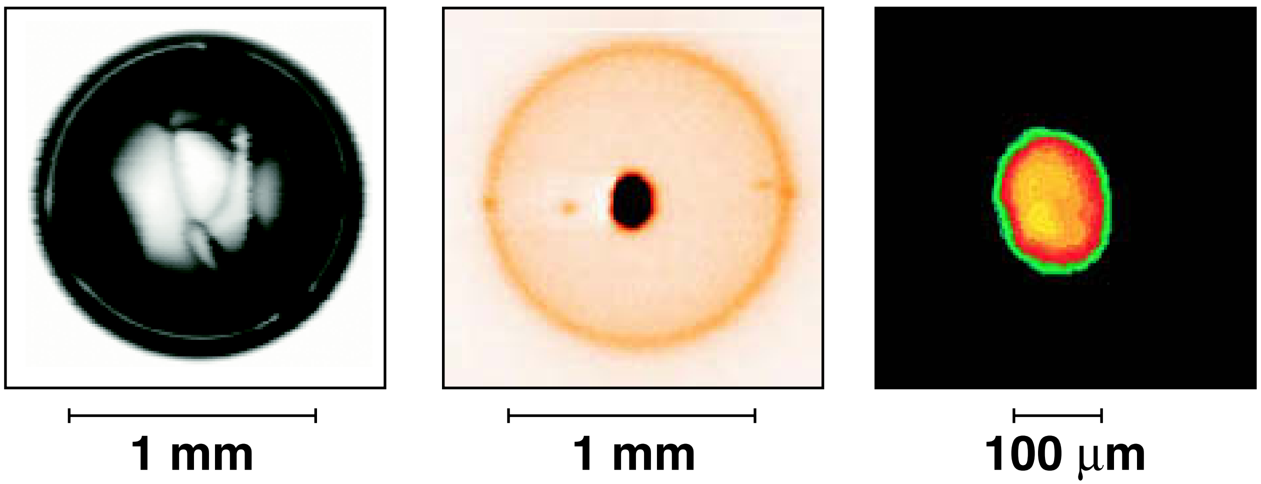
First Results from Cryogenic-Target Implosions on OMEGA



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Summary

OMEGA cryogenic targets have shown 30% of 1-D yields

UR LLE

- The technology to fill, layer, characterize, and shoot direct-drive cryogenic targets has been validated.
- Five thin-walled (~ 3 μm CH) cryogenic targets with an ice layer of 80 to 100 μm (three of them adequately characterized) have been shot during a two-week campaign.
- The targets have shown up to 30% of 1-D yield and 60% of 1-D areal densities with ~ 9 μm rms inner-ice-surface nonuniformity.
- Layering studies after the experimental campaign have demonstrated ~ 3 μm rms inner-ice-surface roughness, with a design goal of 1 μm.
- These initial results are encouraging for future direct-drive cryogenic implosions on OMEGA and the NIF.

Outline

- Introduction
- Cryogenic Target Handling System
- Target characterization
- Experiments
- Outlook and summary

Cryogenic targets are essential to achieve ignition and gain in direct drive inertial confinement fusion

The advantages of using cryogenic DT for the fuel and the ablator are:

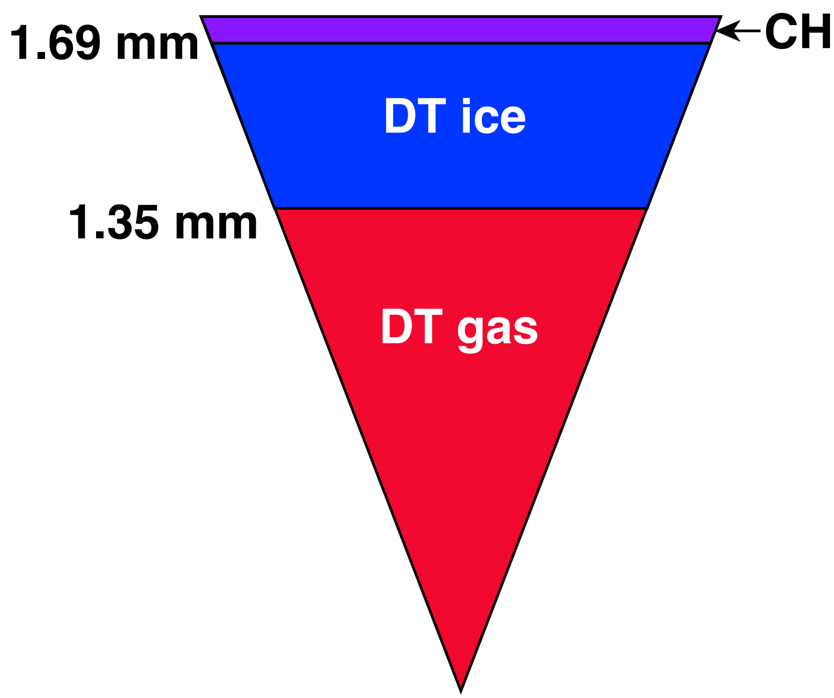
- It reduces the laser requirements to achive a high areal density compressed core because of the high initial fuel density (1000× gas density)
- It reduces the Rayleigh–Taylor growth rates at the ablation surface during the acceleration phase due to its higher ablation velocity
- It eliminates the radiative cooling from the mixing of high Z-material into the fuel during the deceleration phase

The NIF base-line direct-drive ignition target is a thick DT-ice layer enclosed by a thin CH shell

UR LLE

- Target designs are characterized by the isentrope parameter α:

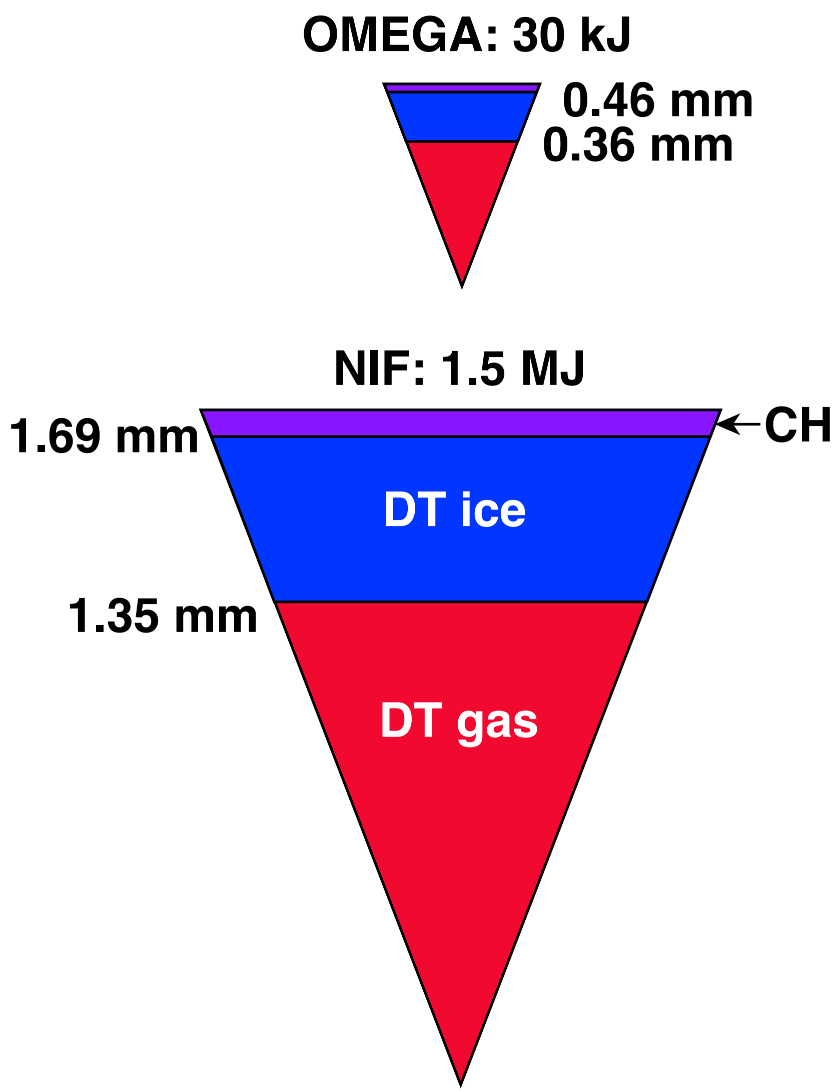
$$\alpha = \frac{\text{Electron pressure}}{\text{Fermi-degenerate pressure}}$$



