Status of internal target polarimeters at Nuclotron

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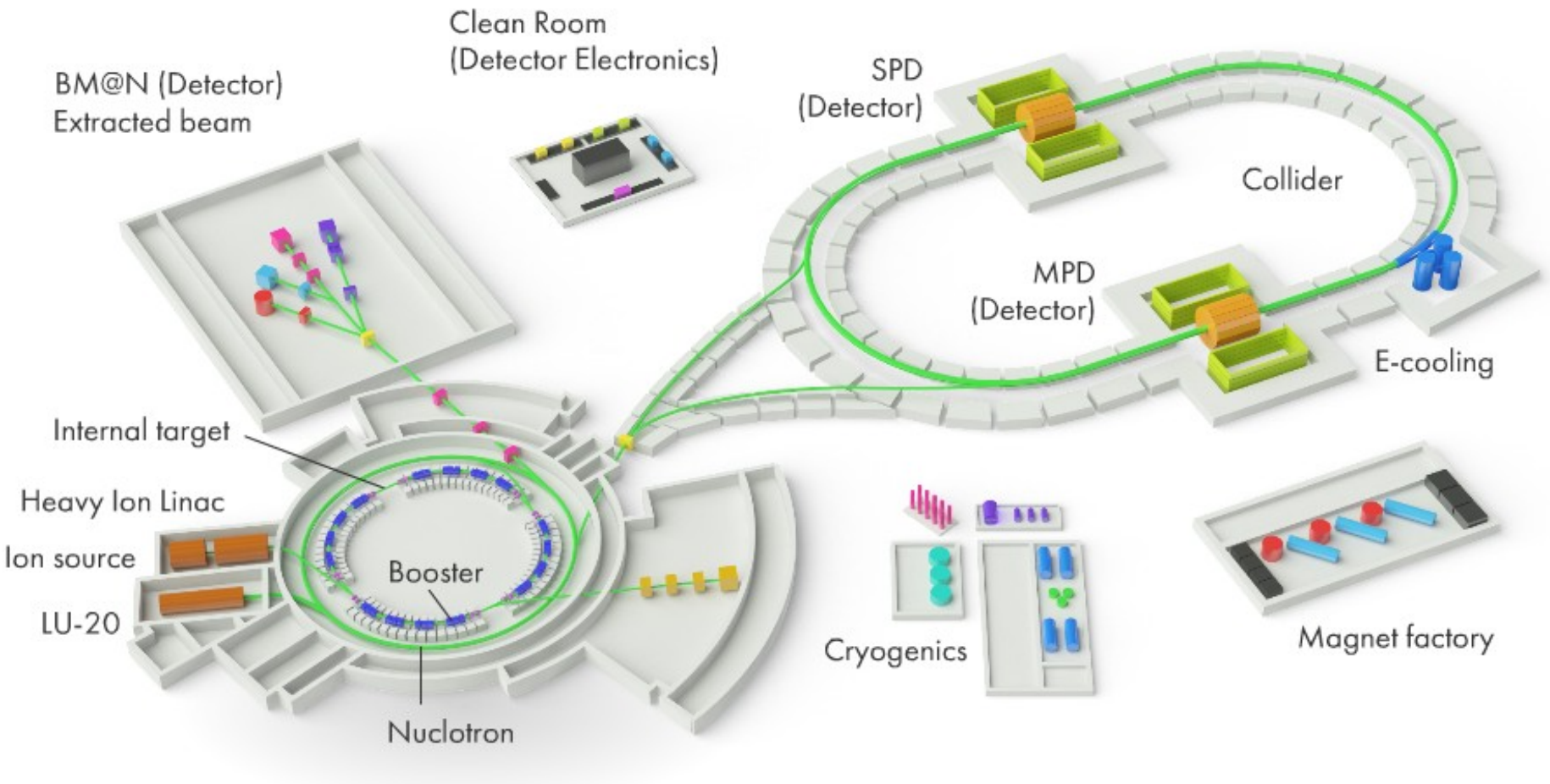
LHEP JINR, Dubna, 12 November 2025

NICA complex



Both collider (SPD, MPD) and fixed target (DSS, ALPOM2) spin experiments require polarized proton and deuteron beams

Studies at ITS at Nuclotron

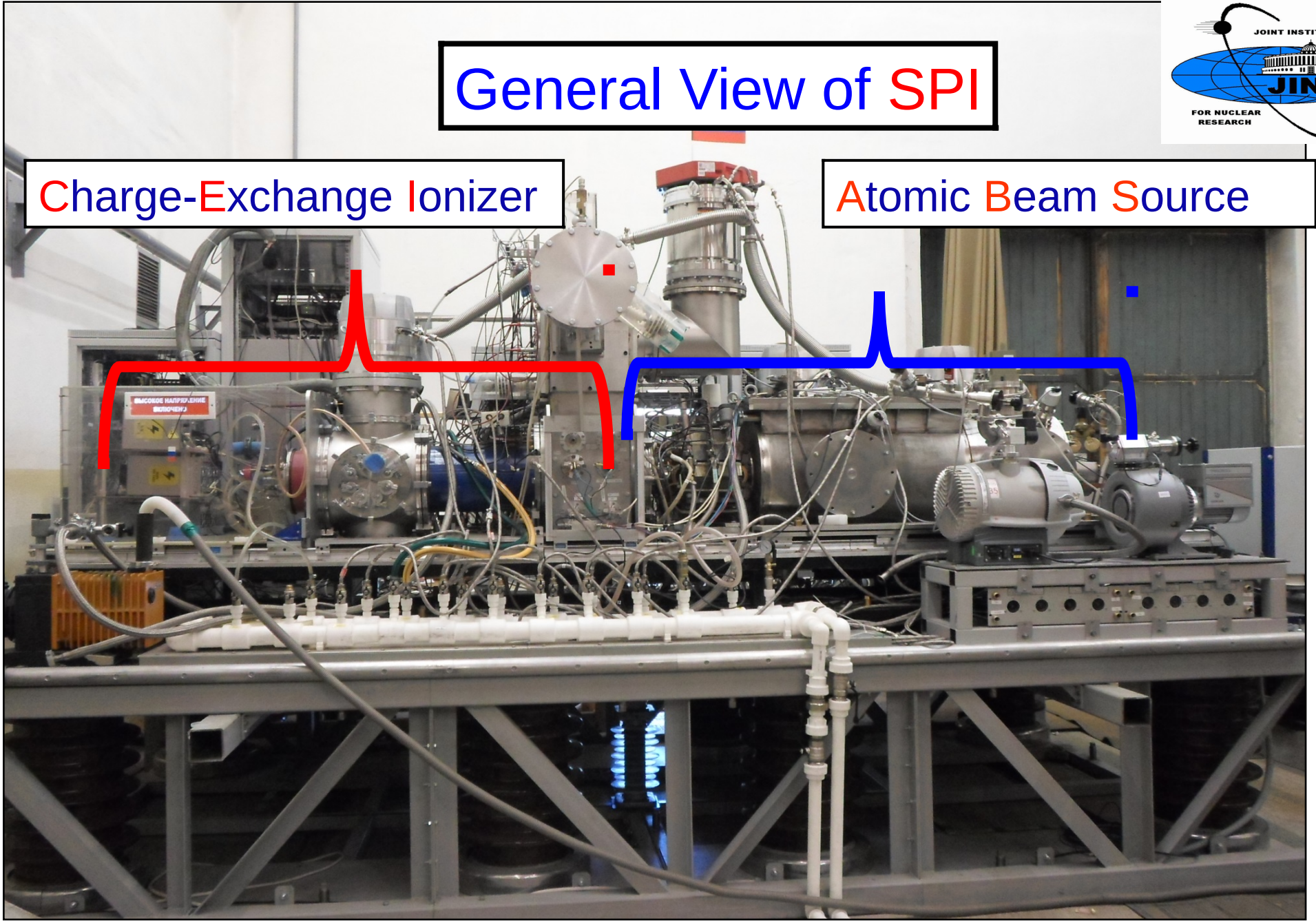
The purpose of the **DSS** experimental program is to obtain the information about 2NF and 3NF (*including their spin – dependent parts*) from the processes:

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.

The DSS studies require good knowledge of the deuteron (proton) beam polarization.

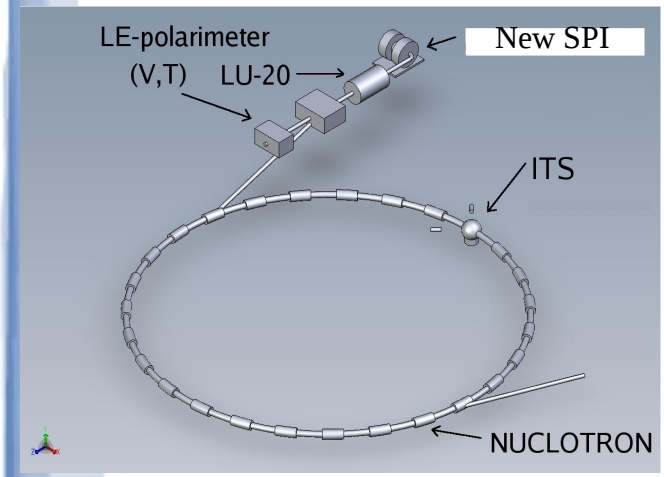
General View of SPI

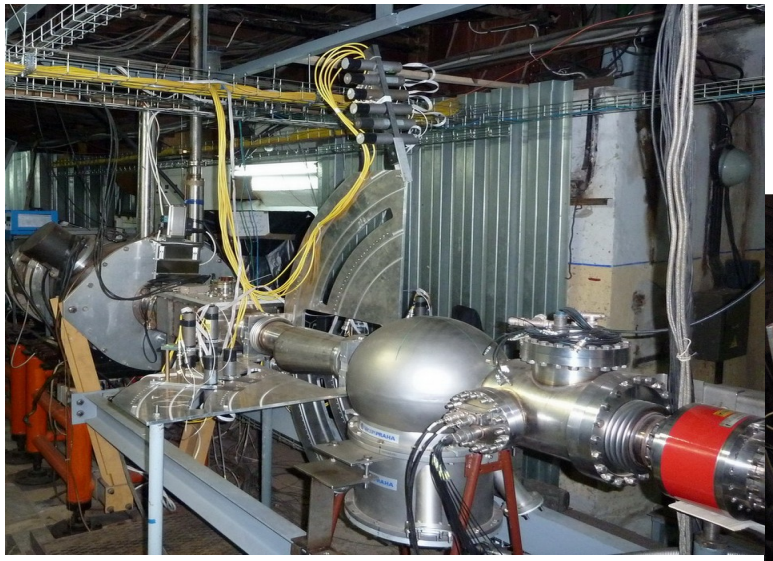


SPI was put into operation in 2016-2017 with deuterons (tested with protons).
SPI current and polarization (for deuterons) are ~3 mA and 70-75%.

Plans are to increase the current up to ~10 mA.

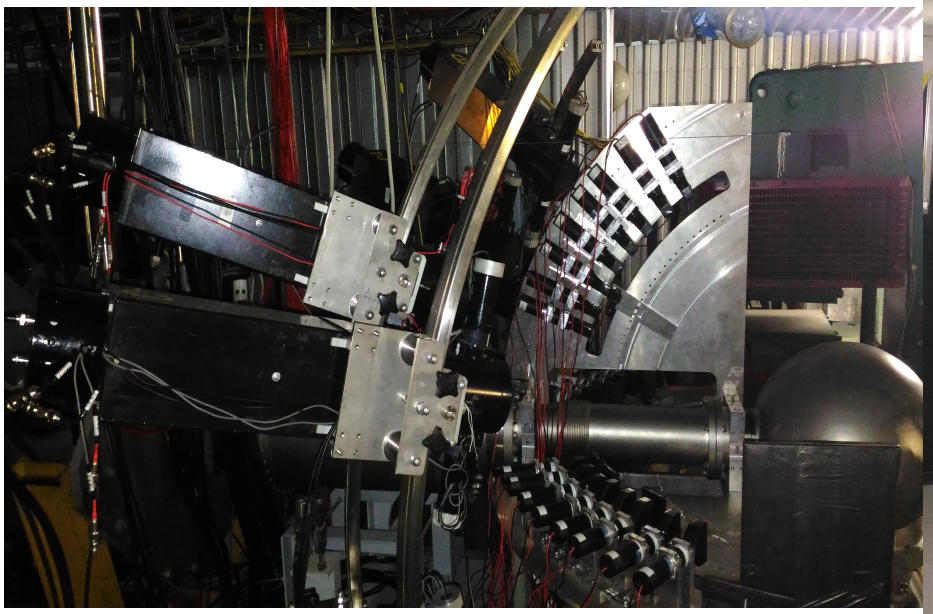
Experiments at Internal Target Station at Nuclotron
DSS-project

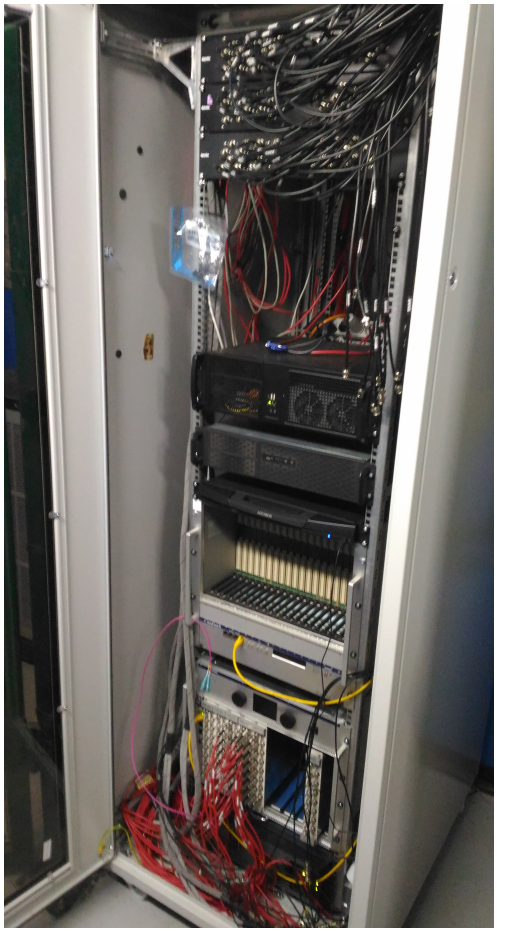




Internal Target Station is very well suited for the measurements of the deuteron- induced reactions observables at large scattering angles.

