A New Generation of EBIS: High Current Devices for Accelerators and Colliders*

E. Beebe, J. Alessi, A. Kponou, A. Pikin, K. Prelec,

BNL, Upton NY 11973, USA

*Work performed under the auspices of the U.S. Department of Energy.

BROOKHAVEN
NATIONAL LABORATORY

The demand for high intensity, highly charged ions

With the advent of heavy ion colliders, such as RHIC at BNL and LHC at CERN, the demand for high charge state ion beam intensities was raised by more than an order of magnitude compared to fixed target operation of existing accelerators.*

Previously, the focus for EBIS sources at accelerator facilities *e.g.*, Dubna, Saclay and Stockholm has been to produce very highly charged ions (charge to mass ratio q/m between 0.25 and 0.5). With those sources, the required intensity was within the bounds available with electron beam operation up to 0.5A.

In the proposed BNL acceleration scheme, more moderate charge states such as Au32+ can be used (q/m~0.16). The BNL EBIS program focus has been to increase EBIS heavy ion yields from a few nC/pulse to >85nC/pulse in a RHIC EBIS.

*H. Haseroth and K. Prelec, Physica Scripta T71, 23 (1997).

BROOKHAVEN
NATIONAL LABORATORY

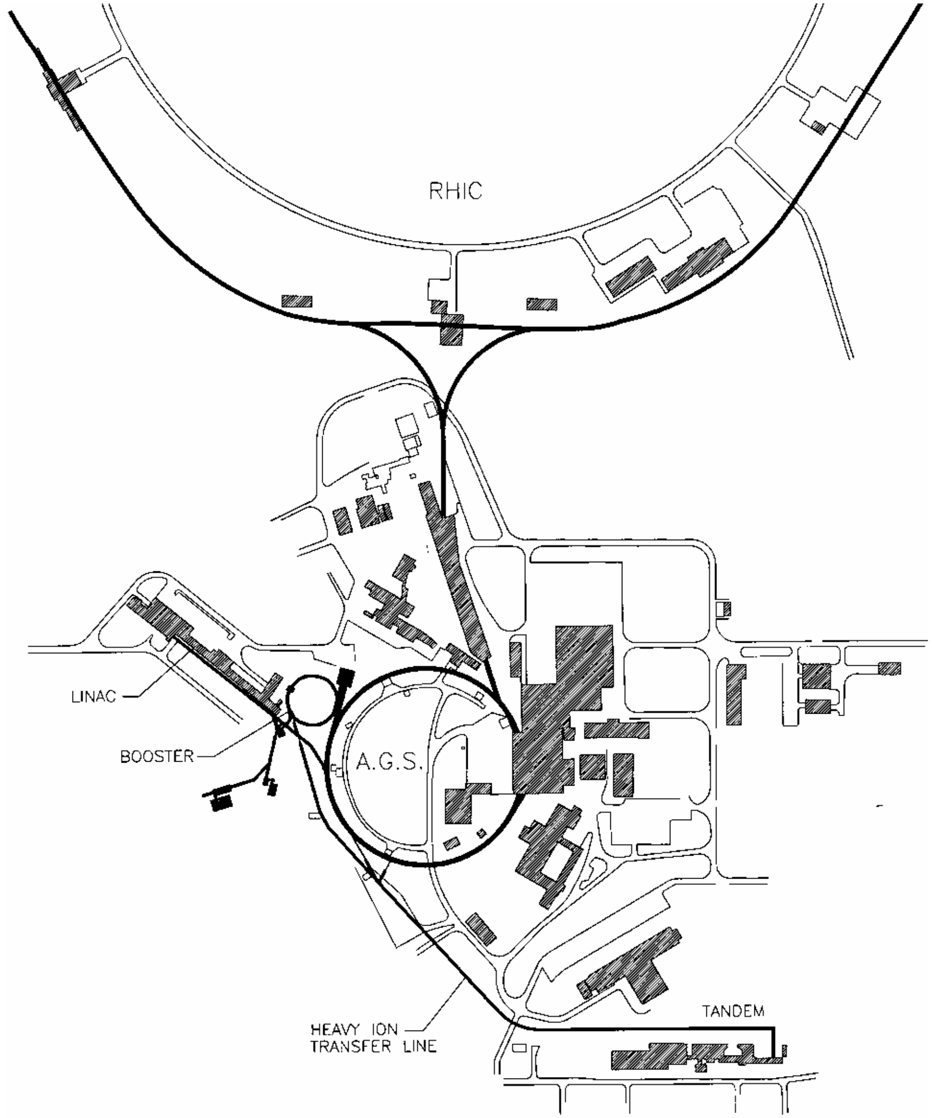
Heavy Ion Preinjector for RHIC

Tandem Van de Graaff presently used

- 860 m transport line to Booster
- Stripping foils at terminal and high energy
- Injection over > 40 turns is required
- Limitations on ion species
- Maintenance, manpower, upgrades, ….

Quite a while ago, we began to investigate alternatives.

