# Extraction and Transport of HCI beams from ECR Ion Sources

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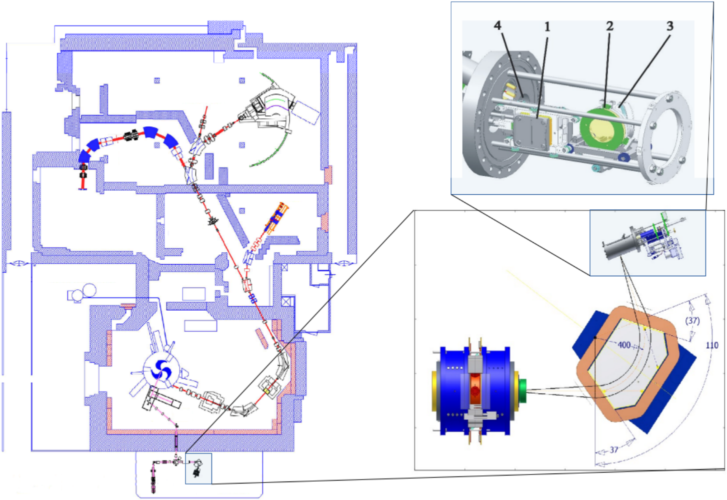
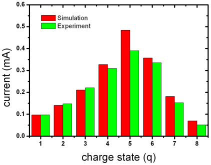
- Experimental setup
- Simulation method
- Results
- Conclusions

# Experimental setup

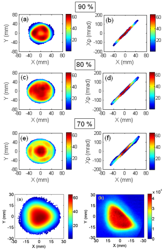


# *Simulation method*

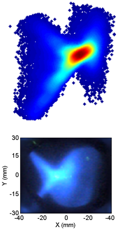
- Previous work: PIC plasma simulations (V. Mironov) and trajectory integration (S. Saminathan)
- Some results for 24$\cdot q$ keV $Ne^{q+}$ beams:




CSD behind M110




Beam profiles and emittances behind ECRIS




Beam profiles behind M90

## *Simulation method*

- Conclusions:
  - PIC simulations describe ion dynamics in ECRIS plasma well.
  - Extracted ion beams are fully space-charged neutralized.
  - Beam emittance behind analyzing magnet increases with $\sim$ factor of 5 to $\sim 300\ \mu$m because of large 2nd-order aberrations.
  - Beam emittance behind analyzing magnet is not very sensitive to details of initial phase-space distribution in front of magnet.
- Present work: Higher-order transfer maps calculated with COSY-INF (R. Kremers):

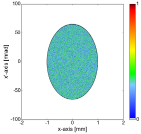
$$\theta_1 = M^{(k)}\theta_0 \qquad \theta = (x, x', y, y')^T$$

# Simulation method

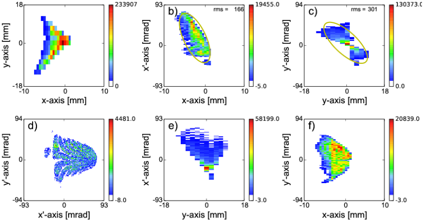
- E.g. 2nd-order transfer map ($k = 2$):

$$\theta_1 = (\theta|x)x_0 + (\theta|x')x_0' + (\theta|y)y_0 + (\theta|y')y_0' + (\theta|xx)x_0^2 + \\ + (\theta|xx')x_0x_0' + (\theta|x'x')x_0'^2 + (\theta|xy)x_0y_0 + (\theta|x'y)x_0'y_0 + \\ + (\theta|xy')x_0y_0' + (\theta|x'y')x_0'y_0' + (\theta|yy)y_0^2 + (\theta|yy')y_0y_0' + \\ + (\theta|y'y')y_0'^2$$

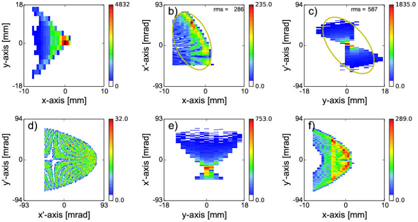
  Dominant 2nd-order terms: $(x|x'x')$, $(x|y'y')$ and $(y|x'y')$
- Initial phase-space distribution before analyzing magnet is upright KV distribution with $\epsilon = 65$ $\mu$m for both transverse planes.



- Measured and simulated phase-space projections of a 25 keV $He^+$ beam behind M110:



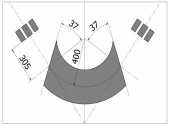

Measured phase-space projections.

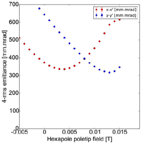


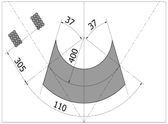

Simulated phase-space projections.

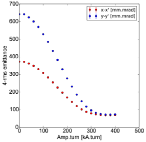
# Results

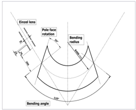
- Mitigation strategies to prevent emittance blowup:

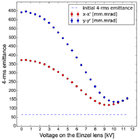


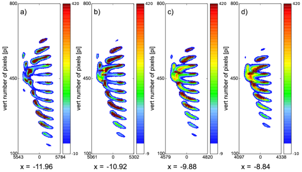



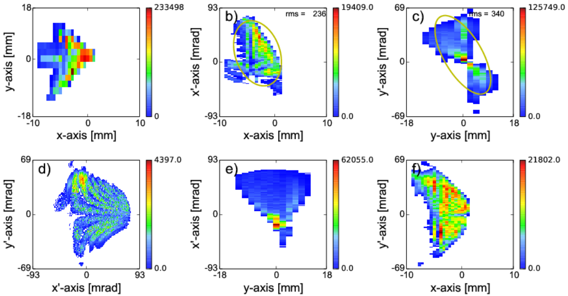



# Results

- Pepper-pot analysis with overlapping beam spots:



# Conclusions

- Extracted ion beams are fully space-charge compensated (at least for beam currents up to $\sim$ 5 mA).
- Low-energy beam transport well described by 2nd-order transfer maps.
- Well-designed analyzing magnet with minimal or compensated fringe fields is essential for efficient beam transport.
- To minimize losses keep beams as paraxial as possible and minimize fringe fields of optical elements.
- A focusing solenoid between ECRIS and analyzing magnet gives best results.