

High Energy Density Plasmas & Fluids at LANL



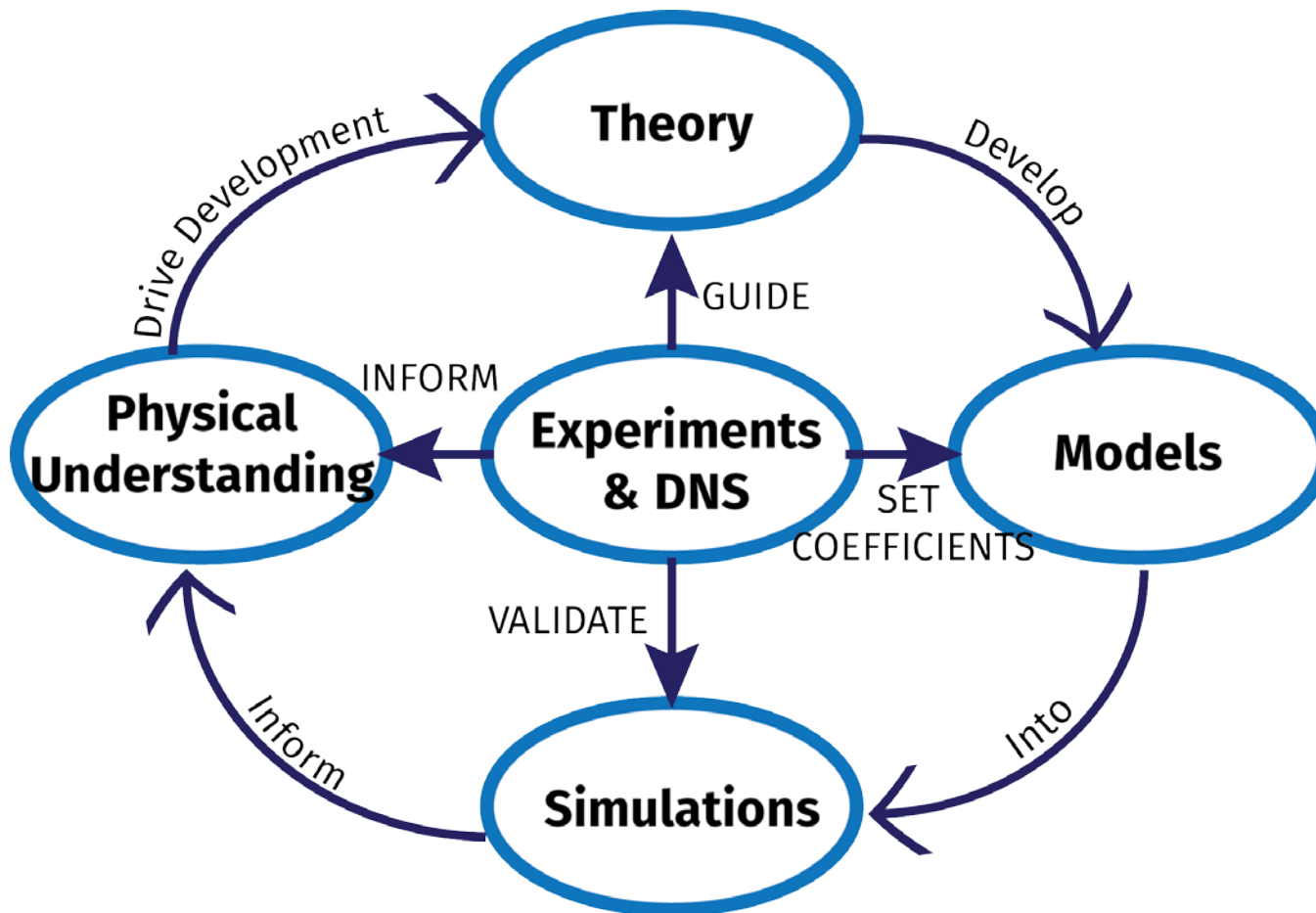
David D. Meyerhofer
Physics Division Leader

November 30, 2016

LANL has a diverse program of High Energy Density Physics and Fluids (HEDP&F) research

- High energy density (HED) conditions occur at pressures above approximately 1 million atmospheres (> 1 Mbar)
- Fluids research is focused on hydrodynamic instabilities, turbulence, and turbulent transport and mix
 - It spans classical through high energy density regimes
- LANL's Inertial Confinement Fusion (ICF) focuses on
 - Alternative paths to high yield (and possibly ignition) and platforms that can be perturbed from 1-D performance
 - Understanding the role of kinetic effects in plasmas
 - Developing transformative diagnostics
- Other physics interests include radiation flow and opacity

LANL's HEDP&F Capability integrates theory, simulation, and experiment for maximal impact



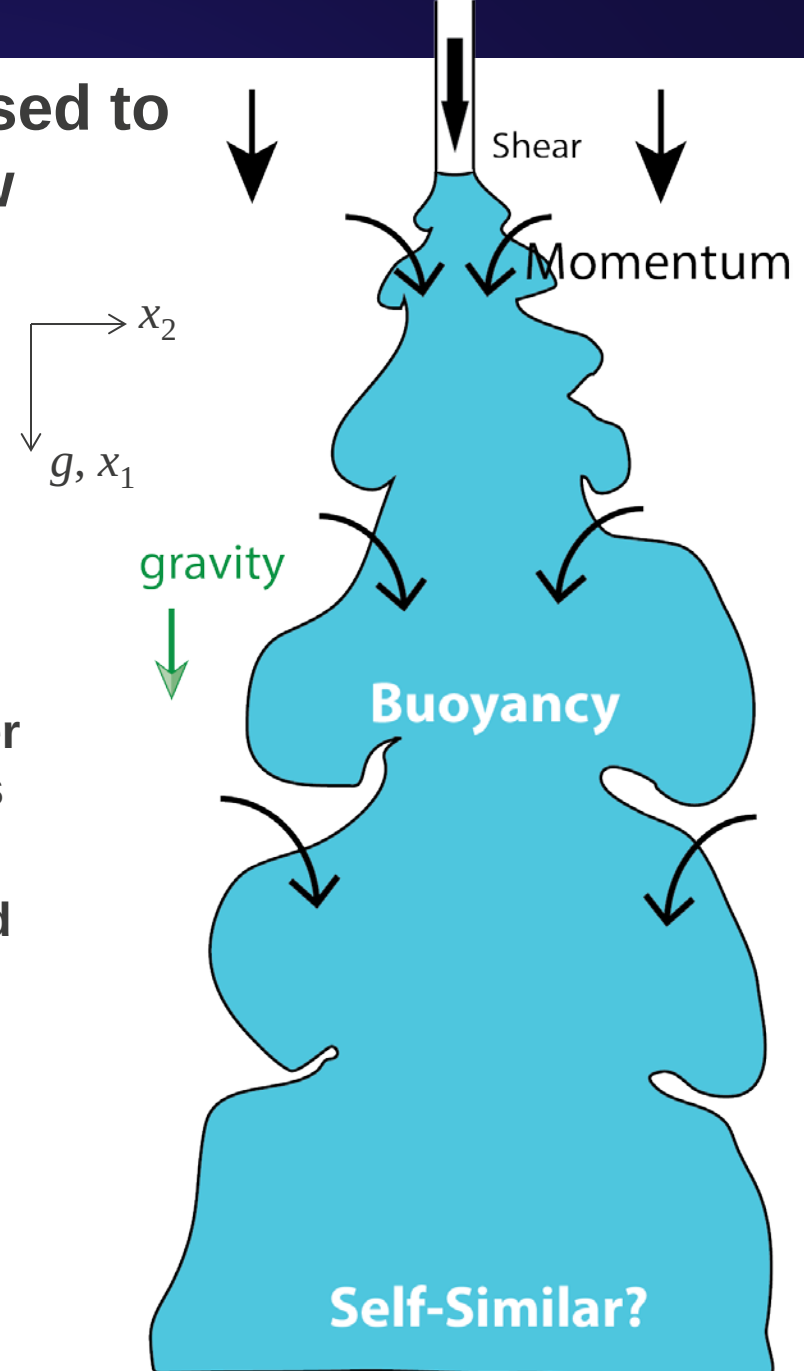
DNS=Direct Numerical Simulations

Los Alamos fluids teams work together to prioritize the physics issues that are most impactful to our programs

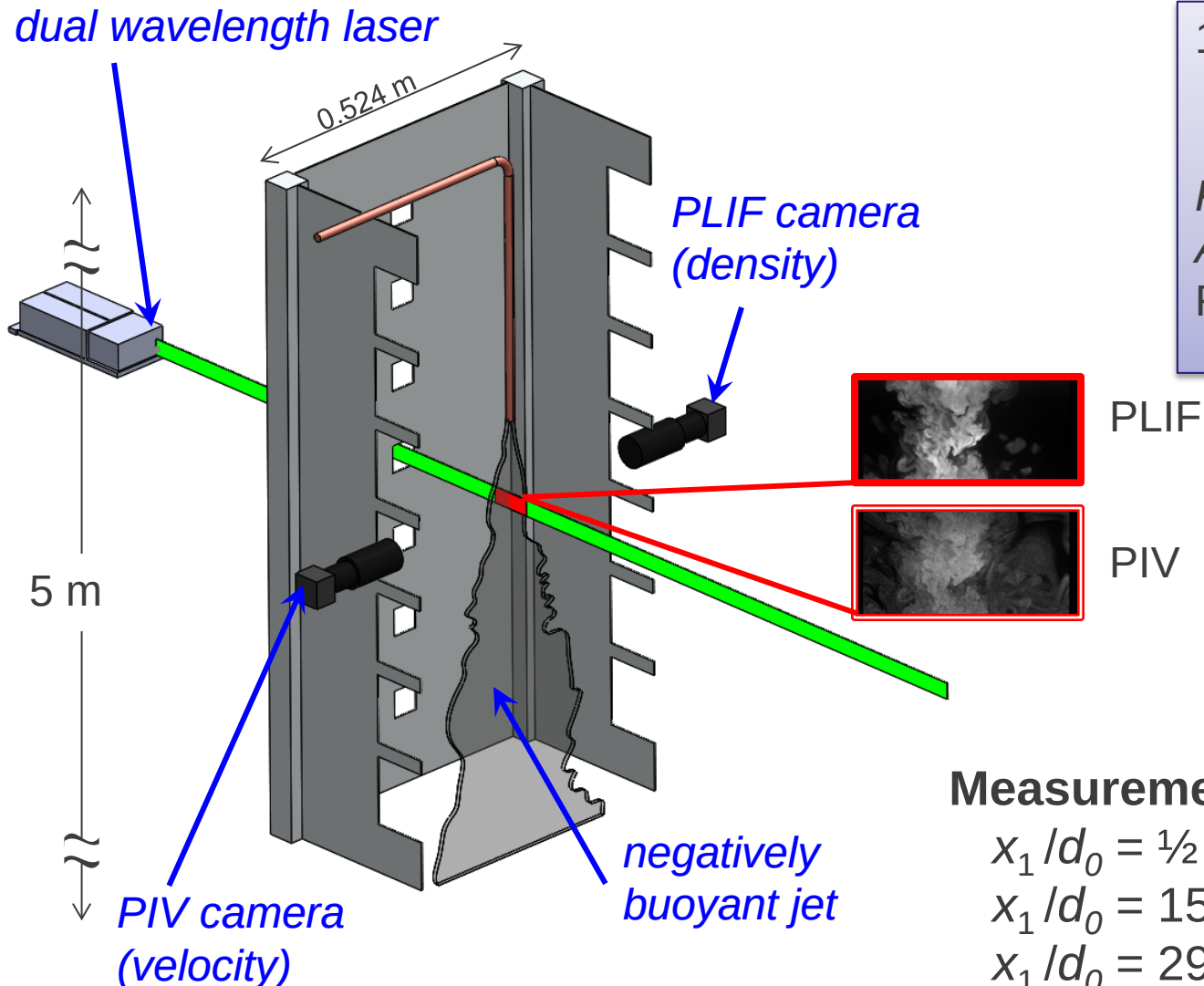
- Mission-related fluids problems are characterized by “extreme” regimes
 - Multiple instabilities (RT, RM, KH)
 - Multiphase flows with particles changing size, shape, 4-way coupling, etc.
 - Unsteady turbulence that remembers its initial conditions
 - Extension into the HED regime
 - **All of the above, with shocks!**
- Three fluids and turbulence facilities:
 - Vertical Shock Tube (VST): Richtmyer-Meshkov mixing
 - Turbulent Mixing Tunnel (TMT): Variable-density mixing (subsonic)
 - Horizontal Shock Tube (HST): Shocked multiphase flow

Buoyant jets in a co-flow are used to test models and search for new physical insights

- Spatially evolving
- Anisotropic (direction matters)
- Inhomogeneous (both in motion and composition)
- How does the resulting turbulence evolve in this flow, and how does it differ from classic Kolmogorov homogeneous isotropic turbulence?
- How do the current models perform, and can we use them to match the experiment?



The Turbulent Mixing Tunnel and diagnostics let us capture the evolution of the inhomogeneities of buoyant jet flows



10,000 velocity/density fields of the flow per case

$Re = 19,000$

$At = 0.1, 0.6$

Resolution $\sim 250 \mu m$

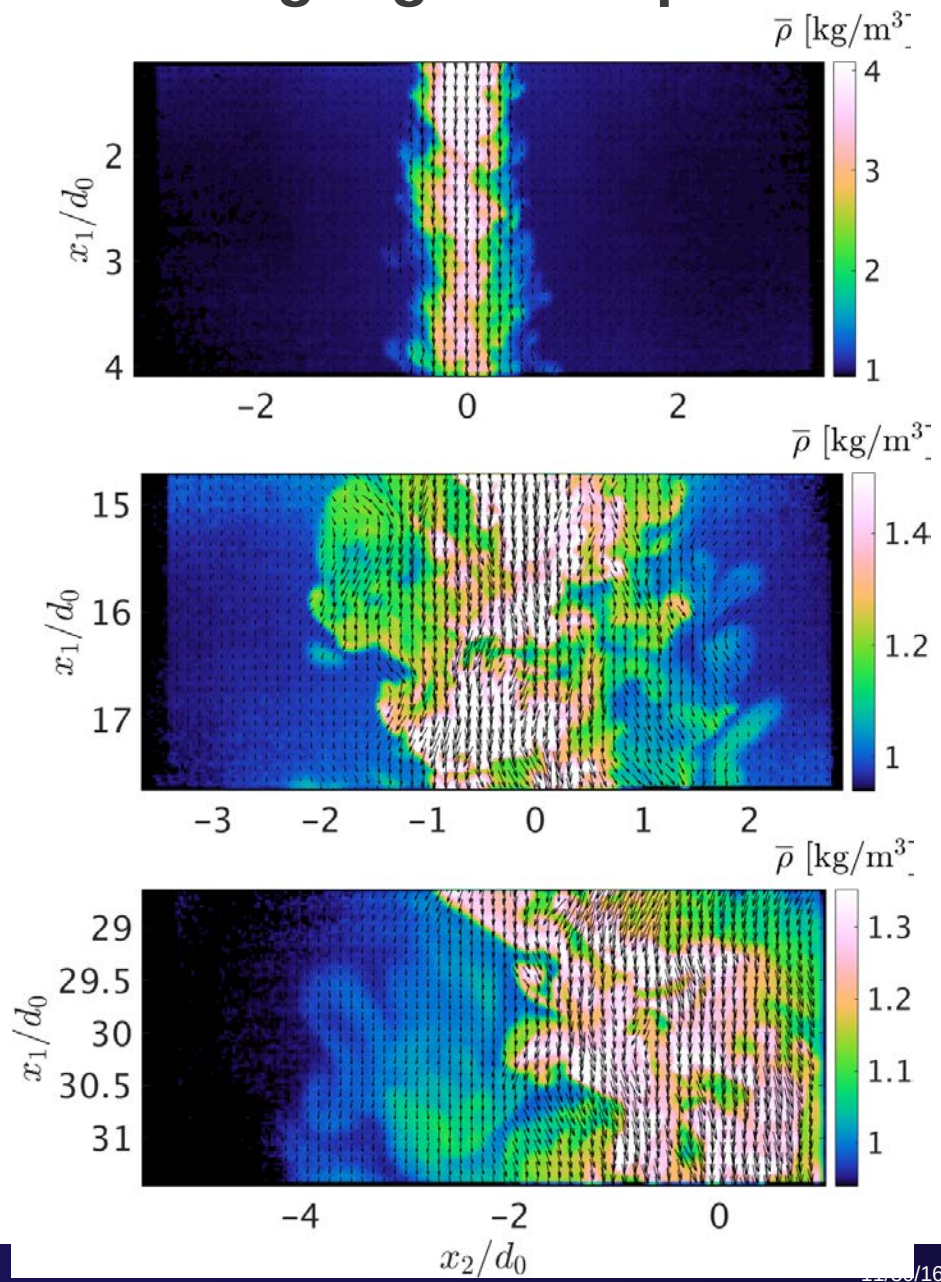
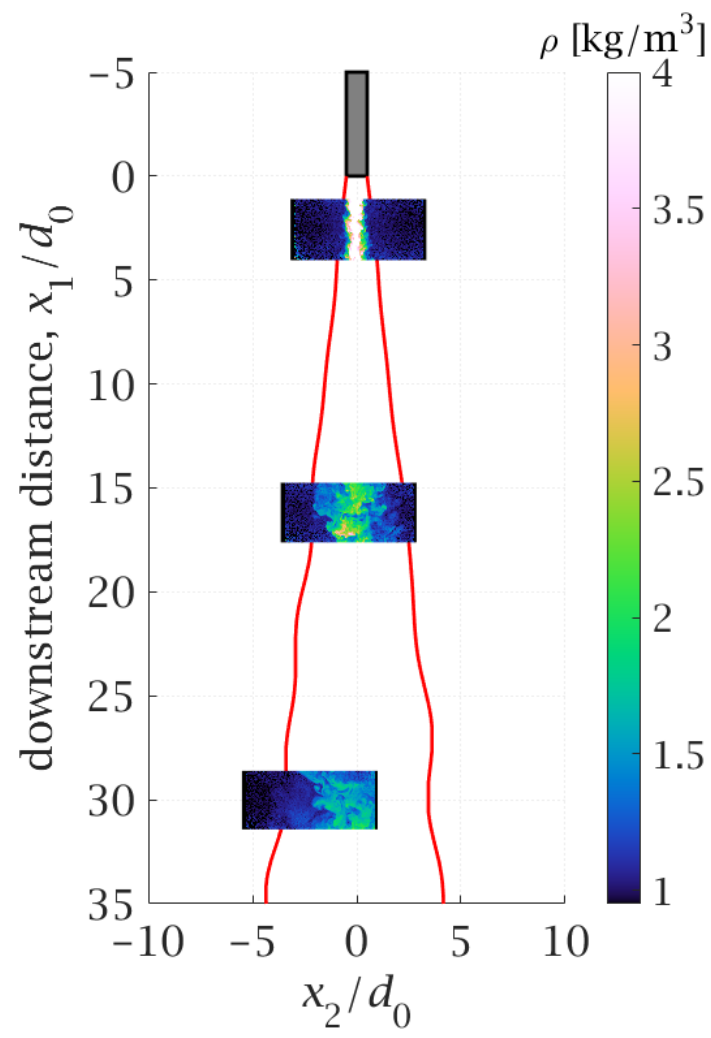
Measurements at:

