28th Linear Accelerator Conference

Installation and on-line Commissioning of Electron Beam Ion Source at ATLAS

Speaker: P.N. Ostroumov

Co-authors: A. Barcikowski, J. Clark, C.A. Dickerson, M. Hendricks, Y. Luo, R.C. Pardo, C. Peters, M. Power, G. Savard, S.I. Sharamentov, R.C. Vondrasek, G. Zinkann

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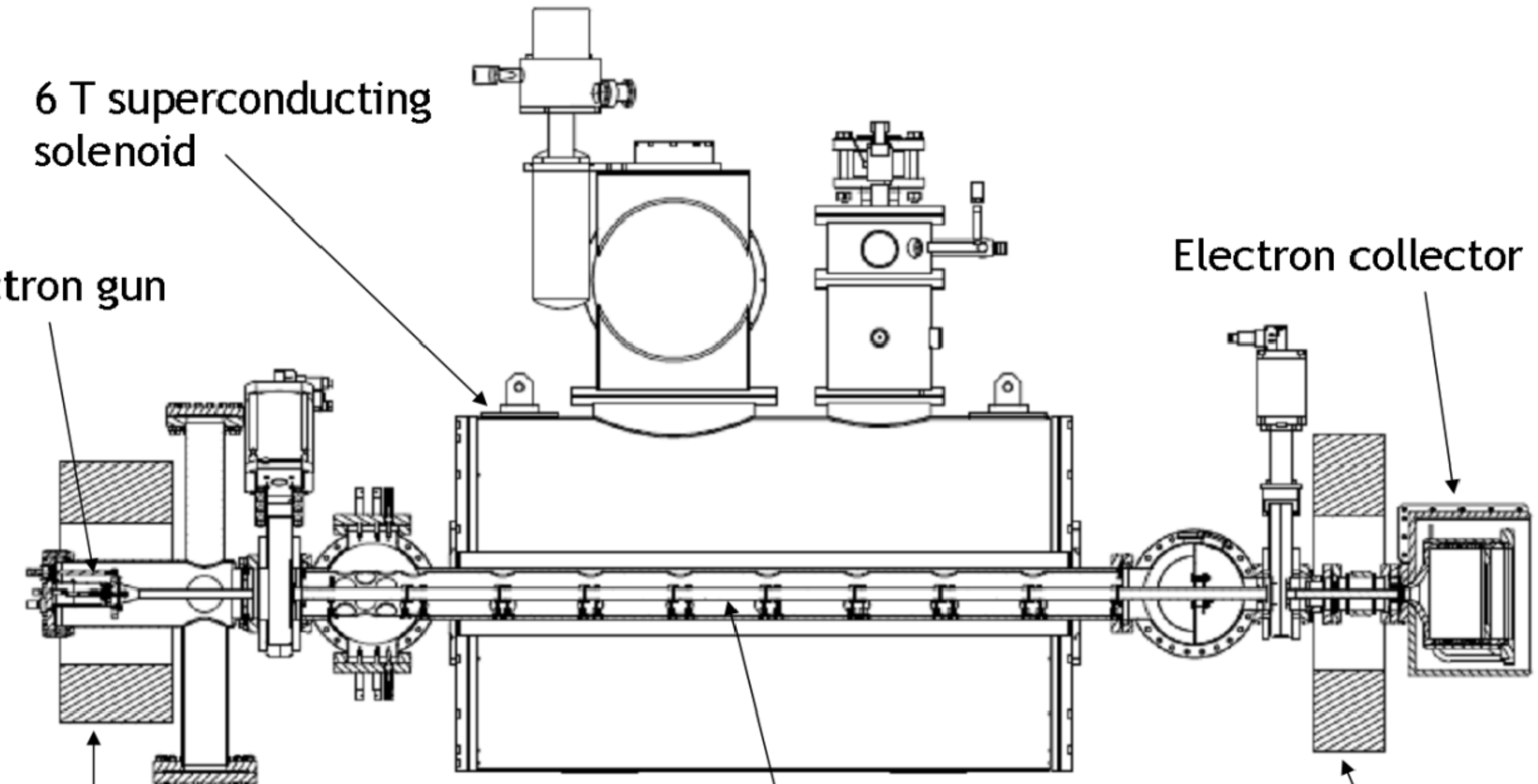
Outline

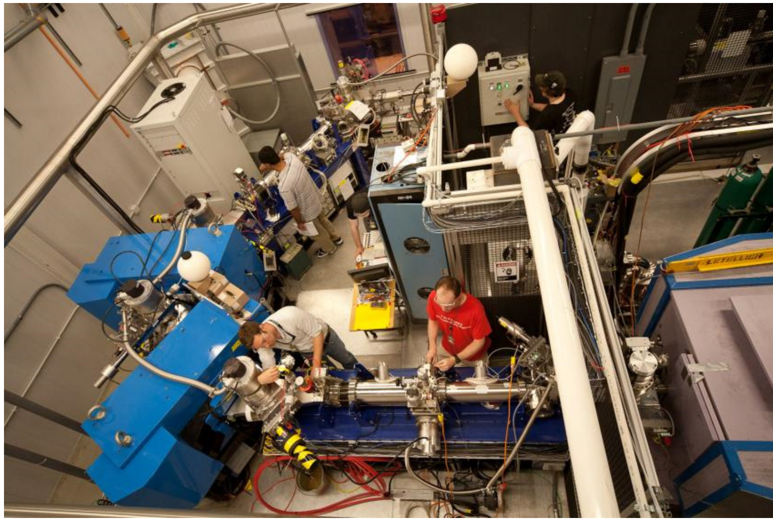
- Electron Beam Ion Source as a Charge Breeder
- CARIBU at ATLAS
- Results of off-line EBIS testing
- Installation and integration into CARIBU and ATLAS
- Acceleration of radioactive beams
- Beam test results

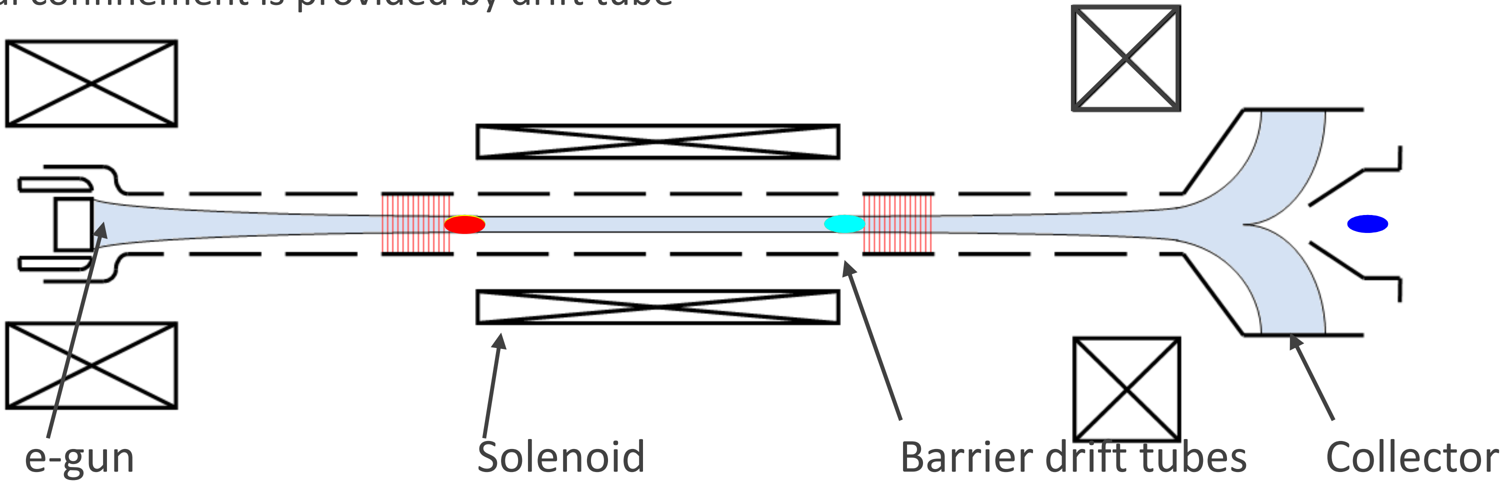
Major Components of Electron Beam Ion Source



