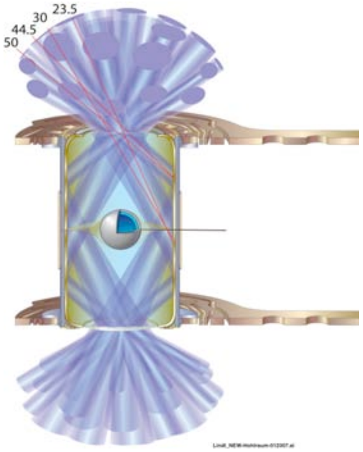
Preparation for Ignition Experiments on the NIF

Fusion Power Associates Annual Meeting
December 4-5, 2007



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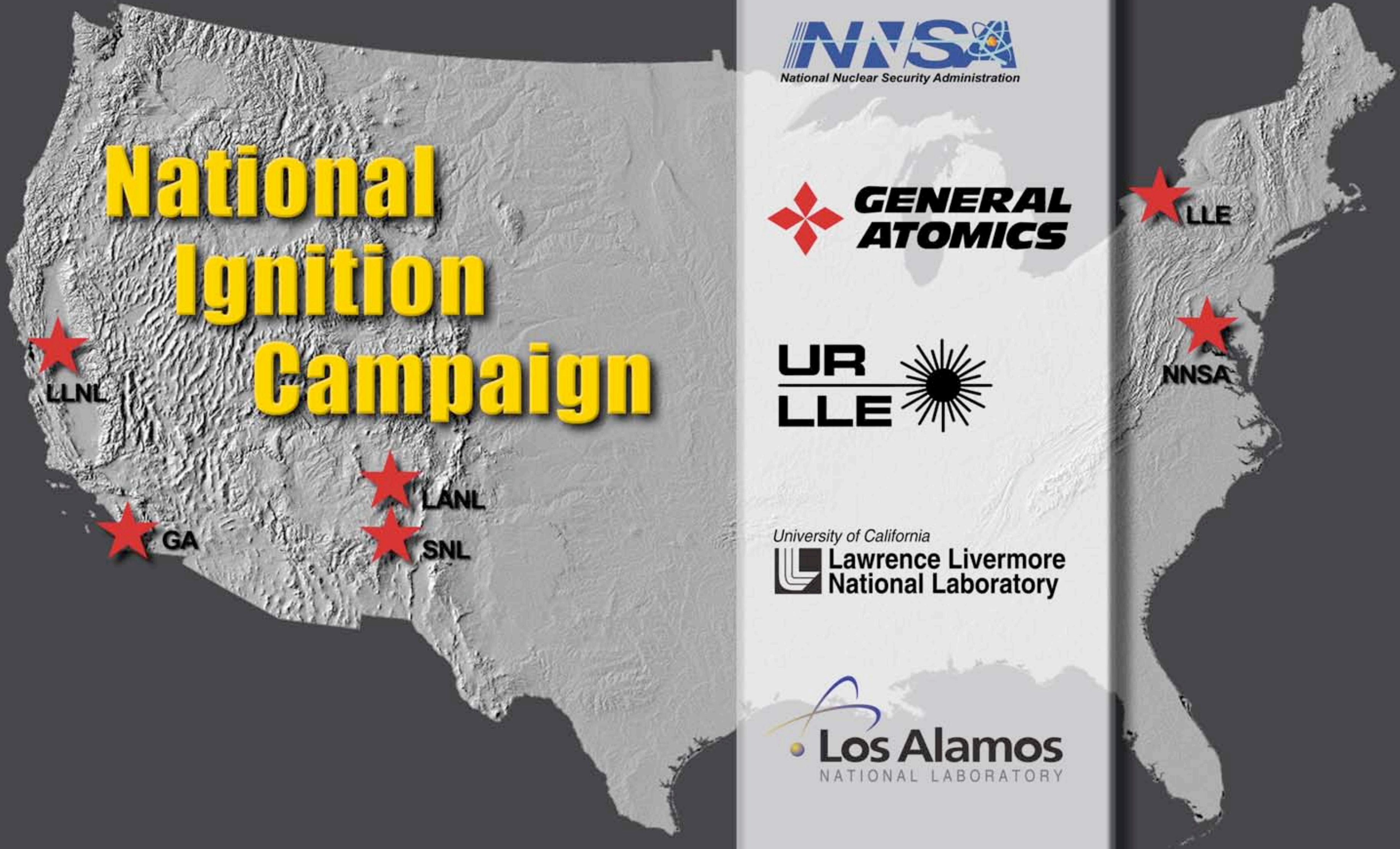
Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344



National Ignition Campaign

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The National Ignition Campaign is focused on preparing for credible ignition experiments in 2010

- We are designing precision experimental campaigns for hohlraum energetics, shock strengths and times, implosion velocity and ablated mass, and symmetry, which will take 100-200 shots leading up to the first ignition attempts

- Targets near 1 MJ of laser energy have a credible chance for ignition in early NIF operations

- The initial ignition experiments only scratch the surface of NIF’s potential

The NIF point design has a graded-doped, beryllium capsule in a hohlraum driven at 285 eV

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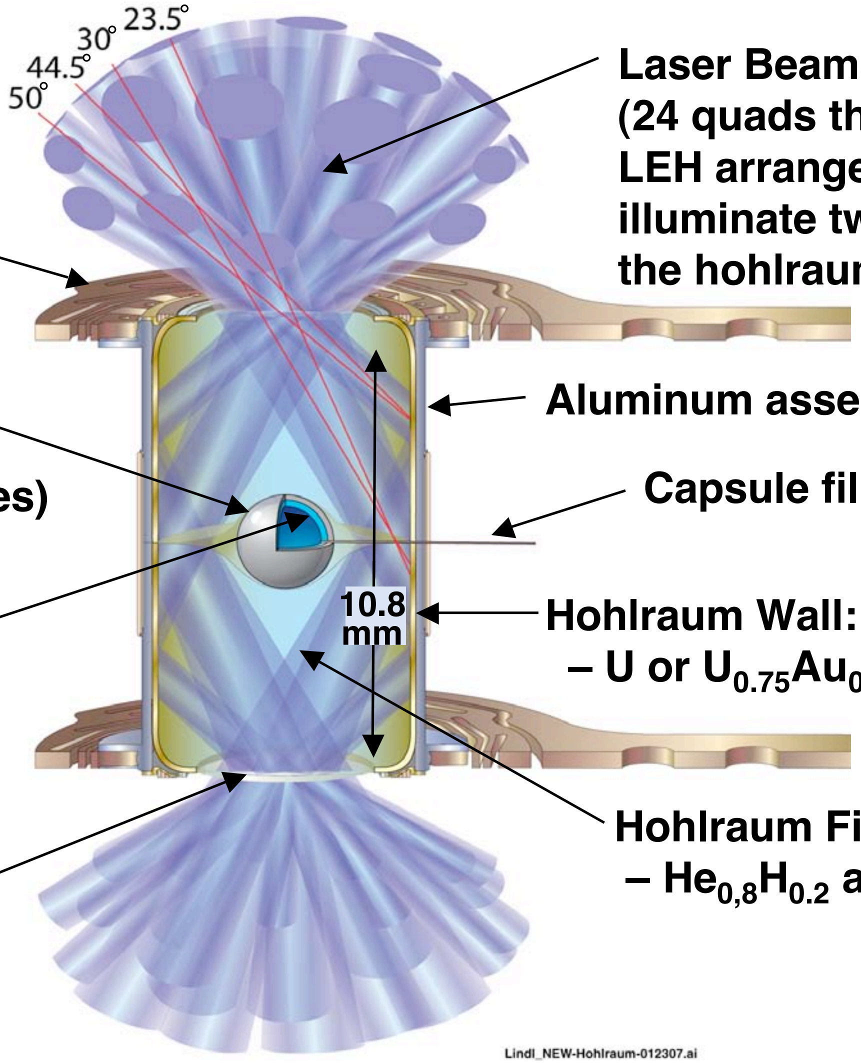


Cryo-cooling Ring

Laser Beams (24 quads through each LEH arranged to illuminate two rings on the hohlraum wall)

Graded-doped Be Capsule (CH and Diamond are alternates)

Aluminum assembly sleeve

Capsule fill tube

Solid DT fuel layer

Hohlraum Wall:

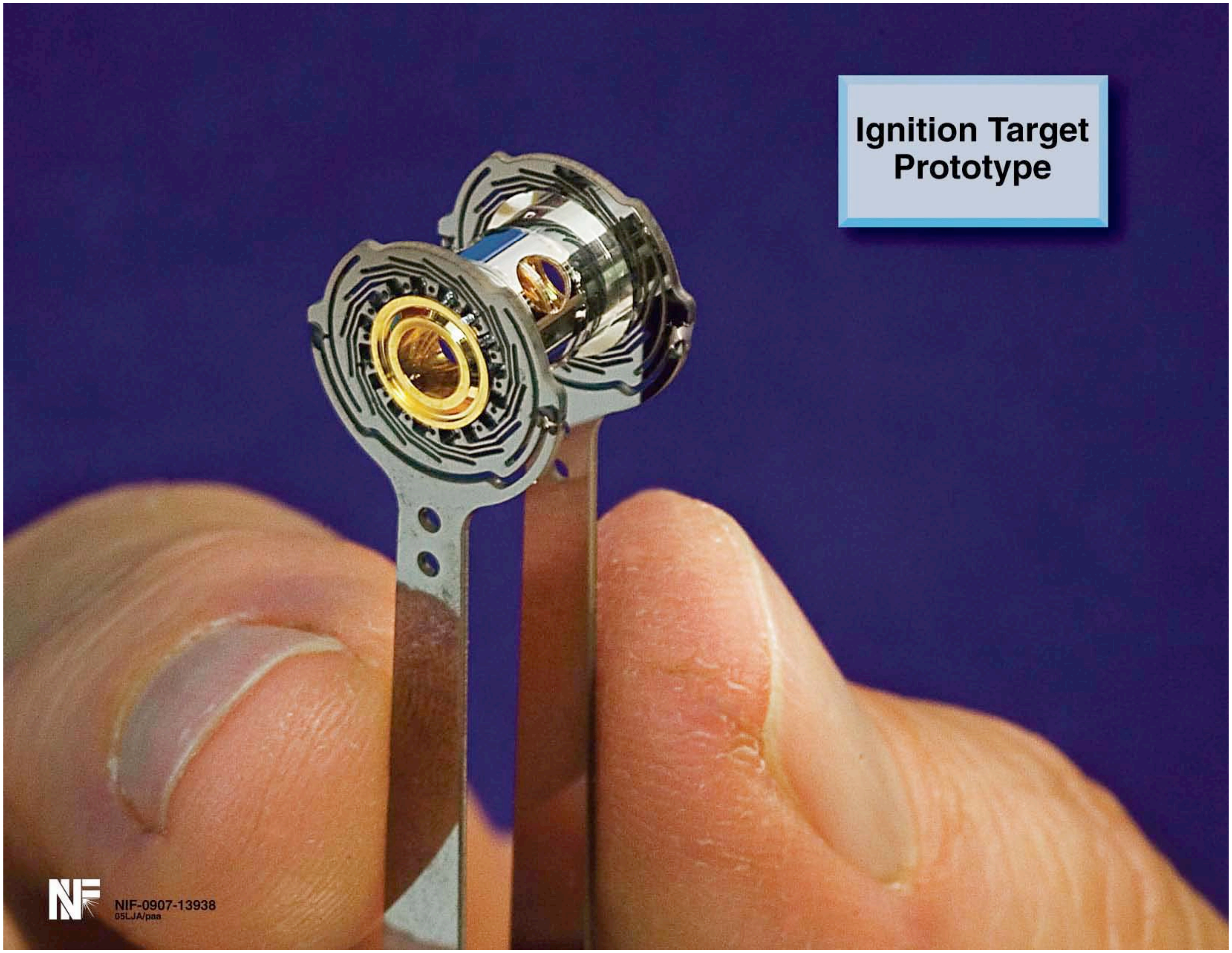
– U or $U_{0.75}Au_{0.25}$

Hohlraum Fill

– $He_{0,8}H_{0.2}$ at 0.9 mg/cm^3

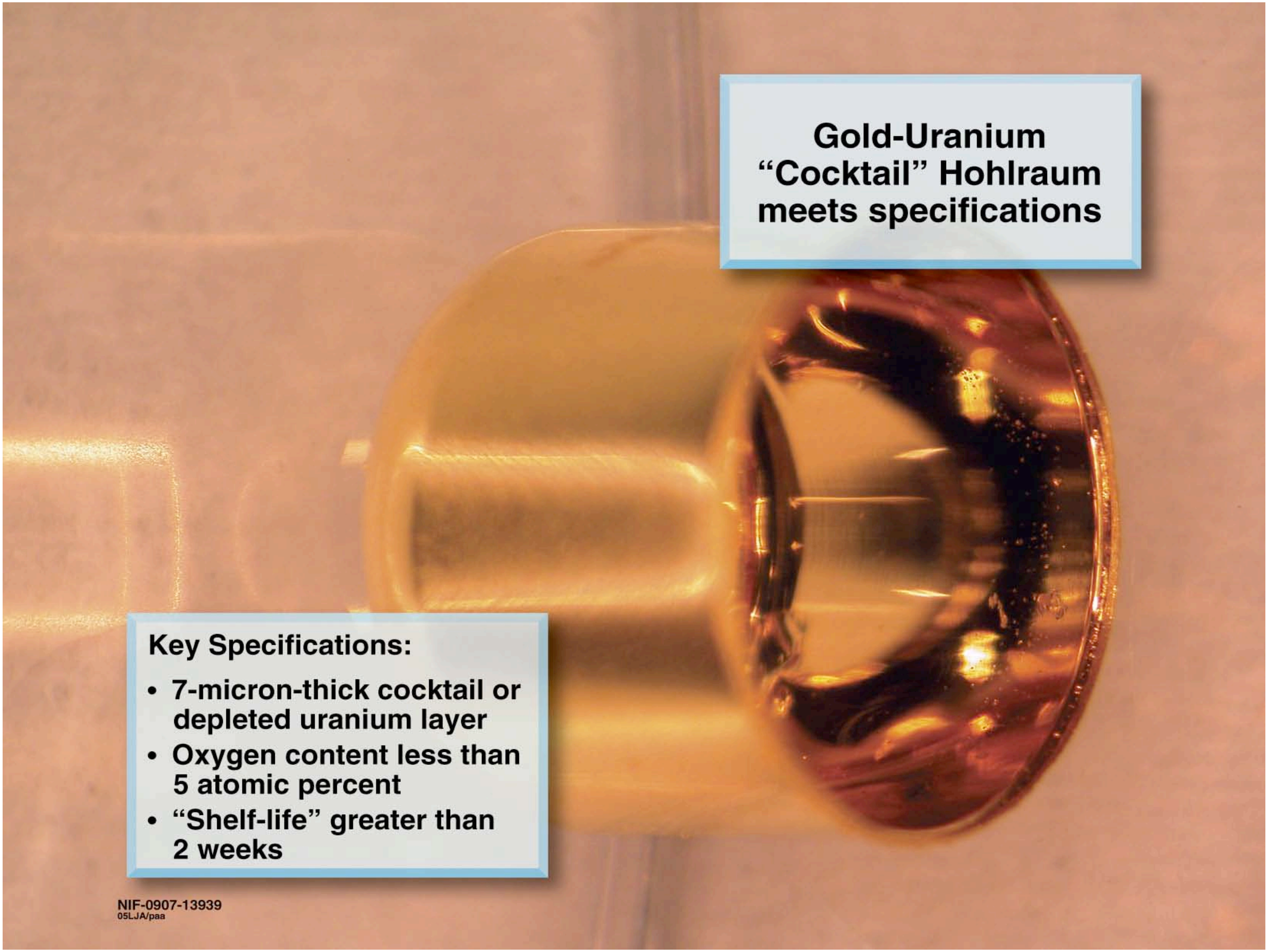
Laser Entrance Hole (LEH) with window

Precision target fabrication and assembly techniques being developed for the NIF meet the ignition target requirements



Ignition Target Prototype

NIF-0907-13938
05LJA/paa



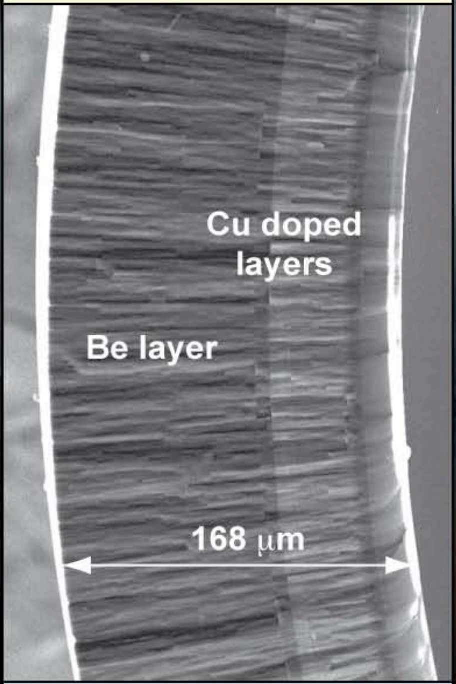
Gold-Uranium "Cocktail" Hohlraum meets specifications

Key Specifications:

- 7-micron-thick cocktail or depleted uranium layer
- Oxygen content less than 5 atomic percent
- "Shelf-life" greater than 2 weeks

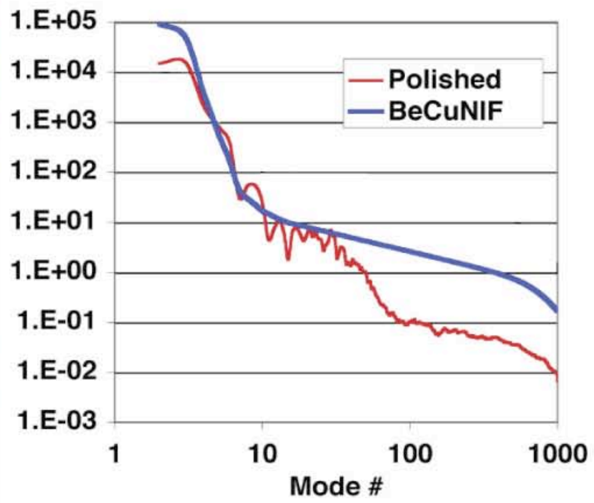
Be Capsule meets specifications

Full Thickness Cu-Doped Be Shell

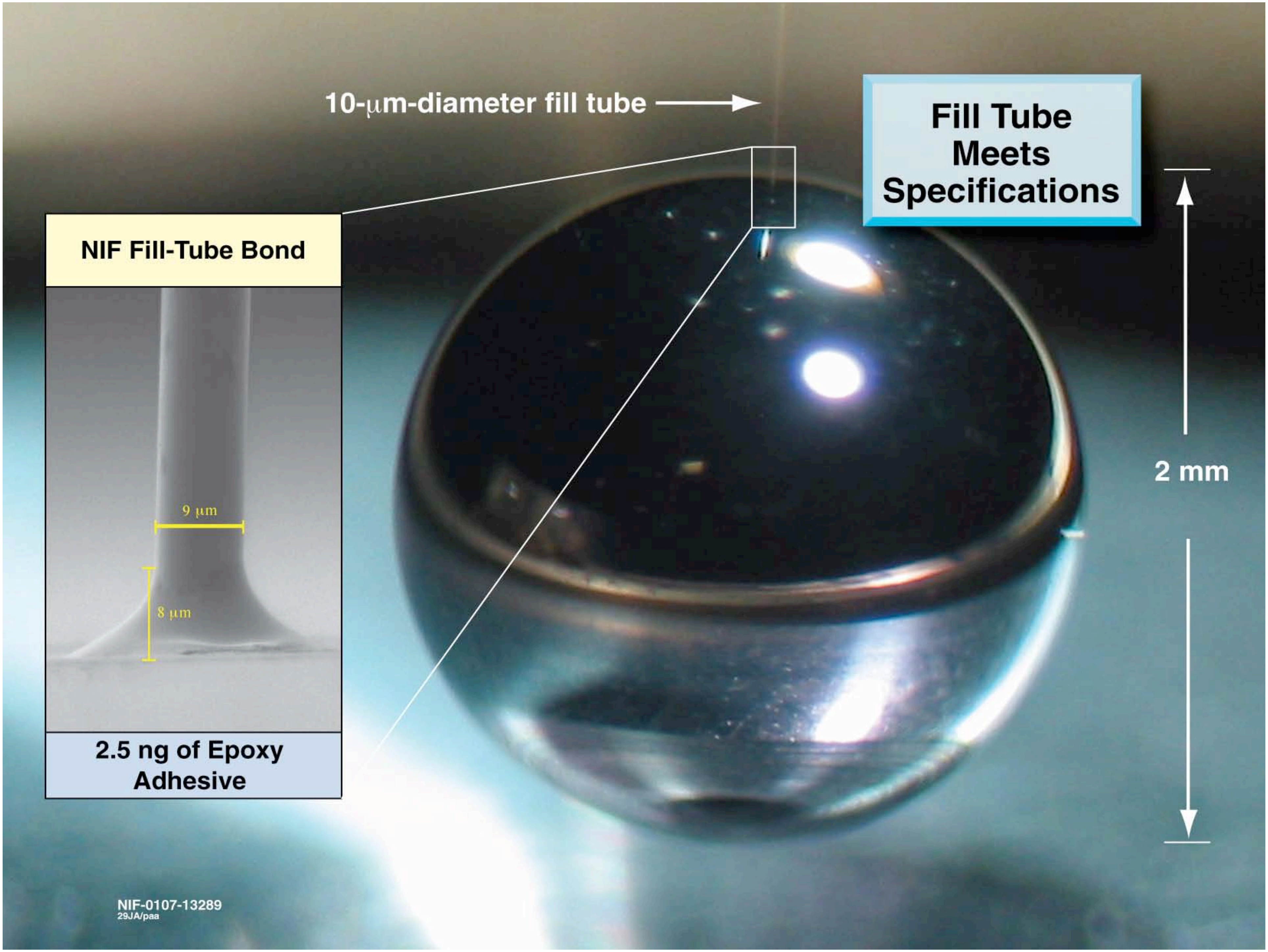


- 95% Dense
- Gas Impermeable

Power Spectral Density (PSD) of Polished and Unpolished Be Shells



Fill Tube Meets Specifications



NIF Fill-Tube Bond

2.5 ng of Epoxy Adhesive

Ignition point design optimization must balance LPI effects, laser performance impacts, and capsule robustness

