# Introduction to the Ignition Fusion Research Program on the National Ignition Facility

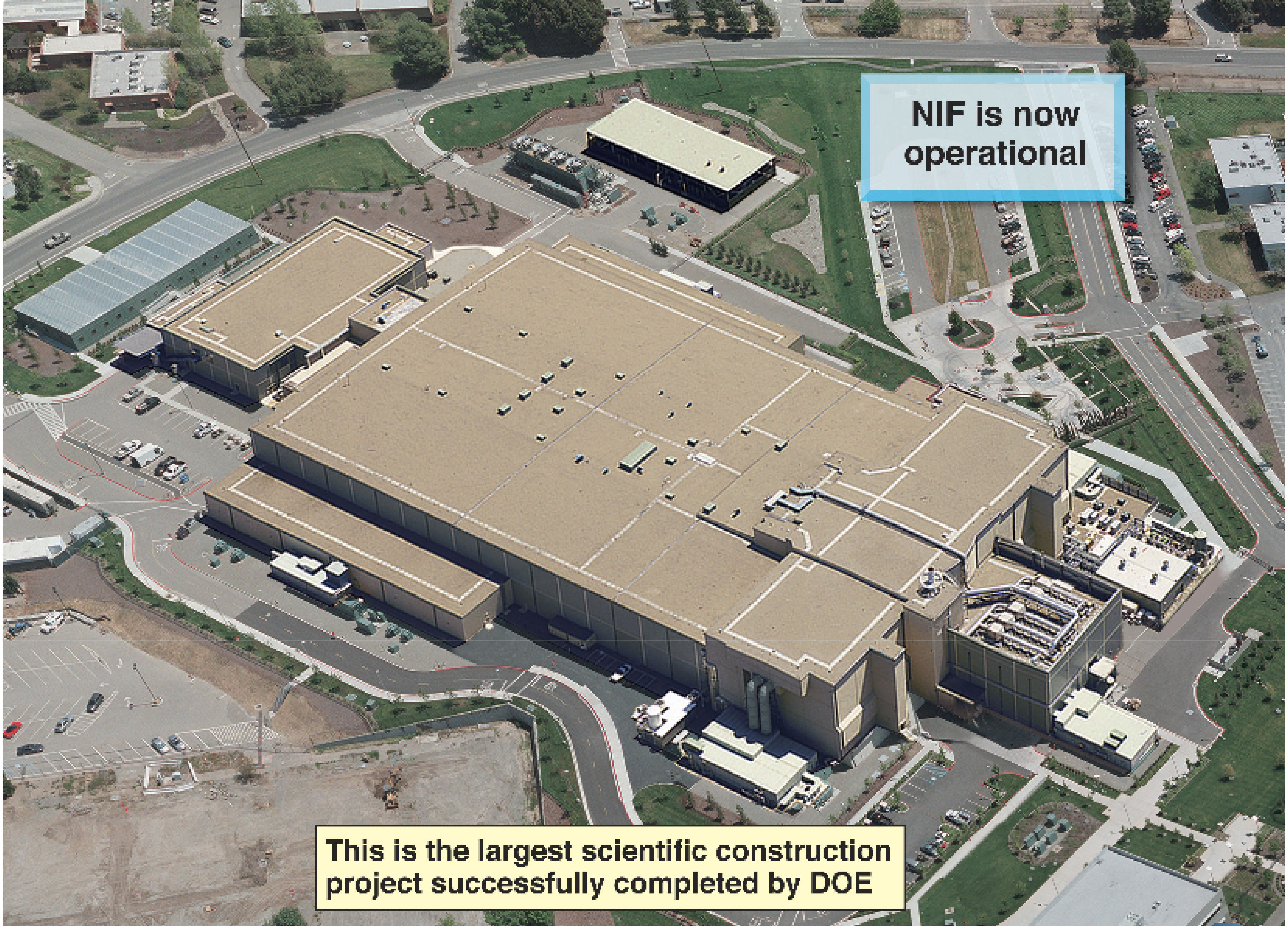
Presentation to
2010 Plasma Physics Summer School in Japan
Kobe, Japan
August 10, 2010

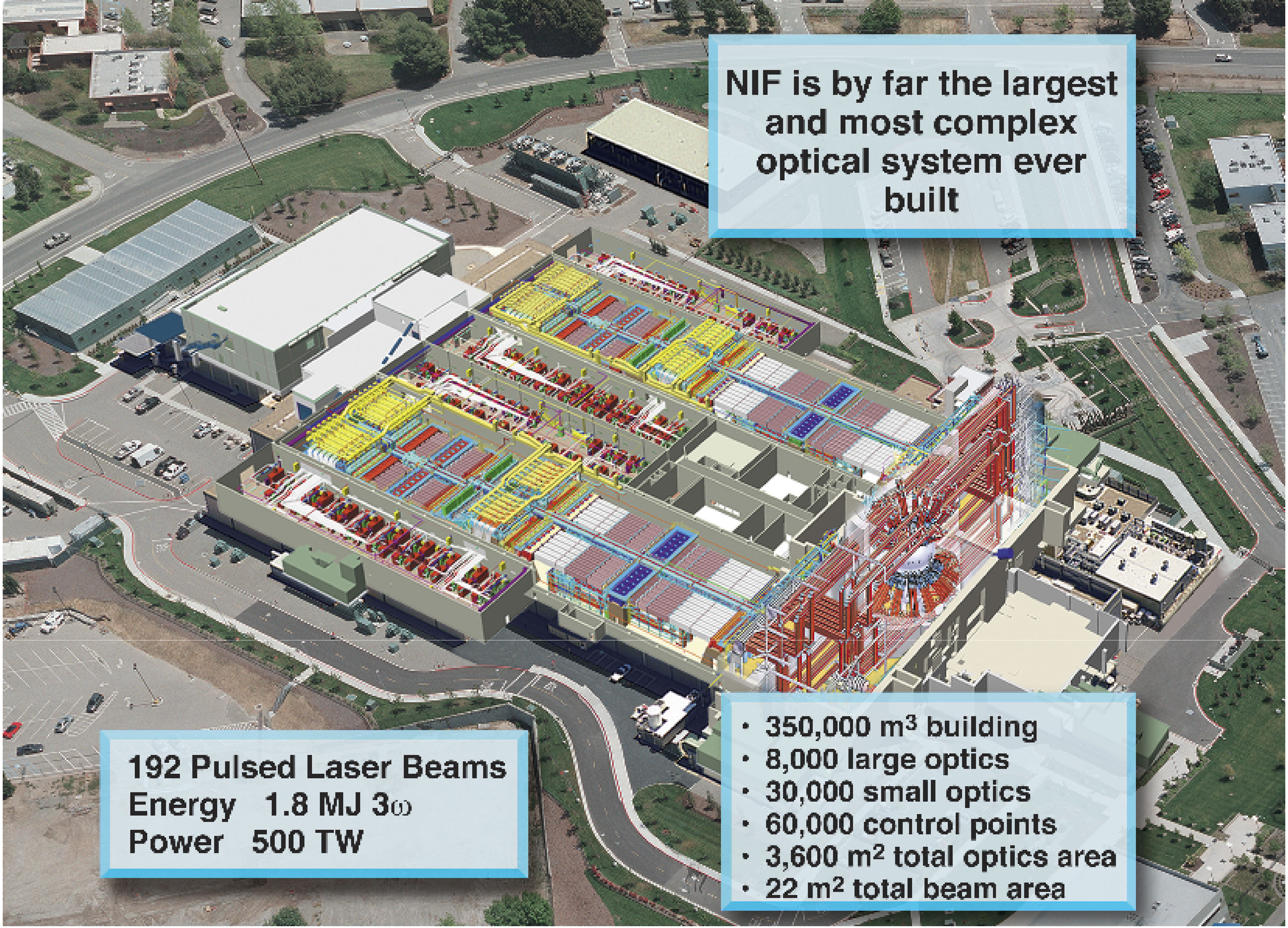
Ramon J. Leeper
Sandia National Laboratories and
The National Ignition Campaign Team


This work performed under the auspices of the U.S. DOE by Sandia, Los Alamos and Lawrence Livermore National Laboratories
under Contracts DE-AC04-94AL85000, DE-AC52-06NA25396 and DE-AC52-07NA27344

# Outline of Presentation

- Introduction to the NIF facility
- NIF indirect drive hohlraum and target
- NIF target diagnostic system
- Summarize energetic hohlraum experiments performed to date on NIF
- Describe NIC experimental plans leading up to ignition
- Summary and Conclusions

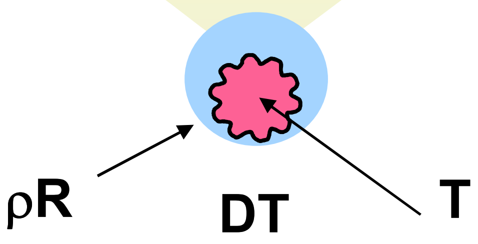

NIF is now operational
This is the largest scientific construction project successfully completed by DOE

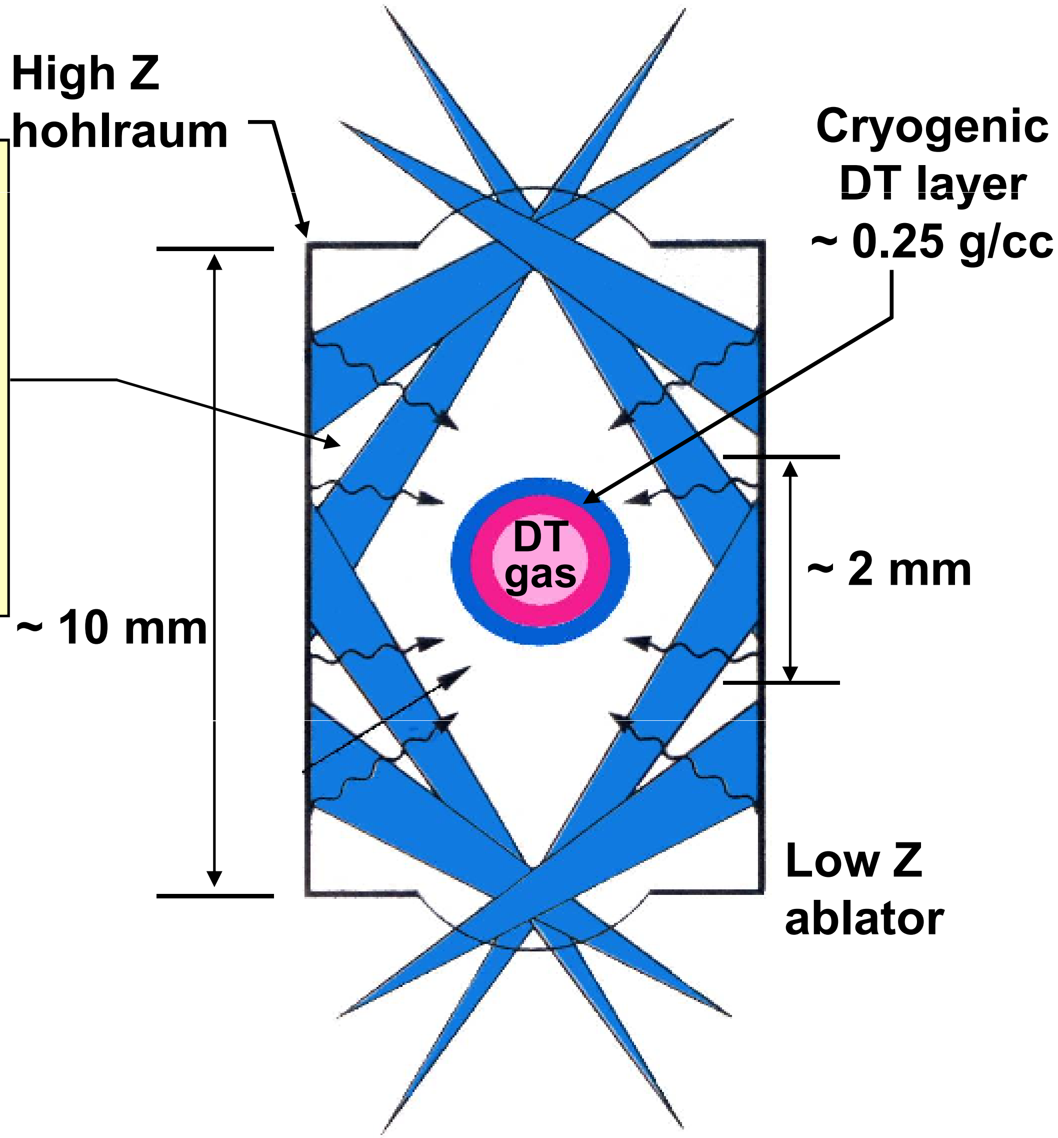

NIF is by far the largest and most complex optical system ever built
192 Pulsed Laser Beams
Energy 1.8 MJ 3ω
Power 500 TW
• 350,000 m3 building
• 8,000 large optics
• 30,000 small optics
• 60,000 control points
• 3,600 m2 total optics area
• 22 m2 total beam area

# On NIF we will use a hohlraum driven implosion to generate the ρR & T needed for ignition

- ~ 1 MJ laser energy
- ~ 3 million degree (300 eV) X-ray bath
- ~ 100 million atmosphere ablative rocket drive
- Accelerates shell to ~ 350 km/s

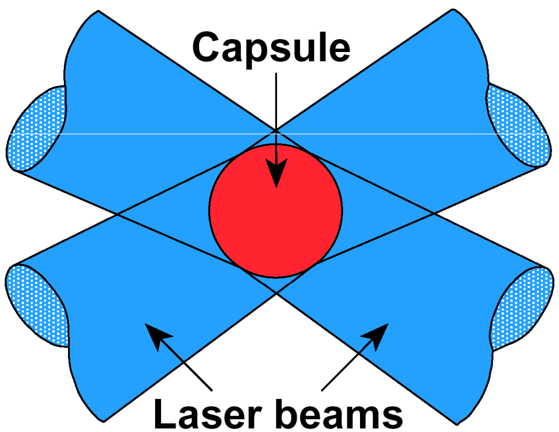
Compresses & heats core, PdV



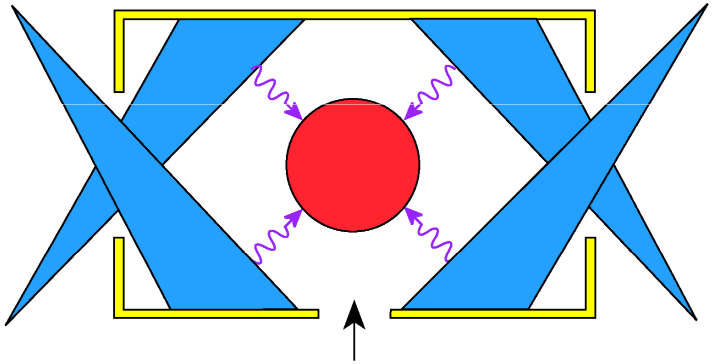



# In contrast to direct drive ICF, in indirect drive ICF the capsule is driven by soft x-rays generated in a hohlraum

**Direct-drive target**




**Indirect-drive target**




*Hohlraum* using
a cylindrical high-Z case

**Features of indirect drive:**

- Soft x-rays couple directly to capsule ablation front
- Beams or power sources originating in a restricted solid angle can be converted into a symmetric x-ray flux onto the capsule
- Symmetry can be tuned by variations in hohlraum to capsule radius ratio
- Ignoring hole losses, the x-ray power flux within a hohlraum is amplified over the input source power flux by a factor of $1/(1-\alpha)$ where $\alpha$ is the wall albedo
  - For a 200 eV Au wall hohlraum, a typical value of $\alpha$ is 0.8 yielding an amplification factor of 5

# To achieve ignition and burn on NIF we have to assemble a hot spot surrounded by dense fuel

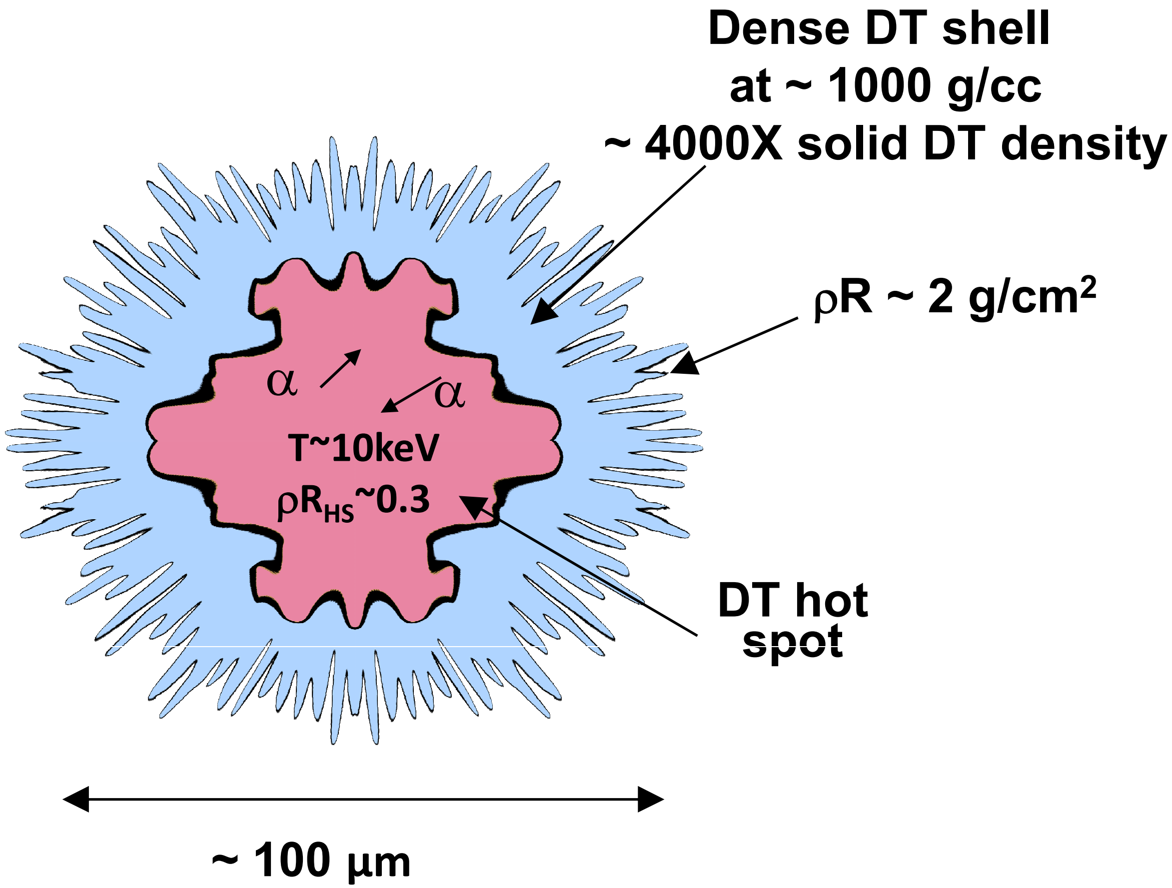
- **Hot spot ignition:** **α heating >> cooling**
  - **$T_{HS}$ ~ 10 keV**
  - **$\rho R_{HS}$ ~ 0.3 g/cm$^2$**

- **High ρR for efficient burn**

$$\frac{dn}{dt} \sim n_D n_T \langle \sigma V \rangle; \;\; \tau \sim \frac{R}{C_s}$$

$$f_b \approx \frac{n\tau}{n\tau + 3\times 10^{15}} = \frac{\rho R}{\rho R + 6}$$

$$\rho R \approx 2 \;\; g/cm^2 \Rightarrow f_b \approx 0.25$$



# Success of ignition is crucially dependent on Mix, Velocity, Adiabat and Shape

**Adiabat**

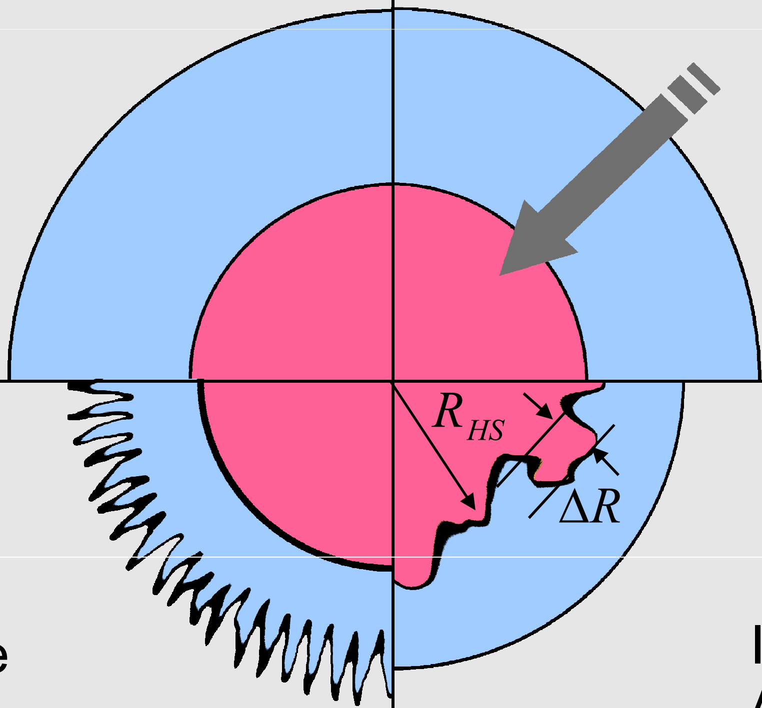
$\beta \leq 4$

Shock pressures
Shock timing
Hot electrons

**Velocity**

$V > 350 \ km/s$

$T_R$
Laser power
Backscatter
Hohlraum efficiency
Ablator thickness




**Mix**

Ablator-fuel interface roughness
Photon preheat
Ablator dopant

$$\frac{\Delta R_{mix}}{\Delta R_{shell}} < 0.2$$

**Shape**

$$\frac{\Delta R_{HS}}{R_{HS}} < 0.18$$

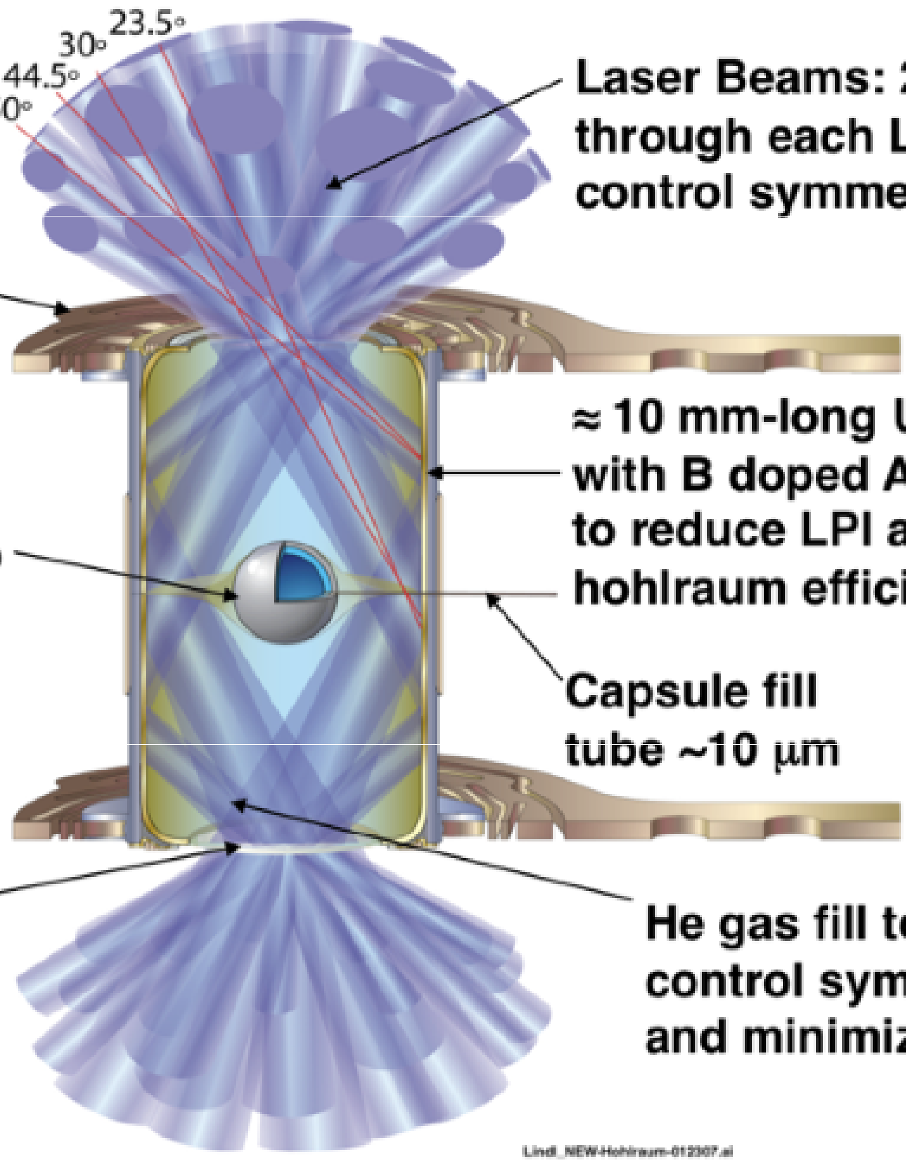
Ice surface perturbations
Ablator low mode surface
Laser power balance
Hohlraum geometry

