Extended EBIS (EEBIS) Status

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RHIC Retreat

Polarized $^3He^{2+}$ source development is made in a collaboration between BNL and MIT

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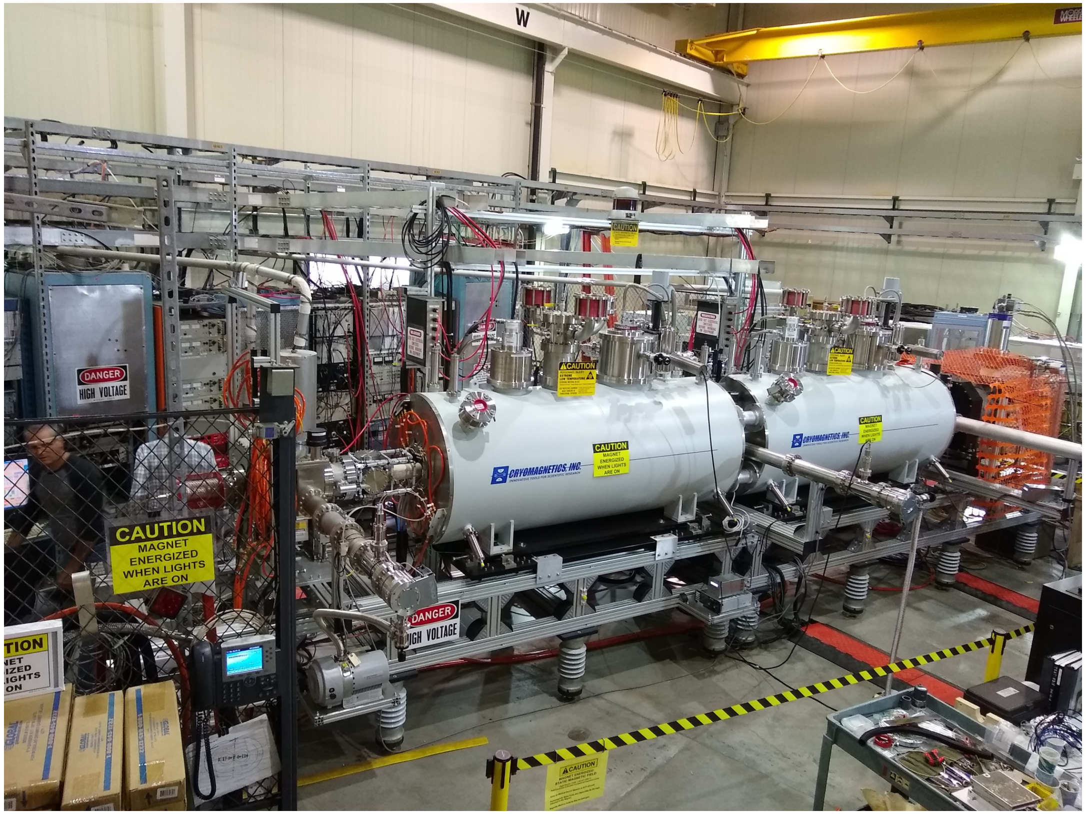
Extended EBIS during development in the EBIS test Lab



Extended EBIS Component Development and Operation in the Test Lab

The Extended EBIS Three trap System:

(gas injection trap, short trap, long trap)

Two identical unshielded 5T superconducting solenoids are used for "Extended" EBIS

The upstream solenoid contains the new features for efficient gas injection and future production of polarized $3He^{2+}$ ion production:

- **gas injection / ionization cell at pressures up to $5x10^{-6}$ mb (2cm diameter, 40cm long)**
- "External drift tube" construction and differential pump out manifold (provides space for gas reservoir(s) and high field 3He polarization cell)
- Pulsed Lorentz valve operating mounted on the gas ionization cell drift tube via a compact insulator
- **"short trap", a 95 cm long** ionization region to provide additional highly charged intensity
- Future installation: High field 3He polarization cell and purification system (tested in a separate solenoid)

The downstream solenoid contains the **"long trap", a 178 cm long** ionization region with good vacuum separation from the upstream modules and the electron collector.

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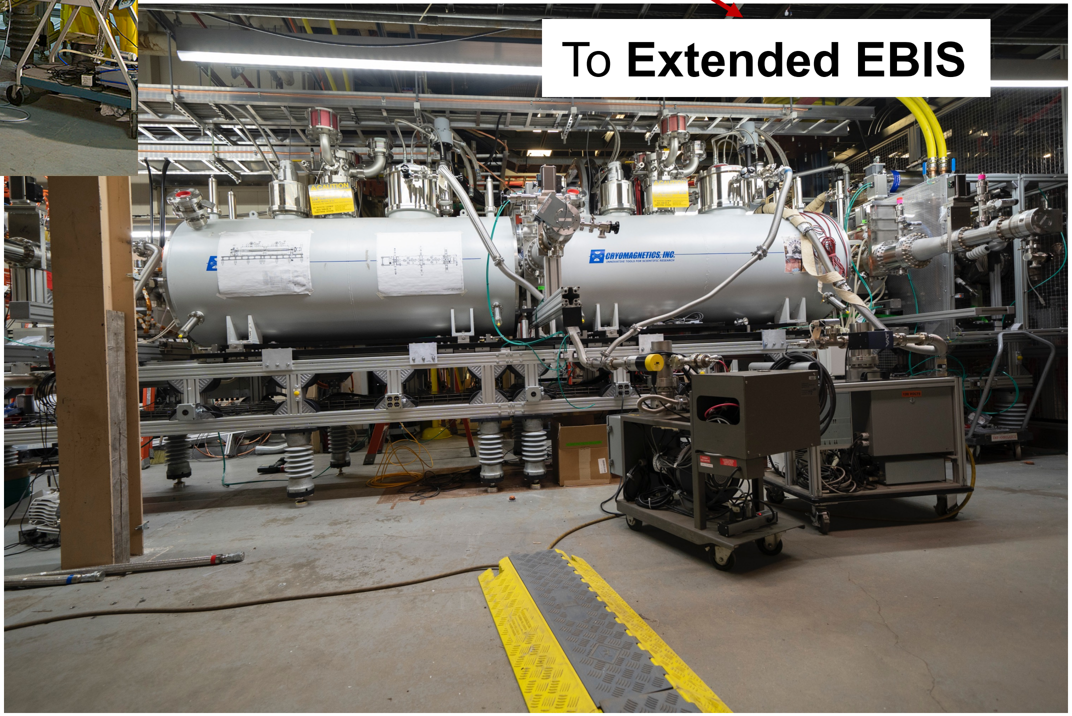
From RhicEBIS to Extended EBIS

