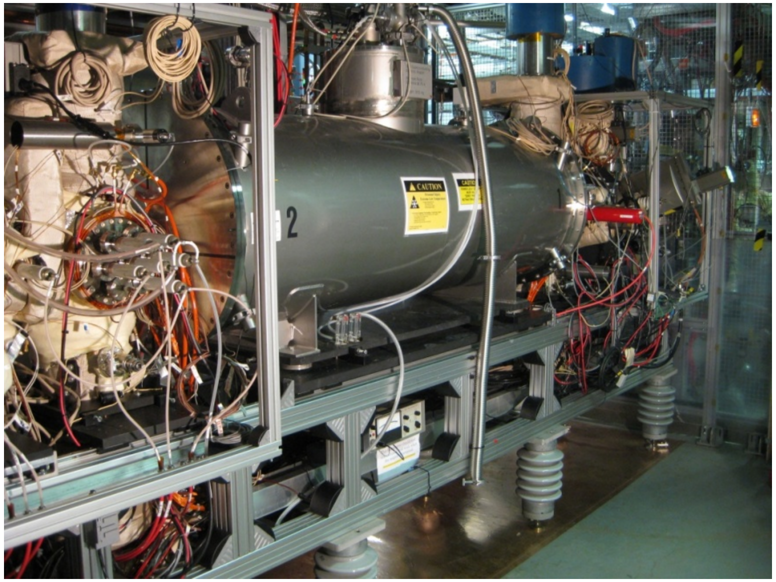
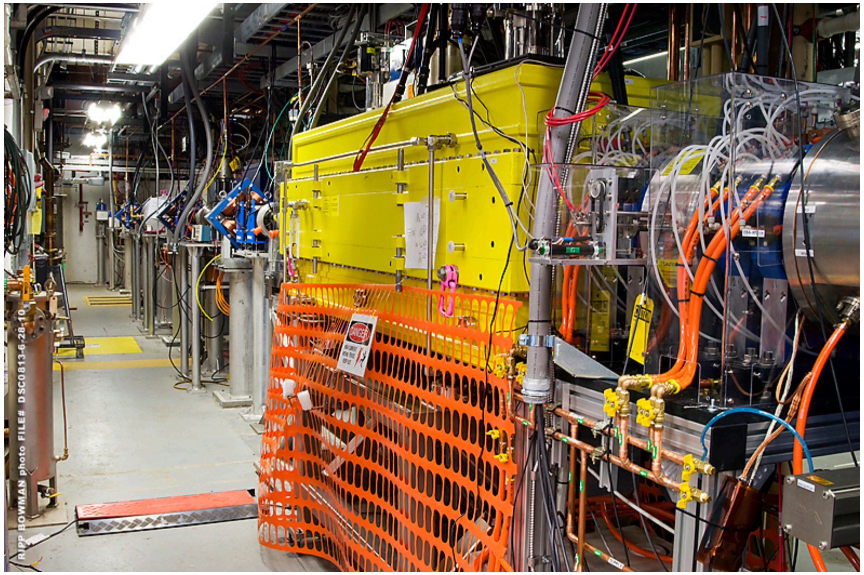
Status of EBIS

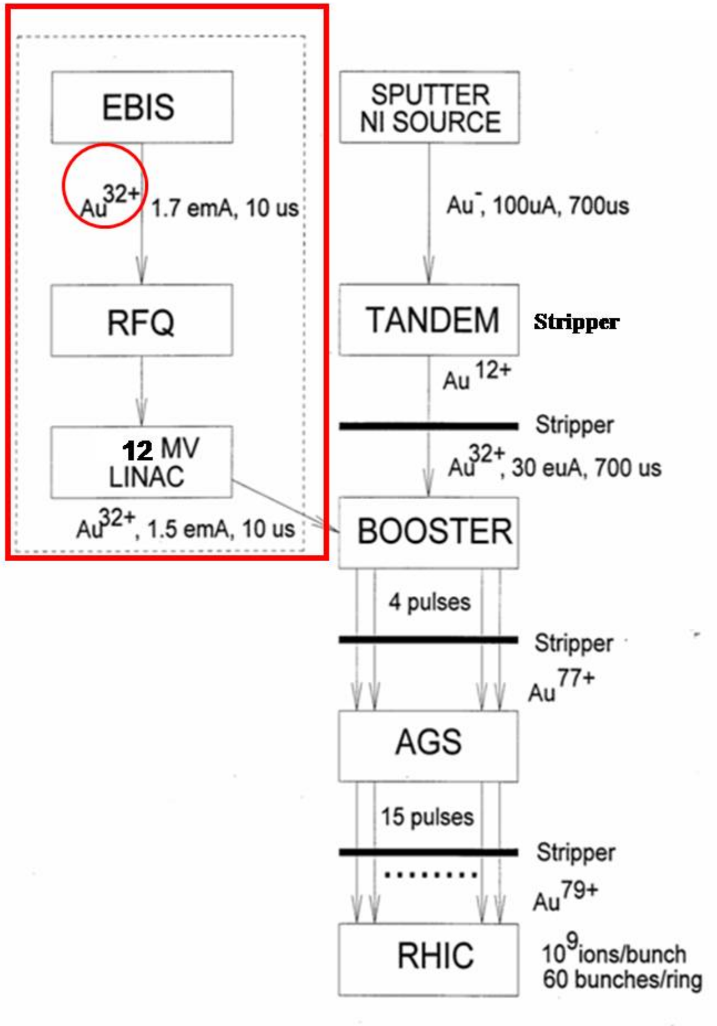
J. Alessi

- Overview
- Performance; operation for NSRL
- Plan for reaching full intensity for RHIC
  - (EBIS will be used for U-U or Au-Cu in Spring, 2012 run)
- Summary

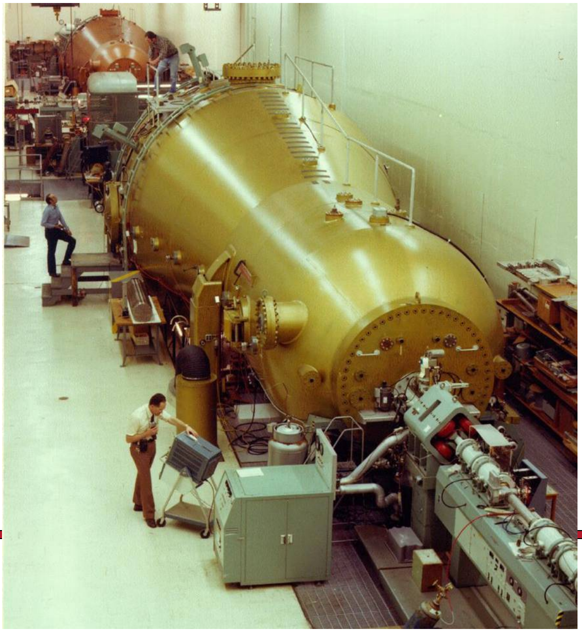




EBIS-based preinjector is the replacement for Tandem



Ions	**He – U**
Q / m	**≥1/6**
Current	**> 1.5 emA**
Pulse length	**10–40ms (few-turn injection)**
Rep rate	**5 Hz**
EBIS output energy	**17 keV/u**
RFQ output energy	**300 keV/u**
Linac output energy	**2 MeV/u**
Time to switch species	**1 second**



Goal was to match the Tandem intensity

Motivation

- Increased flexibility to handle the simultaneous needs of RHIC and NASA (fast switching between species)

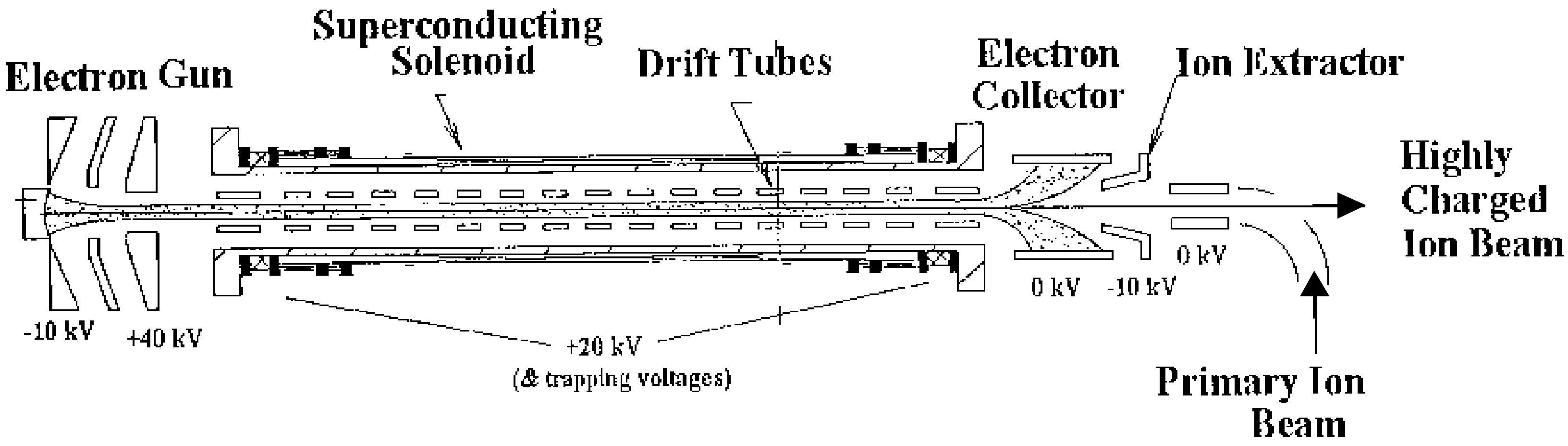
- Capability to provide ions not presently available, such as noble gas ions (for NASA), uranium (RHIC).

- Simpler technology, robust, more modern

- Elimination of two stripping stages and an 860 m long transport line, leading to improved performance (stability, easier tuning).