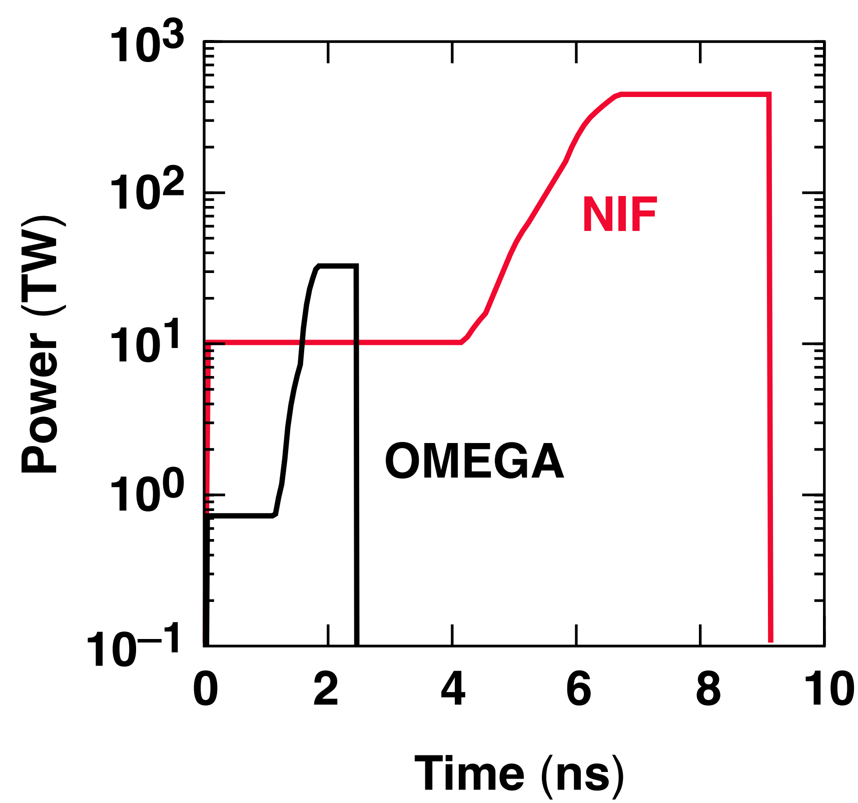
Laser energy	1.5 MJ
Pulse shape	$\alpha = 3$
Gain	45
Yield	2.5×10^{19}
ρR_{peak}	1.3 g/cm^2
$\langle T_i \rangle_n$	30 keV
Hot-spot CR	28
Peak IFAR	60

E11250

OMEGA cryogenic targets are energy scaled from the NIF



Energy ~ radius^3;
power ~ radius^2;
time ~ radius



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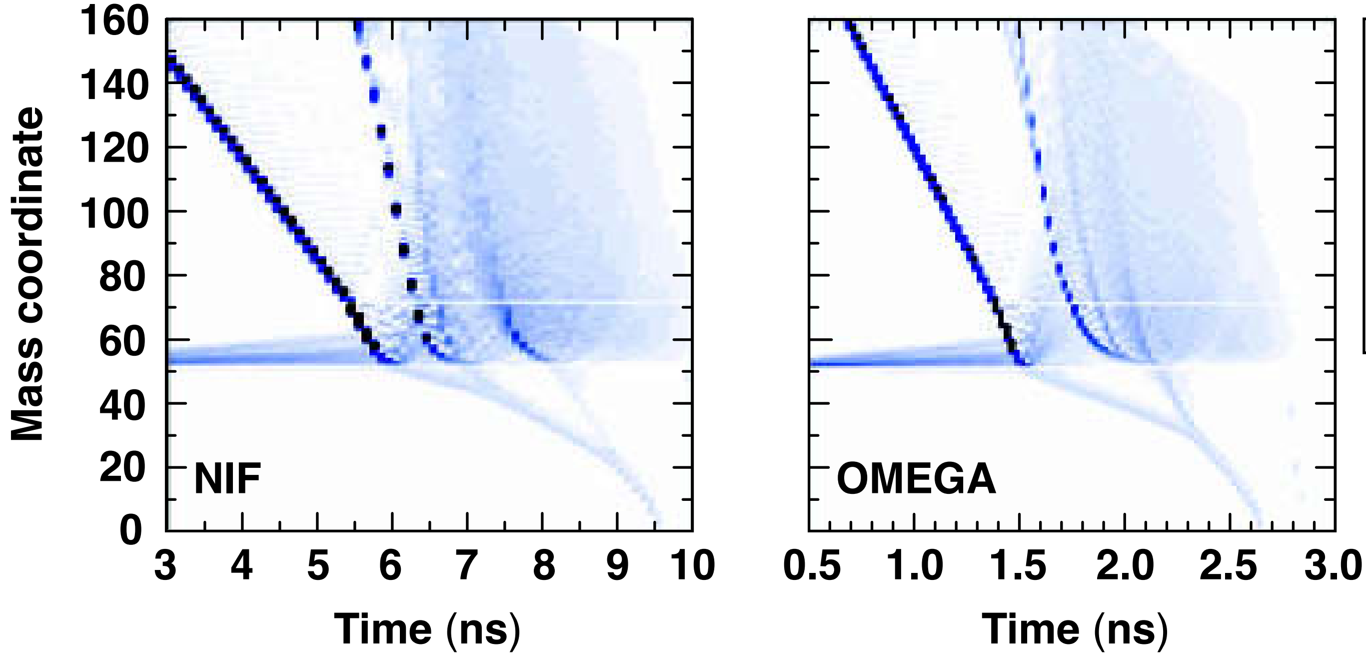
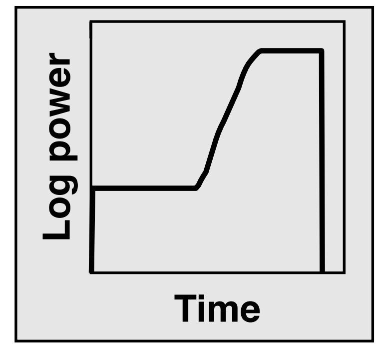
NIF-ignition and OMEGA-scaled DT targets have similar 1-D behavior

