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X-ray all-in-one (AIO)

Spectro-spatial diagnostic for MeV characterisation of x-rays produced from laser plasma interactions

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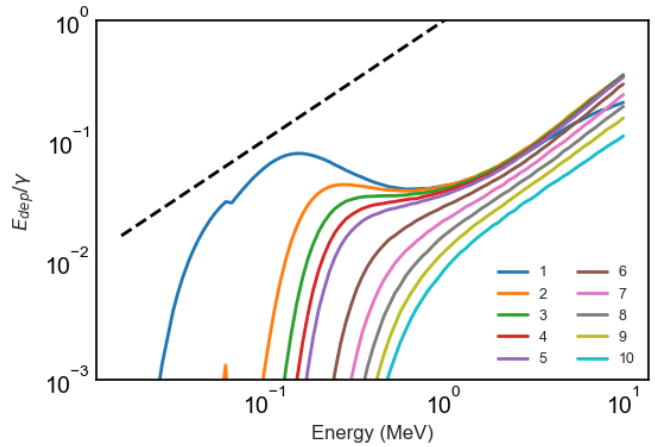

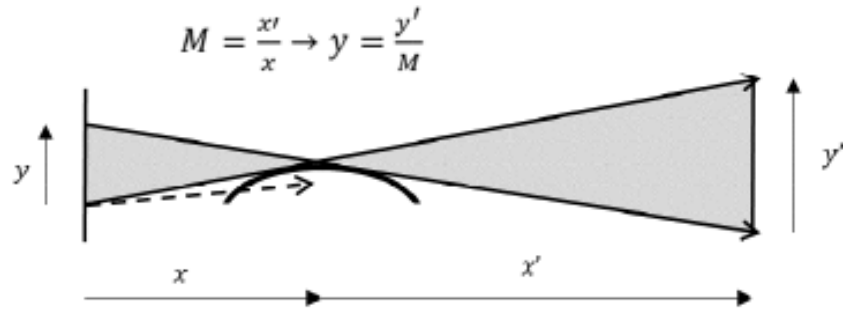

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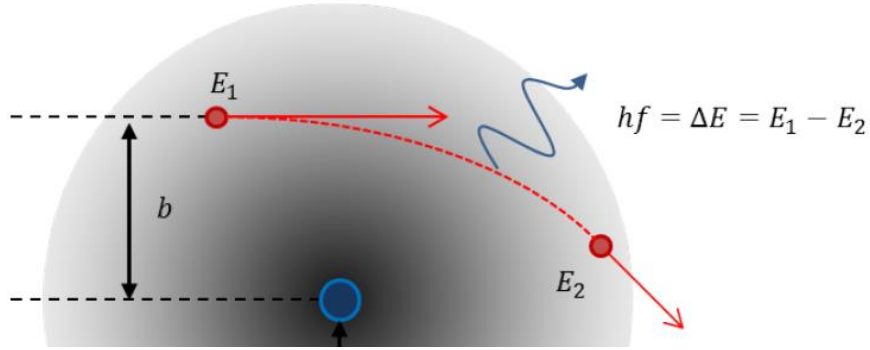
Introduction

X-ray radiation from laser-solid interactions is comprised two parts:

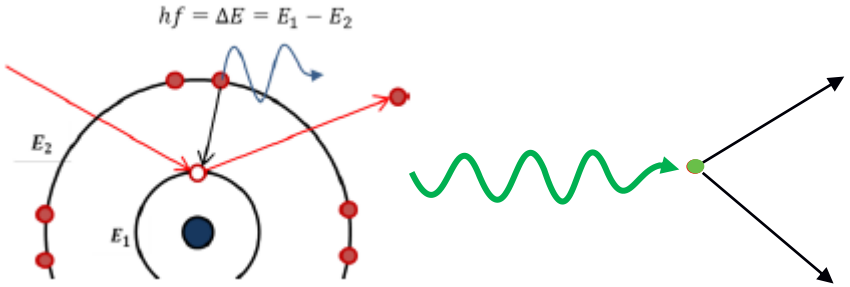
- Bremsstrahlung
- Line-emission (characteristic/pair-production)

Characterising this emission is important **scientifically** and for **image reconstruction**

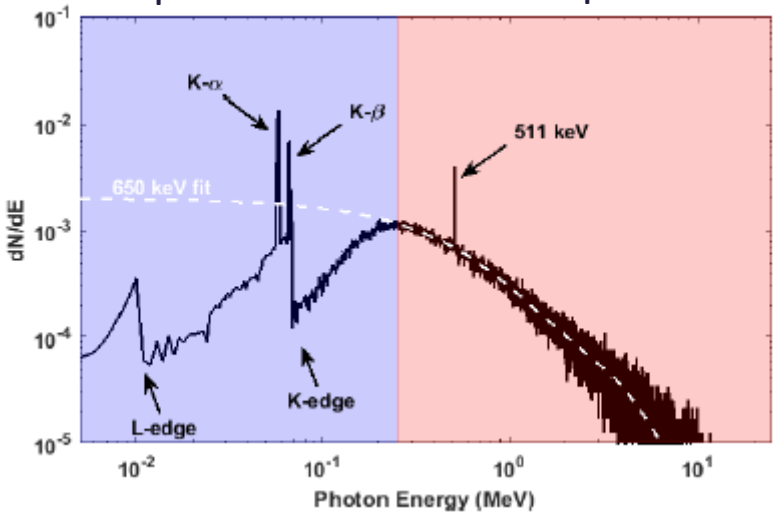
Spectral and spatial measurements combined provide a more complete picture of what is occurring within the target.



