Integrated Modeling Tool for EBIS (Electron-Beam based Ion-Source)*

- SBIR Phase II (8/8/12-8/7/14) : L. Zhao, E. Evstatiev and J.S. Kim

Quasi-3D Model of an ECRIS (Electron Cyclotron Resonance Ion Source)*

- SBIR Phase II (8/15/11-8/14/14) : E. Evstatiev, J.A. Spencer, J.S. Kim

Presented by Jin-Soo Kim

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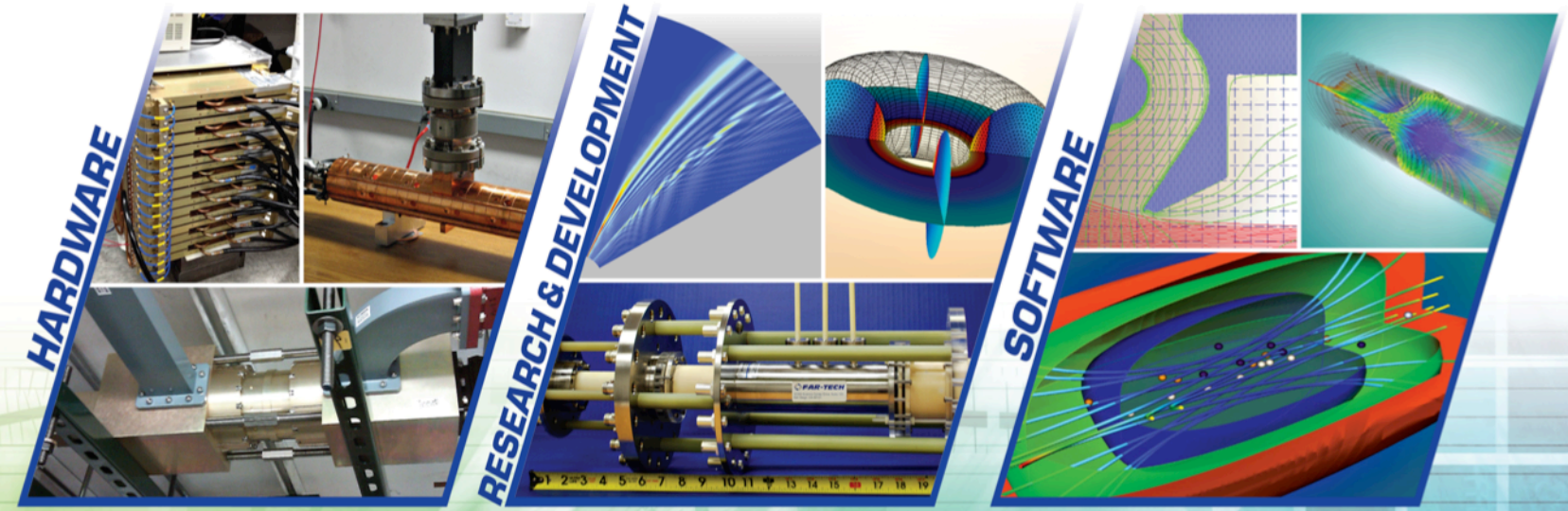


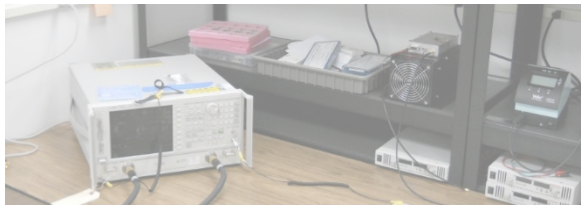
FAR-TECH, Inc. Management and Facility

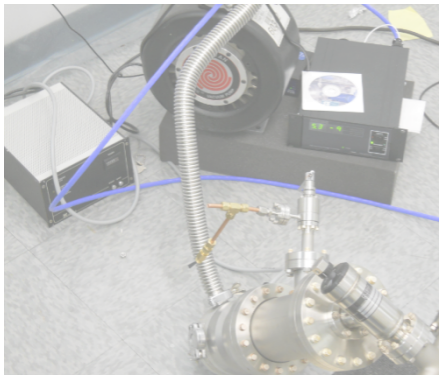
- Located in San Diego, CA

- Founded in 1994 to pursue Fusion and Accelerator Research and TECHnology. Known as Fusion and Accelerator Research (FAR) till 1997.

- Core staff of over 10 PhD scientists/engineers

- Facility:
  - Linux computer cluster (88 processors) with 96GB of memory via Infiniband connection; 15 TB redundant storage
  - RF, UHV, laboratory and assembly





Integrated Modeling Tool for Electron-Beam based Ion-Source

SBIR Phase II (8/8/12-8/7/14) :

L. Zhao, E. Evstatiev and J.S. Kim

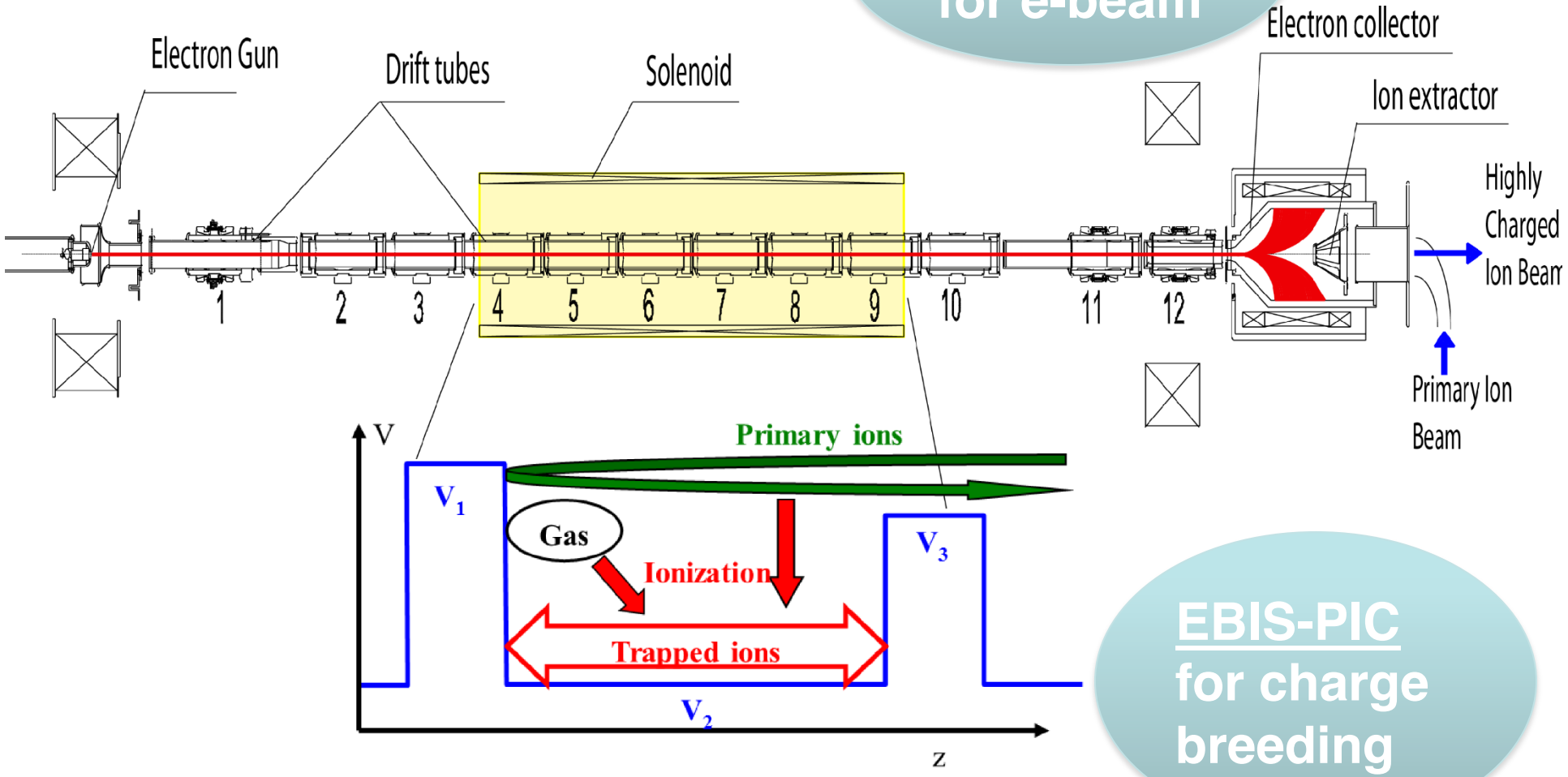
Modeling and Numerical Optimization of ECRIS / ECRCB / EBIS is Necessary

Numerical tools provide understanding of key physics and help interpret experimental results and guide future designs.

