Preliminary Measurements of X-Ray Driven Silicon Ablation on the MAGPIE pulsed power generator

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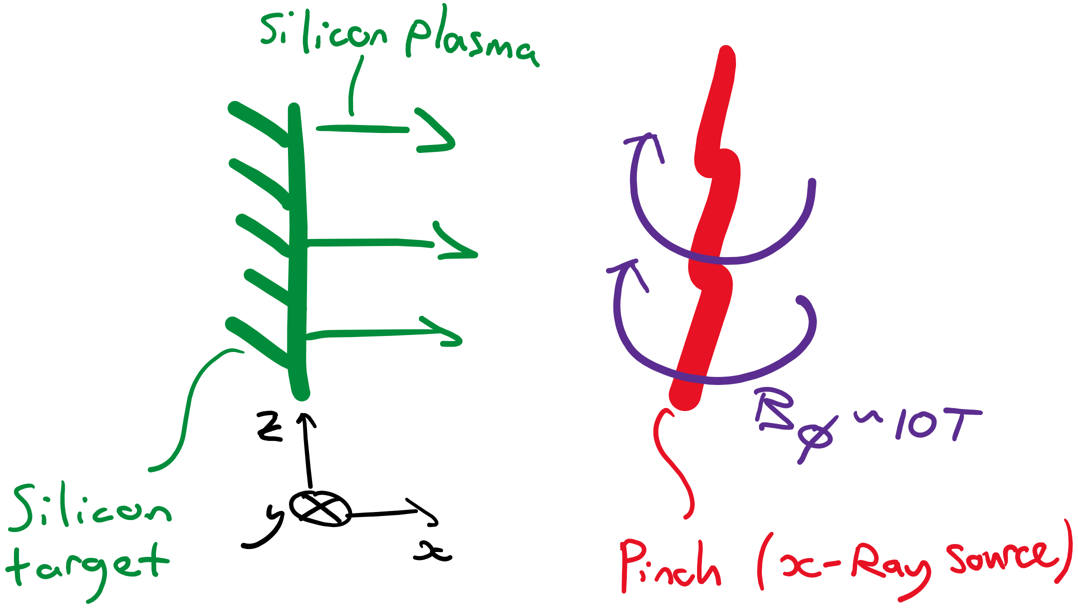
MAGPIE

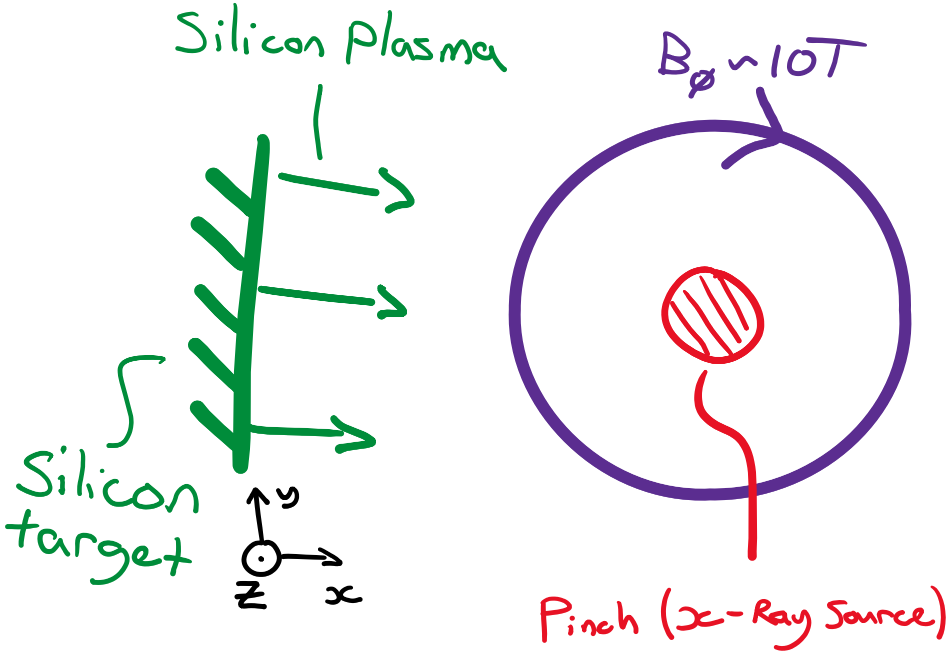
CIFS

University of Nevada, Reno

Experimental Setup – Overview



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



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

- X-Ray radiation from aluminium wire array Z-Pinch drives ablation from a silicon target
- Ablated silicon plasma expands into a magnetic field ($B_\phi \sim 10$ T) supported by current in the pinch
- Target positioned $1-3$ cm from pinch
- Experiments driven by MAGPIE (1.4 MA, 240 ns)

Experimental Setup – Overview

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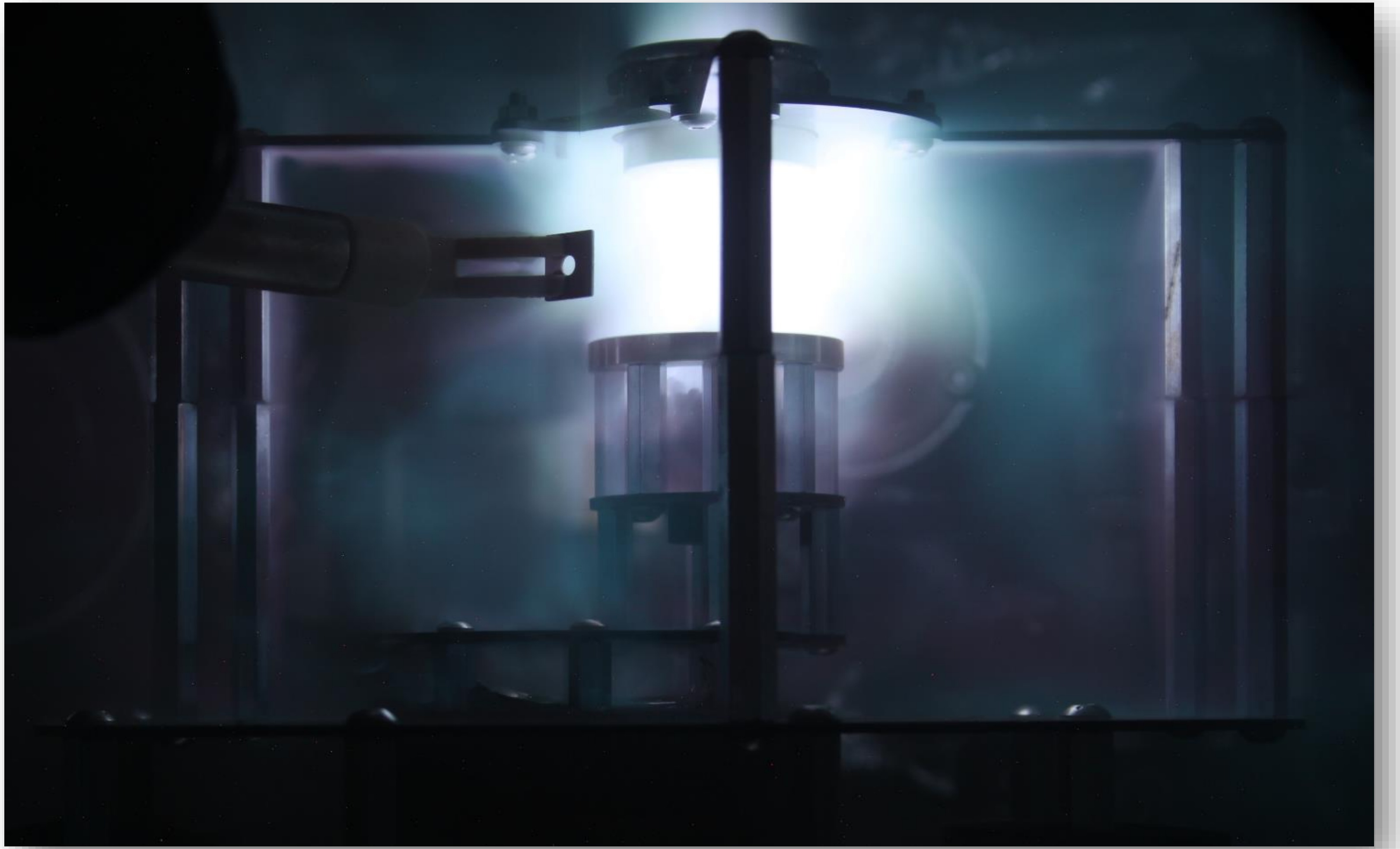


