The NIF Ignition Program

Presentation to
Fusion Power Associates Meeting

John Lindl
Lawrence Livermore National Laboratory

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Outline

The National Ignition Facility

- Ignition Introduction
- Ignition program progress on hohlraums and capsules for ignition experiments.
  - Hohlraums
  - Capsules
- Plan for experiments leading to first ignition target shots in 2010

The scale of ignition experiments is determined by the limits to compression

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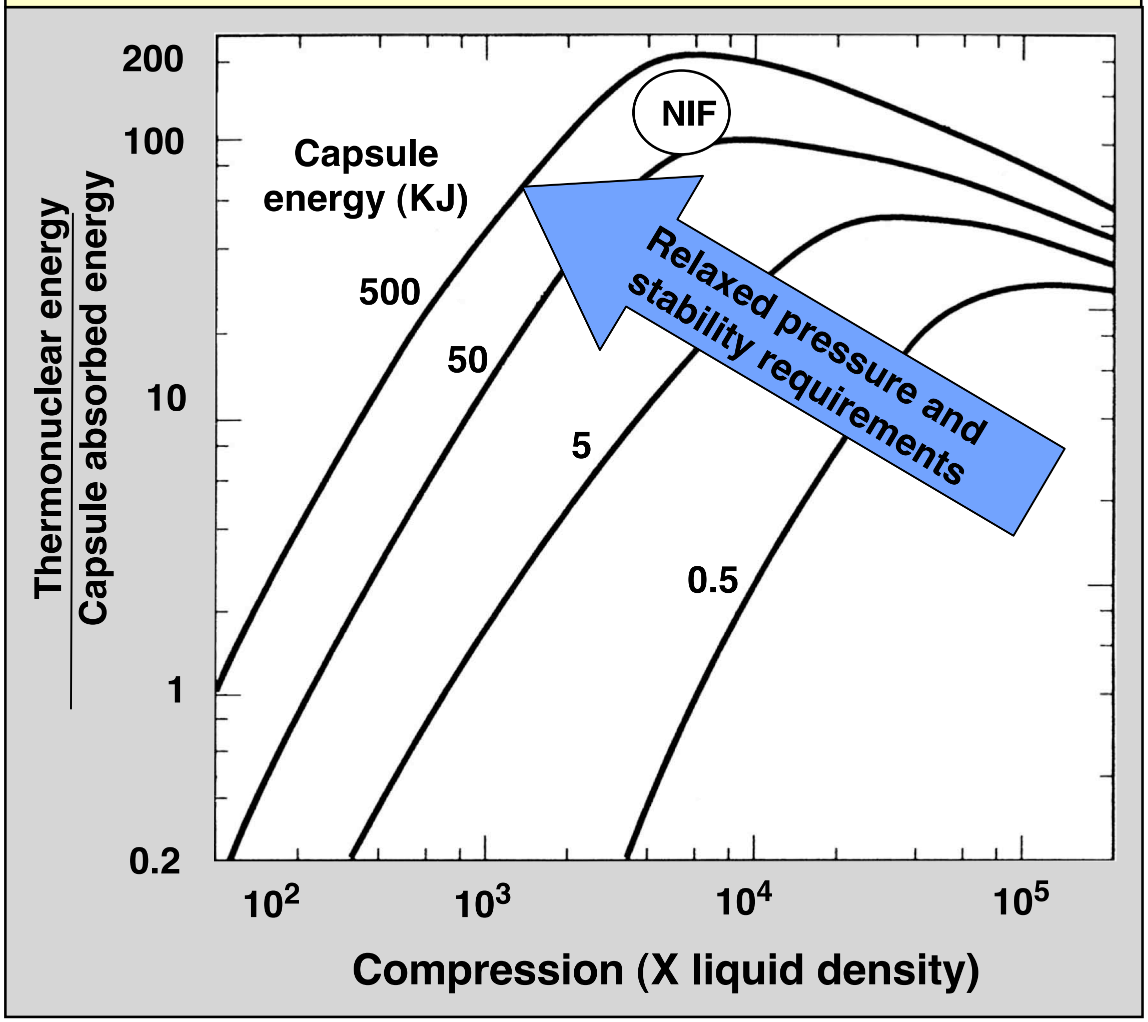
Capsule energy gain plotted versus compression



- Pressure is limited to P(Max)~100 Mbar by Laser Plasma Interaction (LPI) effects

- Given the pressure limits, hydrodynamic instabilities limit implosion velocities to

$$V_{imp} < 4 \times 10^7 \text{ cm/sec}$$

and this limits the maximum compression

- Symmetry and pulse shaping must be accurately controlled to approach the maximum compression

There are two principal approaches to compression in Inertial Confinement Fusion

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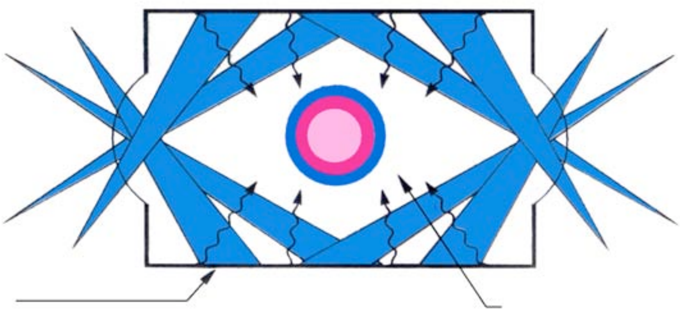
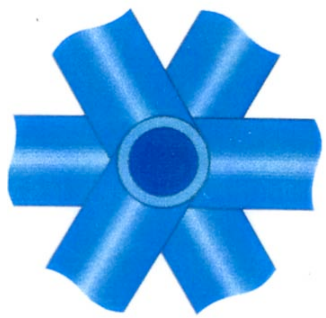
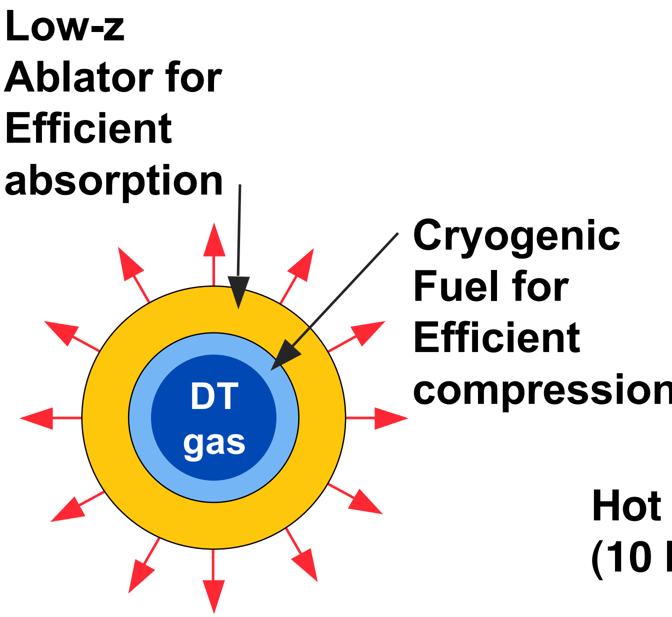
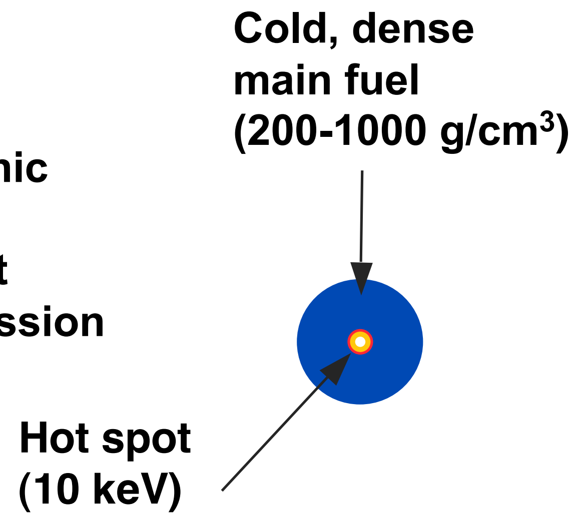
Indirect Drive



Direct Drive







Inertial Confinement Fusion uses direct or indirect drive to couple driver energy to the fuel capsule

Spherical ablation with pulse shaping results in a rocket-like implosion of near Fermi-degenerate fuel

Spherical collapse of the shell produces a central hot spot surrounded by cold, dense main fuel

The impact of most effects that degrade an implosion can be specified as a hot spot perturbation amplitude

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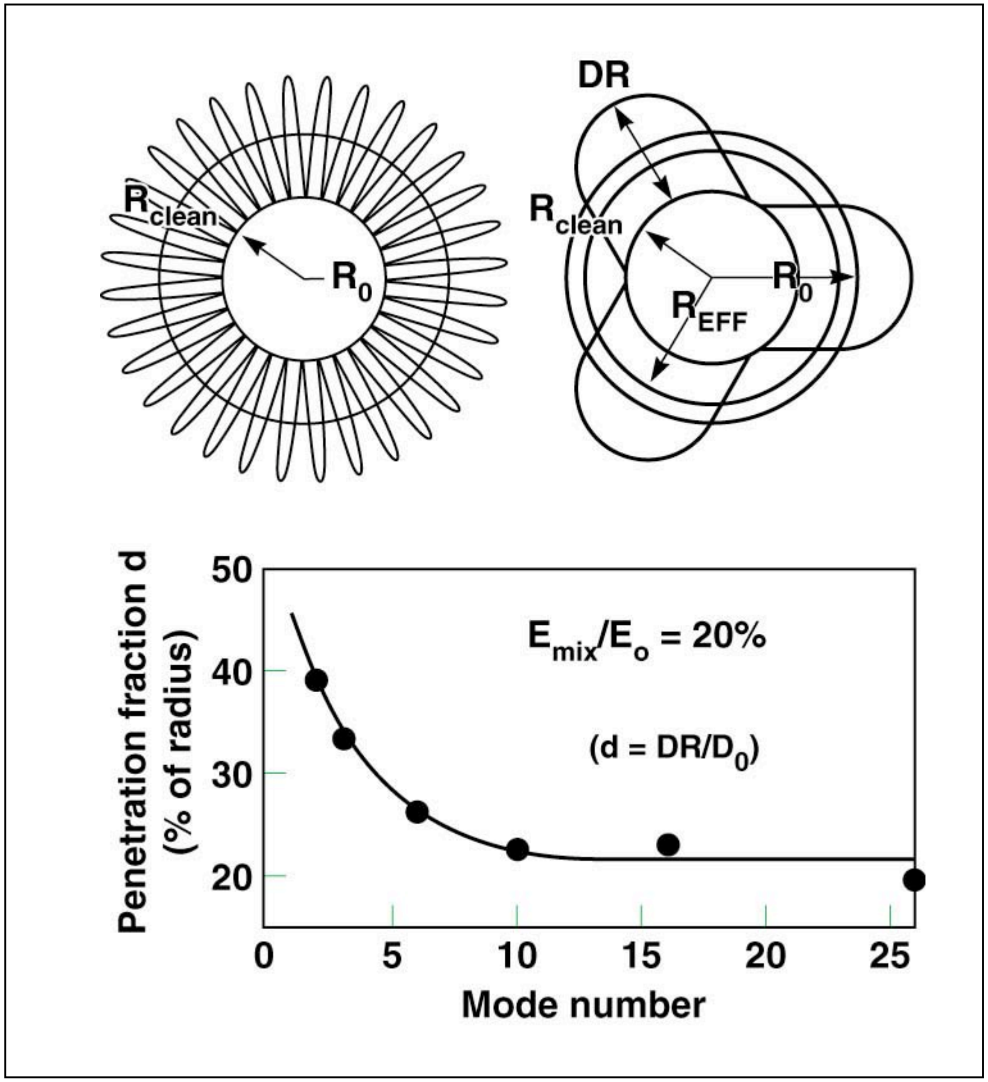

- Long Wavelength Perturbations
  - Hohlraum asymmetry
  - Pointing errors
  - Power Imbalance
  - Capsule misplacement in chamber
- Short Wavelength Perturbations
  - DT ice roughness
  - Ablator roughness
  - Ablator microstructure

The hot spot penetration is the fraction of the hot spot perturbed by the various sources of error

The "ignition island" size provides an integral measure of the robustness of the NIF ignition designs

