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X-ray Generation for Diffraction Experiments on Z

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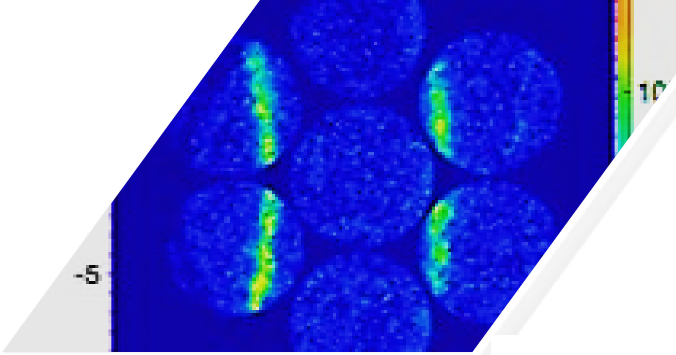
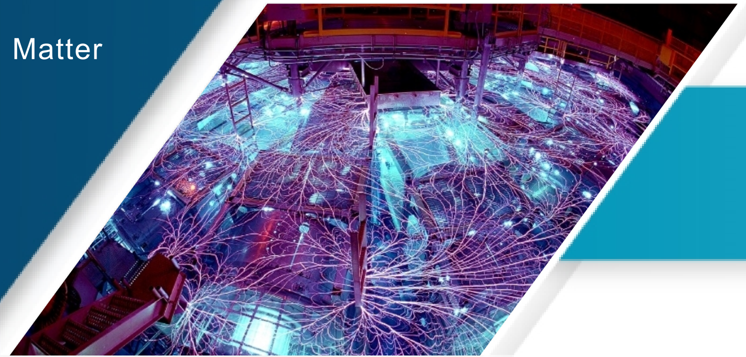
Sandia National Laboratories

37th European Conference on Laser Interaction with Matter

9/17/2024, Lisboa, Portugal





ECLIM 2024

37TH EUROPEAN CONFERENCE ON LASER INTERACTION WITH MATTER

LISBON, PORTUGAL, 16-20TH OF SEPTEMBER 2024

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

- Diffraction is a powerful tool to investigate the structure of solid matter
- We have used a deep-depletion CCD camera in single-hit mode to measure X-ray conversion efficiencies with Z-Beamlet and Z-Petawatt
- Z-Petawatt is superior to Z-Beamlet for X-rays harder than 10 keV
- For diffraction samples with $Z > 42$, we likely require X-rays with 15 keV or higher photon energy (Z-Petawatt).
- We are developing a robust, reproducible setup for X-ray polycapillaries as a part for X-ray diffraction experiments (XRD).

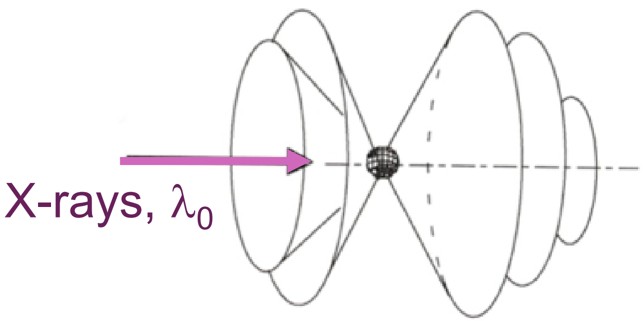
SUMMARY

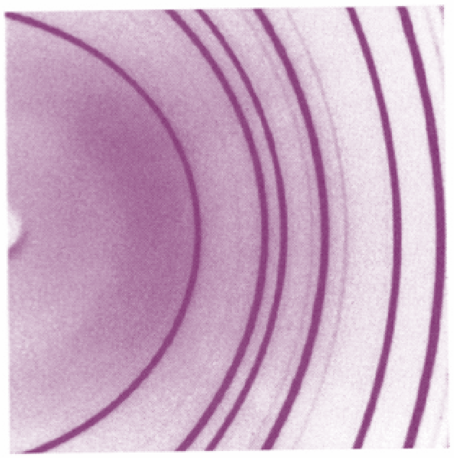
X-ray diffraction can determine material structure

