An EBIS-based RHIC Preinjector

Test EBIS Results

Ed Beebe

Preinjector Group
Collider-Accelerator Department

Linac-based Preinjector - Source "requirements"

1. Intensity for 1 x 10^9 Au ions/bunch in RHIC : ~ 3 x 10^9 Au^{32+} ions/pulse from the source

2. No stripping before Booster injection : $q/m > 0.16$ (Au^{32+}, Si^{14+}, Fe^{21+})

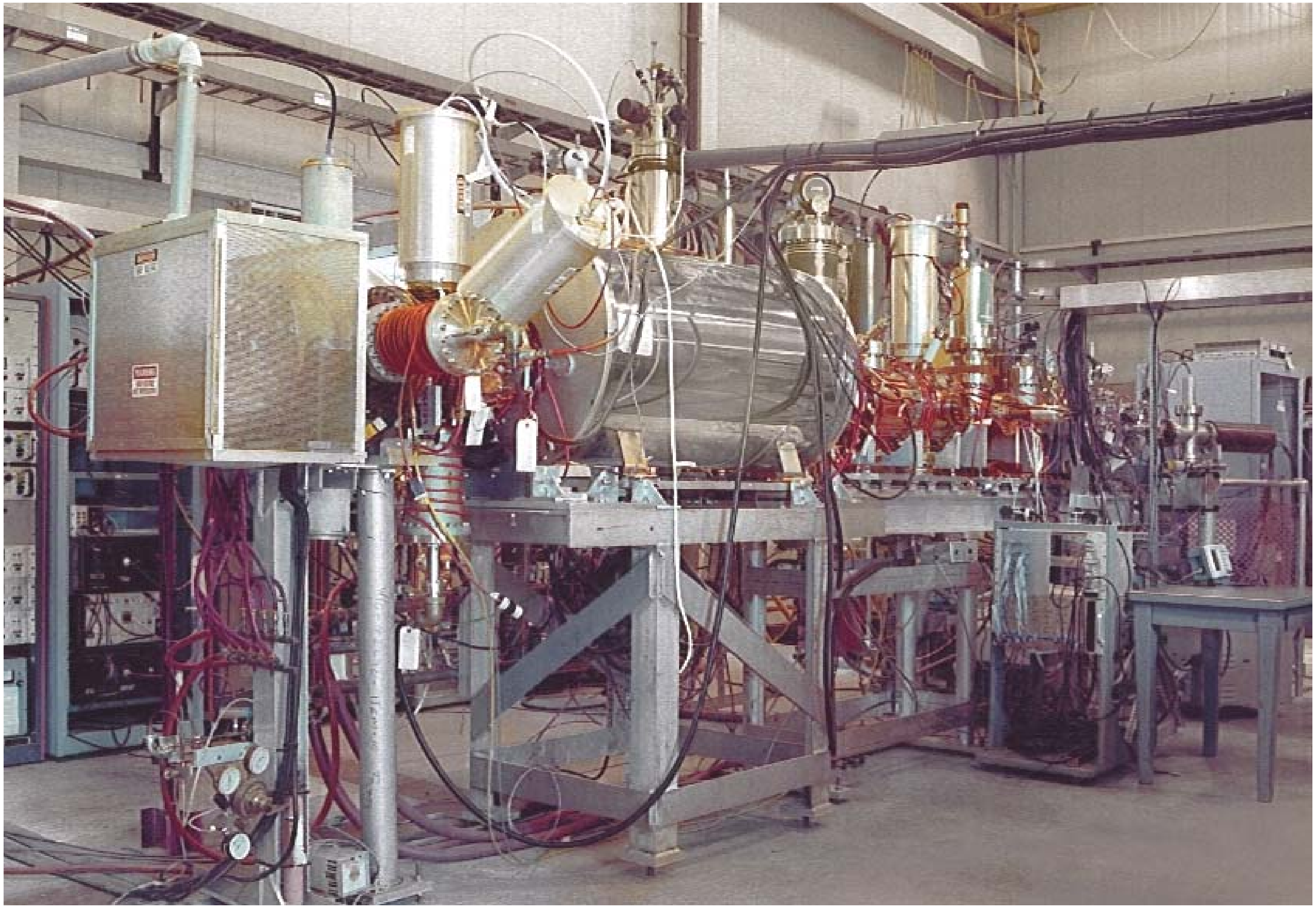
3. 1-4 turn injection into Booster : pulse width 10-40 μs

   (Note - 1 & 3 result in a Au^{32+} current of 1.6 - 0.4 mA)

4. Rep rate : ~ 5 Hz

5. Emittance : $\leq 0.35\ \pi$ mm mrad, normalized, 90% (for low loss at Booster injection)

EBIS Test Stand



EBIS Test Stand - ~1/2 length prototype, but with the full 10A electron beam

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Key hardware features of the Test EBIS

Superconducting solenoid:	
Length	**1 meter**
Maximum field	**5 Tesla**
Bore	**155 mm diameter, warm**
Helium consumption	**0.12 l/hr**
Drift tubes:	
No. of electrodes	**12**
Bore diameter	**31 mm**
Trap length	**0.7 m**
Electron gun cathode	**LaB_6, 8.3 mm diameter**
Electron collector power	**50 kW**
Vacuum	**1 x 10^{-9} to 4 x10^{-10} Torr in most regions (most sections bakeable to 200C, central DT's to 450 C)**
Diagnostics:	
Time-of-flight	**Mamyrin-type, 2 m from ion extractor**
Current meas.	**0.5 and 1.5 m from ion extractor**
Harp	**1.6 m from ion extractor**
Emittance	**1.6 m from ion extractor (under development)**

