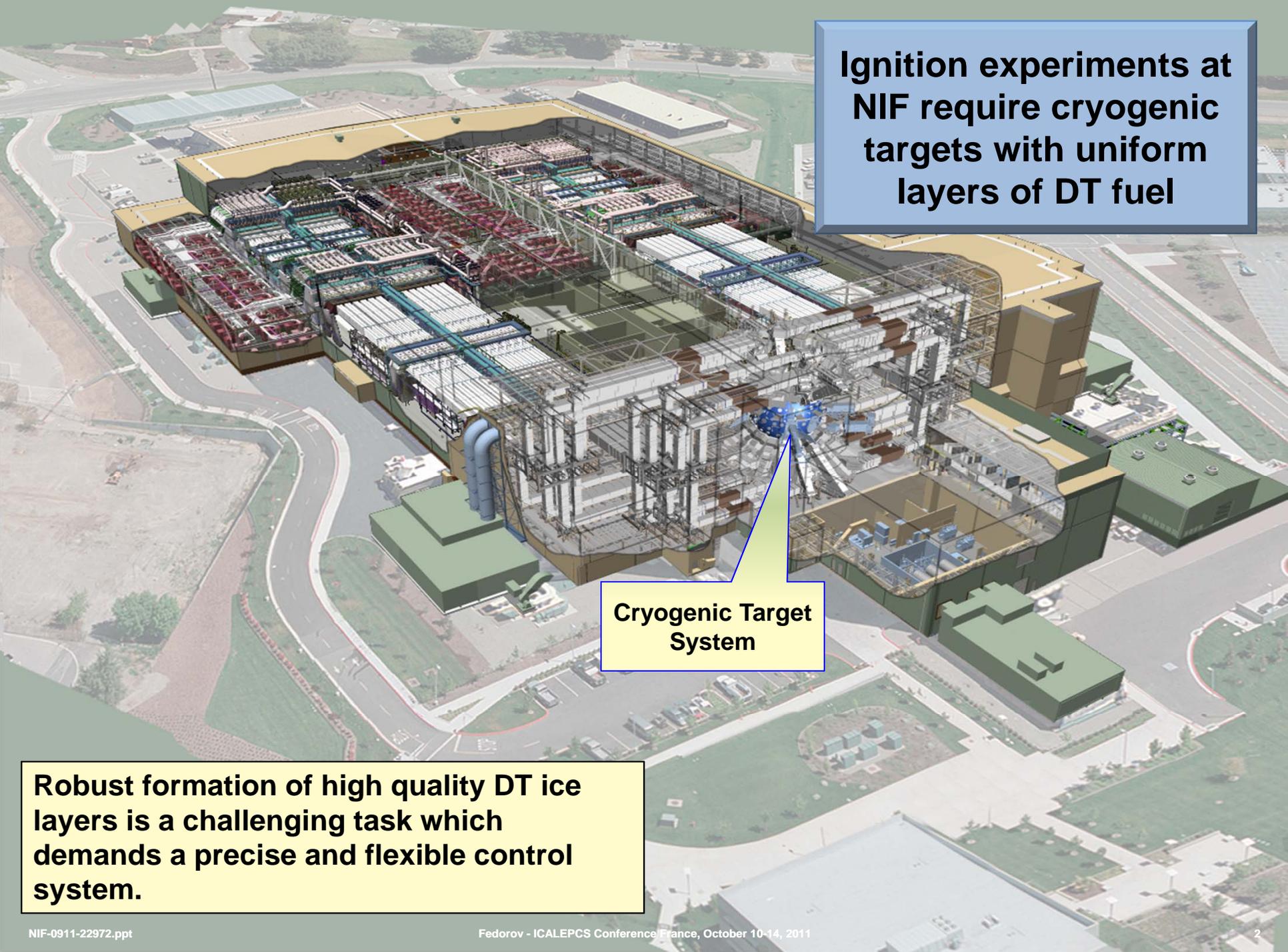


Control System for Cryogenic THD/DT Layering at the National Ignition Facility



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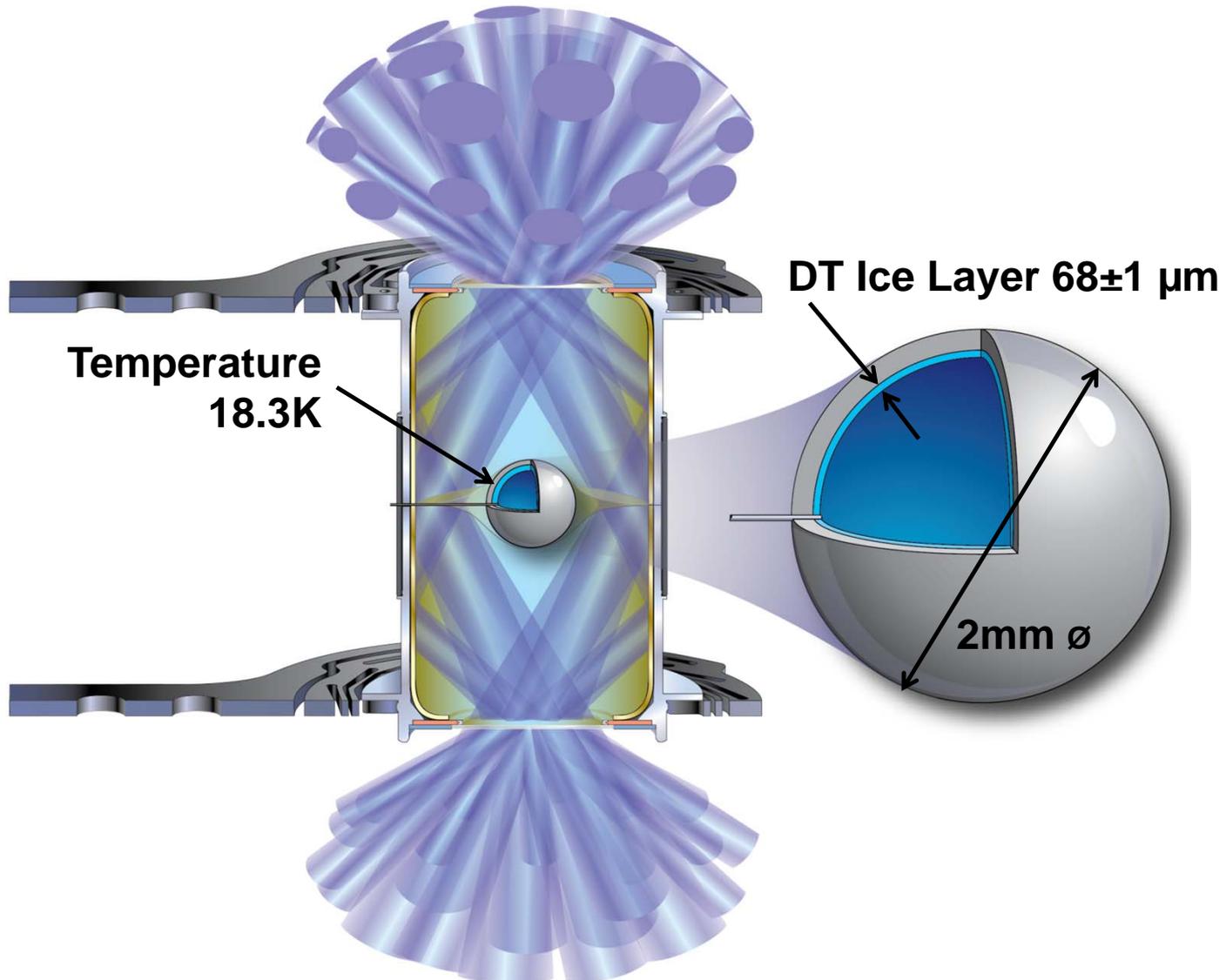