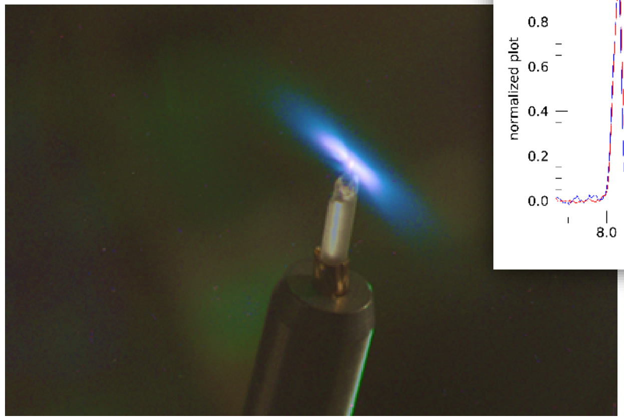
- For monochromatic X-rays, crystalline structures select discrete diffraction angles of X-rays based on lattice spacing and orientation.

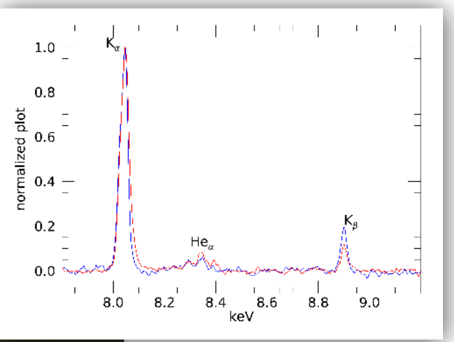
- If a sample contains arbitrarily oriented crystal grains (polycrystalline sample, powder), the diffraction results in the emission cones. In an image plane, cones show up as rings, whose diameters represent diffraction angles that are specific to lattice spacing.

- K-shell emission from laser driven targets is a common source of the required, monochromatic X-rays.





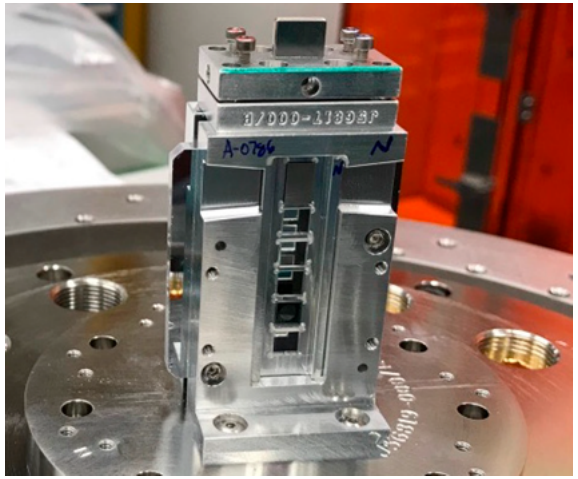




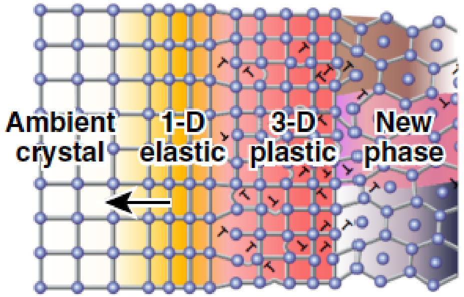
Plasma jets from a copper foil after being hit by Z-Petawatt: Generation of 8.048 keV X-rays.

X-ray diffraction for Material Compression on Z

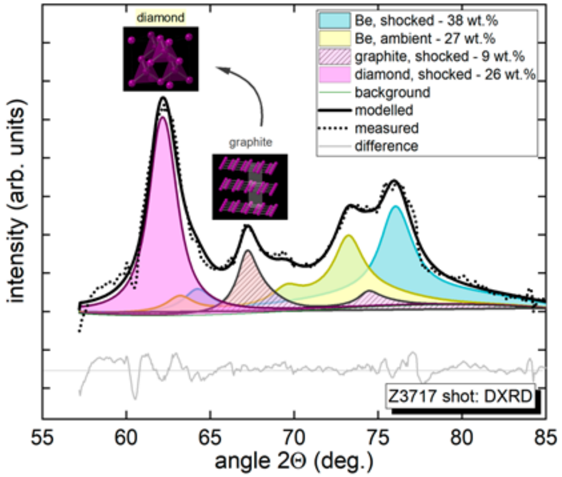
- Flyer plates accelerated by magnetic drive at Sandia's Z-Machine reach > 30 km/s and can produce tens of Mbar of pressure!
- Metals can undergo phase transitions under such conditions.
- Different crystal phases cause diffracted X-rays to cause different patterns.