Some Principles for a Reliable, Low Maintenance EBIS

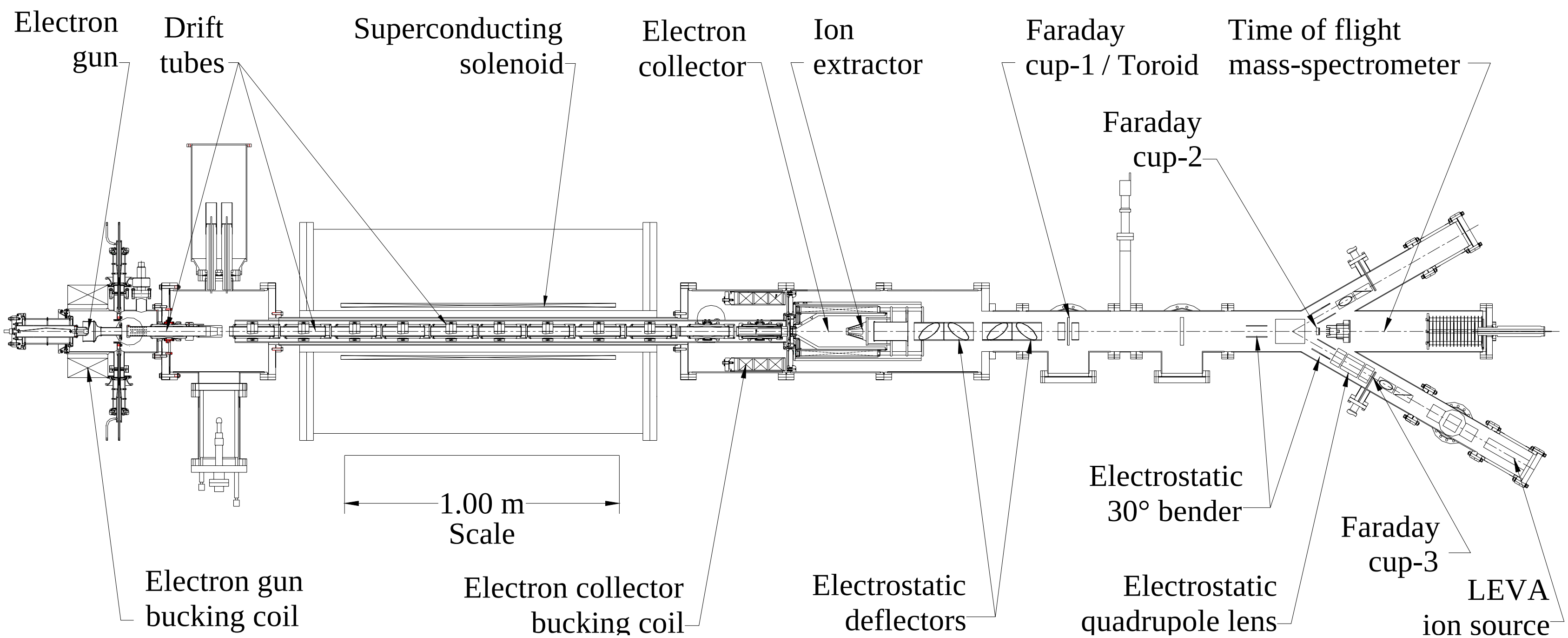
The basic principle that has been followed is to separate the functions of source components and remove as much of the action as possible from the high vacuum ionization region.

Provide beam current loss monitoring on all elements in beam path

Avoid magnetic shims and shields where possible; allow for external corrections or reshaping of magnetic geometry

External ion injection:
EBIS acts as a charge state multiplier, low contamination, high reliability

Test EBIS - showing ion injection, and extraction to TOF



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BNL Test EBIS performance represents *more than an order of magnitude improvement* over past EBIS sources. At the same time, operation has been very reproducible and stable. Some of the key features, almost all of which are unique to this EBIS, are the following:

- A novel electron gun design from Novosibirsk. It uses a convex LaB_6 cathode
- A warm bore, unshielded superconducting solenoid for the main trap region
- Careful vacuum separation of the trap region from the electron gun and electron collector regions
- Large bore (32mm) drift tubes have been used (pumping, reduced alignment precision, fast extraction, reduced RF coupling)
- The use of auxiliary (warm) solenoids & many transverse magnet coils for steering corrections
- The electron beam is pulsed to reduce the average power on the electron collector
- Very versatile controls allow one to easily apply a time dependent potential distribution to the ion trap

