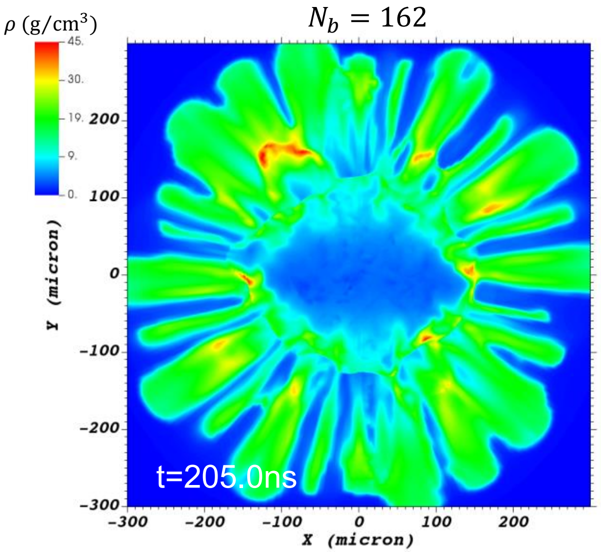
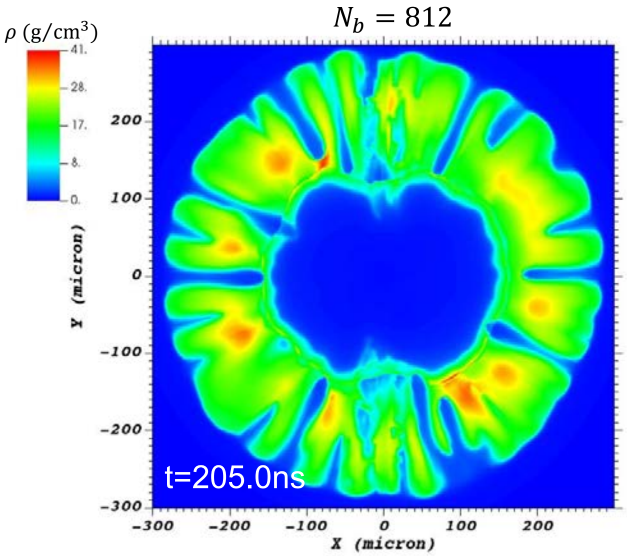
Dynamic shell stability to low-mode perturbations

Density maps of implosion shells from 3-D *ASTER* hydrodynamic simulations

"Broken-shell" implosion





Relatively stable implosion

Igor V. Igumenshchev
University of Rochester
Laboratory for Laser Energetics

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American Physical Society
Division of Plasma Physics
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Summary

Three-dimensional hydrodynamic simulations suggest that dynamic shell (DS) implosions can tolerate perturbations from laser beam overlapping

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- Effects of perturbations from beam overlapping in directly driven DS designs were studied using 3-D *ASTER*† hydrodynamic simulations
- Optimum distributions of beams around targets were found using the triangulated icosahedron geometry modified by the charged-particle method
- Designs with low IFAR‡ (<30) are required for avoiding unstable "broken-shell" implosions
- Beam overlap modes ($\ell \sim {}^{\pi}/_{2}\sqrt{N_b}$) affect DS implosions mainly during the acceleration and hot-spot formation stages

†Igumenshchev *et al*., Phys. Plasmas **24**, 056307 (2017).

‡ IFAR: in-flight aspect ratio.

Collaborators

V.N. Goncharov, E.M. Campbell, T.J.B. Collins, M.J. Rosenberg, N. Shaffer, W. Theobald, W. Trickey, R.C. Shah, and A. Shvydky

University of Rochester
Laboratory for Laser Energetics

A. Colaïtis

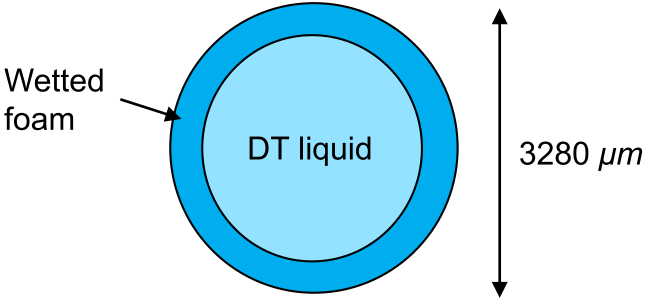
Centre Lasers Intenses et Applications, France

