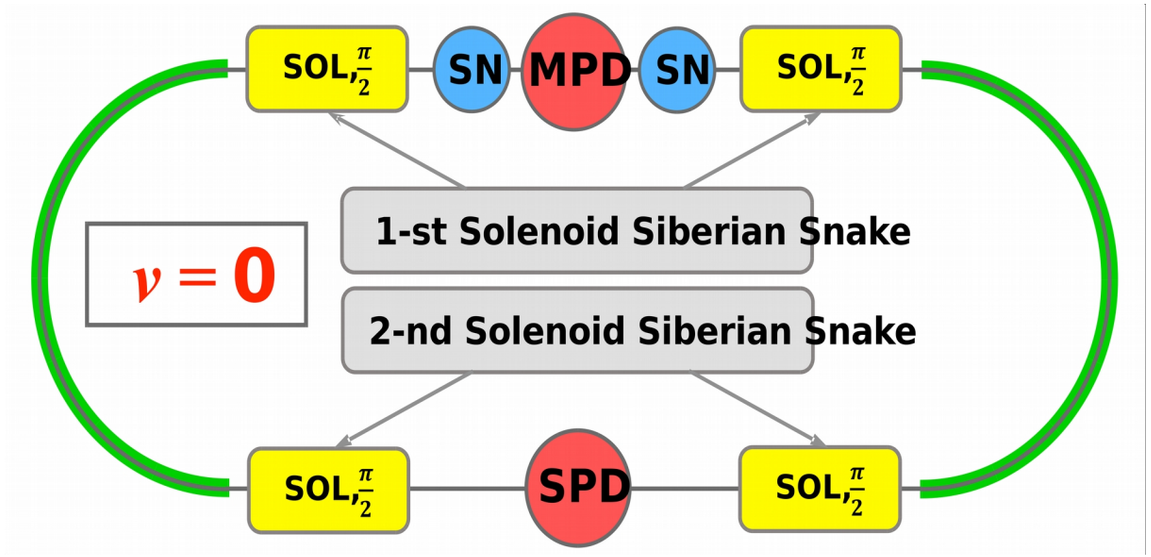
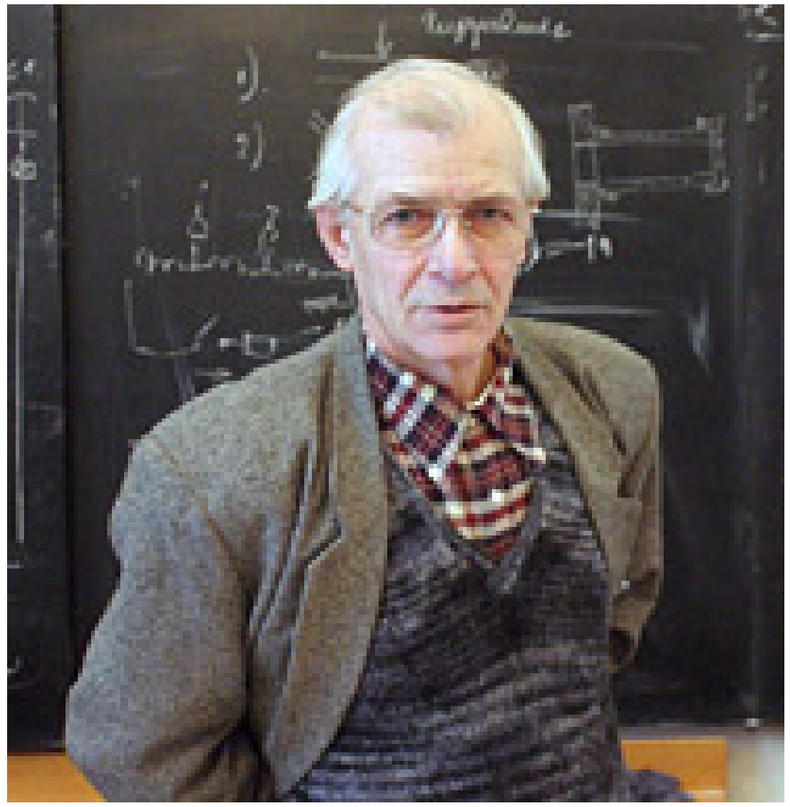
Polarized beams at NICA