Cost reduction is significant for expensive future research facilities.

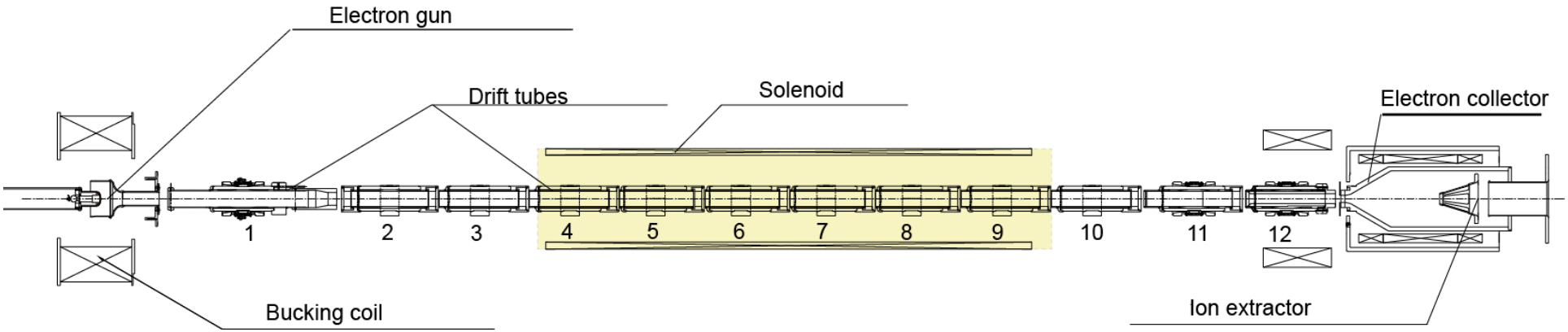
For radioactive ion sources we need to minimize trial-and-error methods.

