LA-UR-01-6602 (Rev)

Improvements to Convergent Cylindrical Plasma Mix Experiments using Laser Direct Drive

Cris W. Barnes*, Steven H. Batha*, A. M. Dunne#, N. E. Lanier*, Glenn R. Magelssen*, Thomas J. Murphy*, Kenneth W. Parker#, Stephen Rothman#, John M. Scott*, David Youngs#

**Los Alamos National Laboratory, Los Alamos, NM USA*

#AWE, Aldermaston, UK

Abstract- LA-UR-01-2545

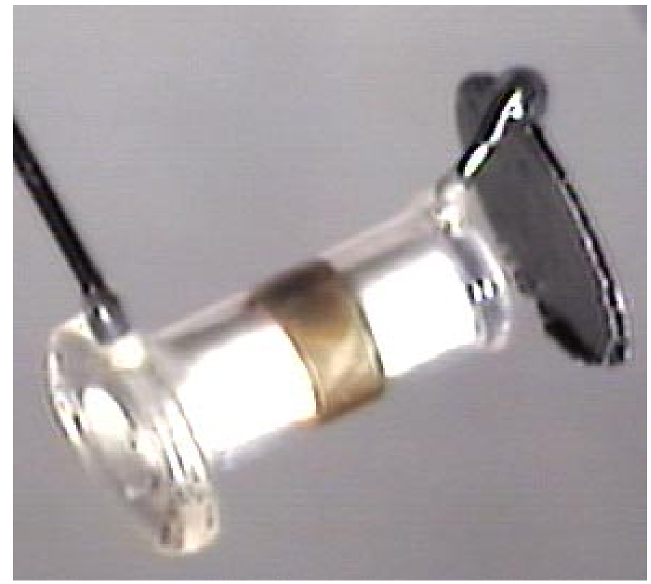
- Experiments studying mix in a compressible, convergent, miscible, plasma system are being conducted on the OMEGA Laser at the Laboratory for Laser Energetics at the University of Rochester. Thin-walled polystyrene cylinders 2.25-mm long and 0.86 mm inner diameter with foam inside are directly illuminated with 351-nm wavelength light from 50 laser beams in a 1-ns square laser pulse. The turbulence driven by the Richtmyer-Meshkov instability by shock passage across a density discontinuity mixes marker material that is radiographically opaque. Initial work using a high-density, high-opacity marker layer of gold between the plastic ablator and foam clearly demonstrated significant measurable mix width. However, the high opacity of the gold prevented determination of a density profile in the mix region, and it was also overly sensitive to hydrodynamic effects at the end of the marker layer. Use of lower opacity marker material will be described and its impact on end effects and the measurements of mix density profile described.
  - **C. W. Barnes et al., Rev . Sci. Instrum. 70 (1999) 471.**
  - **C. W. Barnes et al., submitted to Physical Review Letters (2001).**

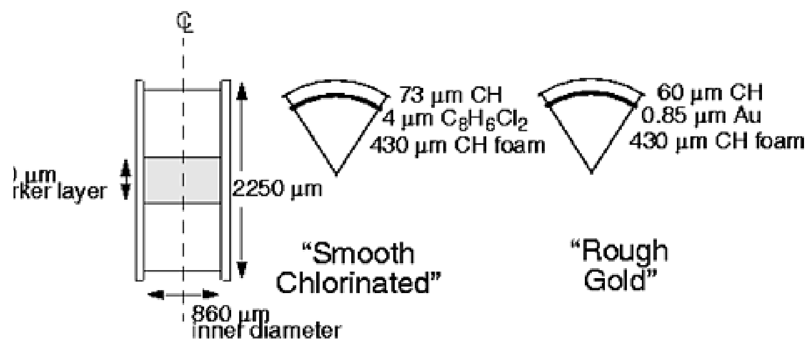
Why use direct-drive cylindrical implosions to study mix?

- **Purpose**
  - Study Richtmyer-Meshkov (RM) instability in *compressible, convergent, miscible, plasma* system
- **Method**
  - Implode cylinder with an unstable interface and measure resulting mix
  - Diagnostic advantages, fewer ends to affect experiment, convergent
- **Strategy**
  - Compare results from wide variations in initial conditions
    - » Smooth Cl vs. Rough Au interfaces (no mix vs. lots of mix)
    - » Smooth Au vs. Rough Au interfaces
    - » Vary surface roughness
  - Improve design (to make less sensitive to small amounts of marker material) using Al marker and epoxy ablator

We have established a useful, laser-based test bed for mix experiments

- Implode cylinder with thick ablator with 1-ns square pulse direct laser irradiation
- Hydrodynamically unstable at plastic/Au and Au/foam interfaces
- Backlight with x rays through cylinder
- Measure radial extent of “mix layer” of Au into adjacent materials
- 1D convergent experiment with Mach number ≈ 20 (pre-shock; Mach ≈ 5 post-shock), convergence ≈ 4, Pressure > 45 Mbars, Reynold’s number $\approx 10^6$*



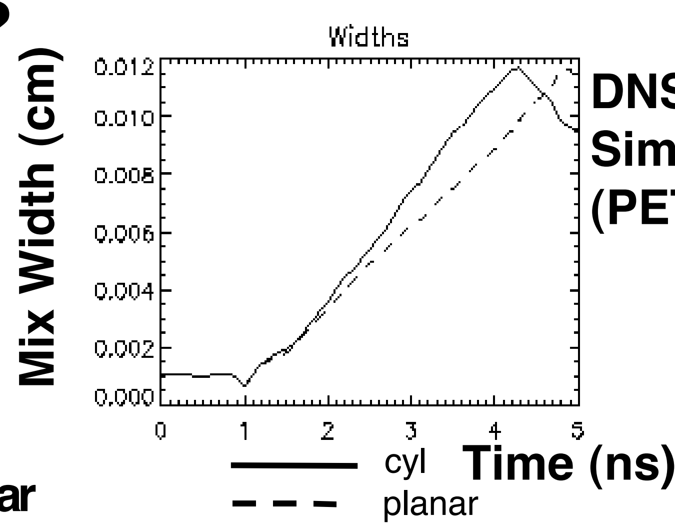


*Galmiche and Gauthier, *Jpn. J. Appl. Phys.* 35 (1996) 4516

NNSA AWE Los Alamos

Compressibility and convergence matter to mix

- **What mix width do we expect?**
- **Planar Meyer-Blewett:**
  - **$dH/dt \sim A^* U \langle k \rangle \langle a_0 \rangle \approx 140\ \mu m$ in 4ns**
    (estimated using measured surface roughness)



