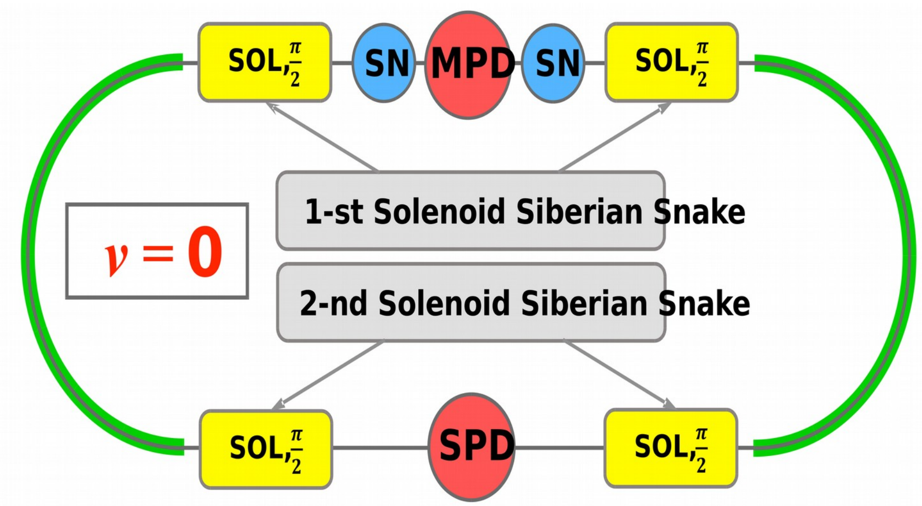
Polarized beams at NICA



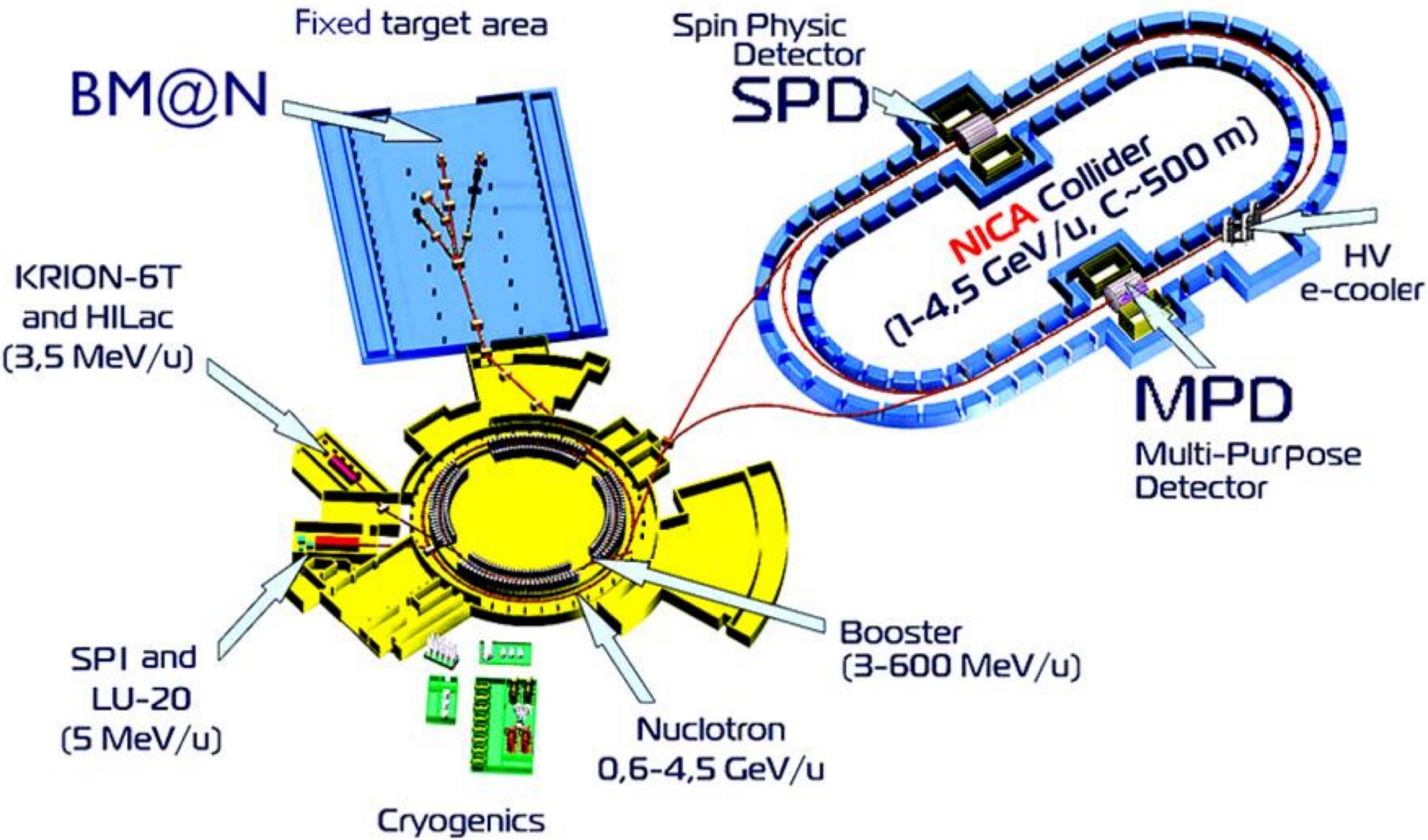
V.P.Ladygin

on behalf of SPD and

Spin Physics Research INfrastructure&Technologies group (SPRINT@NICA)

for SPD DAC meeting 27.02.2024

NICA Complex Main Components



General requirements to the beam facility

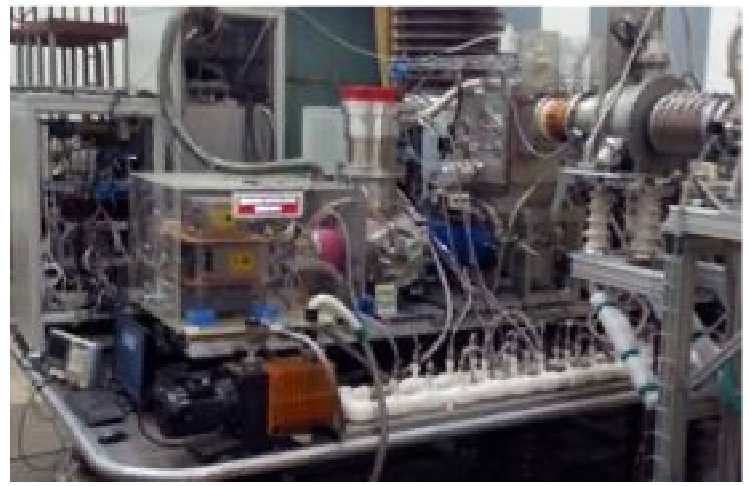
- polarized and non-polarized p-; d–collisions
- $p\uparrow p\uparrow$ at $\sqrt{s_{pp}} = 12 \div 27$ GeV (5 ÷ 12.6 GeV kinetic energy)
- $d\uparrow d\uparrow$ at $\sqrt{s_{NN}} = 4 \div 13$ GeV (2 ÷ 5.5 GeV/u kinetic energy)
- $L_{av} \approx 10^{32}\ cm^{-2}s^{-1}$ (at $\sqrt{s_{pp}} \geq 27$ GeV)
- sufficient lifetime and polarization degree (few hours, 70%)
- longitudinal and transverse polarization in MPD and SPD
- pd collision mode should be available

The facility operation at pp – mode at $\sqrt{s_{pp}} = 27$ GeV reaching average luminosity of $10^{32}\ cm^{-2}s^{-1}$ remain the 1-st priority task for coming years.

Polarized beams at the LHEP

· d↑- was accelerated in 1986 (Synchrophasotron); Nuclotron - in 2002. Spin resonance at 5.6 GeV/u. • p↑- was first obtained in 2017. The first test was performed after analysis of the spin resonances.

• Ion source SPI was used.



NUCLOTRON

6 AGeV SC SYNCHROTRON

CIRCUMFERENCE – 250 m

MAGNETIC FIELD – 2 T

THE FIELD RAMP – 1 T/s

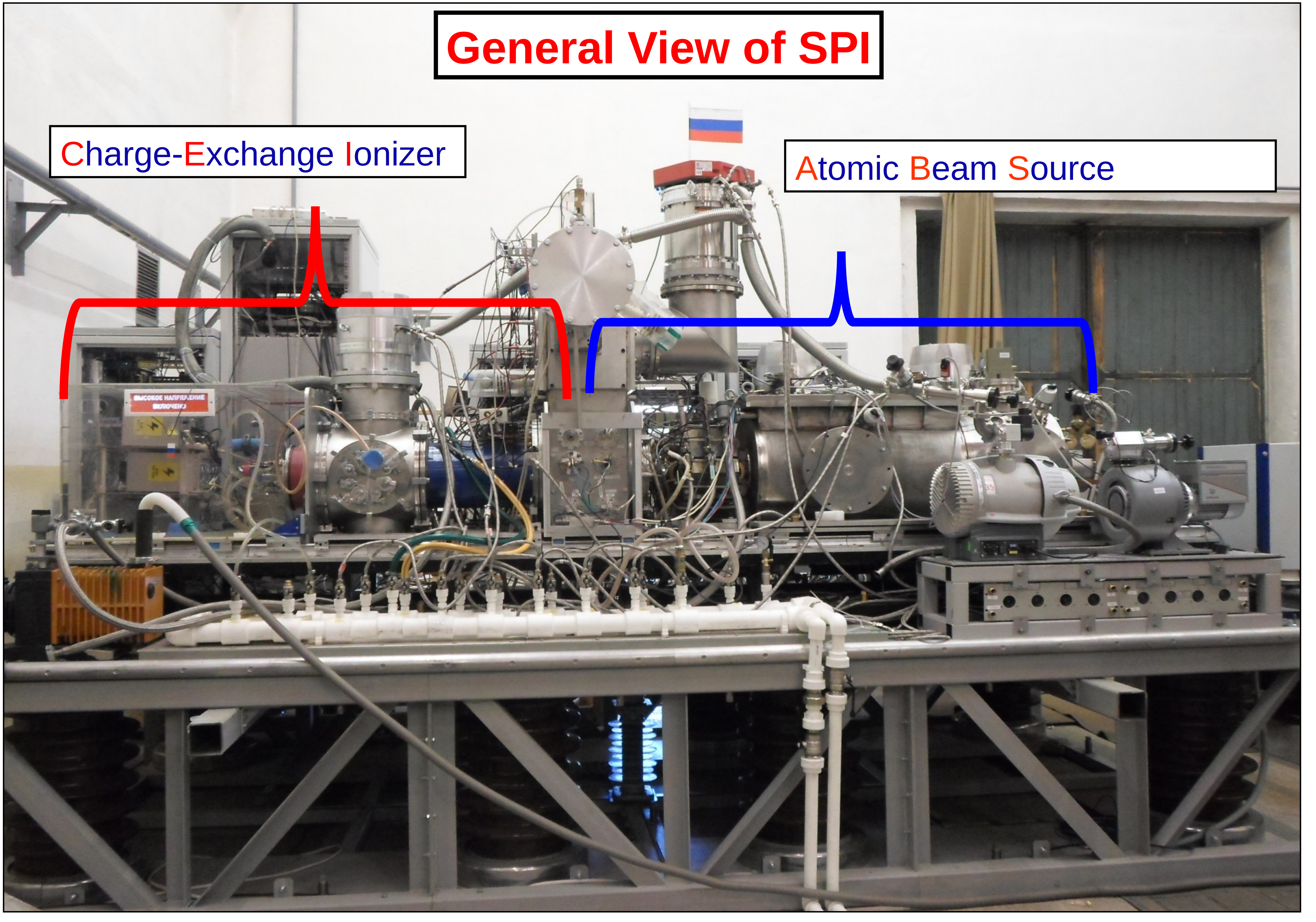
ONE-TURN INJECTION

INJECTION ENERGY 5 MeV/u

RFQ input–up to 3mA, t≈100 mks;
Particle number - $1.5 \bullet 10^{11}$ for 8 mks;
Different spin modes (p_z,p_{zz}) were adjusted;
Polarization degree - 70-75 %