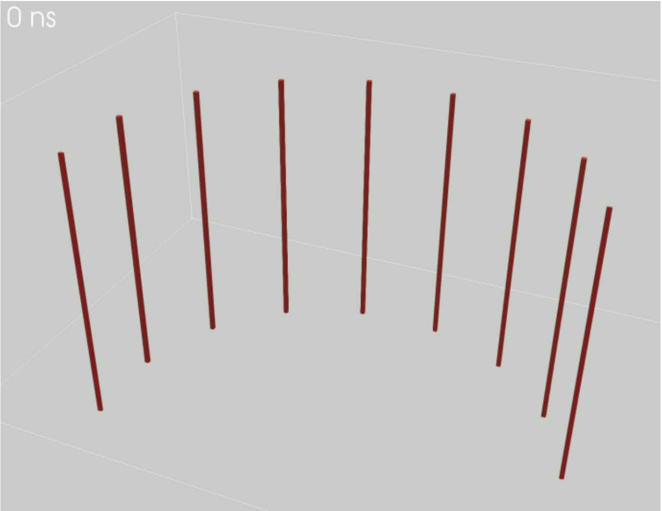
Visible image of a silicon ablation experiment on MAGPIE, taken with a digital camera.

Camera shutter was held open for the duration of the experiment. Emission was filtered with ND (Optical density: 3.0)

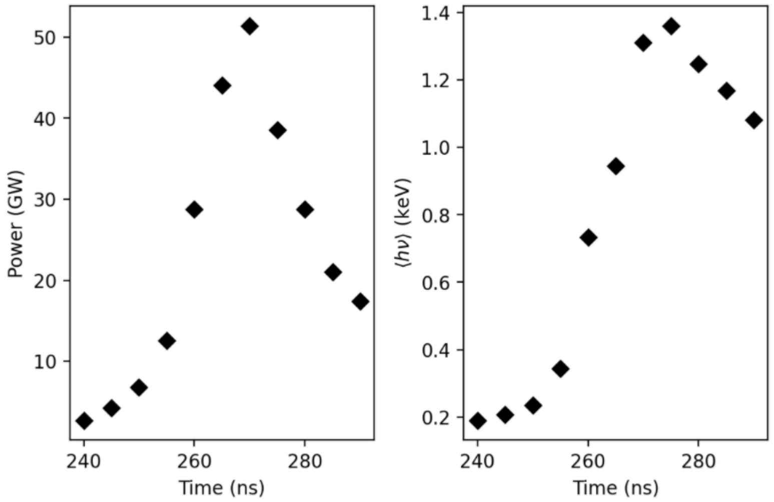
Summary of Results & Potential applications

- Experiments show a smooth ($\sim$1D) expansion of ablated plasma from a silicon target
- Plasma conditions are diagnosable using various laser probing techniques
- The well defined plasma profile makes the experiments an ideal testbed for radiation hydrodynamics and resistive MHD problems
- There is scope to introduce spatial non-uniformity by adjusting the target design
- Potential to tune the experimental design in order to study extended MHD effects.

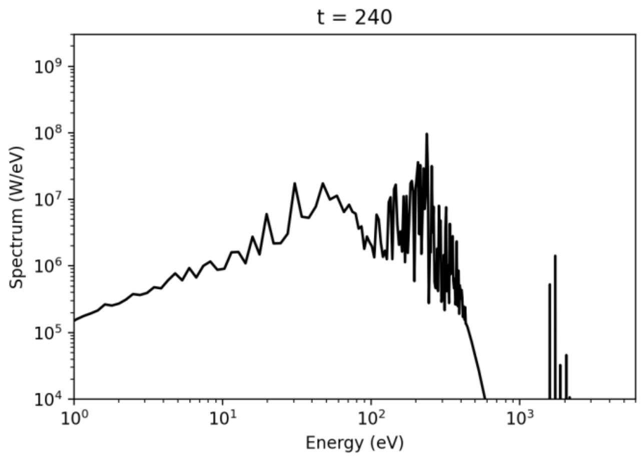
Wire Array Simulations (Imperial-Gorgon + SpK)



