NIC

National Ignition Campaign

The National Ignition Campaign

Presentation to
Fusion Power Associates Annual Meeting

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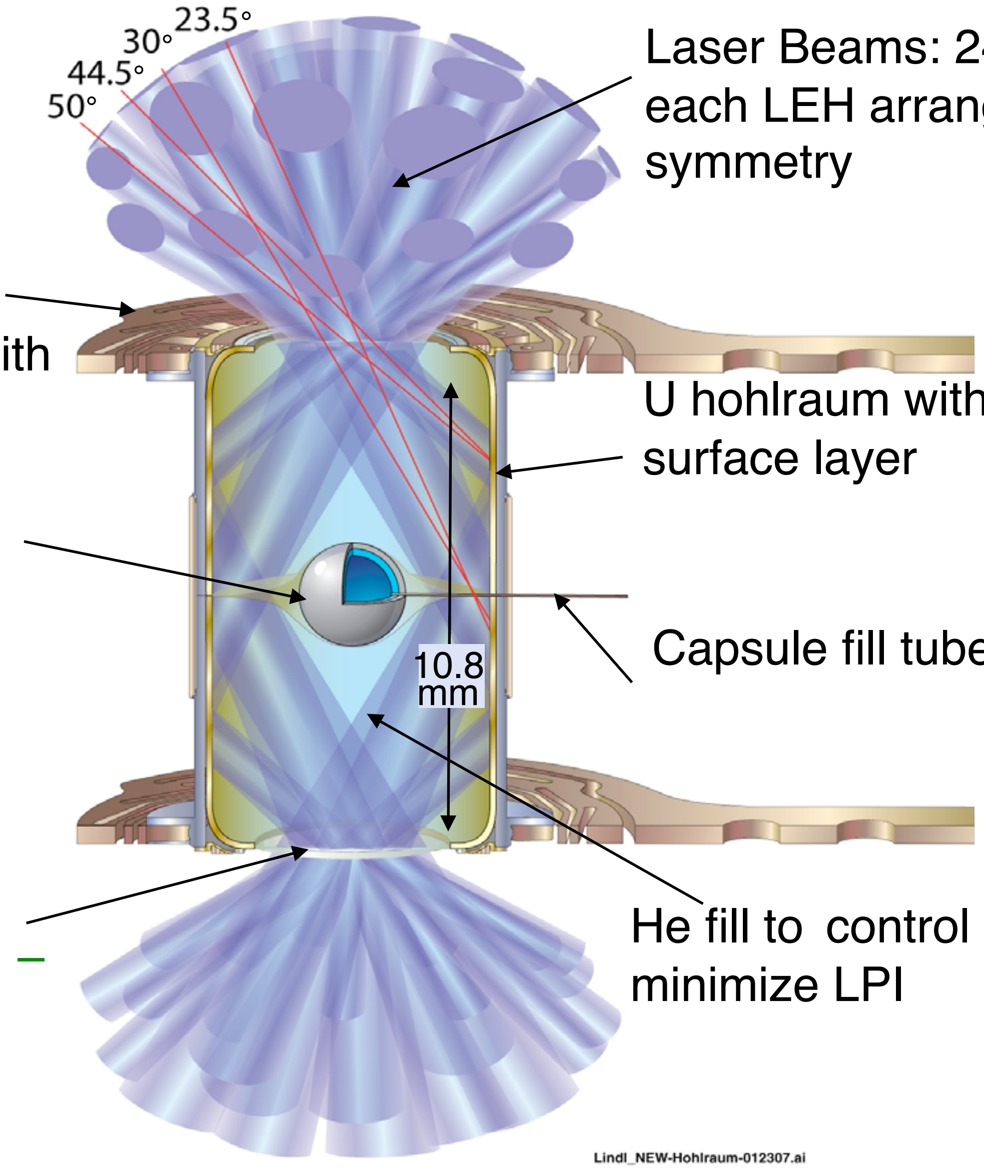
Summary

- **We have successfully tuned the capsule implosion symmetry in fully integrated cryogenic gas-filled hohlraums with 192 smoothed beams on NIF**
  - **Capsules are driven with 270 – 290eV radiation temperature**
  - **3-6% total backscatter at up to 720 kJ total incident energy**
  - **Low hot electron preheat [f_{HOT} = 1-2%]**
  - **Control of implosion symmetry has been demonstrated**
    - **New laser wavelength tuning capability [1.5 Å ≤ $\Delta\lambda$ ≤ 5 Å]**
    - **Gas fill species [He:H versus He]**
- **Precision Capsule tuning followed by cryo-layered implosions will begin following completion of the Ignition Preparation Project to install tritium handling and layer formations capability, additional nuclear diagnostics and shock timing diagnostics, and optics with improved optics finishing to allow routine operation up to 1.3 MJ.**

We have developed ignition designs with either CH or Be capsules in U hohlraums



Laser Beams: 24 quads through each LEH arranged control symmetry

Cu doped Be or Ge doped CH Capsule with cryo fuel layer

U hohlraum with B doped Au surface layer

Capsule fill tube ~10 µm –

Laser Entrance Hole sized to balance LPI and radiative losses - 50% of LEH diameter –

He fill to control symmetry and minimize LPI

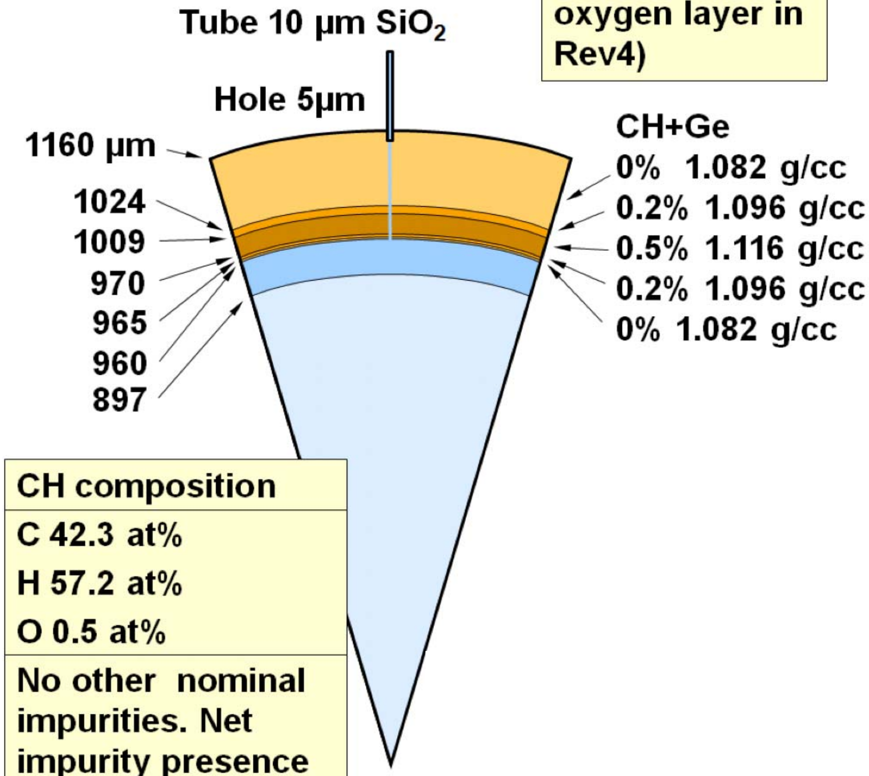
Lindl_NEW-Hohlraum-012307.ai

We will begin the ignition campaign with a CH capsule

We have detailed specifications for a 305 eV CH ignition design at 1.5 MJ

All dimensions and densities are at cryogenic temperature

(No outer high-oxygen layer in Rev4)

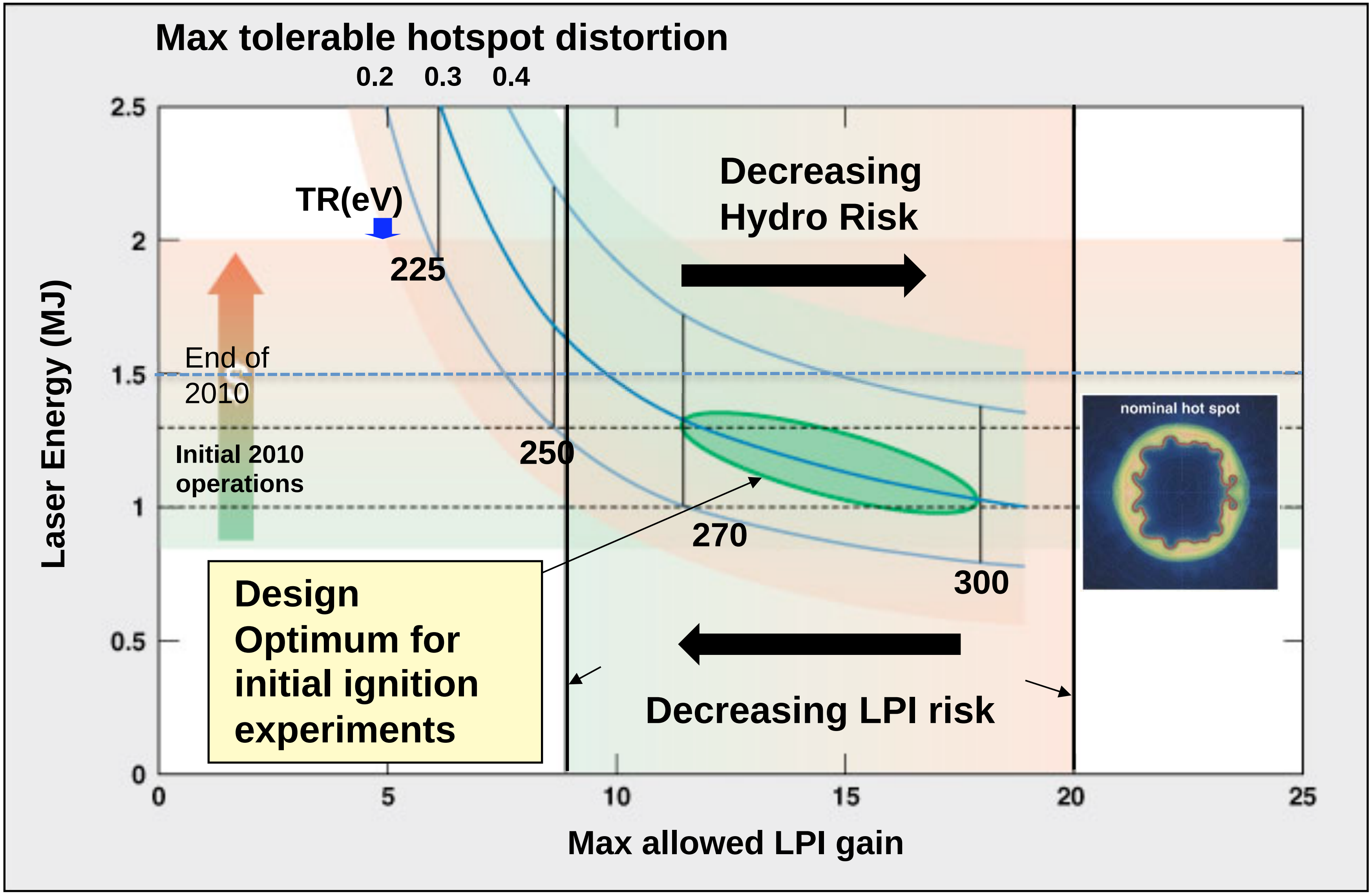


CH composition
C 42.3 at% H 57.2 at% O 0.5 at%
No other nominal impurities. Net impurity presence constrained by radiography.

