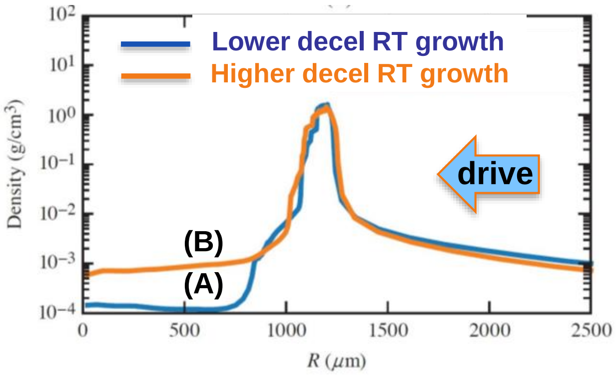
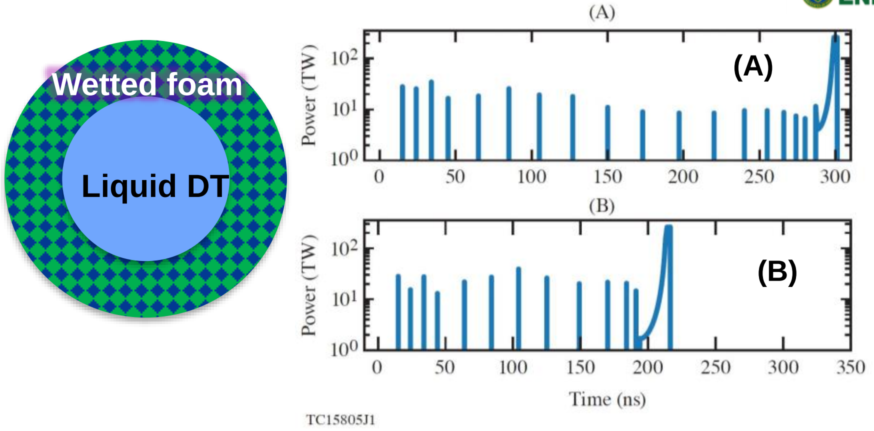
Mitigating Deceleration Rayleigh–Taylor Growth in Inertial Confinement Fusion Designs

Inflight density



Dynamic shell design



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Pittsburgh, PA
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Summary

Deceleration Rayleigh–Taylor instability can be mitigated in ICF designs by reducing density in the central (vapor) region of the target

- In the hot-spot ignition approach, smaller hot spots are advantageous in minimizing the required energy coupled to the target, but they lead to higher shell convergence and larger Rayleigh–Taylor (RT) amplification during deceleration
- Deceleration RT growth can be significantly reduced by lowering the density of the central (void) region in the target*
- Density in the central region and target convergence ratio can be varied over a large range in the dynamic-shell design** by changing the strength of the outgoing blast wave and extending the density relaxation phase

* Y. Lawrence, next talk
** V. Goncharov *et al.*, Phys. Rev. Lett. 125, 065001 (2020).

Collaborators

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Y. Lawrence

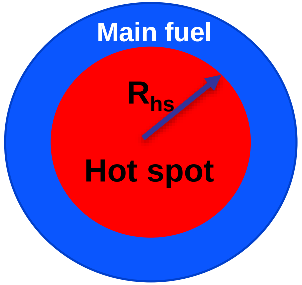
University of Chicago

Smaller hot spots are advantageous for minimizing the hot-spot energy required for ignition