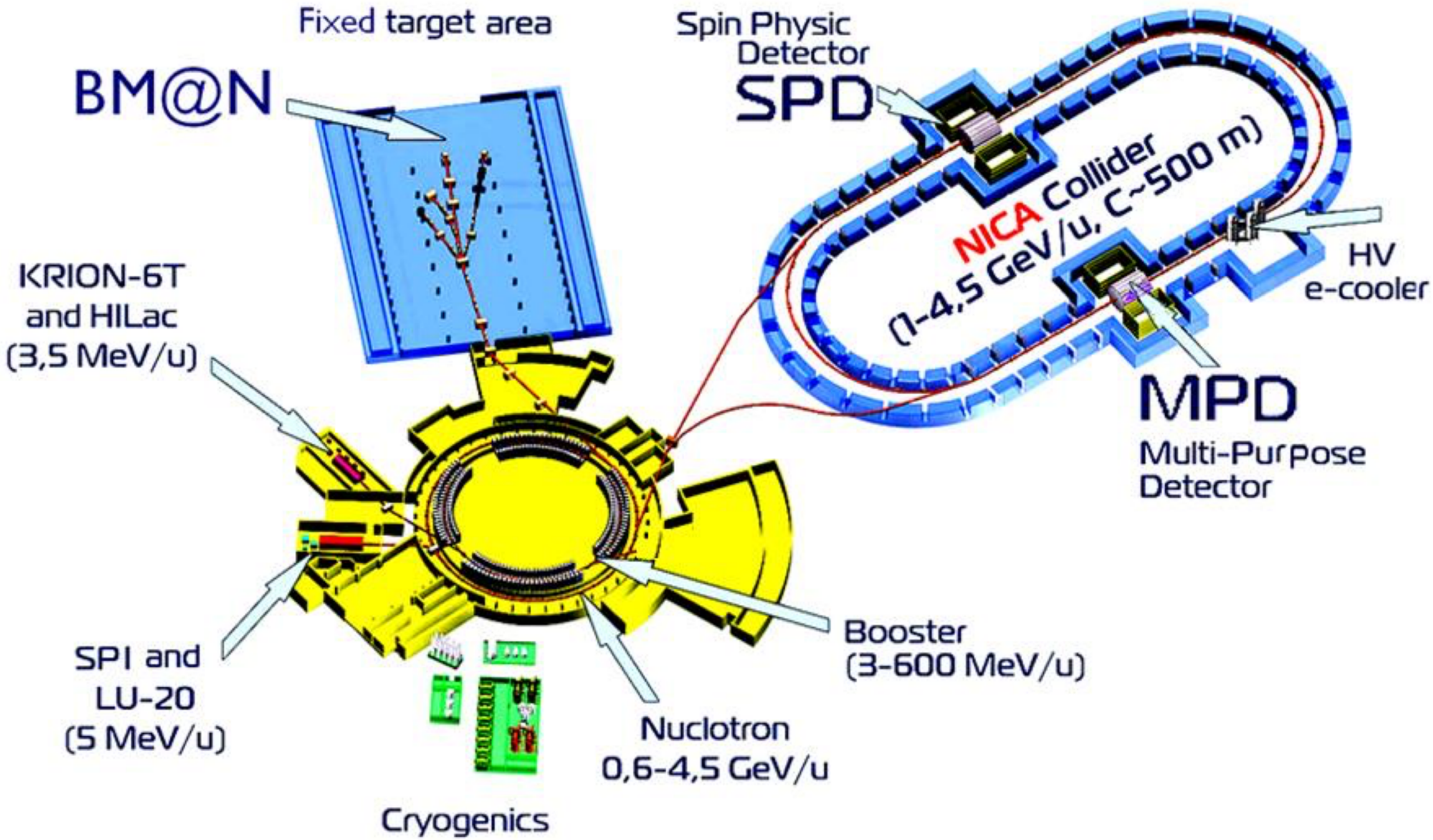
A.D.Kovalenko

31.10.1944-30.03.2021

V.P.Ladygin

for SPD DAC meeting 26.05.2021

NICA Complex Main Components



General requirements to the beam facility

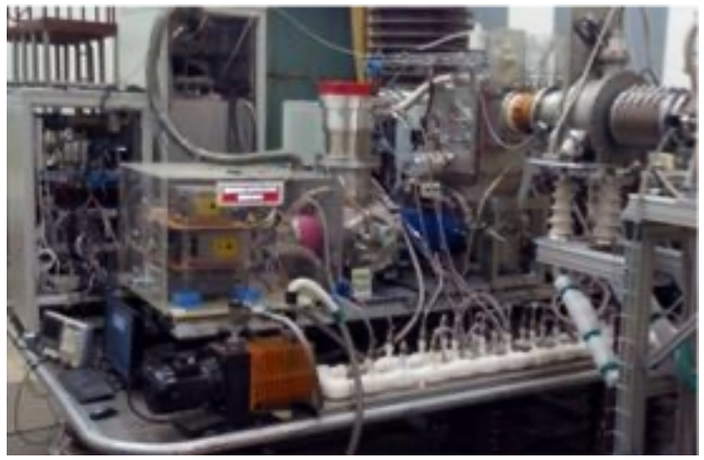
- polarized and non-polarized p-; d–collisions
- $p\uparrow p\uparrow(p)$ at $\sqrt{s_{pp}} = 12 \div 27$ GeV (5 ÷ 12.6 GeV kinetic energy)
- $d\uparrow d\uparrow(d)$ at $\sqrt{s_{NN}} = 4 \div 13$ GeV (2 ÷ 5.5 GeV/u kinetic energy)
- $L_{av} \approx 1 \cdot 10e32\ cm^{-2}s^{-1}$ (at $\sqrt{s_{pp}} \geq 27$ 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 1.0E+32 cm-2•s-1 remain the 1st 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•10e11 for 8 mks;

The spin modes (p_z,p_{zz}): (0,0), (0,-2),

(2/3,0) and (-1/3,+1) 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” is now manufacturing . The LILAC output energy is 12 MeV.

General View of SPI

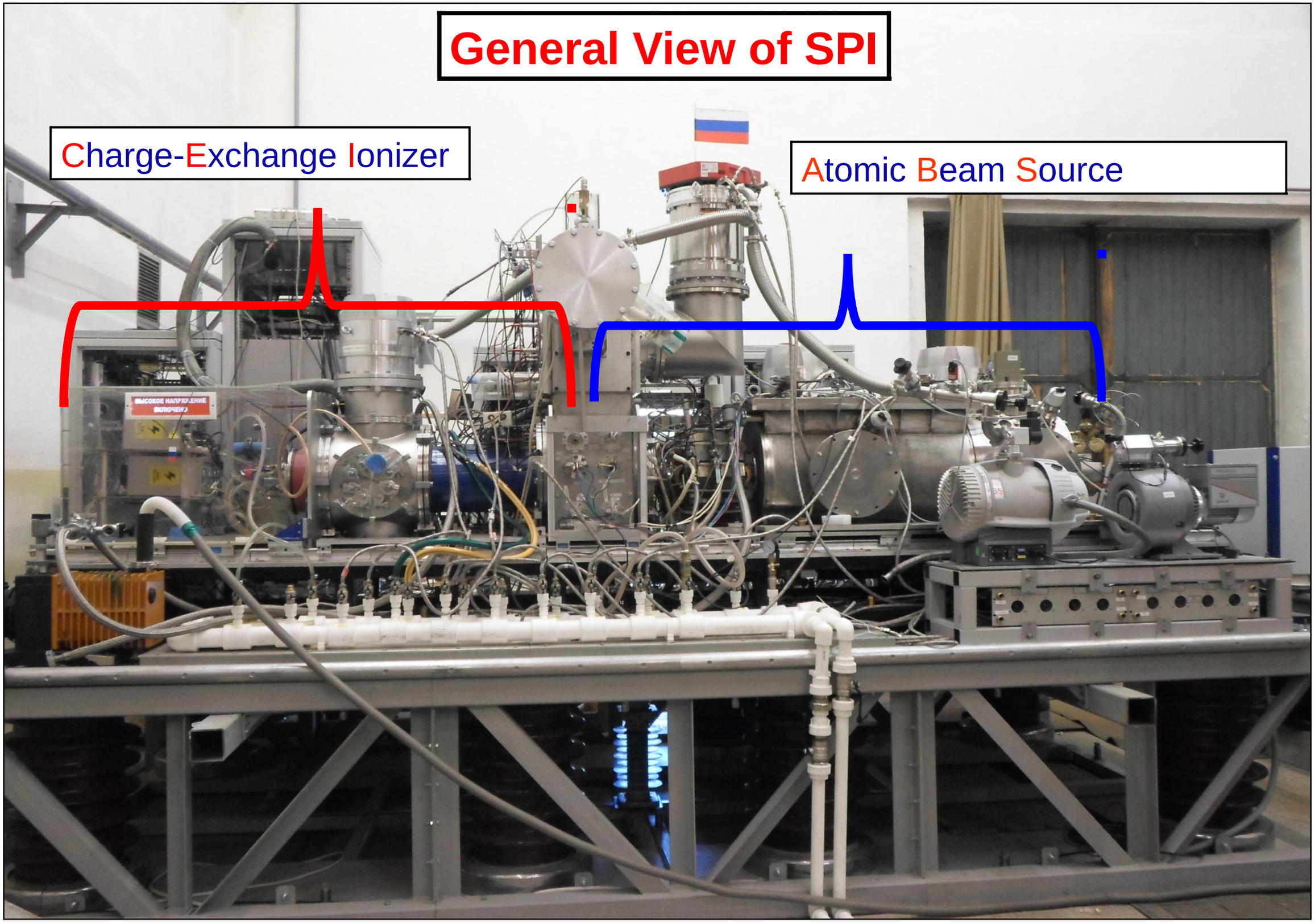
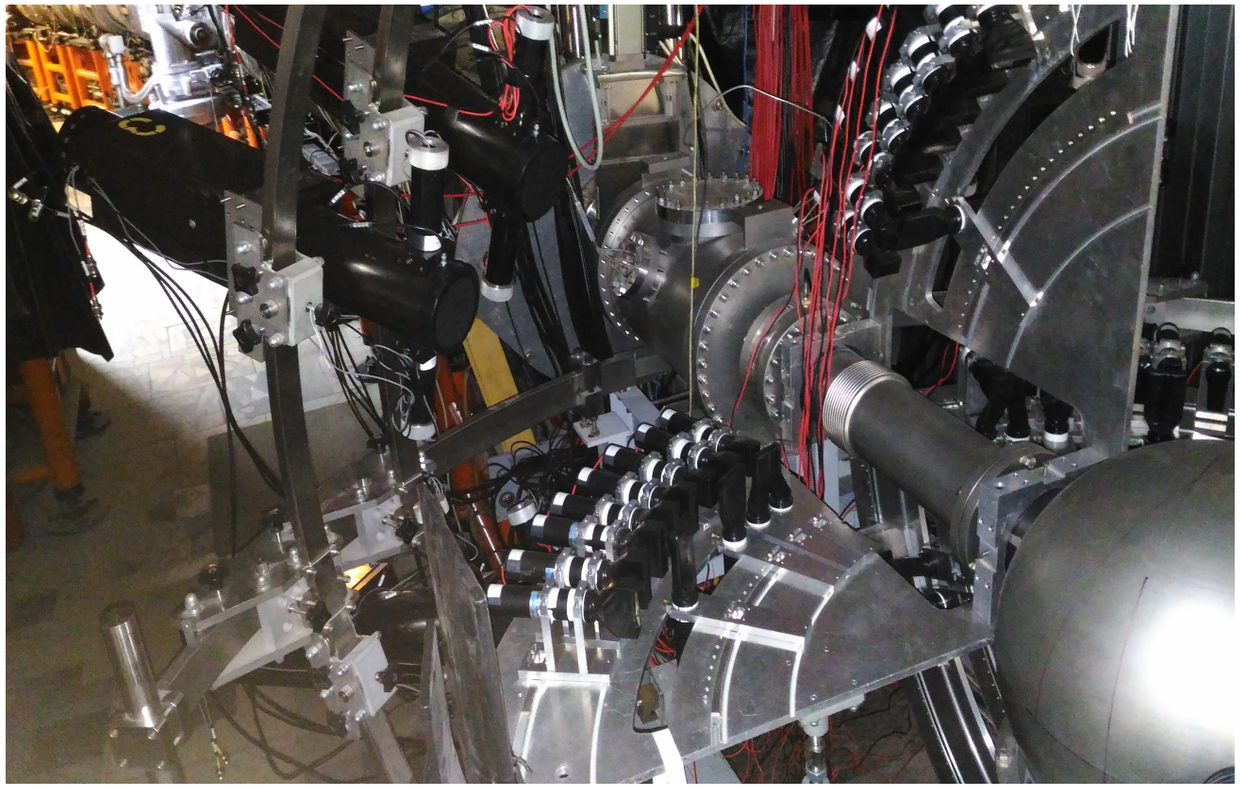
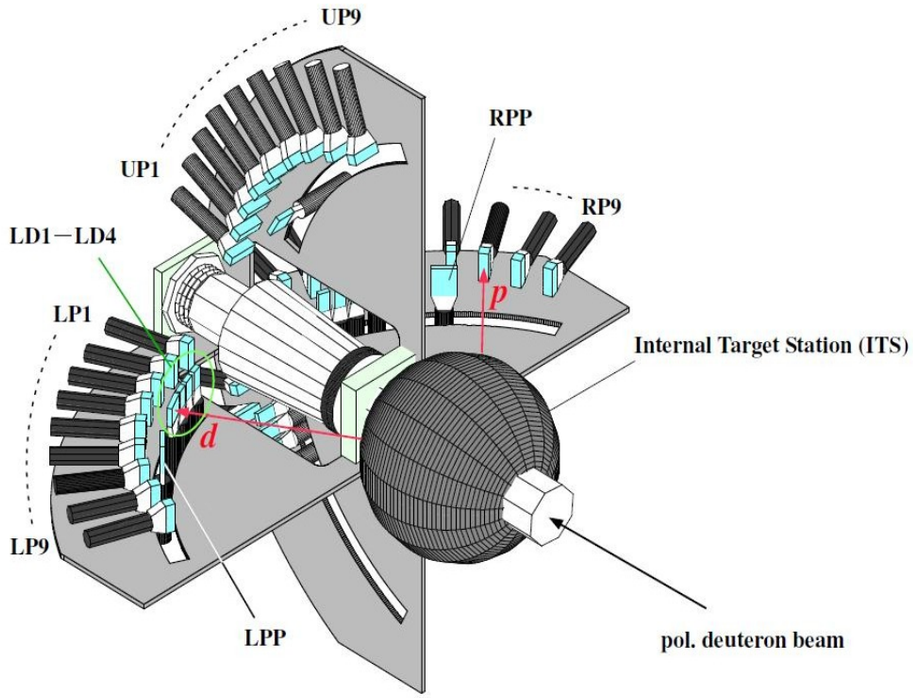