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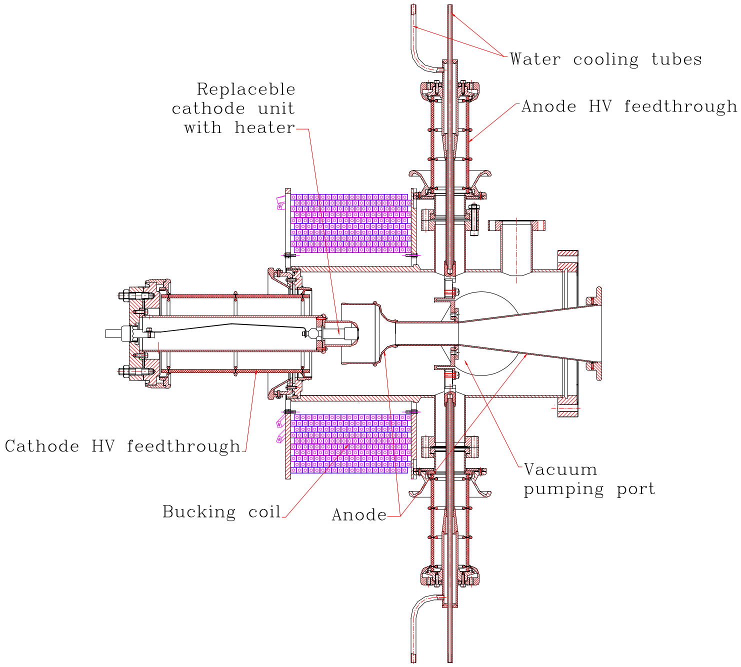
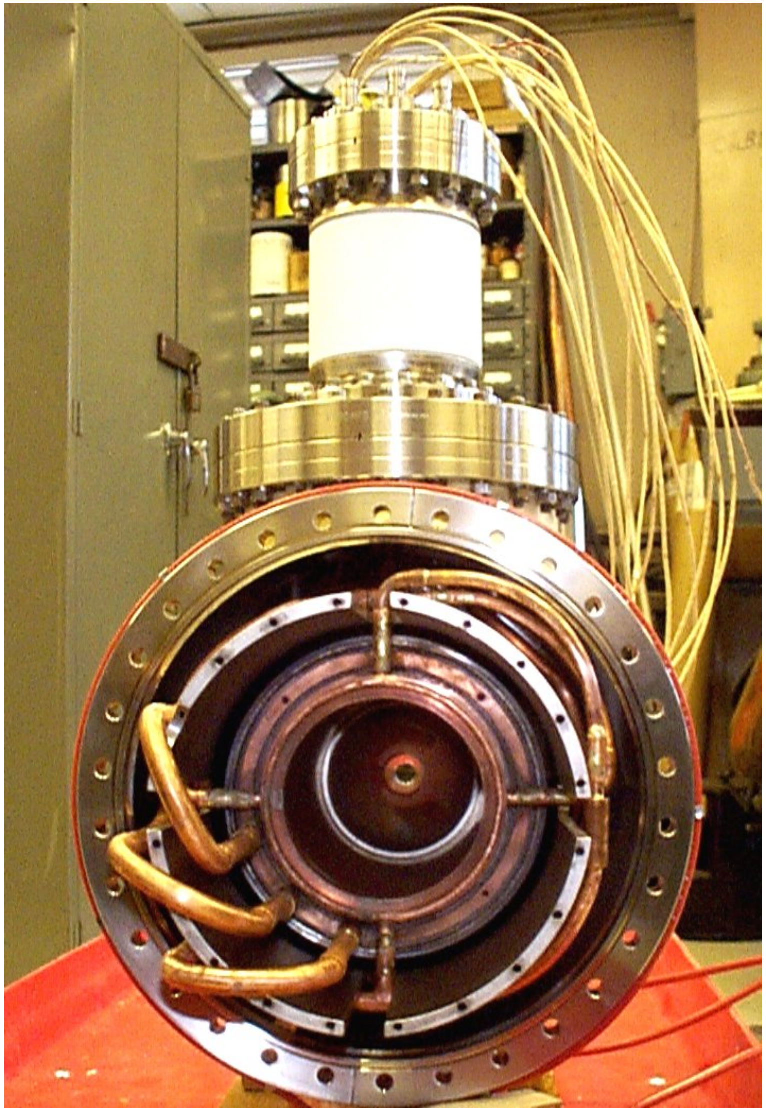
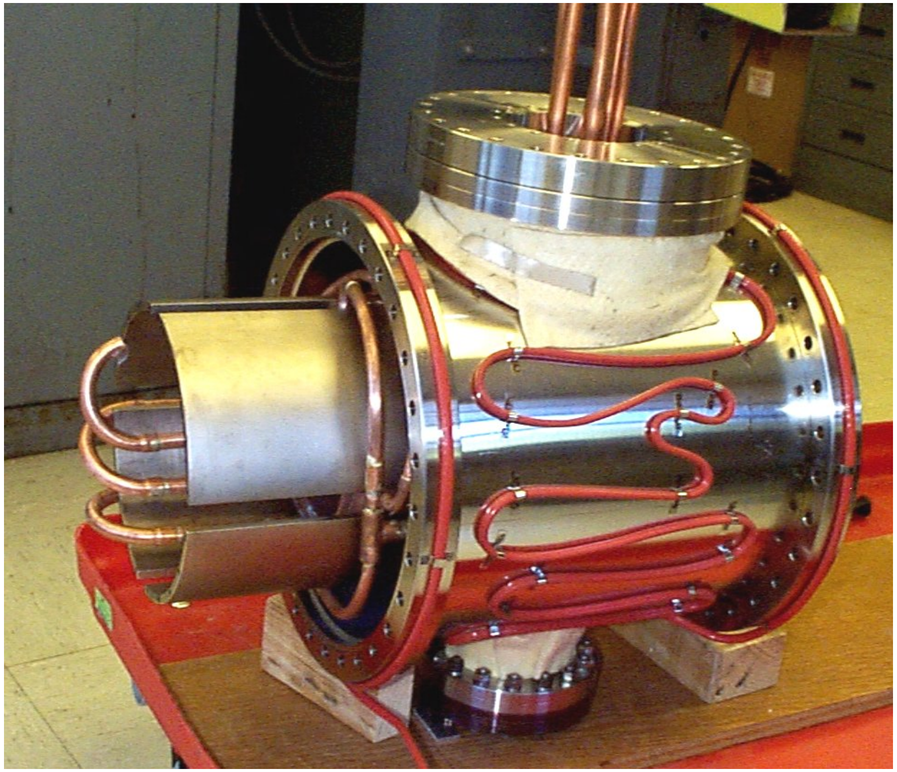
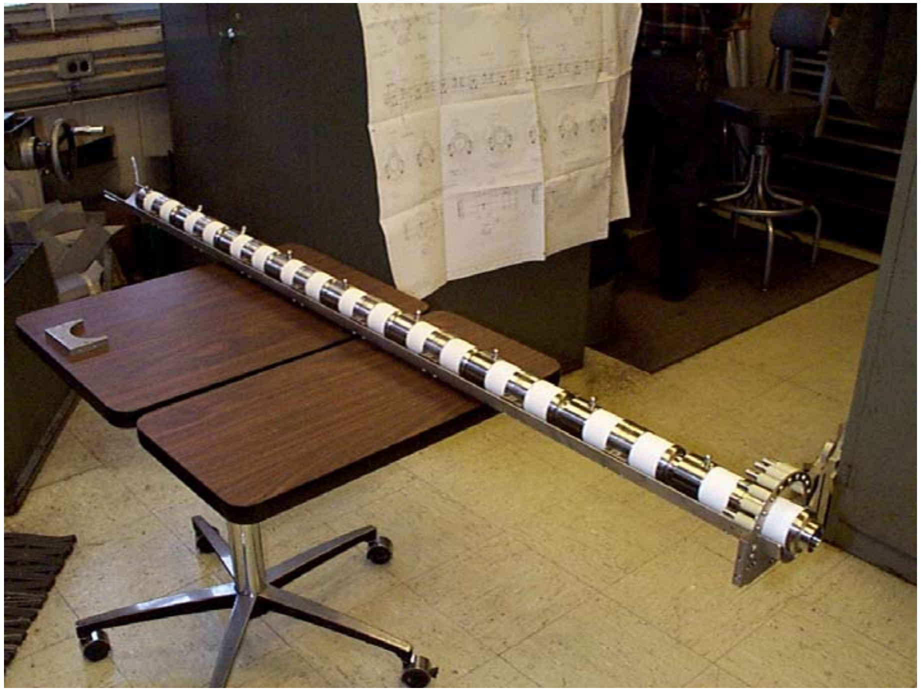
Electron Gun Cathode Assembly







