Direct-Drive Cryogenic Target Implosion Performance on OMEGA

Shot 28900		Shot 26477	
Experimental (α~25)	YOC	Experimental (α~25)	YOC
Yield (1n): 1.27×10^{11}	96%	Yield (1n): 3.17×10^{10}	31%
TCC offset: 14±7 μm		85 μm	

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44th Annual Meeting of the
American Physical Society
Division of Plasma Physics
Orlando, FL
11–15 November 2002

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Summary

High-performance, direct-drive cryogenic D_2 implosions are becoming routine on the LLE OMEGA laser

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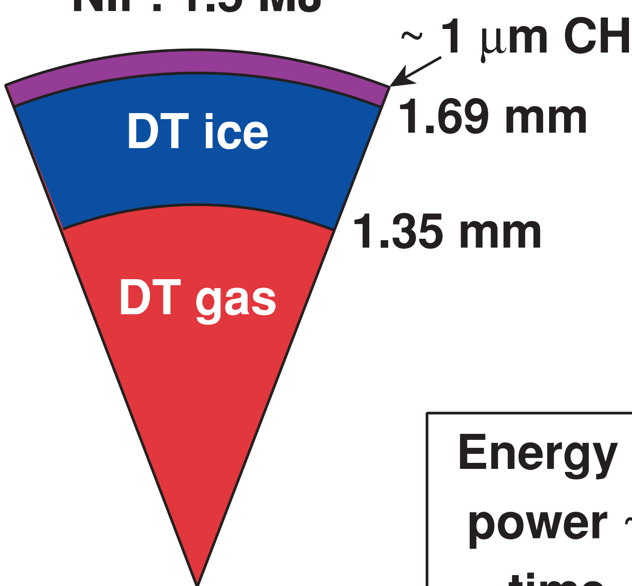
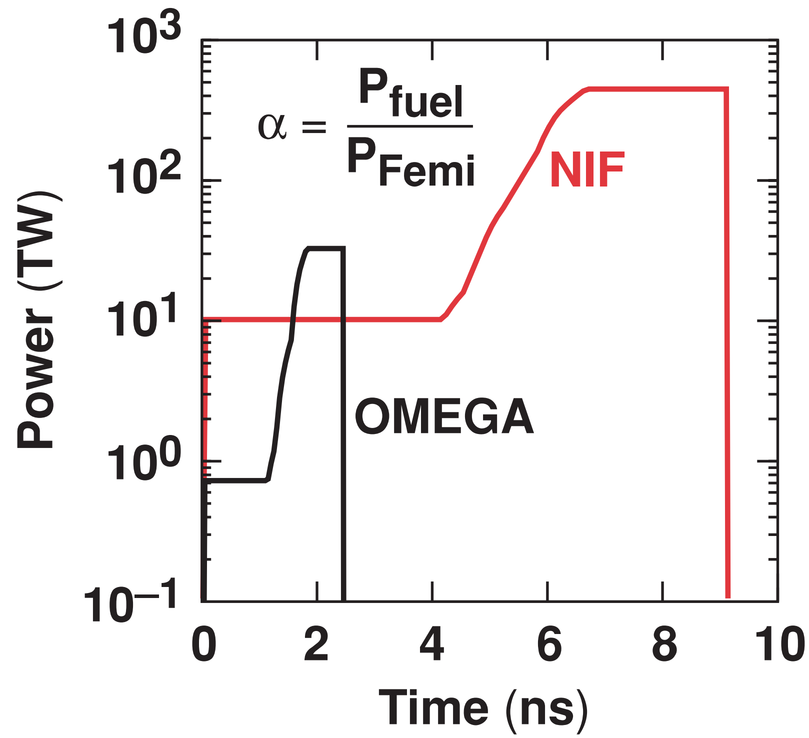
- Near-1D performance has been measured for high-adiabat (α ~ 25) drives.
- Performance for low-adiabat (α ~4) pulses is very close to 2-D *DRACO* predictions.
- The cryogenic $\langle\rho R\rangle$ is approximately two times higher for low-adiabat (α ~4) than for high-adiabat (α ~25) pulses.
- Performance improves significantly with increasing ice smoothness.
- Layering and characterization of cryogenic capsules are now routine; layer quality can be preserved well below the triple point.

OMEGA cryogenic targets are energy scaled from the NIF direct-drive point design

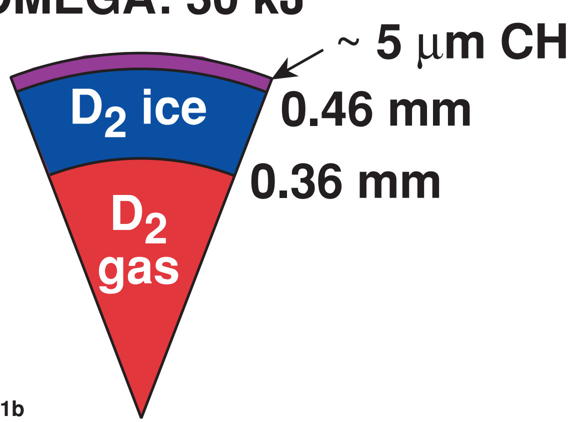
NIF: 1.5 MJ



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



OMEGA: 30 kJ



This "standard" capsule was developed to
- improve production reliability
- increase absorption

The baseline direct-drive capsule will ignite with an α~4 drive pulse.

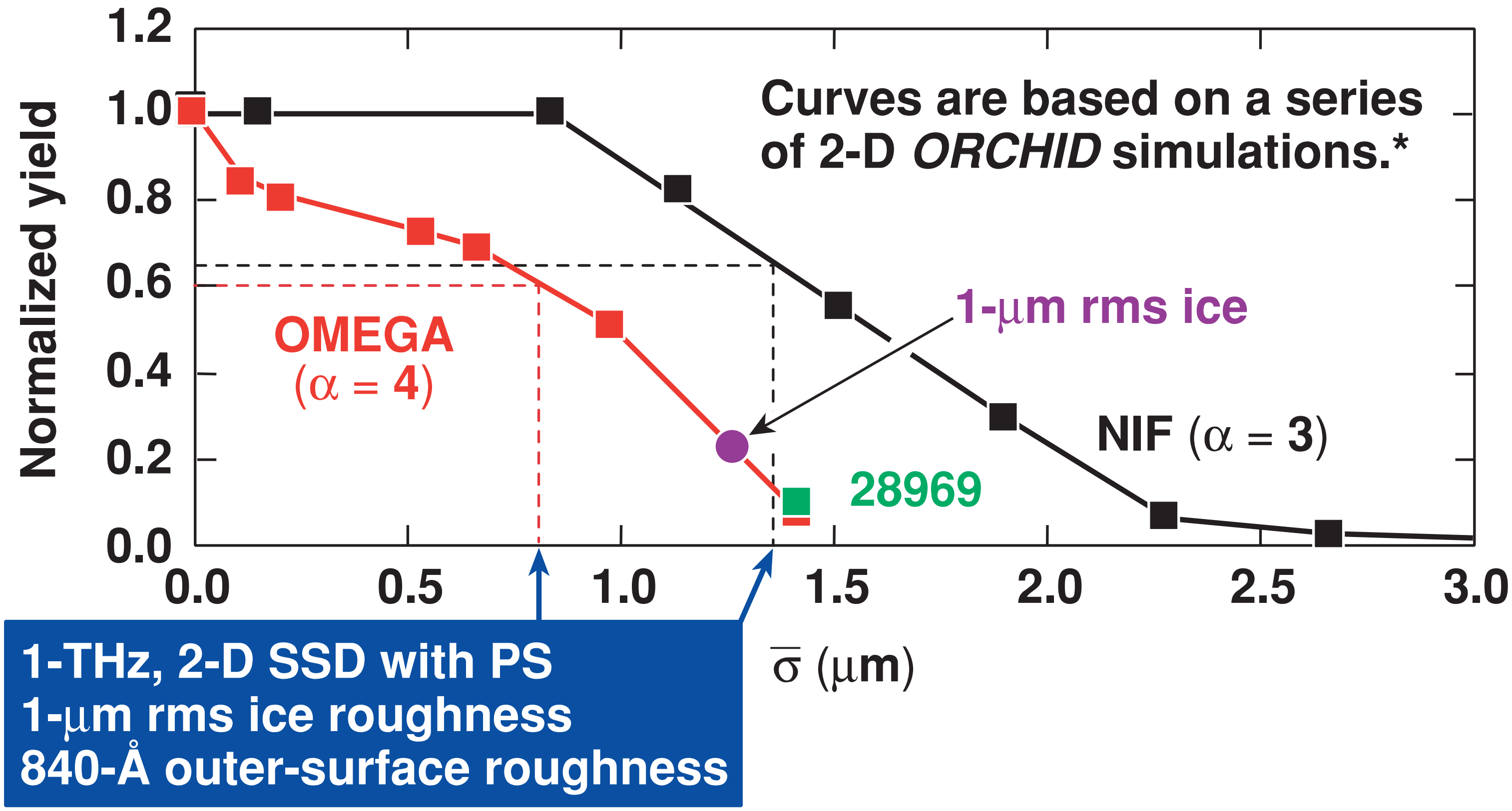
E11251b

A stability analysis* of the α = 4 design defines the ignition scaling performance window for cryogenic implosions

- **The NIF gain* and OMEGA yield can be related by**

$$\bar{\sigma}^2 = 0.06\,\sigma^2_{\ell<10} + \sigma^2_{\ell\geq 10},$$

where the σ_ℓ are the rms amplitudes at the end of the acceleration phase.



