Argonne NATIONAL LABORATORY

# Ion beam transport for the CARIBU EBIS charge breeder

HIAT12

High mass RIB workshop

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Clayton Dickerson

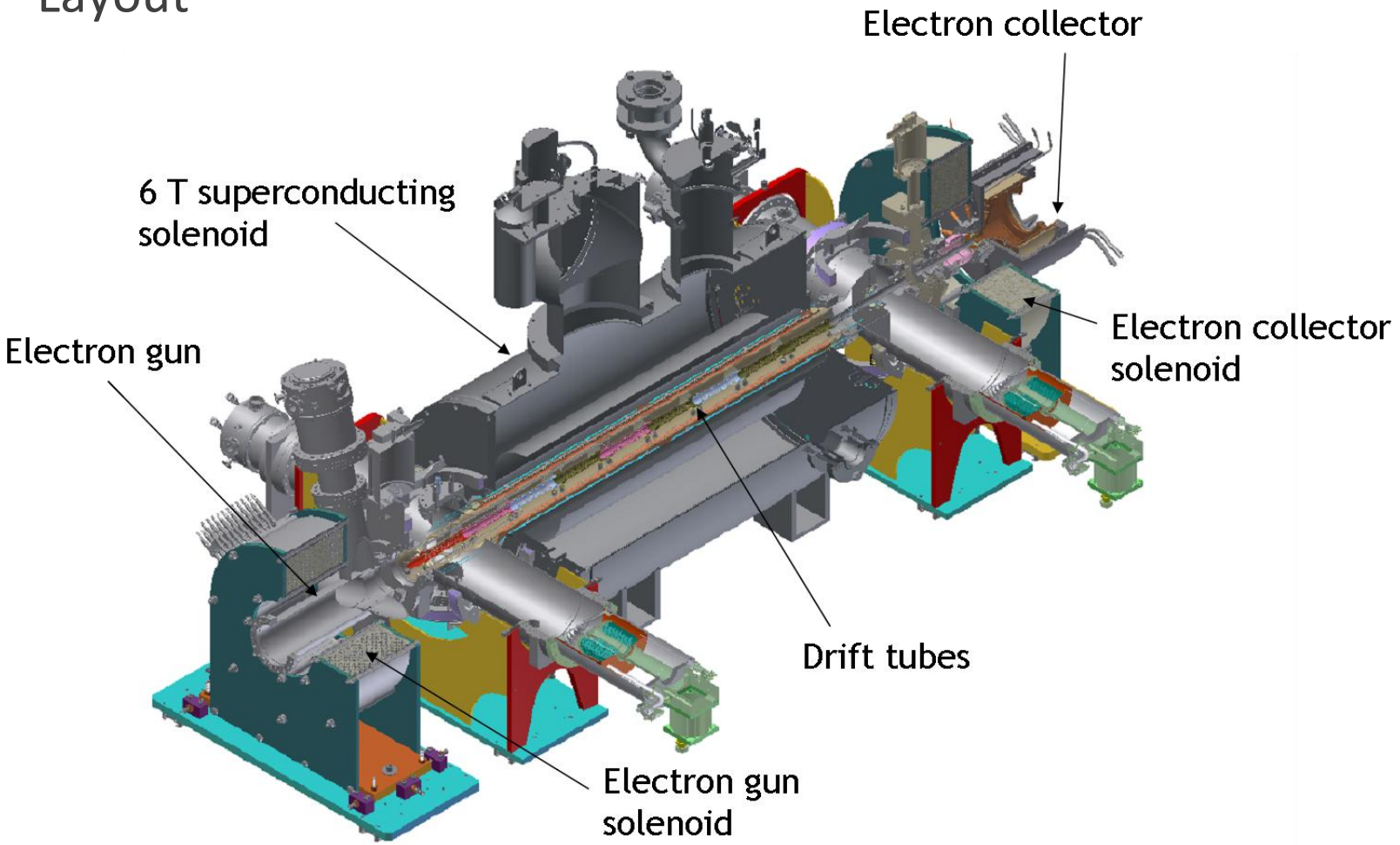
U.S. DEPARTMENT OF ENERGY

# Outline

- CARIBU EBIS charge breeder
- Review of electron beam – ion beam interaction results
- Goals of beam transport systems
- Simulation software
- Ion beam transport results
  - Accelerator Development Test Facility (ADTF) installation
  - ATLAS installation
- Summary