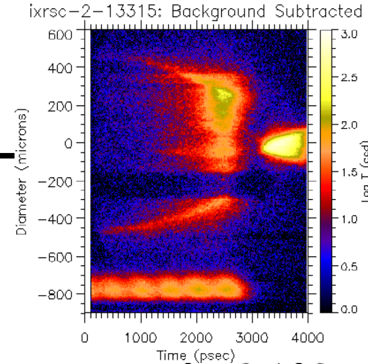
- **Incompressible Bell-Plesset:**
  - **Convergence ratio ≈ 4**
  - **Thickness ≈ 1/δR ≈ 4x more than planar**
  - **Would be big effect**
- **Compressible Bell-Plesset:**
  - **Shock increases density**
  - **Convergence also increases density eventually**
  - **Thickness ≈ 1/δ(ρR) ≈ 1.25x planar, consistent with simulations**

Complete Diagnostic Coverage Available

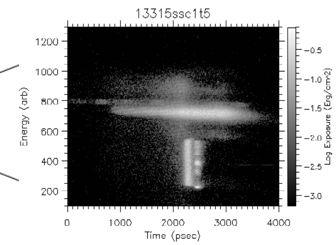
Diagnostics for Shot 13315

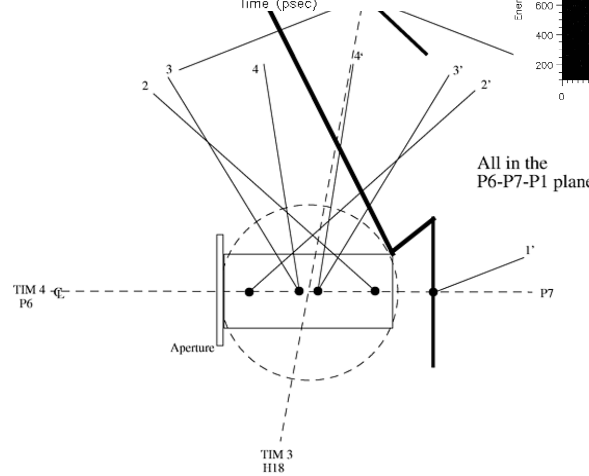
(example from thin ablator Rayleigh-Taylor experiments)

