26-th International Spin Symposium (SPIN-2025)
22-26 September 2025, Qingdao, China

Spin Physics Research INfractrucrure and Technologies at NICA (SPRINT@NICA)

V.P. Ladygin on behalf of SPRINT@NICA group

SPRINT@NICA mission

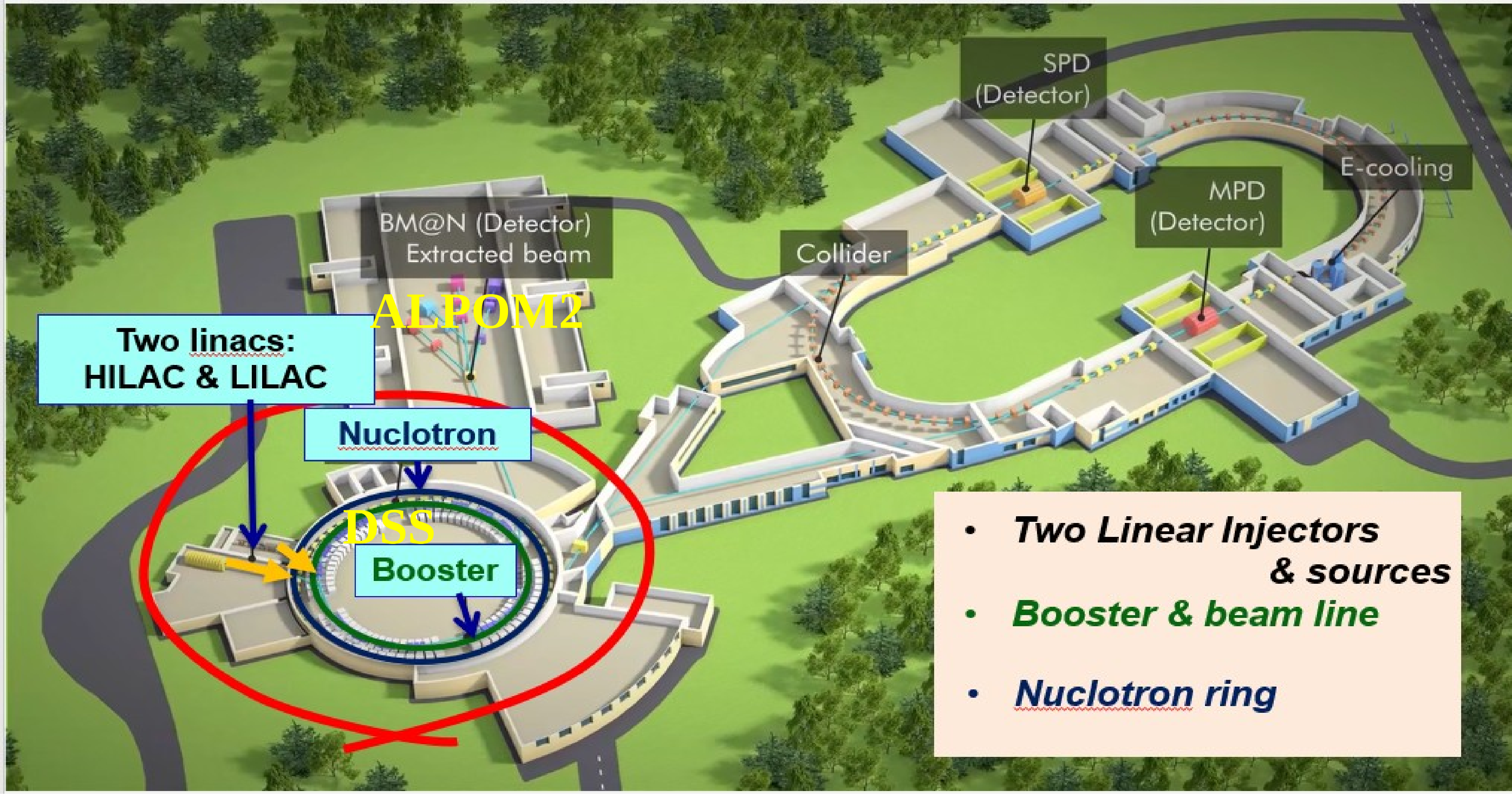
The main goal of the SPRINT@NICA project is to provide the research infrastructure and to develop the technologies for the current and planned spin studies at Nuclotron/NICA.

Main directions of planned developments are:

- **high intensity polarized beams of deuterons and protons**
- **beam polarimetry (LE, HE, CNI, APol, local etc.)**
- **techniques of the spin manipulation to provide Spin Transparency (ST) mode at Nuclotron/NICA**
- **secondary polarized beams (neutrons, protons, HI)**
- **polarized targets (^{3}He)**
- **preparation of the high precision spin experiments (dichroism/birefringence, axionlike particles search, EDM etc.)**

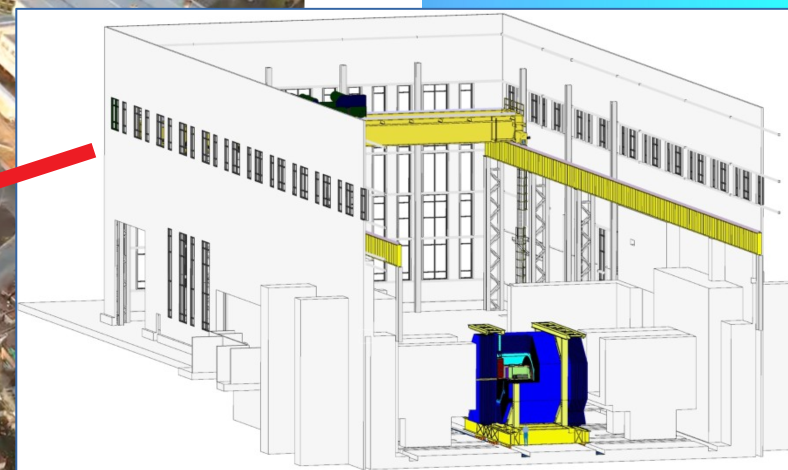
Working group: JINR, MIPT, ITP, INR RAS, INP BSU ….

NICA in 2025



Injection complex is already in commissioning for few years (FT mode).
Run-2023 achievements: 5-8·10^{6} ^{124}Xe ions at 3.9 GeV/n.
Run-2025 started in February also with ^{124}Xe.
Injection to NICA is planned to the end of 2025.

SPD at NICA in 2025



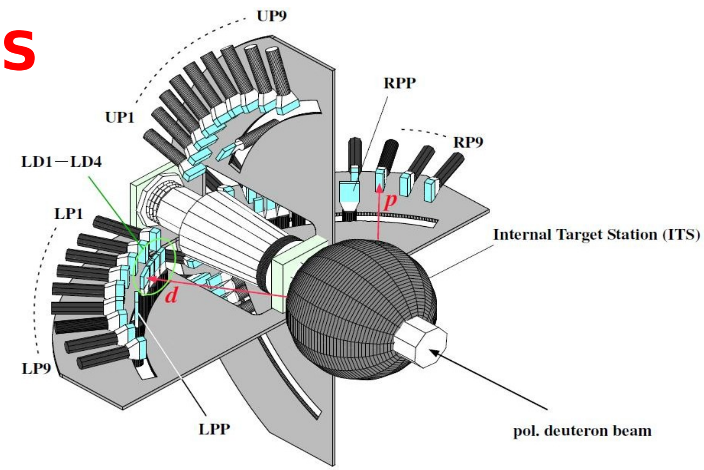
SPD hall

There are plans to study the detector prototypes at the SPD collision point in the fixed target mode (Au,Ag,Al-targets) in current run.
These studies will be continued in the collider mode (including deuterons).

Details on SPD are in the plenary talk of A.Guskov.

Requirements of Fixed Target experiments to polarized beam facility

DSS



Intensity:

~5·10^9 ppp for CH_2 target

~5·10^{10} ppp for nuclear targets

Beams polarizations

Deuterons

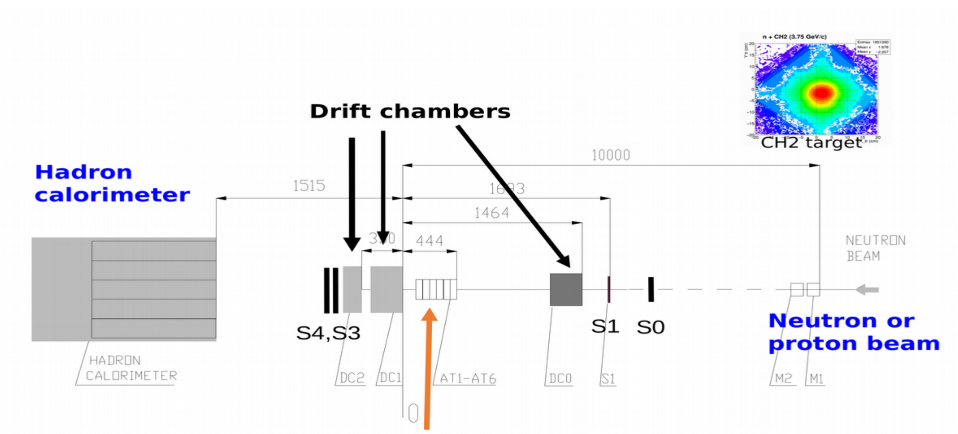
Pzz=-1.4,+0.8

Pz=±0.75

Protons

P= ±0.75

ALPOM-2



Intensity:

~10^{11} ppp

Beams polarizations:

Deuterons

Pz=±0.55-0.75

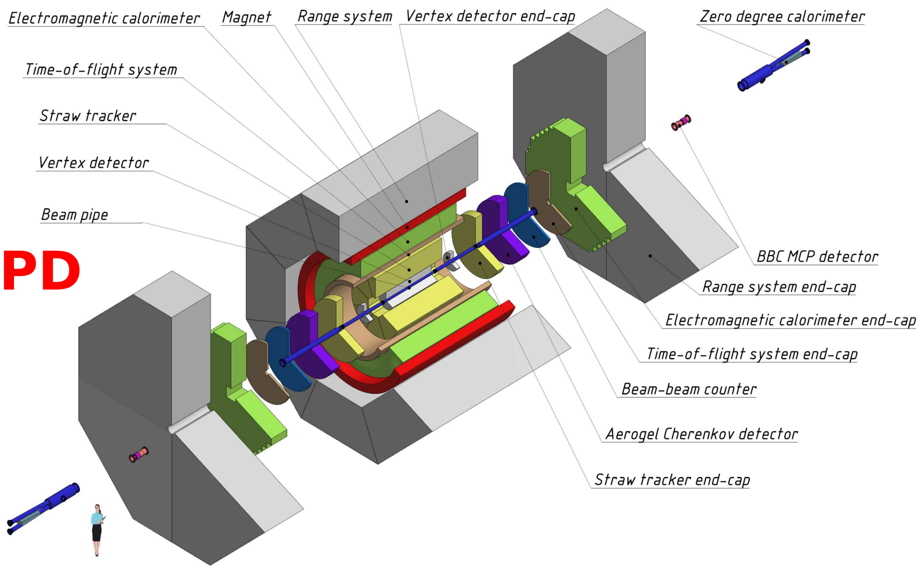
Protons

P= ±0.75

Goals are to increase the beams intensities and proton beam polarization.