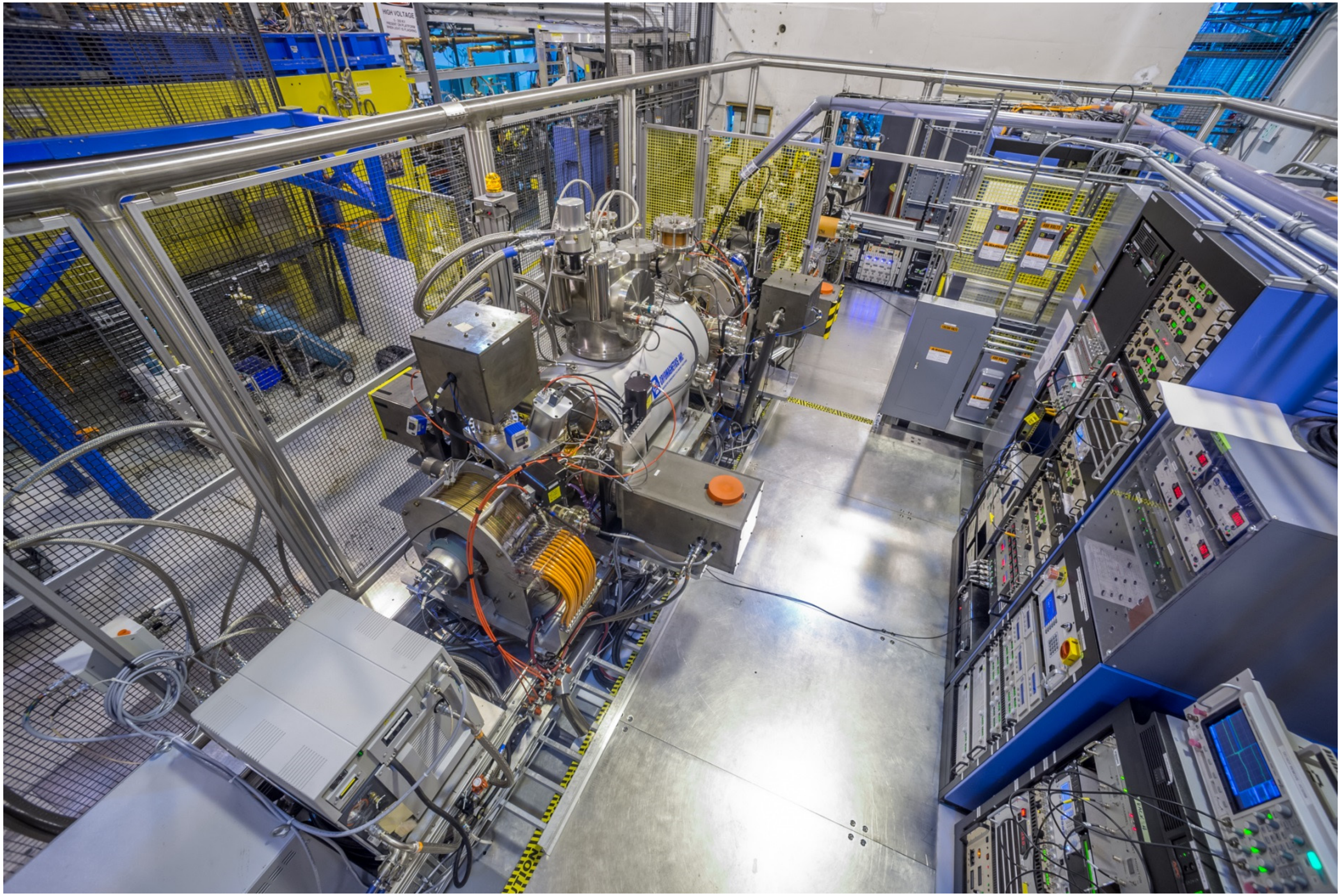
EBIS: Principal of Operation

- 1+ radioactive ions are accumulated in the RFQ cooler-buncher after the isobar separator
- Pulsed extraction from the RFQ-CB, injection into EBIS
- Charge breeding in EBIS while another portion of ions is accumulated in the RFQ-CB
- Highly charge ions are extracted from EBIS, ≥40 μs can be extended to several ms
- This cycle can be repeated every 33 ms
- Transverse confinement is achieved by electron beam space charge
- Longitudinal confinement is provided by drift tube potentials