PBGUNS
for e-beam



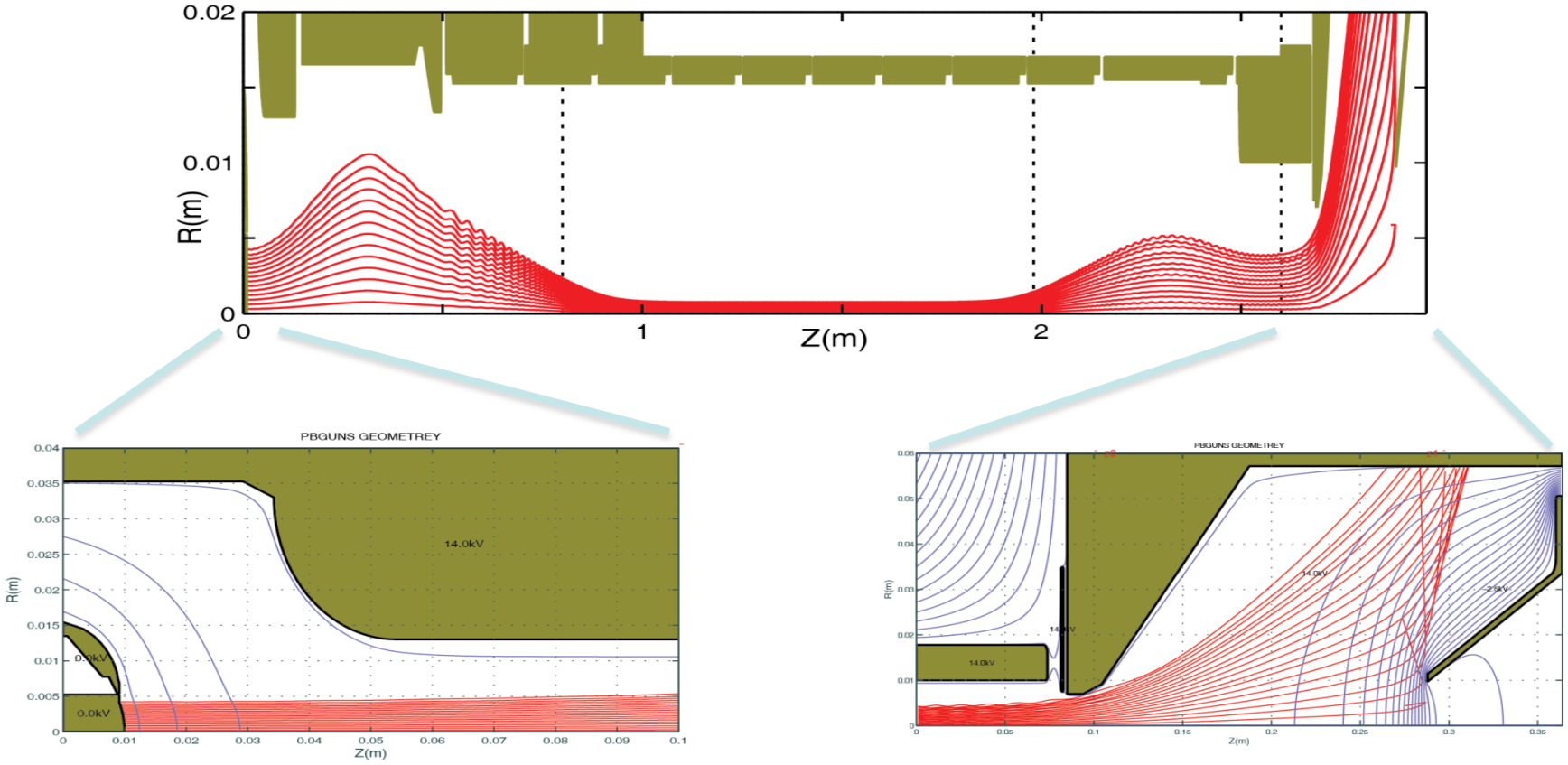
EBIS-PIC
for charge breeding

Example Case: BNL Test EBIS Device



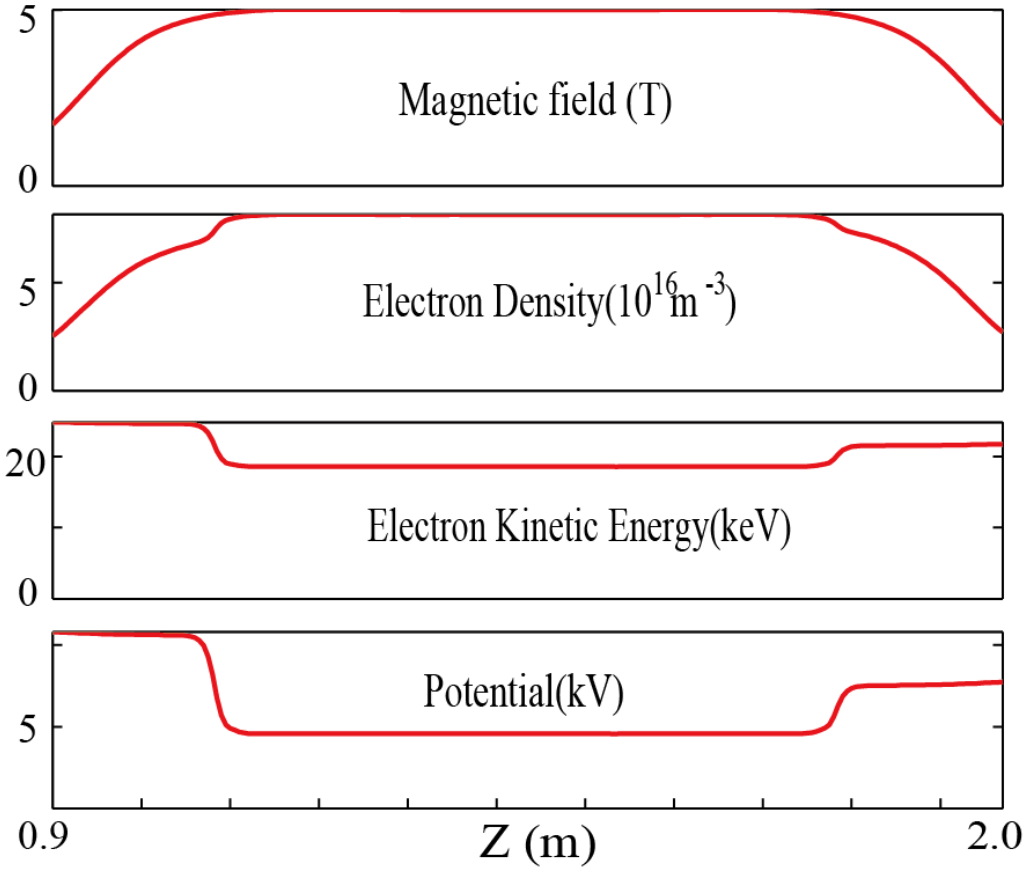
Parameters	Value
Drift tube length	1.07 m
Drift tube radius	1.5 cm
Drift tube voltage	6-13 kV
Magnetic field	5 T
Electron beam current	1.0 -1.5 A
Electron beam radius	0.75 mm
Pressure	5e-10 Torr
Ion Specie	Cs