UR LLE

- Contours of d(ln P)/dr



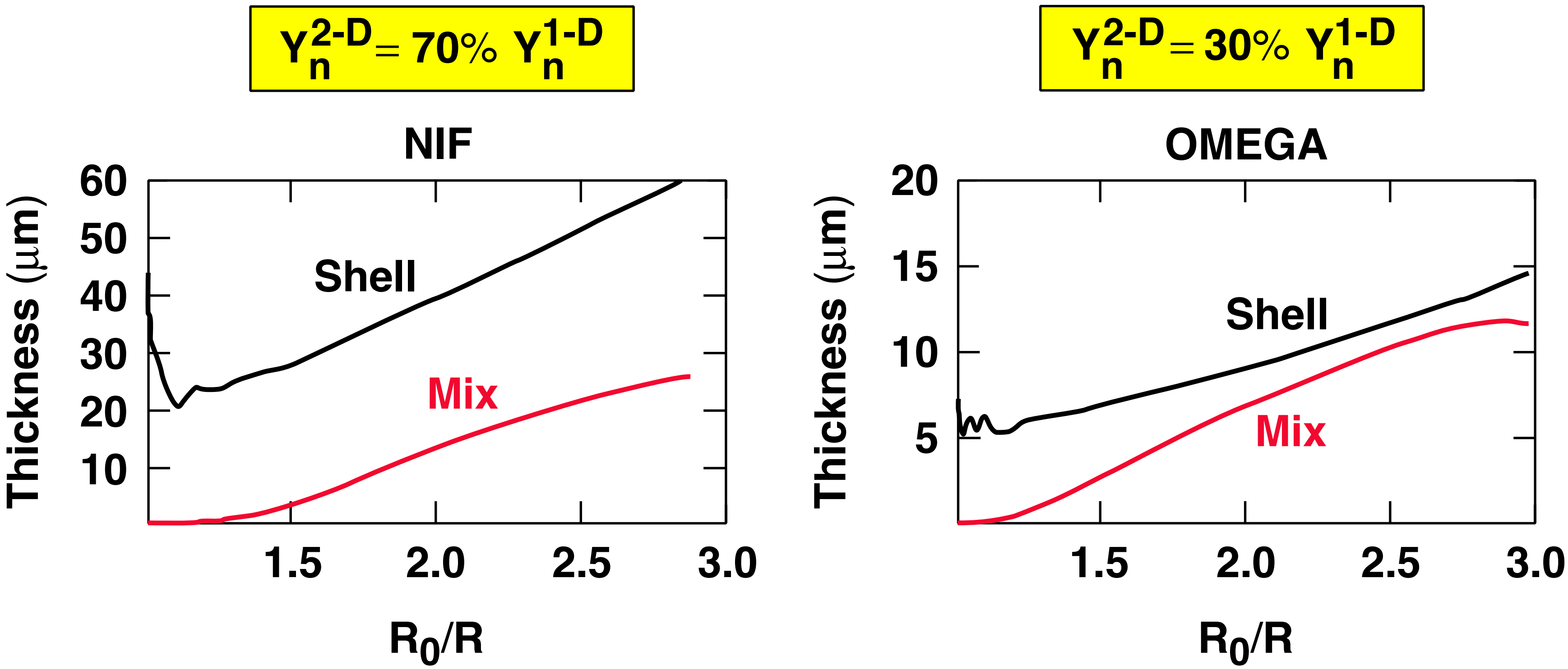


	NIF	OMEGA
Absorption fraction	60%	40%
Shell velocity (cm/s)	4×10^7	3.7×10^7
Yield	2.5×10^{19}	1.8×10^{14}
Hot-spot CR	28	20
ρR_{peak} (mg/cm^2)	1300	300
Peak IFAR	60	50

R. P. J. Town et al., KO2.007

TC5260c

Stability analysis* of the $\alpha = 3$ LLE design shows that the NIF targets are more stable than OMEGA targets



Ice-surface roughness = 1 μm, $\sigma \sim \ell^{-1.5}$

Outer-surface roughness = 840 Å

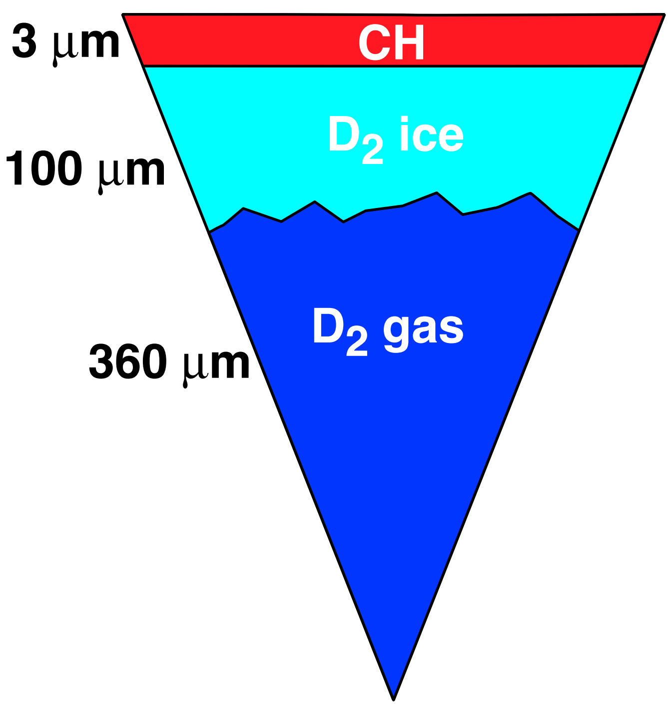
Imprint with 2-D SSD at 1-THz and polarization smoothing

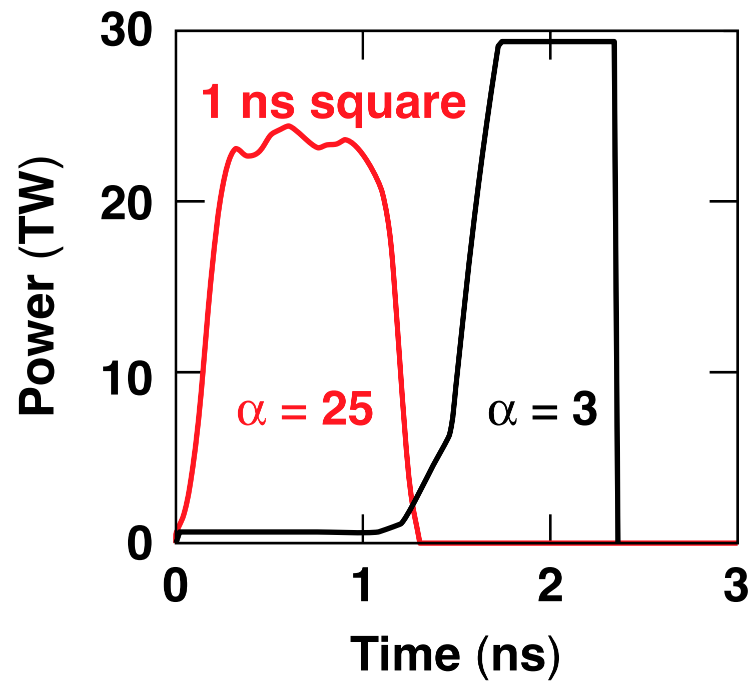
TC5144a

*Goncharov et al., Phys. Plasma 7, 5118 (2000).

Current OMEGA cryogenic targets use D_2-ice layers

- CH thickness ~ 3 μm (design goal: 1 μm)
- Ice roughness ~ 9 μm (design goal: 1 μm)

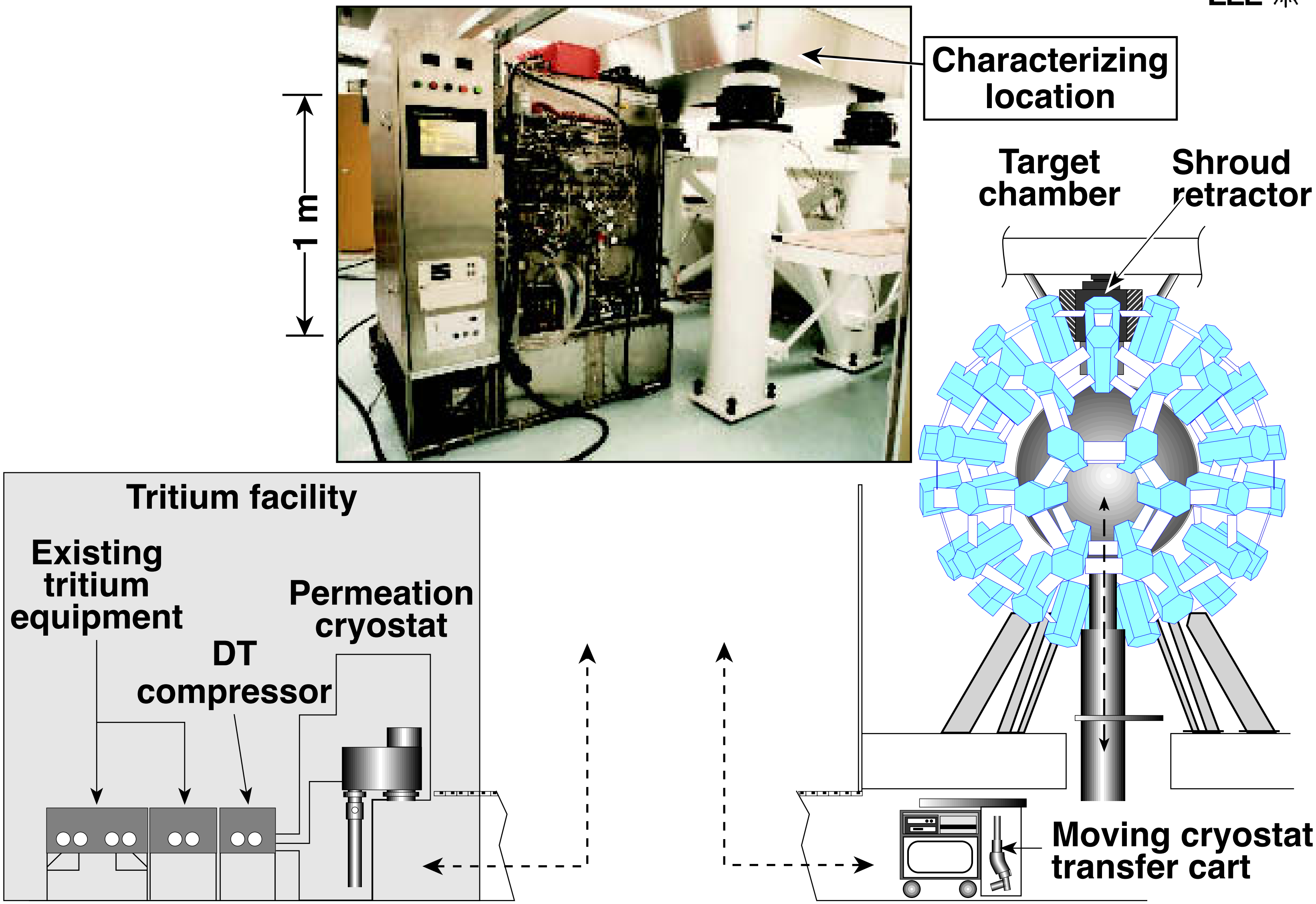




Laser energy	24 kJ
Pulse shape	$\alpha = 25$
Yield	1×10^{11}
ρR_{peak}	43 mg/cm^2
$\langle T_i \rangle_n$	2.1 keV
Hot-spot CR	10
Peak IFAR	40