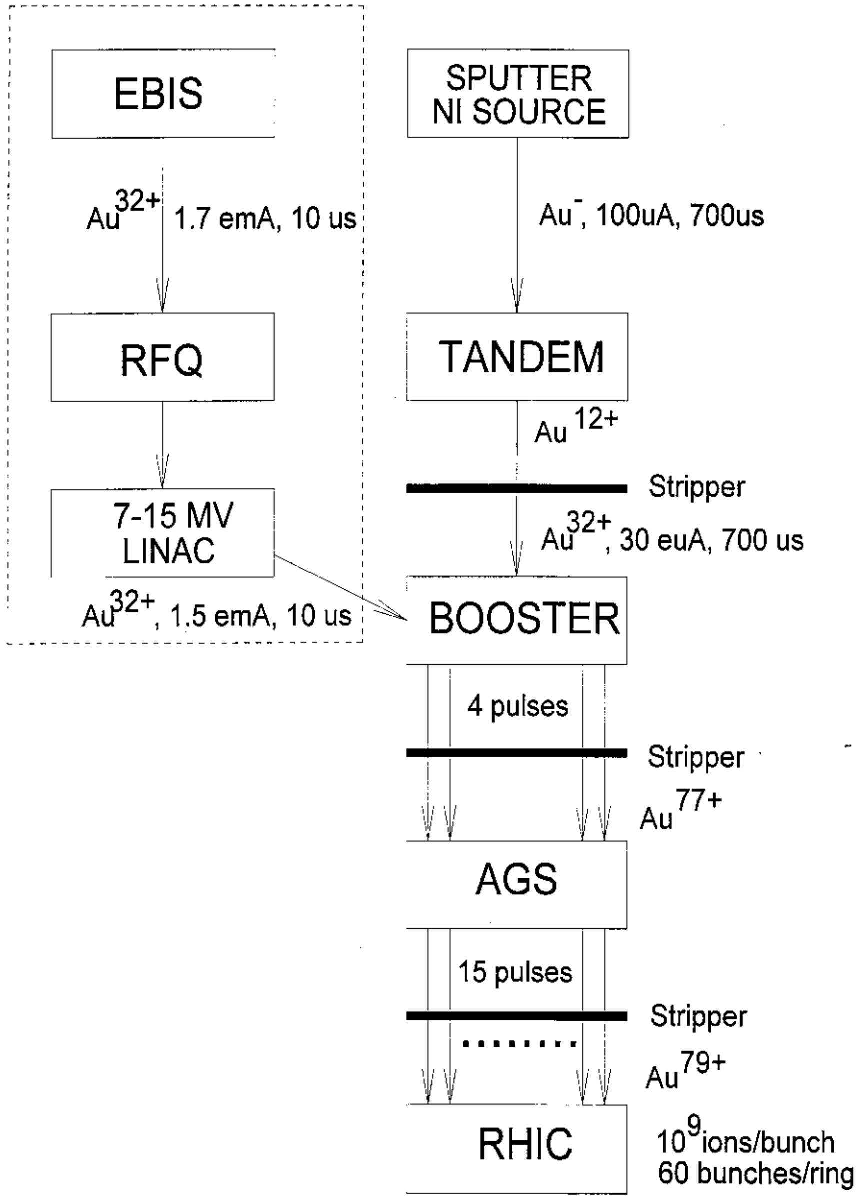
The ion source is the key component.



