

X-ray Nondestructive Characterization of Mesoscale (mm extent with μm features) Objects



Presented by:

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Bernard Koziowski, Inertial Confinement Fusion, Experimental Physicist
Daniel Schneberk, Computations, X-ray imaging and object recovery
Amy Waters, Engineering, X-ray Imaging**

at

Workshop on Emerging Scientific Opportunities Using X-ray Imaging

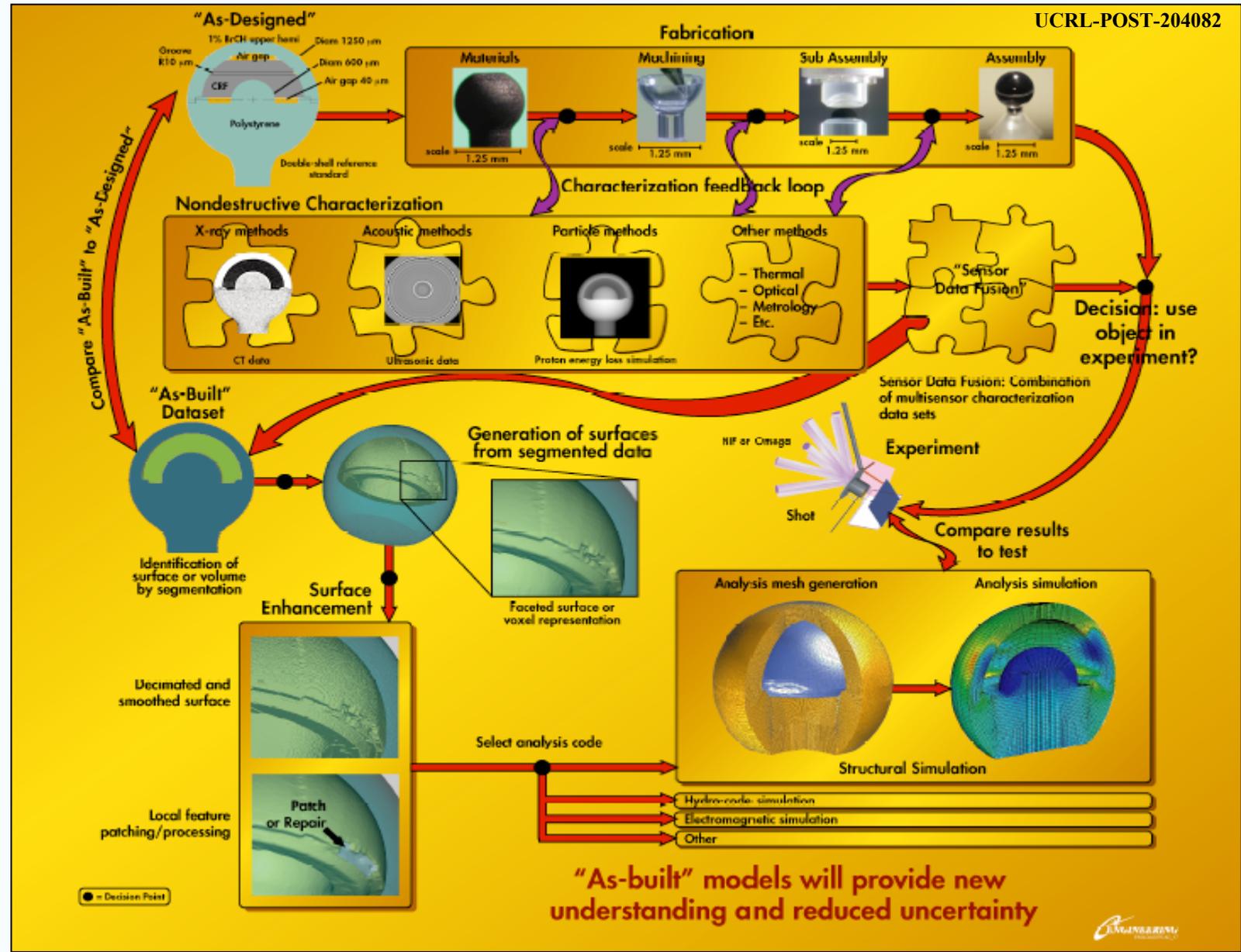
August 29 – September 1, 2004

The Abbey, Fontana, Lake Geneva Area, Wisconsin

Using characterization to close the loop from design, through fabrication and experiment to simulations-ABM



UCRL-POST-204082



Industrial x-ray CT nondestructively evaluates materials, components, and assemblies



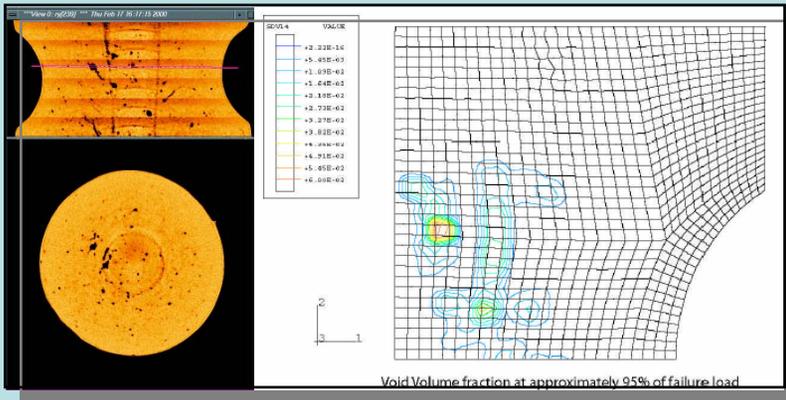
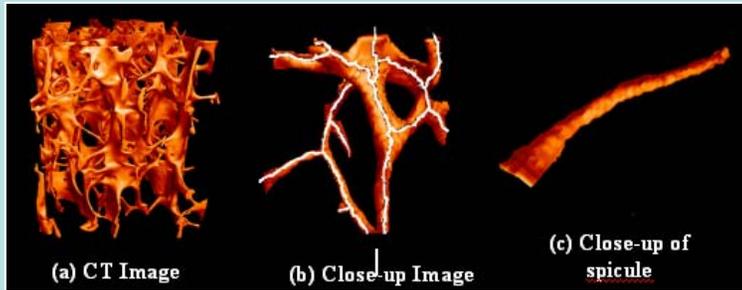
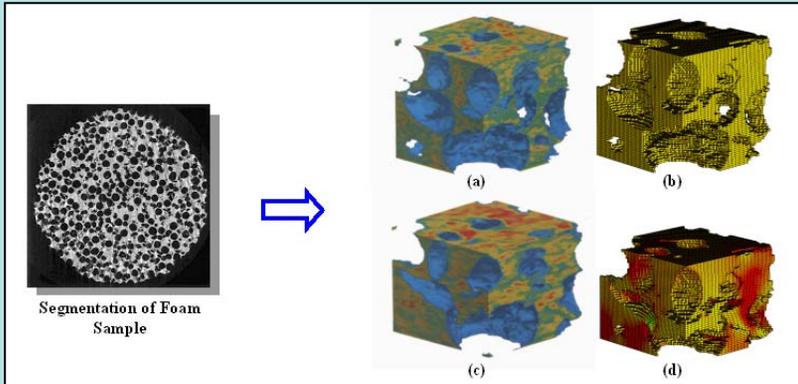
- **Inspection** – Structural integrity using attenuation measurements
 - Uniformity (homogeneity/inhomogeneity, gradients, etc.)
 - Porosity
 - Defect detection (voids, cracks, inclusions, etc.)
 - Dimensions (size, shape, etc.)
 - Assembly verification
- **Characterization** – Quantitative physical properties per voxel using multi-energy attenuation measurements
 - Absolute volumetric density (g/cm^3)
 - Effective atomic number (Z)
 - Component weight fraction (%)
 - Radioactivity (Ci)
 - Electron density (e^-/m^3)