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+}	$N_{Au}{}^{32+}$=	3.1x10^9 [1.9x10^9]



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Expected Extended EBIS intensities based on RhicEBIS performance

The extended EBIS uses the same electron beam launching and collection system system as RhicEBIS. The upgrade to provide (polarized) $^{3}He^{2+}$ ions to RHIC and the future EIC results in increased intensities for other ion species:

- Higher intensity of light ions can be produced from light gases using a highly efficient gas injection system rather than current RhicEBIS ion injection method.
- Ion intensities of externally injected heavy ions benefit from the additional trap capacity provided by the short trap in the first solenoid.

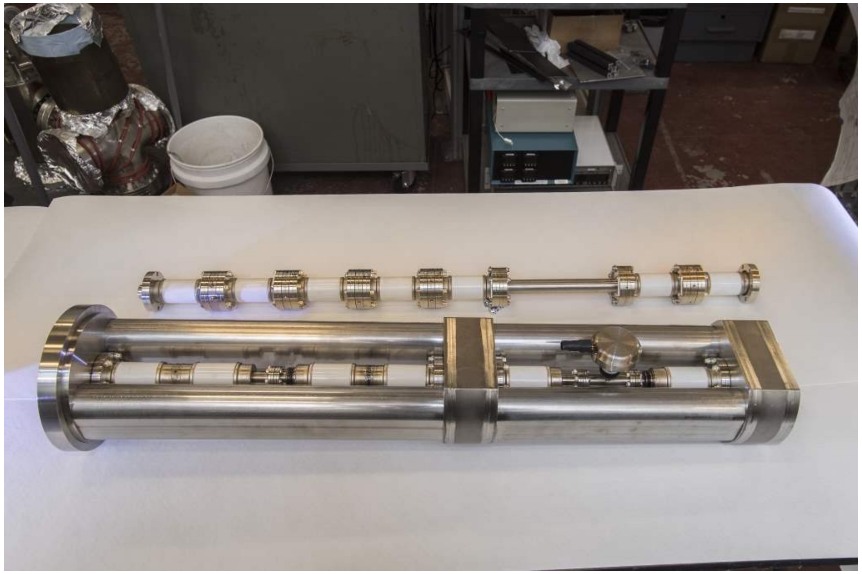
Intensity Estimates for EBIS upgrade (at Extended EBIS exit)

