Atomic processes in X-Ray driven ablation experiments on university scale pulsed power facilities

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CIFS

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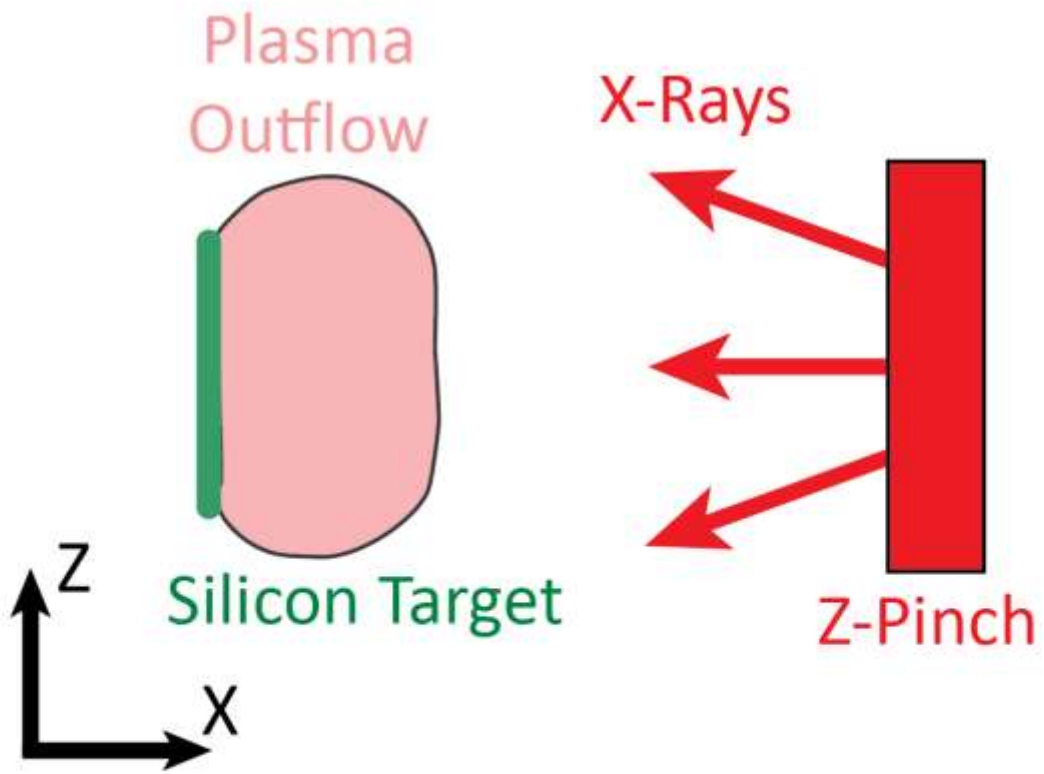
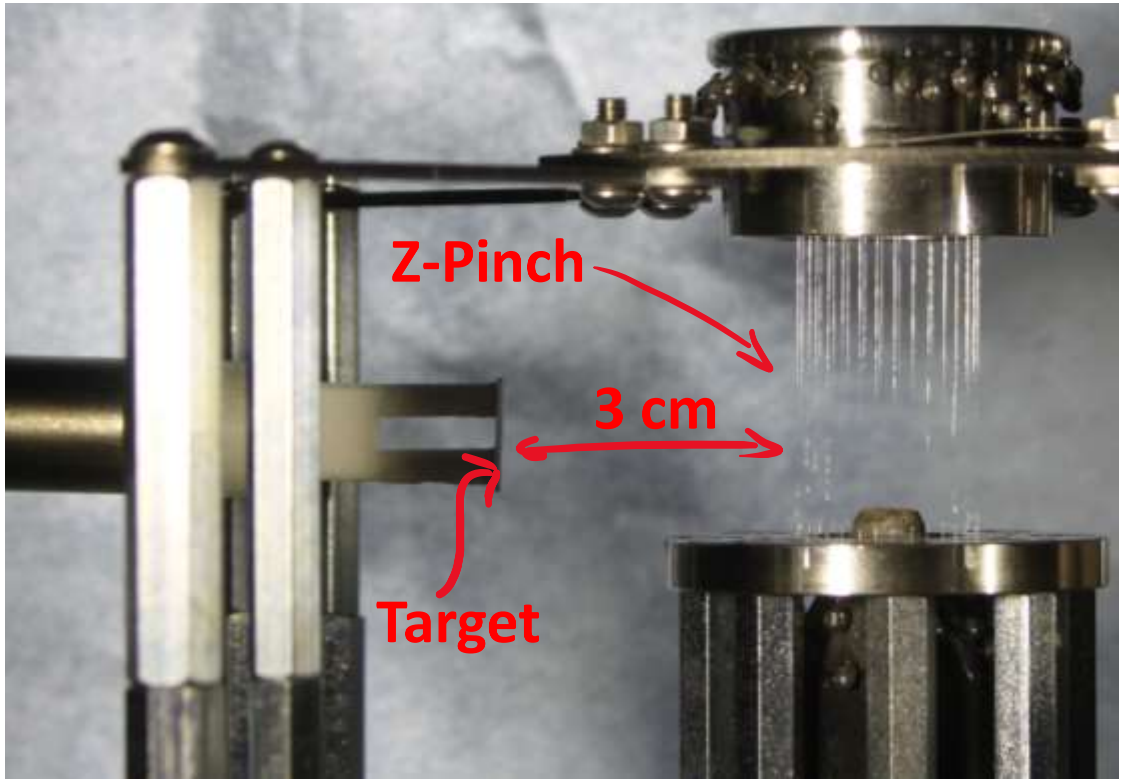
Overview of the experimental design





- X-Rays from imploding wire array Z-Pinch
- Experiments on MAGPIE/COBRA (1 MA, 250 ns)
- Target positioned $1.5 - 4$ cm from pinch
- Brightness temperature on-target ~ 10 eV

Overview & Motivation

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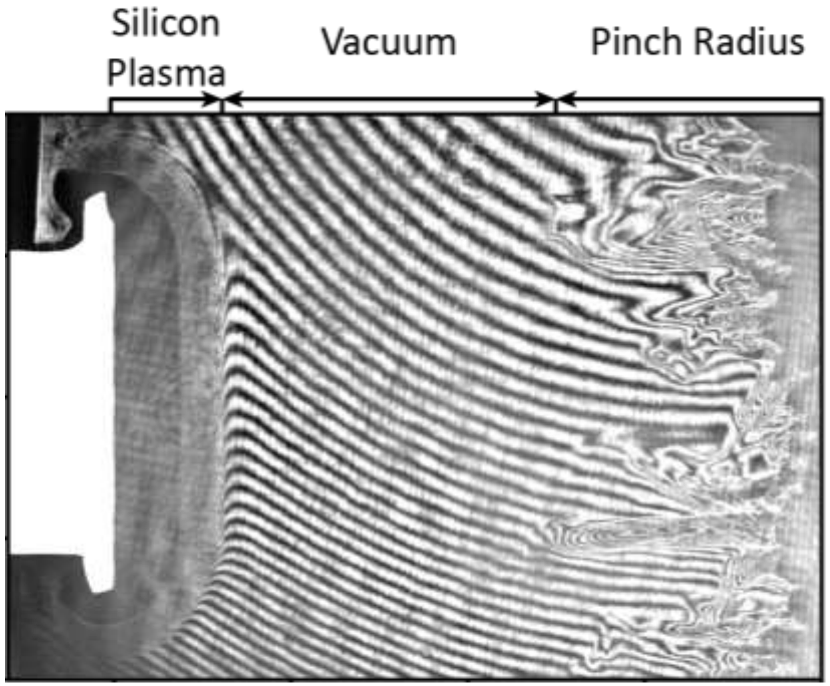
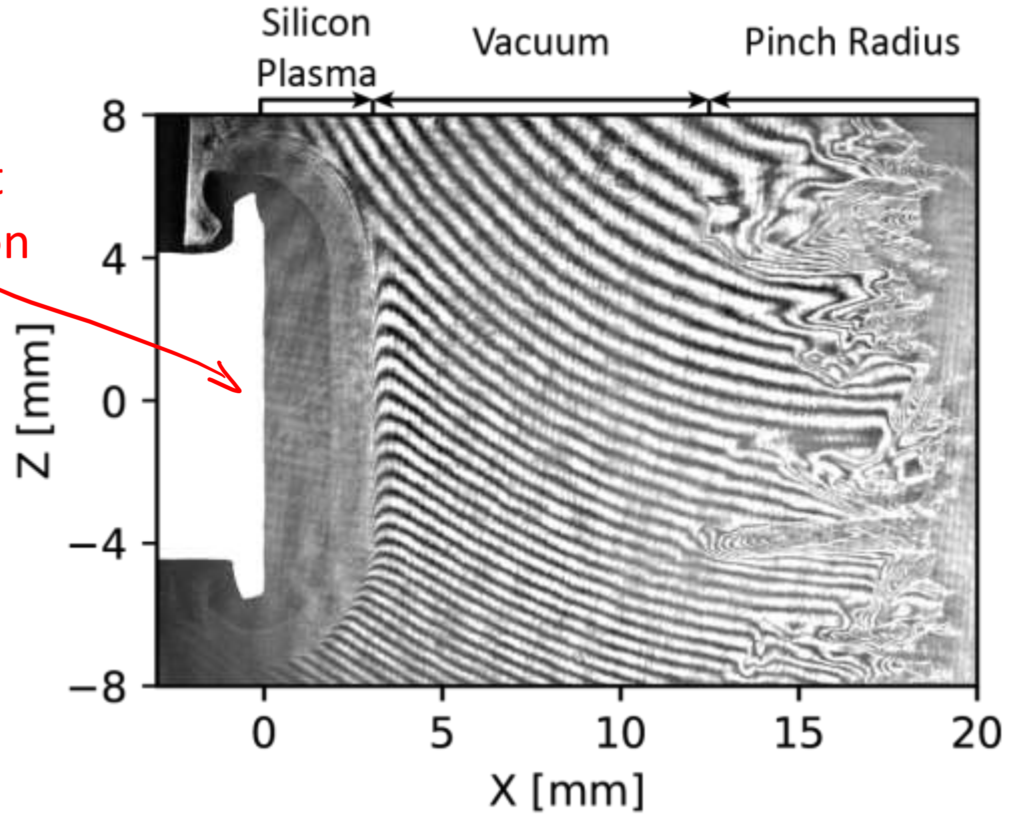
- Laser probing [Halliday+ PoP 2022] characterizes hydro
- X-Ray absorption experiments will characterize atomic physics
- Motivation: Understanding mechanism for satellite solar panel damage in high altitude nuclear weapons tests (lower X-Ray flux than results here)

