Frontiers of X-ray Microdiffraction

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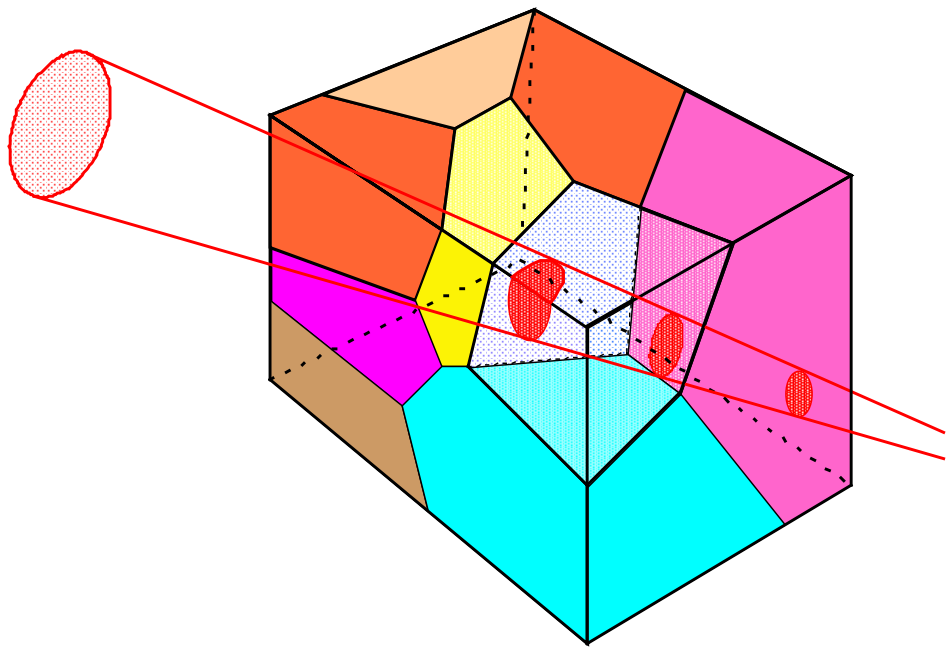
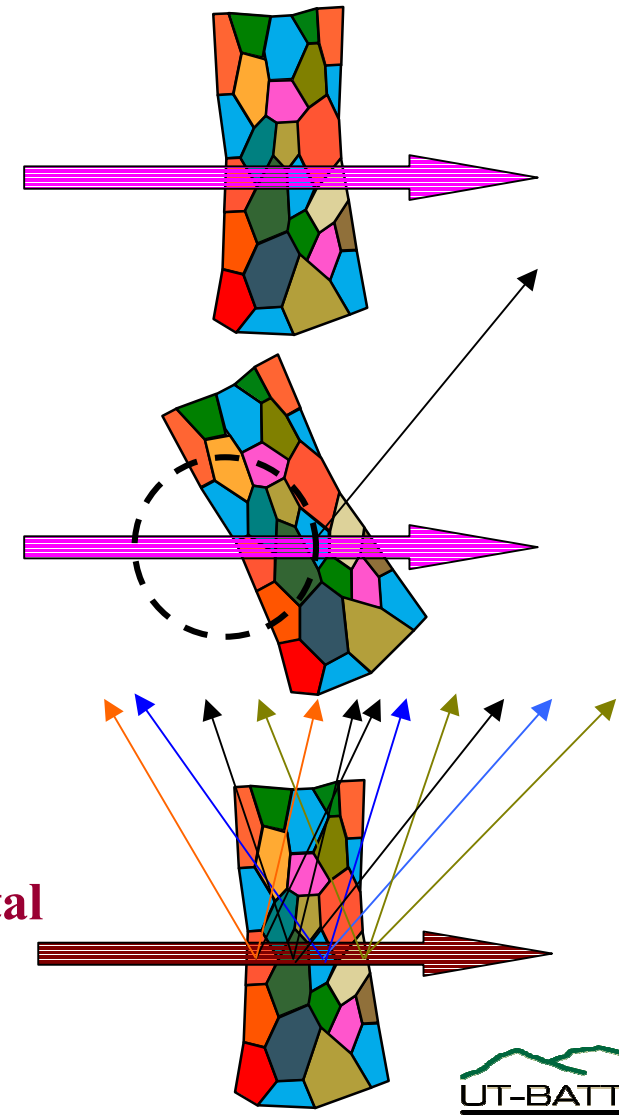


ORNL has demonstrated a new class of microdiffraction instrumentation based on polychromatic x-ray beams

