High-Intensity High-Brightness Polarized and Un-polarized H^- Beam production in Charge-exchange Collisions

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"Siberian snakes"

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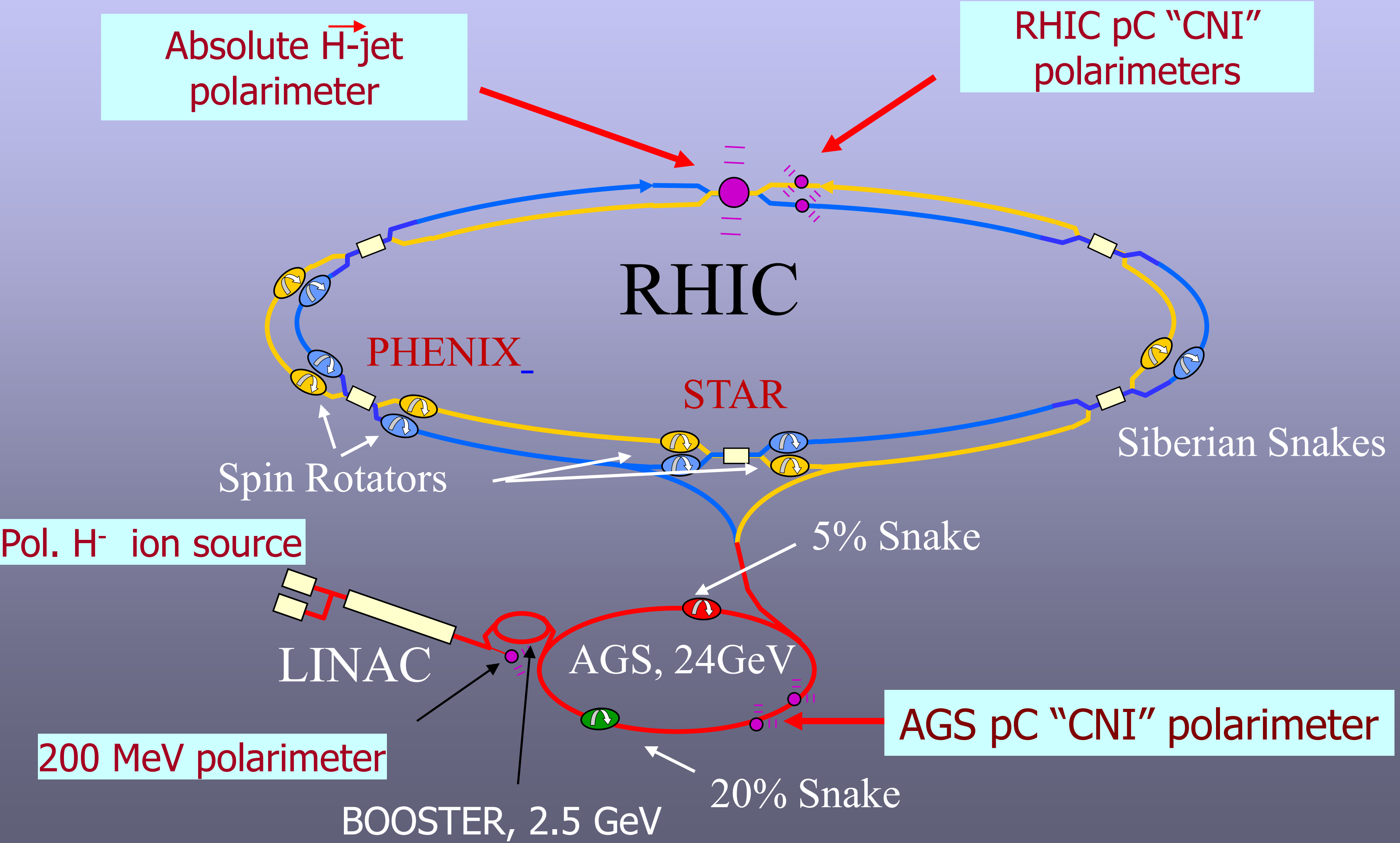
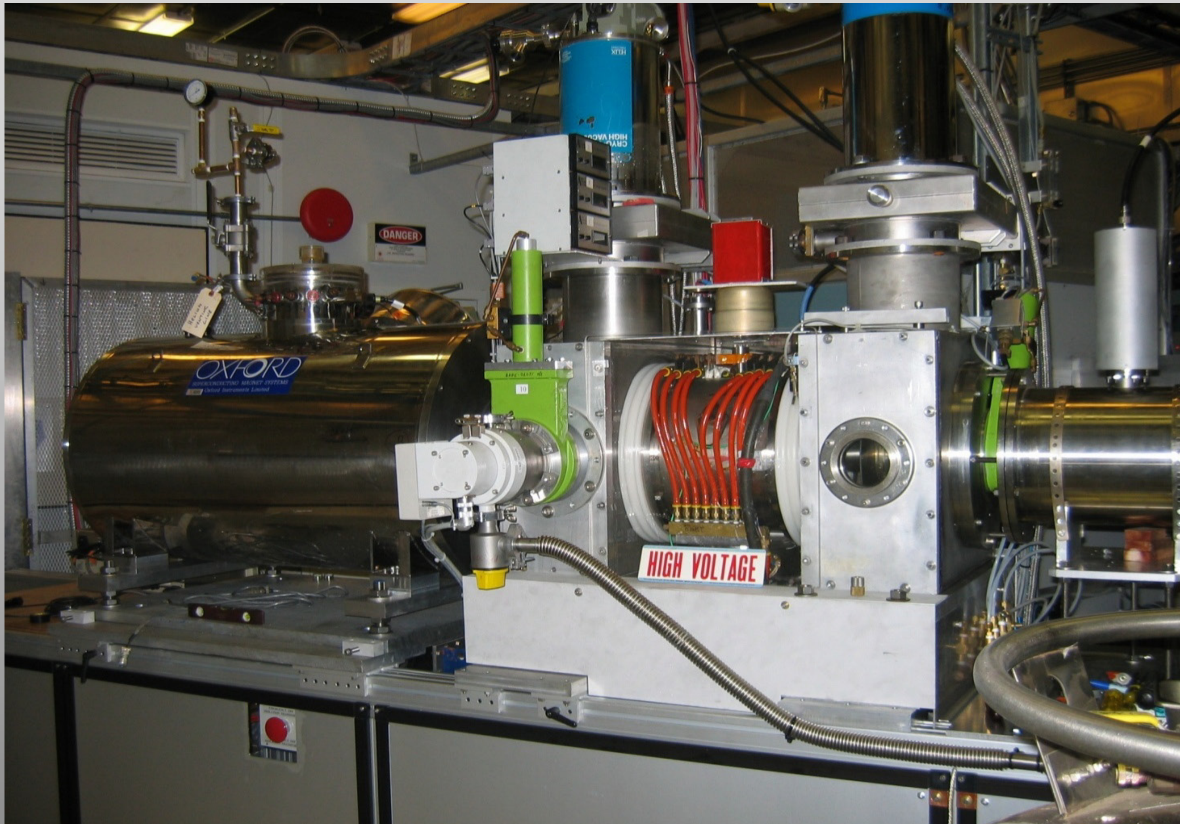
A new polarization technique.
Equal intensity for polarized and unpolarized proton beams.

Polarization facilities at RHIC.

Design goal: P=70%, $L_{max} = 1.6 \times 10^{32}\ s^{-1}cm^{-2}$ $50 < \sqrt{s} < 500$ GeV



Operational Polarized H^- Source at RHIC.



RHIC OPPIS produces reliably 0.5-1.0mA polarized H^- ion current.

Polarization at 200 MeV:

P = 80-85%.

Beam intensity (ion/pulse) routine operation:

Source	- 10^{12} H^-/pulse
Linac	- $5 \cdot 10^{11}$
AGS	- $1.5\text{-}2.0 \cdot 10^{11}$
RHIC	- $1.5 \cdot 10^{11}$ (protons/bunch).

A 29.2 GHz ECR-type source is used for primary proton beam generation.
The source was originally developed for dc operation.

A ten-fold intensity increase was demonstrated in a pulsed operation by using a very high-brightness Fast Atomic Beam Source instead of the ECR proton source .

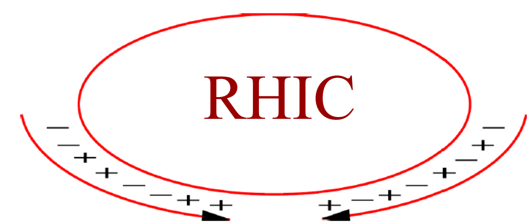
Polarized beams at RHIC.

OPPIS — $10 \cdot 10^{11}$ (maximum $40 \cdot 10^{11}$) polarized H^- /pulse.

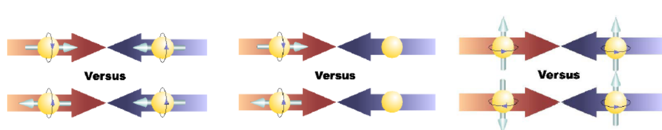
LINAC — $5 \cdot 10^{11}$ polarized H^- /pulse at 200 MeV, P=85-90%

