Inertial confinement fusion target characterization with phase-contrast x-ray imaging

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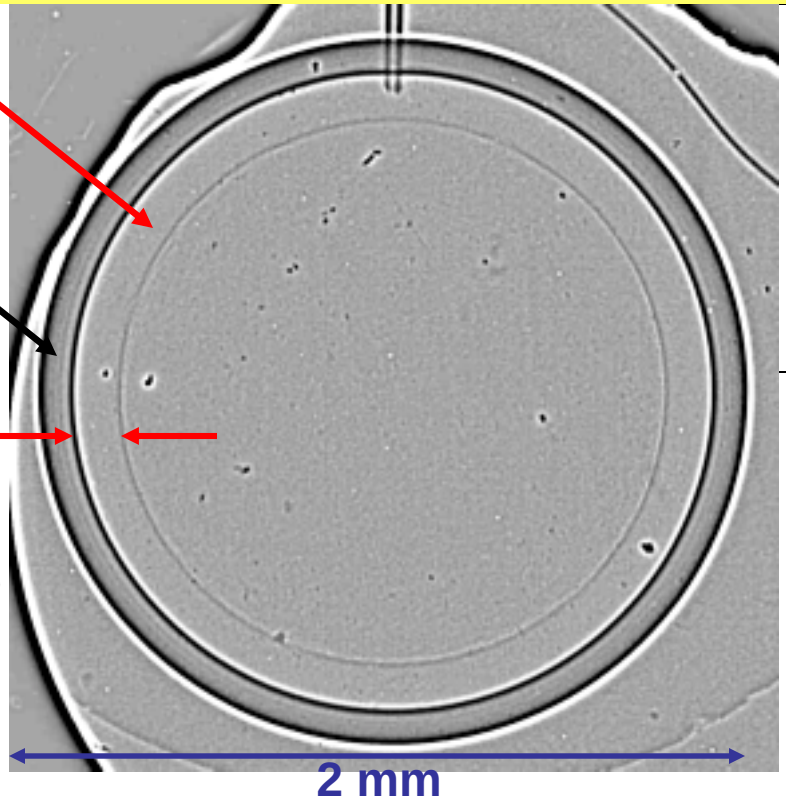
Fusion capsule phase-contrast x-ray image



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APS

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National Ignition Facility researches fusion energy (ICF) and high energy density physics (HEDP)

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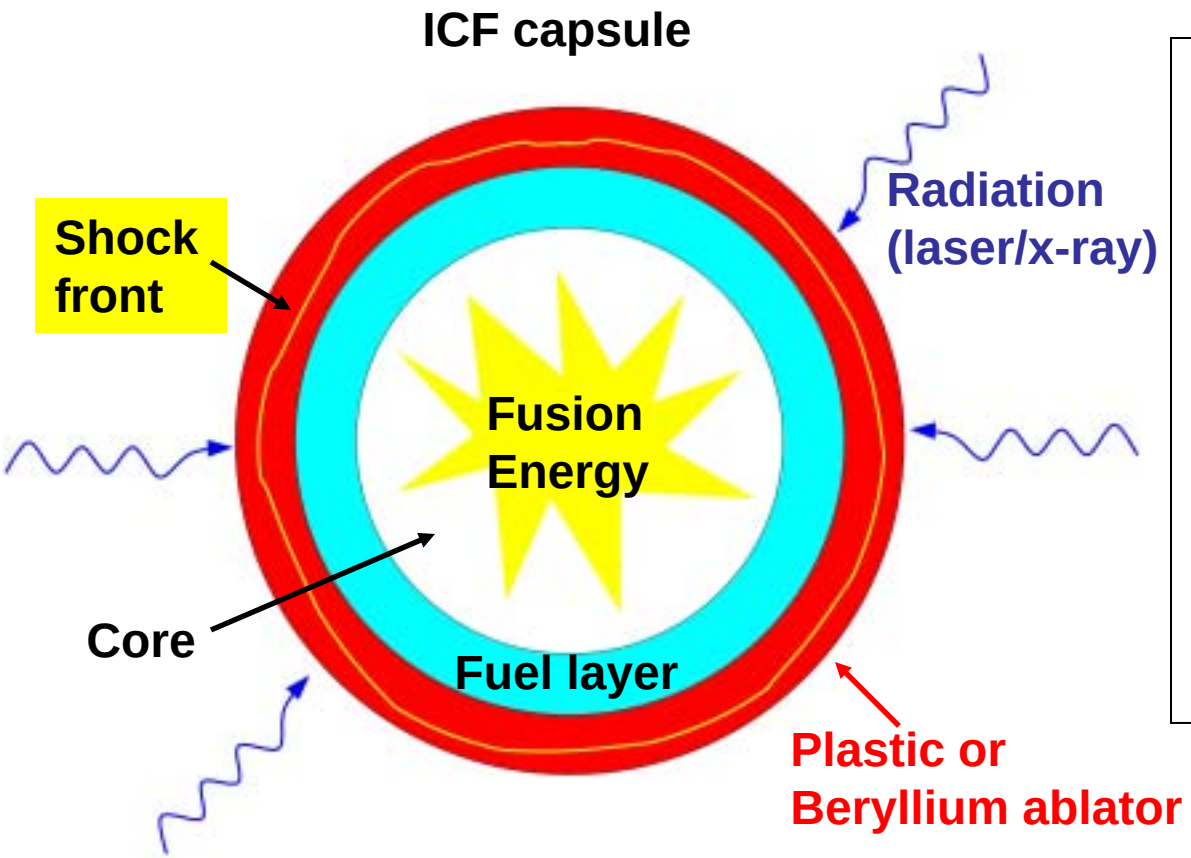

