Particle acceleration in pulsed-power driven magnetic reconnection experiments

J. W. D. Halliday (jack.halliday12@imperial.ac.uk)

Imperial College: J. D. Hare, L. G. Suttle, S. V. Lebedev, S. N. Bland, E. R. Tubman G. C. Burdiak, T. Clayson, F. Suzuki-Vidal

Cornell University: S. A. Pikuz, and T. A. Shelkovenko.

Imperial College London

Talk Outline

- MAGPIE reconnection framework and previous results
- Fast particle diagnostics
- Preliminary measurements of fast particles

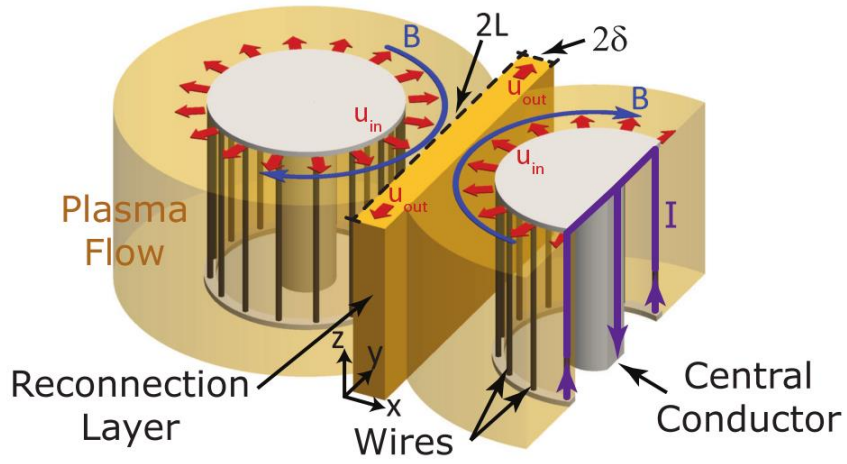
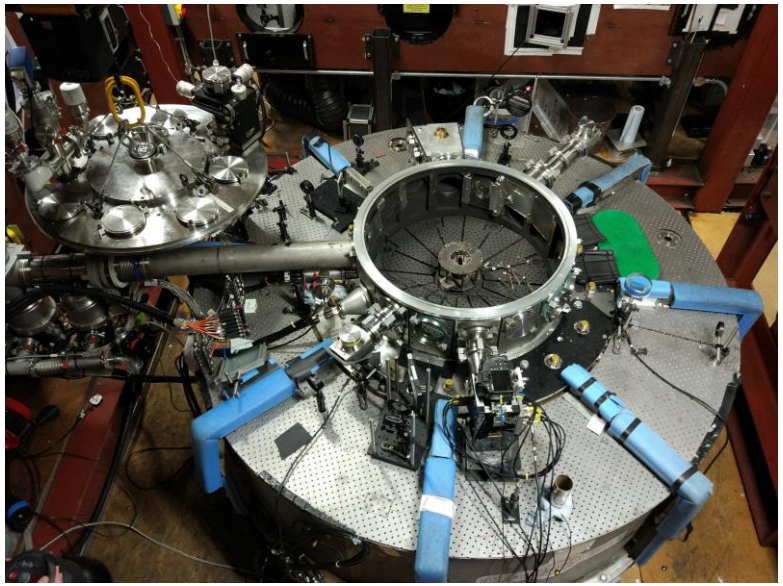


Figure: Schematic of a pulsed-power driven magnetic reconnection experiment

1. L. G. Suttle, J. D. Hare, S. V. Lebedev, et al. 2016. Phys Rev Lett. **116**, 225001
2. J. D. Hare, L. G. Suttle, S. V. Lebedev, et al. 2017. Phys Rev Lett. **118**, 085001
3. J. D. Hare, S. V. Lebedev, L. G. Suttle, et al. 2017. Phys Plas. **24**, 102703

The MAGPIE Pulsed-Power Generator



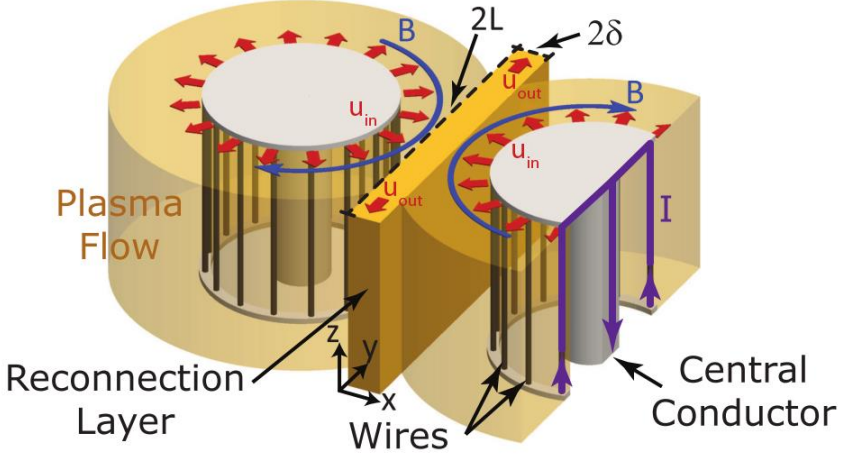
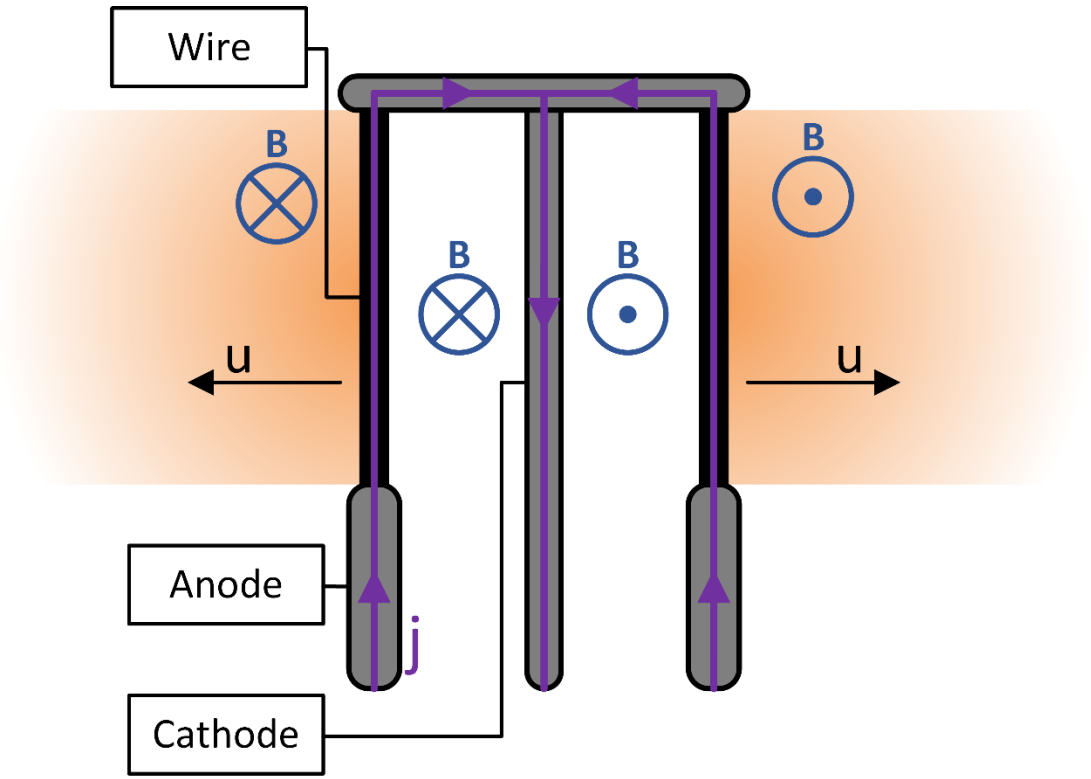


Figure: Schematic of a pulsed-power driven magnetic reconnection experiment

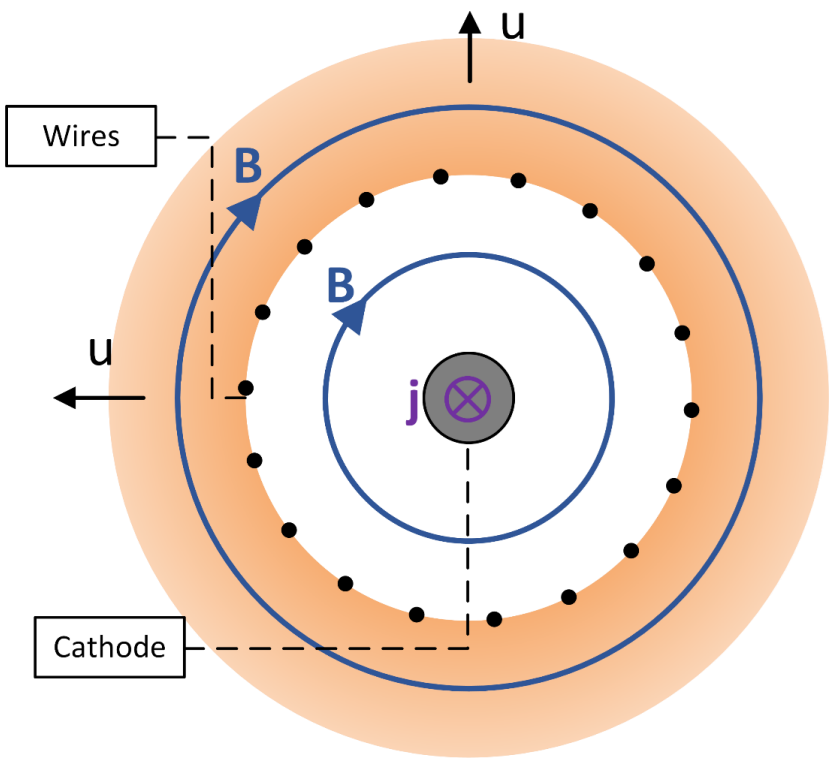
(carbon plasma)

