EBIS Charge Breeder for CARIBU

Sergey Kondrashev, C. Dickerson, A. Levand, P.N. Ostroumov, G. Savard, R. Vondrasek, J. Alessi, E. Beebe, A. Pikin, G.I. Kuznetsov, M.A. Batazova

June 22, 2012

Content

- Motivation for EBIS charge breeder at CARIBU
- Design and parameters of CARIBU EBIS charge breeder
- Commissioning of EBIS charge breeder sub-systems:
  - 6 T superconducting solenoid
  - high-perveance e-gun
- Charge breeding efficiency measurements at BNL Test EBIS
- Summary

Motivation for EBIS Charge Breeder at CARIBU

EBIS vs ECR:

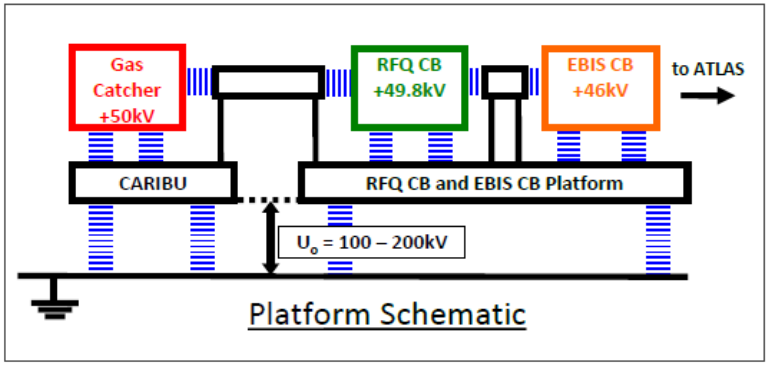
- Higher breeding efficiency (about factor 2)
- Better purity of beams (several orders)
- Shorter breeding time (factor 5-10)

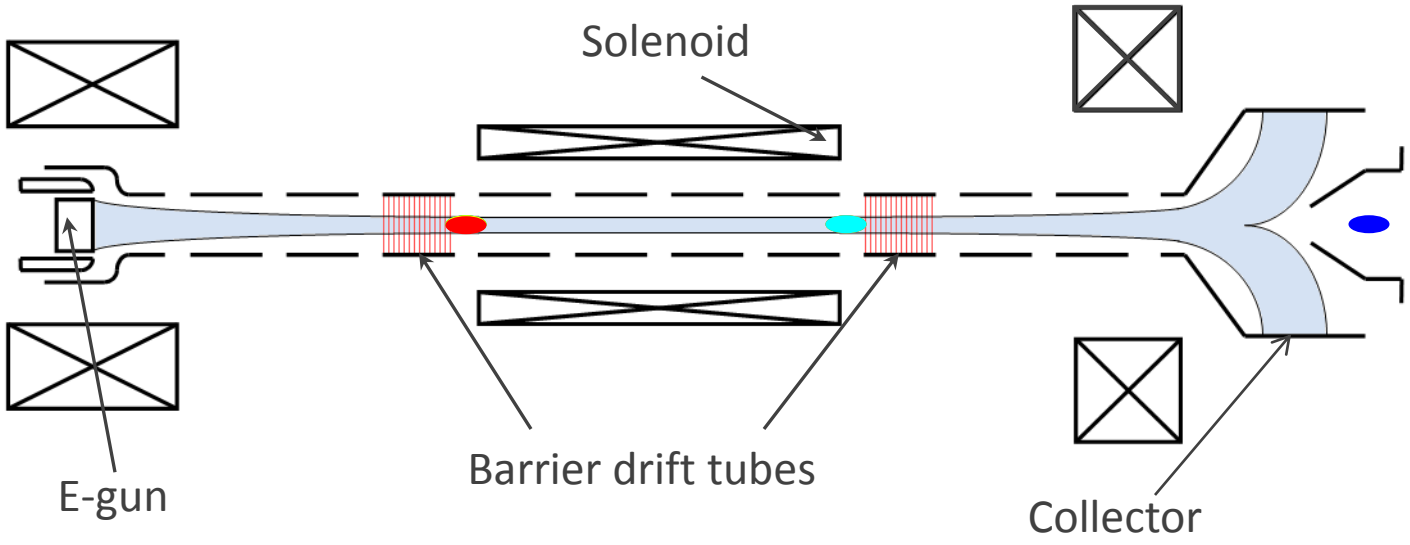
Choice for CARIBU:

- "Classical" EBIS
  - Proven technology (REXEBIS, CERN)
  - Higher acceptance (larger electron beam size) than in case of EBIT
- BNL RHIC and Test EBIS are prototypes (the most advanced EBIS technology nowadays)

EBIS Charge Breeder – Principle of Operation

- 1+ ions are accumulated in the RFQ cooler-buncher
- Injection time ~10 μs
- Breeding time ~33 ms
- Extraction time ~10 μs can be adjusted if necessary
- Repeat with the rate of 30 Hz
- Transverse confinement is achieved by electron beam space charge
- Longitudinal confinement is provided by drift tube potentials

