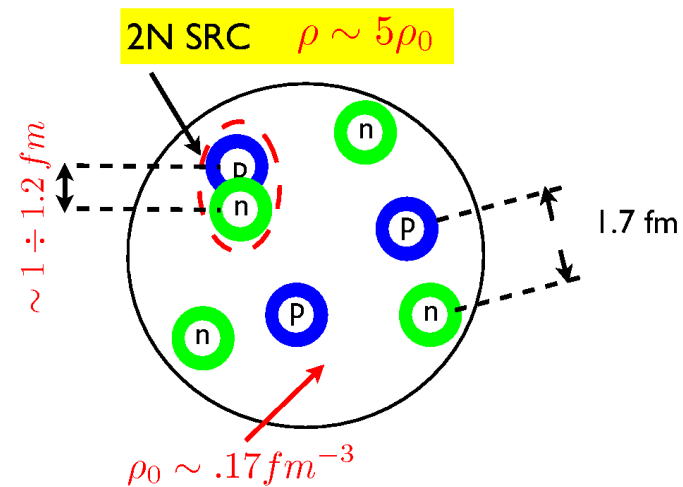
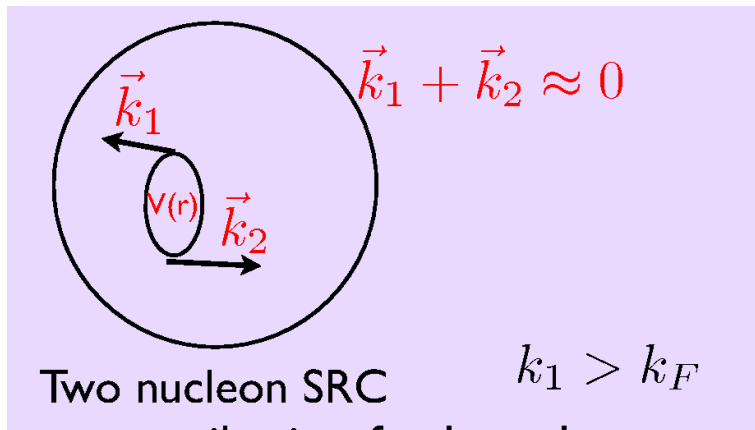
## Outline of the talk

- Introduction
- Recent LHEP results on spin studies for few body systems
- Plans for Nuclotron-M/NICA
- Polarimetry developments
- Conclusions

Collaboration: [Bulgaria-JINR-Japan-Romania-Russia-Slovakia](#)

## 2N short-range correlations (SRC)

From the talk of M.Strikman held at the VI-th International Conference on Perspectives in Hadronic Physics, 12-16 May, 2008, Trieste, Italy



- SRC have densities comparable to the density in the center of a nucleon - drops of cold dense nuclear matter
- Connections to neutron star  $nn(\mathbf{I} = 1)$  correlations, influence of  $np(\mathbf{I} = 0)$ , 3N SRC etc.

## Tools to study **2N** and **3N SRC** with hadron beams

- Deuteron structure at large internal momenta - **2N SRC** (**I = 0**).
- $^3\text{He}$  structure - **2N SRC** (**I = 1**) and contribution of **3N SRC**.
- **SRC** in nuclei from the  $A(p, p'pp)X$ ,  $A(p, p'pn)X$  and other reactions.

Data on the spin structure of **SRC** are almost absent!

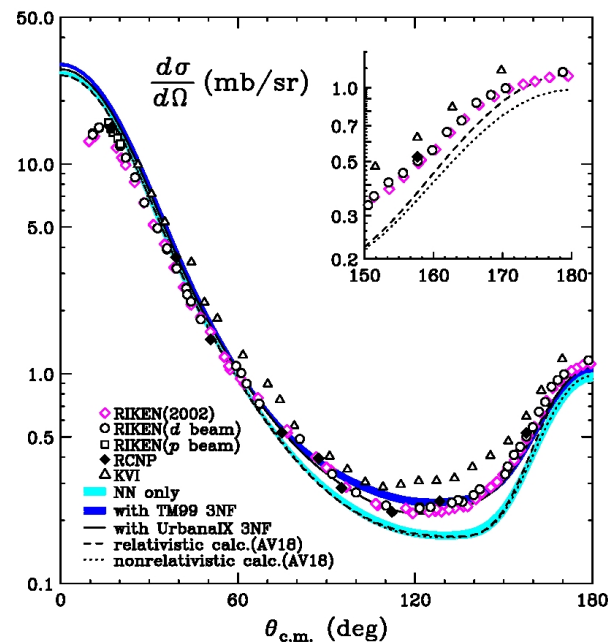


## Study of spin structure of **2N** and **3N** correlations

"classical 2NF&3NF" based on OBE models	below $\pi$ - threshold	cyclotrons <b>Nuclotron-M</b>
SR 2NF&3NF	hundreds MeV	<b>Nuclotron-M</b>
SR 2N&3N correlations	GeV-region	<b>Nuclotron-M</b> NICA

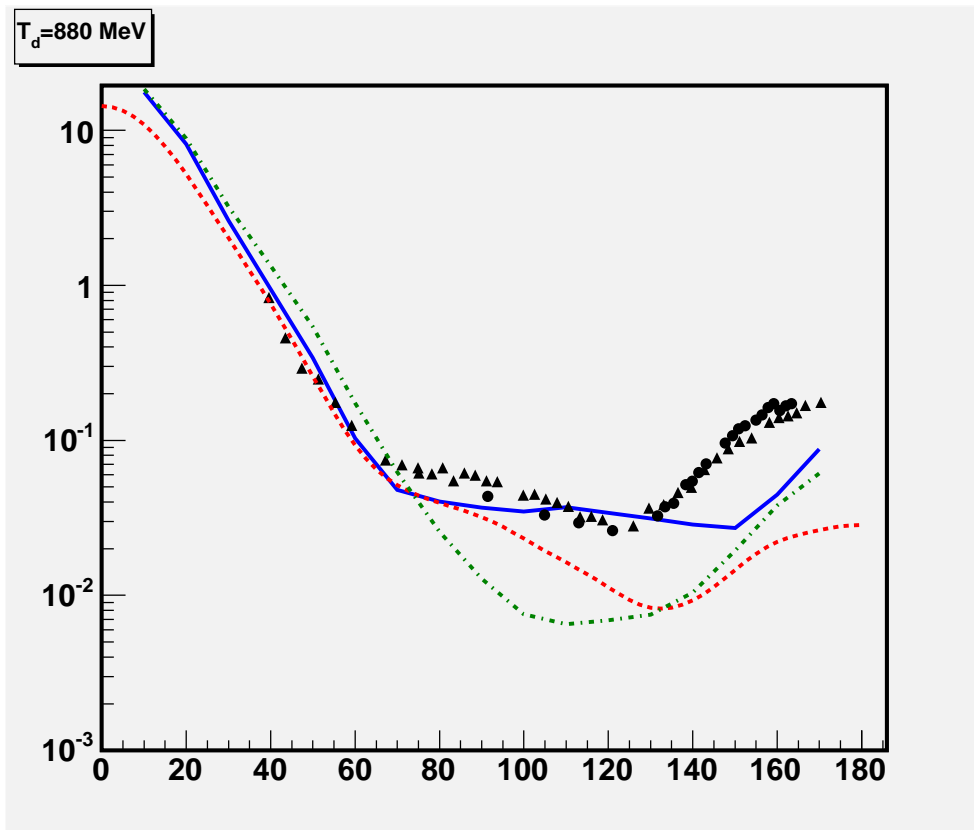
The study of hadronic reactions induced by polarized deuterons at **Nuclotron-M** will allow to study spin structure of **2N** and **3N SRC**.

## Cross section in **dp**- elastic scattering at intermediate energies



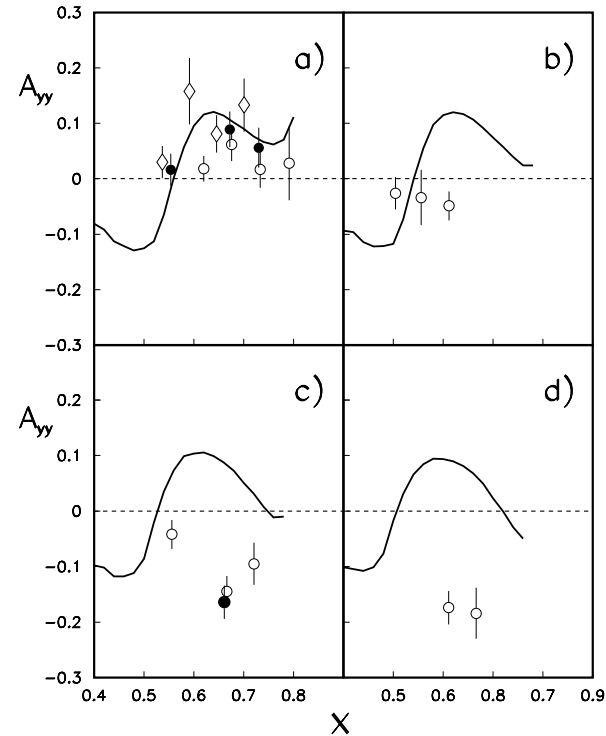
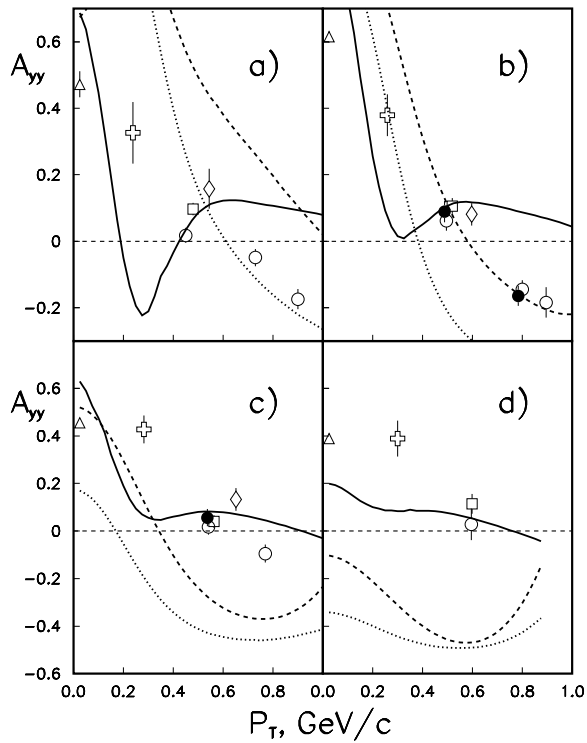
Manifestation of the three-nucleon forces effect in the cross section of **dp**- elastic scattering: up to **30%** in the vicinity of Sagara discrepancy.  
At higher energies - **SR 3NF**.