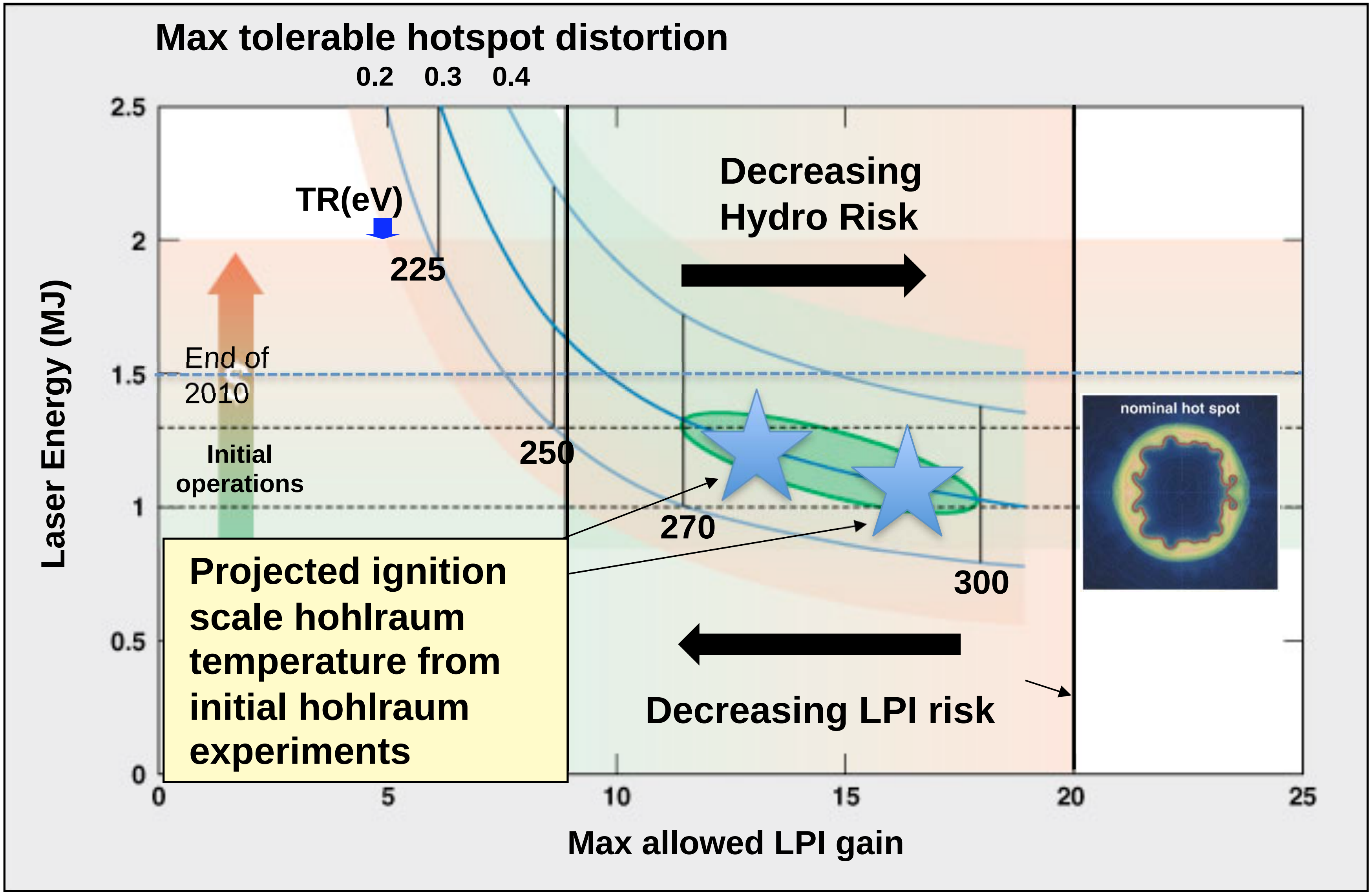
- Amorphous material with no crystal structure issues
- Large data base from Nova and Omega
- Reduced Facility impact
- All of the diagnostics and infrastructure needed for optimizing ignition implosions are essentially independent of capsule ablator

- CH capsule absorbs ~1/4 less energy than Be for the same laser energy
- → ~ 300 kJ more laser energy than Be for equivalent performance

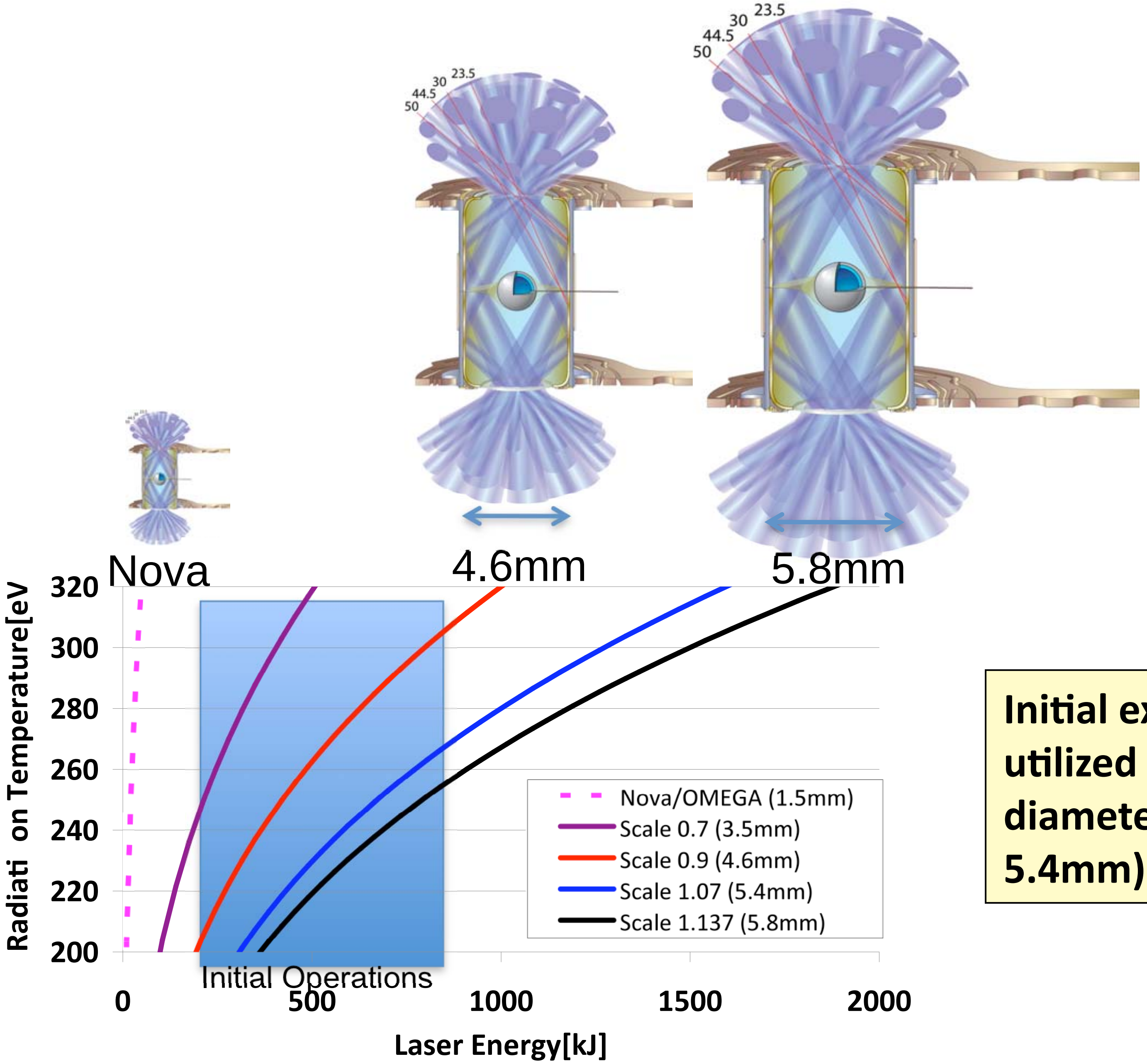
The ignition campaign is designed to identify the optimal tradeoff between Laser Plasma Interaction effects, hydrodynamic instability and laser operation



Initial hohlraum energetics experiments put us into the desired temperature range for ignition experiments



We can study the relevant physics of ignition hohlraums using targets of slightly smaller scale

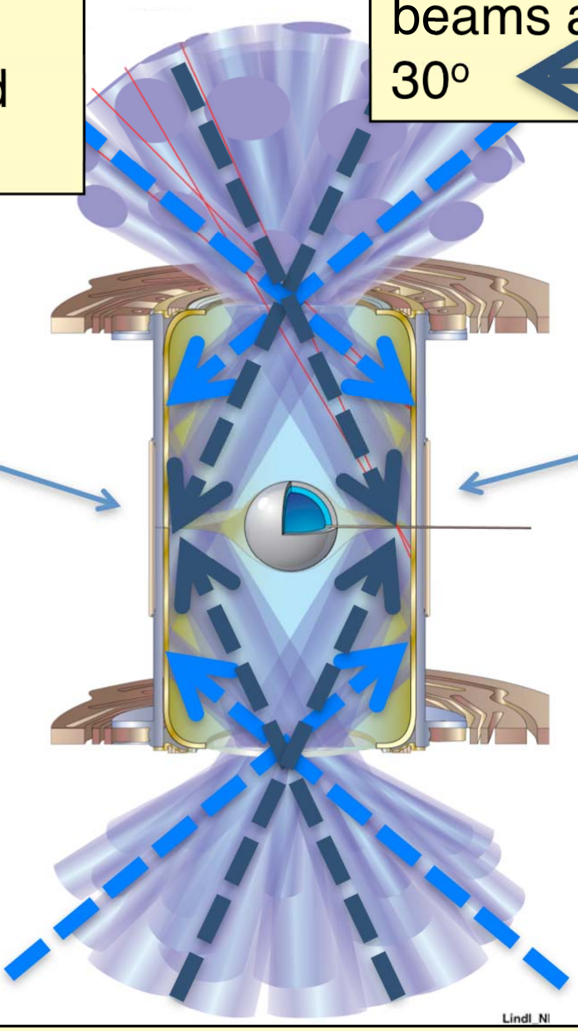


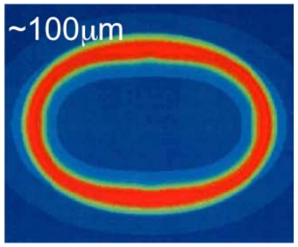
Initial experiments have utilized up to 750kJ in 4.6mm diameter hohlraums (840kJ in 5.4mm)

Adjusting the energy deposition by the inner and outer cone beams is necessary to obtain a round implosion

