Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Extended EBIS (EEBIS) Commissioning & Status

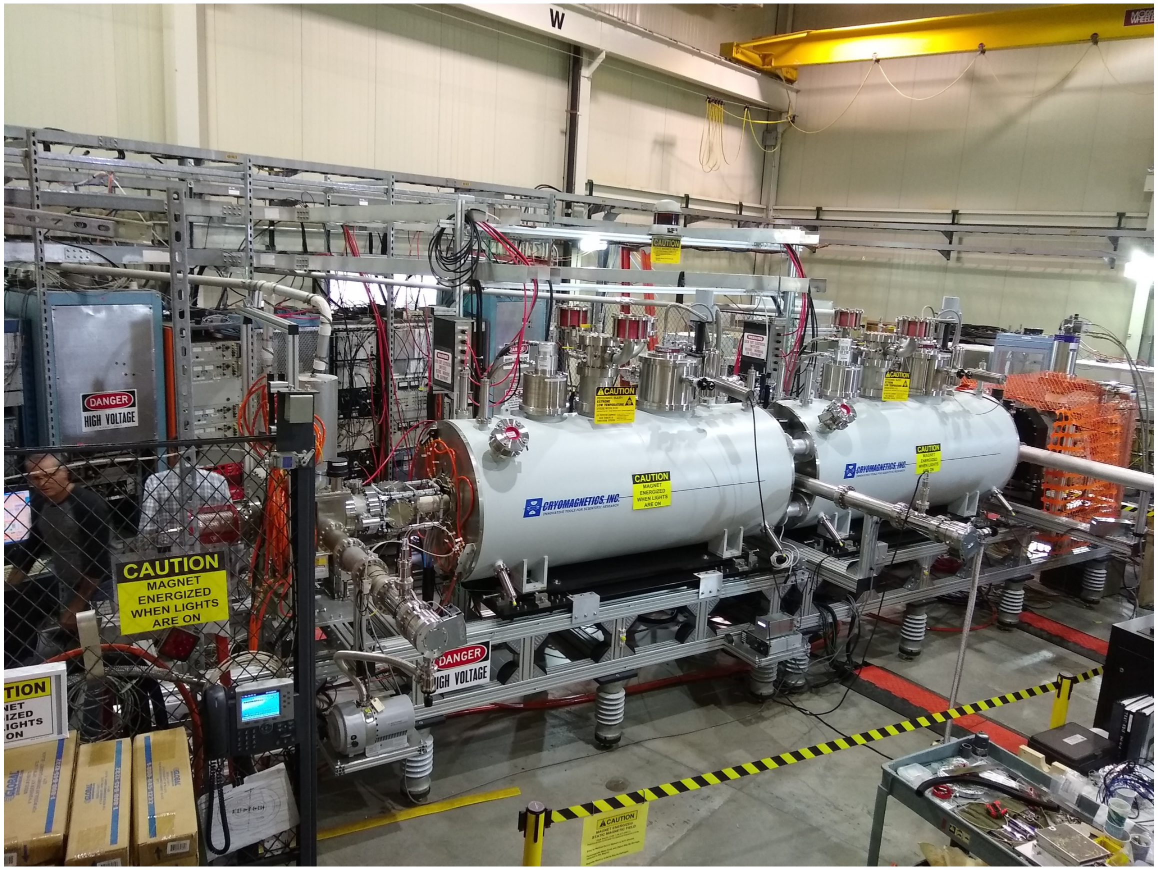
E. Beebe

August 30, 2023

(RHIC Retreat)

@BrookhavenLab

Extended EBIS during development in the EBIS test Lab



Extended EBIS Component Development and Operation in the Test Lab

Brookhaven National Laboratory

The Extended EBIS Three trap System:
(gas injection trap, short trap, long trap)

Two identical unshielded superconducting solenoids are used for “Extended” EBIS

The upstream solenoid contains the new features for the efficient gas injection and eventual polarized 3He ion production:

- **gas injection / ionization cell at pressures up to 5×10^{-6} mb (2cm diameter, 40cm long)**
- “External drift tube” construction with differential pumping stages and custom pump out manifold to provide space for gas reservoir / high field polarization cell
- An innovative pulsed valve operating on the Lorentz force mounted to the gas ionization cell drift tube via a compact insulator
- Future installation: High field 3He polarization cell and purification system (tested in a separate solenoid)

The upstream solenoid also contains the **“short trap”, a 95 cm long** ionization region to provide additional intensity of highly charged ions over the single solenoid RhicEBIS system.

