What Coherence Can Do to CSSI: A Pleasant Surprise

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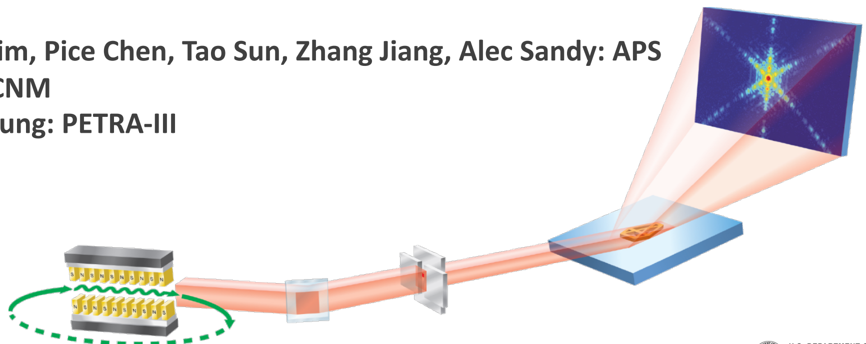
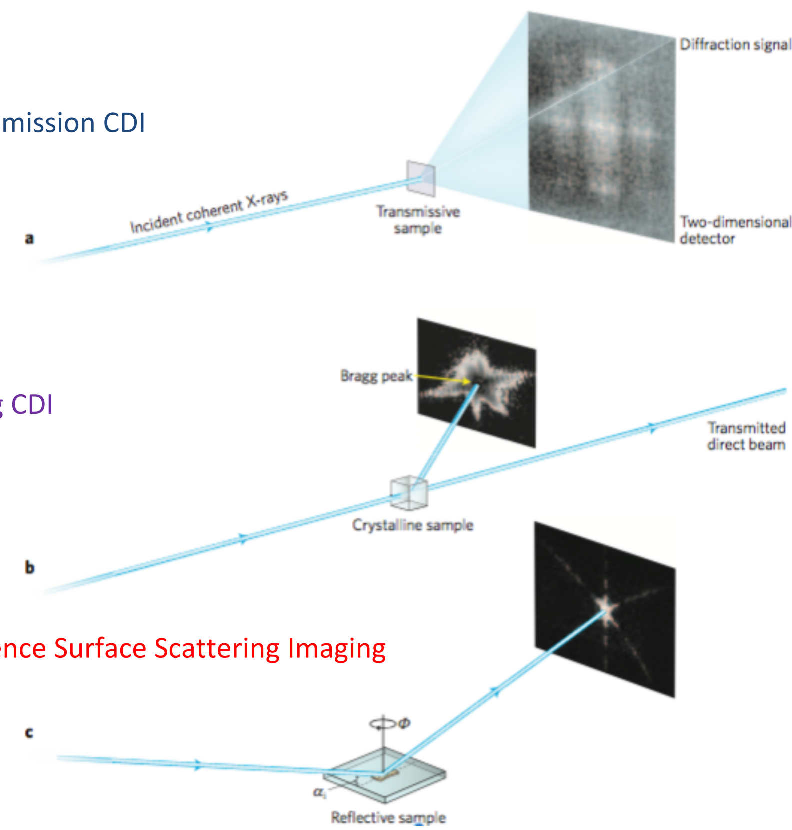
Leo Ocola: CNM
Michael Sprung: PETRA-III



What's CSSI

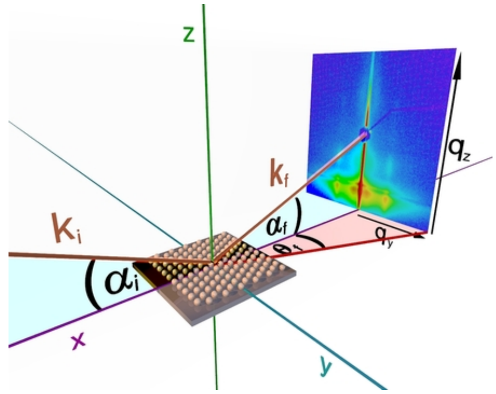
- Transmission CDI
- Bragg CDI
- Coherence Surface Scattering Imaging



NATURE PHOTONICS | VOL 6 | SEPTEMBER 2012 | www.nature.com/naturephotonics p. 574