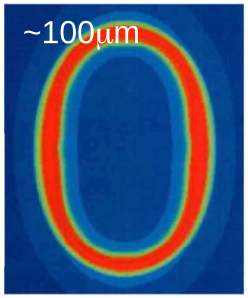
128 outer cone beams at 44.5 and 50º

64 inner cone beams at 23.5 and 30º





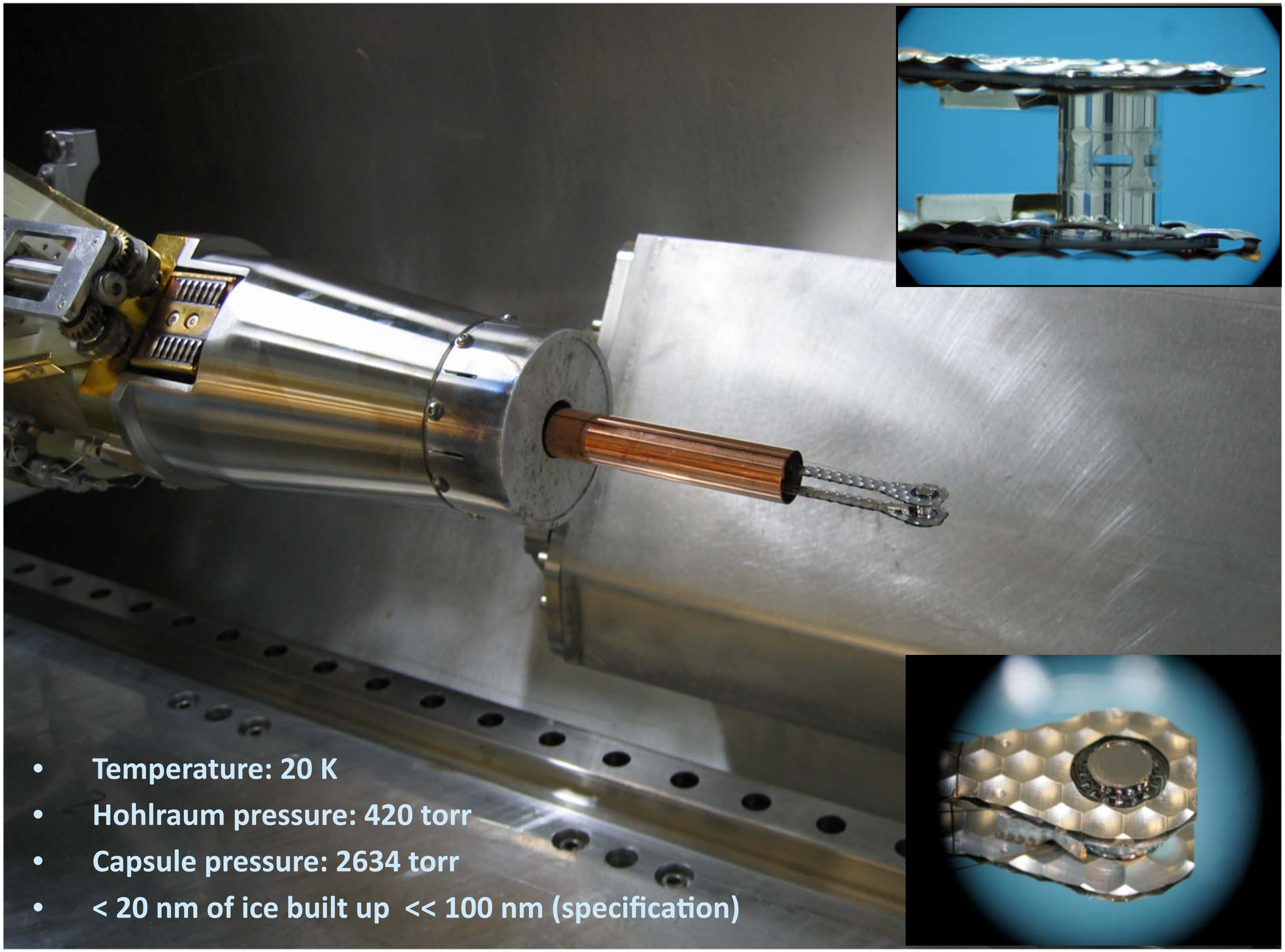
Oblate “Pancaked” implosion – too much power on outer beams



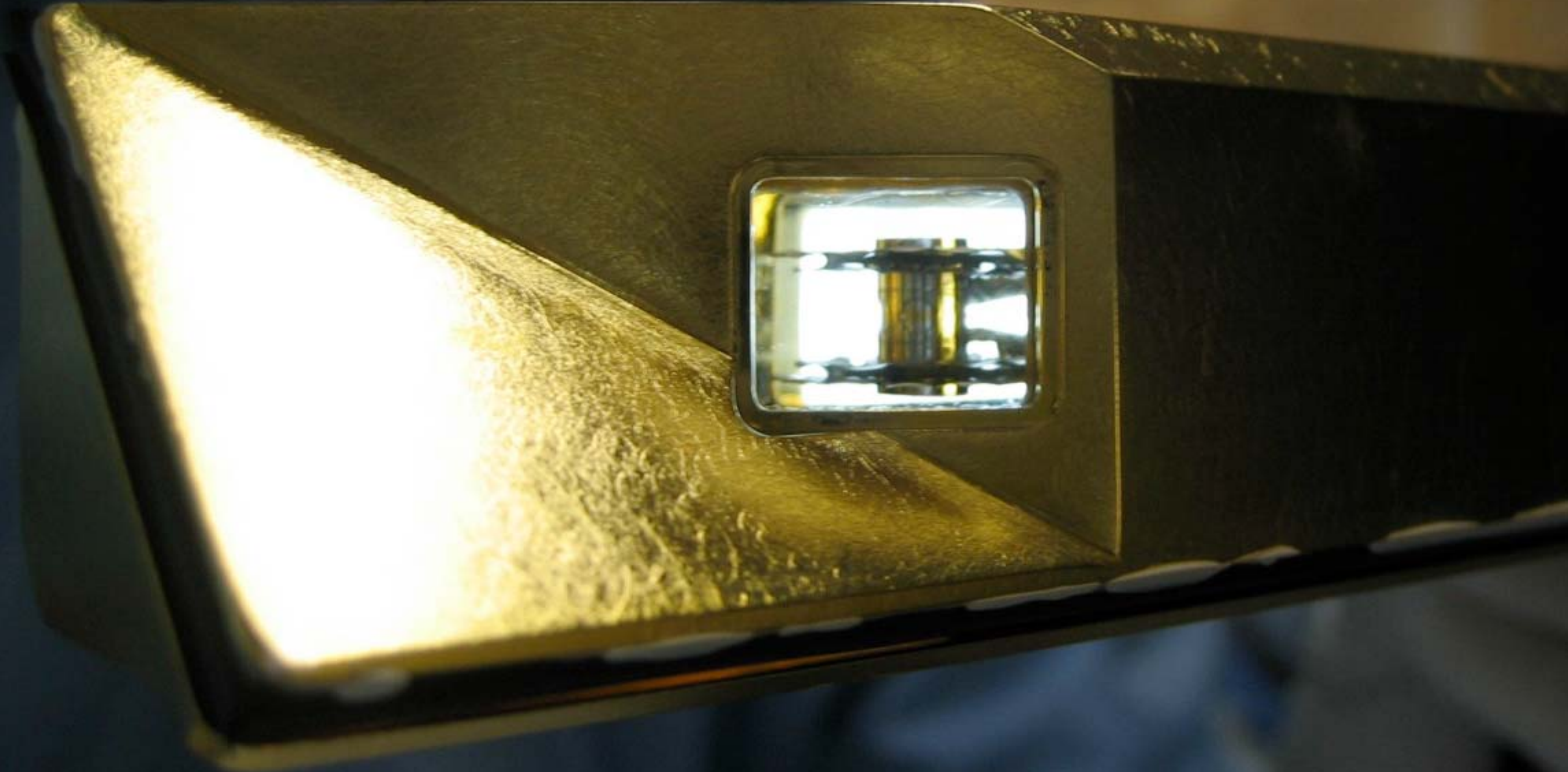
Prolate “Sausaged” implosion – too much power on inner beams

A key deliverable from early experiments is to show that we can tune a round implosion (P_2 better than 10%) in the presence of LPI

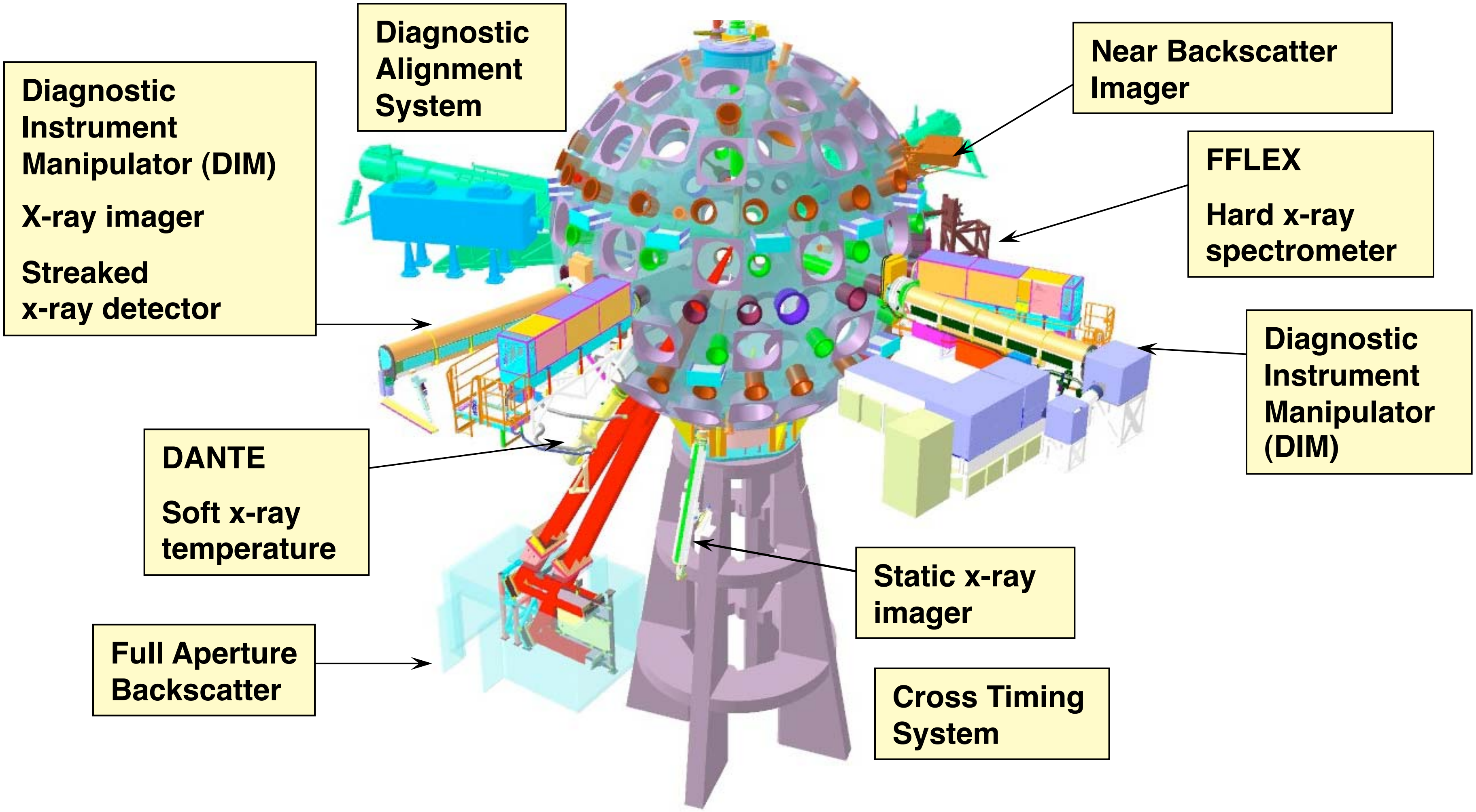
A fast shroud (3 seconds opening time) has enabled cryogenic hohlraum experiments



- Temperature: 20 K
- Hohlraum pressure: 420 torr
- Capsule pressure: 2634 torr
- < 20 nm of ice built up << 100 nm (specification)



Diagnostics with 200 data channels have been activated for the energetics experiments



Diagnostic Instrument Manipulator (DIM)

X-ray imager

Streaked x-ray detector

Diagnostic Alignment System

Near Backscatter Imager

FFLEX

Hard x-ray spectrometer

Diagnostic Instrument Manipulator (DIM)