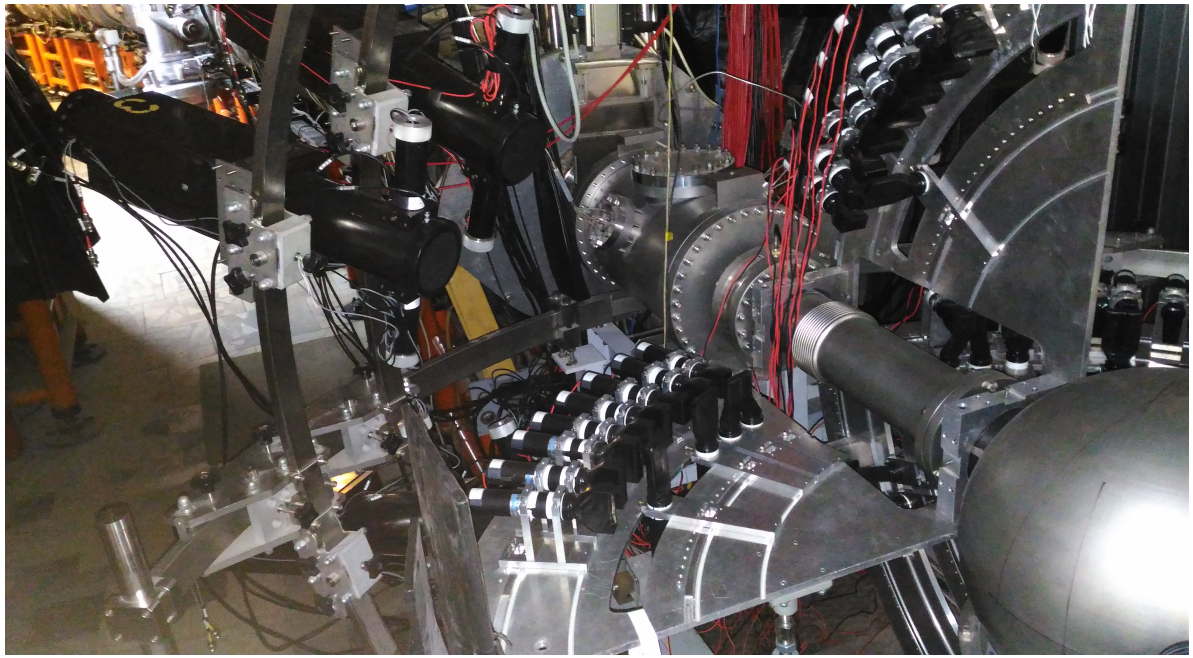
Upgrade of the DSS setup at ITS at Nuclotron





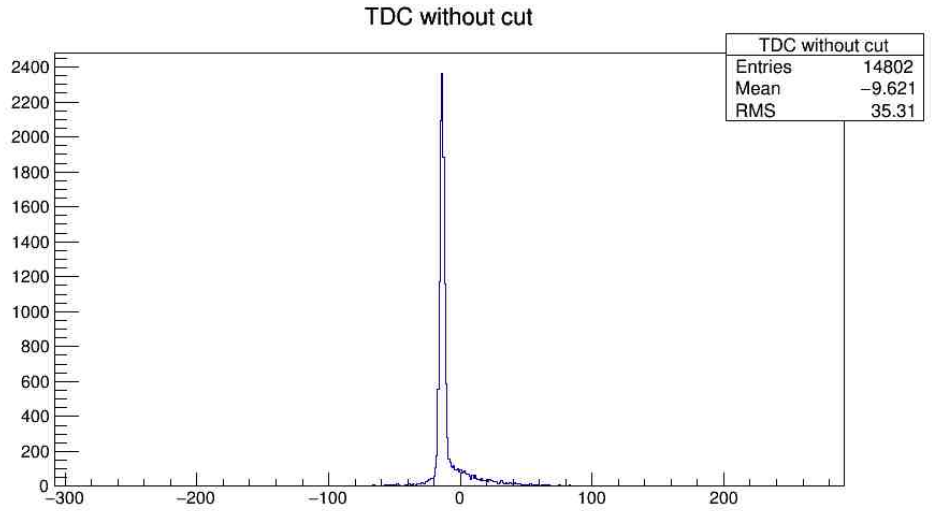
New infrastructure, cabling
New HV system (Mpod)
New VME DAQ
40 counters for dp-elastic scattering studies
8 dE-E detectors for dp -breakup studies

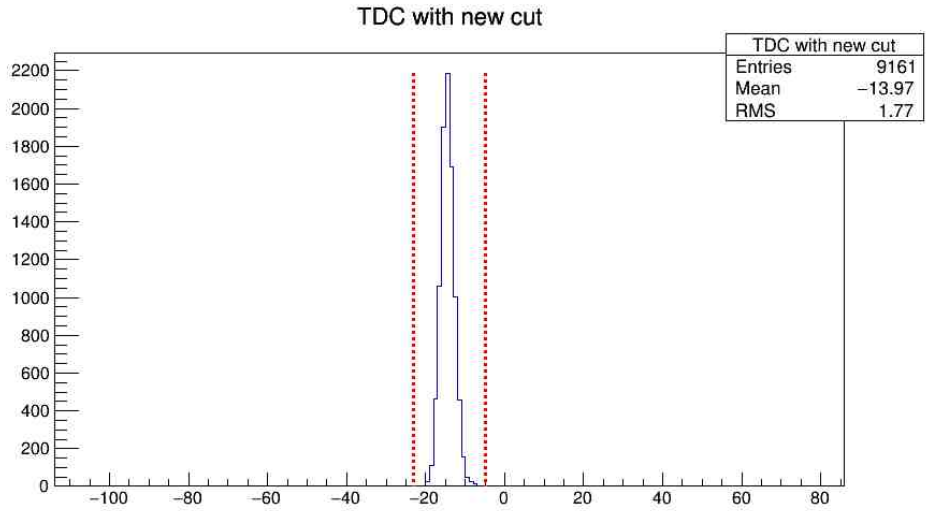
Setup to study dp- elastic scattering at ITS at Nuclotron

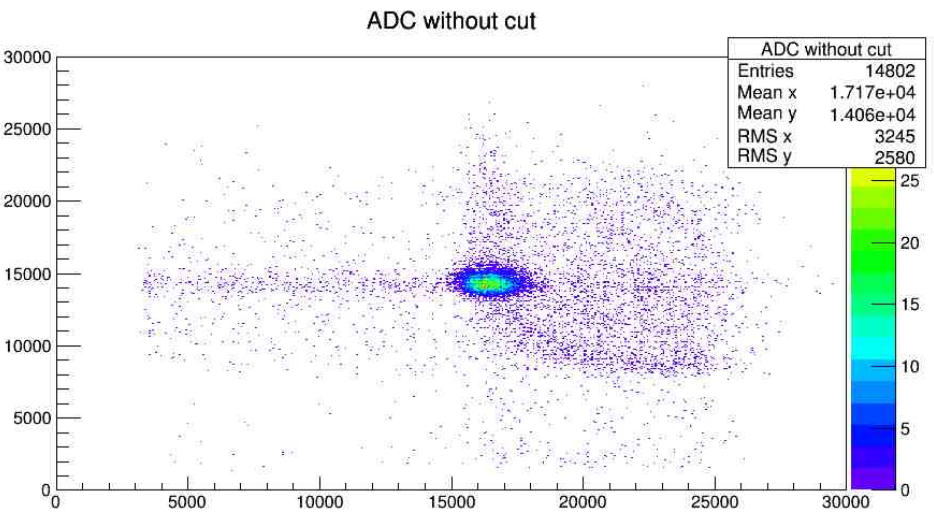


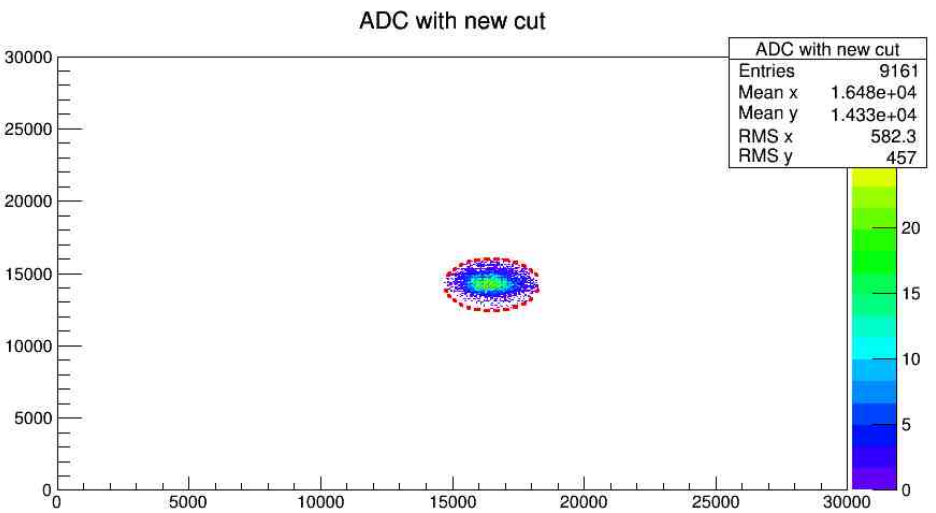
- Deuterons and protons in coincidences using scintillation counters
- Internal beam and thin CH_2 target (C for background estimation)
- Permanent polarization measurement at 270 MeV (between each energy).
- Analyzing powers measurement at 400-1800 MeV
- The data were taken for three spin modes of SPI: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

The dp-elastic scattering events selection at 270 MeV





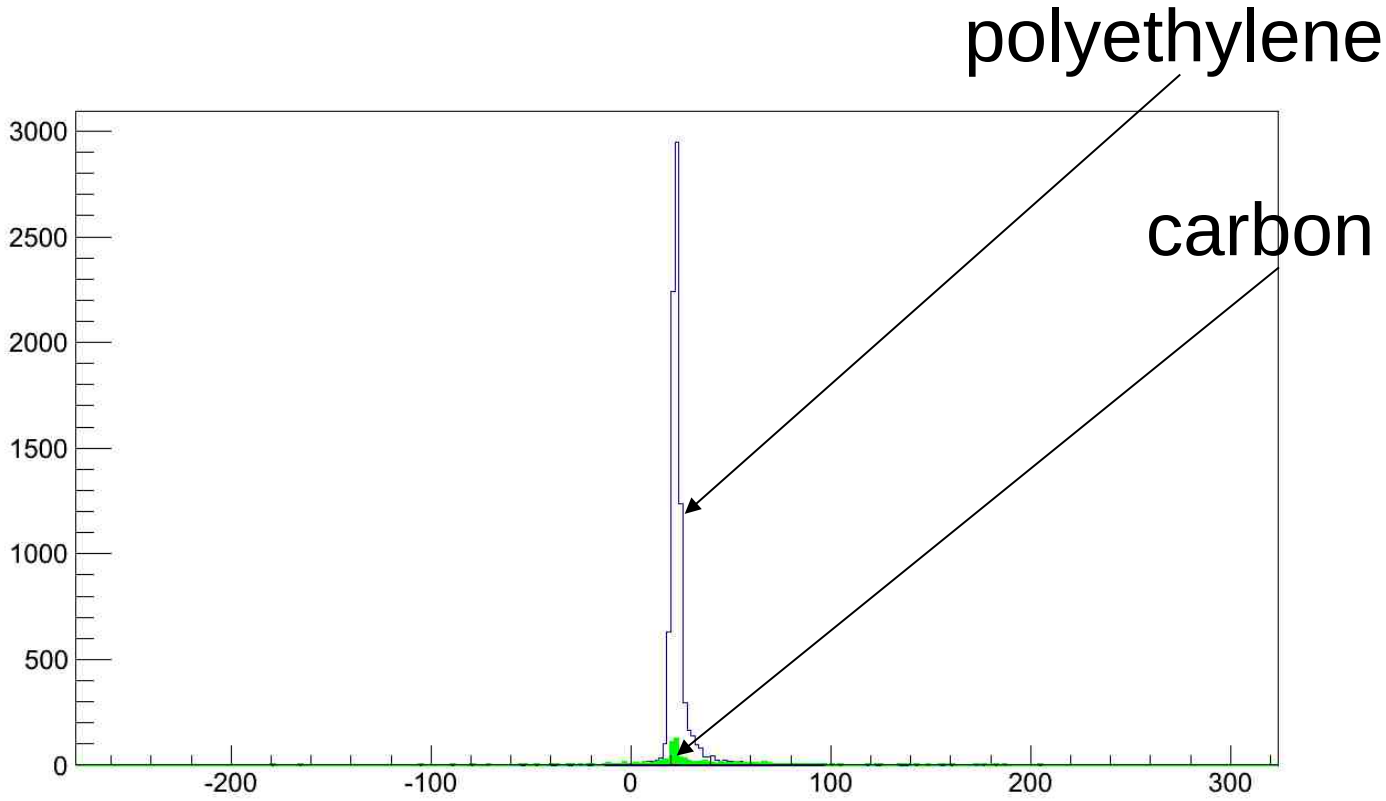




Examples of cuts for the detector pair placed at 105^0 in cms.