Ignition experiments at NIF require cryogenic targets with uniform layers of DT fuel

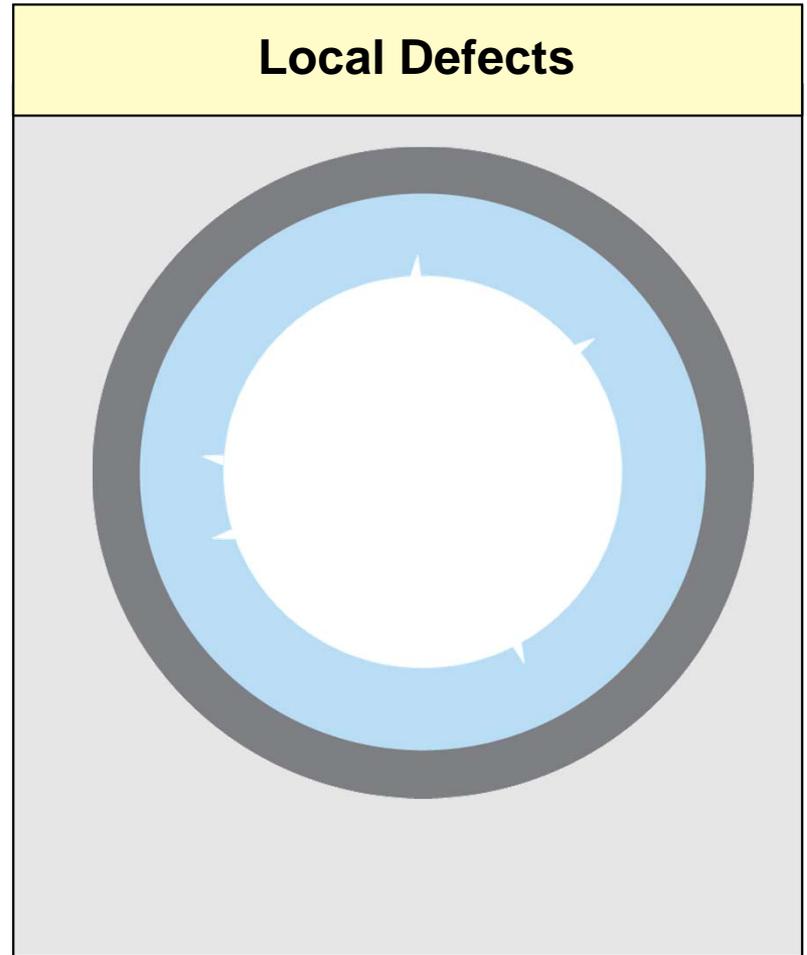
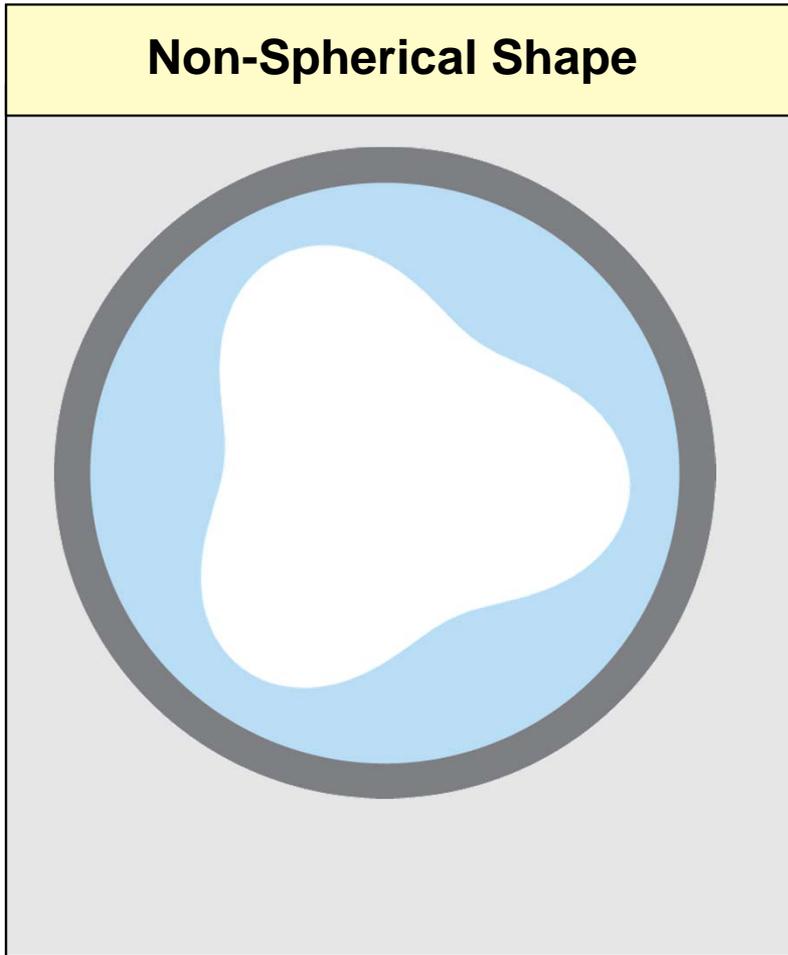
Cryogenic Target System

Robust formation of high quality DT ice layers is a challenging task which demands a precise and flexible control system.