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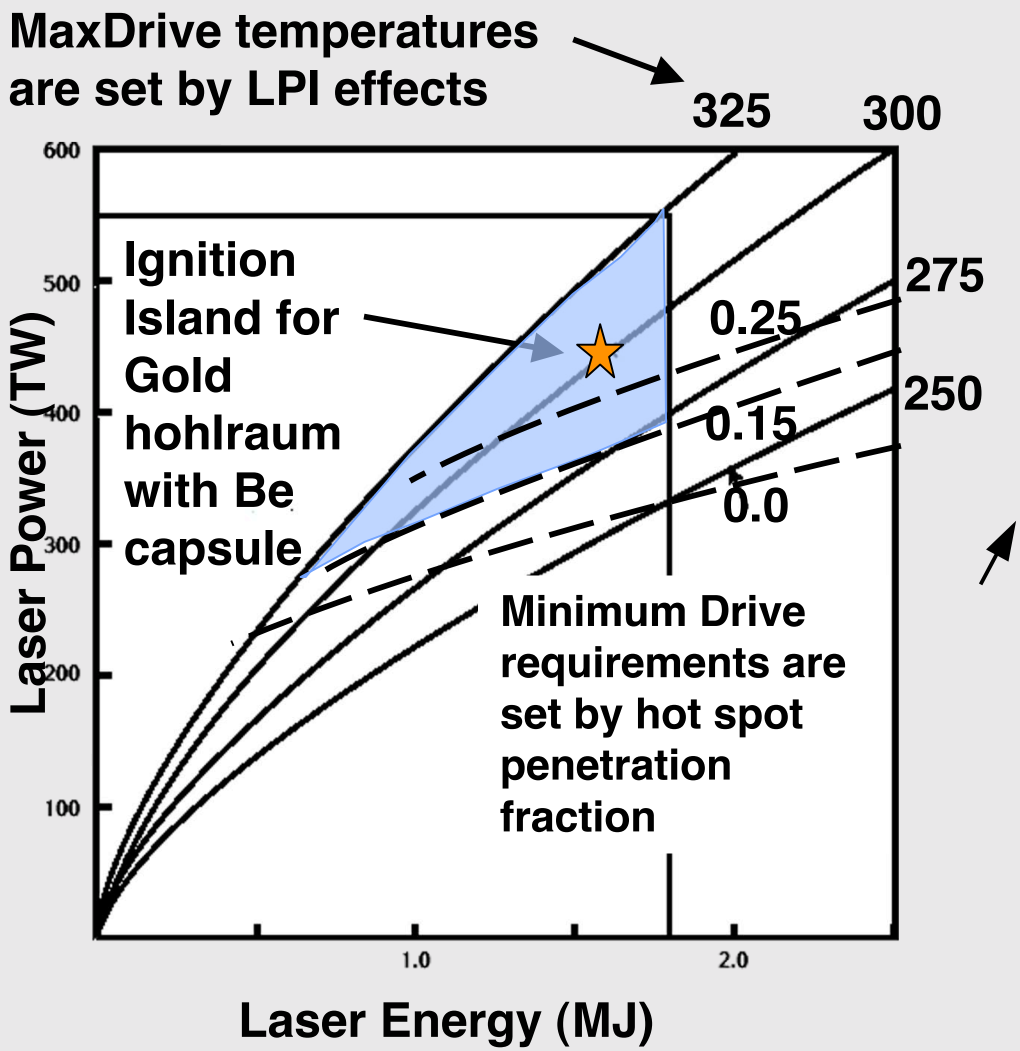

We expect ~15% hot spot penetration fraction based on detailed 2D and 3D calculations at the specified target fabrication and NIF performance levels

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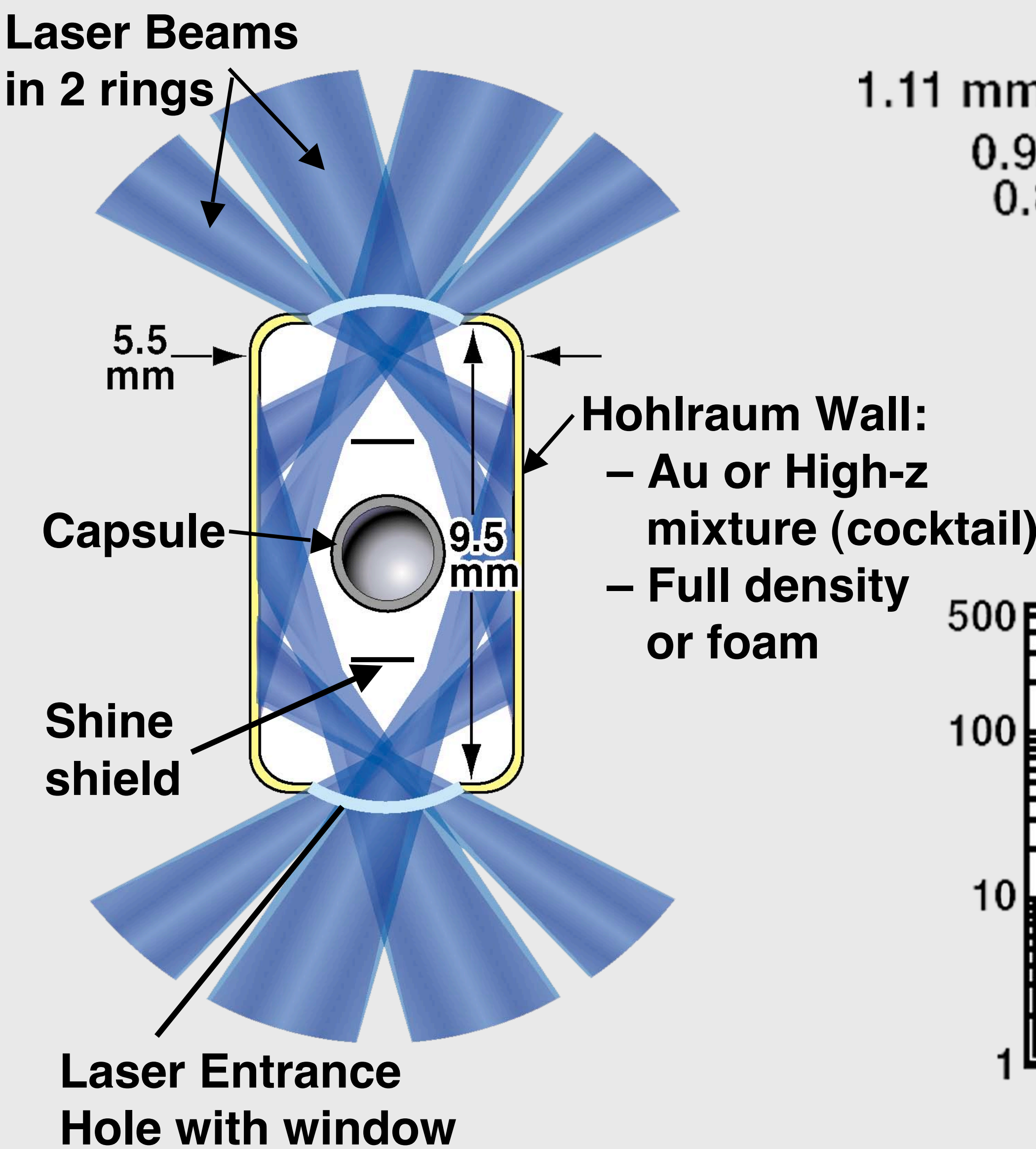
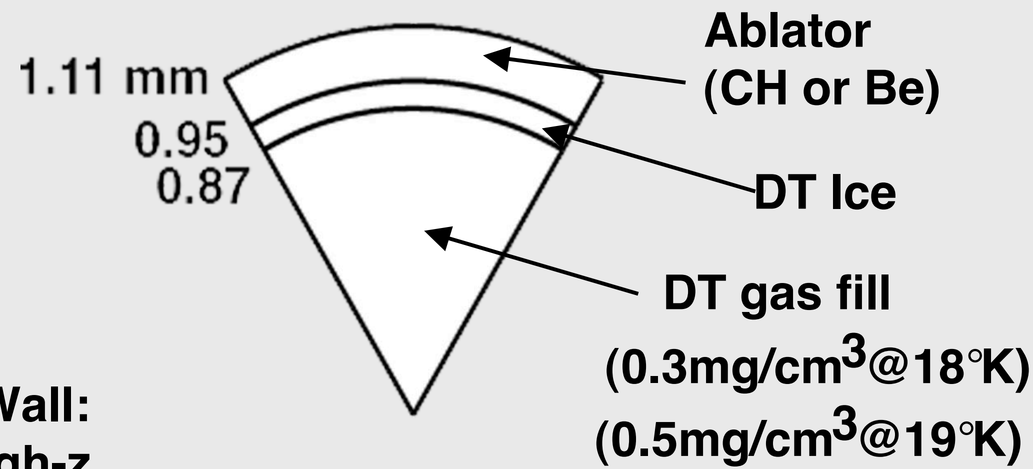
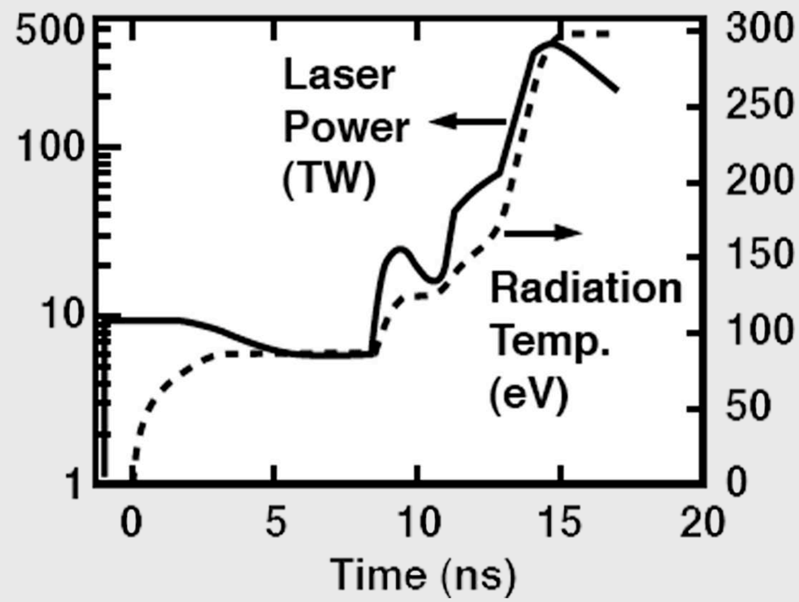
NIF Indirect Drive target schematic

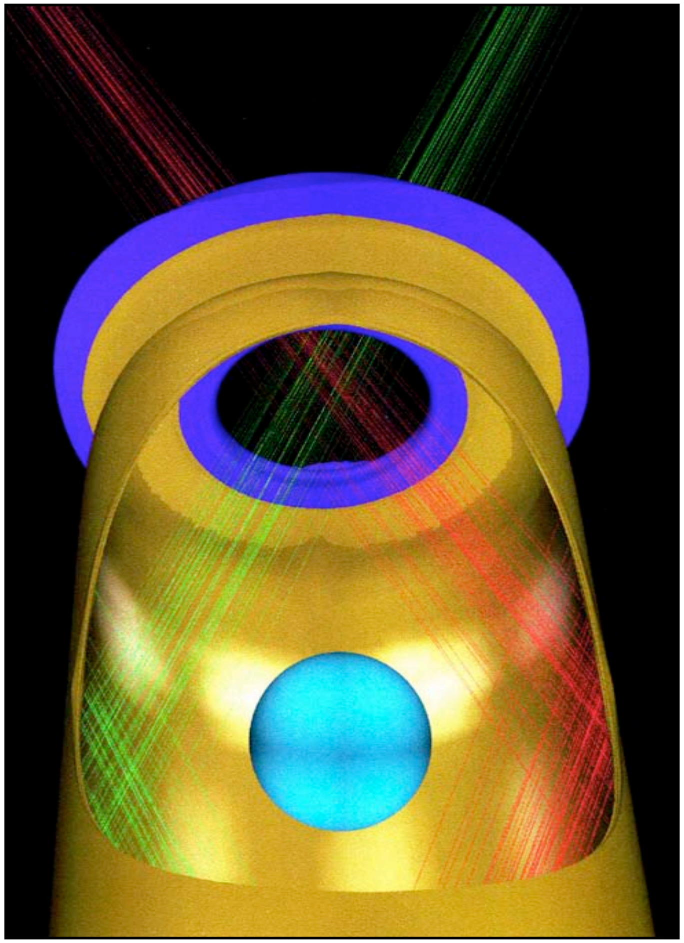




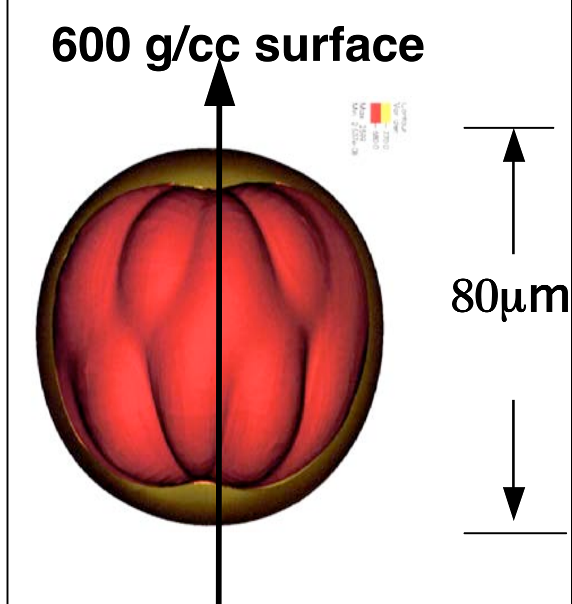
Typical Pulse Shape



The Hydra code is used for 3D calculations on the NNSA ASC computers

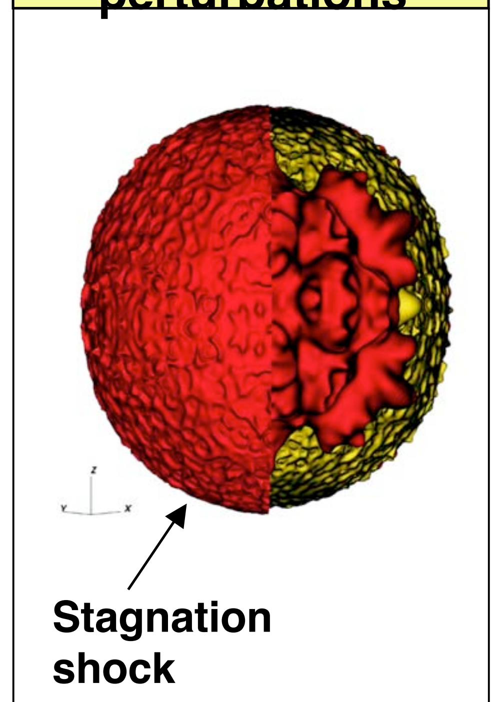


Ignition - hohlraum only perturbations



Hohlraum Axis (z)