E12008

* P. McKenty *et al.*, Phys. Plasma 8, 2315 (2001).

Operational issues have been identified largely through analysis of implosion performance

- Target fabrication and filling
- Layering and characterization
- Moving cryostat reliability (MCTC)
- Layer stability prior to the shot
  (V. Yu. Glebov, GO2.012)
- Target alignment
  (J. M. Soures, GO2.005, and P. W. McKenty, GO2.008)
- Beam pointing and power balance
  (F. J. Marshall, GO2.007)
- Pulse shaping
  (V. N. Goncharov, RI1.004)

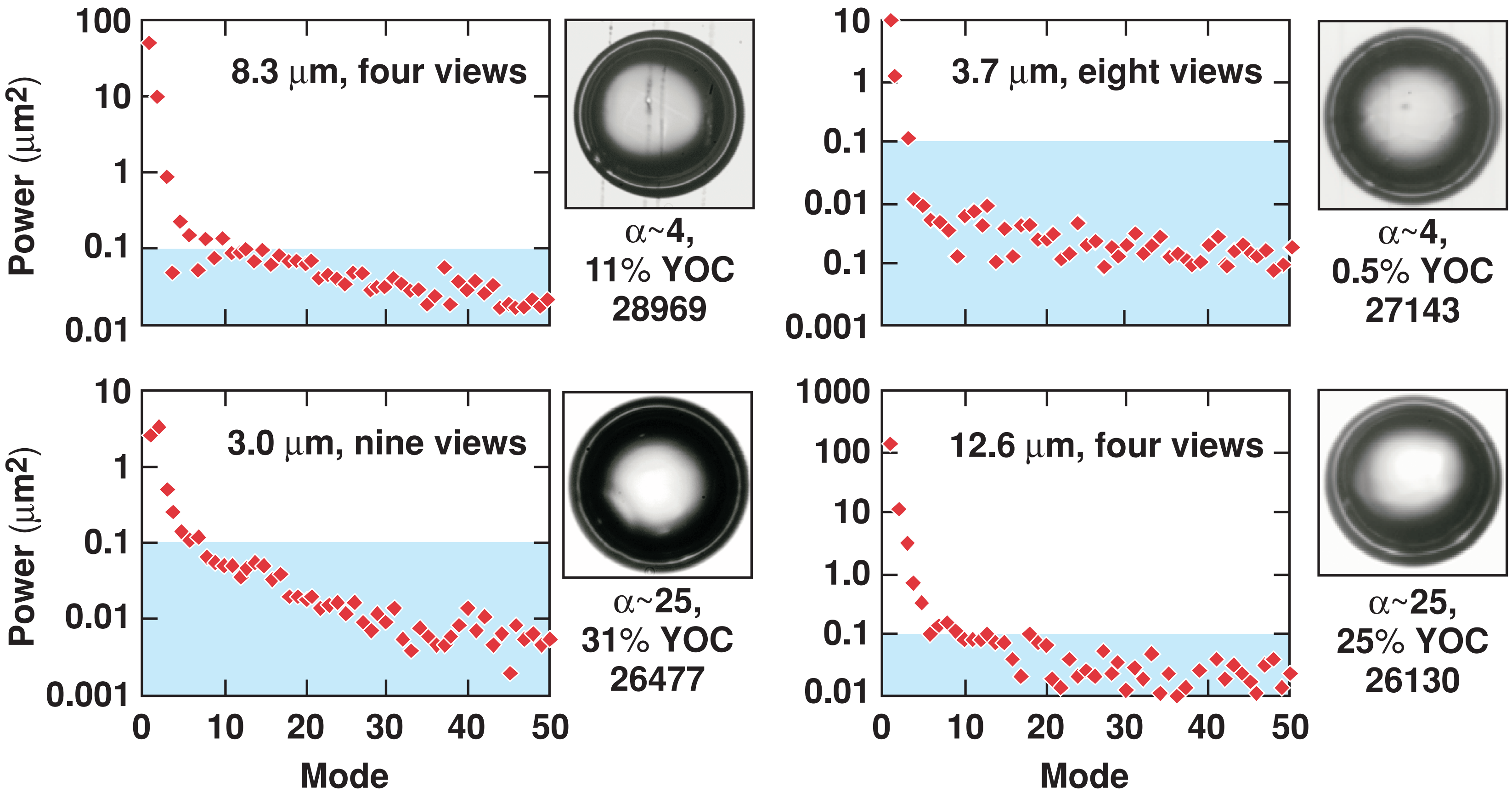
Cryogenic implosions to date (July 01 to October 02):

- 1-ns square (16 shots)
- α~4 (9 shots)
- α~4 with picket (December/January)

25

E12009

The Cryogenic Target Fabrication Group routinely delivers well-layered and fully characterized capsules



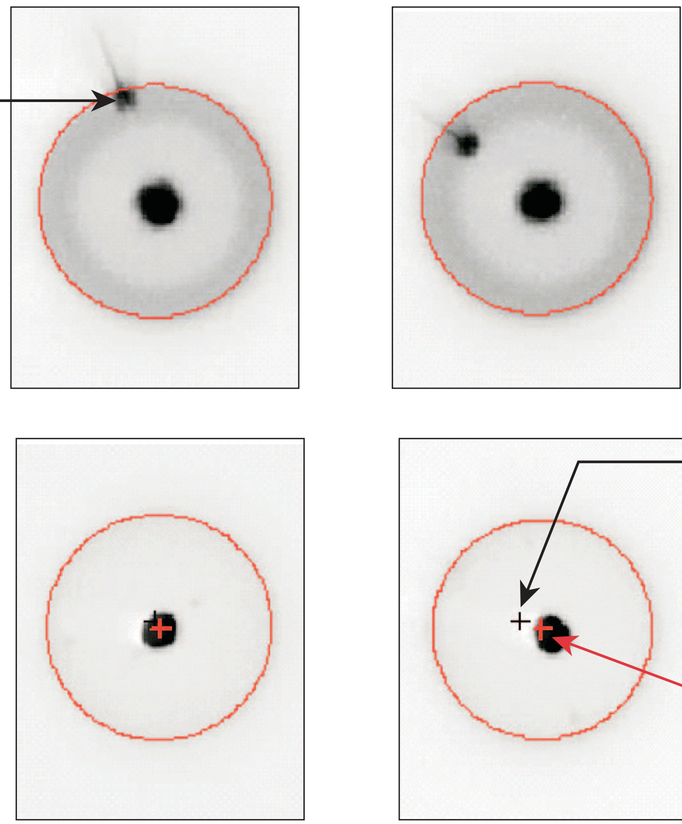
E12010

Analysis of PHC images showed a 60- to 120-μm systematic offset from TCC at the start of the laser pulse

H9 view H3 view

Shot 26479
(stalk mount)

Shot 26477
(cryo)



