Laser driven x-ray radiography for the characterization of dense matter

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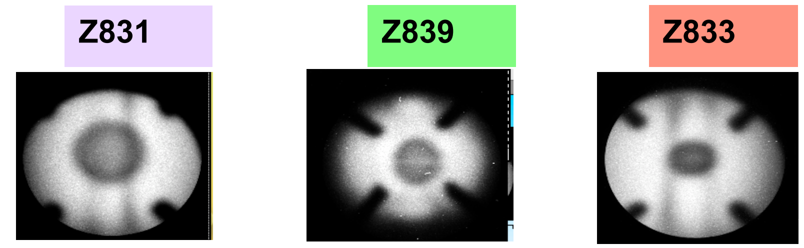
Motivation

- EOS measurements mostly based on velocity measurement (shock+particle)
  - Density sensitive to errors $\frac{\delta\rho}{\rho} = \left(\frac{\rho}{\rho_0} - 1\right)\sqrt{\left(\frac{\delta U_S}{U_S}\right)^2 + \left(\frac{\delta U_P}{U_P}\right)^2}$
- Independent measurement of additional parameter improves EOS determination
- X-rays allow to probe matter directly

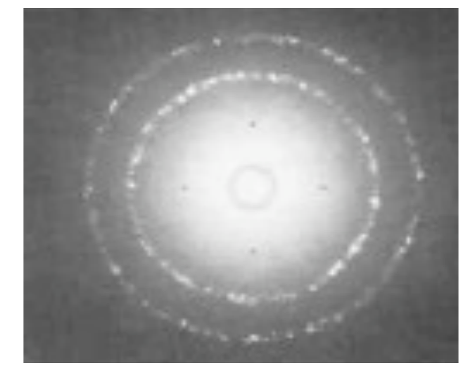
X-ray source studies

x-ray diagnostics



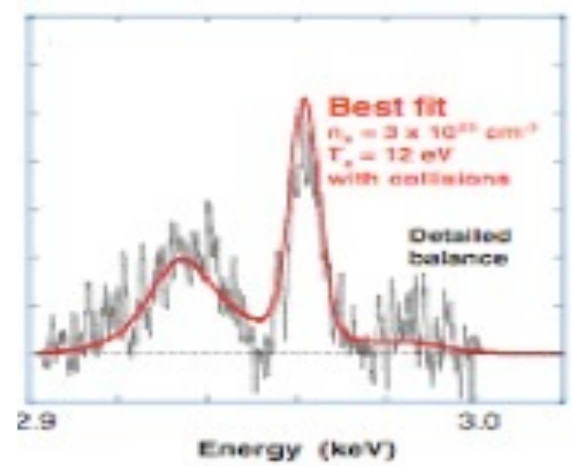
X-ray radiography

Absorption by bound electrons
→ ion density, shape



X-ray diffraction

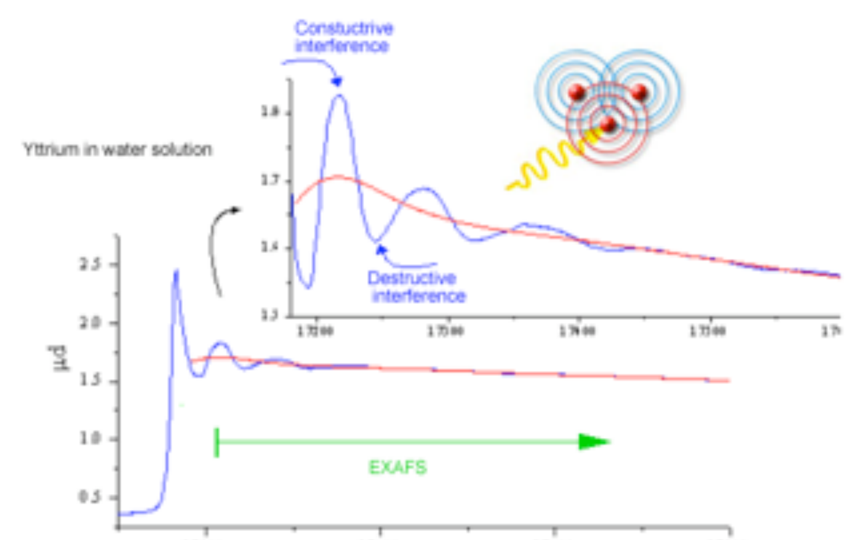
Coherent elastic scattering
→ lattice/ion structure



Glenzer et al. PRL 98,065002

X-ray Thomson scattering

Inelastic scattering
→ electron density and temperature

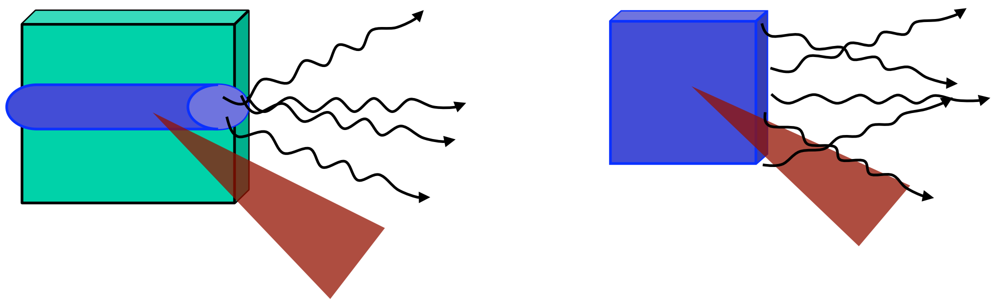


Near edge absorption spectroscopy

→ local chemistry and structure

What do we need?

- High photon energies (5-100 keV)
  - High intensity lasers
- High temporal resolution
  - Short pulse laser
- High spatial or angular resolution
  - Target design

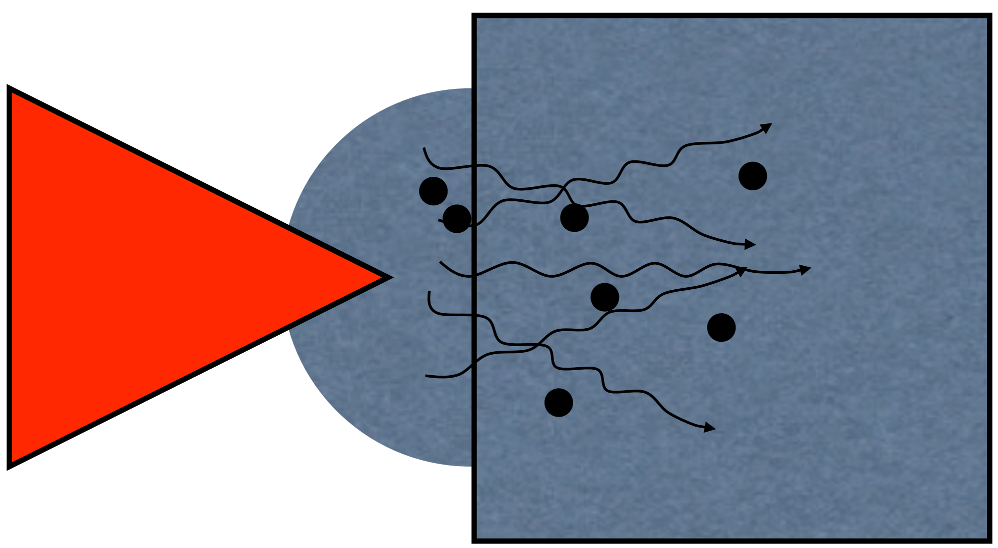


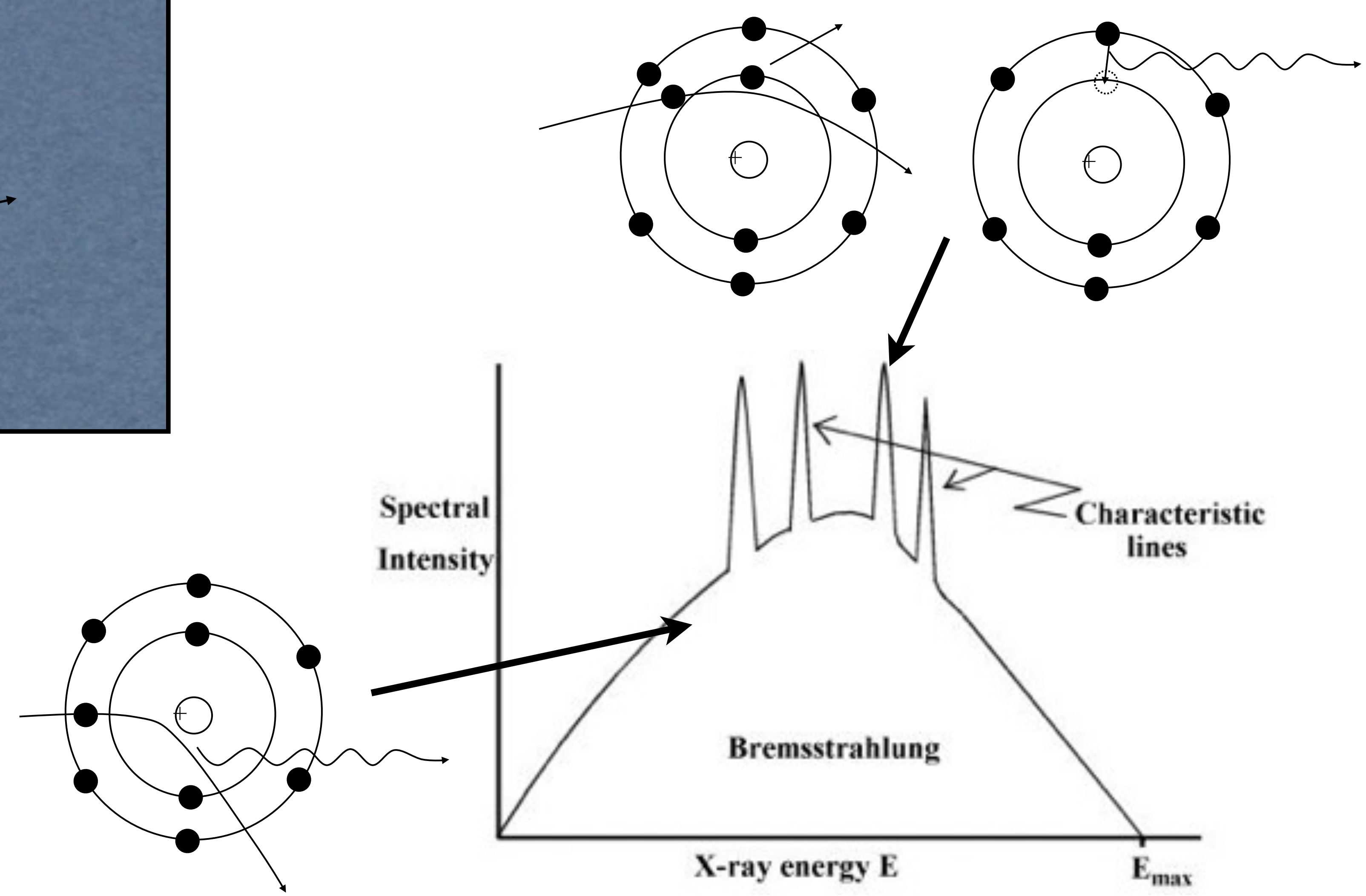
- Monochromatic or flat spectrum
  - Choice of target material, monochromators
- Large number of photons
  - High energy laser systems

X-ray generation with high intensity lasers

Interaction of high intentsity laser with matter creates large number of energetic electrons

