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Dynamic Compression Experiments at the APS

Jensen B. J.[1], Iverson A.J.[2], Branch B.[1], Dattelbaum D.[1], Fredenburg D.A.[1],
Mandal A.[1], Montgomery D.S.[1], Neal W. D.[3], Sanchez N.[1], Willey T.[4],

[1]Los Alamos National Laboratory, Los Alamos, NM USA
[2]National Security Technologies, LLC, Los Alamos, NM USA
[3] Atomic Weapons Establishment, Aldermaston, UK
[4] Lawrence Livermore National Laboratory, Livermore, CA USA

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"Studies of Dynamically Compressed Matter with X-rays"
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Acknowledgments:
B. Branch, E, Cerreta, F.J. Cherne, B. Morrow, S. Clarke, B. Clements, D.A. Fredenburg, C. Johnson, M. Martinez, C. T. Owens, T. Pierce, K. Ramos, N. Sanchez, G. Liechty, B. Branch, D. Dattelbaum**,** M. Prime, M. Short **(LANL)**, T. Willey, M. Kumar, K. Champley, R. Hodgin, L. Lauderbach, M. Bagge-Hansen, C. May, J. Lind, M. Barham, M. Messner, N. Barton **(LLNL)** W. Neal **(AWE),** C. Carlson, M. Teel, A.J. Iverson **(NSTech),** A. Deriy, K. Fezzaa **(ANL),** J. Hawreliak **(LLNL/WSU),** M. Zellner **(ARL)**, Y.M. Gupta and P.A. Rigg (WSU)
and many more..

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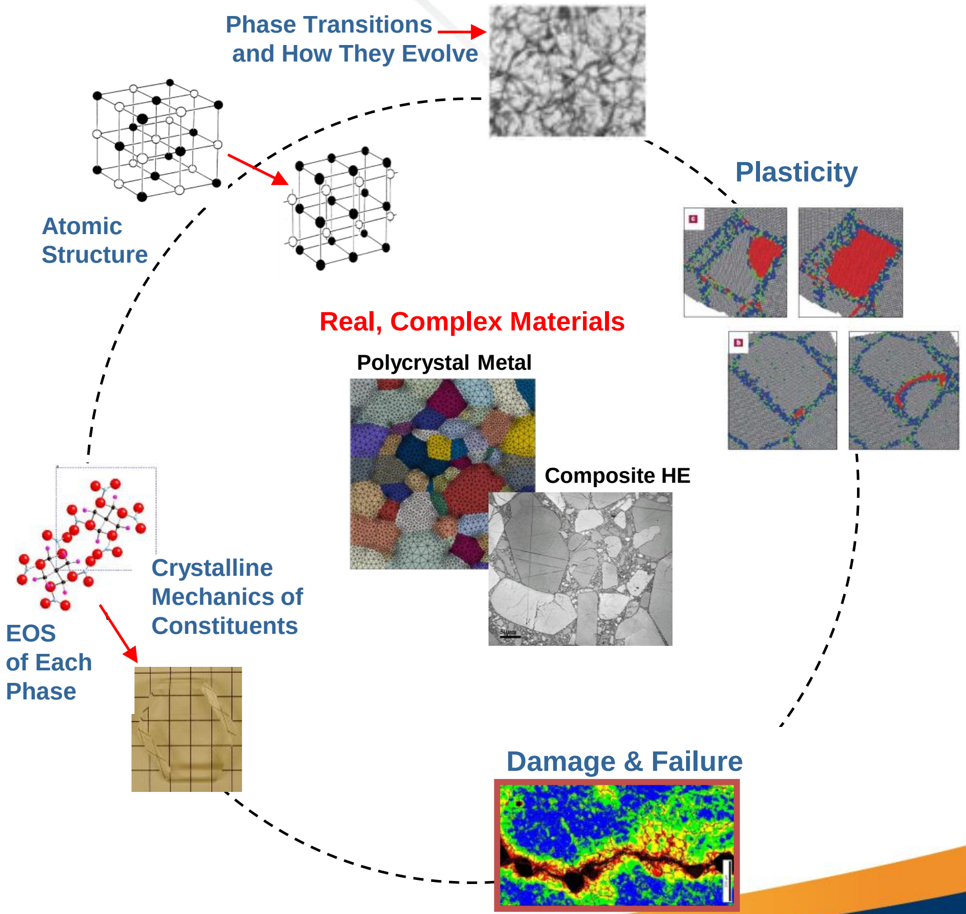
Outline

- Motivation
- Overview of capabilities at the Advanced Photon Source
- Development of LANL's multi-frame X-ray phase contrast imaging (MPCI) system
- Example highlights of experiments at APS
- Summary

Experiments are needed that provide real-time, *in-situ*, spatially-resolved measurements on relevant time scales