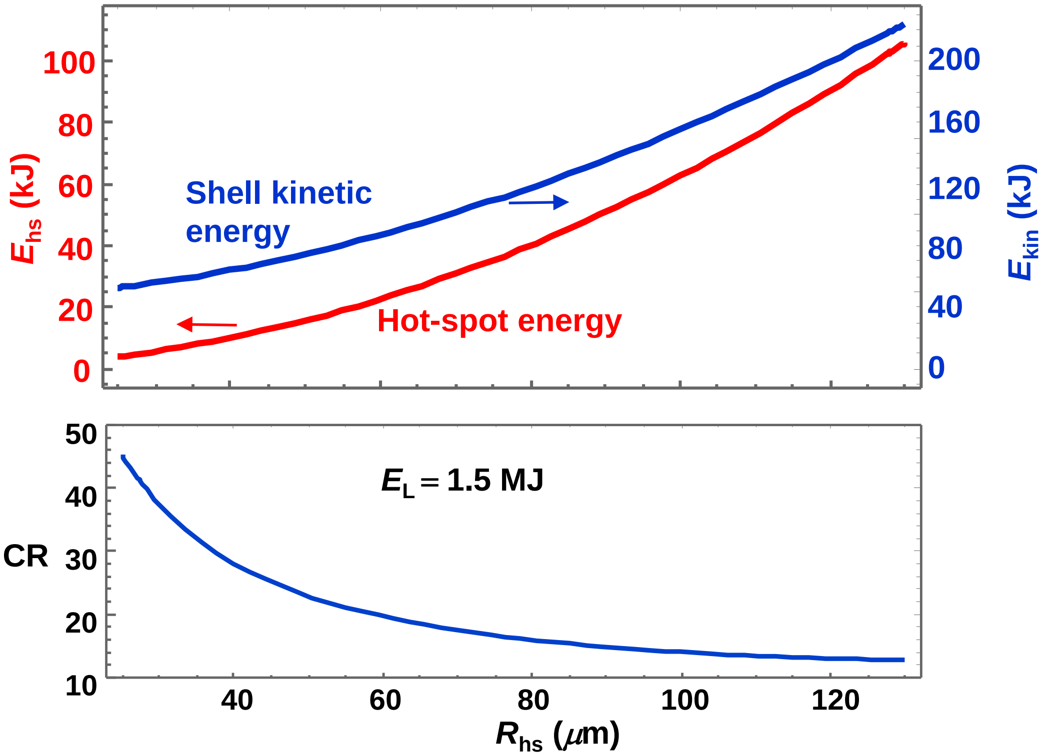
- Ignition criterion

$$P_{hs} R_{hs} > 1\ \text{Gbar} \times \text{cm};\ \ T_i > 4.5\ \text{keV}$$

$$E_{hs} > 16\ \text{kJ} \left(\frac{R_{hs}}{50\ \mu m}\right)^2$$



$$\text{CR} = \frac{R_{\text{inner}}(t=0)}{R_{hs}}$$

