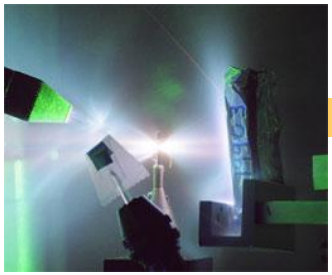
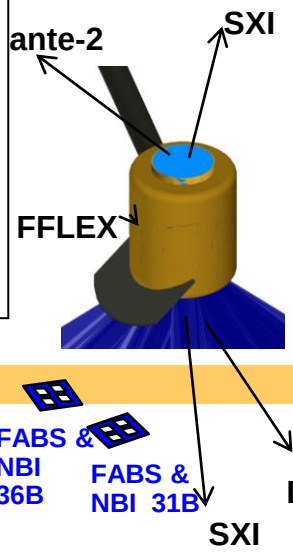
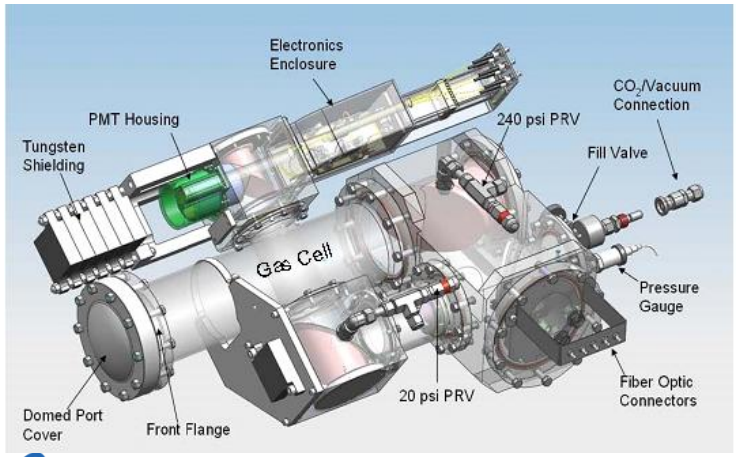


High Energy Density Physics Experiments at Los Alamos



Hans Herrmann

Plasma Physics Group (P-24)



In this photo, Norris Bradbury, Robert Oppenheimer, Richard Feynman, and Enrico Fermi attend an early Los Alamos weapons colloquium.

Los Alamos NATIONAL LABORATORY EST. 1943

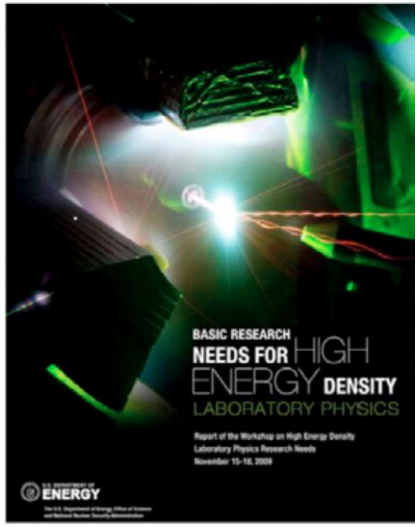
OMEGA Laser User Group Rochester, NY April 29, 2011

Operated by Los Alamos National Security, LLC for NNSA

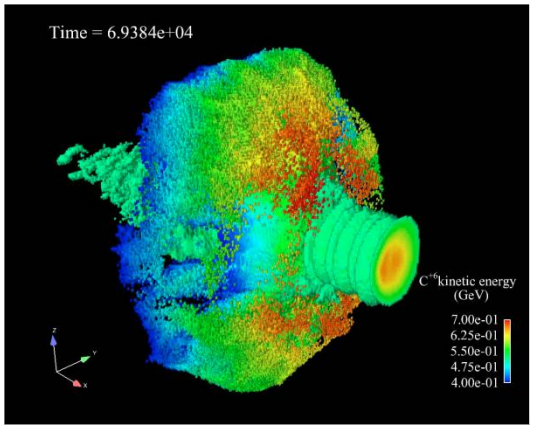
LA-UR 11-02522

NNSA

Los Alamos has a strong program in High Energy Density Physics aimed at National Applications as well as Basic Science



- Inertial Confinement Fusion (ICF)
- Radiation Hydrodynamics
- Hydrodynamics with Plasmas
- Material Dynamics
- Energetic Ion generation
- Dense Plasma Properties
- X-ray and Nuclear Diagnostic Development
- Petaflop performance to Exascale computing
- Magnetic Reconnection
- Magnetized Target Fusion
- High-Explosive Pulsed Power



LANL is a multidisciplinary NNSA Lab. overseen by Los Alamos National Security (LANS) LLC.

People

11,782 total employees: LANS, LLC 9,665; SOC Los Alamos (Guard Force) 477; Contractors 524; Students 1,116

Place

Located 35 miles northwest of Santa Fe, New Mexico, on 36 square miles of DOE-owned property.
> 2,000 individual facilities, 47 technical areas with 8 million square feet under roof, $5.9 B replacement value.
Operating costs FY 2010: **~ $2 billion**

51% NNSA weapons programs	8% Nonproliferation programs	6% Safeguards and Security
11% Environmental Management	4% DOE Office of Science	5% Energy and other programs
15% Work for Others		

Workforce Demographics (*LANS & students only*)

42% of employees live in Los Alamos, the rest commute from Santa Fe, Española, Taos, and Albuquerque.

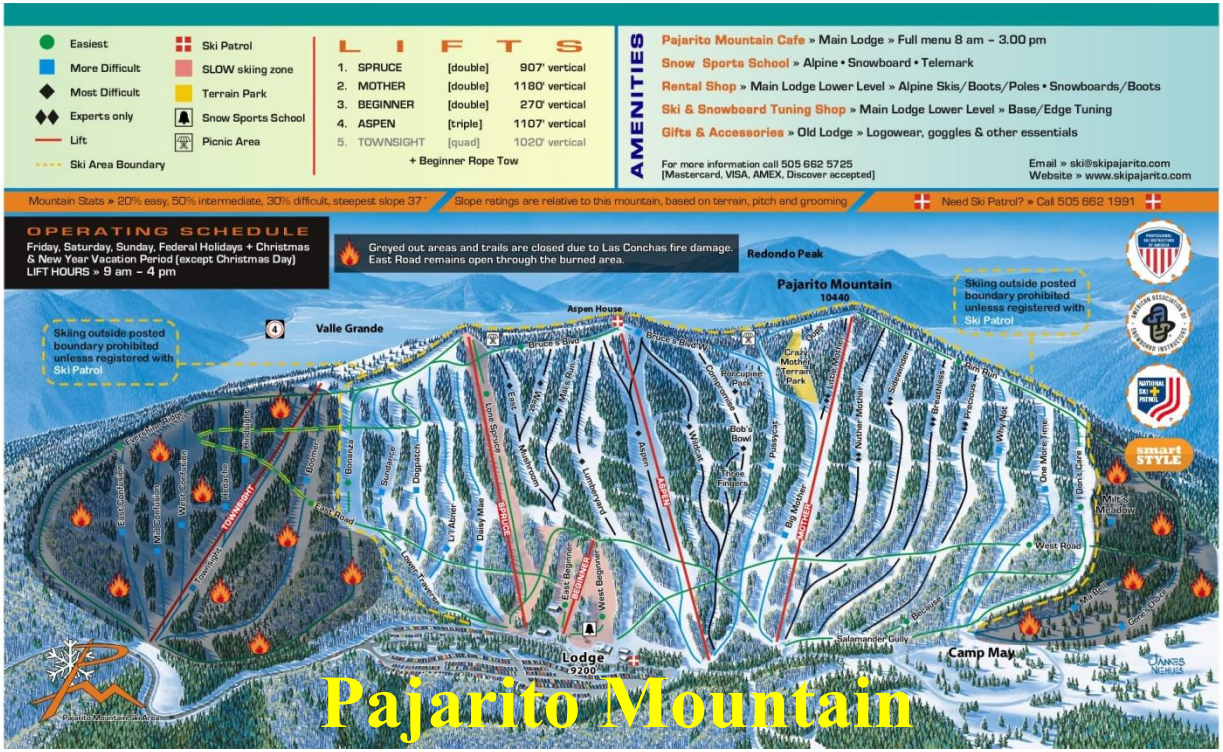
Average Age: 45
67% male, 33% female
43% minorities
72% university degrees
· 31% hold undergrad degrees
· 19% hold graduate degrees
· 22% have earned a Ph.D.

Major Awards

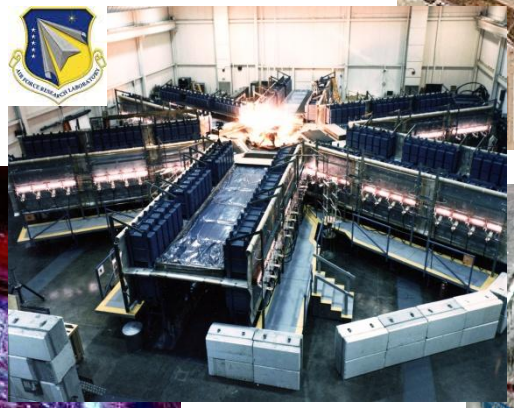
118 R&D100 awards since 1978
28 E.O. Lawrence Awards
The Seaborg Medal
The Edward Teller Medal

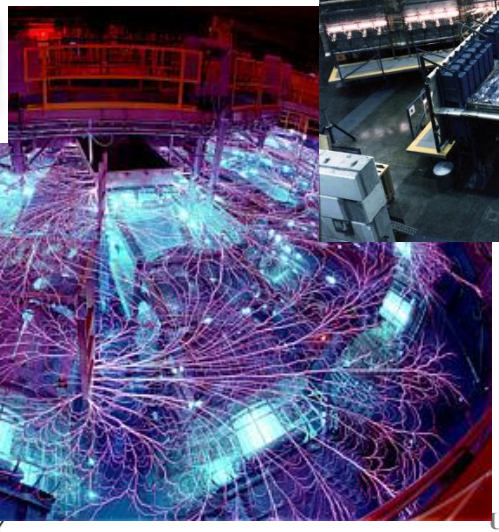
Los Alamos is a great place to live!

- NM- Land of Enchantment
  - >300 days sunshine per year
  - High desert at ~7200 ft
- Outdoor Activities
  - Hiking
  - Biking
  - Climbing
  - Skiing
- Cultural
  - History
  - Santa Fe
- Shopping- not so much



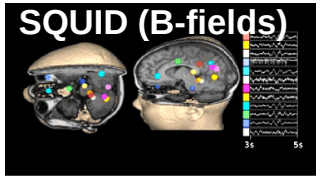
Los Alamos Stages Experiments to the Large Scale National Facilities

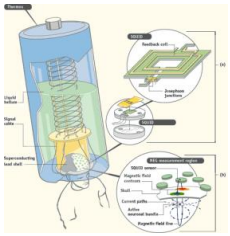


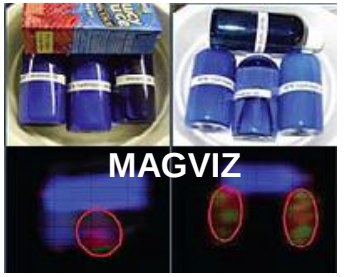


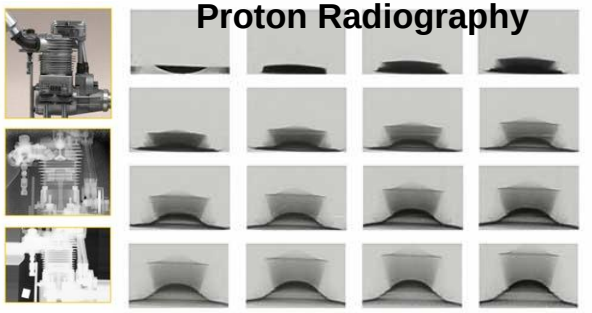
Physics is a multi-disciplinary multi-program experimental Division @ LANL.

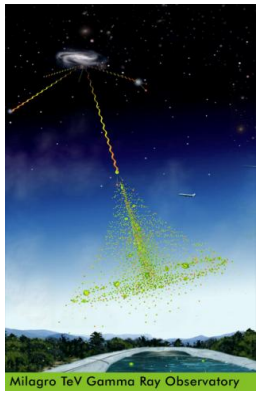
- P-21 Applied Modern Physics
- P-23 Neutron Science and Technology
- P-24 Plasma Physics
- P-25 Sub-atomic Physics

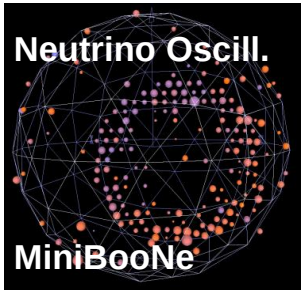






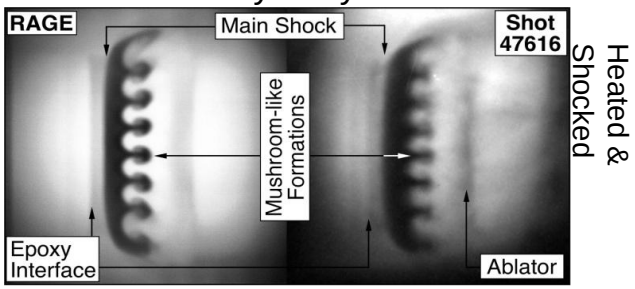




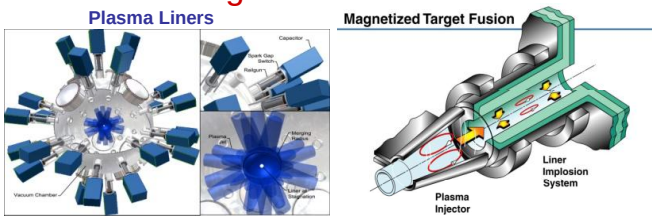


P-24 Plasma Physics is an experimental group addressing topics of national importance.