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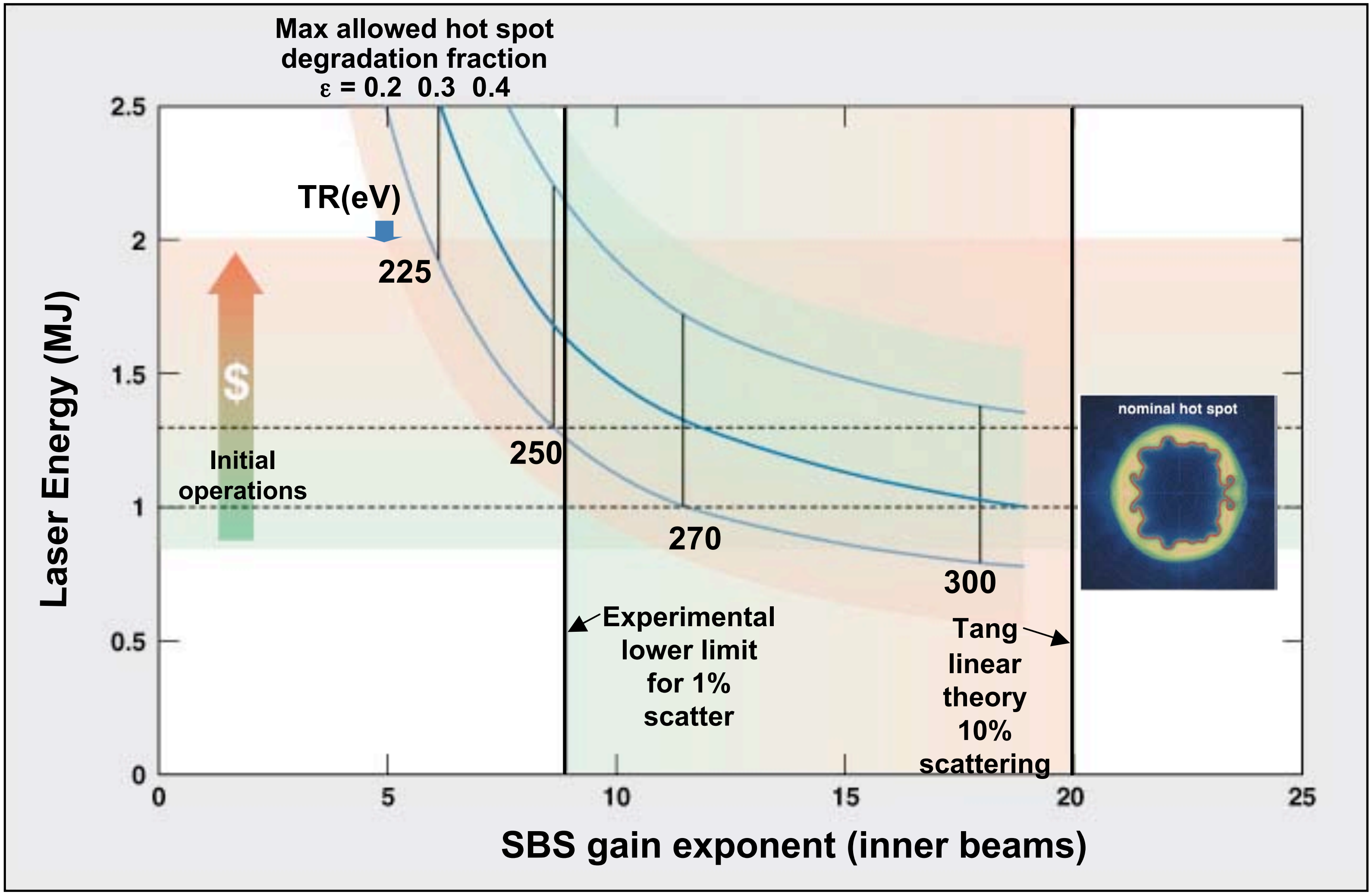

Ignition point design optimization must balance LPI effects, laser performance impacts, and capsule robustness

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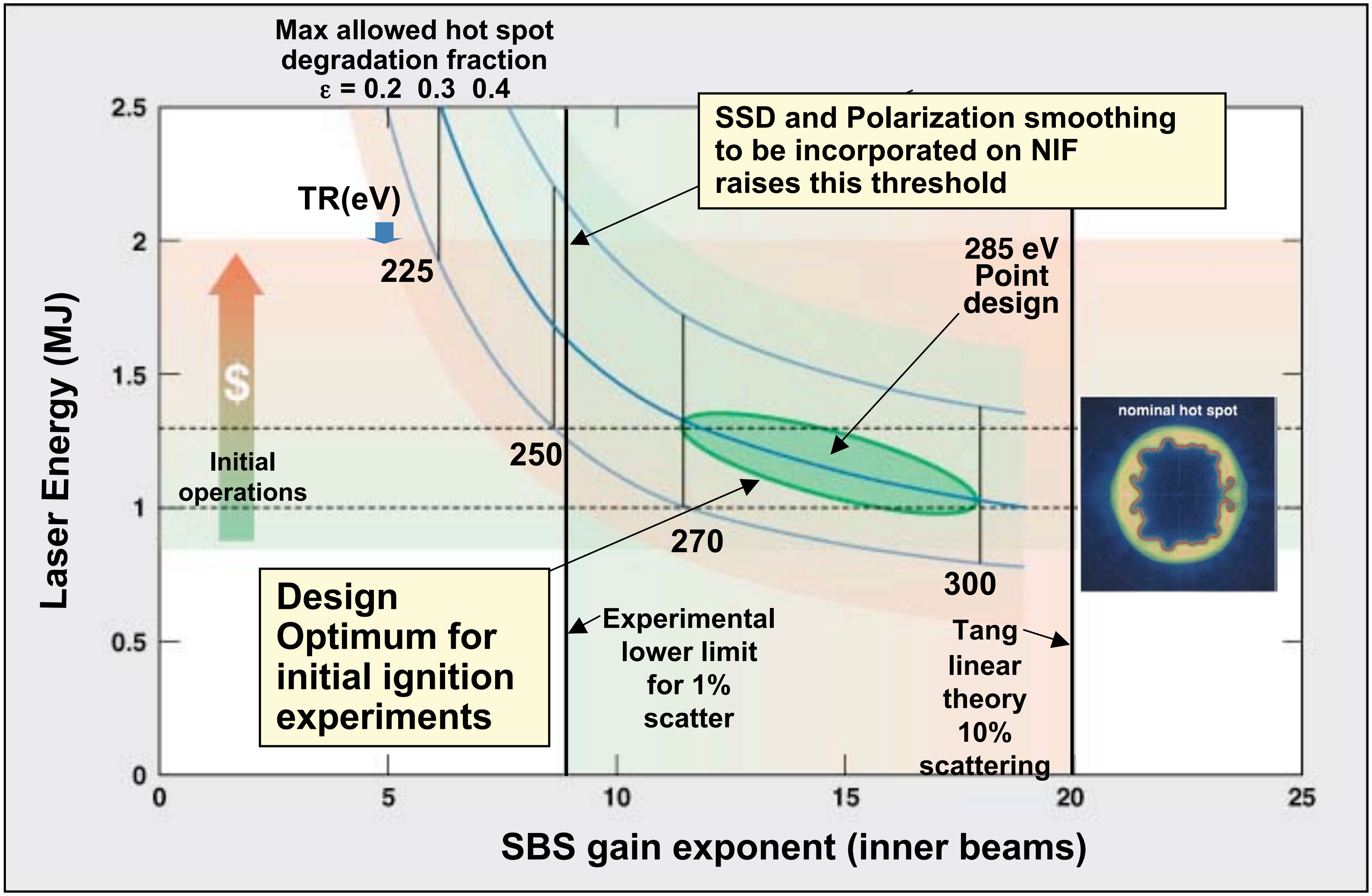


SSD and Polarization smoothing to be incorporated on NIF raises this threshold

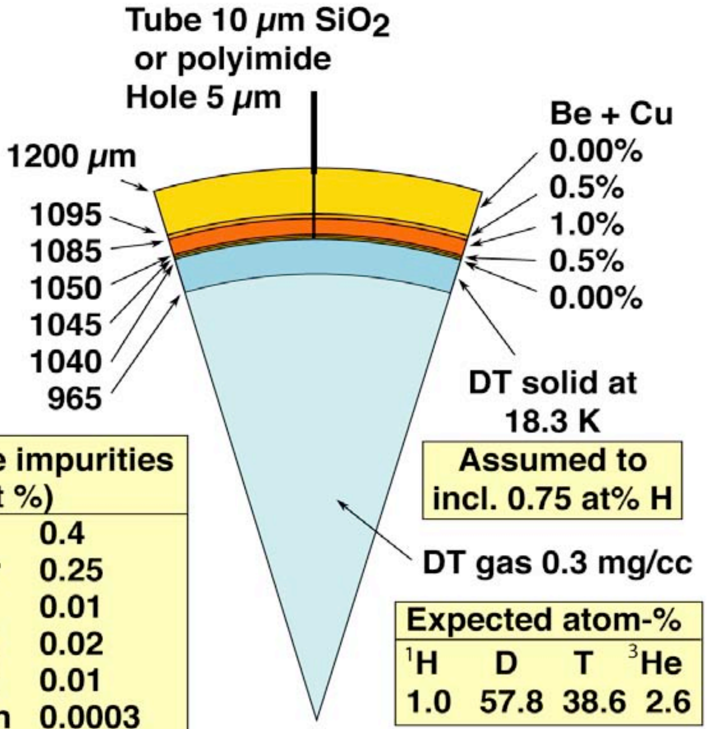
Design Optimum for initial ignition experiments

Experimental lower limit for 1% scatter

Tang linear theory 10% scattering

The point design capsule of copper doped Be driven at 285 eV has been specified in detail

(Cu doped Be shell for 285eV, 1.3 MJ)



Be impurities (at %)	
O	0.4
Ar	0.25
C	0.01
Al	0.02
Si	0.01
Mn	0.0003
Fe	0.01
Ni	0.002

Assumed to incl. 0.75 at% H

Expected atom-%

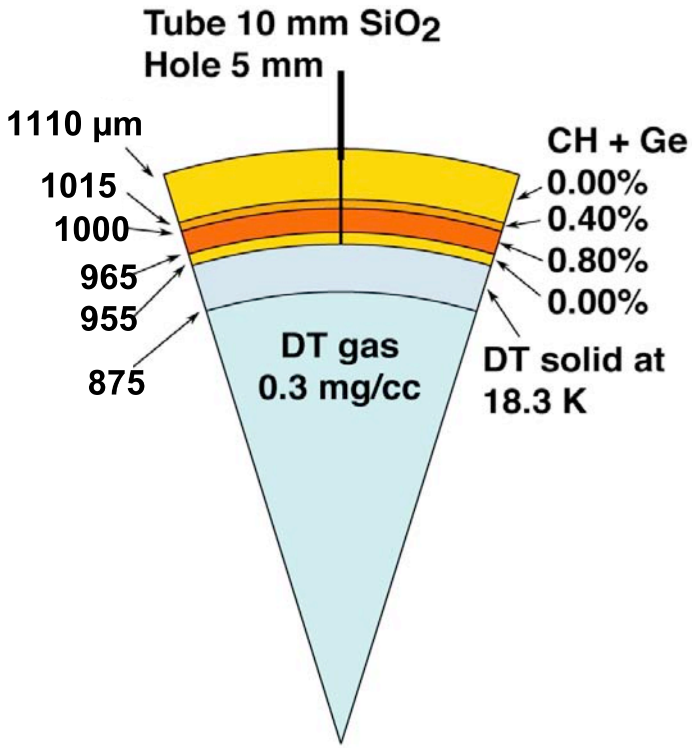
^{1}H	D	T	^{3}He
1.0	57.8	38.6	2.6

Inner 0.75 µm of Be contains two layers of 12-at% Be(B)

