An EBIS-based RHIC Preinjector

RHIC EBIS design

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Project parameters of RHIC EBIS (I_{el}=10A):

• Number of extracted ions of Au^{32+} (ions per pulse):	$3.4x10^9$
• Total extracted ion charge (elem. charges per pulse):	$5.5x10^{11}$
• Capacity of ion trap (elem. charges):	$1.1x10^{12}$
• Extraction time:	10-50 μs
• Electron beam current:	10 A
• Electron beam current density in ion trap:	575 A/cm^2
• Electron energy in ion trap:	20 keV
• Length of ion trap:	1.5 m
• Magnet field in the center of SC solenoid:	8-6 T
• Maximum rep. rate	5 Hz

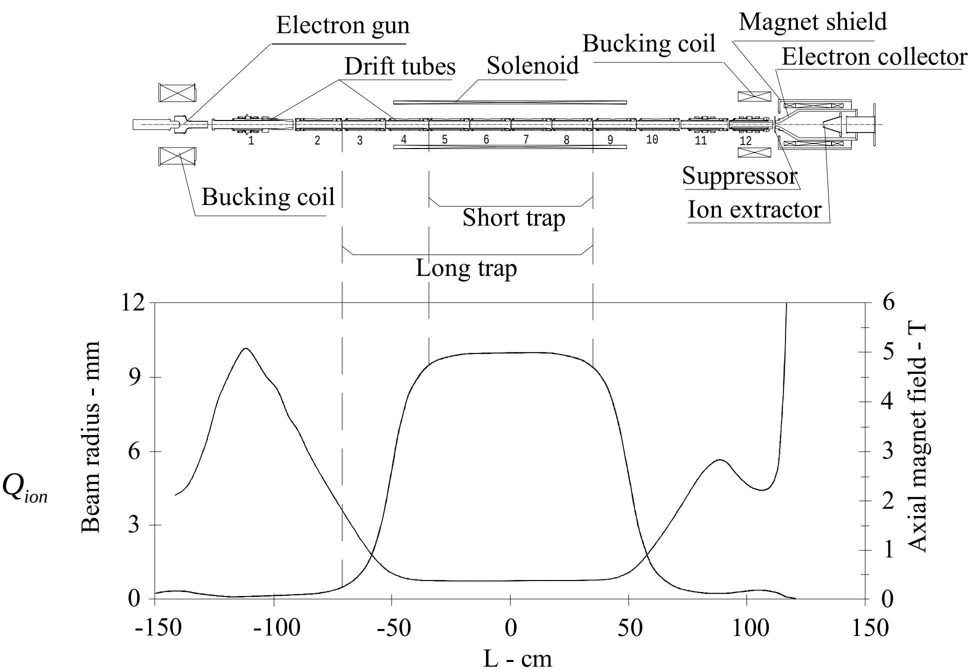
The primary difference in the RHIC EBIS, compared to our Test EBIS, is the doubling of the trap length to increase the ion output. Other new features we plan to incorporate into the final EBIS will be made in order to make the final EBIS more robust.

Electron Beam

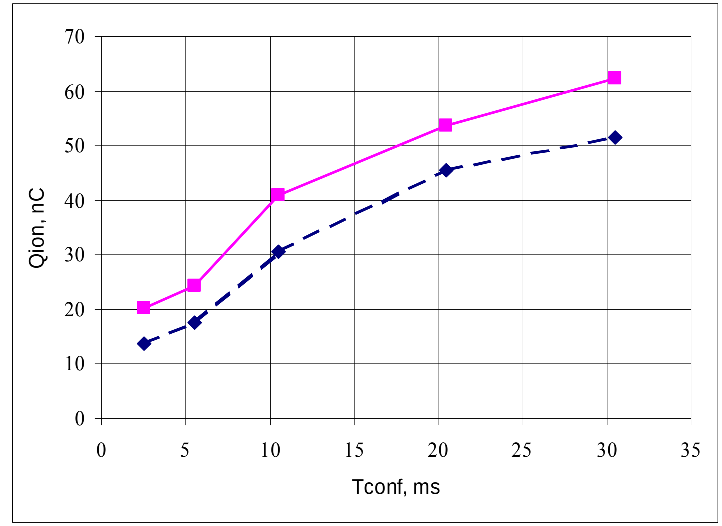
- The existing 10 A electron gun with IrCe cathode meets the RHIC EBIS requirements, with an estimated lifetime of >20,000 hours.
- The present cathode is actually capable of operating at 20 A with lifetime of 3000-5000 hours.
- In order to have a reserve for a possible future increase of the ion beam intensity, we are developing the electron gun electrodes and collector with the capability of operating at 20 A.

Length scaling (our experiment):

Conditions of the experiment: I_{el}=7.5 A, L_{short}=**71** cm, L_{long}=**107** cm, B_{trap}=4.6 T, B_{min}=0.19 T



Geometry of EBTS electro-optical system (top) and axial magnet field distribution with simulated radial profile of electron beam (bottom).



Time evolution of the total extracted ion charge (nC) with Au injection for the long trap (solid line) and short trap (dashed line).