Flyer plate assembly for Z (*)



Pressure compresses crystalline structure, deforms, and ultimately causes a new orientation (phase)

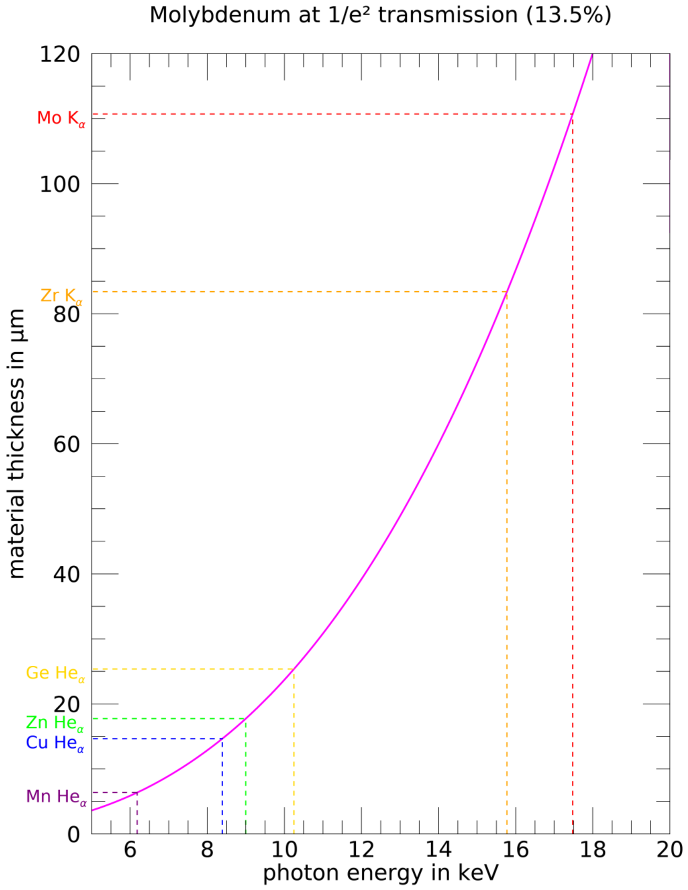


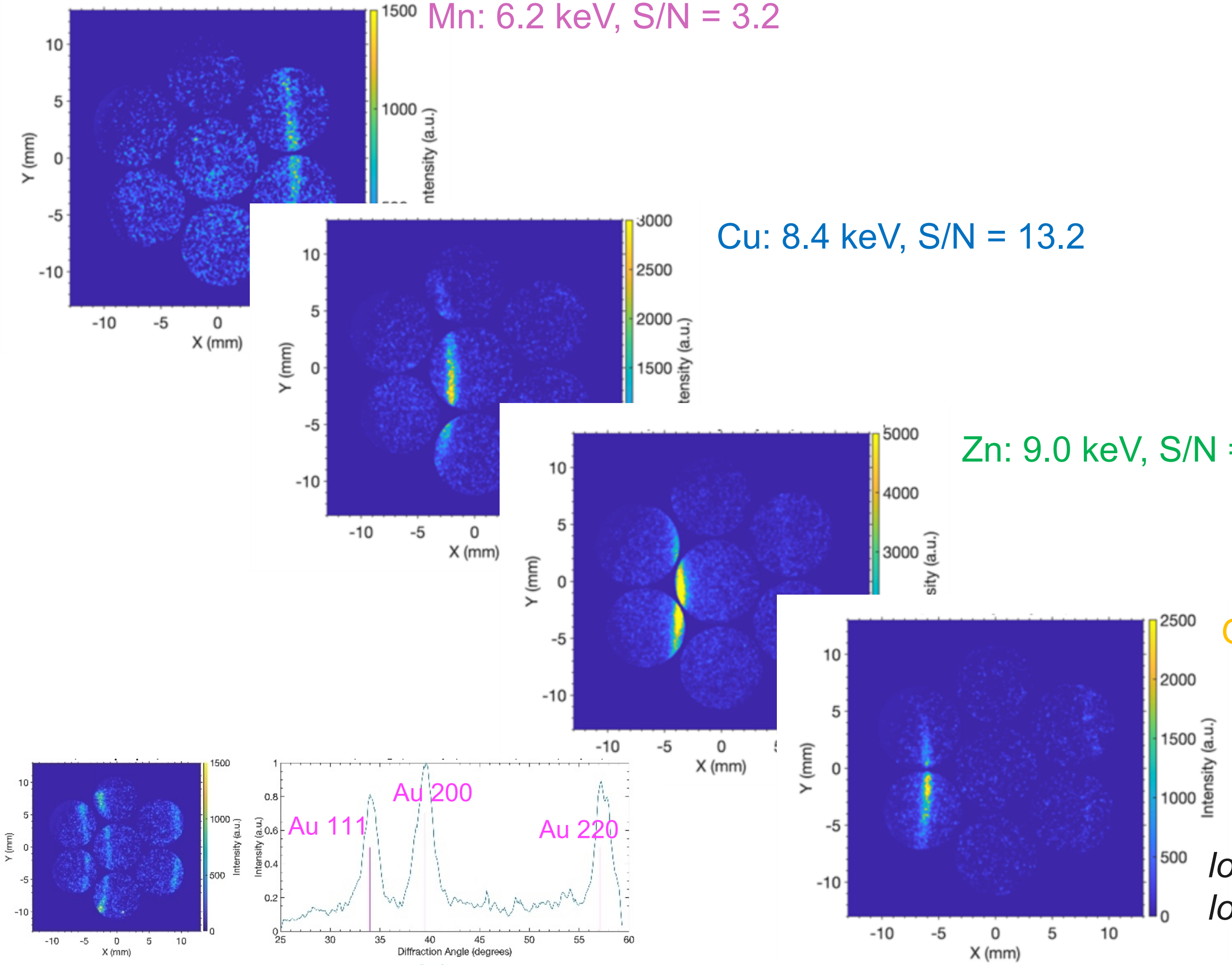
Data acquired on Z with 6 keV photons generated by Z-Beamlet (Mn He_{α}): Transition from graphite to diamond (*)