DANTE

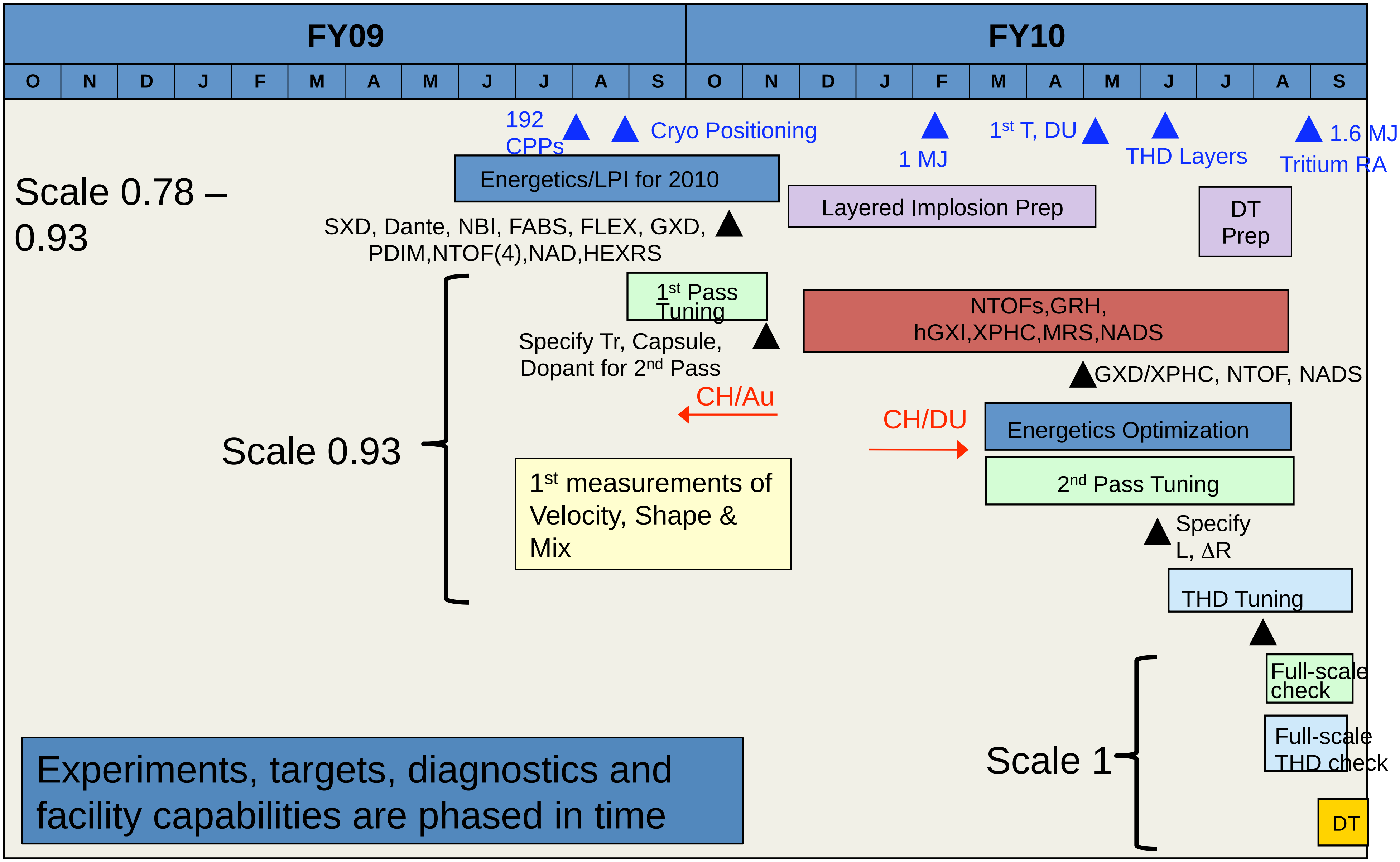
Soft x-ray temperature

Static x-ray imager

Full Aperture Backscatter

Cross Timing System

Our experiments plan has multiple components that prepare for DT implosions



FY09

FY10

O N D J F M A M J J A S O N D J F M A M J J A S

192 CPPs

Cryo Positioning

1 MJ

1st T, DU

THD Layers

1.6 MJ

Tritium RA

Scale 0.78 – 0.93

Energetics/LPI for 2010

Layered Implosion Prep

DT Prep

SXD, Dante, NBI, FABS, FLEX, GXD, PDIM,NTOF(4),NAD,HEXRS

1st Pass Tuning

NTOFs,GRH, hGXI,XPHC,MRS,NADS

Specify Tr, Capsule, Dopant for 2nd Pass

GXD/XPHC, NTOF, NADS

CH/Au

CH/DU

Energetics Optimization

Scale 0.93

1st measurements of Velocity, Shape & Mix

2nd Pass Tuning

Specify L, ΔR

THD Tuning

Full-scale check

Full-scale THD check

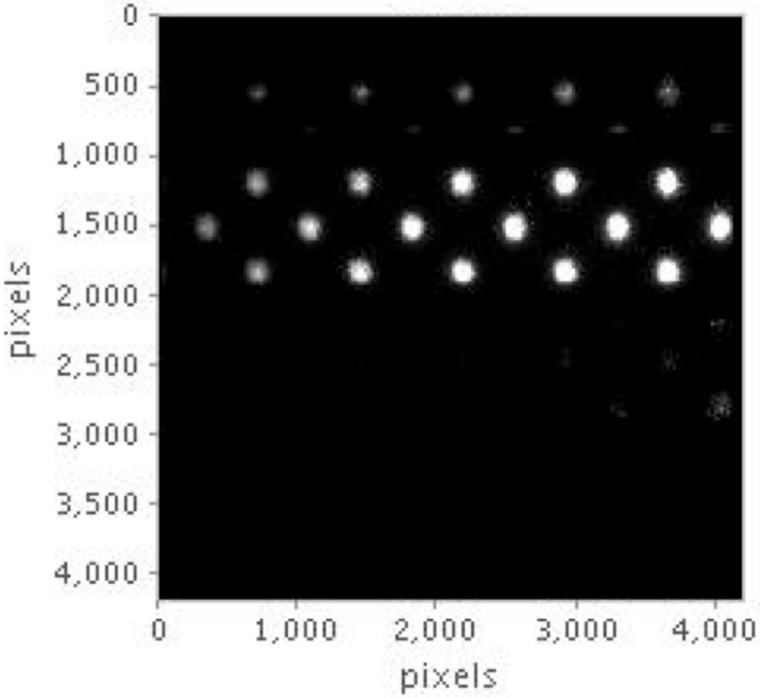
Scale 1

DT

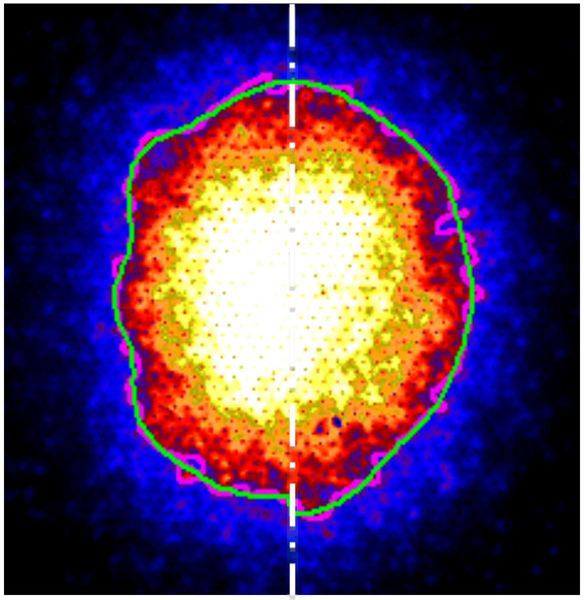
Experiments, targets, diagnostics and facility capabilities are phased in time

NIF's first two shots at 500 kJ with warm gas filled 4.6mm diameter hohlraums, demonstrated symmetry (P_2/P_0) tuning.

Raw GXD data from 8/25/09 shot (warm C_5H_{12} gas-fills)

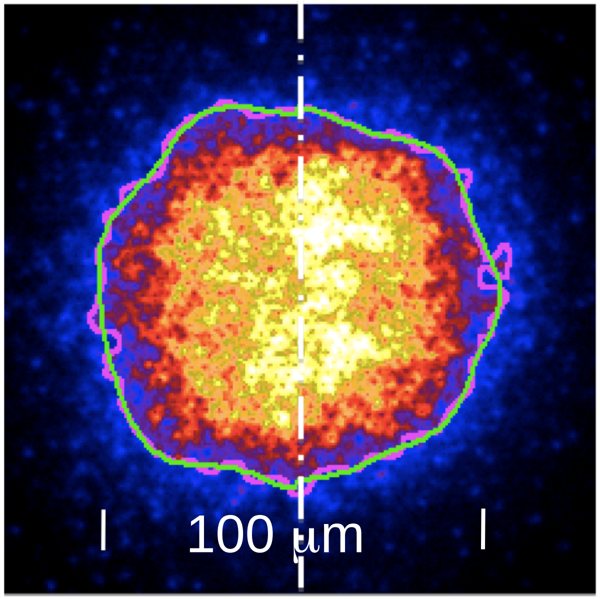


Imploded core emission 8/25/09 $a_2/a_0 \sim +9\%$

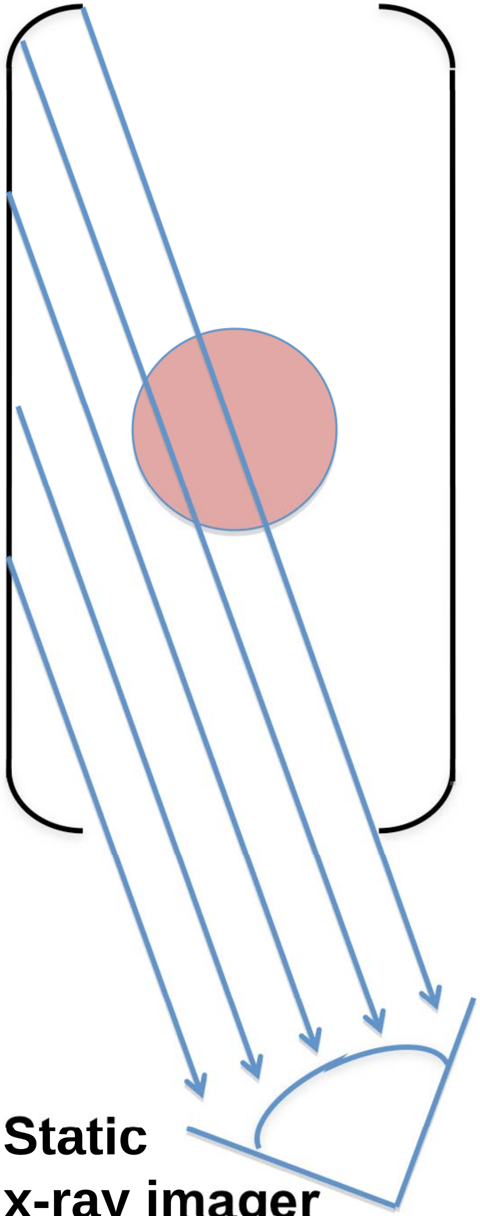


C.F.× 95%

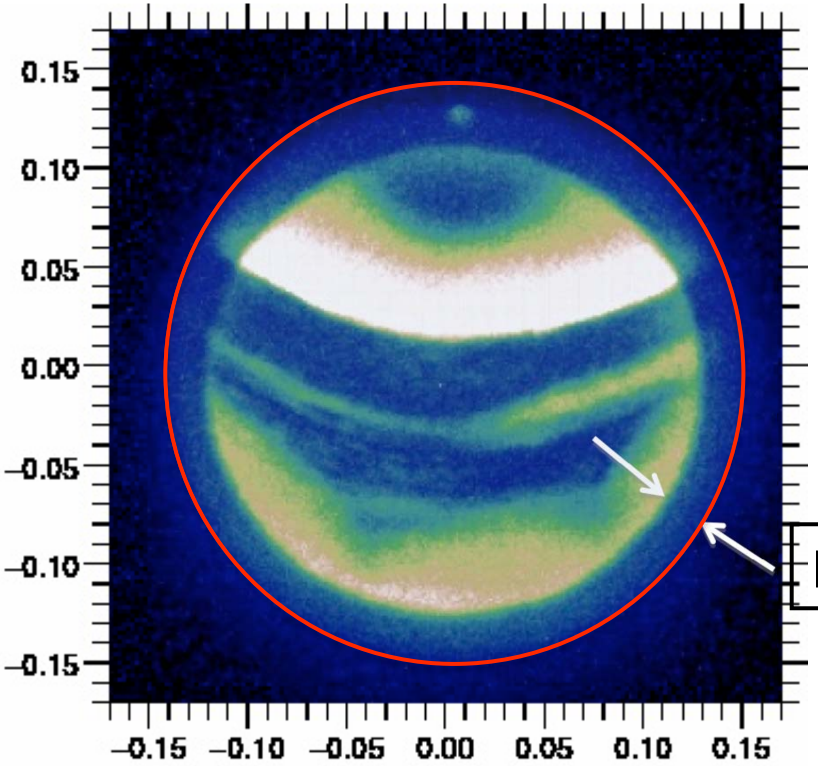
Imploded core emission 8/29/09 $a_2/a_0 < 2\%$