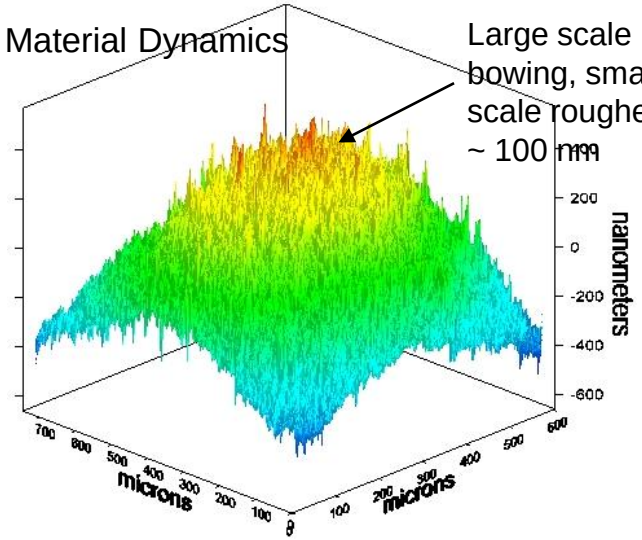
Radiation Hydrodynamics



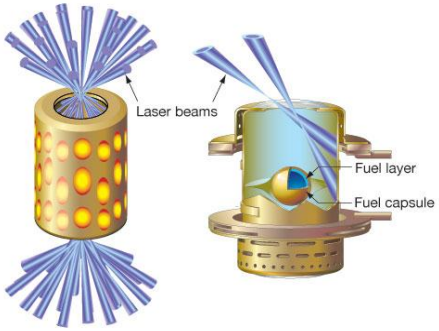
Magneto-inertial fusion

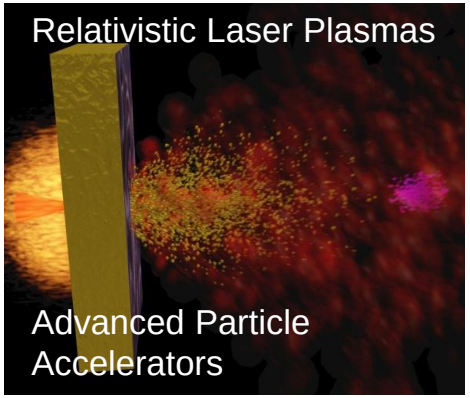


Material Dynamics



Inertial Confinement Fusion





P-24 Metrics, FY11

Workforce: 60

Refereed papers: 80, Cum. Impact: 184.3

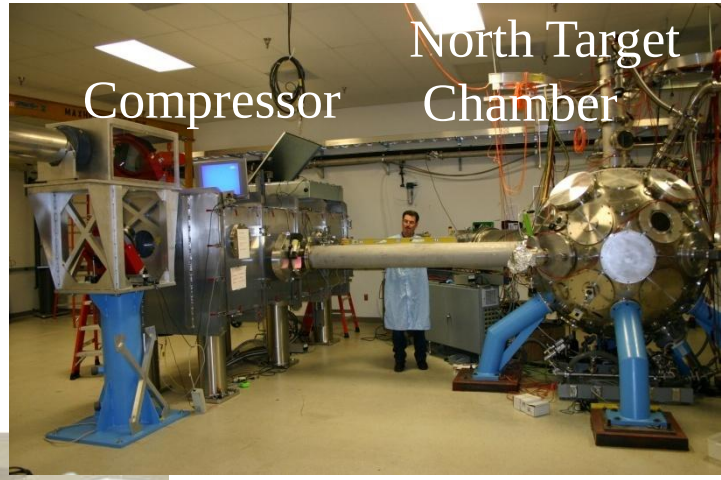
Invited Talks: 23 Patents: 2 Awards: 11

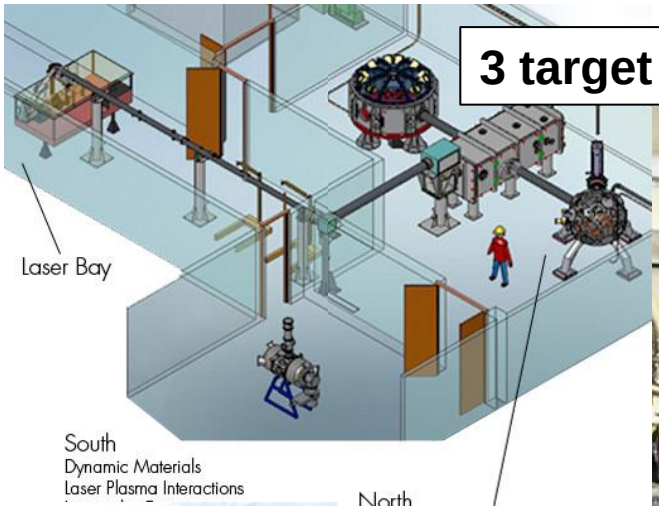
Program development activities: 50

The Trident Laser at Los Alamos is used for basic and applied research as well as staging for OMEGA and NIF

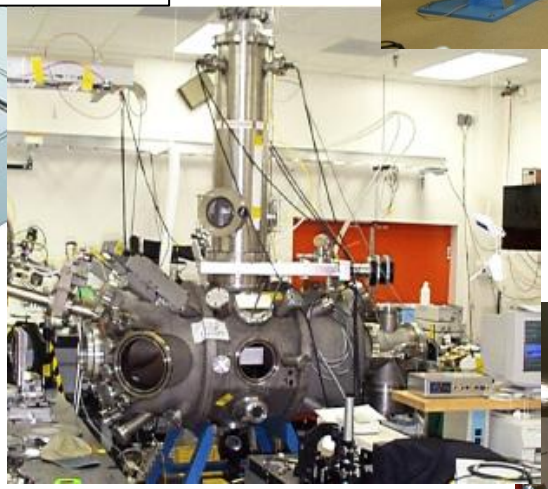
http://trident.lanl.gov/

- **Trident is a world-class HED driver**
- **Flexibility, Contrast, Support**
- **3 beams: 2x 220J (ns) and 1x 100J (ps)**





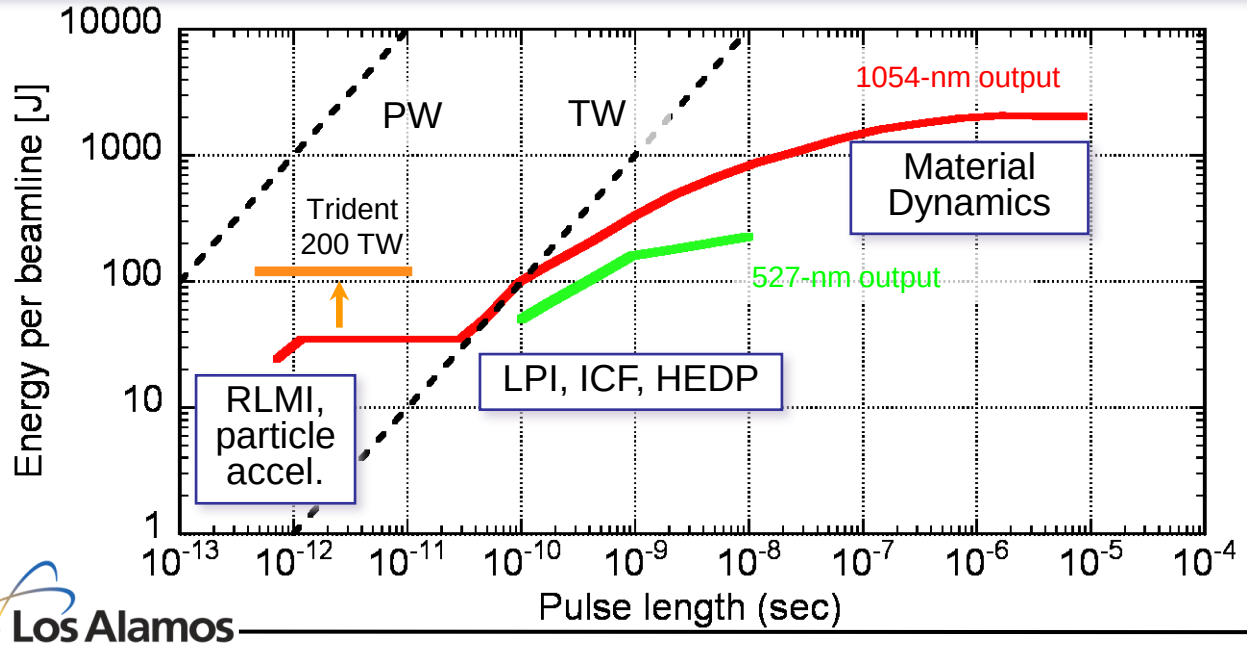
3 target areas



Hands on opportunities

The Trident 200 TW laser facility is a unique asset enabling HEDP research at LANL.

- > 7 orders of magnitude in pulse duration, unique in the world
- Simultaneous μs/ns (2 beams, 0.25 – 1 kJ) and ps pulses (1 beam, 100 J) on target
- Intensity > 10^{20} W/cm^2, comparable or > high energy PW lasers, best diagnosed
- 200-TW pre-pulse contrast >10^{-10}, best in the world (high energy, PW-class)
- unique “dial-a-pre-pulse” and pulse-shaping capability for short-pulse 200-TW

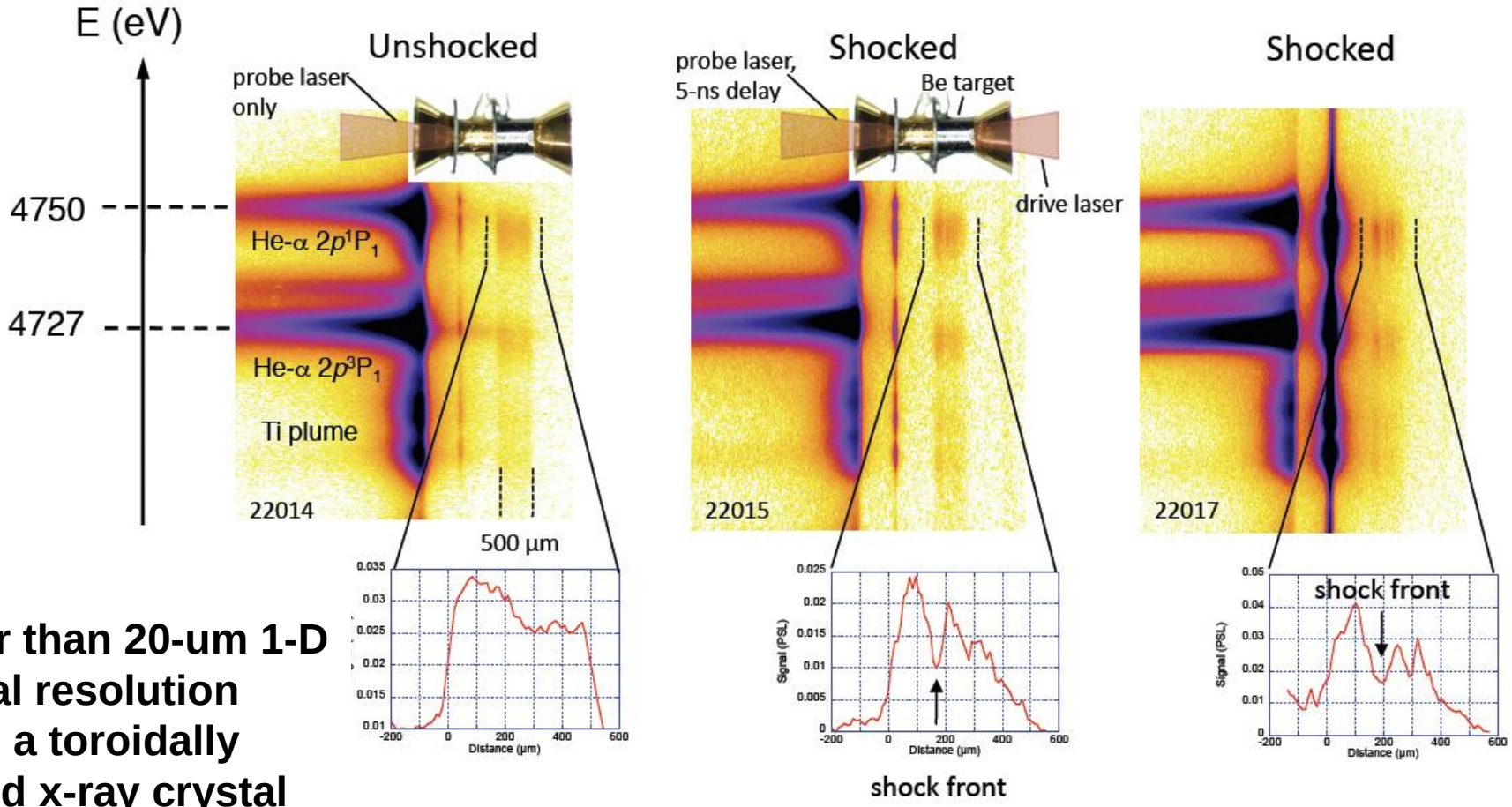


Los Alamos NATIONAL LABORATORY EST.1943

NNSA

Imaging X-Ray Thomson Scattering being developed on Trident for dense plasma characterization