(*) Tommy Ao et al.: *Minerals* **13**, 1203 (2023)

Higher photon energies are more effective for dense samples

For Z > 42 (Mo) we likely need E_{ph} > 10 keV, requiring Z-Petawatt driver

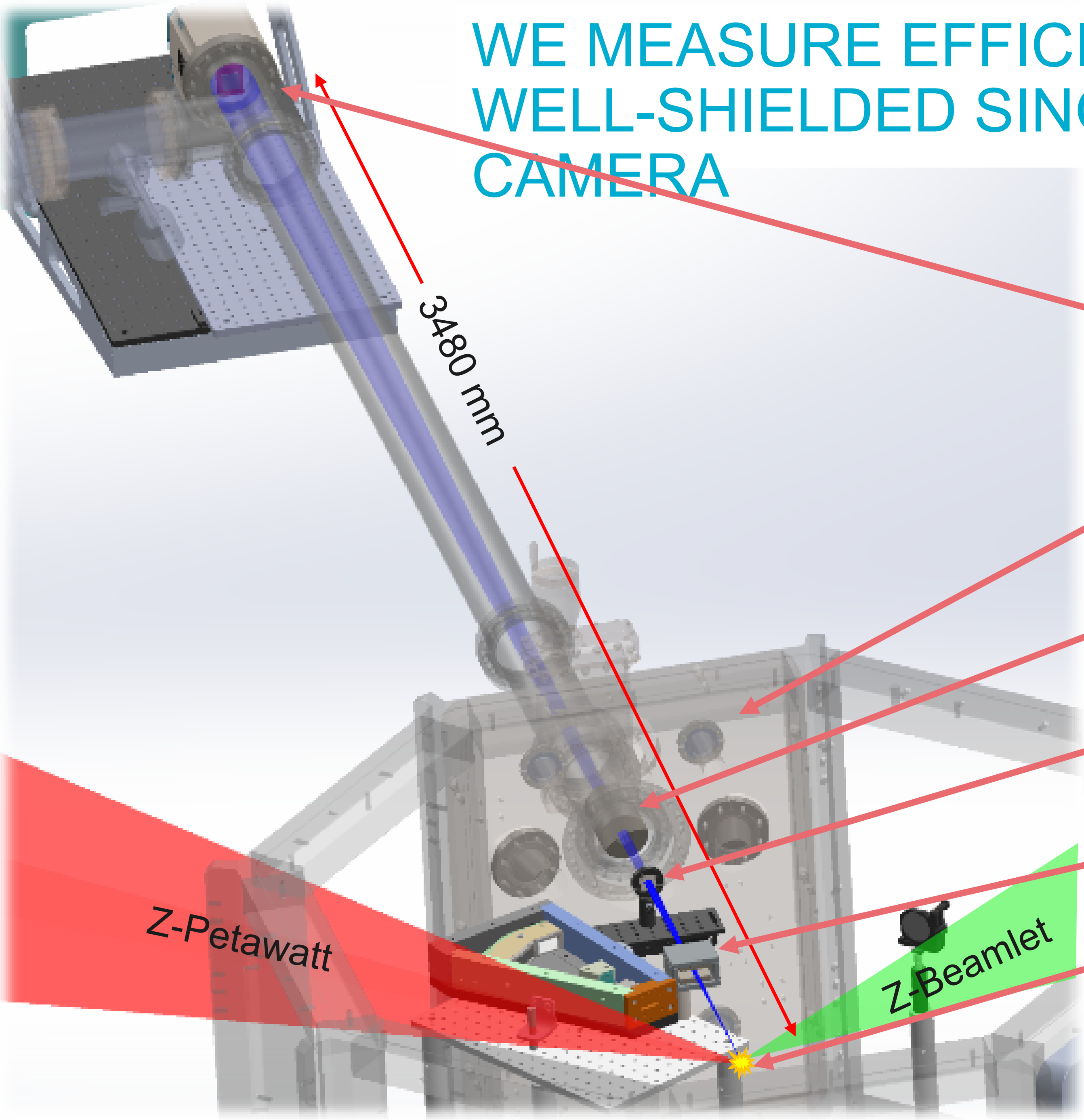