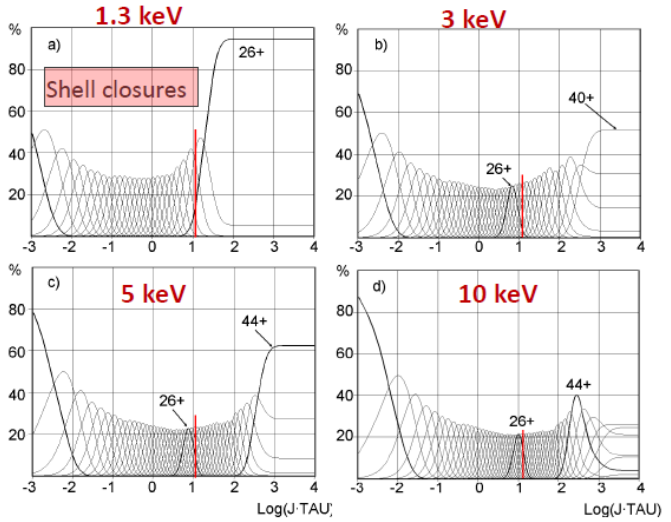




Main Parameters of CARIBU EBIS Charge Breeder

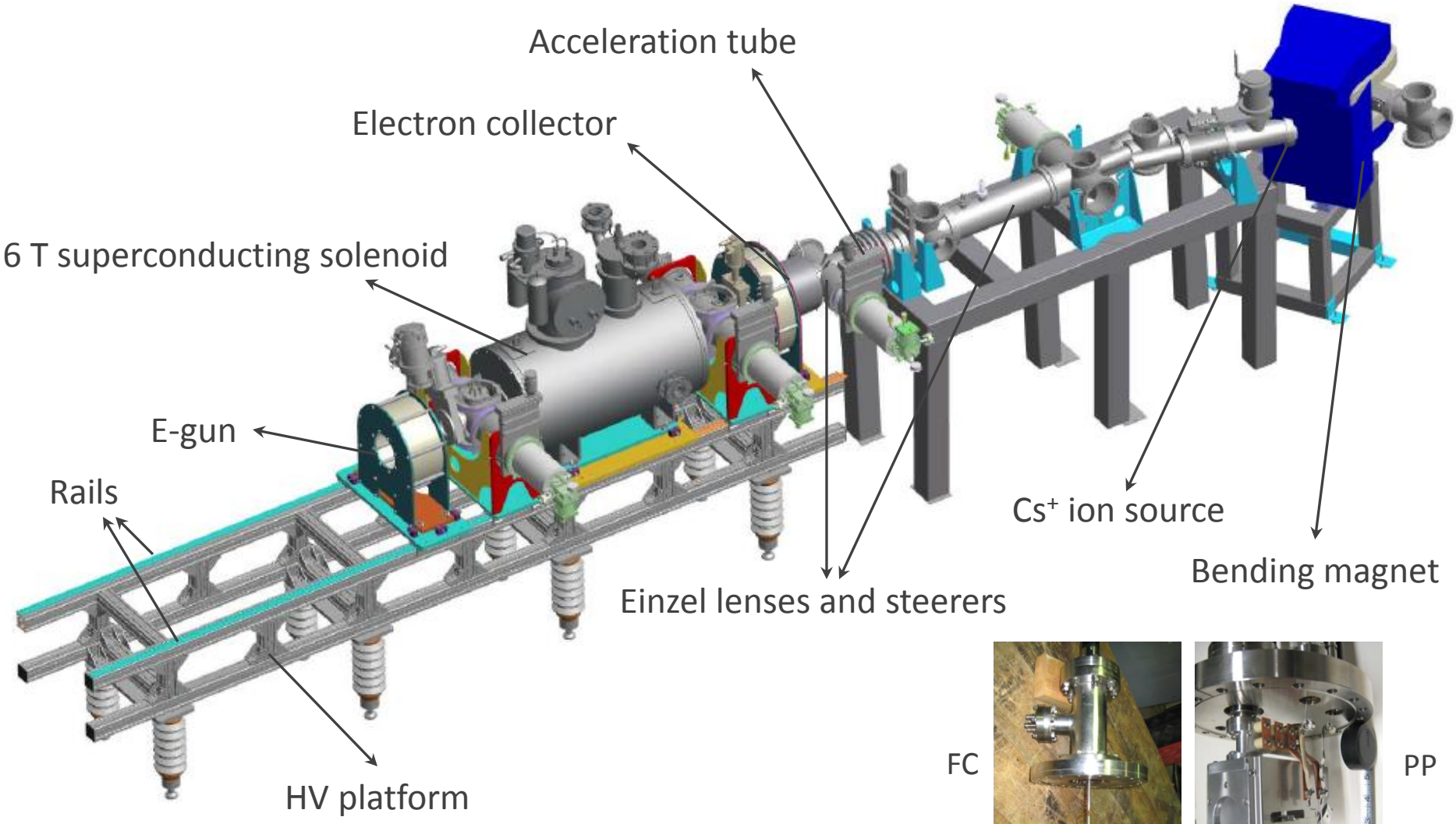
Parameter	Low current e-gun	High current e-gun
Superconducting solenoid: length/ field	1 m/6 T	1 m/6 T
Diameter of the IrCe thermocathode	1.6 mm	4 mm
Electron beam current	0.2 A	2 A
Electron beam energy	~ 2 keV	~ 5 keV
Electron beam diameter in the trap	~ 230 μm	~ 580 μm
Electron beam current density in the trap	~480 A/cm^2	~750 A/cm^2
Ion trap length	0.5 m	0.5 m
Trap capacity (in elementary charges)	~ 4•10^{10}	~ 2•10^{11}

Low current e-gun will be used to study efficiency gain at shell closures



Sergey Kondrashev, EBIS Charge Breeder for CARIBU, High Mass RIB Workshop, June 22, 2012

