LA-UR- 10-03731

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Title: Experiments to Measure Ablative Richtmyer-Meshkov Growth of Gaussian Bumps in Plastic Capsules

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Intended for: 40th annual anomalous absorption conference

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40th Annual Anomalous Absorption Conference
Snowmass Village, CO
June 13-18, 2010

Experiments to Measure Ablative Richtmyer-Meshkov Growth of Gaussian Bumps in Plastic Capsules

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Growth of hydrodynamic instabilities at the interfaces of inertial confinement fusion capsules (ICF) due to ablator and fuel non-uniformities have been of primary concern to the ICF program since its inception. To achieve thermonuclear ignition at Megajoule class laser systems such as the NIF, targets must be designed for high implosion velocities, which requires higher in-flight aspect ratios (IFAR) and diminished shell stability[1]. Controlling capsule perturbations is thus of the utmost importance. Recent simulations have shown that features on the outer surface of an ICF capsule as small as 10 microns wide and 100's of nanometers tall such as bumps, divots, or even dust particles can profoundly impact capsule performance by leading to material jetting or mix into the hotspot. Recent x-ray images of implosions on the NIF may be evidence of such mixing. Unfortunately, our ability to accurately predict these effects is uncertain due to disagreement between equation of state (EOS) models. In light of this, we have begun a campaign to measure the growth of isolated defects (Gaussian bumps) due to ablative Richtmyer-Meshkov[2] in CH capsules to validate these models.

The platform that has been developed uses halfraums with radiation temperatures near 75 eV (Rev. 4 foot-level) driven by 15-20 beams from the Omega laser (Laboratory for Laser Energetics, University of Rochester, NY), which sends a ~2.5 Mbar shock into a planar CH foil. Gaussian-shaped bumps (20 microns wide, 4-7 microns tall) are deposited onto the ablation side of the target. On-axis radiography with a saran (Cl He_α - 2.8 keV) backlighter is used to measure bump evolution prior to shock breakout. Shock speed measurements will also be made with Omega's active shock breakout (ASBO) and streaked optical pyrometery (SOP) diagnostics in conjunction with filtered x-ray photodiode arrays (DANTE) to determine drive conditions in the target. These data will be used to discriminate between EOS models so that one may be selected to design the shape and intensity of the foot in an ignition-level drive pulse so that bump amplitude is minimized by the time the shell begins to accelerate.

*This work conducted under the auspices of US DOE campaign 10 (Inertial Confinement Fusion, Steve Batha program manager) and the National Ignition Campaign.

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[1] C.D. Zhou and R. Betti, "Hydrodynamic relations for direct-drive fast-ignition and conventional inertial confinement fusion implosions", Phys. Plasmas **14**, 072703 (2007).
[2] V.N. Goncharov, "Theory of the ablative Richtmyer-Meshkov instability", PRL **82**, 2091-2094 (1999).

Experiments to Measure Ablative Richtmyer-Meshkov Growth of Gaussian Bumps in Plastic Capsules

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Snowmass, CO

Existing bumps on NIF ablators expected to cause mixing in the hot spot

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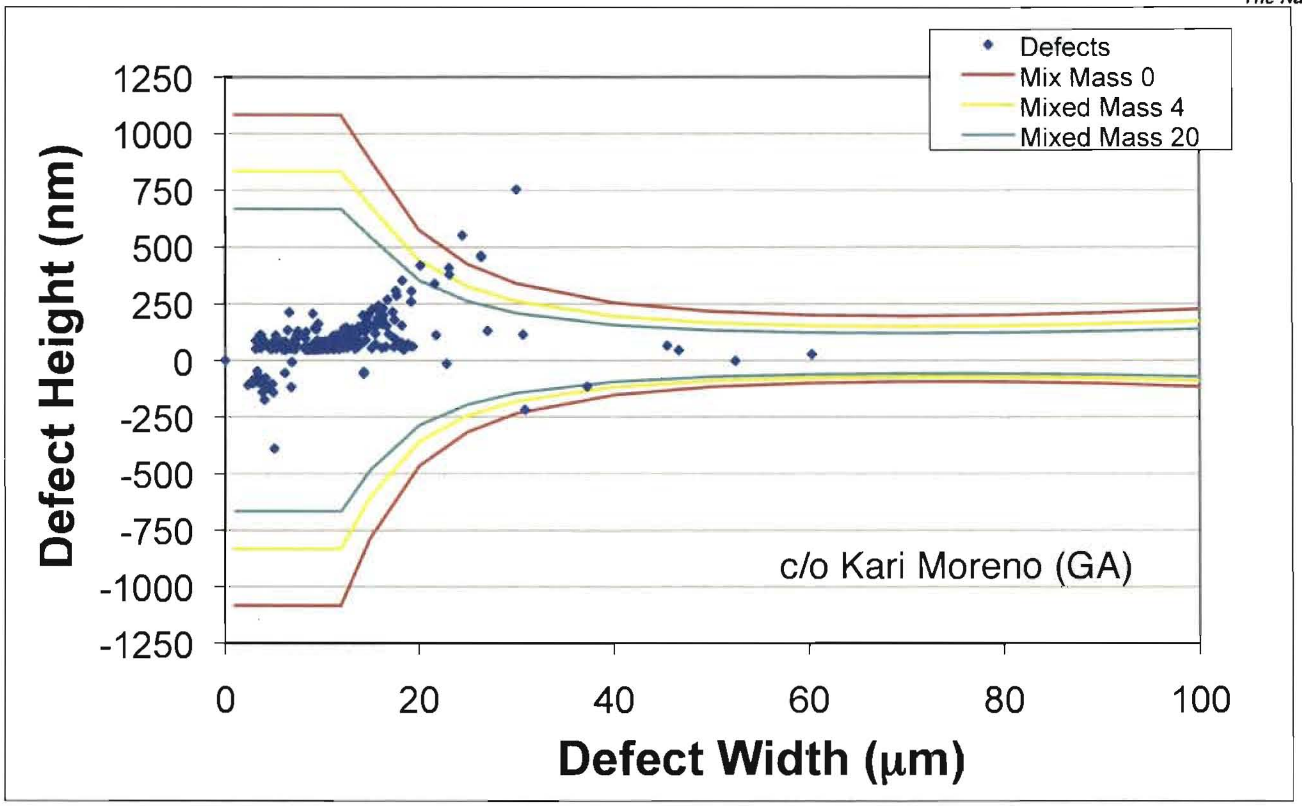

