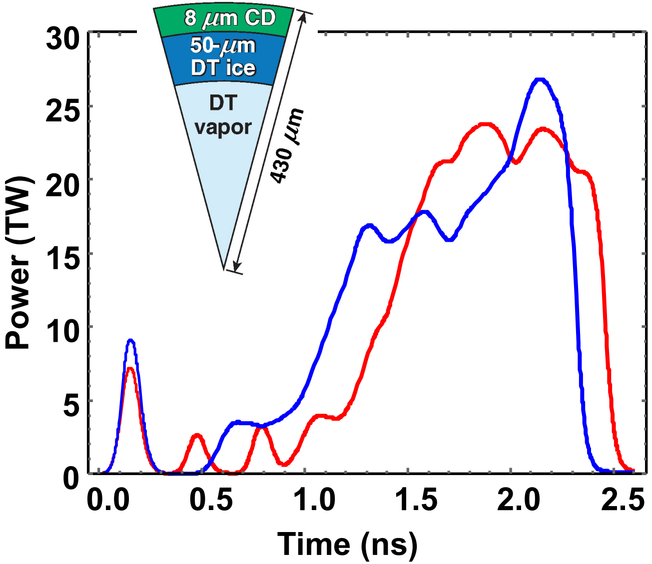
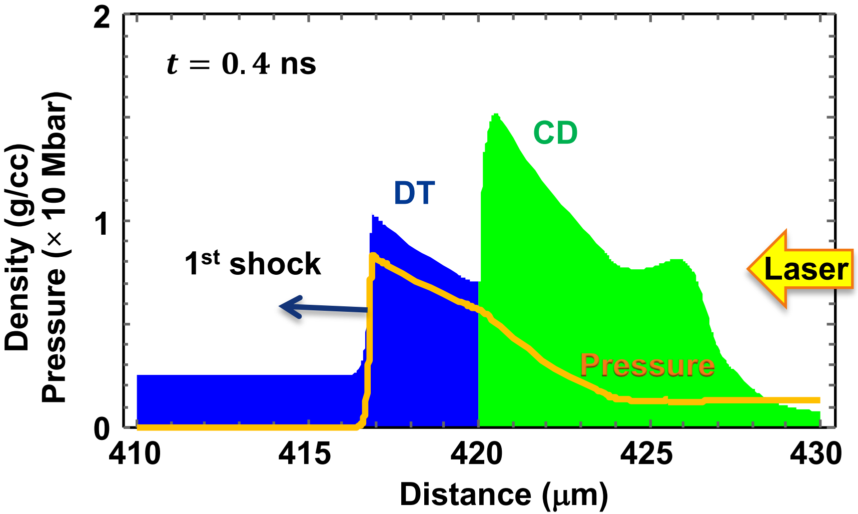
A Survey of Different Perturbation Amplification Mechanisms in the Early Stages of Inertial Confinement Fusion Implosions





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Acoustic waves evolving into shocks play a critical role in determining instability seeding at the early stages of ICF implosions