T_{drive}	L	B_{in}	β_{ram}	$\beta_{thermal}$	S
500 ns	~10 mm	3 T	~ 1	~ 1	~ 100

Cross sections of an inverse wire array

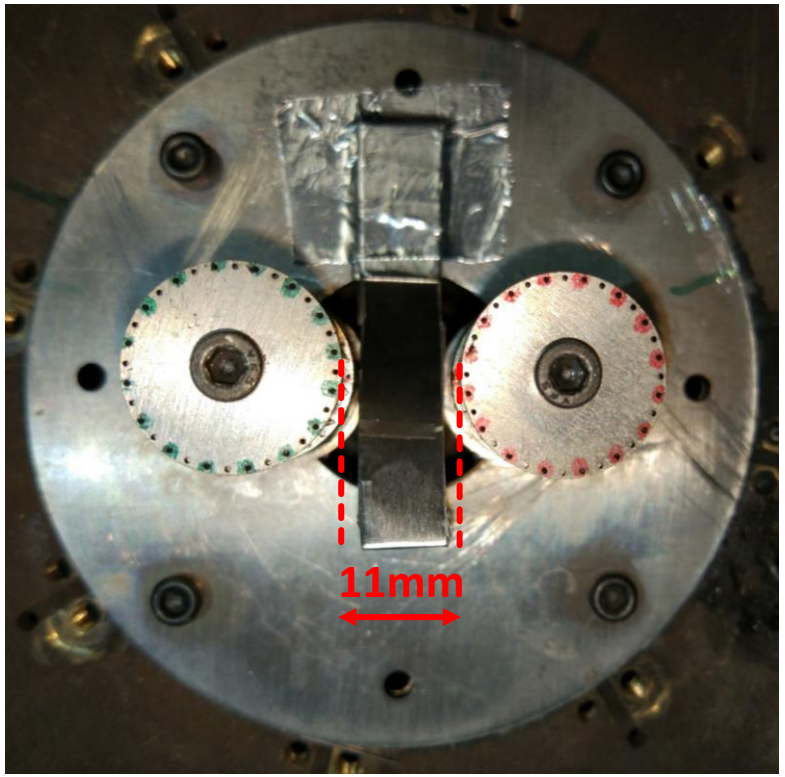


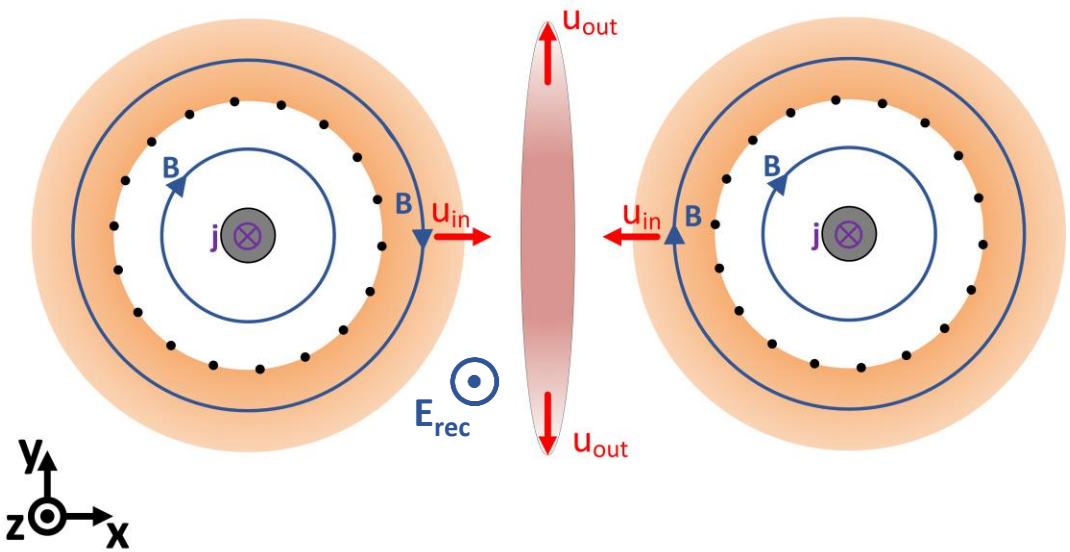
Side-on View



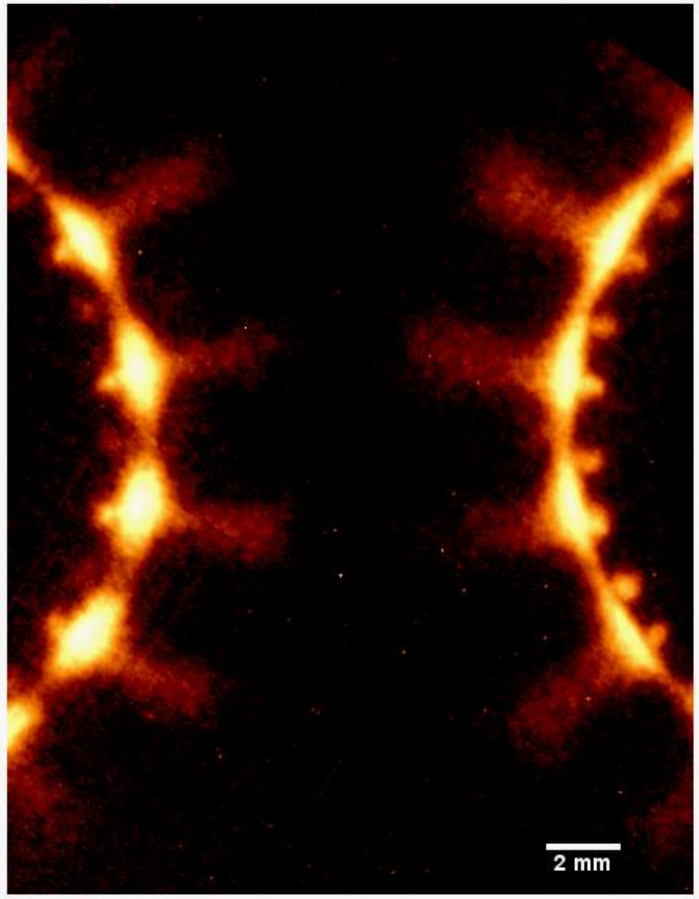
End-On View

Magnetic Reconnection Framework

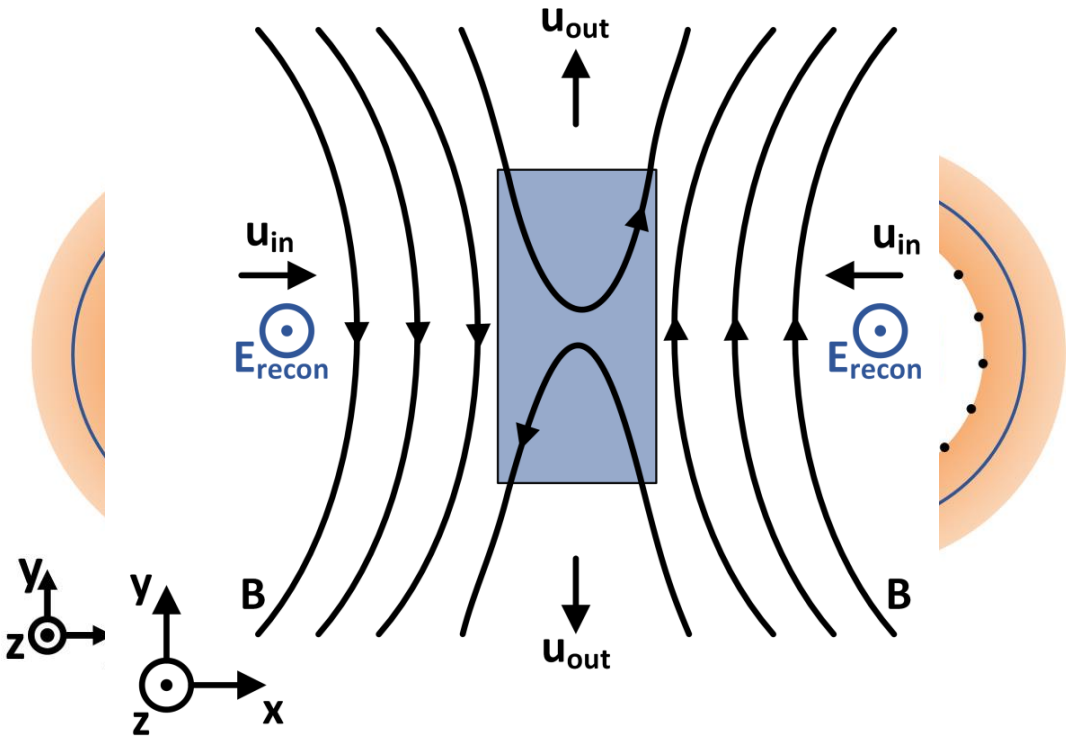




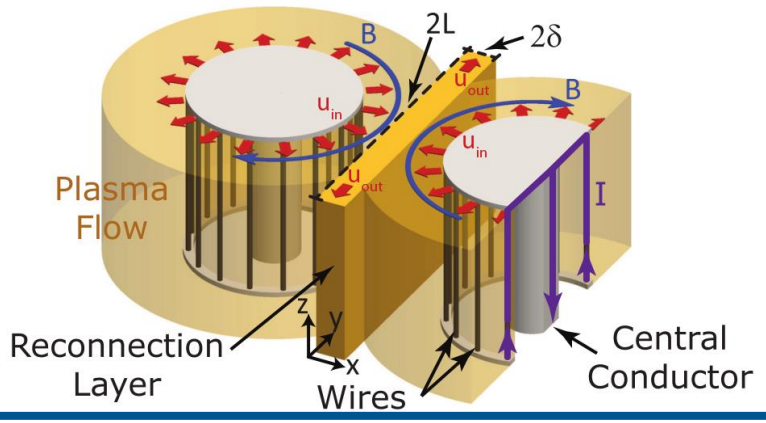
Magnetic Reconnection Framework

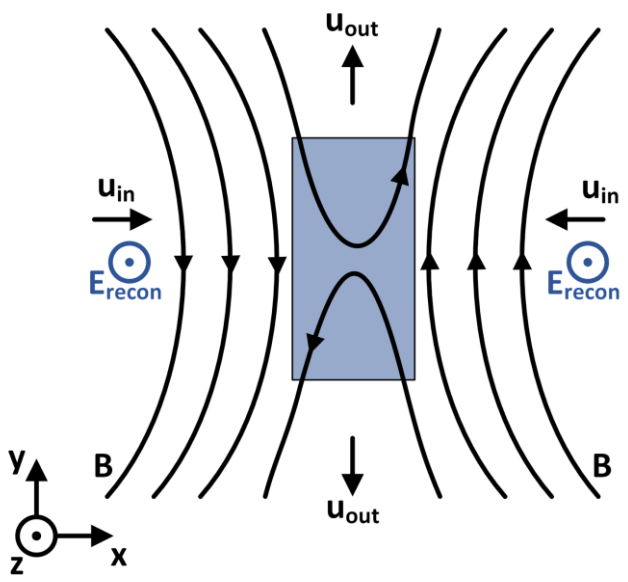
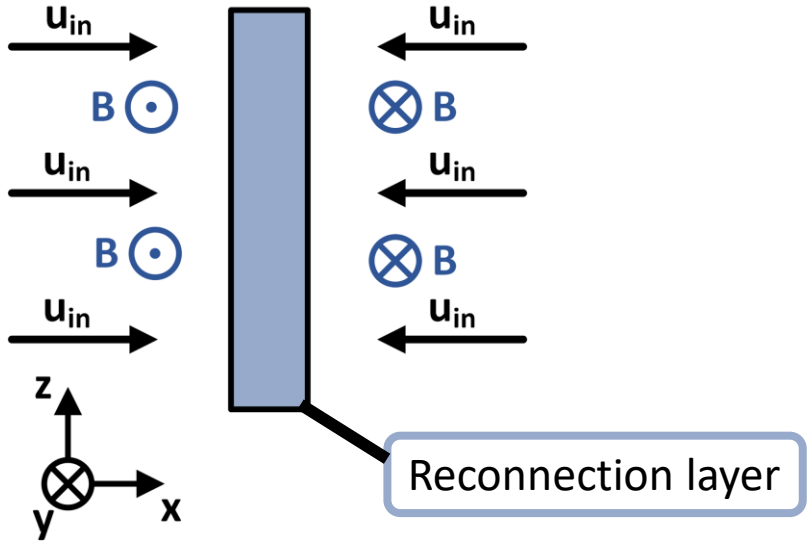


168 ns



Diagnosing Plasma Flows



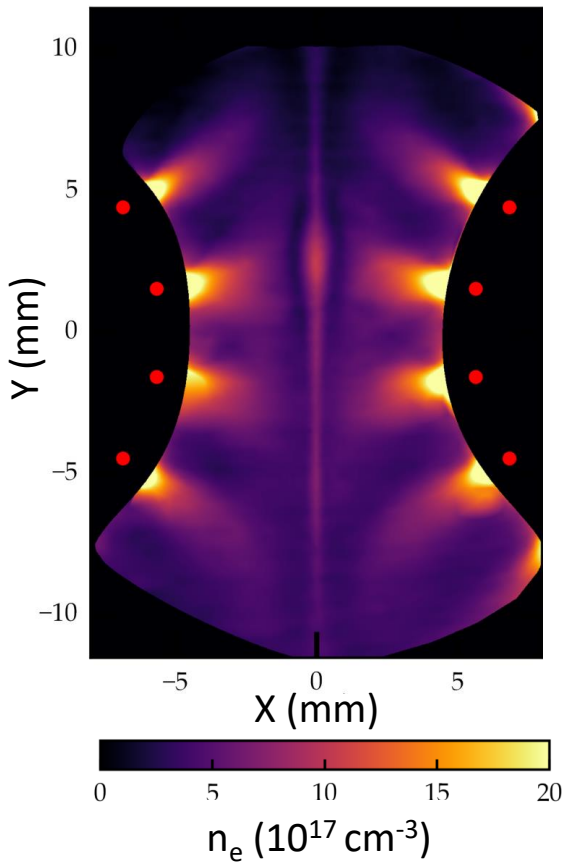
End-On View (X-Y Plane)	Side-On View (X-Z Plane)
	
Interferometry (n_eL) Thomson Scattering (u_x, u_y, T_e, T_i)	Interferometry (n_eL) Faraday Rotation Imaging (B_y)

Diagnosing Plasma Flows

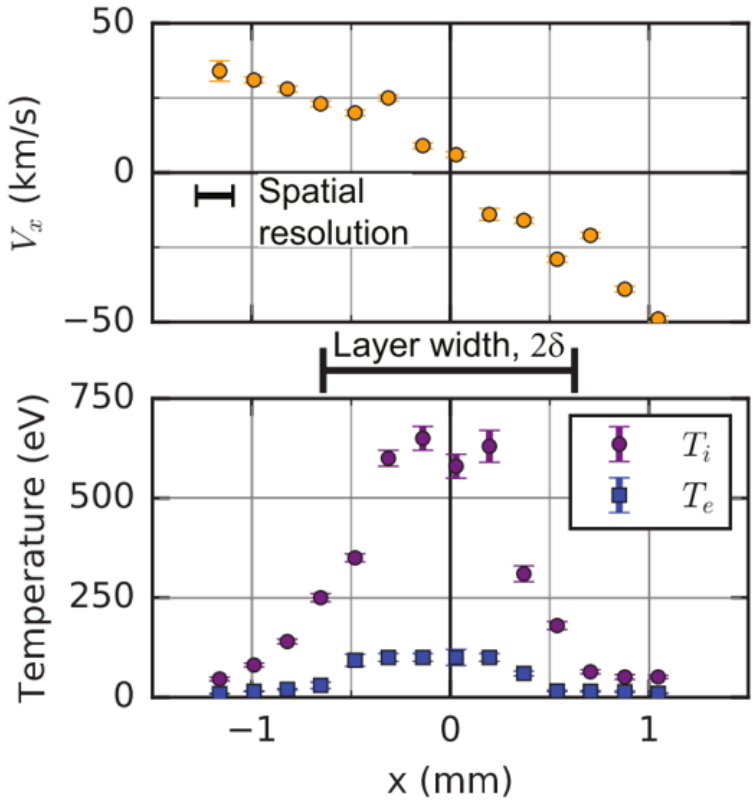
J. D. Hare NI2.00001 (Talk On Wednesday)