$x_1/d_0 = 1/2 - 3$: shear

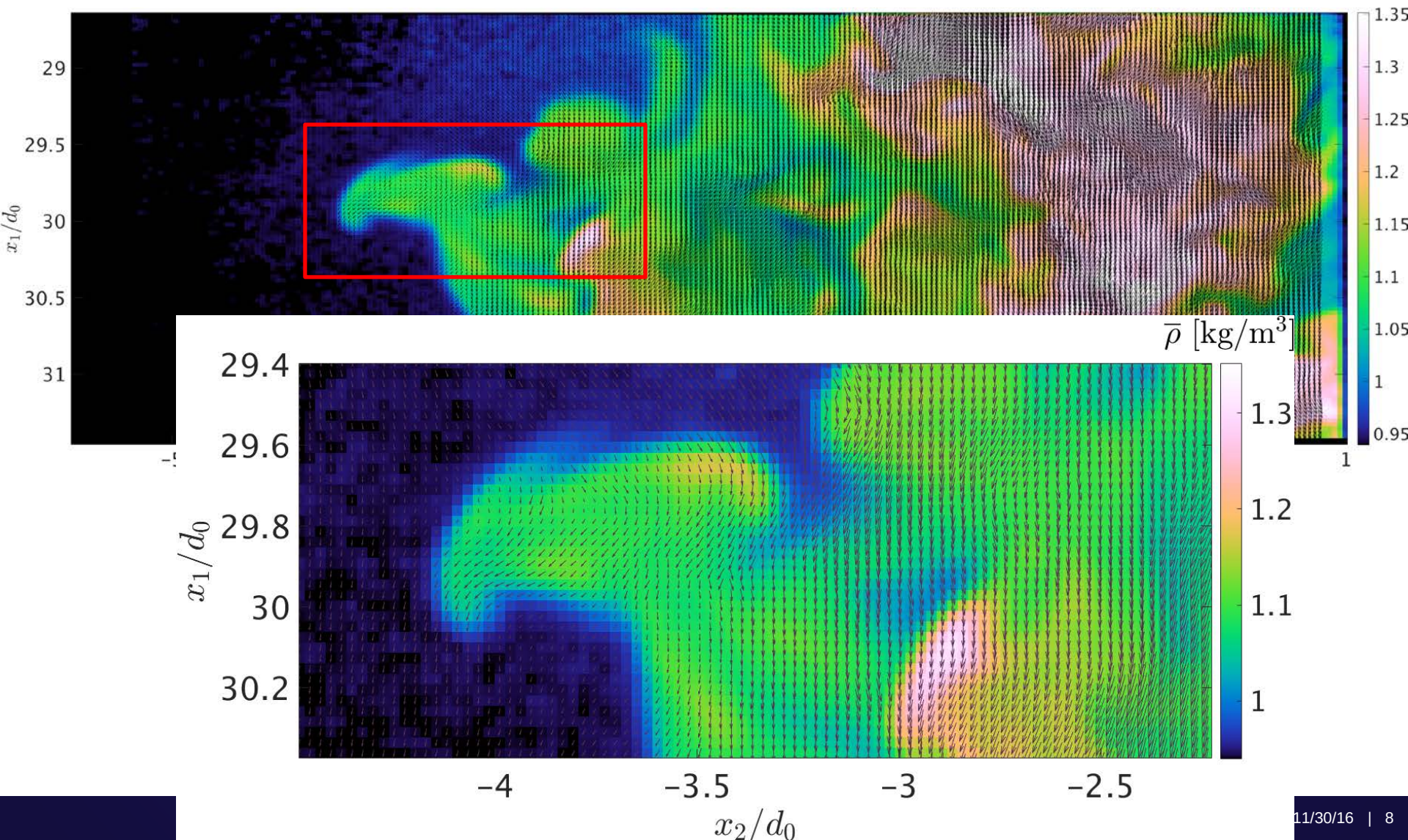
$x_1/d_0 = 15 - 18$: buoyancy

$x_1/d_0 = 29 - 31$: fully developed?

Three locations were selected to highlight the spatial evolution of the physics



At full resolution (~41,000 data sites), the fine detail of the interaction between the density and velocity are clear allowing determination of transport coefficients through correlations



Variable density effects cause the production of turbulent fluctuations (Reynolds stress) and additional mass flux

- Reynolds Stress, R_{ik}

$$\frac{\partial(\bar{\rho}\tilde{R}_{ij})}{\partial t} + \frac{\partial}{\partial x_k}(\bar{\rho}\tilde{u}_k\tilde{R}_{ij}) = \boxed{a_i \frac{\partial \bar{P}}{\partial x_j} + a_j \frac{\partial \bar{P}}{\partial x_i} - \bar{\rho}\tilde{R}_{ik} \frac{\partial \tilde{u}_j}{\partial x_k} - \bar{\rho}\tilde{R}_{jk} \frac{\partial \tilde{u}_i}{\partial x_k} - a_i \frac{\partial \tilde{\tau}_{jk}}{\partial x_k} - a_j \frac{\partial \tilde{\tau}_{ik}}{\partial x_k}} \\ - \frac{\partial}{\partial x_k} \overline{\rho u_i'' u_j'' u_k''} + \frac{\partial}{\partial x_k} (\overline{u_i'' \tau_{jk}''} + \overline{u_j'' \tau_{ik}''}) - \frac{\partial}{\partial x_j} \overline{u_i'' P'} - \frac{\partial}{\partial x_i} \overline{u_j'' P'} + \overline{P' \frac{\partial u_i''}{\partial x_j}} + \overline{P' \frac{\partial u_j''}{\partial x_i}} - \overline{\tau_{jk}'' \frac{\partial u_i''}{\partial x_k}} - \overline{\tau_{ik}'' \frac{\partial u_j''}{\partial x_k}}$$

- Turbulent Mass Flux, $\boxed{a_i \equiv -\overline{u_i''} = \overline{\rho' u_i'} / \bar{\rho}}$

$$\frac{\partial(\bar{\rho}a_i)}{\partial t} + (\rho\tilde{u}_j a_i)_{,j} = \boxed{b(\bar{P}_{,i} - \tilde{\tau}_{ki,k})} - \tilde{R}_{ik}\bar{\rho}_{,k} + \bar{\rho}(a_k a_i)_{,k} - \bar{\rho}a_k \bar{u}_{i,k} - \bar{\rho} \left(\frac{\overline{\rho' u_i' u_k'}}{\bar{\rho}} \right)_{,k} + \bar{\rho} v' (P'_{,i} - \tau'_{ki,k})$$

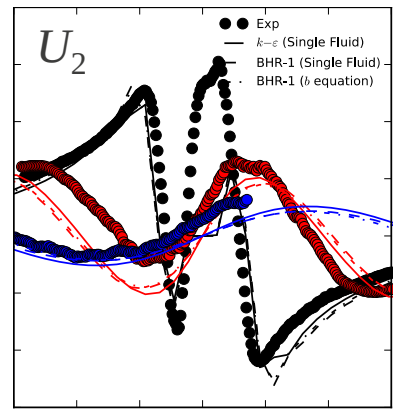
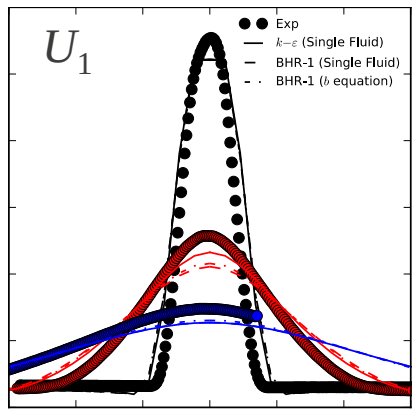
- Density-Specific Volume covariance, $\boxed{b = -\overline{\rho'(1/\rho)'}}$

$$\frac{\partial b}{\partial t} + \tilde{u}_j b_{,j} = -\frac{b+1}{\bar{\rho}} (\bar{\rho} a_k)_{,k} - \bar{\rho} (\overline{v' u_k'})_{,k} - 2\bar{\rho} (\overline{v' u_{k,k}'})$$

$u_i'' = u_i' - a_i$

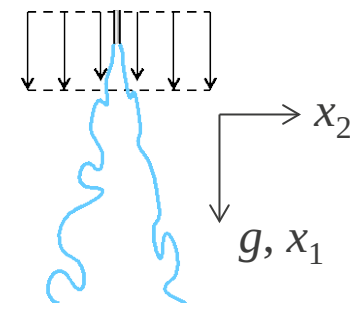
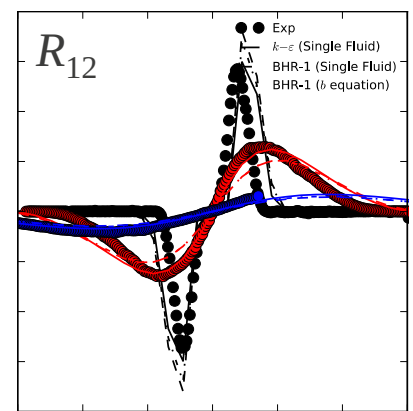
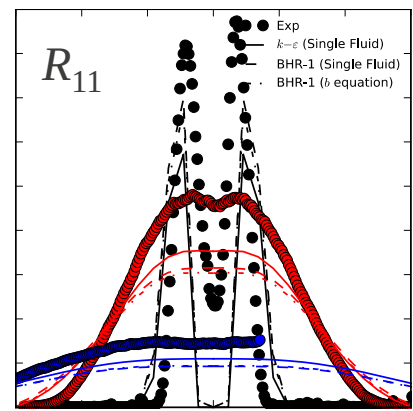
Even with simplified models, agreement with some turbulence quantities is good

velocity

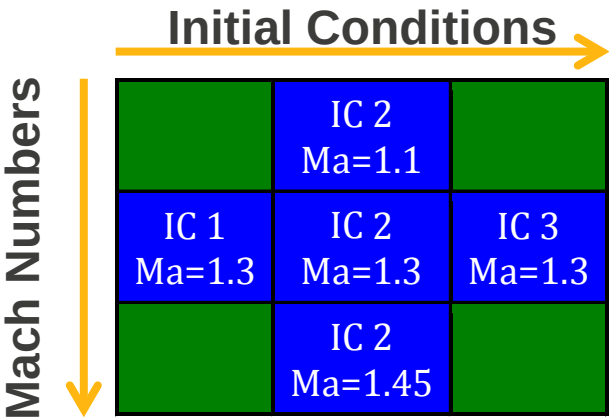
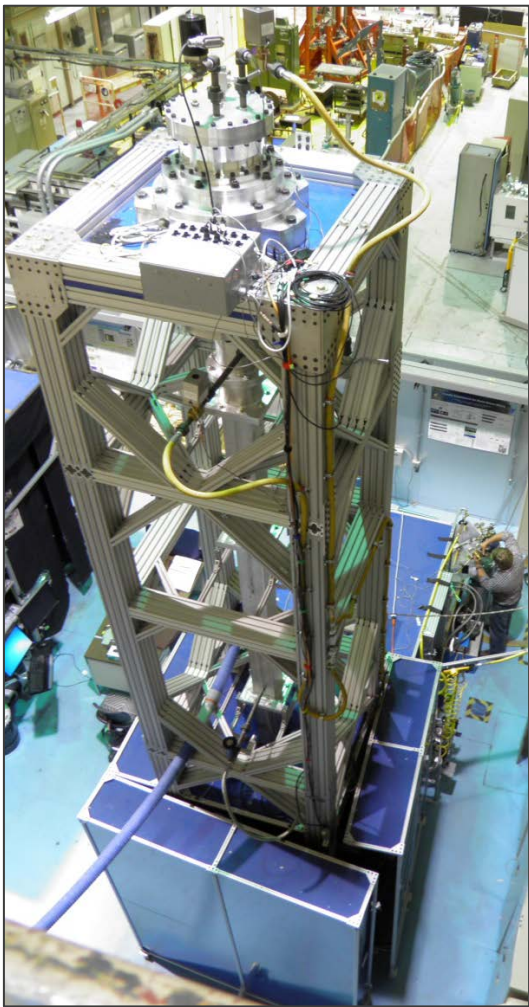


— $3d_0$
— $16d_0$
— $30d_0$

Reynolds
stresses



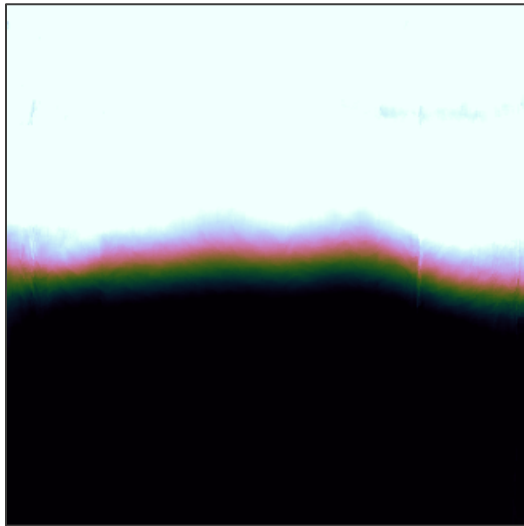
The Vertical Shock-Tube (VST) is LANL’s premier facility for studying the effect of Mach Number and Initial Conditions on RMI



Single Interface	Light (air) to heavy (SF6)
Atwood Number	0.6
Daily Shot Rate	50-100
Velocity Resolution	388 um/vector
Density Resolution	178 um/pixel
Taylor Microscale	~2-5 mm
Turbulence Diagnostics	2-D: Reynolds Stresses, K, a, b, PDFs of fluctuations and gradients

The current setup provides three-distinct regimes of *quantifiable* and *reproducible* initial conditions (ICs) that can be used directly for modeling and simulation

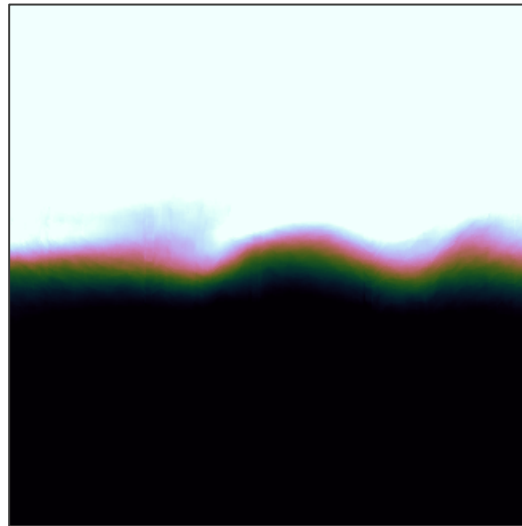
Density Contours



Initial Condition 1

- Horizontal plate
- Weak shear layer

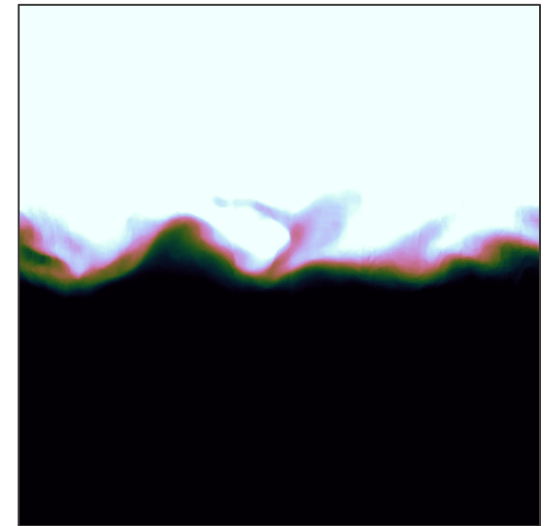
Result:
2D interface with few modes



Initial Condition 2

- Plate inclined 7°
- No flapping
- Stronger shear layer

Result:
Multimode in x-y plane,
single mode in z-plane



Initial Condition 3

- Trimodal flapping profile centered at 7°

Result:
Multimode 3D interface

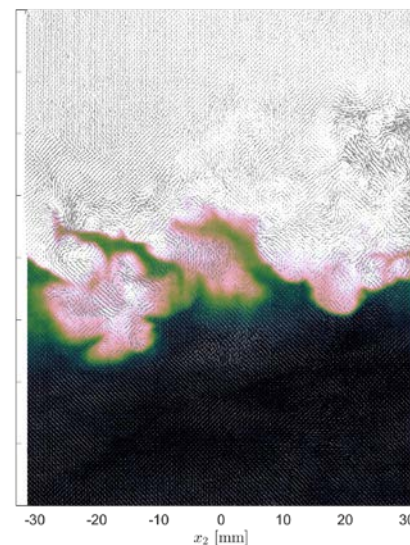
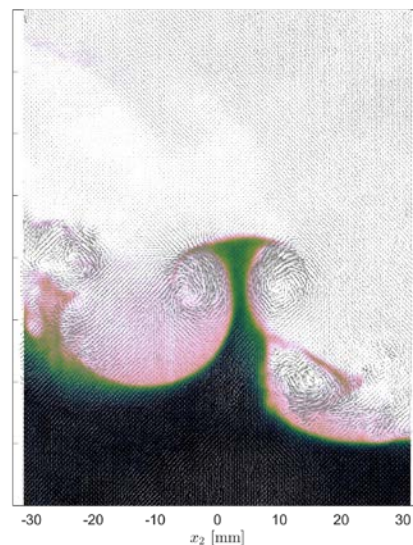
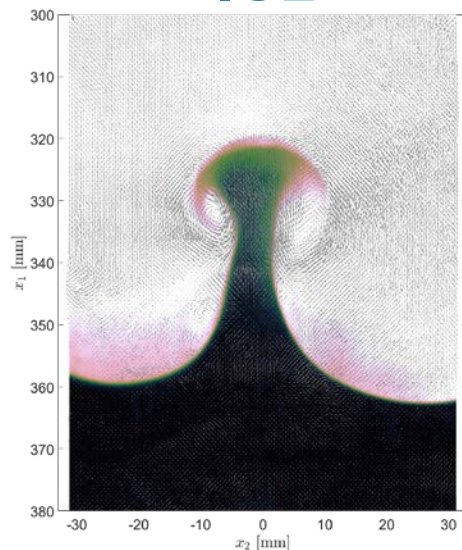
Density Contours

The initial condition are amplified by the RMI in density and velocity fluctuations. The VST has the spatial resolution to calculate turbulent statistics as well.