Future: using EBIS as an ionizer for polarized He-3 looks very feasible (collaboration with MIT)

Electron Beam Ion Source (EBIS)

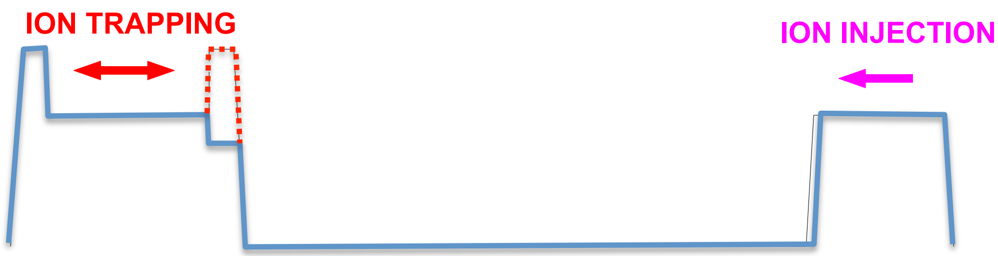


Radial trapping of ions by the space charge of the electron beam.
Axial trapping by applied electrostatic potentials at ends of trap.

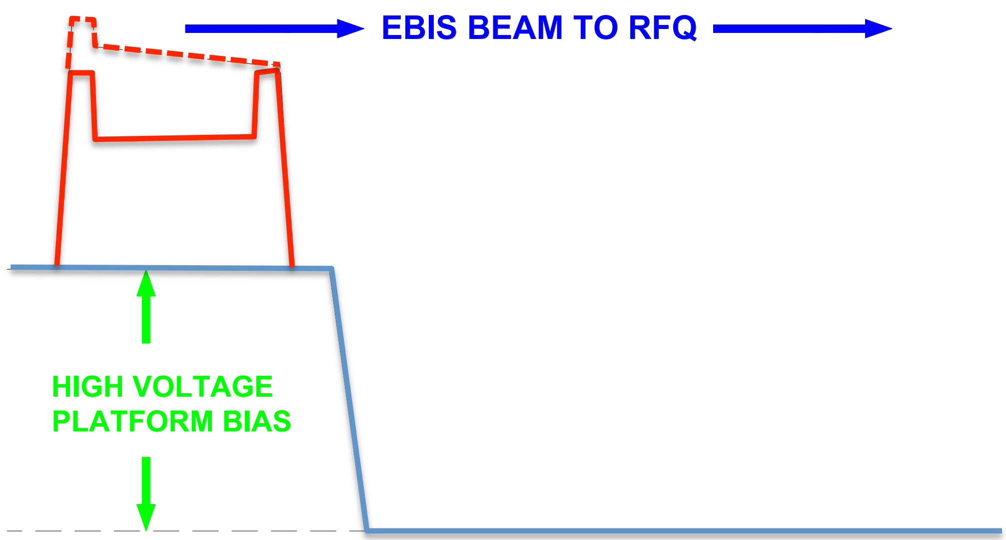
- The total charge of ions extracted per pulse is
  ~ (0.5 – 0.8) x (# electrons in the trap)
  → ion output per pulse is proportional to the trap length and I(e)
- Ion charge state increases with increasing confinement time.
- Output current pulse is ~ independent of species or charge state!

High current, short pulsed output – good for injection into for synchrotrons

EBIS operation with Pulsed High Voltage Platform

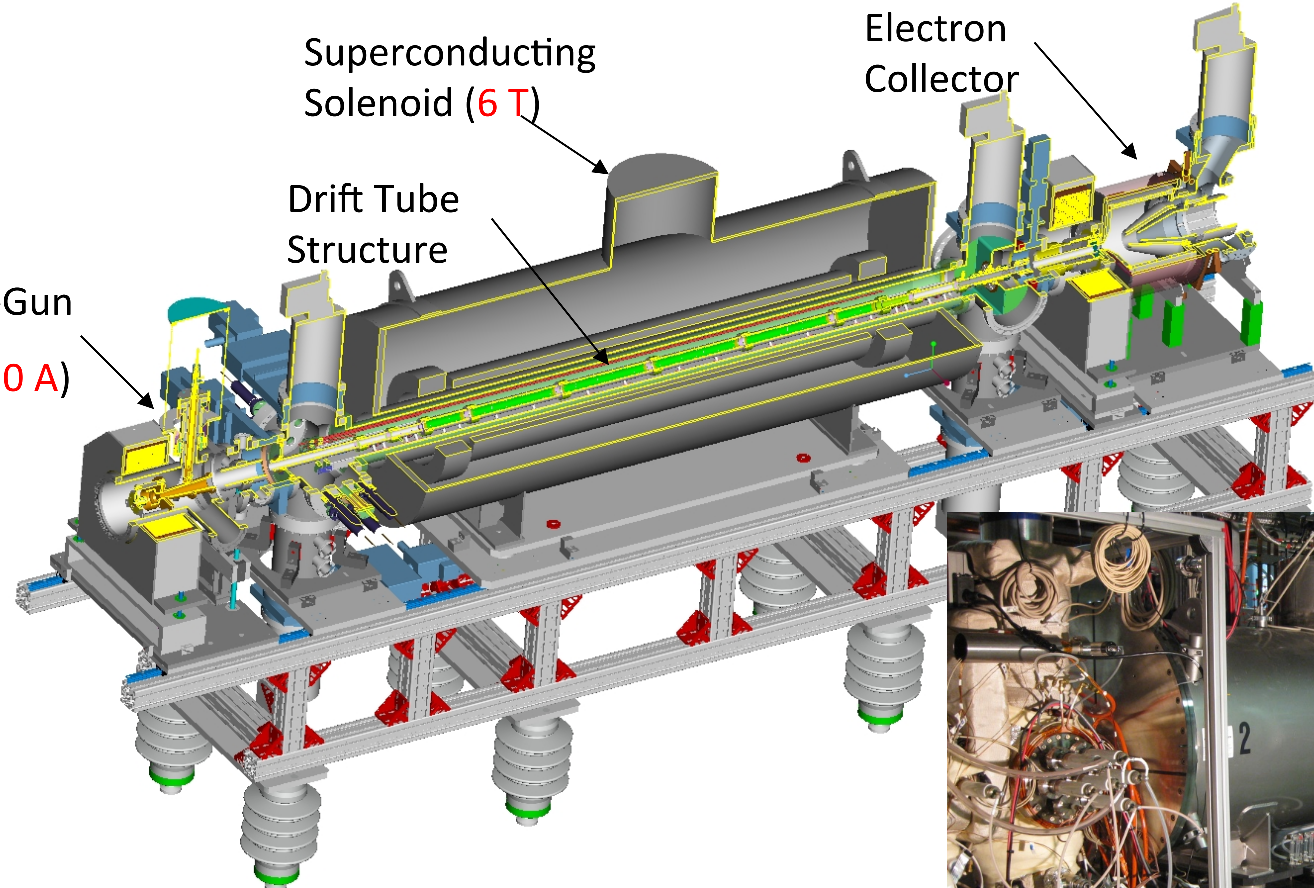


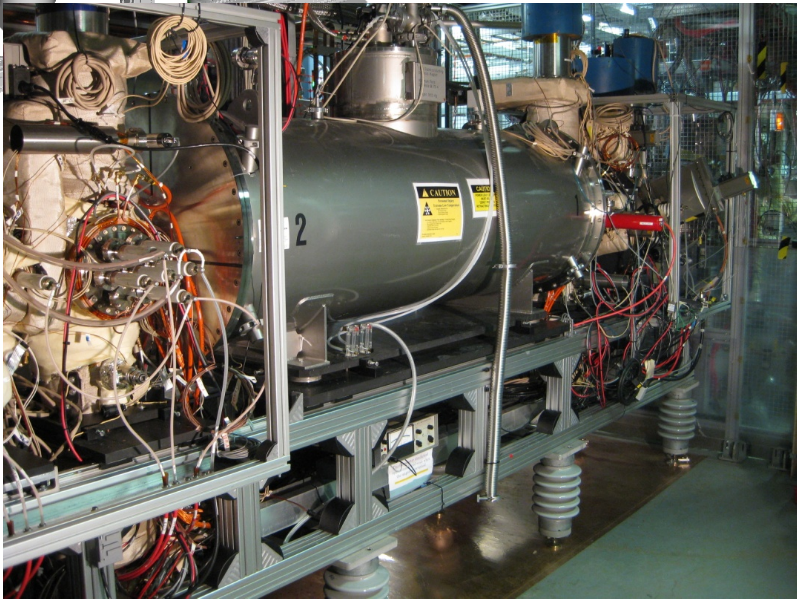
During injection and confinement the RHIC EBIS operates at ground potential.