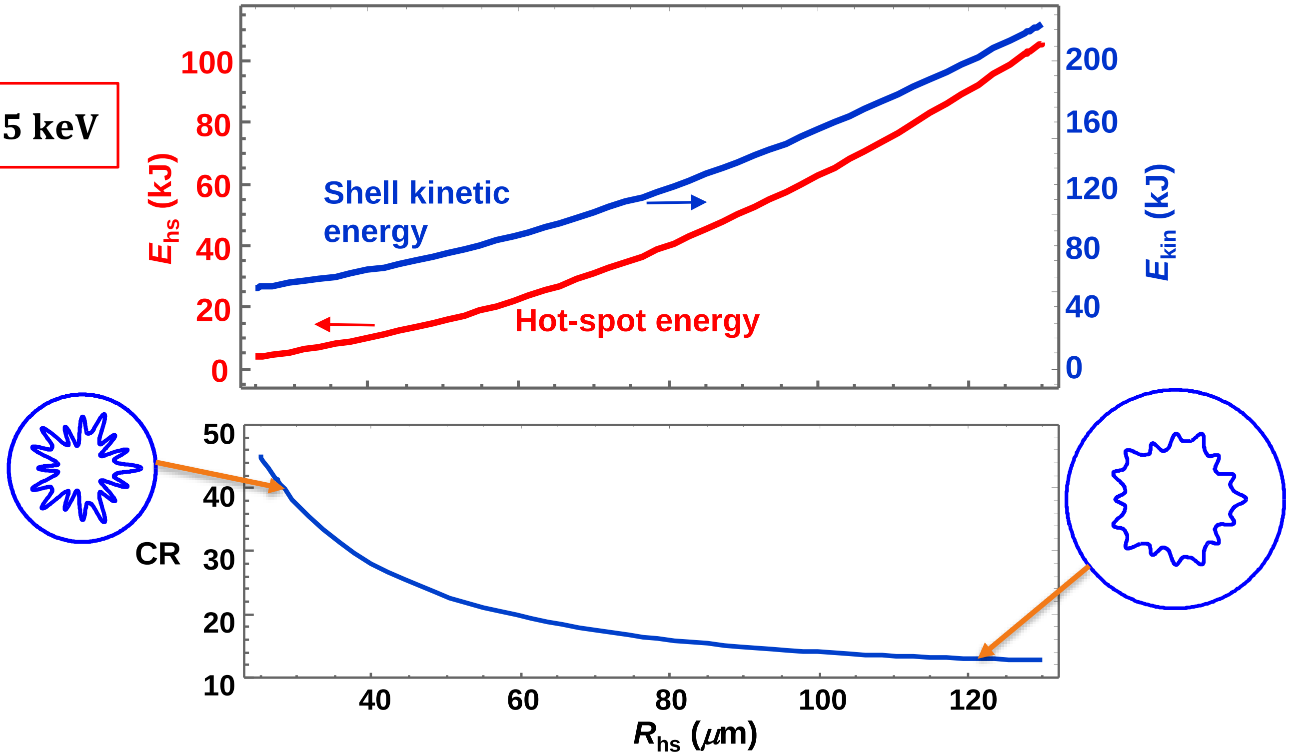


Smaller hot spots, however, lead to enhanced hot-spot and main fuel distortions

- **Ignition criterion**

$$P_{hs}R_{hs} > 1\ \mathrm{Gbar} \times \mathrm{cm};\ \ T_i > 4.5\ \mathrm{keV}$$