J. D. Hare, et al. 2017. Phys Plas. **24**, 102703

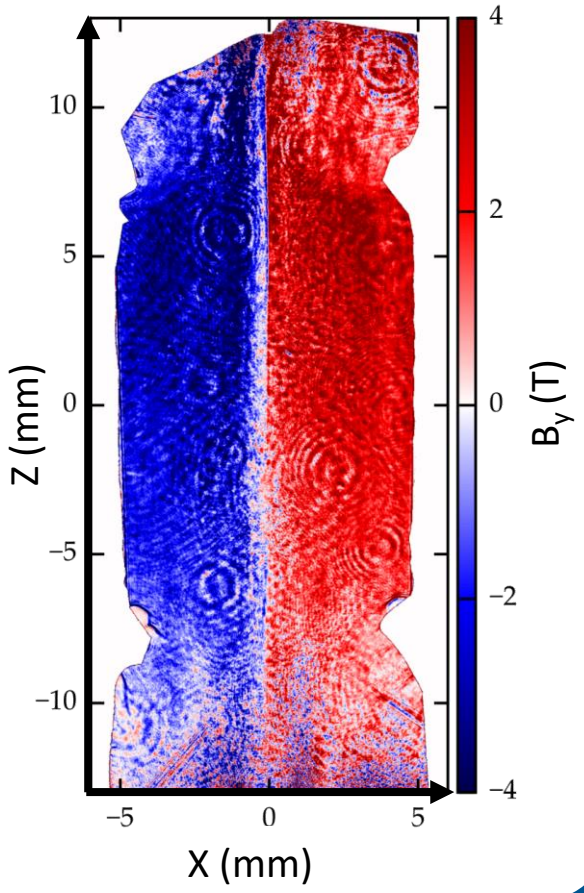
Interferometry



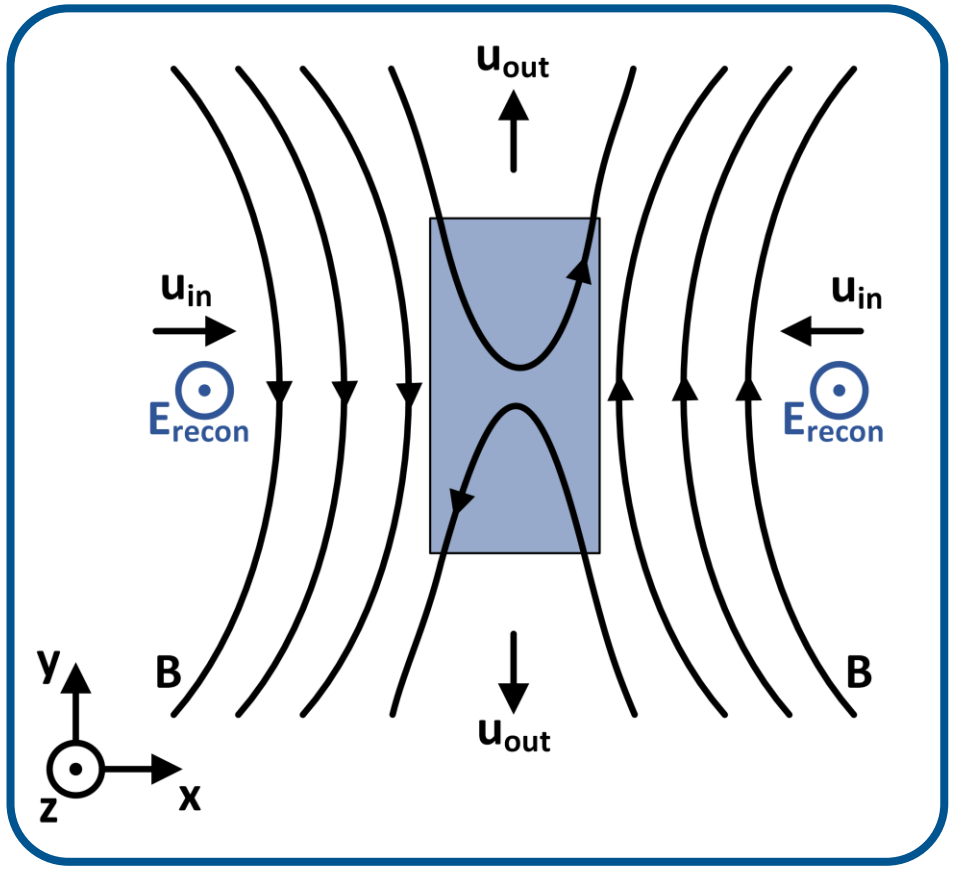
Thomson scattering



Faraday-rotation imaging



Reconnecting Electric Field



Parameter	Value
u_{in}	50 km/s
B_{in}	3 T
L_Z	16 mm

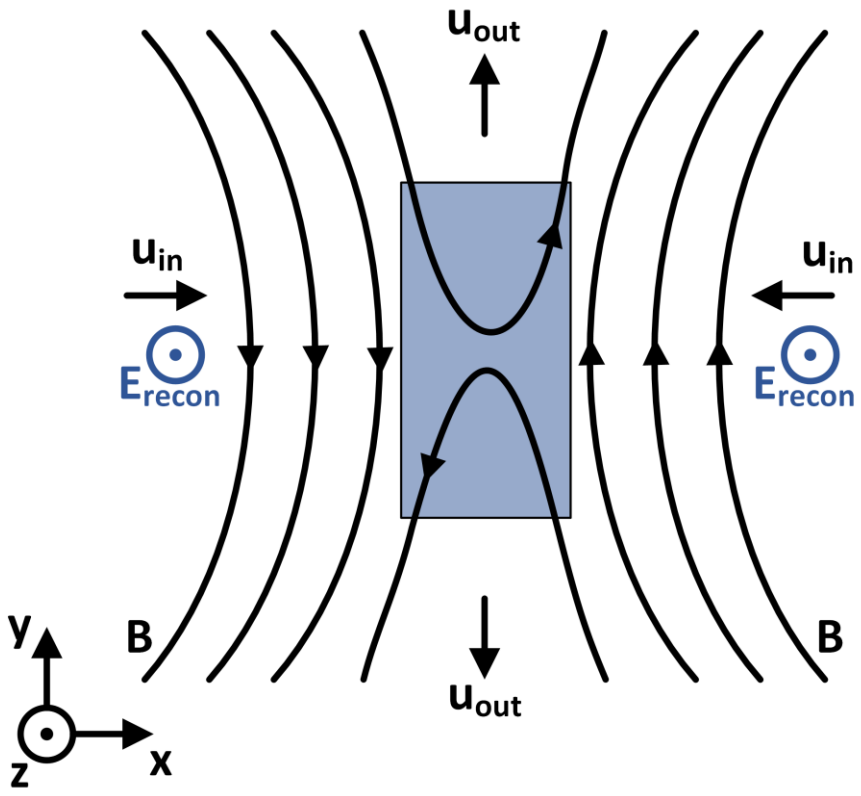
$$\boldsymbol{E} = -\boldsymbol{u} \times \boldsymbol{B} + \eta \boldsymbol{j}$$

$$E_{rec} = u_{in} B_{in} = 150 \text{ kV/m}$$

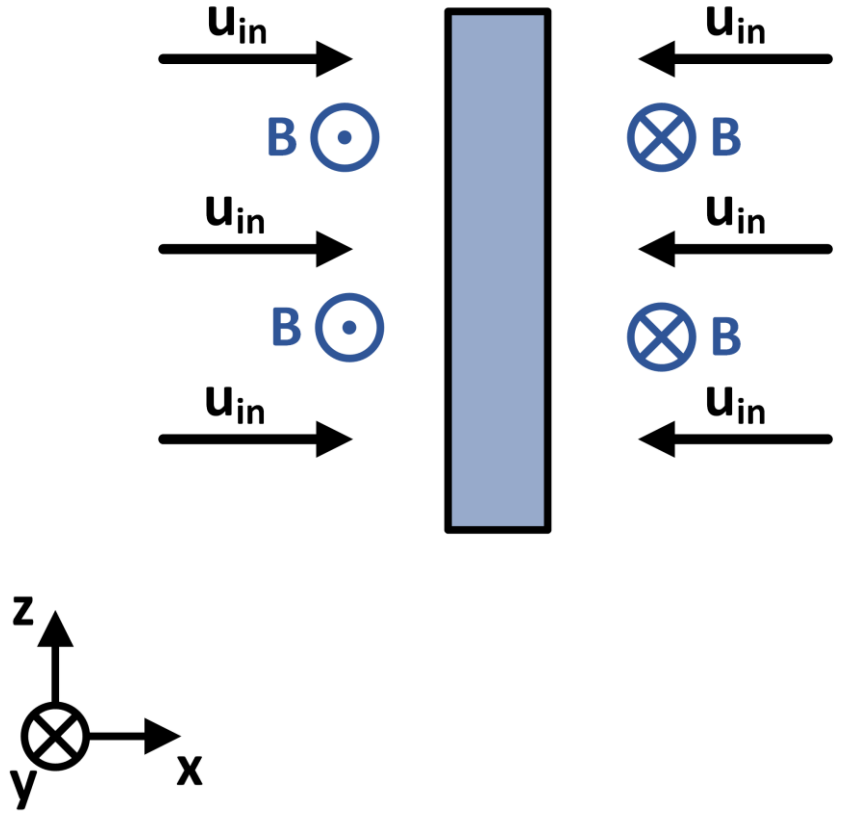
$$\int \boldsymbol{F}.d\boldsymbol{l} \sim e E_{rec} L_z = 2.4 \text{ keV}$$

Diagnosing Accelerated Electrons

End-On View (X-Y Plane)

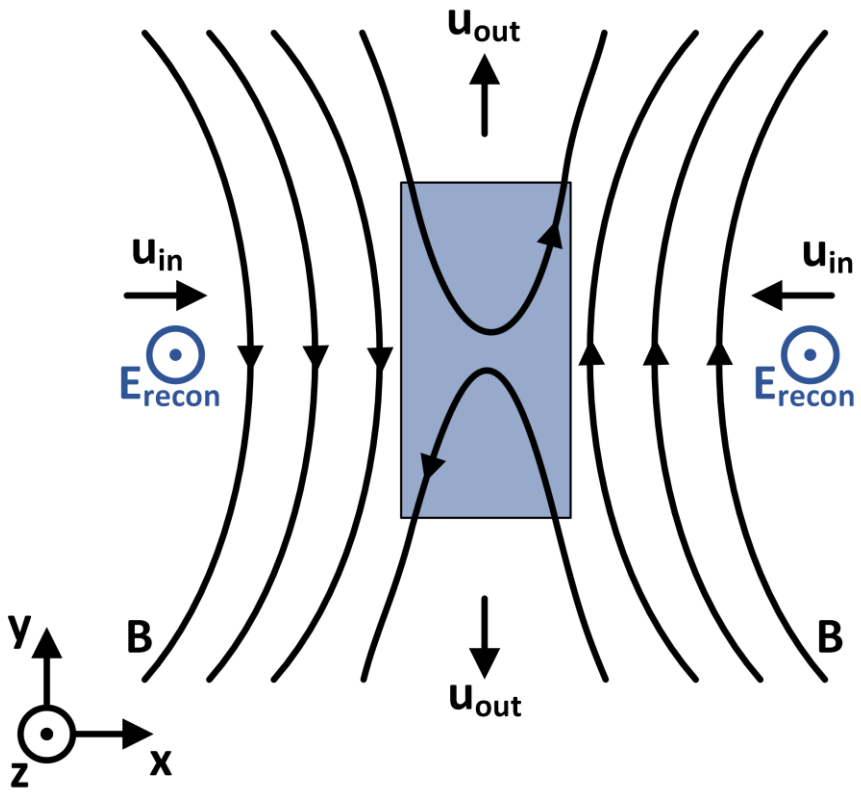


Side-On View (X-Z Plane)