Details in boxes are point-design specifics, not requirements

Parameter	Be(285) "current best calc"
Absorbed energy (kJ)	203
Laser energy (kJ) (includes ~8% backscatter)	1300
Coupling efficiency	0.156
Yield (MJ)	19.9
Fuel velocity (10^7 cm/sec)	3.68
Peak rhoR (g/cm^2)	1.85
Adiabat (P/P$_{FD}$ at 1000g/cc)	1.46
Fuel mass (mg)	0.238
Ablator mass (mg)	4.54
Ablator mass remaining (mg)	0.212
Fuel kinetic energy (kJ)	16.1

A CH capsule at 300eV and 1.3 MJ is the principal alternate to Be at 285 eV



	CH(300)
Yield	17.6 MJ
Eabs	150 kJ
Implosion velocity	3.85×10^7 cm/s
Fuel mass	0.21 mg
Ablator mass	2.3 mg

- Post-processed hohlraum simulations at 300 eV indicate LPI equivalent to or better than Be at 285eV
- Amorphous material with no crystal structure issues
- Large data base from Nova and Omega
- Less efficient ablator but at 1.3 MJ (&300eV), this target looks attractively robust. More work in progress.
- Transparency makes cryo layer easier to characterize but low thermal conductivity makes layer formation in the hohlraum more challenging

We are also evaluating a nanocrystalline diamond ablator option at 270 eV and 1.3 MJ

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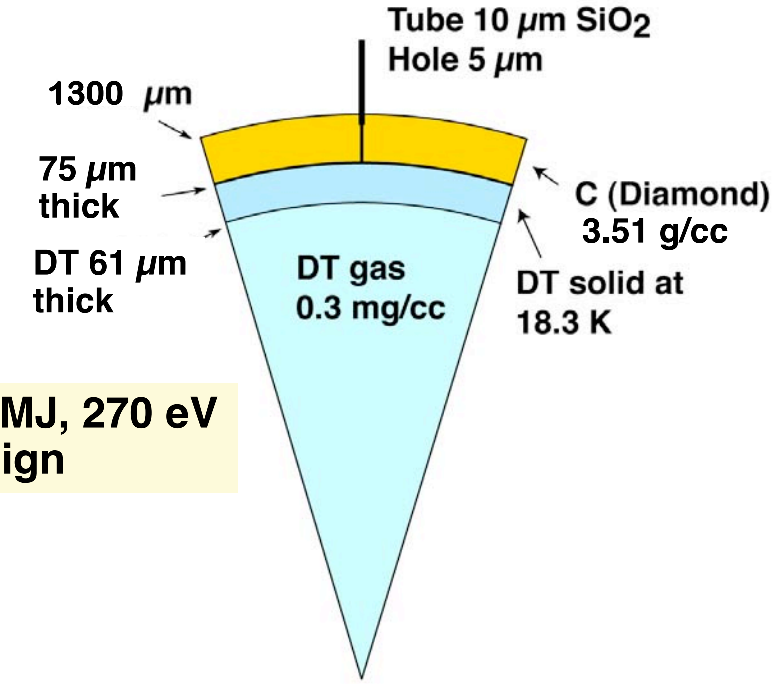

1.3 MJ, 270 eV design

	Diamond(270)
Yield	24.7 MJ
Eabs	260 kJ
Implosion velocity	3.58×10^7 cm/s
Fuel mass	0.27 mg
Ablator mass	5.26 mg

- Higher density: diamond absorbs energy at larger radius. Equivalent to 10 - 20% more laser energy.
- Ablator surface is very smooth. Can tolerate 20x the measured surface roughness.
- LPI analysis indicates 270 eV diamond hohlraum has less risk than Be hohlraum at 285eV
- Complex material properties during pulse shaping: Stays solid after 1st shock, melts with 2nd shock (Be melts with 1st)

Assessment of ignition targets utilizes computer calculations, coupled to planned precision target physics campaigns

- We are designing experimental campaigns for hohlraum energetics, shock strengths and times, implosion velocity and ablated mass, and symmetry, which will take 100-200 shots leading up to the first ignition attempts
- Most physics uncertainties will be normalized out with these "optimization" experiments (Residual physics uncertainties for these items are set by how accurately we can do the experiments - the point design specs include estimates for the achievable accuracy)
- Specifications on target fabrication and laser performance are set to achieve the required precision and reproducibility.
- Uncertainty in some physics issues such as DT thermal conduction and alpha particle deposition in Fermi degenerate DT will remain after these experiments

Our key question is *not* "How well can the codes predict the ignition target a-priori?", but instead "Will the uncertainties and variability that remain after our tuning programs be acceptable?" This is a key focus of our preparations for ignition experiments

The National Ignition Campaign is focused on preparing for the first ignition experiments in 2010

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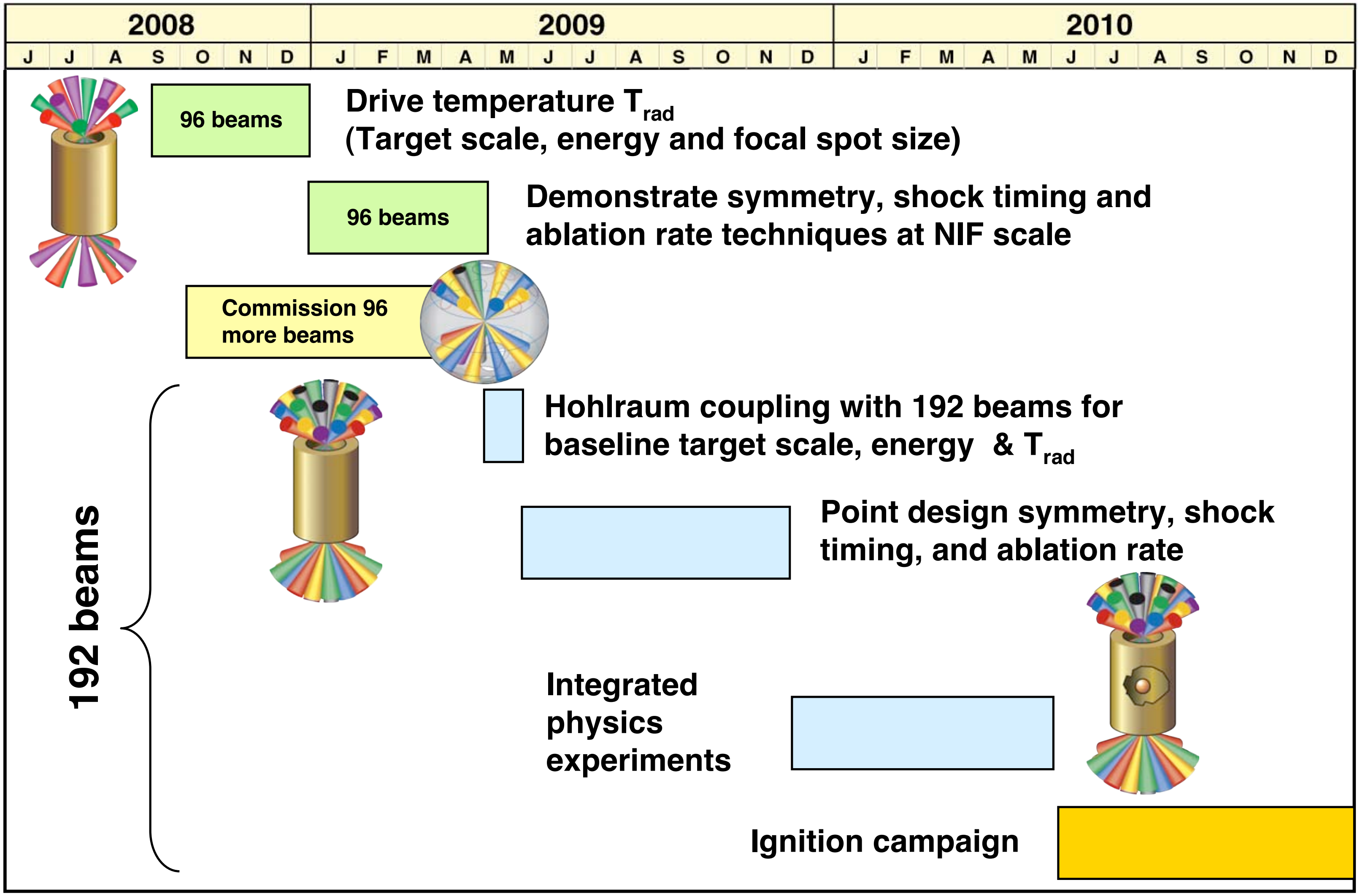
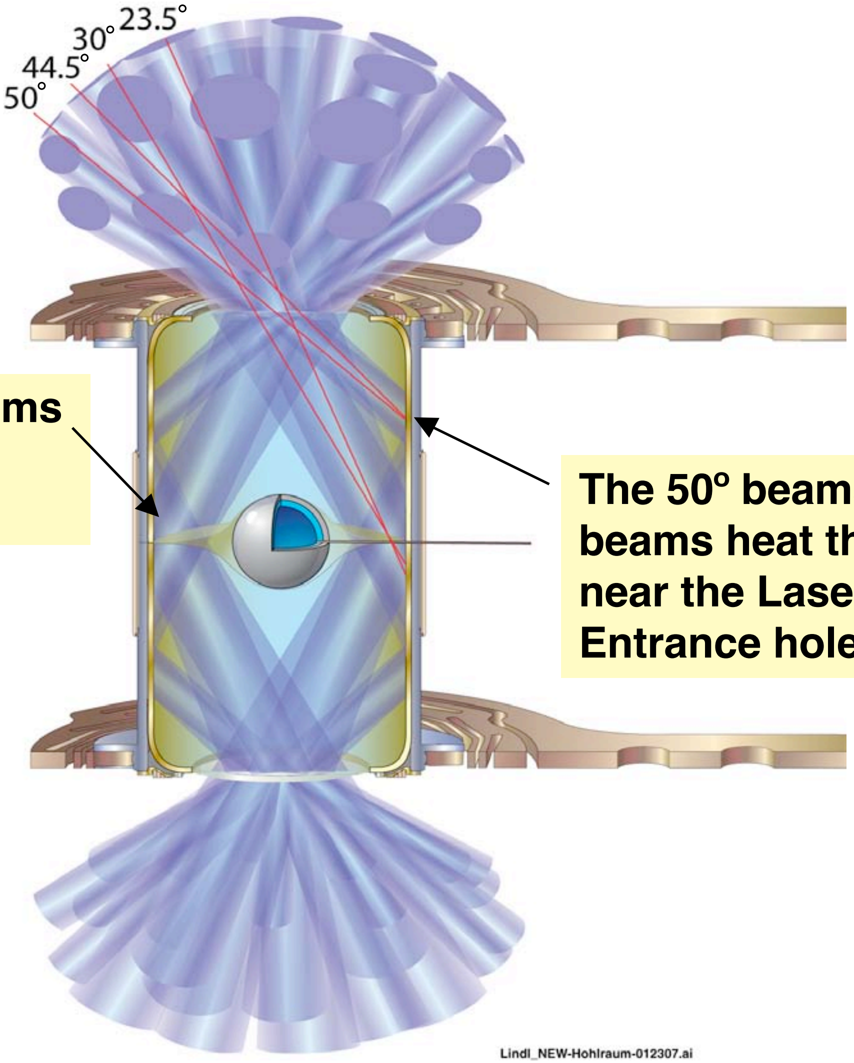


The 96 beam campaign will utilize the 30º and 50º beams to emulate the ignition target



The 23.5º and 30º beams heat the waist of the hohlraum

The 50º beams and 44º beams heat the hohlraum near the Laser Entrance hole

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Resolving laser wavelength scale phenomena in the propagation of a laser beam in an ignition scale plasma is a grand challenge problem.