# The NIF point design is shown here

Cryo-cooling rings to control hohlraum temperature and cryo fuel layer uniformity

≈ 2 mm CH(Ge) or Be (Cu) Capsule with cryo fuel layer to maximize coupling efficiency and minimize mix

Laser Entrance Hole sized to balance LPI and radiative losses




Laser Beams: 24 quads through each LEH arranged control symmetry

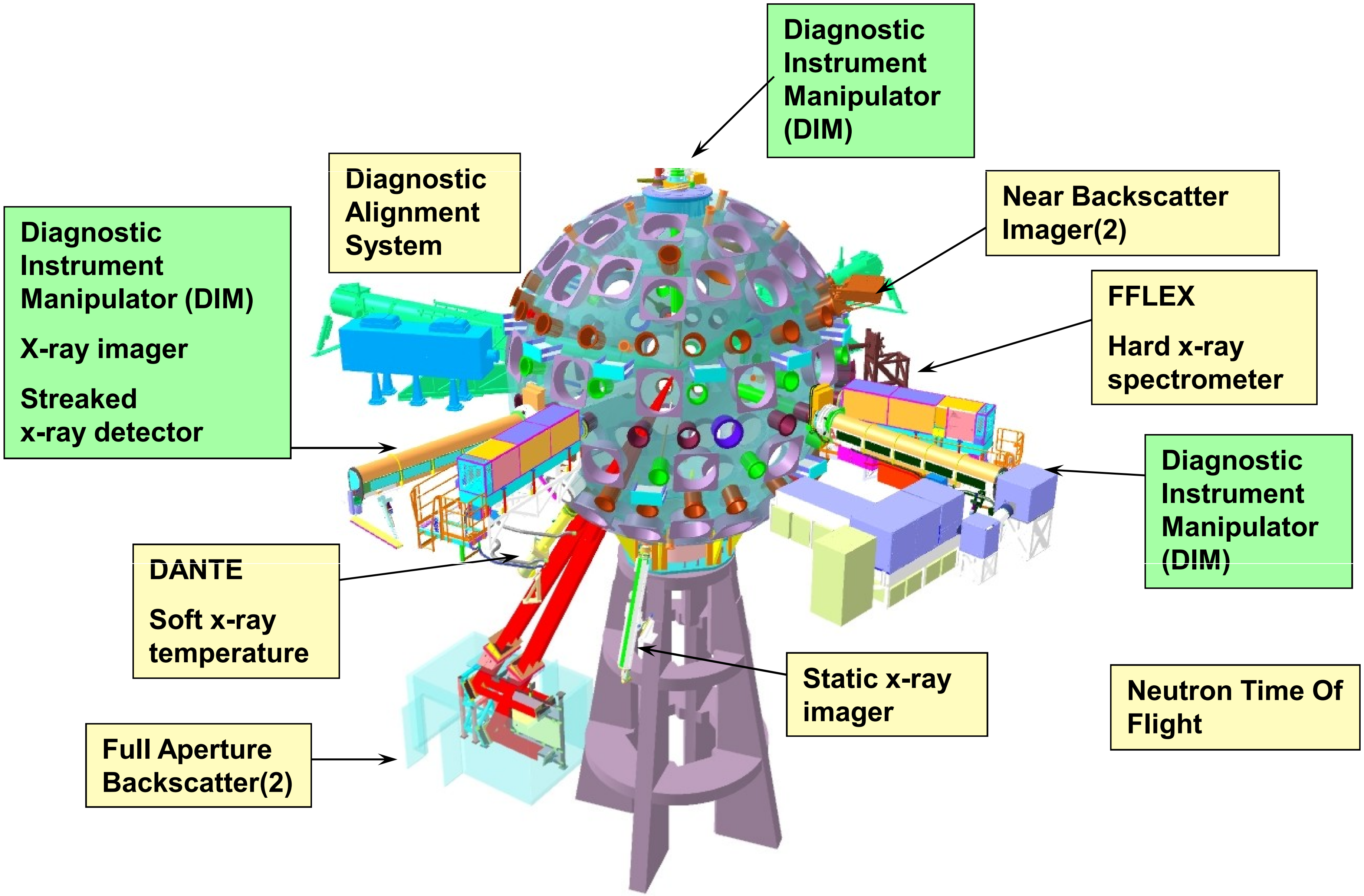
≈ 10 mm-long U hohlraum with B doped Au surface layer to reduce LPI and increase hohlraum efficiency

Capsule fill tube ~10 μm

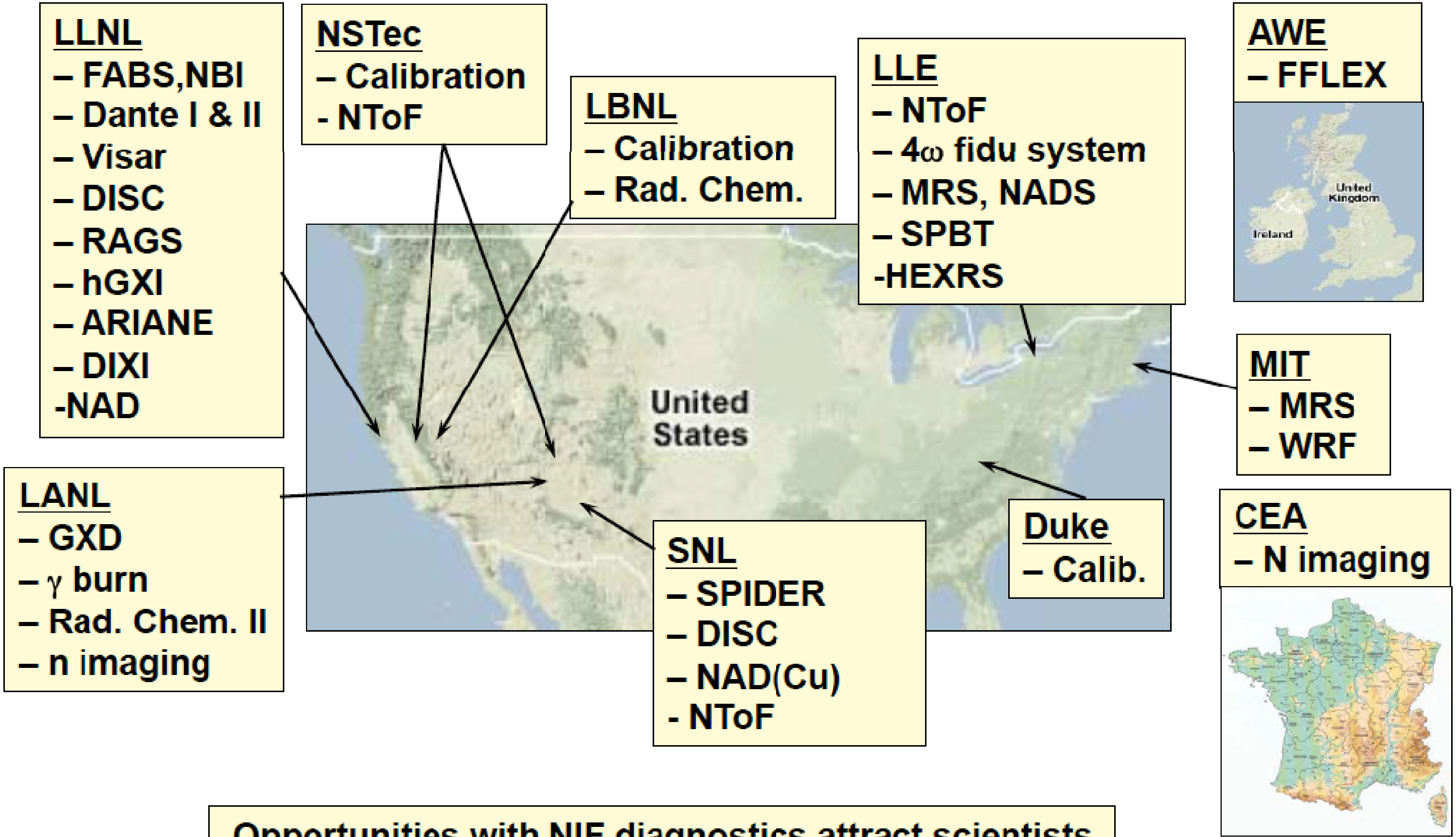
He gas fill to control symmetry and minimize LPI

Lindl_NEW-Hohlraum-012307.ai

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



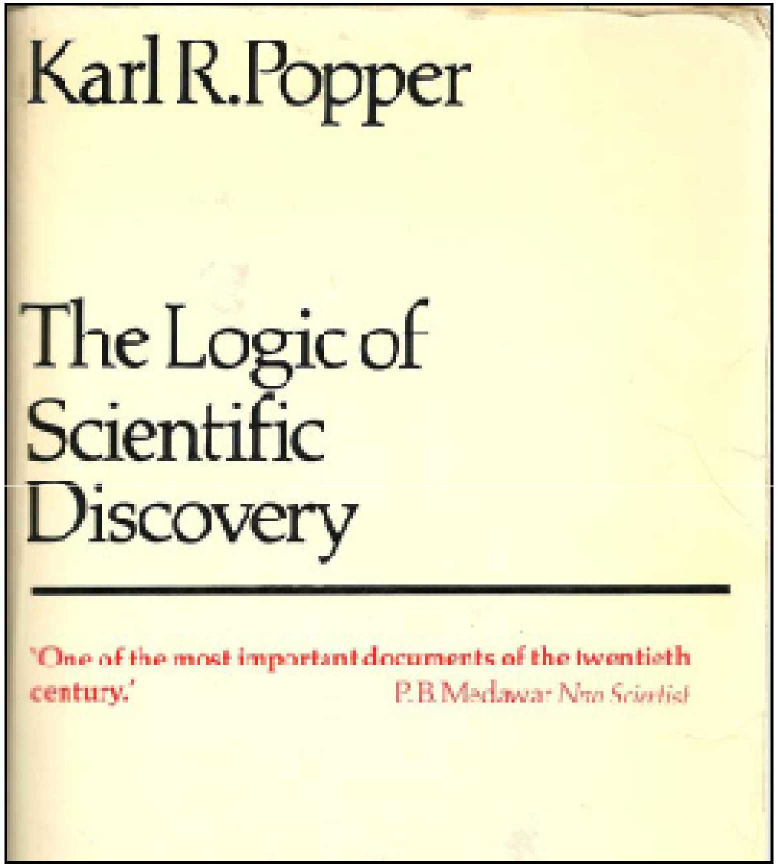
# The NIC diagnostic team is shown here




**Opportunities with NIF diagnostics attract scientists**

# Complementary redundant diagnostics are needed to progress in science

- Karl Popper, Hutchinson Press, 1959: "cannot prove a theory (measurement) is right, can prove it is wrong"- by test (comparison with other diagnostics)




**Falsifiability and Testability**
: "Hypotheses are nets: only he who casts will catch"

- Down Scatter Fraction (DSF): measure by NToF and Magnetic Recoil Spectrometer
- $\rho r$: measure with NToF, MRS, Radchem and by ARC
- Hot spot T measured by x-rays and neutron emission

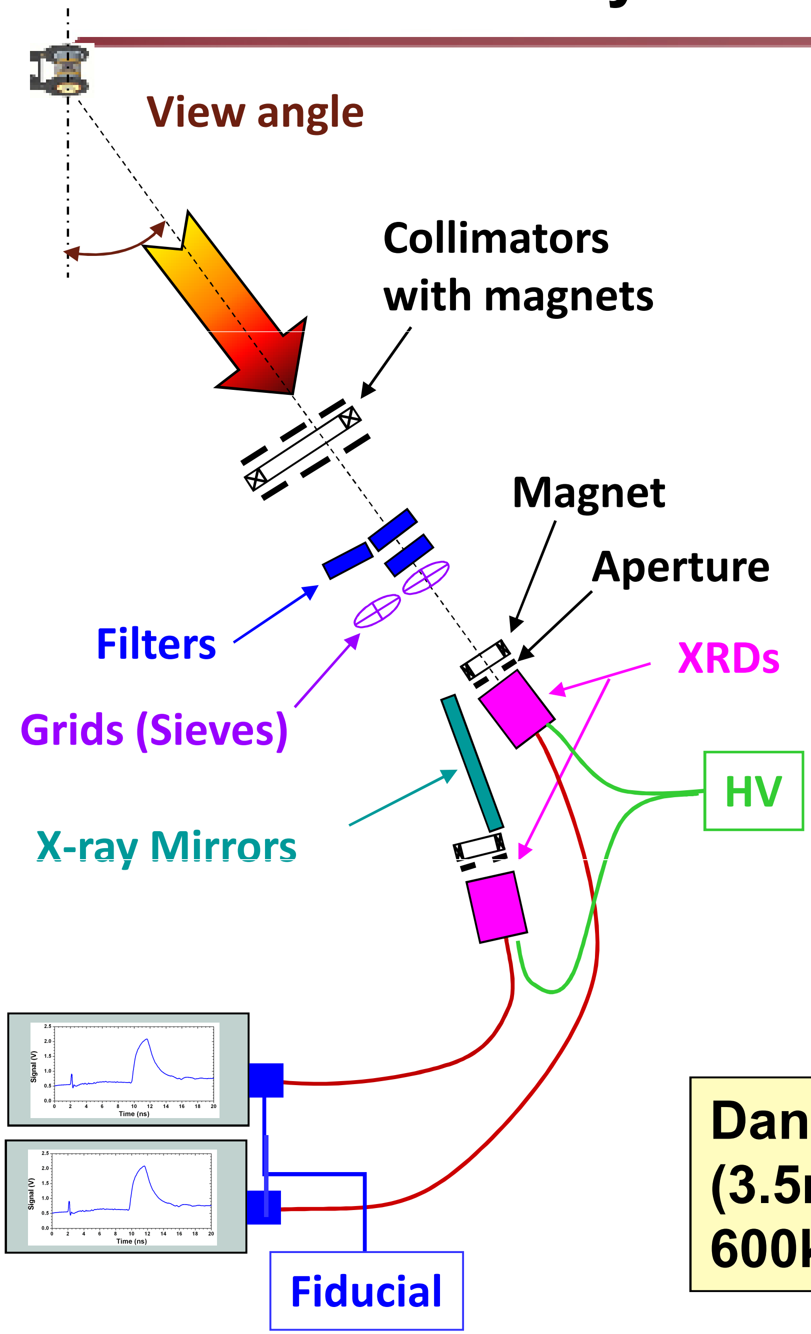
# The matrix of diagnostics (columns) and observables (rows) is not diagonalized-a benefit

**Hot spot** | **Cold Shell**

| | Neutron activation NAD | Neutr. Time of Flight (NToF4,5) | Gated X-ray Imagers(hGXI, ARIANE, DIXI) | X-ray Pinhole Camera (XPHC) | Hardened Streak X-ray Det (SPIDER) | X-ray Spectrometer (XRS) | γ Reaction History (GRH) | Wedge Range Filter (WRF) | Adv. Radiographic Cap. (ARC) | Neutron Time of Flight 20 (NToF 20) | Magn. Recoil Spectr. (MRS) | Radiation Chemistry (radchem) | Neutron Imager p/ds (NI prds) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $<\rho R_{Total}>$ | | | | | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| $<T_{HS}>$ | | ✓ | ✓ | ✓ | ✓ | | | | | ✓ | ✓ | | |
| $Y_{r,x}$ | ✓ | ✓ | | ✓ | | | | ✓ | | ✓ | ✓ | ✓ | |
| $<R_{HS}>$ | | | ✓ | ✓ | | | | | | | | | ✓ |
| $t_{Burn}$ | | | ✓ | | ✓ | | ✓ | | | | | | ✓ |
| mix | | | ✓ | | ✓ | ✓ | | ✓ | | | | ✓ | |

**Why so many? No diagnostic makes a perfect measurement, complementary and redundant diagnostics essential**

# DANTE: Soft X-ray Power Diagnostic - Overview

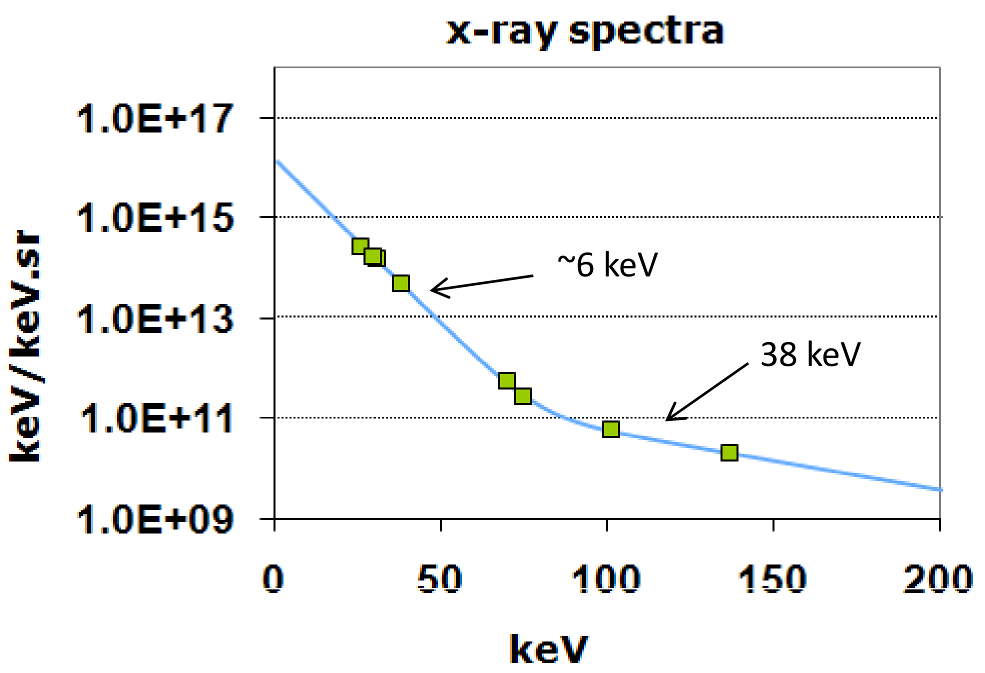



- 18 individual Channels
- Specific filter, mirror, X-ray diode (XRD) combination for each channel providing broad spectral coverage (60 eV to 20 keV)
- Temporal resolution of the XRD approx. 150ps
- Time fiducials are combined with the signal for cross timing
- All components are calibrated (e.g., filter transmission, mirror reflectivity, XRD sensitivity)

**Dante was commissioned by irradiating scale-0.7 (3.5mm) vacuum hohlraums at energies from 14 to 600kJ with up to 192 beams**

# Hard x-ray diagnostic, FFLEX, measures bremsstrahlung from hot electrons produced by LPI

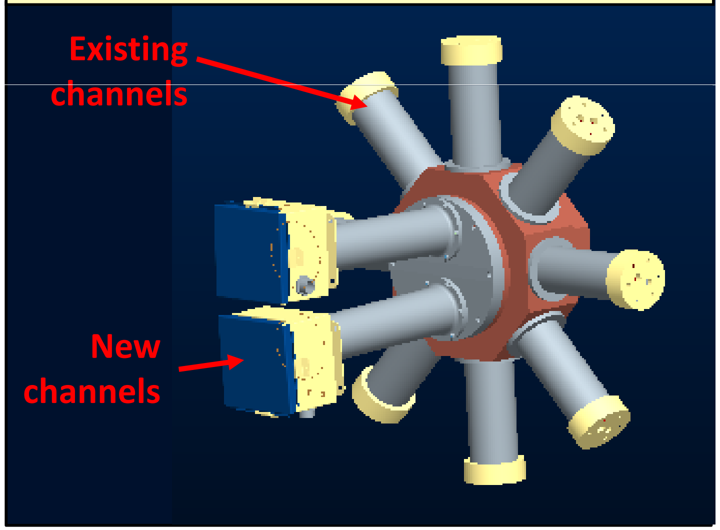
**Two temperature measurement from 250 kJ gold hohlraum**