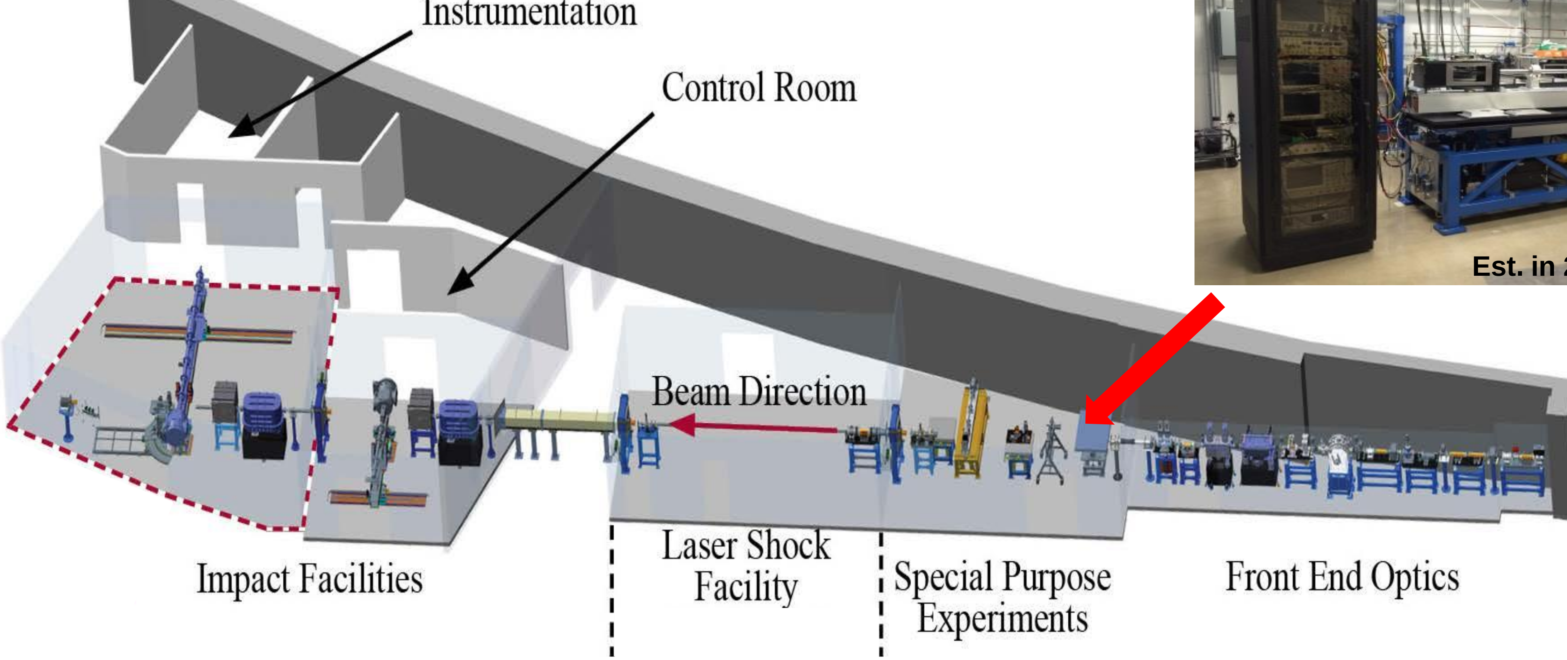
- Traditional shock wave diagnostics provide indirect information about the underlying microscopic mechanisms governing material response.
- Diagnostics such as phase contrast imaging (PCI) and x-ray diffraction (XRD) offer unique opportunities for high-resolution spatially-resolved measurements.
- Platforms are needed that can access a wide range of (P,T) states that couple to advanced light sources including the APS.
- Dynamic experiments at advanced light sources are challenging because of synchronization issues, short-lived dynamic states, and low-photon counts.



The Dynamic Compression Sector and IMPULSE are two NNSA funded capabilities providing direct access to a synchrotron

DCS is an NNSA funded capability that couples dynamic loading platforms to a *dedicated* X-ray beam line at the APS

LANL IMPULSE



DCS@APS

Layout of the DCS (PI: WSU)

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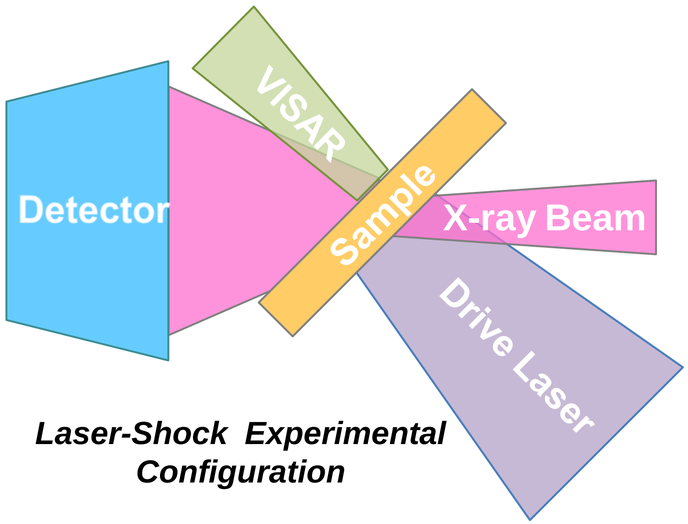
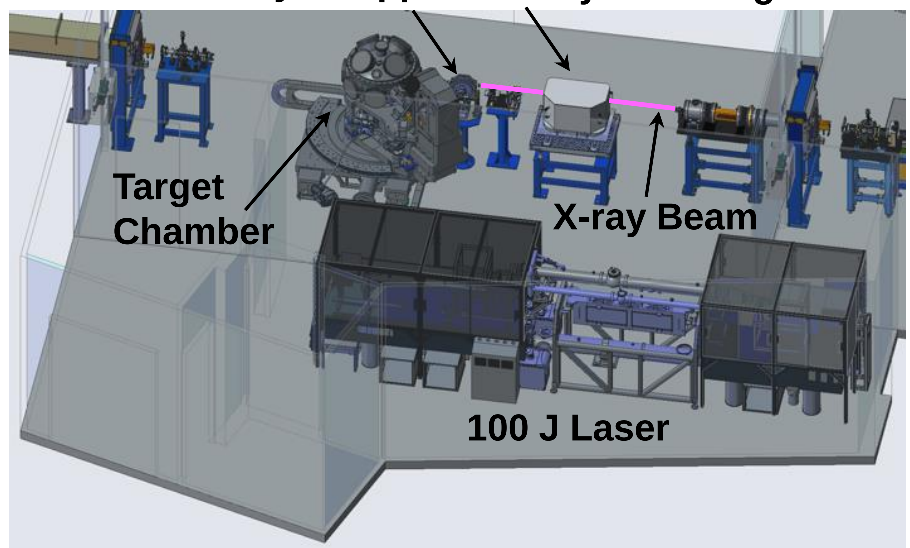
DCS Laser-Shock Station: Overview