Figure of merit will be increased in future by a factor ~10^2-10^3

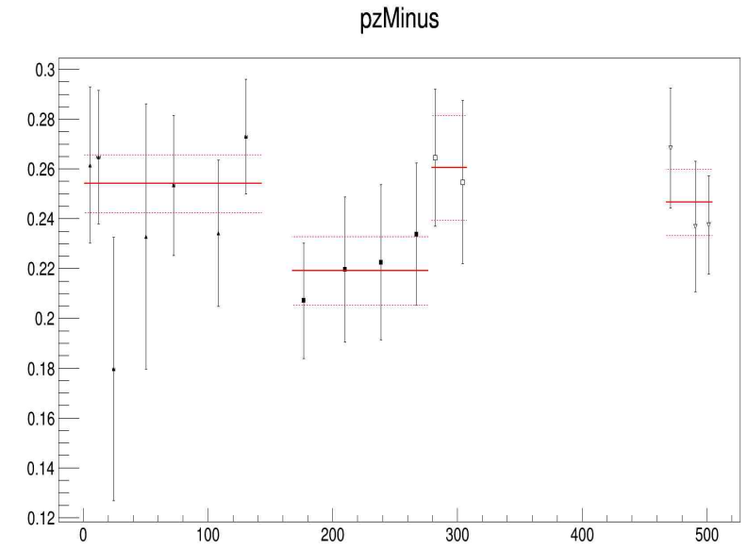
DSS polarimeter at Internal Target Station at Nuclotron