BROOKHAVEN
NATIONAL LABORATORY

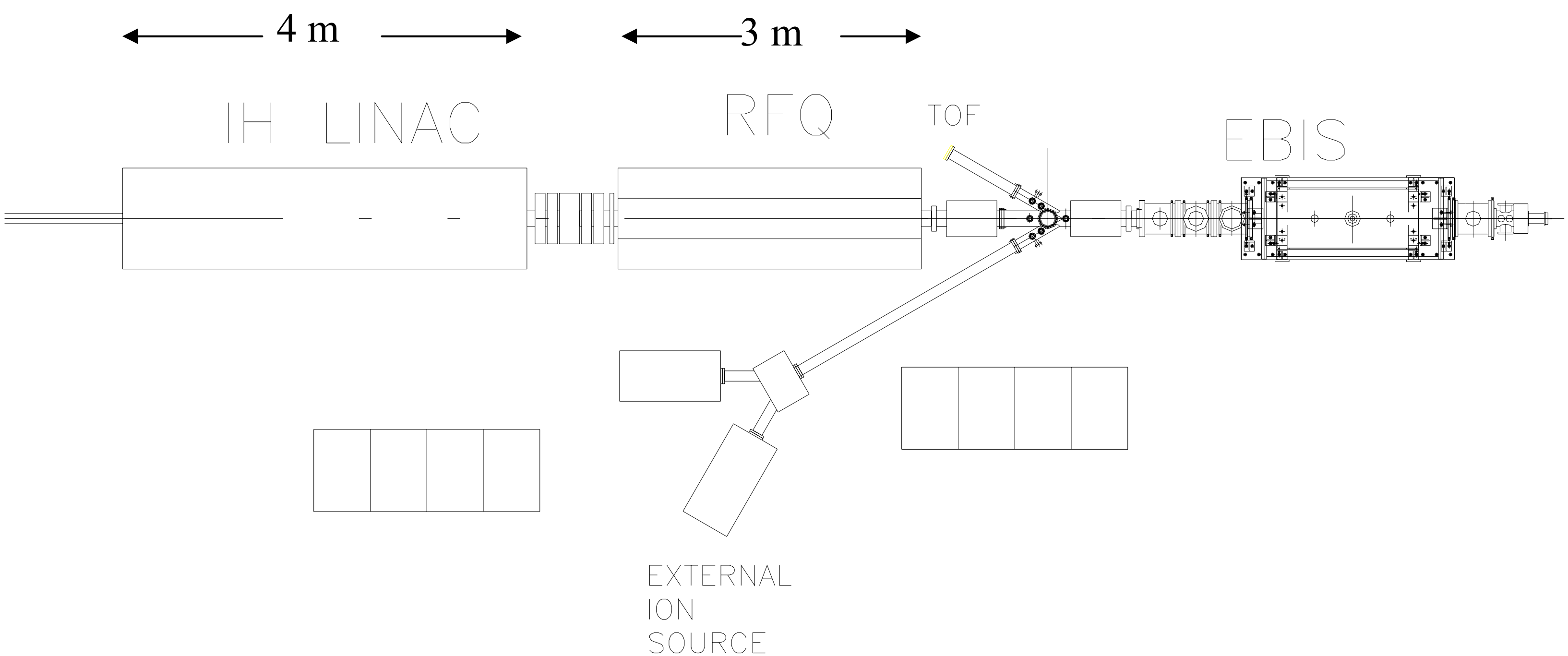
Attractive features of an EBIS

- **One has control over pulse width, extracting a fixed charge – a good match to synchrotron requirements**
- **EBIS produces a narrow charge state distribution (20% in the desired charge state), so there is less of a space charge problem in the extraction and transport of the total current**
- **One has control over the charge state produced (easy to get intermediate charge states, such as Au^{32+} or U^{45+})**
- **An EBIS can produce any type ions – from gas, metals, etc., and is easy to switch species**
- **The scaling laws are understood**
- **The source is reliable, and has excellent pulse-to-pulse stability, long life**



BROOKHAVEN NATIONAL LABORATORY

Proposed Linac –Based Rhic Preinjector



RFQ: 8.5 - 300 keV/u; 100 MHz

Linac: 0.3 - 2.0 MeV/u; 100 MHz

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

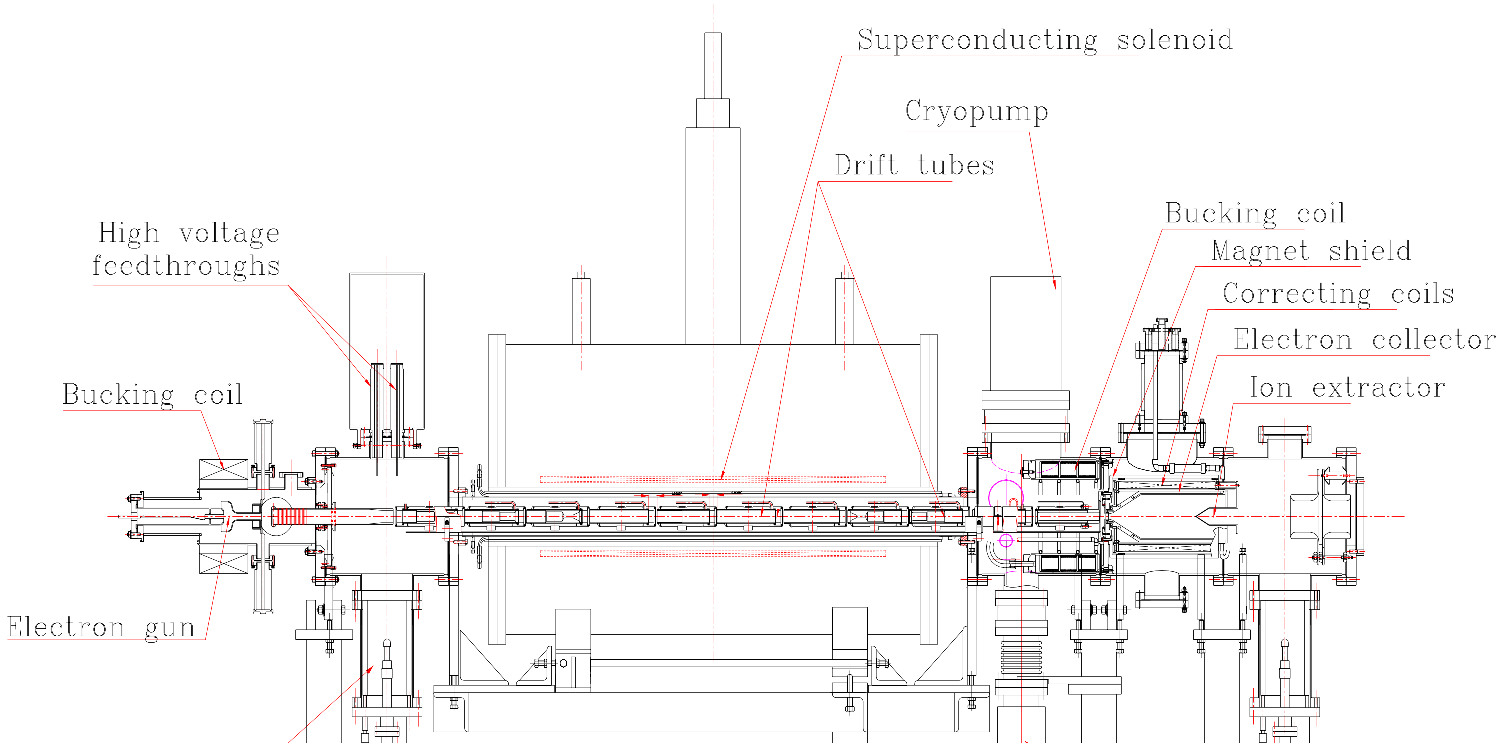
(Note - 1 & 3 result in a Au^{32+} current of 1.6 - 0.4 mA)

4. Rep rate : ~ 10 Hz
5. Emittance : ≤ 0.35 π mm mrad, normalized, 90% (for low loss at Booster injection); source emittance ~0.1 π mm mrad, normalized, 90%

BROOKHAVEN NATIONAL LABORATORY

Parameter	RHIC EBIS	EBTS
e-beam current	10 A	10 A
e-beam energy	20 keV	20 keV
e-beam density	~575 A/cm^2	~575 A/cm^2
Ion trap length	1.5 m	0.7 m
Trap capacity (charges)	1.1 x 10^{12}	5.1 x 10^{11}
Yield positive charges	5.5 x 10^{11}	2.6 x 10^{11}
Yield Au^{32+}, design value	3 x 10^9 ions/pulse	
Yield U^{45+}, design value	2 x 10^9 ions/pulse	

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



EBIS Test Stand (prototype)

Design Choices 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.

