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Reproducibility of NIF#Hohlraum Measurments

J. D. Moody, J. E. Ralph, D. P. Turnbull, D. T. Casey, F. Albert, B. L. Bachmann, T. Doeppner, L. Divol, G. P. Grim, M. Hohenberger, M. Hoover, A. Kritcher, O. L. Landen, B. J. MacGowan, P. A. Michel, A. S. Moore, J. E. Pino, M. B. Schneider, R. E. Tipton, V. A. Smalyuk, B. Spears, D. J. Strozzi, K. Widmann

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Reproducibility of NIF hohlraum measurements

57th Annual meeting of the APS/DPP

November 19, 2015

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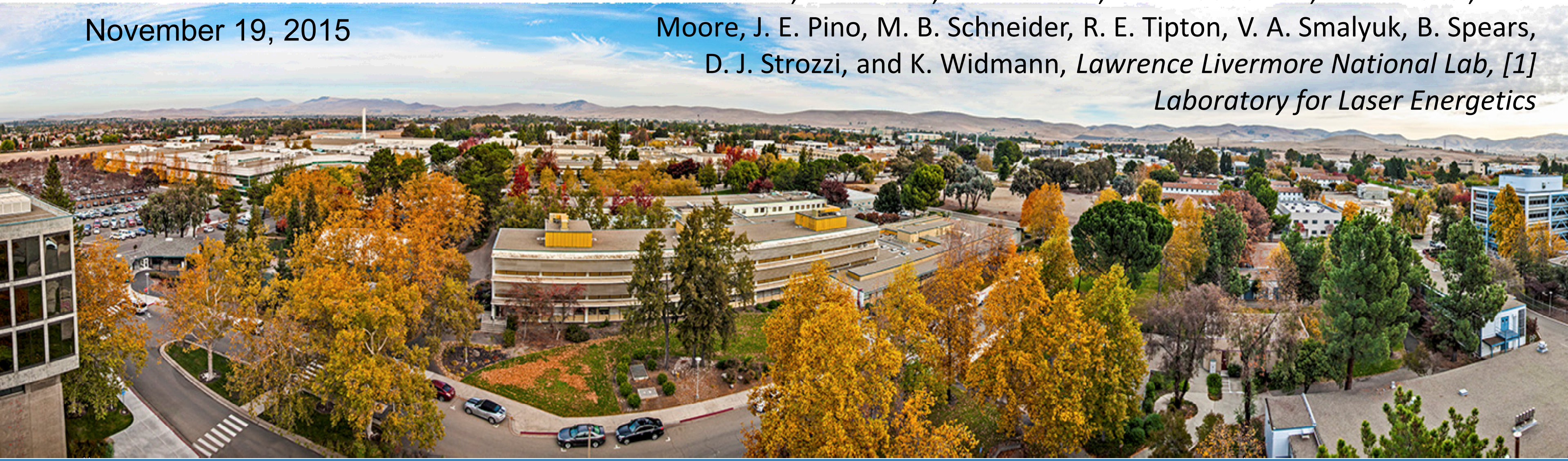
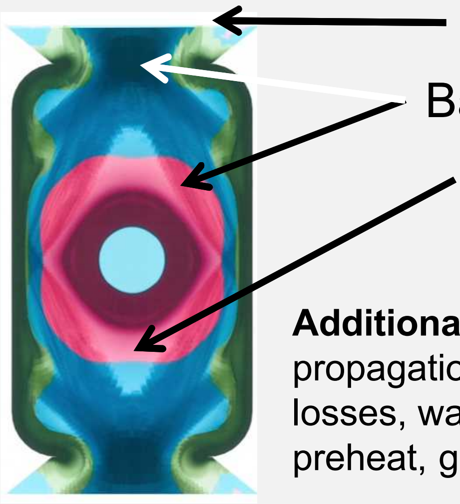


This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Goal: Estimate the significance of shot-to-shot variations in hohlraum parameters