## Cross section in **dp**- elastic scattering at 880 MeV



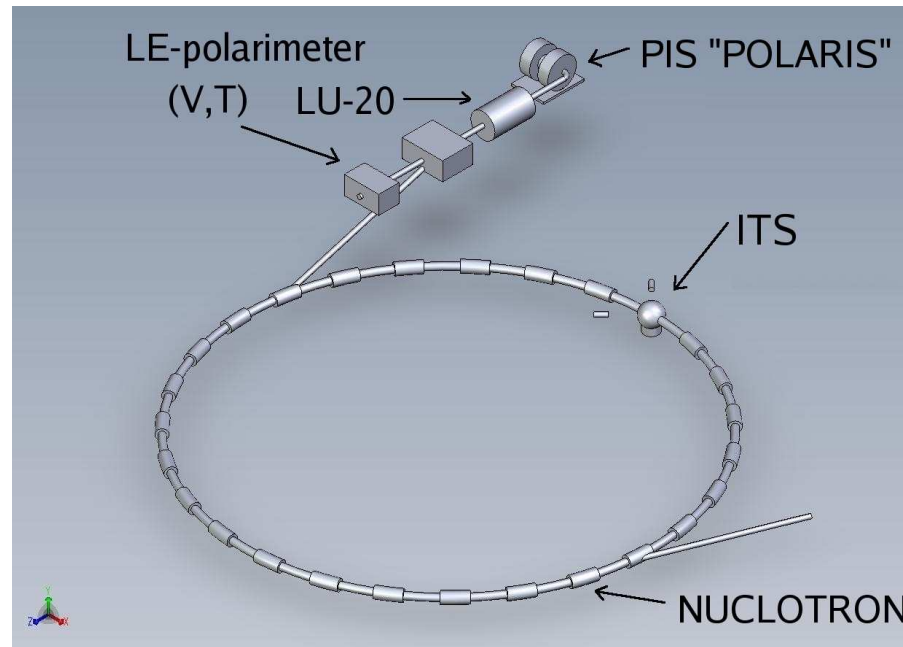
- The results of the multiple scattering model are in agreement with the cross section data in the range **30 – 130°**.
- Double scattering dominates over single scattering at the angles larger than **70°**
- The deviation of the data on the calculations at backward angles are related with the **s – type** of **FM 3NF**.
- Is the deviation of the data on the calculations around **90°** manifestation of **3N SRC**?

# Tensor analyzing power $A_{yy}$ in the ${}^1\text{H}(\text{d}, \text{p})\text{X}$ reaction



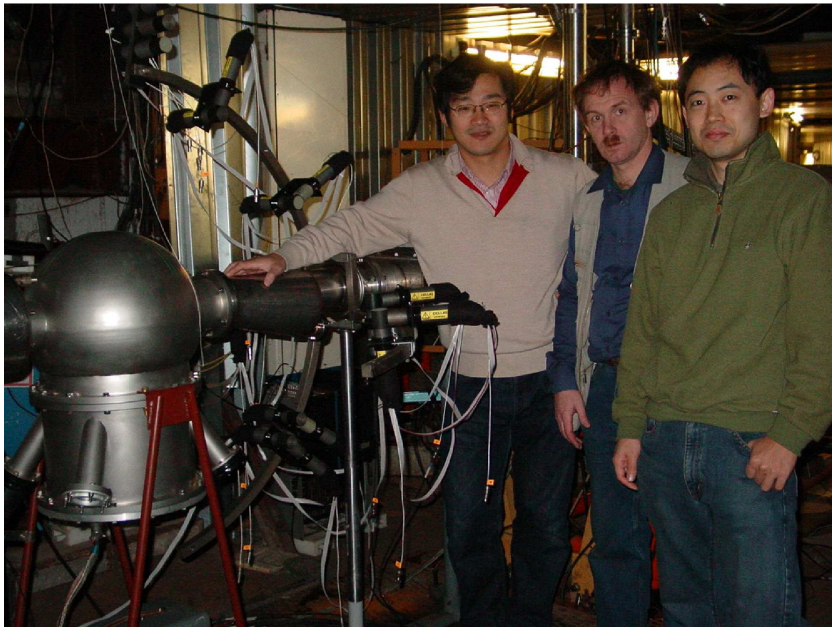
- $A_{yy}$  in deuteron inclusive breakup demonstrate the dependence on 2 internal variables:  $p_T$  and  $x_F$ .
- $A_{yy}$  change the sign at  $p_T \sim 600$  MeV/c independently on  $x_F$ .
- $A_{yy}$  demonstrates kind of negative asymptotic at large  $p_T$ .

# Polarized deuterons at Nuclotron Accelerator Complex



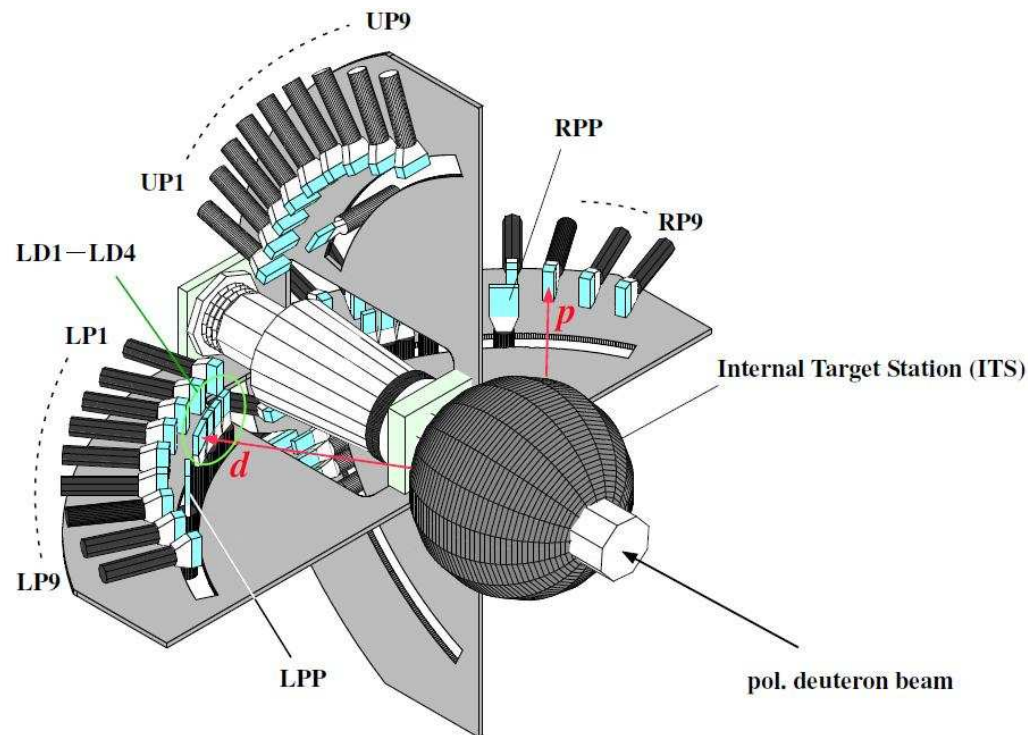
- PIS **POLARIS** on 360 kV terminal.
- 5 MeV/A (20 MeV protons) LINAC **LU20**.
- Tensor and vector **LEPs** based on the  $d^3\text{He} \rightarrow p(0^\circ)^4\text{He}$  and  $d^4\text{He} \rightarrow d^4\text{He}$  reactions, respectively.
- Nuclotron Ring: 6 GeV/A deuterons.

## Joint **CNS-JINR** experiment at Internal Target Station at Nuclotron-M (**DSS-project**)



New Internal Target Station is very well suited for the measurements of the **dp**- elastic scattering observables at large angles in the cms due large opening angle.

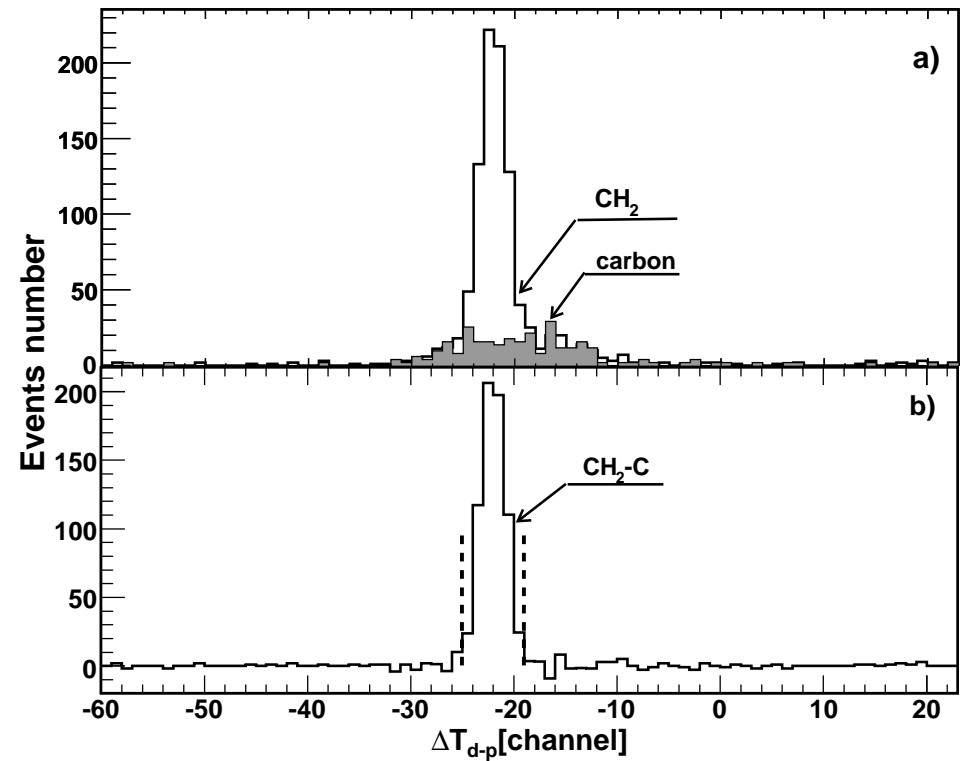
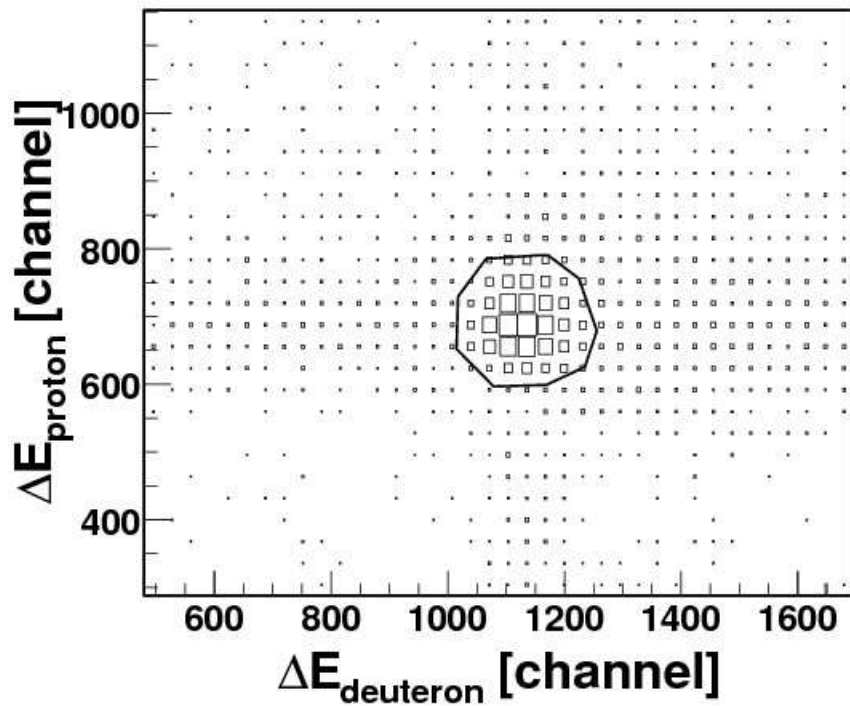
## CNS-JINR setup to study $dp$ - elastic scattering



