# Polarization facilities at the JINR accelerator complex (September 2024)

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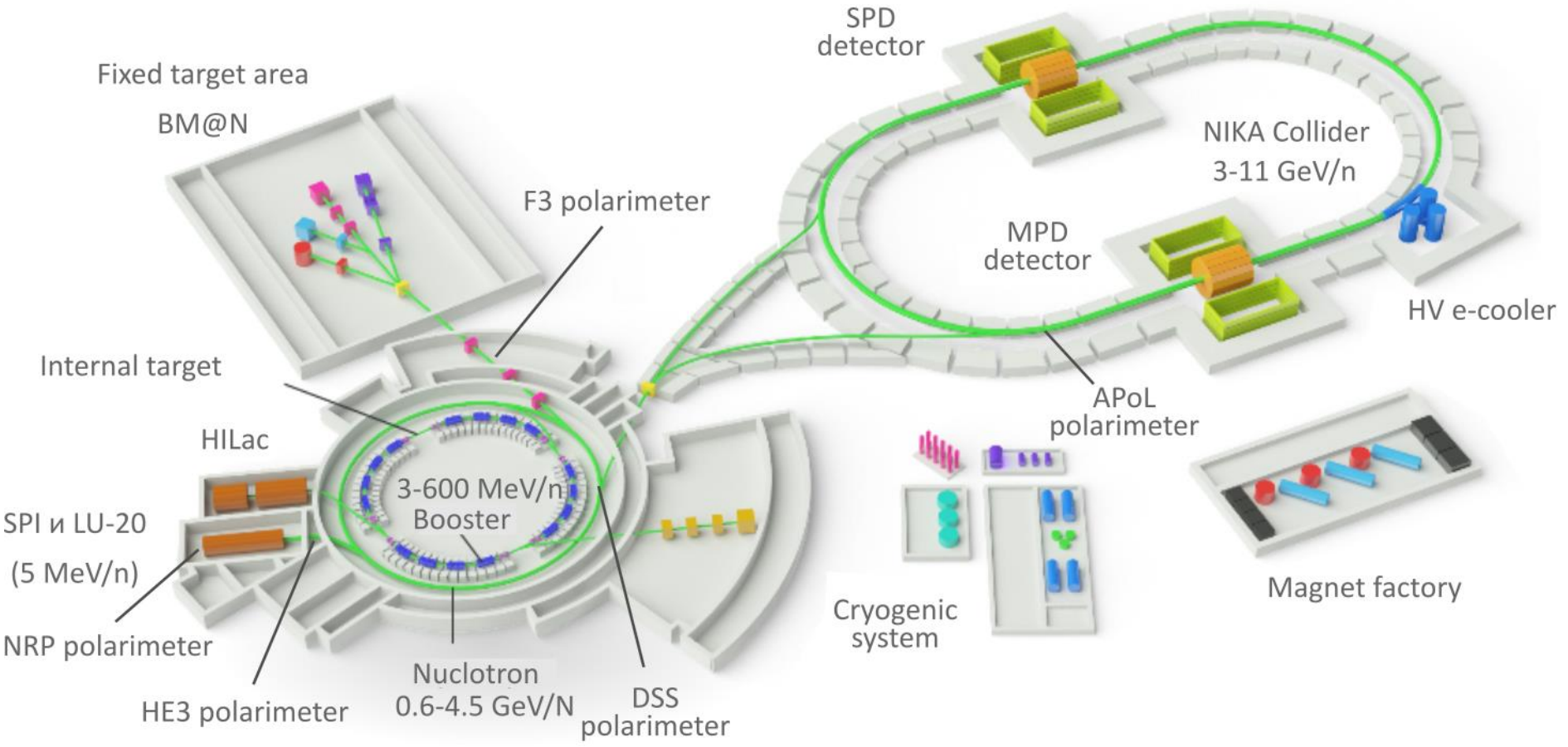
# Implementation of polarization program



Polarization facilities are being developed at the JINR accelerator complex in the framework of the polarization research program under the NICA project.

- polarized deuteron and proton source SPI,
- SPI low energy and linac output polarimeters,
- the absolute polarimeter at the NICA collider.