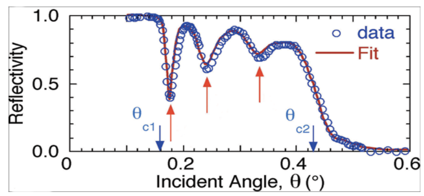
GISAXS with Coherent Beam

- Grazing incidence small-angle x-ray scattering



$$
\begin{cases}
q_x = \dfrac{2\pi}{\lambda}(\cos(\alpha_f)\cos(2\theta_f) - \cos(\alpha_i)) \\
q_y = \dfrac{2\pi}{\lambda}\cos(\alpha_f)\sin(2\theta_f) \\
q_z = \dfrac{2\pi}{\lambda}(\sin(\alpha_i) + \sin(\alpha_f))
\end{cases}
$$

- Access the 3rd dimension
  - Analogous to reflectivity
  - Electron density in z-direction

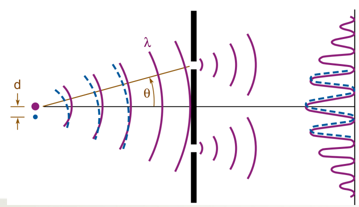


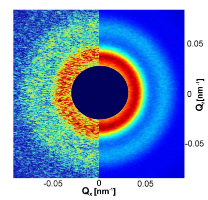
Z. Jiang, et al., PRB 84, 75440 (2011)

- Coherent scattering
  - 3D reconstruction
  - Model independent

Transverse Coherence

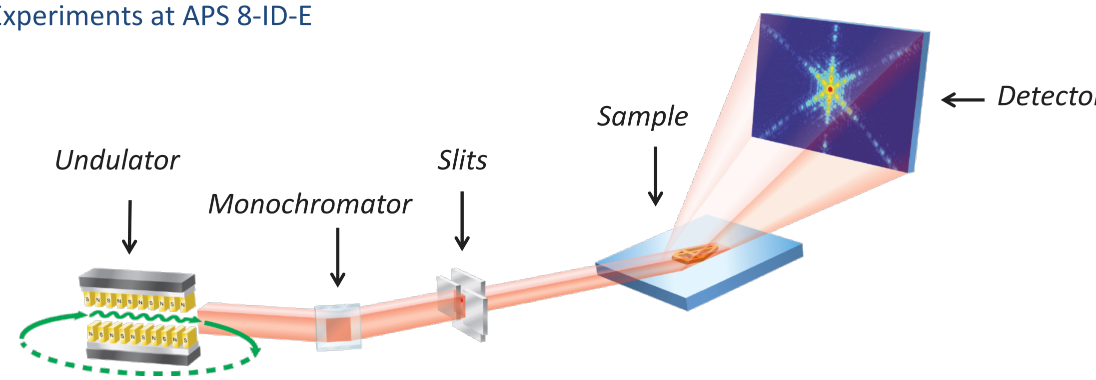
$\propto \lambda \left(\dfrac{R}{d}\right)$





Coherent surface scattering imaging (CSSI)