- Deuterons and protons in coincidences using scintillation counters
- Internal beam and thin  $\text{CH}_2$  target (C for background estimations)
- Polarization measurements at 270 MeV
- Analyzing power measurements at 880 and 2000 MeV



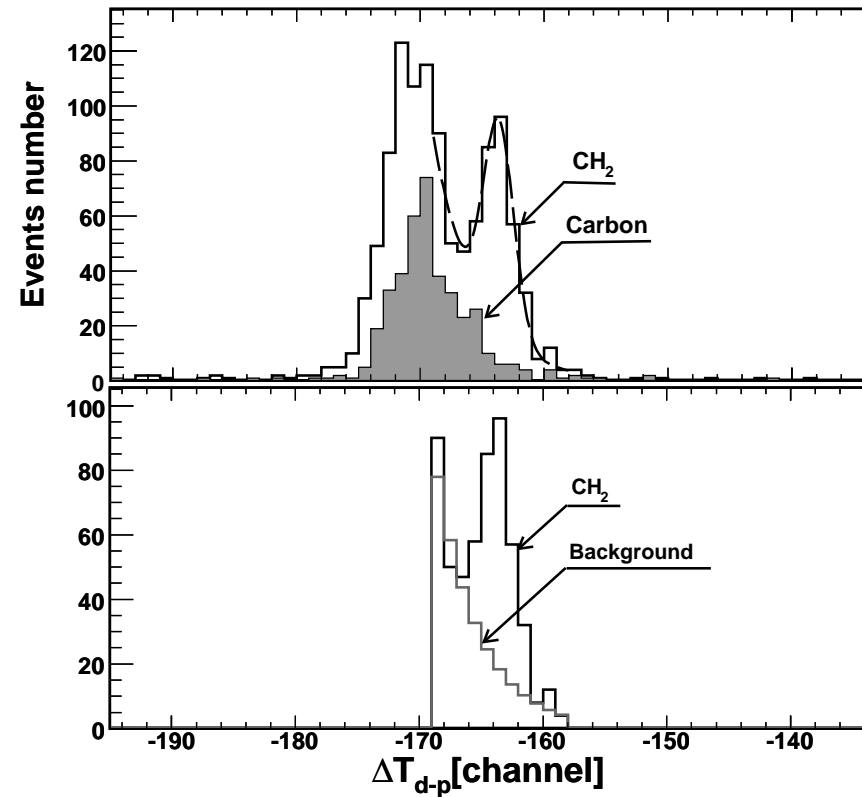
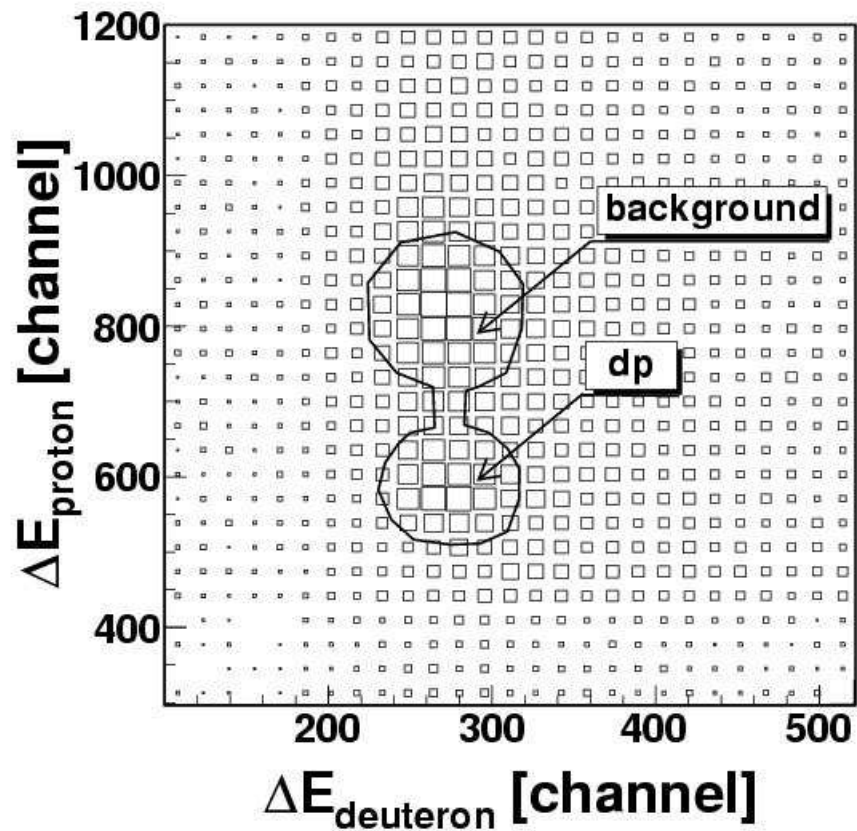
## Elastic events selection at 880 MeV



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

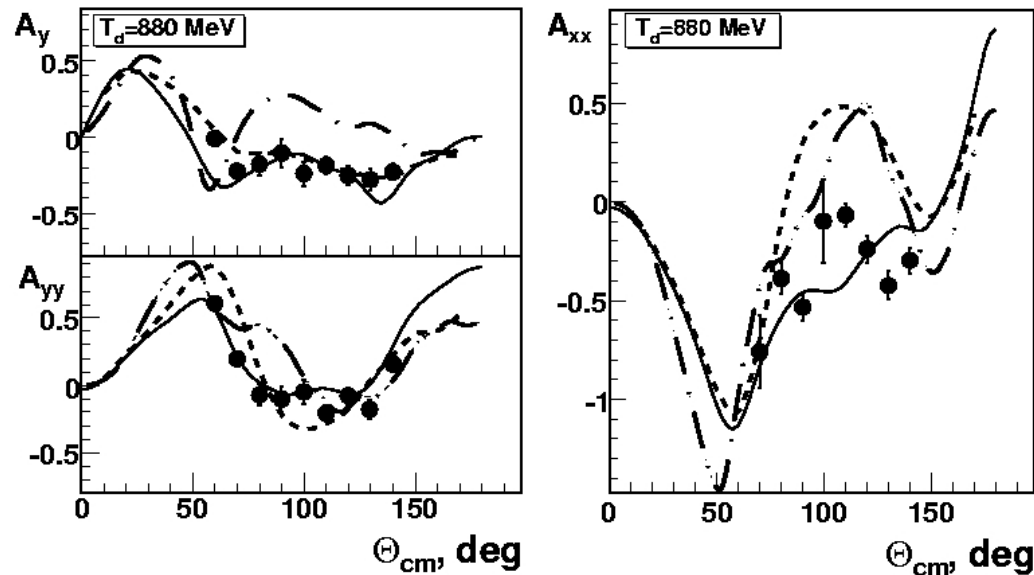


## Elastic events selection at 2000 MeV



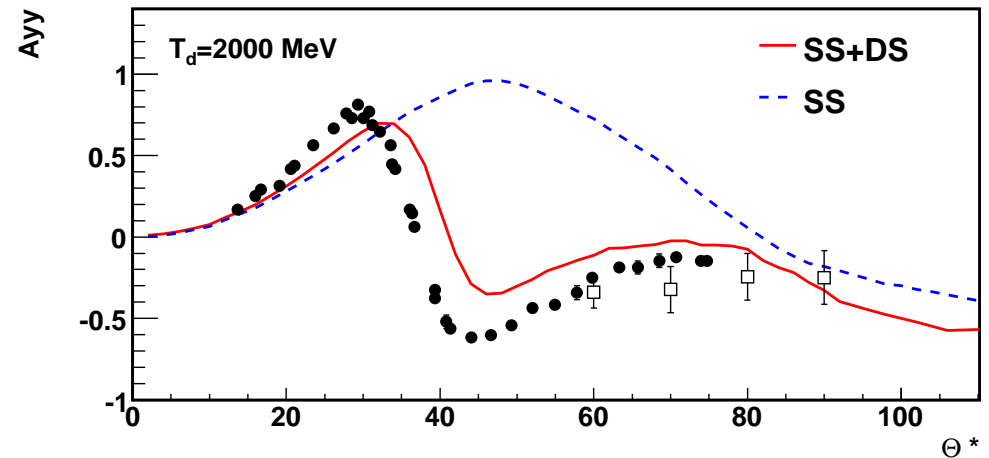
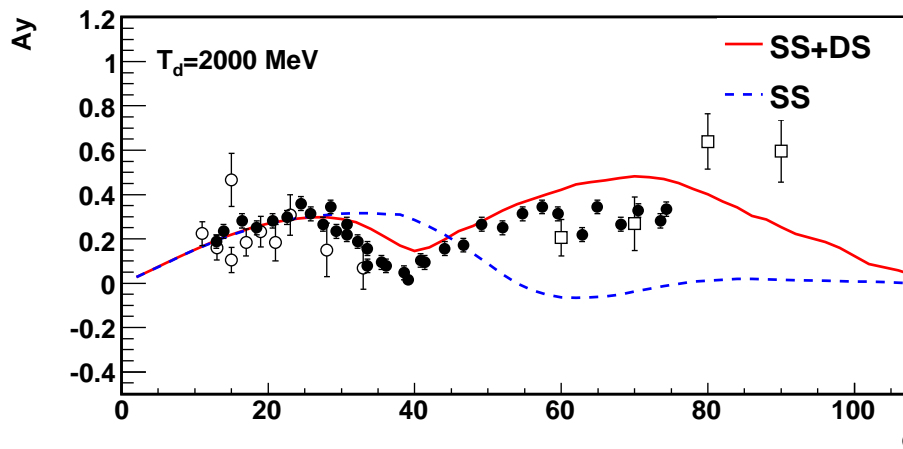
Event selection using signal amplitudes correlations, time-of-flight difference target position and **CH<sub>2</sub> – C** subtraction for each **PIS** spin state.