Booster — $2 \cdot 10^{11}$ protons /pulse at 2.3 GeV

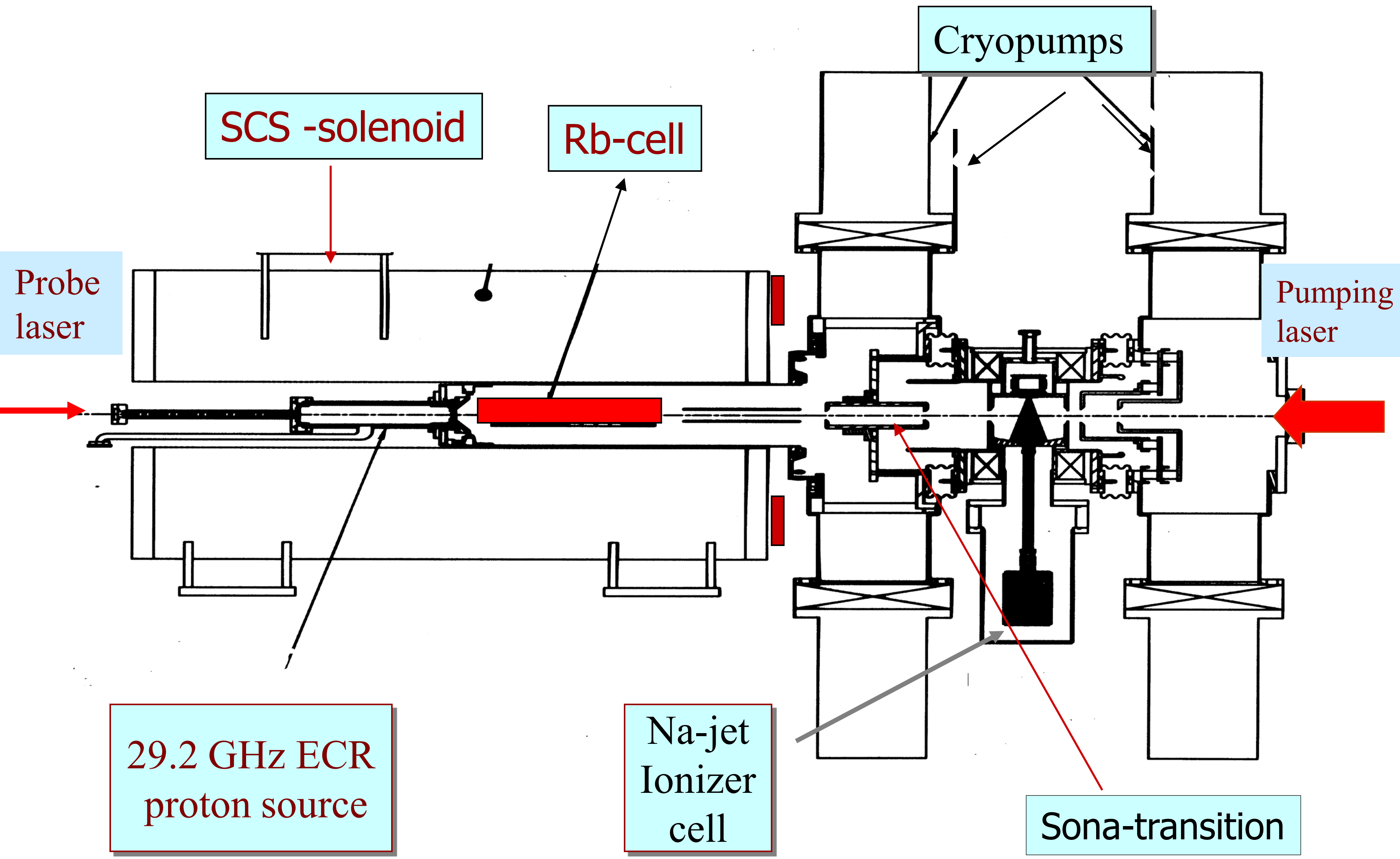
AGS — $1.7 \cdot 10^{11}$ p/bunch



~$1.5 \cdot 10^{11}$ p/bunch, P~60-65% at 100 GeV
P ~ 50% at 250 GeV

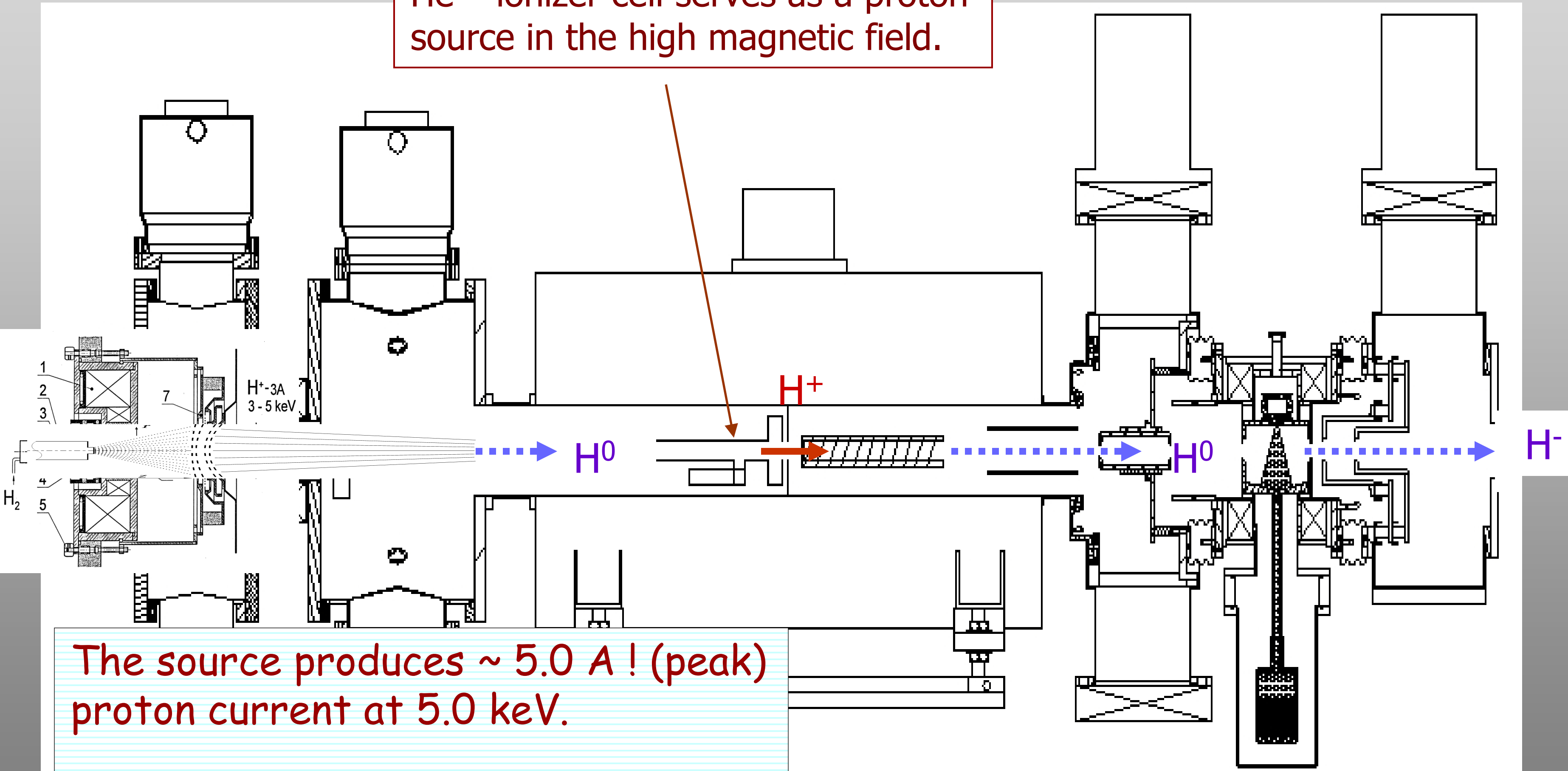


Schematic Layout of the RHIC OPPIS



OPPIS upgrade with the Fast Atomic Beam Source (FABS). The Third- Generation.

He – ionizer cell serves as a proton source in the high magnetic field.



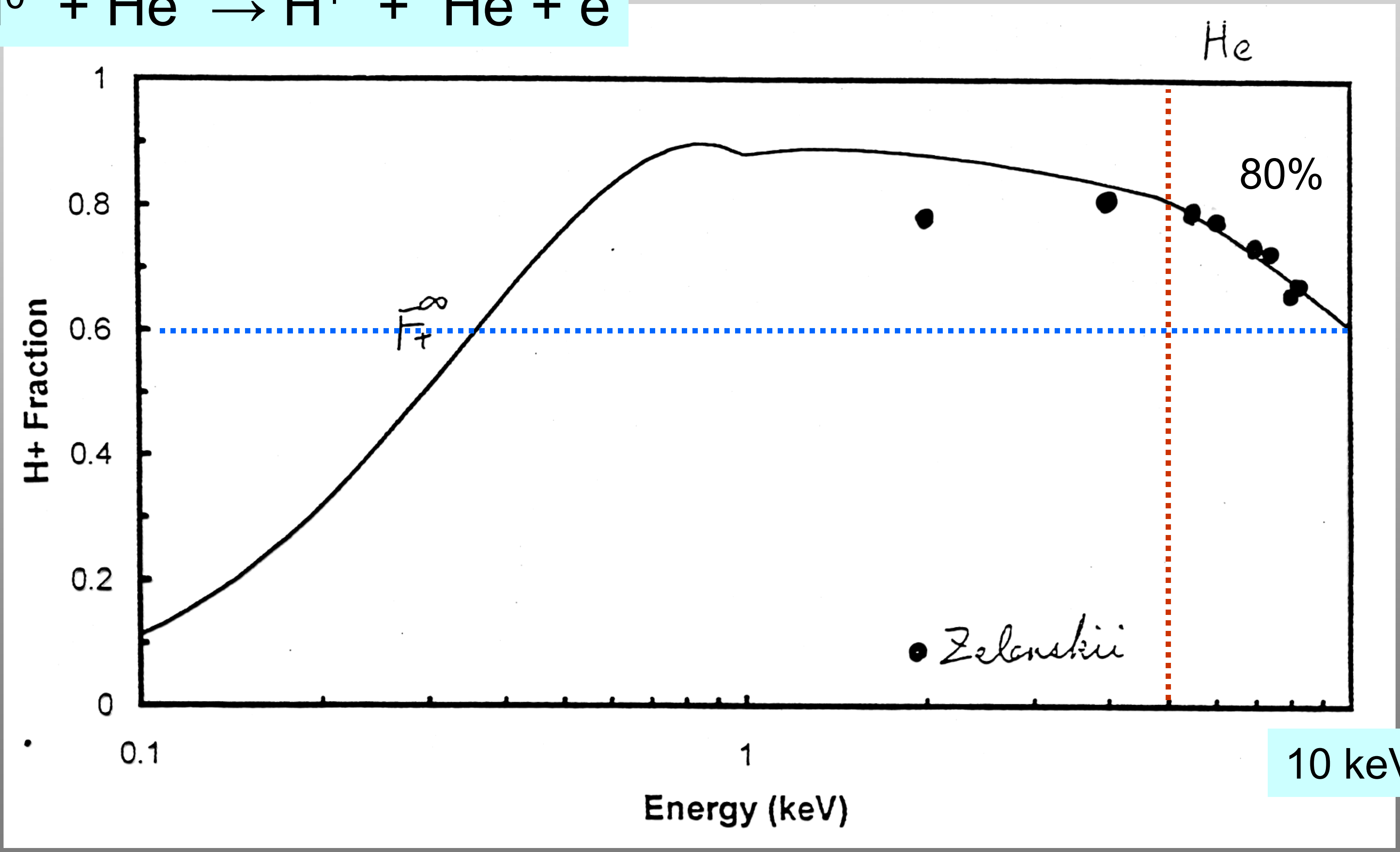
The source produces ~ 5.0 A ! (peak) proton current at 5.0 keV.

~ 10 mA H^- current, P = 85-90%.

~ 300 mA (high-brightness) unpolarized H^- ion current.