Electron Collector Assembly

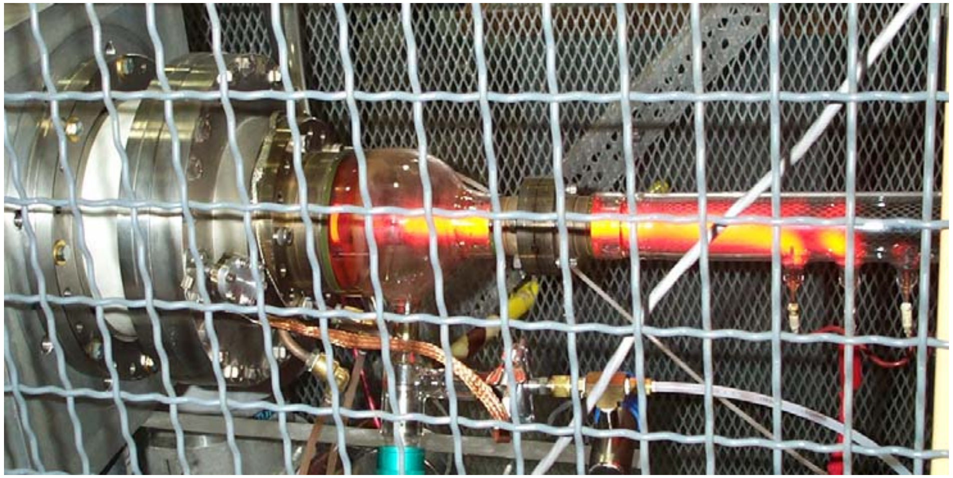


Drift tube electrode assembly

Low Energy Vacuum Arc Ion source

Low charge state Au ions are injected into the EBIS from this source

Hollow Cathode Ion Source

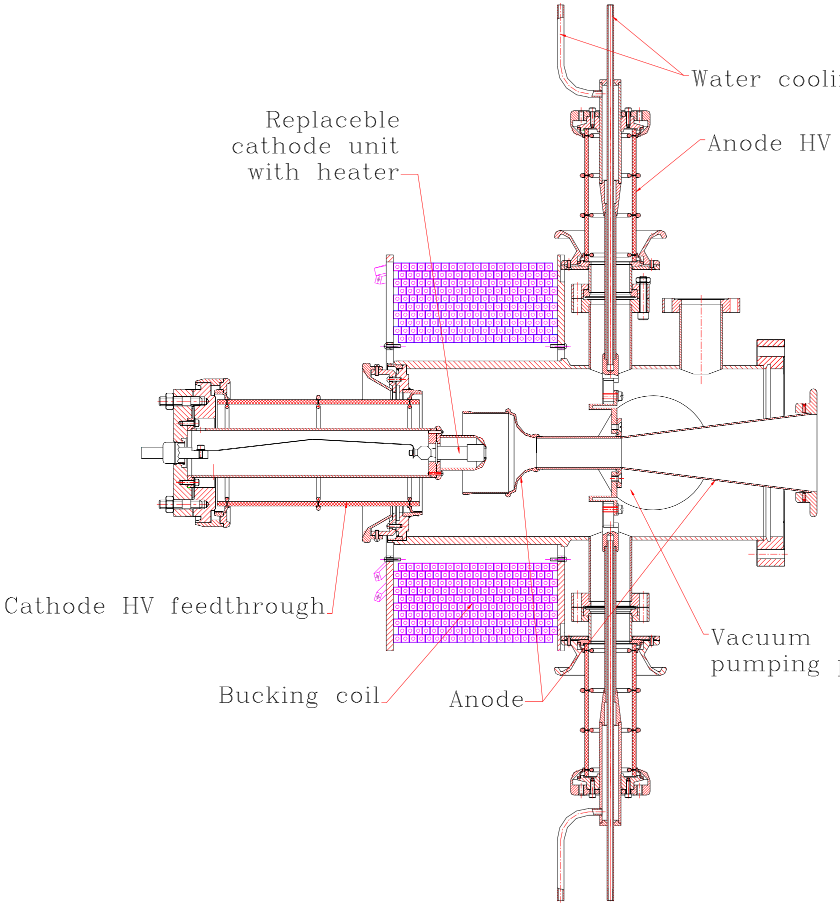


A variety of low charge state gaseous and metal ions can be produced in this ion source which has been obtained from Saclay and bench tested at BNL

Development of the 10A electron Gun

This was a key element, since previous EBIS operation was typically at 0.5A or less

- Collaboration with BINP on the development of a LaB6 – based electron gun.
- This gun has produced currents of up to 13A, has a good lifetime, and excellent beam optics.
- The unique optics for extraction and matching into the strong magnetic field allows a very stable operation over a broad range of electron beam currents.