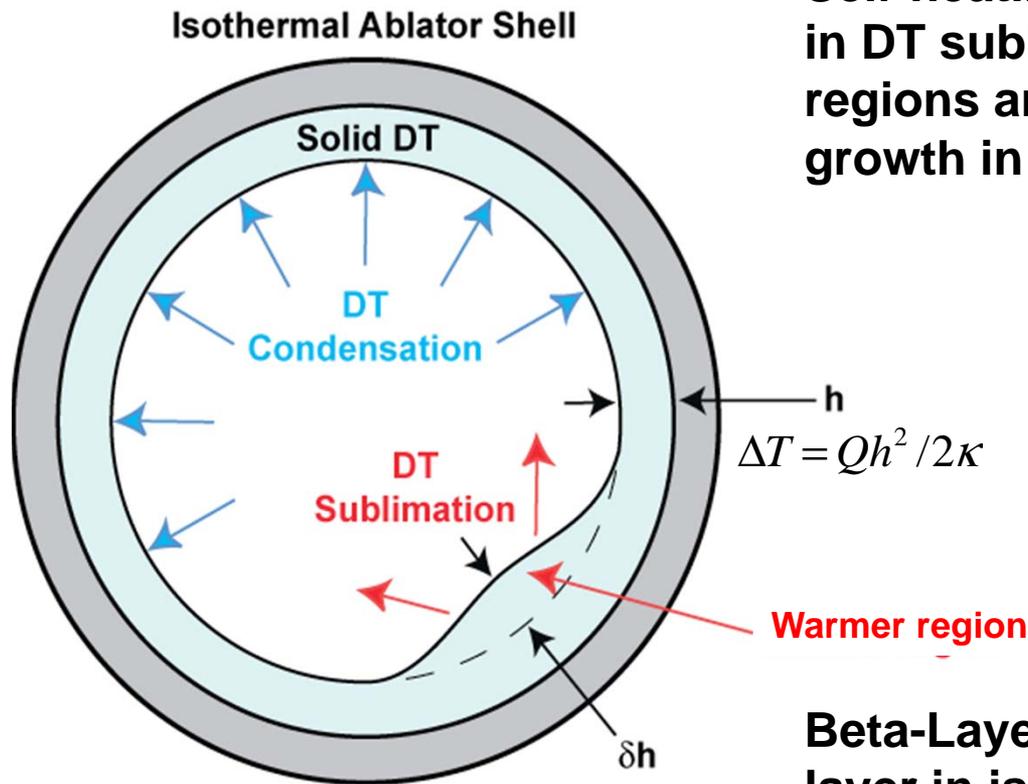
The Deuterium-Tritium (DT) ice layer is an integral component of the ignition target design



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



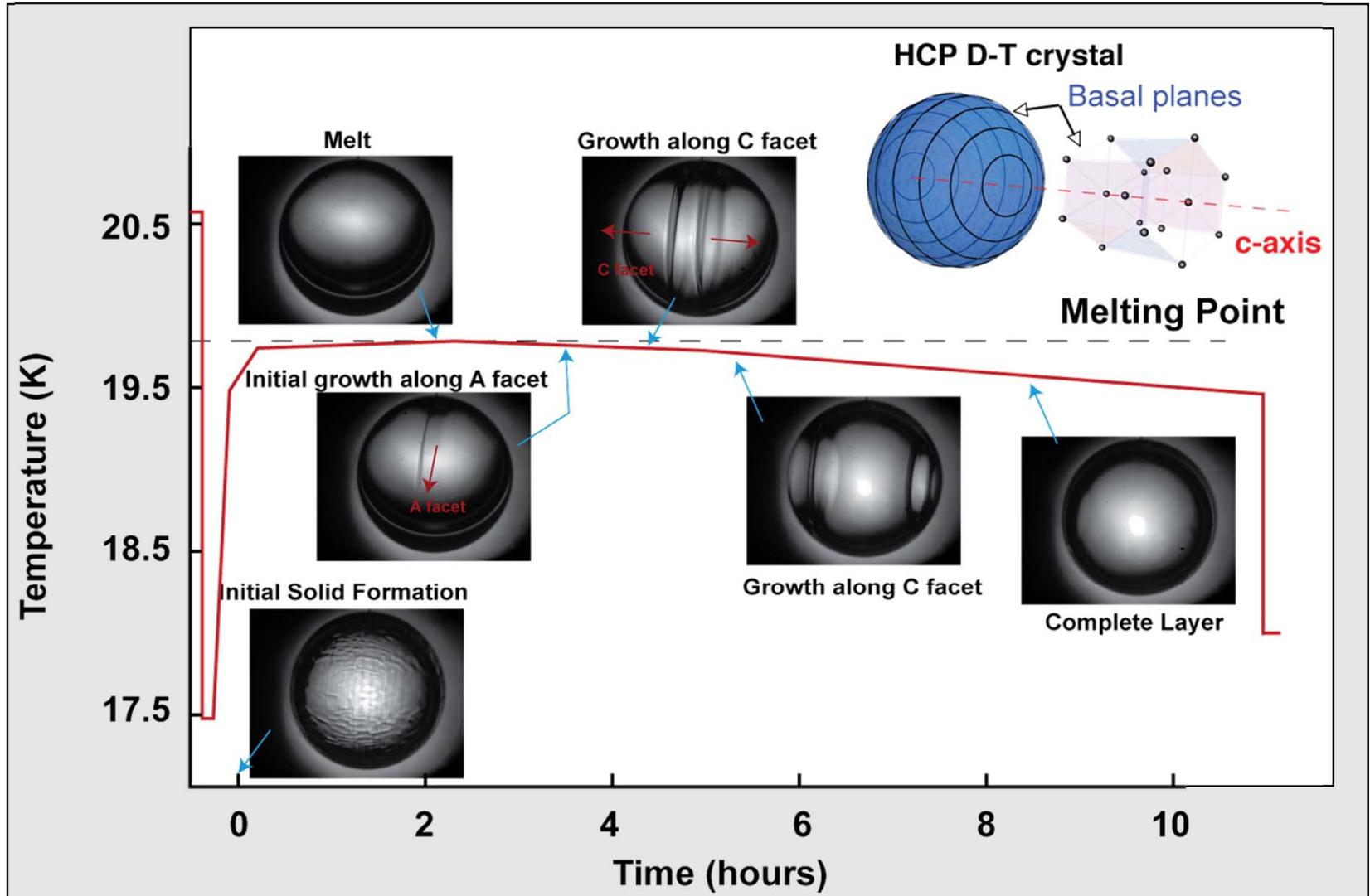
Spherical layers are formed in a uniform thermal environment using Beta-Layering



