The deuteron beam polarimetry at Nuclotron-NICA

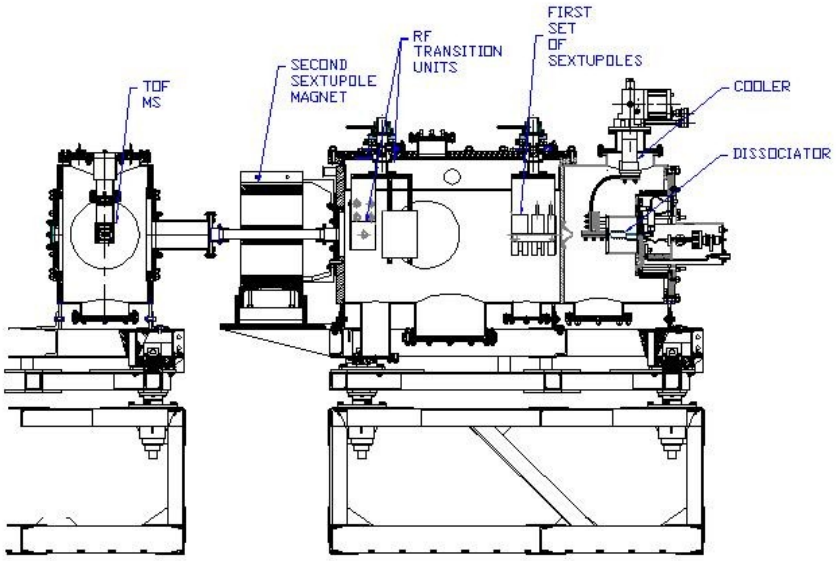
V.P. Ladygin *on behalf of Nuclotron polarimetry team*

20-24 October, 2014, Beijing

Outline

- **Concept of the polarimetry at NICA**
- **Deuteron polarimetry for Internal Target Experiments @Nuclotron**
- **Low Energy Polarimeter**
- **High Energy Polarimeters for extracted beam Experiments @Nuclotron**
- **Conclusion**

New Polarized Deuteron and Proton Source for LHEP



New source will provide up to 10^{10} ppp and higher values of polarization than POLARIS.

Part of the IUCF source can be used for the construction.

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 will be increased by a factor ~ 10^3

In future it will be used to provide polarized protons

Concept for the polarimetry at Nuclotron-NICA

1. **Efficient polarimeters at different key points of accelerator complex: LINAC, Nuclotron ring, booster, transportation lines, collider. Evaluation of the polarization standards for deuterons and protons.**
2. **Absolute calibration of the beam polarization for protons**

   (and for deuterons-?).
3. **The optimal usage of the same experimental equipment for the deuteron and proton polarimetry.**
4. **Permanent monitoring of the beam polarization by the basic polarimeters.**
5. **Local polarimetry at BM@N, SPD, MPD etc.**

The goal is to have the systematic error due to beam polarization 5%

Conception for the deuteron beam polarimetry at the Nuclotron

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

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

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

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

- Absolute calibration of the beam polarization

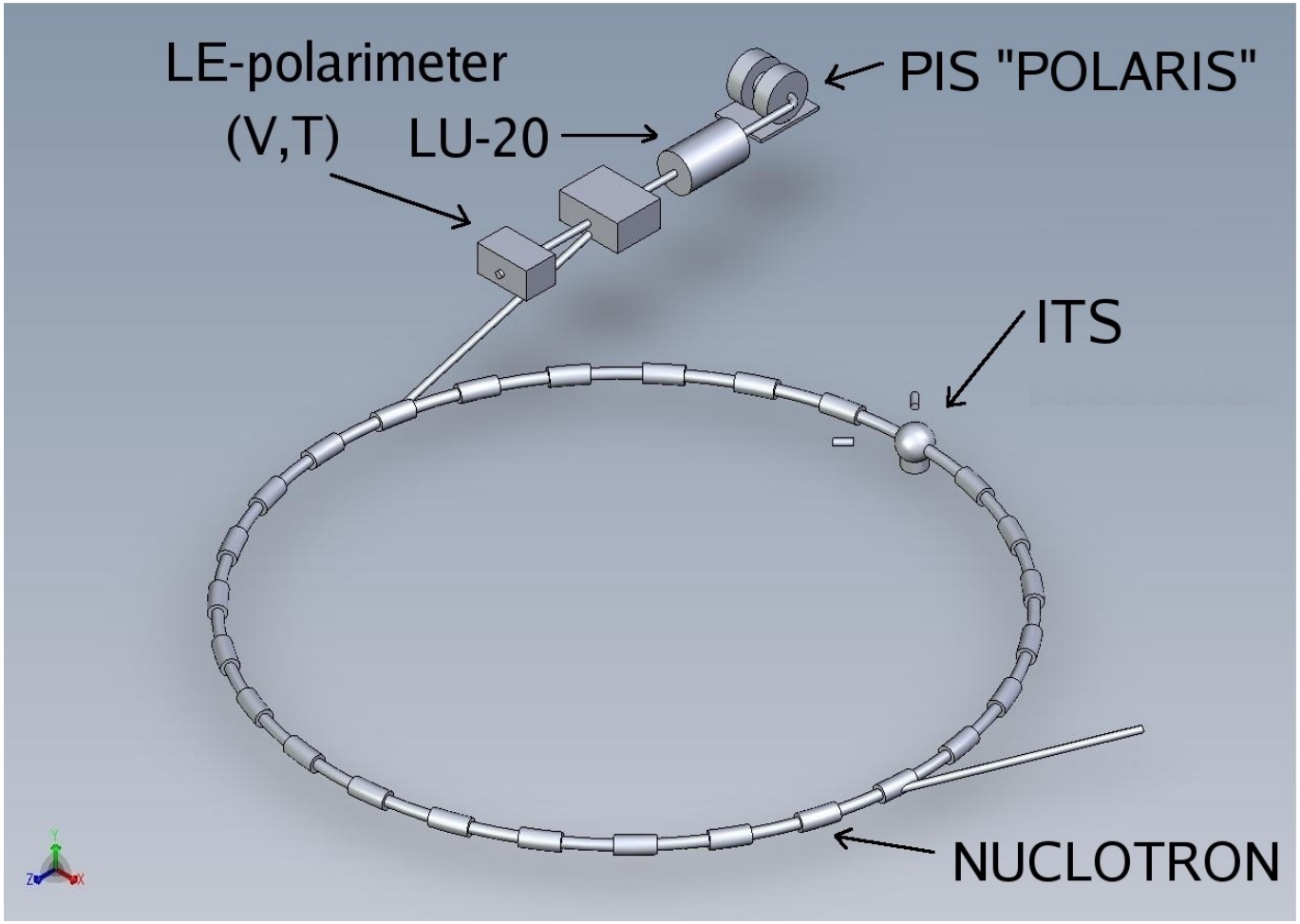
$A_y = \frac{1}{2}$ for $^{12}C(d, \alpha)^{10}B^*[2^+]$ reaction (K.Suda et al.,)

Deuteron beam polarimetry in a GeV energy range.

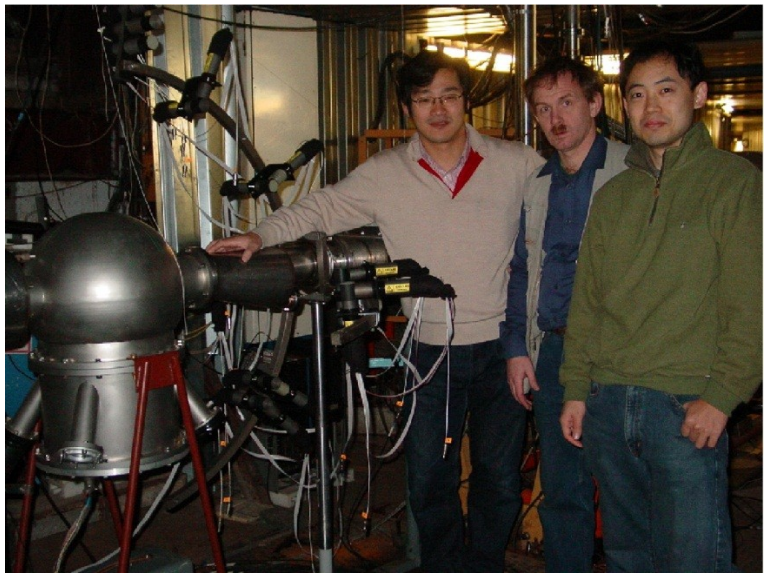
- The use of ***dp*** elastic scattering at large angles ($\Theta_{c.m.}$>60º) for the deuteron beam polarization measurements at the 270-2000 MeV energy range.
- Advantages
  - Analyzing powers this reaction have large values
  - The kinematical coincidence measurements of deuteron and protons with plastic scintillation counters suffice for the dp elastic events identification.

- Motivation
  - Deuteron spin structure, spin effects in 2N and 3N systems, in meson production.
  - Measurements for polarization studies at other facilities (Jlab).