Mass density from a Gorgon MHD simulation



X-Ray power (left), and average photon energy (right), as a function of time

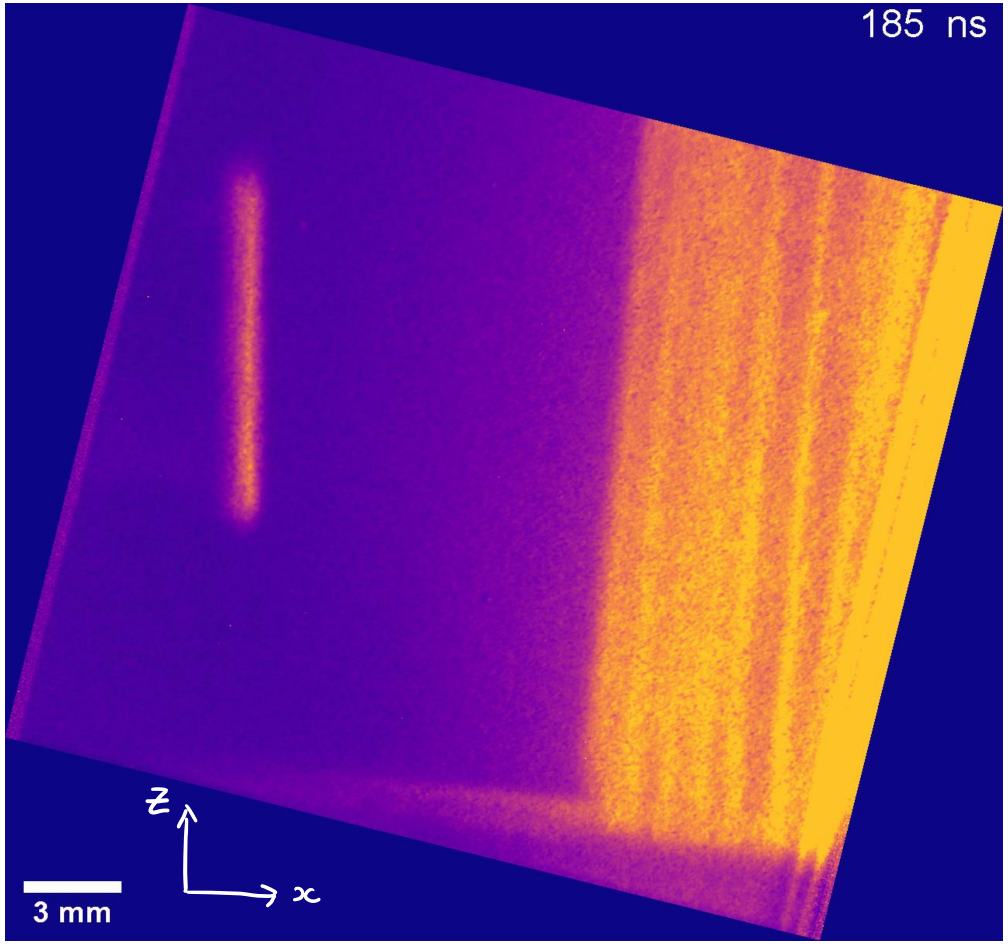


Photon energy resolved emission spectrum

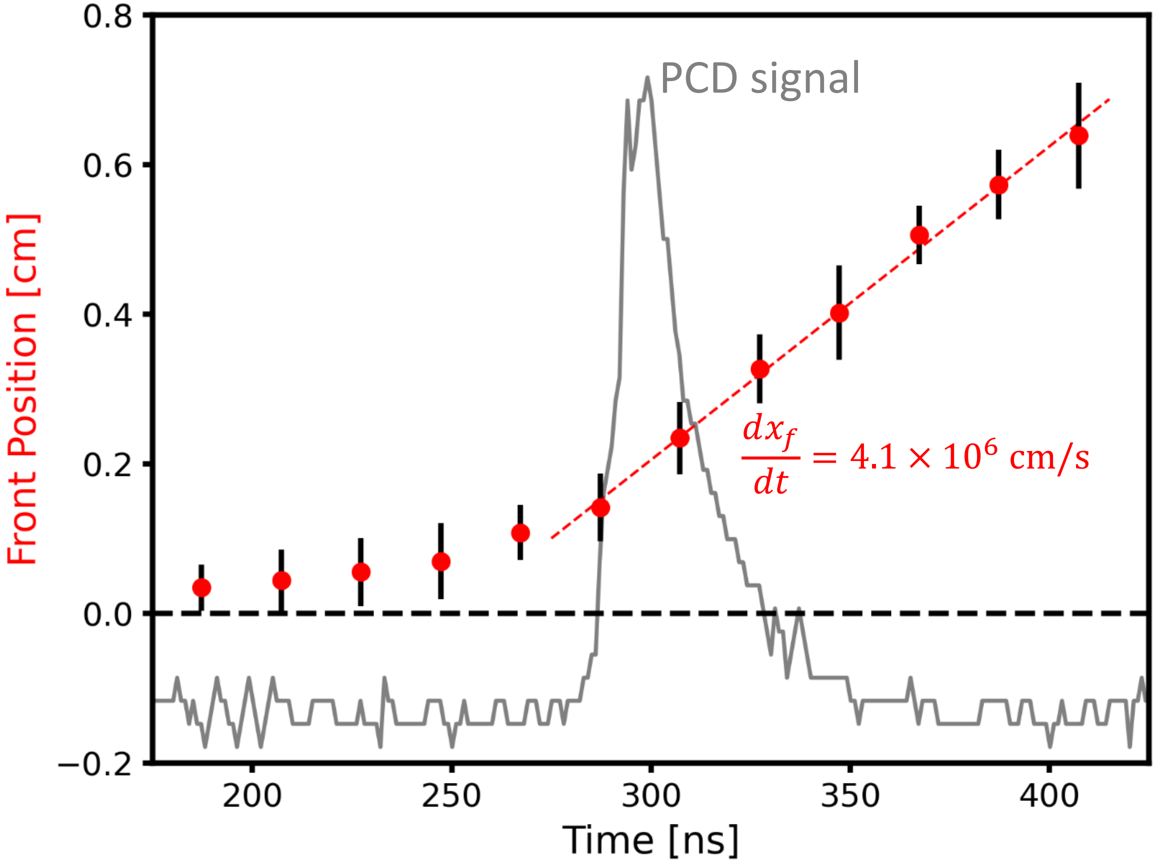
Load Parameters
32 Wire aluminium array
13 µm Wire diameter
16 mm Array diameter
20 mm Array height
Driven with MAGPIE (1.4 MA, 240 ns)

Results obtained by post processing a Gorgon simulation using the atomic physic code SpK

Optical Self Emission Images



Optical self emission images [$600 \lesssim \lambda \lesssim 900$ nm]



Front positions [x_f] extracted from self emission images and plotted with the signal from a filtered (20 μm beryllium, $\varepsilon_\gamma \gtrsim 1$ keV) PCD monitoring emission from the array.