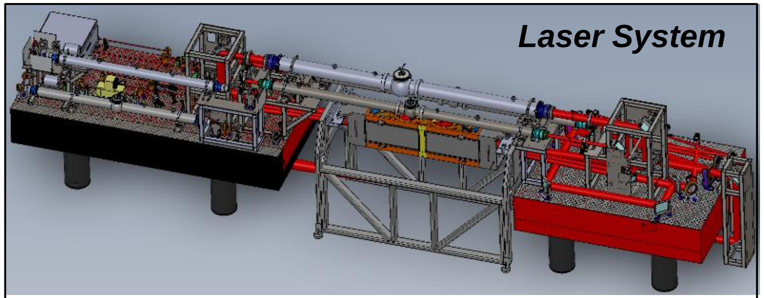
Laser-Shock Experimental Configuration



- 100J laser system (351nm) on target to achieve high stresses (>350 GPa)
- Multiple x-ray focusing mirrors to achieve small spot size (<50x50μm^2)
- High-speed chopper for single x-ray pulse (80ps) isolation
- Rayonix SX165 for 165mm x-ray area detection and high sensitivity
- Simultaneous x-ray measurements and velocimetry allow precise determination of compressed state at different length scales

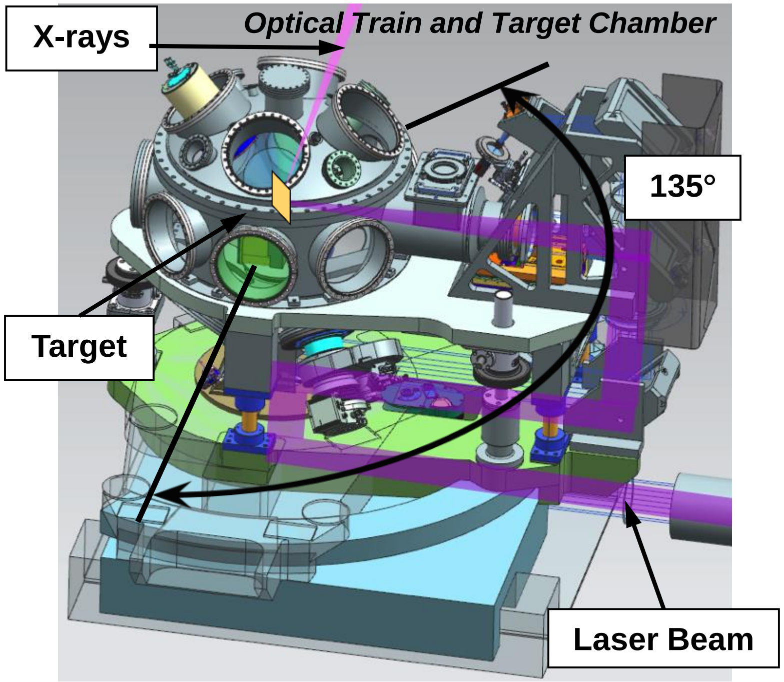
Precise compression loading coupled to well-characterized, hard x-rays

DCS Laser-Shock Station: Laser and Target Chamber



- *Laser development and operation completed per specifications*
- *Only one operator needed for laser*

- Smooth focal profile for uniform compression loading
  - (500µm, 250µm)
- Shock and ramp compression with high reproducibility
  - (5-12ns pulse duration)
- One shot every 20 minutes
- Excellent synchronization to obtain real-time x-ray data and wave profiles
- UV light (351nm) to eliminate plasma effects



- Large translation range to intersect focused and unfocused x-rays
- 135° rotation to vary angle between x-ray probe and laser drive
- 100µm positioning, 50µm pointing accuracy
- Multiple ports for simultaneous diagnostics
- Target holder for up to 24 targets

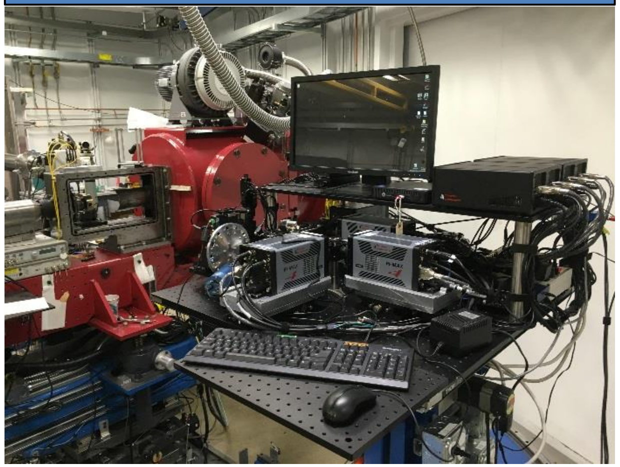
Highly flexible to accommodate scientific needs

LANL and collaborators continue to advanced the capabilities for dynamic experiments at the APS and DCS

IMPULSE System

15g Explosive Vessel

X-ray PCI System



- Many experiments continue in the B-hutch of DCS using the LANL IMPULSE capability and other platforms including the LLNL HE tank and ARL Kolksy bar.
- A new 15-gram HE vessel has been received for explosive experiments including SAXS, detonators, and explosive flyer experiments. Explosives allow for easier synchronization to the beam (standard and hybrid)
- New improved X-ray PCI system with more frames, more efficient design, and multiple zoom. Plan to develop a multiple scintillator capability for phase retrieval. System is now available for use on the DCS gun systems.

