Polarization facilities at the JINR accelerator complex

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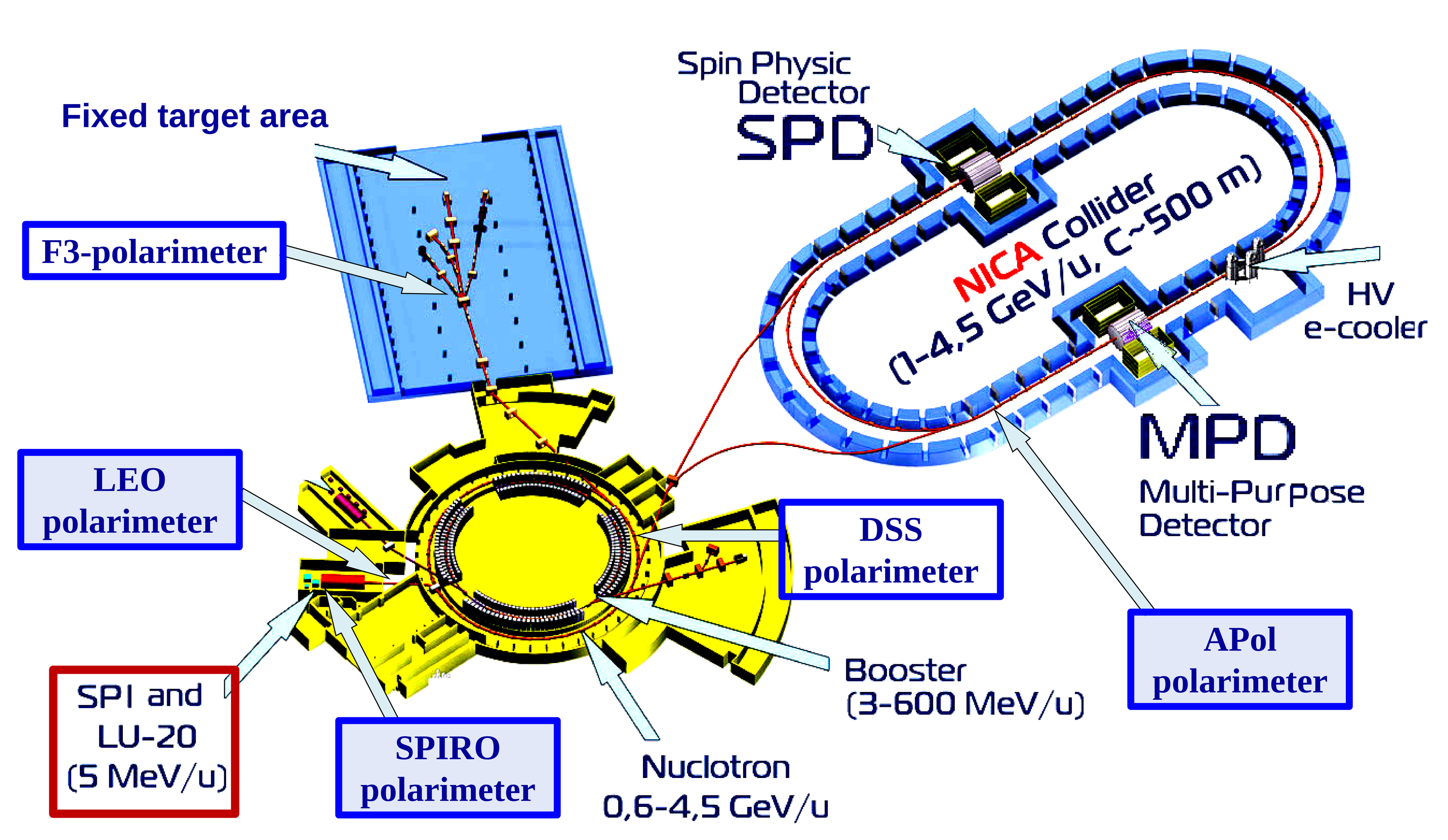
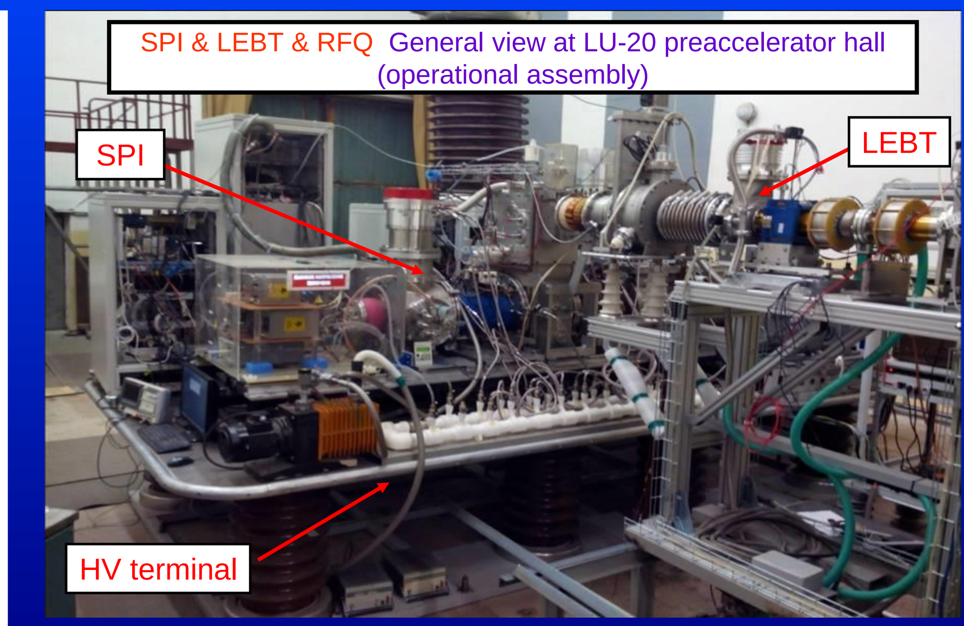
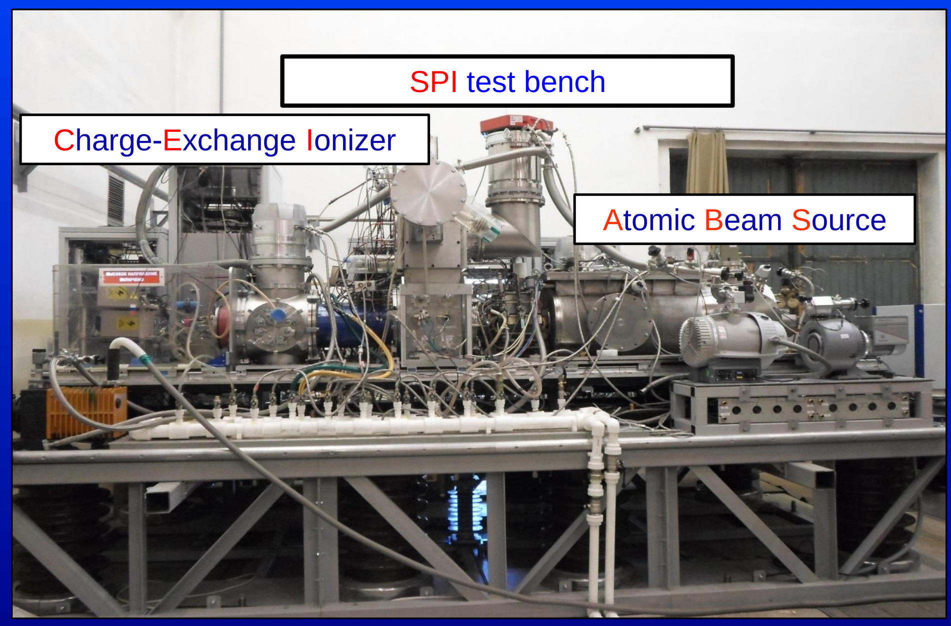
Polarization facilities are being developed at the JINR accelerator complex in the framework of the polarization research program under the NICA project. Those are the polarized deuteron and proton source SPI, SPI low energy and linac output polarimeters, and the absolute polarimeter at the NICA collider. The status of the above facilities and the results achieved are presented.