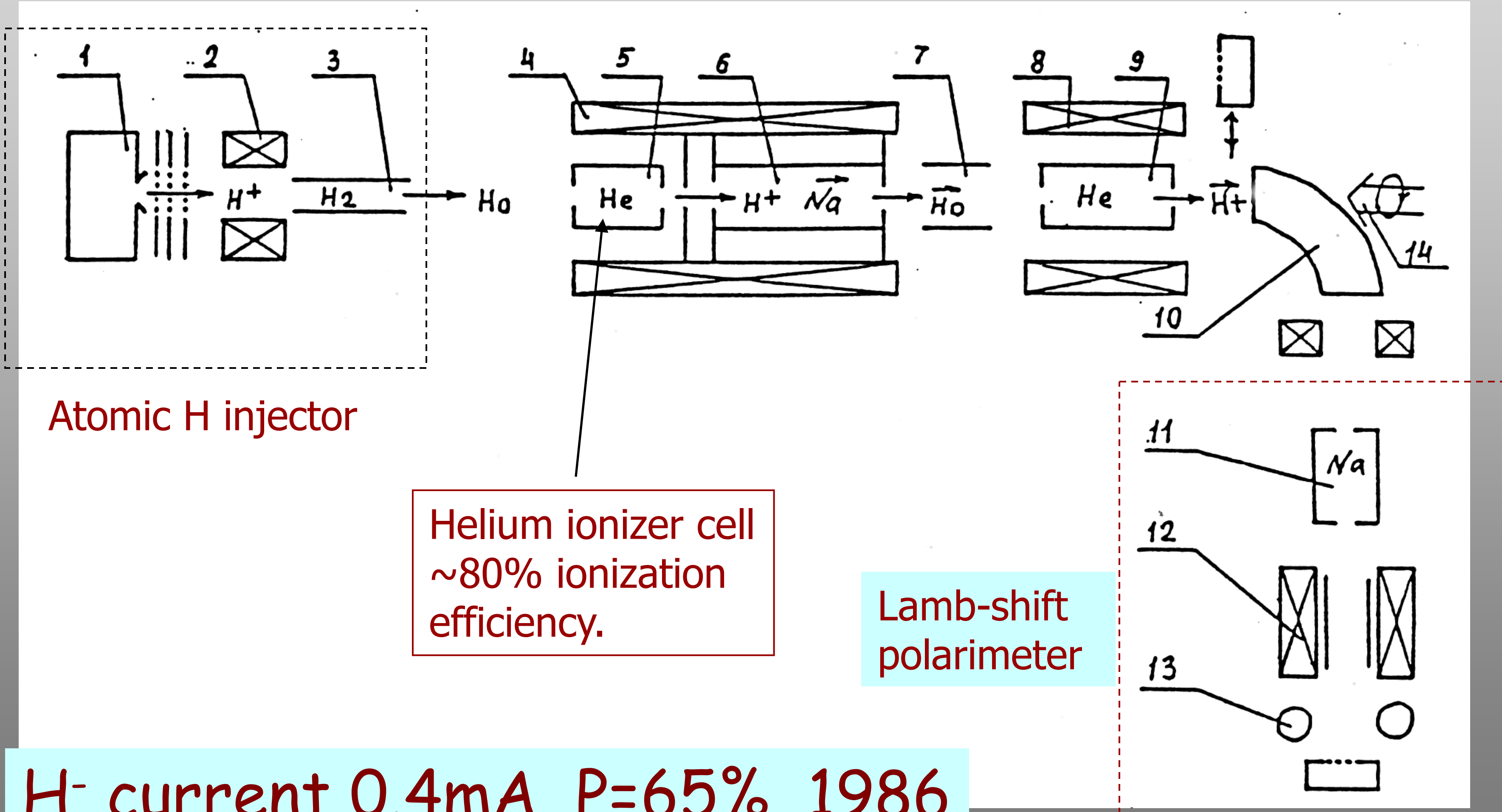
Hydrogen atomic beam ionization efficiency in the He- cell.

$H^0 + He \rightarrow H^+ + He + e$



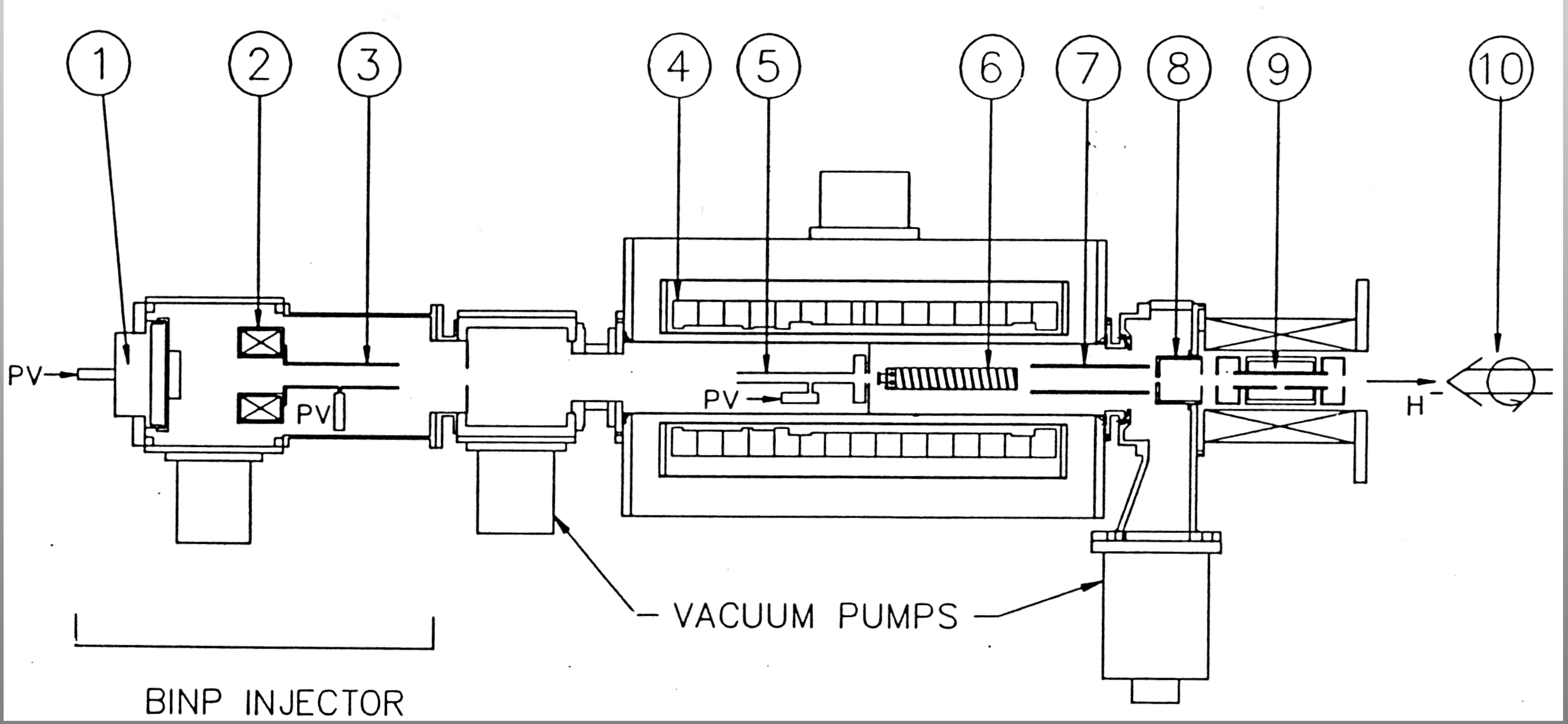
10 keV

Pulsed OPPIS with the atomic hydrogen injector at INR, Moscow, 1982-1990.
The First-Generation.



H^- current 0.4mA, P=65%, 1986

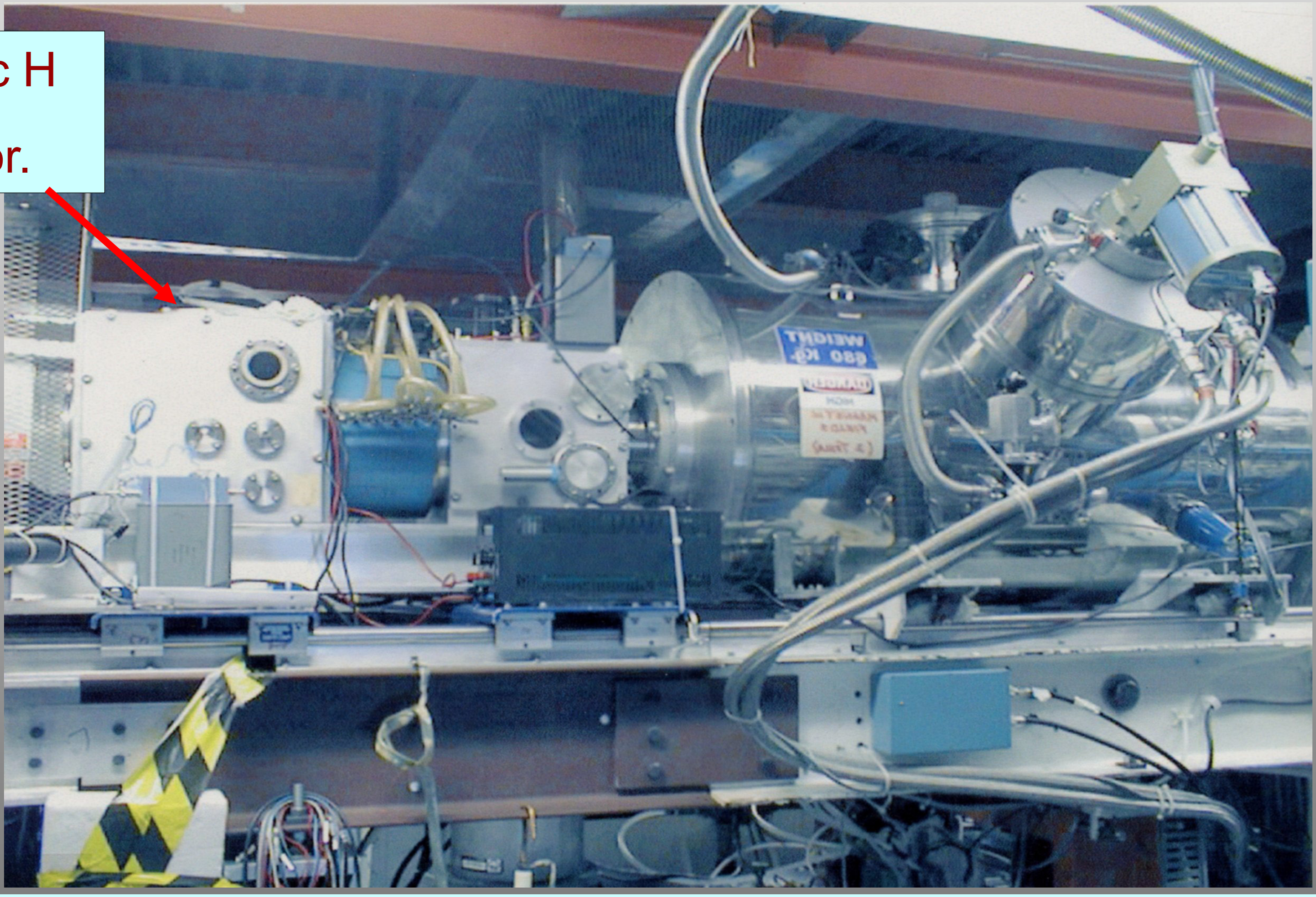
Feasibility studies with Atomic Beam Injector at TRIUMF, 1997-99.
The Second Generation.



