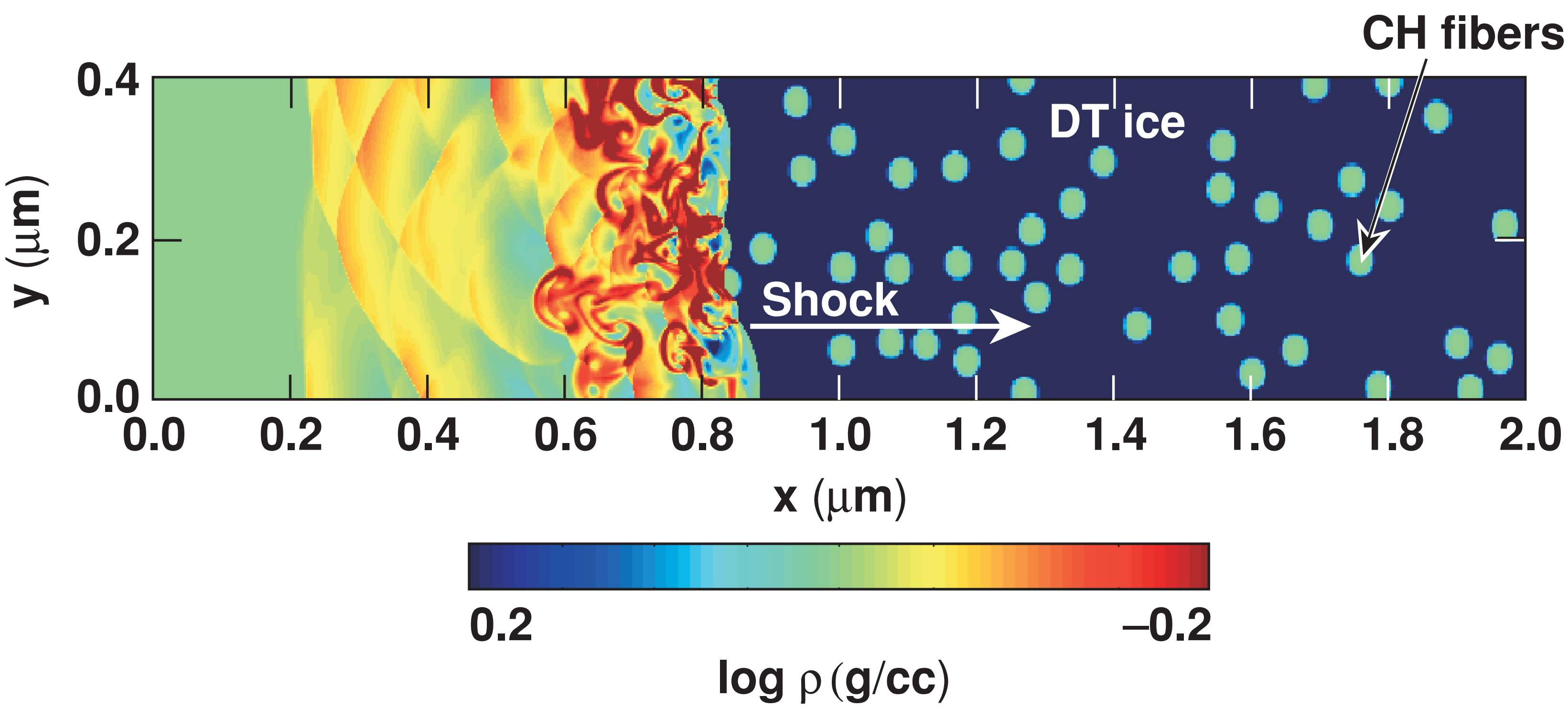
The Effects of Foam Microstructure on Shock Propagation in High-Gain Wetted-Foam NIF Target Design



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Summary

The calculated shock-speed increase due to foam microstructure has little effect on target performance

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- Wetted-foam target designs couple more energy to the target, allowing higher gains.
- The foam microstructure increases the shock speed compared to that of a homogeneous mixture.
- The foam microstructure makes no significant contribution to feedthrough.

Wetted-foam targets have higher laser absorption and more fuel, resulting in higher target gain

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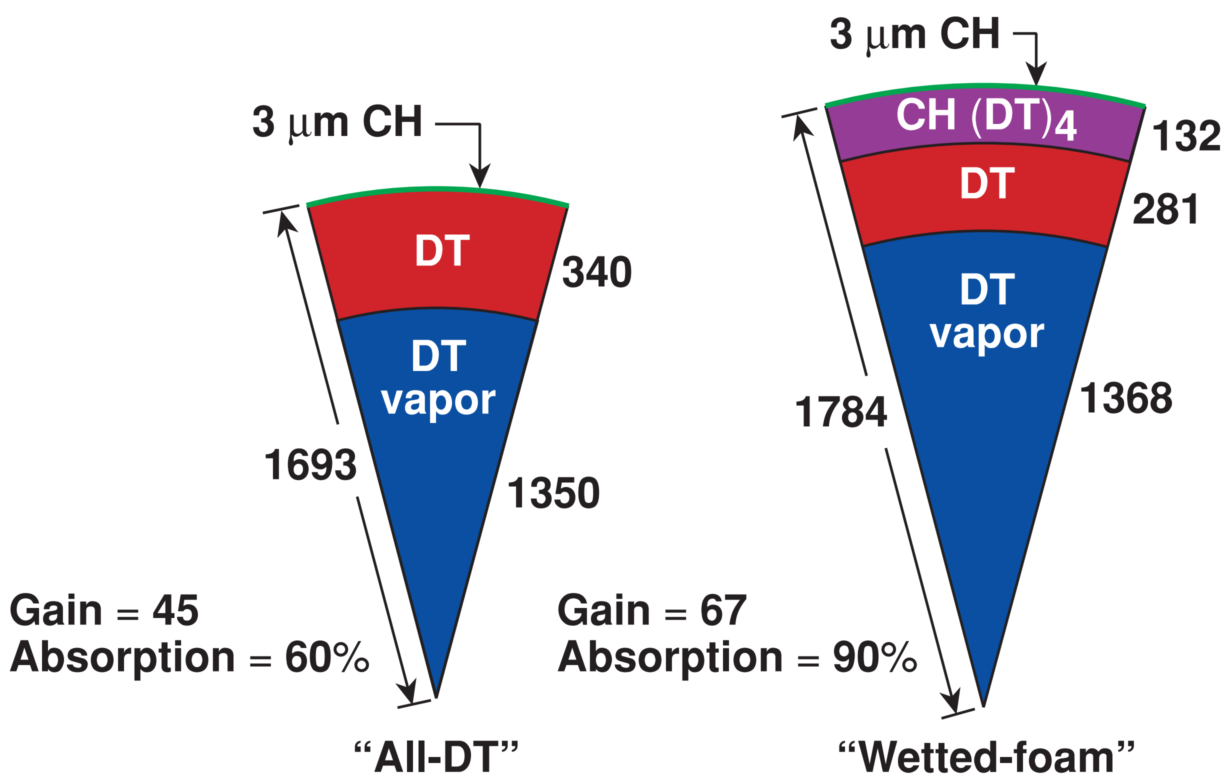
- Foams have been used previously to selectively radiatively preheat the ablator.[1]