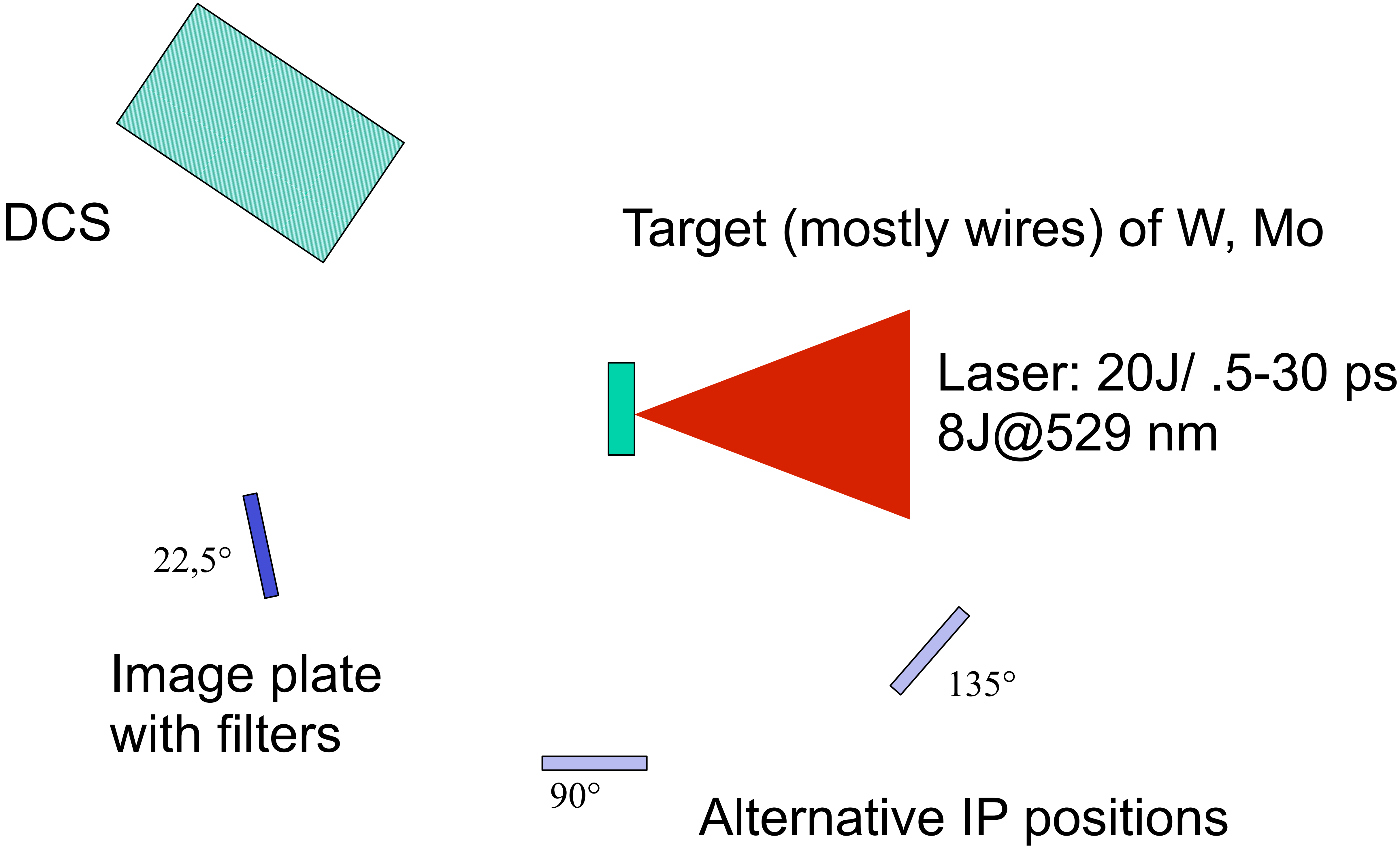
Interaction of these electrons with the bulk material creates x-rays (and other things)