Ignition - capsule and hohlraum perturbations



400 g/cc density isosurface

Yields calculated in 3D are near 1D yields with both Gold and cocktail wall hohlraums and plastic or Be capsles

The Indirect drive ignition point design continues to evolve to optimize coupling efficiency

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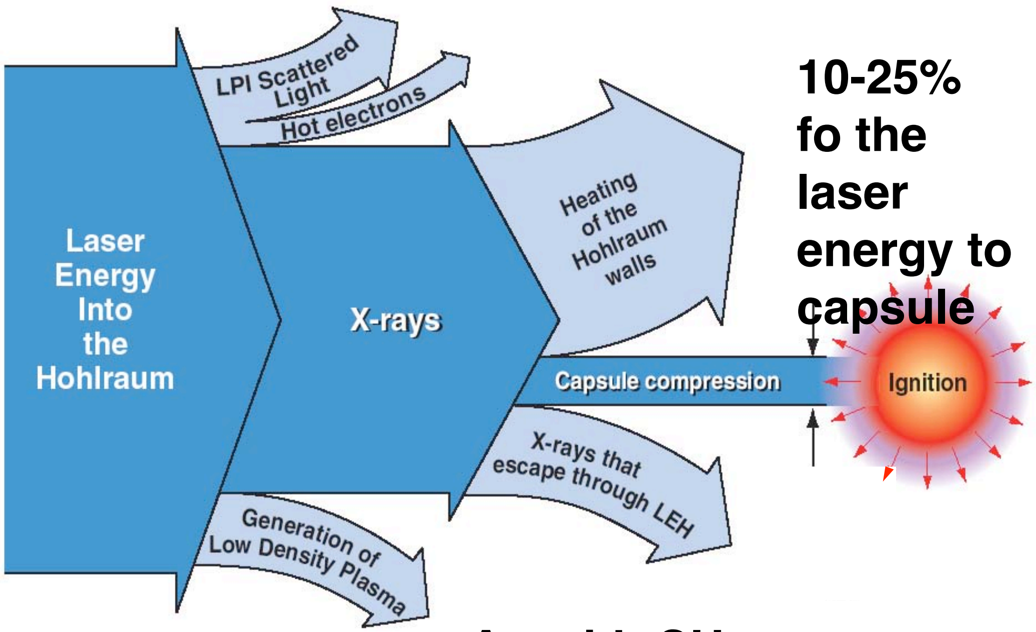

10-25% fo the laser energy to capsule

	Au with CH Capsule	Au with Be Capsule	Cocktails with Be Capsule
Laser light	1.45	1.45	1.45
(MJ) Absorbed	1.30	1.30	1.30
xrays	1.10	1.10	1.10
wall loss	0.65	0.62	0.53
hole loss	0.30	0.28	0.33
capsule	0.15	0.20	0.24
efficiency (%)	10.5%	13.5%	16.5%

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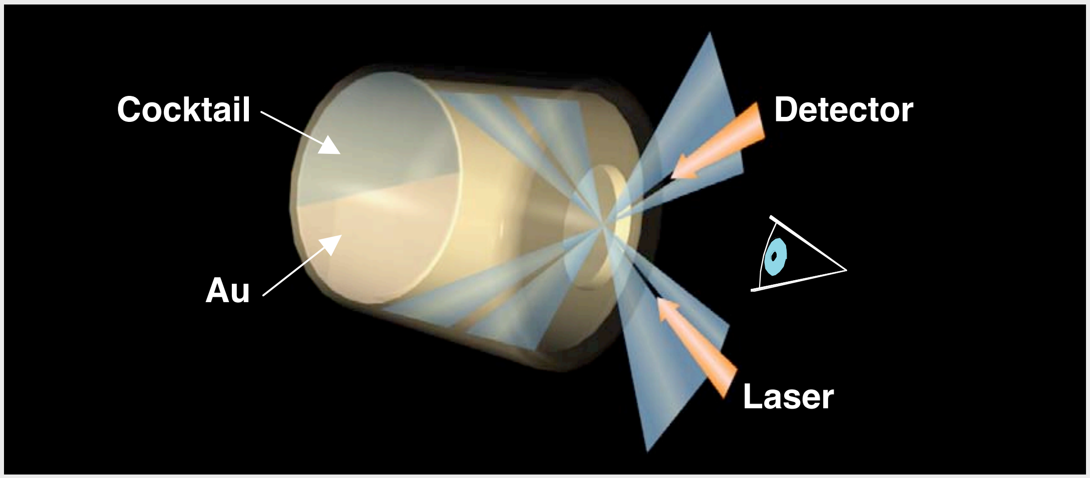
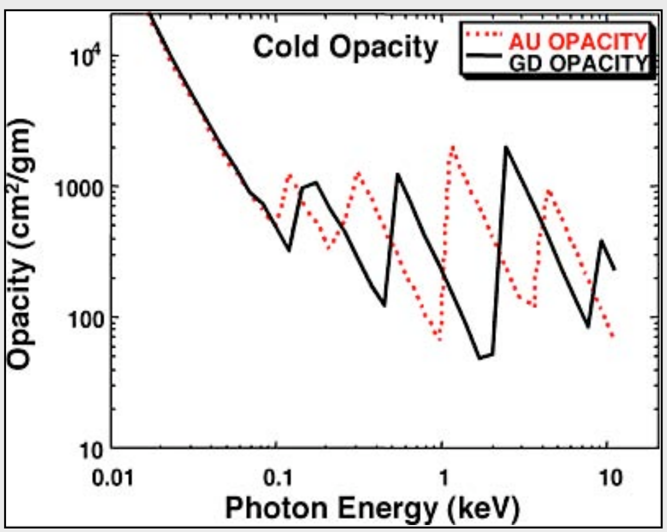
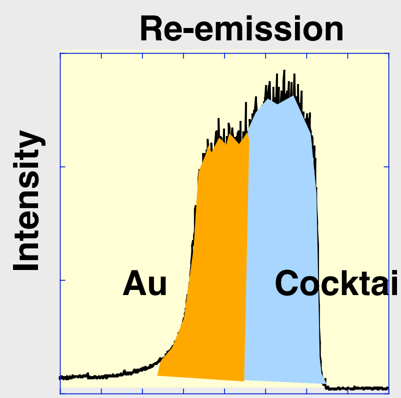
Omega experiments show larger albedo for cocktail walls made of $((U\ Nb_{0.14})_{0.6}, Au_{0.2}, Dy_{0.2})$

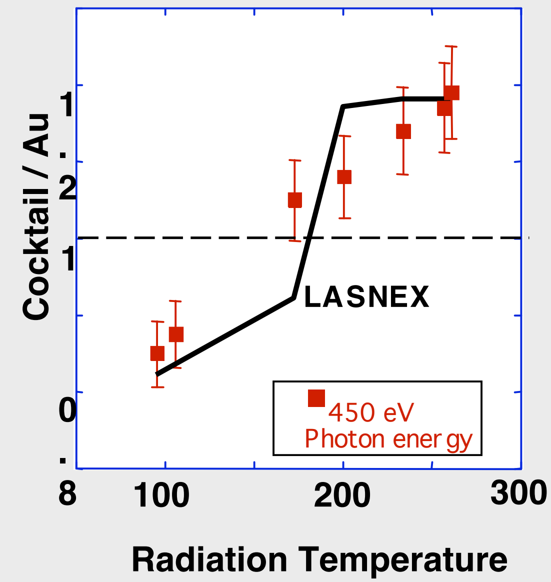
Hohlraum experiments with split back plate verify high x-ray re-emission





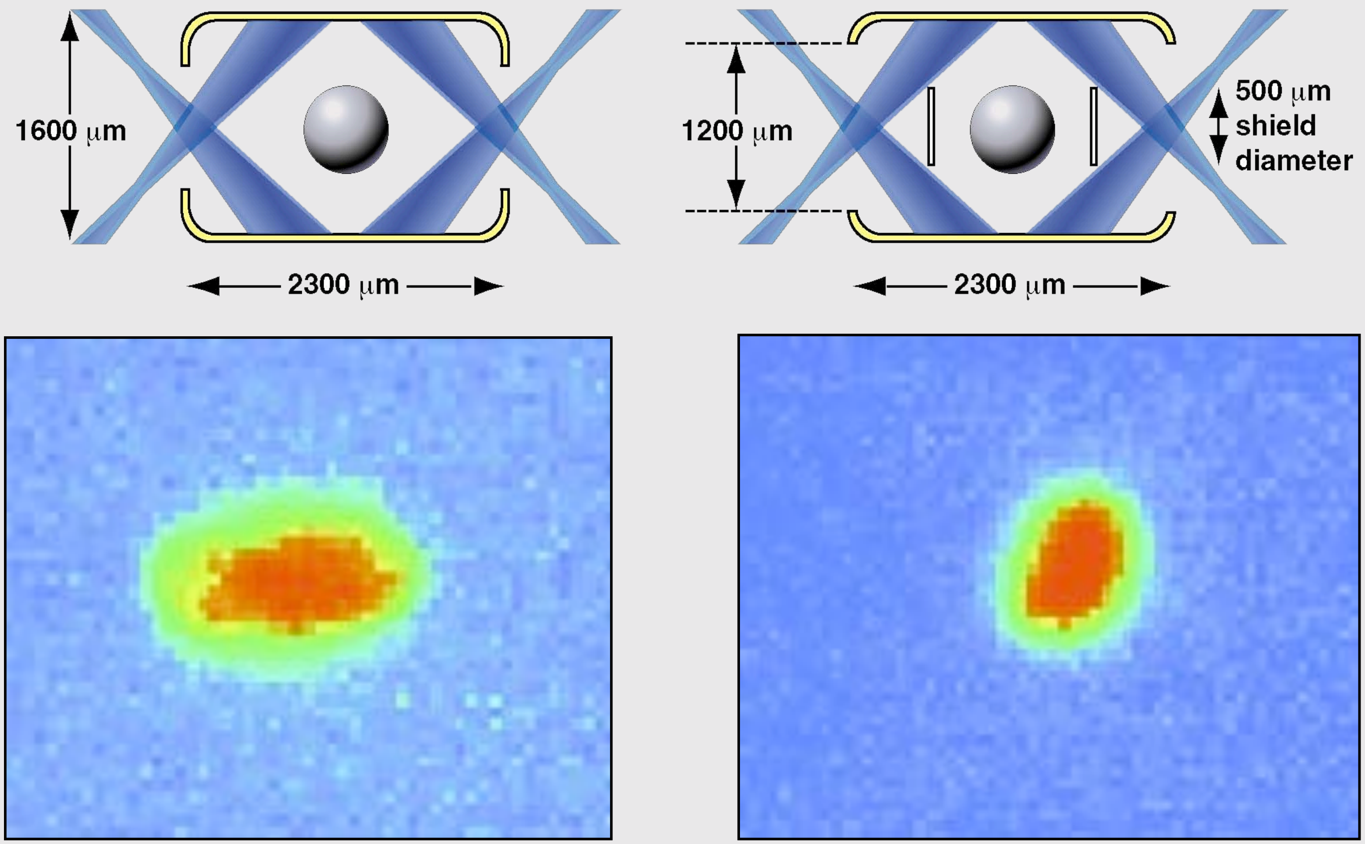


Intensity ratio of Cocktail/ Au is in agreement with LASNEX calculations



Agreement with LASNEX calculations indicate that cocktail materials may be advantageous compared to Au. Integrated hohlraum experiments with unsmoothed beams have not demonstrated higher T_{RAD} but measure higher laser backscatter

LEH shields provided a 20% increase in capsule radiation flux at Nova and an extra symmetry tuning degree of freedom



1 ns square pulse - identical pointing

- LEH shields will be retested on Omega in NIF-like multicone geometry
- Similar advantages possible for NIF ignition hohlraums - depends on beam propagation with added plasma source

Enhancements in hohlraum coupling efficiency expected by 2010 will substantially increase the ignition island