Imaging X-Ray Streak Camera

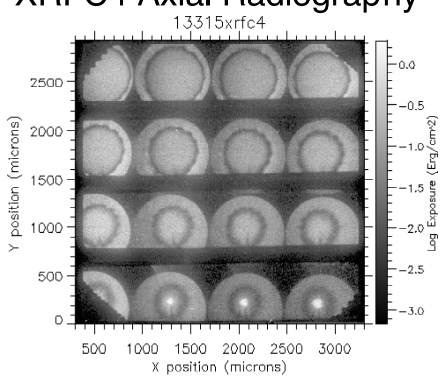


SSC1 Streak of Backlighter

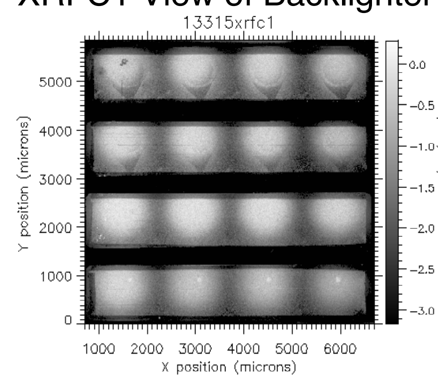




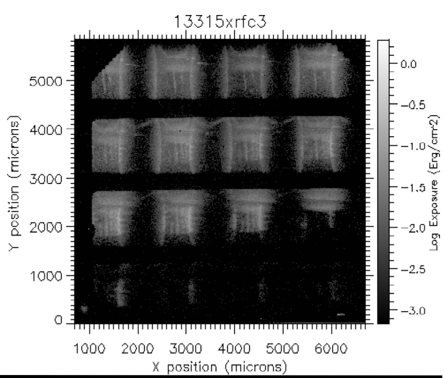
XRFC4 Axial Radiography



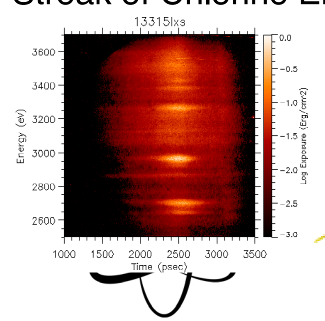
XRFC1 View of Backlighter



XRFC3 Transverse View of Self-Emission

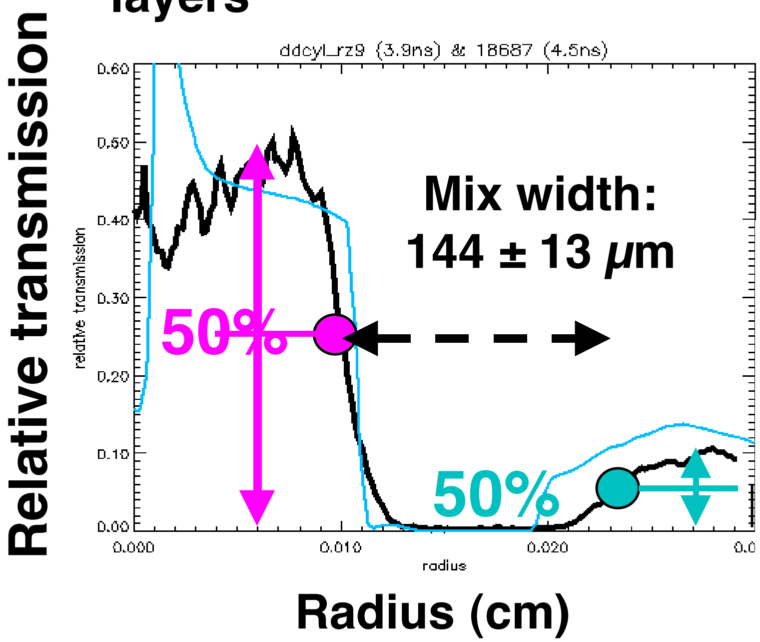


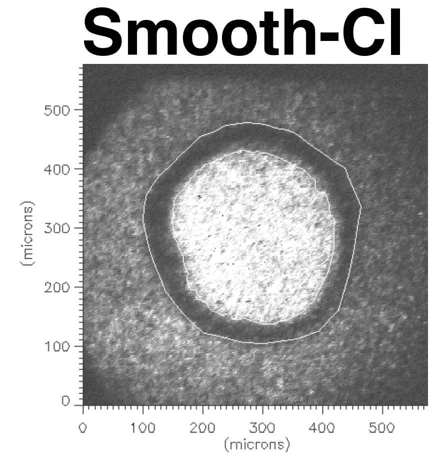
LLE X-Ray Spectrometer Streak of Chlorine Emission

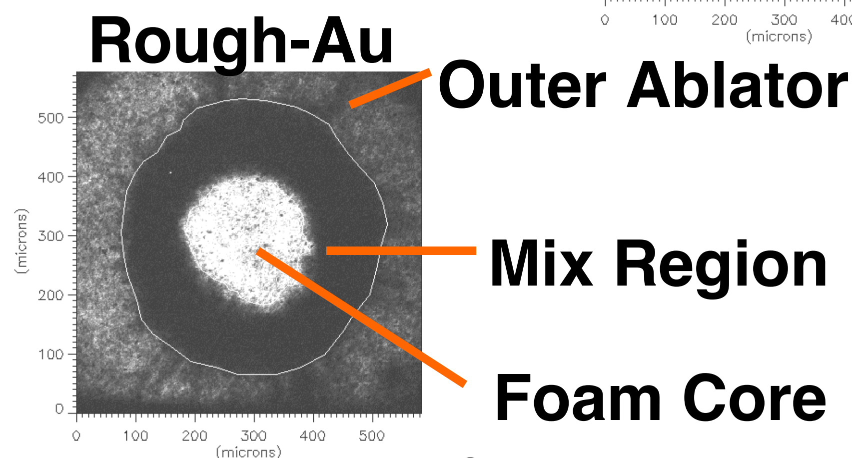


Extremes of mix/no-mix measured, demonstrating principle of experiment

- **Different surface roughness**
- **Different marker layer density**
  - Did not change the Atwood number significantly
  - Changed the behavior at the end of the marker layers

