Modeling ECRIS Using a 1D Multi-Fluid Code

Michael Stalder

Extraterrestrische Physik
Universität Kiel

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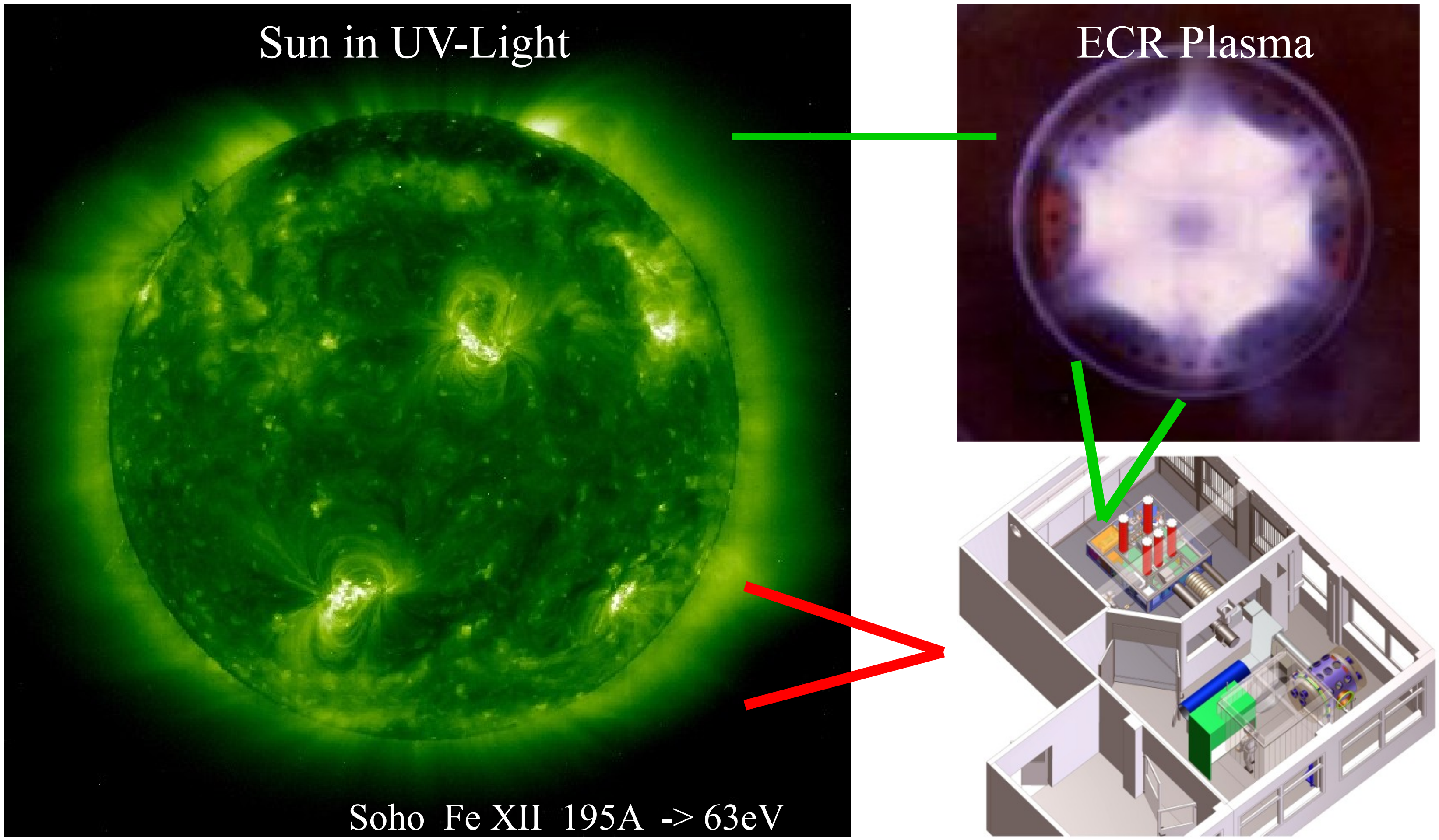
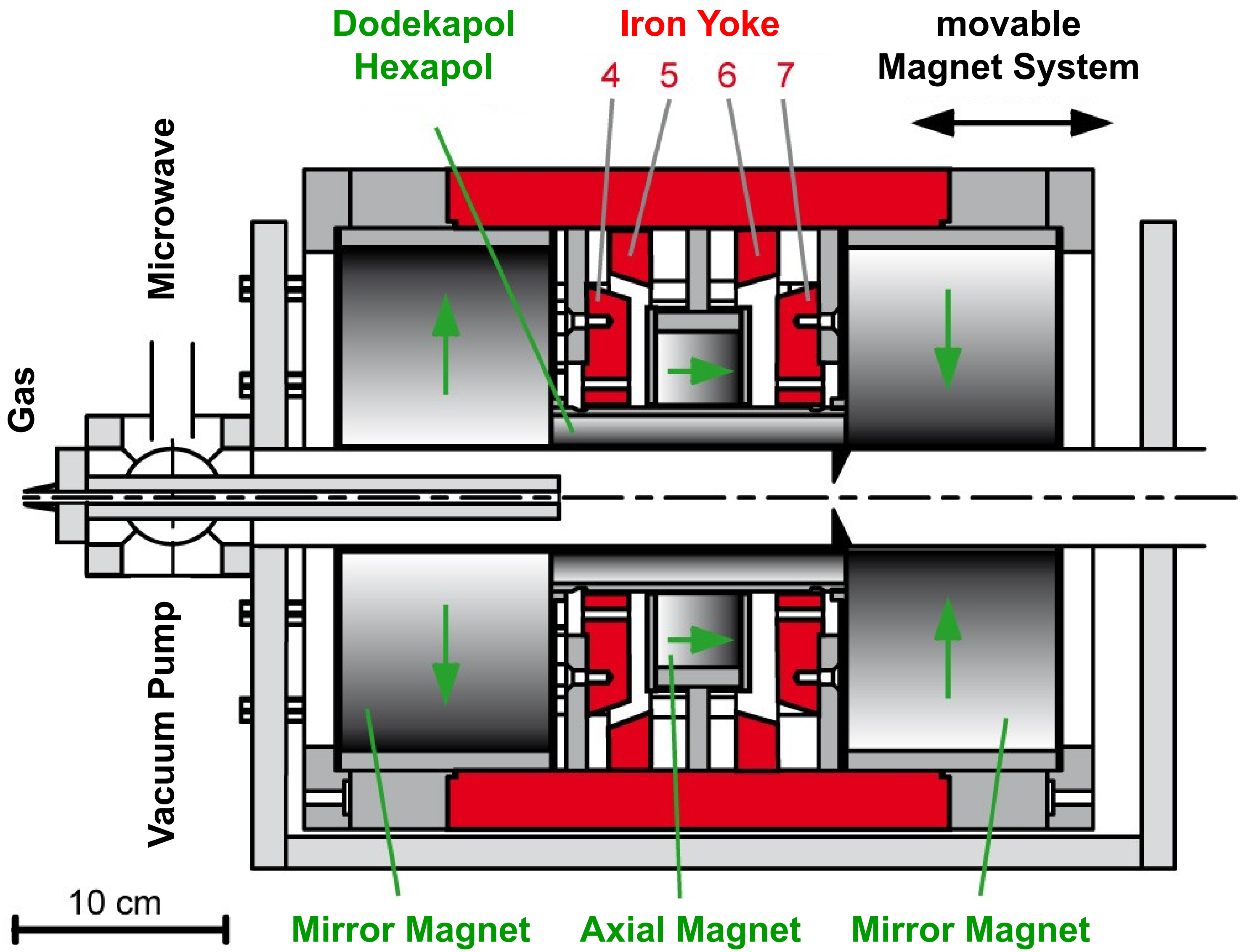
Outline