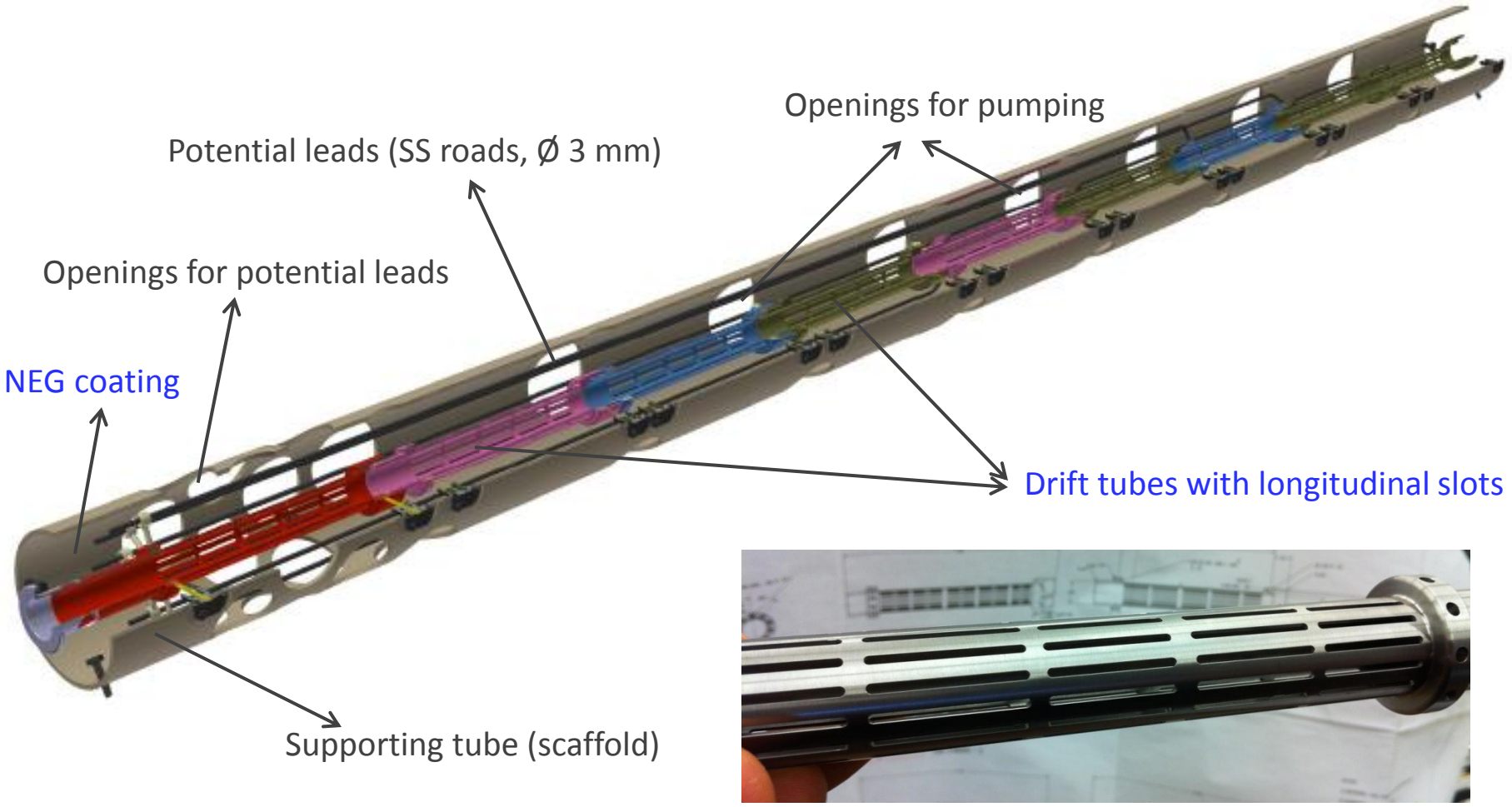
Off-line Commissioning Configuration



FC

PP

Drift Tube Structure



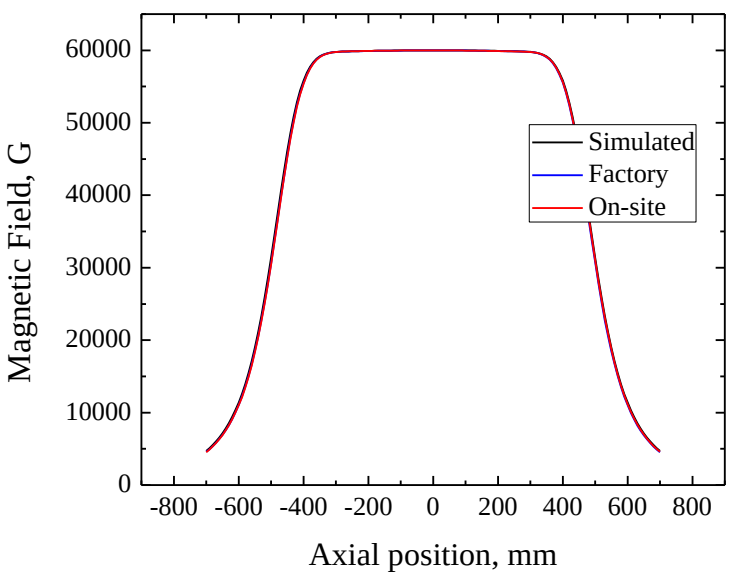
Commissioning of 6 T Superconducting Solenoid

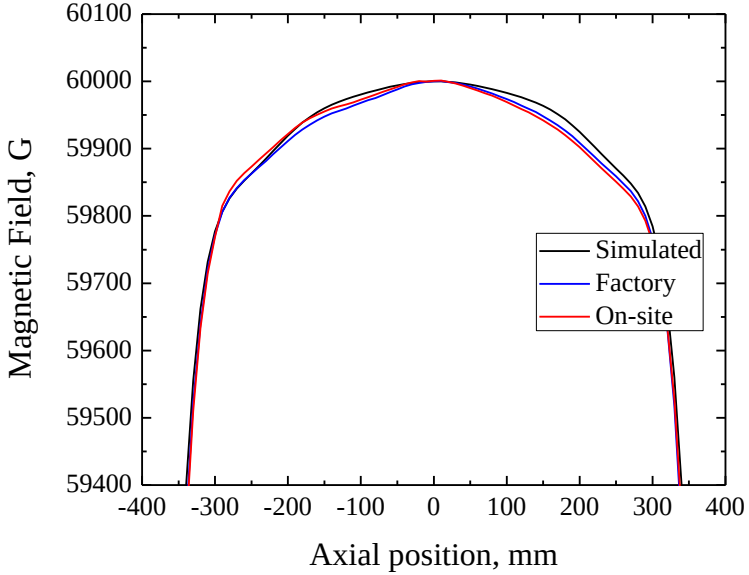
- Unshielded solenoid with warm bore
- Supplier: Cryomagnetics, Inc.
- Delivered: October 2011