- Number of bumps in each region used to estimate mix and thus sets requirements on bump dimensions

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Experimental Motivation and Objectives

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- Bumps, divots (formed during fabrication), and even dust particles on the outer surface of plastic ICF capsules are predicted to negatively impact capsule performance during an ignition-scale implosion due to mix caused by hydrodynamic instability growth
- The shape of a NIF foot pulse can be tailored to minimize the amplitude of these features at shock break-out
  - EOS models disagree for growth rate of bumps in the ablative Richtmyer-Meshkov regime
- Experiments are thus need to be performed to support these predictions

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Description of the ablative Richtmyer-Meshkov instability

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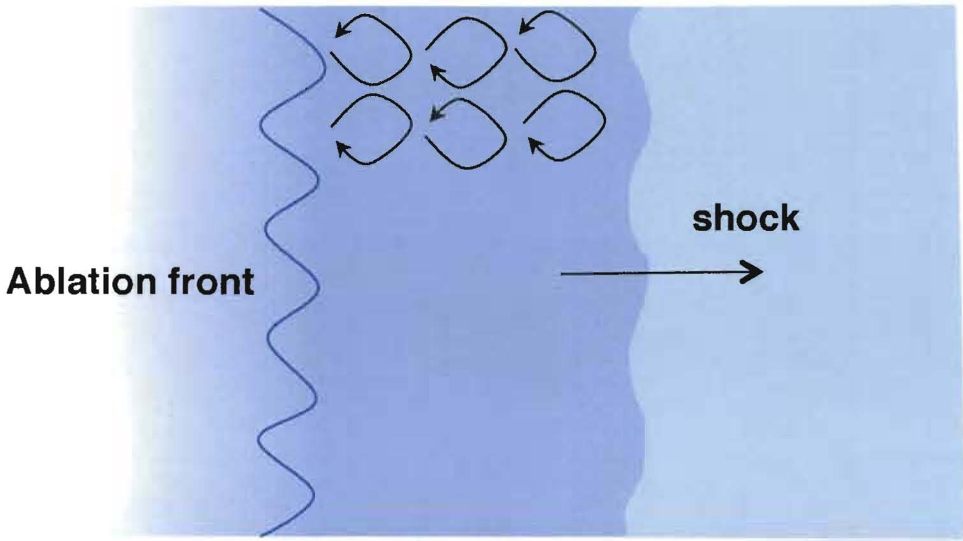

From the full theory[1]:

$$\eta \propto e^{-2kV_a t} \cos\left(\sqrt{k^2 V_a V_{bl}}\, t\right) + \eta_{vort}$$

Where shock-induced vorticity dominates at late time.

- Single mode, direct drive experiments (short density scale length) have observed these mass oscillations out to ~1 oscillation period (reflected rarefaction then broke out and accelerated ablation surface)[2]
- Growth behavior is expected to differ for indirect drive

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1) V.N. Goncharov, PRL 82 (10): 1999.
2) Y. Aglitskiy et al. PRL 87 (26): 2001.