Nuclotron-M accelerator complex

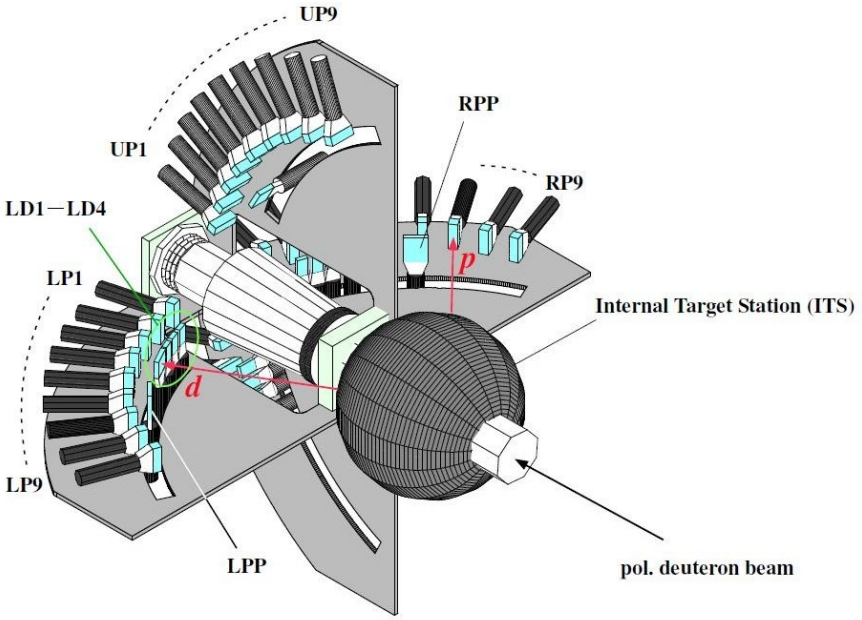


Joint CNS-JINR experiment at Internal Target Station at Nuclotron (DSS-project)



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.

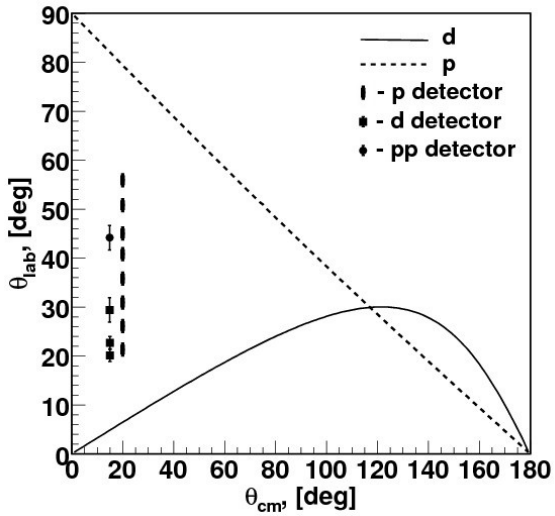
Setup to study dp- elastic scattering at ITS at Nuclotron



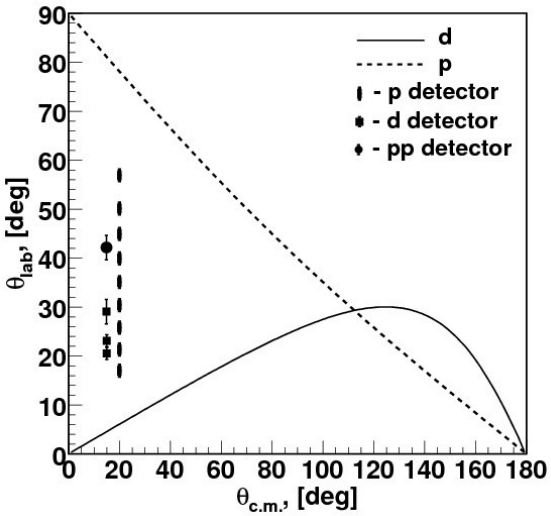
- Deuterons and protons in coincidences using scintillation counters
- Internal beam and thin CH_2 target (C for background estimation)
- Polarization measurement at 270 MeV
- Analyzing powers measurement at 880 and 2000 MeV
- The data were taken for three spin modes of PIS: unpolarized, “2-6” and “3-5”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

Arrangements of detectors.

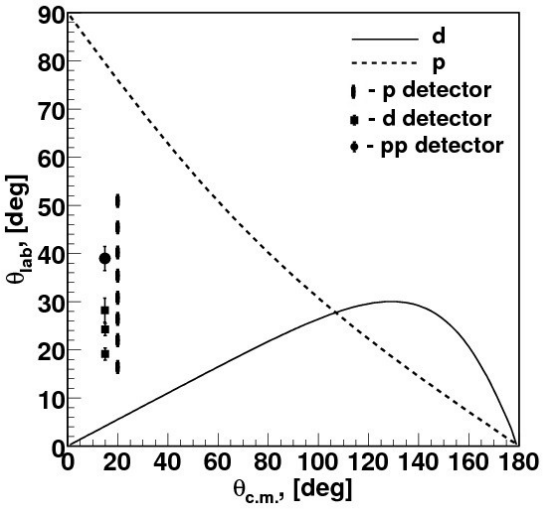
270 MeV



880 MeV



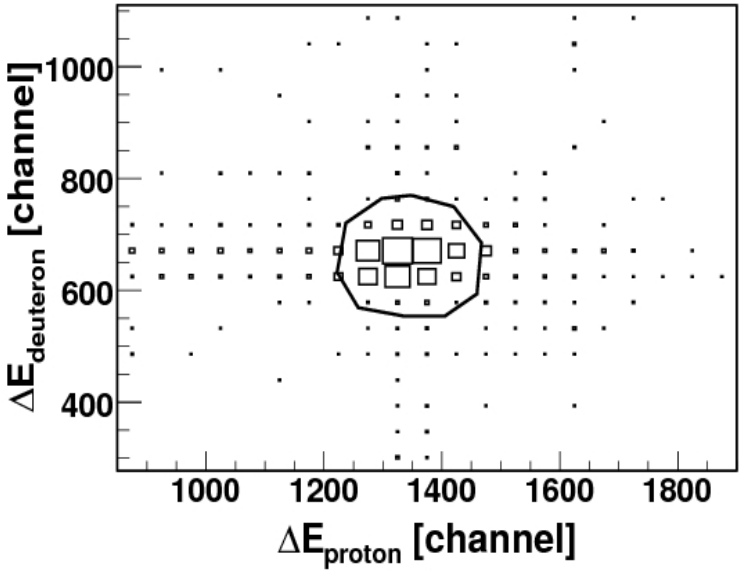
2000 MeV



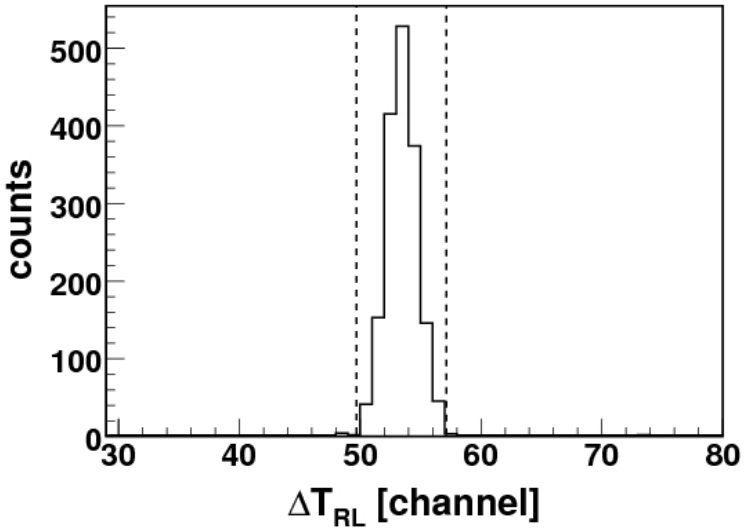
Kinematics of the dp elastic scattering at Ed = 270, 880 и 2000 МэВ. Setting angles of the detectors are presented in laboratory frame.

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

(dp- elastic events selection)

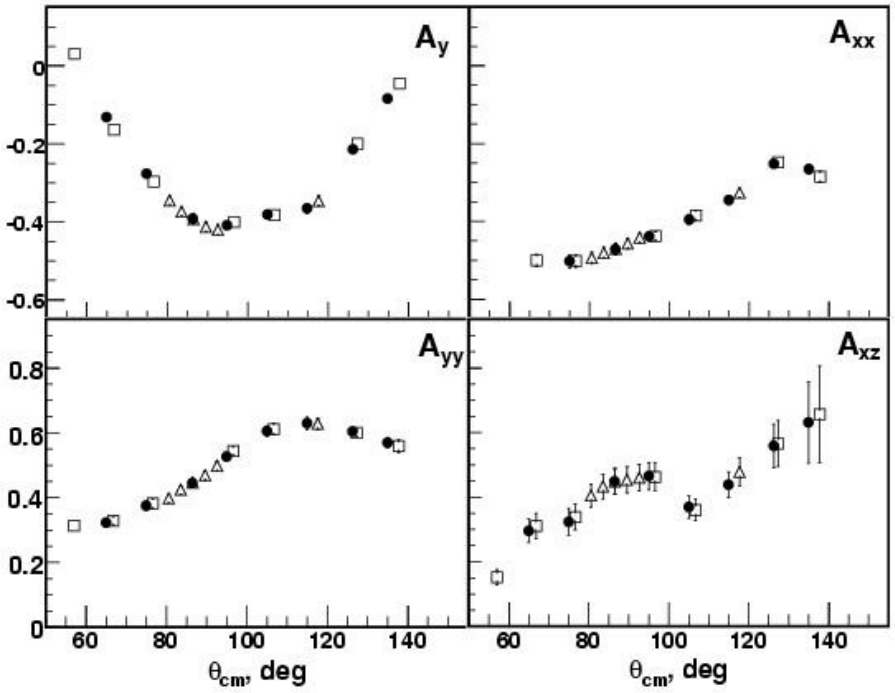


The correlation of the energy-loss signal for a pair of the deuteron and proton detector. The solid line is a graphical cut for the dp-elastic events selection.