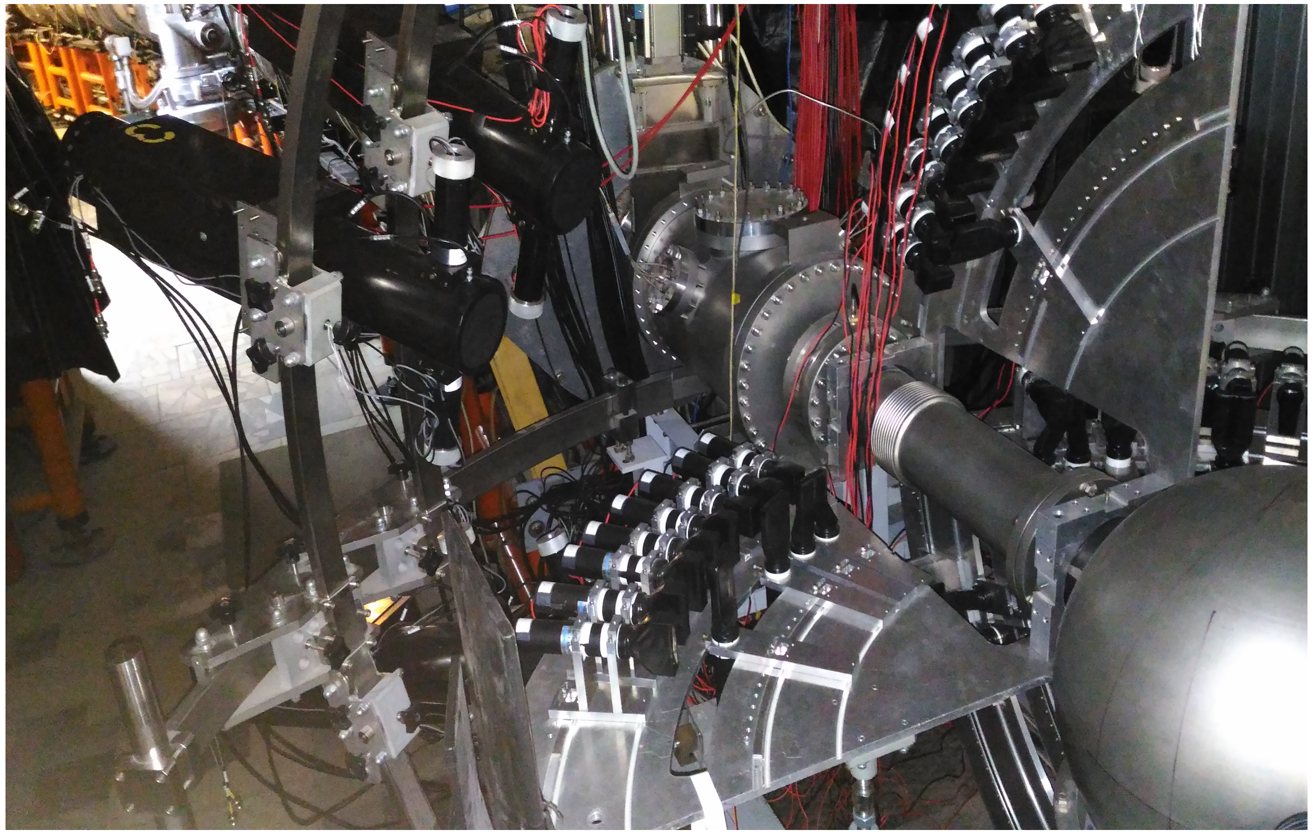
The RFQ, put limit for proton energy - 5 MeV at the linac LU-20 output (instead of 20 MeV). The new proton and light ion linac “LILAC” will have the output energy of 12 MeV. Due to sanctions search for new manufacturer.

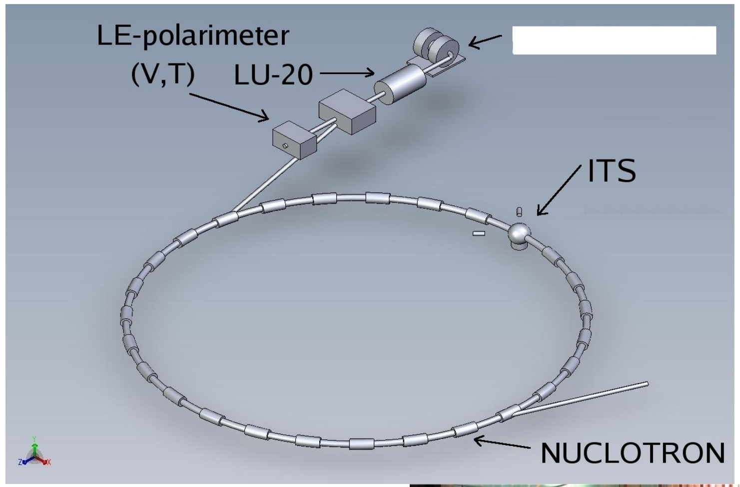
General View of SPI



New SPI will increase beam figure of merit by a factor ~10^3

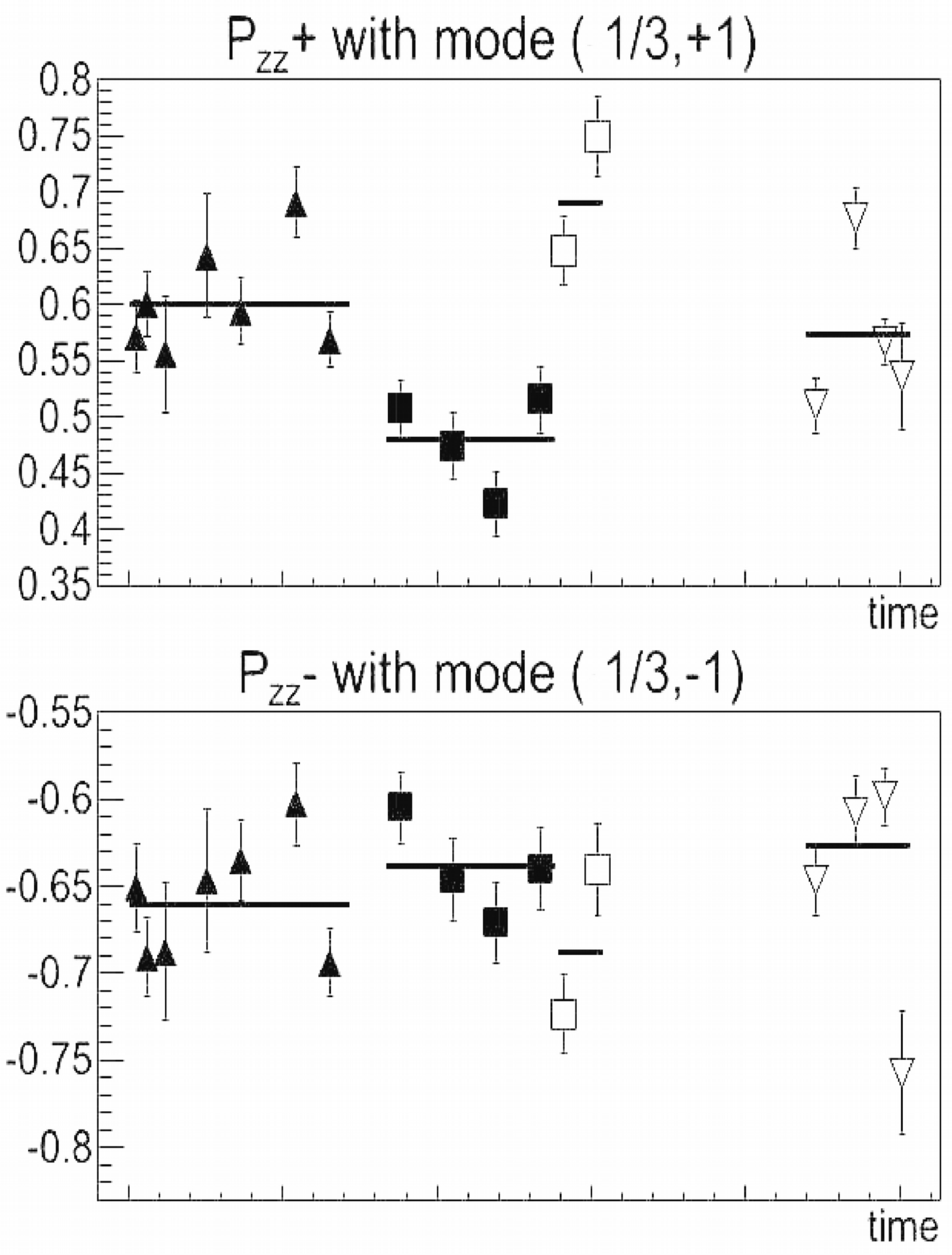
DSS polarimeter at Internal Target Station at Nuclotron

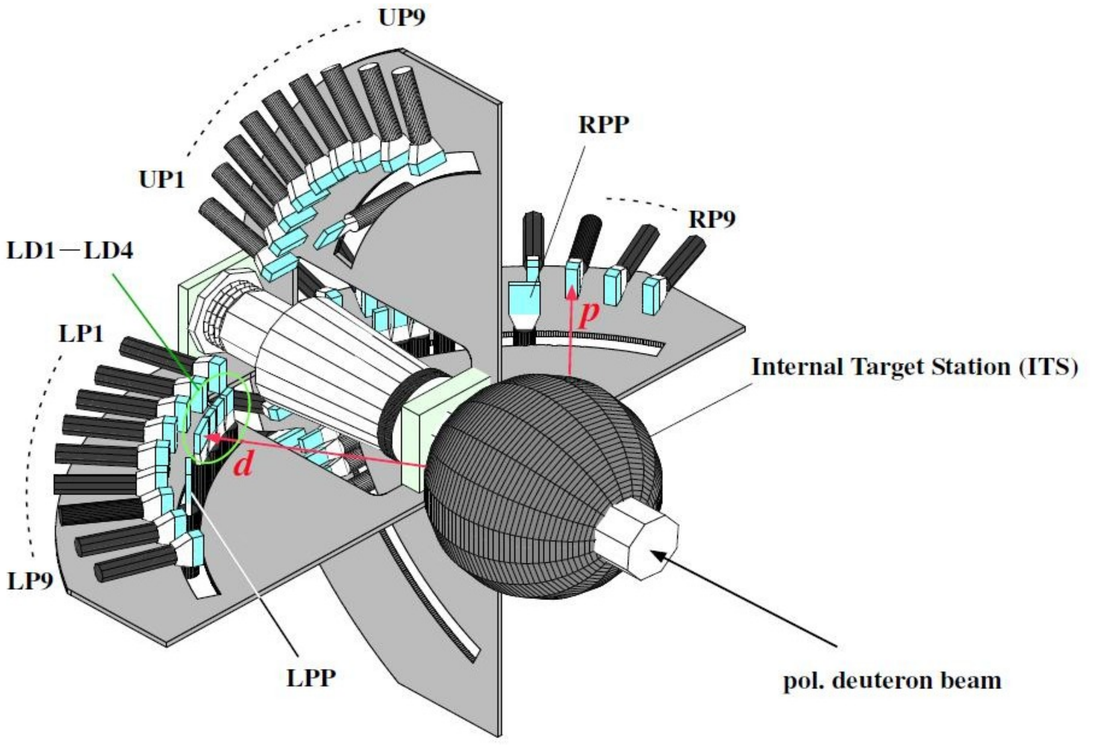




Deuterons and protons in coincidences using scintillation counters
Internal beam and thin CH_2 target (C for background estimation)
Permanent polarization measurement at 270 MeV (between each energy).
Analyzing powers measurement at 400-1800 MeV
The data were taken for three spin modes of SPI: unpolarized, “2-6” and “3-5” (p_z,p_{zz}) = (0,0), (1/3,1) and (1/3,-1).
Typical values of the polarization was 70-75% from the ideal values.
Typical intensity was $2\text{-}4 \cdot 10^8$ ppp.