Optical Self Emission Images

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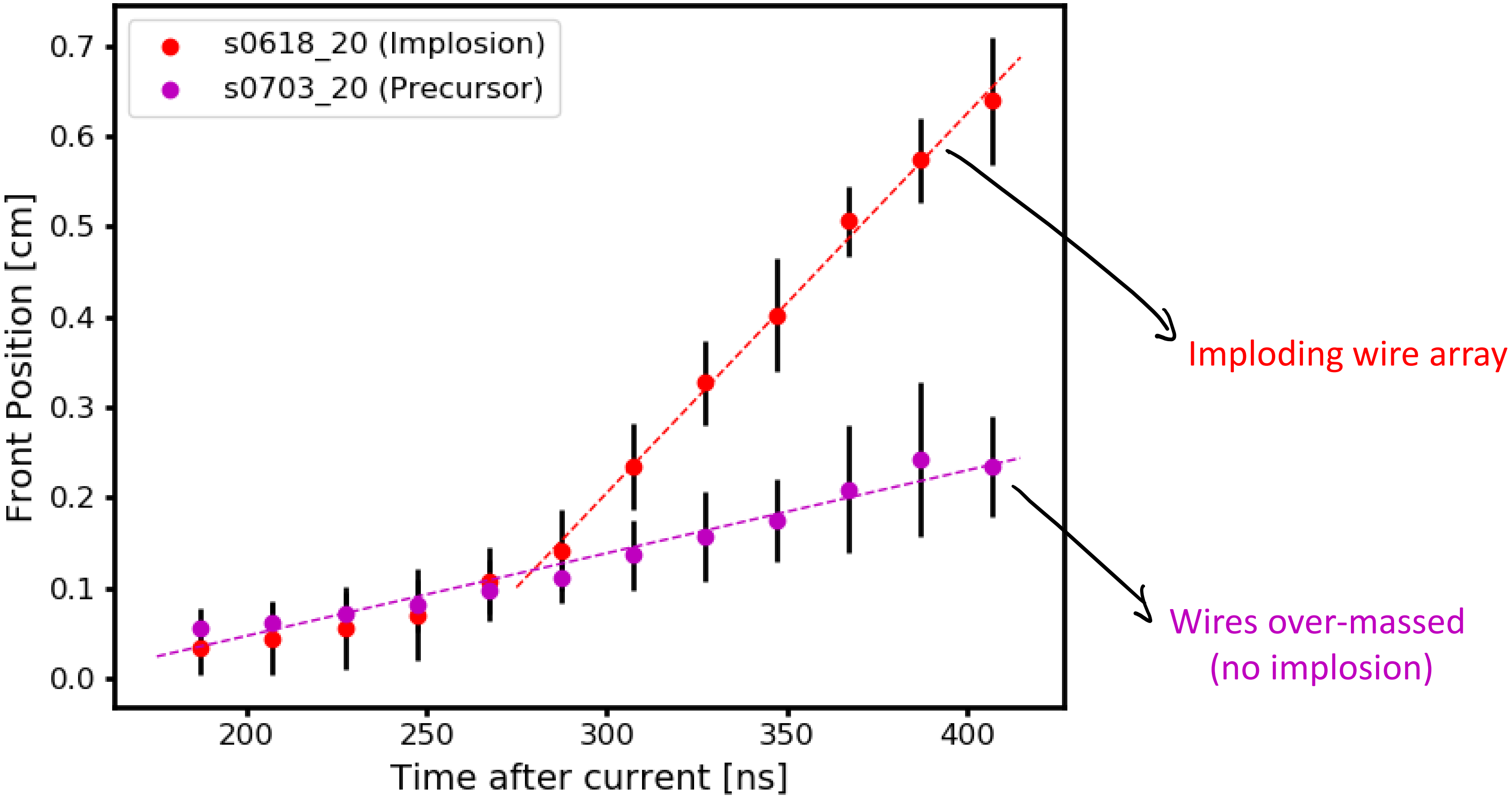
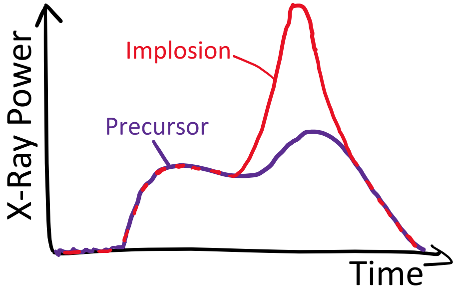
Comparison of front velocity in 2 separate experiments:

1) Full Z-Pinch implosion
2) Precursor only

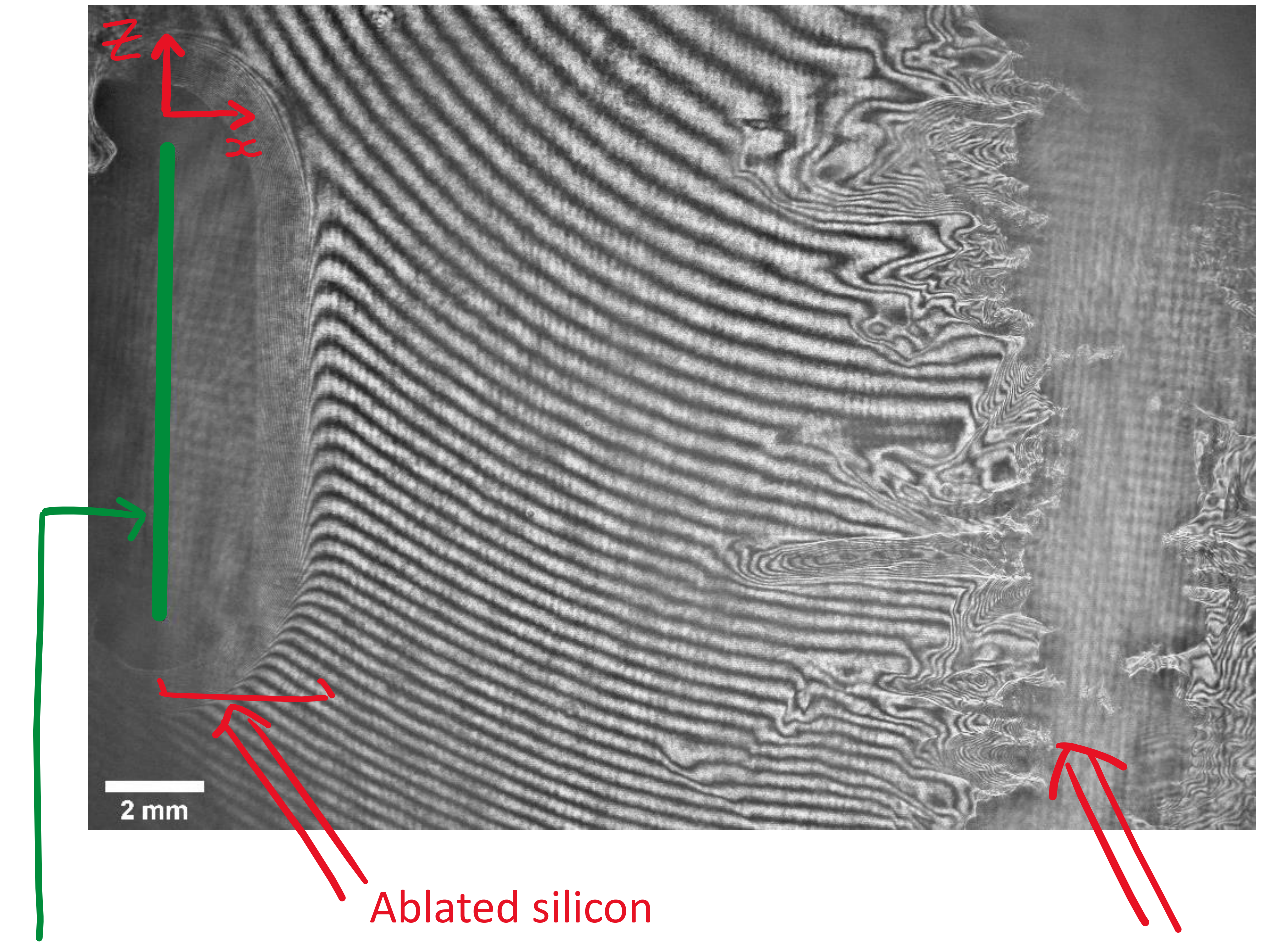
Early-time radiation drive is similar for both experiments.