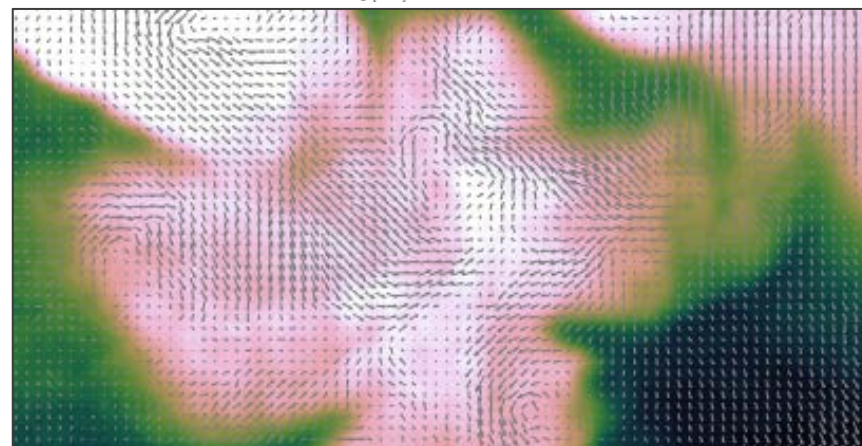
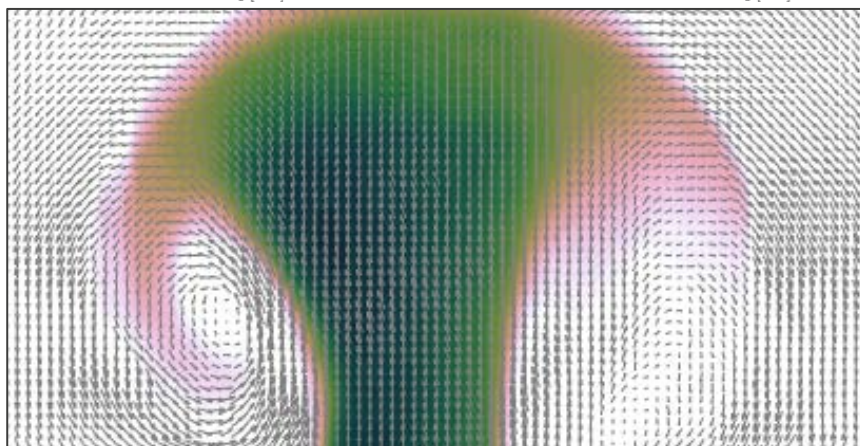
IC1

IC2

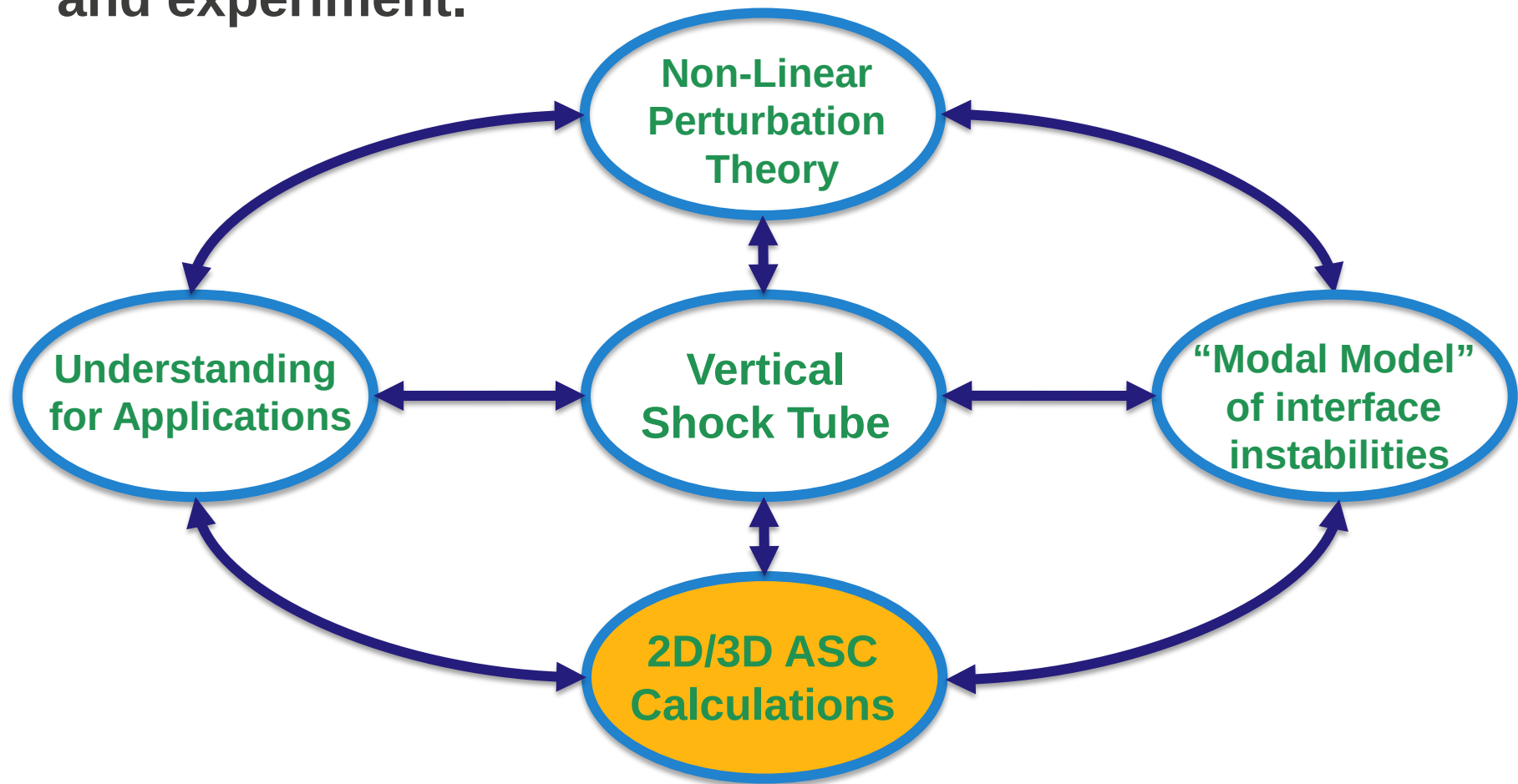
IC3



$t = 3.4$ ms



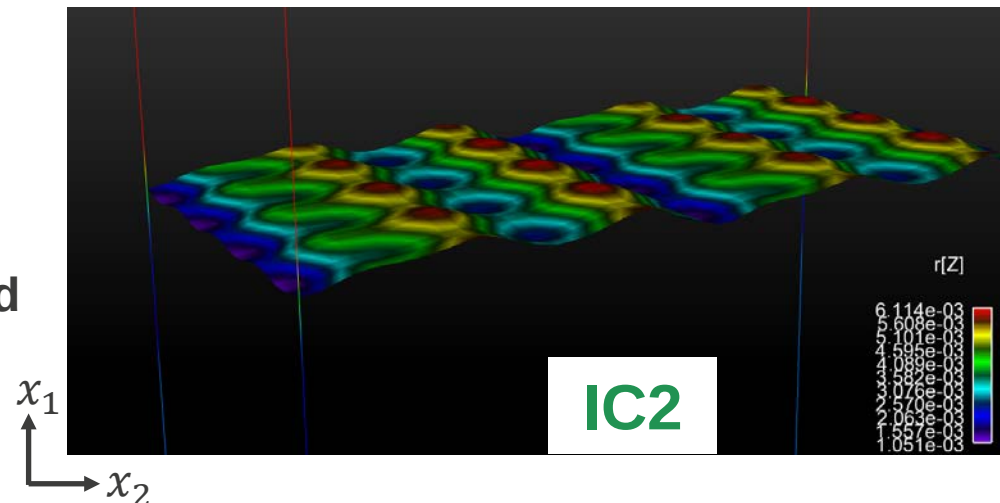
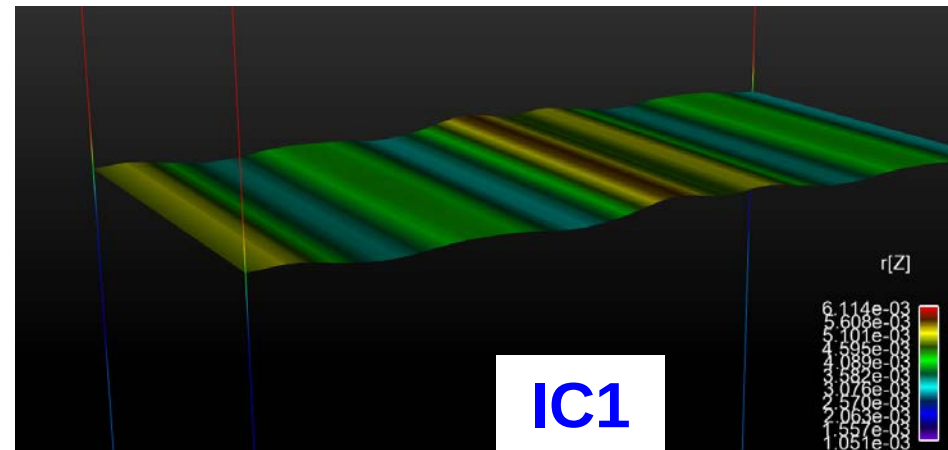
Richtmyer-Meshkov instability research highlights the connections between theory, modeling, computation and experiment.



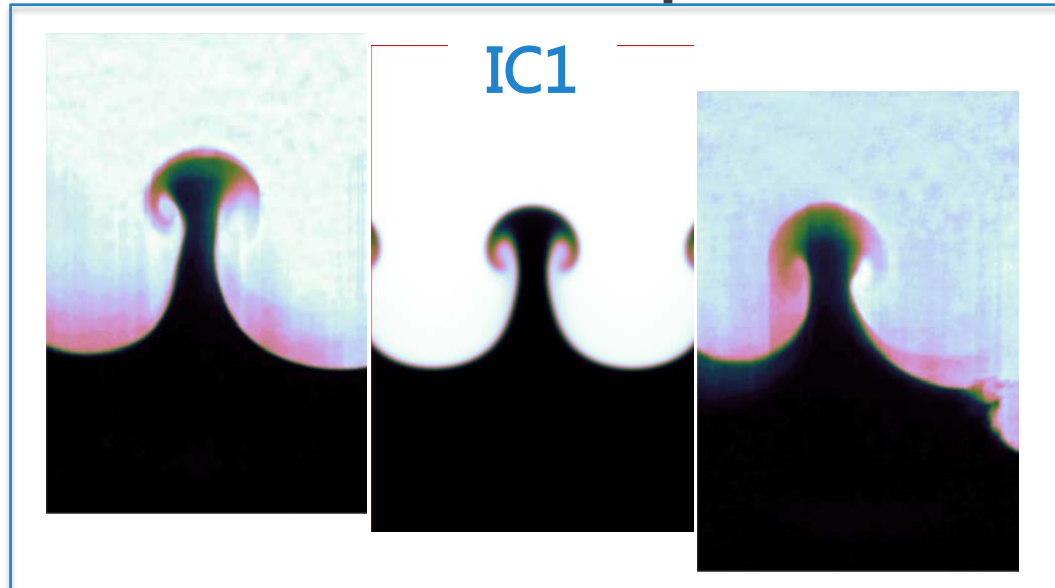
We want to know when/if a flow of interest will become turbulent.

The LANL/ASC Code FLAG is being used to do scale-resolving (LES) calculations of the VST. FLAG enables the user to easily initialize many types of perturbations.

- Interface conditions were specified as a Fourier Series with up to 38 coefficients in " x_2 " and a combination of Heaviside/Exponential functions in " x_1 " to describe the diffusion layer.
- The period/amplitude of the flapper was added to the " x_3 " direction for IC2
- These functions were added directly to the FLAG input file, which also supports randomized Fourier Series and spherical harmonic expansions for 3D geometries.

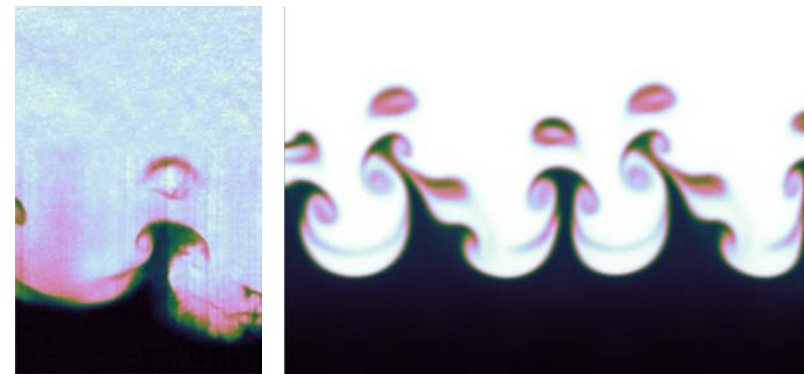


FLAG simulations reproduce the qualitative features of the VST initial conditions. 3D calculations on CIELO helped us understand some experimental observations



3D FLAG Centerline

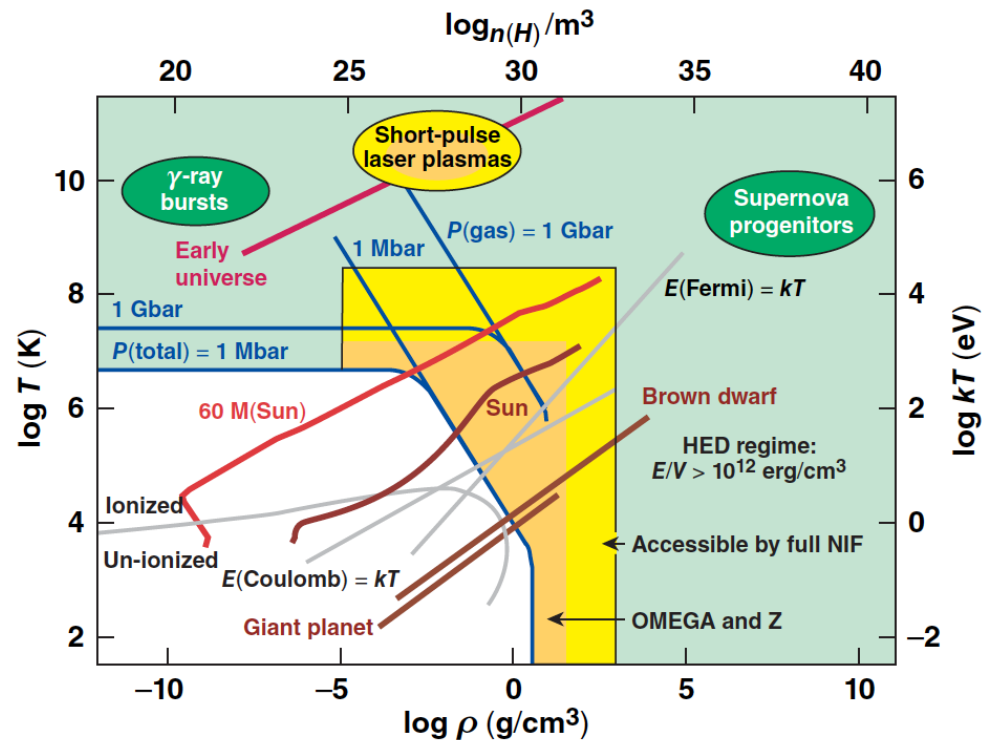
IC2



3D FLAG Off-Center

High energy density (HED) conditions are found throughout the universe*

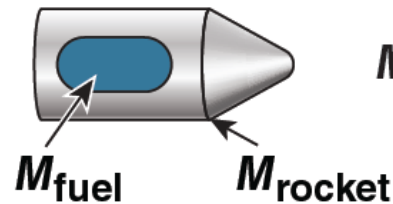
- HED conditions can be defined in various ways
 - Solids become compressible when the pressure is sufficiently large
 - Typical bulk moduli < 1 million atmospheres (Mbar)
 - $\text{HED} > \sim 1 \text{ Mbar}$
 - $1 \text{ Mbar} - 10^5 \text{ J/cm}^3$
- The dissociation energy density of a hydrogen molecule is $\sim 1 \text{ Mbar}$
- HED systems typically show
 - Collective effects
 - Full or partial degeneracy
 - Dynamic effects that often lead to turbulence



*Frontiers in High Energy Density Physics: The X-Games of Contemporary Science (The National Academies Press, Washington, DC, 2003).

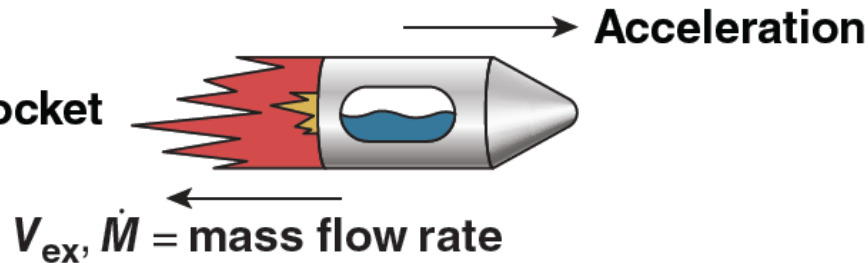
Ablation is used to create HED conditions – the “rocket” effect is driven by conservation of momentum

**Rocket at rest
(initial condition)**



$$M_0 = M_{\text{rocket}} + M_{\text{fuel}}(0)$$

Accelerating the rocket



$$F = \dot{M}V_{\text{ex}} = [M_r + M_f(t)]a_r$$

$$a_r = \frac{\dot{M}V_{\text{ex}}}{M_r + M_f(0) - \dot{M}t}$$

$$V_r(t) = V_{\text{ex}} \ln \left[\frac{M_r + M_f(0)}{M_r + M_f(0) - \dot{M}t} \right] = V_{\text{ex}} \ln \left[\frac{M_0}{M(t)} \right]$$

Laser ablation applies pressure to the targets through the “rocket” effect

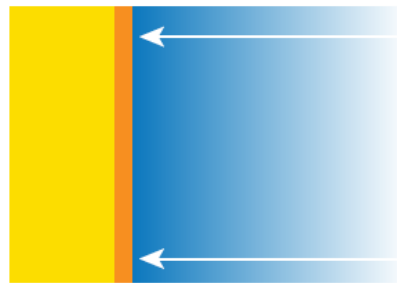
Initial target



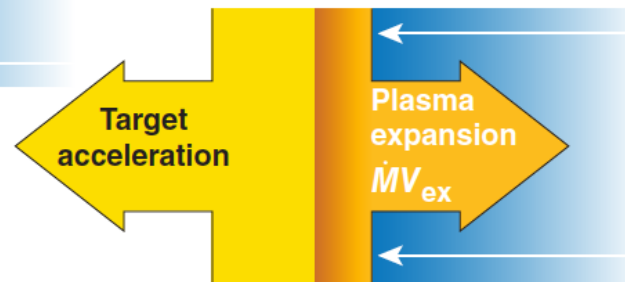
$$P_{\text{abl}}^* (\text{Mbar}) = 40 \left[\frac{I (10^{15} \text{ W/cm}^2)}{\lambda (\mu\text{m})} \right]^{2/3}$$

at $I = 10^{15}$, $\lambda = 0.35 \mu\text{m}$, $P_{\text{abl}} = 80 \text{ Mbar}$

The target surface is heated



The plasma expands off the front surface, applying pressure to the target



*J. D. Lindl, *Inertial Confinement Fusion: The Quest for Ignition and Energy Gain Using Indirect Drive* (Springer-Verlag, New York, 1998).