Solves intrinsic problem with conventional microdiffraction-

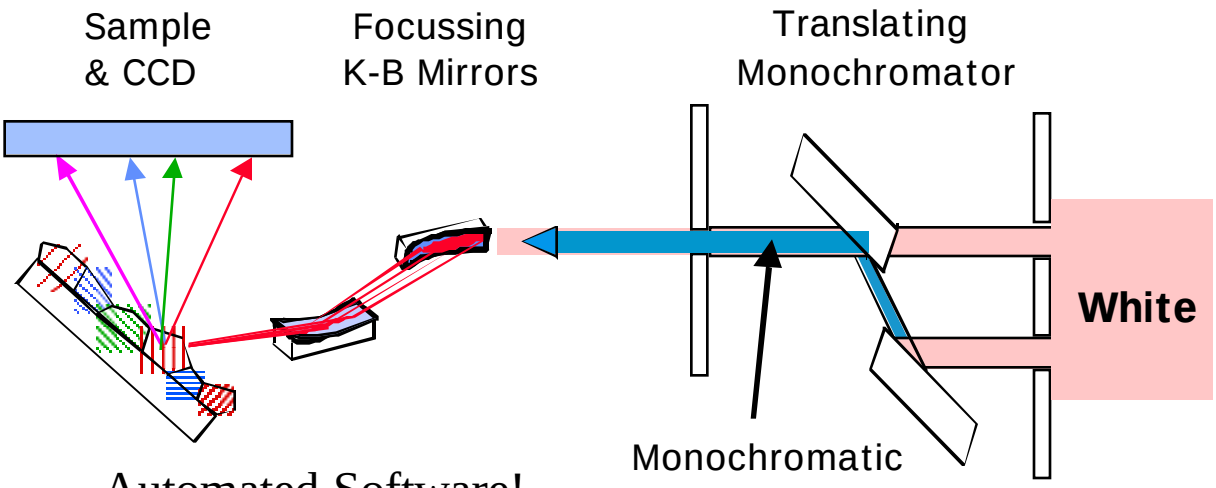
-Sample does not need to be rotated!

Special software required- Can index polycrystalline samples



3D nondestructive probe of stress/strain/crystal structure!

Polycrystalline microdiffraction station has four key elements



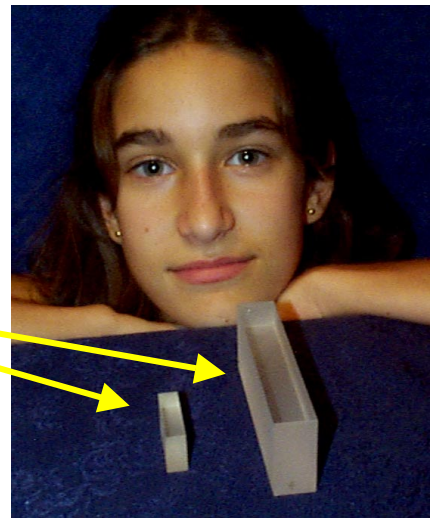
Automated Software!

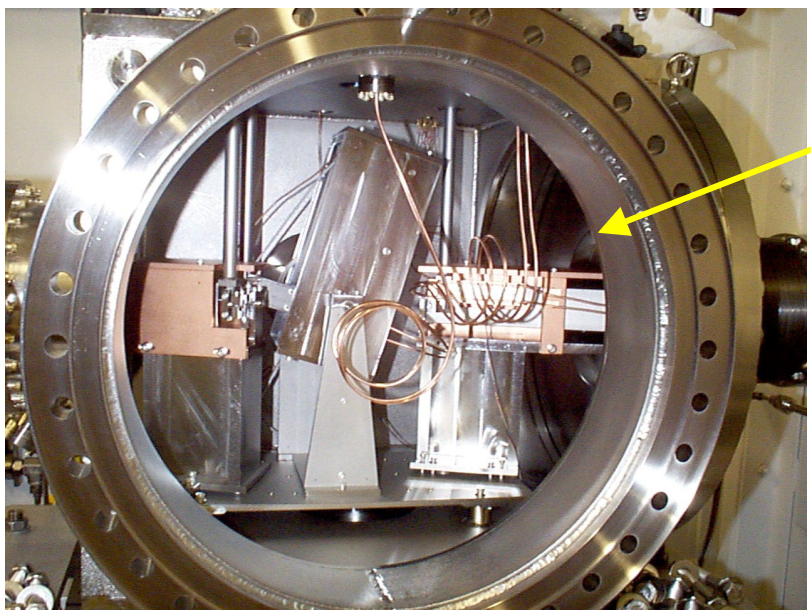
Current 3-D resolution: **<0.4 x 0.5 x 0.7 μm^3**