A pulsed H^- ion current of a 10 mA was obtained in 1999.

Pulsed OPPIS at TRIUMF, 1997-99.

Atomic H Injector.



A pulsed H^- ion current of a 10 mA was obtained in 1999.

Small diameter beam in the FABS.

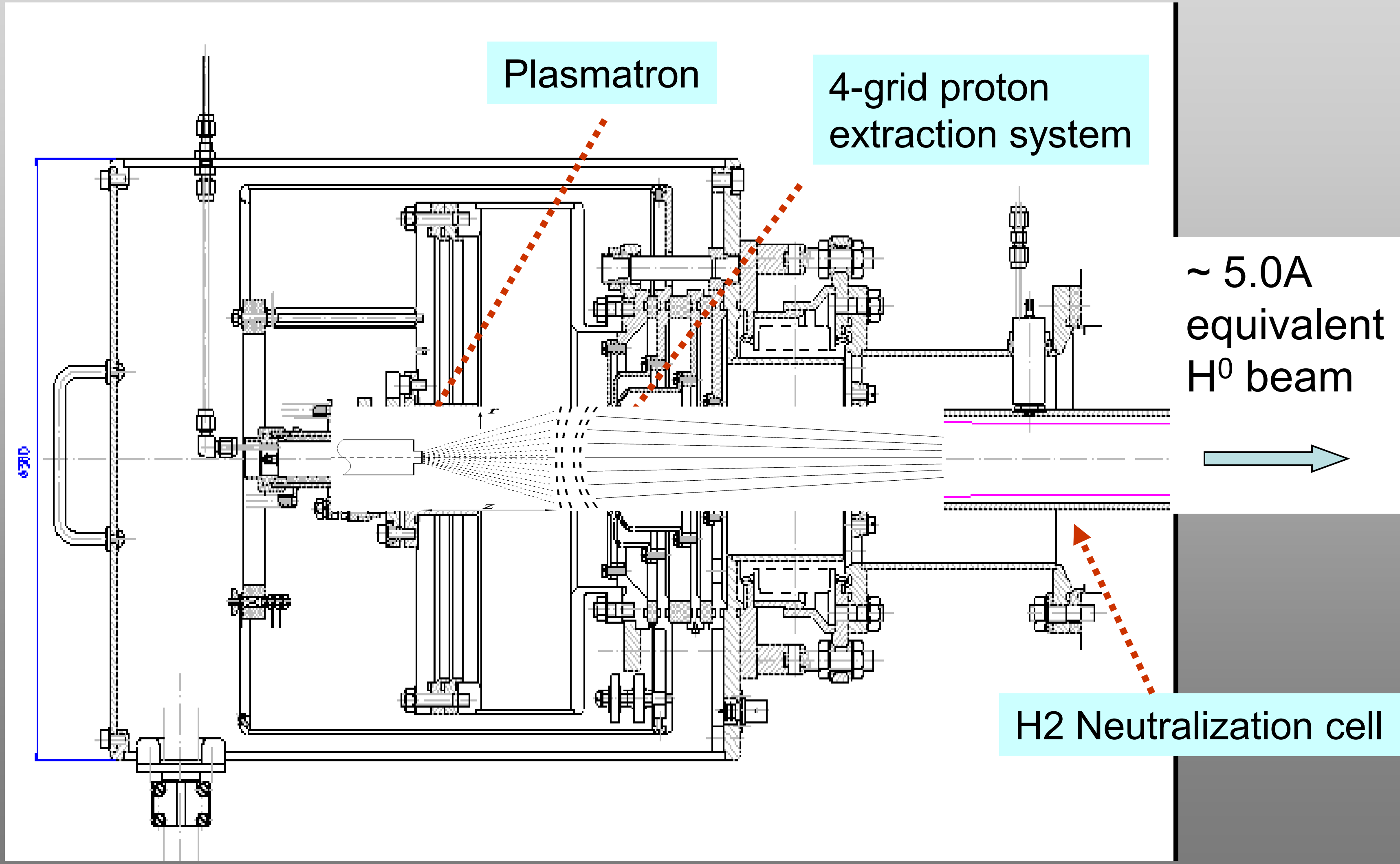
- Atomic H^0 injector produces an order of magnitude higher brightness beam. A 5-10 mA H^- ion current can be obtained with the smaller, (about 15 mm in diameter) beam.
- Higher Sona-transition efficiency for the smaller beam radius.
- Smaller beam emittance : $\varepsilon_n \sim B \times R^2$

The Atomic Hydrogen Injector

Collaboration agreement with BINP, Novosibirsk on polarized source upgrade.

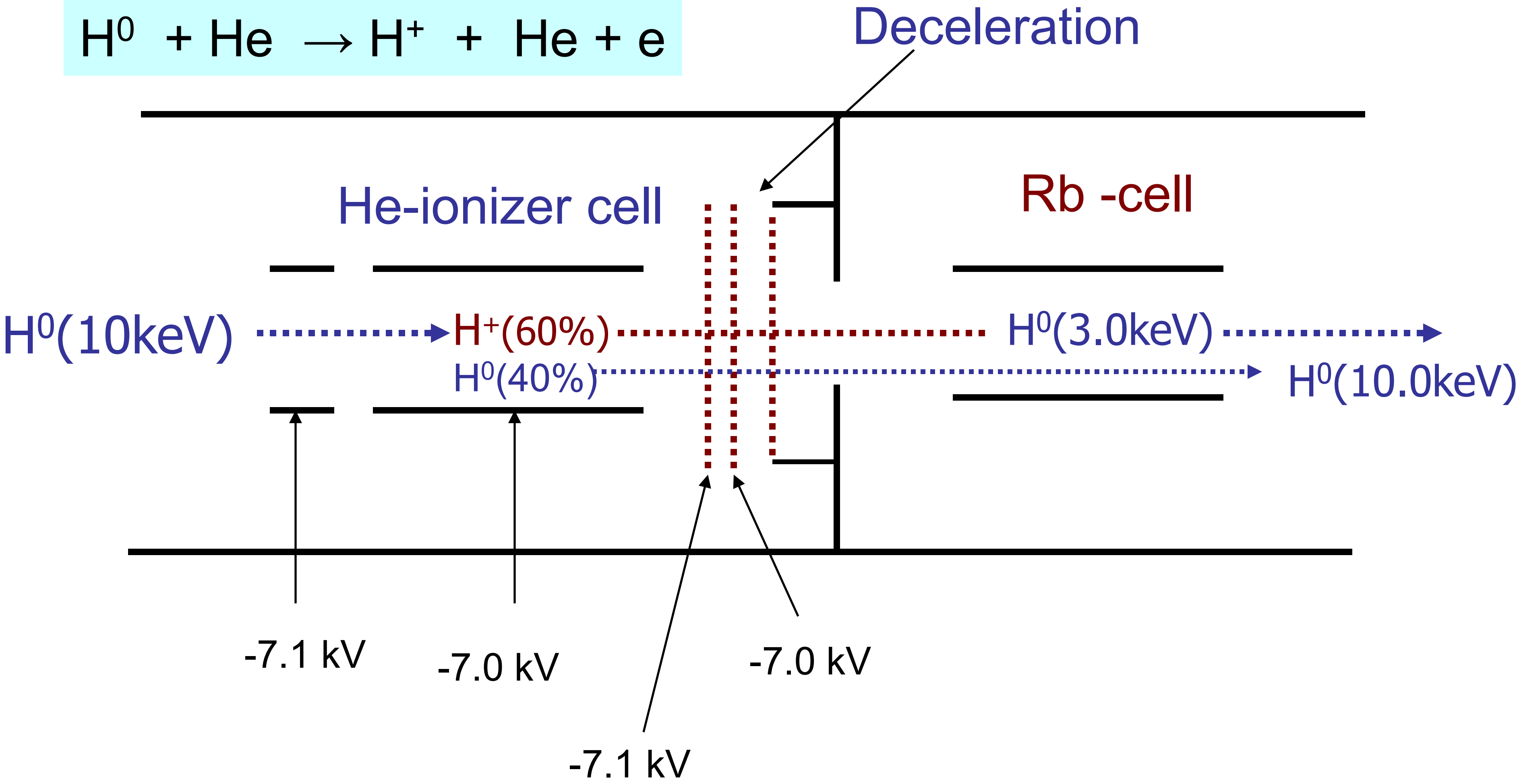
- Contract with BINP, Novosibirsk. Delivery: May, 2011.
- Two sets of sources and power supplies, local control system.
- 4- sets of spherical extraction grids (focal length ~150 cm) for polarized source.
- 2- sets of shorter focal length (~ 50cm) grids for studies of basic limitation of high-brightness H^- ion beam production in the charge-exchange process.

BINP design for the “Atomic Beam Injector”.

