BNL Electron Beam Ion Sources: status and challenges

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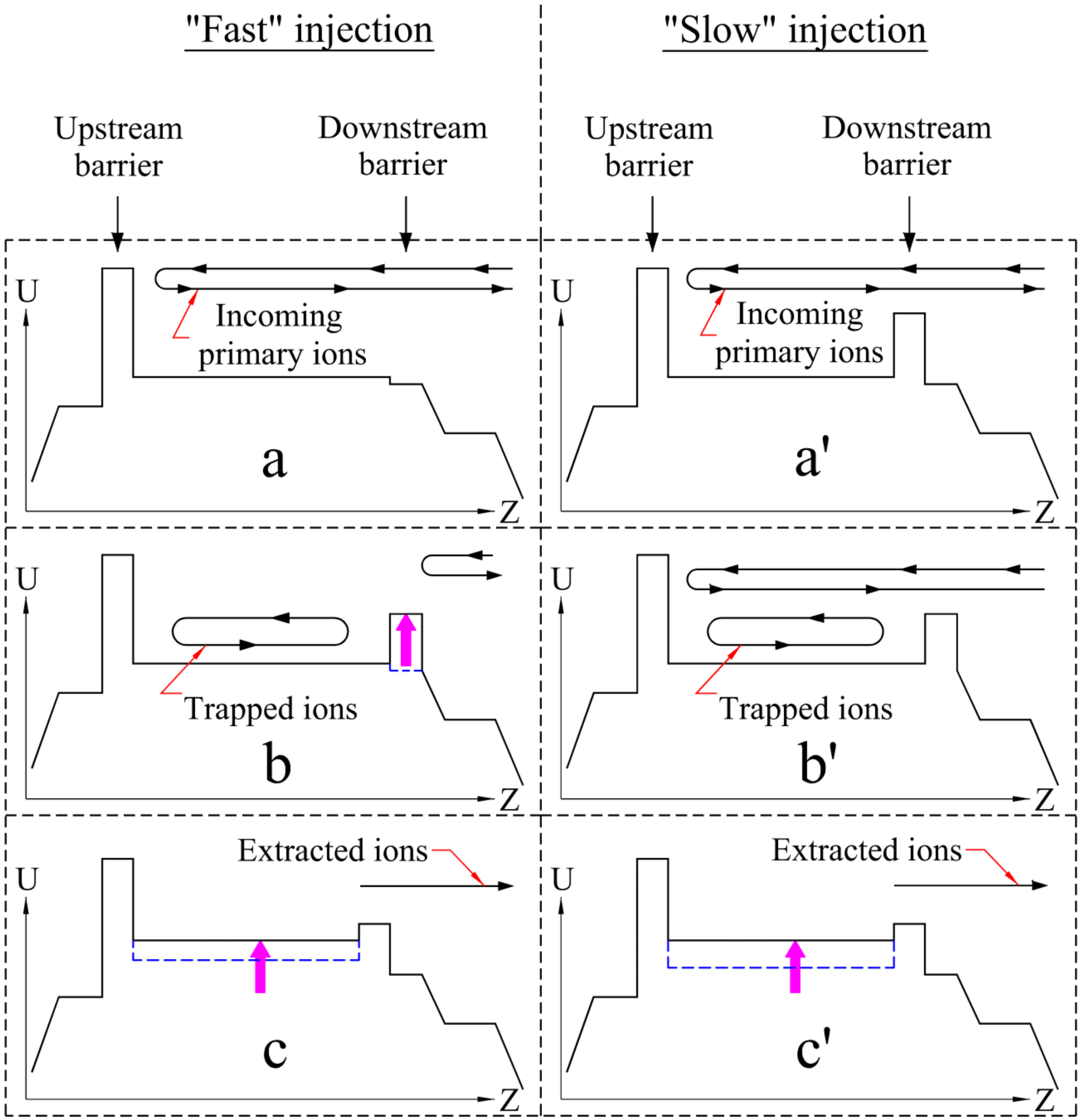
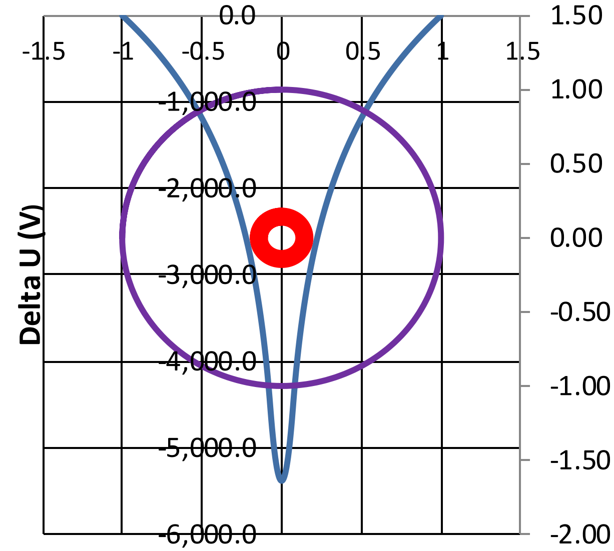




1. The electron beam space charge provides the radial confinement of ions in EBIS.
2. The axial confinement is done with potential barriers on both sides of the ion trap.
3. All operations with ion injection, confinement and extraction are done by controlling the axial potential distribution on the drift tubes.

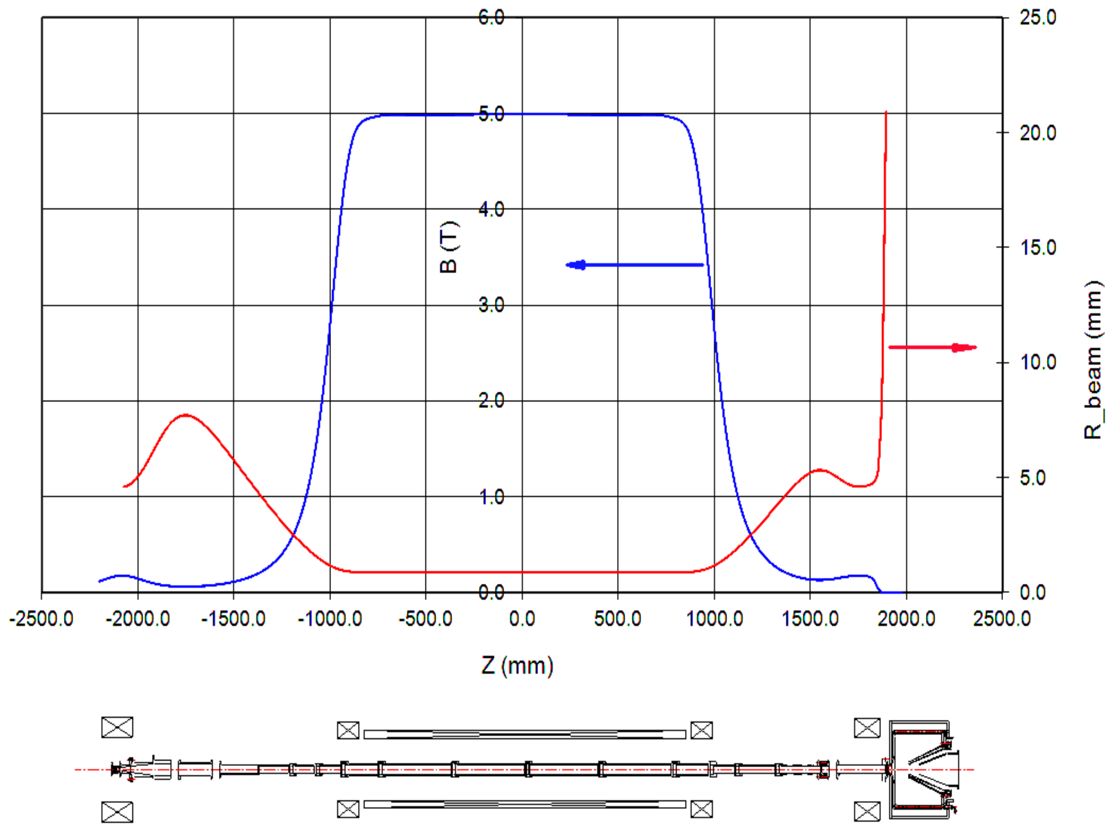
$$r(z) = r_c \cdot \sqrt{\frac{B_c}{B(z)}}$$

Immersed electron beam: the cathode of the gun is in a strong magnetic field (1.4 kGs), the electrons propagate along magnetic field lines, the magnetic flux is conserved within the beam cross-section.