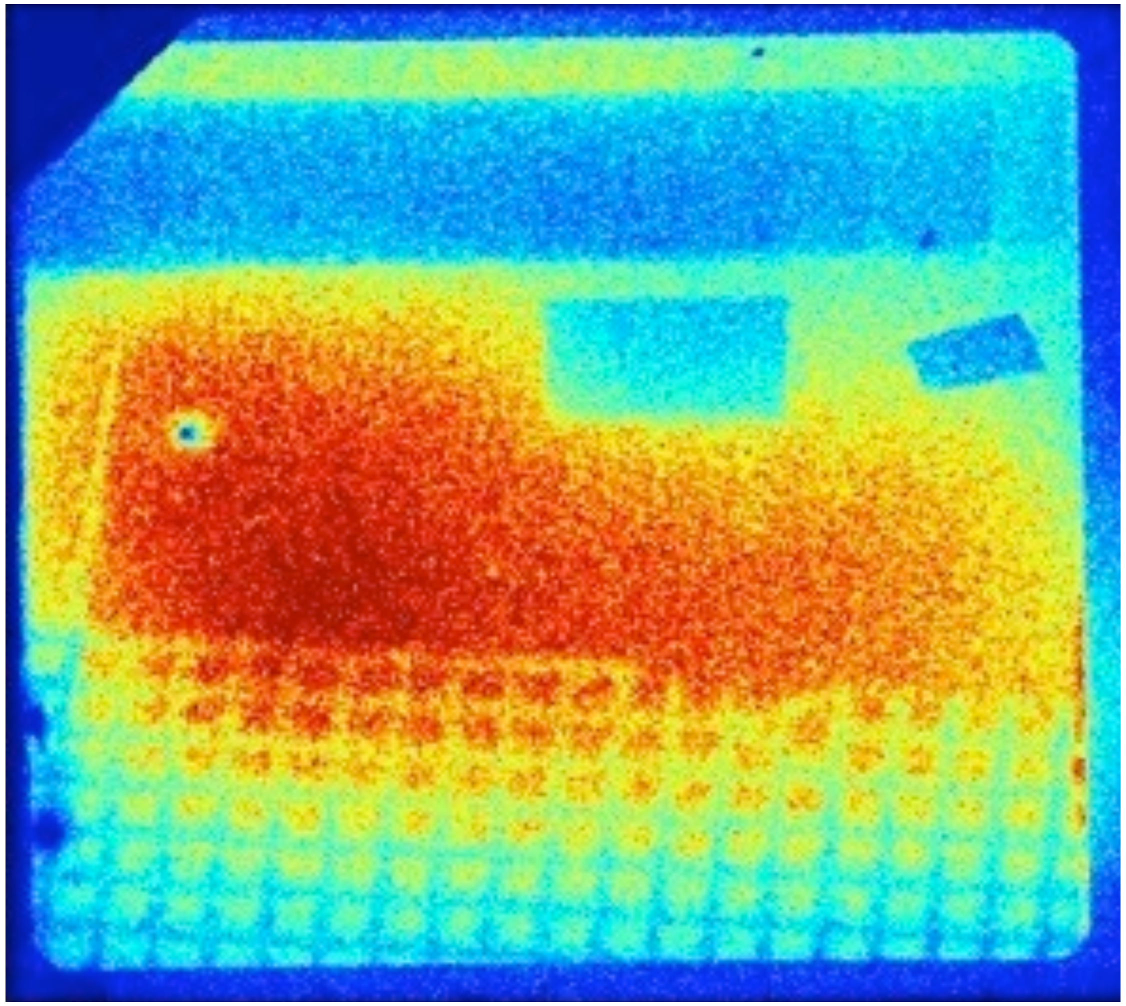


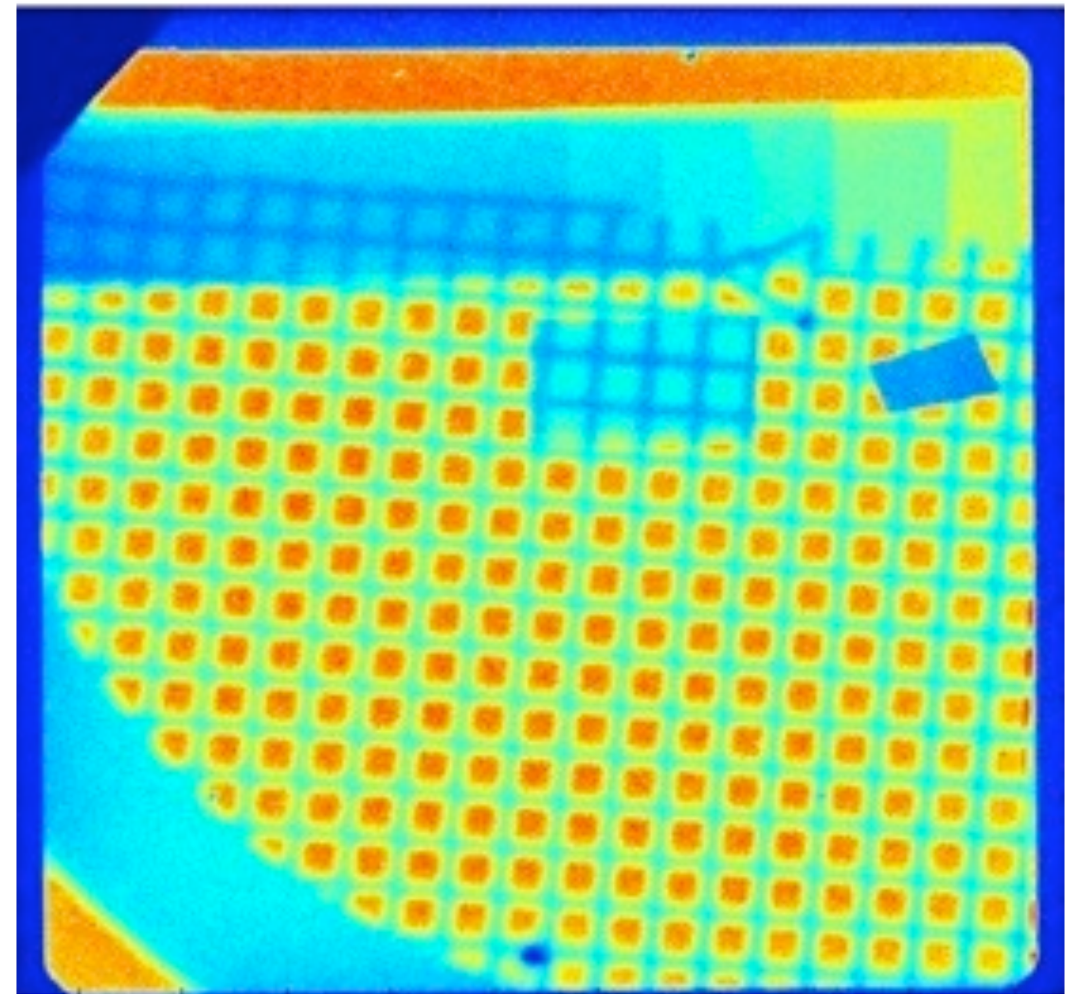
Laser driven x-ray tube

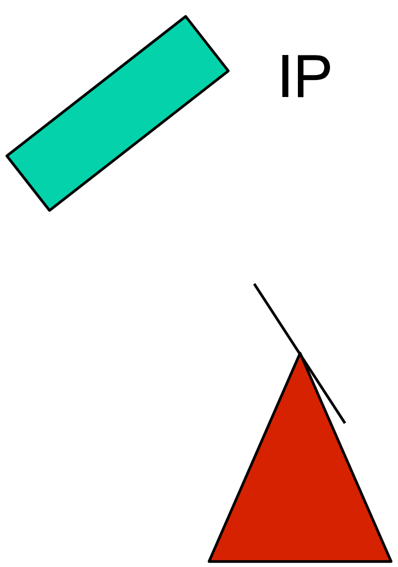
Experimental setup



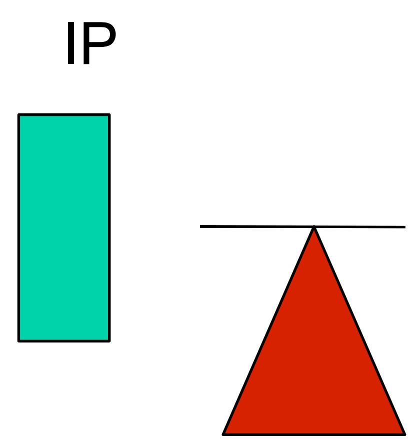
Role of the experiment geometry





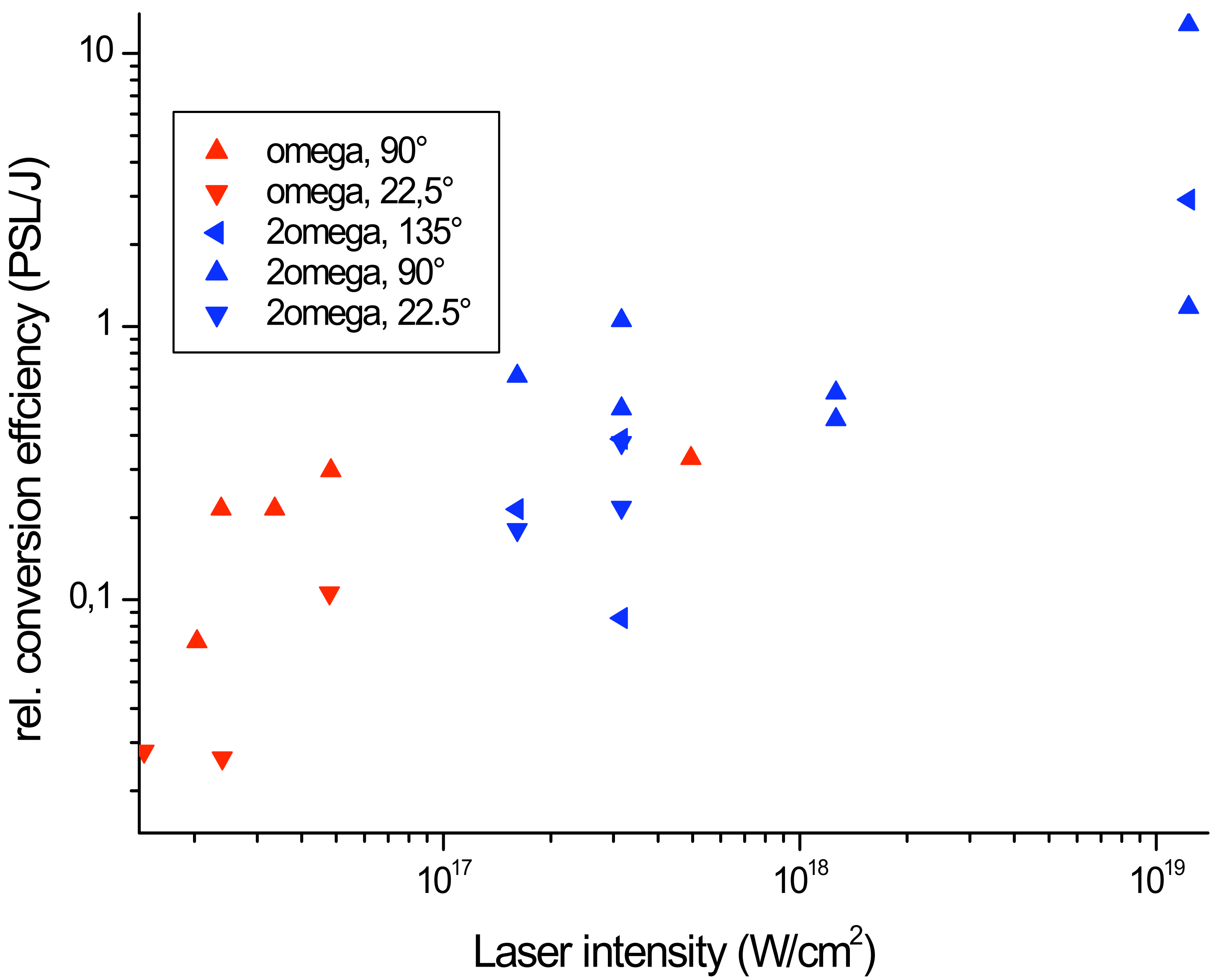


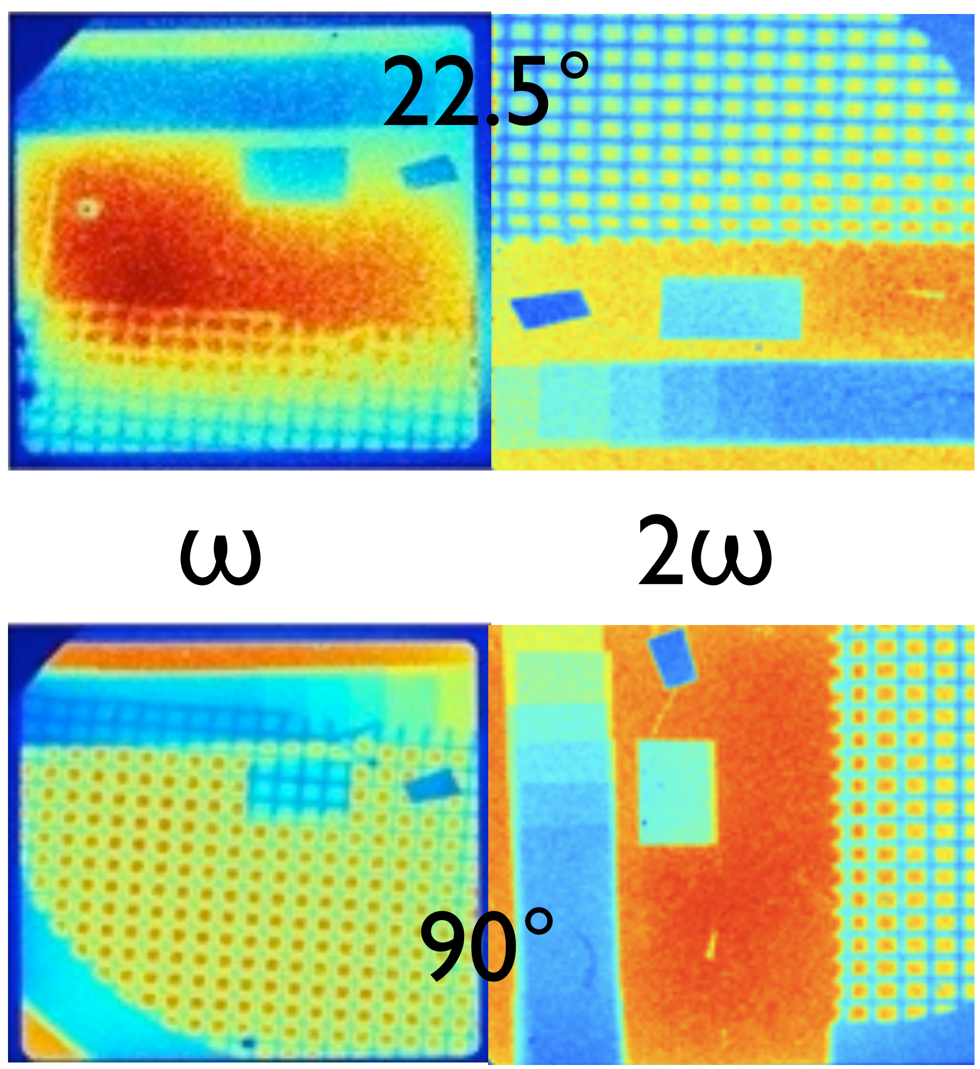
oblique incidence
22,5°



Perpendicular
incident:

Effect of the pre-plasma

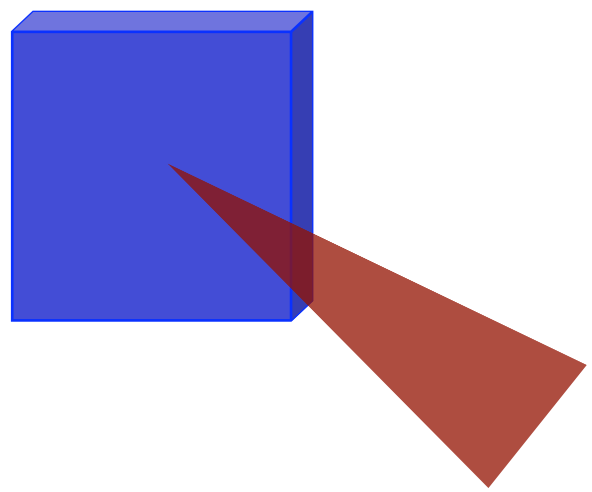




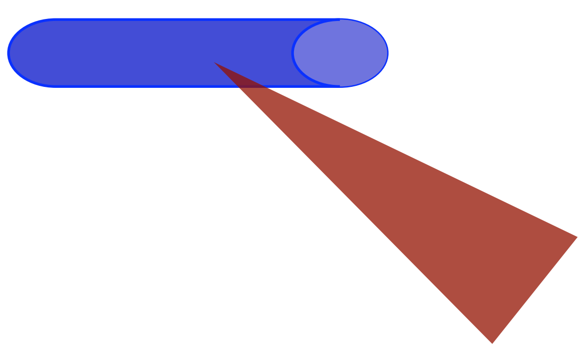
Optimization of laser parameters targets
and experimental geometry

Brambrink et al. PoP 2009

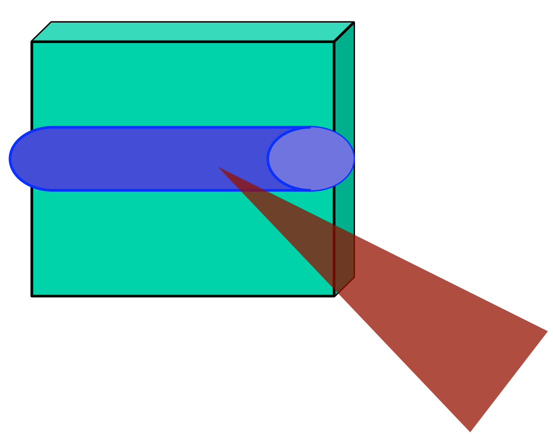
Target types



Flag target, 1 D resolution
easy to build, easy to shot



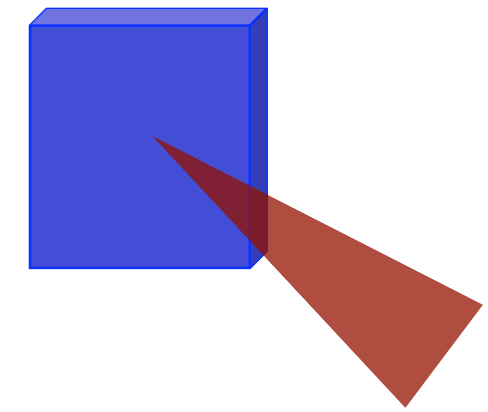
Free standing wire, 2D resolution
more difficult to build, pointing!!