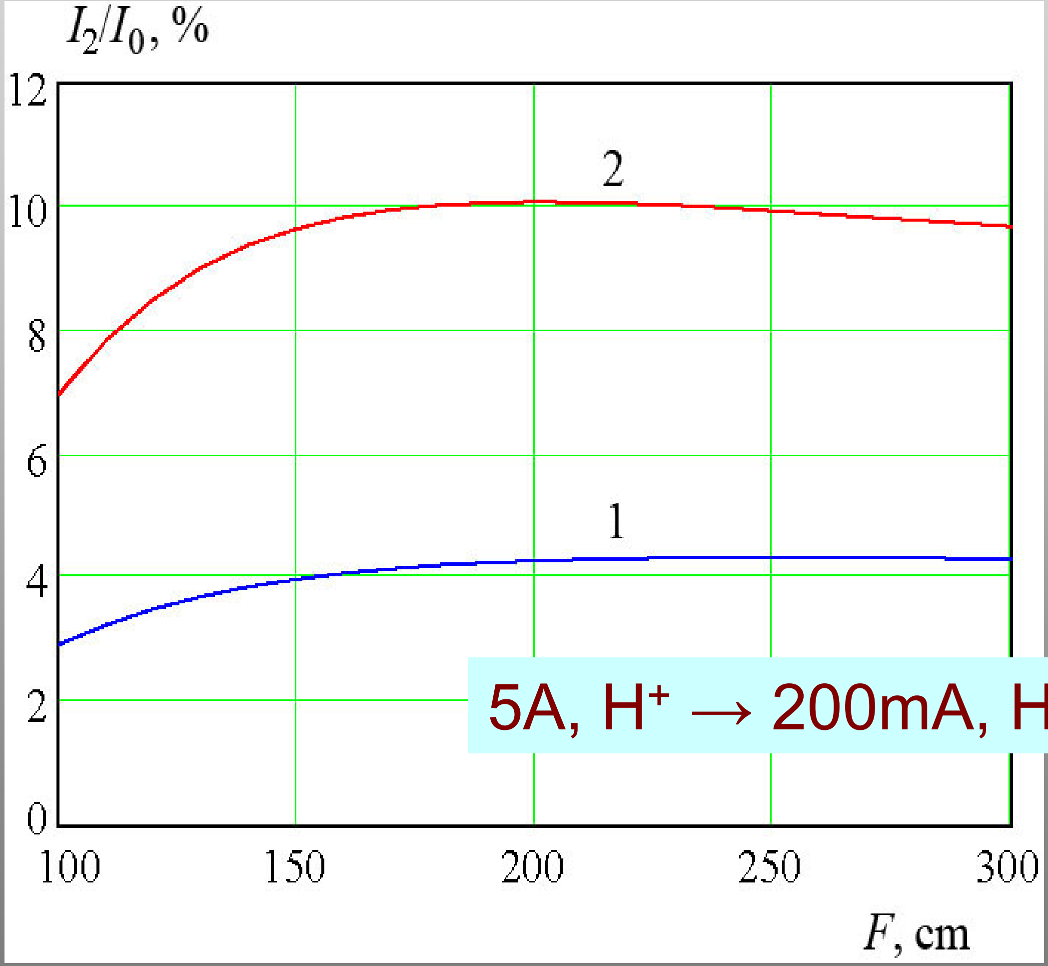


Residual unpolarized H^0 beam component suppression by the energy separation.

$H^0 + He \rightarrow H^+ + He + e$



Ratio of the target to the emitter current density vs spherical grids focal length.



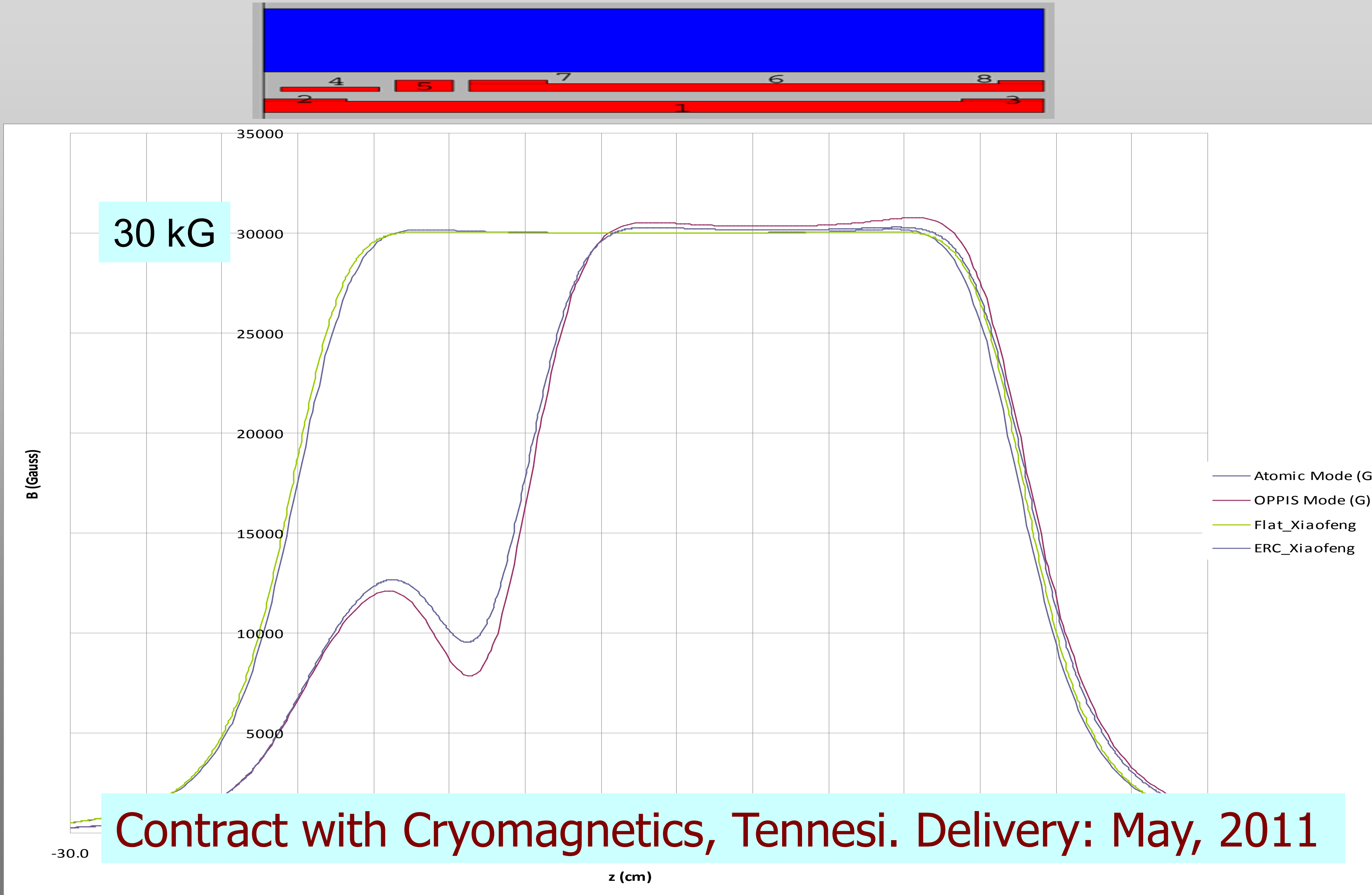
5A, $H^+ \rightarrow$ 200mA, $H^0 \rightarrow$ 16 mA, H^-

Fig. 8. Ratio of the target current to the emitter current vs focal distance:
1 – without magnetic field, 2 – with magnetic field.

A new superconducting solenoid.

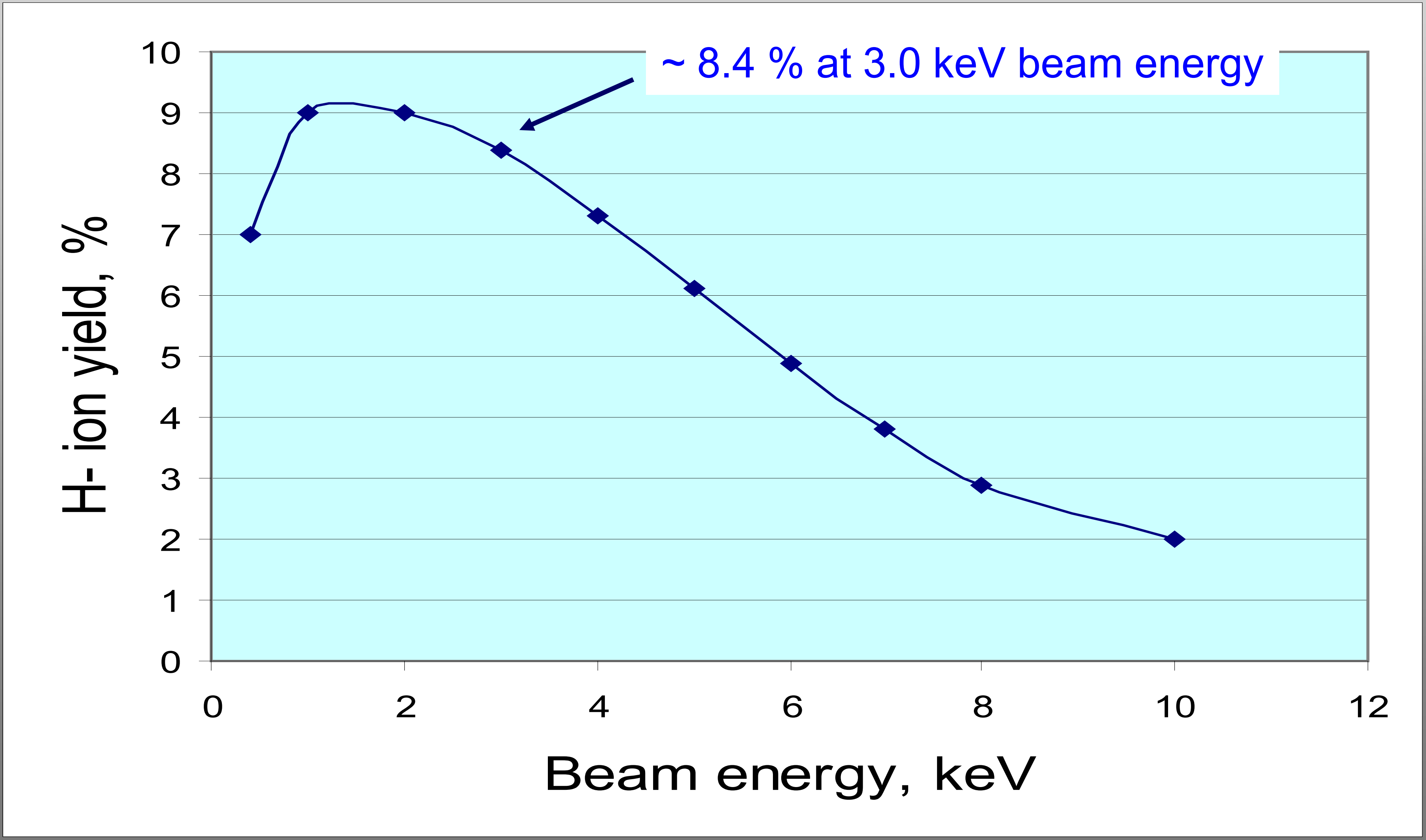
- Contract with Cryomagnetics, Tennesi.
- Delivery: May, 2011.
- Higher 30 kG field. Better field shape. Cold iron yoke.
- He- re-condenser, low maintenance cost.
- Two mode of operations. Atomic beam mode –long flattop.
- ECR- mode provides field shape for the conventional ECR-mode operation.

A new superconducting solenoid. ECR-mode.