Bumps on ICF capsules contain broadband spatial frequencies

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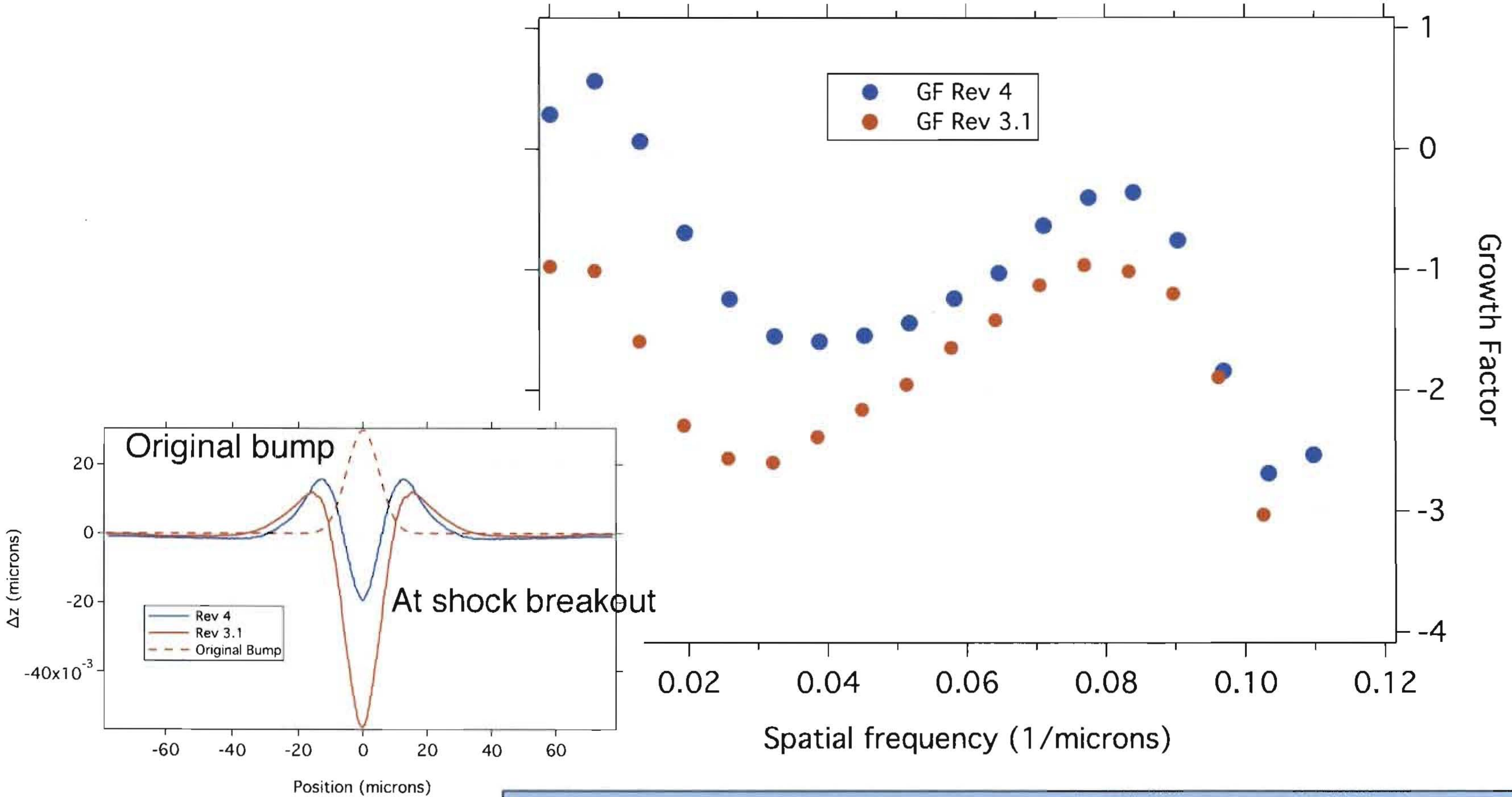

- Not only height, but shape of bump changes during ablation process

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EOS models predict different growth rates of isolated bumps

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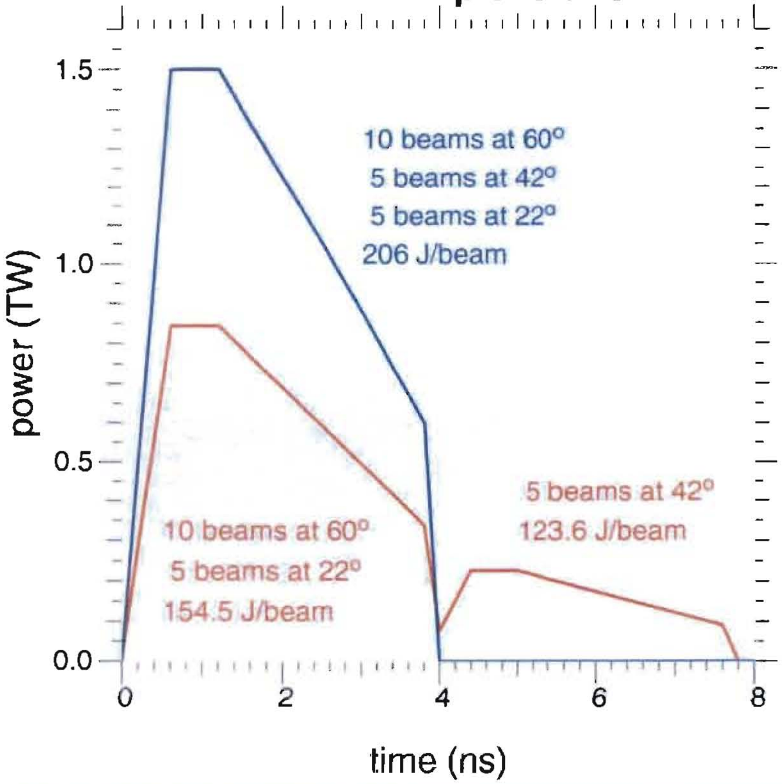
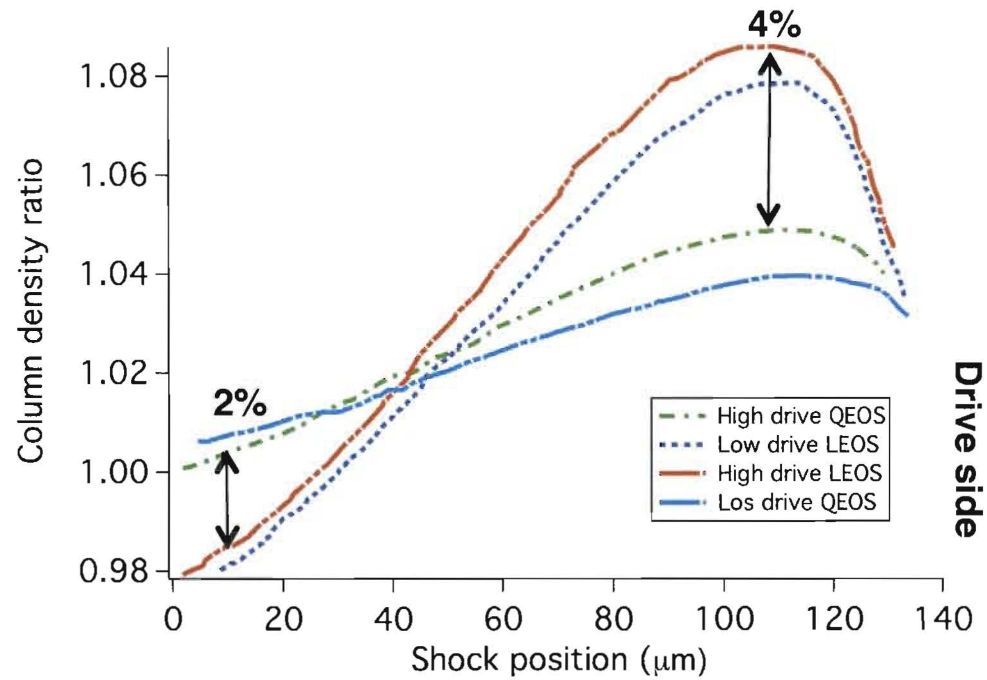
Laser drive pulse shapes used to simulate bump evolution