E11271

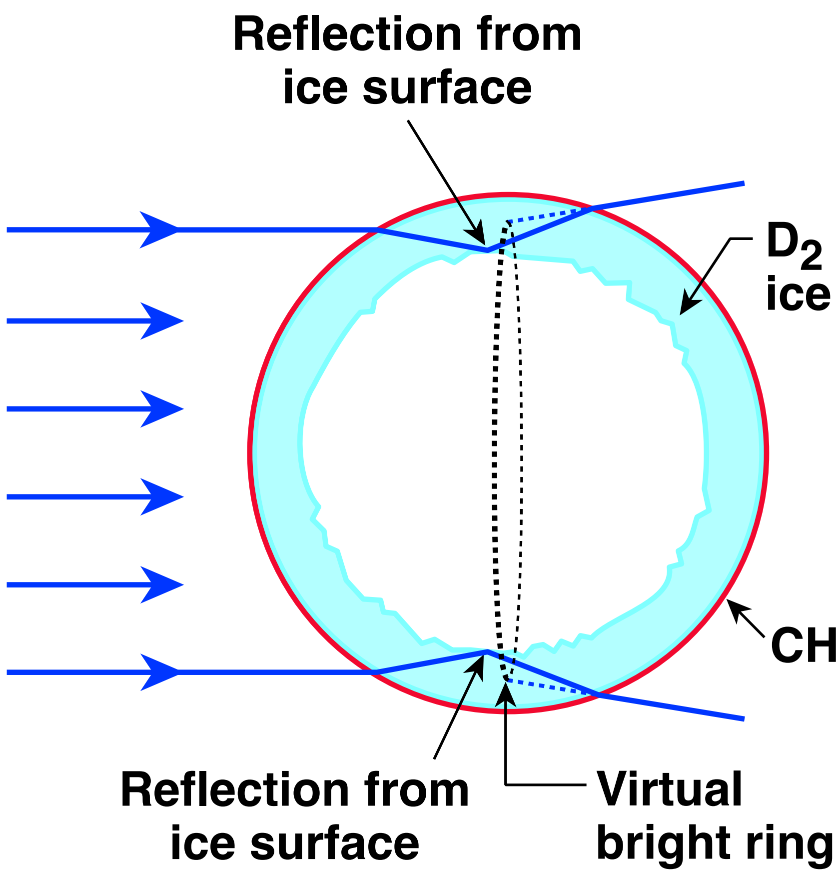
The targets must be transported, layered, characterized, and shot at temperatures below 18.7 K



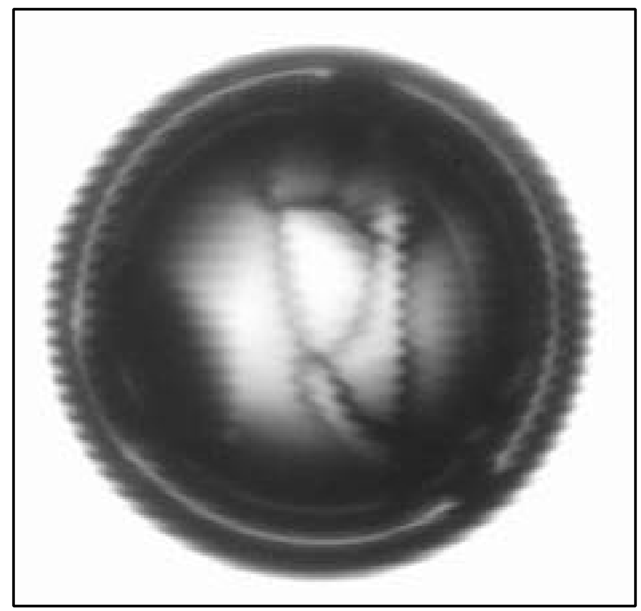
E11252

D. Harding et al., KO2.006

The layered cryogenic targets are characterized using a shadow graphic technique

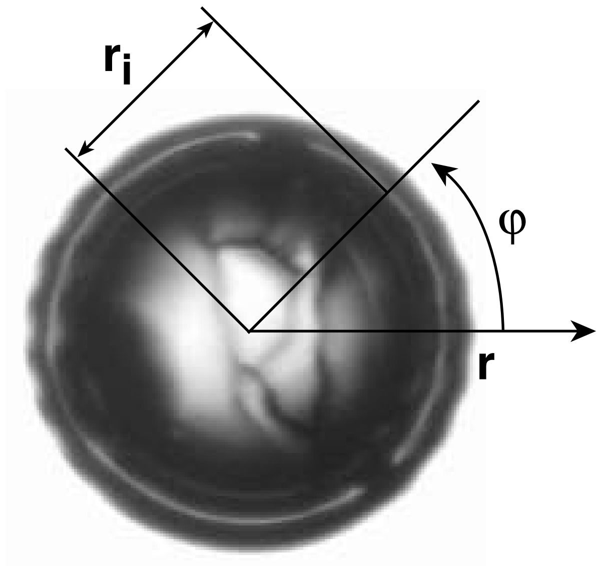


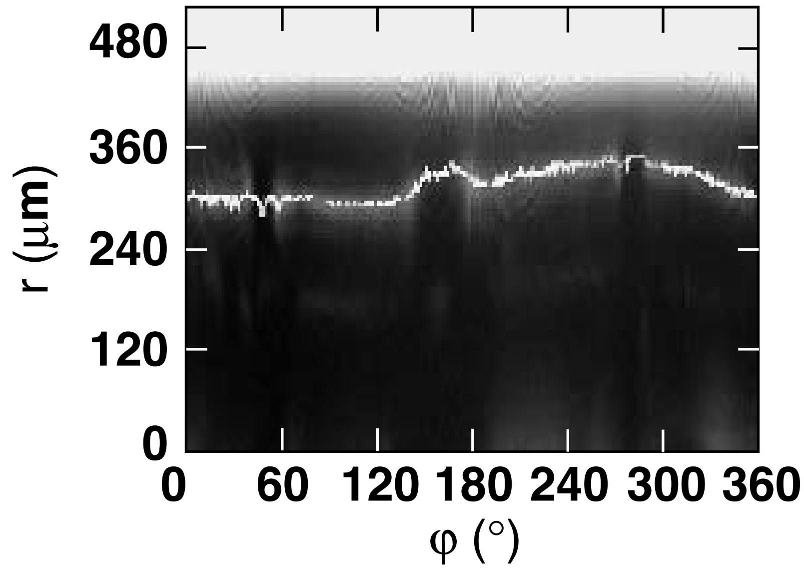
Shadowgram of 3-μm-wall CH target with 100-μm-thick D_2 ice

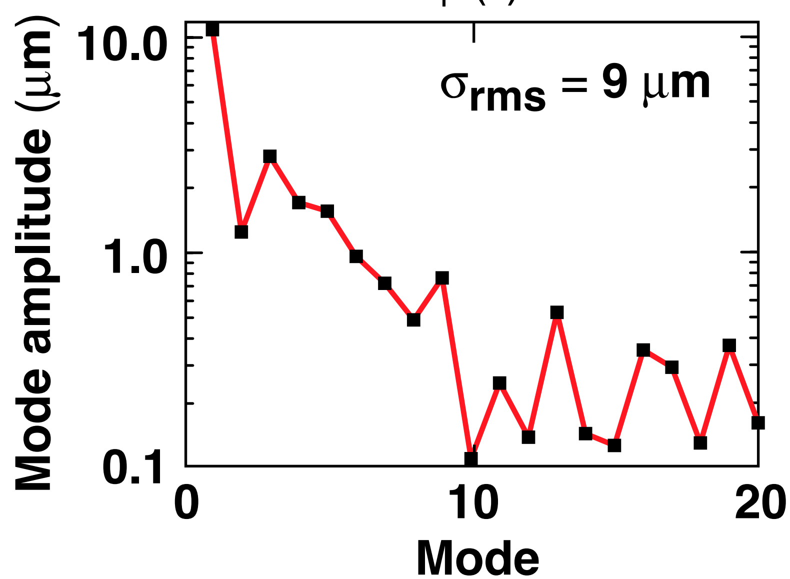


D. Harding et al., KO2.006

The nonuniformity spectrum of the inner ice surface is obtained by unfolding the shadowgraphic image







- The targets used in the experiments were characterized with only one view.
- Multiple views are necessary to accurately map the inner-ice-layer nonuniformities.

