First Results from Pink Beam Tomography at 13-BM-D

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Outline

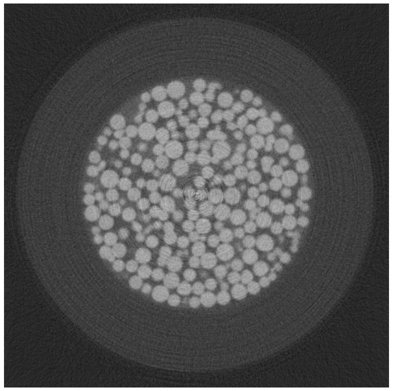
- Motivation
- Fast Point Grey camera (quick review of previous TWG presentation)
- Acquisition setup
- Mirror performance
- Tomography results

Motivation

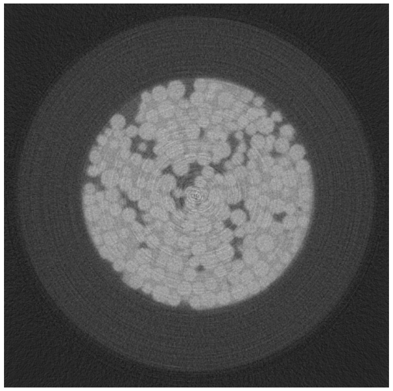
- Most tomography at 13-BM-D has been monochromatic with Si 111 monochromator
  - High-quality data, no beam hardening
  - Can make measurements above and below absorption edges
  - Commonly work at I (33.169 keV) and Cs (35.985 keV) for studies of fluids in porous media
    - Not accessible at 2-BM
  - Exposure times range from 0.25 to 5 seconds depending on energy and resolution, so 3-30 minutes for complete data set, depending on energy and resolution
- Want to go much faster to study fluid flow dynamics

Differential Absorption Tomography
Clint Willson (Louisiana State University)

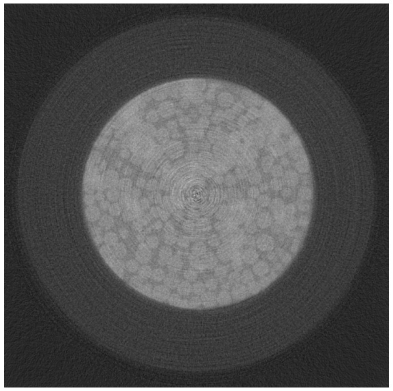
8mm diameter sand column with aqueous phase containing Cs and organic phase containing I.



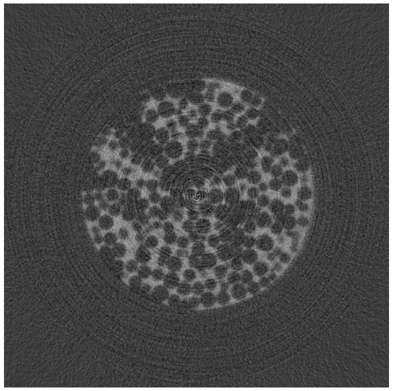
32.5 keV, below I and Cs K absorption edges



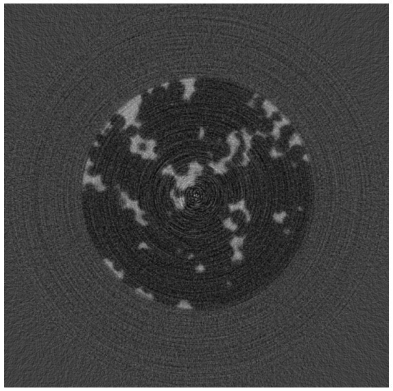
33.2 keV, above I and below Cs K absorption edges



36.0 keV, above I and Cs K absorption edges



33.2 - 32.5 keV, showing distribution of I in the organic phase



36.0 - 33.2, showing distribution of Cs in the aqueous phase

Point Grey USB-3.0 Camera Grasshopper3 GS3-U3-23S6M

- 1920 x 1200 global shutter CMOS
- Sony IMX174 1/1.2
- No smear • Distortion-free
- Dynamic range of 73 dB
- Peak QE of 76%
- Read noise of 7e-
- 12-bit or 8-bit data
- Max frame rate of 162 fps
  - ~356 MB/S, >3X faster than GigE
- USB 3.0 interface
- $1,295

Comparison to Other Cameras

	Grasshopper3	Photometrics CoolSnap HQ^2	Andor Zyla	Andor Neo
Format	1920 x 1200	1392 x 1040	2560 x 2160	2560 x 2160
Interface	USB 3.0	PCI Proprietary	CameraLink 10-tap	CameraLink 3-tap
Maximum frame/s	162 (8-bits) 80 (12-bits)	10 (12-bits)	100 (Rolling, 12-bit) 75 (Rolling, 16-bit) 50 (Global 12/16-bit)	30 (Rolling or Global) 79 (1920x1080)
Cooled	No	-30°C	0°C	-30°C
Full-well e^-	32,513	16,000	30,000	30,000
Read noise e^-	7	5.5	1.2 (Rolling) 2.5 (Global)	1.0 (Rolling) 2.3 (Global)
Price	$1,295	~$15,000	$19,500	~$15,000

Grasshopper3 GS3-U3-23S6M Applications

- I originally purchased the camera for fast pink-beam tomography
  - Not a full-time need, did not want to spend $15K for Andor Neo/PCO Edge or $100K for PCO Dimax
  - Radiation damage worry. $1,295 can be replaced frequently if needed
- Starting in 2014-2 run Grasshopper3 has replaced CoolSnap HQ2 as standard camera even for monochromatic tomography at 13-BM-D
  - 13 ms readout vs 100 ms in 12-bit mode, 6 ms in 8-bit mode
  - 2.5 more voxels in reconstruction
  - Equivalent quality
- Did first pink-beam tomography in July 2014, reported in this talk.

Acquisition Setup

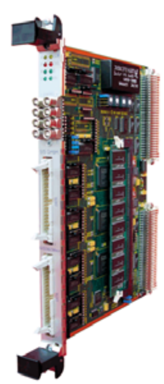
- On-the-fly scanning
- Detector trigger driven by motor steps
- SIS3820 and BNC-505 could be replaced with softGlue

OR

- SIS3820 alone could be used if pulse output width and polarity were programmable (coming soon?)