Electron Gun: (Designed in Novosibirsk: Kuznetsov, Tiunov)
A convex cathode produces a low rotational electron beam well suited for the accelerations and decelerations common in the EBIS transport system

Magnetic System:
Warm bore superconducting solenoid: pumping separate from cryosystem
Auxiliary launch and Collection solenoids: differential pumping
Transverse Steering coils for corrections

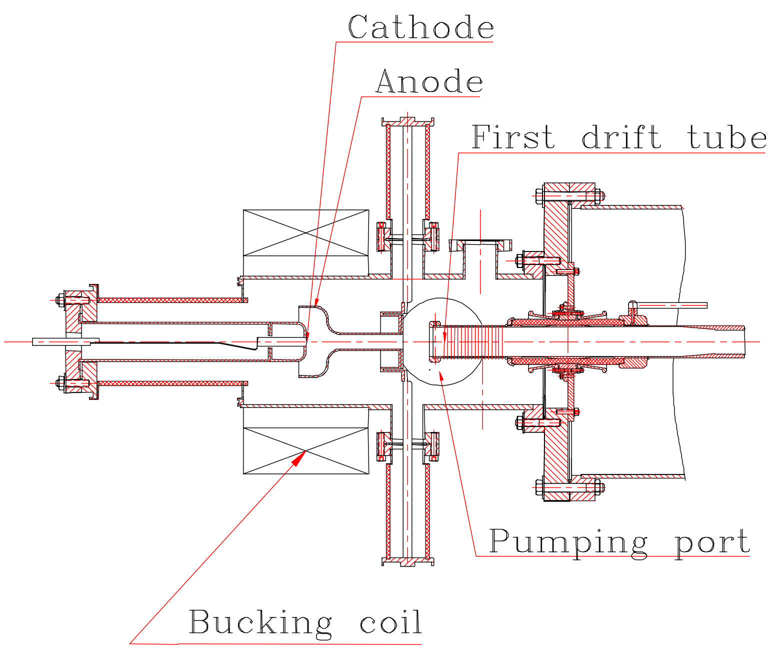
Large diameter drift tubes (32 mm diameter):
Pumping, RF coupling, fast extraction, alignment precision

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

(Poster THPRI002 Recent Results…Pikin *et. al.)*

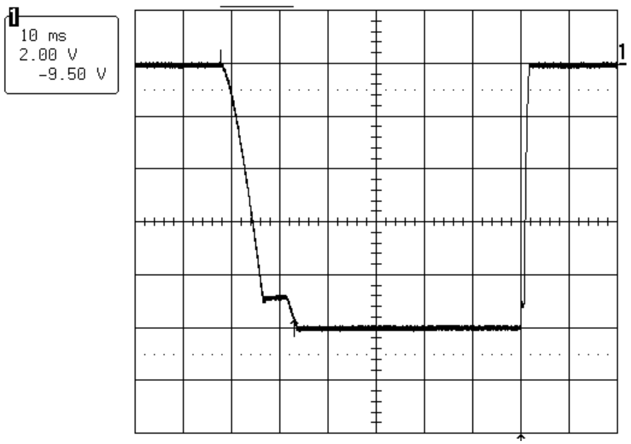
BROOKHAVEN NATIONAL LABORATORY

Development of the 10 A electron gun – Collaboration with BINP on the development of a LaB_6–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.