In collaboration with U. Michigan

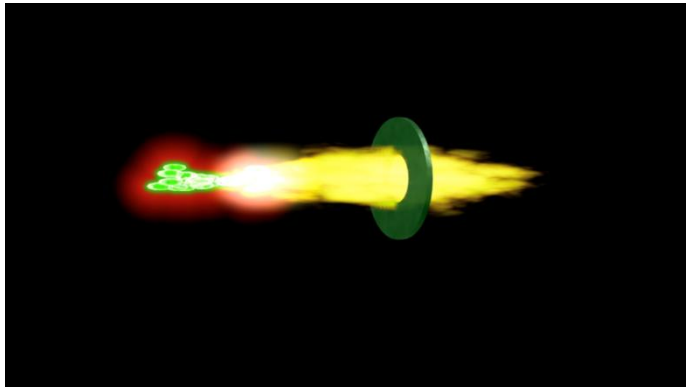


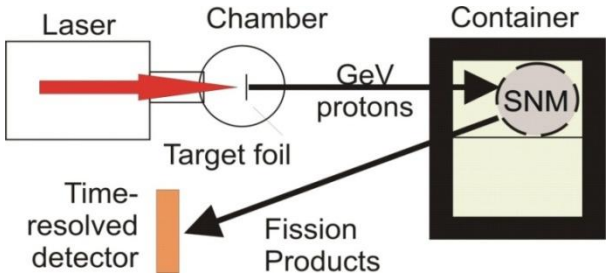
Better than 20-um 1-D spatial resolution using a toroidally curved x-ray crystal

Results from un-shocked and shocked Be targets

GeV Proton Generation for Active Interrogation is Being Developed on Trident

- **Our research: demonstrate the technical basis for a compact high-gradient, high-current laser-driven proton accelerator for special nuclear materials (SNM) detection, *i.e.*, validate modeling tools.**

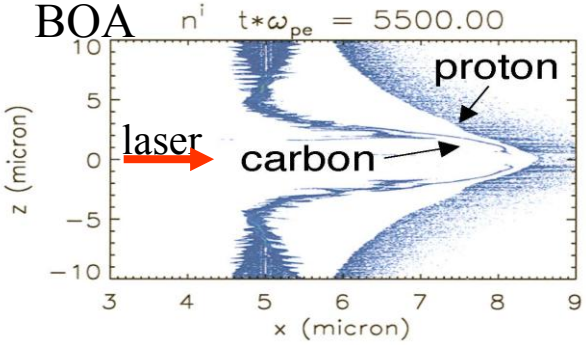




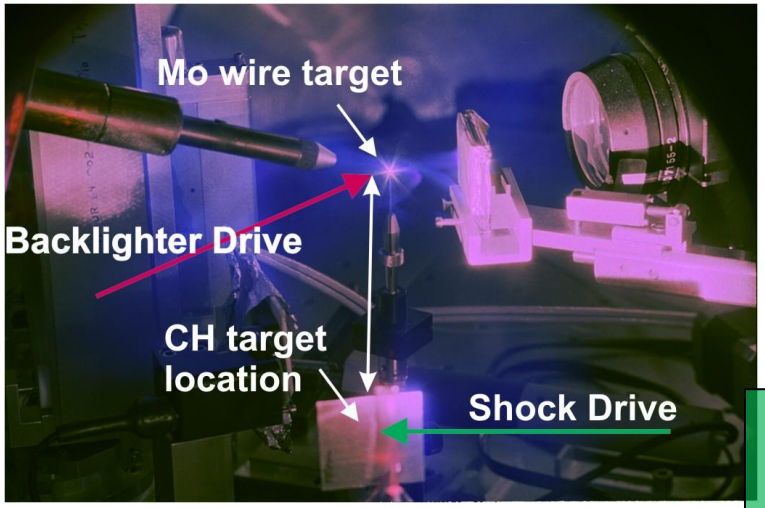
***Relativistically* transparent**, overdense targets

Break out afterburner is one approach:

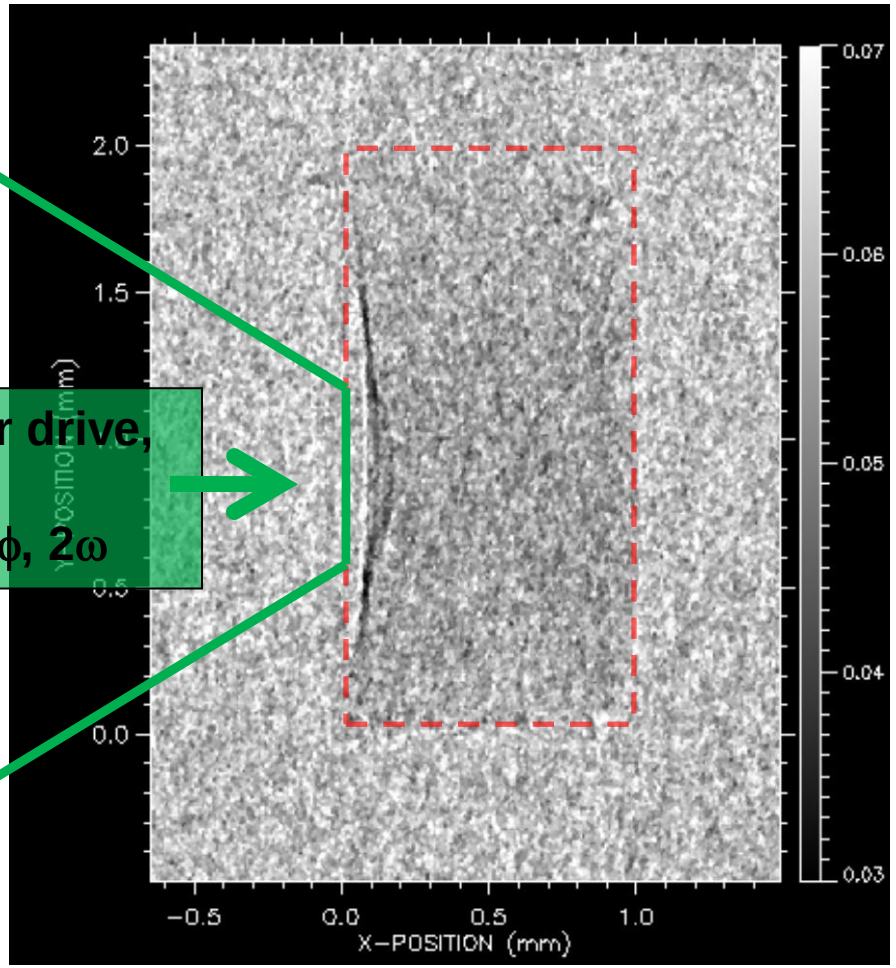
L. Yin *et al.,* Laser Part. Beams **24,** 291 (2006) ; Phys. Plasmas **14,** 056706 (2007)

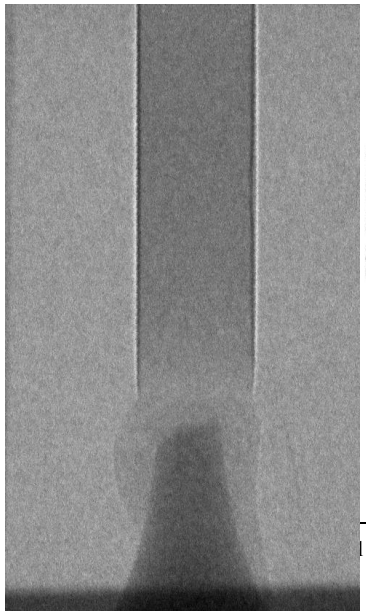


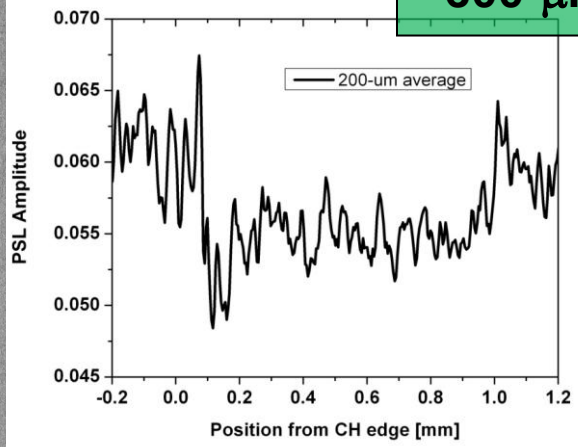
Phase contrast Imaging at High X-Ray Energies is Being Developed on Trident for Application to Dense Targets



2-ns laser drive, 200-J ~600-μm ϕ, 2ω



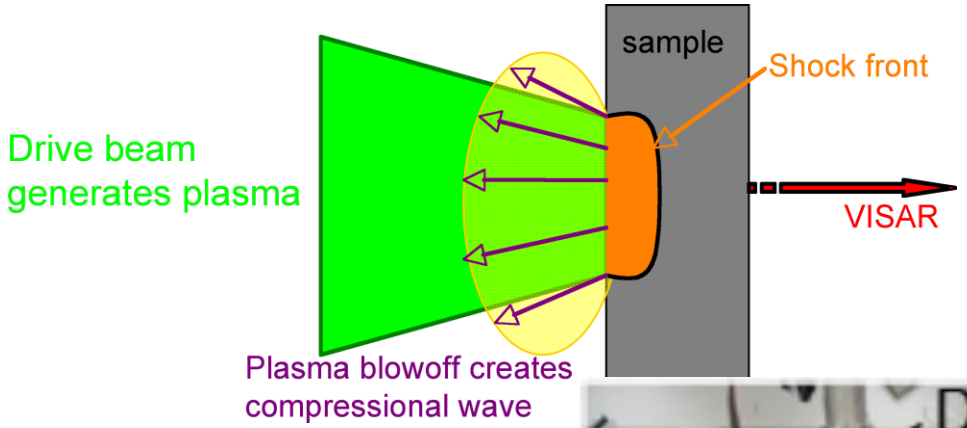


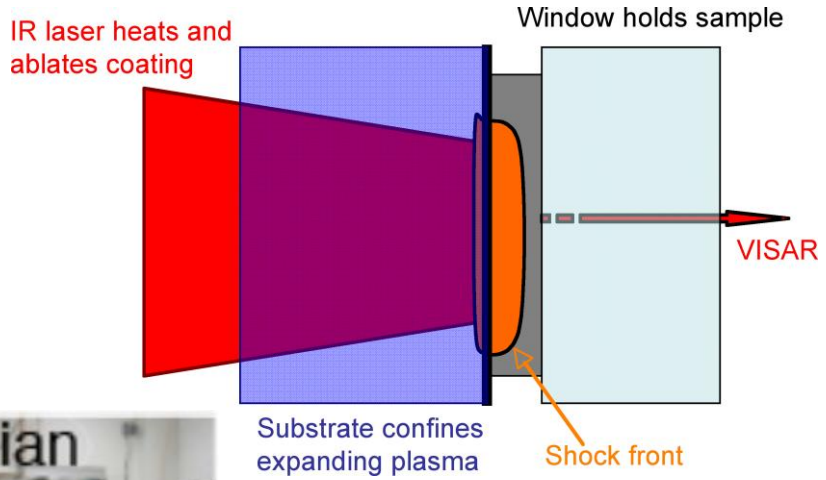


Mo wire (12-μm) located 30-cm from CH disk (1-mm thick, 3-mm diameter). Image plane located 90-cm from object. Magnification-4

Trident provides a unique driver for dynamic materials experiments

- **Basic understanding of material properties under extreme conditions and applied applications to ICF materials**



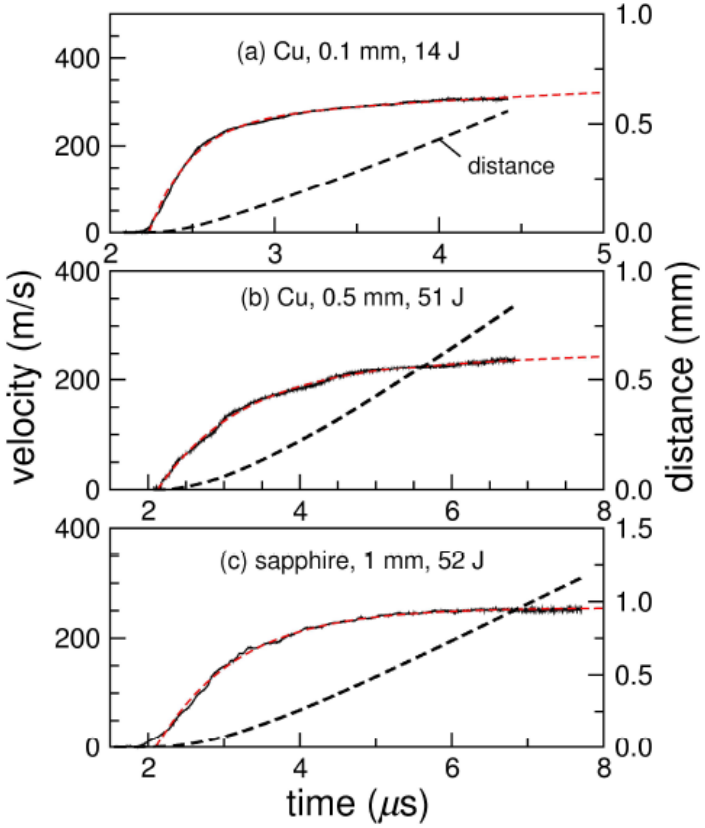


Direct Drive: plasma expands into vacuum
2.4 ns or less at 527 nm (Trident)
1 mm (high pressure) or 5 mm (moderate pressure) spot size