OMS-58 (Pulse out) → SIS-3820 (÷ N) (Motor pulse per pixel) → BNC-505 (Pulse width=exposure time) → Grasshopper camera

OMS-58 (Pulse out) → Step-Pak → Rotation stage

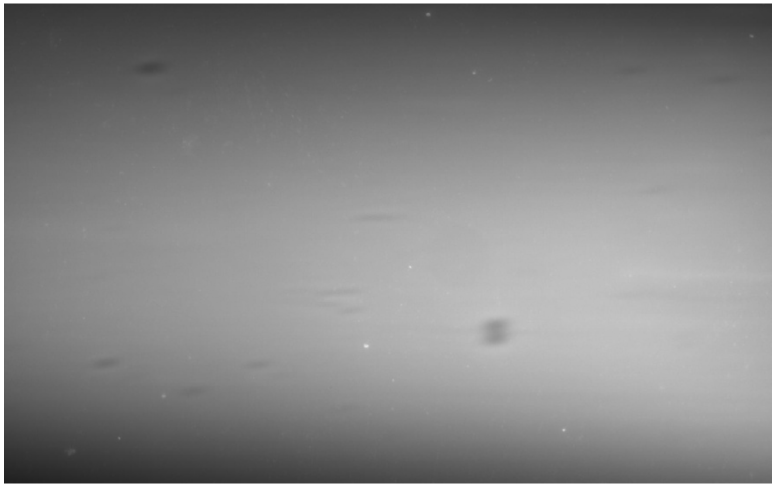


Pink Beam Setup

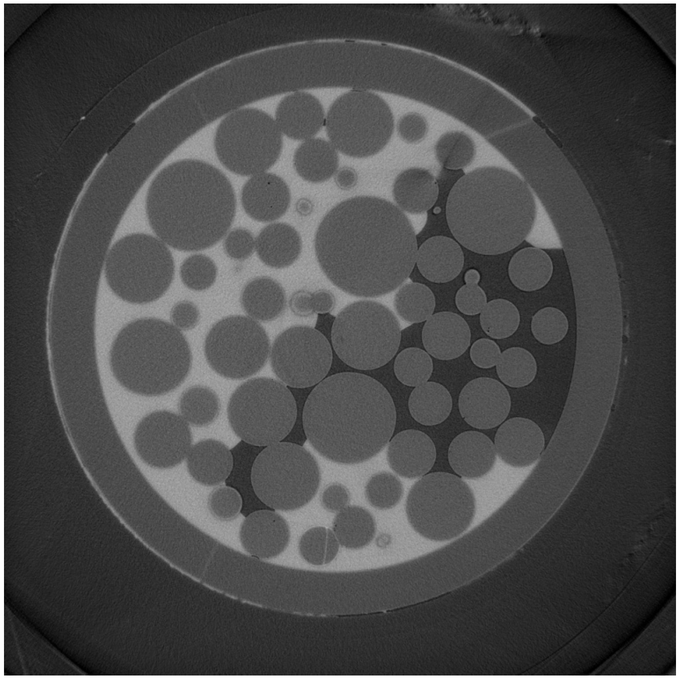
- 13-BM-D bending magnet beamline
- White-beam capable mirror
- 49.5 m from source
- 1.2 m long mirror, 1.0 m optical aperture
- Bounces down
- Pt coated
- Can adjust pitch and bending
- Pitch controls cutoff energy to eliminate high-energy photons
- Bending curvature can be positive (focusing) or negative (defocusing)
- Use negative curvature to increase vertical beam size on sample at small pitch angles

Monochromatic Beam Measurement

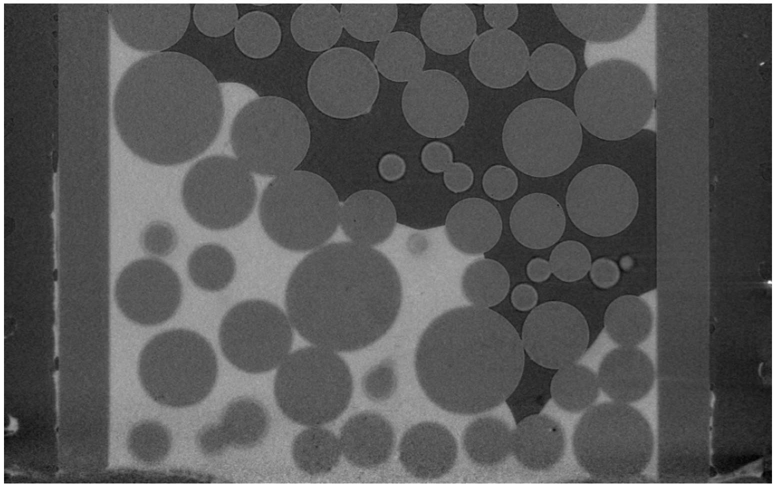
- This is the standard for comparing pink beam experiments
- Energy=36.100 keV (115 eV above Cs K-edge)
- 1.0 second exposure time, 900 projections, 900 seconds (15 minutes) total time
- 4.21 mm/pixel, 1920x1200 pixels projections
- 1920x1920x1200 reconstructed volume, 8.2GB
- Field of view = 8.08x5.05 mm