Bremsstrahlung



K-Alpha **Pair-production**



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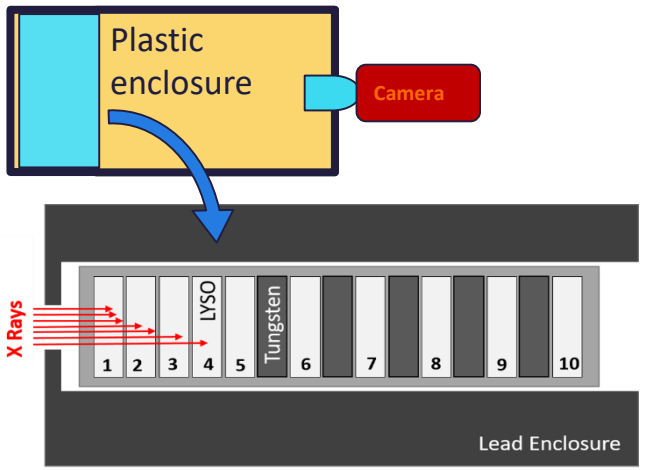
Spectral Measurements

- Attenuation spectrometers offer a simple way to resolve the spectral shape
- A 1D array of scintillators attenuate and detect the x-ray signal.
- Signal detected in each layer is a convolution of the incident x-ray signal and the attenuation from the rest of the stack.
- Resolving of the diagnostic is limited by the spatial uniformity of the crystals, and the accuracy of the trial spectral shape



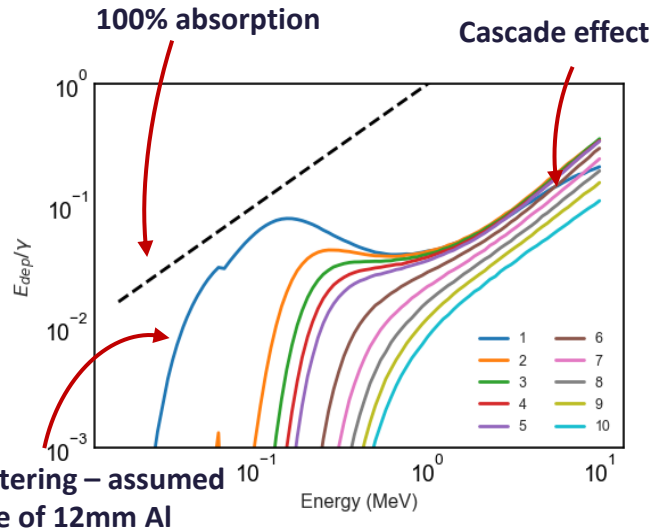
R

S

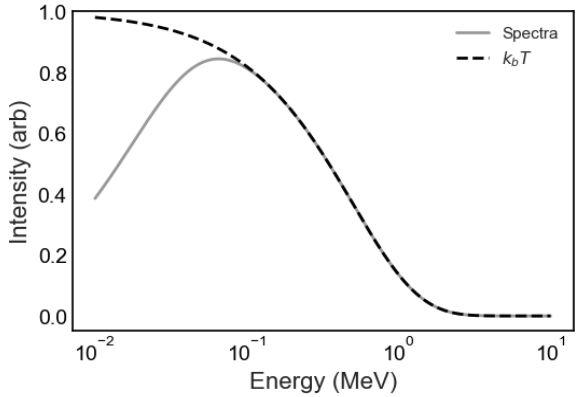
$$R * S = L$$

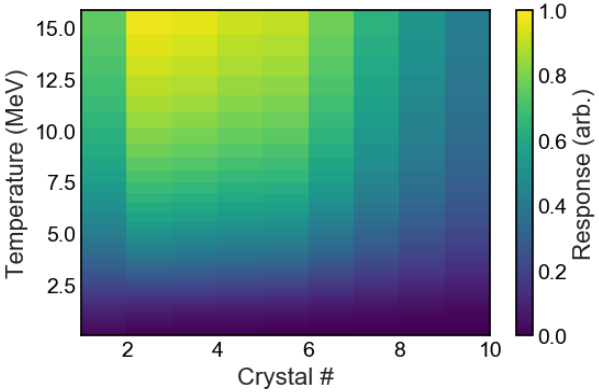
$$\begin{bmatrix} R_{L_1,E_1} & R_{L_1,E_N} \\ R_{L_N,E_1} & R_{L_N,E_N} \end{bmatrix} * \begin{bmatrix} S_{E_1} \\ S_{E_N} \end{bmatrix} = \begin{bmatrix} L_{E_1} \\ L_{E_N} \end{bmatrix}$$