$$E_{hs} > 16\ \mathrm{kJ} \left(\frac{R_{hs}}{50\ \mu\mathrm{m}}\right)^2$$



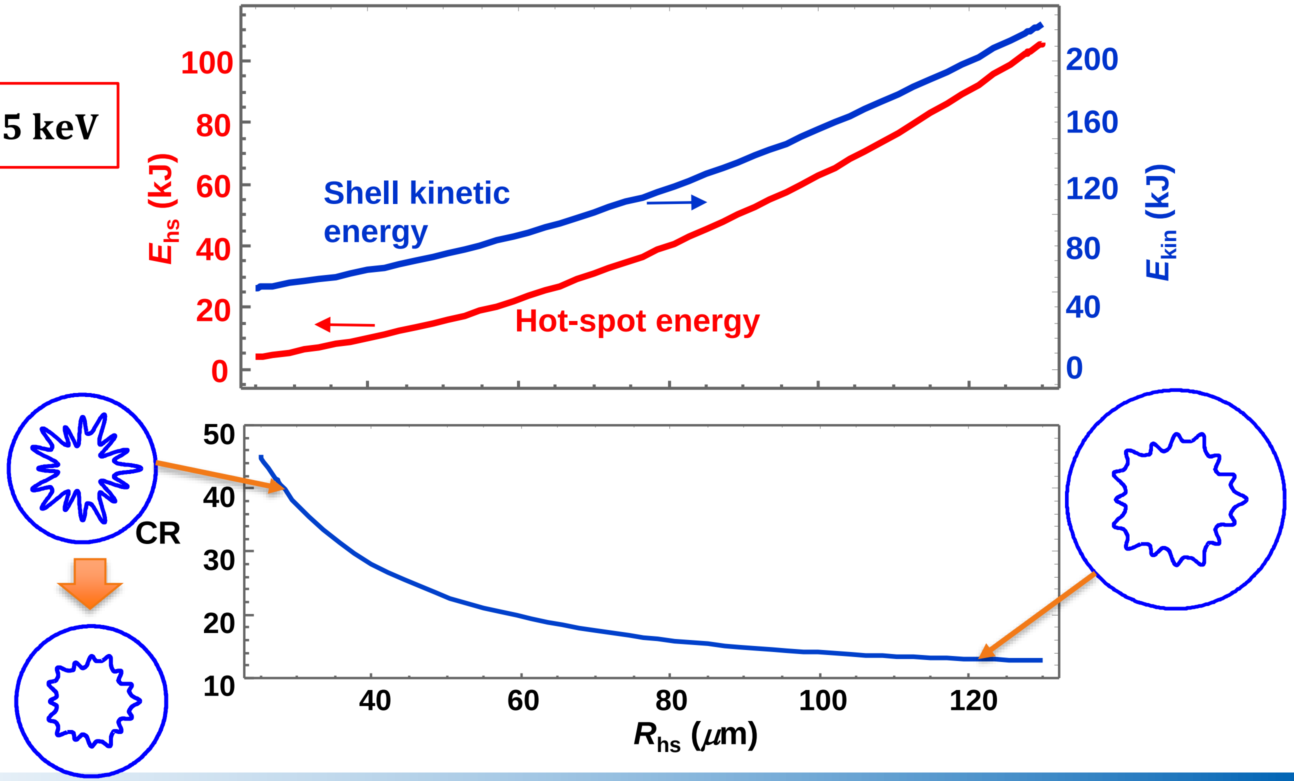
Smaller hot spots lead to enhanced deceleration RT growth

- Ignition criterion

$$\boxed{P_{\mathrm{hs}}R_{\mathrm{hs}} > 1\ \mathrm{Gbar}\ \times\ \mathrm{cm};\ \ T_{\mathrm{i}} > 4.5\ \mathrm{keV}}$$

$$\boxed{E_{\mathrm{hs}} > 16\ \mathrm{kJ}\left(\frac{R_{\mathrm{hs}}}{50\ \mu\mathrm{m}}\right)^2}$$

Can deceleration RT be mitigated for high CR designs?



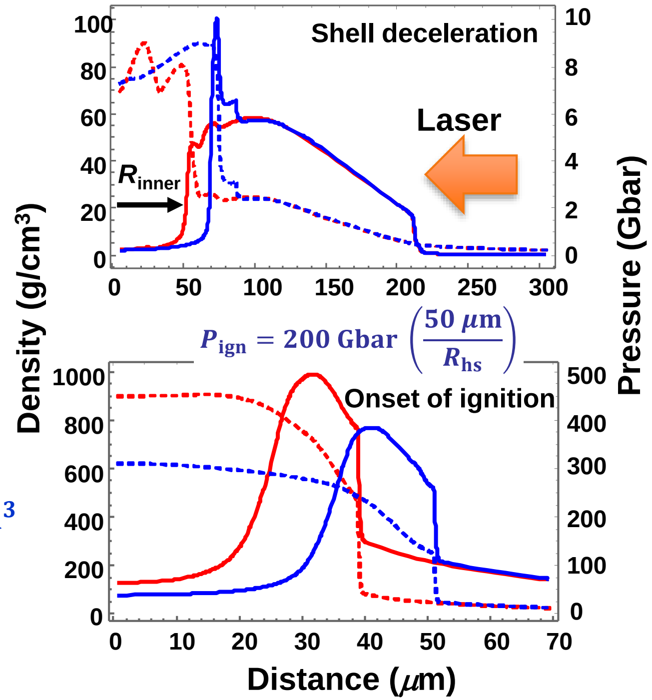
Reducing the target central density leads to shorter shell deceleration distance and larger ablation stabilization*

