LLNL-PRES-501052

Control System for Cryogenic THD/DT Layering at the National Ignition Facility

13th International Conference on Accelerator and Large Experimental Physics Control Systems
October 13, 2011

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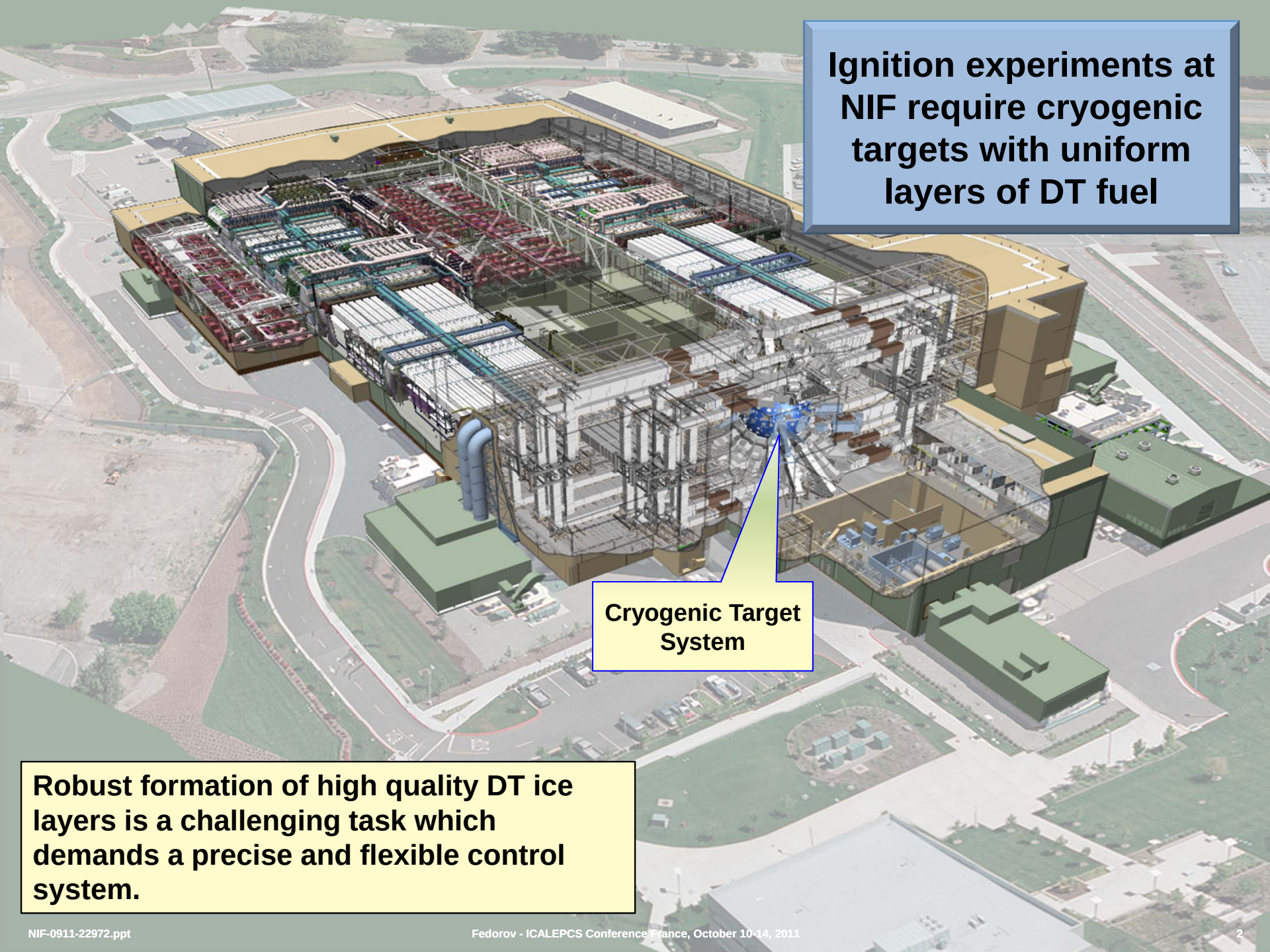
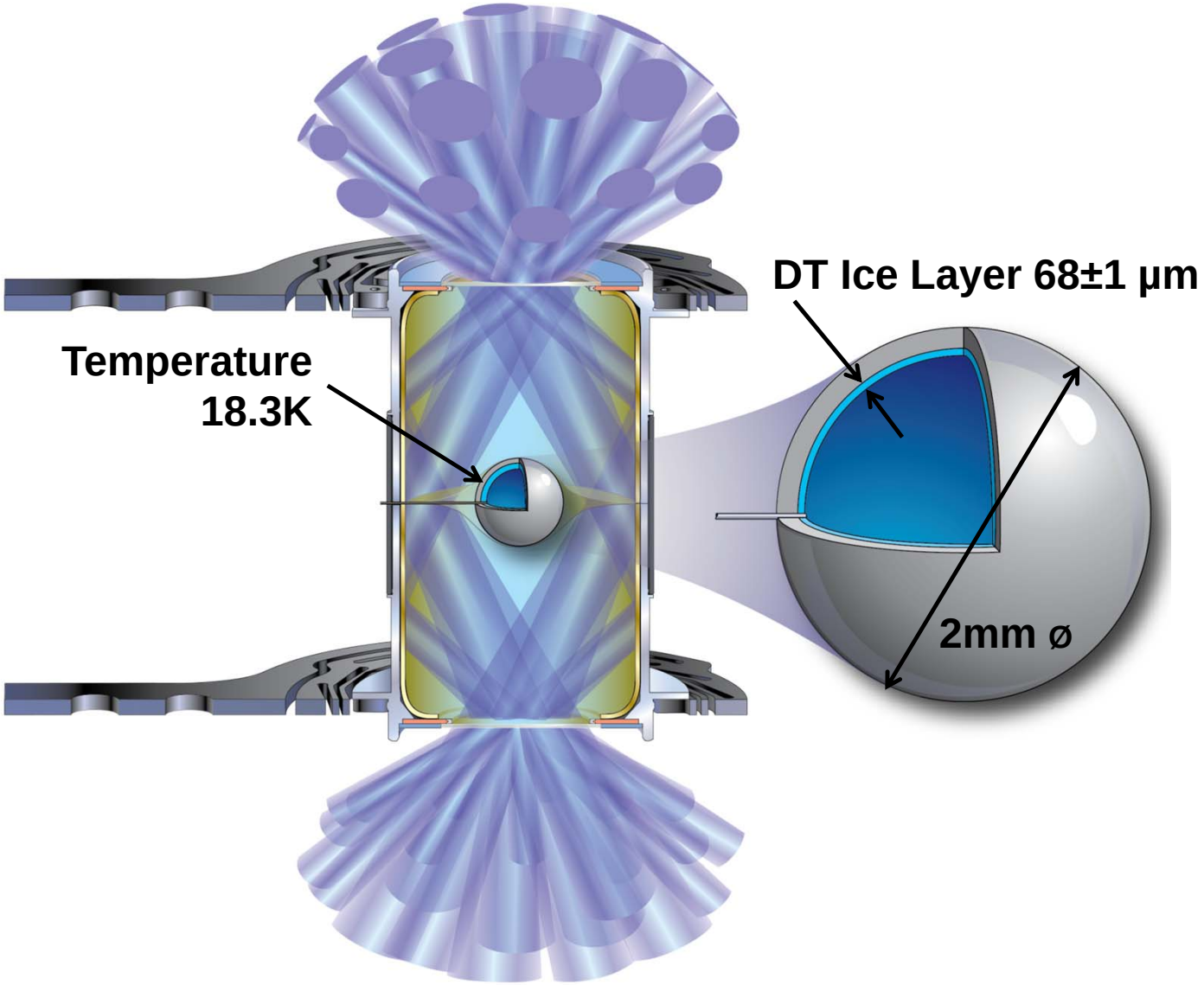
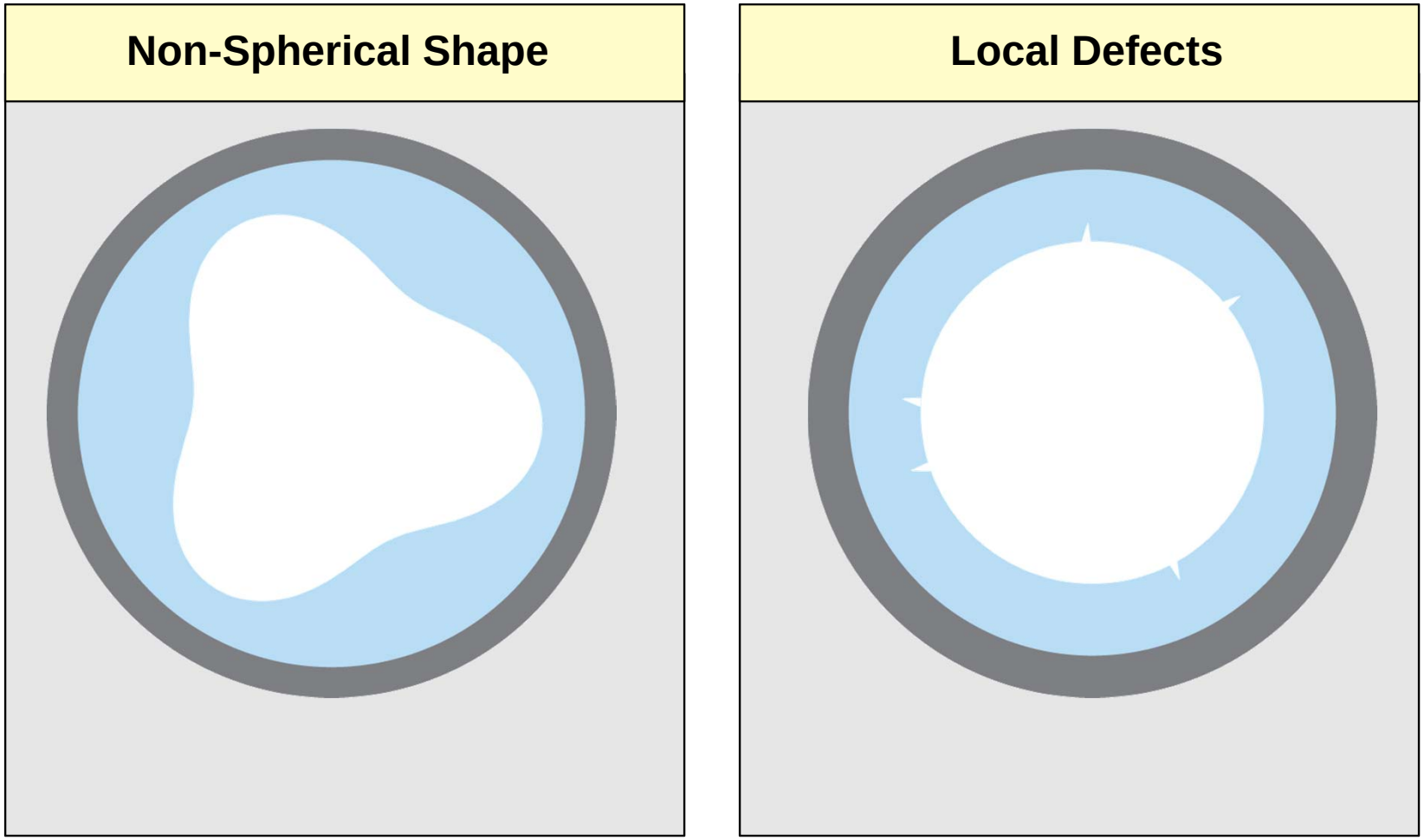
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344


