SPIN 2016

Current Results on Implementation of the Nuclotron/NICA R&D Program with Polarized Beams

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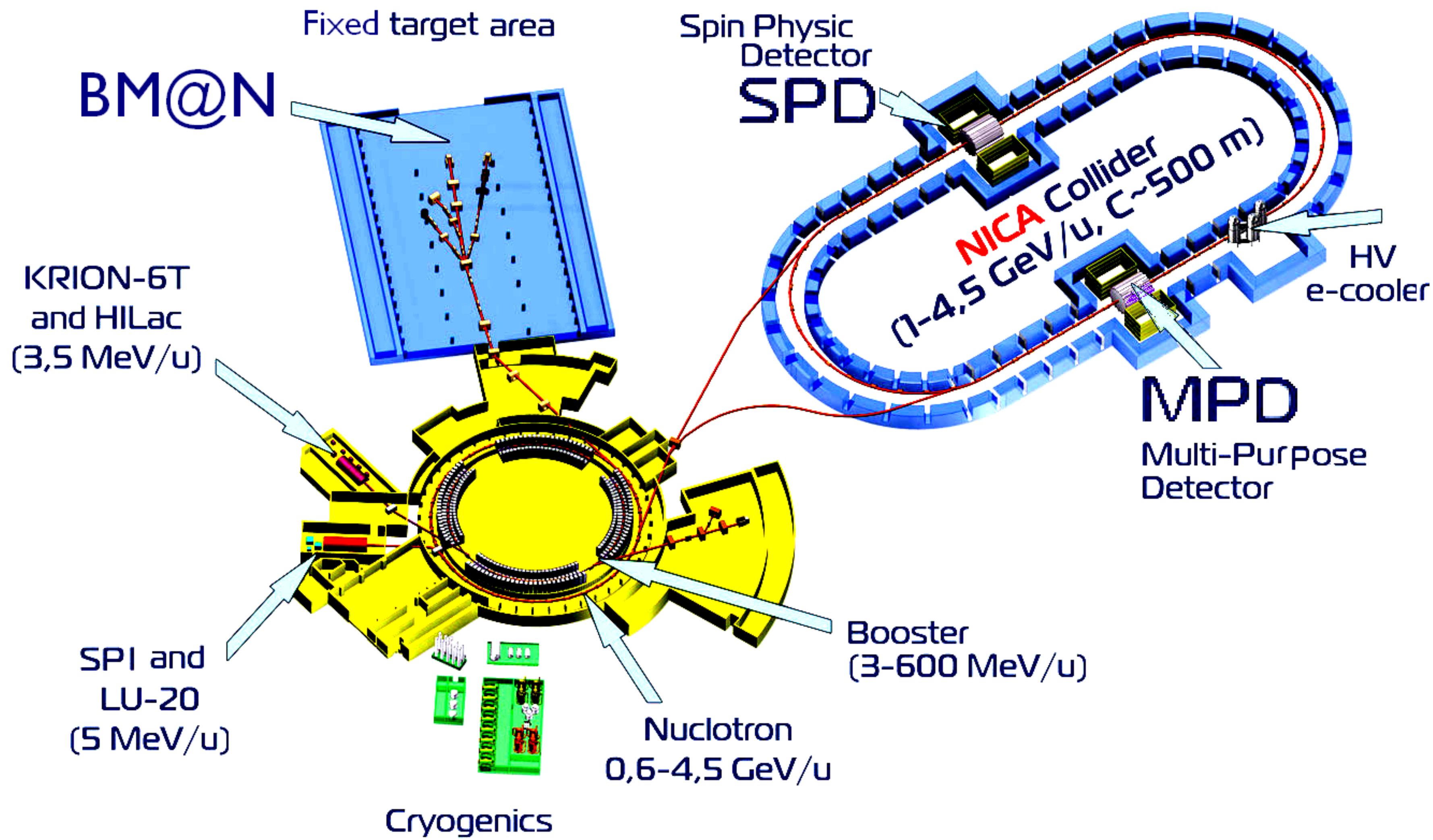
OUTLINE

- Nuclotron/**NICA@JINR**: General status
- Layout in polarized mode
- Implementation of polarized beam program
- June_2016 run with d-polarized at Nuclotron
- Near future plan

NICA site in DUBNA area

Superconducting accelerator complex NICA
(Nuclotron based Ion Collider fAcility)



NICA construction area

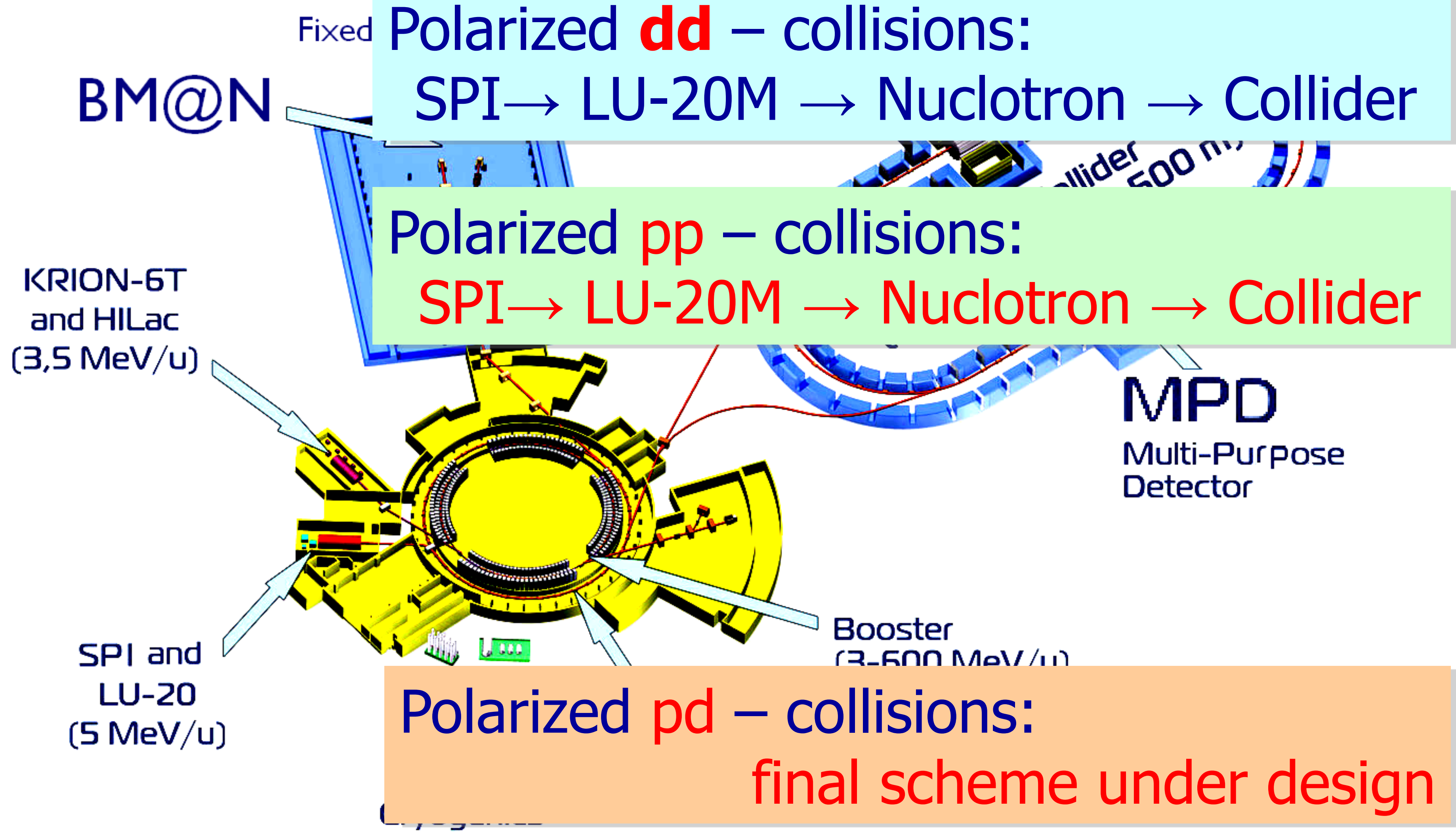
Requirements to the facility in polarized mode

