Development of the Optically Pumped Polarized Ion Source for Polarized Negative Ion Beam Production

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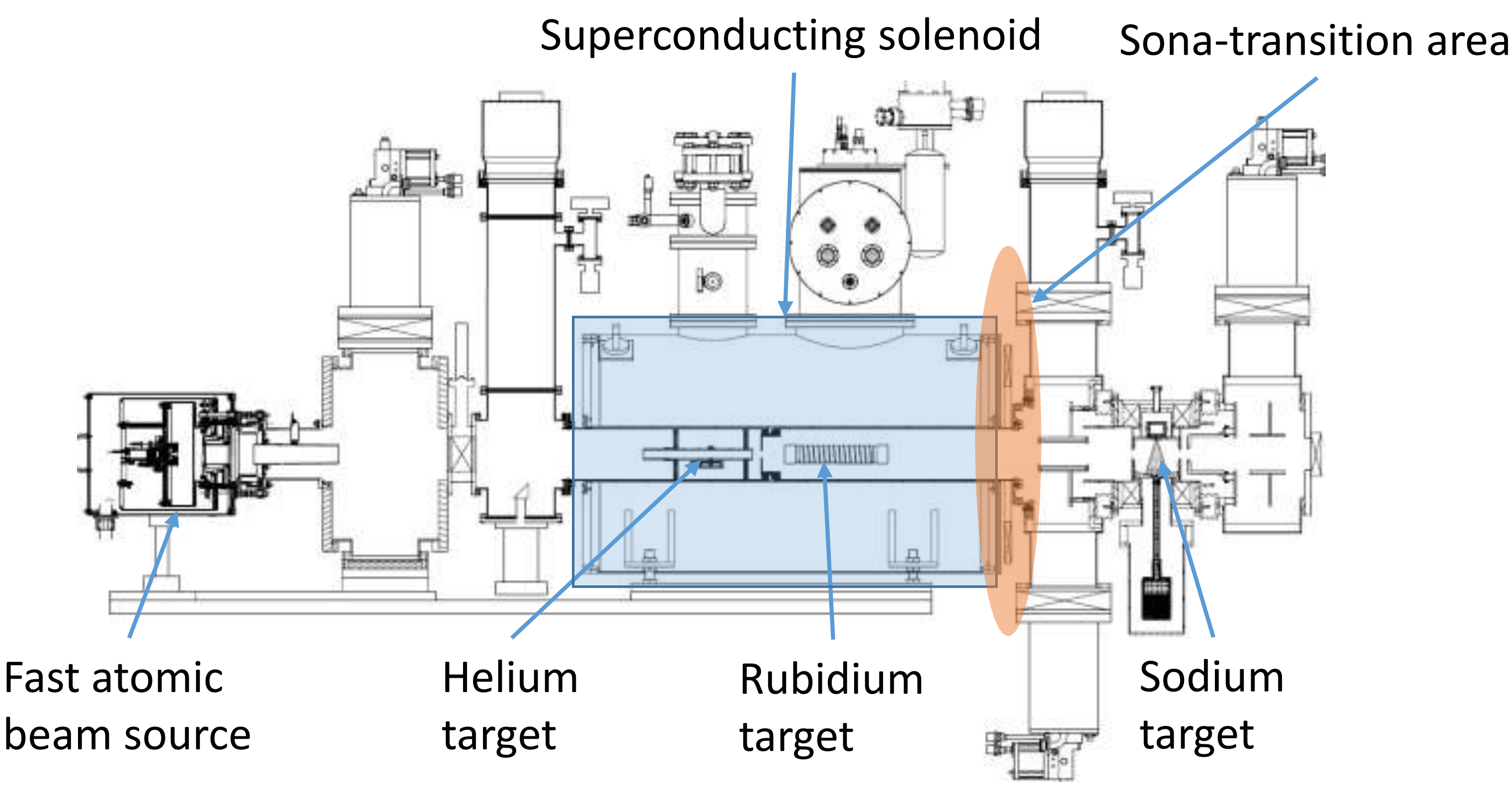
Outline

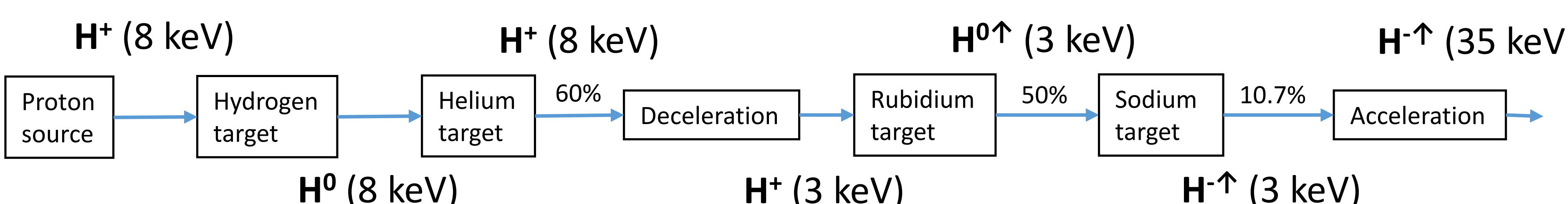
- Upgrade of the OPPIS Ion Source for Polarized Negative Ion Beam Production for use in the RHIC polarization physics program
- Development and experimental research of principal OPPIS elements
- Results of use of upgraded OPPIS at RHIC
- Experiments on production of unpolarized H^- beam by charge-exchange method

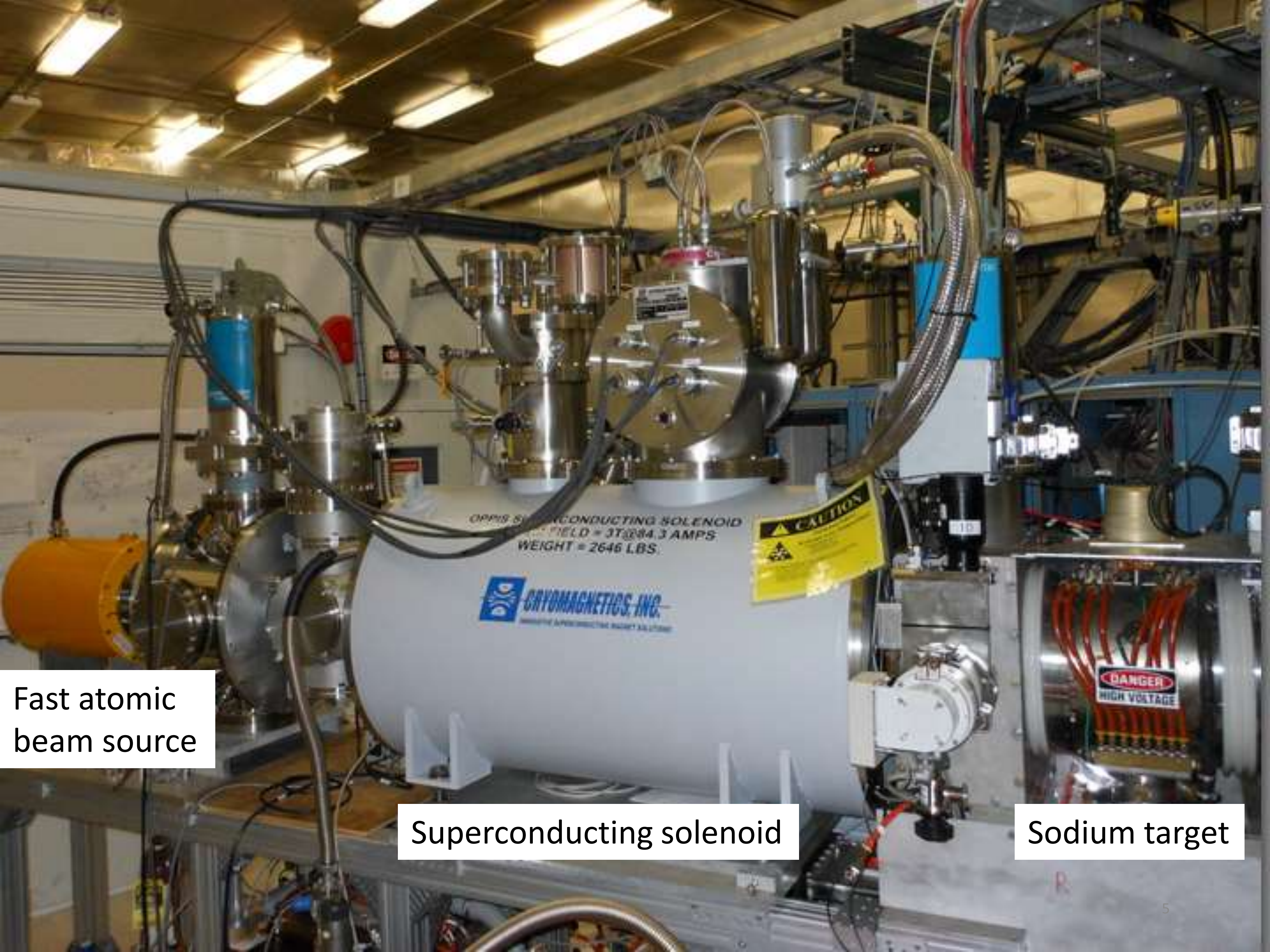
Motivations

- Physicists at Brookhaven and BINP, Novosibirsk have proposed that the RHIC operational polarized ion source will be upgraded to higher intensity and polarization for use in the RHIC polarization physics program at enhanced, high luminosity RHIC operation.
- The projected OPPIS parameters after upgrade are as follows:
  - H^- ion beam current (peak) 5-10 mA
  - Pulse duration 300 us
  - Repetition rate 1 Hz
  - Normalized emittance 2.0 pi mm mrad
  - Polarization 85-90%