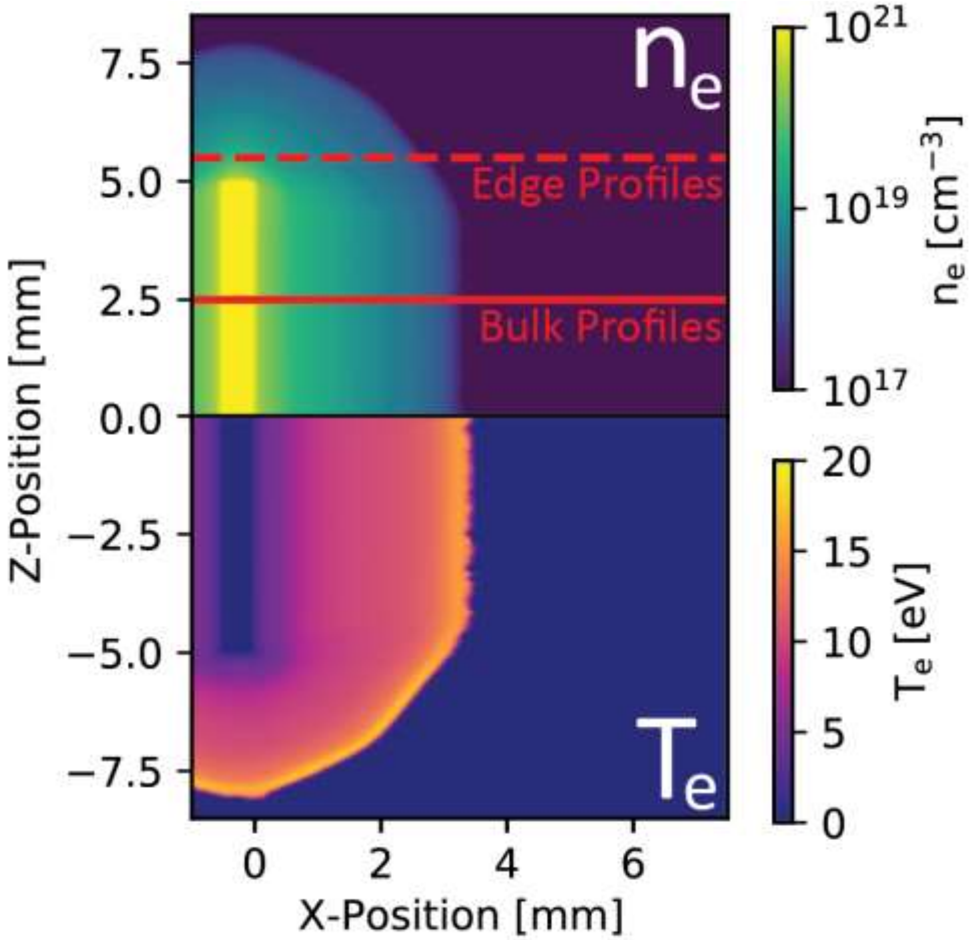


Atomic physics strongly influenced by driving radiation pulse & conditions are characterized using independent diagnostics. This means experiments represent a novel testbed for atomic theory / modelling

Plasma outflow is extremely simple

Target position

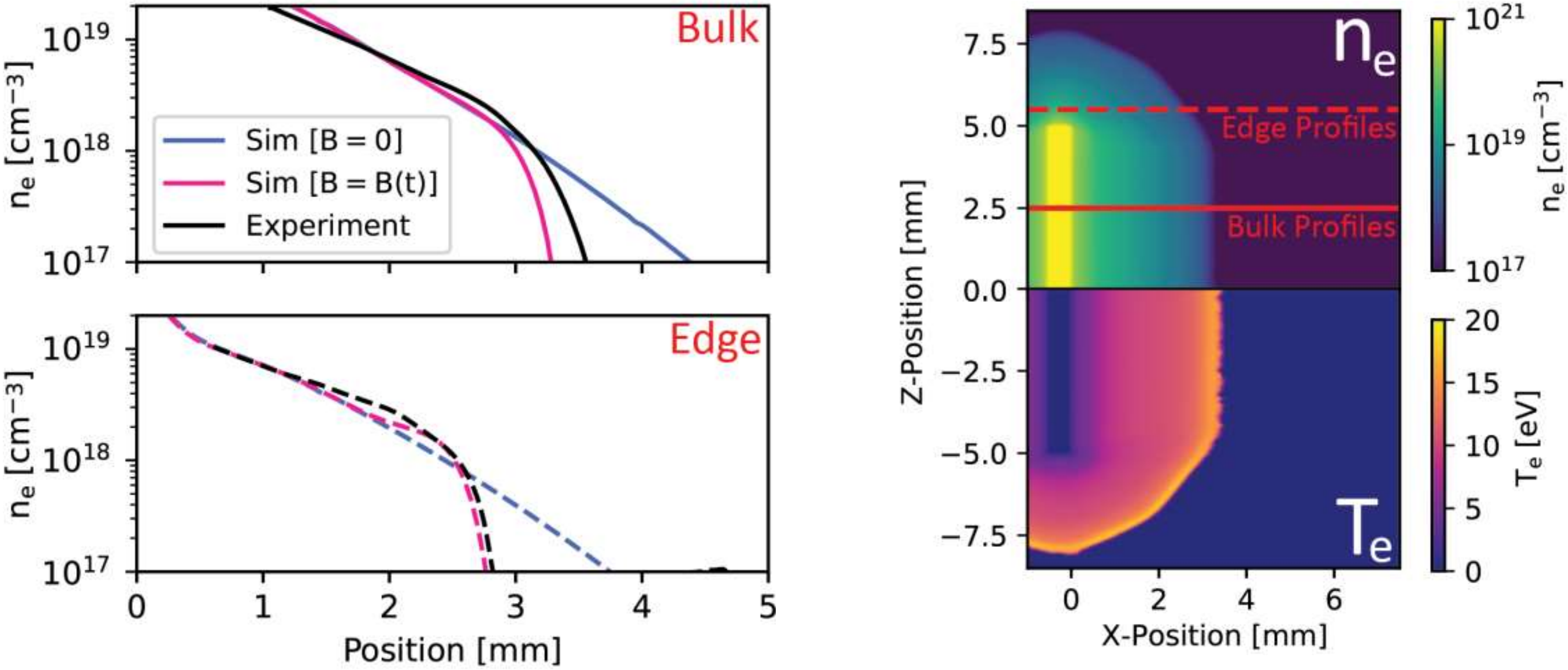




- Smooth ~1D expansion profile confirmed by orthogonal laser probing
- Density profiles well reproduced by R-MHD simulations performed with Chimera

Halliday+ PoP 2022

R-MHD simulations were performed with Chimera



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

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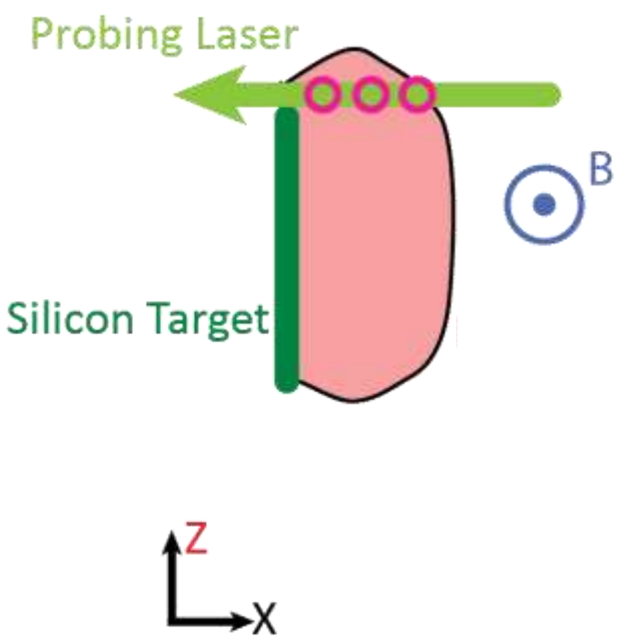

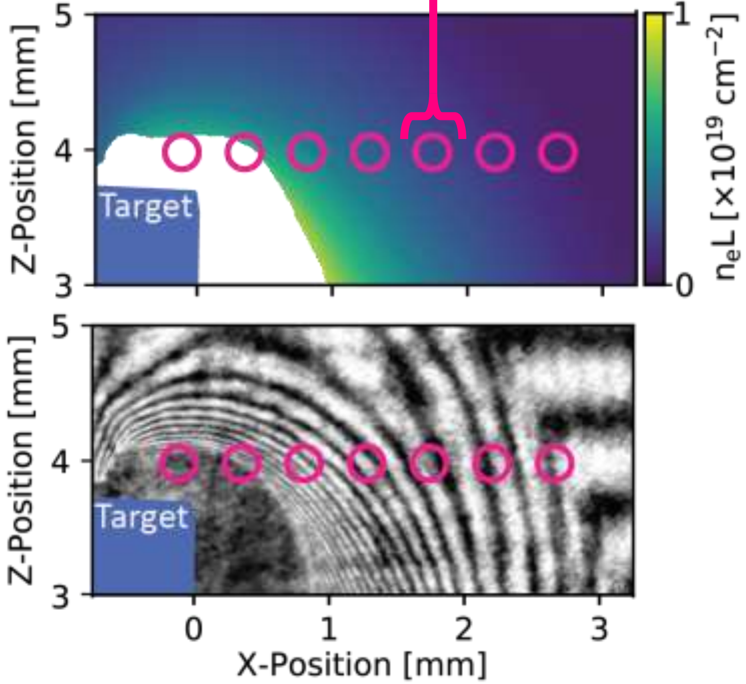

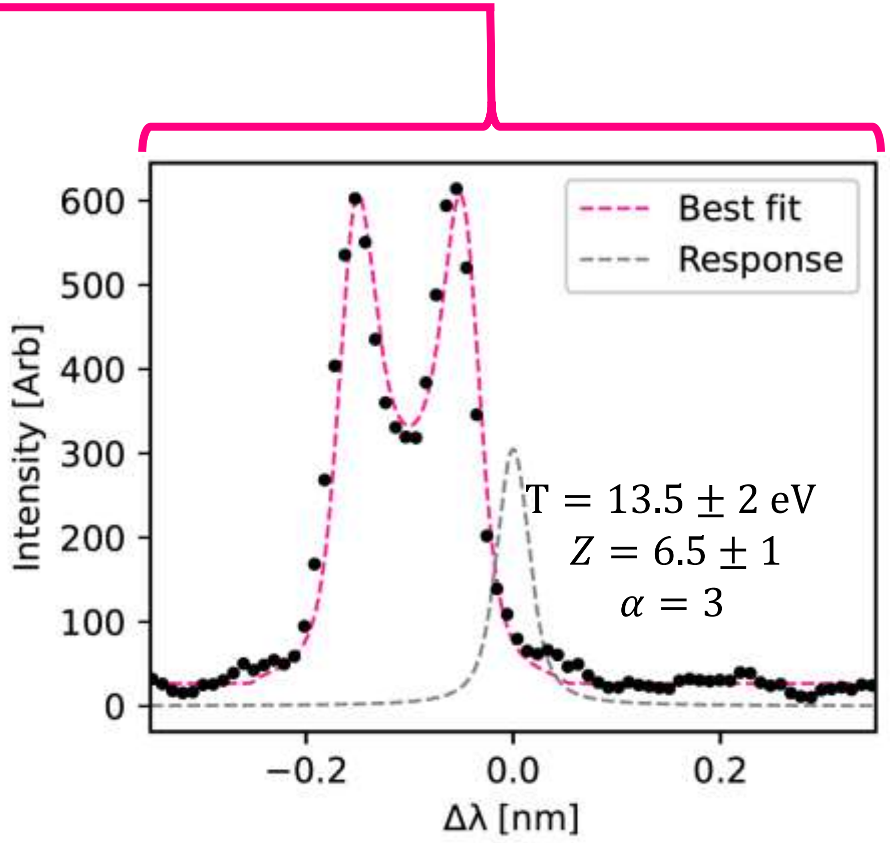

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Measured $\bar{Z}$ is higher than the CR equilibrium value