We consider the variation of several key hohlraum parameters



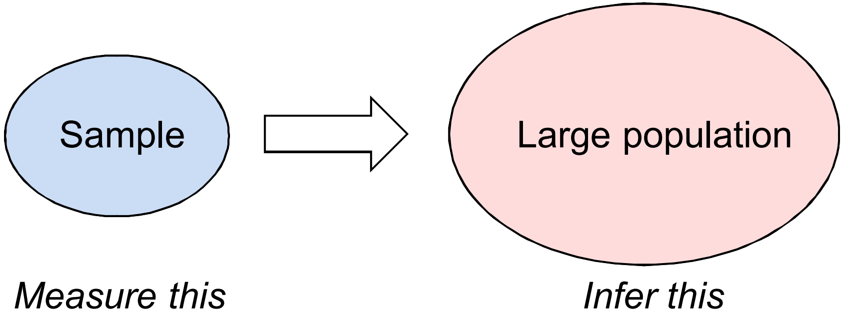
Additional parameters: Beam propagation, X-ray conversion, wall losses, wall blow-in, hot-electron preheat, glint, re-amplification…

Variation means:

$$\frac{\sigma_X}{\mu_X}$$

σ_X: The large population standard deviation

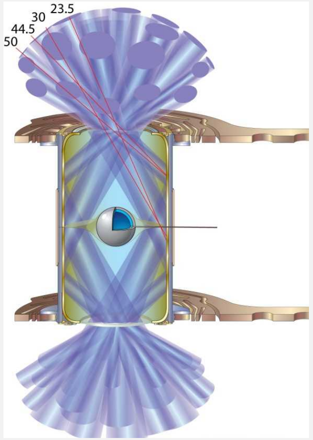
μ_X: The large population average



We use exact statistics to determine confidence levels for NIF shot variations using a limited sample

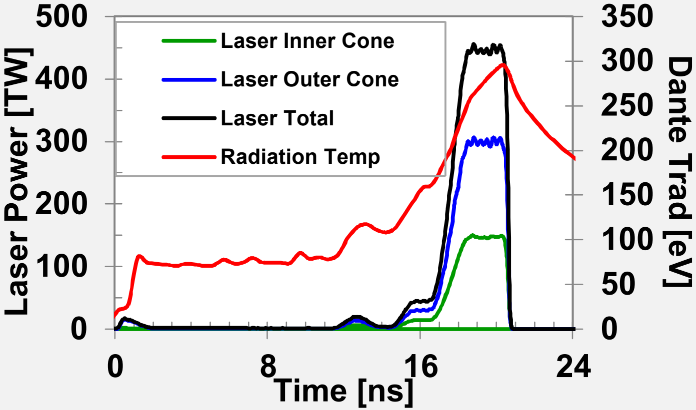
We studied 15 shots from the “CD mix” shot series