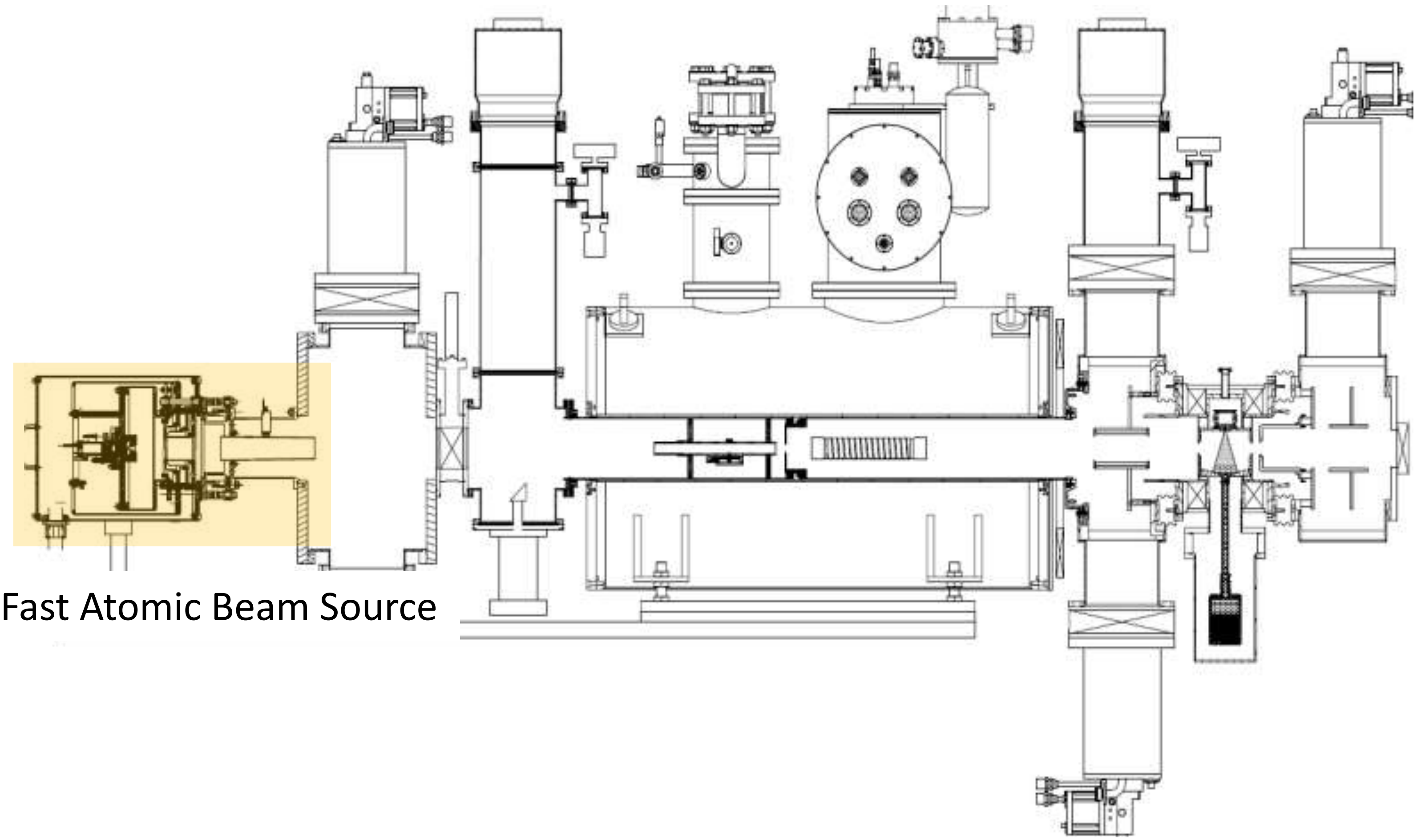
Optically Pumped Polarized Ion Source






Fast atomic beam source
Superconducting solenoid
Sodium target
WEIGHT = 2646 LBS.
CRYOMAGNETICS, INC.
CAUTION
DANGER
HIGH VOLTAGE

OPPIS principle elements

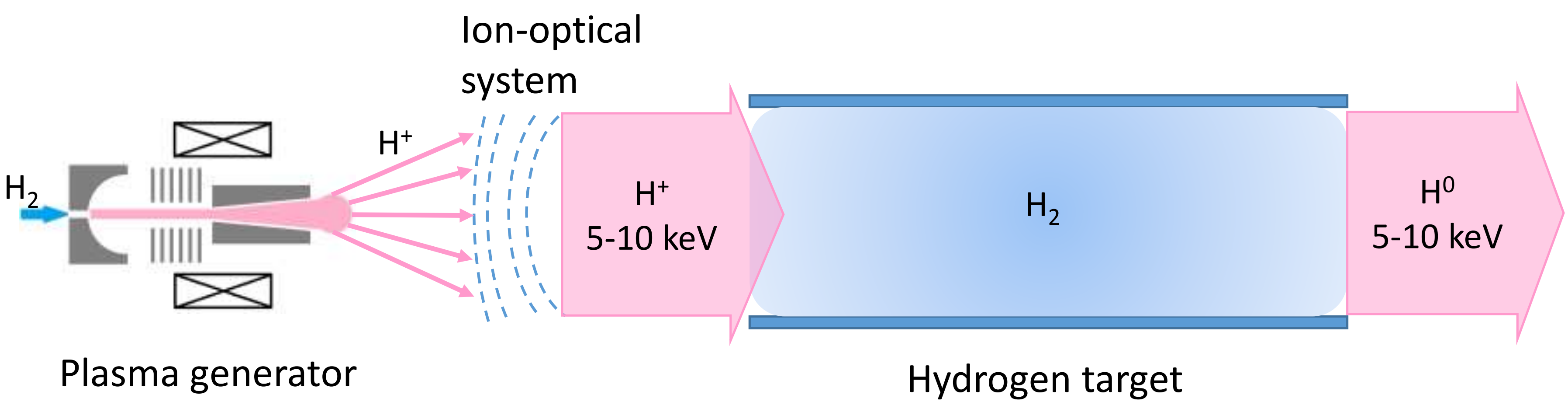


Fast Atomic Beam Source

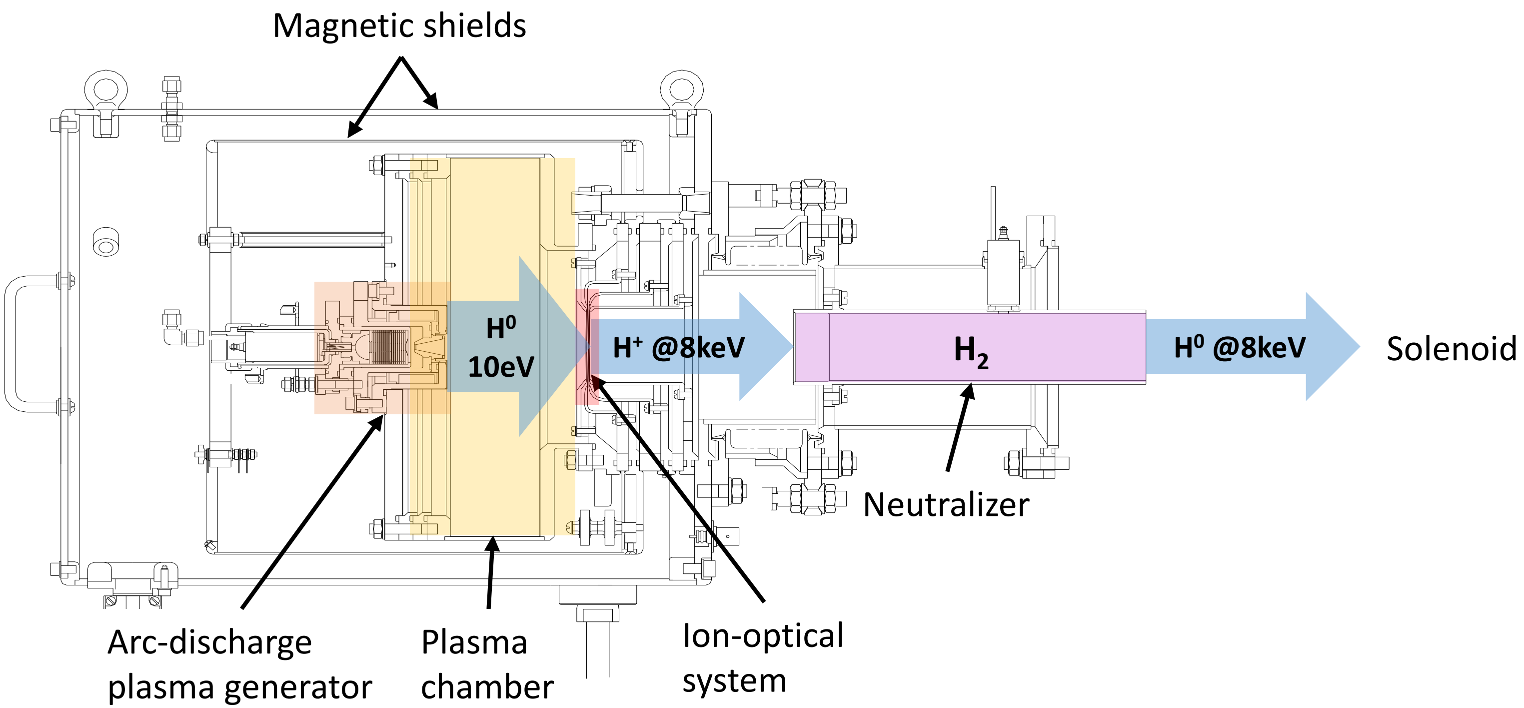
Fast Atomic Beam Source

Requirements:

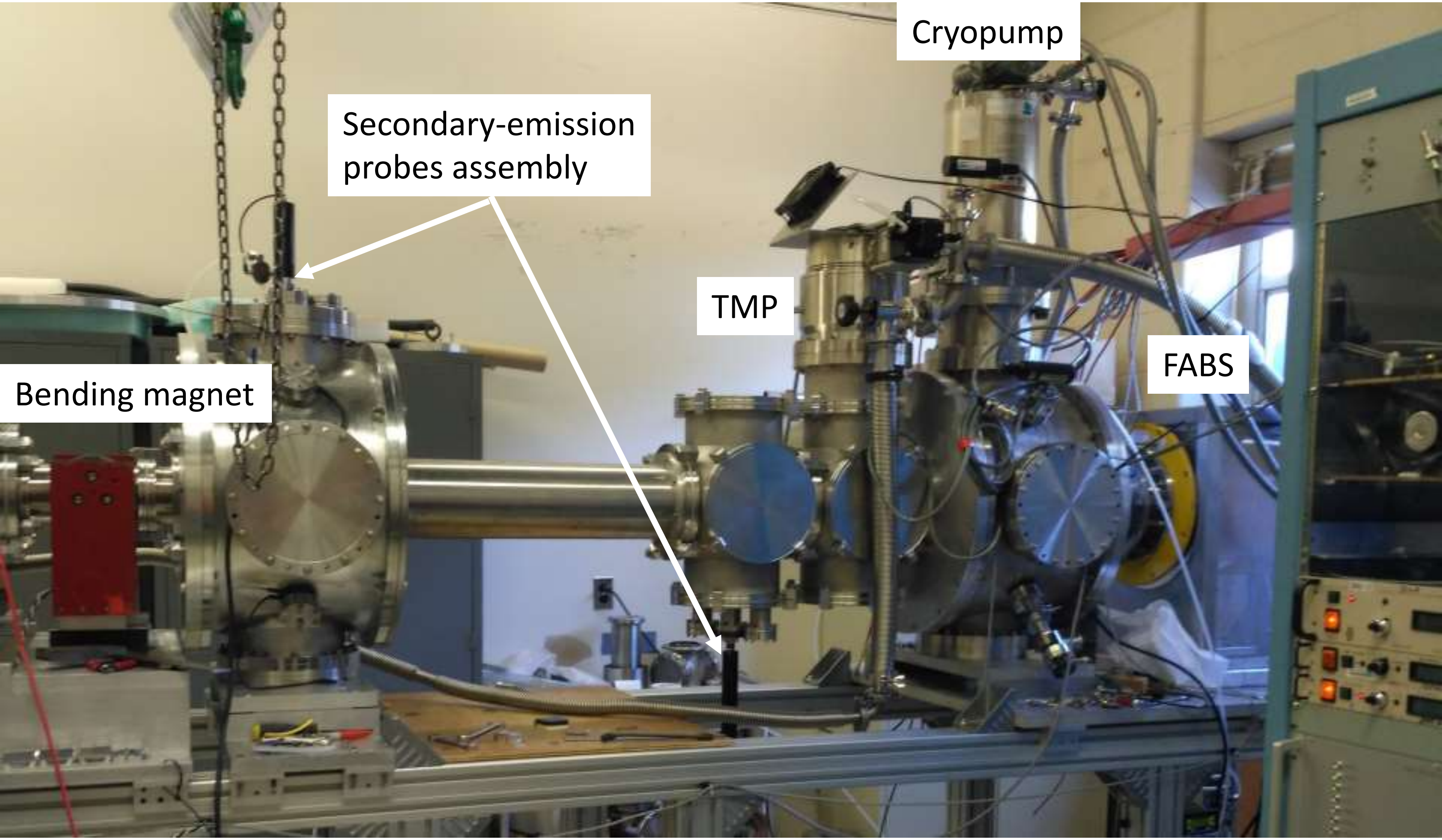
• Particle energy	5-10 keV
• Equivalent hydrogen beam current in focus	≥ 100 mA/cm^2
• Pulse duration	0.5 ms
• Repetition frequency	1 Hz