## $A_y$ , $A_{yy}$ and $A_{xx}$ in **dp**- elastic scattering at 880 MeV



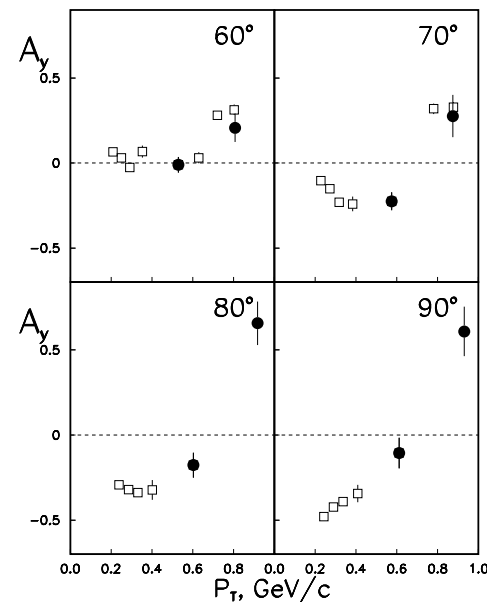
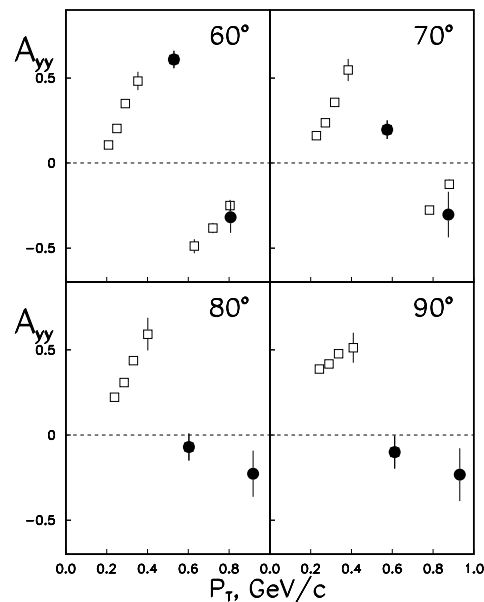
- Dashed lines are the multiple scattering model calculations using CD-Bonn DWF (N.B.Ladygina, Phys.Atom.Nucl.71 (2008) 2039.);
- Solid lines are the Faddeev calculations using CD-Bonn potential (H.Witala, private communication);
- Dott-dashed lines are the optical-potential calculations using Dibaryon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

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



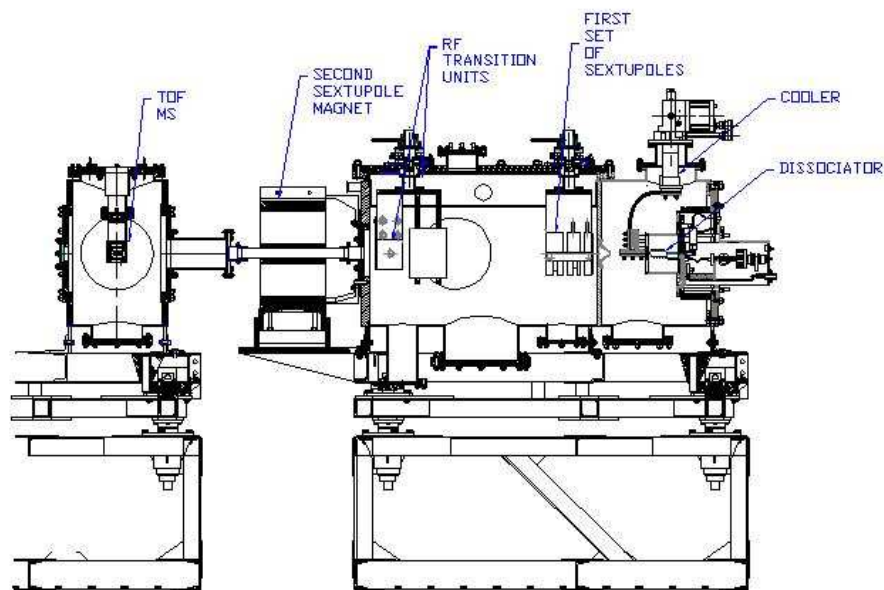
- Open points are obtained at JINR.
- Dashed and solid lines are the relativistic multiple scattering model calculations using **CD-Bonn** DWF taking into account single scattering and single+double scattering, respectively.

## Energy dependence of the **dp**- elastic scattering analyzing powers



- Kind of asymptotic in the behavior of  $A_{yy}$  is observed.
- "Krisch"- effect in the behavior of  $A_y$  is observed at rather low  $p_T$ .
- Study of the energy dependence of the **dp**- elastic scattering analyzing powers at large  $p_T$  is one of the tools to study **cold dense matter**.

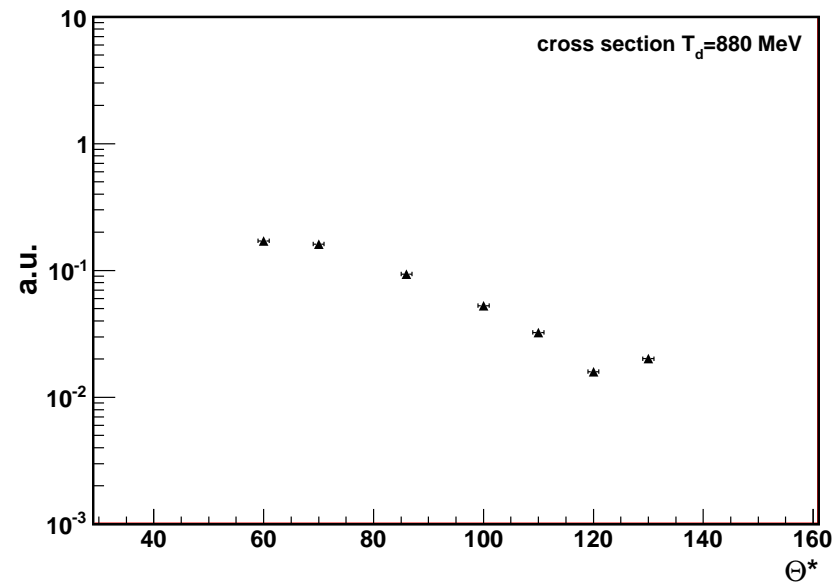
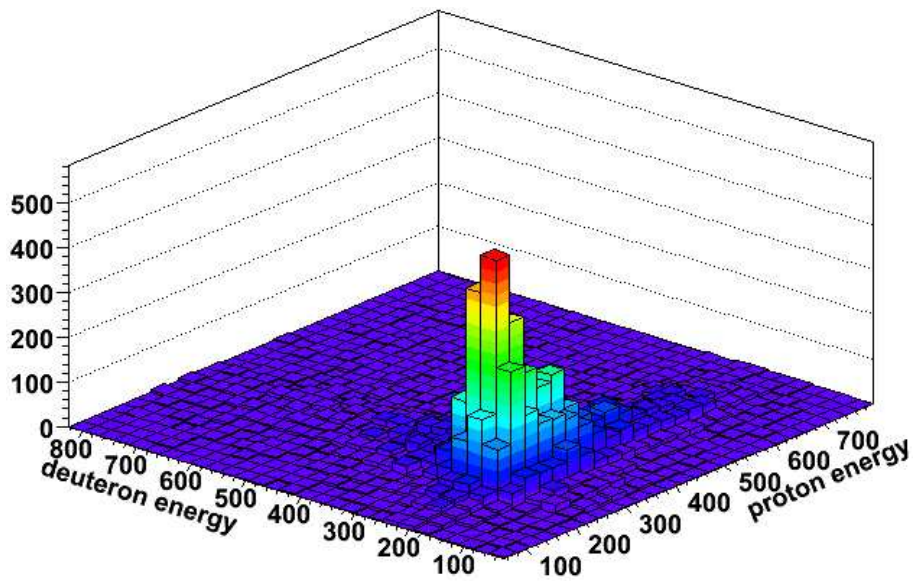
## New Polarized Deuteron Source for LHEP



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

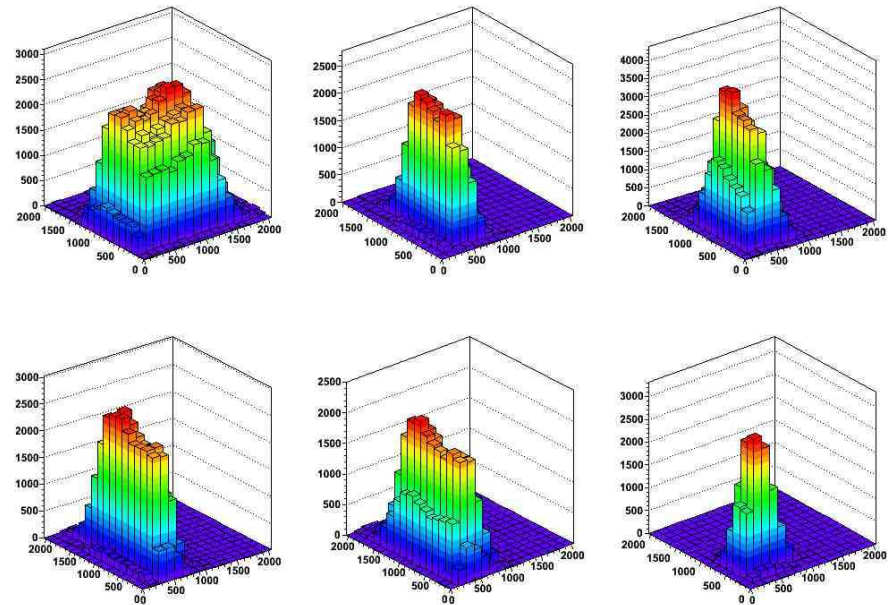
Figure of merit increasing by a factor  $\sim 10^3$

## dp- elastic scattering at ITS



- Commissioning experiment with the upgraded setup has been performed in March 2010 at 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.

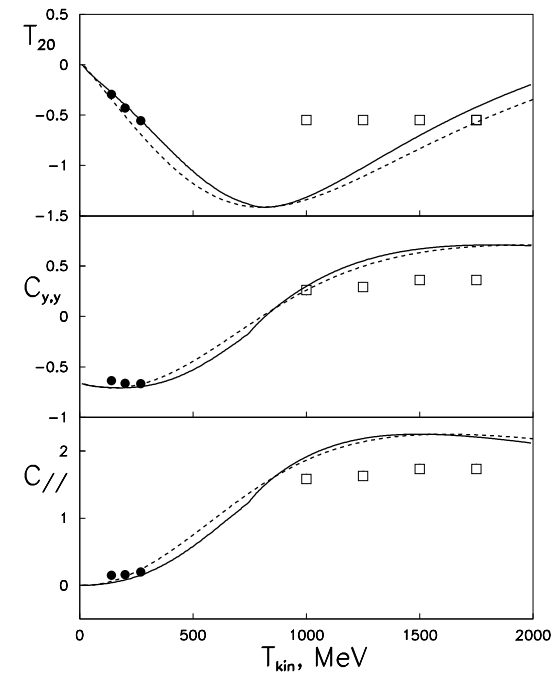
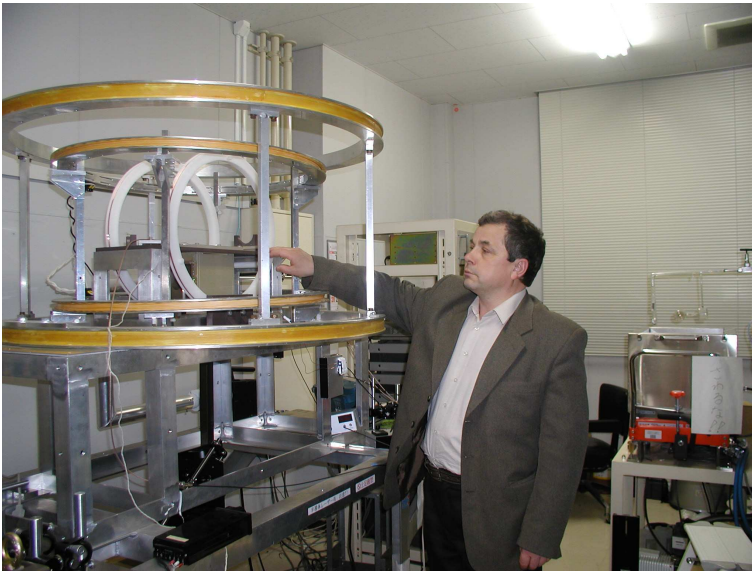
## dp- breakup study at ITS