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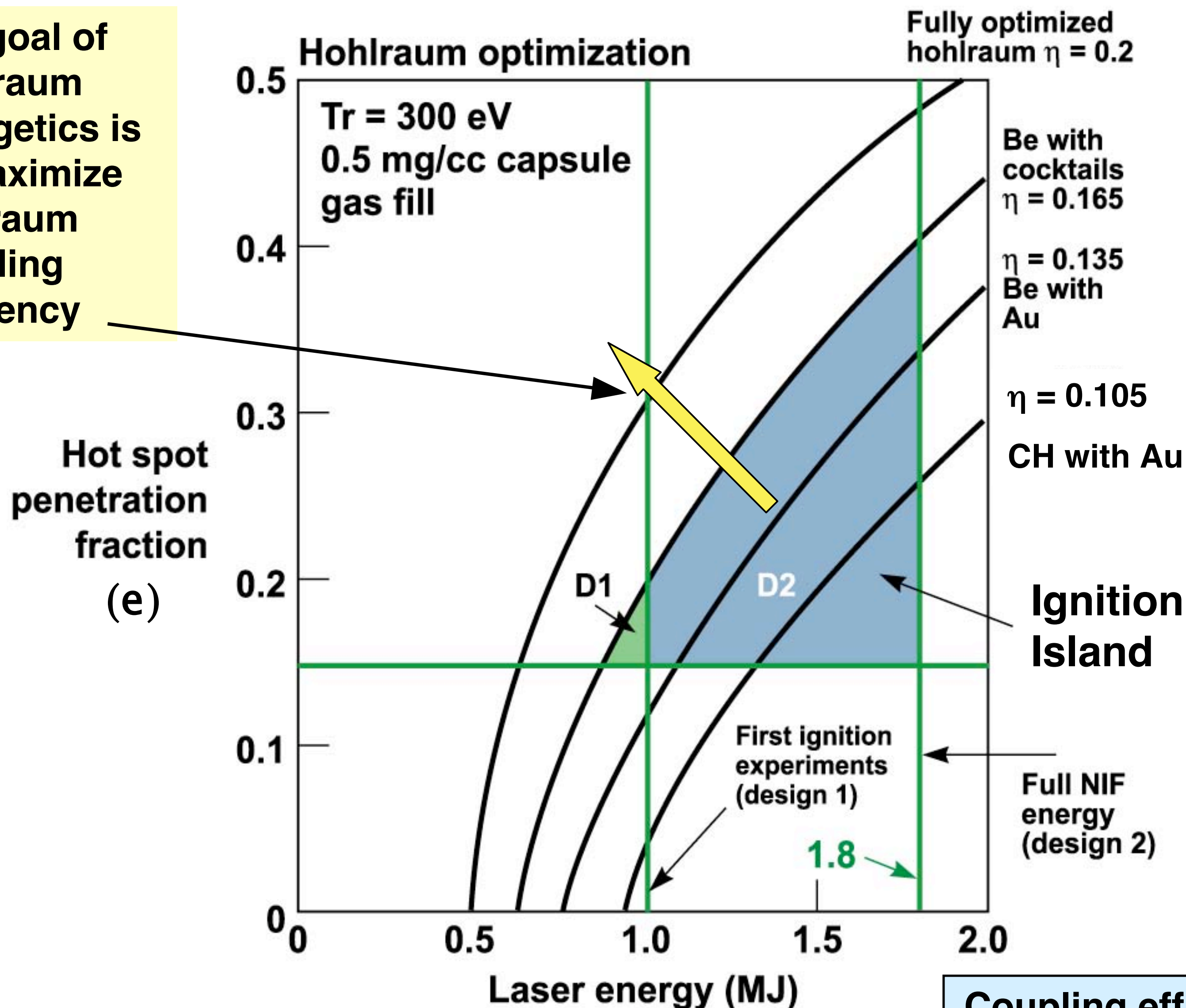
The goal of Hohlraum Energetics is to maximize hohlraum coupling efficiency



Coupling efficiency = $\eta_{abs}\eta_{H}$

η_{abs} = 1 - backscattered fraction

η_{H} = hohlraum coupling efficiency

At 3ω, drive measurements and Lasnex simulations agree closely over >two orders of magnitude in T^4_R

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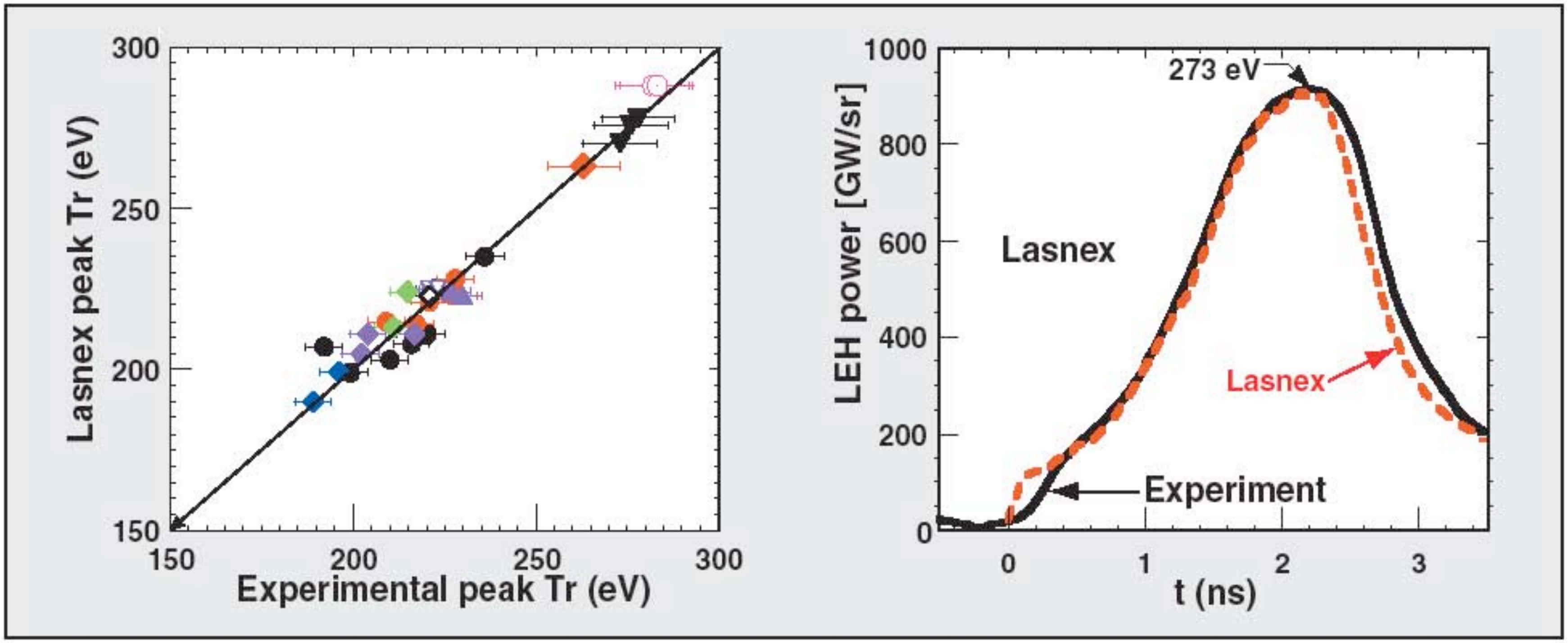
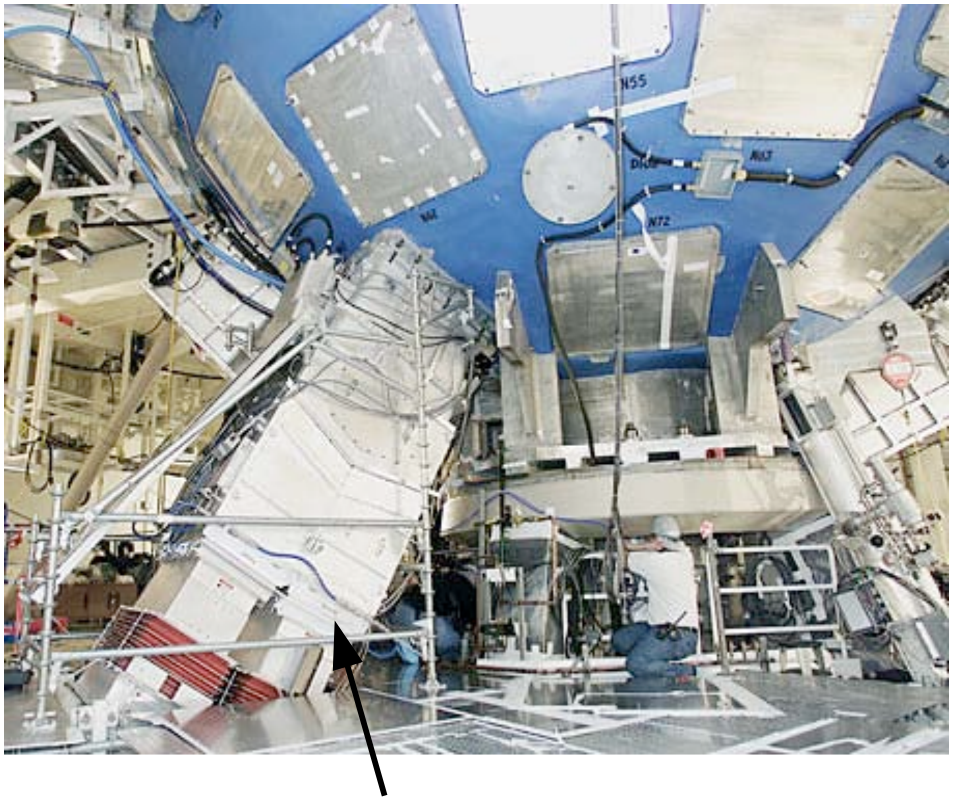
Nova and Omega Experiments



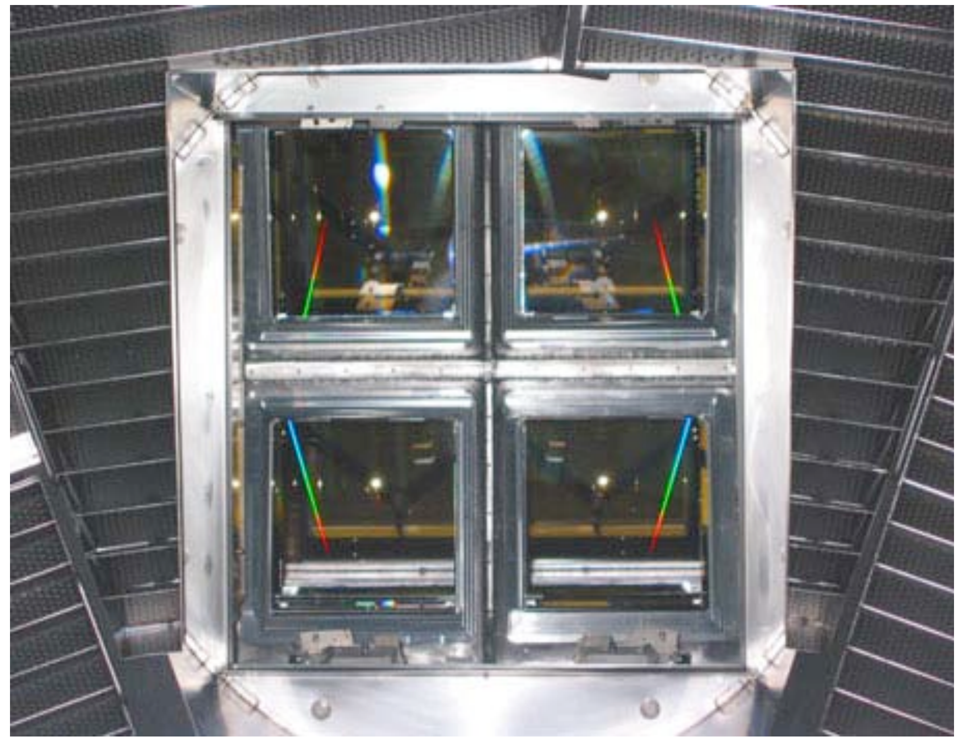
Vacuum and gas-filled hohlraums with 2.2 ns shaped pulses (3:1 and 5:1 contrast ratio)

Lasnex can predict hohlraum drive to ±10%

The first four NIF beams are operational and have been used for a number of experiments



Quad 31b beamtubes



View from inside the target chamber

An international team has successfully activated hohlraum diagnostics at NIF and the first hohlraum experiments are in close agreement with calculations

Energetics

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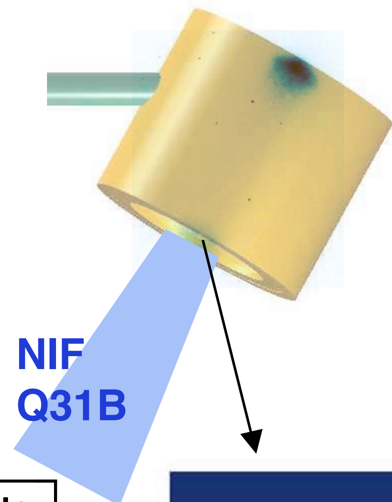
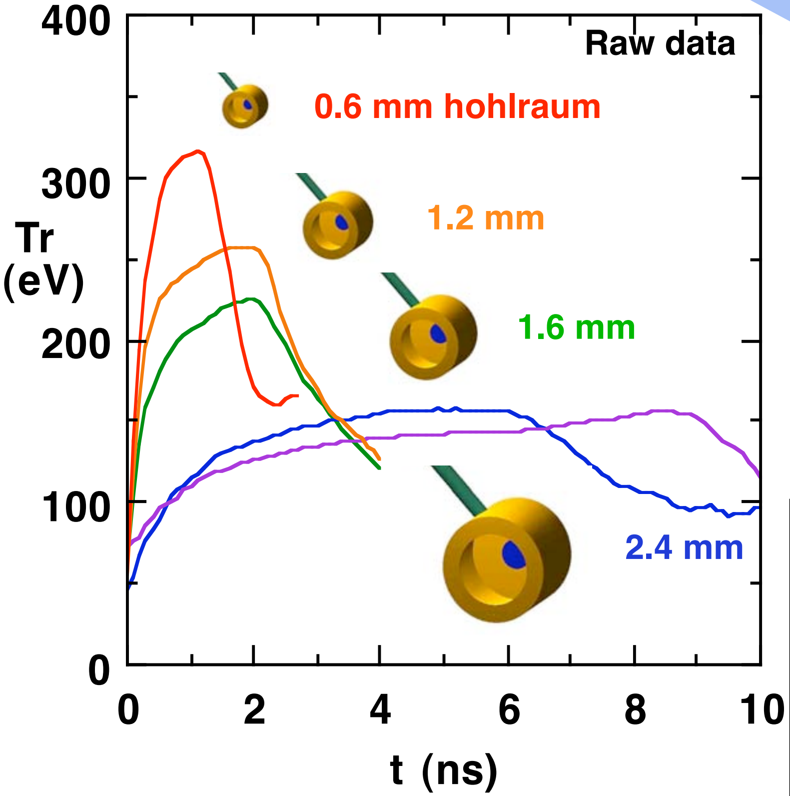
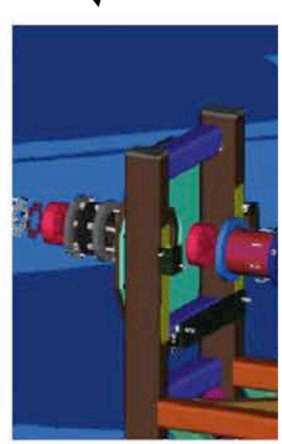
Thinwall Au Hohlraum