To meet these evaluation objectives requires artifact-free quantitative data

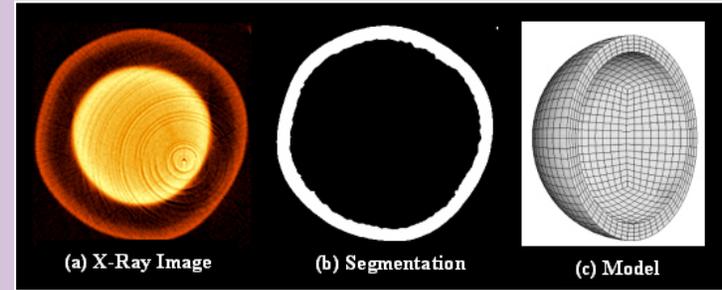
NDC applications at LLNL range from small to large objects and require a range of x-ray imaging systems



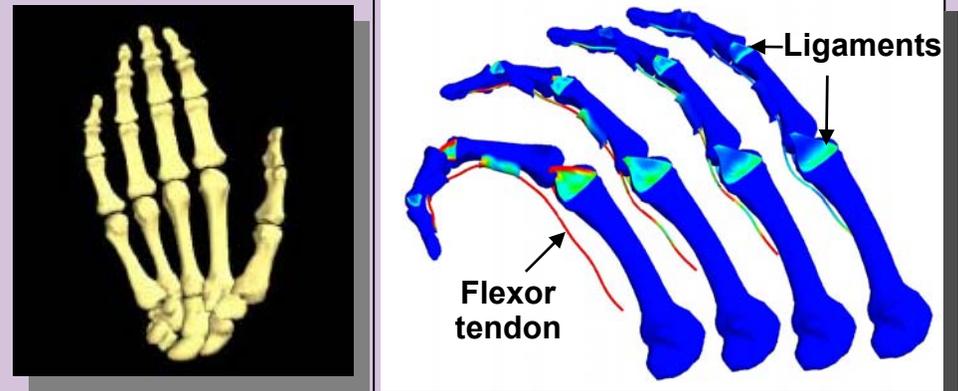
XTM at SLAC



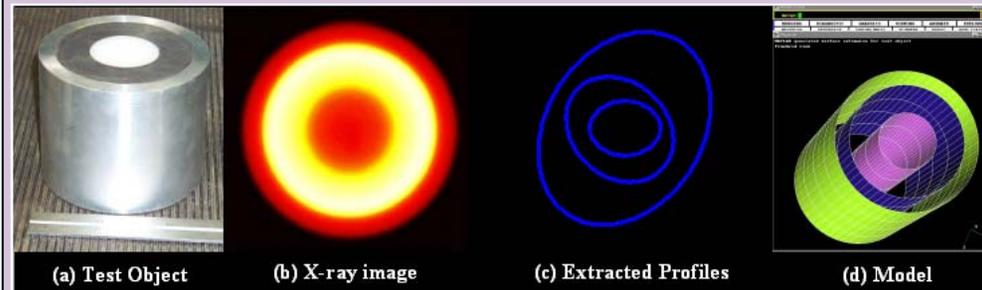
KCAT at LLNL



LCAT at LLNL



HECAT at LLNL



Current emphasis is on mesoscale objects of strategic importance to Lawrence Livermore National Laboratory



Program

Applications

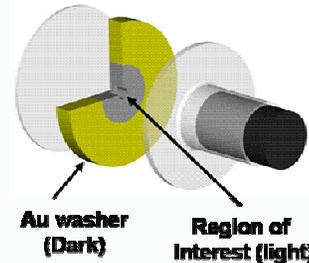
ICF

DT layer in Be shell

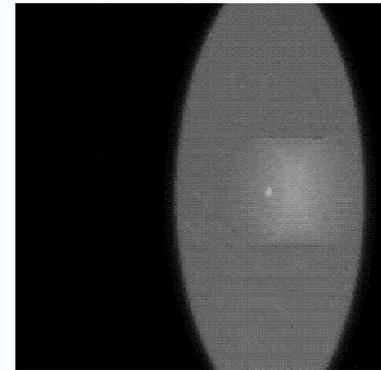
HED

Planar, 2D hydro
Planar features
Rad. Transport
Convergent hydro

Schematic of 2D hydro target



Movie of digital radiographs (%Transmission)



Xradia DR data

DOD

Low-collat. HE
Shock-dissip. fuels
Enhanced-blast HE
Detonators, etc.