[1] D.G. Colombant *et al.*, Phys. Plasmas 7, 2046 (2000).

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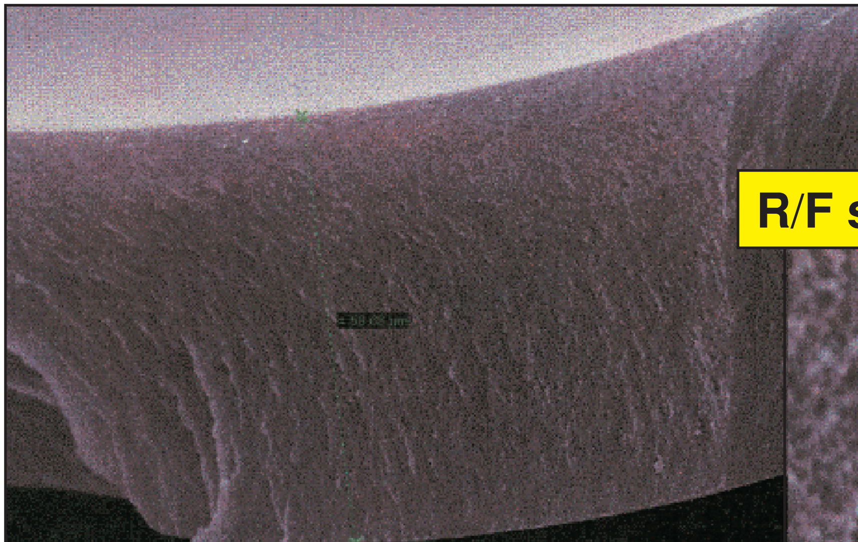
Resorcinol formaldehyde (R/F) foam has a microstructure with scale lengths ~ 0.1 μm

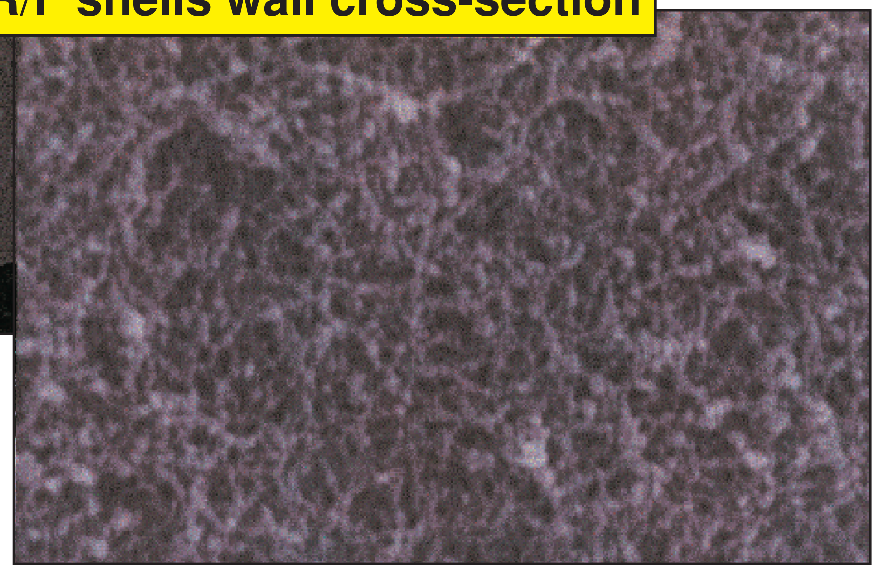
- The pore size varies little with density.



10 μm

- Typical foam parameters are 30 mg/cc dry [$CH(DT)_{20}$], 140 mg/cc dry [$CH(DT)_4$].