Just before ion extraction the EBIS Platform Voltage is applied such that the ions are extracted through 100kV (nominal) to attain the ~17keV/amu needed for acceleration by the RFQ

EBIS Assembly

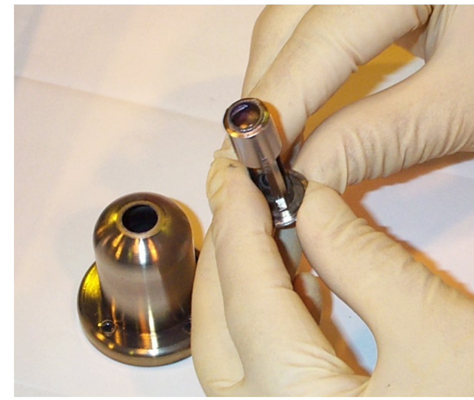


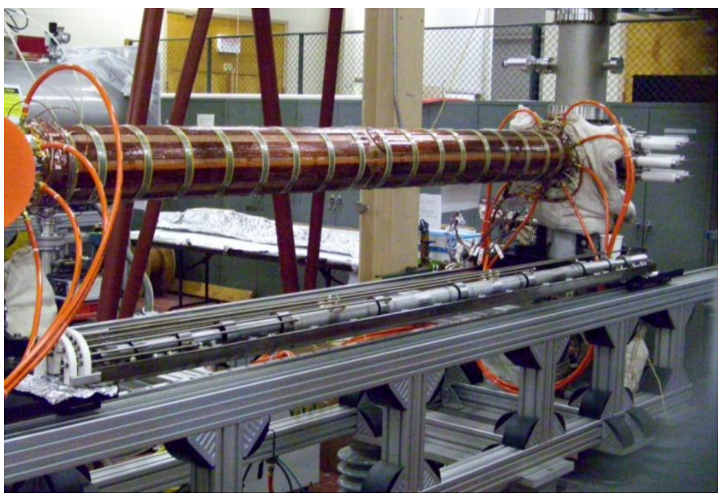


Design features of the Brookhaven EBIS

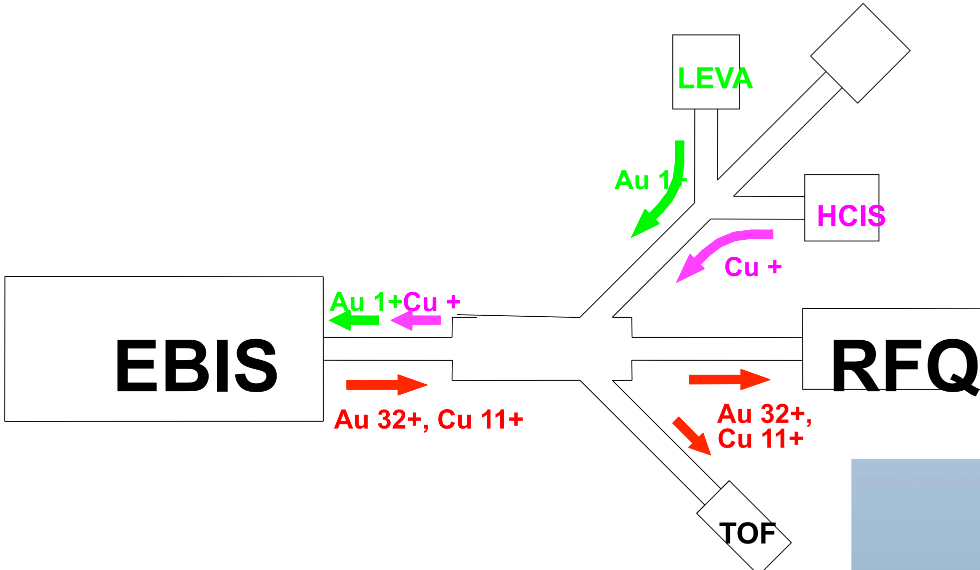
- ***<u>10A electron beam</u>*** **(very stable, reproducible)**
- **1.5 m trap**
- **5T, 1.9m SC solenoid, 8" warm bore**
- **Pressure in trap in 10^{-11} Torr range, even when running 10A, 65 ms electron beam pulses**
- **2 external ion source / injections lines for pulse-to-pulse switching of species**

IrCe cathodes from BINP





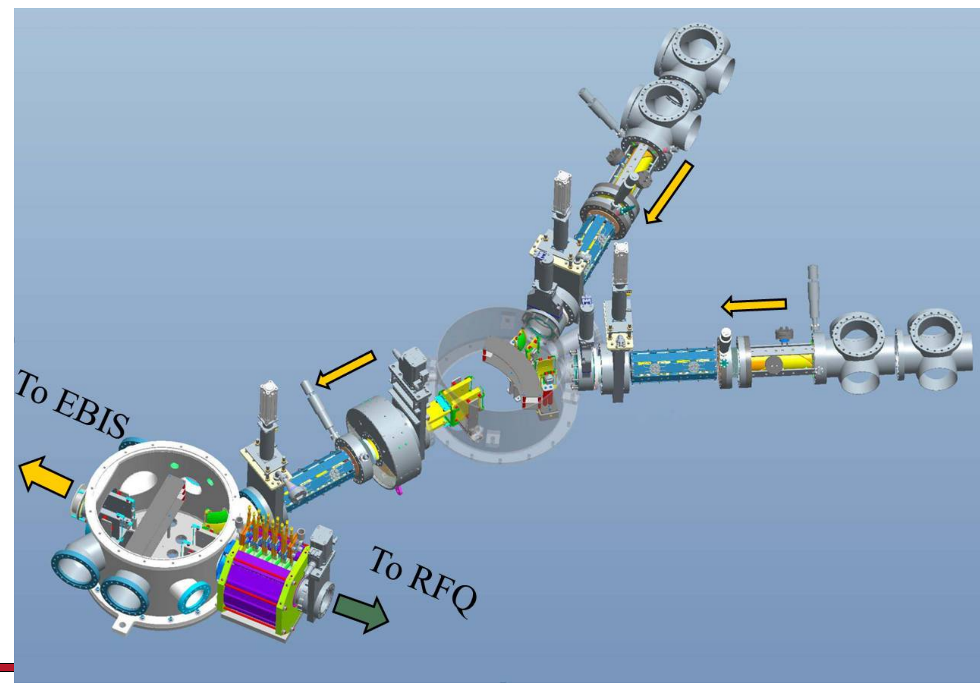
Ion Injection and Extraction from the EBIS



External ion injection provides most ion species
(EBIS ~ a charge breeder)

One can change species and charge state **on a pulse to pulse basis**

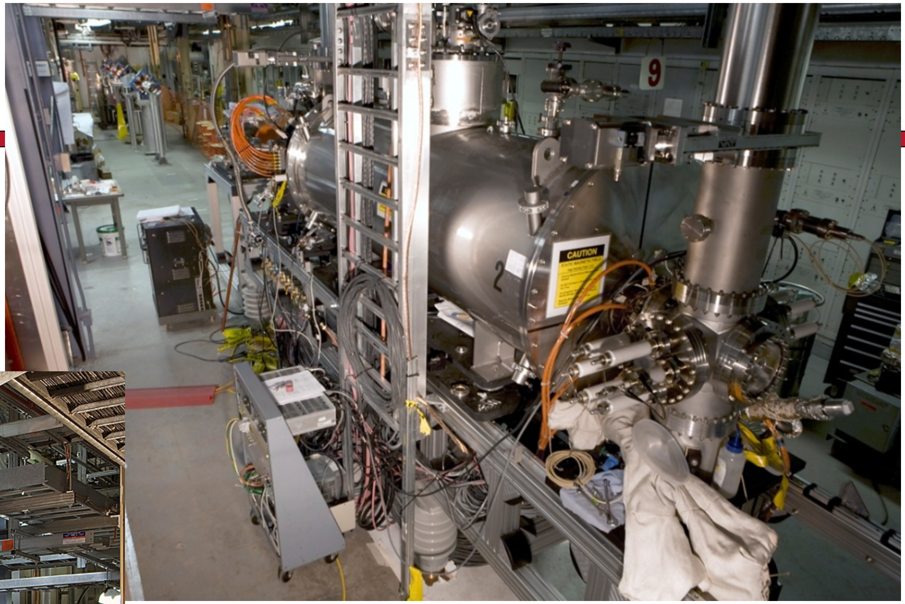
(no contamination or memory effect)

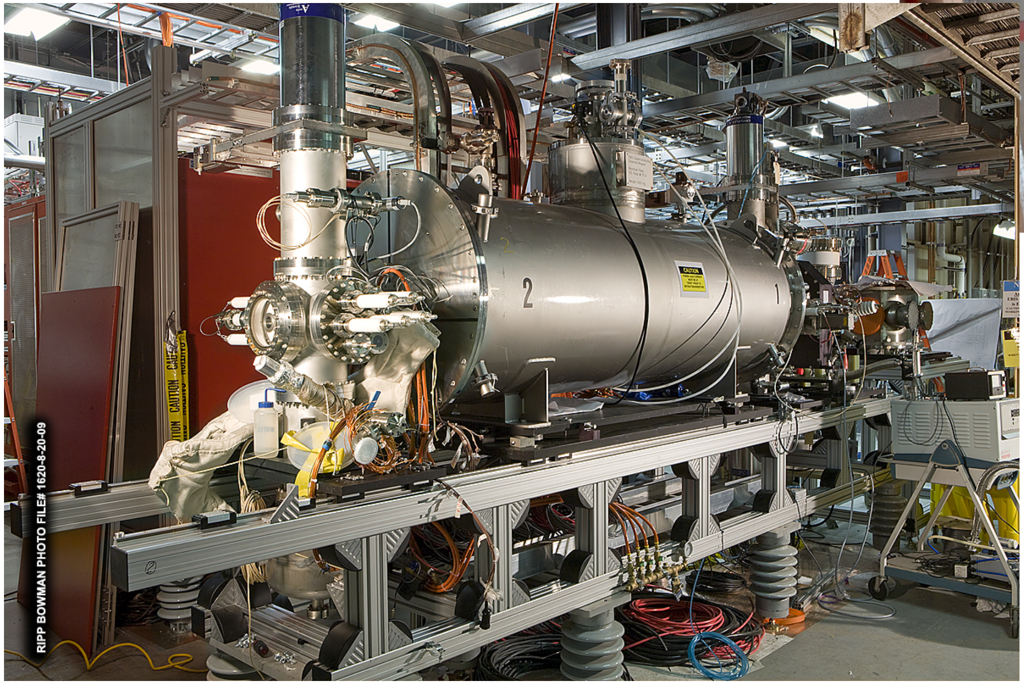


RHIC EBIS design parameters

Parameter		RHIC EBIS
Max. electron current	I_{el}=	10 A
Electron energy	E_{el}=	20 keV
Electron density in trap	j_{el}=	575 A/cm^2
Length of ion trap	l_{trap}=	1.5 m
Ion trap capacity	Q_{el}=	1.1x10^{12}
Ion yield (charges)	Q_{ion}=	5.5x10^{11} (10 A)
Yield of ions Au^{32+}	$N_{Au}{}^{32+}$=	3.4x10^{9}