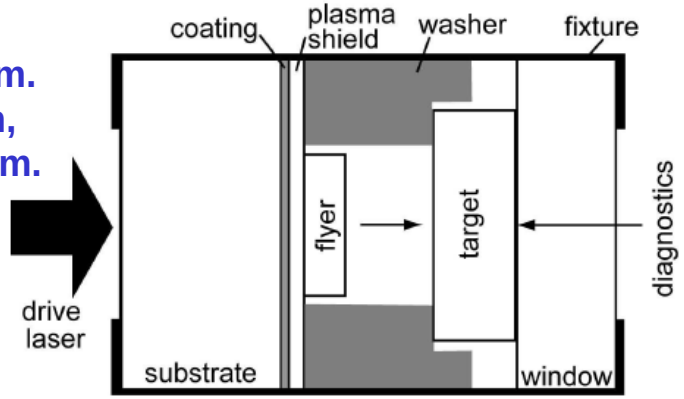
Confined ablation: plasma confined by substrate
Similar to flyer, except target, window, and substrate are in intimate contact
Attainable pressures lower than that of flyers, but diagnostic timing easier

Laser-flyers generated on Trident provide constant velocity drive with 1-D shocks

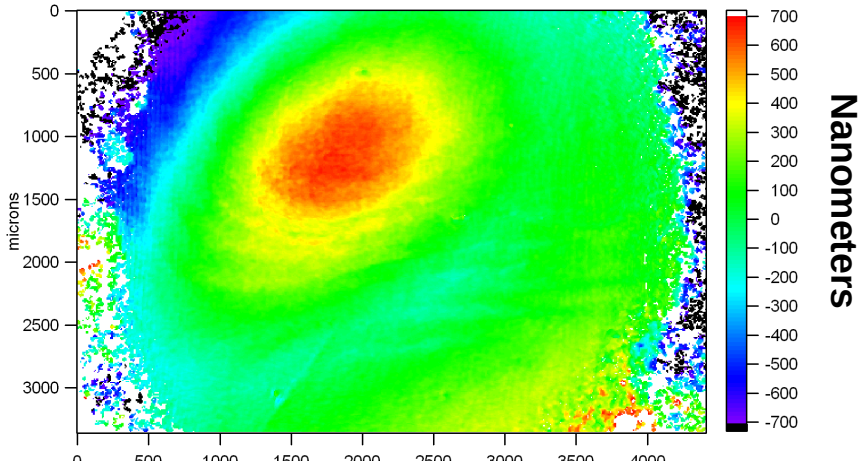
Examples of flyer plate acceleration history



Flyer: ϕ=8 mm, thickness 0.1-2 mm. Target: ϕ=10 mm, thickness 0.1-4 mm.



TIDI = transient imaging displacement interferometer measures drive uniformity to 10-nm resolution



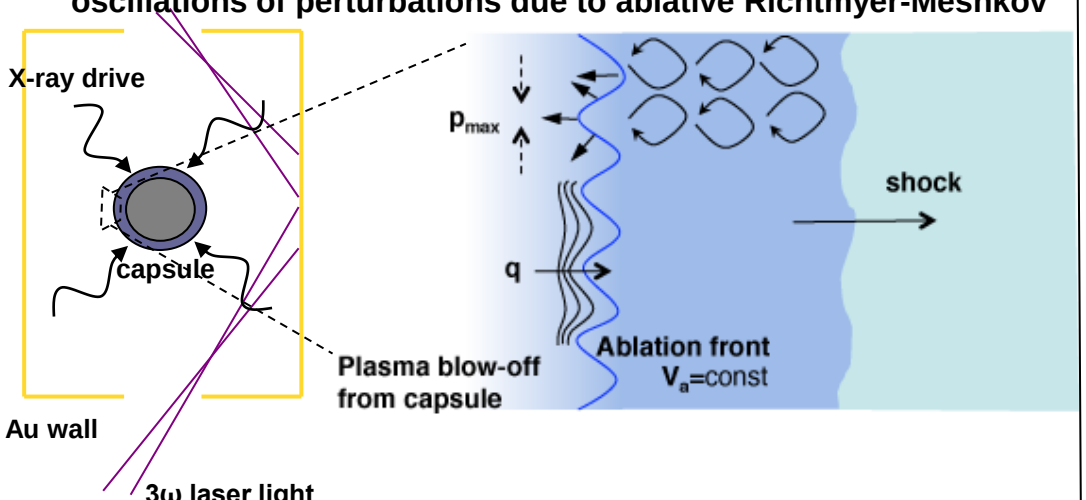
Peak to valley ~1.5 μm over ~4x4-mm: the planarity of shock is better than 10^{-3} radians

OMEGA Activities Support ICF and Basic Science

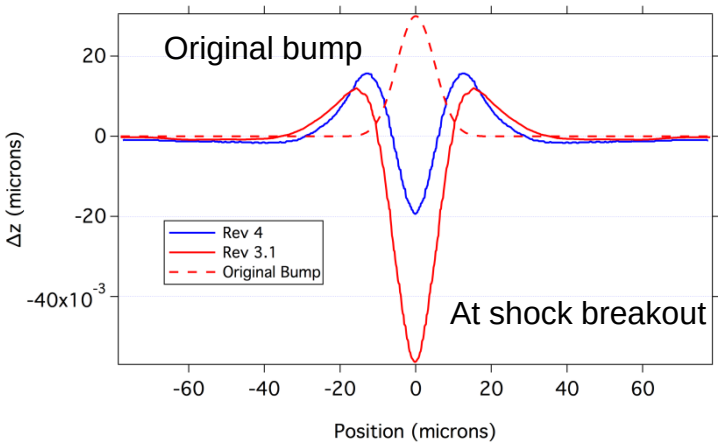
- **Hydrodynamic Instabilities and mix**
  - Richtmyer Meshkov
  - Rayleigh Taylor
  - Kelvin Helmholtz
- **Defect effects on ICF capsule performance**
  - ABEX
  - DIME
- **Energetic Ion Generation**
  - Active Interrogation
  - Fast Ignition
  - Defect Generation
  - Creation of Warm Dense Matter
- **Radiation Transport**
- **Properties of Dense Plasmas, Warm Dense Matter**
- **Nuclear Physics**
- **Diagnostic Development for NIF**
  - X-Ray Absorption Spectroscopy
  - Gamma Reaction History
  - Neutron Imaging

CHARM: Existing surface defects on NIF ablators must be controlled to maximize capsule performance

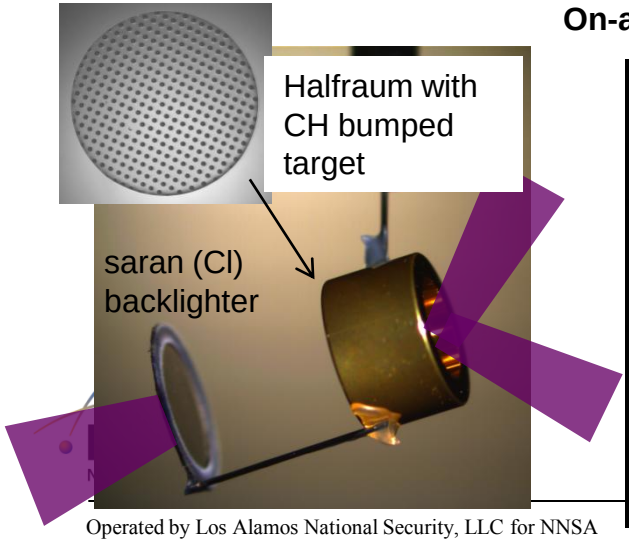
X-ray driven ablation of plastic ablators produce mass oscillations of perturbations due to ablative Richtmyer-Meshkov

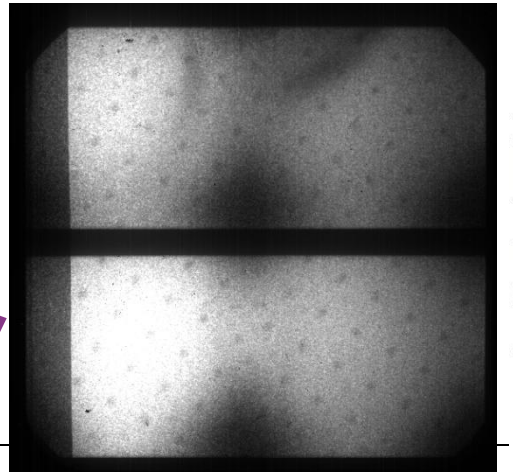


Shaping of ignition pulse can be used to alter bump height at onset of Rayleigh-Taylor growth

