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U.S. DEPARTMENT OF ENERGY

Extended EBIS Development and Plans

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Extended EBIS and the upgrade to a Polarized 3He2+ source is made in a collaboration between BNL and MIT

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The Extended EBIS

Two identical unshielded superconducting solenoids are used in the “Extended” EBIS design.

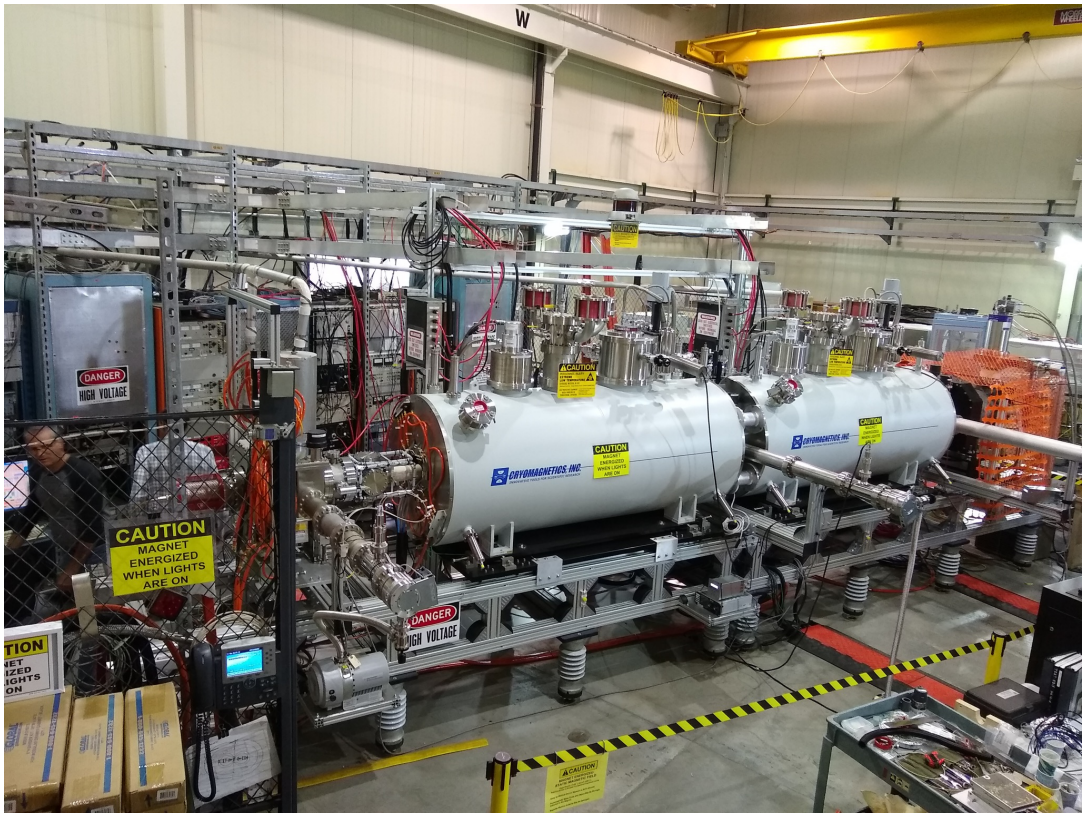
The upstream solenoid contains most of the new features for the polarized 3He ion production:

- **gas injection/ionization cell operating at pressures up to 5x10^{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.

Extended EBIS in Test Lab



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Extended EBIS Performance Goals

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 then the EIC leads also to increases in other ion intensities.

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

Intensity Estimates for EBIS upgrade (at Extended EBIS exit)

Au^{32+} ~2.6×10^{9} ions/pulse (1.4-1.5 times the RhicEBIS output)

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

H^{+} ~5 – 10 x 10^{11} ions/ pulse

Extended EBIS Development

Work in the Test Lab has concentrated on:

1) Verification of Extended EBIS electron beam in two solenoid system

2) Development of Highly efficient gas injection system

3) Verification of Ion transfer and extraction

4) Magnetic Alignment and Beam steering techniques to assure timely re-establishment of operation after Extended EBIS move to accelerator

5) Development of pumping systems compatible with gas injection in addition to ion injection

External Ion injection and Fast extraction will be developed at the accelerator location after Extended EBIS installation using existing beamlines, with some control system and power supply additions.

New Features

High-capacity NEGs + Turbo Pumping Provide high pumping speed where needed; eliminate most cryopumps that needed high vacuum conductance to ionization region and that are problematic with high helium loads

Align while EBIS is running
(HV cage is partitioned and HV connections are protected such that while EBIS is operating without the HV platform voltage necessary for ion acceleration through the RFQ, 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
(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)

Initial Operation after Installation

Initial installation at the accelerator will include a highly efficient gas injection system for light ions and an extended trap region for increased Au32+ production.

Polarized 3He2+ will not be available from Extended EBIS until the polarized upgrade is made, but **tests of unpolarized 3He and perhaps H+ could be made during the first year of operation depending on schedule.**

Future upgrades will include 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.

