Radiatively driven plasma flows in experiments on the MAGPIE pulsed-power generator

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Imperial College (CIFS, Computational): A. Crilly, J. Chittenden, S. Rose

University of Nevada, Reno: R. C. Mancini

Imperial College London

MAGPIE

CIFS

University of Nevada, Reno

Overview of experimental setup

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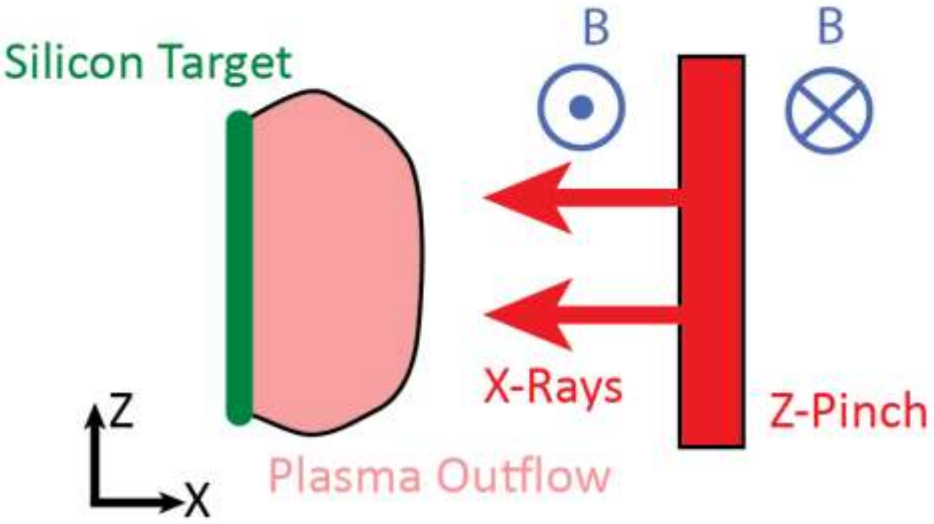
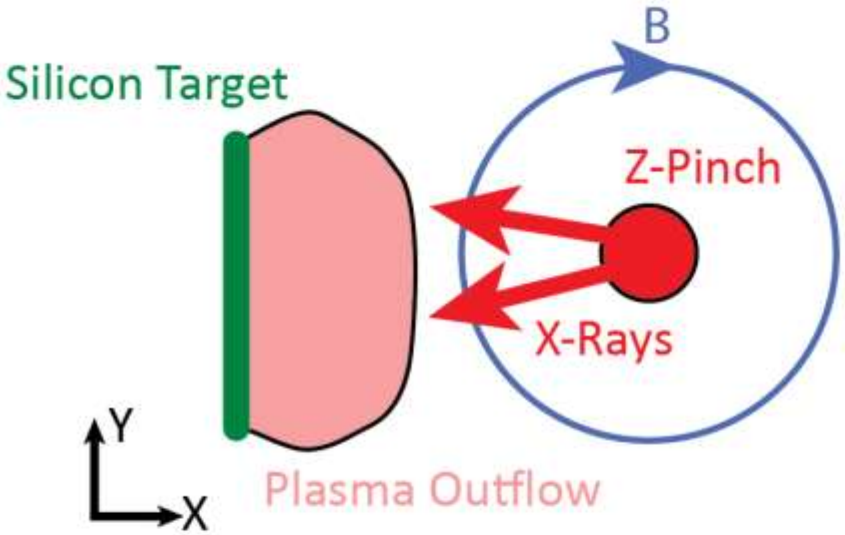


Side-On (X-Z plane) view of the experiment



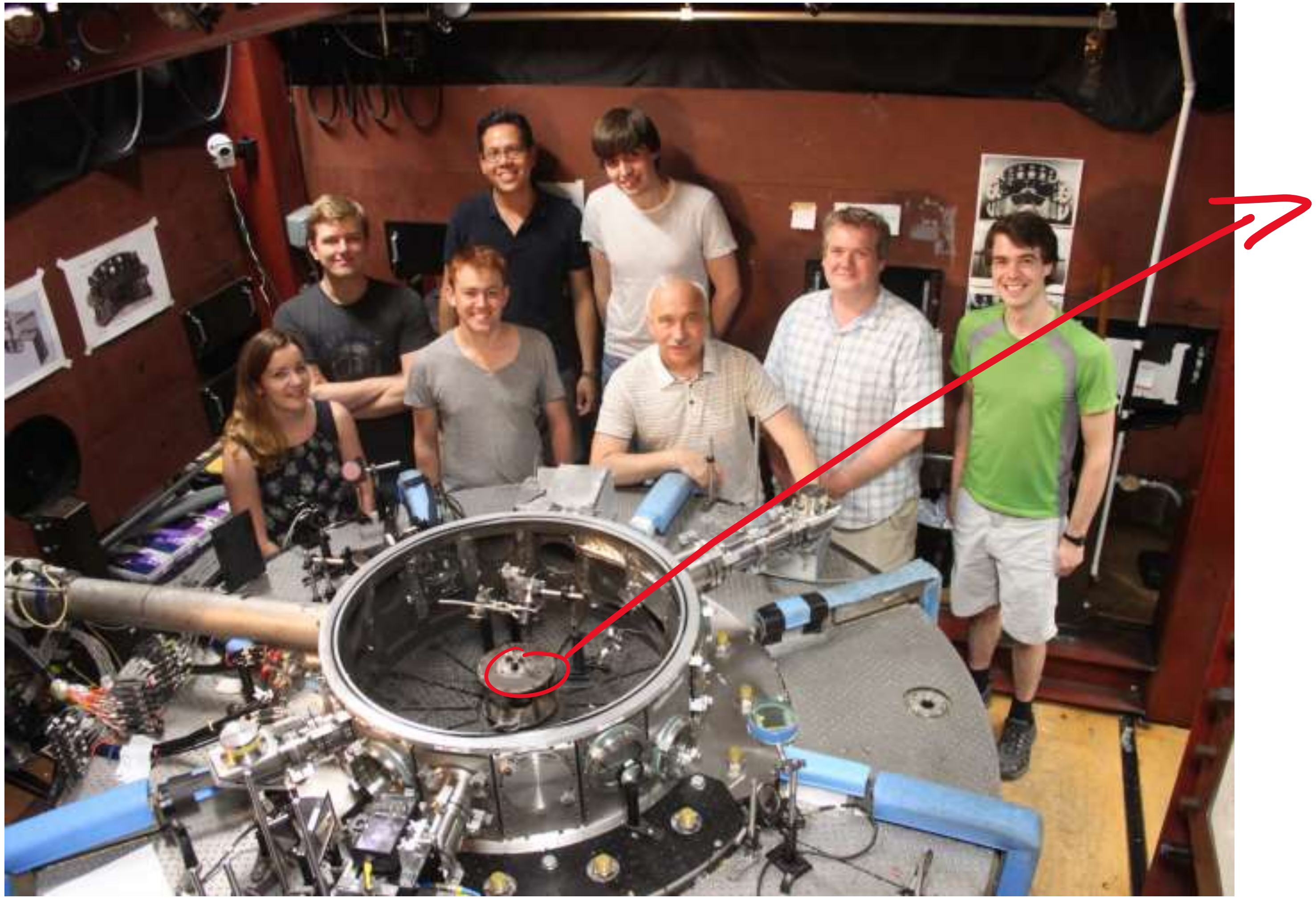
End-On (X-Y plane) view of the experiment

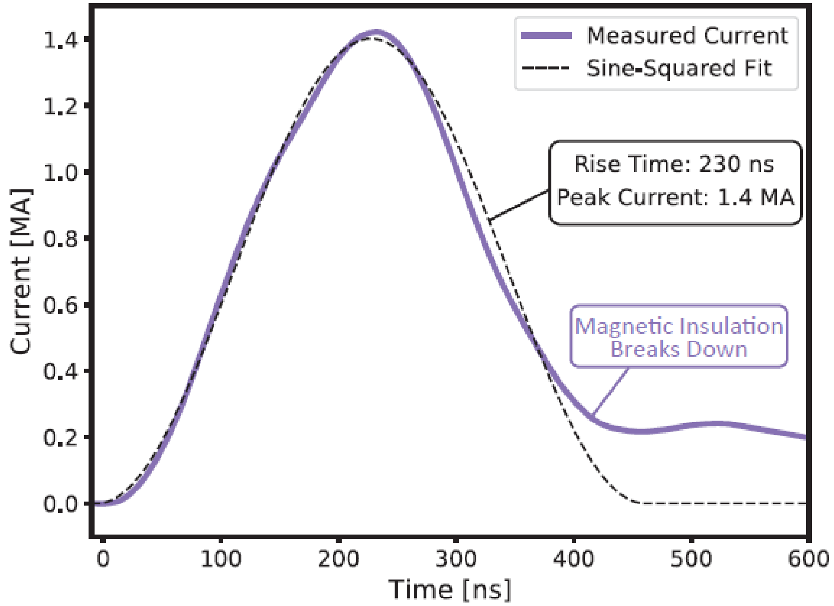
- X-Rays from aluminium wire array Z-Pinch
- Experiments driven by MAGPIE (1.4 MA, 240 ns)
- Ablated silicon plasma expands into $\sim 10\ \mathrm{T}$ magnetic field
- Target positioned $1.5 - 4\ \mathrm{cm}$ from pinch

Structure of talk

- Discuss X-Ray driver (MAGPIE generator, wire array Z-pinches)
- Diagnosis of self-emission / laser interferometry & comparison with R-MHD simulations
- Velocity, temperature, & ionisation profiles from Thomson scattering
- Magnetic field profiles from Faraday rotation imaging

The MAGPIE pulsed power generator

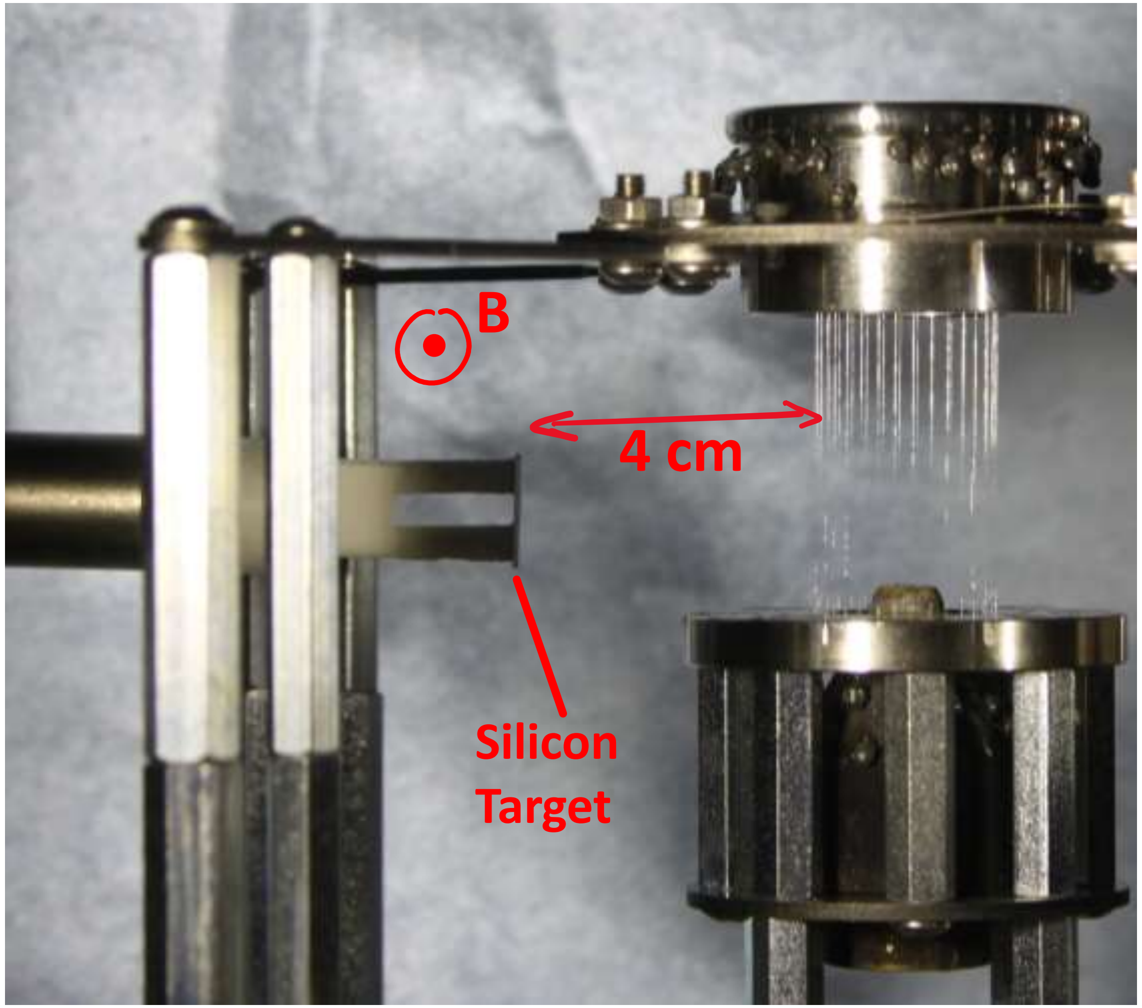


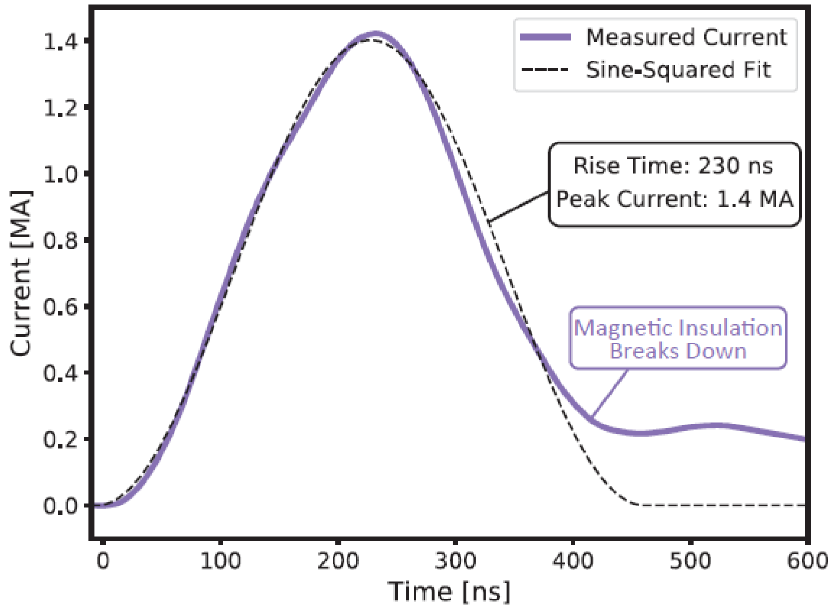


1.4 MA, 240 ns Current Pulse

X-Ray Pulse ~ 1 TW

Wire Array Z-Pinches are an Efficient X-Ray Source

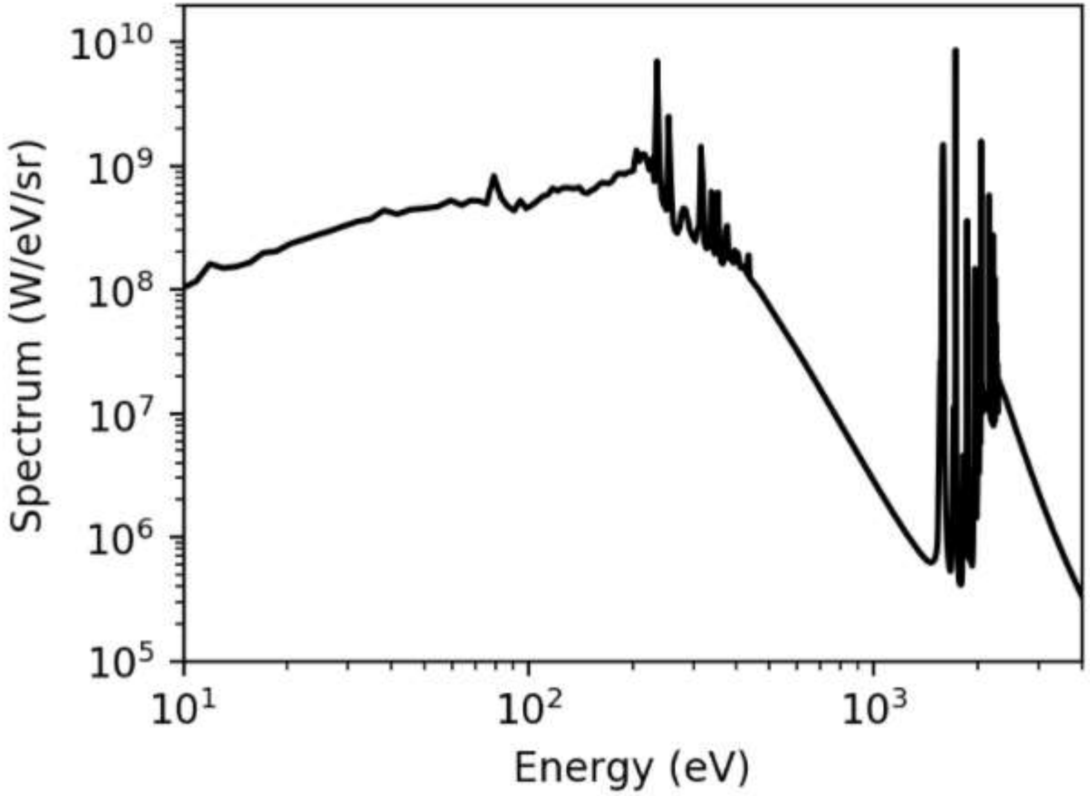




1.4 MA, 240 ns Current Pulse

X-Ray Pulse ~ 1 TW

Spectral Character of Radiation at ~1 MA Level



- Aluminium wire array
- Emits ~15 kJ over ~30 ns
- Color temperature $T_c \sim 150$ eV