Ignition experiments at NIF require cryogenic targets with uniform layers of DT fuel
Cryogenic Target System
Robust formation of high quality DT ice layers is a challenging task which demands a precise and flexible control system.

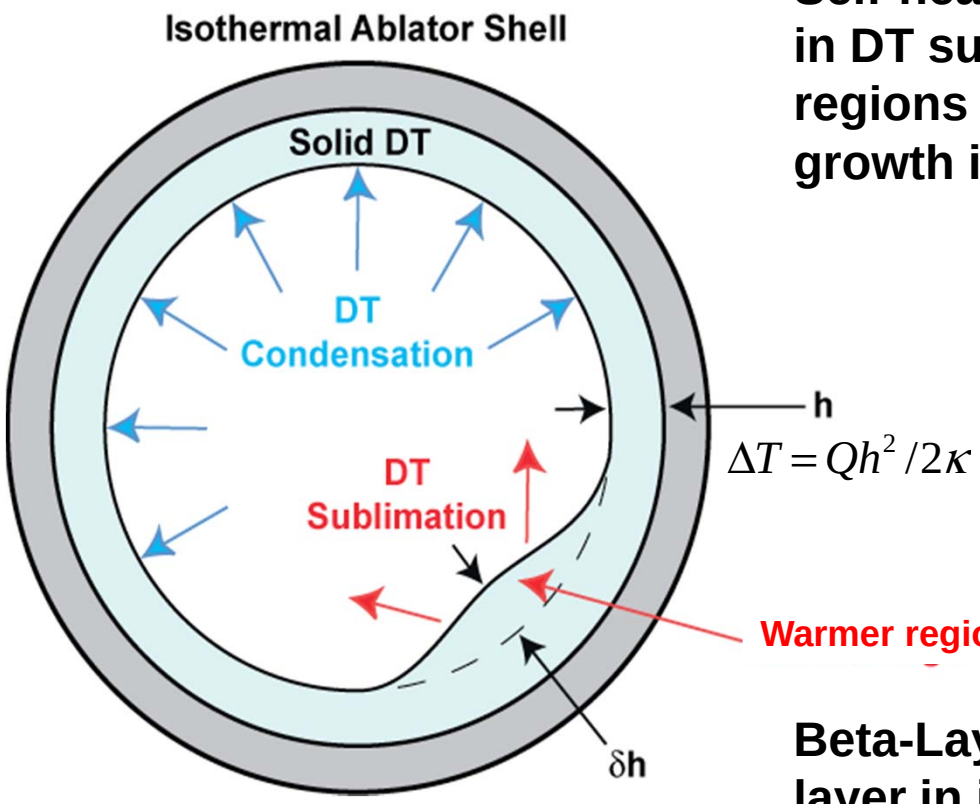
The Deuterium-Tritium (DT) ice layer is an integral component of the ignition target design