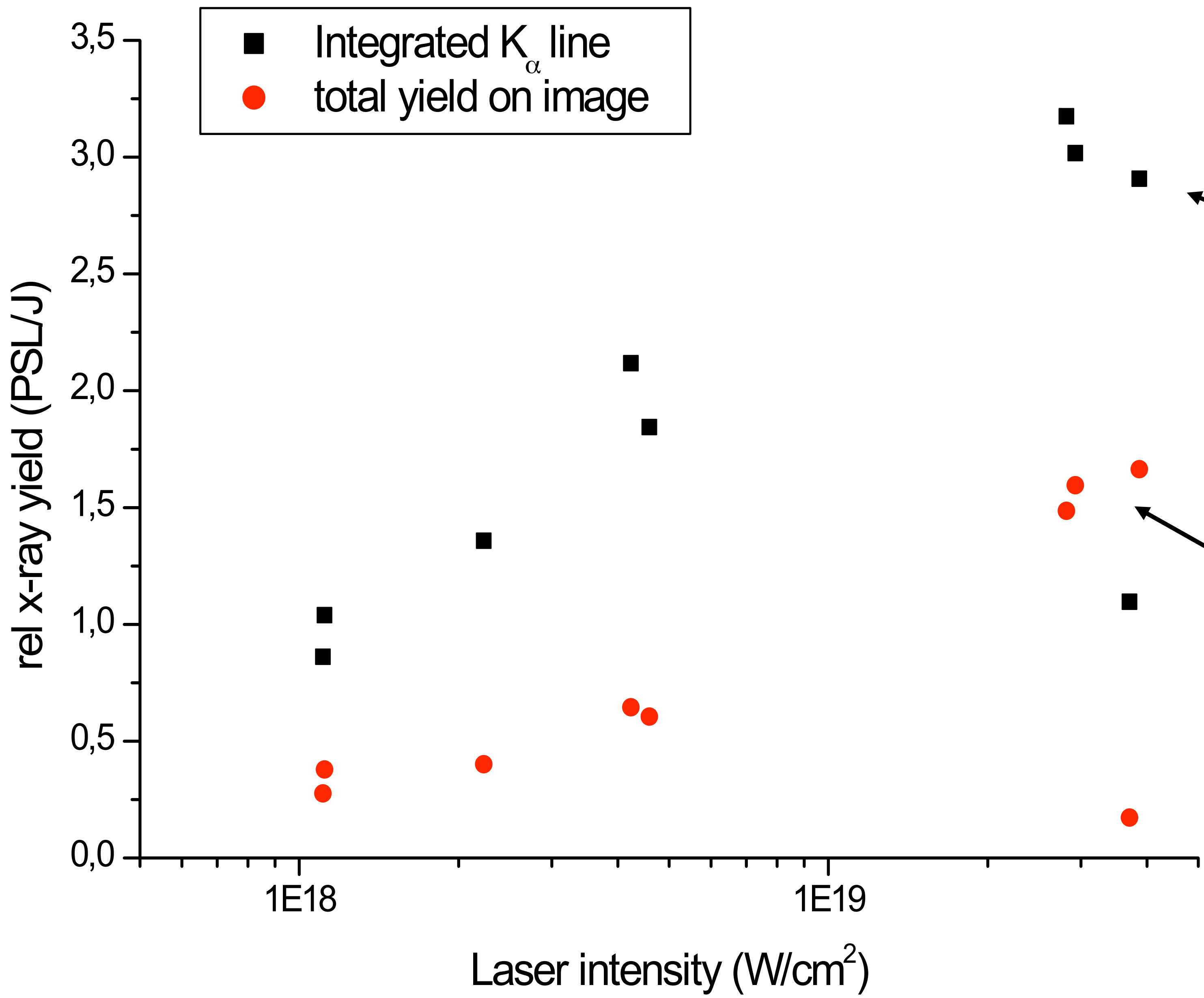


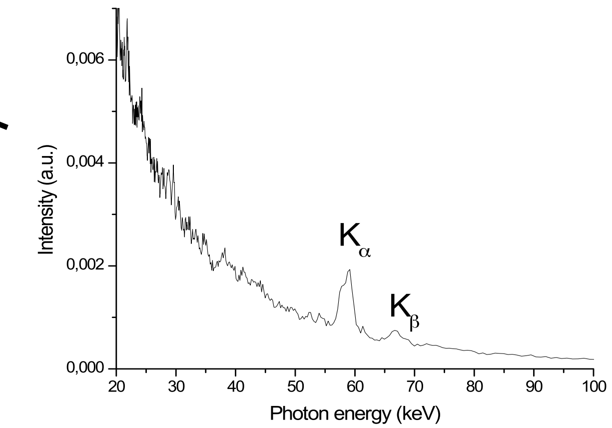
Wire glued on plastic, 2D resolution?
manufacturing

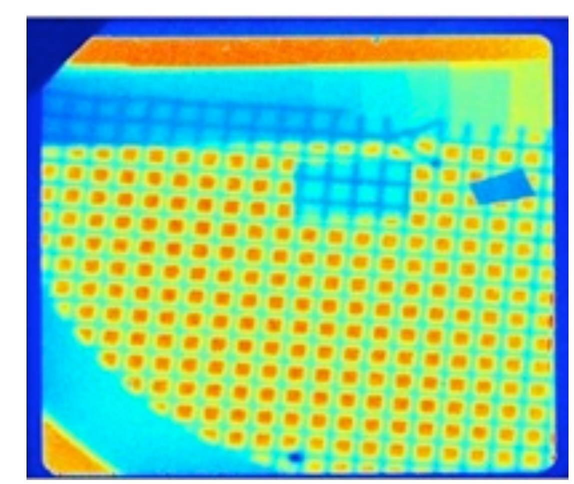
Required resolution ≈10 μm ➡small targets