# CARIBU EBIS charge breeder

- Layout



# CARIBU EBIS charge breeder

- Design parameters

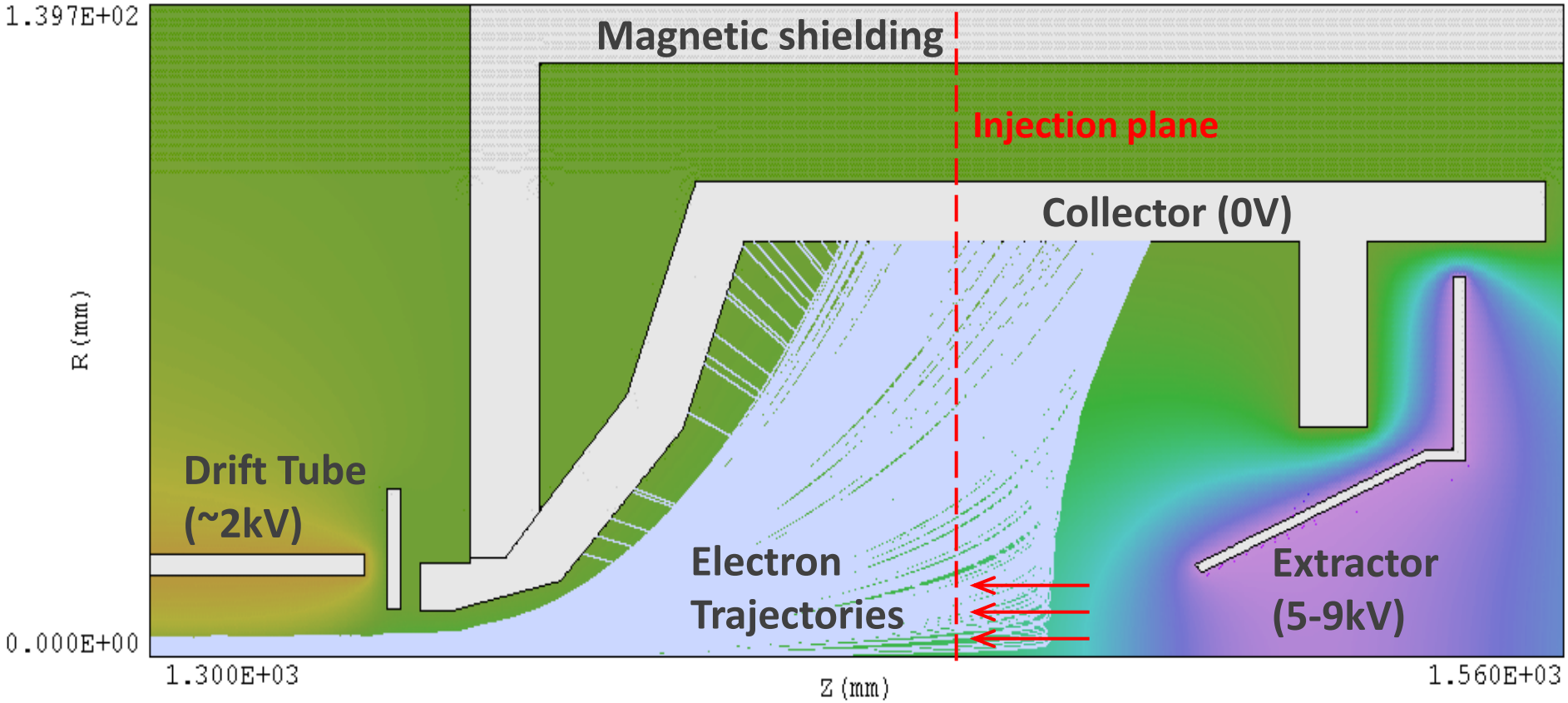
| Parameter | Electron gun | |
|---|---|---|
| | High current | Low current |
| Maximum current | 2 A | 0.2 A |
| Nominal trap solenoid magnetic field | 6 T | |
| Trap length | 700 mm | |
| Trap current density | 500 A/cm$^2$ | |
| Electron beam energy (gun/trap) | 10/4–5 keV | 7.7/1.2–2 keV |
| Cathode diameter | 4 mm | 1.6 mm |
| Drift tube diameters | 20 mm | |