R/F shells wall cross-section



1 μm

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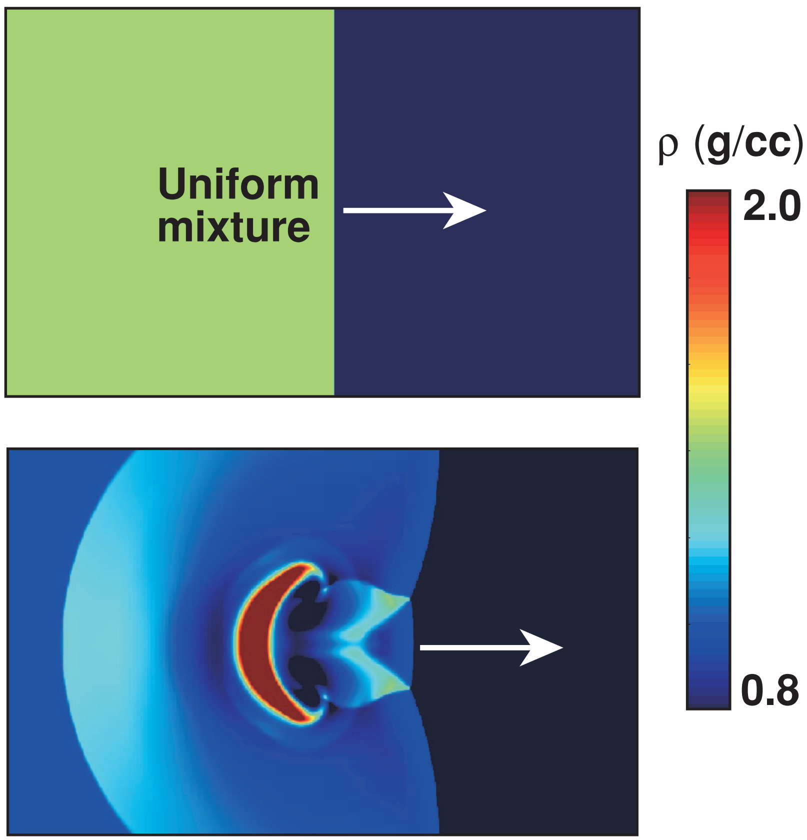
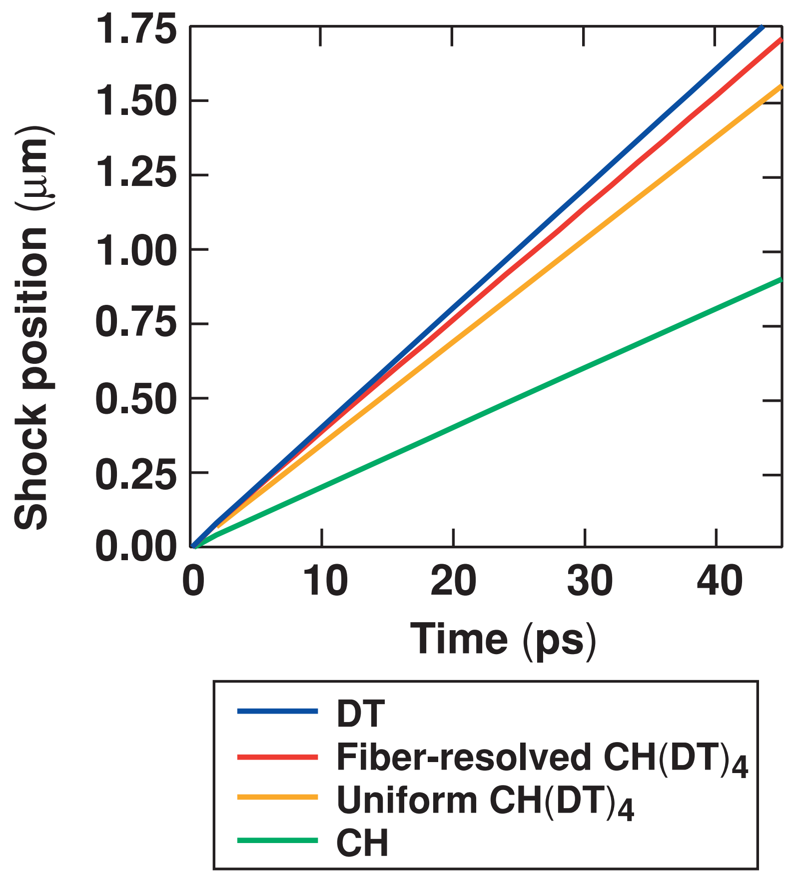
Images courtesy of David Harding (LLE) and Abas Nikroo (GA).

The higher shock speed in DT more than compensates for the lower shock speed in CH

Despite the slow shock speed in the fiber, the average shock speed is greater than in a homogeneous mixture:





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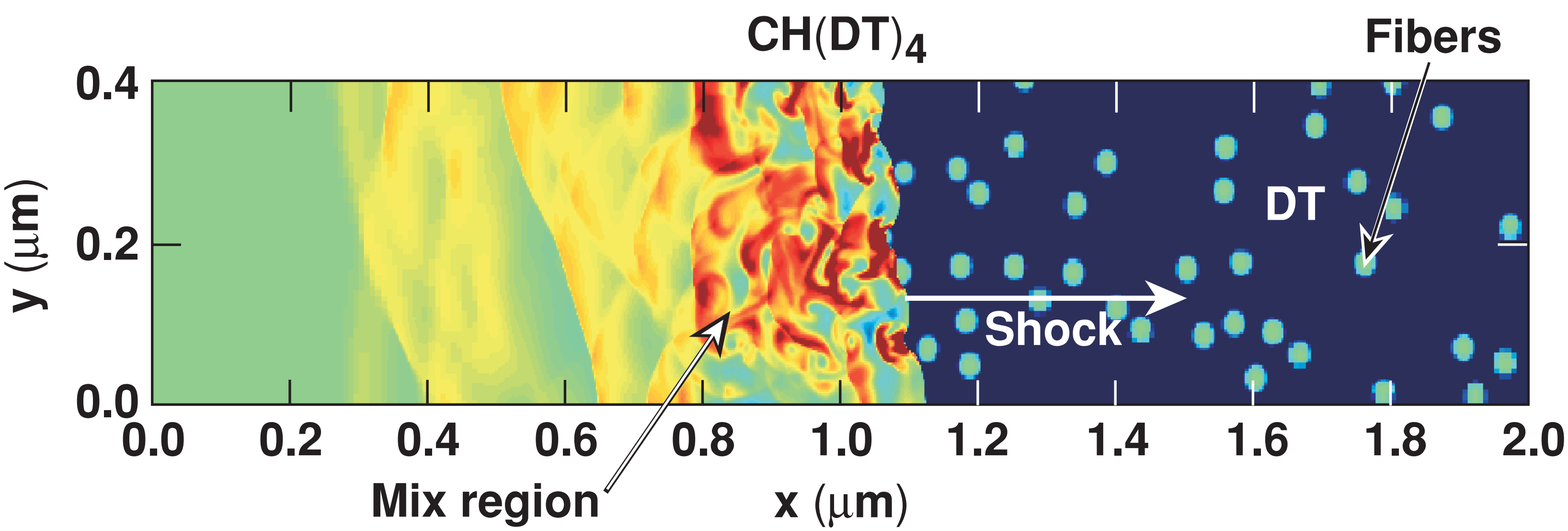
Foam microstructure affects wetted-foam shock speeds