4-16 kJ, 1- 9 ns, 10^{15}-10^{16} W/cm^2 with beam smoothing



Hohlraum Tr vs time

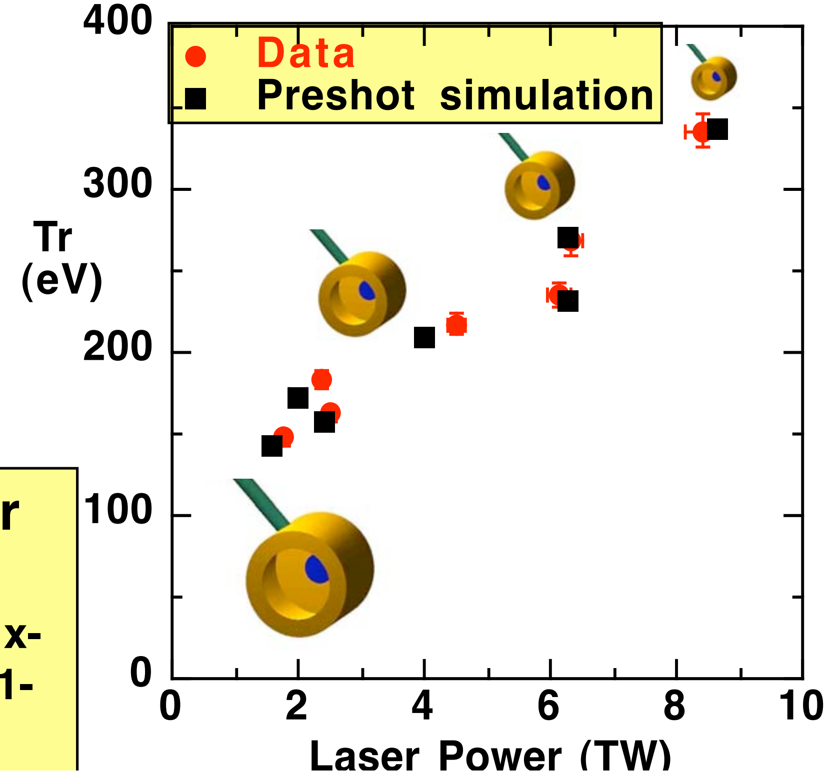




Hohlraum Tr (Dante)

18 channel soft x-ray detector (0.1-10 keV)

Peak Hohlraum Tr vs Laser Power



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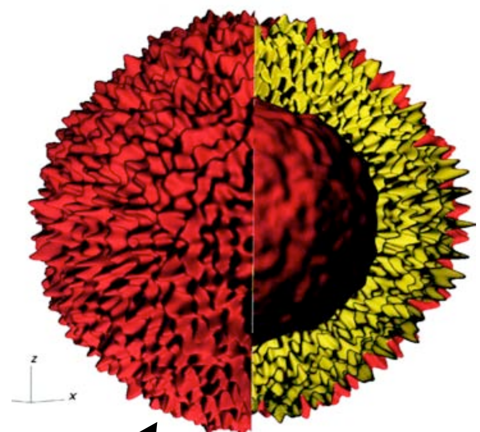
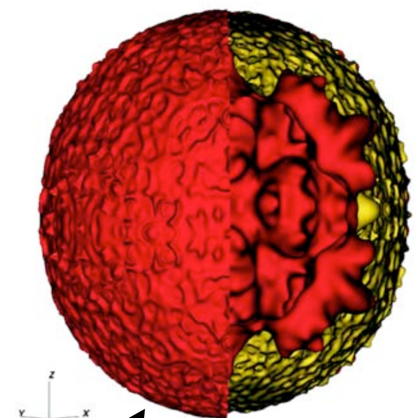
Several developments have led us to adopt the current Beryllium capsule point design

- With a given ignition hohlraum drive , beryllium absorbs ~1/3 more energy than plastic
- Beryllium has better short wavelength stability - an experimental program will be required to establish the acceptable level of Be microstructure
- Many previous difficulties in Be fabrication have been solved (filling, diagnosing layer)
- Compatibility with fill tubes allows a staged cryo system with an initial less complex (and less costly) warm transport capability (instead of a cold transport system)
- Although fill tubes are a design and target fabrication complexity, current simulations and fabrication progress lead us to conclude we can make them small enough for success - an experimental program is needed to test the calculations

3D calculations show the importance of controlling capsule surface roughness

- Capsule simulations have asymmetry and fabrication perturbations
- 3D asymmetry inferred from integrated hohlraum simulation
- Nominal “at spec” perturbations on ice and ablator in low, intermediate, and high modes
- Gave 21 MJ (90% of 1D calculation)

140 ps before ignition time	Ignition time
 Plastic/DT interface; ↕ Hohlraum axis	 Stagnation shock
60 g/cc density isosurface	400 g/cc density isosurface (different scale)

Be Capsule designs using graded dopants for pre-heat shielding have the best calculated performance

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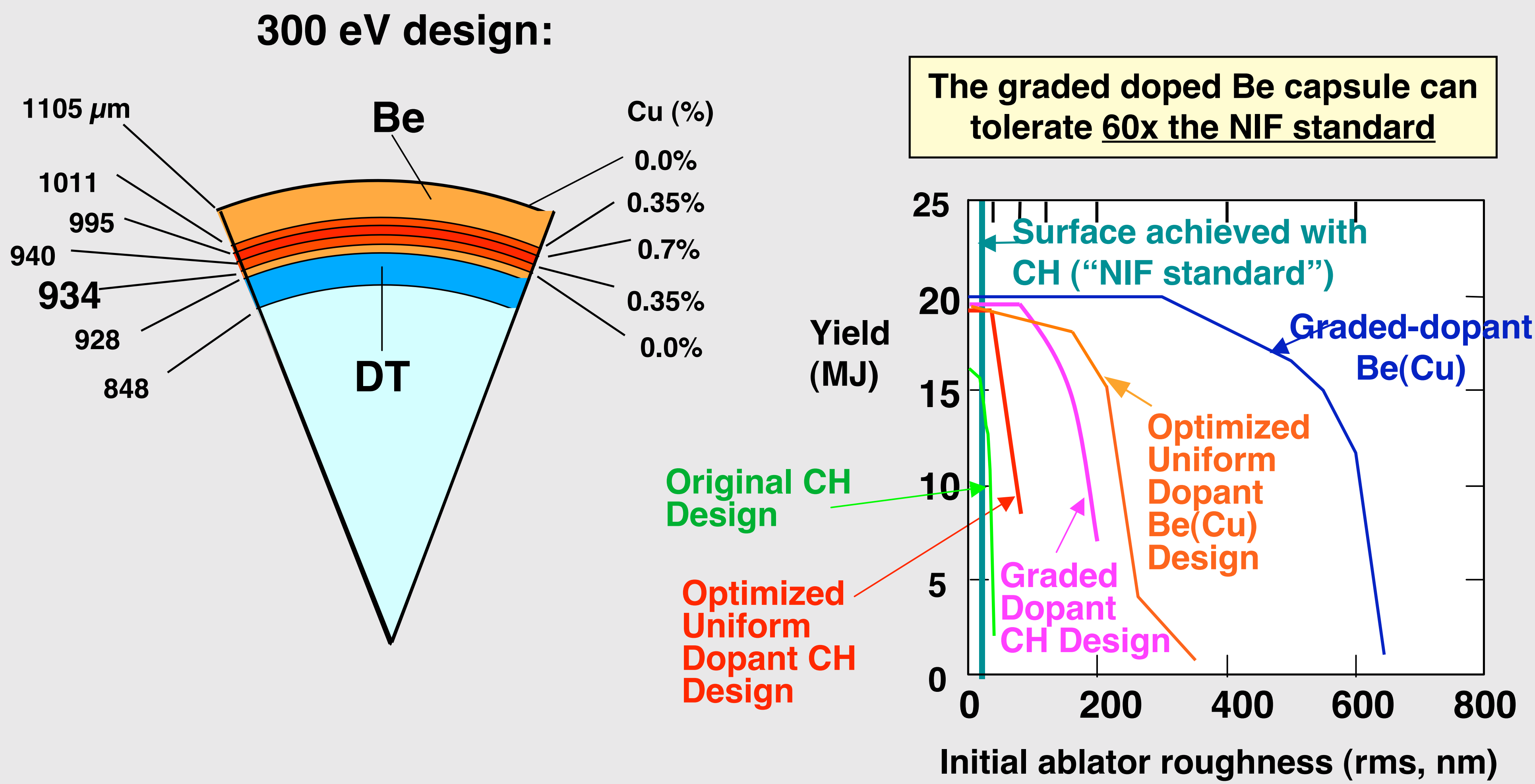

Tolerance to ice roughness is also better (5 μm compared to 1 μm)

We have produced graded Cu-doped Be capsules at NIF-scale by sputter deposition

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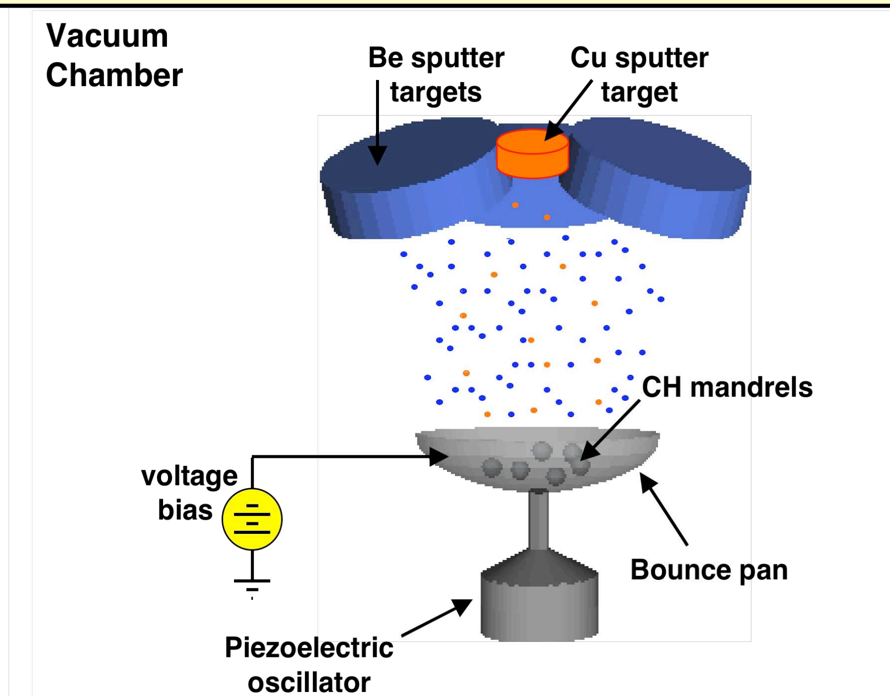
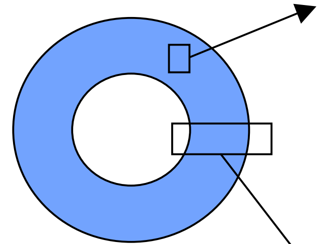
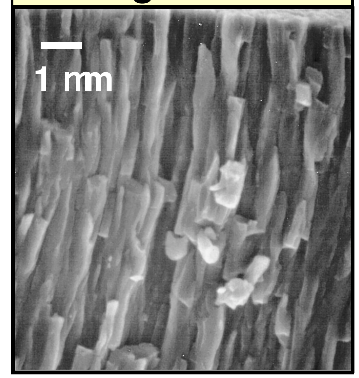
Sputter deposition on CH mandrels



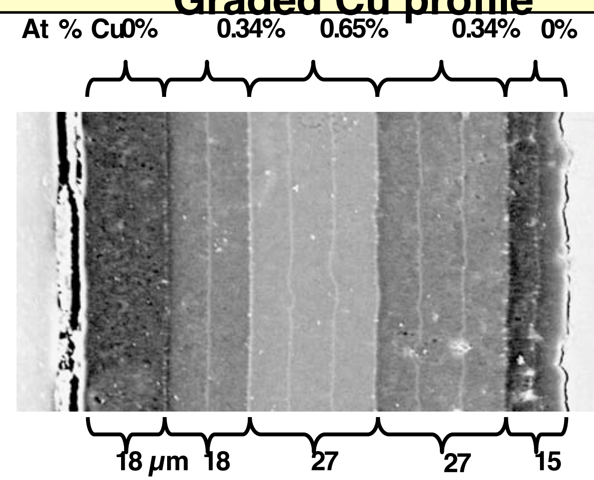


Sub-micron grains



High mode morphology

Graded Cu profile



The surfaces of our first graded dopant Be capsules don’t meet specifications, but improvements are planned