# Beam dynamics in the CARIBU EBIS

- Review
  - Acceptance – injection criterion
  - Extracted beam characteristics

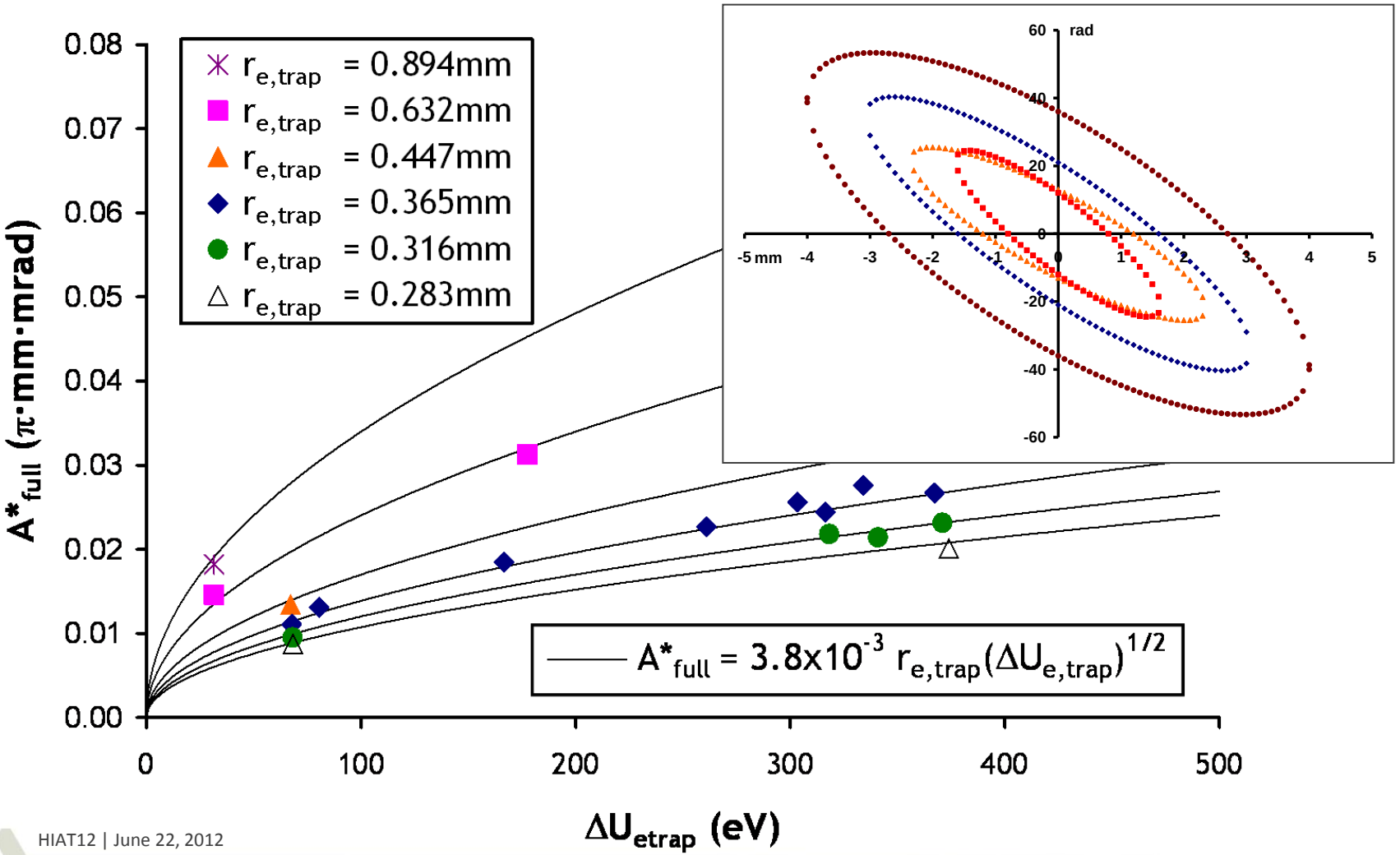
# Review - Acceptance

- Acceptance was determined by injecting ions into the EBIS fields from a plane within the collector



# Review - Acceptance

- Acceptance was calculated for wide range of conditions



# Review - Extraction

- Determining the extracted beam emittance
- Analytically
  - Magnetic contribution

$$\varepsilon_m^* = \frac{2\pi eqBr^2}{4mc} \cdot 10^6 \left[\pi \cdot mm \cdot mrad\right]$$

  - Electric contribution

$$\varepsilon_e^* = 2r\left(\frac{k_B T_\perp}{mc^2}\right)^{1/2} \cdot 10^6 \left[\pi \cdot mm \cdot mrad\right]$$

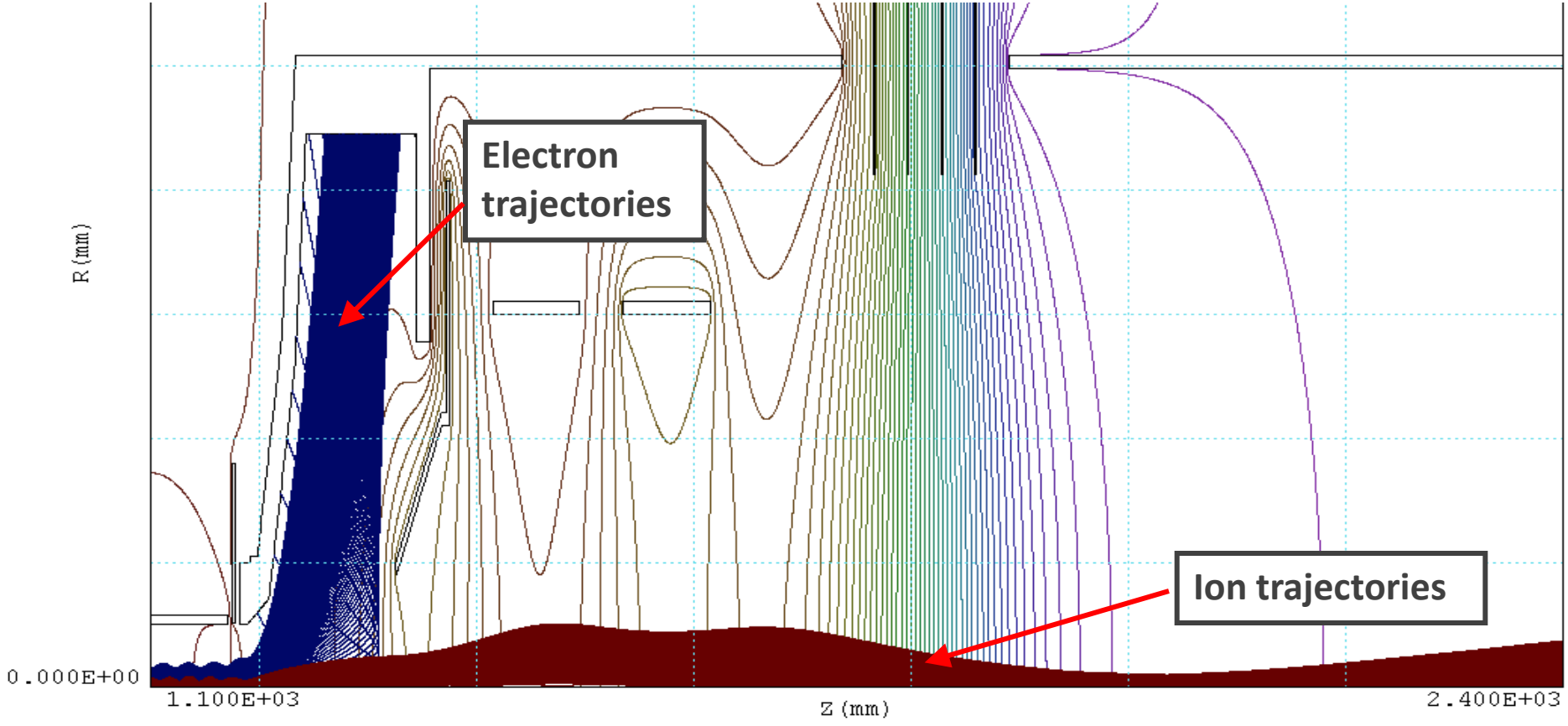
  - Upper limit for the extracted beam emittance for $^{133}Cs^{+20}$