The time difference between deuteron and proton detector for CH_2 target. The dotted line is a time gate for the dp-elastic events selection.

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



Vector Ay and tensor analyzing powers A_{yy}, A_{xx} and A_{xz} of dp- elastic scattering as a function of deuteron scattering angle in c.m.s. at deuteron beam energy of 270 MeV. □, Δ- the world data. Extrapolated values of the analyzing powers are marked by ●.

Cubic spline interpolation:

(x_i,y_i) на [A,B]

$f(x) = ax^3 + bx^2 + cx + d$

$f''(A) = f''(B) = 0$

K.Sekiguchi et al.,

Phys. Rev. C65 (2002) 034003

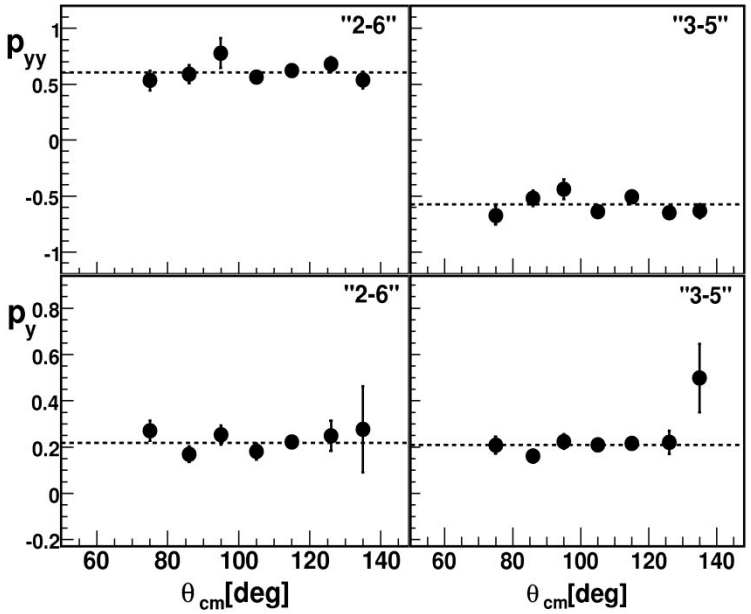
K.Sekiguchi et al.,

Phys. Rev.C70 (2004) 014001

K.Suda, et al.,

Nucl. Instr. Meth. in Phys. Res. A572 (2007) 745

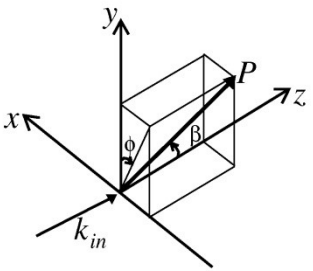
Measurement of the deuteron beam polarization at ITS using CNS detection system at 270 MeV



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 cms.

	Pol.	Mode ”2-6”	Mode ”3-5”
ITS	T	0.605 ± 0.025	-0.575 ± 0.020
ITS	V	0.216 ± 0.015	0.208 ± 0.012
L,R,U,D		$\theta_{c.m.} \geq 105^o$	
LEP	T	0.69 ± 0.13	
L,R,U		$\theta_{c.m.} < 105^o$	

ß = -90.3º ± 1.2º



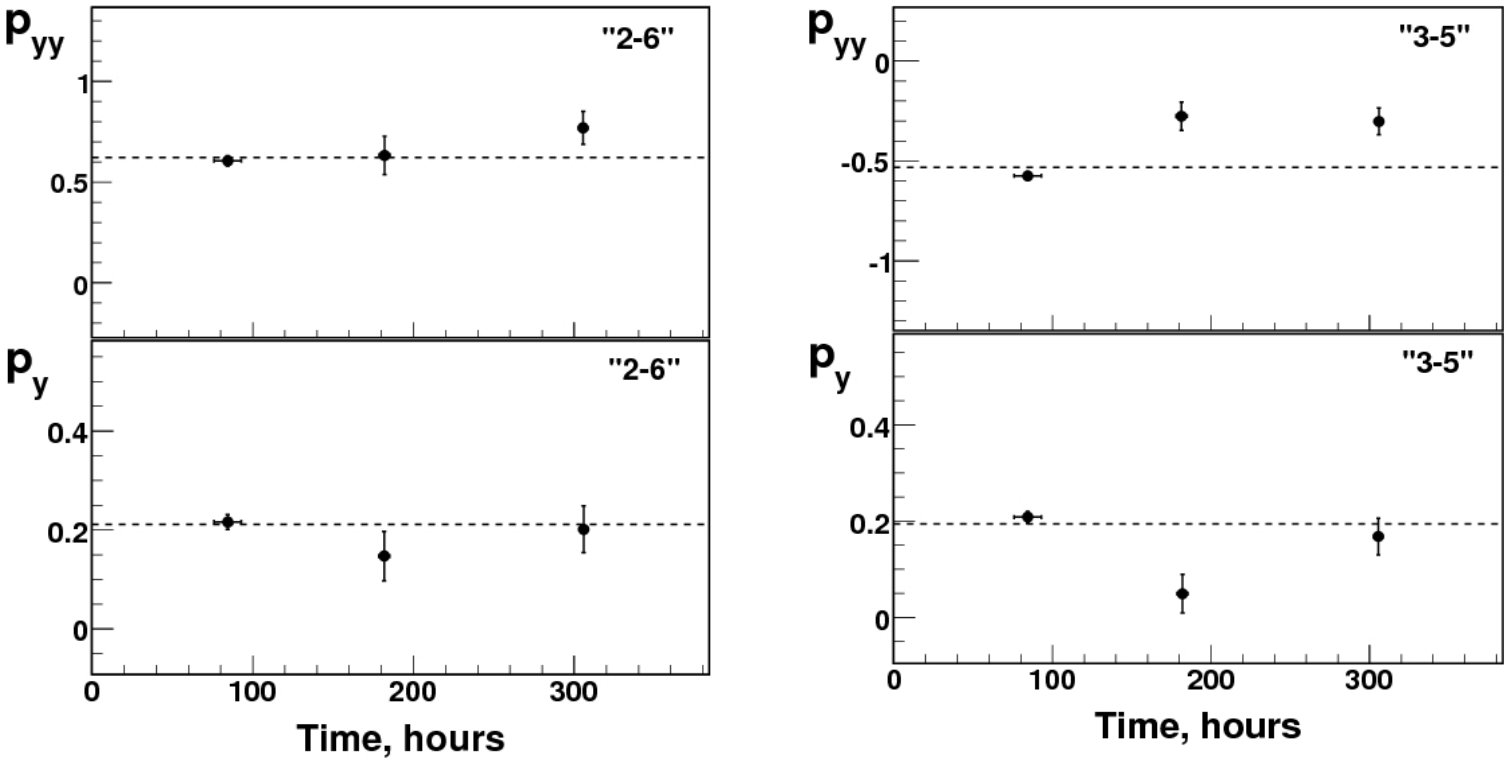
$$F_i^2 = \int \varepsilon A_i^2 \, d\Omega$$

$F_y \sim 1.0 * 10^{-4}$, $F_{yy} \sim 1.8 * 10^{-4}$, $F_{xx} \sim 0.8 * 10^{-4}$

- **Reference deuteron beam polarimeter at Nuclotron.**

P.K.Kurilkin et al., Nucl. Instr. and Meth. A 642 (2011) 45

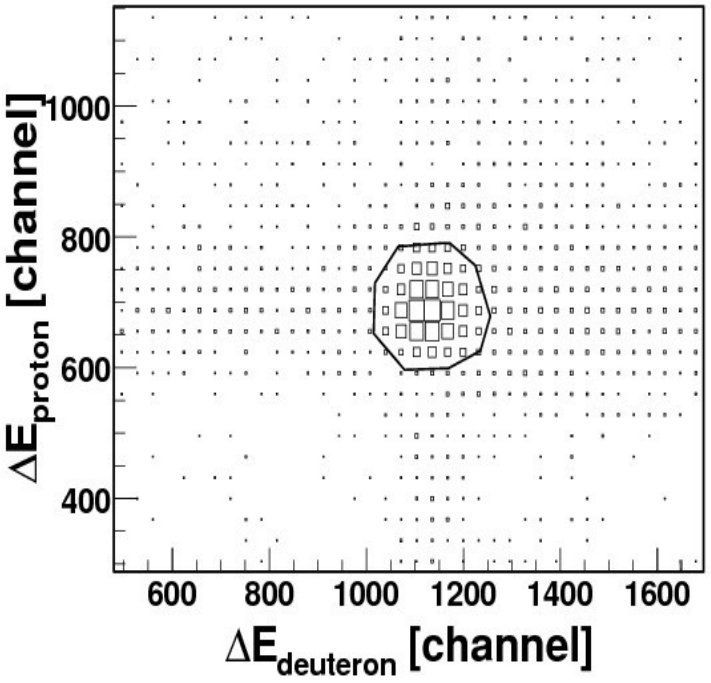
Long term stability of the beam polarization at 270 MeV