- 1-D and 2-D simulations of wetted-foam designs generally assume a homogeneous mixture for the wetted-foam layer.
- This assumption changes the simulated shock speeds.[1]
- Adaptive-mesh-refinement (AMR) makes larger fiber-resolved simulations feasible.
- Our code uses an ideal-gas EOS and no radiation or thermal transport.



[1] A. Kotelnikov and D. Montgomery, Phys. Fluids 10, 2037 (1998); G. Hazak *et al.*, Phys. Plasmas 5, 4357 (1998).

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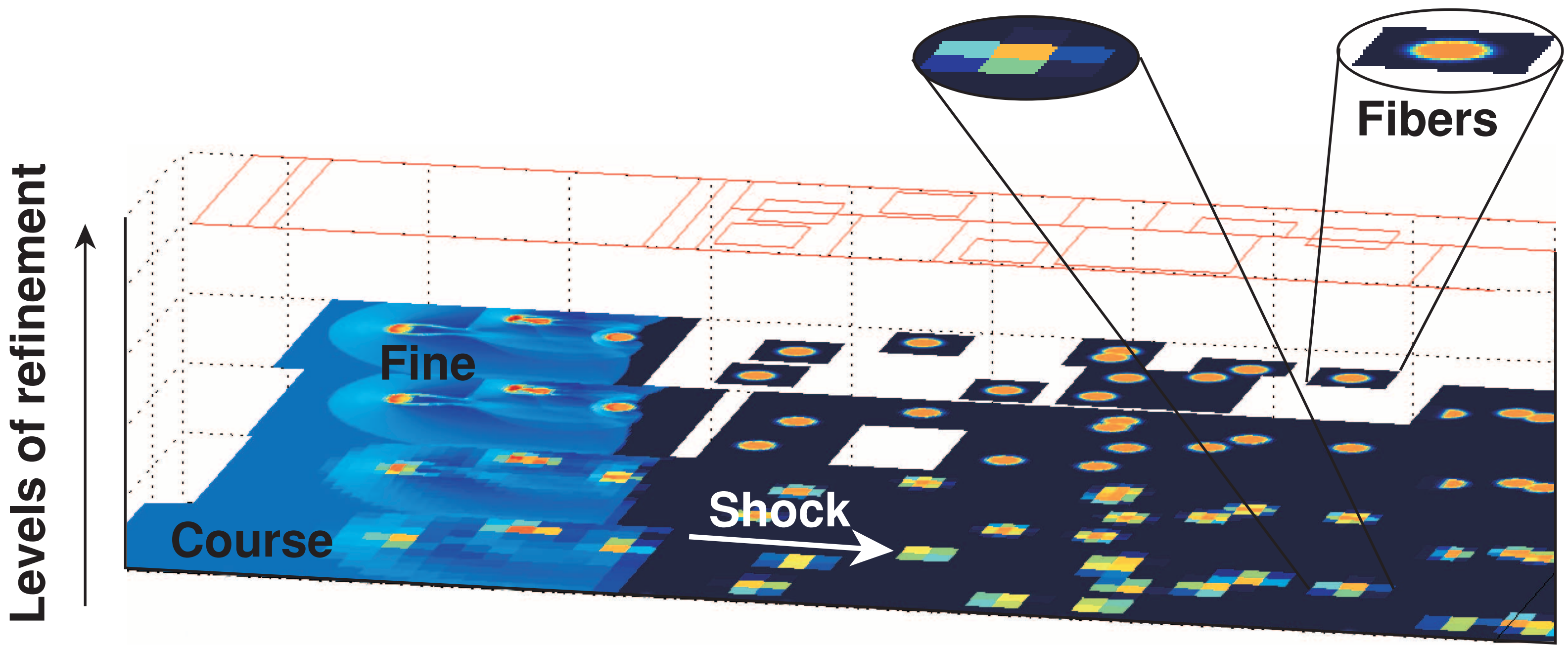
AMR simulations with *BEARCLAW*[1] use higher resolution only where needed