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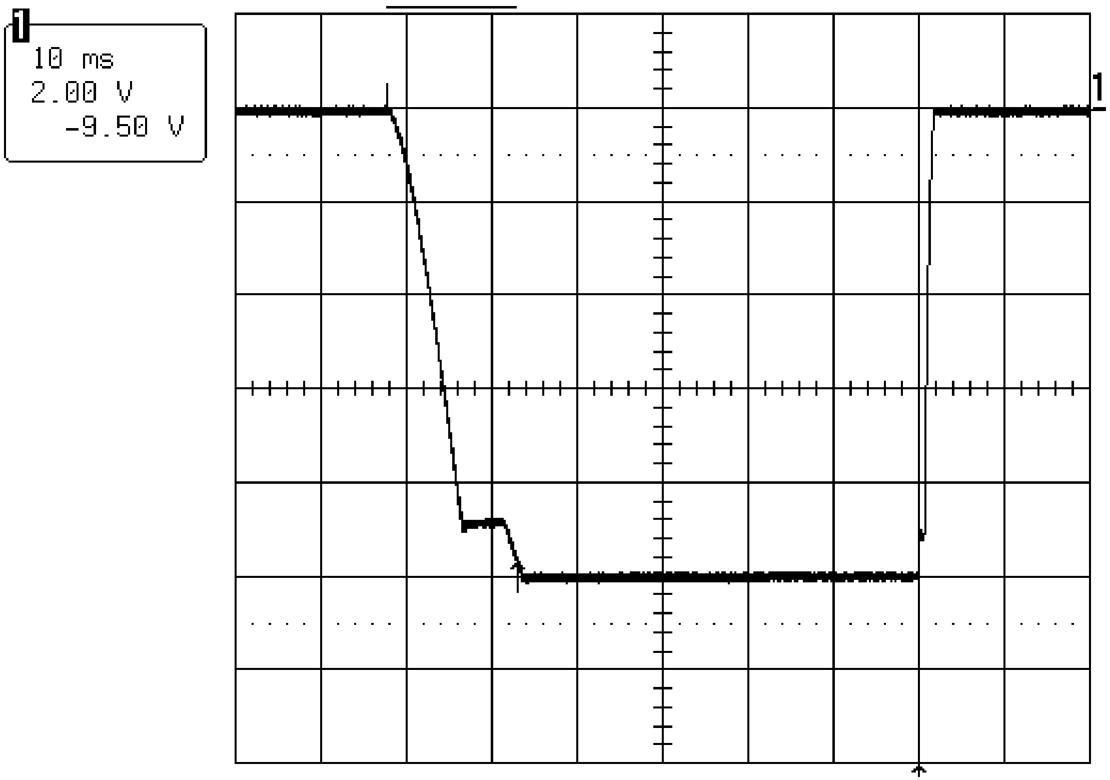
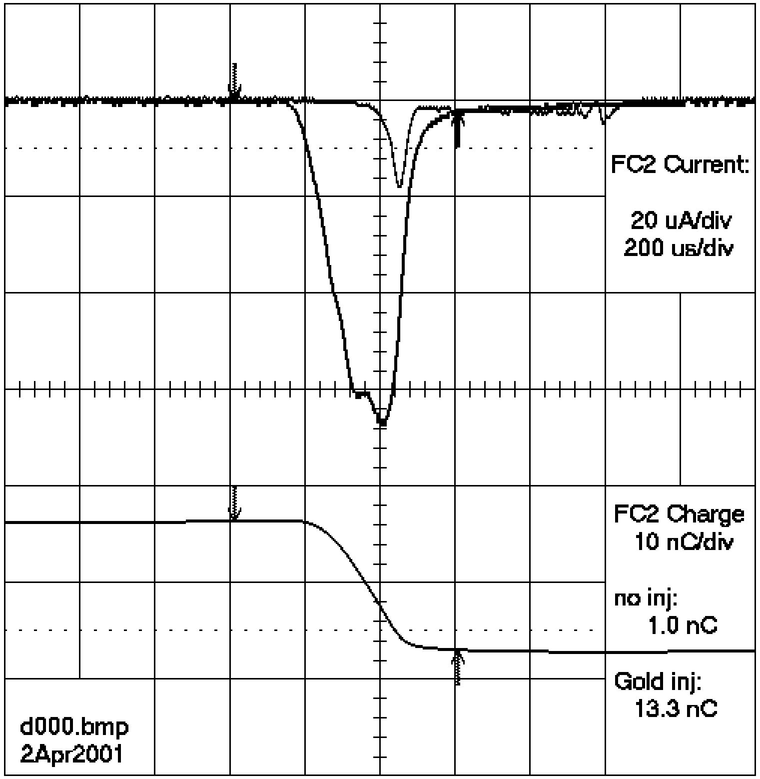
Propagation of a 10A electron beam through the BNL Test EBIS



The electron beam current faithfully responds to the ramping commands issued by the control system as illustrated by the 10A, 50ms electron beam pulse above.

Gold Injection from the LEVA auxiliary ion source

External ion injection allows various ion species to be introduced into the EBIS in a precise and rapid manner. This allows the EBIS to produce a high purity beam highly charged ions of the injected species.