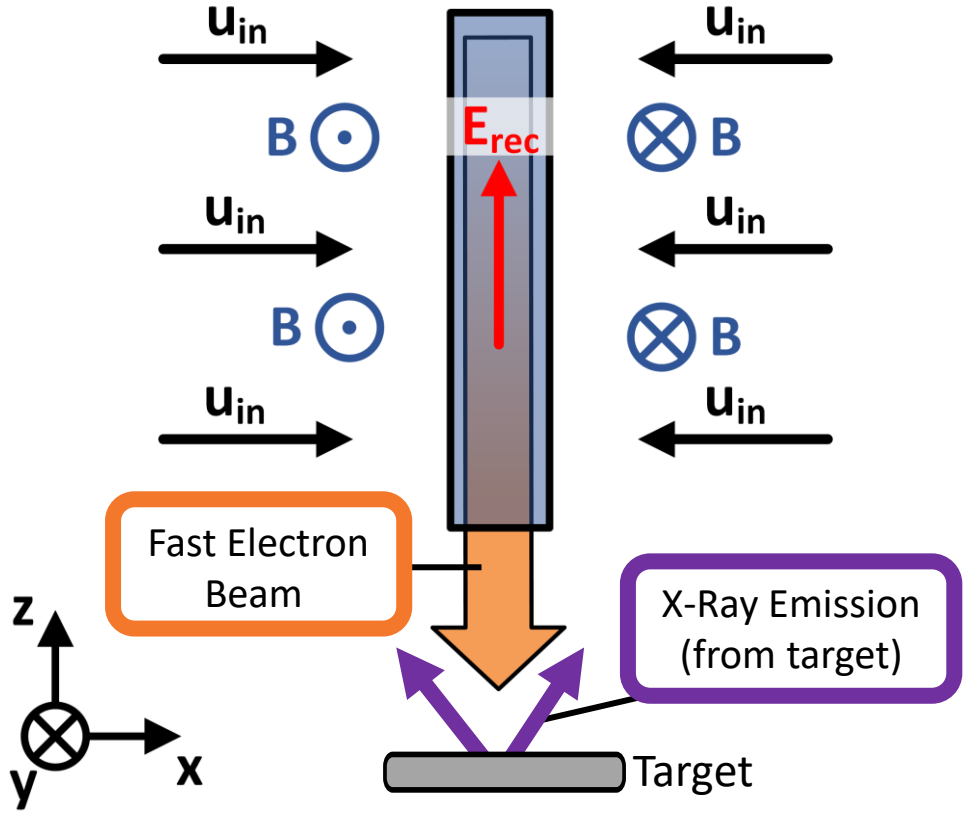


Diagnosing Accelerated Electrons

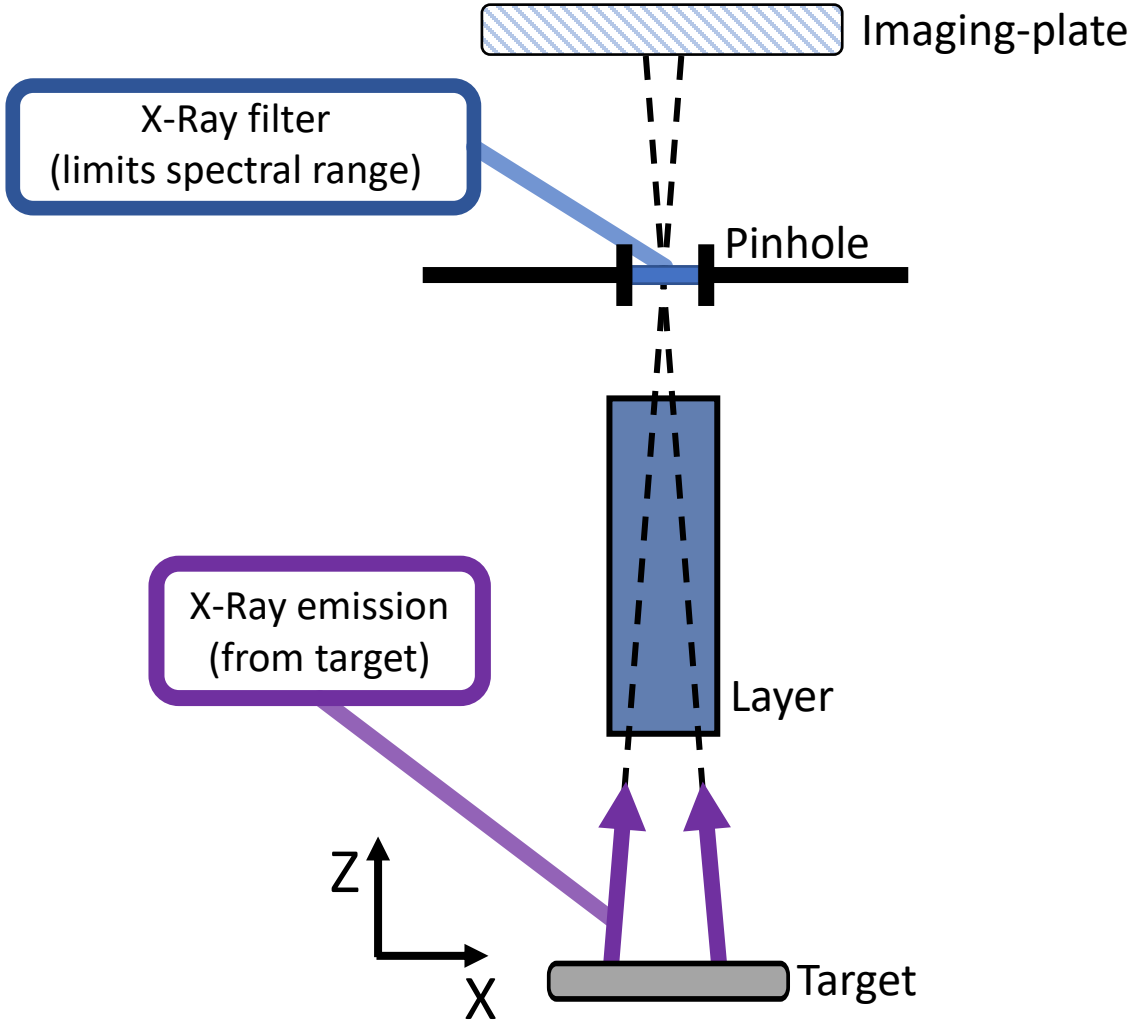
End-On View (X-Y Plane)

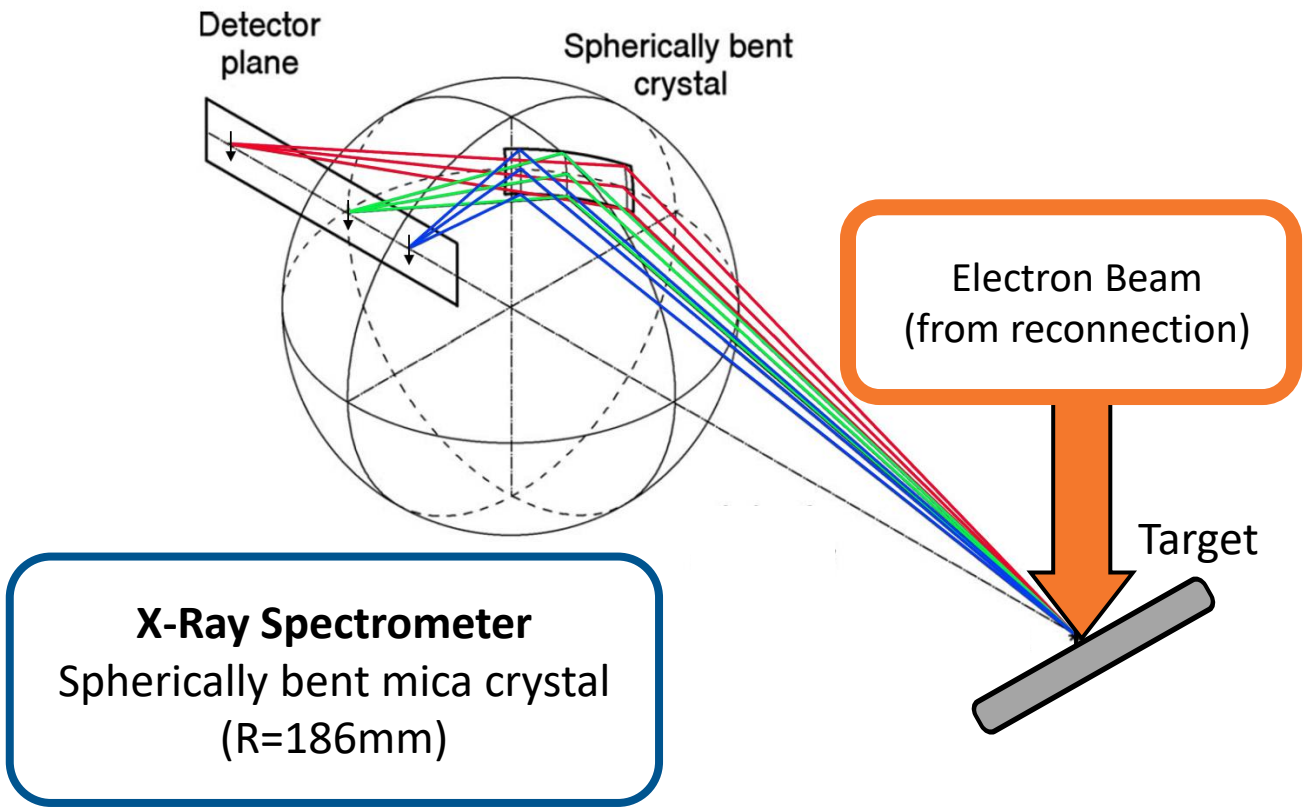


Side-On View (X-Z Plane)



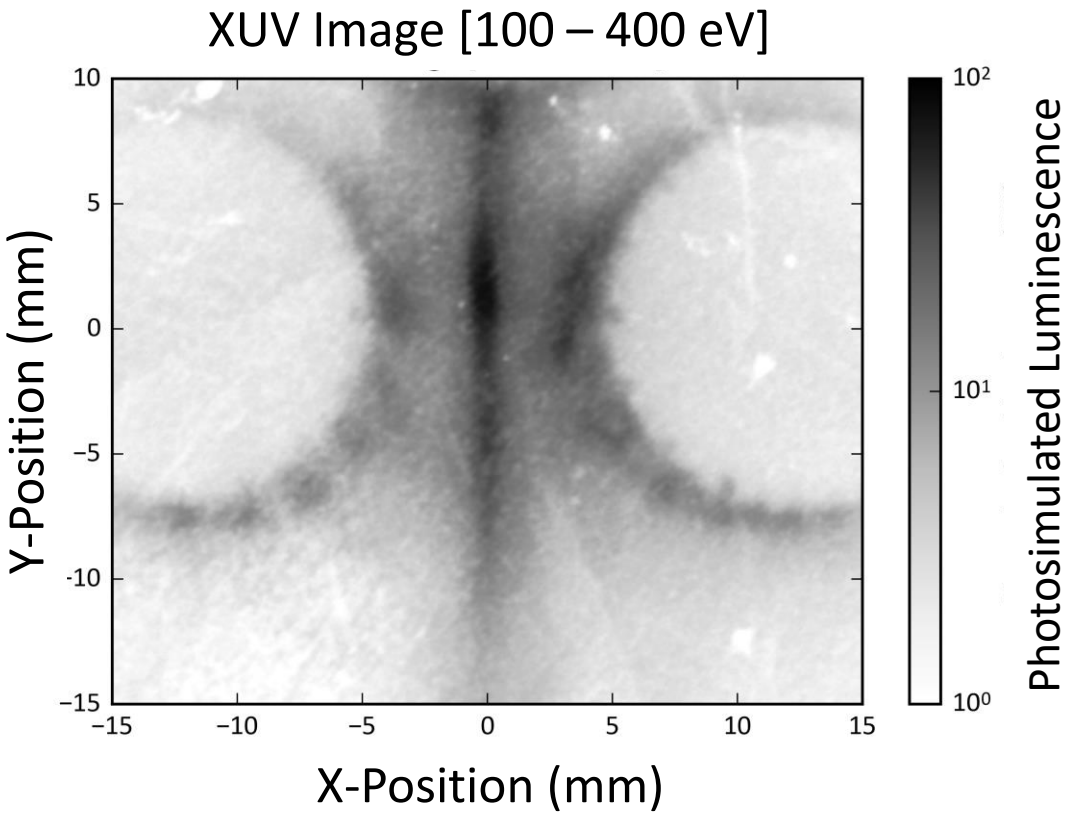
X-Ray Imaging and Spectroscopy

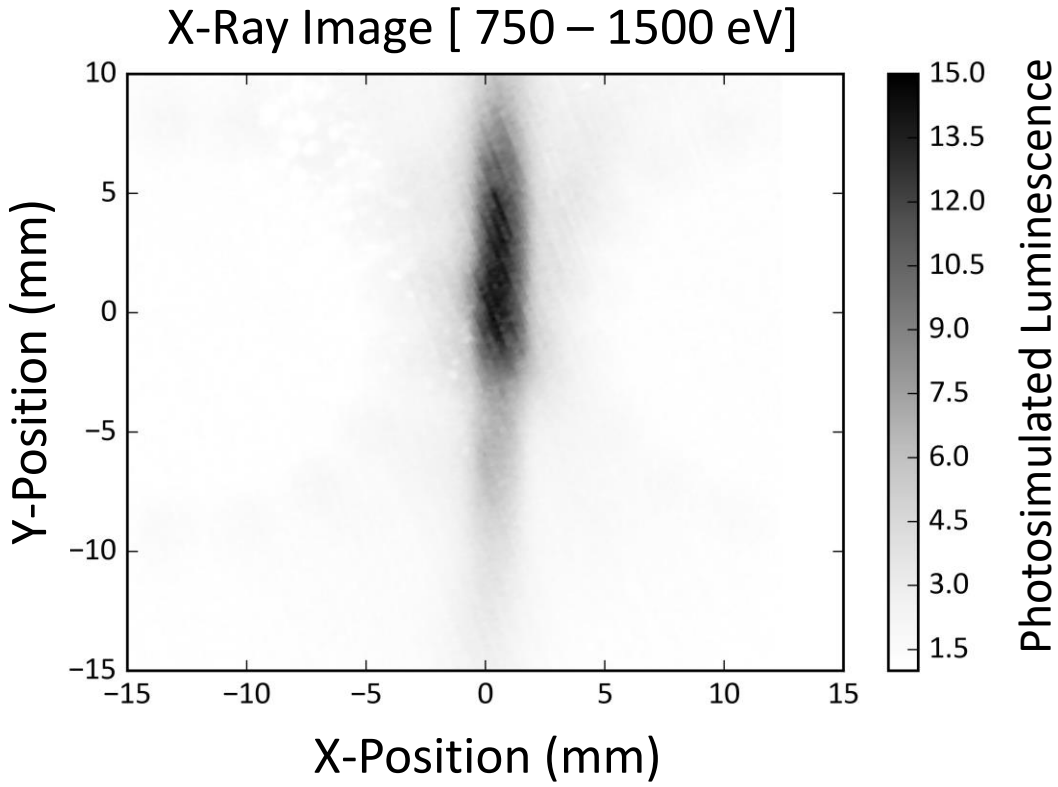




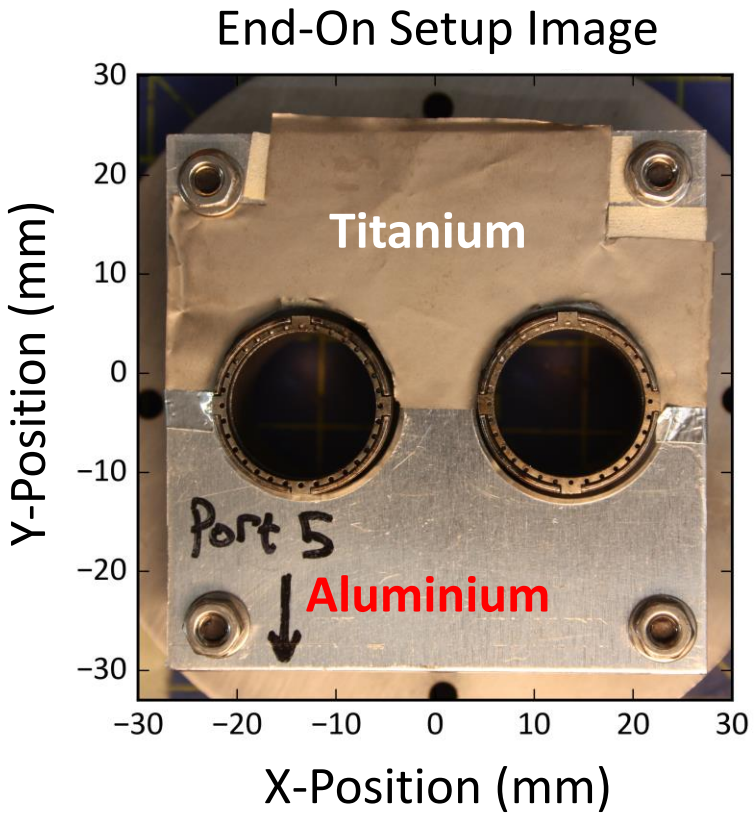
(Adapted from S. A. Pikuz et al. 2008. Rev Sci Instr. 79, 013106)