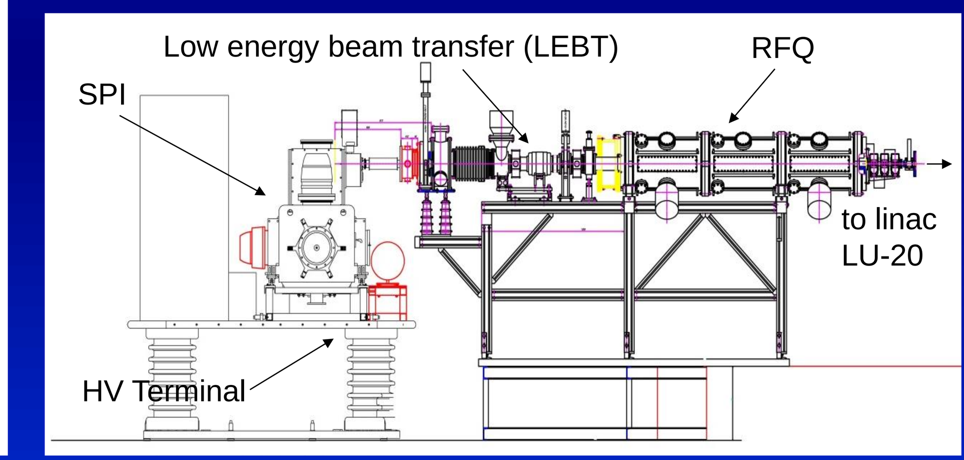
Implementation of polarization program



Physics with polarized light ion beams is considered as an important part of the NICA program







- ✓ The SPI was installed at linac preaccelerator hall of the NUCLOTRON in May 2016. The source has been commissioned and used in the NUCLOTRON runs in 2016 and February – March 2017
- ✓ Polarized&unpolarized deuteron and proton beams were produced for acceleration in the NUCLOTRON
- ✓ Deuteron beam polarization of 0.6-0.88 of theoretical values for different modes of the HFT units operation has been measured by internal polarimeter in NUCLOTRON ring
- ✓ SPI tests are ongoing and polarized deuteron beam with pulsed current up to 6 mA has been produced
- ✓ SPI operating improvements of parameters are continued

Source of Polarized Ions (SPI)

SPI ABS

The Source of Polarized Ions (SPI) is developed as a **high-intensity setup of polarized deuterons & protons beams**

The main purpose of the SPI-project is to increase the intensity of the accelerated polarized beams at the JINR Accelerator Complex up to **$5 \cdot 10^{10}$ d(p)/pulse**

The design output current of the SPI is up to **10 mA** for ↑D⁺ (↑ H⁺)

The D^+ (H^+) polarization will be up to 90% of the maximal vector (±1) & tensor (+1,-2) polarization

ABS tests results

Atomic D & H beam intensities were measured. The averaged beam intensities are

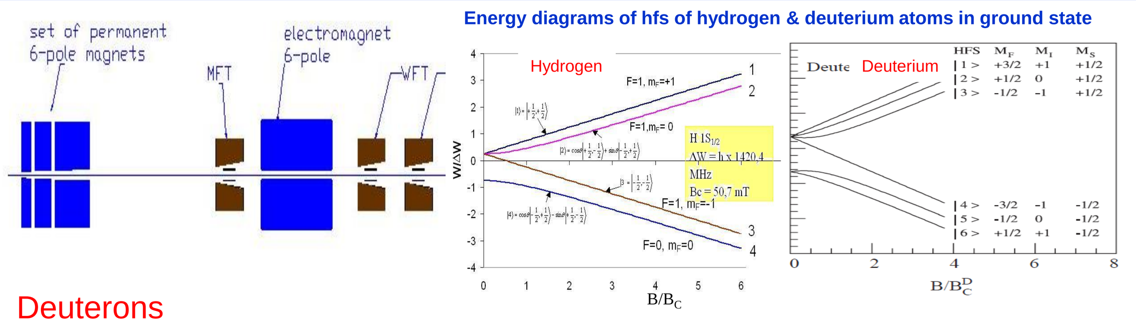
$I_D = 8 \cdot 10^{16}$ at/s $I_H = 5 \cdot 10^{16}$ at/s