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

Brookhaven National Laboratory

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.

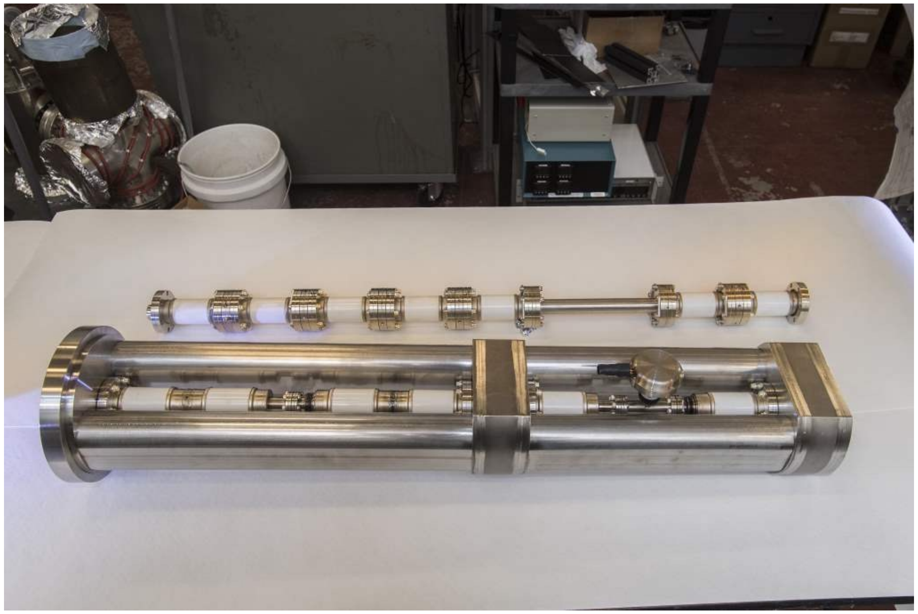
Intensity Estimates for EBIS upgrade (at Extended EBIS exit)

