Novel, high-pressure instability experiments using imploding cylindrical liners with liquid deuterium fill

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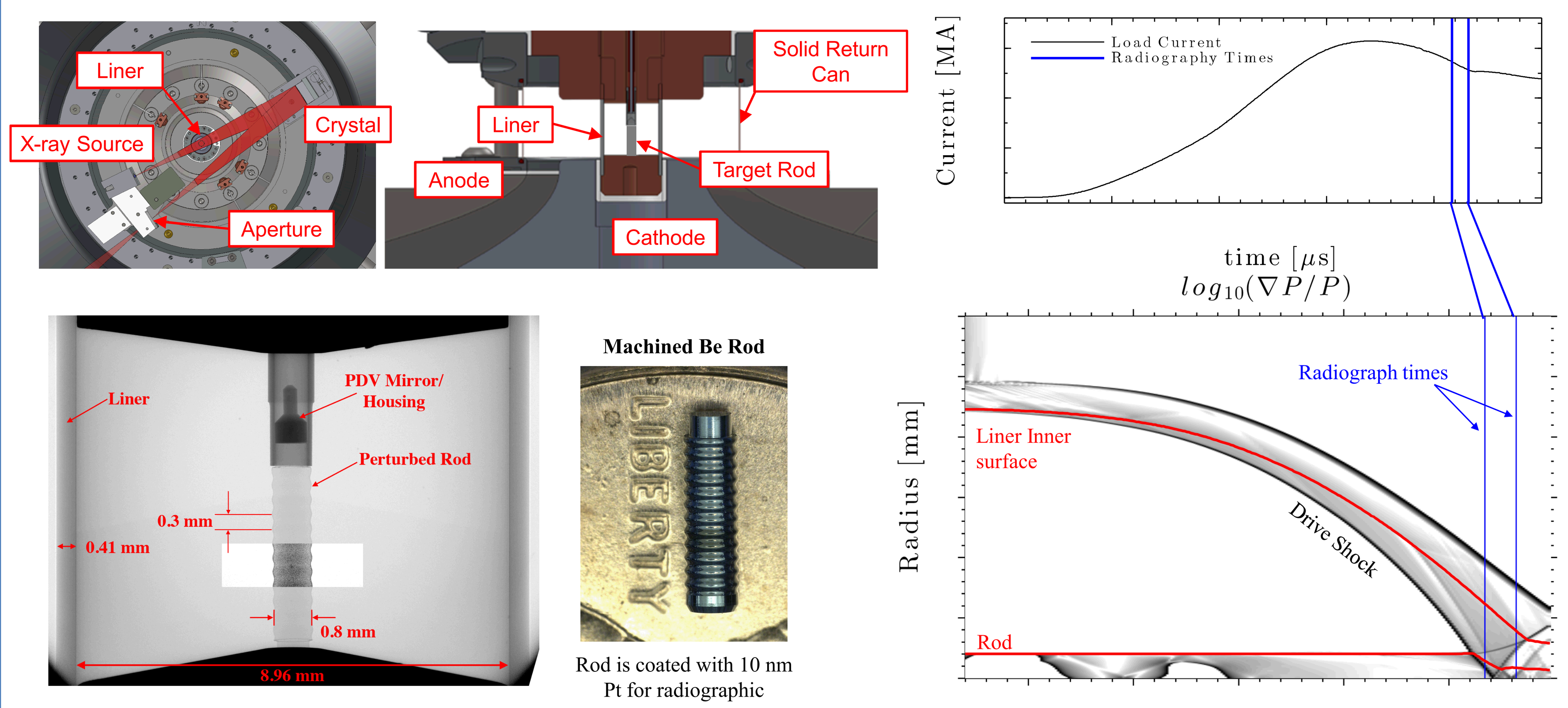
Abstract