Flat field



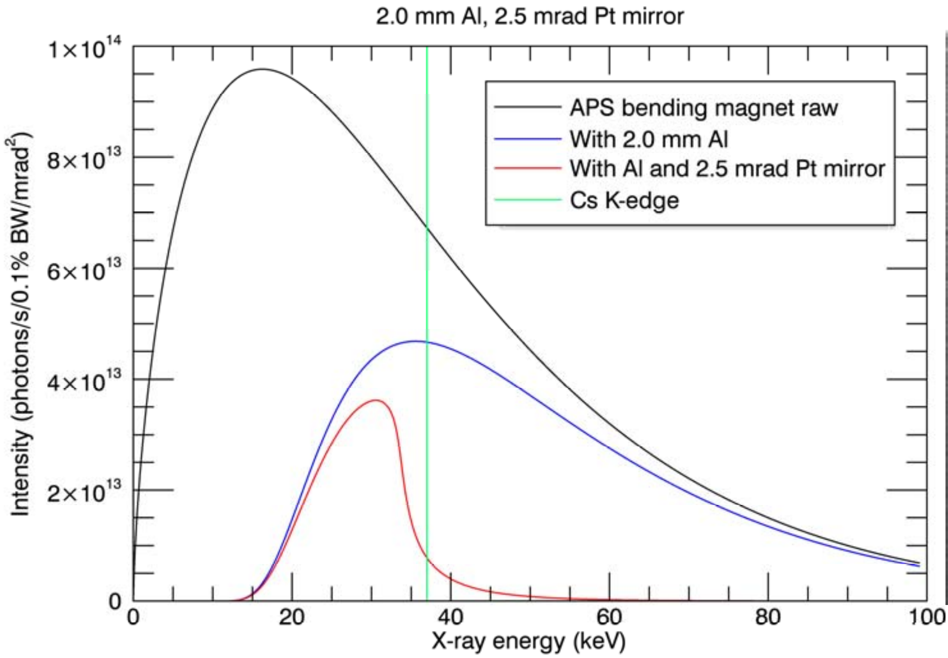
Horizontal slice

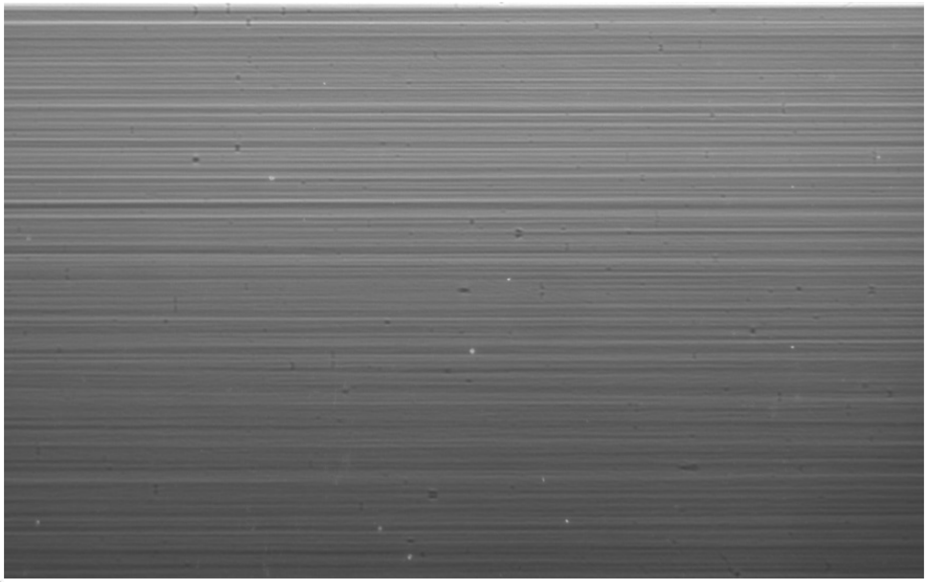


Vertical slice

Pink Beam, Mirror=2.5 mrad

- Mirror angle=2.5 mrad (Beads_Pink_A)
- 2 mm Al absorber
- 12-bit data
- 1 ms exposure time, 70.7 frames/s, 12.7 seconds total
- Rotation axis orientation *not* corrected for mirror angle





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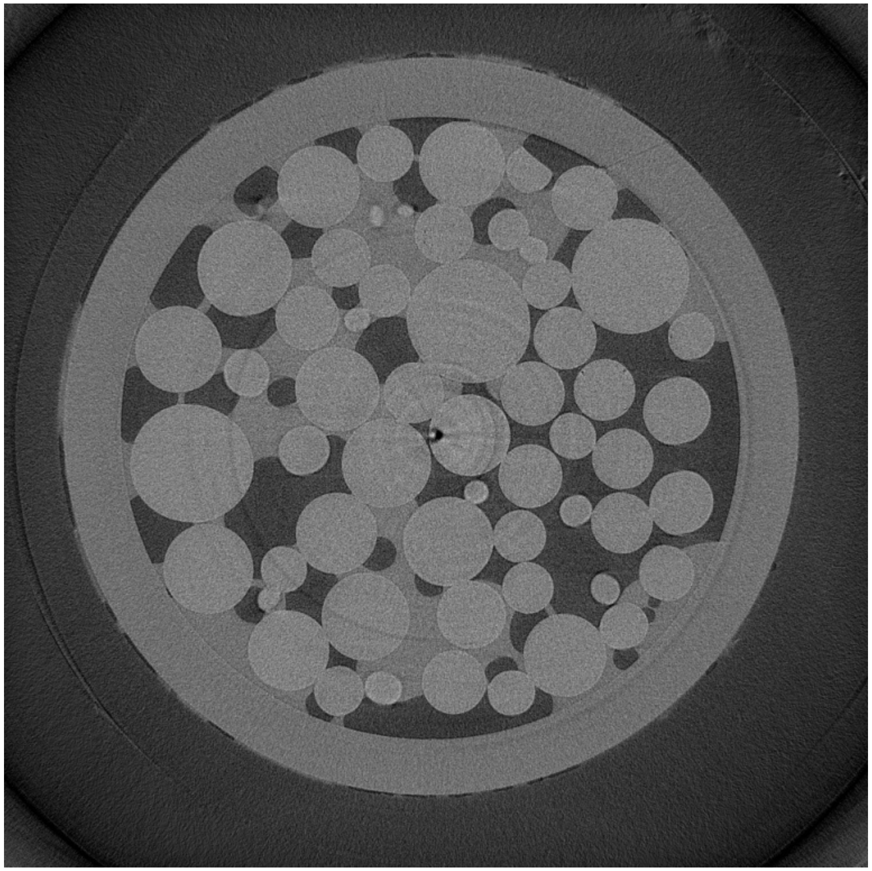
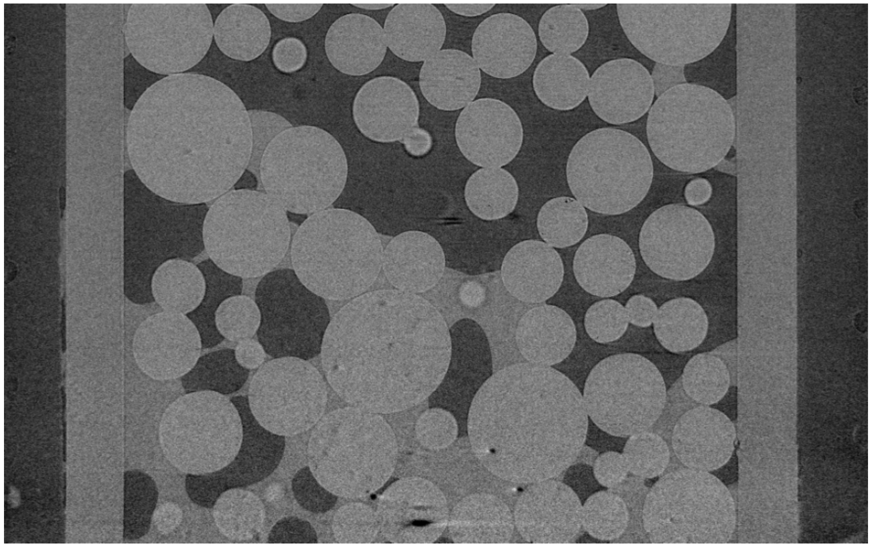