SPD requirements to polarized beam facility

SPD

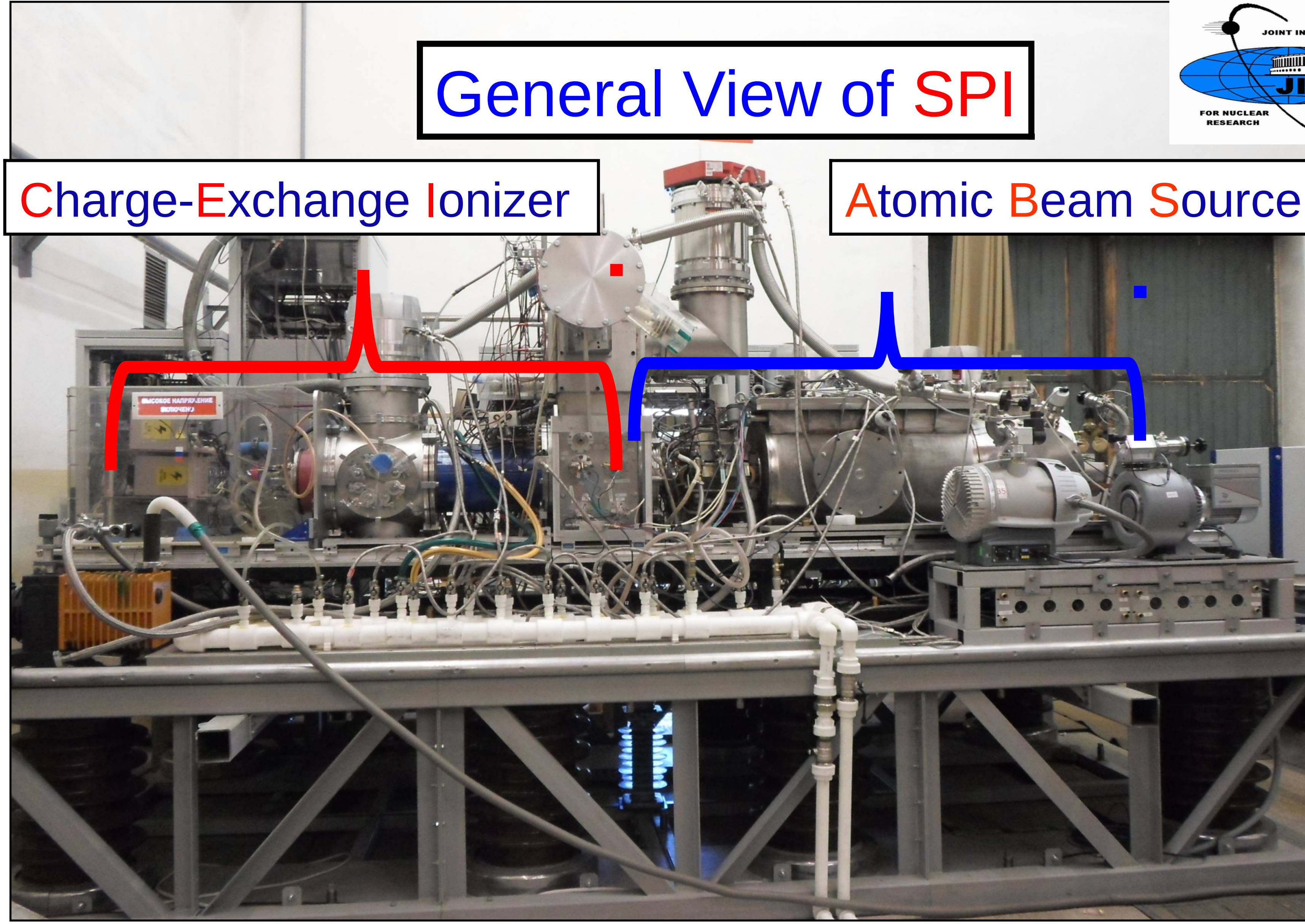


- polarized and nonpolarized pp- , dd–collisions
- p↑p↑(p) at $\sqrt{s}_{pp}$ = 12 ÷ 27 GeV
- d↑d↑(d) at $\sqrt{s}_{NN}$ = 4 ÷ 13 GeV
- $L_{av} \approx 10^{+32}$ $cm^{-2}s^{-1}$ (at $\sqrt{s}_{pp} \geq 27$ GeV)

- sufficient lifetime and polarization degree (few hours, ~70%)
- longitudinal and transverse polarization at the SPD IP
- pd- collision mode should be available

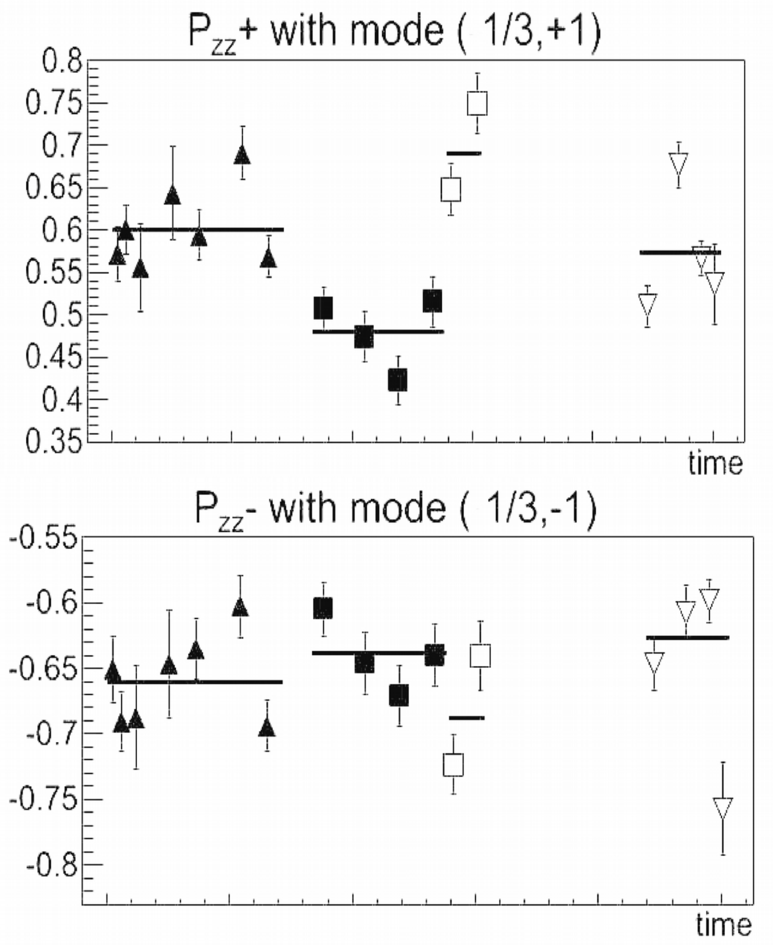
The facility operation in pp – mode at $\sqrt{s}_{pp}$ = 27 GeV reaching average luminosity of 10^{+32} $cm^{-2}\cdot s^{-1}$ remains the first priority task for coming years.

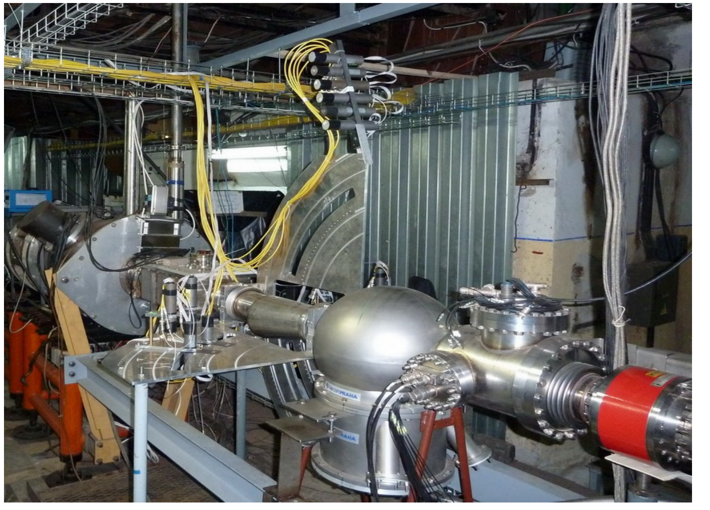
General View of SPI



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. (See V.V.Fimushkin talk)

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

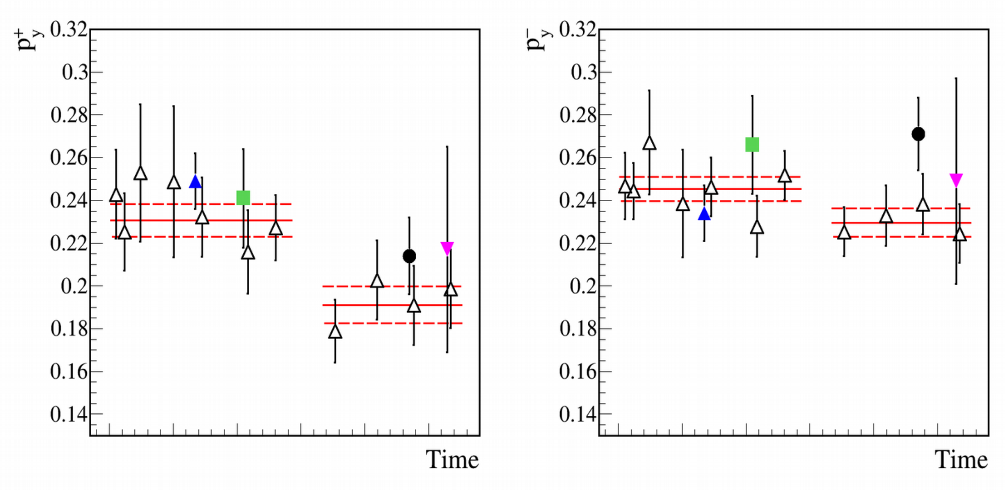


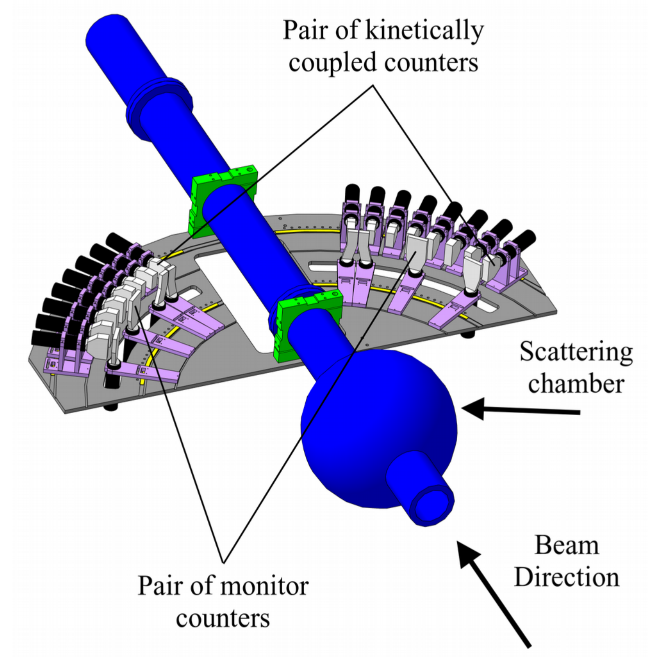


P.K.Kurilkin et al., NIM A642 (2011) 45.