Fast Atomic Beam Source



- Low grids thickness (0.38 mm) and elementary aperture diameter (0.8mm) of ion-optical system
- Increased plasma chamber volume allows forming of the plasma emitter with low transversal temperature (~0.2 eV) and high proton fracture (>90%)

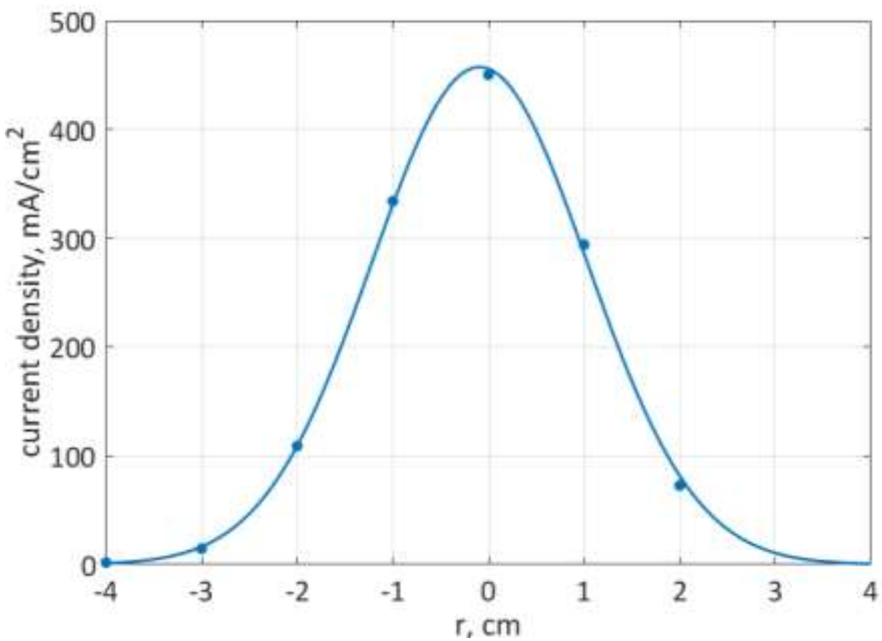

Cryopump
Secondary-emission probes assembly
TMP
FABS
Bending magnet

Fast Atomic Beam Source

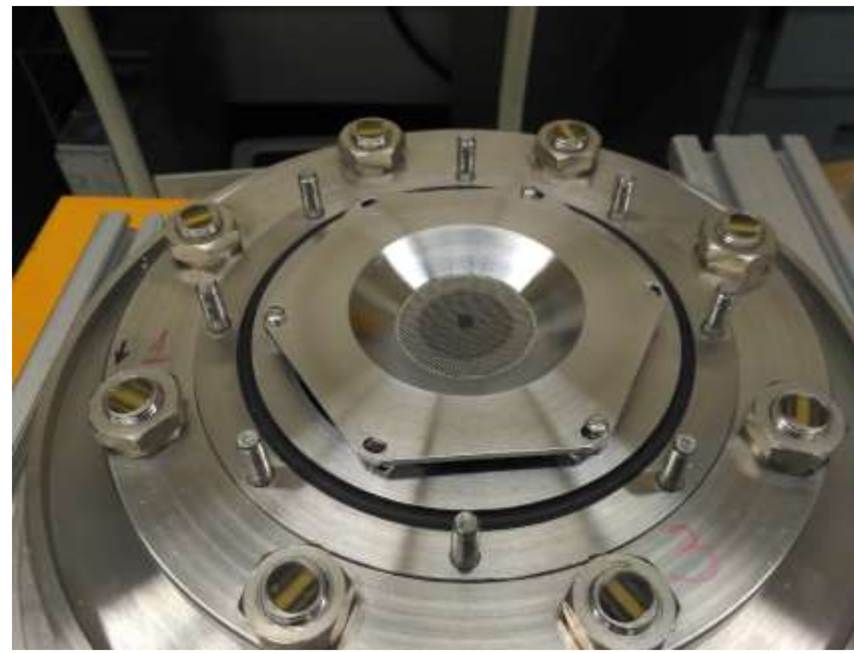
FABS beam parameters:

- Equivalent beam current @8 keV 3.2 A
- Focal length 230 cm
- Beam size in focus (1/e) 2 cm

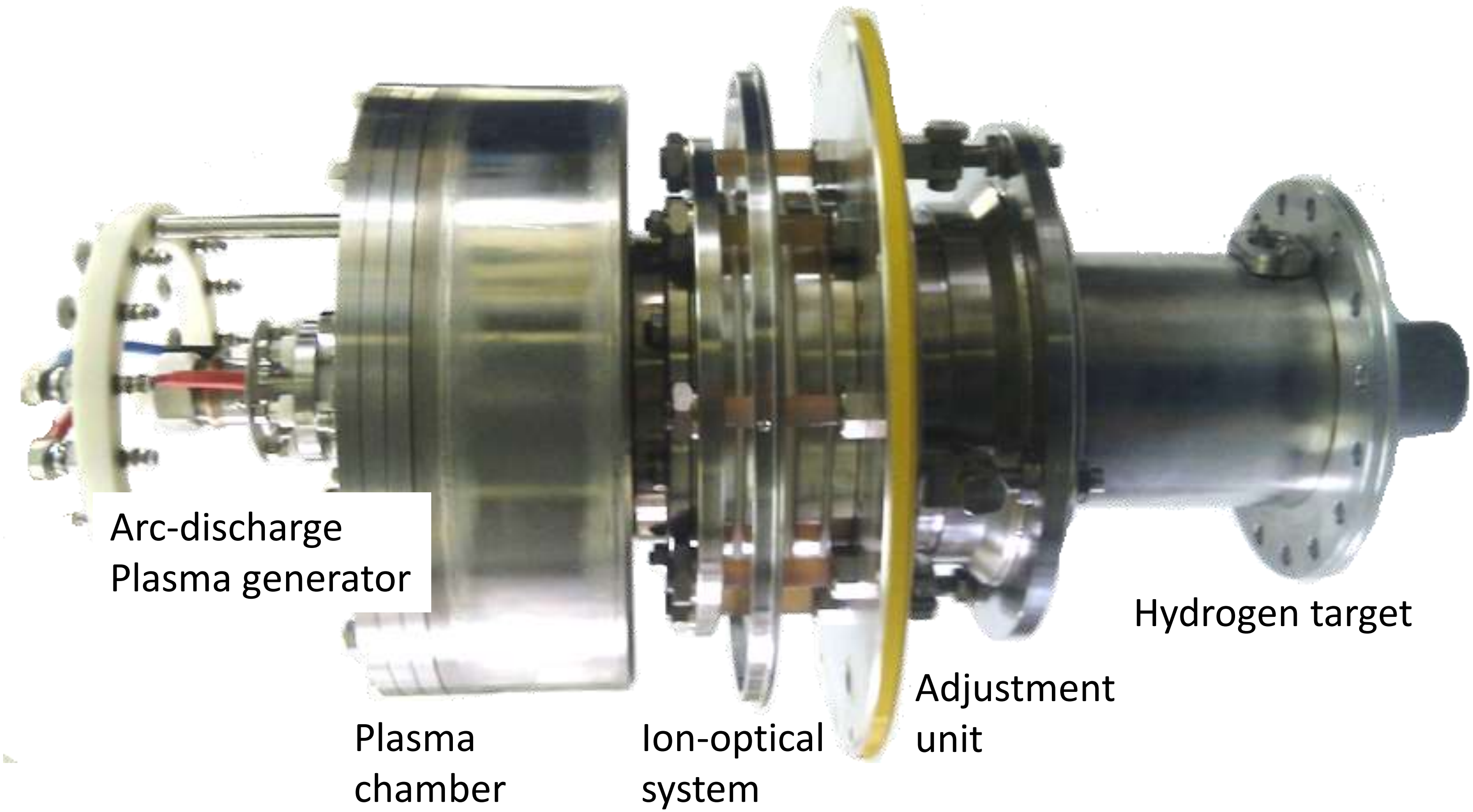
Beam profile in focus:



Four grid ion-optical system with ballistic focusing:



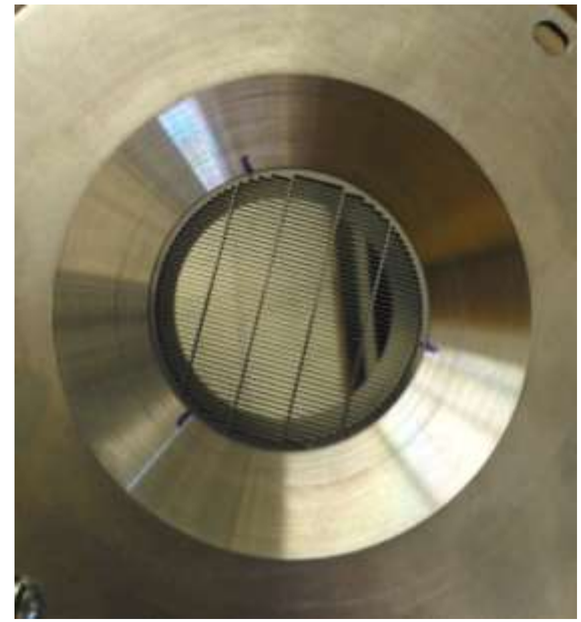
Fast Atomic Beam Source



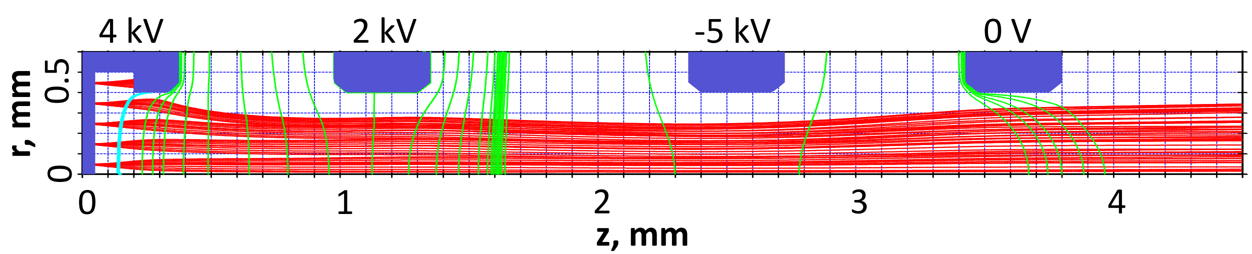
Fast Atomic Beam Source Evolution

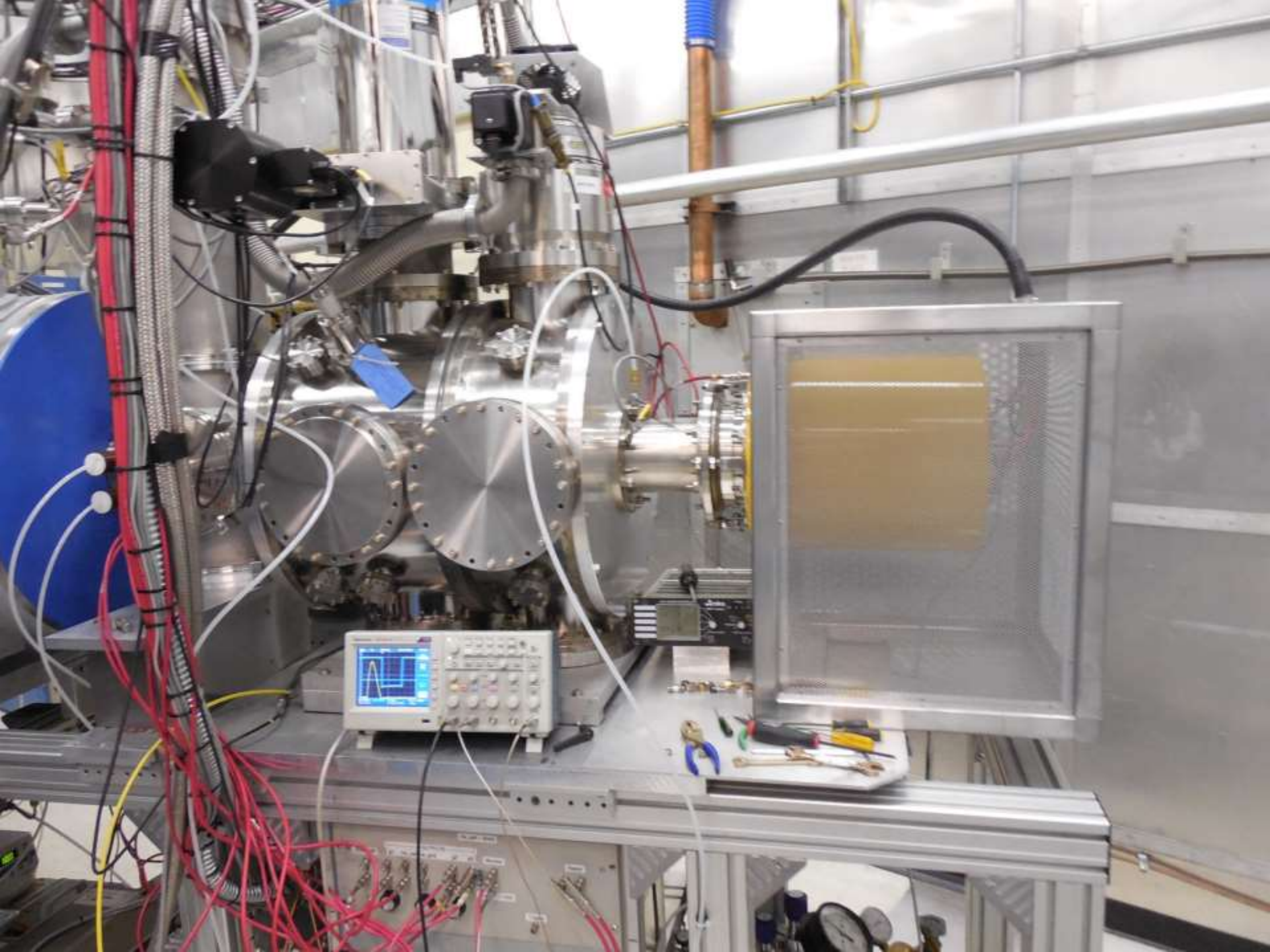
- **Grids with increased transparency**
  - Transparency 60% (now 50%)
  - Beam current @8 keV > 4 A
  - Beam divergence 10 mrad
- **Slotted grids**
  - Transparency > 80%
  - Beam current @6.5 keV 6 A
- **“Accel-decel” system**
  - Proton energy 4 keV
  - Emission current density 0.7 A/cm^2
  - Beam divergence 16.5 mrad