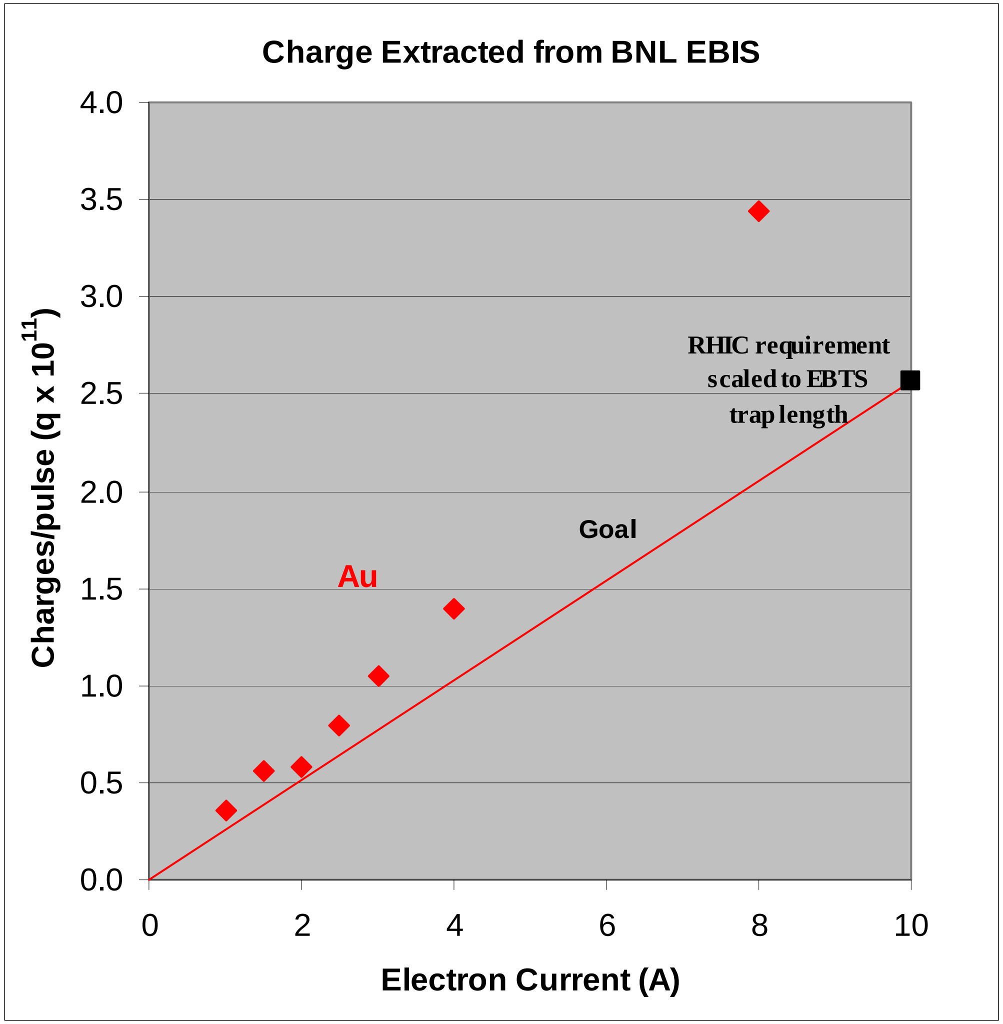


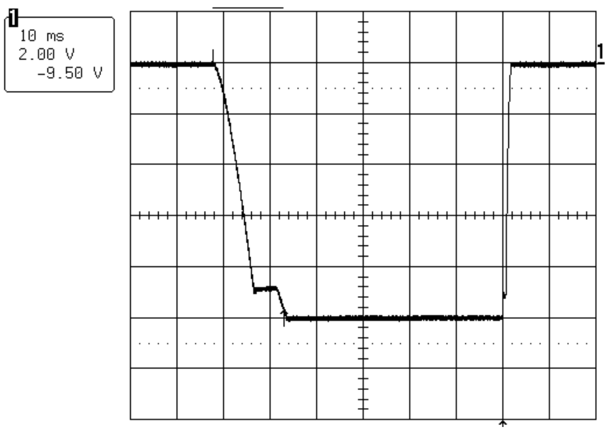
The upper traces show EBIS extracted ion current measured on a Faraday cup with and without Au injection and 200 μs capture time.

The lower trace shows the total charge extracted from EBIS 2ms after the Au injection.

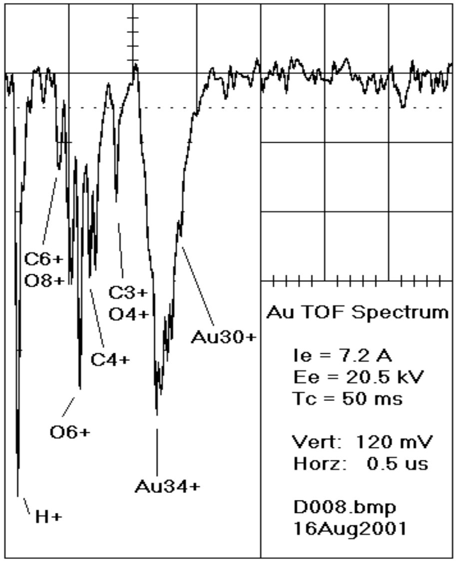
(Ie = 4A, Tinj ~ 200 μs, Tc = 2ms)

Results from Test EBIS (½ Length of RHIC EBIS)





10 A, 50 ms Electron Beam Pulse



Time-of-flight spectrum peaked at Au 34+

5.5 x 10^{11} charges/pulse are required for RHIC. By doubling the EBIS trap length to 1.5 m, we will exceed this requirement. (The ion yield has been shown to scale linearly with trap length).

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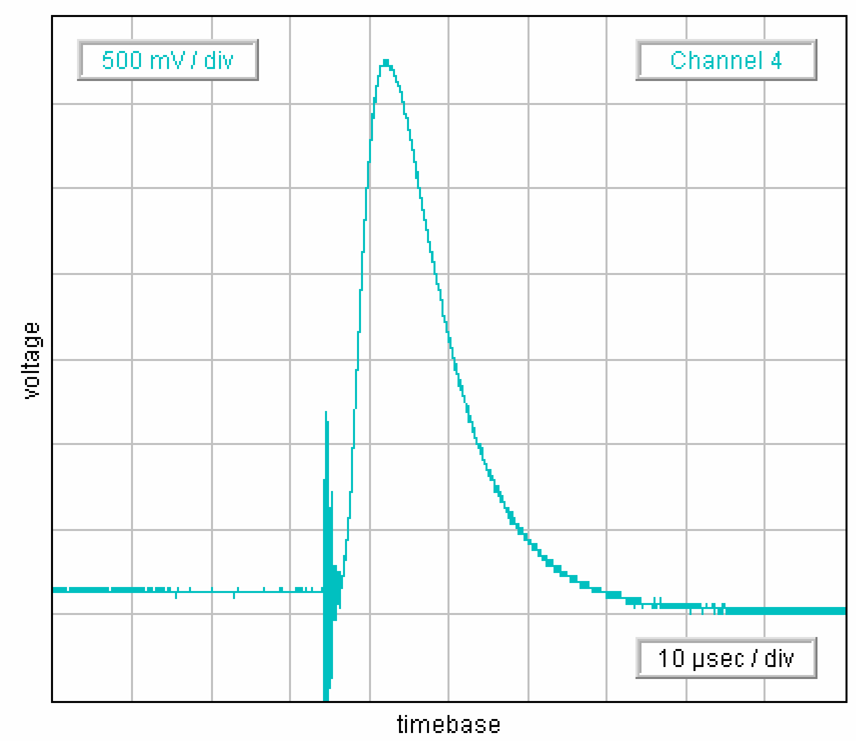
Fast Extraction of Ions from the EBTS