Contract with Cryomagnetics, Tennesi. Delivery: May, 2011

H^- yield vs beam energy



Sodium-jet ionizer cell

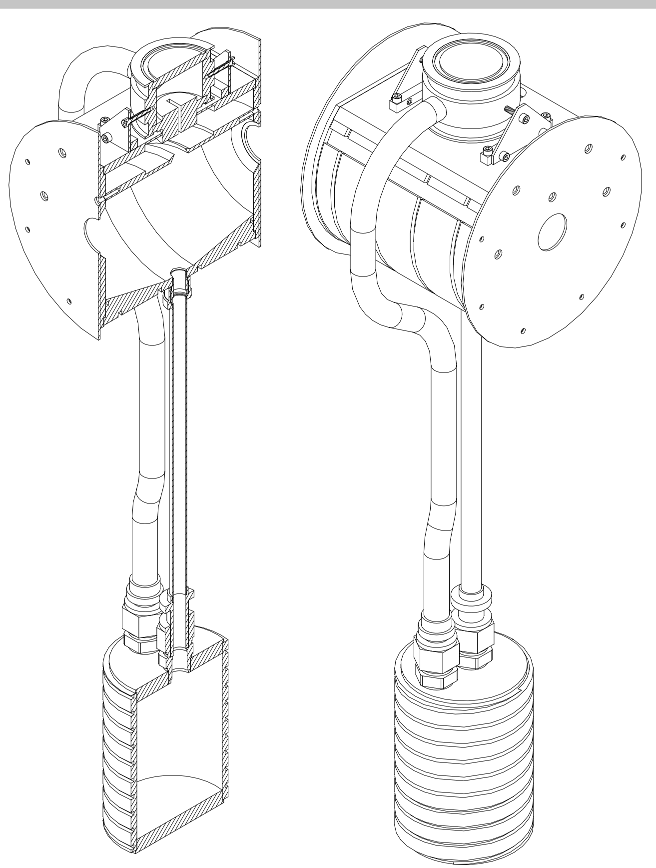
- An application of conventional "hot-pipe" sodium vapor cell for high-intensity H^- ion beam production in charge-exchange collisions is limited by the fast increase of the sodium losses, which are proportional: $\sim n^3 / L$,

  where n is vapor density and L- is the cell length.

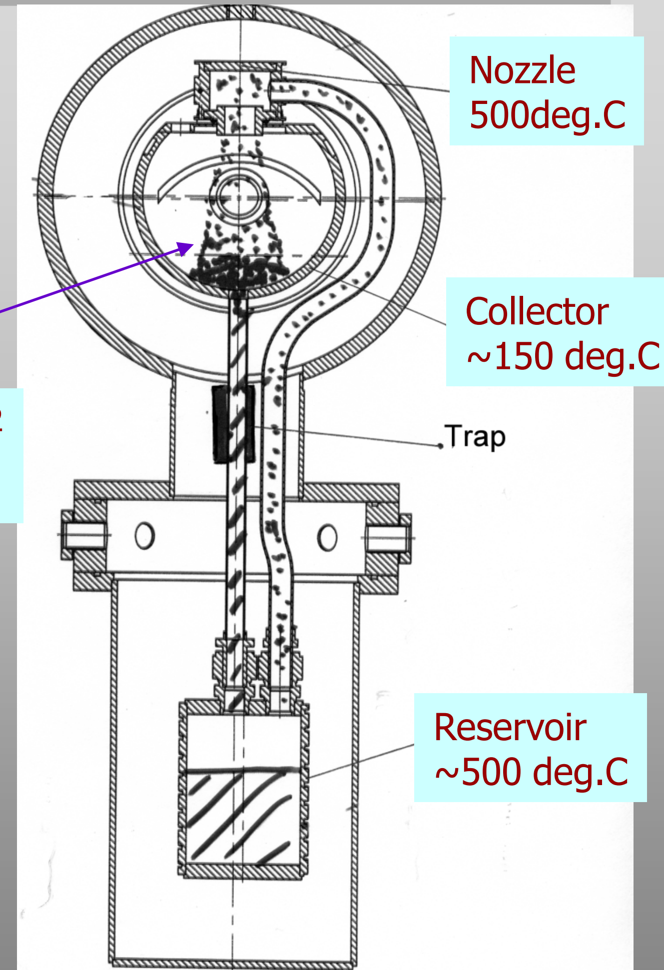
The solution is the Jet-ionizer cell.

Sodium-jet ionizer cell

Transversal vapor flow in the N-jet cell.
Reduces sodium vapor losses for 3-4 orders of magnitude, which allow the cell aperture increase up to 3.0 cm .

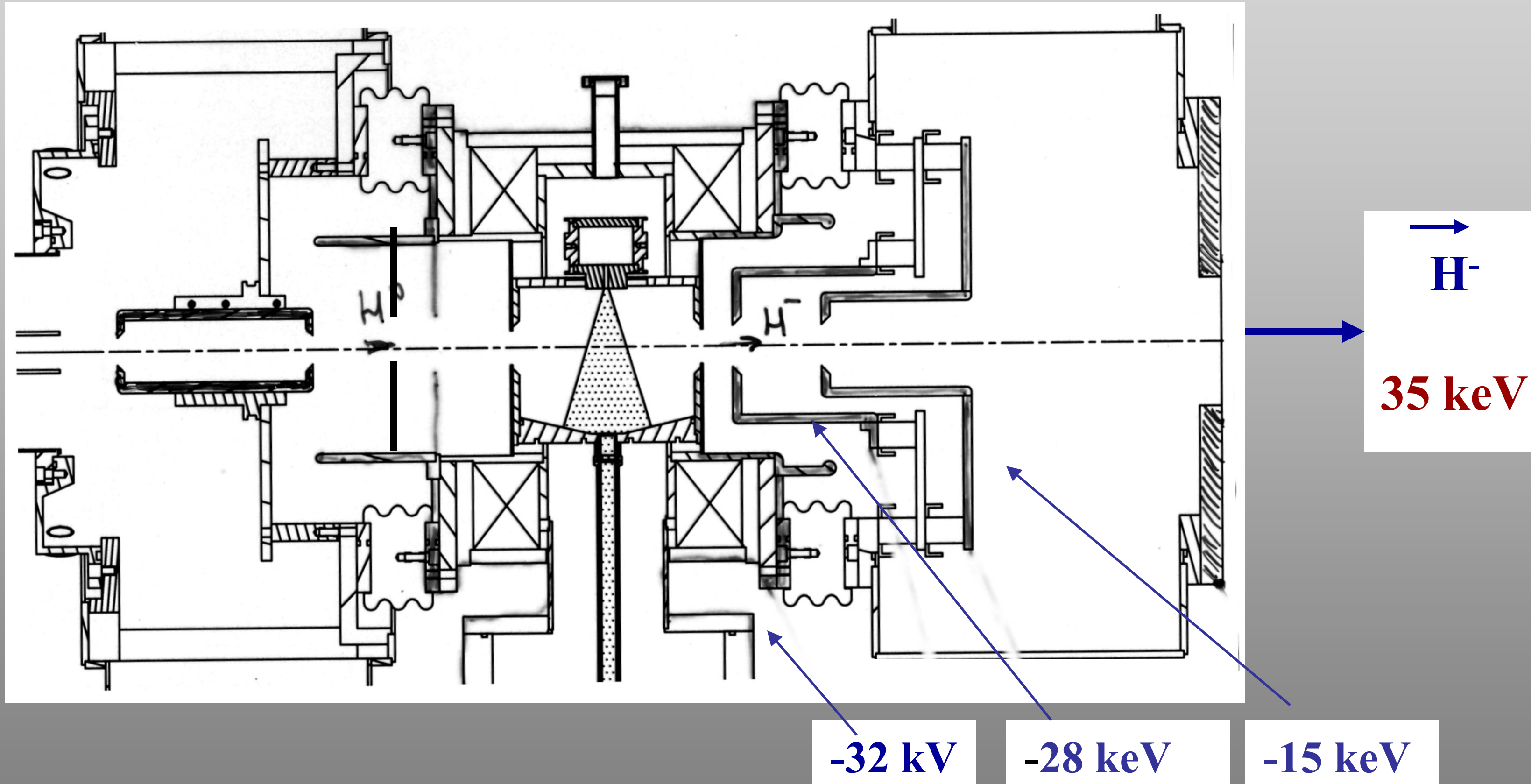


NL ~$2 \cdot 10^{15}$ atoms/cm^2
L ~ 2-3 cm



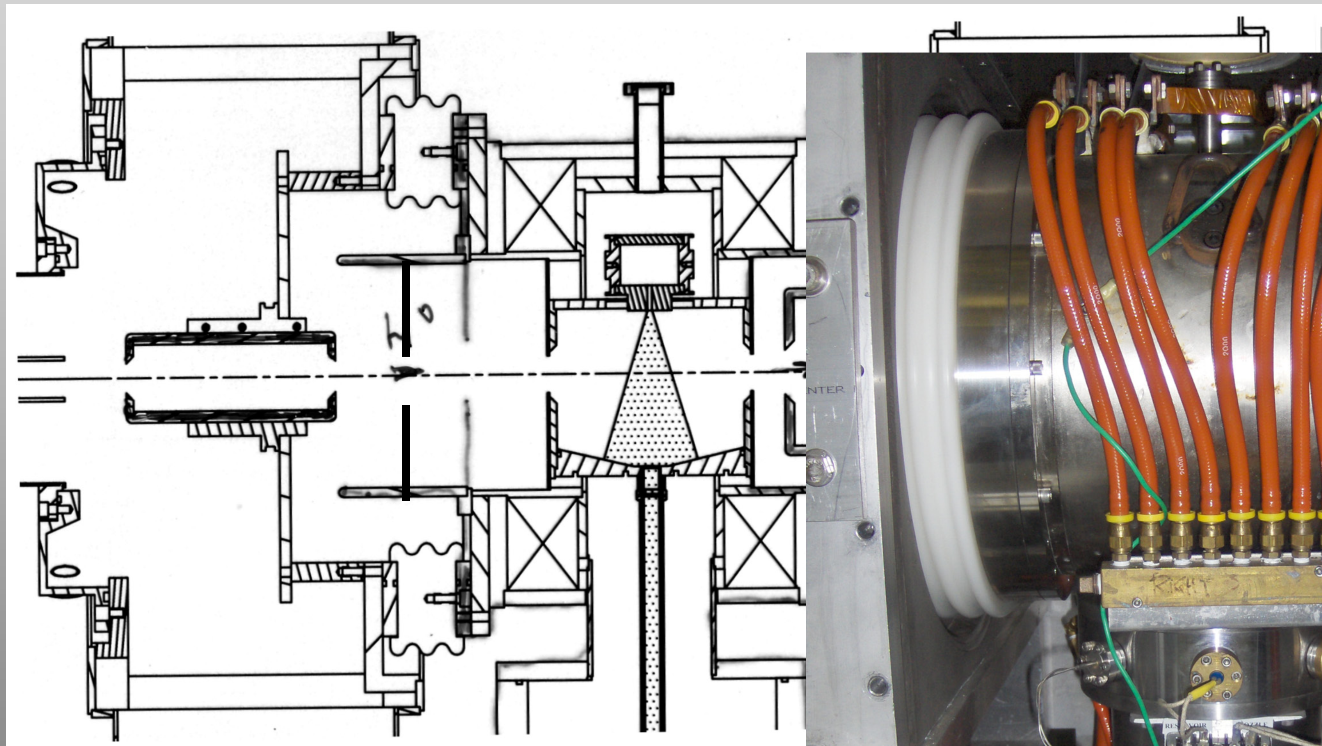
Reservoir– operational temperature. Tres. ~500 ^{o}C.
Nozzle – Tn ~500 ^{o}C.
Collector- Na-vapor condensation: Tcoll.~120^{o}C
Trap- return line. T ~ 120 – 180 ^{o}C.