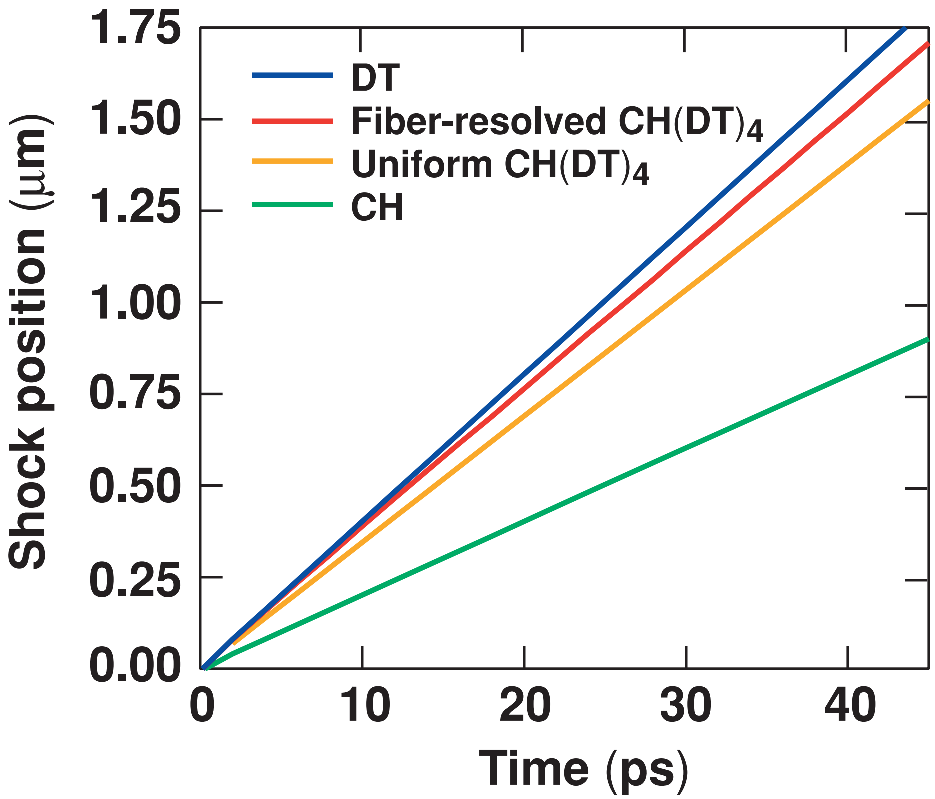
- AMR simulations *BEARCLAW*[1] use higher resolution where the gradients are larger or where increasing resolution changes the result.
- This allows greater simulation sizes than standard simulations.



[1]http://www.amath.unc.edu/faculty/mitran/bearclaw.html.

AMR simulations were performed of wetted-foam slices for a range of dry-foam densities

- 3-Mbar supported shock.
- Fiber spacing 0.1 μm
- Ideal-gas equation of state is used.
- Radiation and thermal transport are not modeled.
- Since these are dissipative mechanisms, these simulations provide a worst case.



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Simulations are comparable to a simple shock-speed prediction assuming no shock reflections or refractions

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- The ratio β of inhomogeneous (fiber-resolved) shock speed D_i to homogeneous (with average density) shock speed D_h is

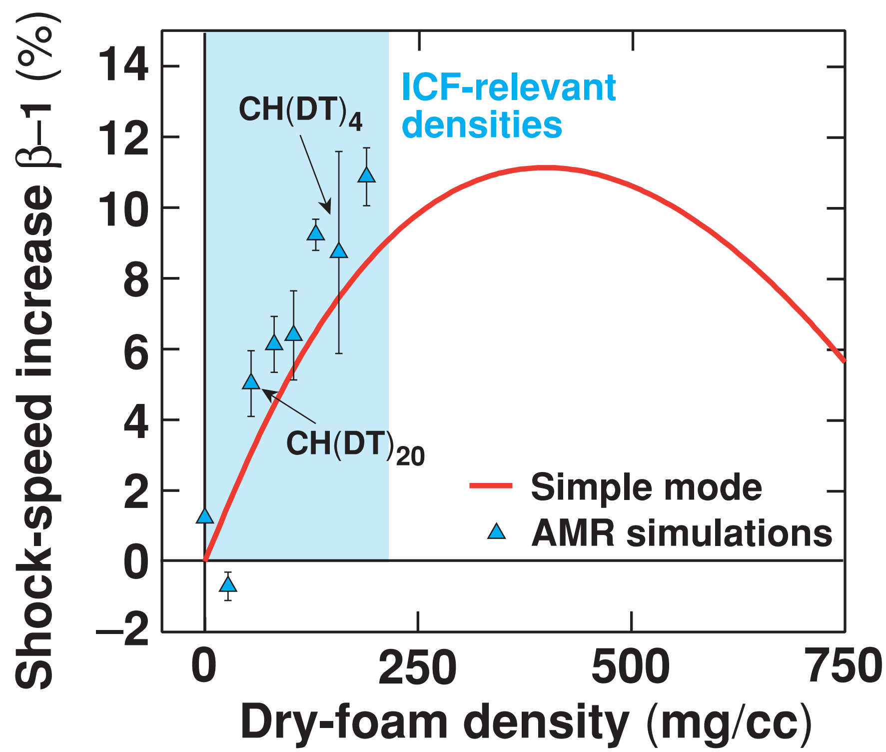
$$\beta \equiv D_i / D_h = \sqrt{1+3\pi\varepsilon^2}\left[1+\frac{\pi}{2}-2\varepsilon-2\left(1-4\varepsilon^2\right)^{-1/2}\arctan\sqrt{\frac{1-2\varepsilon}{1+2\varepsilon}}\right]$$

where $\varepsilon \equiv \sqrt{\rho_{dry}/\pi}$ and ρ_{dry} is the dry-foam density.

- For low and high ρ_{dry}, one material (DT or CH) dominates and $\beta - 1 \rightarrow 0$.

- For intermediate ρ_{dry}, the higher DT shock speed means $\beta - 1 > 0$.

- AMR simulations for a 3-Mbar shock were performed.