S. Atzeni and L. Savino

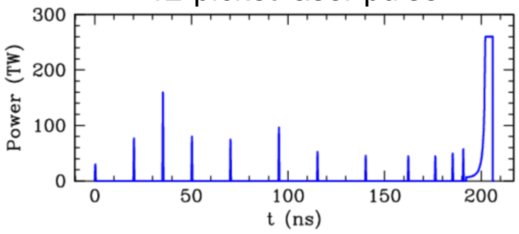
Università degli Studi di Roma “La Sapienza,” Italy

A novel dynamic shell concept[a,b] in ICF was proposed for enhanced control of 1-D implosion dynamics and easier target fabrication

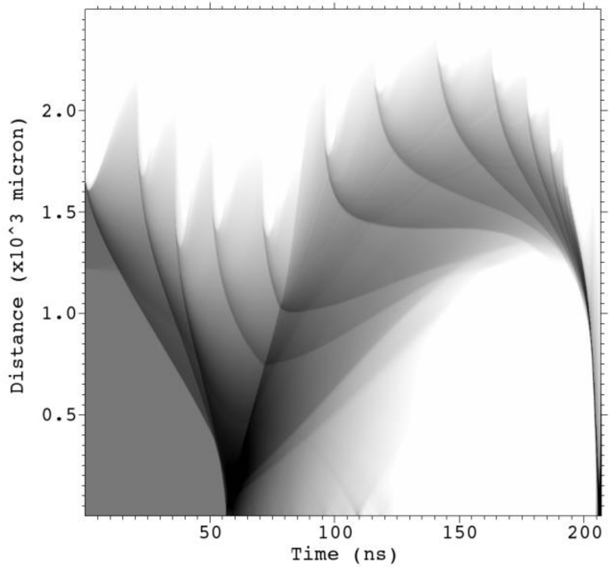
Design with the gain of ~100 using 1.3-MJ laser energy and dynamic beam zooming (IFAR ≈ 27)



12-picket laser pulse



Shock diagram from 1-D simulations
(log-density map in time-distance coordinates)



[a] Goncharov *et al*., Phys.Rev. Lett. **125**, 065001 (2020).

[b] V. Goncharov, talk NO04.00012 in this session.

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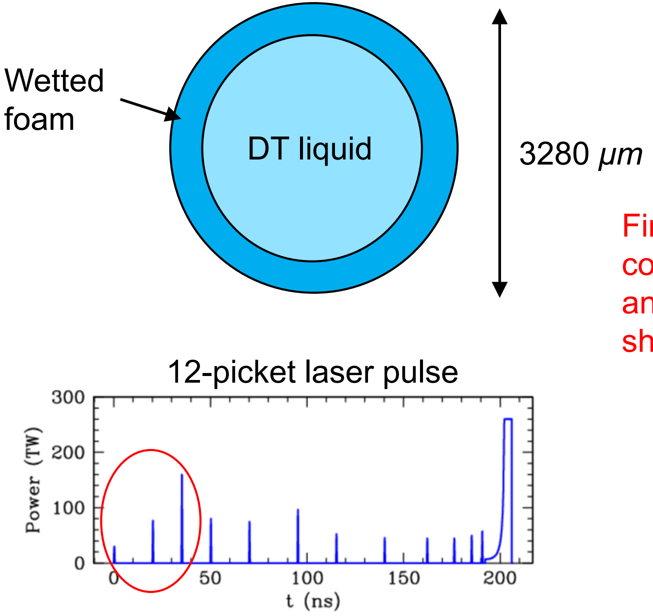
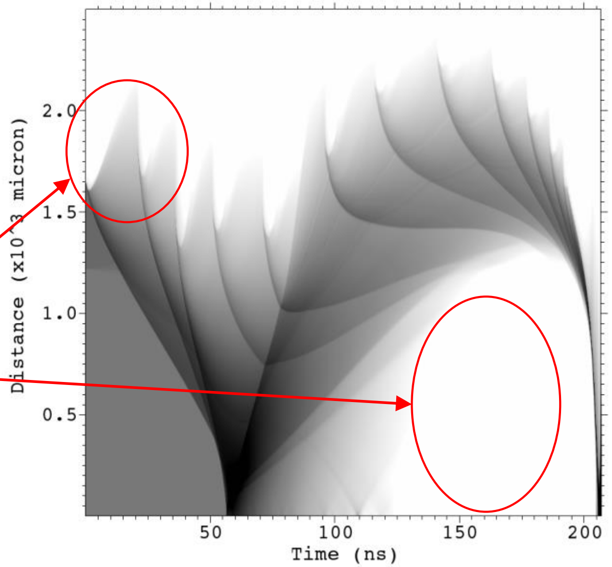