$$\varepsilon_{tot}^* \approx 0.2 \left[\pi \cdot mm \cdot mrad\right]$$

- BNL results from Test EBIS
  - 0.08-0.1 $\pi$·mm·mrad for 1-3 mA of $Au^{32+}$

# Review - Extraction

- Assume $r_{i,t} = 1.5 * r_{e,t}$ and $\varepsilon^*_{tot} = 0.1\ \pi \cdot mm \cdot mrad$ for $^{133}Cs^{20+}$
- Ion beam transported within electric field of electron beam simulation solution



# Ion transport goals

- Minimize beam distortion
- Match the injected ion beam to the EBIS acceptance
- ATLAS installation
  - Implement sufficient differential pumping between gas catcher and EBIS
- ADTF installation
  - Mimic the ATLAS installation environment
    - Similar platform potentials to create the same beam energy
    - Beam emittance
  - Ensure individual charge states are resolvable through analyzing magnet

# Simulation Software

- TriComp
  - Calculates 2-d planar or axisymmetric electrostatic and magneto static fields from actual component cross sections
  - Numerically solves the Poisson equation for charged particles moving in the static fields
  - Accounts for the space charge of the electron beam
- TRACK
  - Integrates the equations of motion for particles in 3-d fields
  - Reports emittance evolution well
- EM Studio
  - Generates complex 3-d static fields for TRACK
  - Used to optimize component design and configuration

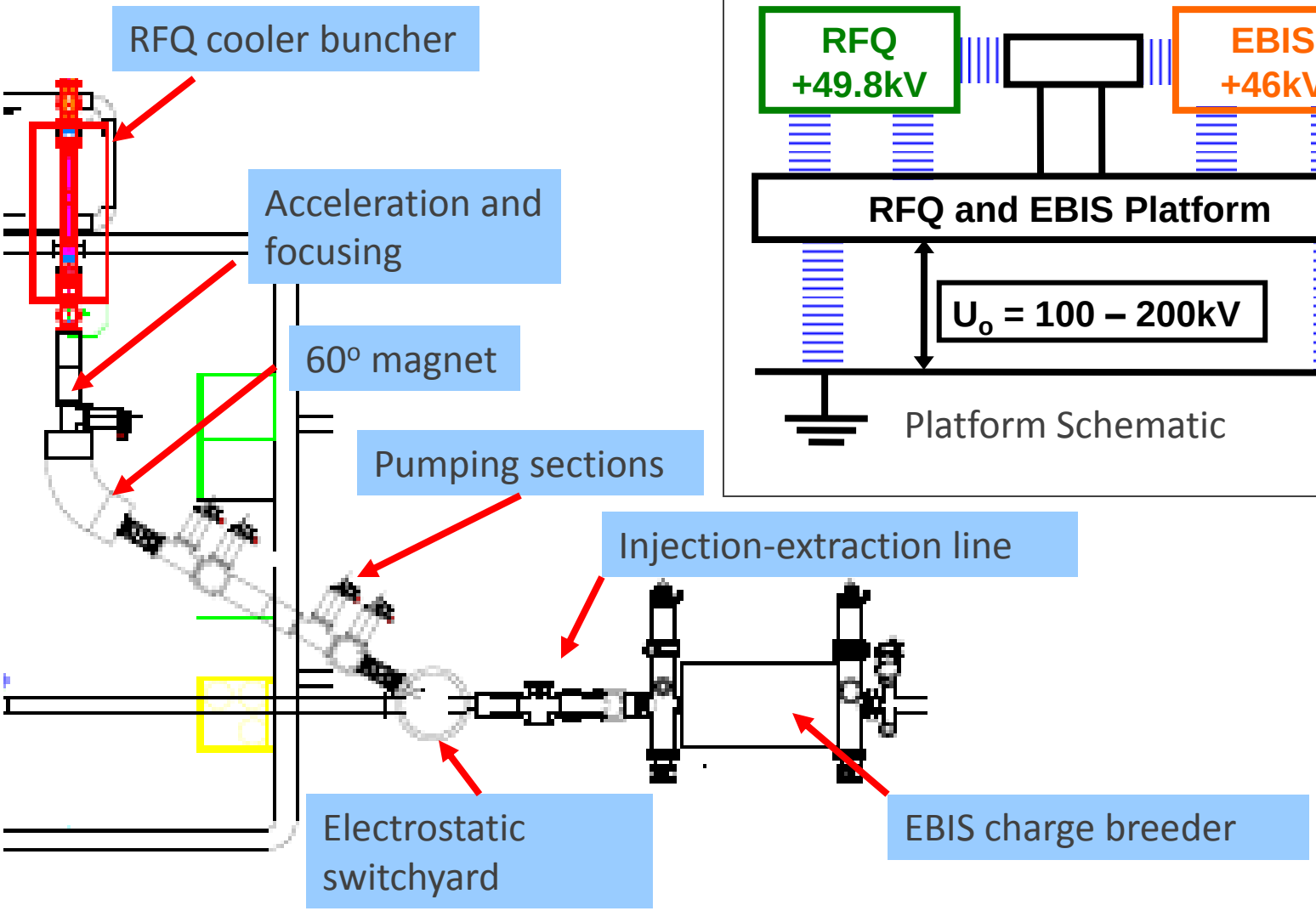
# Ion Transport Optics - Injection Requirements