Electron Beam Modeling by PBGUNS

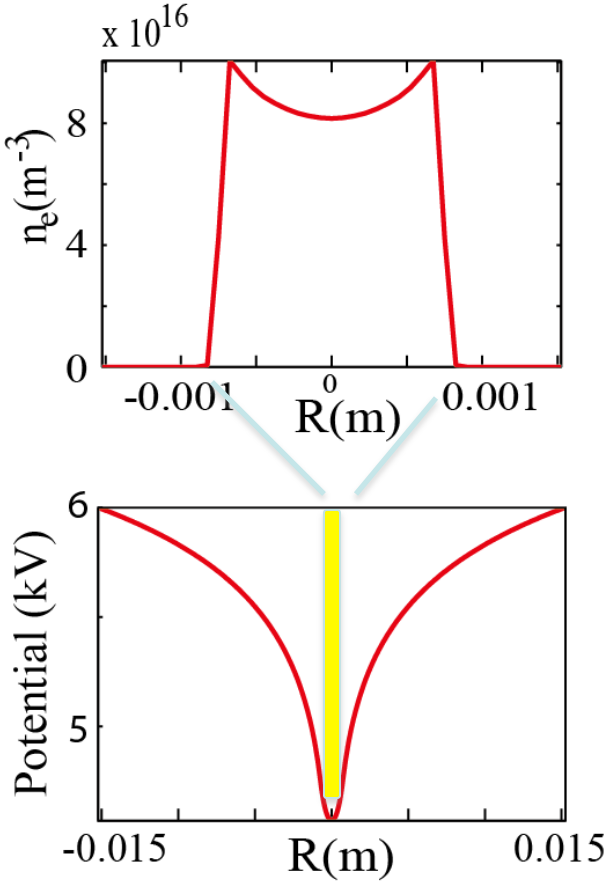


2D (r,z) Profiles of Electron Beam

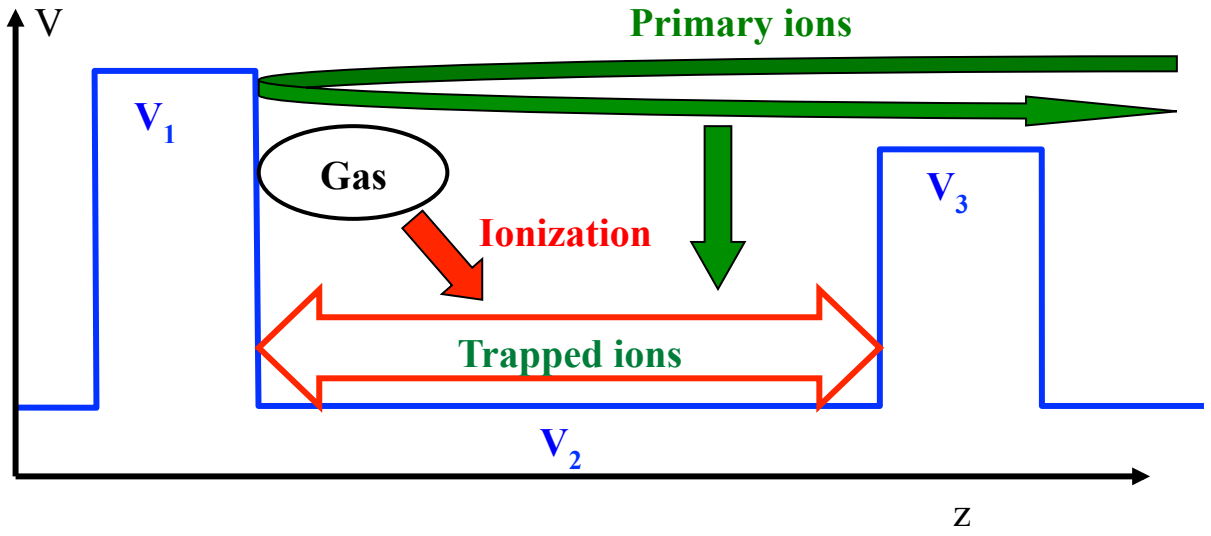
Axial Profiles



Radial Profiles

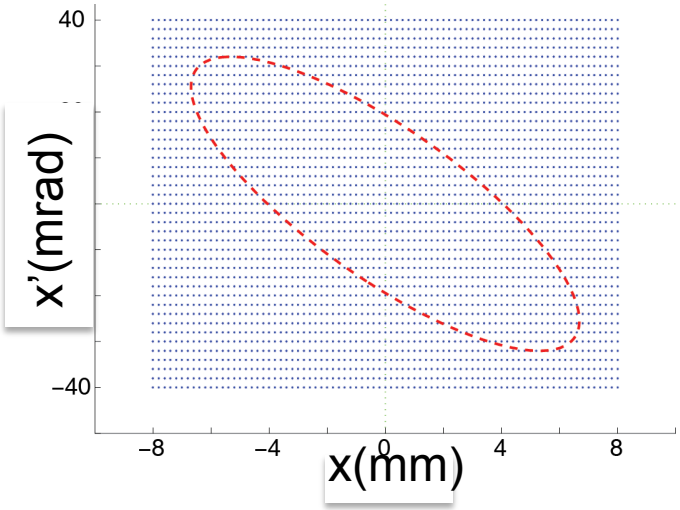


EBIS-PIC Model for Charge Breeding



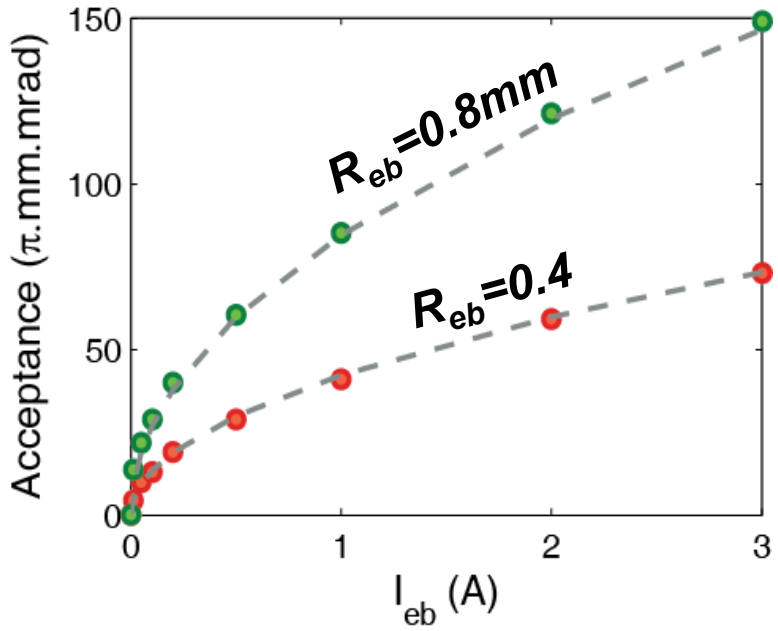
- The background **electron beam** distribution is calculated by PBGUNS. In EBIS-PIC, the electron beam is assumed to be fixed on field flux surfaces while the electron density is updated according to the changes of space potential.
- The **primary ions** and **neutral gas ions** are tracked by Monte Carlo method which includes: Ionization, charge exchange, radiative recombination, Coulomb collisions with electrons, Coulomb collision between primary ions and neutral gas ions, self-consistent electrostatic field (PIC)

Primary Ion Acceptance



Acceptance is the emittance of the initial ion beam whose orbits overlap with the electron beam 100% in the trap.

$$A = \varepsilon_{ems} = 4\sqrt{\overline{x^2}\cdot\overline{x'^2} - \left(\overline{x\cdot x'}\right)^2}$$



Acceptance is function of I_{eb} and R_{eb}.

$$A = 1.06\times10^5\, R_{eb}\sqrt{I_{eb}}\ \left(\pi\cdot mm\cdot mrad\right)$$

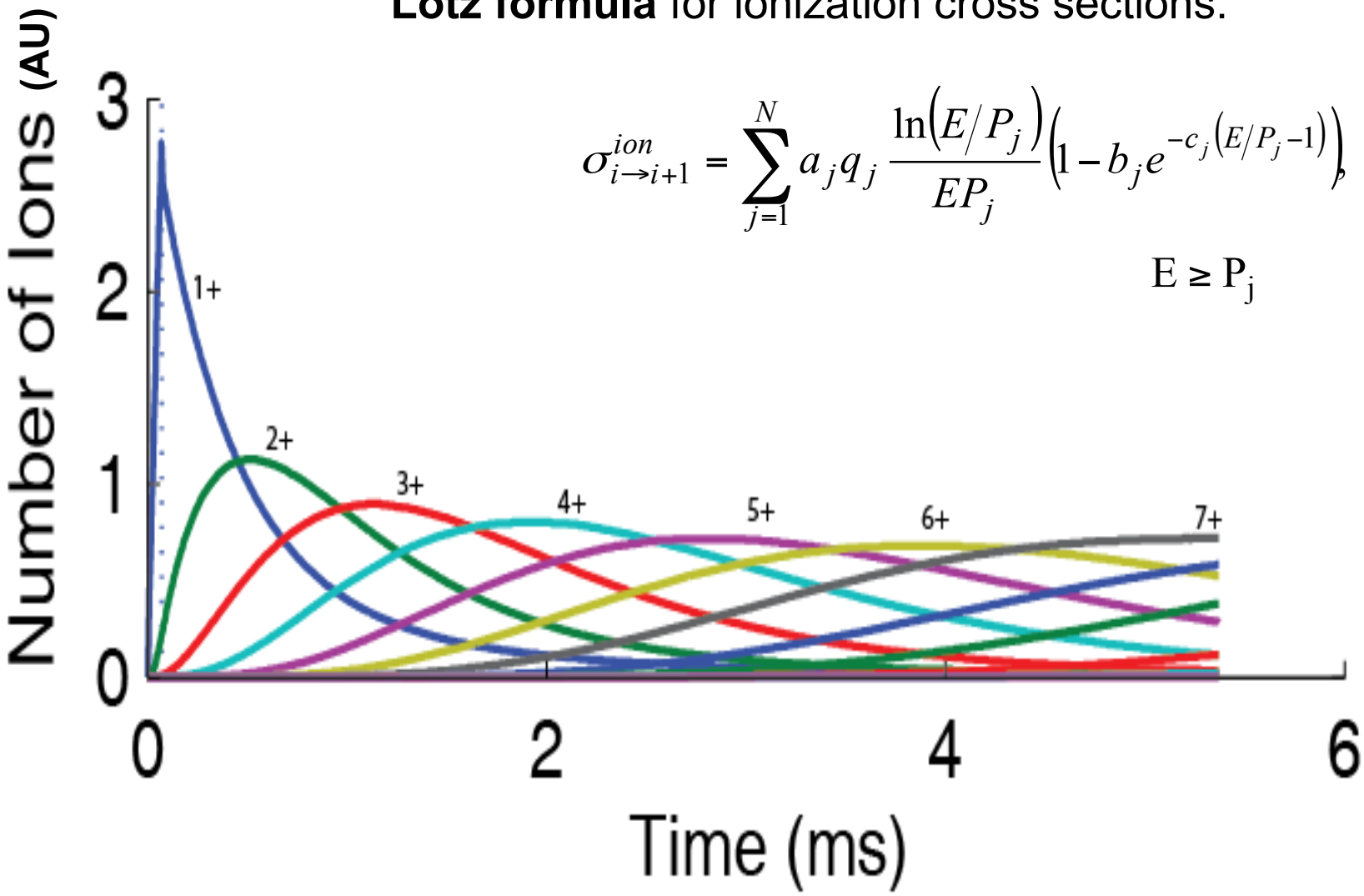
Acceptance has little dependence on B field and ion beam energy.

Evolution of Cs Ion CSD Predicted by EBIS-PIC

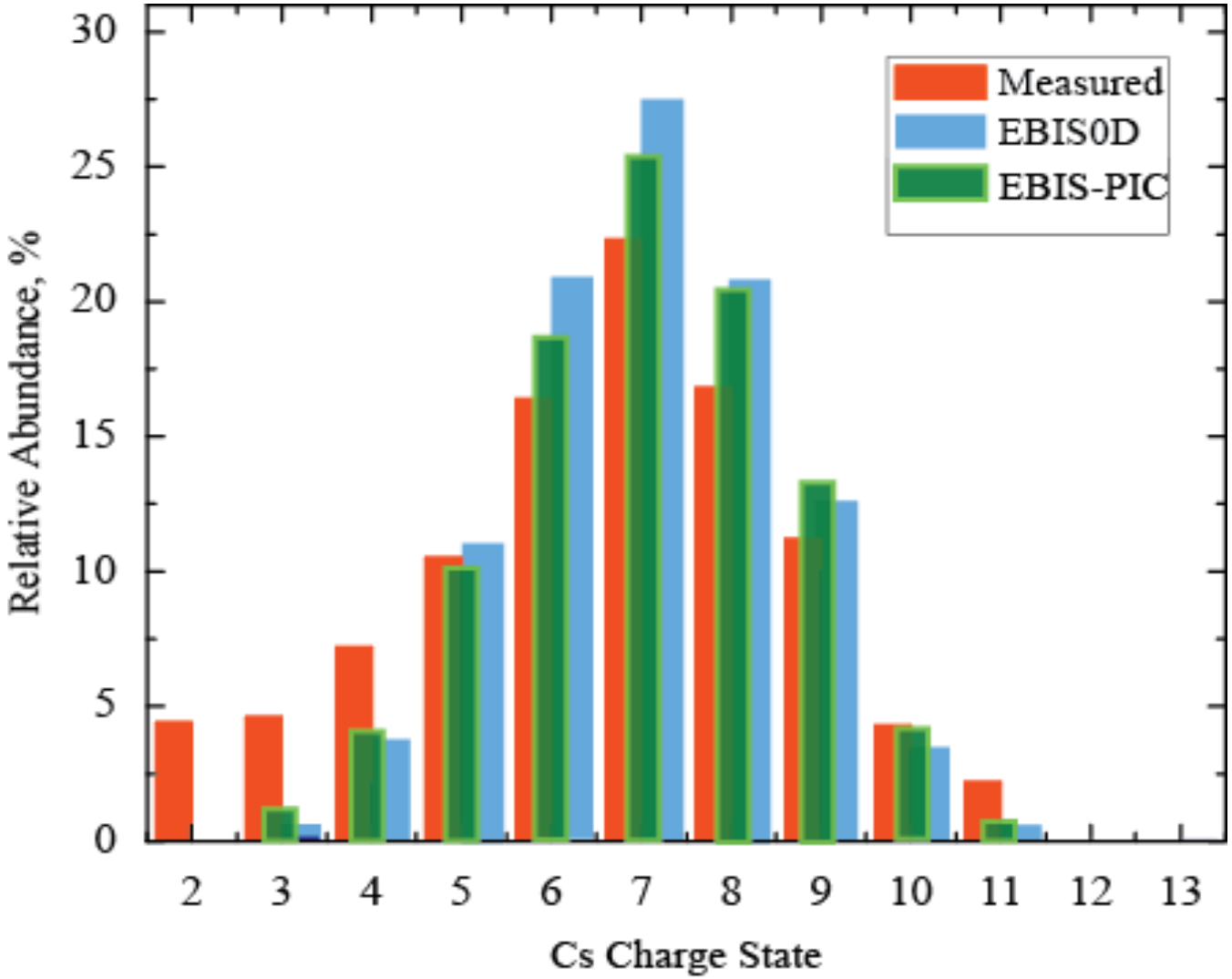
Lotz formula for ionization cross sections:

$$\sigma_{i\to i+1}^{ion} = \sum_{j=1}^{N} a_j q_j \frac{\ln\left(E/P_j\right)}{EP_j}\left(1 - b_j e^{-c_j\left(E/P_j - 1\right)}\right),$$

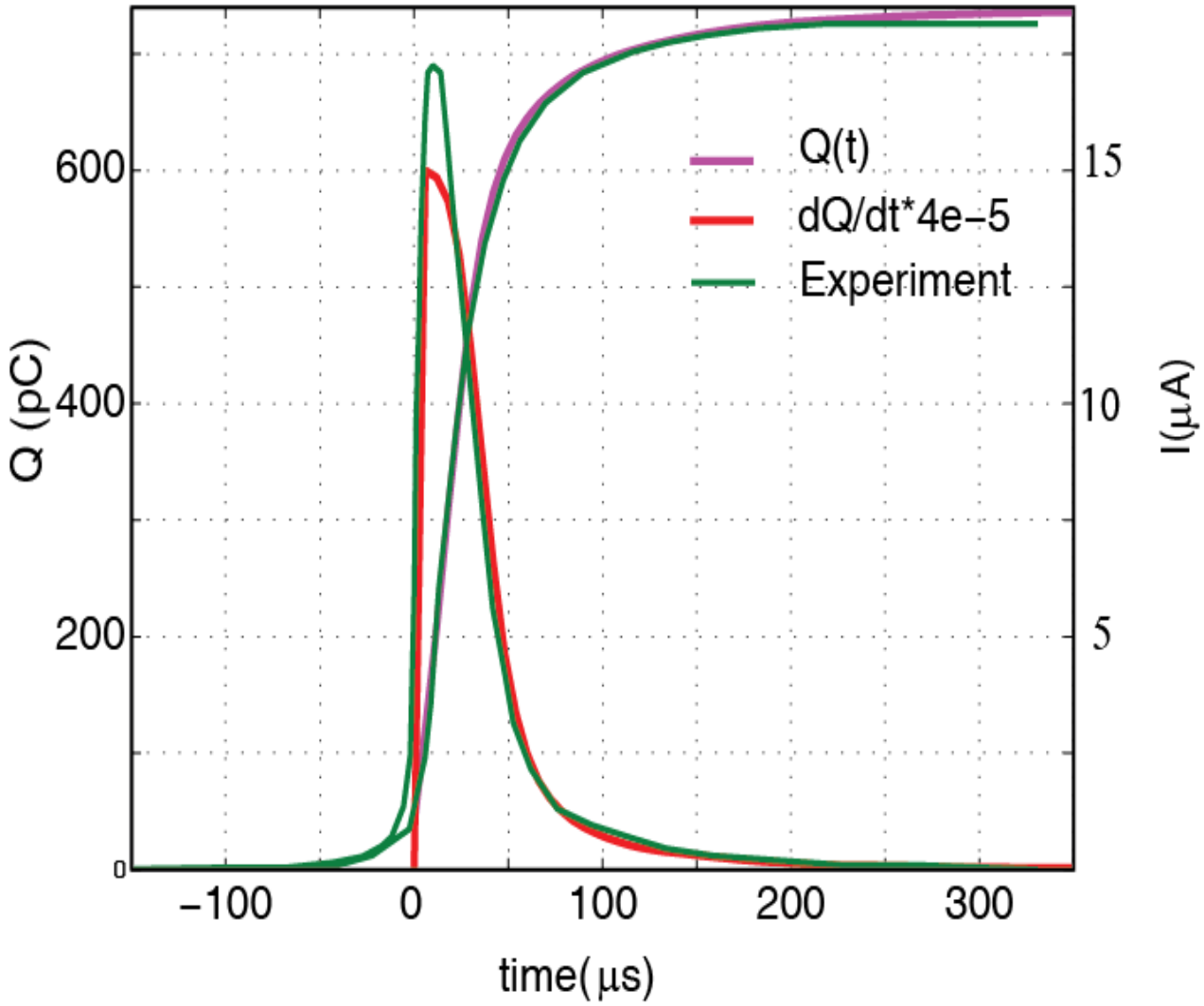
$E \geq P_j$



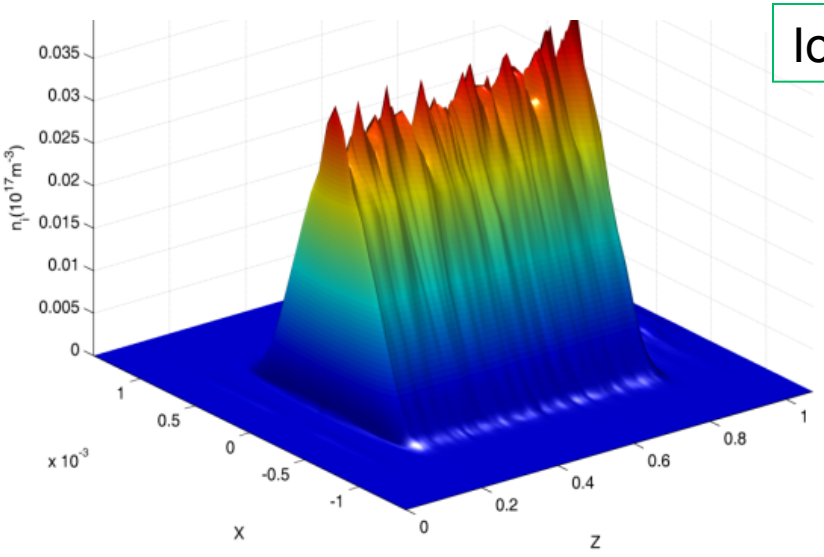
Cs Charge State Distribution After ~5.3 ms Trapping