DSS polarimeter results for deuteron beam polarization

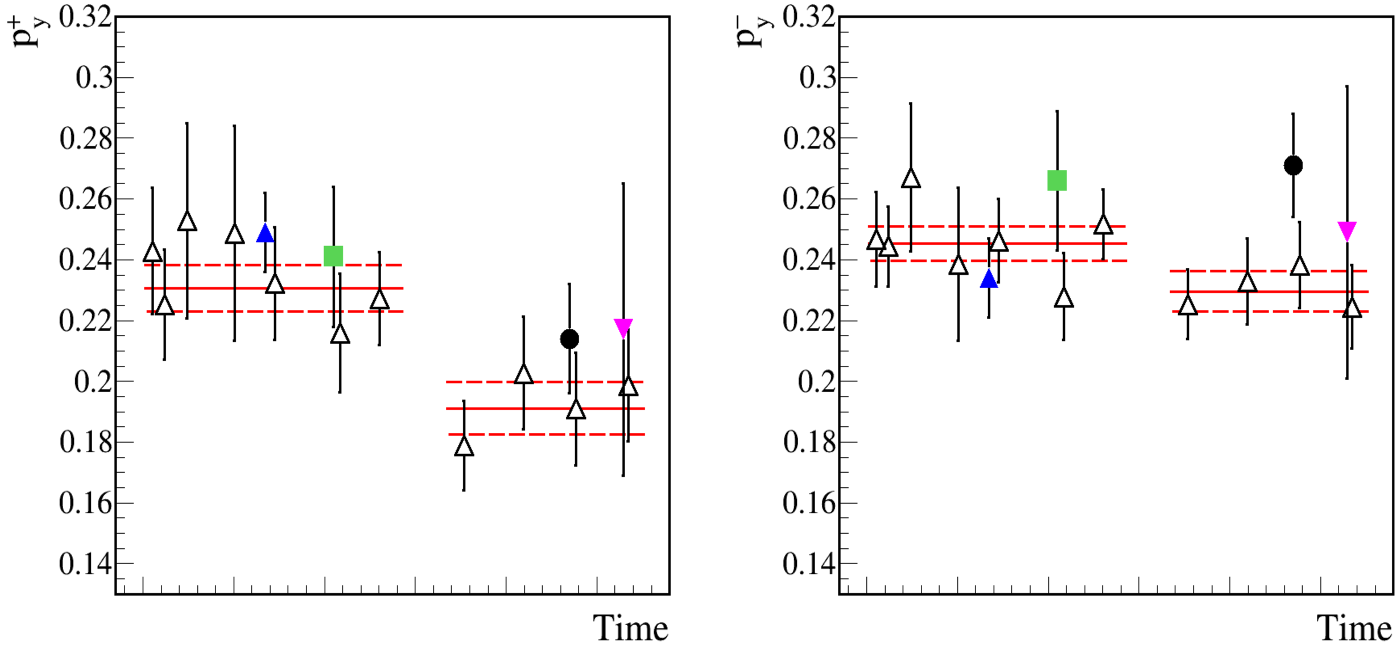


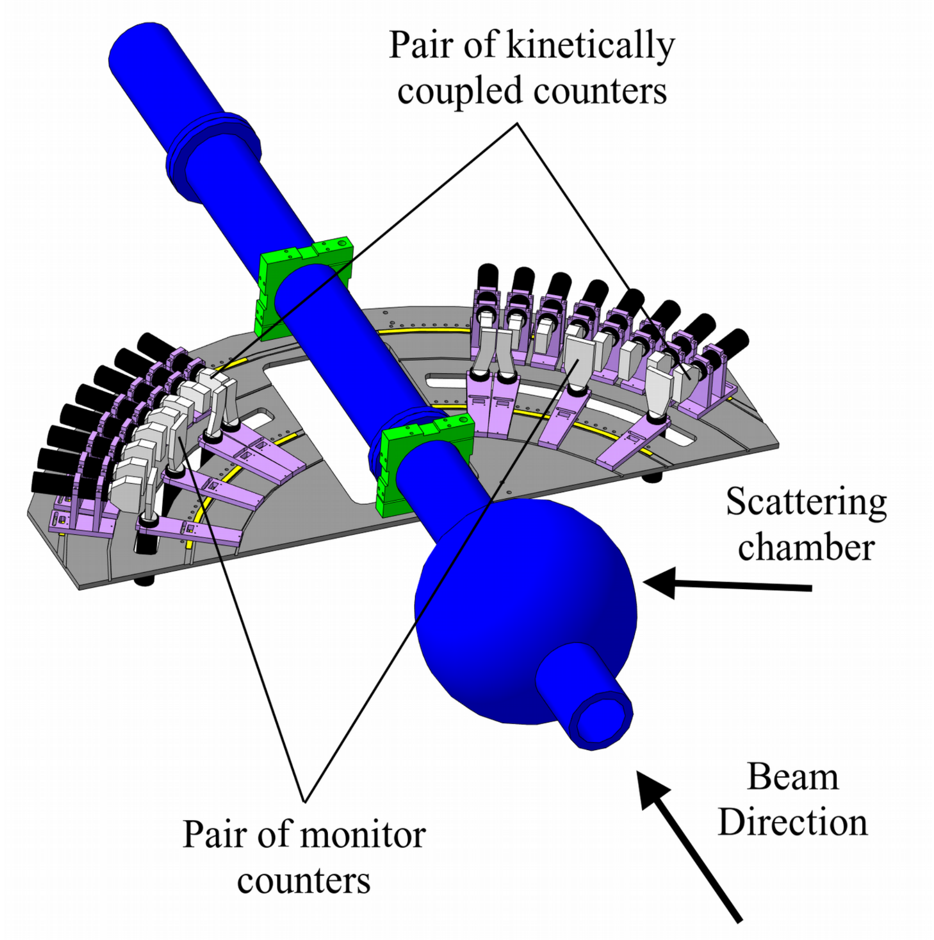


P.K.Kurilkin et al.,
NIM A642 (2011) 45-51.

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- 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 the beam polarization values for the pp- quasi- elastic scattering measurements.

Both methods give the similar results!

First polarized proton beam 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

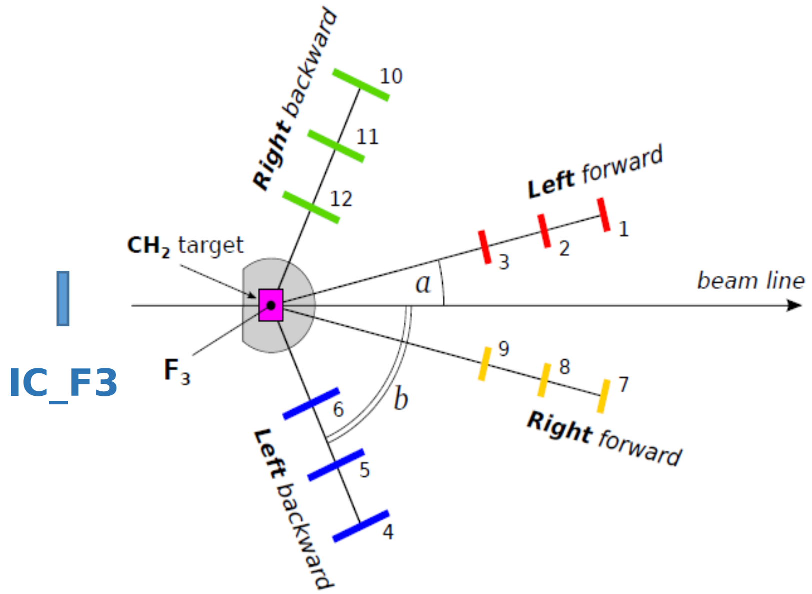
IPol=1 P=1 (WFT 1→3)
IPol=2 P=0 (unpolarized)
IPol=3 P=1 (WFT 1→3)

Having left-right 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

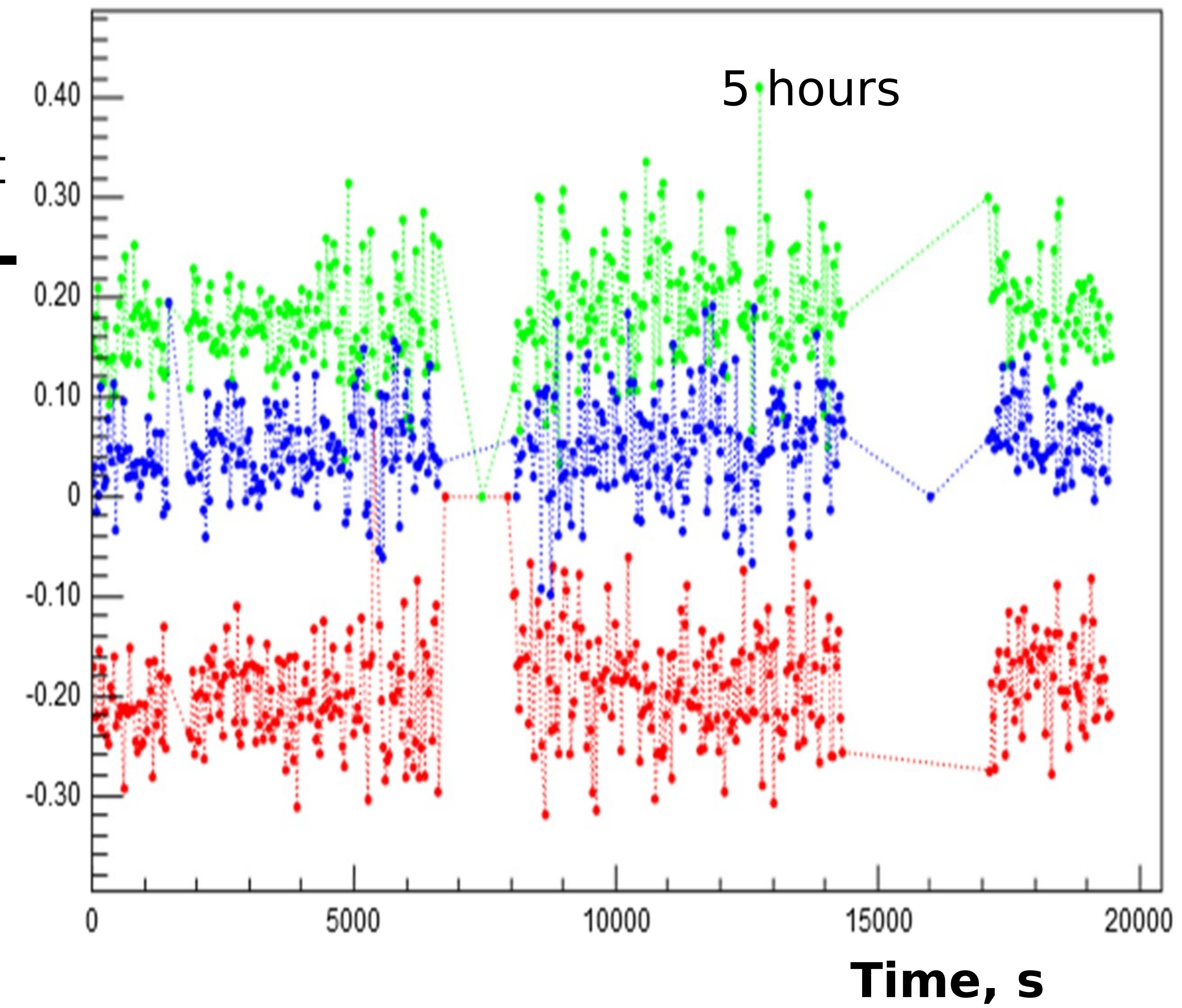
New detection system for proton polarimeter is under preparation.
A.A.Terekhin et al.,Phys.Part.Nucl. 54 (2023) 634.