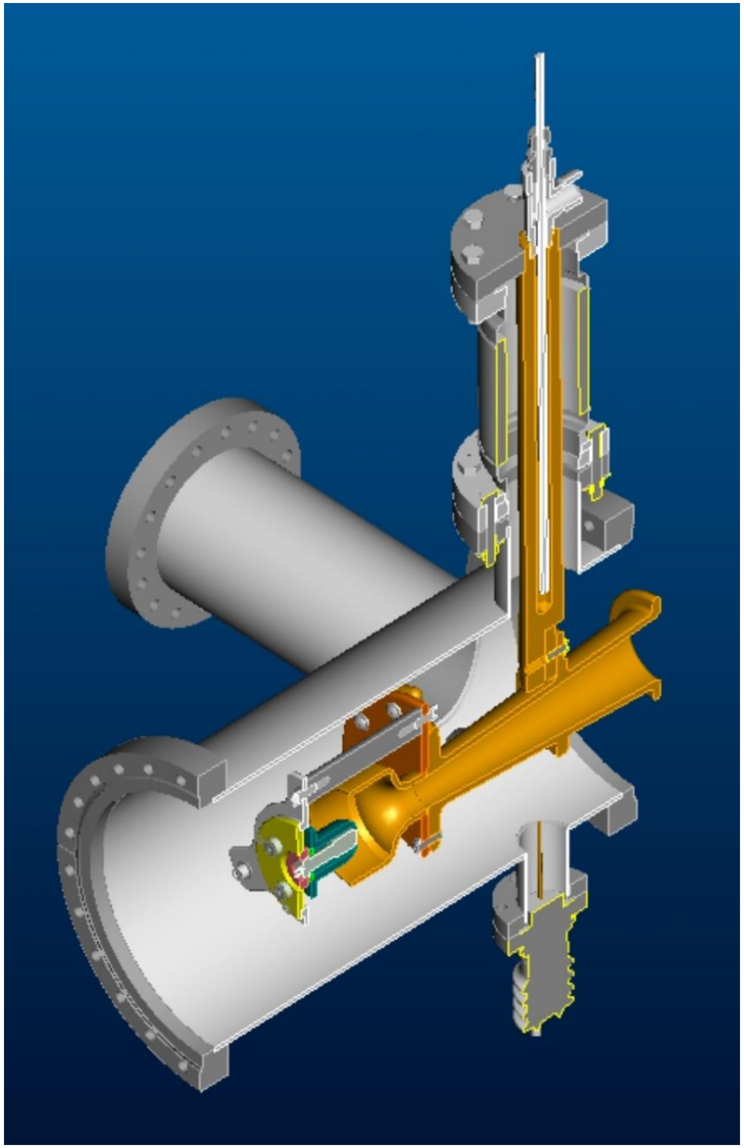
$$j_{el}(z) = j_c \cdot \frac{B(z)}{B_c}$$

Separate magnetic control of ionization region, electron gun and electron collector regions.

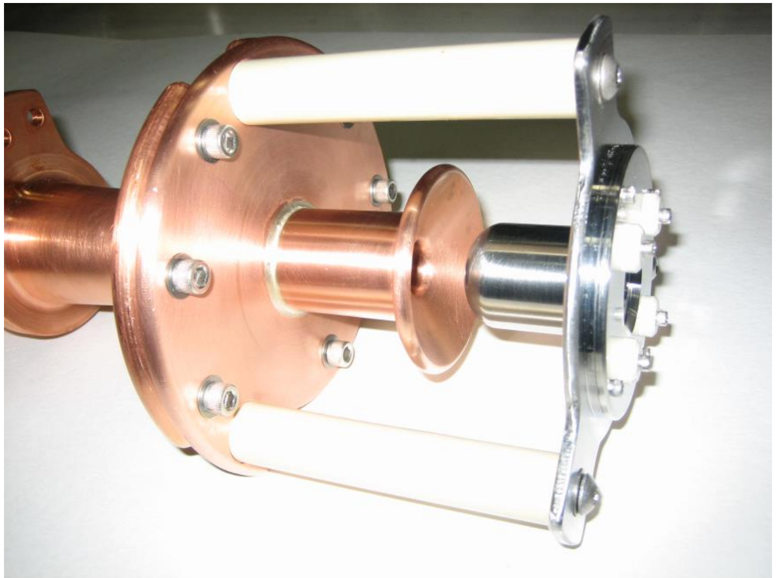
It provides good vacuum conductance from pumps to the central region in a conventional ("warm") vacuum system and a good voltage hold-off for high-voltage leads.



Electron gun in its chamber



Gun assembly



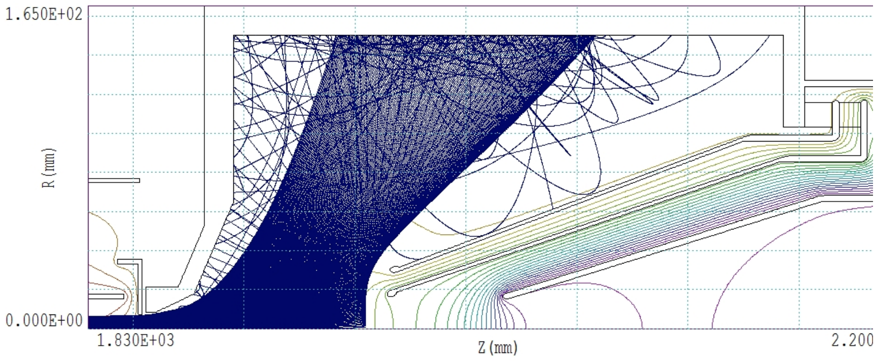
Cathode unit

IrCe cathode (Ø9.2 mm)

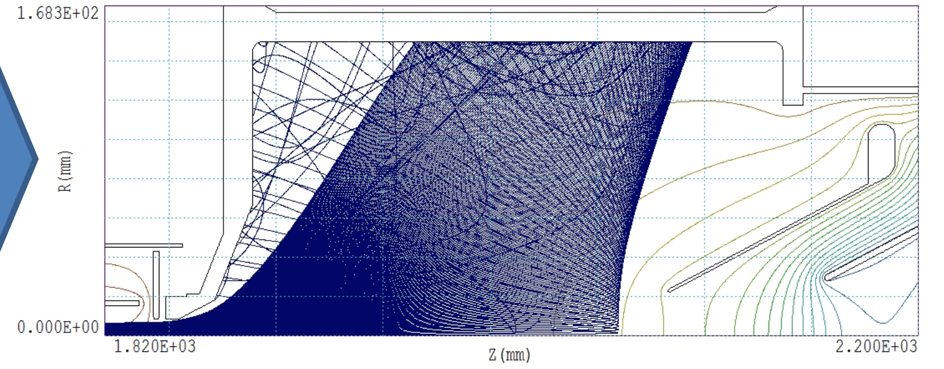
We replace cathodes once a year during maintenance works as a precaution