Nozzle temperature was scanned over a range of **16…100 K**

The optimum nozzle temperature is about **80 K**

The optimum feed rate is about **0.045 mbar · l / pulse**

SPI Nuclear polarization



Deuterons

HFT between 6-poles	HFT after 6-poles	Final state	P_Z	P_{ZZ}
MFT 3 → 4	WFT 1,2 → 3,4	3,4	-1	+1
MFT 3 → 4	SFT 2 → 6	1,6	+1	+1
MFT 1 → 4	SFT 3 → 5	2,5	0	-2
MFT 1 → 4	SFT 2 → 6	3,6	0	+1
MFT - off	SFT 3 → 5	1,2,5	+1/3	-1
MFT - off	SFT 2 → 6	1,3,6	+1/3	+1
MFT - off	WFT 1 → 4	2,3,4	-2/3	0
MFT 3 → 4	SFT 2 → 6	1,6	+1	+1

Protons

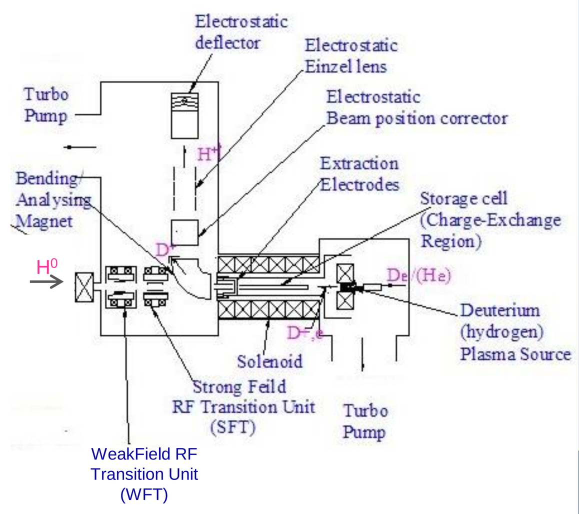
HFT between 6-poles	HFT after 6-poles	Final state	P_Z
MFT - off	WFT 1→ 3	2,3	-1
MFT - off	SFT 2→ 4	1,4	+1