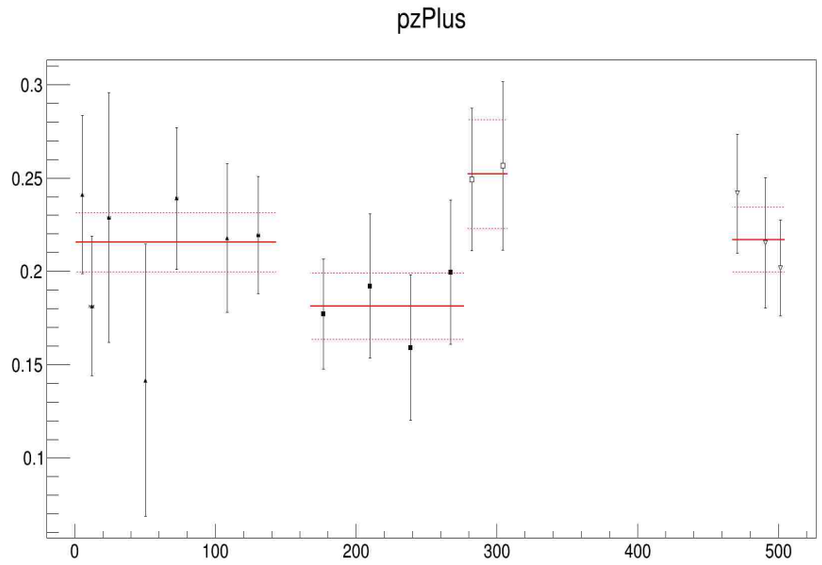


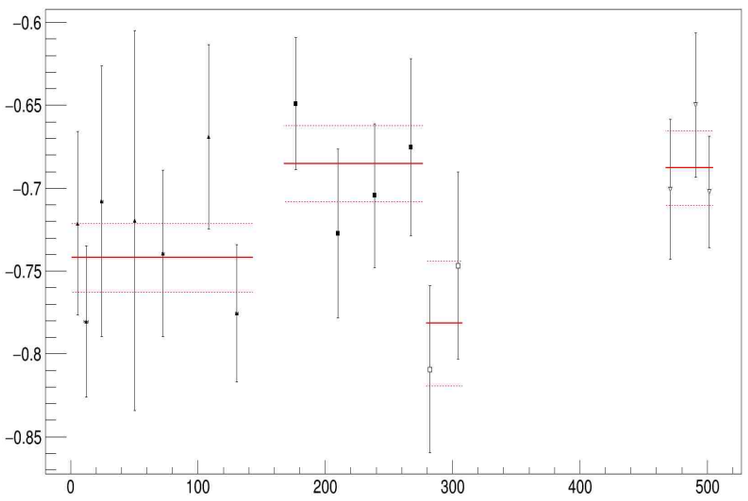


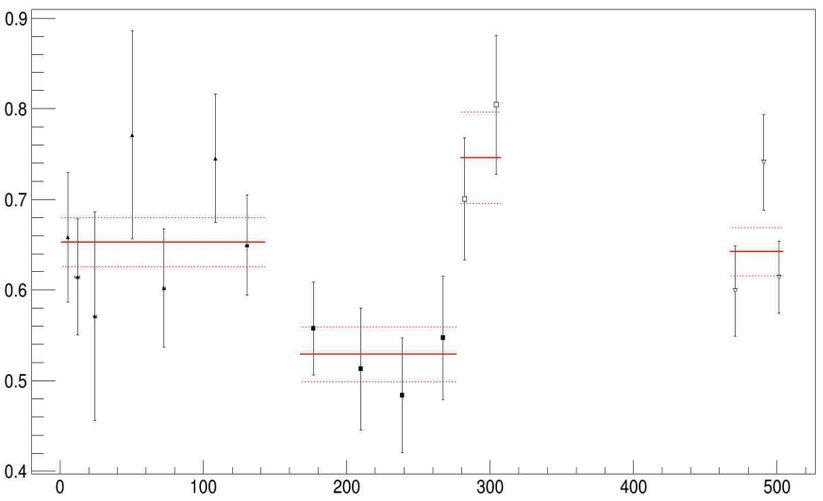
Deuterons and protons in coincidences using scintillation counters
Internal beam and thin CH_2 target (C for background estimation)
Permanent polarization measurement at 270 MeV (between each energy).
Analyzing powers measurement at 400-1800 MeV
The data were taken for three spin modes of SPI: unpolarized, “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 $2\text{-}4\cdot10^8$ ppp.

DSS results for deuteron beam polarization



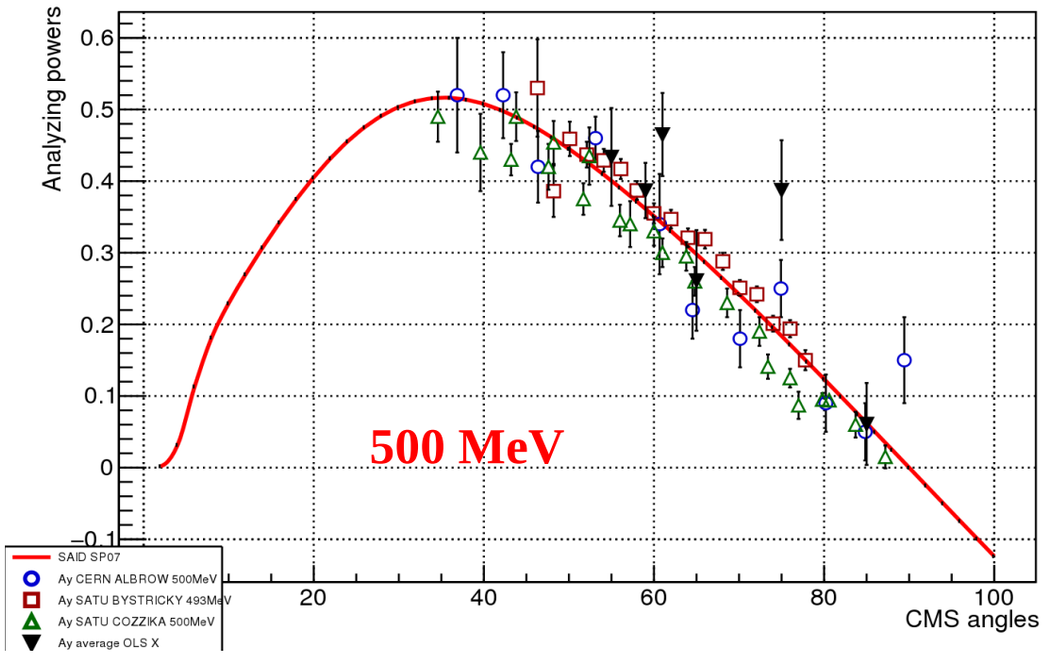


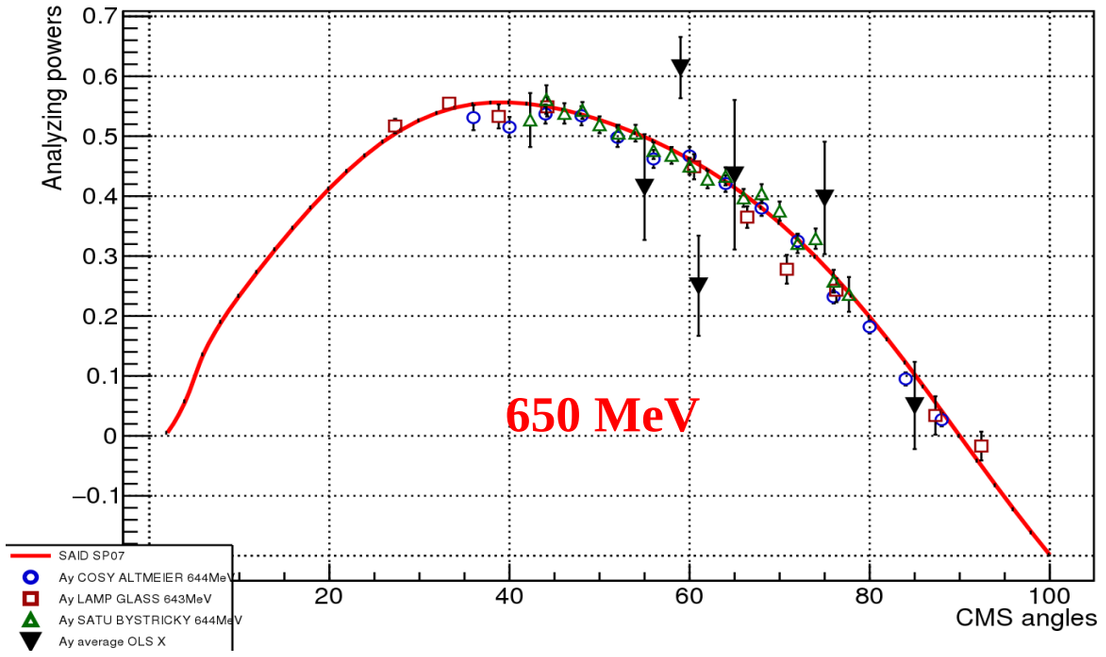




SPI was tuned for 6 spin modes
(p_z,p_{zz}) = (1/3,1), (1/3,-1), (0,+1), (0,-2), (-2/3,0),(+1,0).

DSS results for proton beam polarization





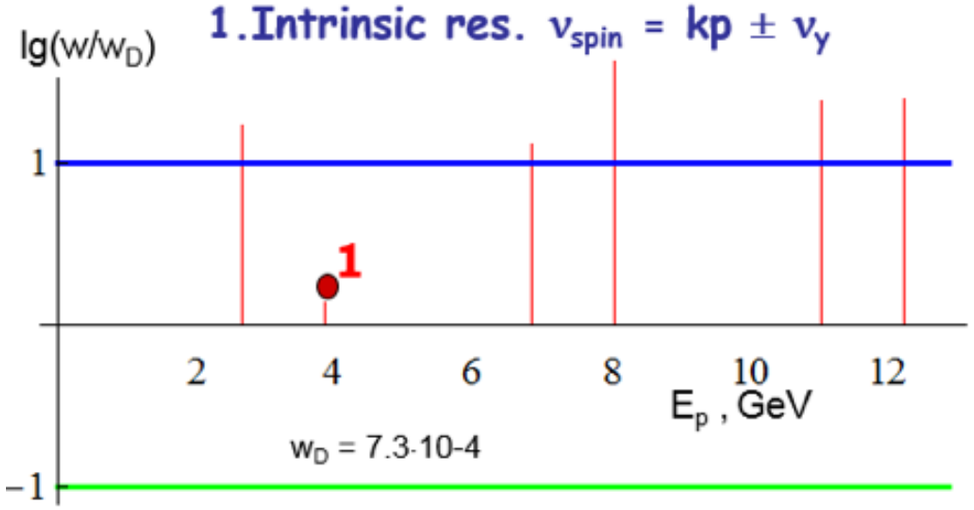
Injection of 5 MeV protons into Nuclotron ring.
Acceleration up to 500 MeV- no serious depolarization resonances (Yu.Filatov).