The high quality DT ice layers are spherical and smooth, meeting the specification metrics



Spherical layers are formed in a uniform thermal environment using Beta-Layering

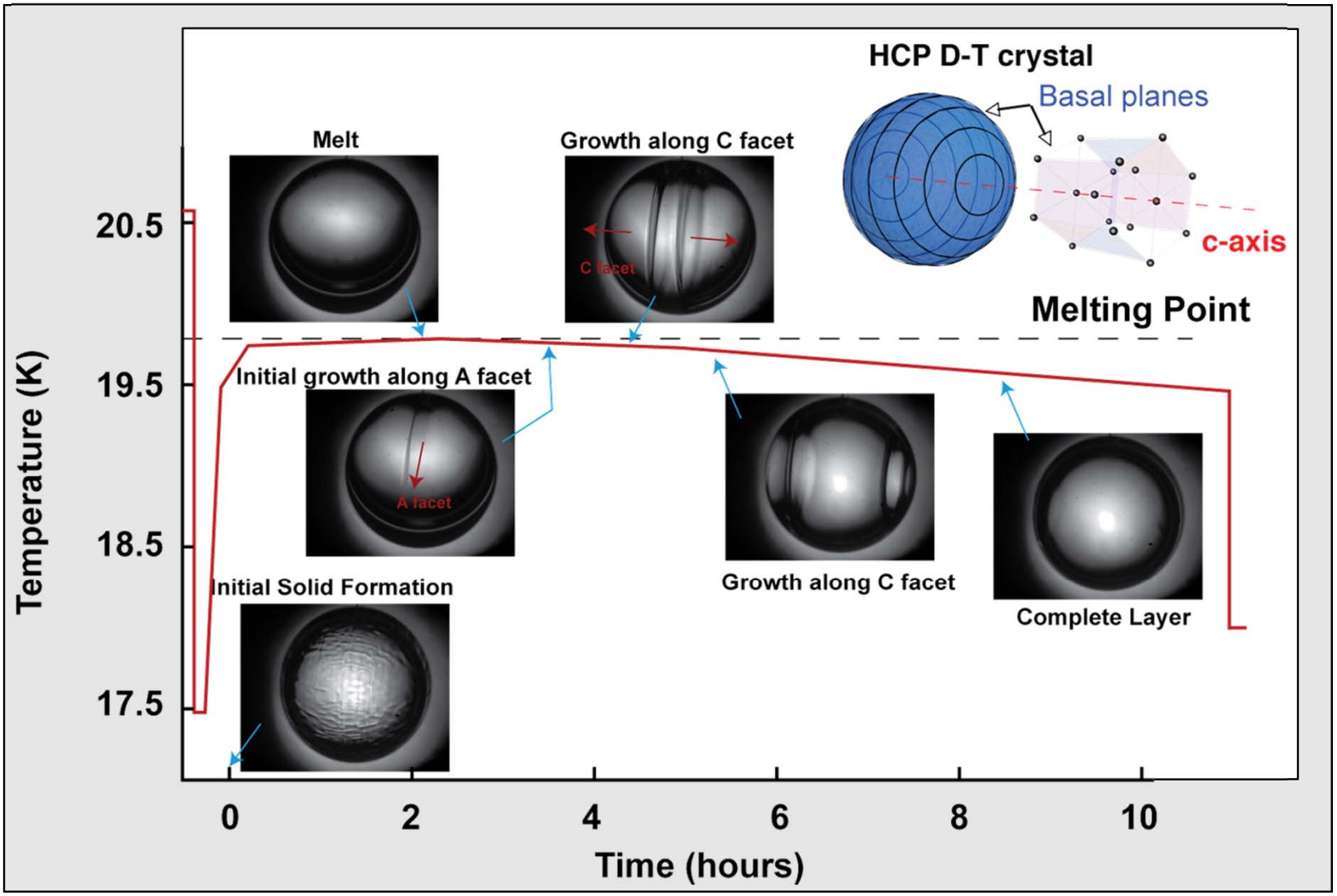


$$\Delta T = Qh^2 / 2\kappa$$

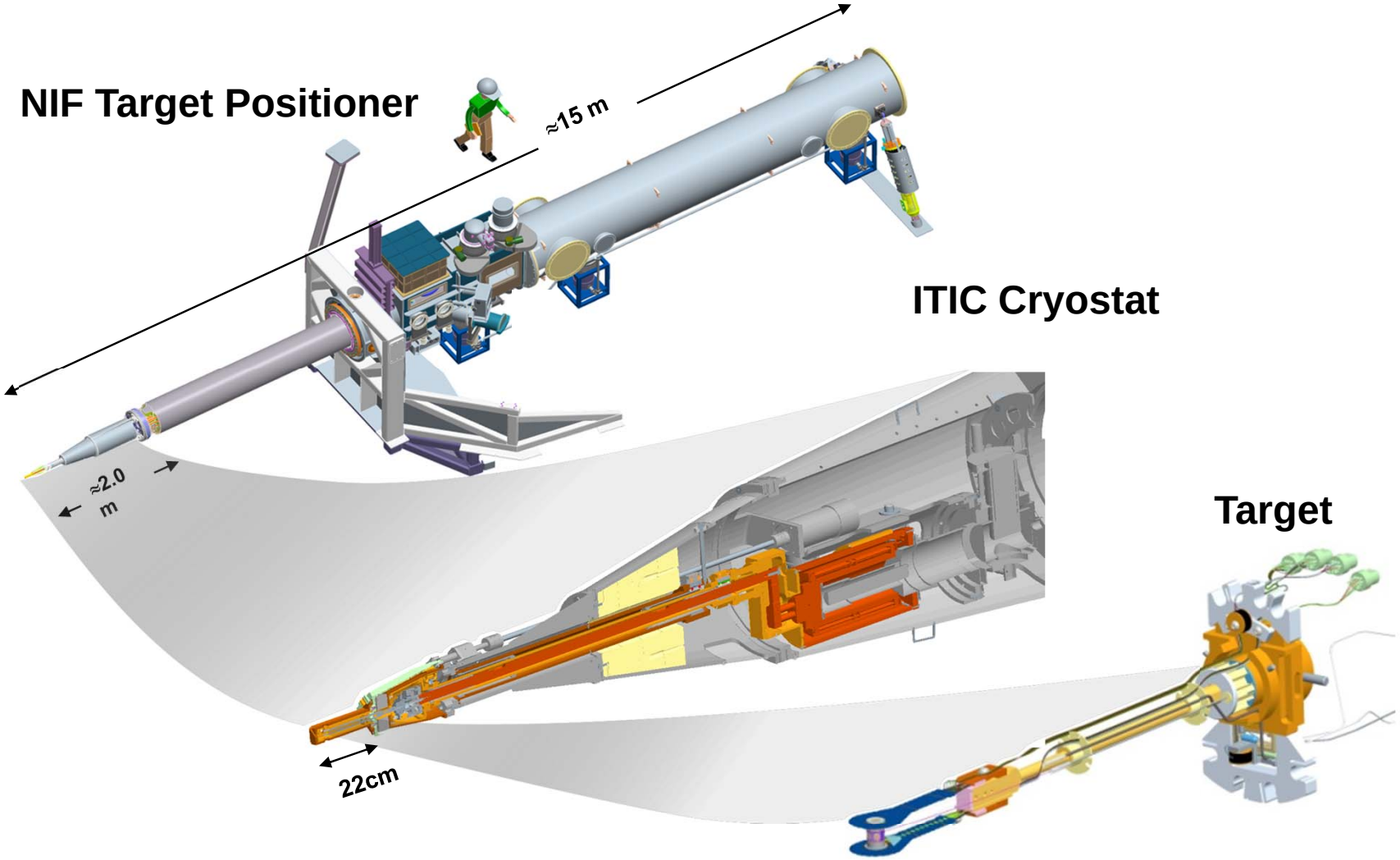
Self-heating due to beta decay results in DT sublimation from thicker, warmer regions and condensation, ice layer growth in thinner areas