- The phase space acceptance of the EBIS established the stopping condition for the injection transport line
- ATLAS installation
  - Ions will emerge from RFQ cooler buncher

| Transverse Normalized Emittance | Pulse Length of the Ion Beam | Number of Ions per Pulse | Frequency |
|---|---|---|---|
| ~0.003 $\pi$·mm·mrad | Adjustable in the range of 0.1-20 $\mu$s | $10^2 - 10^6$ | 1 – 30 Hz |

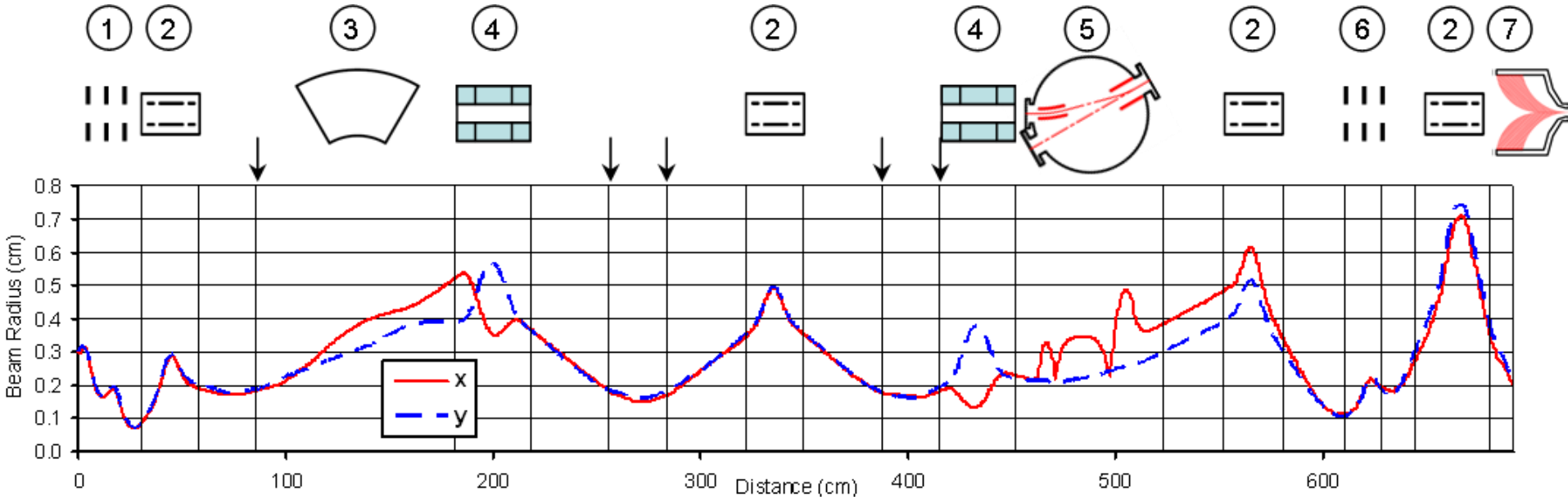
  - Beamline will require differential pumping; RFQ: ~$1x10^{-4}$ torr, EBIS: ~$1x10^{-11}$ torr
- Avoid beam losses and emittance growth
  - The acceptance of low current electron beams approaches the emittance of the beam from the RFQ cooler buncher
- During ADTF testing Cs surface ionization source will be used