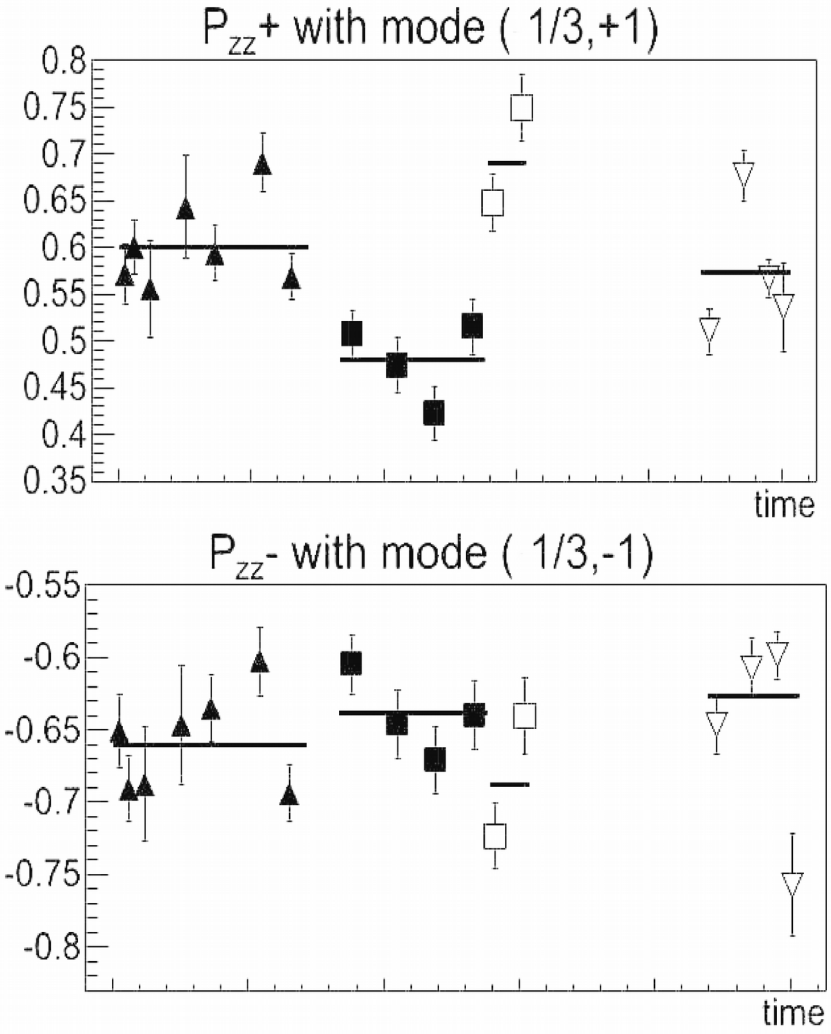
The background estimation

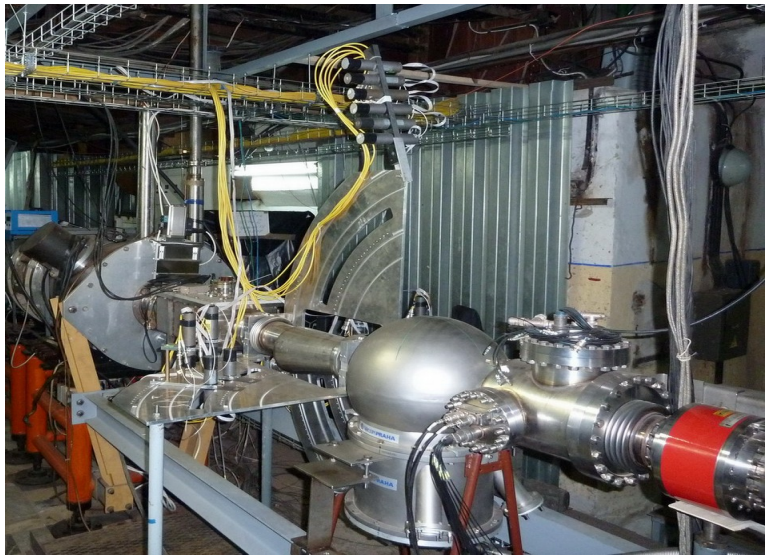
TDC spectra for polyethylene and carbon were normalized on the luminosity.



Time of flight difference between the signals for deuteron and proton detectors for polyethylene and carbon targets. The carbon integral refers to the polyethylene integral as 0.5 %

Vector and tensor deuteron beam polarizations using dp- elastic scattering at 270 MeV at ITS





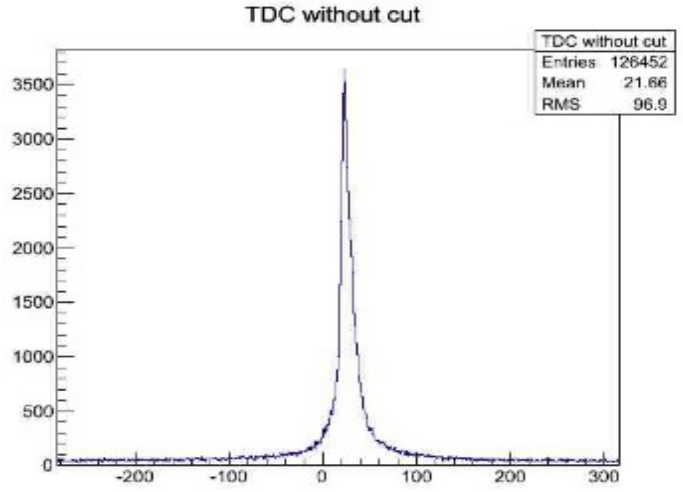
P.K.Kurilkin et al.,
NIM A642 (2011) 45.

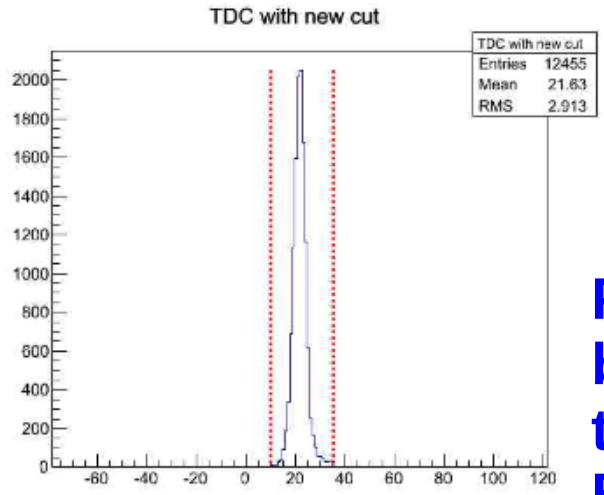
SPI was tuned for 6 spin modes (p_z,p_{zz}) = (1/3,1), (1/3,-1), (0,+1), (0,-2), (-2/3,0),(+1,+1).

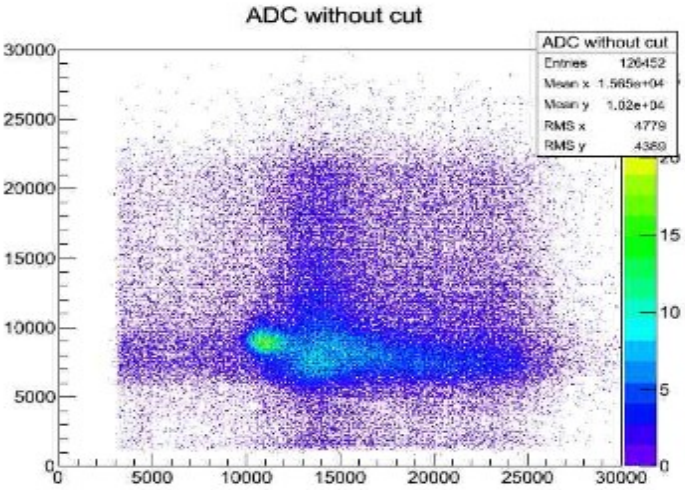
The vector and tensor polarization for different spin modes of SPI

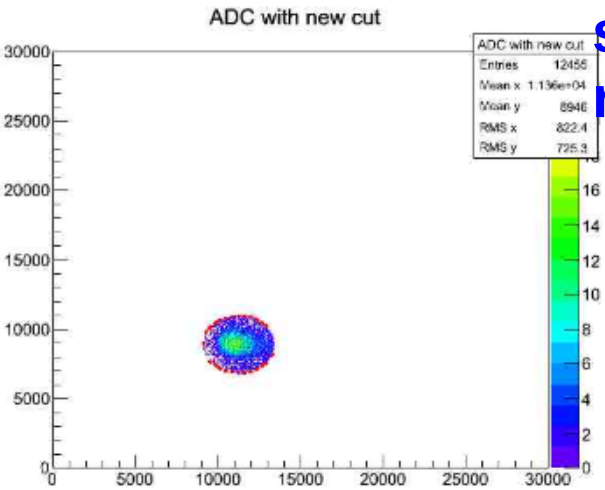
Polarization values (p_z, p_{zz})	P_z	dP_z	P_{zz}	dP_{zz}
(+1/3,+1)	0.254	0.022	0.631	0.045
(+1/3,-1)	0.223	0.017	-0.621	0.030
(0,+1)	0.030	0.027	0.880	0.049
(0,-2)	0.046	0.015	-1.469	0.031
(+1,+1)	0.648	0.016	0.628	0.027
(+2/3,0)	0.427	0.021	0.061	0.037