Maximum electron beam power to the collector: 300 kW (20Ax15 kV)

Previous version of the electron collector



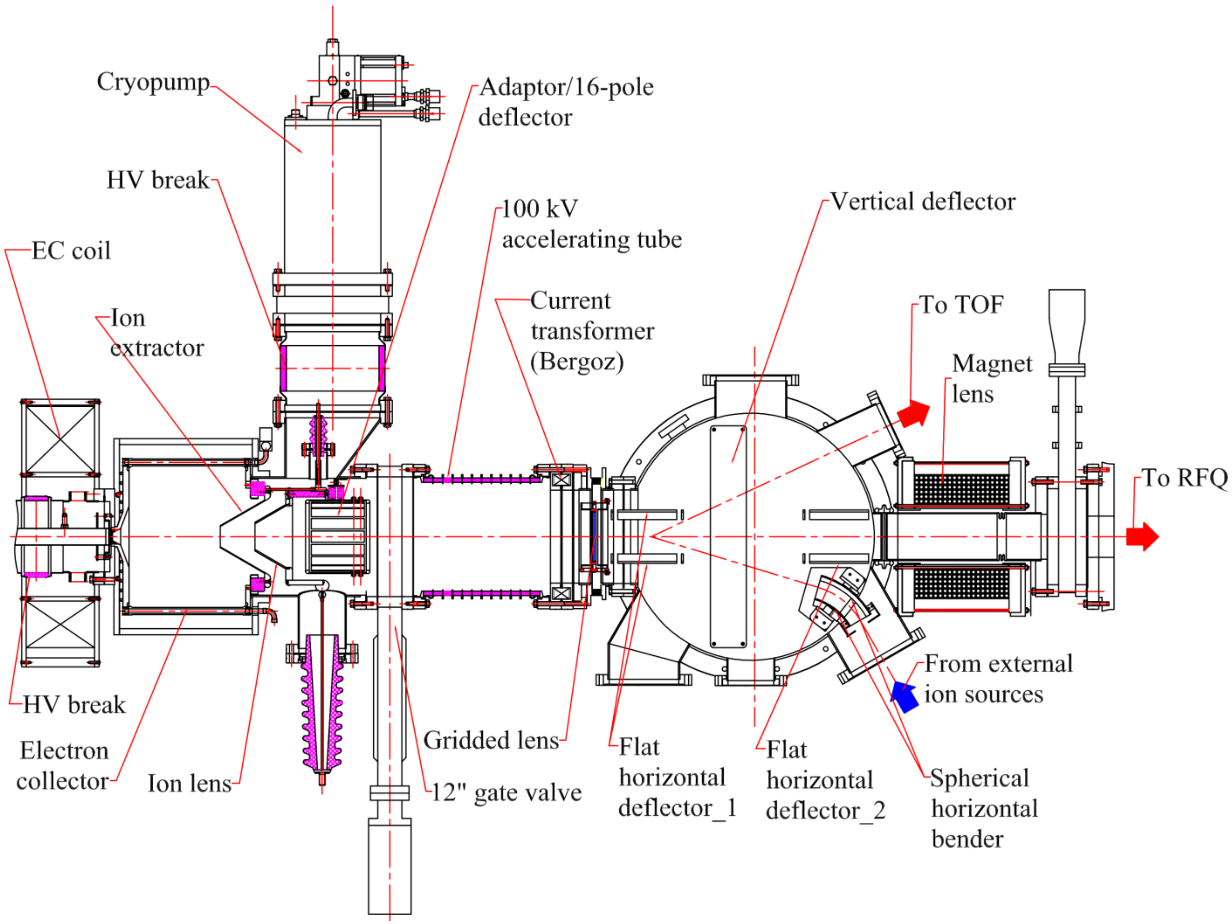
Present version of the electron collector



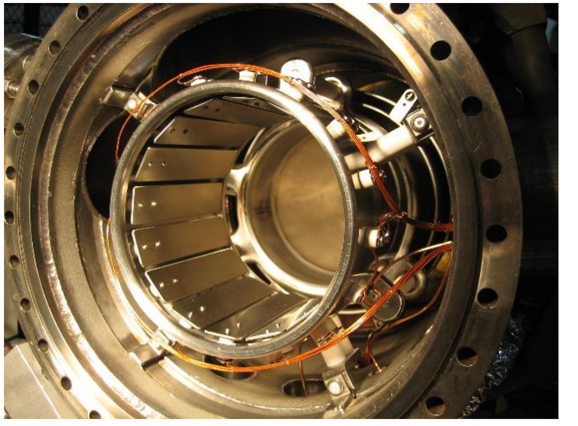
The purpose of modification was to eliminate the heating of the internal electrode inside the electron collector.

Relatively small change of optics practically preserved the ion beam transmission and the effect on its emittance.