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



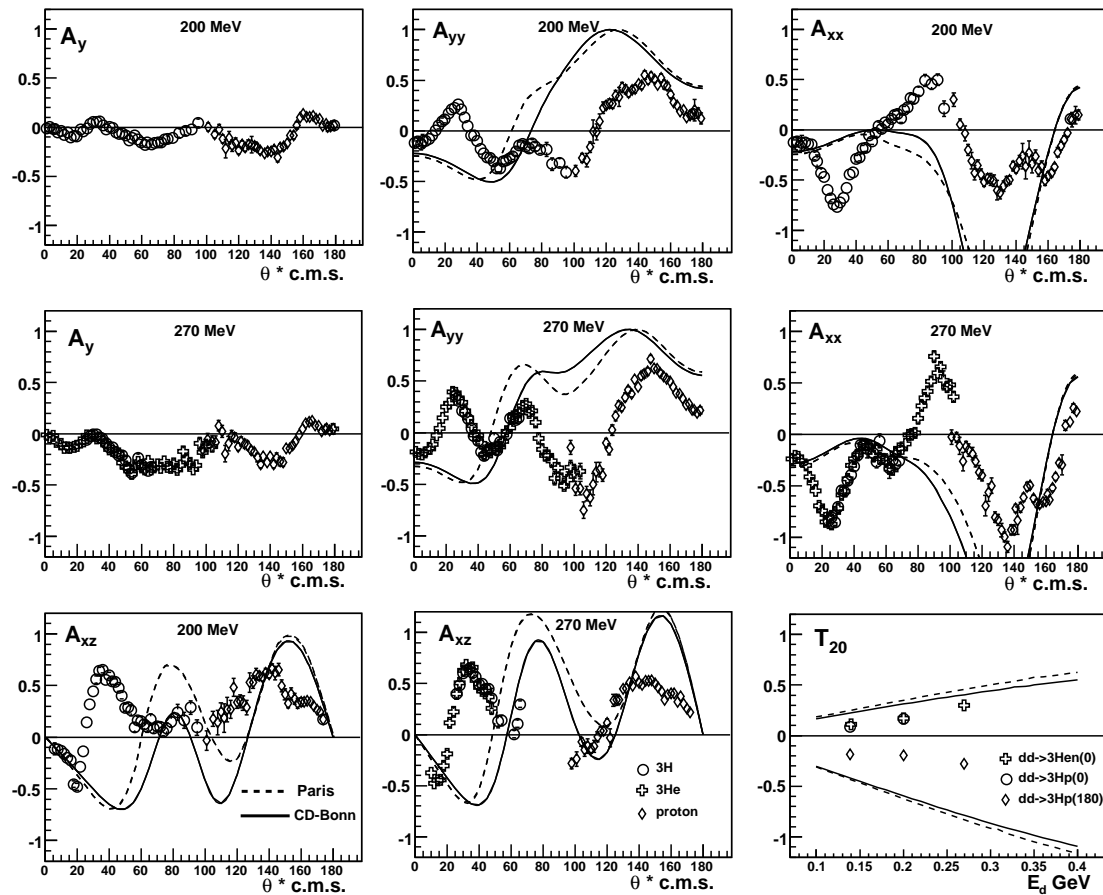
# Polarization observables for the ${}^3\text{He}(\text{d}, \text{p}){}^4\text{He}$ reaction (DSS-project)



- The main goal of the project is the measurements of the tensor analyzing power  $T_{20}$  and spin correlation  $C_{y,y}$  in the  ${}^3\text{He}(\text{d}, \text{p}){}^4\text{He}$  reaction in the deuteron kinetic energy range between 1.0 and 1.75 GeV.



# SRC from the $dd \rightarrow {}^3\text{He}({}^3\text{Hp})$ reactions (CNS-JINR)



The study of  $T_{20}$  in the  $dd \rightarrow {}^3\text{He}({}^3\text{Hp})$  reactions at Nuclotron-M.

## In-flight conclusions

- The results obtained recently at LHEP with polarized deuterons are sensitive to the **SRC** spin structure.
- The spin structure of **2N** and **3N** correlations can be studied at **Nuclotron-M** both at internal and extracted beams in the few-nucleons interaction.
- The putting into operation new **PIS** will significantly increase the potentialities of these studies at **Nuclotron-M**.

## Conception for deuteron beam polarimetry at Nuclotron-M

- Absolute calibration of the beam polarization.
- Efficient calibrated polarimeters. Polarization standard.
- Permanent monitoring of the beam polarization.
- Local polarimetry.

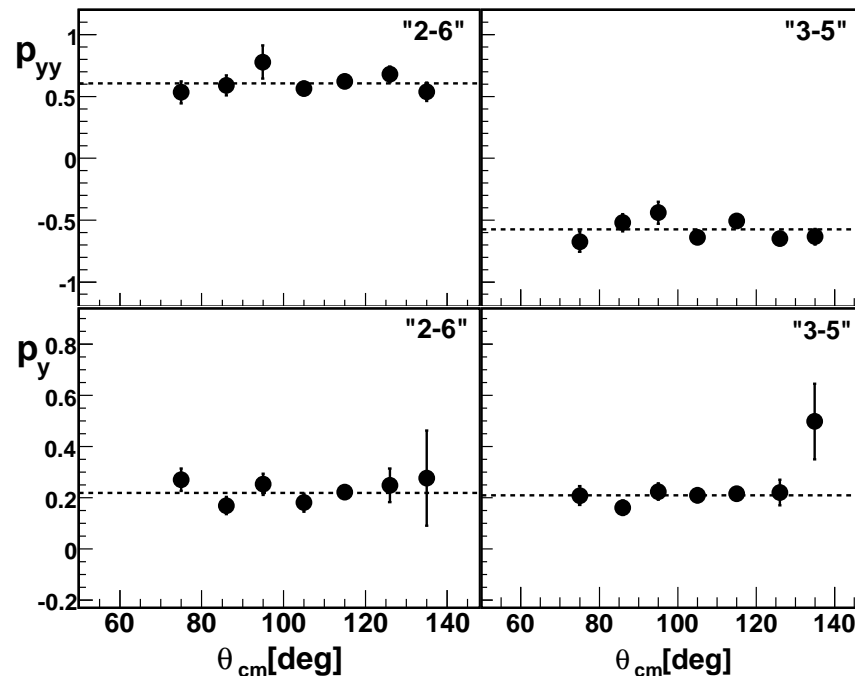
$$\sigma = \sigma_0 \left( 1 + \frac{3}{2} p_y \cdot A_y + \frac{1}{2} p_{yy} \cdot A_{yy} \right)$$

If the analyzing powers take known from the theory values one can obtain the beam values polarization avoiding systematic error due to uncertainty of the analyzing powers of the polarimeter -

absolute calibration of the beam polarization

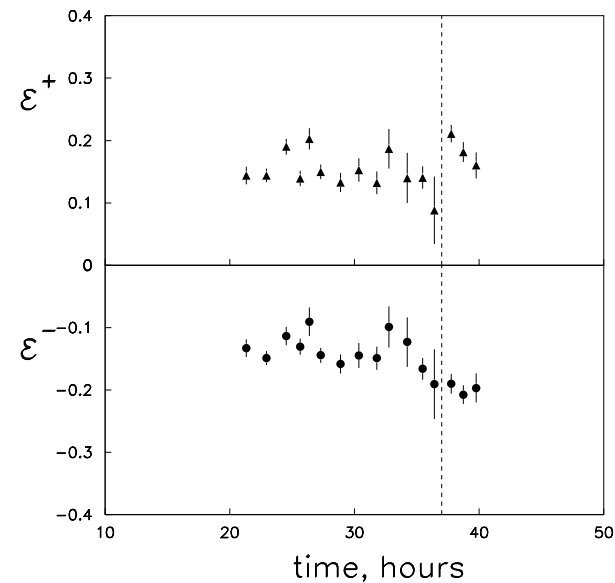
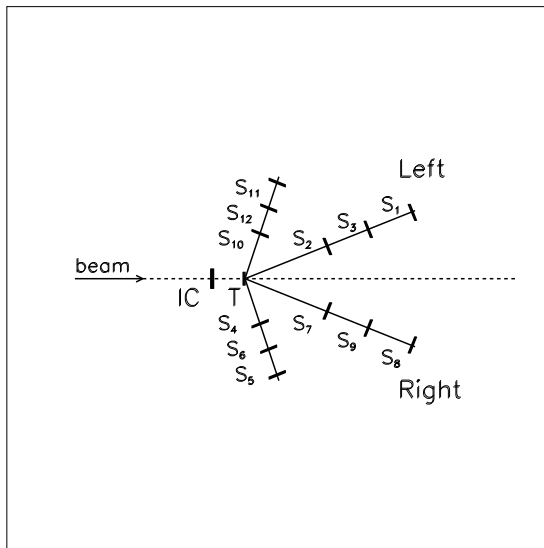
$A_{yy} = -\frac{1}{2}$  for  $^{12}\text{C}(\mathbf{d}, \alpha)^{10}\text{B}^*[2^+]$  reaction (K.Suda et al.)

# Measurements of the deuteron beam polarization at 270 MeV at **ITS** using **CNS** detection system



- The polarimeter allows to extract vector and tensor components of the beam polarization as well as the vector polarization direction.
- It was found  $\beta = -90.3^\circ \pm 1.2^\circ$ .
- Figures of merit  $F_y$ ,  $F_{yy}$  and  $F_{xx}$  are comparable with those for extracted beam polarimeter at RIKEN.
- Polarimeter at **ITS** is assumed to be the main polarimeter at Nuclotron.

## Vector polarization of the extracted deuteron (proton) beam

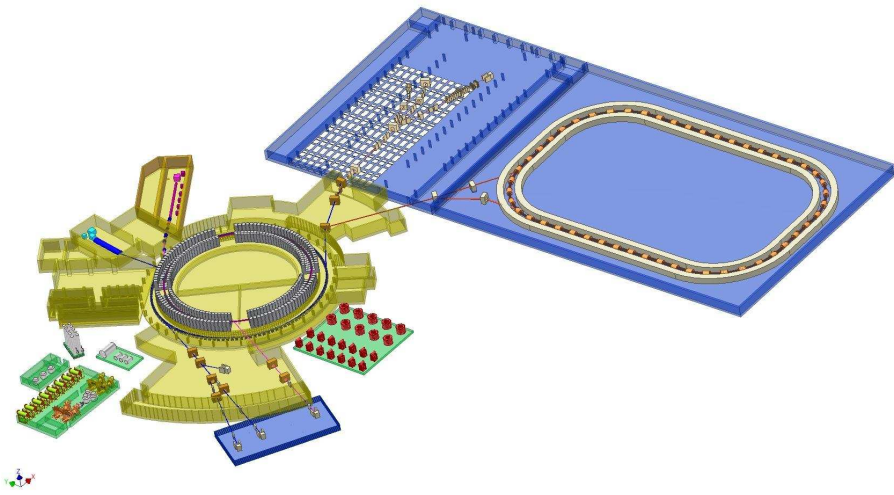


- Vector polarimeter is based on the left-right asymmetry measurement in quasi-elastic **pp** scattering (5% of systematics).
- Measurements of the deuteron beam vector polarization have been performed at **3.5** and **5.0 GeV/c**.
- There is no depolarization at Nuclotron.