Slotted ion-optical system

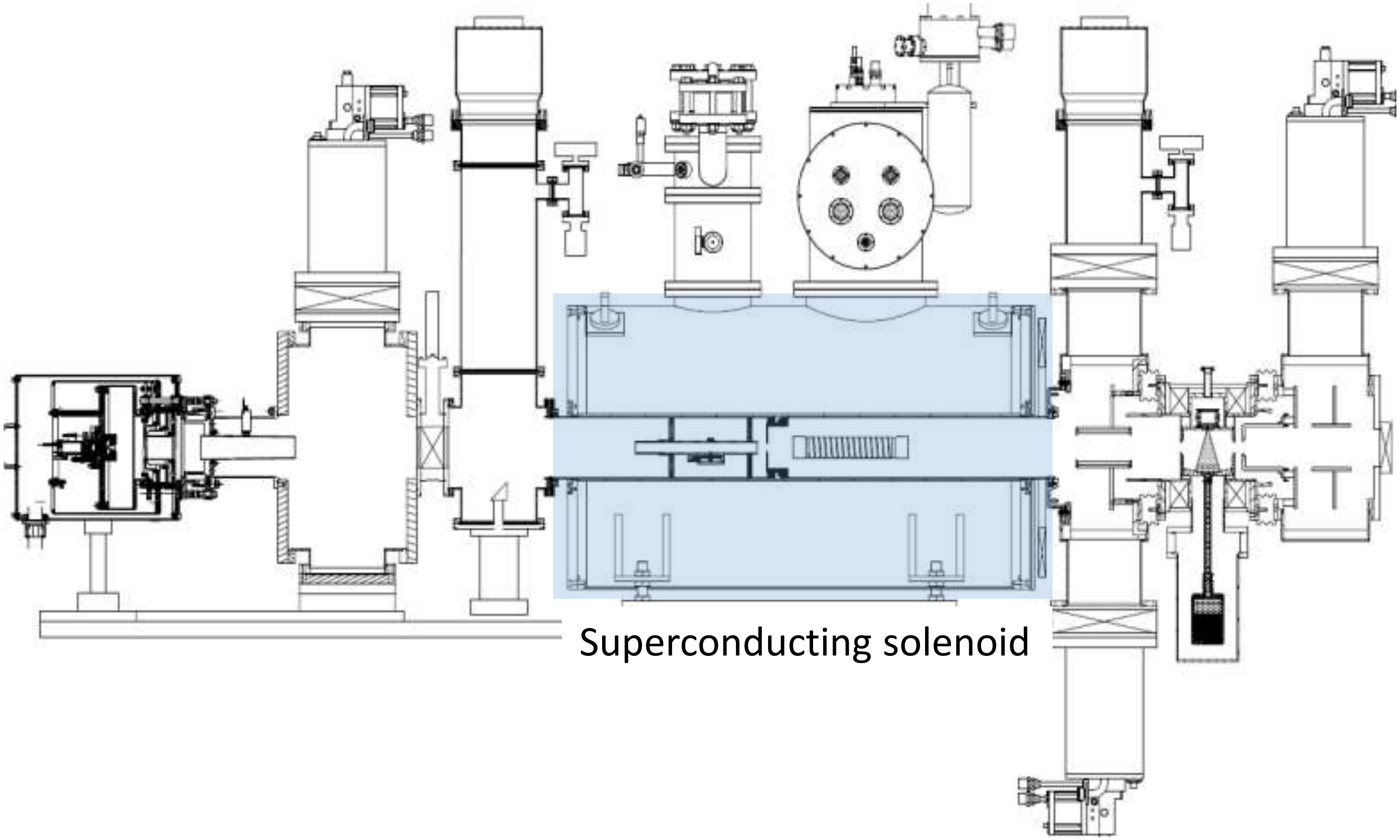


Trajectories of protons in the elementary cell of “accel-decel” system

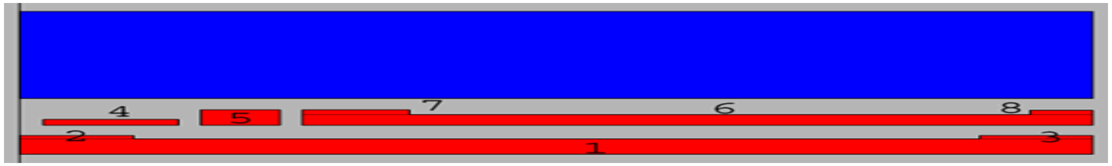


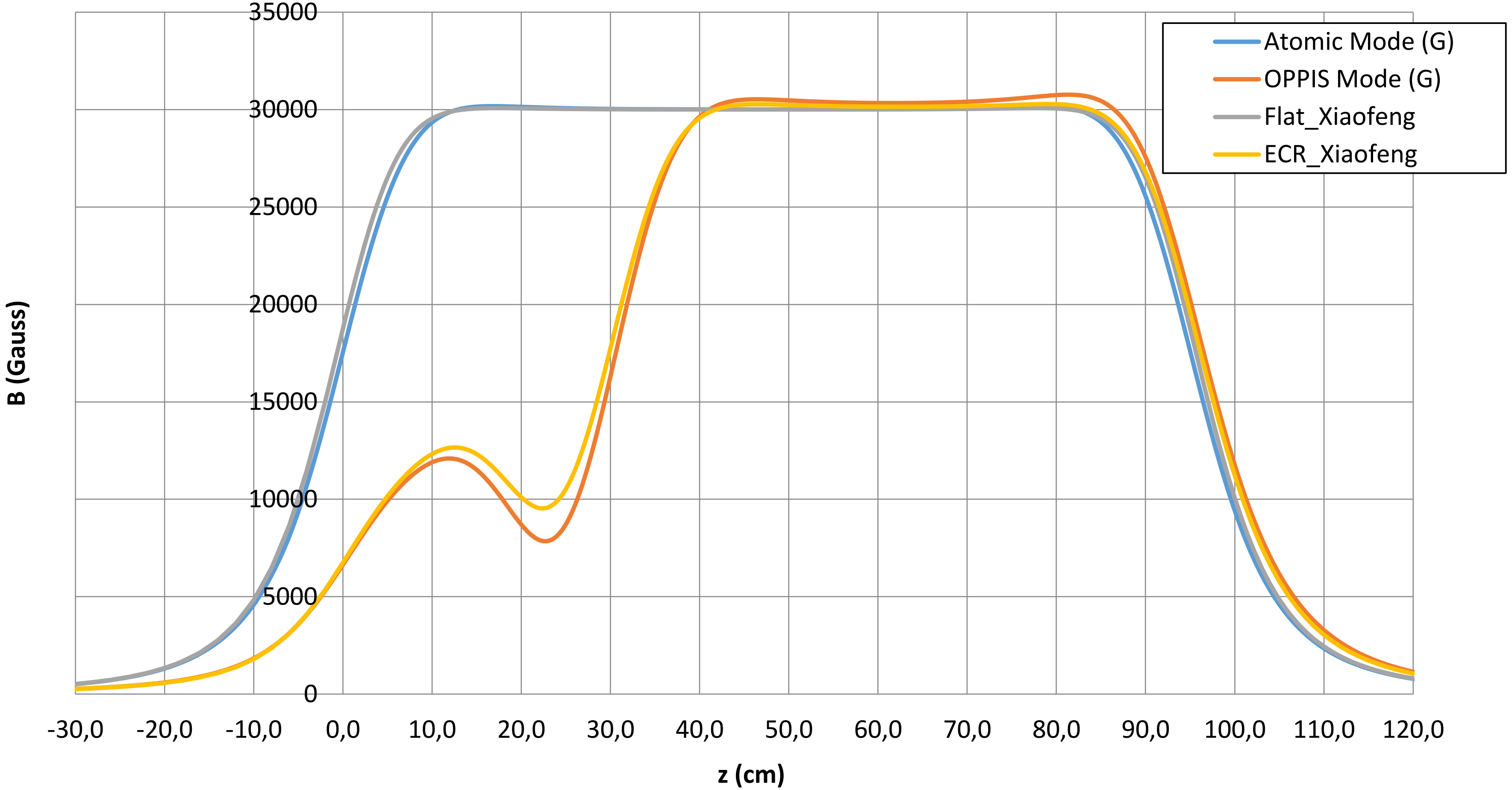


OPPIS principle elements



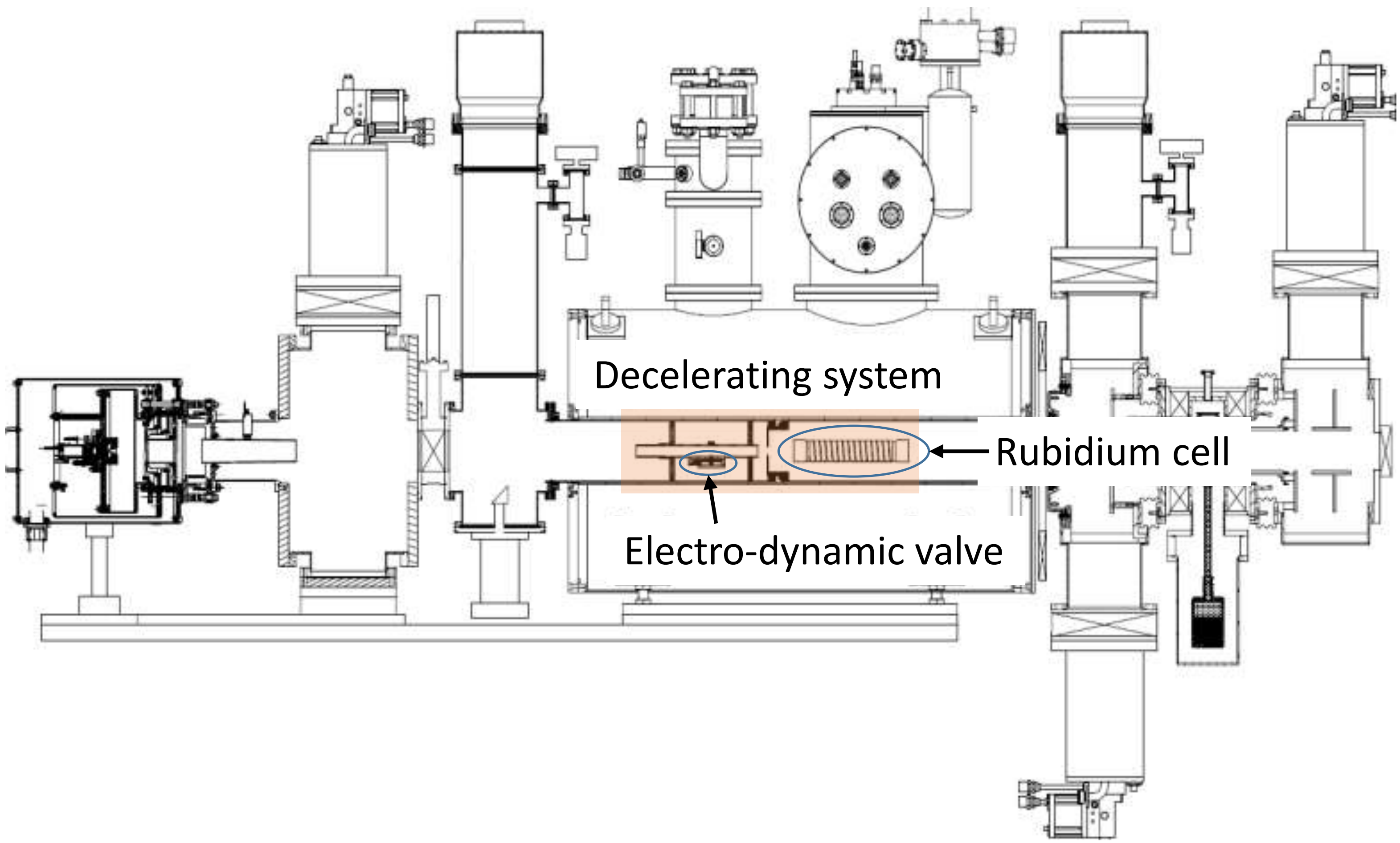
Superconducting Solenoid



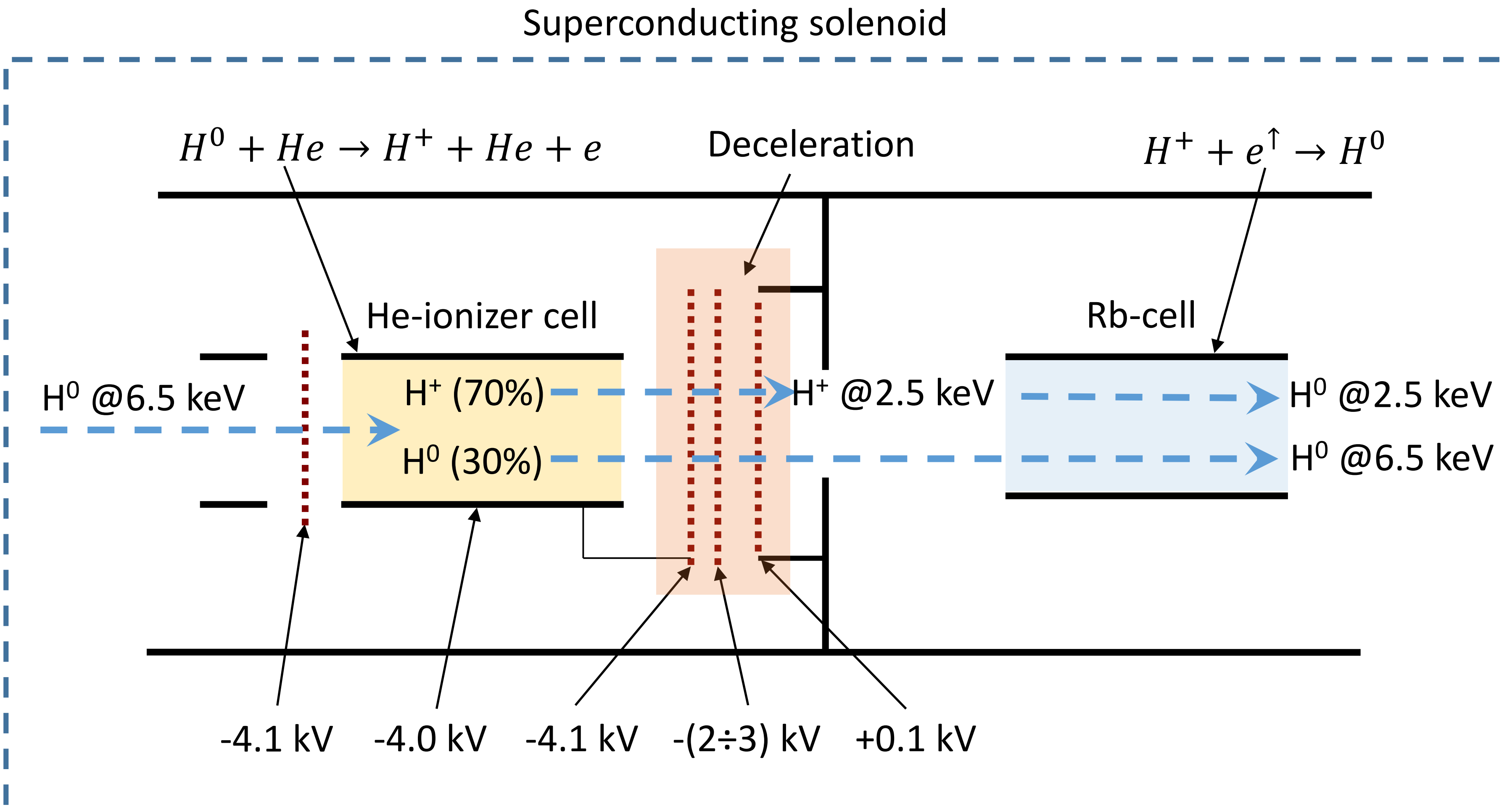


Superconducting Solenoid

OPPIS principle elements

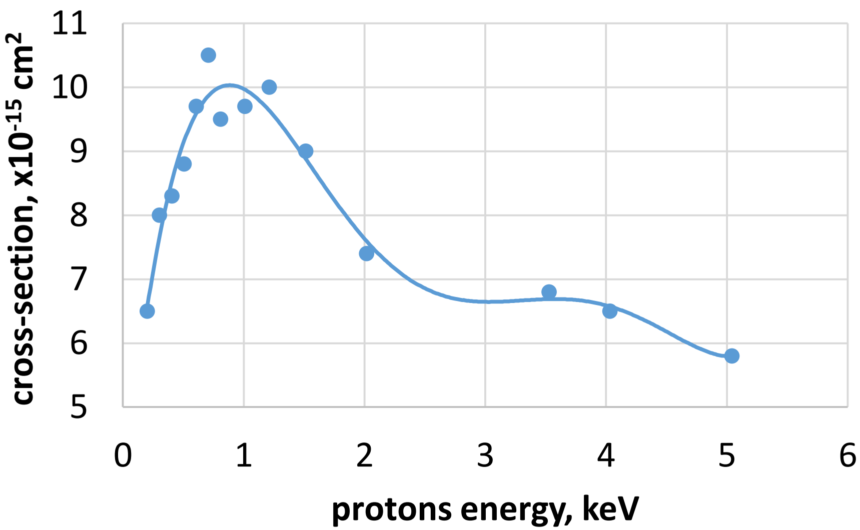


Decelerating 3-electrode system



Rubidium cell

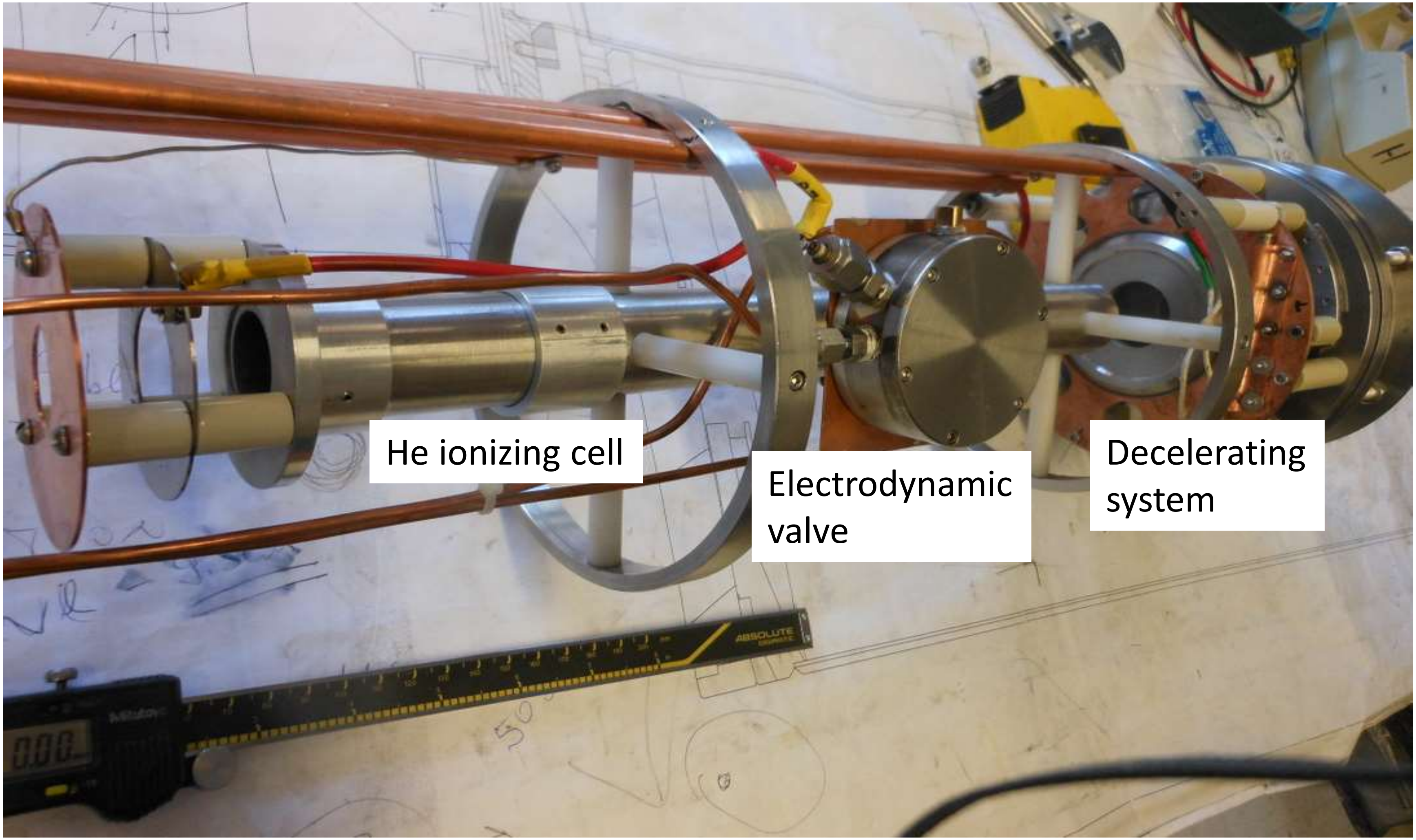
Cross-section of the electron capture by hydrogen in Rb vapor