Shock diagram from 1-D simulations (log-density map in time-distance coordinates)

First three pickets compress the target and define the inside shell density



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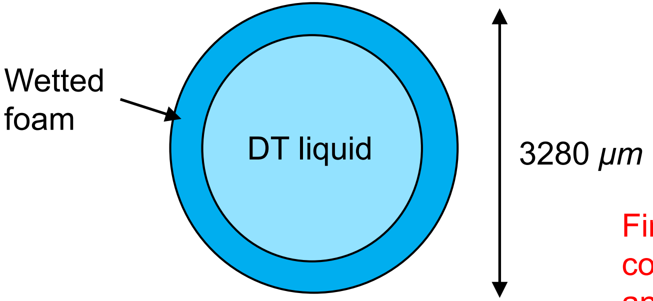

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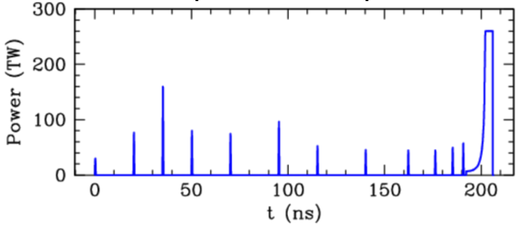

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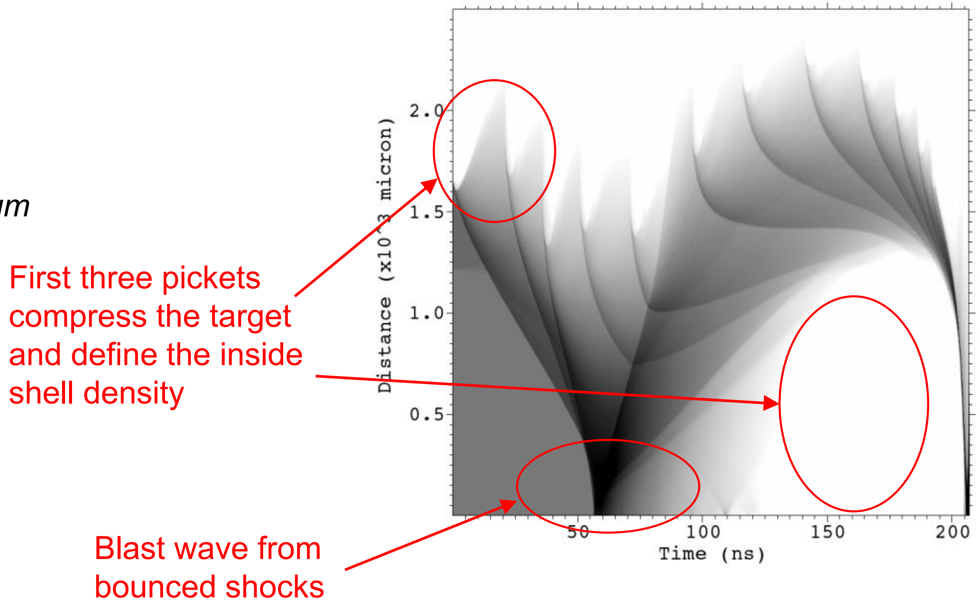

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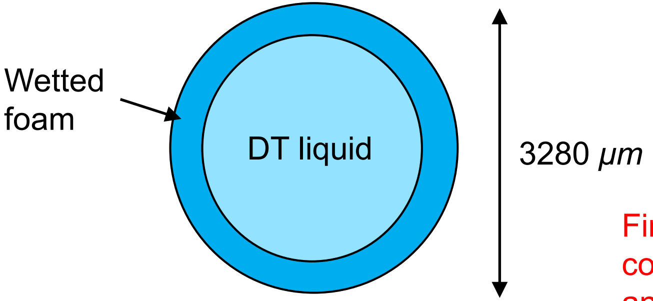