Measured offset:
d = 85 μm
(θ, ϕ) = 99°, 251°

TCC defined by stalk-mounted images above

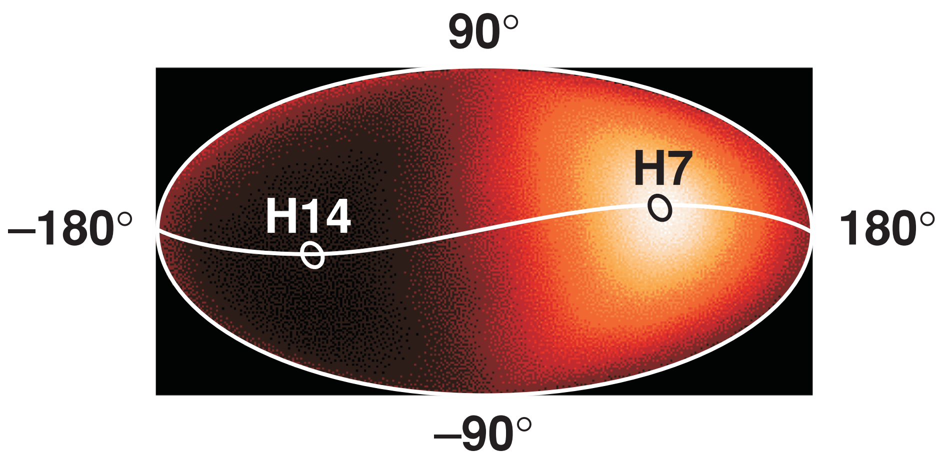
Cryo capsule center at T_0

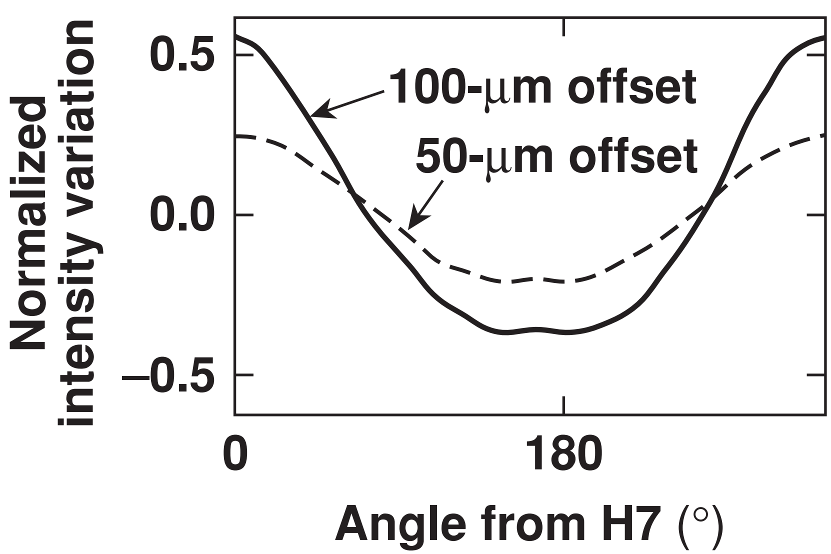
Note further core offset.

The offset is computed as the average of up to five PHC views on each shot, reducing the errors significantly.

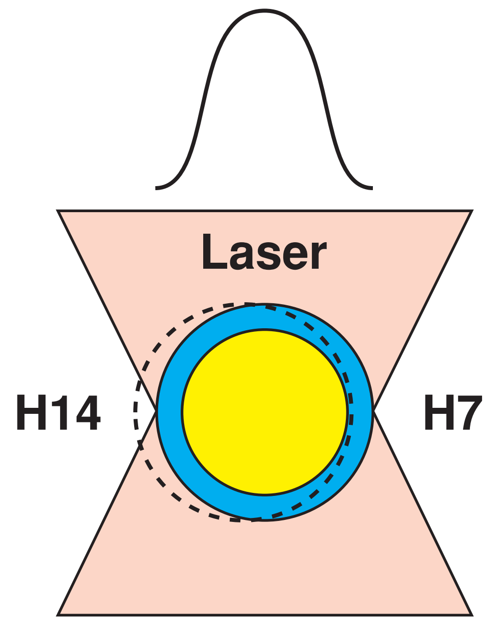
Misplacing a capsule from TCC introduces a large peak-to-valley intensity variation on the capsule surface

Aitoff projection of intensity variation





Intensity profile is an order 2.2 super-Gaussian

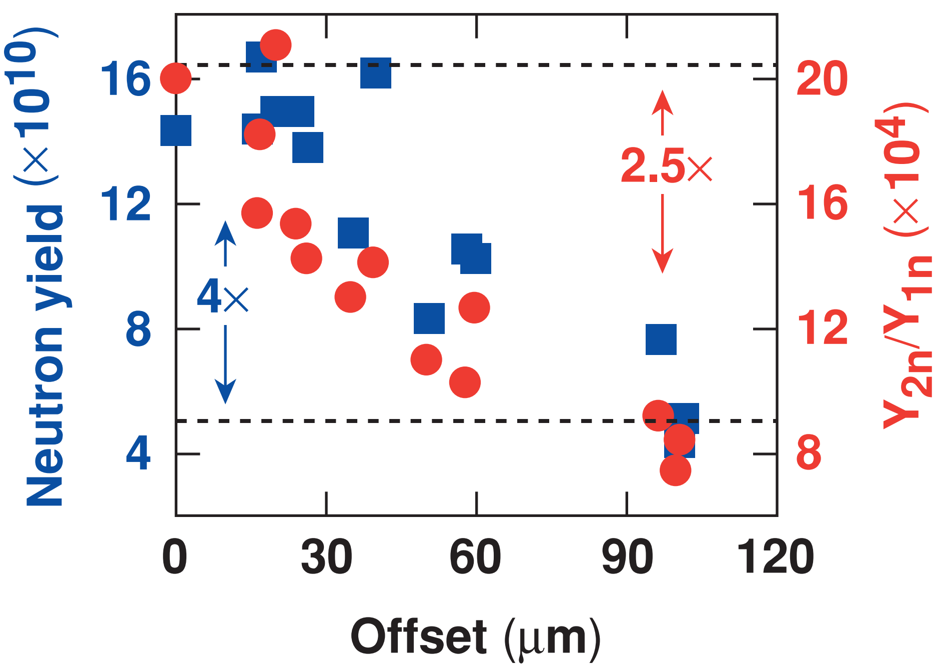


Related talks:
F. J. Marshall, GO2.007
J. M. Soures, GO2.005
P. W. McKenty, GO2.008

Deliberate TCC offsets have a significant impact on implosion performance using D_2-filled CH capsules

UR LLE

Neutron yields from D_2-filled, 20-μm CH capsules offset along the H7–H14 axis (J. M. Soures, GO2.005)



For cryogenic implosions:

Average offset prior to these experiments: 81 μm

"Smoking gun": sapphire windows (6) providing a view of the capsule

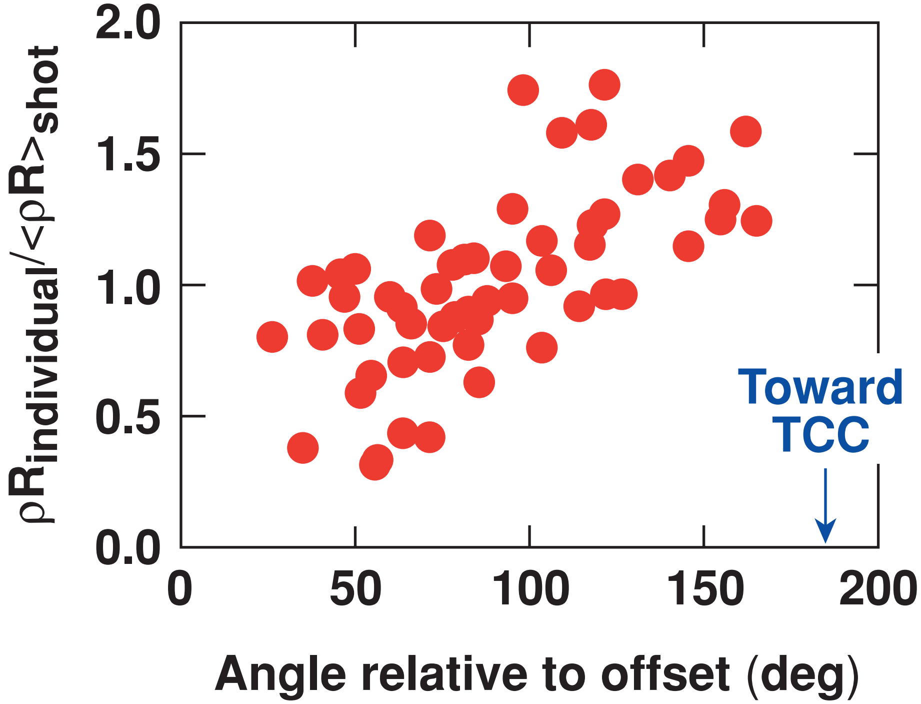
Average offset after re-engineering and cold calibration: 19 μm

Warm surrogate implosions showed that a systematic offset from TCC would likely explain the cryogenic implosion performance.