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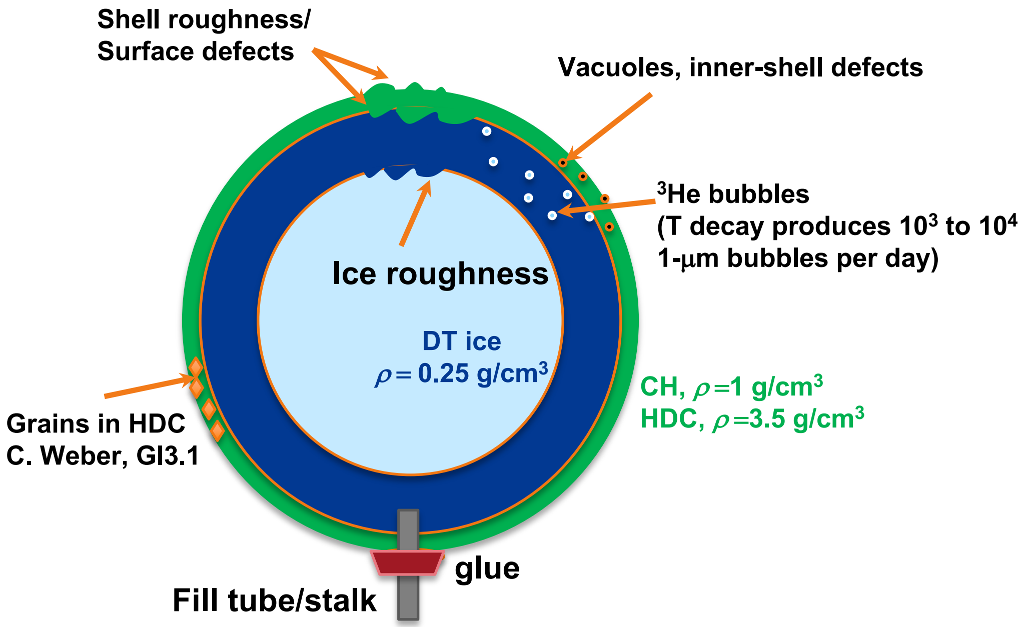
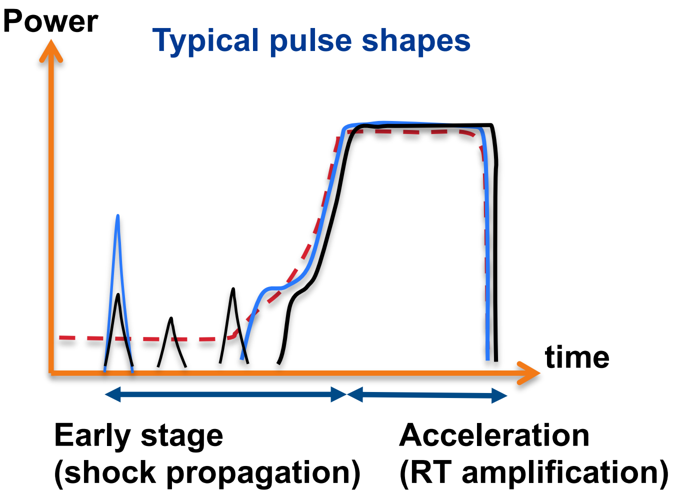
- Perturbations of fluid velocity in a simple acoustic wave are exponentially amplified if the wave travels in the direction of convergent characteristics (i.e., wave front steepens)
- Time variation in the drive pressure or a wave reflection from various material interfaces in the ablator cause acoustic wave steepening at the early stages of an ICF implosion
- Accurate multi−dimensional modeling of the evolution of such waves is challenging but critical for defining seeds for the Rayleigh−Taylor instability developed during shell acceleration

There are several sources of Rayleigh–Taylor (RT) seeding in ICF targets





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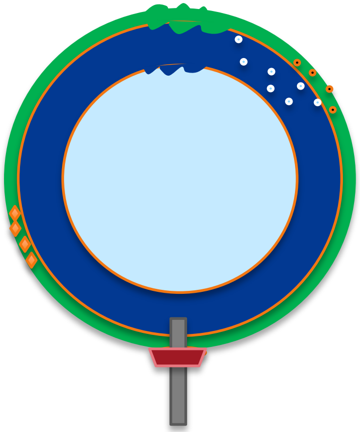
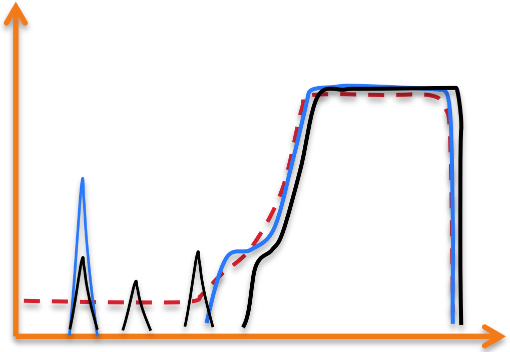