15 shots using the same hohlraum

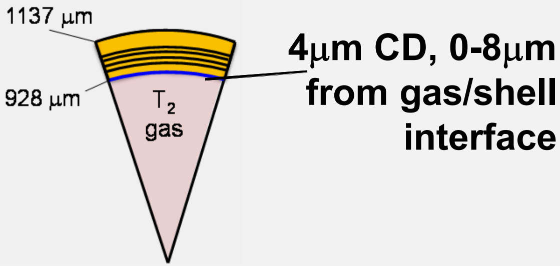


CD mix series

Same laser and Trad



Same capsule – different CD layer



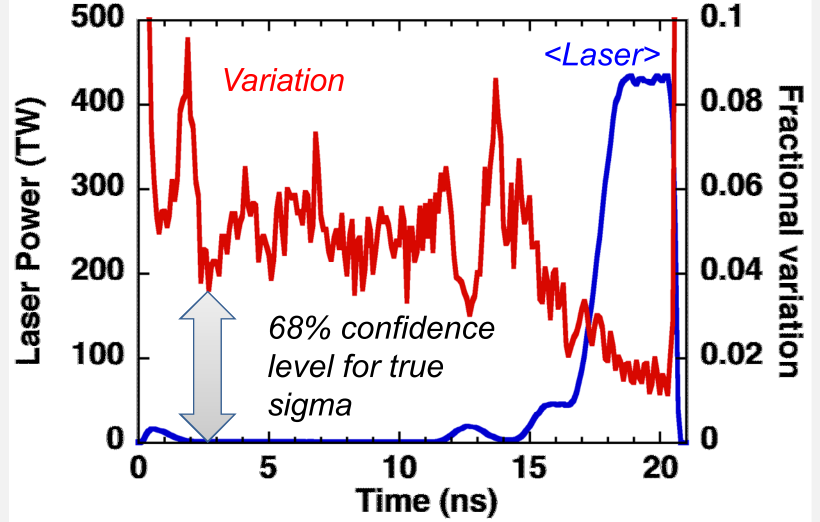
Convergence ~15
11 ± 0.5 mg/cc T_2 gas

Convergence ~20
5.5 ± 0.5 mg/cc T_2 gas

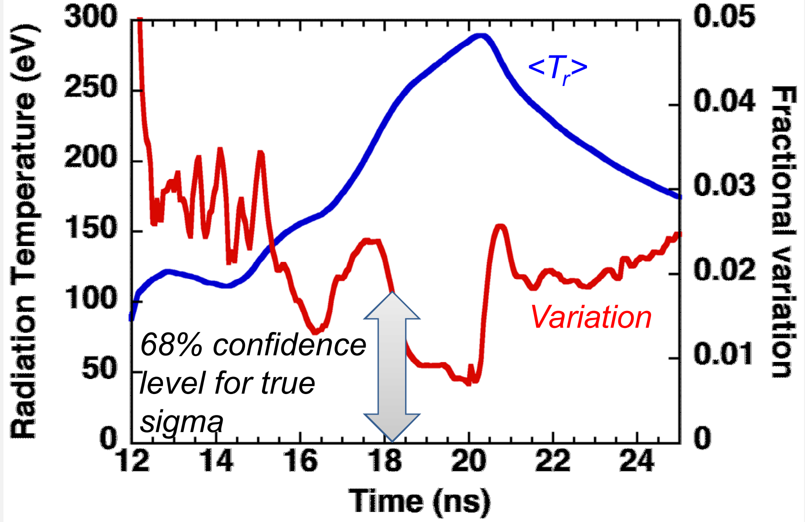
Other parameters are within the ignition spec

The variation in radiation temperature and laser delivery are approximately consistent

Laser delivery ranges within 2 to 9% of request



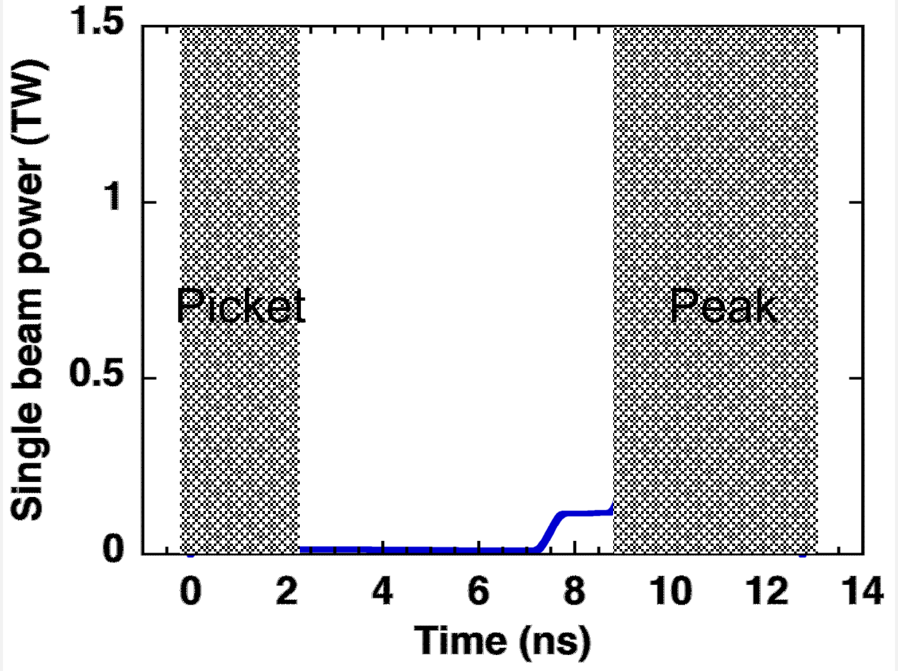
Radiation temperature varies from 1 to 3%