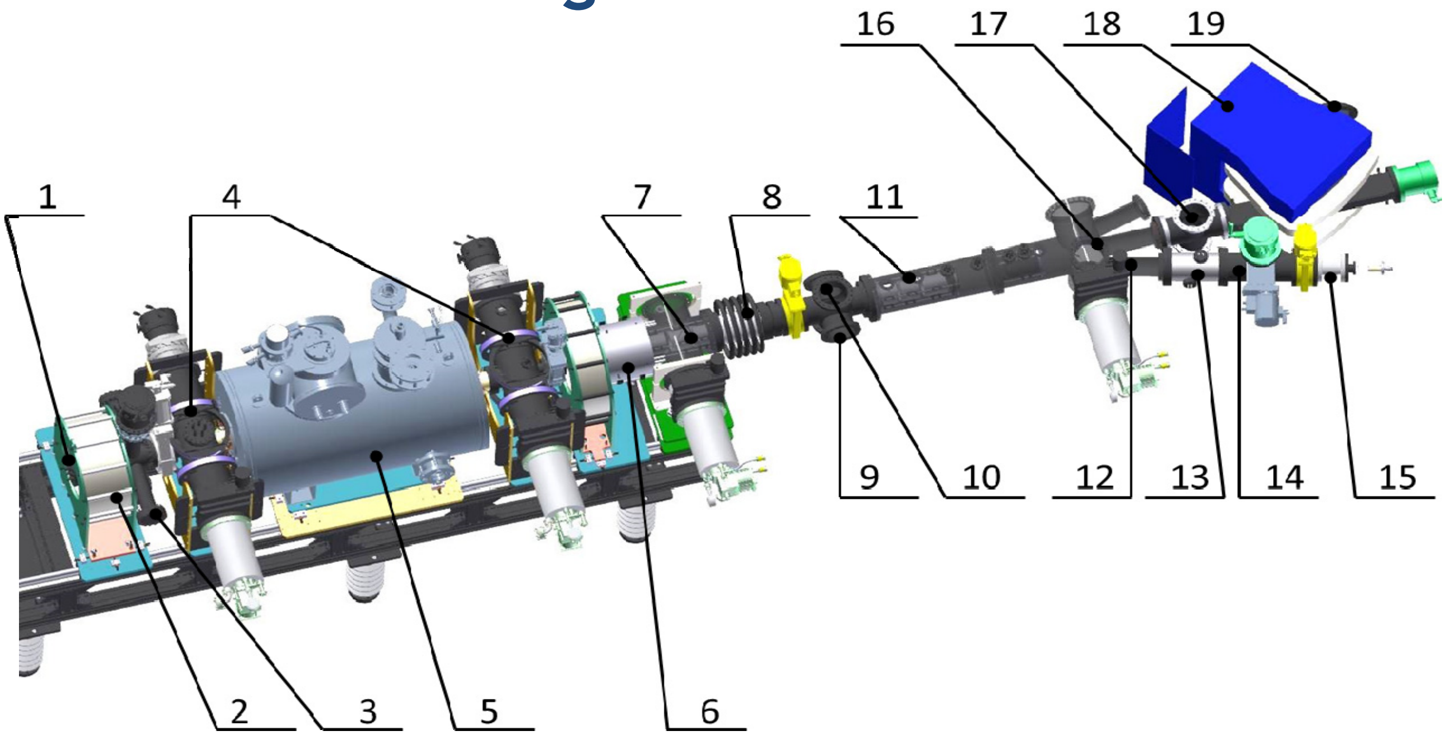
EBIS Charge Breeder at ATLAS



EBIS and Electron Beam Parameters

Parameter	Operational	Possible ultimate	Units
Magnetic field	5.0	6.0	T
Electron beam current, I_e	1.6	2.0	A
Cathode radius	2.1	2.1	mm
Magnetic field on cathode	0.15	0.15	T
EBIS platform bias voltage	20	50	kV
Trap length	0.5	0.7	m
*Electron beam radius in the trap	364	332	µm
*Electron beam density in the trap	385	577	A/cm^2
*Electron beam energy in the trap	6495	6265	eV
*Space charge potential well	299	374	V
**Normalized full acceptance	0.024	0.024	$\pi \times \mu m$
*Trap capacity	23	30	nC
Repetition rate	up to 10	30	Hz
Duty cycle	up to 60	90	%
Vacuum	$\sim 1\times10^{-10}$		Torr

Layout of EBIS Testing

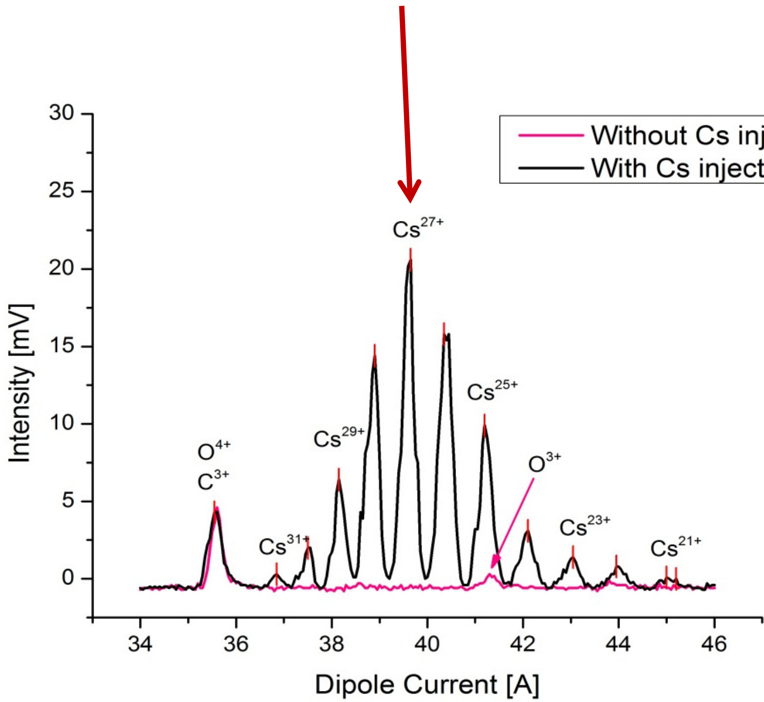


- 3D model of CARIBU EBIS CB (1- e-gun, 2- room temperature solenoid, 3 – recently installed NEG pump, 4 - end crosses of the ion trap chambers, 5 - 6 Tesla superconducting solenoid, 6 - electron collector with room temperature coil, 7 - Einzel lens and steerers (EBIS potential), 8 - 75 kV accelerating tube, 9 – Faraday Cup for cesium beam (FC2), 10 – pepper pot MCP-based emittance probe, 11 - Einzel lens and steerers (ground potential), 12 - Faraday Cup for cesium beam (FC1), 13 - steerers, 14 – quadrupole lenses, 15 – Cs+ ion source and accelerating tube, 16 - electrostatic switchyard, 17 - Faraday cup for charge bred beam (FC3), 18 - 70° bending magnet, 19 – slits and Faraday Cup (FC5).