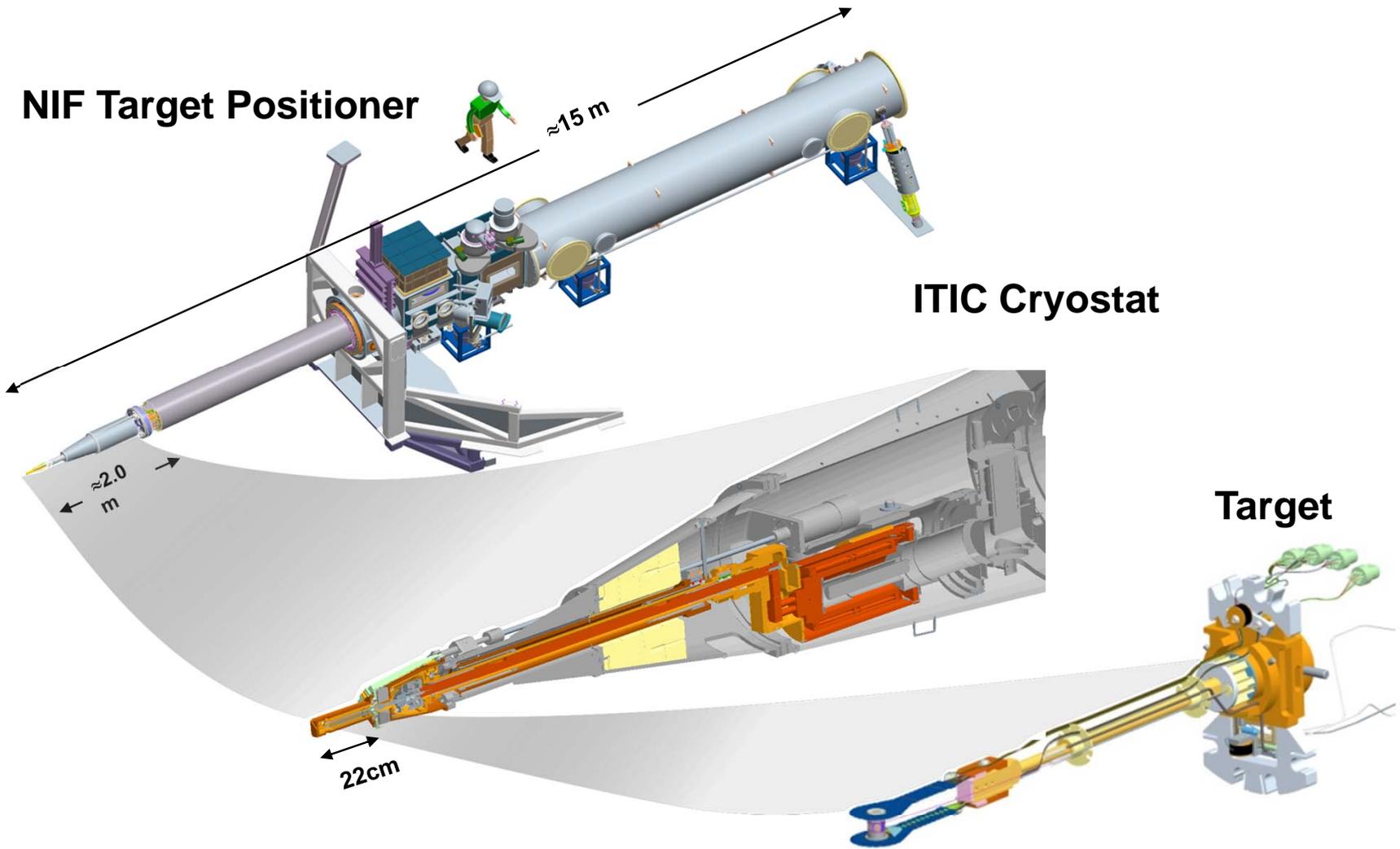
Self-heating due to beta decay results in DT sublimation from thicker, warmer regions and condensation, ice layer growth in thinner areas

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



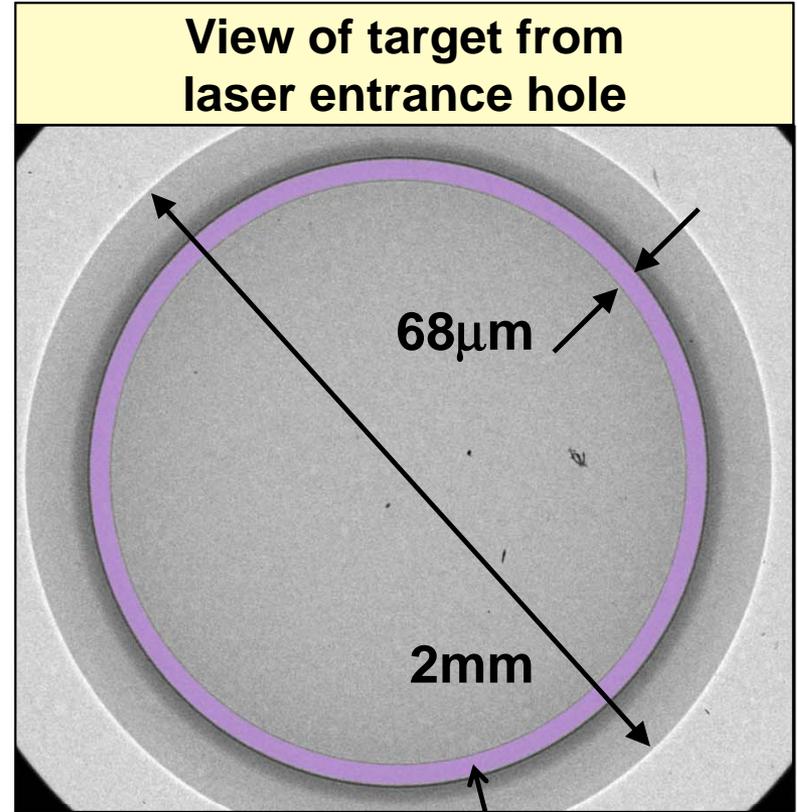
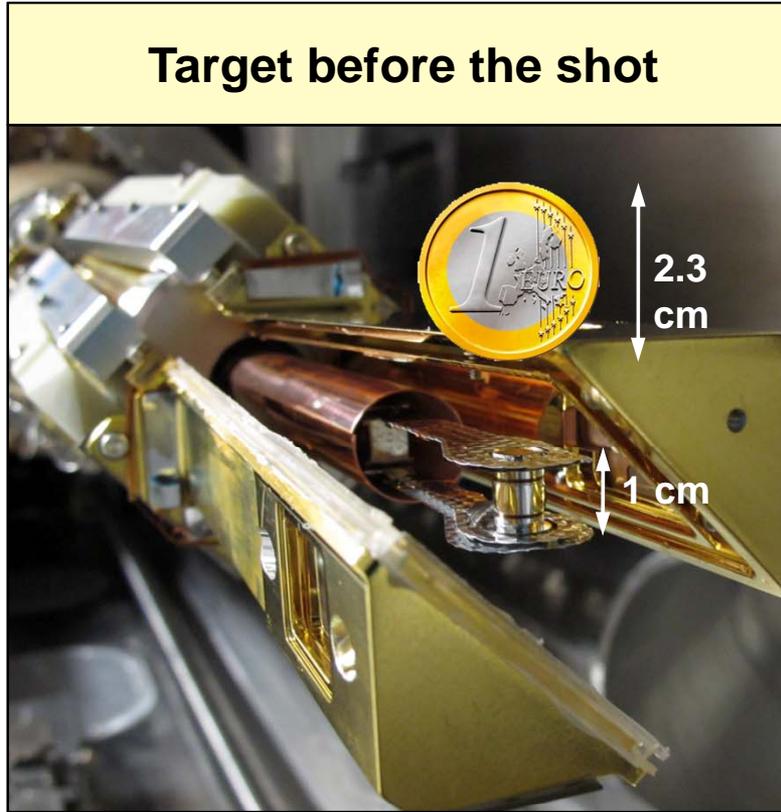
Both Beta-Layering and Single Seed Crystal Growth require precise cryogenic temperature controls