# Injection – CARIBU



# CARIBU Injection

- RFQ cooler buncher emittance assumed to be 0.0116 $\pi$·mm·mrad, $I_i$=~1 nA

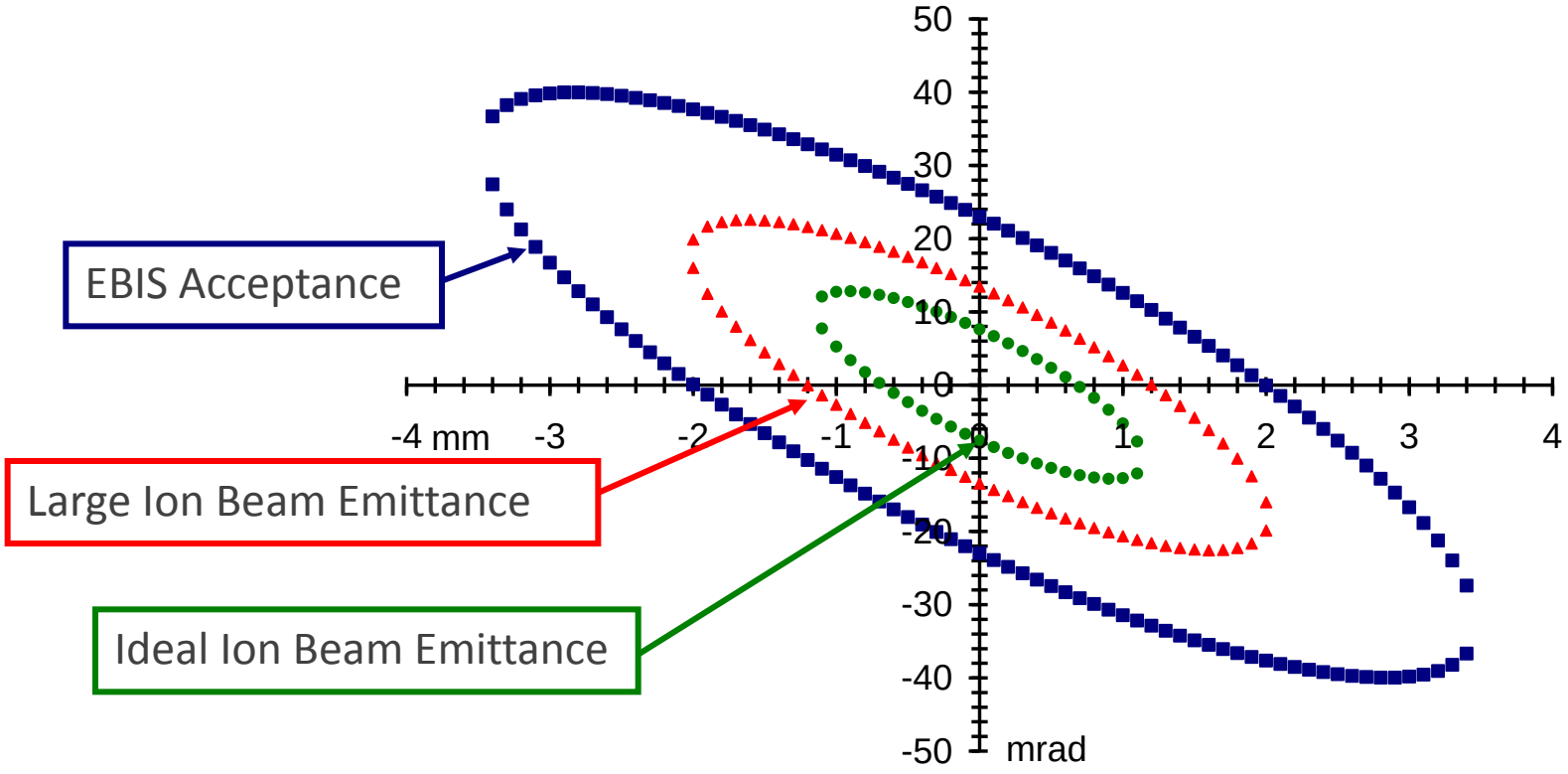



1. Accelerating lens
2. Einzel lens
3. 60° magnet
4. Electrostatic triplet
5. Switch yard
6. Decelerating tube
7. EBIS collector

↓ indicate aperture positions

# EBIS Matching

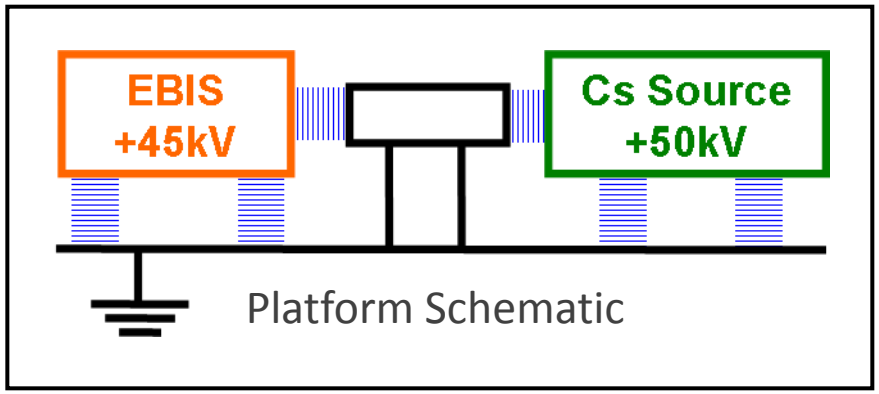
- The end of the injection line simulation corresponded to the plane at which the EBIS acceptance had been calculated
- Focusing elements were able to achieve good matching between the ion and electron beams