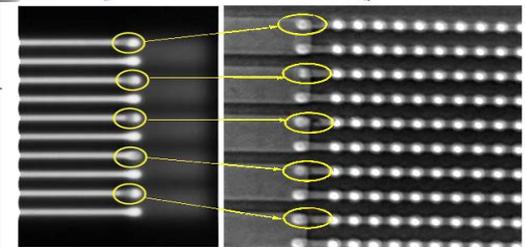
KCAT
DR



Xradia CT data

NAI

Adv. communications
Sensor modules



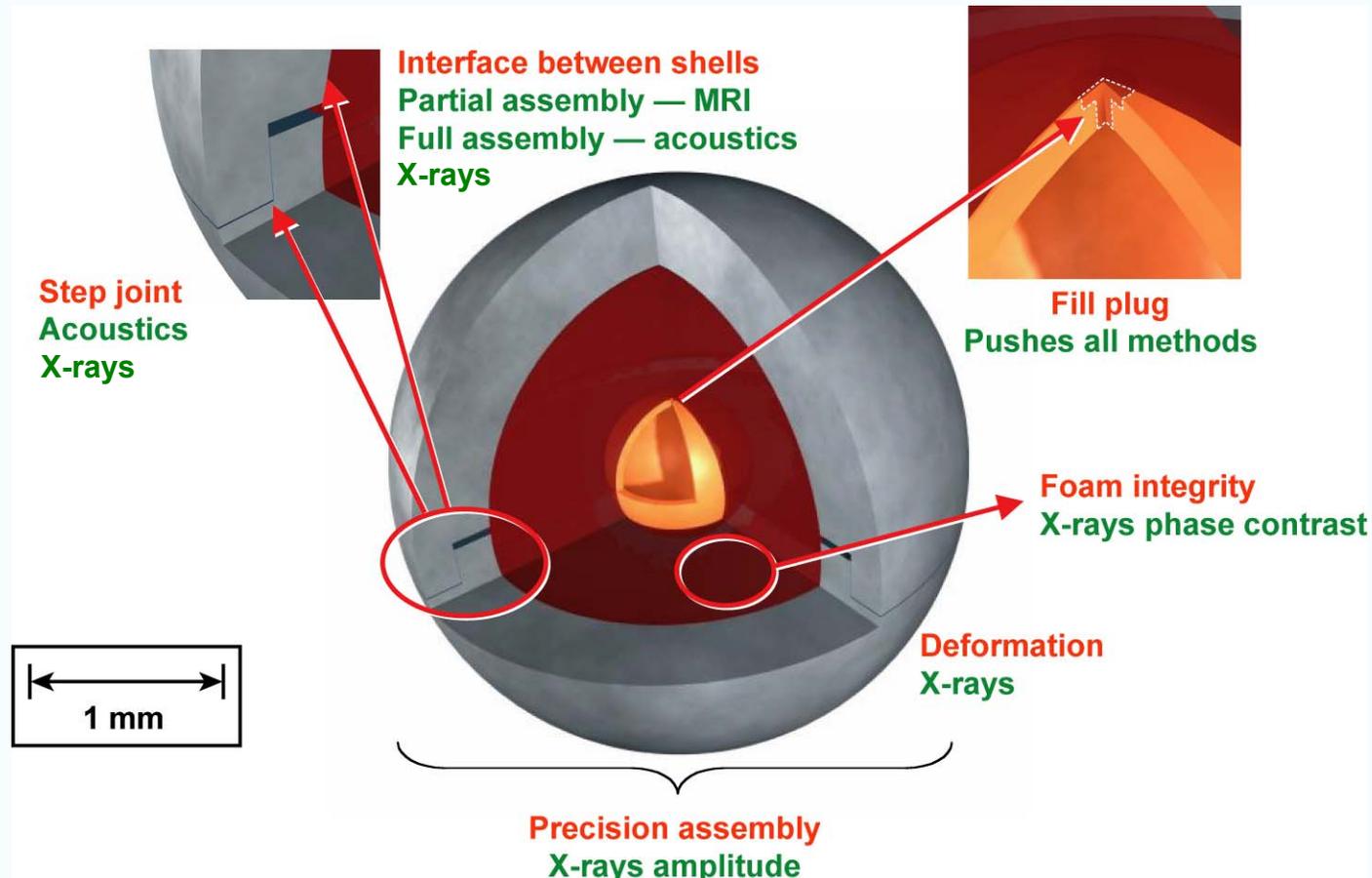
SEM Image

X-Ray Image

WFOs

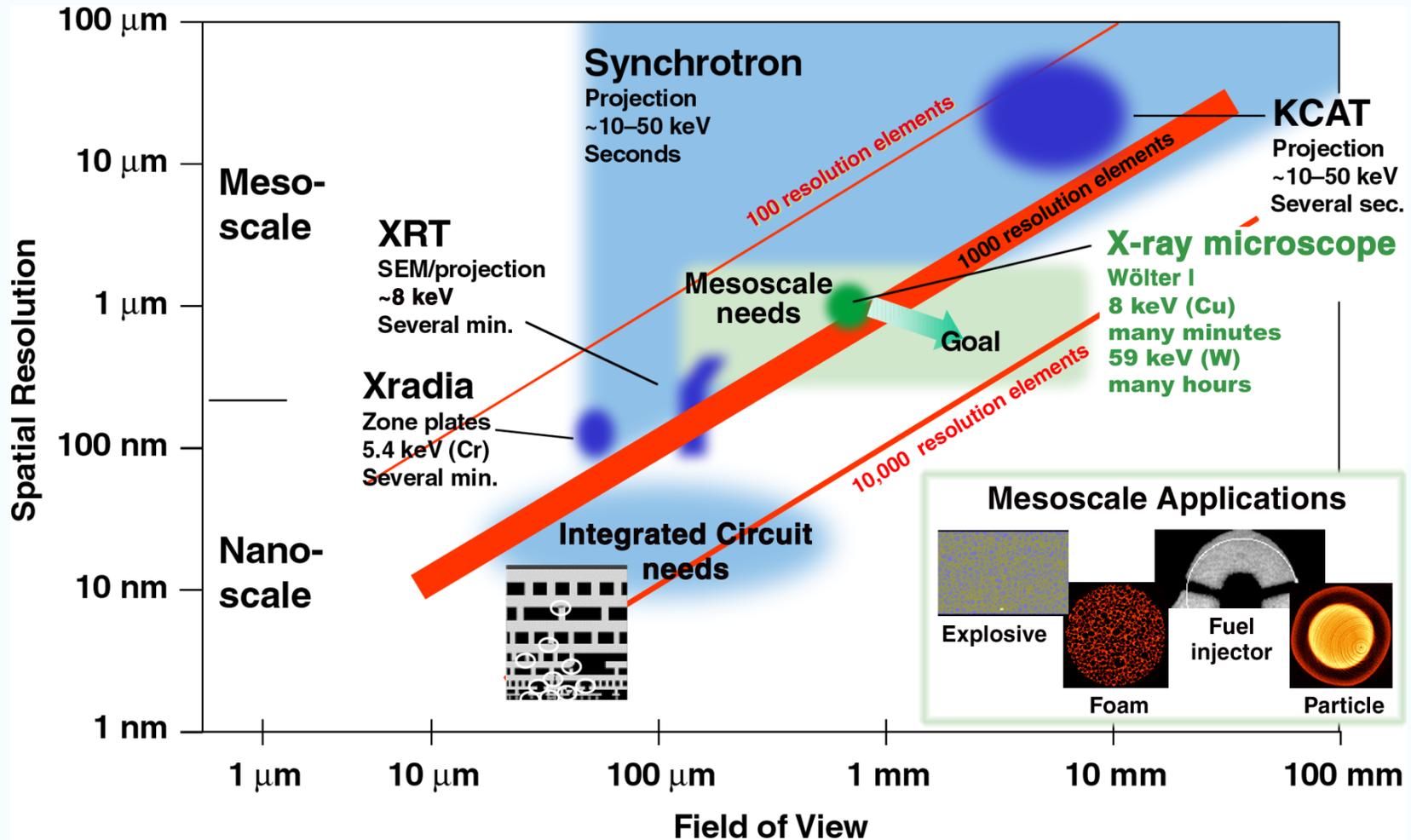
NASA, KAPL, ORNL, and others TBD...