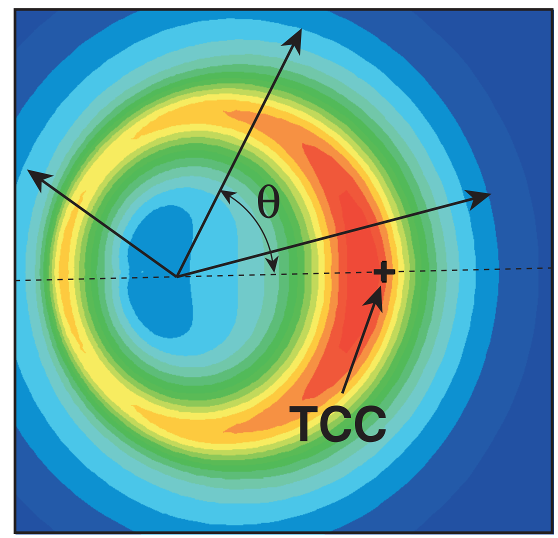
E12013

Individual cryo ρR measurements show the expected correlation with angle relative to the capsule offset

Fuel ρR is systematically higher on the side of the capsule toward TCC.



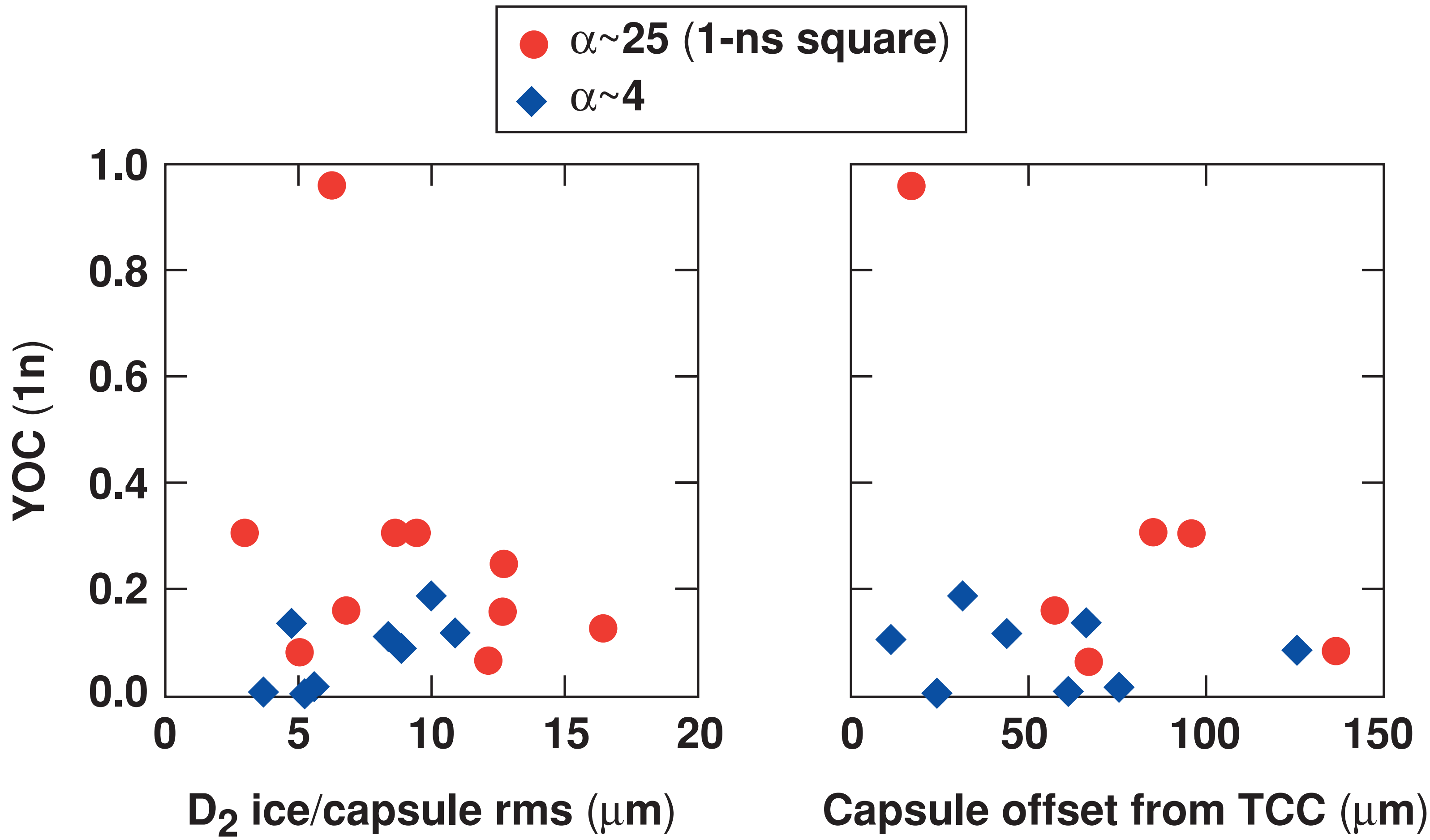
Density contours at peak burn from 2-D *DRACO* for a capsule offset by 50 μm with 1-μm-rms ice.



This "geometric" analysis gives us confidence that we can accurately measure the capsule offset and understand the resulting performance.

E12014

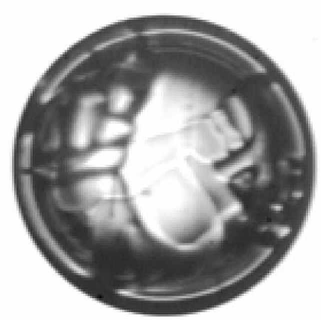
The primary neutron YOC shows a strong correlation with capsule TCC offset and D_2-ice-layer rms



Capsule performance with a low-adiabat drive pulse is more sensitive to ice roughness and target alignment than with the 1-ns (α~25) pulse.

E12015

A comparison of shots 28900 and 26477 clearly shows the result of accurate TCC alignment (with $\alpha \sim 25$)