We use the static x-ray pinhole camera to assess laser-entrance hole closure



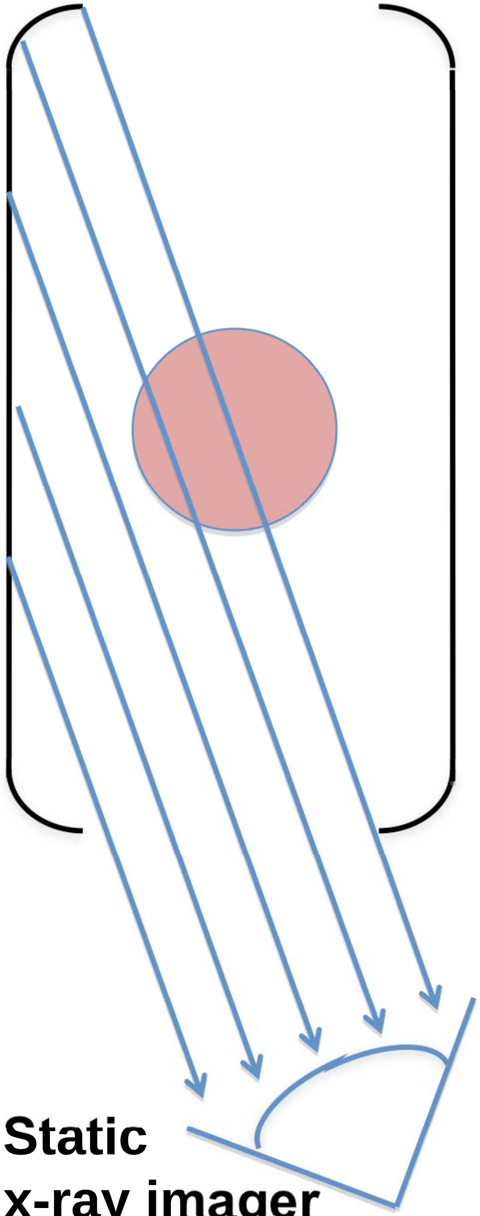
Static
x-ray imager



Initial LEH Diameter

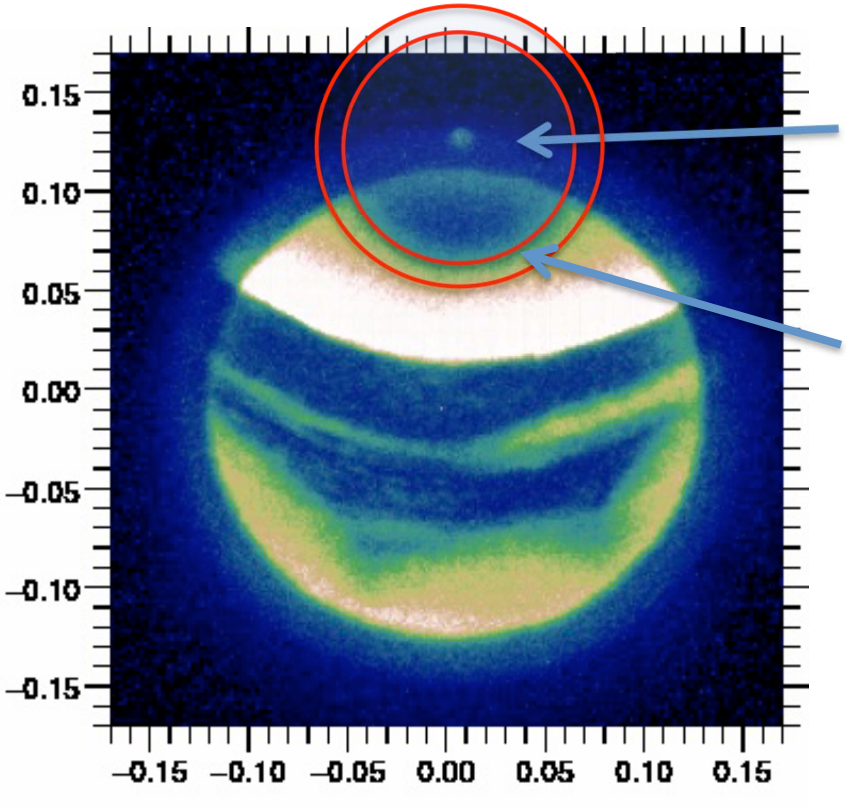
Static x-ray image at 18 °

We use the static x-ray pinhole camera to assess laser-entrance hole closure



Static x-ray imager

But we also capture an image of the imploded capsule which shows the 15-20 fold convergence of the initial NIC implosions



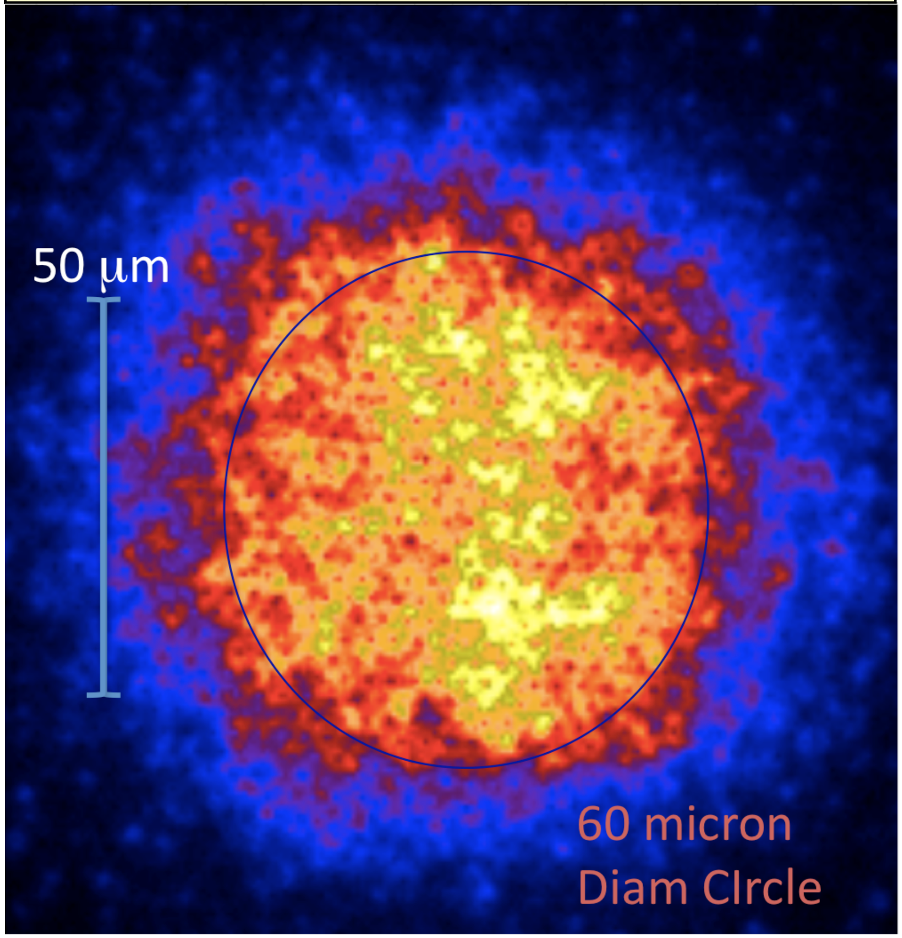
Emission from Imploded Capsule

Initial Capsule Diameter

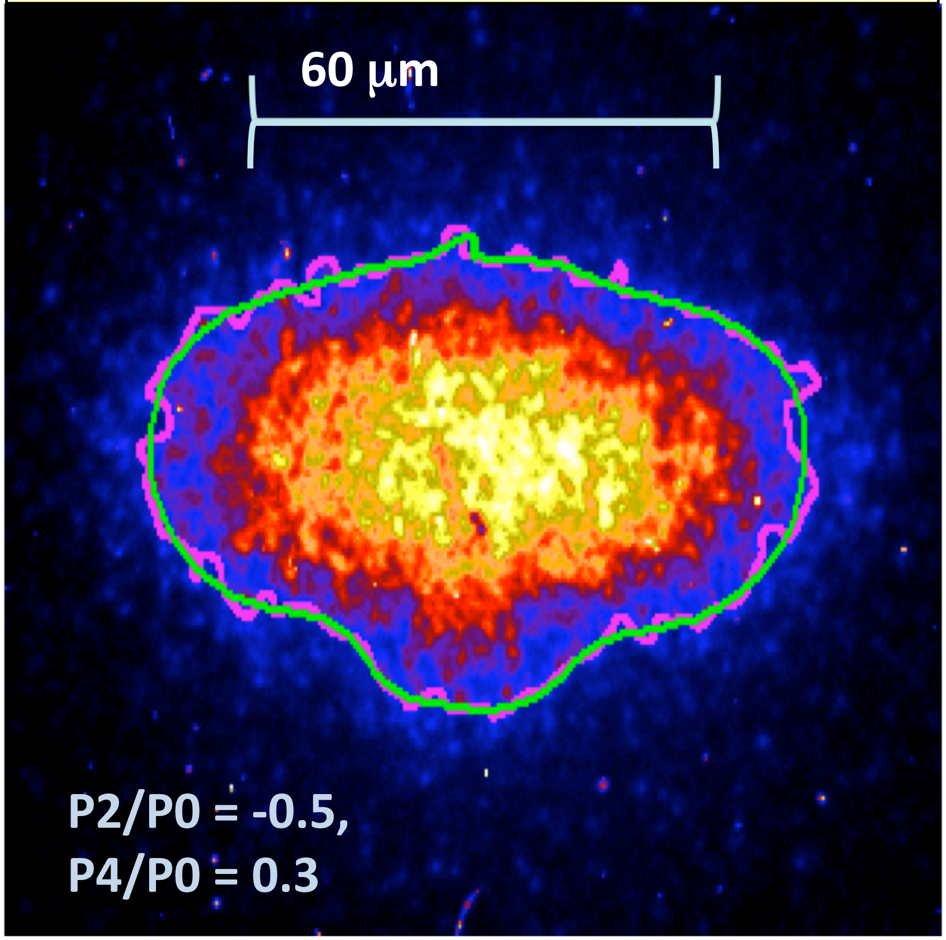
Static x-ray image at 18 °

The first implosion at 500 kJ in a cryogenic He-H hohlraum indicated reduced coupling on the inner beams