- Experiments at APS 8-ID-E



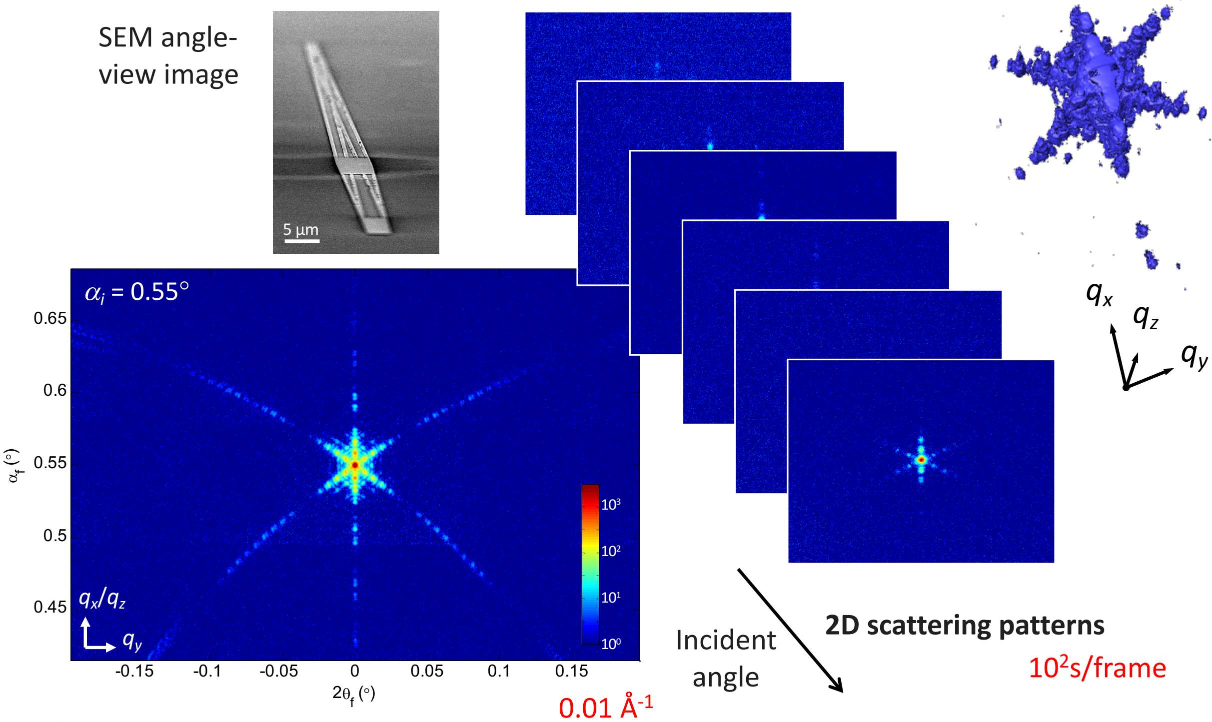
Beamline: 8-ID-E at the APS
Beam energy: 7.35 keV
Beam size: 15 x 15 μm^2
Coherent Flux: ~ 5×10^8 ph/sec

Sample-to-detector: 0.7 m
Detector: Coolsnap HQ^2
5x lens (pixel dimension ~1.3 μm)
Incident angles: 0.35~0.9°

Similar to CDI, the unique advantages of coherent scattering imaging is lensless.

Tao Sun, et al., **Nature Photonics** *6*, 586 (2012).

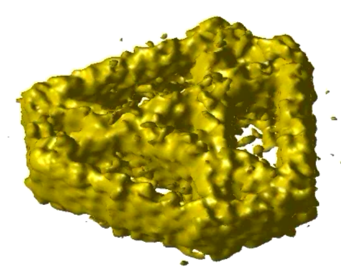
Coherent Scattering from Surface Structures

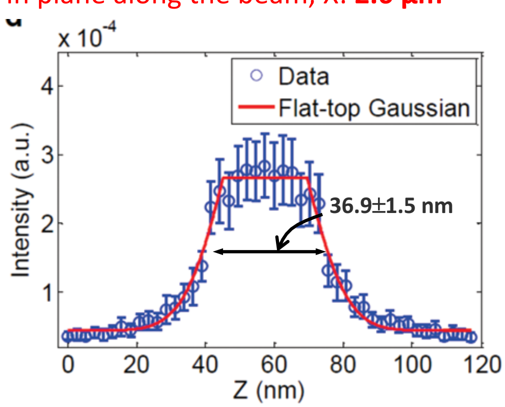


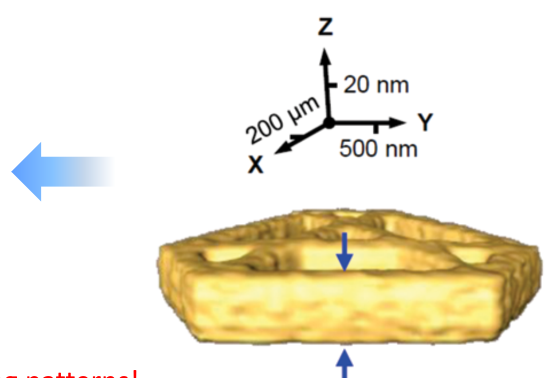
3D Reconstruction of Surface Structures

Incident angles: 0.56~0.9 °

- 2D reconstruction + Z
  - Spatial resolution:
  - Perpendicular to the surface Z: **2.7 nm**
  - In plane, perpendicular to the beam, Y: **22 nm**
  - In plane along the beam, X: **2.6 µm**