L



Prefiltering – assumed flange of 12mm Al





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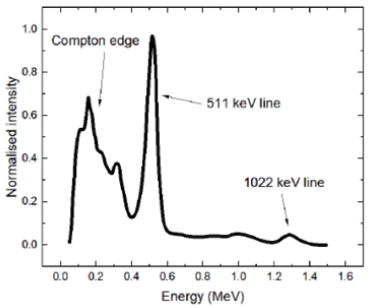
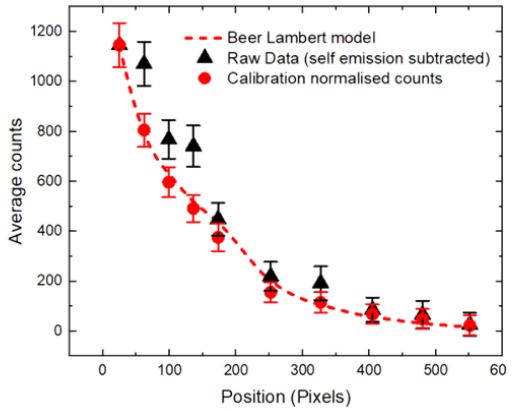
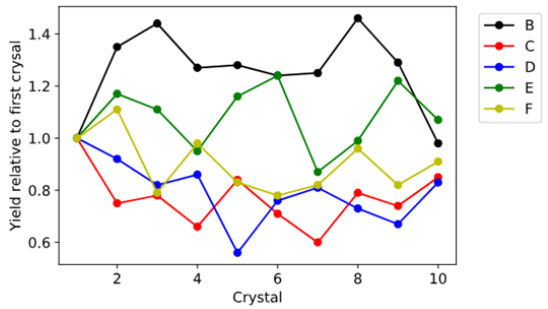
Spectral Measurements

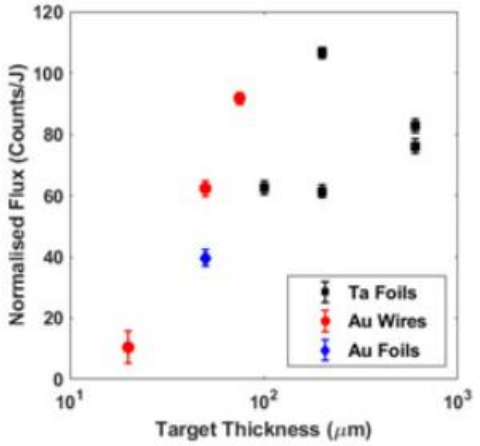
Calibrations



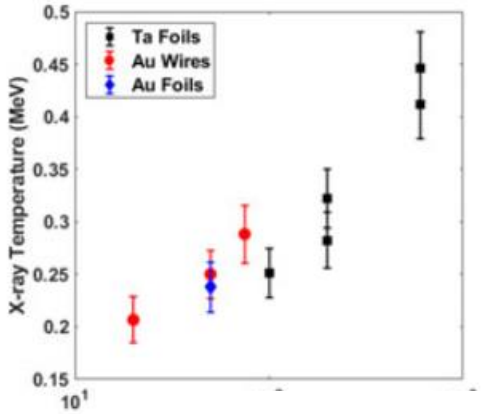


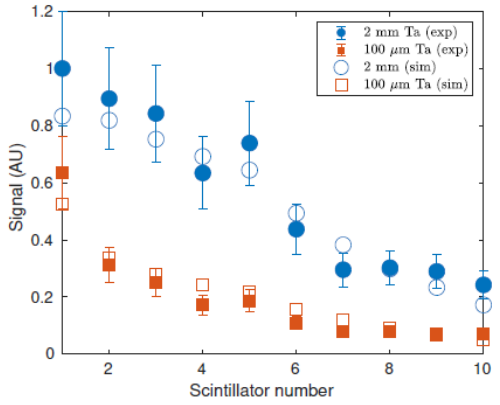


Experimental Data



(b) X-ray Flux





(c)

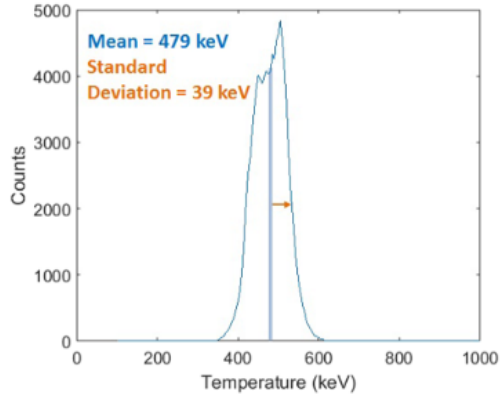


FIG. 5. A histogram of the fitted temperatures from a simple measurement by comparing the predicted output of the diagnostic for different simulated x-ray spectra multiple times. Each time errors from the experimental data are randomly added. The mean is taken as the temperature of the data, and the standard deviation from this mean is the error in the temperature measurement.