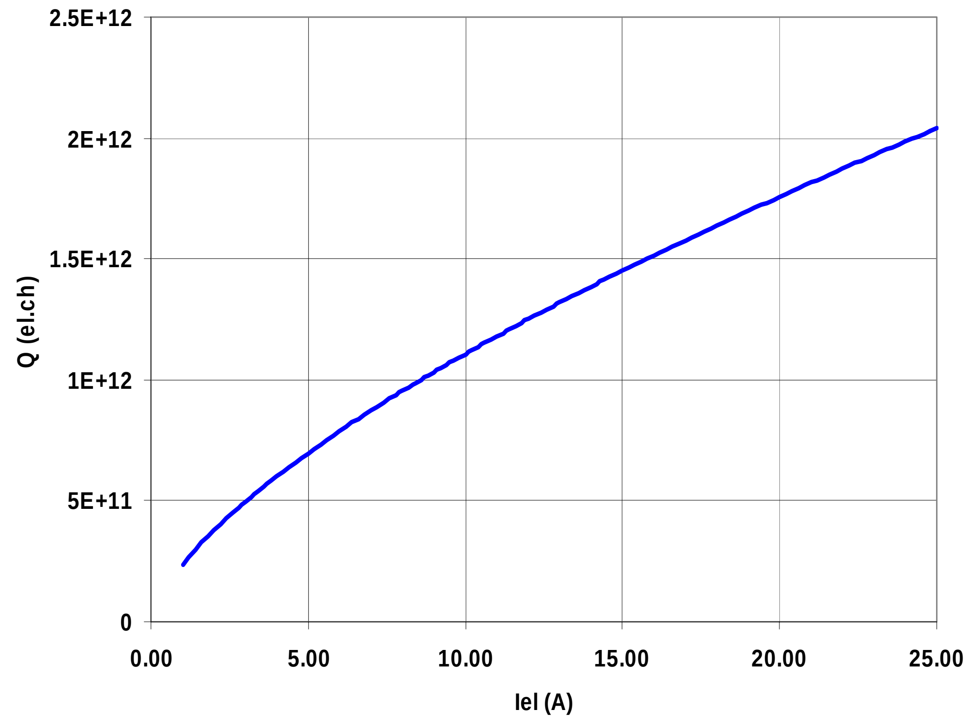
Result: with good precision the capacity of ion trap is proportional to the length of the trap. (As typically observed in any EBIS)

We have a good reason to expect doubling the ion intensity with doubled trap length.

Electron current and ion intensity scaling

With optimum perveance of the electron beam in a trap of our EBIS
P_{trap}=3.54x10^{-6} A/V$^{3/2}$
and the length of the trap l_{trap}=1.5 m
the capacity Q of the the ion trap (space charge of electrons within the ion trap boundaries) depends on the electron current I_{el} as:

$$Q[elem.ch.] = 2.385\times10^{11}\times I_{el.}{}^{2/3}[A]$$



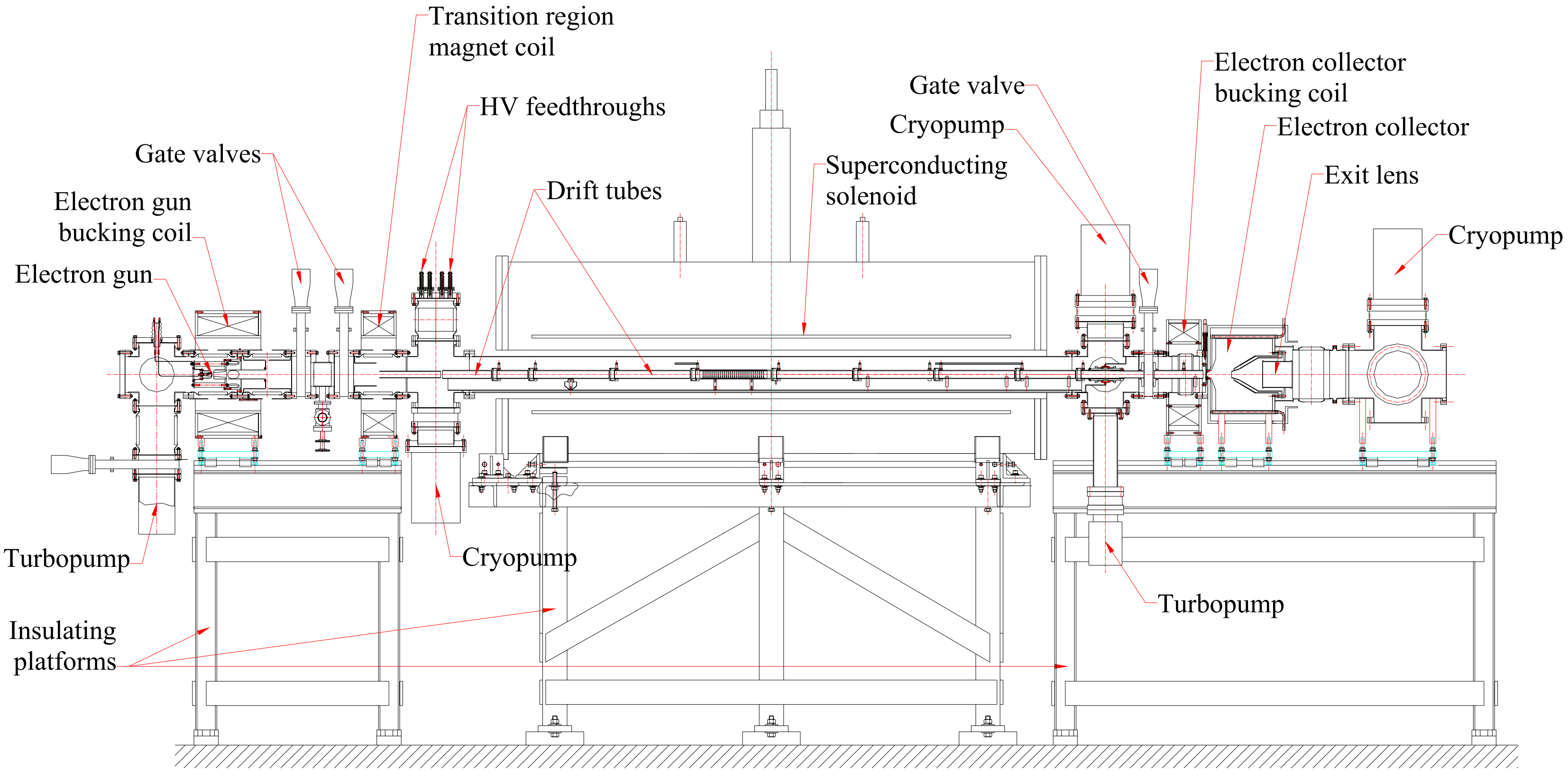
With electron current up to I_{el}=10 A the number of extracted ions can be determined by the formula:

$$N_{ion} = K_{neutral} \times K_{spectrum} \times \frac{Q}{Z_{ion}}$$

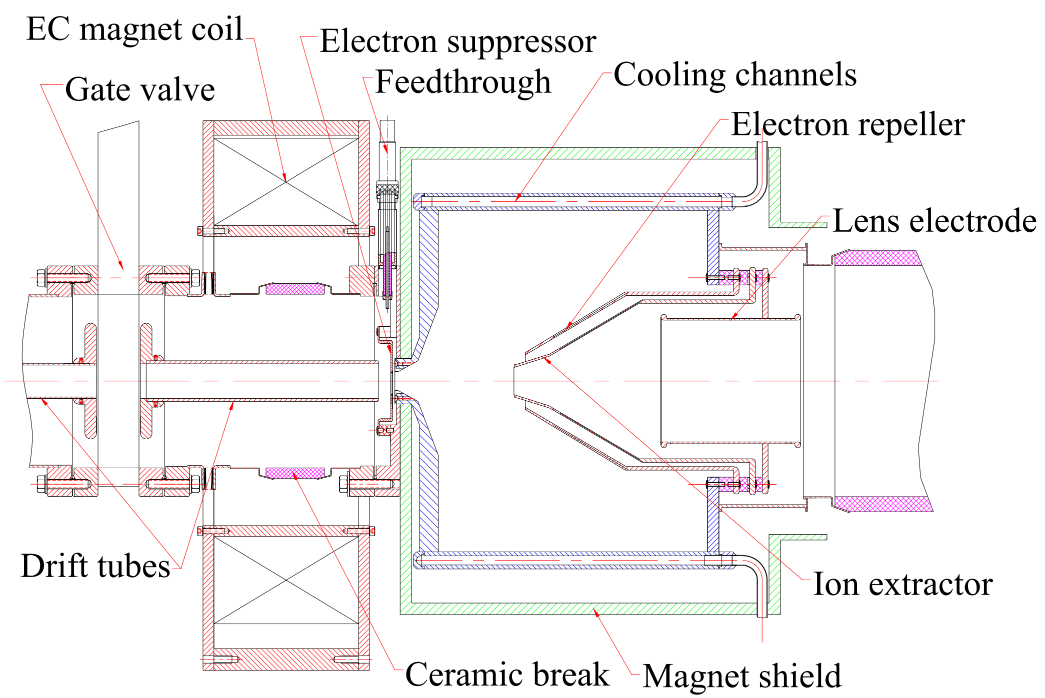
$K_{neutral}$ – coefficient of neutralization of the electron beam space charge by ions
$K_{spectrum}$ – fraction of ions with charge state Z_{ion} in the ion spectrum

Scaling EBIS to I_{el}=20 A, for $K_{neutral}$=0.5, we can expect the intensity of ions Au^{32+} to increase from 3.4x10^{9} to **5.5x10^{9}** per pulse. (**60% increase)**

Schematic of EBIS for RHIC



Electron collector (assembly)