6 T solenoid installed at HV platform
In final position for on-site commissioning

Magnetic axis was aligned with mechanical axis of warm bore in real magnetic environment

Results of 6 T Solenoid Commissioning

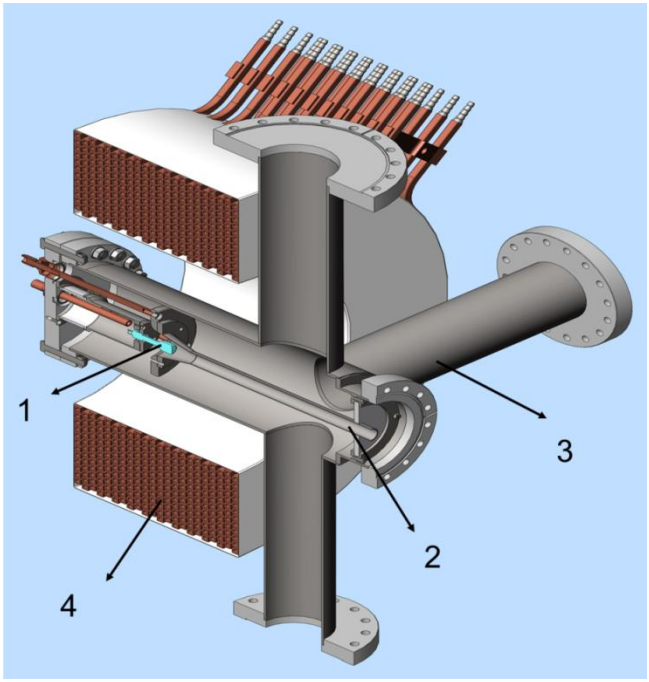




Parameter	Specification	Measurements
Central Field	6.0 T	6.05 T @ 82.66 A
Maximum Field	6.6 T	6.6 T @ 90.17 A
Charge Time to 6 T	70 min	70 min
Field Homogeneity	± 0.4% over ± 30 cm on axis	± 0.2% over ± 30 cm on axis
Coil Inductance	195 H	193 H
Field Decay Rate	< 1 ppm/hour	< 0.01 ppm/hour

Sergey Kondrashev, EBIS Charge Breeder for CARIBU, High Mass RIB Workshop, June 22, 2012

Electron Guns



Engineering model of e-gun (1 – IrCe thermionic cathode, 2 – anode, 3 – vacuum chamber, 4 – magnetic coil)

Supplier: BINP (Novosibirsk, Russia)

Delivered: April 2012

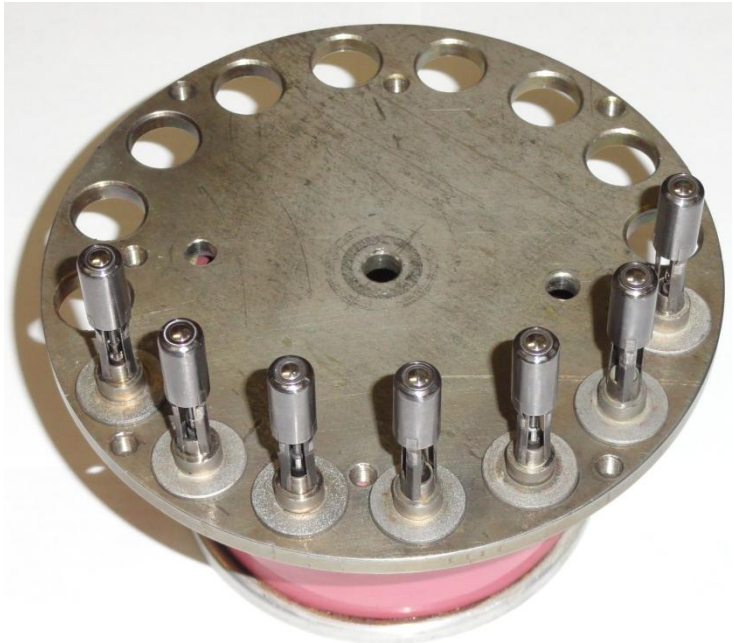
Parameter	CARIBU (high current)	CARIBU (low current)
Current	Up to 2 A	Up to 0.2 A
Current density at the cathode	10–15 A/cm^2	10–15 A/cm^2
Magnetic field at the cathode surface	~ 0.15 T	~ 0.15 T
Cathode material	IrCe	IrCe
Cathode diameter	4 mm	1.6 mm
Radius of cathode convex surface	6.6 mm	1.8 mm
Expected cathode lifetime	~ 20000 hours	~ 20000 hours

IrCe thermionic cathodes demonstrated the longest live time

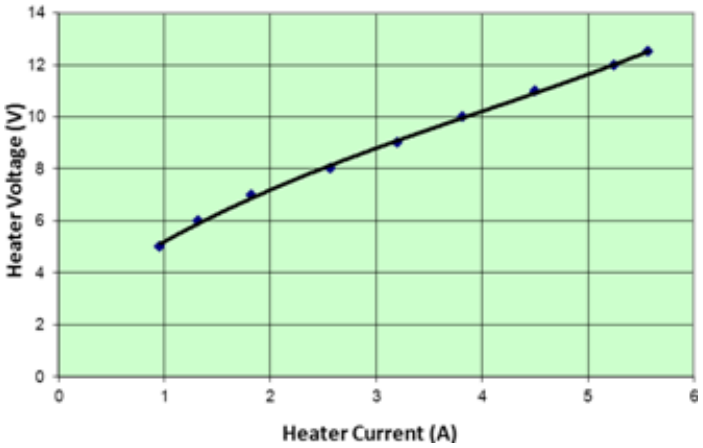
2 A and 0.2 A e-guns are exchangeable by exchanging cathode units