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Armstrong *et al.* High Power Laser Science and Engineering, (2019), Vol. 7, e24.
Rusby *et al* Rev. Sci. Instrum.89, 073502 (2018)
Singh *et al* PoP, (2020) *Submitted To*

Spatial Measurements

- Rolled edge penumbral imaging offers a high resolution, high energy option for spatial measurements
- Unlike pinholes/knife edge, doesn't suffer from vignetting or transmission issues.
- Using a curved foil allows scaling to high energies and simple construction
  - 300um W foil pinned to ROC of ~ 1m
- PSF of penumbral foil is <5um up to MeV
  - Detector limits the image resolution to ~40um
  - Geometric setup of x10-20 magnification for foil limited resolution

Knife-edge issues

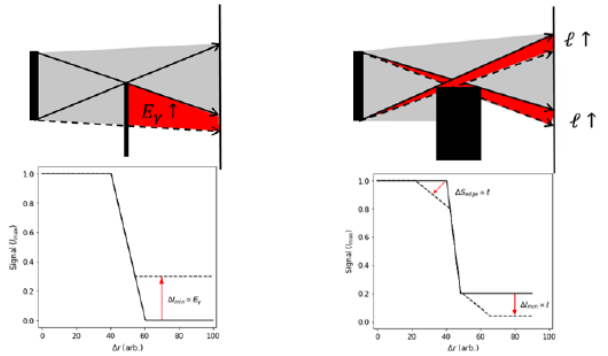
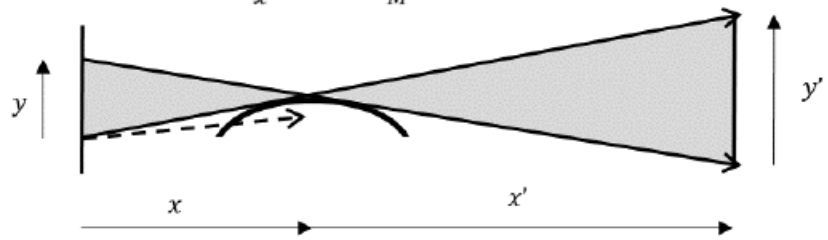
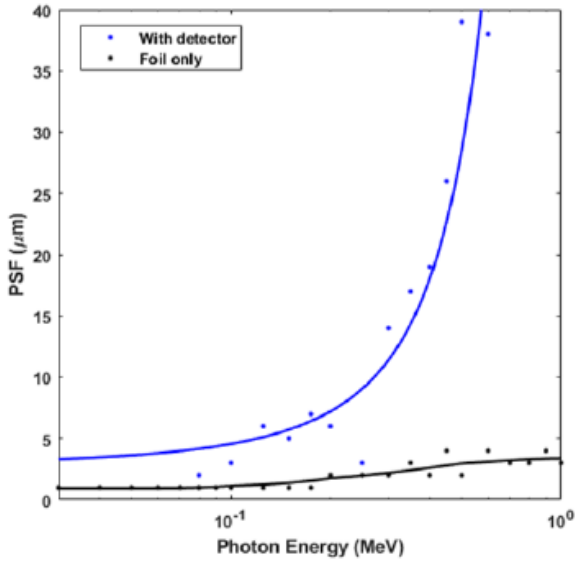
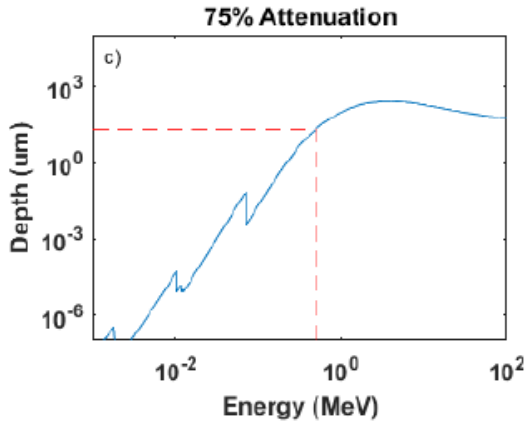


Figure 4.9: Schematic of issues with the standard penumbral technique at high energies. LHS shows increasing energy for a thin foil, RHS shows that increasing the foil thickness to offset the increased transmission introduces a different error.