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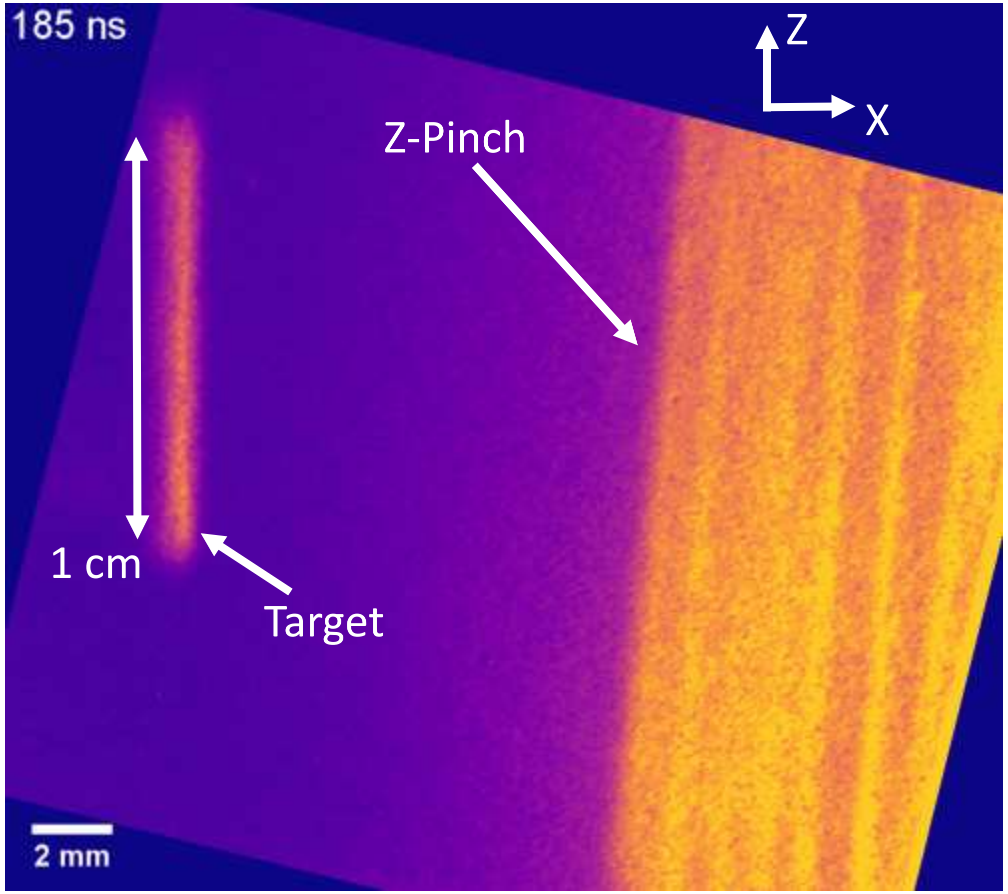
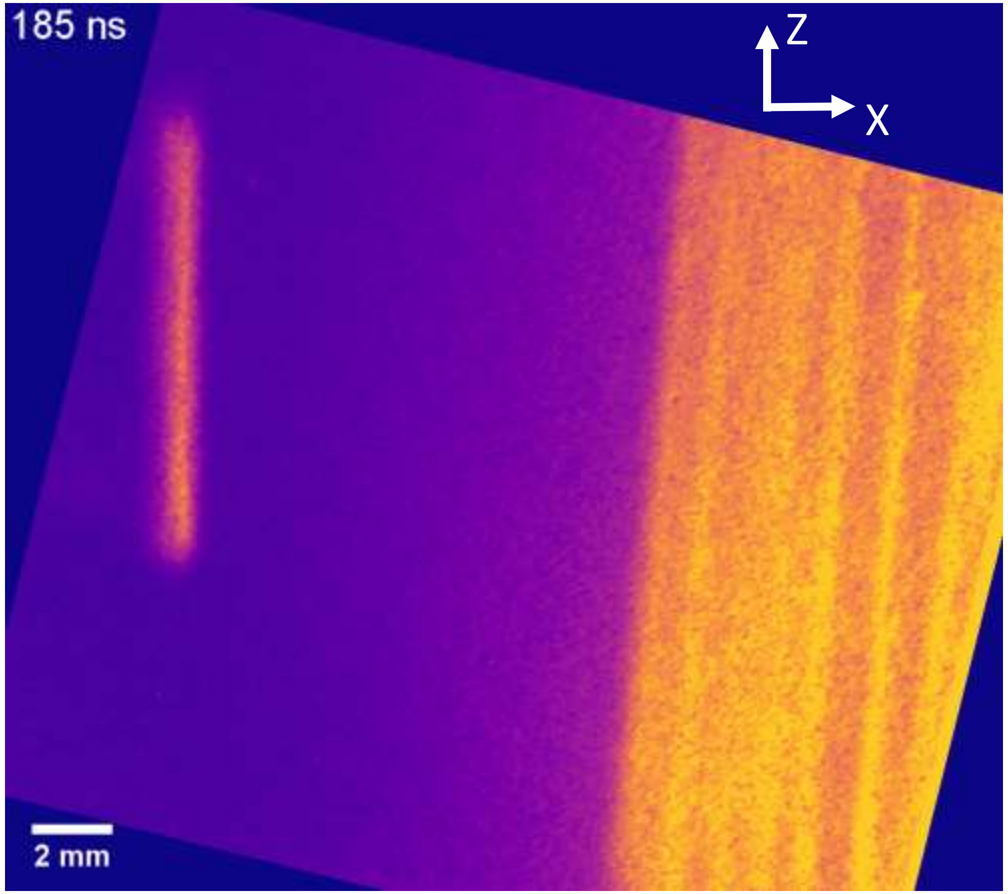
Optical self emission images [qualitive dynamics]



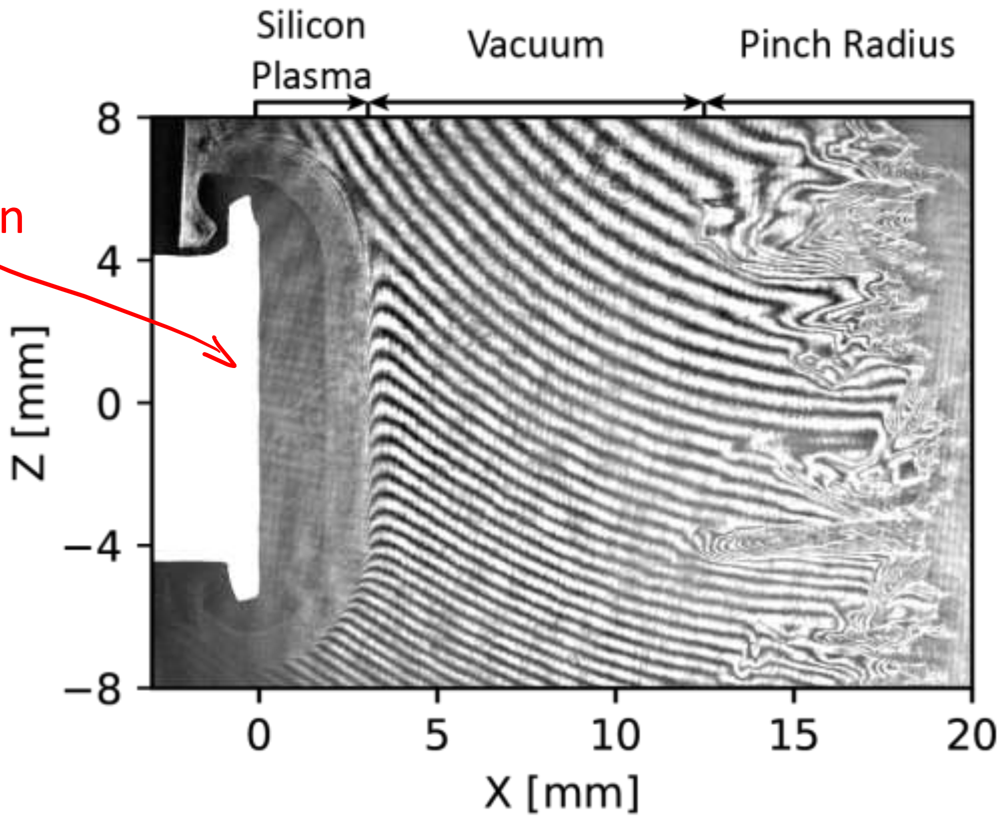
Self emission images [$600 \lesssim \lambda \lesssim 900$ nm]

Optical self emission images [qualitive dynamics]

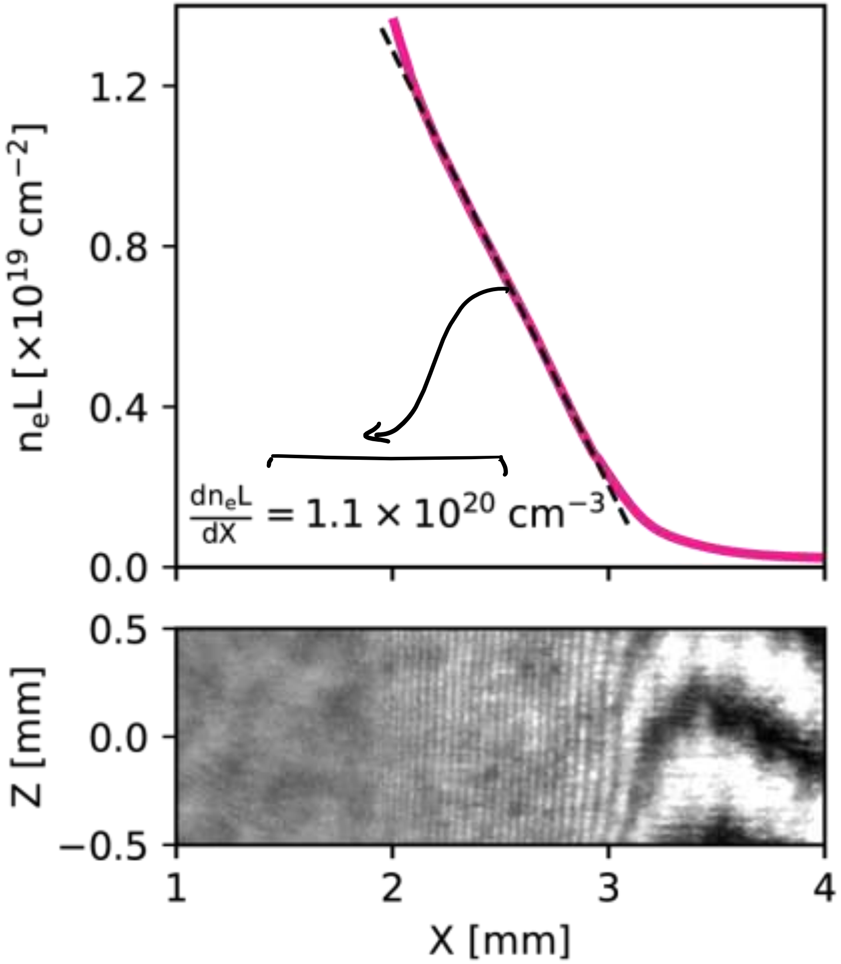


Self emission images [$600 \lesssim \lambda \lesssim 900$ nm]

Interferometry [line integrated electron density]