Comparison between EOS models for high and low laser power bump evolution



Experiments must discern 4% difference in $(\rho z)_{bump}/(\rho z)_{trough}$ at peak bump height

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CHaRM platform measures bump evolution with face-on radiography at 60-beam Omega

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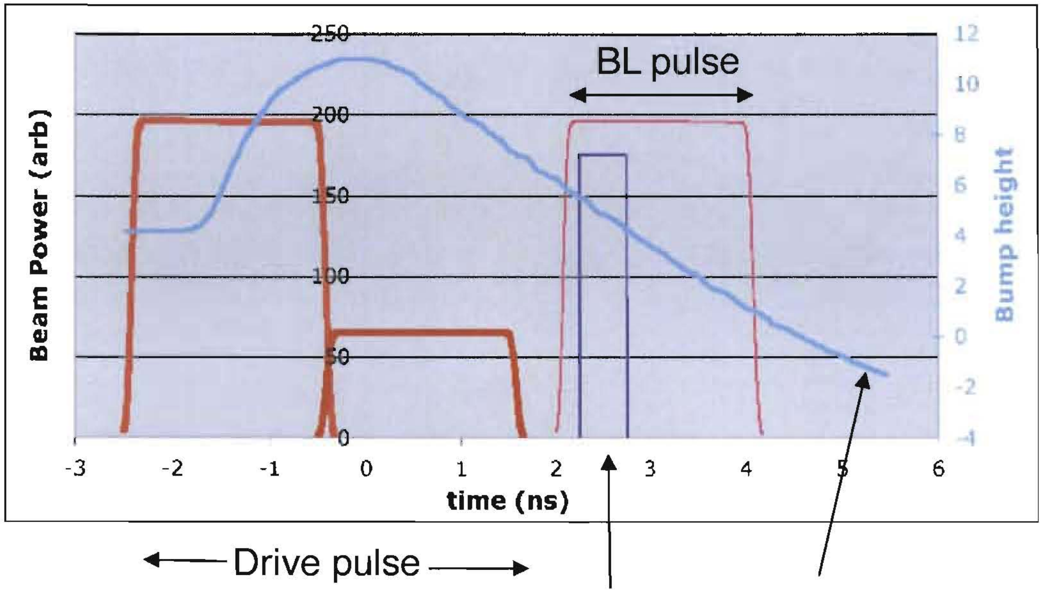
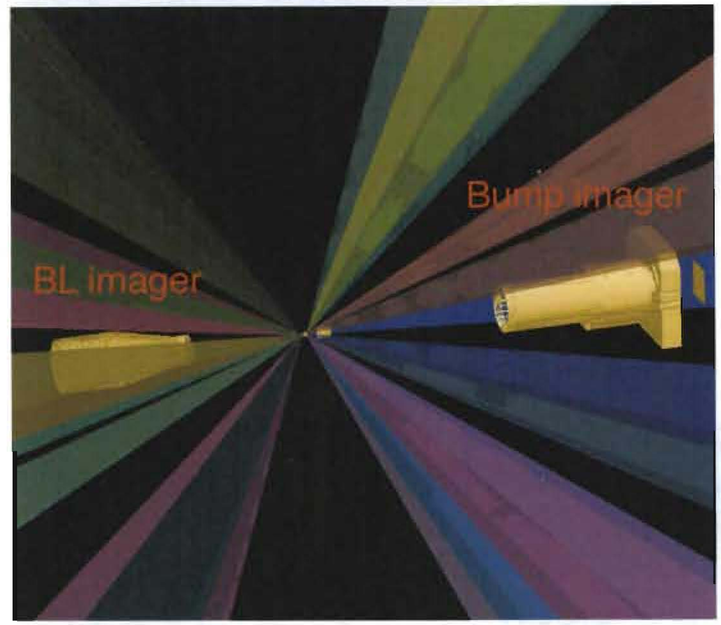
Timing of BL shot at mid time



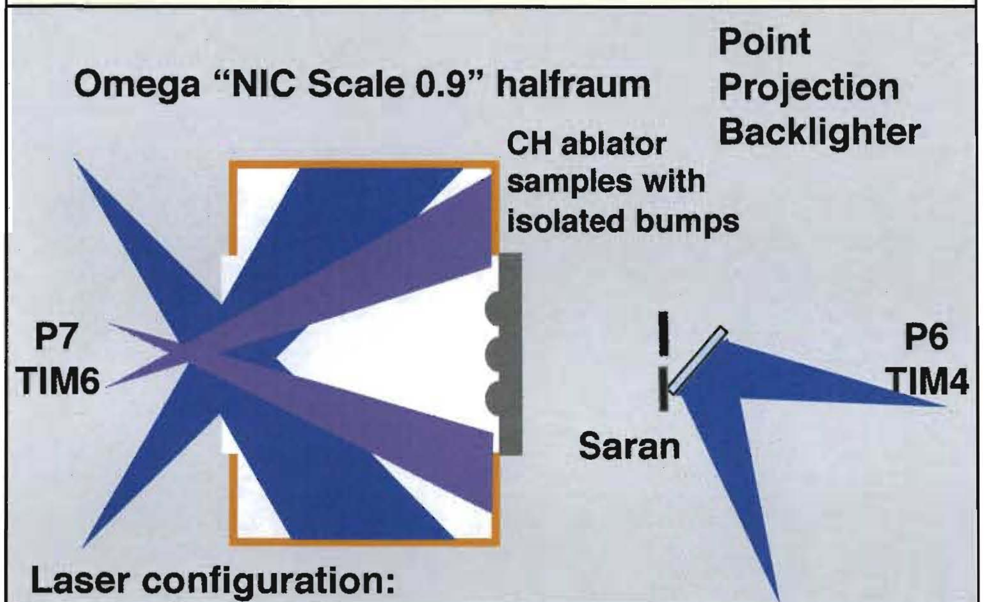
VisRad model of experimental configuration