- **polarized and non-polarized p-; d–collisions**
- **p↑p↑(p)** at $\sqrt{s_{pp}}$ **= 12 ÷ 27 GeV** (5 ÷12.6 GeV kinetic energy)
- **d↑d↑(d)** at $\sqrt{s_{NN}}$ **= 4 ÷ 13 GeV** (2 ÷5.5 GeV/u kinetic energy)
- $\mathbf{L_{average}} \approx 1\cdot 10E32\ cm^{-2}s^{-1}$ (at $\sqrt{s_{pp}} \geq 27$ GeV)
- sufficient lifetime and degree of polarization
- longitudinal and transverse polarization in MPD/SPD
- asymmetric collision mode, pd, should be possible

Tasks for realization of polarization research at Nuclotron/NICA

- New polarized proton and deuteron source – SPI
- New RFQ pre-injector and LU-20 front end upgrade
- Upgrade of polarimeters:
  - at the linac output
  - at circulating beam in Nuclotron ring
  - at the extracted beam
- Design of new approach to proton polarization meas..nts for the momentum region above 6 GeV
- Design of the Solenoid Snake
- Further simulations of polarized beam dynamics in the Nuclotron and NICA collider

NICA operation in Polarized Mode (1)



Polarized **dd** – collisions:
SPI→ LU-20M → Nuclotron → Collider

Polarized pp – collisions:
SPI→ LU-20M → Nuclotron → Collider

Polarized pd – collisions:
final scheme under design

NICA operation in Polarized Mode (2)

- d↑-beam was accelerated at the Synchrophasotron in 1986; at the Nuclotron in 2002. No dangerous spin resonances up to 5.6 GeV/u. The beam was used for physics data taking

- p↑- beam was never accelerated at the facility. The problem (at Nuclotron, NICA booster and collider) – spin resonances.

NICA operation in Polarized Mode (2)

- d↑- accelerated at the Synchrophasotron in 1986; at the Nuclotron in 2002. No dangerous spin resonances up to 5.6 GeV/u.
- p↑- never been accelerated at the LHEP facility.

The problem with p↑ (at Nuclotron or NICA booster) – numerous spin resonances.

Solution: p↑ acceleration up to 5-6 GeV at Nuclotron with dynamic solenoid Siberian snake → transfer to collider rings → storage, stochastic cooling and further acceleration up to 13.5 GeV in the collider rings.

Polarized Protons at Nuclotron (0)

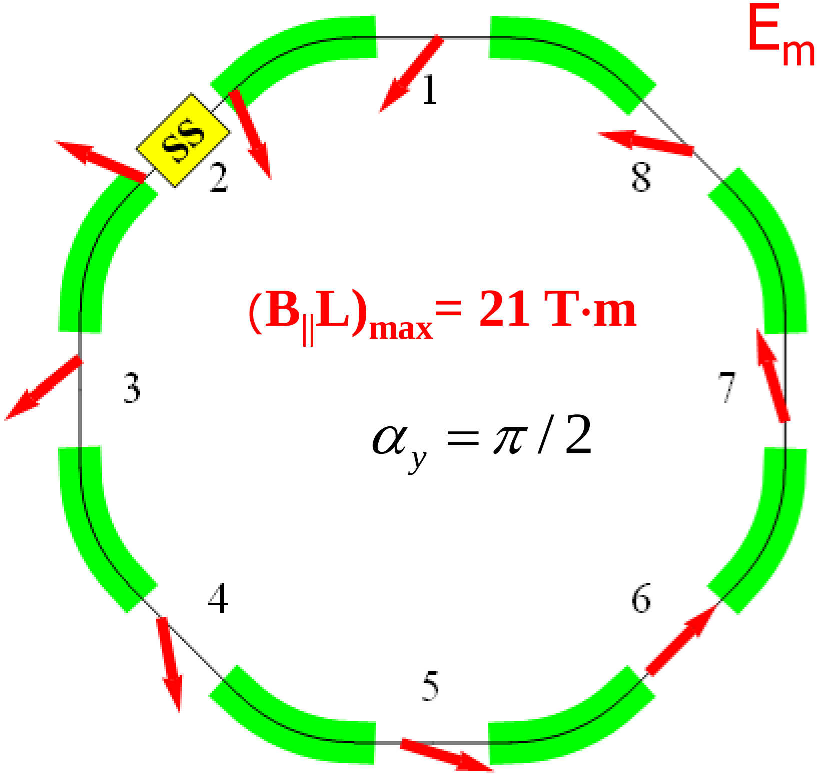
- 6 AGeV STRONG FOCUSING SYNCHROTRON
- SINGLE TURN INJECTION
- INJECTION ENERGY – 20 MeV PROTONS
- \- 5 MeV/u DEUTERONS
- MAXIMUM MAGNETIC FIELD – 2 T
- THE FIELD RAMP – 1 T/s

Polarized Protons at Nuclotron (1)