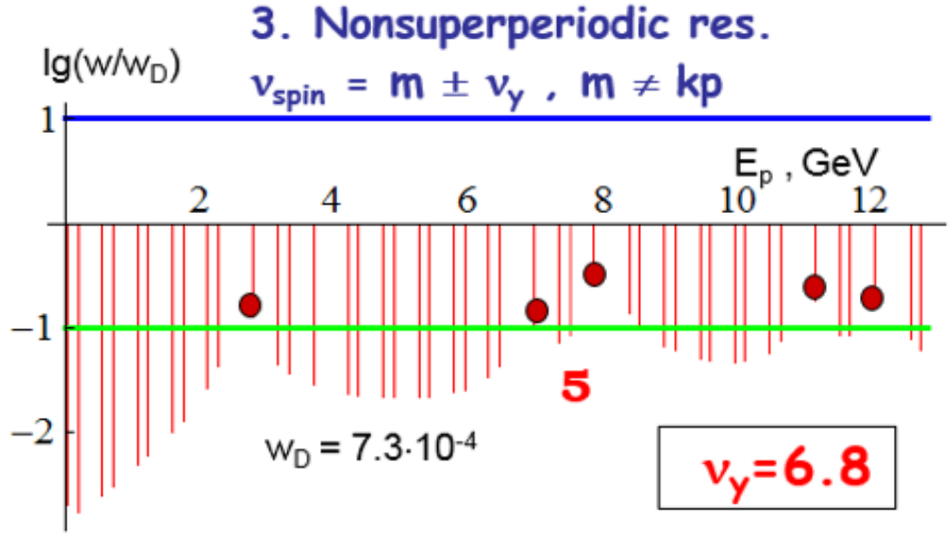
IPol=1 P=1 (WFT 1→3)
IPol=2 P=0 (unpolarized)
IPol=3 P=1 (WFT 1→3)

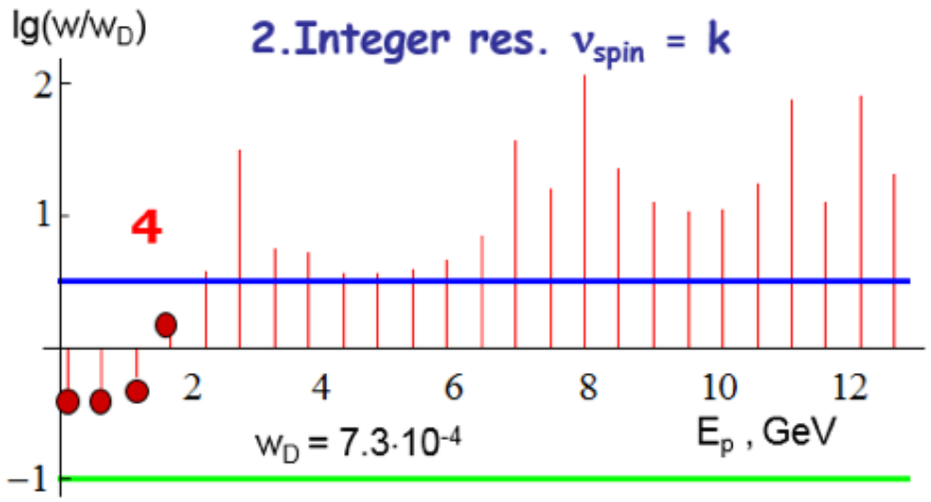
Having the asymmetries for 10 angles (50^0-130^0 in the cms) we obtained the averaged value of the proton beam polarization

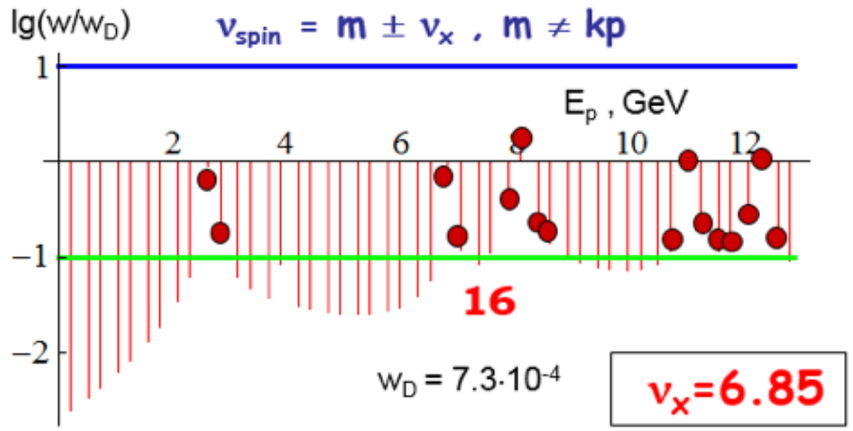
Unpolarized protons: I∼$1.5\cdot10^8$ ppp Py=0.056 ±0.021
Polarized protons: I∼$2\text{-}3\cdot10^7$ ppp Py=0.367 ±0.015

Proton spin resonances at Nuclotron





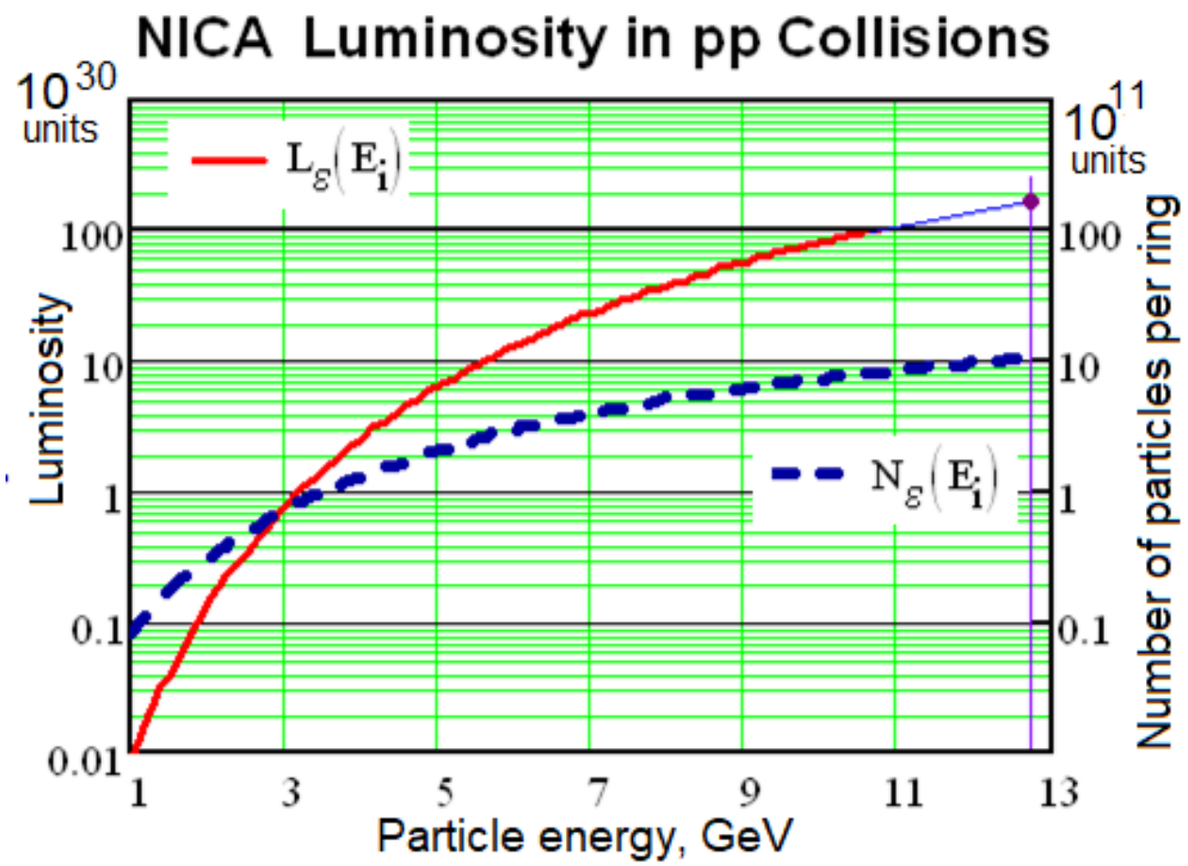




A.M.Kondratenko, Yu.N.Filatov et al.