The status of the above facilities and the results achieved are presented

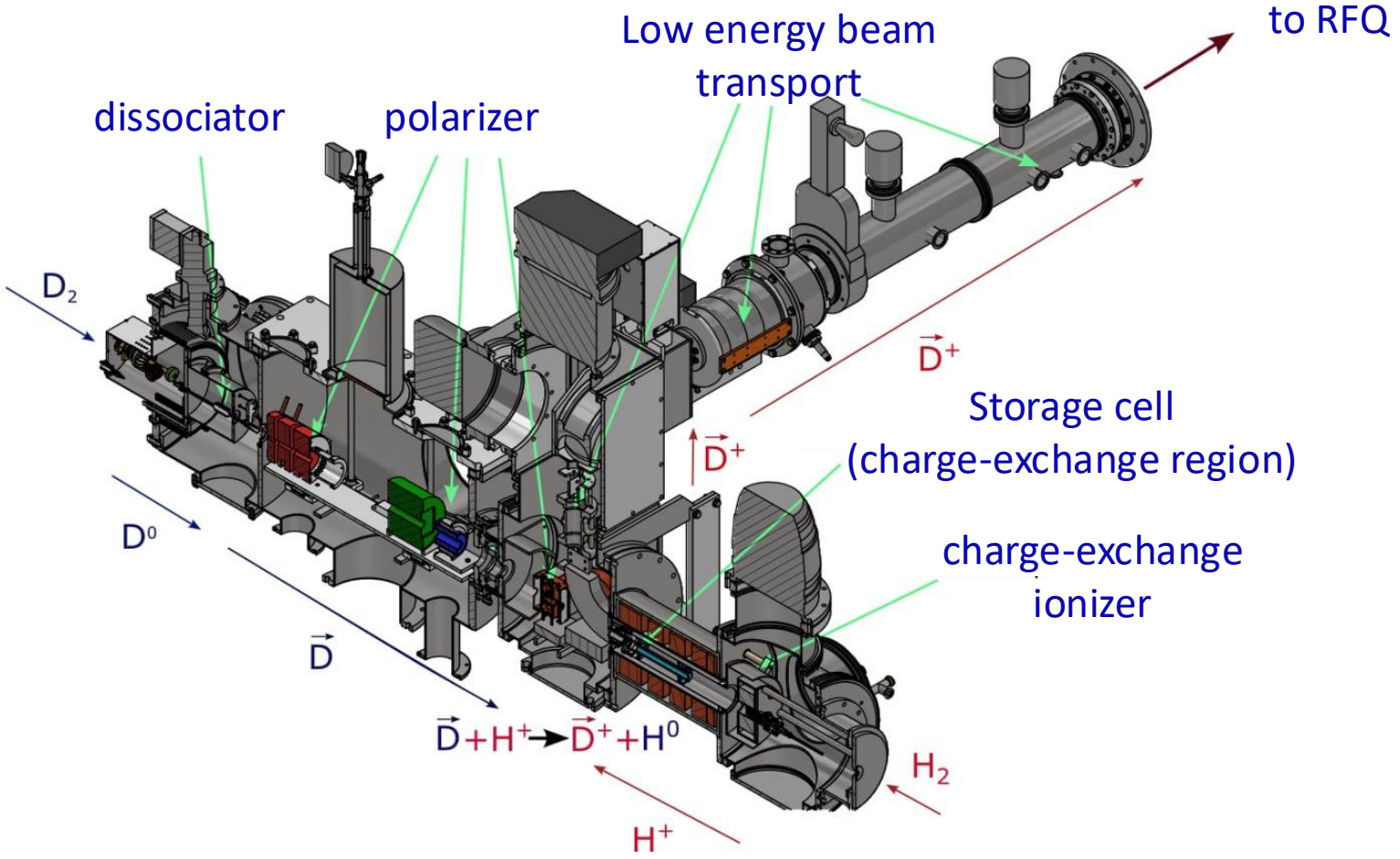
***The project is realized in close cooperation with INR of RAS (Moscow, Russia)***

**S**ource of **P**olarized **I**ons **(SPI-project)** being developed is 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**

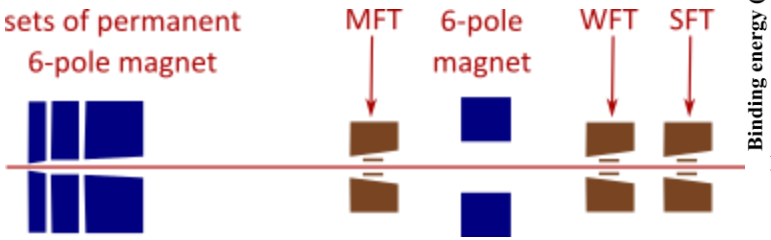
The design output current of the SPI is up to 10 mA for **$\uparrow D^+$ ($\uparrow H^+$)**
The $D^+$ ($H^+$) polarization will be up to 90% of the maximal vector (±1) & tensor (+1,-2) polarization