- Introduction
- The 1D Multi-Fluid Model
- Characteristic Charge State Distributions
- The Influence of the Ion-Temperature T_i
- Conclusions

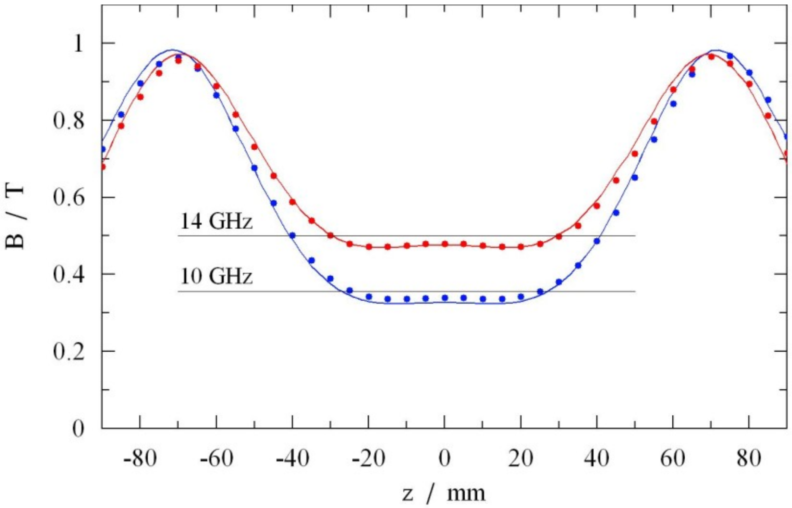
The Solar Wind Calibration Facility

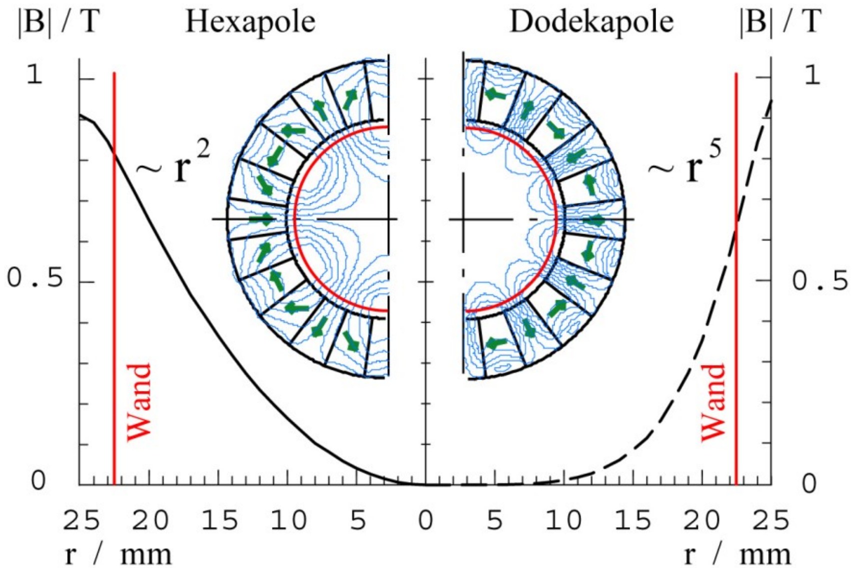


The Kiel ECRIS



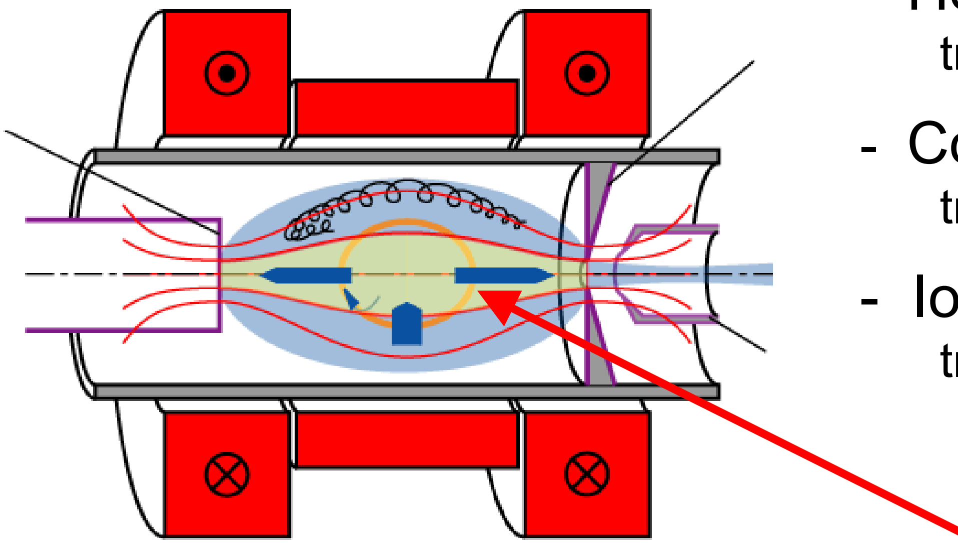
B-Field Simulation and Measurment

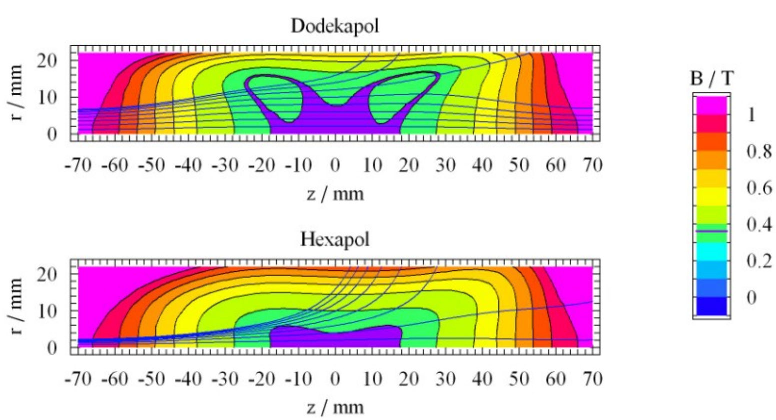


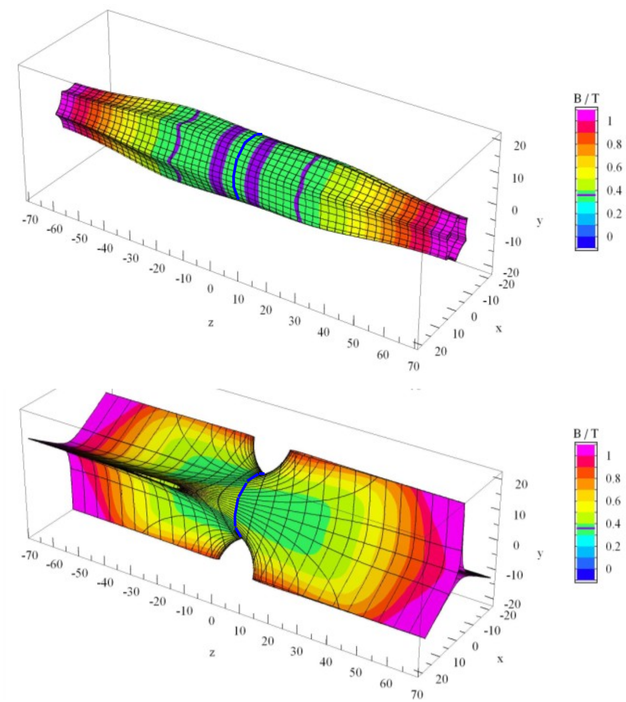


Plasma Confinement / B-Field Configuration

- Hot Electrons
  trapped magnetically
- Cold Electrons
  trapped magnetically and electrically
- Ions
  trapped by quasineutrality







The 1D Multi-Fluid Simulation

How is the measured chargestate distribution connected to the plasma parameters?

- What is the influence of the size of the ECRIS

- What ist the influence of the drift between the individual ion fluids and of the ion temperature Ti

Basic assumptions for the 1D multi-fluid model:

- Collision-dominated, isotrop ion-populations with constant temperature Ti are treated as individual fluids with interactions caused by friction forces.

- The electron distribution function f(z,E), and the neutral gas pressure n0 are chosen as free start parameters → this model is not selfconsistent!