Current strain tensor resolution: **~10^{-4}-10^{-5}**

Technical challenges addressed to make microscope practical

- R&D 100 award winning mirrors

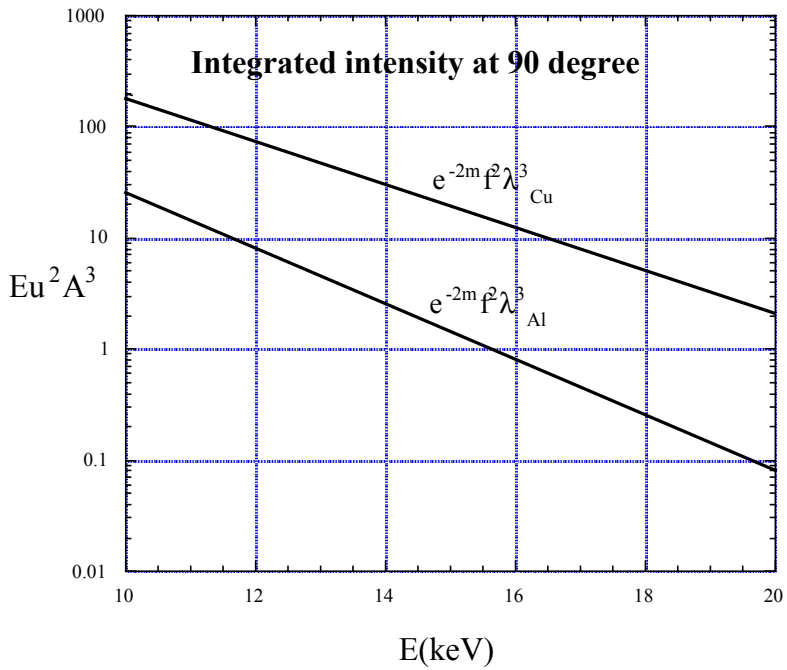




- Unique micro-monochromator
  - Ultra-stable/nondispersive
  - Full strain tensor
- ORNL aquistion/analysis software-
- Differential triangulation microscopy

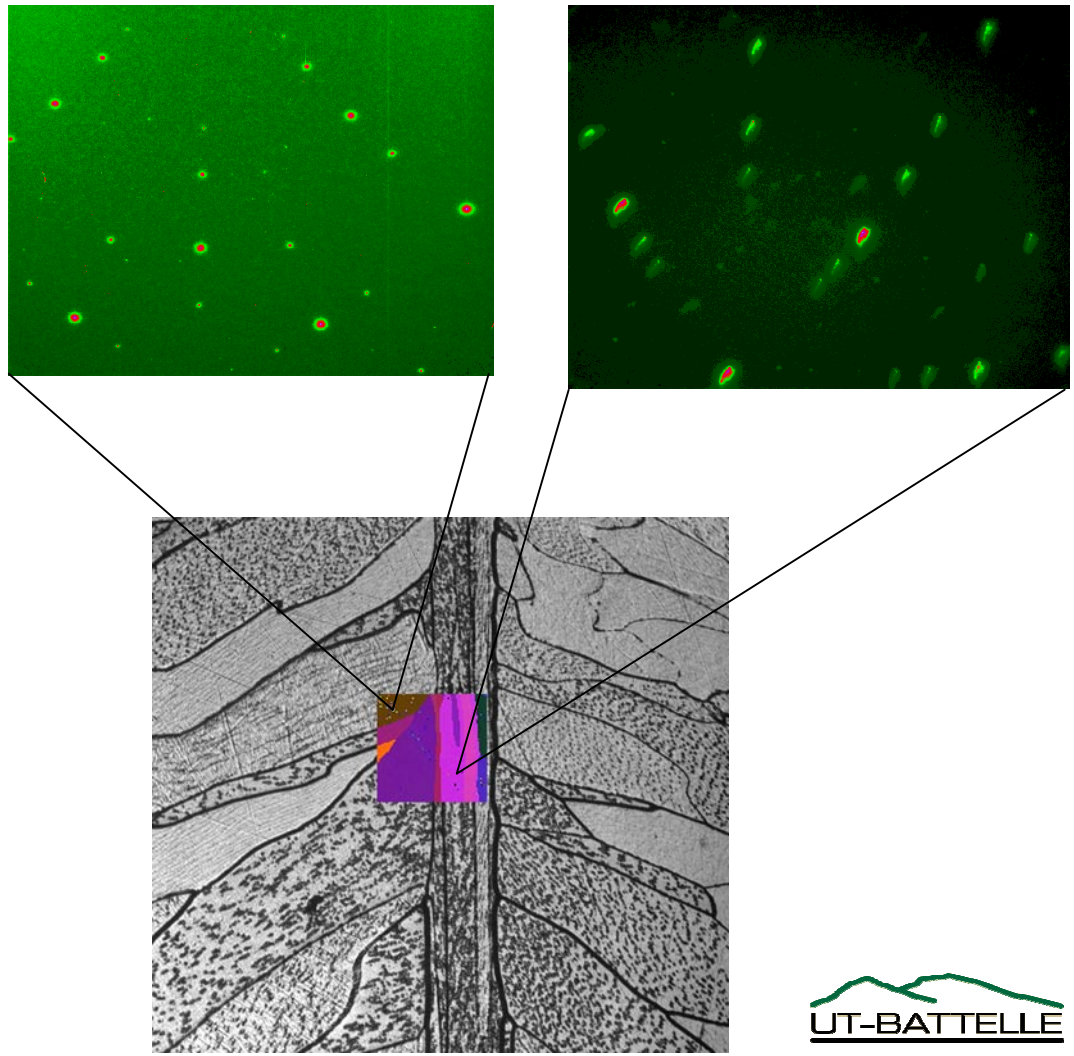
Optimization complex and can depend on particular experiment