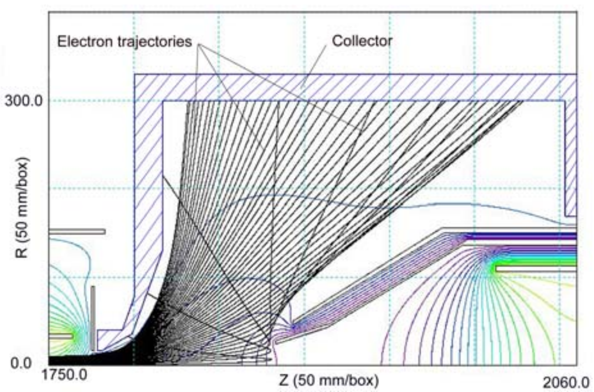
- Designed to dissipate P_{el}= 300 kW peak power
- More uniform distribution of e-beam
- Increased surface area (2200 cm²)
- Calculated max power density on EC surface (for 300 kW): p_{max}= 485 W/cm²
- Outer surface of collector is at atmosphere (~ no internal cooling lines).

• Cooling channels: ID 9 mm in a cylinder 15 mm thick, 10 parallel loops, each consisting of 6 individual channels connected in series.
• Cooling water: pressure P=20 bar, flow= 4 GPM per loop.
• Calculated critical heat flux is CHF=790 W/cm² (Biasi) or CHF=1290 W/cm² (Bowring). With expected max. power density 485 W/cm² we have a comfortable safety factor of 2 or more. Pressure rise increases CHF because the boiling temperature increases.

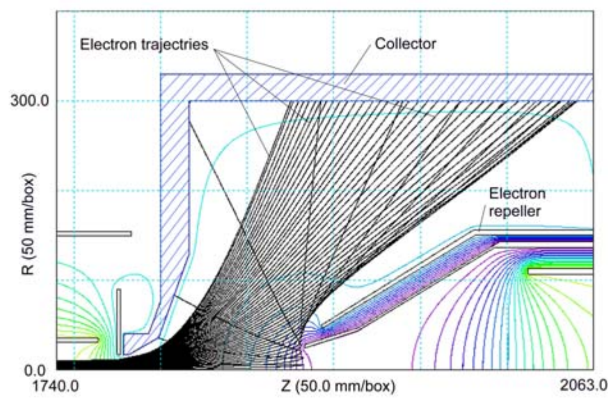
Simulation of the electron collector

Simulations of the 20A electron beam transmission in EC

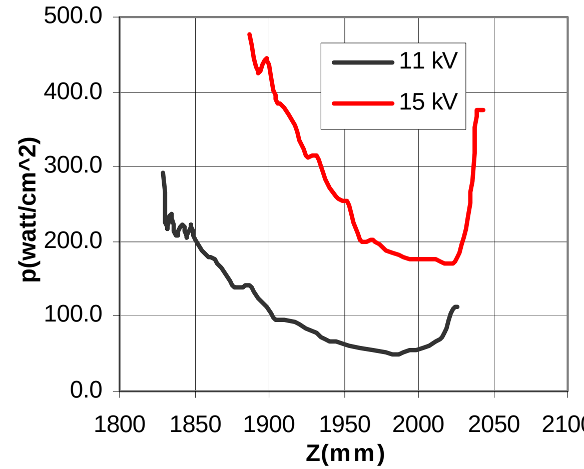
E_{el}=11 keV

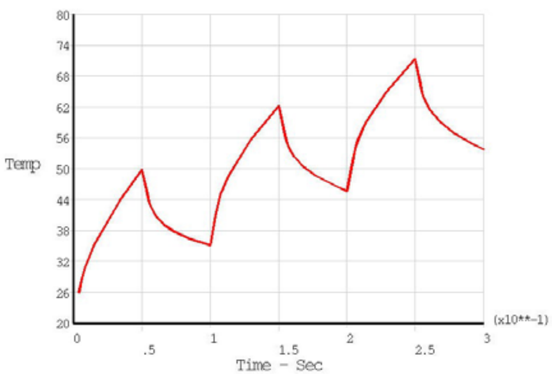


E_{el}=15 keV

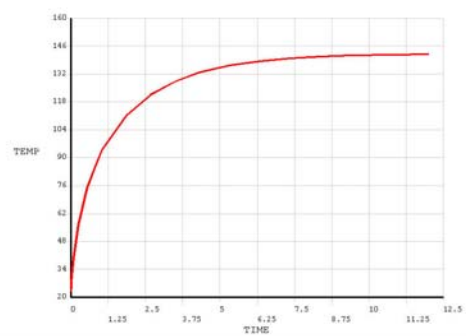


Electron beam power density distribution on EC surface

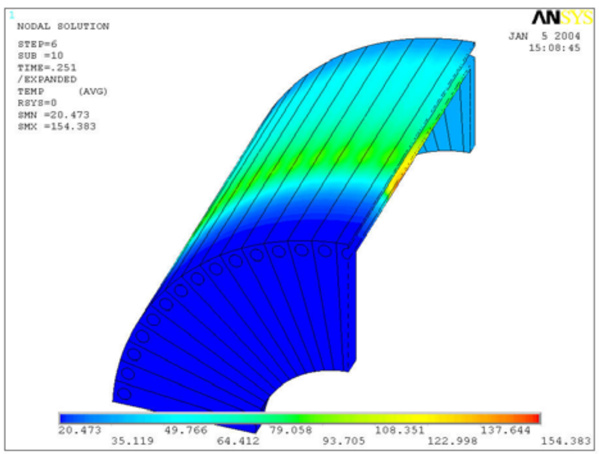




Temperature cycling at the beginning of power load with 50% duty cycle (20A, 15 keV)