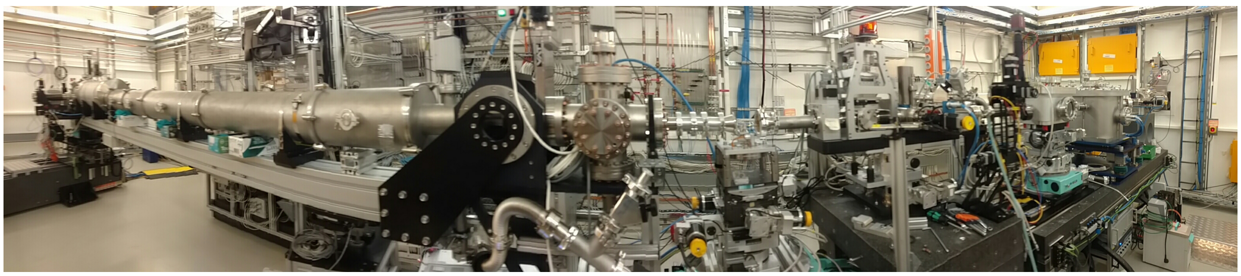


>10 hours to collect the full sets of scattering patterns!

Need of More Coherent Photons

PETRA-III P-10 beamline:

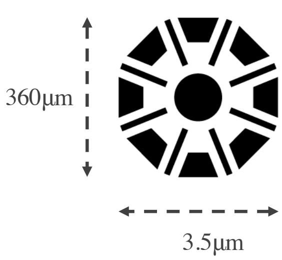
- PETRA-III: 3x better coherence than the APS
- standard 5-m long U29 undulator (3x Undulator A flux)
- Coherent flux 10^{11}/s
- Focused beam at the samples 2.2 µm x 2.6 µm
- Eiger 4M detector (75 µm x 75 µm, 2070 x 2167 pixels)
- Sample to detector distance 5 m
- Dedicated setup for coherence-based experiments

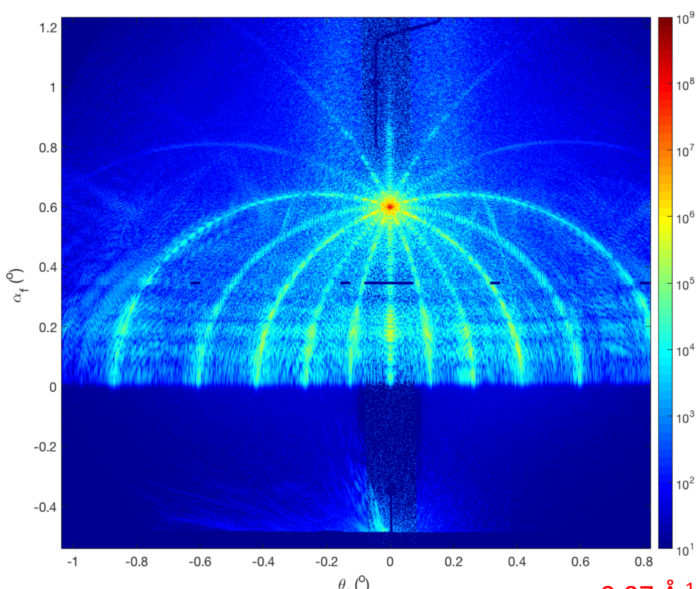


Preliminary Results from PETRA-III Run

With much smaller and more complex patterns on the order of 50 µm x 1 µm

- Speckle patterns can be observed in a much larger q-range: high spatial resolution
- The data collection efficiency is improved by at least a factor of 10^5