- In $2\theta=90°$ geometry signal $\propto E^{-7}$
- Number of reflections $\propto E^3$
- Absorption length $\propto E^3$
- Thermal load $\propto E^{-2}$
- Diffraction limit $\propto E^{-1}$



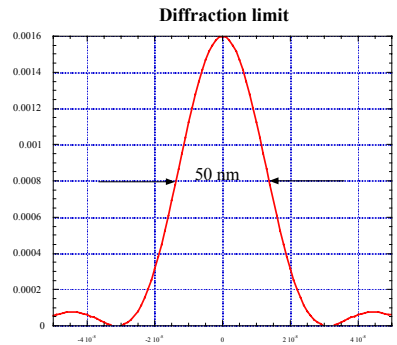
Nondestructive in-situ characterization of materials properties.

- Penetrating 3-D
- Grain orientation/ morphology
- Grain phase
- Gain strain
- Plastic deformation



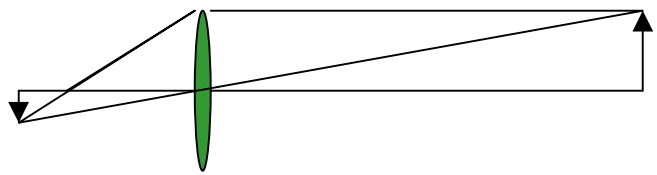
Current performance is limited by geometrical demagnification/ mirror perfection/windows