Beta-Layering helps forming a spherical layer in isothermal capsule. Not efficient in preventing local defects, "grooves".

Local defects are eliminated by executing the Single Seed Crystal Growth layering protocol



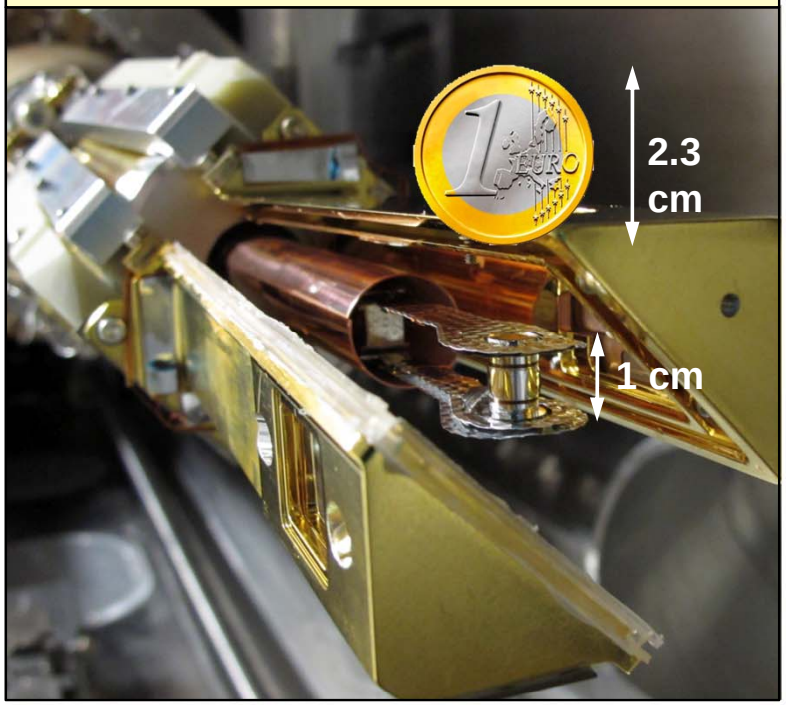
Both Beta-Layering and Single Seed Crystal Growth require precise cryogenic temperature controls



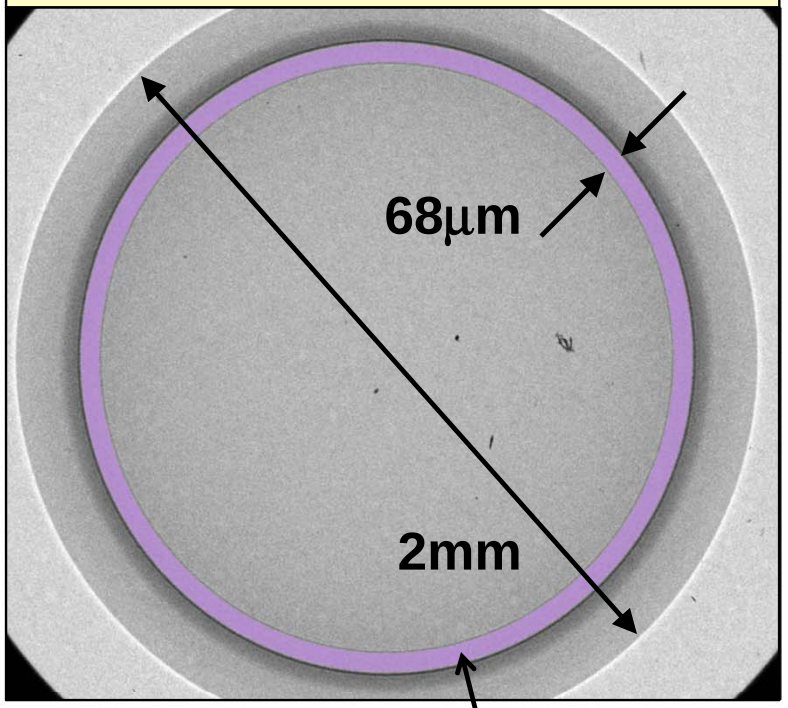

CryoTARPOS

Ignition Target Insertion Cryostat (ITIC) provides a controlled cryogenic environment