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

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

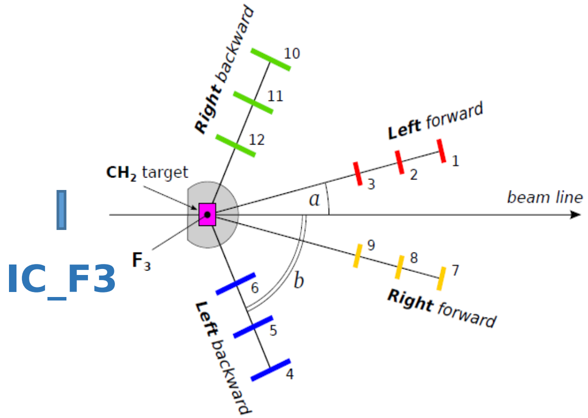
Both methods gives similar results!

I.S.Volkov et al., Phys.At.Nucl. 87 (2024) 459

Upgrade is in progress:

A.A.Terekhin et al., Phys.Part.Nucl. 54 (2023) 634

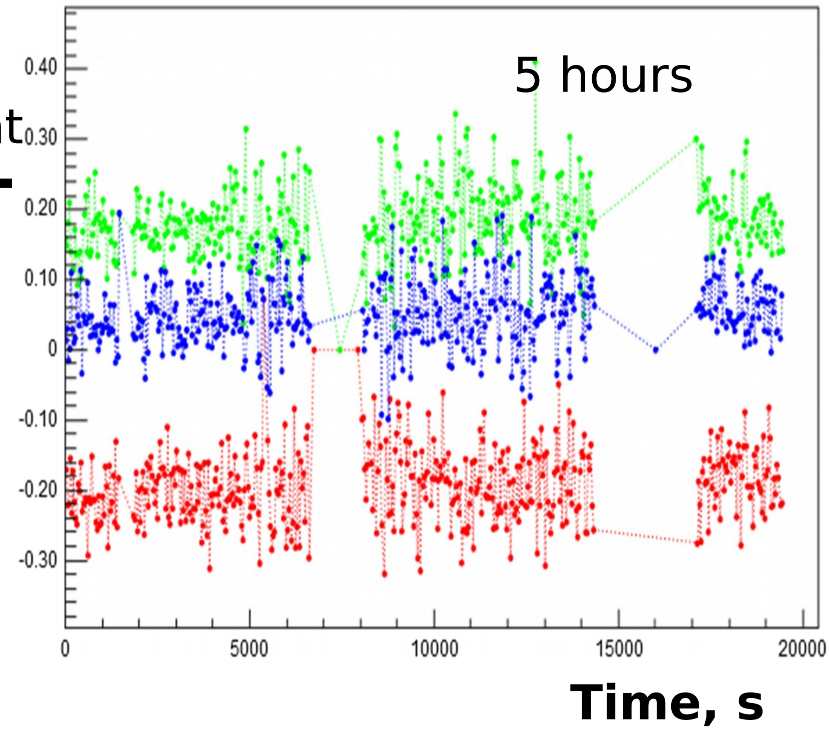
Deuteron extracted beam polarization measurements (vector component) using pp- quasielastic scattering



Upgraded polarimeter:
L.S.Azhgirey et al., NIM A497 (2003)340.

$$\frac{\text{Left-Right}}{\text{IC\_F3}}$$

each point corresponds to one spill.

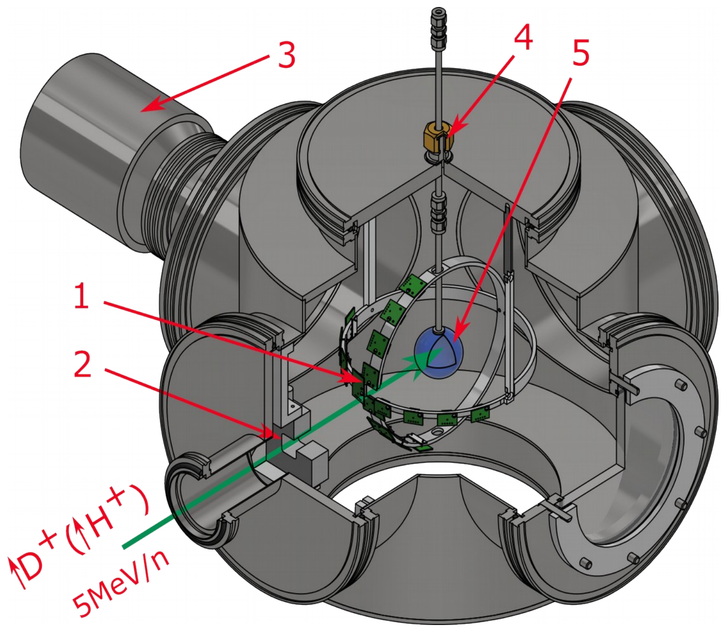


The polarization in one mode is two times lower than the other one

$$P(+) - P(-) = 0.96 \pm 0.05$$

HE tensor polarimeter is needed!

LE polarimetry developments



1 - array of 16 silicon detectors with an active area of 5x20 mm each
2 - variable diaphragm
3 - turbomolecular pump
4 - gas inlet syste
5 - a high-pressure (3 bar) mylar spherical target (**150 μm**)

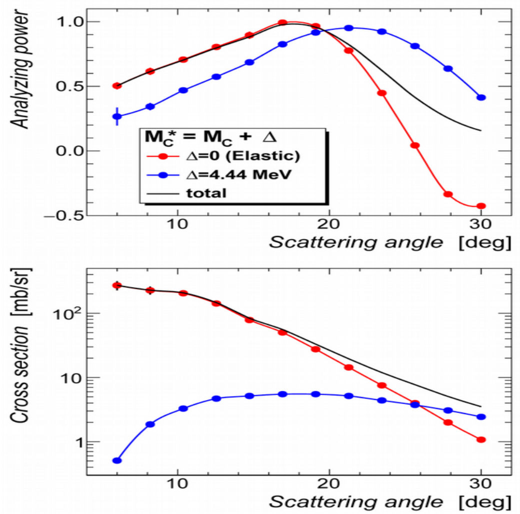
Under construction!
See V.V.Fimushkin talk

Deuteron(proton) energy is 5 MeV/nucleon after RFQ&LINAC.

The ^{3}He target (3bar) enables to measure both the proton polarization using ^{3}He(p,p)^{3}He elastic scattering reaction and the vector and tensor polarizations of deuterons using ^{3}He(d,d)^{3}He elastic scattering as well as ^{3}He(d,p)^{4}He reaction.

The detection of the secondary particles will be provided by the silicon detectors. The detector positions can be adjusted according reaction kinematic.

Absolute proton polarimetry developments



APol 3D view

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

$$A = 0.993 \pm 0.003$$

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

The polarimeter can be installed at the Nuclotron ITS.

2. Since for pp- elastic scattering beam and target analyzing powers equal:

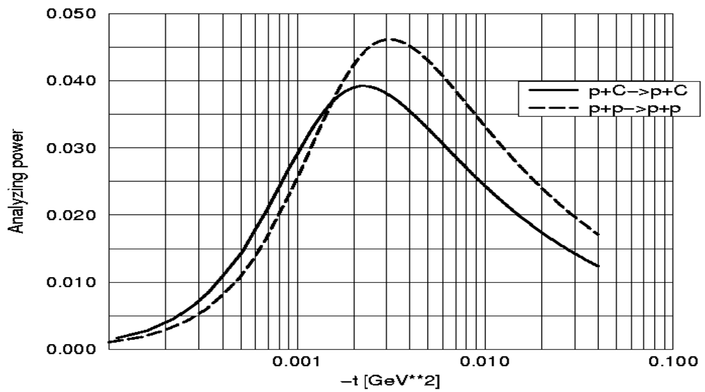
$$A_{beam} = A_{target}$$

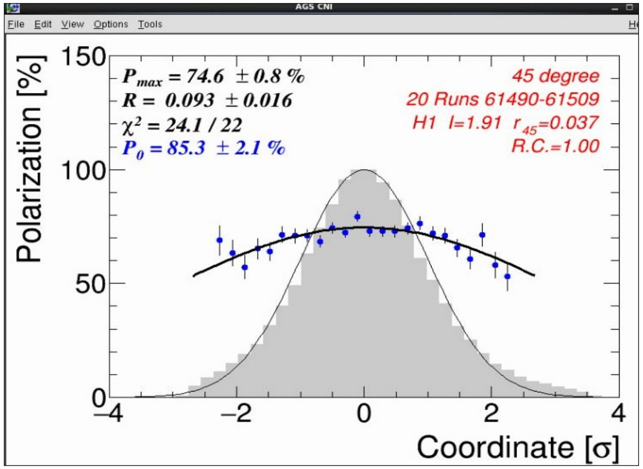
the polarization of the proton beams can be obtained using left-right asymmetry from polarized H-jet target by an absolute method.

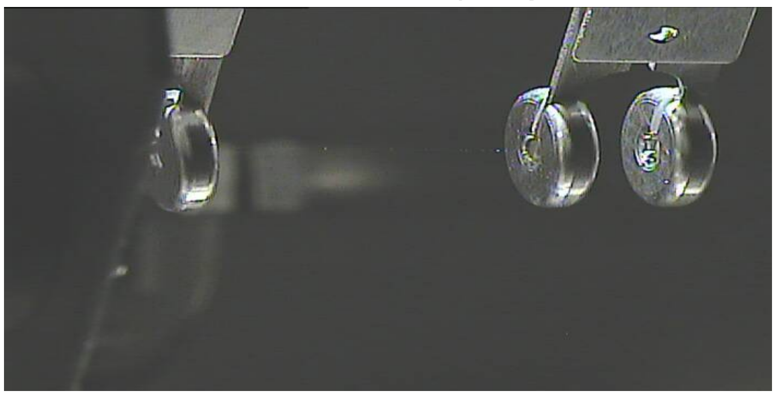
The ABS is ready, chamber and detection system are under construction.

V.V.Fimushkin, M.V.Kulikov

CNI proton polarimetry developments



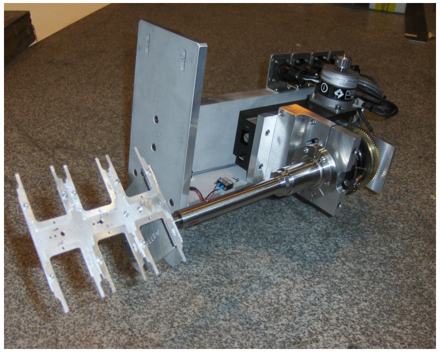


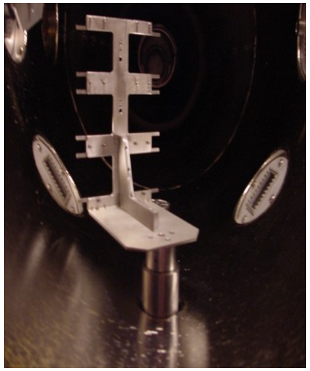


CNI proton polarimetry at NICA energies is not an absolute method because of non-zero spin-flip hadron amplitude (AGS results).

The selection of the events will be provided by the detection of the recoil carbon using SSD.

CNI polarimeters will be able to measure the proton beam polarization profiles using advanced ribbon target.