Extended EBIS Operating Modes:

RHIC Au32+: External Ion injection Combined Long and short trap

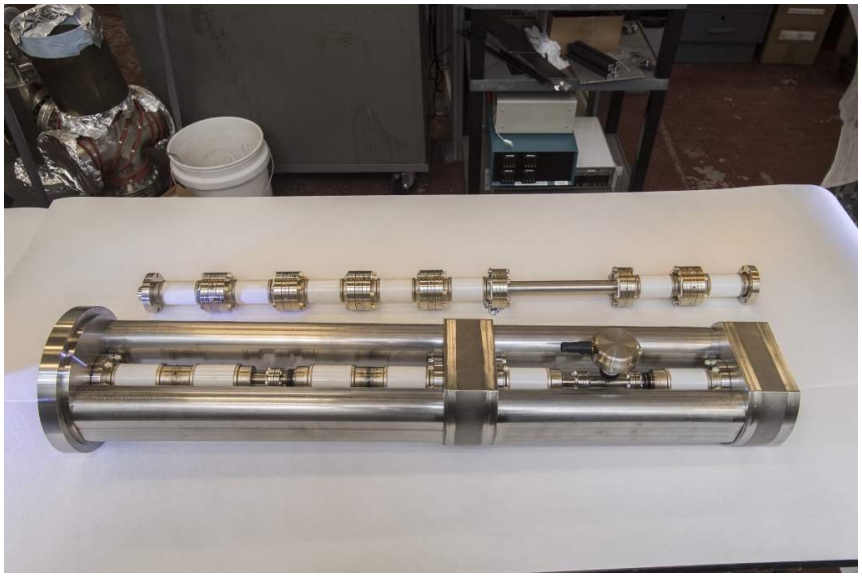
NSRL High charge state ions: External Ion Injection Long trap
(Very good vacuum conditions for very high charge state ions)

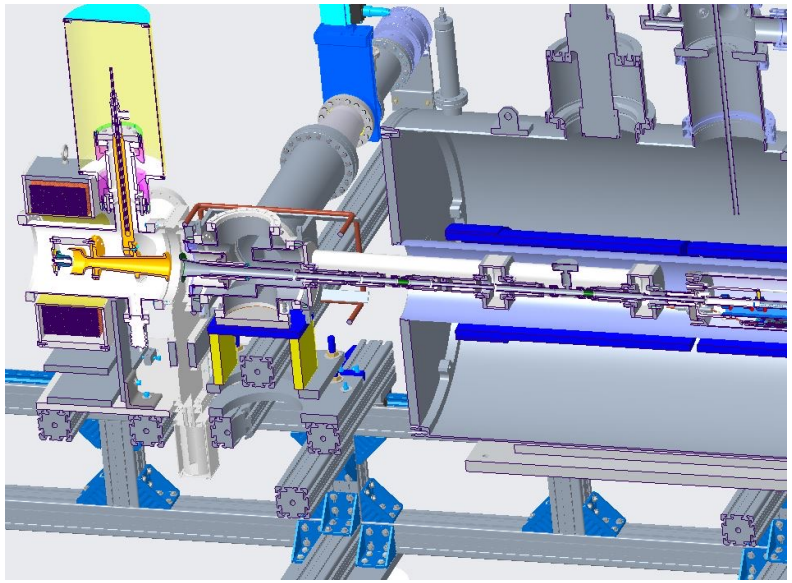
Light Ions: He, H Internal gas injection