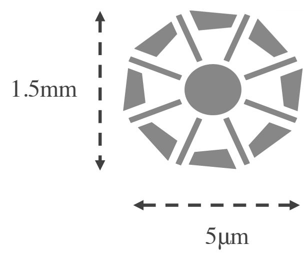


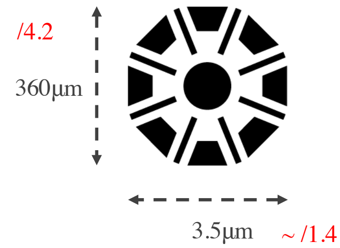


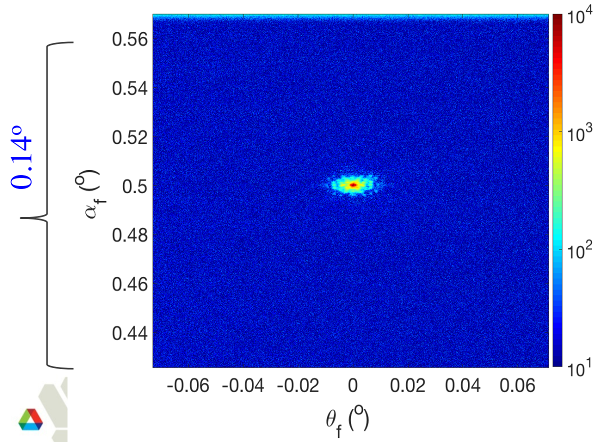
Comparison

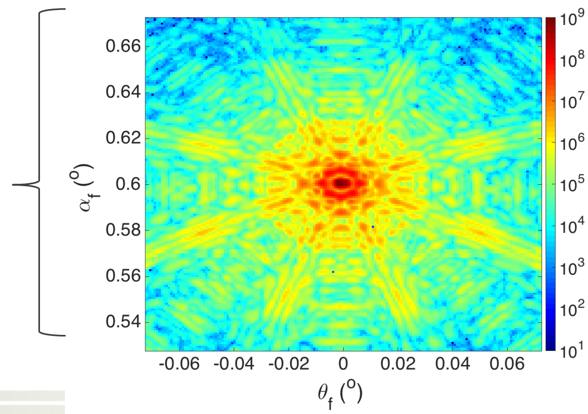
8-ID-E/APS

P-10/PETRA-III



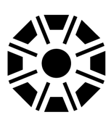


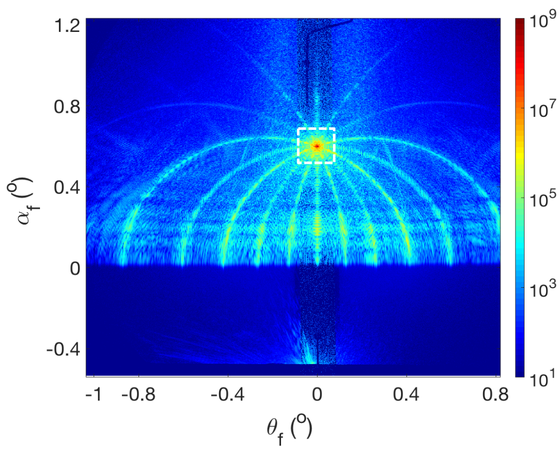


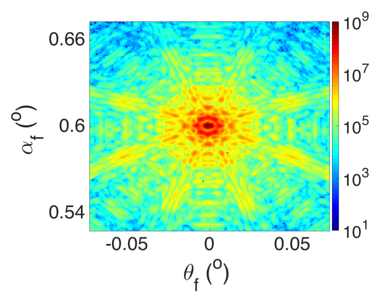


Comparison: 8-ID-E and P10 raw data

P10 data

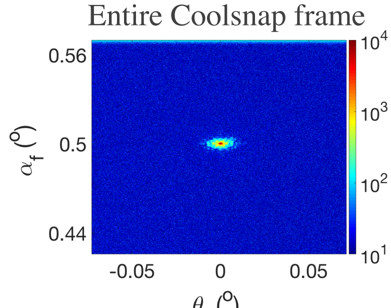






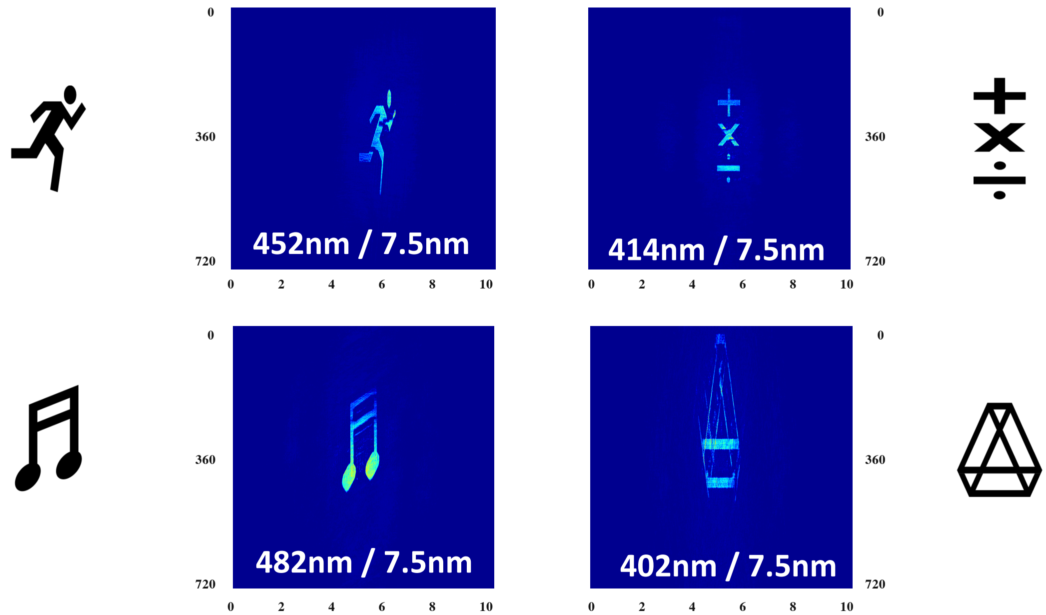
Exposure: 2 s
w/ attenuation
of 40 times

8-ID-E data
Entire Coolsnap frame



750 s no filter
(7 times bigger
sample in area)

Reconstruction for Single-shot 10-Second Exposure



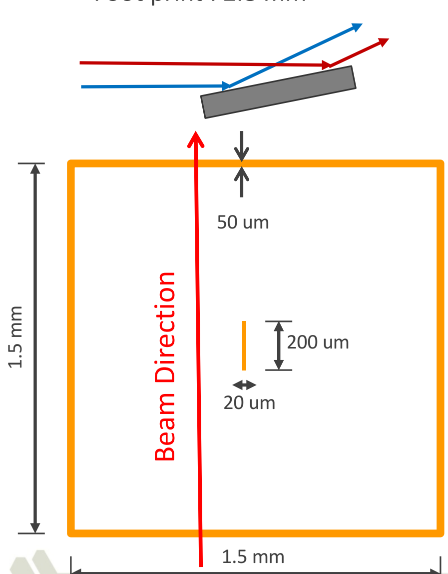