- Single and multi-strip x-ray framing cameras used to image bumps
- Multiple imaging techniques available

Pinhole-apertured point projection backlighting (PAPBL)

Experimental Config #1



Laser configuration:

Beams	# CPPs	CPP size	Pulse	**Special**
10 C3 + 5 C2 + 5 C1 P7	20	SG 4 & IDI 300	sg2006	-2.5 ns
10 assorted, 45 deg P6	10	IDI 300	sg2006	+4.5 ns

•BL measurement when drive beams turn off

Pros

- Large magnifications
- High source brightness/resolution element
- Minimal degradation in image quality from plasma spatial structure

Cons

- High alignment sensitivity
- Resolution due to pinhole closure changes with time
- Greater risk of hot electron generation
- Greater risk of damage to recording instruments

A.B. Bullock, O.L. Landen et al., RSI 72 (1): 2001.
J. Workman et al., RSI 75 (10): 2004.

Area backlighting at 21.5x magnification

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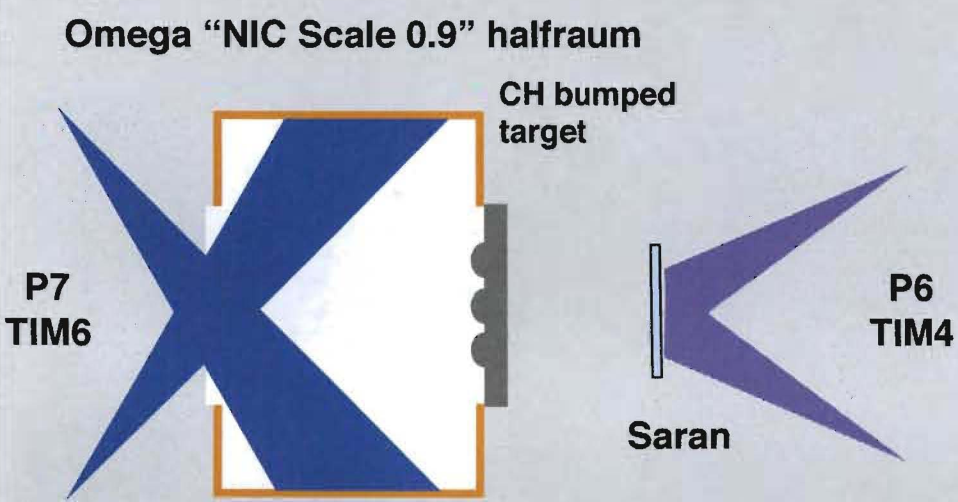
Experimental Config #2



Laser configuration:

Beams	# CPPs	CPP size	Pulse	**Special**
10 C3 + 5 C2 P7	15	SG4	sg2007	-2.6 ns
C1, C2, C3 P6	20	SG8/SG4	sg2007	+4.6 ns

Pros

- Easy to align
- Low damage risk
- Constant resolution element size
- Capable of taking multiple images on single shot

Cons

- Difficult to obtain high magnification
- Greater laser power requirements
- Spatial structure in emitting plasma may be present
- Field of view limited by source size

Simulated radiographs are used to predict observable bump heights

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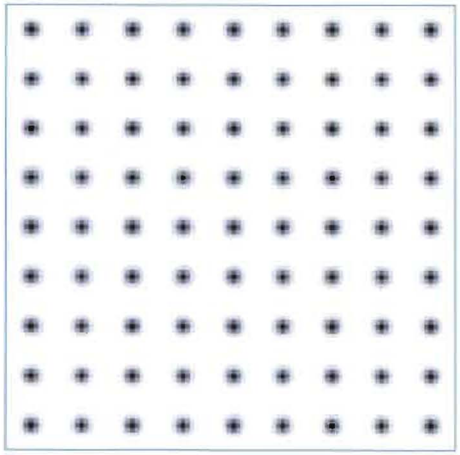
noise

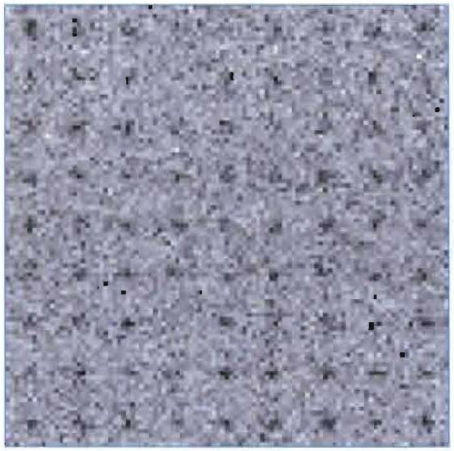
- PAPBL radiographs of 140 micron thick plastic with 4 micron tall bumps based on photometric calculations (O.L. Landen)

Signal (10 um resolution at target)