3He: Internal gas injection; 3He2+ extraction from Long Trap

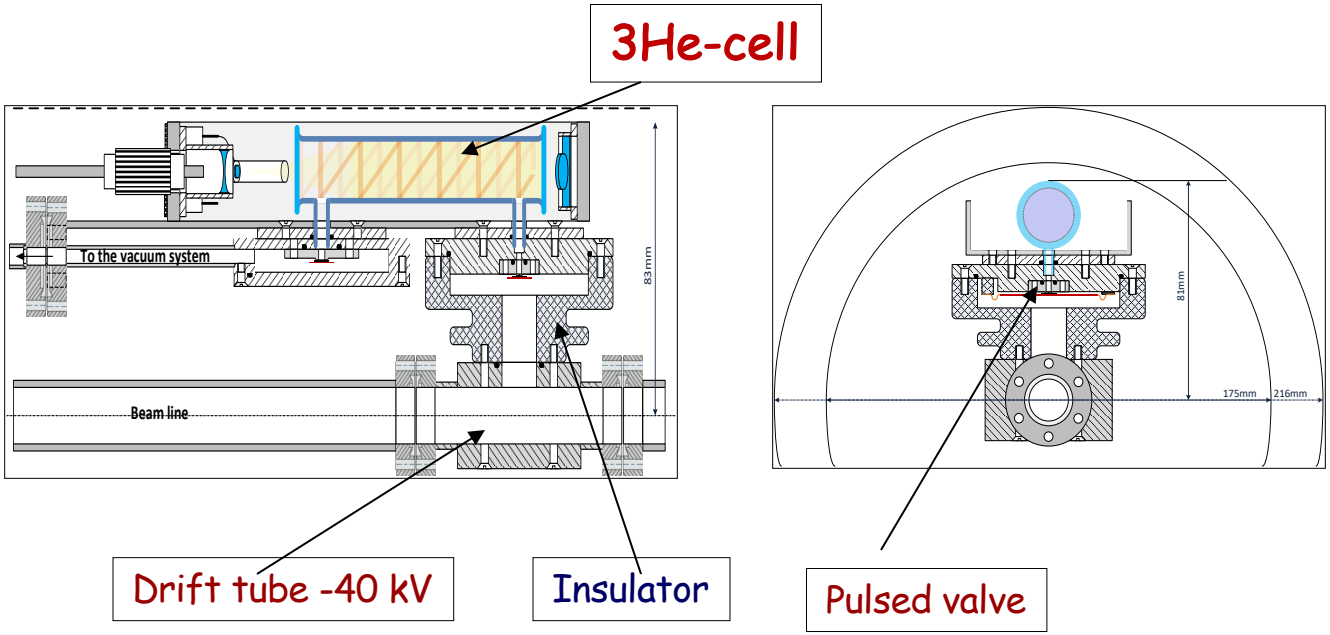
Extended EBIS Component Development

Gas Cell





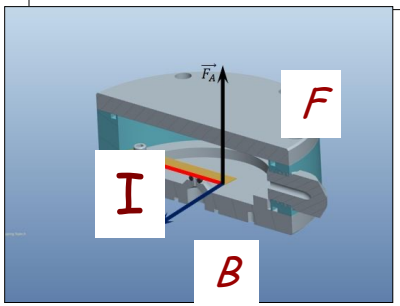
3He –optically-pumped cell in the high magnetic field (For installation at ExtEBIS during future upgrade)



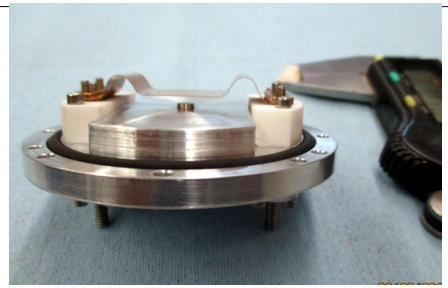
Long, small diameter drift tube works like a 3He storage cell, which reduces gas load to the EBIS vacuum system and increases polarization due to ionization localization in the high magnetic field region.

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

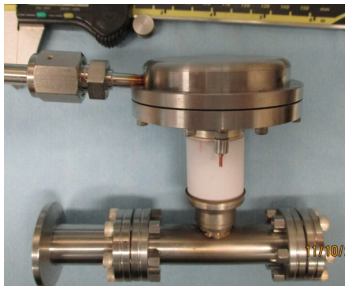
Lorentz (Laplace) force moves the flexible conducting plate in the high (~ 3-5 T) magnetic field.
For I=10 A, L=5 cm, F=2.5 N. Current pulse duration ~100-500 us



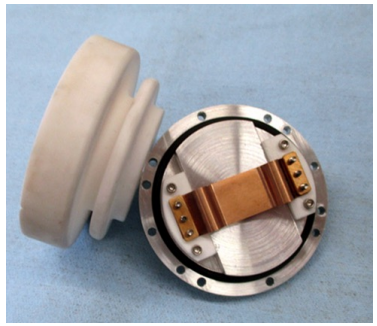
$$d\vec{F_A} = I[d\vec{l}\,\vec{B}]$$



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



Pulsed valve for
Un-polarized gas
Injection to the EBIS



Upstream Drift Tubes (right foreground)

Two module ZAO high-capacity NEG pump unit (left foreground)
---custom BNL design for activation by electrical heating