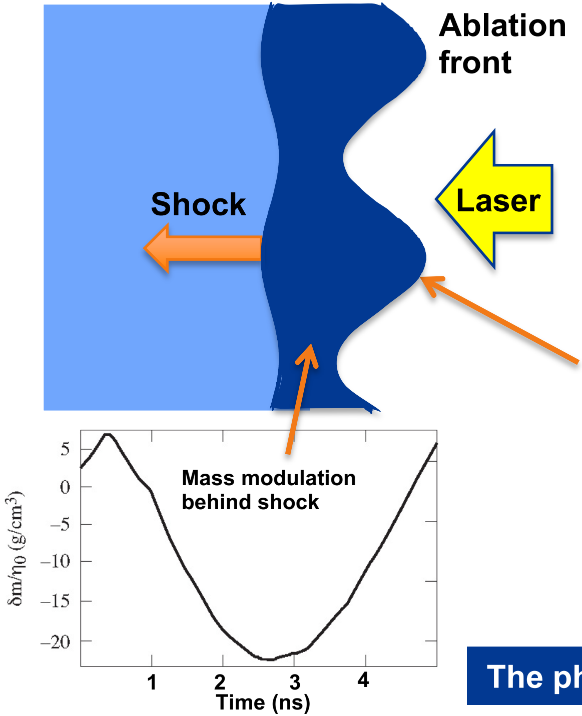


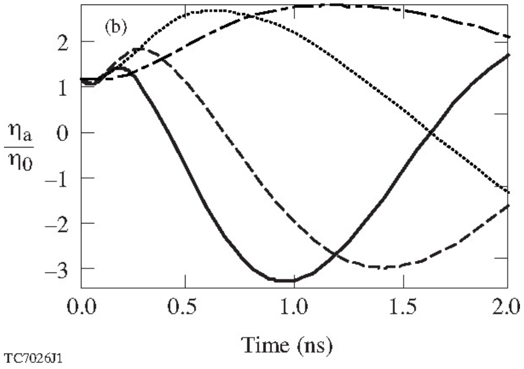
- **Complex hydrodynamic evolution of shell nonuniformity seeds can only be fully captured multi-dimensional simulations. To ensure code prediction validity:**
  - **Theoretical analysis of different evolution mechanisms must be performed**
  - **Focused experiments must be carried out at high resolution (ideally less than 1 μm, zone plates will help*)**

*F. Marshall UO7.1

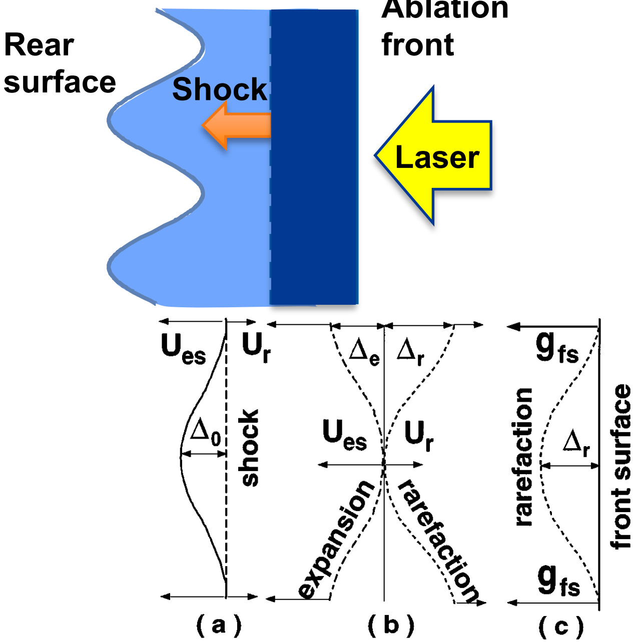
Commonly known mechanisms for the seed evolution describe mainly the surface features and laser imprint

Outer-surface roughness and imprint (ablative Richtmyer−Meshkov instability)