The presence of a plasma modifies the dispersion relationship of electromagnetic waves

In a vacuum, $\omega = ck \left(\omega = 2\pi\nu, k = \frac{2\pi}{\lambda} \right)$

In a plasma, $\omega^2 = c^2 k^2 + \omega_{pe}^2$, with $\omega_{pe}^2 = \frac{4\pi e^2 n_e}{m_e}$, n_e = electron density

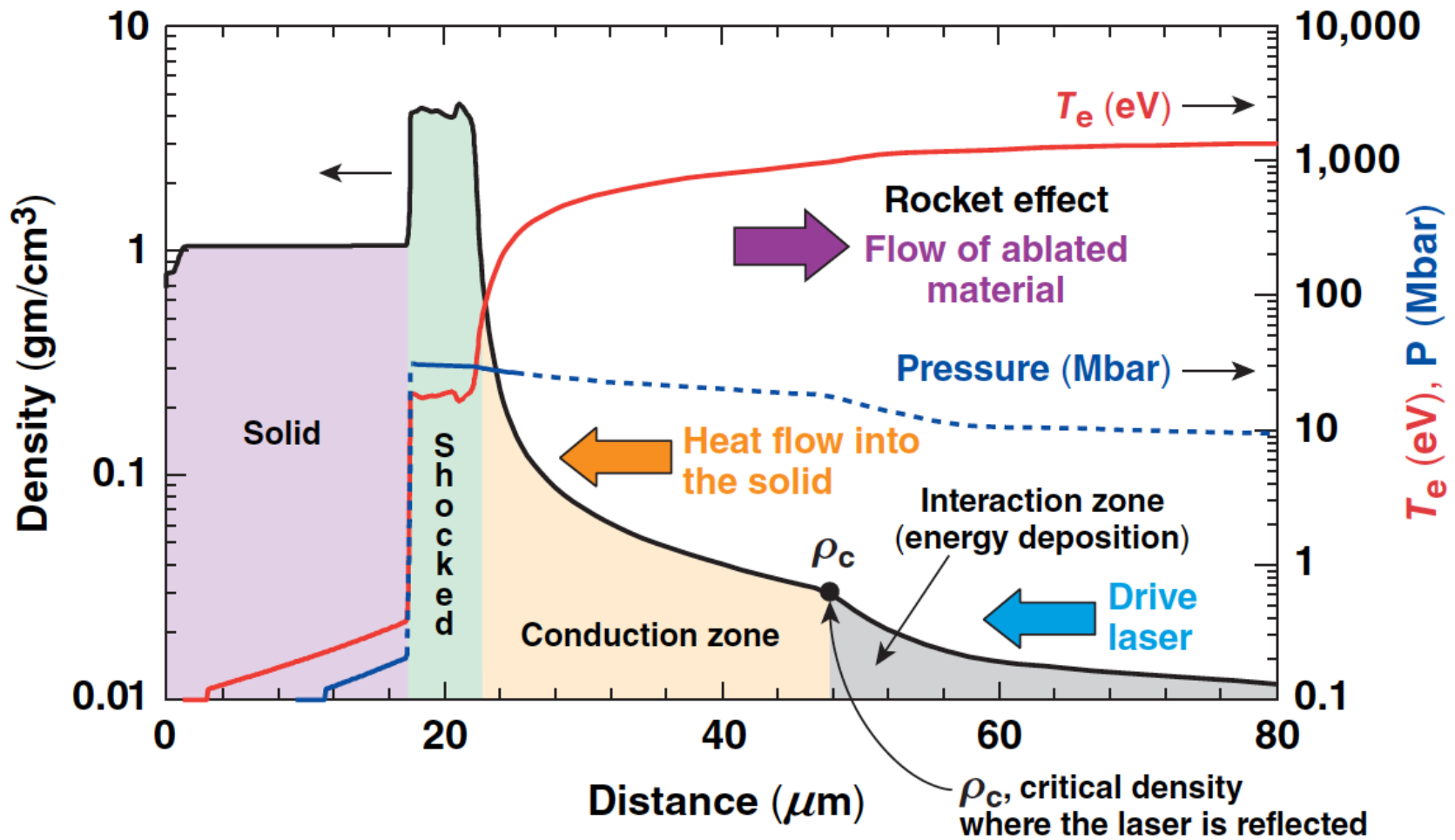
Consider k , $k = \frac{\omega}{c} \left(1 - \frac{\omega_{pe}^2}{\omega^2} \right)^{1/2}$: if $\omega^2 = \omega_{pe}^2$, $k = 0$

At $\omega^2 = \omega_{pe}^2$, $V_\phi = \frac{\omega}{k} = \infty$, $V_g = \frac{\partial \omega}{\partial k} = \frac{c^2 k}{\sqrt{c^2 k^2 + \omega_{pe}^2}} = 0$ **Reflection!**

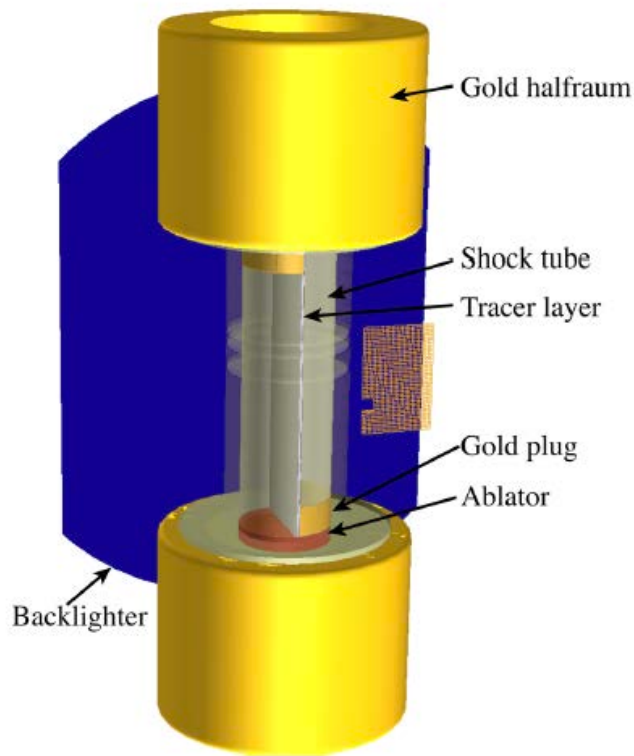
The critical electron density is where $\omega^2 = \omega_{pe}^2$, $n_c (\text{cm}^{-3}) = \frac{1.1 \times 10^{21}}{\lambda^2 (\mu\text{m})}$

The index of refraction in a plasma is < 1 , $n = \frac{ck}{\omega} = \left(1 - \frac{n_e}{n_c} \right)^{1/2}$

Intense lasers or x-rays interacting with the target produce shock waves through ablation



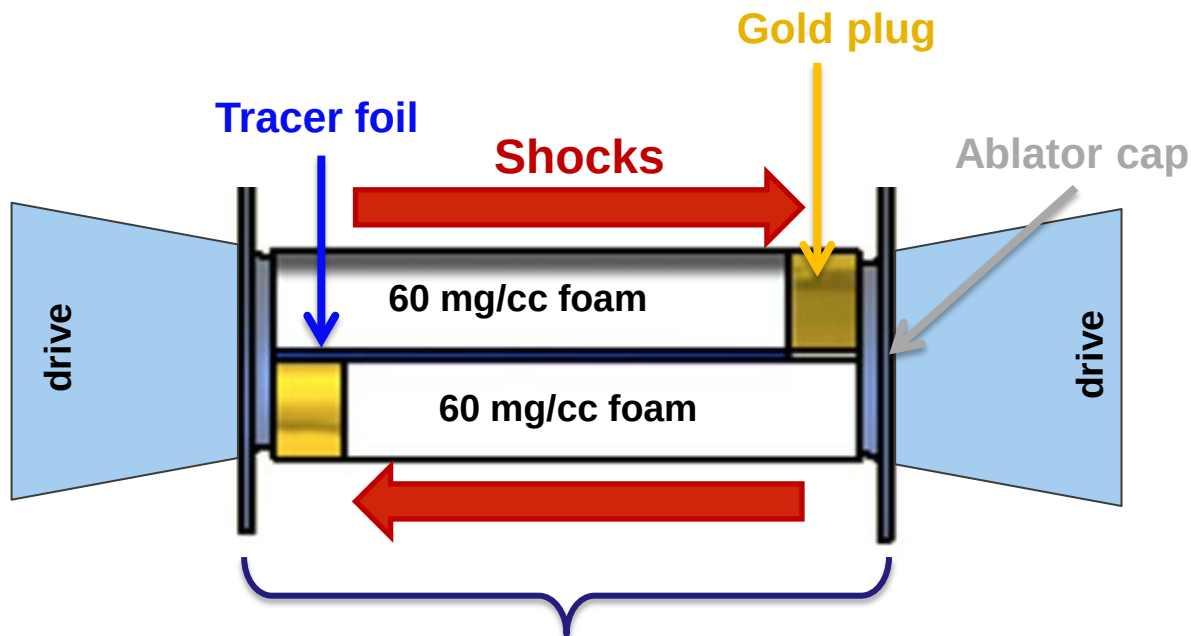
The counter-propagating (CP) shear campaign is extending shear instability and turbulence experiments into the high-energy-density (HED) regime



- Experiments are in the HED plasma regime where fluid dynamics approximations **may** break down
- Relevant to mix in ICF capsules and astrophysics
- Used to benchmark hydrodynamics and turbulence models
 - Low-energy-density/fluid regime experiments such as shock tubes do not include HED effects
- Shock/shear “mini shock tube” experiments have made the **first observations of emergent mixing layer features (Kelvin-Helmholtz) in plasma flows**

“The Shock/Shear platform for planar radiation-hydrodynamics experiments on the National Ignition Facility,” Doss et al. 2015, Phys. Plasmas

The experiment geometry reduces the model complexity using pressure-balanced, semi-to-fully supported, anti-symmetric flows



After shock crossing

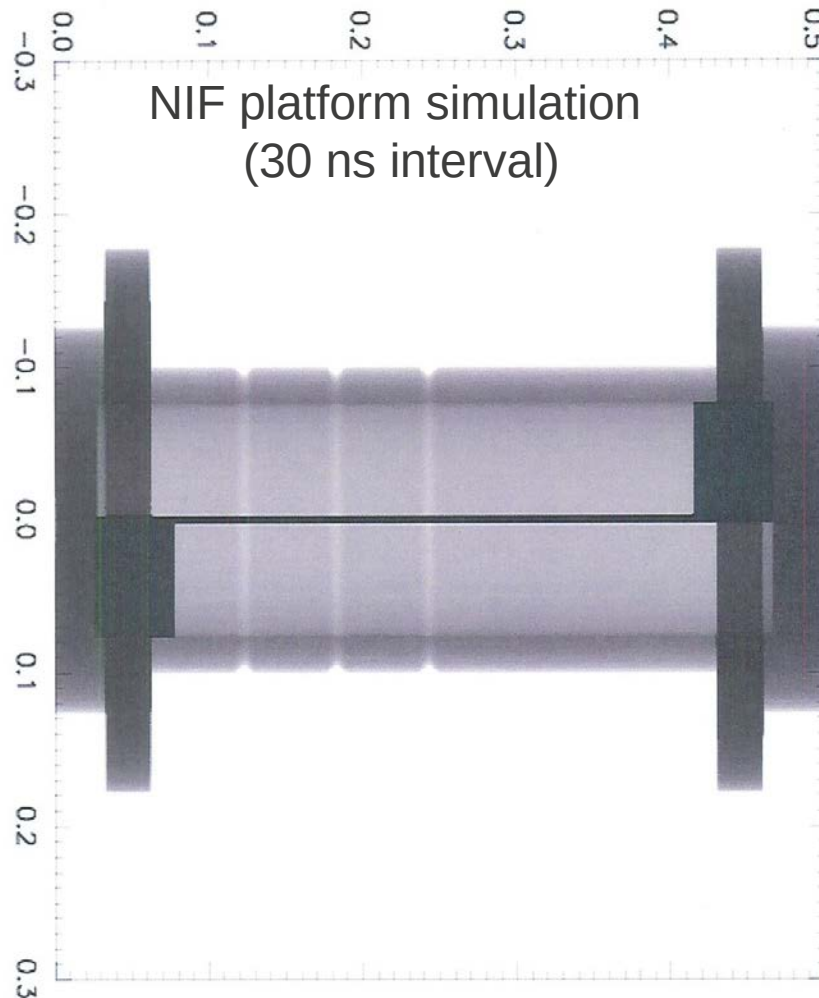
$$\frac{\partial P}{\partial x_i} \longrightarrow \text{small}$$

$$\frac{\partial u_i}{\partial x_i} \longrightarrow \text{small}$$

OMEGA
 $u_s \sim 110 \text{ km/s}$
 $u_f \sim 70 \text{ km/s}$

NIF
 $u_s \sim 130 \text{ km/s}$
 $u_f \sim 110 \text{ km/s}$

The experiment geometry reduces the model complexity using pressure-balanced, semi-to-fully supported, anti-symmetric flows

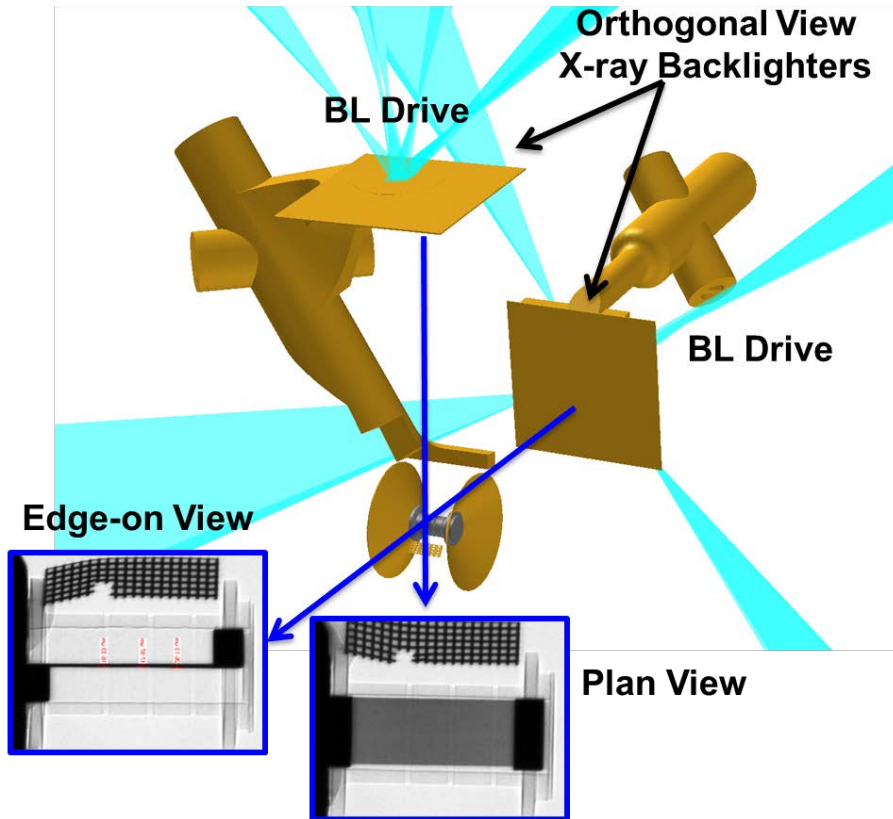


After shock crossing

$$\frac{\partial P}{\partial x_i} \longrightarrow \text{small}$$

$$\frac{\partial u_i}{\partial x_i} \longrightarrow \text{small}$$

The experiment is diagnosed with radiography in geometry similar to that used in many canonical fluid shear experiments



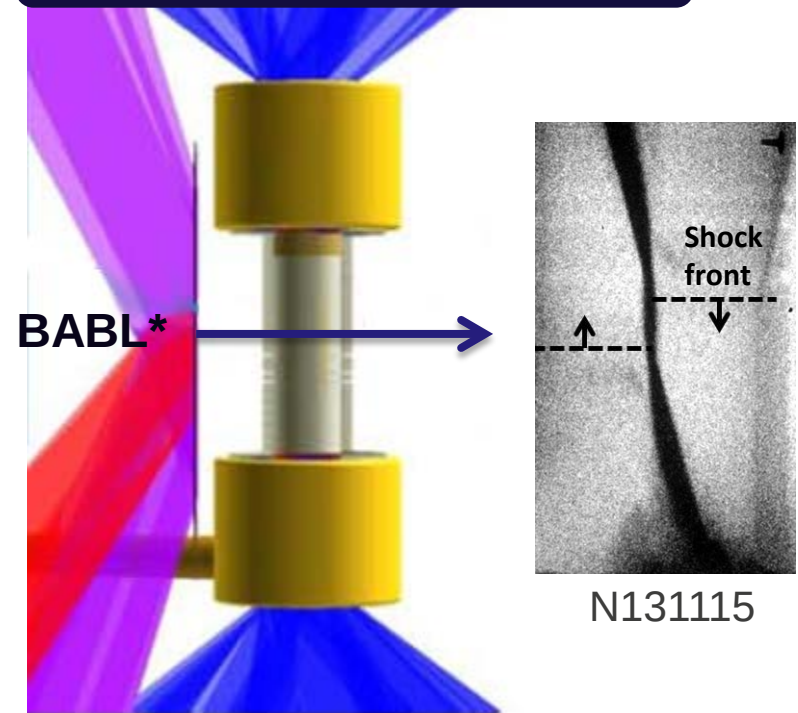
OMEGA: One image per shot in two orthogonal views

Slide 19

Merritt and Doss, submitted to *RSI* (2015)

*Flippo *et al.*, *RSI* 85 093501 (2014)

Flippo *et al.*, accepted to *JPCS* (IFSA 2015)

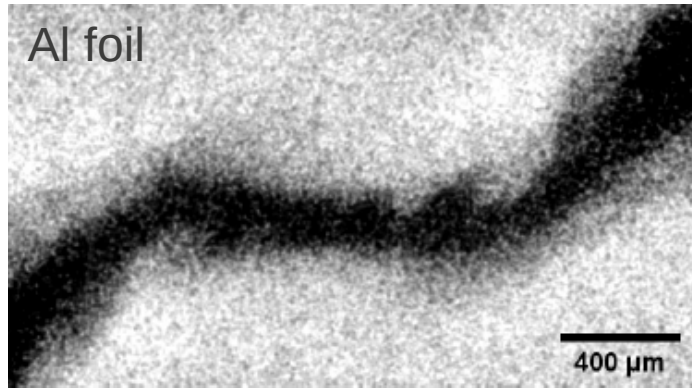


NIF: Multiple images per shot in one of two views**

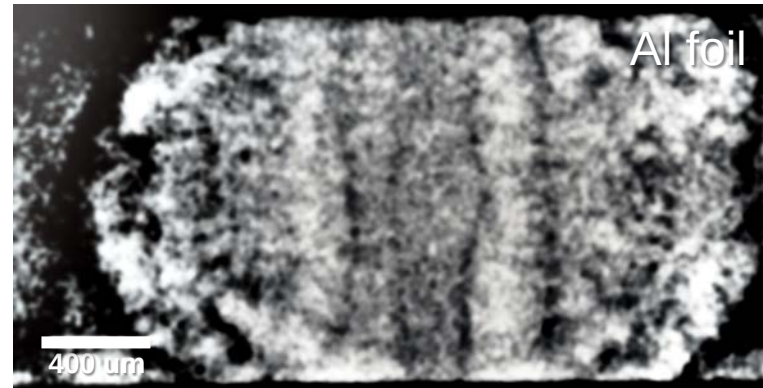
**Doss *et al.*, accepted to *JPCS* (IFSA 2015)