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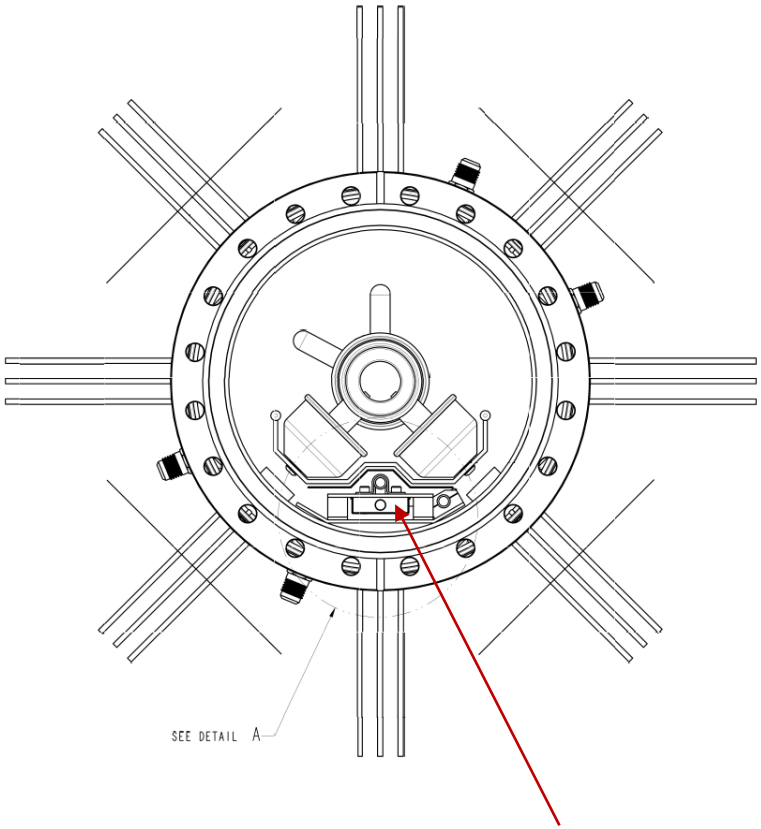
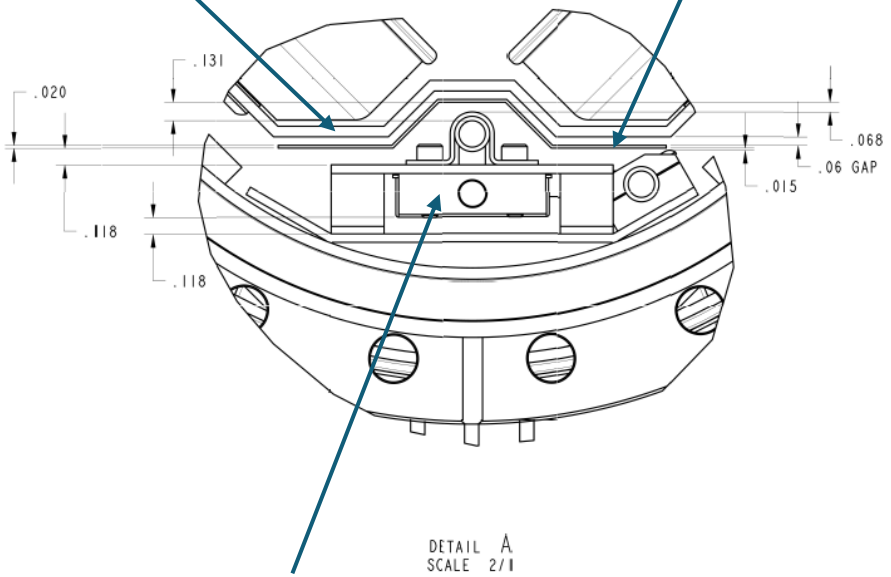
Design of ZAO NEG Linear Pumping System