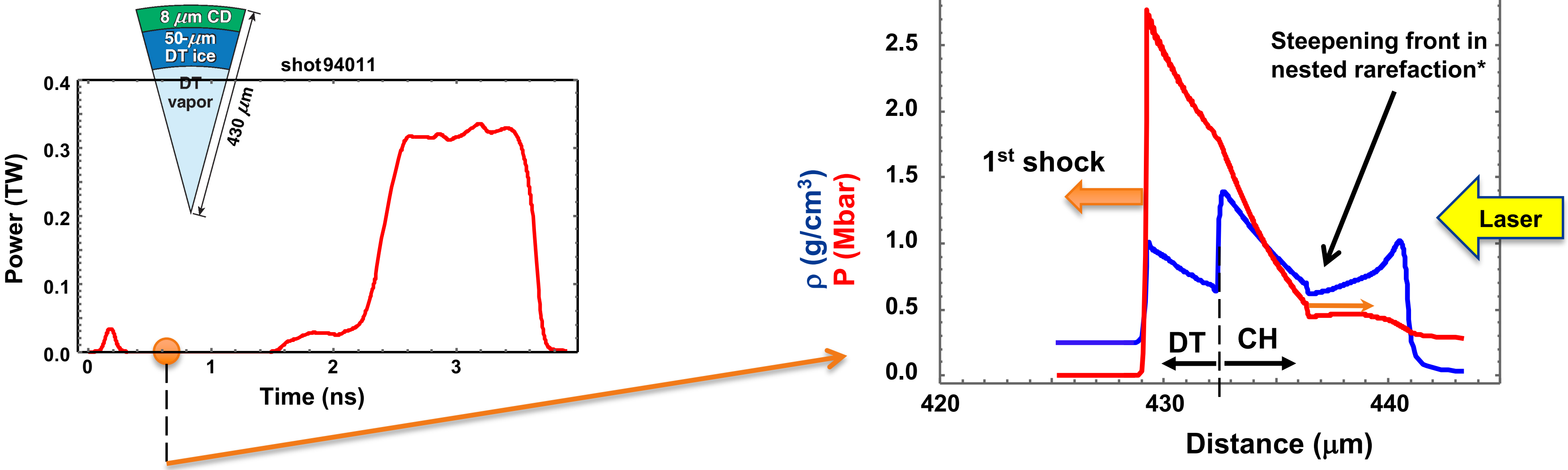


Rear-surface roughness (feedout)



The physics of these effects are well understood and modeled in hydrocodes.

Internal ice and ablator nonuniformities evolve with the acoustic waves launched by the drive pressure variations and wave interactions with material interfaces



*S. Miller, next talk; V. Goncharov, APS 18

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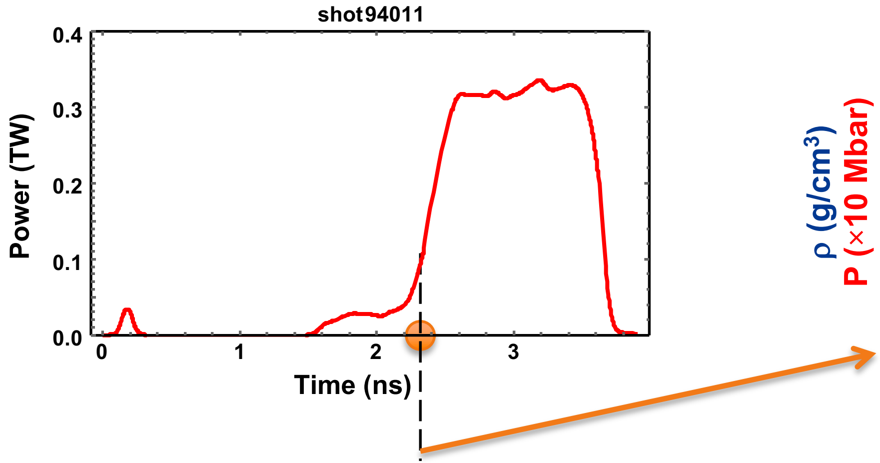