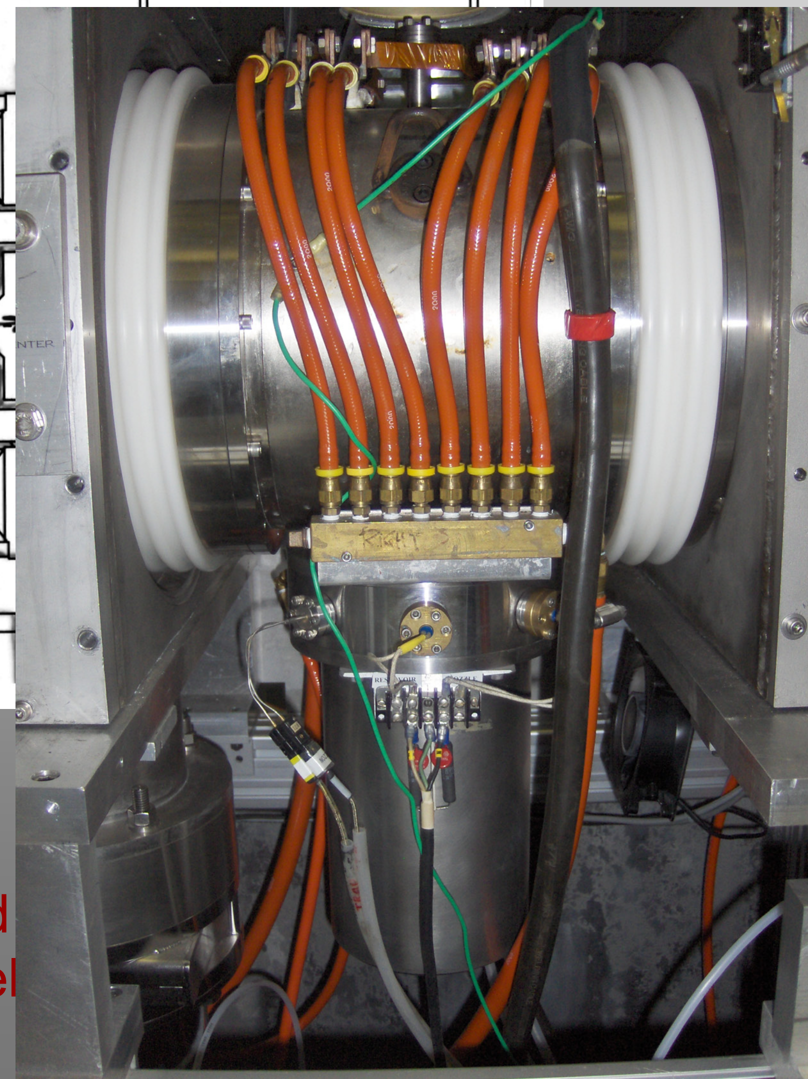
H^- beam acceleration to 35 keV at the exit of Na-jet ionizer cell



Na-jet cell is isolated and biased to – 32 keV. The H^- beam is accelerated in a two-stage acceleration system.

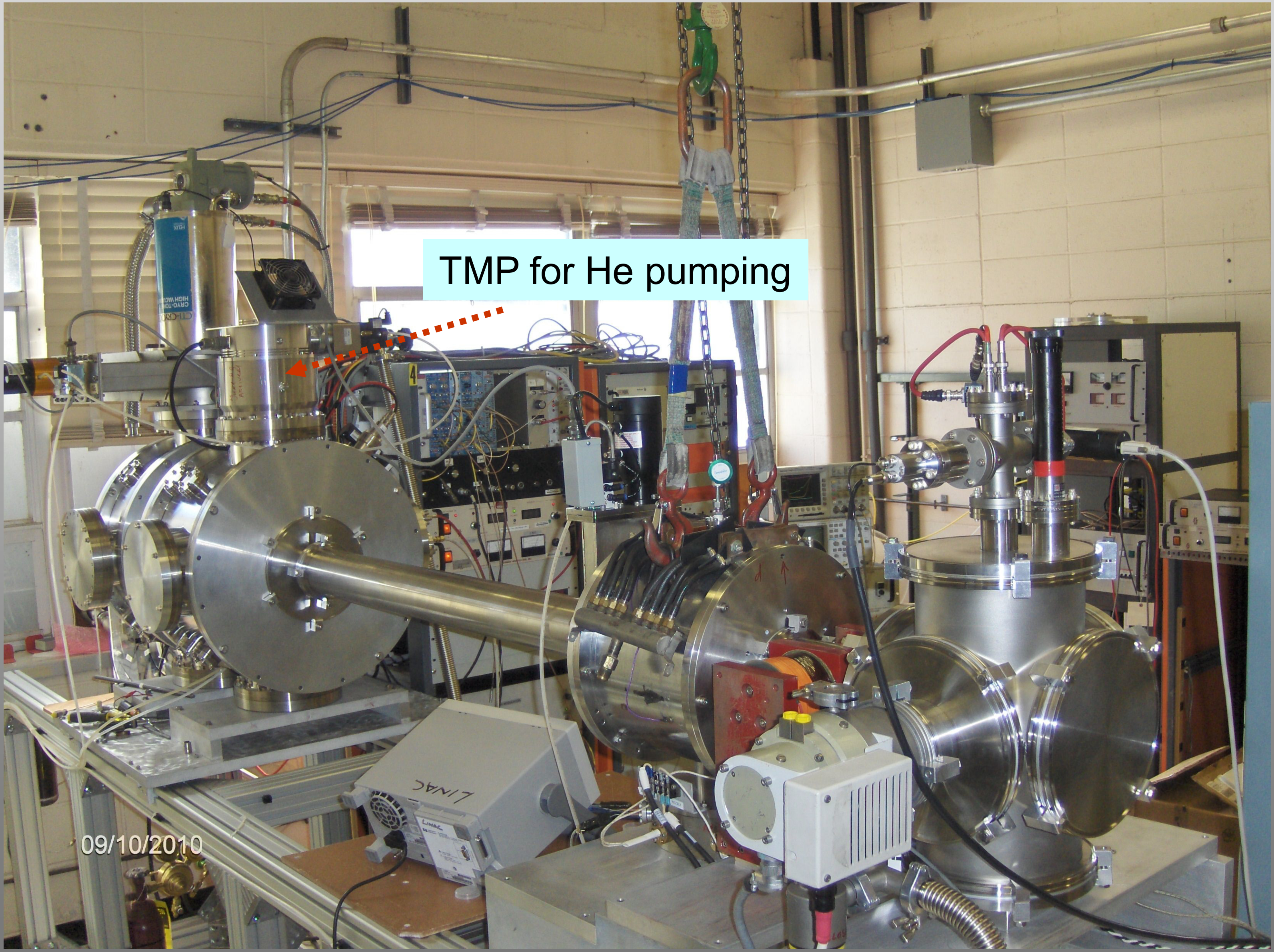
H^- beam acceleration to 35 keV at the exit of Na-jet ionizer cell