8 keV Implosion core image from C_5H_{12} gas-filled hohlraum



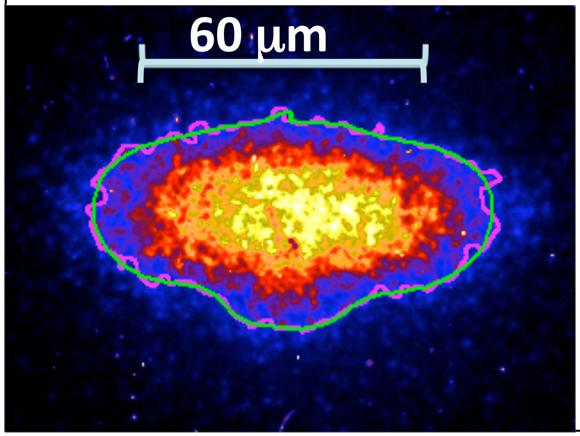
8 keV Implosion core image from the first H/He gas-filled hohlraum shows P2/P0 = -0.5

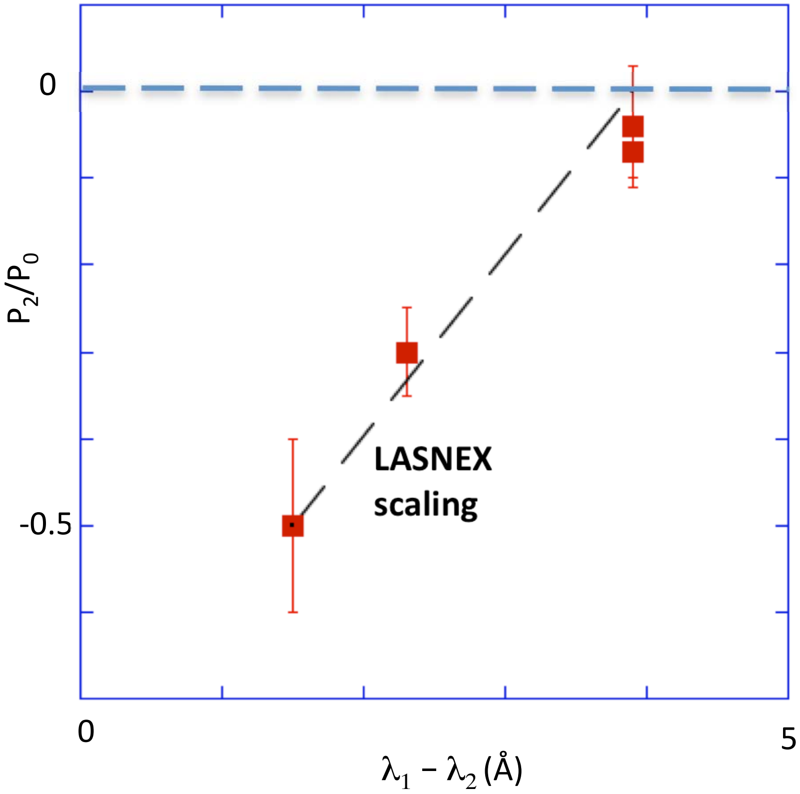


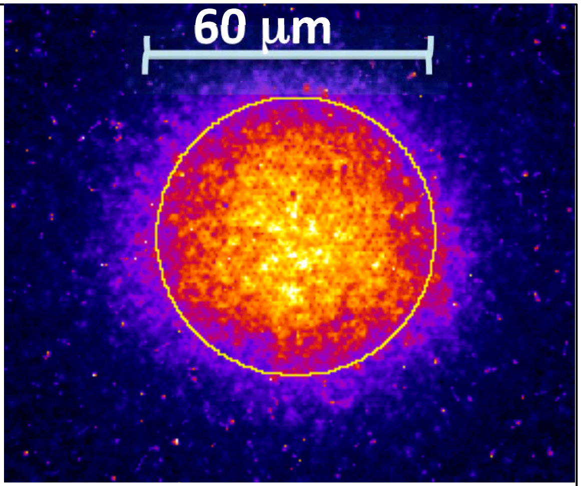
Implosion symmetry was achieved by tuning the wavelength of the outer cone

A two-color tuning allowed us to bring an initially “pancake” implosion to round without changing the laser cone fraction

P2/P0 = -0.5,
P4/P0 = 0.3



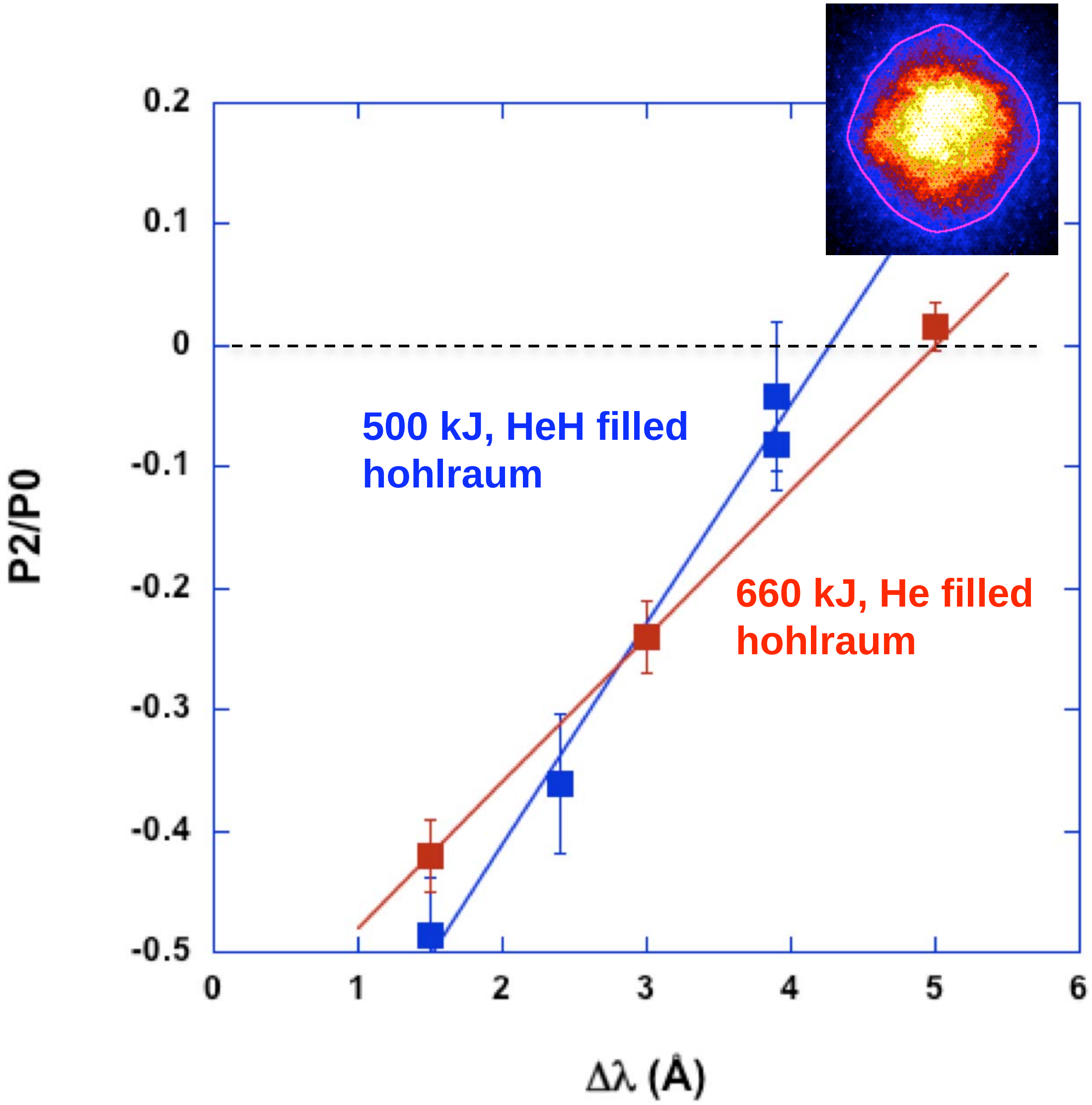




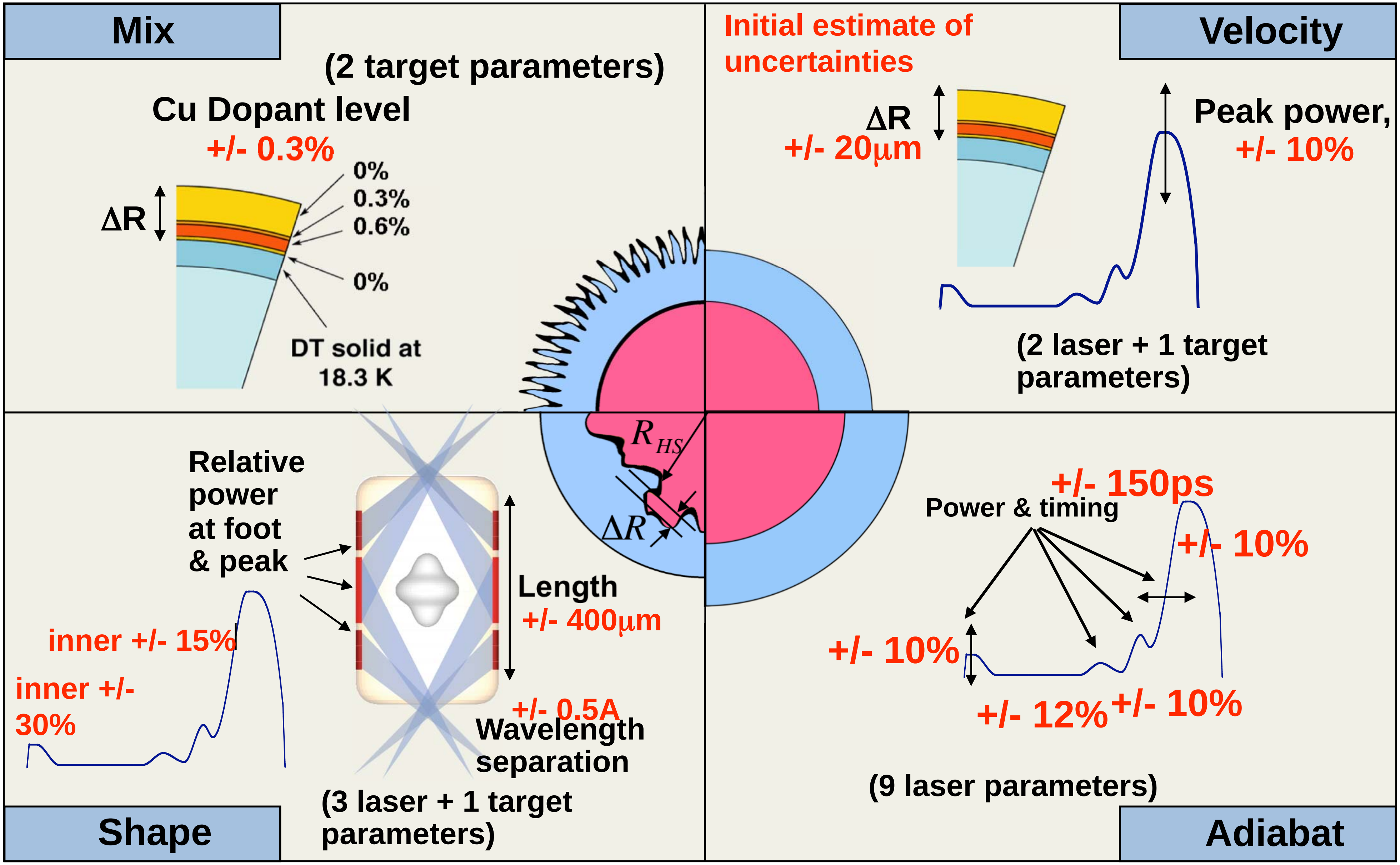
P2/P0 = -0.07,
P4/P0 = -0.03

This change in symmetry was been predicted by LASNEX calculations that included crossed beam transfer in the laser entrance hole area