Deuteron extracted beam polarization measurements (vector component) for ALPOM-2



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

each point corresponds to one spill.



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

Upgraded polarimeter:

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

P(+) – P(-) = 0,96 ± 0,05

Proton beam polarimetry at NICA

1. NICA injection beamline polarimeters based on pp-elastic scattering (under discussion).

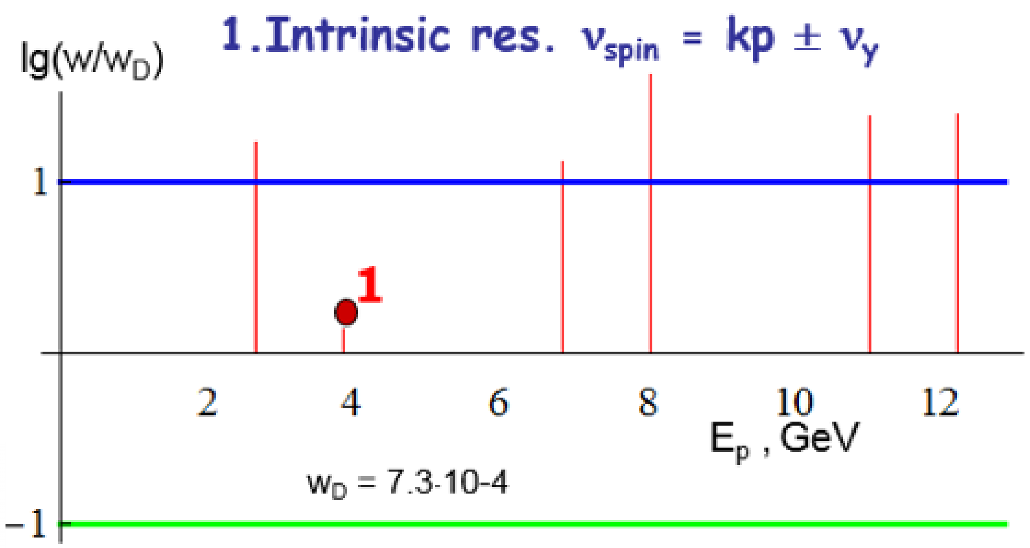
2. Absolute polarimeter based on the pp- elastic scattering using polarized Jet Target (based on the relation $A_{00n0}=A_{000n}$). Systematic error is 3% coming from NMR method.

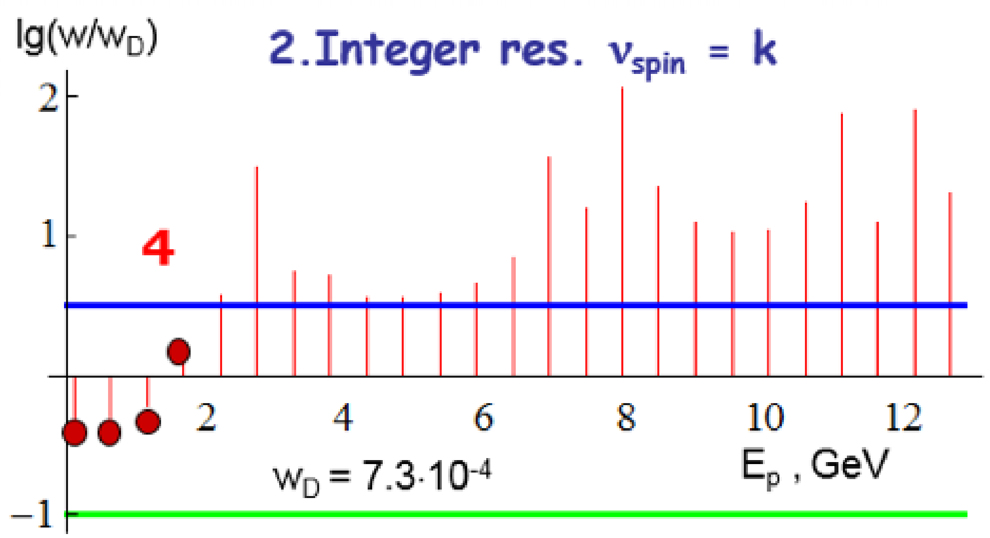
3. Beam polarization profiles from pC- elastic scattering in CNI region.

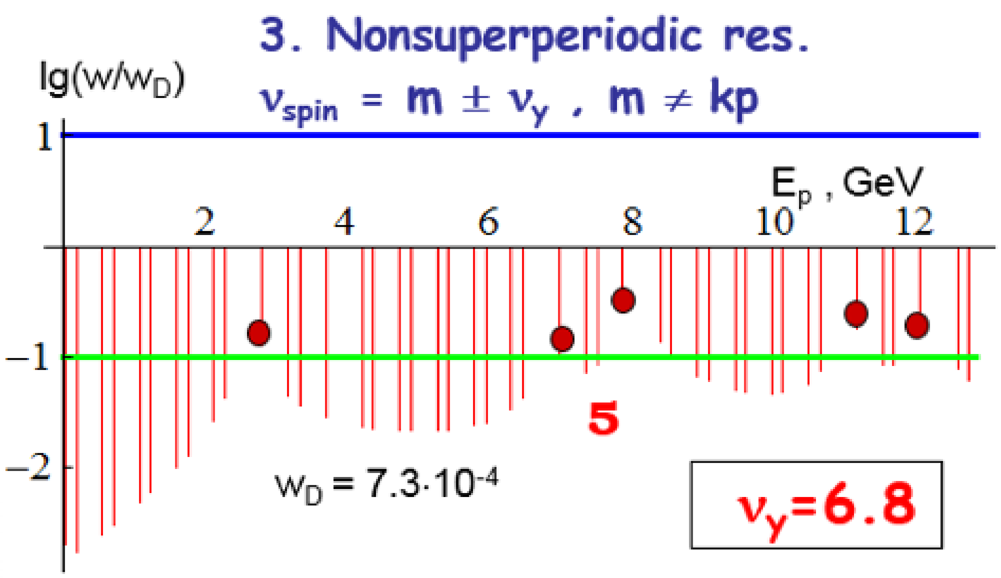
4. NICA beam polarimeters based on pp- elastic or pA- quasielastic scattering using cluster target (H2, D2, CH4, Ar etc.) (under discussion).

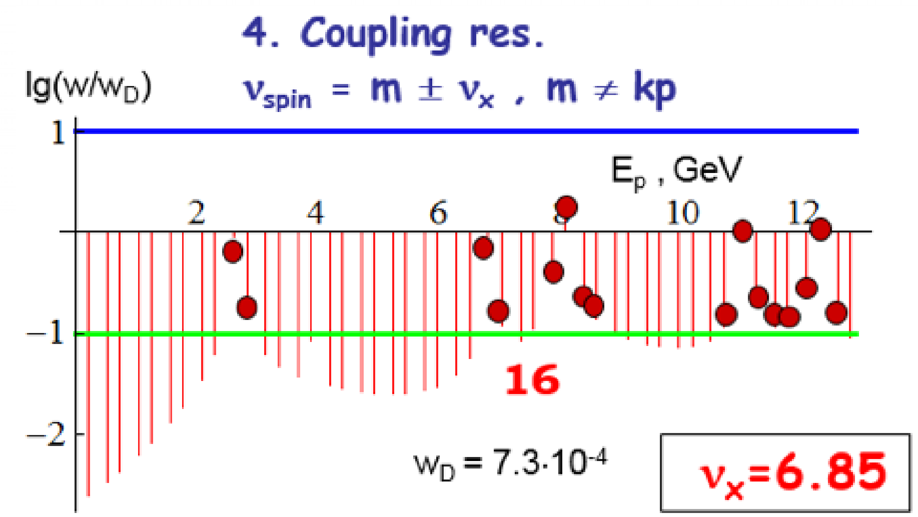
5. Local polarimetry at SPD (BBC, forward ECal).

Proton spin resonances at Nuclotron







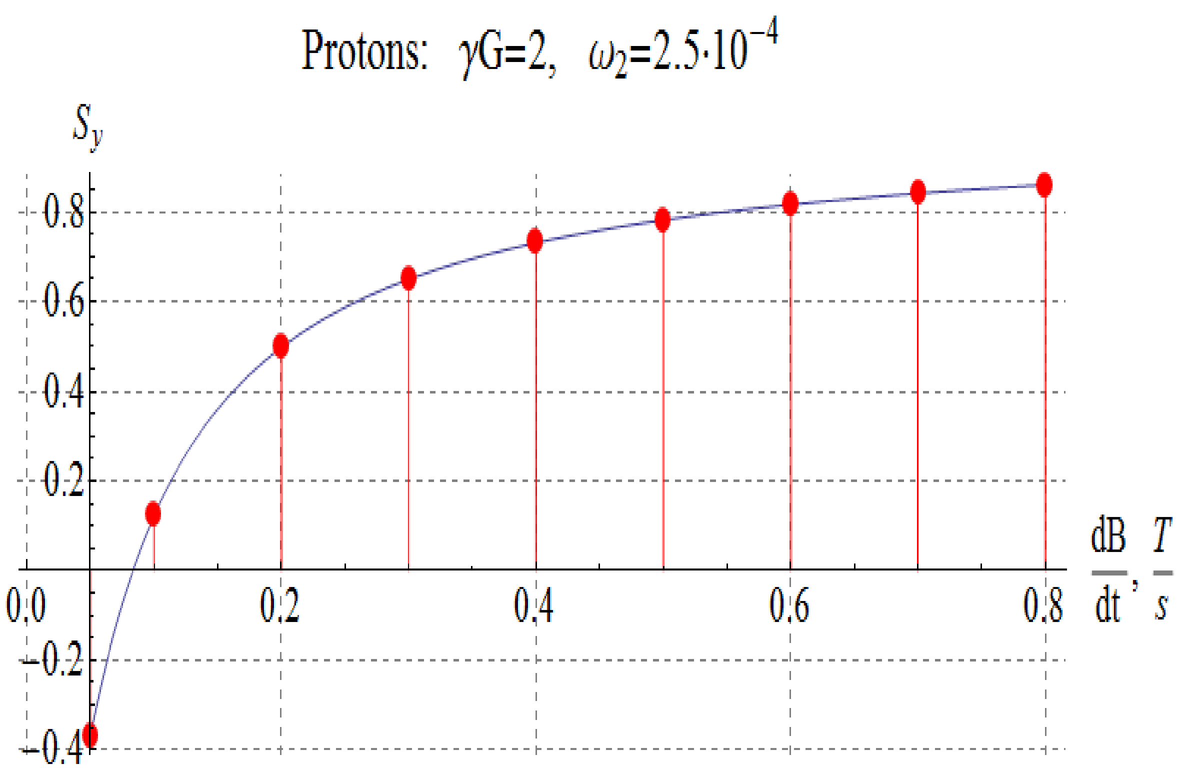


A.M.Kondratenko, Yu.N.Filatov et al.

1. weak solenoid (up to 50 mT·m) preserves the proton spin up to 3.5 GeV/c
2. partial solenoidal snake (12-20 T·m) preserves the proton spin up to 13.5 GeV/c

Effective proton polarimetry at Nuclotron ring is very important!

