Experimental Results: Charge-State- and Current-Density Distributions at the Plasma Electrode of an ECR Ion Source

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CDD and CSD - Results From Other Groups

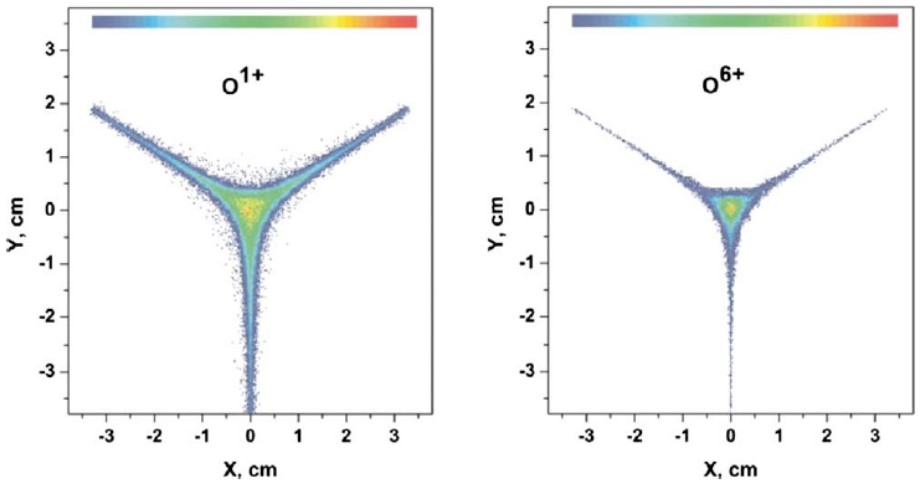


FIG. 2. (Color online) Calculated x-y profiles of O^{1+} and O^{6+} ions in the ECRIS extraction plane.

[1]

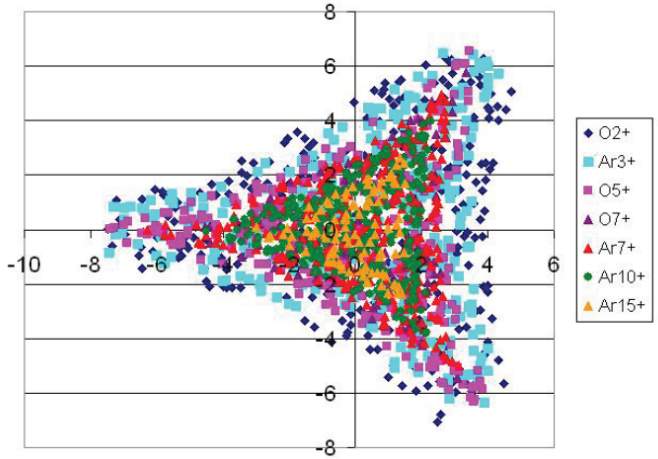


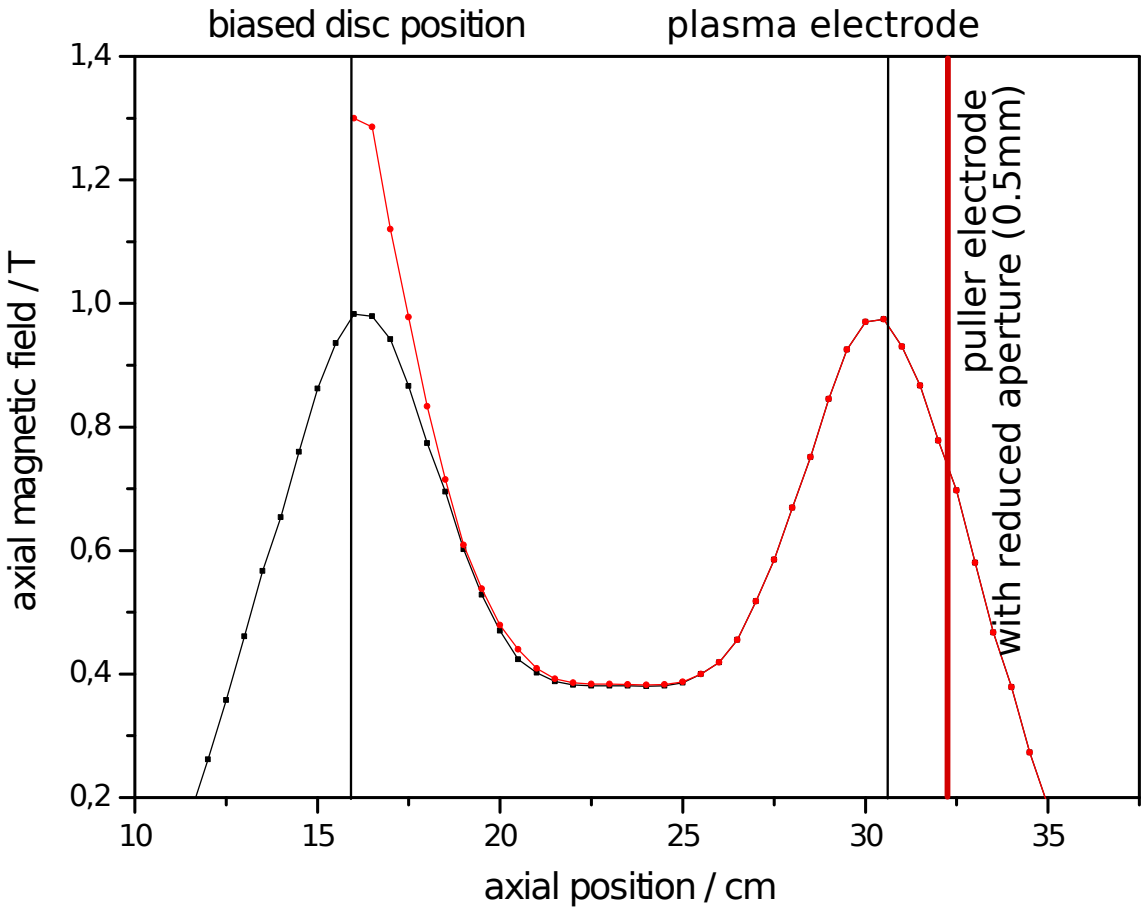
Figure 9: Initial ion distribution representing a real spectrum measured with the SUPERSHyPIE ECRIS

[2]

Important findings:

- Each ion species is arranged in a triangular symmetry.
- The current of each ion species peaks at center.
- Higher charge states are concentrated closer to the axis.