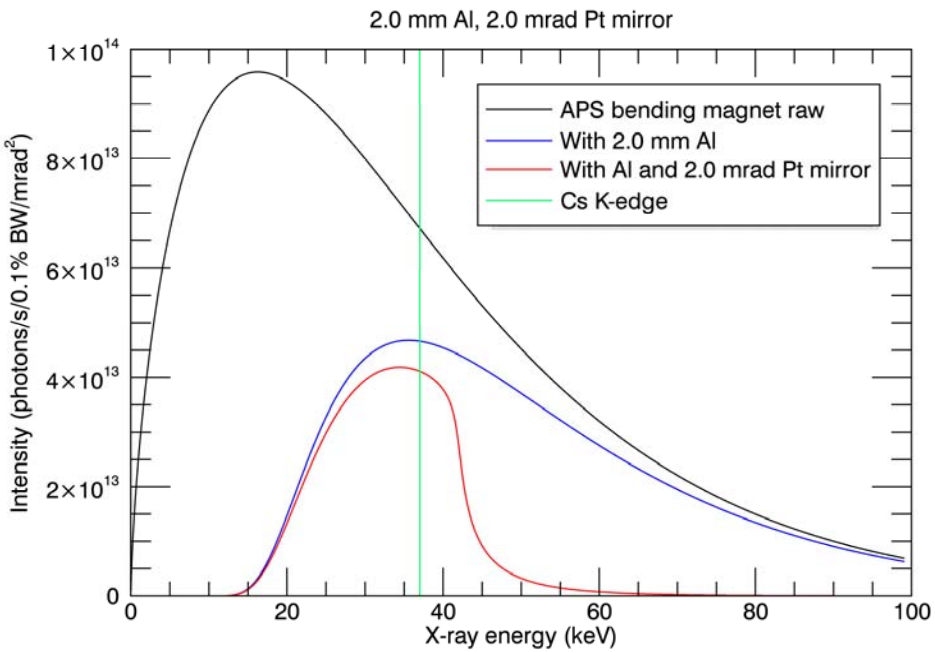
Horizontal slice

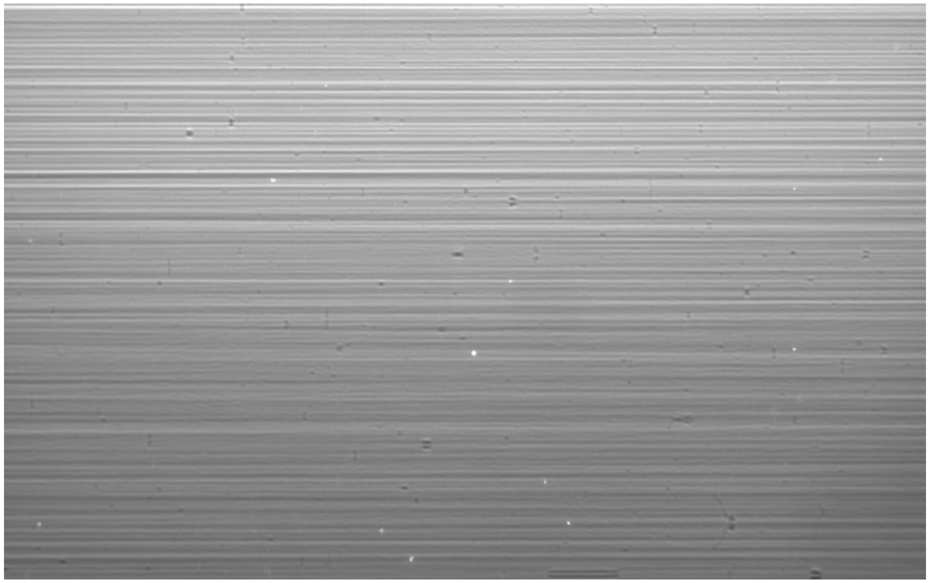


Vertical slice

Pink Beam, Mirror=2.0 mrad

- Mirror angle=2.0 mrad (Beads_Pink_H)
- 2 mm Al absorber
- 8-bit data
- 1 ms exposure time, 124 frames/s, 7.3 seconds total
- Rotation axis orientation corrected for mirror angle

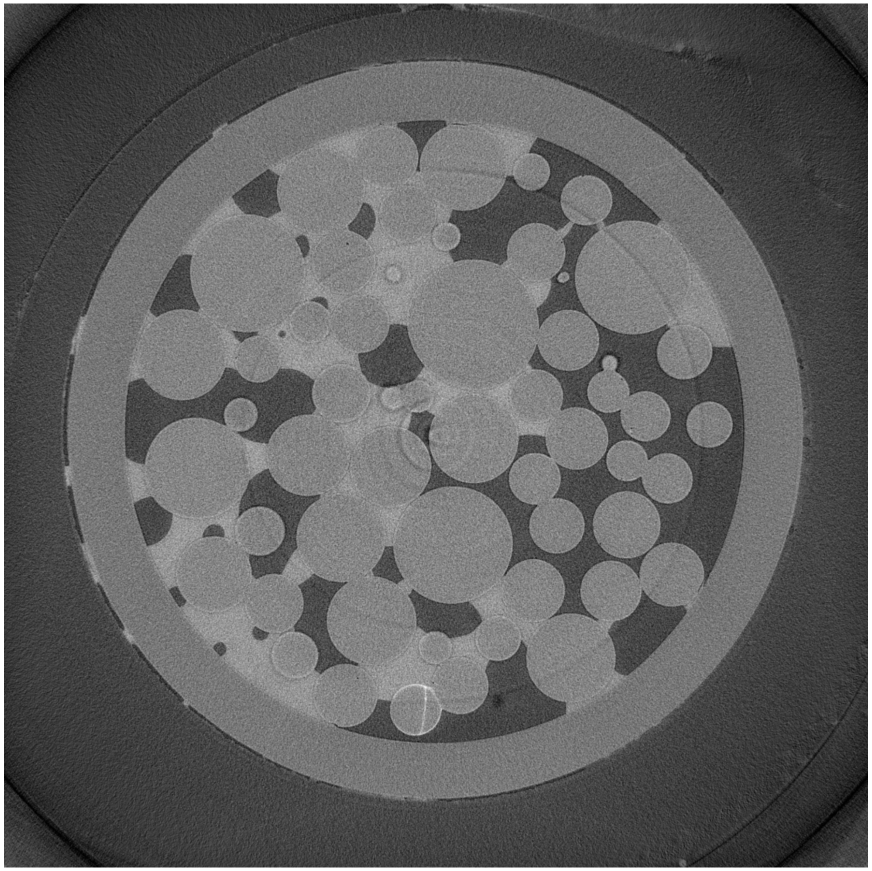




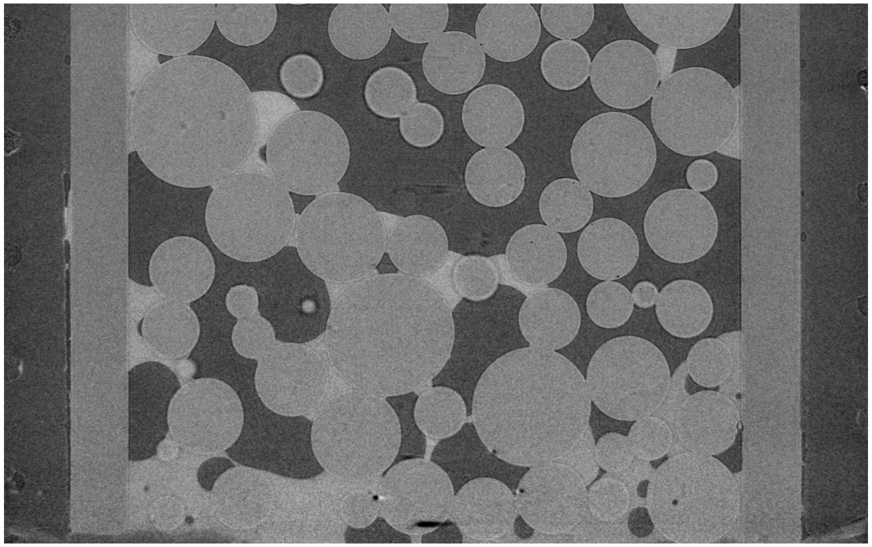
Flat field

Pink Beam, Mirror=2.0 mrad

- Mirror angle=2.0 mrad (Beads_Pink_H)
- 2 mm Al absorber
- 8-bit data
- 1 ms exposure time, 124 frames/s, 7.3 seconds total
- Rotation axis orientation corrected for mirror angle