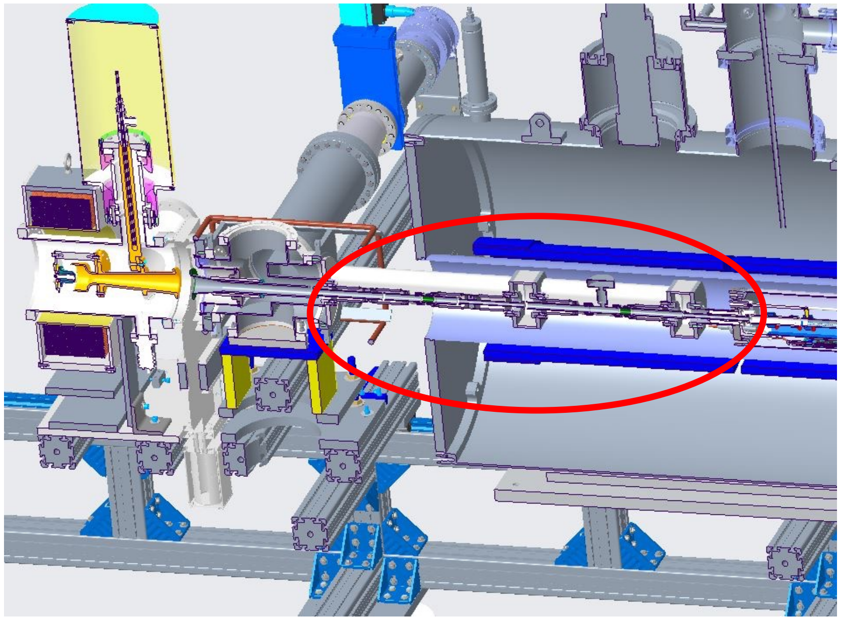
He^{2+} ~ 2.5 - 5 x 10^{11} ions/pulse

H^{+} ~5 – 10 x 10^{11} ions/ pulse

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

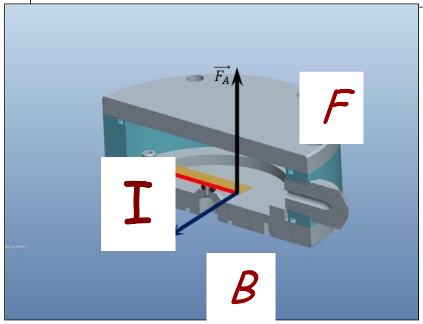




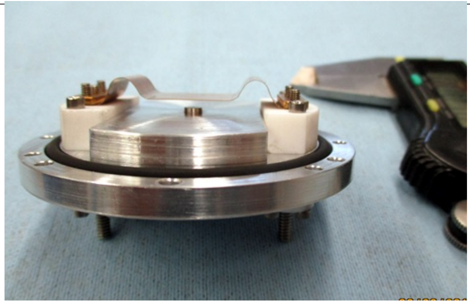
Fast Pulsing Gas Valve

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

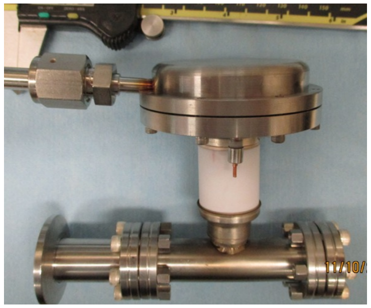
Lorentz (Laplace) force moves the flexible conducting plate in the high (~ 3-5 T) magnetic field.
For I=10 A, L=5 cm, F=2.5 N. Current pulse duration ~100-500 us



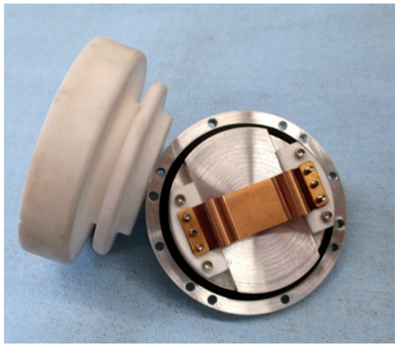
$$d\vec{F_A} = I[d\vec{l}\,\vec{B}]$$



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



Pulsed valve for
Un-polarized gas
Injection to the EBIS



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

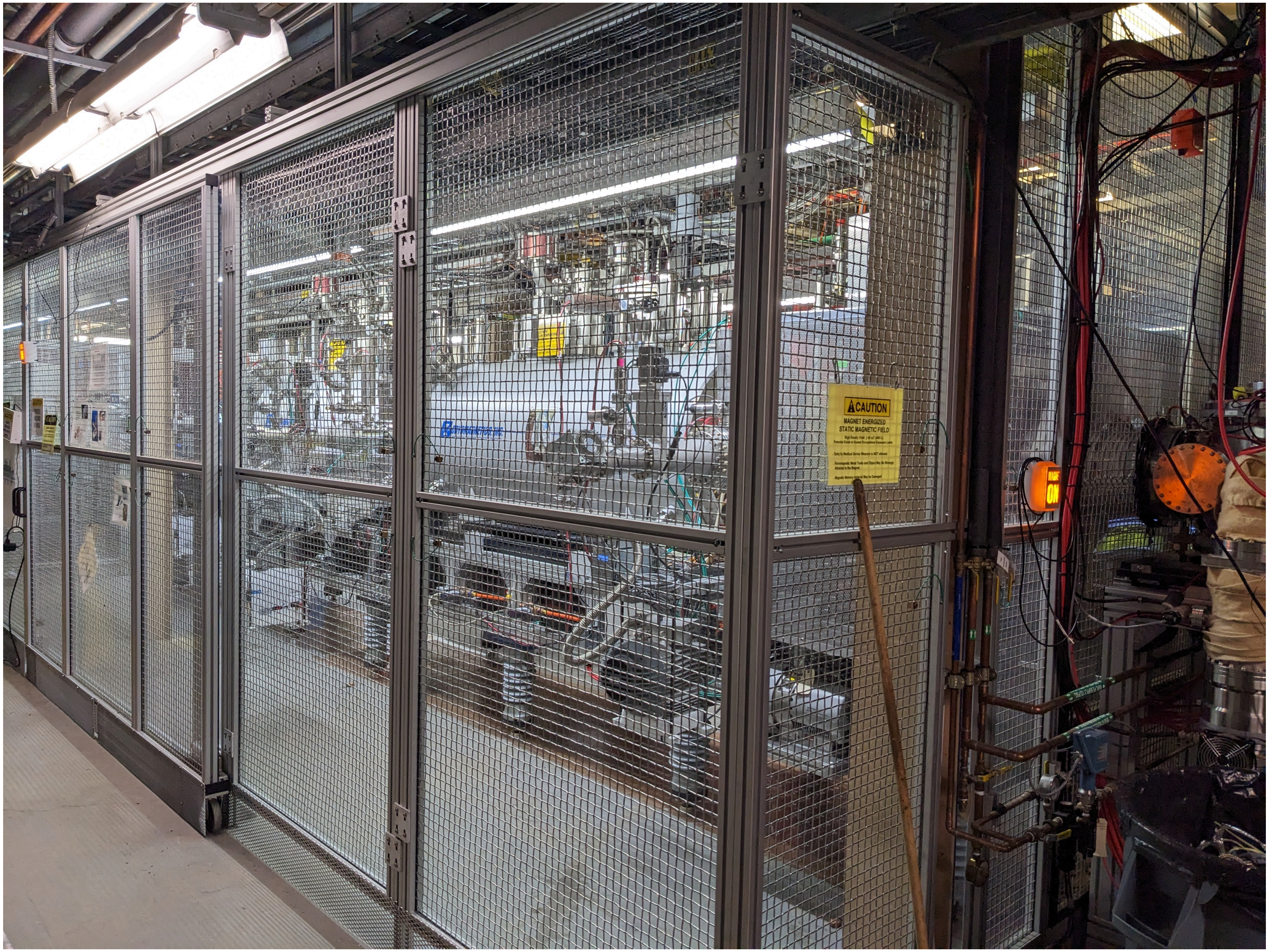
New Electron Gun Cathode:
3M lower temperature oxide cathodes. improved reliability and lifetime, improved beam quality, domestically available, important for BNL and our other colleagues at ANL and FRIB