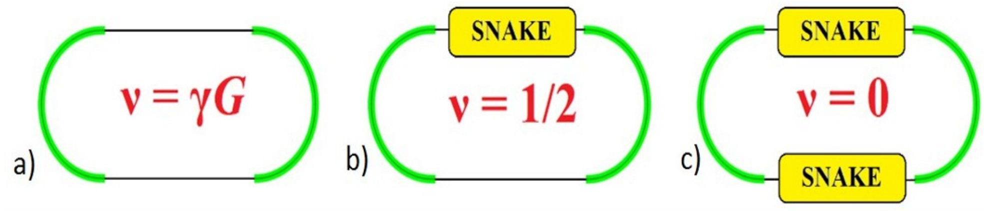




Very thin carbon strip target-20um x 25 nm

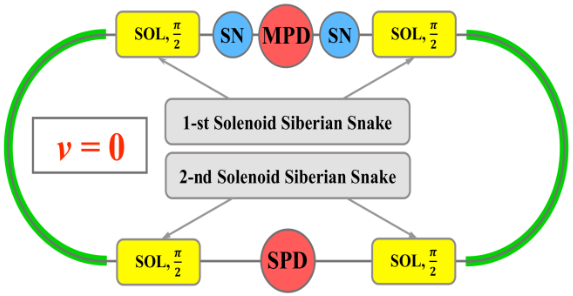
V.V.Fimushkin, A.N.Zelenski

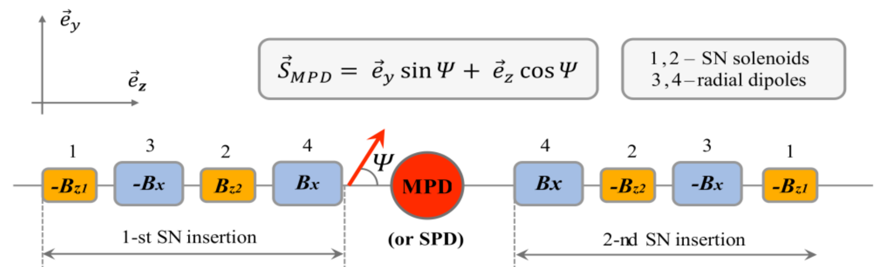
Proton spin manipulation at NICA



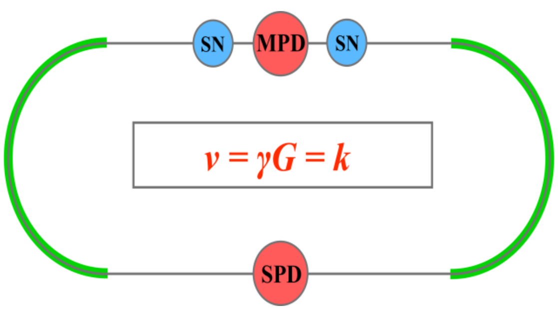
RHIC

LE-regime





HE-regime



Spin transparency (ST) mode with ν=0 is very well suited to the SPD physics tasks.

Realistic scenario.

LE-regime: ST up to $\sqrt{s_{pp}}$ = 6-7 GeV using ~12 T·m Siberian snakes in each ring.

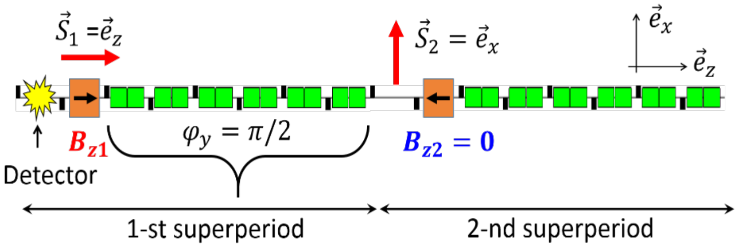
HE-regime: ST at the integer resonances k at $\sqrt{s_{pp}}$ > 6-7 GeV (E_p= 0.108+k·0.523 GeV).

Details:

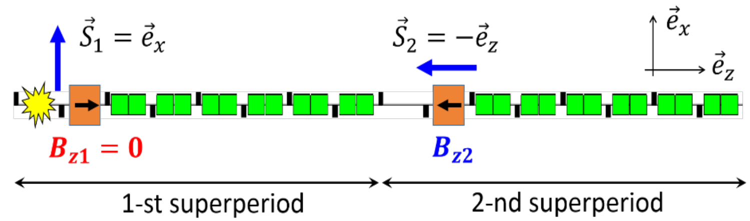
Yu.N.Filatov,Phys.Part.Nucl.56 (2025) 363.
E.M.Syresin et al., Phys.Part.Nucl.52(2021) 997.

Proton spin manipulation at Nuclotron

Stage 1.
Nuclotron with Spin Navigator based on 2 additional weak solenoids
Experimental verification of the ST mode at integer spin resonance $\gamma G=2$ (108 MeV)



Longitudinal polarization at the detector



Radial polarization at the detector

Stage 2.
Nuclotron with Spin Navigator based on regular correction dipoles
Experimental verification of the ST mode at integer spin resonance $\gamma G=7$ (2723 MeV)

Stage 3.
Modernized Nuclotron with ~12 T·m solenoidal Siberian snake
ST mode up to proton energy of 13.5 GeV

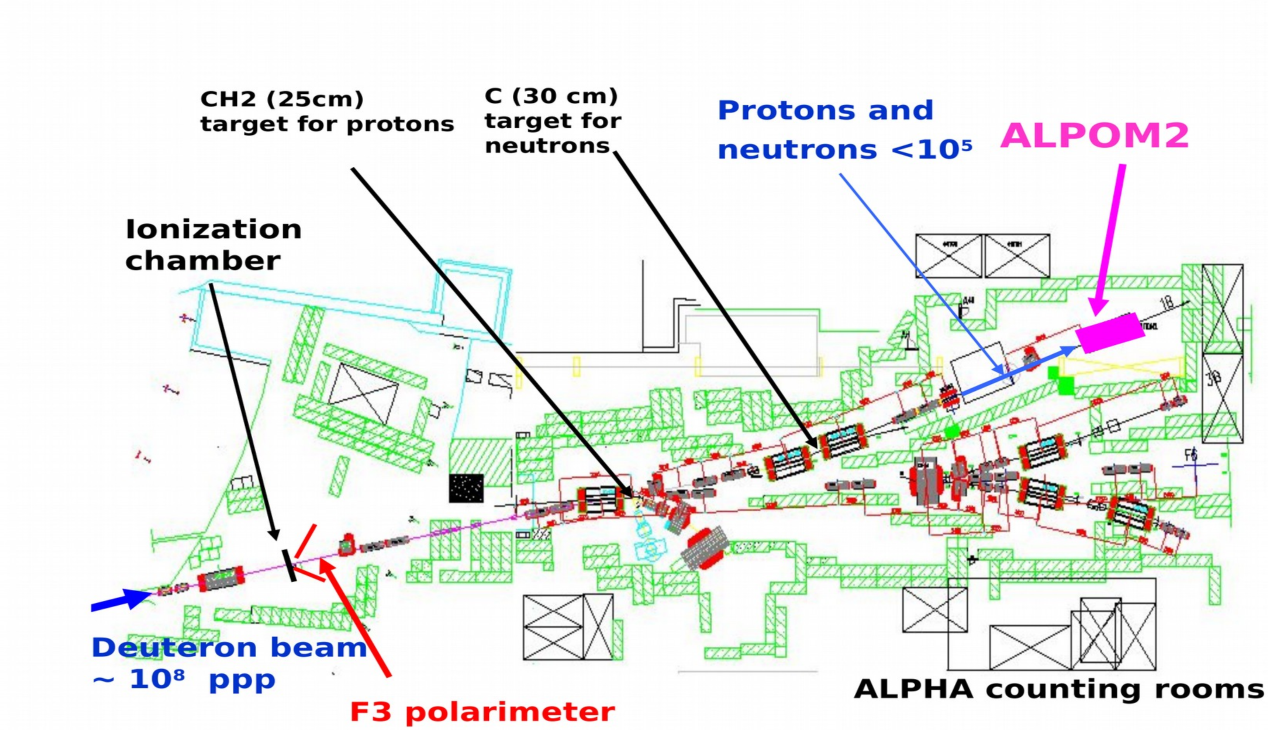
Experimental proof of ST requires serious upgrade of the proton beam polarimetry at Nuclotron

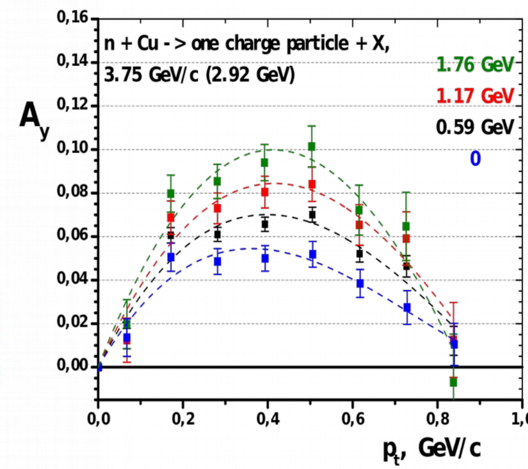
Yu.N.Filatov, A.M.Kondratenko

Supported by:

RFBR 20-02-00808, RSF 22-42-04419, RSF 25-72-30005

Secondary proton and neutron polarized beam at Nuclotron

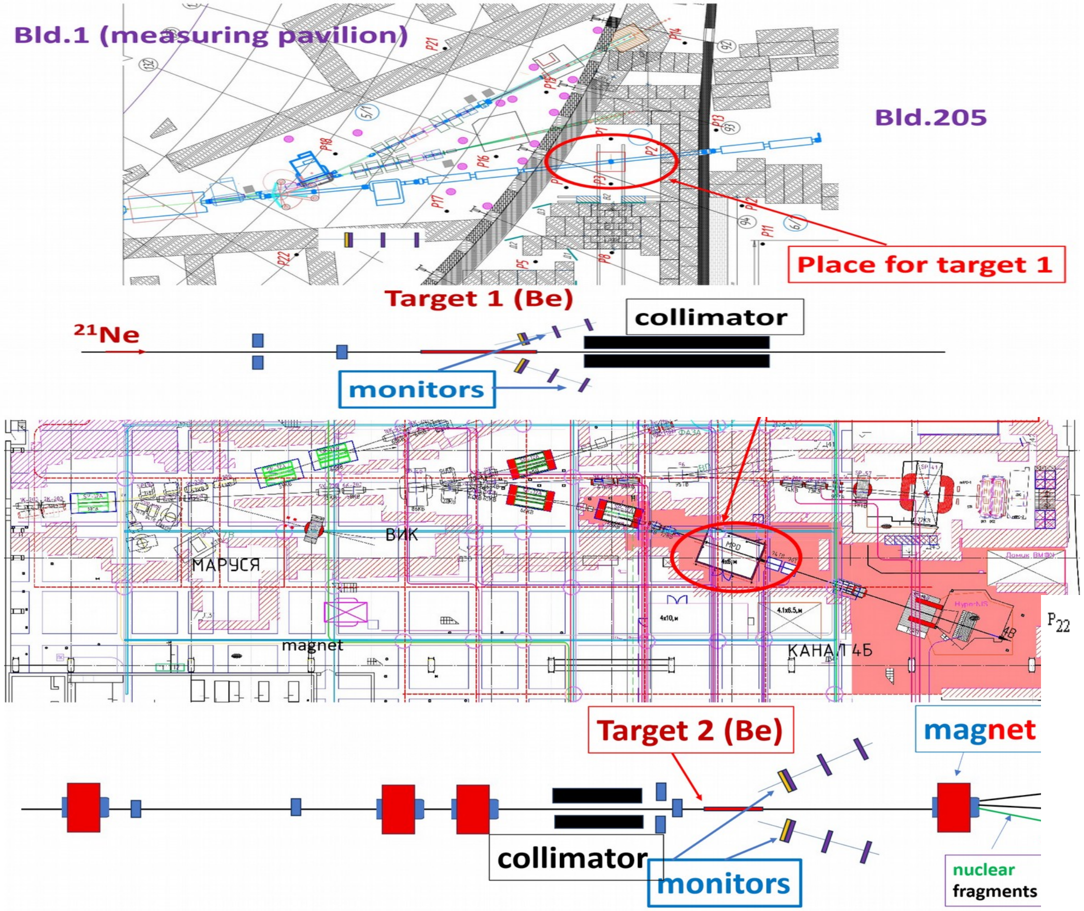




S.N.Basilev et al., Eur.Phys.J.A 56 (2020) 26

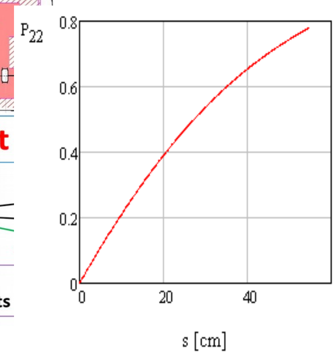
Required intensity for physics is $\sim 10^{11}$ ppp
The beam line was built for spin correlation np- scattering experiment: the upgrade of existing polarized target is under consideration.