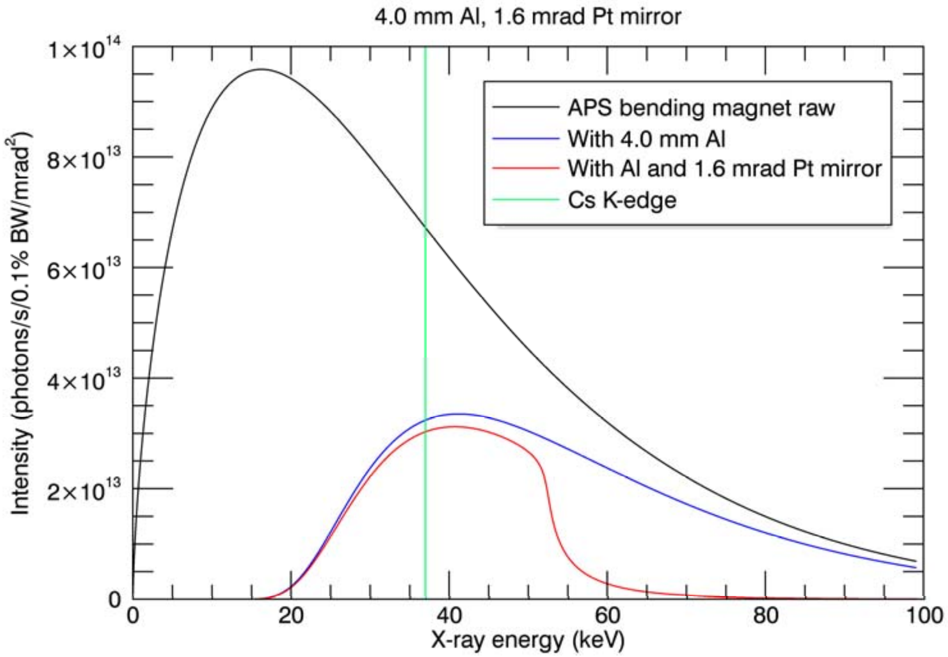
Horizontal slice

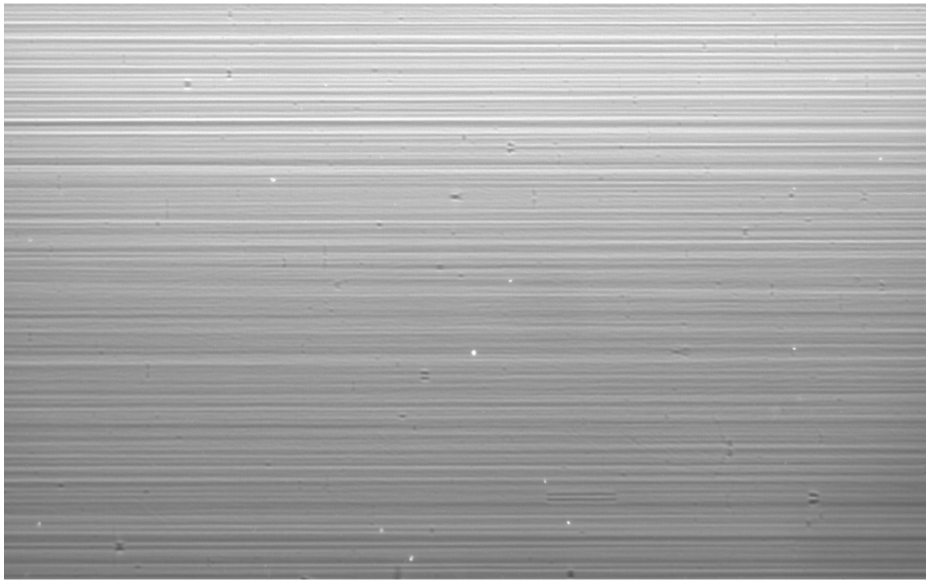


Vertical slice

Pink Beam, Mirror=1.6 mrad

- Mirror angle=1.6 mrad (Beads_Pink_P)
- 4 mm Al absorber
- 12-bit data
- 2 ms exposure time, 66 frames/s, 13.6 seconds total
- Rotation axis orientation corrected for mirror angle