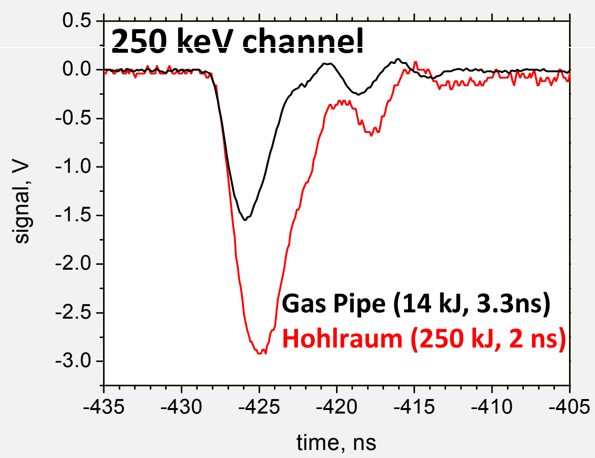



$T_1$=6.0 keV, $T_2$=38 keV, $E_2(f_{hot})$=7.2 J (0.003%)

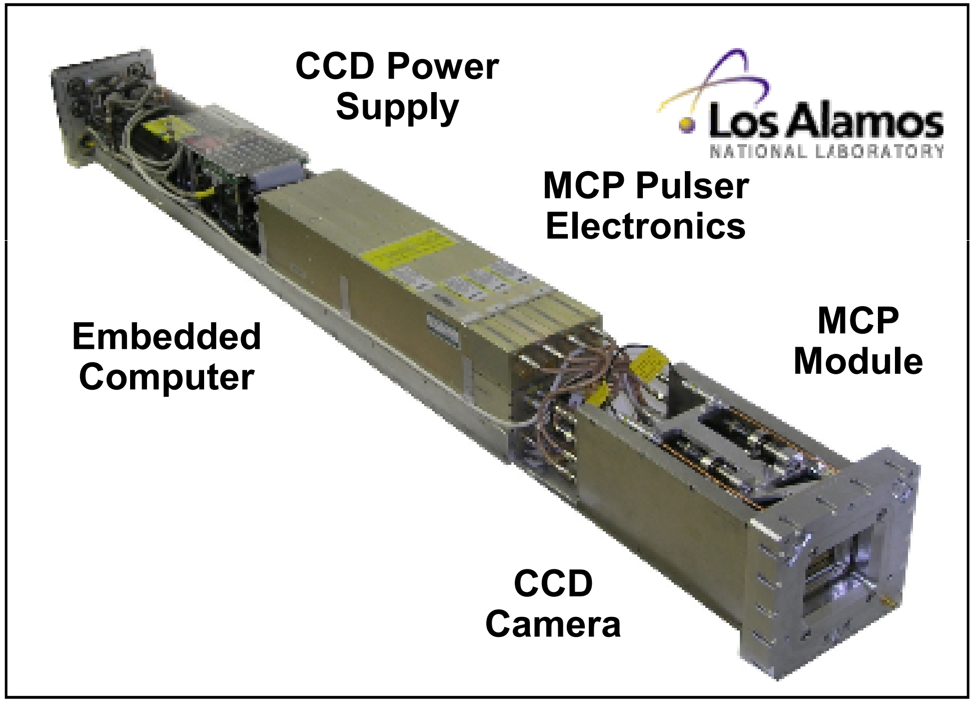
- New time-resolved capability on high-energy channels

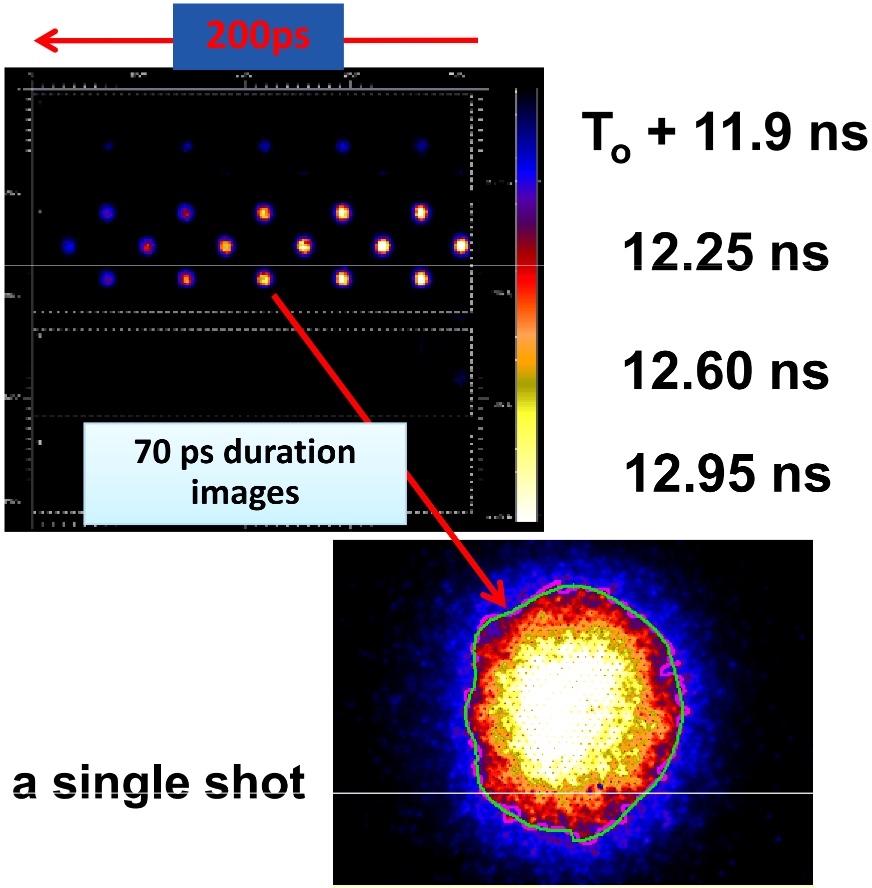
**Upgraded FFLEX design provides time-resolved hard x-ray data at 250 keV and 400 keV**



# The NIF Gated X-ray Detectors (GXD) are smart versions of detectors fielded on Omega and Nova




P0 = 100 μm
P2/P0 = 0.089+/-.008
P4/P0 = 0.037+/-0.10

- The GXD monitors almost 800 data fields on a single shot
  - constant polling
  - voltage & current on MCP & phosphor,
  - Pressure, relative humidity
  - Cooling water temperature & flow
- Temperature is measured on 22 different components
  - trigger delays are adjusted based on T to give <30 ps jitter
- Diagnostic can turn itself off in when out of spec and tell you when and why

# The first nuclear diagnostics were commissioned on NIF during the first hohlraum energetic experiments last fall

- Implosion capsules are filled with $He^4$ or $He^3$ and doped with a few percent of deuterium to keep $Y_{n,p} \sim 10^{10}$

- Very low yields of thermonuclear products are produced by:-

$$D + D \longrightarrow n\ (2.45\ \text{MeV}) + {}^3He$$

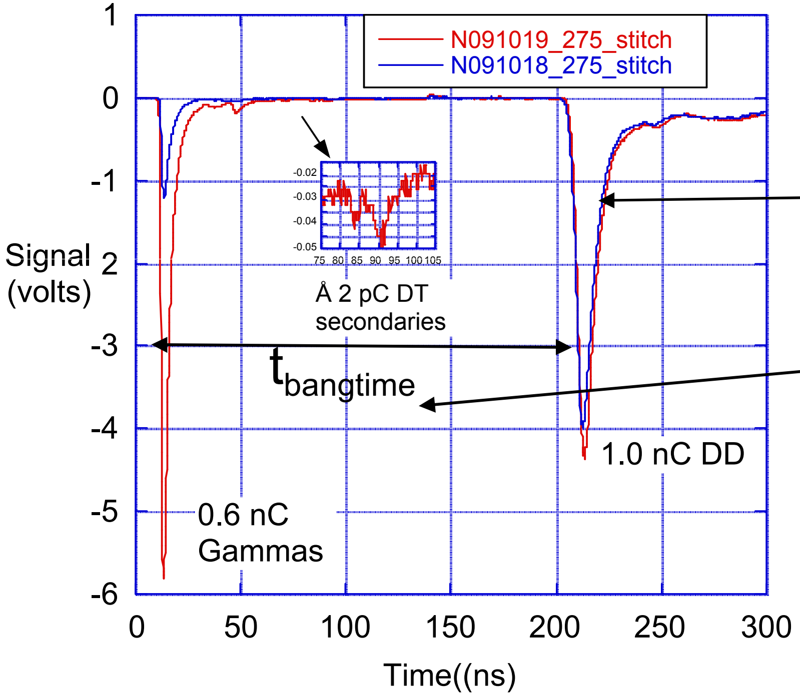
or

$$D + {}^3He \longrightarrow p\ (14.7\ \text{MeV}) + T$$

- 11/09: five nuclear diagnostics are installed and were qualified:-
  - ~~Neutron time of flight detectors~~
  - Nuclear activation detectors
  - Wedge range filter using nuclear track detectors( CR39) measure the range and therefore energy loss of the protons

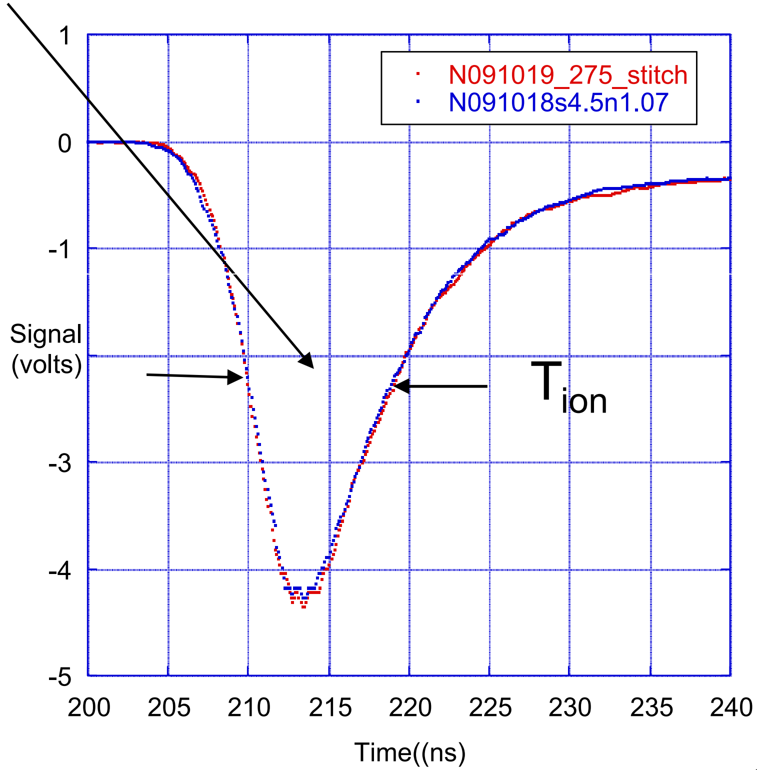
First Neutron time of flight detector

# Yield, ion temperature and bang time were measured in the first hohlraum energetic experiments




**Neutron time of flight measures:**

- **-Yield**
- **- Bang time**
- **- $T_{ion}$**

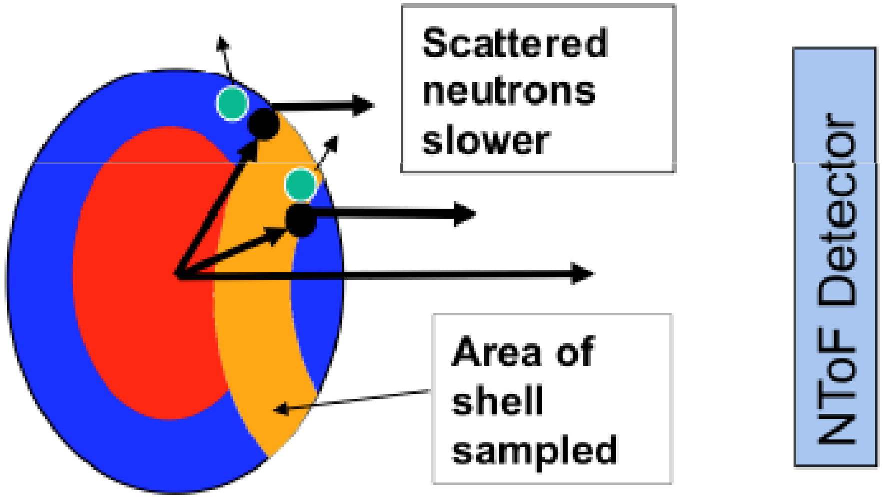



**Yields up 1.5 x $10^{10}$ DD neutrons are being measured**

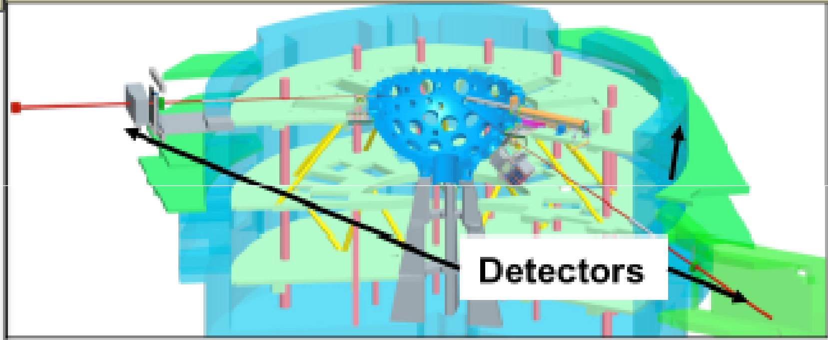
**$T_{ion}$ of 2.5 to 3.5keV**

# Areal density from Neutron Time of Flight

## Principle of operation



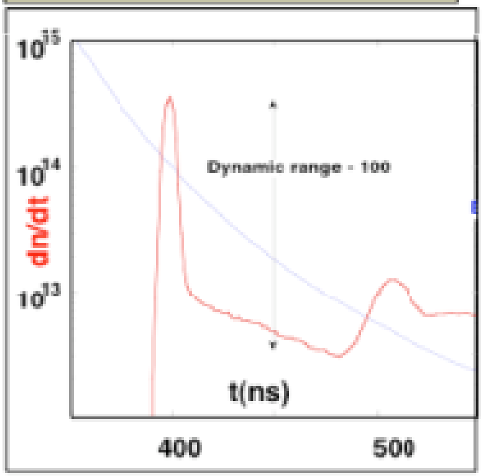

## Screening NToF20s: outside bio-shield




## Range, accuracy

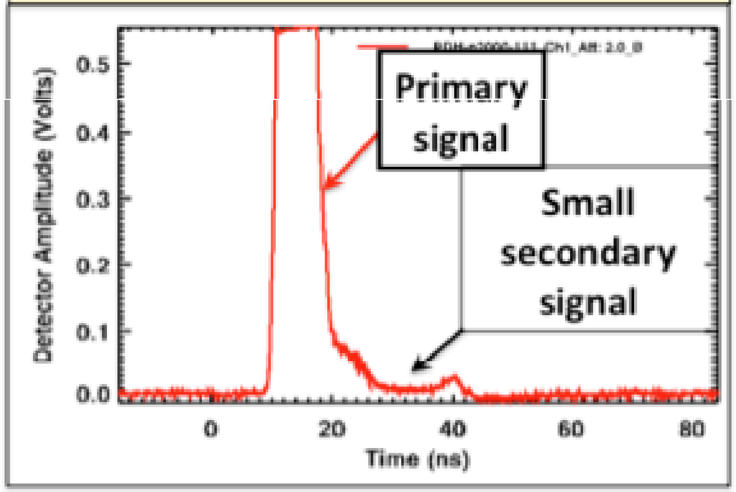
- n screening
- Fast scintillator
- accurate instrument function

Neutron arrival rate



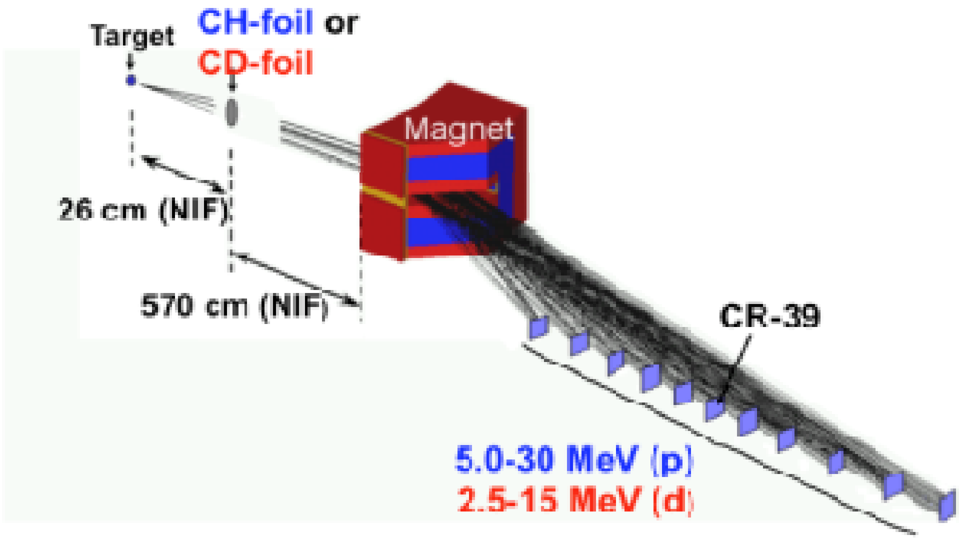

- LLE cal.
- SNL, NsTEC cal
- .
- LLNL installatior

## PMT calibrations NSTeC



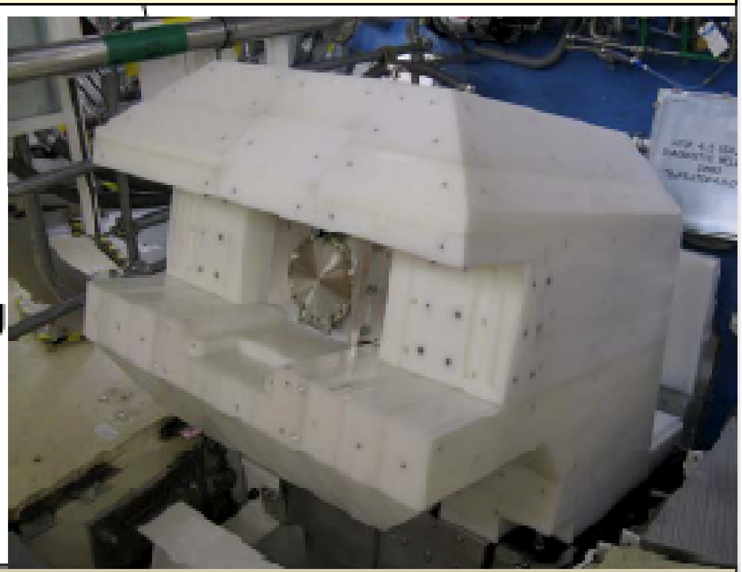
# Areal density, yield, and $T_{ion}$ from the Magnetic Recoil Spectrometer (MRS)