New Solid State Electron Collector Supply:
(Arrived too late for installation)
Expect less down time with faster reset time, collector voltage can be varied during a single species beam time as well as optimized for each species (future installation date to be decided).

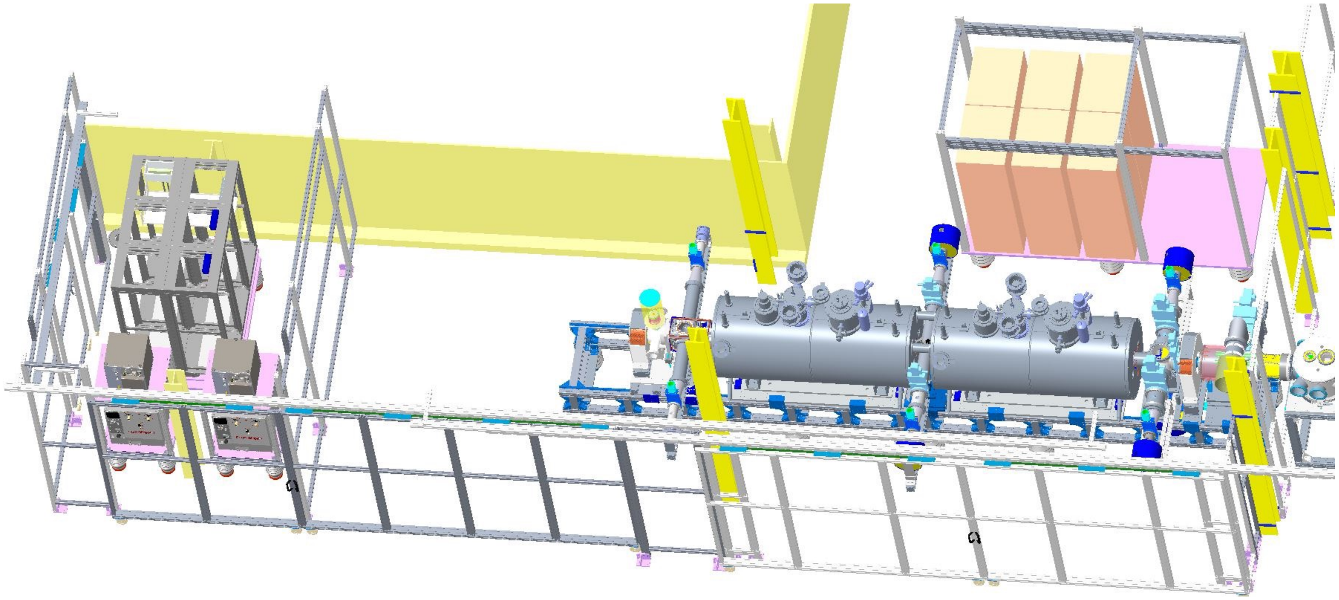
Extended EBIS Installation at the Accelerator Location

Brookhaven National Laboratory

EEBIS – HV Cage



Extended EBIS Installation at Accelerator with High Voltage enclosure



Left: Solid State 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.