Intensity scan flag targets



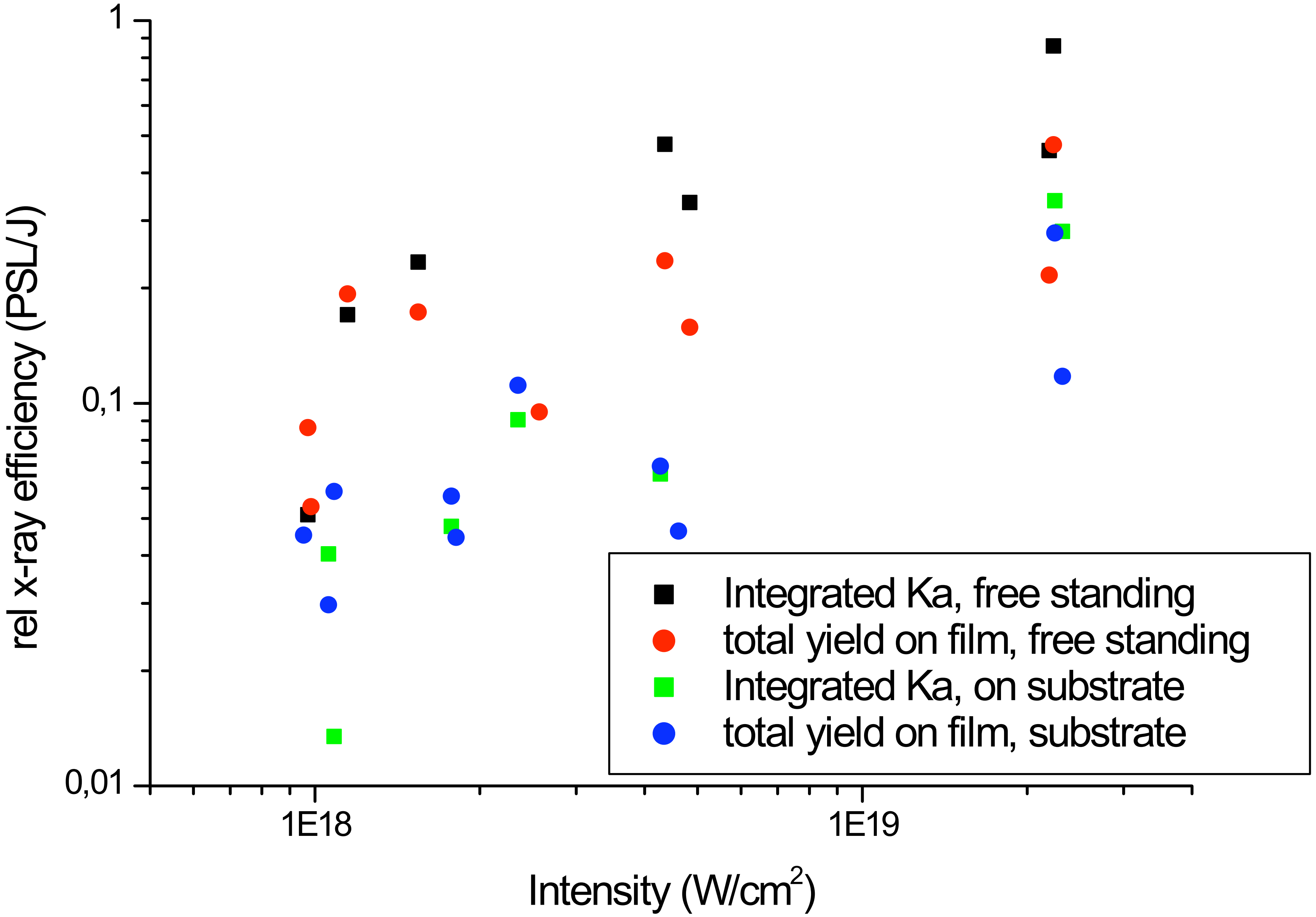


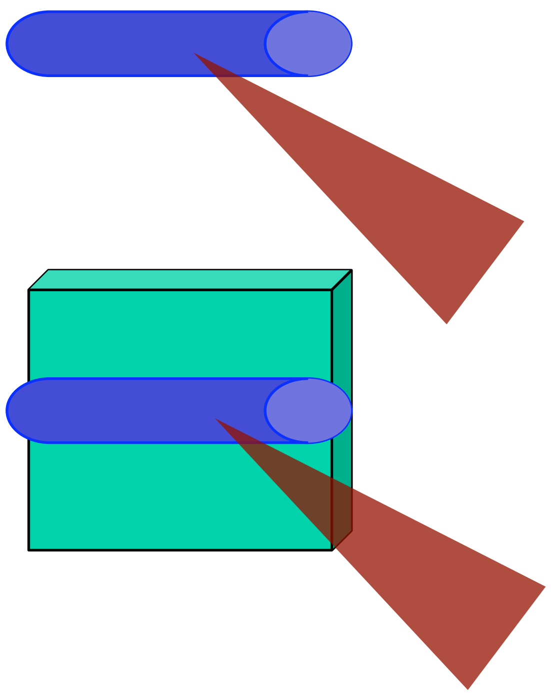




X-ray conversion efficiency increases with laser intensity

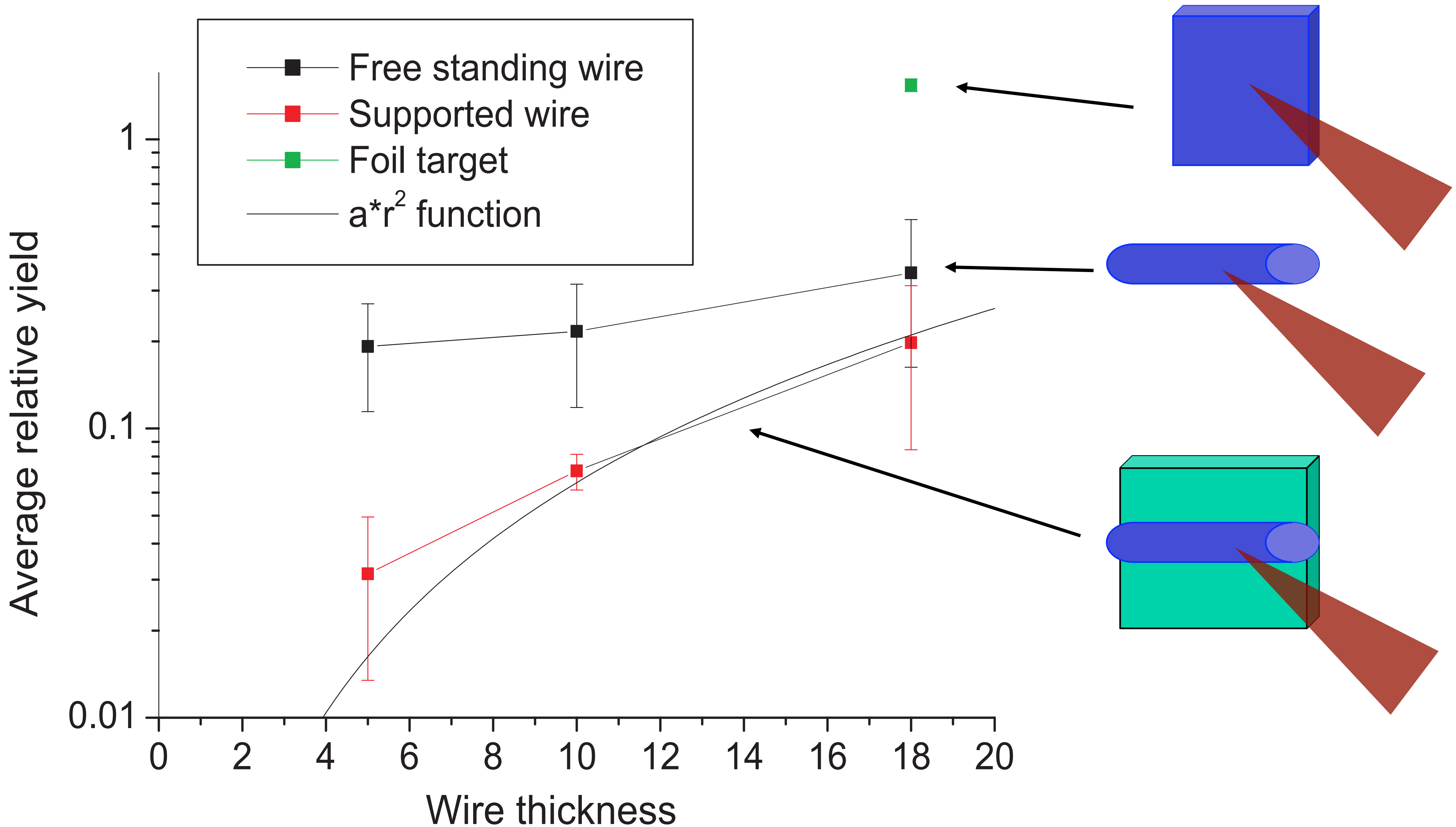
Wire intensity scan





Conversion efficiency increases with intensity also for wire targets

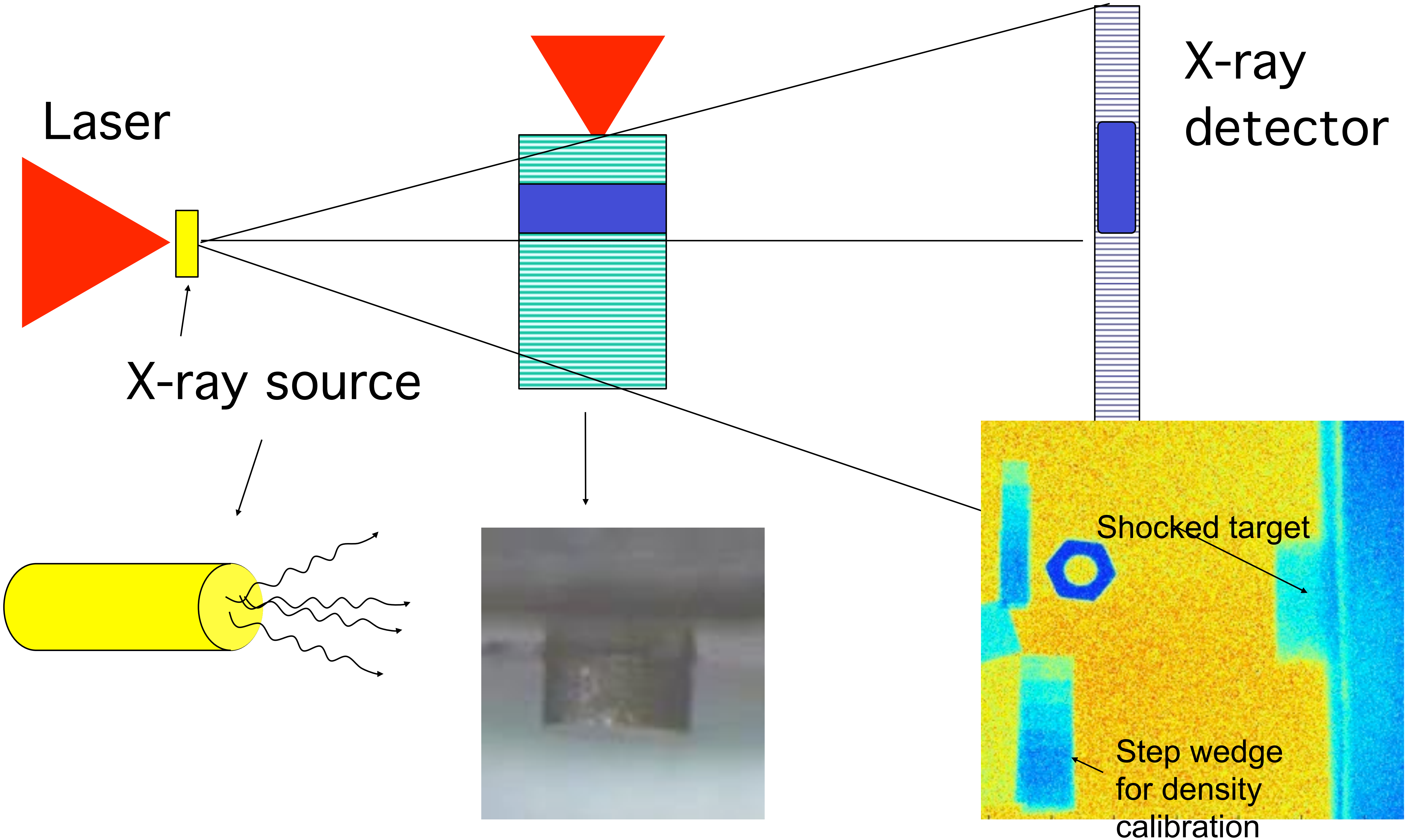
Free standing wires vs. substrates



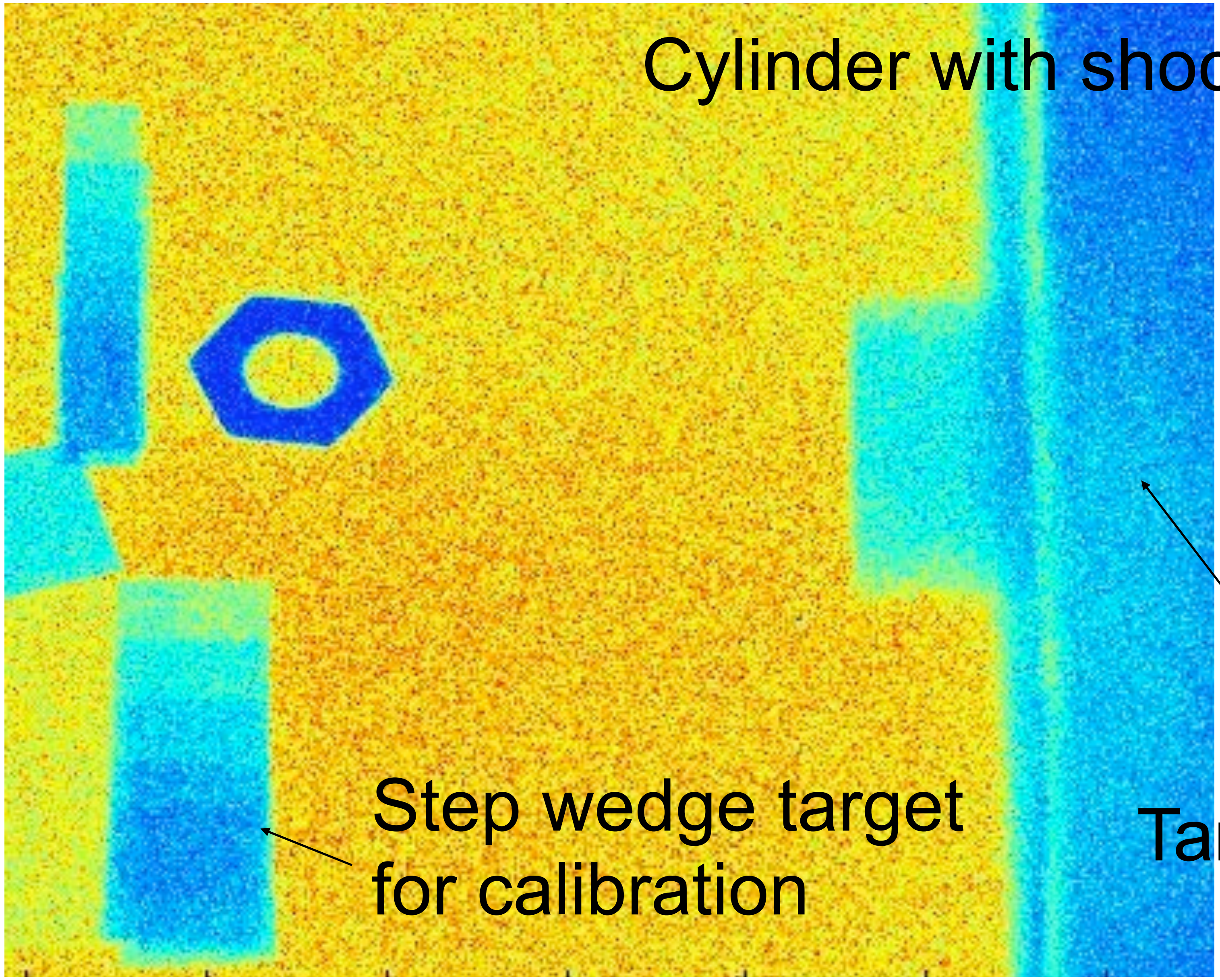
Free standing wires perform better, but pointing stability of the laser is crucial