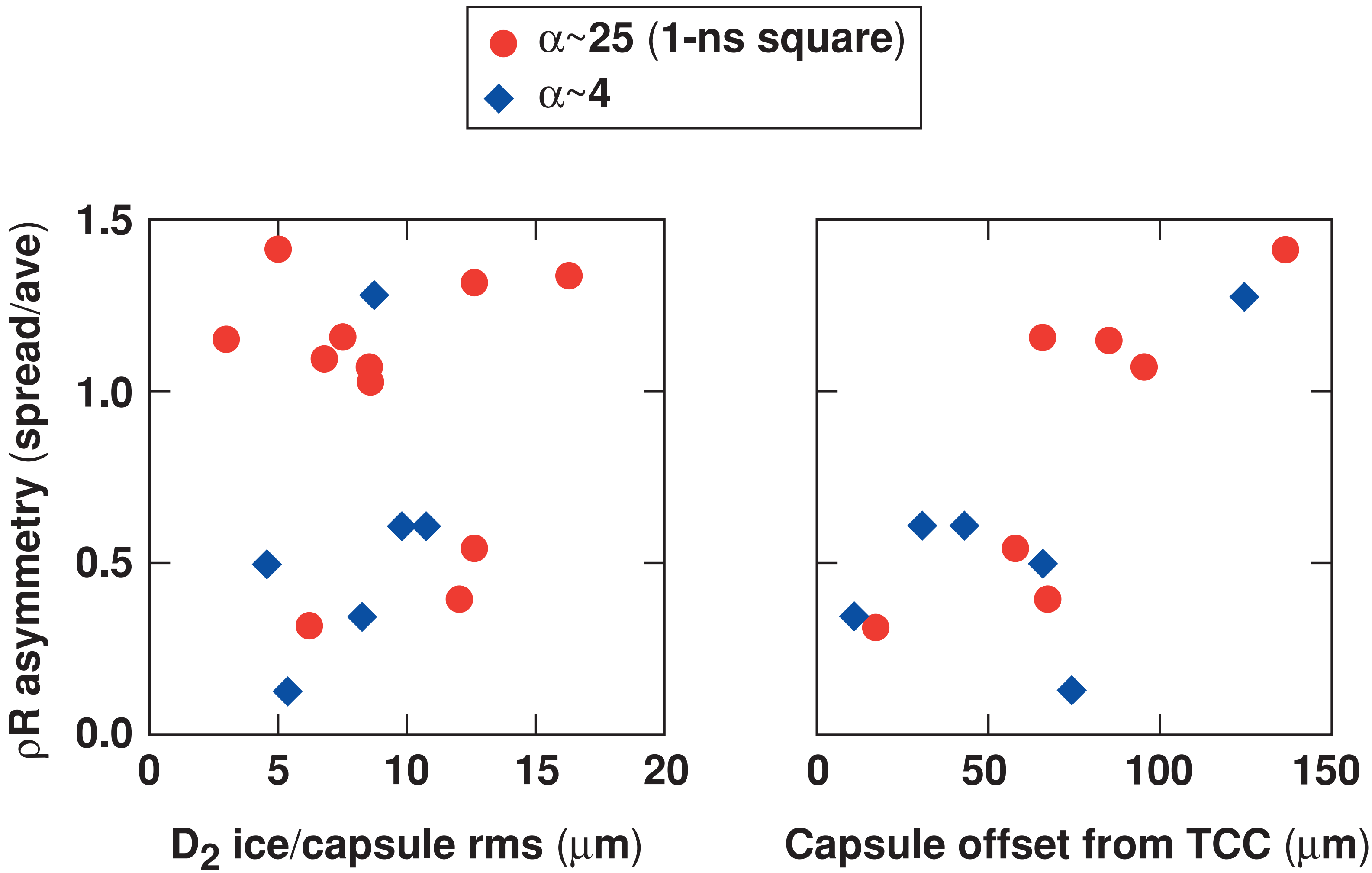


Drive pulse: 1ns ($\alpha \sim 25$)

	Shot 28900 Experimental	Clean 1-D (%)	Shot 26477 Experimental	Clean 1-D (%)
Yield (1n):	1.27×10^{11}	96	3.17×10^{10}	31
Yield (2n):	1.17×10^{9}	84	3.05×10^{8}	32
Yield (2p):	2.03×10^{8}	112	2.67×10^{7}	21
$\langle\rho R\rangle$:	61 mg/cm^2	133	30 mg/cm^2	80
T_{ion}:	3.6 keV	157	2.6 keV	117
Y_{2n}/Y_{1n}:	0.0092	85	0.0096	102
Y_{2p}/Y_{1n}:	0.0016	114	0.00084	66
TCC offset:	$14 \pm 7 \mu m$		85-μm	

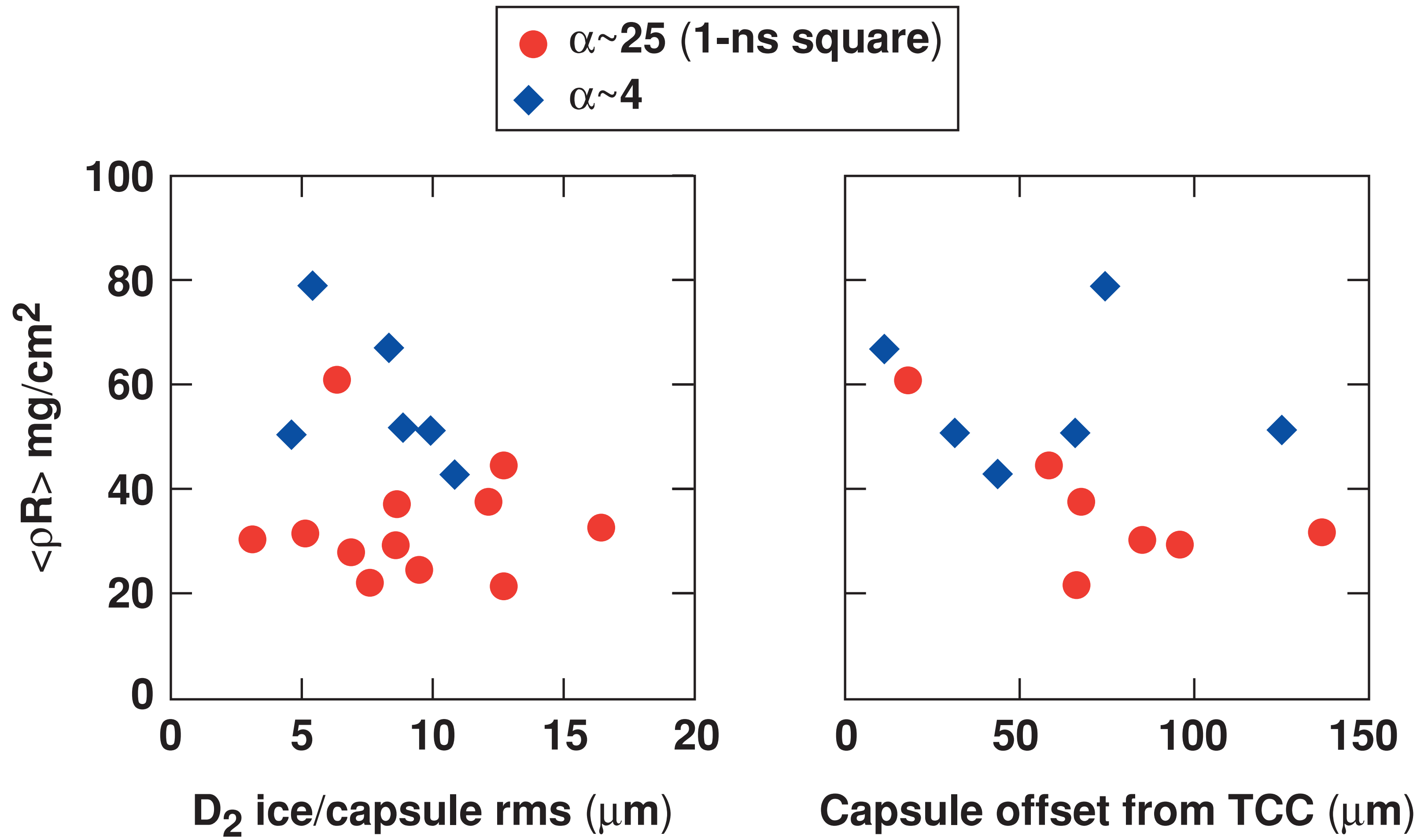
ρR asymmetry shows a strong correlation with capsule TCC offset but no correlation to ice smoothness

UR LLE



E12017

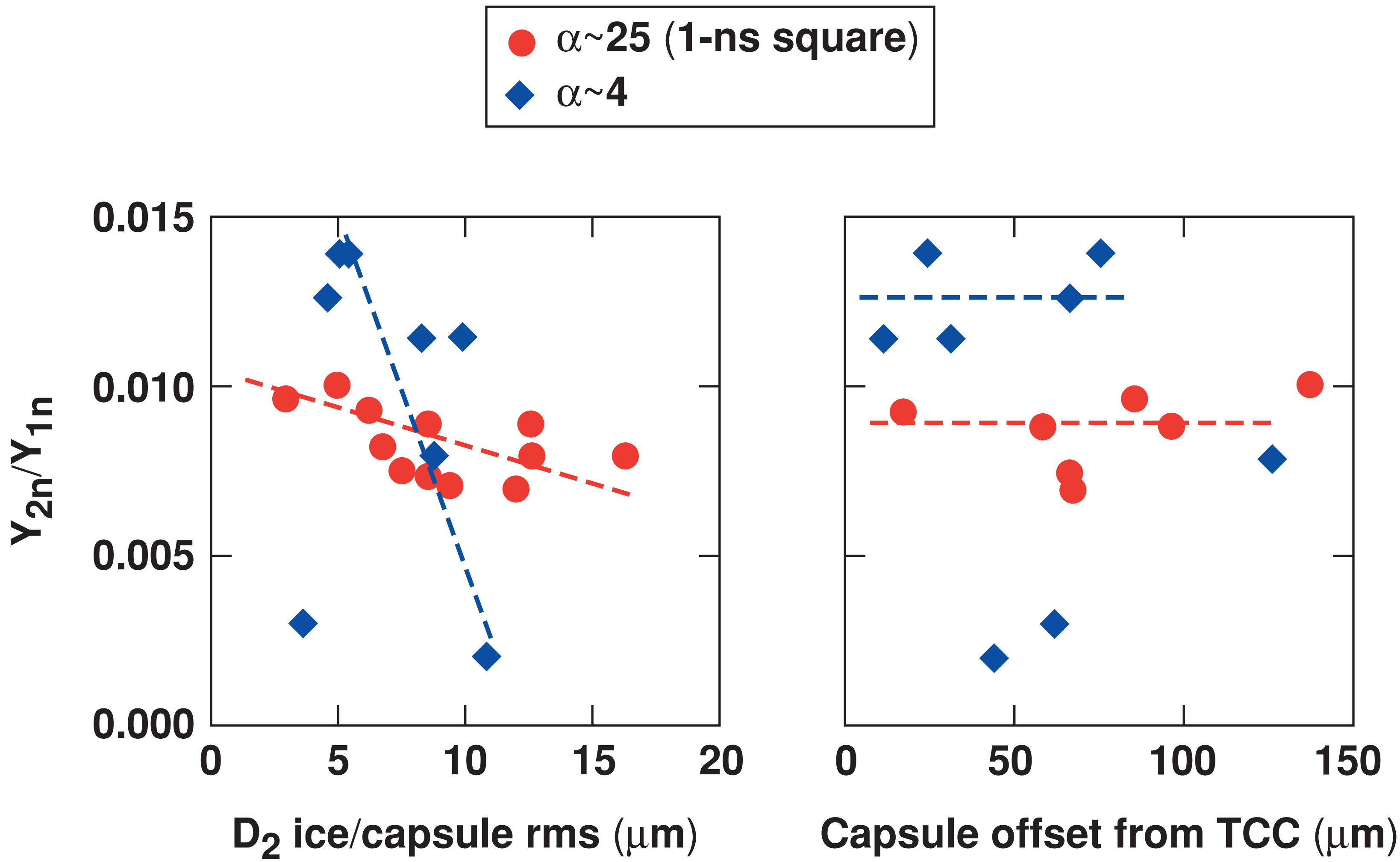
The <ρR> shows a strong correlation with capsule TCC offset but only low α shows a correlation with ice RMS