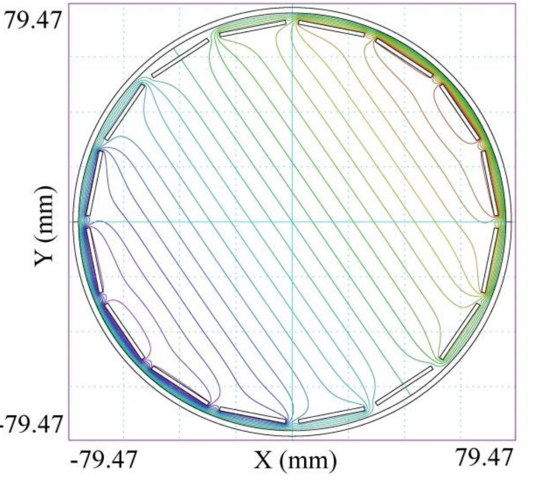
Structure of RHIC EBIS ion optics



16-pole adaptor-deflector



Electrostatic field distribution Inside 16-pole adaptor-deflector



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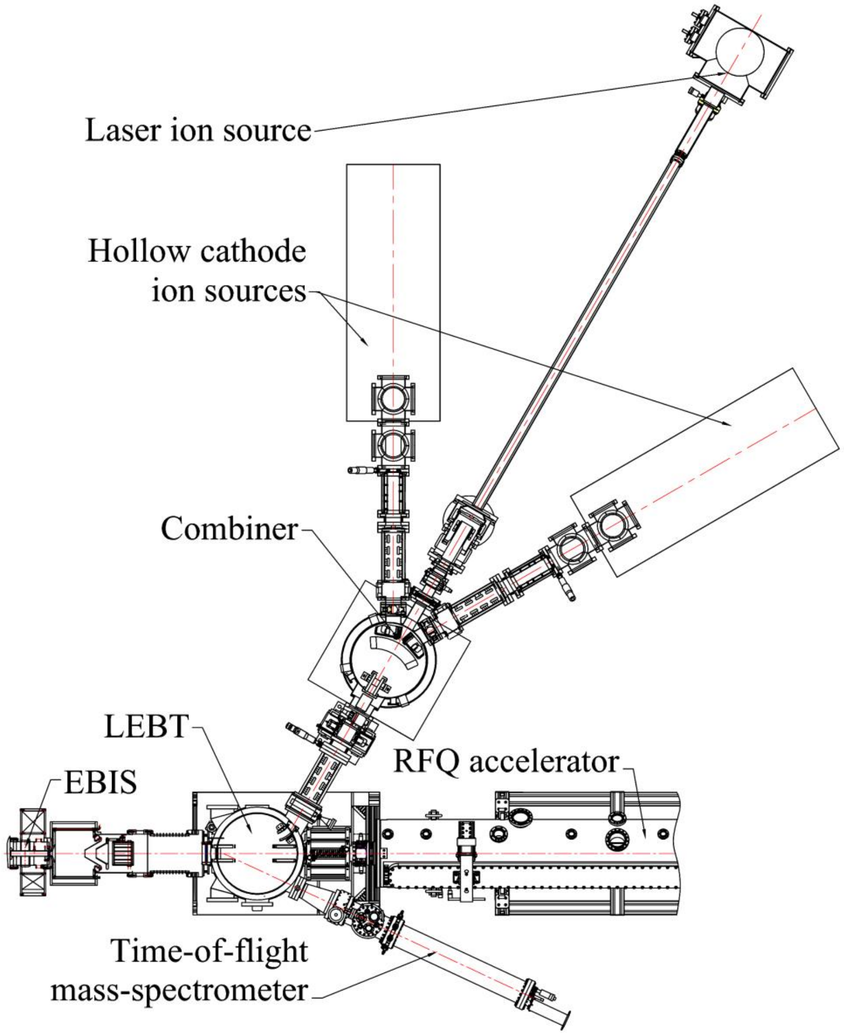
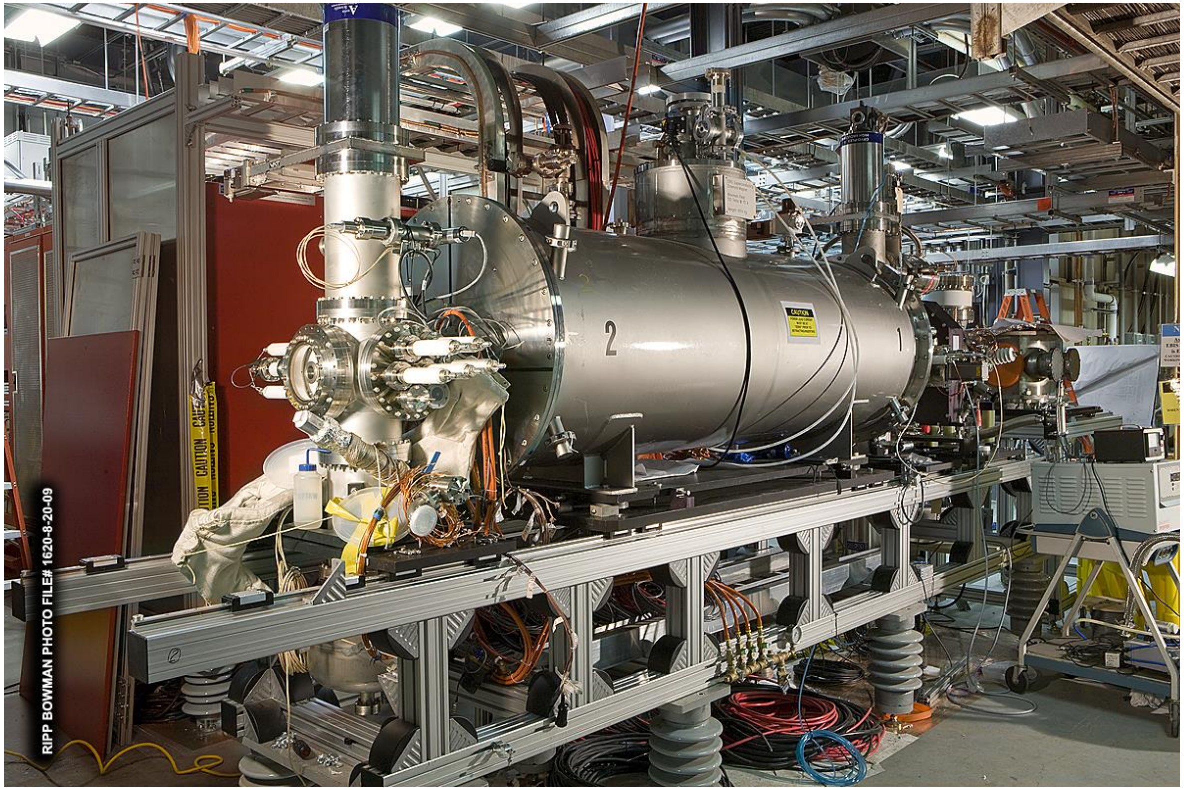
Schematic of ion optics for external ion injection



3 external ion sources allow us to switch ion species in 0.2 seconds using electrostatic ion optics.
The laser Ion source came in line this year and proved to be a versatile and reliable primary ion source.



After its commissioning in September of 2010 RHIC EBIS routinely supplies multicharged ions to RHIC accelerating facility.
The main users are RHIC and NASA Space Radiation Laboratory (NSRL).
While RHIC takes ion beams from EBIS usually January to June, NSRL uses beams from EBIS some 6 months, with some time simultaneously with RHIC.

Ion beams from RHIC EBIS to users

He-4	1+, 2+	RHIC & NSRL
He-3	2+	AGS
C	5+	NSRL
O	6+	NSRL
Ne	5+	NSRL
Si	11+	NSRL
Ar	11+	NSRL
Ti	18+	NSRL
Fe	20+	NSRL
Cu	11+	RHIC
Kr	18+	NSRL
Xe	27+	NSRL
Ta	38+	NSRL
Au	32+	RHIC & NSRL
Pb	34+	AGS
U-238	39+	RHIC

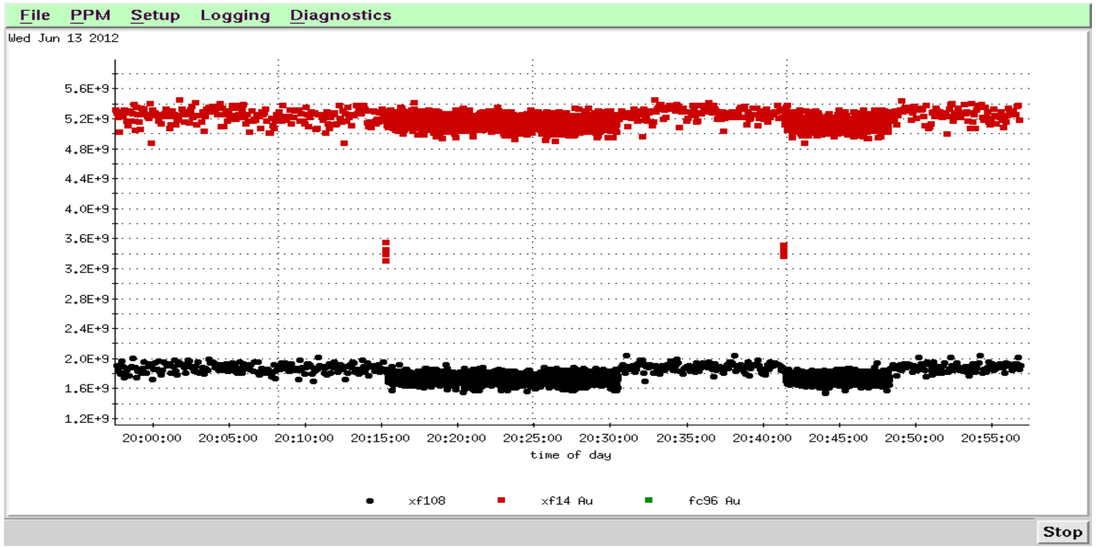
Gas injection

To date ions of 16 elements, 18 ion species have been delivered to accelerator for users