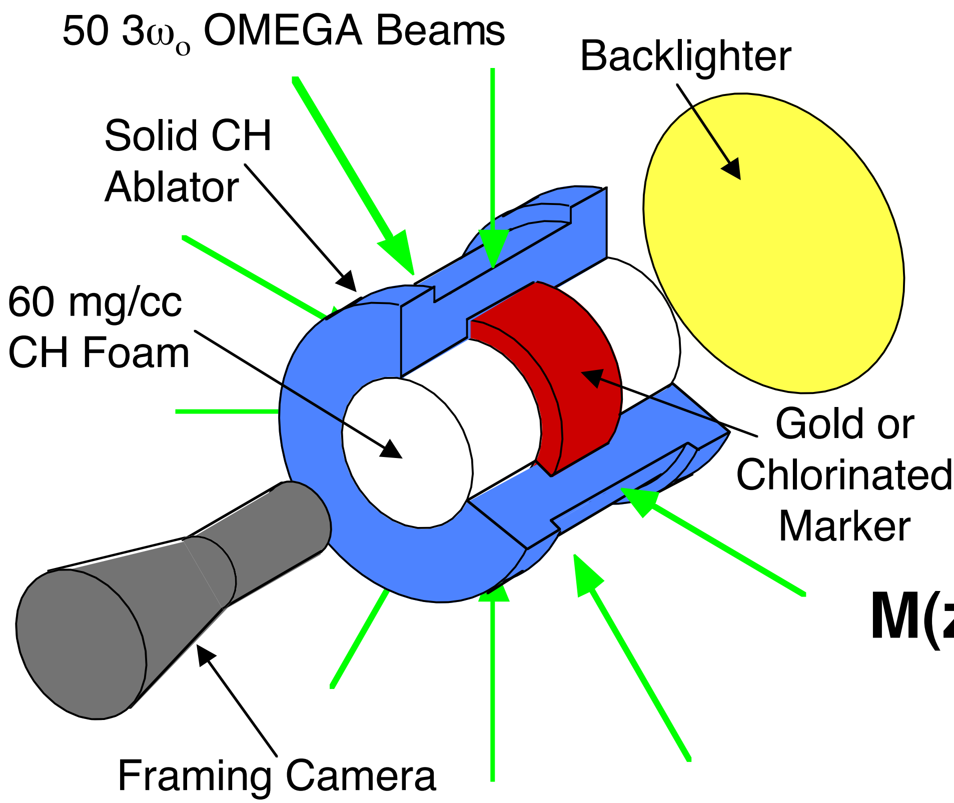


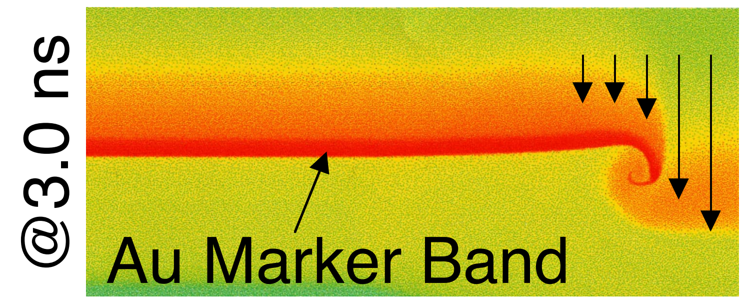




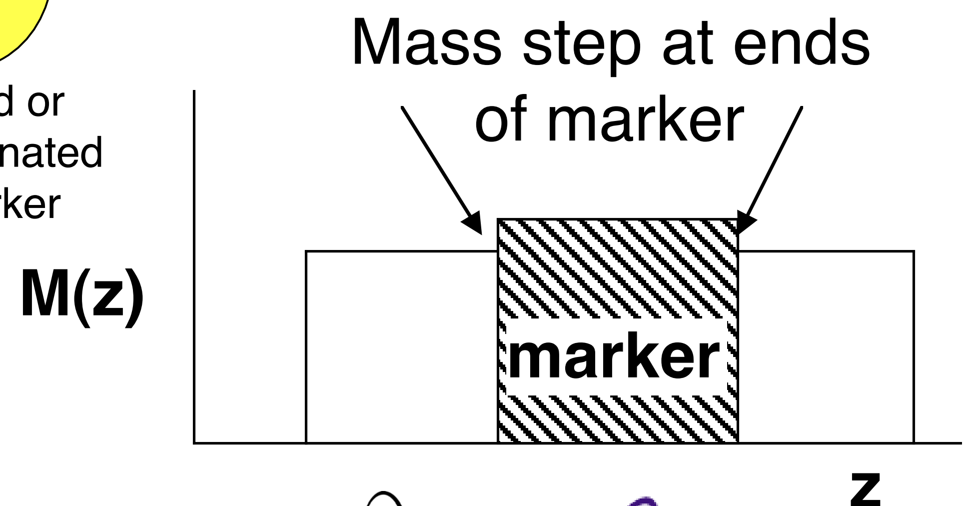
Creation of vorticity at ends of marker layer can increase apparent marker layer width

Experimental Set-Up





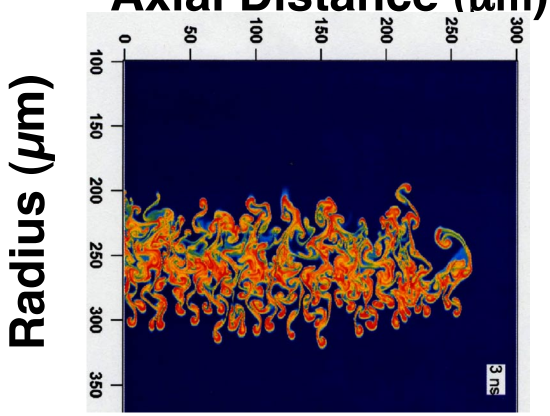
$$M(z) = \int_0^\infty \rho(r,z)\, dr$$



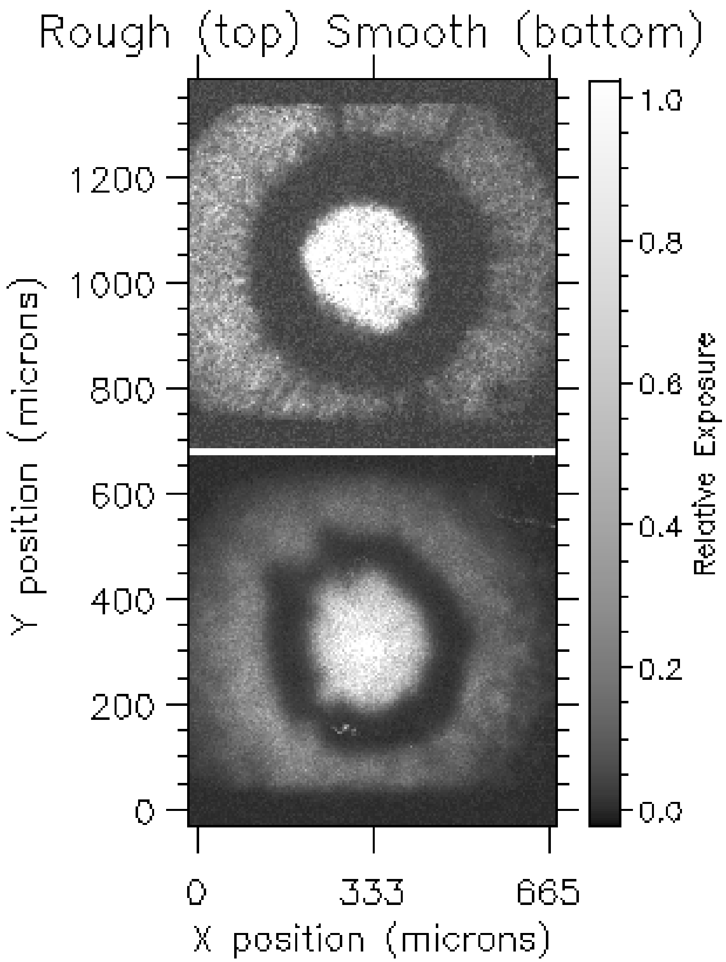
Smoother surfaces don't show as much mix

- **Same material**
  - **Same Atwood number and end effects**
- **Smooth mix width: ≈ 95 μm**
- **Rough mix width: 144 μm**
- **Mixing from larger surface roughness overwhelms end effect, which dominates smooth case**

RAGE DNS calculation



Au volume fraction



Numerical simulations help uncover the important physics in mix

A wide range of simulations are underway at LANL and AWE

- SOXO : 1D Lagrangian + dynamic mix model
- PETRA : 2-D R-Θ and R-Z semi Eulerian
- TURMOIL : 2D & 3D perfect fluid code
- LASNEX : 2D R-Z
- RAGE : 2D R-Z and R-Θ

Can use measured surface roughness

RAGE does highly resolved simulations*

- **RAGE is an Eulerian, radiation-hydrodynamics code with continuous adaptive mesh refinement**
- **Unlike LASNEX, RAGE can calculate** *Rough* **surfaces**
- **All calculations included:**
  - **One group (grey) radiation diffusion used in** *smooth* **cases**
  - **Radiation transport was turned** ‘off’ **for** *rough* **simulations**
    - » **Similar radiographs are produced with radiation transport** ‘On’
  - **Sesame equation-of-state and opacities**
  - **LTE**
- **Caveat :**
  - **Rage lacks 3-D Laser raytrace package**
    - » **Laser energy is deposited directly into cylinder surface with an energy source**