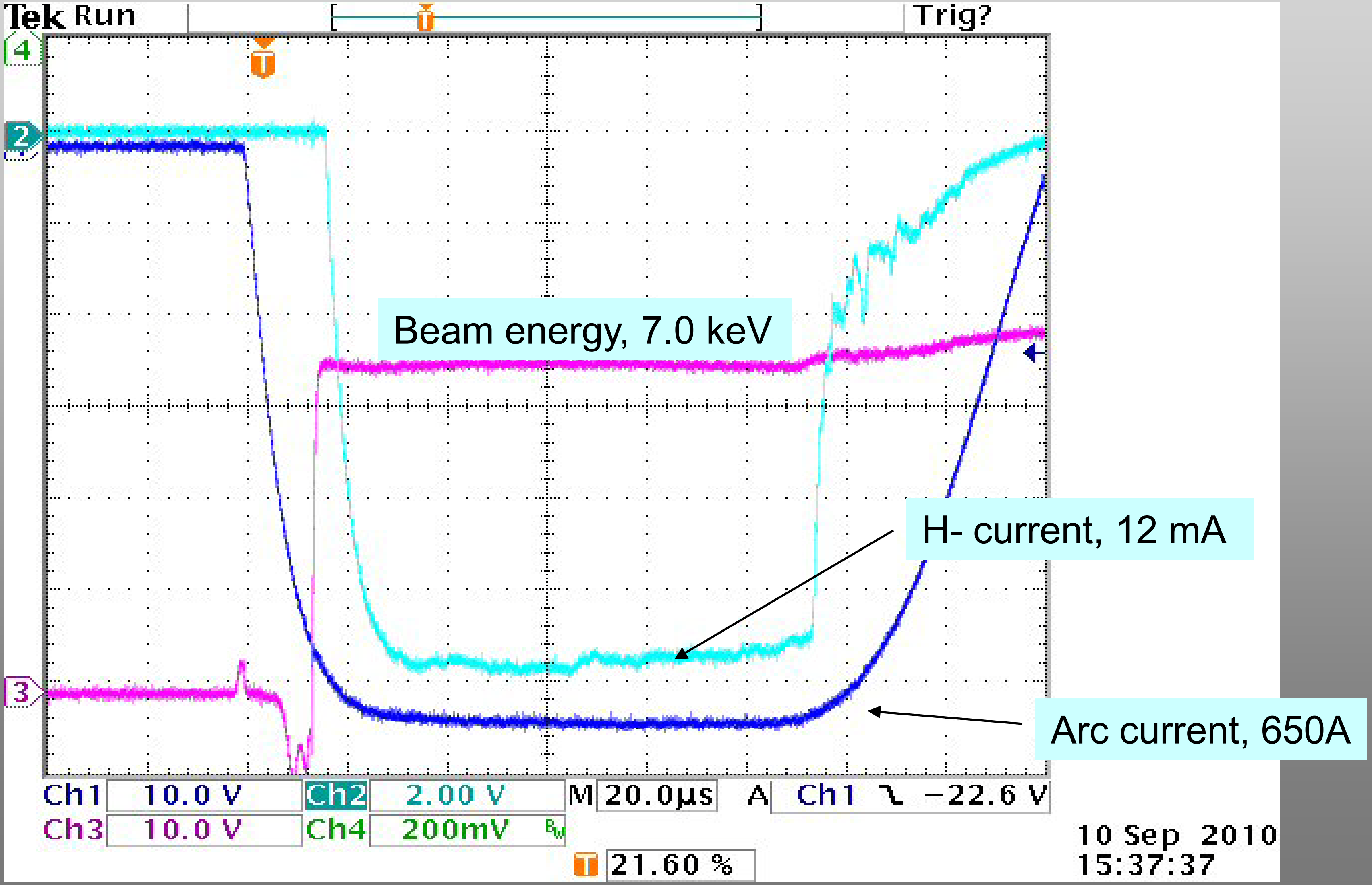


Na-jet cell is isolated and biased
accelerated in a two-stage accel

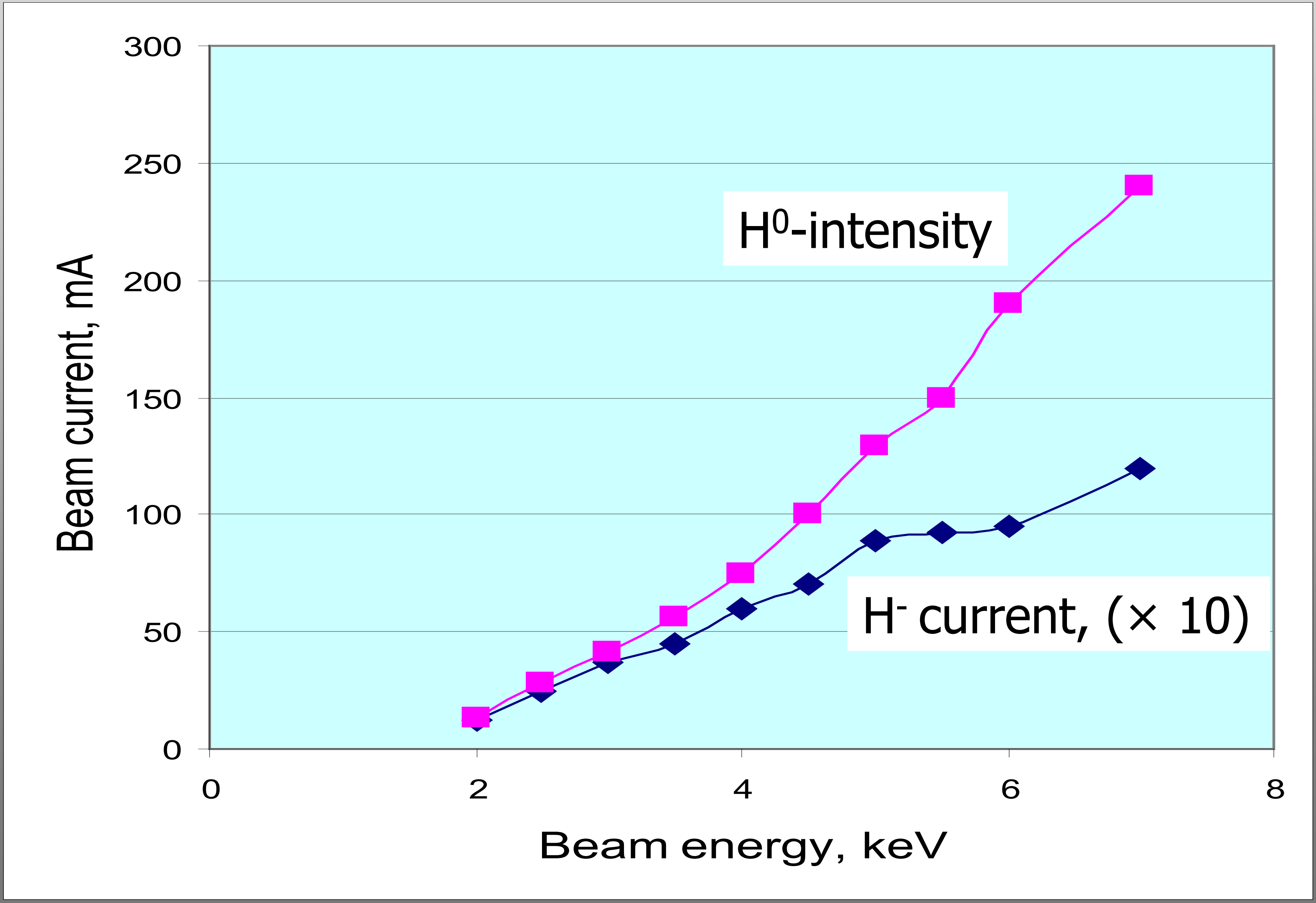
A new FABS test bench.



FABS operation



H^- ion beam current vs beam energy (within 25 mm ionizer acceptance).



Basic limitation on the intensity of H^- beam production in the Na-jet cell.

- According to paper: A.I.Krylov, V.V.Kuznetsov. *Fizika Plasmy*, **11**, p.1508 (1985), influence of secondary plasma on a Na-jet stable operation is determined by parameter :

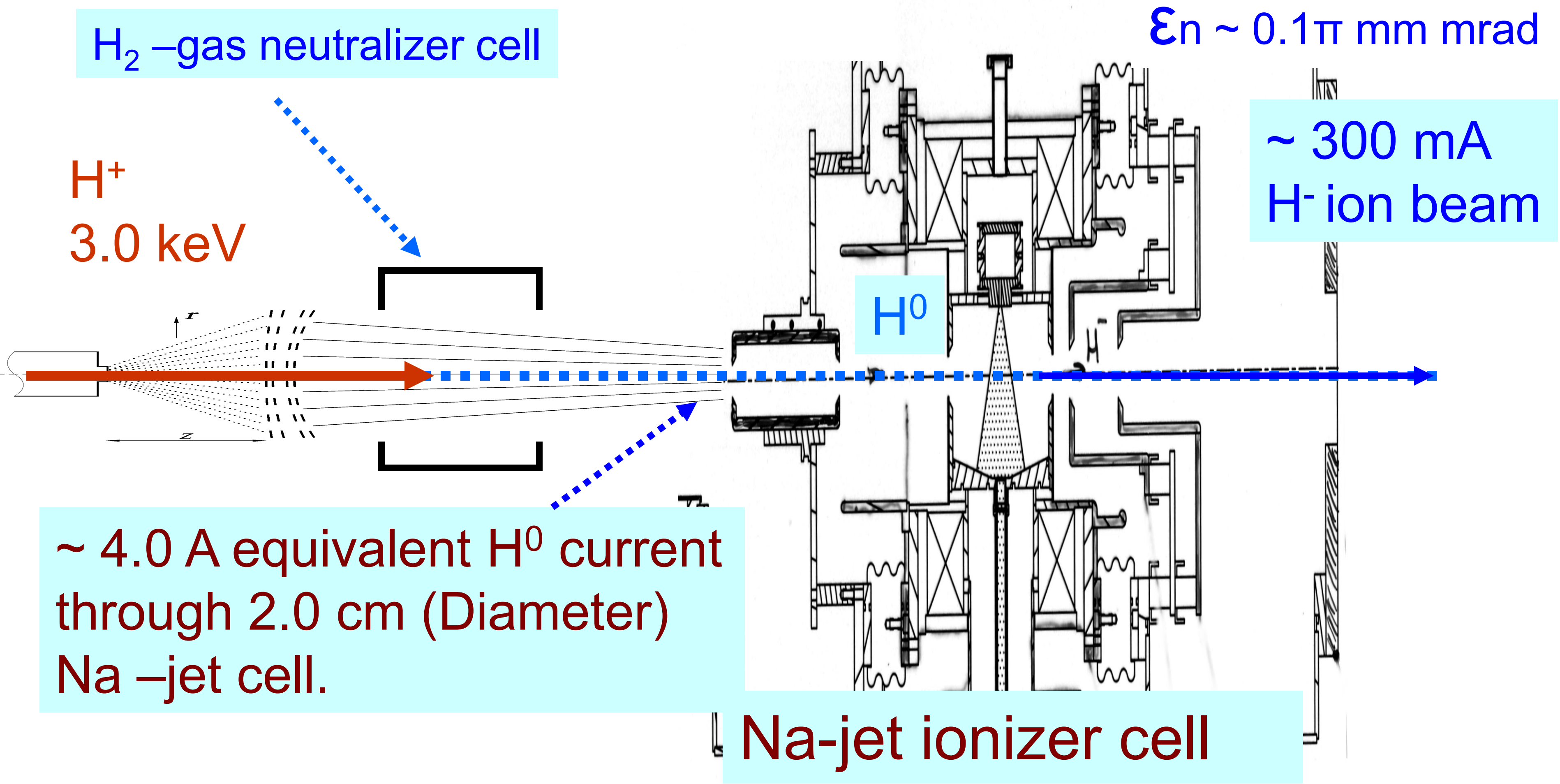
$$\alpha = J\sigma_{ion} / ev_0$$

  where: J - beam current (per cm) of jet-target length; σ_{ion} – cross-section of ionization of atoms of a target, v_0 – atoms velocity in the Jet.

  Critical value (Jet instability) of α is ~ 0.06.
- The cross section of charge exchange of protons on sodium atom has value of: $1.2 \cdot 10^{-14}$ cm^2.
- The electron capture cross section for hydrogen atoms in Na-jet is of: $5 \cdot 10^{-16}$ cm^2.

The separation of neutralization and H^- production cells should allow current density increase to: J ~1.5 A/cm^2, without impact on the Na-jet operation.

High- brighthess un-polarized H^- ion beam production



OPPIS upgrade with the “Fast Atomic Hydrogen Source”

- Higher polarization is expected with the fast atomic beam source due to:

  a) elimination of neutralization in residual hydrogen;

  b) better Sona-transition efficiency for the smaller diameter beam;

  c) use of higher ionizer field (up to 3.0 kG), while still keeping the beam emittance below 2.0 π mm·mrad, due to the smaller beam diameter.

- All these factors combined will further increase polarization in the pulsed OPPIS to *over 85%.*

Summary

- Atomic H injector produces an order of magnitude higher brightness beam than present ECR source.

- *A* 5-10 m*A* H^- ion current (50-100 m*A* proton current) can be obtained for the smaller (higher brightness) beam.

- The basic limitation on the production of the high-intensity (~300 m*A*) , high-brightness unpolarized H^- ion beam in charge – exchange collisions will be also studied.

Primary proton beam energy (~ 10.0 keV) choice.

- Higher energy gives higher beam intensity.
- Lower ionization efficiency in the He-cell (~60%).
- Larger deceleration (~7.0 keV) after the He-cell is required.
-
- H^- yield reduction for 10 keV residual unpolarized H_0.
- Higher energy increases the energy separation efficiency.
- At least 10 keV energy is required for molecular H_2^+ beam component suppression.