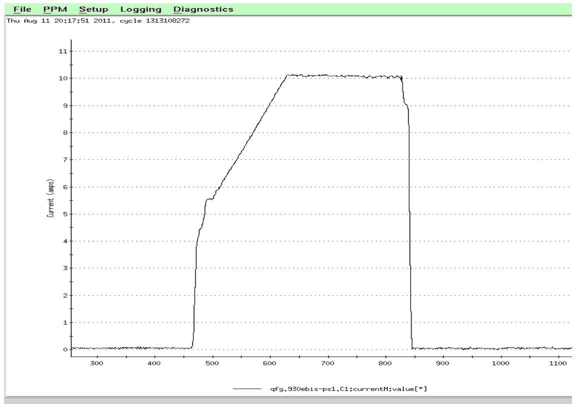
EBIS during installation



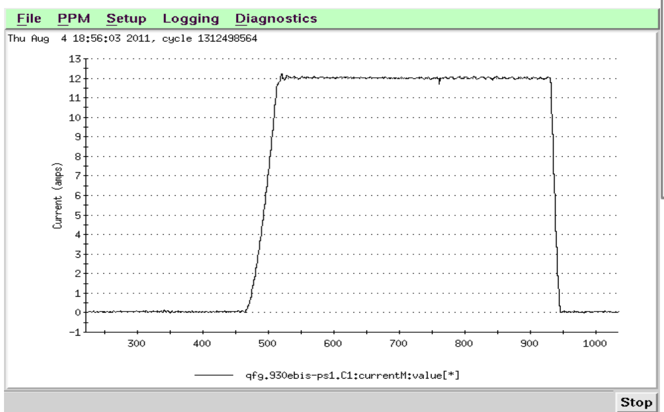


11 Racks of power supplies for EBIS, all pulsing to 100 kV along with the EBIS, during ion extraction.

EBIS has operated at the full 10A electron current

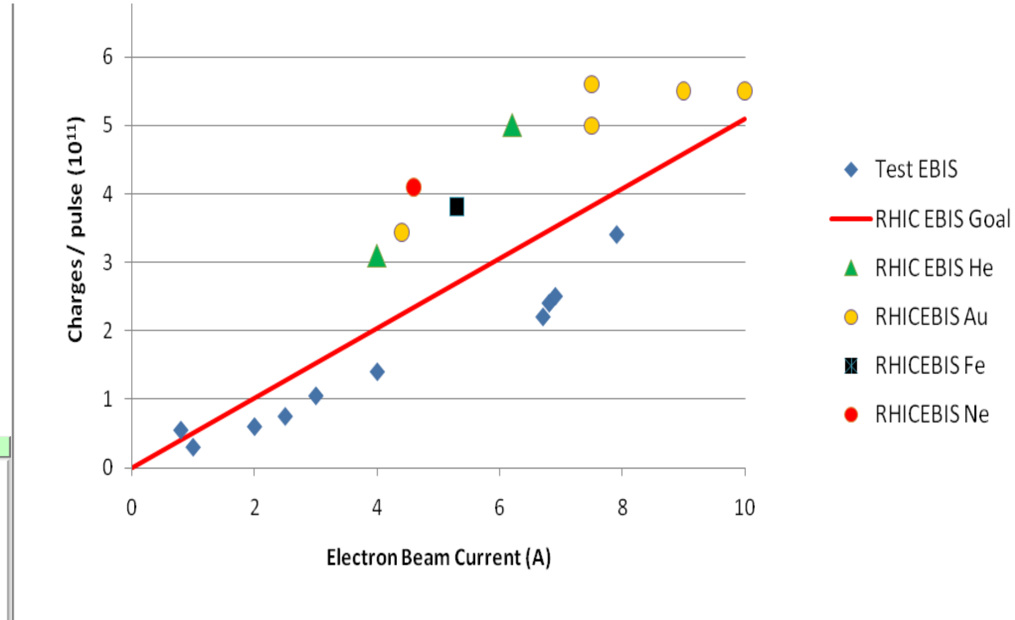


10A, 35ms used for Au ion production



12A, 40ms ebeam

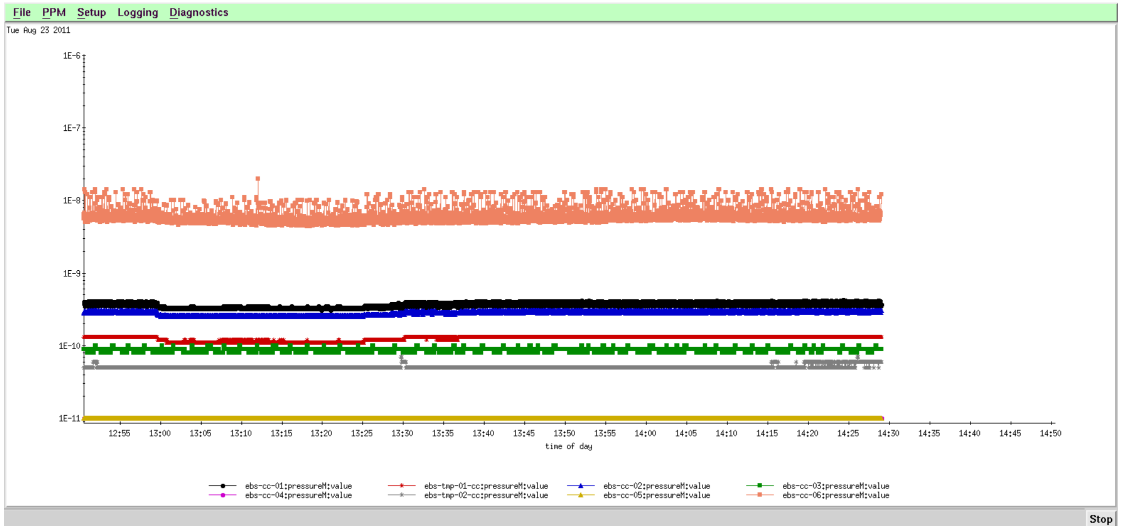
Ion Yields from Rhic EBIS (and Test EBIS)



- **Output has scaled properly with trap length (Test EBIS vs. RHIC EBIS)**
- **Output scales with electron beam**

Gold produced in RHIC EBIS for 9 & 10 Amps has not yet been optimized (needs more Au 1+ injected current)

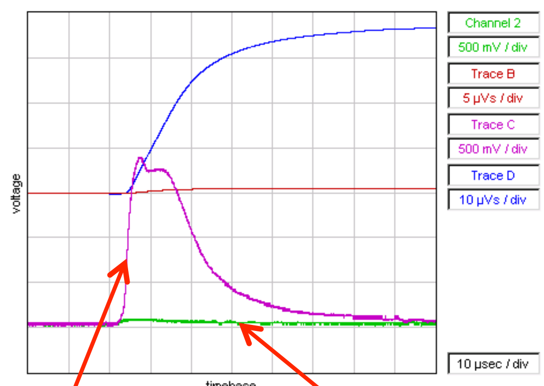
Well baked system and excellent electron beam propagation result in <u>very pure Au spectrum</u>