- Diffraction limit ~50 nm
  - 20 keV x-rays
  - 1-2 mrad convergence



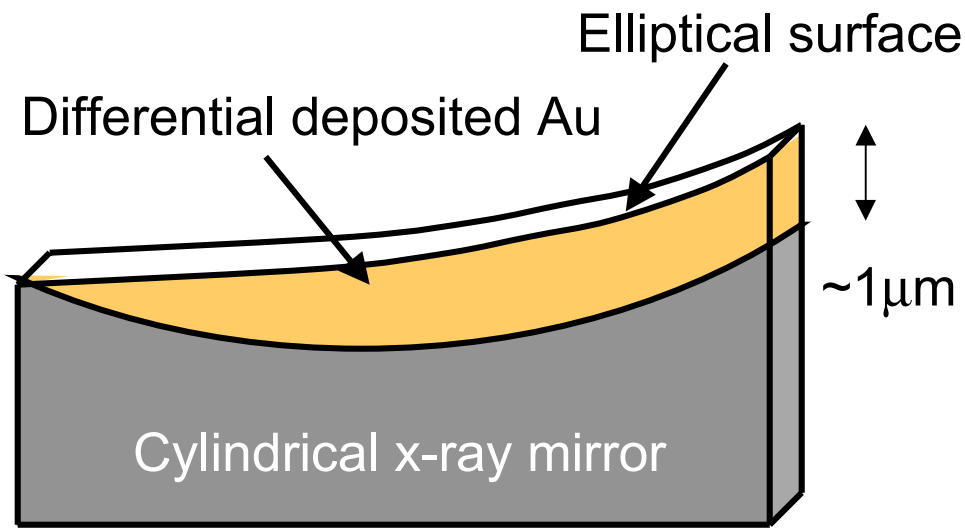
- Geometrical demagnification ~500 nm

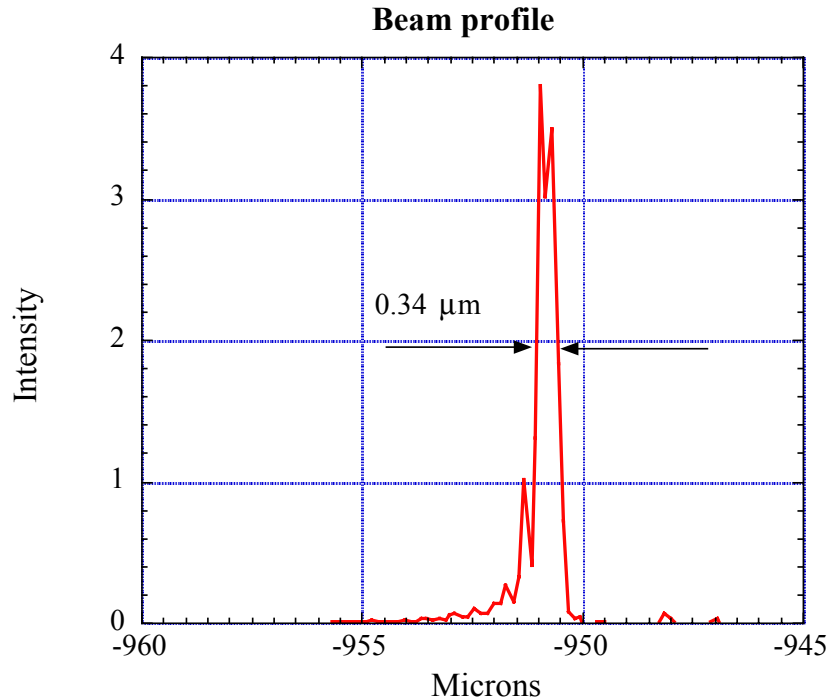
- Mirror figure errors ~ 250 nm
  - Emerging technologies for superior figure/roughness



Differential deposition profile transforms cylindrical to elliptical

- **Can simultaneously correct small imperfections**
- **Fit final mirror to optimize focal length and tilt**