Target before the shot

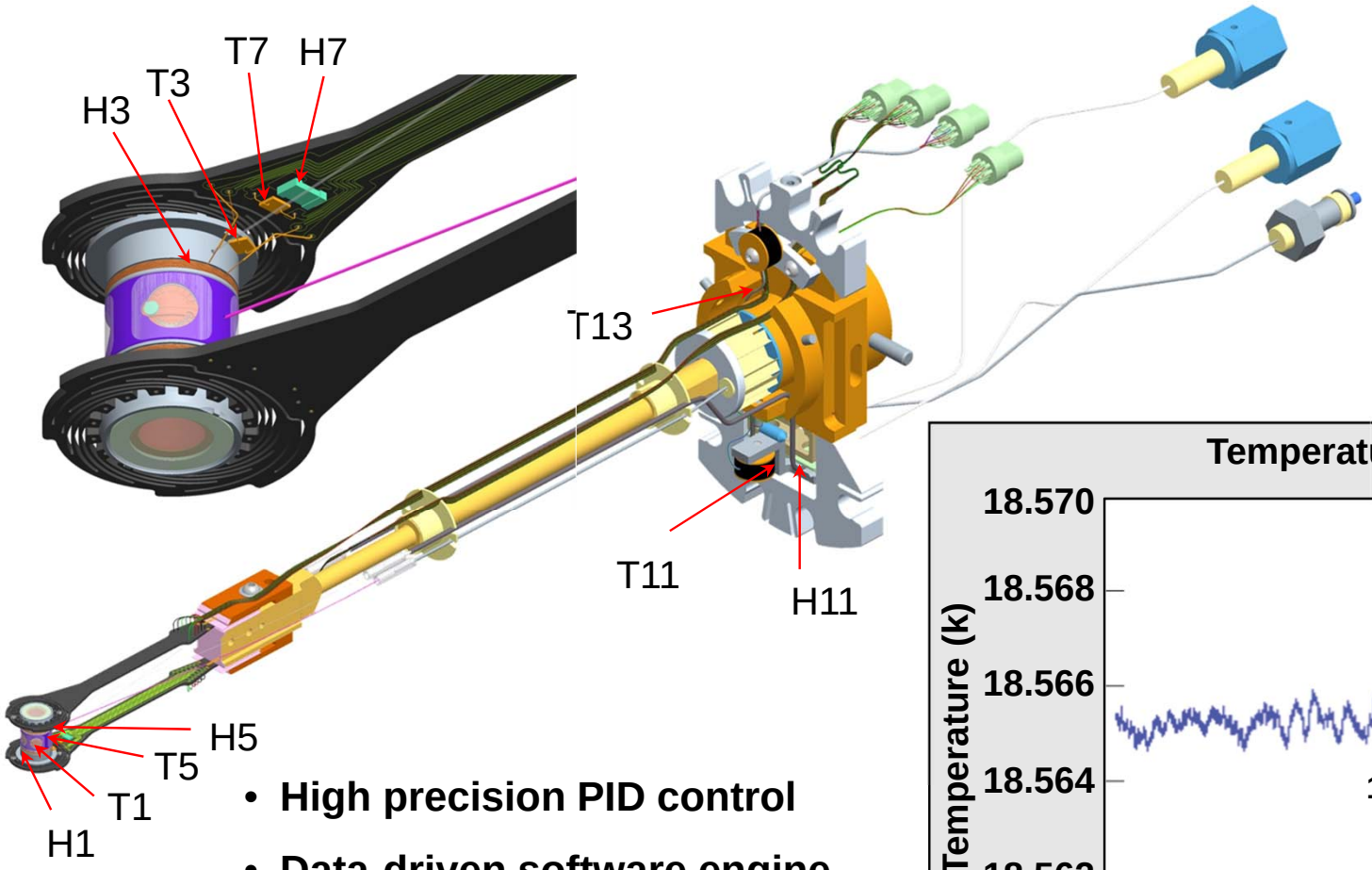


View of target from laser entrance hole

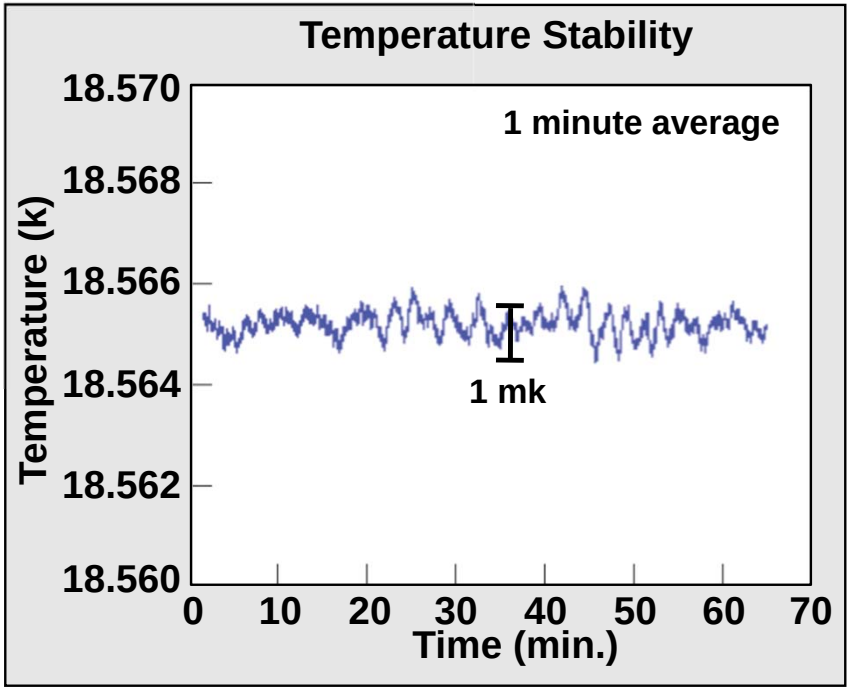


“Cryo THD ice layer” at ~19 deg K

Target temperatures are controlled down to 1 mK precision at multiple points

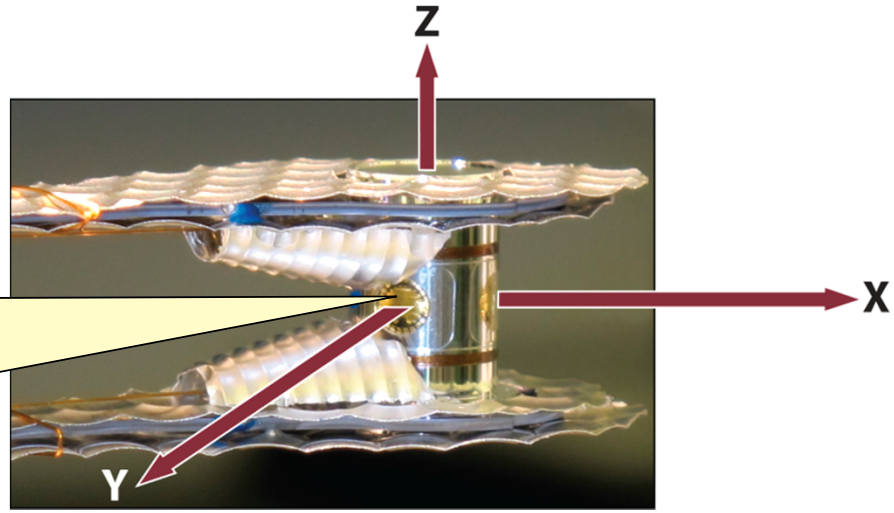


- High precision PID control
- Data-driven software engine
- Helium tank thermal capacitor
- Thermal shielding and isolation