SPI Charge-Exchange Ionizer

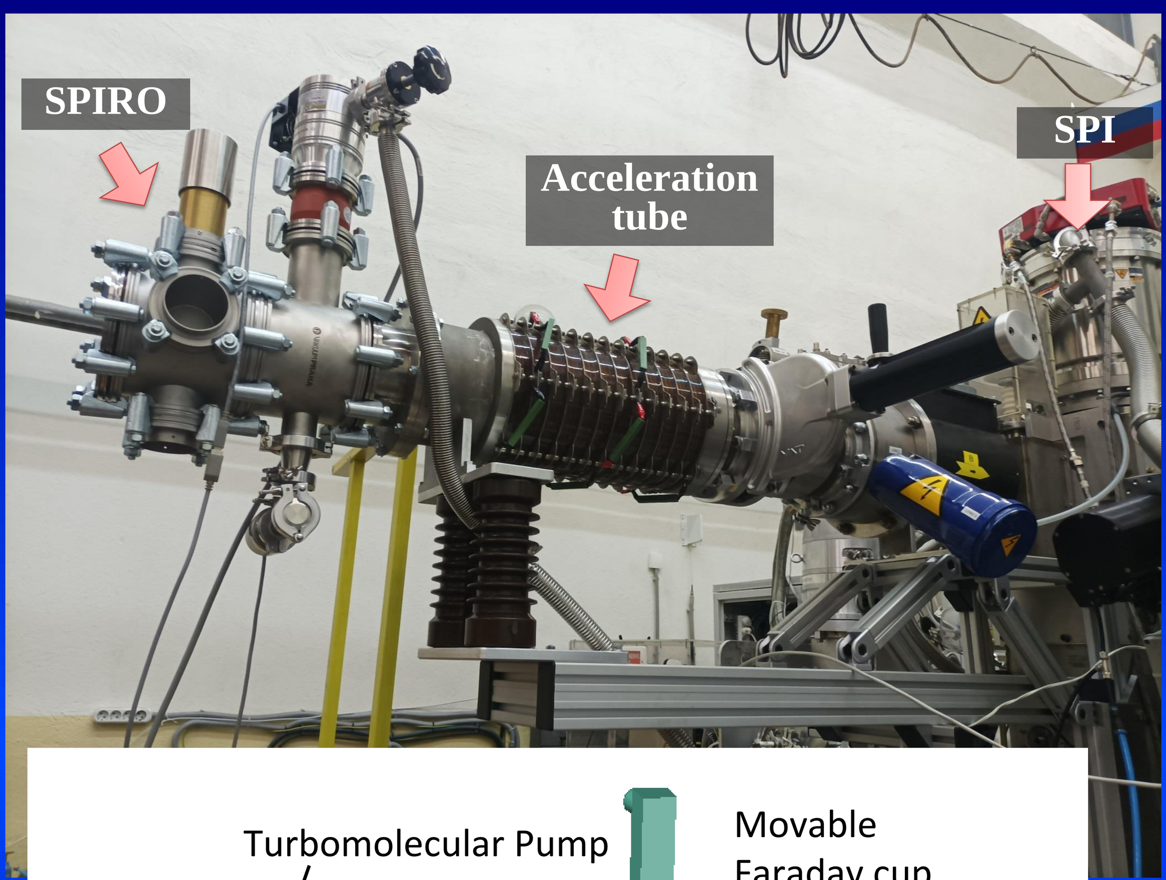
- Nearly resonant charge-exchange reactions for production of polarized protons & deuterons are used:

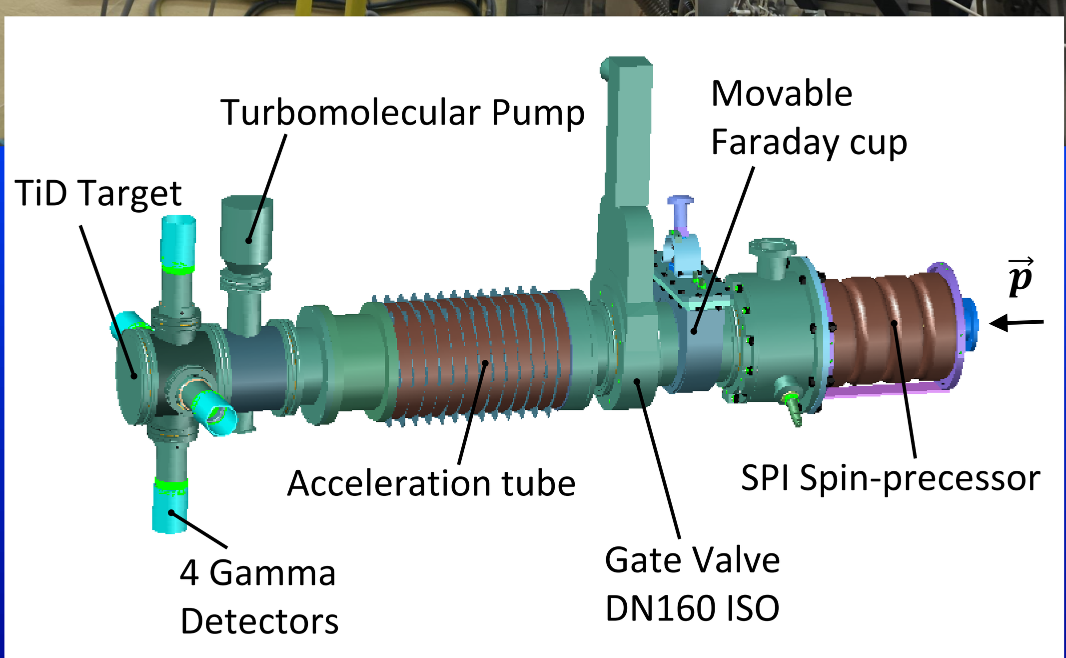
$$H^0\uparrow + D^+ \Rightarrow H^+\uparrow + D^0$$
$$D^0\uparrow + H^+ \Rightarrow D^+\uparrow + H^0$$
$$(\sigma \sim 5 \cdot 10^{-15}\ cm^2)$$