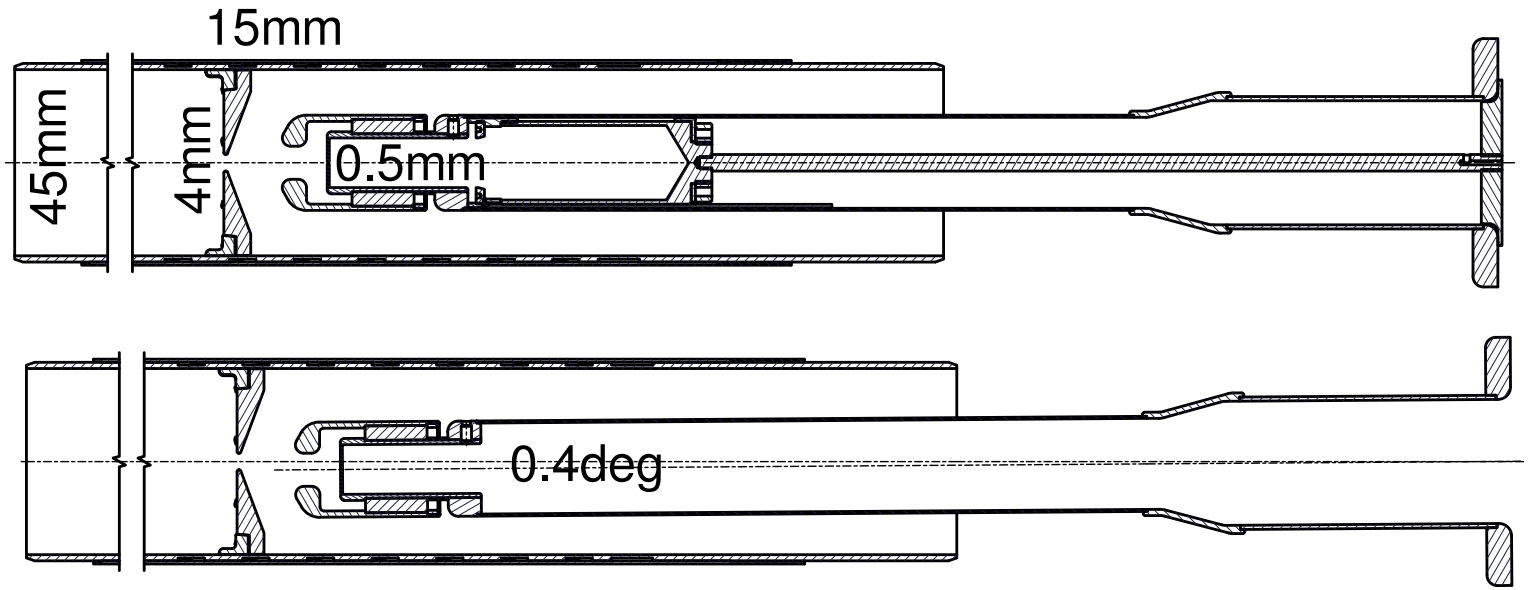
Axial Magnetic Field and the Plane of Particle Limitation



The limitation of the extracted ions takes place in the plane of the puller electrode with its reduced aperture.

$\rightarrow$ The recorded CDDs represent the beam profiles in this plane!

3D-Movable Customized Puller Electrode



- Customized Faraday cup included into the puller electrode
- Its geometry and the use of a negatively-biased repeller prevent secondary electron escape
- Reduced aperture (0.5 mm) limits the area of the effectively extracted beam to a small region of the neutral plasma sheath
- Local ion composition is conserved in the effectively extracted beam

Plasma Parameters

Fixed parameters:

- Injected microwave power: 50 W at 11 GHz
- Extraction voltage: 7 kV (a compromise between good transmission and low voltage)
- Axial position of the puller electrode

Variable parameters:

- Pressure inside the plasma chamber (5E-7 to 1E-6 mbar)
- Ion composition (residual gas only or helium added)

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Variable parameters:

- Pressure inside the plasma chamber (5E-7 to 1E-6 mbar)
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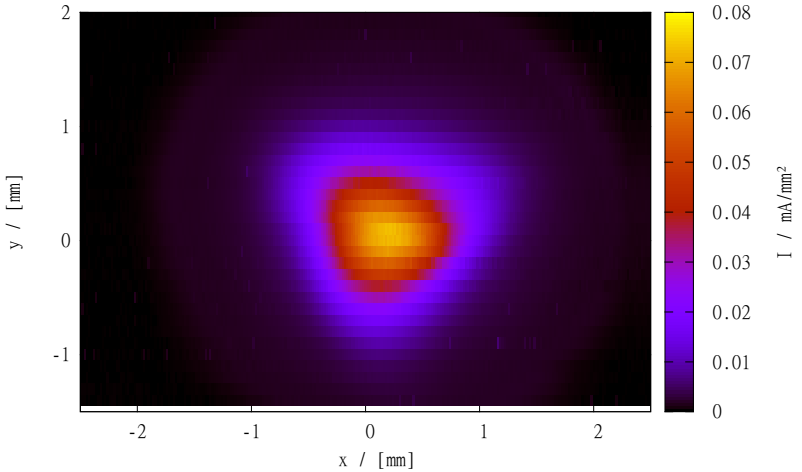
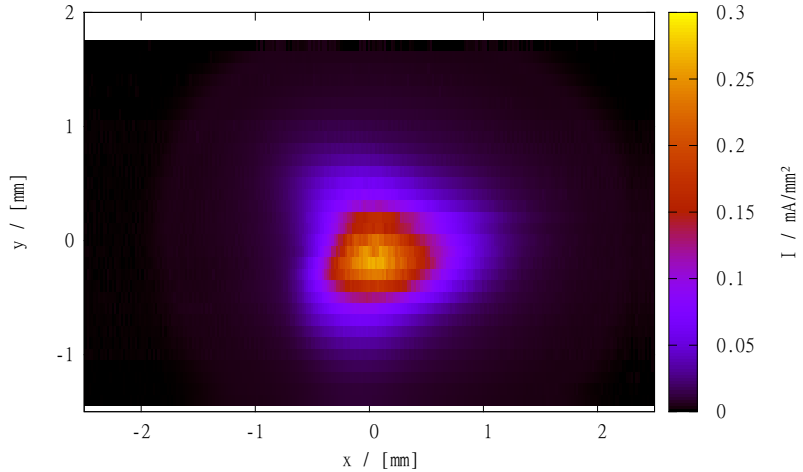
Definition of two settings:

RG: residual gas only at 5E-7 mbar
RGHe: helium added until 1E-6 mbar

Current Density Distributions



Setting RG

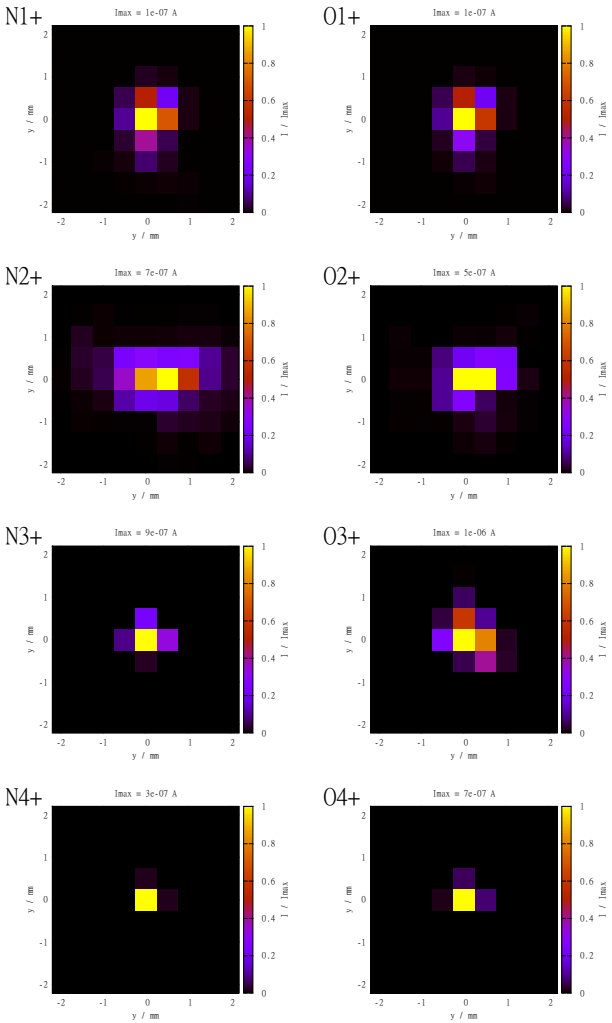


Setting RGHe

- The circular plasma electrode is visible
  - $\rightarrow$ extracted beam is limited to a small source region
  - $\rightarrow$ high spatial resolution in absolute current values
- The current density is peaking at the centre
- Areas with similar current density are grouped into triangular structures
- The orientations and sizes of the triangular structures differ

$\rightarrow$ The ionic composition of those structures is still unknown!

Spatially Resolved Charge State Distributions



Setting RG

- the current density is peaking at the centre
- the effective radii decrease with increasing charge state
- charge states $\geq 5+$ were only found at exactly central position

Ion-optical reasons for the observed trends can be excluded as ions with higher charge state are observed to have a lower emittances! [3]

BUT:

- the particular ion species were detected behind the sector magnet
- the transmission efficiencies for different ion species depend on the focussing
- by changing the extraction voltage the focussing is changed
- for different extraction voltages we expect (slightly) different distributions

$\rightarrow$ The recorded CSD represent only a 'snapshot' for current focussing settings as regarded from behind the sector magnet.

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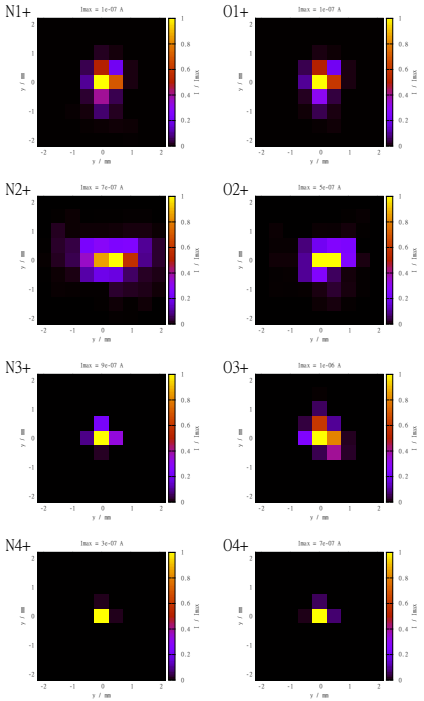
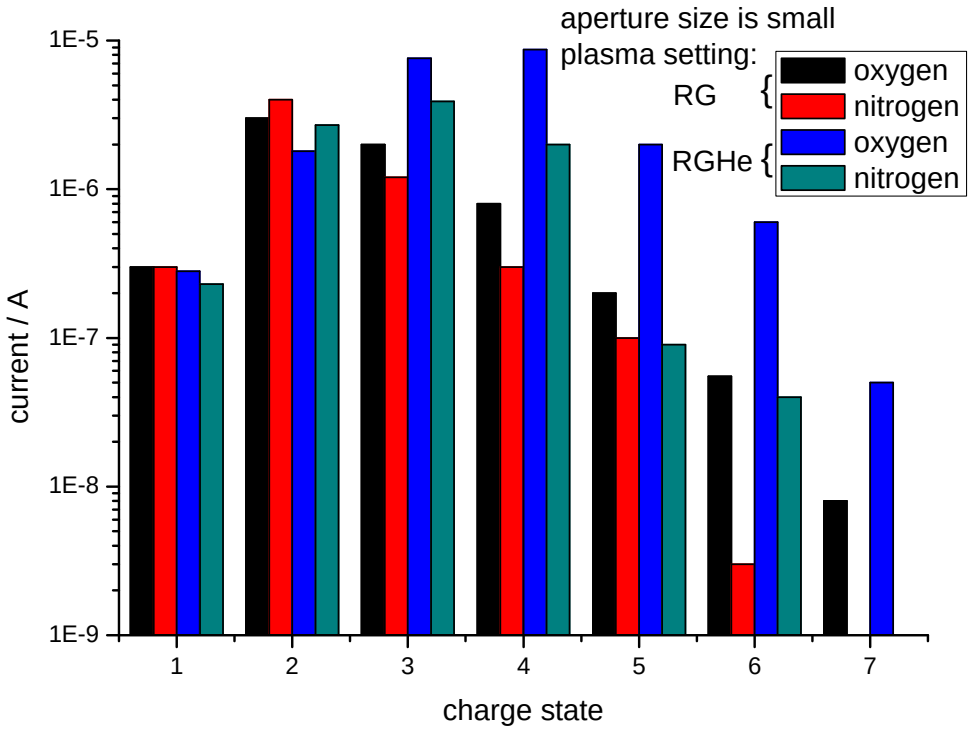
$\rightarrow$ The recorded CSD represent only a 'snapshot' for current focussing settings as regarded from behind the sector magnet.

For beams having passed the sector magnet the presented CSDs can be regarded as source regions for the particular ion species at the neutral plasma sheath (the magnetically-induced rotation then needs to be included).