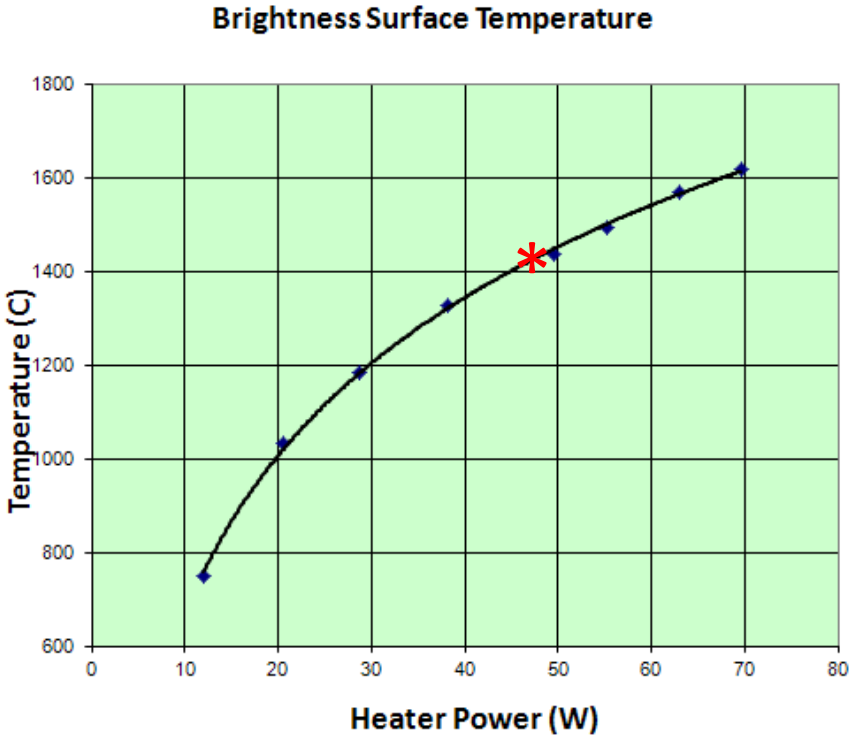
Sergey Kondrashev, EBIS Charge Breeder for CARIBU, High Mass RIB Workshop, June 22, 2012

IrCe Thermionic Cathodes Tests

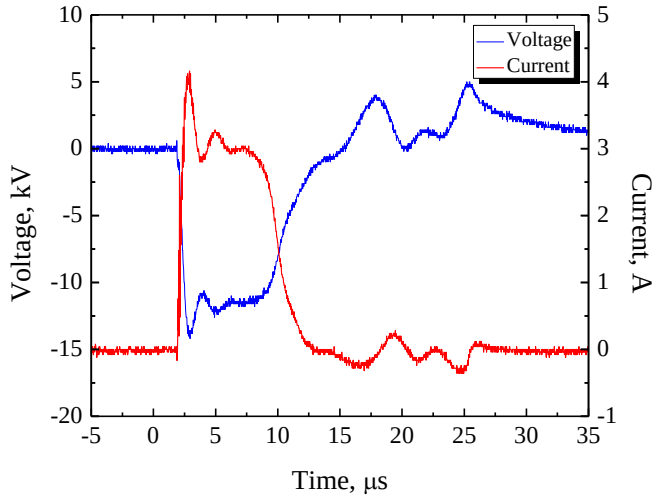


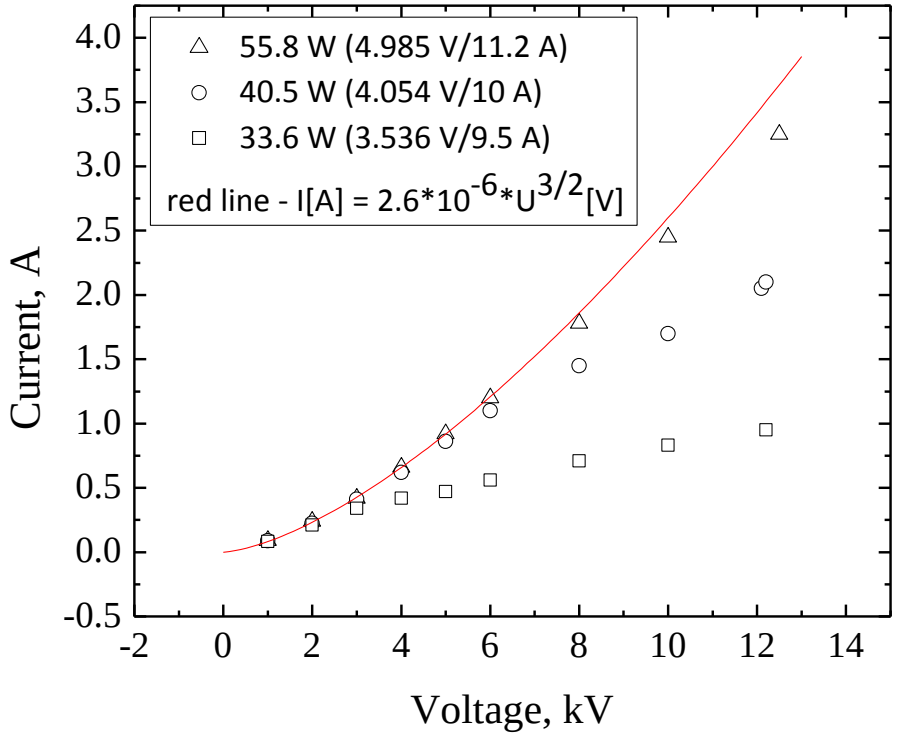
Current-Voltage Heater Curve (4 mm diameter cathode)