unit: μm

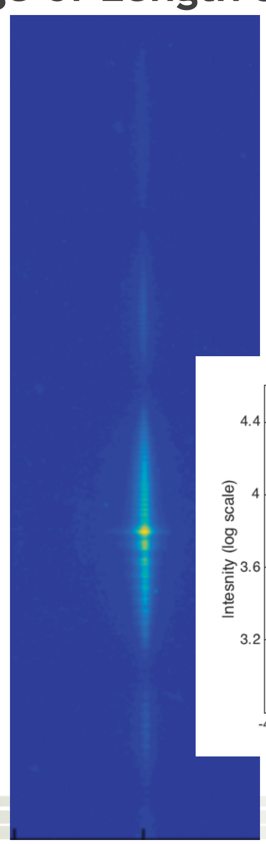
Probing a Large Range of Length Scales

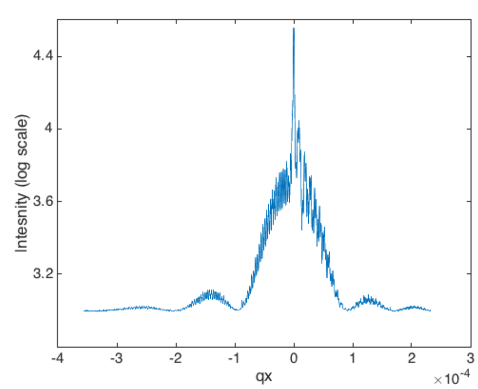
Largest feature: 1.5 mm

Smallest feature: 200 nm

Beam size : 20 x 20um
Incident angle : 0.4°
Foot print : 2.8 mm







Observations

- Compared to 8-ID-E, at P10/PETRA-II , the data collection efficiency gain is > 10^5
  - Coherence flux 10x
  - focusing 20x
  - Detector >100x
- Well, think about the APSU, > 10x more coherent flux than PETRA-III, 10^{12}

- With a dedicated beamline at APSU CSSI Resolution improvement:
  - 1-2 nm in all directions
  - High throughput
  - Time-resolved experiments

- Probing length scale
  - From nm to mm
  - unique to the geometry