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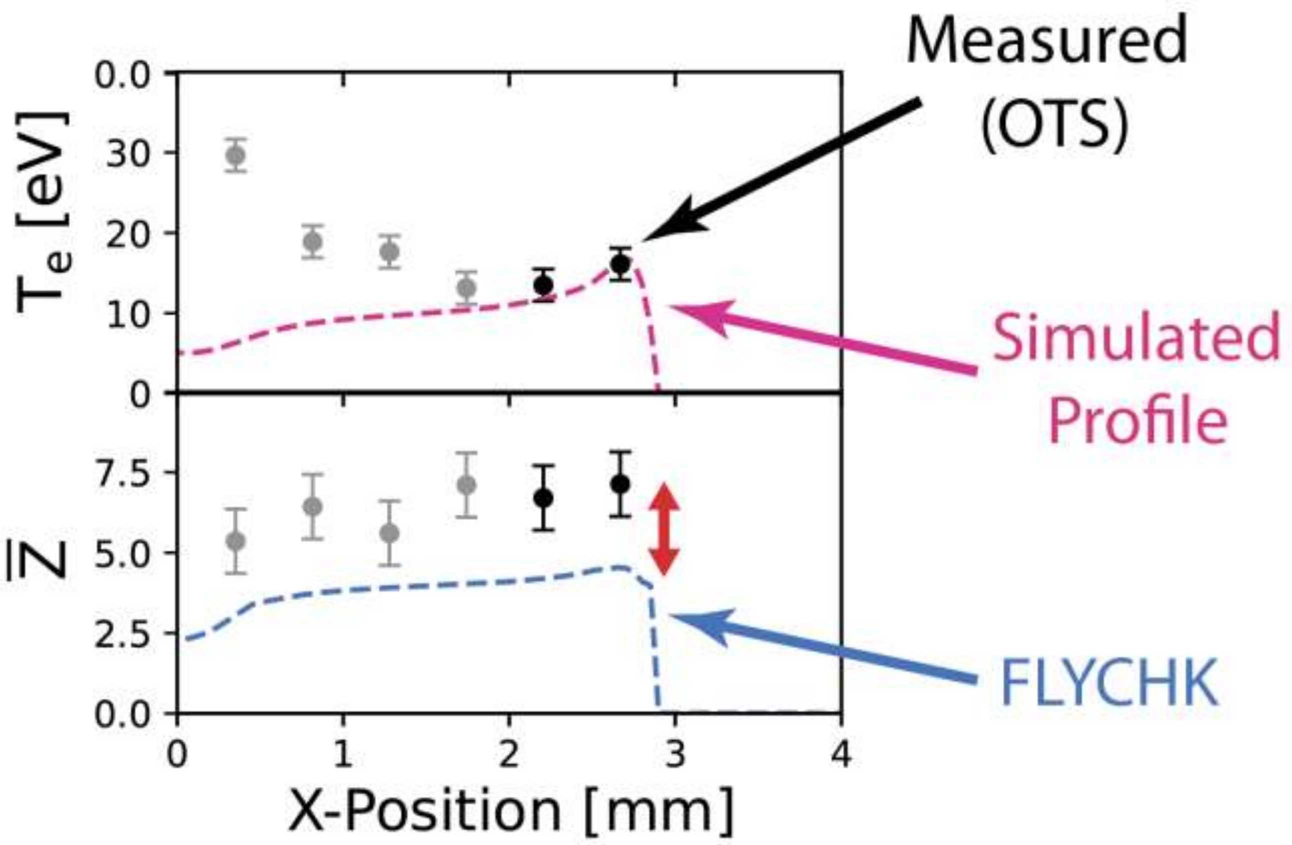
- Data points are experimental measurements from IAW Thomson scattering
- Pink curve indicates results from R-MHD simulations
- Blue curve derived by applying simulated n_e and T_e values to FLYCHK simulations (no external radiation field)
- **Significant disagreement in $\bar{Z}$ values**



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Charge state distribution altered by driving radiation?

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- PrismSPECT results with:

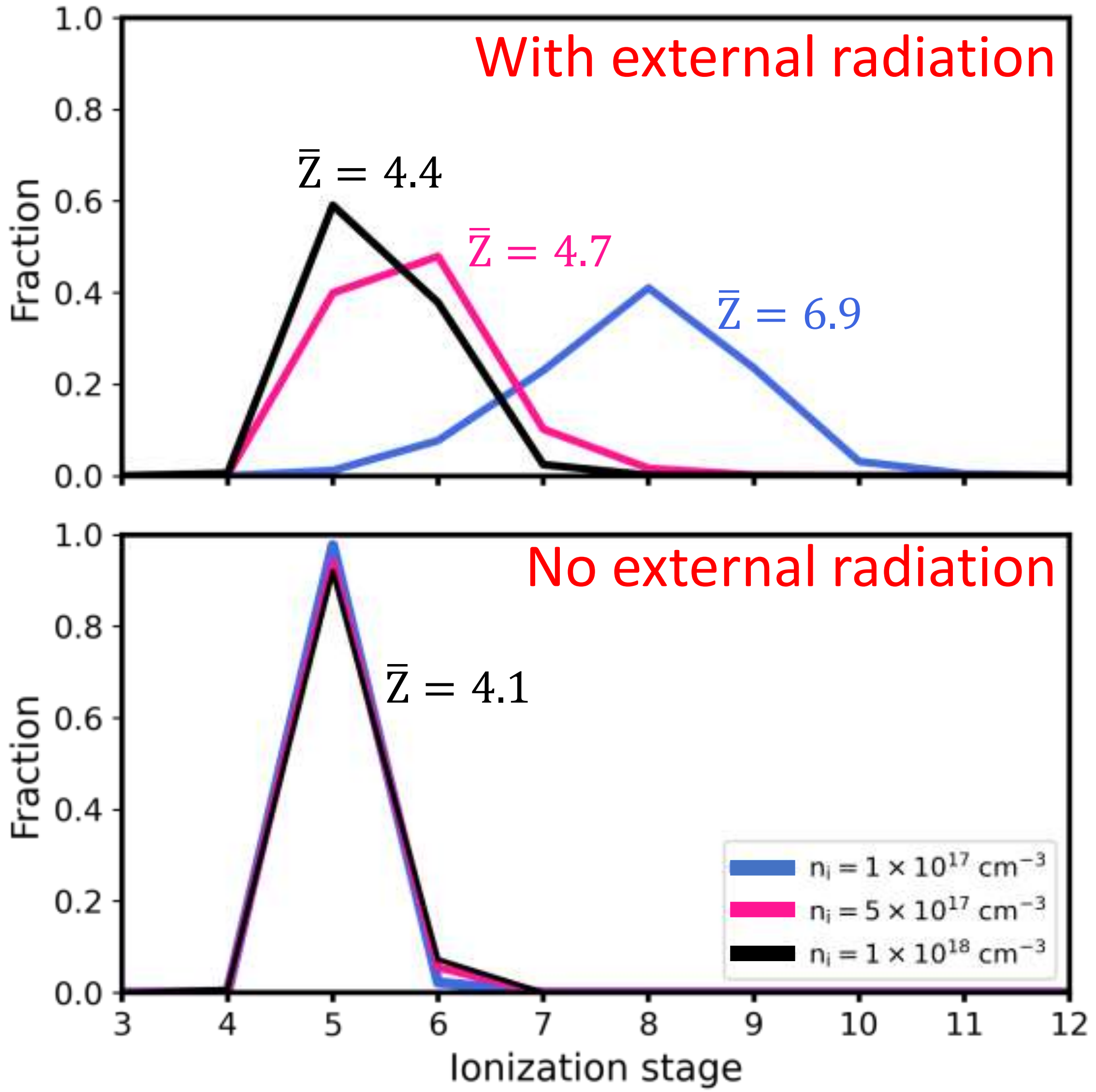
$$T_e = 10 \text{ eV}, \qquad n_i = \begin{matrix} 1 \times 10^{17} \text{cm}^{-3} \\ 5 \times 10^{17} \text{cm}^{-3} \\ 1 \times 10^{18} \text{cm}^{-3} \end{matrix}$$

- Applied external radiation field (approximates pinch at peak emission):

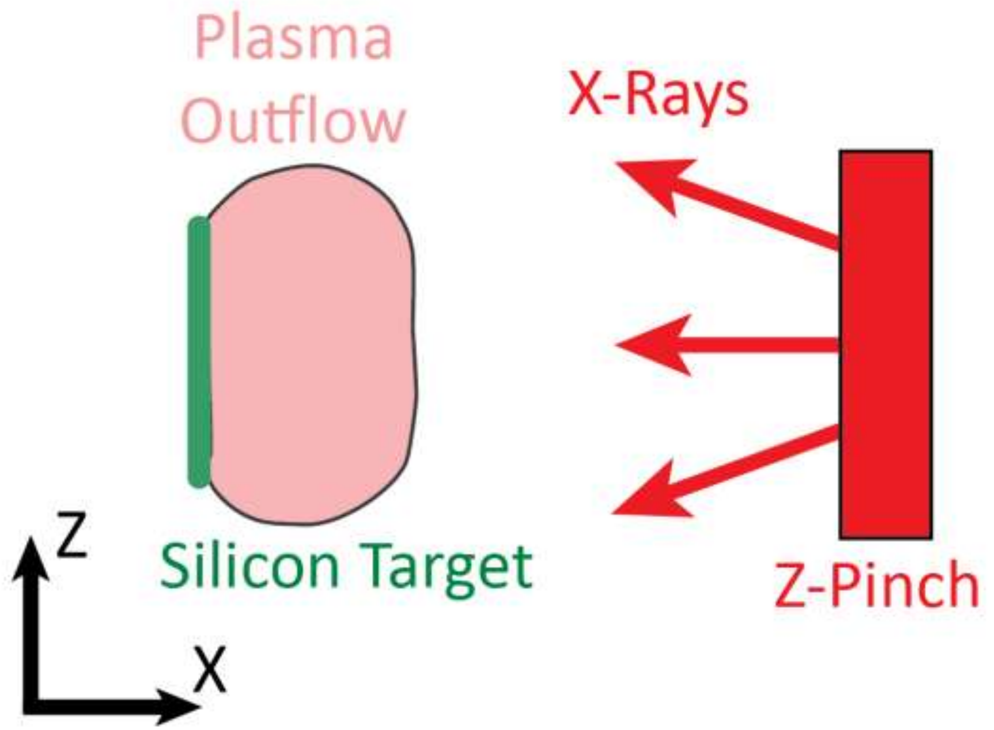
$$T_c = 150 \text{ eV}, \qquad T_B = 10 \text{ eV}$$