LINAC current and polarization dependence on Rb target thickness

nL, 10^{-13} cm^2	LINAC current, uA	Polarization, %
4.5	500	84
5.5	560	83
7.5	680	80.5
10.4	750	78.5

He ionizing cell with valve and decelerating 3-electrode system

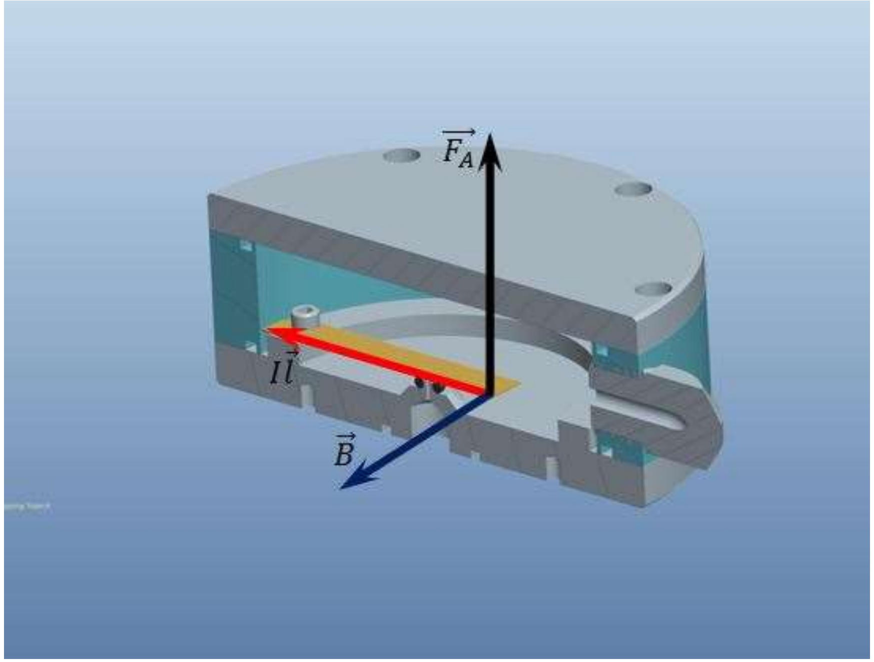


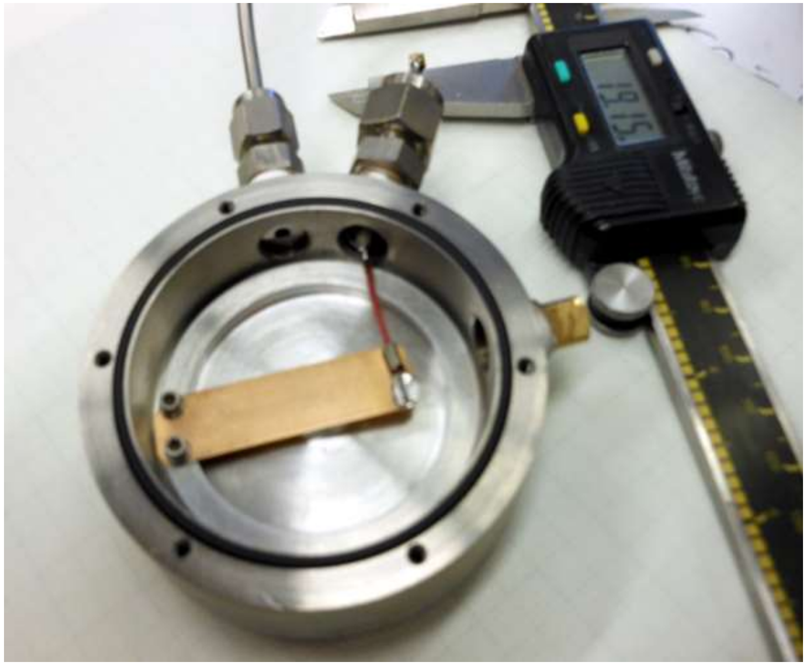
Electro-dynamic Valve

Force to the conducting plate in the magnetic field:

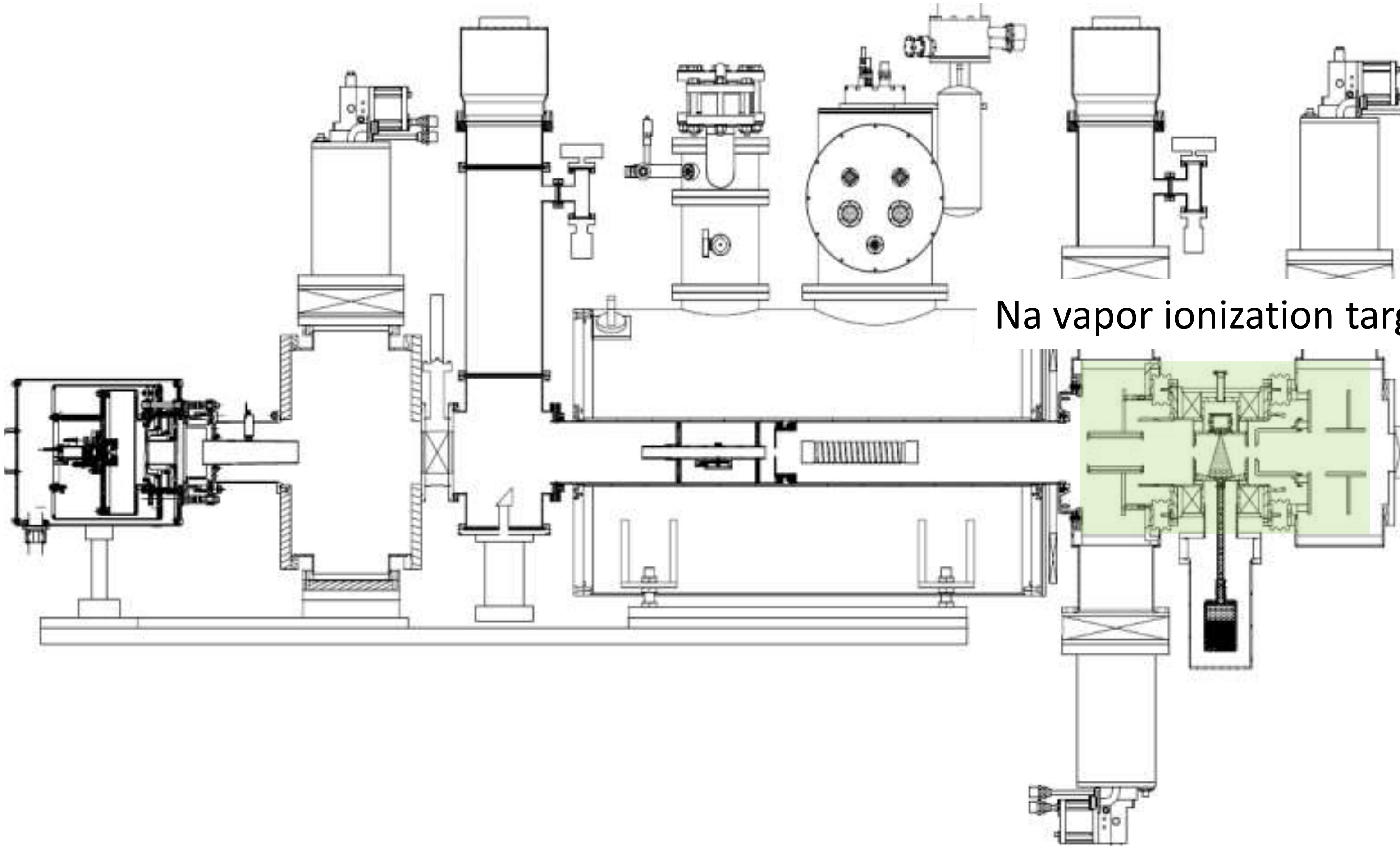
$$\vec{F} = I \cdot [\vec{L} \times \vec{B}]$$

$B \approx 3$ T, $I = 100$ A, $L = 5$ cm => $F = 15$ N).