- Ablator is low-Z material (CH plastic or Be)
- Fuel is solid deuterium-tritium mixture (D-T)
- Ablator and fuel layer must be characterized before laser shot
- Core size, shock velocity, symmetry measured during compression

30x radius decrease in nanoseconds

D-T fuel layers in transparent plastic capsules are characterized with visible light

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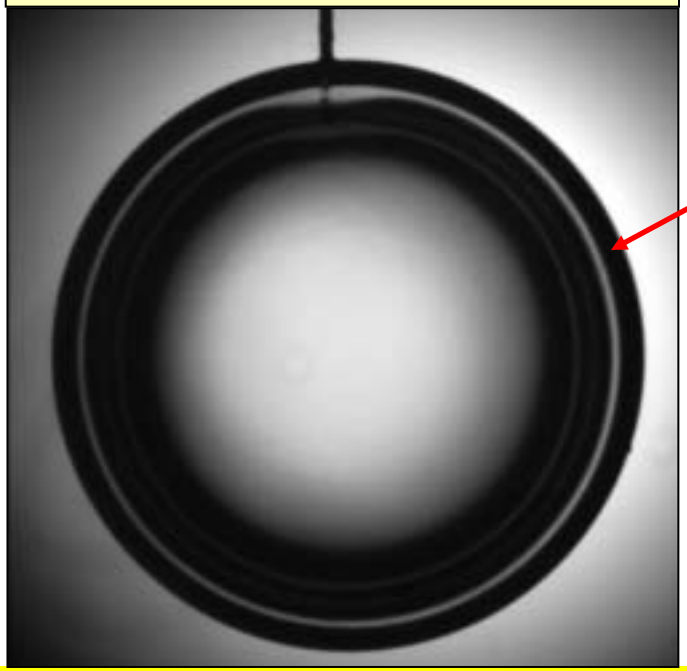
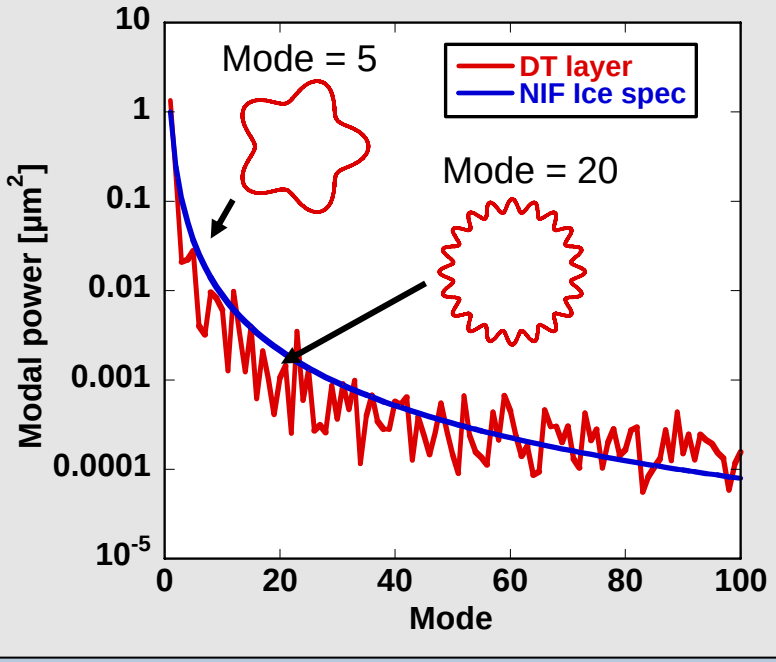
Smooth DT layer in 2 mm diameter transparent shell



Fuel layer at 18 K

Solid D-T fuel layer formed by slow cooling, imposing thermal gradient

Mode spectrum



RMS = 0.5 μm (modes 4-128)
This meets reqs for CH designs

Beryllium ablators more robust, but we cannot characterize the fuel layer optically!