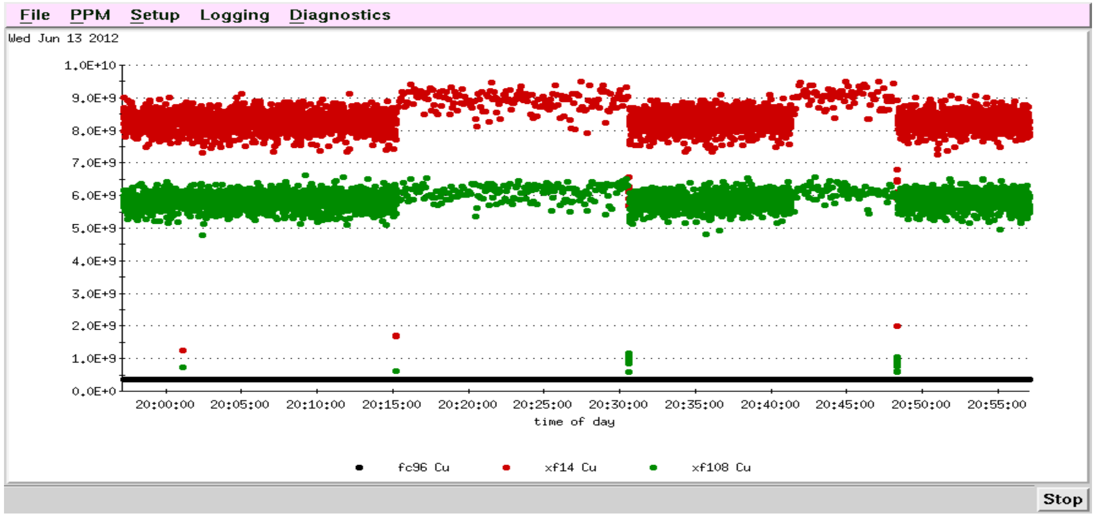
2.3E9 ions/pulse from EBIS

Cu-Au run: beam intensity traces

Au



Cu



Two regimes of RHIC EBIS operation:

For RHIC run EBIS produces 8 pulses with frequency 5 Hz in each supercycle (4-5 s)during the rings fill.

Between fills RHIC EBIS either runs for NSRL (1 pulse per supercycle) or runs for itself with 1 pulse per supercycle, just to keep EBIS ready for fills.

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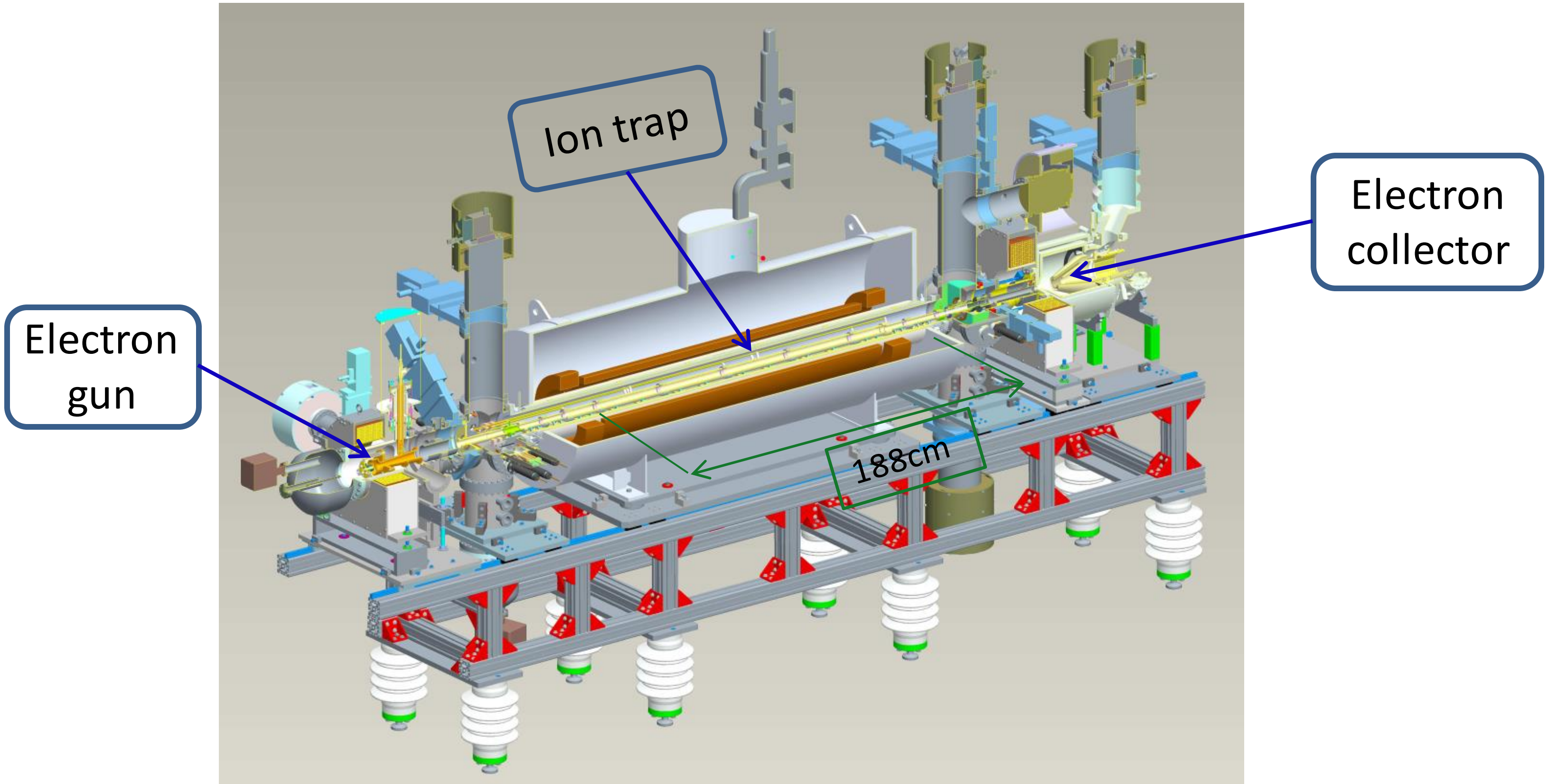
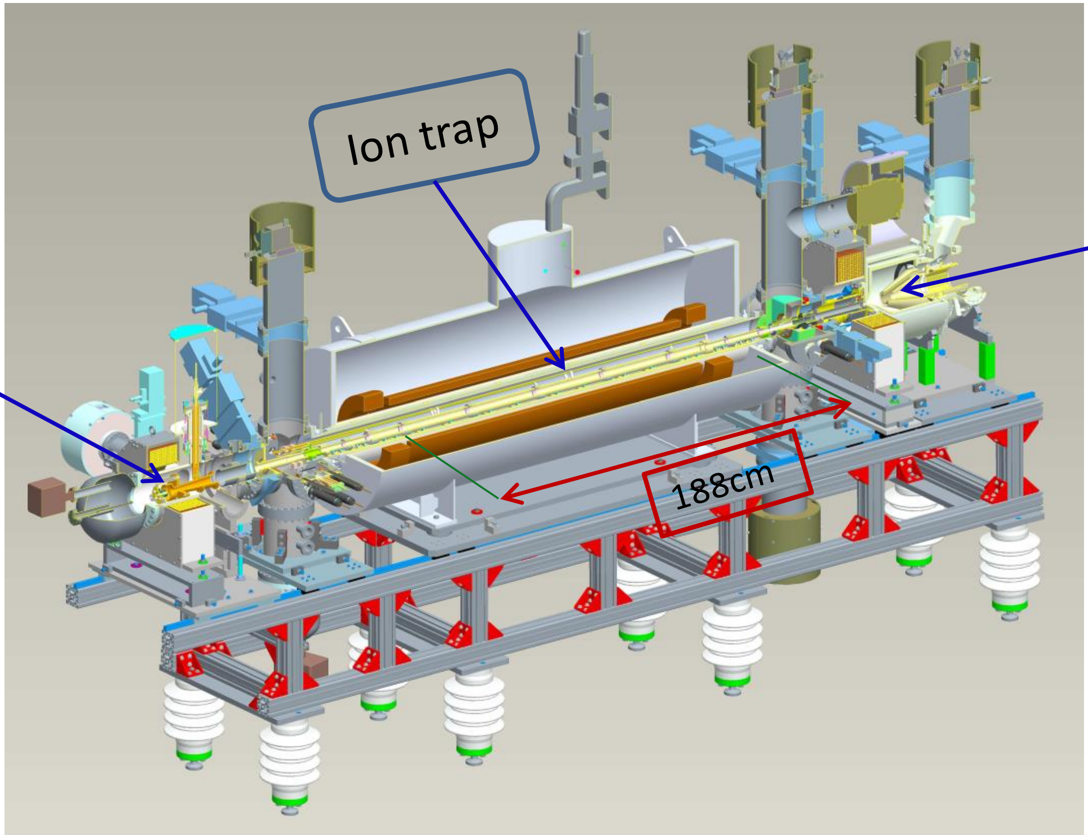
1. Total extracted ion charge from EBIS is typically > 100 nC/pulse (6.25E11 el. charges).
2. Only the gun cathode requires regular replacement (once a year, just as a precaution).
3. Liquid Helium refill in Superconducting solenoid is done every 25 days and takes approx. 1.5 hours.
4. Small maintenance works (cryo-pump regeneration, flashing the Ti sublimation pumps) are usually done during RHIC stores and do not affect the RHIC schedule.
5. The most frequent stops were due to the electron collector and RFQ power supplies trips.
6. RHIC EBIS operation is fully automated. Even for runs with He - Au collisions, involving both He gas and Au ion injection and when substantial modification of vacuum system was necessary for each species, EBIS was running practically without operator interference.
7. The availability of the ion beam from EBIS during the RHIC run was 99.8%.