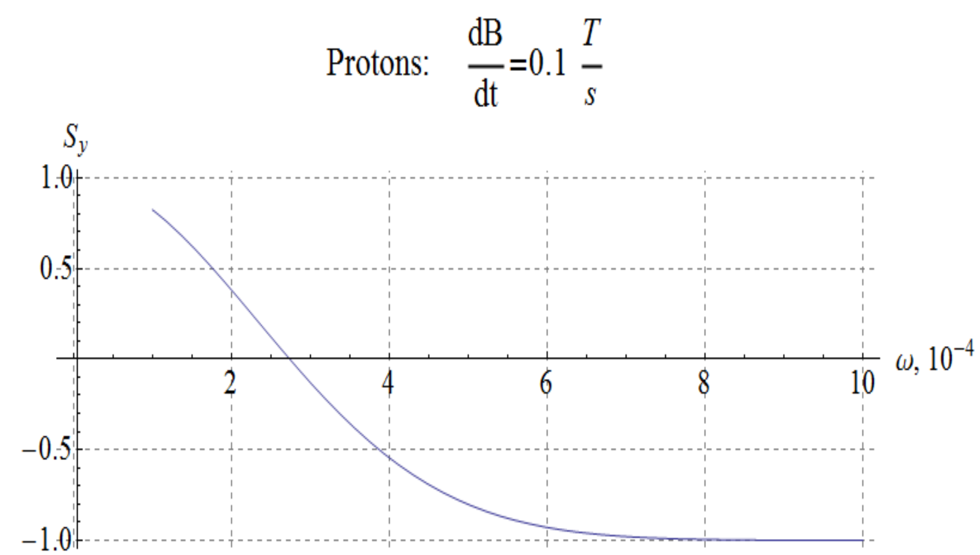
New experiments on the proton spin manipulation

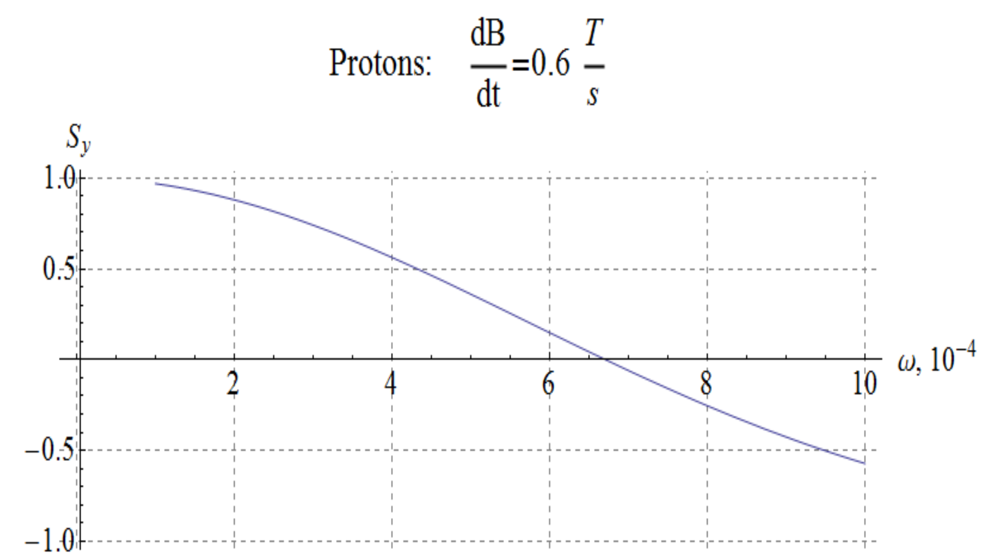


Measurements of the integer resonance **γG=k=2** power (Tkin=108 MeV)

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

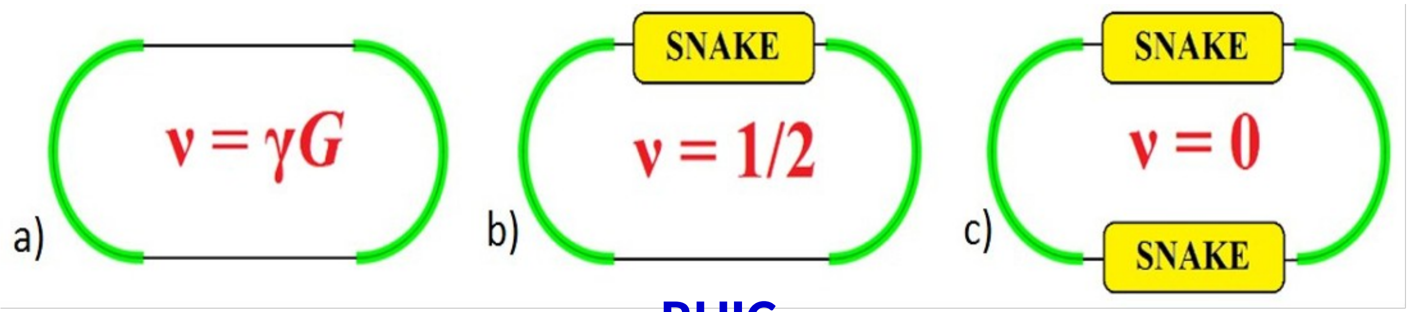
The final goal is to prove the possibility of Spin-Transparent mode at integer resonances (for SPD at NICA)



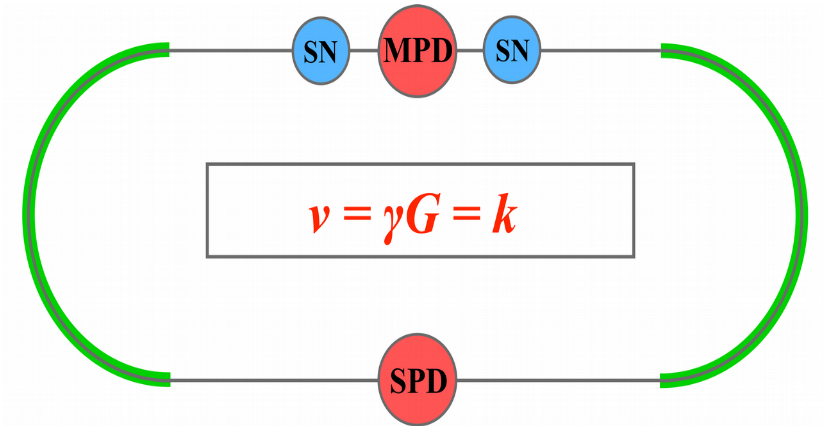


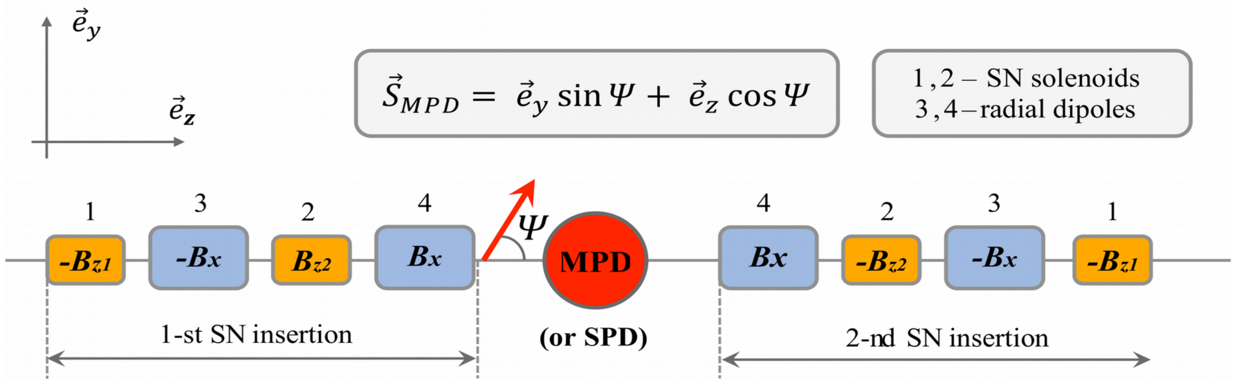
Yu.N.Filatov et al.,
JETP Lett. 116 (2022) 413;
JETP Lett. 118 (2023) 387.

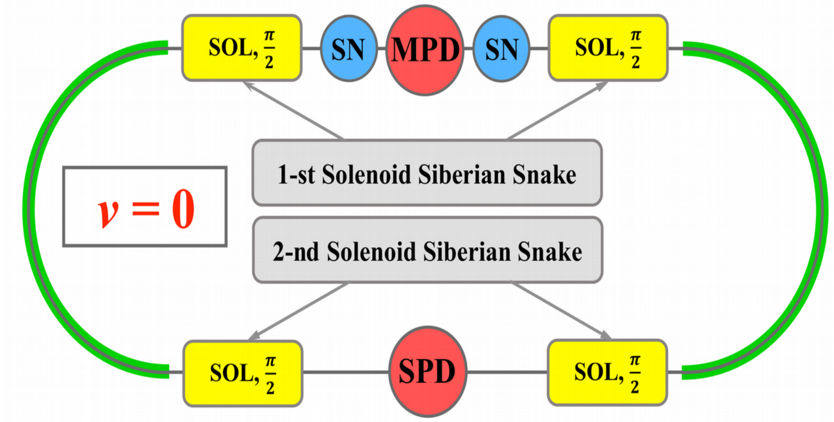
Spin manipulation at NICA



RHIC







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

1-stage of NICA operation:
¼ of the proton energy range is ST-mode
¾ of the proton energy range is work at the integer resonances γG=k.

A.M.Kondratenko, Yu.N.Filatov et al.

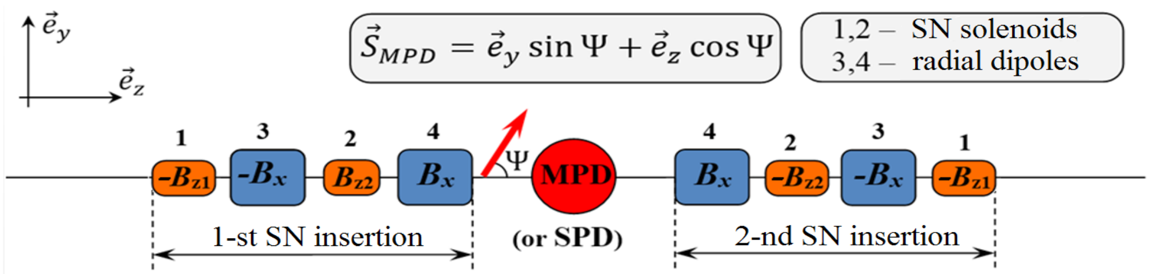
Polarization control at ν = 0. Spin-flip in ST

Technology of “Siberian snake” was proposed for NICA

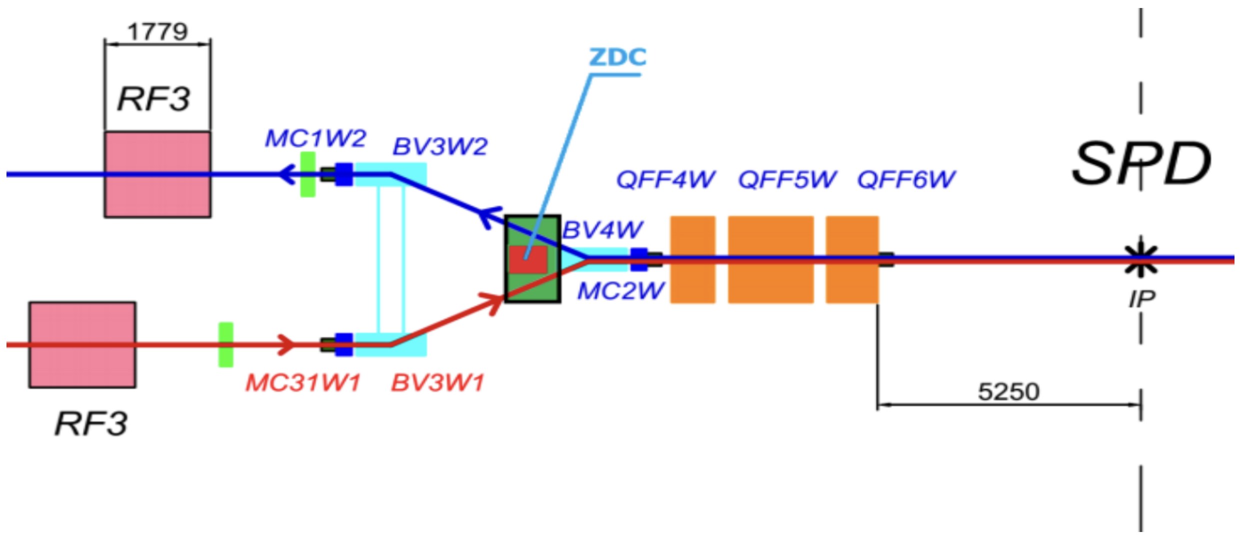
Analysis of different “snakes” (dipole, spiral dipole, solenoid) was performed: **solenoidal structure is optimal.**