NIF Shear experiments produced the first observations of emergent coherent rollers associated with KH mixing in the HED regime

Edge View: N141016, 34.5 ns

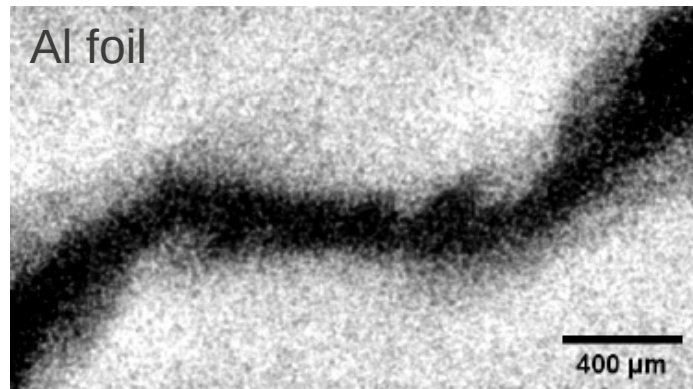


Plan View: N150527, 30.5 ns

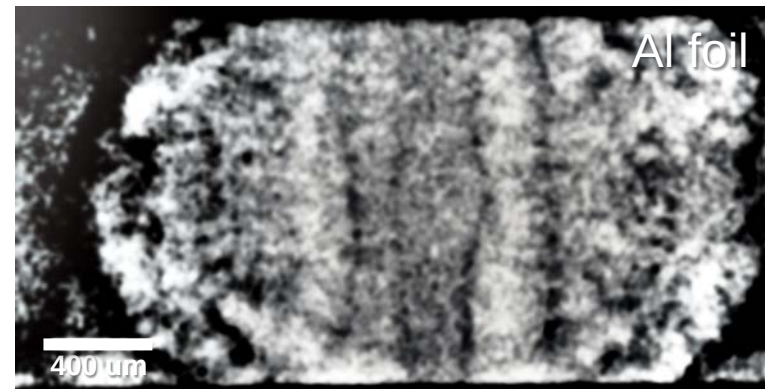


NIF Shear experiments produced the first observations of emergent coherent rollers associated with KH mixing in the HED regime

Edge View: N141016, 34.5 ns

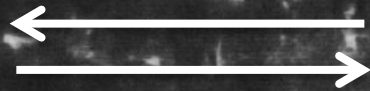


Plan View: N150527, 30.5 ns



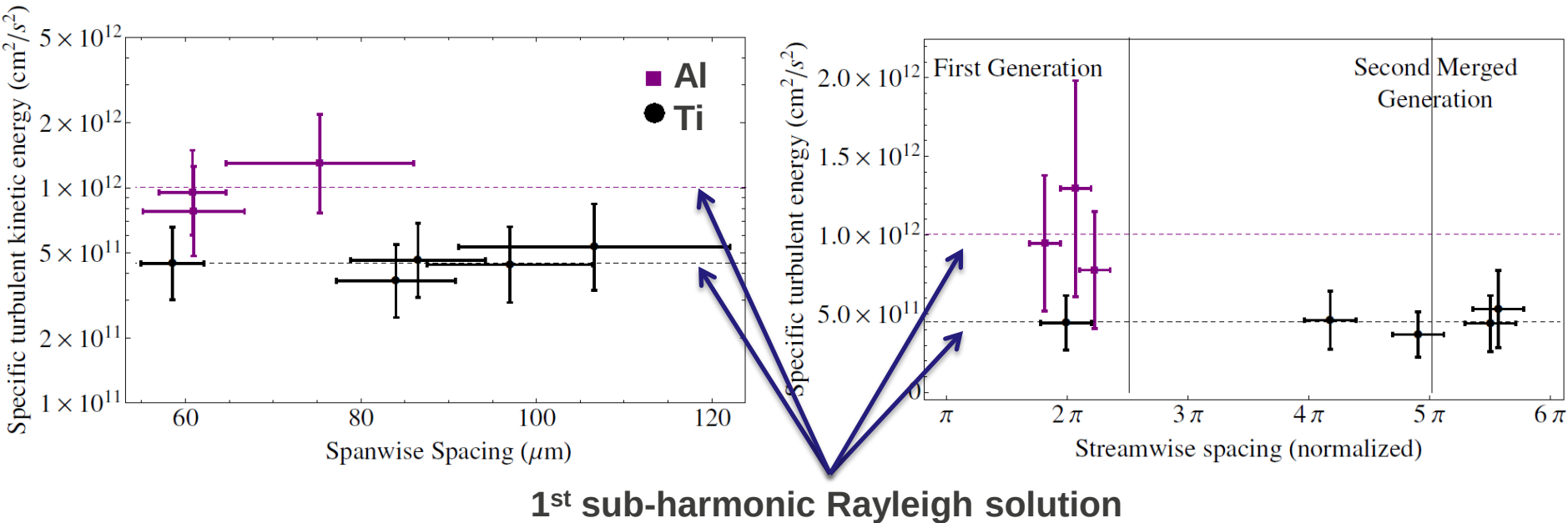
Breidentahal J. *Fluid Mech.* **109** 1 (1981)

Counter-shear



NIF experiments establish preservation of hydrodynamic scaling across over eight orders of magnitude in time and velocity and we can analyze the results in context of the large body of work on planar mixing layer phenomenology

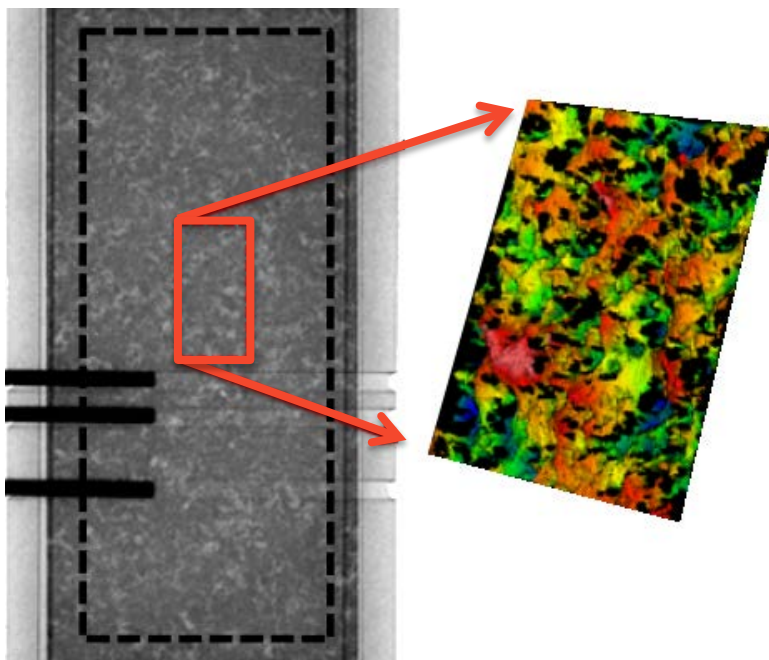
The periodicity of the streamwise and spanwise structures provide estimates of fluctuating velocity data otherwise unobtainable in the HED environment



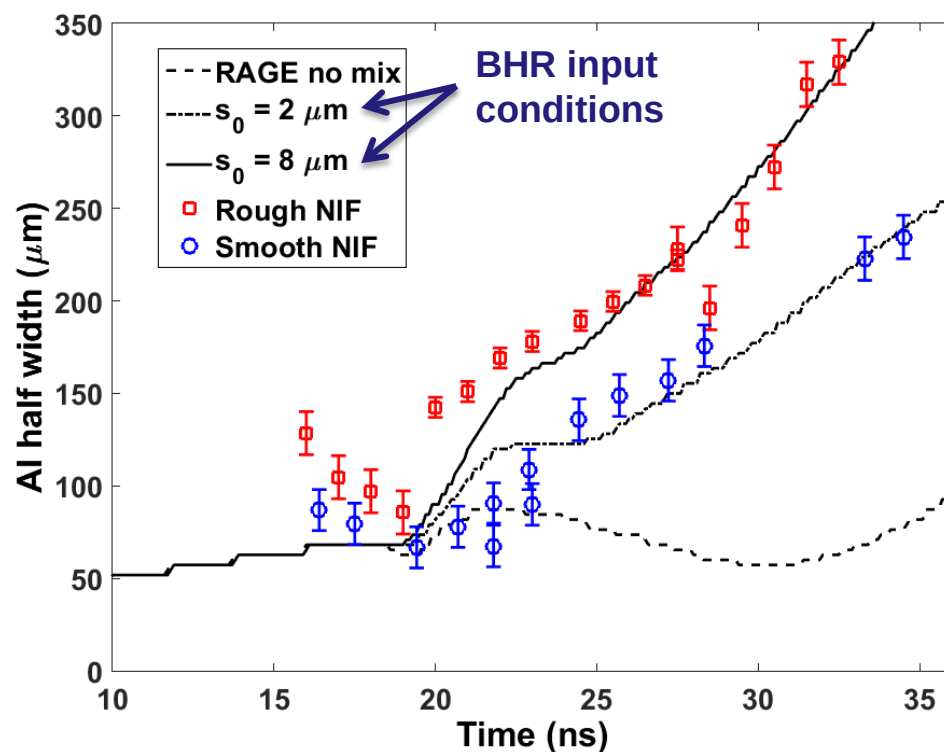
This analysis indicates shear-induced turbulent energies in the NIF experiments are 10^6 - 10^7 times higher than the nearest conventional experiment

Doss *et al.*, Submitted to *PRE* (2016)

An advantage of initially solid targets is the capability to engineer a variety of complicated boundary profiles to test experiment sensitivity to initial conditions



Merritt *et al.*, *Phys. Plasmas* **22**, 062306 (2015)
 Flippo *et al.*, submitted to *PRL* (2016)



Experiments with roughened foils have shown increased mixing rates suggestive of an increase in the model initial conditions, which is a potential avenue for connecting model parameters and various experimental scales

LANL Inertial Confinement Fusion Uses 3 Threads to Support Stewardship

- **Burning Plasma Platforms**
 - Create a burning plasma platform, or
 - Understand why not
 - *Use innovative platforms and approaches*
- **HED Physics**
 - Hydrodynamics
 - Mixing & models
- **Diagnostics**
 - Gamma-ray measurements
 - Neutron Imaging
 - *25% of the Transformative Diagnostics*
- **Infrastructure important to executing program**
 - Target fabrication and operations

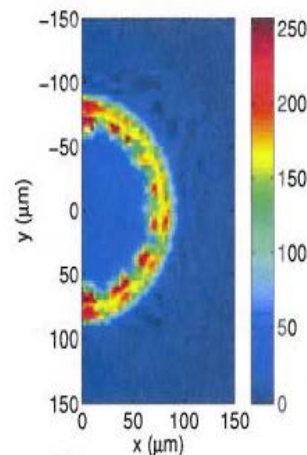
LANL RAGE Code Now Used Routinely After Long Investment by ICF and Science

- **Laser Ray-Trace package added in collaboration with U. Rochester**
 - Working well for direct drive, hohlraum capability imminent
- **First Omega experiment completely designed & analyzed using RAGE**
- **Indirect drive capsule implosions now routine (need link from HYDRA)**
- **Provides a second look at ignition since code architecture and models very different**

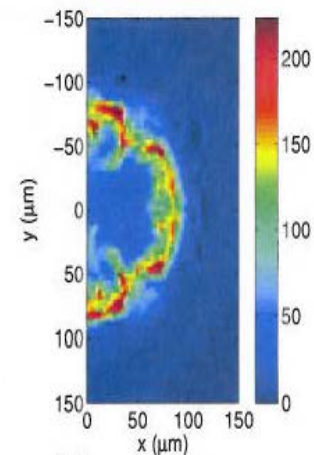
Vapor
density
(g/cm³)

4.0

Surface roughness only



Surface roughness, fill
tube, tent



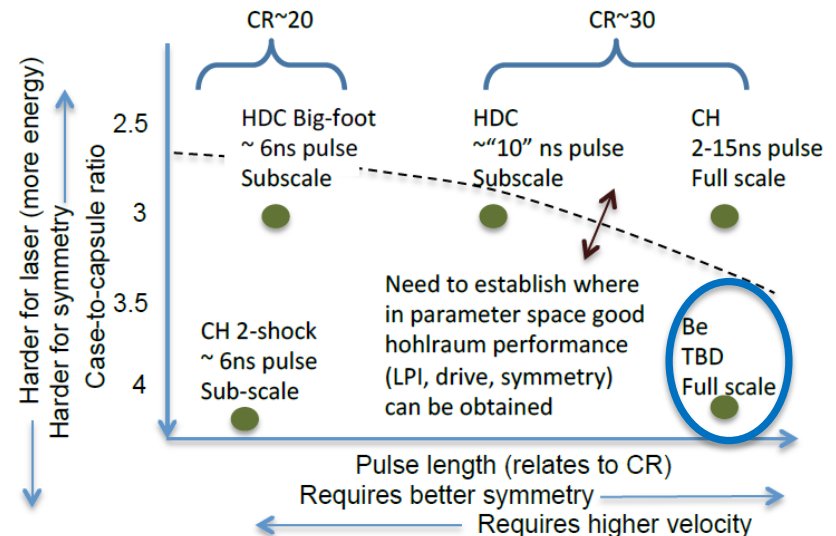
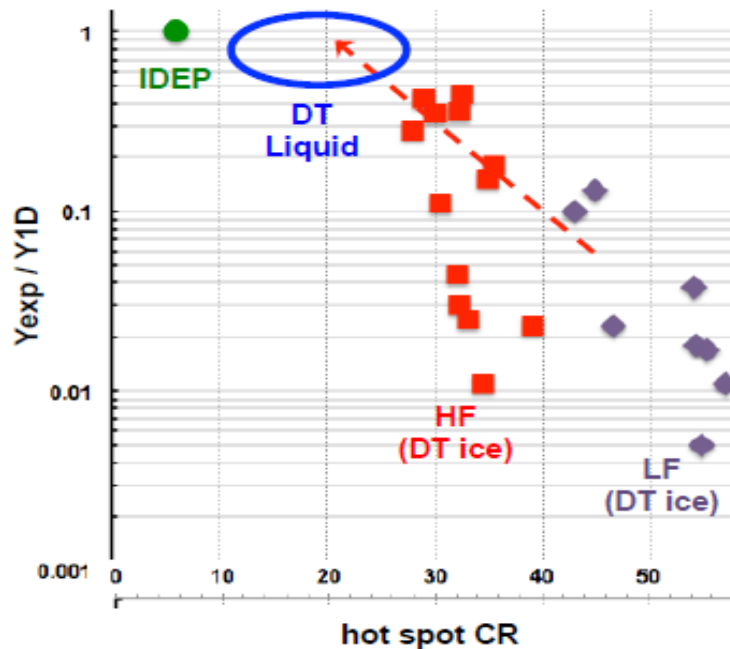
LANL's Ignition Science Goal Is To Achieve “1D Performance” Using 3 Platforms

- **Hypothesis:**
 - Codes are not complete and not predictive
 - Move to regimes where 1D codes are predictive, *i.e.* “1D Performance”
 - Example: Predict Radius(t), Tion, density, shape, hot-spot pressure, ...
 - Intentional perturbations will identify incomplete models
- **LANL is addressing two issues identified in indirect-drive reviews**
 - Symmetry (& capsule support)
 - Convergence Ratio (R_i/R_f)
- **We are using three platforms**
 - High case to capsule ratio experiments (Be capsules, in particular)
 - Wetted Foam capsules
 - Double shell capsules

The National Indirect Drive Program Will Span Parameter Space

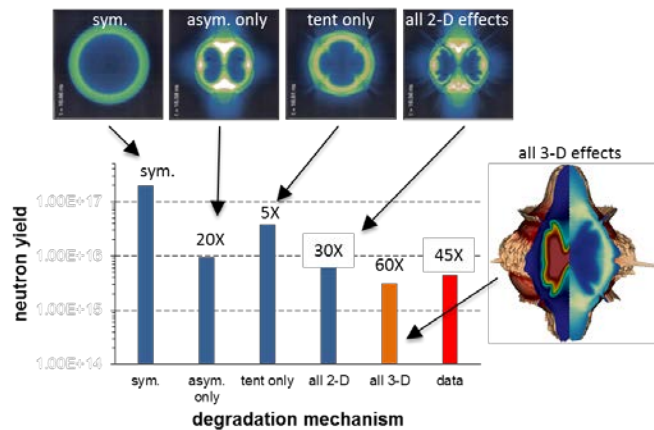
- LANL will test changes in convergence ratio and go to the extreme of case to capsule ratio

Our hypothesis is that, without further reduction of 3D effects, experiments and 1D simulations will become similar at CR ~ 20.