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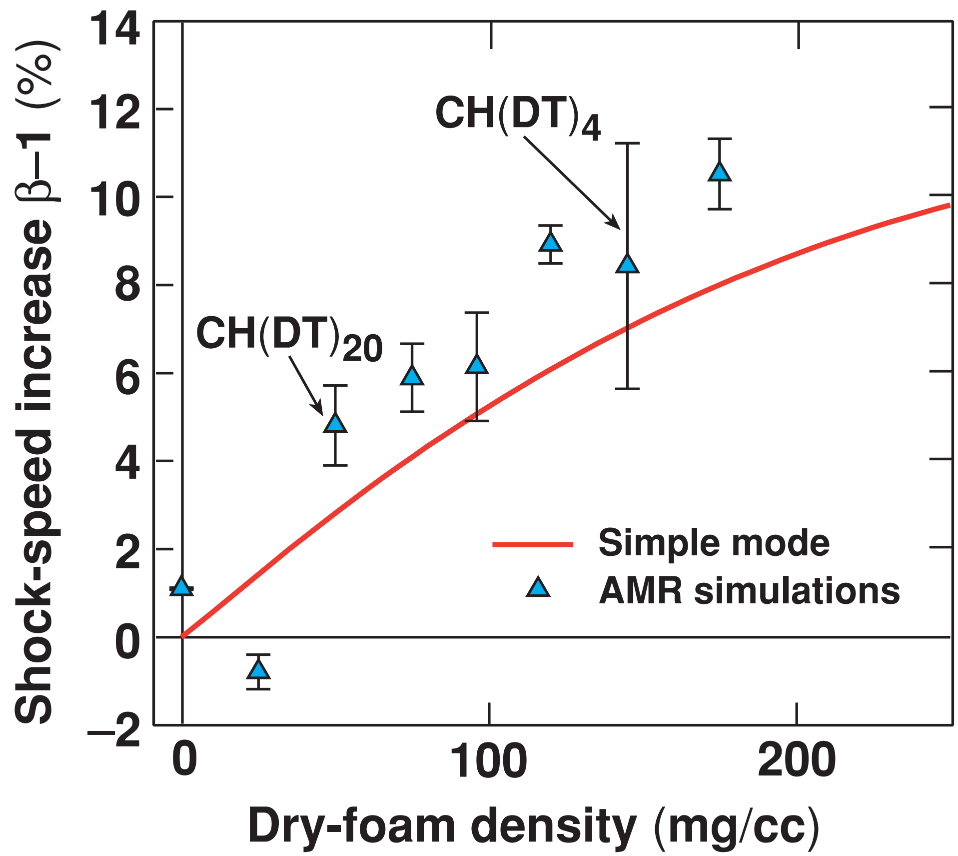
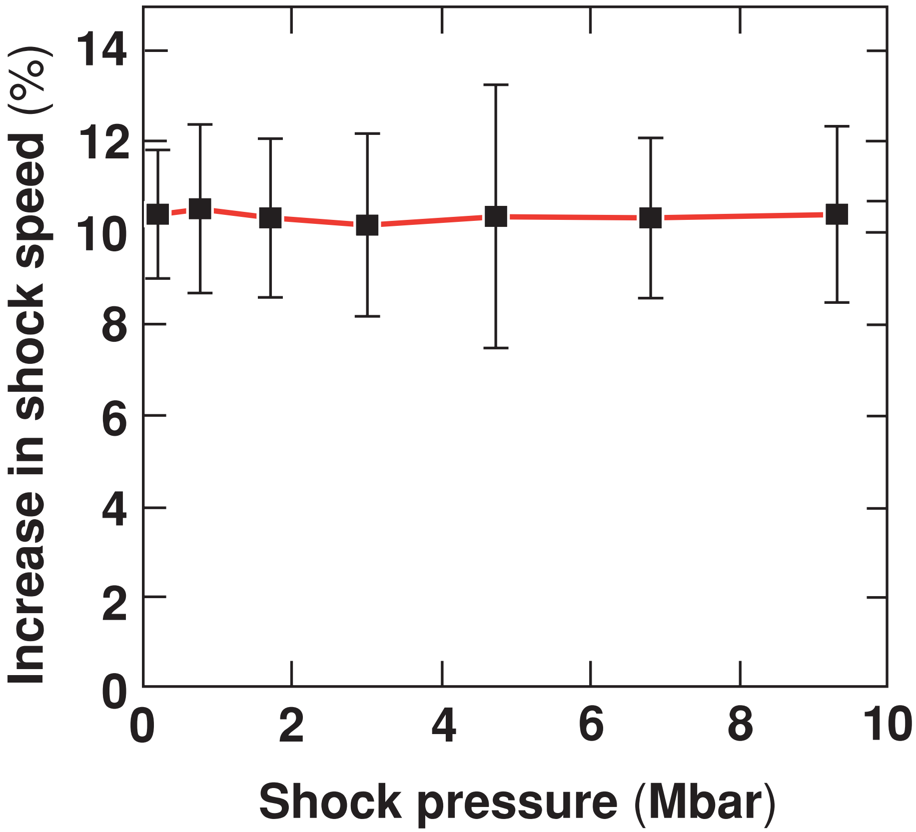
Simulated shock speeds follow the same trend for ICF-relevant values of the dry-foam density ρ_{dry}

- Each point represents an AMR simulation.
- For a single AMR simulation, the shock speed is not constant in time.
- The variation in time of the shock speed is represented by the error bars.