# Source of Polarized Ions (SPI)

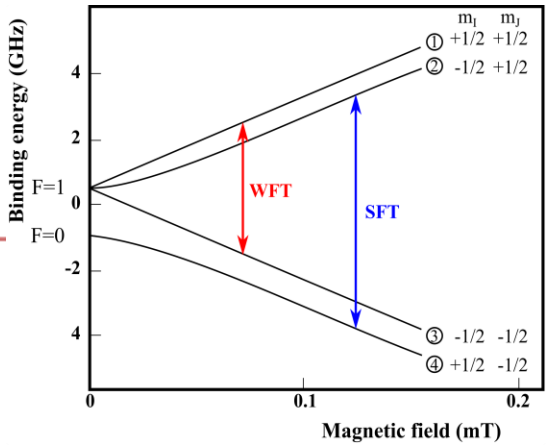


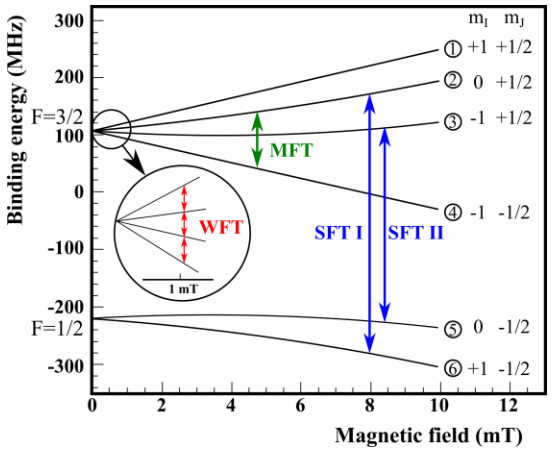

- Hydrogen (deuterium) atoms are produced in RF discharge dissociator.
- The production of an electron polarized atomic beam is done in an inhomogenious magnetic field of three permanent sextupole magnets (polarizer).
- Nuclear polarization is produced by RF transitions units (polarizer).
- Polarized atoms are converted into polarized ions by charge-exchange ionizer.
- Polarized ions are transported to linac by low energy beam transport.

# SPI Nuclear polarization




**Energy diagrams of hfs of hydrogen & deuterium atoms in ground state**



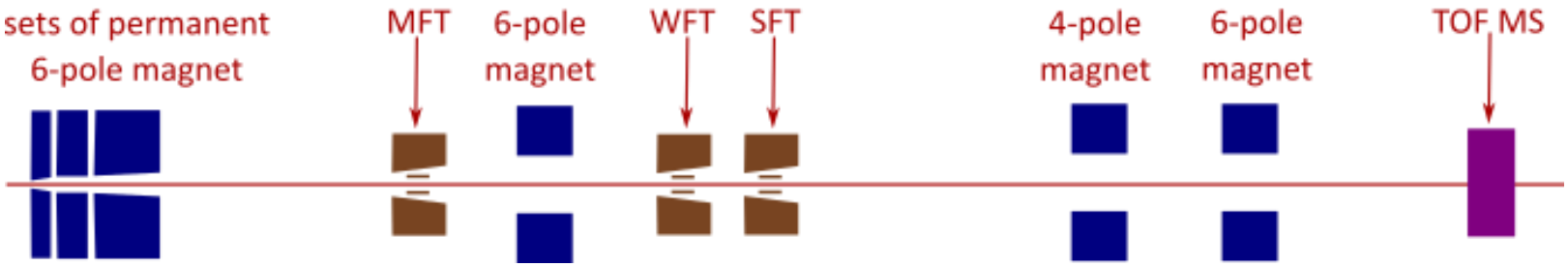

## Deuterons

| 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

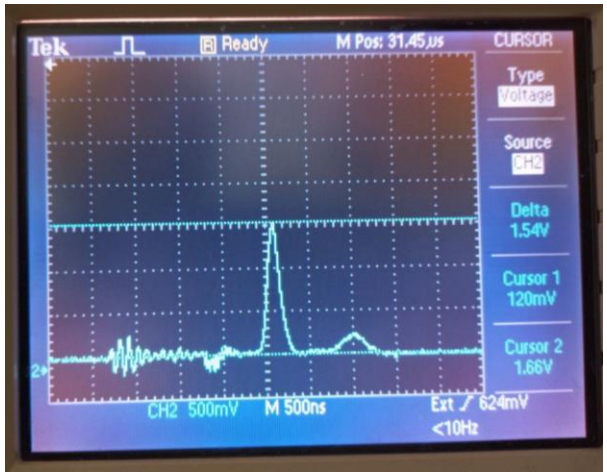
| | | | | |
|---|---|---|---|---|
| MFT - off | WFT 1→ 3 | 2,3 | -1 | |
| MFT - off | SFT 2→ 4 | 1,4 | +1 | |