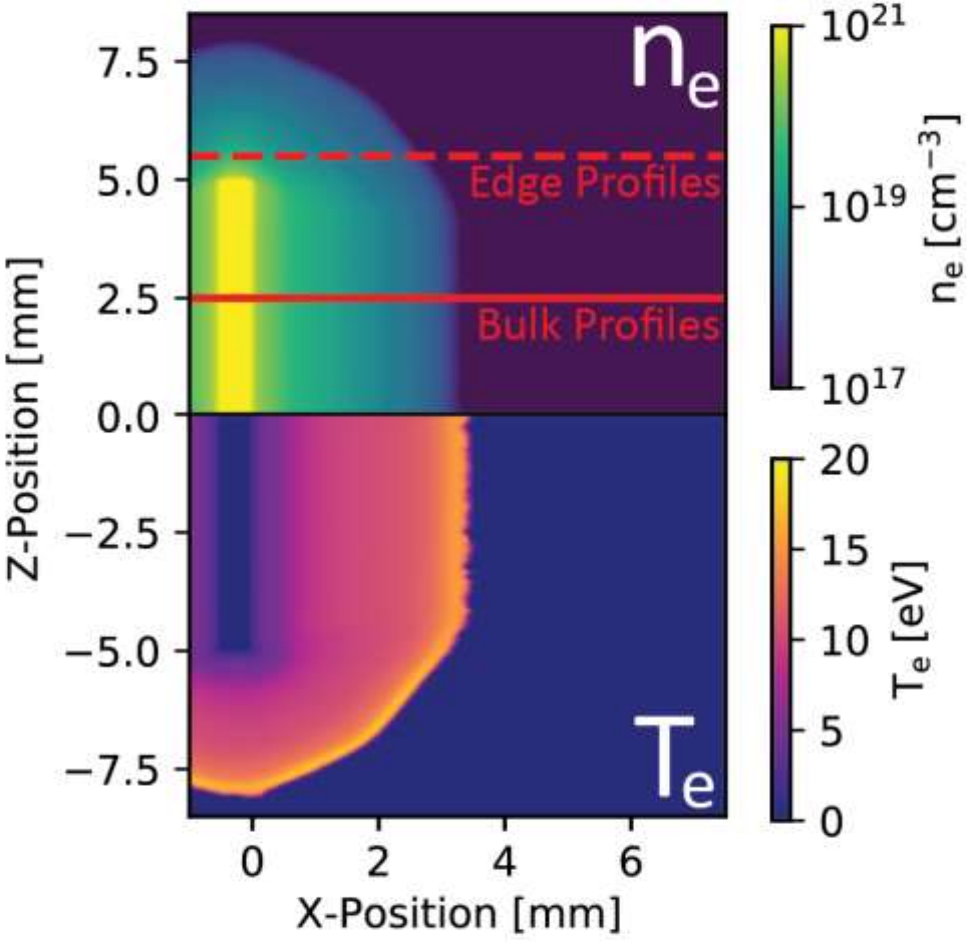


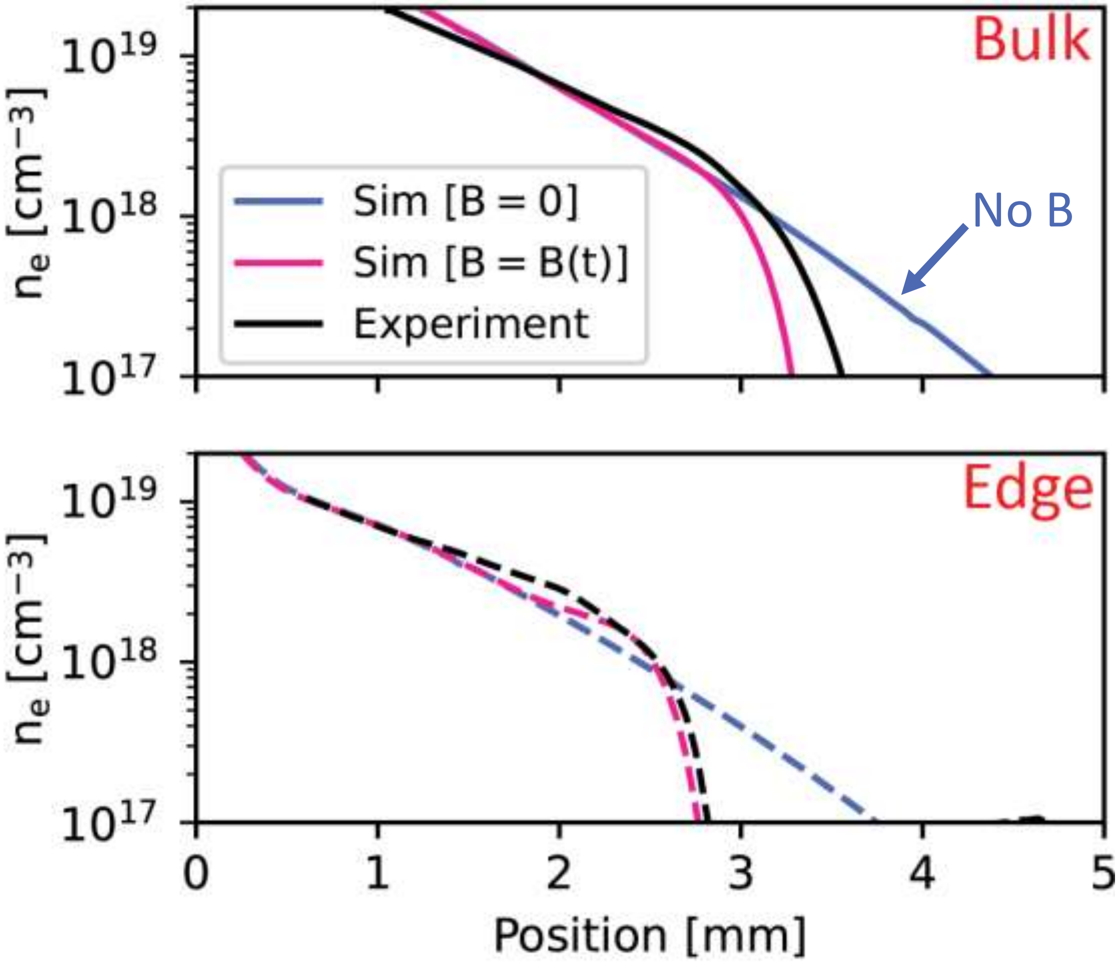
Target position



- Interferogram captured at $t = 320$ ns
- Smooth $\sim$1D expansion profile confirmed by orthogonal laser probing

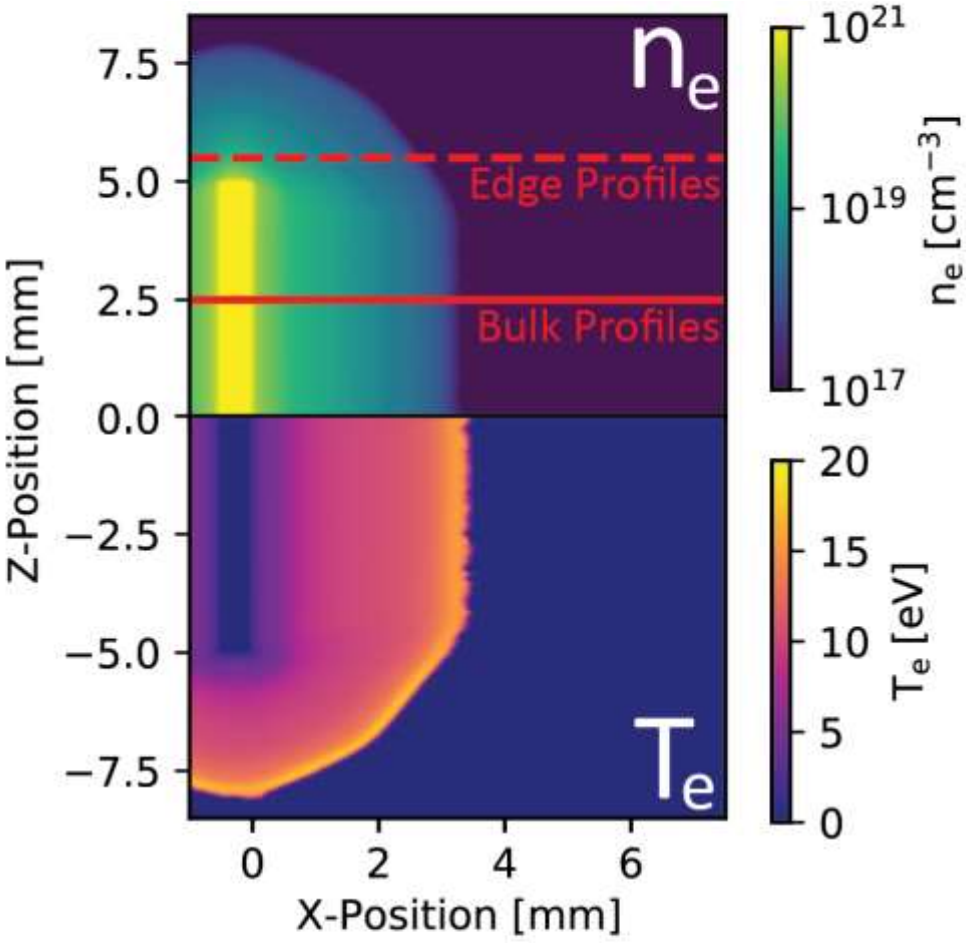
Radiative MHD simulations [Chimera]

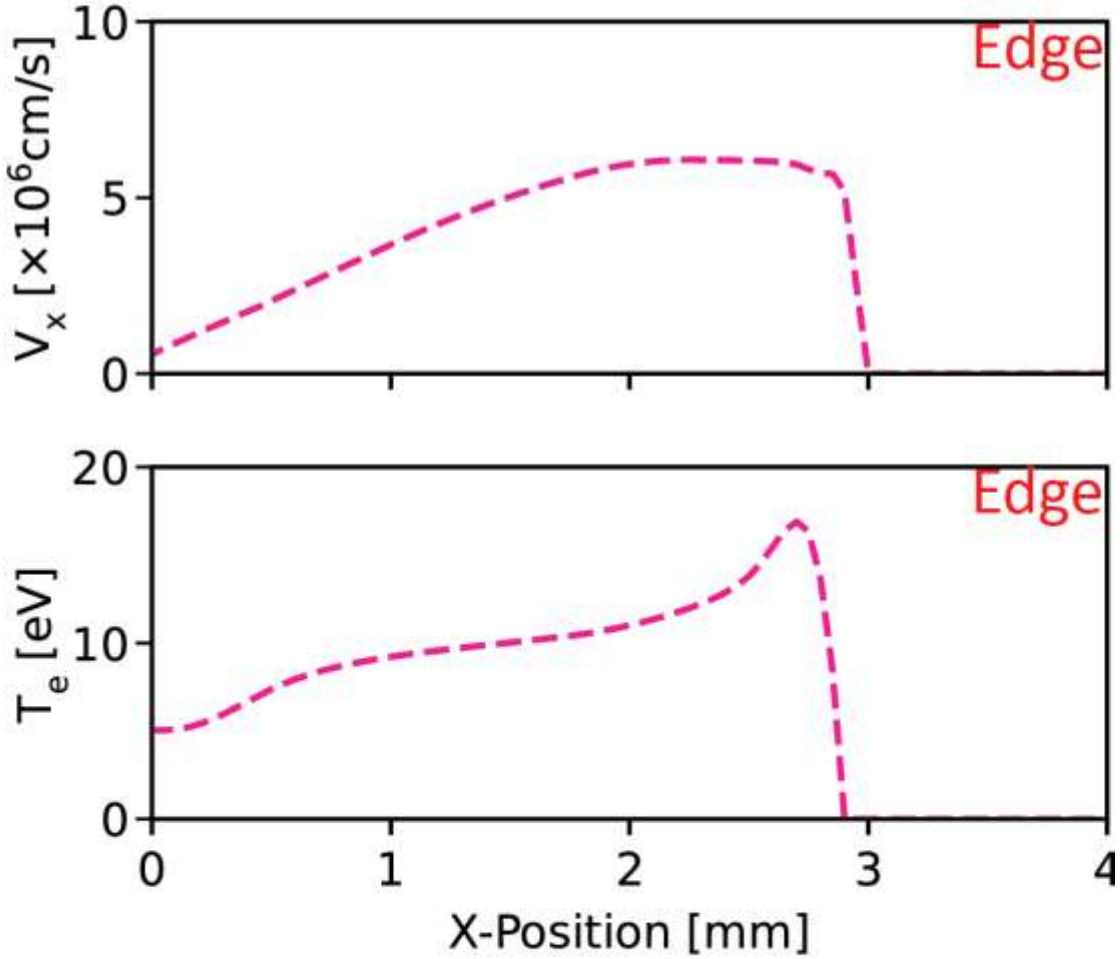




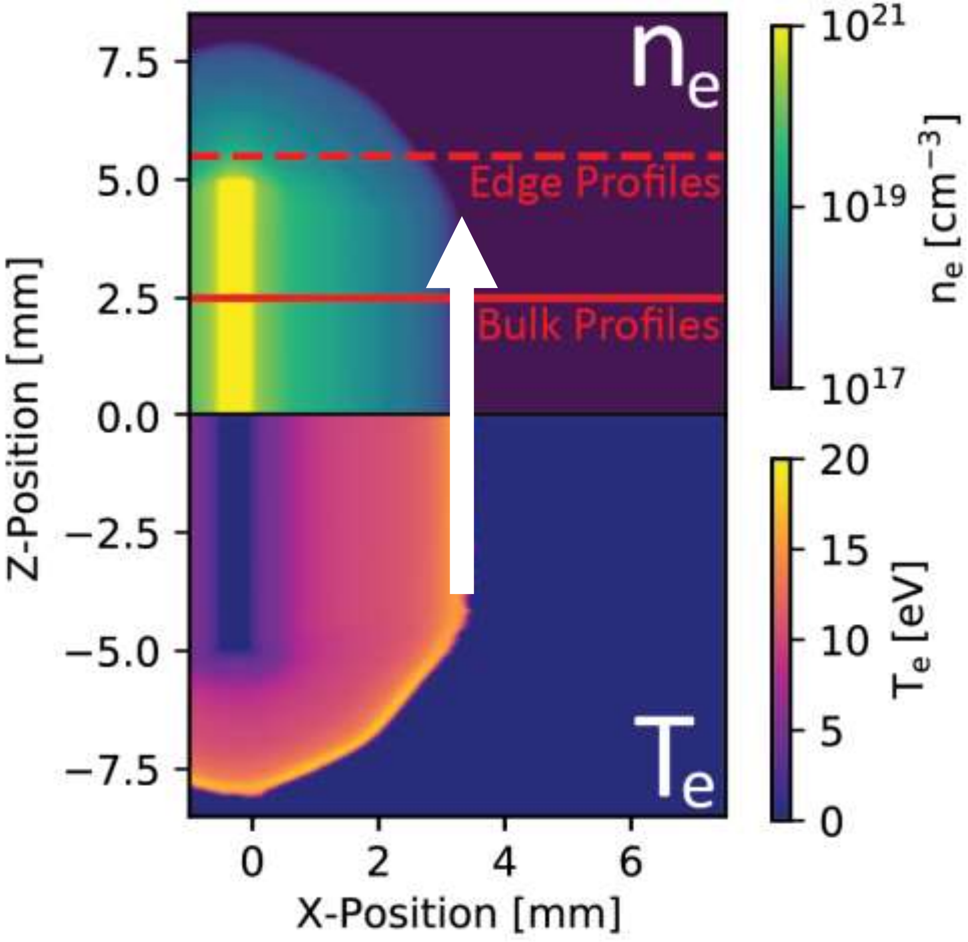
Density profile is affected by B-Field.

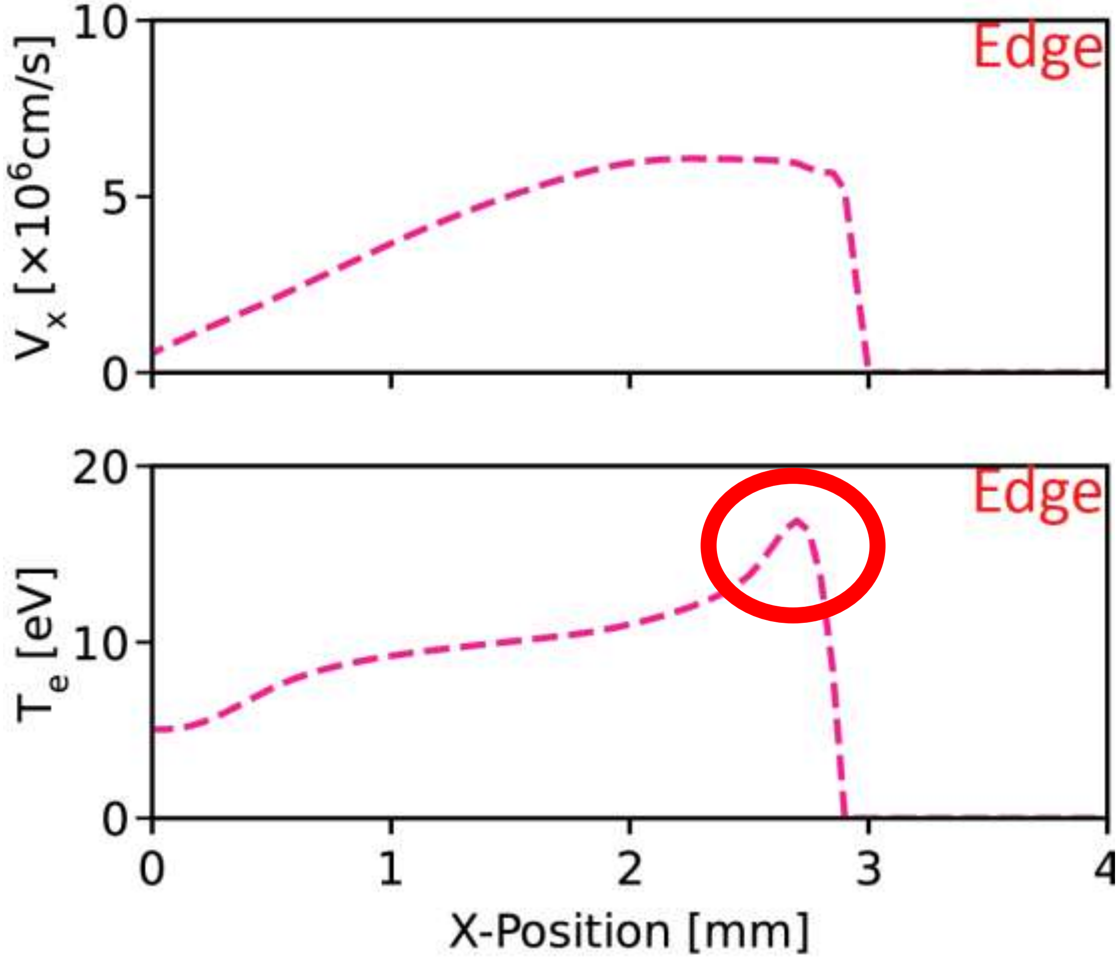
Radiative MHD simulations [Chimera]





Radiative MHD simulations [Chimera]