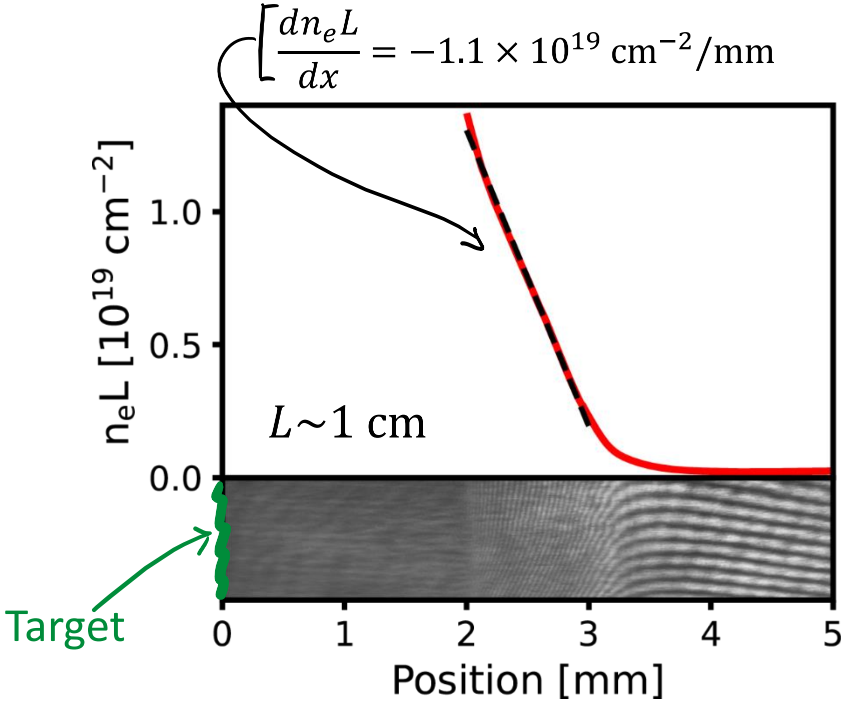
After implosion, the hardness and flux of the drive increase in experiment 1.





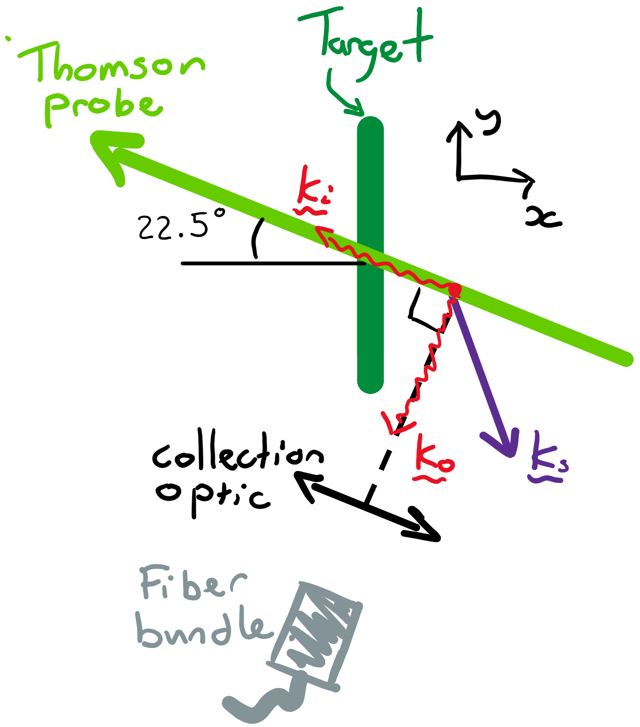
Laser Interferometry [Electron Density]



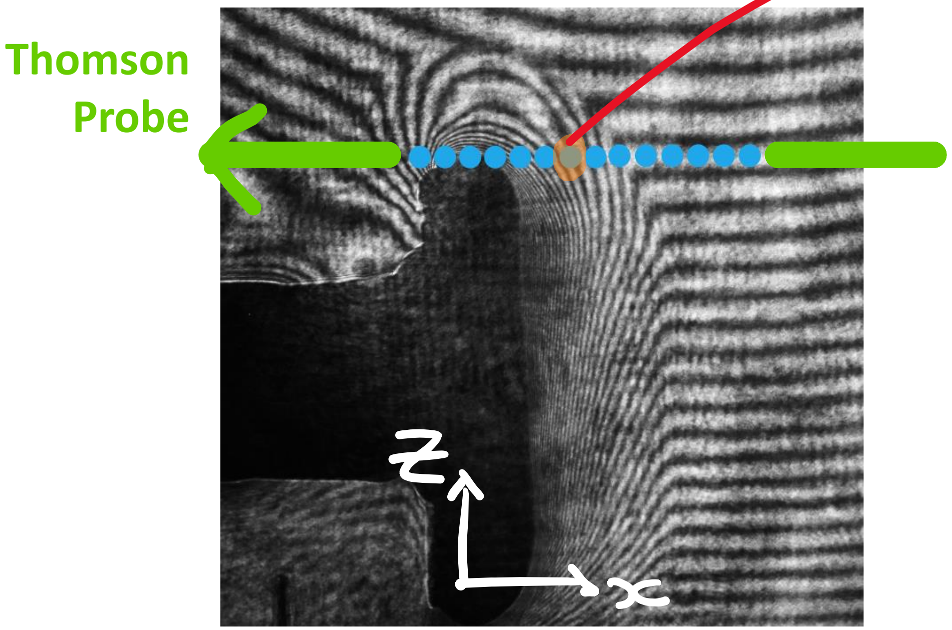


- Interferogram captured at $t = 320$ ns
- Smooth $(\sim 1\mathrm{D})$ expansion profile confirmed by orthogonal laser probing

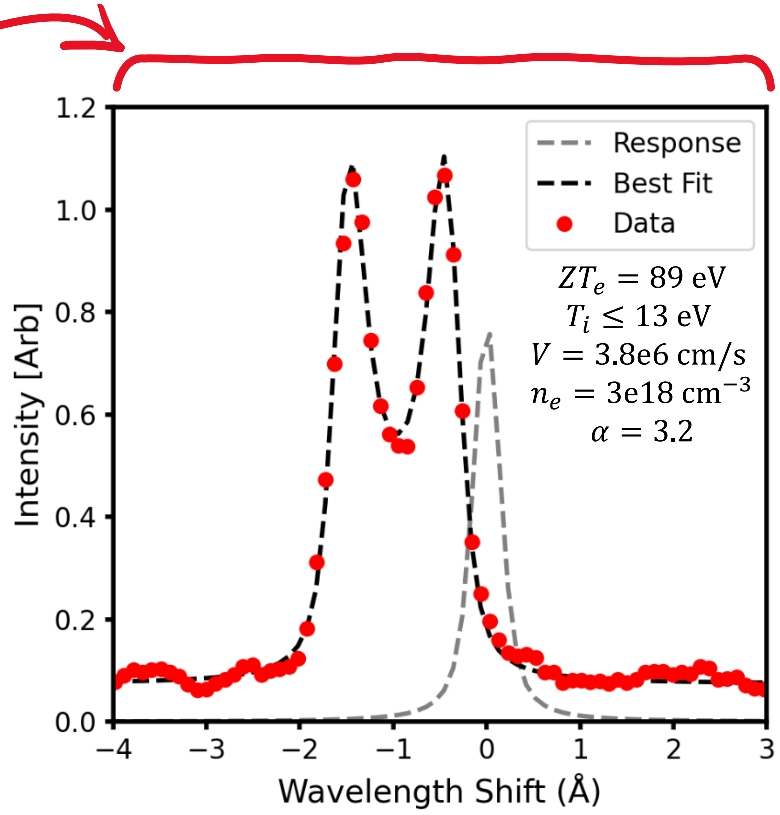
Thomson Scattering [Ion feature - V, T_i, ZT_e]



End-on (**X-Y plane**) sketch of an experiment, showing the scattering geometry. Scattered light is imaged onto a linear array of 14 fibers. TS spectra are recorded for each volume which is imaged onto a fiber.



Side-on (**X-Z plane**) interferogram showing the position of the Thomson volumes. The probing laser passed over the top of the target (possibility of edge effects).