- Ionization efficiency is about 10%
- $D^+\uparrow$ ($H^+\uparrow$) beam energy 25 – 26 keV
- Normalized emittans 1.2 π mm mrad
- Pulse duration 100 μs
- Pulse repetition rate 0.2 Hz
- The storage cell allows:
  - increase intensity of the polarized D^+ (H^+) beam
  - reduce emittance of the polarized beam
  - considerably reduce H_2^+ ion current which is difficult to be separated from polarized D^+ due to similar mass of the ions



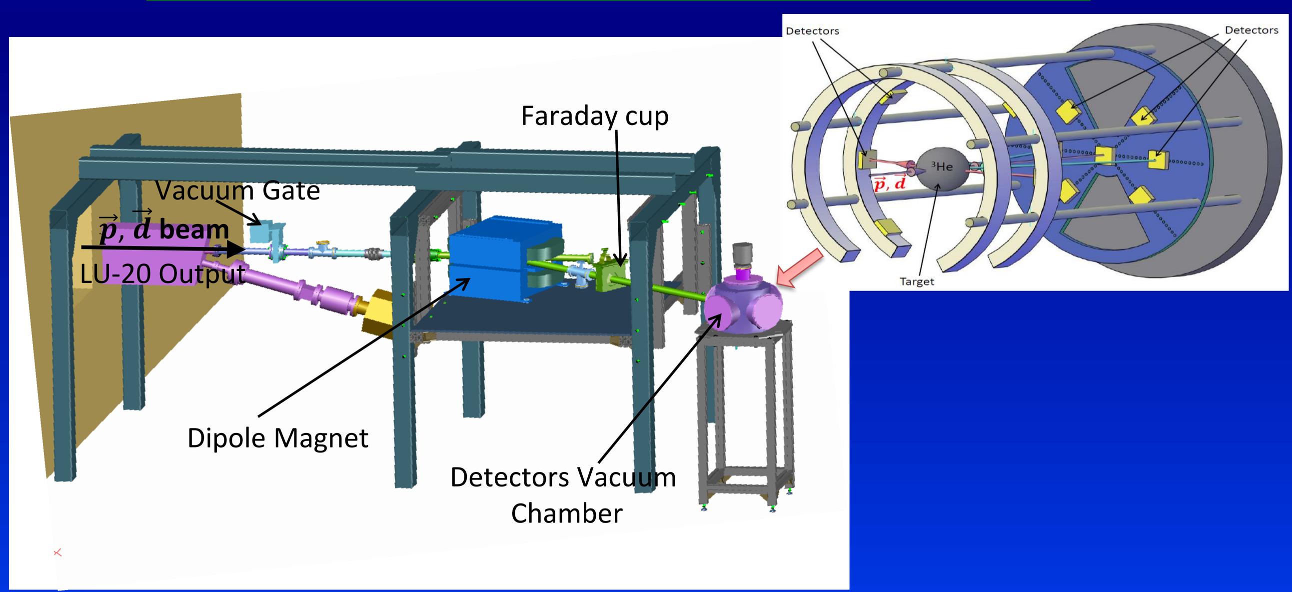
SPI Low Energy Polarimeter (SPIRO)