The convergent hydrodynamic or double shell design pushes fabrication and nondestructive characterization capabilities



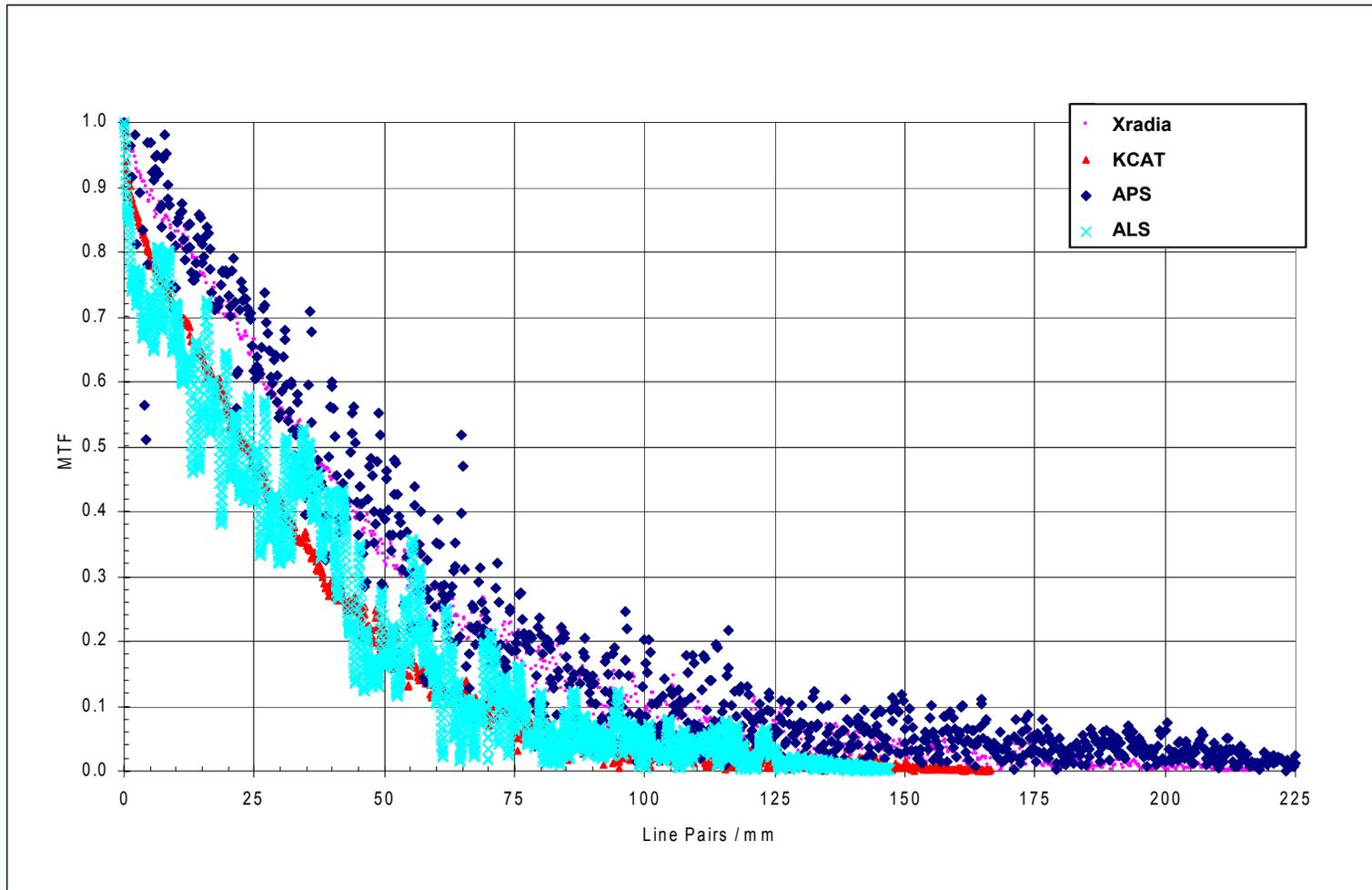
The nondestructive characterization requirement is 3D imaging at better than a micrometer spatial resolution

The goal is micrometer resolution over mm FOV at very high collection efficiency to maximize phase and amplitude contrast for mesoscale objects

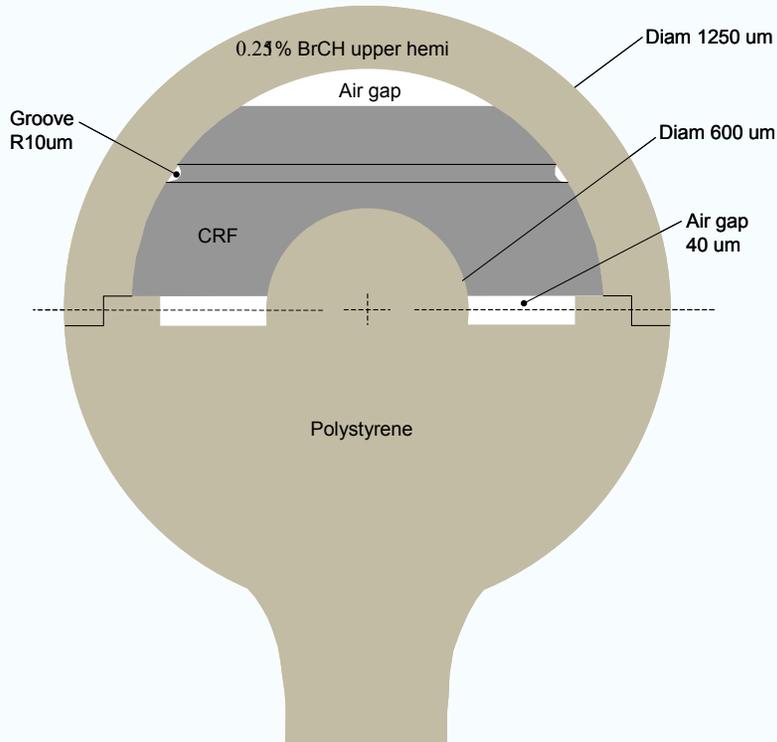


Reference standards will be used to
benchmark these possible x-ray NDC candidates