Recent experiments at 660kJ have demonstrated symmetry tuning at temperatures above 280eV



There are 14 laser and 3 target parameters that need to be adjusted to “tune” the target to compensate for uncertainty in physics models



Mix

(2 target parameters)

Cu Dopant level
+/- 0.3%

Velocity

Initial estimate of uncertainties

ΔR
+/- 20μm

Peak power,
+/- 10%

(2 laser + 1 target parameters)

Shape

Relative power at foot & peak

inner +/- 15%

inner +/- 30%

Length
+/- 400μm

+/- 0.5A
Wavelength separation

(3 laser + 1 target parameters)

Adiabat

+/- 150ps
Power & timing

+/- 10%

+/- 10%

+/- 12%

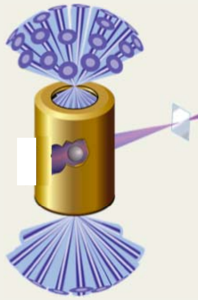
+/- 10%

(9 laser parameters)

A variety of surrogate targets are used to tune the laser and target parameters

Mix

Layered target implosions



X-ray spectromete

Material in hot spot

Nuclear diags

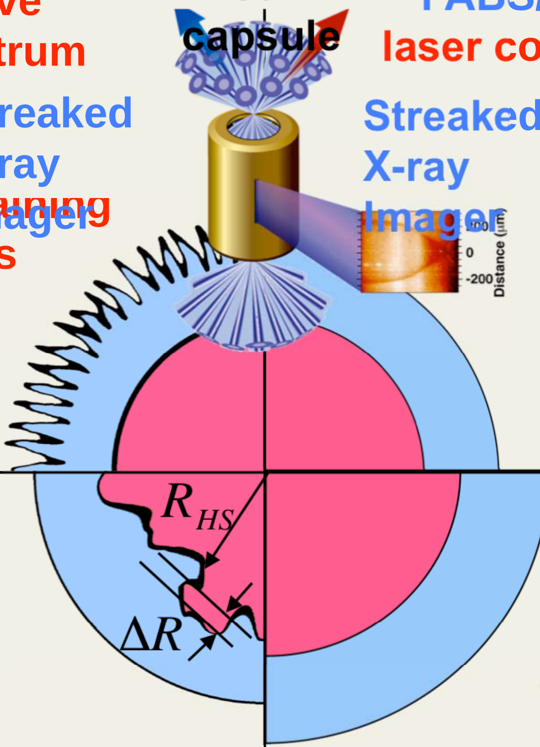
Yield, Tion, ρR

DANTE
drive spectrum

Streaked X-ray Imagers

remaining mass

Gas filled capsule



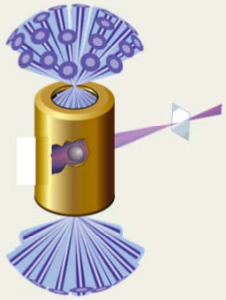
DANTE T_R
FABS/ NBI
laser coupling

Streaked X-ray Imager

Shell velocity

Velocity

Gas filled capsules and layered target implosions

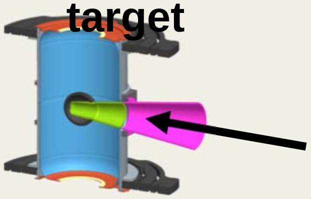


X-ray Imager

Shape of hot spot

Shape

Liquid filled keyhole target



GXD
shock sphericity

VISAR
SOP
Shock strength and times

FFLEX
hot electrons

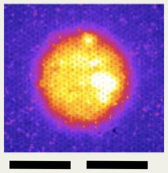
Adiabat

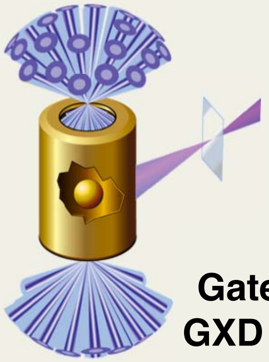
Gas filled capsule “Symcap” sets peak inner to outer cone power ratio and hohlraum length

Experimental Geometry

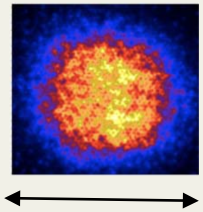
DHe-filled capsule “Symcap” replaces layered capsule

NIF data
(polar view)





NIF data
(equator view)



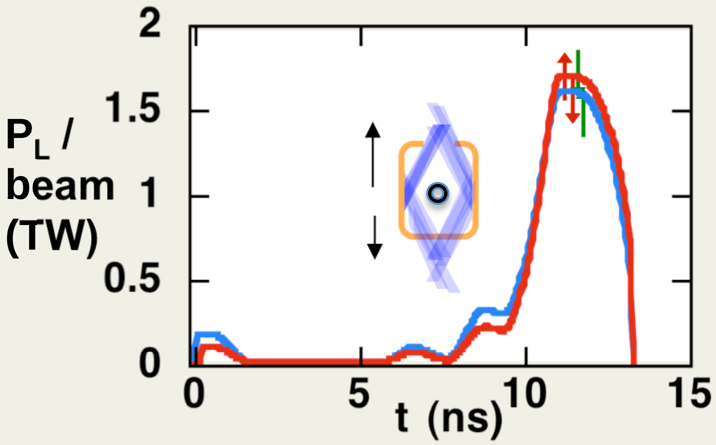
100 µm

Gated 8 keV X-ray images
GXD at 128 cm w 15x snout

Hot spot P_2, P_4 to 0 ± 7, 10%
+Bragg crystal for check of mix (Ge 10-13 keV K-shell)

Facility Requirements

Full pulse 960 kJ



First 0.78 Scale: Aug. 2009

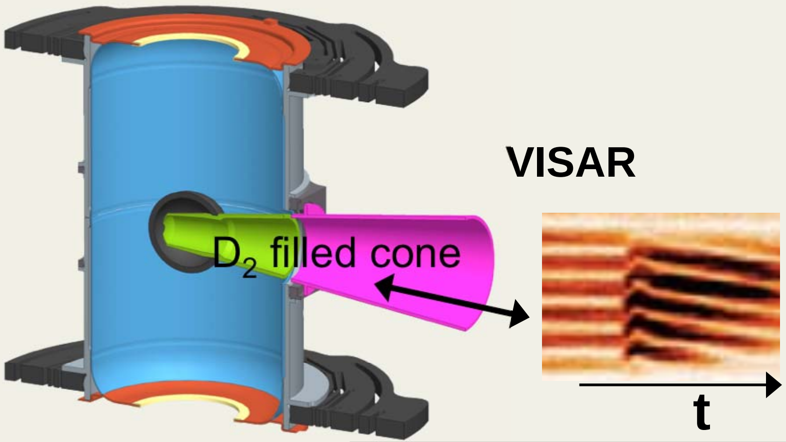
First 0.94 Scale: Oct. 2009

Transparent Keyhole is used to tune the velocity and timing of the shocks

Experimental Geometry

Liquid D_2-filled Cone-in-sphere "Keyhole" replaces layered capsule

Boehly, PoP (2009)



Fringe shift vs t

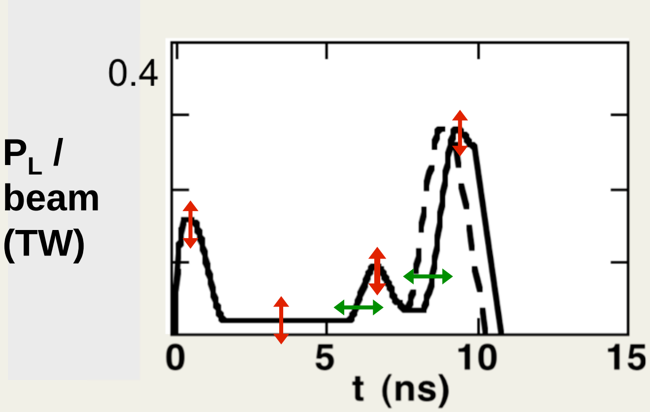
1st (2nd-3rd) shock velocities to ± 5% (2%)

Merger depth to ± 6 μm

7%

Facility Requirements

Truncated ≈ 185 kJ pulses with delayed 3rd pulse when tuning 2nd pulse

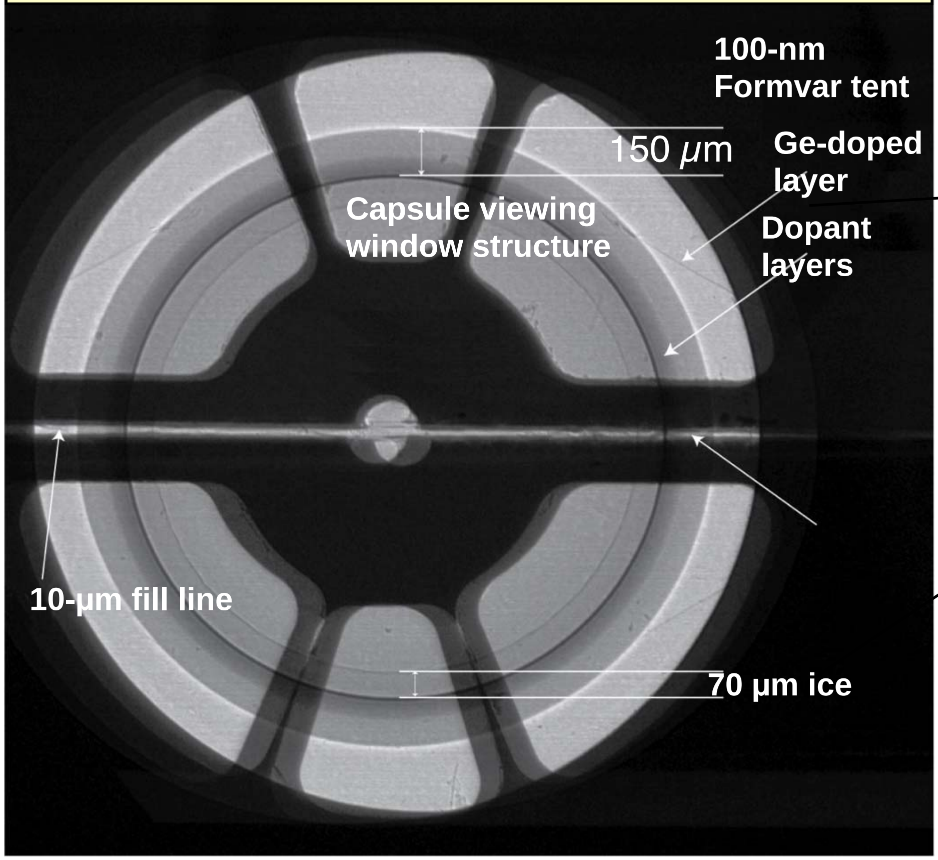


VISAR Qualification: 2004

First NIC shots: 2010

Once the target is tuned adequately using surrogate targets we begin layered implosions