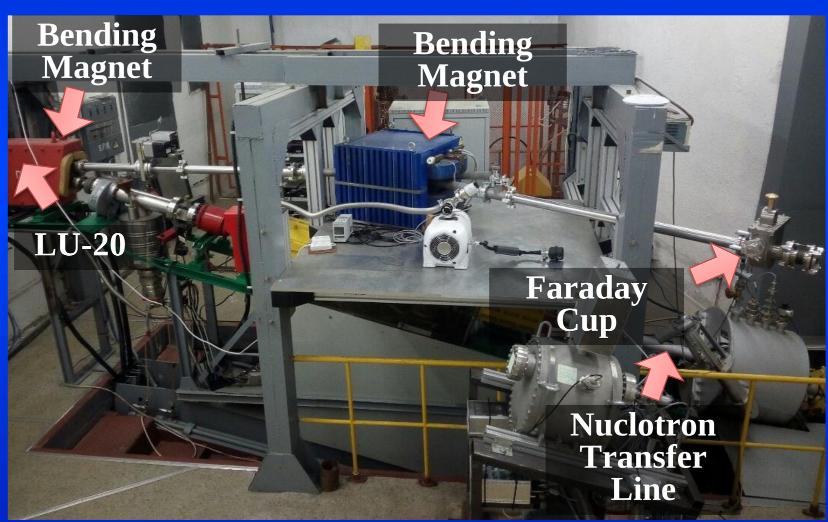




To measure the protons and deuterons beam polarization directly at the exit of the source of polarized ions SPI, the polarimeter **SPIRO** is being developed. It is designed to work with beam energies from **25 to 100 keV**. This polarimeter will make it possible to control the beam polarization and tune the operation of the SPI nuclear polarization cells, as well as to determine the influence of the perturbing devices of the installation on the polarization of the beams. For polarized protons, it is proposed to use the **$D(p,\gamma)^3He$** fusion reaction, where solid deuterated titanium TiD will be used as a target. For polarized deuterons, the **$D(d,p)T$** fusion reaction is used with the same TiD target.

Low Energy Polarimeter (LEO)