## In-flight conclusions for deuteron polarimetry at Nuclotron-M

- The main polarimeter for deuterons (at **ITS**) is
  - to be able to measure both tensor and vector polarizations due to mixed spin modes of new **PIS**,
  - to measure the direction of the polarization vector,
  - analyzing powers are obtained by the absolute method of the beam polarization measurements (at **270 MeV** at **RIKEN**).
- Permanent monitoring of the beam polarization
  - the use of **2 flattops** of the Nuclotron field: one of them for **ITS** polarimeter.
  - small scattering angle polarimeter at the extracted beam.
- In the first run with polarized deuterons from new **PIS**-
  - measurements of the beam polarization at **270 MeV** at **ITS**.
  - calibration of **ITS** polarimeter at **270-2000 MeV**.
  - simultaneous calibration of **ITS** and extracted beam polarimeters at **1600 MeV**.Polarization standard for **Nuclotron-M**.
- This procedure will provide the error of  $\sim 3\%$  at the energies of **270-2000 MeV** and better than **5%** at higher energies.

## Spin-NICA activity

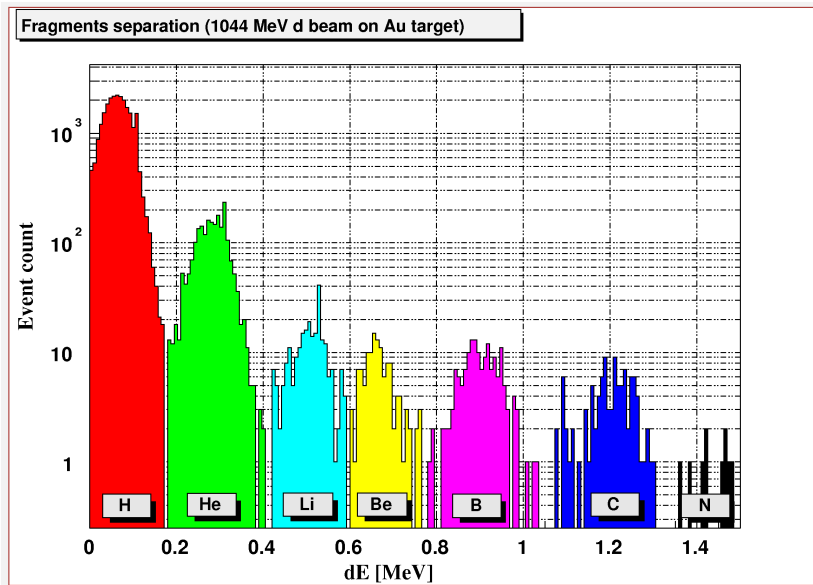


- Spin content of nucleon from DY and charmonium.
- Spin structure of cold dense matter.
- Both fixed target and collider experiments.
- Efficient polarimetry.

New facility is planned to work at  $\sqrt{s_{NN}} = 4 \div 12$  GeV for deuterons and up to  $\sqrt{s_{NN}} = 27$  GeV for protons.

Serious advantage is the availability of polarized deuterons (neutrons).

## CNI polarimeter based on the **dC** elastic scattering.



- **pC** elastic scattering in **CNI** region is used for polarimetry at AGS and RHIC.

**pC** **CNI** polarimeter at **ITS** at **Nuclotron** should work. If it is calibrated, one can reproduce the same inside collider **NICA**.

- The experience to detect slow nuclear fragments at **ITS** exists.
- However, no experience in **dC** **CNI** polarimetry exists.

Spin structure of **dC** elastic scattering is complicated: 5 complex amplitudes.

Energy dependence for analyzing powers is not clean.

- Serious amount of theoretical work on the **pp**, **dd**, **pC**, **dC** elastic scattering in **CNI** region is required.



## Conclusions

- The important data on the SRCs spin structure are already obtained at Nuclotron-M.
- Future plans of such investigations at internal and extracted beams in the few-nucleons interaction at Nuclotron-M are based on the use of new PIS.
- The collider mode and availability of polarized beams could give serious advantages to study 2N and 3N SRC at NICA.
- The conception of the polarimetry for Nuclotron-NICA is formulated. Polarimetry developments are started.

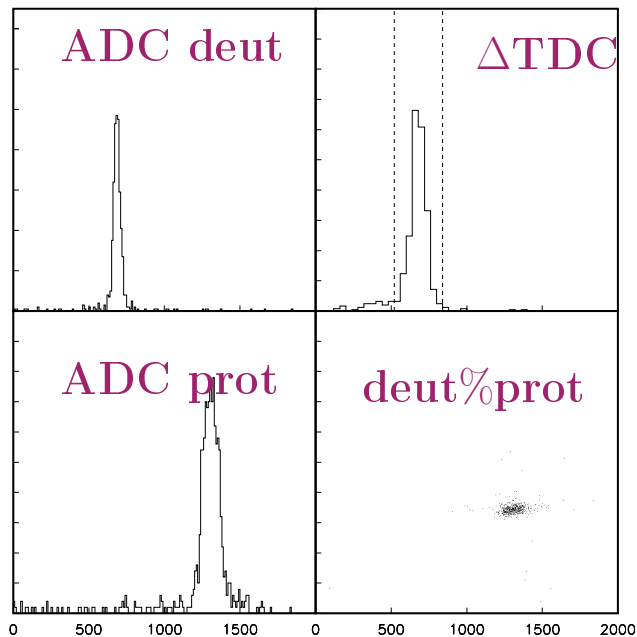
surRealistic status of  $2N$  and  $3N$  correlations



- Good experimental data exist or will appear soon.
- But, lack of theoretical interpretation!

Backup slides

## Vector and tensor polarizations measurements at 270 MeV

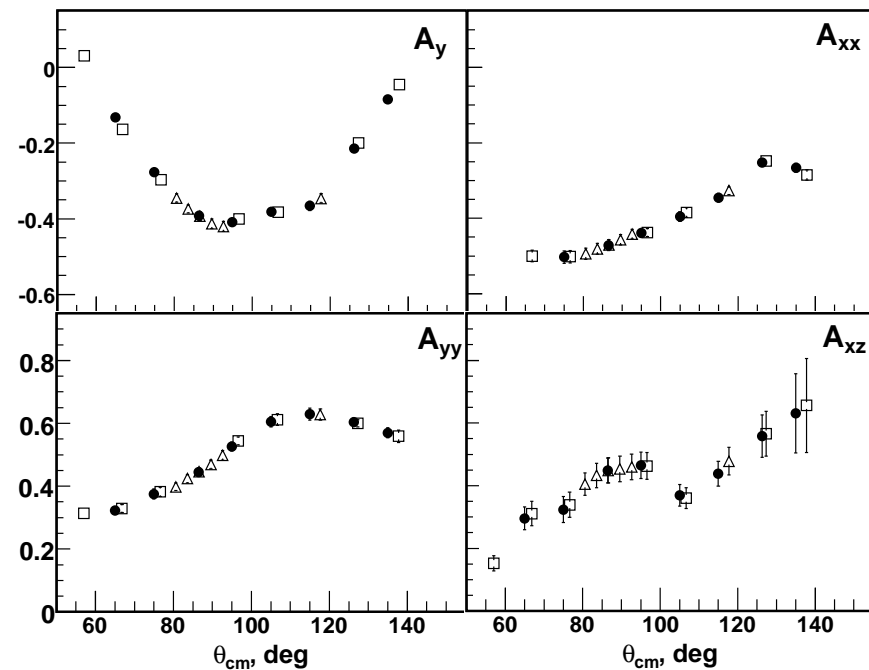
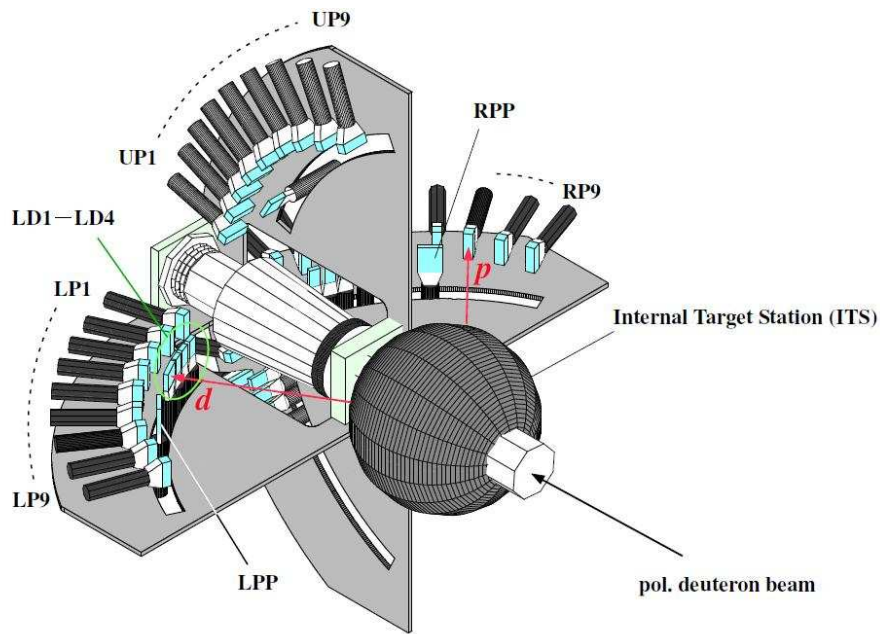


channel

	Pol.	Mode 2-6	Mode 3-5
ITS	T	$0.619 \pm 0.023$	$-0.532 \pm 0.019$
ITS	V	$0.210 \pm 0.013$	$0.193 \pm 0.011$
LEP	T	$0.69 \pm 0.13$	$-0.67 \pm 0.16$