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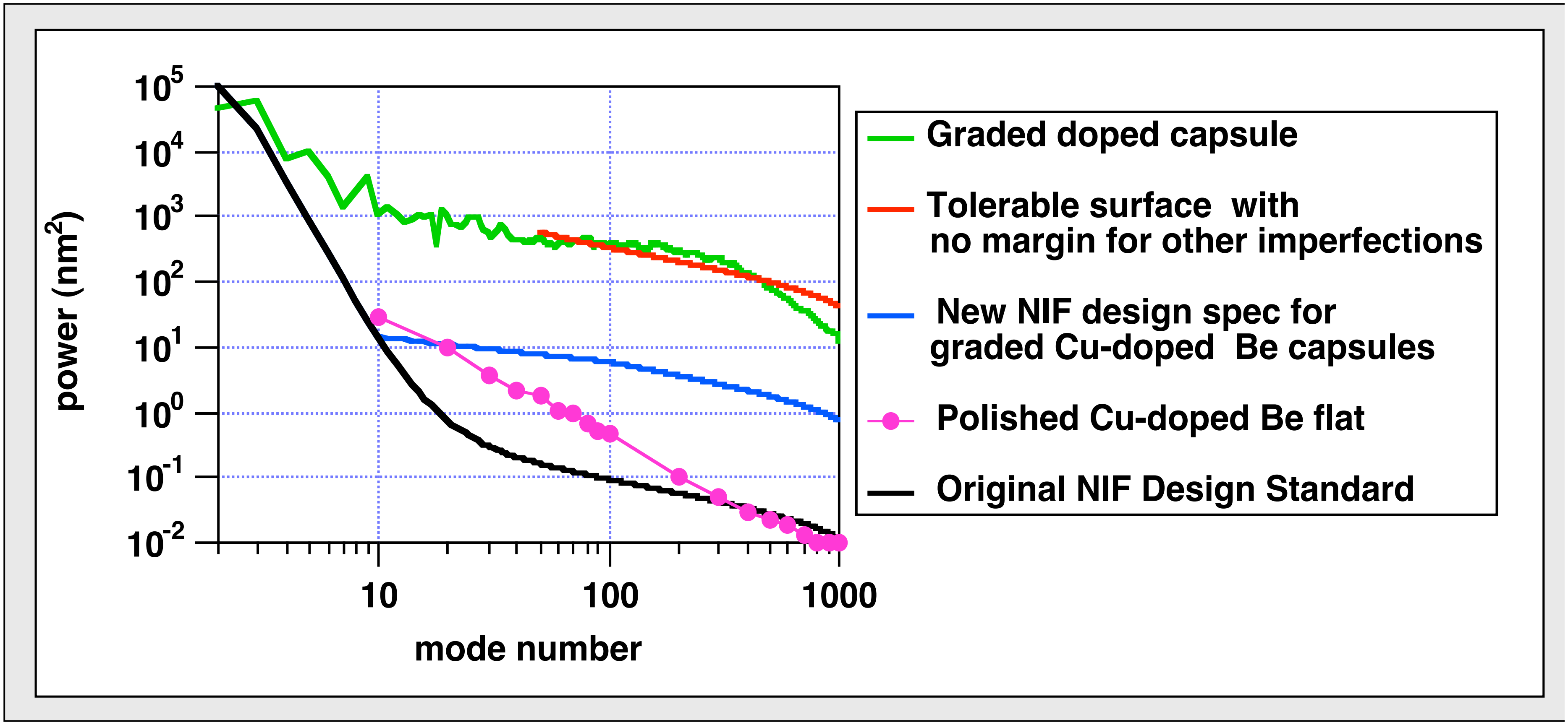

- We plan to investigate use of ion bombardment and other methods as means to improve surface finish and coating density
- In FY05 LANL will study shell polishing

Be is non-permeable, and requires a fill hole through the ~100-μm-thick ablator for filling

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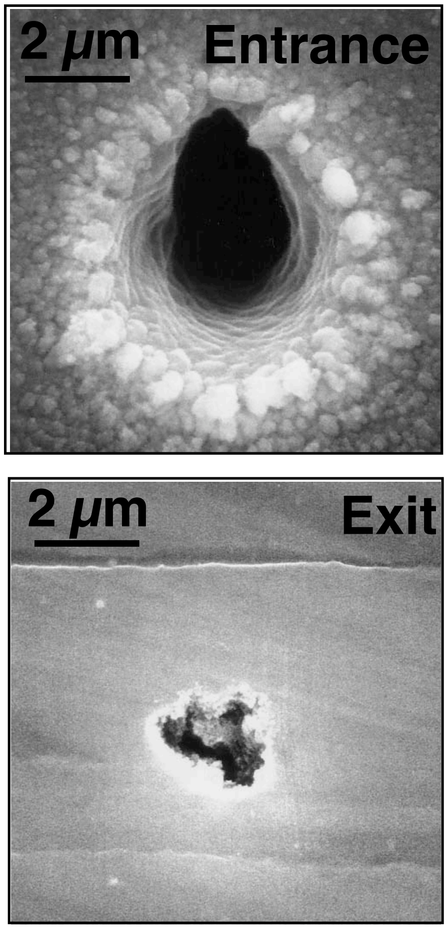
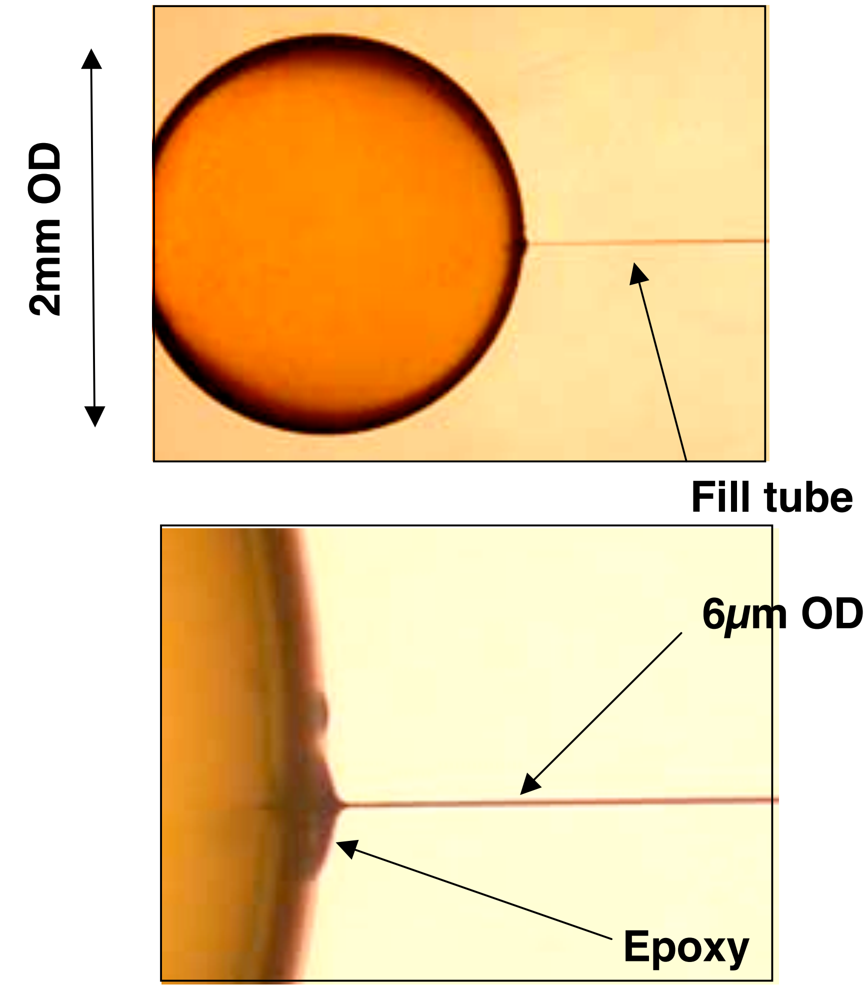
Laser:
Ti:sapphire
405 nm, <1 μJ,
120 fs, 3.5 kHz
drilling time:
~40 sec



- Two routes to filling beryllium capsules
  - Fill Tube
  - Drill, Fill and Plug (Strong Capsules)

Fill Tube



Current effort:
minimizing the glue joint

Simulations indicate that a 10 μm tube with a 3 μm hole has an acceptable impact on the implosion

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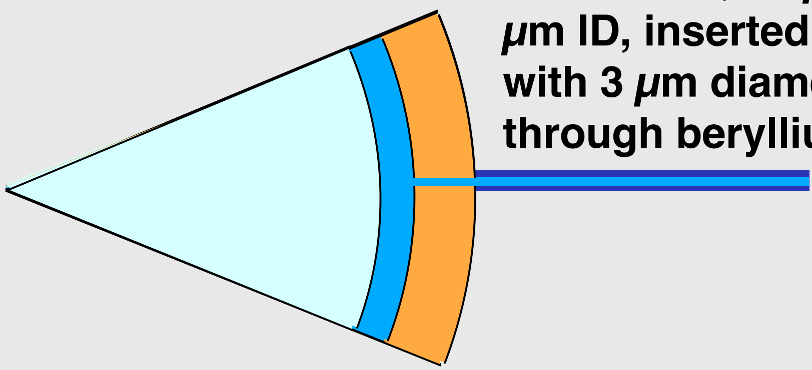
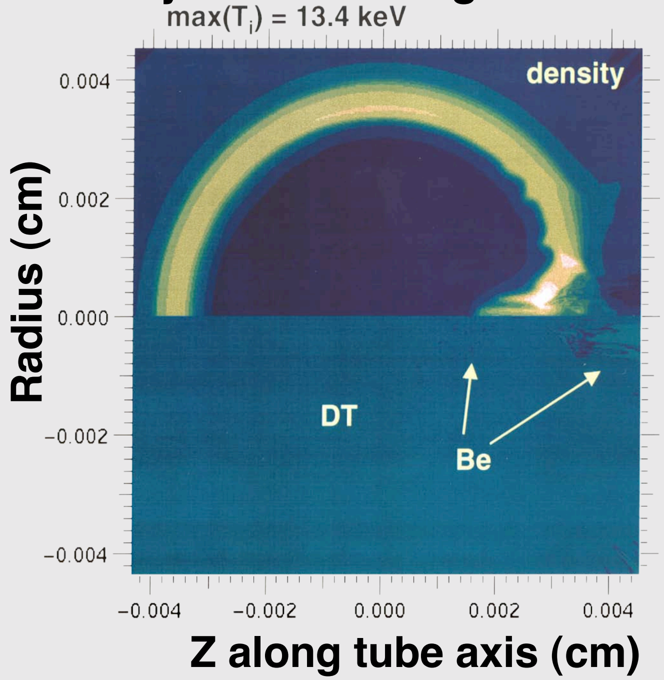


Density contours at ignition time



- Uniformly doped Be(Cu) capsule
- Calculation ignites and burns to same yield as 1D clean -- 21.7 MJ
- Simulations have also been carried out with graded doped Be and CH capsules with fill tubes up to 20 microns diameter.

The target is filled through the small fill-tube using a self-contained fuel reservoir

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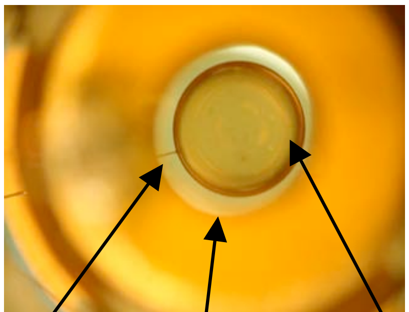
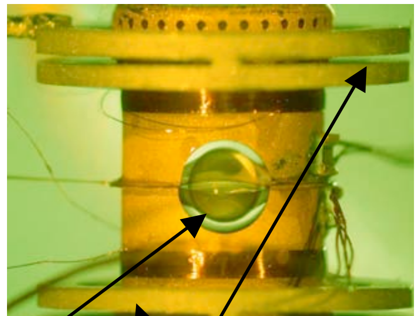
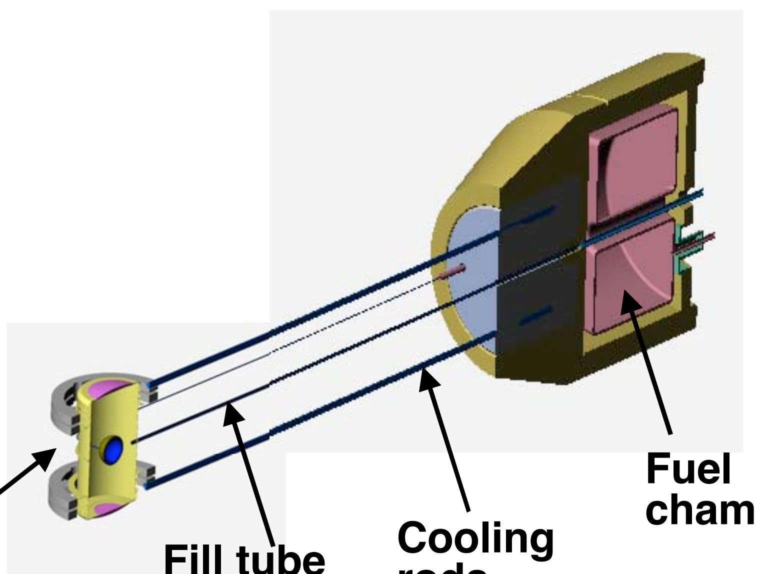
View of 2mm shell through laser entrance hole