- Steady-state, nLTE simulation

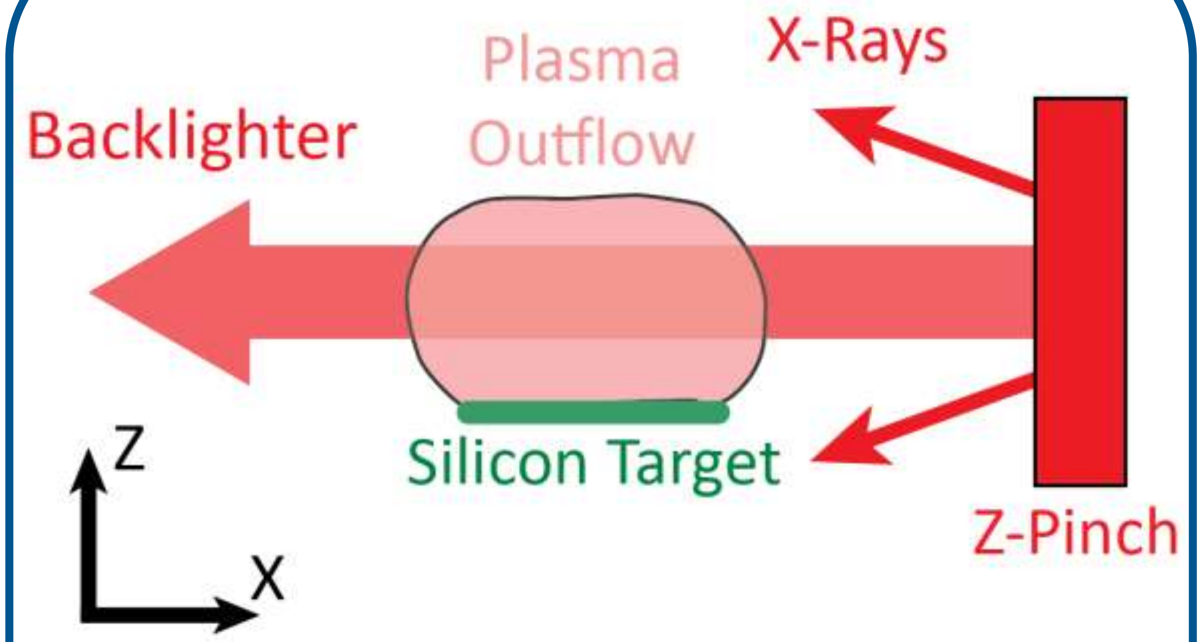
- **Driving radiation perturbs charge state distribution**



Modified setup for X-Ray absorption measurements



Existing experimental setup



Modified design for X-Ray absorption spectroscopy measurements

First experiments will be performed on COBRA (Cornell University) next week!

Spatially resolve spectra to sample range of n_e values

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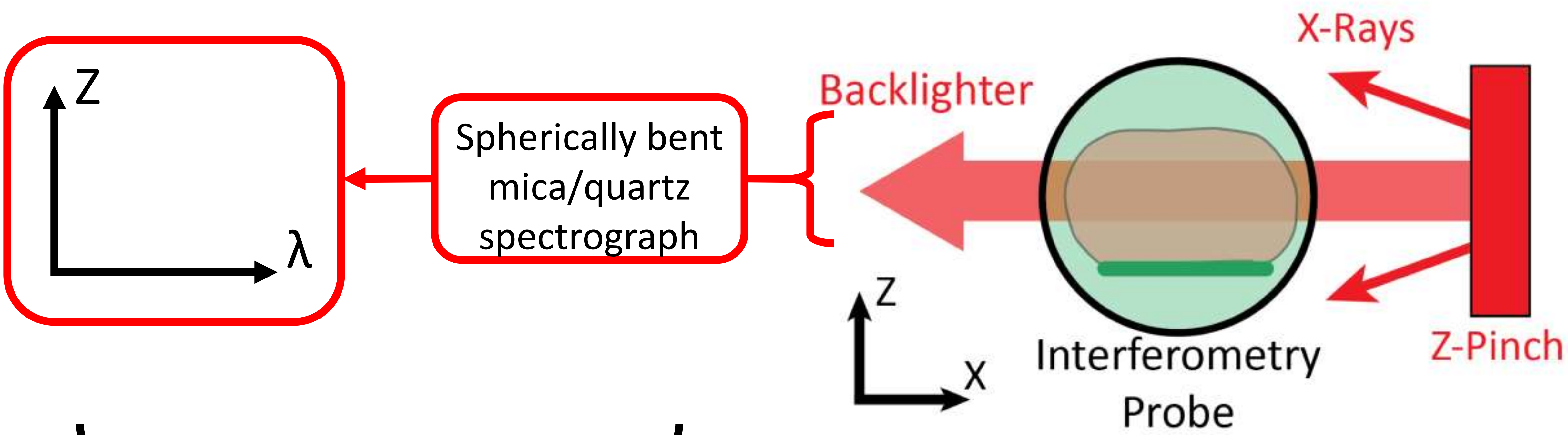

Field a curved-crystal spectrometer for spatial resolution in the direction aligned with the axis of the Z-Pinch

Probe orthogonal axis with interferometry (diagnoses $n_e[x, z]$)

Diagnose silicon K-Shell absorption features

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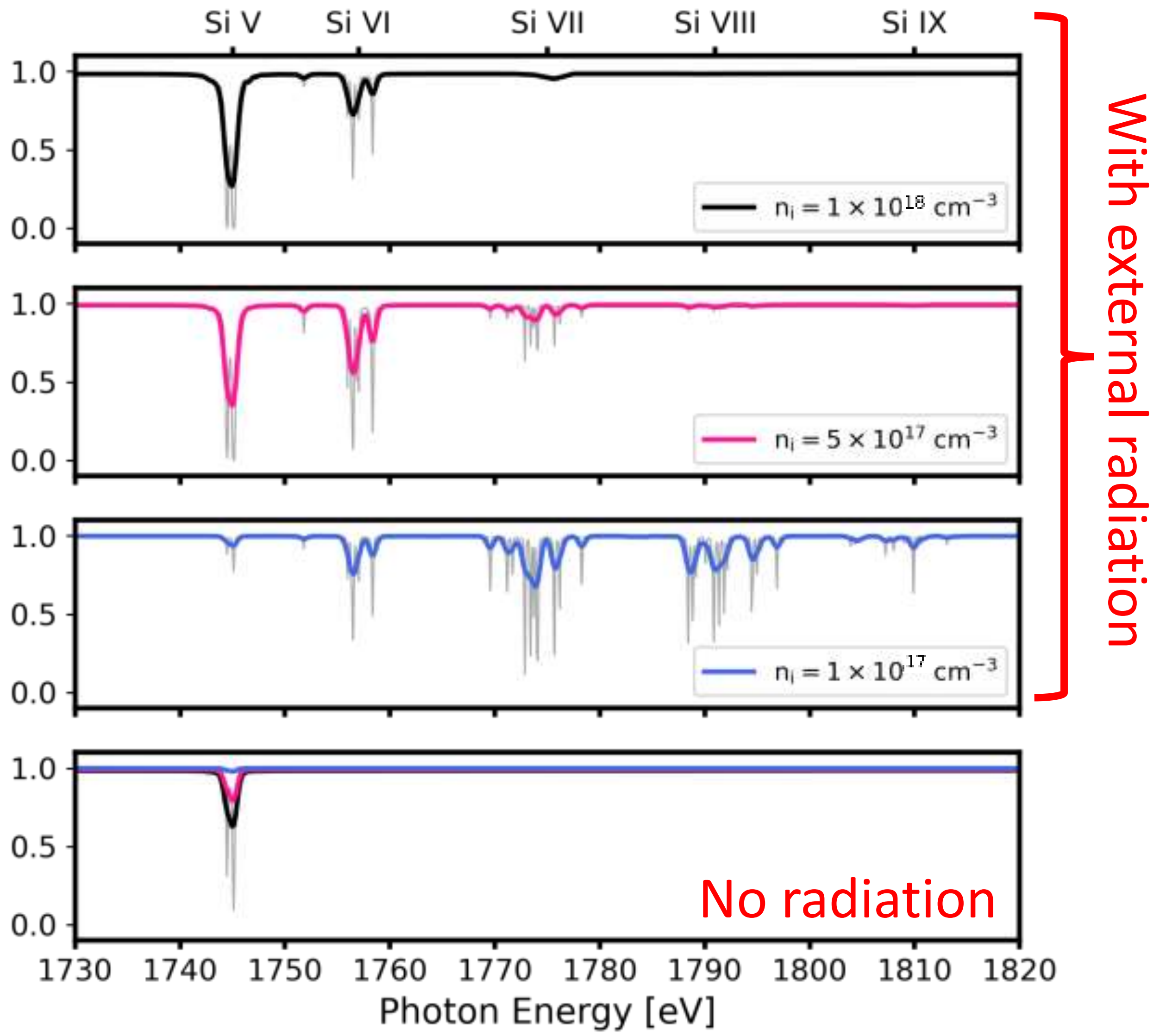
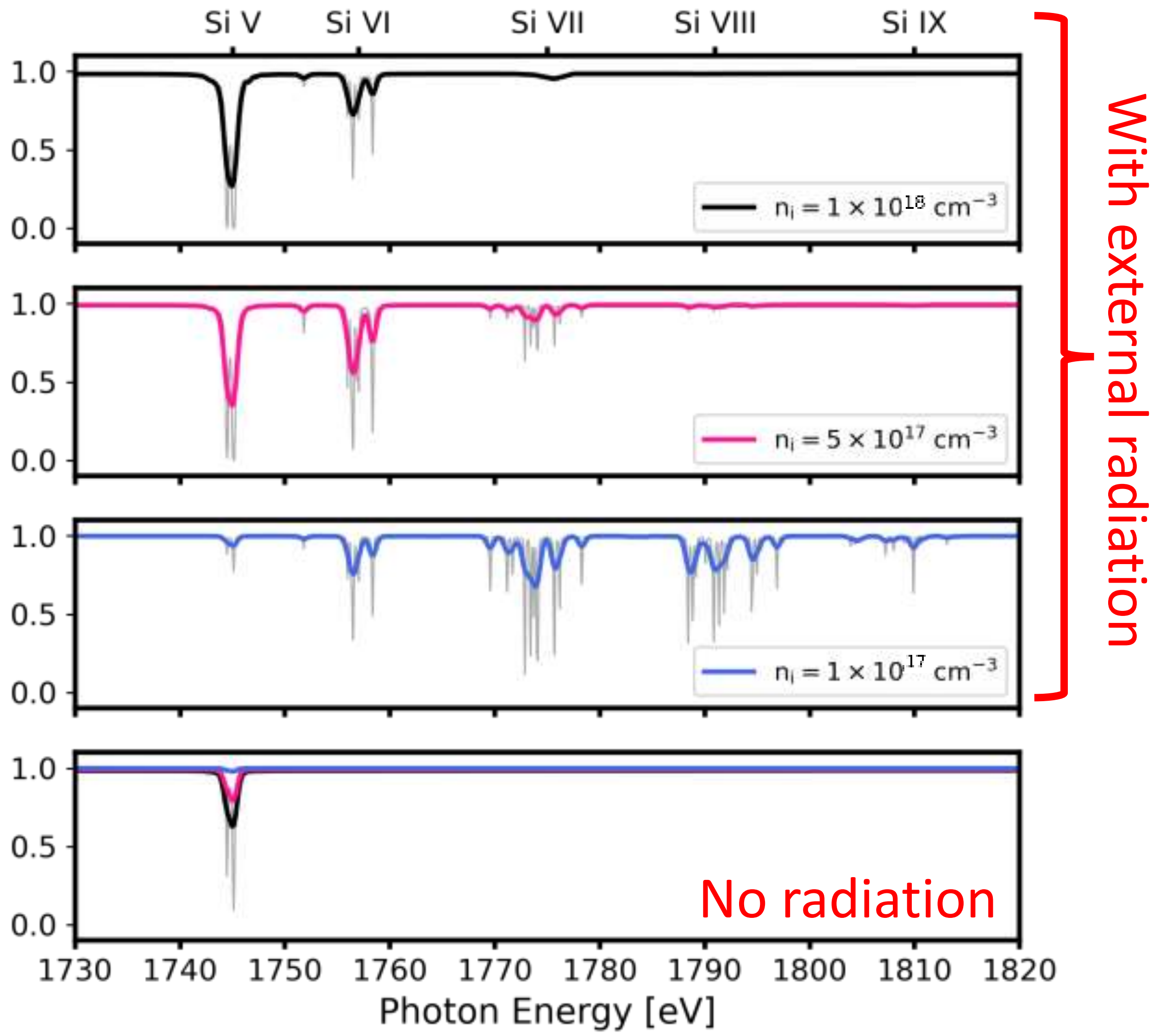
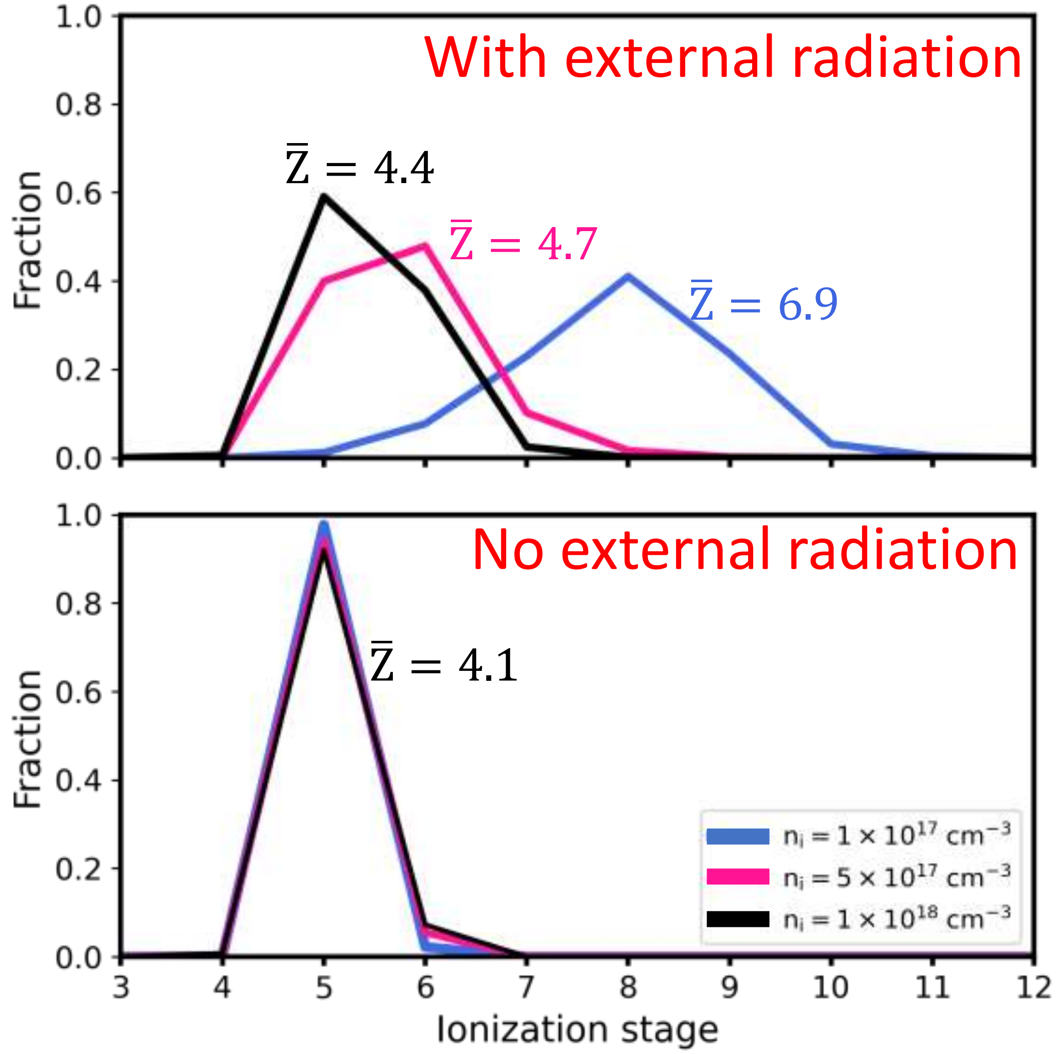