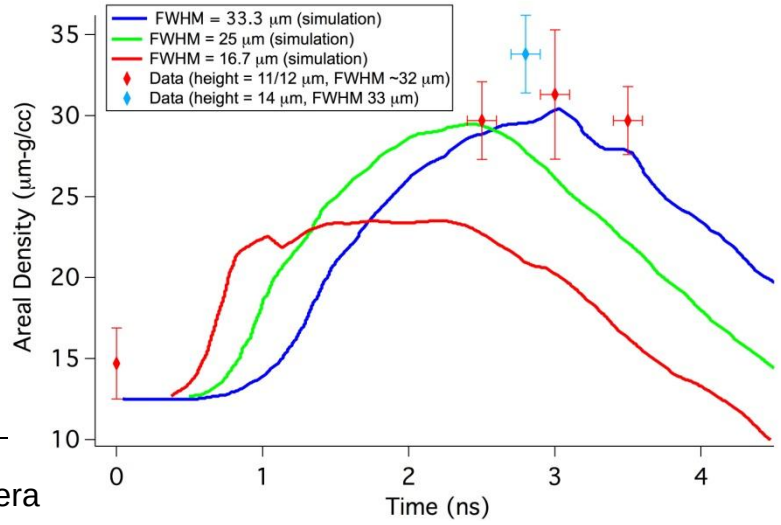


On-axis area backlighting radiography experiments validate numerical simulations

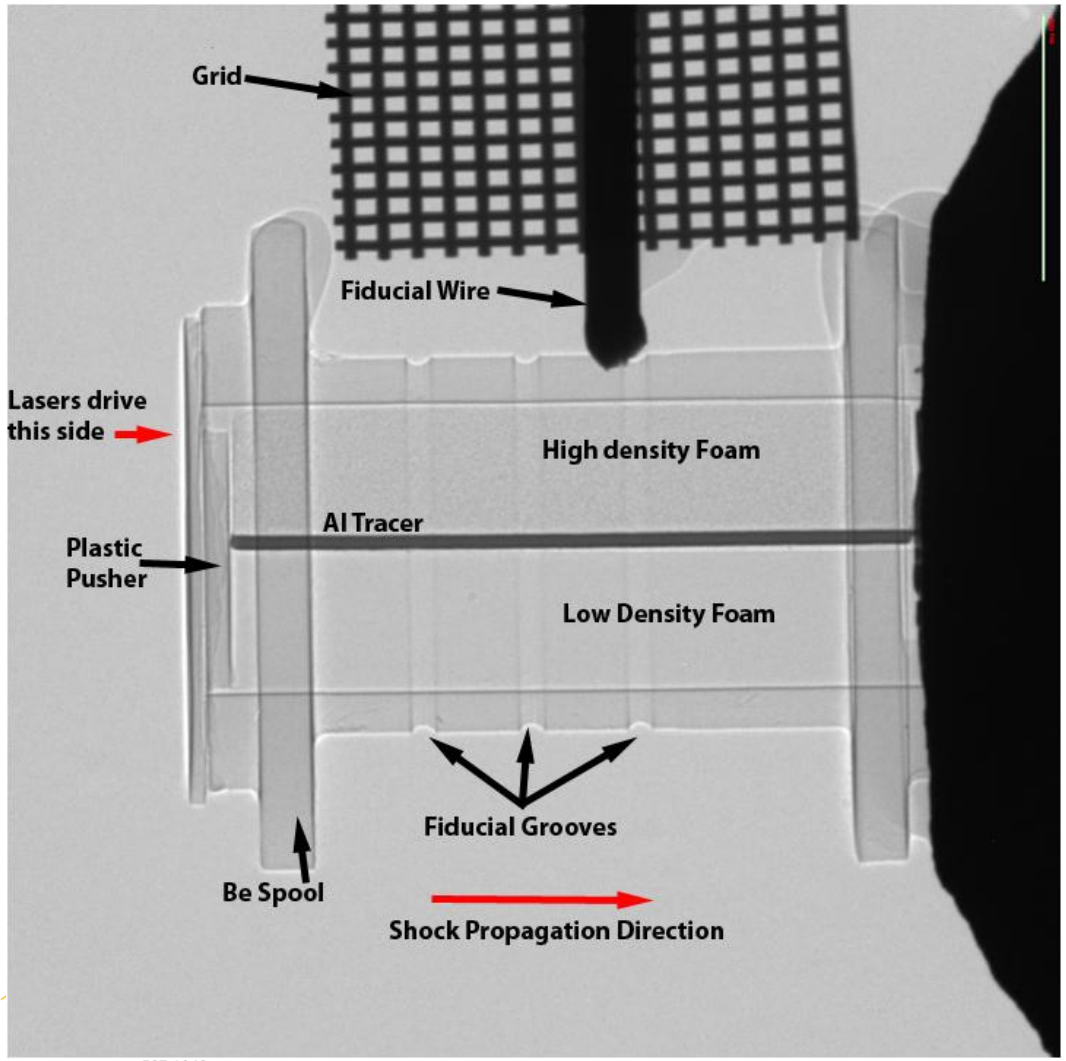




Bumps imaged with x-ray framing camera



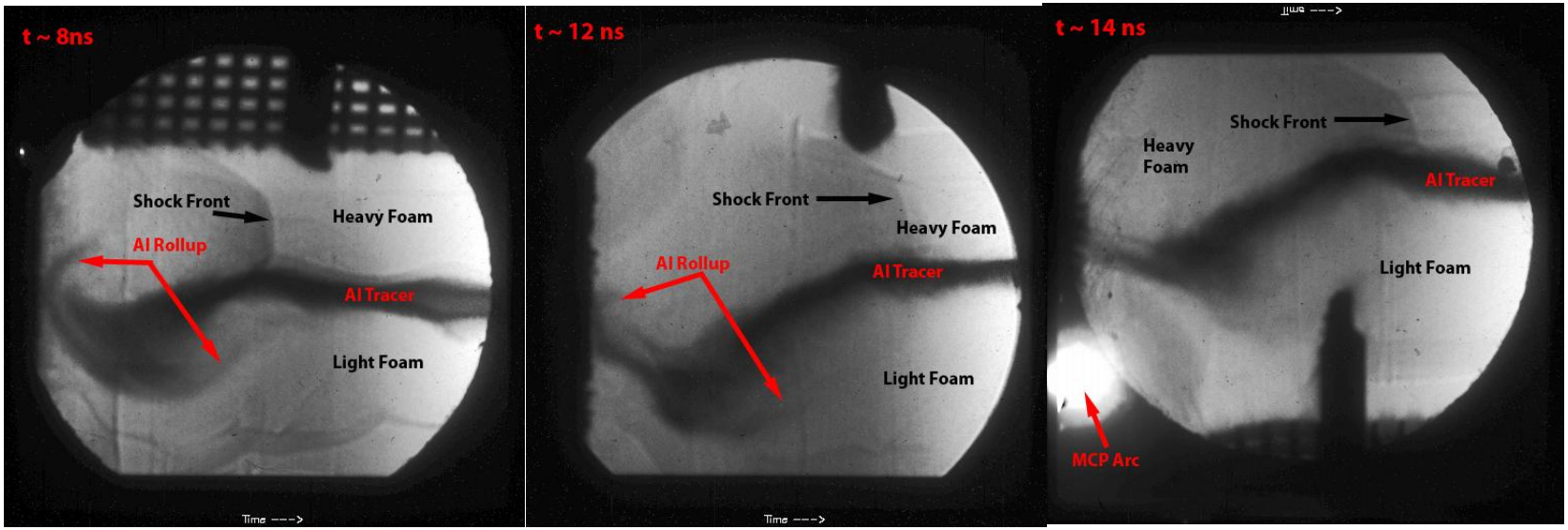
The Shear campaign studies the growth of instabilities in the presence of a strong shearing flow on OMEGA

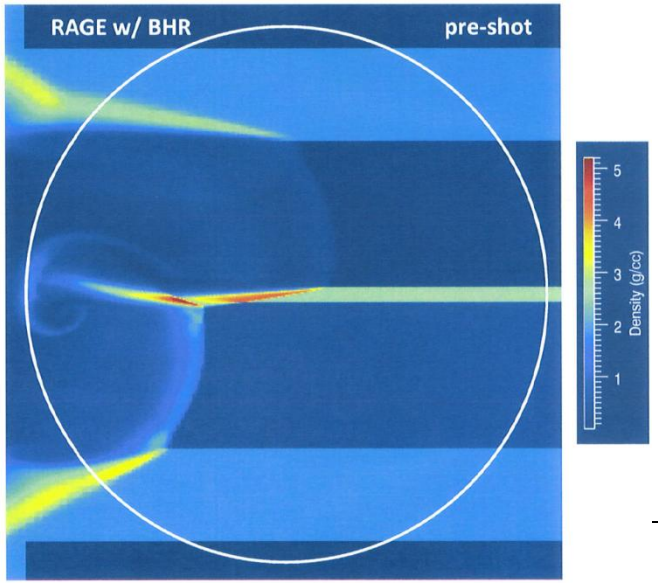


- Laser drive shocks from the left hand side, which propagate to the right
- Evolution of Al tracer layer as a function of time measured via X-ray radiographs
- Data is compared to simulations
- Results from experiments used to constrain coefficients used in mix models

EST.1943
Operated by Los Alamos National Security, LLC for NNSA
NNSA

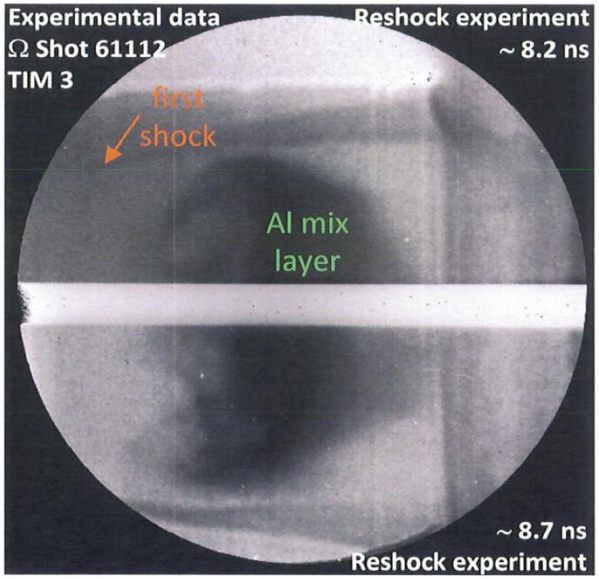
Hydrodynamic evolution of the Al tracer layer and shocks are observed



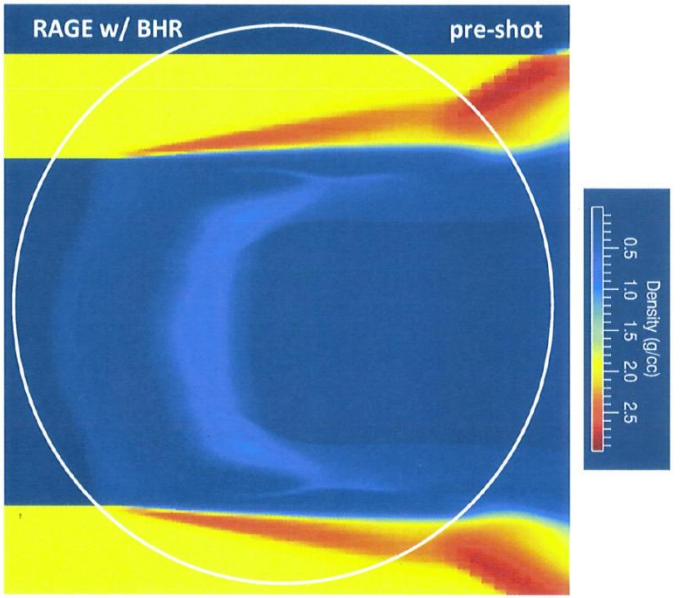


Time sequence of shear flow that will be compared to simulation to help constrain coefficients in the BHR mix model

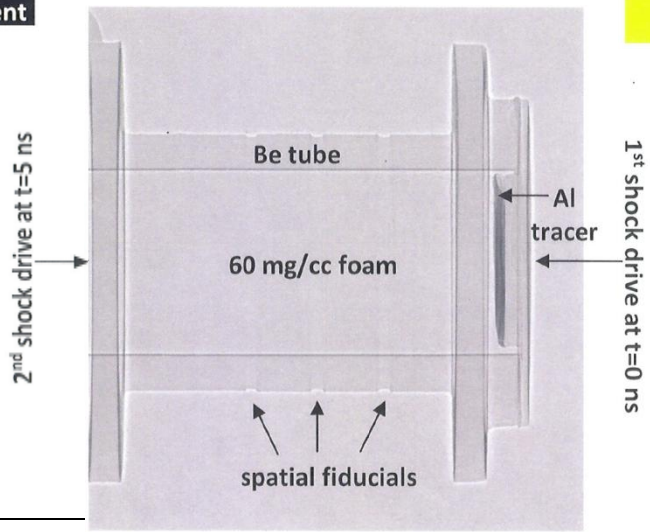
Colliding Shock Experiments on OMEGA Study Mix Layer Behavior with Multiple Strong Shocks



This OMEGA experimental campaign aims to provide data to further constrain the BHR mix model.



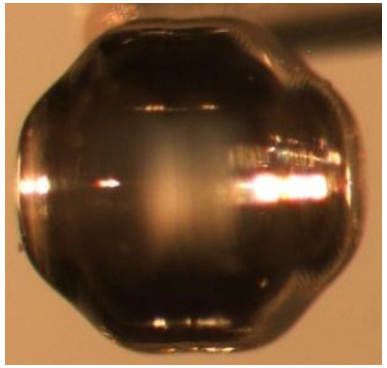
Lasers drive shocks from both sides of the target to create colliding shocks of variable strength and timing.



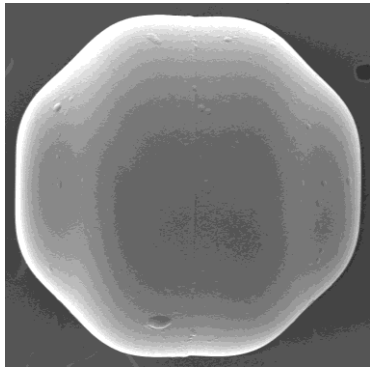
Pre-shot calculations are dominated by a deformed shock front not seen in the data. Work continues with the goal of identifying physics missing from the simulations.

ABEX will determine effects of low-order asymmetry on burn performance in ICF

- **Purpose: Experimentally characterize the effects of low-order (P8) implosion asymmetry on fuel-shell mixing and fusion burn performance.**
- **Motivation: High resolution simulations suggest that asymmetric drive produces obliquely interacting shocks resulting in unstable vortical structure and turbulence in the gas which leads to enhanced fuel-shell mixing and degraded burn performance.**



machined mandrel ready for GDP overcoat



SEM of completed prototype GDP shell (Jan 2011)

LANL is using PDD single-shell capsules to quantify mix in ICF capsules with defects

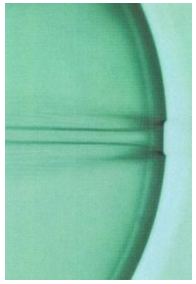
OMEGA

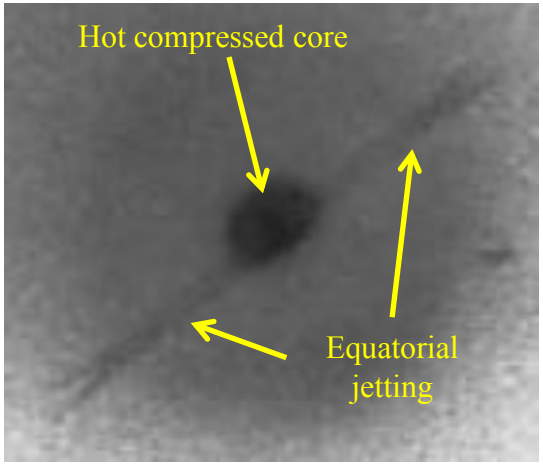
Goal: Extend 4π mix models to more accurately model mix both with and without high mode-number features

- **Current Omega experiments transition to NIF in FY12**

Backlit PPD implosions being performed on Omega using defect capsules to validate shell hydrodynamics