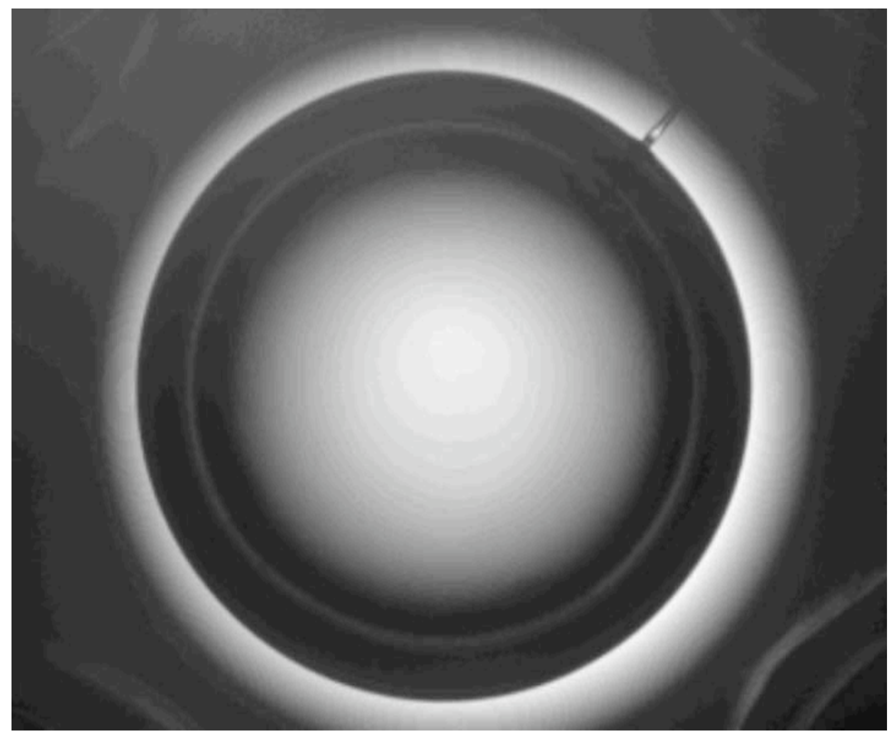
View of 2mm shell through side hole



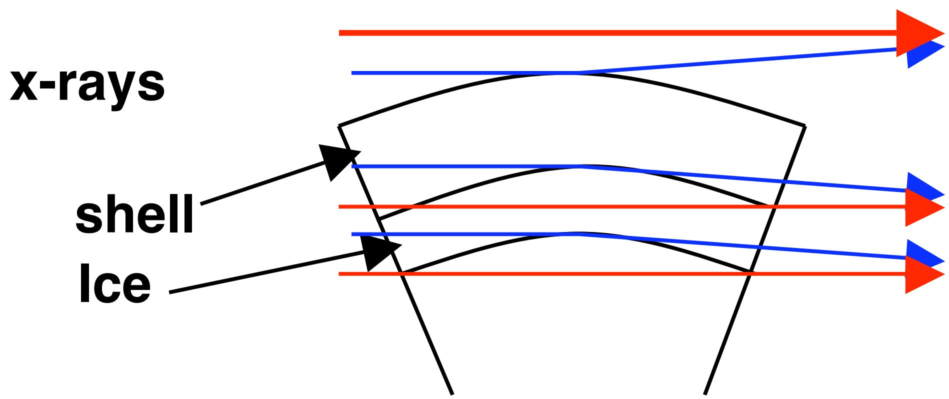


- **Fuel pressure 2-3 atm**
  - **~ 5 Ci DT**
- **Capsule filled *in target inserter* by temperature control on fuel reservoir and hohlraum**

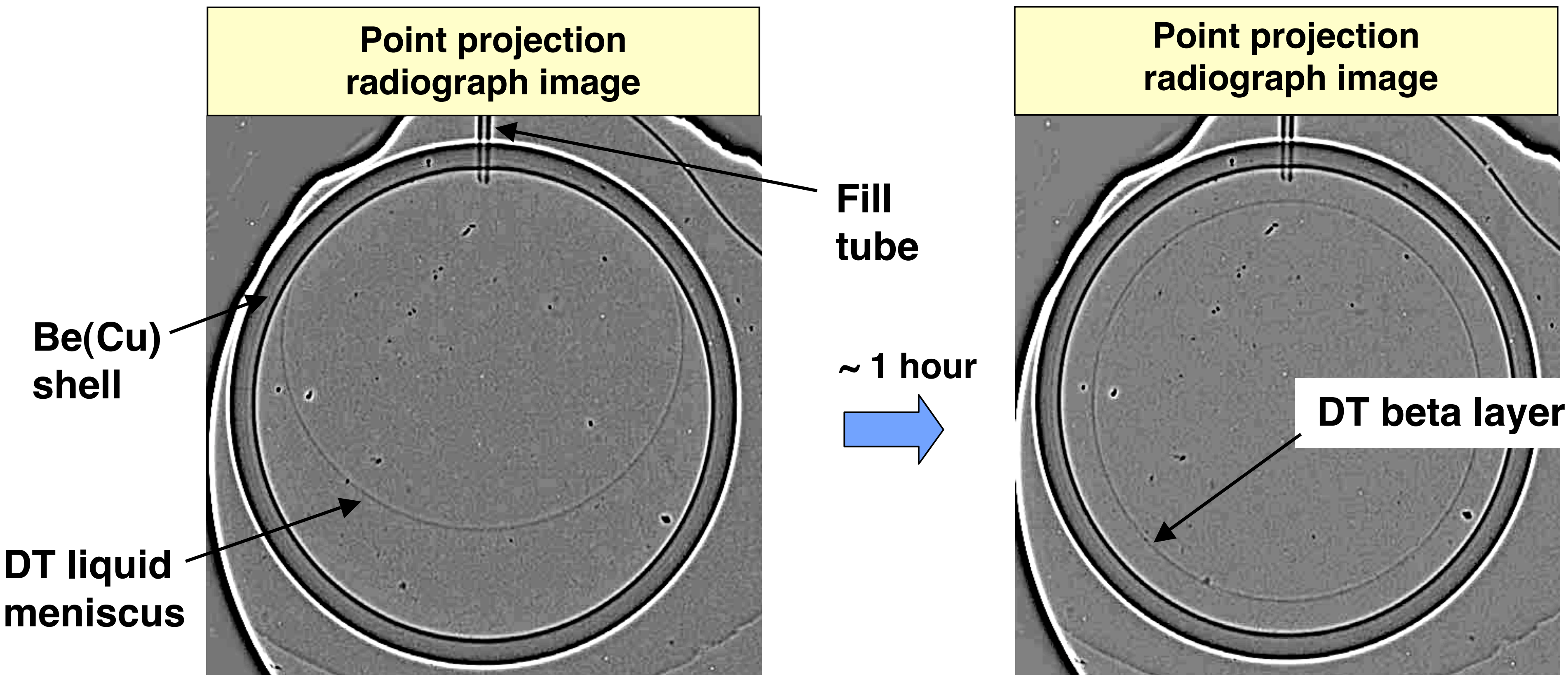




The DT fuel layer in optically opaque beryllium has been recently characterized with x-ray refraction

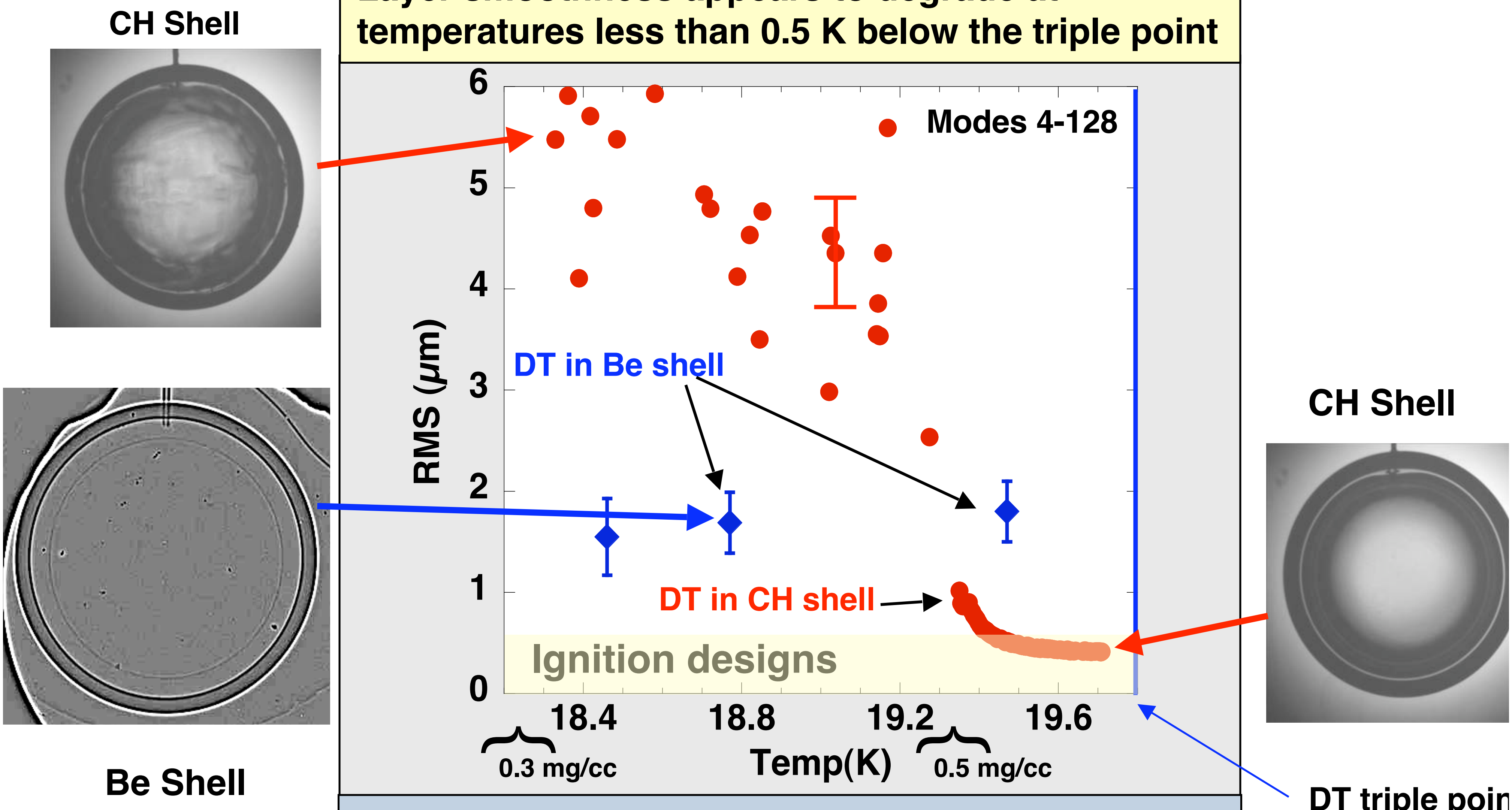


- Rays tangent to surface are slightly deflected
- Other rays are very nearly un-deflected
- This method is many times more sensitive than absorption



The best cryo layers are formed near the triple point

Layer smoothness appears to degrade at temperatures less than 0.5 K below the triple point



IR enhanced layering is one technique shown to keep the layer smooth at temperatures down to 1.5 K below the triple point

The lower gas fill obtained with lower temperature cryo fuel layers lowers the energy required for ignition

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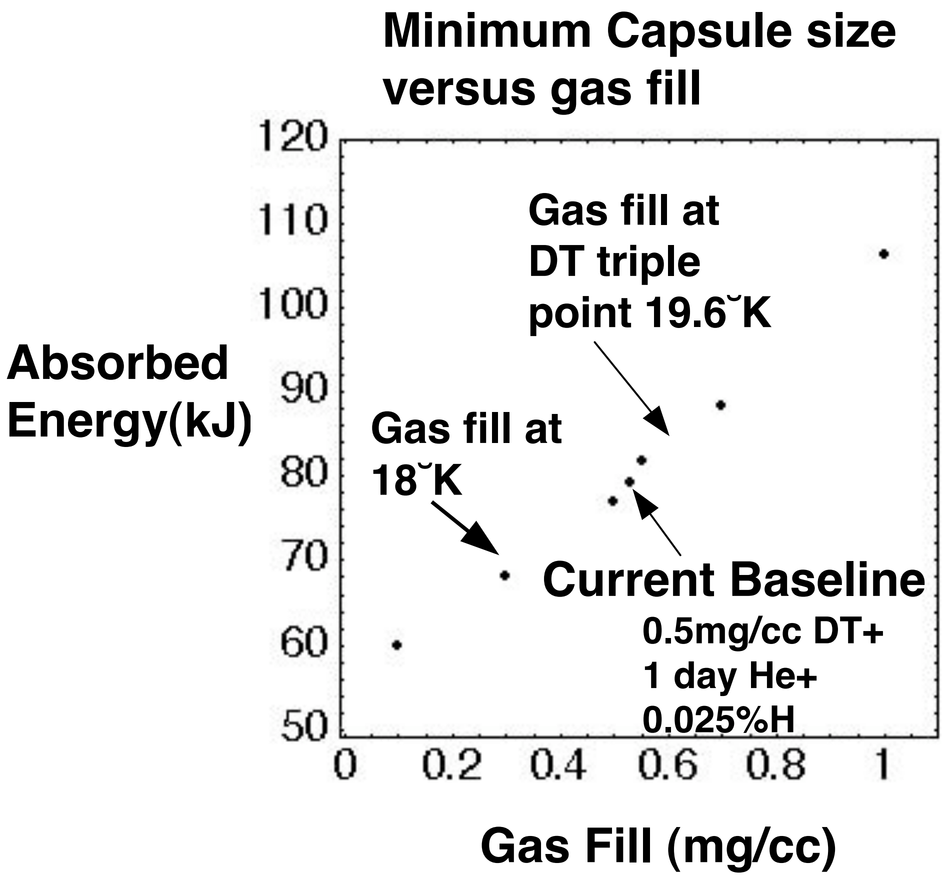