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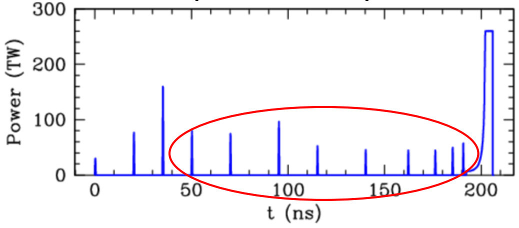

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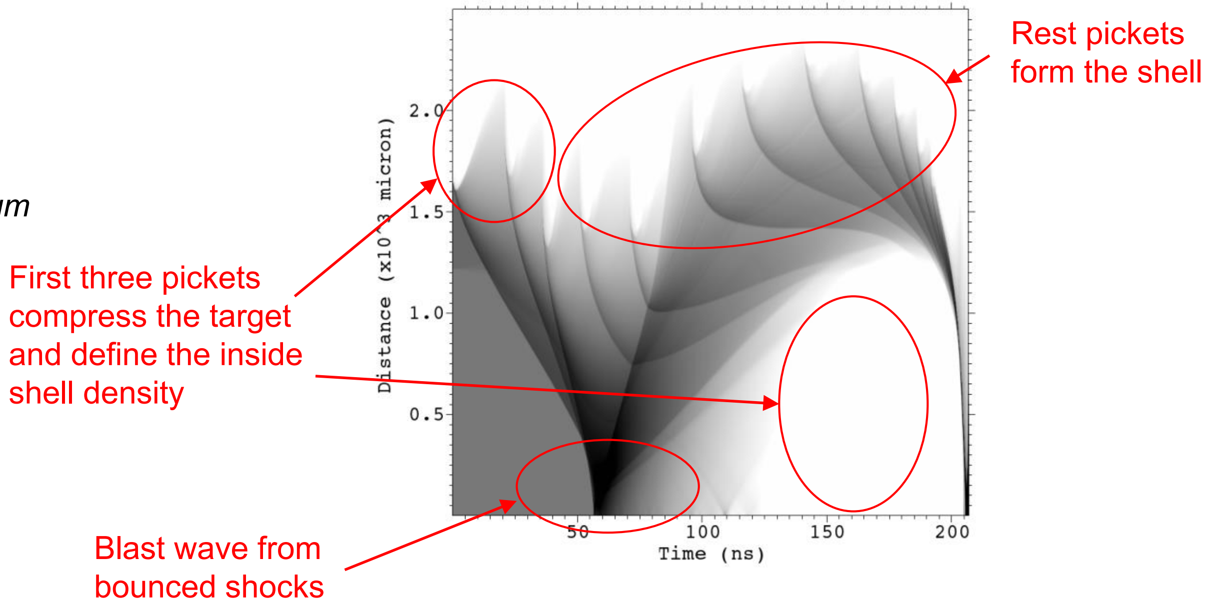

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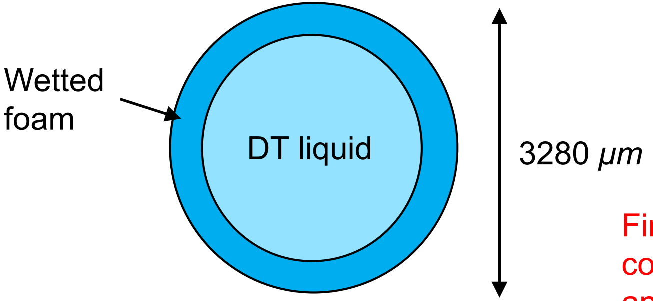

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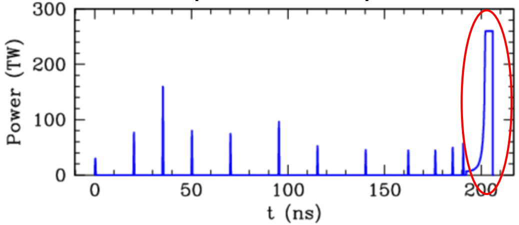