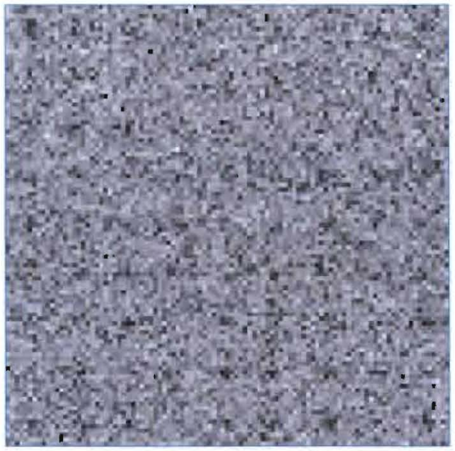
3420 to 3570 detected photons

SNR=2.43



$\sigma = \sqrt{N_{transmitted}}$

SNR=1.35



$\sigma = \sqrt{N + (N * FPN)^2}$

For 8 micron bump, SNR = 2.65 with FPN

Drive conditions based on halfraum radiation temperature not always reliable

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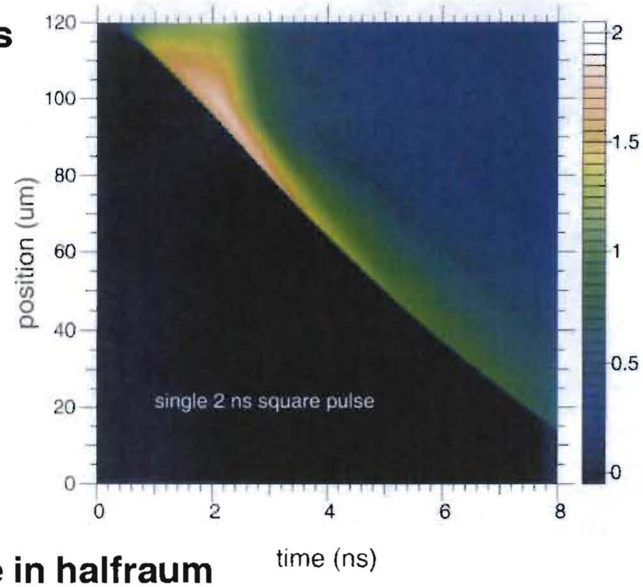
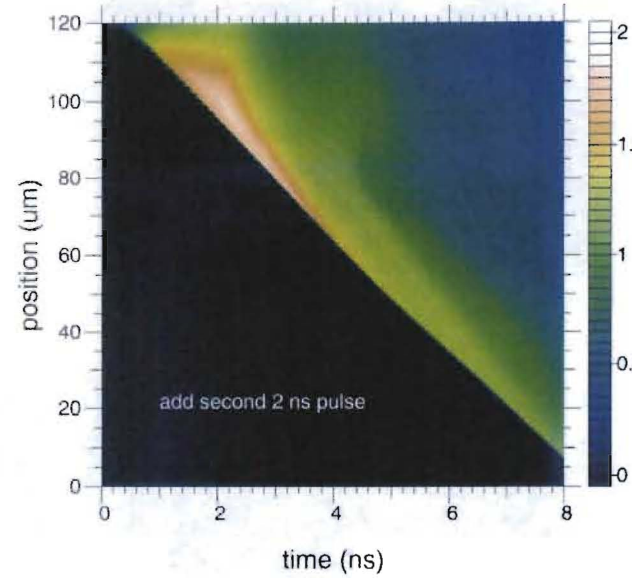
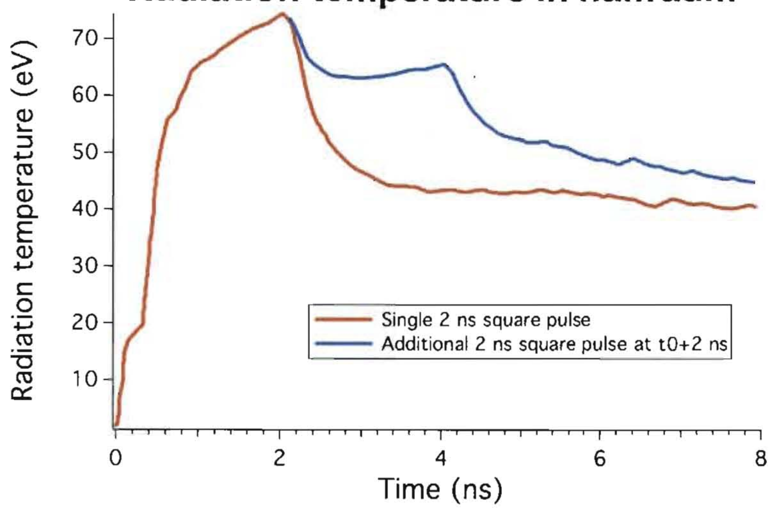
Simulated pressure histories (Mbar) in plastic ablator





Radiation temperature in halfraum



- Need an independent measure of target conditions for assessment of bump evolution

