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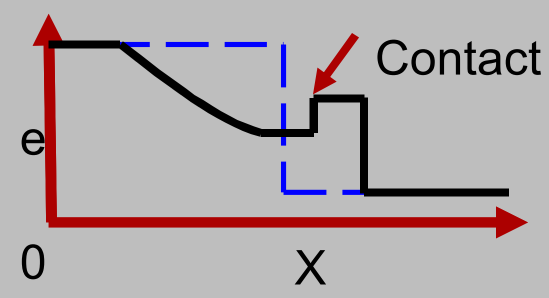

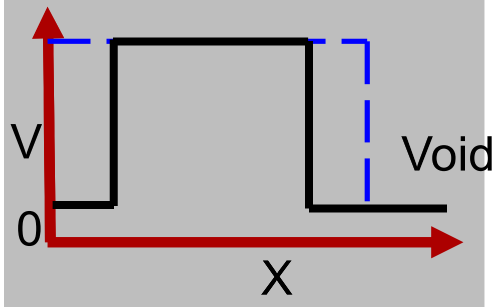

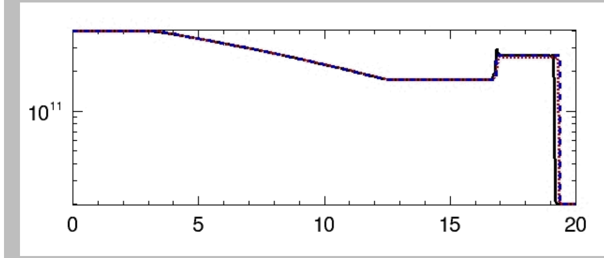

Current Status of the MPM in CTH

K. P. Ruggirello & S. C. Schumacher

8th MPM Workshop
Oregon State Univ. Corvallis, OR
Sept. 25th-26th, 2014

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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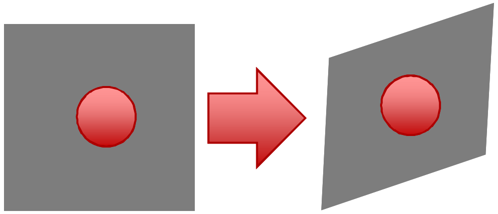
MPM and CTH

- MPM has been implemented into CTH at SNL
  - Joint effort with LANL, and Univ. Utah for CPDI* implementation
- On going verification of method has led to numerous bug fixes/improvements over the last year
- Majority of use cases involve shocks
  - Verification of shock response of MPM needed

CPDI Particle Domain



*A. Sadeghirad, R. M. Brannon, and J. Burghardt, "A convected particle domain interpolation technique to extend applicability of the material point method for problems involving massive deformations," *International Journal for Numerical Methods in Engineering*, vol. 86, pp. 1435-1456, (2011).

Verification and Validation Problems

- Sod shock tube
  - Comparison with analytical solution for a variety of shock strengths
  - Initial discontinuity can be replace with a material discontinuity
- 1D Flyer plate
  - Verification of shock response with material strength
  - Void interaction
- Taylor Anvil comparisons
  - Helps to validate material model response with method
- Breaking Dam
  - Identified as a good test problem by MPM community to show "popping" behavior
- MMS provides additional verification, but hard to implement currently in CTH

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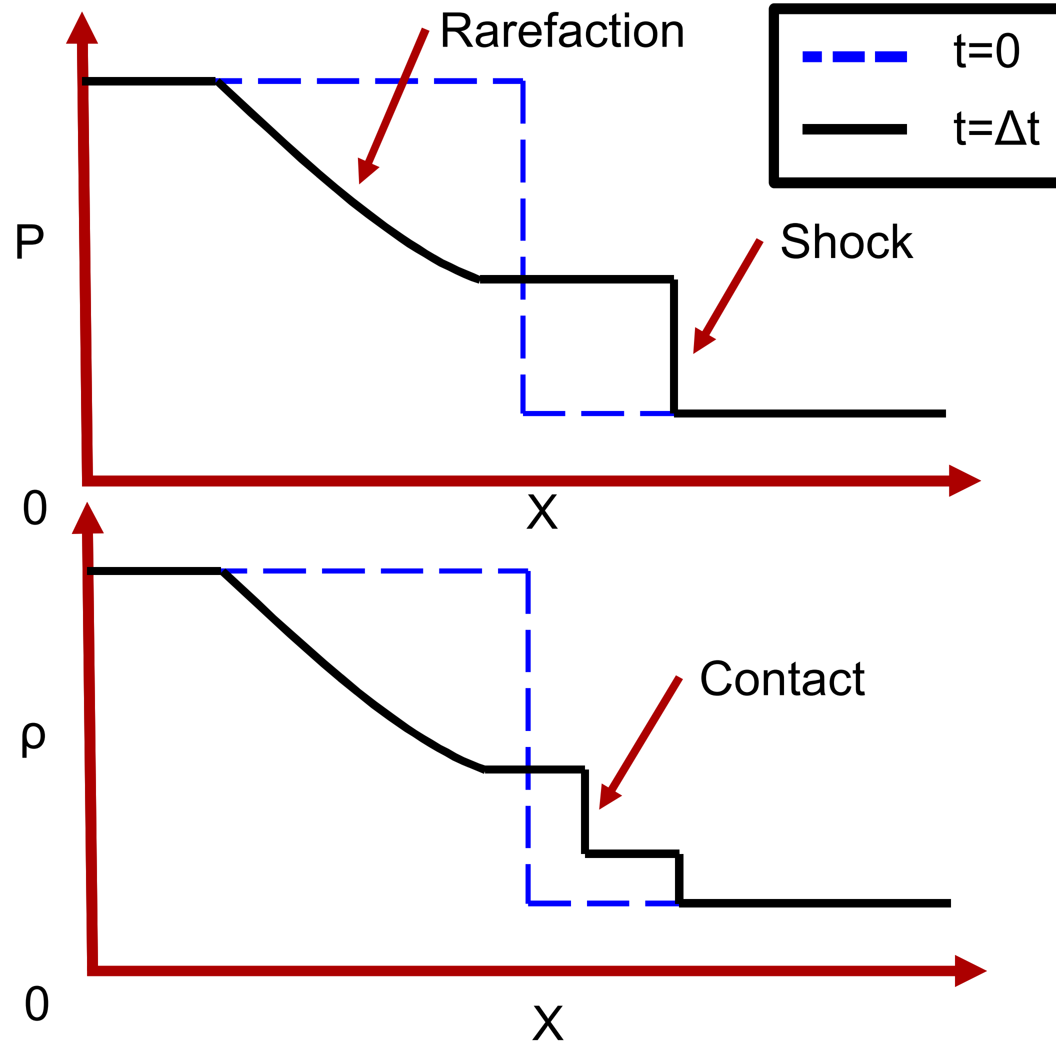
Sod Shock Tube*: Analytical Soln.

- Ideal gas
  - γ=1.67
  - C_v=2.0E11 $\frac{\text{erg}}{\text{g eV}}$
- 1024 cells
- 4 PPC



*Sod, G. A., “A Survey of Several Finite Difference Methods for Systems of Nonlinear Hyperbolic Conservation Laws”, J. Comput. Phys. 27: 1-31 (1973).