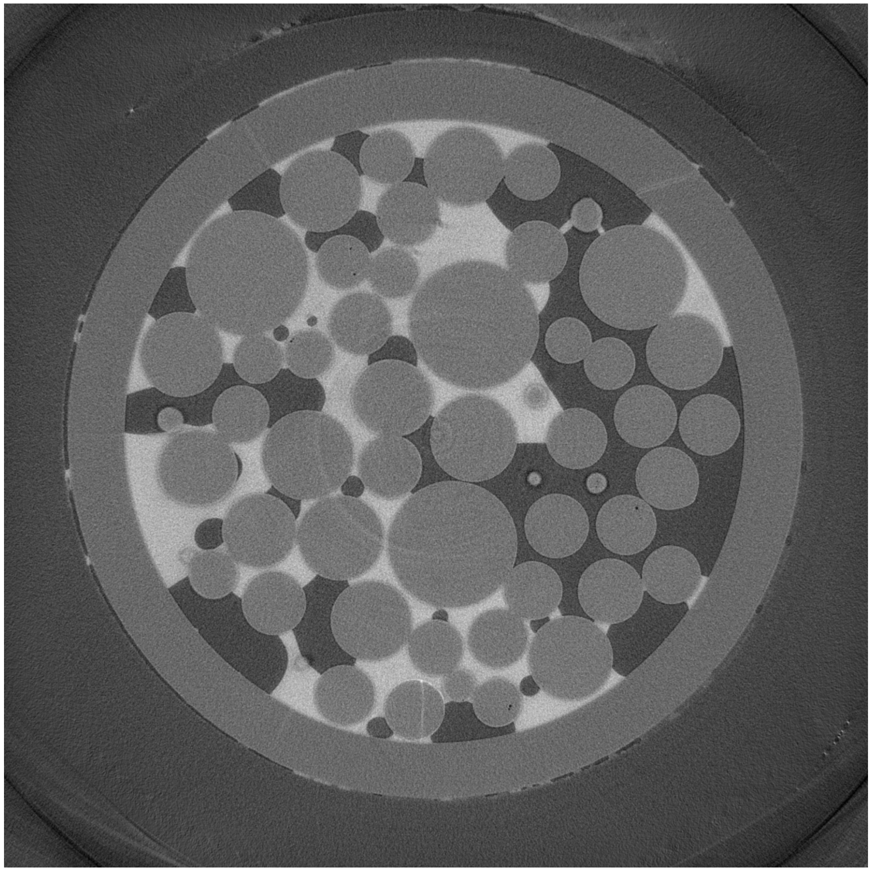




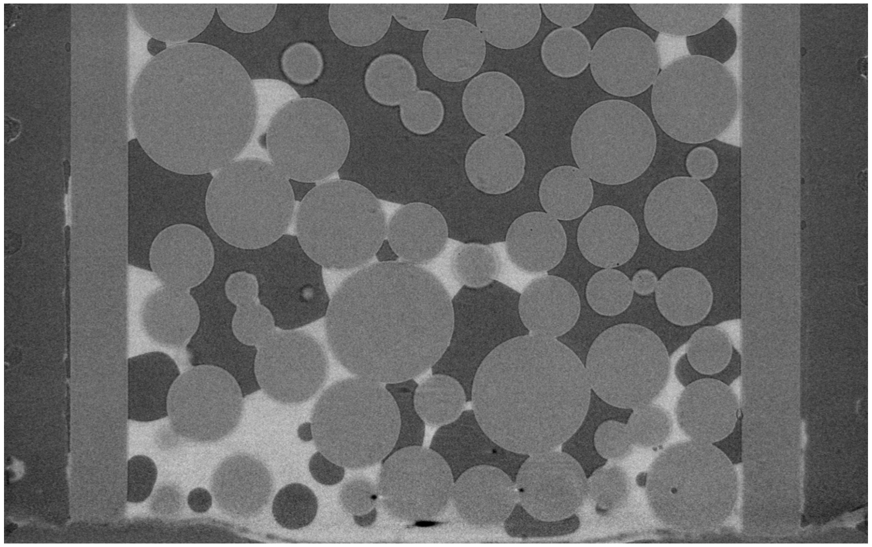
Flat field

Pink Beam, Mirror=1.6 mrad

- Mirror angle=1.6 mrad (Beads_Pink_P)
- 4 mm Al absorber
- 12-bit data
- 2 ms exposure time, 66 frames/s, 13.6 seconds total
- Rotation axis orientation corrected for mirror angle



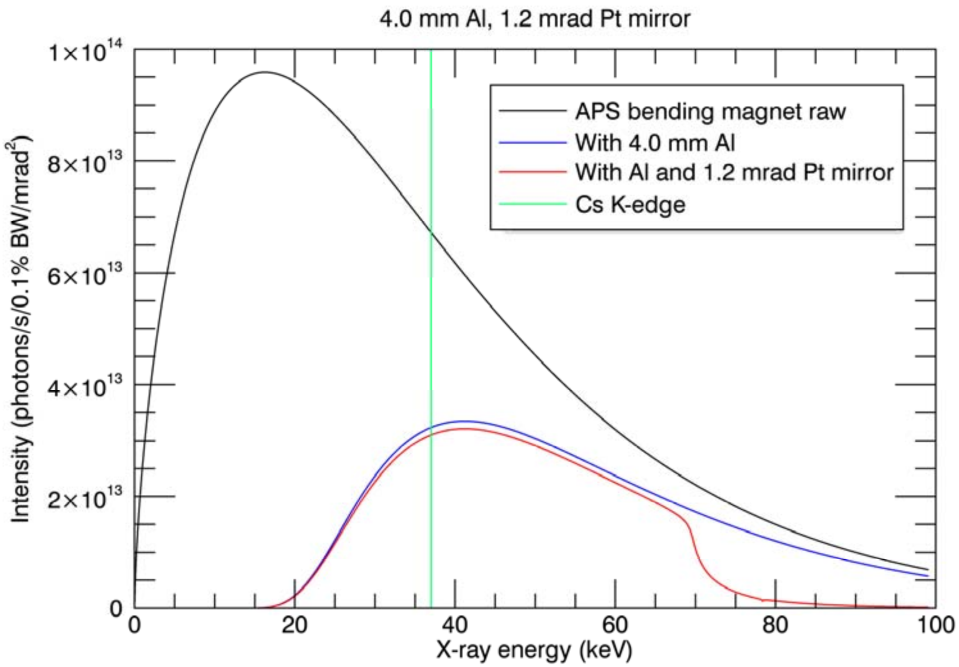
Horizontal slice

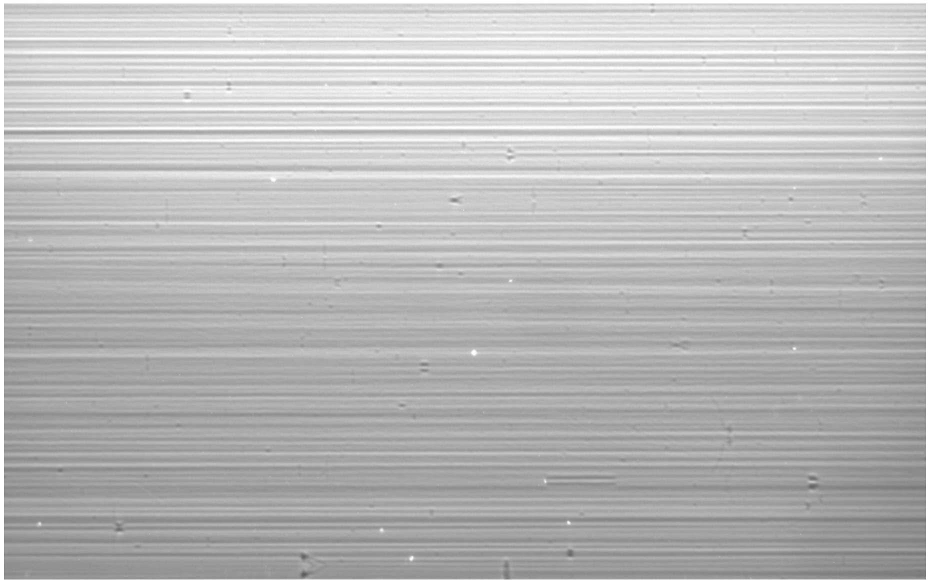


Vertical slice

Pink Beam, Mirror=1.2 mrad

- Mirror angle=1.2 mrad (Beads_Pink_Q)
- 4 mm Al absorber
- 12-bit data
- 2 ms exposure time, 66 frames/s, 13.6 seconds total
- Rotation axis orientation corrected for mirror angle