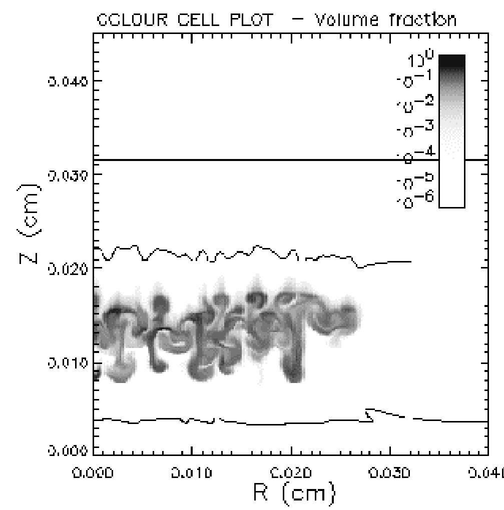
***See poster by John Scott**

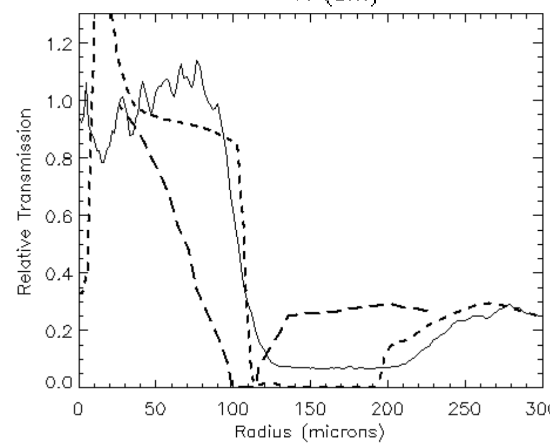
Calculated axial transmission profiles from more detailed simulations agree with experiments

- **PETRA and RAGE (short dashed lines) predictions in general agreement with observations (solid curve) from initially rough gold markers.**

- **Simulations with smooth initial conditions (as with LASNEX, long dashed lines) predict much smaller mix widths**

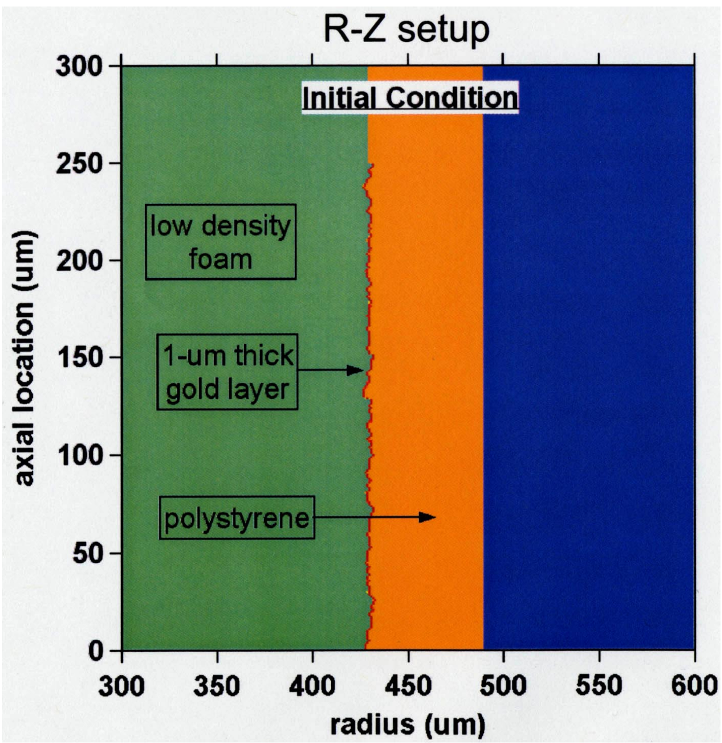
- **Some modeling uncertainties remain:**
  - **Absorbed energy affects zero-order hydro**
  - **R-Z and r-Θ calculations differ at 7% level**