$$M = \frac{x'}{x} \rightarrow y = \frac{y'}{M}$$







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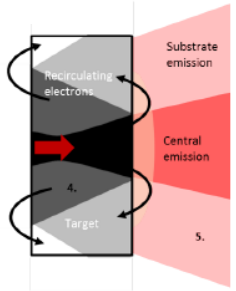
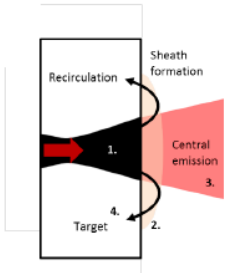
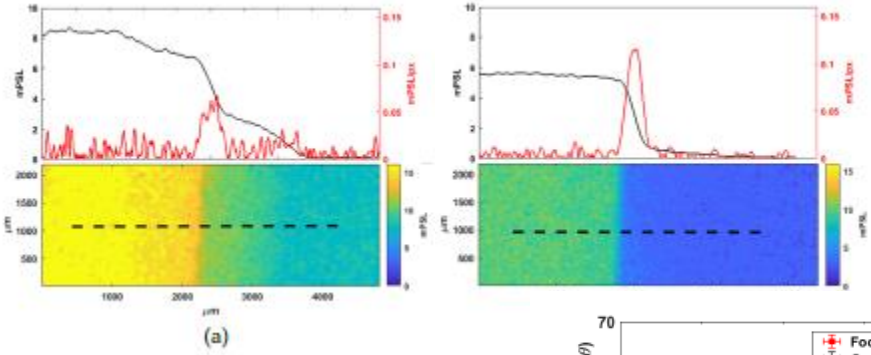
Spatial Measurements

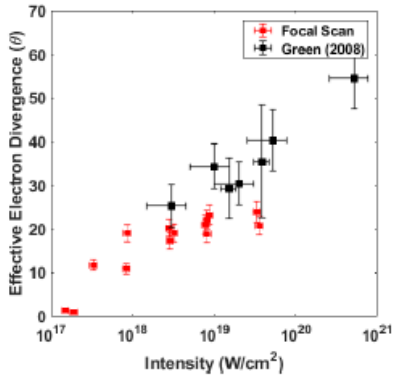
High-refluxing



Low-refluxing







Foil target **Wire target**

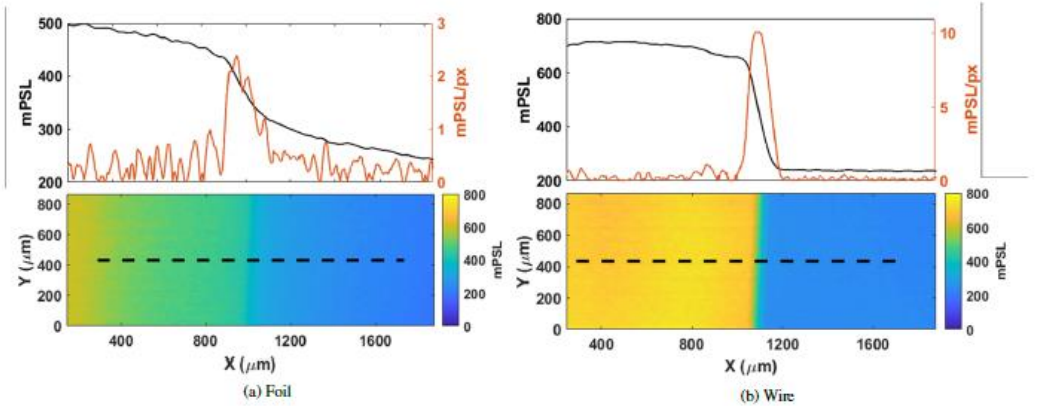


Figure 4: Penumbral radiograph, scale in mPSL (unit of flux for IP), and lineout for a) foil, and b) wire target. The dashed line in each radiograph is where the lineout is determined.

- Diagnostic has been used in numerous campaigns to explore differing properties of x-ray emission
  - Multi-source size control through defocus
  - Global electron divergence through solid target
  - Constrained target emission from wire targets
  - *Etc.*
- Accuracy dependent on the final *energy dependent* resolution of the detector.

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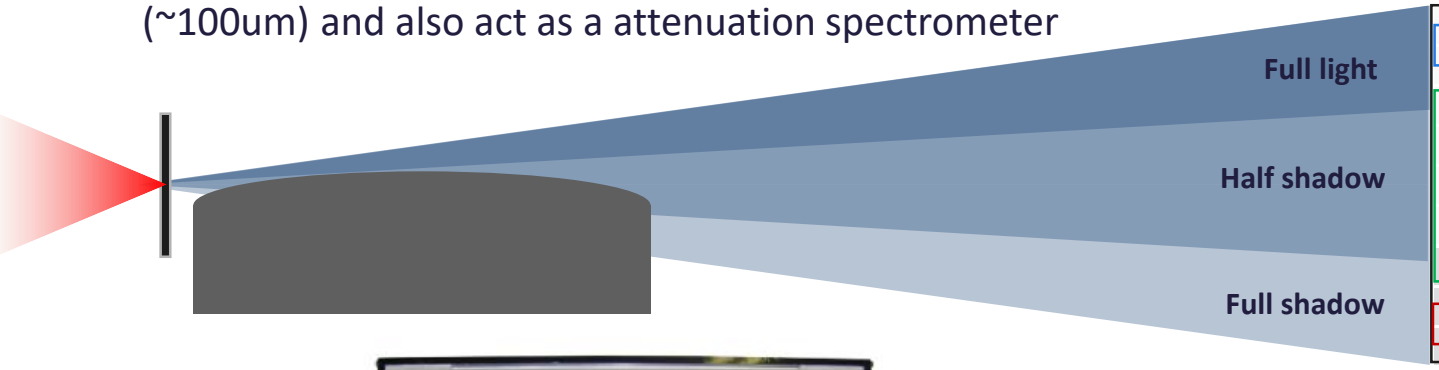
Armstrong *et al* 2019 *Plasma Phys. Control. Fusion* **61** 034001

Armstrong *et al.* High Power Laser Science and Engineering, (2019), Vol. 7, e24.