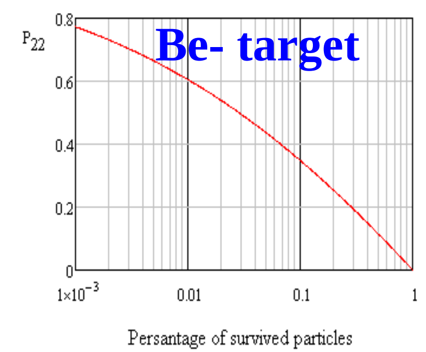
Tensor polarized ^{21}Ne beam at Nuclotron



-Method is based on the large quadrupole deformation of ^{21}Ne (β_2=0.463).

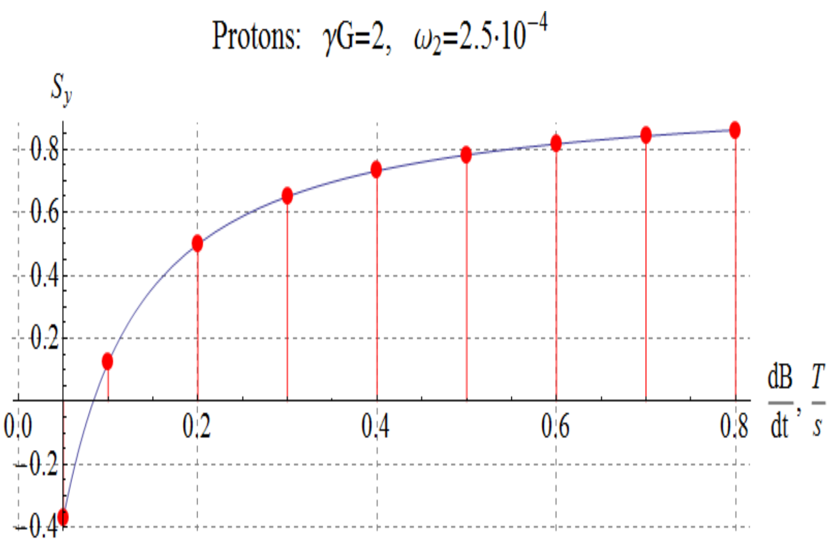
-Tensor polarization appears after passing through the thick nuclear target (Be-20cm).

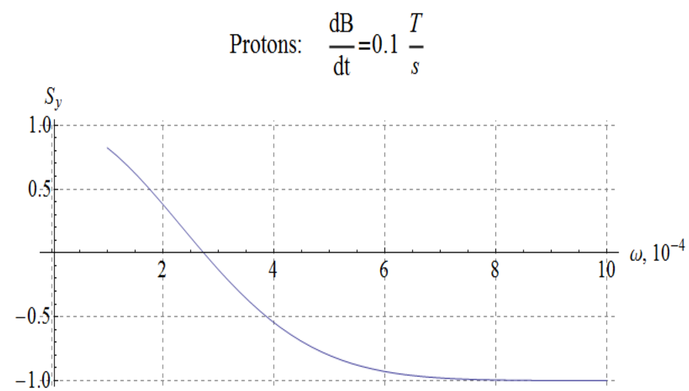


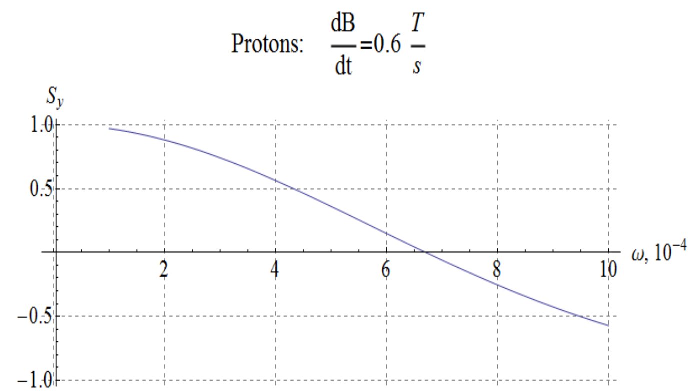


~10^7-10^8 ^{21}Ne ions/spill with the tensor polarization ~0.4 will be available for physics.

New experiments on the proton spin manipulation







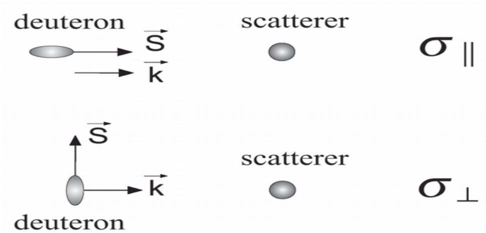
Measurements of the integer resonance γG=k=2 power (Tkin=108 MeV)

Measurements of the proton beam polarization at 100 and 120 MeV at different dB/dt

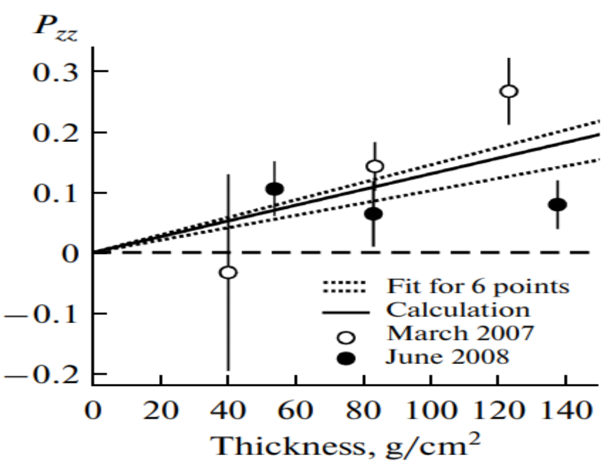
The final goal is to prove the possibility of Spin- Transparency mode at integer resonances (for SPD at NICA)

Yu.N.Filatov et al.,
JETP Lett. 116 (2022) 413;
JETP Lett. 118 (2023) 387.

Deuteron spin dichroism at Nuclotron at 270 MeV



$$p_{zz}(l) = \frac{I_{+1}(l) + I_{-1}(l) - 2 \cdot I_0(l)}{I_{+1}(l) + I_{-1}(l) + I_0(l)} \approx \frac{2}{3}\rho\, l(\sigma_0 - \sigma_1) = -\frac{8\pi}{3}\,\rho\, l\frac{\mathrm{Im}(d_1)}{k}$$



Nuclotron results with the extracted 5 GeV/c deuteron beam.

-Spin dichroism effect is one of the phenomena acquiring by the deuteron beam passing through the nonpolarized target.

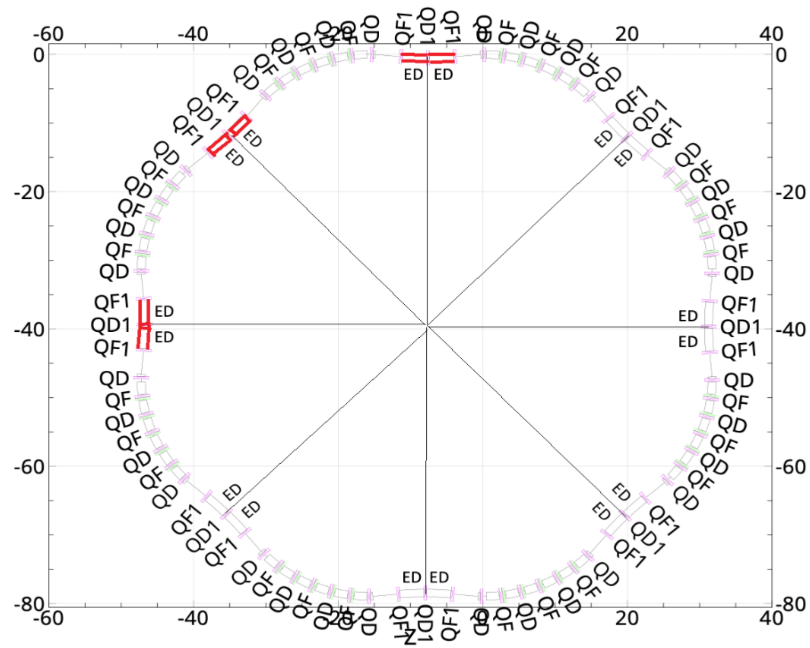
-The method is the measurement of the tensor polarization acquiring by a nonpolarized deuteron beam moving in Nuclotron and passing through the internal target.

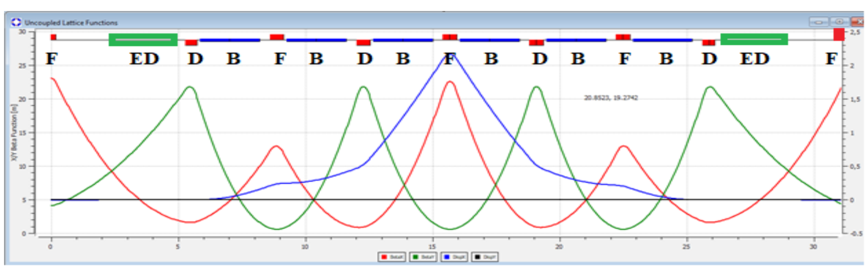
-The polarization measurements will be provided by the vector-tensor deuteron polarimeter based on the measurements of dp- elastic scattering at 270 MeV.

V.G.Baryshevsky et al.,

arXiv: 2508.11718v1[nucl-th]

Deuteron EDM studies at 270 MeV





Option for Nuclotron in "quasi-frozen spin" mode with electrostatic deflectors (ED)

-Search for EDM of nucleons and nuclei is necessary to understand the origin of CP violation and baryogenesis in the Universe.

-The method is the measurement of the transverse polarization appearing for the longitudinally polarized particles.

-Several options of the magnetic optics are under consideration:
-NICA with bypasses,
-modernized Nuclotron ring,
-separate low energy (~300 MeV) ring.