Expect $\delta T_r/T_r$ = ¼ $\delta I_{Las}/I_{Las}$; data is close to this. Differences may be additional error from the diagnostics

Backscatter fluctuations can impact the hot-spot shape at stagnation

Laser pulse shape



The various ignition hohlraum designs tend to show backscatter in the **picket** and/or the **peak**

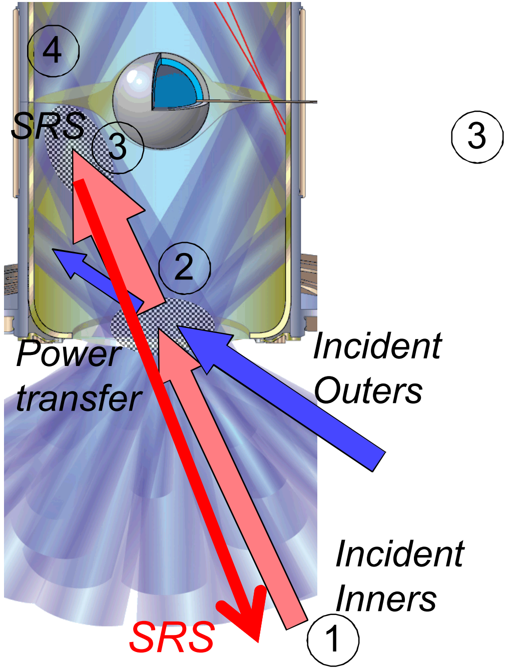
Picket backscatter variations:

- Can disrupt initial capsule compression symmetry

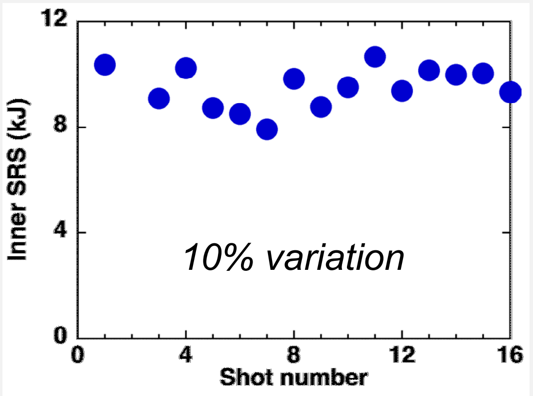
Peak backscatter:

- Can disrupt final capsule implosion symmetry

Late-time backscatter fluctuations can lead to 10% variations in laser power reaching the hohlraum wall

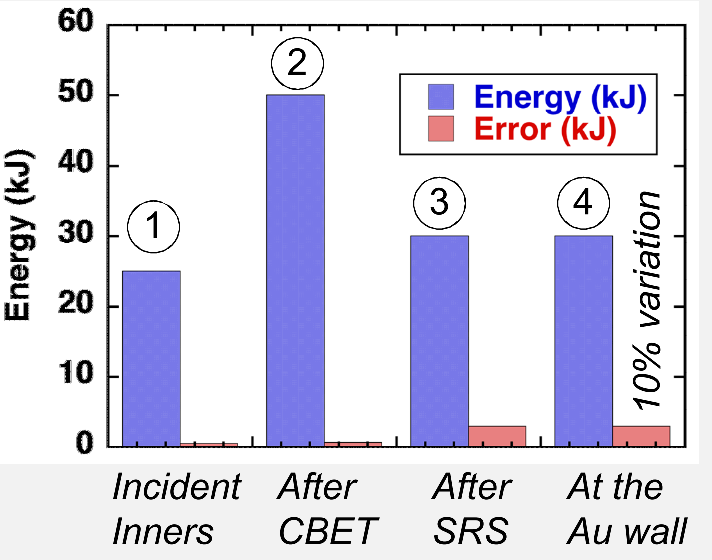


SRS late-time backscatter



Outer beam SBS variation is ~ 5% (0.6 kJ out of 11.7 kJ)