D-T fuel layers in opaque capsules are characterized with 5-15 keV x-rays

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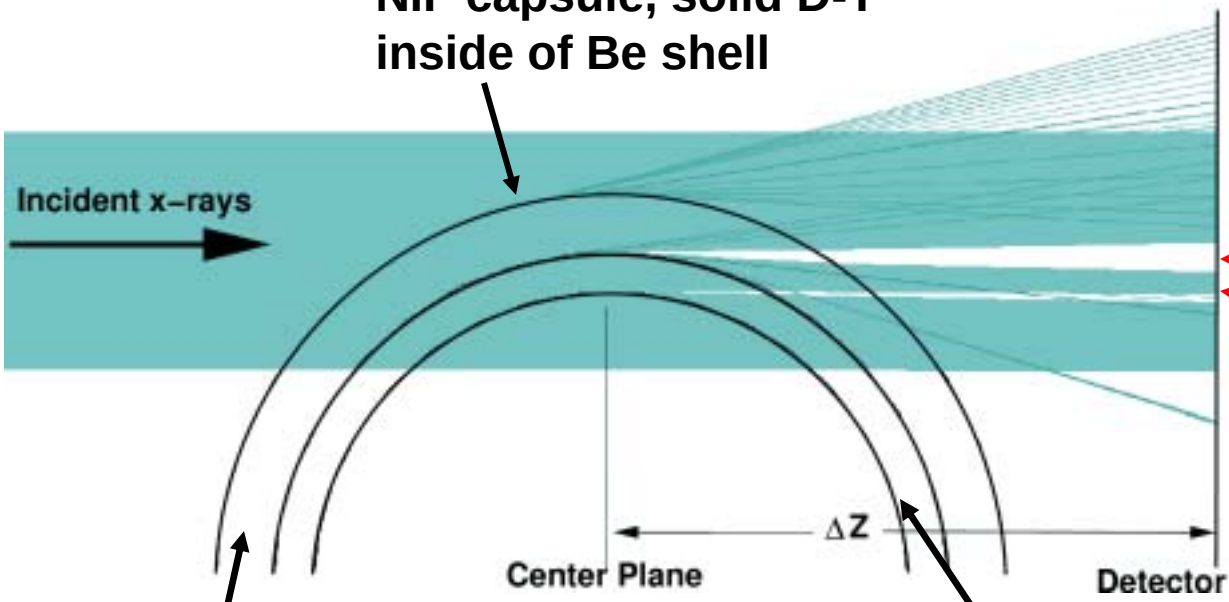

Phase enhanced imaging has been successfully demonstrated at synchrotrons for low Z materials

First proof-of-principle experiment at the APS 1-ID beamline

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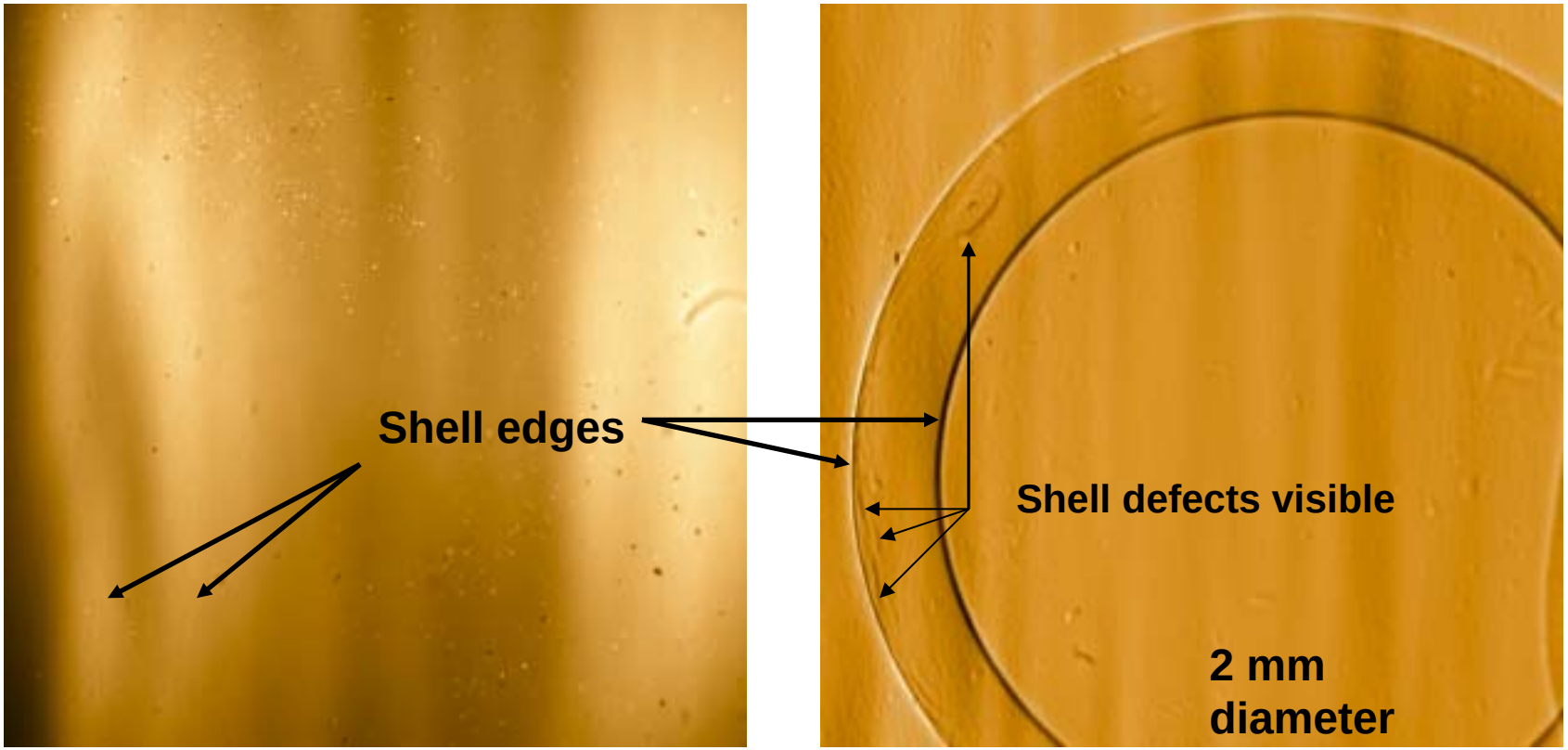
Absorption image
Object-detector = 2 mm