## n's knock p or d in foil, magnetically analyzed

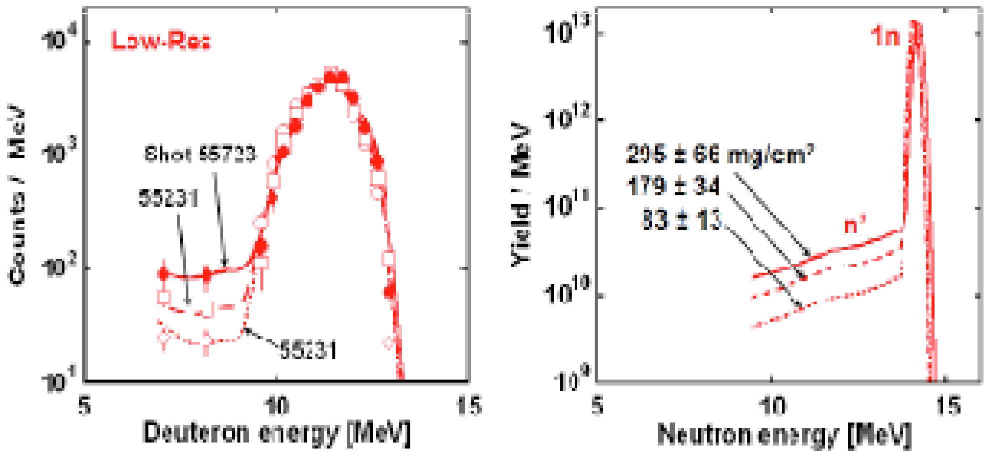



## n screening- NIF operation at hi yield

- LLE, MIT Designed & built
- n screening Allows Y ~ $10^{18}$



## OMEGA:exp. with sim. +instrument

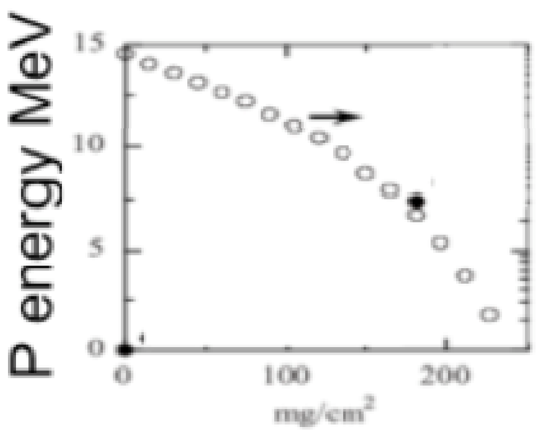


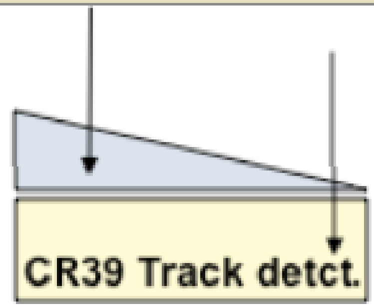

## Built by LLE and MIT, installed at NIF

- LLE developed and demo of rho-r
- 2 day turnaround

# Areal density from Wedge Range Filter (WRF) using solid state detector CR-39

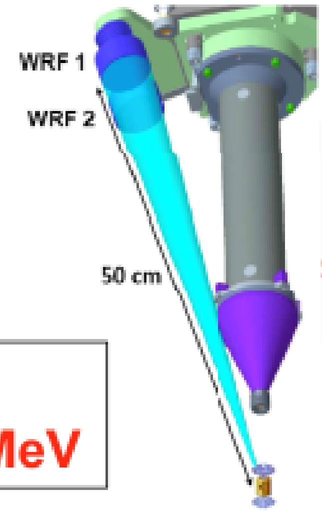
## Principle of operation




## WRF packages used fall 2009 campaign

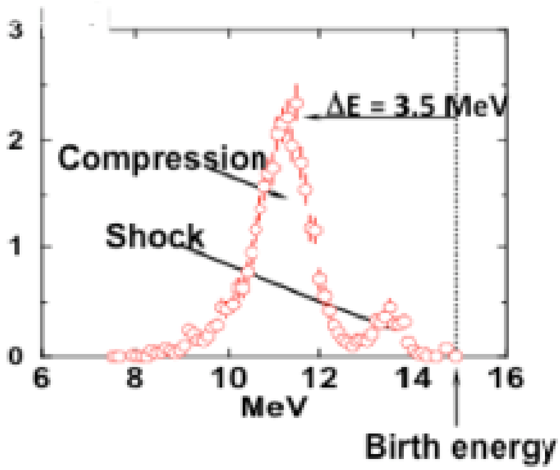
D + $^{3}$He → $^{4}$He + p (14.7 MeV



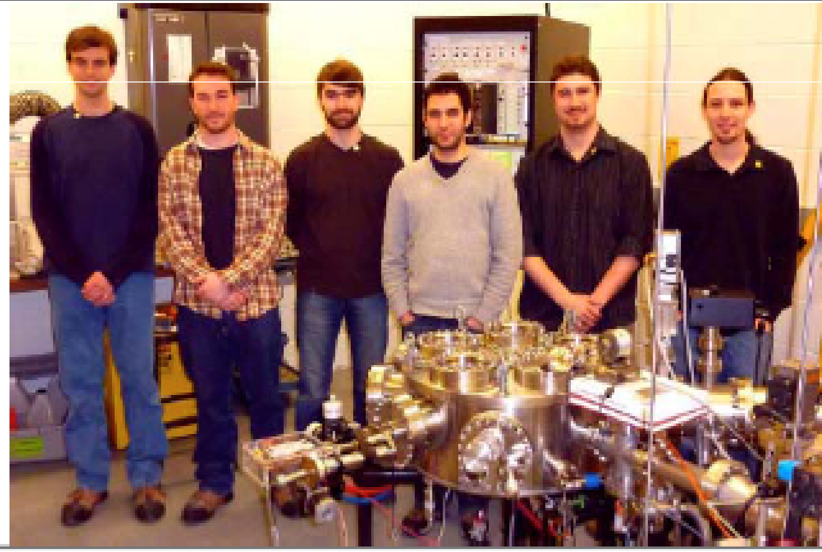

## 14.7 MeV protons range out ~ 0.2 g/cm$^2$

Exp 091123

Shock 41mg/cm$^2$
Compress. 110 mg/cm$^2$




## MIT students calibrate CR39



# Initial hohlraum energetics experiments have demonstrated a path forward to ignition hohlraums

- **We can make round implosions.**
  - — **We have used Δλ tuning to turn cross-beam transfer into a tool.**
- **We measure < 5 % total backscatter reflectivity.**
  - — **Reflectivity vs. intensity is saturated up to ignition intensities.**
- **We are driving the capsule at radiation temperatures sufficient for ignition.**
  - — **Capsule drive is close to rad-hydro code predictions using the standard ignition point design models .**

**We believe that we will be able to drive 1.2-1.5 MJ targets at 285-300 eV as required for the ignition point design hohlraum.**

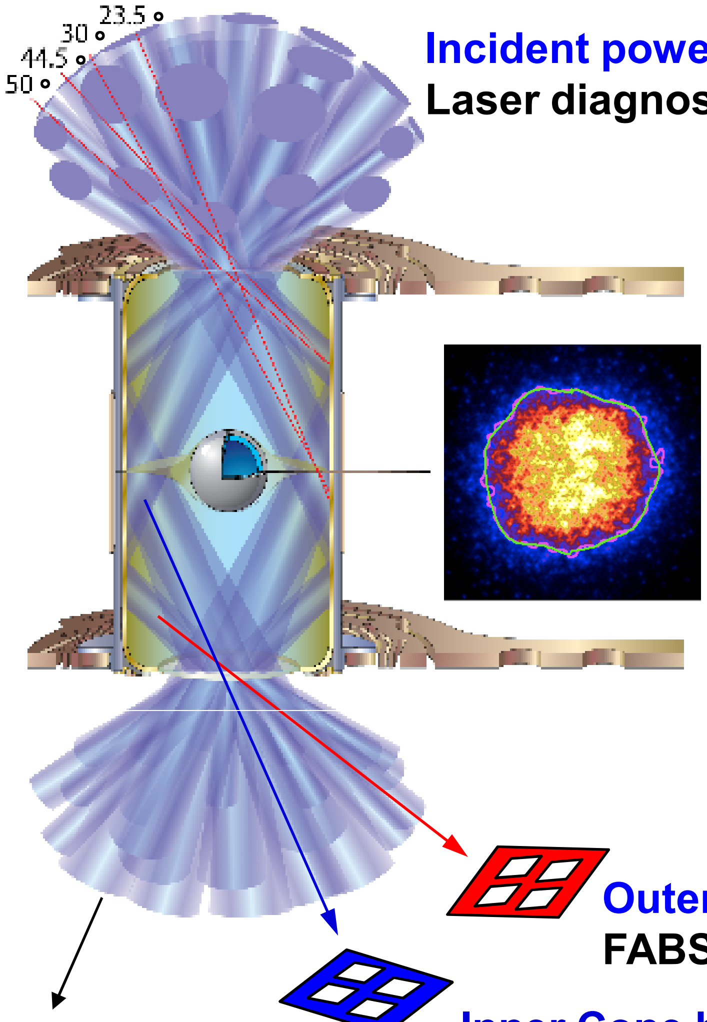
# The hohlraum energetics experiments enabled us to measure how much power stays in the hohlraum *and* where the power goes

Measure incident laser power and energy

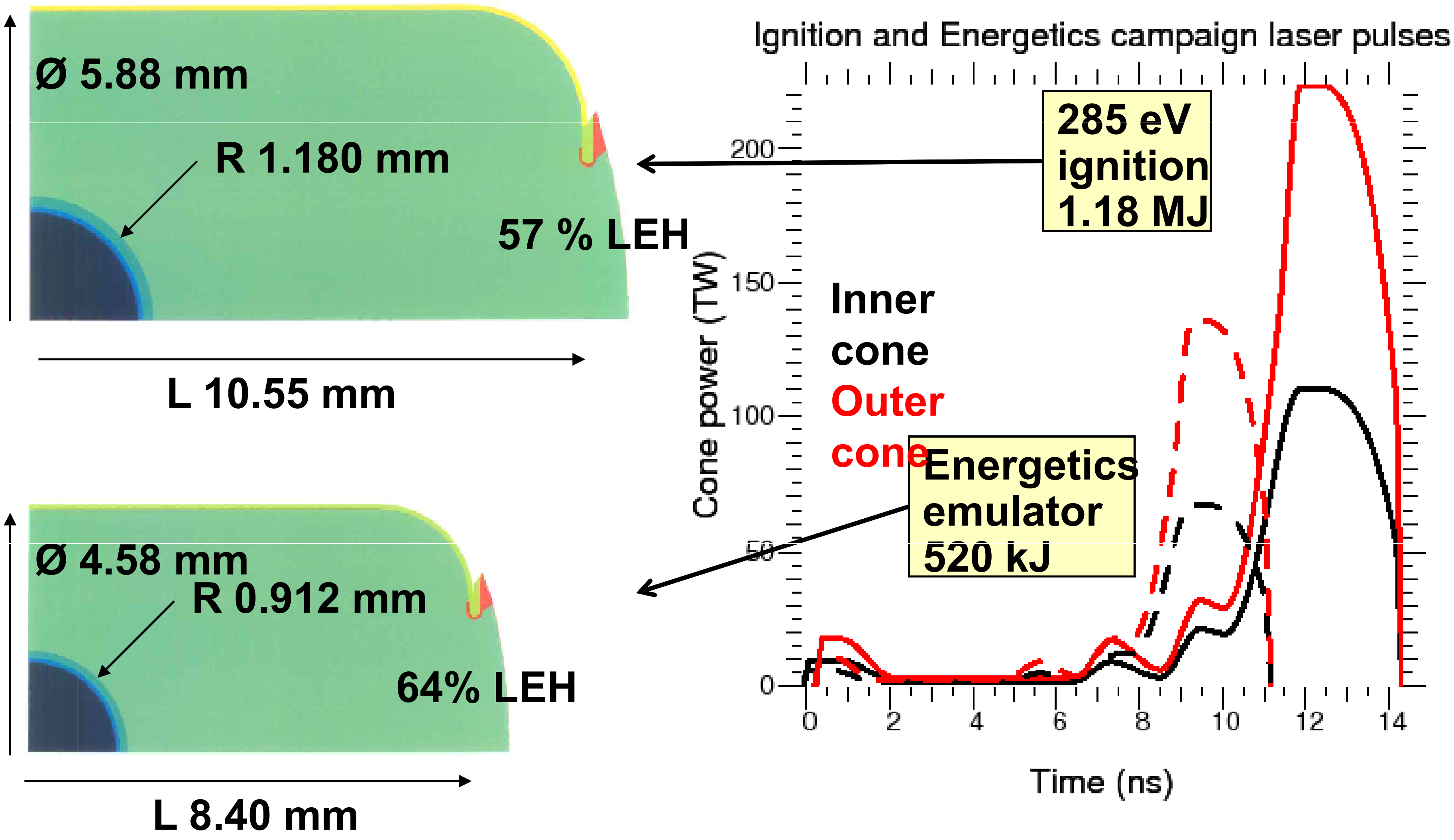
Measure and tune implosion symmetry.

Measure backscattered power and energy

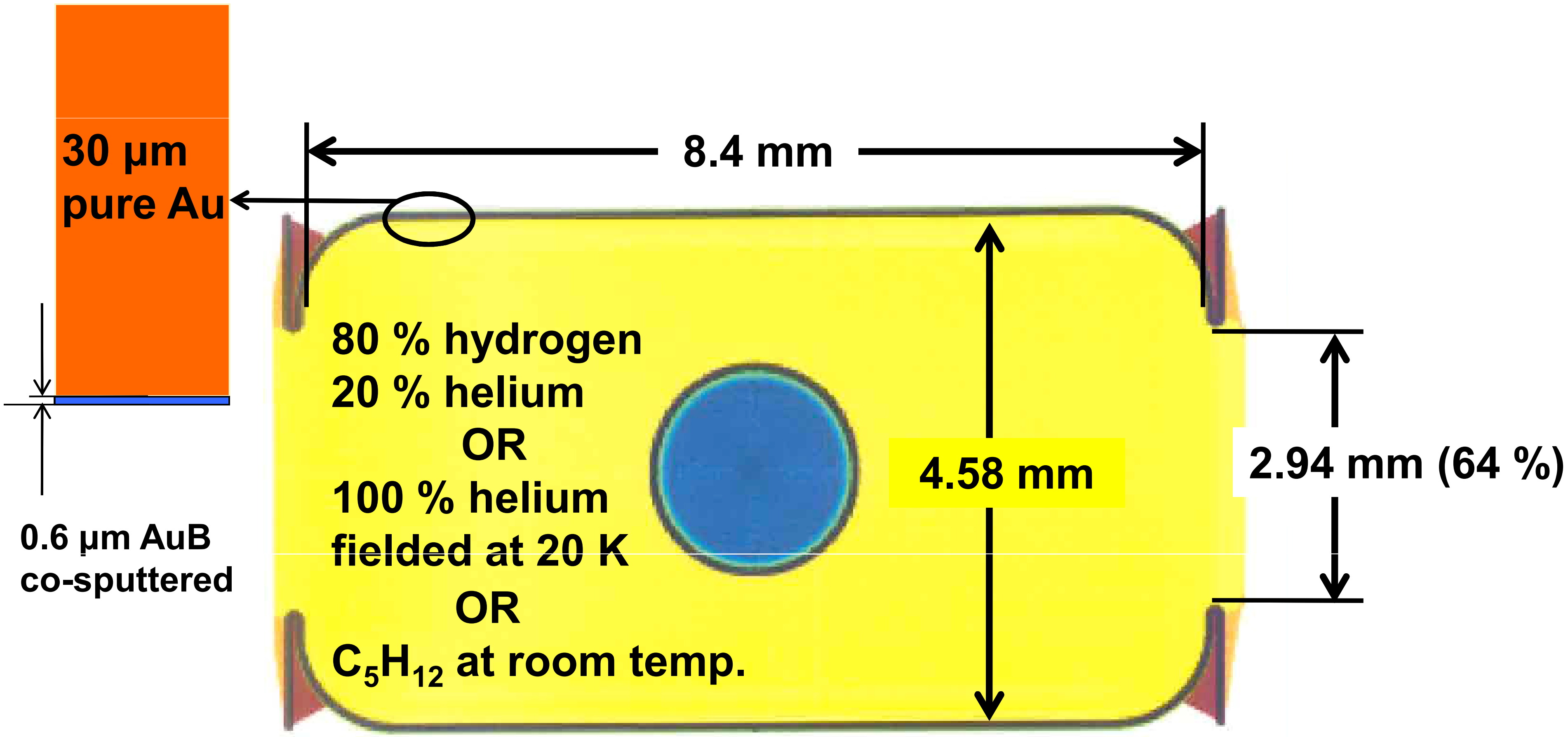
Measure x-radiation drive



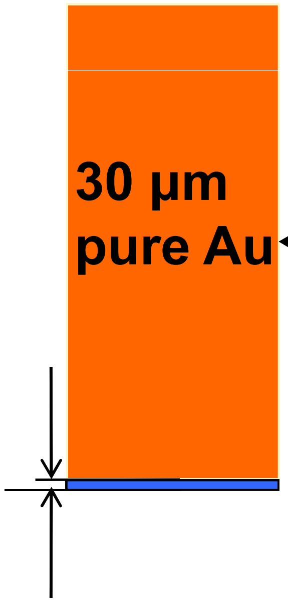
# The energetics emulator target is a 285 eV ignition hohlraum scaled down by 78 %

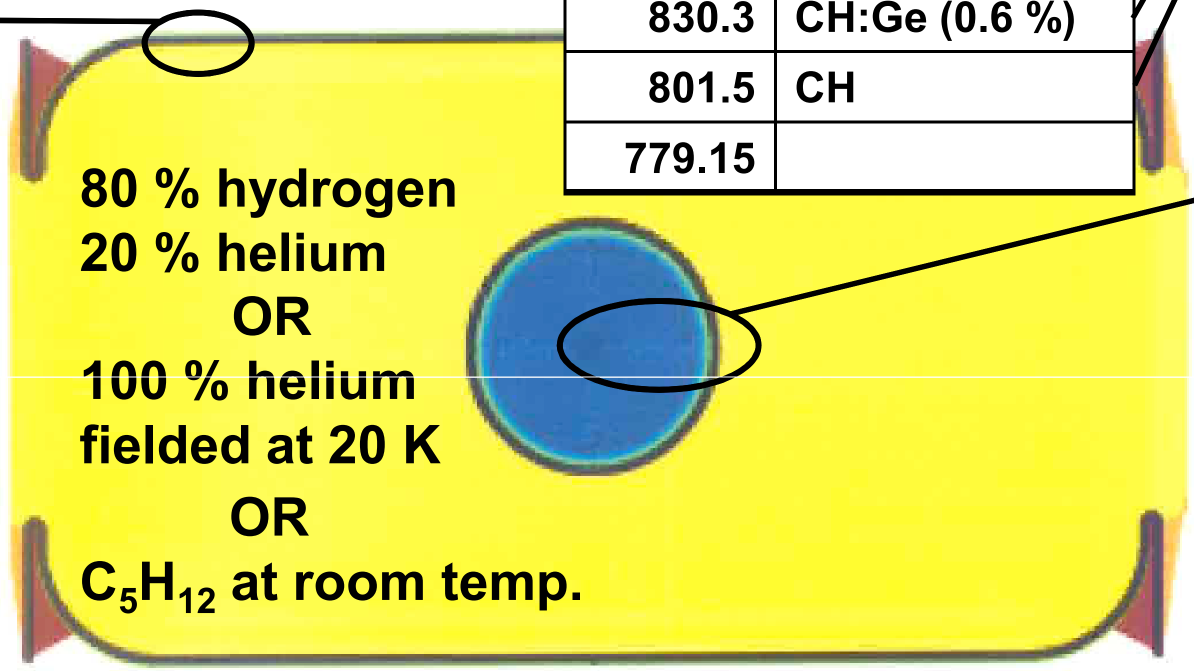


# The energetics emulator hohlraum contains the relevant materials of an ignition hohlraum

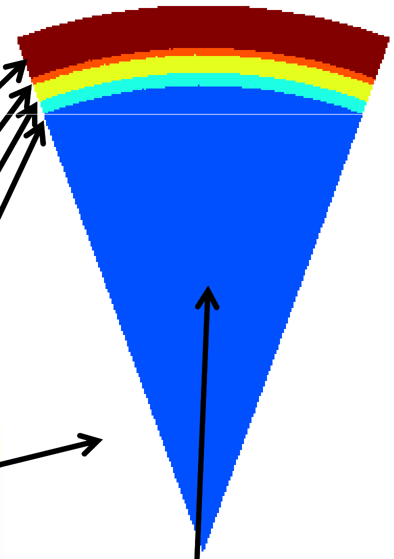


# The emulator symmetry capsule used in the hohlraum energetics experiments is plastic with graded Ge dopant and helium + $D_2$ gas fill

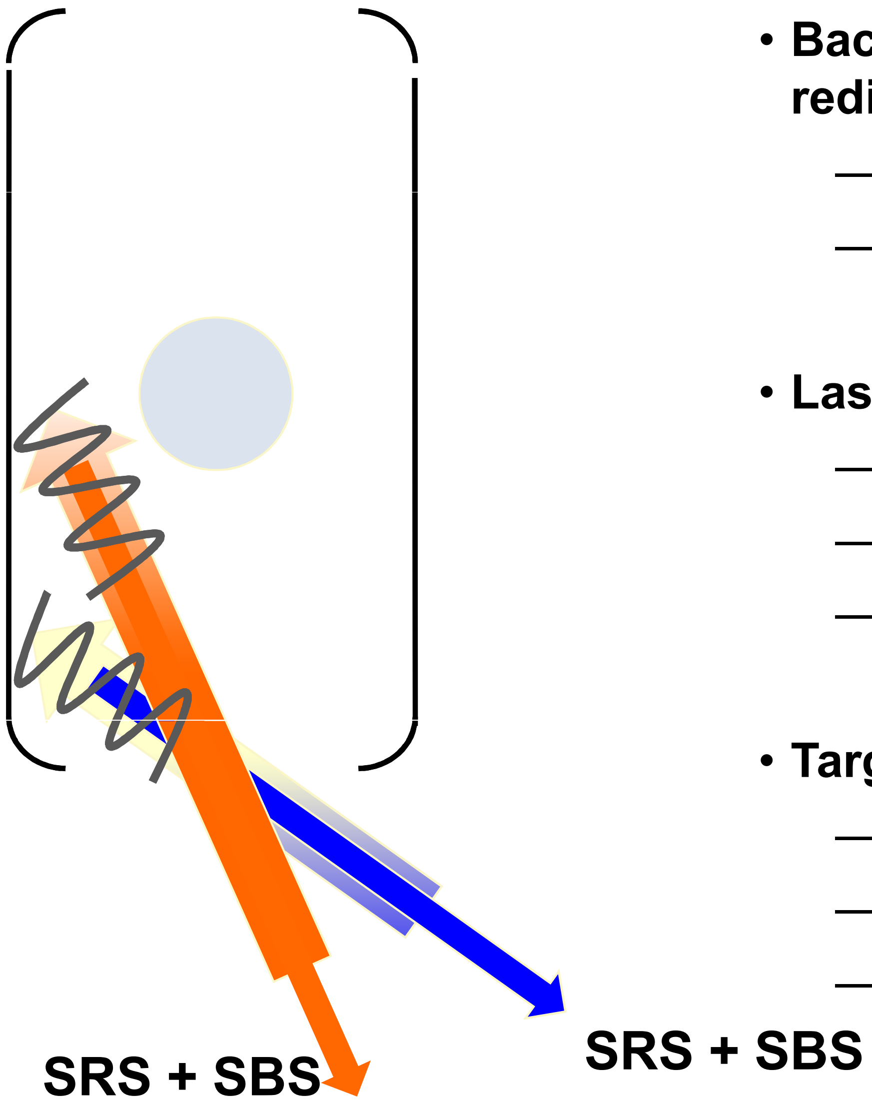



| Radii | Composition |
|---|---|
| 912 | CH |
| 842.7 | CH:Ge (0.3 %) |
| 830.3 | CH:Ge (0.6 %) |
| 801.5 | CH |
| 779.15 | |



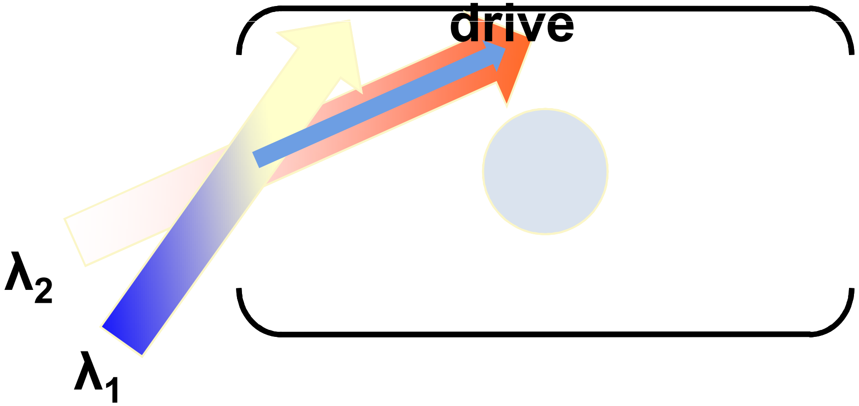
# Laser-target system used in the hohlraum energetics experiments were designed to mitigate backscatter in the hohlraum plasma.