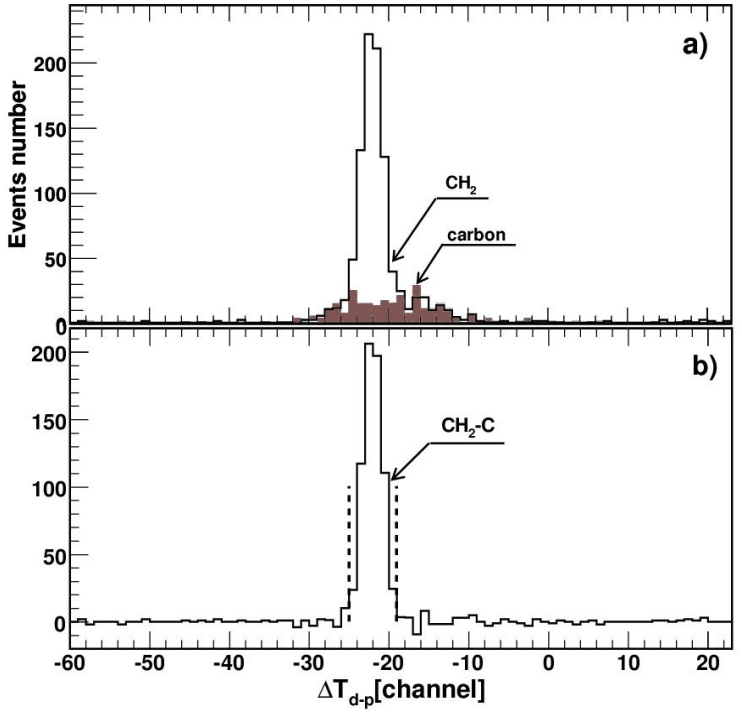
Tensor p_{yy} and vector p_y components of the deuteron beam polarization for “2-6” and “3-5” spin modes of PIS POLARIS as a function of the measuring time.

Analyzing powers measurement at 880 MeV

(The dp- elastic events selection)



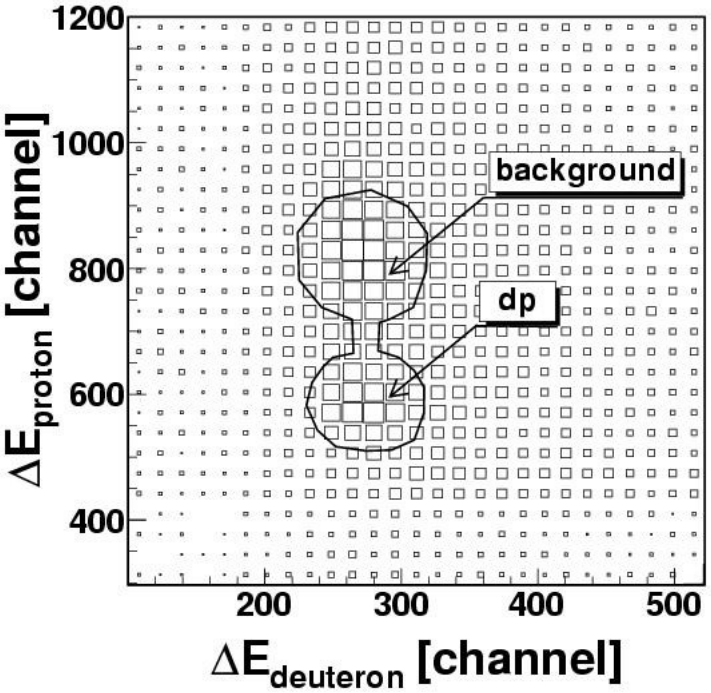
The correlation of the energy-loss signal for a pair of the deuteron and proton detector at 80° in c.m.s. The solid line is a graphical cut for the dp-elastic events candidate selection.



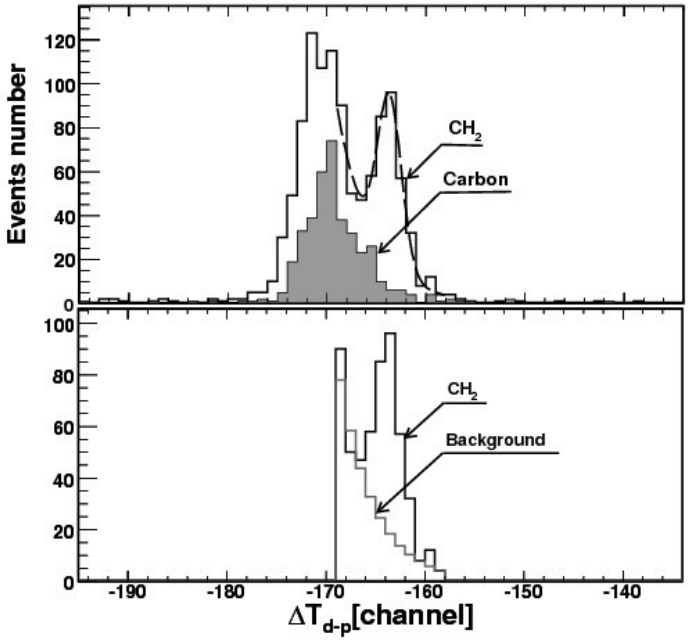
Selection of the dp elastic events by the time difference $\Delta T_{d\text{-}p}$ between the signal appearance from deuteron and proton detectors with the criteria on the amplitude signal correlation.

Analyzing powers measurement at 2000 MeV

(The dp- elastic events selection)



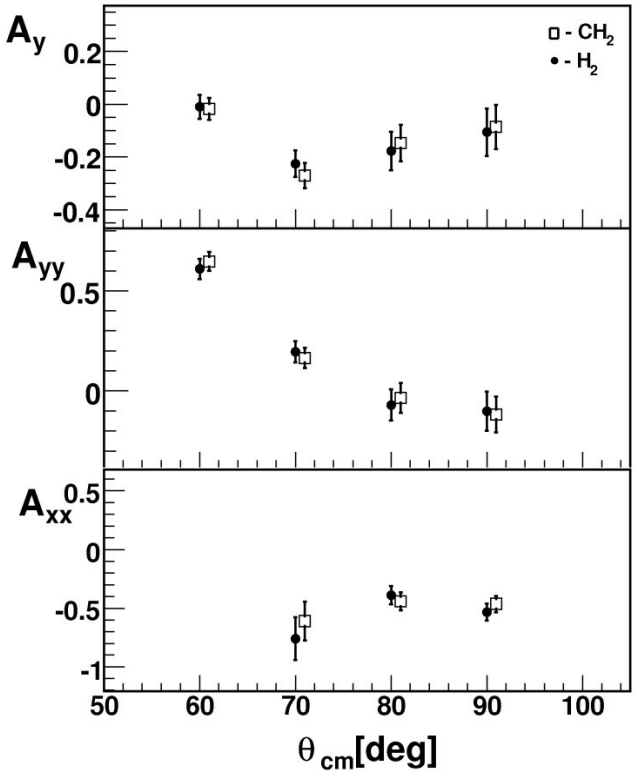
The correlation of the energy-loss signal for a pair of the deuteron and proton detector at 70° in c.m.s. The solid line is a graphical cut for the dp-elastic events candidate selection.



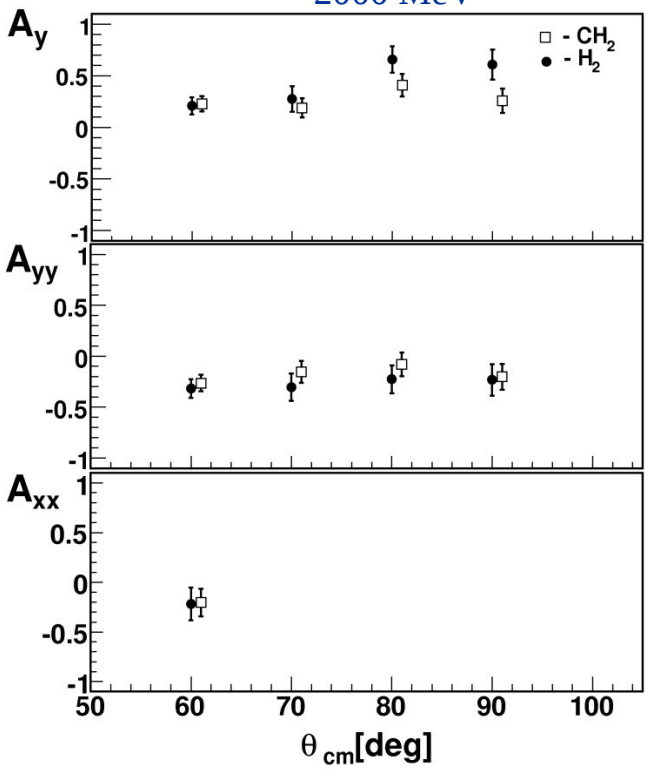
Selection of the dp elastic events by the time difference $\Delta T_{d\text{-}p}$ between the signal appearance from deuteron and proton detectors with the criteria on the amplitude signal correlation.