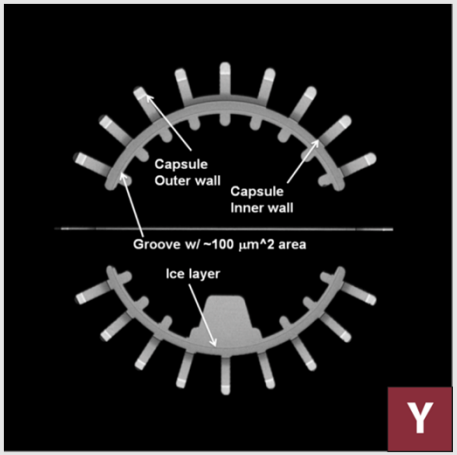


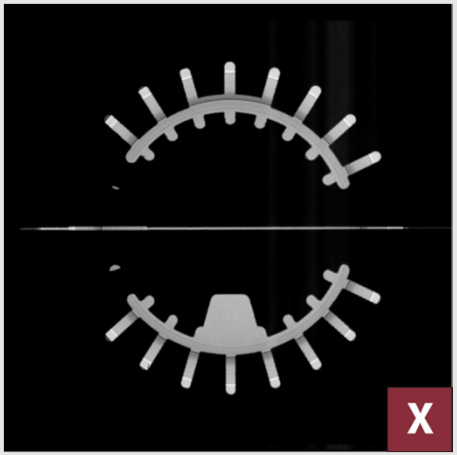
Distribution of DT fuel is monitored and measured using a three-axis x-ray imaging system

Computer-enhanced, phase-contrast x-ray imaging reliably detects the ice layers inside of a Beryllium (Be) or a Plastic (CH) capsule