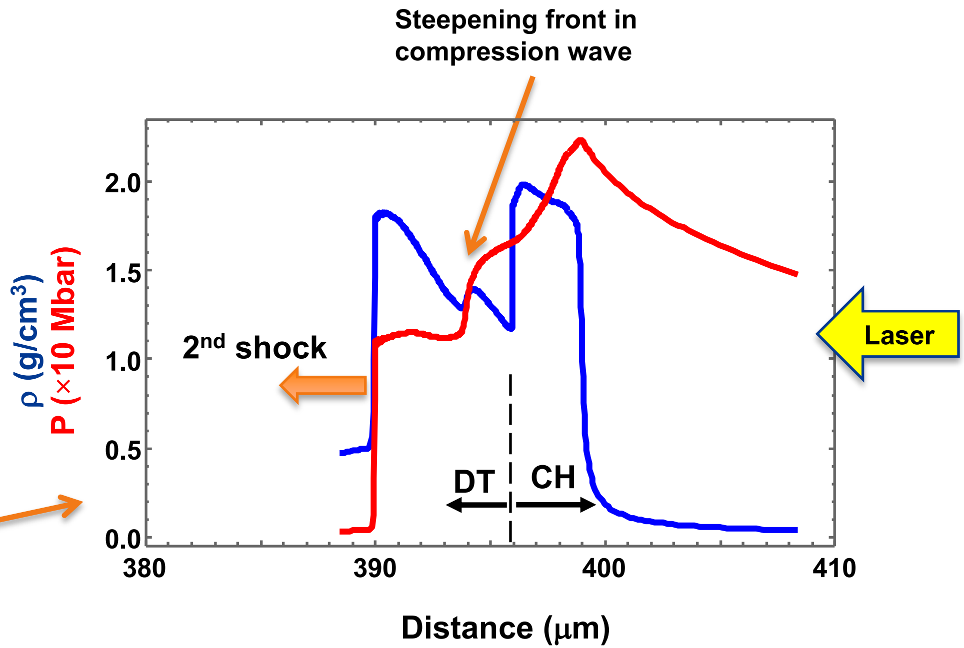

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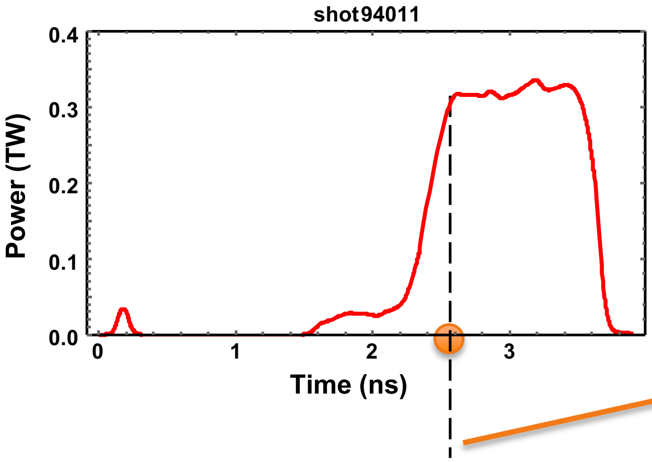
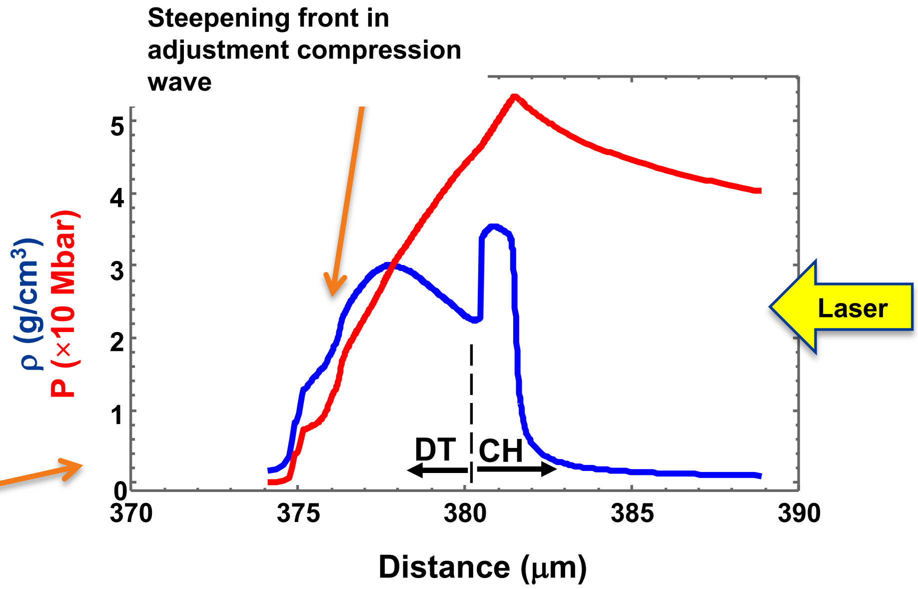
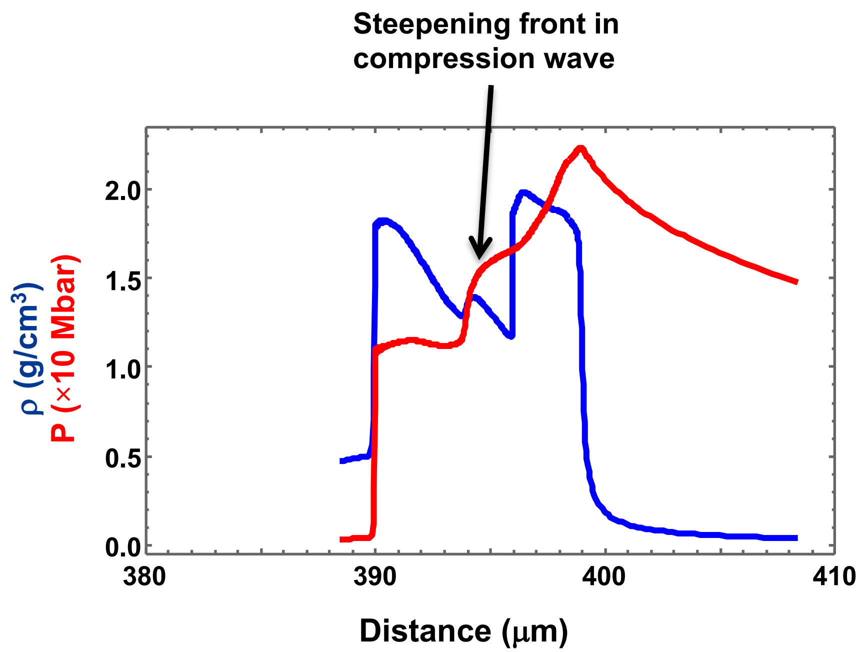
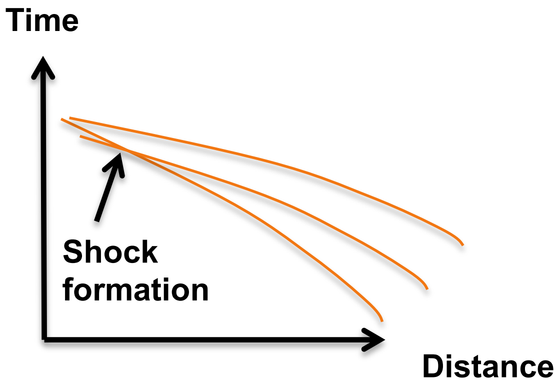