# Breit – Rabi polarimeter

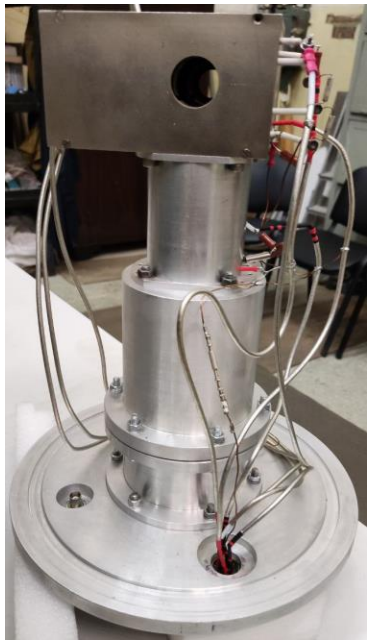



- The sensitivity of the TOF mass spectrometer provides detection of atoms and molecules of the beam density $10^{10}$ - $10^{12}$ cm-3 . The time resolution of the mass spectrometer is 10 μs.

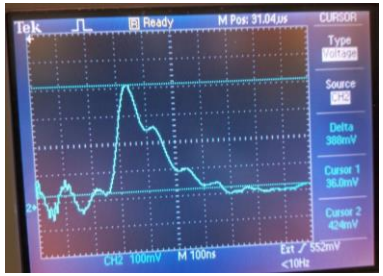
- Two additional permanent magnets are used.



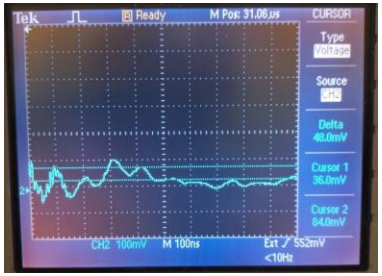

Dissociation degree



TOF
mass spectrometer




Polarization off




Polarization on

# SPI Charge-exchange ionizer

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

  $H^0\uparrow + D^+ \Rightarrow H^+\uparrow + D^0$

  $D^0\uparrow + H^+ \Rightarrow D^+\uparrow + H^0$

  ($\sigma \sim 5 \cdot 10^{-15}\ cm^2$ )