Pressure log for 7.6A e-beam with a 65ms ion confinement

P_{gun} = 1.5 E-10
P_{trap} = 9 E-11
$P_{collector}$ = 5 E-9

UHV - proper materials, baked, etc,



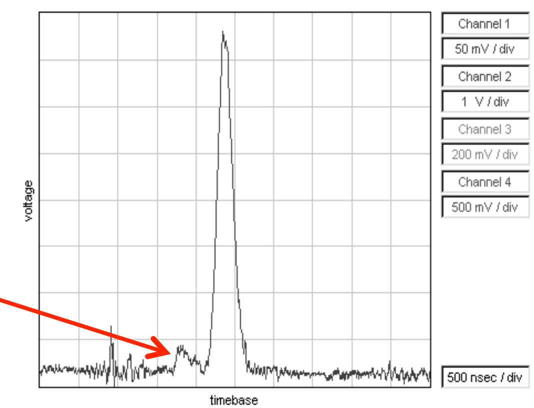
With Au injection; 70 nC

No Au injection; 1 nC

65ms confinement; peaked at Au32+

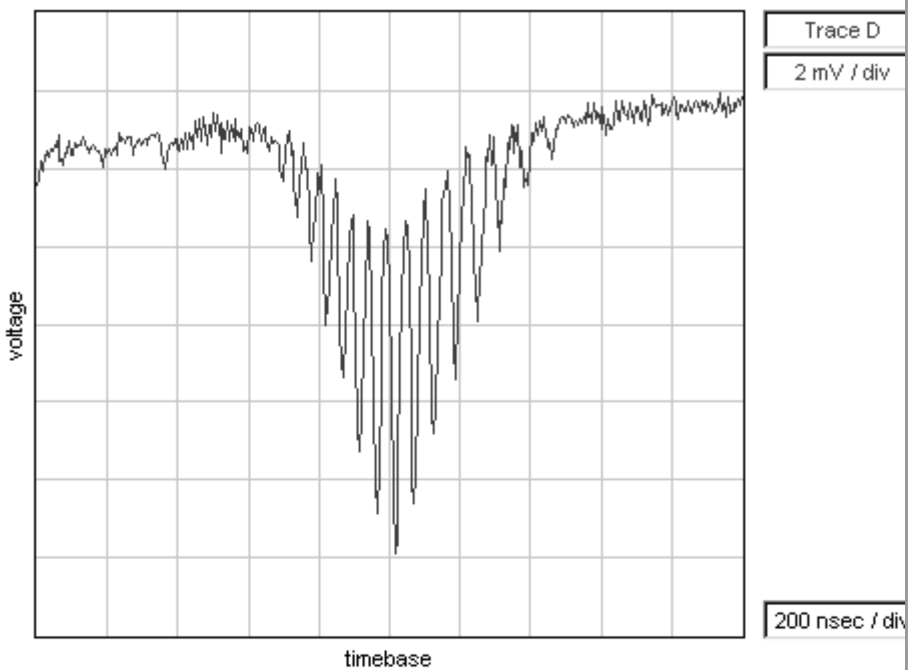
Background peak is very small

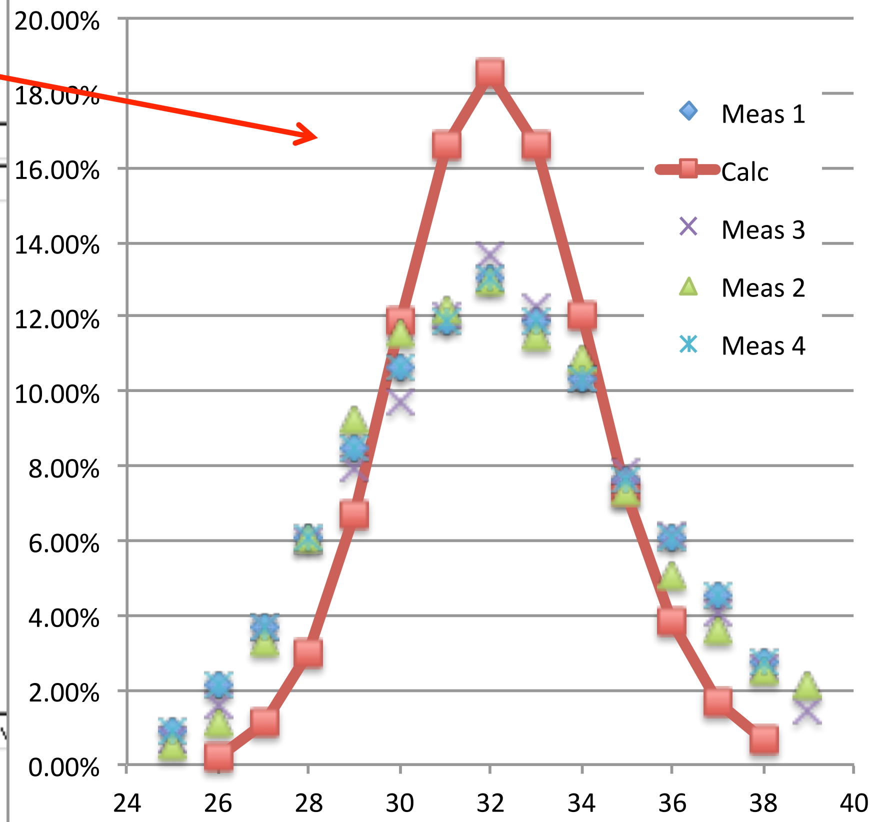
Low resolution TOF



EBIS Charge State Distribution Measured with Time-of-flight

Measured distribution, peaked at Au^{32+}, is **broader than expected.**





The proper distribution had been achieved on the Test EBIS.
Need to work on ion injection to increase the intensity of Au^{1+} in the electron beam, in order to improve the charge state distribution.

RHIC EBIS - present performance

At 7.9 A, 74 nC at the RFQ input Faraday cup (all Au charge states)
88% grid transparency → 84 nC out of the EBIS.

Trap capacity at 7.9A, 29.7 kV = 110 nC → Extracting 76% of the trap capacity ✔

74 nC * 13.5% in Au $^{32+}$ → 10 nC = 1.95e9 Au $^{32+}$ / pulse at RFQ input

Parameter		RHIC EBIS
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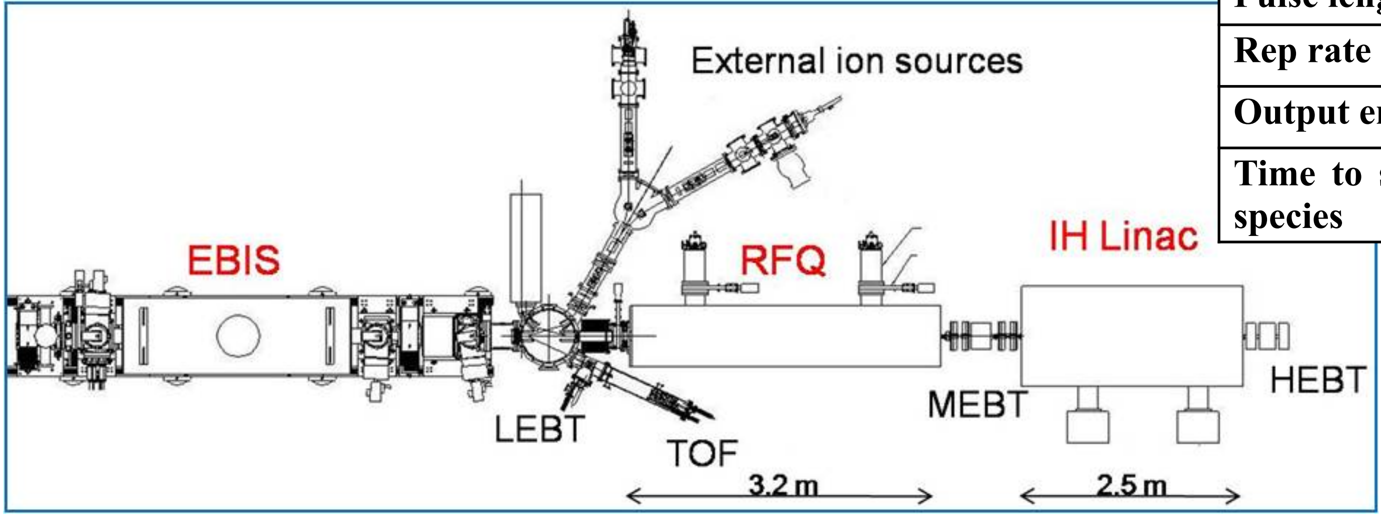
Yield of ions Au^{32+}	$N_{Au}{}^{32+}$=	3.4×10^9

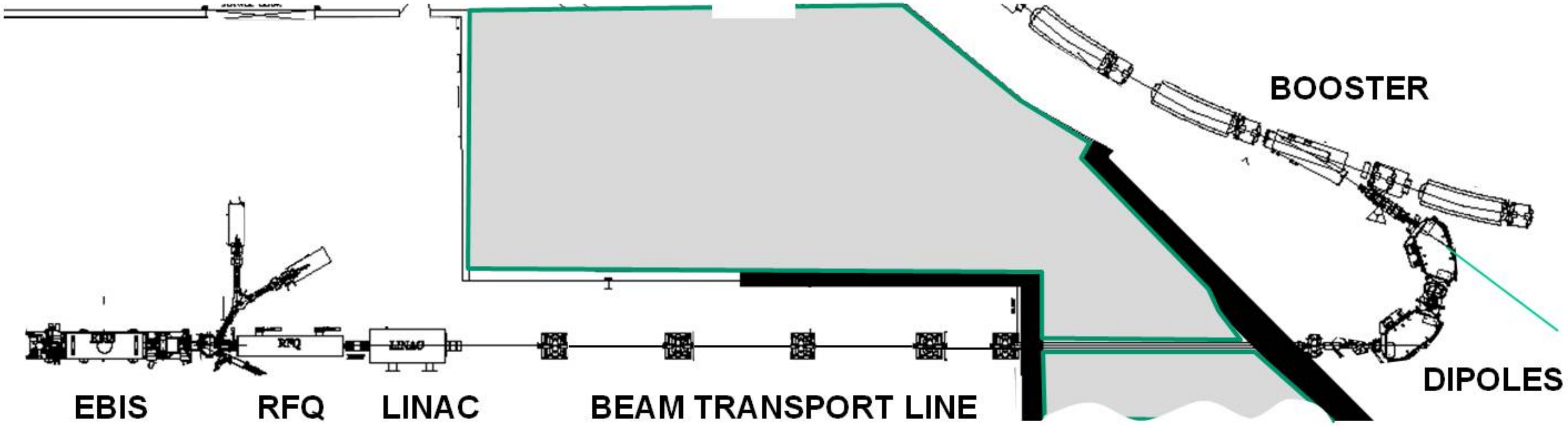
1.95e9
x (10A/7.9A) x (18.5%/13.5%)

= 3.4 x 10^9 Au^{32+}/pulse at RFQ input, projected once optimized (equals design value)