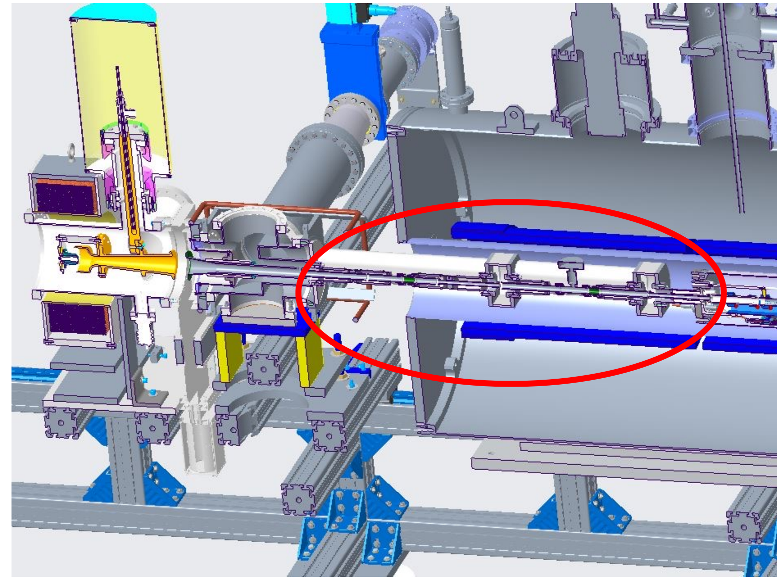
He^{2+} ~ 2.5 - 5 x 10^{11} ions/pulse

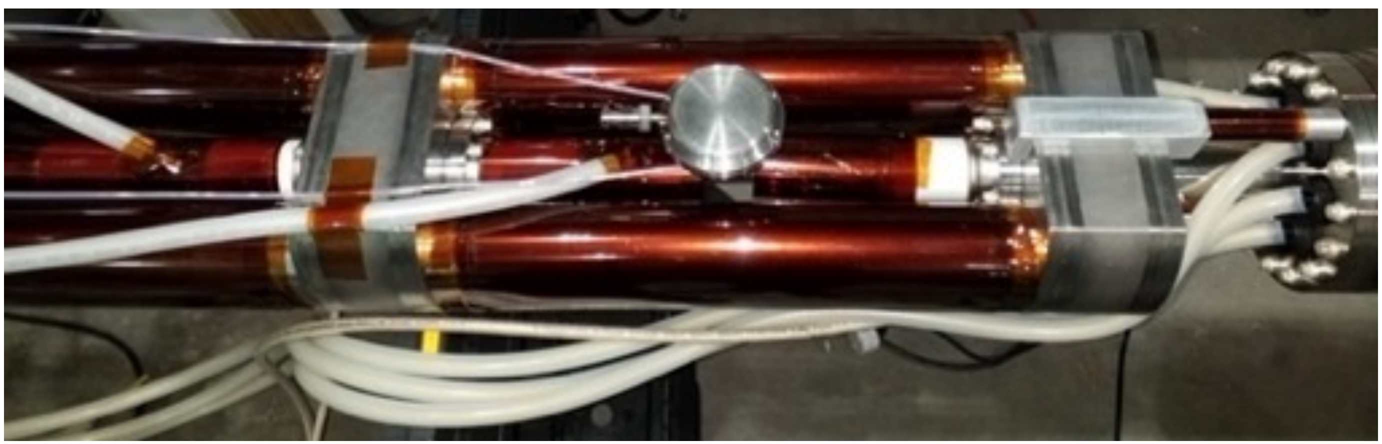
H^{+} ~5 – 10 x 10^{11} ions/ pulse (2.3 x 10^{11} ions/ pulse achieved to date)

Au^{32+} ~2.6x10^{9} ions/pulse (1.4-1.5 times the RhicEBIS output)

Gas Cell with pump out manifold and external drift tube connections



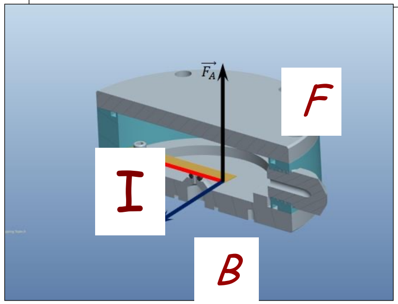




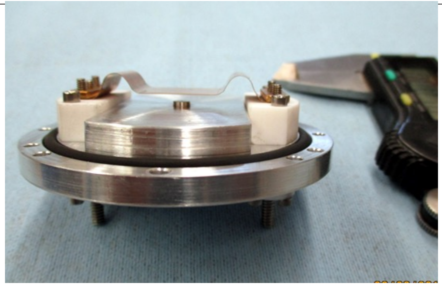
Fast Pulsing Gas Valve

"Electro-magnetic", [IxB] valve operation principle

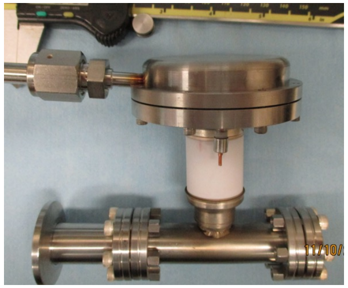
Lorentz (Laplace) force moves the flexible conducting plate in the high (~ 3-5 T) magnetic field.
For I=10 A, L=5 cm, F=2.5 N. Current pulse duration ~100-500 us



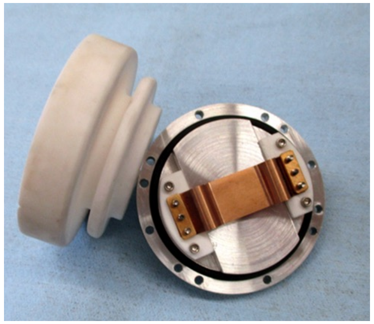
$$d\overrightarrow{F_A} = I[d\vec{l}\ \vec{B}]$$



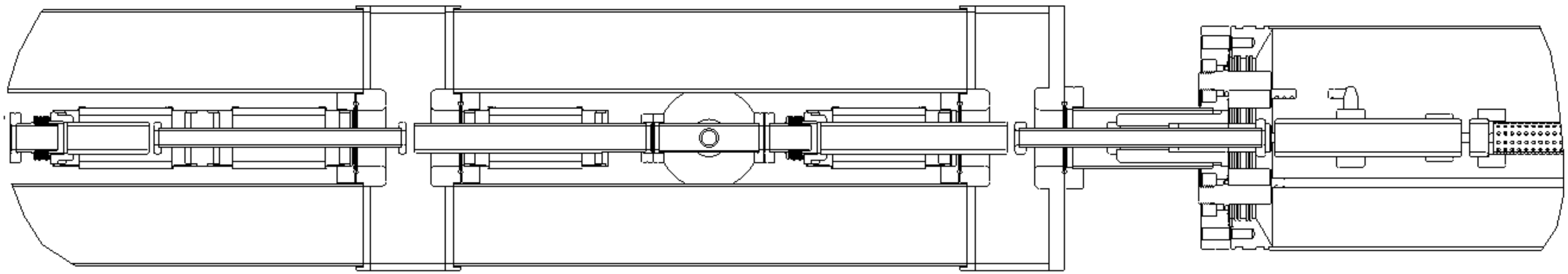
Prototype of the pulsed (isolated valve) for the gas injection to the extended EBIS.