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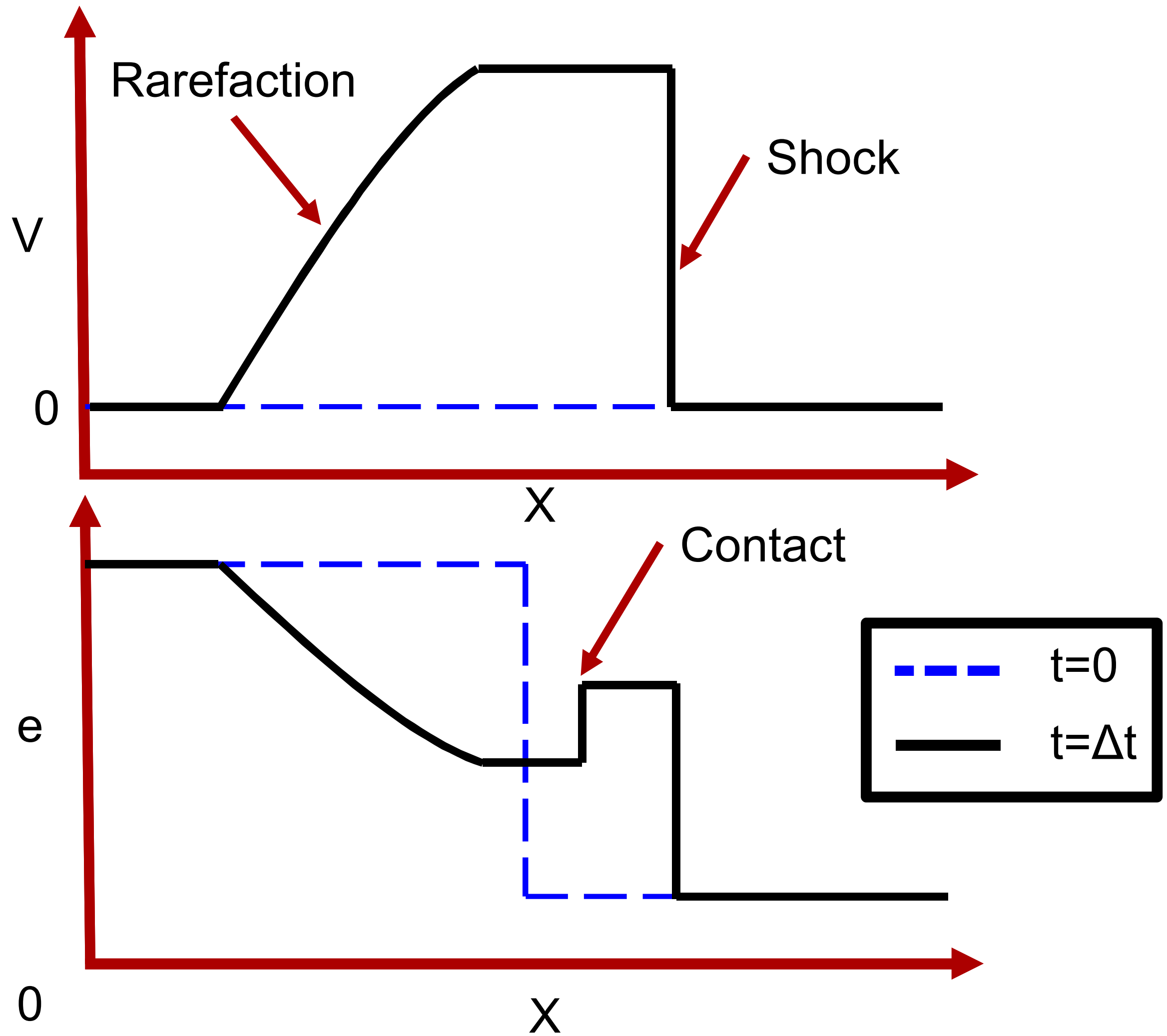

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Sod Shock Tube: FLIP Results

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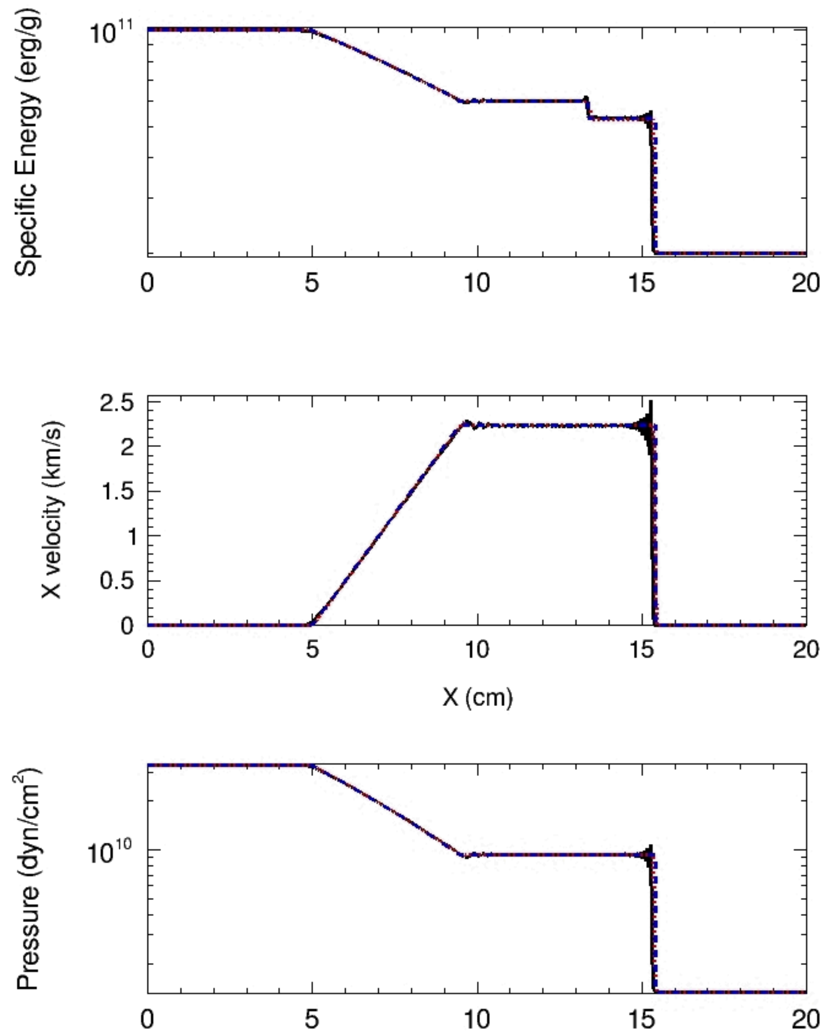
Weak Shock		
Property	Left	Right
T (eV)	0.5	0.1
P (g/cm^3)	0.5	0.1