Dynamic Solenoid Siberian Snake

Full Siberian Snake

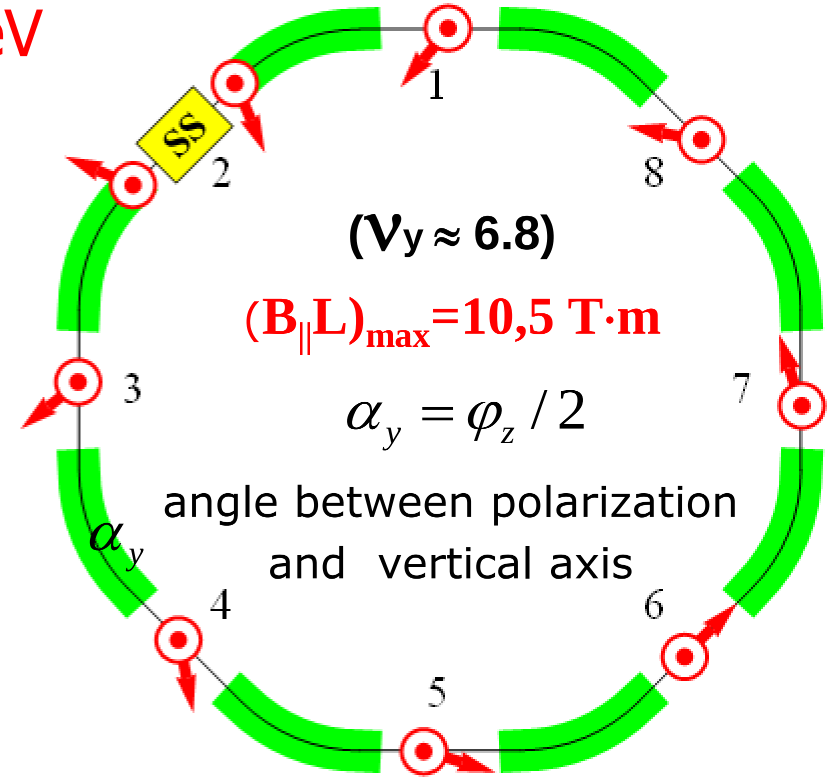
E_{max}= 6 GeV



$(B_{||}L)_{max}$= 21 T·m

$$\alpha_y = \pi / 2$$

Partial Siberian Snake



$(\nu_y \approx 6.8)$

$(B_{||}L)_{max}$=10,5 T·m

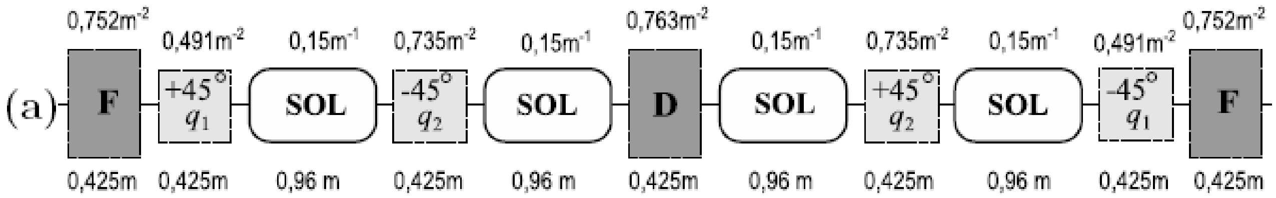
$$\alpha_y = \varphi_z / 2$$

α_y angle between polarization and vertical axis

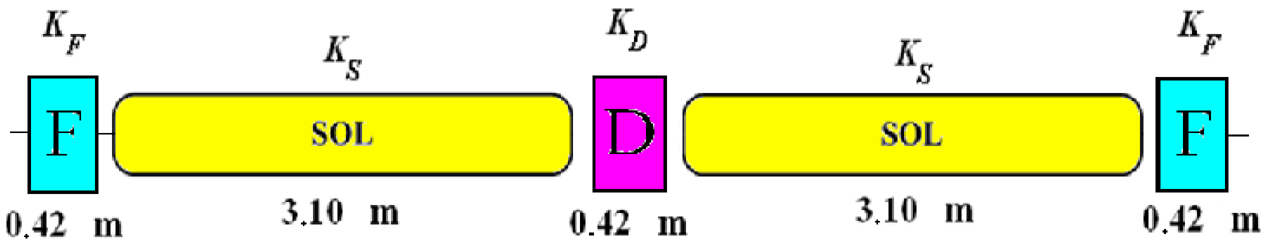
Polarized Protons at Nuclotron (2)

The Snake structure:

a) Scheme with compensating skew quadrupoles



b) Scheme without skew quadrupoles

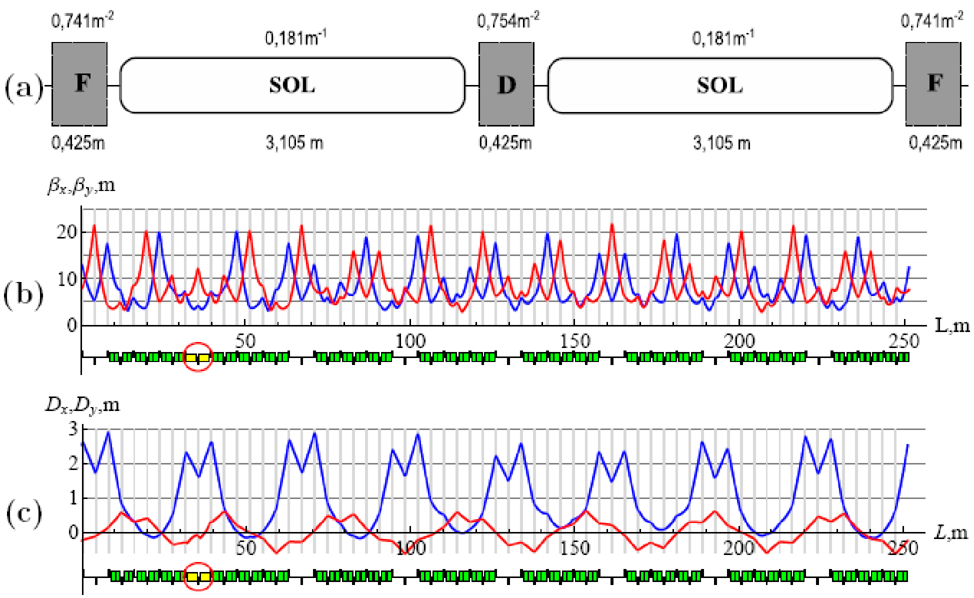


- Magnetic field (specified) – 3.387 T (full snake); 1.694 T (half snake)
- Maximum supply current, – 12.0 kA 6.0 kA
- Stored energy per section – 278 kJ 69.6 kJ

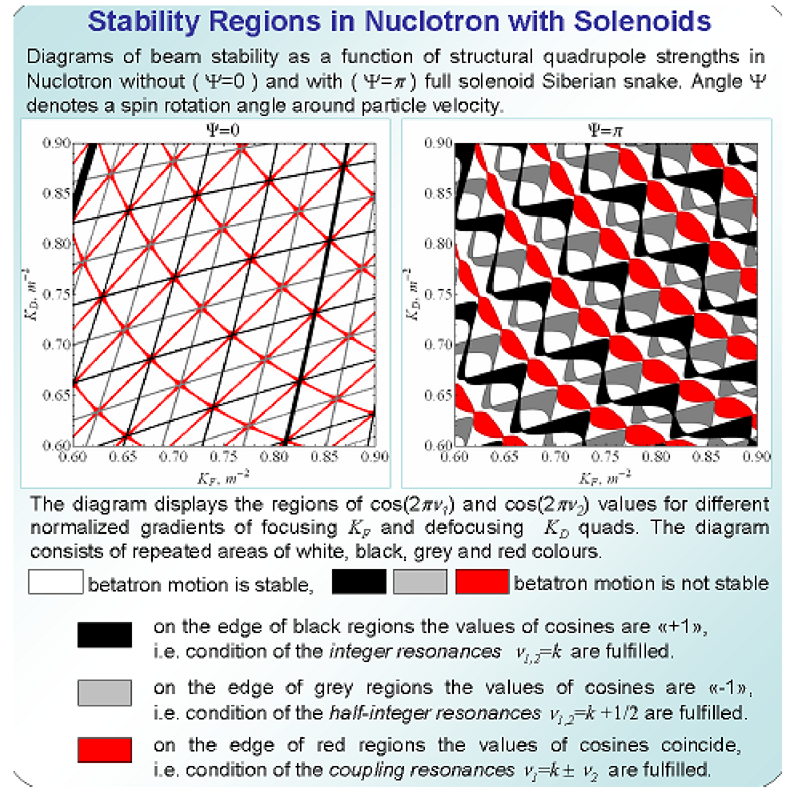
Will stable motion be guaranted in the case (b)?

Polarized Protons at Nuclotron (3)

The analysis of betatron motion in linear approximation have shown regions stability regions in the case of the betatron tunes coupling.



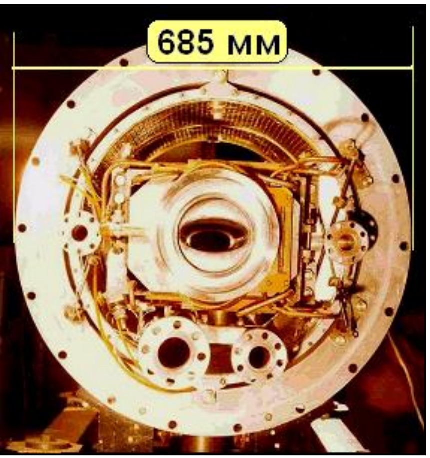
Stable motion can be provided by proper choice of the tunes.