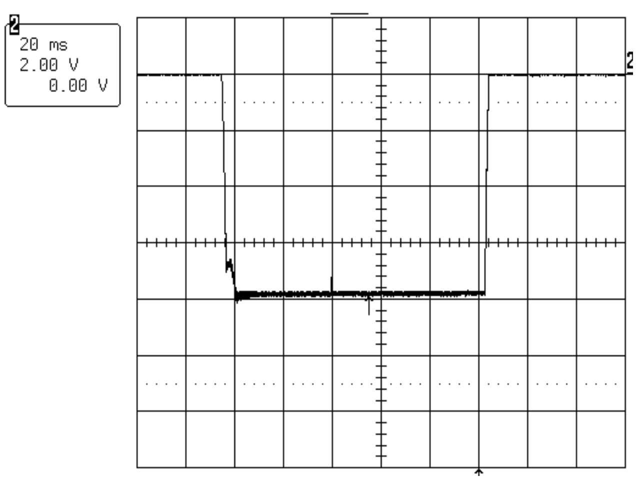


Propagation of a 10 A electron beam through the EBIS trap

10 A, 50 ms Electron Beam Pulse



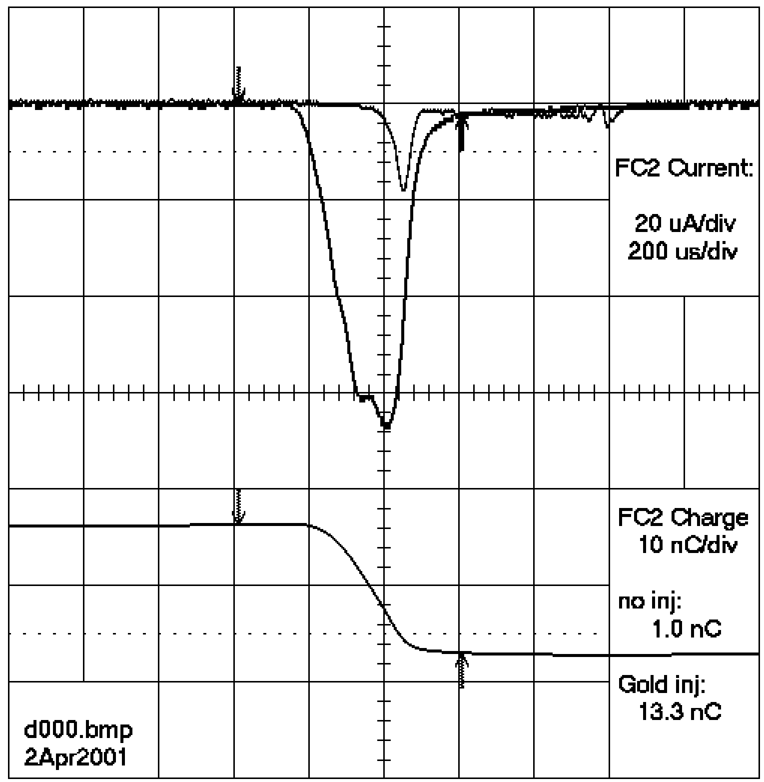
8 A, 100 ms Electron Beam Pulse



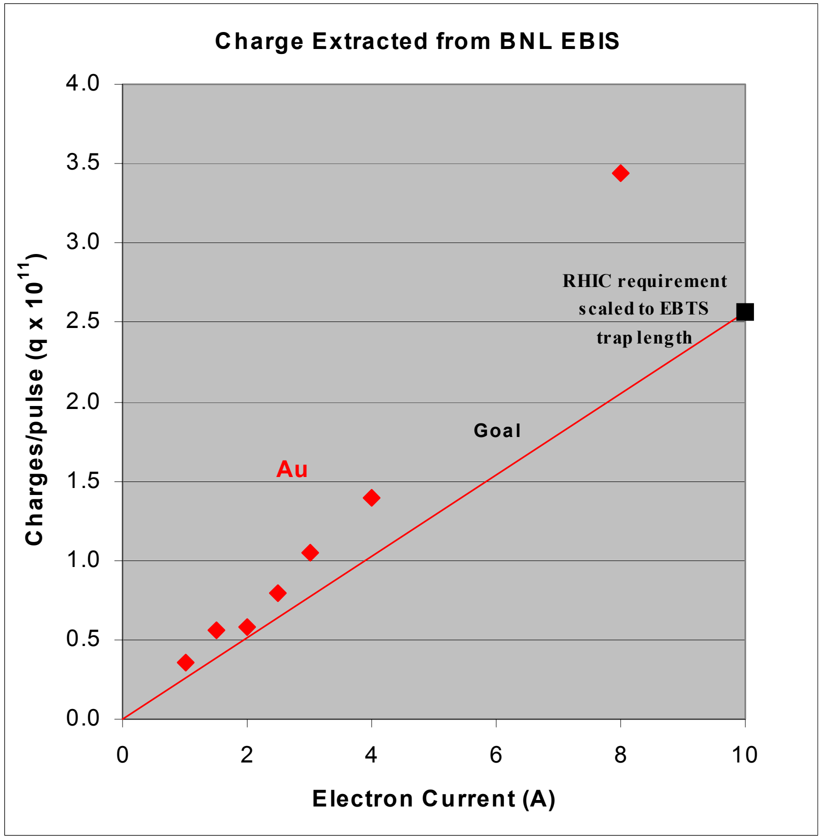
BROOKHAVEN NATIONAL LABORATORY

Gold Injection from Leva: FC2 Current and Charge Extracted from EBTS

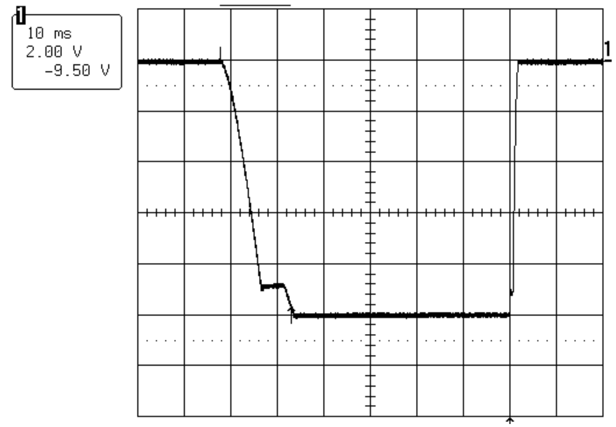
(Ie = 4A, Tinj ~ 200 μs, Tc = 2ms)



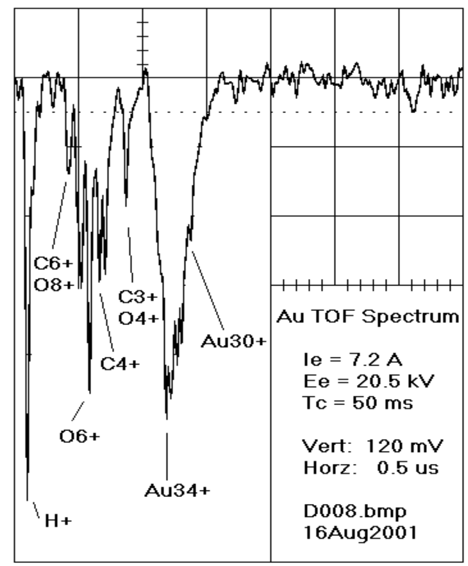
Present EBIS Results



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).