Tray supporting drift tubes

Heat shield

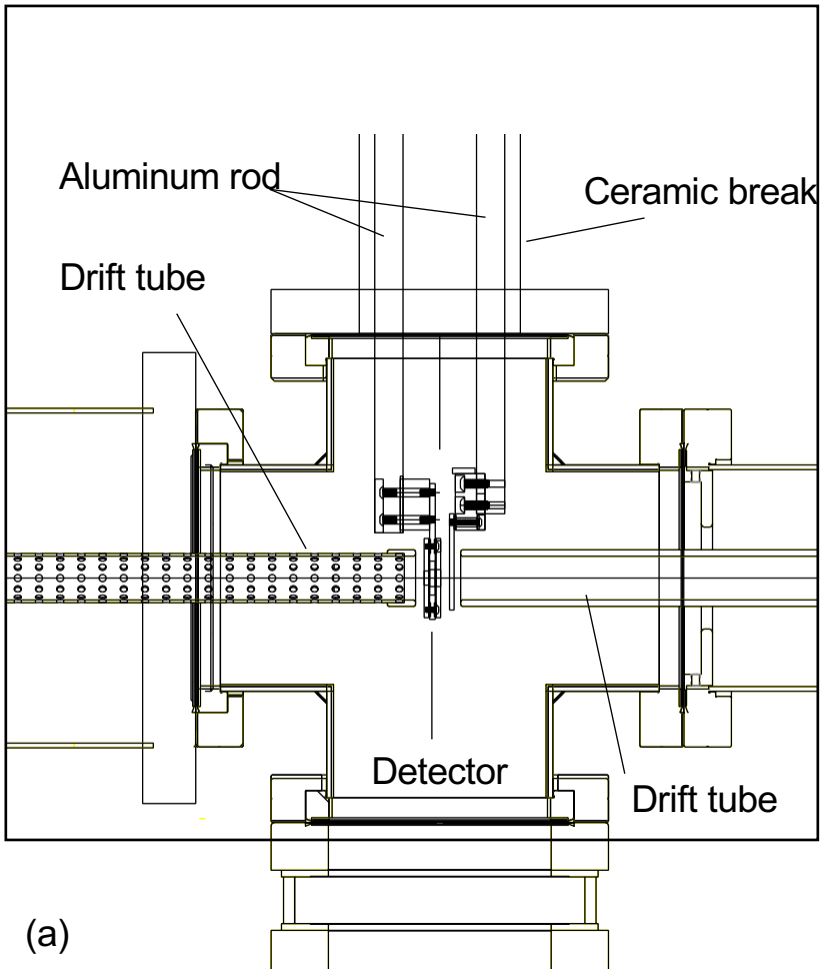


ZAO NEG linear pumping system

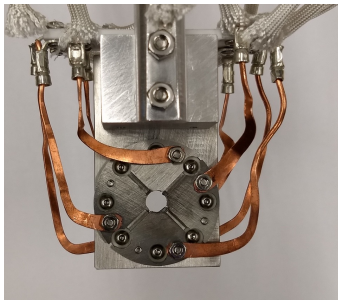
ZAO NEG linear pumping system will be placed under tray supporting drift tubes

Downstream Drift Tubes and Custom Linear NEG Module (Installed for May 2022)

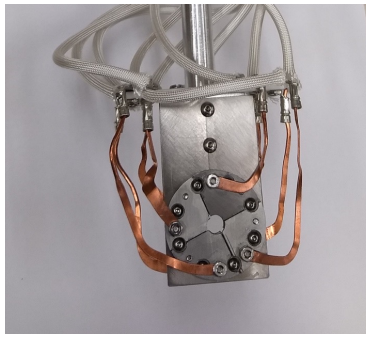
Quadrant electron beam detectors



(a)



(b)



(c)

Independent quadrant detectors were installed in a temporary central chamber between the two superconducting solenoids. They are useful during electron beam alignment procedures and used to detect primary electrons as well as electrons reflected or backscattered from the electron collector.

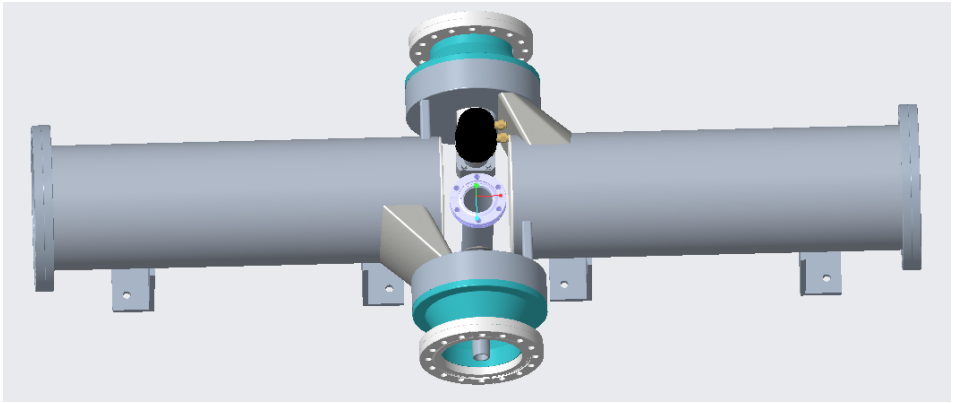
Used in tests through Sept 2021
(To be re-installed June 2022)

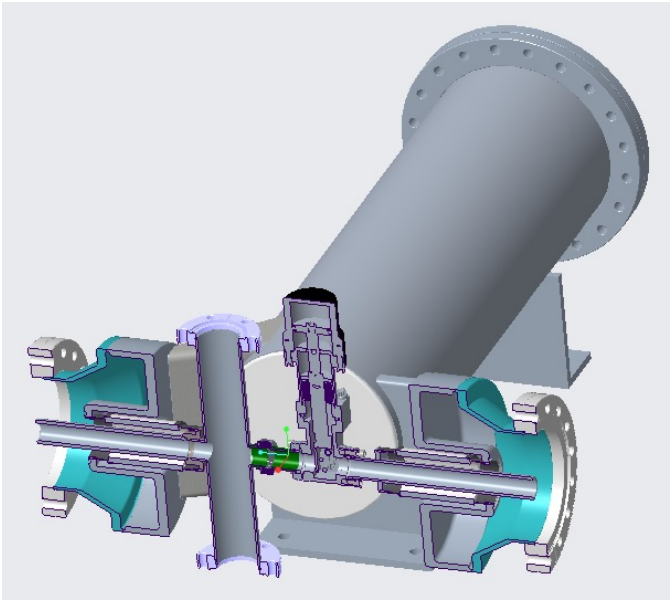
Center Vacuum Chamber (installed for operation in May2022)