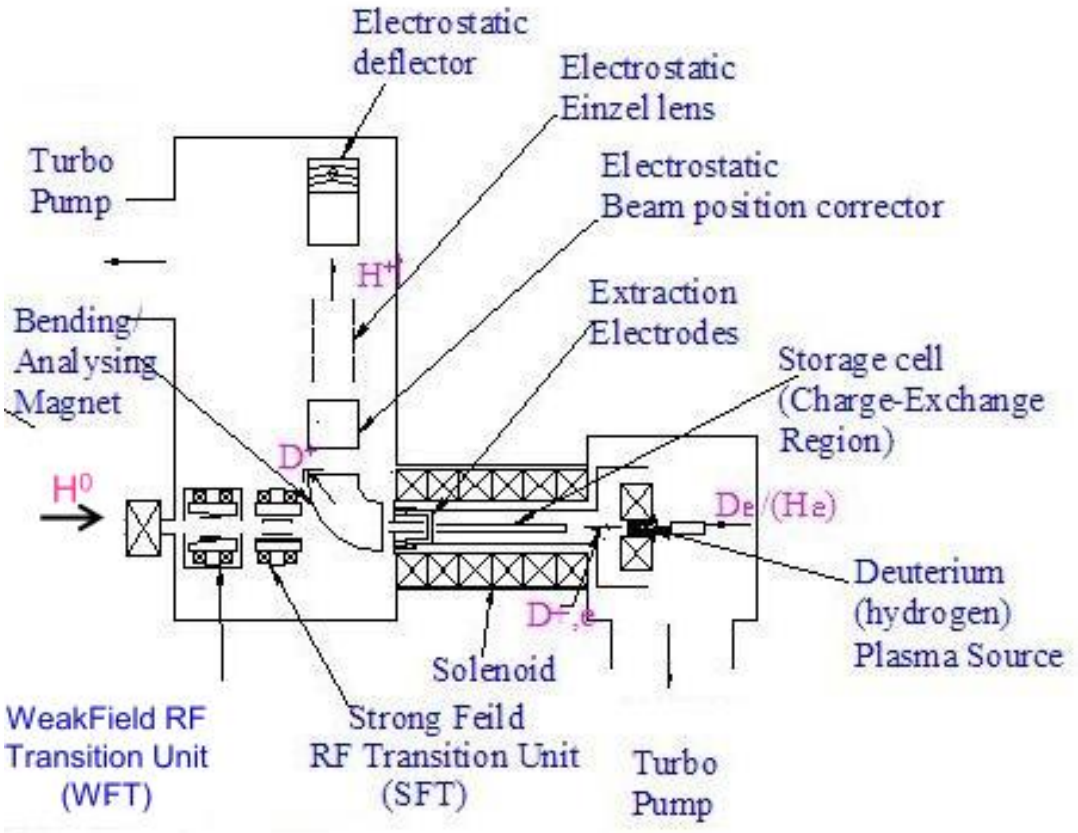
- Ionization efficiency is about 10%

- <u>The storage cell allows</u>:

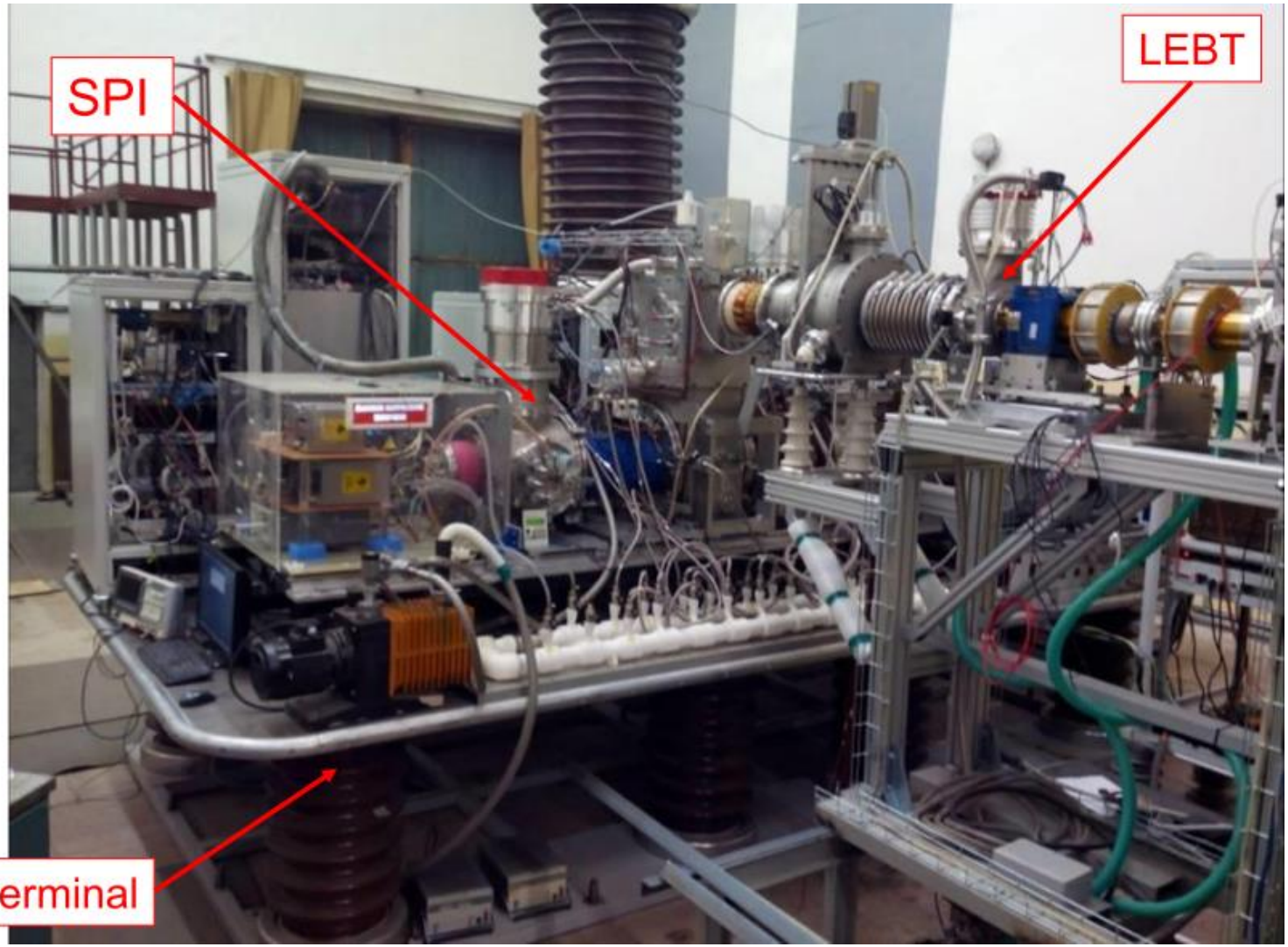
  - increase intensity of the polarized $D^+$ ($H^+$) beam