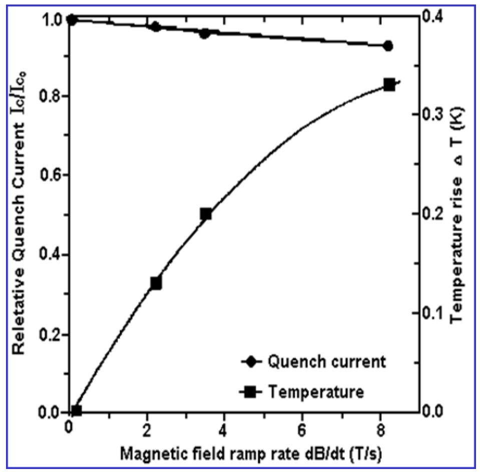


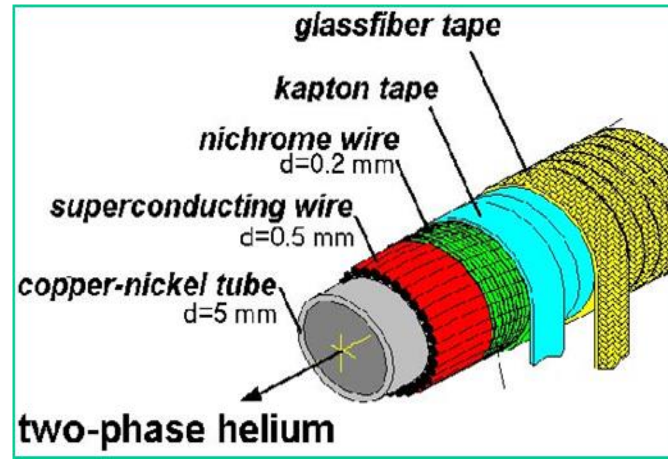
IPAC2014 , Dresden, June 2014

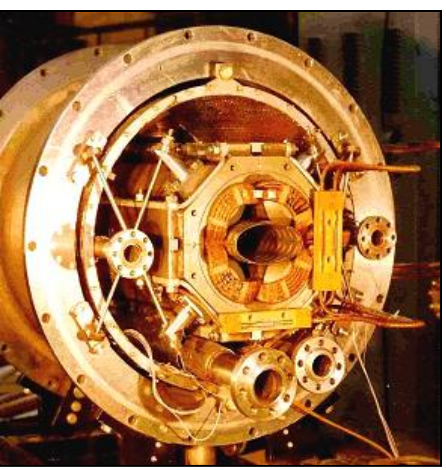
Polarized Protons at Nuclotron (4)

Necessary solenoid can be manufactured base on a hollow Nuclotron-type SC cable and the new SC wire.









Critical current of Nuclotron magnets at B = 2 T, dB/dt = 4 T/s, f = 1.0 Hz exceed 8000 A.

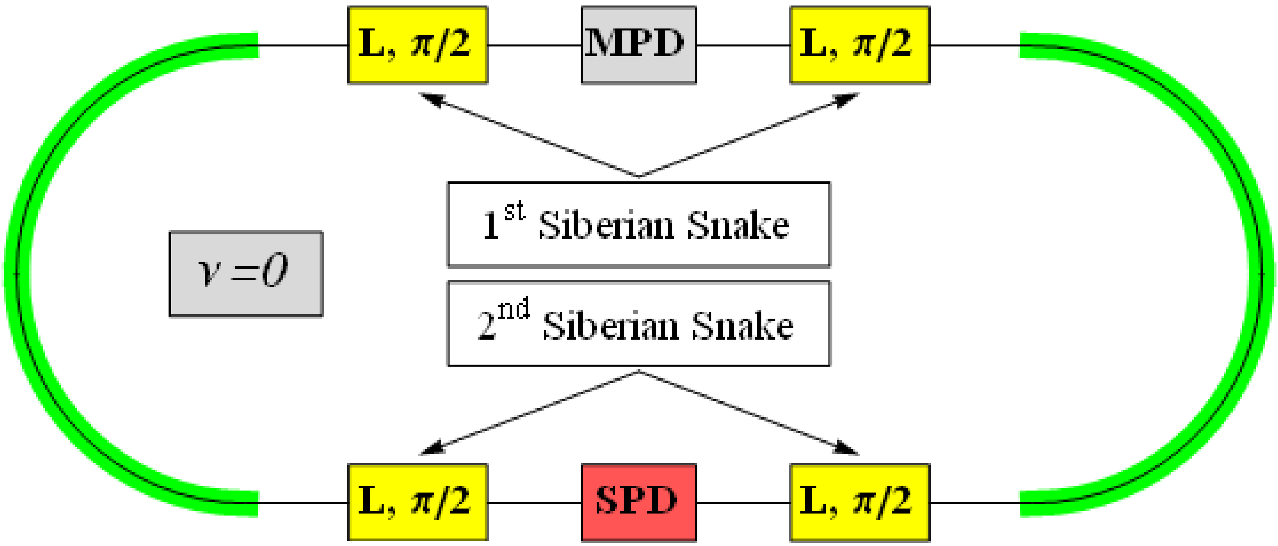
Suitable NbTi wire was designed by the Bochvar company for **6 T, 1 T/s** magnet of SIS300 R&D program.

Polarized Protons at Nuclotron (5)

- Technical design of the Snake itself, cryostat, cooling system etc. is in progress.
- Detailed calculations of the solenoid is continued.
- The model solenoid manufacturing and it tests is high priority task for coming 2-3 years.

Polarization control scheme in the Collider with spin tune $\nu = 0$

Solenoid-based Siberian Snake at particle momentum:



p=(2.5÷13)GeV/c

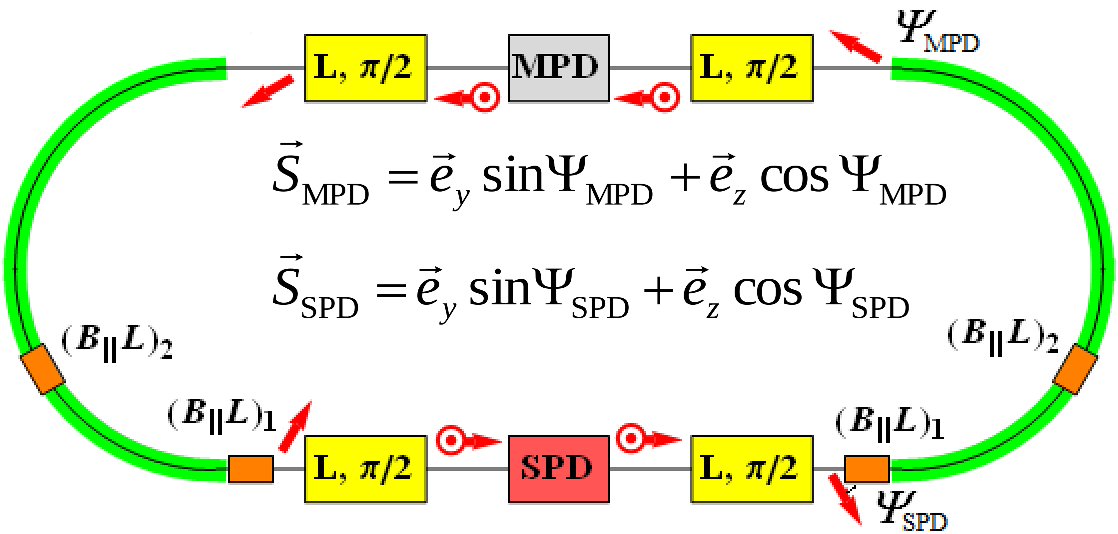
protons:

$(B_{||}L)_{max}=4\times(5\div25)$ T·m

deuterons:

$(B_{||}L)_{max}=4\times(15\div80)$ T·m

Polarization control in the Collider by means of small longitudinal field integrals



$$\vec{S}_{\mathrm{MPD}} = \vec{e}_y \sin\Psi_{\mathrm{MPD}} + \vec{e}_z \cos\Psi_{\mathrm{MPD}}$$

$$\vec{S}_{\mathrm{SPD}} = \vec{e}_y \sin\Psi_{\mathrm{SPD}} + \vec{e}_z \cos\Psi_{\mathrm{SPD}}$$

$$\varphi_{z1} = \pi\nu \frac{\sin(\varphi_y - \Psi_{\mathrm{SPD}})}{\sin\varphi_y}$$

$$\varphi_{z2} = \pi\nu \frac{\sin\Psi_{\mathrm{SPD}}}{\sin\varphi_y}$$

$$\Psi_{\mathrm{MPD}} = \gamma G\pi + \Psi_{\mathrm{SPD}}$$

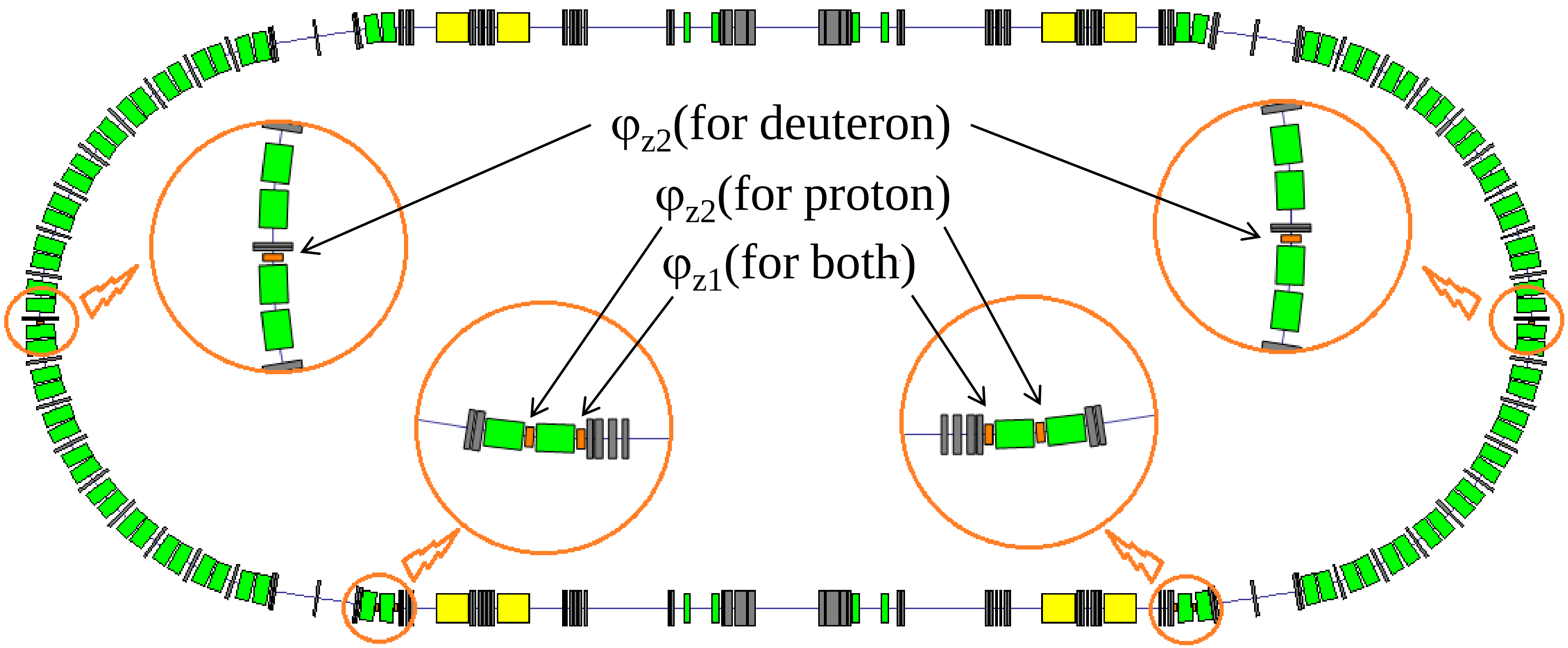
$\varphi_{zi} = (1+G)(B_{\|}L)_i / B\rho$ - the spin rotation angles in the solenoids

$\varphi_y = \gamma G\alpha$ - the spin rotation angle between weak solenoids

α - the orbit rotation angle between the weak solenoids

$\Psi_{\mathrm{SPD}}, \Psi_{\mathrm{MPD}}$ - the angles between the polarization and velocity directions in SPD and MPD detectors

Polarization control scheme for p and d in NICA collider (1)



	number	B_{max}, T	L, m	BL, T·m
Main tune shifts solenoid	8	7,3	5,5	0÷40
Weak solenoid for polarization control (red)	6	1,5	0,4	0÷0,6

Polarization control scheme for p and d in NICA collider (2)

- The proposed scheme is suitable for any type of the particles. Necessary manipulations are provided without re-installations of the equipment at the magnetic system.

- The scheme provides the desired polarization direction in the both IP's (MPD and SPD detectors), and gives also a possibility of simple decision the problems of polarization matching at injection and polarimetery

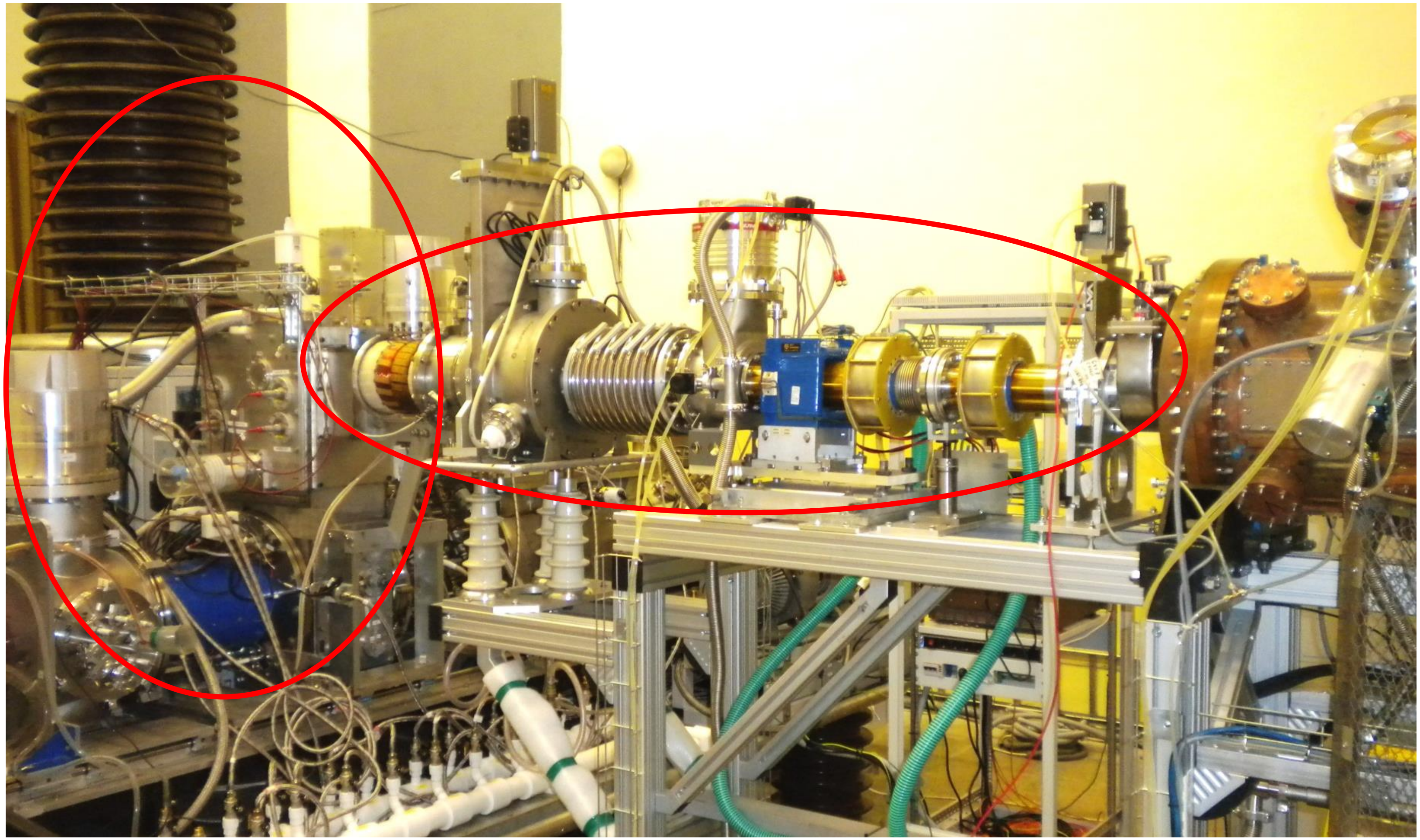
Main magnets for polarization control in Nuclotron/NICA