Effective proton polarimetry at Nuclotron ring is very important!

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	$7 \cdot 10^{10}$	$7 \cdot 10^{10}$
Number of cycles to store $2 \cdot 10^{13}$ 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

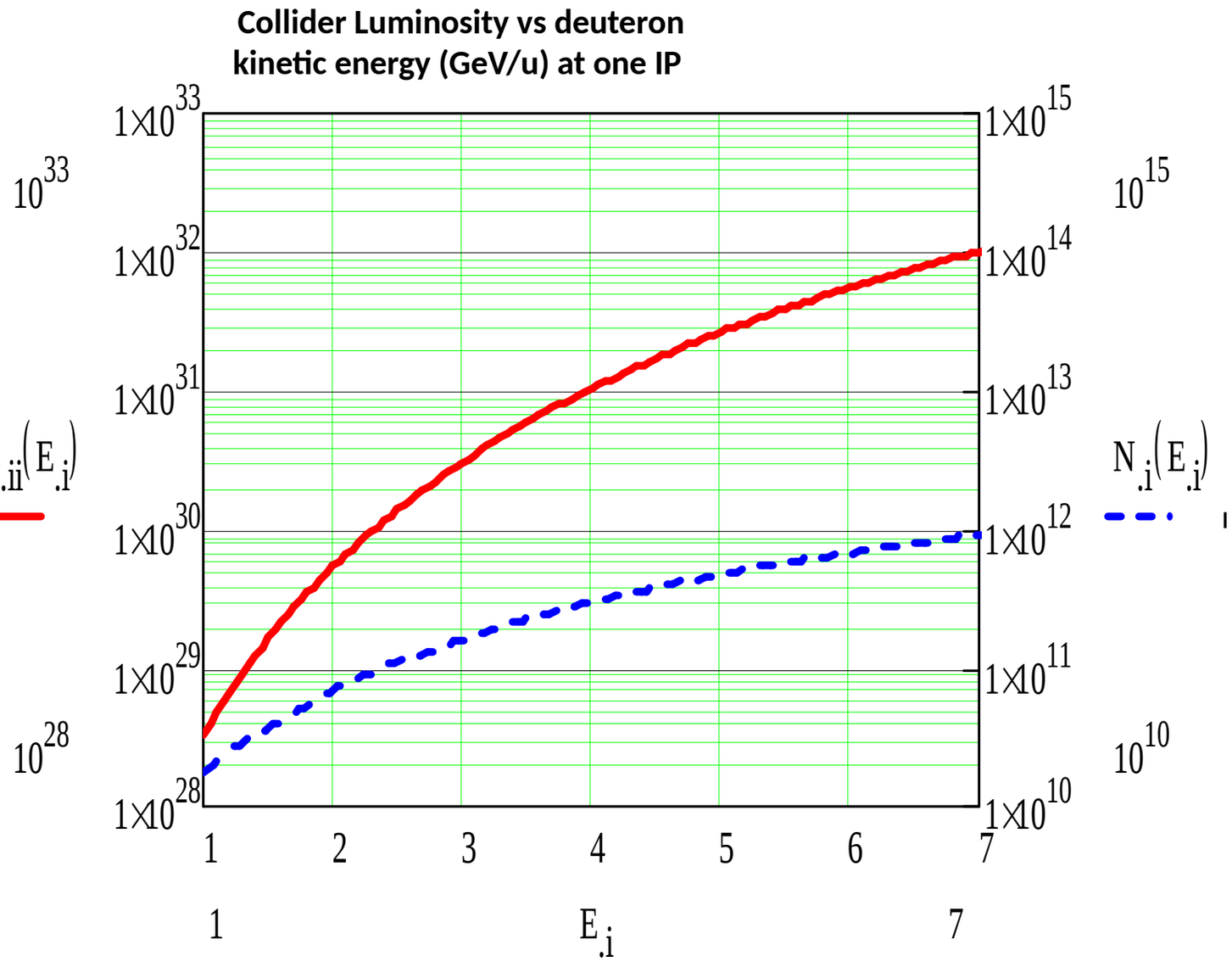
Lpeak ≈ 1.8·E+32 cm-2·s-1 → Lav ≈ (1.0E+32cm-2·s-1)

- 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•10E+8 ppp can be provided;
- The LILAC could be put into operation not earlier than in 2023-24.

NICA dd-collisions luminosity

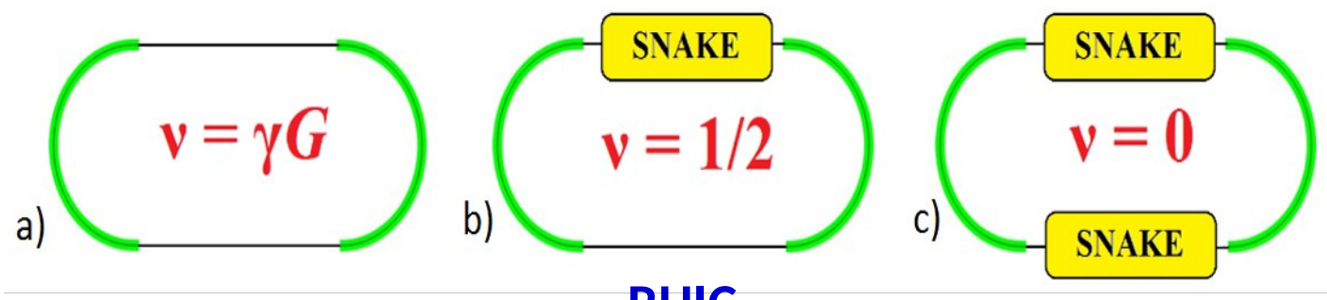
Collider parameters

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

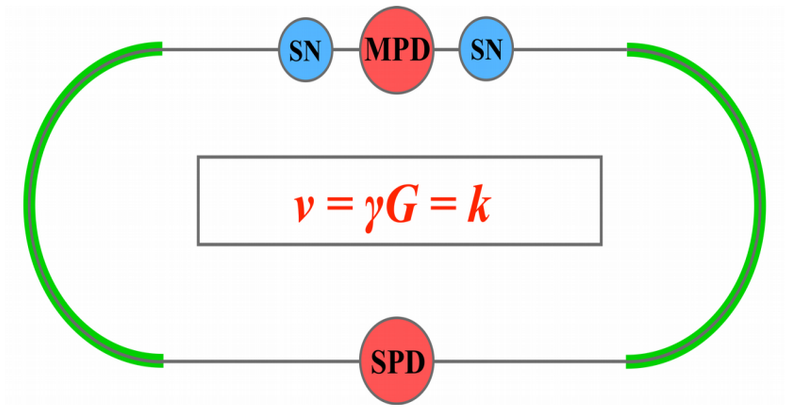


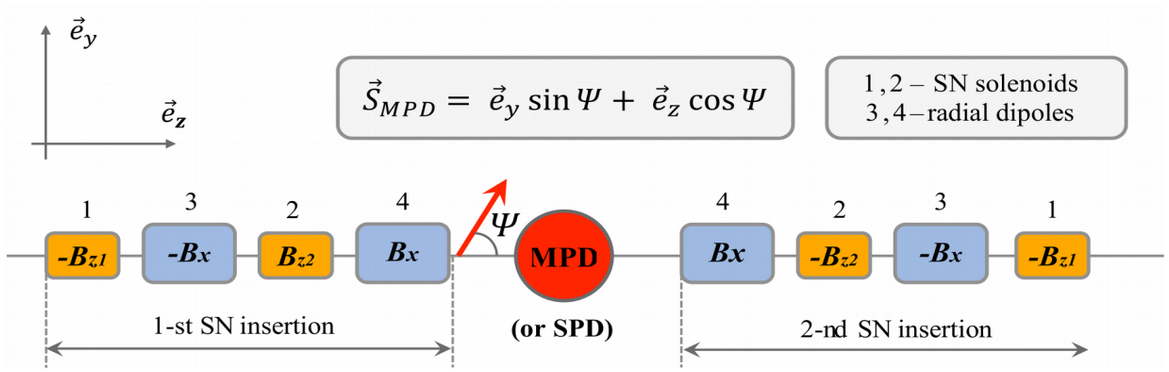
I.N.Meshkov, Phys.Part.Nucl. 50 (2019) 663-682.