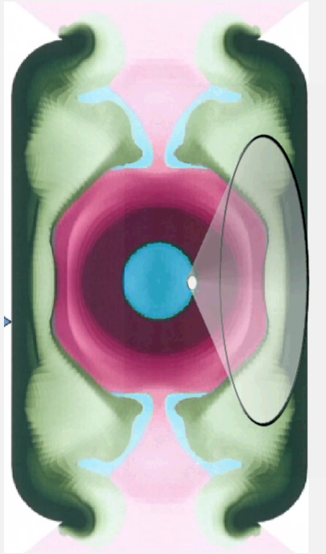
SRS backscatter → ~ a 10% variation in what reaches the wall



Need to determine laser variations in low-mode x-ray flux onto the capsule

We use simple approximations to convert the variation in laser energy to variations in x-ray flux on the shell

The hohlraum averages the laser-spot x-rays



A point on the capsule sees x-ray emission from a large cone area

Mapping laser power variations to x-ray flux variations:

$$\frac{\delta P_2}{P_0} \approx \underbrace{(2n+1)}_{\text{Azimuthal factor}} \times \underbrace{\frac{1}{F}}_{\text{Albedo factor}} \times \sigma_{P2} \times \underbrace{S_{P2}}_{\text{Smoothing factor}}$$

Late-time	16 inners	16 – 44.5°	16 – 50°
Variation	10%	4%	5%

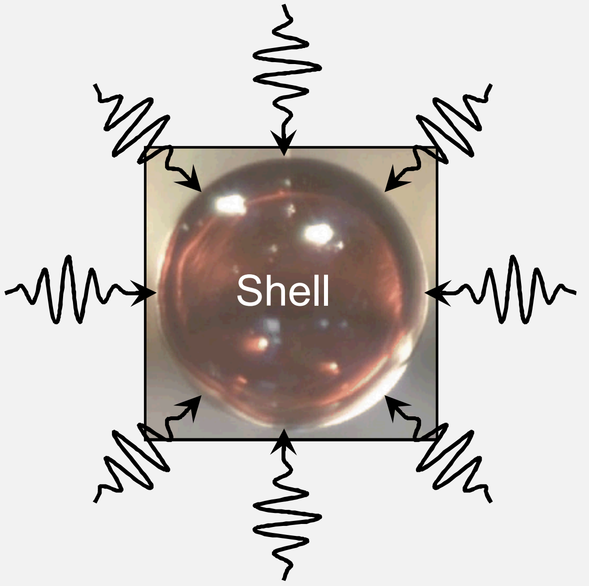
At late times the wall albedo is ~ 90%. Estimate $\delta P_2/P_0$ to get

~**0.7 %** maximum variation in P_{20}

Using the flux variation we can estimate the effect on shape

We use the rocket equation to estimate that late-time backscatter variations produce small late-time shape effects

X-ray flux causes the shell to ablate and implode



$$\frac{dR}{dt} = V_{imp}(\mathrm{cm/s}) = 10^7 \sqrt{T_R} \ln\left[\frac{m(t)}{m_0}\right]$$