Radiography

Radiography of shocked iron

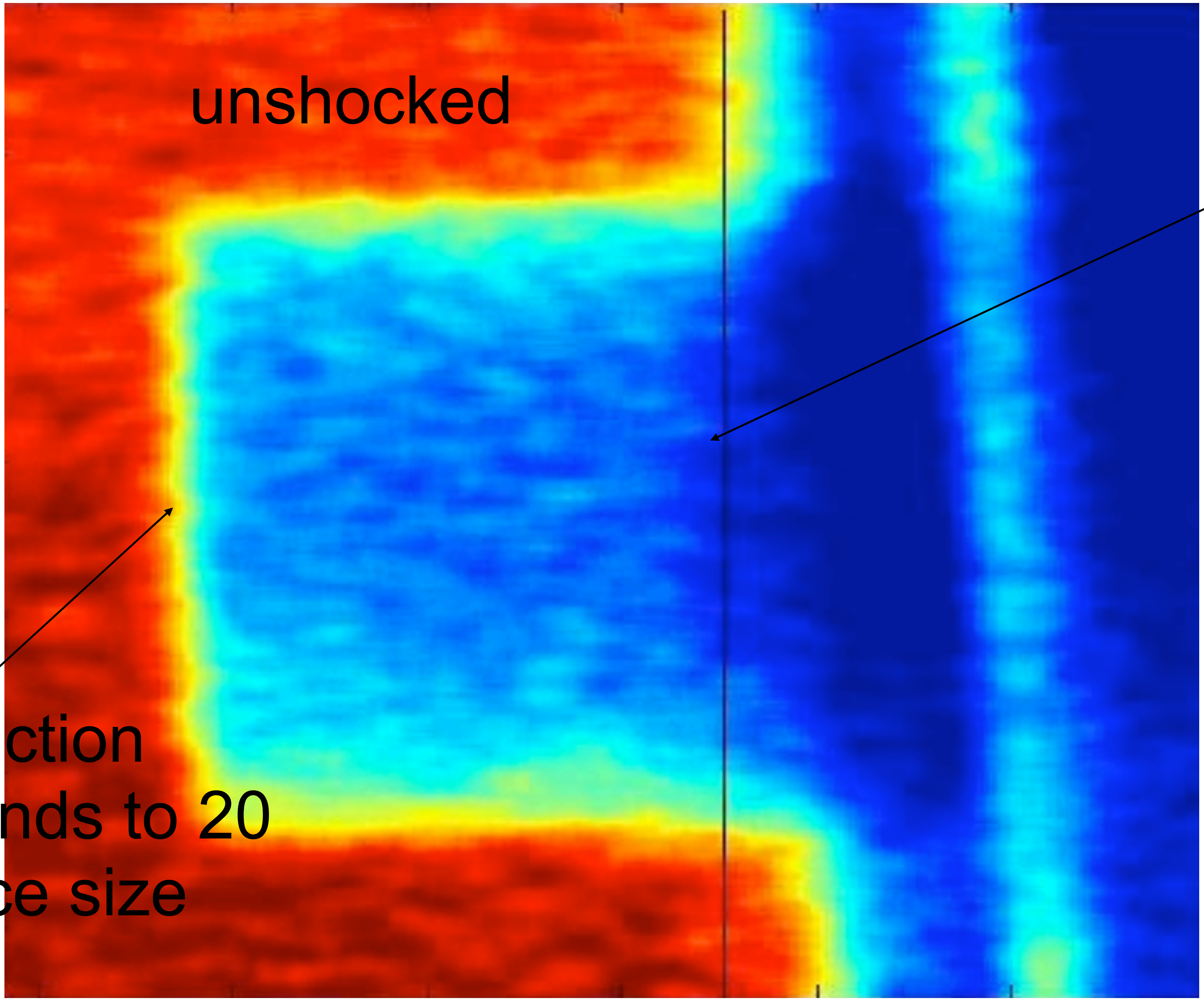


Radiography at 60 keV

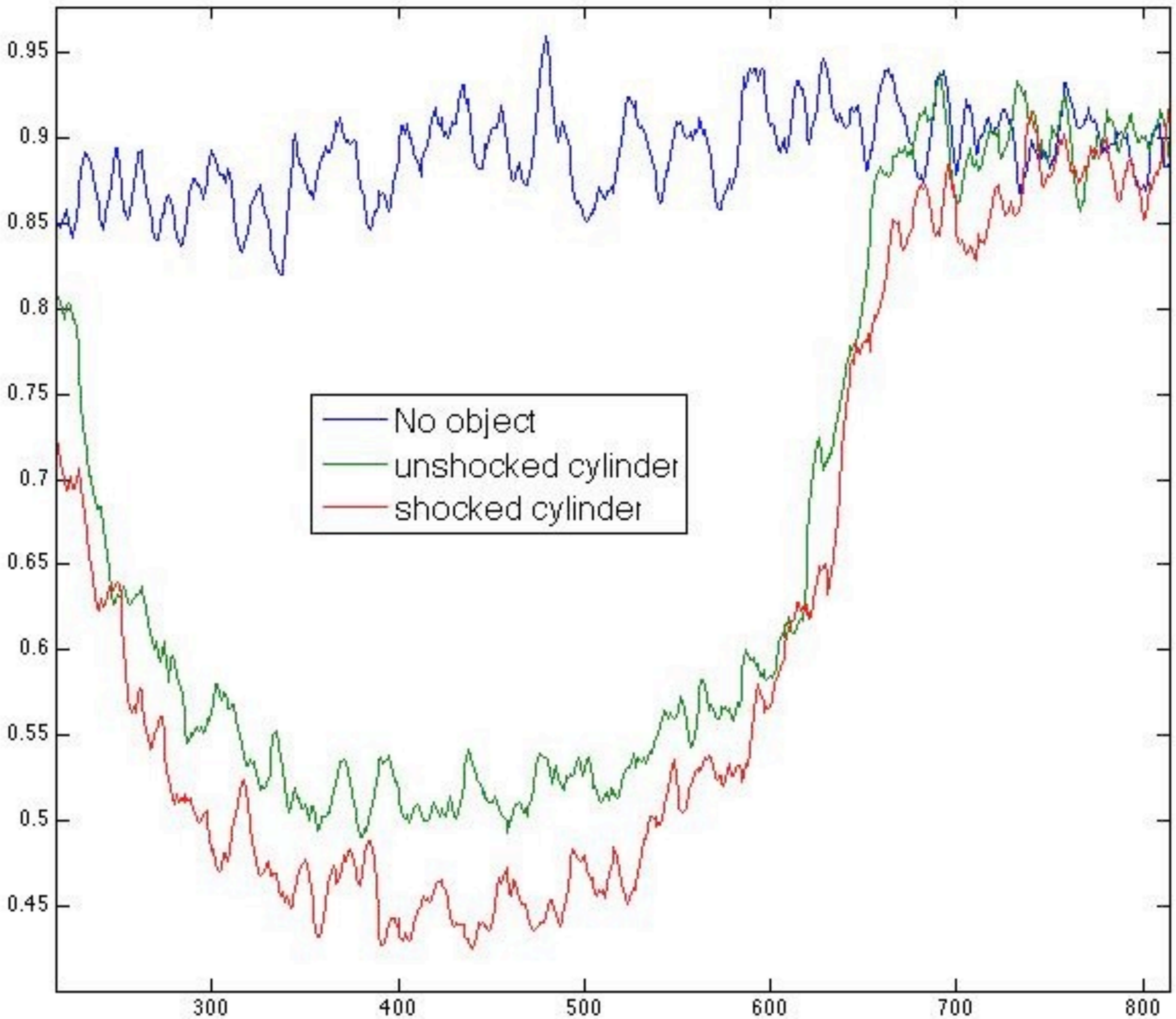


Data very noisy, as x-ray yield was too low

Data smoothing improves dynamic resolution



Transmission is lower in shocked part of cylinder

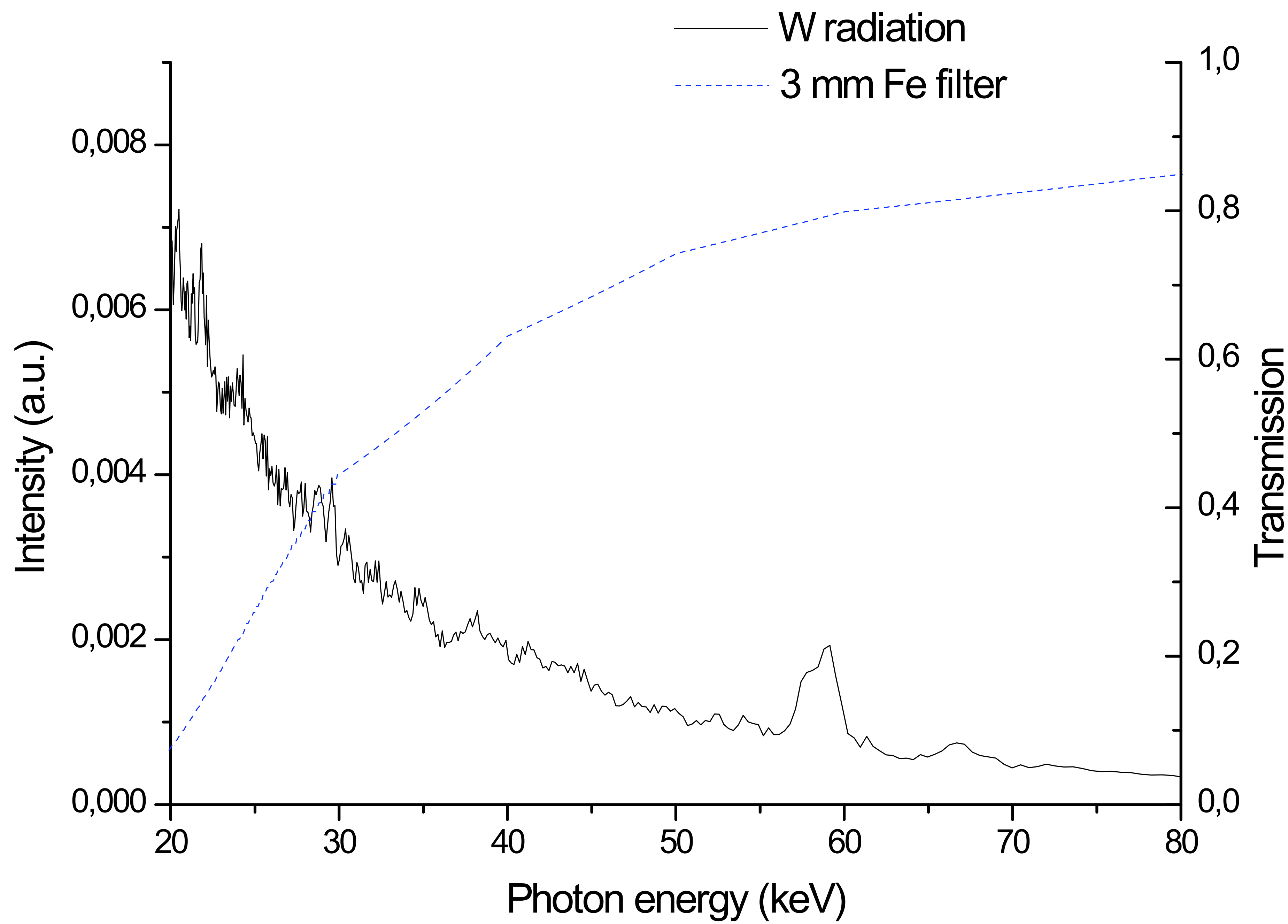


Calculation of line density required

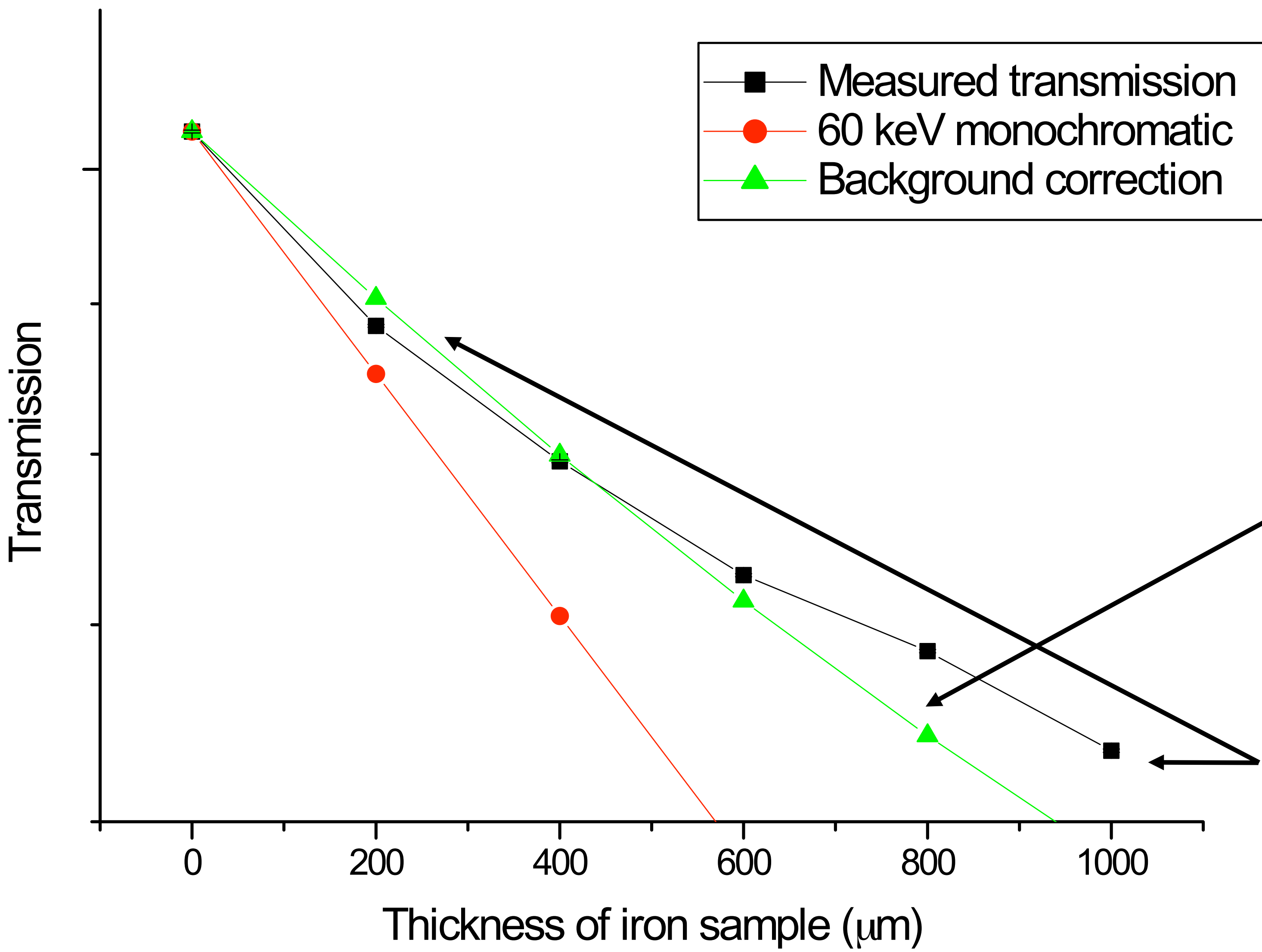
Source is not monochromatic!