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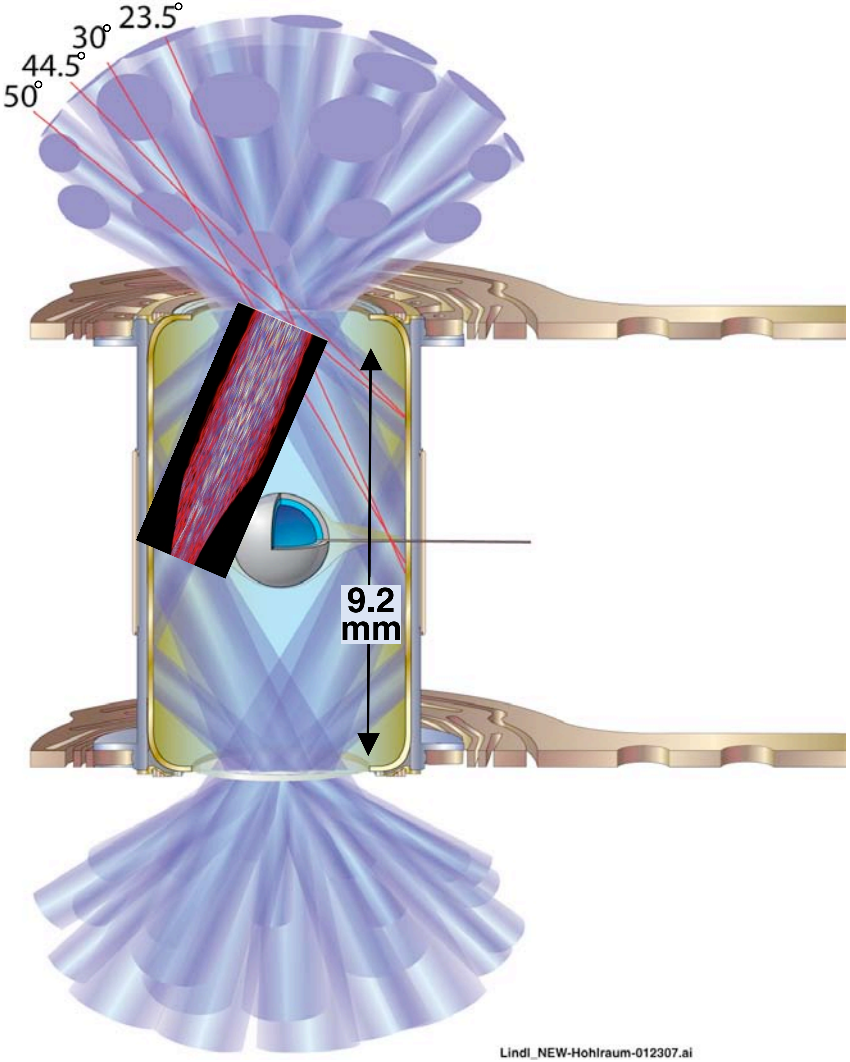
- letterbox" simulations capture the essential physics for "near 2D" situations, like a NIF hohlraum, "

- A letterbox run for 10's of picoseconds using the code pF3D requires 8 Terabytes of memory and ~ 2.5M cpu-hours on the 8000 processor Atlas machine or ~ 15M cpu-hours on 32,000 processors of the 128,000 processor BG/L machine



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The 96 beam emulators are scaled to preserve hohlraum energy density and per beam intensity

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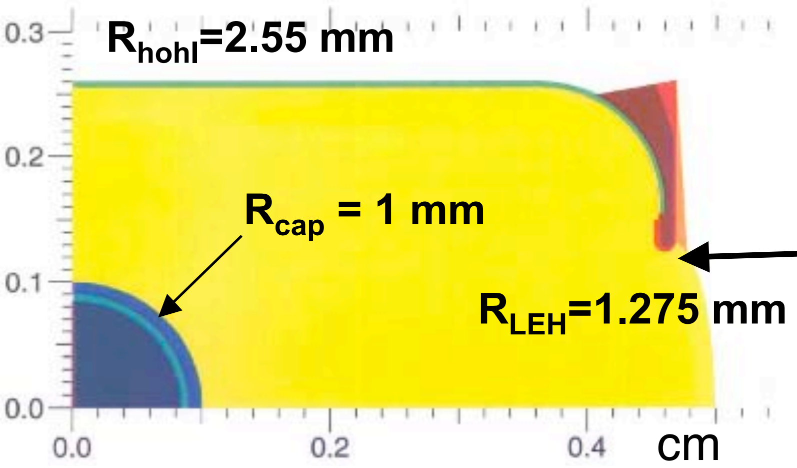
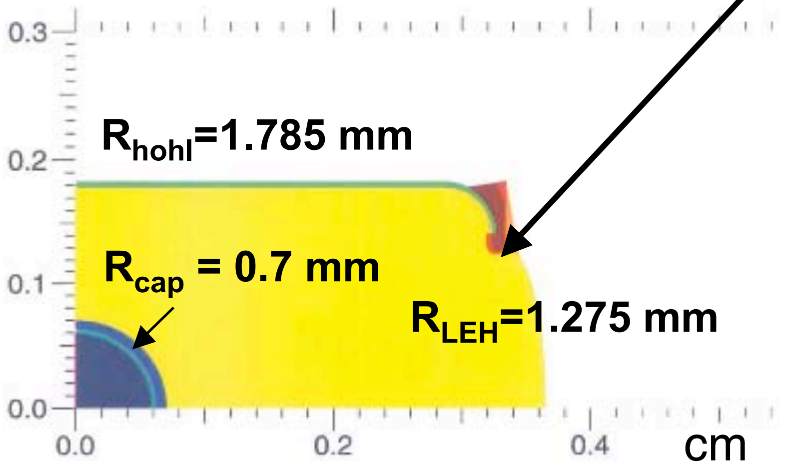
**300 eV
1 MJ,
192
beams)**



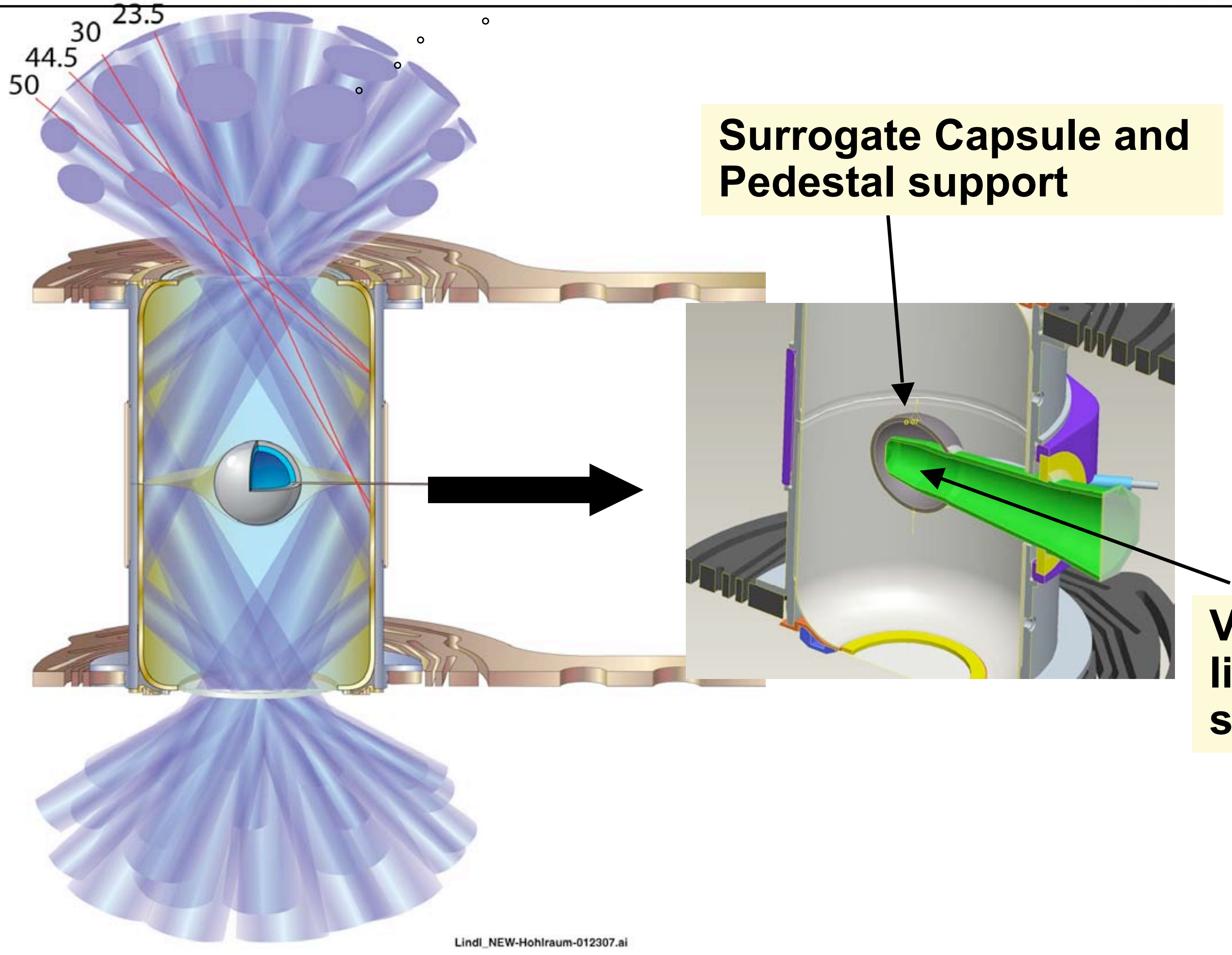
We use full-size phase plates, so the LEH is not scaled.

**96-beam
Emulator
at 70%
scale**



We test various T_{RAD} ignition designs by changing only the laser pulse-shape.