Simplicity ←→ Information about the coupling

→ See the results of Edgell et. al. 2002 (1D); Zaho et. Al. 2007 (2D);

Transport Equations for the 1D Multi-Fluid Simulation

Continuity Equations

$$\frac{\partial}{\partial t} n_i(z,t) = -\frac{1}{A(z)}\frac{\partial}{\partial x}\left(A(z)\, n_i(z,t)\, u_i(z,t)\right) + S_{i-1}(z,t)\, n_e(z,t)\, n_{i-1}(z,t) - S_i(z,t)\, n_e(z,t)\, n_i(z,t) - R_i\, n_0\, n_i(z,t) + R_{i+1}\, n_0\, n_{i+1}(z,t)$$

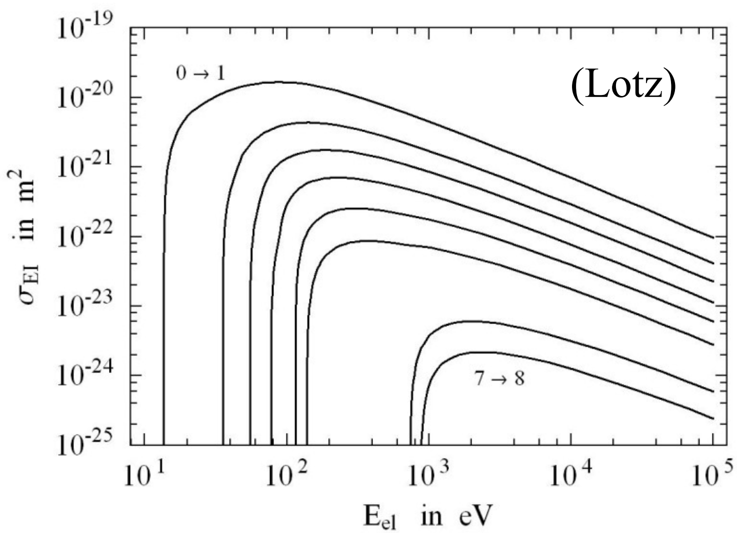
Momentum-Conservation Equations

$$m_i\, n_i(z,t)\, \frac{\partial}{\partial t} u_i(z,t) = -\frac{m_i}{A(z)}\frac{\partial}{\partial x}\left(A(z)\, n_i(z,t)\, u_i^2(z,t)\right) - \frac{\partial}{\partial x} P_i - q\, z_i\, n_i(z,t)\, \frac{\partial}{\partial x} U + m_i \sum_j Q_j(z,t)\, \left(u_j(z,t) - u_i(z,t)\right) + \sum_j R_{i,j}\, n_i(z,t)\, n_j(z,t)\, z_i^2\, z_j^2\, \left(u_j(z,t) - u_i(z,t)\right)$$

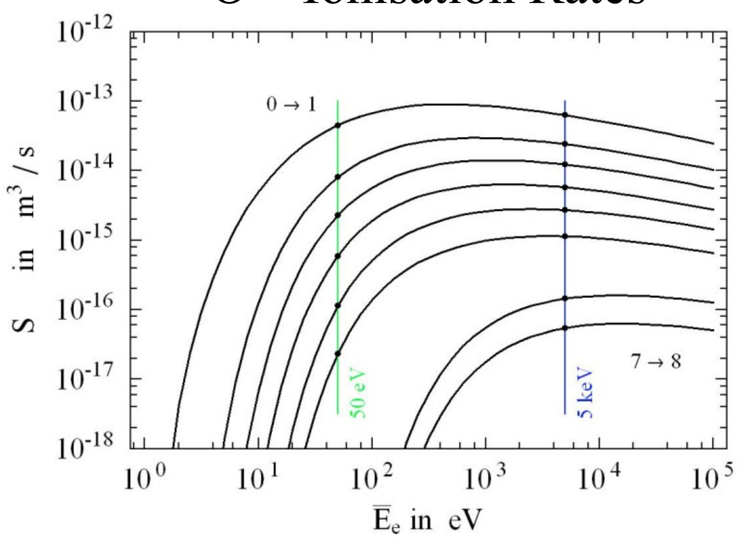
$$\frac{\partial}{\partial x} E(z,t) = -\frac{\partial^2}{\partial^2 x} U(z,t) = \frac{1}{\epsilon}\, \rho(z,t) = \frac{1}{\epsilon}\left(\sum_j n_j(z,t) - n_e(z,t)\right)$$

Oxygen: Ionisation and Recombination

O – Ionisation Crossections



O – Ionisation Rates



O – Recombination Crossections

(Müller, Salzborn)

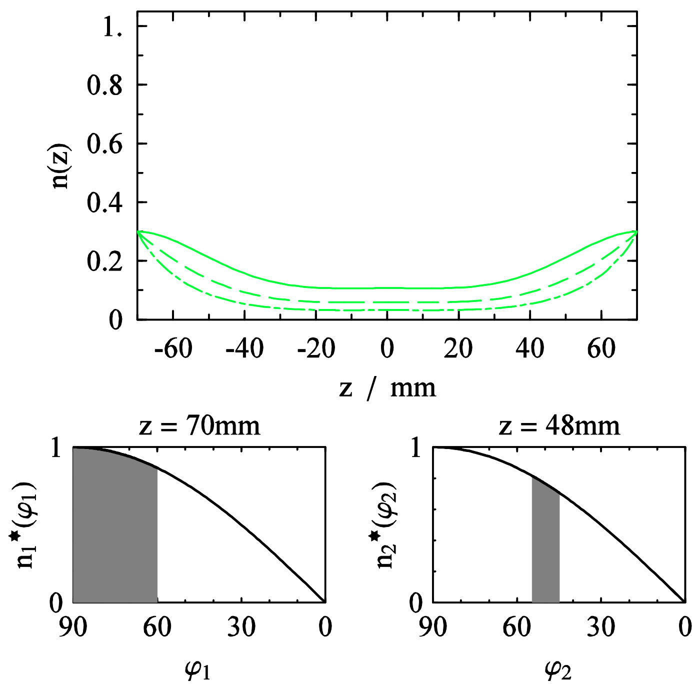
$$\sigma_{z \to z-1} = A_k \, z^{\alpha_k} \, I^{\beta_k}$$