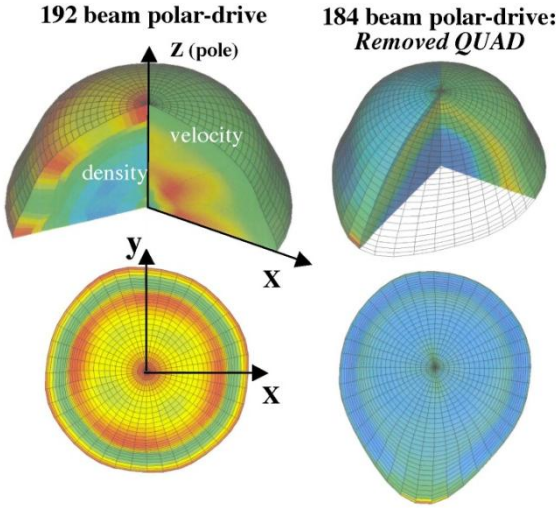
Initial defect





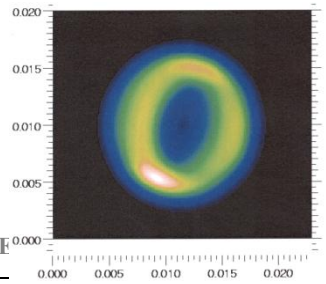
1/25/2011 Omega shot 60901

The first fully 3-D 192 beam PDD Hydra simulations used for NIF designs

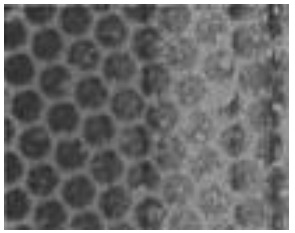


Hi-Z doped capsule layers quantify spatial dependent mix

Synthetic MMI Image

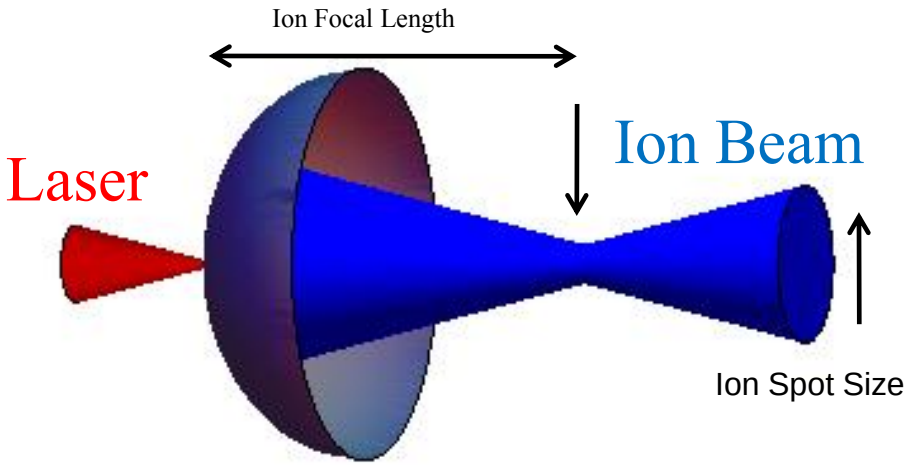


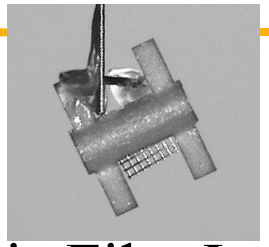
Recent Omega MMI Data



1/25/2011 Omega shot 60896

Ion focusing geometries are being explored on OMEGA-EP for ion beam applications

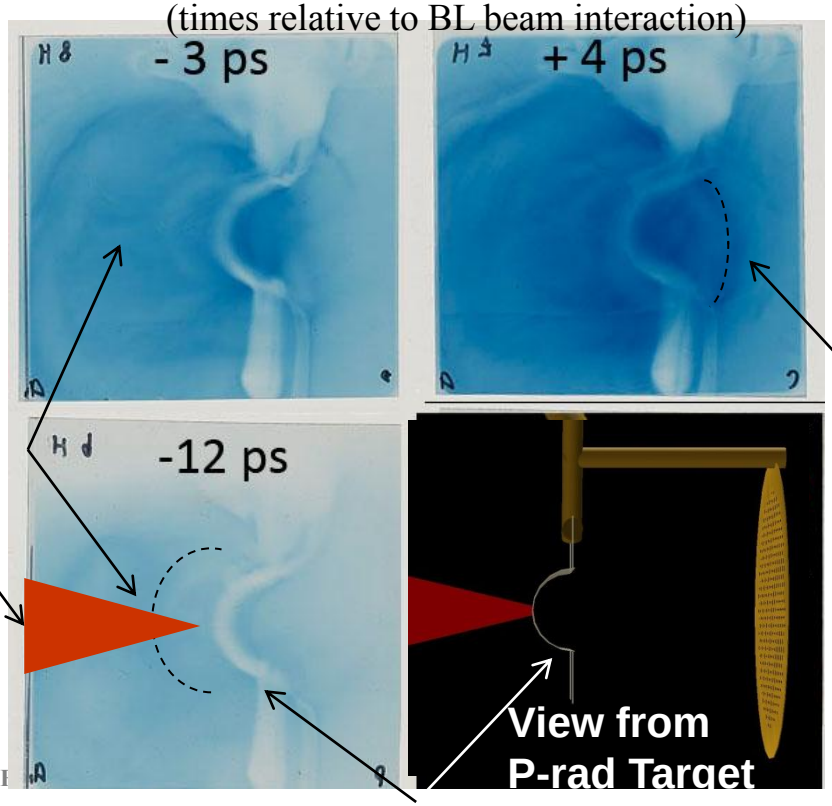




Actual Target (front view)

Radiochromic Film Images

(times relative to BL beam interaction)

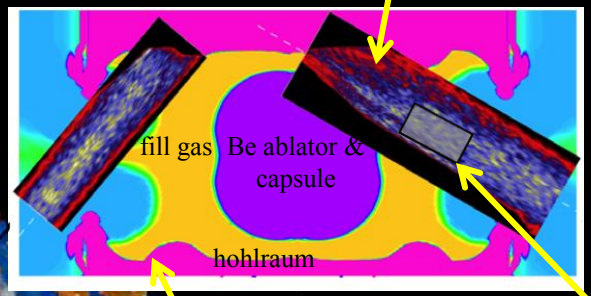


- We used the Omega EP laser to drive a half-pipe with a 1 ps 300 J laser, and radiographed the sheath fields with a 10 ps 800J beam to produce ~50 MeV protons. The sheath was probed with ~25 MeV protons.
- Current experiments will explore hemispherical geometries.

Cylindrical "half-pipe" Target

UNCLASSIFIED

Recent advances in laser-plasma interaction science required Petaflop-scale simulations



LLNL pF3D modeling of laser

LLNL Hydra modeling of ignition capsule

LANL VPIC simulation volume

VPIC simulation of SRS in NIF laser speckle: exhibits phase-front bending and filamentation

- Laser-plasma interaction (LPI) is a source of uncertainty in inertial confinement fusion experiments – LPI scatters laser beams & makes hot e^- that preheat capsule
- With Petaflop/s supercomputing and the best-in-class VPIC simulation code, ab initio "at scale" kinetic modeling offers insight into*:
  - Electron trapping - lowers onset threshold for stimulated Raman scattering (SRS)
  - The nonlinear physics that saturates SRS

* Yin et al. PRL 2007; PoP 2009

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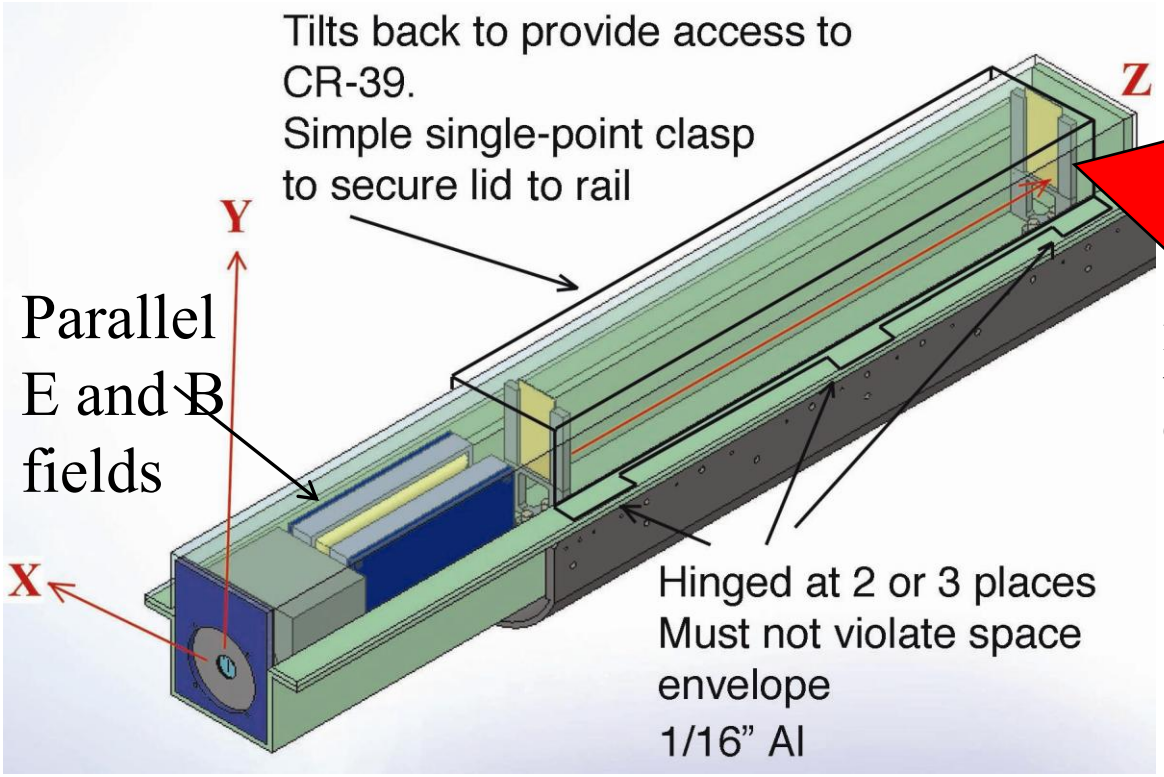
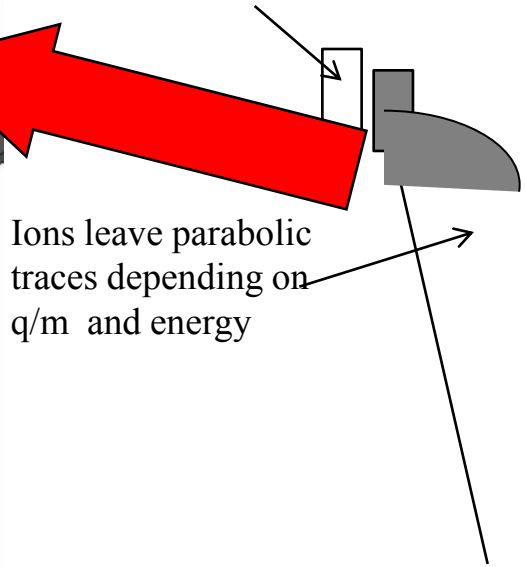
TPIE sits in a TIM on OMEGA-EP and uses both NTD CR-39 and Image Plates



Nuclear Track Detector **CR-39** is a clear plastic used to record heavy ions

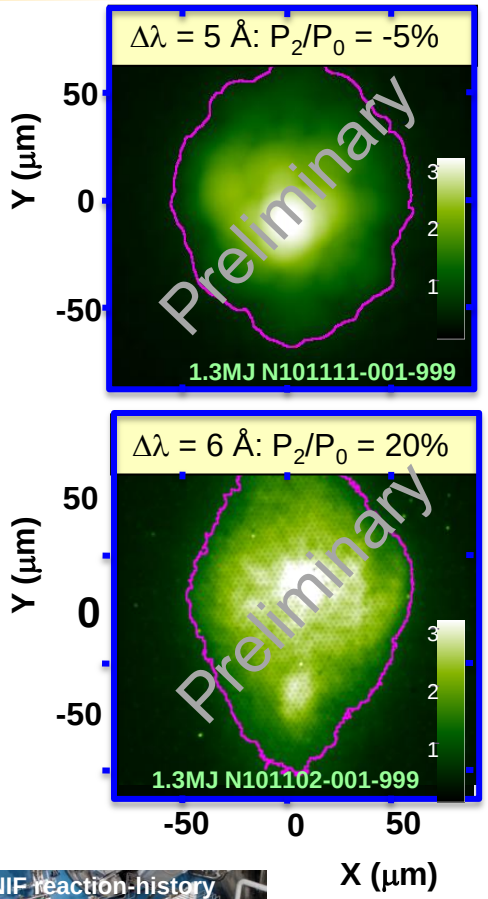


Behind the CR-39 is an **Image Plate** (stimulatable phosphor) used to see protons and energetic heavy ions

today

LANL is directly involved on NIF ignition tuning activities.

- LANL has four research scientists that spend >75% of their time at LLNL working ignition tuning
- LANL has provided lead scientists for experiments and supporting diagnostics
  - LANL scientists have had led experiments during NIF activation,[1] hohlraum energetics, & symmetry tuning.[2]
  - LANL scientists are supporting the gated x-ray diagnostic and Dante, in addition to LANL lead diagnostics (GRH & Neutron Imager)
  - LANL also has a designer and experimentalists working on alpha heating experiments
  - In addition to key personnel, LANL has ~30 people working on other aspects of ignition.
- "Ignition surge" activities
  - LPI hot electrons ➔ L-band x-rays ➔capsule preheat
  - LPI mitigation (gas dopants, STUD pulses[3])
  - Other



[1] J. L. Kline, *et al.*, *Physical Review Letters* **106**, 085003 (2011).
[2] G. A. Kyrala, *et al., Physics of Plasmas* (2011).
3 B. Afeyan, *et al., Proc. IFSA 2011 Conference,* (2012)