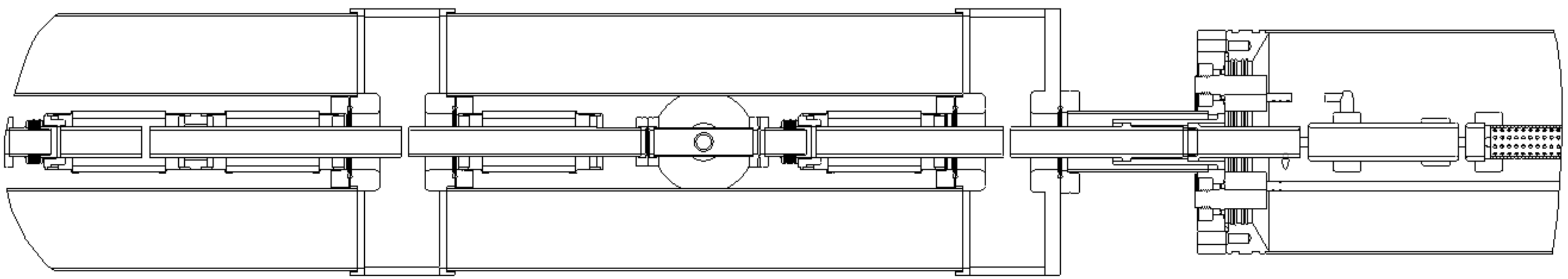
Pulsed valve for
Un-polarized gas
Injection to the EBIS



Proposed Drift tube modifications to gas trap region to eliminate HV discharges (present shutdown period)



EXISTING DESIGN SECTION A-A



NEW DESIGN SECTION A-A

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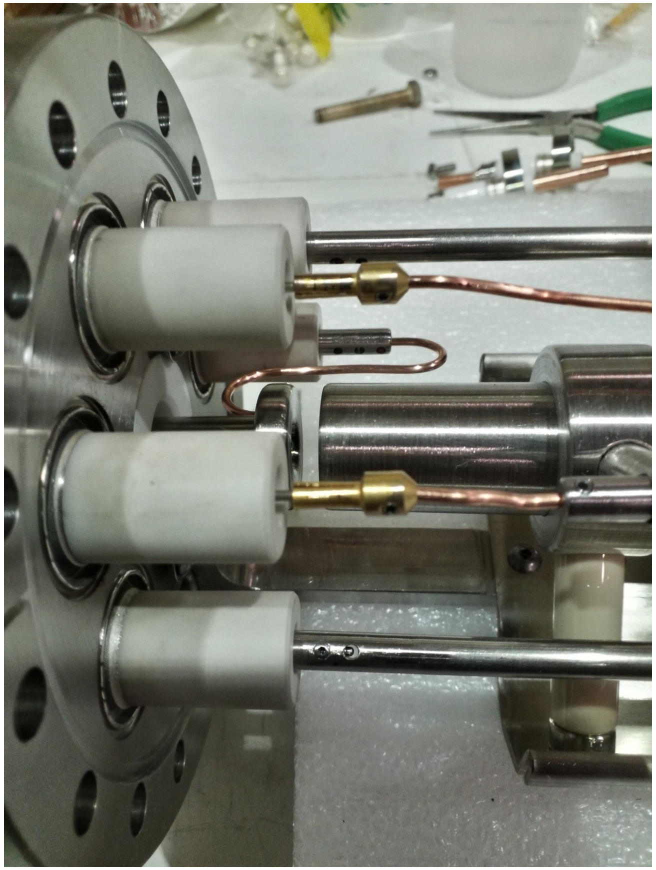
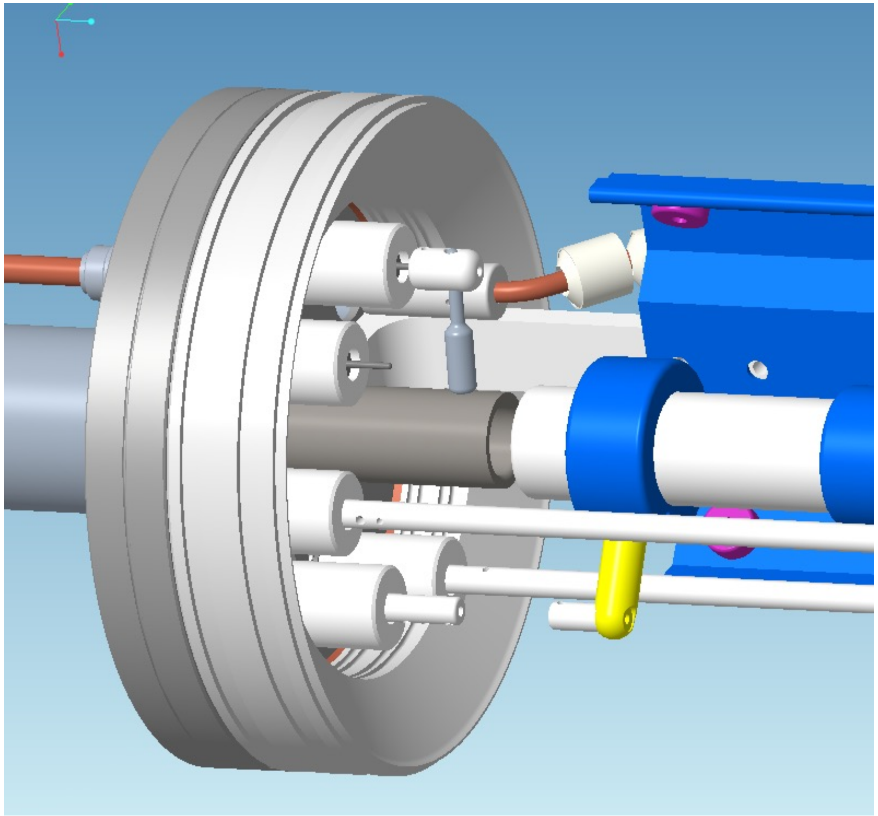
Gas injection region downstream barrier drift tube lengthened

(more direct electrical connection to reduce HV discharging)





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Extended EBIS Features

High-capacity NEGs + Turbo Pumping:
Provide high pumping speed where needed. Pulsed Hydrogen pumping speed measurement system developed to monitor NEG status.