low signal because of low conversion efficiency

Zn on Au: 9.0 keV, S/N = 9.8

WE MEASURE EFFICIENCIES WITH A WELL-SHIELDED SINGLE-HIT CCD CAMERA



deep-depletion CCD camera

2” stainless steel chamber walls

steel collimators

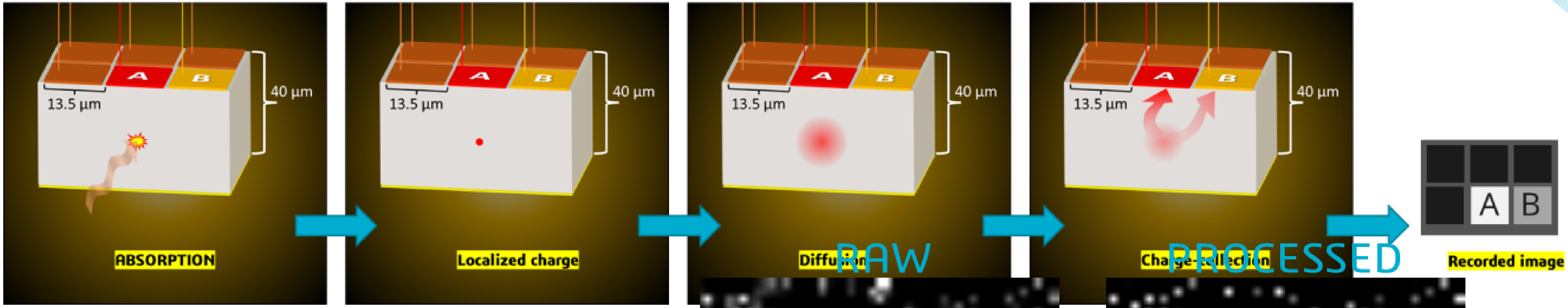
K-edge X-ray filters

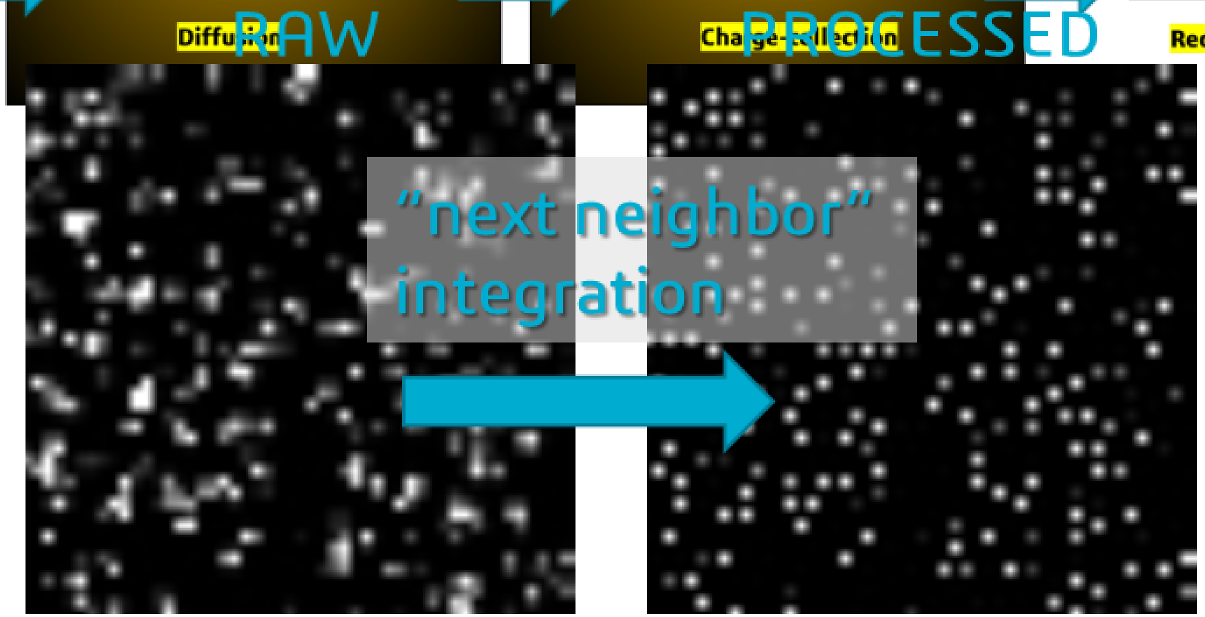
Magnets

Target

RAW DATA NEED TO BE PROCESSED

Diffusion leads to charge-bleed across pixel boundaries