The maximum $\langle\rho R\rangle_n$ expected for α~4 implosions is ~140 mg/cm^2.

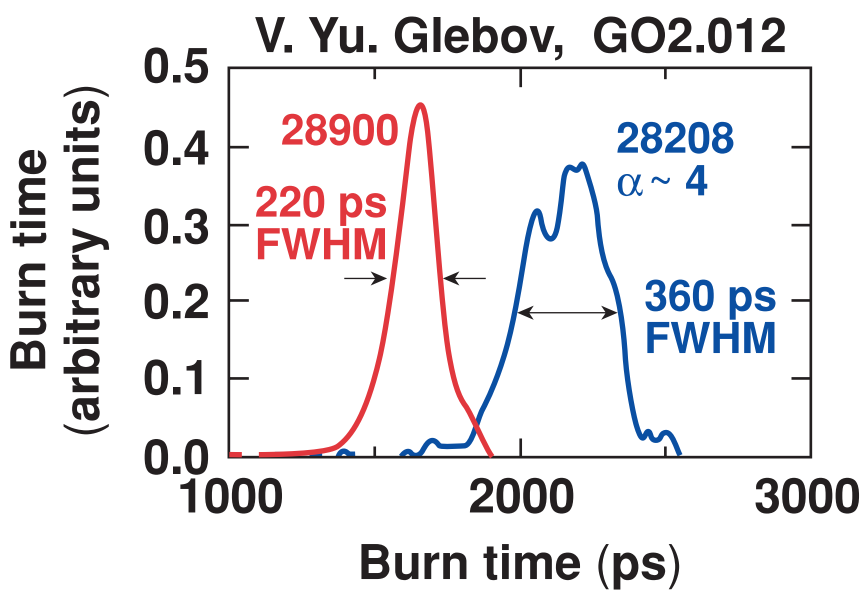
E12018

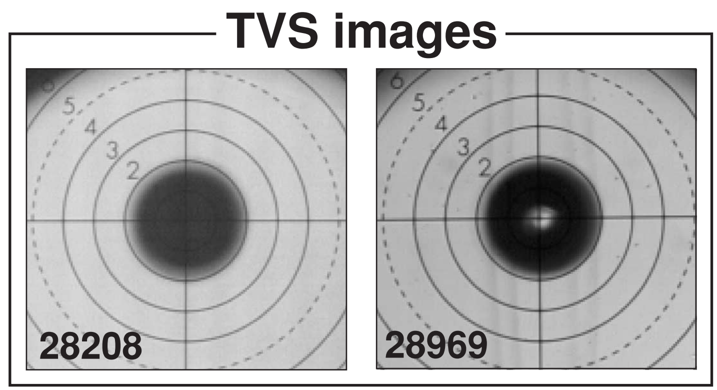
The secondary-to-primary neutron ratio is generally higher for the low-adiabat implosions

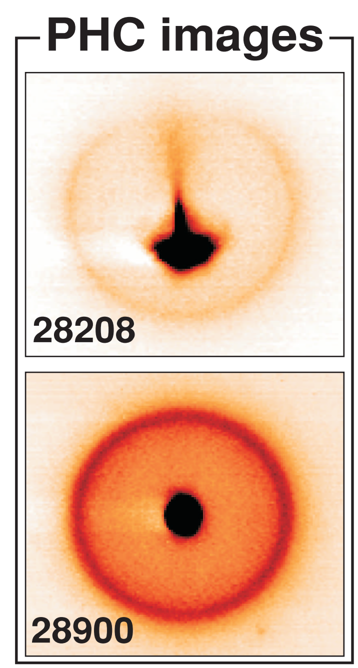


E12019

Many experimental signatures indicate a compromised ice layer





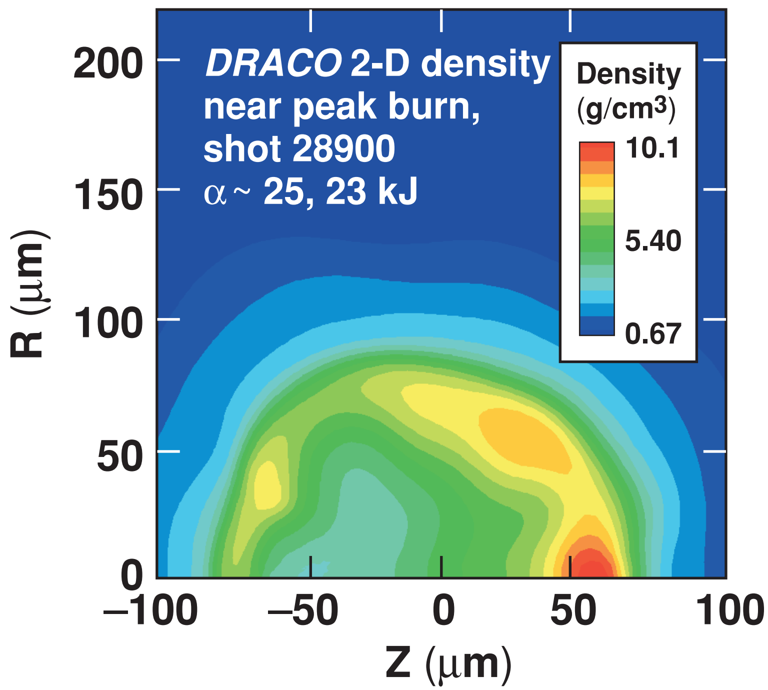


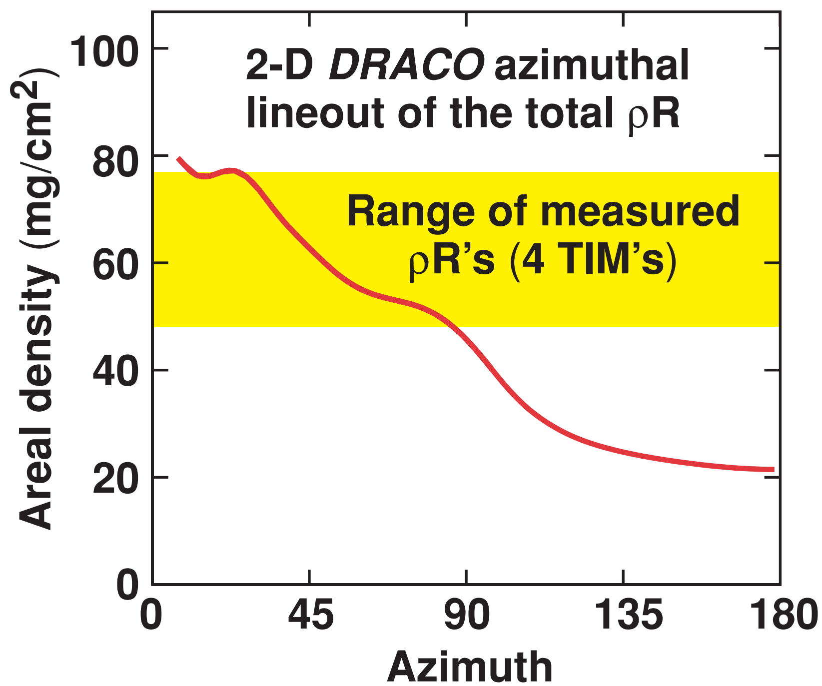
$\langle T_{ion} \rangle$ for obvious layer deterioration: 4.4 keV