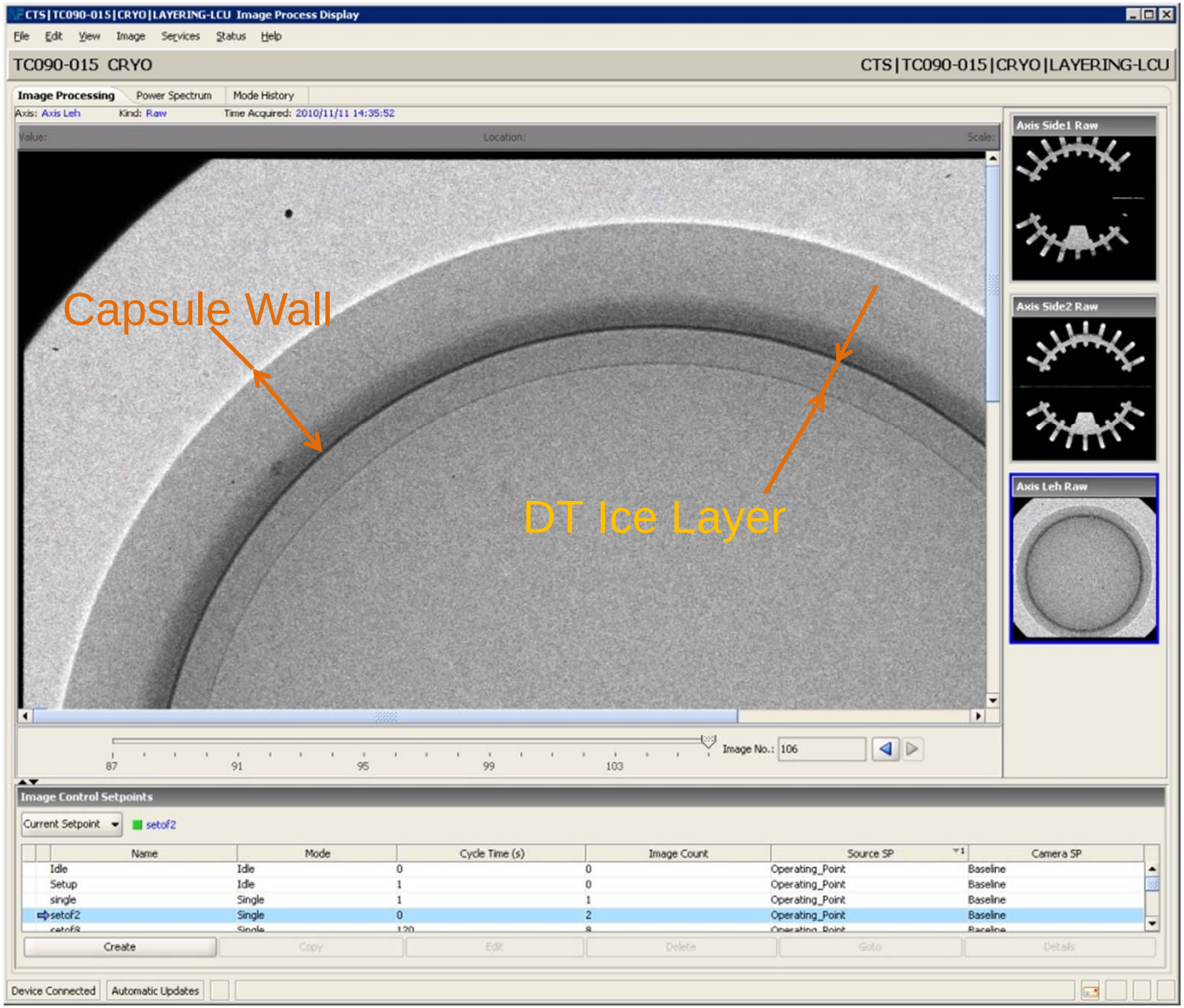


Fuel ice characterized along three orthogonal directions using x-rays

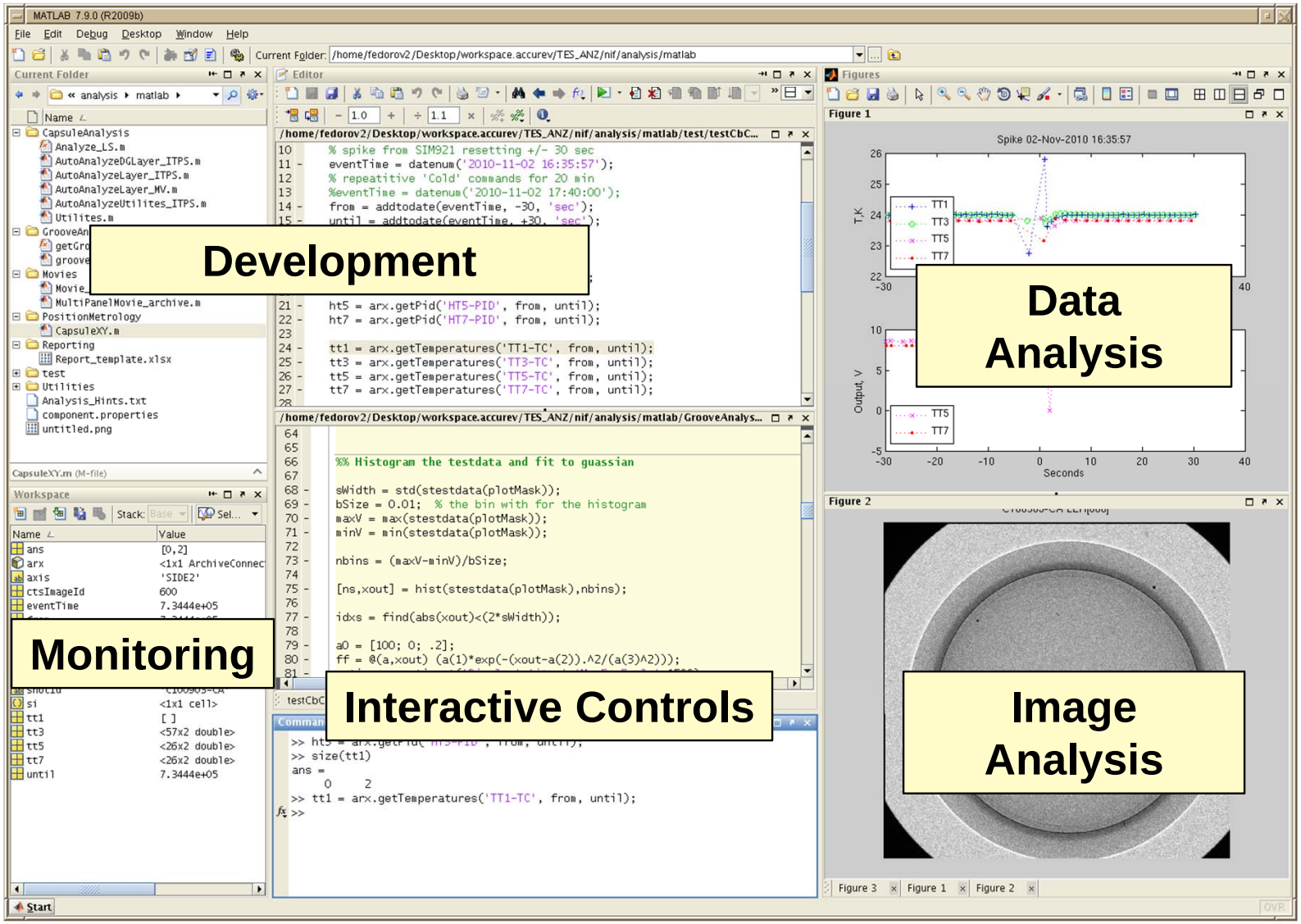




Cryogenic and imaging hardware is controlled by automatic, data-driven software engines

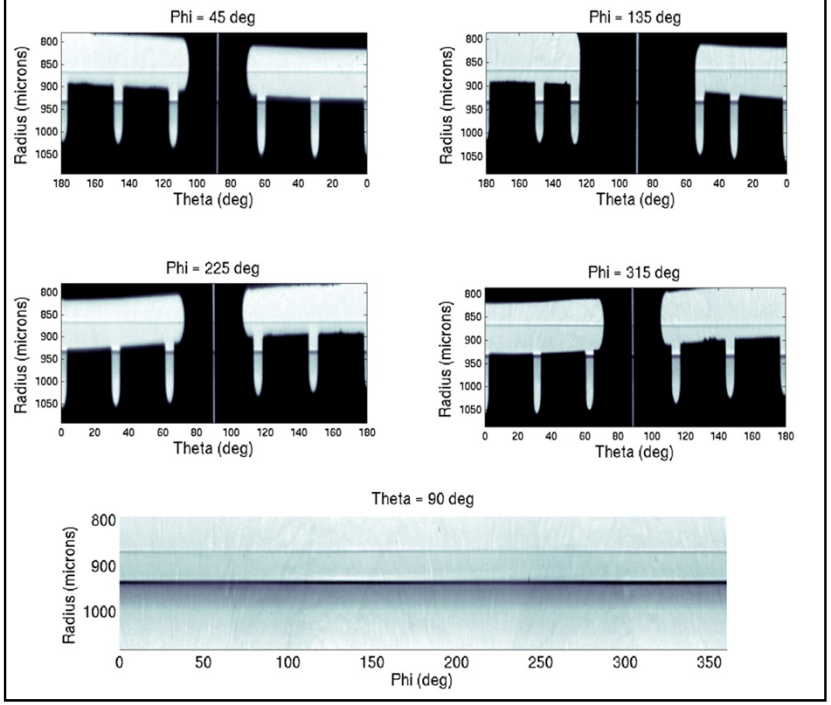


A Layering Toolbox for MATLAB supports interactive development and analysis of evolving protocols