Very high charge state ions were delayed until a bakeout could be fit into the the busy NSRL schedule…but were produced immediately with the vacuum improvement once bakeout by the vacuum group was made.

Gas injection is working with He for NSRL.
Gas is ionized in the gas trap and transferred to the LONG trap for fast extraction by the Behlke HV electronics.

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.

The Behlke fast HV electronics is not yet installed for the short trap, so the short trap is not currently in use for ion capture or high charge state ion extraction. (The tentative installation dates are Thursday and Friday Sept 7-8, 2023, with tuning during the weekend and restart of NSRL operations on Monday Sept 11.)

Commissioning Milestones (March-August 2023)

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 Behlke switch 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 Si11+, Nb23+, Ta38+ and Au32+ easily produced now. The EBIS vacuum is improved greatly after the bake and NEG activation.

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
FC96 = 45 uVs with 6.5A ebeam not fully optimized

EEBIS Operation Status at the accelerator

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

2) He gas injection, ion transfer to the 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) 12P/sc Au32+ operation has had some difficulties due to prolonged HV discharges on drift tubes in the gas injection region. The voltages have been reduced and the electron beam energy has been maintained by operating with a higher cathode bias voltage. (This new distribution has been demonstrated on Sunday Aug 27, 2023 and should allow operations to continue without physical rework of the "problem" drift tubes).

6) Matching of NSRL distributions to the Au32+ distribution is expected to provide better stability for NSRL beams as well.

Future Tasks

Sept 7-8, 2023   Installation of the Short Trap HV extraction system

Combined short and long trap operation for increased Au32+ intensity. (as soon as feasible)

December 2023 Unpolarized 3He2+ ion beams could be transported to test the chicane beam line and polarimeter.

Future upgrades will include:

- installation of the new electron collector supply
- a high field 3He polarization setup in the bore of the first superconducting solenoid, a second gas injection valve and gas handing system, and a gas manifold for remote automatic gas switching.

Reference Material

Infrastructure Timeline (Reference material)

Infrastructure upgrades to the Extended EBIS installation site began just after July 4, 2022, after the end of NSRL operations. The site includes the previous RhicEBIS area plus an adjacent space previously cleared to accommodate the longer Extended EBIS and a new solid state electron collector power supply. Decommissioning of the RhicEBIS was the first task, as it was necessary to remove the ion source to be able to access other equipment and install a new overhead trays and power distribution system for the installation of Extended EBIS.

- Aug. 1, 2022: RhicEBIS removed from installation area.
- Collector Power supply removed and 200kVA Isolation/Rectifier Transformer removed.
- 200kVA 480VAC Isolation Transformer installed for powering new solid state collector supply.
- Sep. 16, 2022: Extended EBIS Beam Tests completed in EBIS Test Laboratory
- Sep. 26, 2022: Pumping Speed vacuum characterization on Extended EBIS
- Superconducting magnetic fields ramped down and Extended EBIS disassembled for move to accelerator site.
- Oct 11, 2022: Extended EBIS moved to accelerator installation location
- Nov 2022 Extended EBIS vacuum system reassembled, mechanically aligned, under vacuums
- Dec 2022 Electrical Infrastructure complete (except final collector supply installation)
- Feb 23, 2023 Accelerator Systems Safety Review Committee (ASSRC) walkthrough of EEBIS. (All prestart items completed).
- March 2023 Rack power supply, controls and vacuum controls completed …some small ongoing tasks remain

- Solid state collector supply installation was expected during January 2023. This was delayed, depending on the ongoing acceptance testing. The old collector power supply was re-installed, taking considerable manpower and requiring an additional month to accomplish.

Upstream Section being installed
(October 12, 2022)

Extended EBIS Installation
(December 8, 2022)