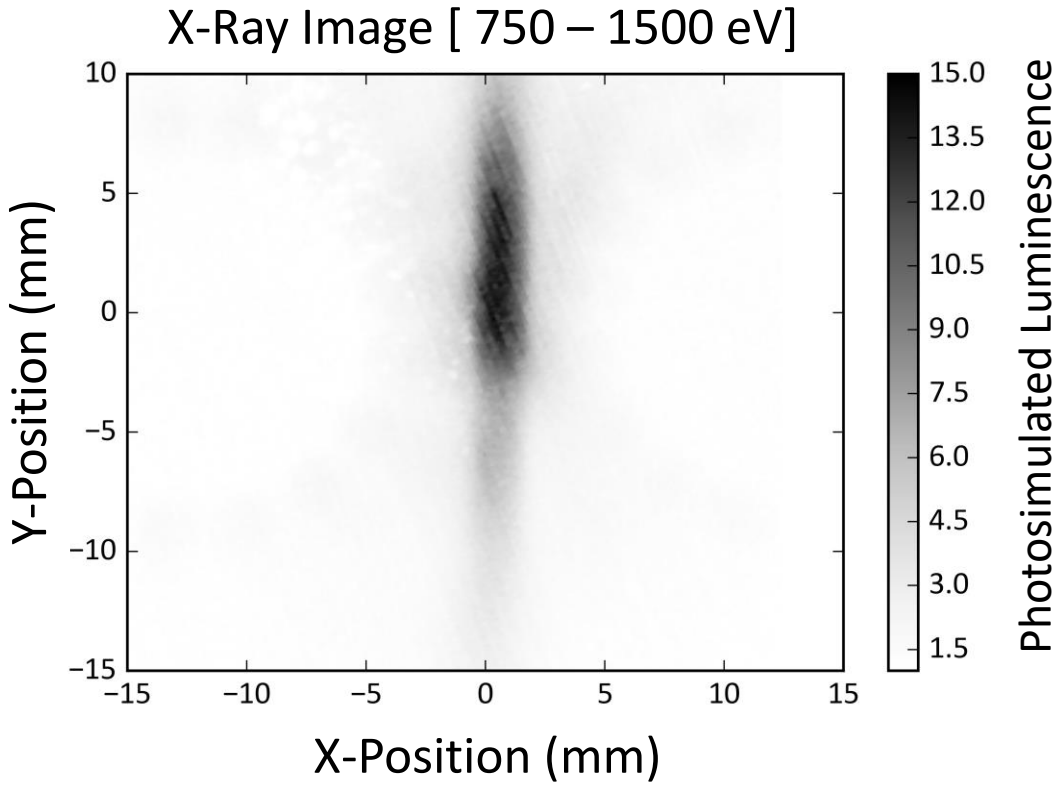
Time-integrated filtered pinhole imaging



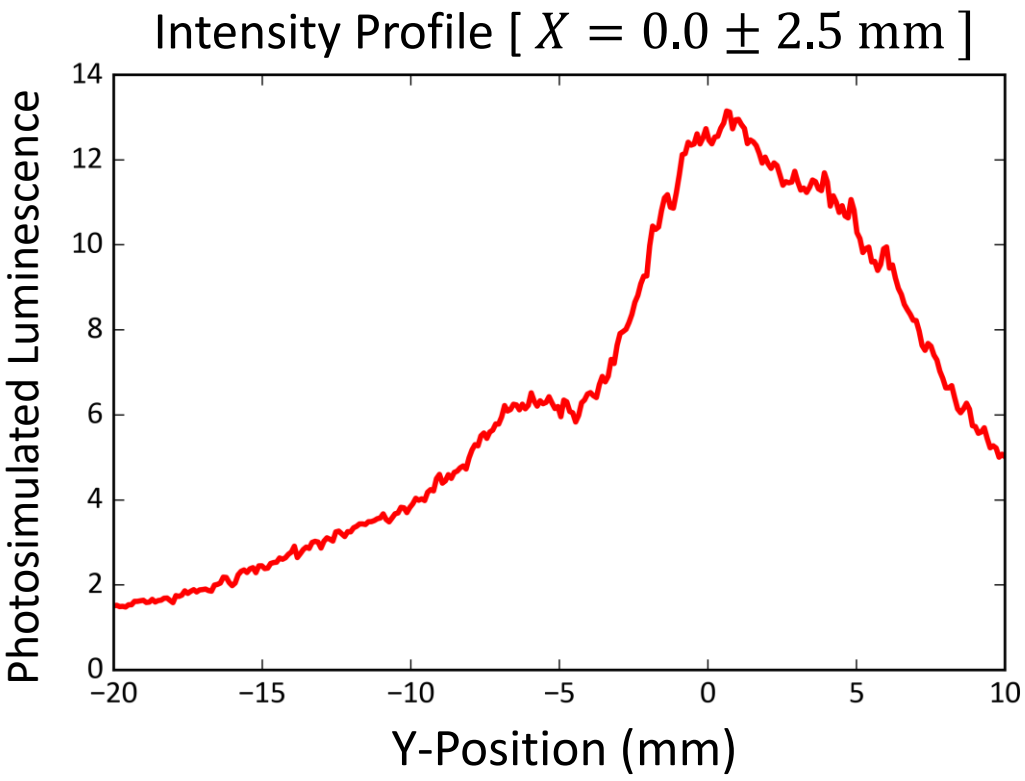


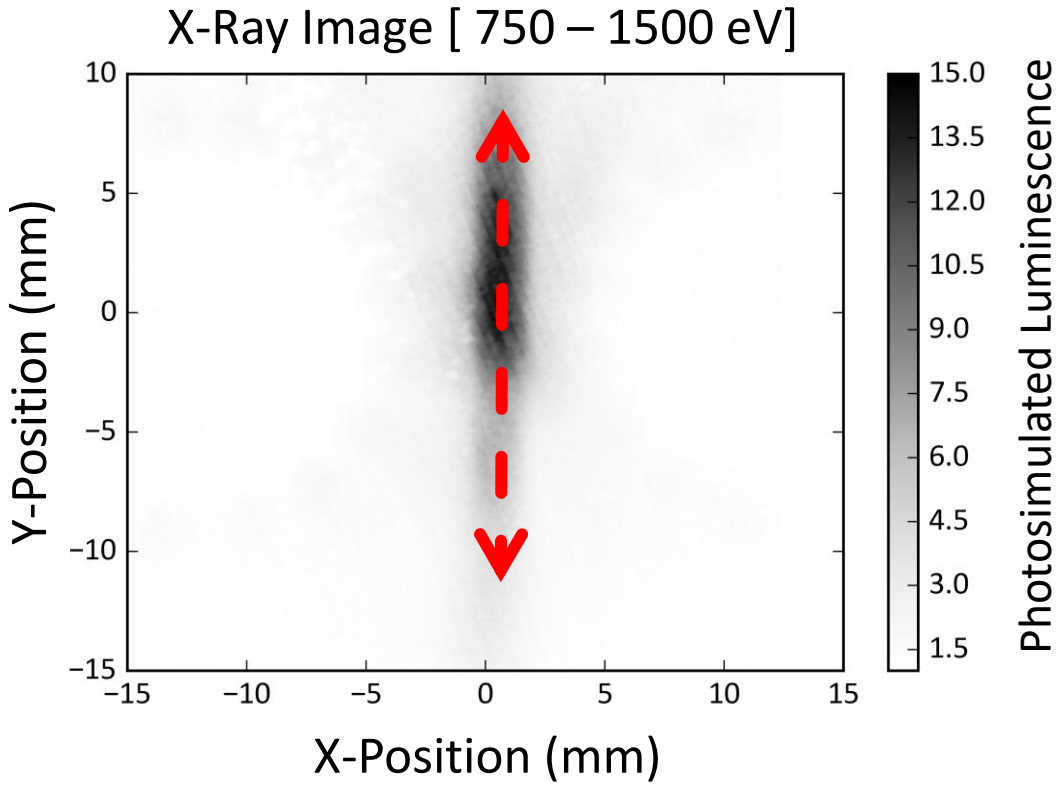
Time-integrated filtered pinhole imaging