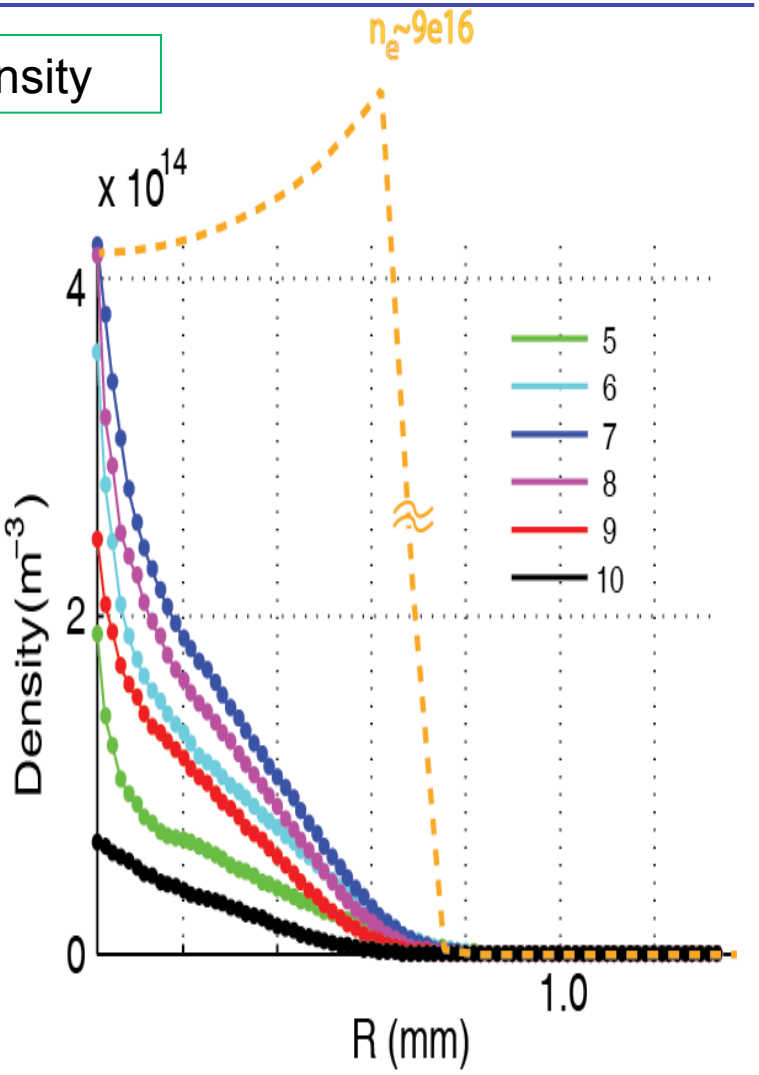
Evolution of Extracted Ion Charge and Current - Comparison



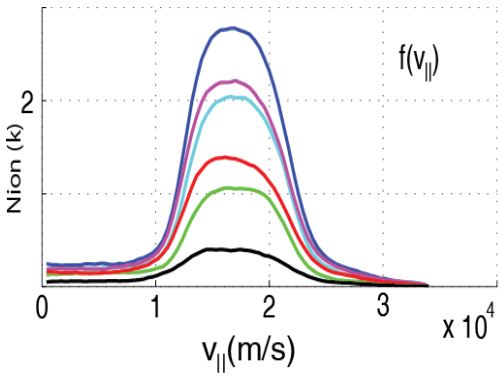
Cs Ion Profiles Calculated by EBIS-PIC After 5.3 ms Trapping