- FLIP result noisy across discontinuities

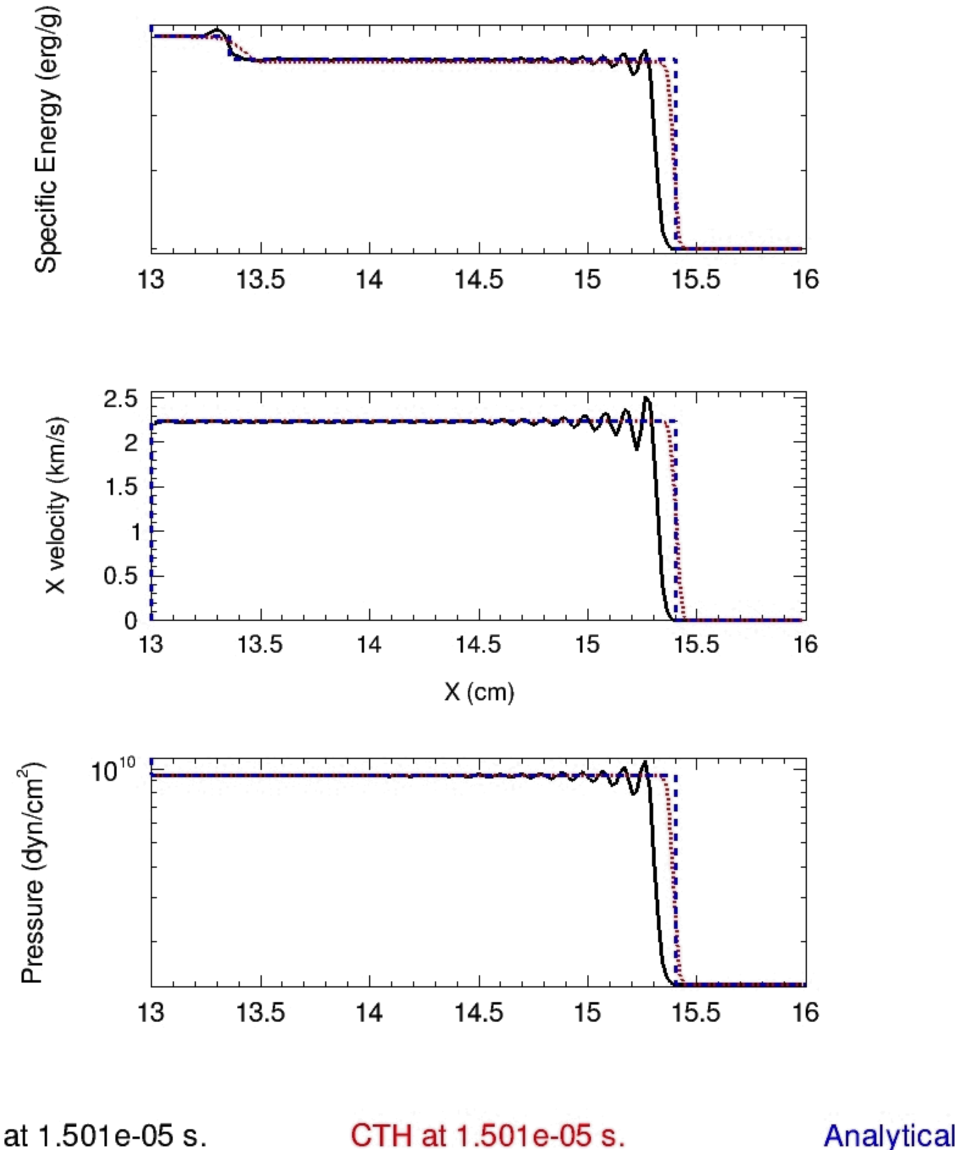


FLIP at 1.501e-05 s. CTH at 1.501e-05 s. Analytical

Sod Shock Tube: FLIP Results

Weak Shock		
Property	Left	Right
T (eV)	0.5	0.1
P (g/cm^3)	0.5	0.1

- FLIP result noisy across discontinuities
- FLIP more diffusive than CTH solution
- FLIP shock speed slightly slower



Limited Artificial Viscosity*

- CTH solution not perfectly monotone across discontinuities
- Limited artificial viscosity implemented to introduce more diffusion and keep the solution monotone

$$Q_i = -\frac{1}{2}\rho_i(B_l \Delta u_i(1-\phi) + B_q |\Delta u_i| \Delta u_i (1-\phi^2))$$

$$\Delta u_{i+\frac{1}{2}} = \Delta t \frac{(P_i + Q_i) - (P_{i+1} + Q_{i+1})}{M_{i+\frac{1}{2}}}$$

$$\phi = \max(0, \min(\frac{1}{2}(R_L + R_R), 2R_L, 2R_R, 1))$$

$$R_L = \frac{\partial u}{\partial x}_L \Big/ \frac{\partial u}{\partial x}_C \qquad R_R = \frac{\partial u}{\partial x}_R \Big/ \frac{\partial u}{\partial x}_C$$

$$\frac{\partial u}{\partial x}_L = \frac{u_{i-\frac{1}{2}} - u_{i-\frac{3}{2}}}{x_{i-\frac{1}{2}} - x_{i-\frac{3}{2}}} \quad \frac{\partial u}{\partial x}_R = \frac{u_{i+\frac{3}{2}} - u_{i+\frac{1}{2}}}{x_{i+\frac{3}{2}} - x_{i+\frac{1}{2}}} \quad \frac{\partial u}{\partial x}_C = \frac{u_{i+\frac{1}{2}} - u_{i-\frac{1}{2}}}{x_{i+\frac{1}{2}} - x_{i-\frac{1}{2}}}$$

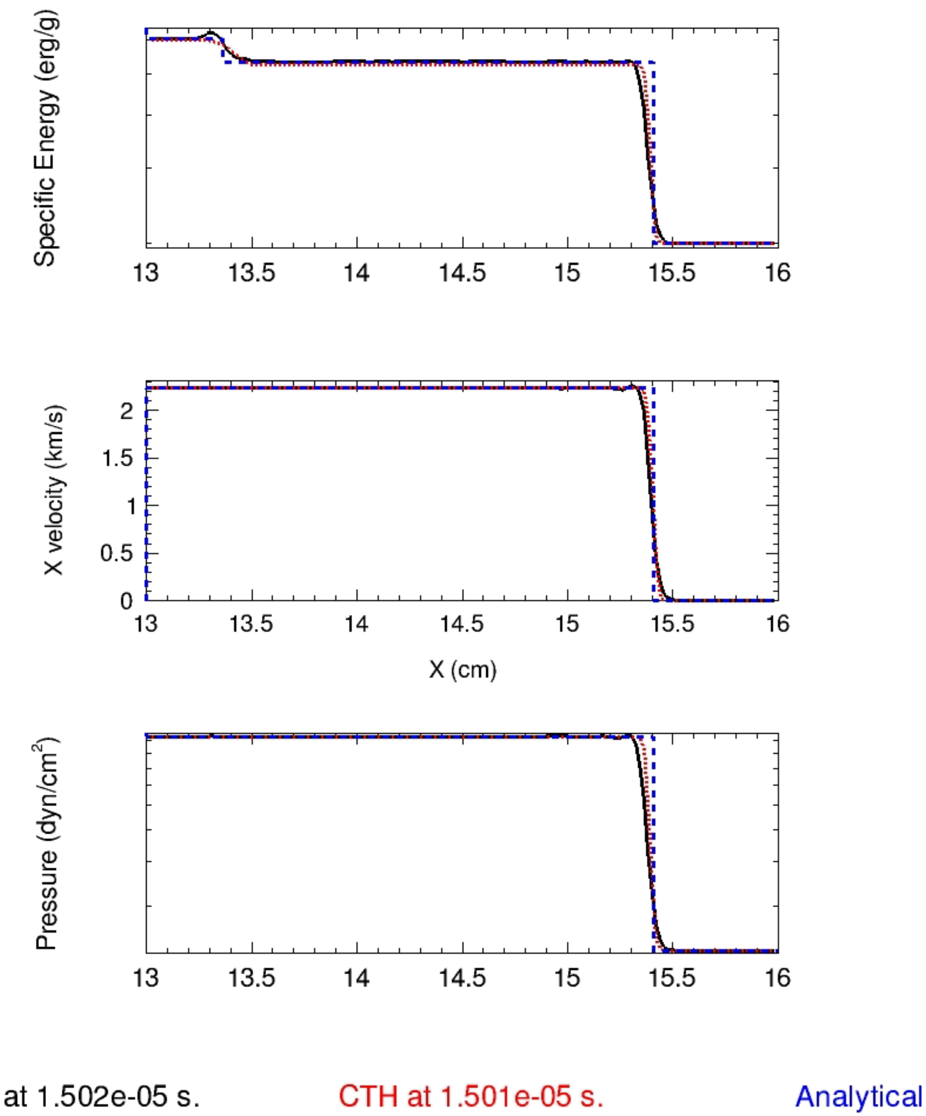
- See R. B. Christensen* for corresponding energy term
- D_L, D_R are left and right divergences of **u**
- B_l=0.167 B_q=0.667 for CTH staggered mesh