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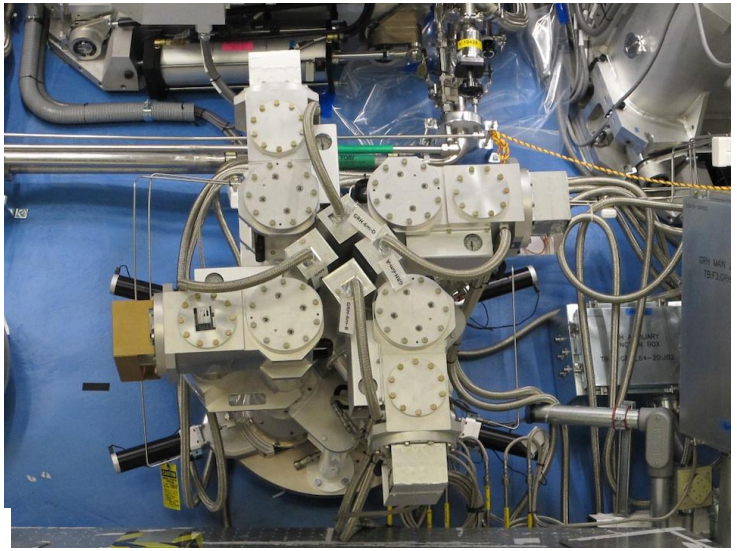
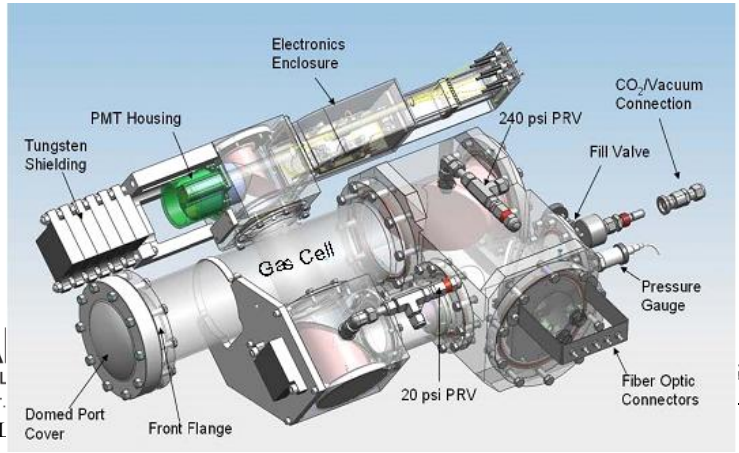
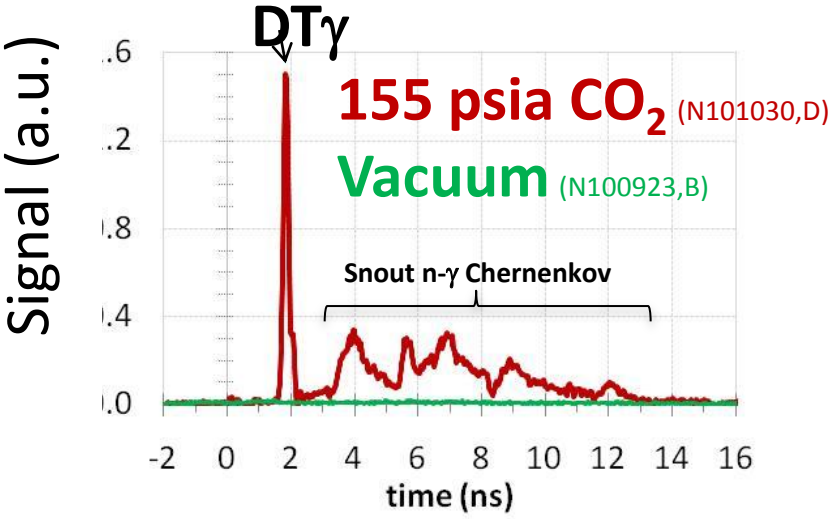
NNSA

LANL's Gamma Reaction History Diagnostic (GRH) on the National Ignition Facility (NIF)

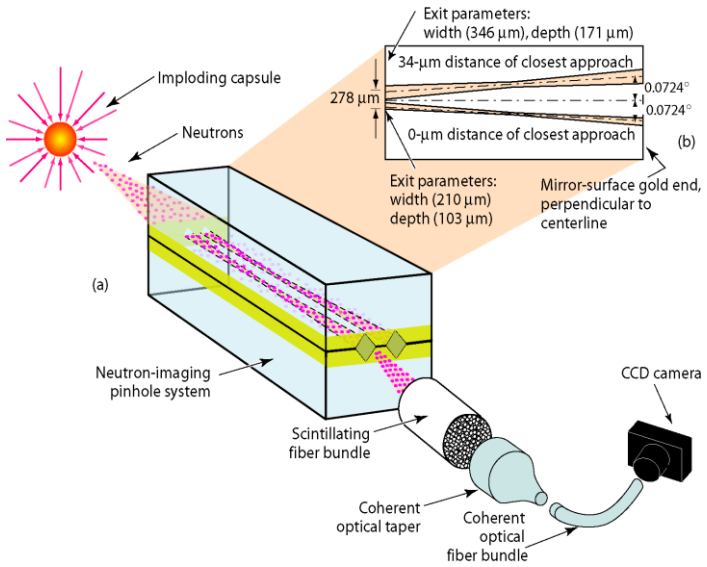
- **Detects Laser-Fusion Gamma-Rays:**
  - **converts MeV γ-Rays to easily detected visible/UV photons through Compton conversion & Cherenkov Radiation**
- **Improved understanding of fusion implosions for the NIC and other HED Physics studies (e.g., stellar nucleosynthesis) through:**
  - Fusion Reaction History (e.g., Bang Time & Burn Width)
  - Total Fusion Yield
  - γ-Ray spectral information

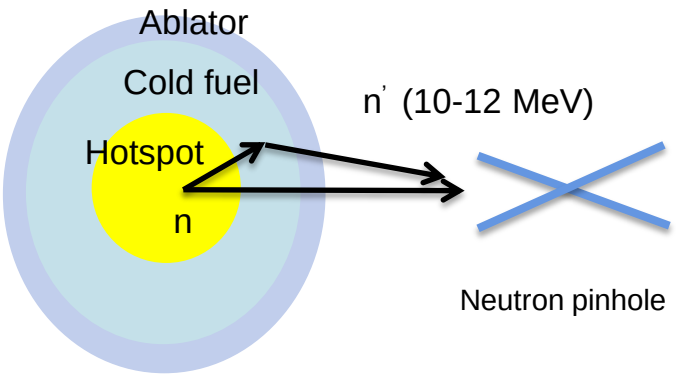






Neutron imaging provides spatial information on neutron production and scattering*





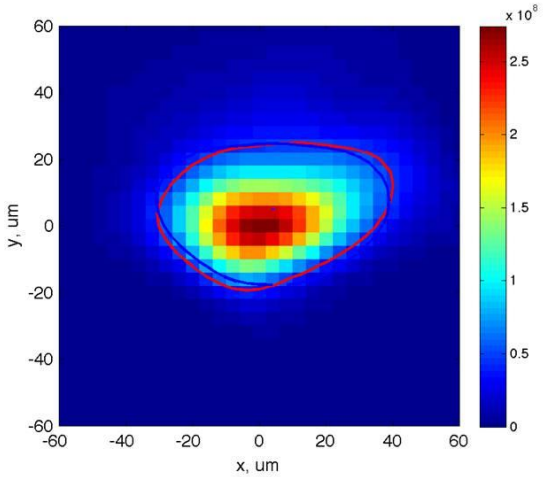
- Images gated on primary neutron time-of-flight provide spatial distribution of burn.
- Images gated after primary neutron provide spatial distribution of scattering material.
- Images gated before primaries provide information on clean burn, and mix.
- Image ratios useful to infer stopping, mix, areal density, etc.

* D. C. Wilson, *et al.,* RSI **74**, 1705 (2003); P. A. Bradley, *et al.,* RSI **74**, 1824 (2003), **77**, 10E707 (2006); G. P. Grim, *et al.,* RSI **75**, 3572 (2004)

We are now regularly collecting primary neutron source distributions and down-scatter neutron source distributions for Cryo-DT and THD experiments.

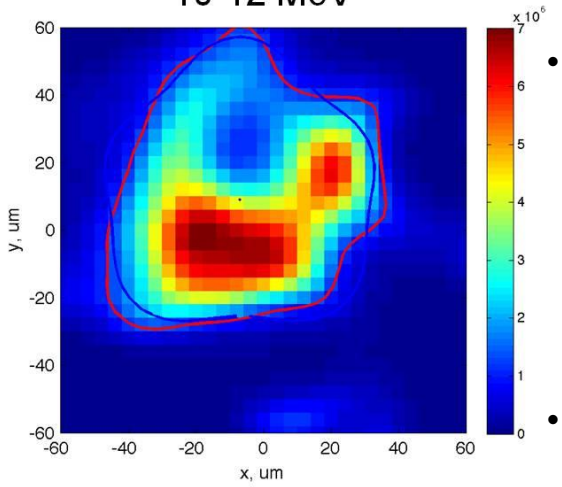
Data collected from N111215-001, a cryo-DT experiment with Y_n of 7.5×10^{14}

13-17 MeV



P0: 28 μm ±2 ±2
P2/P0: -29% ±4 ±4%

10-12 MeV

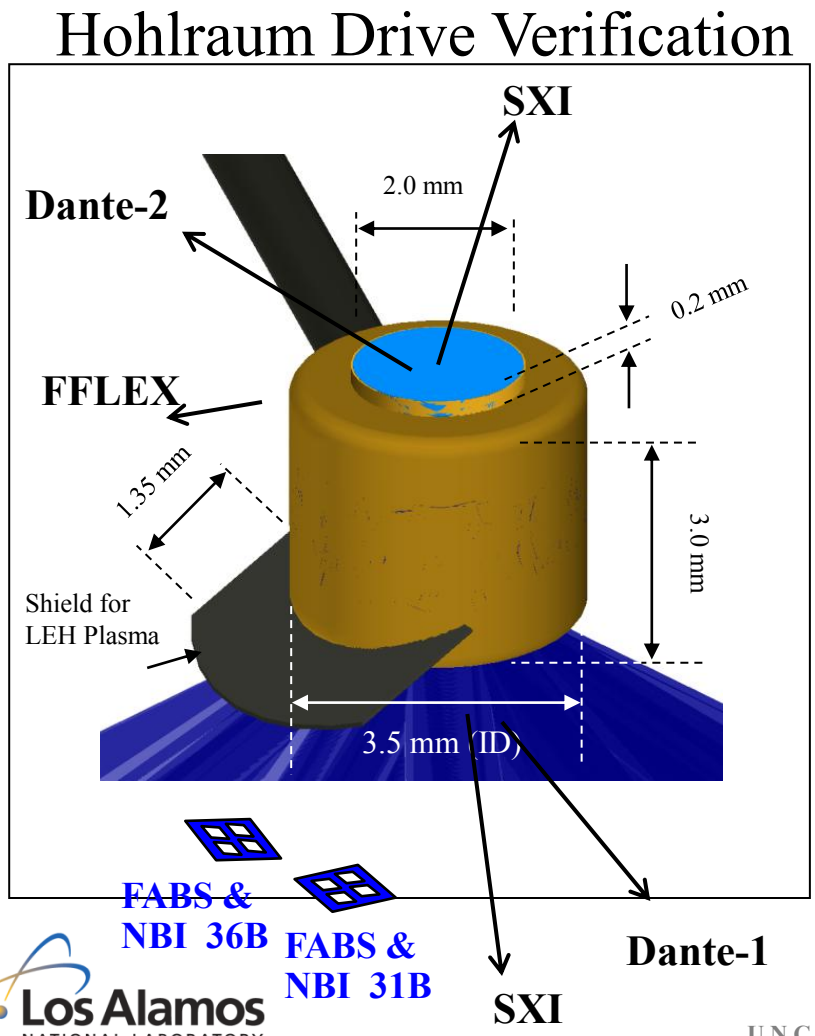


Preliminary analysis:
P0: 43 μm ±4 ±4
P2/P0: -1% ±4 ±4%

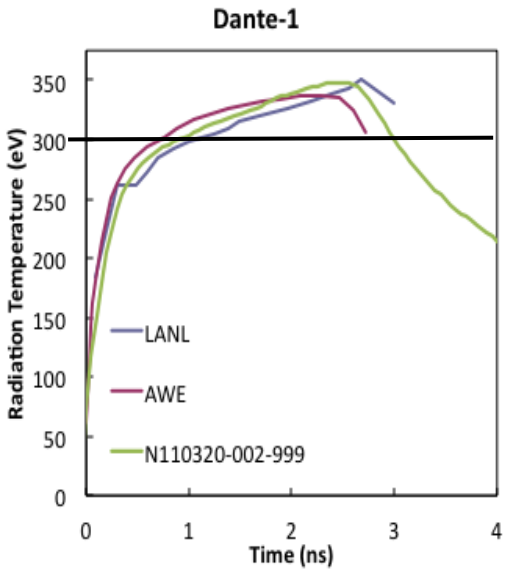
- Increasing yield and the removal of material in the line of sight has significantly improved statistics, allowing reconstructions of the cold fuel distribution.
- Replacement of micro-channel plate has improved image quality

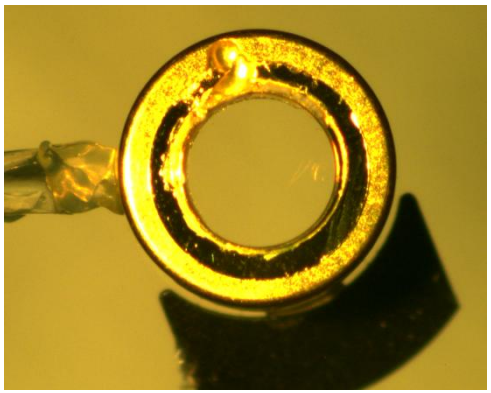
The neutron imaging system was performance qualified (with some exceptions) in early January, 2012

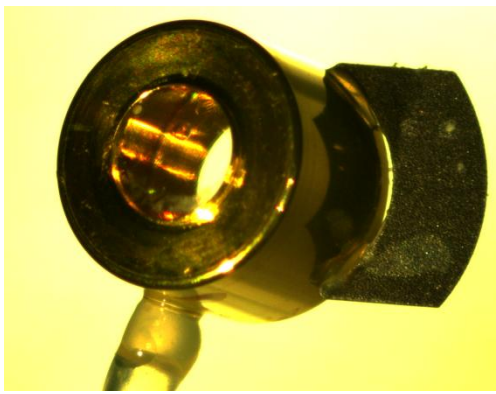
The Pleiades phase I experiment tested a platform for future LANL and AWE experiments at NIF



Gold halfraum walls driven from the bottom by 80 laser beams (345 kJ) with 2.5-ns square pulse