Parameter	Unit	Nuclotron	Collider
Polarized proton mode			
Snake magnet type		solenoid	solenoid
Ramped field	T	0 … 3.6	0 … 2.65
Field ramp	T/s	~ 1.0	~ 0.1
Ramped solenoid length	m	2 x 3	8 x 3
Steady field	T	-	1.25
Steady solenoid length	m	-	8 x 3.6
Peak Field integral(total)	T·m	21	8 x 12.5
Polarization direction		depends on energy	T / L
Stored energy	MJ	~ 0.3	~ 0.6
Operation mode		pulsed	ramped/steady
Beam kinetic energy	GeV	~ 12.6	~12.6
PC solenoid field	T·m	-	~ 0.5

Parameter	Unit	Nuclotron	Collider
Polarized deuteron mode			
Snake magnet type		no snake	solenoid
Ramped field	T	-	up to 2.65
Steady field	T	-	up to 9
Peak Field integral(total)	T·m	-	8 x 40
Beam kinetic energy	GeV/u	~ 5.6	~ 5.6
Polarization direction		T	T / L
PC solenoid field	T·m	-	~ 0.5
Operation mode		-	steady

Some illustrations from June 2016 Nuclotron run

Equipment of new polarized ion source SPI and LEBT part of beam channel to RFQ section



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New Polarized Deuteron Source - SPI

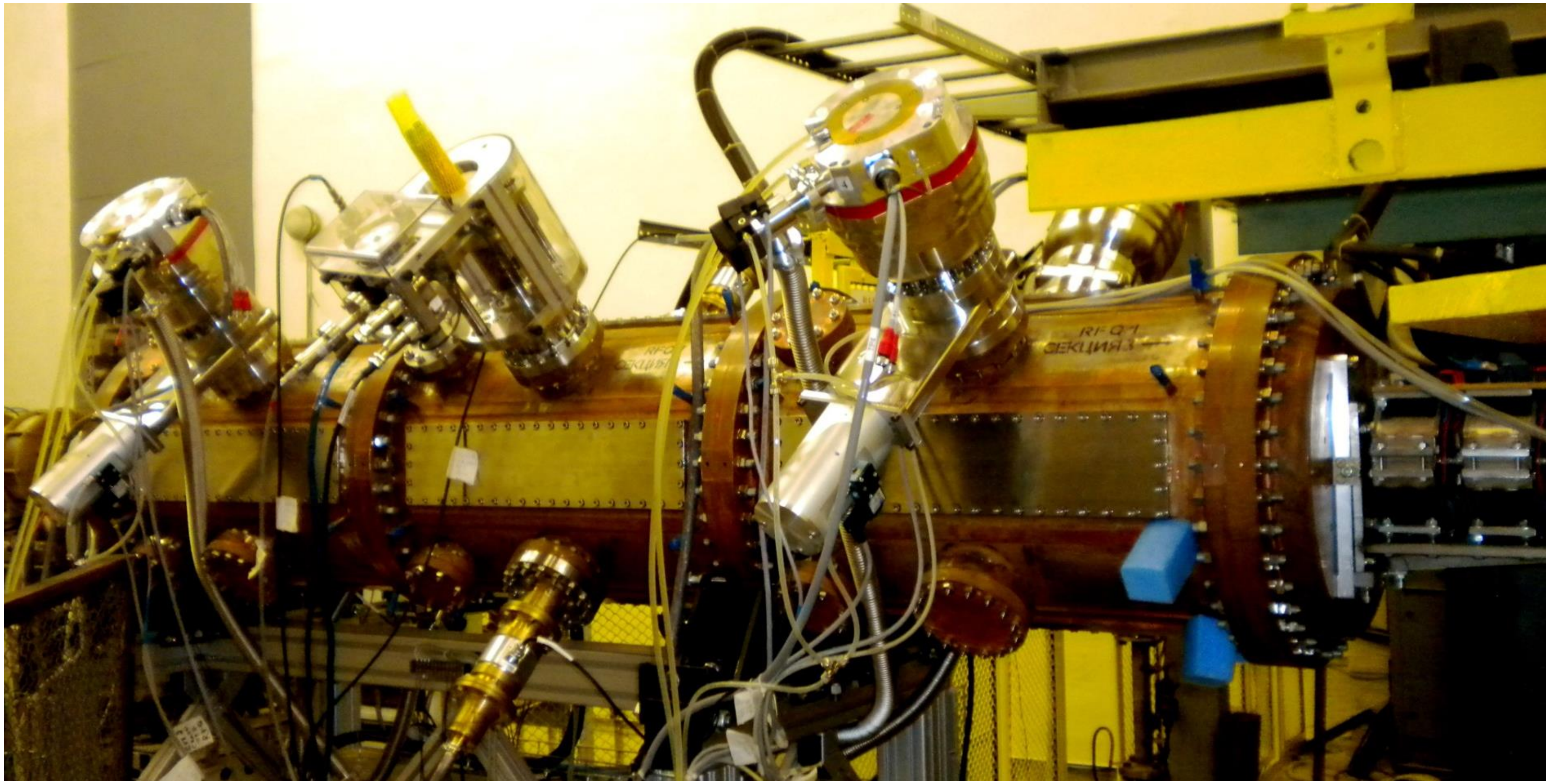
- Parts of the IUCF source is used for the construction.

- The SPI was moved to the Linac hall, assembled at the terminal and commissioned in May 2016.

The D+ ion beam with peak current of 5 mA, pulse duration of 150 μs was used for the RFQ system tests and tuning during the run.