  - reduce emittance of the polarized beam

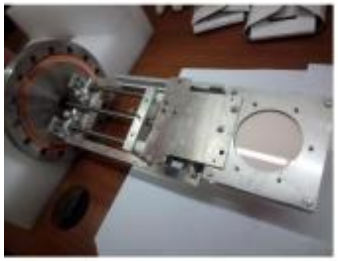
  - considerably reduce $H_2^+$ ion current which is difficult to be separated from polarized $D^+$ due to similar mass of the ions



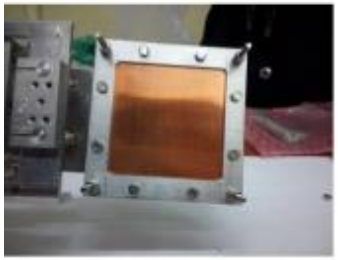
# General view at LU-20 preaccelerator hall (operational assembly)



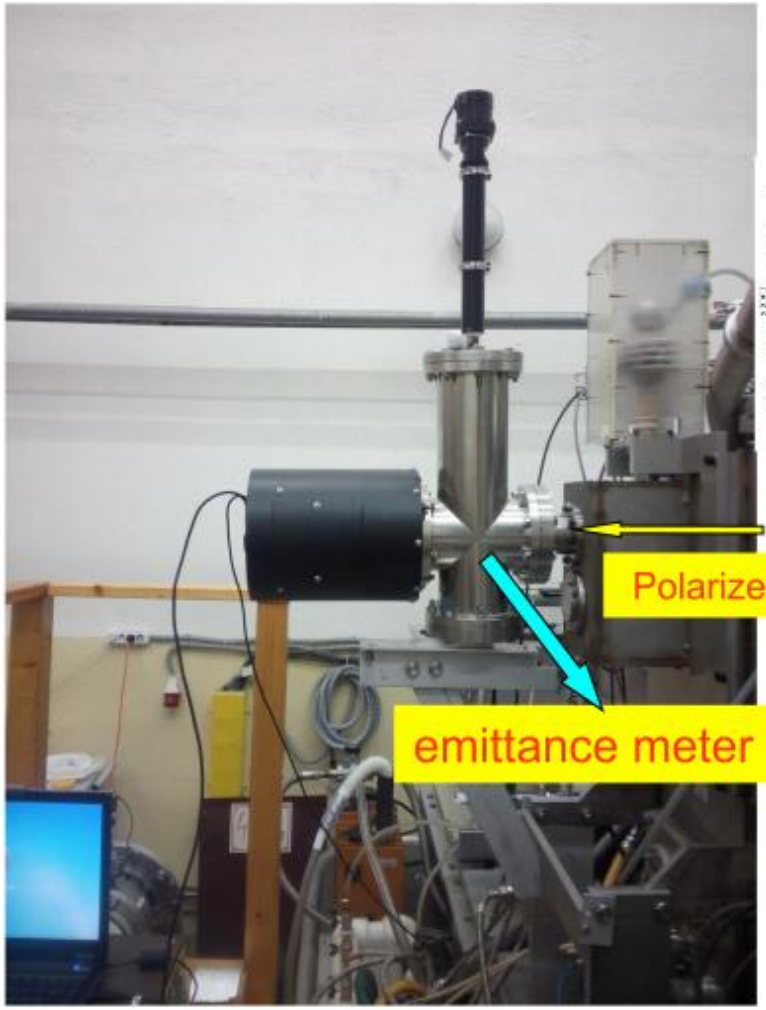
# Emittance measurements of $H_2^+$, $D^+\uparrow$, $H^+\uparrow$ beams