The dp-elastic scattering events selection at high energies





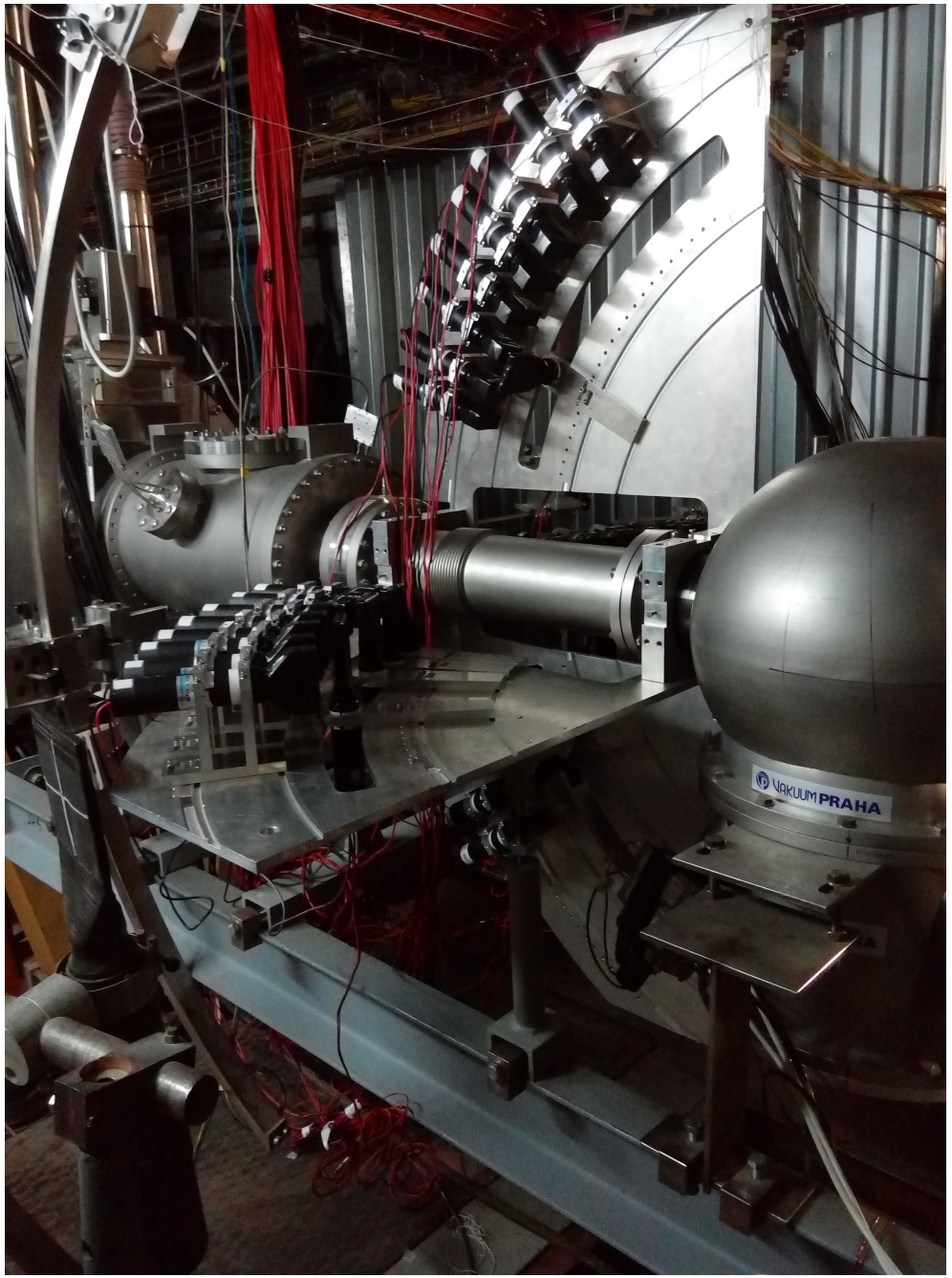


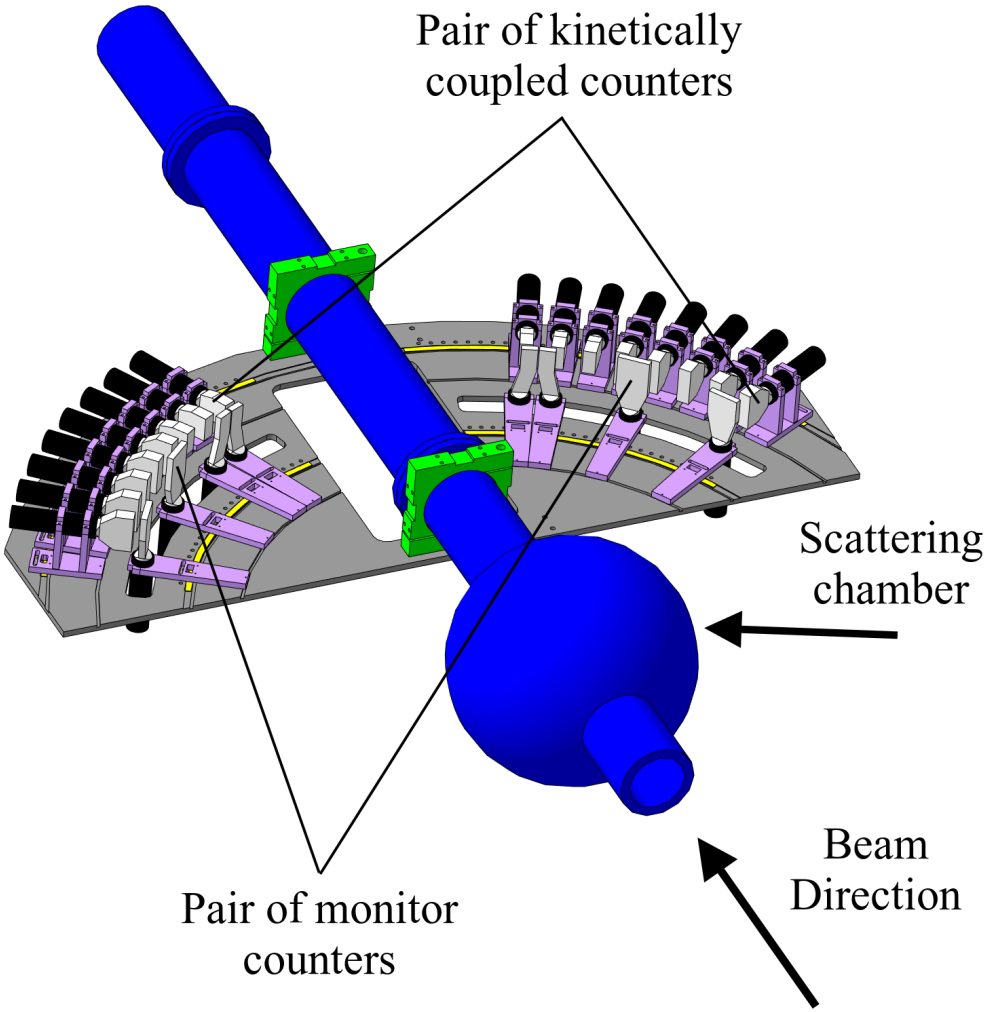


Polarimetry can be extended up to 1300 MeV. But CH_2-C subtraction is required.

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.

The DSS setup for vector polarization measurements

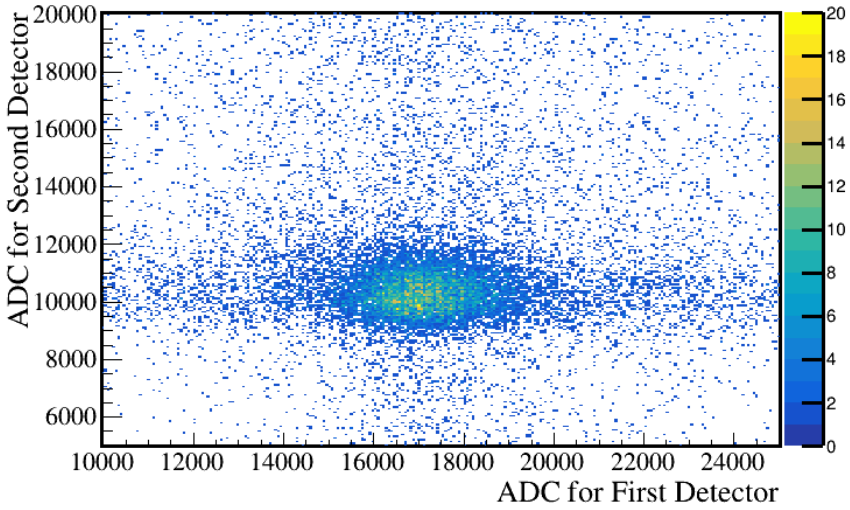


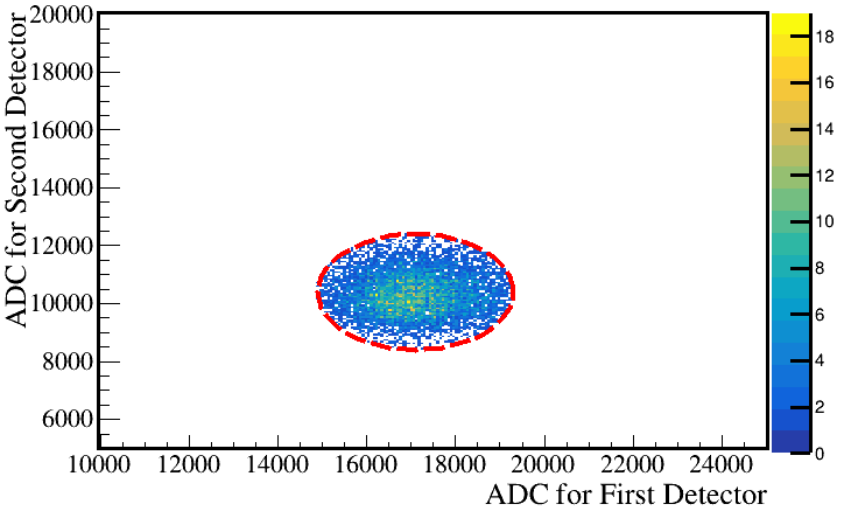


- 6 pairs to the left, 6 pairs to the right; from 55° to 85° in the CM system;
- 1 pair to 90° in CM;
- *pp*-elastic kinematics.

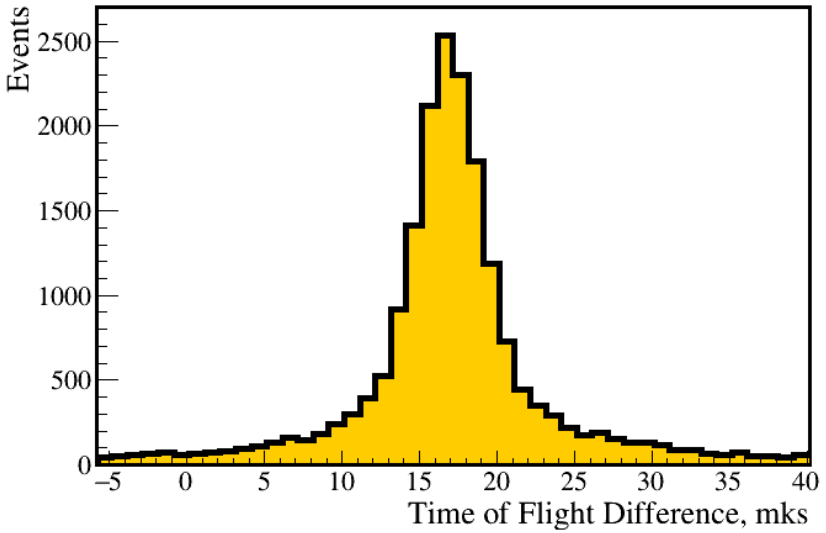
Selection of pp- quasielastic events. Deuteron beam

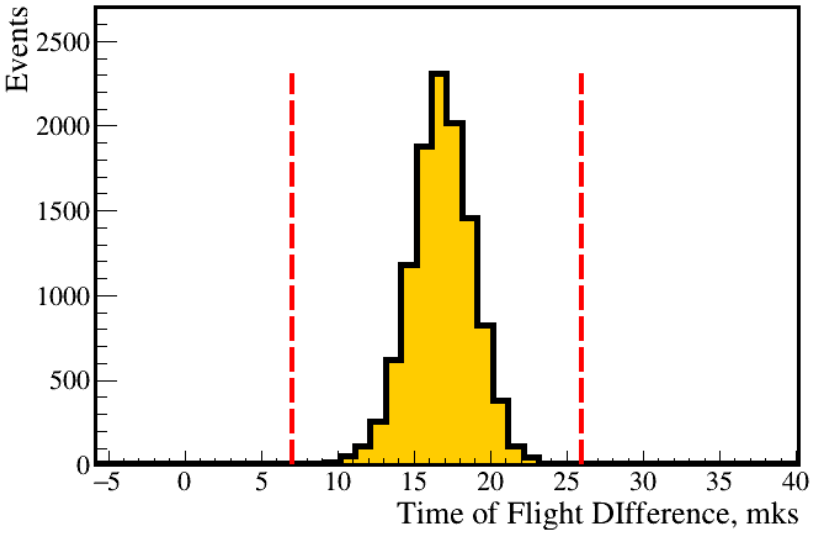
Ionization loss correlation for the counters pair