RHIC EBIS parameters:

- I_{el} = (7 – 10) A
- L_{trap} = 188 cm
- E_{el} = (20 – 24) kV
- j_{el} = (300 – 500) A/cm^2
- B_{trap} = 5 T

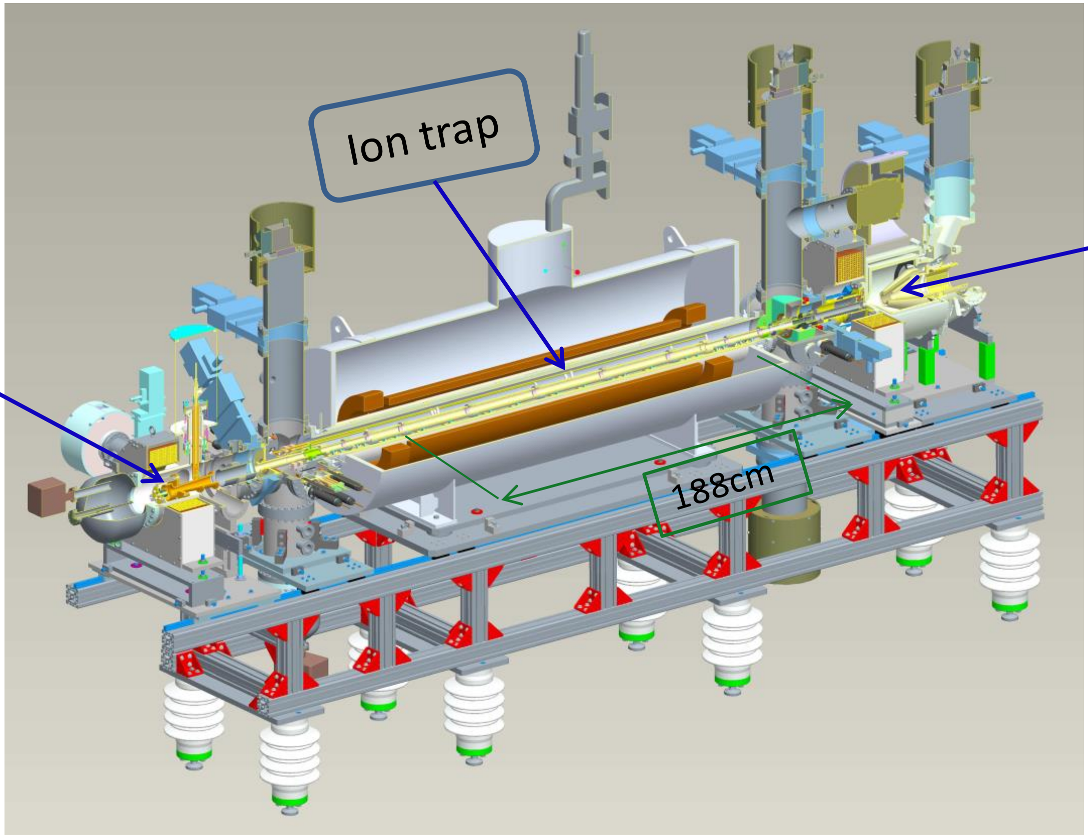
Upgrades?



RHIC EBIS parameters:

Beam intensity

- **I_{el} = (7 – 10) A**
- **L_{trap} = 188 cm** (increased from initial 150cm, ΔB/B=20%)
- E_{el} = (20 – 24) kV
- j_{el} = (300 – 500) A/cm^2
- B_{trap} = 5 T