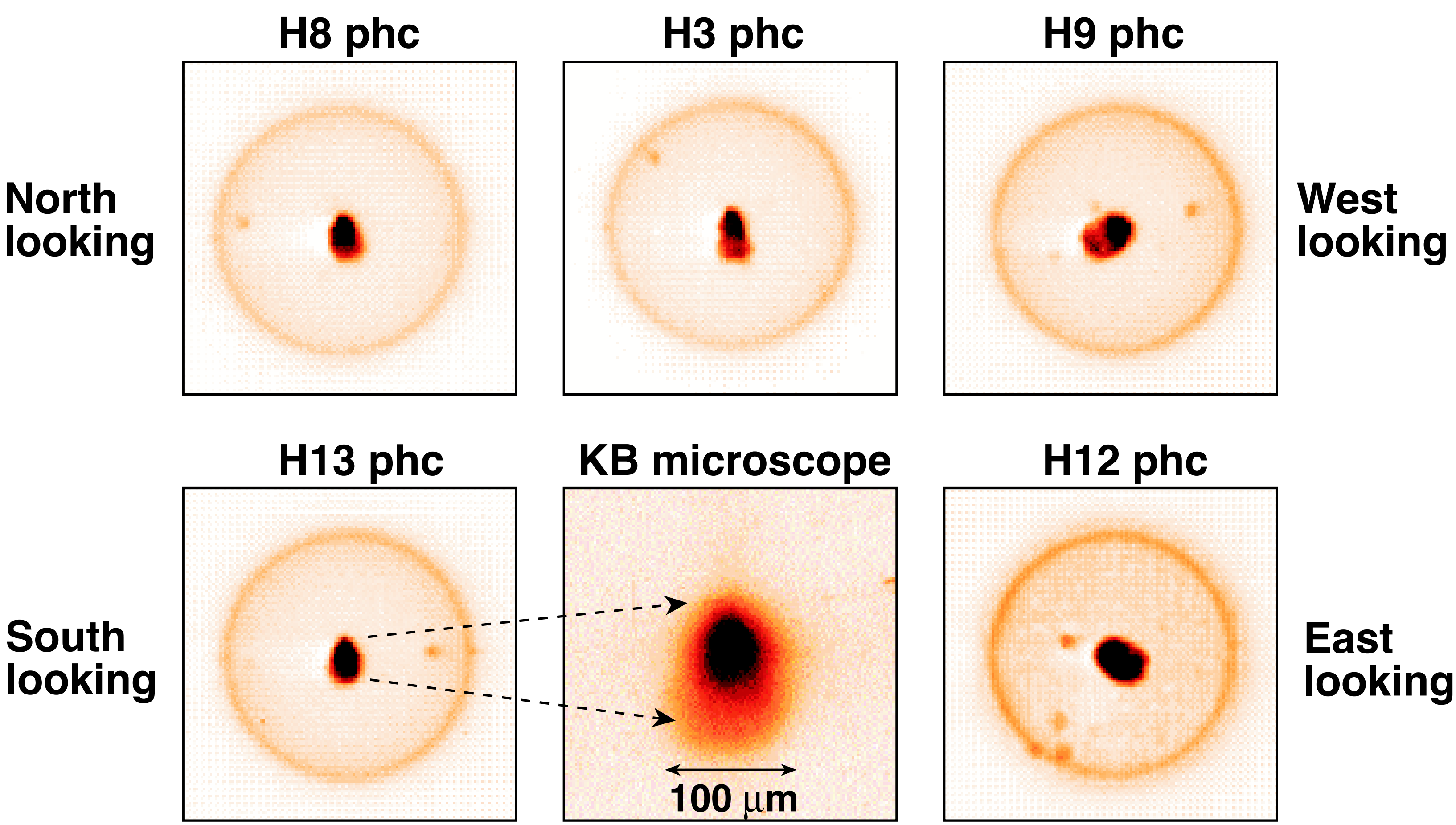
E11247

Multiple views of the target are obtained with static x-ray pinhole cameras and KB microscopes

UR LLE

Shot 24089

σ_{rms} = 19 μm, 16% YOC

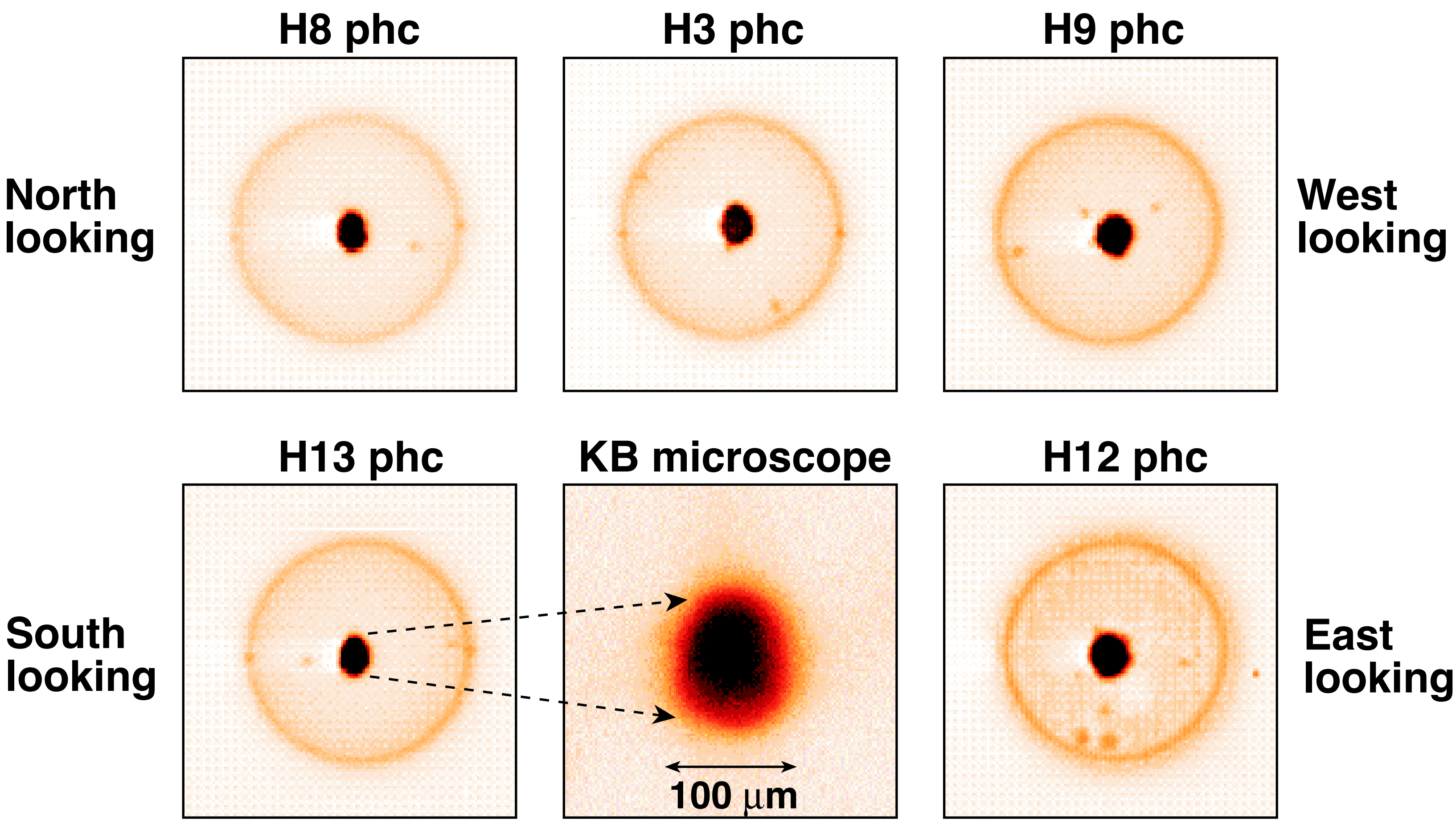


E11288

Multiple views of the target are obtained with static x-ray pinhole cameras and KB microscopes