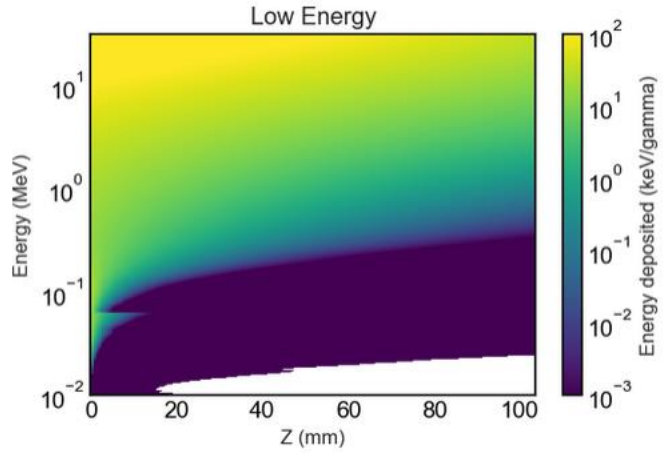
Combination

- Taking what we've learned from developing each diagnostic independently we can create a single All-in-one (AIO) design.

- General principle is to use a 2D scintillator array edge on, with sufficiently resolved pixels to provide spatial resolution (~100um) and also act as a attenuation spectrometer

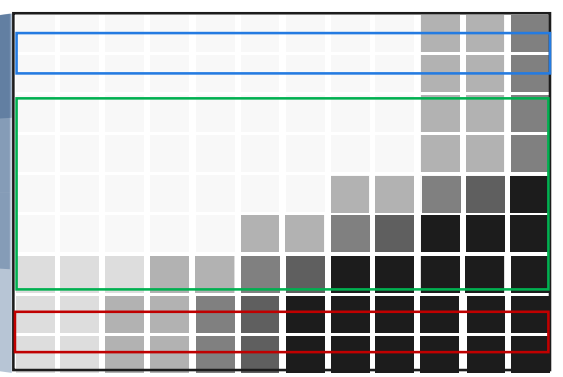


CsI(Tl) Scintillator panel measuring 30cm x 40cm with 0.3mm pixels X-ray thickness 10mm