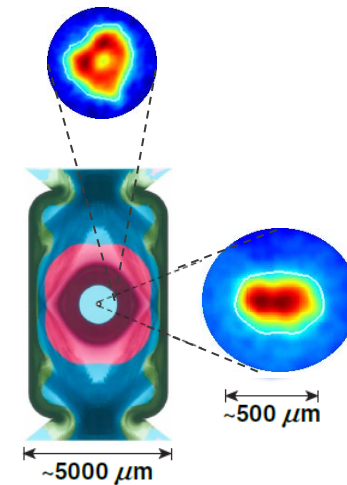
Implosion symmetry has been identified as an important degradation mechanism for NIF ICF implosions

High Res sims show tent, low mode symmetry, and native roughness lead to most performance degradation



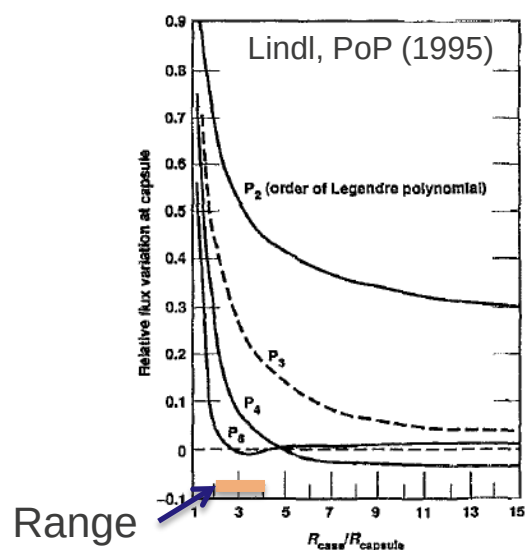
Clark *et al.*, PoP (2016)

Low mode symmetry

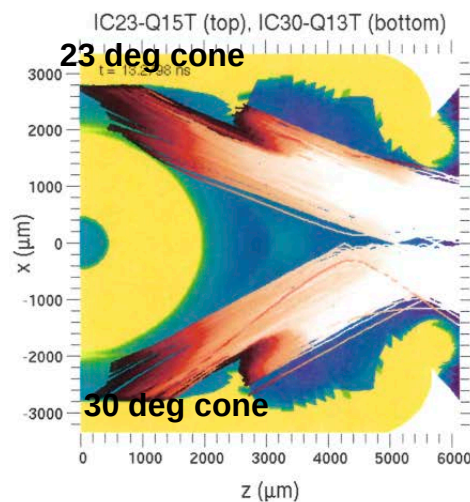


A high case-to-capsule ratio increases the physical separation between hohlraum wall and capsule blow-off plasmas, allowing for better inner cone propagation

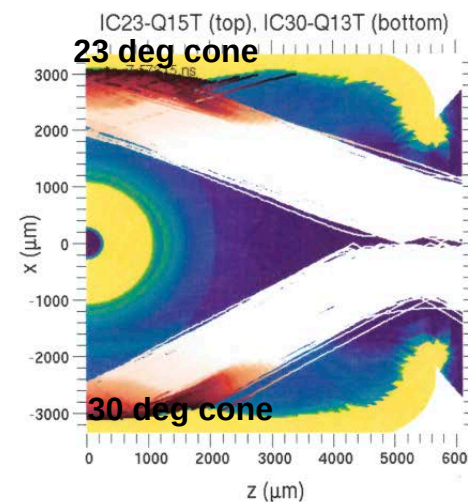
Flux variation as function of case-to-capsule ratio



End of pulse, 1.1 mm O.R. capsule



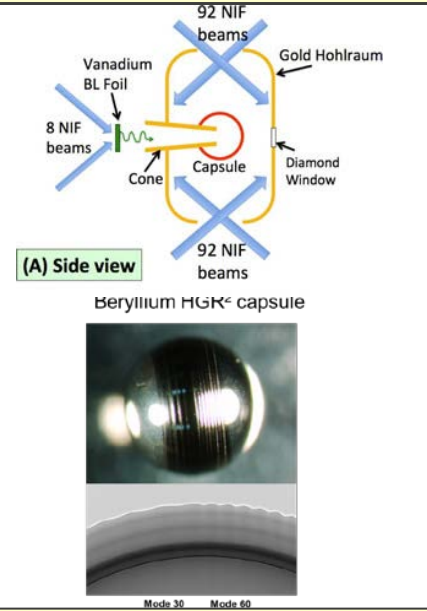
End of pulse, 0.6 mm O.R. capsule



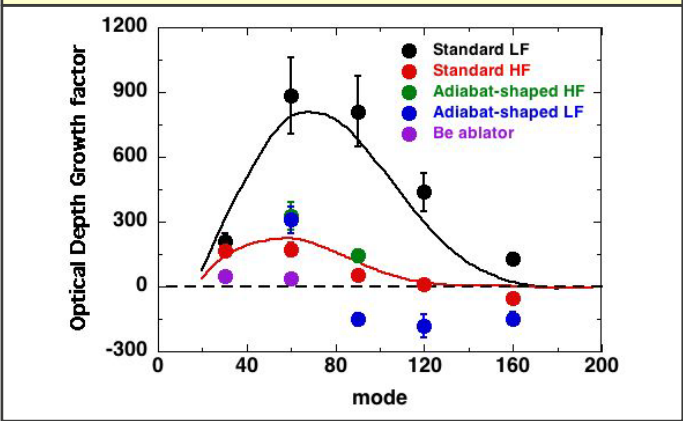
- Symmetry control requires understanding of the coupling between the capsule and hohlraum
- We will start with a case having good symmetry and increase the capsule size to systematically find the largest capsule having a round implosion in a 672 hohlraum

Hydro-growth radiography (HGR) data demonstrate the advantage of Be ablators for controlling ablation front hydrodynamic instability growth

Experimental setup

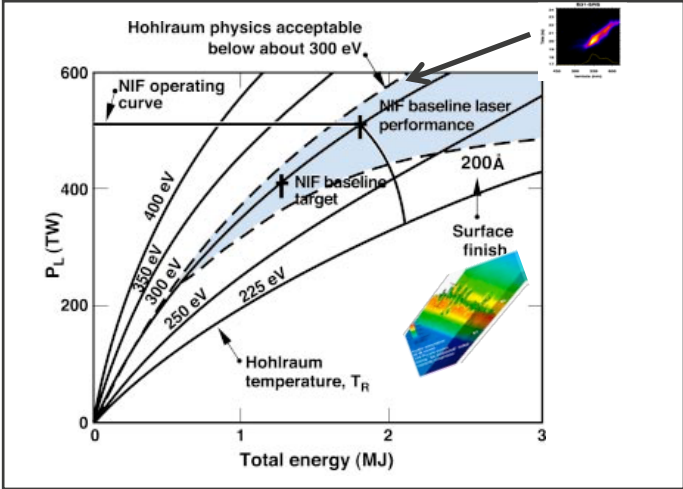


Comparison of measured growth vs mode number for different ablators



$$\gamma = \sqrt{\frac{kg}{1 + kL}} - \beta k V_a, \quad V_a \sim T_{rad}$$

ICF target design space

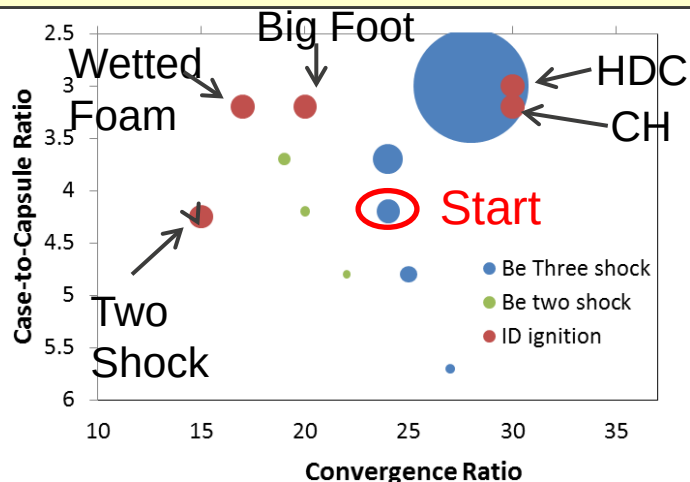


Lindl 2004

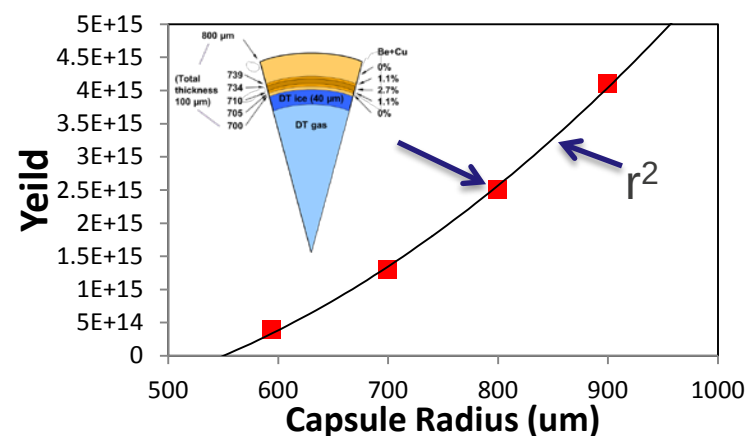
The stability properties of Beryllium capsules allow lower radiation temperature designs by increasing the case-to-capsule ratio to improve symmetry

We have designed a series of hydro-scaled capsules to scan case-to-capsule ratios and determine where symmetry control breaks down

Yield vs CCR and CR for beryllium designs with respect to other ignition base camps



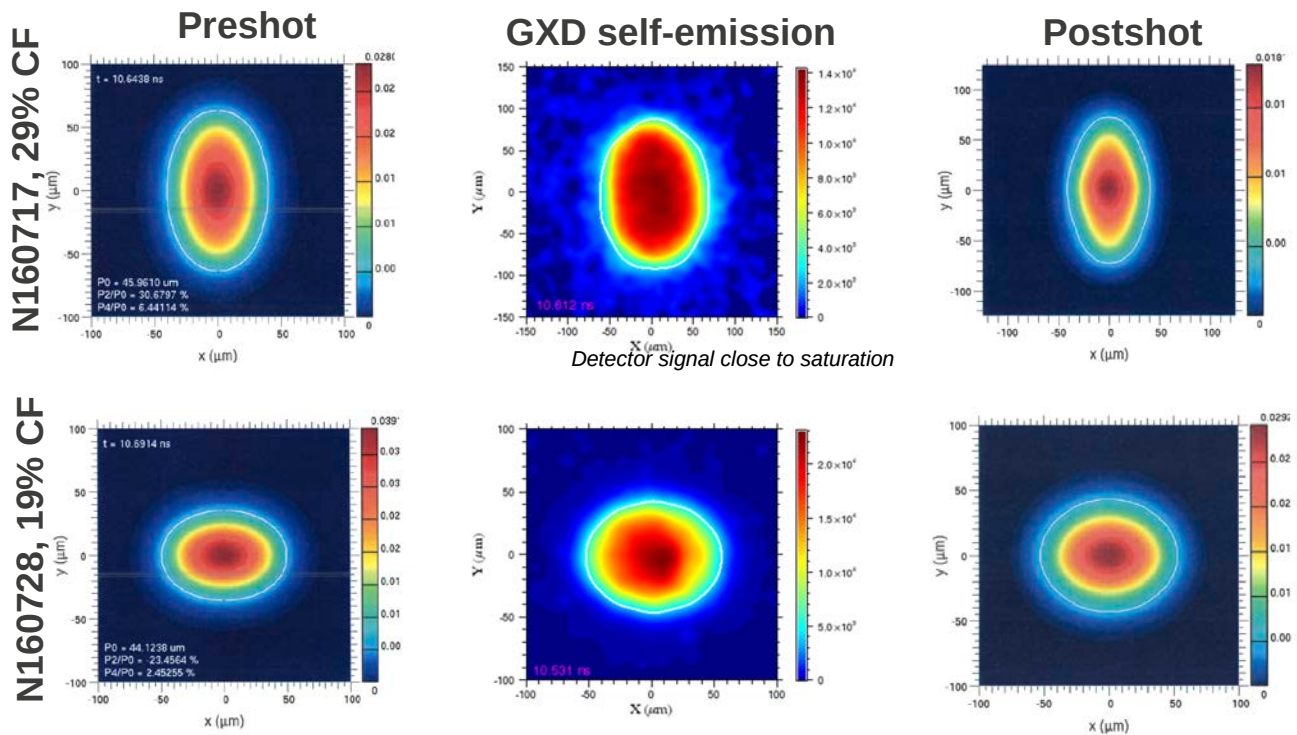
Hydro-scaling ($\sim r^2$) is used to compare different performance at different CCRs



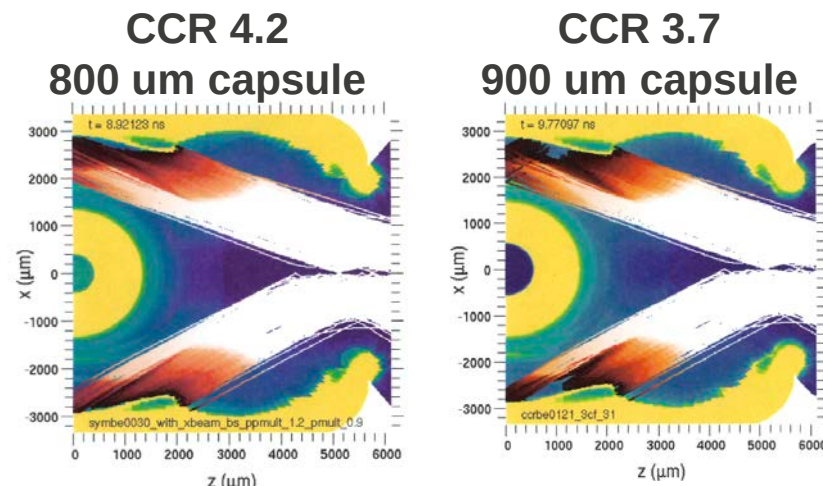
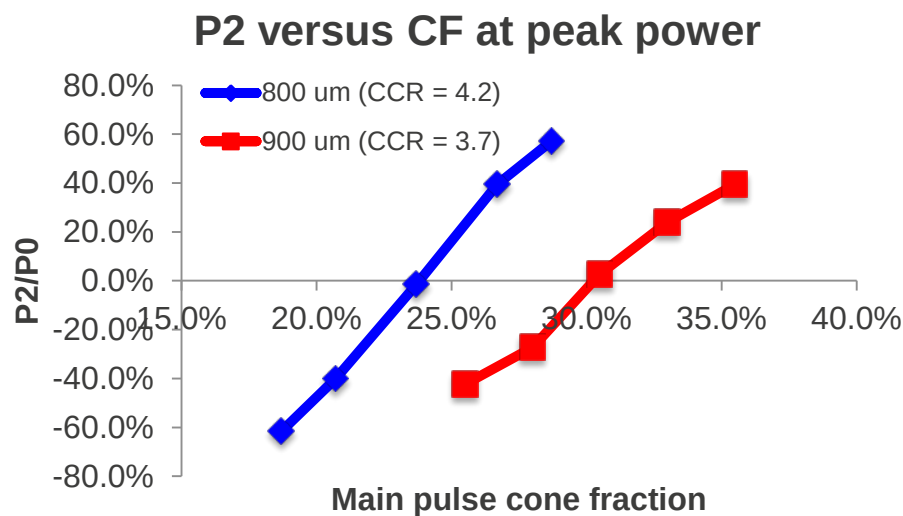
- Two shock experiments demonstrated round implosions with convergence ratio of 15 – 20

Our current designs focus on round implosions with high YOC, not ignition

Experiments at a case-to-capsule ratio of 4.2 show good agreement with simulations



For the next campaign, we will move from a CCR = 4.2 to 3.7, by increasing capsule radius from 800 to 900 μm in a 672 hohlraum



Simulations predict a round implosion at $\sim 1/3$ cone fraction at CCR = 3.7, with inner cone propagation not much worse

Wetted Foam Experiments Test Convergence Effects and Hot-Spot Formation

Advantages:

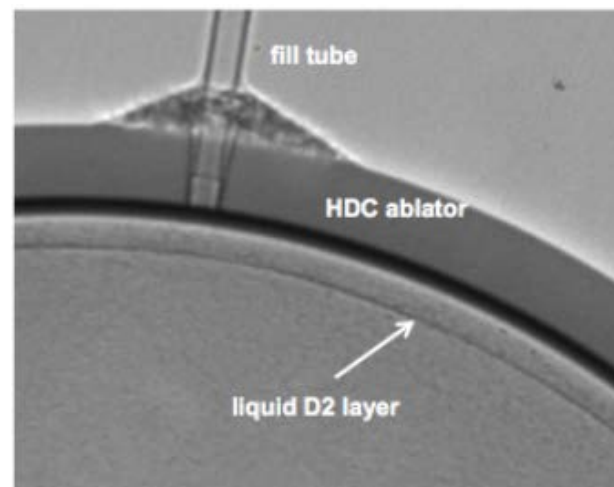
- Easily controlled convergence ratio
- Better hot-spot formation

Goal:

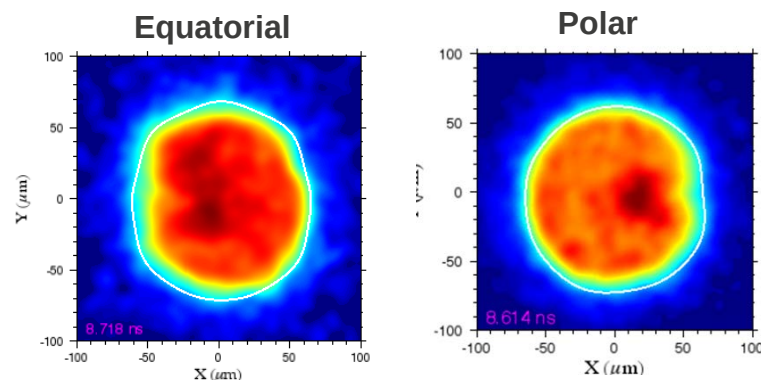
- Establish 1D-like implosion performance at low CR
- Determine where 1D-like behavior breaks down
- Wetted foam targets create many options for future experiments

Status:

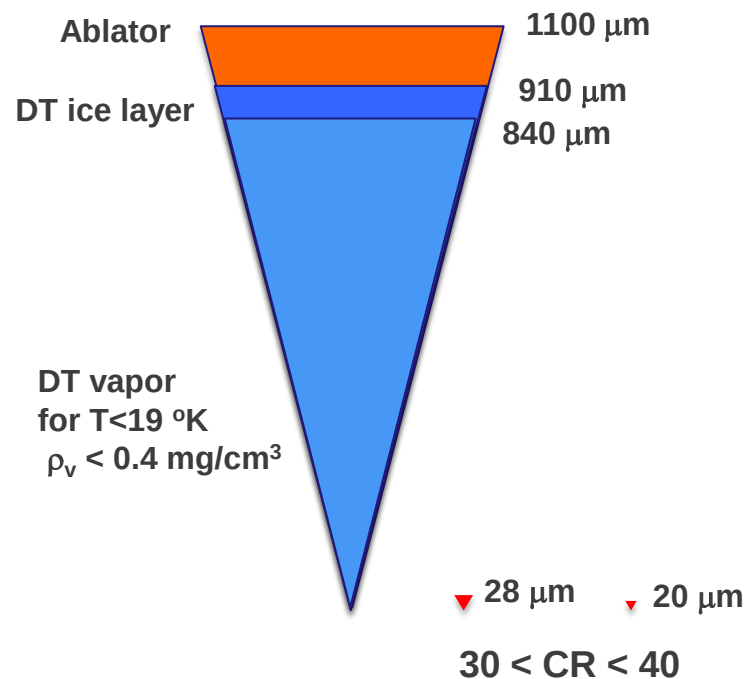
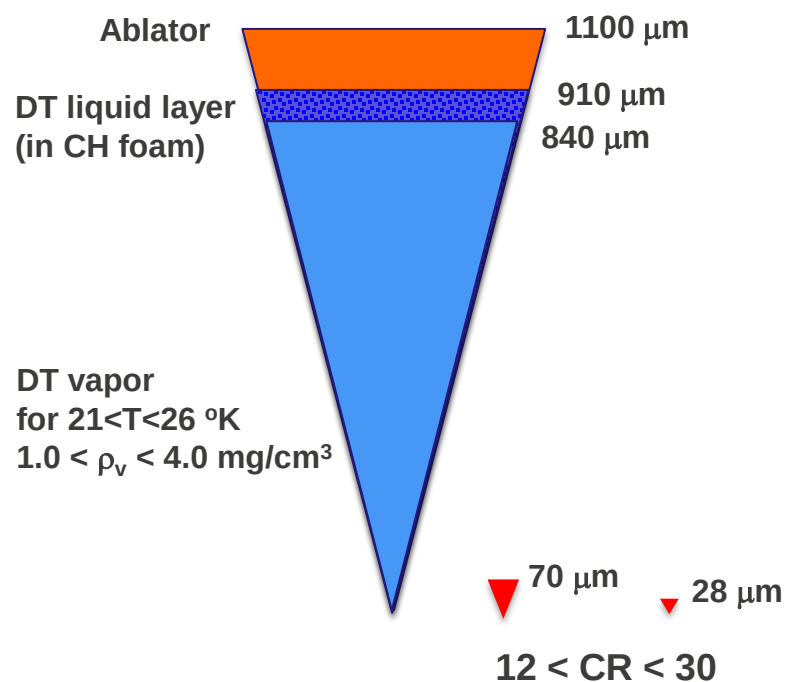
- First two wetted foam implosions successfully shot on NIF using a liquid D₂ or DT layers, with CR ~ 14.
- We will change convergence via vapor density
- *Critical target fab support from LLNL*