Beginning of shell acceleration



Prior to forming a shock, the steepening front of an acoustic wave travels along converging characteristics





Velocity perturbation amplitude is amplified along converging characteristics

- Simple acoustic wave $\tilde{p} = \rho c_s \tilde{v}$
- Adiabatic flow $p \sim \rho^{\gamma}, \tilde{p} = c_s^2 \tilde{\rho}$

Perturbed momentum equation:

$$\partial_t \tilde{v} + \tilde{v}\partial_x U + U\partial_x \tilde{v} = -\frac{\partial_x \tilde{p}}{\rho} + \frac{\tilde{\rho}}{\rho^2}\partial_x P$$

Conservation equation for $\tilde{v}$:

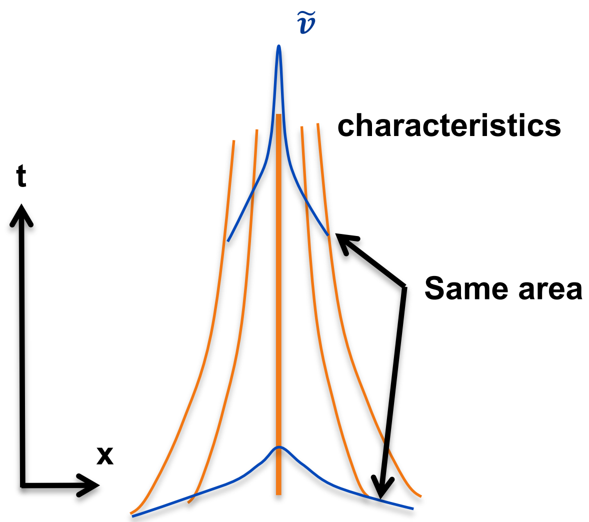
$$\partial_t \tilde{v} + \partial_x[\tilde{v}(U + c_s)] = 0$$