Cs Breeding

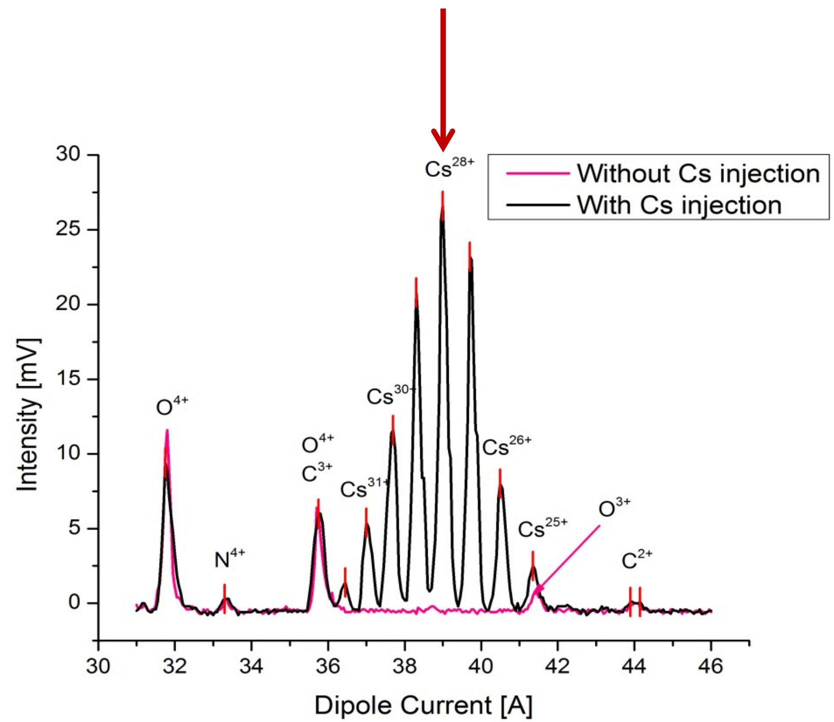
20 msec

Cs^{27+}, A/Q=4.925



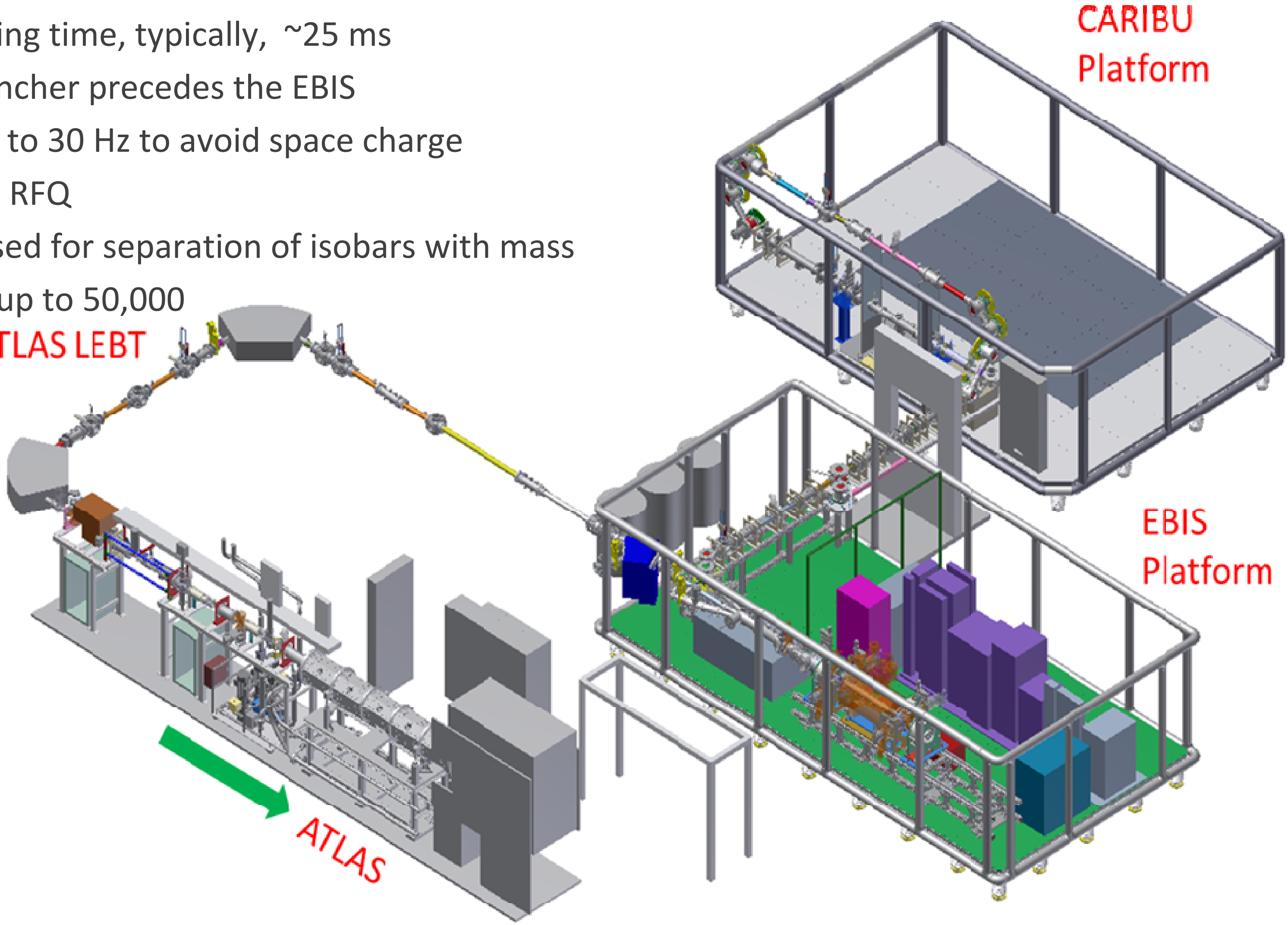
30 msec

Cs^{28+}, A/Q=4.75



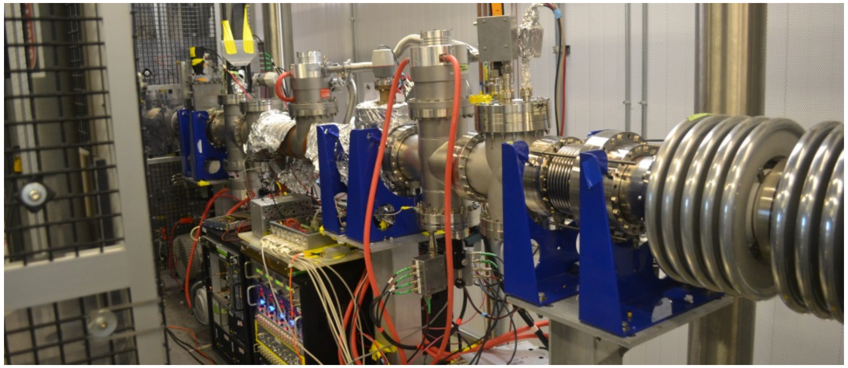
EBIS Integration

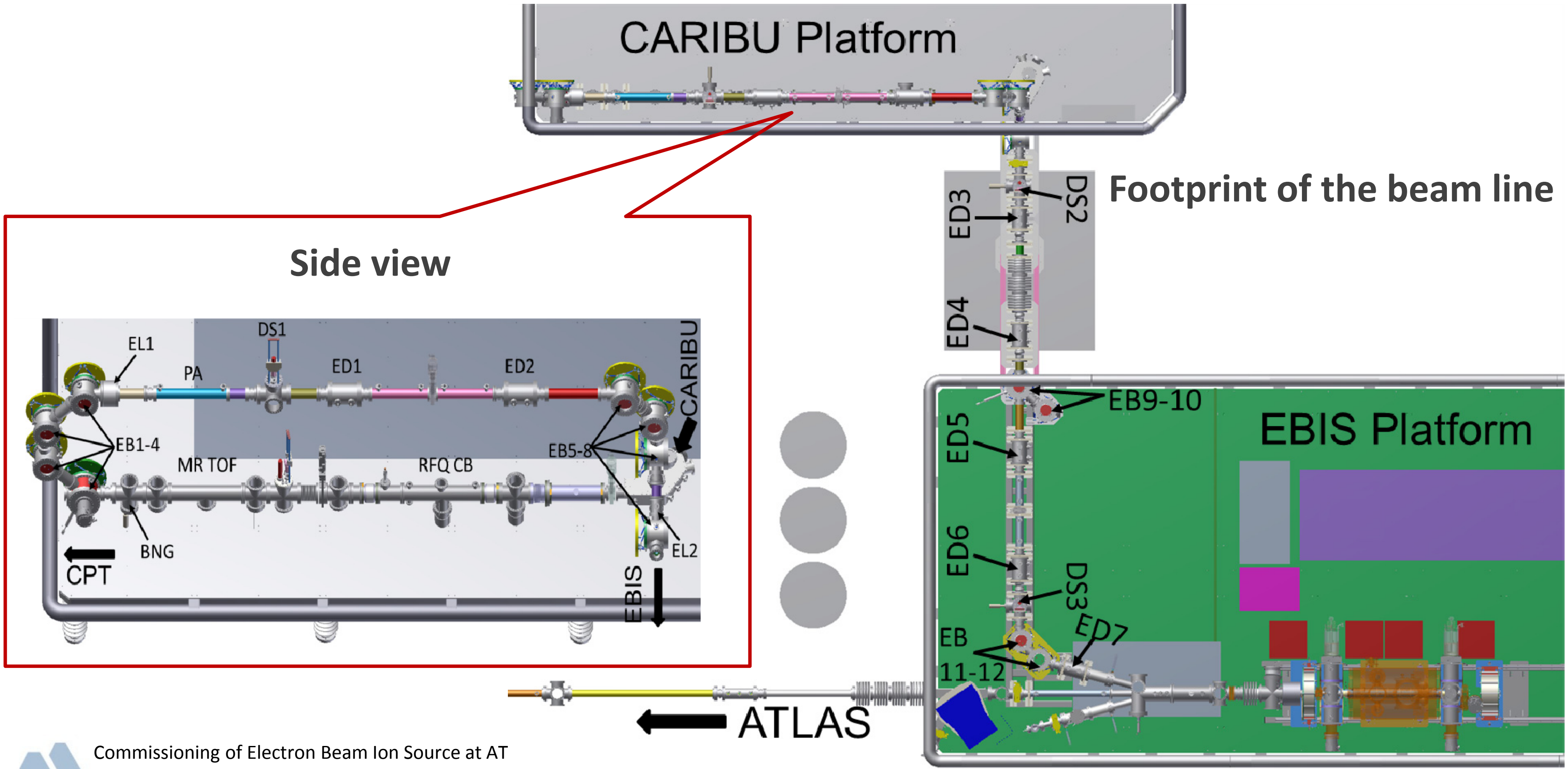
- Provides several important gains versus ECR charge breeding at CARIBU
  - Higher charge breeding efficiency for pulsed injection operation
  - Suppression of stable ions background
  - Faster breeding time, typically, ~25 ms
- An RFQ cooler buncher precedes the EBIS
  - Rep. rate up to 30 Hz to avoid space charge effects in the RFQ
- MR-TOF can be used for separation of isobars with mass resolving power up to 50,000