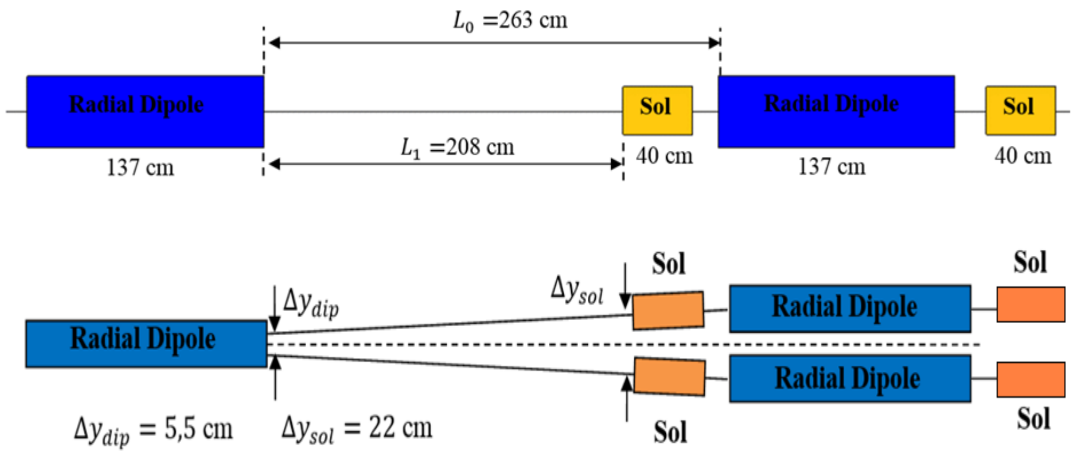
p: $(B_{||}L)_{max}=4\ast(5\div25)T\ast m$,

d: $(B_{||}L)_{max}=4\ast(15\div80)T\ast m$



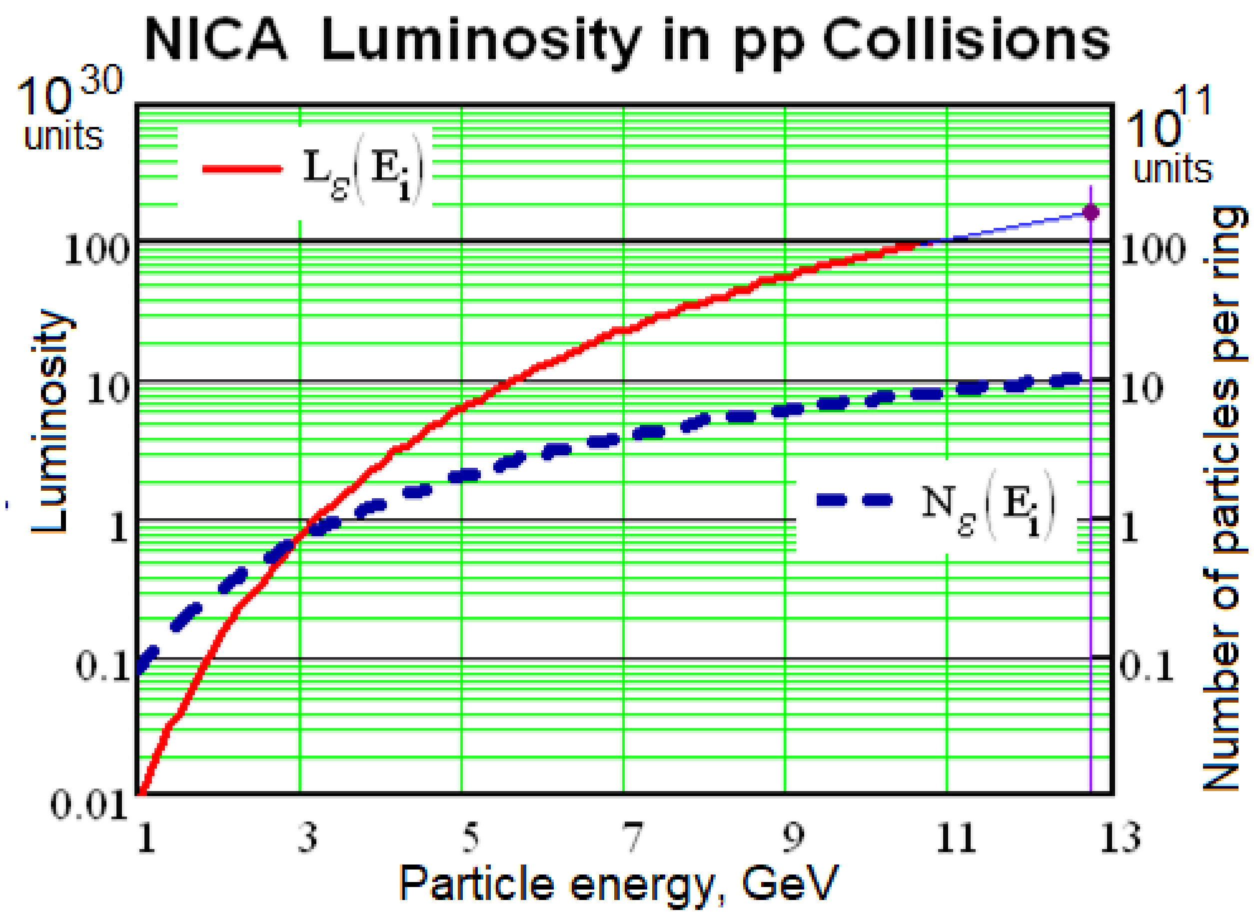
Ψ — angle between the polarization and the particle velocity. The field integral of 0,6 T·м, provides $\Delta\nu = 0.01$ for protons and $\Delta\nu = 0.003$ for deuterons. Minimum spin reversal time - 1 ms for protons and 10 ms for deuterons.





The collider lattice fragment where weak “navigator” solenoids are installed

NICA pp-collisions luminosity



Parameter	beam energy	
	2.0 GeV	7.2 Gev
Nuclotron Dipole Field Ramp up, T/s	0.6	0.6
Nuclotron Dipole Field Ramp down, T/s	1.0	1.0
Magnet field flat top duration, s	0.5	0.5
Total useful cycle duration, s	1.62	4.02
Dipole Magnetic Field	0.42	1.22
Acceleration time, s	1.67	1.67
Number of accelerated protons per pulse	$7\cdot10^{10}$	$7\cdot10^{10}$
Number of cycles to store $2\cdot10^{13}$ particles	2x285	2x285
Collider filling time at cycle duration, s	923.4	2291
Preparation of the beam in the collider (cooling, bunching emittance formation), s	100	100
Magnetic field ramp in the collider, T/s	0.06	0.06
Acceleration time from E_i to 12.6 GeV	~ 27	~ 13
Luminosity life time (30% polarization degradation due to spin resonances), s	5400	5400
Beam deceleration up to the new injection	~ 1.7	~ 0.8
Total cycle duration, s	6450	7803
Working part, %	~ 83	~ 70

❑ IP parameters: **β** = 35 cm, bunch length **σ** = 60 cm
bunch number – 22, collider perimeter **C** = 503 m

Lpeak ≈ $1.8\cdot10^{32}$ $cm^{-2}\cdot s^{-1}$ → Lav ≈ $10^{32} cm^{-2}\cdot s^{-1}$

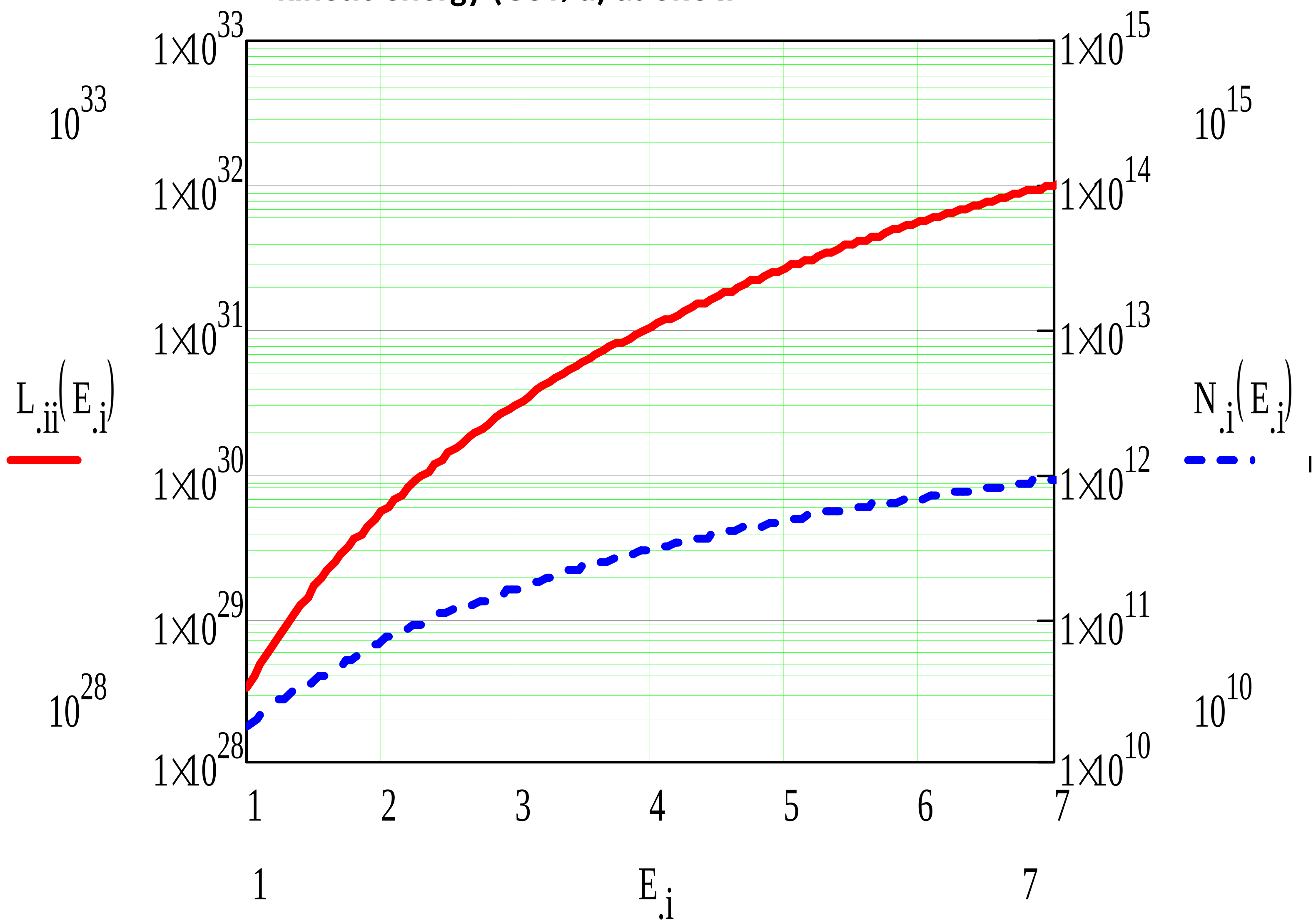
- The tests on polarized p-beam injection, storage, electron cooling can be started at ~2 GeV energy level from the beginning of the collider operation. The intensity of $5\cdot10^{8}$ ppp can be provided;
- New LILAC could be put into operation not earlier than in ….