N160421 GXD images

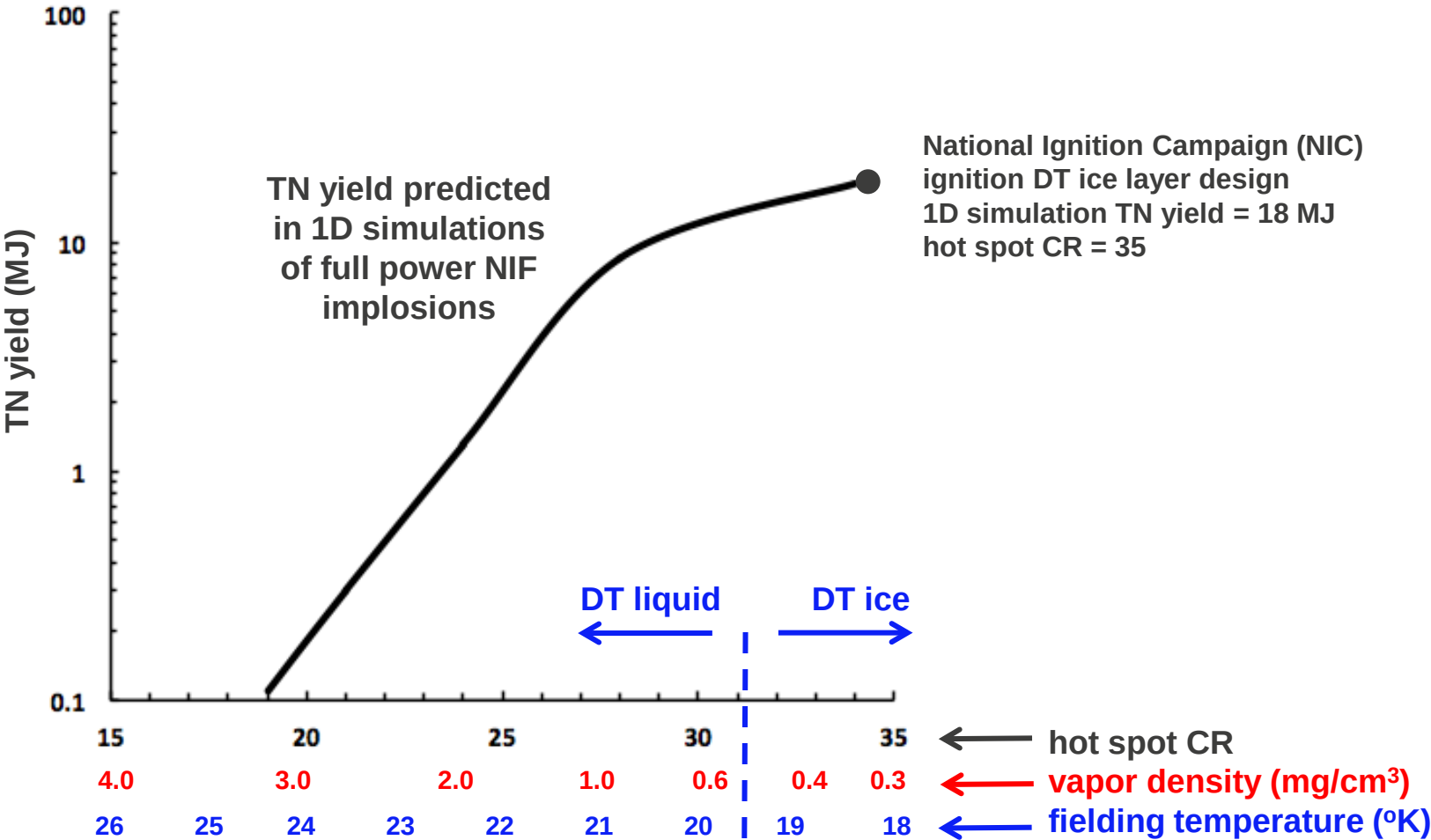


A liquid DT layer (wetted CH foam) allows for a higher vapor density compared to a DT ice layer. This provides flexibility in hot spot CR.



A detailed comparison of the performance of DT liquid layer and DT ice layer capsules in
R. E. Olson and R. J. Leeper, Phys. Plasmas 20, 092705 (2013).

In a 1D world, TN yield increases as CR increases.
The *predicted* 1D yield for a DT ice layer is 18 MJ – we are looking for where performance starts to deviate from 1-D



The LLNL code Hydra¹ and the LANL code Rage² are being used to simulate and understand the wetted foam experiments. The April 21 experiment performed reasonably close to expectations.

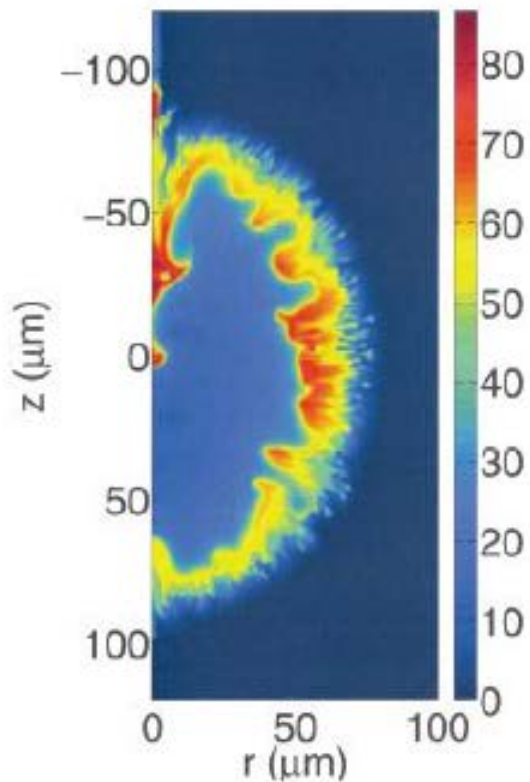
	N160421	Hydra	1D Rage (clean)	1D Rage (mix)*
DT neutrons (10 ¹⁴)	4.5 ± 0.1	6.4	6.1	5.8
bang time (ns)	8.72 ± 0.08	8.6	8.5	8.5
T _{ion} , burn avg (keV)	3.2 ± 0.1	3.3	3.3	3.3
DT burn width (ps)	313 ± 30	287	234	243
hot spot radius (μm)	64.8 ± 4.8	61.8	65.4	65.4
inferred Pr _{hs} (Gbar)	16.5 ± 2.6	18.5	17.3	17.3

¹M. M. Marinak *et al.*, *Phys. Plasmas* 3 2070 (1996).
²M. Gittings *et al.*, *Computational Science & Discovery* 1, 015005 (2008).

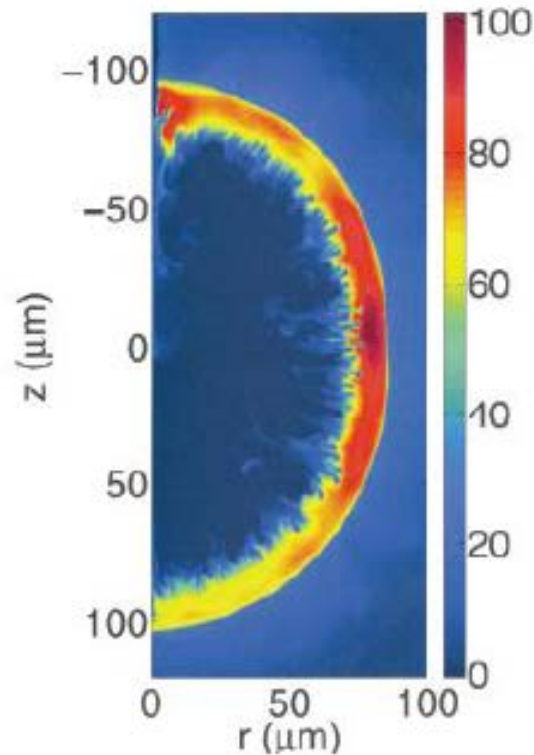
In the DT, CR=12 shot, material from the 30 μm dia. fill tube is simulated to enter the hot spot

2D RAGE calculated density contours at bang time

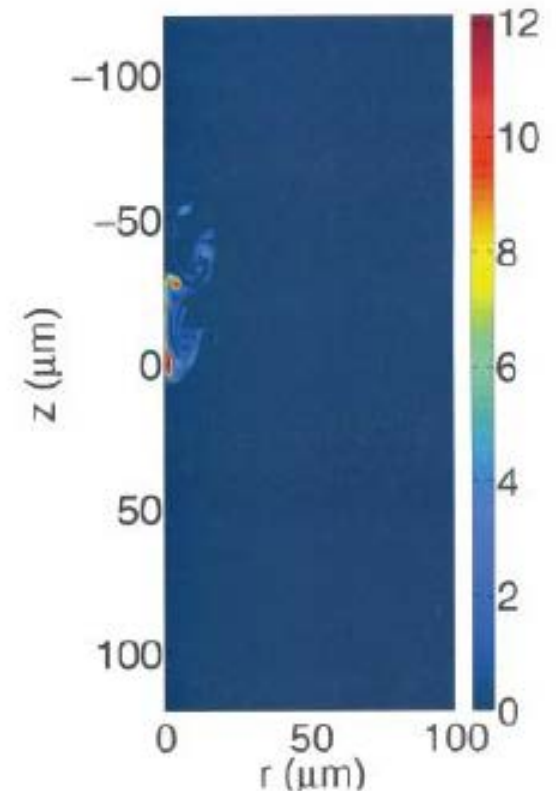
Fuel



Shell



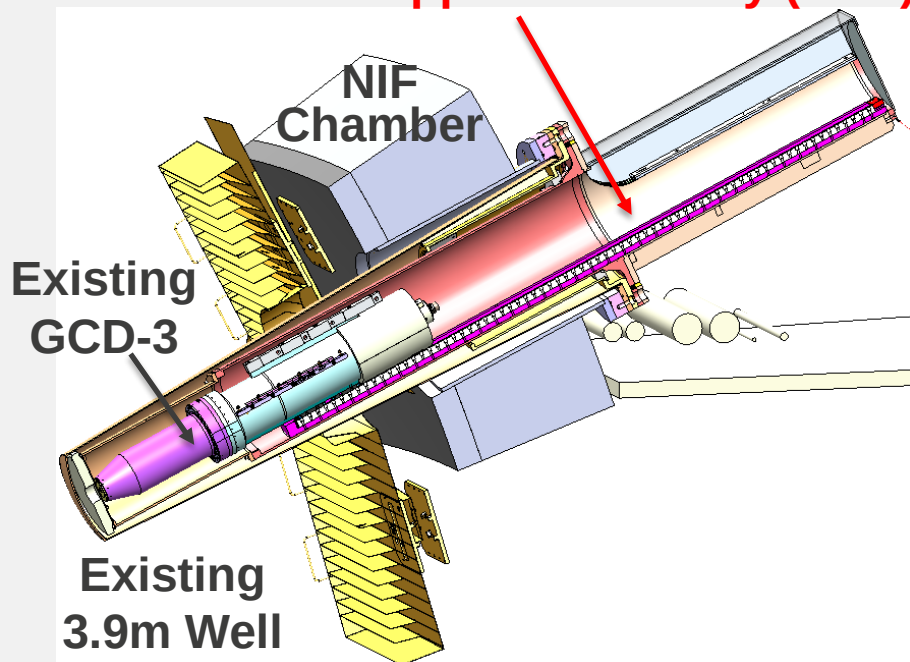
Fill Tube



LANL is Building 2 of 8 Transformative Diagnostics To Understanding of Stagnation & Burn

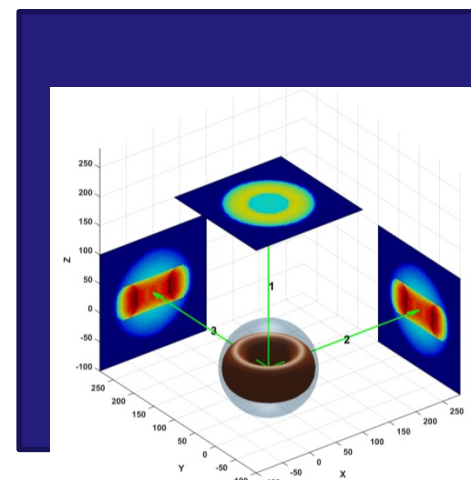
Bringing GCD-3 from OMEGA to NIF

New Carrier Support Assembly (CSA)



Goal: Enhanced Gamma-Ray Sensitivity, Temporal & Spectral Response relative to GRH-6m

3D Neutron Imaging
Polar, primary image only
installed in Q2FY17



Three views give tomographic imaging
Significant changes to present NIS to meet constraints

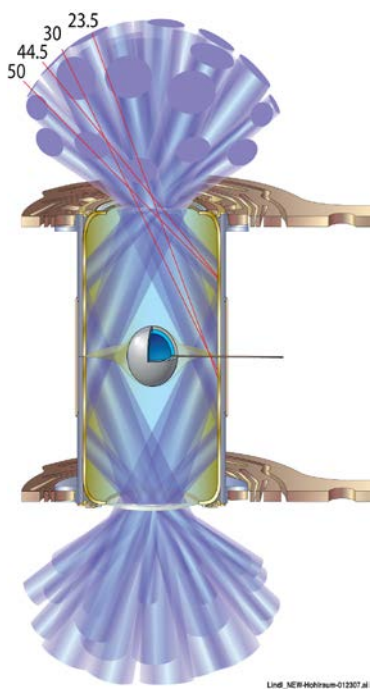
LANL has a diverse program of High Energy Density Physics and Fluids (HEDP&F) research

- High energy density (HED) conditions occur at pressures above approximately 1 million atmospheres (> 1 Mbar)
- Fluids research is focused on hydrodynamic instabilities, turbulence, and turbulent transport and mix
 - It spans classical through high energy density regimes
- LANL's Inertial Confinement Fusion (ICF) focuses on
 - Alternative paths to high yield (and possibly ignition) and platforms that can be perturbed from 1-D performance
 - Understanding the role of kinetic effects in plasmas
 - Developing transformative diagnostics
- Other physics interests include radiation flow and opacity

Backup

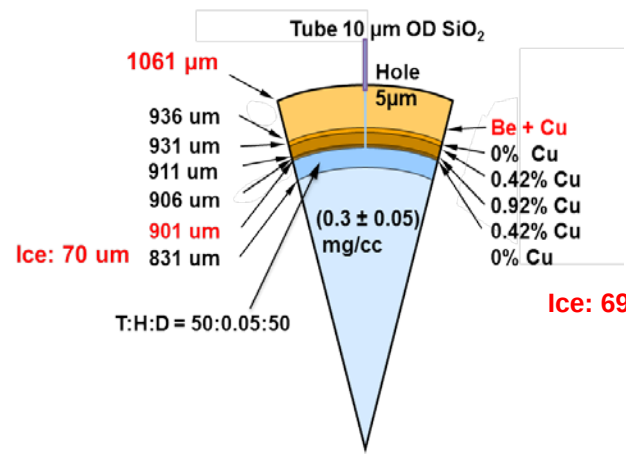
The first experiment Showed That Be Capsules Work and the Hohlraum Is the Problem

The only difference between in hohlraum fielding is the LEH diameter: **3461 μm for Be** vs **3101 μm for CH**

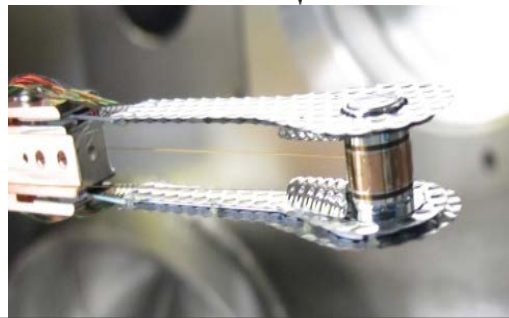
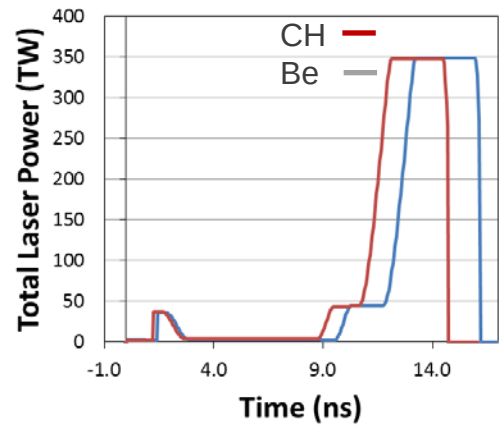
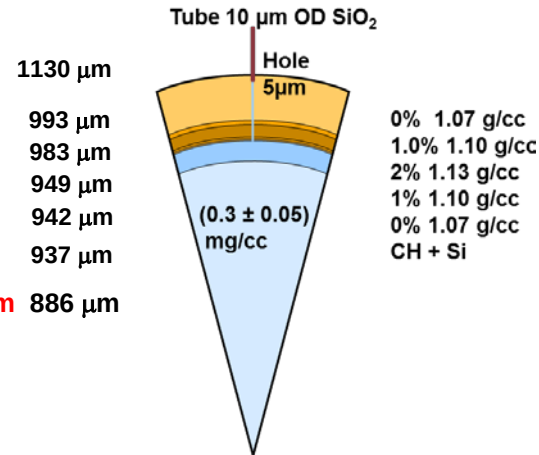