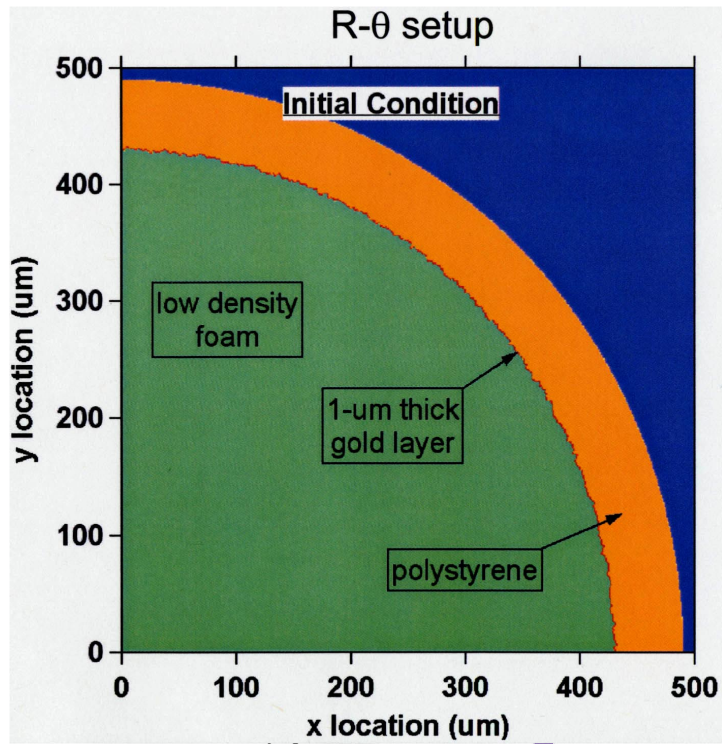




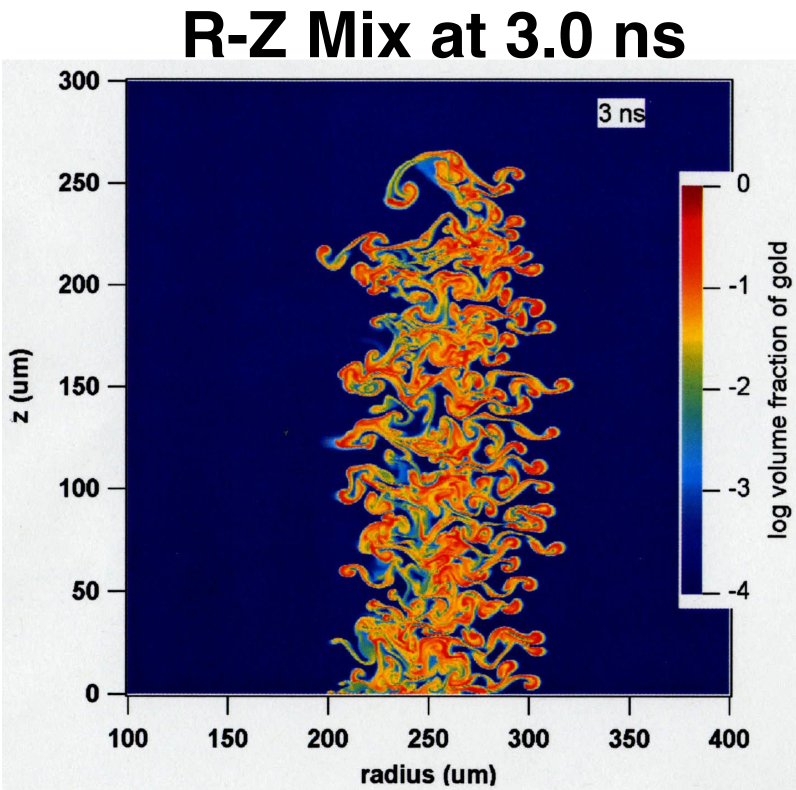
RAGE can simulate as shot *Rough* interfaces, in both R-Z and R-Θ geometries

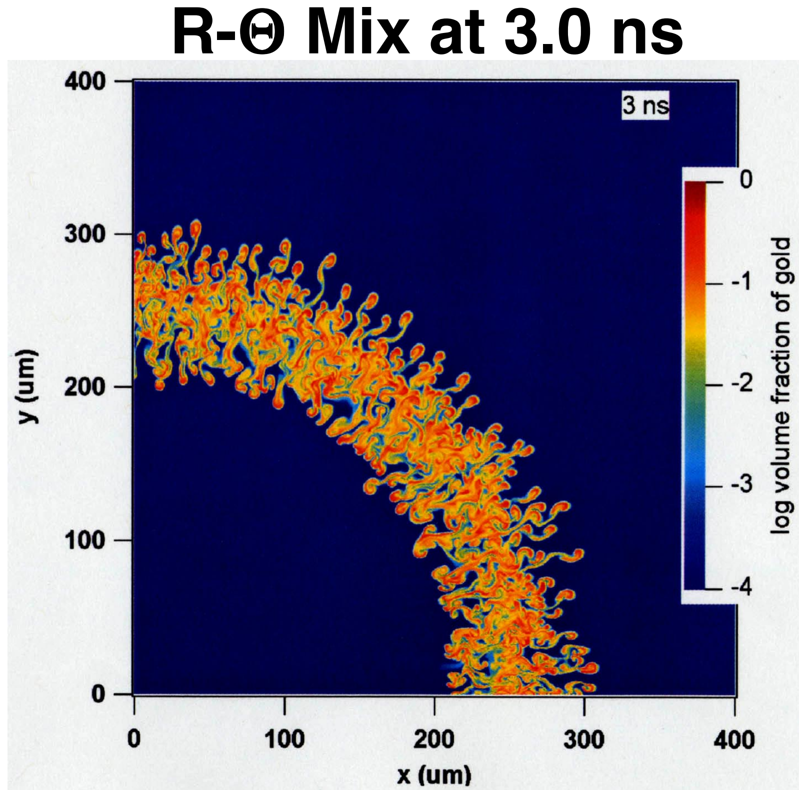
- **Initial R-Z and R-Q setups with as-shot *rough* surface finish**





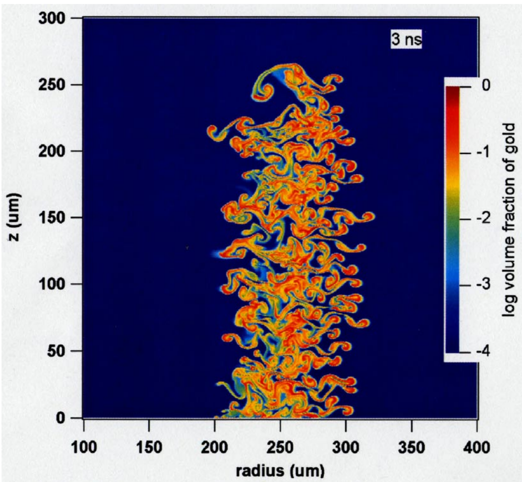
RAGE predicts mix from *Rough* surfaces overwhelms the filigree