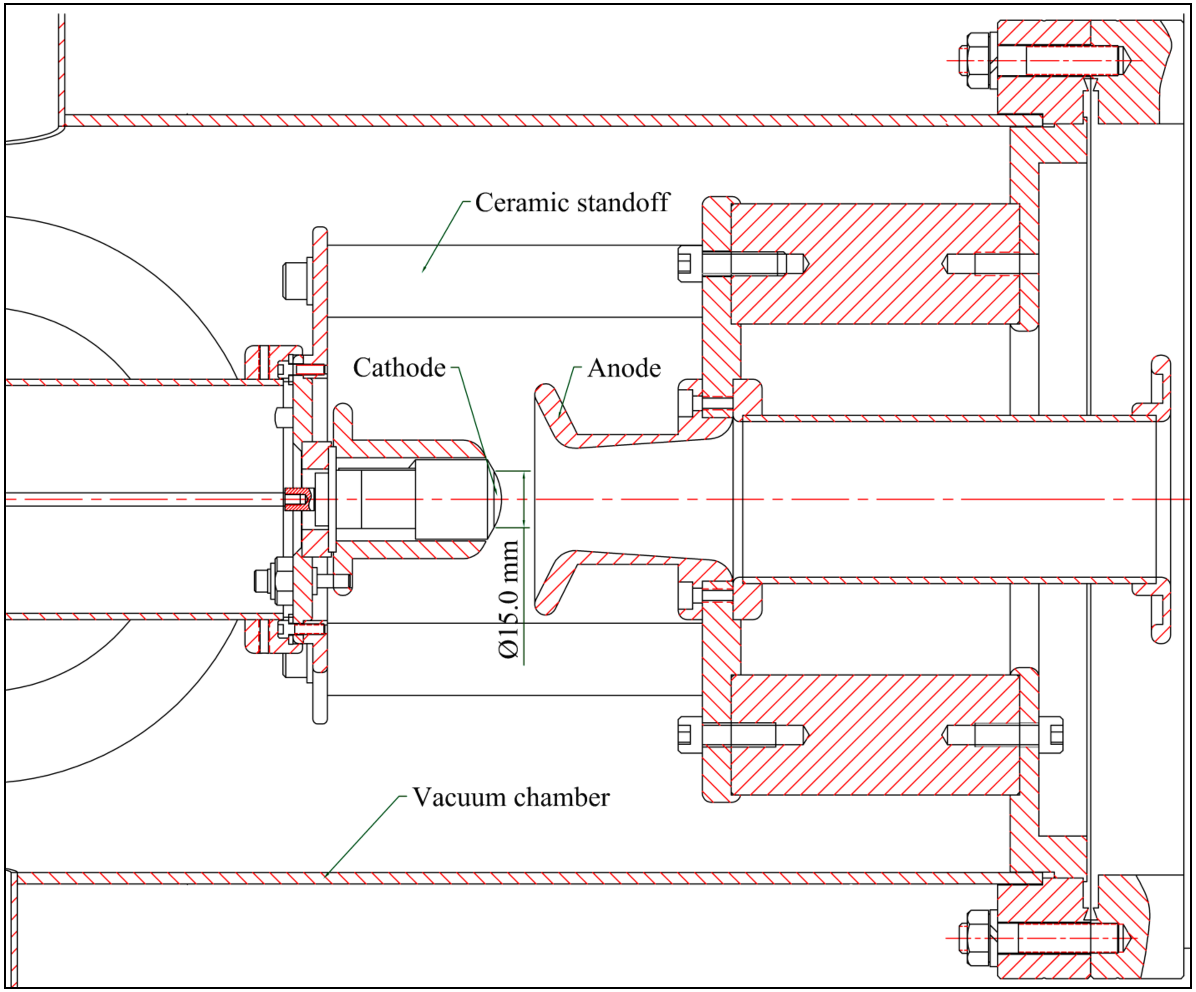
Beam intensity

Charge state

RHIC EBIS parameters:

- I_{el} = (7 – 10) A
- L_{trap} = 188 cm (increased from initial 1500mm, ΔB/B=20%)
- E_{el} = (20 – 24) kV
- j_{el} = (300 – 500) A/cm²
- B_{trap} = 5 T

A new electron gun with IrCe cathode diameter 15.0 mm.



1. The new gun design requires minimum modification of the existing electron gun with cathode 9.2 mm.

2. We will need to double the current in the EC magnet coil of RHIC EBIS to transmit the electron beam through the EC entrance aperture.

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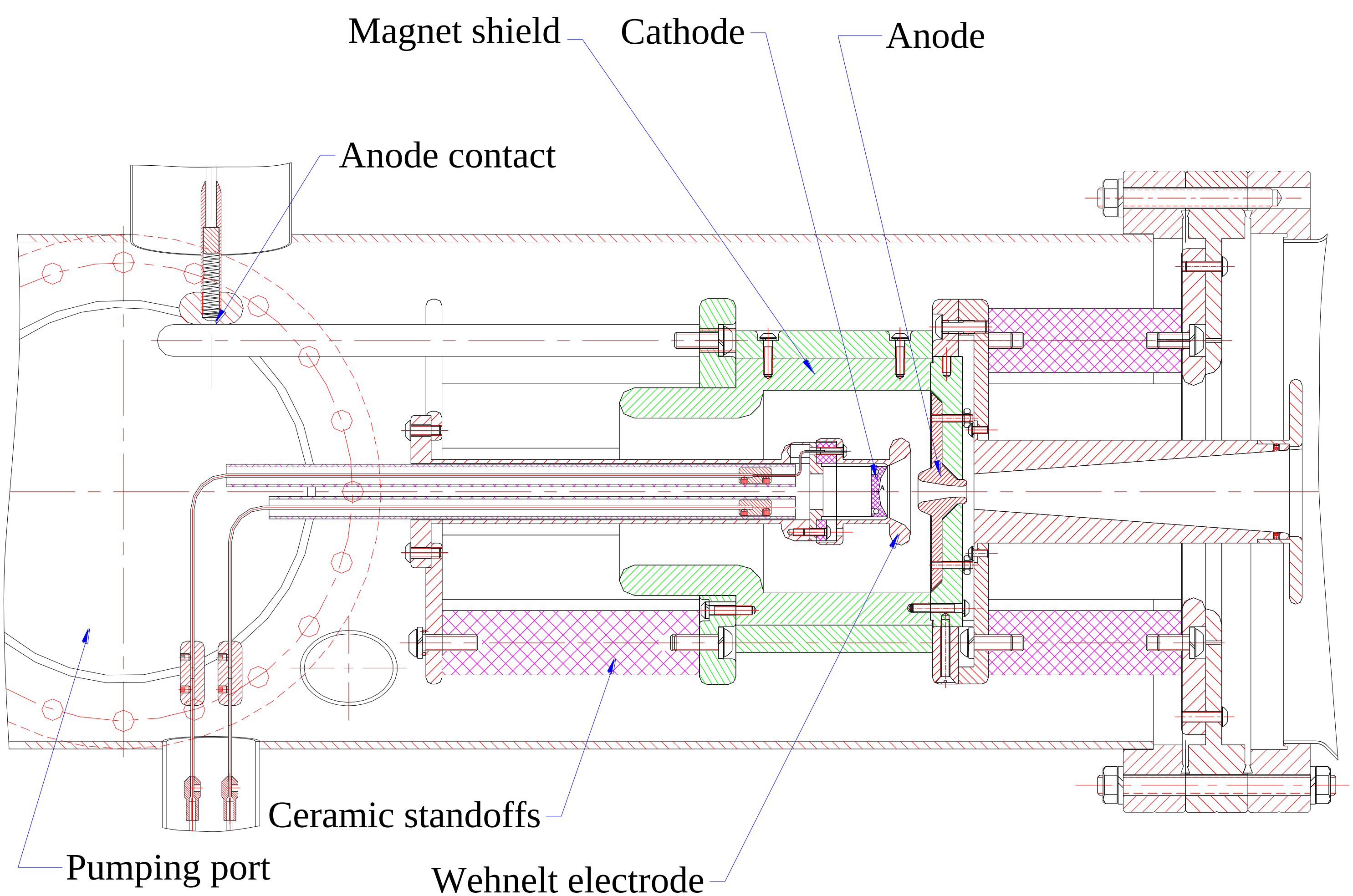
Both BNL and CERN are interested in developing of EBIS with high-current density electron beam:

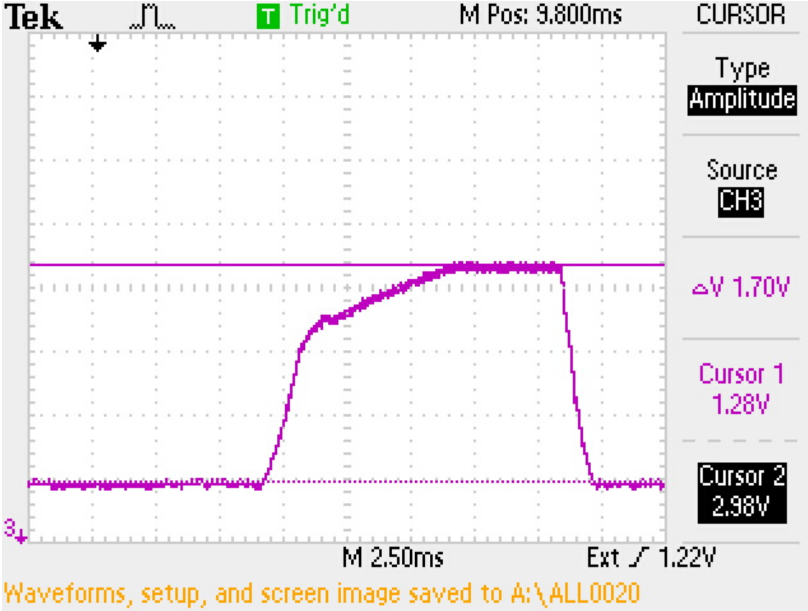
1. Increase the ion charge state and therefore the ion energy after the BNL Booster for NSRL experiments.
2. Reduce the confinement time and therefore the contamination of the ion beam.
3. Reduce the power dissipation in EC and improve the vacuum conditions.
4. Possible reduction of the ion beam emittance due to a smaller electron beam size .
5. Possibility of generating very high ion charge states for ISOLDE even for heavy elements.