Shot 24096

σ_{rms} = 9 μm, 30% YOC



E11289

The performance of the target depends on the inner ice surface nonuniformity

Shot 24089

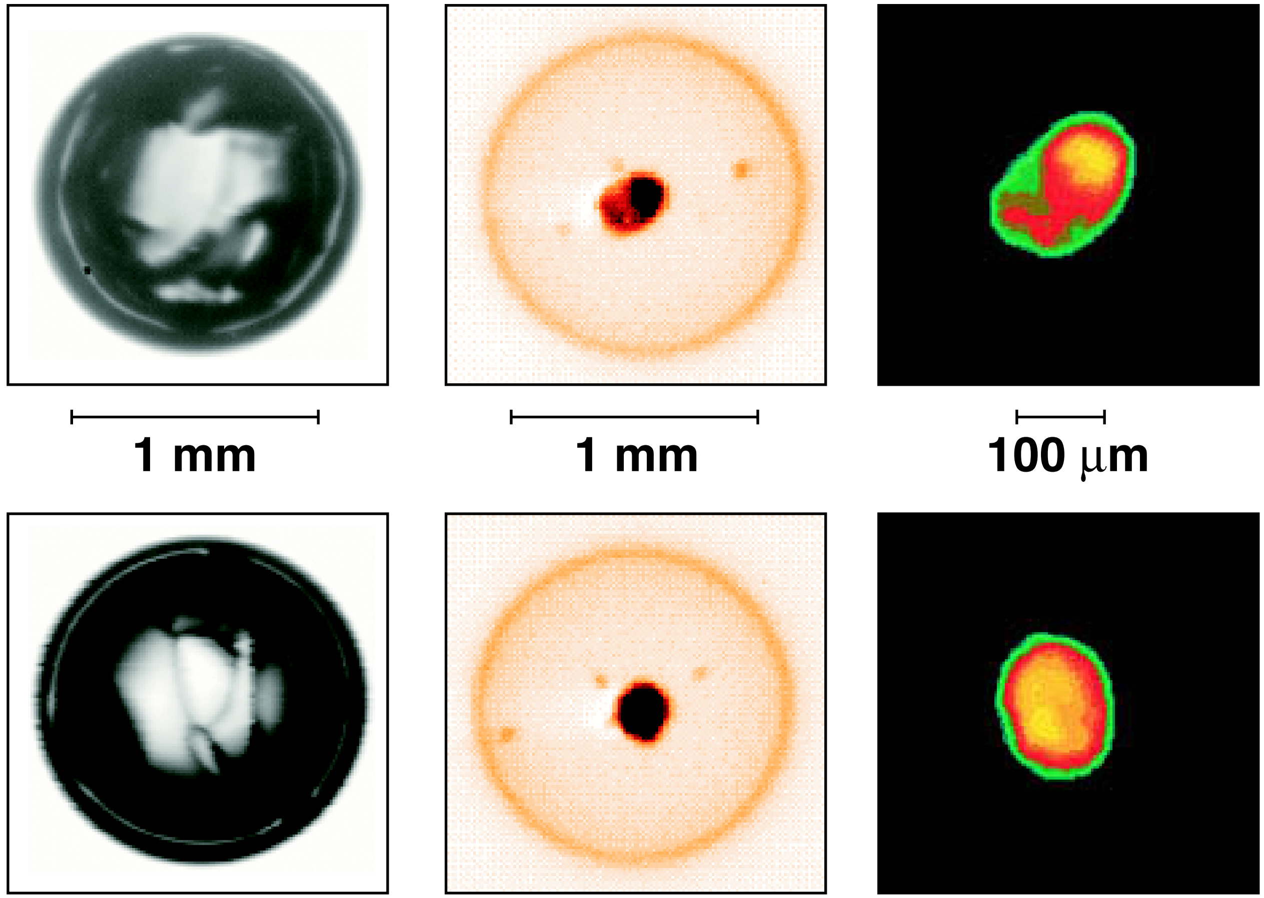
σ_{rms} = 19 μm

YOC = 16%

Shot 24096

σ_{rms} = 9 μm

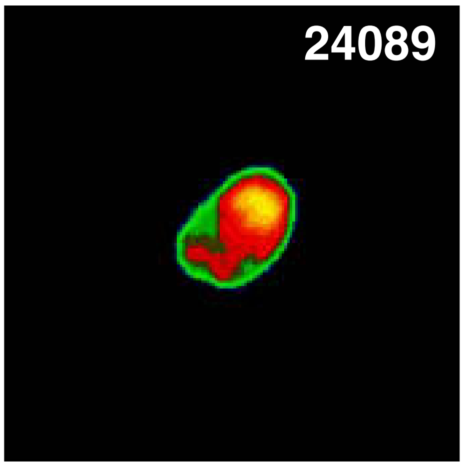
YOC = 30%

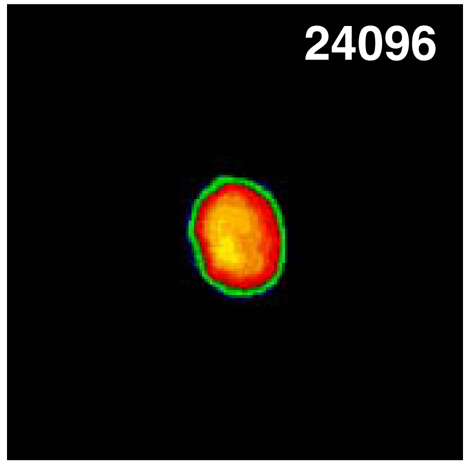


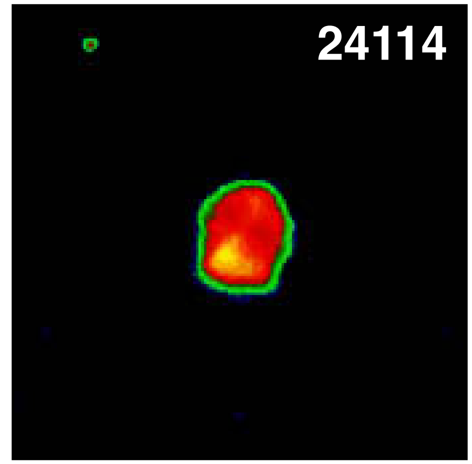
Target shadowgram | **Time-integrated x-ray pinhole camera image** | **X-ray framing camera snapshot**

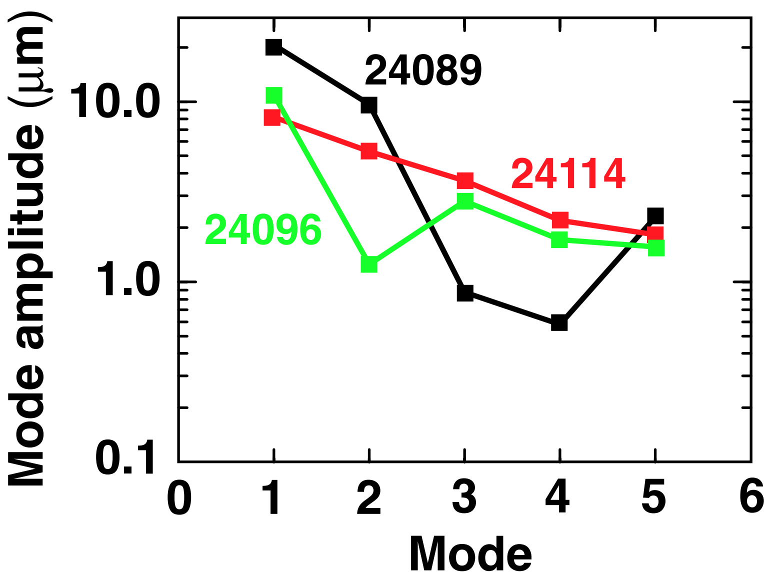
E11249

The mode structure of the inner ice surface translates into the shape of the compressed core