60 mm

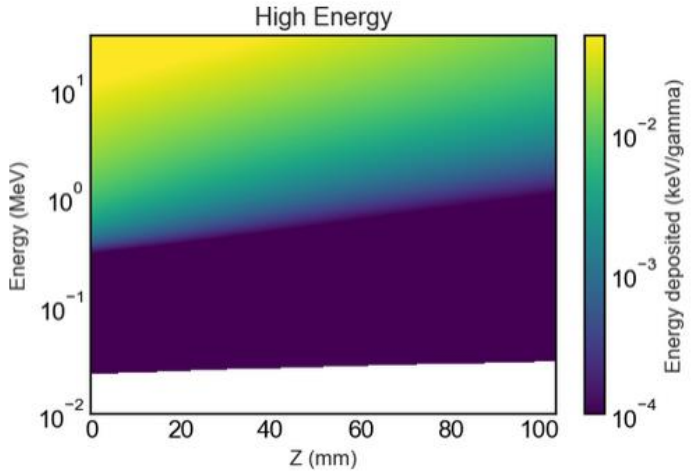
100mm



Low energy spectra
~20mm

Penumbral image
~20mm

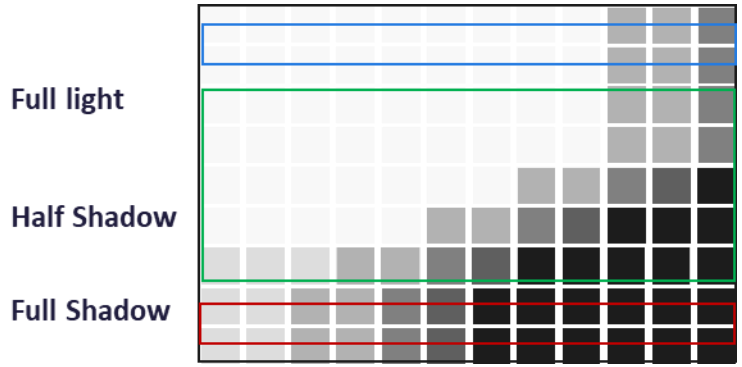
High energy spectra
~20mm



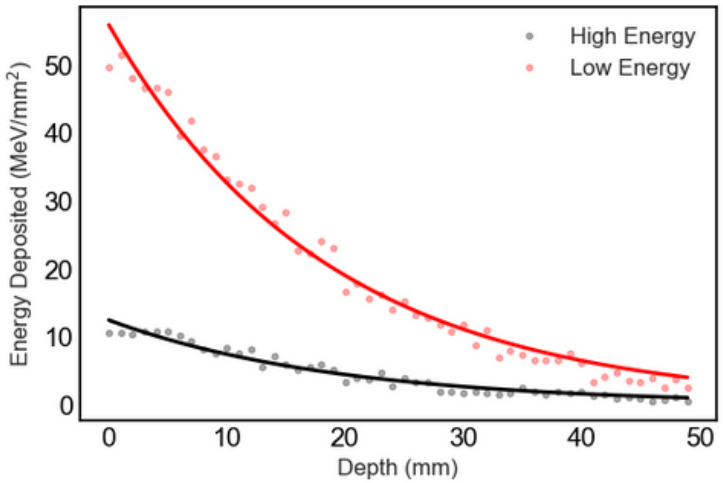
https://www.crystals.saint-gobain.com/sites/imdf.crystals.com/files/documents/array-brochure.pdf

Combination

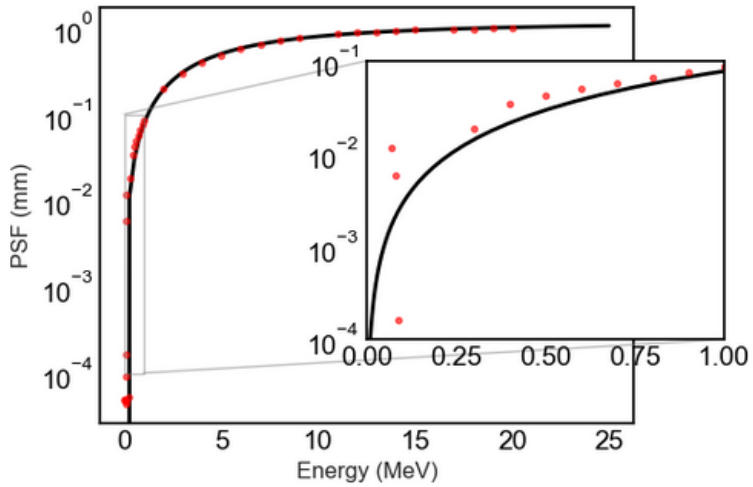
- GEANT4 Simulation demonstrates the spectral-spatial response
- Horizontal bins are summed to 600um (2px) for sufficient attenuation, vertical bins in penumbral region are kept to 300um to maintain resolution
- At 10x geometric magnification, each diagnostic pixel ~30um at source. Penumbral region should ~central third of array, leaving another third for “full light” and “full shadow” regions.



Spectral Response



Spatial Response



PSF < 100um up to 1 MeV in energy

Non-linearity around the k-edge of the scintillator

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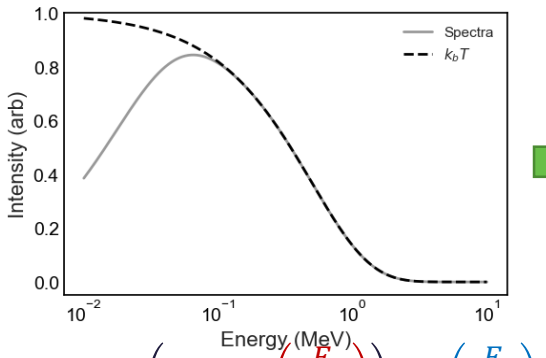
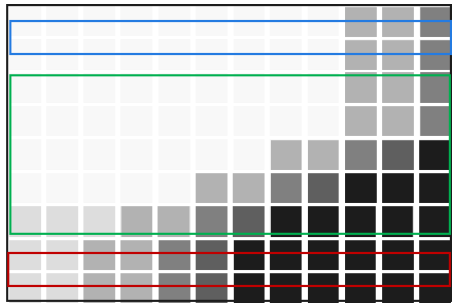
~~Experimental~~ Demonstration

- Diagnostic to be trialled on (now) upcoming experiment – originally planned for March this year, however…
- A simulated response will have to suffice…

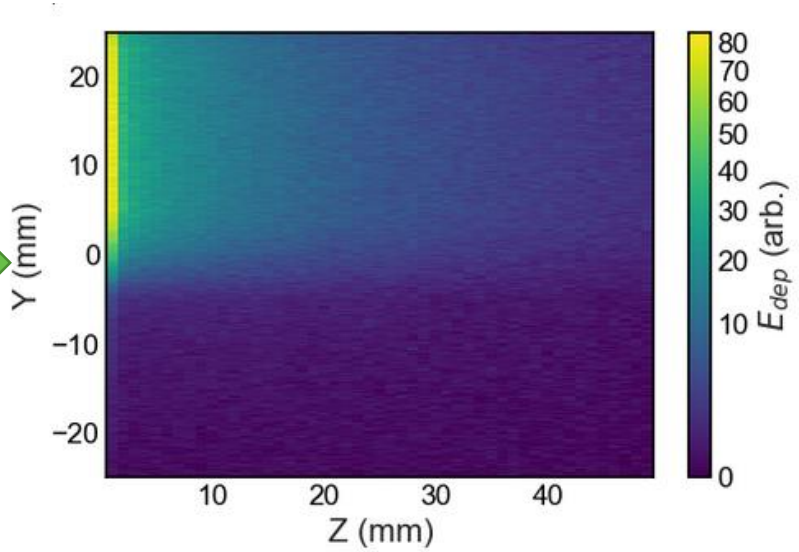


$$f(E, k_bT) = \left(1 - \exp\left(\frac{E}{0.05}\right)\right) \exp\left(\frac{E}{k_bT}\right)$$