Calculated Total CSDs

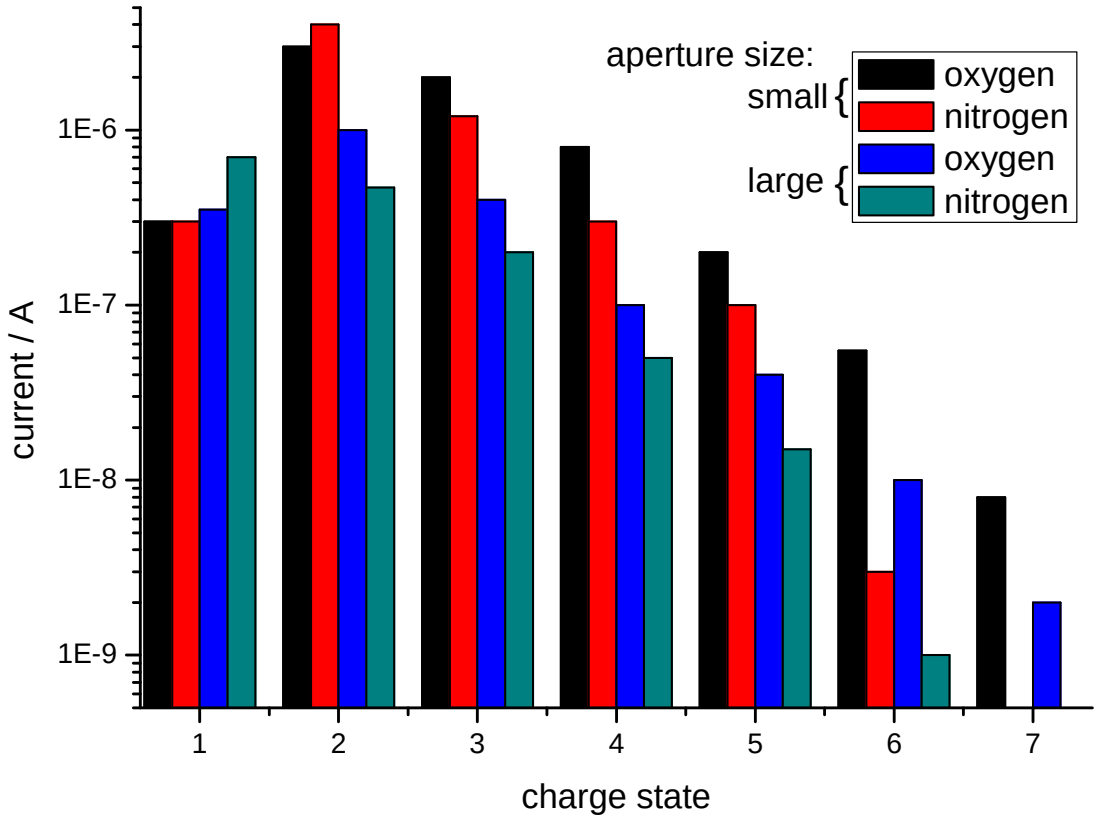




Dominant charge states:
RG: 2+ and 3+
RGHe: 3+ and 4+

The effect of gas-mixing can be observed.

Comparison: Standard Size vs Reduced Aperture



Both apertures show same trends in the calculated CSDs:
$\rightarrow$ The small-sized aperture does not reduce the total transmissivity!

A multi-aperture-like effect can be observed: The added currents of the small-aperture extraction result in higher total currents.

Summary of the Most Important Observations

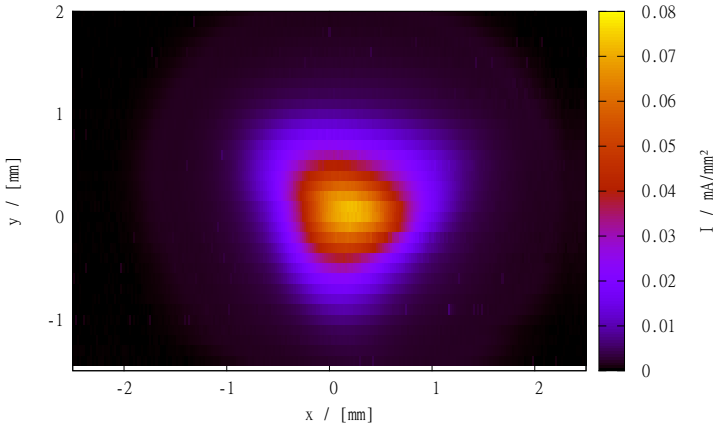
CDD:

- triangular structures of different sizes and orientations were observed only 15 mm downstream of the plasma electrode
- the ionic composition of these structures is still unknown
- their orientation at the extraction is still unknown

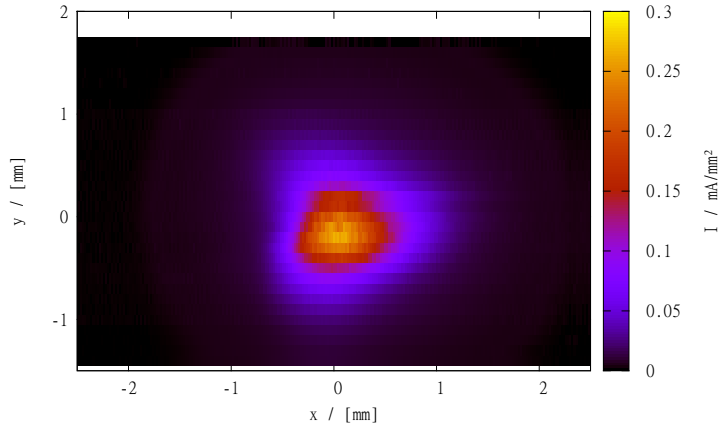
CSD:

- both extraction apertures (standard and reduced) show comparable transmissivities and trends in the CSDs
  $\rightarrow$ we know the main characteristics of the total CSD emitted by the source

Combination of the Results



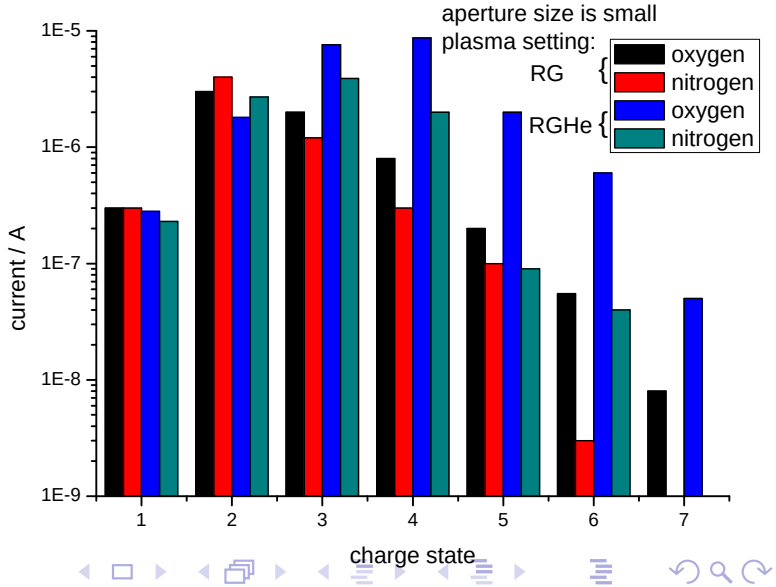
Setting RG



Setting RGHe

3 Assumptions:

- Each triangular structure is populated by ions of the same charge state
- Ion species dominant in the CSDs are dominant in the CDDs
- More highly-charged ions are concentrated closer to the centre



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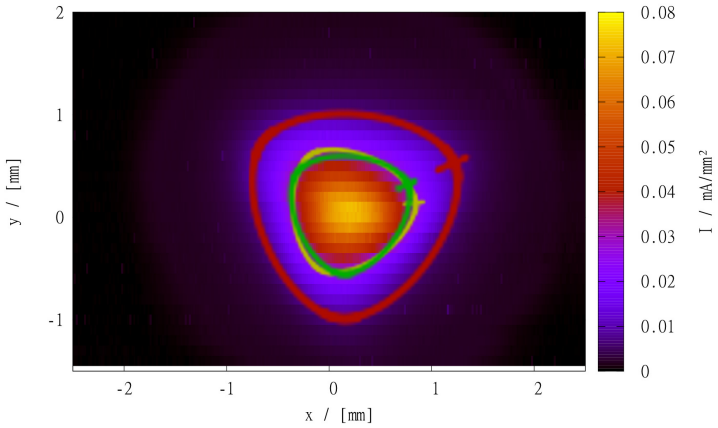