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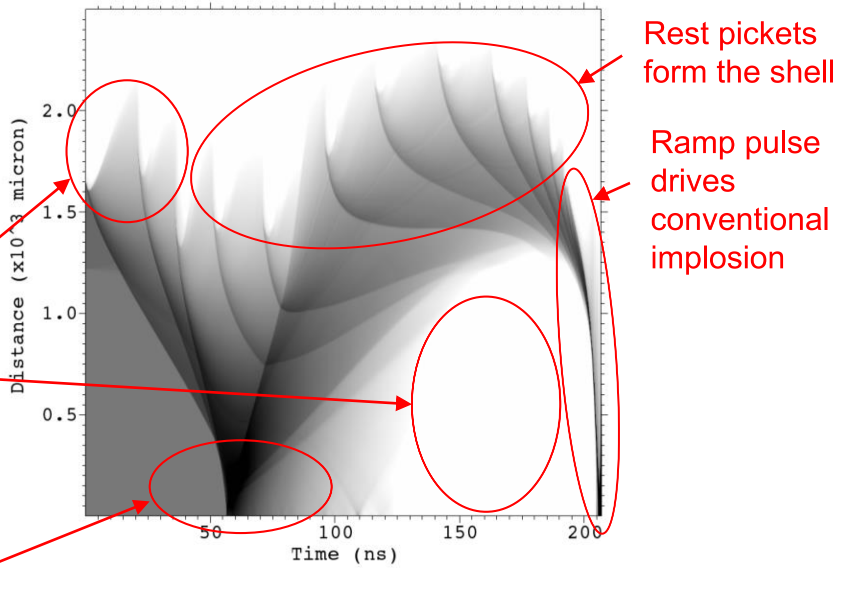

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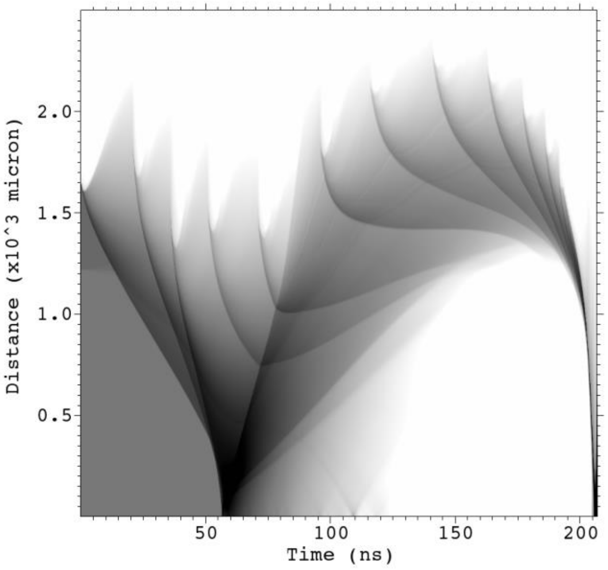
Stability analysis of dynamic shell designs should consider each evolution stage

Shock diagram from 1-D simulations



- Long evolution (~200 ns) can enhance the secular and hydrodynamic instability growths
- Large variation of the target outer radius can increase perturbations from laser beam overlap
  - increased number of beams and dynamic beam zooming might be necessary
- Optimization of beam geometry and zooming can reduce specs for the number of beams
- Low IFAR improves implosion stability but reduces 1-D performance
- Laser imprint seeding small-scale perturbations is expected to be less important (will be tested in future work)

The geometry of beams around targets crucially impacts the stability of implosion shells

- Beam configurations are chosen based on the geometry of triangulated icosahedrons [a]

- For beams in vertices, relatively large mode 6 perturbations exist even for large numbers of beams

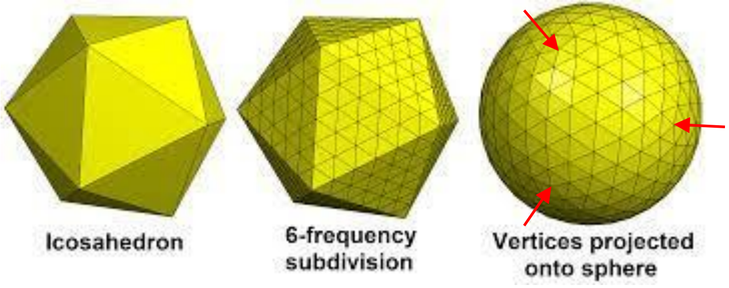
- Mode 6 is suppressed applying the charged-particle (CP) method[b]

$$\frac{d^2\hat{r}_i}{dt^2} = \sum_{j=1(j\neq i)}^{N_b} \frac{\hat{r}_i - \hat{r}_j}{\left|\hat{r}_i - \hat{r}_j\right|^{1+\alpha}} - \frac{d\hat{r}_i}{dt}$$

$\hat{r}_i$ − unit vector toward i−particle

$\alpha = 2$ for the Coulomb interactions

12 vertices   362 vertices



- 3-D simulations suggest that nonsymmetric beam configurations (random seed + CP) result in more distorted implosions

[a] W. Trickey, talk NO04.00014 in this session.