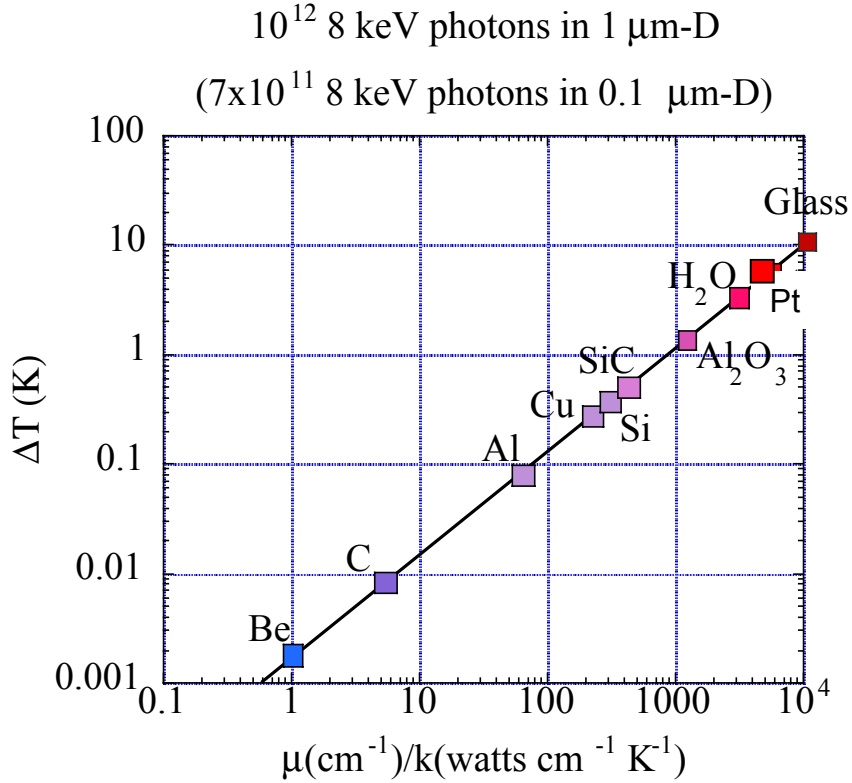




FWHM ~ 0.4 x 0.5 μm^2

Thermal loading will become important with ERL and advanced optics

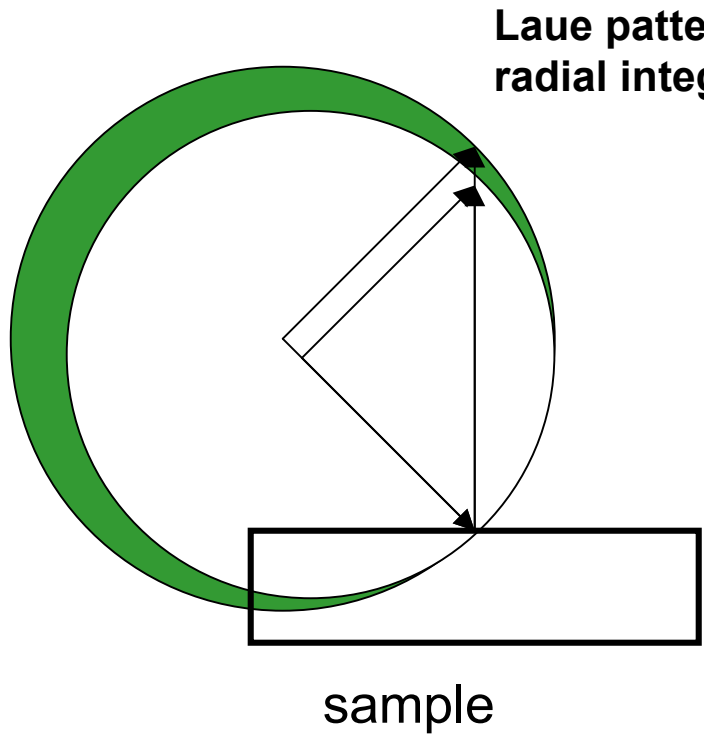
- **Surprisingly *benign* focused white beams**
  - **Linear with power**
  - **Weakly with focal spot size**
- **Simple extension of current techniques impractical - less efficient approaches offer new opportunities!**



$$\Delta T \sim (P_T)(\mu/k)[1/2+\ln R_2/R_1)/2\pi$$

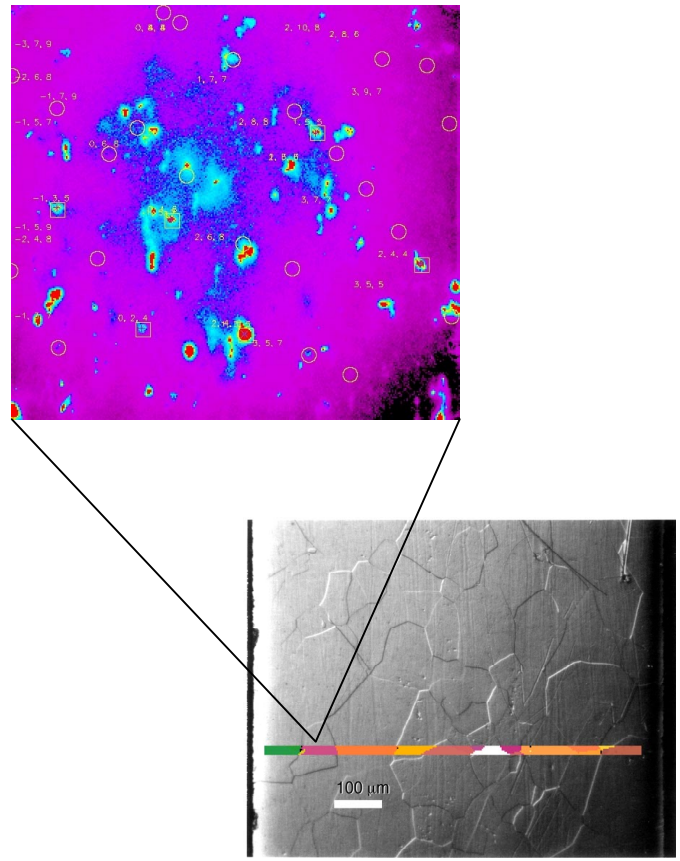
High performance of ERL will extend technique

- *Energy scan* mode
  - Much better signal-to-noise
  - Complete reciprocal space
- Diffraction limited focus
  - ~50 nm radius will reduce thermal load by 100
- High energy
  - Deep 3-D measurements