Example of a fit to the Ion Feature. The scattering is in a collective regime and electron density is constrained from interferometry.

Thomson Scattering [Ion feature - V, T_i, ZT_e]

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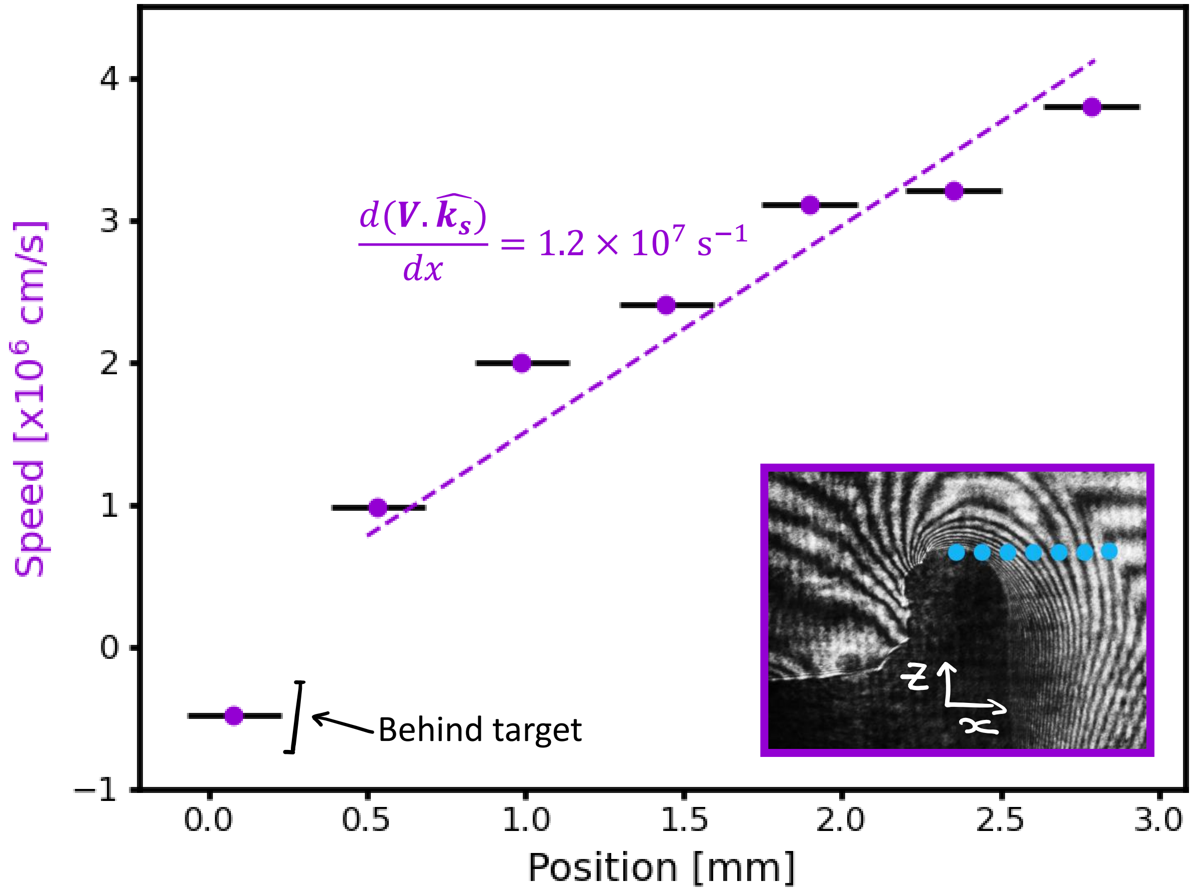
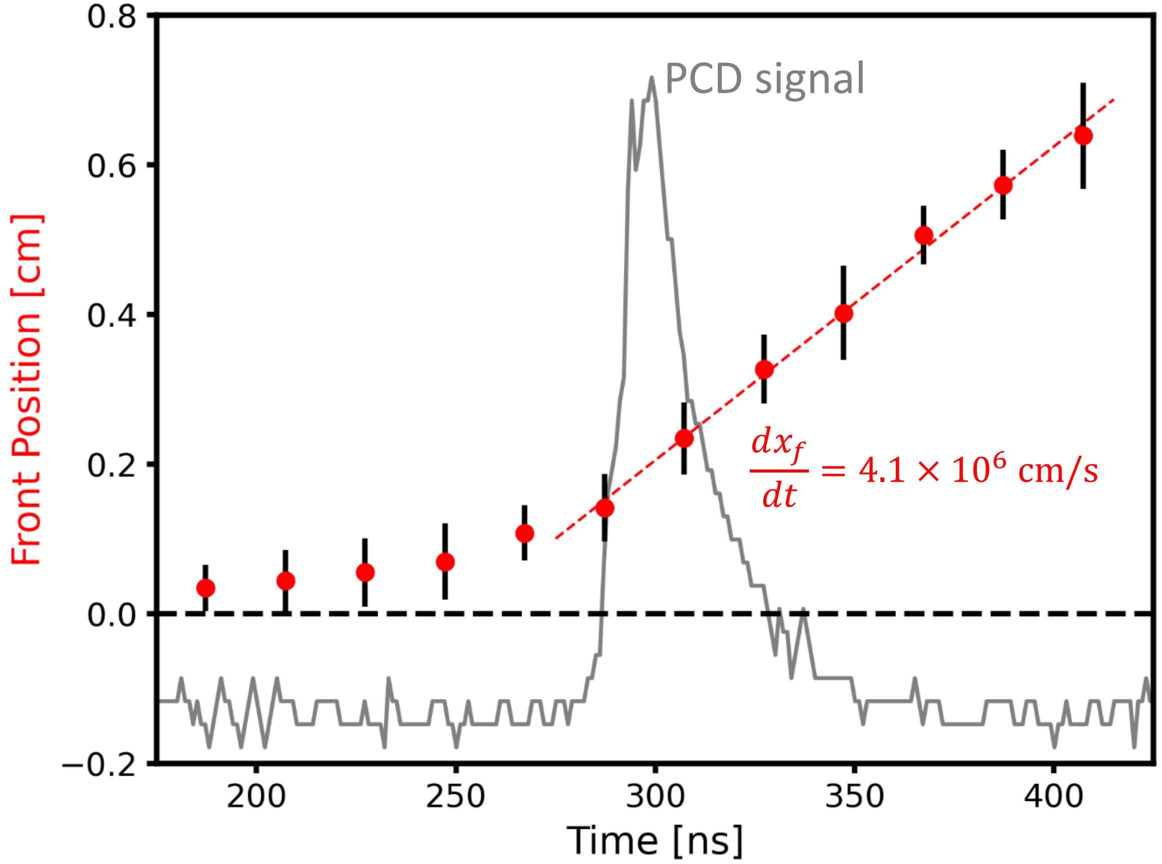
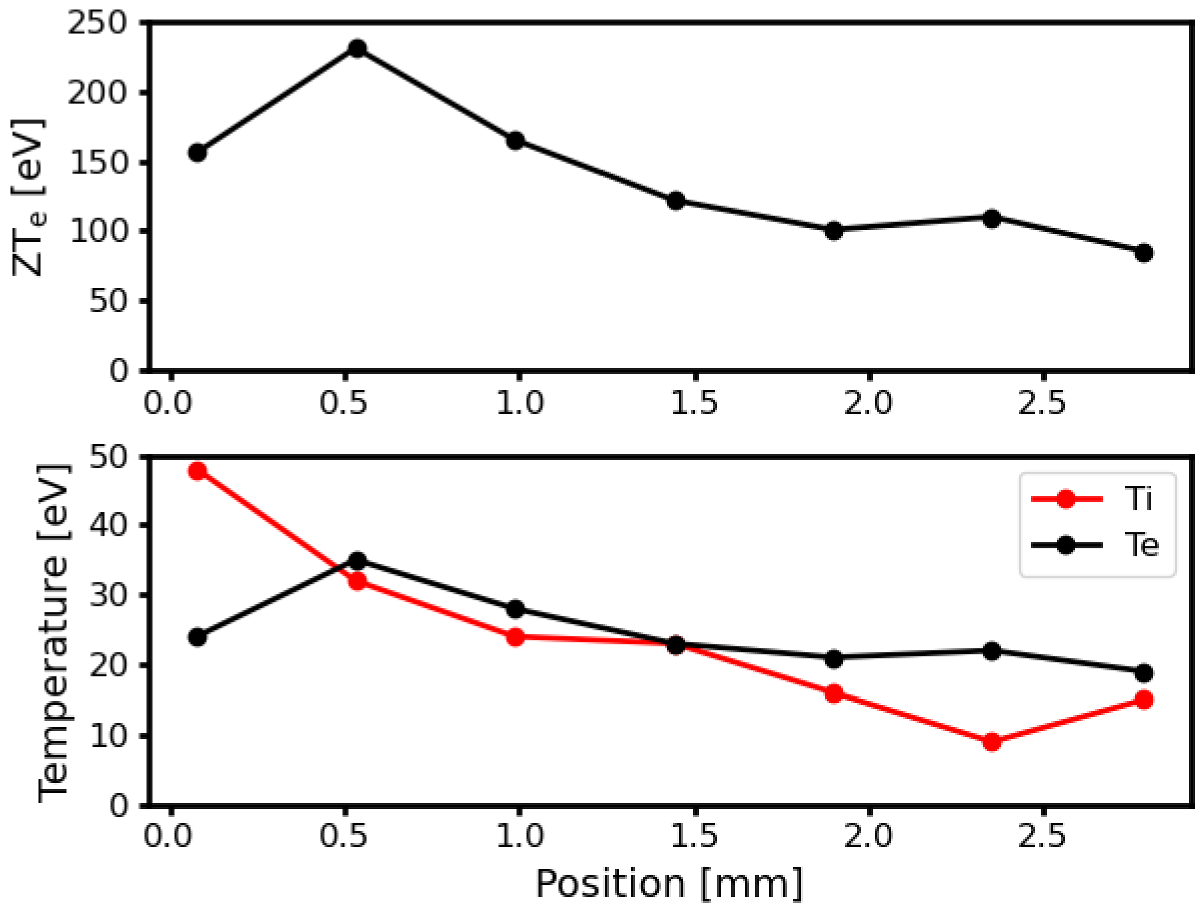