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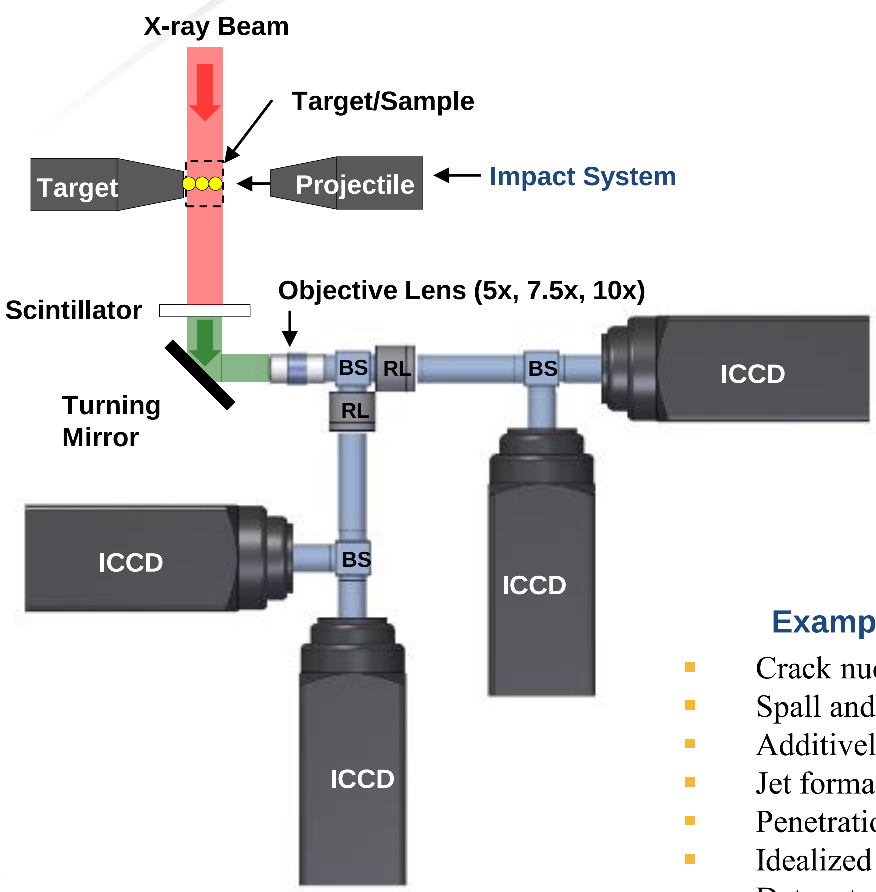
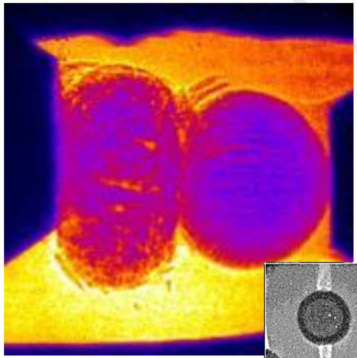
LANL's X-ray PCI system has been used to examine a wide range of phenomena during dynamic compression

Experiment configuration for X-ray PCI

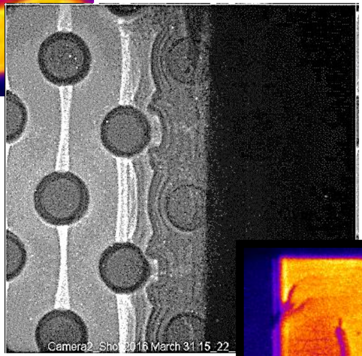


Idealized sphere compression



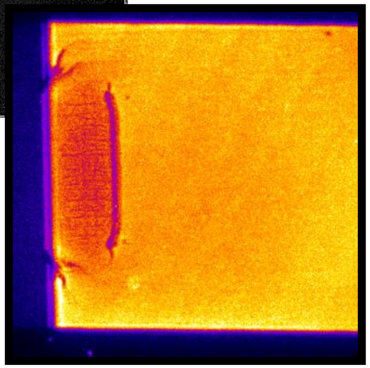
B. Jensen (LANL)

Response of AM Materials



B. Branch, D. Dattelbaum (LANL)

Slappers in Flight



N. Sanchez (LANL)

Example PCI Experiments

- Crack nucleation and propagation
- Spall and damage
- Additively Manufactured Samples
- Jet formation to examine strength
- Penetration mechanics; ballistics
- Idealized compression/compaction
- Detonator dynamics, etc.

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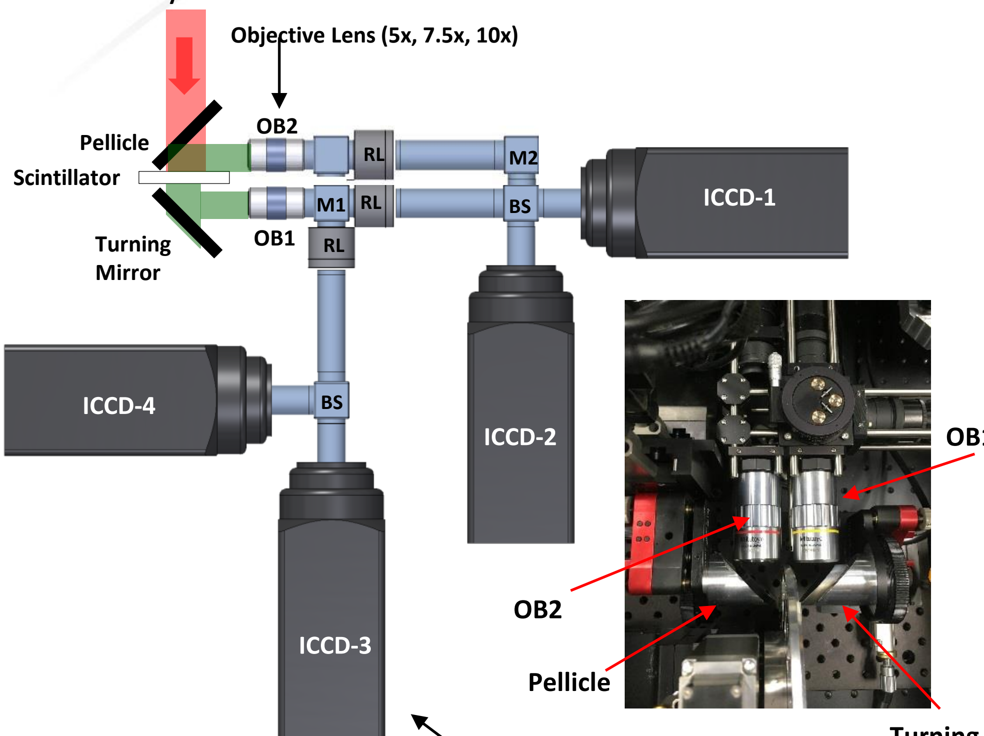
Participants: B.J. Jensen, A.J. Iverson, C. Carlson