Phase-contrast enhanced image
object-detector = 1150 mm



- **Low density CH foam shell surrogate for solid D-T**
- **Refractive index of CH foam comparable to solid D-T**
- **Successfully imaged CH foam shows D-T imaging is possible!**

Phase contrast enhanced imaging shows rough inner surface

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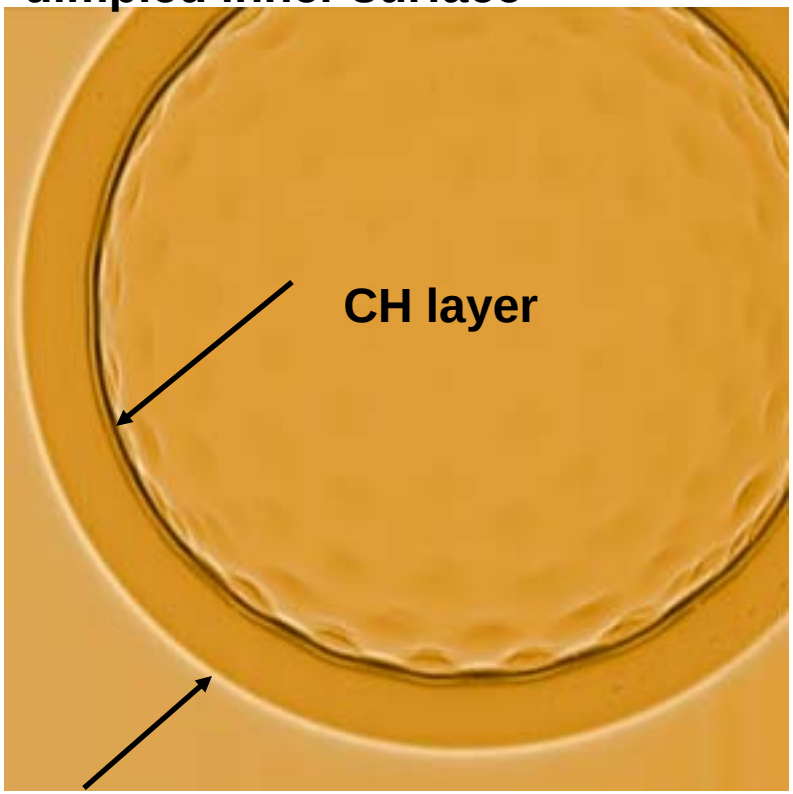
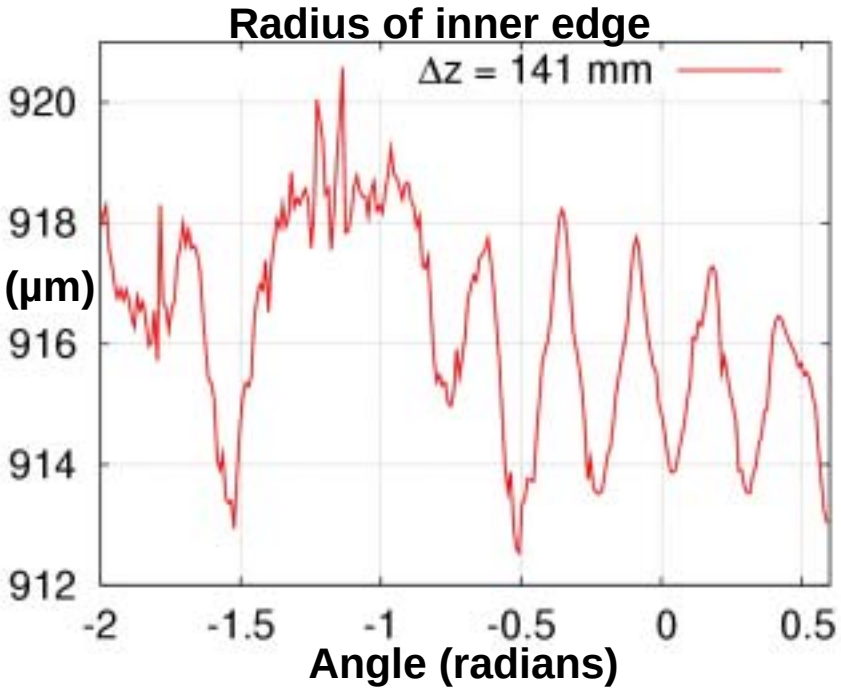
Polyimide on thin CH shell with dimpled inner surface