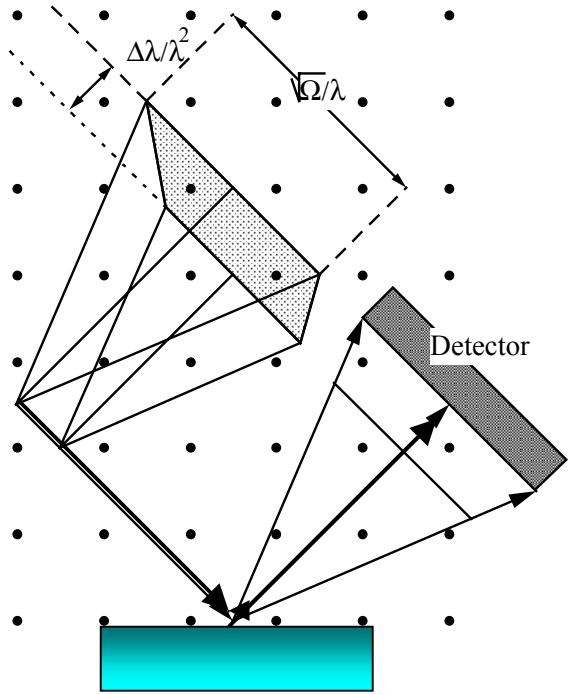
High performance of ERL will open up new regimes

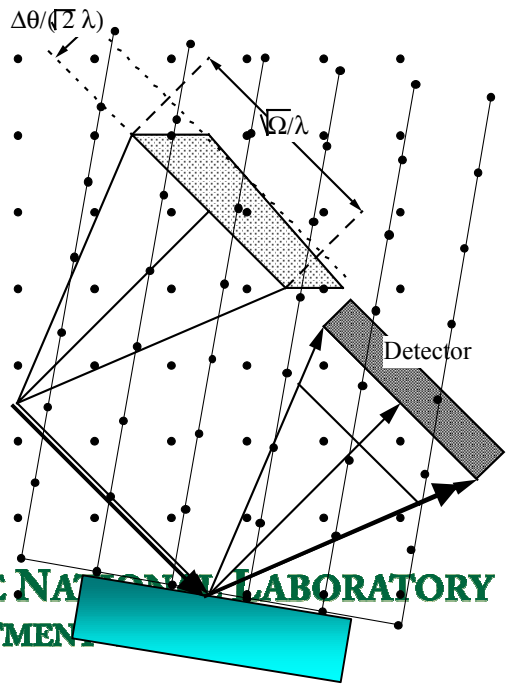
- Better spatial resolution
  - Nanoscale materials
  - Fracture (local environment)
  - Nucleation and growth
  - Fine grain mosaic materials
- Better signal-to-noise
  - Fluorescing materials
  - Highly deformed/mosaic materials
- High Energy
  - 3D in high Z materials



Number of reflections detected can be controlled

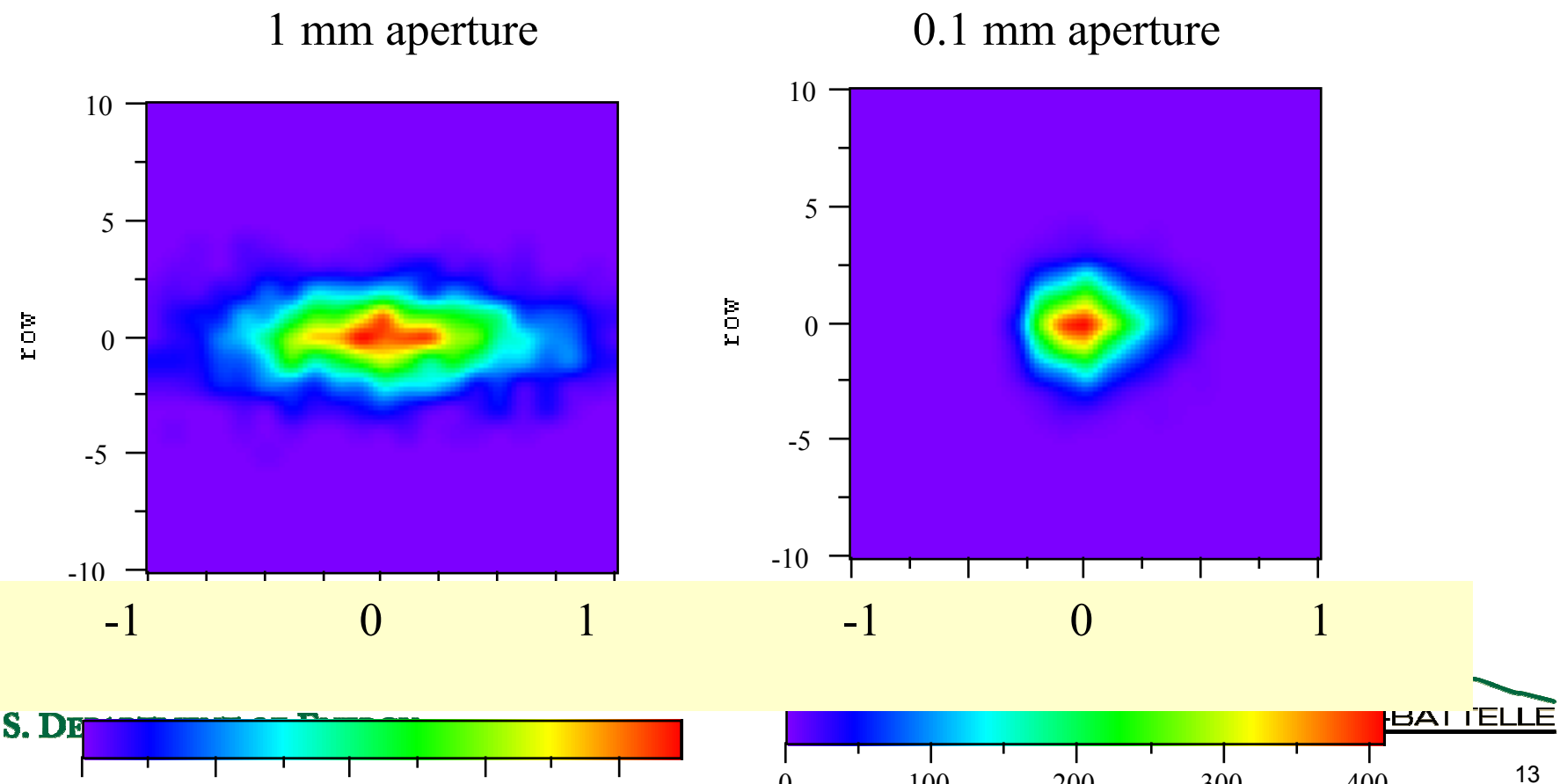
- Increase detector solid angle ~1 steradian
- 1 mrad →1/3 reflection
- 10% bandpass @ 20 keV→4-5