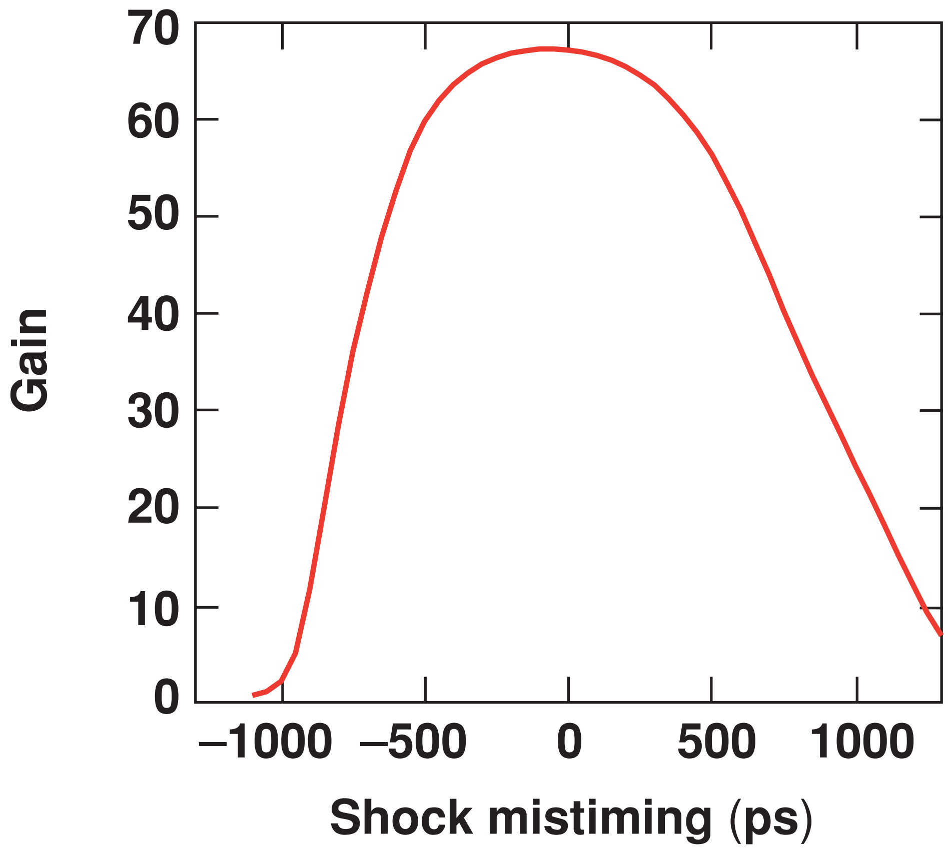
The increase in shock speed due to foam microstructure is insensitive to shock pressure

- The shock speed for $CH(DT)_4$ is ~10% faster for the fiber-resolved simulation than for a uniform mixture of the same density.
- The analytic estimate predicts no dependence on shock strengths.
- Over the range of 0.2 to 10 Mbar, the increase varies by ~0.1%.



The current high-gain, wetted-foam design is robust to wetted-foam shock mistiming

- A 10% change in shock speed for this design corresponds to ±300-ps shock mistiming.
- This target is still viable for shock mistiming less than ~ 400 ps.
- Actual shock speeds in wetted foam will be determined experimentally.



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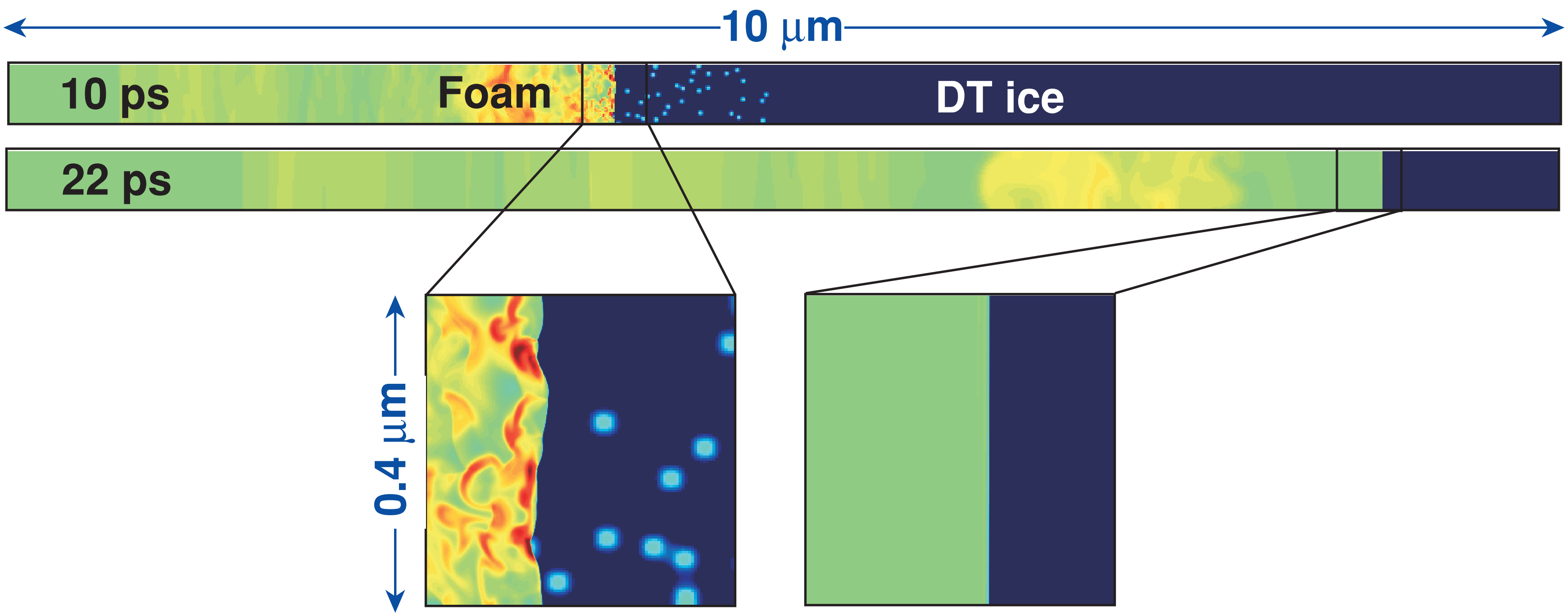
Shock-front perturbations from the foam layer decay quickly after the shock enters the DT-ice layer