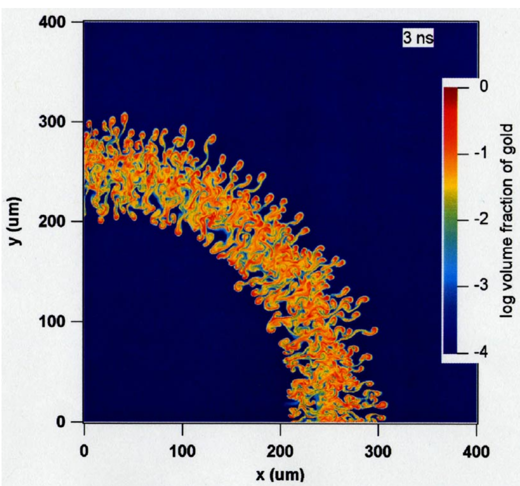




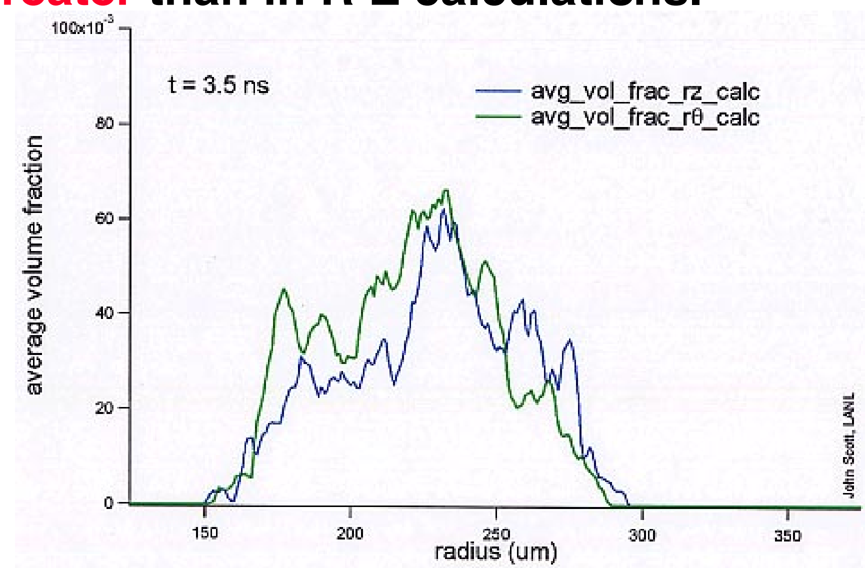
- Even at 3.0 ns, predicted mix is significant
- Of order ~100 μm

R-θ and R-Z calculations in RAGE agree in implosion hydro and volume fraction

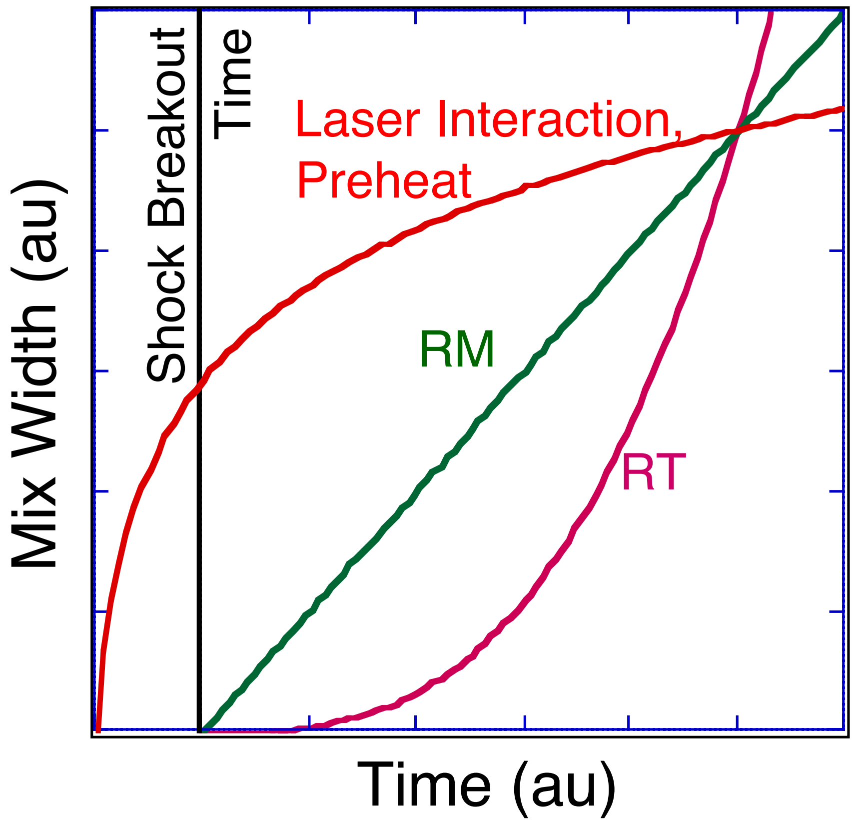




- The zeroth-order hydro is the *same* in RAGE for R-Z and R-θ calculations (same implosion for same energy boundary condition)
- The volume fraction profiles are the same
- The mix width of simulated radiography transmission profiles in R-θ calculations is greater than in R-Z calculations.



What kind of temporal evolution is expected?



- Preheat effects or strong laser interaction with marker, could make marker initially very wide with little or no subsequent evolution.

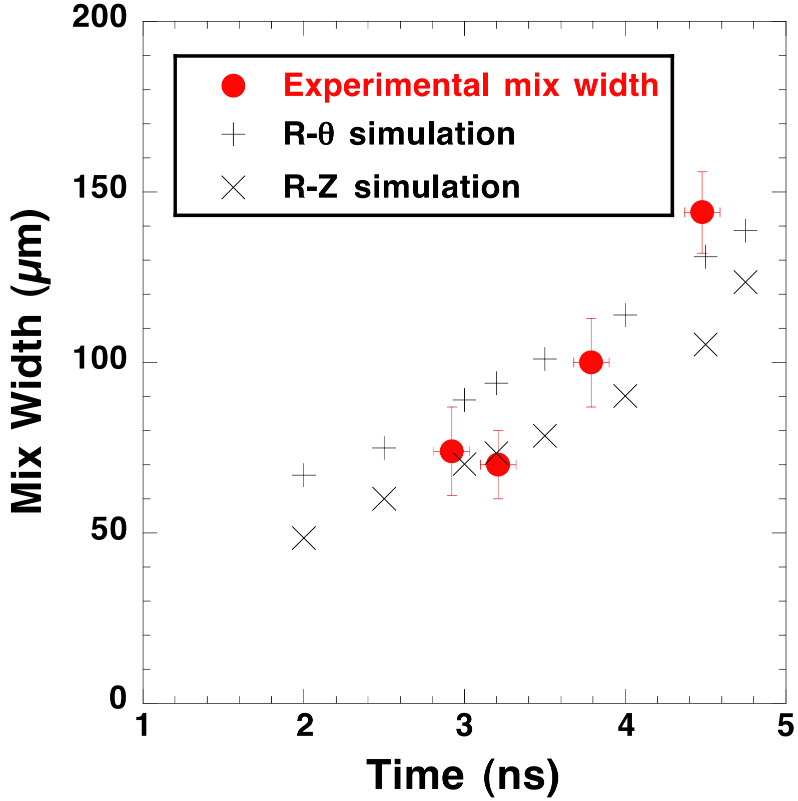
- Late-time Rayleigh-Taylor from deceleration could make marker grow quadratic or faster late in time.