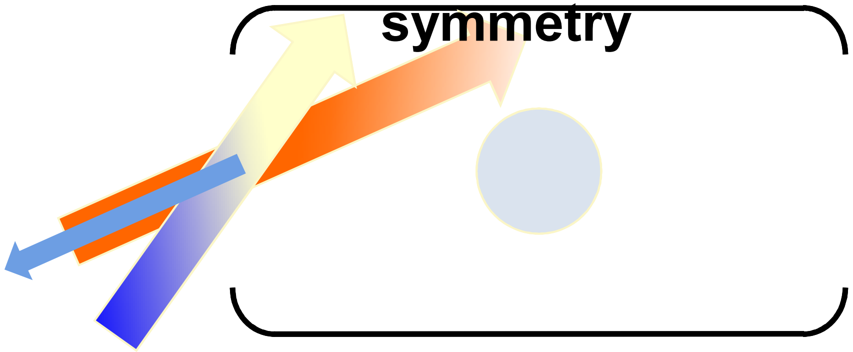

- Backscatter instabilities reflect and redirect laser power.
  - Reduces drive on the capsule
  - Affects implosion symmetry.
- Laser beam smoothing:
  - Large spots
  - Polarization smoothing
  - Smoothing by spectral dispersion
- Target materials:
  - Gold-boron-lined hohlraum walls
  - Helium/hydrogen or helium gas fill
  - CH capsule

# Laser-plasma interactions of crossing beams can both transfer power and amplify backscatter

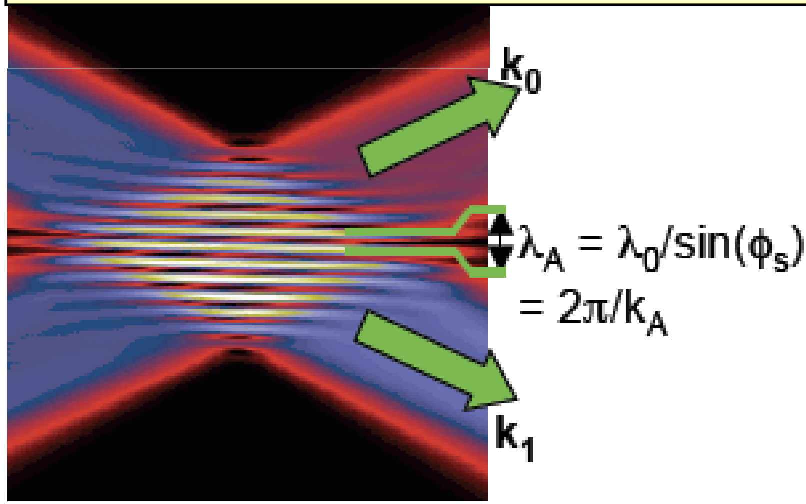
**FORWARD transfer:**
**Affects symmetry, but not drive**




**BACKWARD transfer:**
**Affects drive and symmetry**

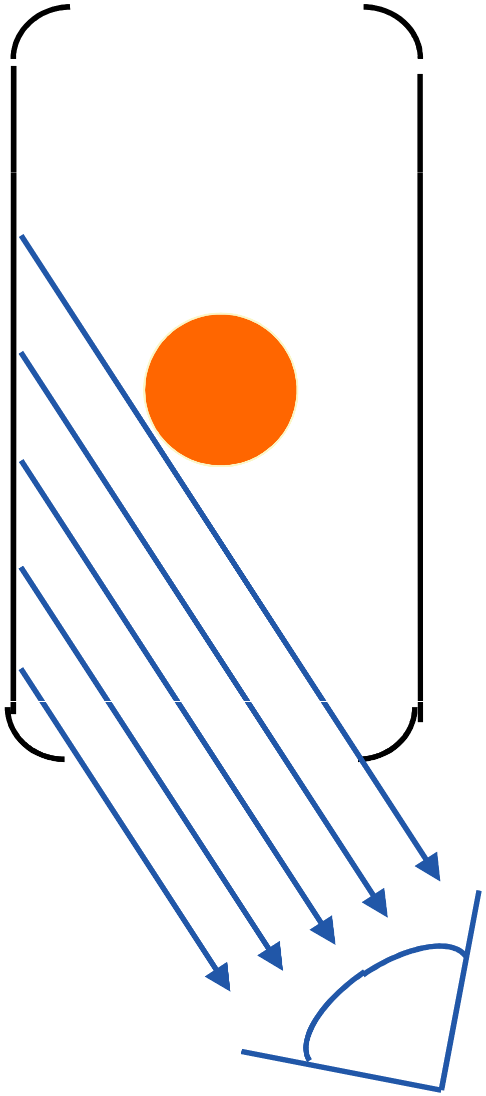


**Laser power scatters from one quad to another via an ion or plasma wave.**

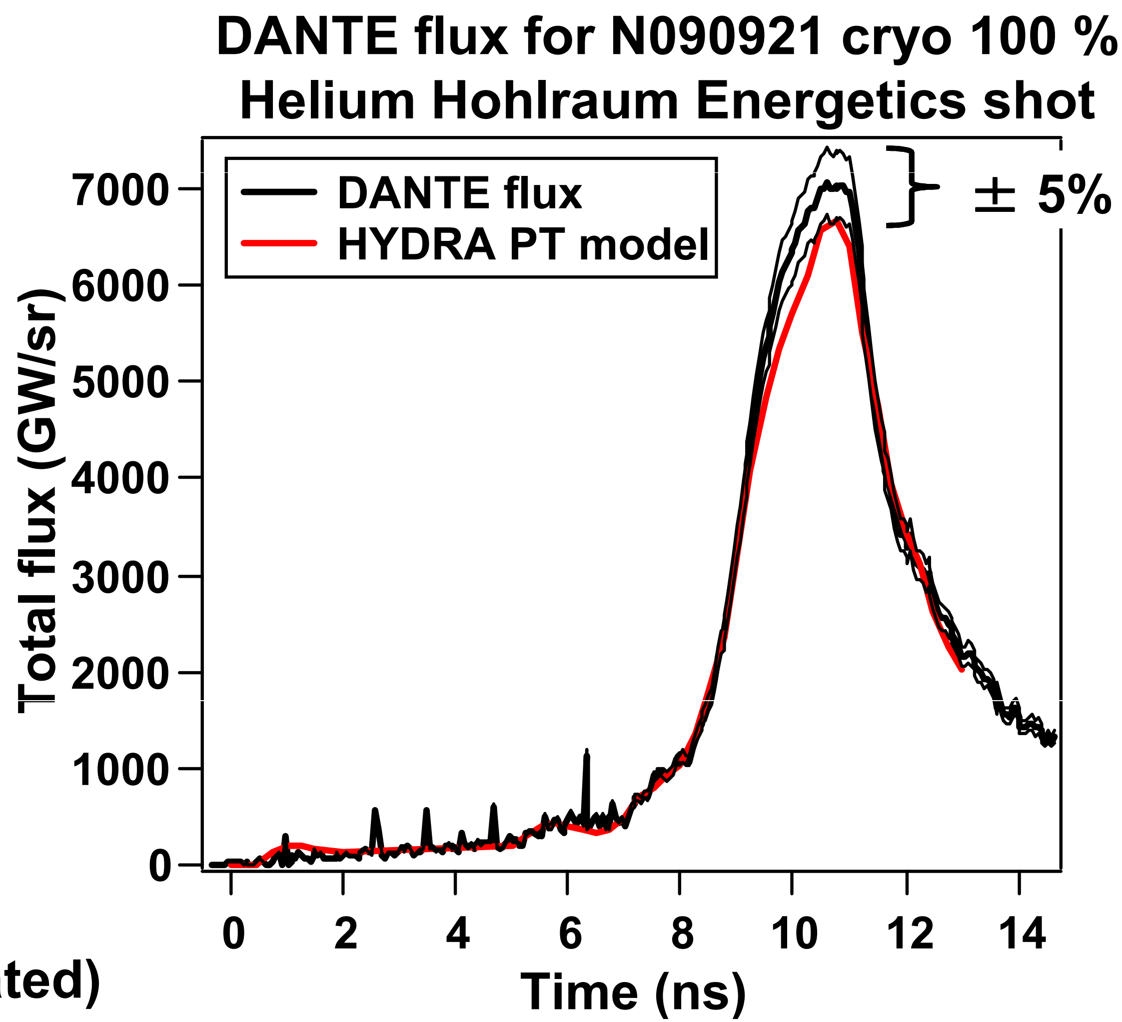



**Forward transfer an be controlled by changing $\Delta\lambda = \lambda_2 - \lambda_1$**

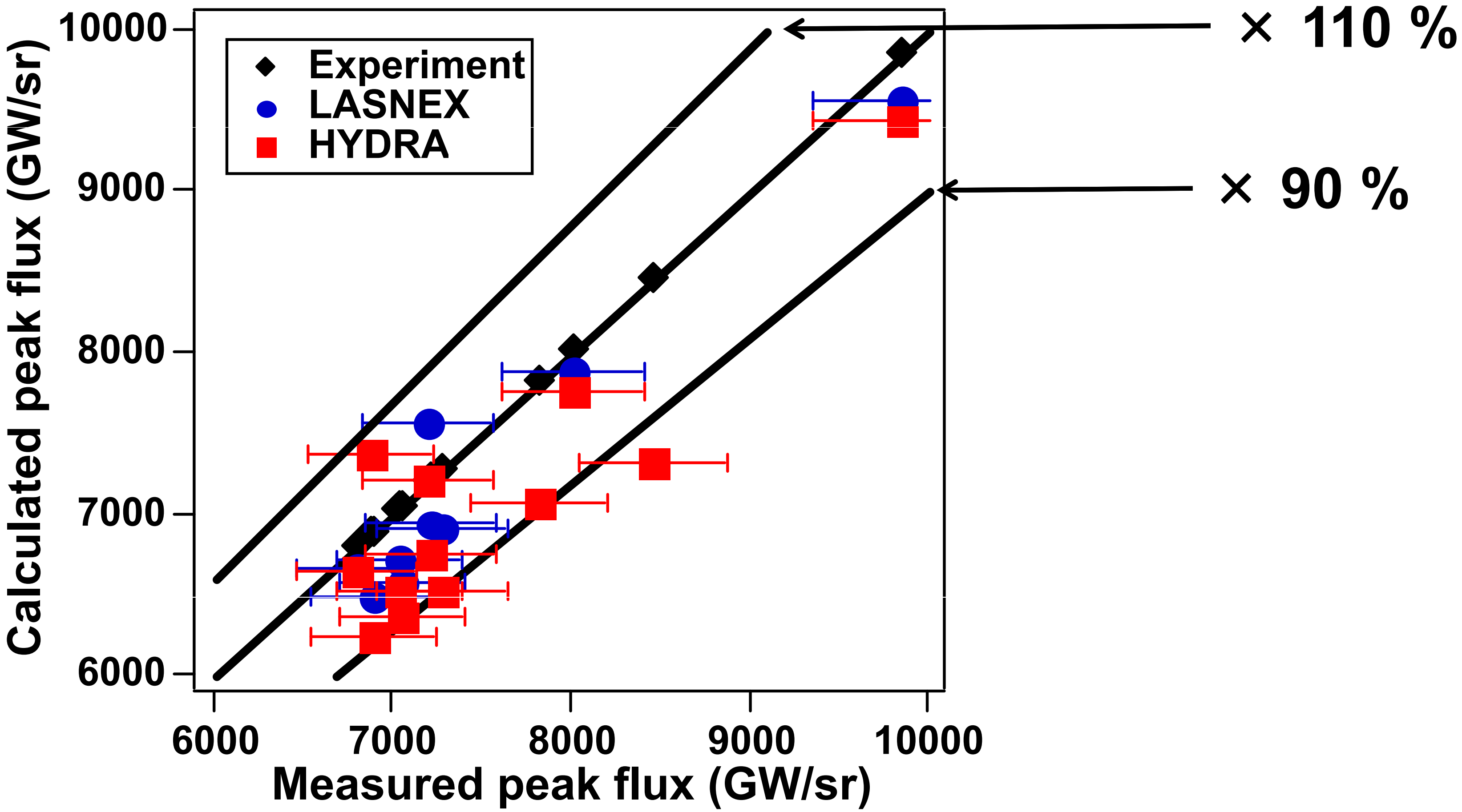
# The DANTE x-ray spectrometer views the inner hohlraum wall through the laser-entrance hole



(Simulated) DANTE



# Standard 2-D rad-hydro calculations lie within 10% of the experimental peak DANTE flux




Some of the scatter in the data is due to 3-D effects, e.g., missing quads on some shots.

# The initial energetic hohlraum experiments have demonstrated a path forward to ignition hohlraums

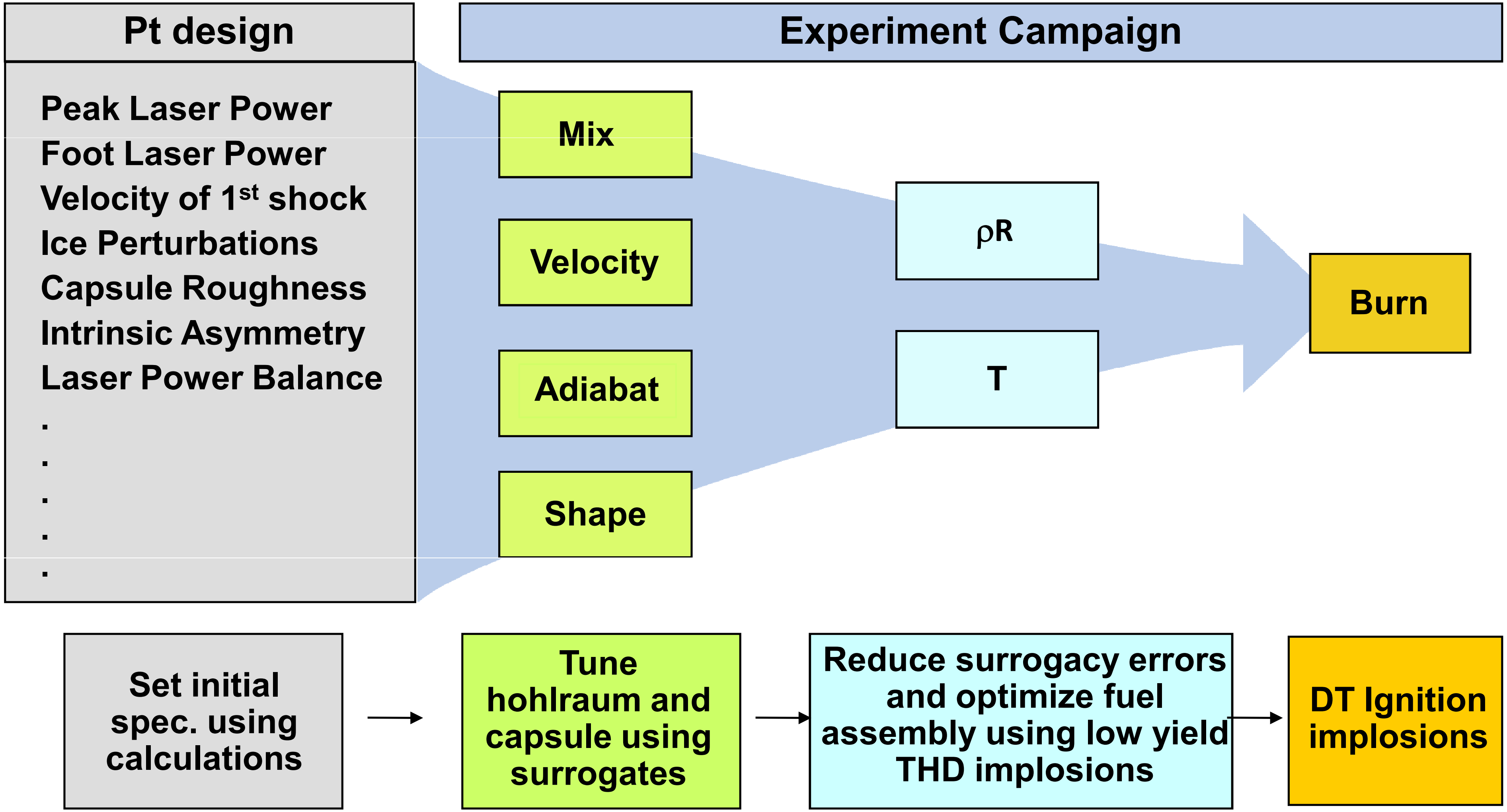
- We can make round implosions.
  - We have used Δλ tuning to turn cross-beam transfer into a tool.

- We measure <5 % total backscatter reflectivity.
  - We measure ~ 10 % reflectivity on the inner cone—1/3 of NIF's energy.
  - We measure < 3 % reflectivity on the outer cone—2/3 of NIF's energy.
  - We have reduced SRS backscatter by changing plasma composition.
  - Reflectivity vs. intensity is saturated up to ignition intensity levels.

- We are driving the capsule at radiation temperatures sufficient for ignition.
  - Capsule drive is close to rad-hydro code predictions using the standard ignition point design models .

**We believe that we will be able to drive 1.2-1.5 MJ targets at 290-300 eV as required for the CH ignition point design.**

# The experimental campaign adjusts laser and target parameters to compensate for physics uncertainties to obtain the desired ρR and T for ignition

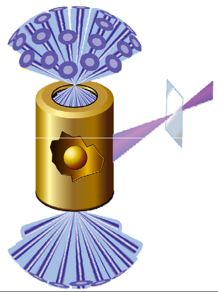


# We use a variety of targets to tune the capsule velocity, adiabat, shape, and mix through mass remaining

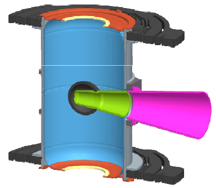
**Deliverables:**

- Shot-to-shot variability
- Sensitivity
- Mean and uncertainty in laser or target parameter

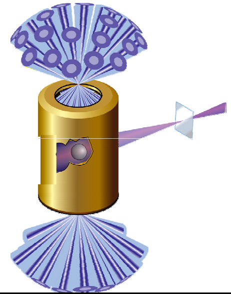
Solid high-Z sphere

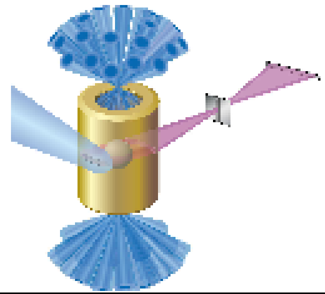


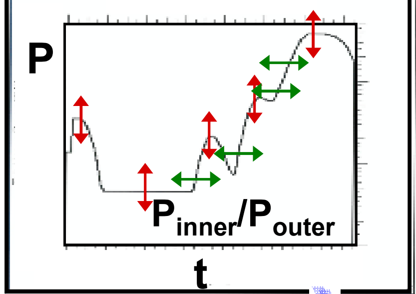
Liquid D2-filled capsule

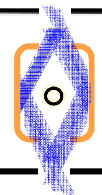


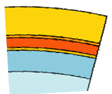
Both Gas-filed and THD Cryo-layered Capsules









| | | Reemit | Keyhole | Symmetry Capsule | Backlit Capsule |
|---|---|---|---|---|---|
| Laser | P vs. t ($P_{inner}/P_{outer}$) | P2 Shape, Adiabat (Foot) | Adiabat (Foot and 4th Rise) | P2 Shape (Foot + Peak) | Velocity, Mix = f(Mass Remaining) (Peak) |
| Hohlraum | Hohlraum Length | | | P4, P2 Shape (Foot + Peak) | |
| Capsule | Ablator Thickness ΔR | | | | Velocity, Mix = f(Mass Remaining) |

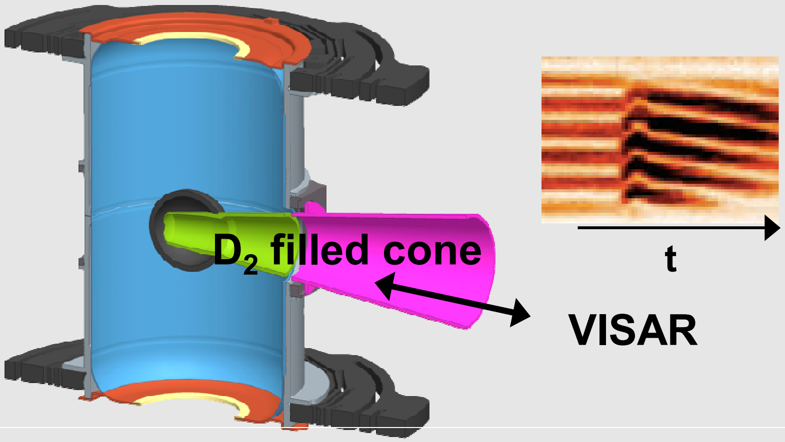
**All the techniques have been demonstrated at OMEGA**
**The symmetry and backlit capsules have now also been validated at NIF**

# Transparent Keyhole sets first four pulse levels and second two shock launch times to minimize fuel entropy

## Experimental Geometry

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

Boehly, PoP (2009)