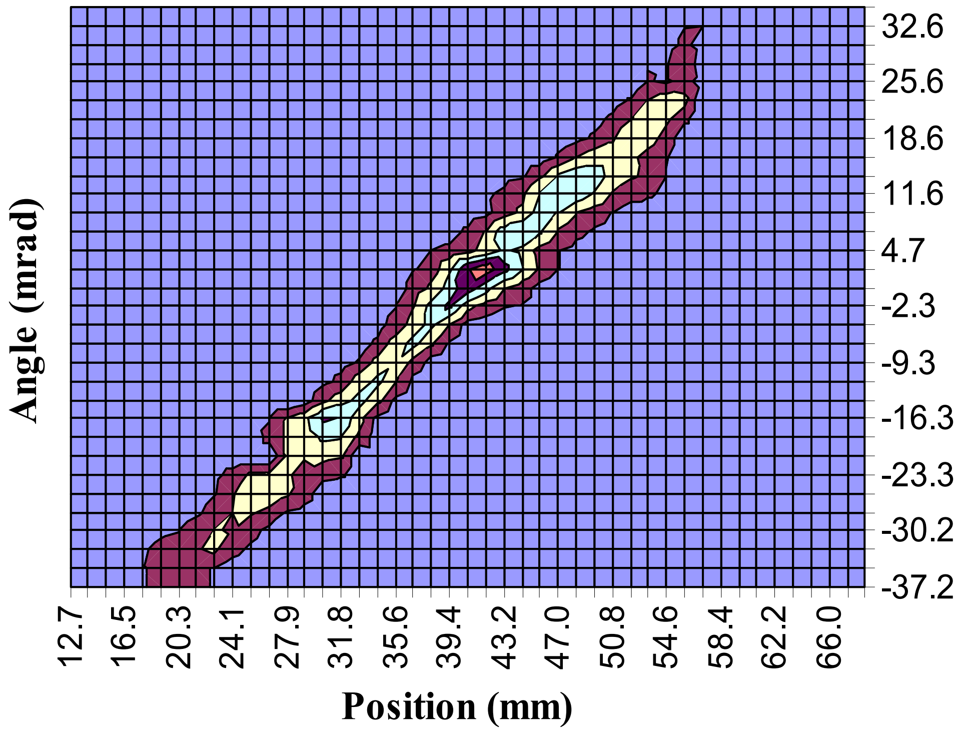
10 A, 50 ms Electron Beam Pulse



Time-of-flight spectrum peaked at Au 34+

BROOKHAVEN NATIONAL LABORATORY

Emittance



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

BROOKHAVEN NATIONAL LABORATORY

Extraction of ions from the EBIS trap

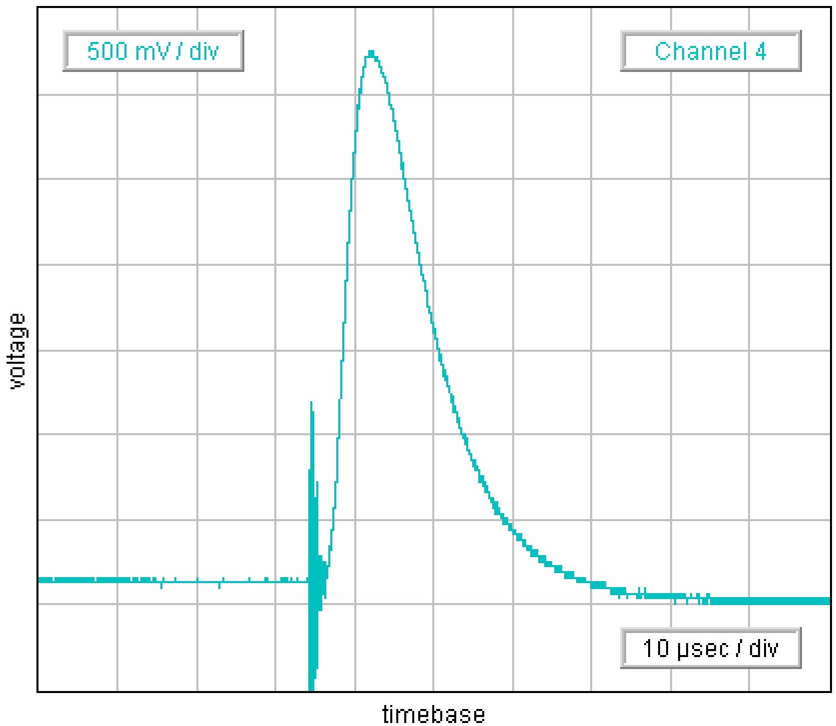
We have achieved excellent ion yields from the trap, with very high neutralization efficiencies.

Ion	I_e	Charges/pulse	Neutralization
Au	8 A	3.4×10^{11}	85%
Xenon	7 A	1.9×10^{11}	55%

5.5×10^{11} charges/pulse are required for RHIC, from a trap length of 1.5 m, and assuming operation at 10 A electron current. (The ion yield has been shown to scale linearly with trap length and electron current).

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.