O – Recombination Rates

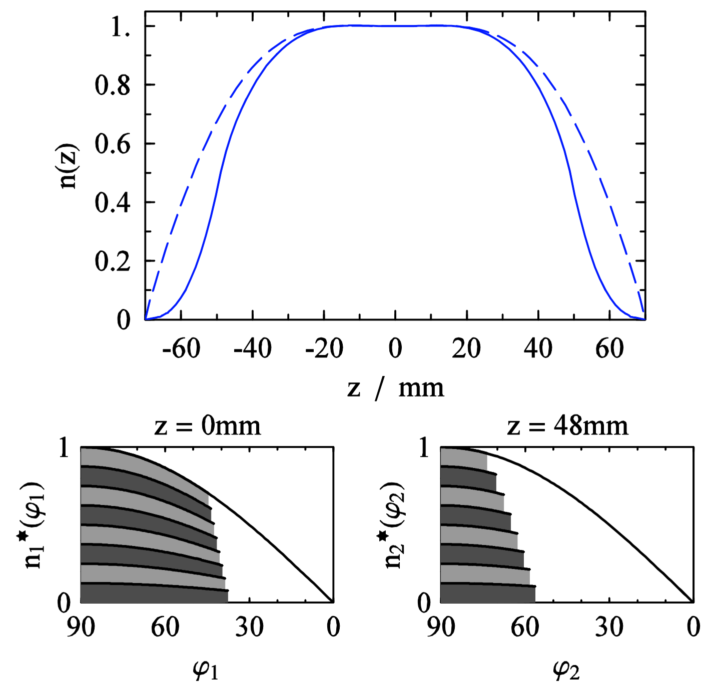
$$R_i = v_i \, \sigma_{z \to z-1} = \sqrt{\frac{2\,k\,T_i}{m_i}} \, \sigma_{z \to z-1}$$

Electron Density Distribution

Cold Electrons: Te=50eV
magnetically and electrically trapped

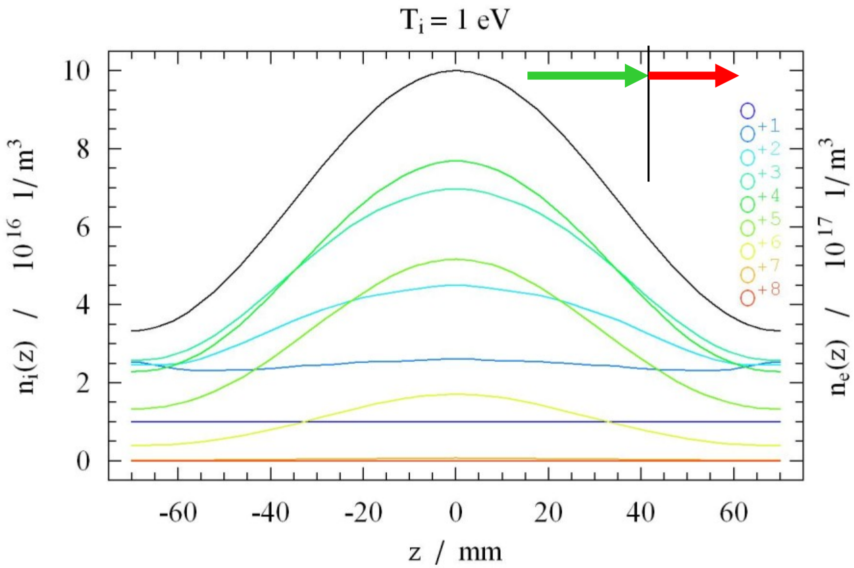


Hot Electrons: Te=5keV
magnetically trapped



The ratio of cold to hot electrons is strongly related to the electron density ratio in the middle and at the edge of the ECRIS

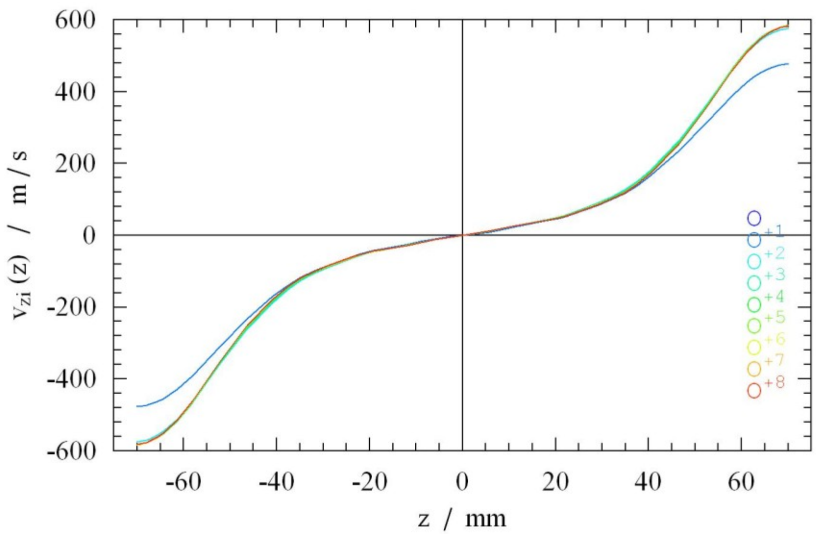
Simulation Results for the Density and the Velocity