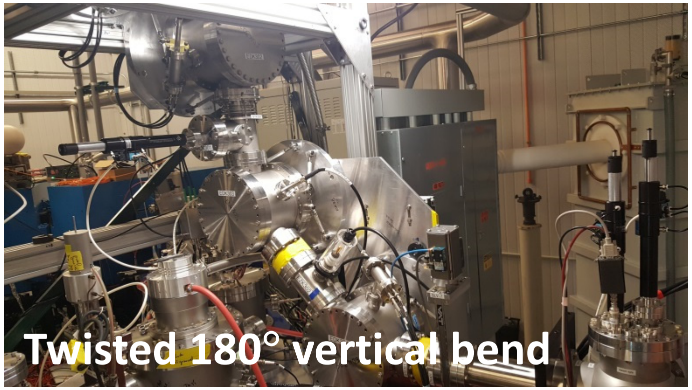
CARIBU to EBIS Beamline

- 3 keV beam after the RFQ-CB
- Pulsed acceleration in “elevator”
- Two 180° turns due to limited space



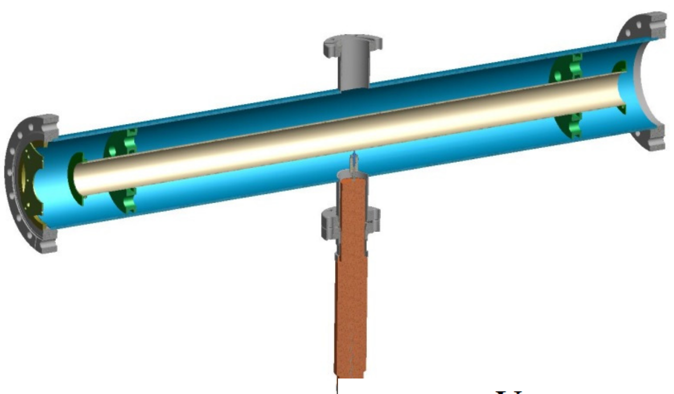


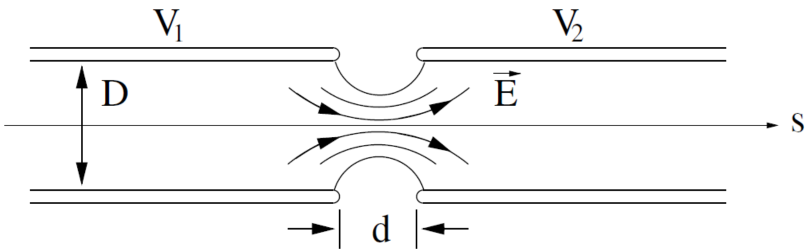
Beamline from MR-TOF to EBIS



Pulsed Acceleration of Short Bunches

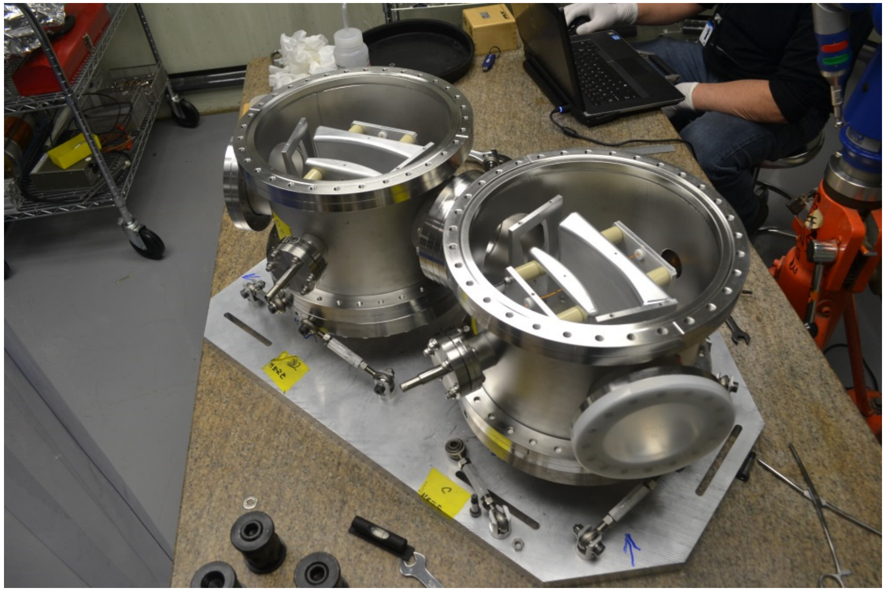
- Two step acceleration from 3 keV to 20 keV to avoid strong over focusing
- The beam energy should match to the deceleration voltage of the EBIS platform bias
- Solid state Belhke switches are used to pulse DC HV power supplies
- Limits the beam pulse length to ~2.5 µs



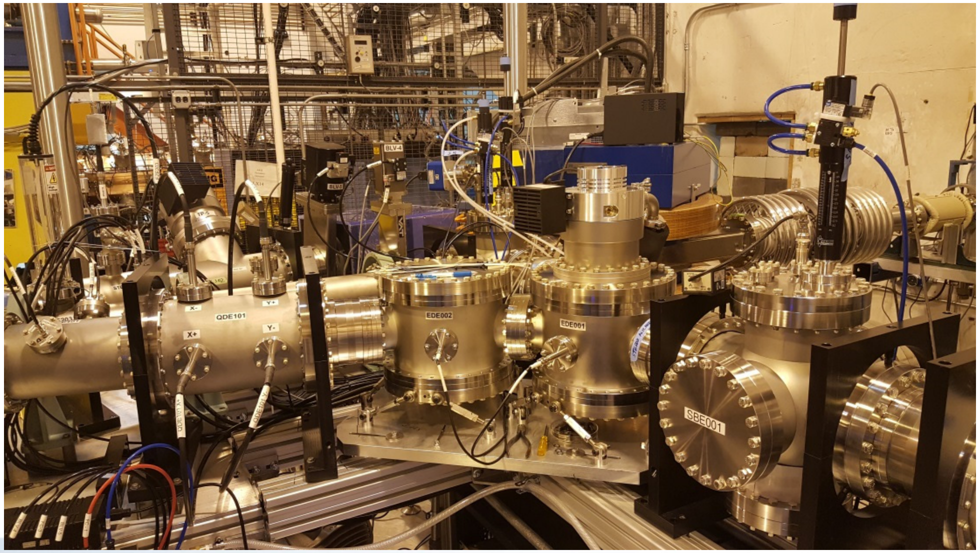


Electrostatic Beam Diverters

- 30° and 45° electrostatic diverters
- Spherical electrodes
- Linear optics in wide aperture