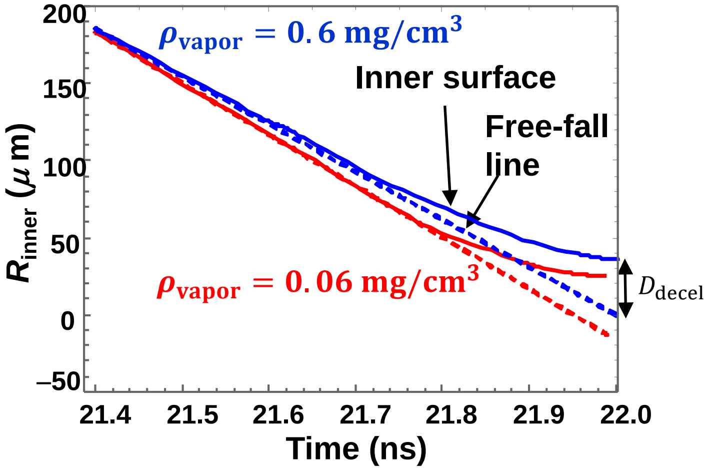
Nominal layered DT target

$\rho_{\mathrm{vapor}}(19.7\ \mathrm{K}) = 0.6\ \mathrm{mg/cm^3}$

Reduced vapor density

$\rho_{\mathrm{vapor}} = 0.06\ \mathrm{mg/cm^3}$





$GF_{\mathrm{RT}} \sim \exp\left(\sqrt{2\ell D_{\mathrm{decel}}}\right)$

Shell deceleration delay leads to shorted deceleration distance in lower vapor density targets.

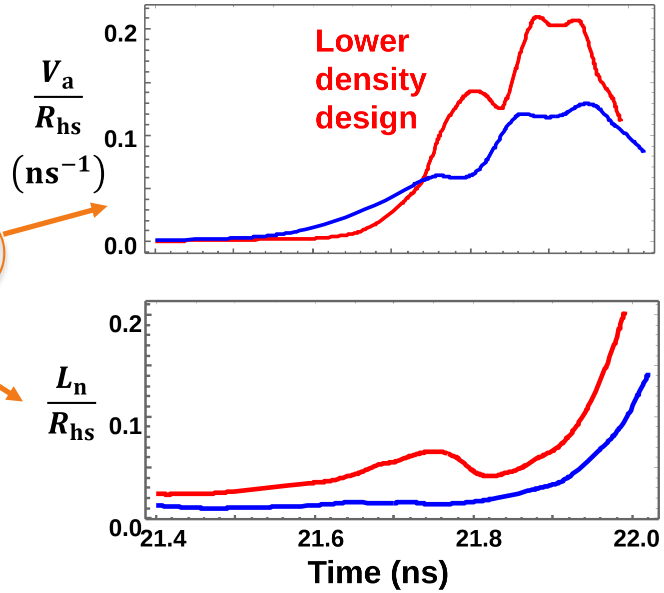
*Y. Lawrence, next talk

Reducing the target central density leads to shorter shell deceleration distance and larger ablation stabilization*

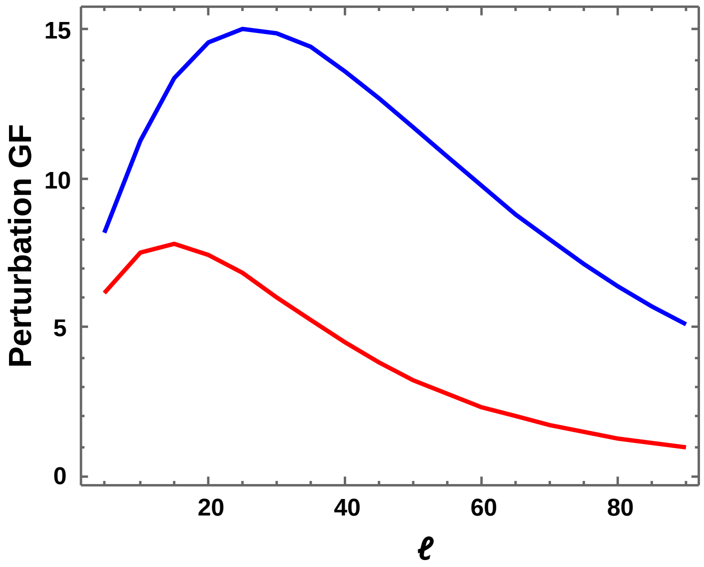
- Smaller R_{hs} leads to greater V_{abl} and ablation stabilization*