$$\dot{m}(\mathrm{g/cm^2}) = 3\times10^5 T_R^3$$

$$m(t) = m_0 - 3\times10^5 T_R^3 t$$

$$\frac{\delta T_R}{T_R} = \frac{1}{4}\frac{\delta F}{F}$$

This gives: $$\frac{\delta R}{R} = \frac{3}{4}\frac{\delta I}{I}$$

For 0.007 $\delta I/I$ this is ~ 5 μm

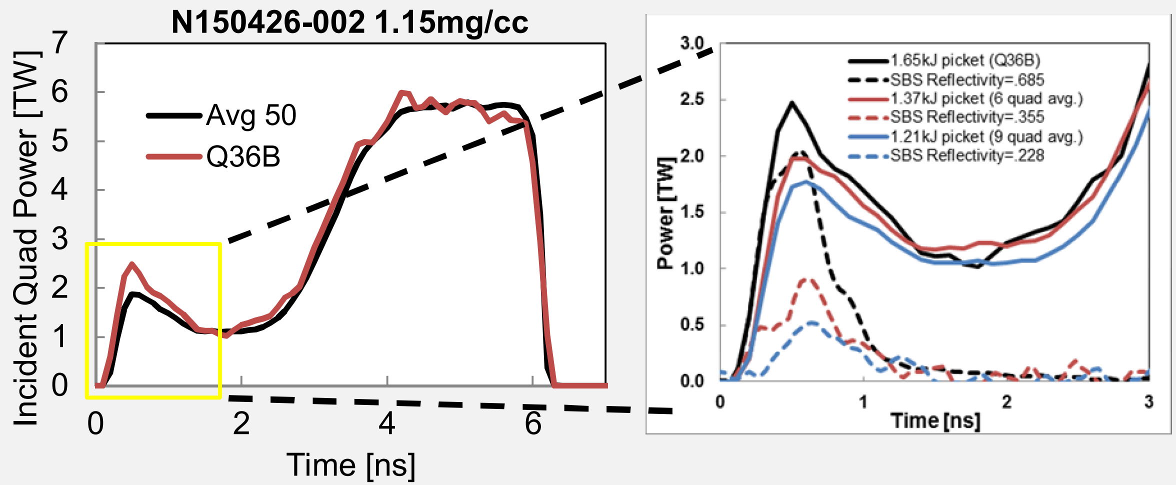
Small effect

Late-time laser variations generate insignificant variations in the implosion shape

Early-time backscatter variations may have a larger effect

Use different hohlraum experiments for this study

Outer cone backscatter shows significant variation at early time



- SBS produces ~ 37% variation in laser power on the wall
- Flux variations reaching the capsule estimated to be ~ 2.1%
- First shock break-out time varies by < 50 ps; shocks 1 and 2 merger location varies by ~ 5 μm

Possibly important effect

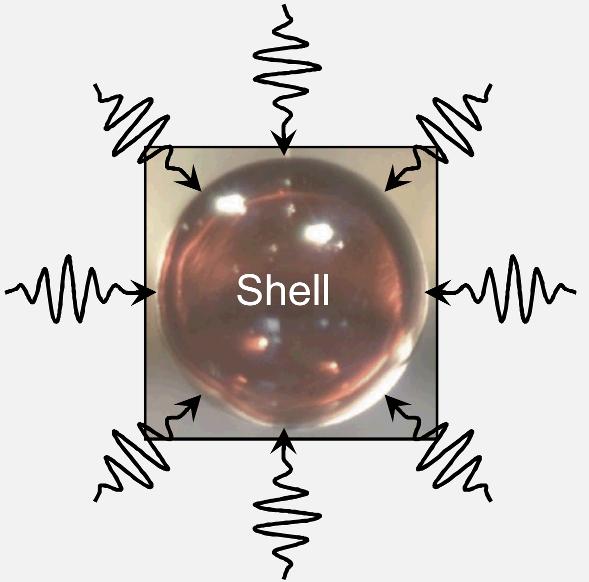
Early-time laser variations may generate noticeable variations in the implosion shape

Summary

- Laser variations are consistent with variations in the hohlraum radiation temperature
- Typical late-time backscatter variations are not important for shape at stagnation
- Early-time backscatter variations may be important in affecting the break-out time and merger time
- Future work will define a limit to the early-time scatter fluctuations for different ignition hohlraum designs

We use simple estimates to convert the variation in laser energy to variations in x-ray flux on the shell

X-ray flux causes the shell to ablate and implode



Mapping laser power variations to x-ray flux variations:

	16 inners	16 – 44.5°	16 – 50°
Variation	10%	4%	5%

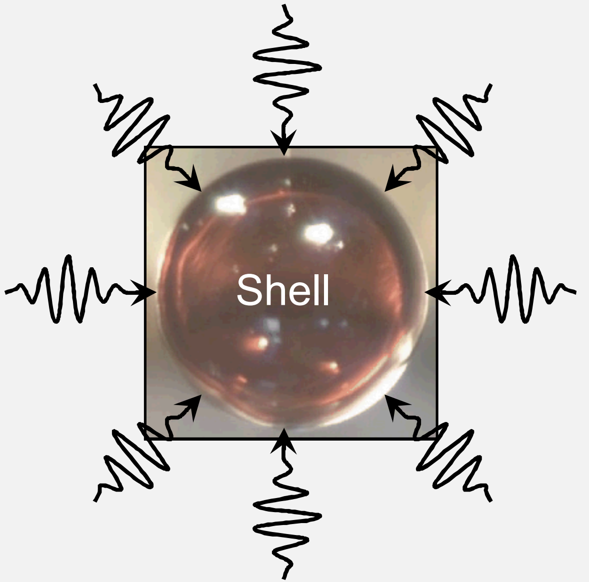
At late times the wall albedo is ~ 90%. Estimate $\delta P_2/P_0$ to get