Alignment during EBIS electron beam propagation:
HV cage is partitioned and HV connections are protected such that EBIS experts can enter the HV cage for initial mechanical magnetic alignment

New Electron Gun Cathode:
3M lower temperature oxide cathodes. improved reliability and lifetime, improved beam quality, domestically available, important for BNL and our other colleagues at ANL and FRIB
(Re-testing of higher current IrCe cathode expected before DT modification)

Extended EBIS Installation at the Accelerator Location

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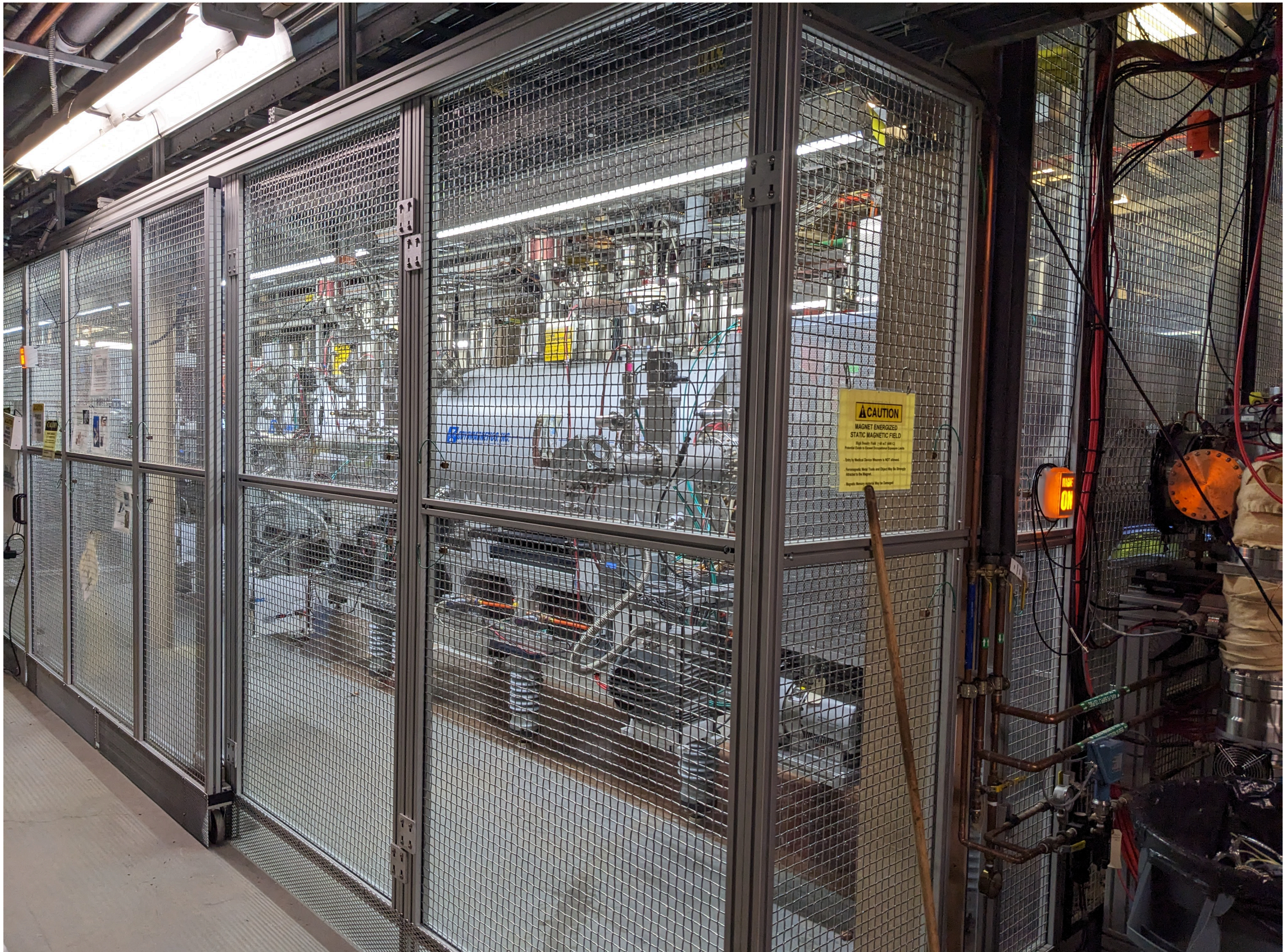
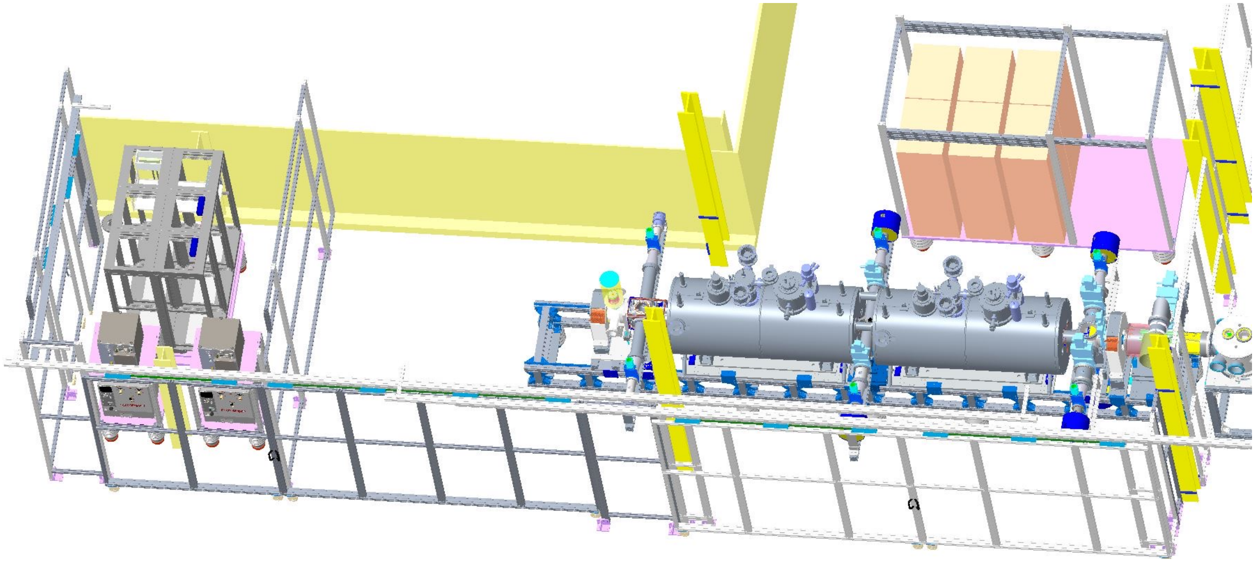
EEBIS – HV Cage