Time-integrated filtered pinhole imaging

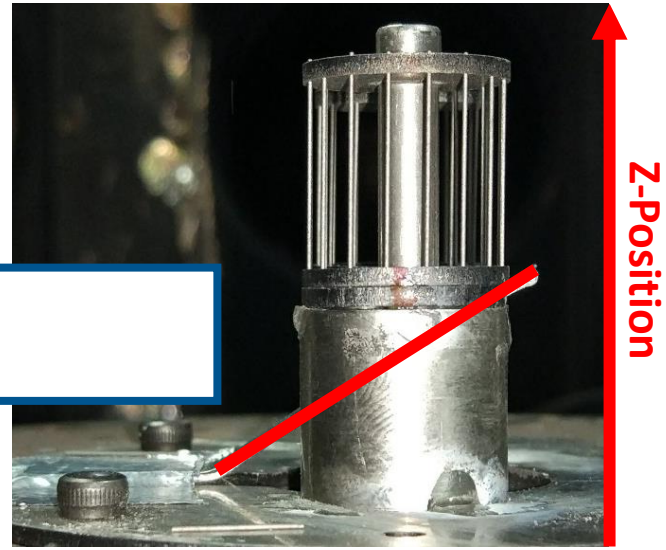


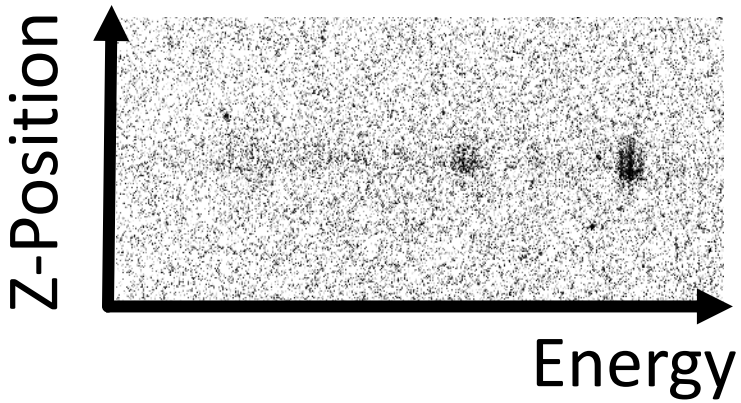


Time-integrated X-Ray spectra

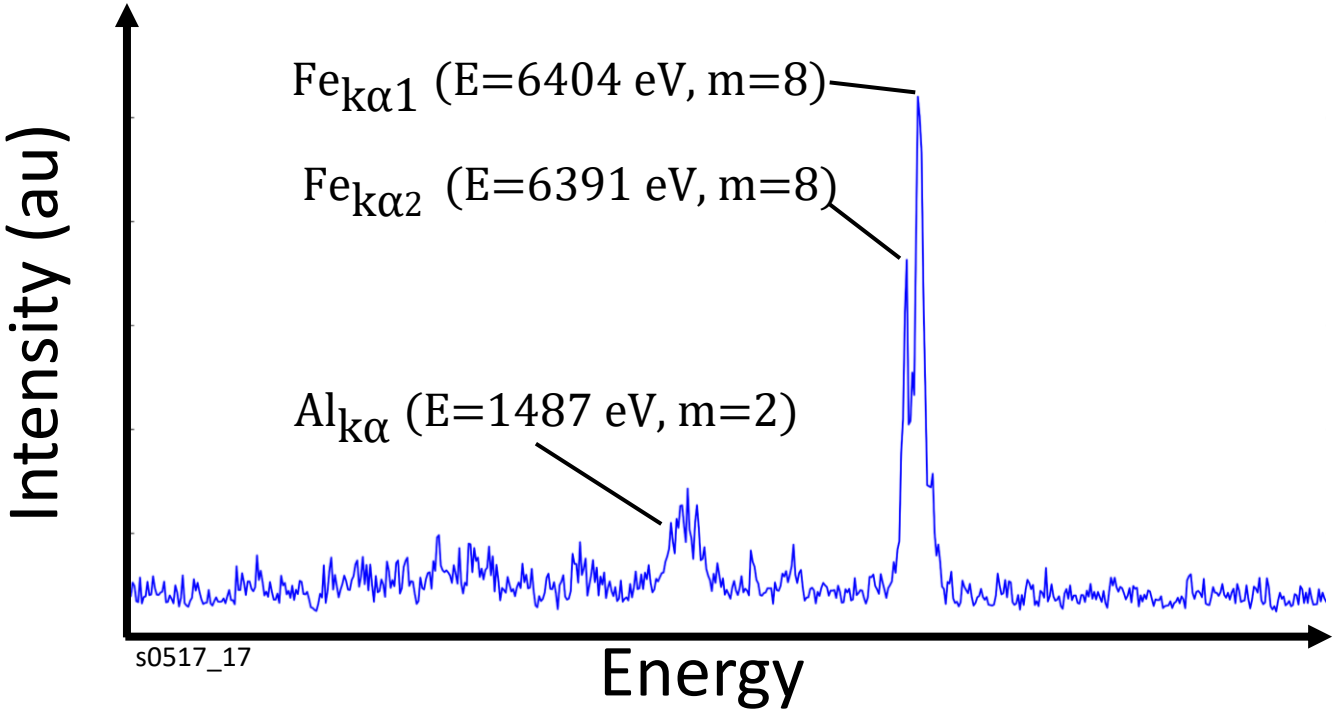
Spherically Bent Crystal Spectrometer

X-Ray Emission



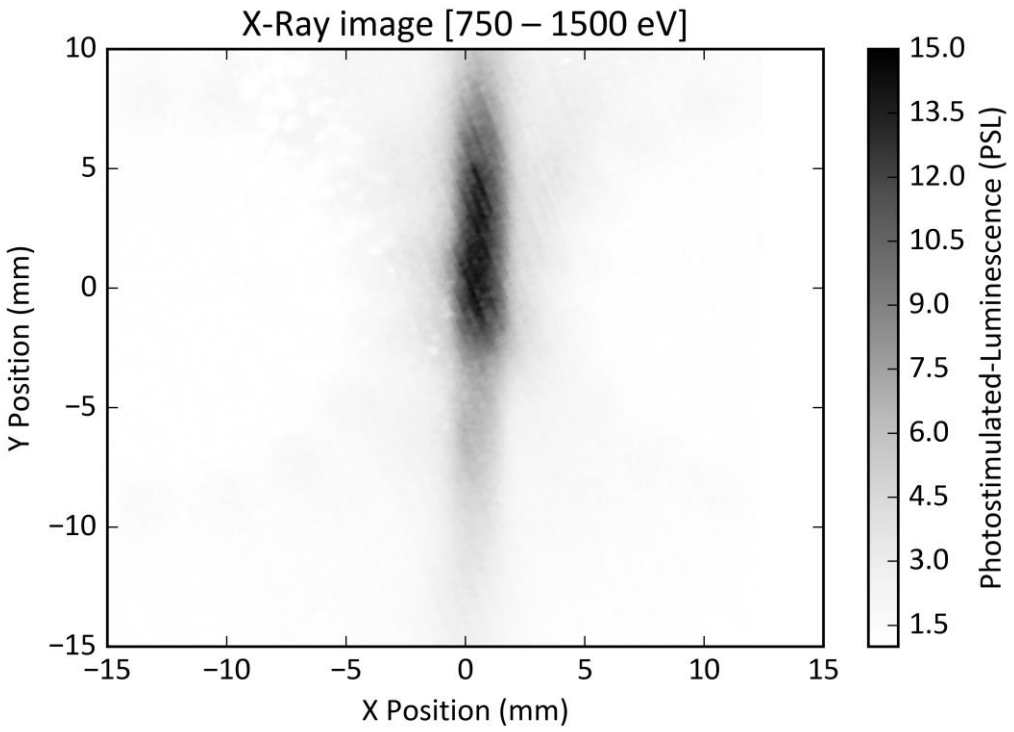


Aluminium witness Plate



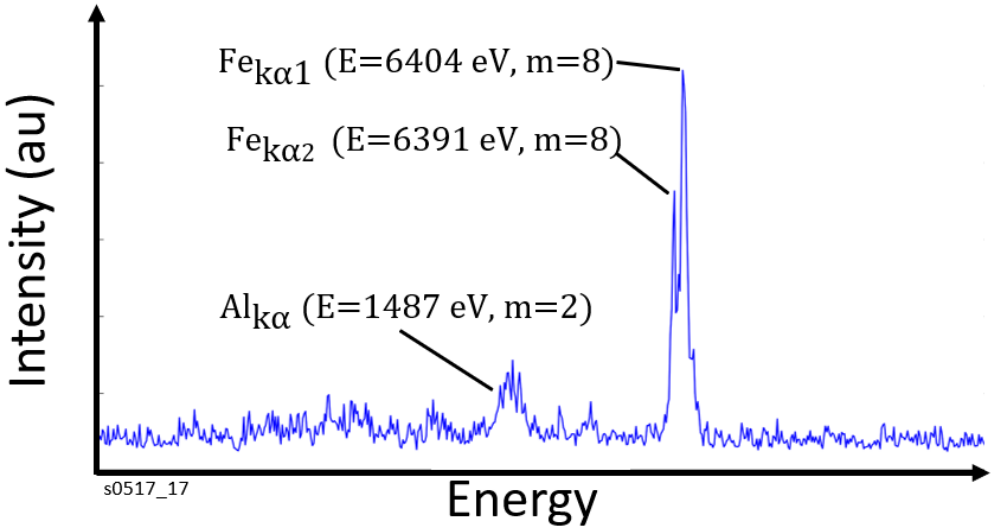
Conclusions

- Particles accelerated to at least 1.5 keV
- Observed fast particles were directed down the reconnection layer
- Consistent with direct particle acceleration by the reconnecting electric field



J. D. Hare. ***Session NI2*** *(Reconnection: Experiments and Observations) on* ***Wednesday, 9:30 AM–10:00 AM,*** *in* **Room 102ABC**.

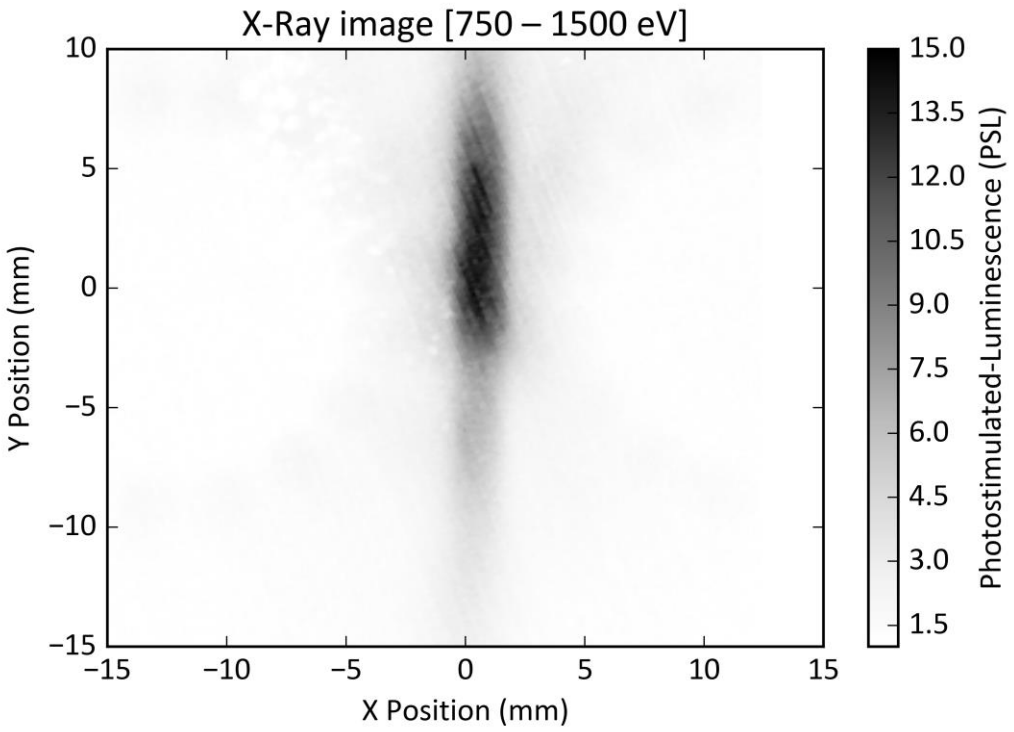
L. G. Suttle. **Session YO6** (Magnetized HEDP and HED Measurement/Diagnostic Techniques) on **Friday, 9:42 AM–9:54 AM** in **Room 202C**.



jack.halliday12@imperial.a

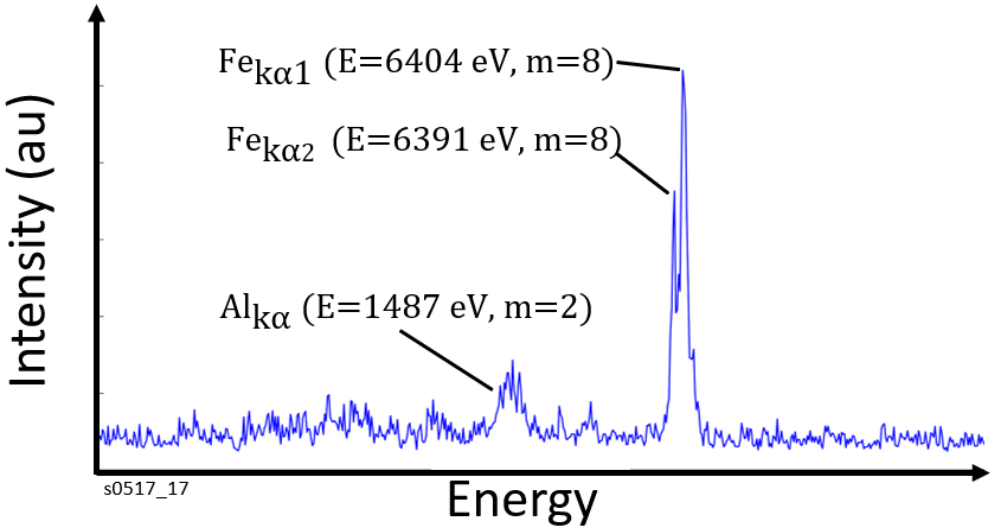
Further Work

- Time resolved measurements
- More emission lines to infer electron energy spectrum



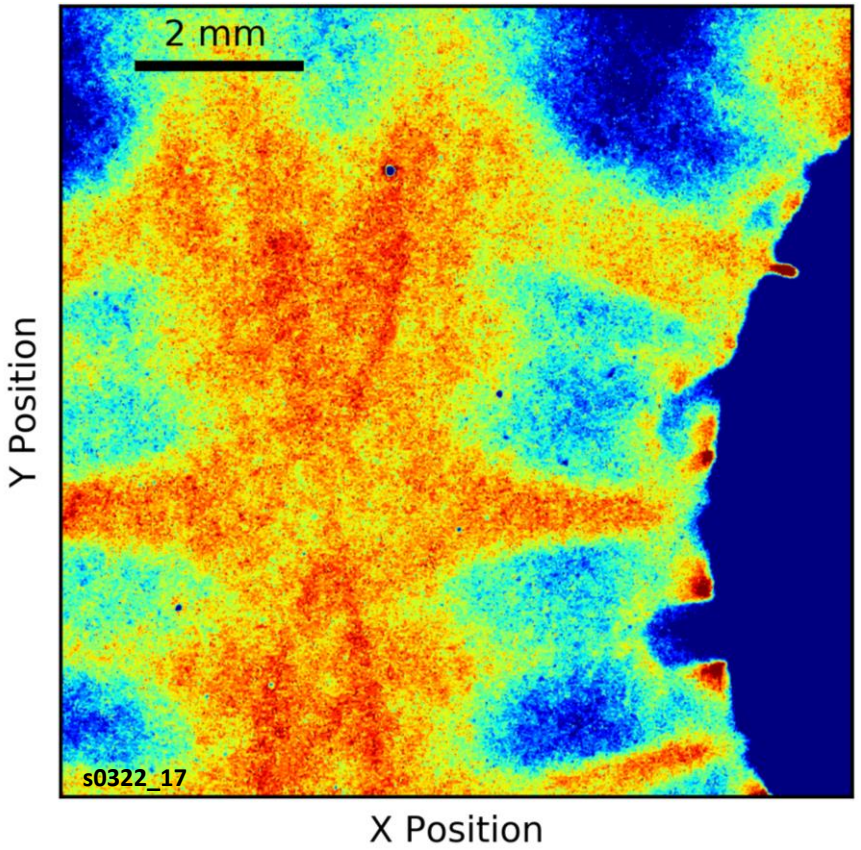
J. D. Hare. ***Session NI2*** *(Reconnection: Experiments and Observations) on* ***Wednesday, 9:30 AM–10:00 AM,*** *in* **Room 102ABC**.

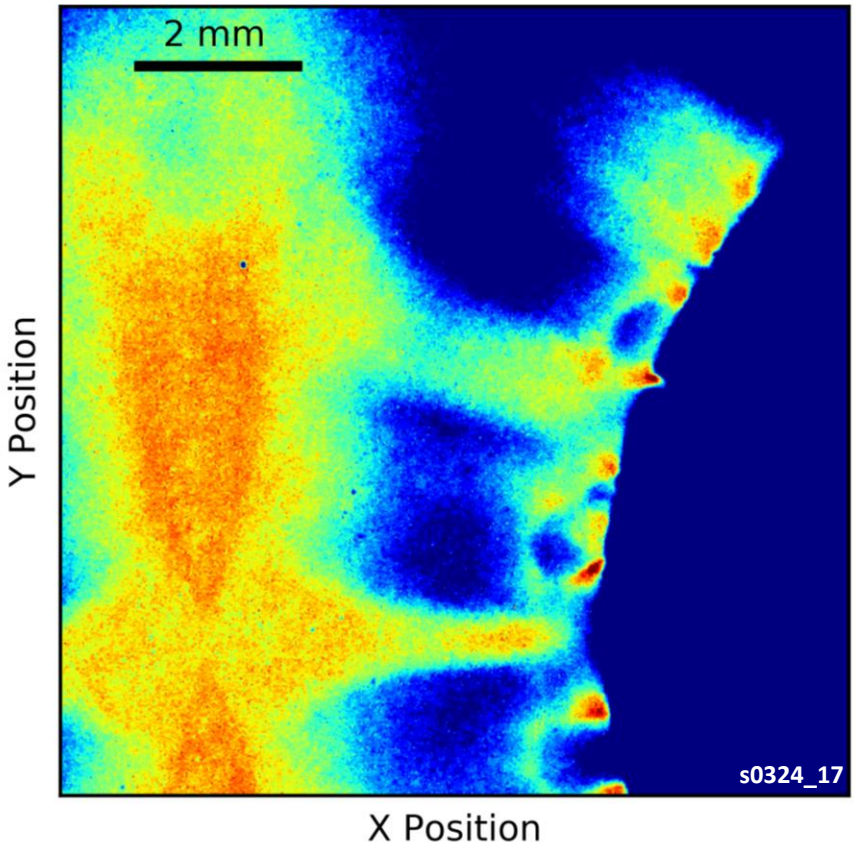
L. G. Suttle. **Session YO6** (Magnetized HEDP and HED Measurement/Diagnostic Techniques) on **Friday, 9:42 AM–9:54 AM** in **Room 202C**.