Measuring shock speed from break-out time

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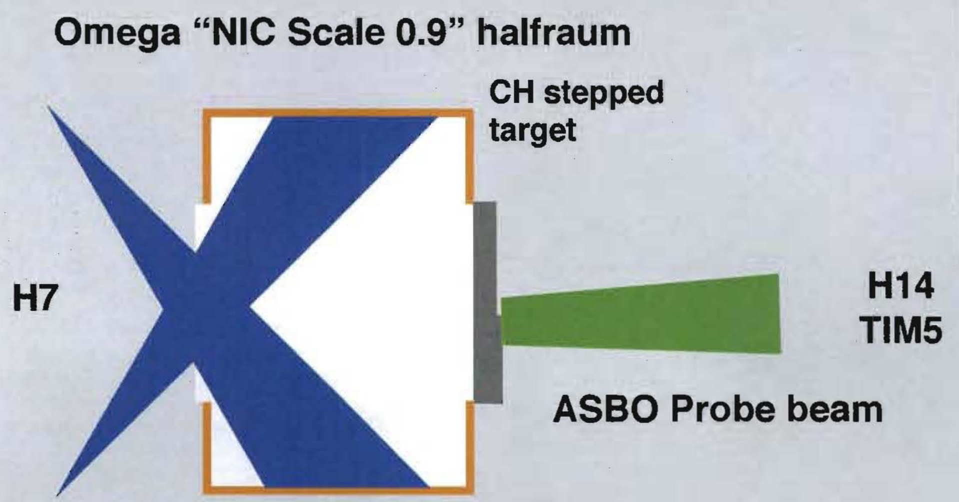
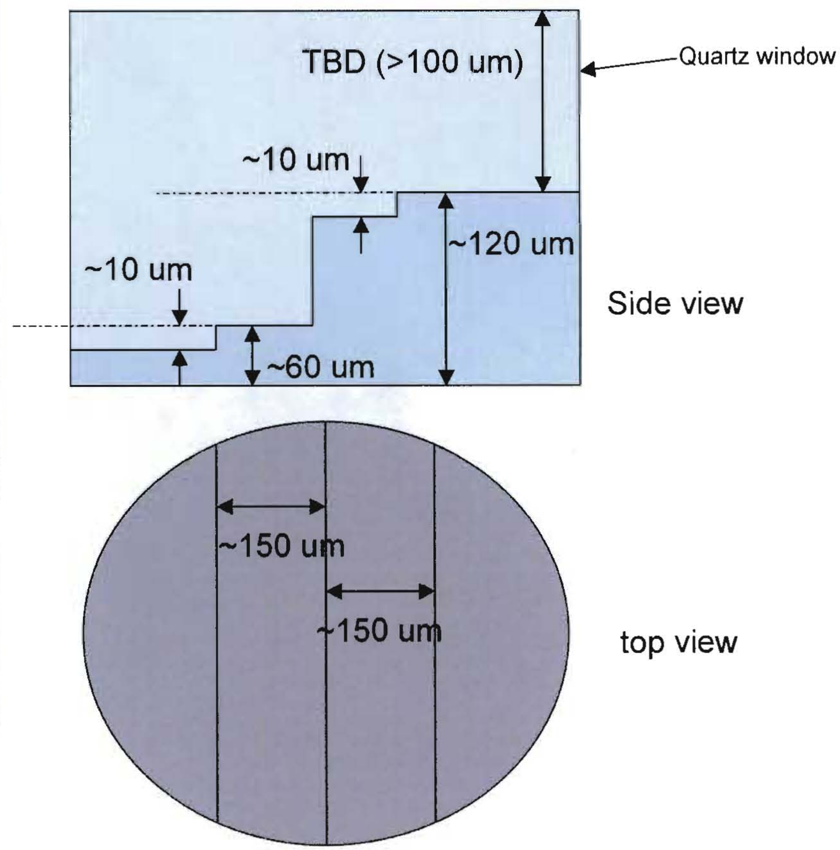
Experimental Config #2



Laser configuration:

Beams	# CPPs	CPP size	Pulse	**Special**
9 C3 + 6 C2 (H7)	15	SG4	sg2007	-2.5 ns

Possible step target geometry



- **Self-emission (SOP) should disappear upon shock breakout**
- **CH and quartz window anticipated to "blank" until M-band drops to low level**

Acknowledgements

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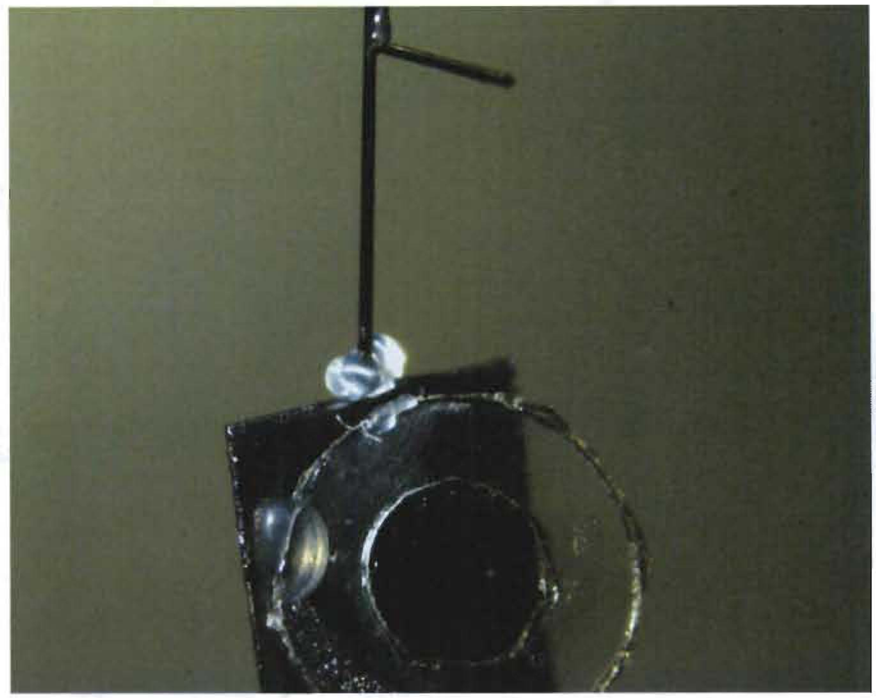
- D. Schmidt, K. Aubrey, P. Reardon, R. Perea (MST-7 target fabrication)
- A. Nikroo, A. Greenwood, Kari Moreno (General Atomics)
- Laboratory for Laser Energetics, University of Rochester
- P. Keiter (LANL) for helpful discussions