LANL's MPCI system has been improved to include 8 frame movies, dual-zoom, more efficient optical coupling

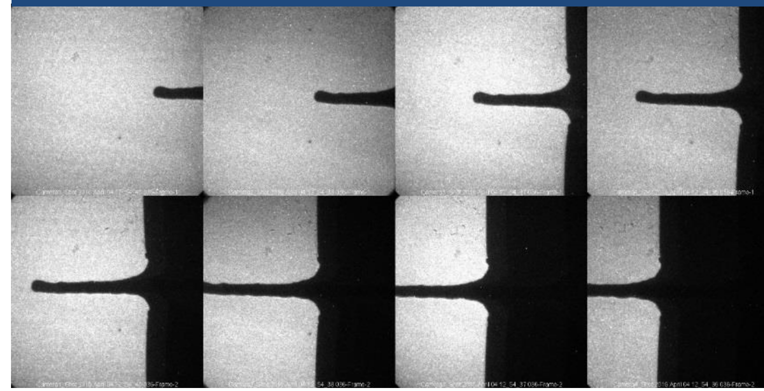
Experiment Configuration for dual imaging PCI system



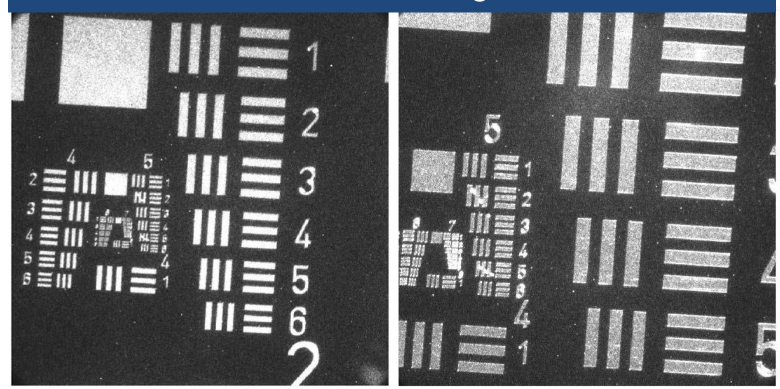
Dual-imaging of scintillator allows for multiple-zoom and increased light efficiency

New PI-MAX 4 ICCDs with DIF Feature provide the first 8-frame shock movies!

8-frame test experiment showing jet evolution in Ce



Simultaneous Dual-Magnification!



5x Magnification   10x Magnification

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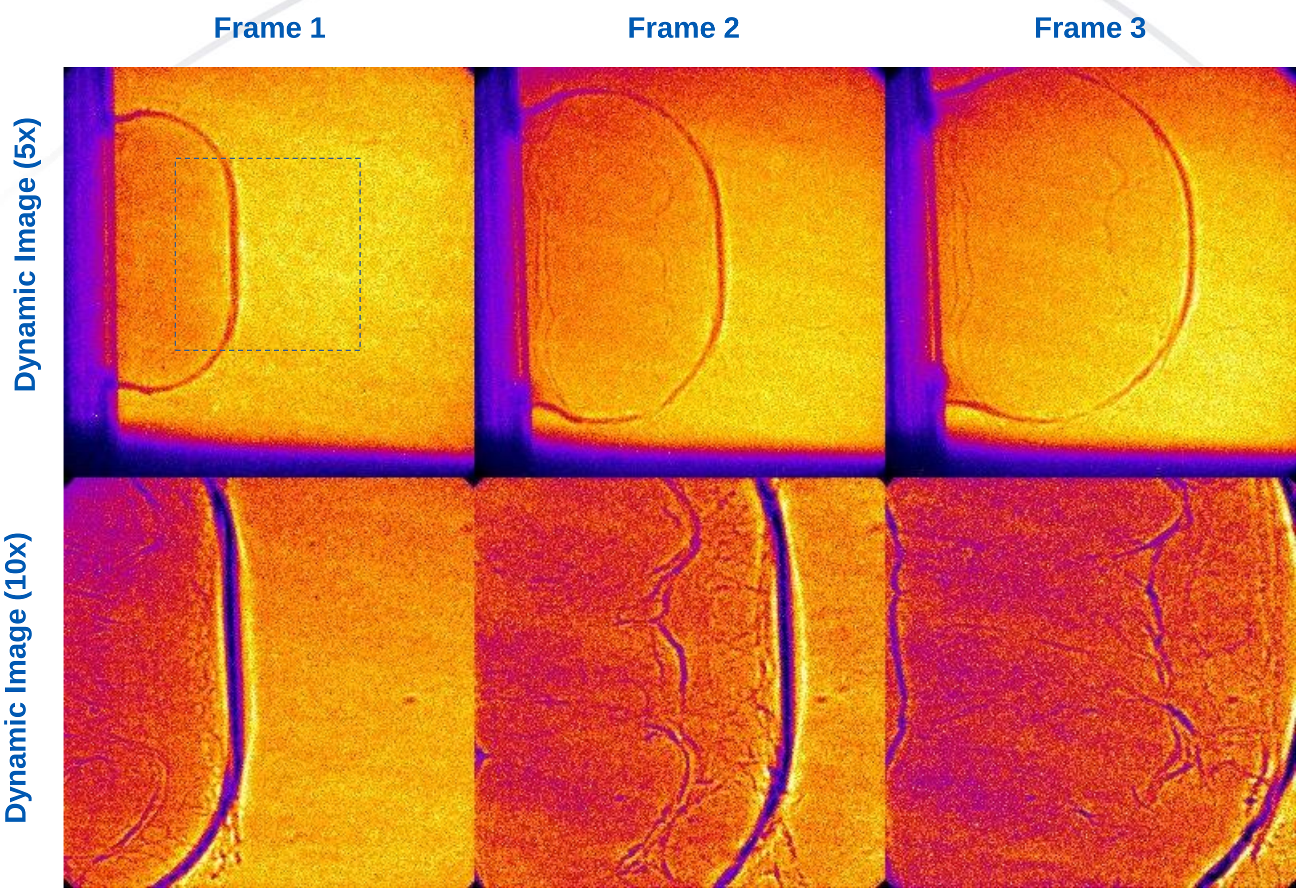
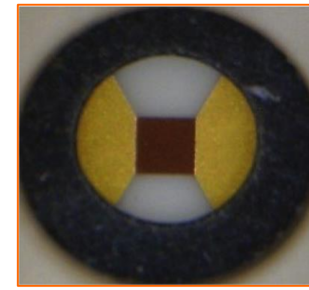
Participants: N. Sanchez, W. Neal, B.J. Jensen, A.J. Iverson, C. Carlson, C.T. Owens, B. Branch