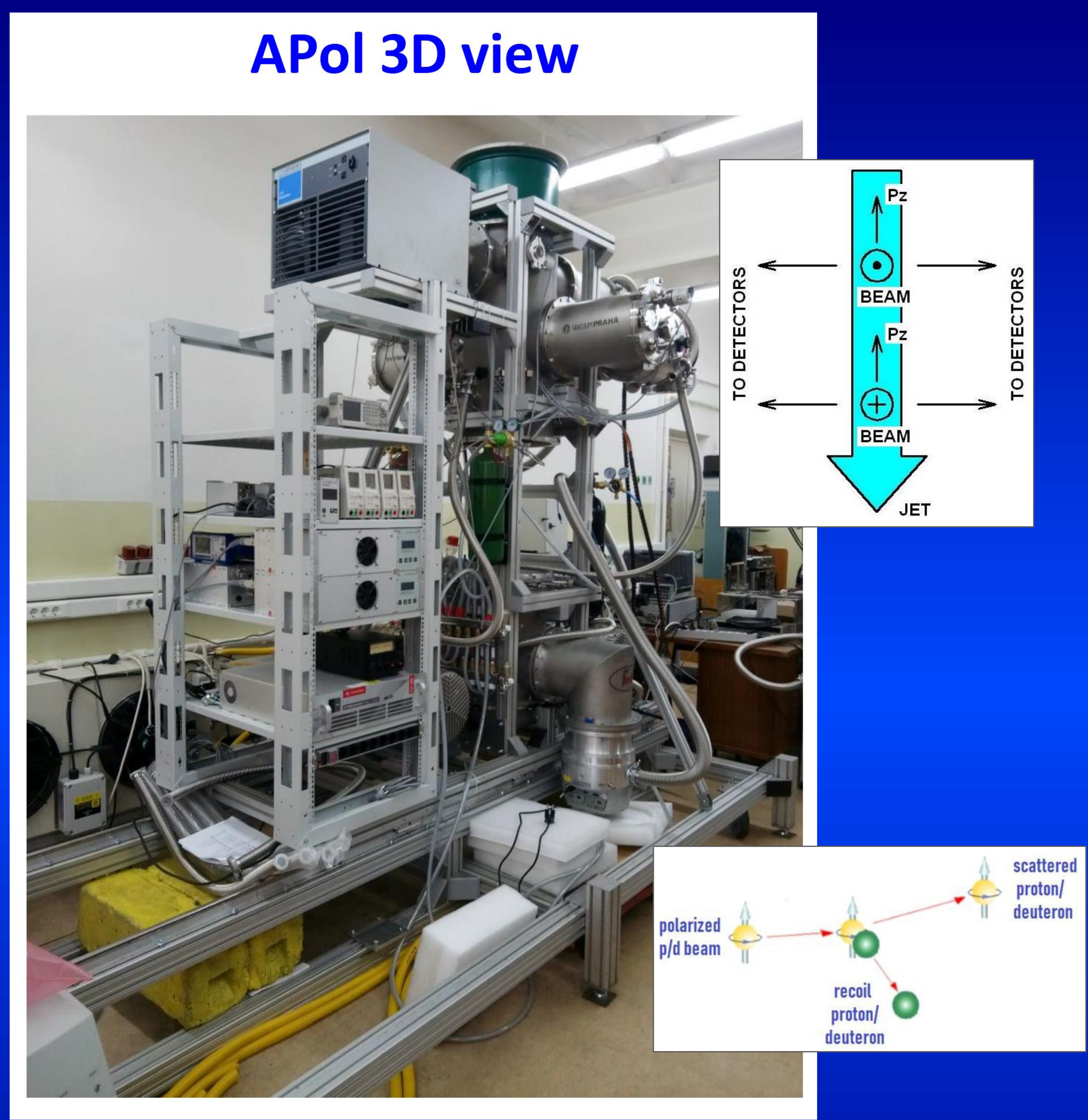


Low energy polarimeter (**LEO**) is placed behind the linear accelerator Lu-20. Its operating energy is **5 MeV** per nucleon. The main advantage of this polarimeter is that the setup may be used not only for polarization measuring but also for tuning SPI RF transition units (WFT, MFT, SFT).

The ^3He target of this setup allows one to measure both the vector polarization of protons (with **$^3He(p,p)^3He$** elastic scattering reaction) and the vector and tensor polarization of deuterons (with **$^3He(d,d)^3He$** elastic scattering reaction and **$^3He(d,p)^4He$** nuclear reaction). The main features of the LEO are:

- Up-to-date fast detectors will be used. It is assumed to measure the polarization of each bunch.
- The data flow will be protected from electromagnetic noises.
- It is assumed that the design of the polarimeter will make it possible to measure vector and tensor polarization of deuterons with one setup at the same time.

Absolute Polarimeter (APol)



To measure absolute values of proton or deuteron polarization at NICA collider rings an Absolute Polarimeter **APol** with the internal polarized atomic hydrogen/deuterium jet target is being built.

Main tasks for APol

- beam polarization testing in tuning of the NICA polarization control system
- determination the effect of disturbing Collider devices on beam polarization
- monitoring the degree of beam polarization during operation of the Collider

APol parameters

Beam energy range: **3..11 GeV**
Recoil particle energy: **200 MeV**
Recoil particle registration angle (in lab system): **75°**
Analyzing power A_N range: **20% .. 8%**

APol Status (Oct. 2021)

- Testing of vacuum equipment has been completely carried out.
- Magnet system measurements and analysis have been carried out (Values are close to optimum).
- Preliminary tests of Dissociator and Atomic Beam Source performance have been carried out. (Atomic hydrogen beam intensity is about $7 \cdot 10^{16}$ atom/s, degree of dissociation is 80%).

Nearest plans

- Atomic Beam mass spectrometry of hydrogen and deuterium.
- Tunning of nuclear polarisation cells

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