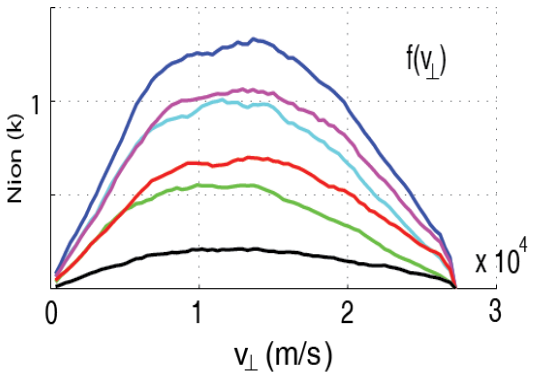


Ion density

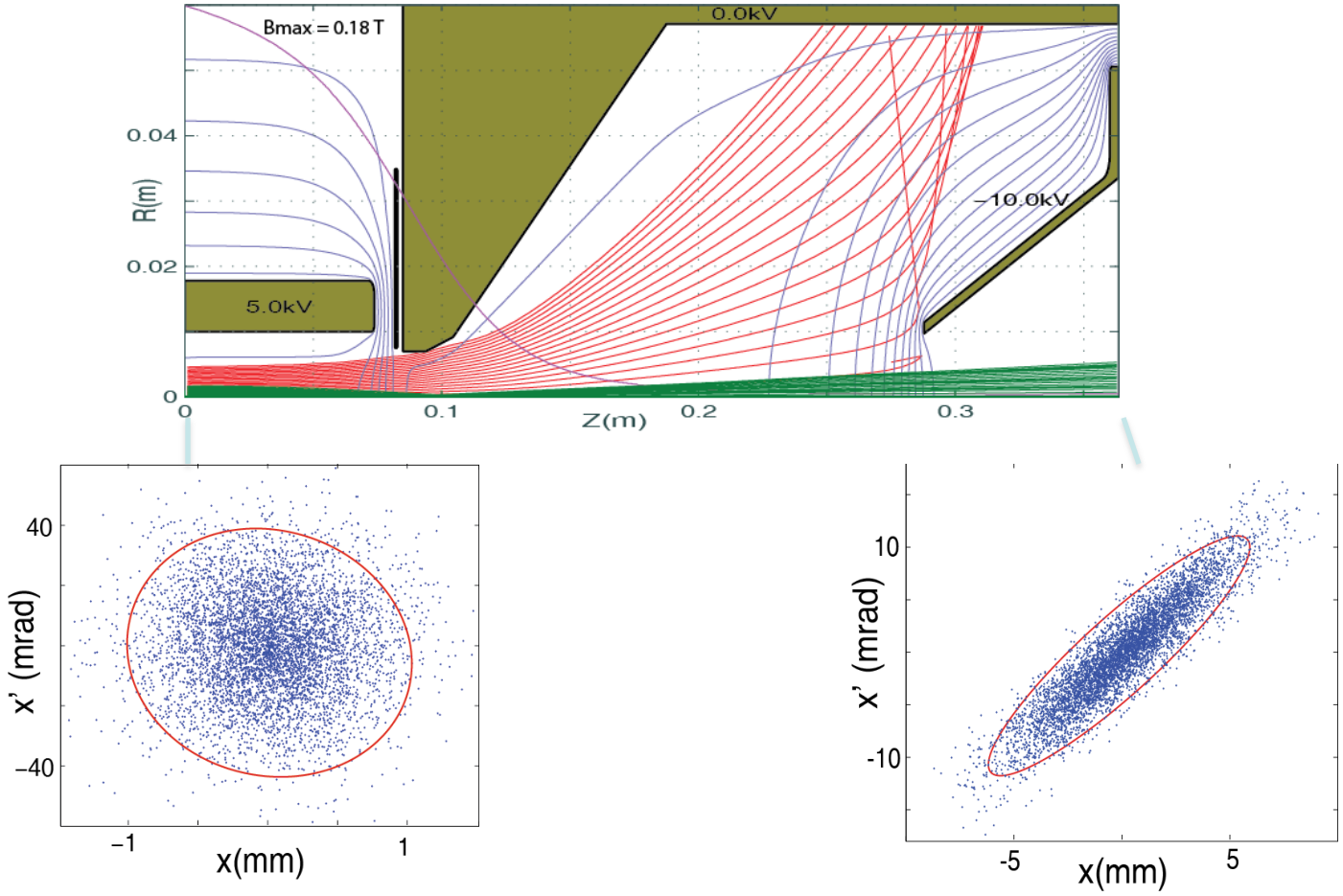


Ion velocity distributions





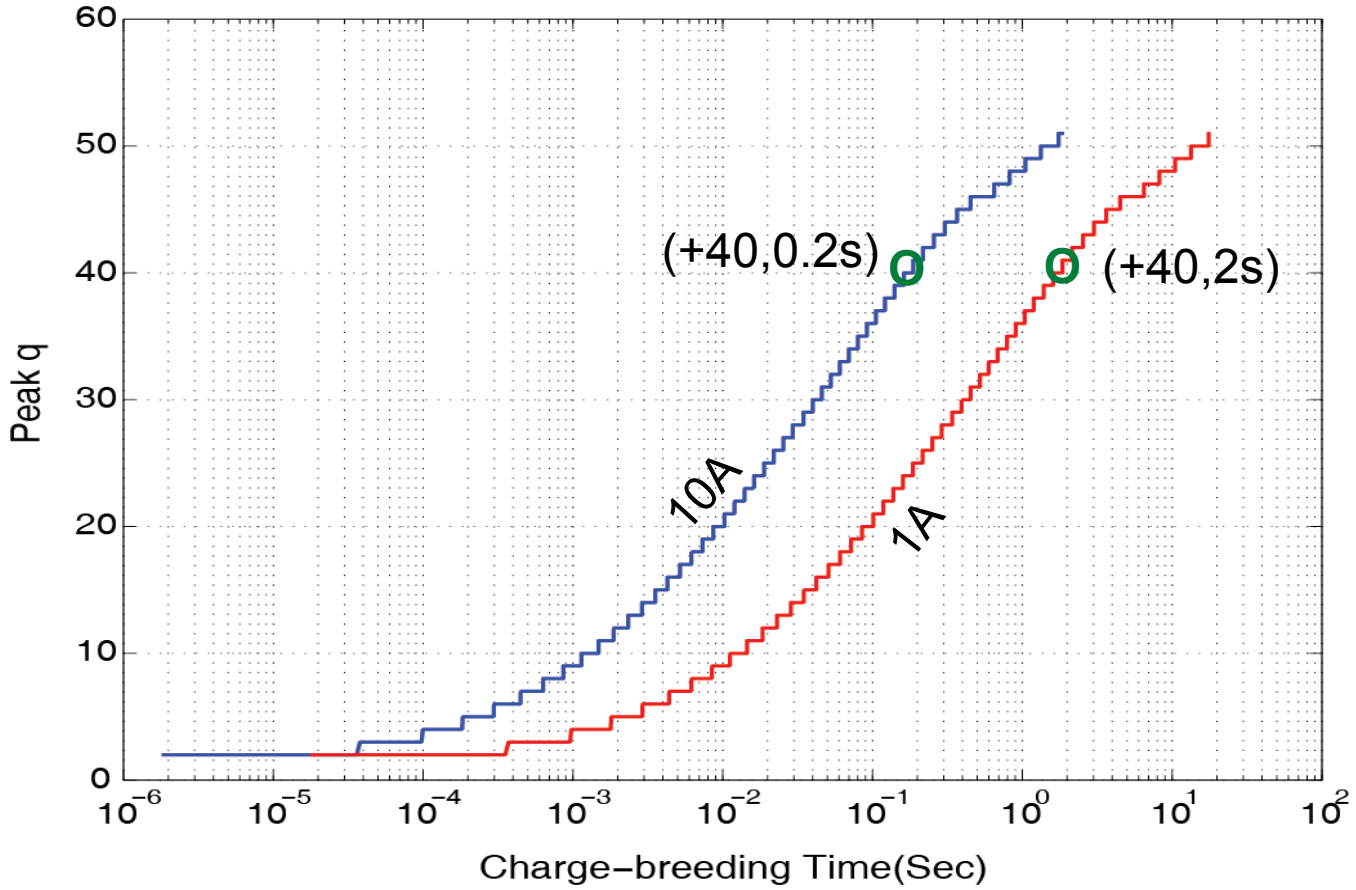
Self-consistent Multiple Ion Species Extraction Modeling