Au32+ Pulsed Ion Currents

	Routine Extraction 100 µs	Extraction 40µs	Fast Extraction 10µs
EBTS 8A e-beam 0.7m trap	55 µA	138 µA	550 µA
RHIC EBIS 10A e-beam 1.5m trap	80 µA	400 µA	1600 µA

By manipulation of the EBIS trap electrodes, the EBIS extracted charge can be delivered in pulse widths necessary to meet single to multi-turn injection requirements of the synchrotron.

An LHC EBIS Option

It has been pointed out previously, that the use of Pb^{54+} directly from an EBIS may offer several advantages:[*,#]

- elimination of the first stripping stage required by a lower charge state source such as an ECR
- elimination of the need to use LEIR for ion accumulation and electron cooling
- 10 Hz linac operation would not be required
- single turn injecton into the PSB
- any ion species, with fast switching, becomes possible

*H. Haseroth and K. Prelec, Physica Scripta T71, 23 (1997)

#F. Wenander, AIP Conf. Proc 572, p.48-58.

BROOKHAVEN NATIONAL LABORATORY

EBIS Applications

	Achieved	**RHIC**	**LHC**
Ion	Au^{32+}	Au^{32+}	Pb^{54+}
I_e	10 A	10 A (15)	20 A
J_e	500 A/cm^2	500 A/cm^2	3000 A/cm^2
$t_{confinement}$	35 ms	35 ms	150 ms
L_{trap}	0.7 m	1.5 m	2.0 m
Capacity	0.51 x 10^{12}	1.1 x 10^{12}	2.4 x 10^{12}
% extracted ions	> 75%	50%	20%
% in desired Q	20%	20%	20%
Extracted charge	> 55 nC	85 nC	77 nC
Ions/pulse	> 10^9 (Au^{32+})	3.3 x 10^9 (Au^{32+})	1.8 x 10^9 (Pb^{54+})
Pulse width	10-20 μs	10-40 μs	5-10 μs

BROOKHAVEN
NATIONAL LABORATORY

Summary

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

> **10 A electron beam. (>10 improvement over previous EBISs).**
>
> **>55 nC pulses of ions extracted from the EBIS trap (less than a factor of 2 is needed for RHIC requirement, at less < 50% of the final trap design length.**
>
> **Au32+ will be produced in only ~30ms. (original design was for 100ms. Less average power on electron collector).**

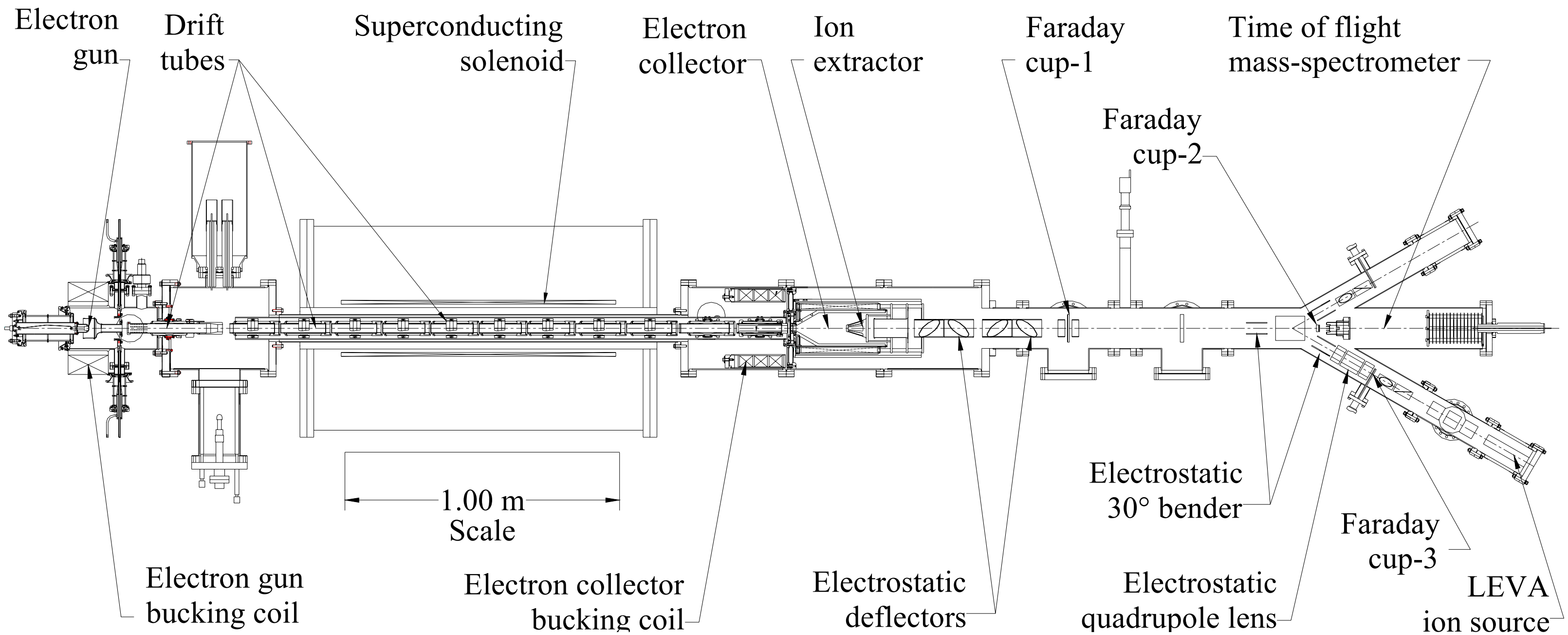
More modest increases in well understood parameters are needed to meet RHIC and LHC requirements.