Includes port for double-sided quadrant detectors

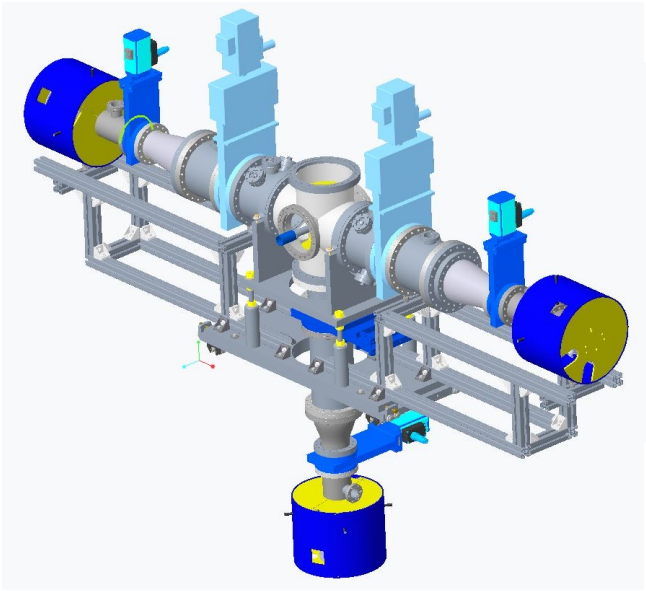
Includes gate valve for isolating upstream and downstream vacuum chambers

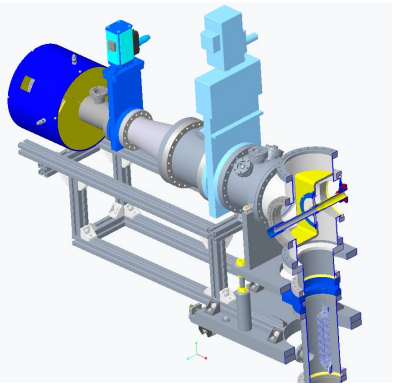
Differential pumping ports for upstream and downstream regions

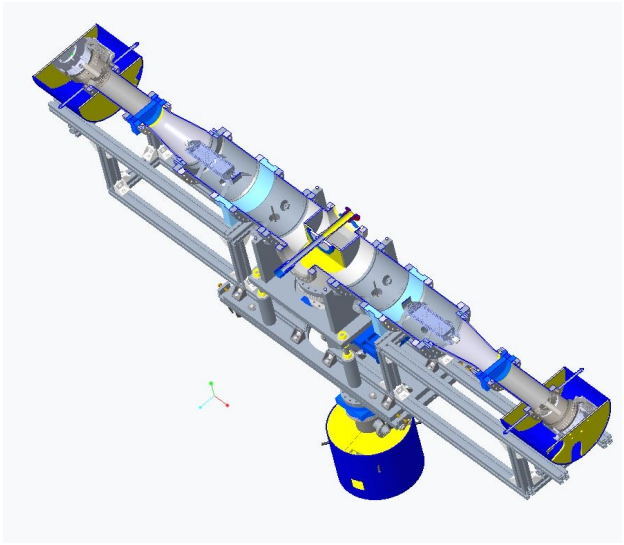




Vacuum chamber with improved differential pumping between downstream ionization trap and the electron collector compared with RhicEBIS (Installed for May 2022)







Electron Beam Results

May 2022 Testing: Complete drift electrode and vacuum system installed.

1) High efficiency gas injection system
2) Upstream short trap (custom NEG not yet activated)
3) differential pumping system and gate valve between solenoids
4) downstream long trap (custom NEG not yet activated)
5) differential pumping system before electron collector

Electron beam results quickly exceeded results of the previous testing phase ending in Sept 2021, by using techniques developed in the earlier tests:

1) low current electron beam verification, with transverse coils
2) magnetic system alignment procedure
    a) low current electron beam (<1A)
    b) no transverse magnetic steering
    c) move all solenoids to eliminate ebeam losses on DTs

Achieves good Magnetic alignment; transverse coils necessary above ~4A

New Electron Beam Results:

8.8A, 1ms pulsed electron beam (Anode power supply voltage limit)
4A, 120ms electron beam
5.2A, 50ms electron beam

Ion production Tests Using gas injection in progress

Gas Injection and Ion Extraction

Sept 2021 Gas injection and Ion extraction results:

1) High efficiency gas injection system
2) Upstream short trap (custom NEG activated)
3) Temporary but functioning drift tubes in the downstream solenoid.

Gas injection cell, Lorentz pulsed valve, and pump out manifold were tested:

1) Helium, Argon and Hydrogen gas.
2) 3A electron beam
3) Verified low gas was seen to migration to down stream regions
4) Ions were created in gas region and transported to traps.
5) Ions extracted to Faraday Cup after electron collector