Line: NEW Hohlraum-012307.ai

Beryllium

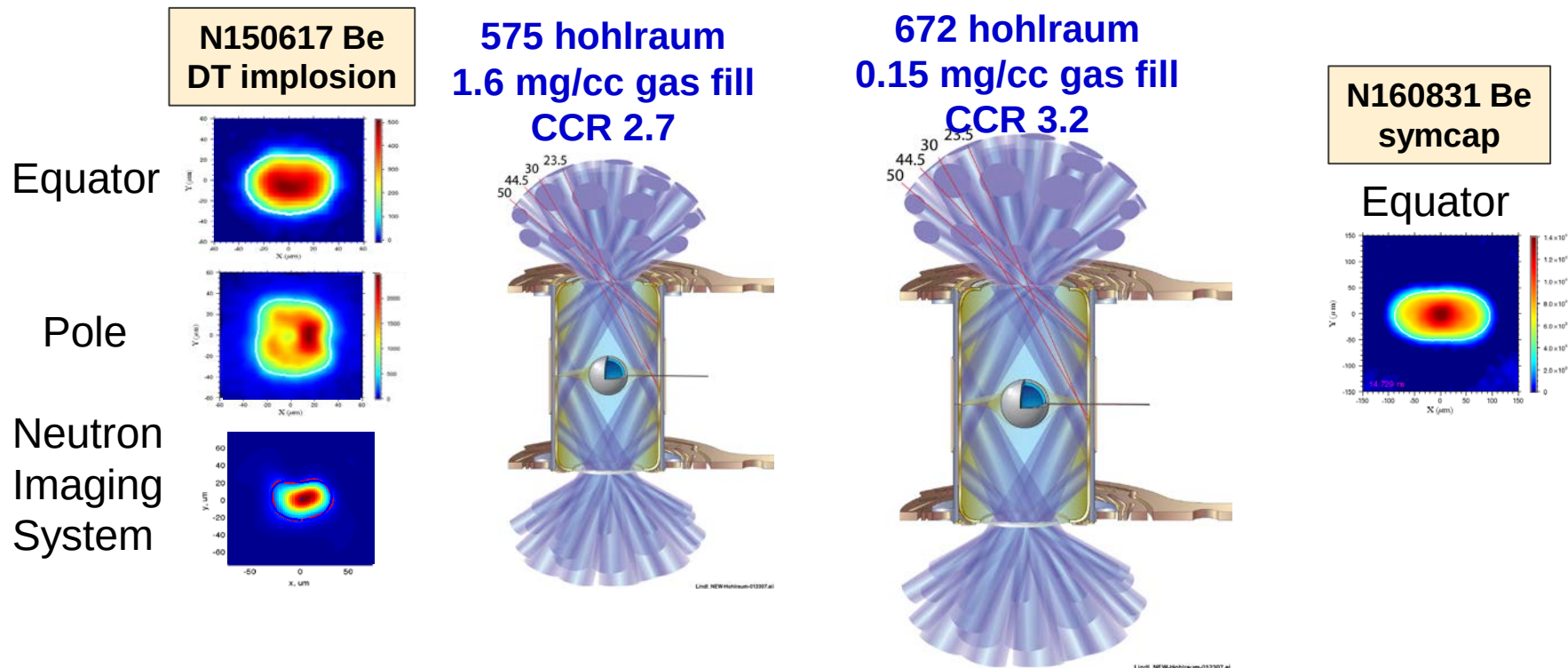


CH



First Beryllium DT layered target

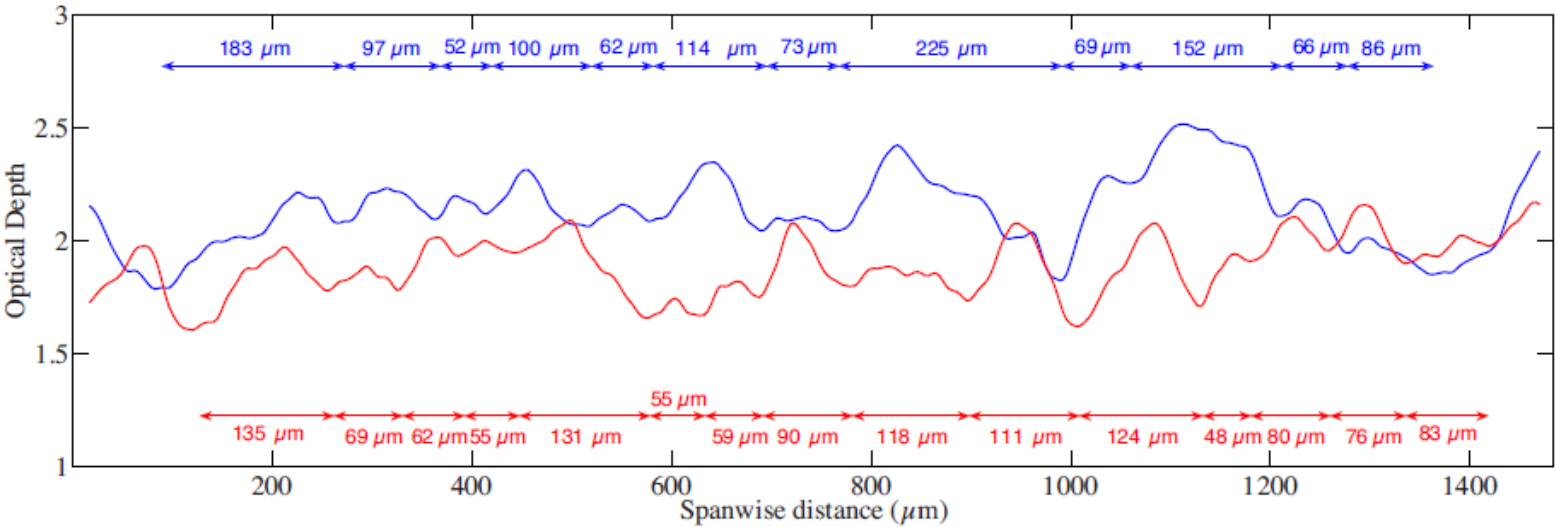
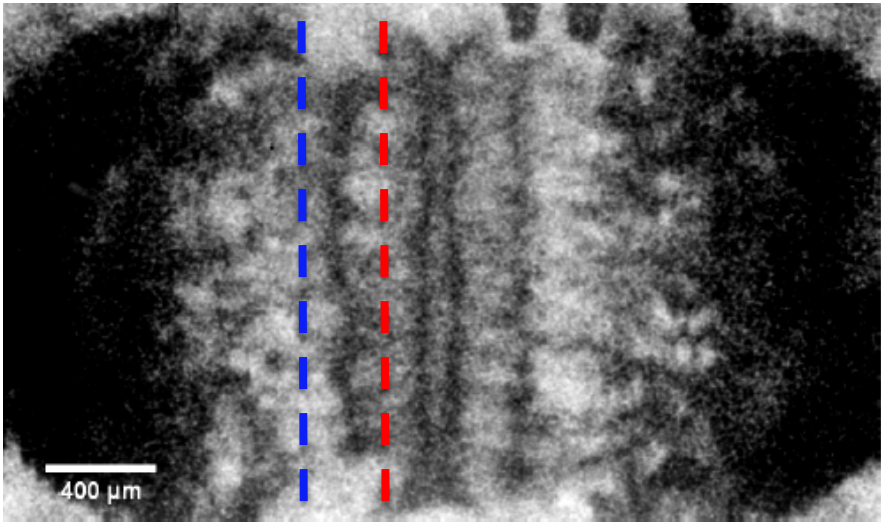
Poor shape control is evident in images of x ray self-emission for small case-to-capsule ratios



This is consistent with work implosions with other ablator materials

The NIF Shear phenomenology also includes spanwise periodic ‘ribs’ associated with secondary shear instabilities

N150604
34.5 ns
Ti Foil

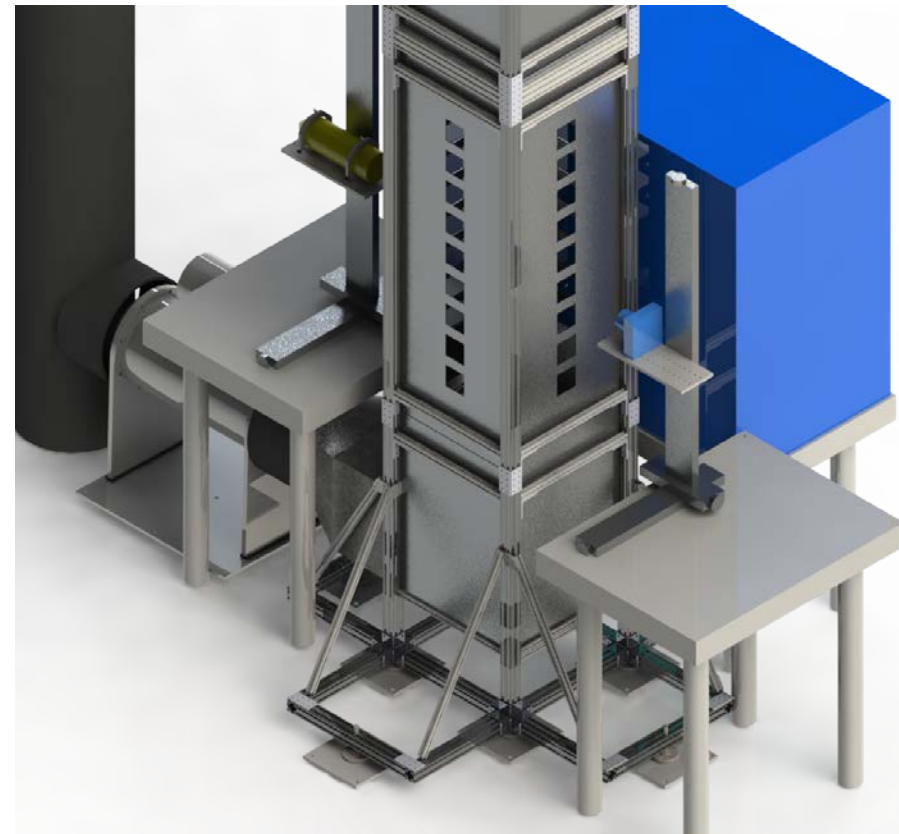


The Turbulent Mixing Tunnel is designed to study subsonic, variable-density mixing in many flow conditions



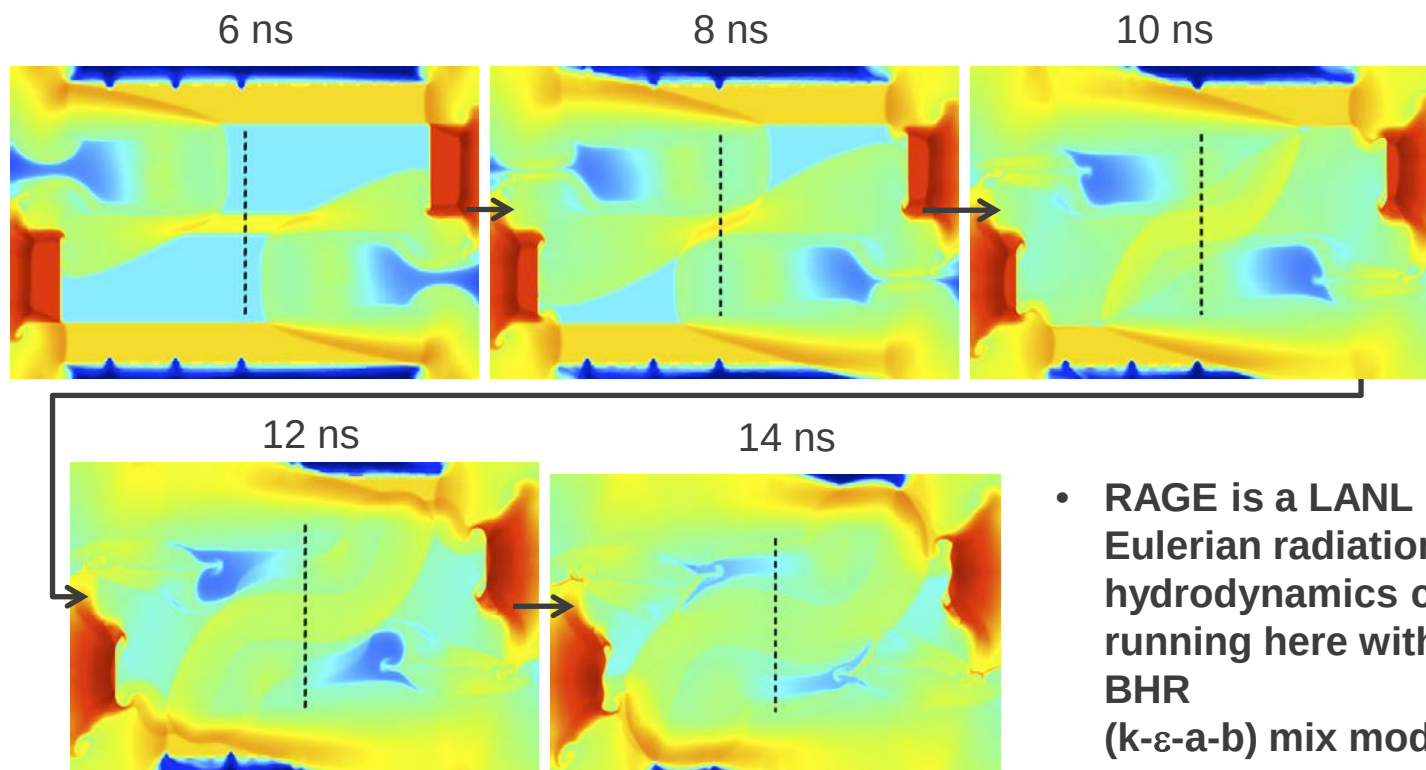
Turbulence Lab

Tunnel Test Section

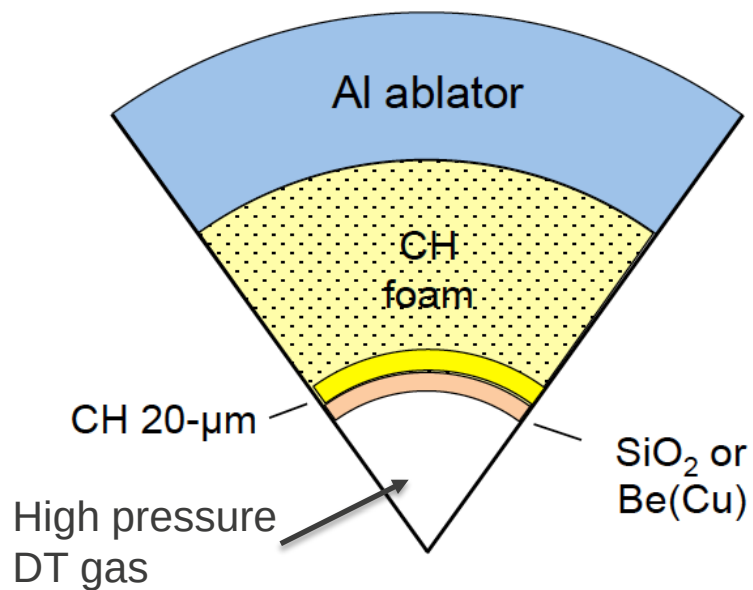


We are comparing this data to simulations in the LANL hydrocode RAGE

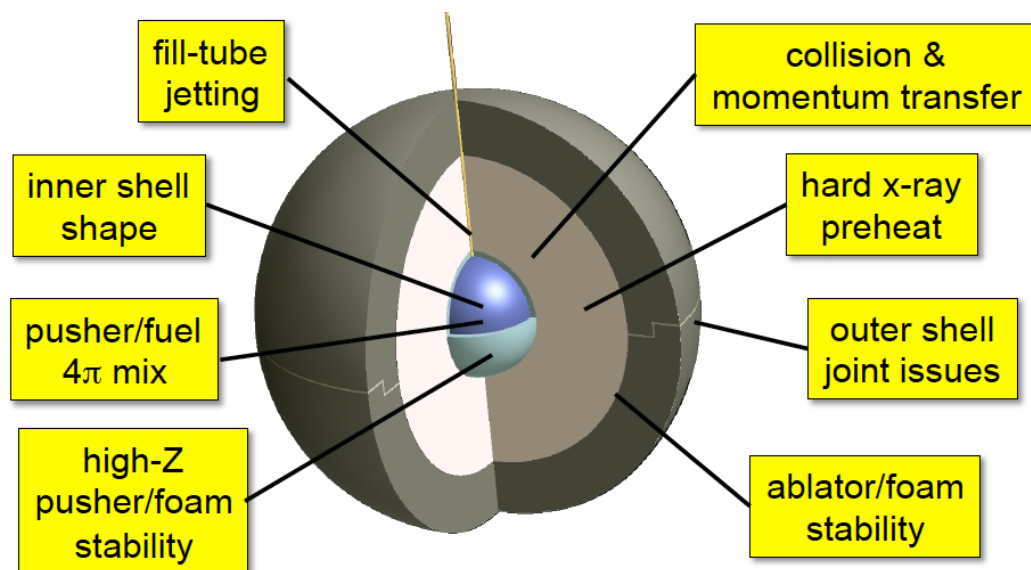
Simulations published in *Phys. Plasmas* **20**, 012707 (2013)



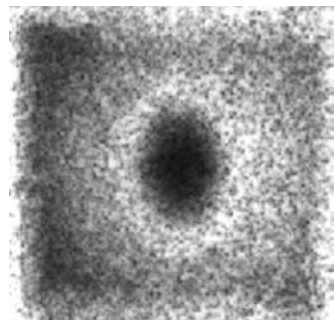
Double shell targets provide a different path to ignition than single shell ones – volume ignition



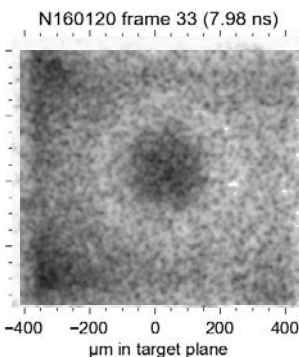
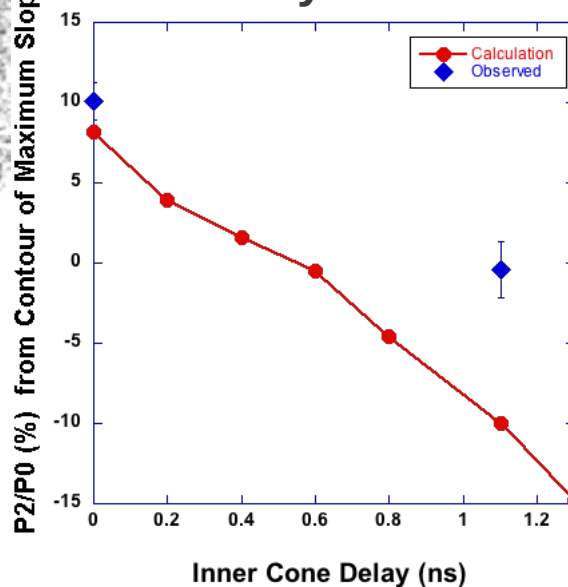
Double shells have different physics issues that will be addressed



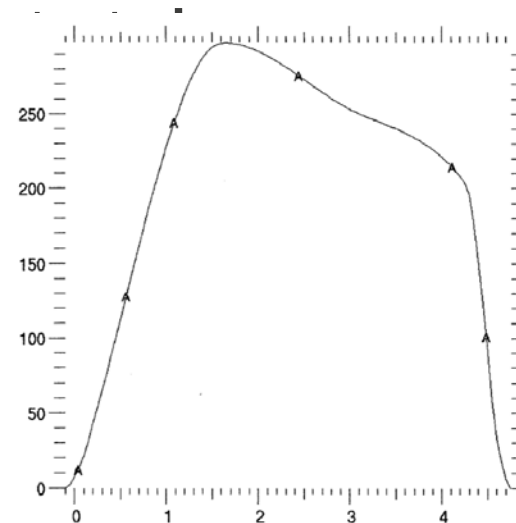
Double Shell Capsules Reduce Convergence, Change Hot-Spot Formation



First shot demonstrated symmetric implosion



- 4.5-ns reverse ramp
- 1 MJ energy
- 97 – 98.5% coupling
- Be(Cu) outer shell
- symmetry tuning



FY17 experiments will examine:
Mid-Z inner shell behavior
Collision elasticity
Shell instability