“Keyhole” targets to meet the shock timing requirements are one of the optimization targets which precede ignition experiments



Surrogate Capsule and Pedestal support

Visar line of sight

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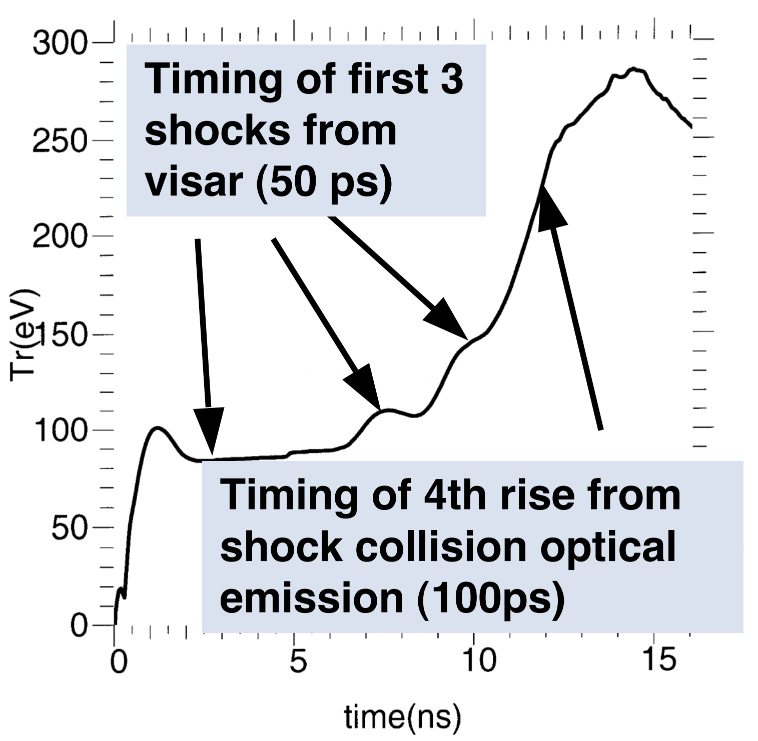
Accurate pulse shaping is a key to “1D” capsule performance

Pulse shape for Be at 1.3 MJ and 285 eV

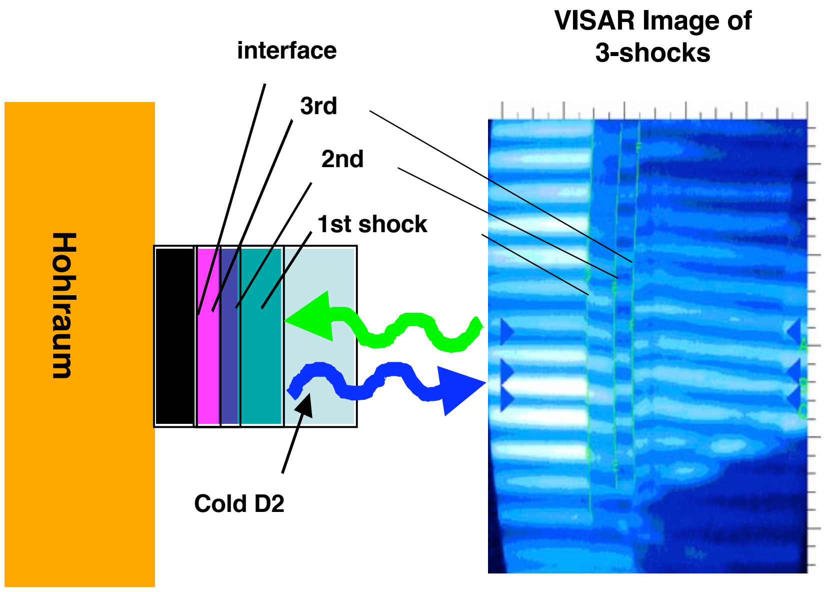


Timing of first 3 shocks from visar (50 ps)

Timing of 4th rise from shock collision optical emission (100ps)

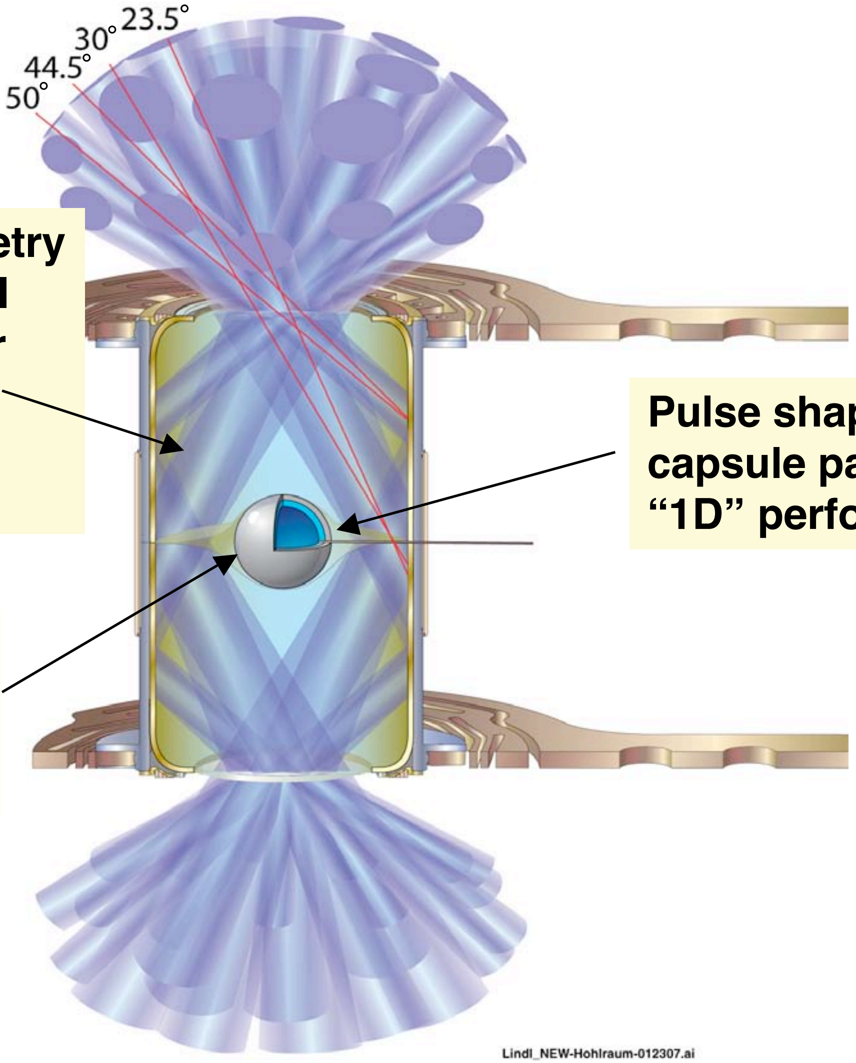
NIF’s pulse shaping system was designed specifically to meet these requirements

VISAR measures shock Front doppler shift



- Jump in fringe shift gives shock arrival
- Fringe position gives shock velocity

We are doing multivariable sensitivity studies to assess the margin and robustness of ignition target designs



Hohlraum drive symmetry including effects of LPI and laser variability for long wavelength 3D performance

Pulse shaping and capsule parameters for "1D" performance

Hydrodynamic instability for shorter wavelength 3D performance

We have identified 34 pulse shaping and capsule parameters that impact 1Dcapsule performance

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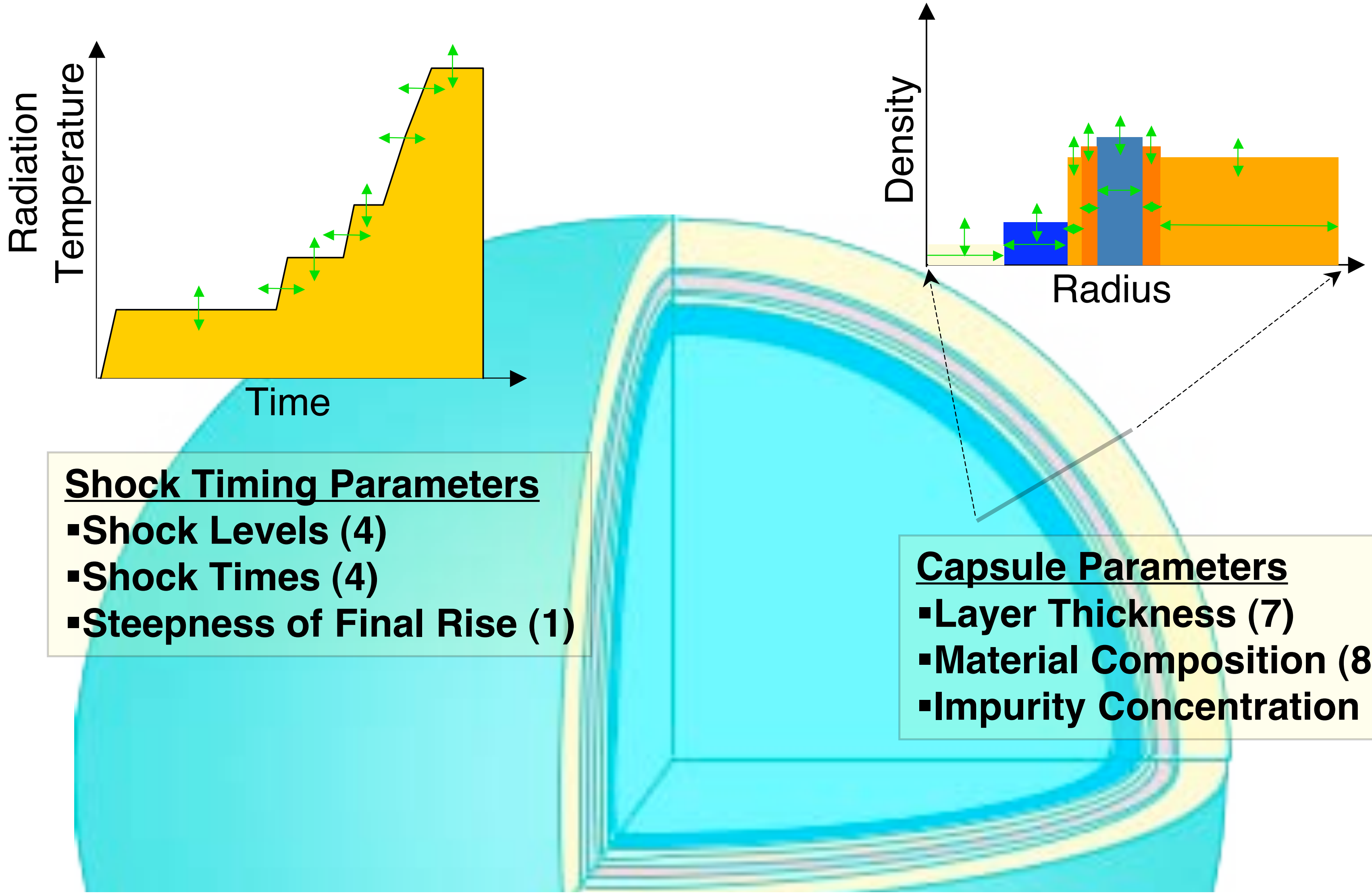