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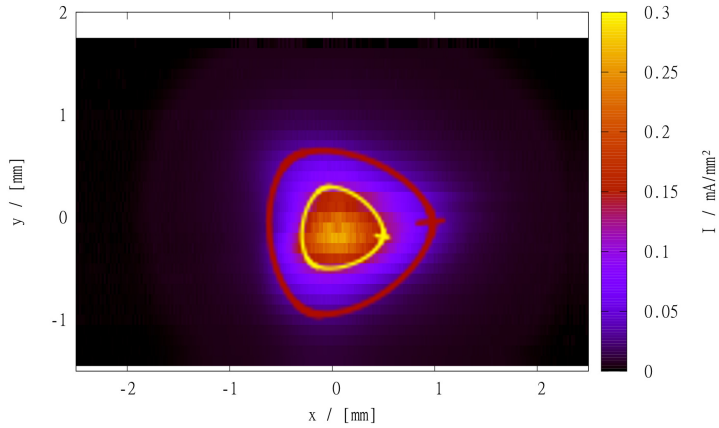

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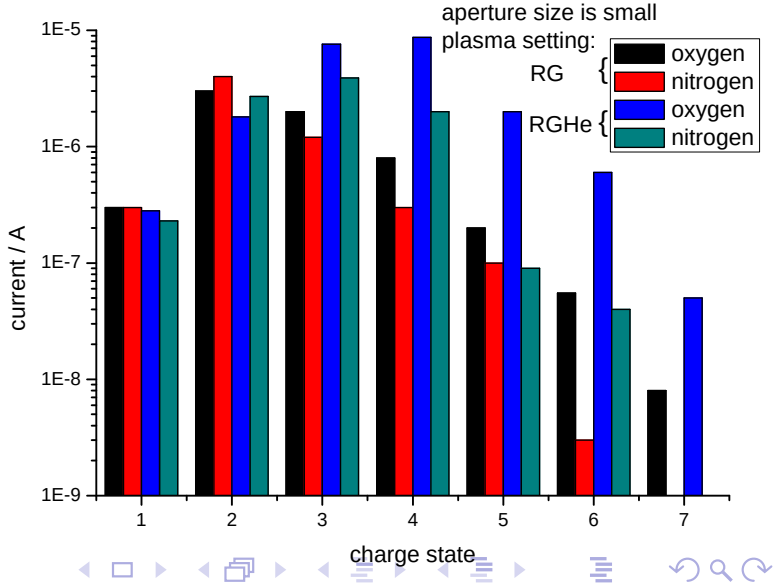

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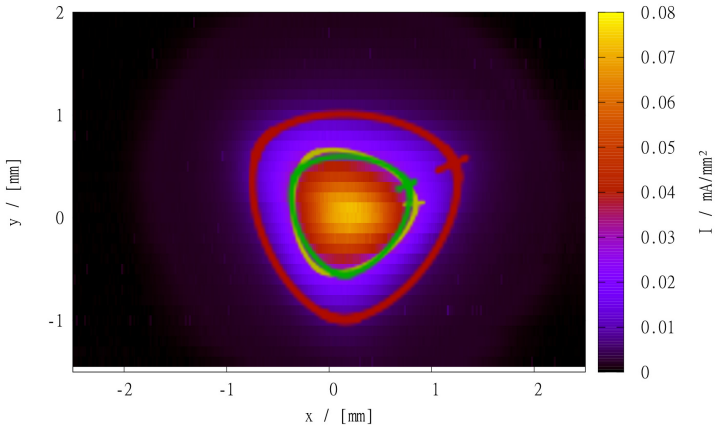

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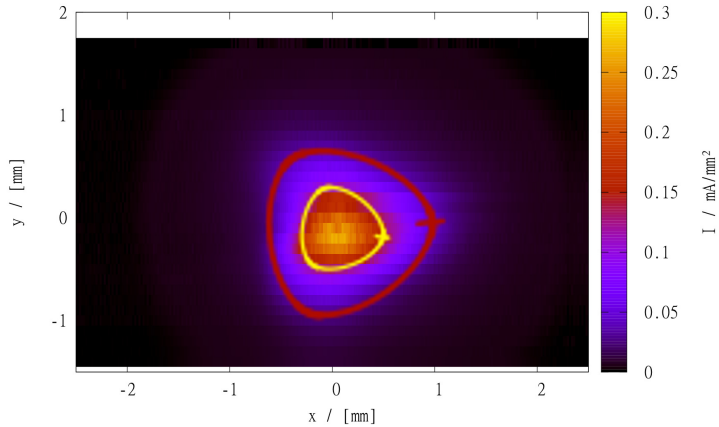
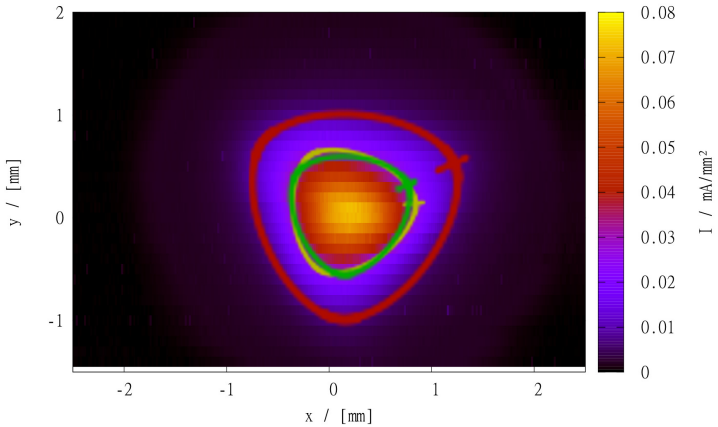


Setting RGHe

considered structure	suspected charge state	observed orientation	calculated rotation	original orientation
RG red	2+	-65°		
RG green/yellow	2+/3+	-65°/-81°		
RGHe red	3+	-81°		
RGHe yellow	4+	-97°		

Combination of the Results



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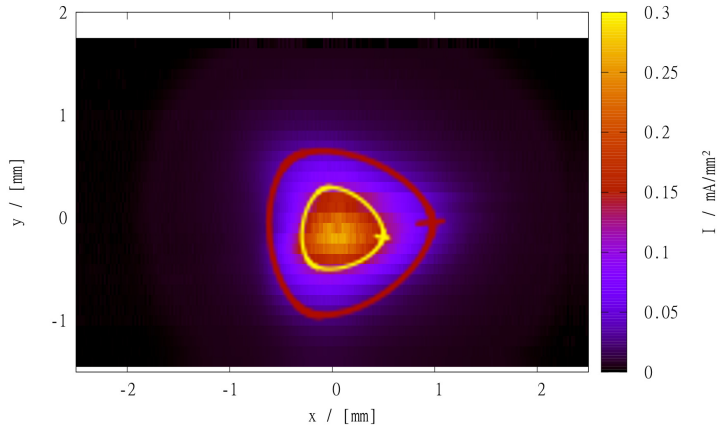