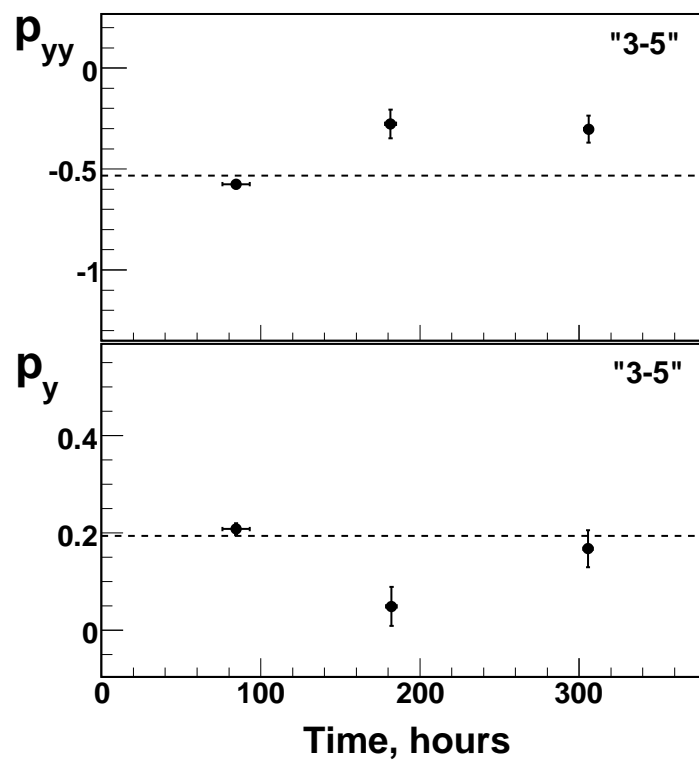
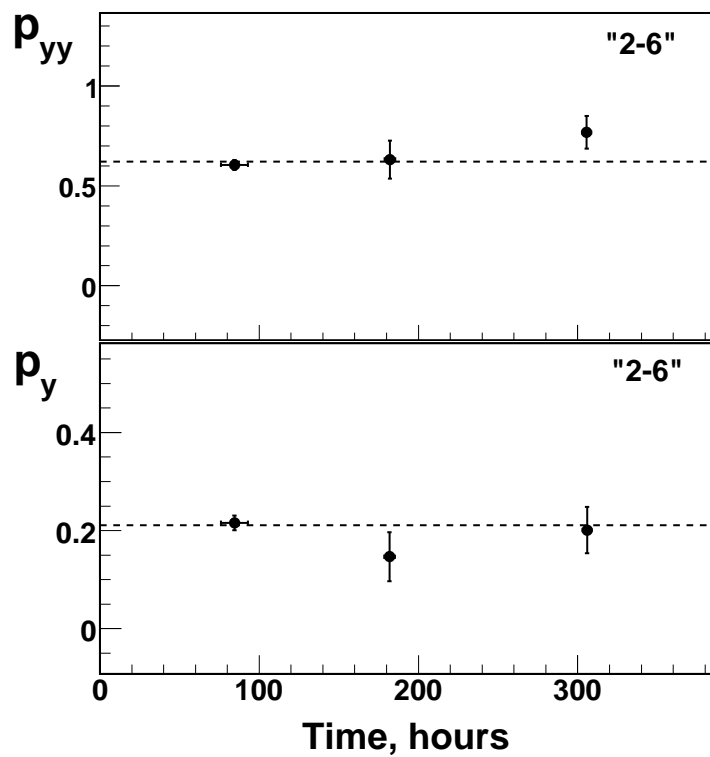
- Polarimeter is based on the asymmetry measurement in **dp** elastic scattering (**2%** of systematics).
- Measurements of the deuteron beam vector and tensor polarization have been performed at **270 MeV** (RIKEN data).

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

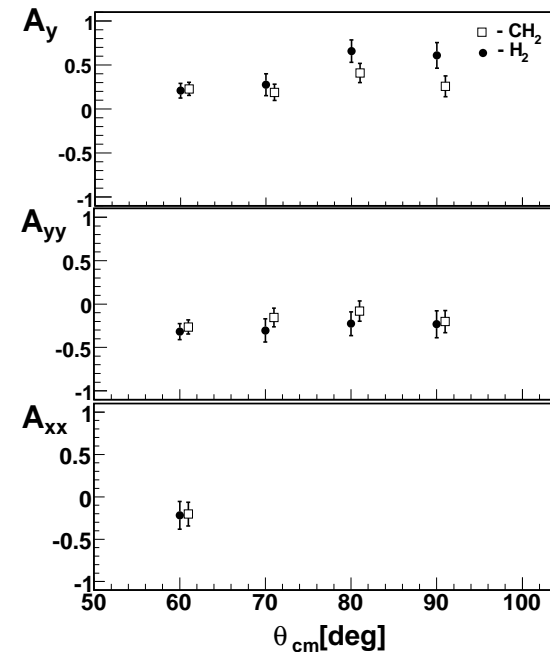
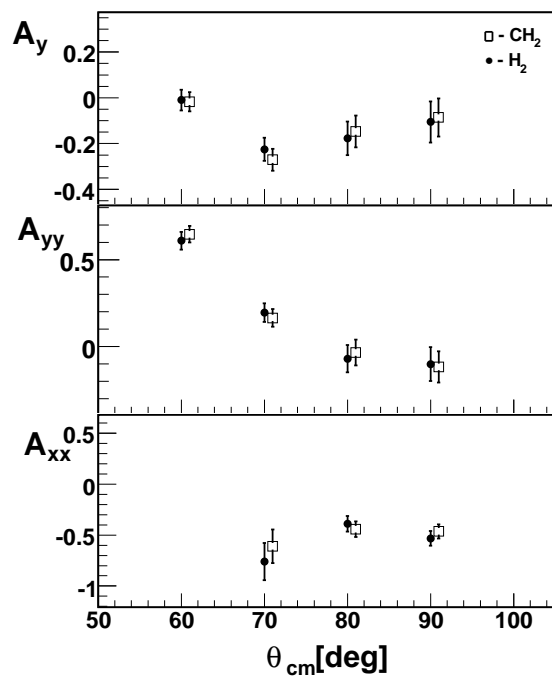


- Scintillation counters (48) based on Hamamatsu H7415 PMTs placed on the left, right, up and down are used at the same time.
- The detectors cover the angular range  $60 - 140^\circ$  in the center of mass.

# Long-term stability of beam polarization at 270 MeV

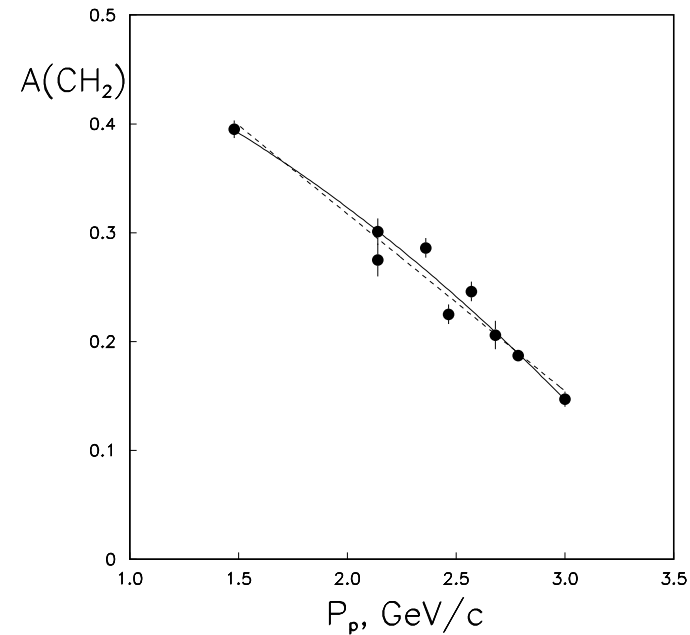
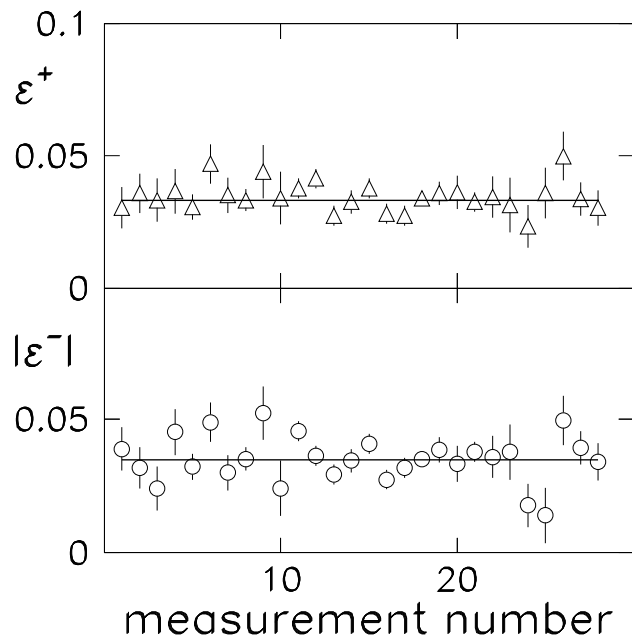


## $A_y$ , $A_{yy}$ and $A_{xx}$ in **dp**- elastic and quasielastic scattering at 880 and 2000 MeV



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

## Permanent monitoring of the beam polarization

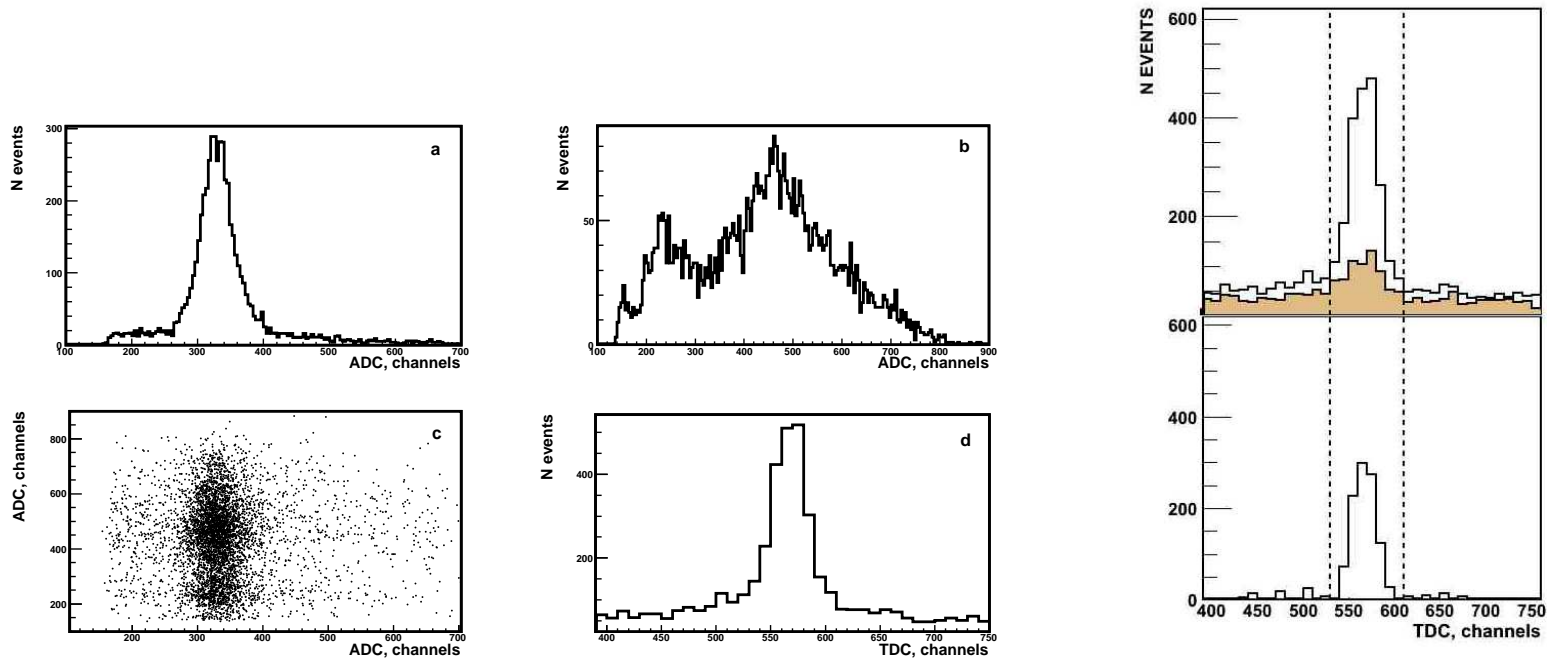


The asymmetry stability during several days of the beam time.