CryoTARPOS

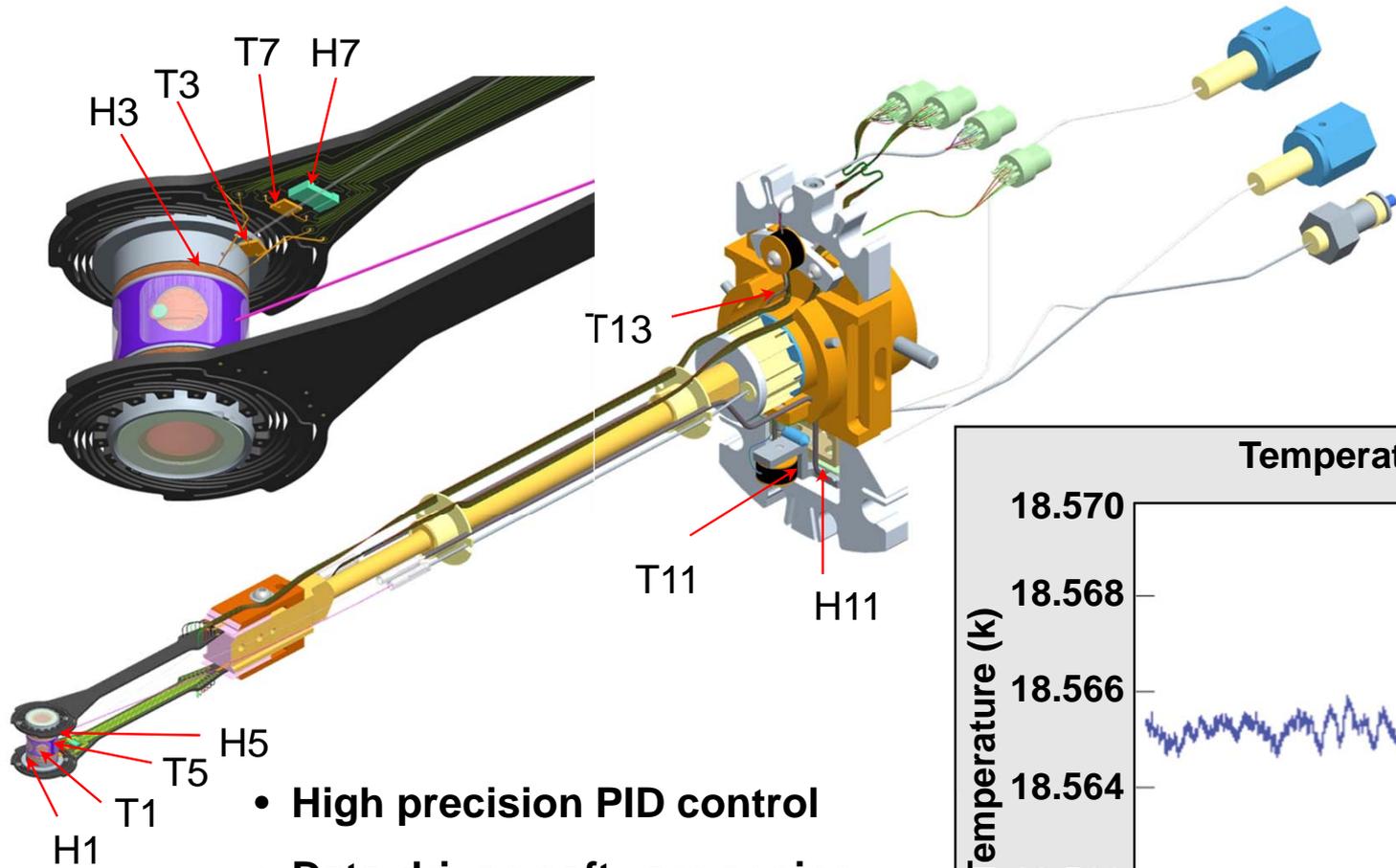


Ignition Target Insertion Cryostat (ITIC) provides a controlled cryogenic environment