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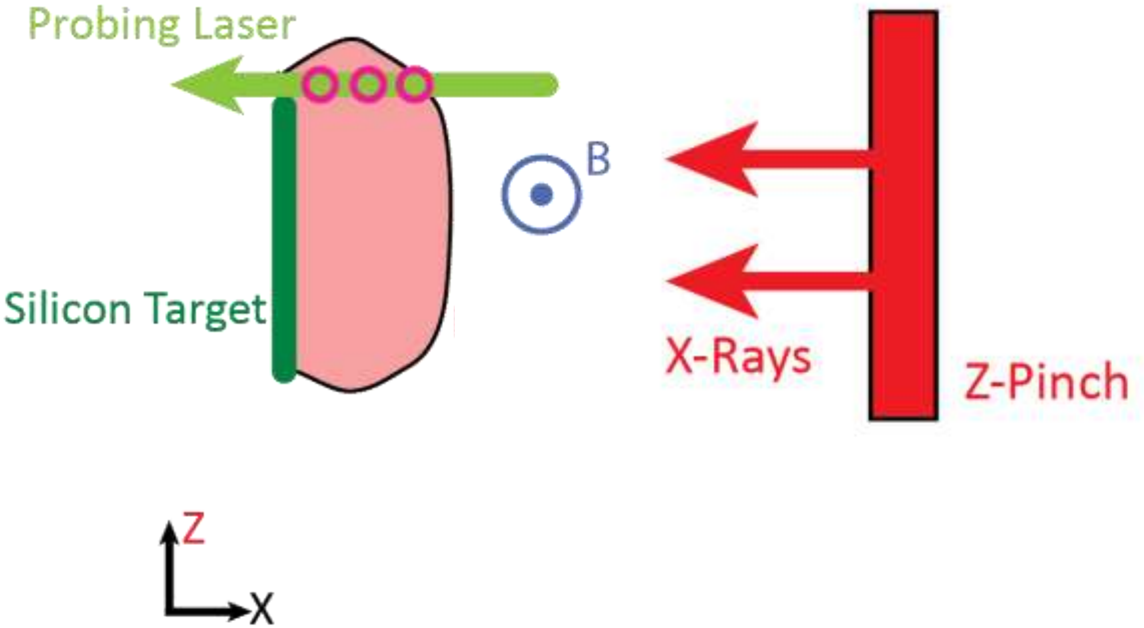
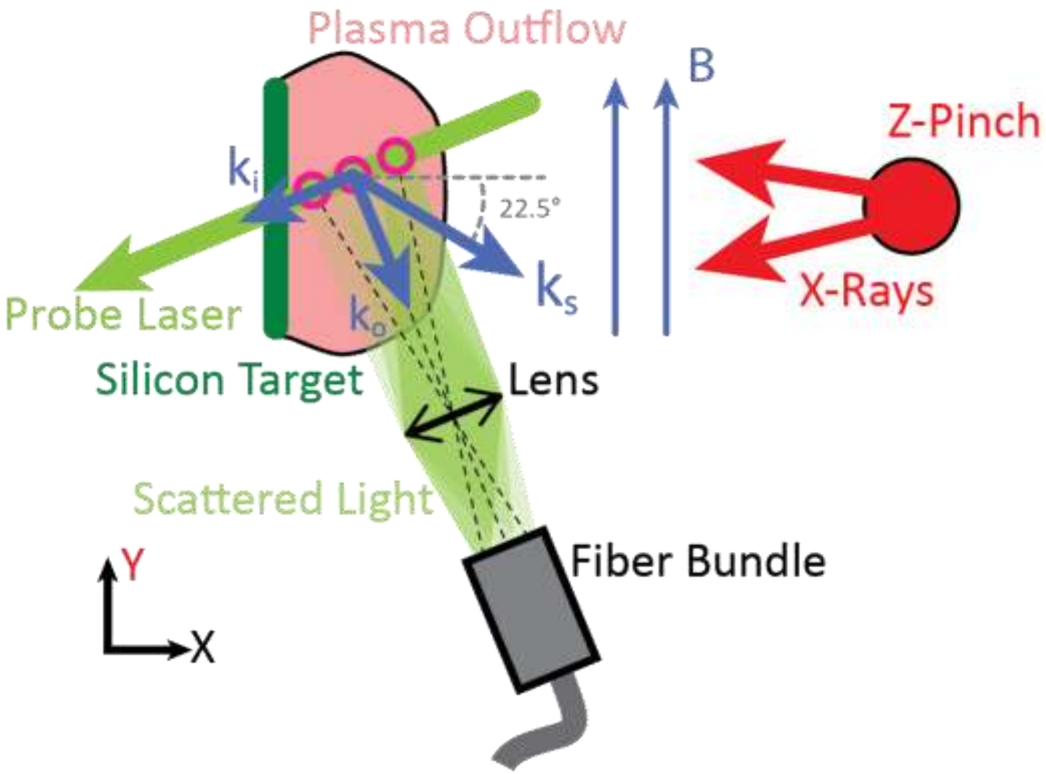
Thomson scattering [localised diagnosis of T, V, Z]

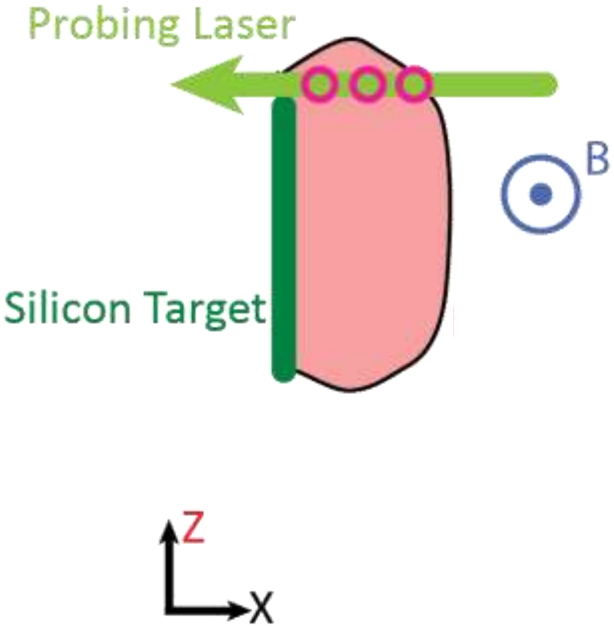


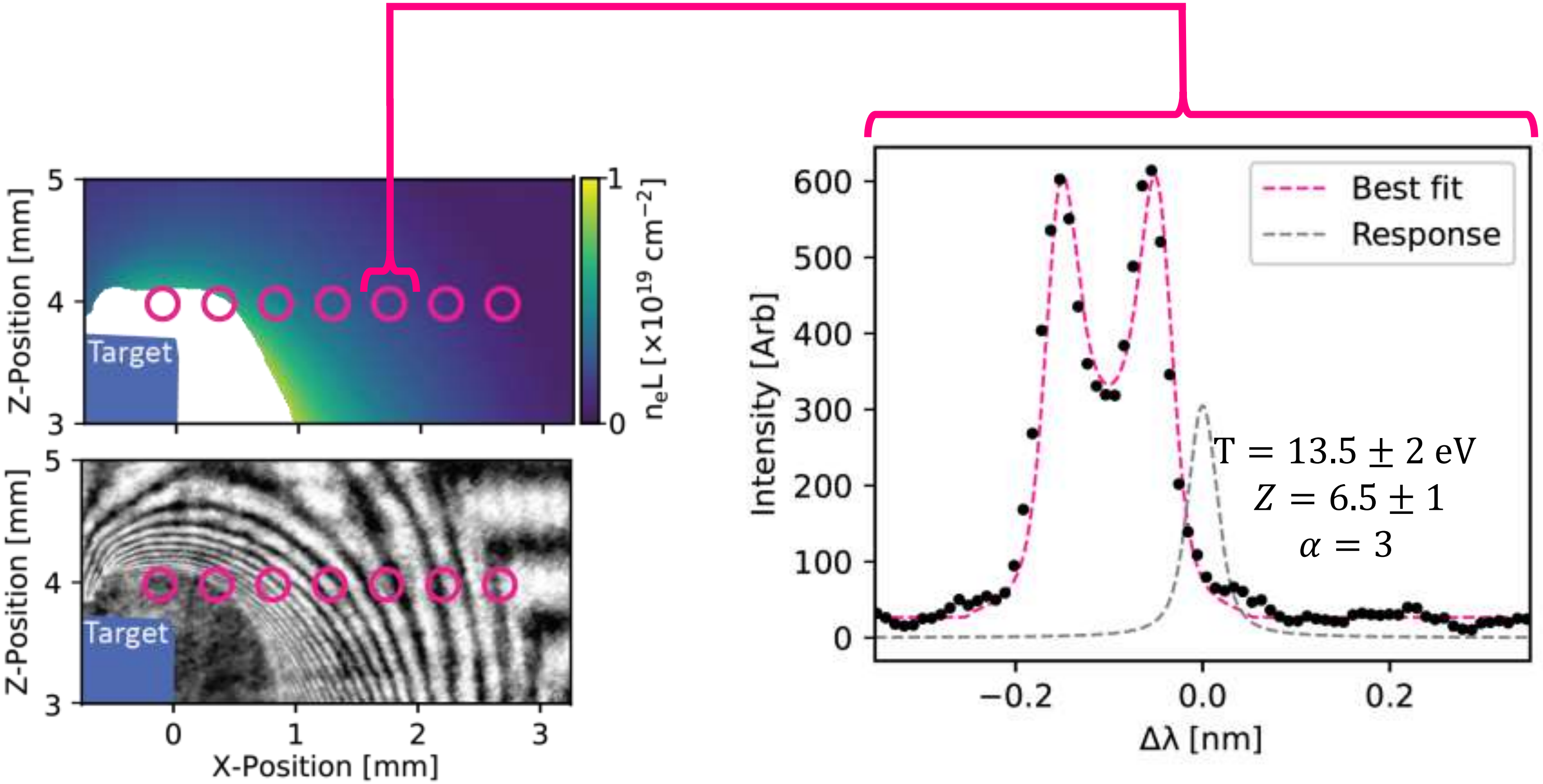
Side-On (X-Z plane) view of the experiment



End-On (X-Y plane) view of the experiment

Thomson scattering [localised diagnosis of T, V, Z]