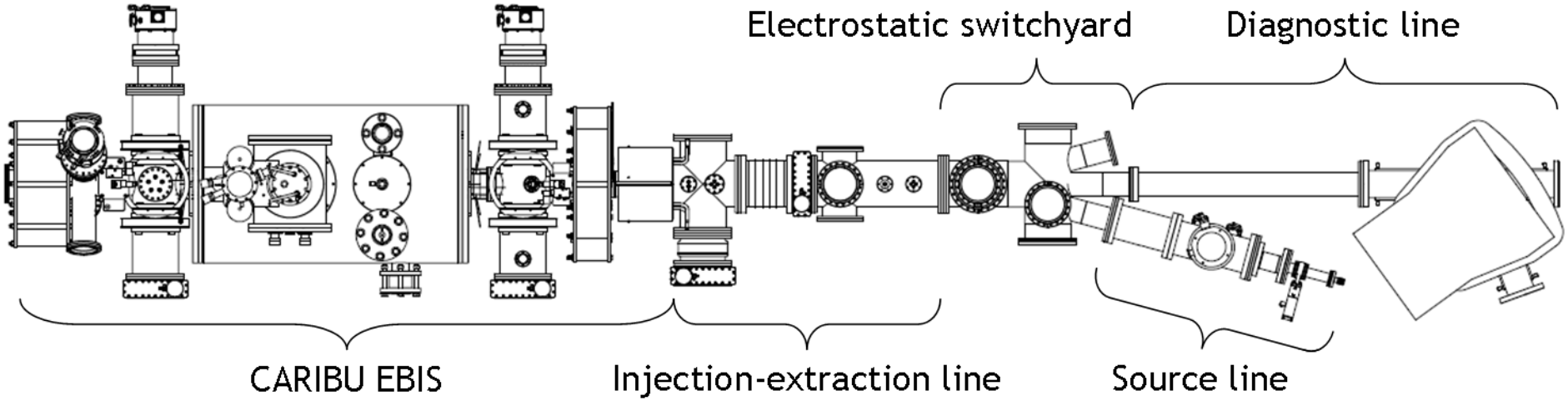


# CARIBU Injection Line Performance

- No ion losses
- Emittance growth
  - Large emittance beam: only a 5% increase in the maximum emittance for x-x’
  - Ideal emittance beam: No emittance growth
- Differential pumping implemented
- Ion beam matched to EBIS acceptance