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

880 MeV



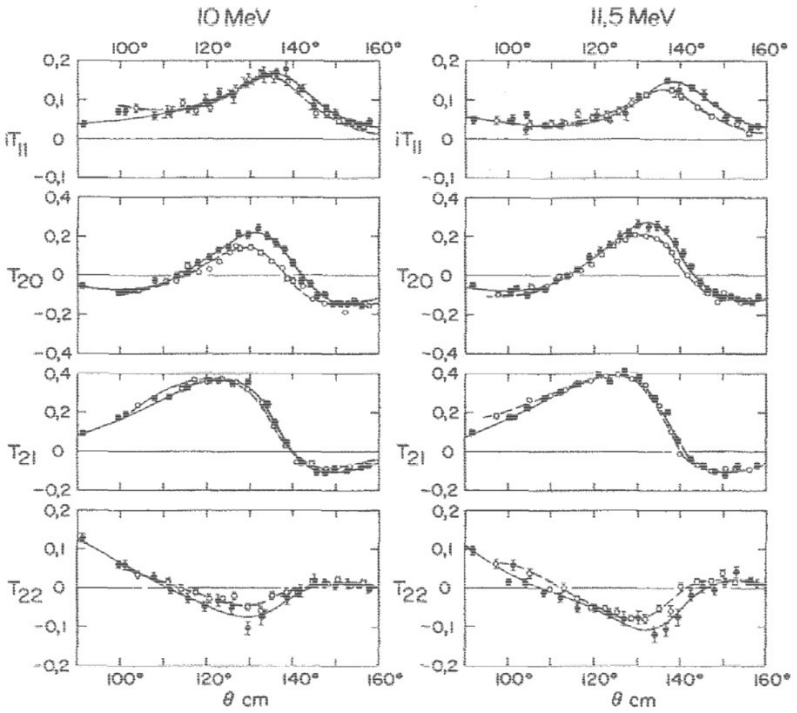
2000 MeV

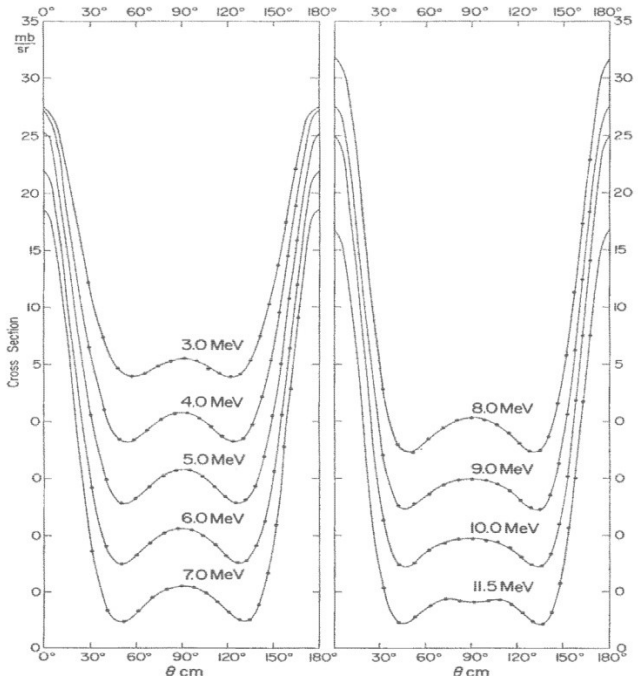


- The analyzing powers in dp-elastic scattering are large enough to provide both the vector and tensor polarimetry at high energies.
- The analyzing powers values for elastic and quasielastic deuteron scattering are comparable. Therefore, polarimeter can used in the counting mode (without event-by-event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

Low energy deuteron beam polarimeter

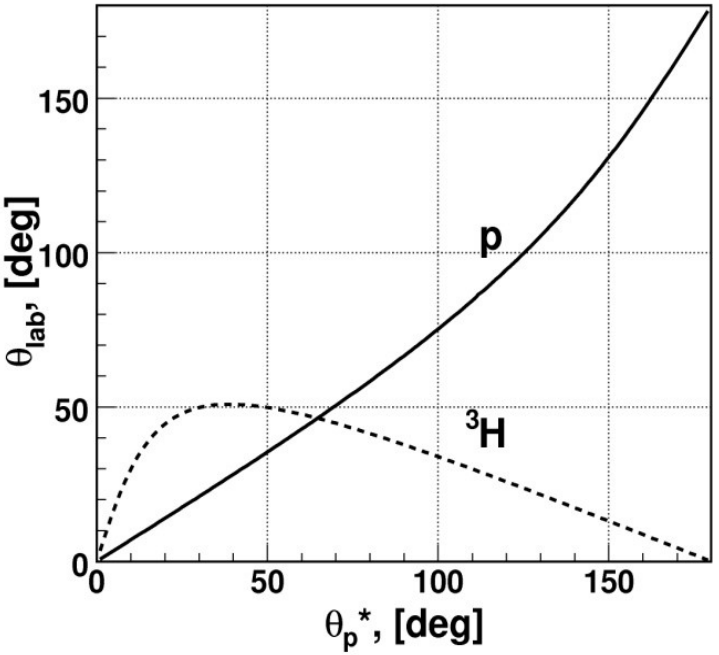
The use of the reaction d(d,p)t at 10 MeV with large values of the cross section and deuteron analyzing powers around 130º in cms

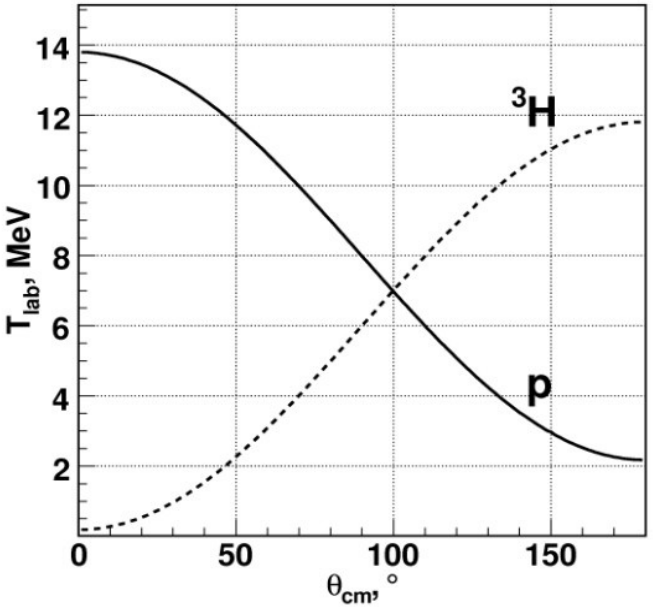




W.Grüebler et al., Nucl.Phys. A193 (1972) 179
V.König et al., Nucl.Phys.A331 (1975) 1

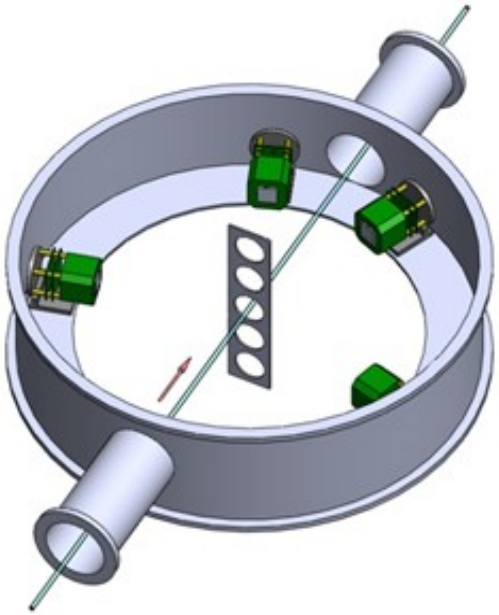
Low energy deuteron beam polarimeter



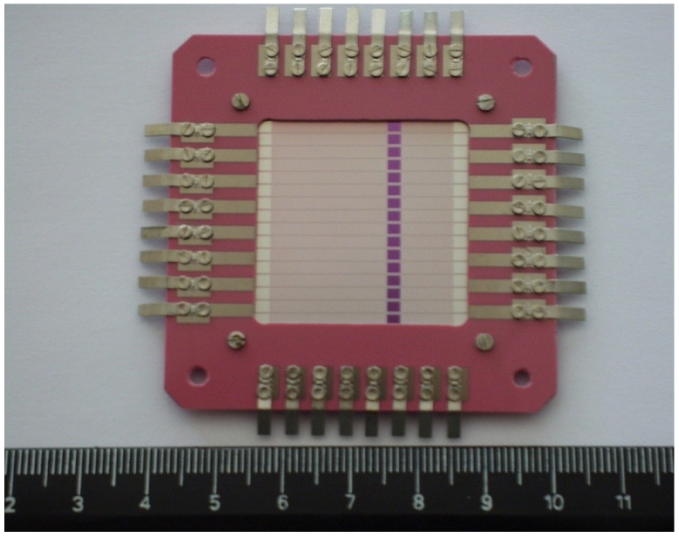


Kinematic relation for p and ^{3}H in d(d,p)t at 10MeV

Low energy deuteron beam polarimeter



Schematic view of the setup for the deuteron beam polarization measurement at 10 MeV