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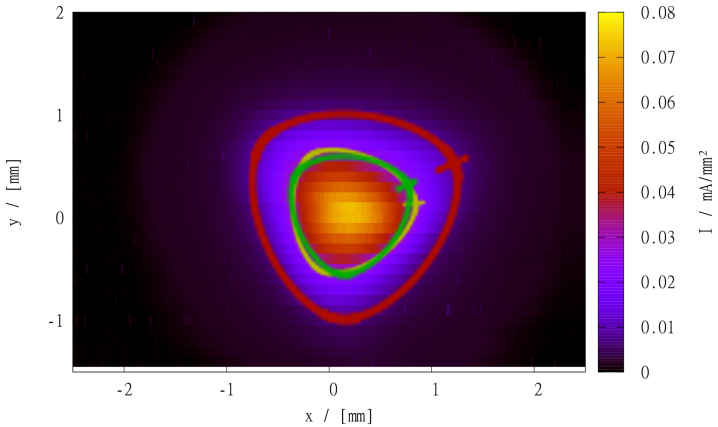
RGHe red	3+	-81°		
RGHe yellow	4+	-97°		

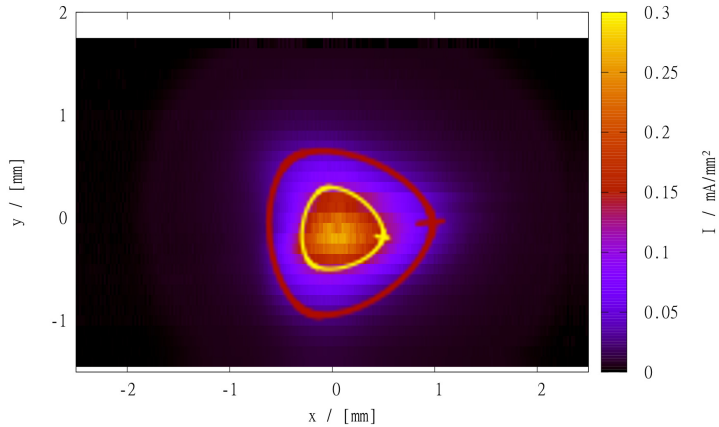
The rotation for different charge states can be calculated:

$$\Theta_{tot} = \sqrt{\frac{q}{8mU_{extr}}} \cdot \int B_z dz \quad [4]$$

Combination of the Results



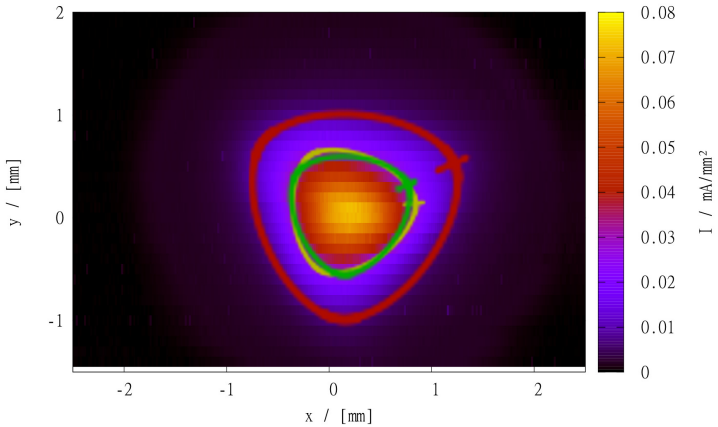
Setting RG



Setting RGHe

considered structure	suspected charge state	observed orientation	calculated rotation	original orientation
RG red	2+	-65°	-78°	
RG green/yellow	2+/3+	-65°/-81°	-78°/-95°	
RGHe red	3+	-81°	-95°	
RGHe yellow	4+	-97°	-110°	

Combination of the Results



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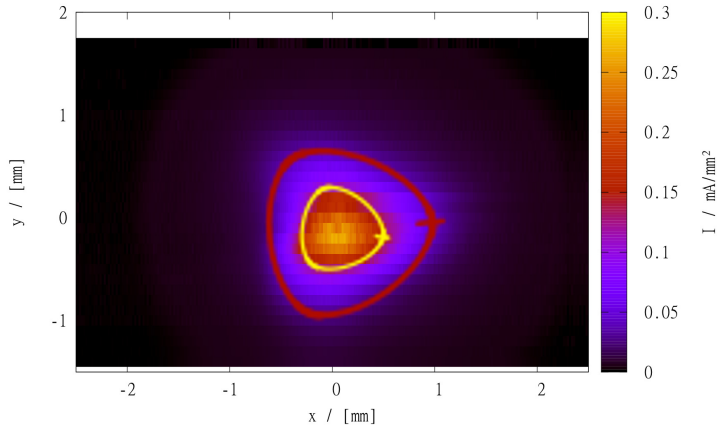
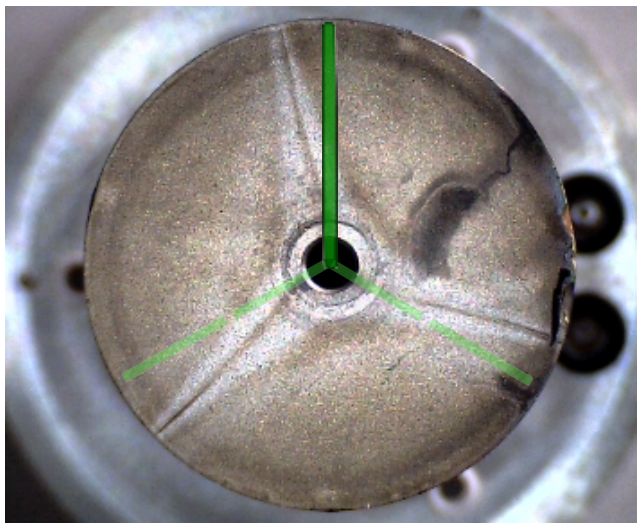


Setting RGHe

considered structure	suspected charge state	observed orientation	calculated rotation	original orientation
RG red	2+	-65°	-78°	+13°
RG green/yellow	2+/3+	-65°/-81°	-78°/-95°	+13°/+14°
RGHe red	3+	-81°	-95°	+14°
RGHe yellow	4+	-97°	-110°	+13°

Combination of the Results

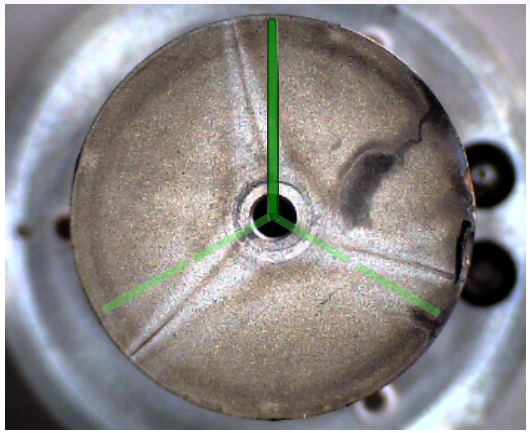


The sputter marks found at the inner side of the plasma electrode (at $\approx 13°$ CCW) agree well with the deduced original orientation (see table below)!
$\rightarrow$ Strong evidence for well chosen assumptions!