Projection of plasma velocity ($\boldsymbol{V}.\widehat{\boldsymbol{k_s}}$) as a function of position, obtained from Thomson scattering data.



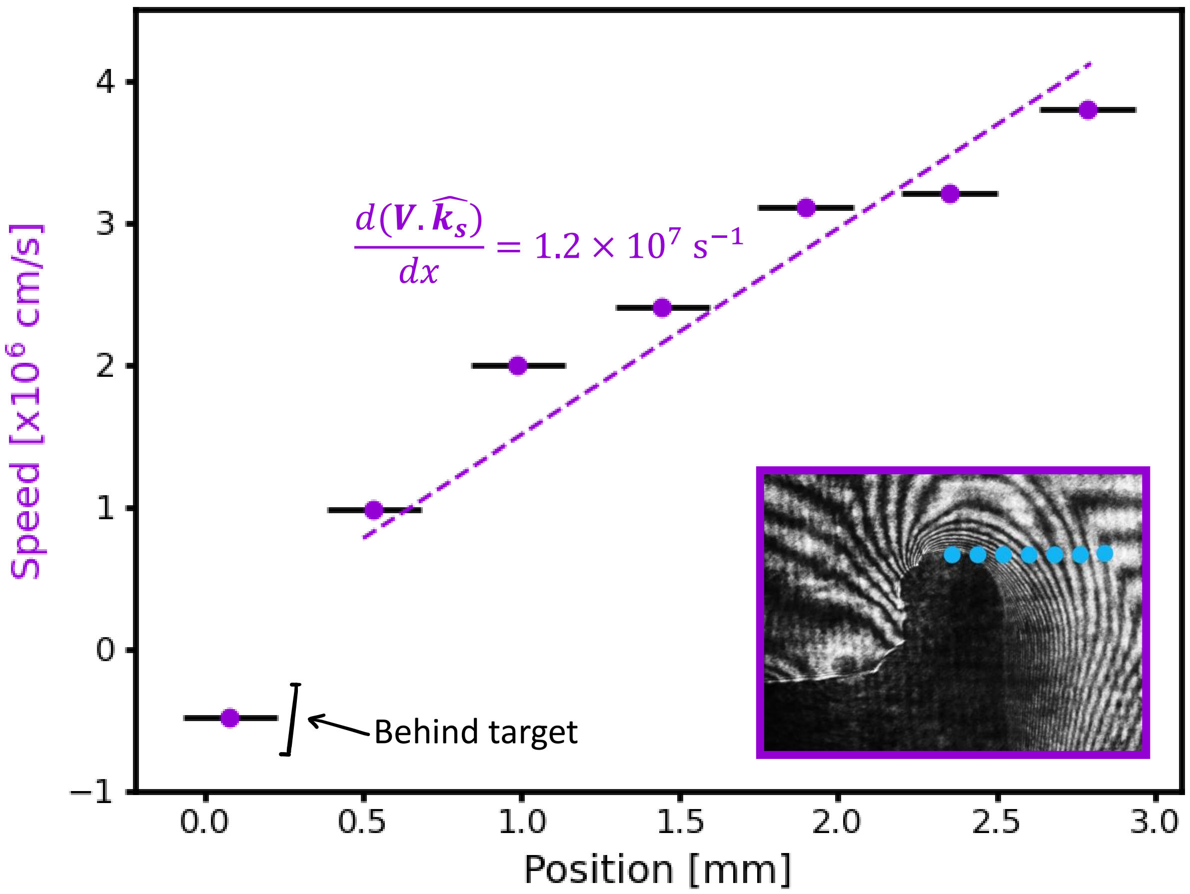
Ablation front position (x_f) as a function of time, obtained from self emission images.