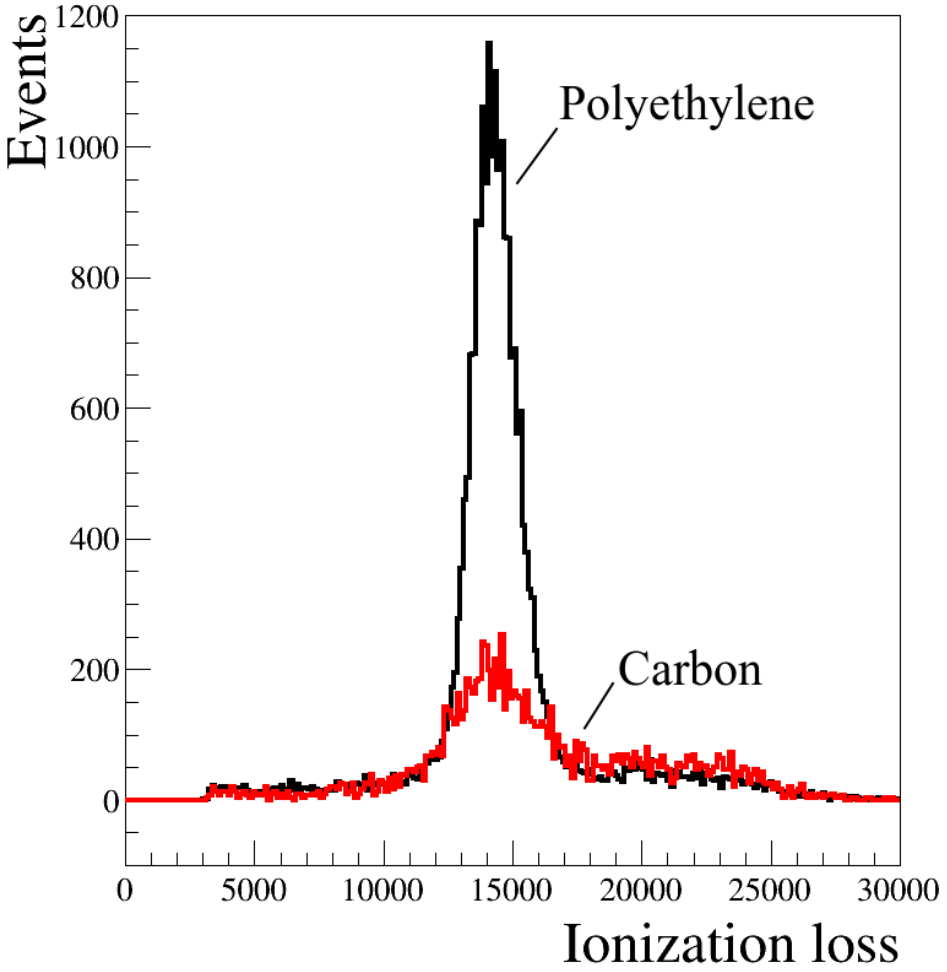
Time-of-flight difference for the pair

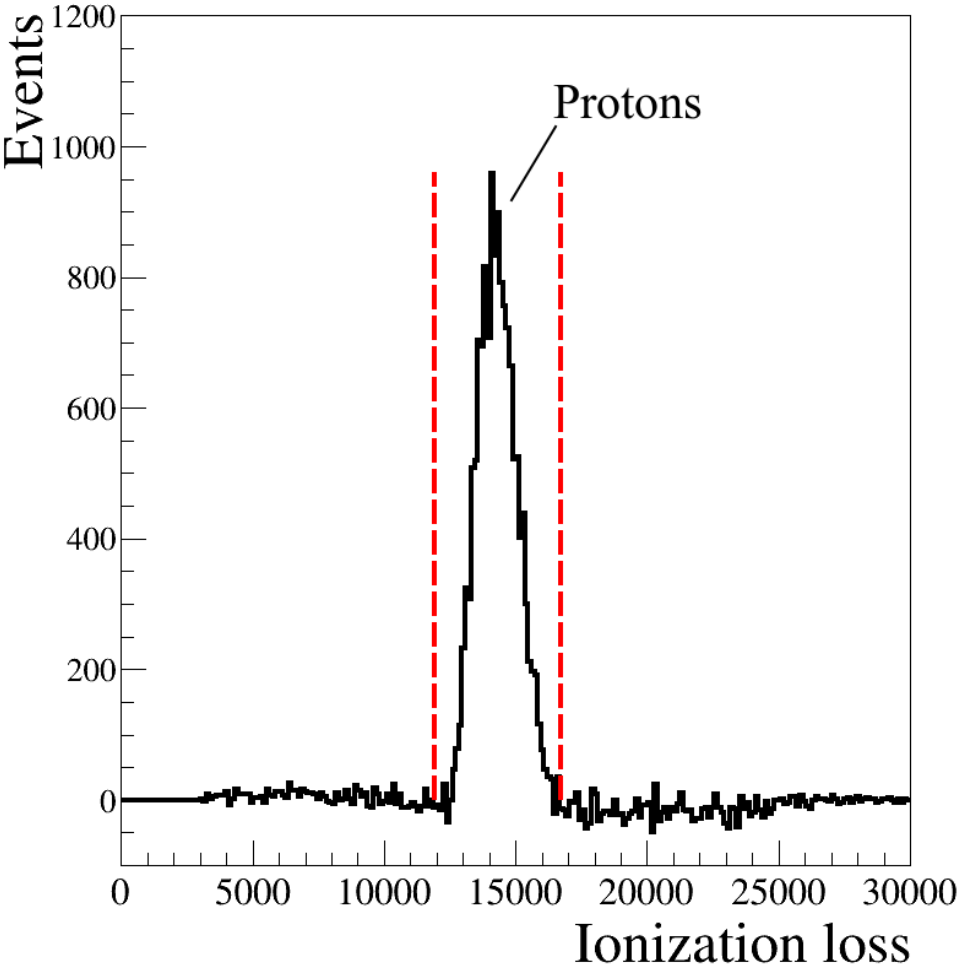




Cuts applied one after the other to achieve better result

The result of the background subtraction.
500 MeV/n, 85° in CM system



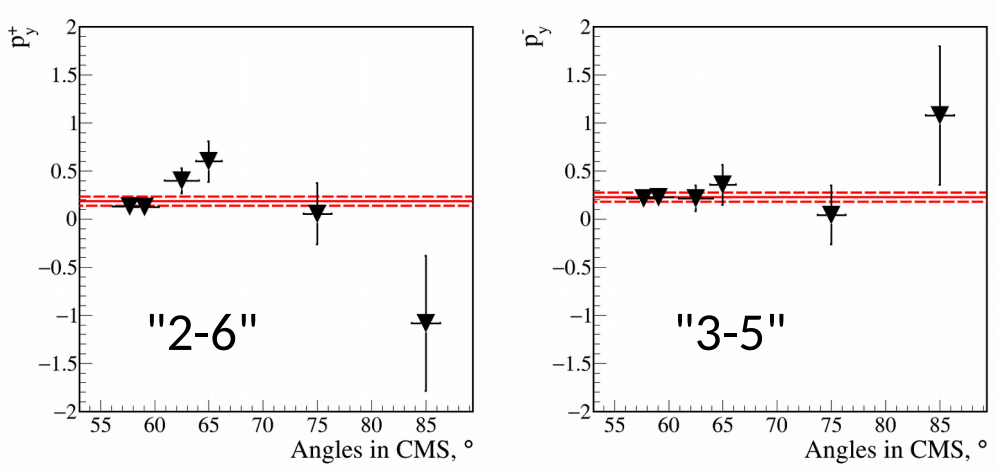


~50% of events is background.
Unpolarized data

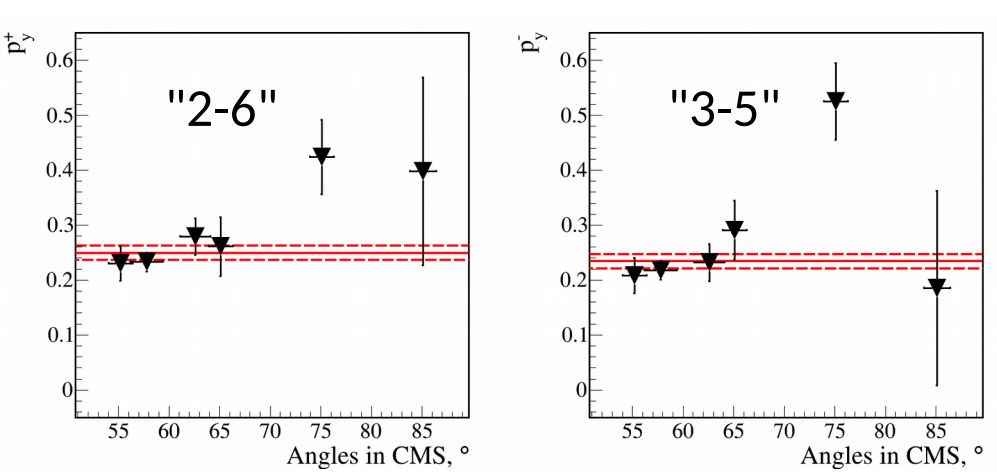
Red lines - cut on ADC.

The deuteron beam polarization values

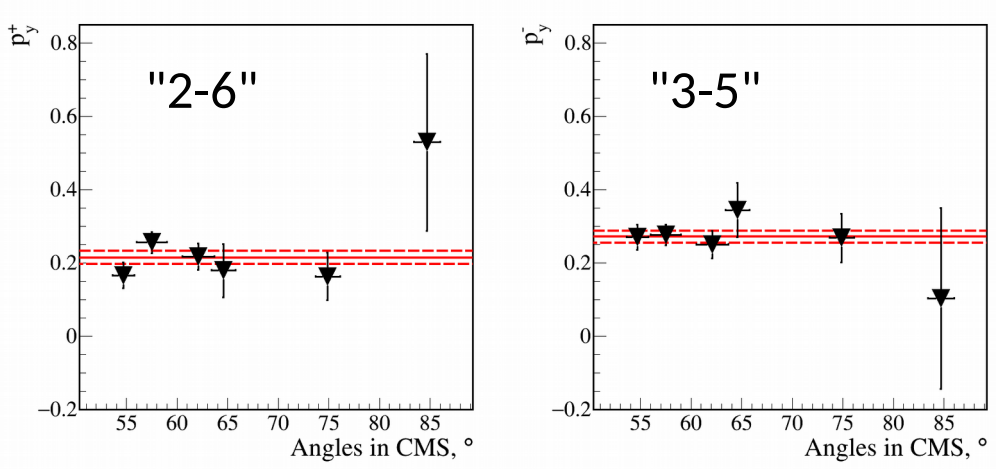
200 MeV/n



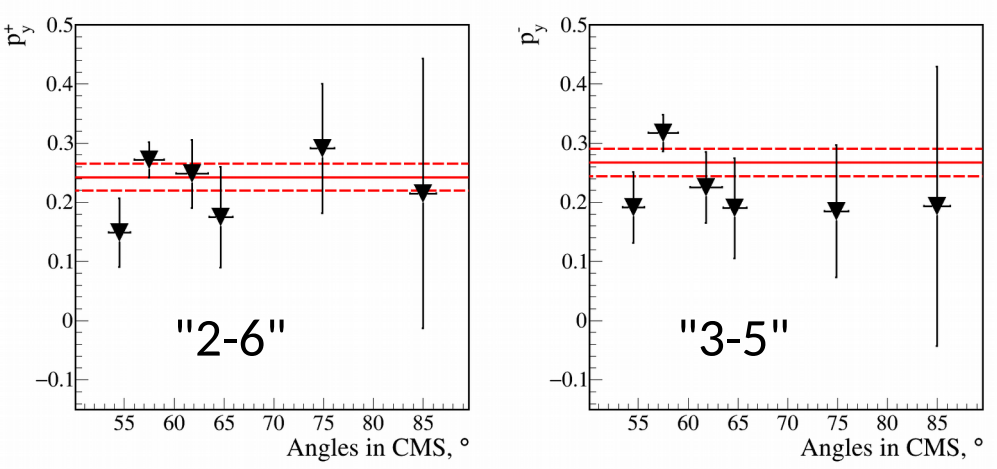
500 MeV/n



550 MeV/n

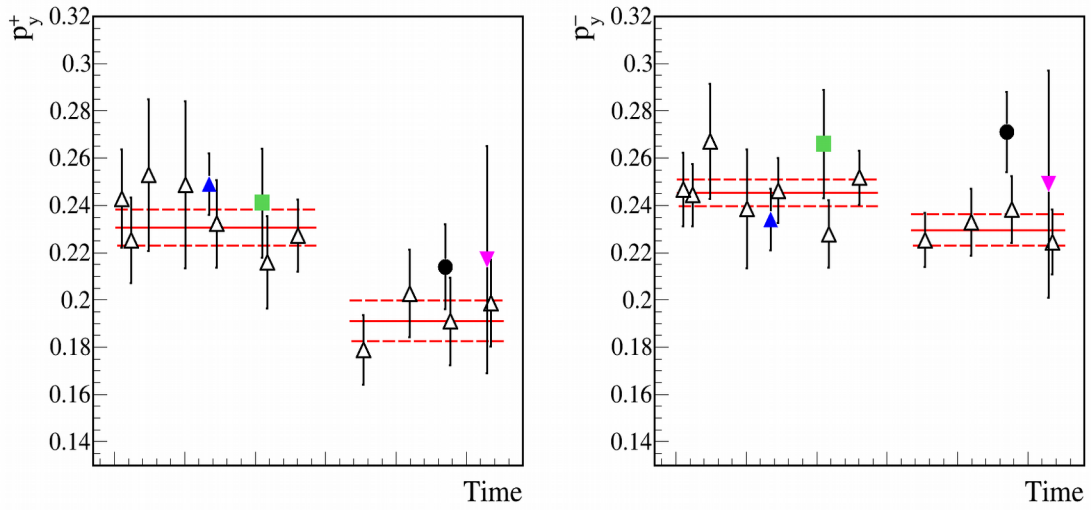


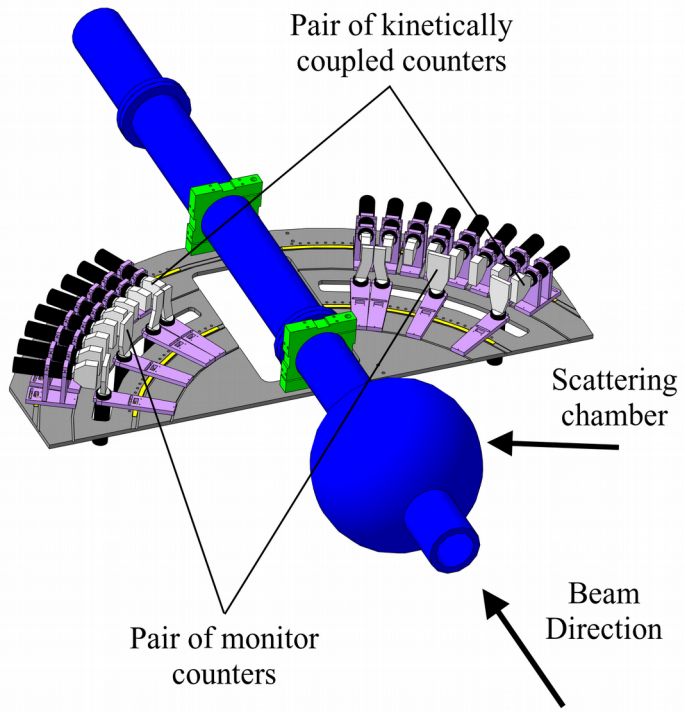
650 MeV/n



Values for each angle (detectors pair) in CM system.
Red lines - weighted average.

Vector polarization of the deuteron beam using dp-elastic scattering at 270 MeV and pp- quasielatic scattering at ITS



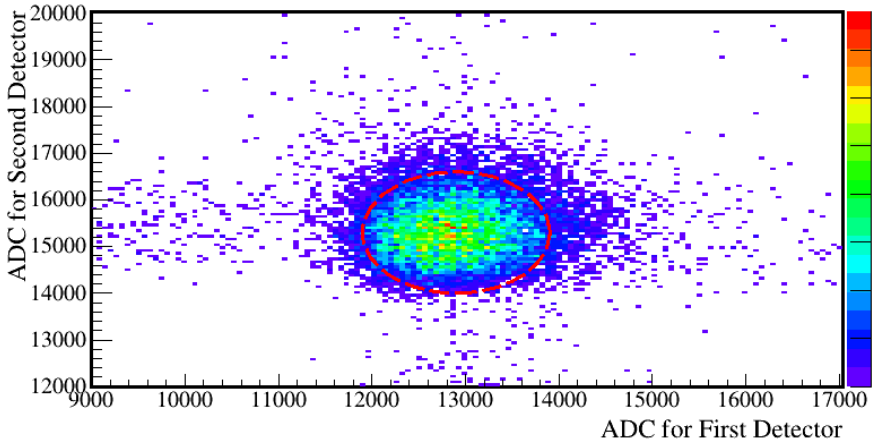


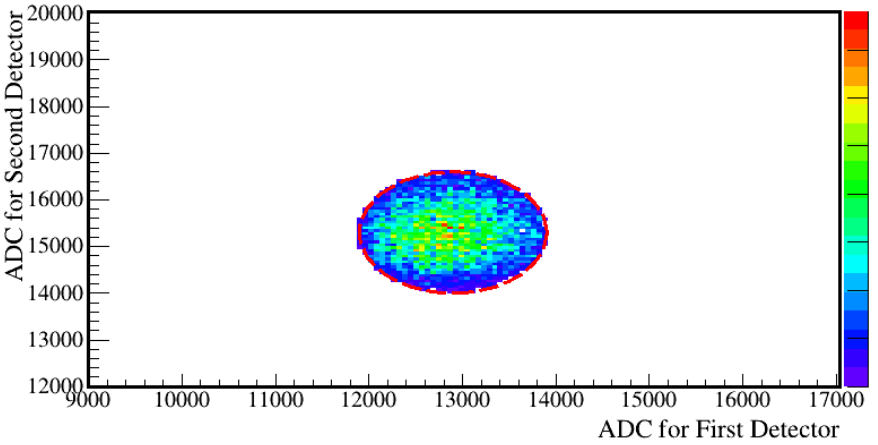
- **Vector component of the deuteron beam polarization has been measured at 500, 650, 550 and 200 MeV/nucleon using pp-quasielastic scattering.**
- **Detectors placed in the horizontal plane only were used.**
- **Analyzing power values from SAID were used to evaluate of the beam polarization values for the pp- quasi- elastic scattering measurements.**

Both methods gives similar results!