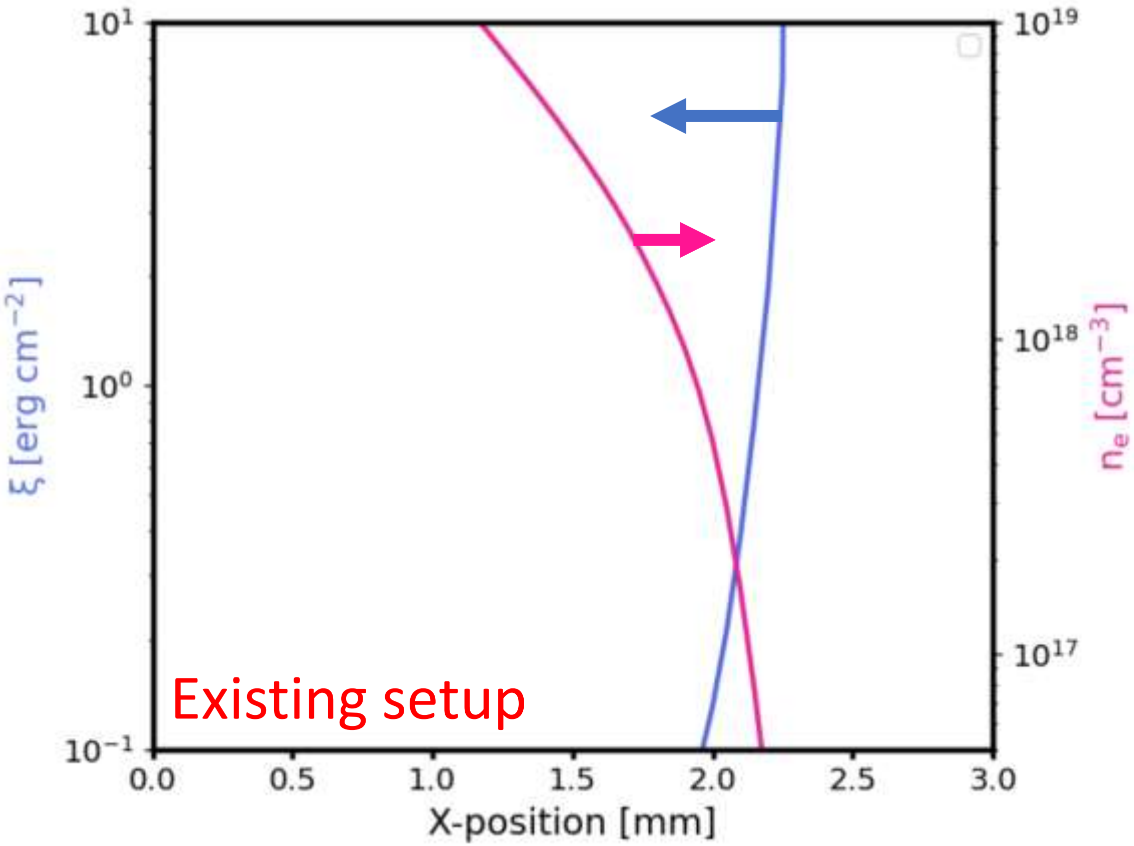
- Transmission spectra are dominated by $n = 1 \rightarrow 2$ absorption features
- Absorption features for different ionisation stages spectrally separated
- Relative intensity provides diagnostic of charge state distribution
- Instrumental broadening is applied to spectra

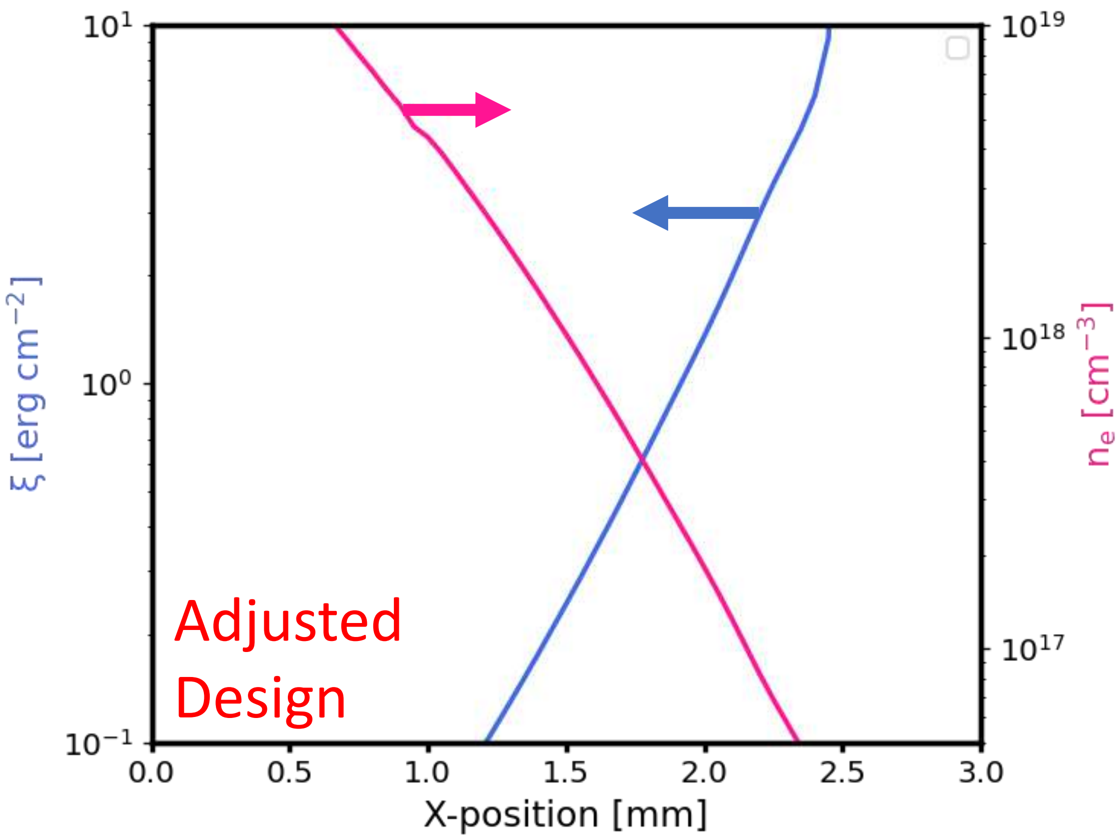
Diagnose silicon K-Shell absorption features





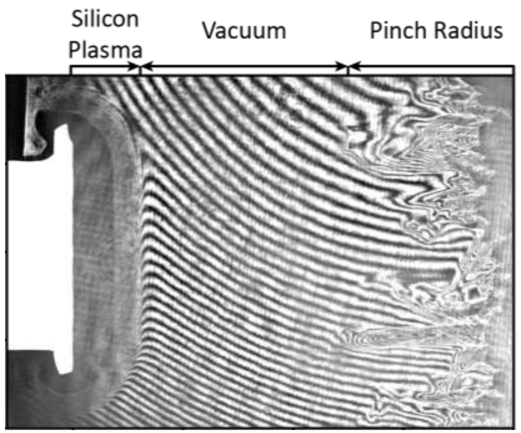
Potential to access a photoionization relevant regime?