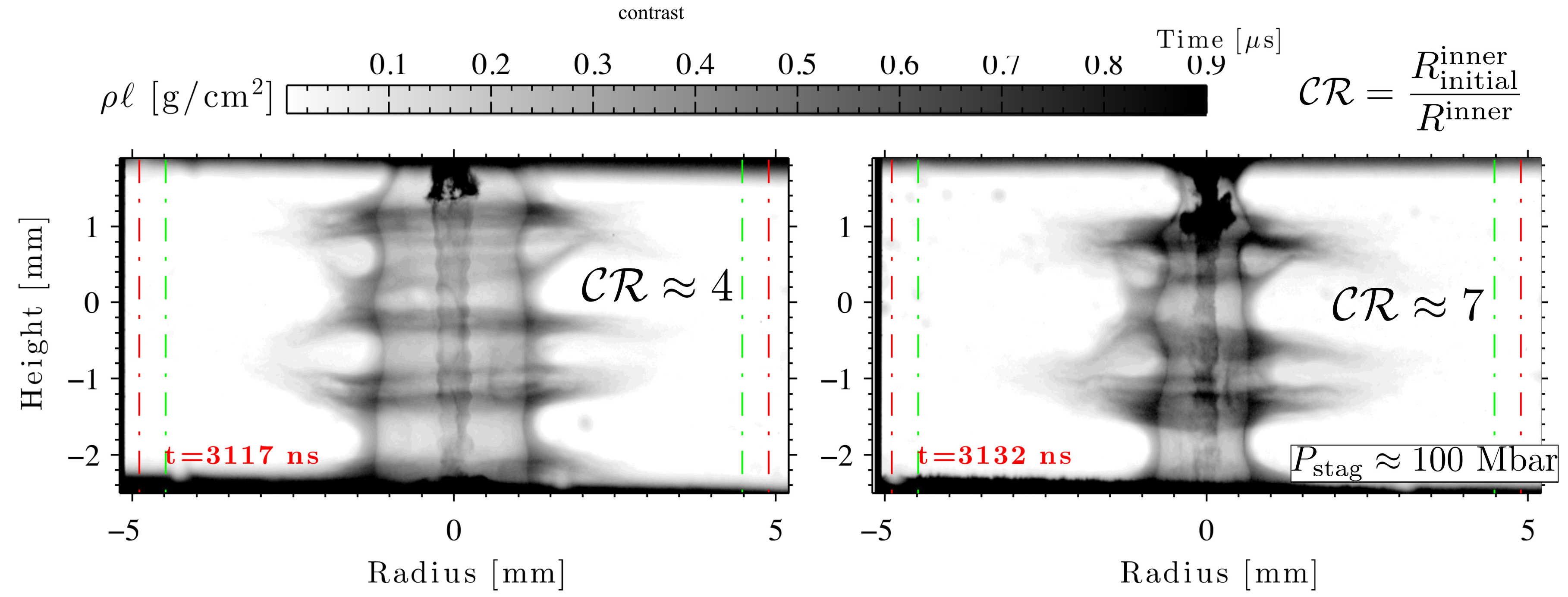
We present preliminary results from experiments where a liquid deuterium filled cylindrical liner is imploded onto a perturbed beryllium rod. The liner implosion creates a shock in the deuterium that strikes the interface twice: once as it implodes, and once again after the shock reflects off of the axis. This causes the perturbation to grow due to the Richtmeyer-Meshkov[1] instability and the Rayleigh-Taylor instability[2] while also generating significant vorticity as the shocks cross the interface. In the initial experiments growth of the perturbation is observed after 1st shock, however, after reshock significant three-dimensional structure is observed at scale lengths much smaller than the initial perturbation. At this time, very little evidence of the seeded mode remains. Pressures exceeding 100 Mbar are predicted at stagnation with an Atwood number at the unstable interface of about 1/3. Analysis of the images will be presented. Additionally, future plans will be discussed. Emphasis in the near future will be on improving image contrast and data collection.