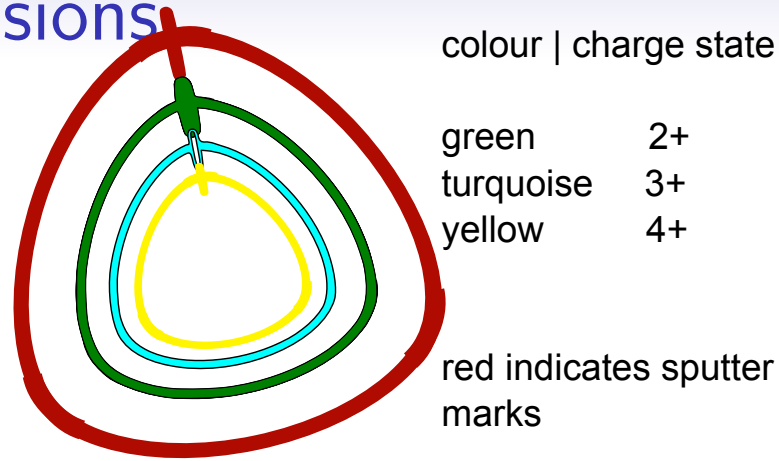
3 Assumptions were:

- Each triangular structure is populated by ions of the same charge state
- Ion species dominant in the CSDs are dominant in the CDDs
- More highly-charged ions are concentrated closer to the centre