*R. B. Christensen, “Godunov Methods on a Staggered Mesh – An Improved Artificial Viscosity”, UCRL-JC-105269, LLNL (1990).

Sod Shock Tube: FLIP Results

Weak Shock		
Property	Left	Right
T (eV)	0.5	0.1
P (g/cm^3)	0.5	0.1

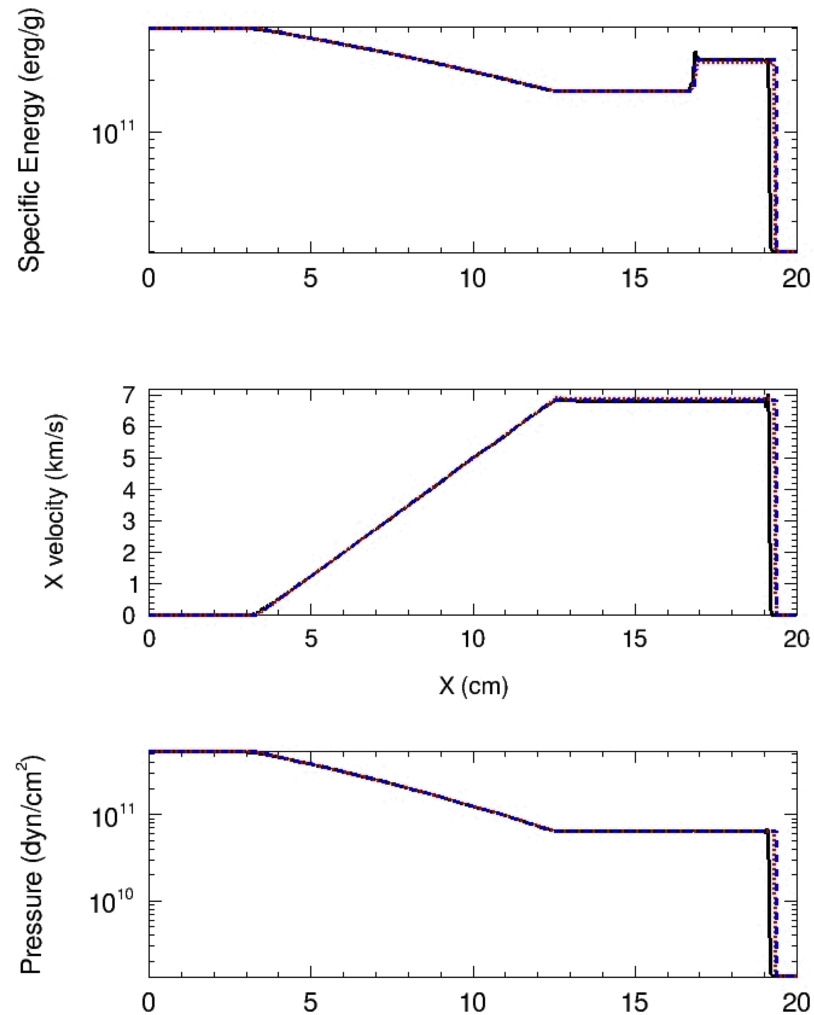
- Using limited artificial viscosity removes oscillations at shock
- Shock speed comparable to CTH
- FLIP solution 2-3 cells more diffusive than CTH



Sod Shock Tube: FLIP Results

Strong Shock		
Property	Left	Right
T (eV)	2.0	0.1
P (g/cm^3)	2.0	0.1

- Need limited artificial viscosity to get solution
  - Oscillations produce negative densities
- FLIP shows oscillations at discontinuities