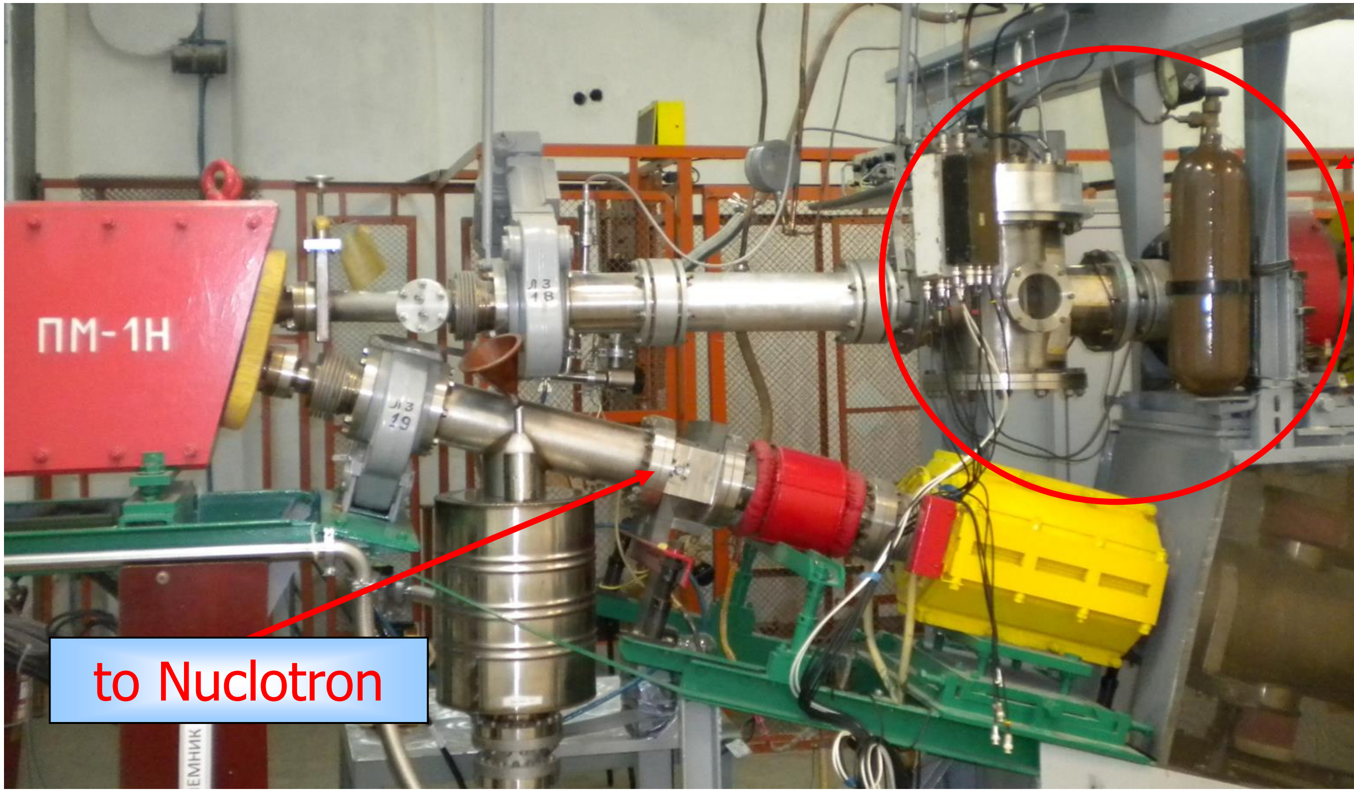
The spin modes (p_z,p_{zz}): (0,0), (0,-2), (2/3,0) and (-1/3,+1) were adjusted.

New RFQ section as fore-injector LU-20



Technical design of the system performed in collaboration with ITEP and MEPHI (Moscow)

Implementation of polarized beam program (3)

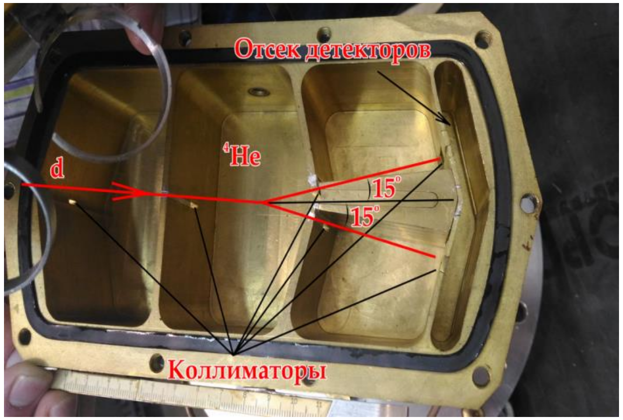


Output beam channels from linac LU-20

Implementation of polarized beam program (3a)

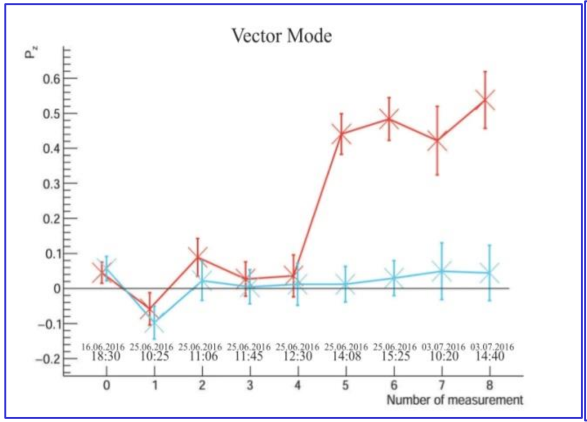
Upgrade of the low energy polarimeter (LEP)

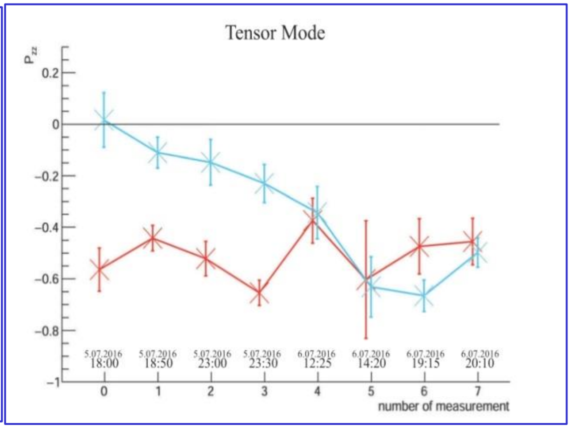
Vacuum chamber of polarimeter



Vector polarimeter use d^4He - elastic scattering reaction, whereas the tensor one: $d^3He \rightarrow p^4He$ process.

The measurements (June 2016): 10 MeV deuteron beam

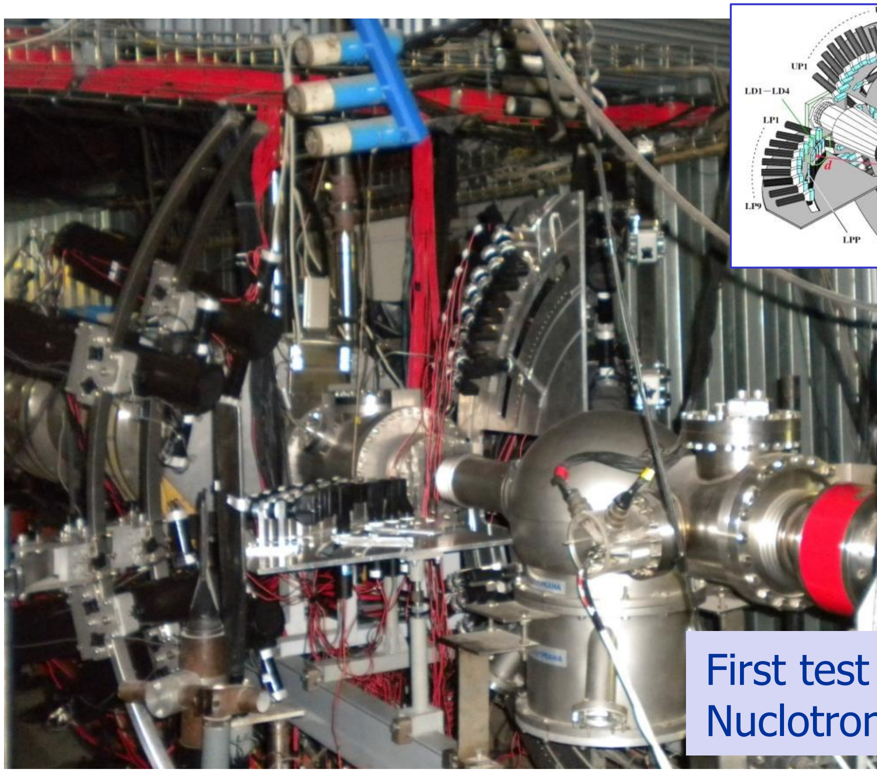


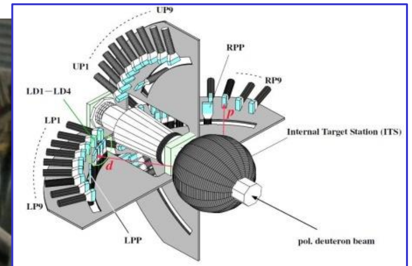


Red symbols are the 1-4 transition with $(p_z,p_{zz}) = (+1/2,-1/2)$.
Blue symbols are the 3-4 transition with $(p_z,p_{zz}) = (-1/2,-1/2)$.