Extended EBIS Installation at Accelerator with High Voltage enclosure



Left: Electron collector supply
Middle: Extended EBIS with two Superconducting Solenoids
Right: Existing Ion injection and LEBT beamlines

Collector supply partition and EBIS shielded connections allows EBIS experts to enter the EBIS and power supply cage during electron beam aided source alignment and other operations not needing platform high voltage. (The entire cage is off limits during HV pulsing for ion injection from the laser ion source (LION) and ion extraction for beam propagation to the accelerator)

Present State of the EBIS source:

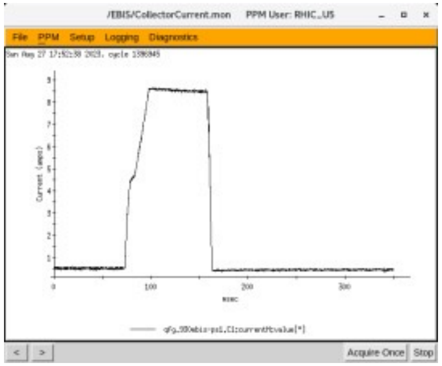
EEBIS startup went very quickly with He2+ beam being delivered to NSRL within 3 weeks of the initial electron beam at the accelerator location.

Gas injection is working with H, 3He, 4He, Ne.
136-Xe gas tests on hold for now.
Remote control of gas handling system valves and pump out system has been established.

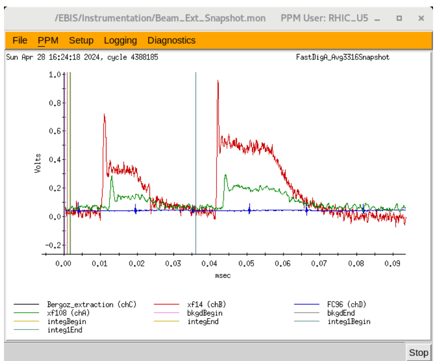
Singly charged ion injection from LION into the EBIS LONG TRAP is working with both the Au rotating target for RHIC operations and the various targets Si, Fe, Bi, Ta, Ti, etc. in the xy target system. HCIS2 is operating for Ne+ injection and can be used for Kr+ and Xe+ injection.

Au32+ production for RHIC operations utilizes Au+ injection into both the SHORT and LONG TRAPS. Fast Behlke HV electronics provide 1+ ion capture, confinement and high charge state ion extraction from EEBIS.

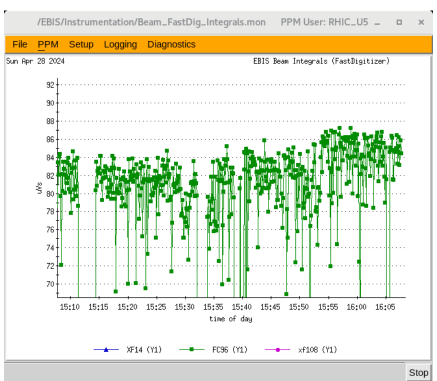
Measurements at EEBIS



8.1A electron beam
Conf2= 60ms wide (at peak value)



Red: xf14 signal
Green: xf108 signal
Blue: FC96 signal
(withdrawn during this snapshot).



Integral of series of FC96 waveforms

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Short and Long Trap Ion Pulse Merging

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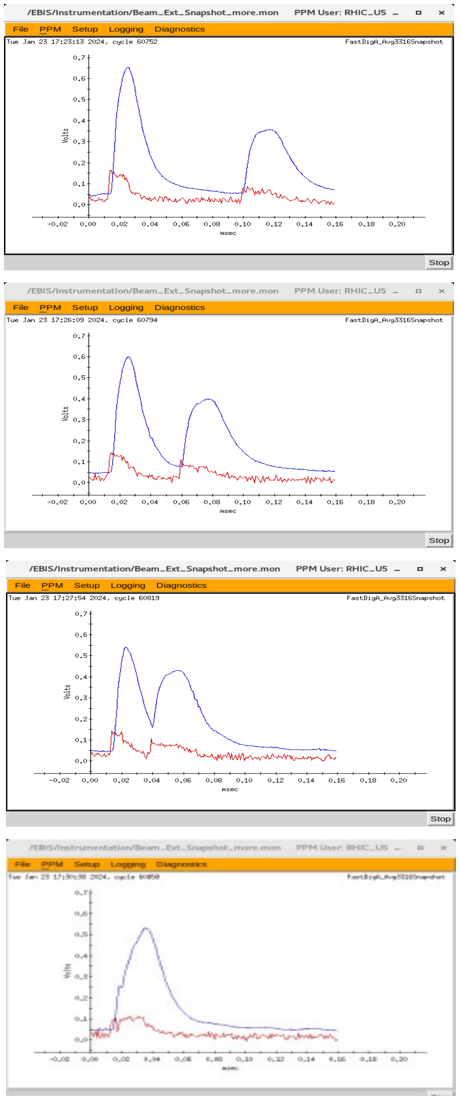


TIME

Peak Separation ~90uS

Peak Separation ~30uS

Timing of the 20kV Behlke Switches is adjusted to extract ions towards the RFQ, first from the Short Trap, and then from the Long Trap.