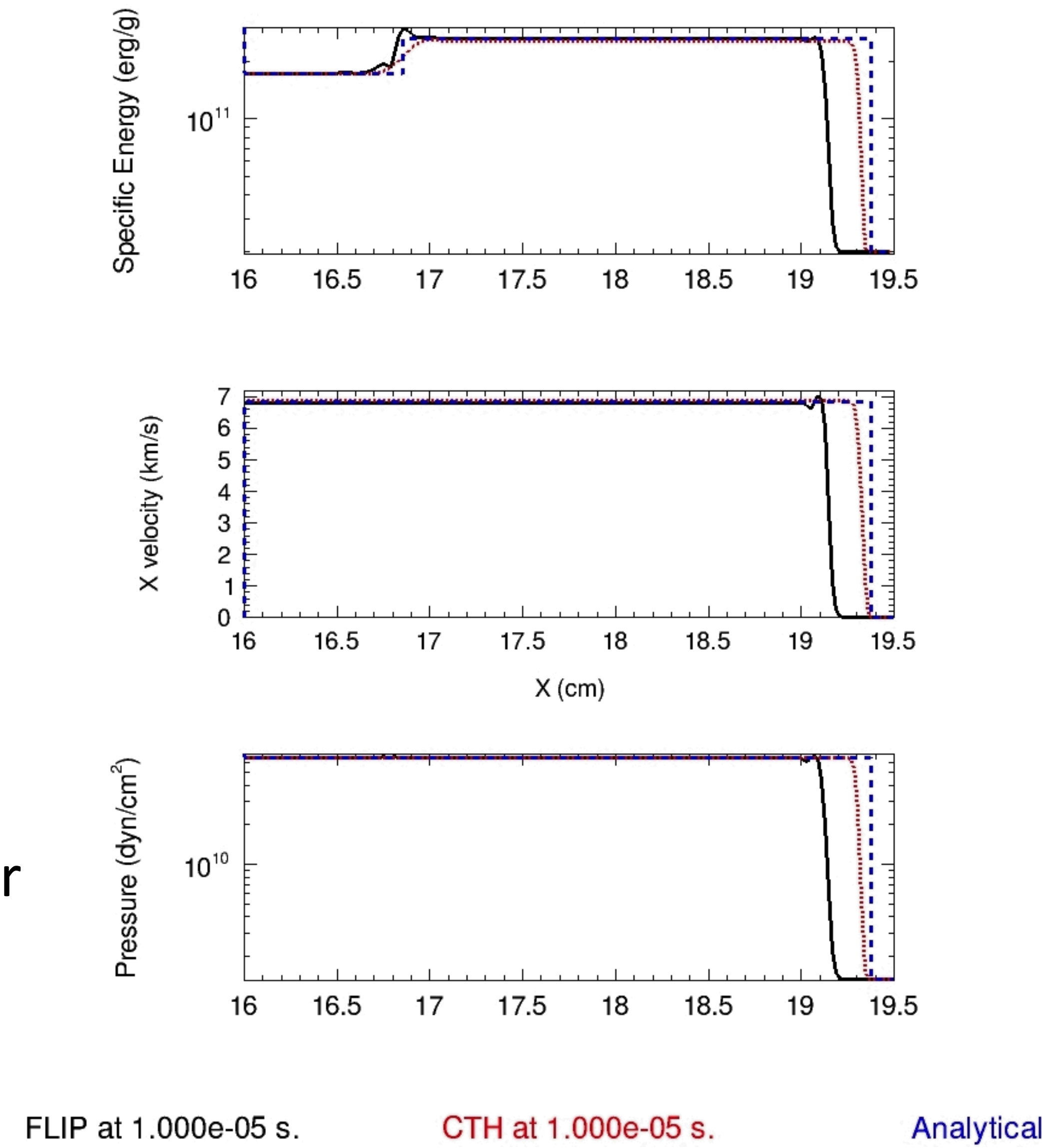


FLIP at 1.000e-05 s. CTH at 1.000e-05 s. Analytical

Sod Shock Tube: FLIP Results

Strong Shock		
Property	Left	Right
T (eV)	2.0	0.1
P (g/cm³)	2.0	0.1

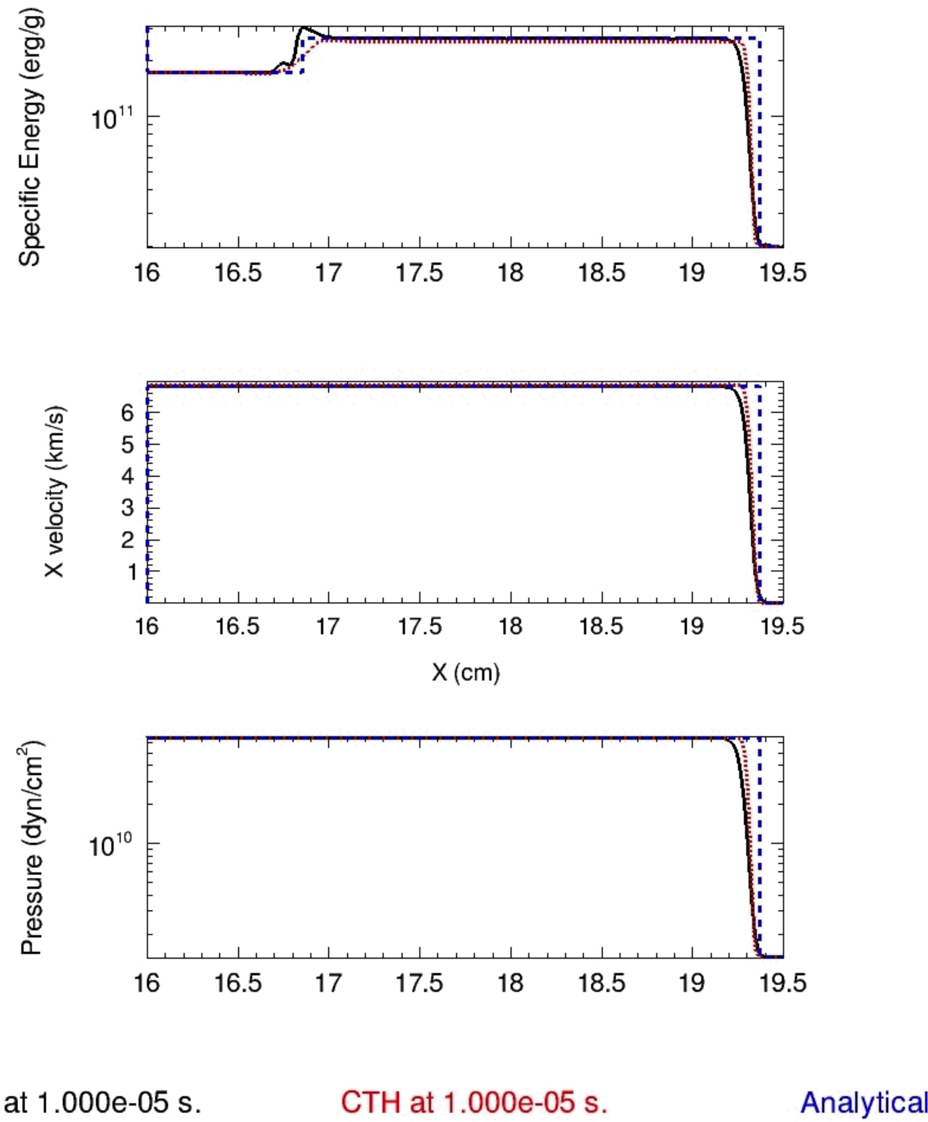
- Need limited artificial viscosity to get solution
  - Oscillations produce negative densities
- FLIP shows oscillations at discontinuities
- FLIP Shock speed slower than CTH
- “Odd” oscillation at contact surface



Sod Shock Tube: FLIP Results

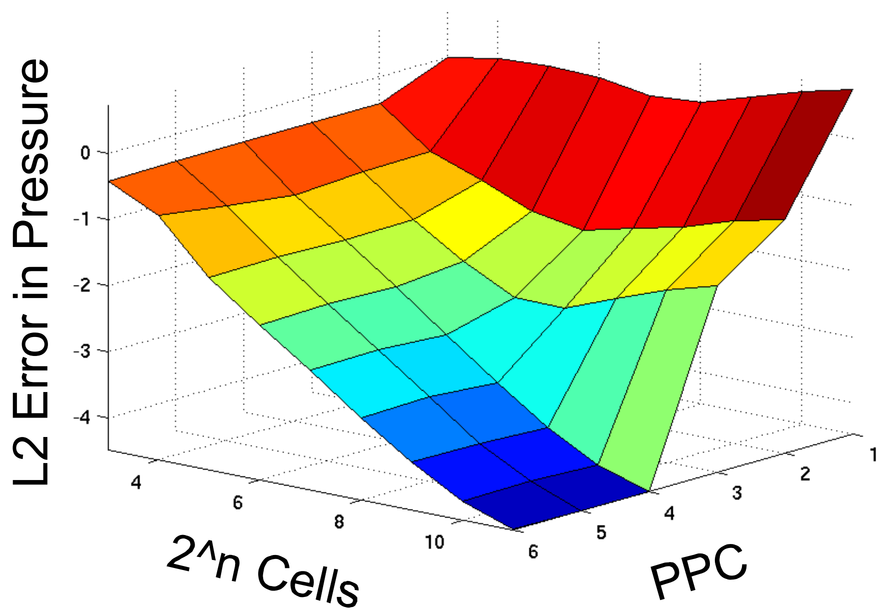
Strong Shock		
Property	Left	Right
T (eV)	2.0	0.1
P (g/cm^3)	2.0	0.1