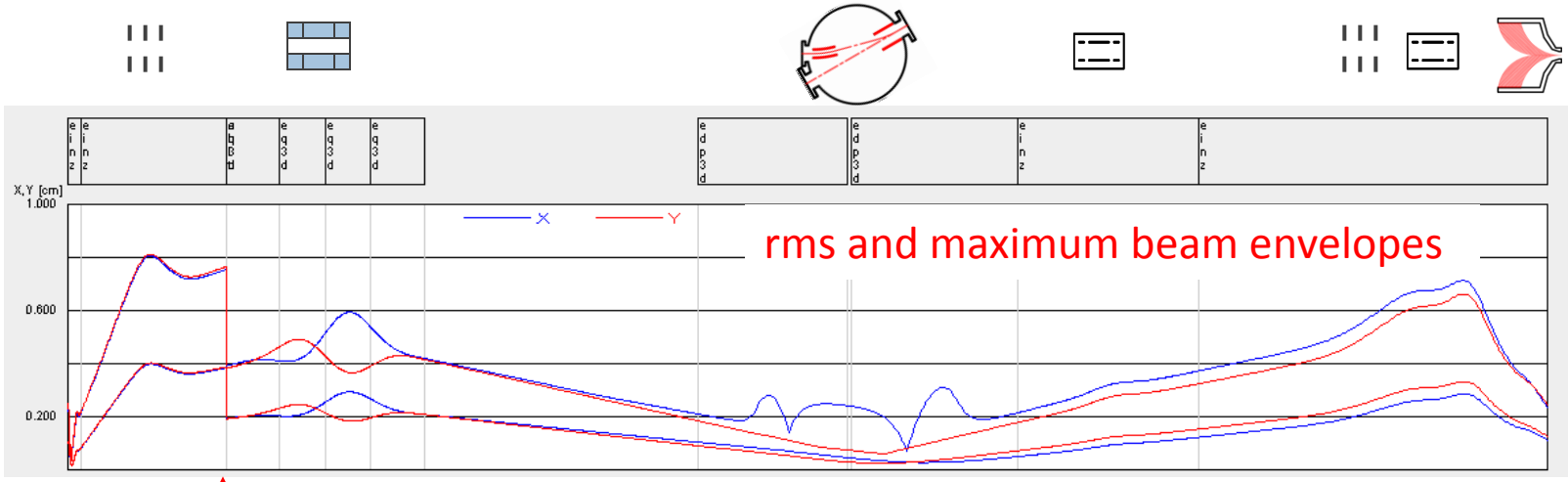
# ADTF Testing – Ion Transport



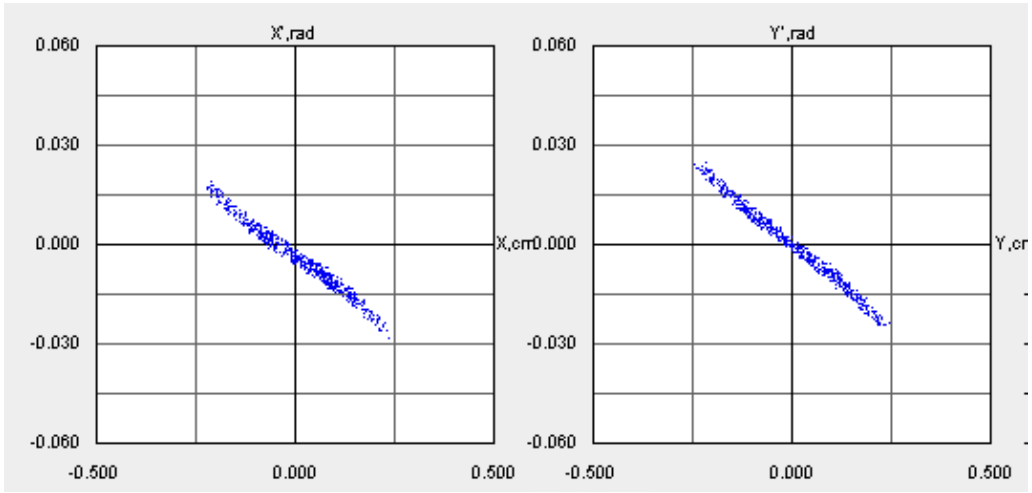



# ADTF - Injection

- Aperture required to control beam emittance, ~1/4 of the source current is transmitted



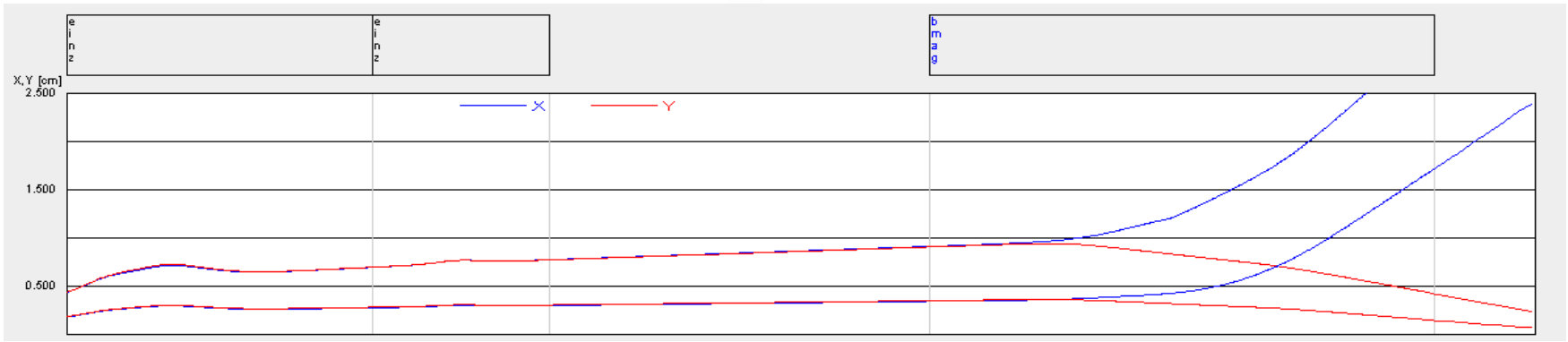

Aperture location




Output ion distributions

# ADTF - Extraction

- Goal was to ensure clear delineation between charge states
- Energy spread of $2\Delta U_{trap}$ was included

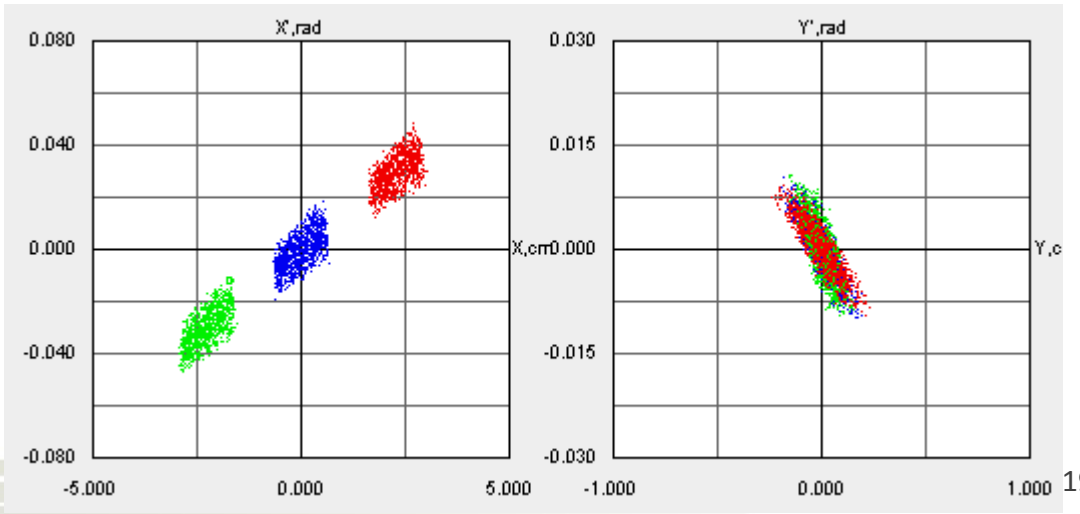



rms and maximum envelopes

No emittance growth through electrostatic elements

Charge state distributions

(q = 19 to21)



# Summary

- Ion injection from the CARIBU RFQ-CB is possible with little emittance growth and no losses
- The ion optics can adequately match the injected beam to the EBIS acceptance in both the ATLAS and ADTF installations
- Testing of the EBIS charge state distribution in the ADTF will be possible