The Short Trap is located upstream of the Long Trap, so short trap ions must not be impeded by the Long Trap potential barriers during the ion injection or extraction processes.

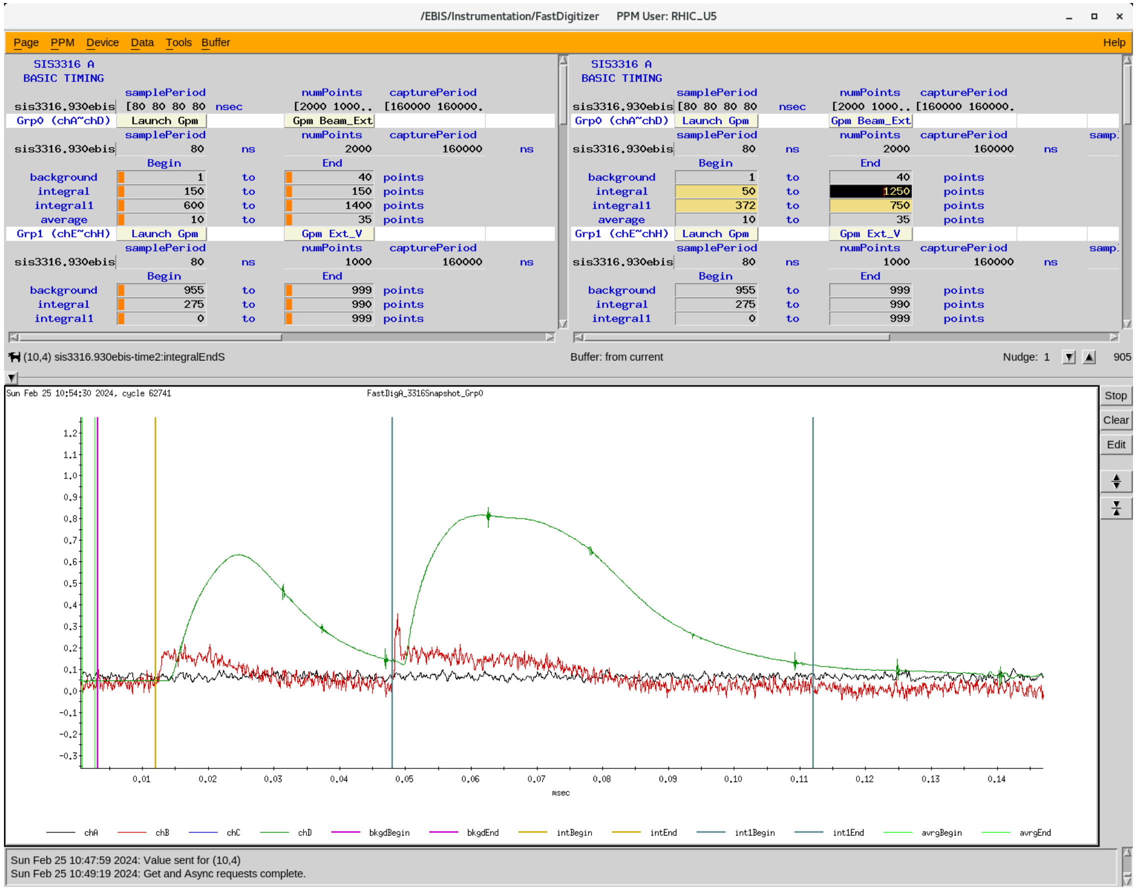
Gold Status with EEBIS

Au32+ ion intensities measured for a 6.9A ebeam (20240428):
FC96 ~ 87uVs
xf108 ~ 5.0uVs (~1.4E9 Au32+ ions/pulse)
(about 53% of the Au32+ goal for a 10A ebeam)

The precent focus is on RHIC Au32+ development with the goal of doubling the present output. This will be done mainly by increasing the electron beam current to the 8-10A level and increasing the Drift Tube voltage holding.

Improvement of ion transport in the LEBT region, for both injected Au+ and extracted Au32+ ions is expected.

Integration Adjustment of Short and Long Trap Au32+ pulses



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EEBIS Operation Status at the accelerator

1) Electron Beams up to 8.3A for Au32+ production

2) He gas injection, ion transfer to the short or long trap and 4He2+ extraction for NSRL operations

3) External ion injection of 1+ ions into the EBIS long trap with subsequent high charge state extraction to the RFQ, LINAC and Booster.

4) Two user operation on the same super cycle:
NSRL (Various very high charge state ions) + RHIC Au32+

5) Development of the RHIC 12P/sc Au32+ operation has been difficult due to vacuum deterioration in the gas injection region. Adjustment of the potential distribution, cathode heating and source biasing has helped us reach the former RHIC EBIS parameters.

6) Matching of NSRL distributions to the RHIC Au32+ distribution provides better source stability.