MPCI system with dual zoom capability used to obtain images of flexible foil slapper initiators



Typical Bridge Geometry



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  - Response of additively manufactured (AM) materials
  - Application to detonator initiator systems
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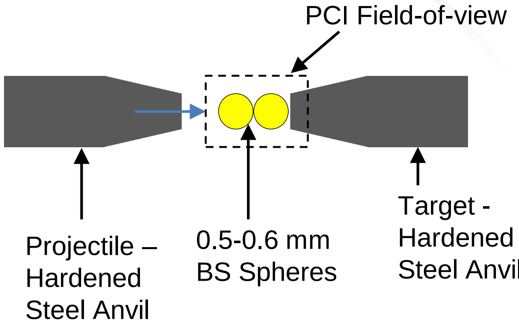
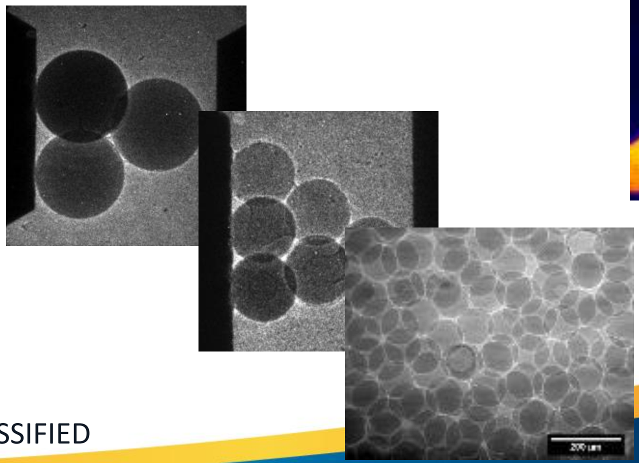
Use X-ray imaging to gain insight into the fundamental mechanisms that occur at the mesoscale during compaction

- **Why:** Found everywhere in nature and in applications yet there is a lack of understanding of the underlying mechanisms that govern their response.
- **Applications:** Planetary impacts, geological materials, national security interests (reactive fragments, armor/penetrator survivability, blast mitigation)
- **Goal:** Identify a key set of experiments that will use PCI to examine the response of *ideal or engineered* systems with systematically increasing complexity
- **Purpose:** Test current models, formulate new models inclusive of particle-level physics bridging quasi-static and dynamic compaction mechanisms.
- **Initial Focus:** on idealized systems of spheres while reducing size and increasing complexity while identifying pathways to studying non-ideal systems (powders, foams, reactive mixtures, etc.)

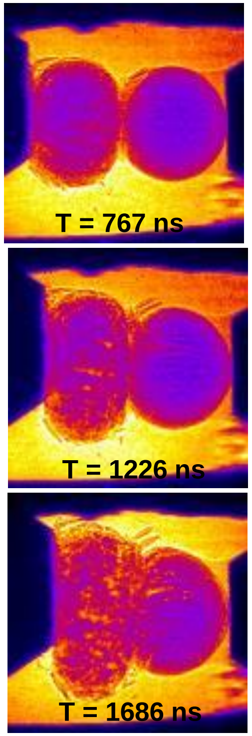
Experiment Concept for Compaction of Borosilicate spheres using X-ray PCI