The strip double sided silicon detector for proton and triton detection in the coincidences

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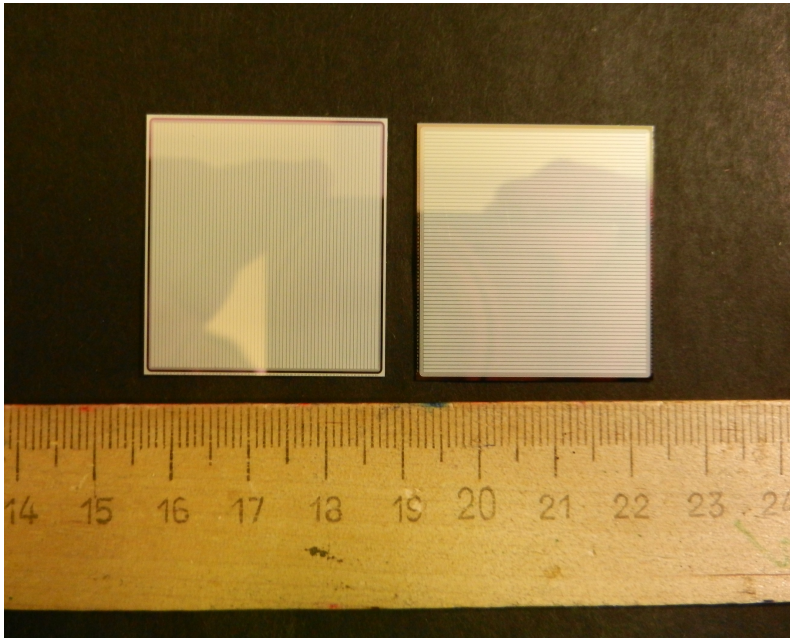
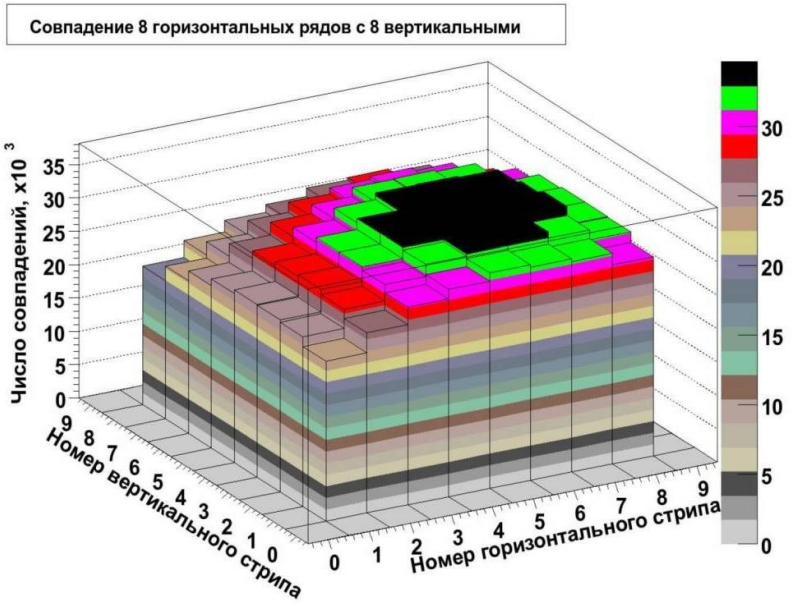
Detector for low energy polarimeter

The strip double sided silicon detector for proton and triton detection in the coincidences

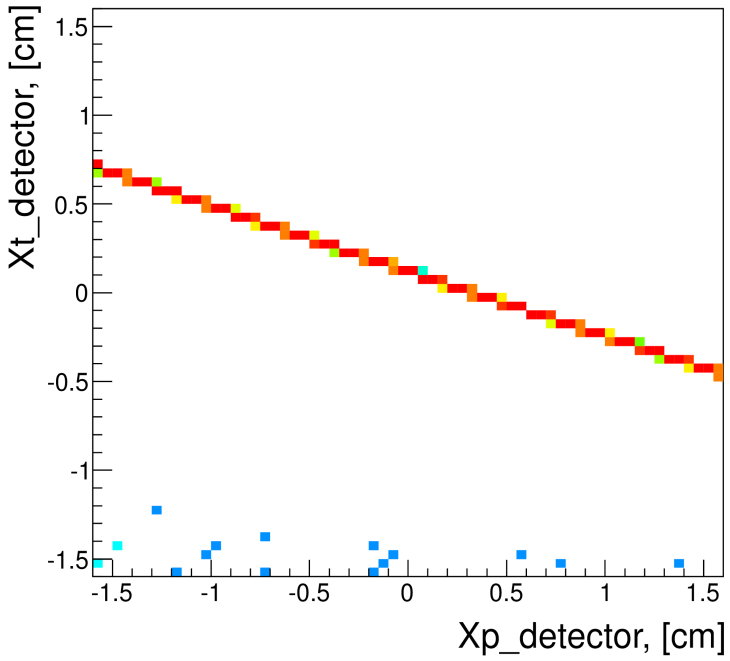


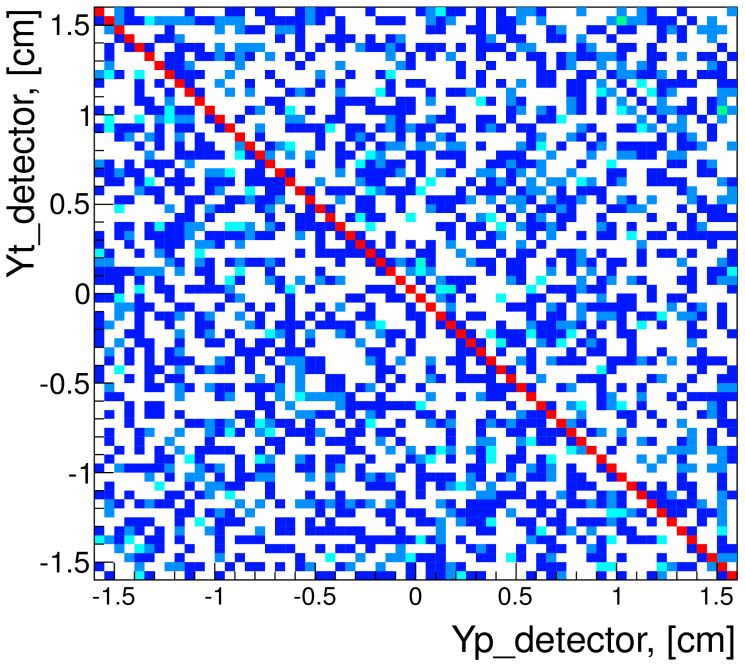


The the double side detector prototype 64*64 strips is produced in Zelengrad, the work on the FEE is started.

R&D is supported by SPD, BM@N, Cooperation programs JINR-Slovakia, JINR-Romania, RFBR etc.

Low energy deuteron beam polarimeter





The d(d,p)^{3}H events selection using the relation between scattering angles of protons and tritons and at 130 in c.m. at 10 MeV and distance of 20cm from the target. The energy loss information will be also used in the analysis.