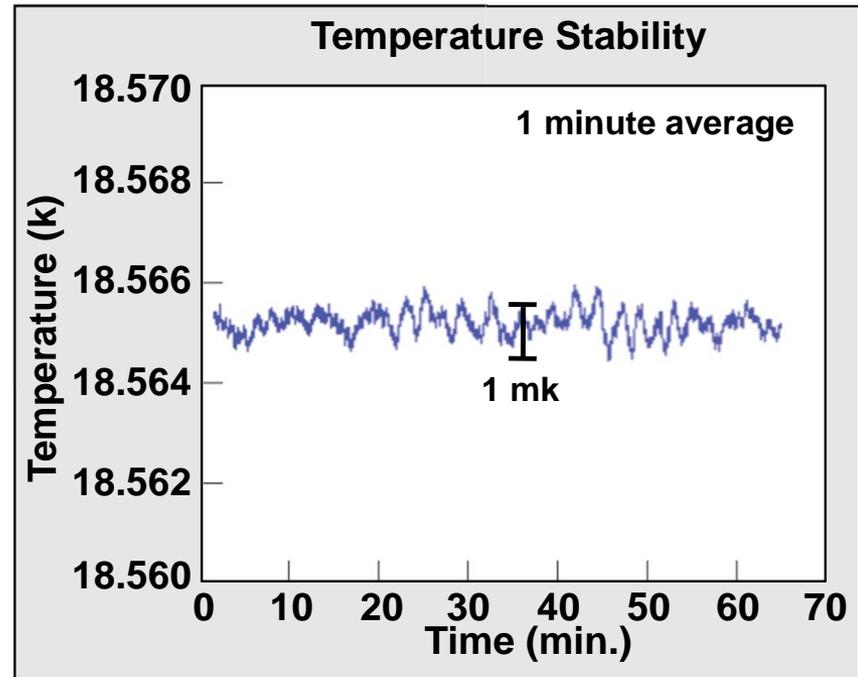


“Cryo THD ice layer” at ~19 deg K

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

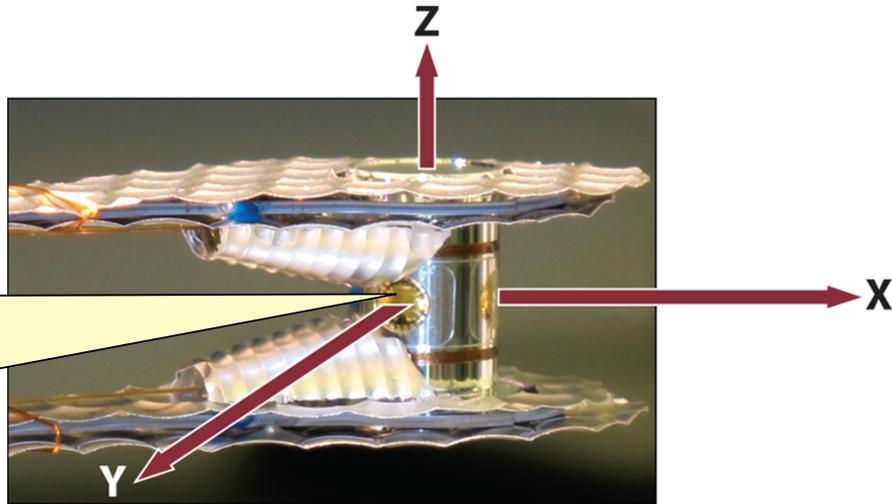


- High precision PID control
- Data-driven software engine
- Helium tank thermal capacitor
- Thermal shielding and isolation

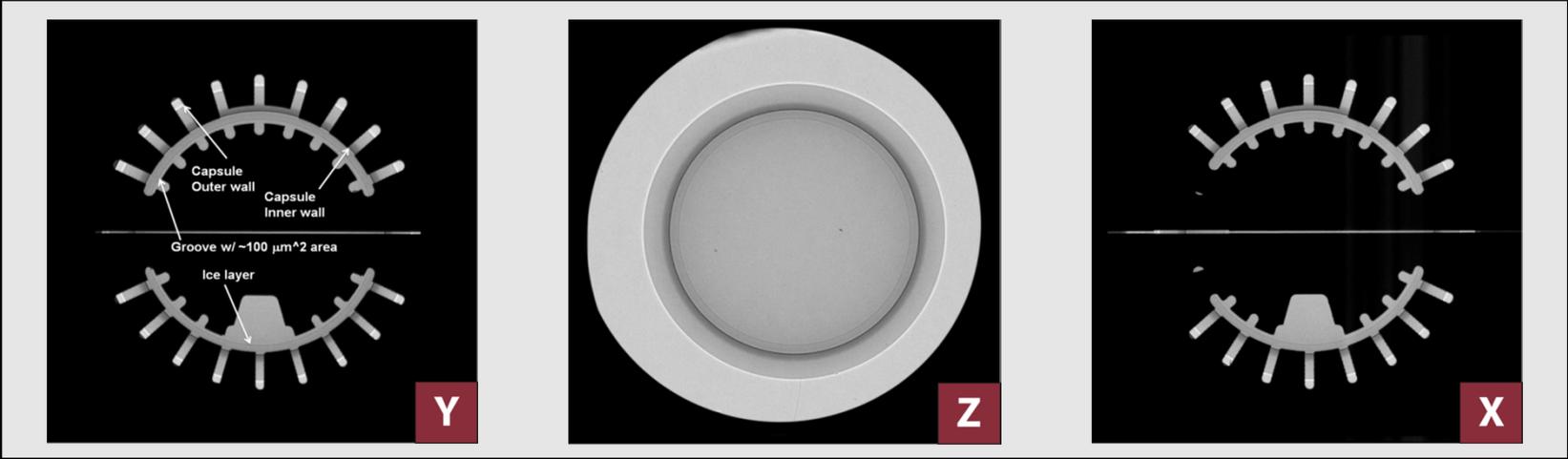


Distribution of DT fuel is monitored and measured using a three-axis x-ray imaging system

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

The screenshot displays the 'Image Process Display' software interface for 'TC090-015 CRYO'. The main window shows a grayscale cross-sectional image of a capsule. Two orange arrows point to the 'Capsule Wall' and 'DT Ice Layer'. The interface includes a menu bar (File, Edit, View, Image, Services, Status, Help), a toolbar, and a thumbnail gallery on the right with three images labeled 'Axis Side1 Raw', 'Axis Side2 Raw', and 'Axis Leh Raw'. The bottom panel, 'Image Control Setpoints', contains a table with the following data:

Name	Mode	Cycle Time (s)	Image Count	Source SP	Camera SP
Idle	Idle	0	0	Operating_Point	Baseline
Setup	Idle	1	0	Operating_Point	Baseline
single	Single	1	1	Operating_Point	Baseline
setof2	Single	0	2	Operating_Point	Baseline
catofR	Single	1.20	R	Operation_Point	Baseline

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

The image displays the MATLAB 7.9.0 (R2009b) environment with four main components highlighted by yellow boxes:

- Development:** The Editor window shows MATLAB code for data acquisition and processing. The code includes comments and functions for setting event times, getting temperatures, and fitting histograms.


```

10 % spike from SIM921 resetting +/- 30 sec
11 eventTime = datenum('2010-11-02 16:35:57');
12 % repetitive 'Cold' commands for 20 min
13 %eventTime = datenum('2010-11-02 17:40:00');
14 from = addtodate(eventTime, -30, 'sec');
15 until = addtodate(eventTime, +30, 'sec');

21 ht5 = arx.getPid('HT5-PID', from, until);
22 ht7 = arx.getPid('HT7-PID', from, until);

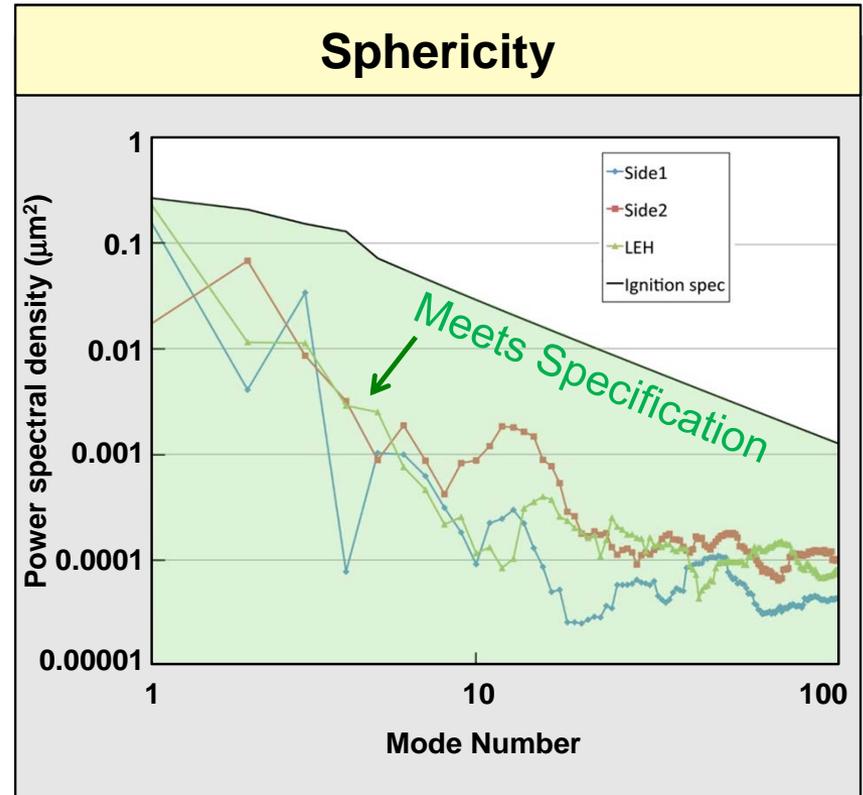
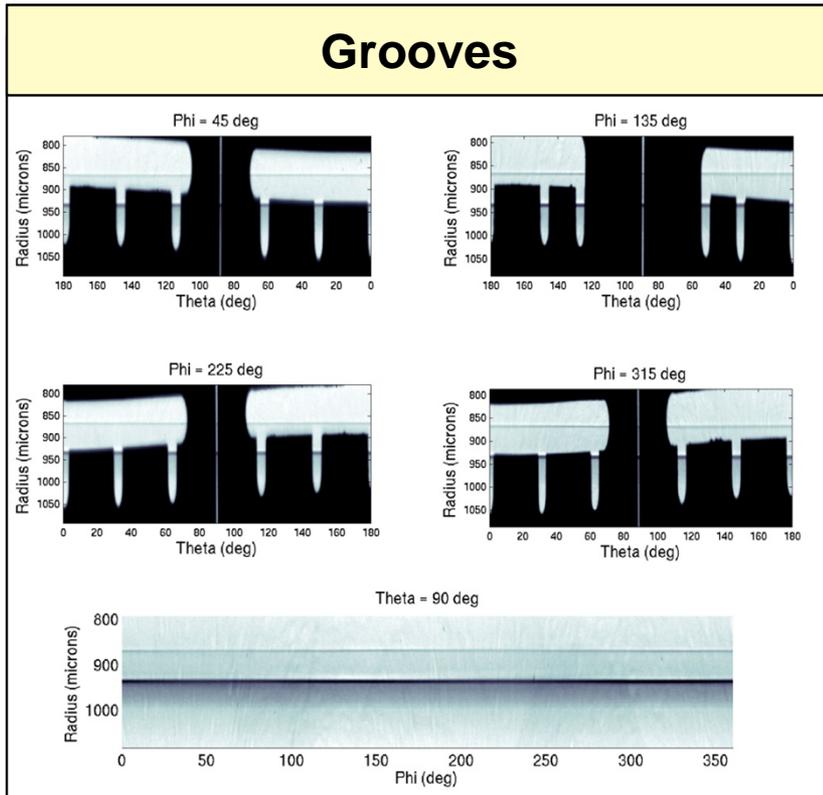
24 tt1 = arx.getTemperatures('TT1-TC', from, until);
25 tt3 = arx.getTemperatures('TT3-TC', from, until);
26 tt5 = arx.getTemperatures('TT5-TC', from, until);
27 tt7 = arx.getTemperatures('TT7-TC', from, until);

64
65
66 %% Histogram the testdata and fit to gaussian
67
68 sWidth = std(stestdata(plotMask));
69 bSize = 0.01; % the bin with for the histogram
70 maxV = max(stestdata(plotMask));
71 minV = min(stestdata(plotMask));
72
73 nbins = (maxV-minV)/bSize;
74
75 [ns,xout] = hist(stestdata(plotMask),nbins);
76
77 idxs = find(abs(xout)<(2*sWidth));
78
79 a0 = [100; 0; .2];
80 ff = @(a,xout) (a(1)*exp(-(xout-a(2)).^2/(a(3)^2)));
81

```
- Data Analysis:** The Figures window shows a plot titled "Spike 02-Nov-2010 16:35:57". The y-axis is labeled "T,K" and ranges from 22 to 26. The x-axis is labeled "Seconds" and ranges from -30 to 40. The plot shows a sharp spike at approximately 0 seconds, with data points for TT1, TT3, TT5, and TT7.
- Monitoring:** The Workspace window shows a table of variables:

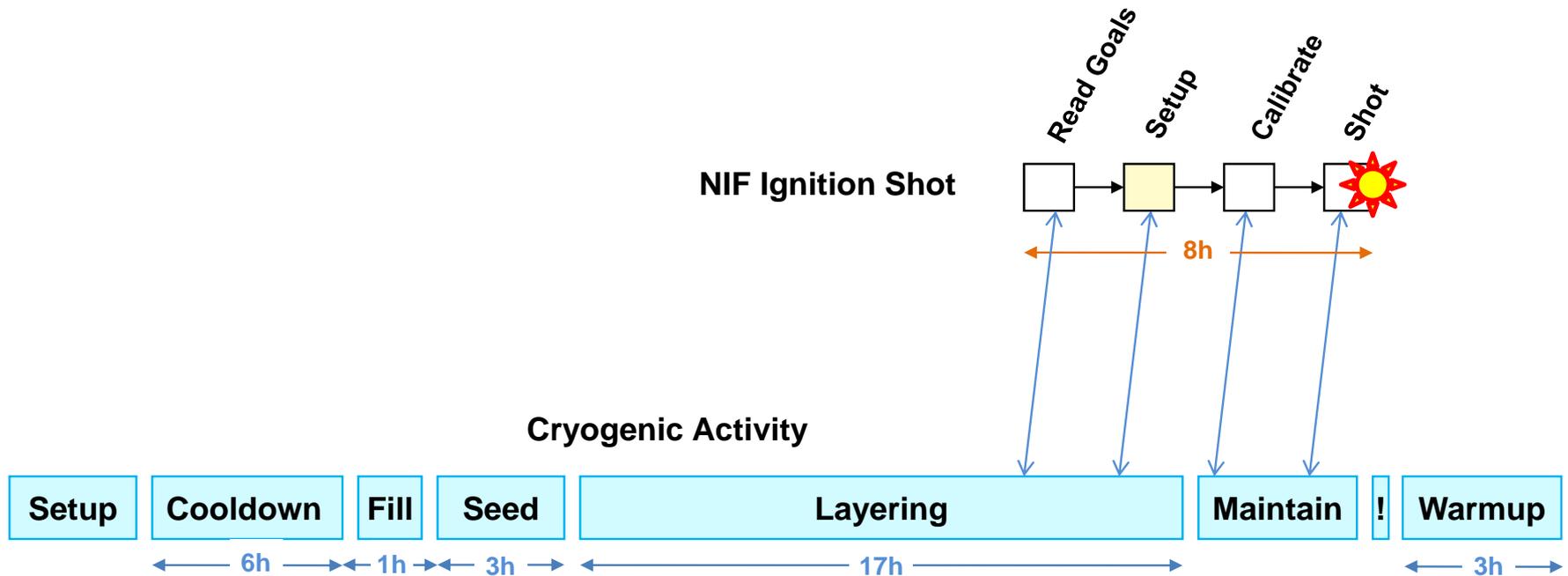
Name	Value
ans	[0,2]
arx	<1x1 ArchiveConnec
axis	'SIDE2'
ctsImageId	600
eventTime	7.3444e+05
- Image Analysis:** The Figures window shows a grayscale image of a circular object, likely a component of a reactor, with a central hole and concentric rings.

A Layering Report determines target readiness for an ignition experiment

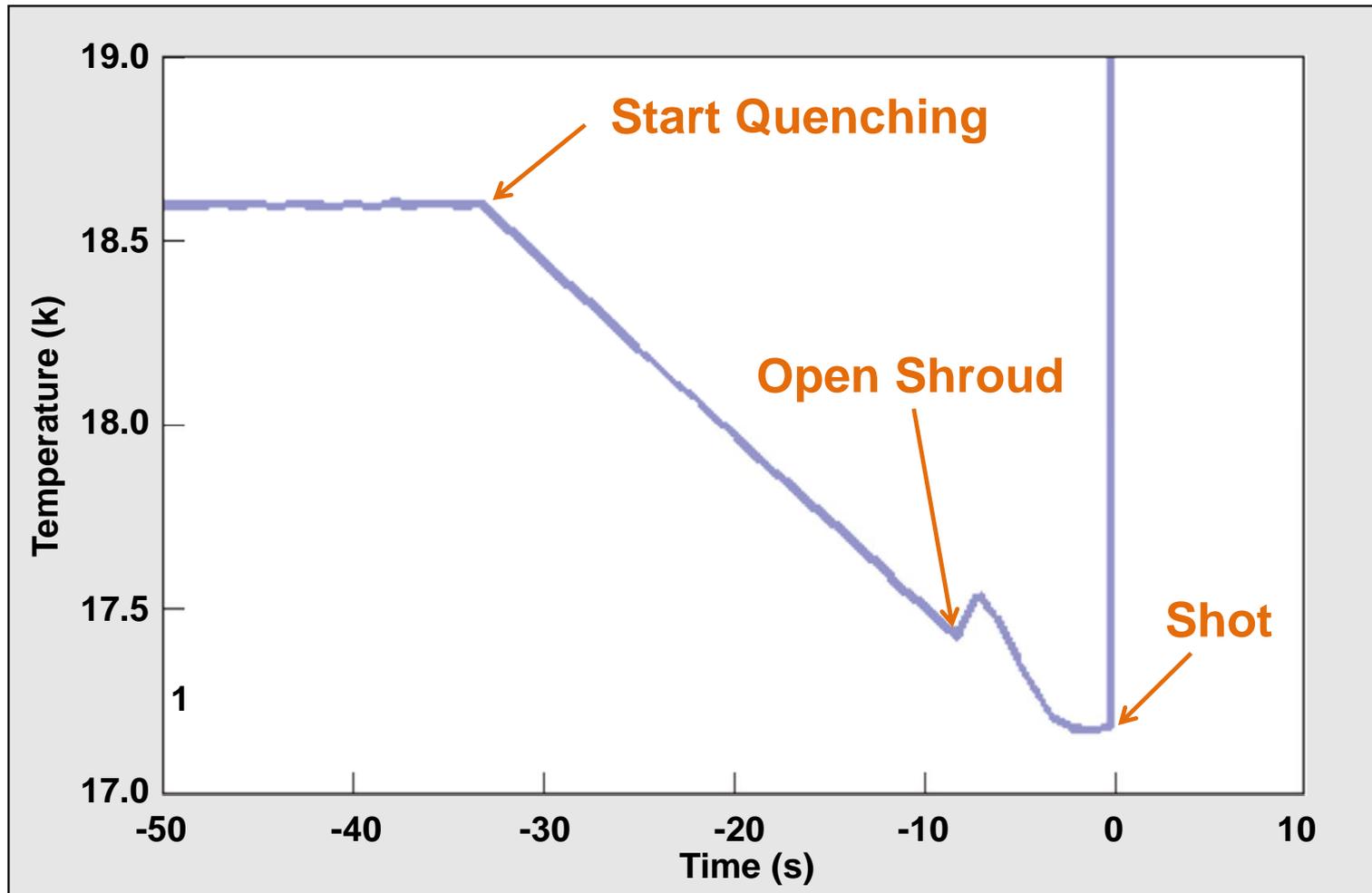


Report recommendation "all specs met, shoot"

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