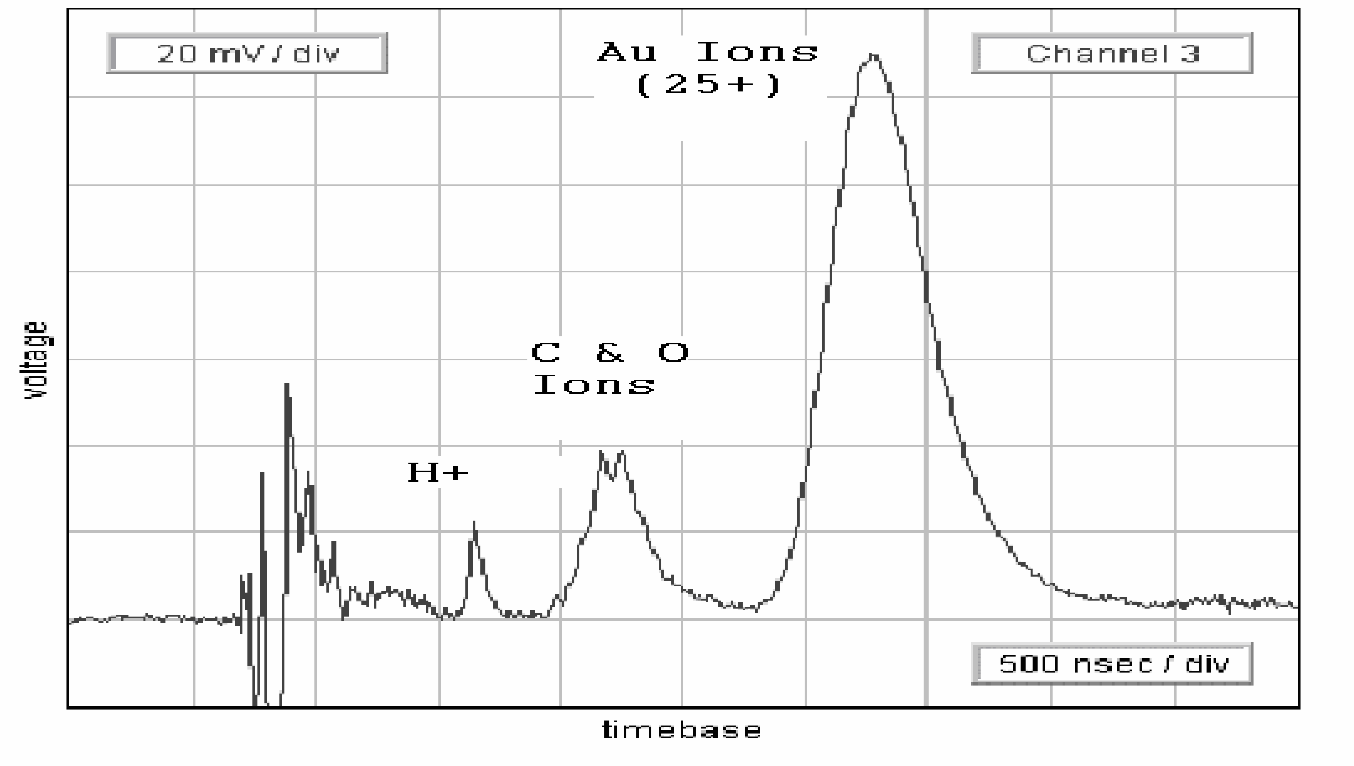
(for single turn injection into Booster)



A 3.2mA, 12µs FWHM, (40nC) ion pulse was obtained at the source exit toroid using a 6.8A e-beam and Au external ion injection, after a 15ms confinement. (85 nC required for RHIC)

Faster extraction has been obtained earlier by applying a gradient to the well floor during extraction. In the future, the pulse shape will be tailored by applying an appropriate voltage pulse to the well.

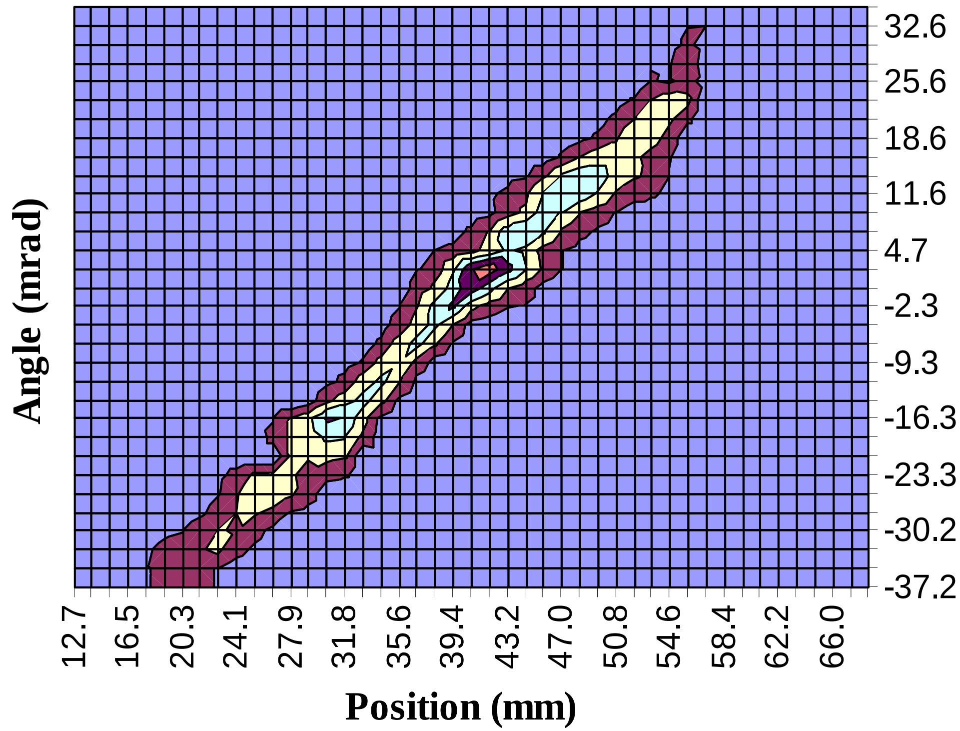
Inline Time-of-Flight



- A 100 ns sample of EBIS total extracted ion current pulse was made and measured on a Faraday Cup about 1.5 m downstream.
- The fraction of charge in Au was greater than 80%.