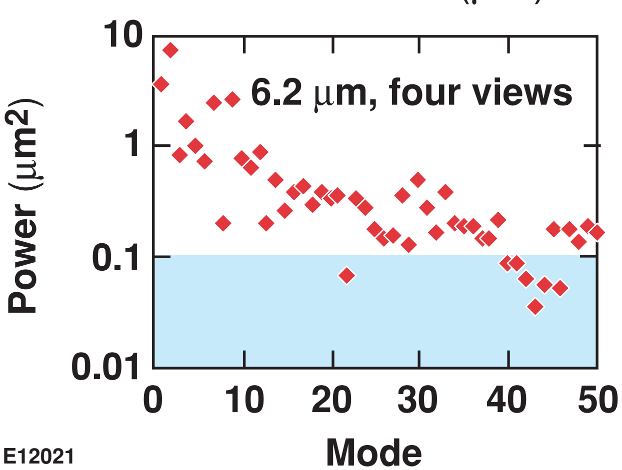
$\langle T_{ion} \rangle$ for obvious "intact" layers: 2.7 keV

The Cryo Target Characterization Diagnostic (CTCD) will provide a single view for a shadowgraphic layer characterization at TCC within 50 ms of the shot.

2-D *DRACO* accurately predicts the cold fuel areal density in shot 28900 ($\alpha \sim 25$)





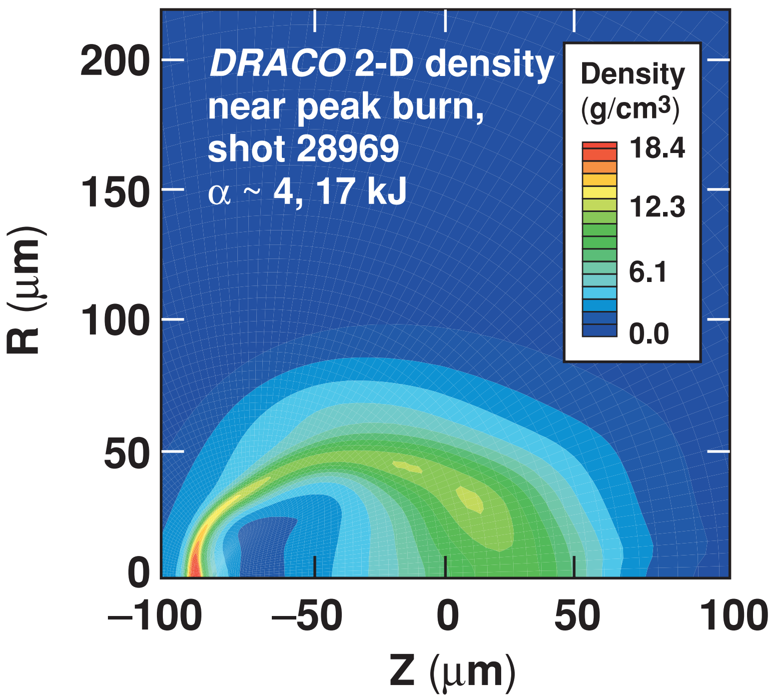


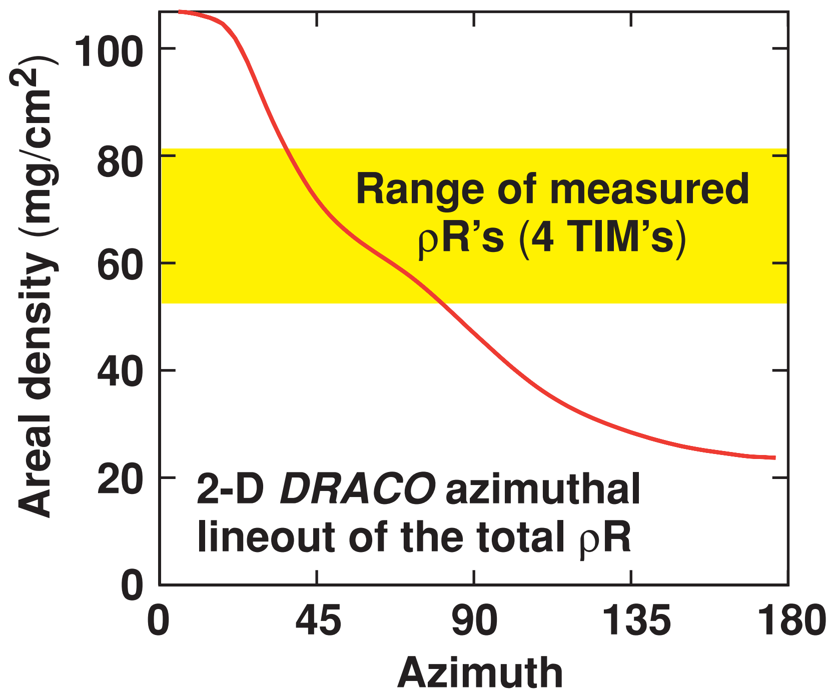
1 ns,
96% YOC
28969

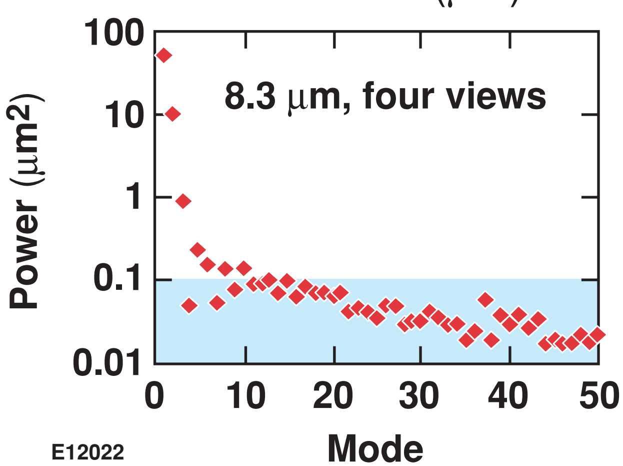
	Expt	1-D	2-D
Y_{1n}	1.27×10^{11}	1.32×10^{11}	7.45×10^{10}
Y_2	1.17×10^{9}	1.40×10^{9}	8.87×10^{8}
$\langle \rho R \rangle$	61	45	50
T_{ion}	3.6	2.3	2.6

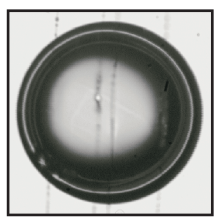
E12021

2-D *DRACO* predicts 9% of the 1-D yield for shot 28969 ($\alpha \sim 4$) while the experimental measurement is 11%