$$\gamma = \sqrt{\frac{kg}{1 + kL_n}} - kV_a$$

$$k = \frac{\ell}{R_{hs}}$$



Sharp-boundary deceleration RT model**

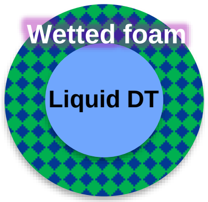


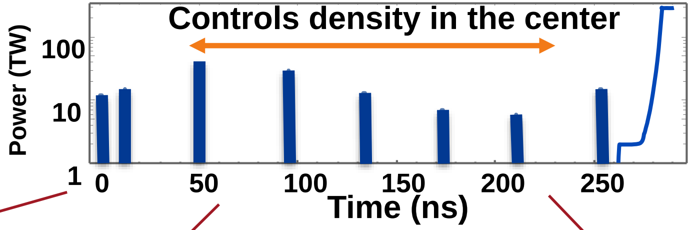
Density in the central region can be reduced by
- Lowering target temperature to 18K (only × 0.4 reduction – not enough and ice uniformity problem)
- Using dynamic shell design (x 0.1 and lower is achievable)

*Y. Lawrence, next talk
**V.N. Goncharov et al., Phys. Plasmas 7, 5118 (2000)

The dynamic-shell design evolves through three stages*

* V. Goncharov *et al.*, Phys. Rev. Lett. 125, 065001 (2020).