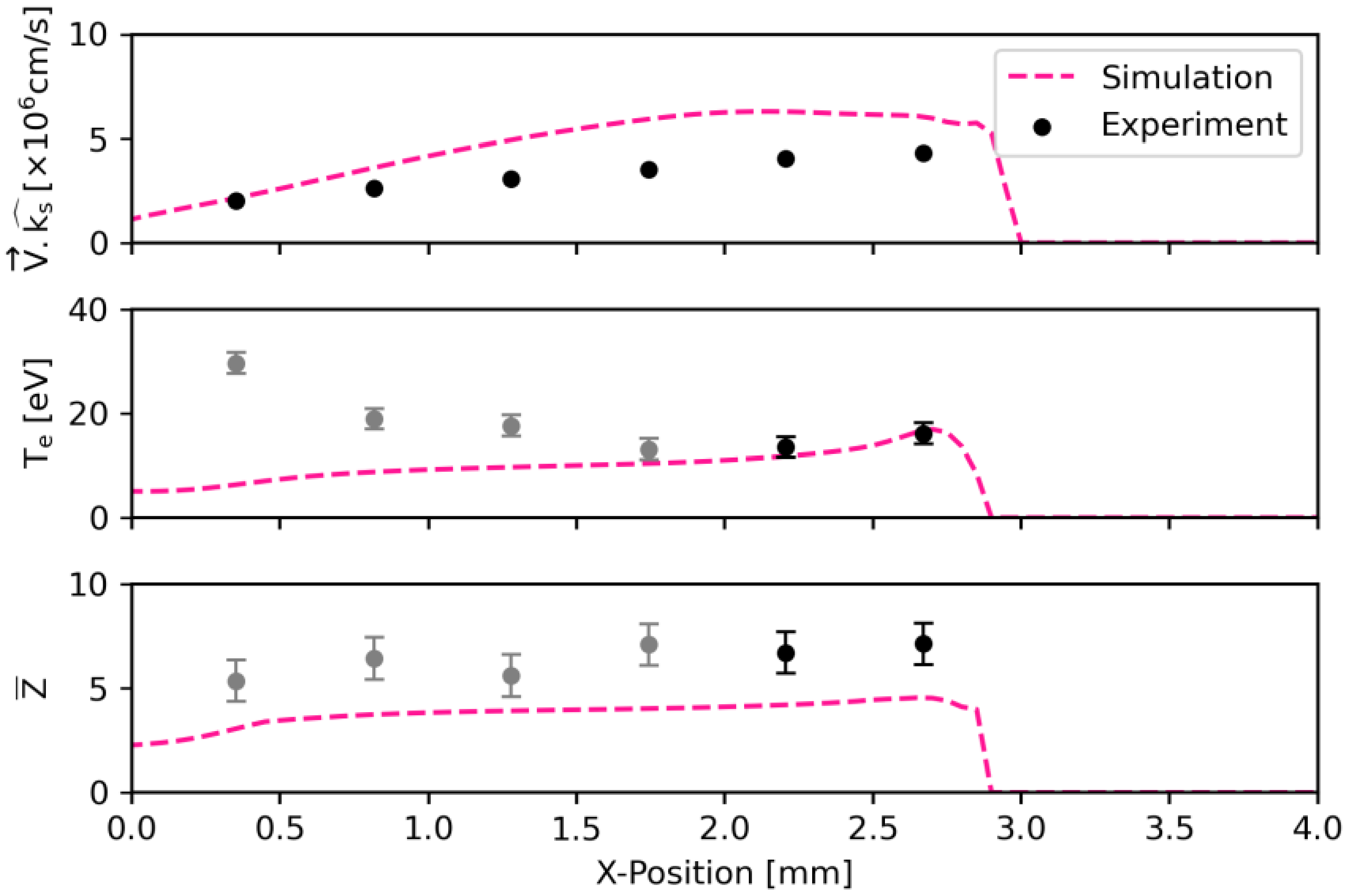


$\mathrm{T} = 13.5 \pm 2$ eV

$Z = 6.5 \pm 1$

$\alpha = 3$

Analysis of Ion-Acoustic Thomson Scattering Data



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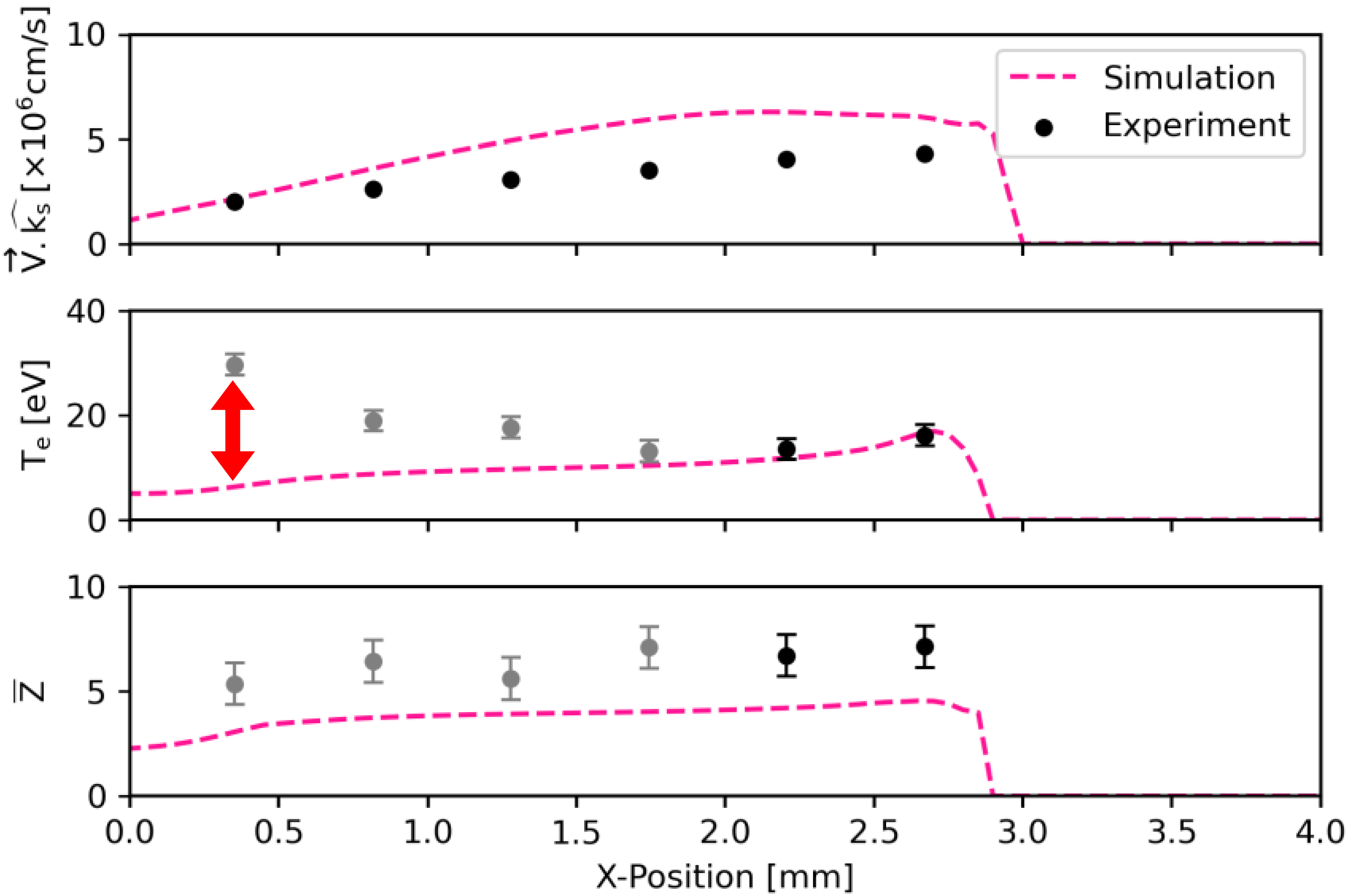
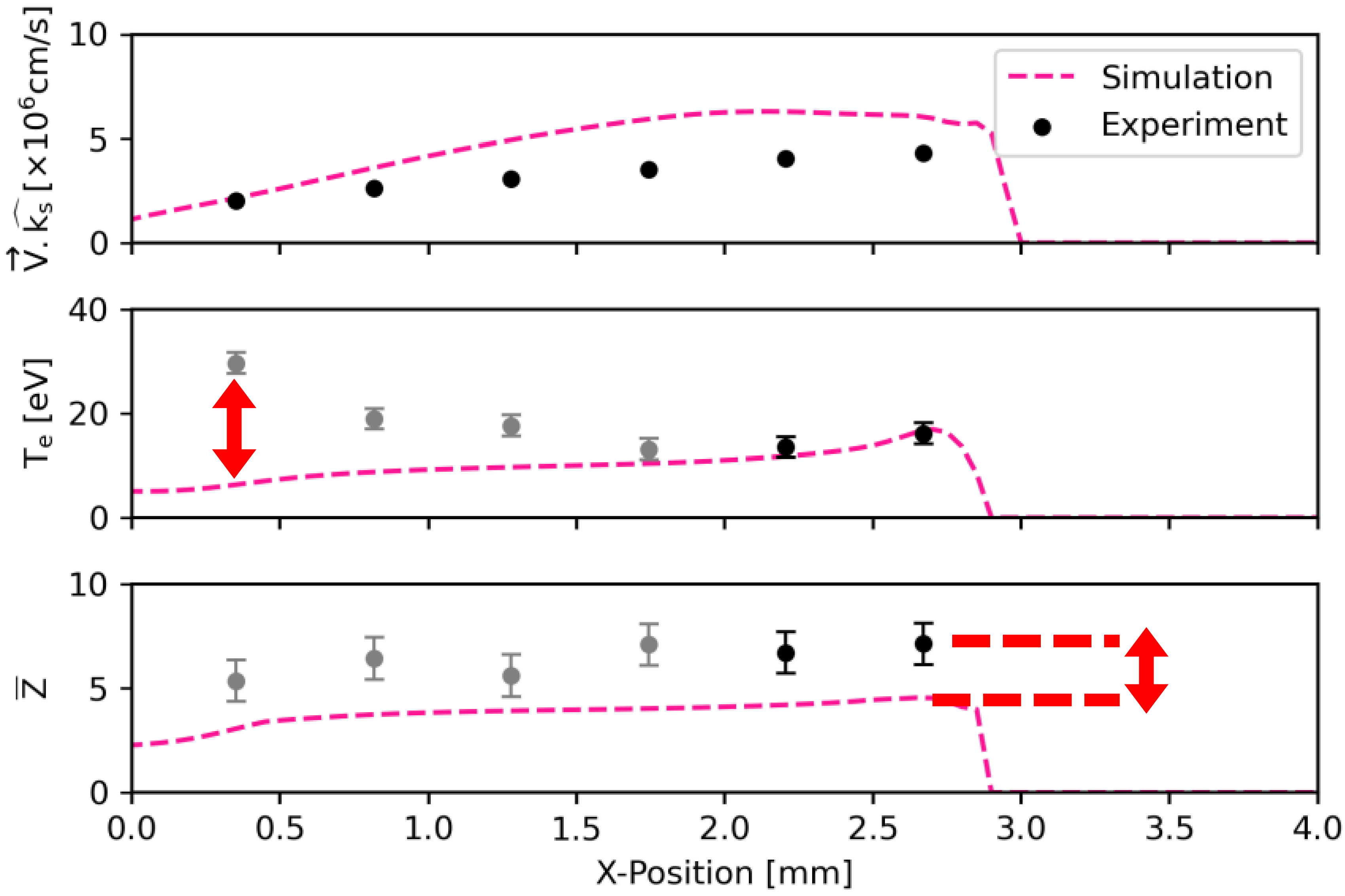
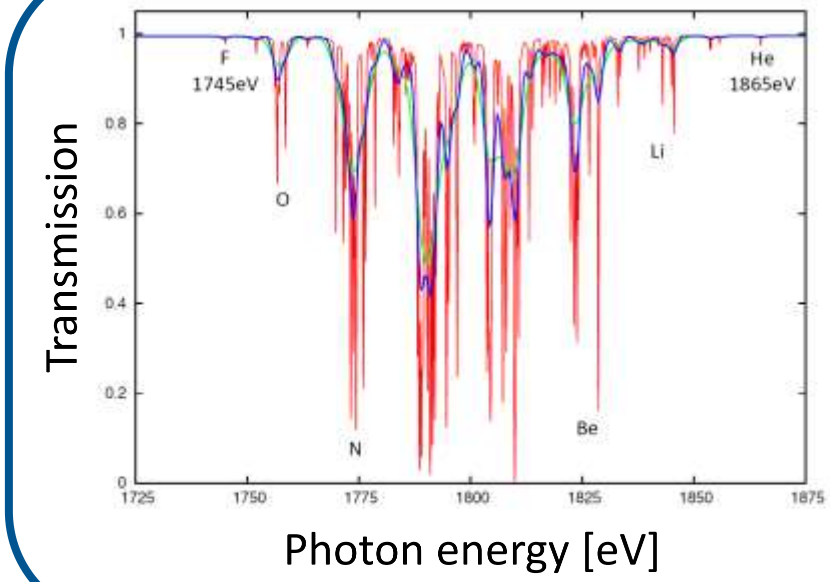


Analysis of Ion-Acoustic Thomson Scattering Data

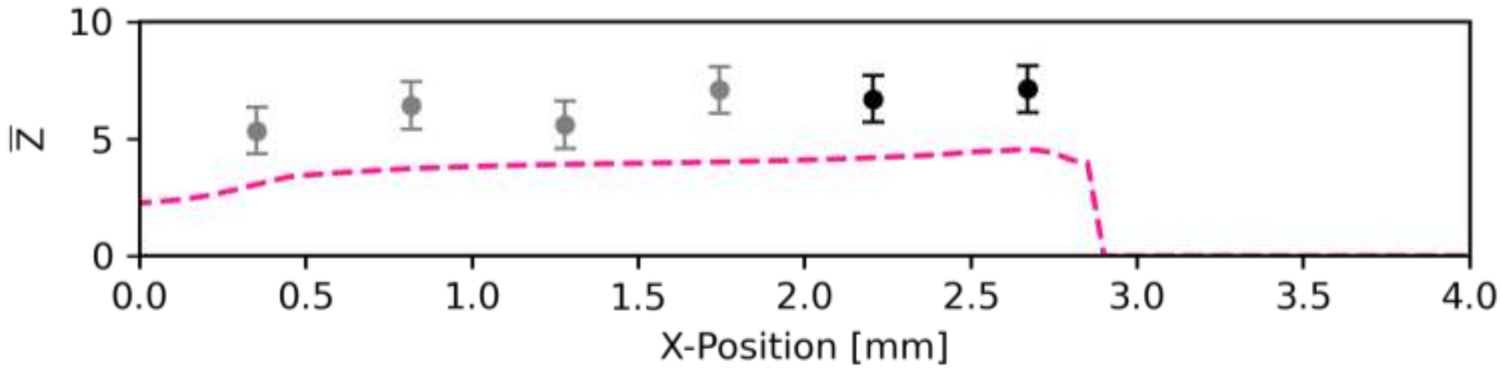


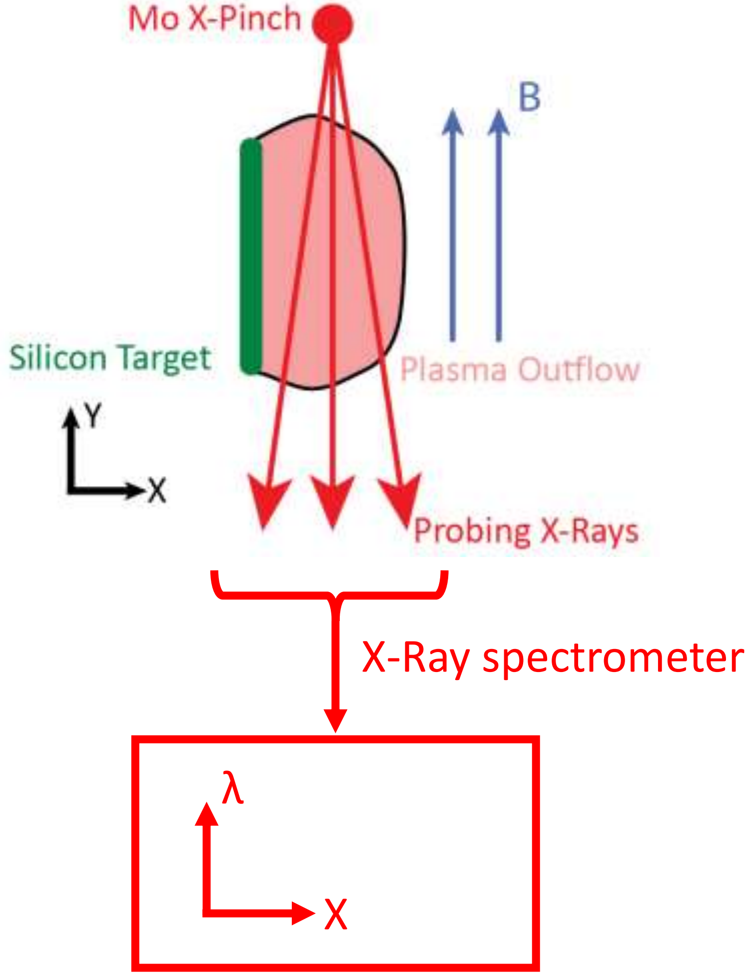
Future work – Diagnosis of Charge State Distribution



Silicon K-Shell absorption spectrum from Helios-CR.

(No MHD, inline atomic kinetics)





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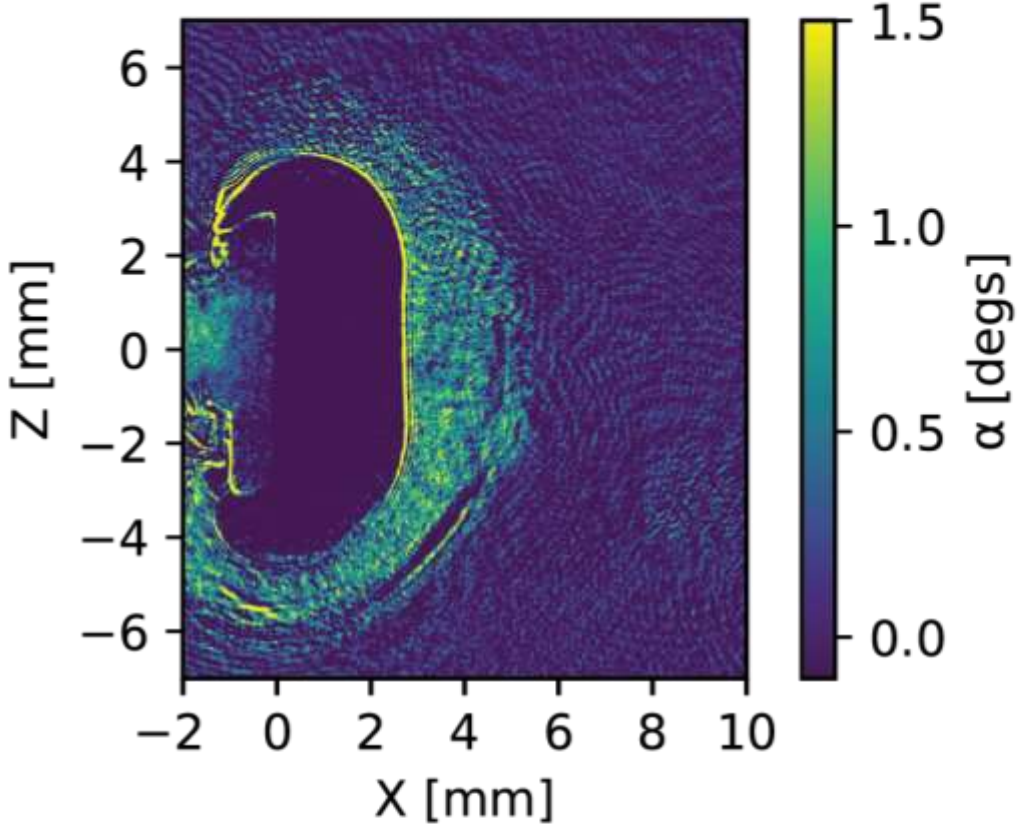
Faraday rotation imaging [weighted average of B_y]

Imperial College London



- Measure rotation applied to laser polarisation:

$$\alpha \propto \lambda^2 \int n_e \vec{B} . d\vec{y}$$

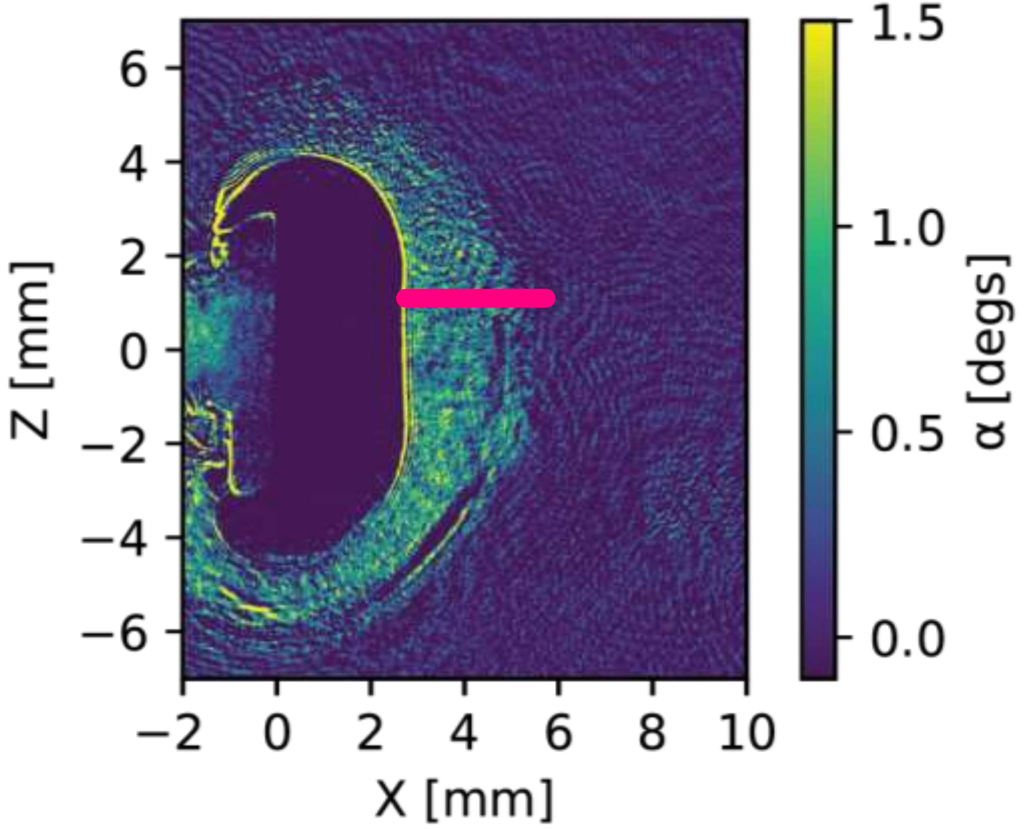
- Obtain interferometry along same line of sight:

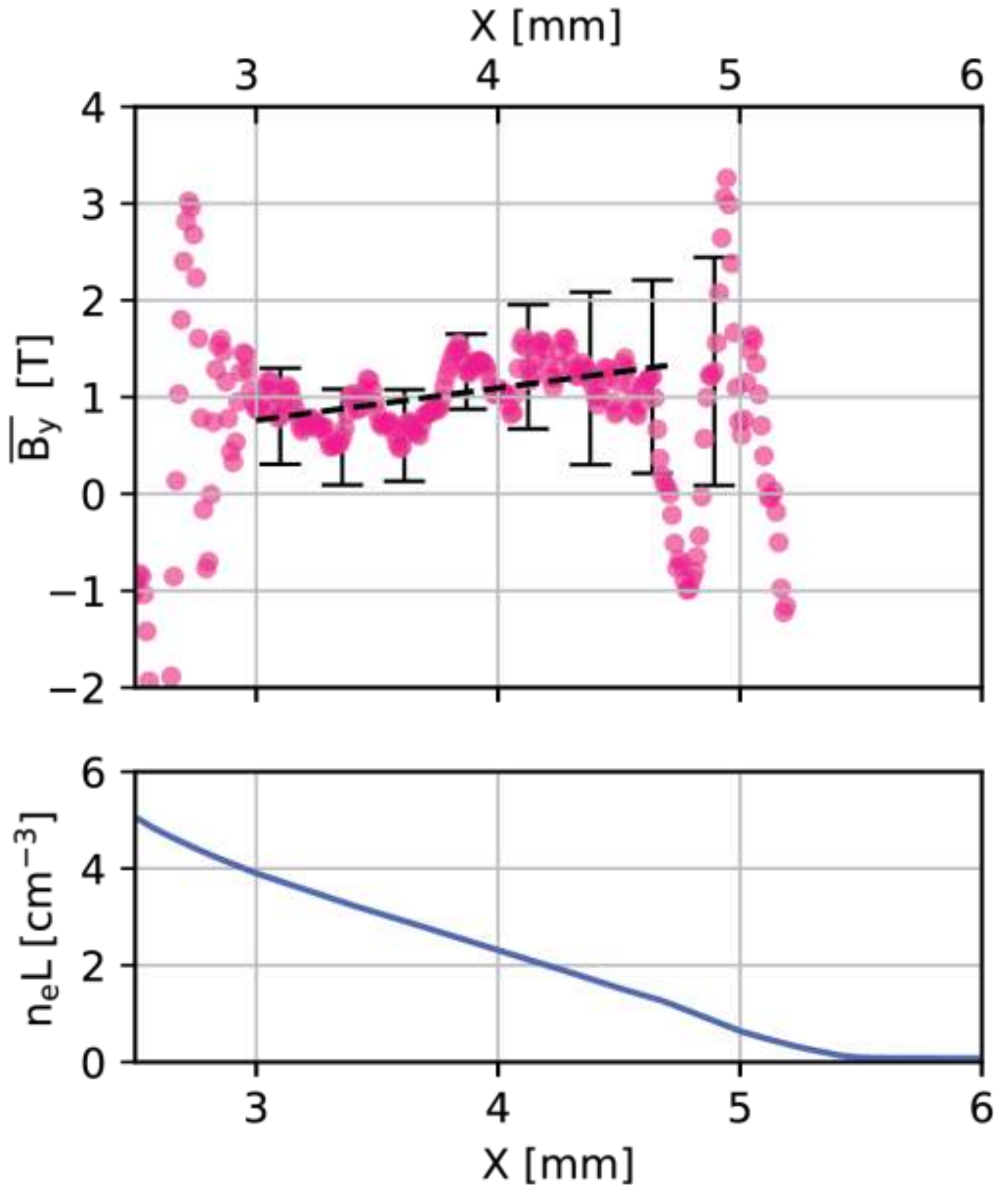
$$n_e L = \int n_e dy$$

- Combine data to back-out **weighted average** magnetic field:

$$\overline{B_y} = \frac{\alpha}{n_e L} \propto \frac{\lambda^2 \int n_e \vec{B} . d\vec{y}}{\int n_e dy}$$

Faraday rotation imaging [weighted average of B_y]





Faraday rotation imaging [weighted average of B_y]

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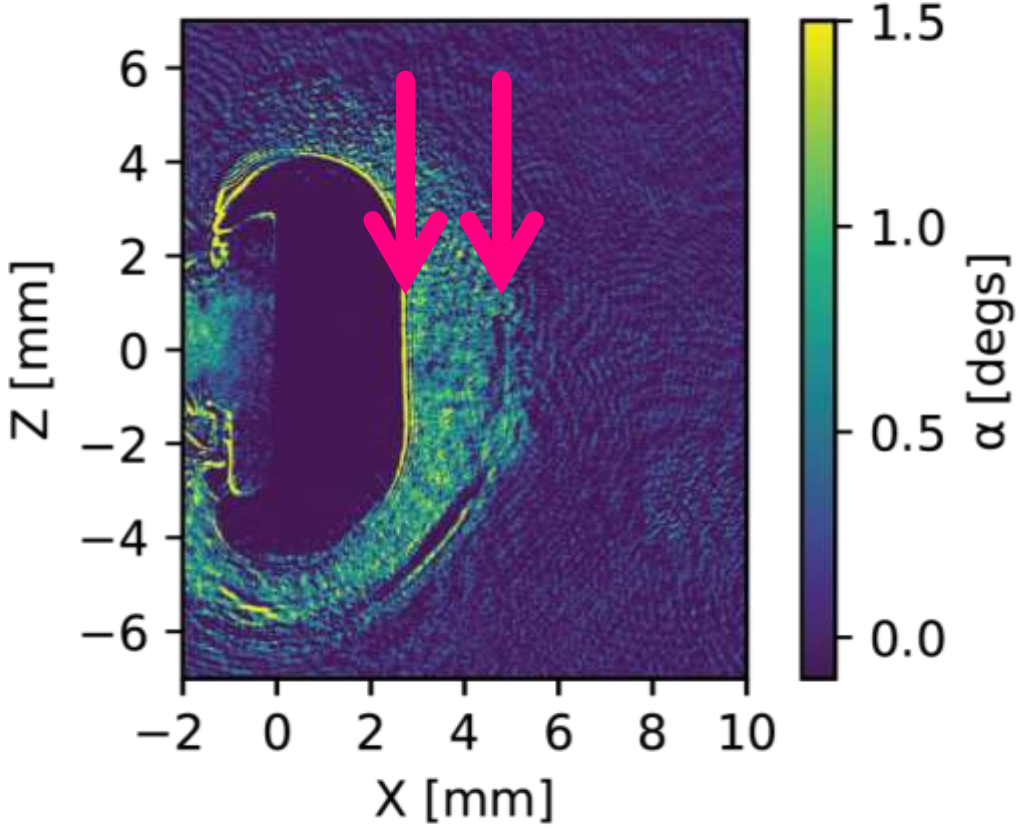
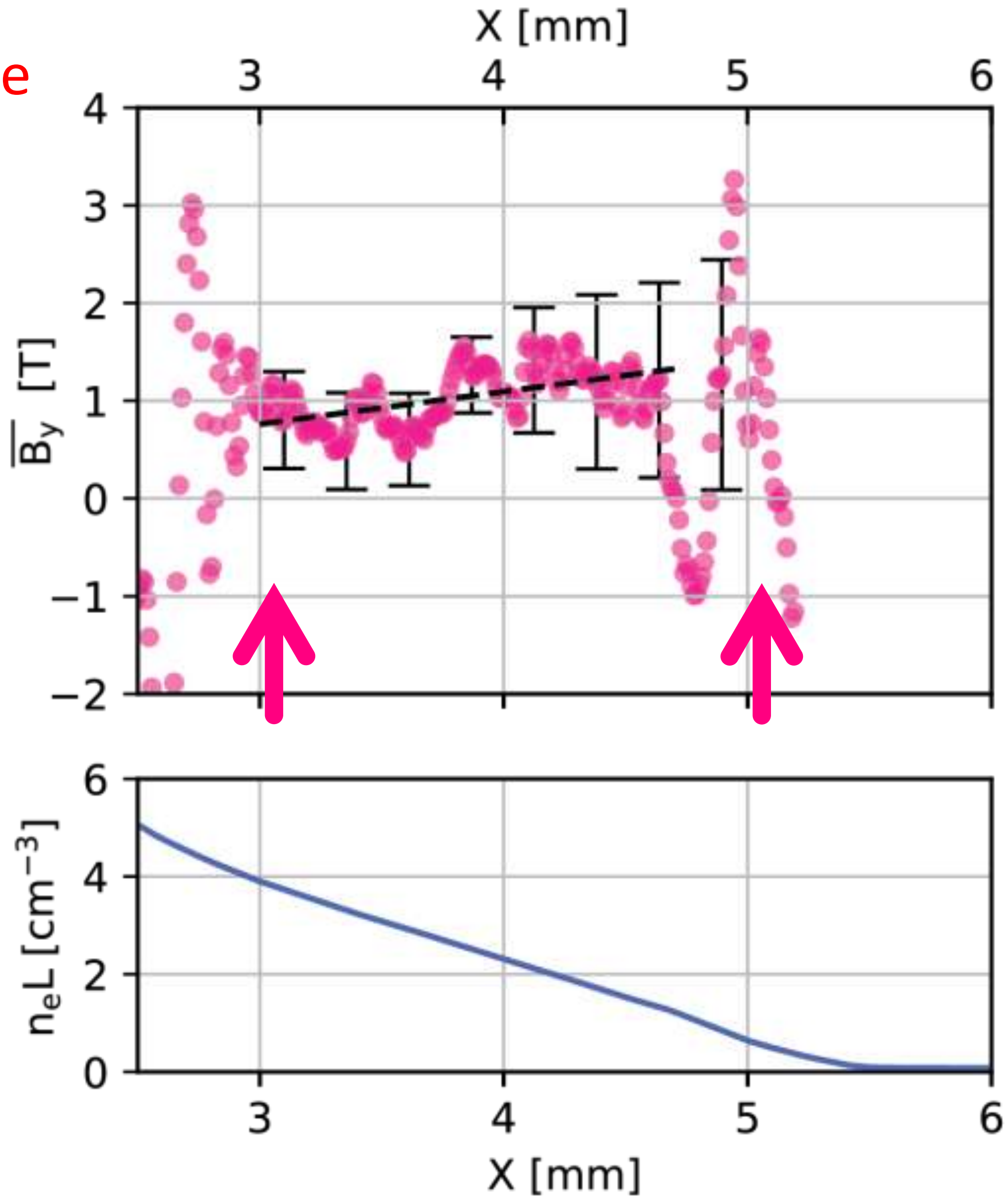
Arrows indicate caustics ⟹ B field not representative





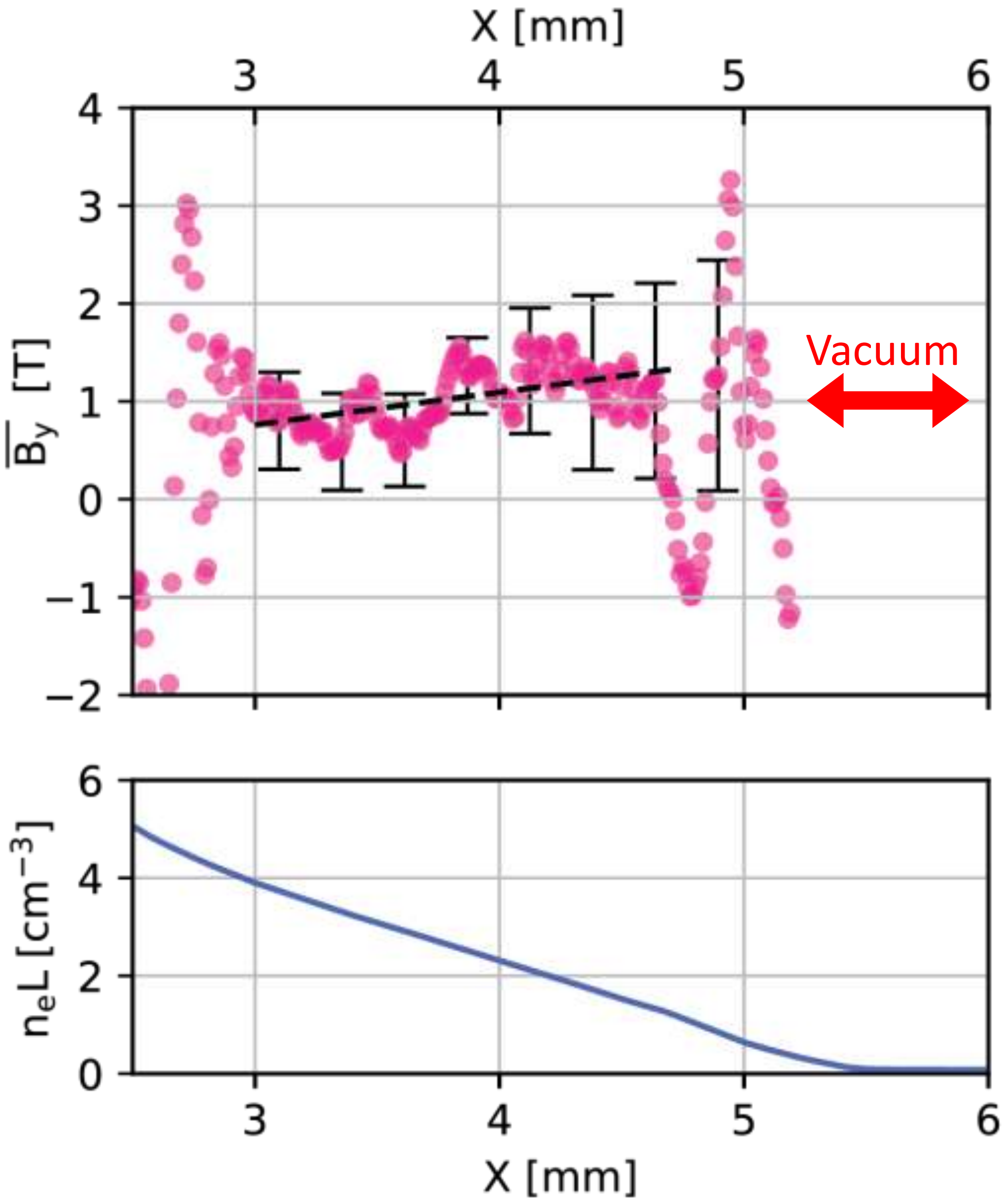
Faraday rotation imaging [weighted average of B_y]

- Diagnostic measures weighted average magnetic field:

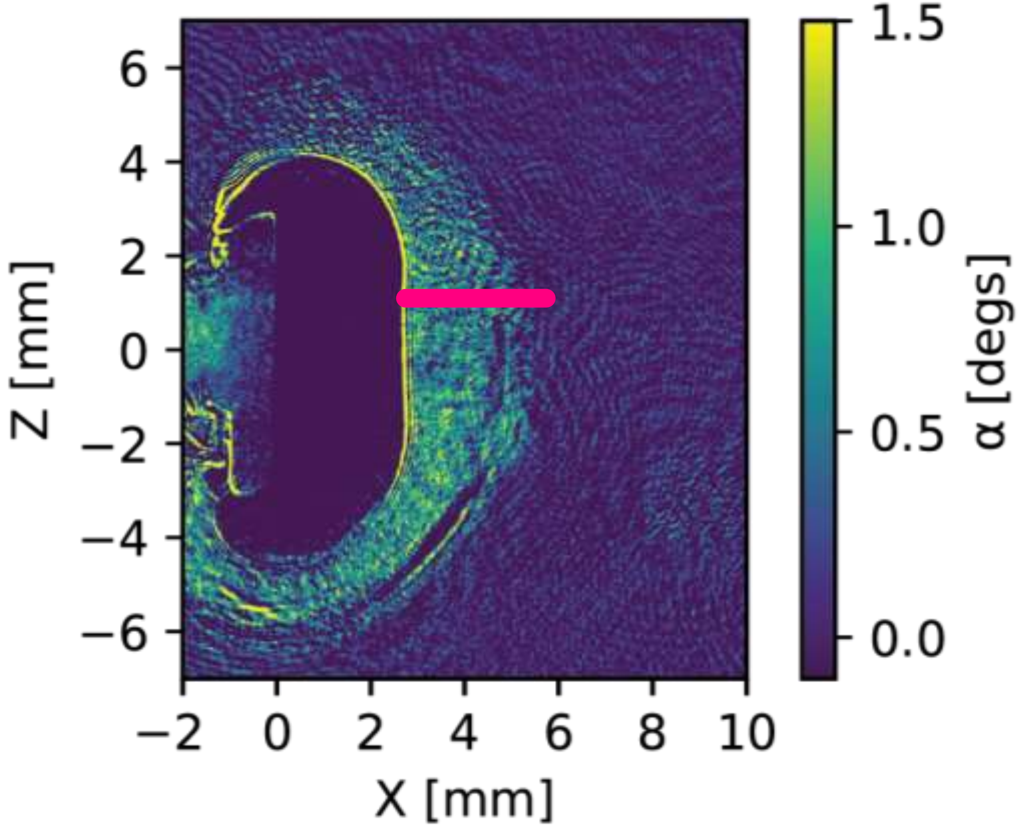
$$\overline{B_y} = \frac{\alpha}{n_e L} \propto \frac{\lambda^2 \int n_e \vec{B}.d\vec{y}}{\int n_e dy}$$