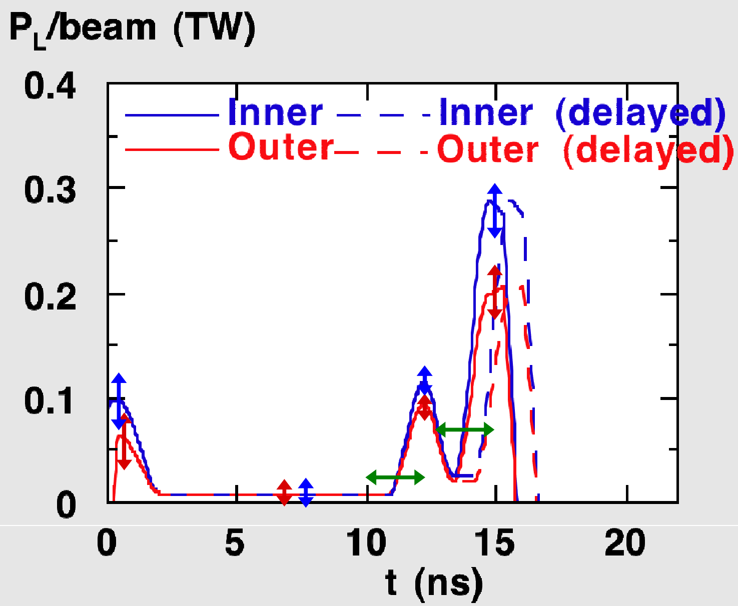

**Observable:**
**Fringe shift ~ v vs t**

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

Set merger depth to ± 6 μm

## Facility Requirements

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



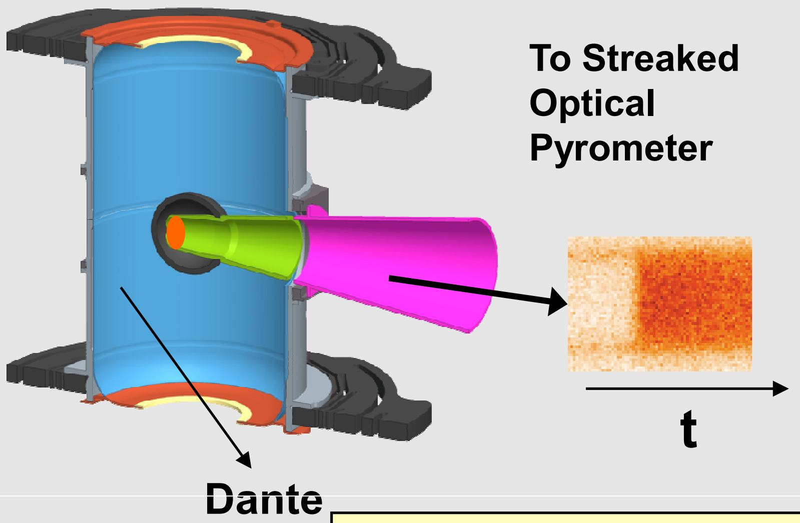

Set 1st, trough, 2nd and 3rd pulse levels to ±10, 10, 4 and 4%

Set 2nd and 3rd shock launch time to ± 50 ps

# Keyhole with witness plate and Dante sets 4th rise launch time and slope to minimize late time adiabat

## Experimental Geometry

Liquid $D_2$-filled capsule with Au witness plate replaces layered capsule




Robey, PoP, accepted (2009)

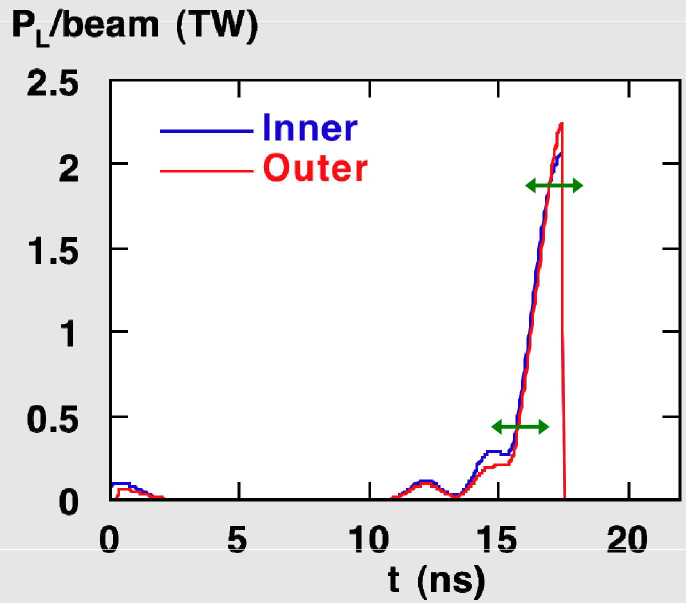
**Observables: Shock break-out time and Dante**

**Set 4th shock break-out to ± 100 ps**

**Set 4th rise slope to ± 3 eV/ns**

## Facility Requirements

Truncated ≈ 650 kJ pulses




**Set 4th rise launch time to ± 100 ps**

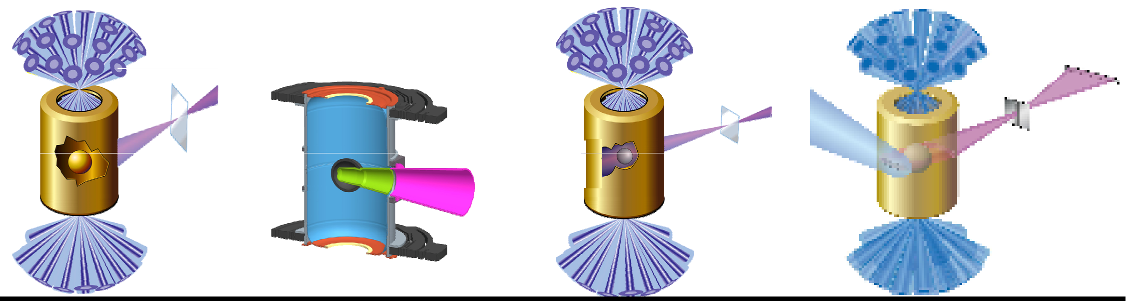
**Set 4th rise duration to ± 100 ps**

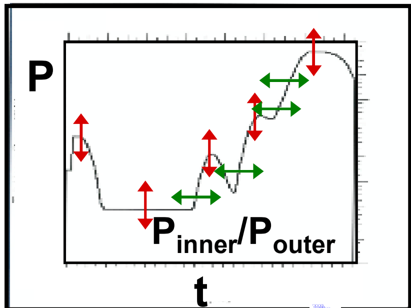
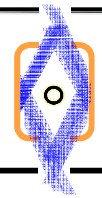
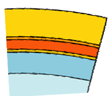
# We use a variety of targets to tune the capsule velocity, adiabat, shape, and mix through mass remaining

**Deliverables:**

- Shot-to-shot variability
- Sensitivity (Slope)
- Mean and uncertainty in laser or target parameter

Solid high-Z sphere | Liquid D2-filled capsule | Both Gas-filed and THD Cryo-layered Capsules



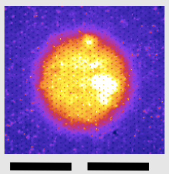
| | | Reemit | Keyhole | Symmetry Capsule | Backlit Capsule |
|---|---|---|---|---|---|
| Laser |  | P2 Shape, Adiabat (Foot) | Adiabat (Foot and 4th Rise) | P2 Shape (Foot + Peak) | Velocity, Mix = f(Mass Remaining) (Peak) |
| Hohlraum | Hohlraum Length  | | | P4, P2 Shape (Foot + Peak) | |
| Capsule | Ablator Thickness $\Delta R$  | | | | Velocity, Mix = f(Mass Remaining) |

**All the techniques have been demonstrated at OMEGA**
**The symmetry and backlit capsules have now also been validated at NIF**

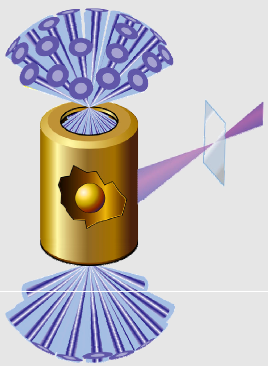
# Symmetry Capsule sets peak cone power ratio, Δλ and hohlraum length to minimize low mode core asymmetry

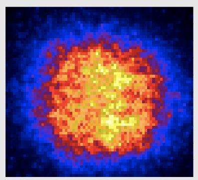
## Experimental Geometry

Both D-$^3$He-filled capsule and THD cryo- layered capsule



Gated 10 keV X-ray images





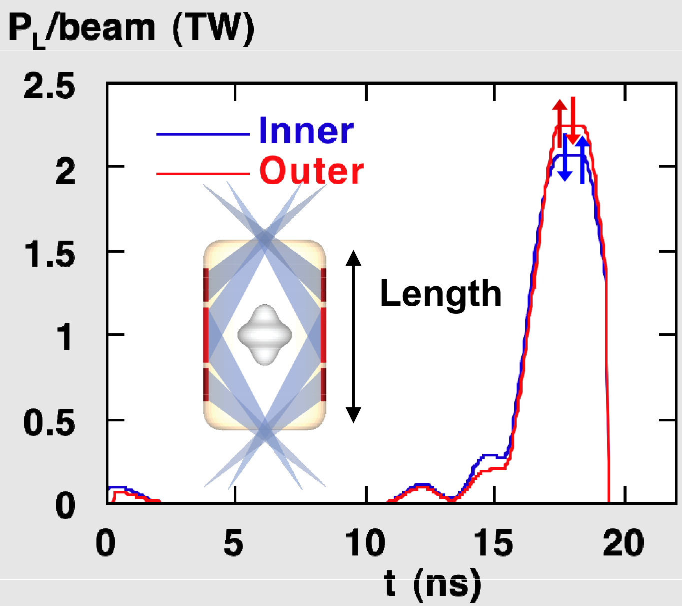
100 µm

**Observable:20 % emission contour shape**

**Set Hot spot $P_2$, $P_4$ to 0 ± 5, 5%**

## Facility Requirements

Full pulse 1200 kJ




**Set Hohlraum Length to ± 200 µm**

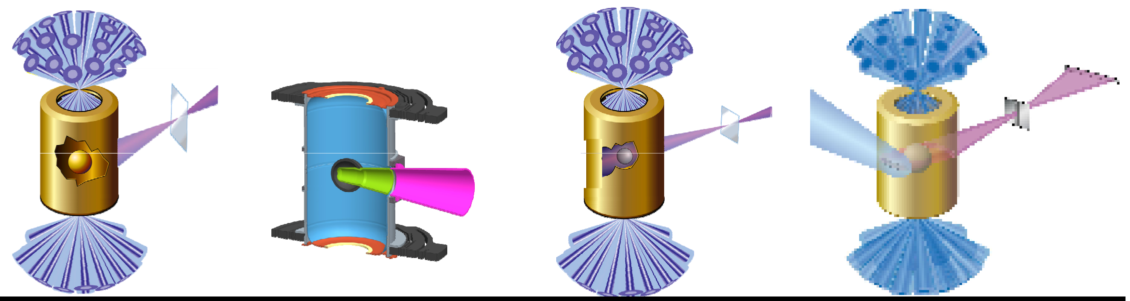
**Set Peak Power Cone Fraction to ±5%**

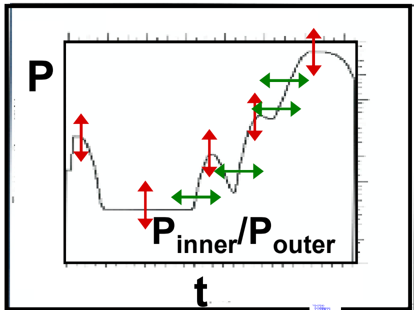
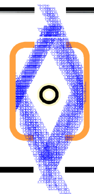
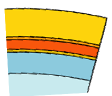
# We use a variety of targets to tune the capsule velocity, adiabat, shape, and mix through mass remaining

**Deliverables:**

- Shot-to-shot variability
- Sensitivity (Slope)
- Mean and uncertainty in laser or target parameter

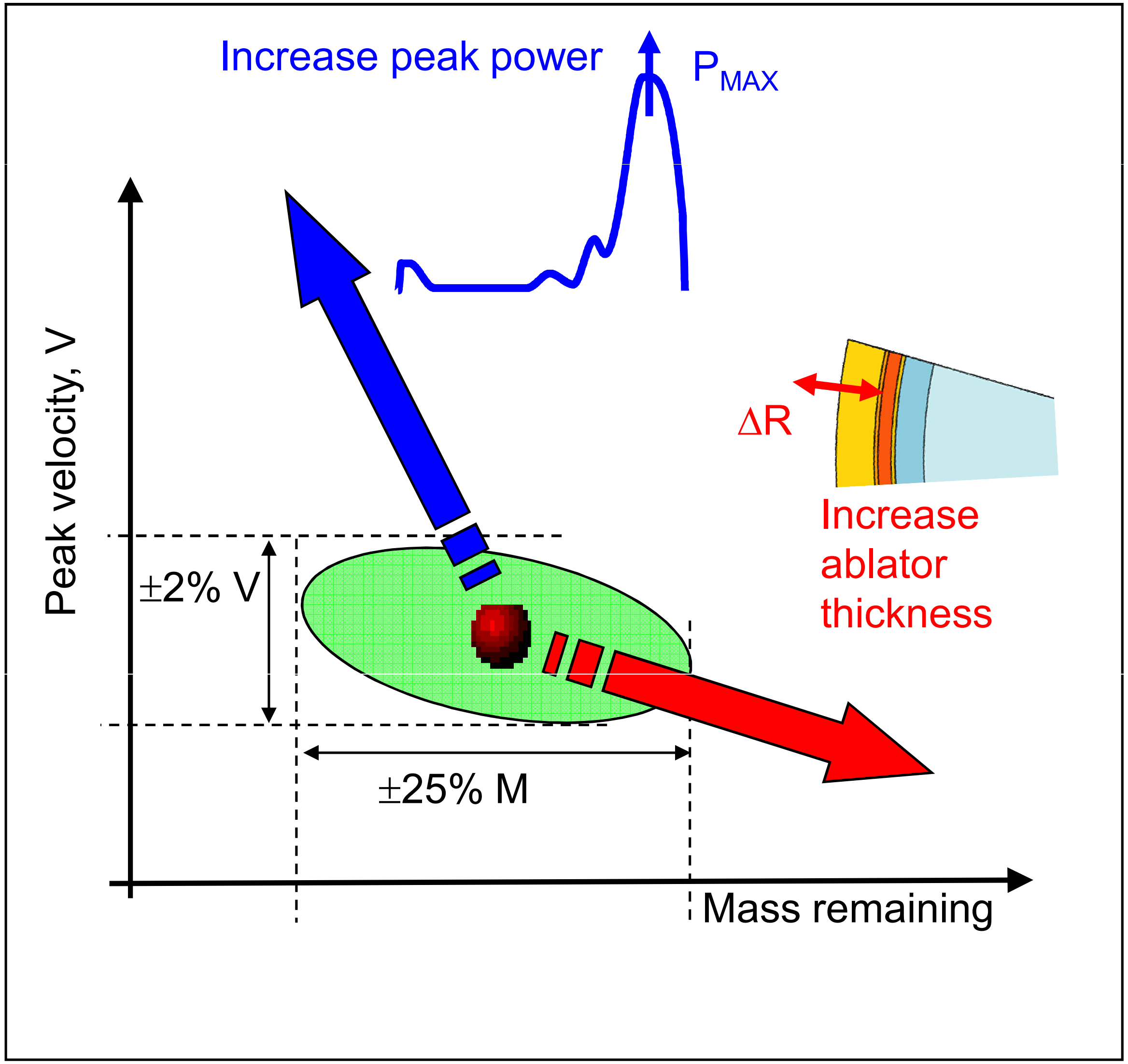
Solid high-Z sphere | Liquid D2-filled capsule | Both Gas-filed and THD Cryo-layered Capsules



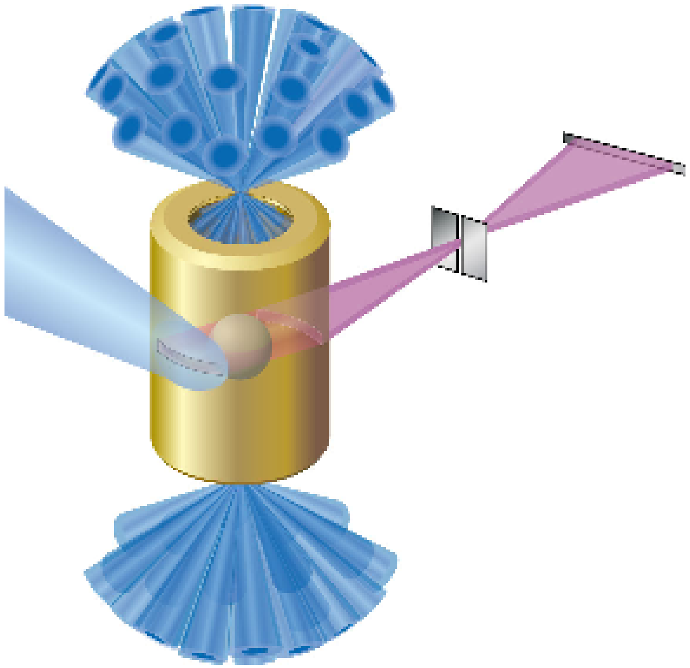
| | | Reemit | Keyhole | Symmetry Capsule | Backlit Capsule |
|---|---|---|---|---|---|
| Laser |  | P2 Shape, Adiabat (Foot) | Adiabat (Foot and $4^{th}$ Rise) | P2 Shape (Foot + Peak) | Velocity, Mix = f(Mass Remaining) (Peak) |
| Hohlraum | Hohlraum Length  | | | P4, P2 Shape (Foot + Peak) | |
| Capsule | Ablator Thickness $\Delta R$  | | | | Velocity, Mix = f(Mass Remaining) |

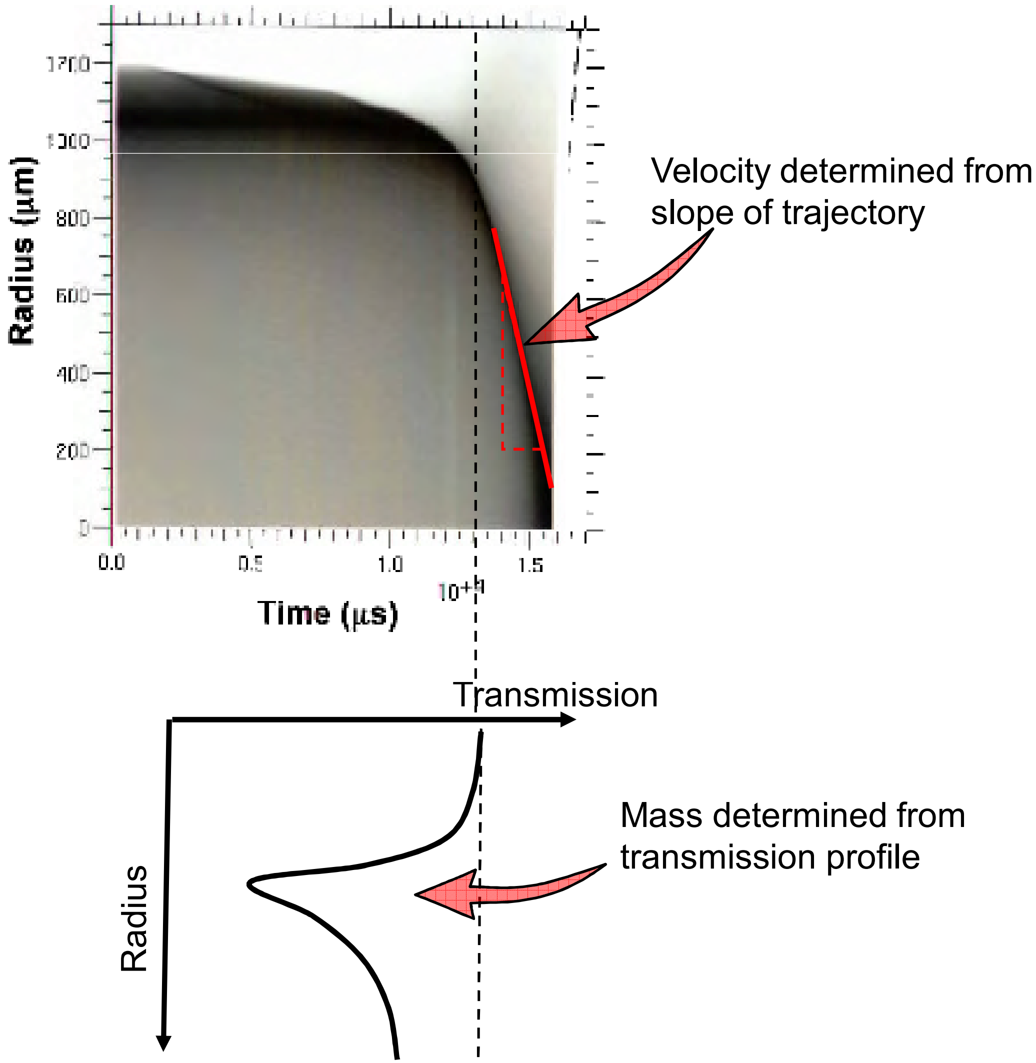
**All the techniques have been demonstrated at OMEGA**
**The symmetry and backlit capsules have now also been validated at NIF**

# Tuning strategy: Adjust peak laser power and ablator thickness to achieve the required ablator mass and velocity



# Ablator mass and velocity are determined from a single, streaked x-ray radiograph

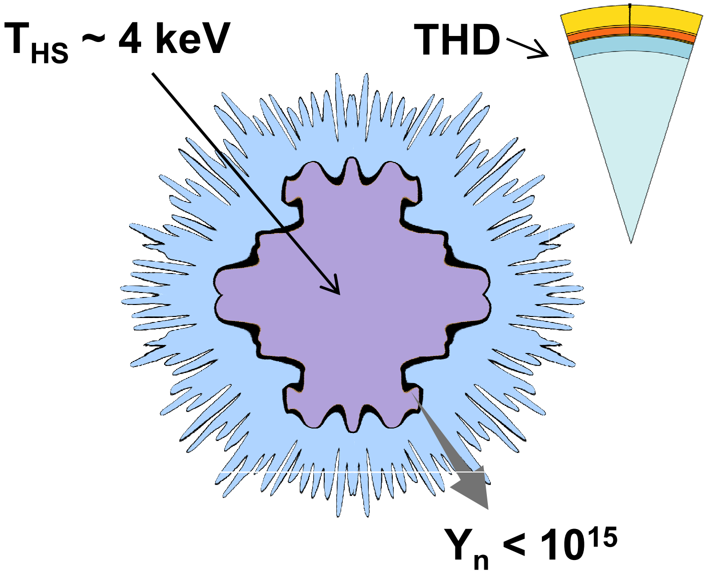




# The THD targets and the DT targets are designed and fielded to be hydrodynamically similar

## THD

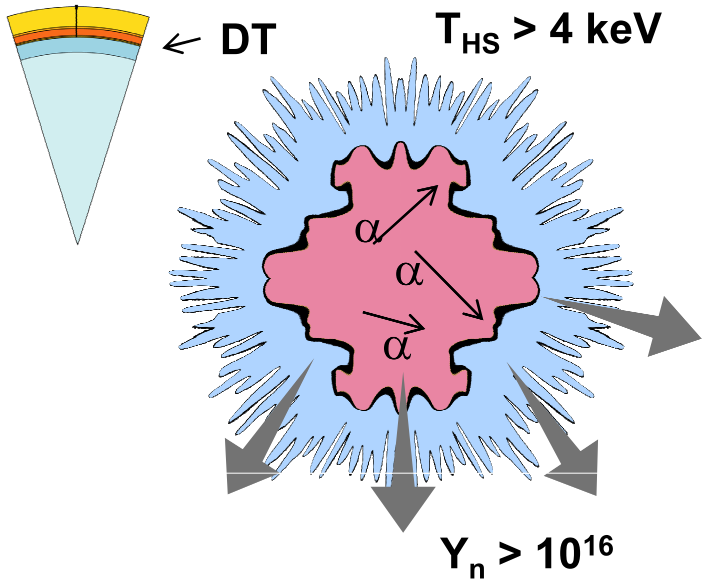
**Hydro assembly of fuel**




- Low yield $T_{\sim75\%}H_{\sim25\%}D_{<5\%}$ fuel
- Yield does not affect hydro
- Diagnostics rich environment