- Increasing B_q from 0.667 to 1 removes oscillations at shock
- Shock speed comparable to CTH with increased B_q
- "Odd" oscillation at contact surface
- CPDI did not improve solution significantly



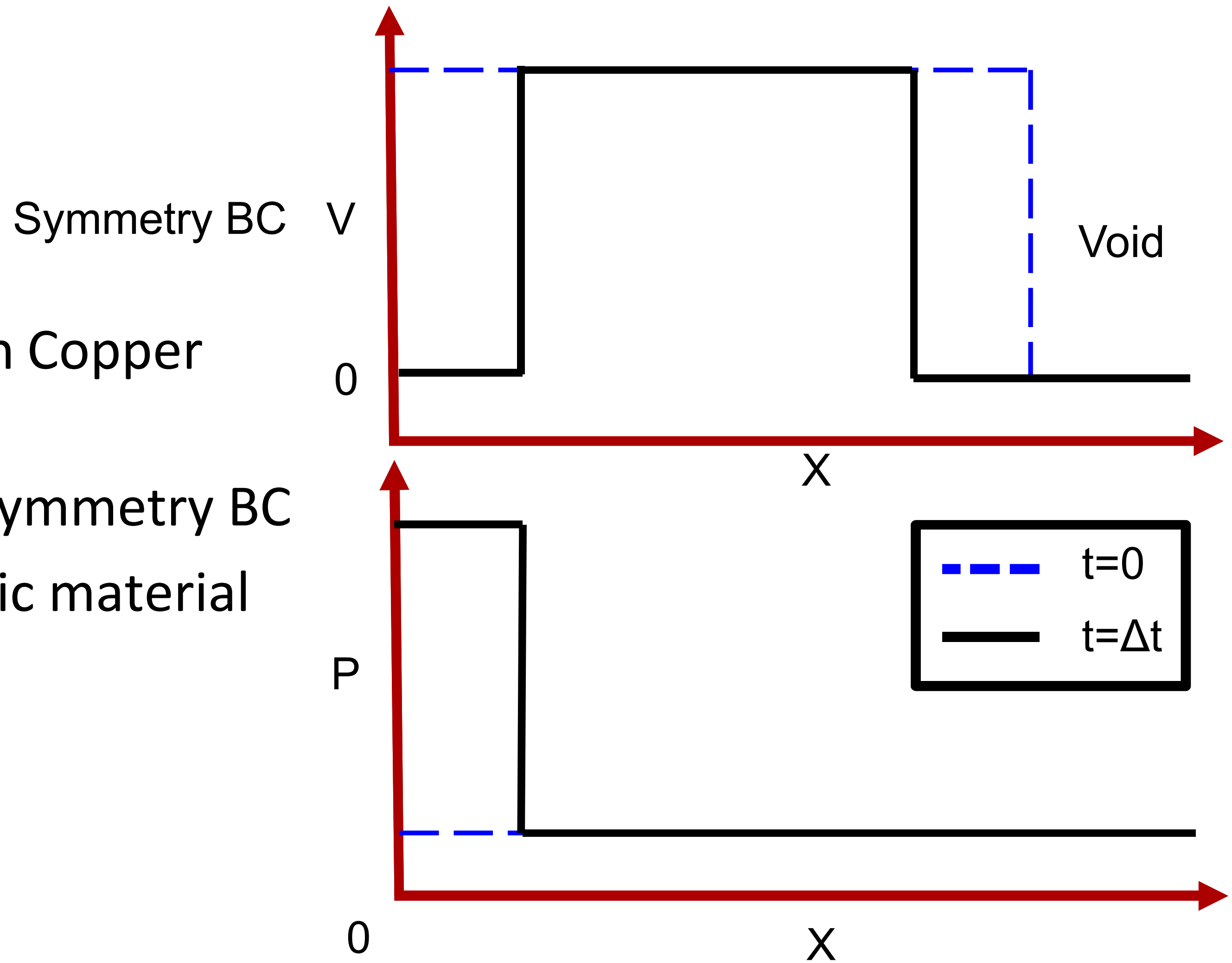
Sod Shock Tube: Convergence

- Convergence based on L2 norm found to be approximately 0.55 for both CTH and FLIP
- FLIP showed no convergence for PPC of 1-3
- PPC 4 and above converged
- Higher PPC than 4 did not show better convergence



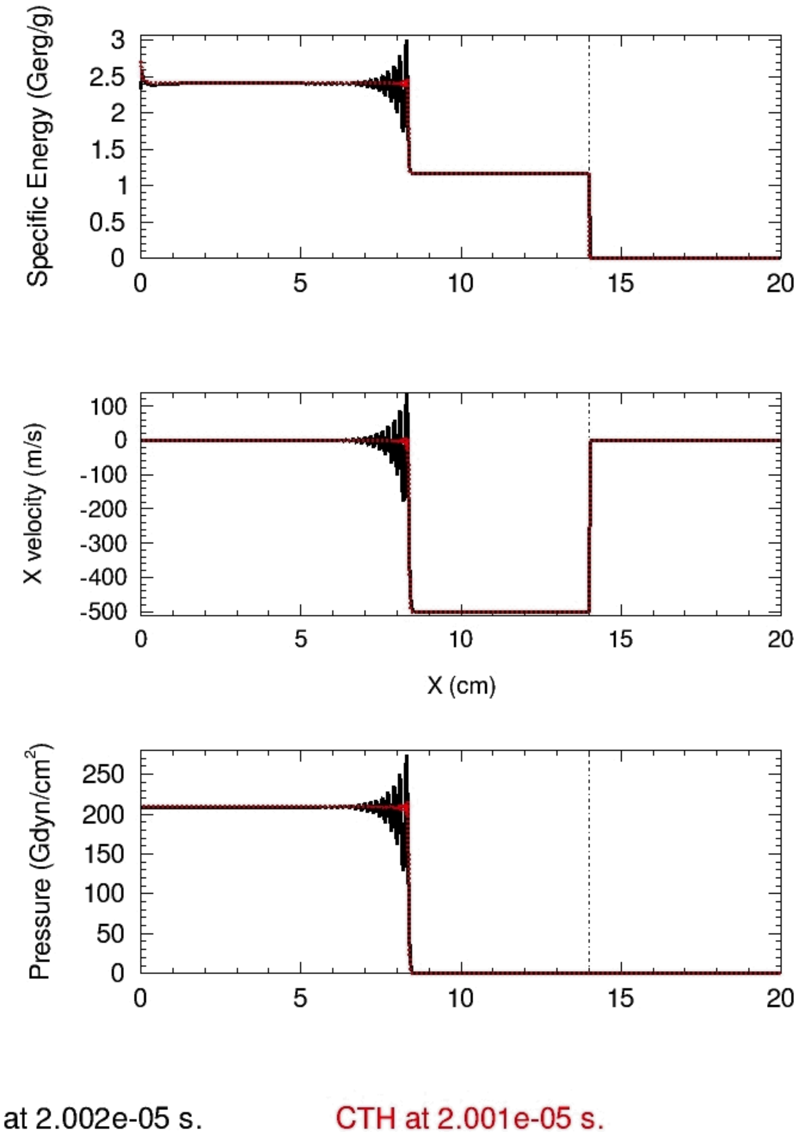
Flyer Plate: Problem Setup

- Mie-Gruneisen Copper EOS
- 500 m/s into symmetry BC
- Perfectly elastic material model
- 1024 cells
- 4 PPC