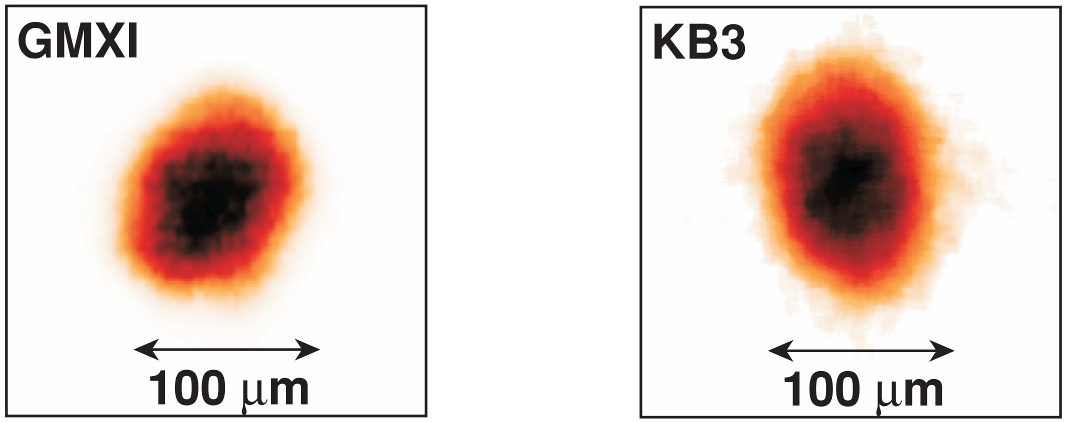
α~4,
11%YOC
28969

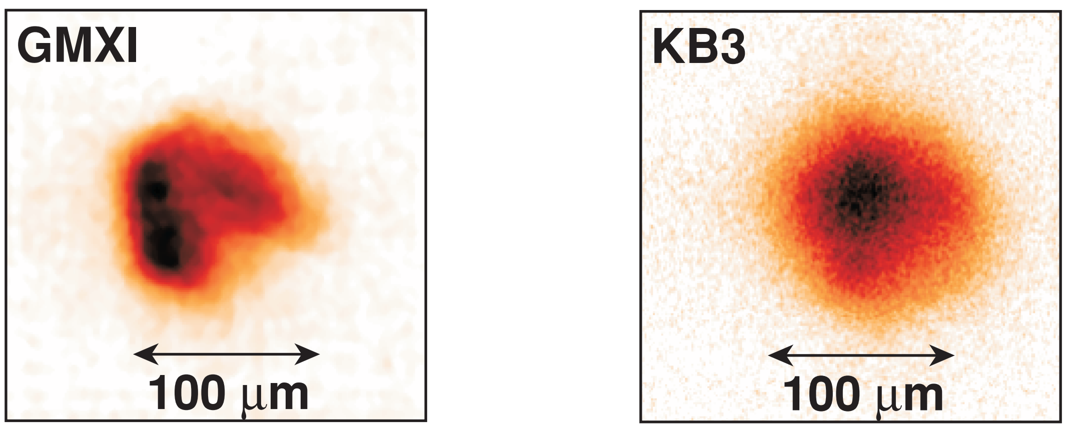
	Expt	1-D	2-D
Y_{1n}	5.95×10^9	5.60×10^9	5.32×10^9
Y_2	6.75×10^7	6.94×10^8	6.31×10^7
<ρR>	67	80.0	58
T_{ion}	2.5	1.7	2.0

E12022

The imploded cores show perturbations from residual low-mode power imbalance and ice-layer roughness

Shot 28900, 1 ns (α ~25), 23.3 kJ, offset = 17±7 μm





Shot 28969, α = 4 pulse, 16.6 kJ, offset = 11±19 μm

E12023

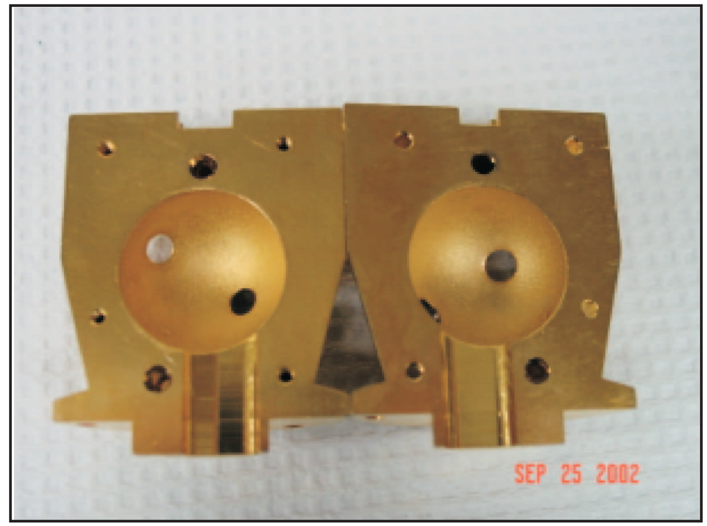
Scaled ignition performance with cryogenic implosions on OMEGA is within reach

UR LLE

Improved ice-layer quality: 1 μm rms

- Feedback on IR power delivered to the layering sphere
- Blast damage to layering sphere
- Vibration mitigation
- MCTC reliability (4× carts)

Layering sphere



Improved laser system uniformity: <1% rms

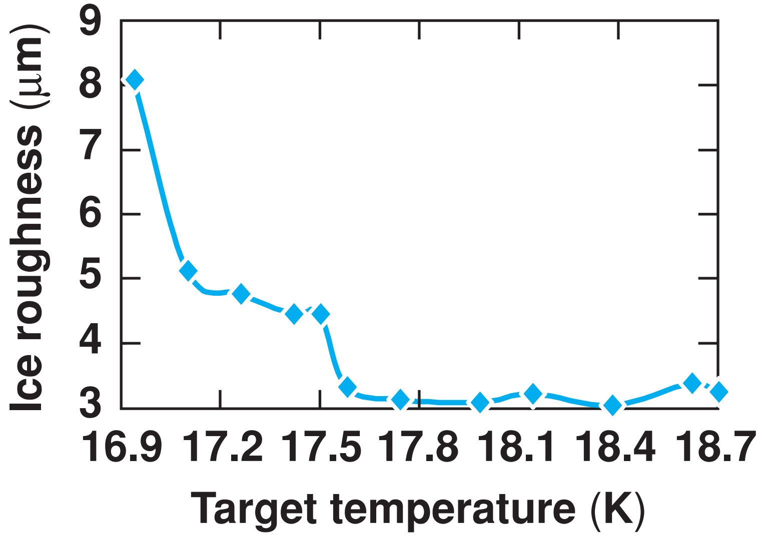
- Target alignment to <10 μm (1% diam)
- Beam pointing (Marshall GO2.007)
- Power balance
- Beam shape (new DPP's, summer '03)

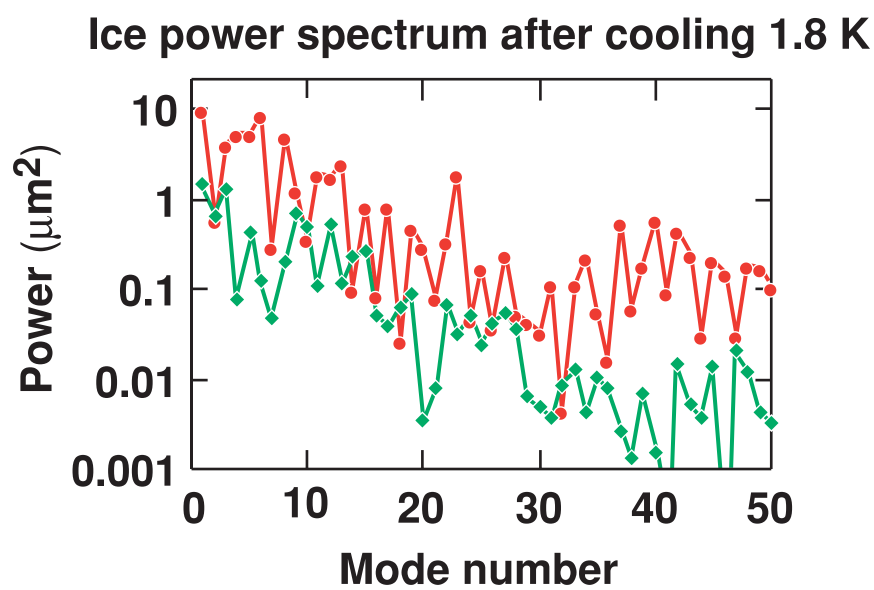
New diagnostics:

- Stepped wedged range filters (MIT): 4- to 18-MeV proton spectroscopy to measure ρR up to ~250 mg/cm^2
- HSRHOR (LLNL): absolute multispectral absorption spectroscopy to infer hot-spot electron temperature and density
- SHIMG (LLE): differential shell imaging to infer shell areal density modulations

E12024

The initial ice-layer rms at the triple point can be recovered after cooling 1.8 K





- rms ice roughness at discrete temperatures as target is cooled below the triple point.

- After annealing overnight (17 h), the power spectrum approached the original smoothness.

While layering is performed at the triple point, implosion performance is optimal at a temperature ~ 1.8 K colder.

E12025

Summary/Conclusions

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- Performance for low-adiabat (α ~4) pulses is very close to 2-D *DRACO* predictions.
- The cryogenic $\langle\rho R\rangle$ is approximately two times higher for low-adiabat (α ~4) than for high-adiabat (α ~25) pulses.
- Performance improves significantly with increasing ice smoothness.
- Layering and characterization of cryogenic capsules are now routine; layer quality can be preserved well below the triple point.
- Layering studies with DT and foam shells should begin within a year.
- Implosions with picket pulses will begin soon (December/January).

E12040