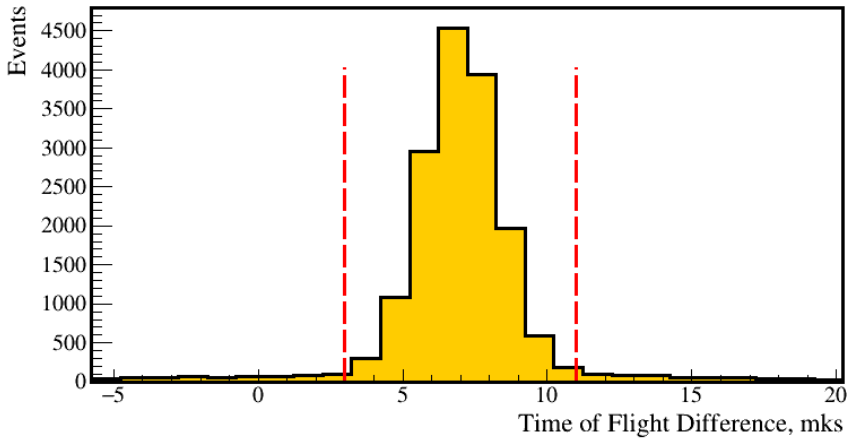
Selection of pp- quasielastic events.
Proton beam

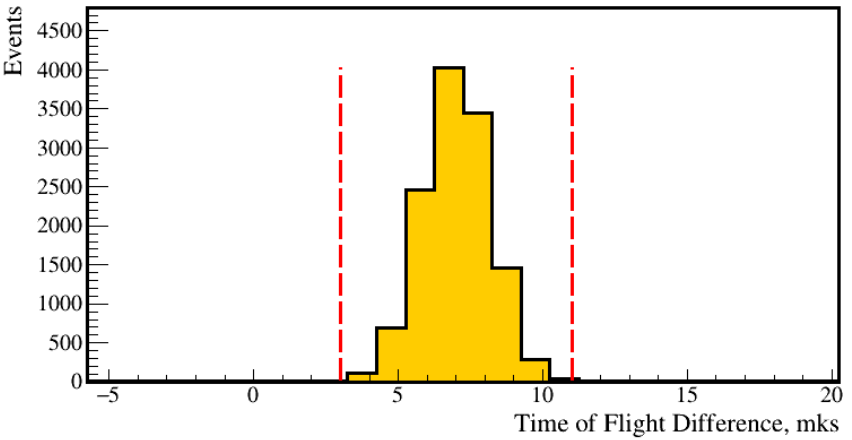
Ionization loss correlation for the counters pair





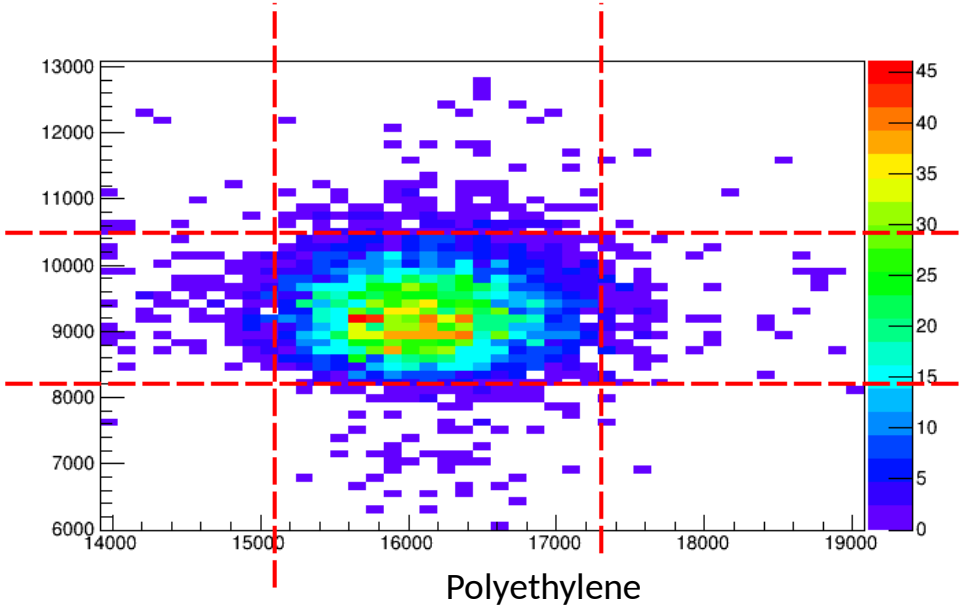
Time-of-flight difference for the pair



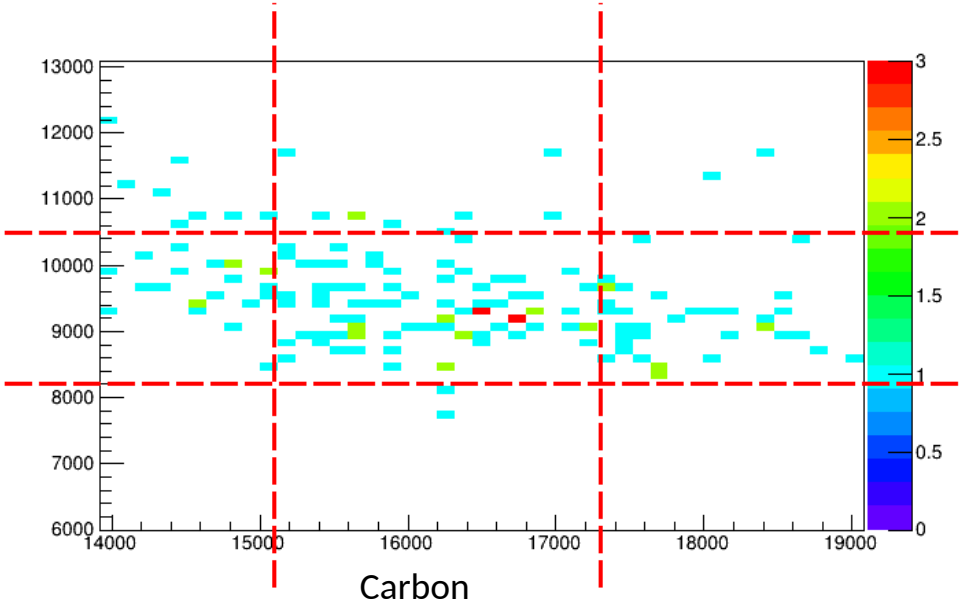


Cuts applied one after the other to achieve better result

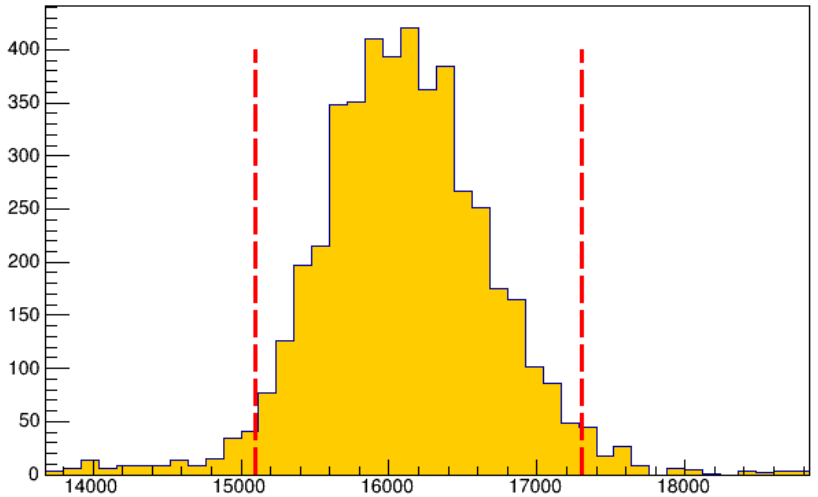
Background subtraction procedure.
Proton beam



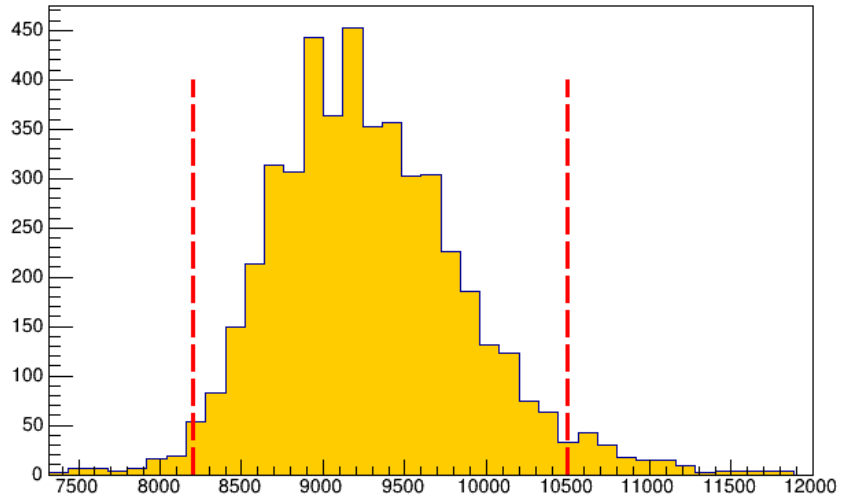
Polyethylene



Carbon



X polyethylene projection

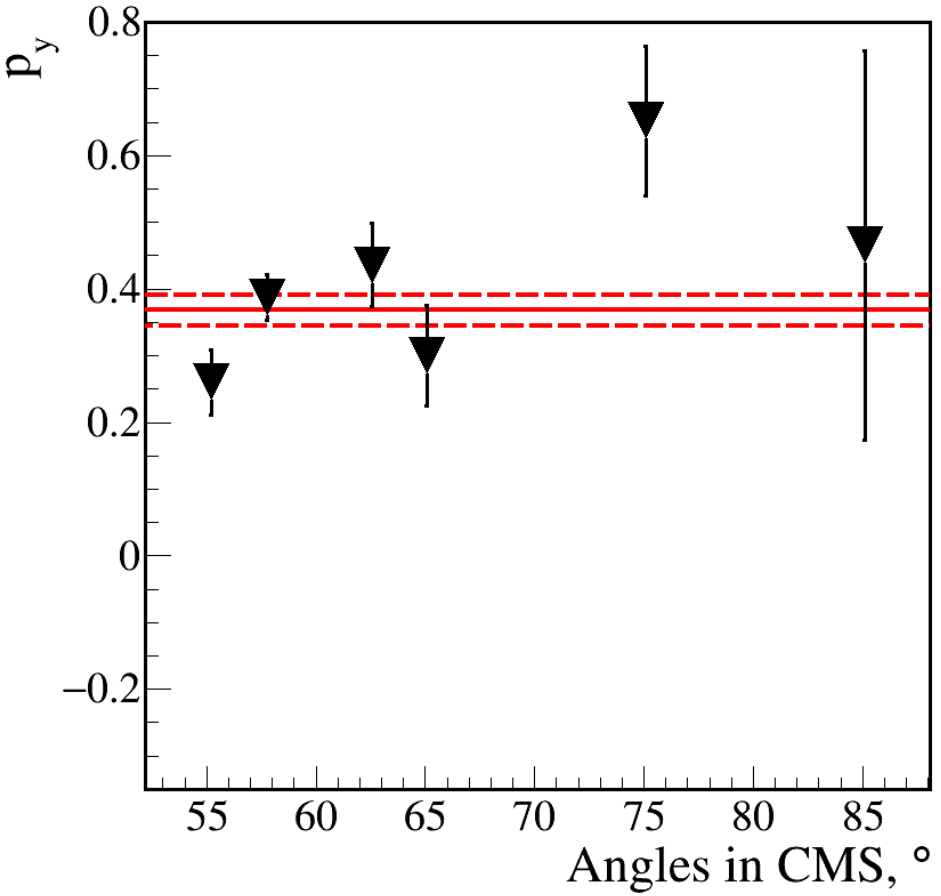


Y polyethylene projection

The proton beam polarization values at 500 MeV

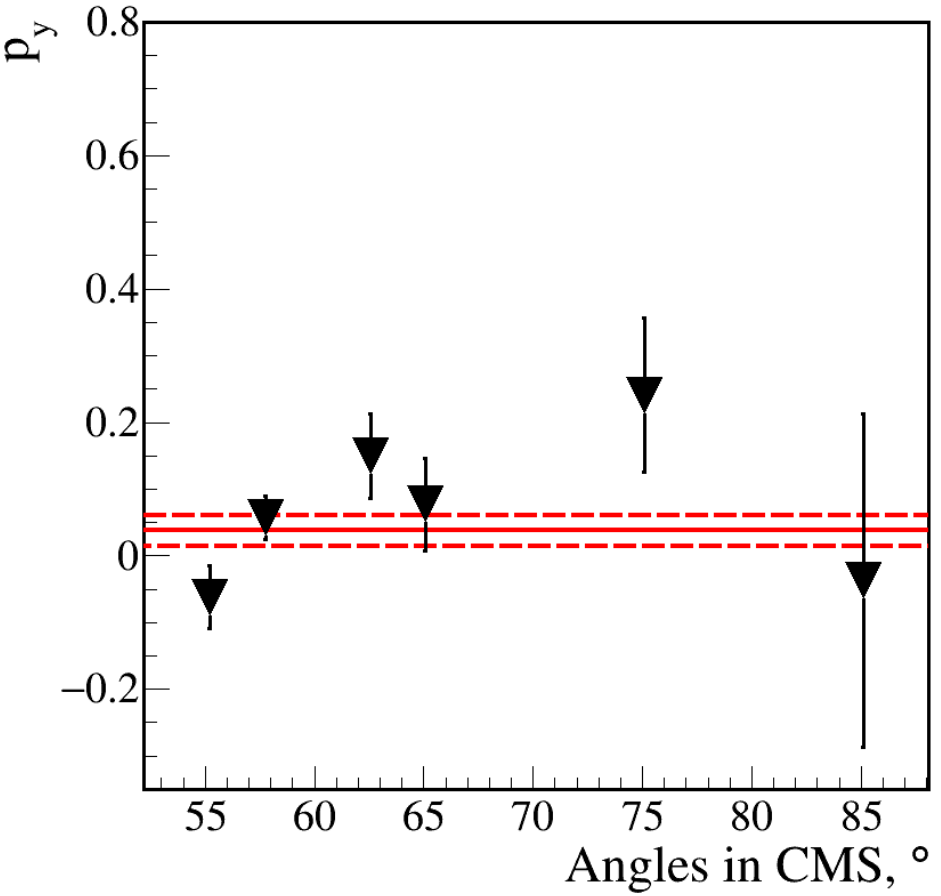
Polarized beam, "1-3" mode of SPI

p_y = 0.368 ±0.023



Unpolarized beam

p_y = 0.038 ±0.023



Polarized protons at Nuclotron.