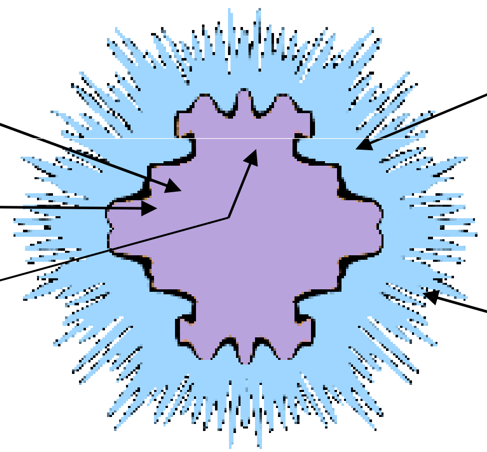
## DT

**α-heating and ignition**




- High yield $TD_{\sim25\text{-}50\%}$ fuel
- Yield affects hydro
- Harsh environment

# The goal of the THD experiments is to assemble a hot spot surrounded by cold fuel

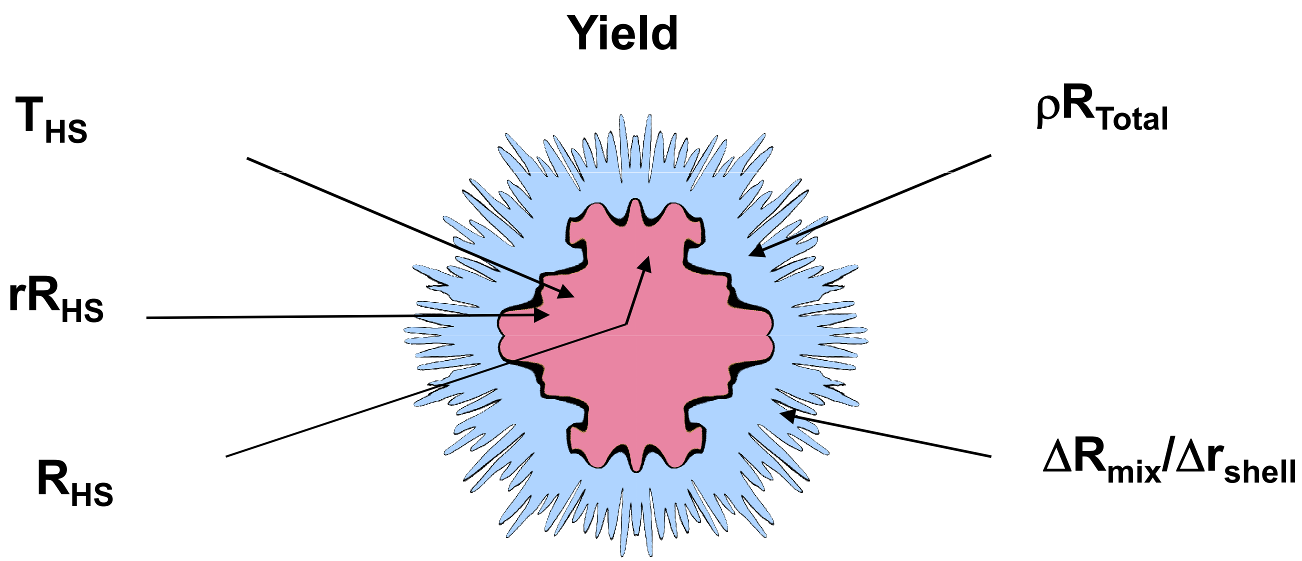



| Hot Spot | |
|---|---|
| $T_{HS}$ | 4 keV |
| $\rho R_{HS}$ | 0.2 g/cm$^2$ |
| $<R_{HS}>$ | 25μm |
| $Y_n$ | $10^{14}$ |
| $t_{burn,bang}$ | 100 ps |

| Cold Fuel | |
|---|---|
| $<\rho R>$ | > 1.7 g/cm$^2$ |
| $\Delta\rho R(\theta)$ | < 0.4 g/cm$^2$ |
| $\Delta R_{mix}/\Delta R_{shell}$ | < 0.25 |

**We use neutron, X-ray and $\gamma$-ray diagnostics to measure these attributes**

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

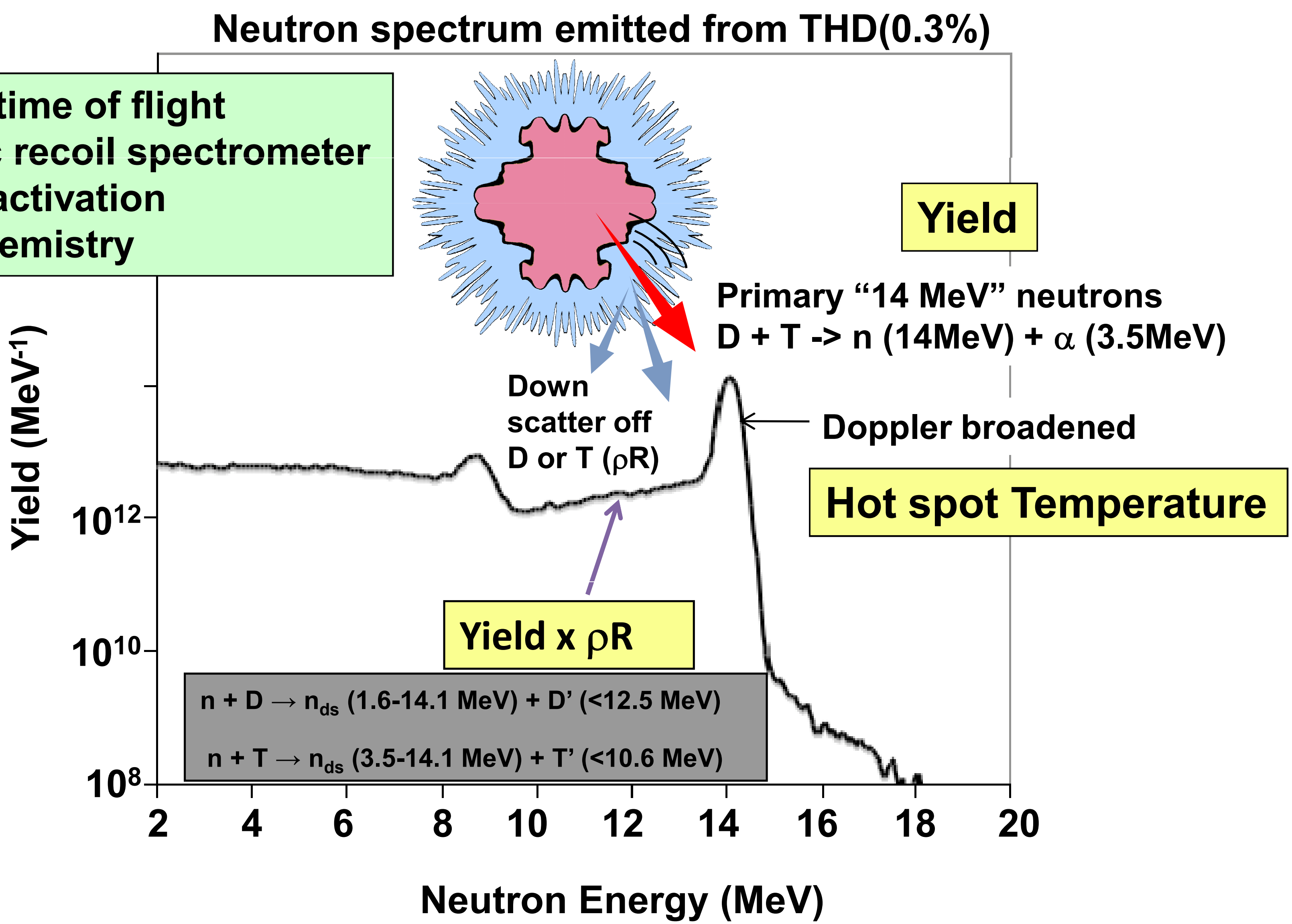



| Hot Spot for THD | |
|---|---|
| $T_{HS}$ | 4 keV |
| $\rho R_{HS}$ | 0.2 g/cm$^2$ |
| $\langle R_{HS}\rangle$ | 25 µm |
| $t_{X\text{-ray}}$ | 100 ps |
| $Y_n$(2%D) | 2x10$^{14}$ |

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

# A number of diagnostics will be used to measure features of the neutron spectrum

Neutron time of flight
Magnetic recoil spectrometer
Nuclear activation
Radio chemistry



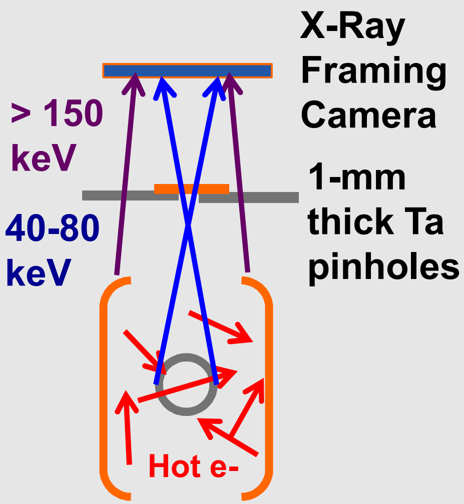
# Summary and Conclusions

- NIF is now up and running as a fully operational facility
- The initial energetic hohlraum experiments have demonstrated a path forward to ignition hohlraums
- A comprehensive diagnostic suite is now available for NIC experiments
- 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
- The first attempt at ignition on NIF will occur later this year
- It is a truly exciting time to be a part of the NIC team

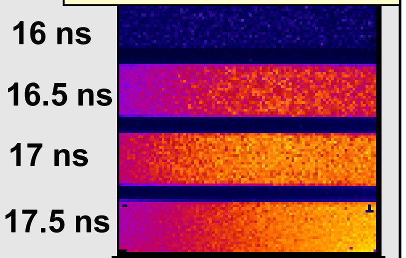

NIC

# We propose to infer hot electron capsule preheat through gated imaging of > 50 keV shell Bremsstrahlung

**First polar imaging attempt swamped by > 150 keV Au hohlraum Bremsstrahlung**



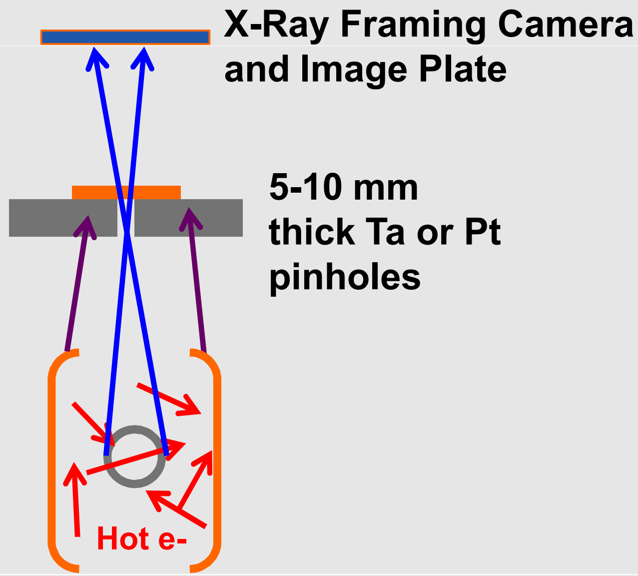

**Gated polar data at onset of peak drive (1.2 MJ shot)**




**Featureless, but gated**

**Demonstrated framing camera is capable of > 40 keV gated detection**

**Future: Thicker pinholes still providing ≈300 μm resolution**



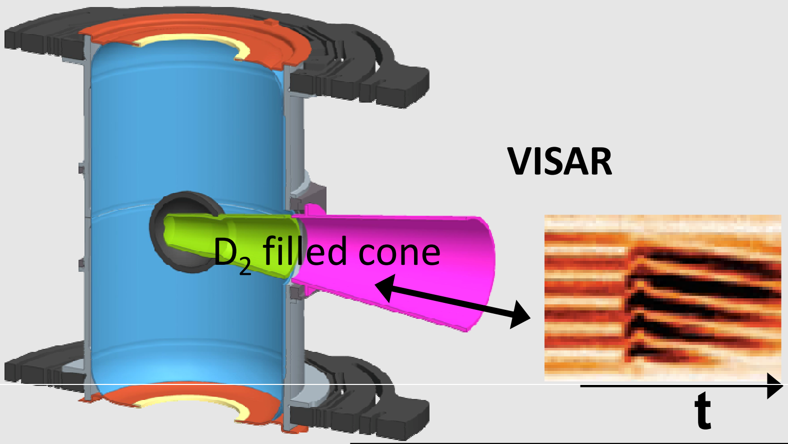

**Also evaluating option of high Z inner layer on capsule as localized tracer of hot electron fraction reaching fuel**

# 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)



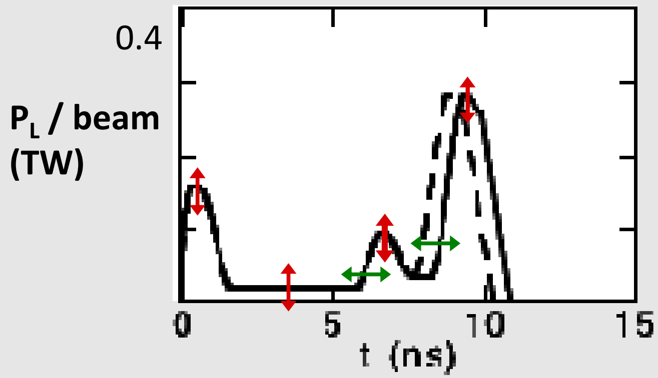

**Fringe shift vs t**

**$1^{st}$ ($2^{nd}$-$3^{rd}$) shock velocities to ± 5% (2%)**

**Merger depth to ± 6 μm**

## Facility Requirements

Truncated ≈ 185 kJ pulses with delayed $3^{rd}$ pulse when tuning $2^{nd}$ pulse

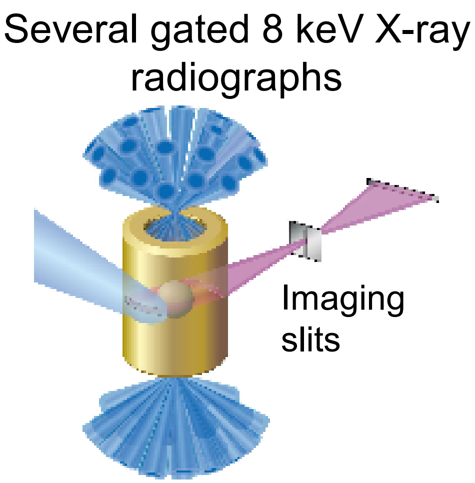


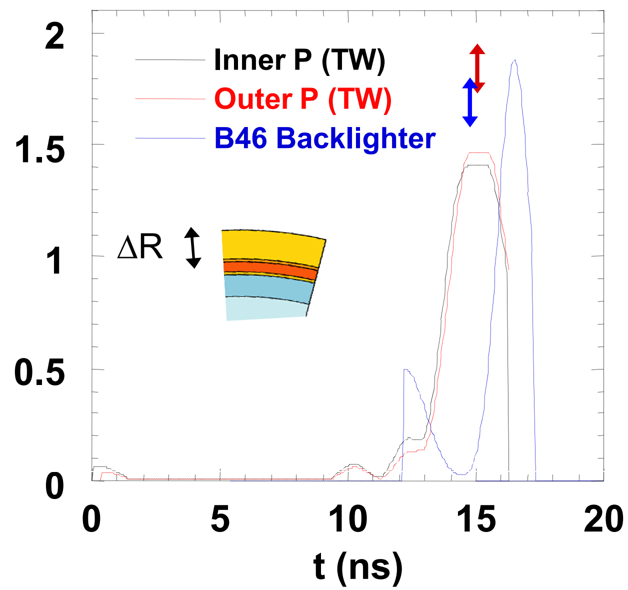

**VISAR Qualification: 2004**

**First NIC shots: 2010**

# First NIF backlit in-flight capsule experiment was performed on Scale 4.6 mm, 660 kJ hohlraum drive

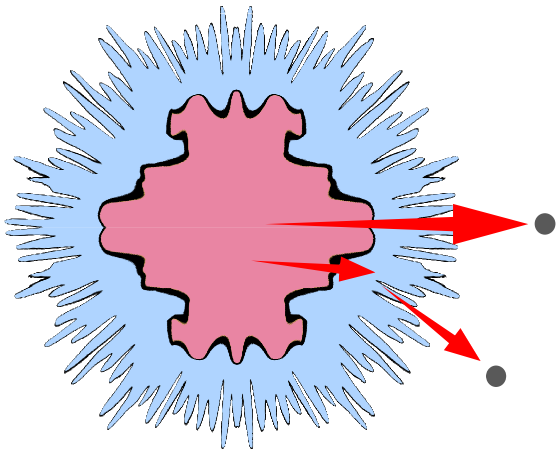
| Experimental Geometry | Laser drive |
|---|---|
| D-$^3$He-filled capsule | 0.66 MJ main pulse<br>+ 30 kJ 8 beam backlighter |



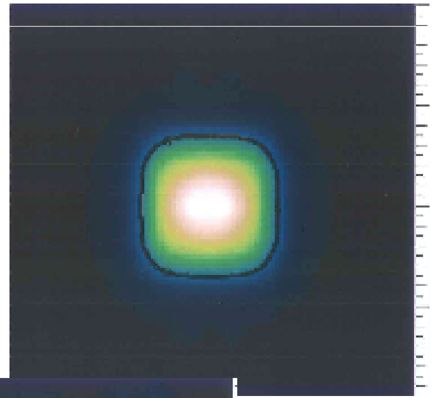



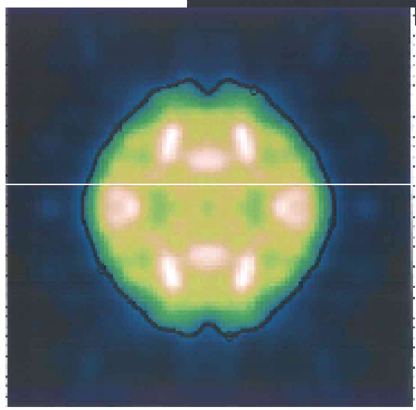

A gated imager (rather than a streak camera) was used to take 1-D images of the equator at discrete times towards the end of the implosion

# Neutrons can also be imaged to provide hot spot (and cold fuel) shape information



**Simulated primary neutron image of hot spot**





**Simulated image of neutrons scattered by dense shell**

# There has been a National Effort on NIF Diagnostics for a long time

Presented at

NIF Diagnostics Workshop

Santa Fe, NM

February 16, 1995

by

Mary Hockaday
Los Alamos National Laboratory

A Perspective on the NIF Measurement Environment

Allan Hauer
Los Alamos National Laboratory

*presentation to workshop on NIF diagnostics*
*Santa Fe*

*2/14 / 95*

NTS NEUTRON IMAGING EXPERIMENTS AND CURRENT LANL IMAGING PROJECTS
RELEVANT TO NIF

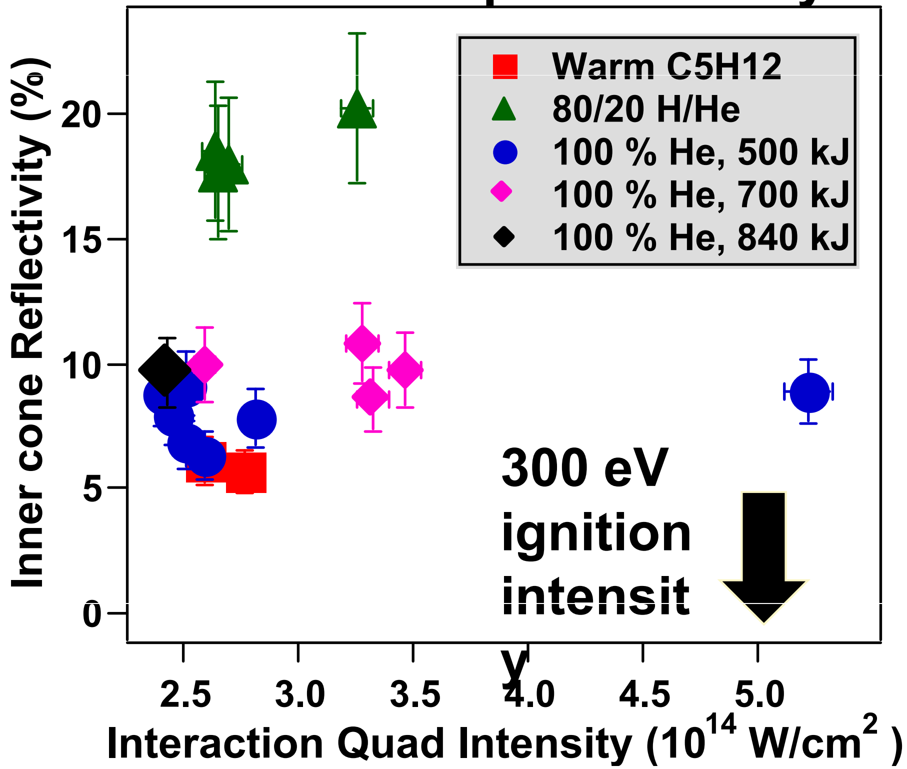
N.S.P. King, A.W. Obst, and M.W. Wilke
Physics Division
Los Alamos National Laboratory

Santa Fe Meeting on NIF Diagnostics
February 14 - 16, 1995

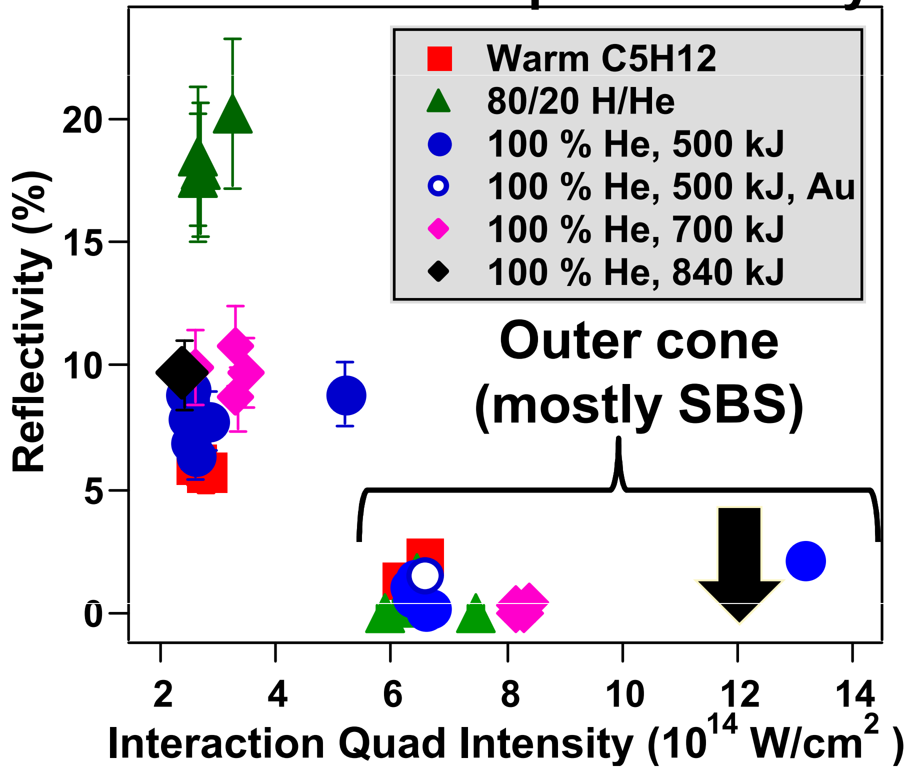
**Reinvigorated National Diagnostic Program**

# Backscatter on the outer cone < 3 %, even for peak intensity > $10^{15}$ W/cm$^2$ on the interaction quad

**SRS Inner Reflectivity vs. interaction quad intensity**




**Inner and outer reflectivity vs. interaction quad intensity**




The hot electron fraction $f_{hot}$ ~ 1 % on most shots, < 2 % on all shots.