Flyer Plate: MPM Results

- CTH solution not monotone
- Oscillations amplified for MPM at shock
- Shock speed the same for CTH and MPM, within 1% of analytical solution



Flyer Plate: MPM Results

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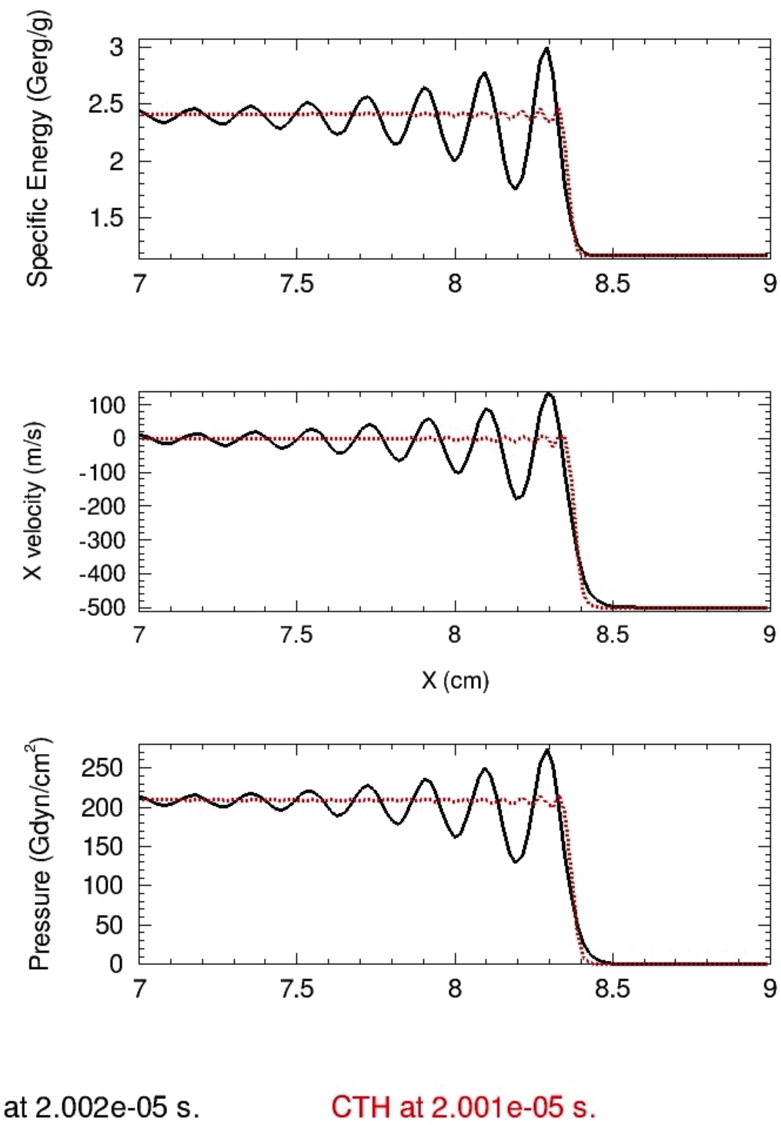
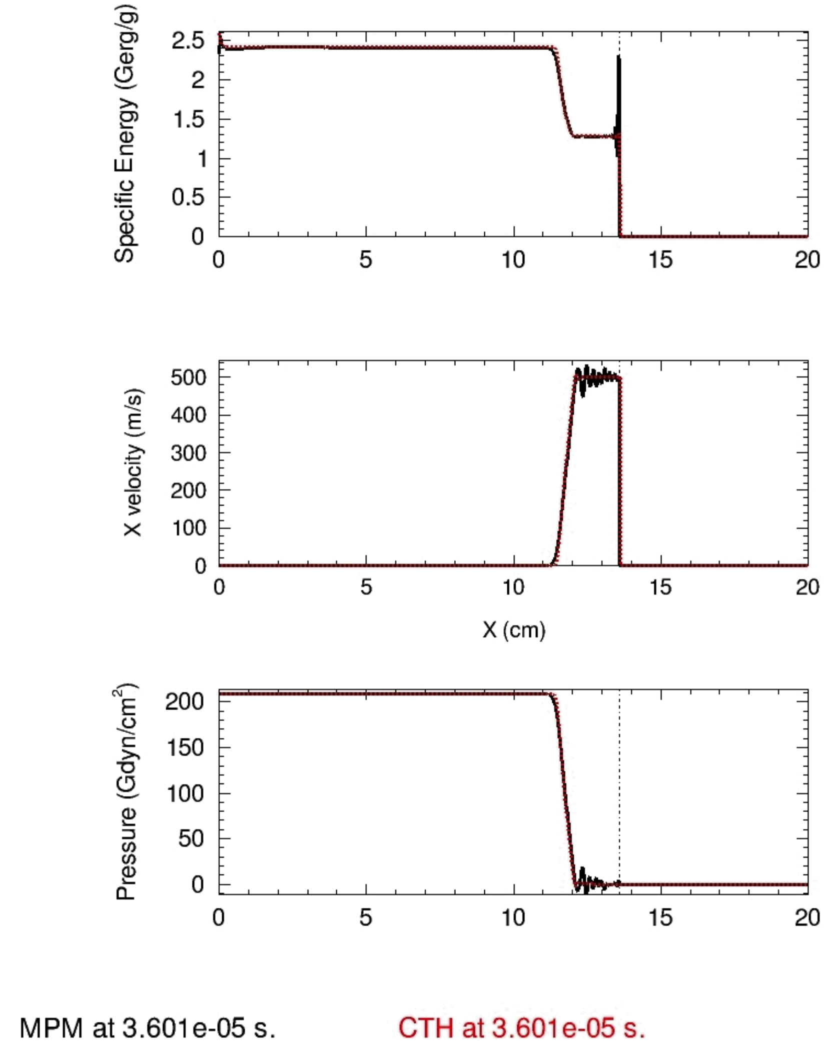
- Oscillations amplified for MPM at shock
- Shock speed the same for CTH and MPM, within 1% of analytical solution
- MPM solution has about 3 additional cells of diffusion



Flyer Plate: MPM Results

- Shock reflection off void interface at end of the rod
- Reflected shock speed the same for MPM and CTH
- Large oscillation in energy/density at interface that does not dampen for MPM
- Velocity/pressure have oscillations for MPM