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

Unpolarized protons: I∼1.5·10^8 ppp
Polarized protons: I∼2-3·10^7 ppp

IPol=1 P=1 (WFT 1→3)
IPol=2 P=0 (unpolarized)
IPol=3 P=1 (WFT 1→3)

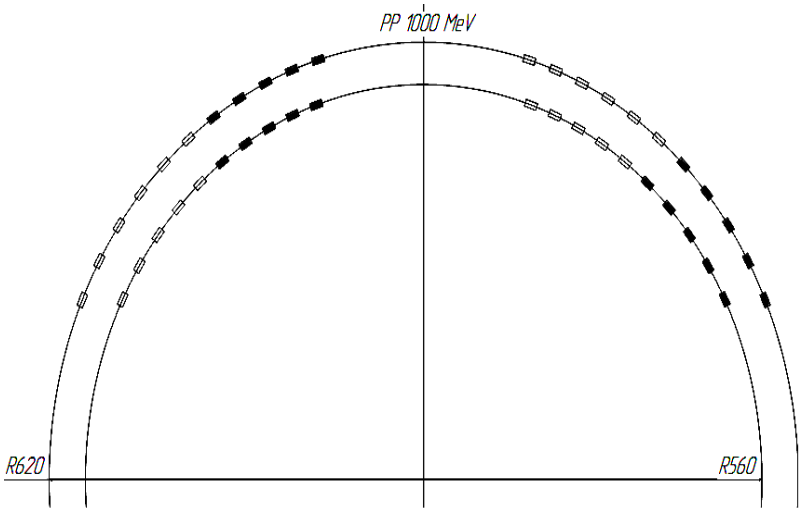
beam 2/3 of time.

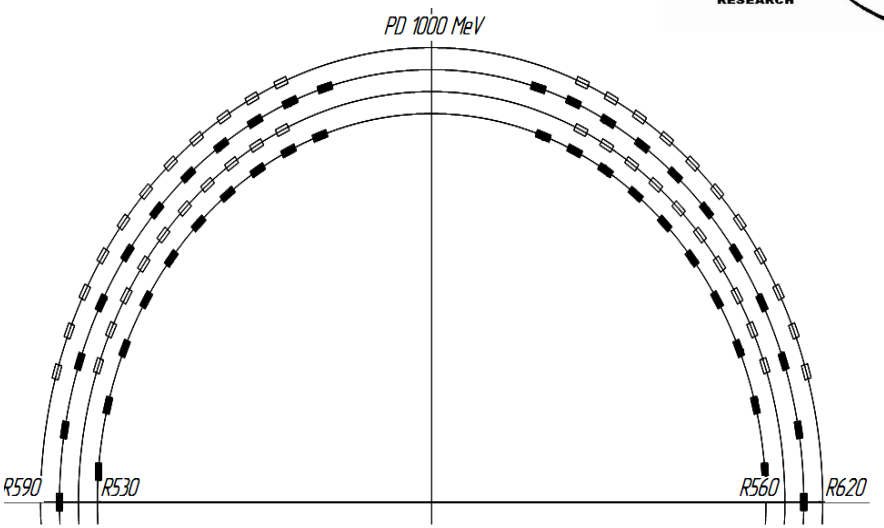
Having the asymmetries for 6 angles (55^0-85^0 in the cms) we obtained the averaged value of the proton beam polarization

Unpolarized protons: P= 0.038 ±0.023
Polarized protons: P= 0.368 ±0.023

New detection system for proton polarimeter is under preparation.
A.A.Terekhin et al.,Phys.Part.Nucl. 54 (2023) 634.

New detectors for pp- and pd- elastic scattering



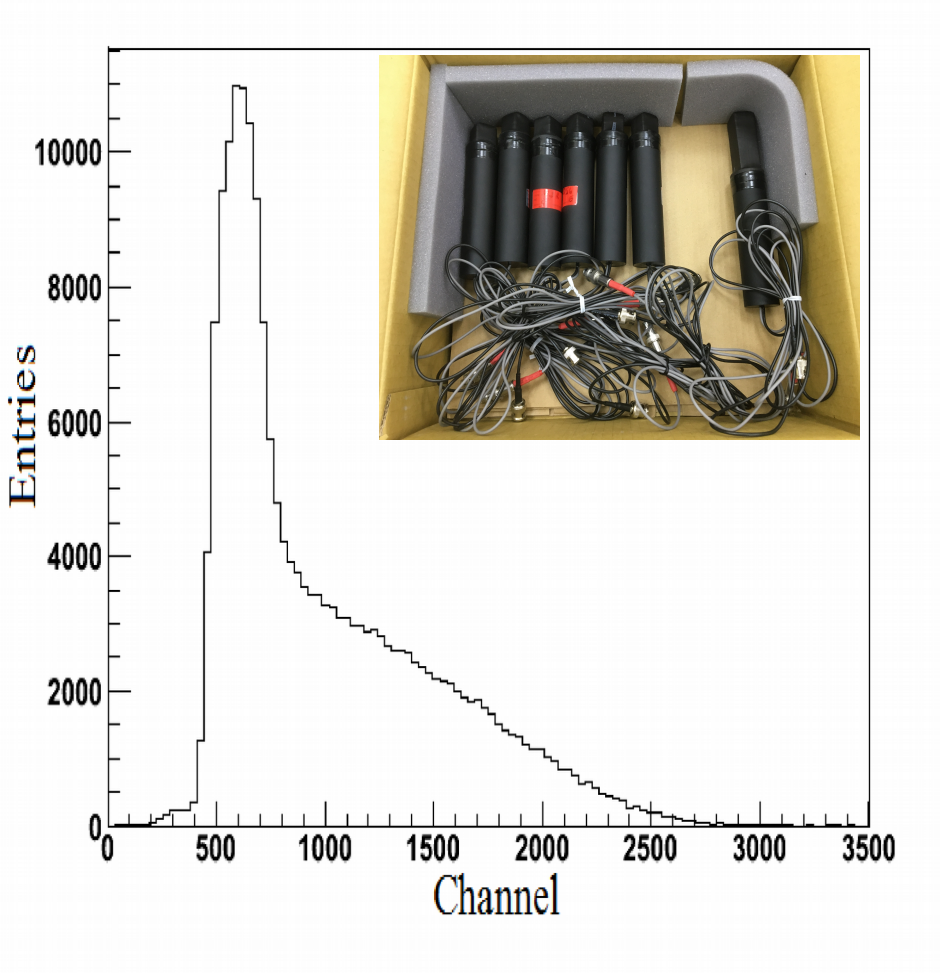


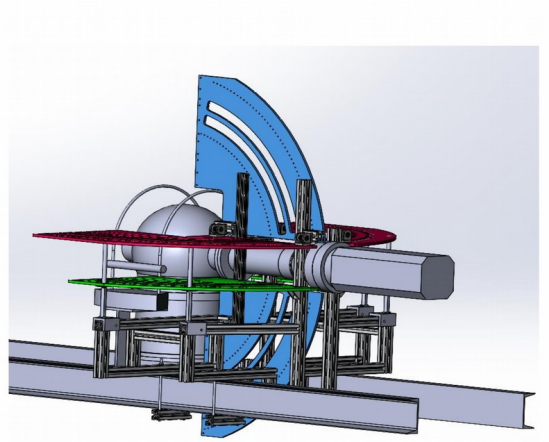
The scheme includes 42 detectors for pp-elastic scattering. The counters will be placed every 5° in the c.m.s. and will cover the range 40° $<\theta_{c.m.}<$90°. The calculation using the Pluto simulation give that ratio of the kinematical coincidence detectors should be equal 1/3. The detector sizes were proposed as 2x2x2 cm and 2.3x6x2 cm.

The scheme includes 80 detectors for pd-elastic scattering. The counters will be placed every 5° in the c.m.s. and will cover the range 30° $<\theta_{c.m.}<$125°. The detector sizes were proposed as 2x2x2 cm and 2.3x6x2 cm.

New schemes will allow to extend the polarimeter working range up to 1000 MeV.

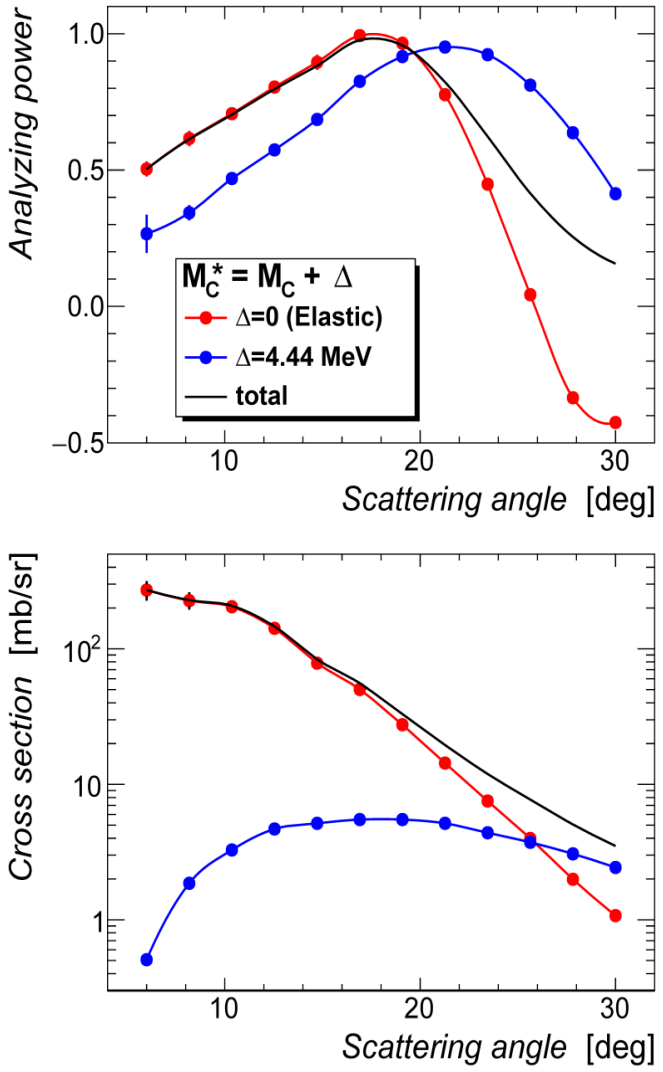
Status DSS polarimeter upgrade





>80 new scintillation counters (BC-408 and H7415 PMT) produced, tested with RA source, 10% are tested with parasitic beam at ITS.
Mechanics -design is performed, almost ready.

Absolute proton polarimetry developments



Proton-carbon elastic scattering at 200 MeV at the scattering angle of 16.2º in lab. has very large analyzing power close to an absolute value

A = 0.993 ±0.003

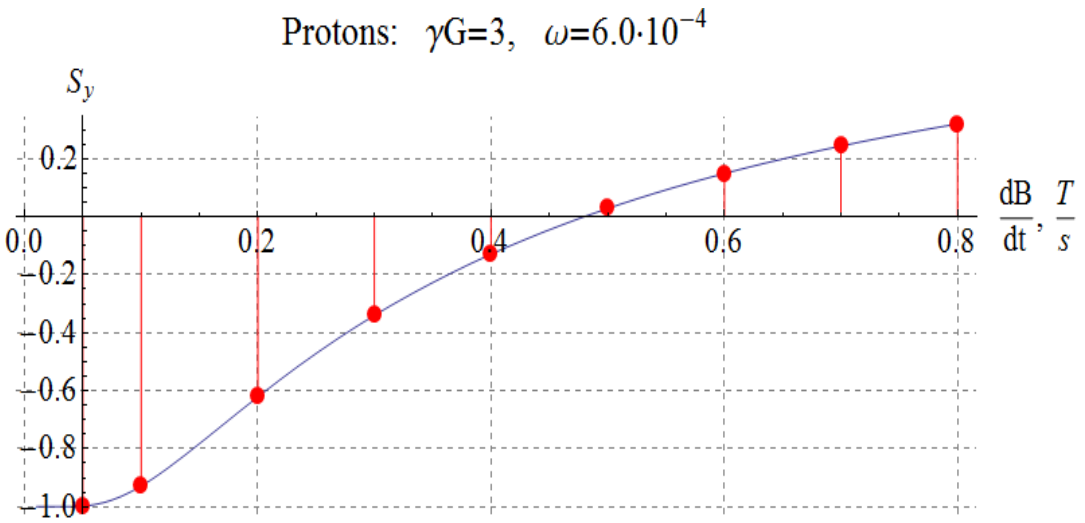
Elastic events will be selected using sets of scintillation detectors with absorbers.

The polarimeter can be installed at the Nuclotron ITS.

Geant-4 simulation should be performed.

First experiments with polarized protons: γG=3

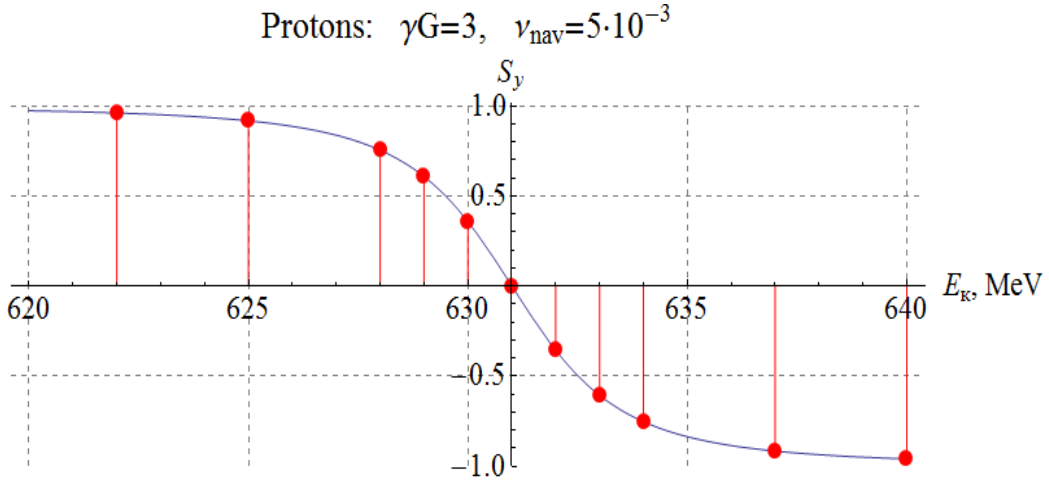
1.