NICA dd-collisions luminosity

Collider parameters

Parameter	Value
β^* , m	0.6
σ_s , m	0.6
$\varepsilon_{x,y}$, $\pi \cdot$ mm $\cdot$ mrad	1.1
N_{IP}	2
E_i , GeV/u	1.0 – 6.5
$\sqrt{s}$, GeV/u	3.86 – 14.86

Collider Luminosity vs deuteron kinetic energy (GeV/u) at one IP



No need in Siberian snakes→

I.N.Meshkov, Phys.Part.Nucl. 50 (2019) 663-682.

First phase SPD program with polarized deuterons

Technical issues for spin research program at Nuclotron/NICA in 2024-2026

-Continue operation and further improvement of the source of polarized ions SPI; waiting for the beam time at Nuclotron with LU-20 – 2025;

-Upgrade of the polarimeters: linac output; ring and extracted beams – 2024-2026;

-Preparation of the SPI spin modes control system for Nuclotron – 2024;

-Preparation of the first line experiments on the deuteron and proton spin manipulation at Nuclotron – 2024-2025;

-Design and manufacturing of the equipment (reduced BBC) for the SPD test bench at the collider – 2024-2025;

The major goal (for SPD) is to prove the possibility of the ST mode operation and the polarimetry development.

Technical issues for spin research program at NICA

-Preparation of new injection line for SPI for HILAC input
(polarized deuteron option together with HI option for NICA)>2024;

-Solenoidal snake with 12-20 T·m design, manufacture and installation at Nuclotron >2025;

-New LILAC design, manufacturing and tests >2024;
(after clarification of the LILAC situation ordered and paid in Germany);

-New electron cooling system for polarized proton option at NICA design, manufacture and installation;

-New solenoidal snakes(4*6T·m) design, manufacture and installation at NICA;

-Beam polarimetry development;

The goal is to reach the suitable for SPD phase 1 program luminosity and polarization of the polarized beams.

CONCLUSION

LHEP JINR has good experience in spin physics, especially, with polarized deuteron beam.

The results obtained during last years demonstrate the progress in the development of the spin research infrastructure (ion source, deuteron and proton polarimetry etc.).

Further development of the proton beam polarimetry, especially, inside the Nuclotron ring is necessary.

Experiments with the transversally polarized deuteron beams can be started at the first stage of the NICA spin research infrastructure commissioning.

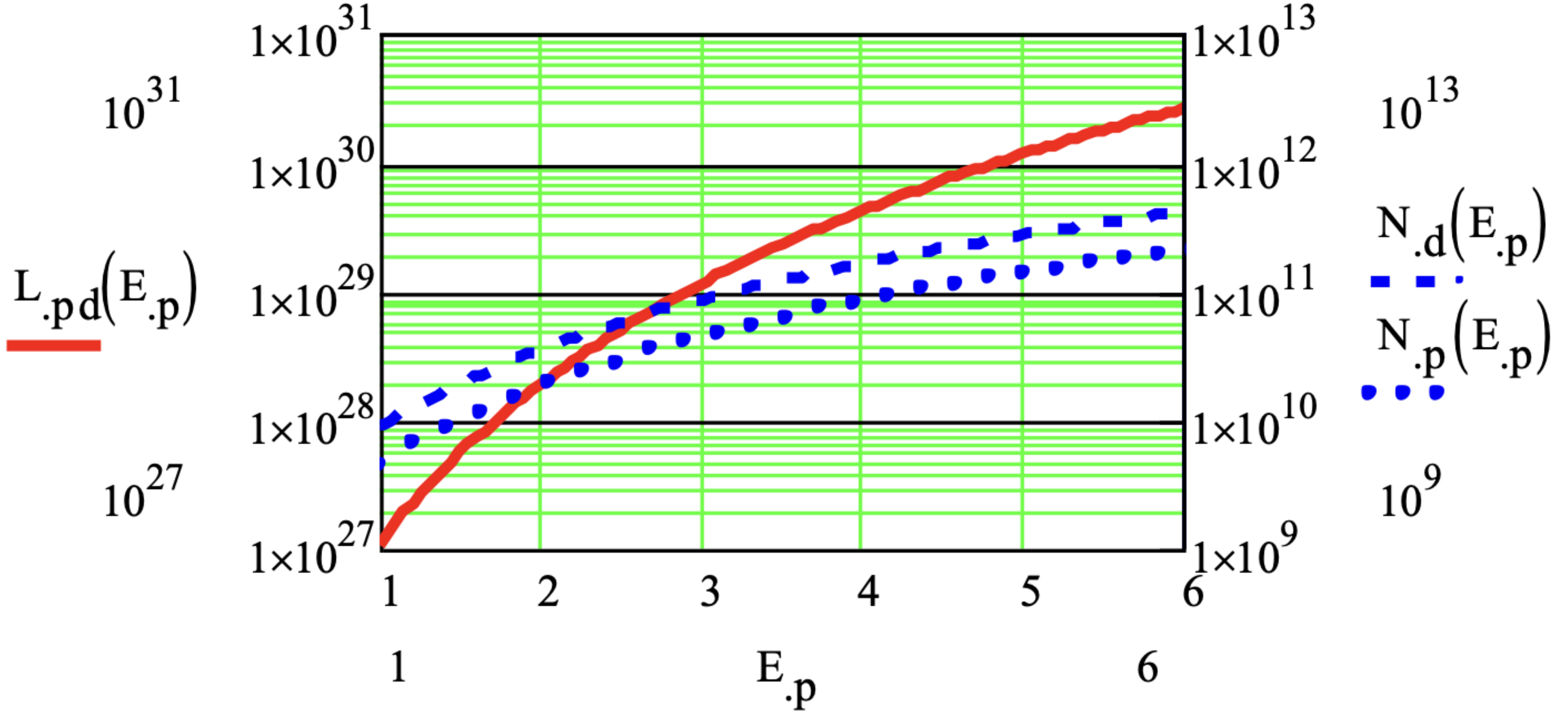
Experiments with the polarized protons at the integer resonances $\gamma G=4\text{-}7$ (up to 3.5 GeV/c) also can be started at the first stage.

The urgent technical task is to check the possibility of the ST mode using Nuclotron spin infrastructure.

Backup

NICA dp-collisions: luminosity & scenarios

2 IP, but the Luminosity optimized for 1 IP

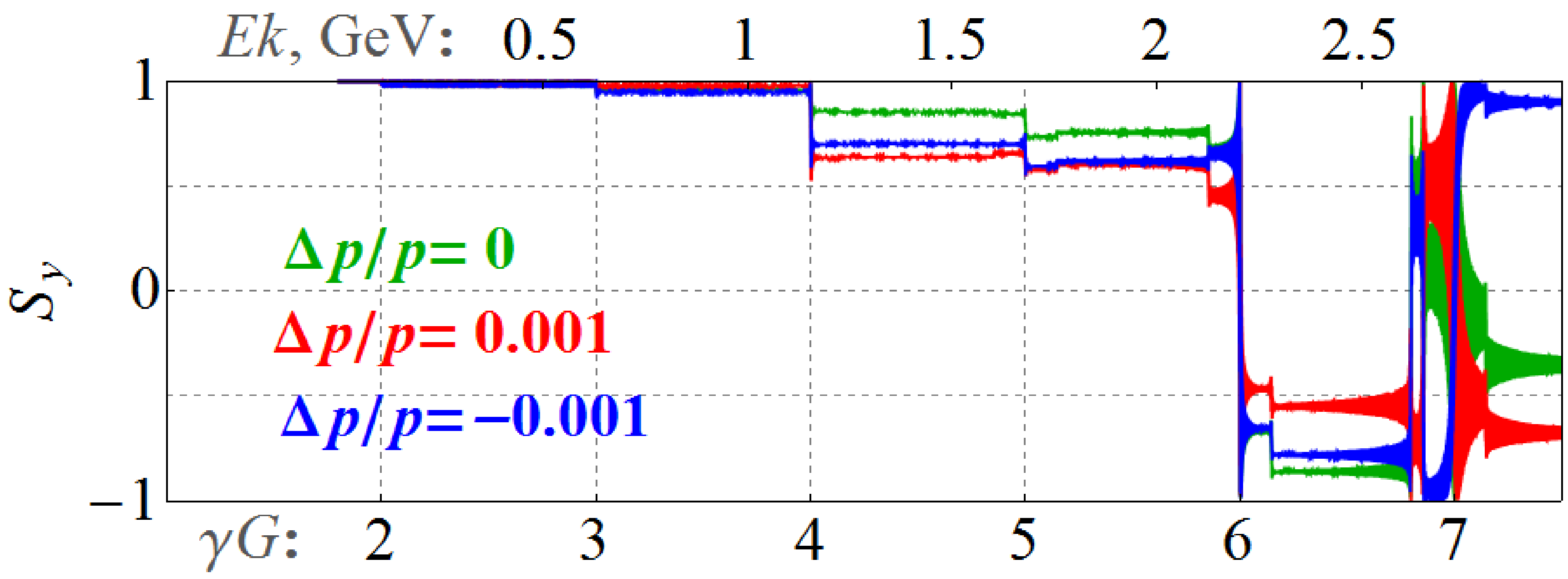


- N_d, N_p - are particle number per bunch;
- Storage mode are necessary;
- Bunch number - 22

- Both injection chains are used. HILAC cannot provide polarized particles:
- Single asymmetry measurements only.

- Preparatory tests on storage, electron cooling (?) and experiments can be started over full energy range from the beginning of the collider operation;
- **Lower energy scenario:** Extraction from Nuclotron at 1-1.5 GeV, storage, deceleration, bunch formation etc.