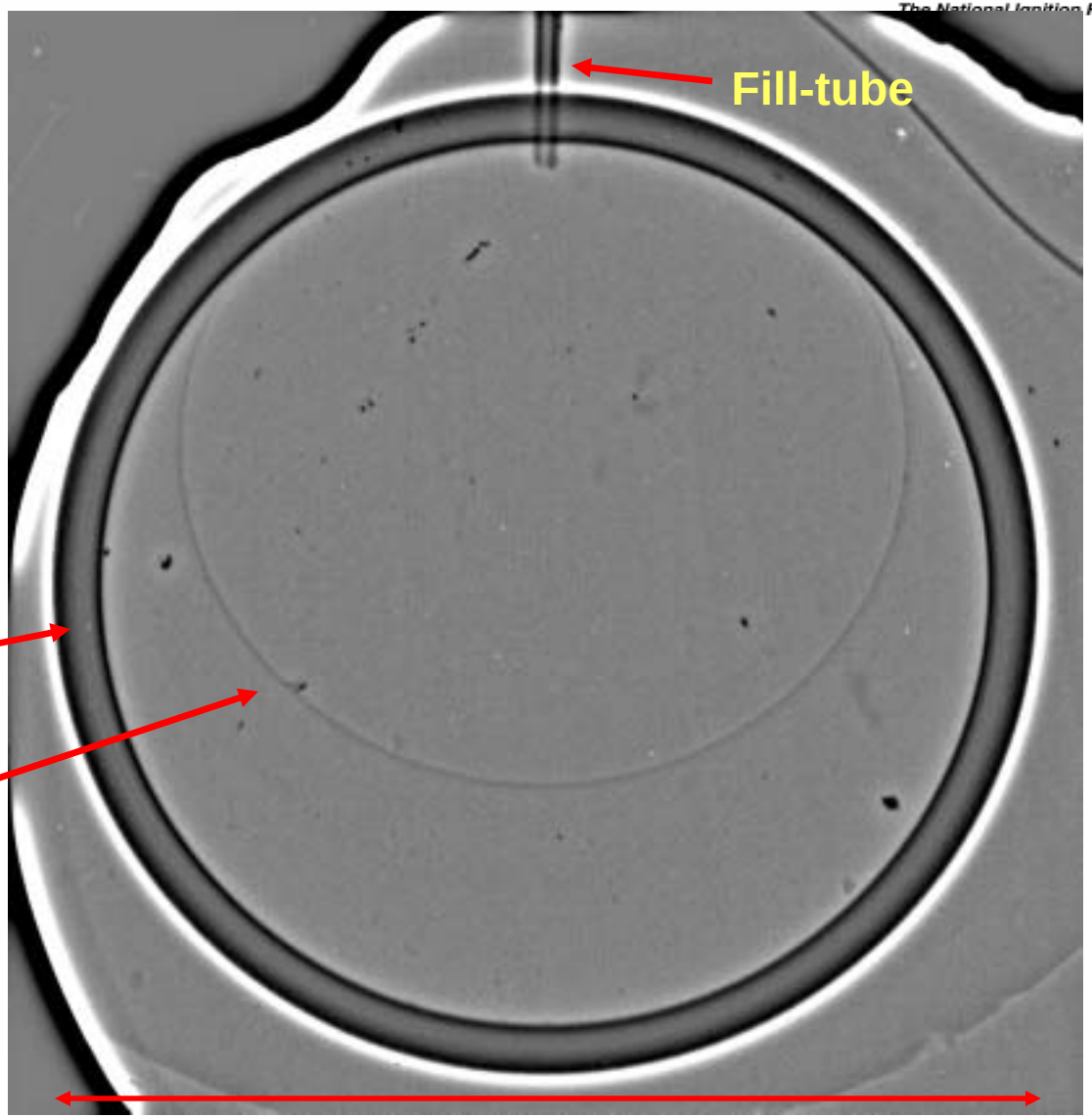


- **Image obtained at the APS 1-ID beamline**
- **Demonstrates that a rough surface can be characterized**