Plans

Work during this shutdown:

- Re-establish EBIS operation --- post gun solenoid overheating incident
- Switch to IrCe cathode for high electron current, 12P/sc, 5Hz operation
- Open vacuum chamber containing gas trap and short trap, inspect elements and make modifications towards elimination HV discharges

  - Improve intensity and stability of Au^{32+} ion beam (12 pulses at 5 Hz)

- Installation of new laser ion source (LION → LION2)

  - Increase Energy and 1+ ion currents for injection into EEBIS
  - Increase the number of targets available during operation
  - More diagnostics

Future upgrades (after next run)

- Install new solid state electron collector supply for better reliability
- high field 3He polarization setup in the first superconducting solenoid
- Install second gas injection valve with remote gas switching

Summary

- Extended EBIS commissioning at accelerator location (March 2023):
  - March 22 First electron beam
  - March 29 First ions from Long Trap residual gas
  - April 10 4He2+ set up in Booster from internal gas injection in EEBIS
  - April 22 NSRL operations with He+,He2+, C5+, O5+, Si9+ beams setup for use with NSRL GCR testing

- Since then, EEBIS provided **4He2+, C5+, O7+, Si11+, Ti17+, Ti18+, Fe20+, Nb23+, Ag29+, Tb35+, Ta38+, Au32+, Au43+, Bi43+** ion beams with required intensity for NSRL operation, and intense beams of unpolarized **3He2+** ions for the accelerator R&D program

- Extended EBIS performance of Au32+ at 12P/sc, 5 Hz is currently limited by a pressure rise in the gas trap region and by the relatively low emissivity of the BaO cathodes. This will be addressed during the current shutdown with Drift tube modifications and a switch to an IrCe cathode (used previously in RhicEBIS).

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Reference Material

Commissioning Milestones (March 2023-April 2024)

March 23 Initial Electron Beam off cathode 200-300mA 0.2Hz, 1-3mA

March 24 1A electron beam to collector after reversing Gun solenoid leads
(limited by drift tube power supply)

March 27-28 Magnetic Mechanical Alignment using electron beam
3A, 30ms e-beams no transverse magnetic steering used
6A, 0.4ms e-beam with some steering correction

March 29-30 First ions from Long Trap residual gas: 8nC, 3A e-beam, 5ms conf.
Helium Gas injection and RGA monitoring systems installed

March 31 Ion output vs Conf time for Gas, Short and Long Traps (Pressure probe)
Helium gas injection tests (3.5nC Helium ions from gas trap)
HV platform pulsing test to 500V (for ion beam transport to RFQ)

April 1-2 150C Bore vacuum system bakeout and NEG pump 550C activation

April 3-4 Three Behlke Switch Fast Capture and Extraction system debugged
4He Gas injection, He+ transfer to Long Trap, Ion extraction demonstrated
11nC total charge, at least 50% helium ions

April 8 He2+ propagation through RFQ and HEBT to FC96
April 10 He2+ set up in Booster from internal gas injection in EEBIS

April 11 Long Trap Behlke switches configured for 1+ ion capture by EBIS from LION

April 17 PPM control feature added for CAEN transverse magnetic steering

April 22 First NSRL operations with EEBIS ion beams He+,He2+, O5+, Si9+, C5+ beams from Extended EBIS were setup for use with NSRL GCR testing.

April 24 Ti13+ setup in booster for NSRL

April 27 Fe15+ setup in booster for NSRL
(This allowed Tandem to start RHIC operations with Au)

May NSRL operations

May 26 – June 12 EBIS High Temperature Bake by Vacuum Group
NEG Activation
Flange leak in collector transition found and eliminated

June 13 Pulsed H2 NEG pumping speed measurements
New cathode activation

June 14-17 Superconducting solenoid problems: multiple quenches and recovery

June 17-18 EEBIS Electron beam restart after vacuum improvement by baking, etc.
(4.1A ebeam)

June 19 -20	High Charge states Si11+, Nb23+, Ta38+ and Au32+ easily produced now. The EBIS vacuum is improved greatly after the bake and NEG activation.
June 22	Very high charge states Bi43+ and Au43+ developed
July 1	8A electron beam (1P/sc)
July 8	Au32+ 12P/sc (5.2A ebeam, 35uVs at FC96)
July 27	Au32+ improved distribution, 12P/sc intensity doesn't change with rep. rate Stable with most NSRL beams for several hours.
Aug 27	Au32+ Low voltage drift tube distribution with increased cathode bias. 8.3A electron beam achieved (1P/sc operation) FC96 = 45 uVs with 6.5A ebeam not fully optimized
Oct 2	Short Trap Behlke Switch Partial Mechanical installation
Dec 05-06	4He2+ from EEBIS transported through chicane to FC96 16-18uVs obtained about 80-90% as obtained in the direct beamline.
Dec 22	Short trap Behlke Switch Fast Electronics Installation
Dec 29	Short Trap Behlke Switch High Voltage Testing Complete

Jan 6, 2024 First Highly charged ions after Short Trap installation (Si11+)
(Injected ions trapped and extracted using Long Trap only).

Jan 8-9 Re-start of NSRL setup with EEBIS Beams through ETB line to xf108
Transport of Si11+, Ti17+, Fe20+, Ag29+ Tb35+, Bi43+ from Long Trap

Jan 22 Au+ from LION captured in EEBIS Short Trap; Au32+ extracted

Jan 24 He gas injection with capture and extraction of He2+ from Short Trap
FC96 ~23uVs, XF108 ~2.1uVs (exceeded current Long Trap values)

April 19 Ne+ injected into EBIS from HCIS2; Ne8+ from EBIS used in Booster Ring

April 21 7.1A ebeam; Au32+ FC96 ~ 58uVs

April 27 HV tests with cold cathode (no ebeam): No Discharges Observed

April 28 Au32+ FC96 ~87uVs (1.85E+9 ions/pulse) (1P/sc, 6.9A ebeam);
Au32+ xf108 ~5uVs (1.4E+9 ions/pulse) (~53% of XEBIS goal for 10Ae-)
12P/sc 200ms FC96 ~70uVs , about 20% reduction