Comparison of Ta edge MTFs for KCAT, Xradia, ALS and APS x-ray imaging systems



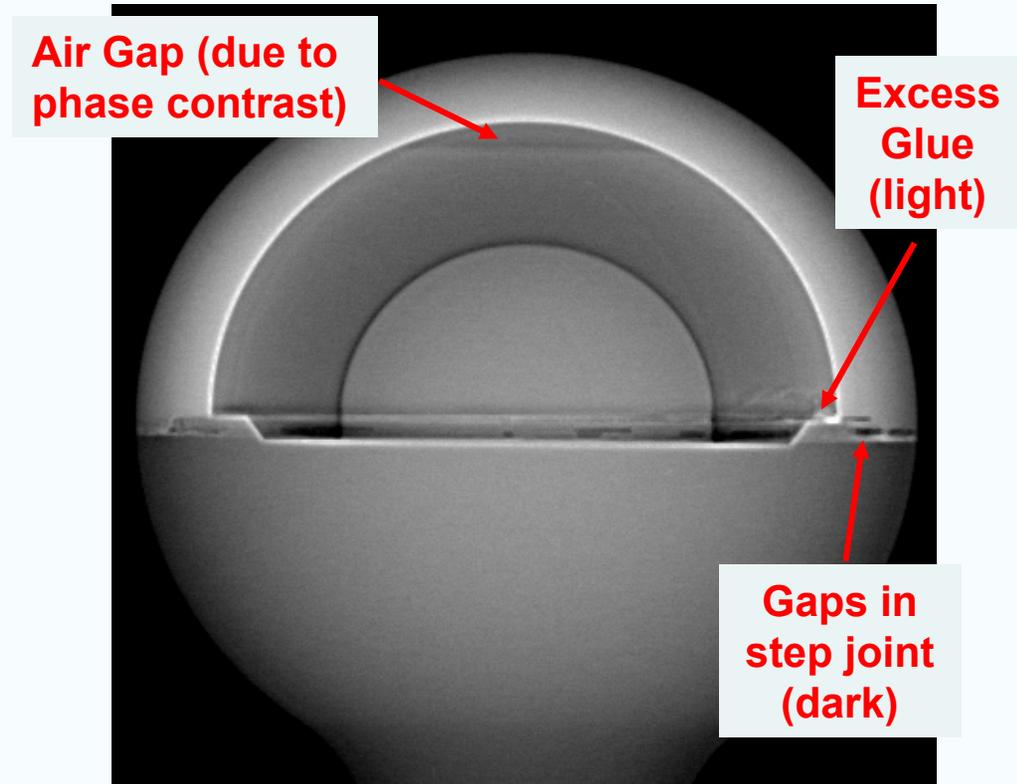
KCAT digital projections of a double-shell spherical reference standard reveals several key features



Spherical reference standard:

- Polystyrene and low-density foam
- Features are machinable and measurable
- Simulated internal capsule that is dimensionally stable
- Has air gaps, defects, step joint and two materials for NDE

KCAT Attenuation image ($\ln I_0/I$)

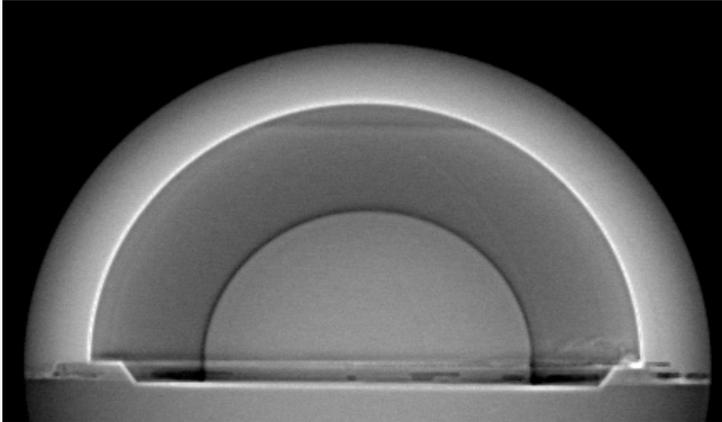


We have acquired data on the spherical reference standard using KCAT, Xradia, APS and ALS



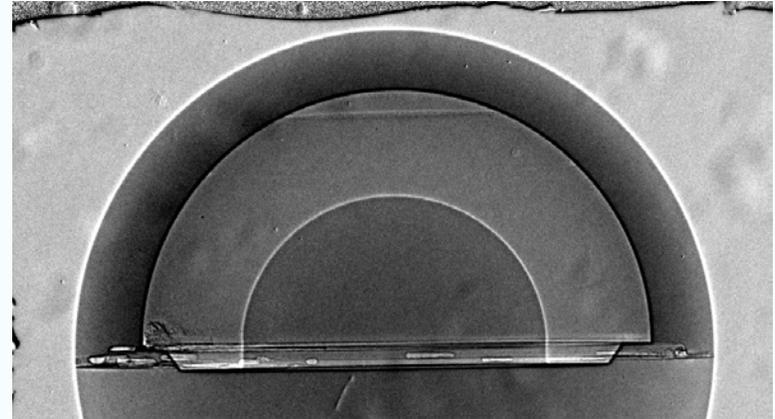
KCAT

Attenuation image ($\ln I_0/I$)



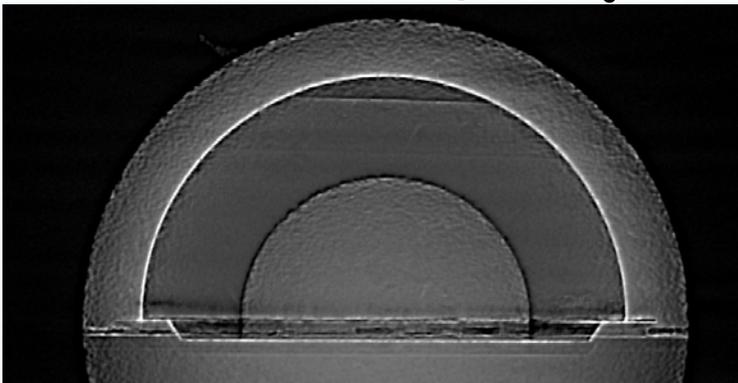
XRADIA

Transmission image (I/I_0)



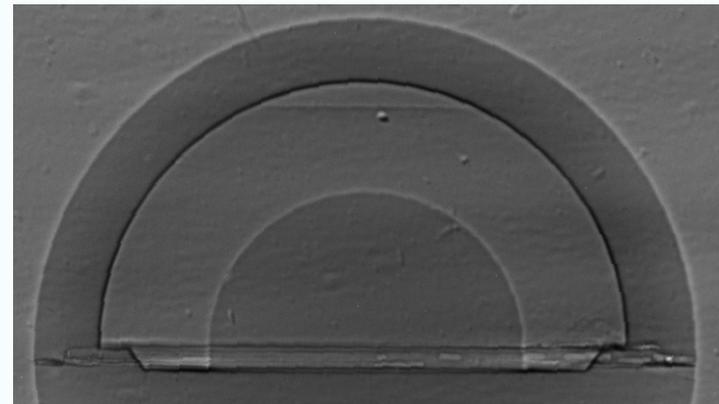
ALS

Attenuation image ($\ln I_0/I$)



APS

% Transmission image ($I/I_0 * 100$)