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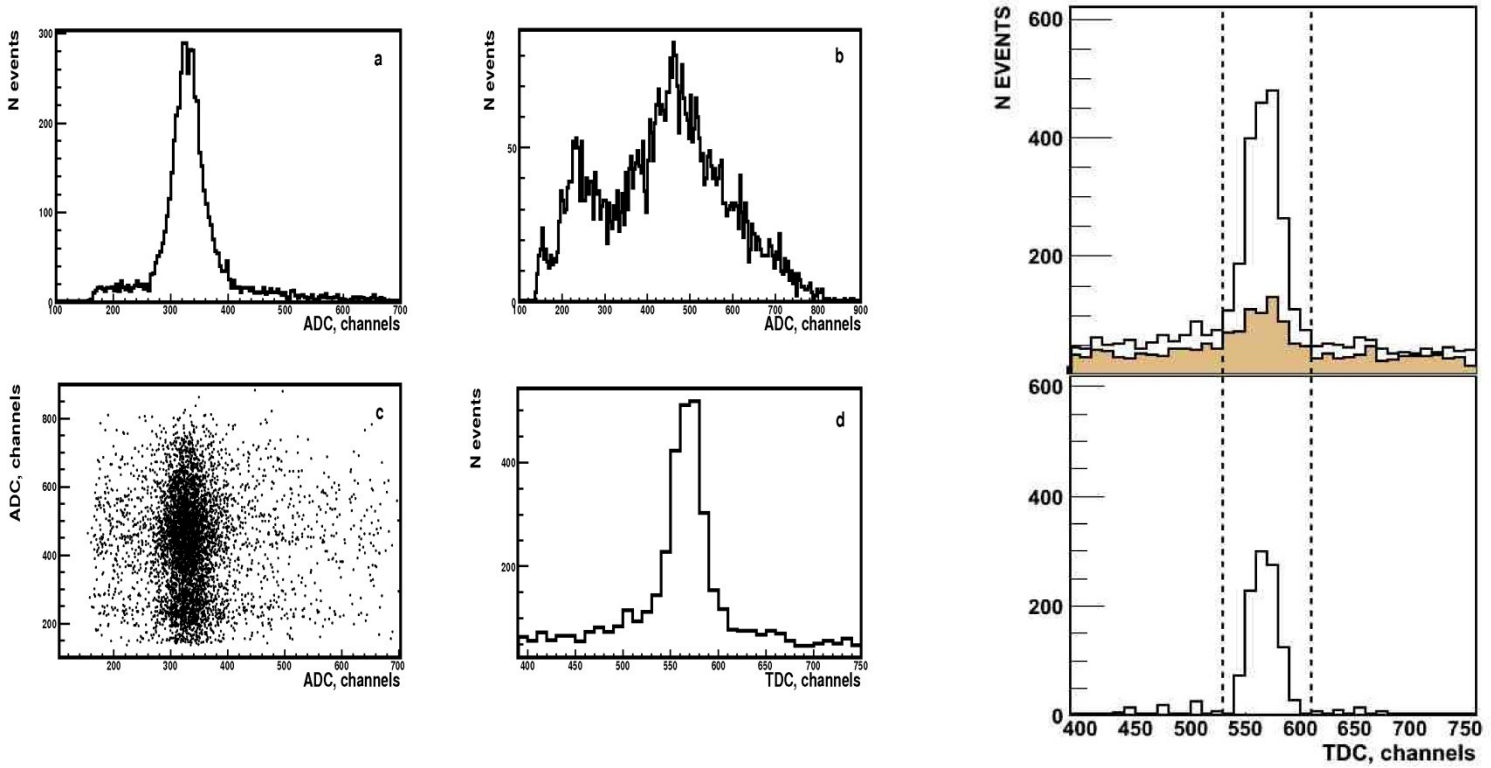
dp- elastic scattering at 1600 MeV at extracted beam (solution for the HE extracted beam polarimer)



Feasibility of the dp- elastic events selection using information on the energy losses in the scintillators and timing information was demonstrated at T_d = 1600 and 2000 MeV and $\Theta \sim 8^0$

***Yu.V.Gurchin et al.*, Phys.Part.Nucl.Lett 8 (2011) 566-570**

Detector for extracted beam line polarimeter at Nuclotron

Option 1. Detector should by based on the SciFH with the use of multianode PMTs (H6568) and usual scintillation counters.

Option 2. Silicon strip detectors and usual scintillation counters.

Supported by BM@N, Program of JINR-Romania, RFBR etc.

Conclusions

- **The reference polarimeters for deuterons must satisfy to the following requirements:**

  a) to be able to measure both tensor and vector polarizations due to mixed spin modes of new PIS

  b) to measure the direction of the polarization vector

  c) analyzing powers must be obtained by the absolute method of the beam polarization measurements.

Such a polarimeter based on dp- elastic scattering exists at ITS

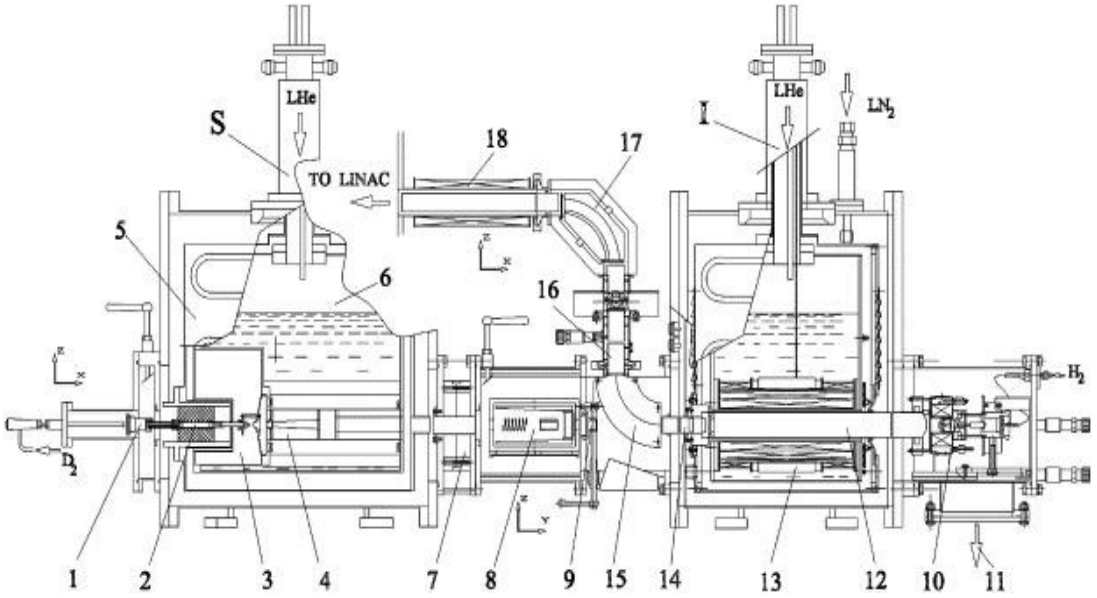
(Needs upgrade - 50k$!)

- **LE polarimeter can be based on the use of silicon strip detectors to detect tritons and protons from the d(d,p)t reaction.**
- **The extracted beam line polarimeters should be based on the use of dp-elastic scattering at small scattering angles, it will work up to 2000 MeV.**
- **This procedure will provide the error of 3% at the energies of 270-2000 MeV and better than 5% at higher energies.**

No clean solution for deuteron polarimetry at higher energies!

Thank you for the attention!!!

Polarized ion source POLARIS



Схематичный вид ИПИ ПОЛЯРИС

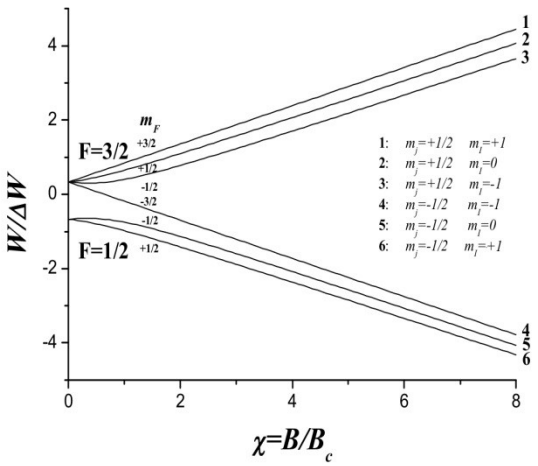


Диаграмма энергетических уровней атома дейтерия в магнитном поле B.

$$P_z(I=1)=\frac{N_{m_I=+1}-N_{m_I=-1}}{N_{m_I=+1}+N_{m_I=0}+N_{m_I=-1}}$$ - vector polarization

$$P_z(I=1)=\frac{N_{m_I=+1}+N_{m_I=-1}-2N_{m_I=0}}{N_{m_I=+1}+N_{m_I=0}+N_{m_I=-1}}$$ - Tensor polarization

Mode “2-6”: (P_z,P_{zz}) = (1/3,1)

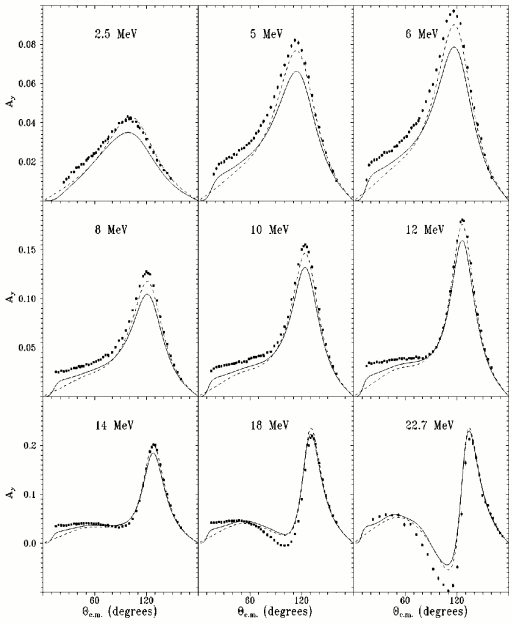
Mode “3-5”: (P_z,P_{zz}) = (1/3,-1)

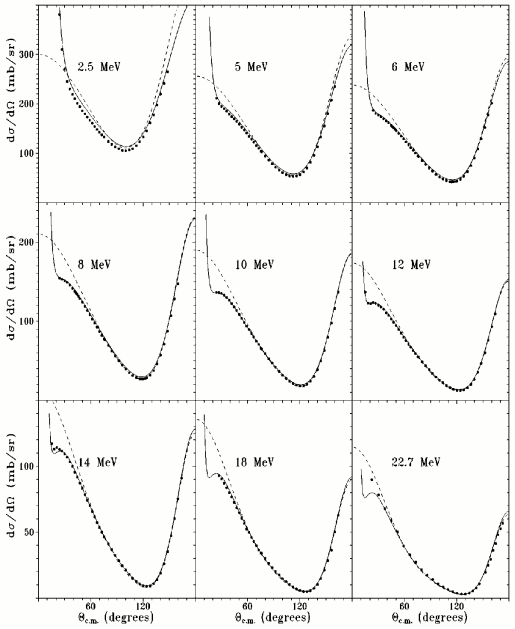
Proton polarimeters for Nuclotron/NICA

- LEP for 20 MeV protons based on pd-elasic scattering
- ITS polarimeter pp-elasic scattering in a GeV range
  Absolute calibration using pA-elasic scattering
- Beam line polarimeters are based on pp-elasic scattering at small scattering angles.
- pC CNI polarimeters at NICA
  $\vec{p}\vec{p}$-elasic scattering for an absolute calibration.