PAPBL metrology



Summary from February shots

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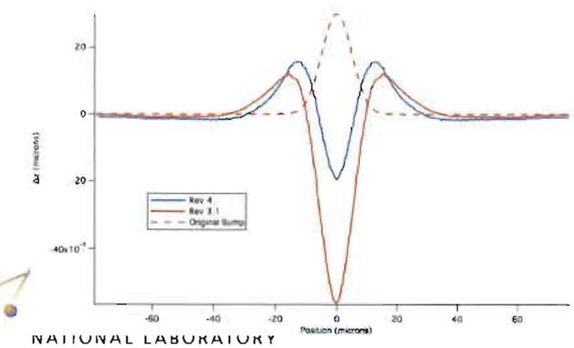
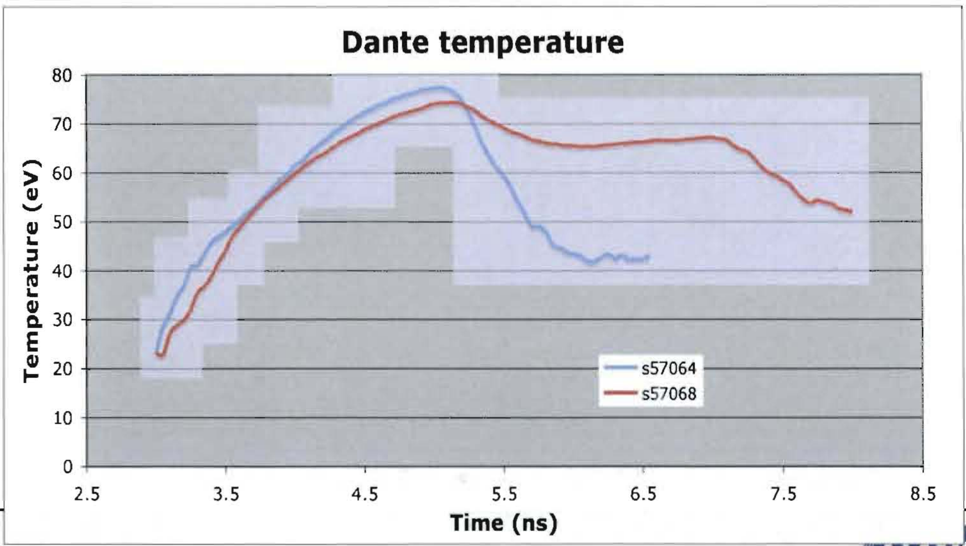
- Less than desired success…
- Had to use 4 shots to assess damage in on-axis PAPBL configuration
  - Used too long of snout
  - <u>Had</u> to use 15 mils Be blast shield
- ASBO/SOP mirror (apparently) did not survive radiation environment
- No bump contrast, but did image square plastic filter at MCP
  - Measured optical depth suggested 8-10 keV x-rays in system, probably due to overdriving saran BL producing hot electrons
- Some BL timing issues encountered. Jitter caused the MCP strips to fire ahead of BL pulse





System spectral response using PET

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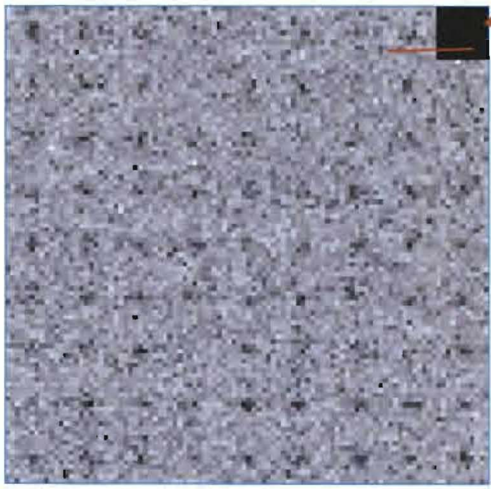
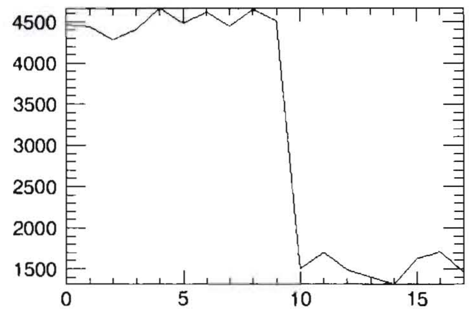
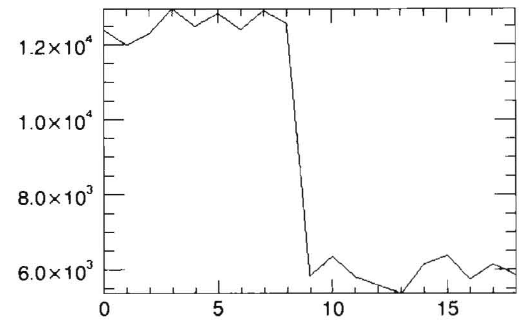


16 mils Be, 1 mil saran
2.8 keV
S/N = 2.05
N = 4500, ΔN = 270



E = 2.8 keV
τ = 1.1



E = equal initial intensities, first 5 Cl lines
τ = 0.73

- Tau of PET should have been 1.1 for 2.8 keV only
- Measured tau
  - Shot 57068 (20 drive beams): 0.47
  - Shot 57070 (BL only): 0.1
  - Shot 57073 (15 drive beams to image plate): 0.026
- ≥ 8 keV x-rays needed to produce these values

$$\frac{I}{I_0^{PET}} = \exp(-\tau) = \sum_{\nu} T_{\nu}^{PET} f_{\nu}$$