[b] Murakami *et al*., Phys. Plasmas **17**, 082702 (2010).

The largest suppression of icosahedral mode-6 perturbations in the absorbed light was found using the charged-particle method with $\alpha = 0$

$N_b = 162$

$\ell \sim \pi/2 \sqrt{N_b} = 20$

$R_b/R_t = 1$, SG = 4.5

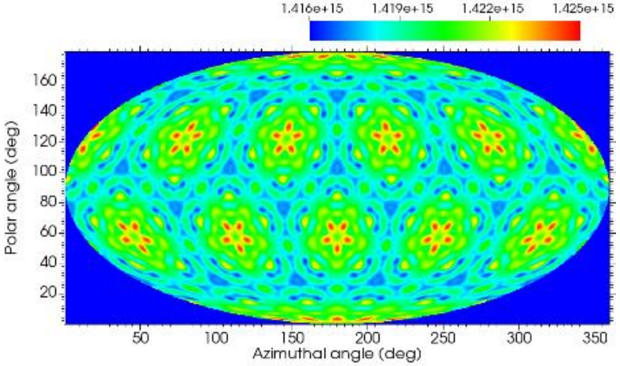
Distribution of absorbed light in the beginning of the laser pulse

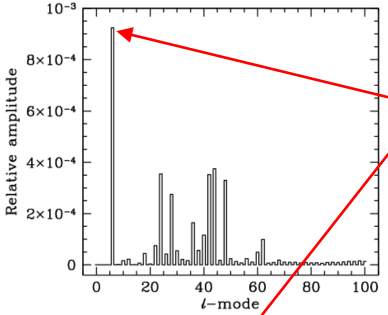
Perturbation spectrum

$\alpha = 2$ (Coulomb)