Systematically Increasing Complexity



X-ray Image
12 Kev



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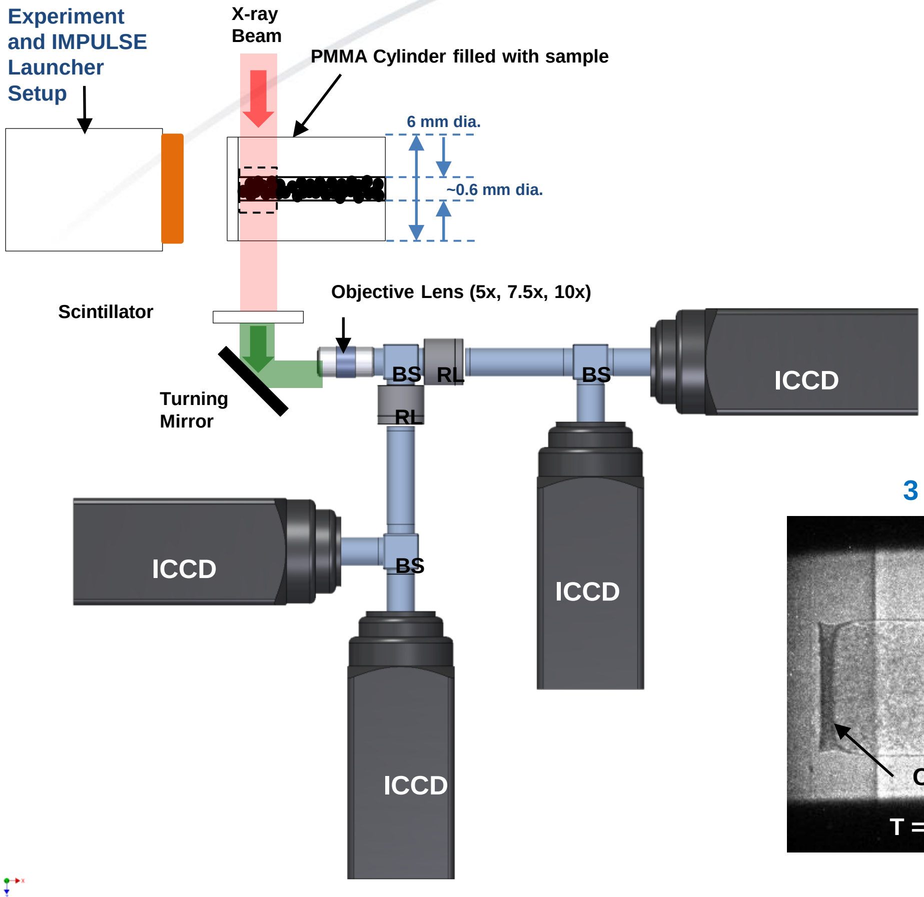
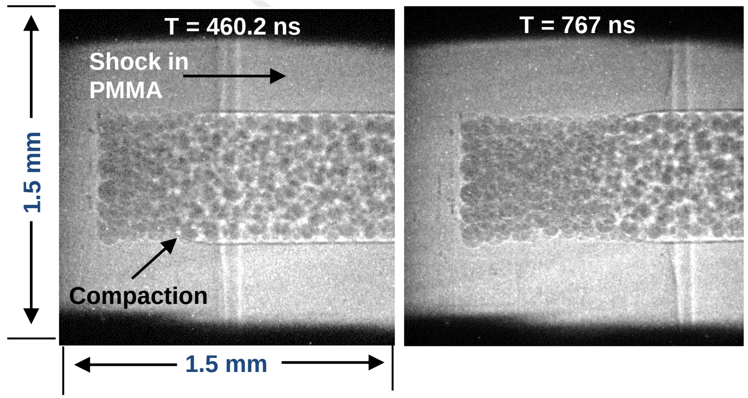
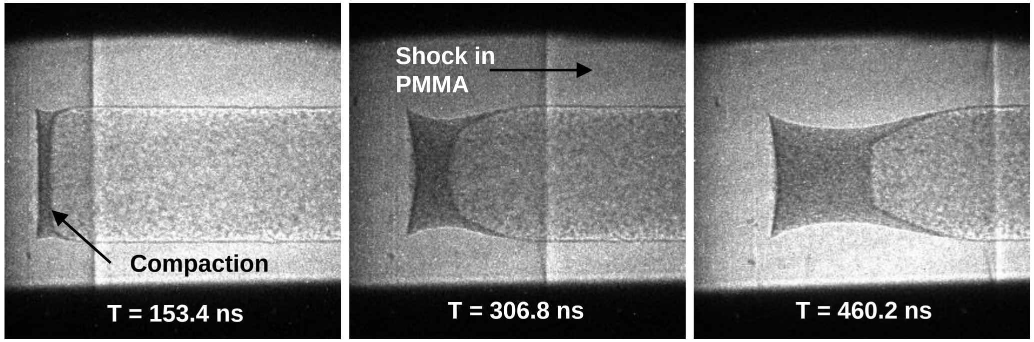
Use X-ray imaging to gain insight into the fundamental mechanisms that occur at the mesoscale during compaction



2 frames showing compaction of 100 μm borosilicate spheres



3 frames showing compaction of a regolith sample (< 45 μm)



- New experiments at the APS are providing insight into the compaction process
- Data analysis underway to retrieve the spatially resolved density profiles
- Recent testing using X-ray diffraction to study microstructure successful

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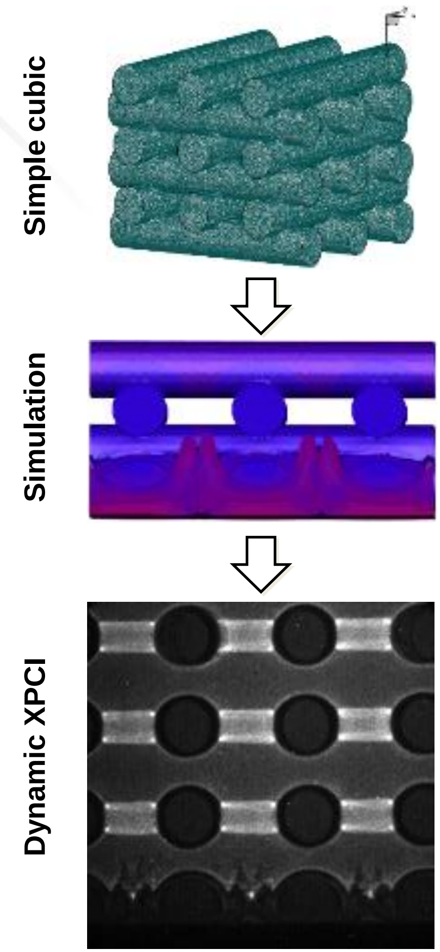
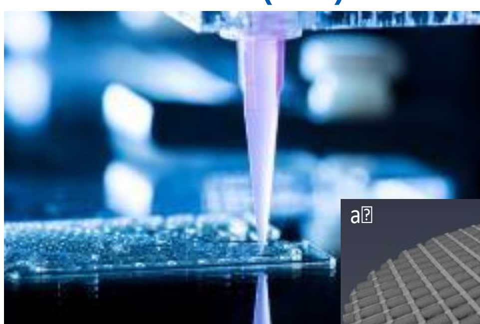
PCI coupled with modeling is allowing us to understand and tailor the dynamic response of Additively Manufactured (AM) materials

- **Background:** AM is an attractive approach toward achieving or designing materials with unprecedented mechanical properties in lightweight materials
- **Purpose:** Learn how to tailor quasi-static and dynamic compressive response; develop systems that allow us to study microstructure affects on shock propagation and compression/compaction.
- **Initial Focus:** We begin with simple structures to observe with PCI the compression response for impact loading. Results are compared to model simulations. Future work includes compression of structures using reactive materials