Electron gun design

This electron gun is installed on Test EBIS



Results of experiments with electron beam transmission



Trace of the electron beam current on a collector CT (0.5 A/div)

I_{el}=1.7 A,
U_{an}=15.6 kV,
P_{beam}=0.87E-6A/$V^{1.5}$

1. Maximum electron current transmitted to the electron collector is 1.7 A

2. With higher electron current the beam loss on anode reaches 20 mA, which is a current limit for TREK 20/20. It seems such load is manageable and outgassing from the anode can be reduced by training. Which means that a power supply with higher acceptable load can be used for the anode.

3. With sufficient heating power the perveance of the electron gun is P_{exp} =0.93E-6 A/$V^{1.5}$ (simulated value P_{sim} = 0.934E-6 A/$V^{1.5}$)

Our experimental results and observations give reason to believe, that the current load on the anode of the gun is caused primarily by reflecting of some primary electrons from the magnetic mirror at the entrance into the superconducting solenoid on their way to the trap:

$$r_{mirror} = \frac{B_{max}}{B_{min}}$$

Transmission cone: $\frac{v_\perp}{v_\parallel} < \frac{1}{\sqrt{r_{mirror}}} [< 0.17]$ (for I_{el}=1 A)

The electrons with larger angles are reflected back.
The most susceptible for reflection are the peripheral electrons with the largest angles.

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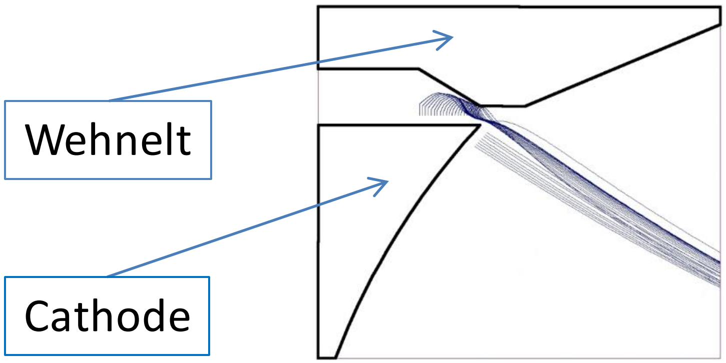
Possible reasons of electron beam quality degradation in our case:

1. Axial movement of the gun parts due to thermal expansion (up to 1.5 mm). It can result in a not optimum position of the cathode with respect to the anode and magnetic shim, causing increase of radial oscillation.

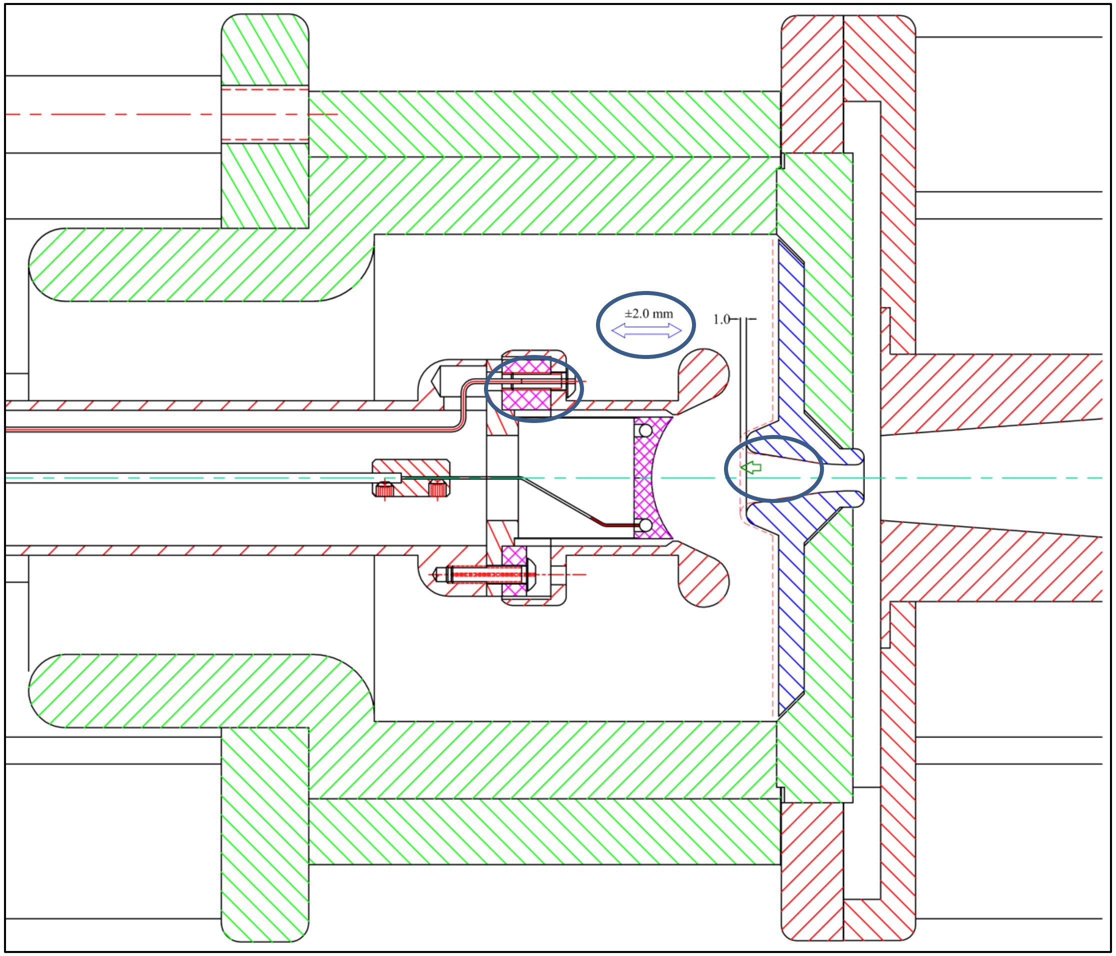
1. Cathode edge aberrational effect with relatively large radial gap between the cathode and the Wehnelt electrode (0.4 mm).

2. Emission from the side of the cathode produces a beam component with large aberration and with current reaching several percents of the total beam:



Simulation for the existing conditions: $U_{Cath} = U_{Wehnelt}$

With existing magnetic and vacuum structures in Test EBIS the best way to increase current of the transmitted electron beam can be improving the electron beam quality – reducing the amplitude of radial oscillation.



1. Move the anode with respect to the magnetic shim to the position optimized with relativistic simulation

2. Add an option to move the cathode unit axially from outside the vacuum chamber to optimize its position in a gun.

3. Isolate the Wehnelt electrode from the cathode and energize it independently.

4. Future step: Injection of the electron beam into a stronger magnetic field to reduce the magnetic mirror effect.

1. RHIC EBIS is a major source of multiply charged ions in RHIC facility operating unattended most of the time.
2. The availability of ion beams for RHIC was 99.8%.
3. It takes about 1 second to switch ion species in RHUIC EBIS.
4. The maintenance work is done during RHIC fills and does not affect RHIC schedule.
5. A Brillouin electron gun has been tested and electron beam up to 1.7 A has been transmitted to the electron collector. The anode load was the only beam loss component after EBIS tuning.
6. Modification of Test EBIS is in progress with a goal to increase the current of the transmitted electron beam according to our understanding of its physics.