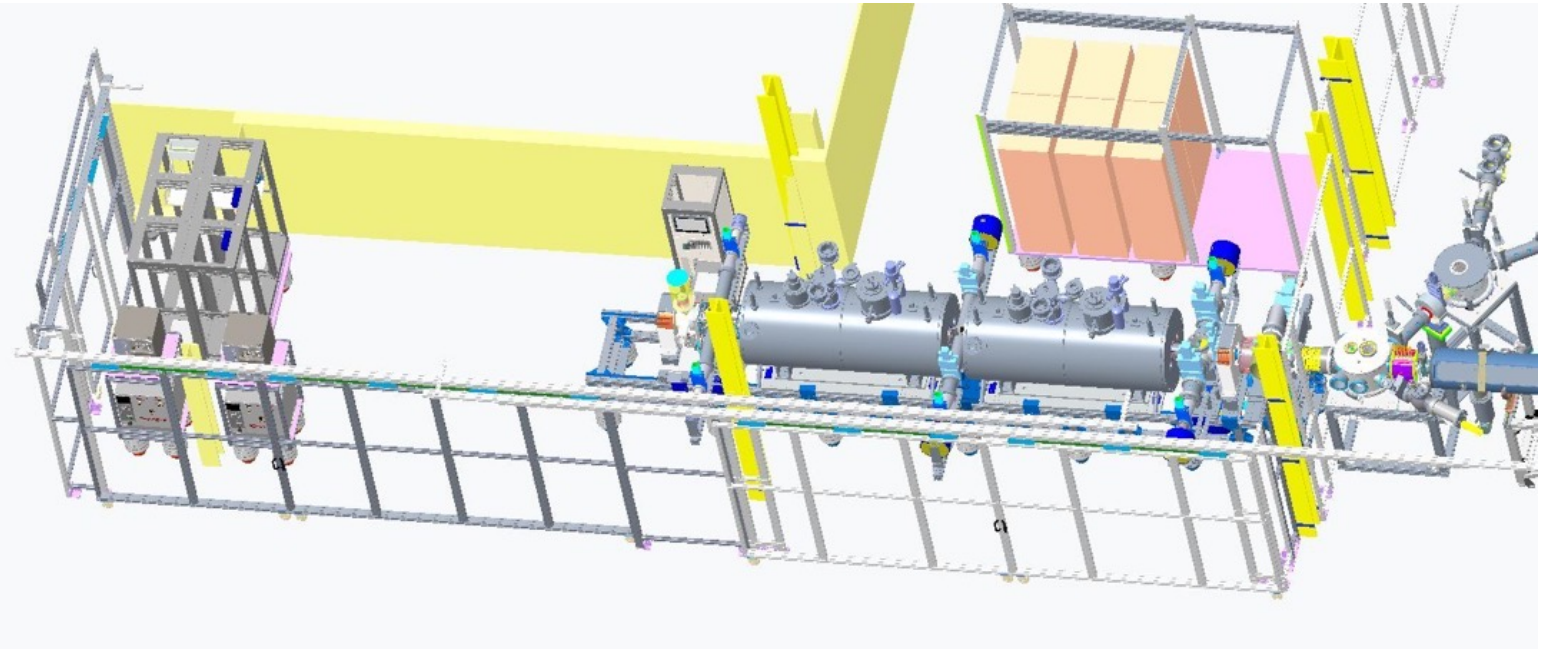
The upstream short trap performed very well.

Downstream trap hampered by poor vacuum.
(Only the upstream NEG pump was installed and activated. The differential pumping was not installed between the solenoids or before the electron collector).

Schedule

May–Aug 2022:	Tests of Ext-EBIS final configuration (in Test Lab)
June 13-24	Light Bake and NEG Activation (in Test Lab)
July 2022	Gas injection and Ion Extraction (in Test Lab)
July 2022:	RhicEBIS decommissioning
July—Aug 2022:	Electrical and Water infrastructure Installation
Aug 15, 2022:	Installation of Ext- EBIS at accelerator
Sept-Oct 2022:	Electrical, vacuum, controls connections
Nov - Dec 2022:	Safety Review and Commissioning of Ext-EBIS
Jan 2022:	Ion Injection and Extraction Tests/Operation
*Oct-Nov 2022 ?	New or Old Collector Power Supply Installation