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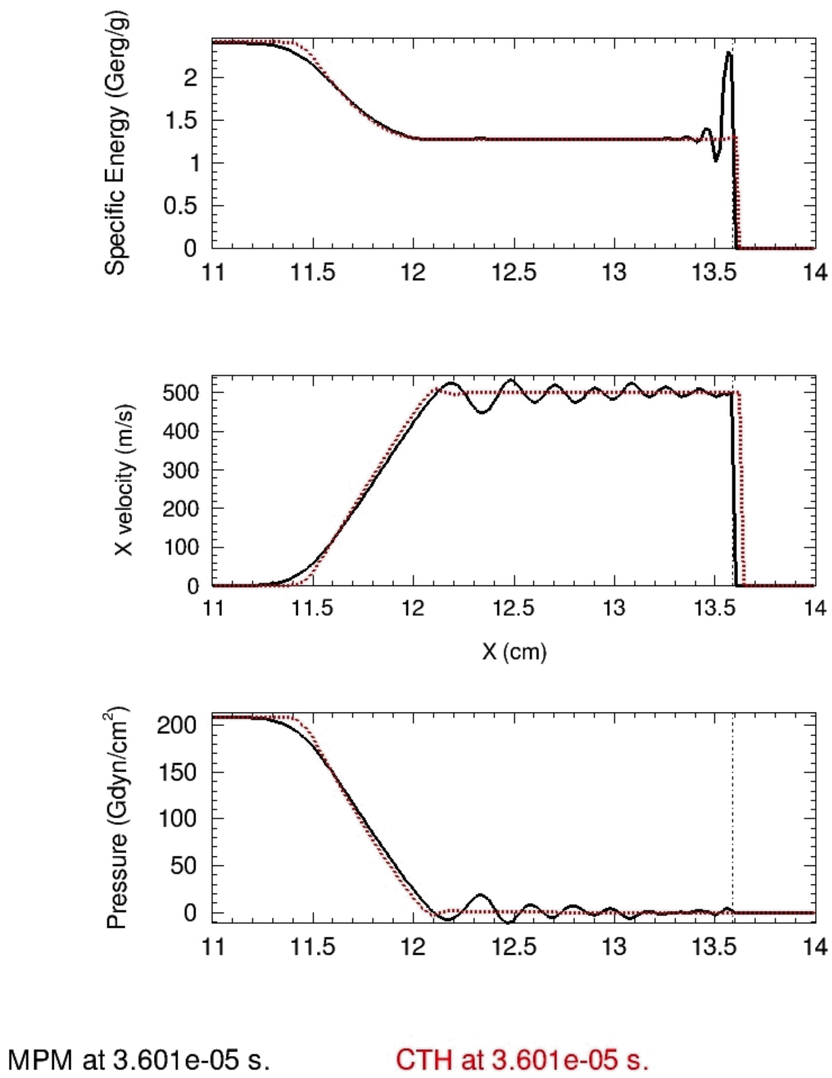
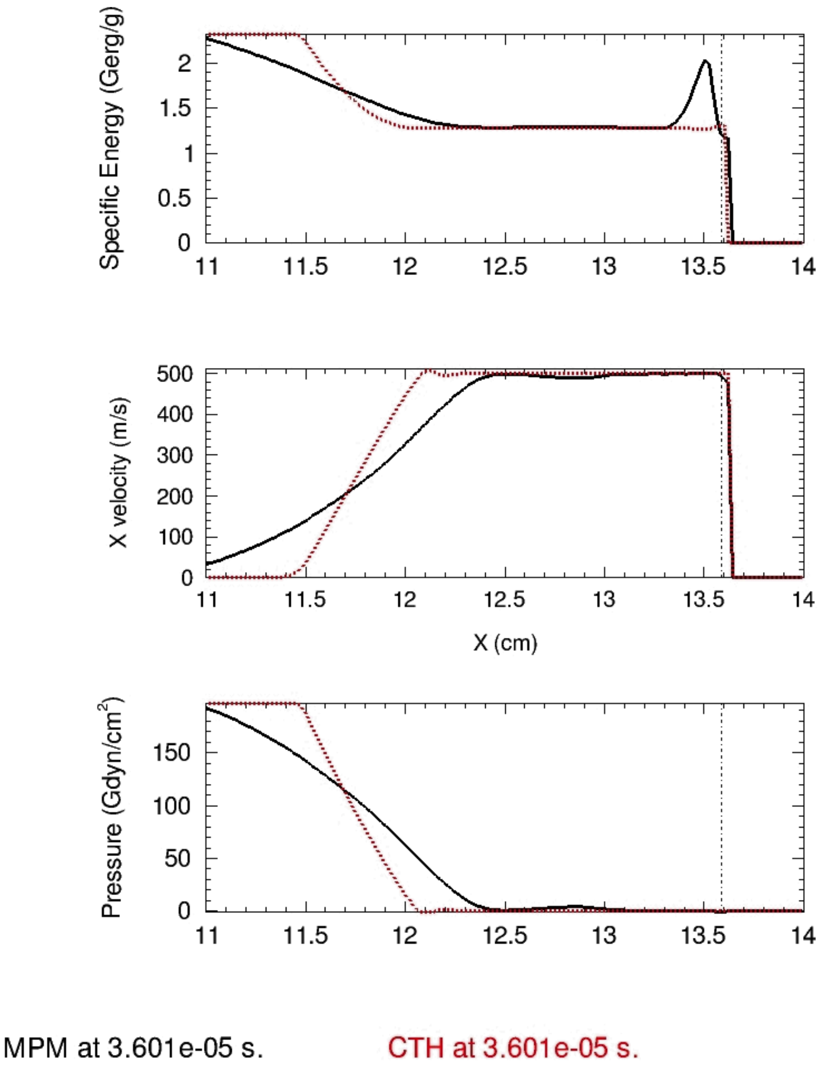


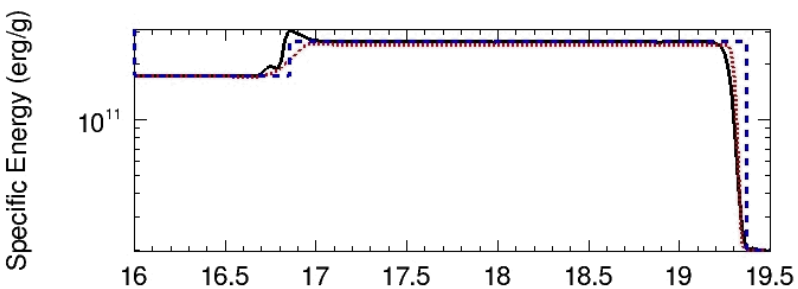
Flyer Plate: MPM Results

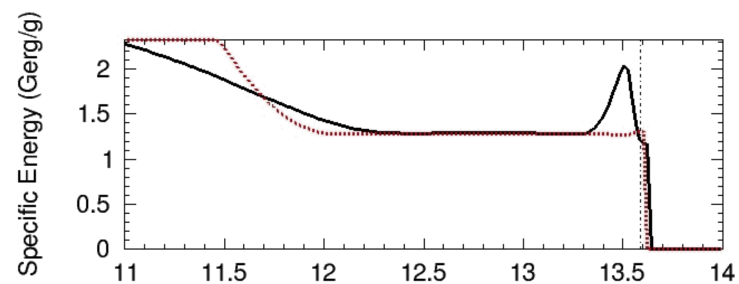
- Limited artificial viscosity removes most oscillations
  - Energy jump still present but diffused over ~15 cells now
- Increasing/decreasing artificial viscosity coefficients did not significantly improve the solution
- Possibly related to oscillation in energy at contact surface of shock tube problem



Conclusions

- FLIP and the MPM are very sensitive to monotonicity of underlying numerical method
- Additional diffusion included through the use of limited artificial viscosity to enforce monotonicity at discontinuities
- Still looking at the energy jump at contact/material interfaces





Questions

Thank you