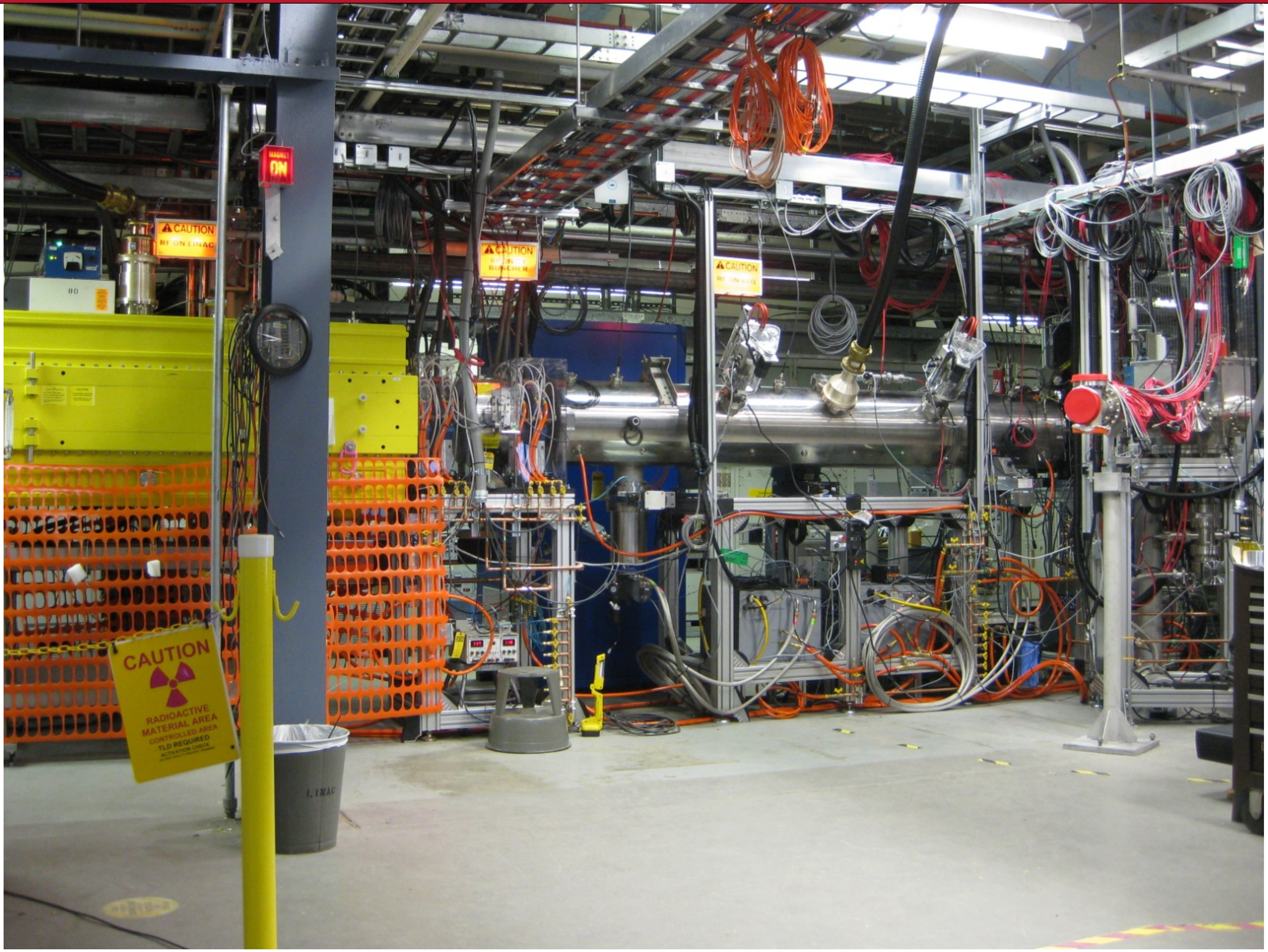
Acceleration and transport to Booster

Ions	He - U
Q / m	≥1/6
Current	> 1.5 emA (10 μS)
Pulse length	10-40 μs
Rep rate	5 Hz
Output energy	2 MeV / u
Time to switch species	1 second

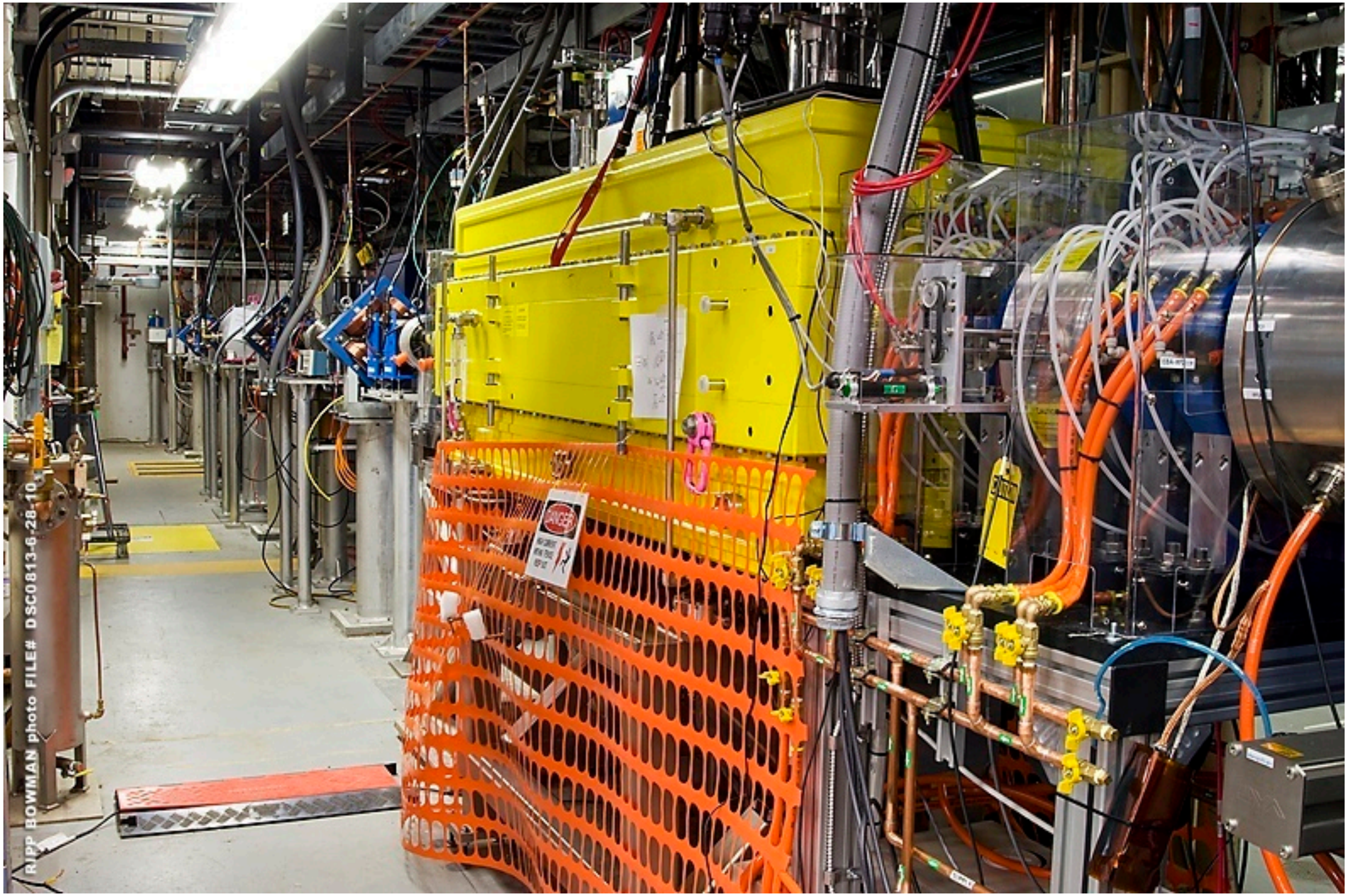




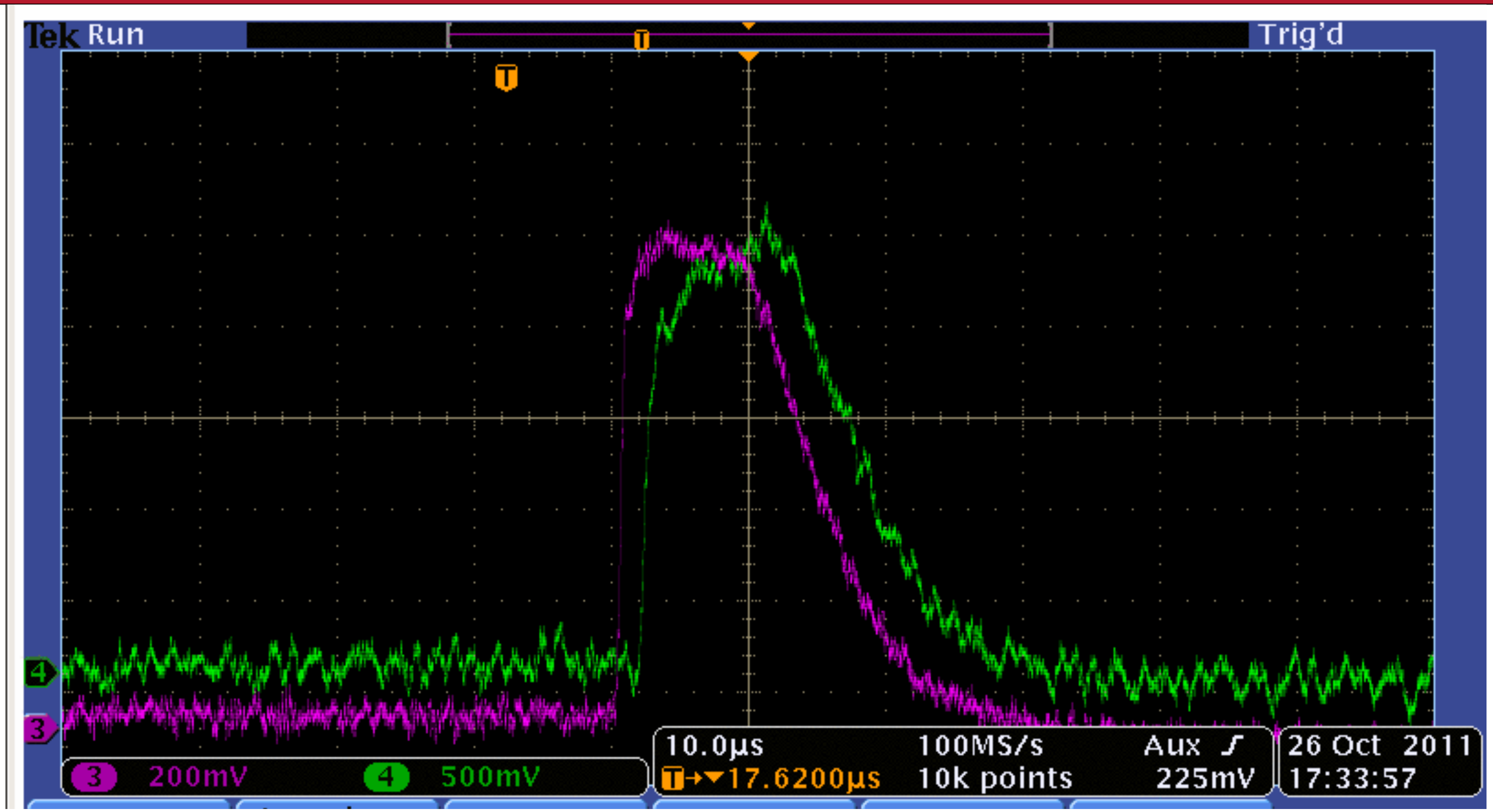
RFQ, MEBT, and Linac



Linac and EBIS-to-Booster transport



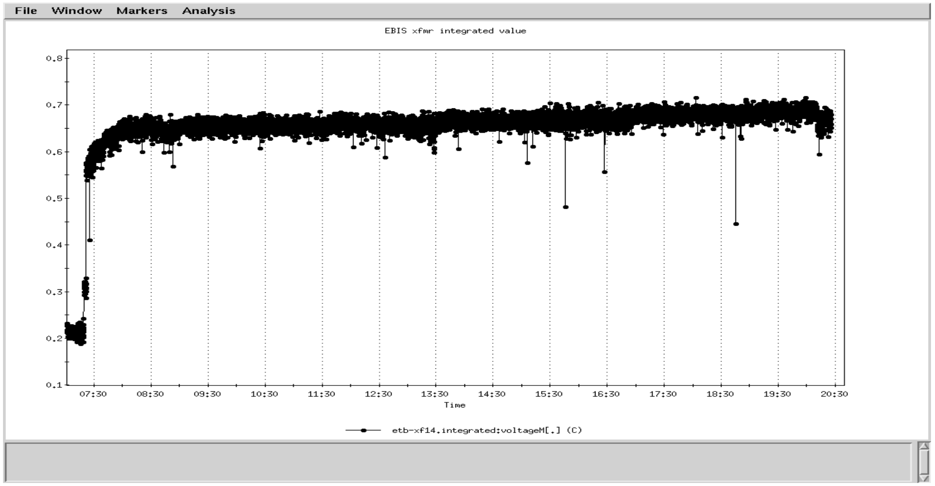
Example of Au current pulse at Linac output & Booster input