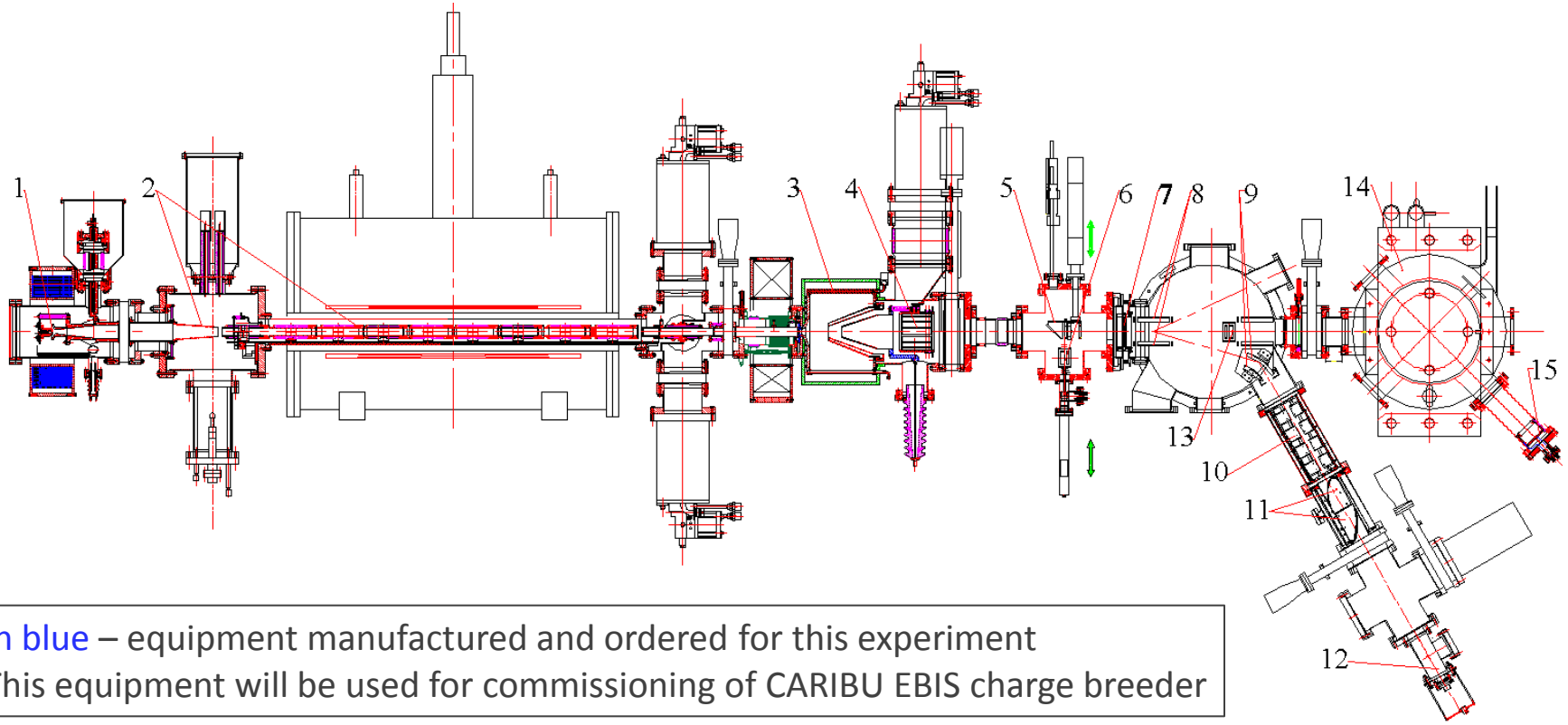
E-gun Commissioning Results





Perveance is about $2 \cdot 10^{-6}$ A/V$^{3/2}$

Experimental Set-up



In blue – equipment manufactured and ordered for this experiment
This equipment will be used for commissioning of CARIBU EBIS charge breeder

Experimental set-up: 1 – EBIS e-gun, 2 – EBIS drift tubes, 3 – EBIS electron collector, 4 - 16-plate-wide aperture deflector/lens, 5 – Faraday cup (FC1), 6 – pepper pot emittance meter, 7 – gridded electrostatic lens, 8 – planar bender, 9 – spherical bender, 10 – quardrupole quadruplet lens, 11 - vertical and horizontal steerers, 12 – Cs^+ surface ionization ion source, 13 - Faraday cup (FC2), 14 - 45° bending magnet, 15 – Faraday cup (FC3).