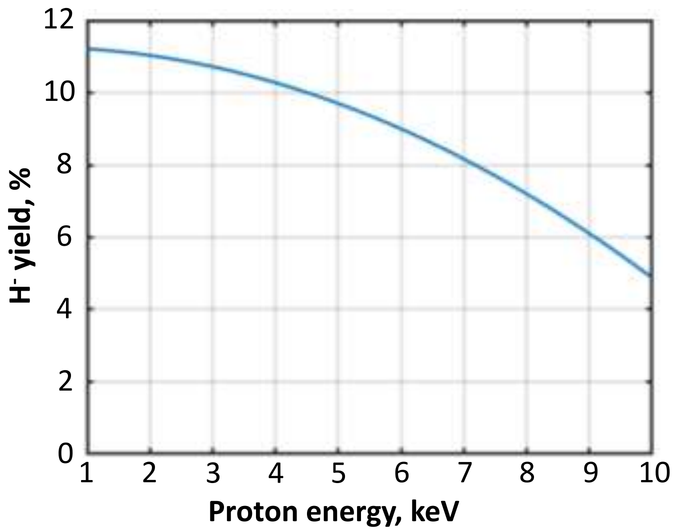


OPPIS principle elements

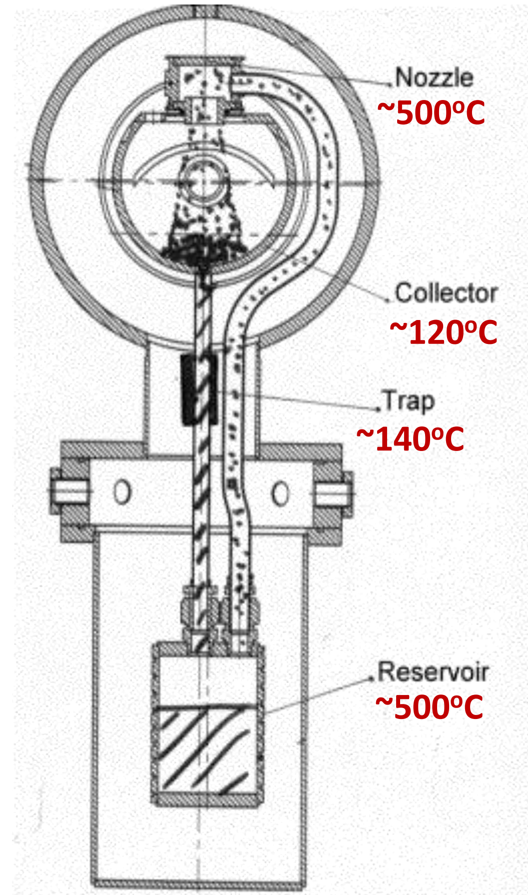


Stationary recirculating sodium vapor ionization target

H^- equilibrium yield from sodium vapor



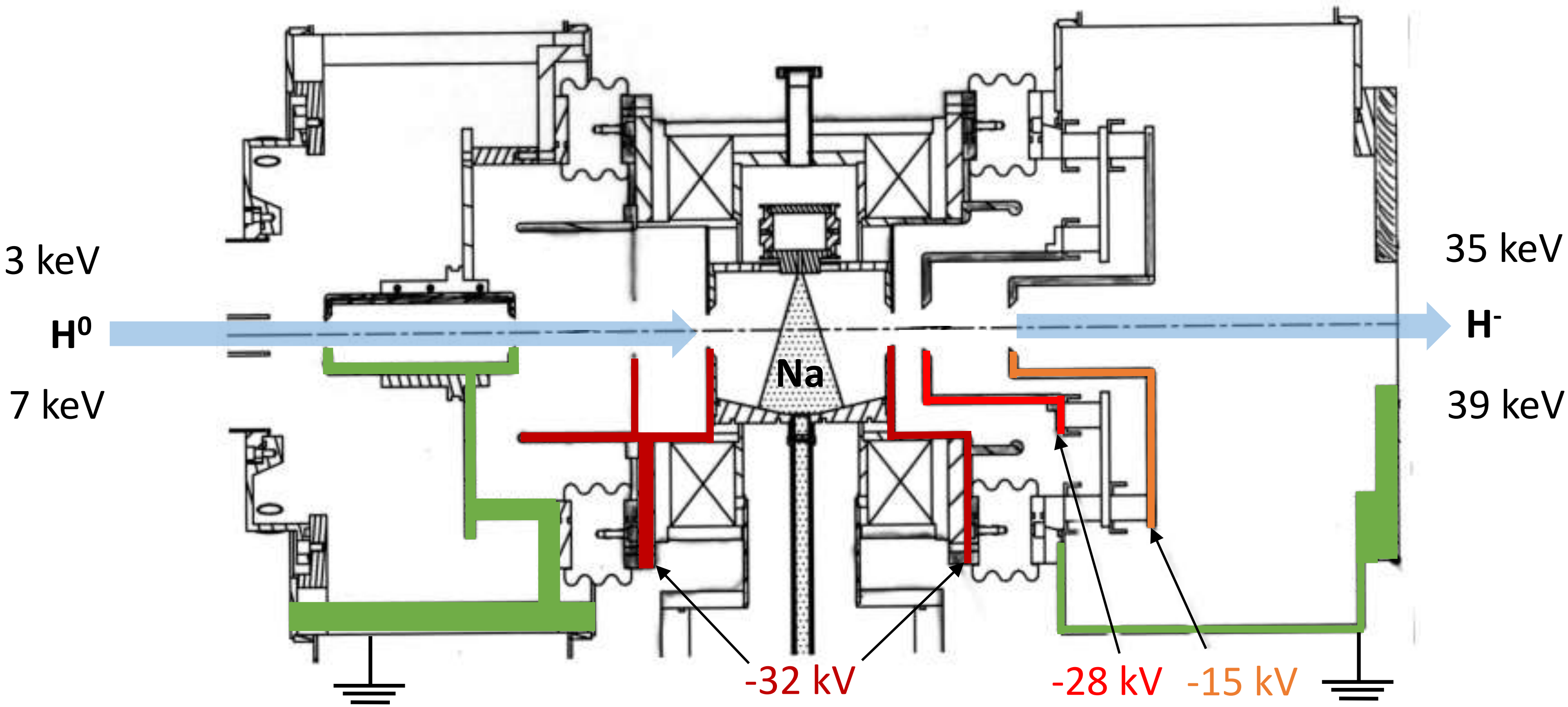
Sodium vapor ionization target:



Na vapor ionization target parameters:

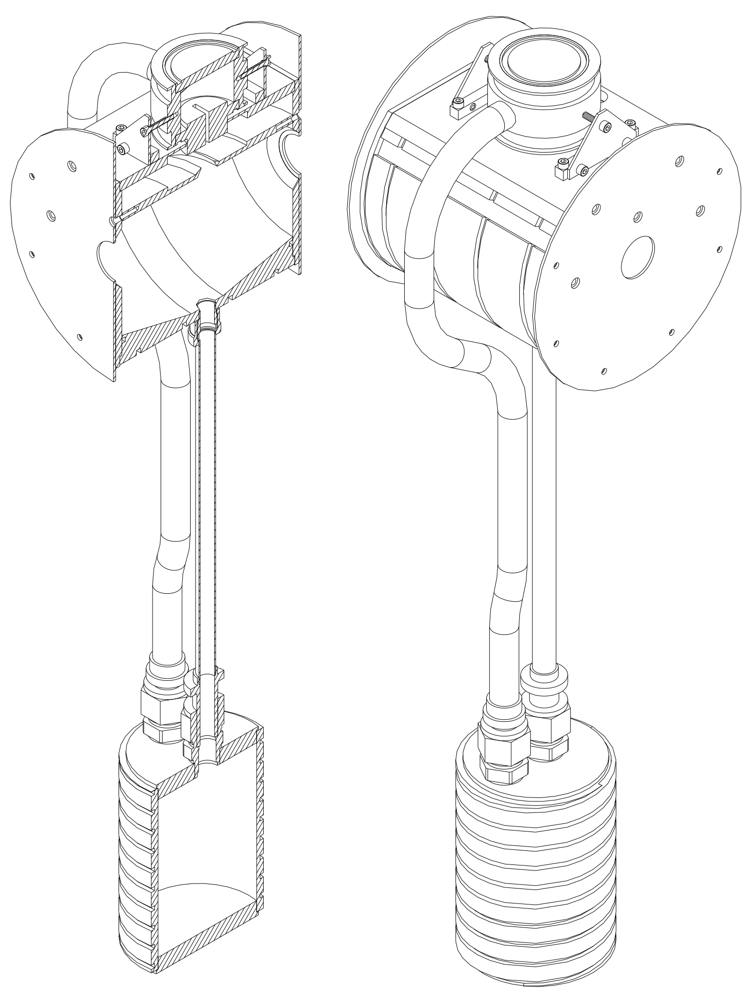
- Target thickness: $n \cdot L \approx 2 \cdot 10^{15}$ cm^{-2}
- Target length: $L \approx 2 \div 3$ cm
- Transversal vapor flow in the Na-jet cell reduces sodium vapor losses for 3-4 orders of magnitude

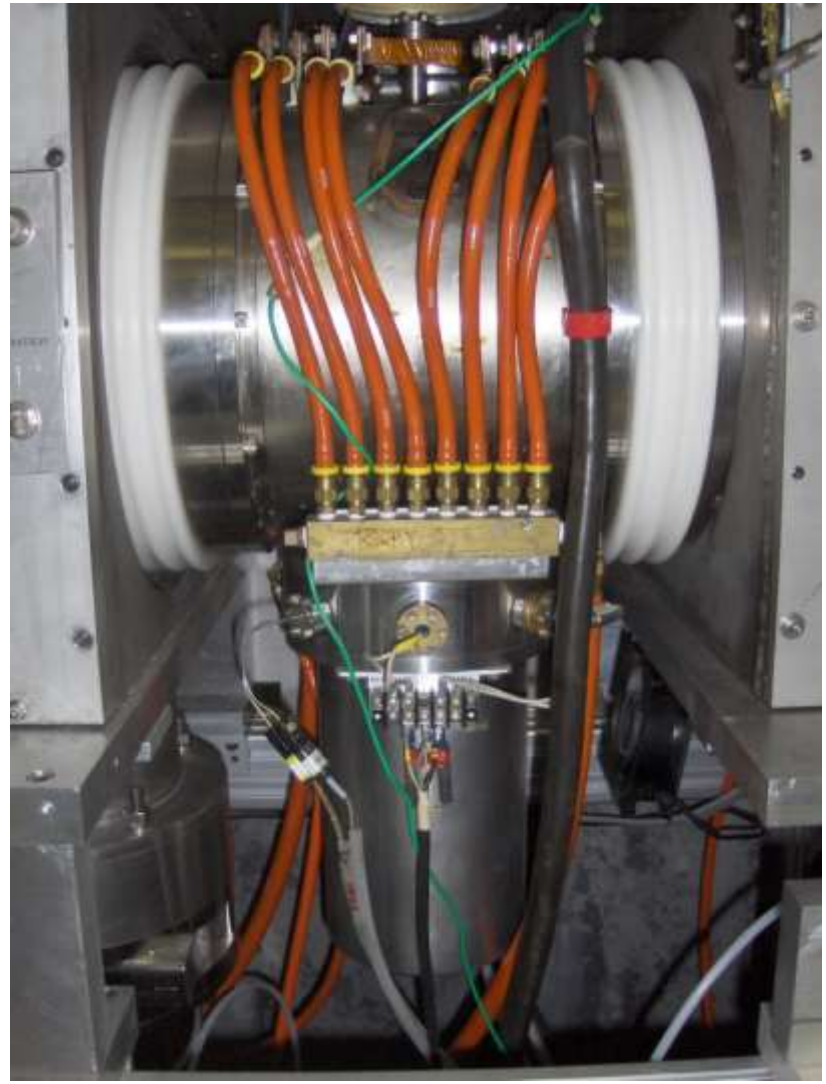
Stationary recirculating sodium vapor ionization target



Fine tuning of the potentials on the electrodes allows increasing the H^- beam fraction with 35 keV energy to 99%.