$\sigma_{rms} = 1.2 \times 10^{-3}$

$P - V = 6.2 \times 10^{-3}$



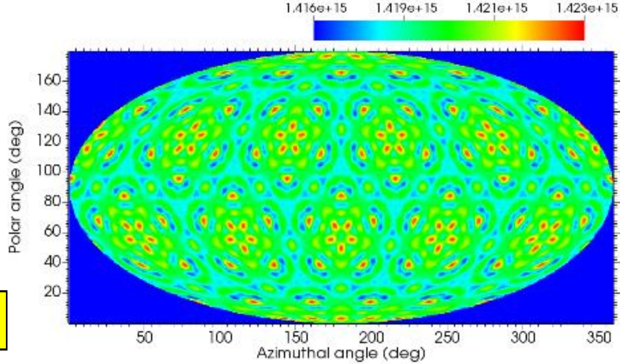


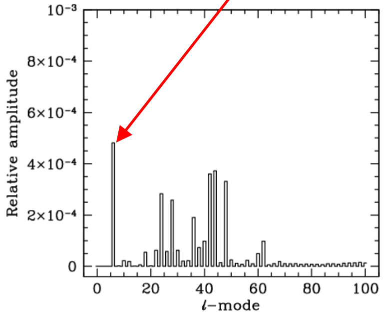
Factor of 2 reduction of mode 6

$\alpha = 0$

$\sigma_{rms} = 9.2 \times 10^{-4}$

$P - V = 5.0 \times 10^{-3}$





Methods other than CP are explored

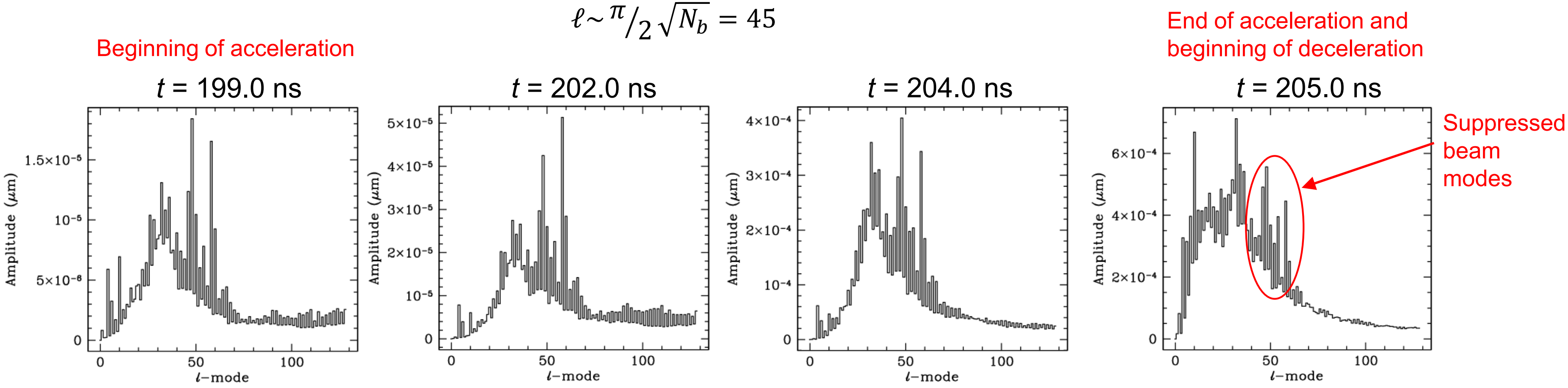
Three-dimensional simulations suggest that beam modes are mostly imprinted and grow during the shell acceleration/implosion stages

- Initially imprinted short-wavelength beam modes decay during the initial target compression and shell formation stages[a]
- The ablative RT instability results in predominant growth of longer-wavelength modes and suppression of short-wavelength modes during the shell acceleration stage

Evolution of areal density perturbation spectrum during shell acceleration

$$N_b = 812$$

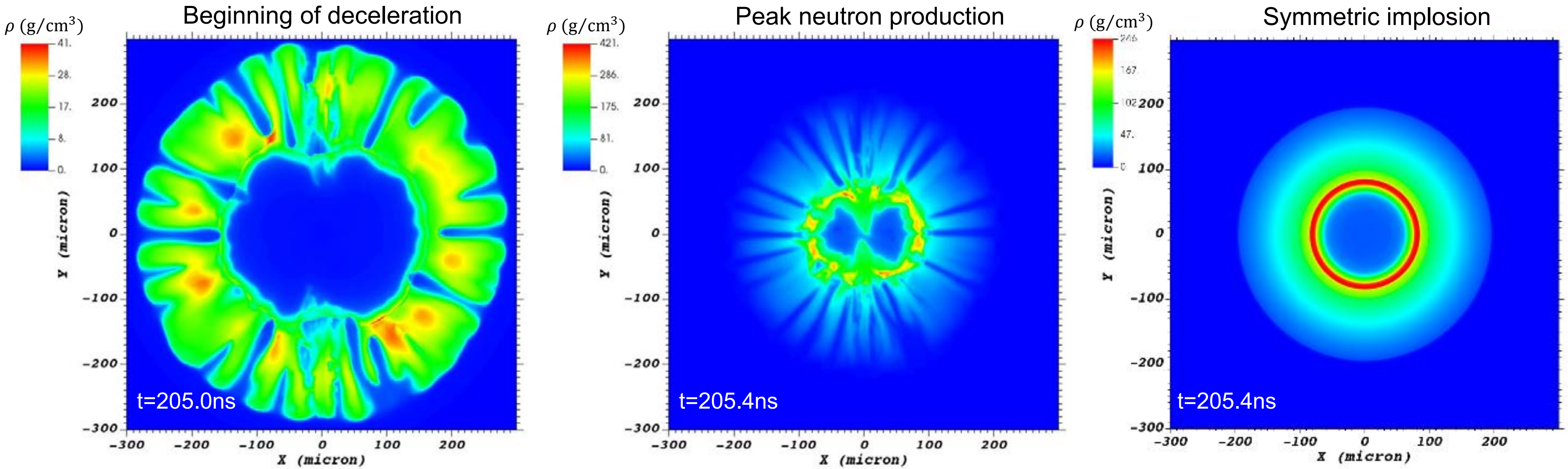
$$\ell \sim {}^{\pi}/_{2}\sqrt{N_b} = 45$$



[a] Igumenshchev *et al*., Phys. Rev. Lett. **123**, 065001 (2019).