Time dynamics of the average temperature in a hottest spot with 50% duty cycle (20 A, 15 kV)



ANSYS simulation of temperature distribution in EC in the equilibrium at the hottest node.
20 A, 15 kV, 50% DC

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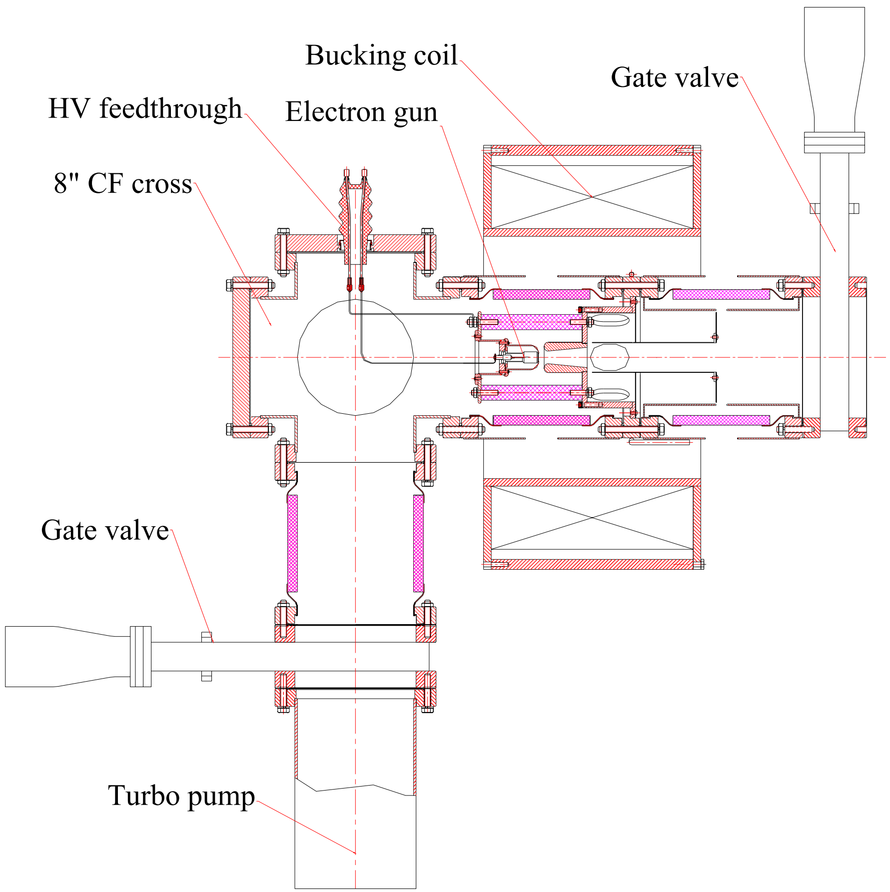
Electron gun

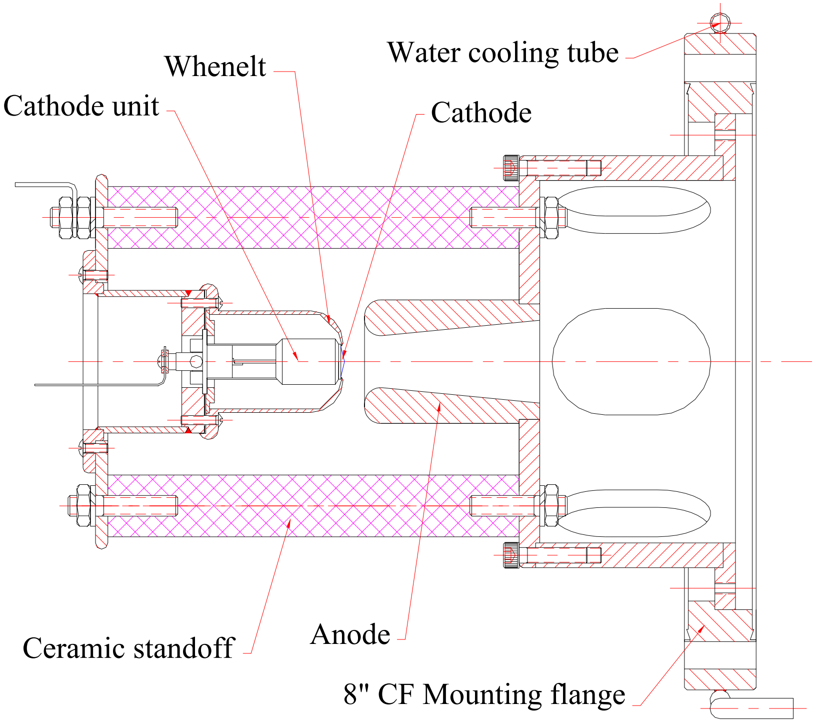
- Method of forming the electron beam – the same as in existing electron gun: magnetic compression of the beam generated by a cathode immersed in a magnetic field.
- Perveance: $P=2.5\times10^{-6}\ A/V^{3/2}$ (2 times higher than we have now, to allow operation at reduced voltage) *with bell-shaped radial current emission profile*
- Electron current $I_{el.\ max}=20$ A at $U_{anode}=40$ kV
- Magnet field on the cathode: $B_{cathode}=0.18$ T
- Cathode material: IrCe
- Maximum emission current density $J=40\ A/cm^2$ for life time 3-5 thousand hours.
- Cathode diameter: 9.2 mm,
- Convex shape, $R_{sphere}=10$ mm,