Spectral distribution only partly known

Source is not monochromatic



Absorption of test sample

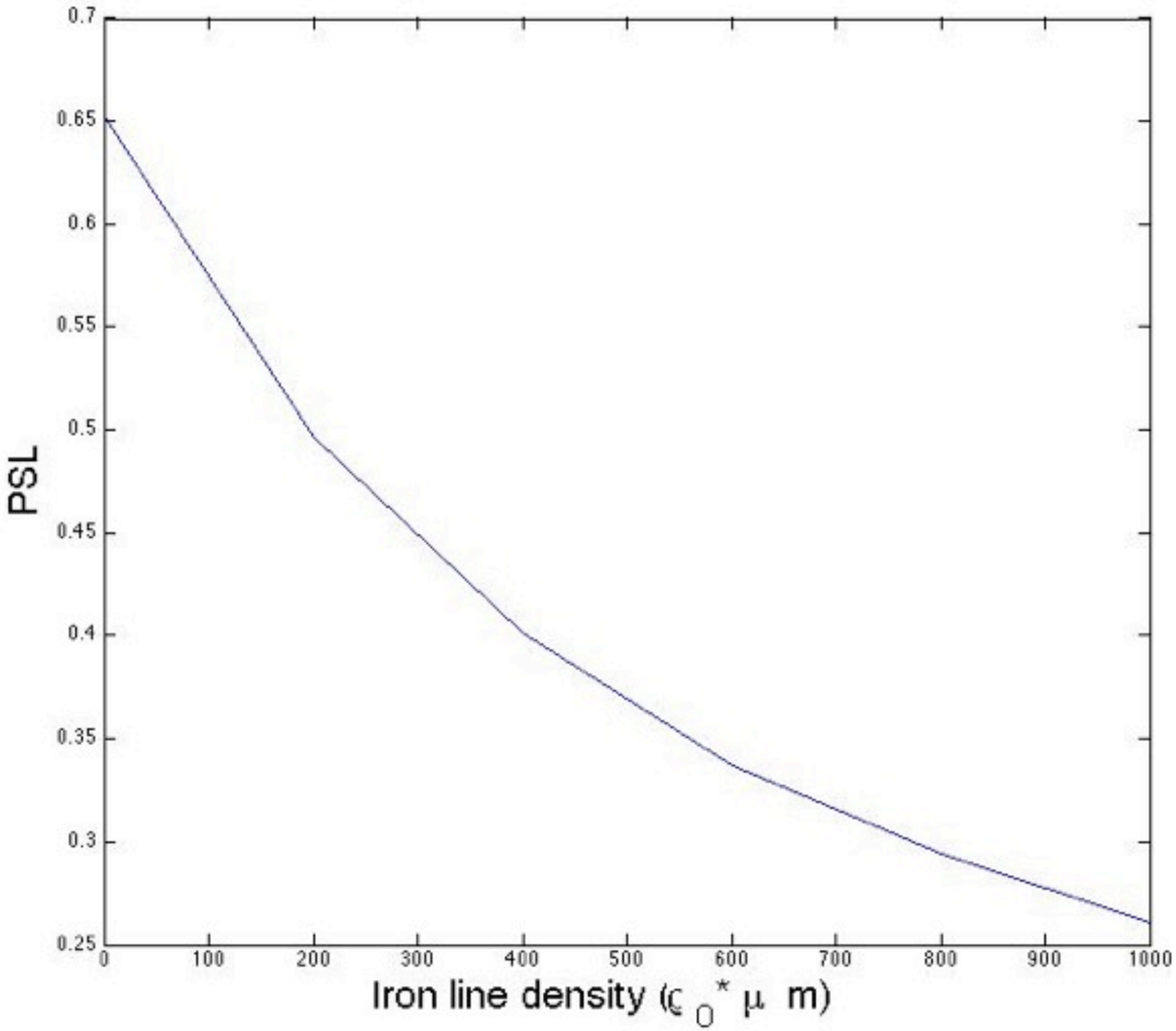


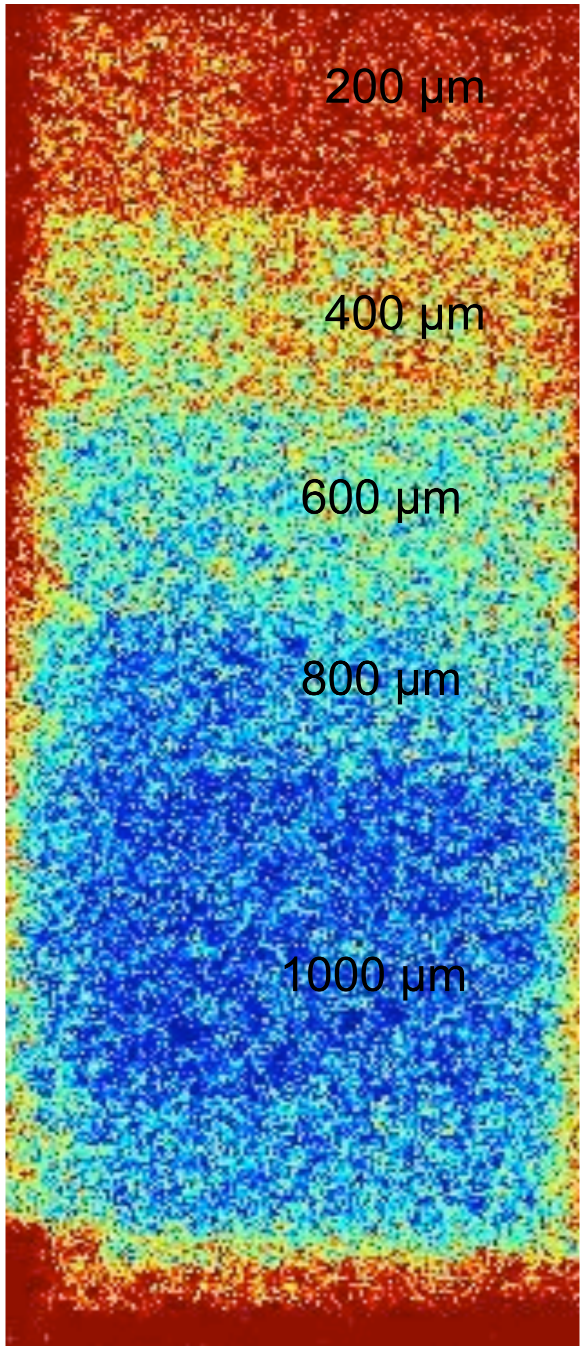
Deviation from ideal absorption of 60 keV radiation in iron

Hard x-rays produce background (can be subtracted)