Ie= 7A; Tc=10 ms; Au = 83%; C&O = 15%; H = 2%

Emittance



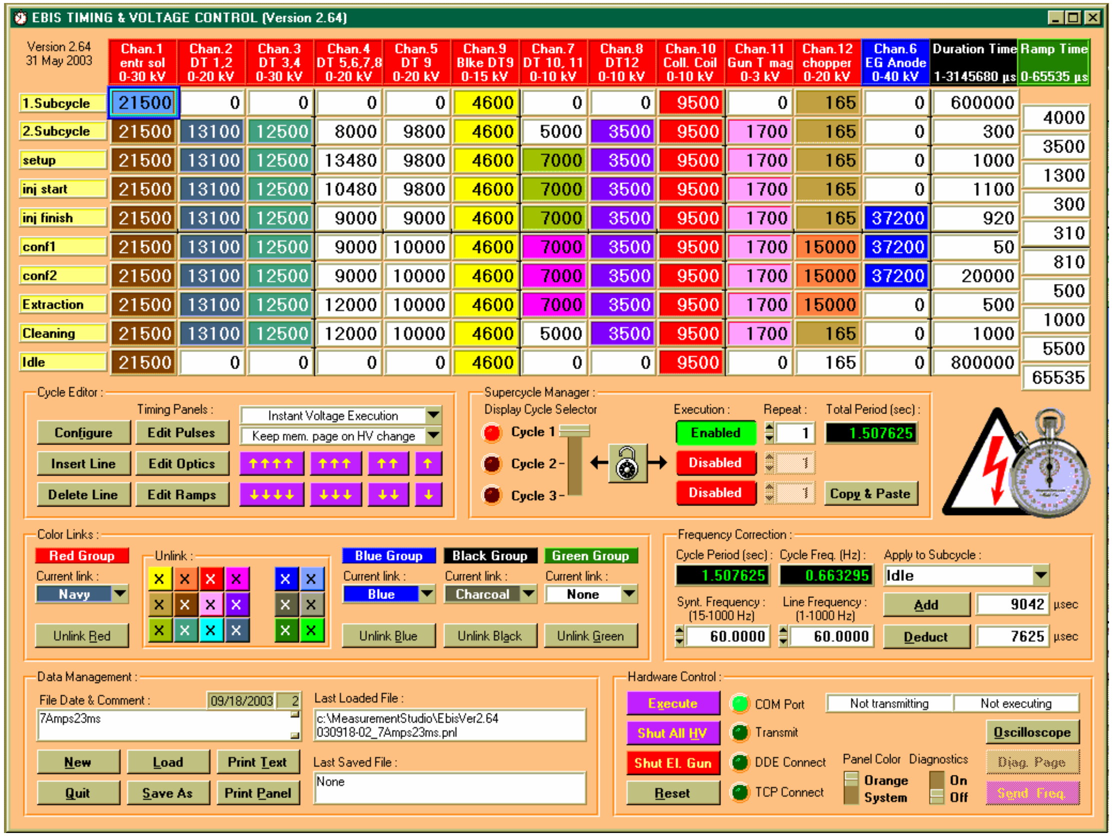
Emittance of a 1.7 mA extracted beam from EBIS, with Au injection. ε (n, rms)= 0.1 π mm mrad.

EBIS Voltage and Timing Controller

The controller coordinates the application of all time dependent voltages and timing references associated with EBIS operation with a time resolution of 1 μs, such as:

- **Time dependent ion trap HV**
- **Electron beam ramping**
- **Table Driven Beamline Optics for Ion injection from Multiple sources and EBIS ion beam extraction**

Screen for controlling EBIS electrode voltages during a cycle



- **The EBIS highly charged ion beam species and charge state can be selected on a pulse to pulse basis.**

- **16 independent beamline optics tables for fast switching between devices.**

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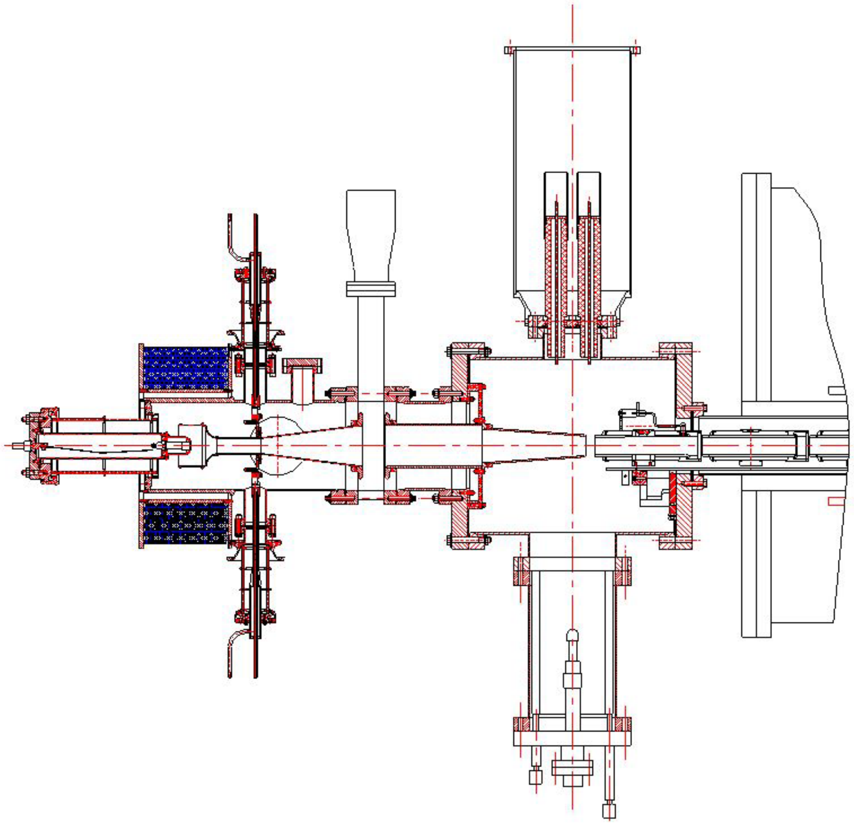
IrCe Gun, Gate Valve, and Anode Modification



- IrCe Cathodes have been delivered from BINP, Novosibirsk. Electron beams up to 10A, 100kW have been propagated with very low loss.
- Cathode replacement and electron gun upgrades without disturbing ionization volume ultra-high vacuum.
- Anode/Drift Tube geometry eliminates need for an additional auxiliary solenoid

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EBIS Status

	Achieved	RHIC
Ion	Au^{32+}	Au^{32+}
I_e	10 A	10 A
J_e	500 A/cm^2	500 A/cm^2
$t_{confinement}$	35 ms	35 ms
L_{trap}	0.7 m	1.5 m
Capacity	0.51 x 10^{12}	1.1 x 10^{12}
% extracted ions	> 75%	50%
% in desired Q	20%	20%
Extracted charge	> 55 nC	85 nC
Ions/pulse	> 1.5 10^9 (Au^{32+})	3.3 x 10^9 (Au^{32+})
Pulse width	10-20 μs	10-40 μs

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Summary

- **With EBTS, more than an order of magnitude improvement in EBIS performance has been achieved.**

- **The RHIC EBIS design will be very similar to the present EBIS operating at BNL.**

- **No significant improvement in performance is required, other than the straightforward scaling of ion output with an increase in trap length. Operation at the required duty factor will be made possible by introduction of an electron collector capable of higher average power dissipation.**

- **Beyond this, changes to the Test EBIS design, which was a device built to demonstrate feasibility, will make the RHIC EBIS an "operational" device, i.e. simpler to maintain, and more reliable due to increased engineering margins on components.**