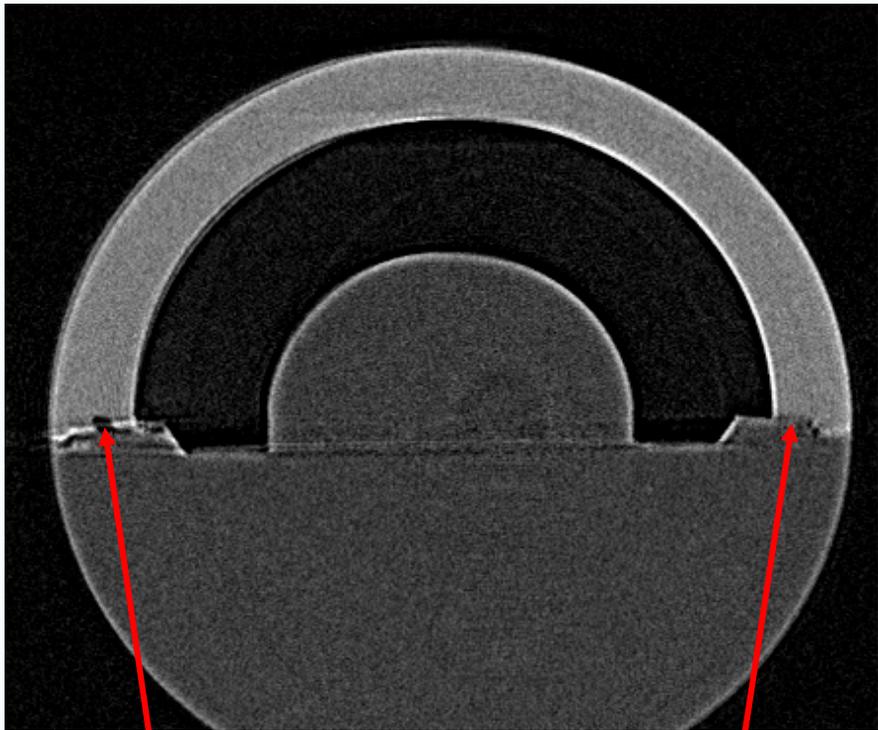


Computed tomography images from KCAT reveal internal features that can impact target performance



KCAT DATA

CT Slice through the X-Z plane

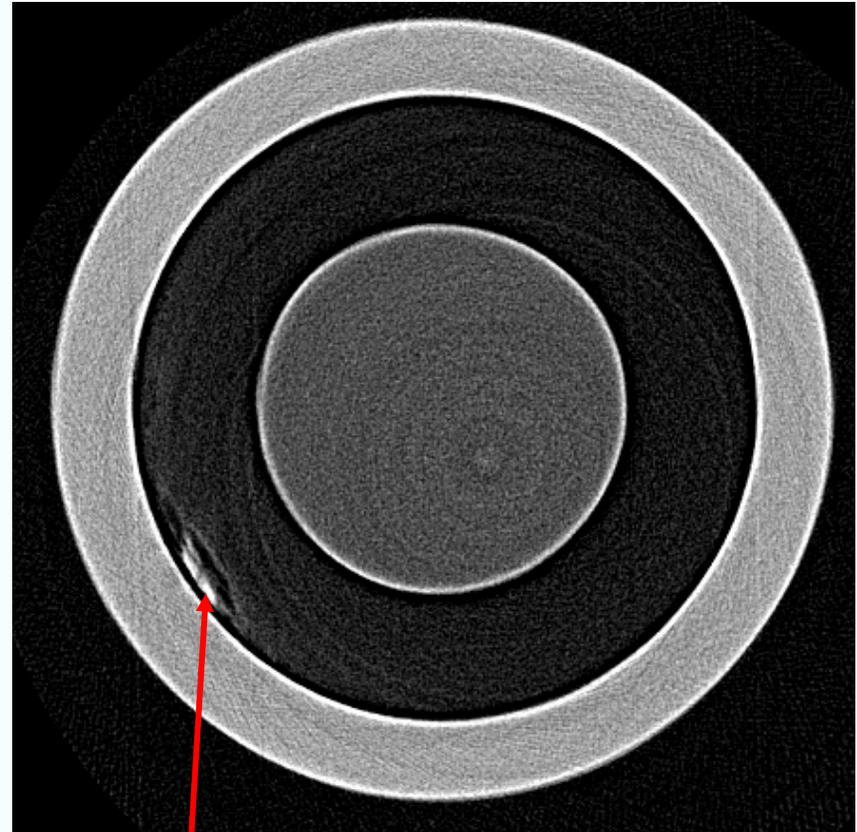


**Air gaps are visible
Gaps seen in step joint**

Better joint

KCAT DATA

CT slice through the X-Y plane
Above step joint



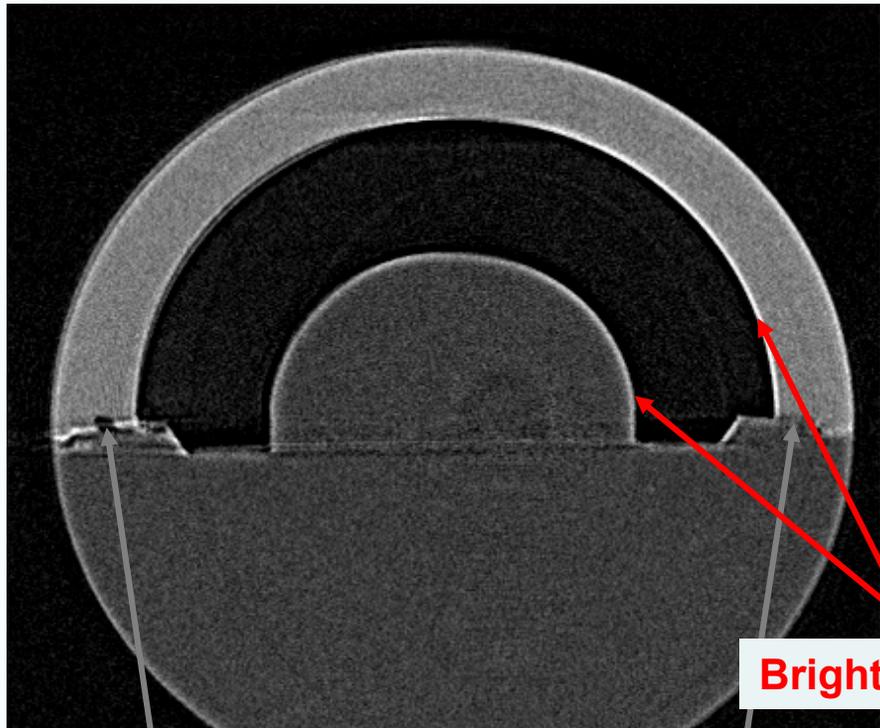
Excess glue material

Computed tomography images from KCAT reveal internal features that can impact target performance