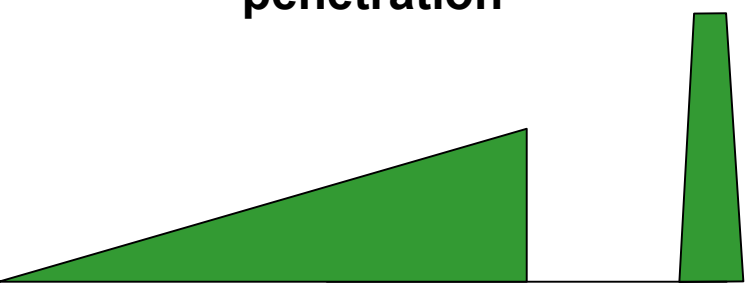
8° rotation = 10% bandpass but blurs resolution for 4μm thick sample.

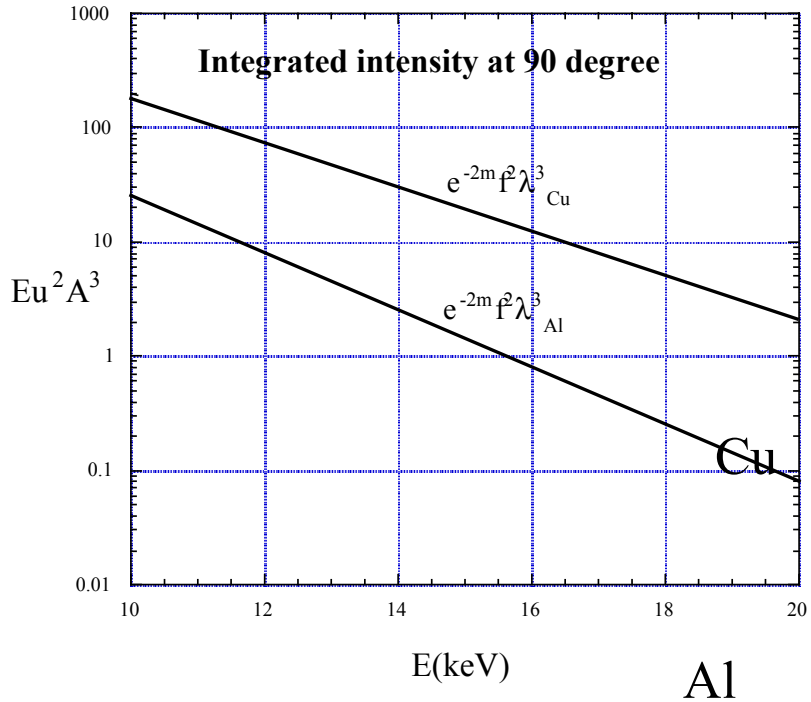
Large horizontal beam size can be mitigated with intermediate aperture



Ideal operating energy/conditions is a compromise

- High energy →many reflections
- Low energy→better reflectivity
- High E →lower thermal load
- High E →deeper penetration





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