The knowledge of the effective analyzing power gives the possibility to obtain the beam polarization values.

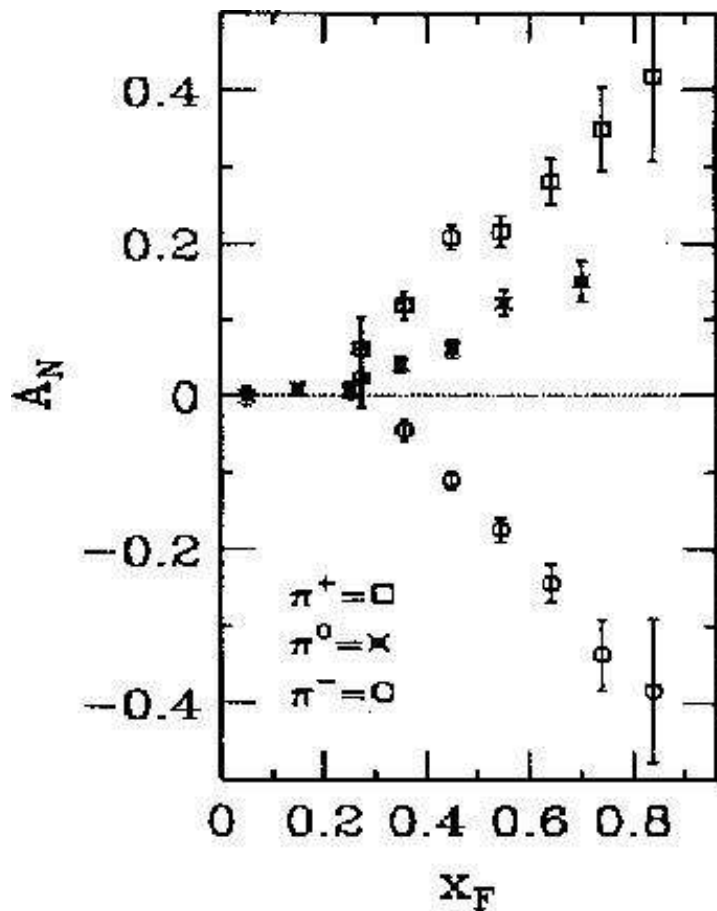


## dp- elastic scattering at 1600 MeV at extracted beam



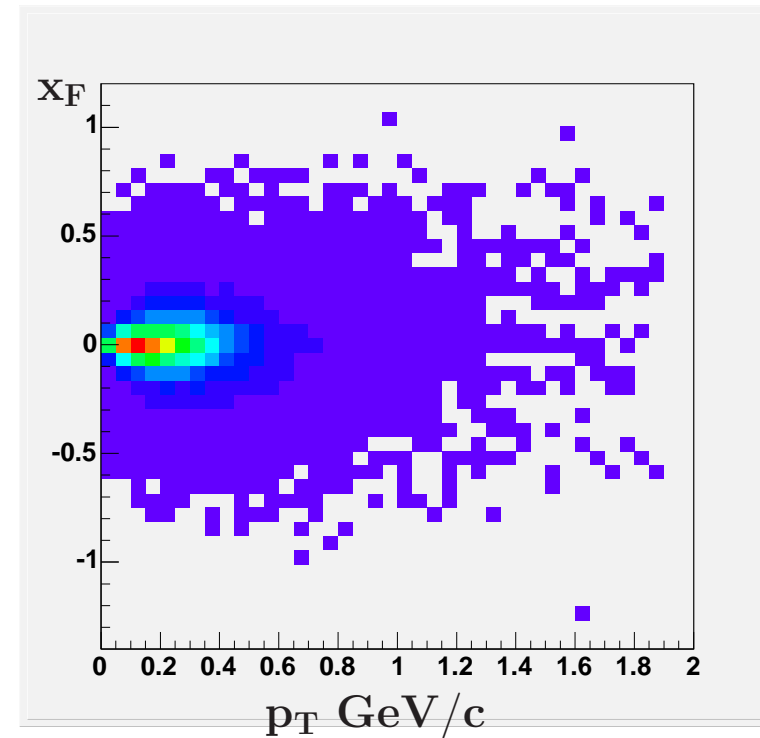
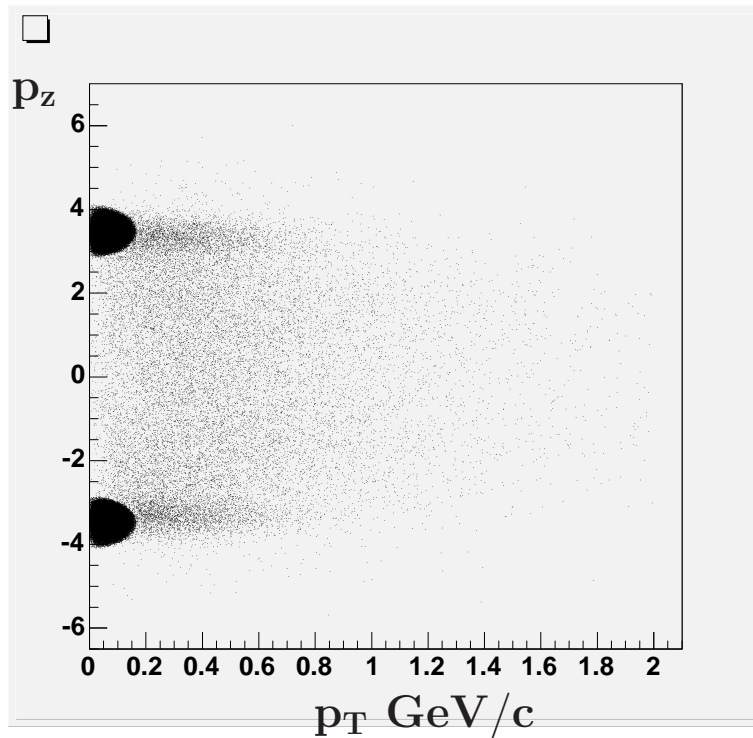
- Feasibility of the dp- elastic scattering events selection using information on the energy losses in the scintillators and timing information was demonstrated at  $T_d=1600$  MeV and  $\theta_{lab} \sim 8^\circ$ .

## Permanent nucleon beam polarization monitoring at NICA from $\vec{N} + \vec{N} \rightarrow \pi + X$ process



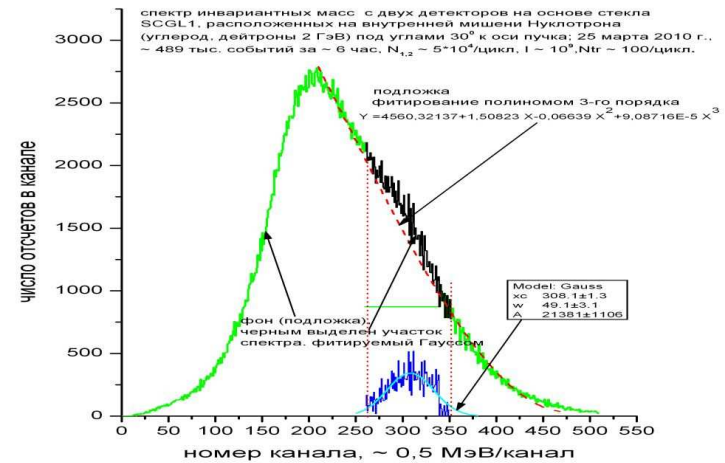
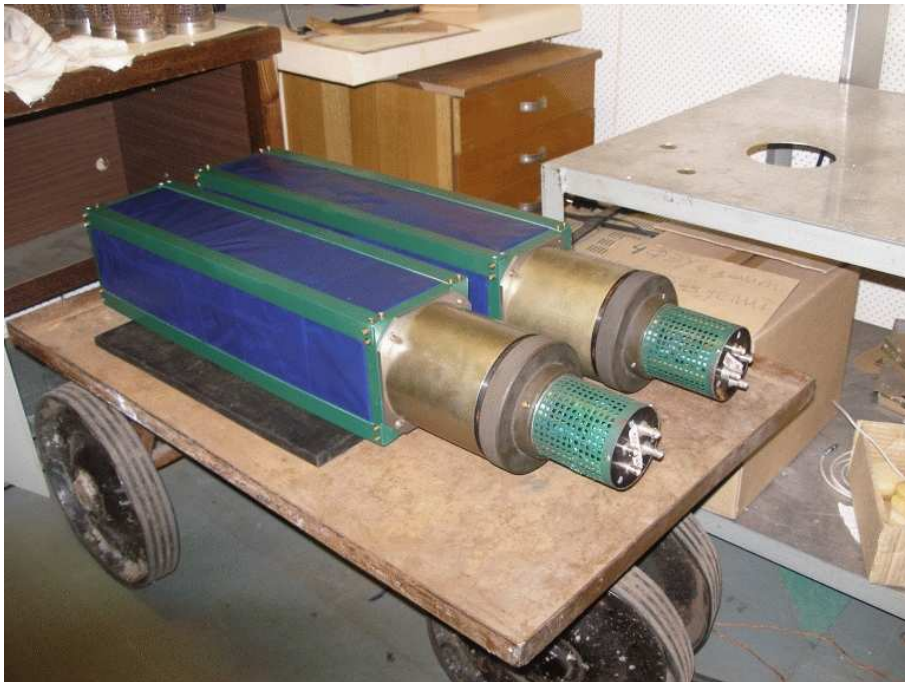
- The perturbative regime in SSA for meson production occurs already at  $T_N = 22$  GeV ( $\sqrt{s_{NN}} \sim 7$  GeV). Large analyzing powers for inclusive pion production at NICA energies.
- For dd and dA collisions necessary to have spectator detector.
- The detection of  $\pi^0$ 's is preferable. (no momentum reconstruction).
- However, figure of merit for  $\pi^\pm$  is higher!
- Serious problem is the possible initial energy dependence.

## SSA in $\pi$ production in $\vec{d}\vec{d}$ collisions



At  $\sqrt{s_{NN}} \geq 7$  GeV different SSA sign is expected for the neutron and proton spectators.

# SCG1 scintillating glass from PINOT spectrometer (JINR-INR-Italy collaboration)



30 blocks  $15 \times 15 \text{cm}^2$  ( $0.675 \text{m}^2$ ) of  $14X_0$  thick

Tests at Nuclotron beam have been performed in March 2010