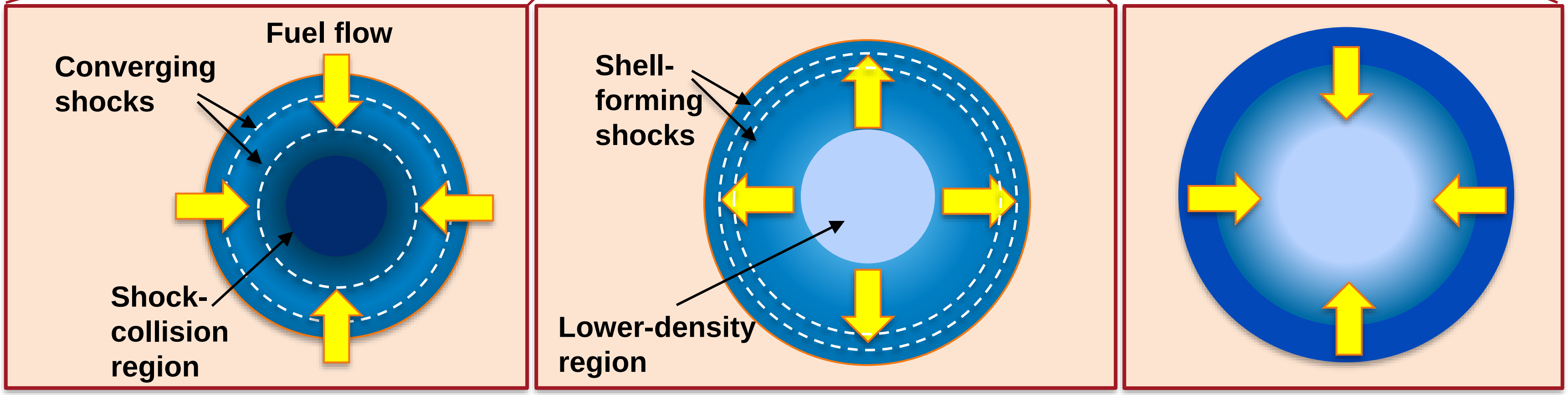




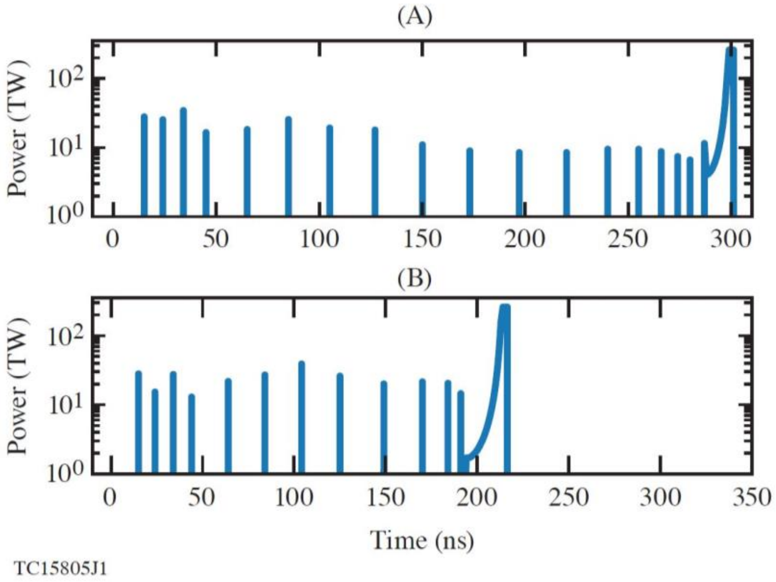
Shock heating

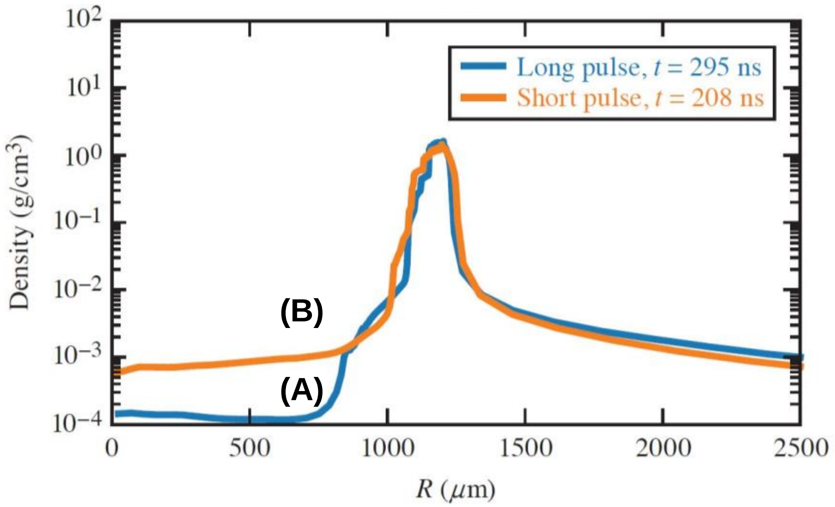
Blast-wave expansion, density relaxation, and shell formation

Shell acceleration and hot-spot formation



Density in the central region can be controlled by changing strength of the outgoing blast wave and duration of the density relaxation phase





Hydrodynamic simulations confirm significant reduction in deceleration RT growth for design A (see next talk by Y. Lawrence)

Stability studies of the dynamic shell designs are currently underway using hydrodynamic simulations

The next three talks will discuss:

- **Deceleration RT growth in low central density and high-density dynamic-shell designs – Yousef Lawrence**
- **Beam illumination symmetry optimization – Will Trickey**
- **3-D *ASTER* simulations of dynamic-shell designs – Igor Igumenshchev**

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