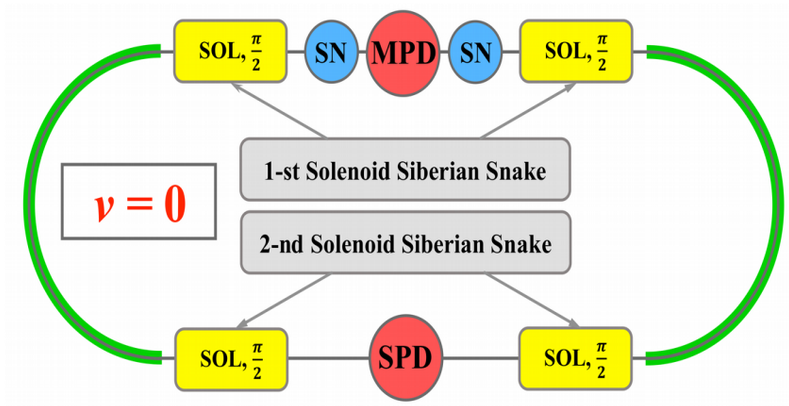
Spin manipulation at NICA



RHIC







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

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

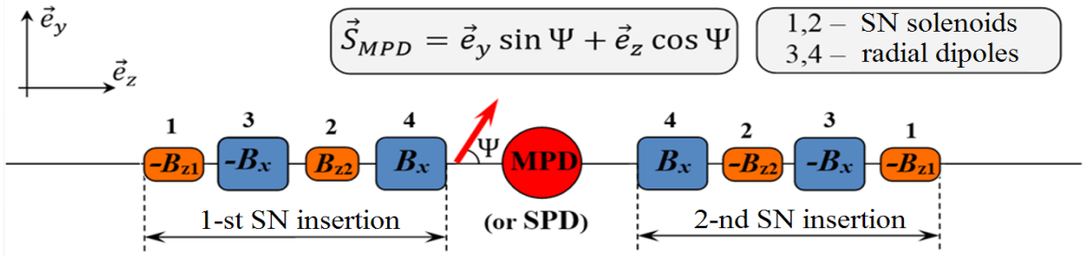
Polarization control at ν = 0. Spin-flip in ST

Technology of “Siberian snake” was proposed for NICA

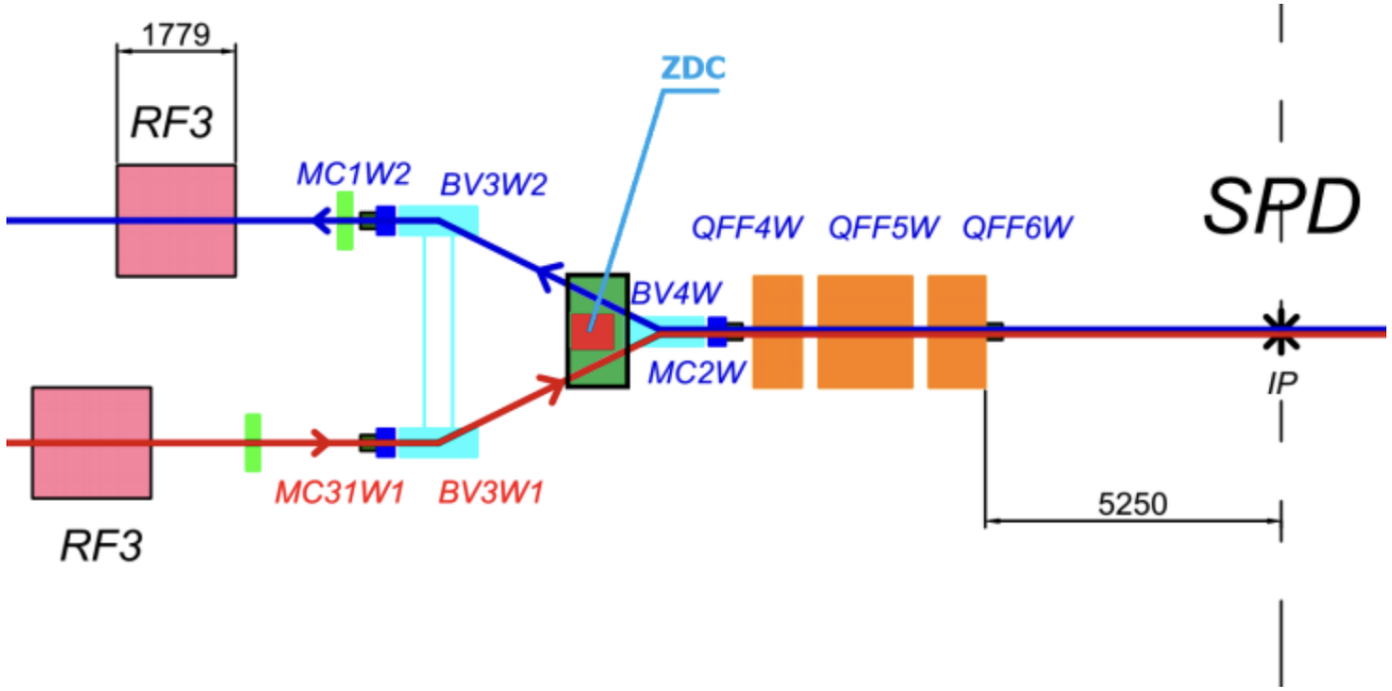
Analysis of different “snakes” (dipole, spiral dipole, solenoid) was performed: solenoidal structure is optimal.

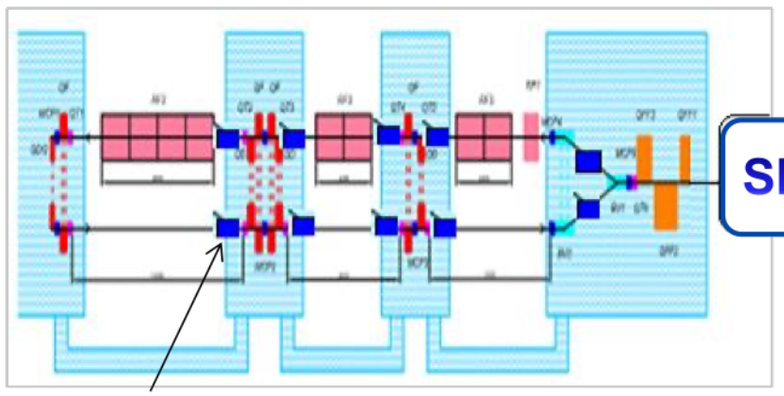
p: $(B_{||}L)_{max}=4*(5\div25)T*m$,

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



Ψ — angle between the polarization and the particle velocity. The field integral of 0,6 Т·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.