Proton beam polarization dependence on dB/dt

Measurements at the energies below and higher 631 MeV.

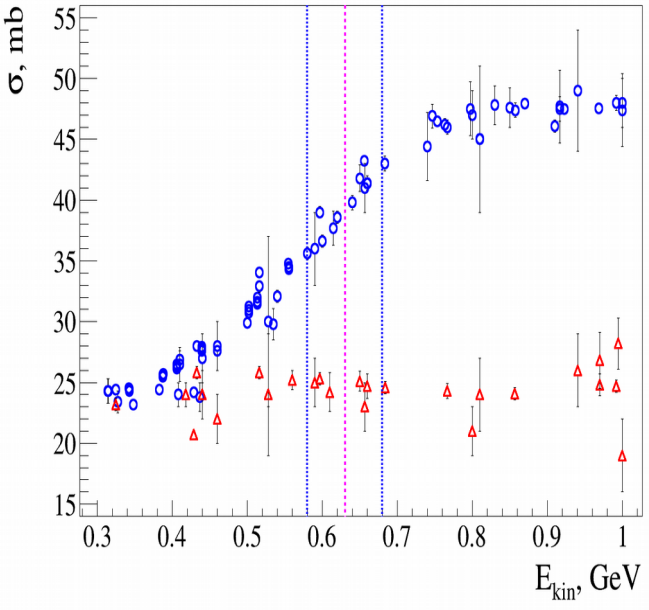
2.



Adiabatic capture of the proton beam polarization near γG=3 resonance

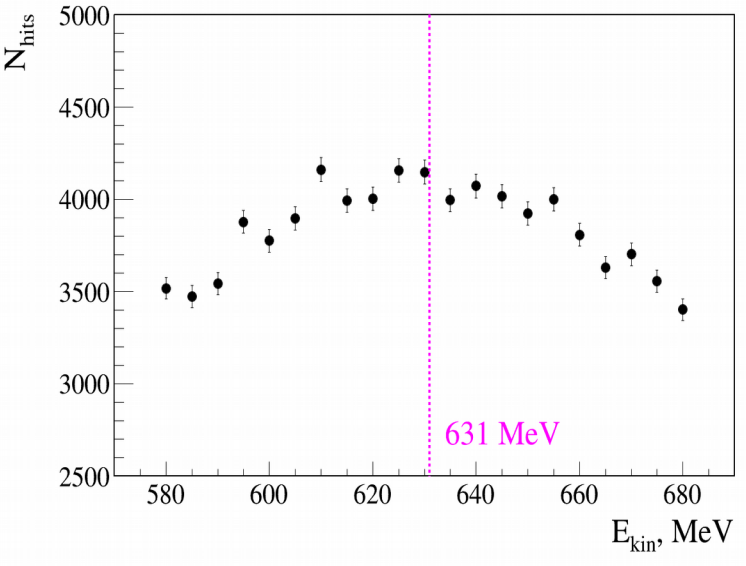
Weak "warm" solenoid

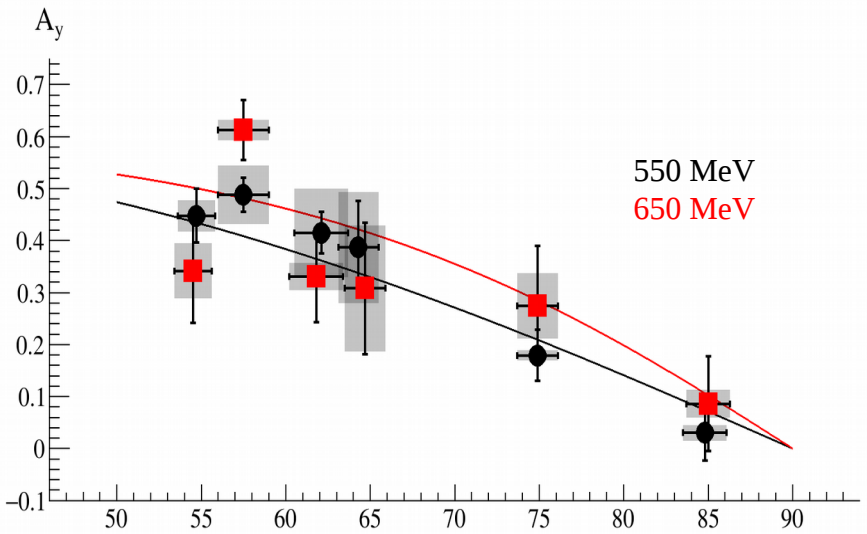
Feasibility studies with Nuclotron ITS Polarimeter around γG=3 resonance at 631 MeV

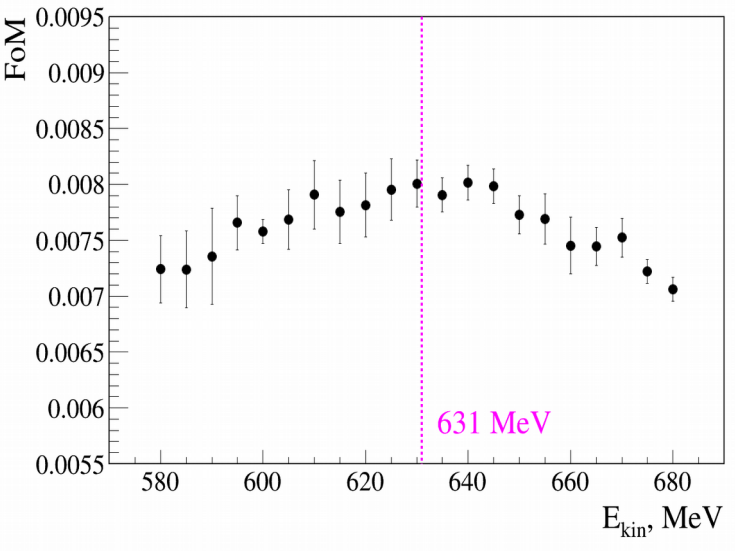


Cross section total
Cross section of elastic *pp*

Pairs of detectors were installed at 55° CM system at 631 MeV. 10M pp-elastic events with Pluto_6.02 generator.







Analyzing power calibration with deuteron beam is required!

Conclusions

The deuteron polarimeter has been used to obtain the vector and tensor polarizations using dp- elastic scattering at 270 MeV. The time stability of the polarization values has been demonstrated for the spin modes (+1/3,+1) and (+1/3,-1). The polarimeter has been used for tuning of the ion source parameters for 6 different spin modes. The polarization values were 70-75% from the ideal ones.

The working range of the current deuteron polarimeter (with higher systematic error) can be extended up to at least 1300 MeV.

The ITS polarimeter has been also used to measure the proton beam polarization at 500 MeV using pp- (quasi)elastic scattering. The plans on the proton polarimeter upgrade and absolute polarimetry at 200 MeV are discussed.

First experiments on the proton spin manipulation in the vicinity of the integer resonance $\gamma G=3$ with the ITS polarimeter are discussed.

Thank you for the attention!

The normalized yields of dp-elastic scattering

$$L = 1 + \frac{3}{2} p_y A_y + \frac{1}{3}\left(2 p_{xx} + p_{yy}\right) A_{xx} + \frac{1}{3}\left(2 p_{yy} + p_{xx}\right) A_{yy}$$

$$R = 1 - \frac{3}{2} p_y A_y + \frac{1}{3}\left(2 p_{xx} + p_{yy}\right) A_{xx} + \frac{1}{3}\left(2 p_{yy} + p_{xx}\right) A_{yy}$$

$$U = 1 + \frac{1}{3}\left(2 p_{yy} + p_{xx}\right) A_{xx} + \frac{1}{3}\left(2 p_{xx} + p_{yy}\right) A_{yy}$$

$$D = 1 + \frac{1}{3}\left(2 p_{yy} + p_{xx}\right) A_{xx} + \frac{1}{3}\left(2 p_{xx} + p_{yy}\right) A_{yy}$$

- L,R,U,D - The normalized yields of dp-elastic scattering events to the left (L), right (R), up (U), down (D);
- A_y, A_{yy}, A_{xx} — analyzing power;
- p_y, p_{yy}, p_{xx} — components of polarization.

The normalized dp-elastic scattering

$$p_x = -P_z \sin\beta \sin\varphi$$

$$p_y = P_z \sin\beta \cos\varphi$$

$$p_z = P_z \cos\beta$$

$$p_{xx} = \frac{1}{2} P_{zz} \left(3\sin^2\beta \sin^2\varphi - 1\right)$$

$$p_{xx} = \frac{1}{2} P_{zz} \left(3\sin^2\beta \cos^2\varphi - 1\right)$$

$$p_{zz} = \frac{1}{2} P_{zz} \left(3\cos^2\beta - 1\right)$$

$$p_{xy} = \frac{-3}{2} P_{zz} \sin^2\beta \sin\varphi \cos\varphi$$

$$p_{yz} = \frac{3}{2} P_{zz} \sin\beta \cos\beta \cos\varphi$$

$$p_{xz} = \frac{-3}{2} P_{zz} \sin\beta \cos\beta \sin\varphi$$

If Y is symmetry axis (β=90°, φ =0°), then polarization is calculate as

$$p_y = P_z$$

$$p_{yy} = P_{zz}$$

$$p_{xx} = p_{zz} = \frac{-1}{2} P_{zz}$$

$$p_x = p_z = p_{xy} = p_{yz} = p_{xz} = 0$$

Vector and tensor polarizations calculation

$$L = 1 + \frac{3}{2} P_z A_y + \frac{1}{2} P_{zz} A_{yy} \quad \rightarrow \quad P_z = \frac{L - R}{3 A_y}$$

$$R = 1 - \frac{3}{2} P_z A_y + \frac{1}{2} P_{zz} A_{yy} \quad P_{zz} = \frac{L + R - 2}{A_{yy}}$$

$$U = 1 + \frac{1}{2} P_{zz} A_{xx} \quad \rightarrow \quad P_{zz} = \frac{2U - 2}{A_{xx}}$$

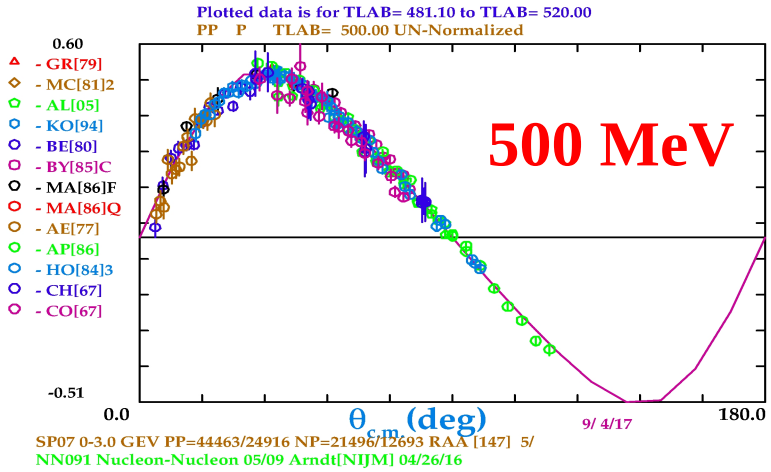
$$D = 1 + \frac{1}{2} P_{zz} A_{xx} \quad P_{zz} = \frac{2D - 2}{A_{xx}}$$

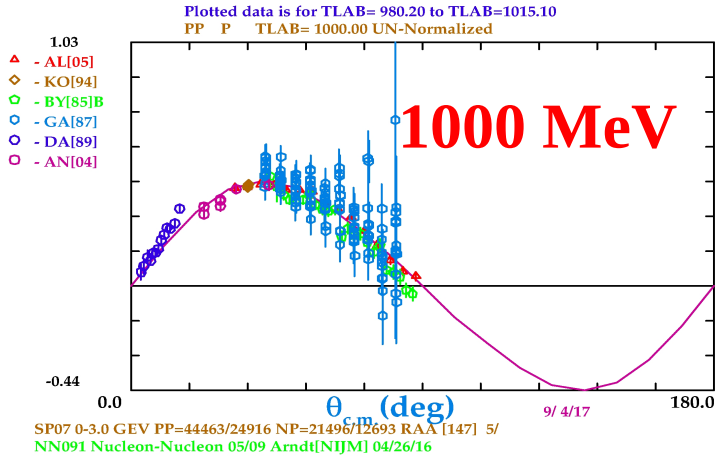
- L,R,U,D - The normalized dp-elastic scattering events to the left (L), right (R), up (U), down (D);
- Ay, Ayy, Axx — analyzing power;
- Pz, Pzz — components of polarization.

MPod power supply system

- We used multichannel high-voltage power supply system to provide power detection framework of the DSS experimental setup, which use scintillation detectors based on Hamamatsu photomultipliers.
- The total detectors number is more than 70. Wiener MPod system has up to 160 channels (maximal configuration) with the SHV connectors type.

Use of pp- quasielastic scattering at ITS for the beam polarization measurements





The use of only proton detectors to detect pp-(quasi)elastic scattering.
Measurement at 8 different angles symmetric with respect to 90^0 in cms.

However, due to current detector support the positions of the scintillation counters is not optimal – no coverage at small (and large) scattering angles.