Shock Timing Parameters

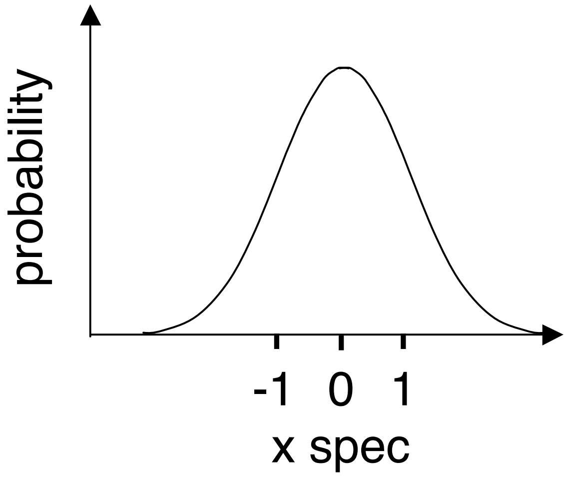
- **Shock Levels (4)**
- **Shock Times (4)**
- **Steepness of Final Rise (1)**

Capsule Parameters

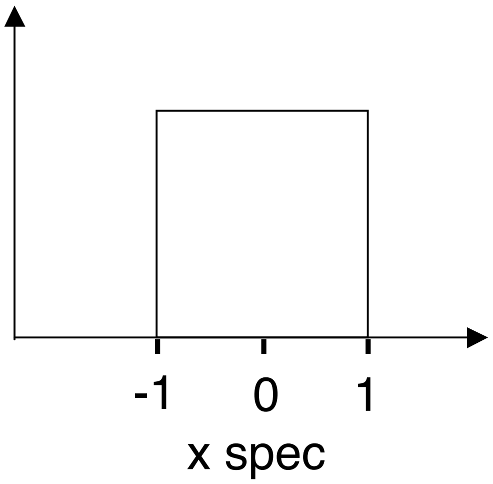
- **Layer Thickness (7)**
- **Material Composition (8)**
- **Impurity Concentration (10)**

In order to vary all parameters simultaneously, we incorporate a distribution for each

Normal distribution



Top-Hat distribution



For complex physical processes such as shock timing and levels that will likely vary normally.

For fabrication specs such as capsule dimensions that can be measured and rejected.

We use ensembles of simulations to estimate the probability of ignition

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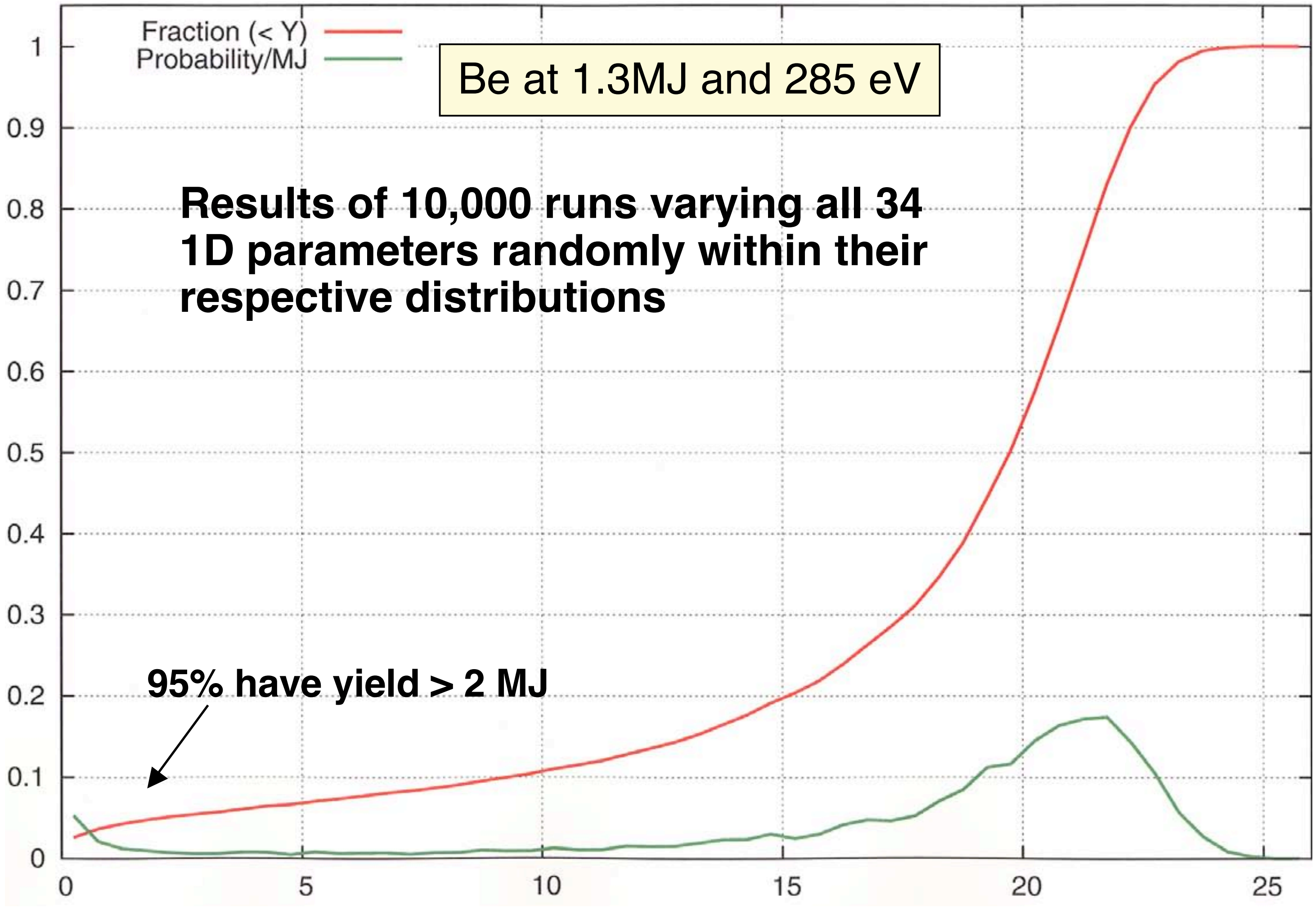

Be at 1.3MJ and 285 eV

Results of 10,000 runs varying all 34 1D parameters randomly within their respective distributions

95% have yield > 2 MJ

Yield(MJ)

Statistical ensembles of 2D simulations include perturbations on all capsule surfaces

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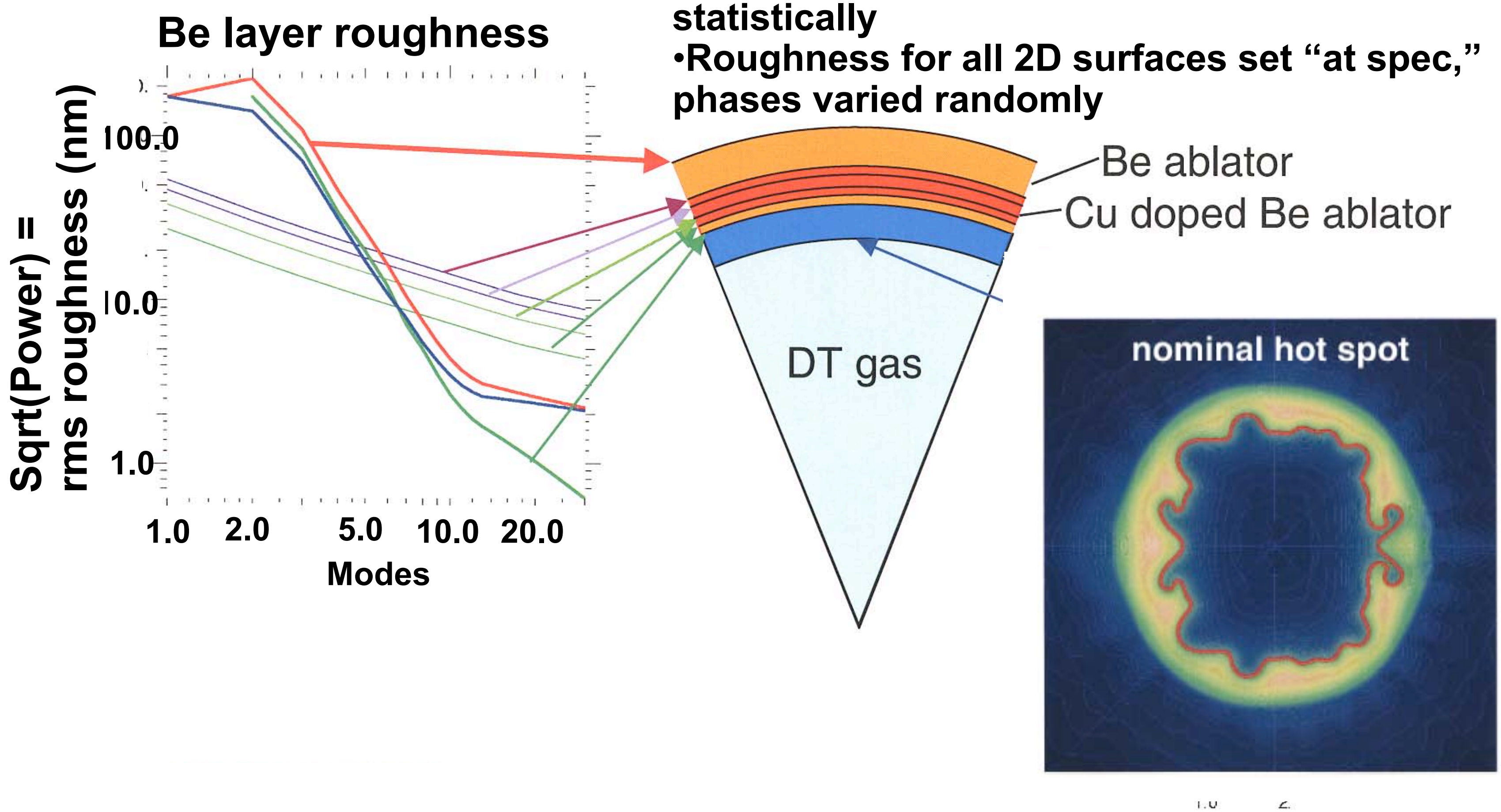
- All 1D parameters (dimensions, compositions, densities, drive parameters) sampled statistically
- Roughness for all 2D surfaces set “at spec,” phases varied randomly