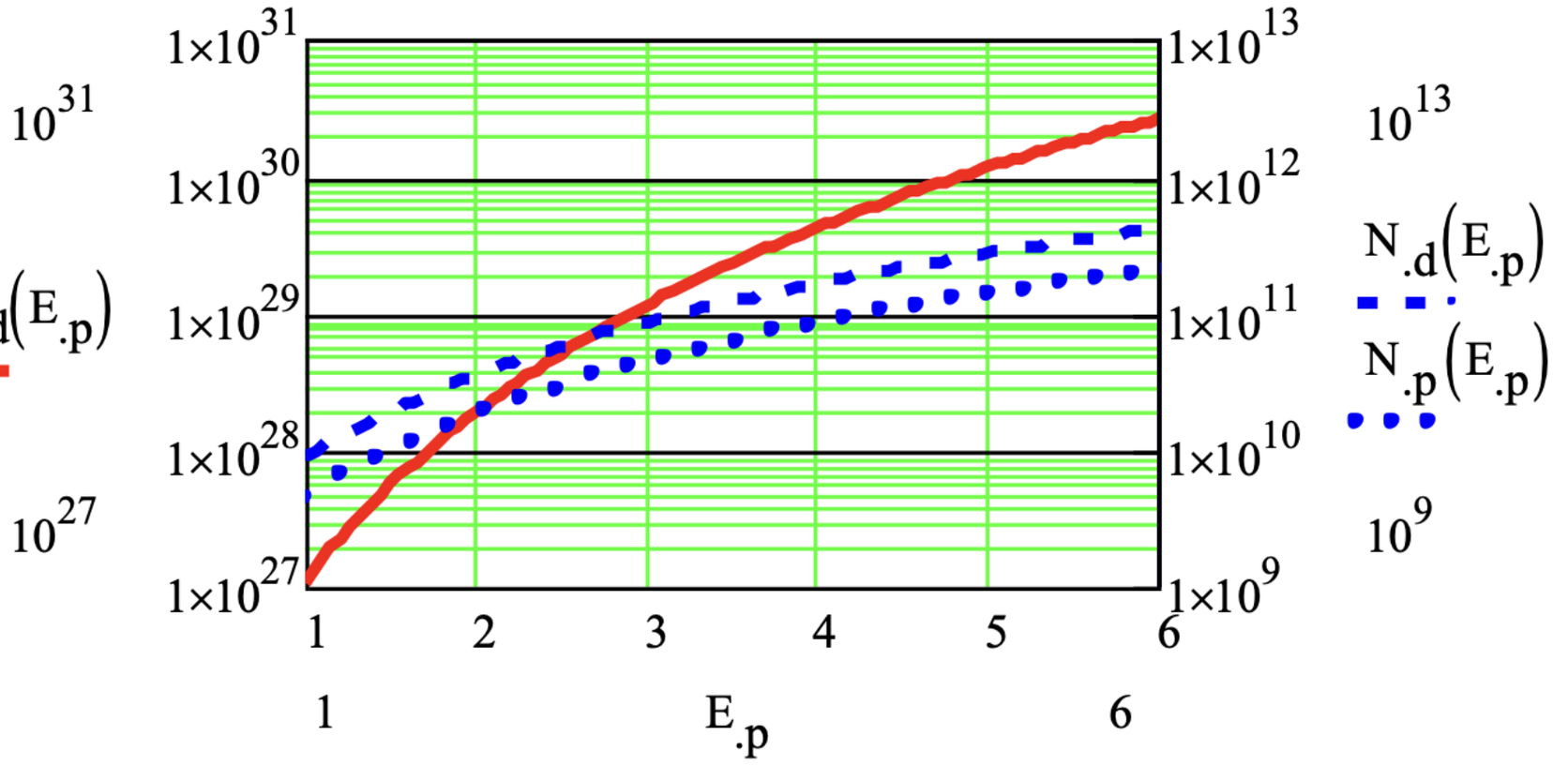




The collider lattice fragment where weak “navigator” solenoids are installed

NICA 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.

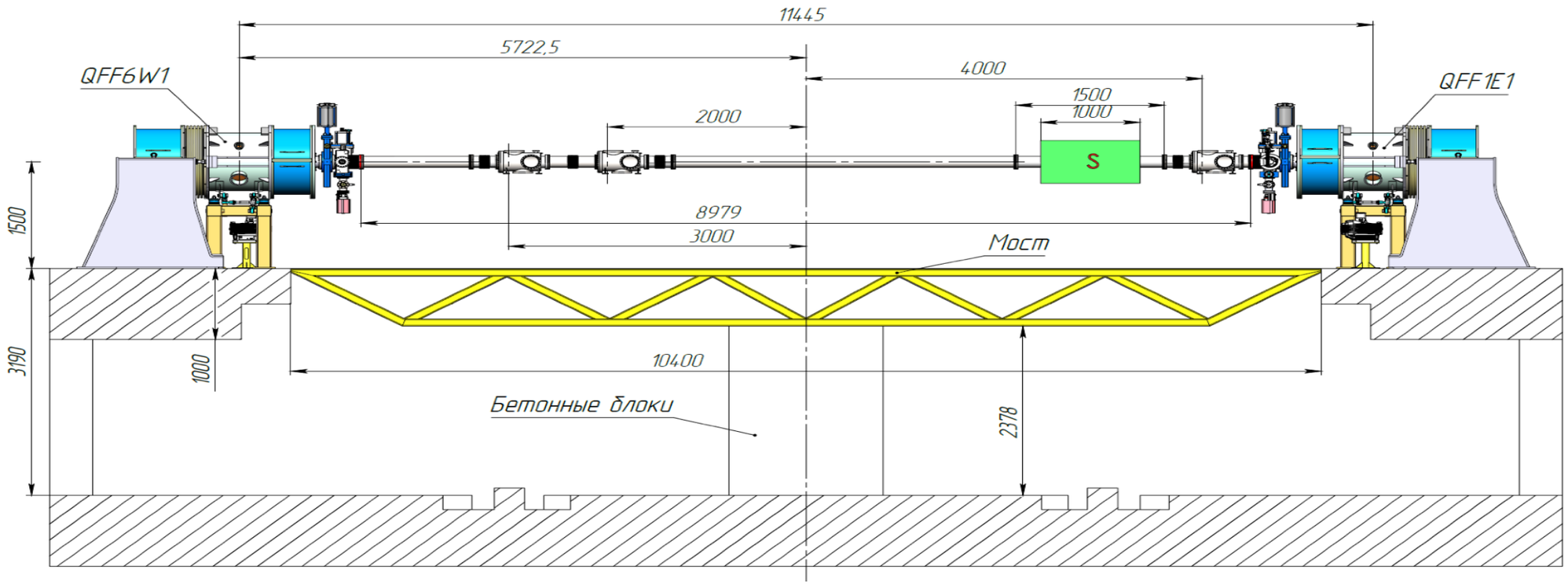
- Preparatory tests on storage, electron cooling (?) and experiments can be started over full energy range from the beginning of the collider operation;
- **Lower energy scenario:** Extraction from Nuclotron at 1-1.5 GeV, storage, deacceleration, bunch formation etc.

Technical issues for spin research program at NICA

- Continue operation and further improvement of polarized ion source SPI, waiting beam time at Nuclotron – 2021-2022;
- Upgrade of the polarimeters: linac output; ring and extracted beams – 2021-2023;
- Manufacturing of the 6T SC-solenoid model for the SPD test bench -2021-2023;
- Design and manufacturing equipment for the SPD test bench at the collider - 2021-2023;
- LILAC manufacturing and tests – 2020-2025;

- Analysis of 3He(2+) polarized ion source based on the SPI upgrade.

SPD zone at NICA in 2021-2023



The idea is to put new 6T solenoid in the linear part of NICA collider (SPD zone). Together with MPD solenoid this will provide opportunity to test the ST mode for protons and deuterons up to √s= 3.71 GeV and 3.88 GeV, respectively.

Urgent need is to design polarimetry detection system!

Status of the ST mode test preparation

1. Contract for 6T solenoid with LPI RAS(Moscow) is signed.

2.1. Contract on the simulation of the ST mode with:

a) 6T and MPD solenoids;

b) 8 6T solenoids (upto √s=6.67 GeV for protons) is signed.

2.2. Contact on the study of the possibility of the deuteron longitudinal polarization at NICA for EDM experiment and cross check of the ST mode is in progress.

2.3. Contact on the study of the possibility of proton EDM experiment at NICA in the ST mode is in progress.

These 3 contacts cost 43k$ in 2021 and at least 25k$ in 2022.

3. There will be no cluster (or jet) target for the tests.

Therefore, SPD collaboration urgently needs to develop polarimetry setup at the SPD linear zone of NICA in the collider mode. The cost estimate is about 200-250k$ - problem!

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

The urgent technical task is to check the possibility of the ST mode at NICA.