Motivation

In any inertial fusion concept, deceleration instability growth is a likely source of pusher/fuel mix late in time that can spoil stagnation[3]. However, data during this phase of implosions is scarce and difficult to obtain because: (i) velocities are large (~100-400 km/s), (ii) scale sizes are small (~25-50 μm) and (iii) optical depths are large. Additionally, imposing perturbations at t=0 on the fuel/pusher interface results in unknown initial conditions at the onset of deceleration. To overcome these challenges we have begun developing a platform that studies perturbation growth on an on-axis rod in cylindrical geometry during the stagnation phase of a magnetically driven implosion. The Z-machine at Sandia National Laboratories[4] is used to implode a liquid deuterium filled, beryllium liner onto a perturbed on-axis Be rod. The rod retains its initial perturbation until the shock strikes it. Soon afterwards, the shock reflects off the axis and strikes the rod/deuterium interface again. Using penetrating radiography to probe the perturbation evolution makes this platform a powerful tool for studying the physics of instability growth and mixing at high convergence and low Atwood number.

Experimental Description



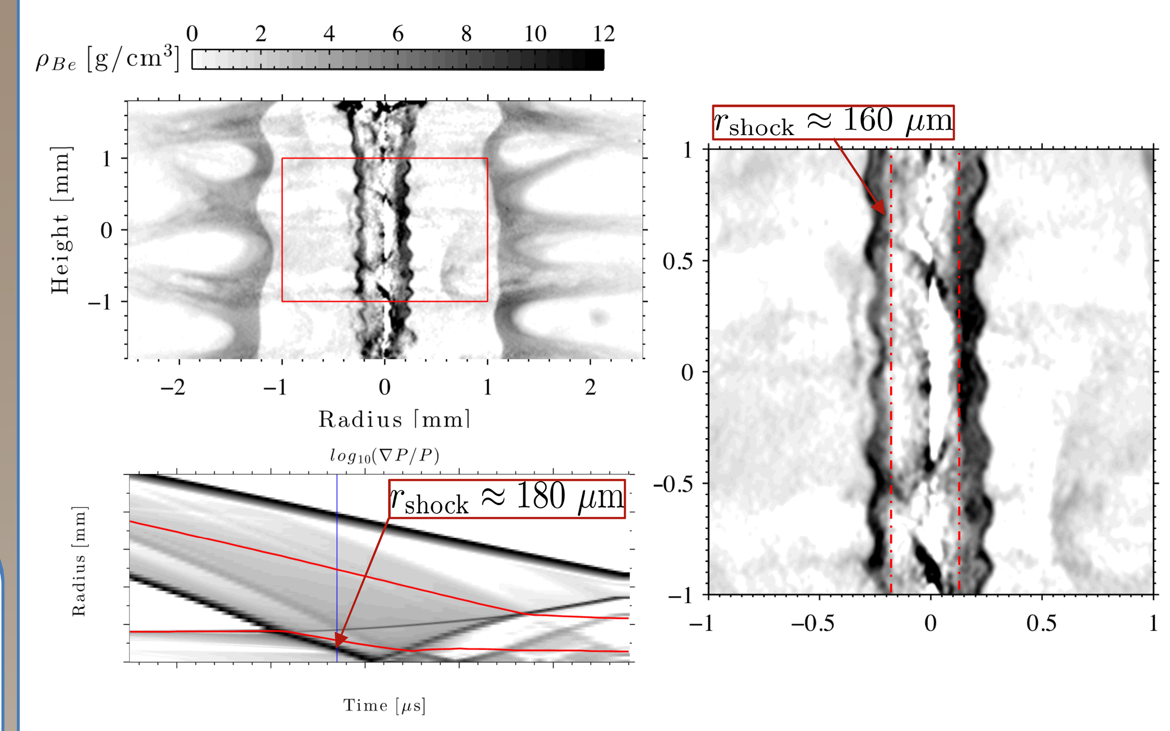


Shock velocity in rod is: $v_{shock} \approx 40$ km/s

Giving a Mach number of: $M_{shock} \approx 3$

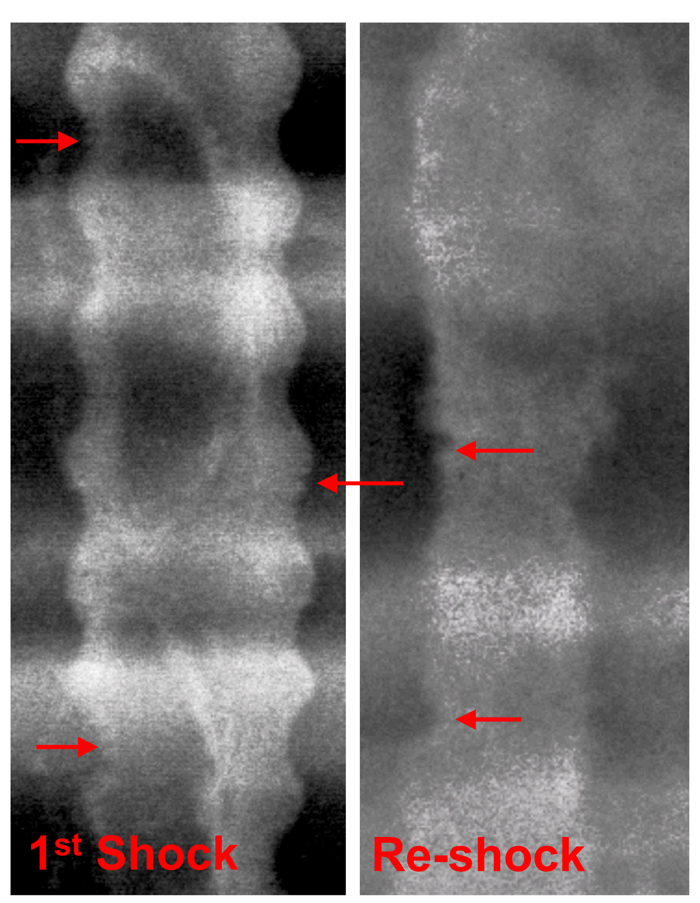
At stagnation the Atwood number is: $A = \frac{\rho_{Be} - \rho_D}{\rho_{Be} + \rho_D} = 0.3 - 0.4$

Interaction of shock with on-axis rod



- 1st radiograph maintains sufficient symmetry and integrity to perform Abel inversion
- Location of shock in the rod is visible and in reasonable agreement with 1D simulation
- Radius of shock is not symmetric, indicating azimuthal asymmetry in incoming shock
- MRT feed-through on the inner surface of the liner is apparent
- These asymmetries could deposit significant vorticity at the rod interface and drive small-scale structures
- Removing both of these sources of asymmetry is a focus of future experiments (in design now)

Direct observation of secondary instability growth



- First diagnosis of short wavelength secondary hydro-instabilities in a convergent liner experiment
- Unexpected development of correlated pockets at scale lengths between seeded instability and secondary instabilities

Acknowledgements: The authors would like to thank Dr. Brent Blue (LLNL) for his work in designing and helping to fabricate the on-axis rod.

References:

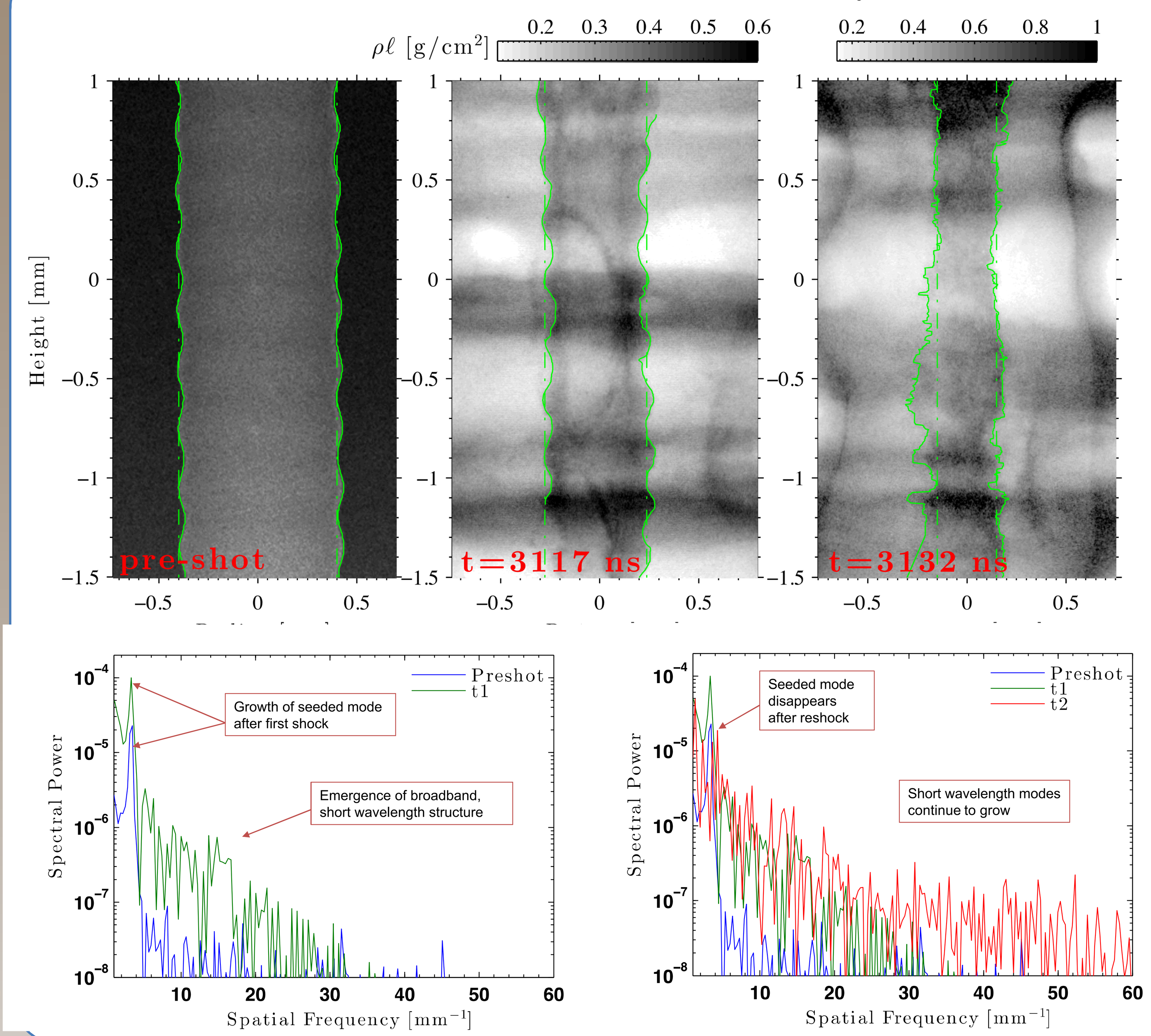
[1] Richard L. Holmes, et al. (1999). Journal of Fluid Mechanics, 389, pp 55-79

[2] H.J. Kull, Theory of the Rayleigh-Taylor instability, Physics Reports, Volume 206, Issue 5, August 1991, Pages 197-325

[3] Betti, R. and Umansky, M. and Lobatchev, V. and Goncharov, V. N. and McCrory, R. L., Physics of Plasmas, 8, 5257-5267 (2001)