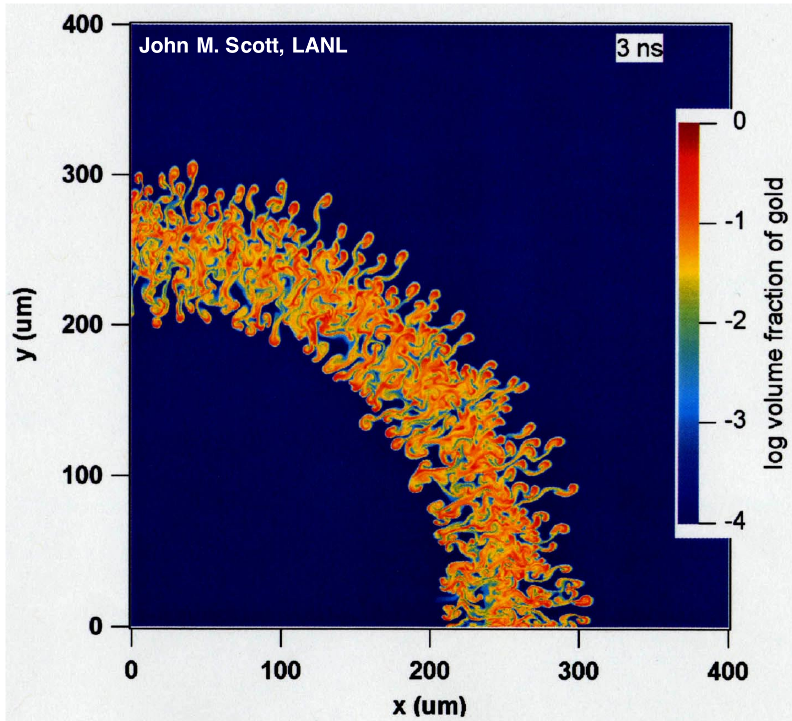
- Linear evolution would be consistent with Richtmyer-Meshkov growth.

Multiple measurements in time required to discern cause of mixing.

Time dependent measurements of compressible mix in a convergent geometry have been made

Comparison of cylindrical mix experimental data with simulation

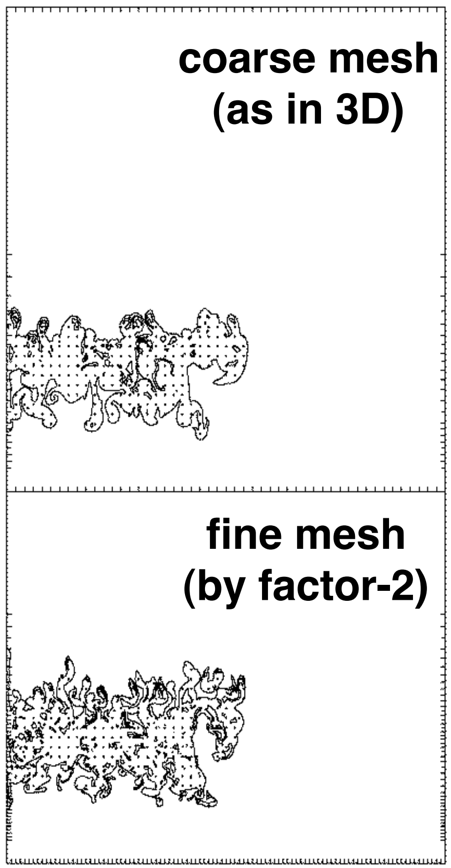




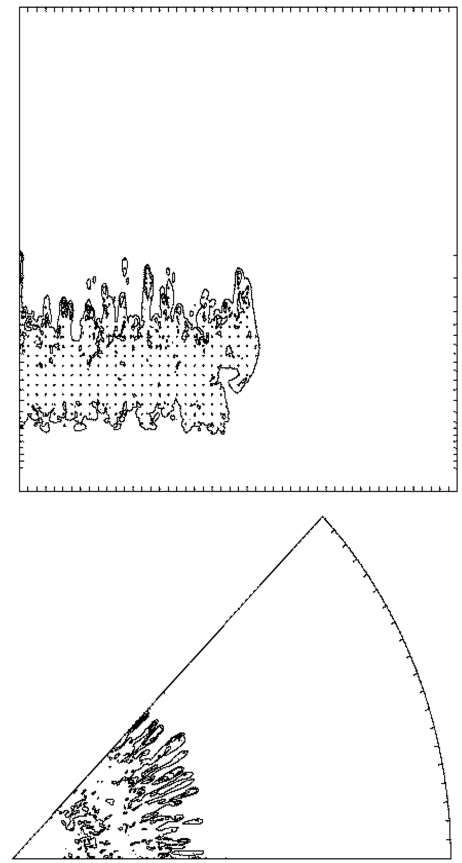
RAGE simulation of experiment

2D and fully 3D TURMOIL calculations predict similar mixing profiles

2D results

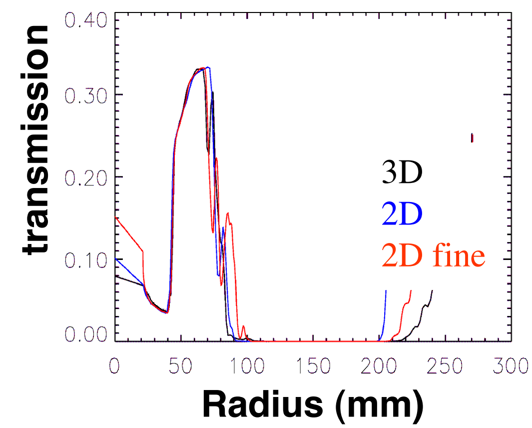


3D results



3D code calculates short-wavelength streamers penetrating to high radius (as seen in experiment?)

Overall mix profile similar



Conclusions

- **We have established a useful, laser-based test bed for convergent, compressible, plasma mix experiments**
- **With sufficiently rough initial surfaces, we see measurable mix which increase close to linearly in time**
- **Results are in agreement with 2-D (in r-Z and r-θ) and 3-D fully resolved direct numerical simulations**
- **Future improvements: A lower opacity marker layer will eliminate the end-effect vortical structures**