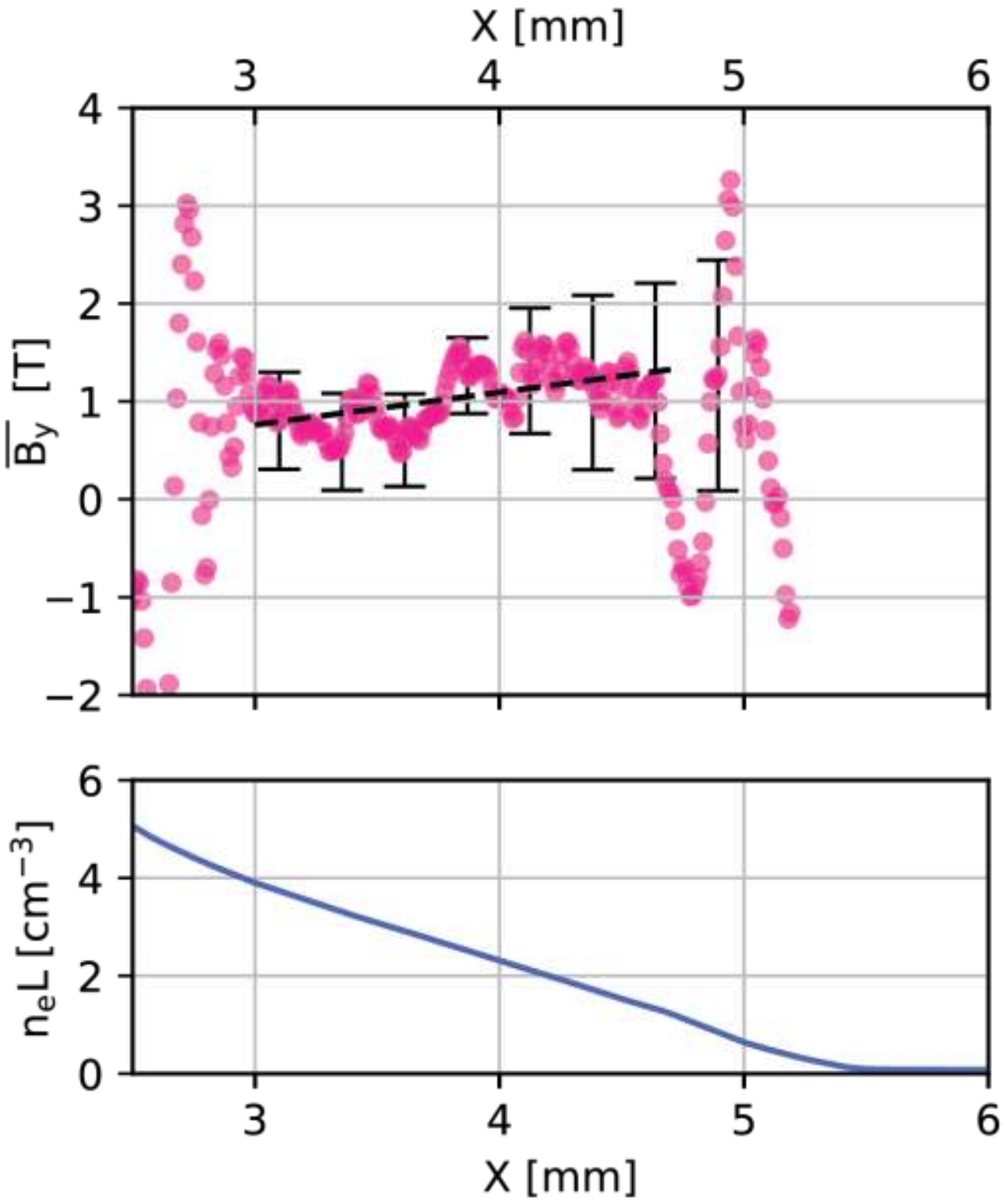
- Cannot diagnose field in the vacuum ($n_e = 0$)

- Within region which can be probed, the field is approximately constant (~ 1 T)



Faraday rotation imaging [weighted average of B_y]





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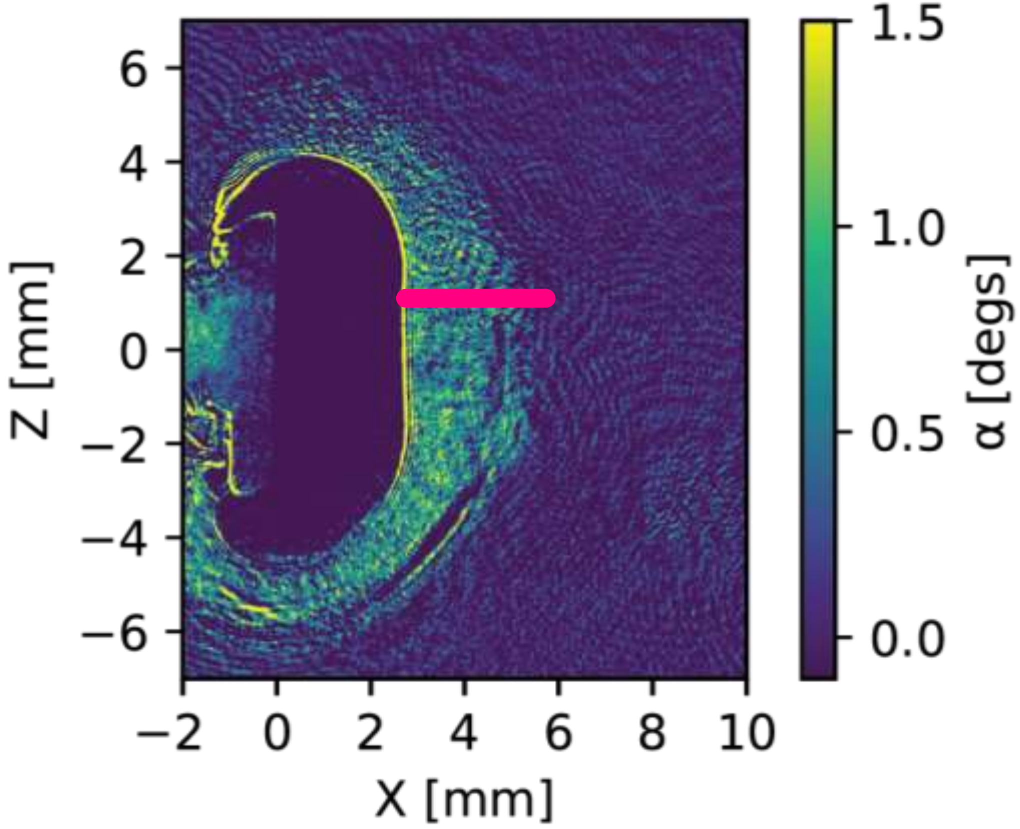

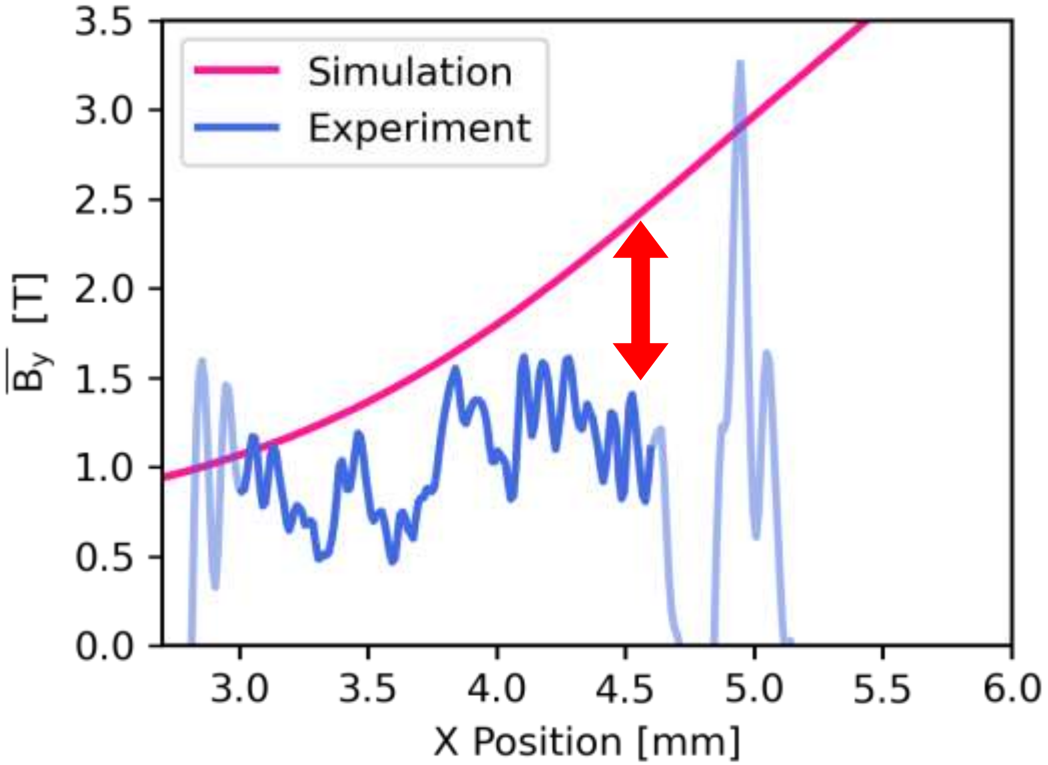

Simulated profile is more diffusive

Faraday rotation imaging [weighted average of B_y]

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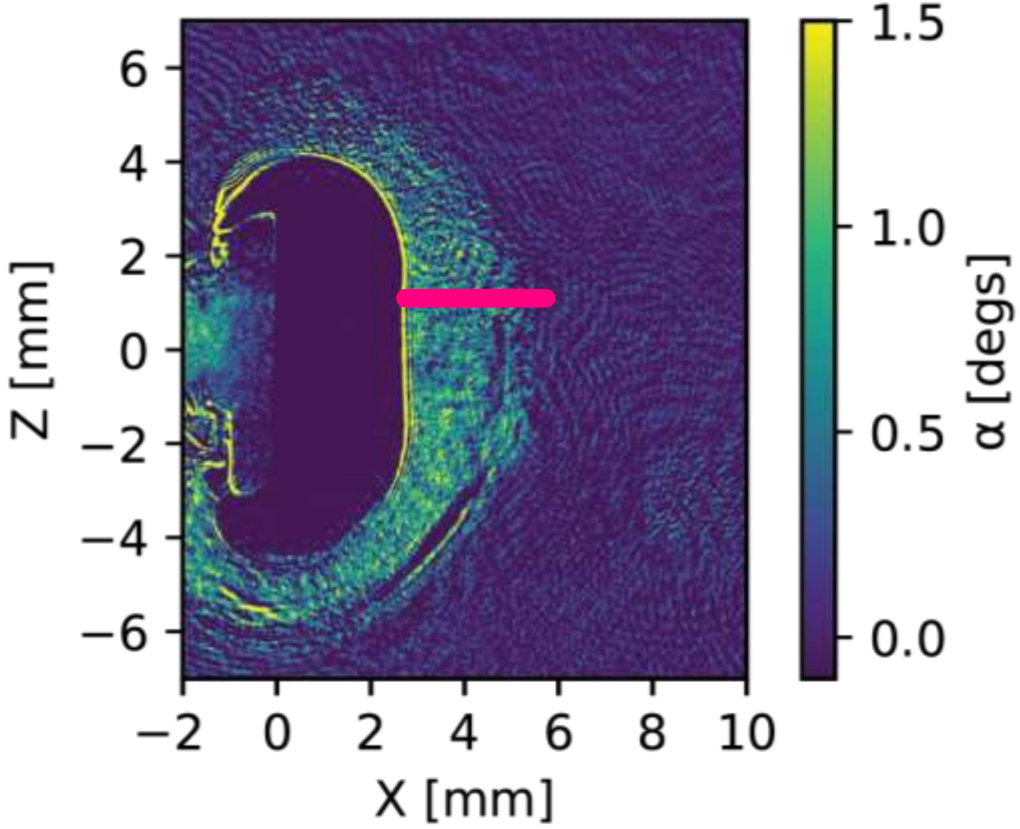
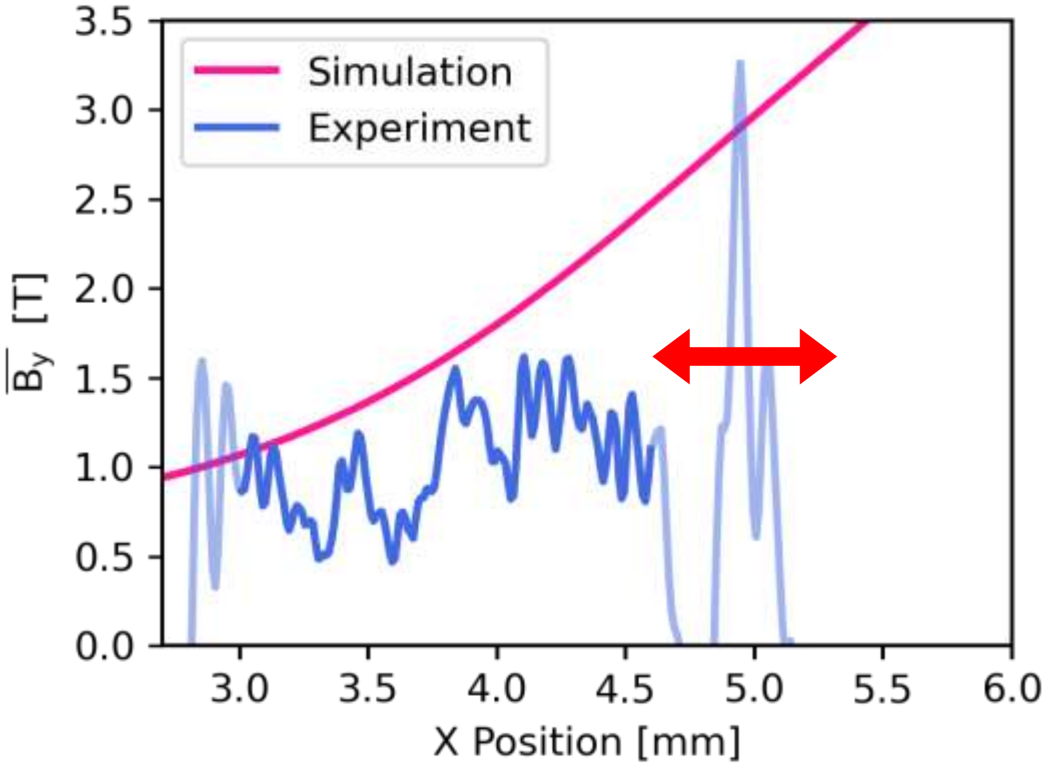


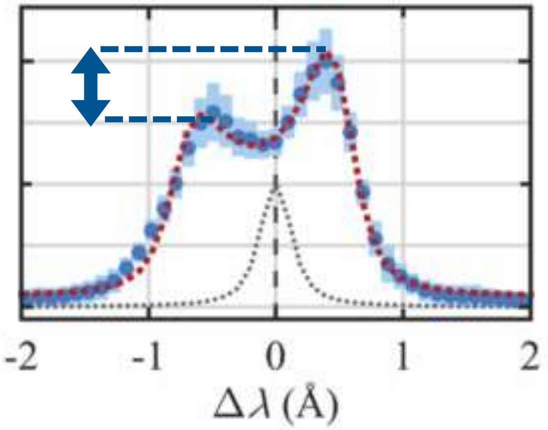


Need to diagnose vacuum boundary!