2D calculations provide an assessment of the impact of non-spherical effects

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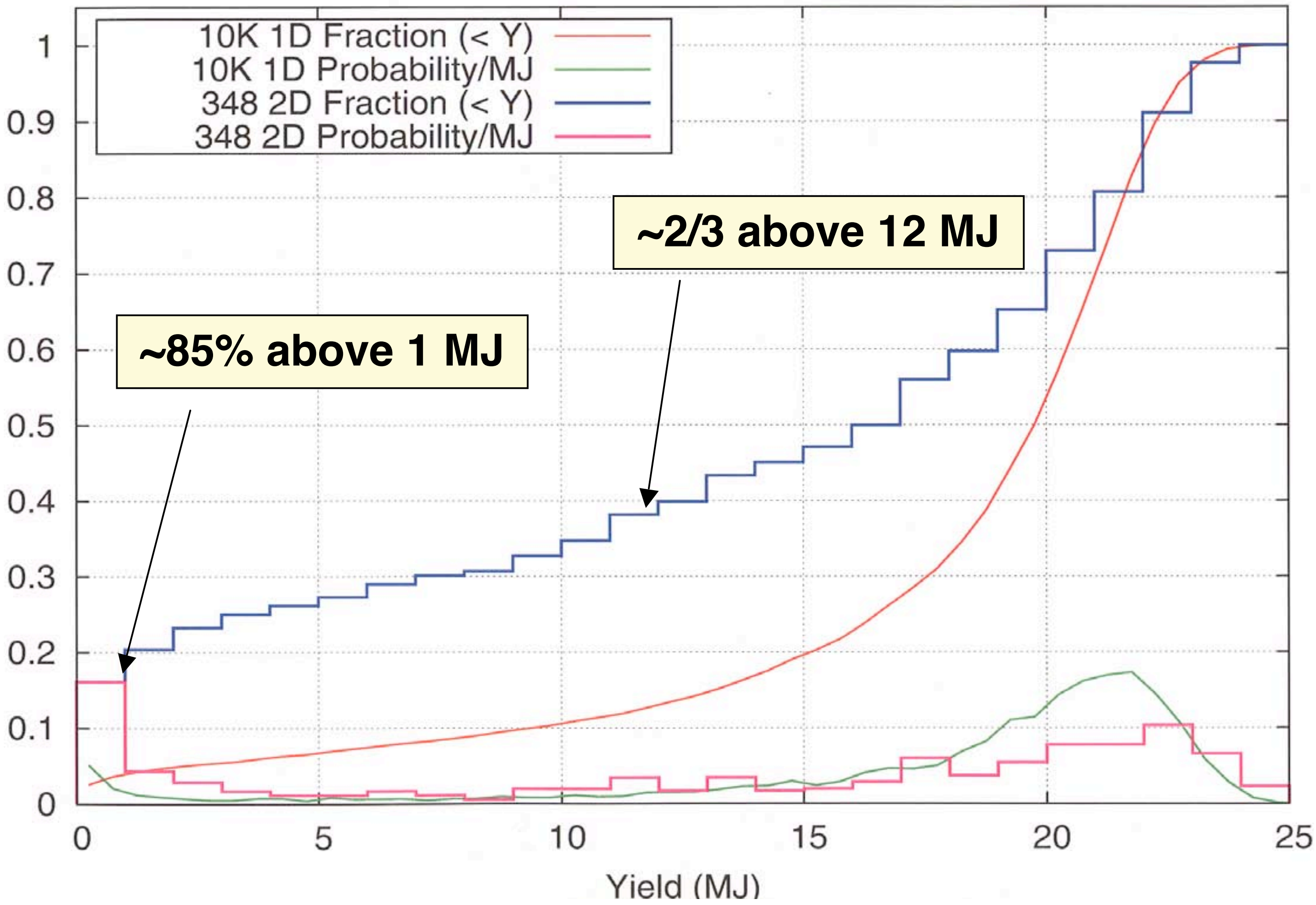
Results of 360 2D simulations (A statistical sample of 60 1D capsules with 6 random number seeds in 2D for each 1D point)



~2/3 above 12 MJ

~85% above 1 MJ

The 285 eV point design has a credible chance for ignition in early NIF operations….

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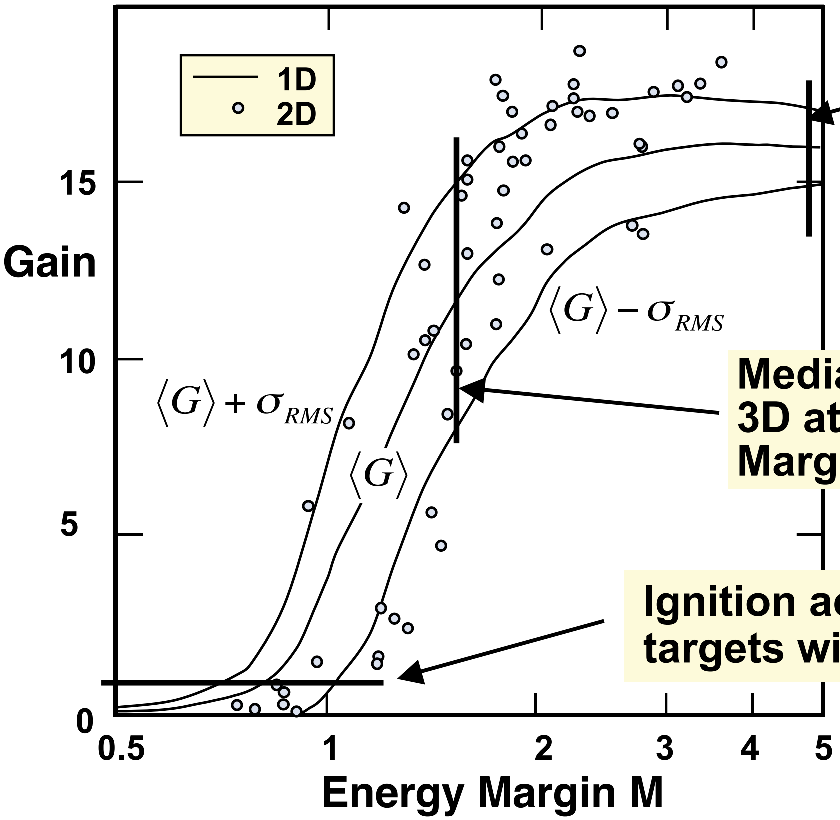
Energy Margin = Target Energy divided by the minimum energy required for ignition



Point design capsule has a margin of 4.8 with all 1D parameters nominal and no 3D effects

Median V,entropy
3D at spec
Margin 1.5

Ignition achieved for targets with Margin >1

Ultimately, yields well in excess of 100 MJ may be possible on NIF

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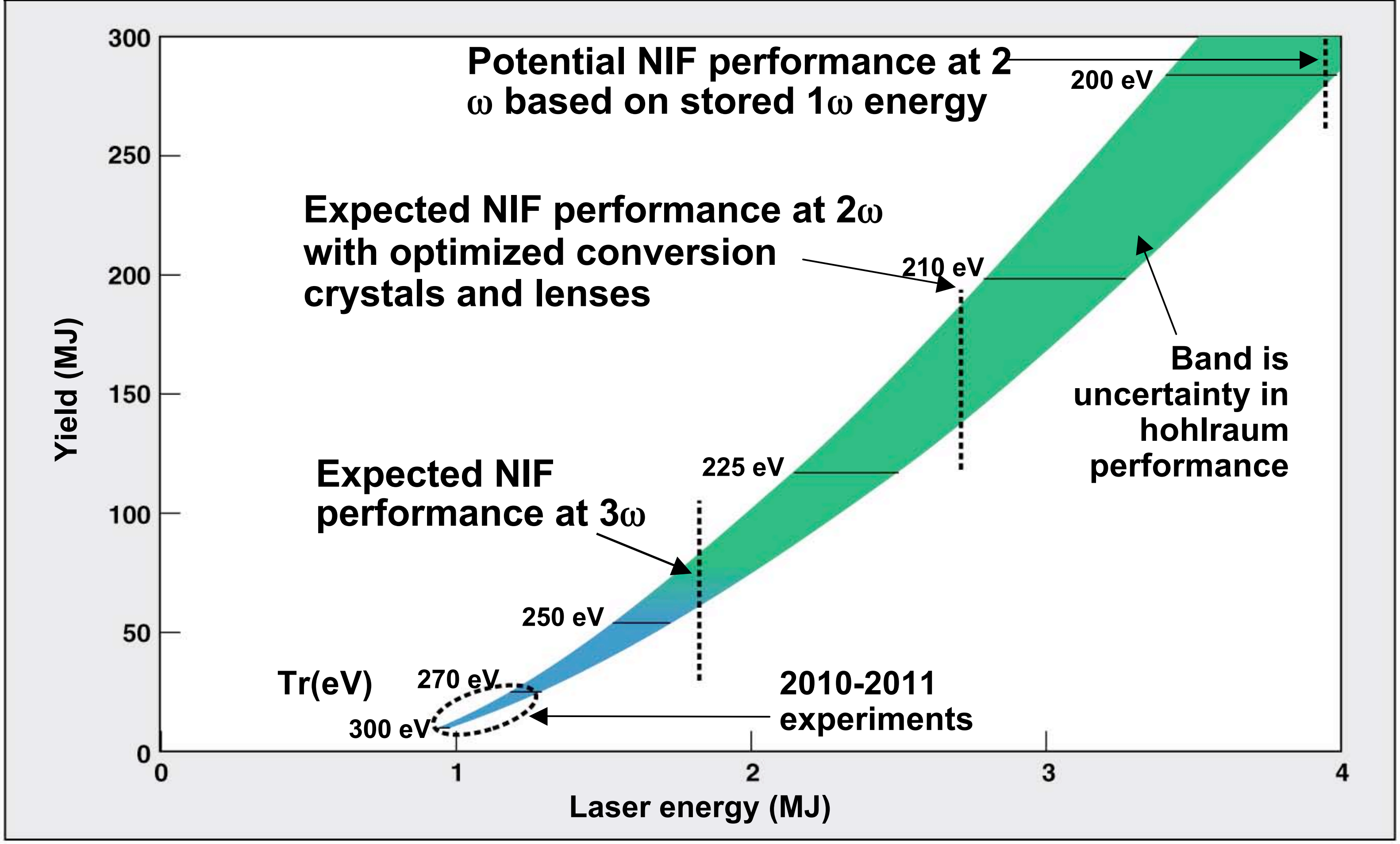
Yields versus laser energy for NIF geometry hohlraums



NIF can explore direct drive or fast ignition as alternate approaches to ignition

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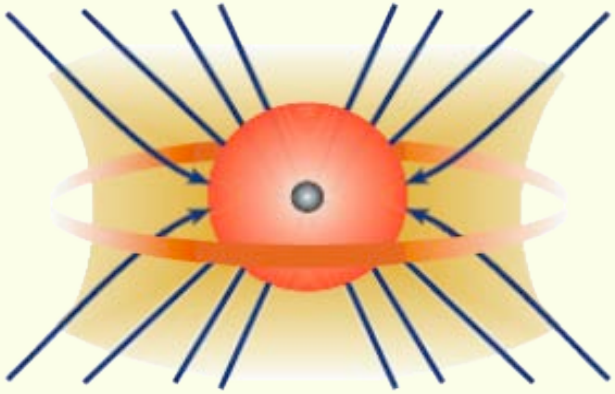
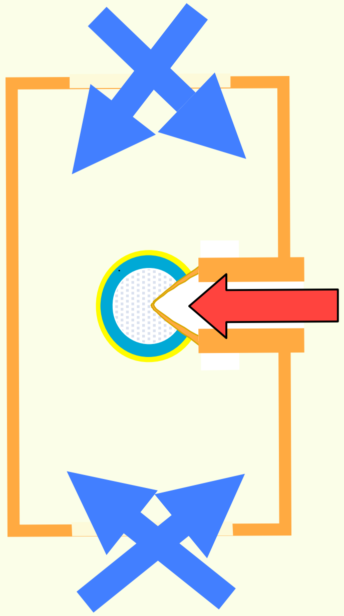
Polar Direct Drive



- Direct Drive in the Indirect Drive Geometry
- Higher coupling efficiency than indirect drive
- Beam smoothing and implosion symmetry are major challenges

Fast Ignition



- Separate compression and ignition
- Potentially highest gain
- Short pulse physics is major issue

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- Targets near 1 MJ of laser energy have a credible chance for ignition in early NIF operations

Ignition is a grand challenge undertaking. It is likely to take a few years to achieve the required level of precision and understanding of the physics and technology needed for success.

- The initial ignition experiments only scratch the surface of NIF's potential

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