If characteristics got compressed, $\max(\tilde{v})$ increases

Solution:

$$\tilde{v} = \tilde{v}_0\left(x e^{\int^t \Gamma\, dt}\right) e^{\int^t \Gamma\, dt}, \qquad \Gamma = -\partial_x(U + c_s)$$

Initial shape



Perturbation amplification at the steepening fronts were studied by solving linearized hydrodynamic equations

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \mathbf{v}) = 0$$

$$\frac{\partial p}{\partial t} + \mathbf{v}\nabla \mathrm{p} + \gamma p \nabla \mathbf{v} = 0$$

$$\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\nabla \mathbf{v} + \frac{\nabla \mathrm{p}}{\rho} = 0$$

$$\rho = \rho_{1-D} + \tilde{\rho}$$

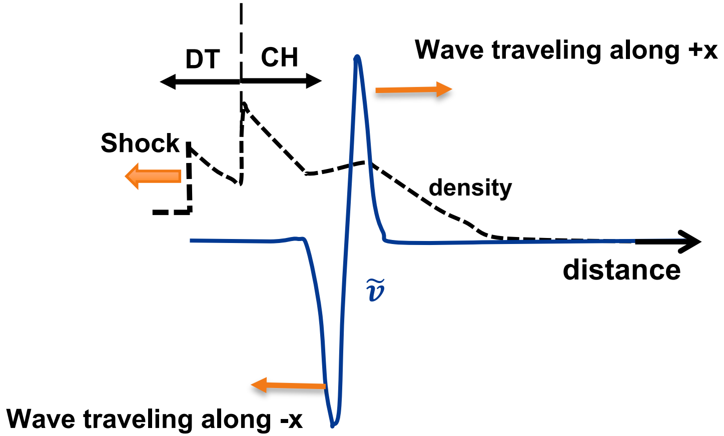
$$p = p_{1-D} + \tilde{p}$$

$$\mathrm{v}_x = \mathrm{v}_{x,1-D} + \tilde{\mathrm{v}}_x$$

$$\mathrm{v}_y = \tilde{\mathrm{v}}_y$$

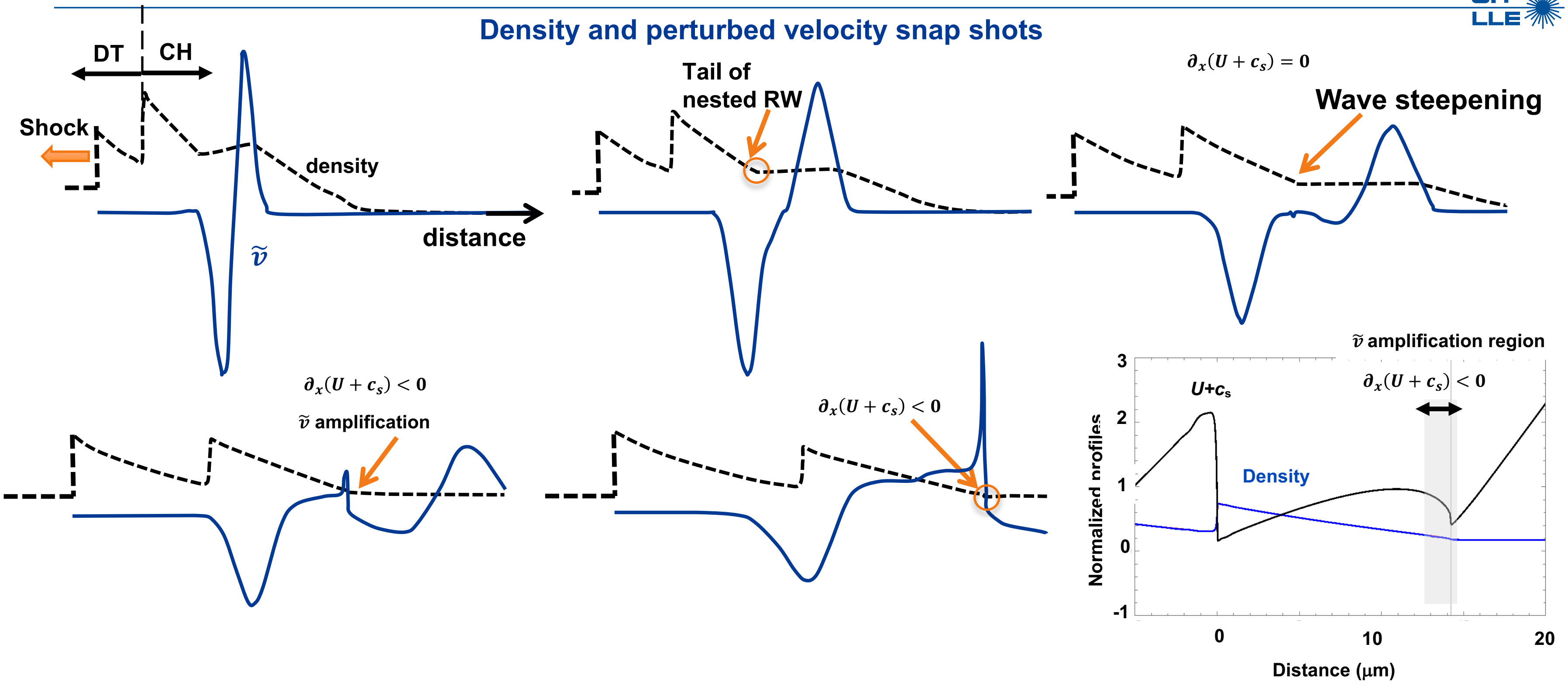
Perturbations are initialized by the pressure perturbation