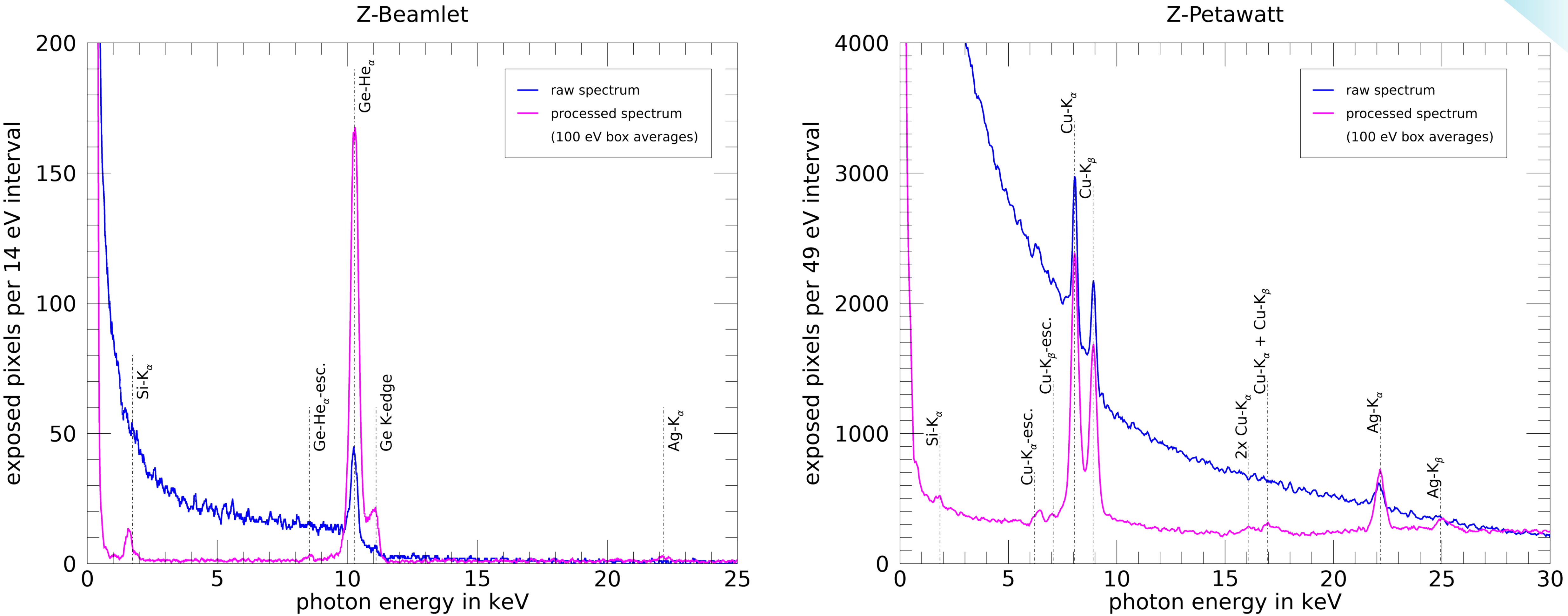




Charge bleeding is NOT due to kinetic energy of the photo-electron!

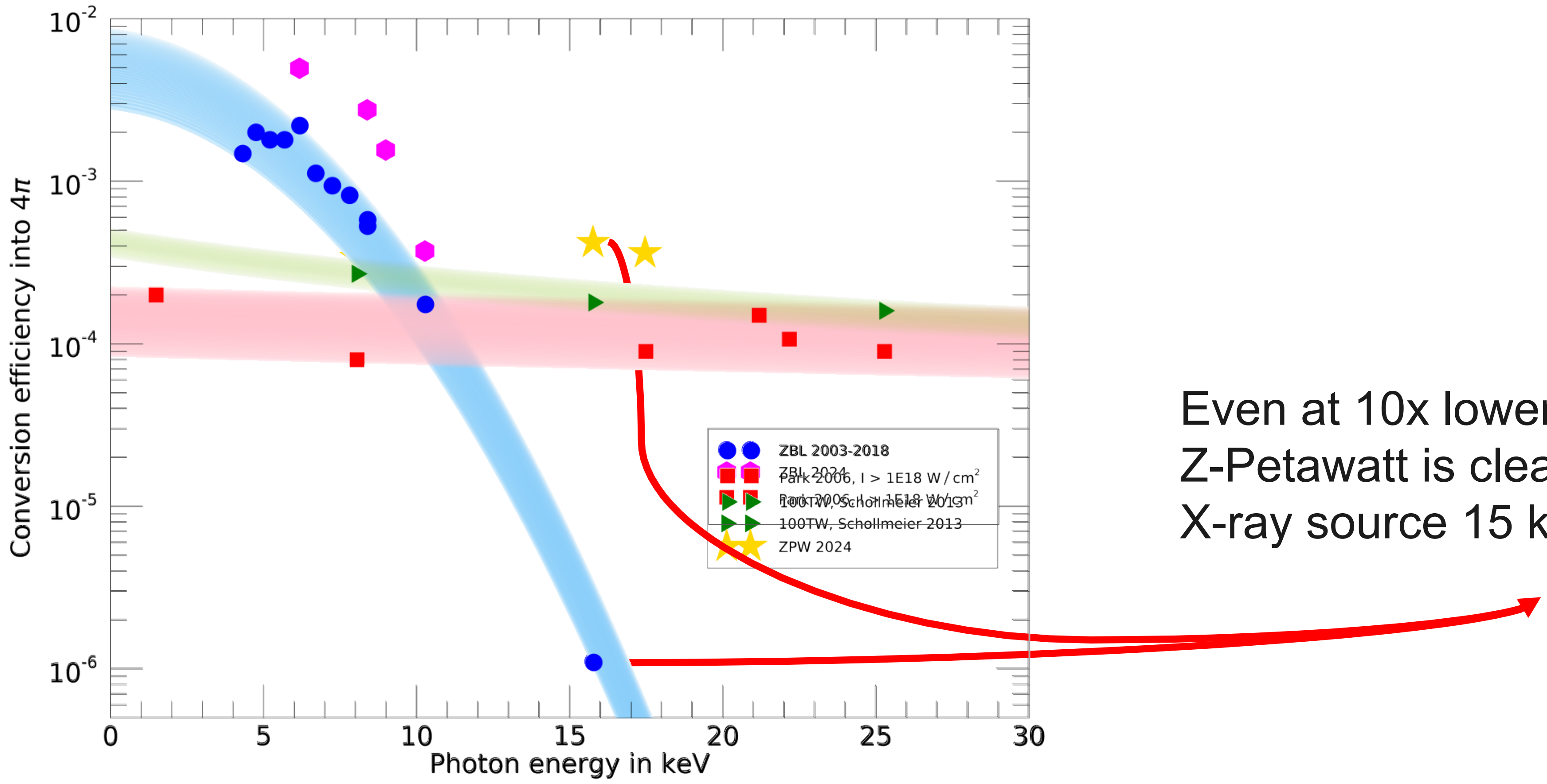
MORE DETAIL IS REVEALED WITH IMAGE PROCESSING