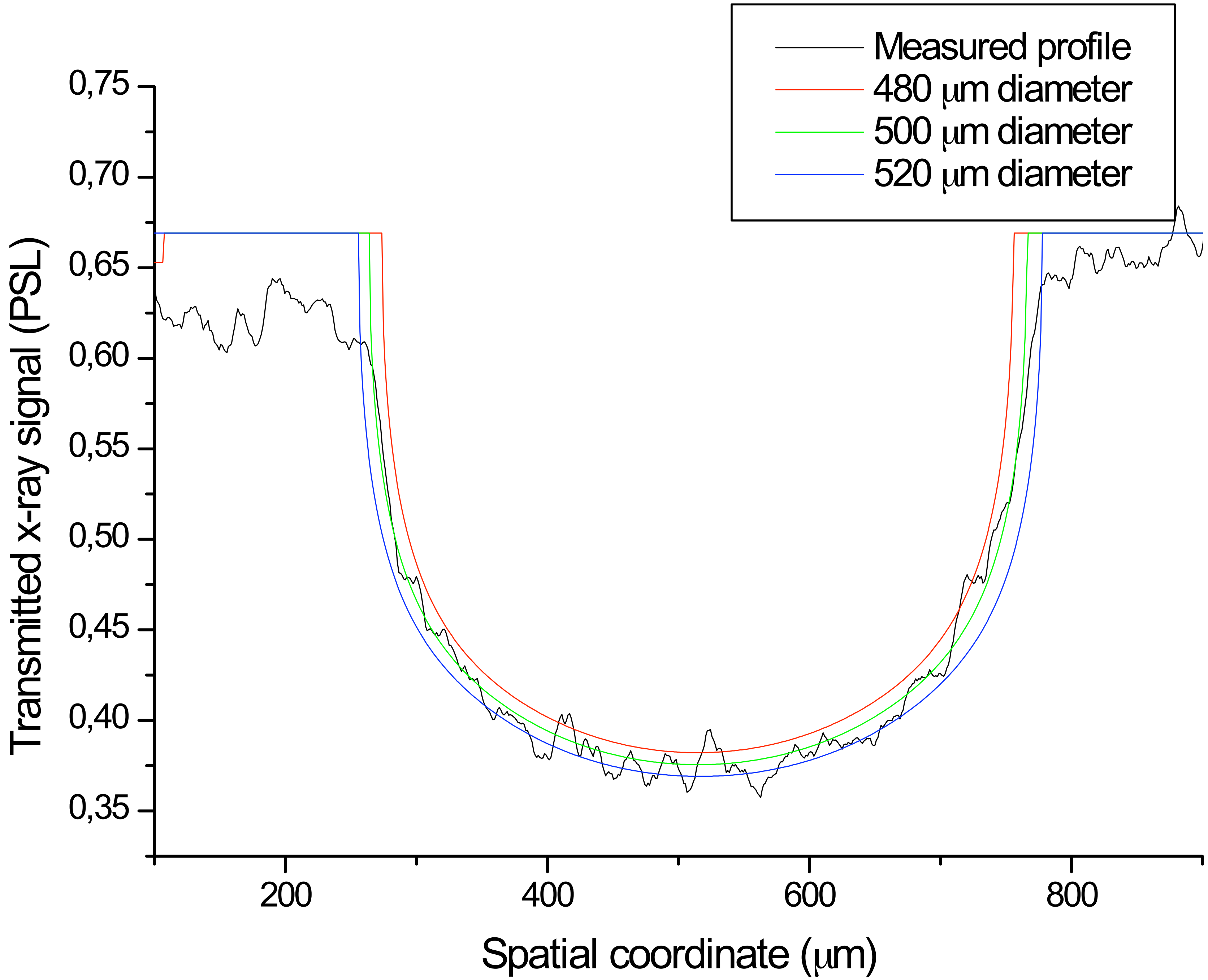
Contributions of low energy spectrum

Step wedge target gives direct calibration of line density

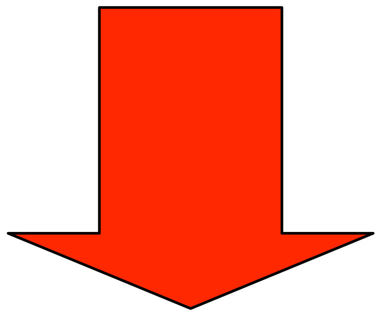




Test of calibration with unshocked region

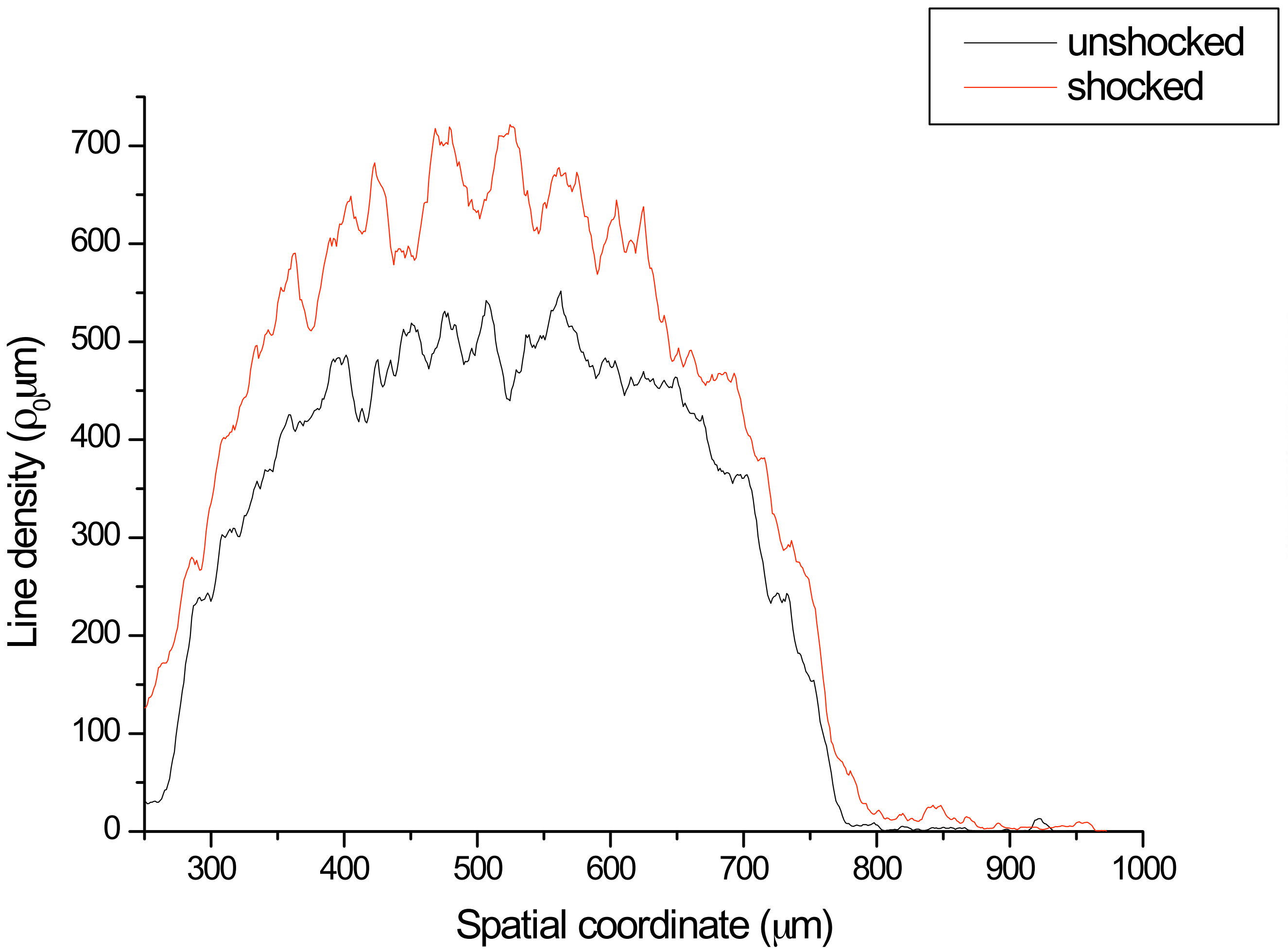


Density profile can be wel
reproduced **without free parameter**

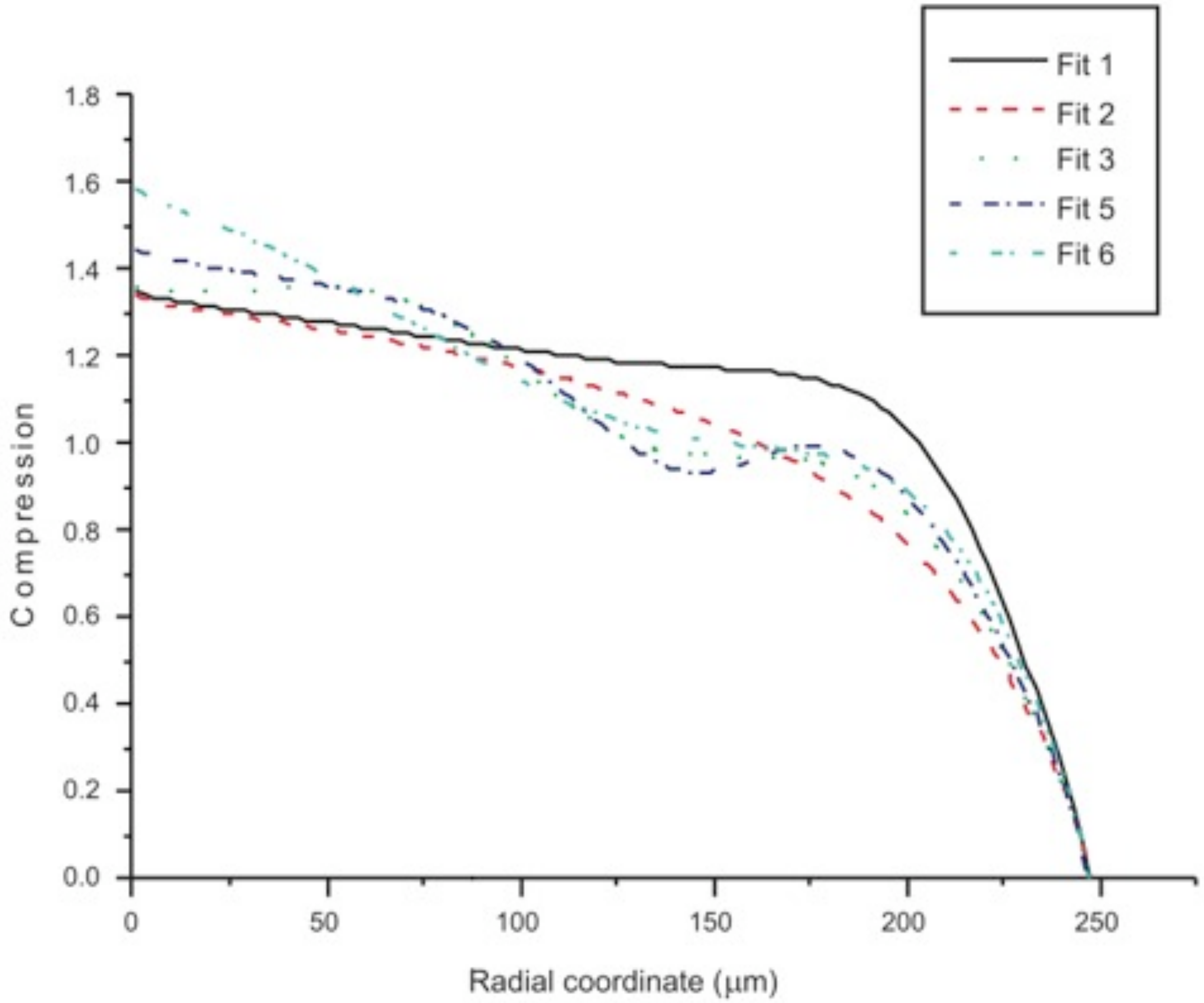


Method to convert detector values to line densities **without** absorption model

Extraction of line densities and radial profile

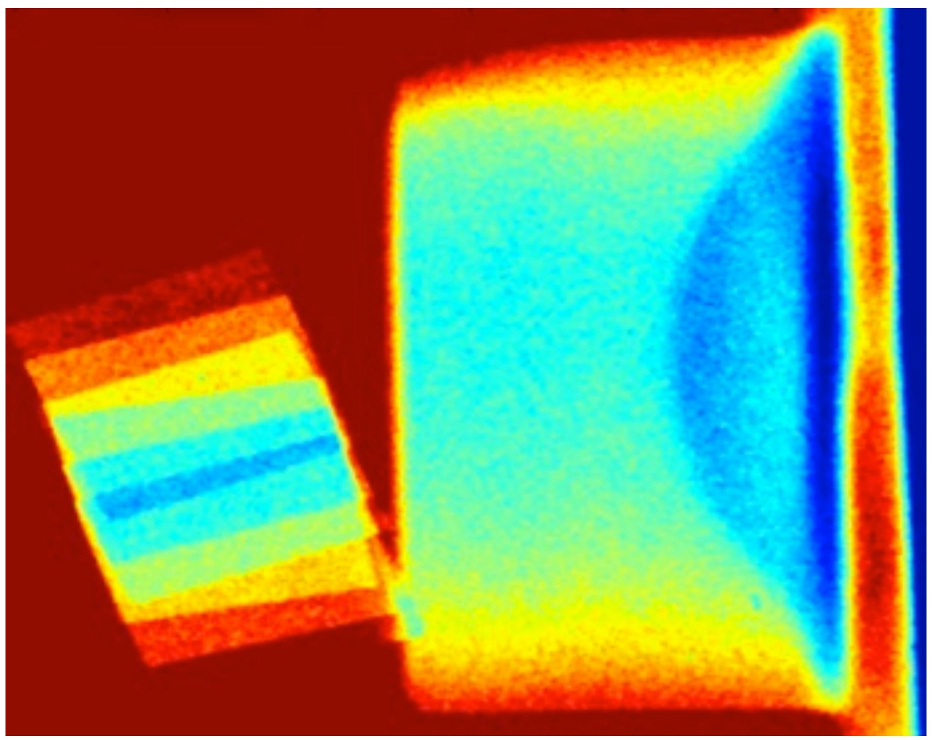


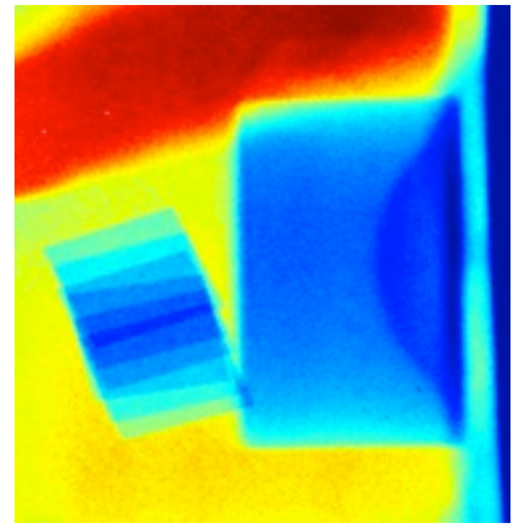
Calculated line densities

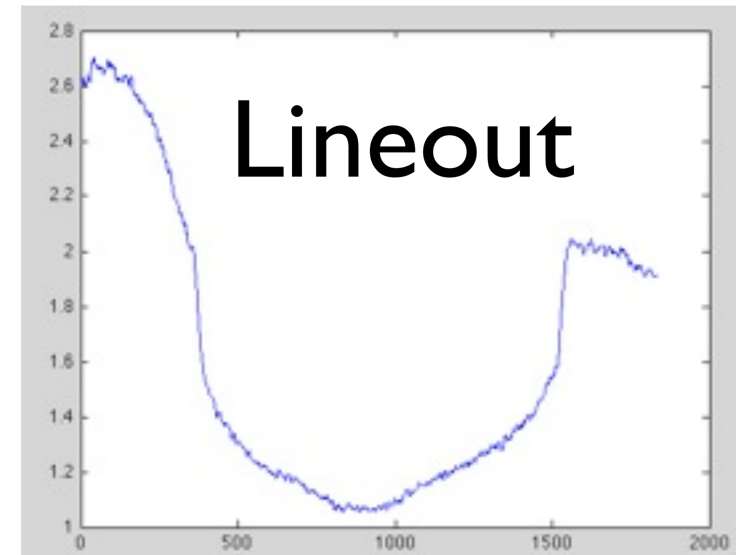


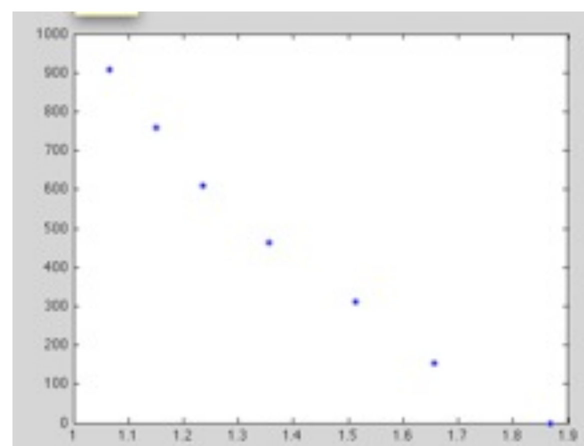
Radial density profile shows compression 1.3-1.6

Radiography of fused silica

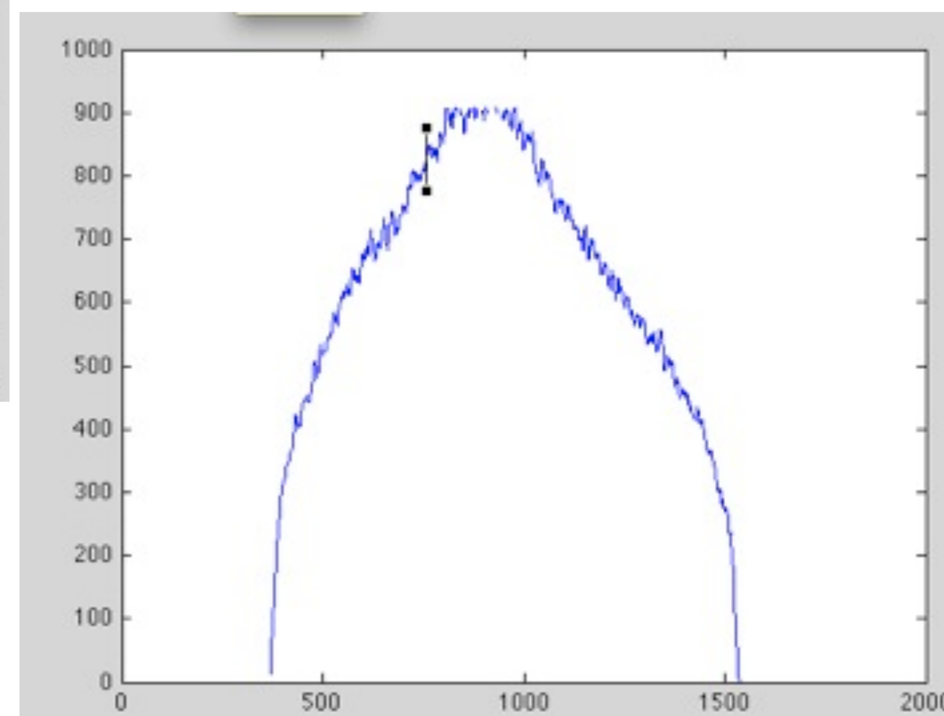








Calibration



Good shot, only one Visar

Line density noise far below 5 %

Experiment still under analysis

Conclusions

- Hard x-ray source for radiography with good spatial and temporal resolution
- Other applications (diffraction, diffusion) require optimization of shielding - still to do
- On shot calibration allows line density measurements with few to sub % precision
- Precision not yet good enough for discrimination of EOS models (Abel inversion, size of the shock)

Collaborators

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