Thomson Scattering [Ion feature - V, T_i, ZT_e]



- Preliminary results: Detailed uncertainty analysis is ongoing
- Sensitivity to T_i is limited by spectrometer response: Values shown are an upper bound!
- Ion-acoustic feature is sensitive to $Z \times T_e$: Self consistent values of Z & T_e are obtained from an nLTE atomic code (SpK)
- Possibility of laser absorption (inverse Bremsstrahlung) close to the target

Thomson Scattering [Ion feature - V, T_i, ZT_e]



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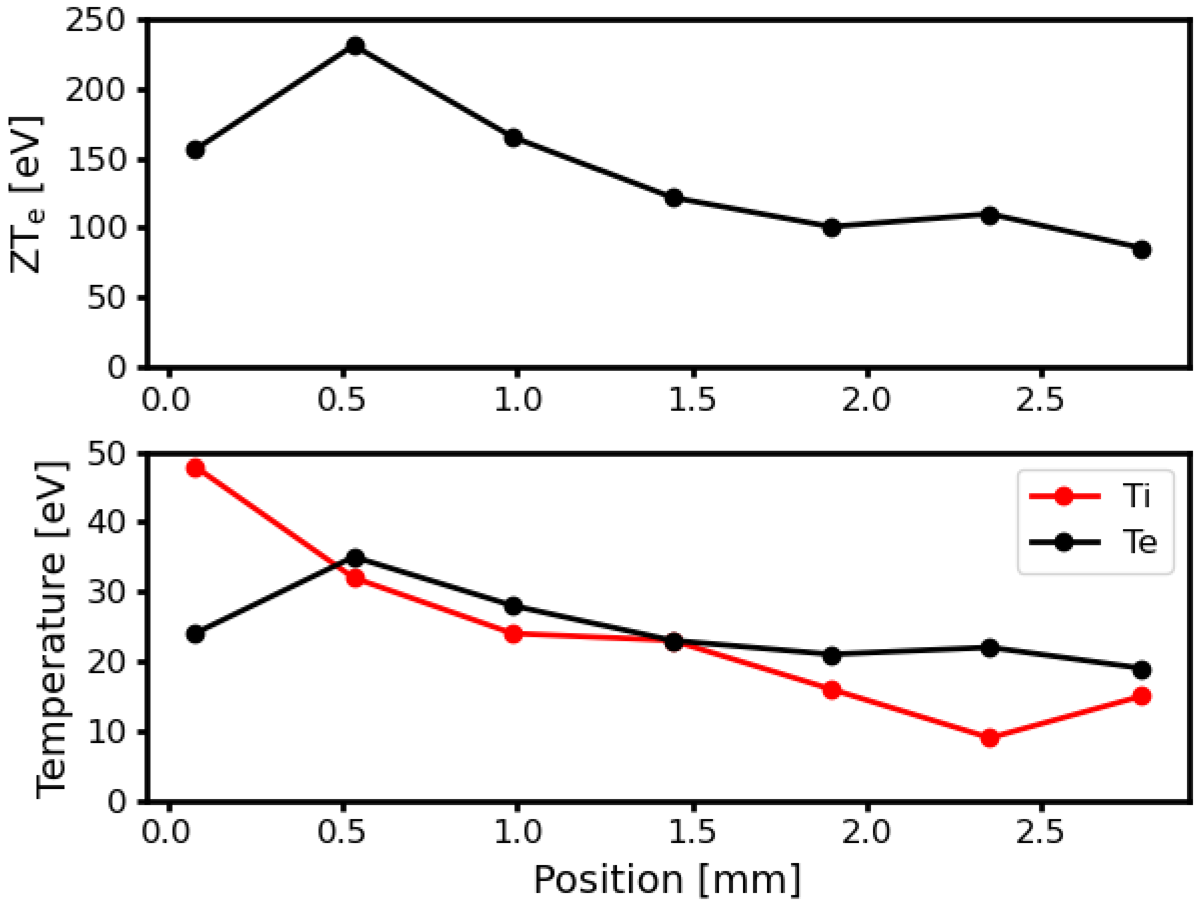

Plasma temperatures obtained from Thomson scattering data.

Next step – Diagnosis of magnetic field strength

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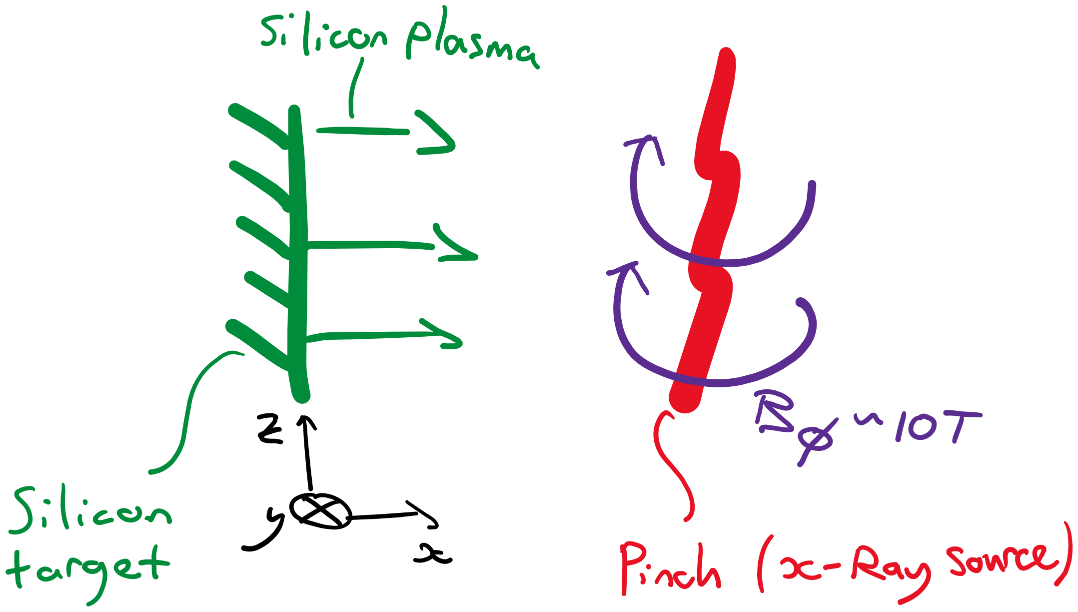
- Current flow through pinch produces azimuthal field $\sim 10\ \mathrm{T}$
- Plasma from target expands into this field
- Can diagnose spatial profile of (weighted average) field strength with Faraday rotation imaging



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

Approximate Plasma Parameters

Parameter	Value
n_e	$1.5 \rightarrow 0.2 \times 10^{19}\ \mathrm{cm}^{-3}$
T_e	$\sim 20\ \mathrm{eV}$
T_i	$\sim 15\ \mathrm{eV}$
B_ϕ	$\sim 10\ \mathrm{T}$
Ionisation stage - Z	~ 6
Velocity - V	$\sim 4 \times 10^6\ \mathrm{cm/s}$
$\beta = P_{th}/P_{mag}$	$1.2 \rightarrow 0.2$
Energy exchange time - $\tau_{ei}^{(E)}$	$1 \rightarrow 7\ \mathrm{ns}$
Diffusive Length - l_D	$1\ \mathrm{mm}$
Electron MFP - λ_{ei}	$1 \rightarrow 10\ \mu\mathrm{m}$
Ion MFP - λ_{ii}	$\lambda_{ii} < 1\ \mu\mathrm{m}$
Electron Magnetisation - $\omega_{Ce}\tau_e$	$0.1 \rightarrow 0.5$
Ion Magnetisation - $\omega_{Ci}\tau_i$	$\omega_{Ci}\tau_i \ll 0.1$