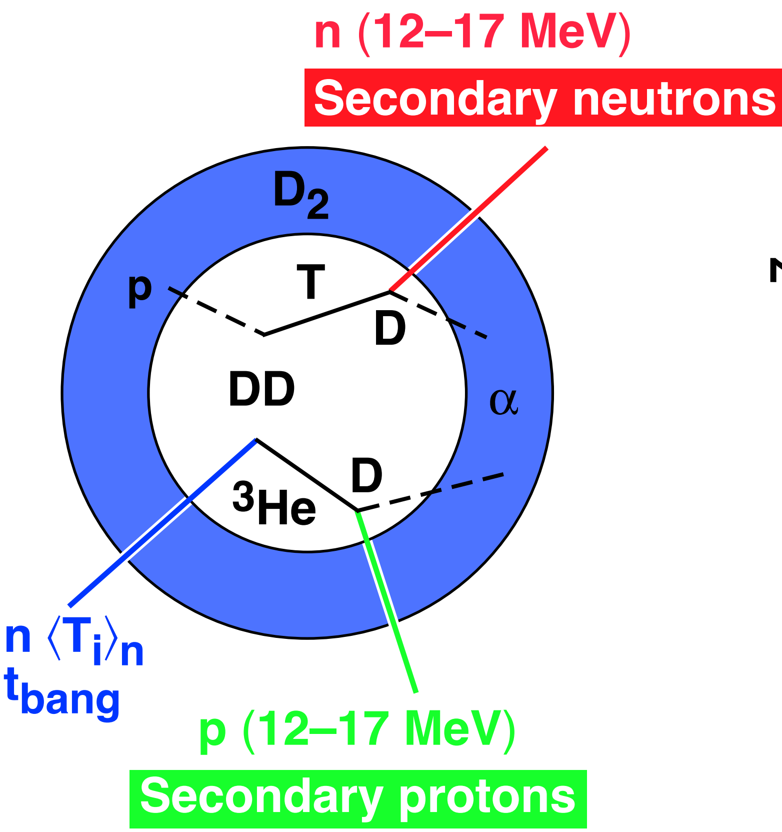


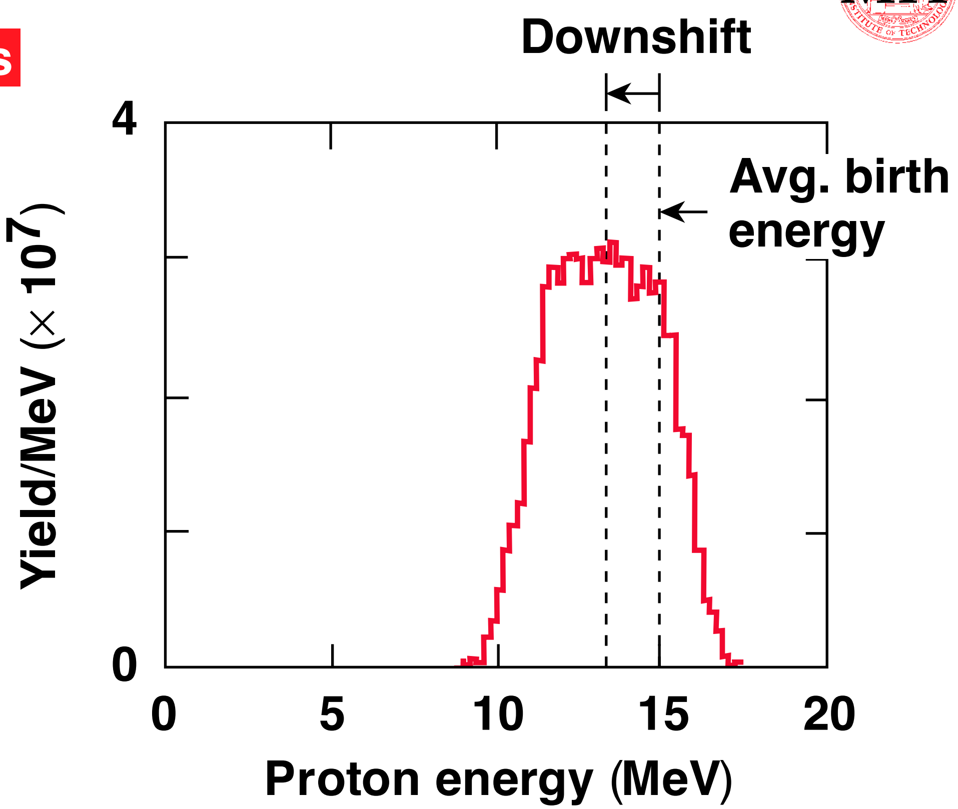


- Shot 24089
  σ_{rms} = 19 μm, 16% YOC
- Shot 24096
  σ_{rms} = 9 μm, 30% YOC
- Shot 24114
  σ_{rms} = 9 μm, 20% YOC

E11313

High-energy particles from primary and secondary nuclear reactions are used to diagnose the compressed core





- The downshift of the secondary proton spectrum provides information on the total ρR.

E11314

Ref: F. H. Séguin et al. (submitted to Physics of Plasma)

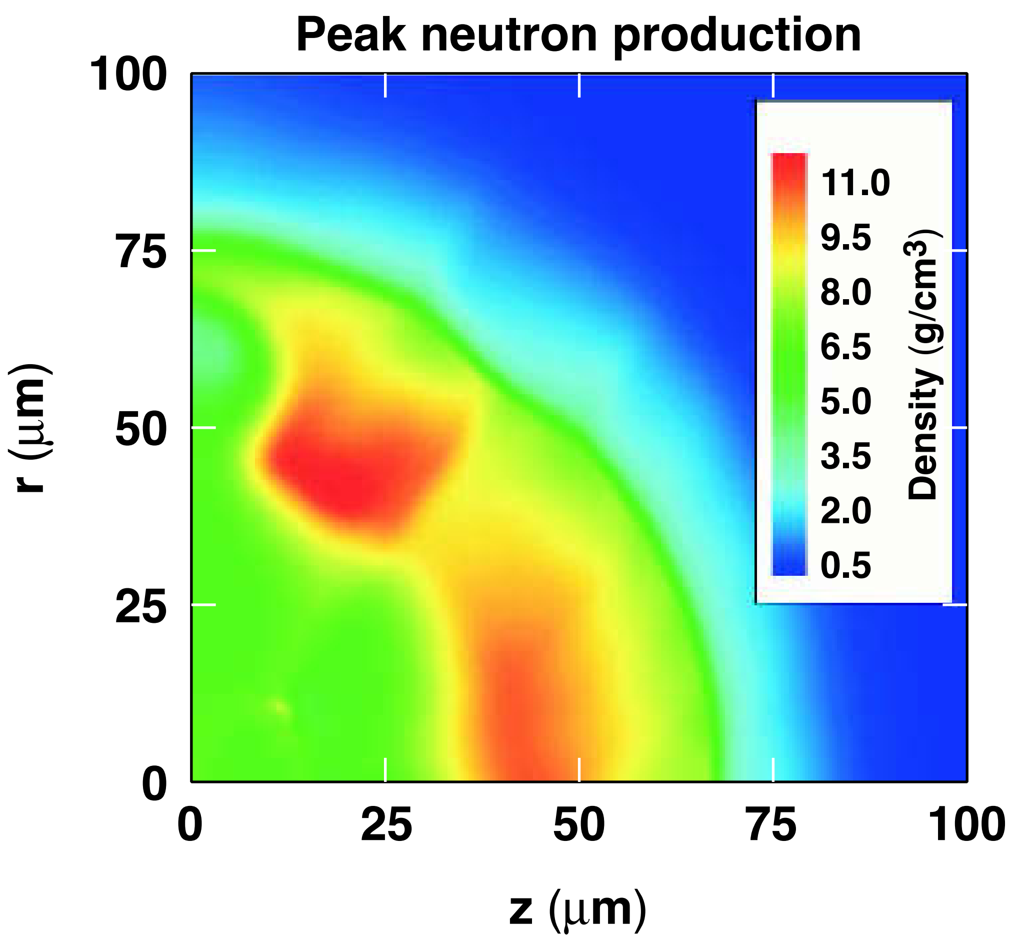
Neutron and particle diagnostics are used to measure yields, ion temperature, and areal density