First test of x-ray microscope with D_2 was successful

- **Liquid D_2 interface visible in image!**
- **Micro-focus x-ray source at LLNL**
- **30 minute exposure**
- **X-rays from 60 kV, 0.082 mA on W target**
- **Image processed with high-pass filter**



D-T layer successfully grown inside of Be shell

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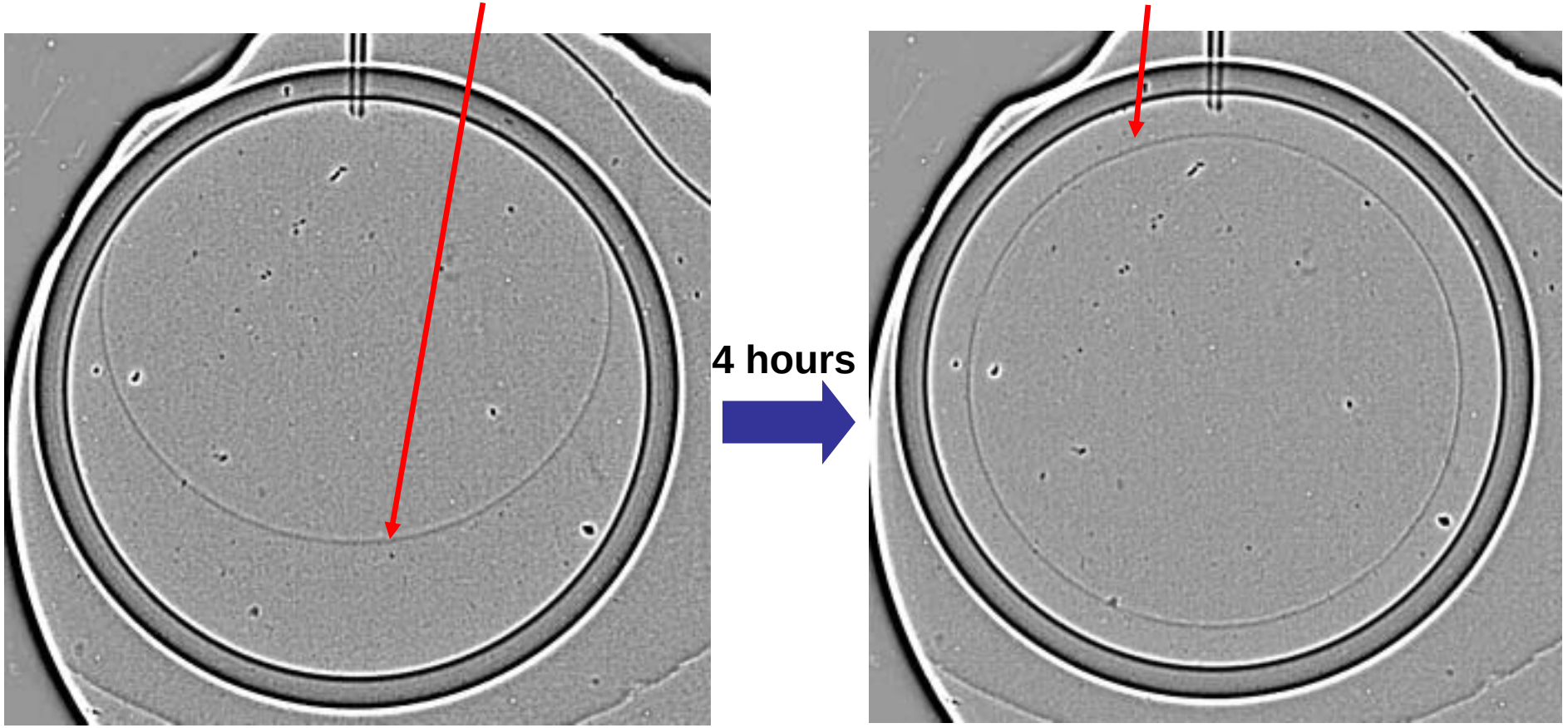
Liquid D-T layer