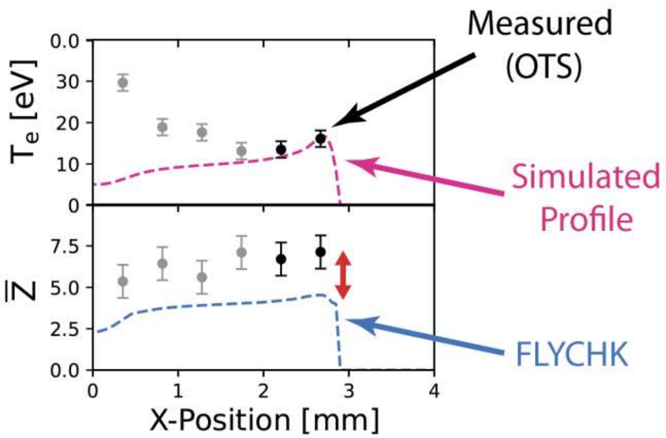


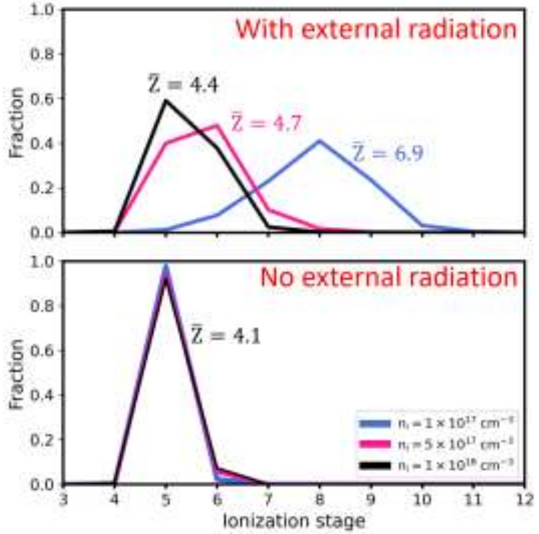


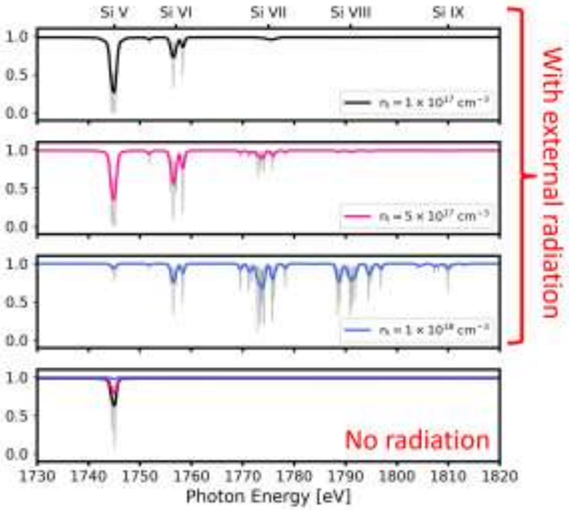
Photoionization parameter, $\xi = \int d\nu F_\nu / n_e$

Conclusions









- Hydrodynamic features are simple & well- characterized
- Thomson measurements hint that driving radiation changes $\bar{Z}$
- Absorption spectroscopy experiments will directly measure charge state distribution
- Novel testbed for comparison with atomic-kinetics models

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Analysis of Ion-Acoustic Thomson Scattering Data

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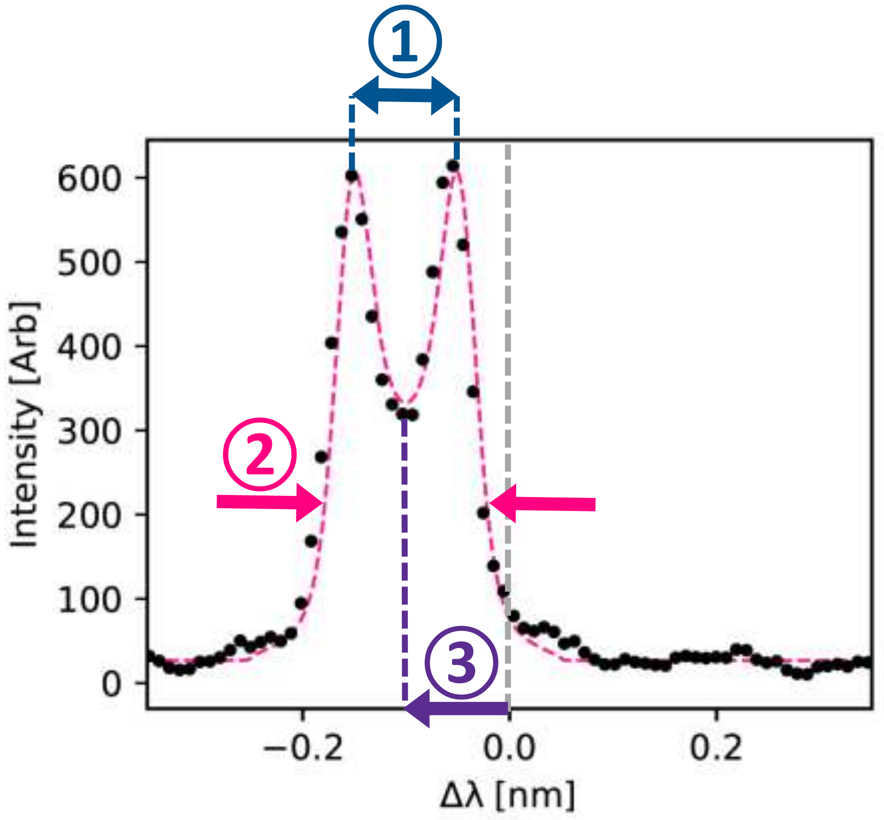
①: Ion Acoustic peak **separation** depends on $\bar{Z} \times T_e$

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

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

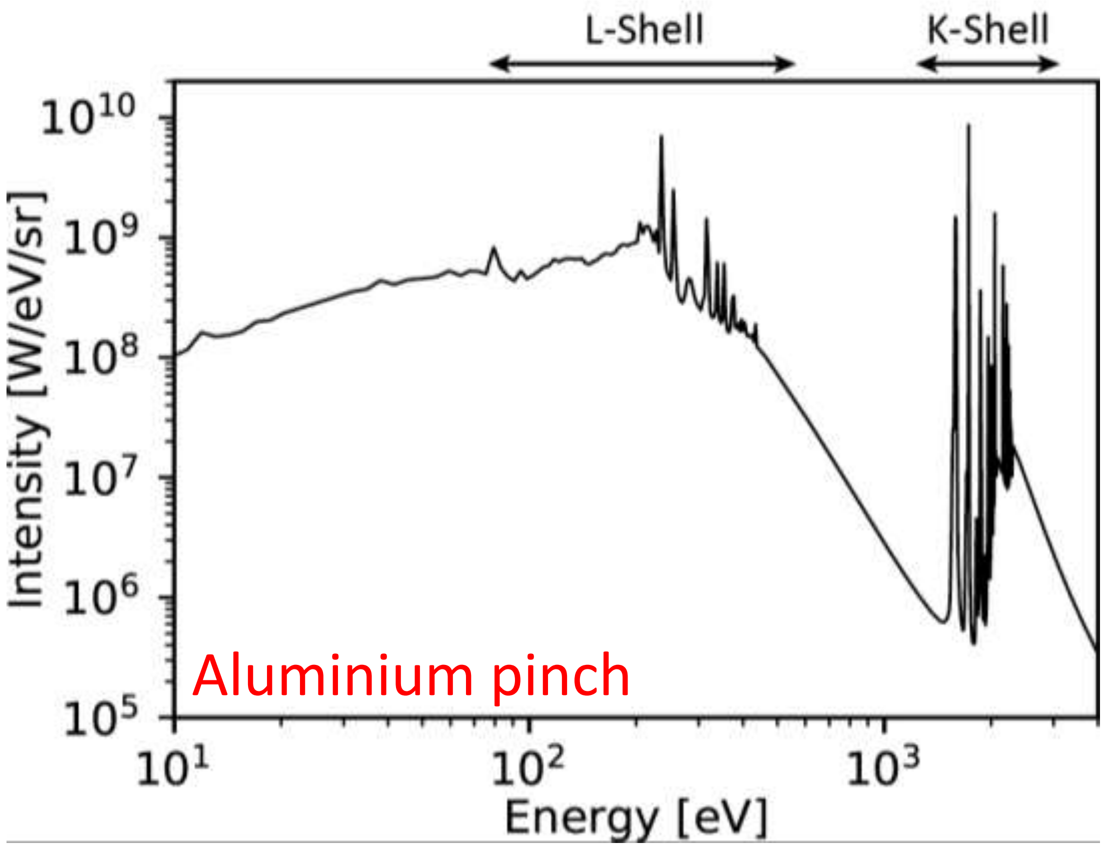


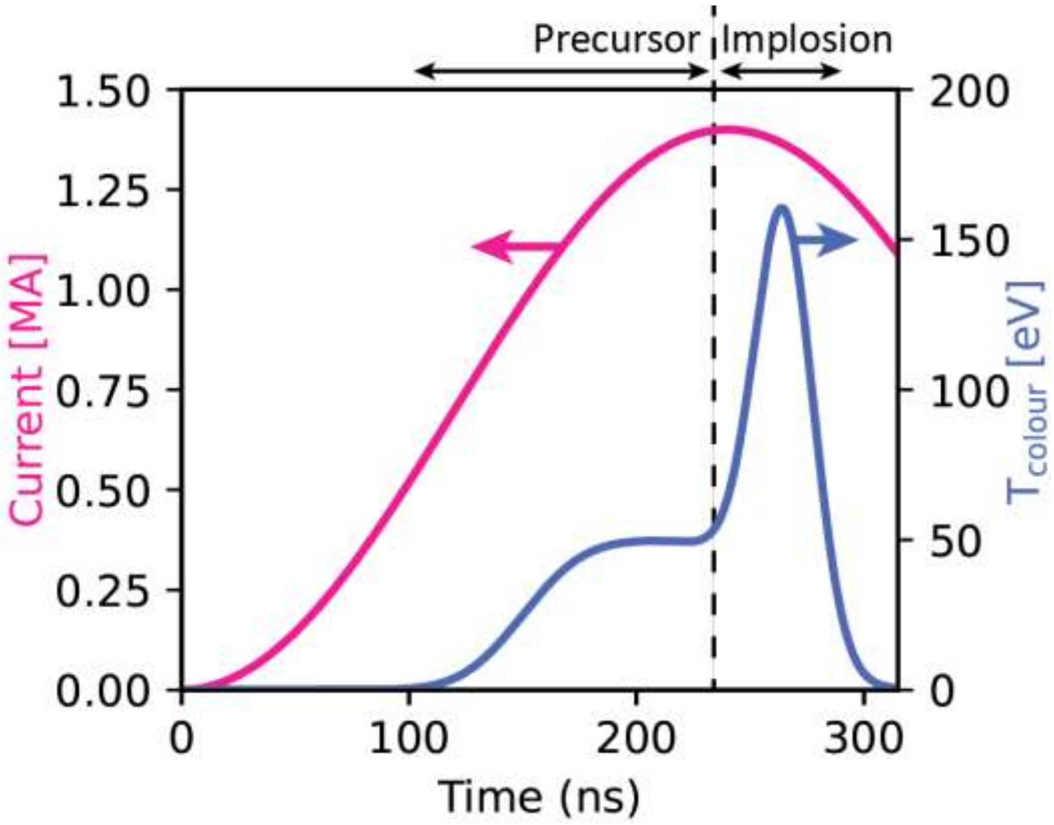
Enforced $\mathrm{T_e} = \mathrm{T_i}$, and allowed $\bar{Z}$ to vary ($\tau_{ei} \lesssim 1$ ns).