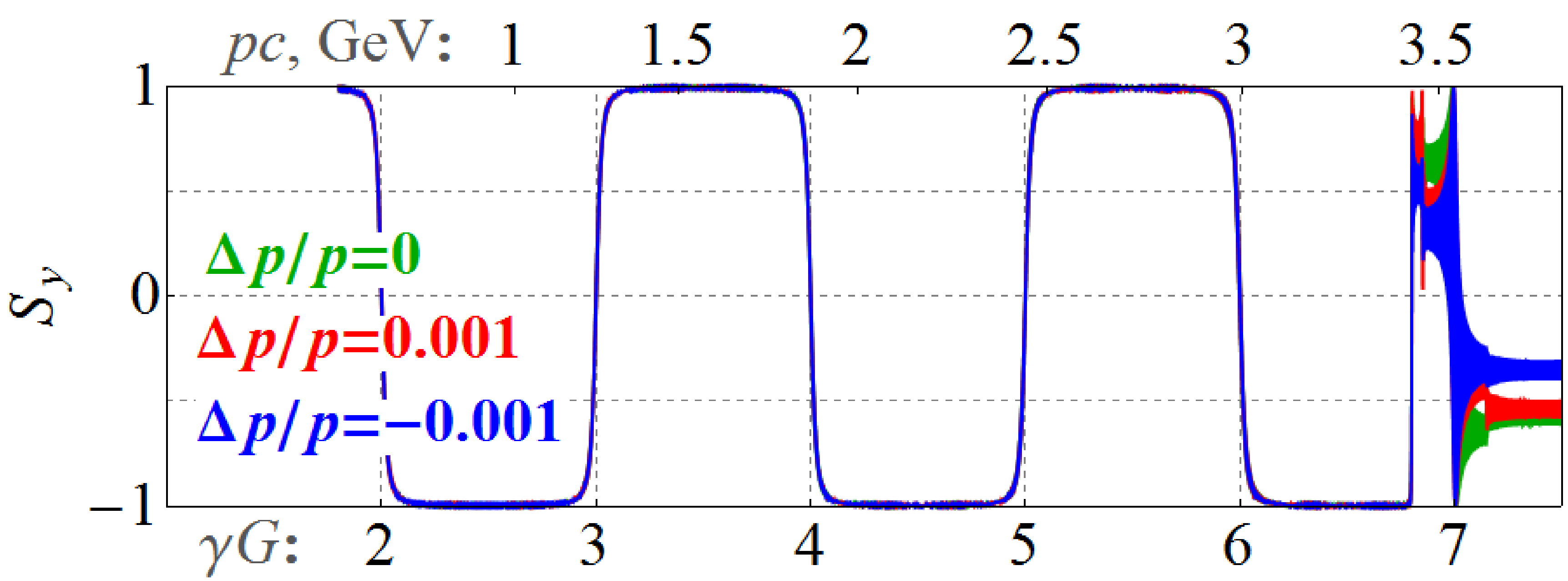
Acceleration of Polarized Proton up to 3.4 GeV/c



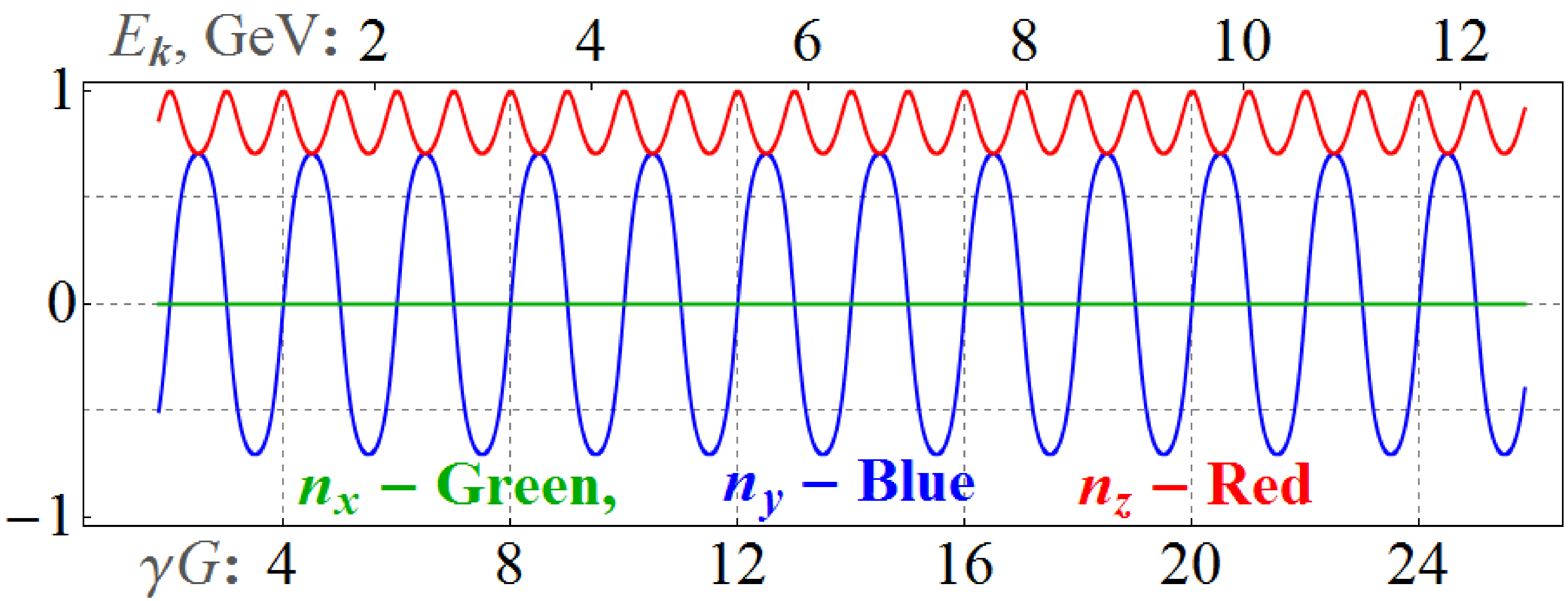
The vertical proton spin components during acceleration of three protons with different momenta in the Nuclotron without partial snake

Synchrotron oscillations have strong influence on the proton spin dynamics

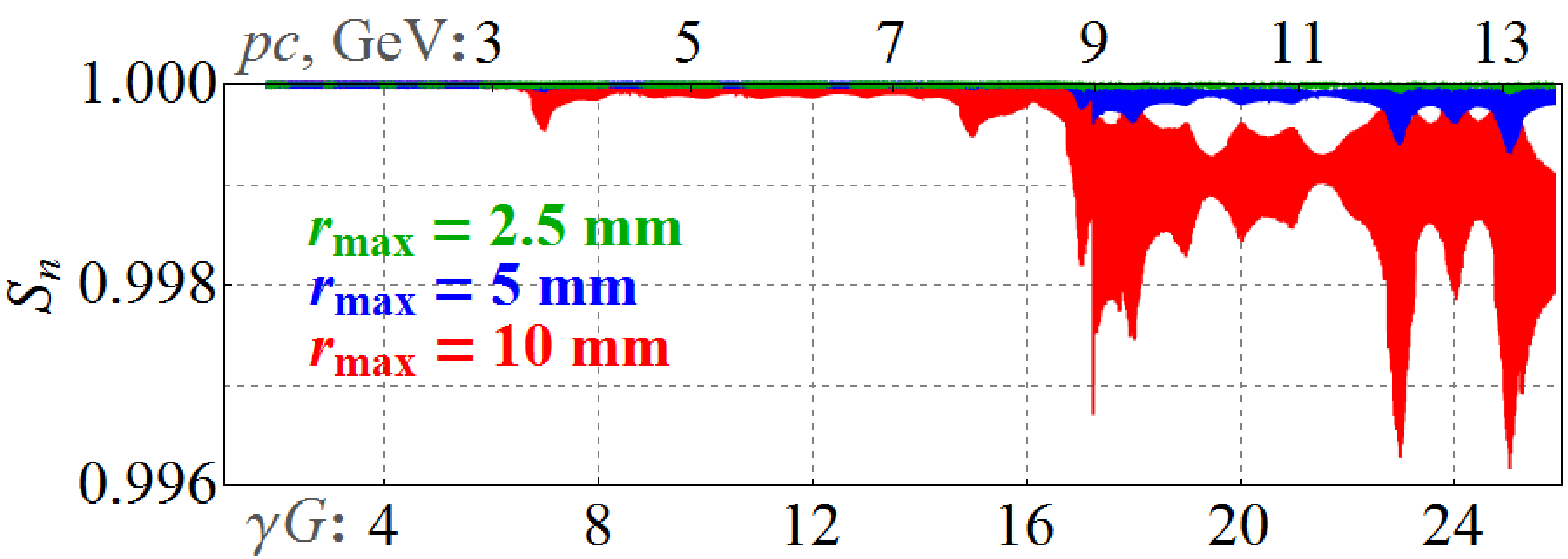
To eliminate a series of integer resonances, it is sufficient to use a partial snake with a **small field integral**.



The 5% solenoid snake is required the solenoid field integral of **0.65 T·m** at the momentum of **3.4 GeV/c**.



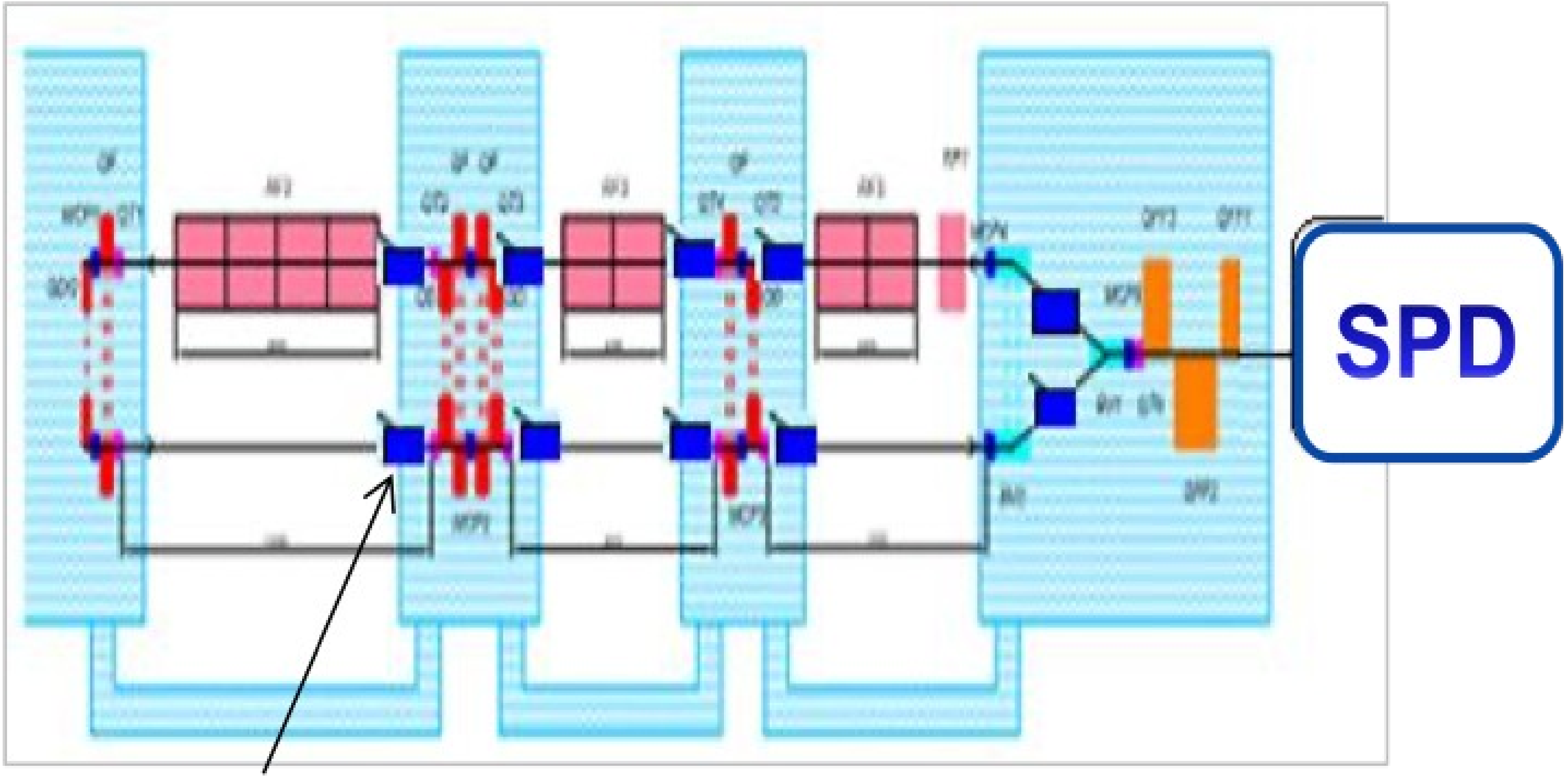
The $\vec{n}$-axis components at acceleration with the 50% solenoidal snake



The $S_n = \vec{S} \cdot \vec{n}$ projections at acceleration of three protons with the 50% solenoidal snake

The requirement solenoid field integrals are of

25 Tm for the **50% snake** and **12.5 Tm** for the **25% snake**


SPD