Magenta: Linac output – 1.5 mA peak (includes several Au charge states)
Green: Au^{32+} at Booster input transformer, 0.42 mA peak

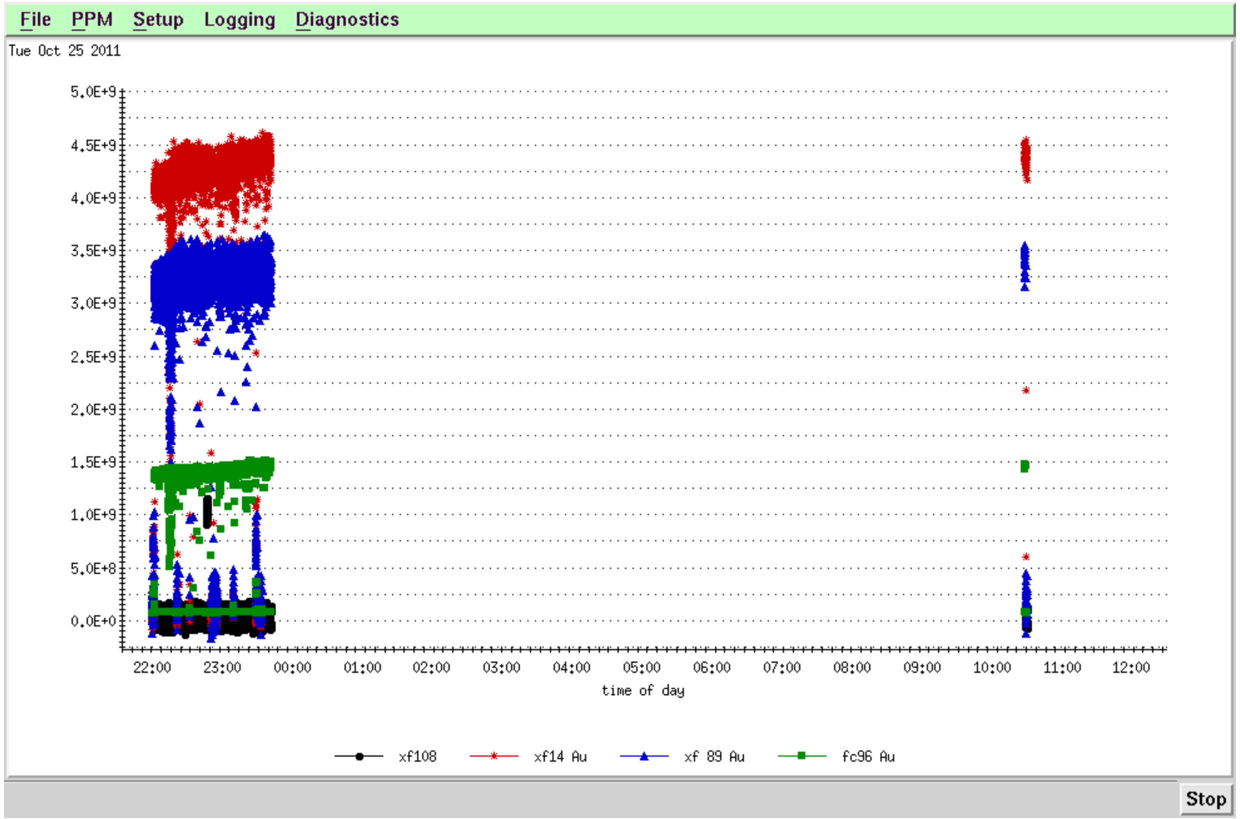
Summary of First Run for NASA Space Radiation Lab (NSRL)

- **EBIS operated ~ 6 days/ week, 12-16 hours/day, from ~ March through June, 2011**
  - **Delivering beam to NSRL, and working on adding species and increasing intensities**
- **Ran 38 days for NSRL biology experiments**
  - **Delivered Fe 20+, He 2+, Ne 5+, Ar 10+, and Ti 18+ beams**
  - **(He, Ne, Ar were new beams for NSRL)**
  - **No downtime**
  - **Excellent stability (eventually got to where it ran for days without any adjustments)**
- **All RF systems and transport magnets ran 24/7 for ~ 4 months**
- **All EBIS source, rf system, and transport magnet settings are very reproducible**



Fe20+ to NSRL:
Each point on the plot is the integrated current in one EBIS pulse
13 hours without a missed pulse

EBIS Stability & Reproducibility



The **first pulse** when EBIS was turned on in the morning at the previous day's settings was the same intensity, all the way to Booster, as the last pulse from the night before.

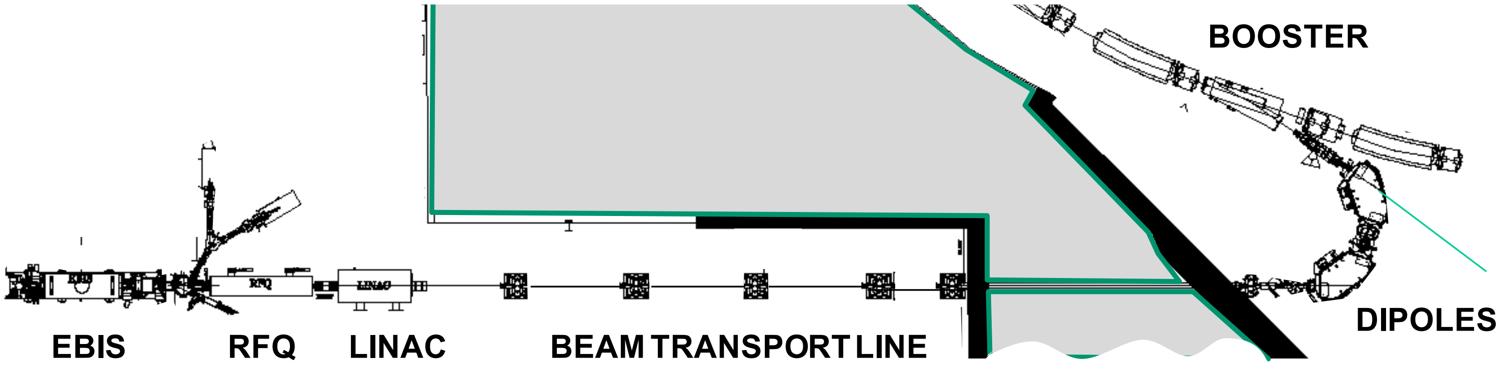
The EBIS then ran the whole day without requiring a single parameter change.

Operation with alternating Au^{32+} and Fe^{20+} beam pulses at Booster input has been demonstrated

0.5 Hz repetition rate

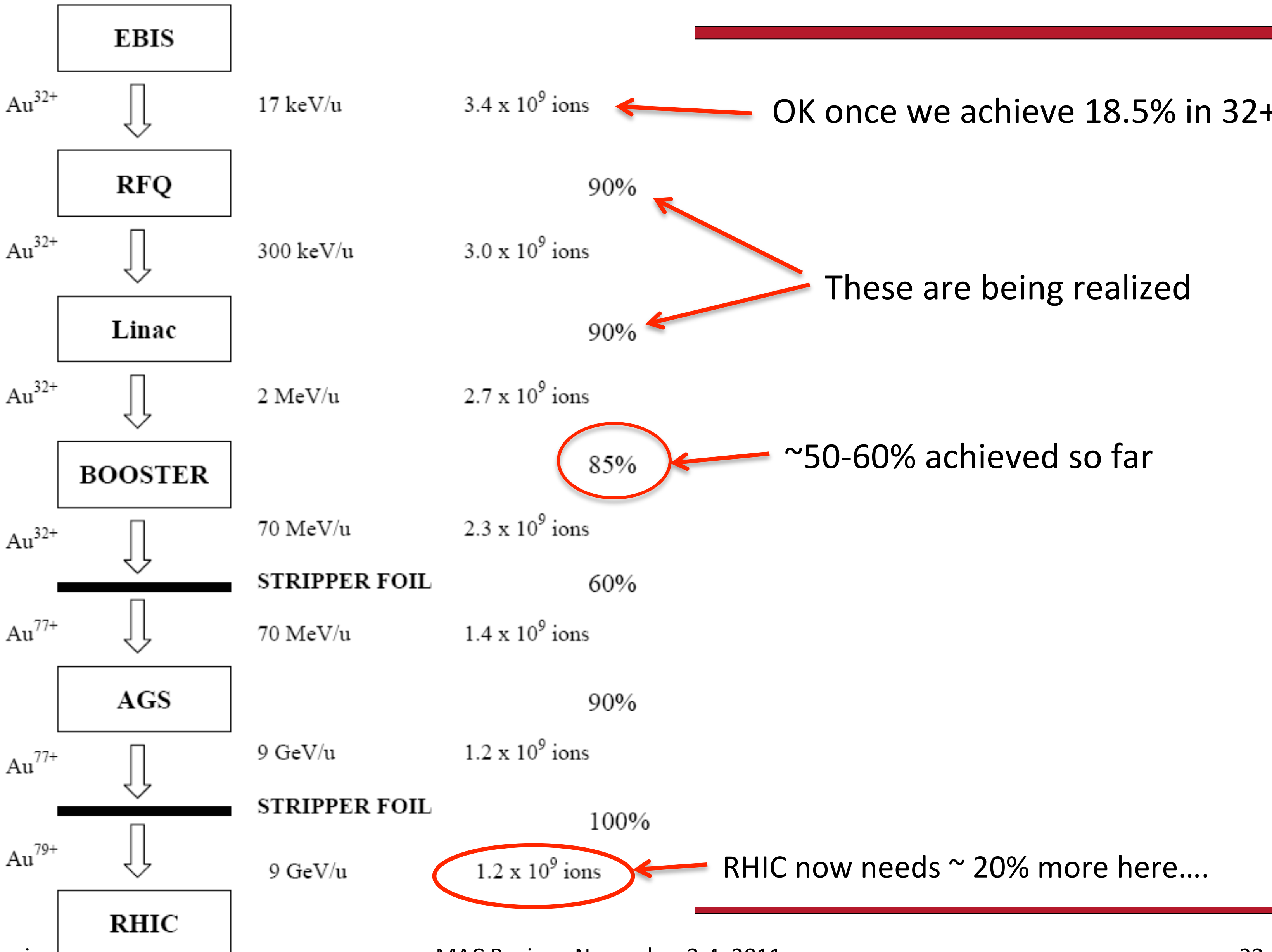
- Ion injection into the EBIS trap alternating between Fe^{1+} and Au^{1+} (two sources)
- EBIS confinement time switching between 65 ms for Au^{32+} and 130 ms for Fe^{20+}
- Switching pulse-to-pulse: platform high voltage, power to all RF systems, current to the large dipoles, and all transport line elements.