Long Confinement Simulation is Needed for High q-ions

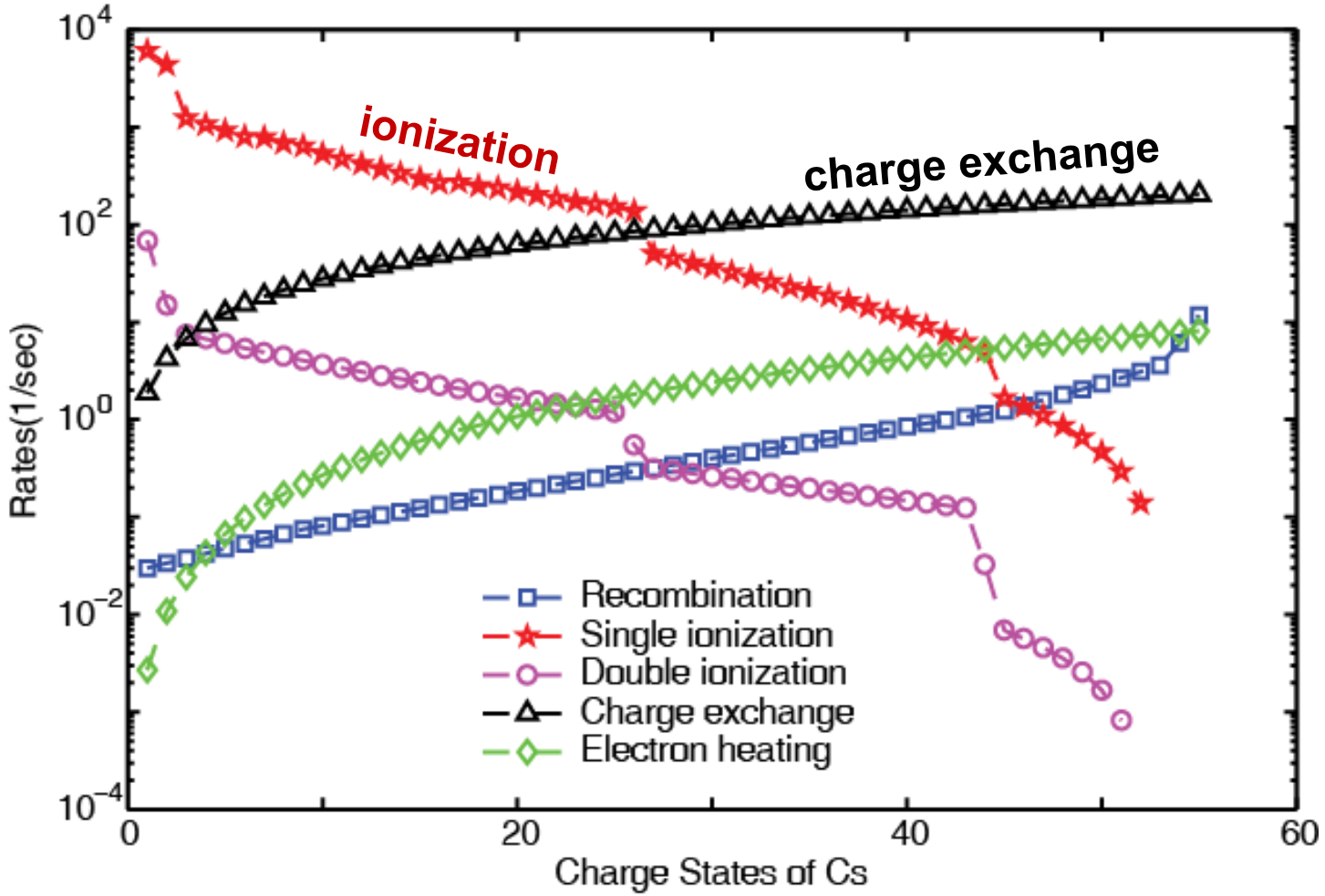
Peak-q vs charge breeding time for Cs

EBIS 0D (Ionization only) taking BNL Test EBIS parameters

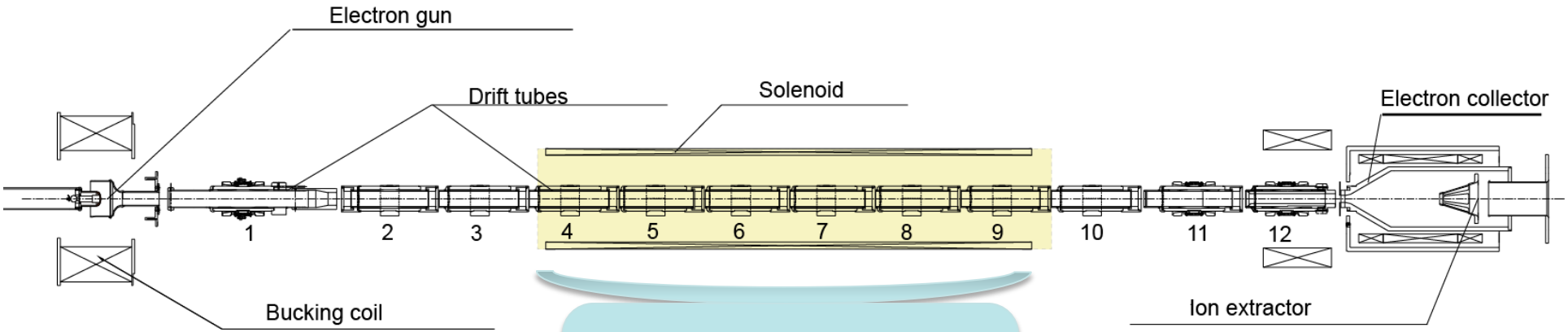


CX Could be Dominant for High-q ions (unless UHV)

Atomic Collision Rates $E_i = 0.2$ keV, $E_e = 20$ keV, $n_e = 10^{17}$ / m^3



Practical Computation



1D (r) geometry
1D fields
2D particle pusher

2D (r,z) geometry
2D fields
3D particle pusher

Use 0D as baseline
Use lower dimensional calculation where possible
Use efficient algorithm, in particular wrt atomic processes
Use MPI

Summary and Future Work

PBGUNS and EBIS-PIC together provide an EBIS modeling tool (under dev).

PBGUNS simulates steady state base e-beam in EBIS

EBIS-PIC simulates ion dynamics and charge breeding in EBIS trap in the presence of e-beam; continued to injection/extraction

Preliminary validation with experiments is made.

Features

Provides full particle information to measurements

Parameter study easier than experiments.

Investigate each atomic processes separately, thus learn what knob to control

Guide experiments and optimize

Future EBIS-PIC work will be focused on:

Simulation of long time confinement

Further benchmarking against experiments

Parameter studies

EBIS facility support

Quasi-3D Model of an Electron Cyclotron Resonance Ion Source

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For introduction of ECRIS please visit

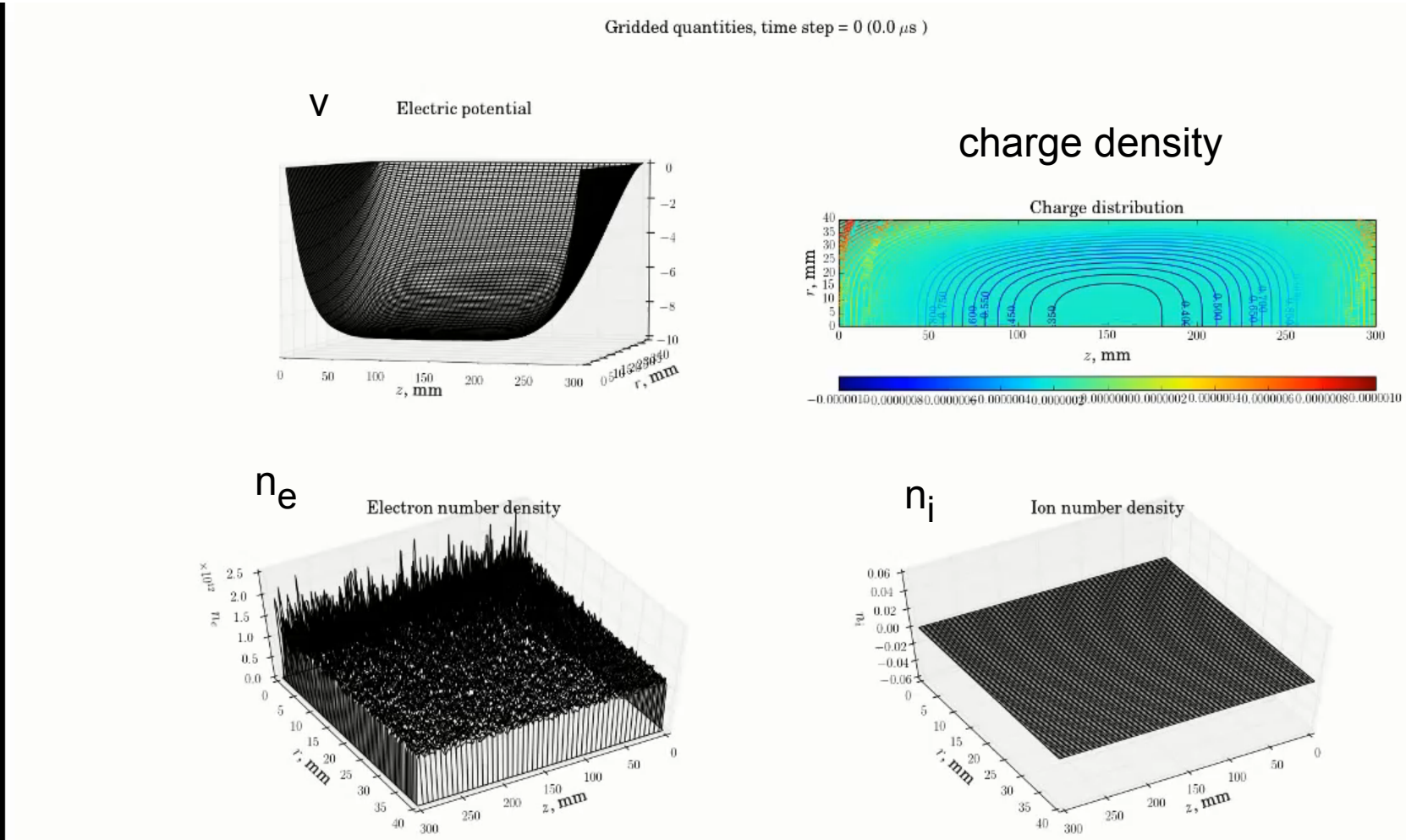
http://far-tech.com/consulting.html#vis

Self-Consistent Simulation of ECRIS plasmas by SIMPL

SIMPL (Simulation of Plasmas)

- 3-D PIC code - self consistent calculations
- Drift kinetic model - electrons by their guiding center motions
  (gyro-radius < 1 mm for 10 KeV electrons)
- RF effect is modeled using the Lichtenberg-Lieberman model.
- Atomic processes
- Particle managing technique - Manage number of computational particles when number of ions increase exponentially due to ionization
- Parallel computing: “domain-cloning" + Multi-threading
- Runs on NERSC as well as FAR-TECH linux-cluster.
- Overall code speed: 50-100 microsec/day on NERSC

Self-consistent ECRIS Plasma Simulation by SIMPL



Summary and Future Work

SIMPL simulates dynamics of ECRIS plasmas

Validation of simulation results against experiments is underway:
Fast camera imaging is being prepared at ANL's ECR-II.

Strategy:

Establish steady state background plasmas (evolution time ~msec):
(takes large CPU time)
Charge breeding of ions from an established steady state should be fast.
Many outstanding issues in ECRIS performance should be resolved by our simulations.

Future Work:

Refine RF heating model (BIG Project)
Support ECRIS facilities
Develop user-friendly GUI

Software Commercialization

PBGUNS (beam source code) : already commercialized
More features with improved GUI

EBIS-PIC : 0D – give away
1D – good commercial potential
2D – mostly for consulting work and support EBIS facilities

SIMPL – Commercial potential for gas electronics
Consulting work and support ECRIS facilities

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Beam Source Modeling
Plasma Technology: Modeling and Diagnostics

Linac Systems: RF source, Structure, Integration
Beam Instrumentation
Solid State Amplifiers

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