KCAT DATA

CT Slice through the X-Z plane

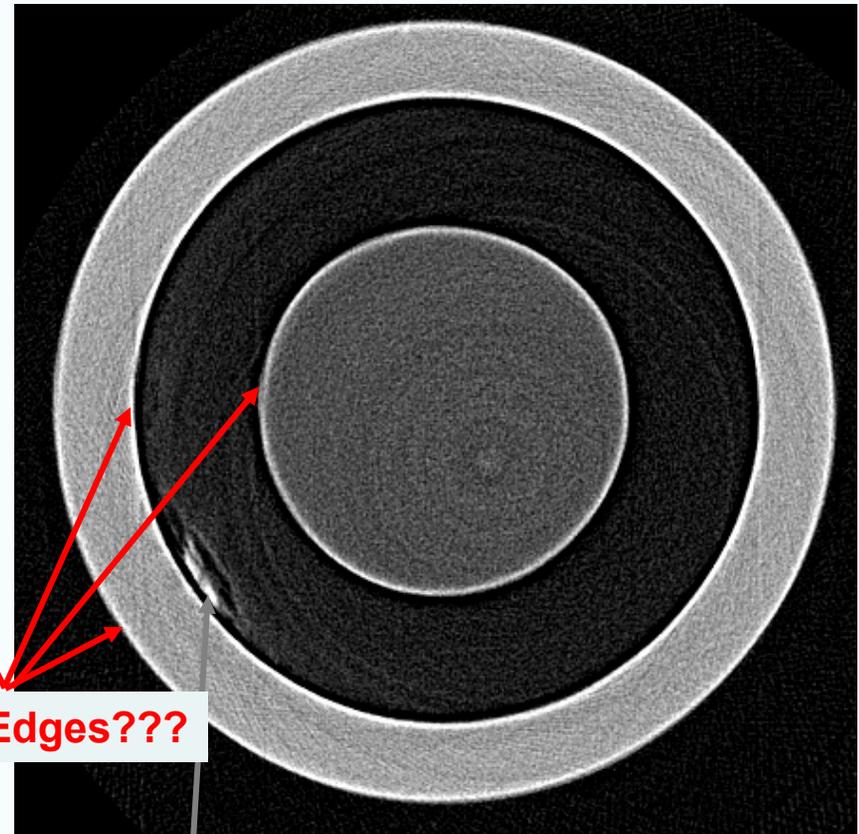


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KCAT DATA

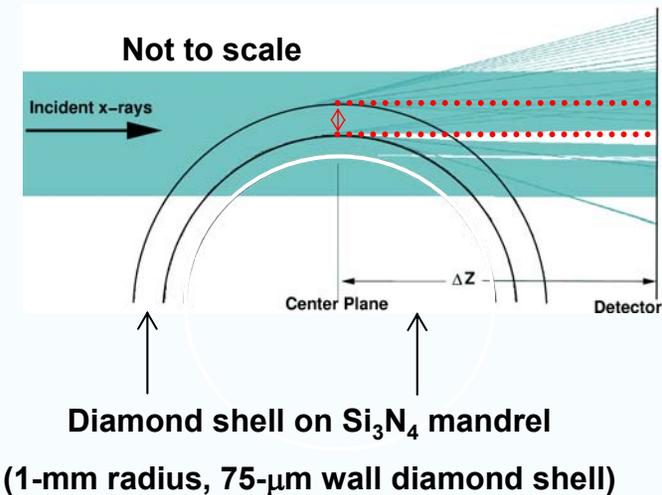
CT slice through the X-Y plane
Above step joint



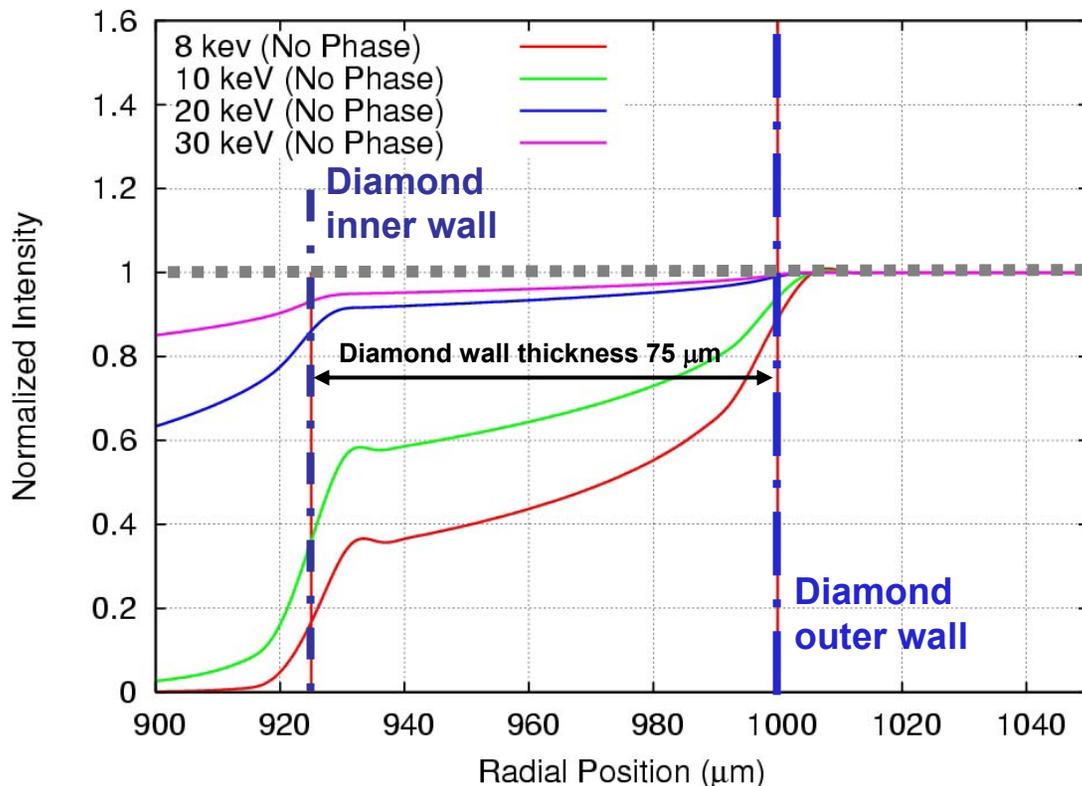
Bright Edges???

Excess glue material

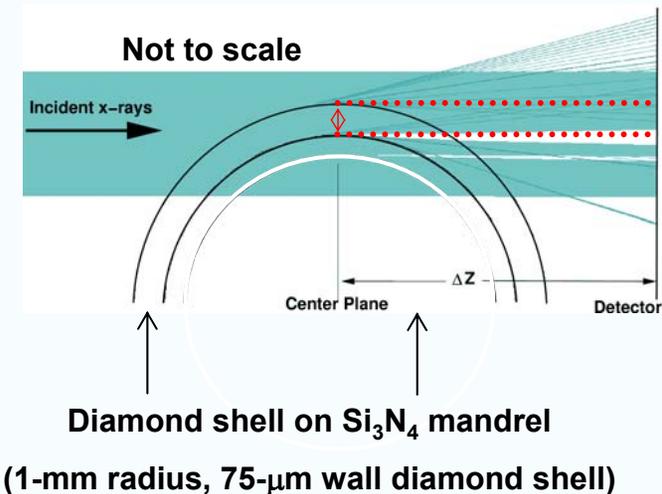
We need to quantitatively account for x-ray phase effects for accurate image analysis results