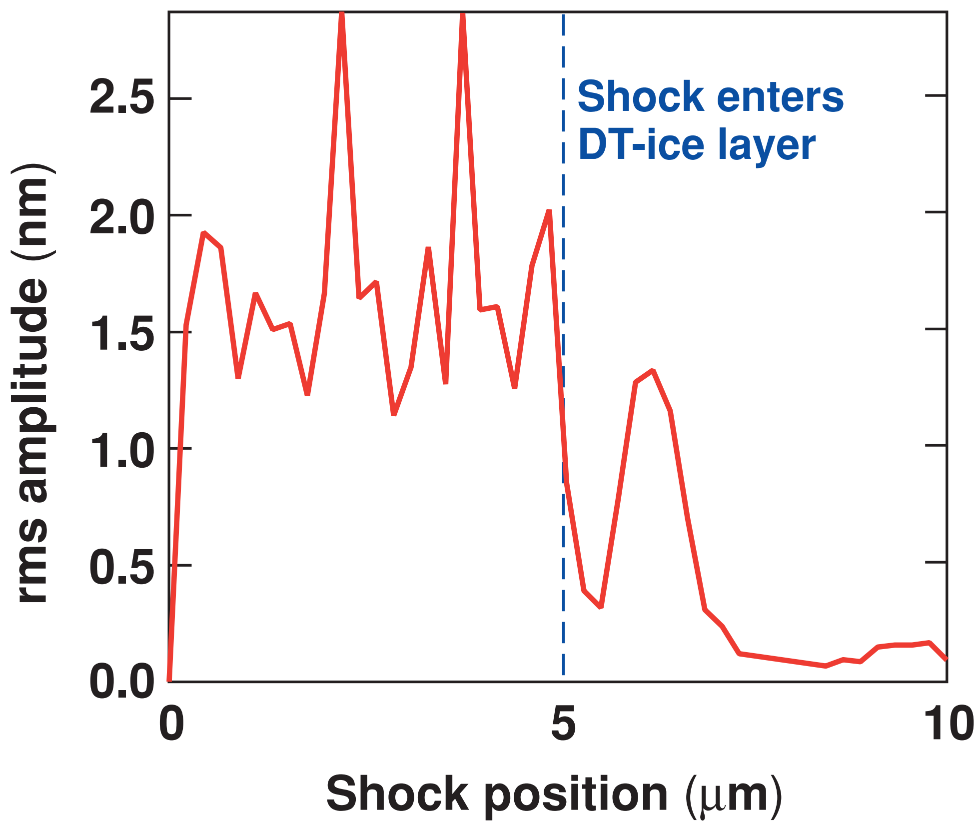
- Shock fronts are stable, so nonuniformities decay in time.[1]
- The shock-front nonuniformities induced by the CH fibers decay to less than 0.1 nm in just 5 μm.

[1] G. B. Whitman, *Linear and Nonlinear Waves* (Wiley, NY, 1974), p. 307; A. E. Roberts, *Stability of a Steady Plane Shock*, Los Alamos Report LA-299 (1945).

TC6386

Foam-induced shock-front perturbations do not significantly contribute to feedthrough

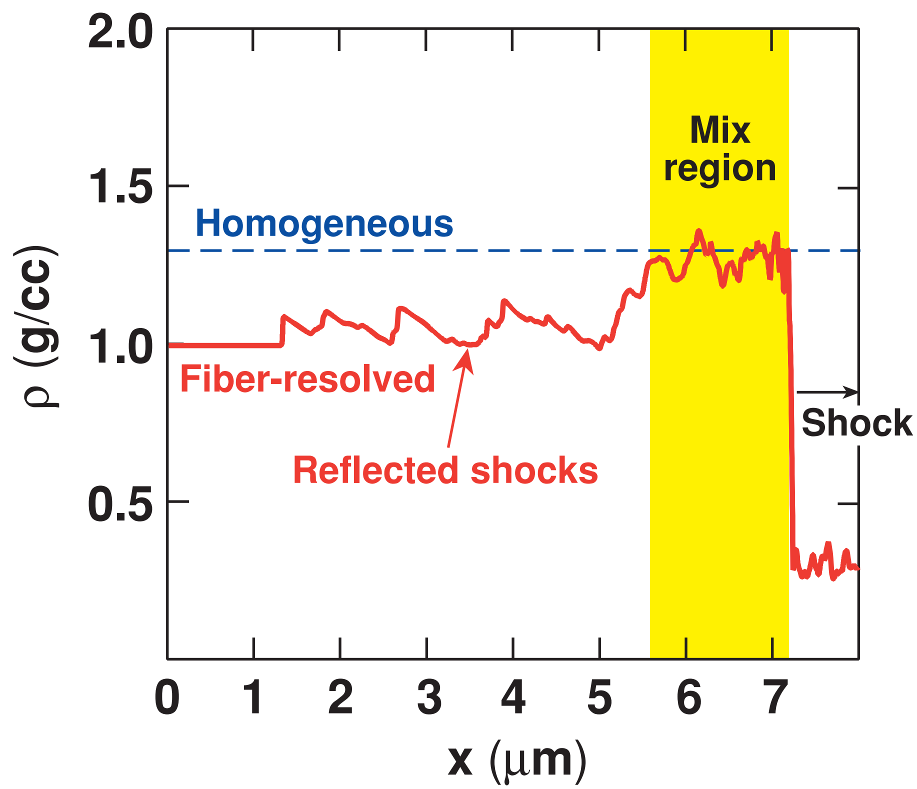
- In the wetted foam, the amplitudes are ~ 1.5 nm.
- In the DT ice, the amplitudes drop to ~ 0.1 nm in just 5 μm.
- These amplitudes are well below the expected level of the inner-surface ice roughness.



For relevant shock pressures, the jump conditions are clearly modified by foam microstructure

- As found by Hazak *et al.* (1998), the average post-shock pressure and density are less than those in a homogeneous medium.
- For a typical wetted-foam design, the effect is ~ 10% in *p* and ~ 25% in ρ.
- As a result, the shell is placed on a higher adiabat:

$$d\ell n\alpha = d\ell n\rho - 5/3\ d\ell n\rho \sim 1/3$$



Summary/Conclusions

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