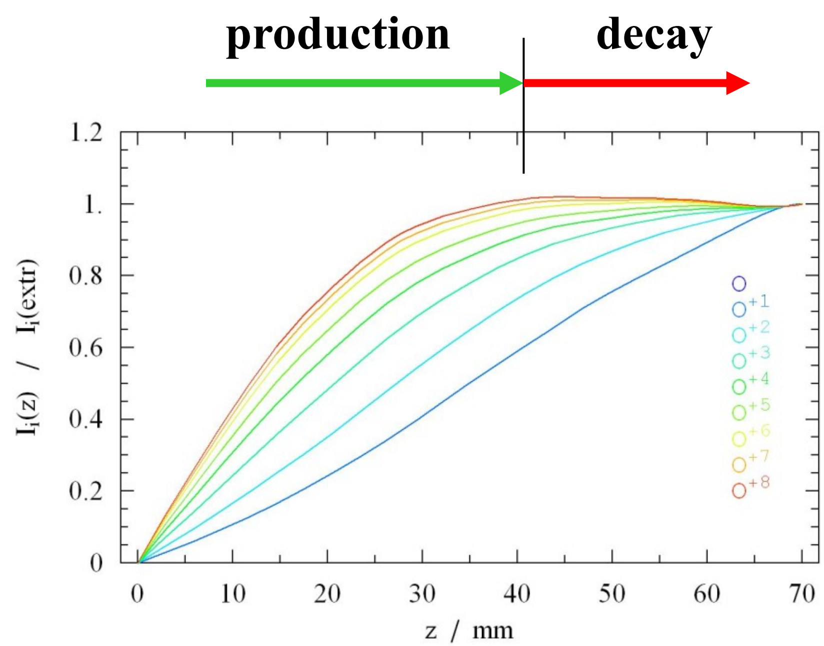


$n_e = 10^{18}$ m^{-3}

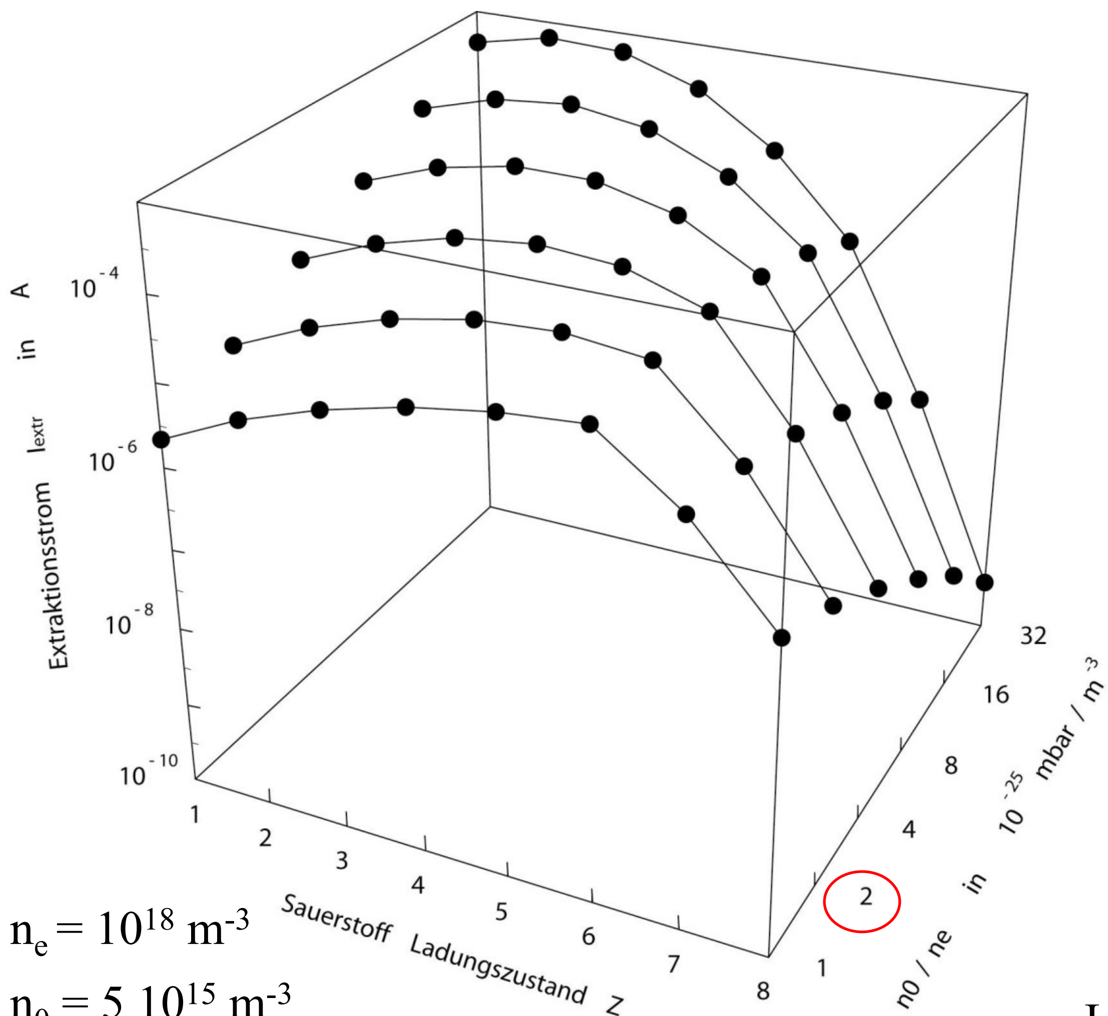
$n_0 = 10^{16}$ m^{-3}

$p_0 \sim 4\ 10^{-7}$ mbar





Charge State Distribution as a Function of n_e/n_0



$n_e = 10^{18}\ m^{-3}$

$n_0 = 5\ 10^{15}\ m^{-3}$

$p_0 \sim 2\ 10^{-7}$ mbar

Scaling the size of $L_0 \rightarrow L_1$