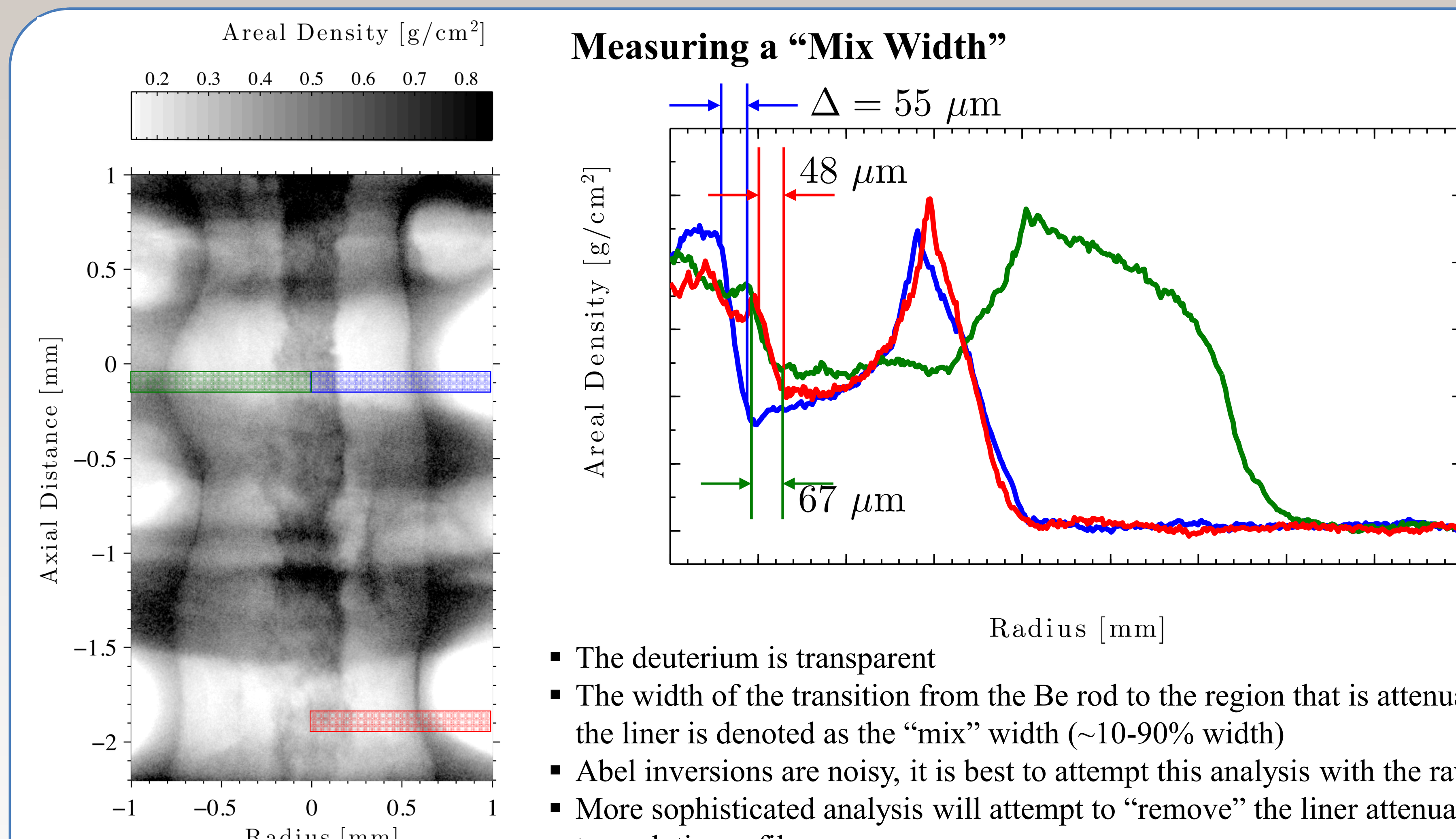
[4] M. Savage, et al., in IEEE International Power Modulators and High Voltage Conference, Proceedings of the 2008 (2008), pp. 93

Perturbation Analysis



- Rod contours found using a gradient based edge detection technique
- Fourier transforms are taken of each of the contours
- At t=3117 ns, the rod has been compressed and the perturbation amplitude is ~2x larger
- Some correlated structures at higher wavenumbers begin to emerge
- At t= 3132 ns, the initial perturbation is completely erased. May be due to a phase inversion
- Strongly 3D, uncorrelated structures are observed at higher wavenumbers
- Transition from Be to deuterium is blurred, presumably due to loss of azimuthal correlation and mixing at the interface

Measuring a "Mix Width"



- The deuterium is transparent
- The width of the transition from the Be rod to the region that is attenuated only by the liner is denoted as the "mix" width (~10-90% width)
- Abel inversions are noisy, it is best to attempt this analysis with the raw data
- More sophisticated analysis will attempt to "remove" the liner attenuation using fit to analytic profile

Conclusions and Future Work

- We have observed development of secondary instabilities at high wave numbers in a high convergence, re-shock experiment
- Seeded perturbation disappears after reshock
- Preliminary analysis of "mix width" suggests a relatively uniform width despite axial variations
- In the future, we plan to lower the liner aspect ratio to improve stability and reduce asymmetries and investigate growth of structures from surface roughness

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