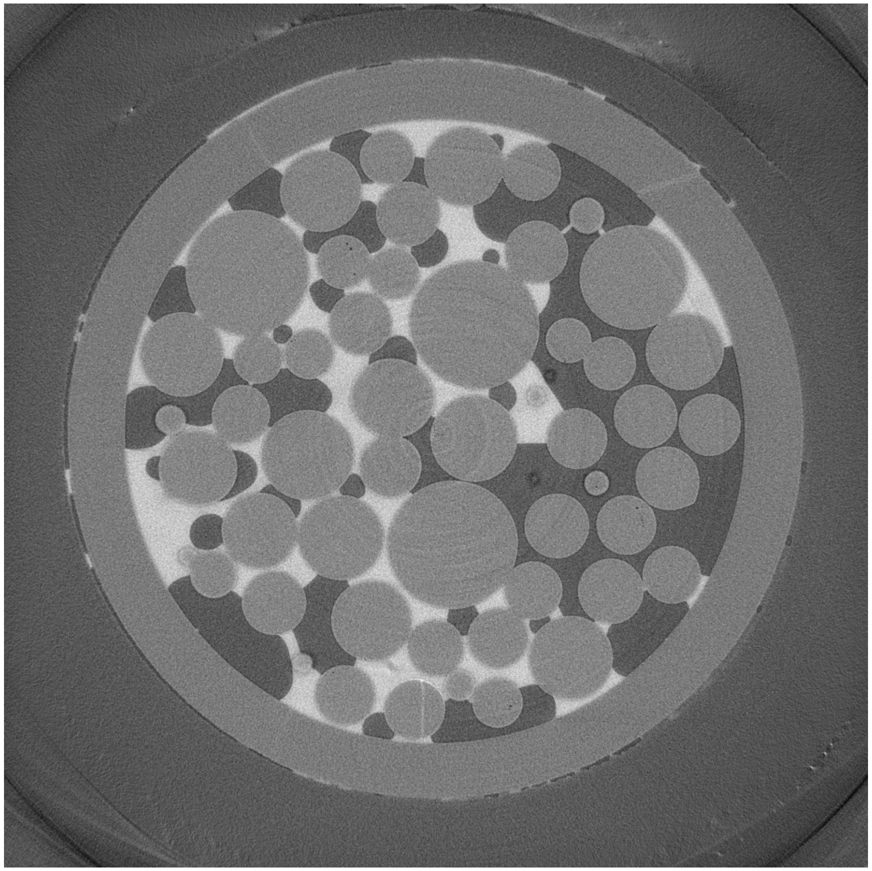




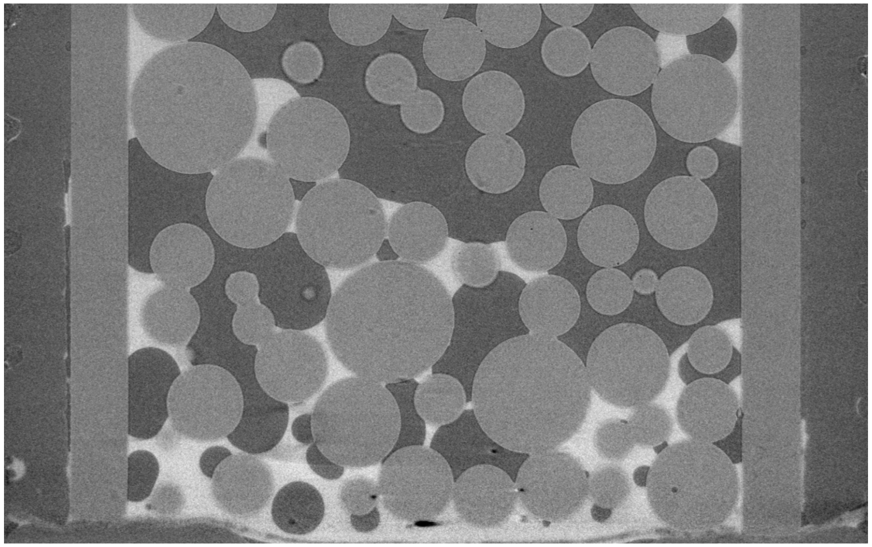
Flat field

Pink Beam, Mirror=1.2 mrad

- Mirror angle=1.2 mrad (Beads_Pink_Q)
- 4 mm Al absorber
- 12-bit data
- 2 ms exposure time, 66 frames/s, 13.6 seconds total
- Rotation axis orientation corrected for mirror angle



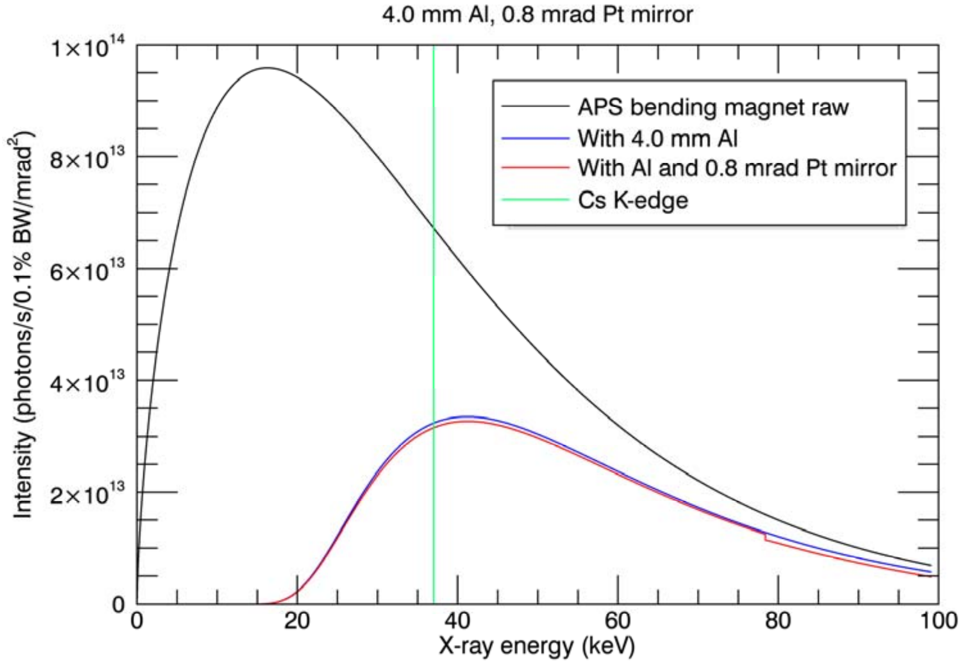
Horizontal slice

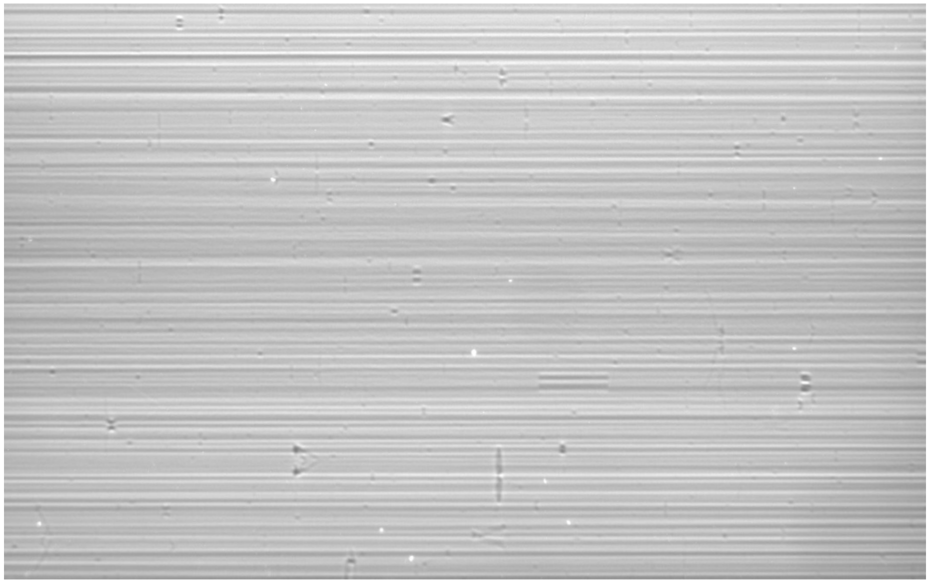


Vertical slice

Pink Beam, Mirror=0.8 mrad

- Mirror angle=0.8 mrad (Beads_Pink_R)
- 4 mm Al absorber
- 12-bit data
- 5 ms exposure time, 55 frames/s, 16.4 seconds total
- Rotation axis orientation corrected for mirror angle