Design of the electron gun

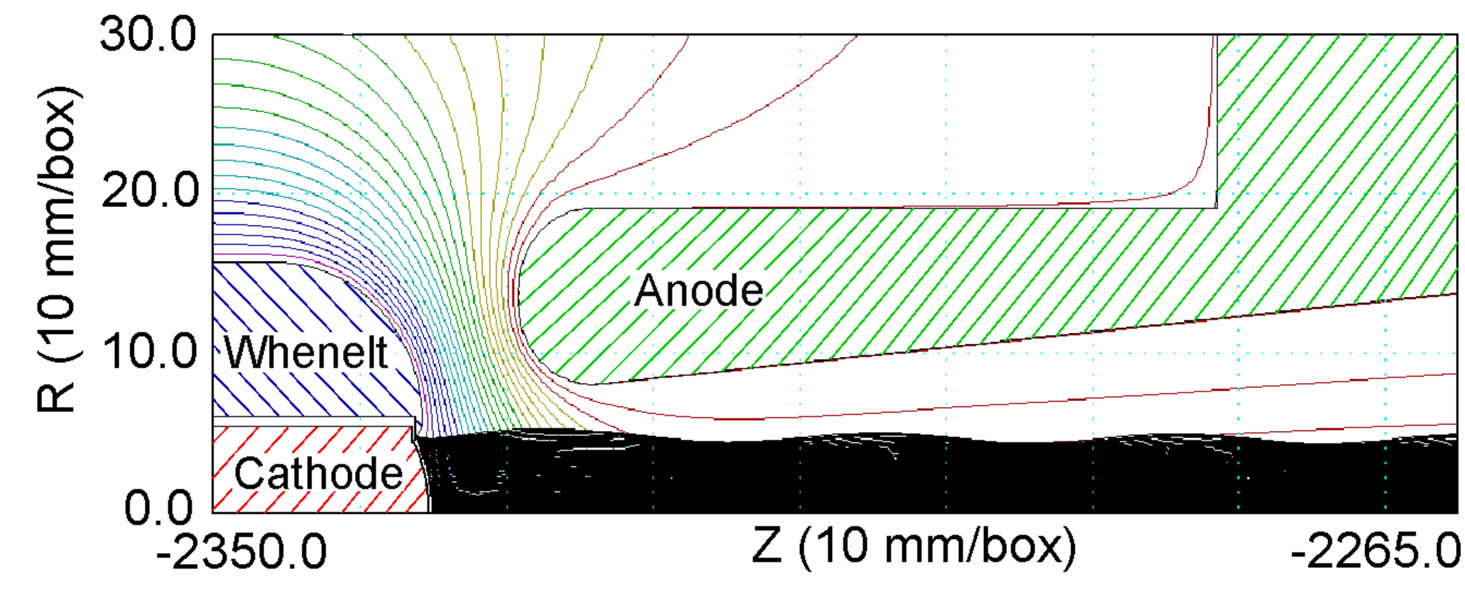
Replaceable gun unit



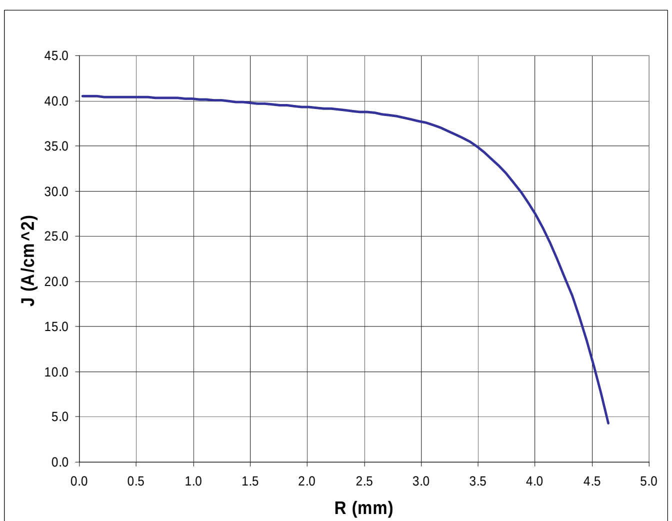
Electron gun



Simulation of the electron beam generation from the electron gun

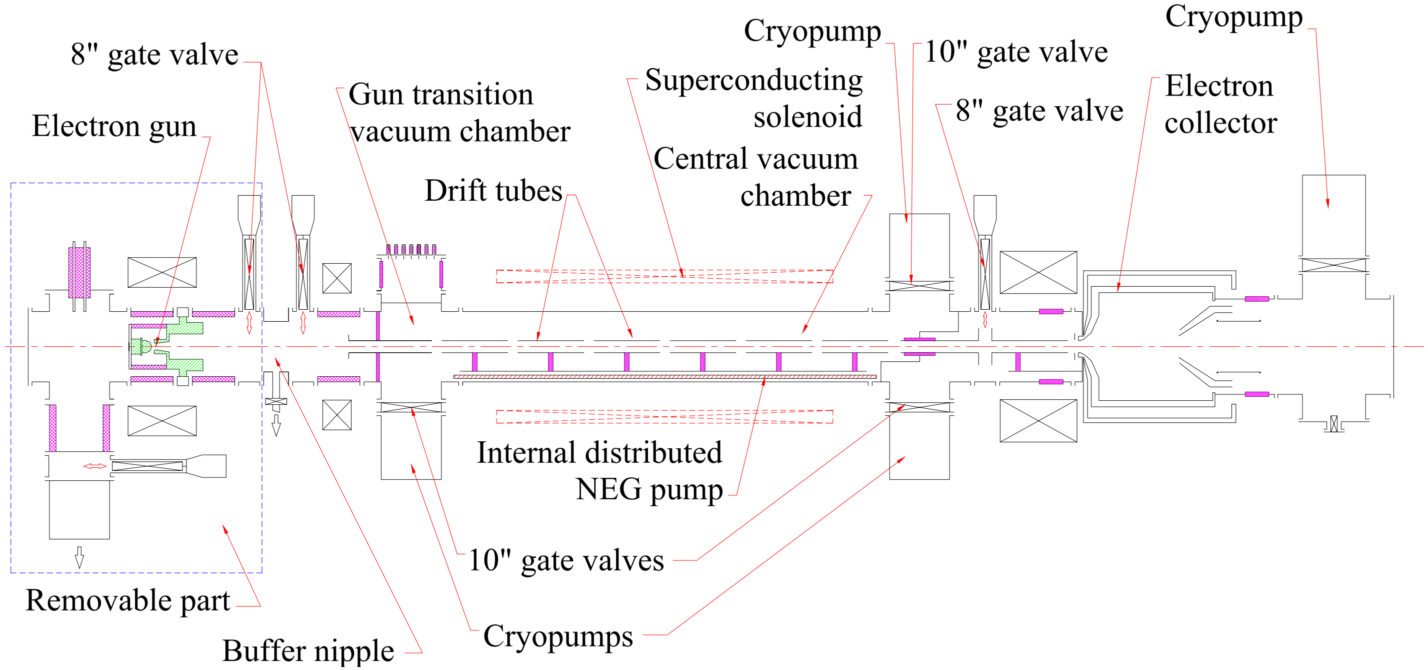


I_{el}=20 A,
U_{an}=40 kV
B_{cath}=0.18 T



Bell-shaped radial distribution of the emission current density from the cathode is produced to distribute the power load on the EC more evenly.

Vacuum



Pressure requirement in the ionization region P=(1-3)x10^{-10} Torr

Approaches (incorporated on the Test EBIS):

• Use of traditional UHV technology including preliminary vacuum firing at 900^{0}C.

• Separating central chamber from the heavily outgasing regions of electron gun and collector with low conductance paths.

Plus:

• Increase ID of the central chamber from 4” to 6” for better pumping on sides and allow for placing strips with NEG (Non-Evaporable Getters) materials inside the central chamber.

• Making the electron gun unit replaceable without breaking vacuum in the rest of EBIS.

Superconducting solenoid (SCS)

- Length of the SCS coil: 200 cm
- Magnet field: 8-6 T
  (Required to provide the same magnet compression of a 20 A electron beam as a 10 A beam, relieving power load on electron collector, providing condition for generating higher ion charge states if needed, increasing magnet field in a drift space outside the SCS)
- ID of the warm bore: 204 mm (8”)
  (vacuum conductance from the center of the ionization region, more room for HV leads)
- Supplemental helium recondenser to eliminate time consuming refilling during run.
- Investigating the possibility of making the SCS in the BNL magnet group

Superconducting Solenoid Requirements

	RHIC EBIS	EBTS
Maximum magnet field:	6-8 T	5T (tested to 5.5)
Inner diameter of the warm bore	204 mm (clearance for 8" flange)	155 mm (clear for 6")
Total length of solenoid	2000 mm	1000 mm
Homogeneity over region 1300x10mm	0.25%	0.25%
Maximum radial shift of magnet field axis over full length of the magnet (documented)	0.2 mm	0.2 mm
Maximum radial deviation of position of solenoid axis from the position of warm bore axis	0.2 mm	0.2 mm
Decay rate of magnet field in coils of solenoid, operating with current leads removed.	$1x10^{-6}$ per hour	1×10^{-5} per hour
Length of vacuum jacket	~ 2300 mm	1300 mm
Period between liquid helium refills	30 days	23 days
Period between liquid nitrogen refills	10 days	12 days

External ion sources

- Requirement: ion sources capable of producing various ions, including Au for RHIC and other ion species (gases and solids) for NSRL applications.