Solid D-T layer



Solid layer grown by slowly cooling liquid

D-T surface roughness characterized by edge detection

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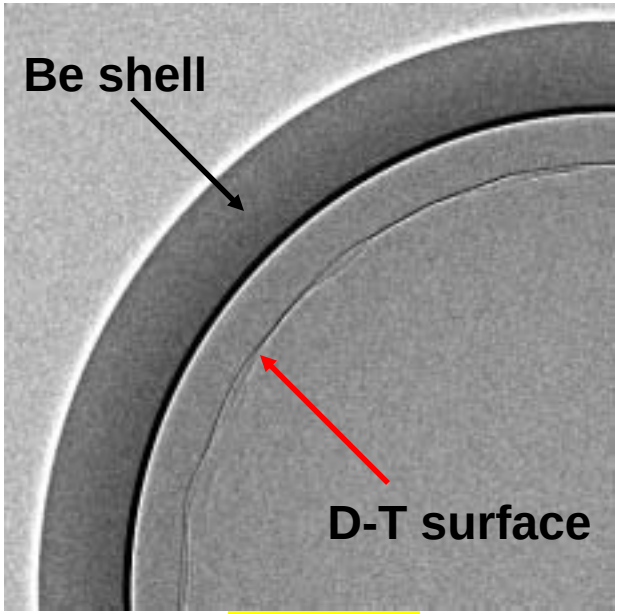
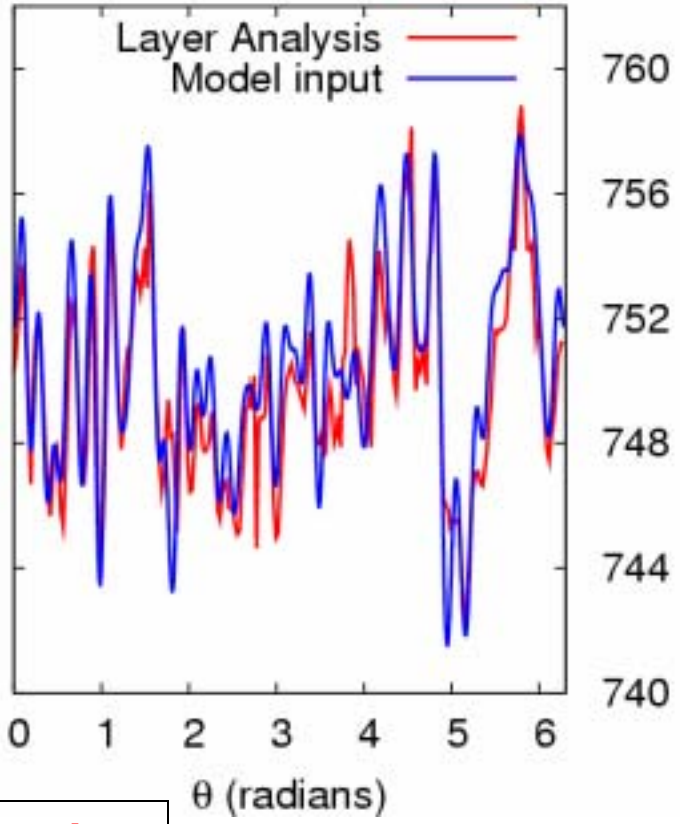
Raytrace of Be shell with 3.4 μm RMS D-T surface



Model

Detect D-T edge

Edge detection compared to input surface



Edge detection follows the modeled surface

We are able to detect changes in layer uniformity caused by convective heating

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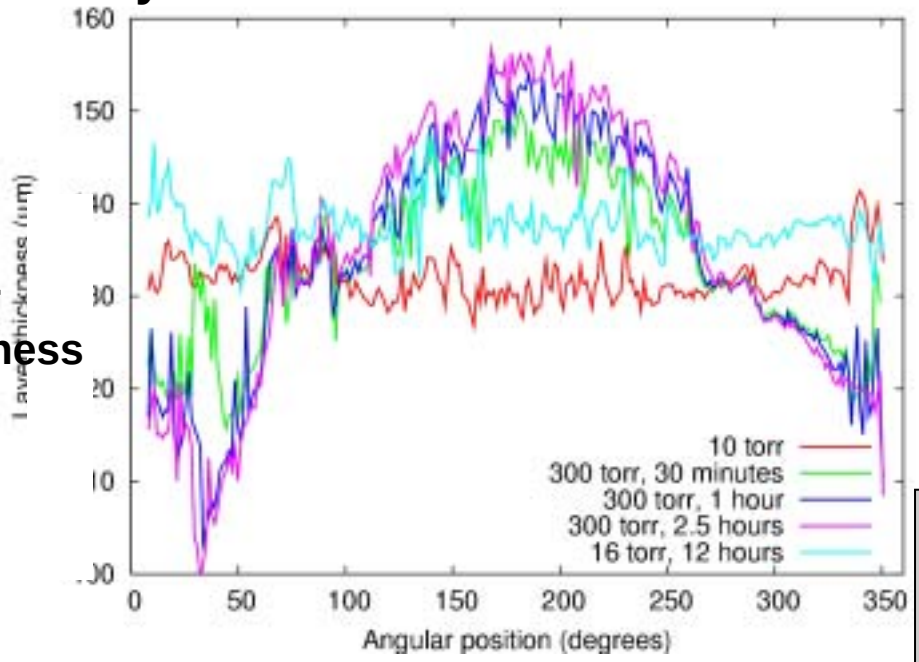
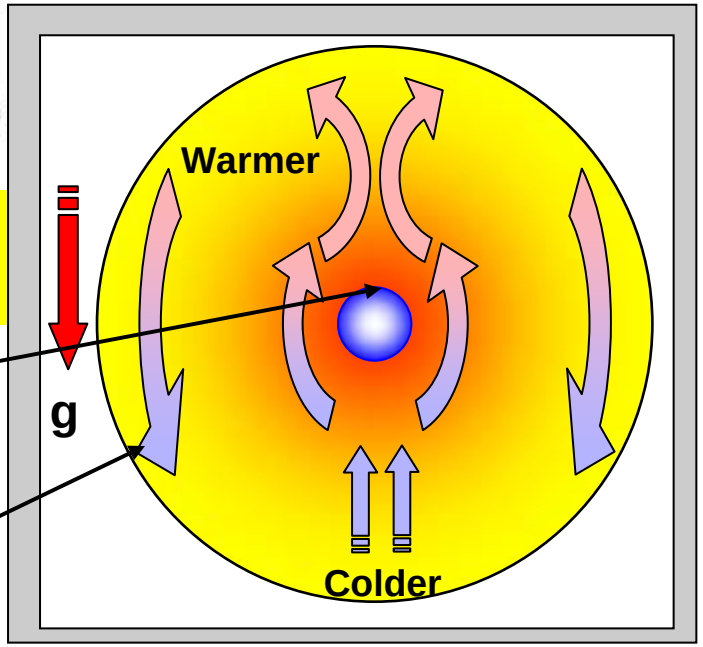
Layer moves due to convection