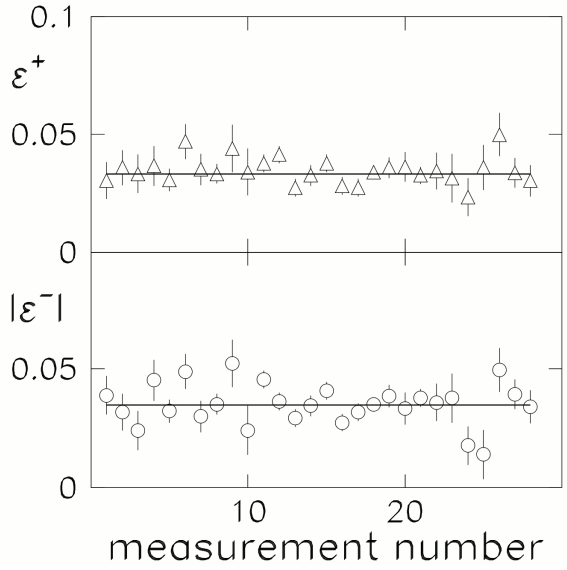
Low energy proton polarimeter

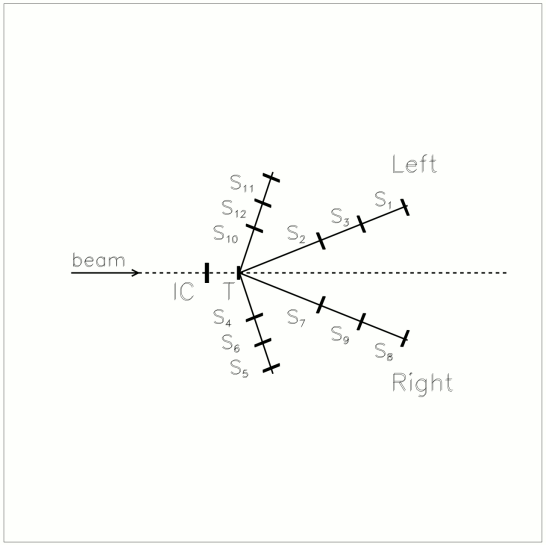
The use of the reaction $\mathrm{d(p,d)p}$ at 20 MeV with large values of the cross section and deuteron analyzing powers around 130° in the cms.





Measurement and monitoring of the beam polarization using pp quasi-elasic scattering up to 4.5 GeV/c



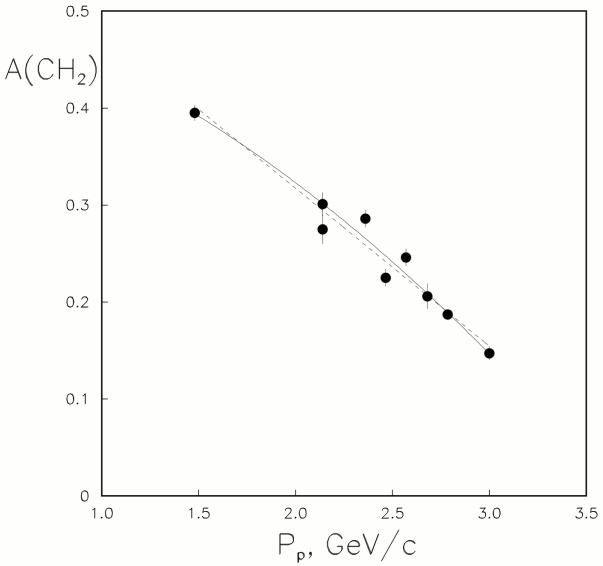


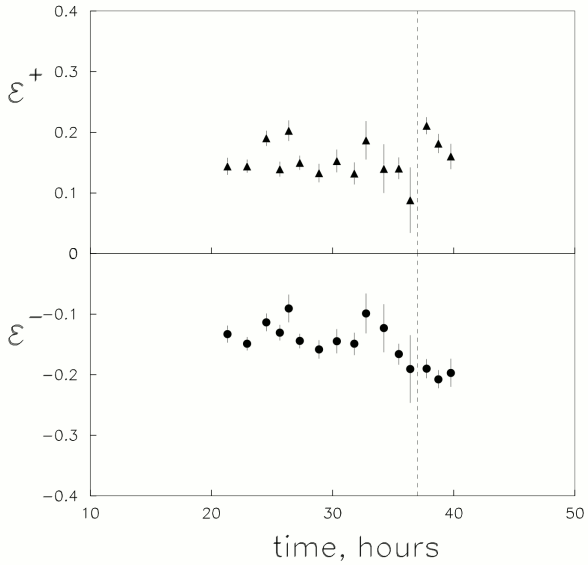
The asymmetry stability during several days of the beam time.

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

L.S. Azhgirey et al., Prib.Tech.Exp.1 (1997) 51; Nucl.Instr.Meth. A497 (2003) 340.

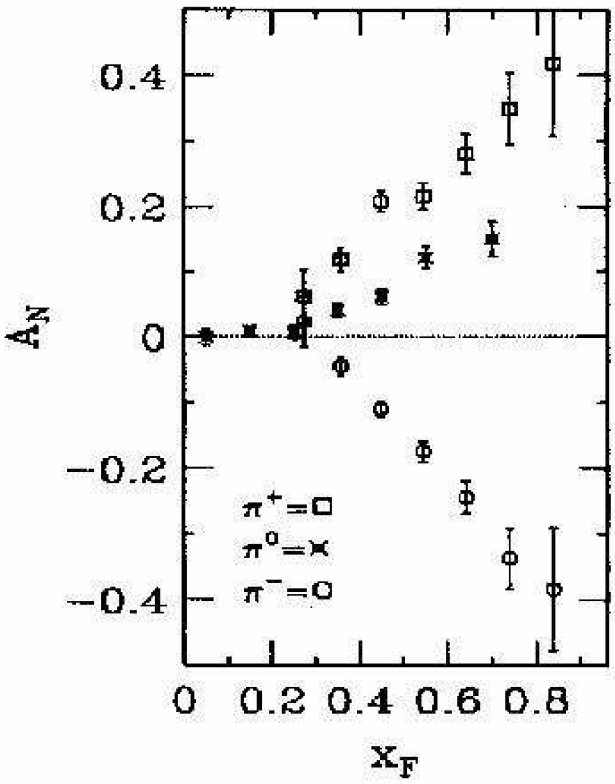
Vector polarization of the deuteron beam (2002)





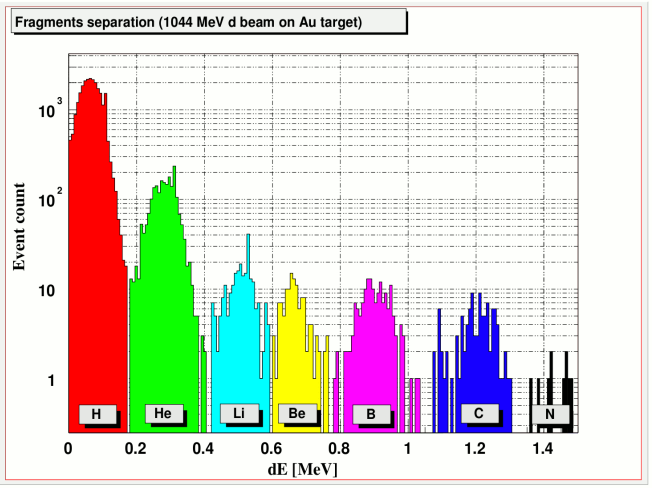
- Vector polarimeter is based on the left-right asymmetry measurement in quasi-elastic pp scattering (5% of systematics).
- Measurements of the deuteron beam vector polarization have been performed at 3.5 and 5.0 GeV/c.
- There is no depolarization at Nuclotron.

Permanent nucleon beam polarization monitoring at NICA from $\vec{N} + \vec{N} \to \pi + X$ 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 π^0's is preferable.
  (no momentum reconstruction).
- However, figure of merit for $\pi^{\pm}$ is higher!
- Serious problem is the possible initial energy dependence.

CNI polarimeter based on the pC elastic scattering.



- pC elastic scattering in CNI region is used for polarimetry at AGS and RHIC.
- The experience to detect slow nuclear fragments at ITS exists.
- Very difficult to measure at ITS due to necessity to have both energy deposition and timing signal for recoil ^{12}C.