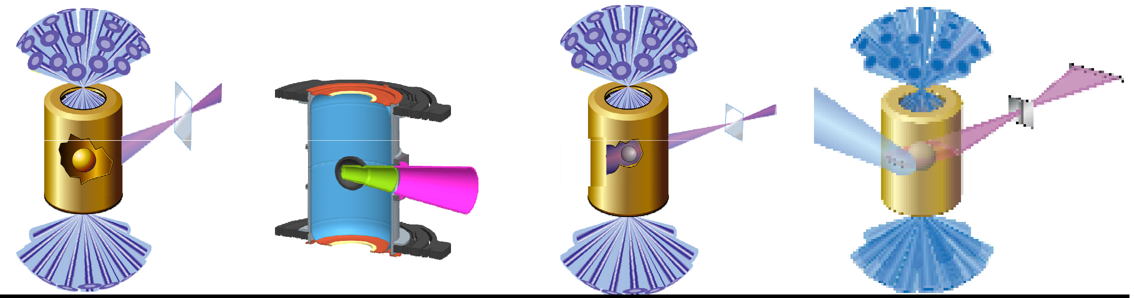
The hot electron temperature $T_{hot}$ varies from 28 – 32 keV.

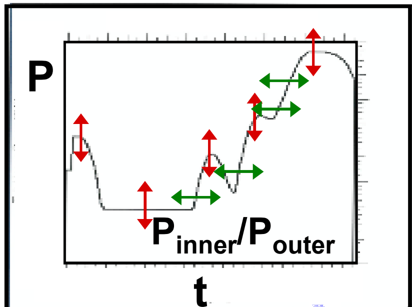
# We use a variety of targets to tune the capsule velocity, adiabat, shape, and mix through mass remaining

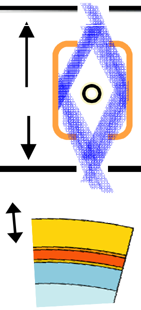
**Deliverables:**

- Shot-to-shot variability
- Sensitivity (Slope)
- Mean and uncertainty in laser or target parameter

Solid high-Z sphere | Liquid D2-filled capsule | Both Gas-filed and THD Cryo-layered Capsules





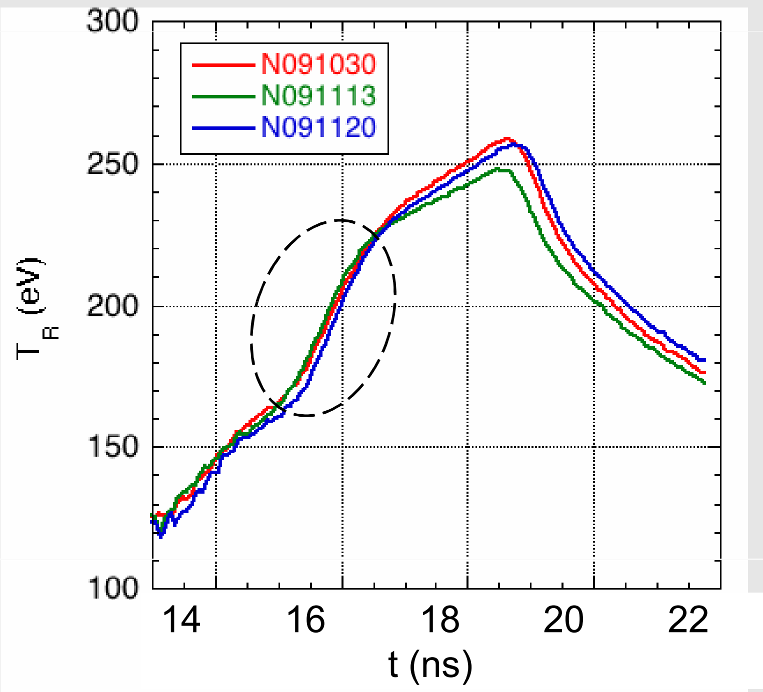




| | Reemit | Keyhole | Symmetry Capsule | Backlit Capsule |
|---|---|---|---|---|
| Laser ($P_{inner}/P_{outer}$) | P2 Shape, Adiabat (Foot) | Adiabat (Foot and 4th Rise) | P2 Shape (Foot + Peak) | Velocity, Mix = f(Mass Remaining) (Peak) |
| Hohlraum (Hohlraum Length) | | | P4, P2 Shape (Foot + Peak) | |
| Capsule (Ablator Thickness ΔR) | | | | Velocity, Mix = f(Mass Remaining) |

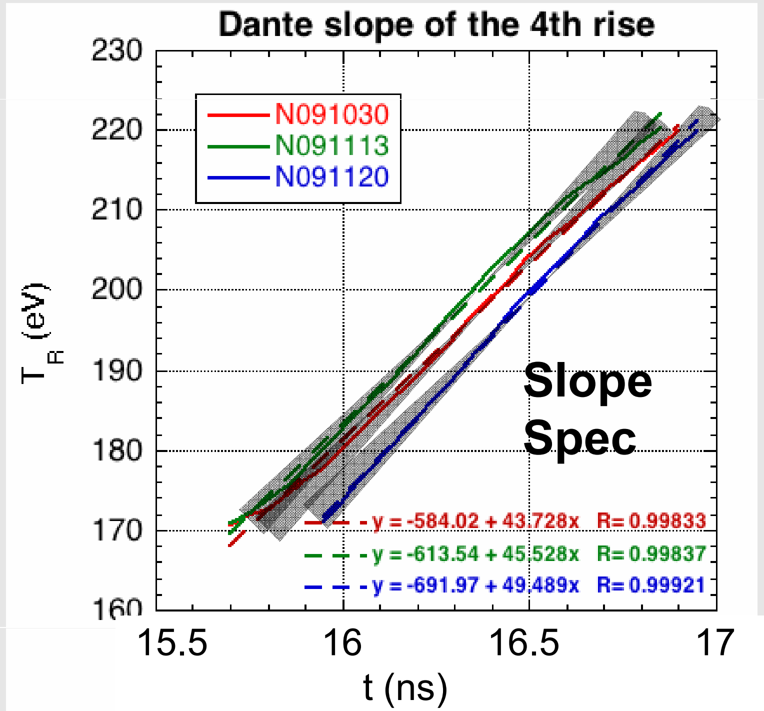
**All the techniques have been demonstrated at OMEGA**
**The symmetry and backlit capsules have now also been validated at NIF**

# Dante has reproducibly measured 4th rise slope at NIF consistent with expectation

**Dante peak drive from 5.4 mm Scale 840 kJ shots**



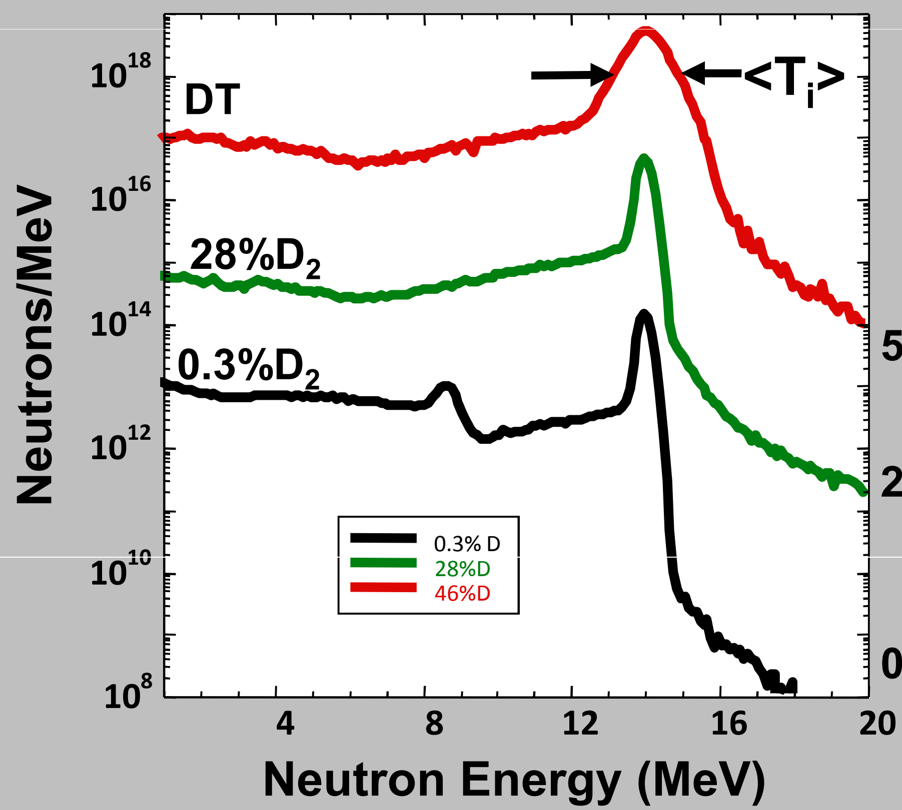

**Close-up of 4th Rise Tr vs time**




**Measured 4th rise slope within required 48 ± 4 eV/ns**

- **Dante statistical accuracy and reproducibility matched expected slope to ± 4 eV/ns requirement, even accounting for ± 2 eV/ns systematic errors**
- **Ready to proceed with 192 beam NIF validation of shock timing techniques**

# The neutron spectrum provides the key signatures of ignition




50% $D_2$, 17 MJ, 6. $10^{18}$ DT

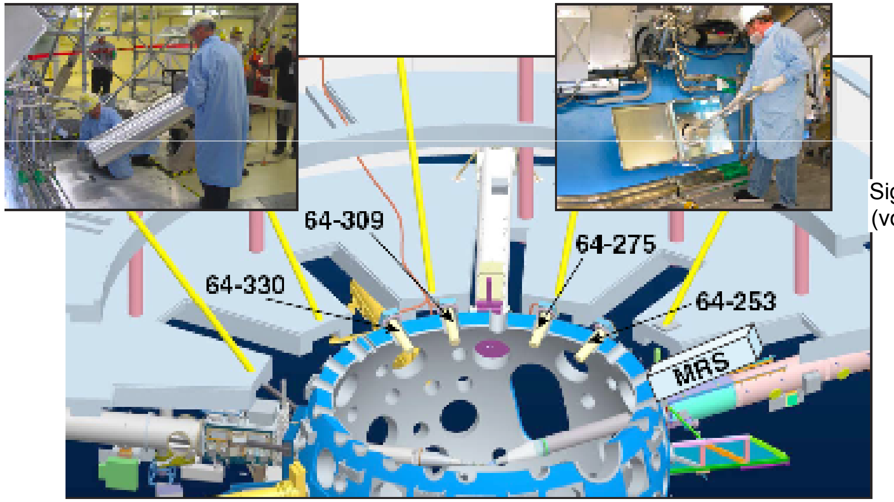
28% $D_2$, 70kJ, 2.5 $10^{16}$ DT

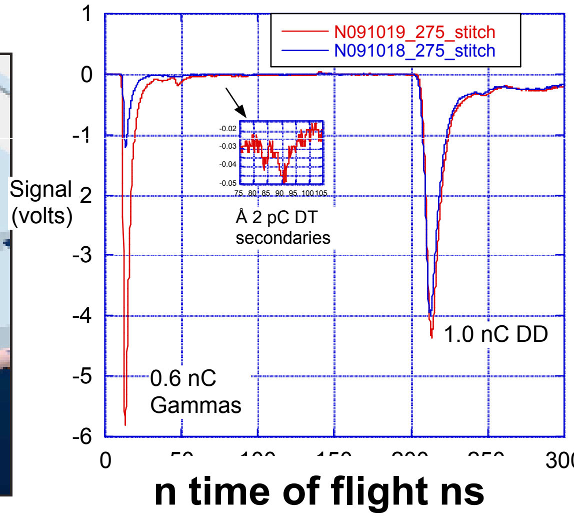
0.3% $D_2$, 0.25kJ ,7.1 $10^{13}$ DT

# The first three types of neutron detectors are being commissioned on NIF

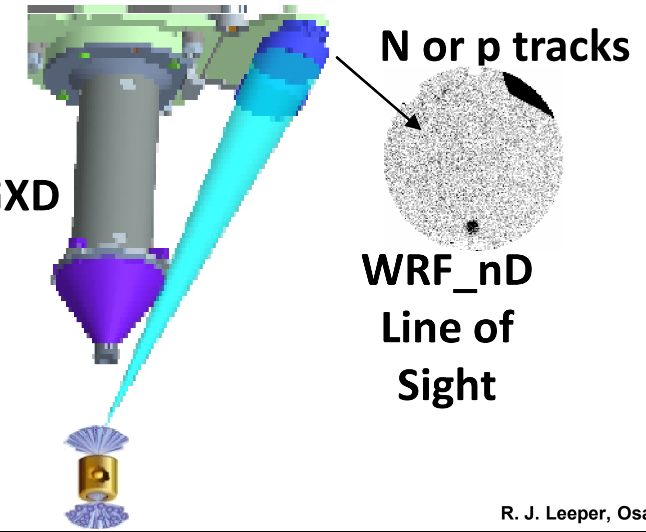
NIC

## Three of the neutron time of flight detectors are operational



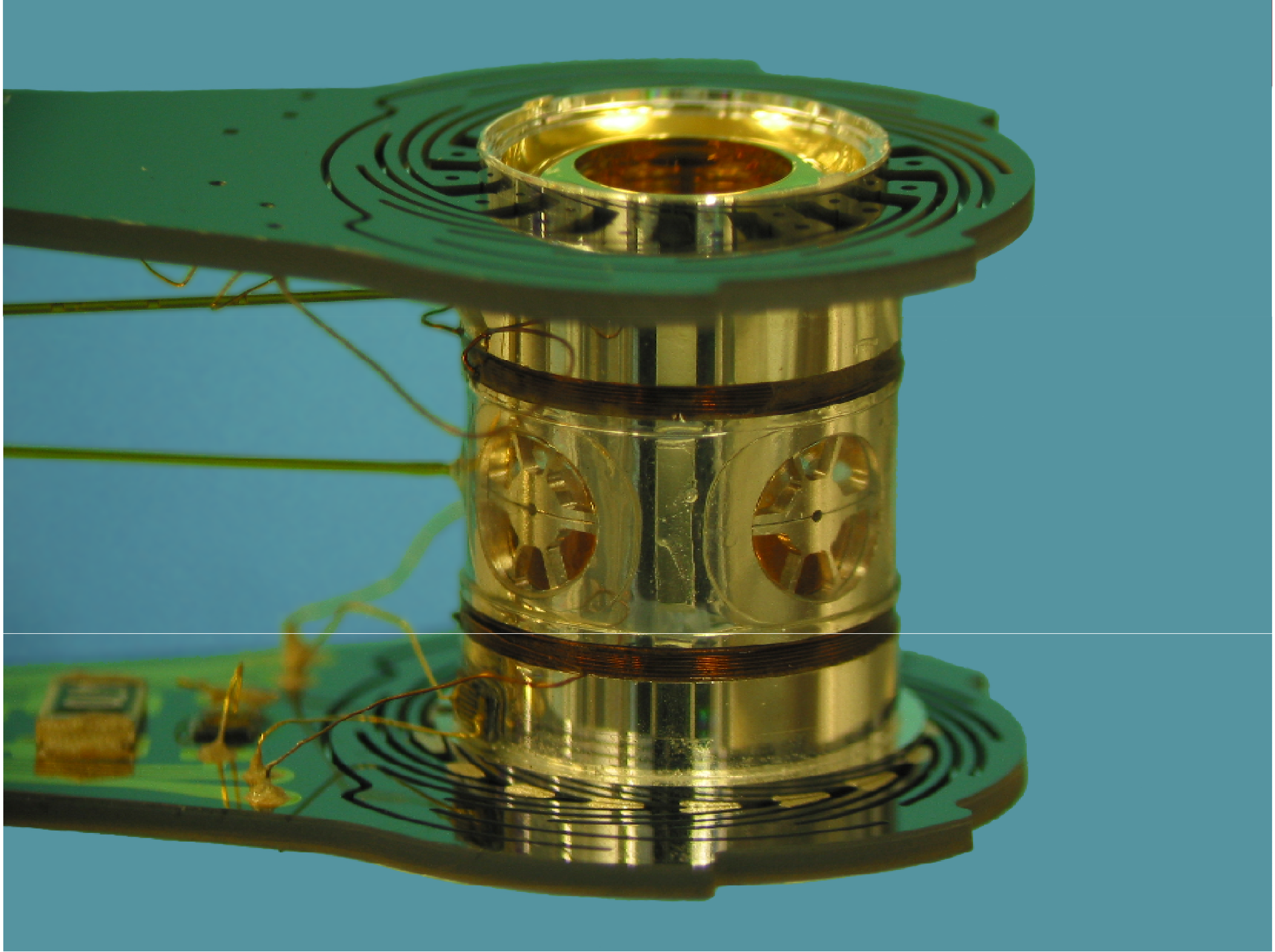

## WRF-Track detectors measure n or p



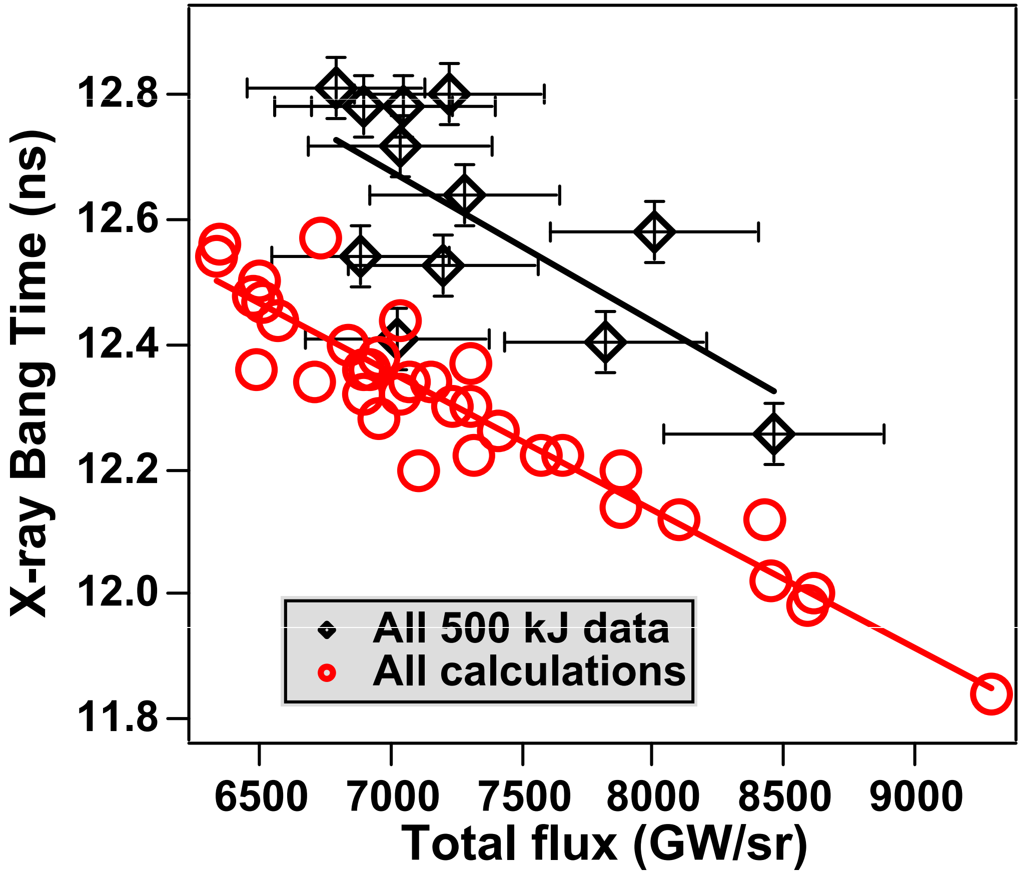

## Nuclear **activation** detector

$$n + In \longrightarrow In^*$$

$$In^* \longrightarrow In + \gamma \text{ ( 4 hours)}$$



# The measured time of peak capsule x-ray emission is ~ 300 ps later than rad-hydro calculations




**The systematic discrepancy in "bang times" is under investigation.**

# We have installed backscatter diagnostics on an inner and outer beam cone