	1-D	24089	24096
Roughness (μm)		19	9
Neutron yield	1.0×10^{11}	$(1.26 \pm 0.1) \times 10^{10}$	$(3.5 \pm 0.1) \times 10^{10}$
Bang time (ns)	1.8	1.8±0.1	1.7±0.1
$\langle T_i \rangle_n$ (keV)	2.1	2.9±0.5	3.5±0.5
Y_{2p}/Y_n	1.2×10^{-3}	$(0.6 \pm 0.1) \times 10^{-3}$	$(0.8 \pm 0.1) \times 10^{-3}$
Y_{2n}/Y_n	9.0×10^{-3}	$(8.0 \pm 0.4) \times 10^{-3}$	$(9.0 \pm 0.5) \times 10^{-3}$
ρR_{hot} (mg/cm^2)	>10	5±1	7±1
ρR_{total} (mg/cm^2)	40	20 - 30 - 58	12 - 25 - 38

E11272

F. Seguin et al., FO2.004

2-D DRACO calculations using the measured inner ice roughness are in progress

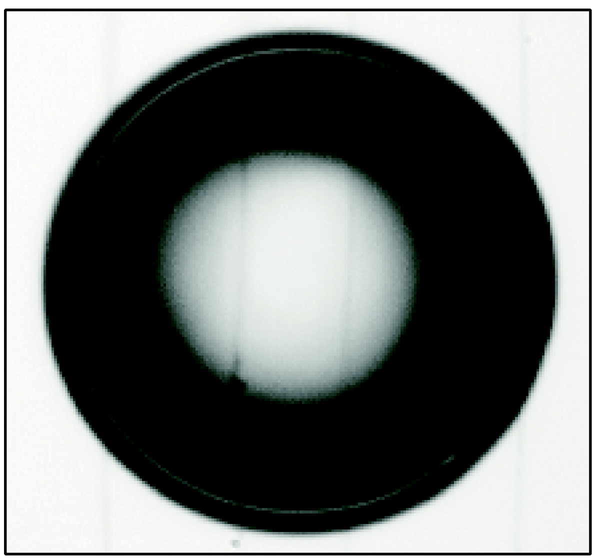


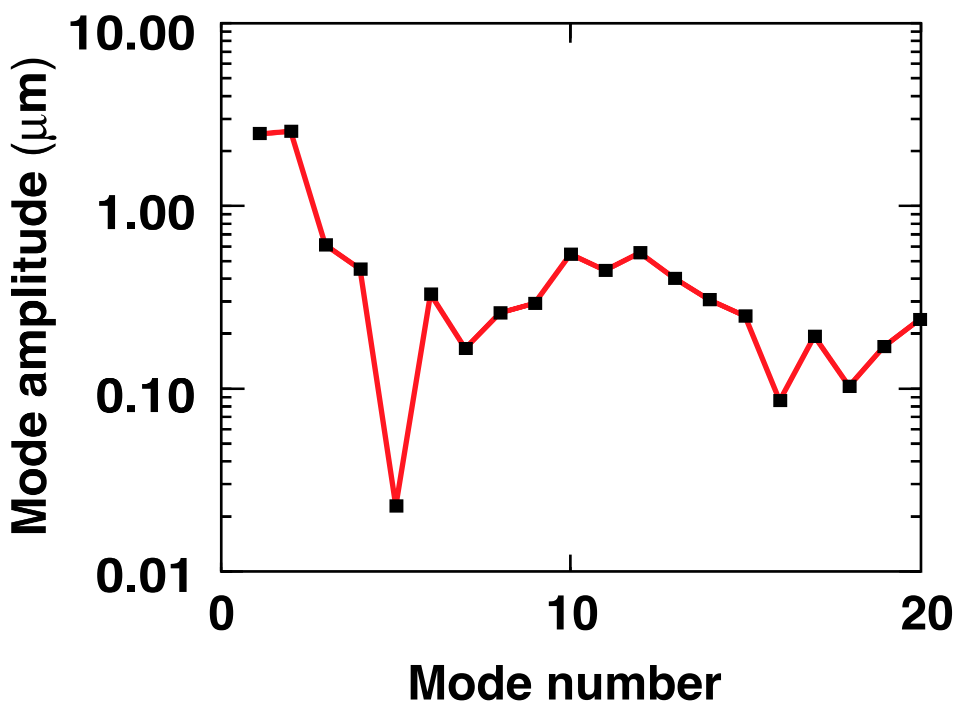
- 1-ns square incident on a 100-μm D_2 ice layer with an 9-μm rms inner ice roughness ($\ell < 30$) gave
  - 60% of 1-D yield and
  - 80% of 1-D areal density.
- Effects of power balance and imprint will be modeled.

TC5728a

Recent layering studies have produced D_2 layers with a inner-ice-surface nonuniformity of ~ 3 μm rms

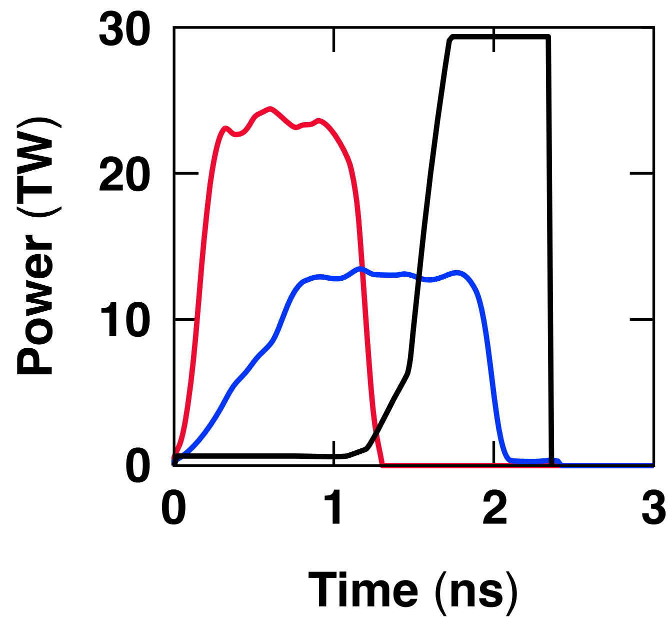
- The first cryogenic campaign had ice layers with σ_{rms} ~ 9 μm.
- Layering studies performed after the experimental campaign have shown improved layer quality.
- The design goal is $\sigma_{rms} < 1$ μm ($\ell \leqslant 50$).

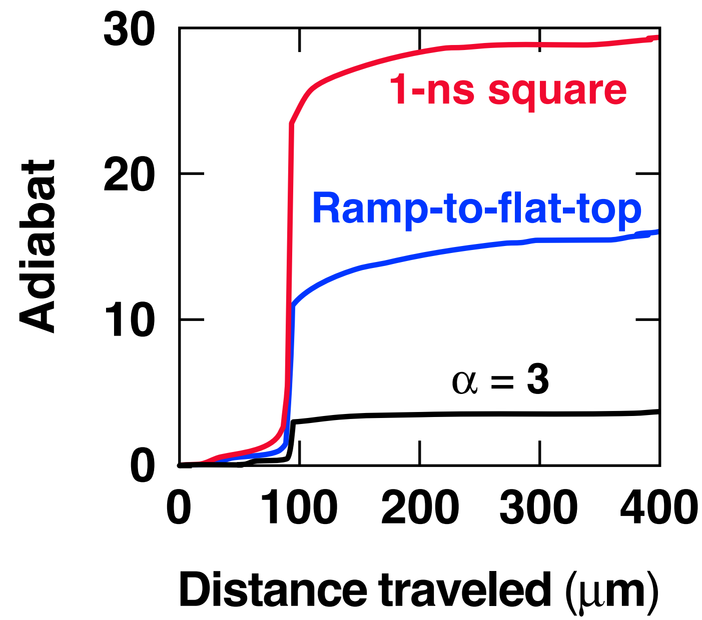




E11253

Near term cryogenic experiments with D_2 ice layers will use lower-adiabat laser pulses





Pulse	Energy ⟨kJ⟩	ρR_{peak} (mg/cm^2)	D_2 yield	Hot spot CR
1-ns square	24	40	1.0×10^{11}	10
Ramp-to-flat	18	60	1.2×10^{11}	11
$\alpha = 3$	30	210	8.8×10^{11}	20

TC5714a

Summary/Conclusion

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- Five thin-walled (~ 3 μm CH) cryogenic targets with an ice layer of 80 to 100 μm (three of them adequately characterized) have been shot during a two-week campaign.
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