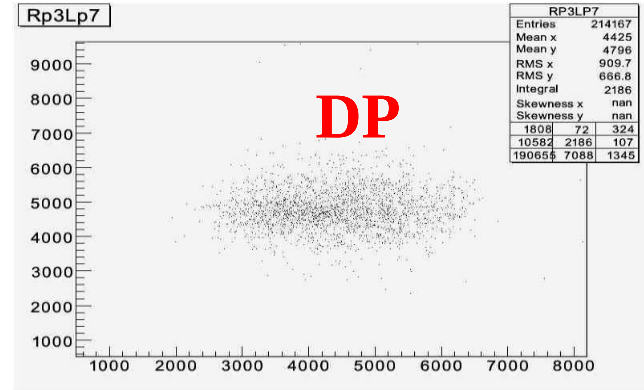
New PIS demonstrated good vector and tensor polarization values for 1-4 transition, while only tensor polarization for 3-4 transition.

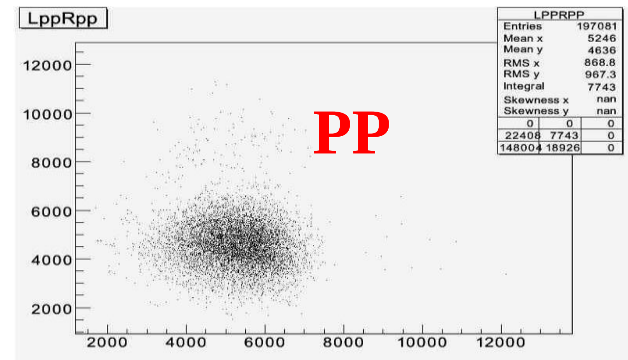
Implementation of polarized beam program (4)





First test results from Nuclotron (June 2016)





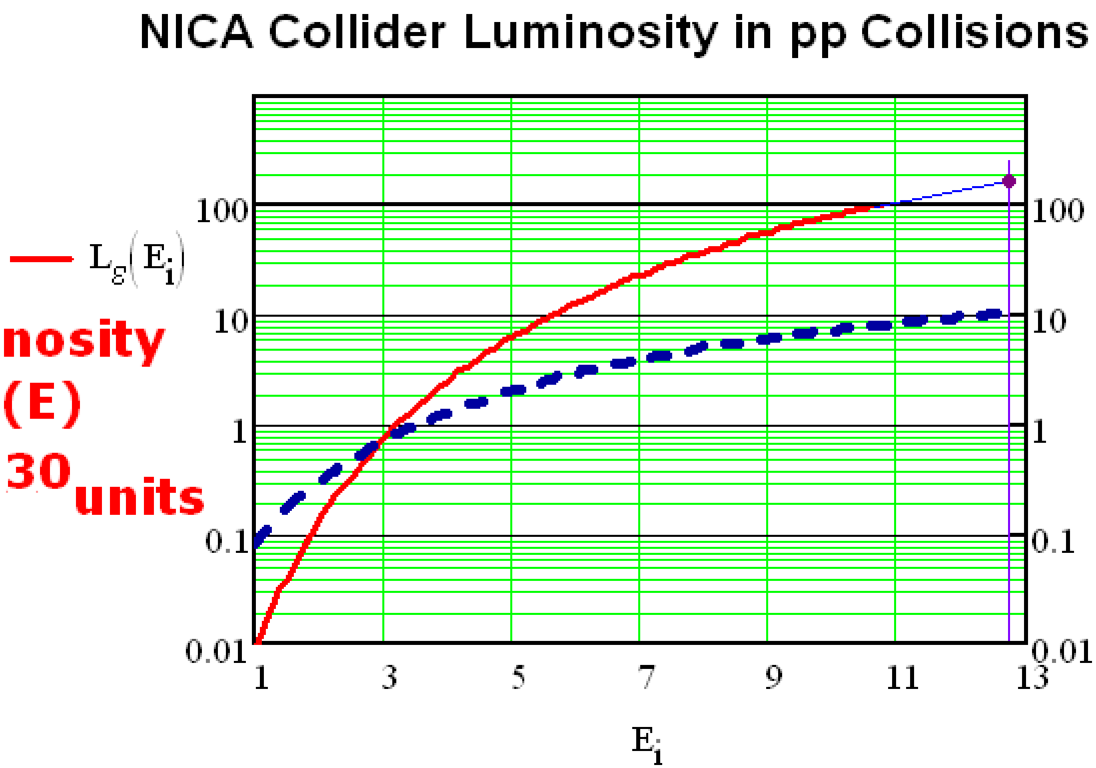
- Deuterons and protons in coincidences using scintillation counters
- Internal beam and thin CH_2 target (C for background estimation)
- Measurements at 270 MeV

Proton and deuteron polarimeter at Nuclotron ring

Implementation of polarized beam program (5)

Proton and deuteron polarimeter at Nuclotron extracted beam (focus F3 point)

NICA pp-collisions peak luminosity



$N_g(E_i)$

Luminosity L(E) in 10^{30} units

Proton energy E in GeV

Lpeak ≈ $1.8 \cdot 10^{32}$ cm-2·s-1

particle number per bunch in 10^{11} units

maximum proton number in each ring – $2.2 \bullet 10^{13}$

- IP parameters: **β** = 35 cm, bunch length **σ** = 60 cm (not optimized), **bunch number** – 22, collider perimeter **C** = 503 m

from I.N.Meshkov 29/11/2012

Polarized pp-collisions: average luminosity

Parameter	Value
Nuclotron Dipole Field Ramp up, T/s	0.6
Nuclotron Dipole Field Ramp down, T/s	1.0
Magnet field flat top duration, s	0.5
Total useful cycle duration, s	3.17
Dipole Magnetic Field at 6 GeV protons, T	~ 1
Acceleration time, s	1.67
Number of accelerated protons per pulse	$7 \cdot 10^{10}$
Number of cycles to store $2 \cdot 10^{13}$ particles	285
Collider filling time at cycle duration 5s, s	1425
Preparation of the beam in the collider (cooling, bunching emittance formation), s	1000
Magnetic field ramp in the collider, T/s	0.6
Acceleration time from 6 GeV to 12.6 GeV	~ 1.7
Luminosity life time (30% polarization degradation due to spin resonances), s	5400
Beam deceleration up to the new injection	~ 1.7
Total cycle duration, s	**7825**
Working part, %	**~ 70**

The time budget and the numbers shown in the Table gives

$L \approx 1.3 \cdot 10^{32}$ cm-2·s-1,

Nevertheless, the further analysis of beam dynamics and development of the models for simulation are necessary.

Summary

- The design concept of Nuclotron/NICA complex operation in polarized proton and deuteron mode is worked out, more detailed technical feasibility studies and steps to final design are in progress;

- Important tests of the new elements of the injector and polarimetry in June 2016 were performed;

- NICA operation with polarized deuterons and middle weight ions (non-polarized) as well could be considered as a start-up program for the collider.

THANK YOU

FOR YOUR ATTENTION

New Polarized proton and deuteron source - SPI