-The polarization measurements must be provided by the 2π-deuteron polarimeter based on the measurements of dC scattering at 270 MeV.

N.N.Nikolaev, Yu.V.Senichev et al.

Conclusion

SPRINT@NICA project is devoted to developments of the research infrastructure and the technologies for the current and planned spin experiments at Nuclotron/NICA.

Several fixed target experiments are already working at Nuclotron using polarized beams provided by new SPI. Part of research infrastructure are ready.

Main directions of planned activity within SPRINT@NICA are further development of the high intensity polarized beams and corresponding beam polarimetry, experimental verification of Spin Transparency mode and preparation of the high precision spin experiments.

SPRINT@NICA group

JINR

V.V.Fimushkin, A.V.Butenko, E.A.Butenko, V.P.Ladygin, E.M.Syresin, S.A.Kostromin, N.V.Dunin, K.A.Ivshin, M.V.Kulikov, A.N.Solovev, I.S.Volkov, V.A.Lebedev, E.E.Donets, V.V.Bleko, S.S.Shimansky, N.M.Piskunov, A.Ya.Silenko, O.V.Teryaev

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INP BSU

V.G.Baryshevsky, S.V.Anischenko, A.A.Gurinovich

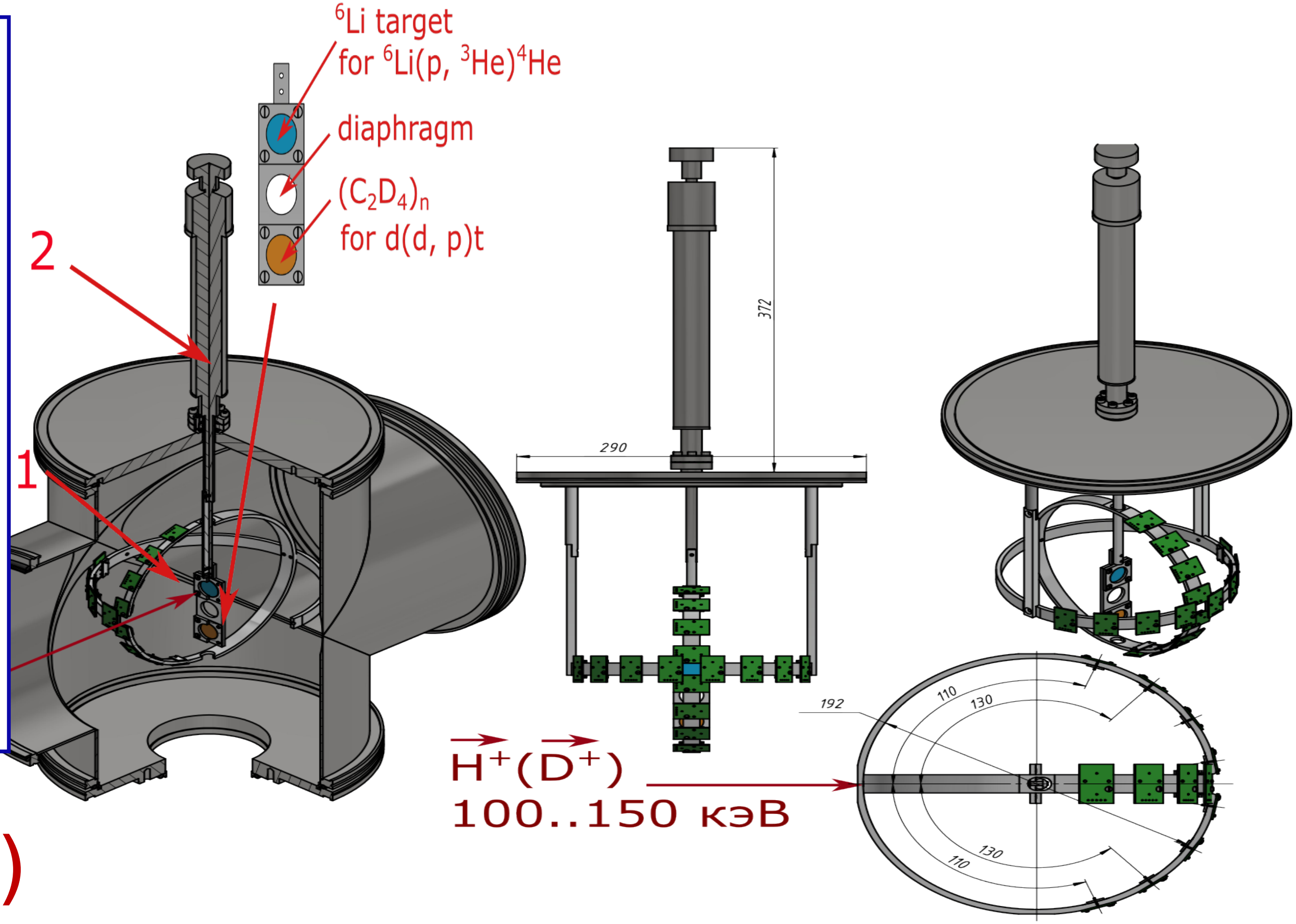
New peoples with their ideas are welcome!

Thank you for the attention!

Nuclear Reaction Polarimeter (NRP)

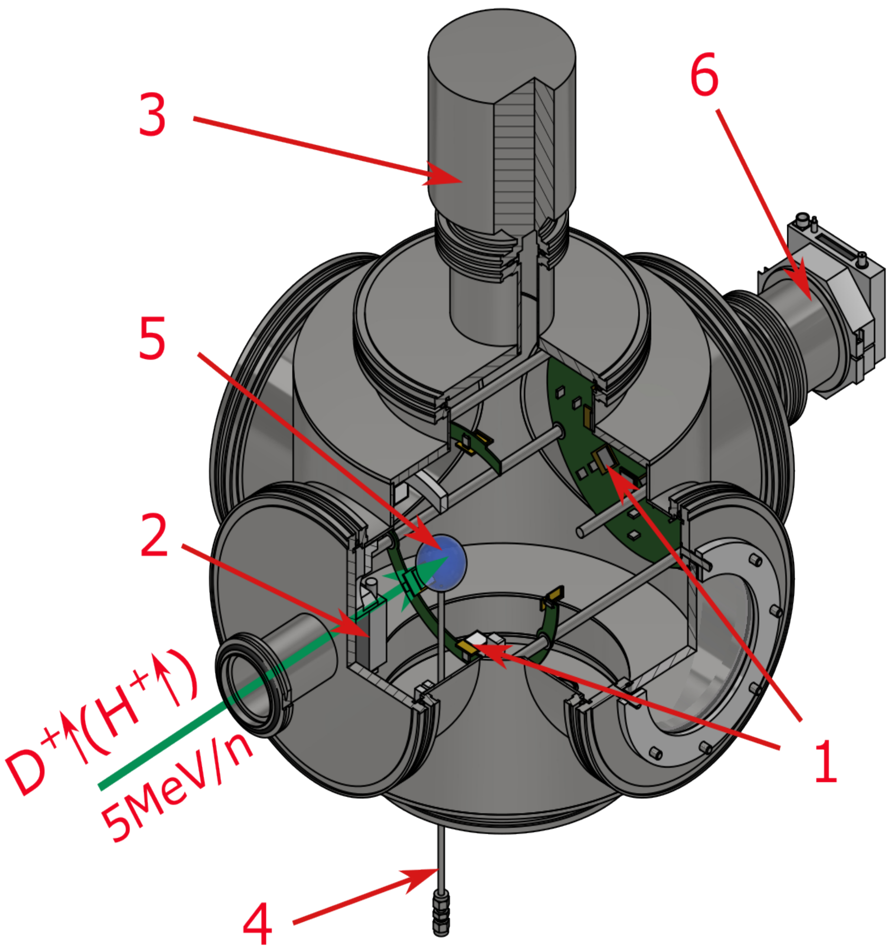
Detector Configuration:

- array of 16 (1) silicon detector units.
- **active Area per Unit: 5 x 20 mm.**
- **sensor Specifications:**
  - Thickness: **300 µm**
- **Performance Parameters:**
  - Maximum Count Rate: **2 MHz**
  - Energy Resolution: < **30 keV**
  - Time Resolution: **500 ns**
- **2 – manipulator**



d, (p)

^{3}He & ^{4}He Polarimeter (first version)



The experimental setup includes:

1 - array of 16 silicon detectors with the active area of 20x20 mm each

2 - variable diaphragm

3 - turbomolecular pump

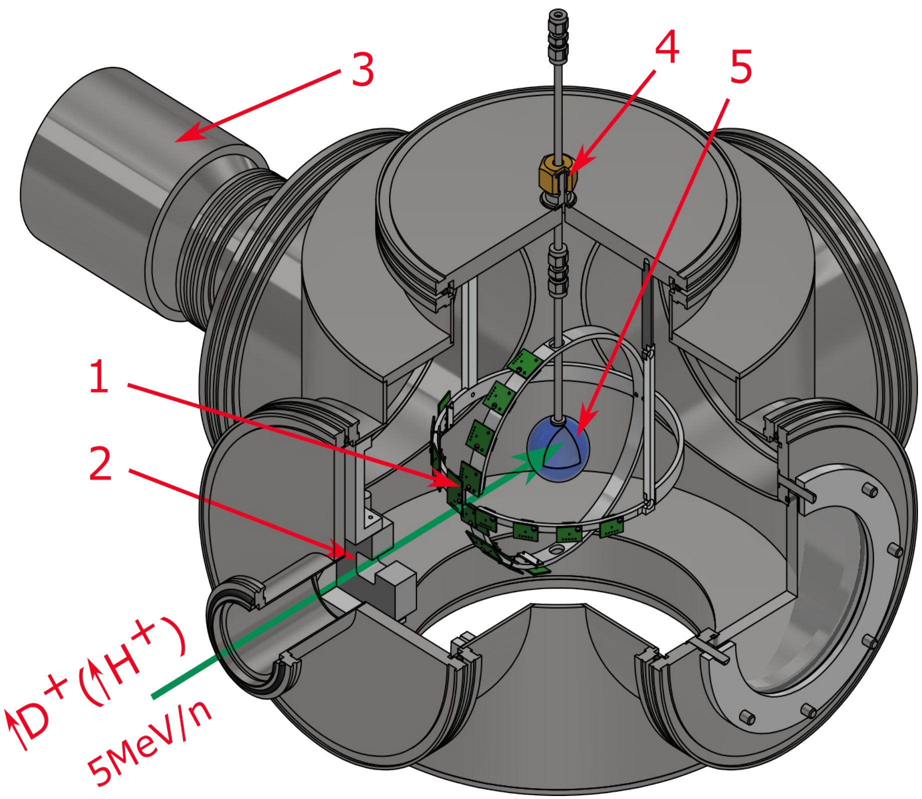
4 - gas inlet system

5 - high-pressure (3 bar) mylar spherical target (**150 µm**) filled with gaseous ^{3}He or ^{4}He

6 - electronic box

- **Detector Configuration:**
- array of 16 silicon detector units
- **active area per unit:** 20 x 20 mm
- **Sensor Specifications:**
  - Thickness: 300 µm

^{3}He & ^{4}He Polarimeter (second version)