The EBIS scaling has worked as expected. The design parameters for the RHIC EBIS are still the same as proposed more than 8 years ago.

A Linac-based preinjector will offer significant advantages in meeting long-term requirements for performance and reliability for the RHIC program.

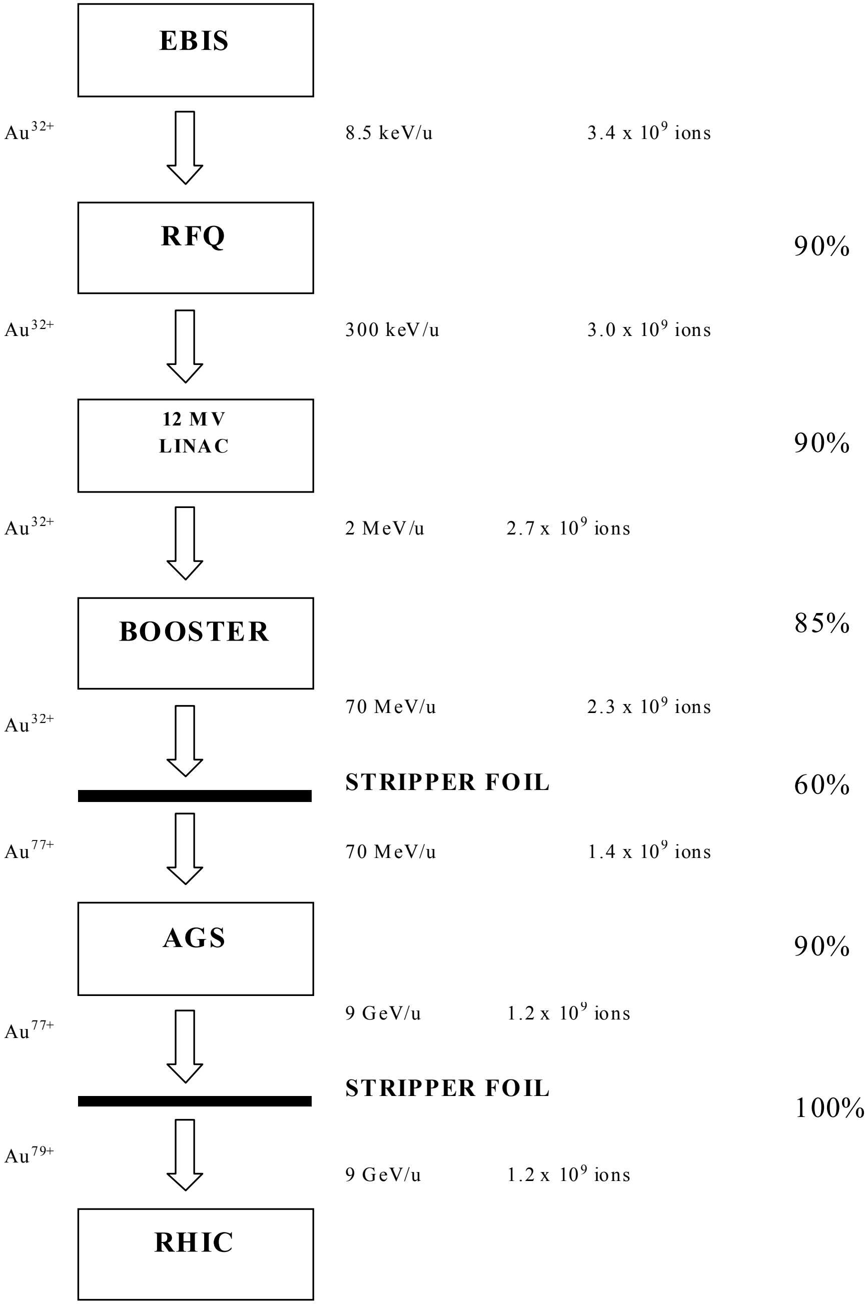
Appendix (extra slides)

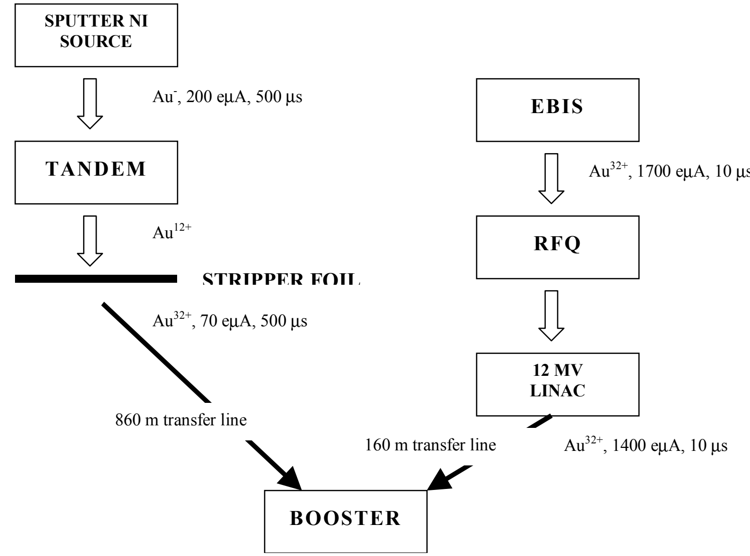
EBTS - showing ion injection, and extraction to TOF



BROOKHAVEN NATIONAL LABORATORY

EBTS and beamline schematic





EBIS inj scheme with tandem comparison

BROOKHAVEN
NATIONAL LABORATORY