This rapid switching of species will be a frequent mode of operation when RHIC and NSRL are both taking beams from EBIS.



Au Intensity

Project CDR – September, 2005
(10 A electron beam)



Booster late / Booster input

Efficiency seems to be independent of intensities and species.

Because with EBIS we have only few-turn injection, the expected (calculated) Booster efficiency was better than from Tandem

Tandem efficiency is ~46% for Au 31+
EBIS was expected to be ~85%, but so far is 50-60%

Is the beam emittance at Booster input larger than expected from EBIS?

EBIS emittances are difficult to measure since the beam out of linac still contains multiple charge states.

Potentially, there can be emittance growth in the linac due to transverse or longitudinal mismatch (presently no steering in MEBT), RFQ misalignment, etc.

EBIS beam emittances

Design value was ~0.17 π mm mrad, normalized, rms at Booster input

Inflector "acceptance" is ~ 29 π mm mrad = 1.9 π mm mrad, normalized

After RFQ/MEBT (measured with slit-collector before Linac was installed):

He = 0.13 π mm mrad

Au = 0.19 π mm mrad

Emittances in ETB, calculated from measured profiles (which have large uncertainties since they still contain multiple charge states), are in range of 0.3-0.6 π mm mrad.

Tuning of the RFQ and Linac rf, adding transverse steering in MEBT, tests of EBIS ion cooling, resurvey of the beamline, etc. are ways we are working to minimize any emittance growth

Increasing the inflector gap from 17 mm to 21 mm will increase the acceptance by 50%. This is planned in November, following the NSRL run

Plan to reach higher intensity

EBIS:

•Work on optimizing output and charge state distribution at 10A electron beam

•Eliminate collector ps voltage droop (passtube), plus other ps improvements for enhanced flexibility, better optics

•Fast ion extraction

Transport:

•Add the ability to steer the beam between the RFQ and linac
(presently 4 quads, 1 buncher, and *no* steering)

•Beam emittance studies at the output of linac (relative, with pepperpot)

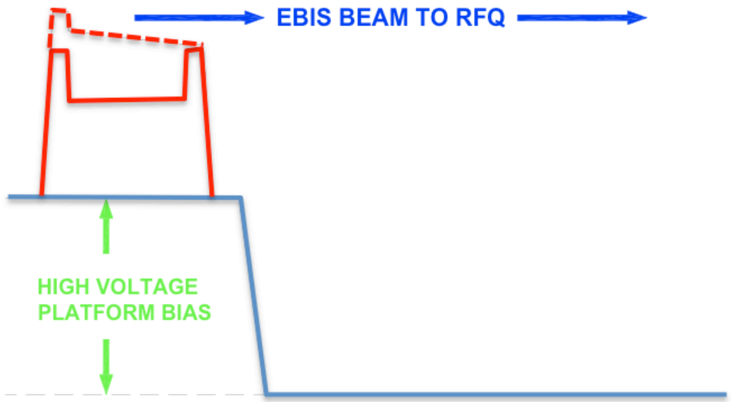
•Resurvey the beamline

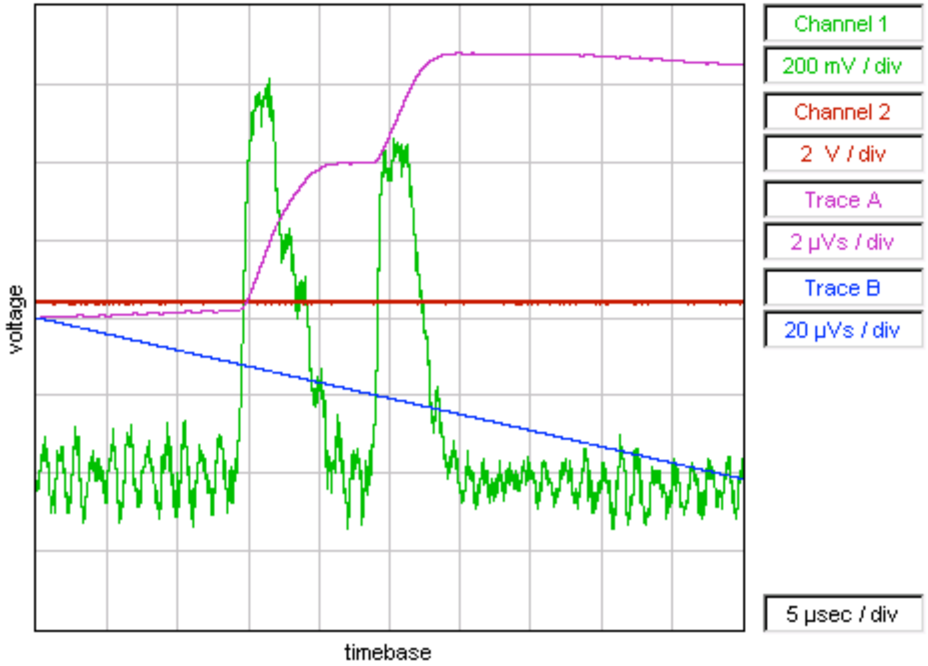
Matching into Booster:

• Increase the inflector gap (from 17 mm to 21 mm ~ 50% more acceptance) – prepared to do this following the NSRL run

Barrier bucket in Booster – extract EBIS ions in 5μs (half-turn in Booster) so there can be **two** EBIS pulses per bunch in RHIC

Short pulses at Linac output (two half-turns)





Au at the linac output, double pulsing trap electrodes to extract ions

Here, extraction is by raising the trap uniformly, rather than with a slope.

Projected Gains

- EBIS:
  - Improve charge state distribution (ion injection): 18.5% / 13.5% → 37% increase
  - I_e 7.9A → 10A: 27% increase
  - (5% from improved grid transparency)
- Booster efficiency:
  - Add MEBT steering & rf tuning to reduce emittance
  - Increase inflector gap to gain 50% in acceptance

  → ~55% total improves to 70% ???

These get us to the design values (CDR) at Booster input

Total gain = factor of 2.2 → 1.8e9 Booster late

With **barrier bucket** 1.3e9 is required to meet RHIC requirements (M. Brennan talk; 2 EBIS pulses/RHIC bunch),

Need ~58% overall gain to reach requirement for this year.

RHIC Run 12 intensity goals (with barrier bucket)

Working backwards from RHIC requirements

	Au	present	U	Cu
Charge state from EBIS	32	32	39	11
RFQ input (all charge states)	70 nC	>74nC	70nC	52nC
Booster input/pulse	2e9	1.5e9	1.6e9	6.5e9
Booster out/pulse (65%)	1.3e9	(~55-60 %)	1e9	4.2e9
Transfer & Strip	54%		48%	77%
AGS out/bunch	1.4e9		0.97e9	6.5e9
RHIC store/bunch	1.3e9		0.9e9	6e9

U, Cu requirements from EBIS are ≤ Au

Once the Au intensity is achieved, U requirement is the same, and Cu is less.

The uranium cathode for the external ion source is on hand, and can be tried at any time. (Uranium was run on the Saclay EBIS using ion injection from the same type hollow cathode ion source).

We have already run Cu on the HCIS.

For RHIC, EBIS will do either U-U (one source), or Au-Cu (two sources).

Summary

- RHIC EBIS and all systems making up the new EBIS preinjector are operating reliably, and with good reproducibility.
- EBIS has delivered beams routinely to Booster for NSRL Biology
  - 38 days; He^{2+}, Ne^{5+}, Ar^{10+}, Fe^{20+}, and Ti^{18+}
- EBIS has operated above its design value of 10A electron beam (12A)
- Extracted ion charge is as expected, and taking into account the present charge state distribution, Au^{32+} at Booster input is as expected.
- The proper charge state distribution is expected from EBIS once ion injection and ion confinement is optimized.
- Improvements are being implemented to increase the efficiency to Booster extraction. (MEBT steering, increased gap of the inflector)
- With the margin gained by using two EBIS pulses per RHIC bunch, the U^{39+} , Au^{32+} and Cu^{11+} intensities for the RHIC 2012 run seem well in hand.