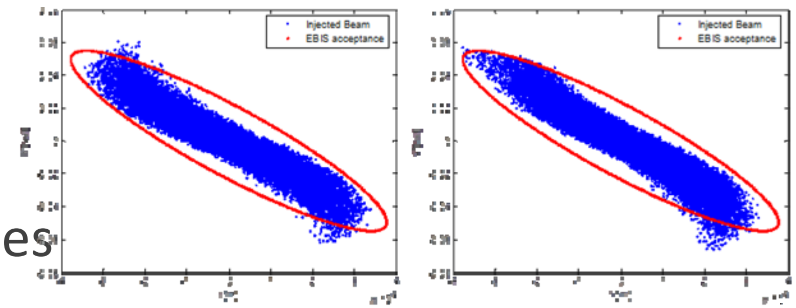
75° bend into EBIS switchyard

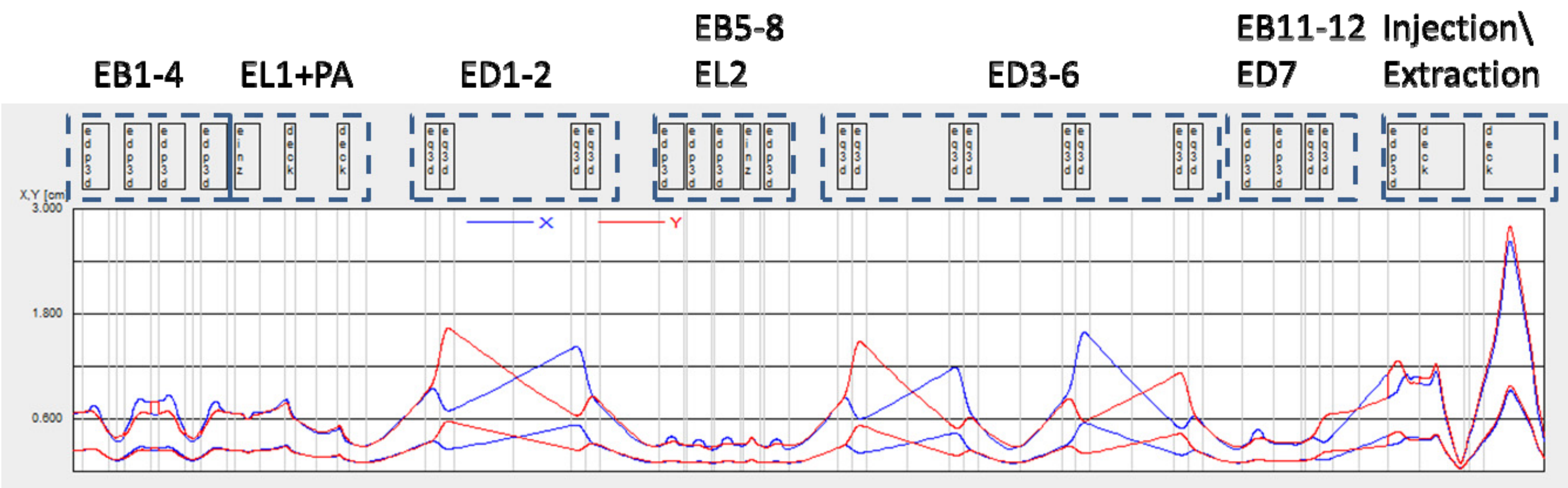


Beam Optics

- All-electrostatic 15-m long beam line
- Emittance growth is minimal
- Beam is well matched
- The simulations were done for 3 times larger emittance than after the RFQ cooler-buncher, 0.003 $\pi \times mm \times mrad$

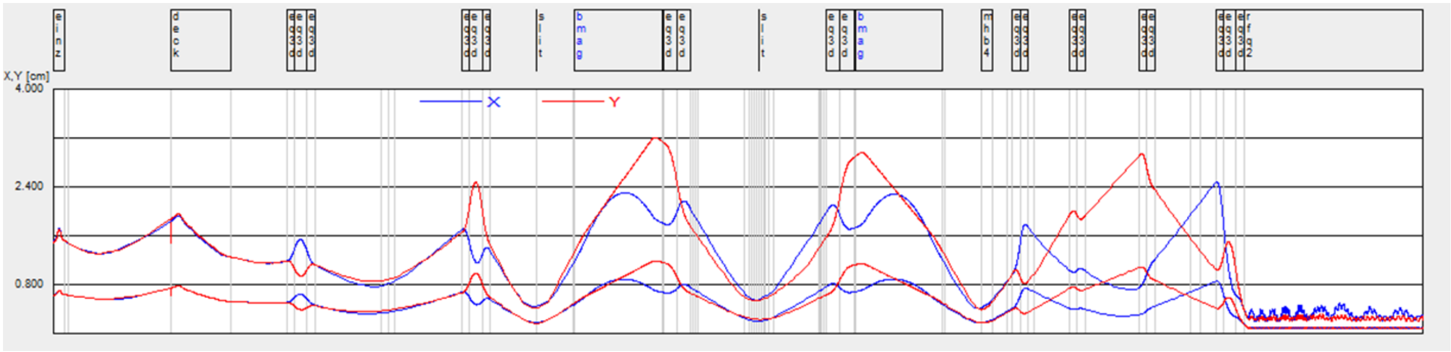
Matching to the EBIS acceptance

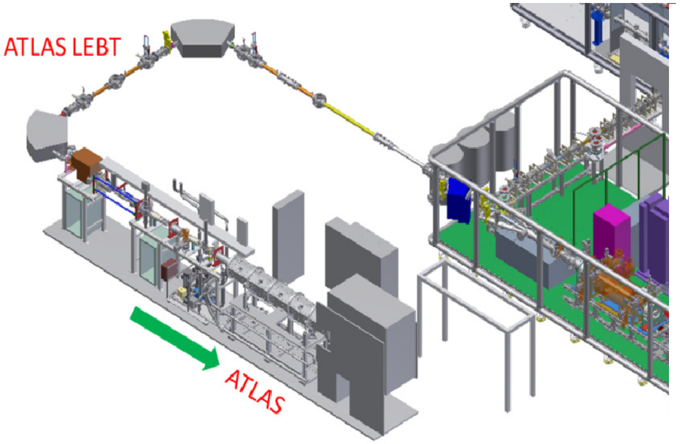


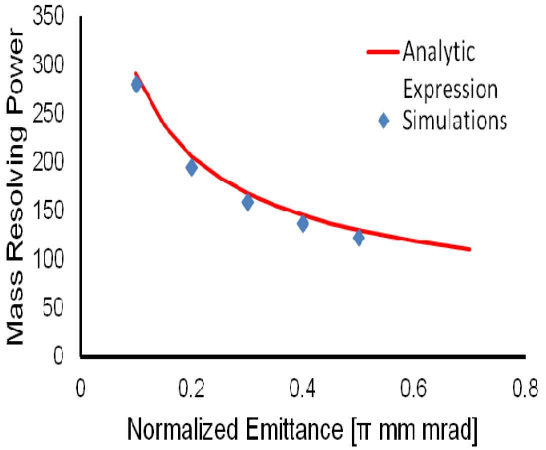


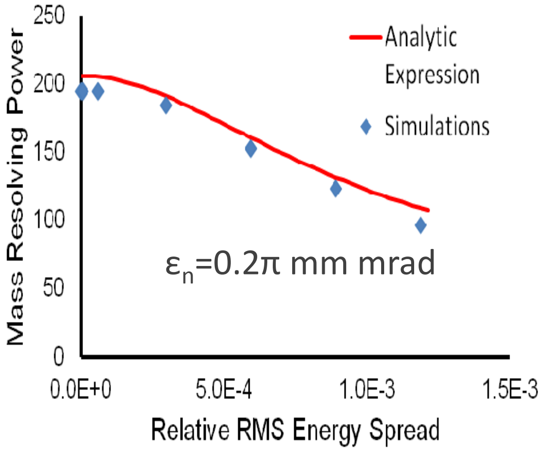
From EBIS to ATLAS RFQ, Q/A≥1/7

- Achromatic transport
- Mass resolving power is nearly 200, depends from the emittance and energy spread
- Additional contamination suppression is in ATLAS RFQ