- LEVA: Available ion source, tested for ion injection.

- Hollow cathode ion source: studied, upgraded, ready to be tested for ion injection: I_{ion}= 15.6 μA (Cu, 14kV), RMS emittance at 14 kV is $\varepsilon=29\pi\cdot$mm·mrad).

- Liquid metal ion source: simulated, designed and is in a process of manufacturing.

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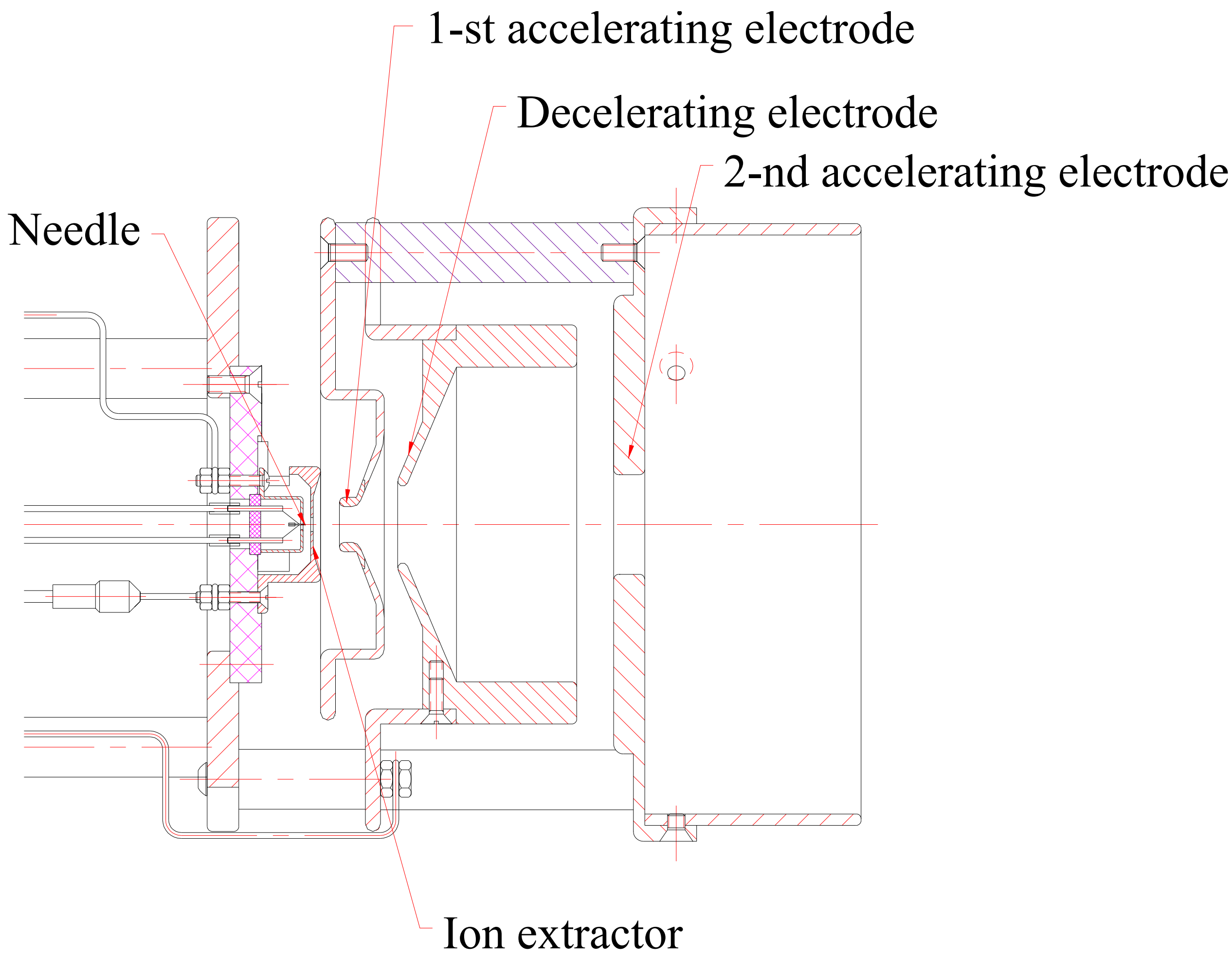
Liquid metal ion source



Conclusion:

- We have a detailed design of most components of EBIS, satisfying the RHIC requirements.

- The design provides high reliability and easy maintainability.

- The ability exists to increase the ion beam intensity up to 60% by upgrading to electron current 20 A.