Convolved calculated spectra with measured spectral response.

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

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





1.4 MA, 240 ns Current Pulse → X-Ray Pulse ~ 1 TW

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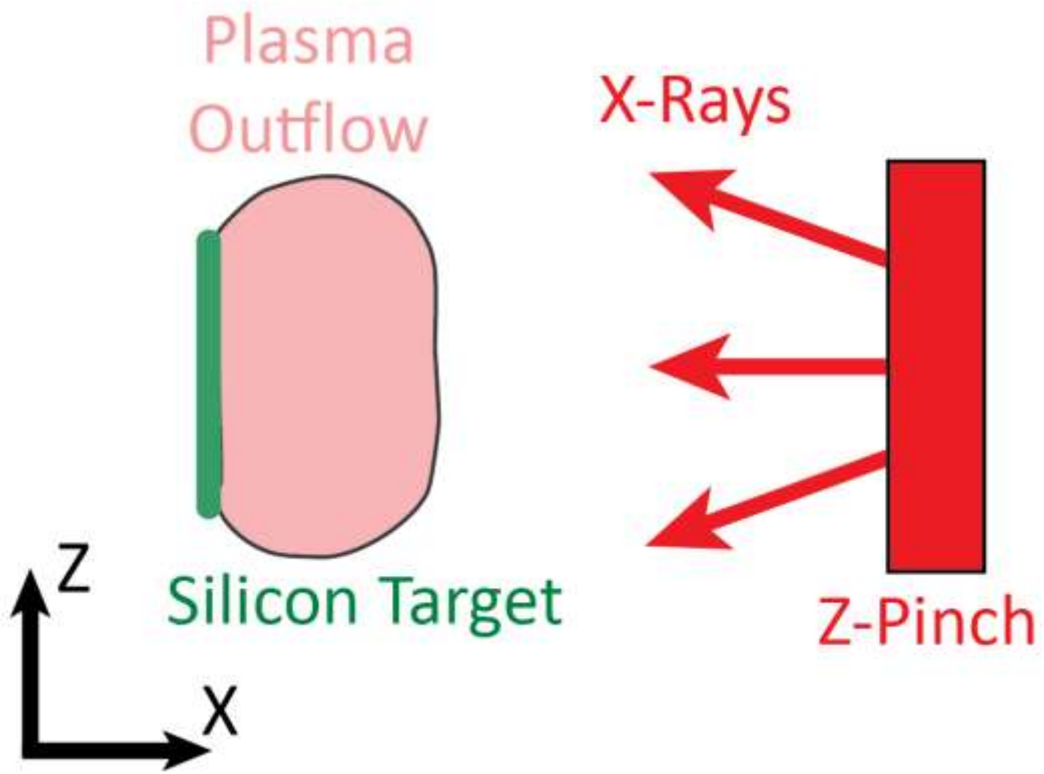

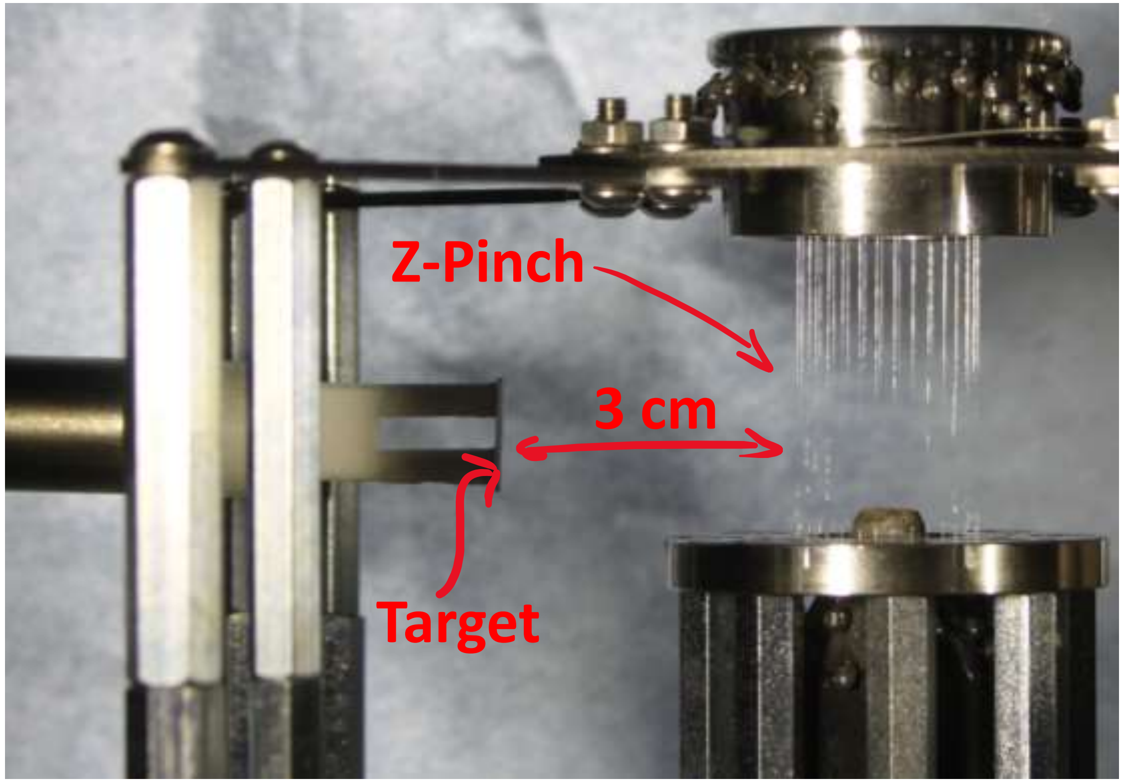

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Optical self emission images [qualitive dynamics]

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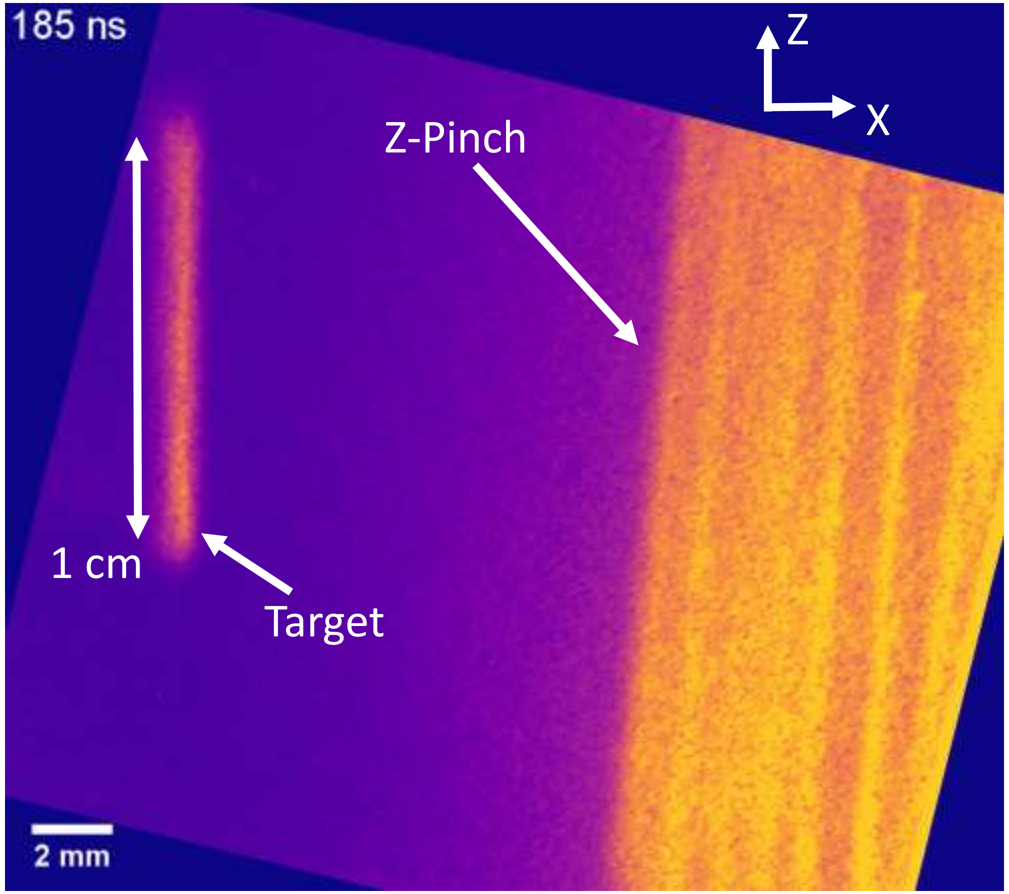
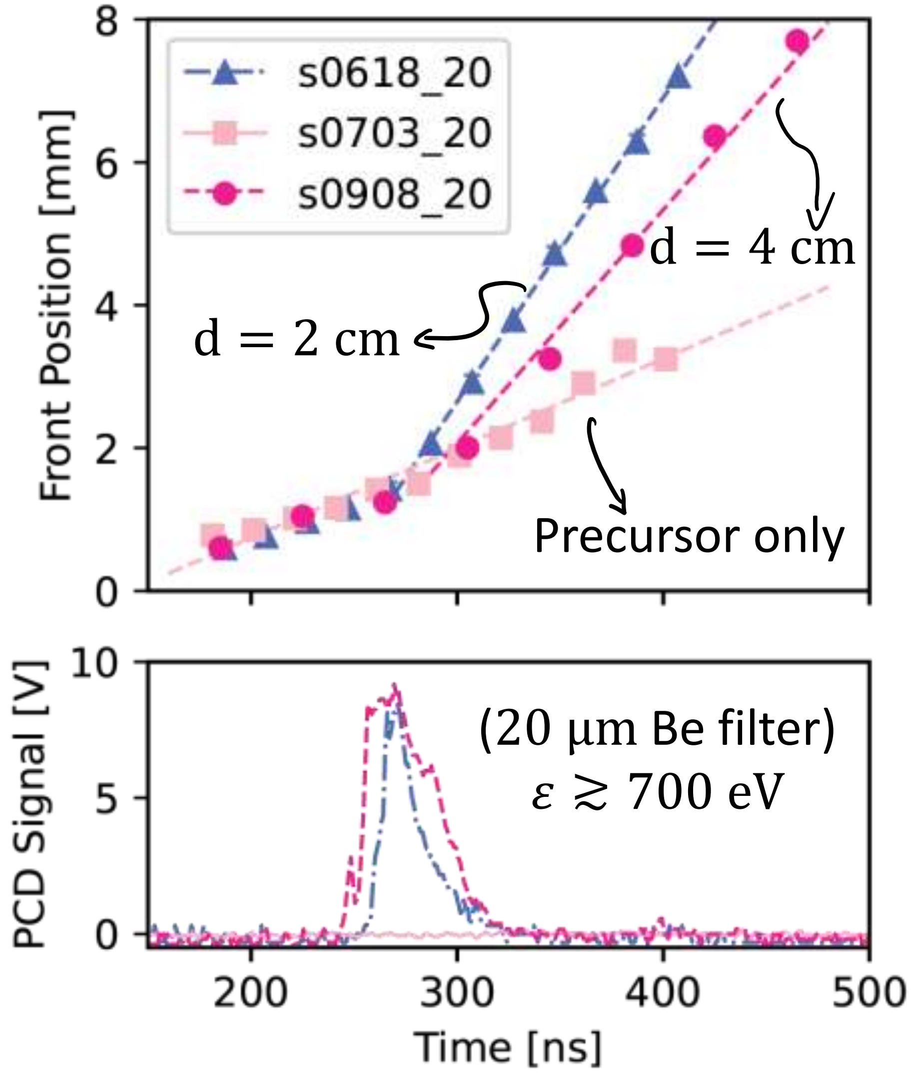