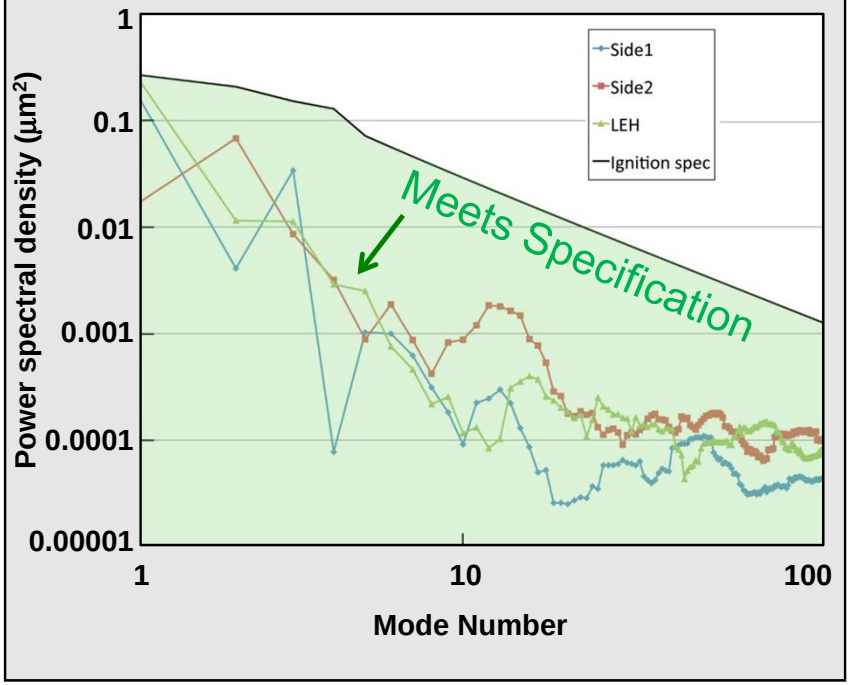


A Layering Report determines target readiness for an ignition experiment

Grooves

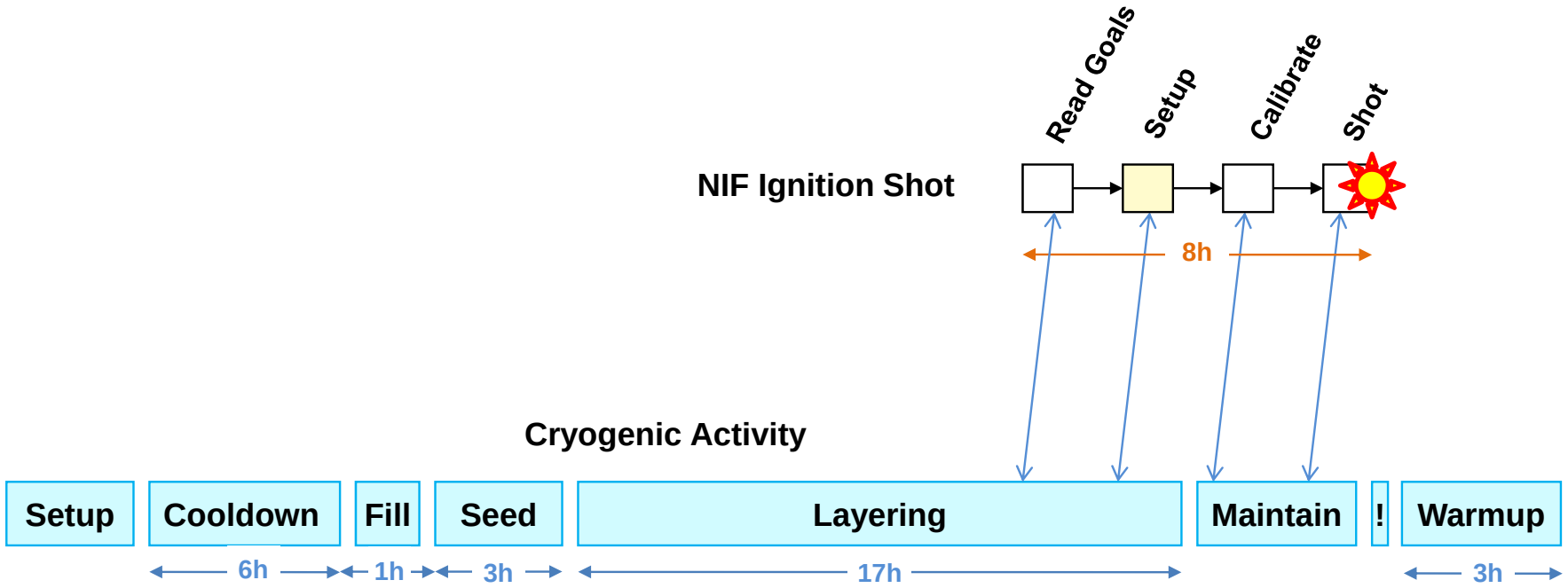


Sphericity

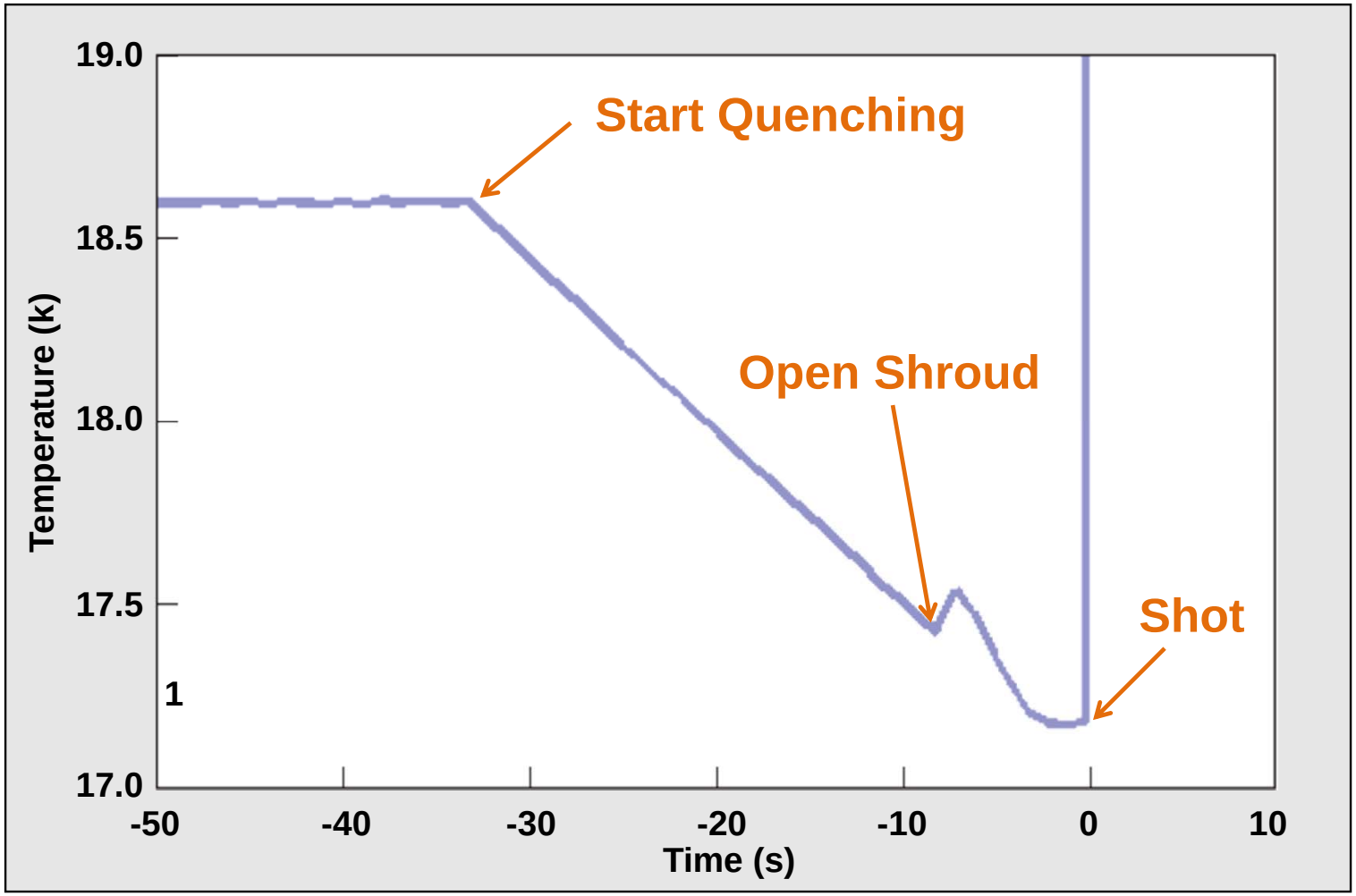


Report recommendation "all specs met, shoot"

Cryogenic Activity starts independently, then joins the NIF Shot Cycle



Final temperature adjustments and shroud opening are performed seconds prior to main laser shot



Since 2010, the Cryogenic Target System supported 72 NIF experiments, including 18 with layered targets

- Integrated hardware-software system provides a robust and accurate platform for cryogenic target experiments
- Automatic data-driven process consistently executes complex layering protocols
- Flexible interactive environment simplifies evaluation of new target designs and supports layering research


NIF