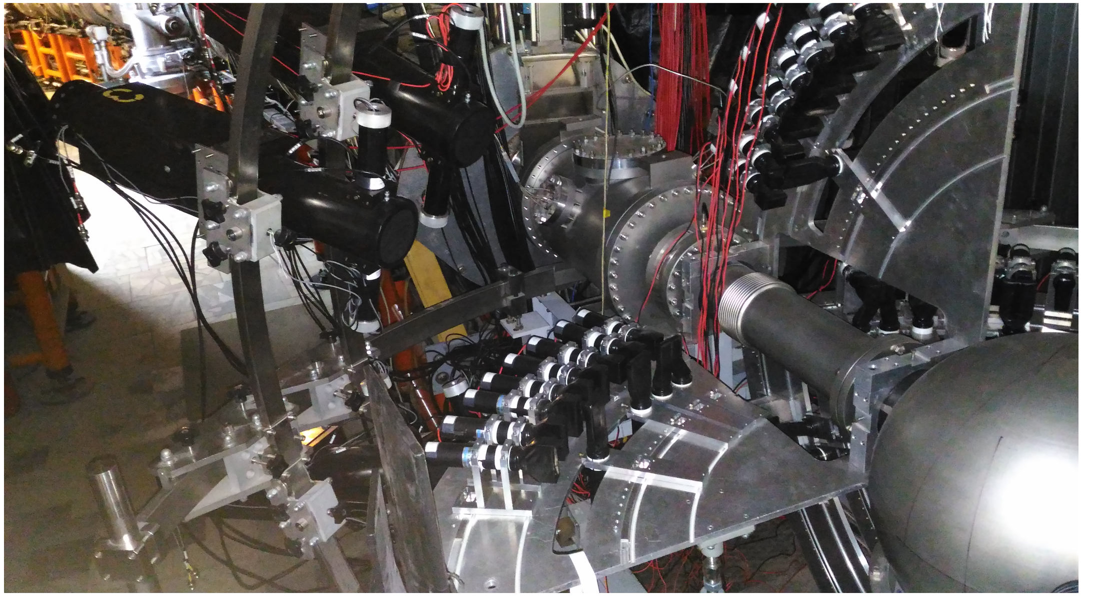


The experimental setup includes:
1 - array of 16 silicon detectors with an active area of 5x20 mm each
2 - variable diaphragm
3 - turbomolecular pump
4 - gas inlet syste
5 - a high-pressure (3 bar) mylar spherical target (**150 µm**) filled with ^{3}He or ^{4}He

The polarimeter operates by detecting protons at approximately 32° and alpha-recoil particles at around 132°, generated from the ^{3}He(d, p)^{4}He reaction https://dx.doi.org/10.1016/0029-554x(80)90946-5

- **Detector Configuration:** An array of 16 silicon detector units.
- **Active Area per Unit: 5 mm x 20 mm.**
- **Sensor Specifications:**
  - Thickness: **300 µm**
- **Performance Parameters:**
  - Maximum Count Rate: **2 MHz**
  - Energy Resolution: < **30 keV**
  - Time Resolution: **500 ns**

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.

Polarized protons at Nuclotron.

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

Unpolarized protons: I~$1.5 \cdot 10^8$ ppp
Polarized protons: I~$2\text{-}3 \cdot 10^7$ ppp

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

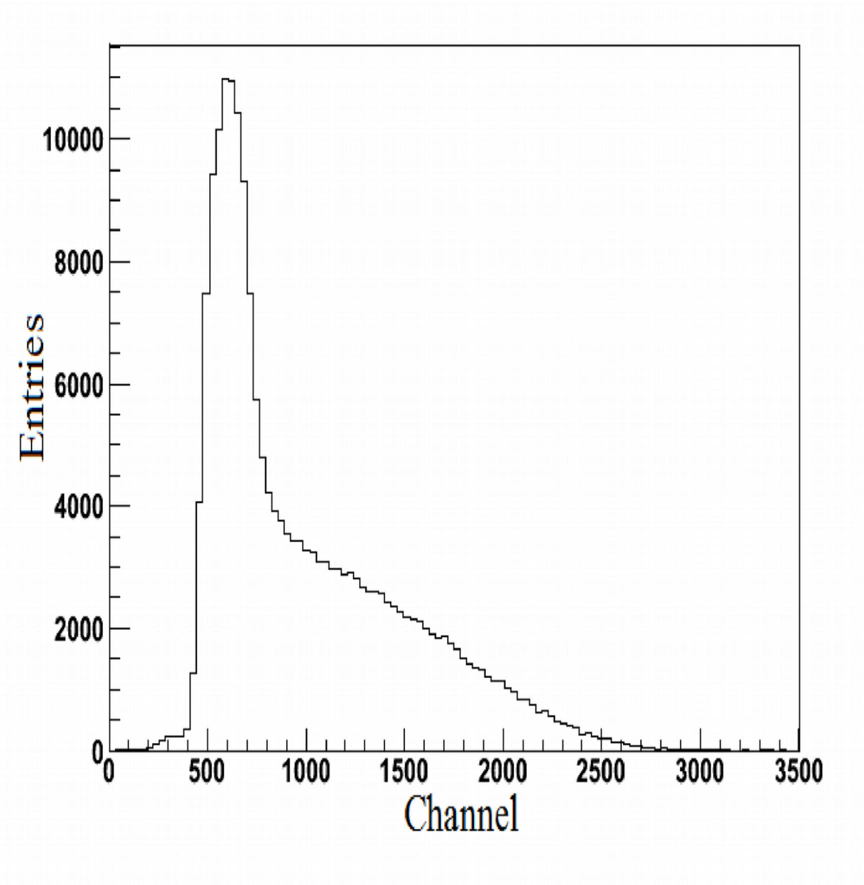
beam 2/3 of time.

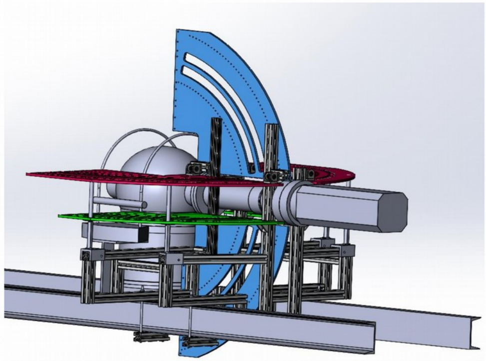
Having the asymmetries for 6 angles (55^0-85^0 in the cms) we obtained the averaged value of the proton beam polarization

Unpolarized protons: P= 0.056 ±0.021
Polarized protons: P= 0.367 ±0.015

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

Upgrade DSS polarimeter



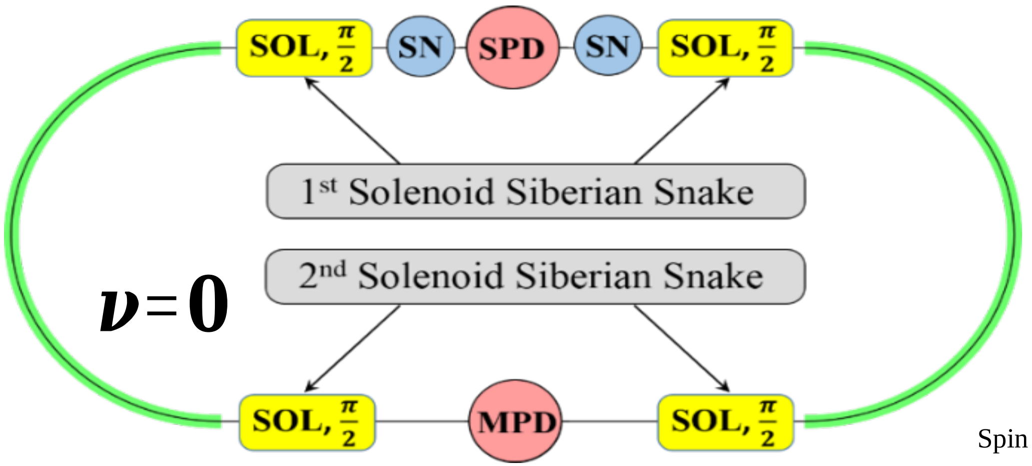


>80 new scintillation counters (BC-408 and H7415 PMT) produced, tested with RA source, 10% are tested with parasitic beam at ITS. Mechanics -design is performed, almost ready.

NICA in 2024

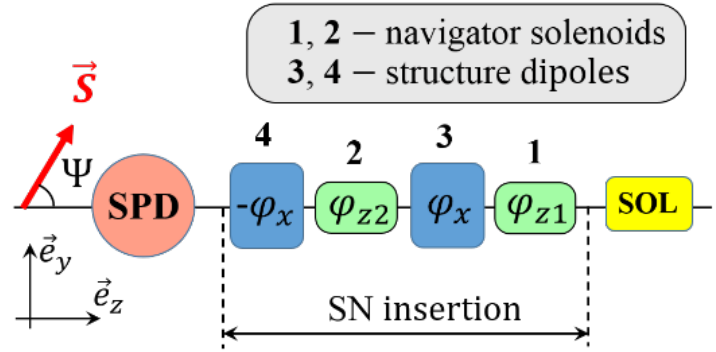
NICA technological launch – 13.06.2024
NICA beam circulation - 2025

Spin Transparency mode in the NICA collider with two snakes



Snake Solenoids provide ST mode:

$BL = 1 \div 25$ T · m (***p***), $BL = 3 \div 80$ T · m (***d***)

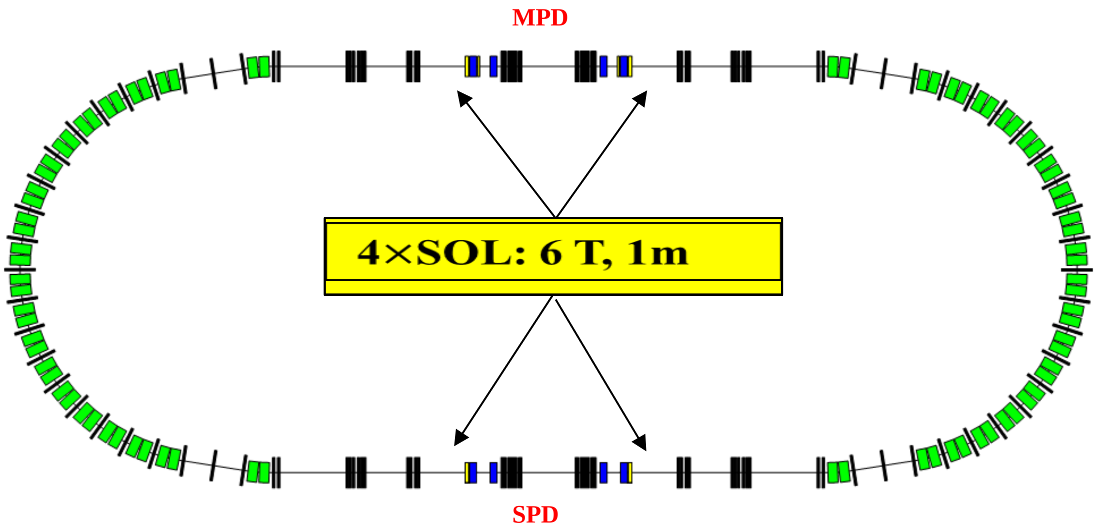


Spin navigators (SN) based on “weak” solenoids stabilize required polarization direction in detectors $(BL)_{\mathbf{nav}}$ **< 0.6 T · m** (***p,d***)

The spin transparency mode of the NICA collider allows to

- control ion polarization using SN without affecting the orbital properties of the beam
- accelerate the beam without loss of polarization
- ensure polarization stability throughout the entire experiment
- provide any desired polarization orientation at any point of the collider's orbit
- change the polarization direction using spin navigators during the experiment.
- perform frequent spin flips of all bunches to reduce the experiment's systematic errors.
- conduct high-precision experiments with polarized beams.