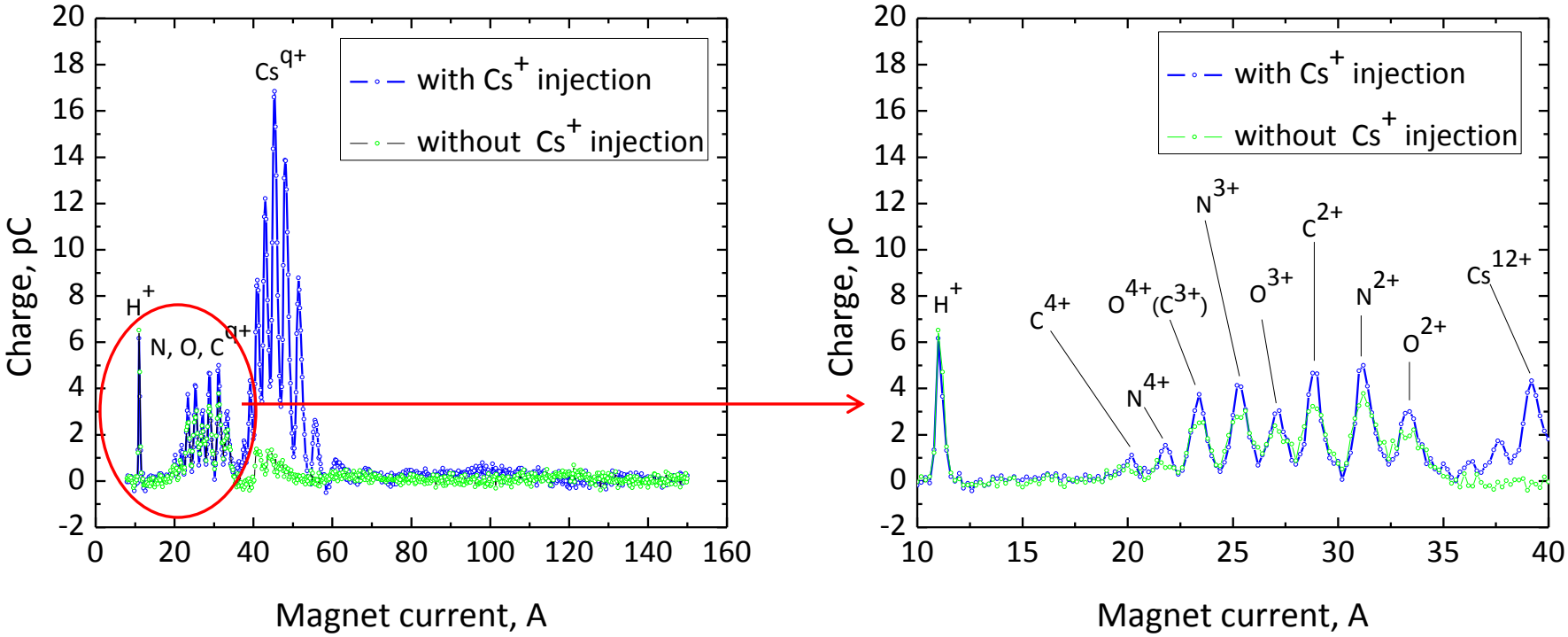
Main Parameters of BNL Test EBIS

Parameter	Nominal	Used in experiment	CARIBU EBIS CB
Superconducting solenoid: length/ field	1 m/5 T	1 m/4.7 T	1 m/6 T
Diameter of the IrCe thermocathode	9.2 mm	9.2 mm	4 mm
Electron beam current	up to 10 A	1 A and 1.5 A	1 – 2 A
Electron beam energy	up to 20 keV	19 keV	6 – 8 keV
Electron beam current density inside trap	up to 575 A/cm^2 (for 10 A)	≈ 51 A/cm^2 and ≈ 76 A/cm^2	~ 500 A/cm^2
Electron beam diameter inside trap	1.6 mm	1.6 mm	0.58 mm
Ion trap length	0.7 m	0.7 m	0.7 m
Trap capacity (in elementary charges)	$5.1 \cdot 10^{11}$ (for 10 A/20 keV)	$5.2 \cdot 10^{10}$ and $7.8 \cdot 10^{10}$	10^{11}

5.3 ms breeding time was chosen for all measurements by two reasons:

- To fully resolve highly charged Cs ions at the exit of magnetic spectrometer
- To reduce overlapping between highly charged Cs and residual gas ions