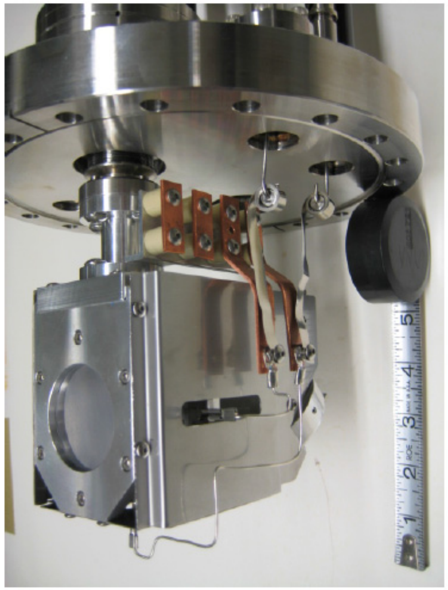


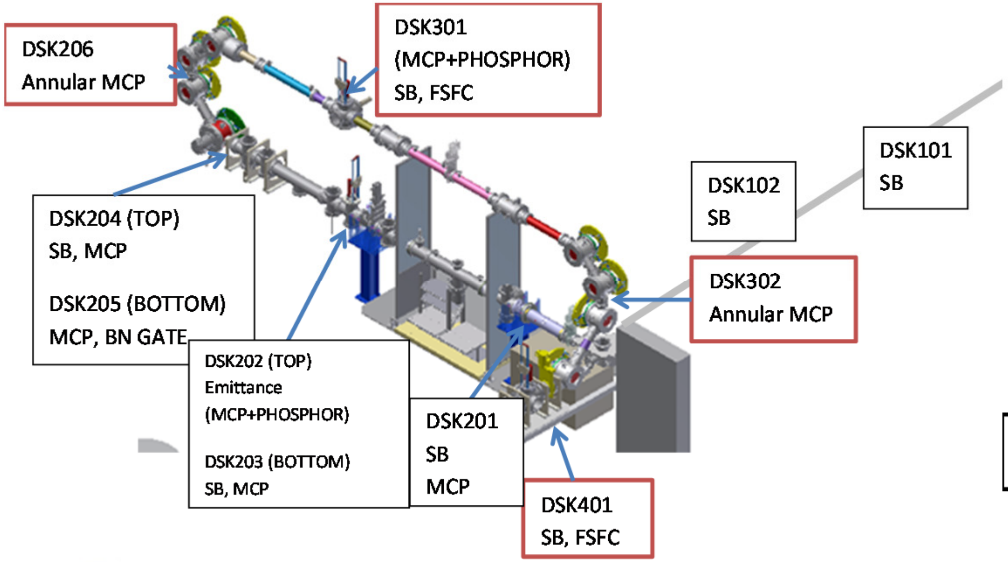


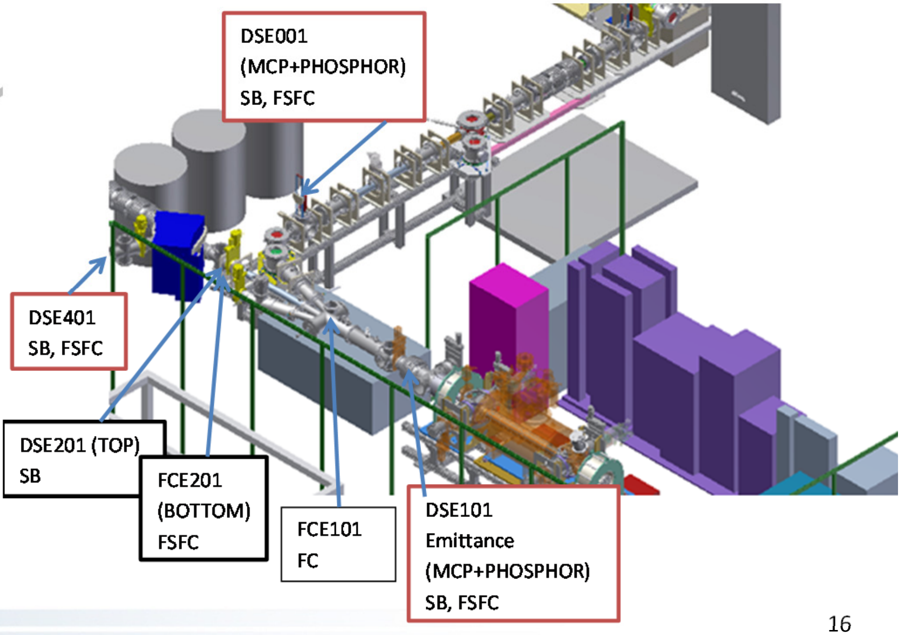


Beam Diagnostics

- Shielded Faraday Cups (FC)
- FCs based on multichannel plates (MCP)
- Pepper-pot emittance probes with MCPs
- Annular MCPs. The primary ion beam generates secondary electrons from an aluminum target. The electrons are accelerated backwards and collected by the annular MCP.
- Silicon detectors for the measurement of radioactive beam intensity by counting β–decay events.







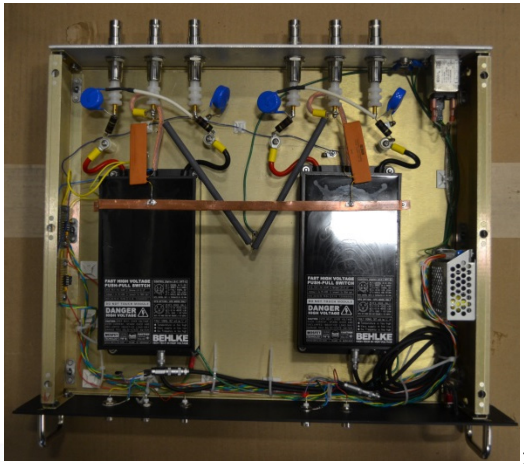
Timing and Synchronization

- Digital delay generators
- Function generators
- Fiberoptics to transfer control signals across multiple high voltage platforms
- HV amplifiers for pulsed power supplies
  - Anode voltage
  - Collector voltage
  - Beam steering (injection/extraction)
- Solid state Belhke switches
  - Barrier voltage
  - Switchyard voltage
  - Pulsed accelerator
  - Pulsed einzel lenses