Conclusions



Sputter marks at the inner side of the plasma electrode

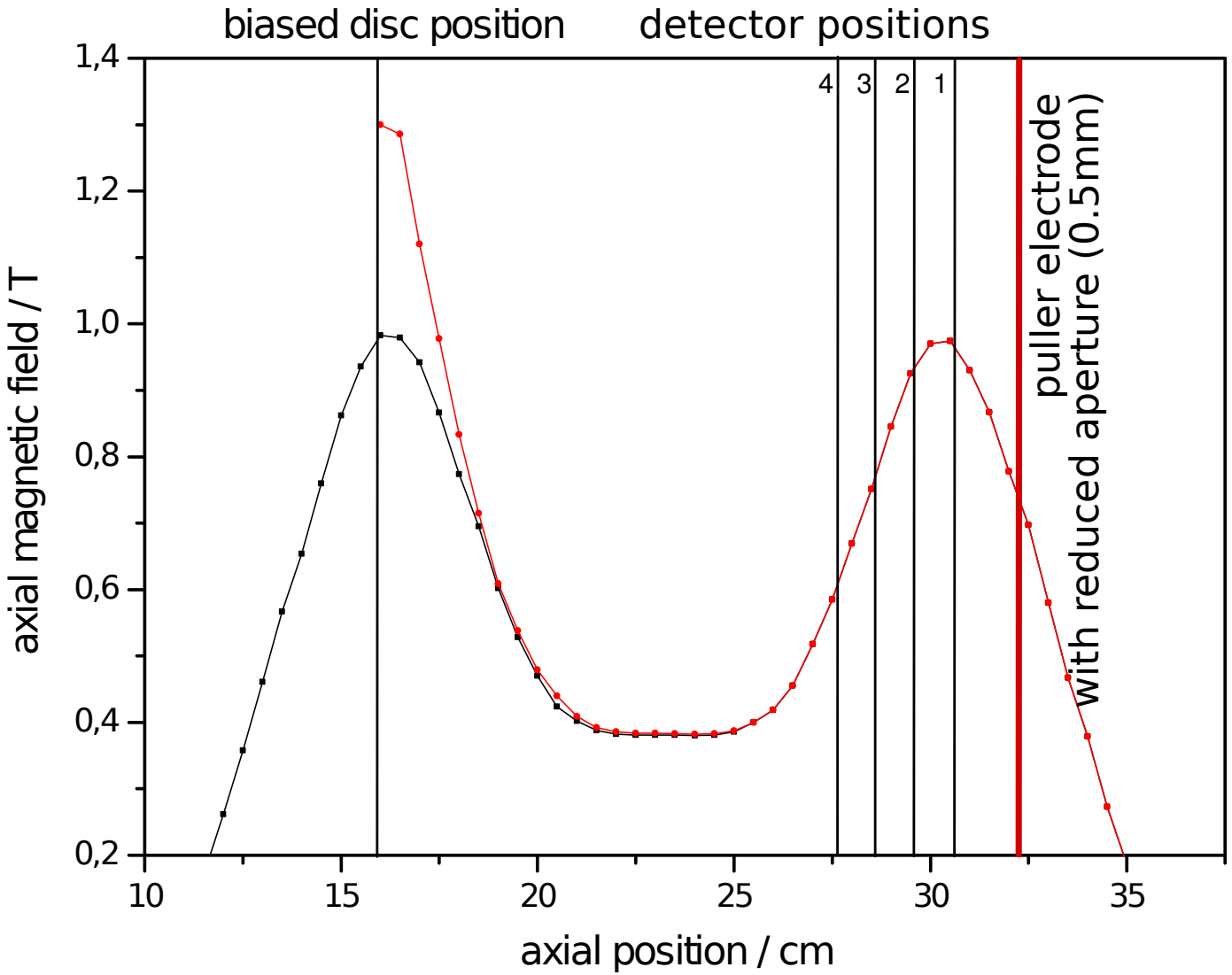


Deduced, schematic CSD at the plasma electrode for charge states 2+ to 4+

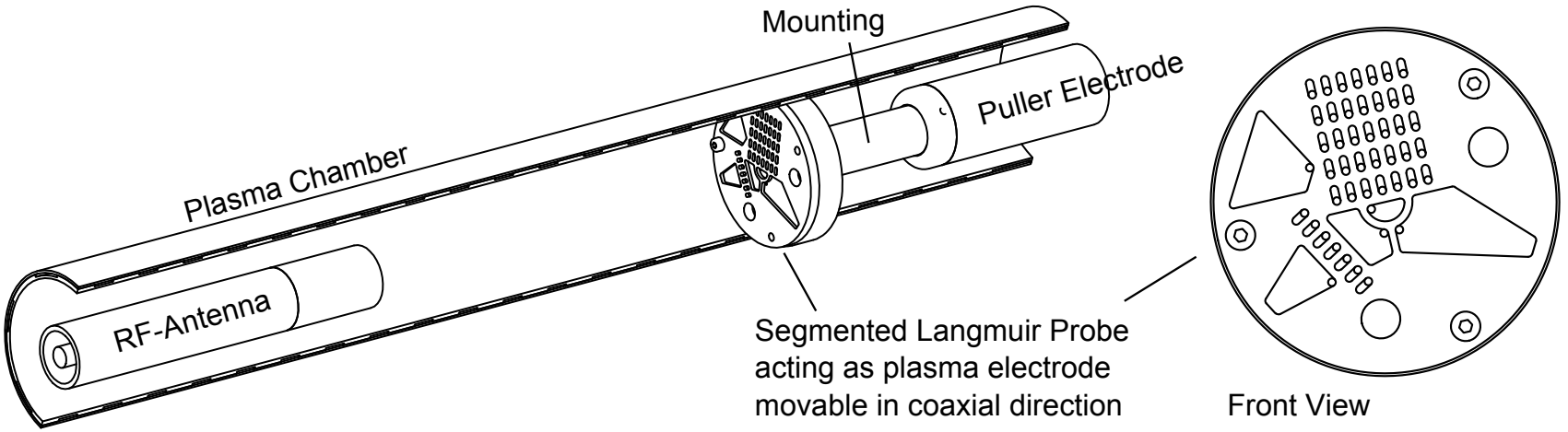
We conclude that

- each ion species is arranged in a (bloated) triangular-like structure in the plane of the plasma electrode.
- their identical orientation is defined by the radial magnetic fields.
- the effective radii decrease with increasing charge state.
- the current for each ion species peaks at the center.

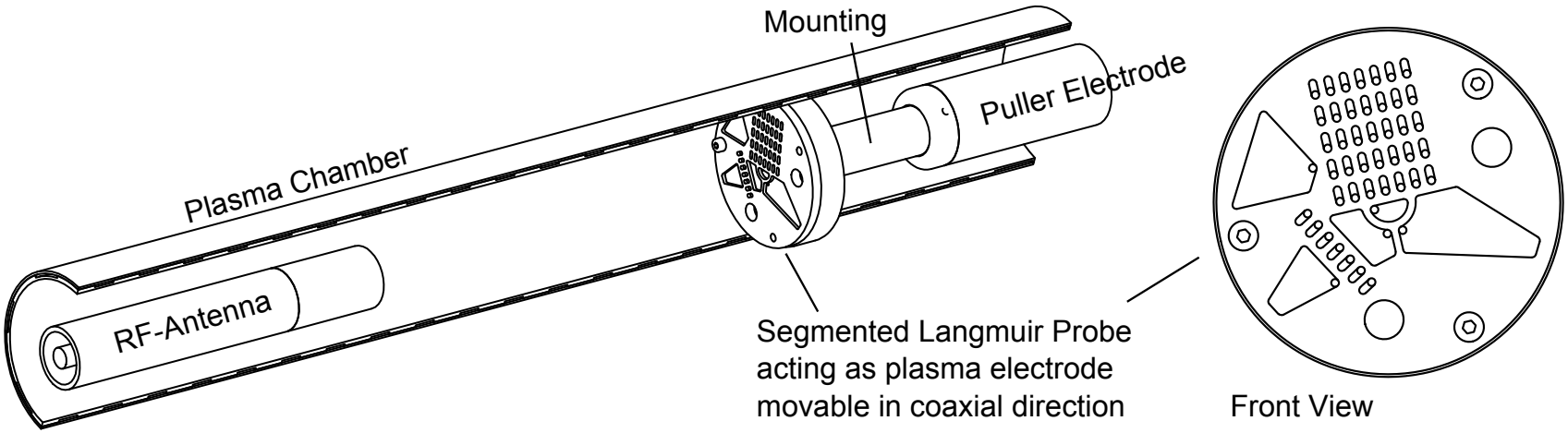
Outlook (CDDs Inside the Source)

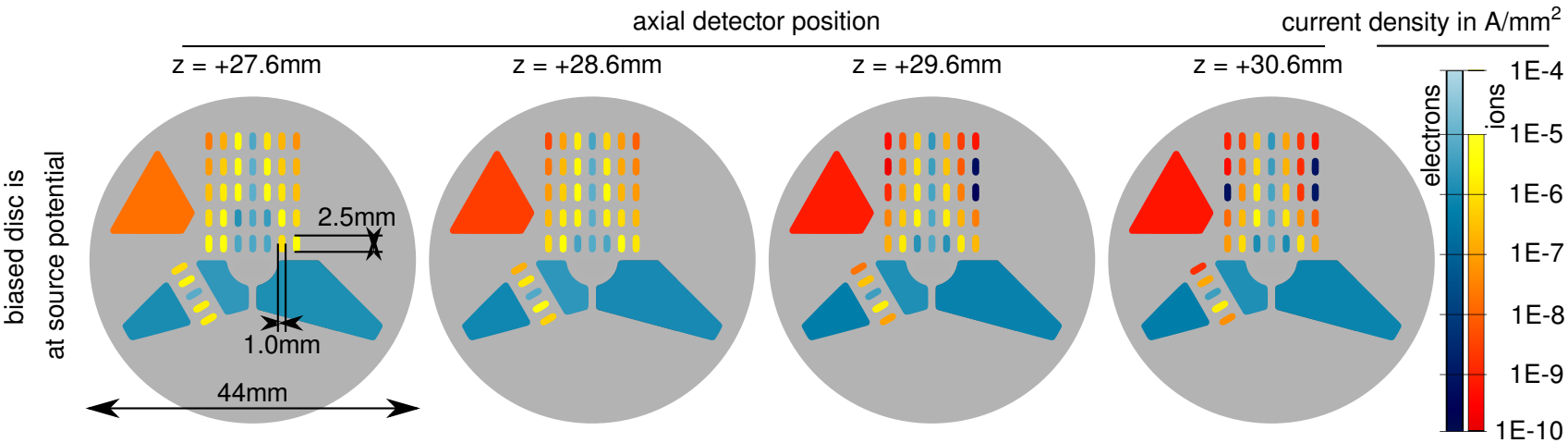


Outlook


Mounting
Puller Electrode
Plasma Chamber
RF-Antenna
Segmented Langmuir Probe
acting as plasma electrode
movable in coaxial direction
Front View

Outlook





[submitted at RSI]

References

[1] J. P. M. Beijers and V. Mironov. Three-dimensional simulations of ion dynamics in an electron cyclotron resonance ion source. *Review of Scientific Instruments*, 81(2):02A307, 2010.

[2] L. Maunoury, C. Pierret, and J.Y. Pacquet. Extraction from ECR ion sources: a new way to increase beam brightness. In *Proceedings of ECRIS08 18th International Workshop on ECR Ion Sources*, pages 224–228, 2008.

[3] M.A. Leitner, C.M. Wutte, and Lyneis C.M. Design of the extraction system of the superconducting ecr ion source venus. In *Particle Accelerator Conference, 2001. PAC. IEEE*, 2001.

[4] W. Glaser. *Grundlagen der Elektronenoptik*. Wien, 1952.