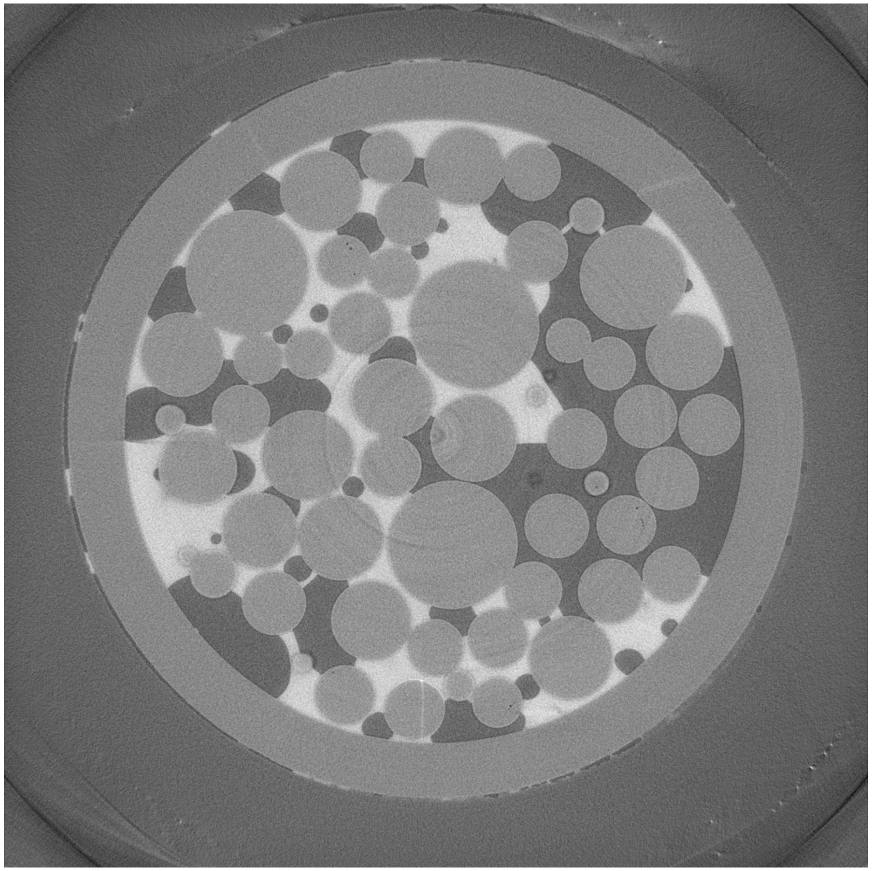




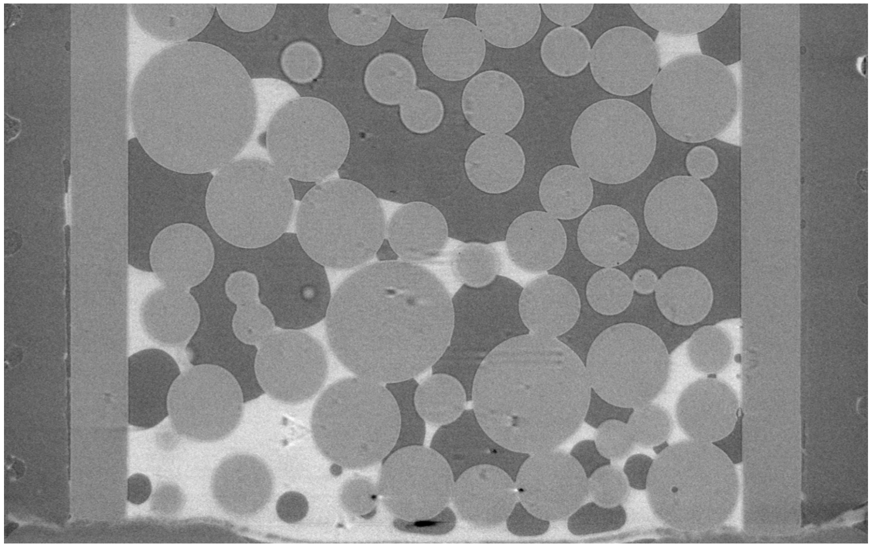
Flat field

Pink Beam, Mirror=0.8 mrad

- Mirror angle=0.8 mrad (Beads_Pink_R)
- 4 mm Al absorber
- 12-bit data
- 5 ms exposure time, 55 frames/s, 16.4 seconds total
- Rotation axis orientation corrected for mirror angle



Horizontal slice



Vertical slice

Conclusions

- Can get nice uniform 5mm vertical field to >100 keV using bent mirror
- Vertical field of view is ~constant with mirror angle at a given bending radius.
- Can collect high-quality tomography data in under 10 seconds with a $1,300 camera
- Radiation effects on liquids need to be studied more to see if this technique can be useful in practice.

How many bits do I really have/need?

Common misconceptions about required number of bits in a camera

- The ADC should be set so 1 LSB is ~read noise.
- The number of bits required is then given by the ratio of the full-well capacity to the read noise. Example of Grasshopper3:
  - Full well = 32,513 e^-
  - Read noise = 7 e^-
  - Ratio = 4644 = 12.18 bits, so 12 bits required
- But this does NOT mean that the full-well is captured with 12 bit precision!
  - Noise in full-well measurement = sqrt(30,000) = 173 e^-
  - Signal to noise in full-well measurement = 30,000/173 = 173. This is less than 8 bits!
  - So a 12-bit camera is not required to digitize the full-well with full precision.

How many bits do I really have/need?

- Example: Tomography where air/flat field use full-well (close to saturation) and maximum absorption is 80%.
- Darkest pixels have 20% transmission = 30000 * 0.2 = 6000 e^-
- Noise in darkest pixels is sqrt(6000) = 77 e^-
- Brightest pixels are 30000 e^-, so dynamic range is 30000/77 = 387. This is 8.6 bits. So a 9 bits is all that is required for this application.
- Collecting 12 or 16 bits is completely overkill for a camera with 30000 e^- full-well UNLESS the range of the pixel intensities in a single image really covers the entire range from the read-noise to the full-well capacity. This applies to Andor and PCO Edge cameras.