Function generator

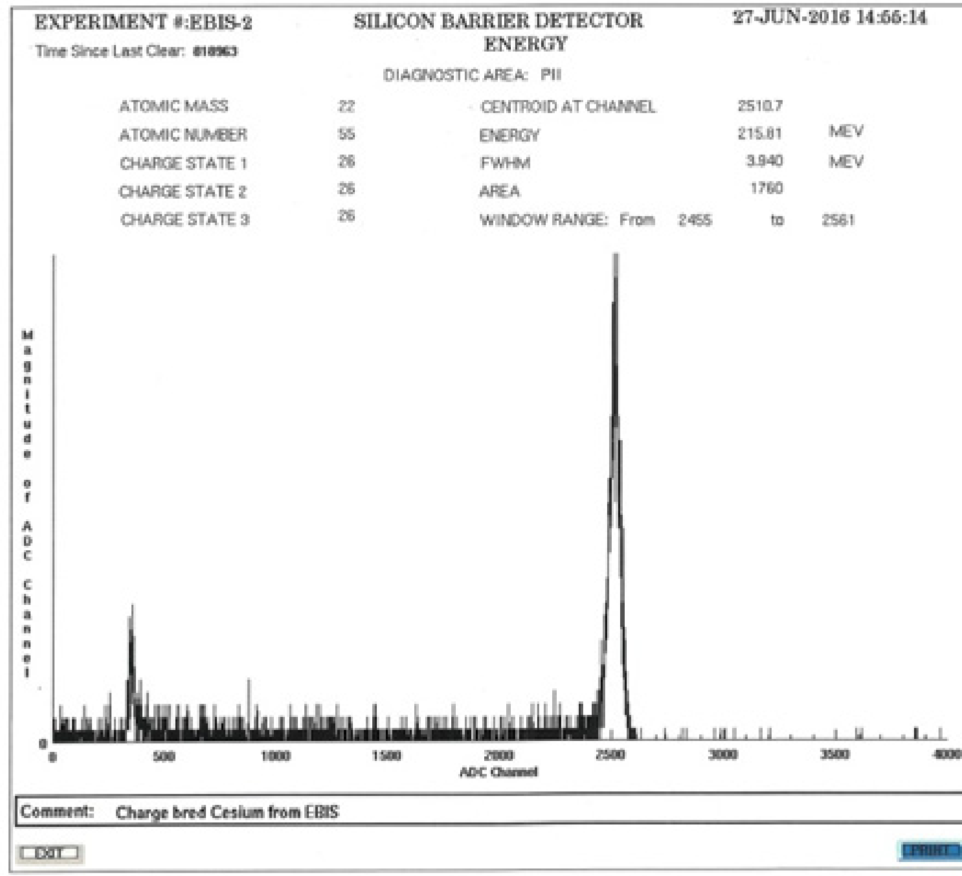
Digital delay generator

2-channel voltage switch with solid-state Belhke switches



Cesium Beam Acceleration

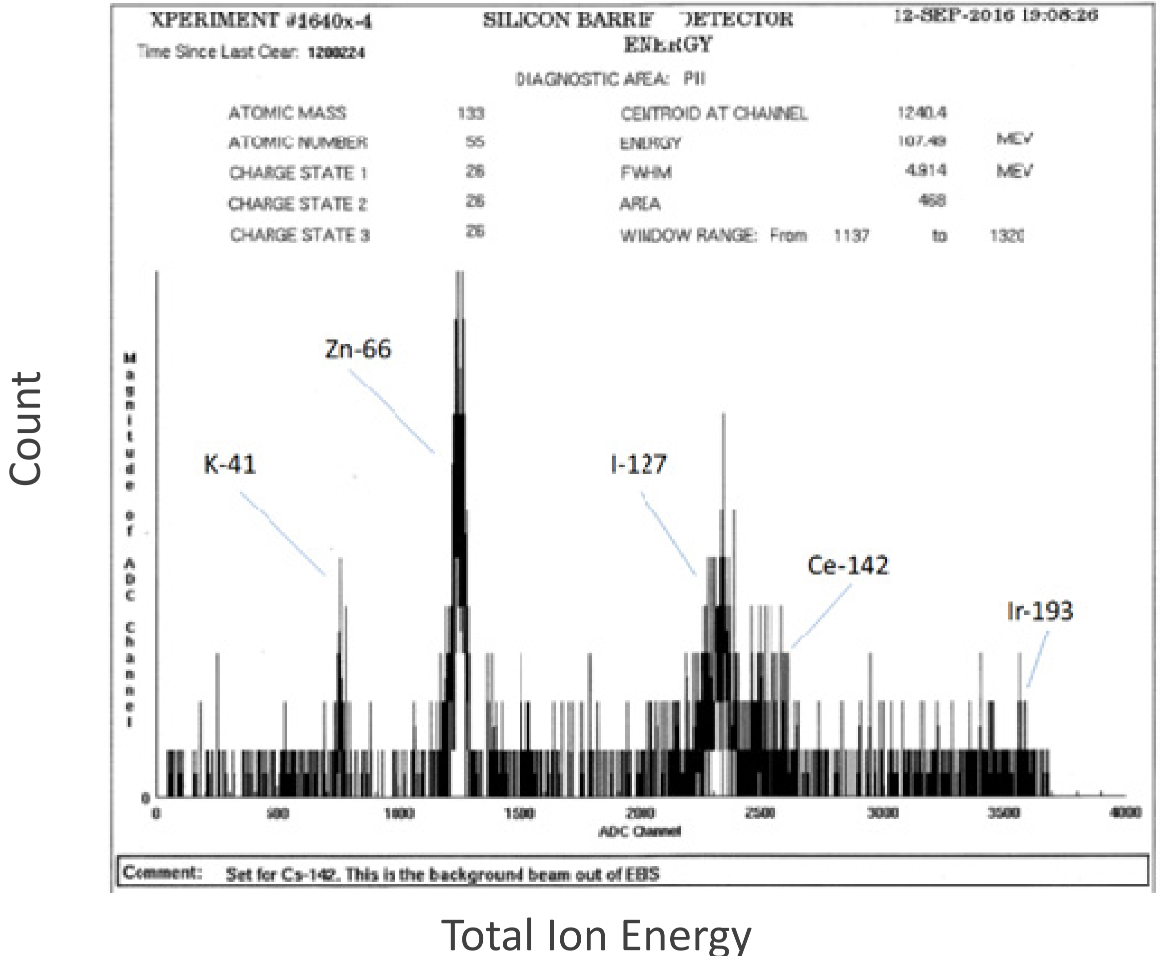
- The guide beam is stable $^{133}Cs^{26+}$ ions
- Energy spectrum taken after the first 3 cryomodules (PII)
- Transmission through the accelerator (MHB, RFQ, Linac) is 80% as expected
- Major losses are between the EBIS and mass separation slits
  - Requires more beamtime for beam measurements and tuning



- After tuning with the guide beam, the LEBT and accelerator were scaled for radioactive cesium $^{142}Cs^{28+}$
- Radioactive beam was immediately observed at the exit of PII

Energy Spectrum of Background Ions

- The rate of background ions is ~ 1Hz
- When we operated ECR charge breeder the background rate was ~1 kHz



Summary

- The Electron Beam Ion Source was successfully integrated with CARIBU and EBIS.
- The singly charged radioactive beam, $^{142}Cs^{1+}$, was transported to EBIS with matching injection energy and charge bred to $^{142}Cs^{28+}$ with an absolute efficiency of 10%.
- Very low contamination of accelerated RIBs was immediately confirmed when the LEBT and PII were tuned for acceleration of radioactive ions and accelerated background ions were measured without injection of radioactive ions into EBIS.
- As expected there were multiple occasions of unstable operation of some hardware inherent to the beam commissioning stage. The transmission efficiency and availability of the accelerated radioactive beams will be significantly improved in the next accelerator run in upcoming weeks.