$n_{e1}(z_1) = n_{e0}(z_1 * L_0 / L_1)$

$n_{01}(z_1) = n_{00}(z_1 * L_0 / L_1)$

→ $n_{i1}(z_1) = n_{i0}(z_1 * L_0 / L_1)$

→ $u_1(z_1) = L_1 / L_0 * u_0(z_1 * L_0 / L_1)$

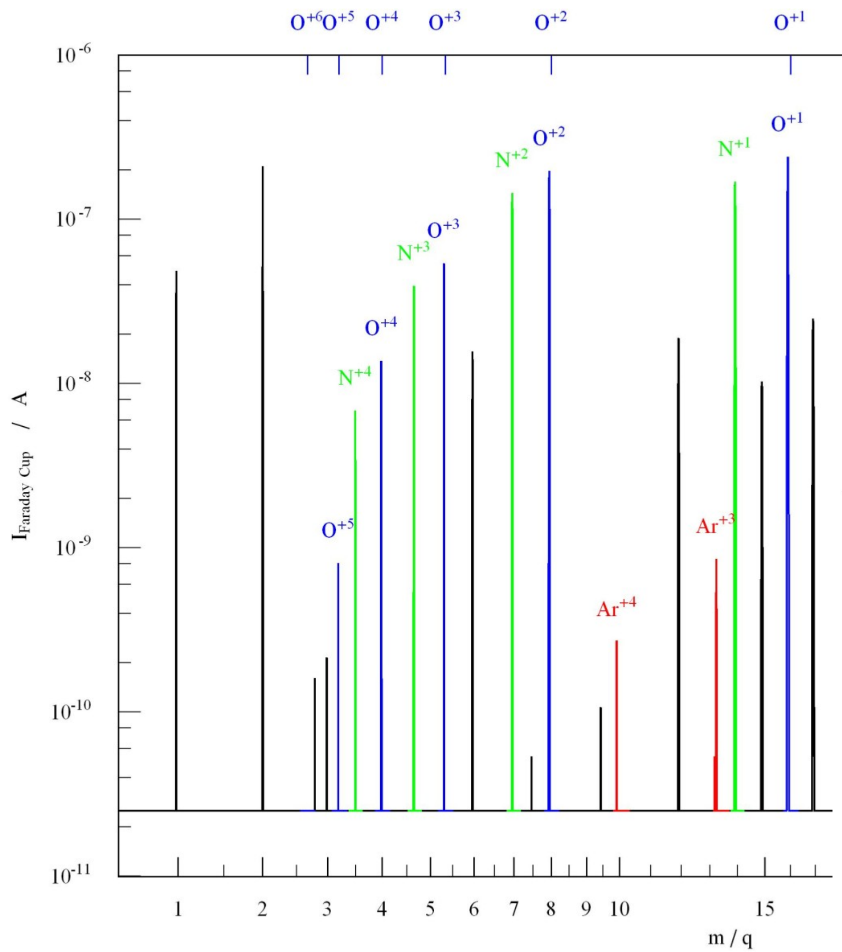
→ $\tau_{i0} = \tau_{i1}$

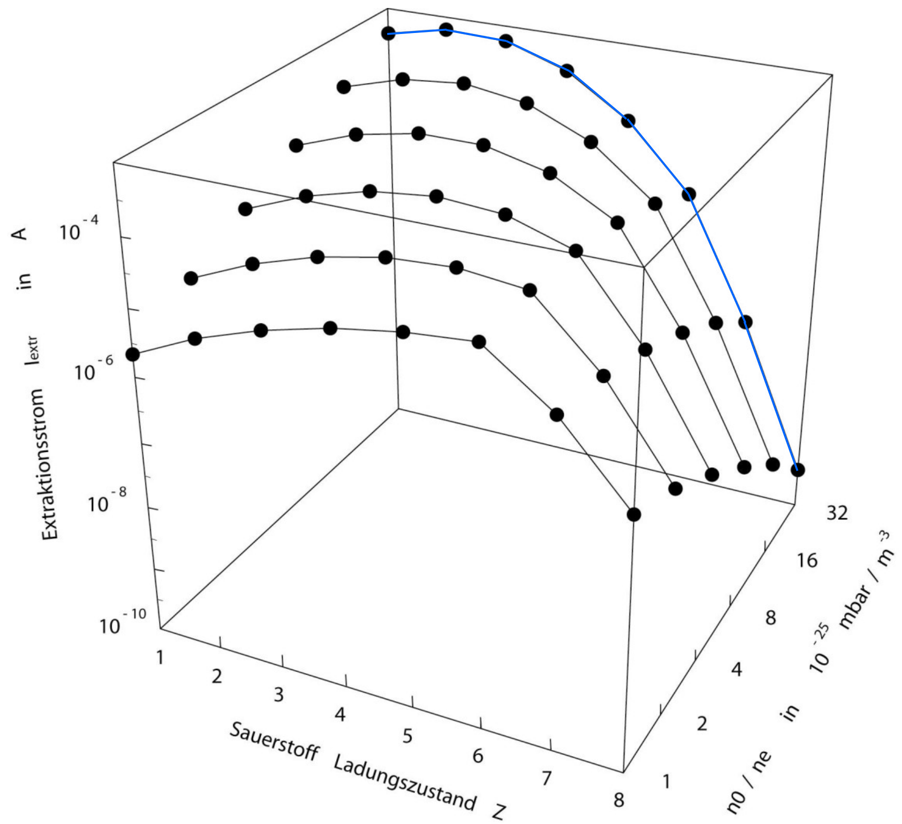
Similar scaling of the density

For the extracted currents:

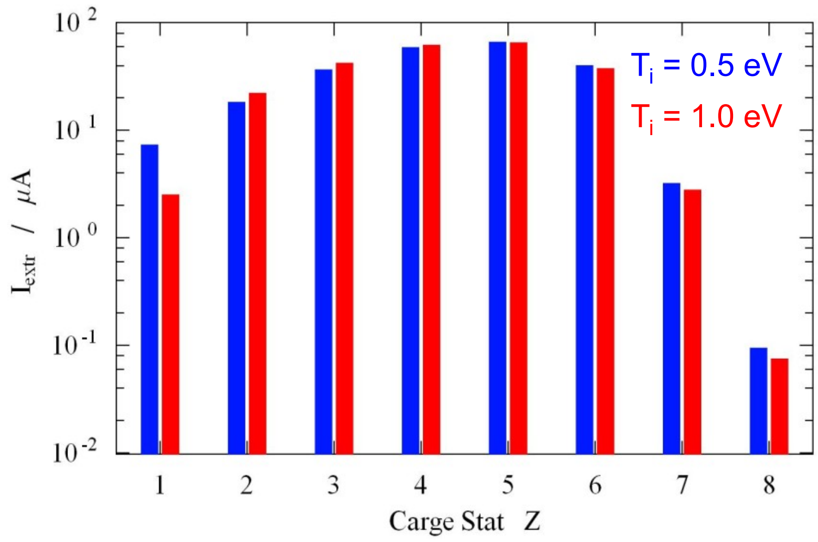
$I_{i\_Extr\ 1} = I_{i\_Extr\ 0} * L_1 / L_0 * (n_{e1}/n_{e0})^2$

Comparison of Measurements and Simulations





The Influence of the Ion Temperature T_i

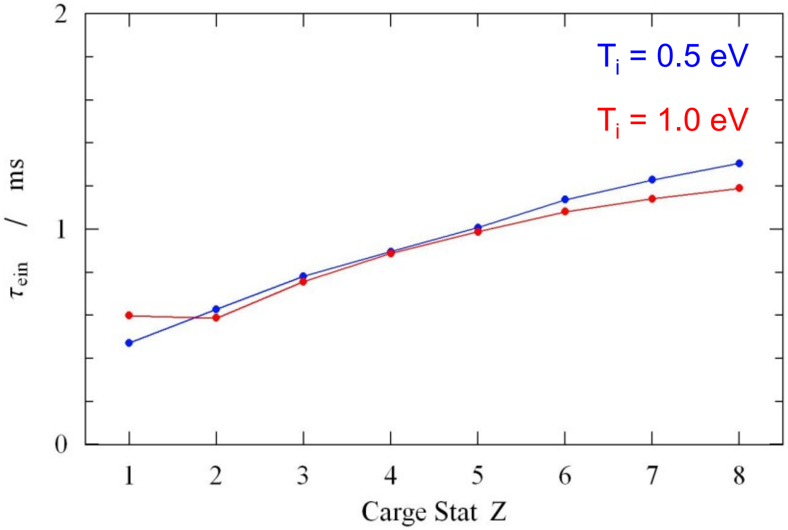


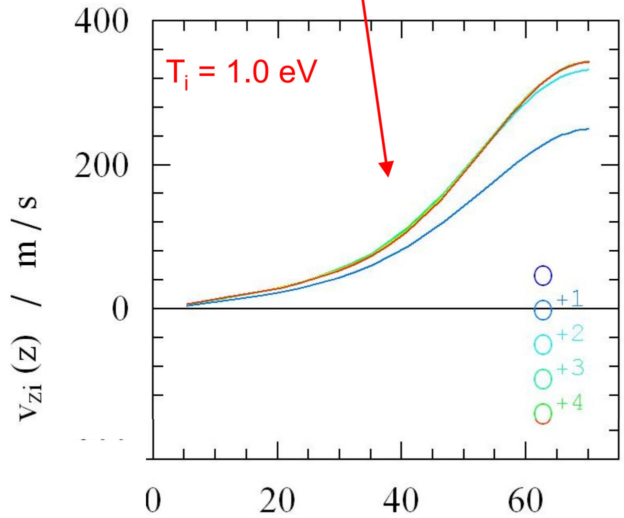
$n_e = 10^{18}$ m^{-3}

$n_0 = 5\ 10^{15}$ m^{-3}

$p_0 \sim 2\ 10^{-7}$ mbar

$$u_{di} \sim \frac{E}{R} \sim \frac{T_i}{T_i^{-3/2}} \sim T_i^{5/2}.$$





Conclusions

- The simulations reproduce the expected characteristic charge state distributions
- The influence of individual fluid velocities is small but can be relevant for the higher charge states
- singly charged ions are not well modeled as a fluid
- For medium electron densities ($n_e \sim 10^{18}$ 1/m^3) ion drifts make about half of the influence of the ion temperature to the extracted currents of highly charged ions
- Very low neutral gas pressure could allow us the production of highly charged ions

Thank You for Your Attention