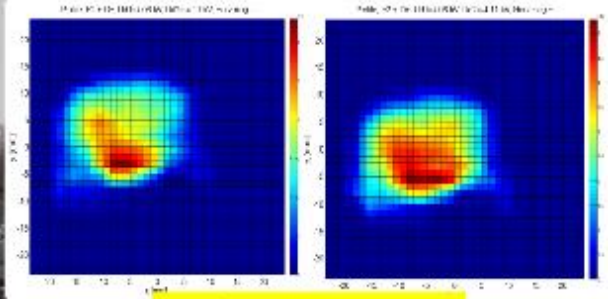
luminophore



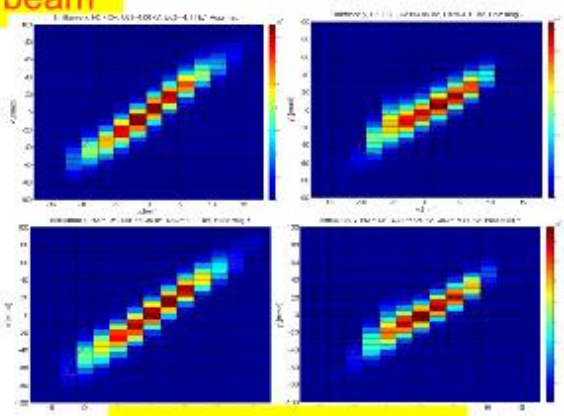
pepper-pot




$D^+\uparrow$

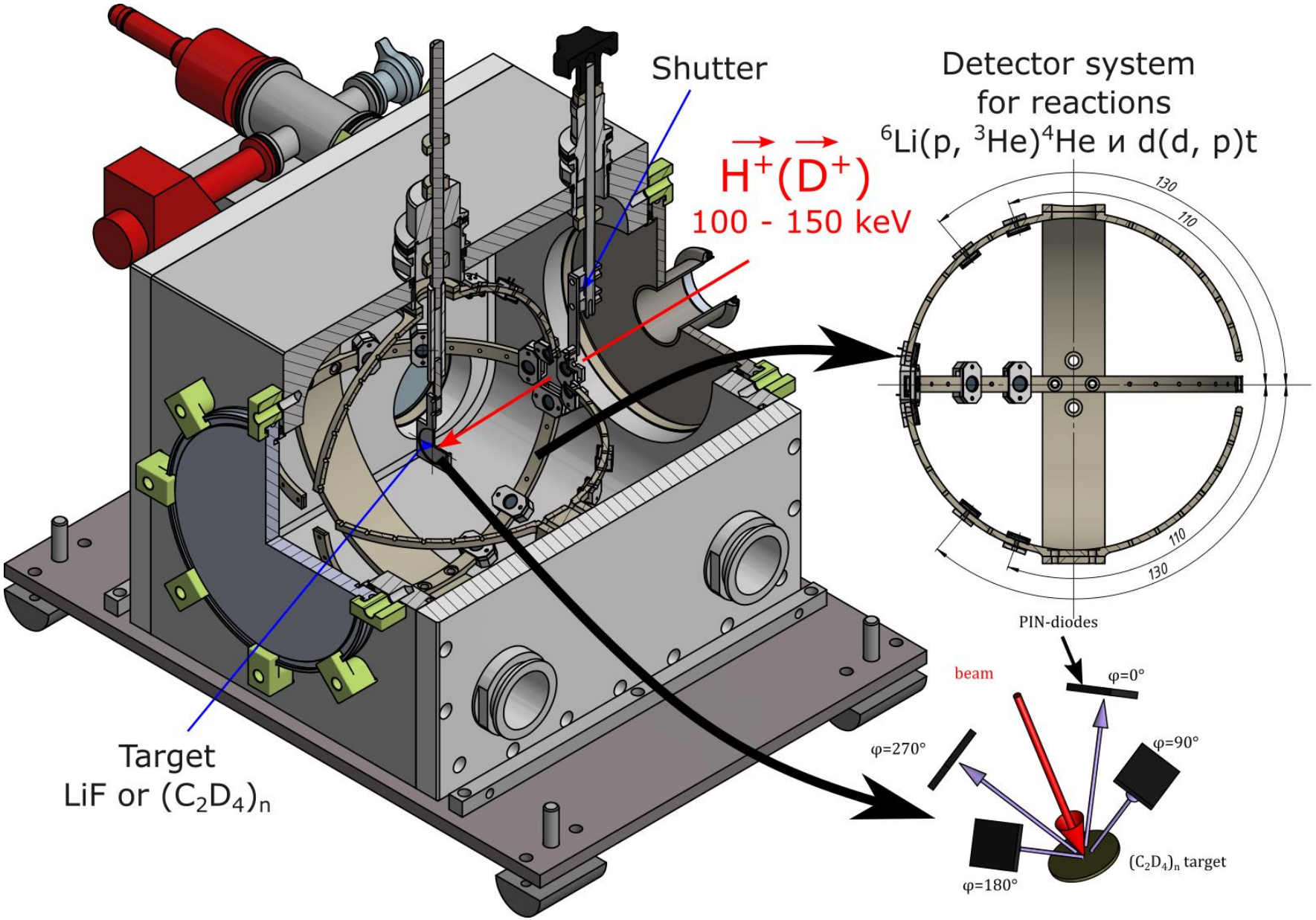


$D^+\uparrow$ Beam profiles



$D^+\uparrow$ Emittance

# Nuclear Reaction Polarimeter (NRP)



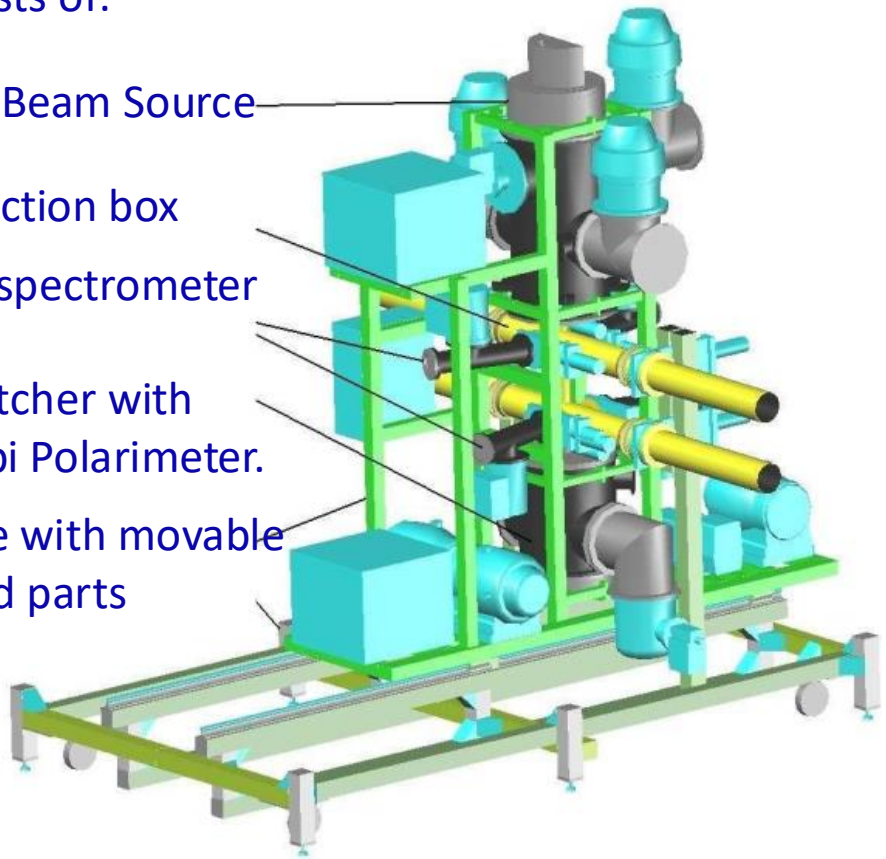
# NIKA Absolute Polarimeter

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

APol photo

APol consists of:

- Atomic Beam Source
- Interaction box
- Four spectrometer Arms.
- Jet catcher with Breit-Rabi Polarimeter.
- Frame with movable and fixed parts



APol 3D view

# Main operational parameters of APol

- steady operation mode
- throughput of $H_2/D_2$
  Q = 1 torr·l/s = $3.4 \cdot 10^{19}$ molecule/s = $6.8 \cdot 10^{19}$ atom/s
- nozzle temperature $T_N$=80°K
- speed of nozzle outflow (=speed of sound):
  for hydrogen - $c_H=(\gamma k_B T/m_H)^{0.5}$ = 1 km/s
  for deuterium – $c_D=(\gamma k_B T/m_D)^{0.5}$ = 0.75 km/s
- Mach number in atomic beam M=2.9
- most probable velocity for atomic beam velocity distribution:
  for hydrogen – 1940 m/s
  for deuterium – 1370 m/s
- beam temperature (=width of velocity distribution) T=23°K
- pole tip magnetic field of Nd-Fe-B sextupole magnets $B_0$=1.5T
- atomic beam intensity in the interaction region – $10^{17}$ atom/s
- target thickness of the atomic beam in the box – $10^{12}$ atom/cm

# Current works and prospects

- SPI dissociator upgrade
- Optimization of the magnetic system of the SPI polarizer
- Upgrade of the existing plasma generator of the charge exchange ionizer
- Development of a low-energy polarimeter based on the 6Lip and dd reactions.
- Optimization of the absolute polarimeter operation:
  - Development and creation of the MFT cell of the polarimeter
  - Development of a system for measuring the beam intensity and profile
- Optimization of the SPI ion beam transport system to RFQ
- Development of a Lamb-Shift polarimeter at the output of the SPI source

*Thank you*