Future work – Local Current Density Measurement

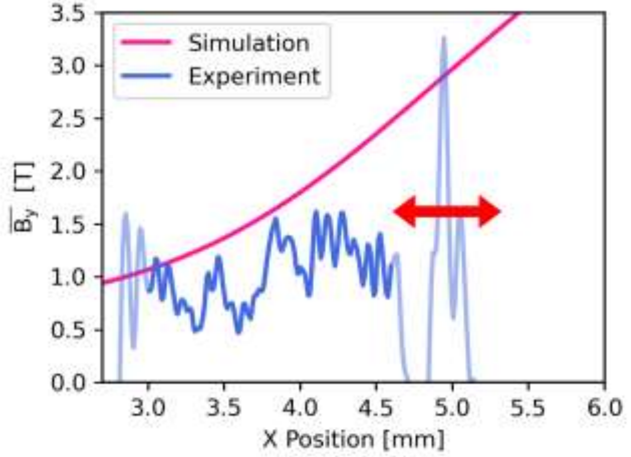
Peak **asymmetry** depends on $\boldsymbol{\widehat{k_s}.V_d}$

L. G. Suttle *et al* “Collective Thomson scattering in pulsed-power driven HED experiments” RSI 2021.



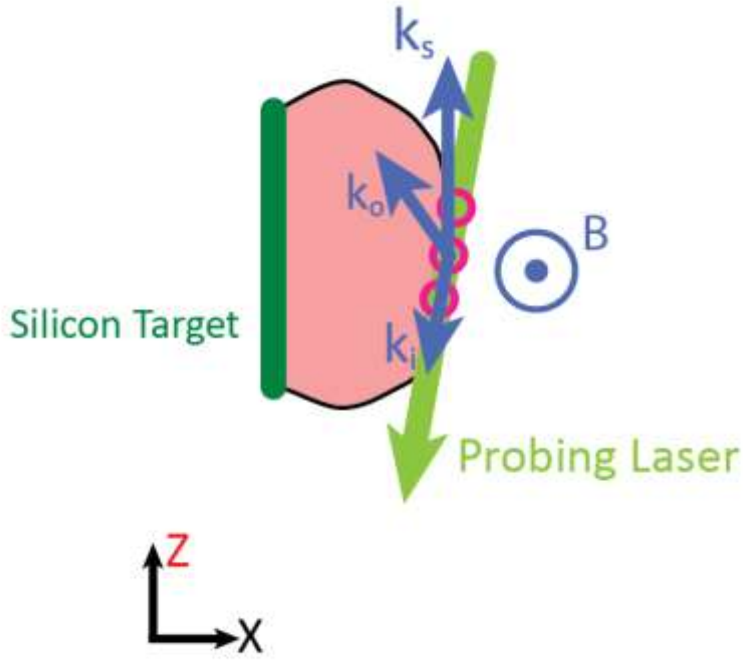
Diagnose current at vacuum boundary with Thomson:

- Can probe smaller n_e
- Reduce λ for less diffraction

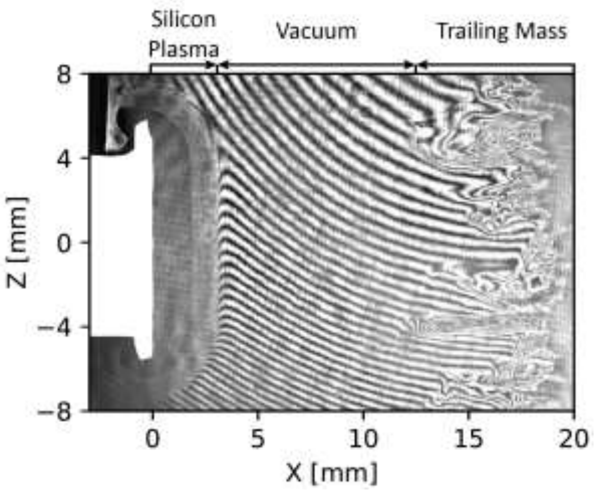


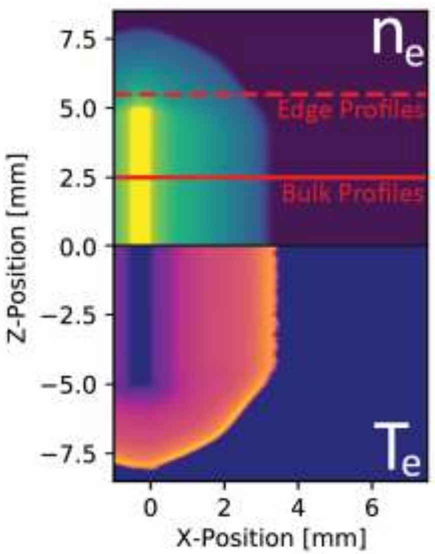
Need to diagnose vacuum boundary!

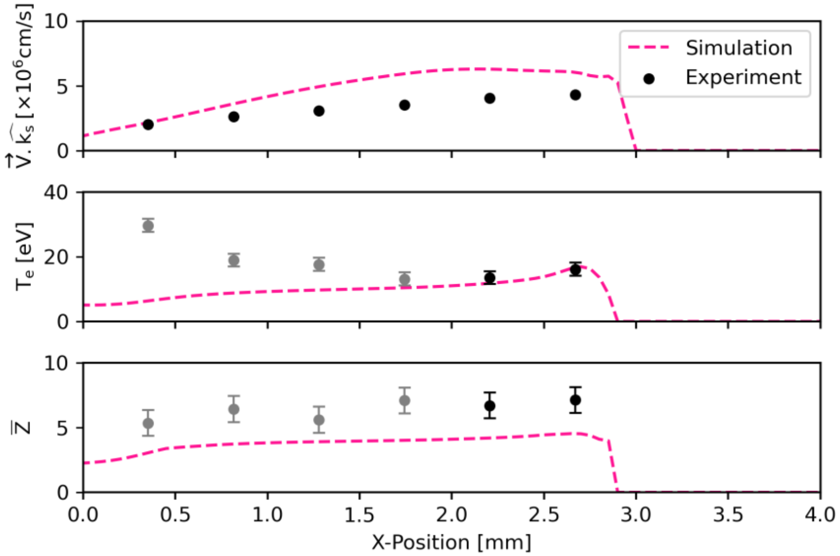
New setup ⇒ $k_s \parallel J$

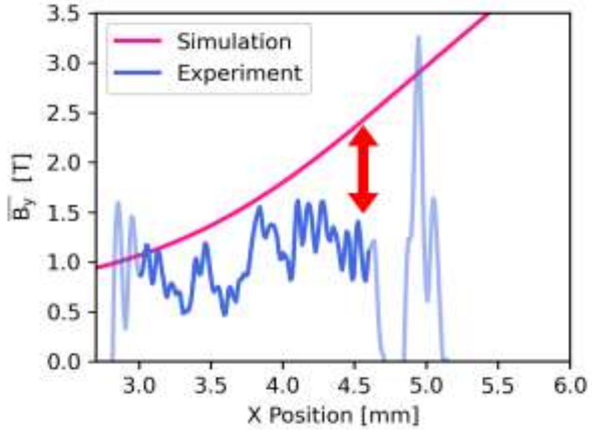


Summary









J. W. D. Halliday et al. Physics of Plasmas (2022):

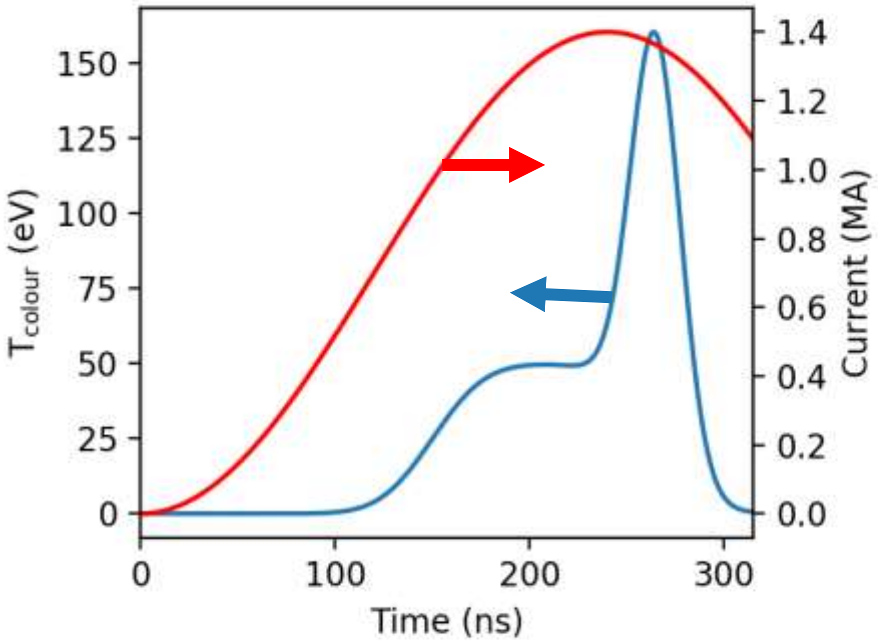
Experimental morphology well reproduced by simulations

Probe heating perturbs temperature in Thomson scattering data

Radiation field plays a role in charge state distribution (?)

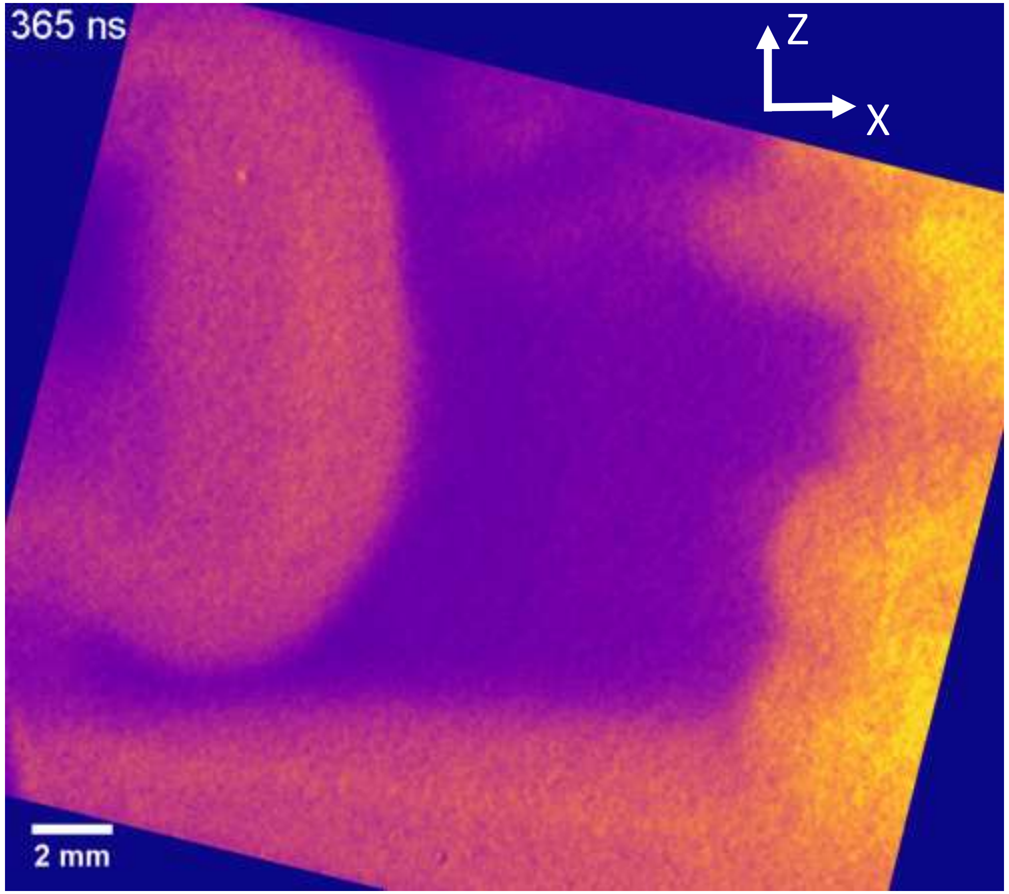
Simulated B field is more diffusive than experiment

Spectral Character of Radiation at ∼1 MA Level

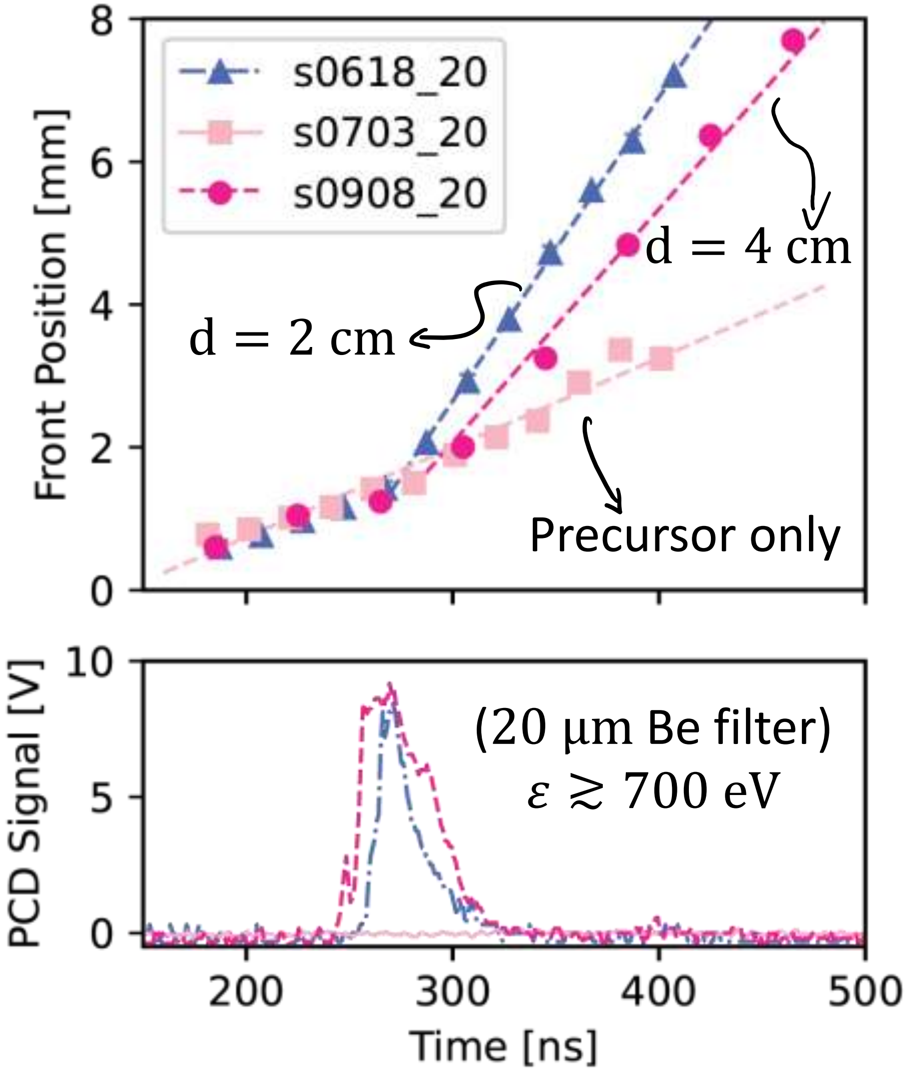


- **Precursor (pre-pulse):**
  - Colder spectral character (T_c∼ 50 eV)
  - Radiates ∼ 400 J in total
  - Time duration ∼100 ns
- **Implosion:**
  - Emitted radiation∼15 kJ over ∼30 ns
  - Estimate T_c∼ 150 eV

Optical self emission images [qualitive dynamics]



Self emission images [$600 \lesssim \lambda \lesssim 900$ nm]



(20 µm Be filter)
$\varepsilon \gtrsim 700$ eV

Analysis of Ion-Acoustic Thomson Scattering Data

Imperial College London

①: Ion Acoustic peak **separation** depends on $\bar{Z} \times T_e$

②: Feature **width** depends on n_e, T_i, and spectral response

③: Doppler **shift** from probe wavelength depends on $\vec{V}.\widehat{k_s}$

Enforced $\mathrm{T_e} = \mathrm{T_i}$, and allowed $\bar{Z}$ to vary ($\tau_{ei} \lesssim 1$ ns).

Convolved calculated spectra with measured spectral response.

Constrained value of $\mathrm{n_e}$ from (near simultaneous) interferometry.