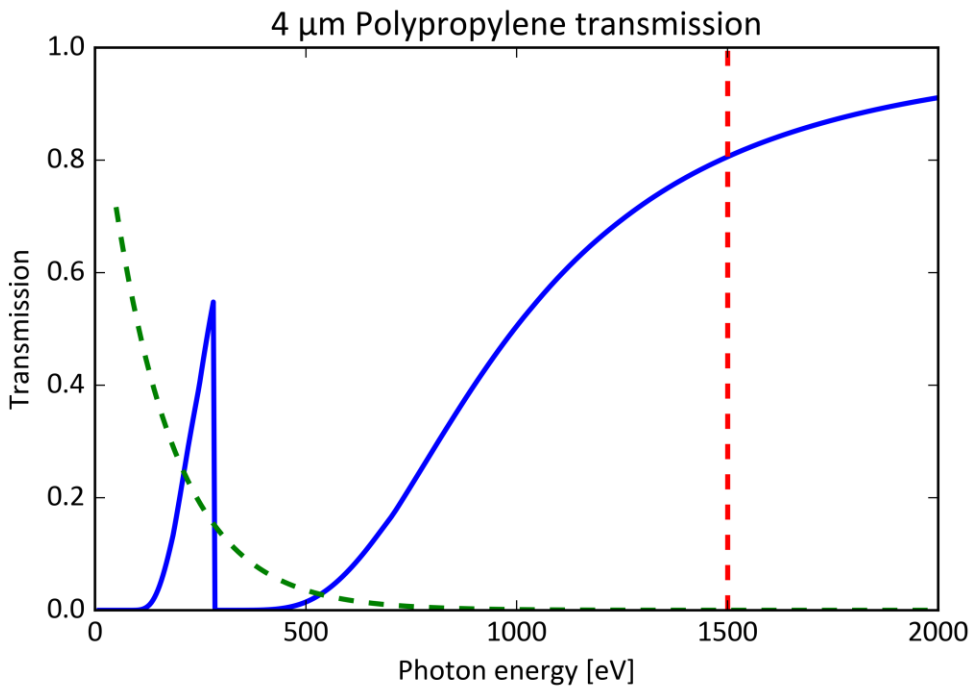
jack.halliday12@imperial.a

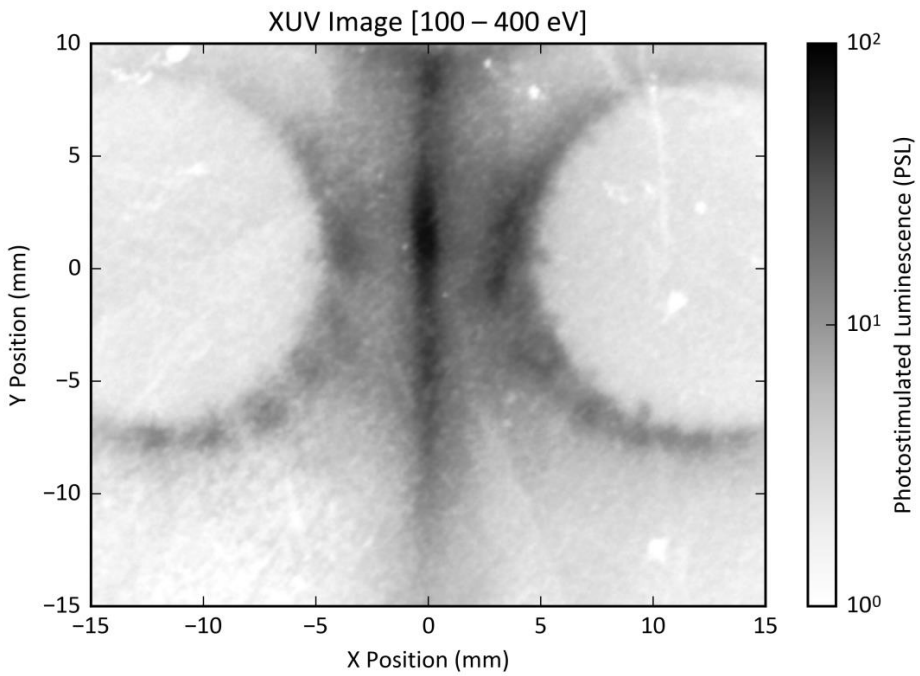
Time gated XUV self emission images



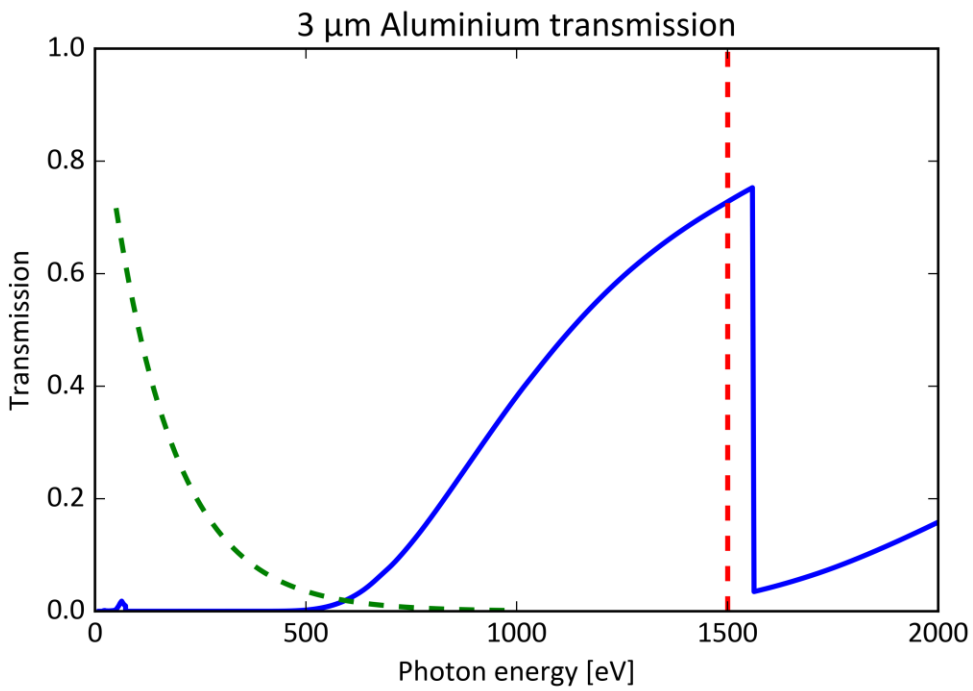


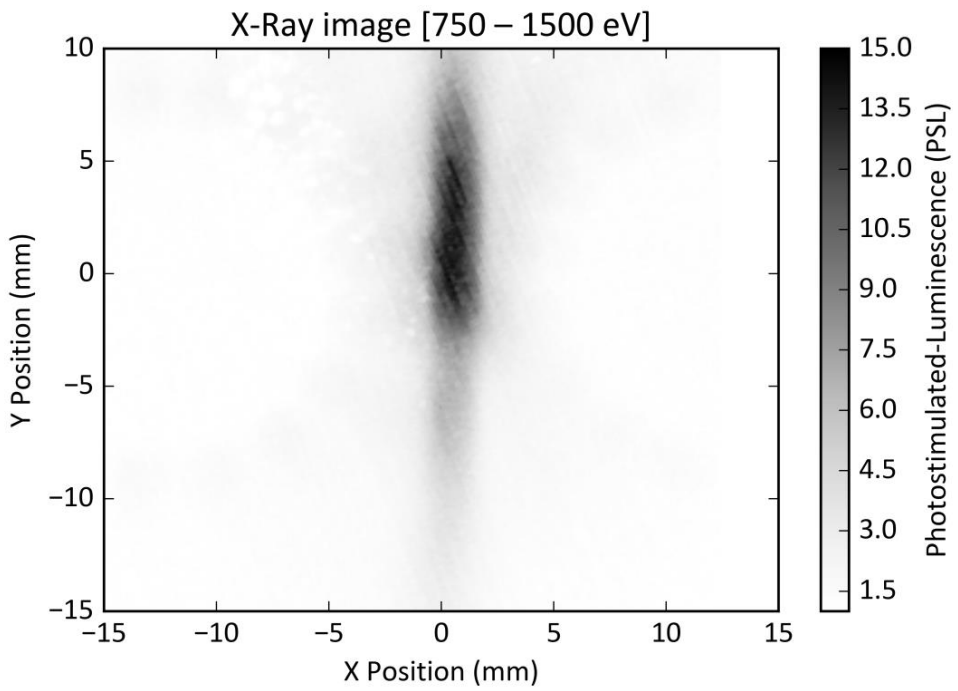
Polypropylene filter transition



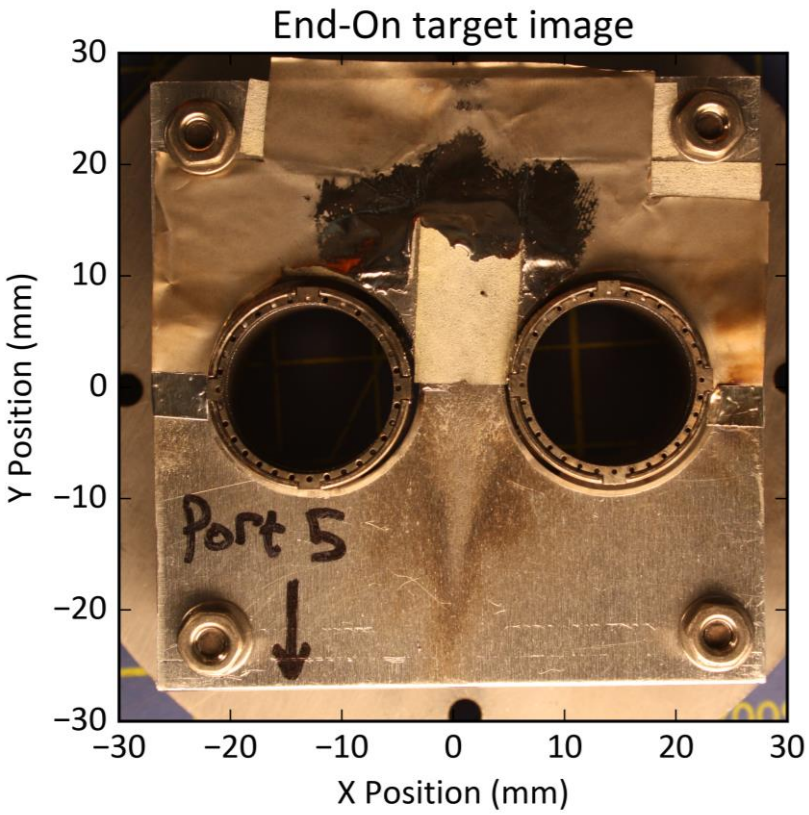


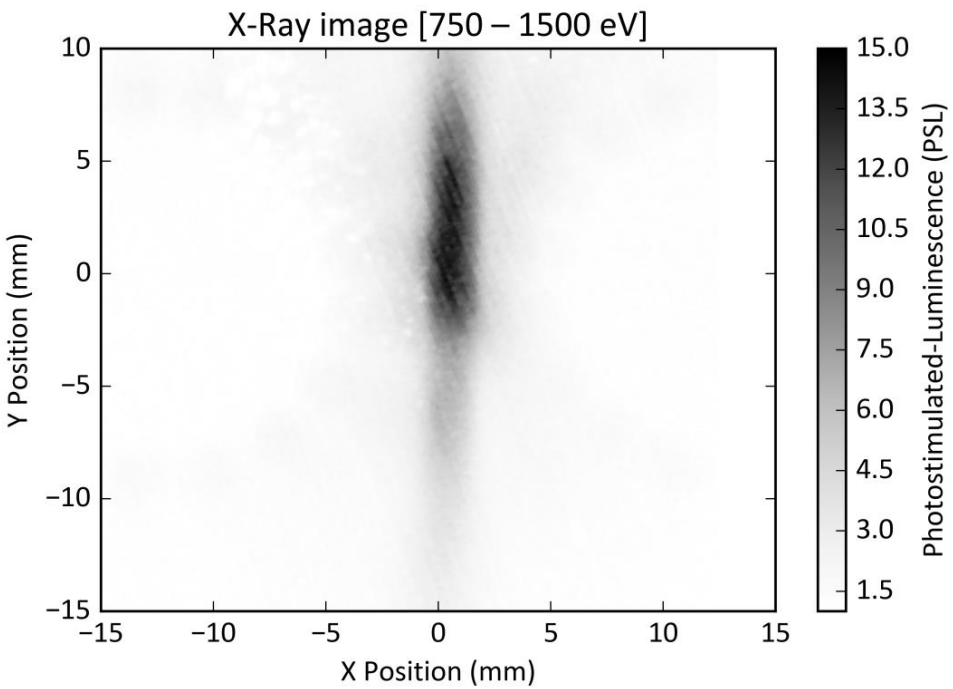
Aluminium filter transition



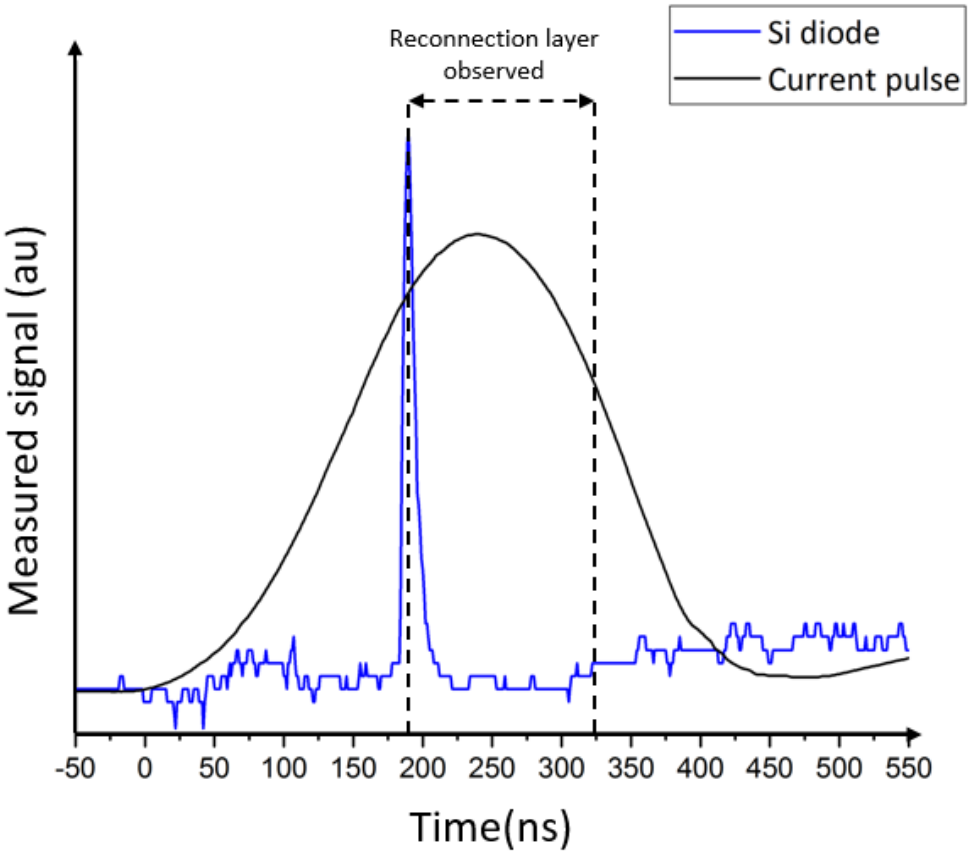


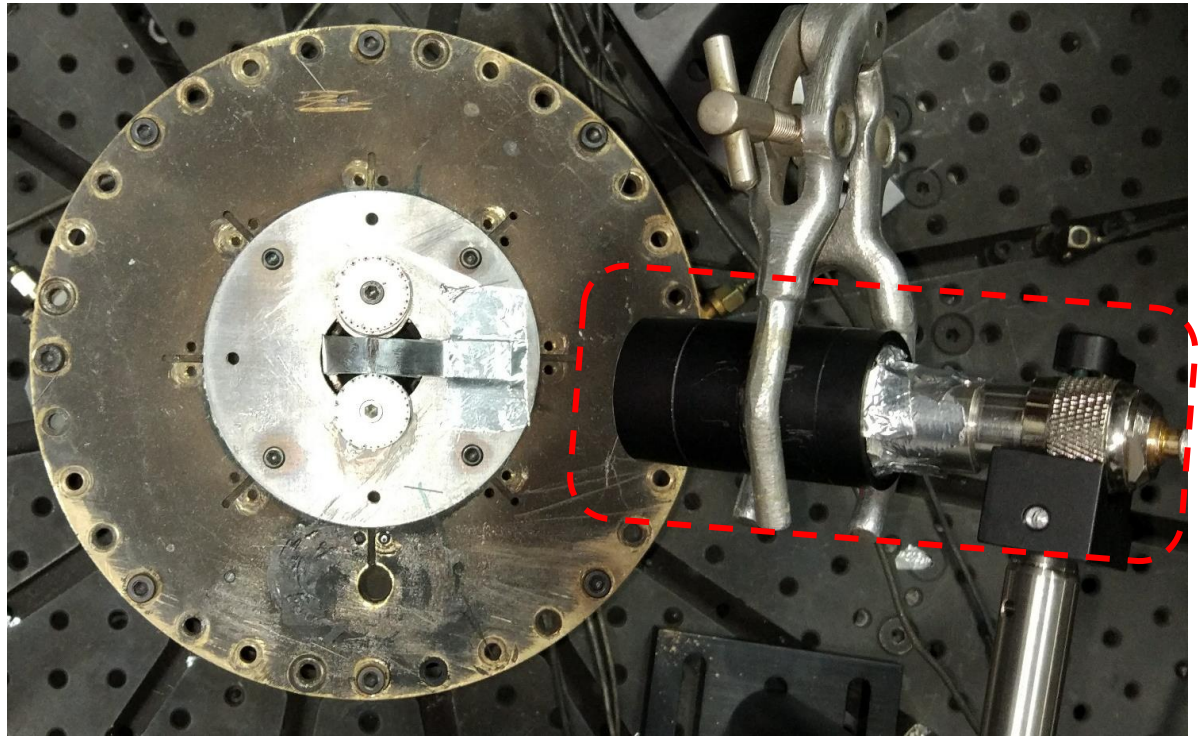
Post-shot images of target



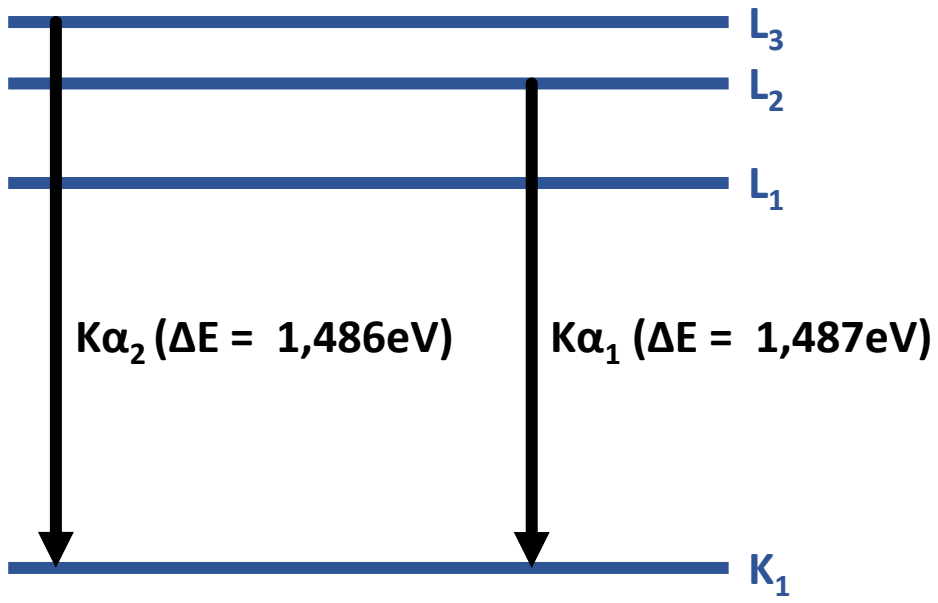


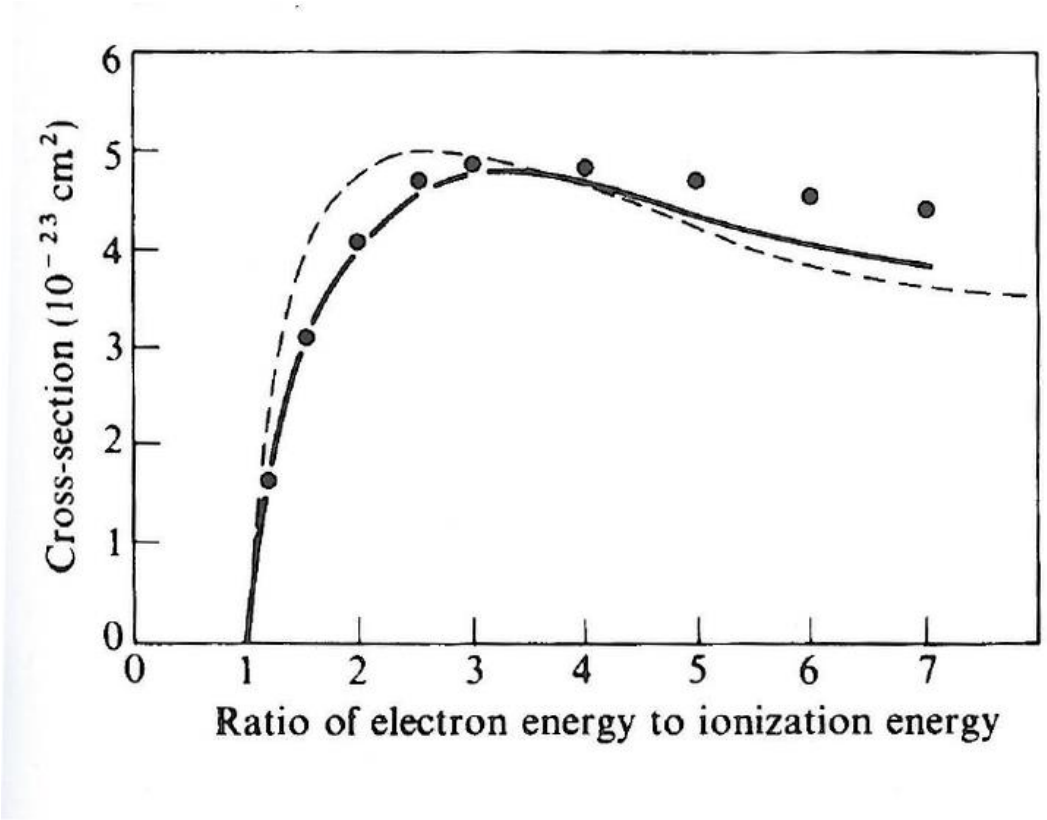
Time resolved measurements





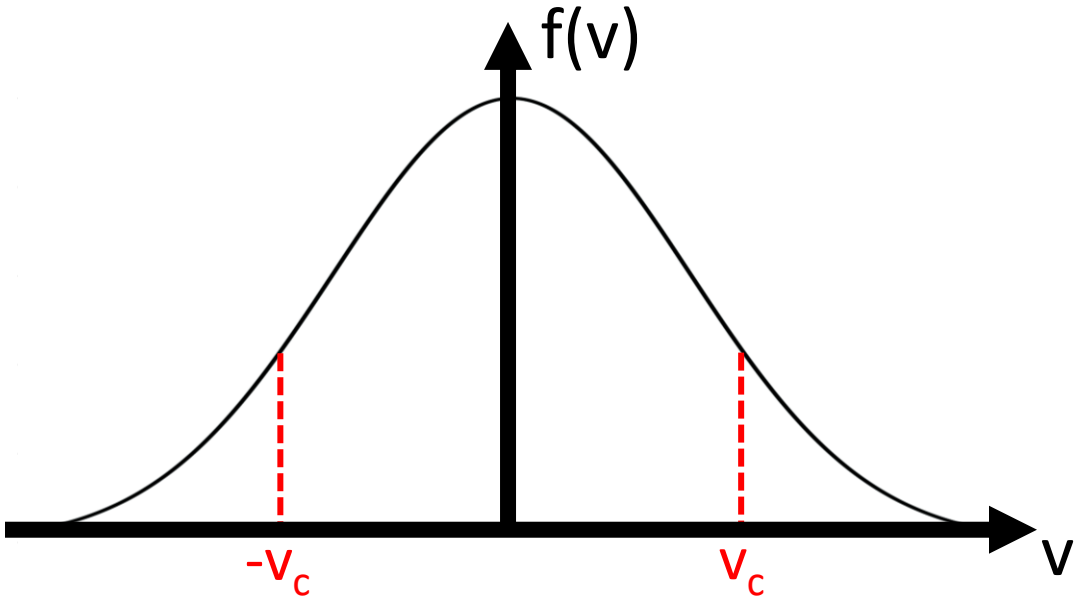
Ionisation cross section





Ref: Dyson, N. A. (2009) X-Rays in atomic and nuclear physics

Runaway electrons



Runaway electrons require: $$\frac{m_e v_c^2}{2T_e} > \frac{(2+Z_i)E_D}{|\boldsymbol{E}|}$$

E_D is the Dreicer field: $$E_D = \frac{mev_{Te}\nu(v_{Te})}{eZ_i}$$

$$E_D = 4.6\ \mathrm{MV/m}$$

$$\Rightarrow \varepsilon_c = \frac{1}{2}m_e v_c^2 = 24\ \mathrm{keV}$$

No' of runaway $\propto \exp(-\varepsilon_c/T_e) \sim 10^{-56}$

$$|\boldsymbol{E}| = 150\ \mathrm{kv/m}$$

$T_e = 100$ eV (Thomson scattering)

$Z_i = 6$ (carbon)

$n_e = 6 \times 10^{17}\ \mathrm{cm}^{-3}$ (Laser interferometry)

Ref: J. D. Callen, *Fundamentals of Plasma Physics (draft).* July 2006.