$$\tilde{p} = \tilde{p}_0(x)\, cos(ky)$$



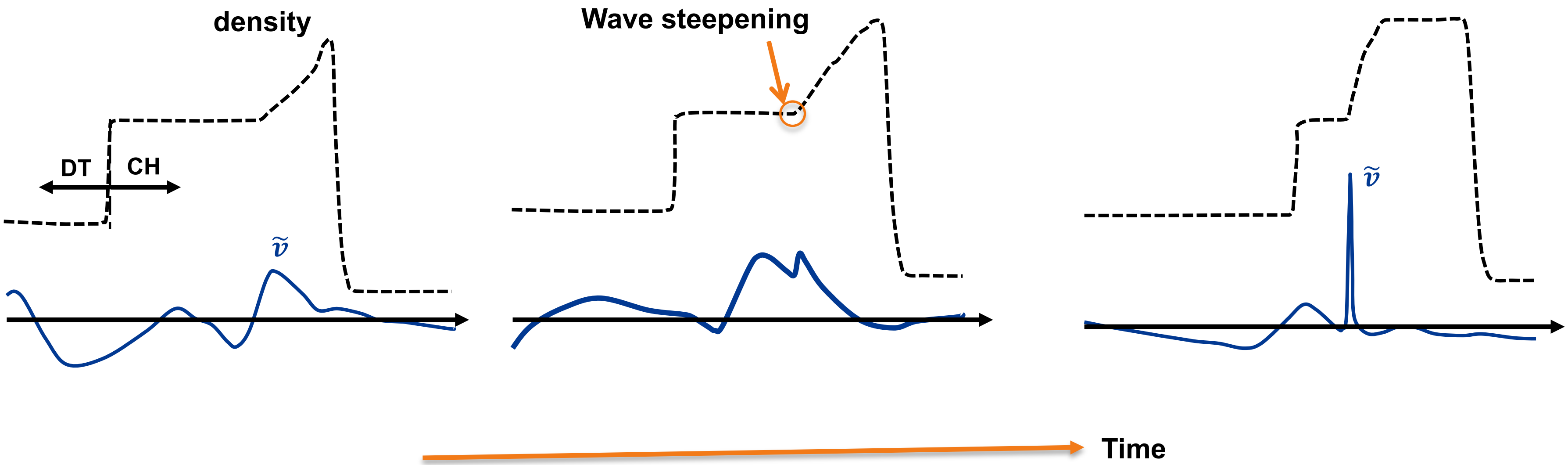
As the first decaying shock passes through the DT−CH interface, the velocity perturbation gets amplified near the tail of reflected rarefaction

Density and perturbed velocity snap shots



Compression wave steepening leads to perturbation amplification

Density and perturbed velocity snap shots



Do commonly used ICF codes accurately capture this perturbation amplification* ?

*see next talk by S. Miller

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