First stage of ST mode in NICA



ST mode with four

6T-solenoids

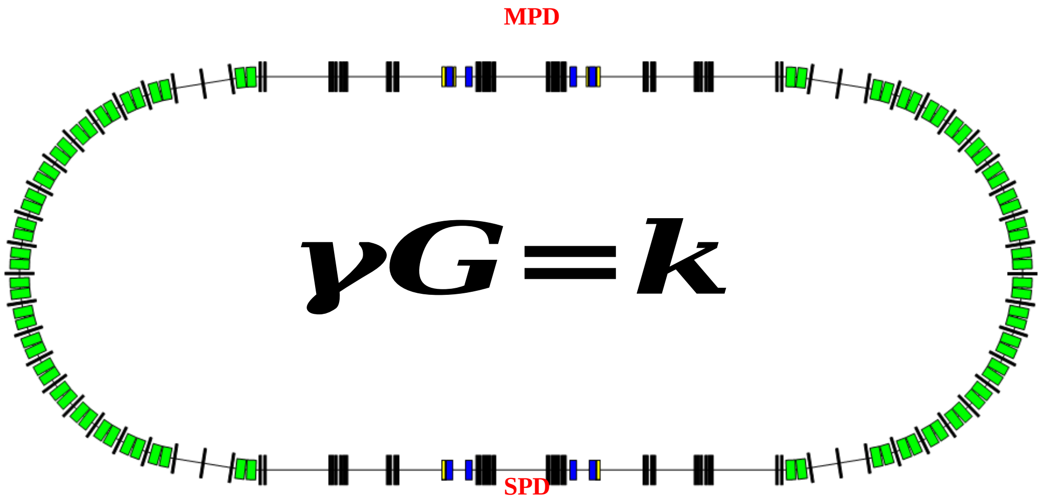
p	up to 3.20 GeV/c
d	up to 0.98 GeV/c
He3	up to 7.32 GeV/c

Snakes eliminate both **resonant depolarization** during beam acceleration and the **influence of synchrotron oscillations** on the spin dynamics in the ST mode

Snakes together with navigators **allow to compensate** the coherent influence on spins of the NICA magnetic **lattice imperfections**

It becomes possible to carry out **high-precision** experiments, such as **measurement of the G-factors of deuterons and protons**

ST mode at an integer spin resonance in NICA



$$\gamma G = k$$

Protons

$$pc > 3.2\ \mathrm{GeV}$$

Energy step

$$\Delta E \approx 523\ \mathrm{MeV}$$

The possibility of **using 6T solenoids to preserve proton polarization** during acceleration in the NICA collider should be considered

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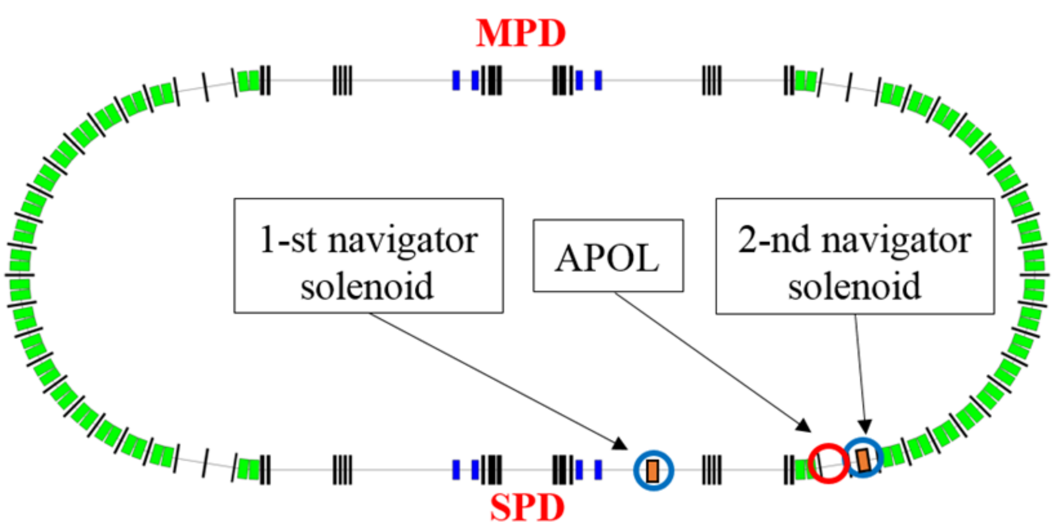
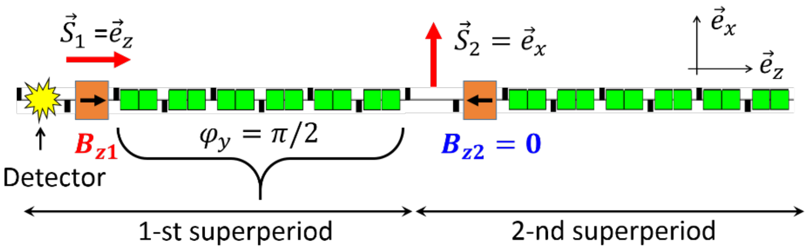


Spin navigator based on two weak solenoids

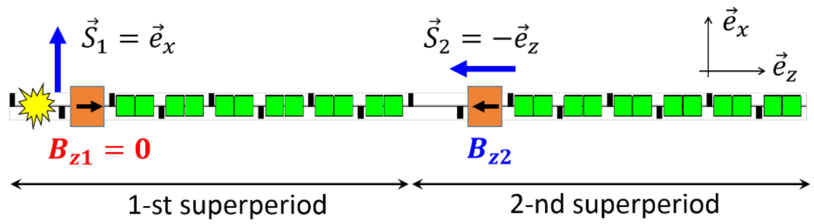
polarization control in the collider plane (radial and longitudinal polarization)

Russian Foundation for Basic Research project № 20-02-00808 (2020-2021) Development of a methodology of an experiment to test a spin-flip system in the momentum range of protons up to 3 GeV / c in the Transparent Spin mode of Nuclotron (JINR)

Experimental verification of ST mode at integer spin resonance $\gamma G = 2$. Spin-navigator based on two weak solenoids



Longitudinal polarization at the detector



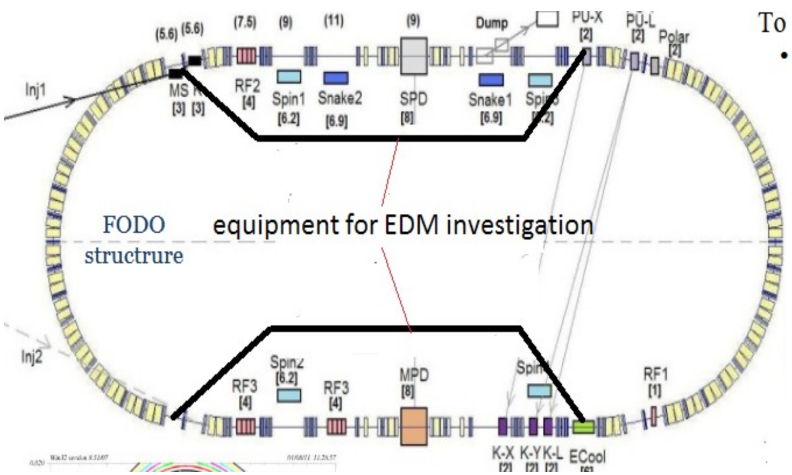
Radial polarization at the detector

Russian Science Foundation project № 22-42-04419 (2022-2024) Spin transparency as a new approach to precision tests of fundamental symmetries in polarization experiments at colliders and storage rings: theory and experiment

Experimental verification of ST mode at integer spin resonance $\gamma G = 7$. Spin-navigator based on regular correction dipoles.

Russian Science Foundation project № 25-72-30005 (2025-2028) Development of innovative technologies of operation with polarized beams for realization of the polarization physics program of the NICA facility at JINR, with further extension toward research in fundamental symmetries

Deuteron and proton EDMs studies at NICA



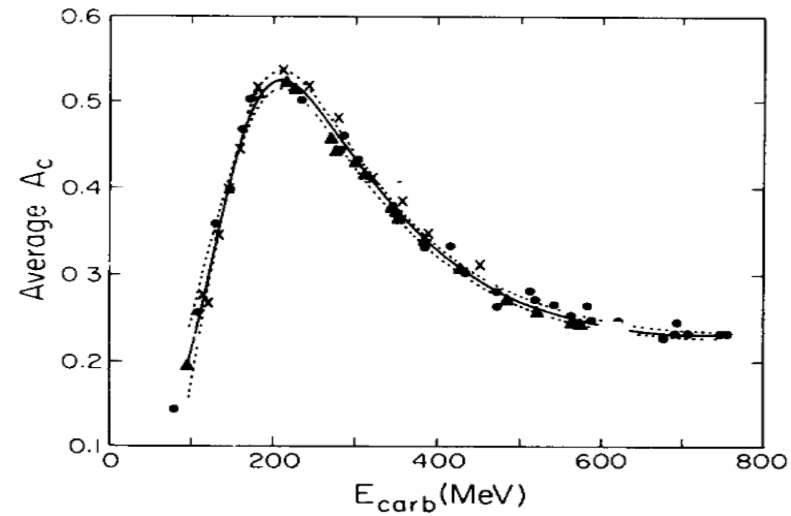
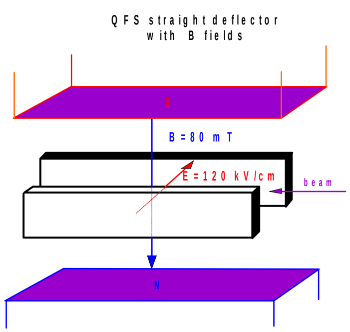


Fig. 8 Single energy (points) and energy dependent (solid line) $\bar{A}_c$ from $\theta_{lab} = 5°–20°$ are plotted. Data points are from SIN (△), TRIUMF (×), and LAMPF (●). Dotted lines show estimated error corridor.



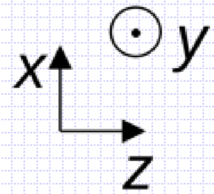
The proton polarization measurements must be provided by the 2π- polarimeter based on the measurements of pC scattering.

Option for NICA in "quasi-frozen spin" mode

Deuteron dichroism (internal nonpolarized target)

Magnetic field presents in the ring and it is parallel to y-axis. It rotates spin component, which is parallel to the particle motion plane (xz).

TOP VIEW



Internal nonpolarized target

Nonpolarized deuterons ($p_{zz}=0$)

$$N_{+1}=N_{-1}=N_0$$

Deuterons with nonzero tensor polarization ($p_{zz}\neq 0$)

$$N_{+1}=N_{-1}\neq N_0$$

Particle	Target	E, MeV	N_{bunch}	σ, b	Δσ/σ	$<p_{zz}>$	$T_{1\%}$
d	CH_2	270	10^{10}	0.8	0.06	$1\cdot10^{-2}$	~1 hour
d	CH_2	270	10^{10}	0.8	0.01	$2\cdot10^{-3}$	30 hours