Self emission images [$600 \lesssim \lambda \lesssim 900$ nm]



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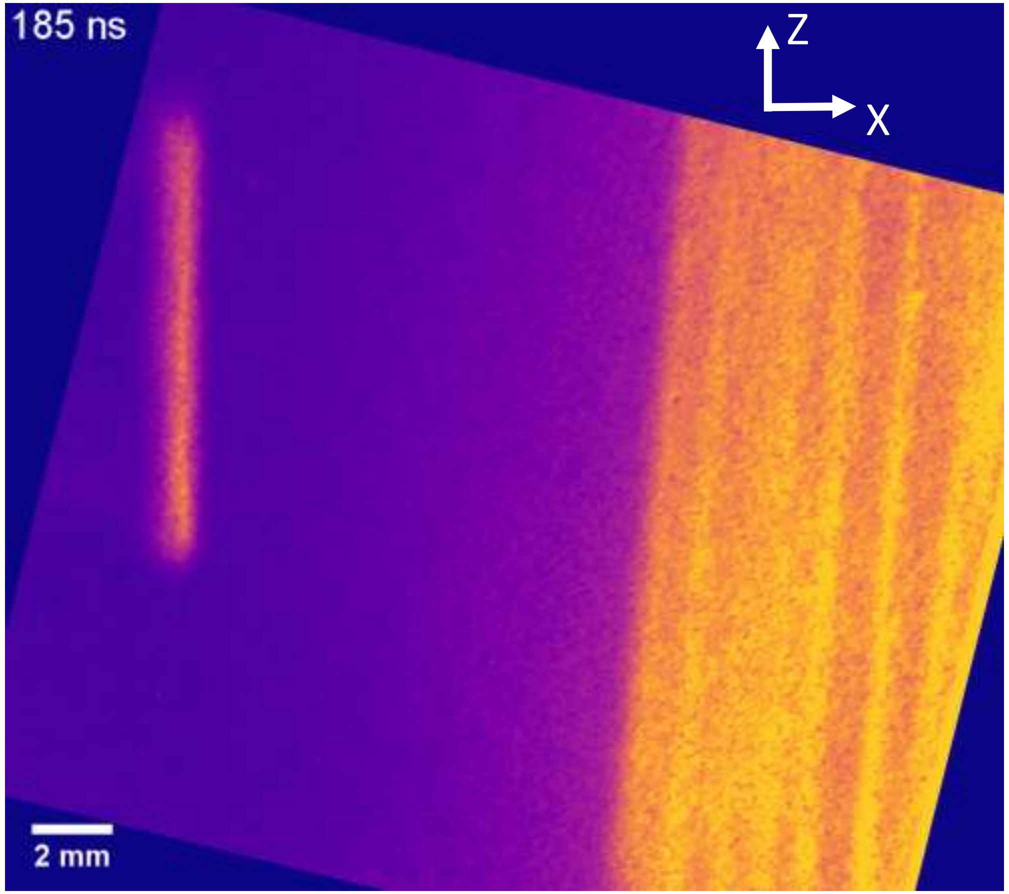

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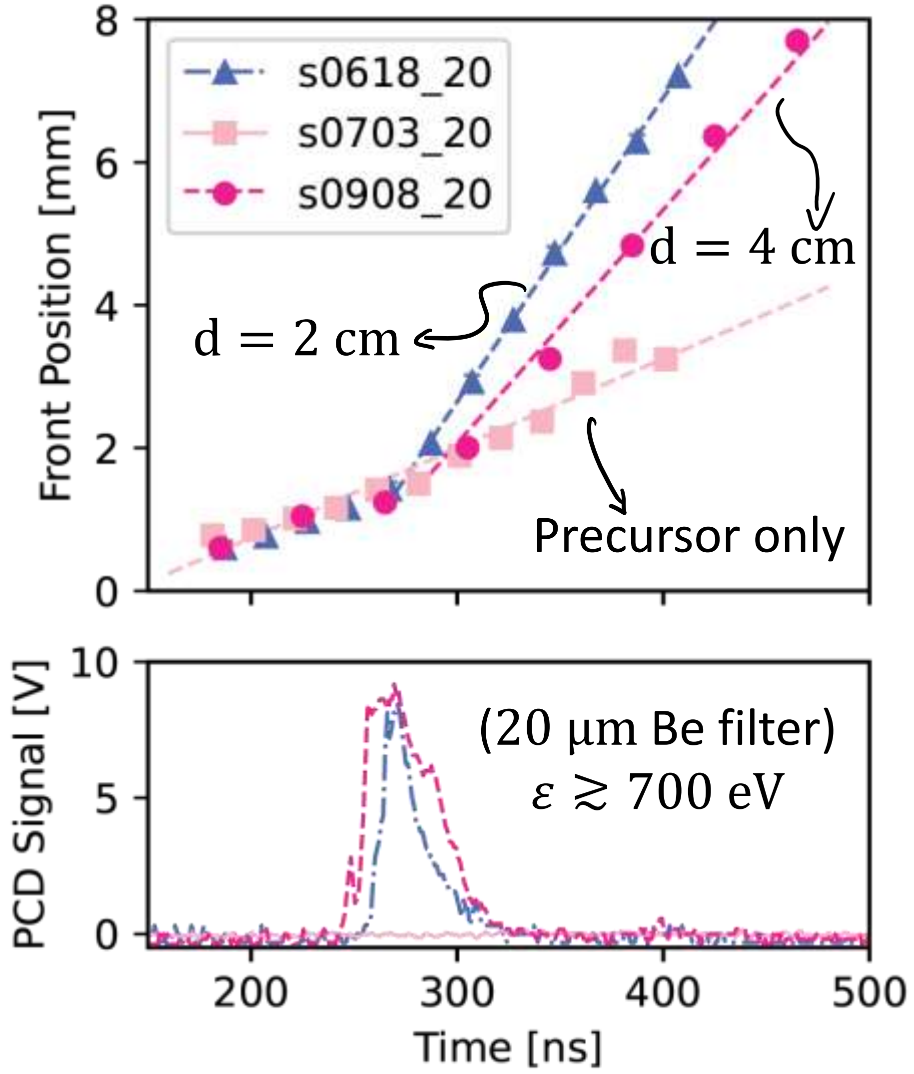

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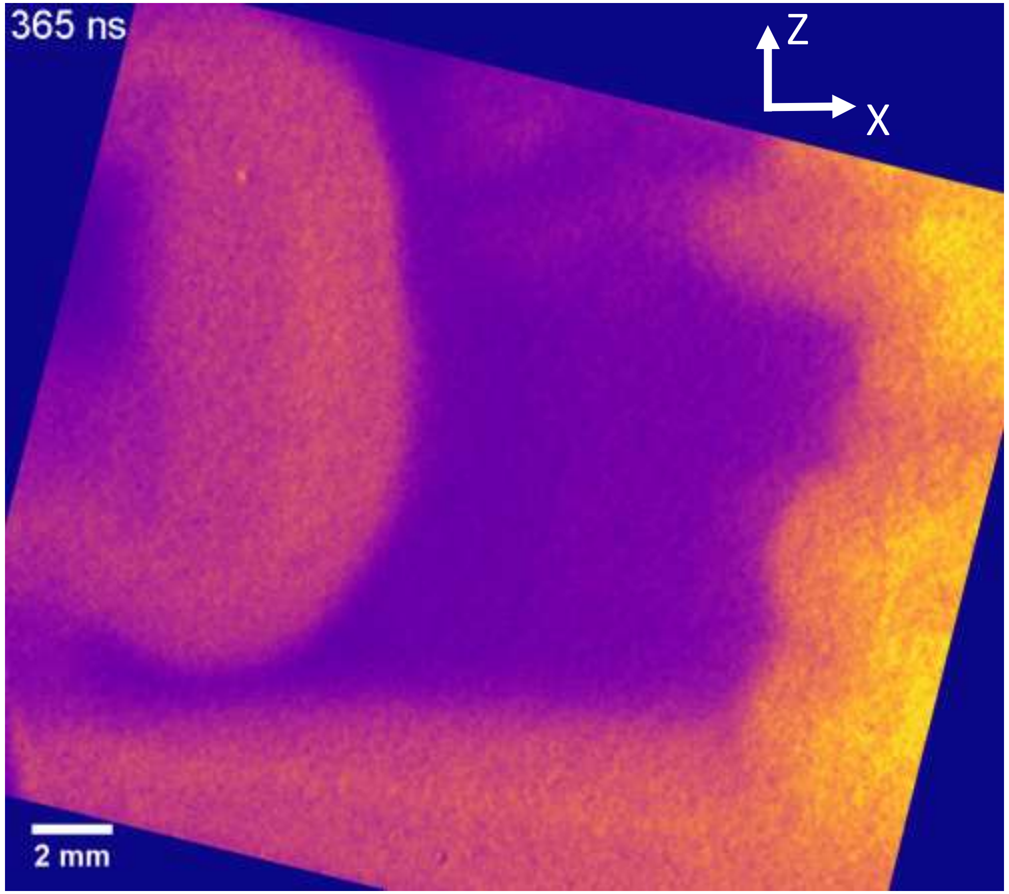

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