Target Attenuation **Slope temperature**



Simulated via GEANT4 with 10^8 particles across the distribution



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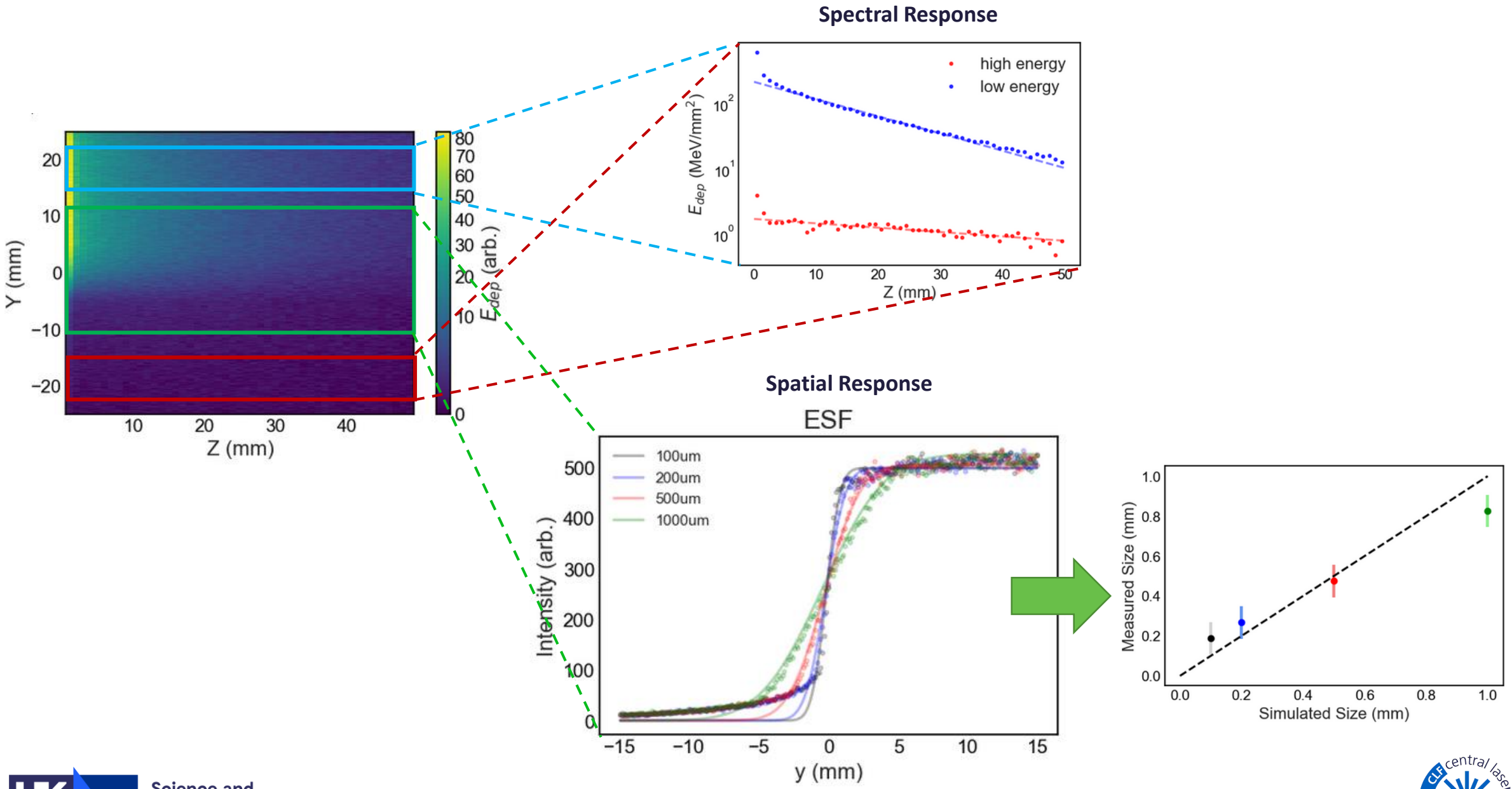

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Summary

- Combining multiple distinct diagnostics in an X-ray All-in-one (AIO) design allows for a single point to characterise x-ray emission from laser solid interactions
- PSF and simulated reconstruction demonstrates reasonable reconstruction between 100-1000um sources
- Spectral reconstruction requires a detector with ~3 orders of magnitude in dynamic range and some additional work to deconvolve.
- Experimental demonstration upcoming…

Thanks for listening

Many thanks to collaborators from ELI, QST, LLNL, and the CLF.

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