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

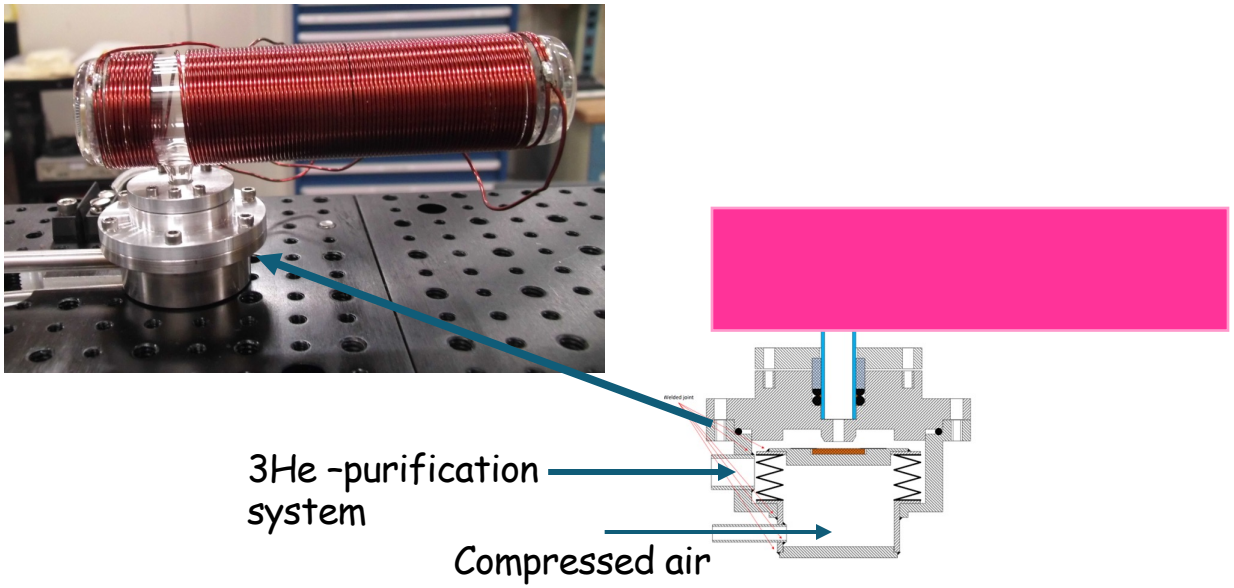
Summary

- The Extended EBIS magnetic system, electron optics, high efficiency gas injection system, and final vacuum system and drift tube electrodes have been installed and operated in the Test EBIS lab.
- Electron beams up to 1A were used to align the magnetic system and electron beams up to 8.8A were propagated to the electron collector with very little loss with the aid of transverse magnetic steering coils.
- Preliminary tests (Sept2021) of the high efficiency gas injection system with a custom precision gas pulsed gas valve was tested with He, Ar and H2 gas. This most critical test went very well. Ions were easily formed and transported to downstream traps and then extracted to a Faraday cup after the electron collector.
- A custom, high-capacity linear NEG pump was installed int the short trap and activated for the ion extraction tests. The NEG performed as expected.
- Final Drift tube electrodes and complete vacuum system installed.
- Tests with electron beams, gas injection and ion extraction with the final vacuum configuration are expected continue until August 2022.

Recent Developments towards 3He Polarization and 3He2+ transport and Measurement

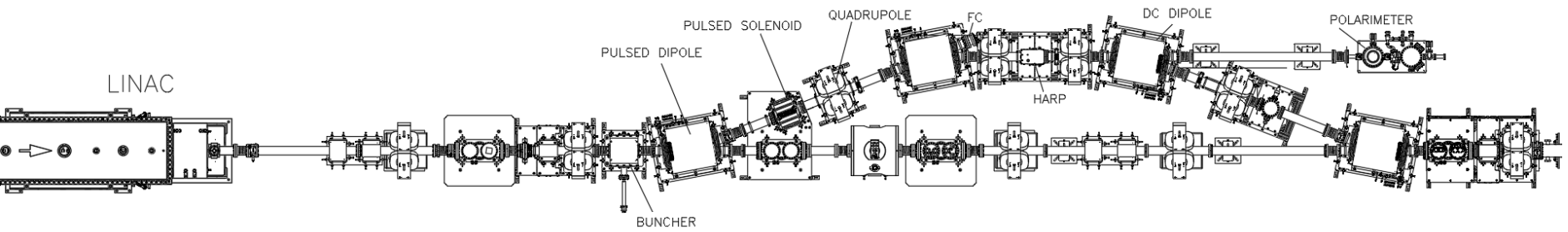
(Additional Material)

"Open" cell with inductive RF power input and new pneumatic 3He-filling valve.



$^3He^{++}$ spin rotator and polarimeter in the EBIS HEBT line at 6.0 MeV beam energy

3He-4He-scattering



The development of the 3He polarizing apparatuses, the spin-rotator, and the nuclear polarimeter at the 3He++ ion beam energy 6.0 MeV (in the high-energy beam transport line after the EBIS drift-tube Linac). Completion in 2022

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$^3He^{++}$ spin rotator and polarimeter in the EBIS HEBT line at 6.0 MeV beam energy

Progress:
-Buncher Cavity fabricated and tested
-Solenoid fabricated
-DC Dipoles, Faraday cup and Harp installed
-Stands fabricated
-Vacuum Chambers fabricated
-Pulsed Dipoles fabricated

Status of Optically-pumped $3He^{++}$ cell development at EBIS

Optical pumping studies of He- in high magnetic field is in progress.

Cryogenic He-3 gas delivery system provided required gas purity.

He-3 cell and laser system for the optical pumping is near completed.

Pneumatic gas filling valve was successfully tested.

Pulsed electromagnetic valve developed for the polarized gas injection to the EBIS.

Polarized He-3 cell development for installation to the extended EBIS is in progress.

3He Spin-rotator and absolute polarimeter (based on 3He3-4He elastic scattering) development is in progress.

Hiring process is beginning to replace two physicists from MIT that have left the research team.