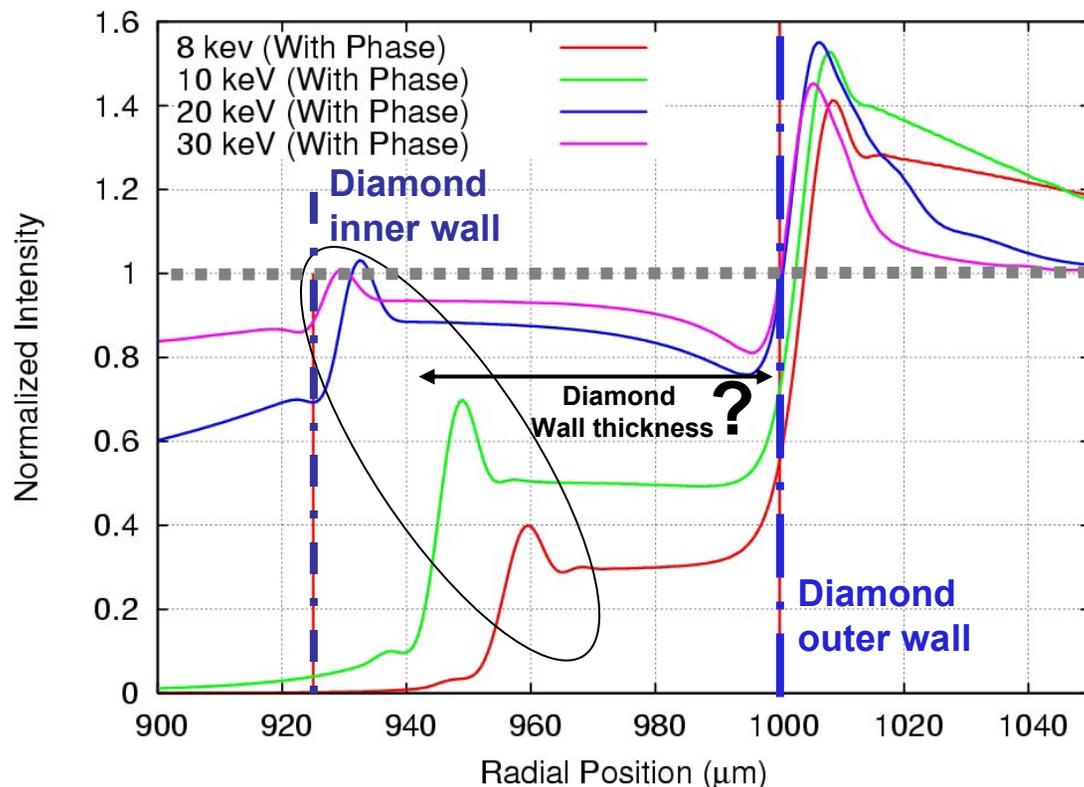
Simulation with only amplitude NO phase effects



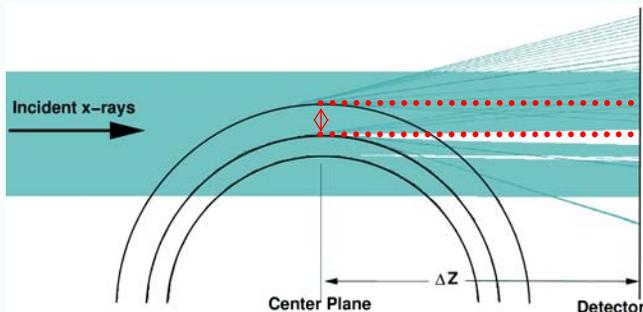
We need to quantitatively account for x-ray phase effects for accurate image analysis results



Simulation with amplitude and phase effects



We need to quantitatively account for x-ray phase effects for accurate image analysis results



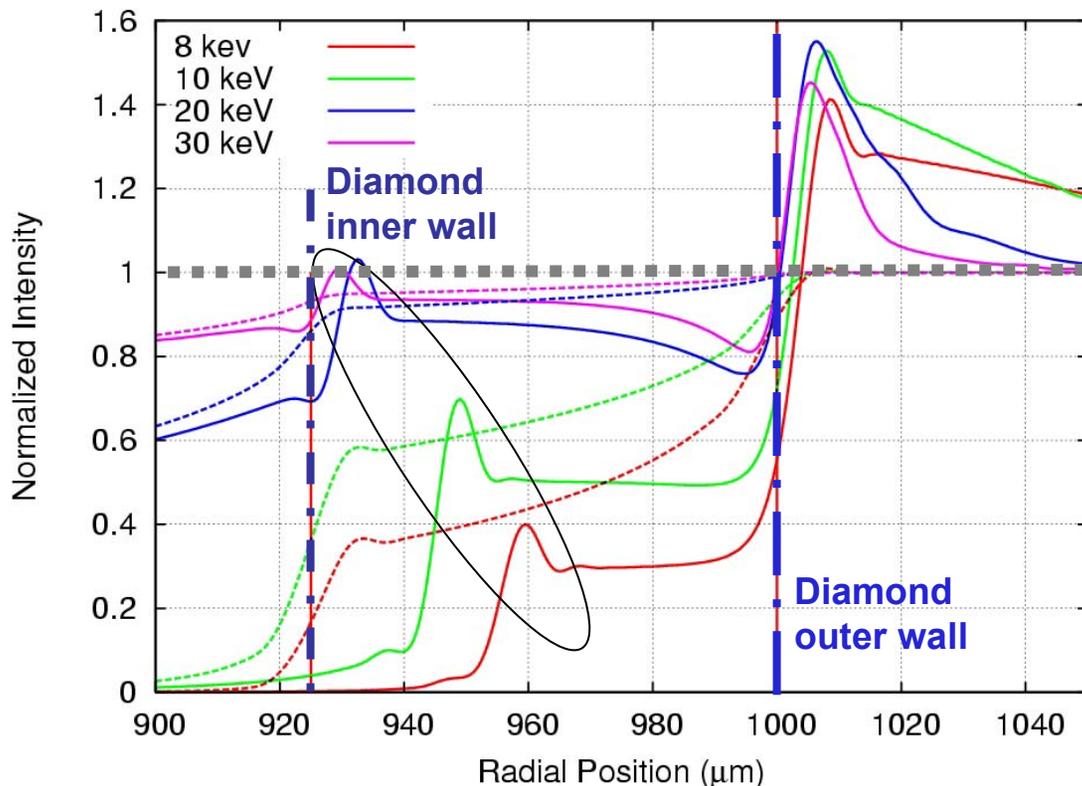
Comparison with and without phase effects

Phase effects change with

- Object materials & geometry
- Source-object-detector geometry
- Source energy
- Spatial resolution

Phase effects can generate

- Dimensional errors
- Fictitious gaps
- Wrong material identification



Phase effects impact both radiographic and tomographic x-ray imaging

Comparison between synchrotron and lab x-ray sources



Synchrotron

- **Advantages**
 - High flux
 - Monochromatic
 - Tunable
 - Parallel beam
- **Disadvantages**
 - Expensive
 - Not Local
 - Low Availability
 - Non-uniform beam profile
 - Time varying beam
 - Limited energy range

Lab sources

- **Advantages**
 - Cheap
 - Local
 - High Availability
 - Uniform beam profile
 - Stable beam
 - Large energy range
- **Disadvantages**
 - Not brilliant
 - Polychromatic
 - Limited tunability
 - Non parallel
 - Spot size

Better sources—stable tabletop synchrotrons...???

Better detectors—high brightness, high-optical-quality scintillators...???