The ignition island is increased by improving target fabrication

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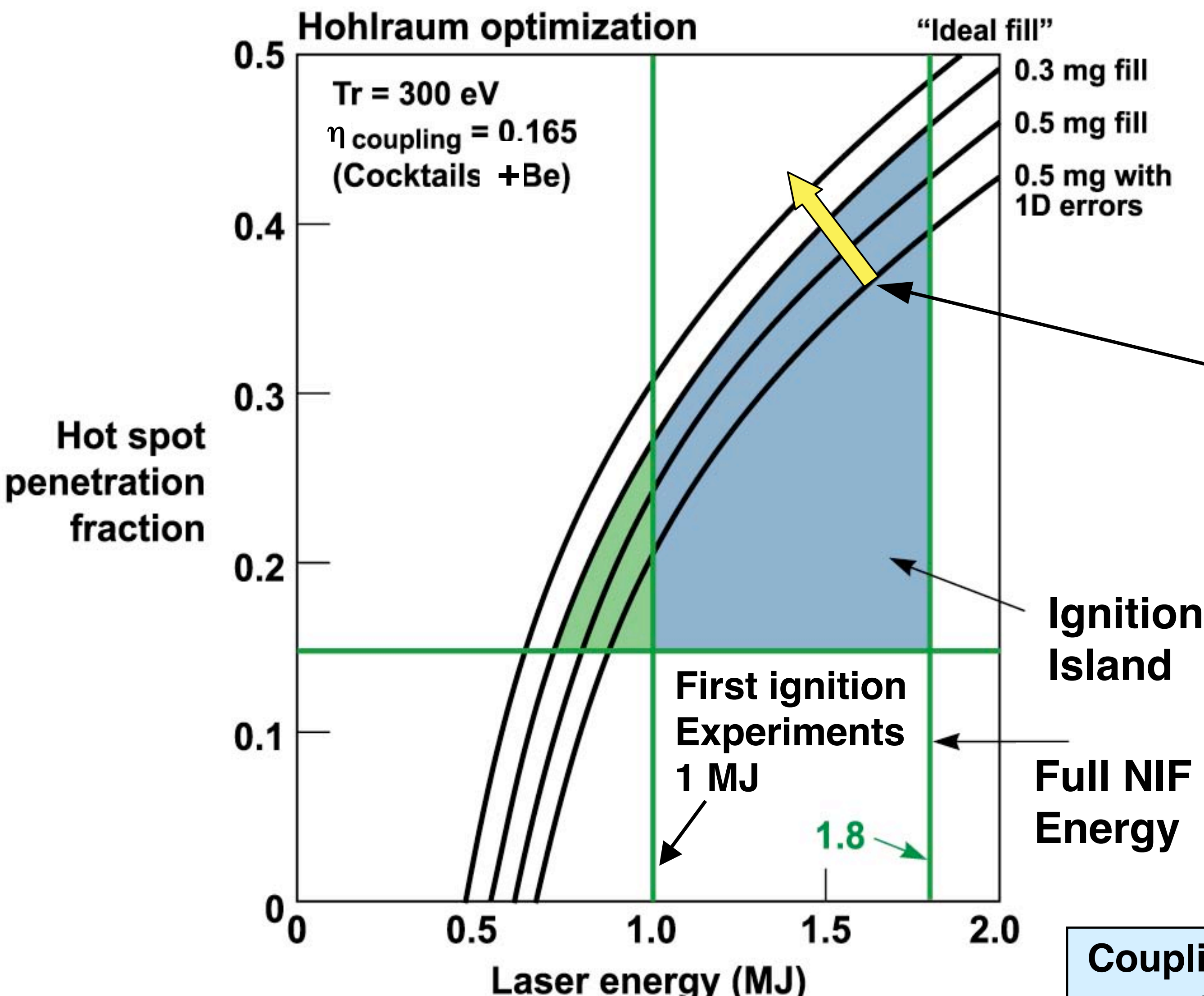

The goal of target fabrication and the implosion dynamics campaign is to achieve capsule performance which is near the ideal limit

Coupling efficiency = $\eta_{abs}\eta_H$
η_{abs} = 1 - backscattered fraction
η_H = hohlraum coupling efficiency

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NIF's 192 beams are organized into "bays", "clusters", "bundles", and "quads"

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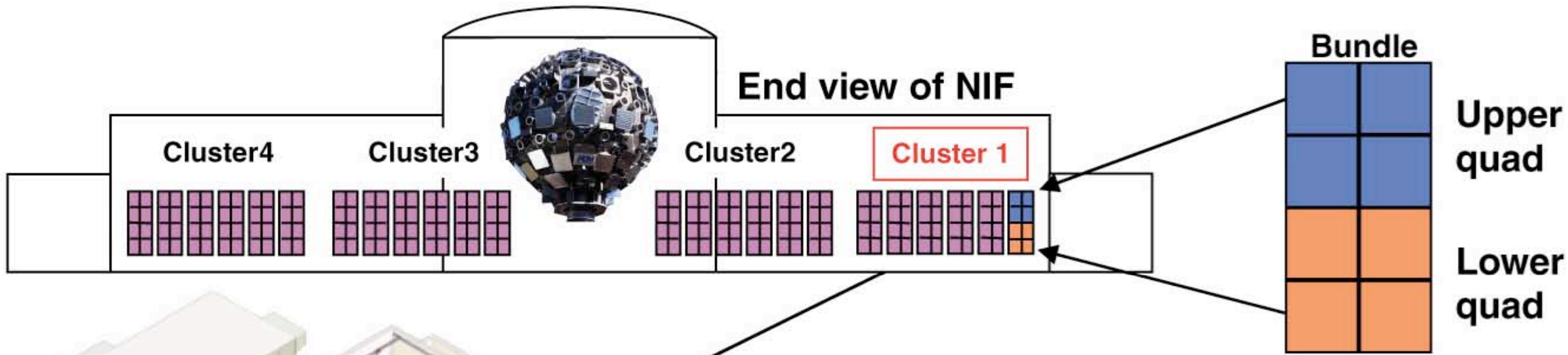

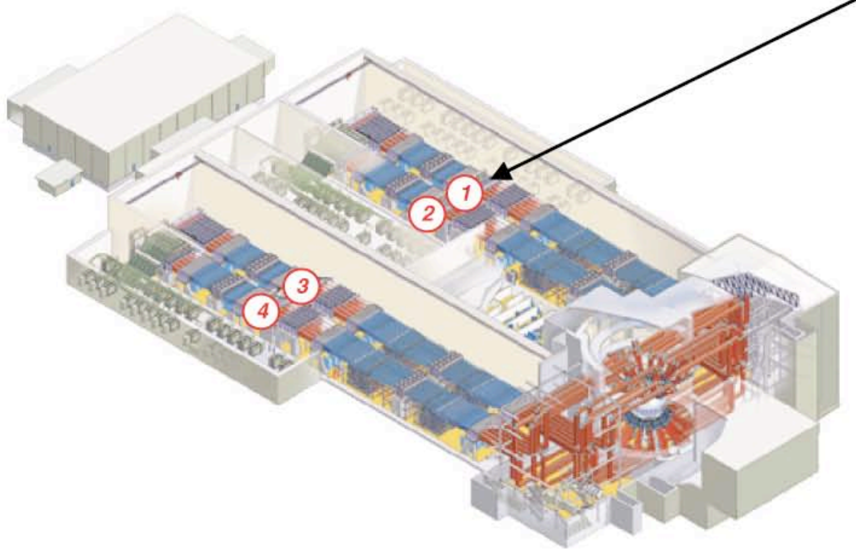

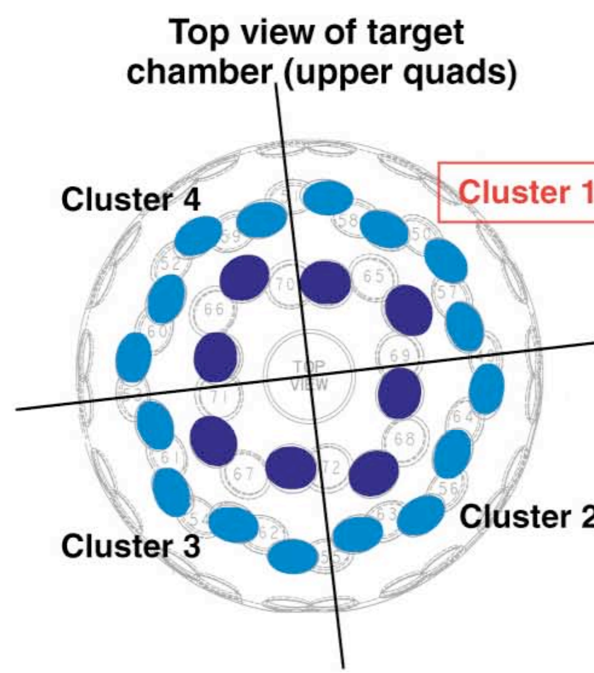

"Quads" are the basic building blocks of a NIF experiment, 4 beams with the same pulse shape and time delay

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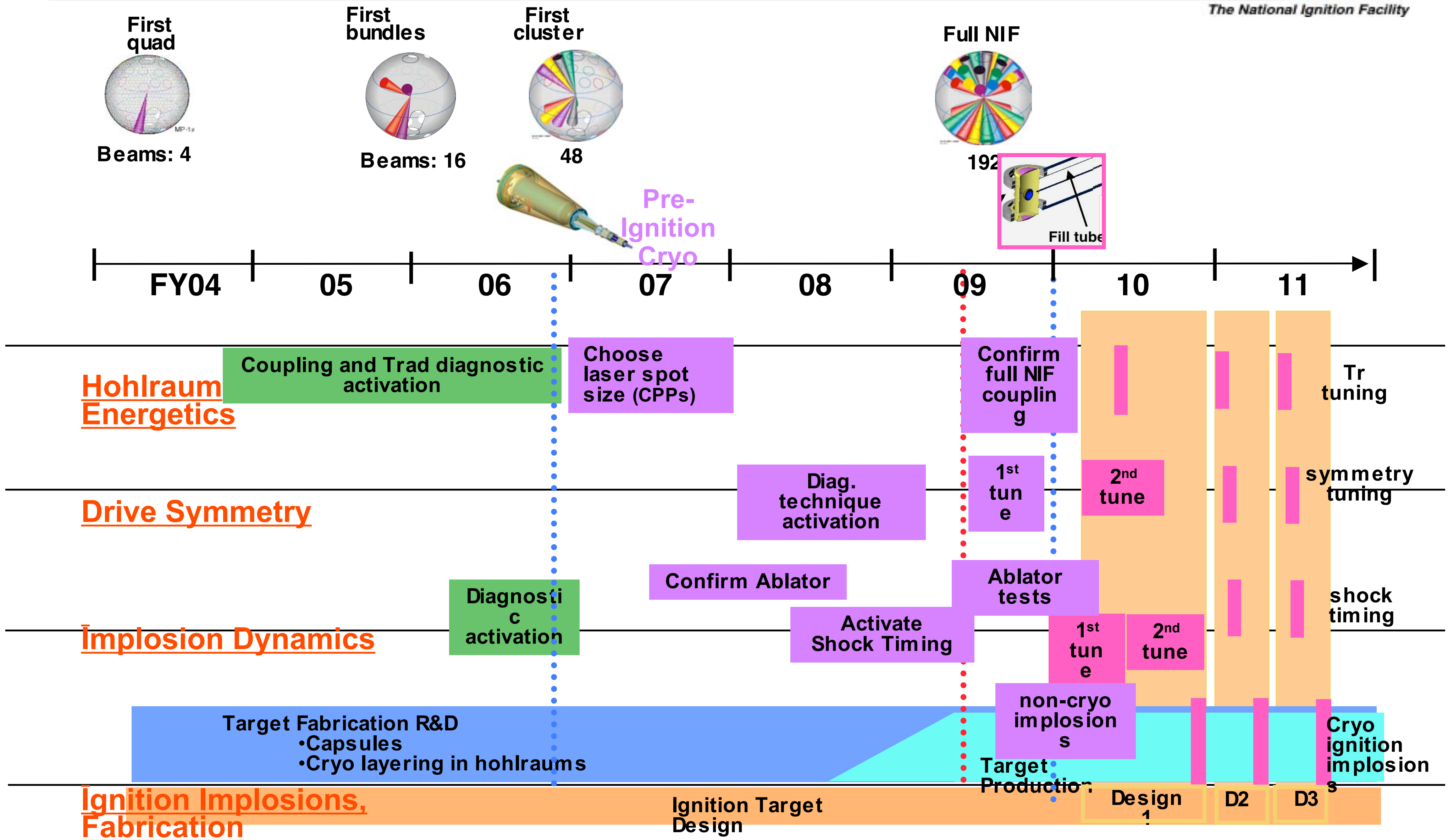
The beampath infrastructure for all 192 beams is complete and the first four beams have been activated for experiments

The NIF Early Light (NEL) commissioning of four laser beams has demonstrated all of NIF's primary performance criteria on a per beam basis

- 21 kJ of 1w light (Full NIF Equivalent = 4.0 Mjoule)
- 11 kJ of 2w light (Full NIF Equivalent = 2.2 Mjoule - non-optimal crystals)
- 10.4 kJ of 3w light (Full NIF Equivalent = 2.0 Mjoule)
- 25 ns shaped pulse
- < 5 hour shot cycle (UK funded shot rate enhancement program)
- Better than 6% beam contrast
- Better than 2% beam energy balance
- Beam relative timing to 6 ps

Key NIF ignition experiments begin following first cluster completion and full system ignition experiments start in FY9-10 following project completion

The National Ignition Facility



Cuts in the NIF Project funding for FY05 will delay near term objectives but we are working with NNSA to develop a plan which will preserve the goal of Ignition in 2010

Summary/Conclusions

The National Ignition Facility

- Be targets are ~1/3 more efficient than earlier CH designs and more robust to hydrodynamic instability.

- Major advances in Be capsules filled through a few micron fill tube have opened up the possibility of implementing a greatly simplified cryo target support system on NIF for early ignition experiments

- Success with Be capsules, and the use of "cocktail" wall hohlraums would result in a target which is about 2/3 more efficient than the original baseline targets.

- This would enable successful ignition experiments at ~1 MJ in the first couple of years after completion of the NIF and allow much higher yields when NIF operates at its full design energy of 1.8 MJ.

- Additional optimization and hohlraum features such as laser entrance hole shine shields can yield further increases in coupling efficiency and yields.