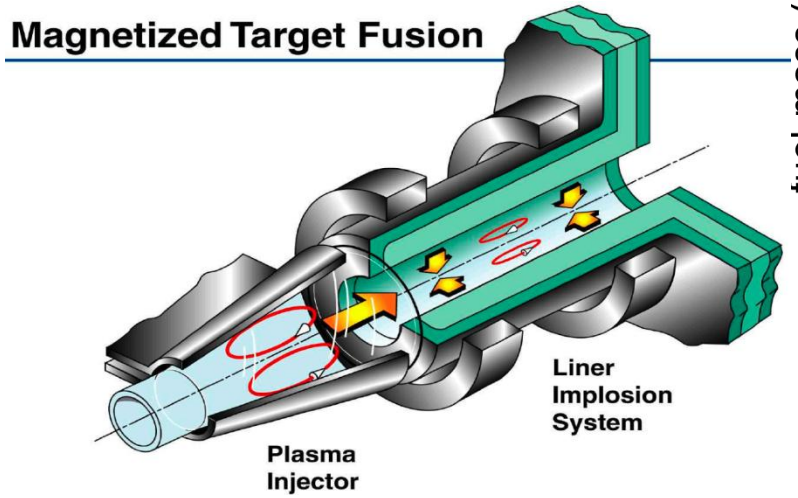




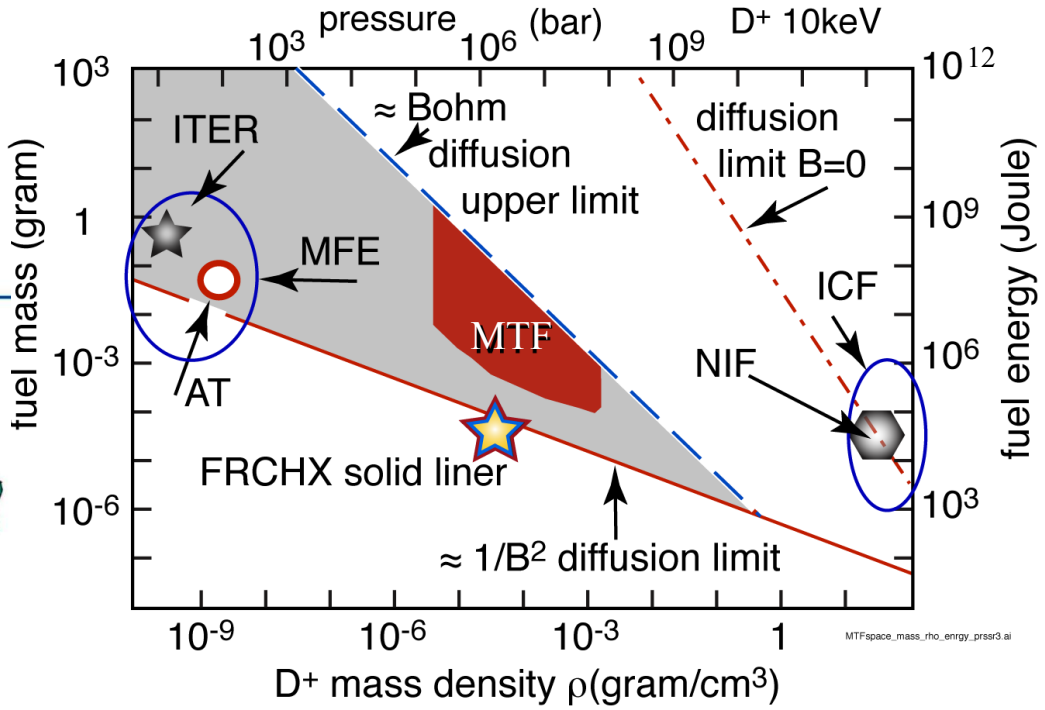
As built target images

Magnetized Target Fusion: between MFE and ICF

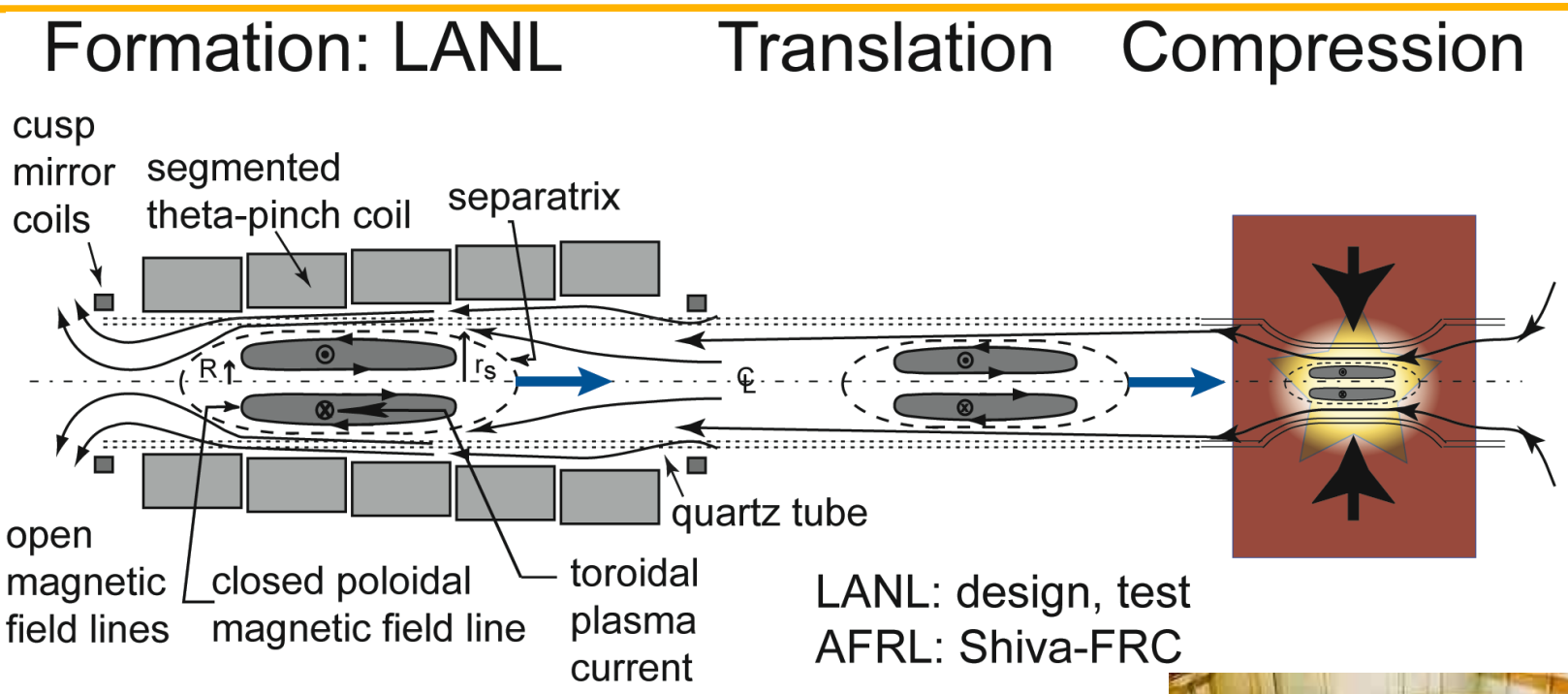
- **MTF: high n, B, for several transport assumptions**



Compare classical, Bohm, diffusion transport



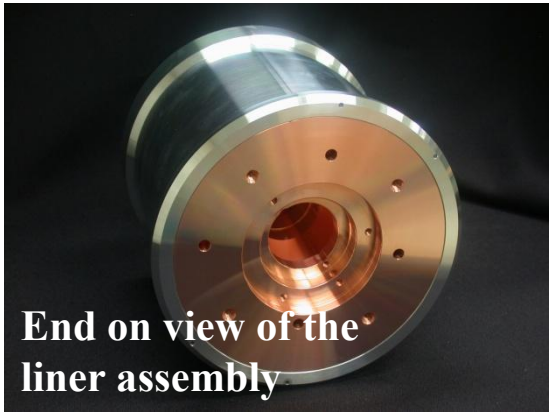
MTF: Potential low cost path to fusion

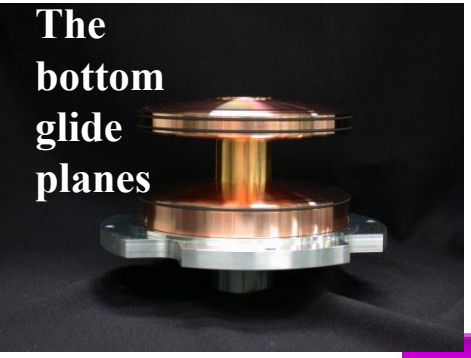


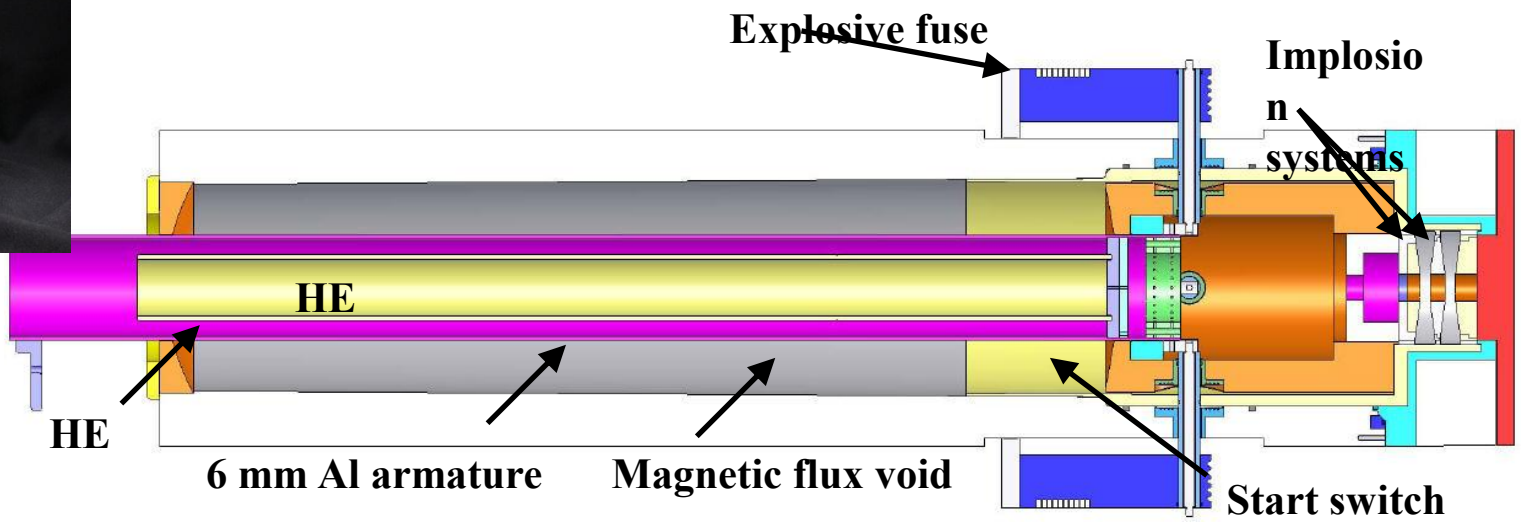
- **Pulsed, high pressure approach to fusion**
- **Inertial + magnetic confinement**
- **Magnetic field plays essential role**

Energy available from a Ranchero High Explosive Pulse Power generator opens up a new realm of HED experiments

HEDP thrives in energy rich environments. If you can get MJ's of energy in cm^3 volumes interesting experiments become possible







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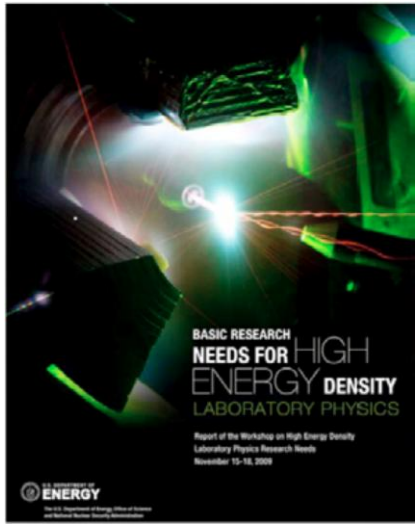
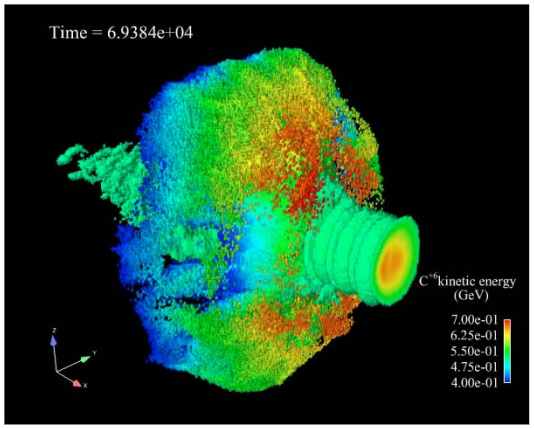
Operated by Los Alamos Natic

Los Alamos has a strong program in High Energy Density Physics aimed at National Applications as well as Basic Science



- Inertial Confinement Fusion (ICF)
- Radiation Hydrodynamics
- Hydrodynamics with Plasmas
- Material Dynamics
- Energetic Ion generation
- Dense Plasma Properties
- X-ray and Nuclear Diagnostic Development
- Petaflop performance to Exascale computing
- Magnetic Reconnection
- Magnetized Target Fusion
- High-Explosive Pulsed Power



Opportunities at Los Alamos

- **Visit http://www.lanl.gov for general information**

- **Student, Undergrad and Grad Opportunities**
- **http://int.lanl.gov/education/jumpstart/**

- **Staff Opportunities**
- **http://www.hr.lanl.gov/FindJob/**