- Convection driven by gas pressure, D-T self-heating
- Uniform thickness when no convection
- 20 μm perturbation with convection

Surface position determined using image edge detection algorithm



How can the NIF program make use of the APS?

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Clearly cannot use APS at the NIF site for real time characterization

Parts not rugged enough to transport

Can use surrogate materials

Characterize crack growth in D-T layers on short time scales

Rapidly test imaging methods, optics on reference parts

3D reconstruction from limited views?

Particularly interested in phase imaging and object reconstruction methods

Gain understanding of imaging from APS community

D-T fuel layers are successfully characterized using phase-contrast x-ray imaging

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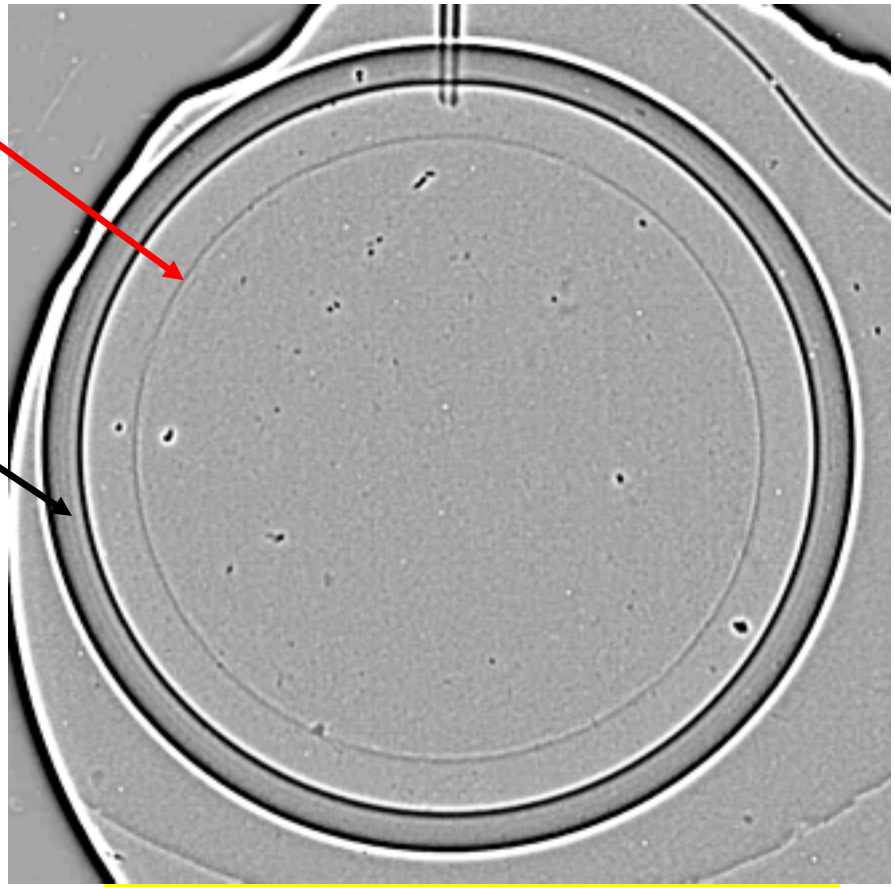
Phase-contrast x-ray image

Solid D-T surface

Optically opaque beryllium capsule



Provides path using Be capsules at NIF

ICF and HEDP targets present many characterization challenges

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Plasma physics

Shock interaction

High density(opacity) mismatch

Short time scales

(Show picture of laser-matter interaction, plasma blowing off, shock moving through material, etc).

Pre-shot characterization

Small perturbations can grow; need careful characterization

Many materials are resistant to current characterization methods.

Many applications for phase-contrast enhanced imaging methods.