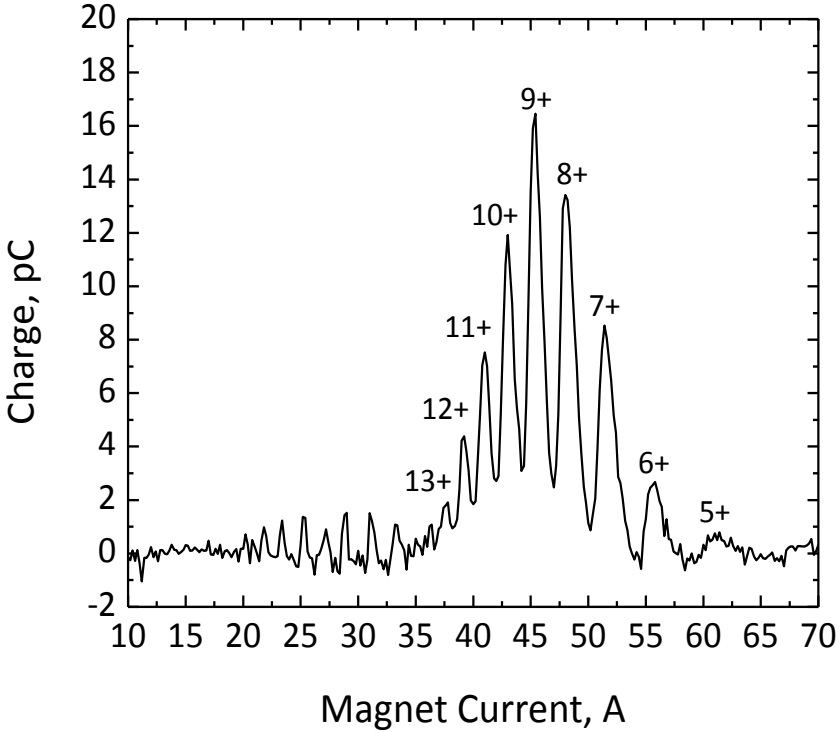
Mass and Charge State Distributions

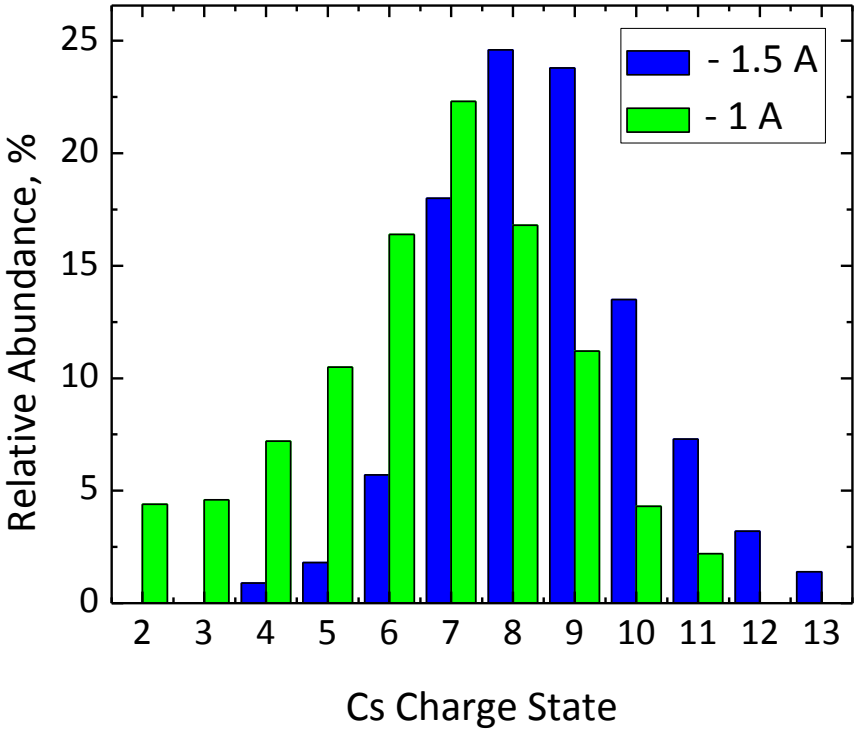


Mass and charge state distributions with (blue line) and without (green line) Cs^+ ion injection into EBIS for 1.5 A electron beam current (measured downstream bending magnet with 2 mm output slit) .

Distribution is peaked at Cs^{9+}.

Charge State Distributions

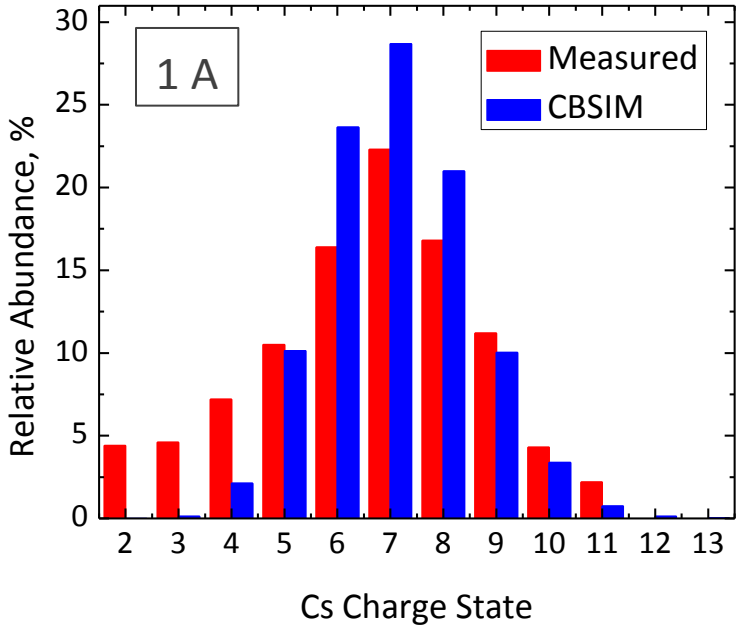


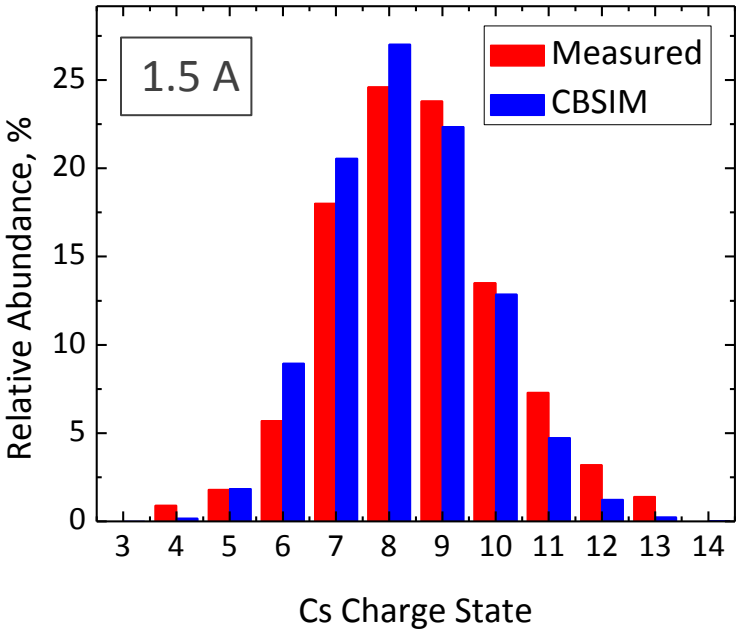


Spectrum of charge state bred Cs ions
for 1.5 A electron beam current.

Results on Breeding Efficiency

Electron beam current	1 A	1.5 A
Electron beam current density in the trap	≈ 51 A/cm^2	≈ 76 A/cm^2
Most abundant charge state	7	8
Average charge state	6.6	8.5
Injection/extraction efficiency	75%	71%
Breeding efficiency into the most abundant charge state	16.7%	17.5%





*S. Kondrashev, et al., Nucl. Instr. and Meth. A **642** (2011) pp. 18-24*

Summary

- EBIS charge breeder is an excellent choice for acceleration of CARIBU beams
- Design of CARIBU EBIS charge breeder has been completed and manufacturing of different components is in progress
- 6 T superconducting solenoid and high-perveance e-gun have been recently commissioned and met all specified parameters
- Injection/extraction efficiency above 70% and breeding efficiency into the most abundant charge state ~17% have been measured at BNL Test EBIS for 1 A and 1.5 A electron beam currents over a breeding time of 5.3 ms
- Good agreement between measured and simulated (by CBSIM code) relative abundances of charge-bred Cs ions has been found for proper pulsed injection into EBIS