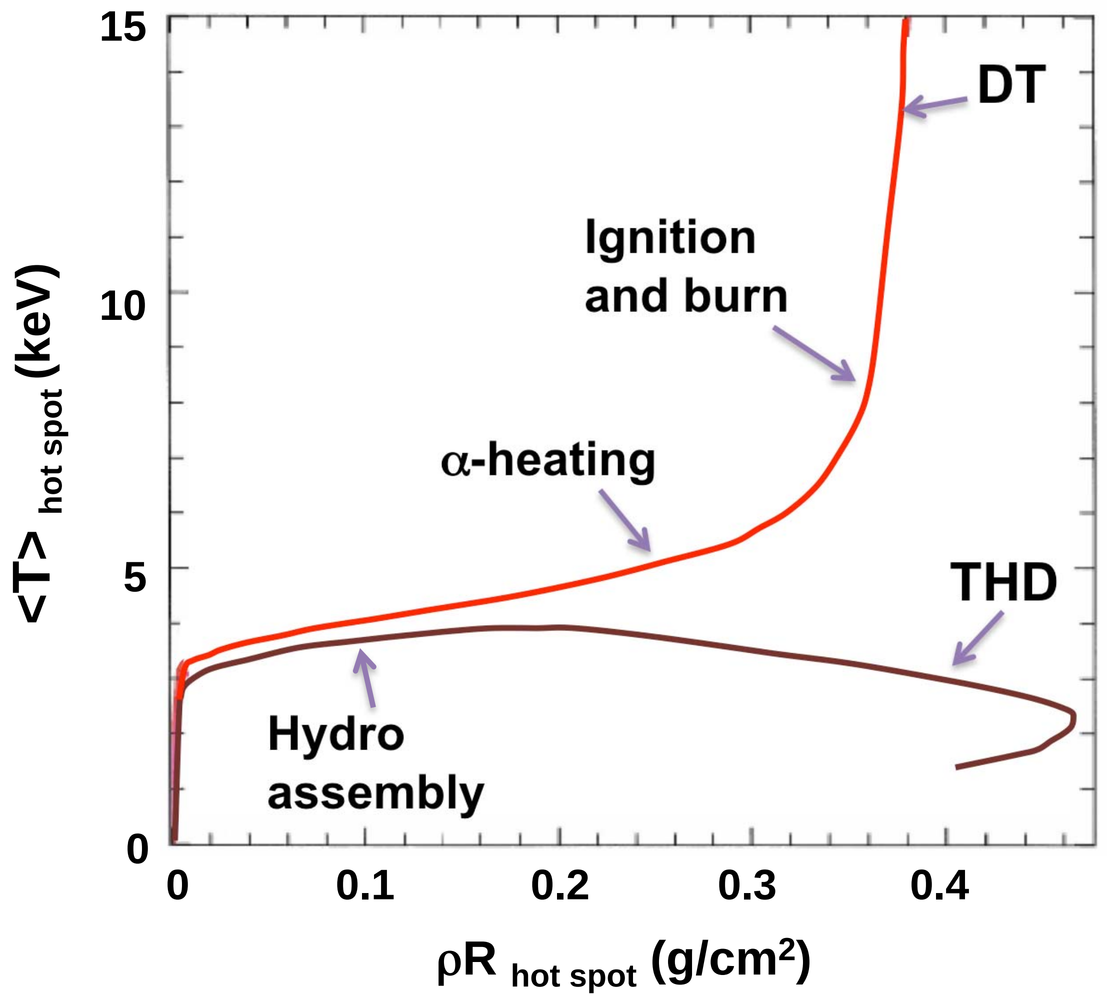
X-ray image of ice layer



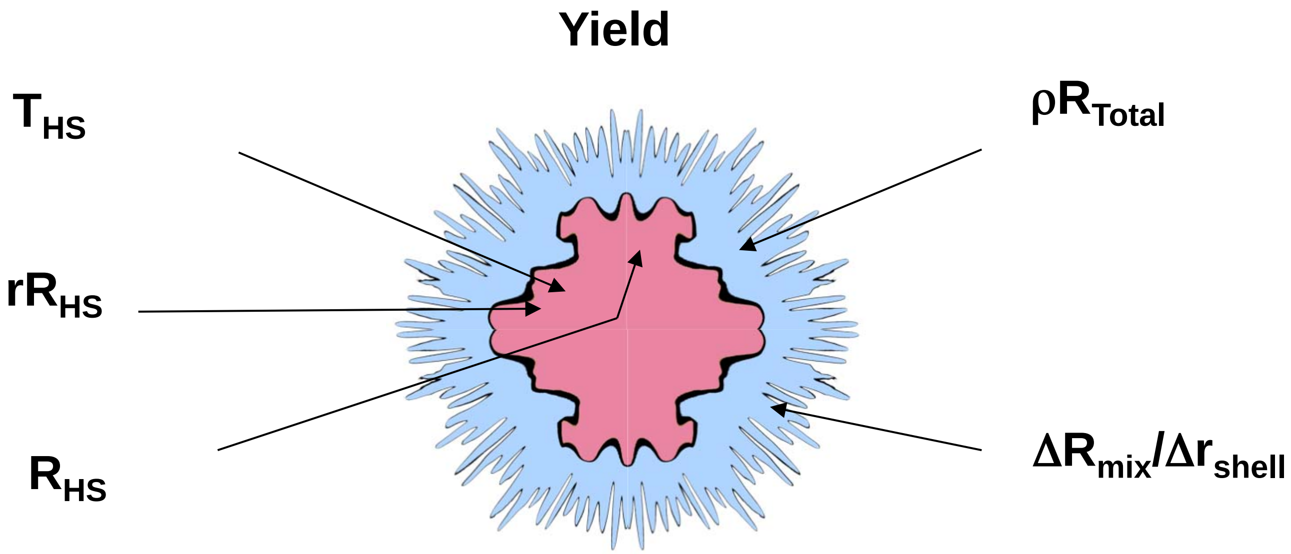
- X-ray image created from 20-30 frames each taking » 4 sec to capture for » 2 minutes total
- Temperature: 18K ±0.001K control
- Target position stability for X-ray imaging : < 2 μm p-p

THD targets study the hydrodynamic phase of hot spot formation and fuel assembly

Hot spot formation and trajectory in ρR, T



An igniting plasma is larger, hotter and faster than THD, and produces a harsher environment



Yield

T_{HS}

rR_{HS}

R_{HS}

ρR_{Total}

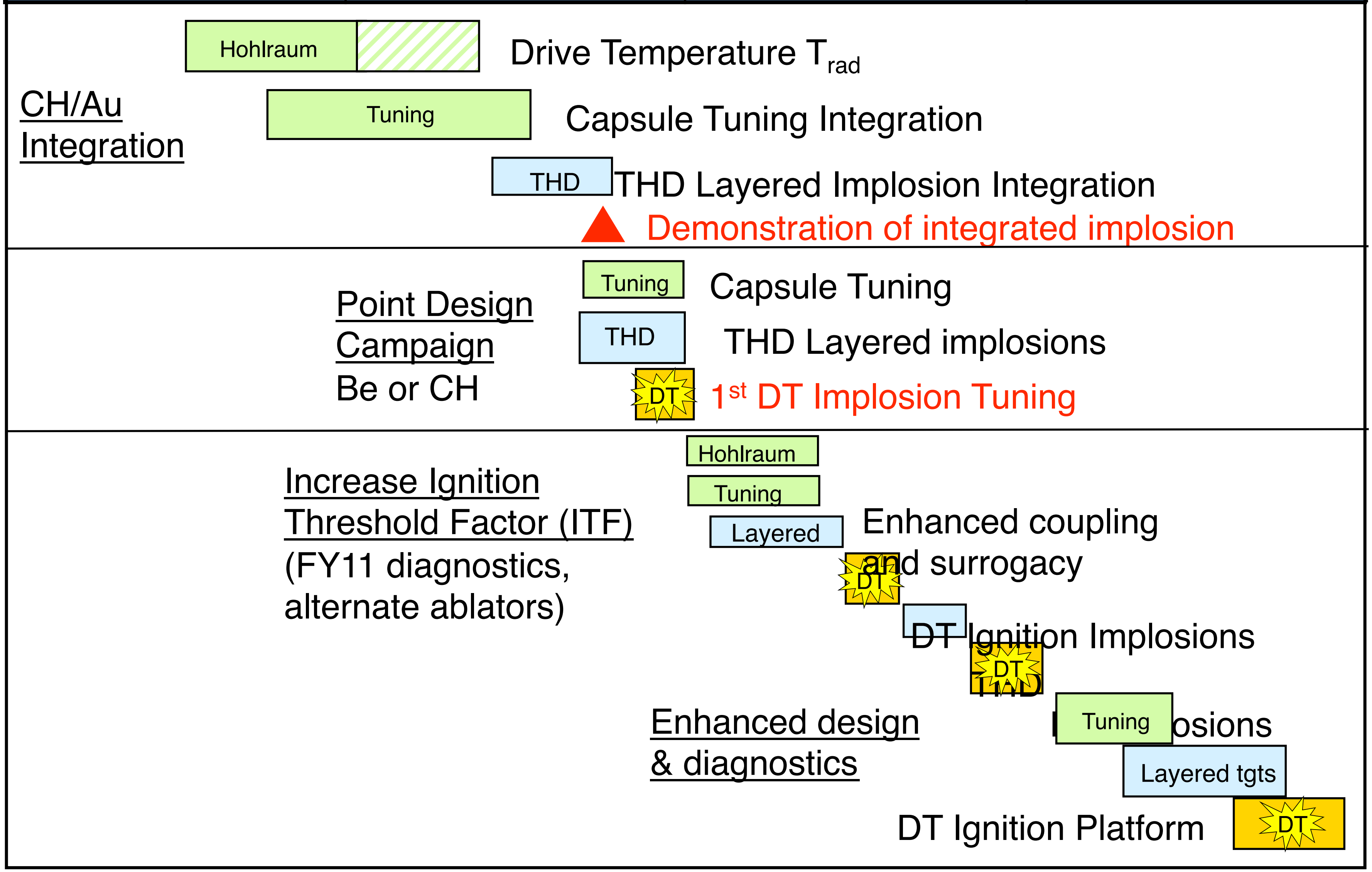
$\Delta R_{mix}/\Delta r_{shell}$

Hot Spot for THD	
T_{HS}	4 keV
ρR_{HS}	0.2 g/cm^2
$<R_{HS}>$	25 µm
$t_{\text{ X-ray}}$	100 ps
Y_n(2%D)	2x10^{14}

Ignition Burn averaged performance	
<T>	~ 30 keV
$<\rho R>$	~ 1.4 g/cm^2
$<R_{HS}>$	~ 70µm
t_{burn}	~ 10 ps
Y_n	~ 5x10^{18}

The NIC goal is to develop a robust burning plasma platform by the end of 2012

FY09	FY10	FY11	FY12
0.5 - 1 MJ ops	1 - 1.5 MJ ops	1 - 1.5 MJ ops	1.5 – 1.8 MJ ops



CH/Au Integration

Drive Temperature T_{rad}

Capsule Tuning Integration

THD Layered Implosion Integration

▲ Demonstration of integrated implosion

Point Design Campaign
Be or CH

Capsule Tuning

THD Layered implosions

1st DT Implosion Tuning

Increase Ignition Threshold Factor (ITF)
(FY11 diagnostics, alternate ablators)

Enhanced coupling and surrogacy

DT Ignition Implosions

Enhanced design & diagnostics

osions

DT Ignition Platform

Summary

- **Ignition requires a precisely controlled implosion to assemble a DT hot spot surrounded by cold DT fuel**

- **Experiments using surrogate targets are required to adjust laser and target parameters to obtain the implosion conditions necessary to achieve ignition**

- **The Ignition Campaign is phased in time to reduce risk and uncertainty in the performance of the point design target, and systematically increase confidence in achieving ignition conditions**

- **An important aspect of this is experiments using dudded fuel layers that provide a diagnostics rich environment to study and optimize the hydrodynamic assembly of the cryogenic fuel**

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Lawrence Livermore National Laboratory

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