Suppression of beam modes in the case of $N_b = 812$ results in a relatively stable implosion

Density maps in the meridional cross-section from 3-D *ASTER* simulations

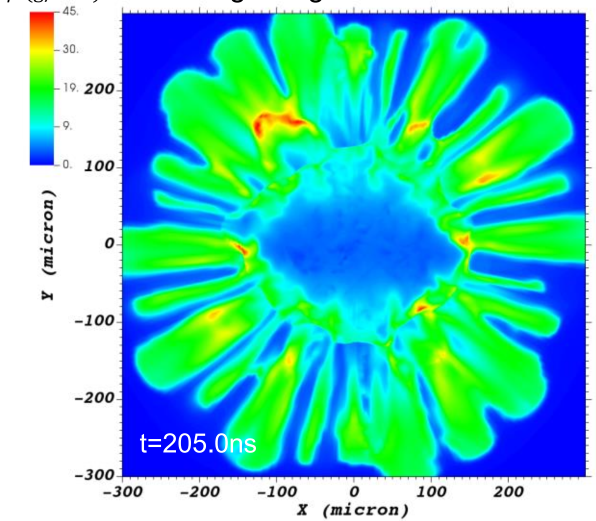


- RT bubbles do not puncture the shell
- 3-D neutron yield/1-D neutron yield = 0.32 (without burn)
- Effects of icosahedral mode 6 are small
- Artificial mode-2 affects the implosion performance (numerical challenge)

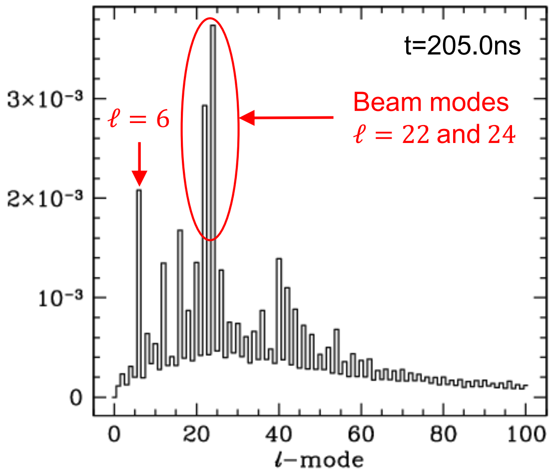
Beam modes in the case of $N_b = 162$ are not suppressed enough and result in a "broken-shell" implosion

Density maps in the meridional cross-section from 3-D *ASTER* simulations

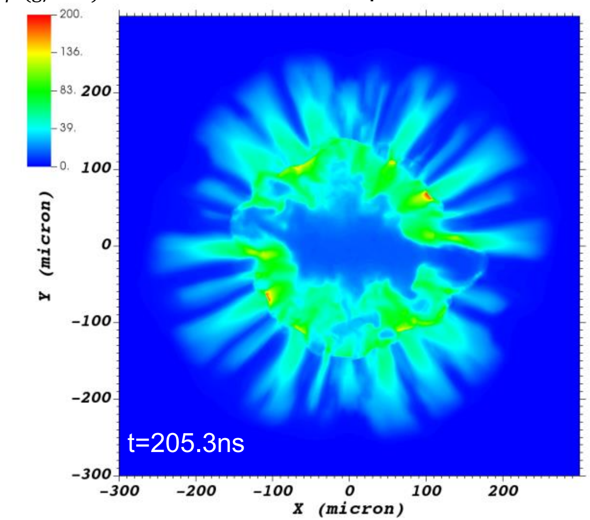
Beginning of deceleration



Areal-density perturbation spectrum in the beginning of deceleration



Peak neutron production



- RT bubbles fully penetrate the shell in the middle of the acceleration stage
- Significant ablator mass injection into hot spot
- 3-D neutron yield/1-D neutron yield = 0.08 (without burn)

- Icosahedral mode 6 is sizable but not dominant

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- Effects of perturbations from beam overlapping in directly driven DS designs were studied using 3-D *ASTER*† hydrodynamic simulations

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‡ IFAR: in-flight aspect ratio.