… and signal gets massively increased



SUMMARY OF CONVERSION EFFICIENCIES

More materials with Z > 42 (Mo) pending



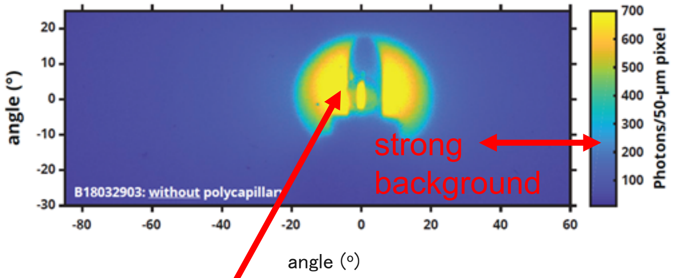
Even at 10x lower pulse energy, Z-Petawatt is clearly the brighter X-ray source 15 keV and above.

A POLYCAPILLARY IS NEEDED WITH Z-PETAWATT XRD

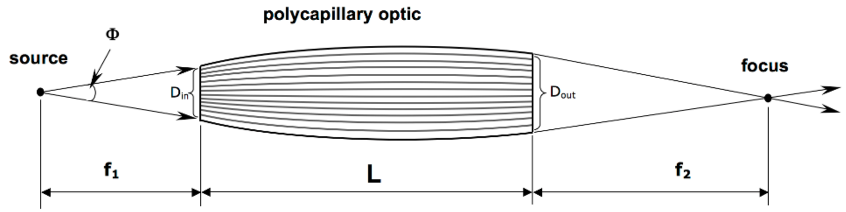
Issues are parasitic radiation, focused X-ray intensity, and sample containment

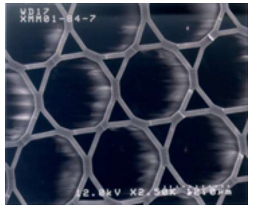
Z-Petawatt sources typically overpower the diffraction samples.

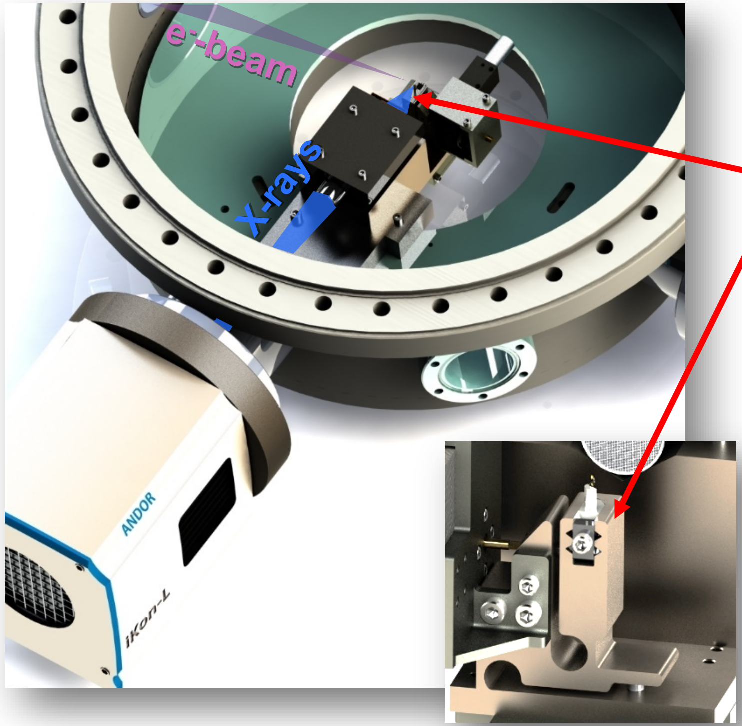
Shielded stand-off and refocusing can mitigate this problem.



undiffracted projection of the sample







Custom ‘flex’ mounts based on material stress/strength will enable precise and durable alignment of target and capillary.

Stand-off with capillary also allows to relay X-rays into hermetically confined containers for hazardous samples.

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