~0.7 % maximum variation in P_{20}

Using the flux variation we can estimate the effect on shape

We use the rocket equation to show that late-time backscatter variations produce negligible variations in late-time shape

X-ray flux causes the shell to ablate and implode



$$\frac{dR}{dt} = V_{imp}(\text{cm/s}) = 10^7 \sqrt{T_R} \ln\left[\frac{m(t)}{m_0}\right]$$

$$\dot{m}(\text{g/cm}^2) = 3\times 10^5 T_R^3$$

$$m(t) = m_0 - 3\times 10^5 T_R^3 t$$

$$\frac{\delta T_R}{T_R} = \frac{1}{4}\frac{\delta F}{F}$$

Integrating over time gives:

Per mode – add Sqrt(3)

$$\delta R = -750\,\mu m \frac{\delta F}{F}$$ (overestimate)

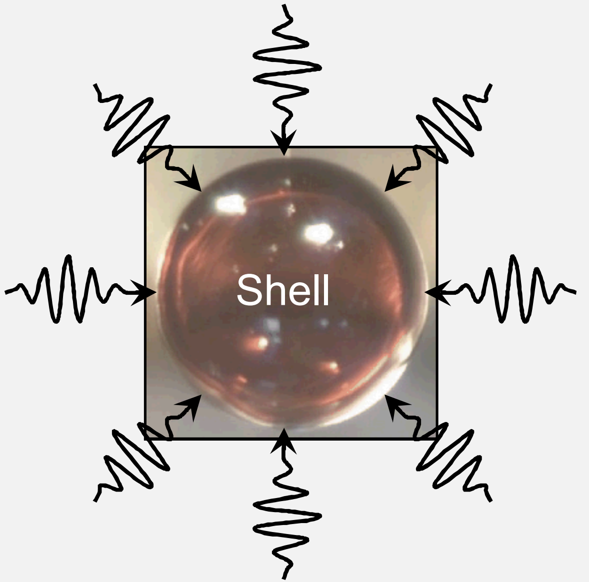
For 0.002 dF/F this is 1.5 μm

Small effect

Late-time laser variations generate insignificant variations in the implosion shape

We use a View Factor model to convert the variation in laser energy to variations in x-ray flux on the shell

X-ray flux causes the shell to ablate and implode



Mapping laser power to x-ray flux requires complex calculations:

Must account for laser intensity, cross-beam, absorption, geometry etc

Generate a matrix which maps laser power variations to flux variations

$$\tilde{\mathcal{P}}_i \cdot \mathcal{VF} = \mathcal{F}_i$$

L. Peterson 2012

Measured backscatter variations produce a **0.2 %** maximum variation in Y_{1-1} and Y_{20}

Using the flux variation we can estimate the effect on shape

The early-time flux variation estimates are based on View Factor calculations at late time

Late time	Early time	Result
Albedo ~ 90% (10 photon scatters)	Albedo ~ 60% (2.5 photon scatters)	4 x HIGHER contrast at early time
10% fluctuations on the inners, 5% outers	37% fluctuations on outermost cone; 4% on the other 3 cones	4 x HIGHER fluctuation level
0.04% fluctuation in Y_{20}	0.64% fluctuation in Y_{20} (estimated)	16 x larger fluctuation at early time
< 1 µm fluctuation in implosion shape	< 20 ps fluctuation in the first shock Break-out time	

Early-time backscatter fluctuations must reach ~ 100% to affect shock-timing in a significant way

Early-time laser variations do not generate significant variations in the first shock break-out time