Stationary recirculating sodium vapor ionization target

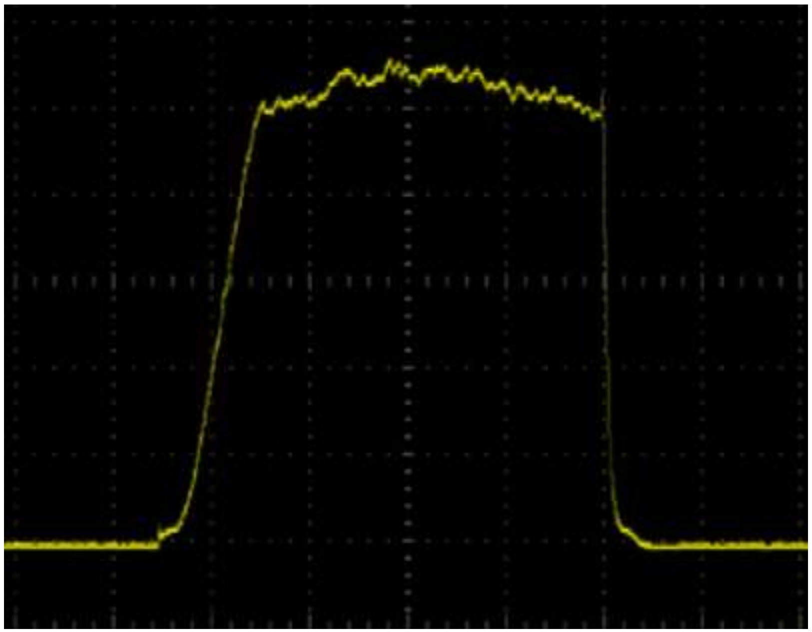




RHIC polarized protons

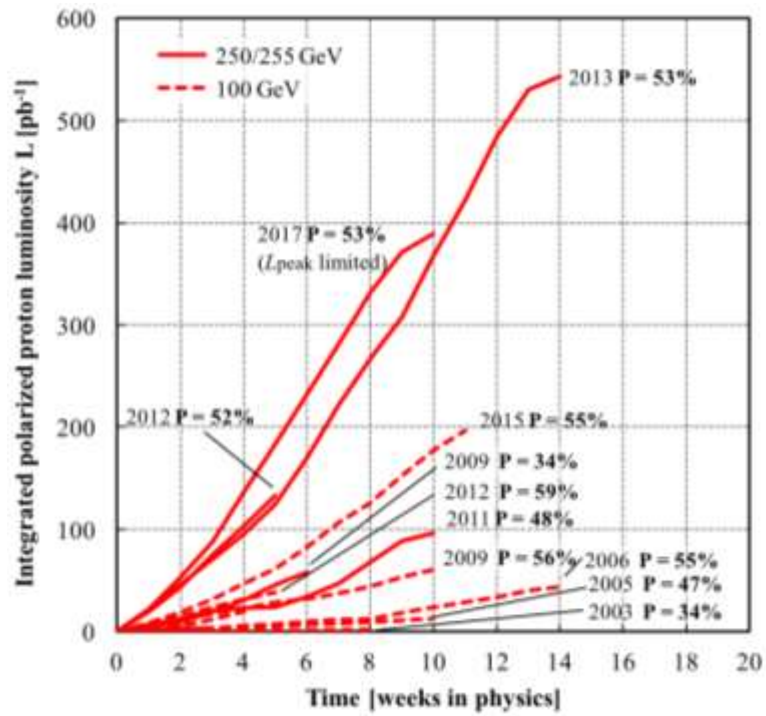
Polarized H⁻ beam current profile after RFQ

200 uA/div



100 us/div

Polarized protons runs



Polarized H⁻ current	1.05 mA
Pulse duration	400 us

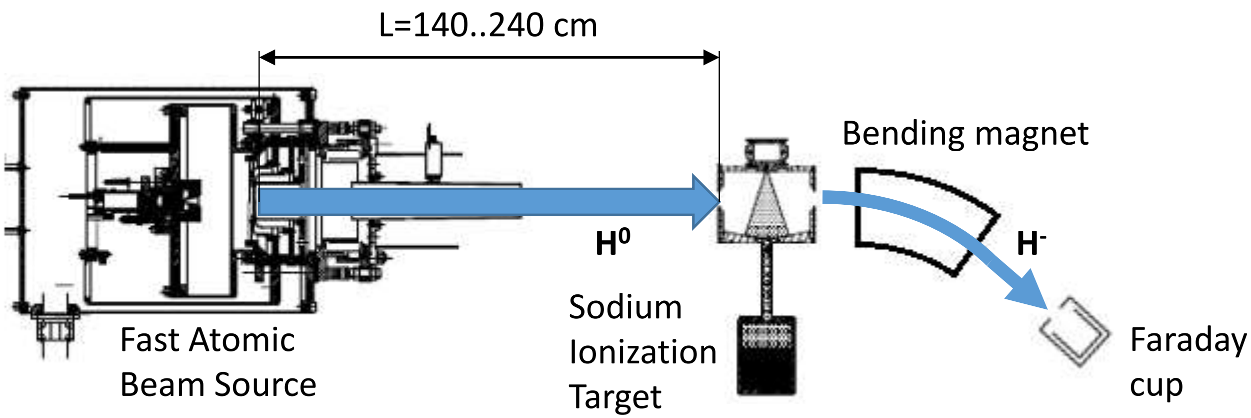
Polarization experiments figure of merit:

~L·P² for single spin experiments

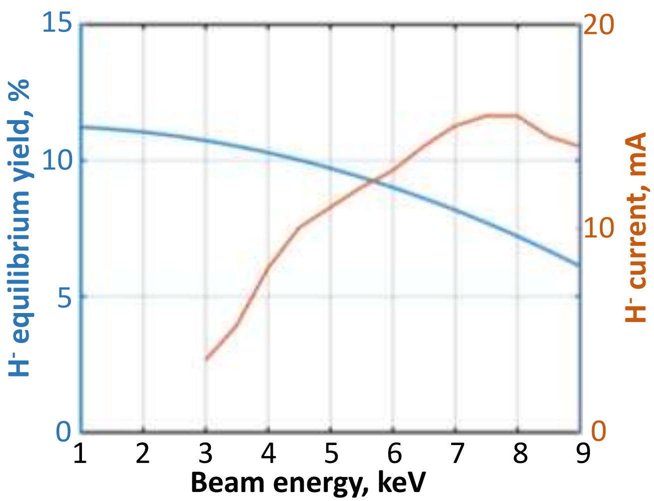
~L·P⁴ for double spin experiments

H^- beam formation by charge-exchange in the sodium ionization target

Experimental setup



H^- beam current @L=240 cm



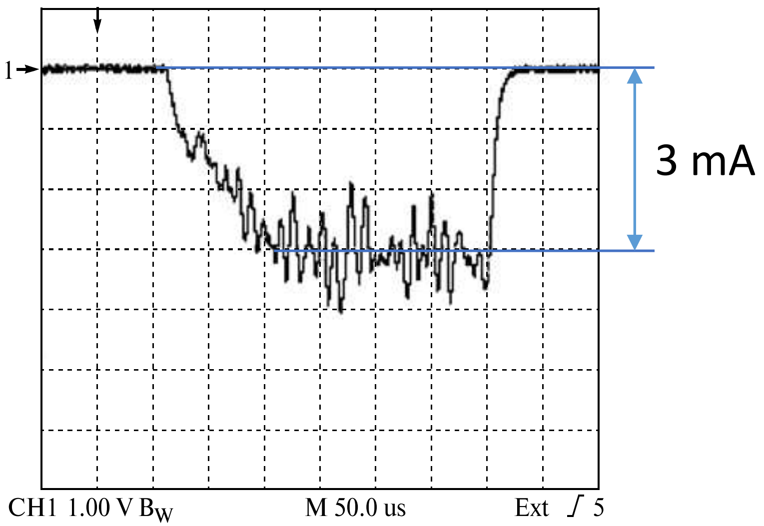
Maximum H^- current

• Distance to target	140 cm
• Current	34 mA
• Emittance	< 0.5 π·mm·mrad
• Pulse duration	500 us

Basic limitations on the high intensity polarized H^- ion beam production and transport

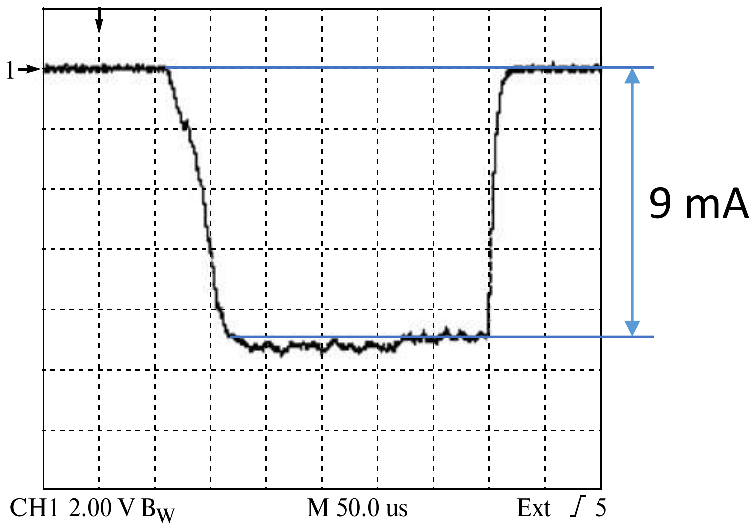
The signal from the Faraday cup after the bending magnet:
H^- beam with energy of 4 keV

Without compensation



P = $1.5 \cdot 10^{-6}$ torr

With compensation by Xe^+

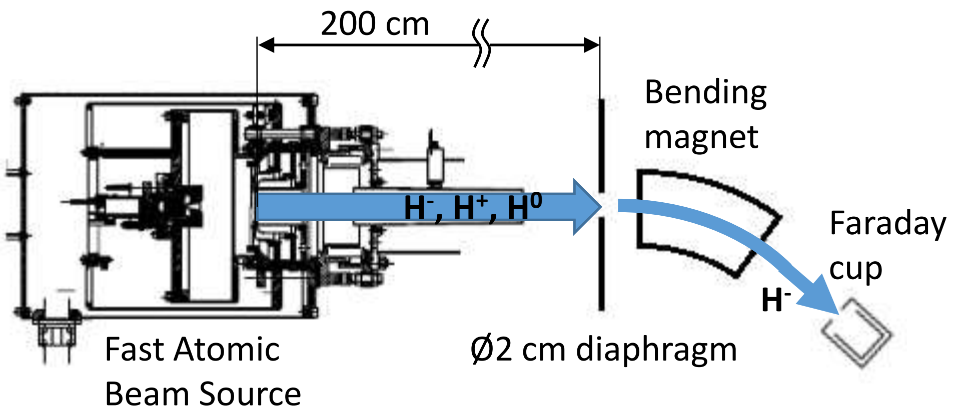


Xe admixture, P = 10^{-4} torr

For intense low energy H^- beam additional charge compensation is required

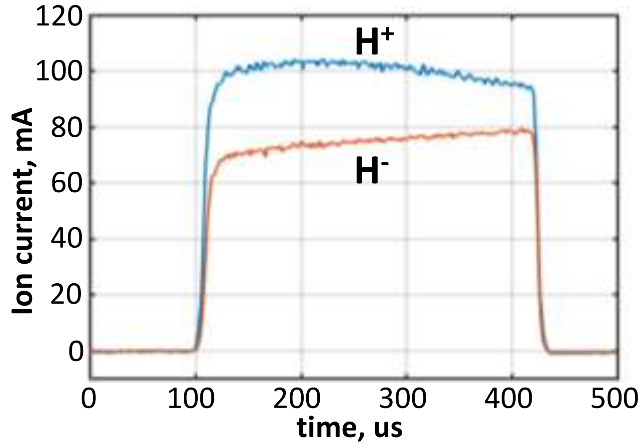
H^- effective transportation in a hybrid hydrogen beam

Experimental setup



Particle energy	10 keV
Beam current	4.7 A
Distance to magnet	200 cm
Diaphragm diameter	2 cm

Charge-exchange in the hydrogen target



	Measured current (mA)	Equilibrium yield (mA)
H^-	**75**	94 (2%)
H^+	100	470 (10%)

Reason: focusing of H^- ions obtained in hydrogen charge-exchange target by a positive potential of the beam plasma

Conclusion

- The new source with atomic beam hydrogen injector and He-ionizer was developed and commissioned for operation.
- It produces significantly higher brightness primary proton beam which resulted in higher polarized beam intensity and polarization delivered for injection to Linac-Booster-AGS-RHIC accelerator chain.
- Practically all OPPIS systems were modified (in addition to the ECR-source): a new superconducting solenoid; new He-ionizer cell with a pulsed He-injection and new pulsed electro-dynamic gas valve; beam energy separation system developed for un-polarized residual beam suppression; new vacuum system with turbo-molecular pumps for He-pumping.