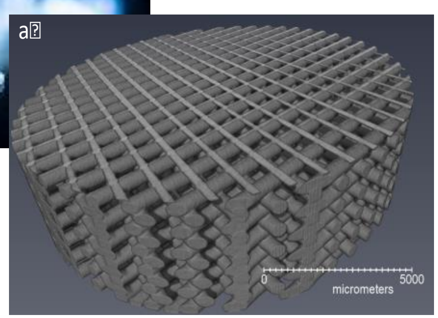


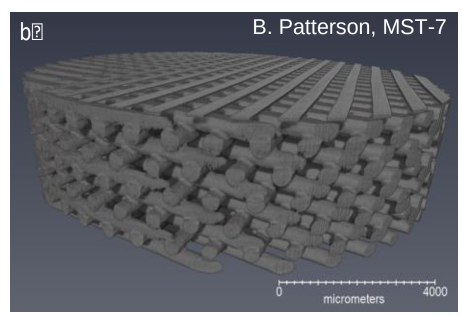
Direct Ink Write (DIW) Method



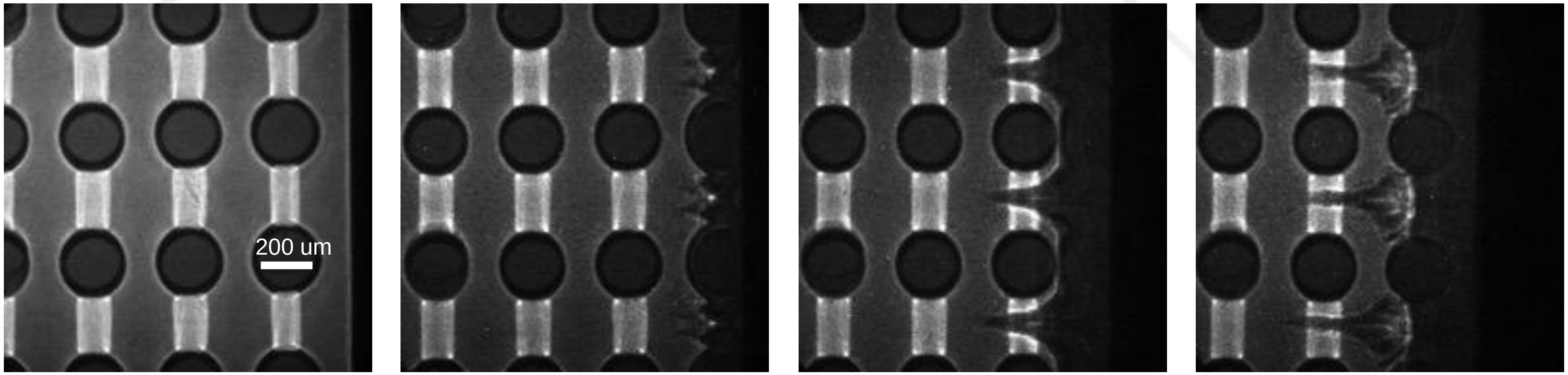
Dow Corning SE1700 polydimethylsiloxane. 11 layers with filament center-to-center spacing of ~440 µm

X-ray Computed Tomography



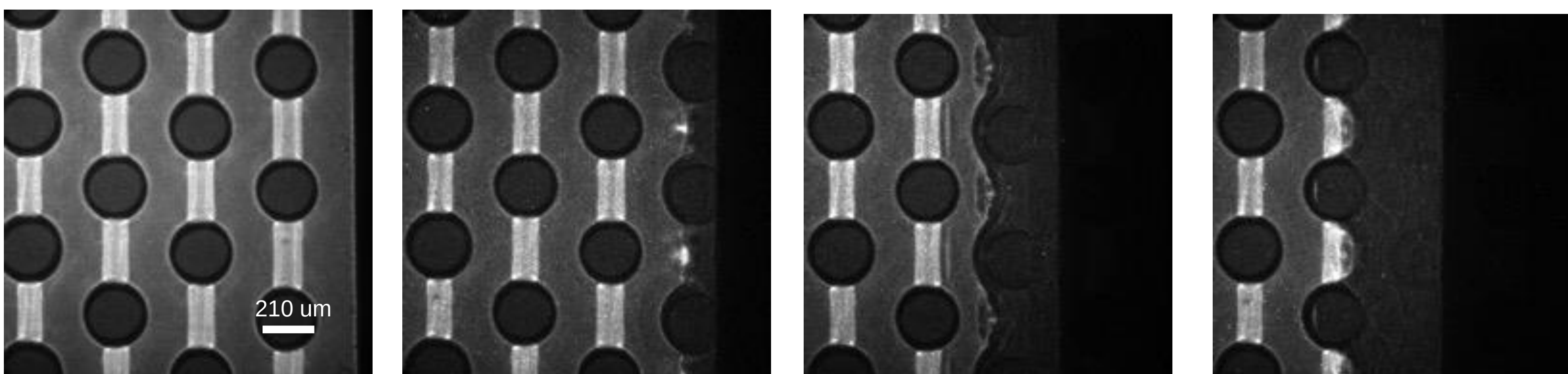


The strut geometries were shown to have a significant effect on shock wave dynamics in the foam microstructures



static 3.985 us 4.138 us 4.292 us

Shot #7 IMP-15-076 (0.7km/s)



static 7.360 us 8.127 us 8.434 us

Shot #10 IMP-15-079 (0.3km/s)

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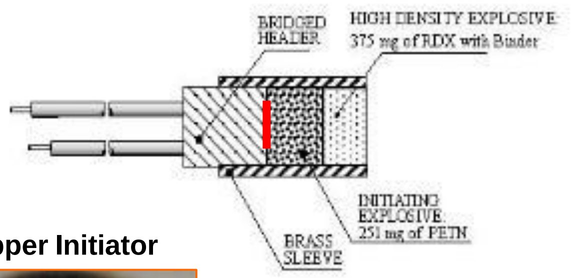
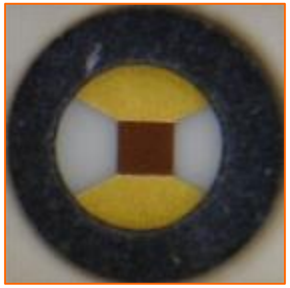
X-ray PCI Is Providing Us with a New Understanding of Initiator-HE Interactions Which is Crucial for Stewardship and Future LEPs

- *Long-standing questions in detonator science* – What are the initiation mechanisms for explosive bridge wire (EBW) and slapper detonators? Is it a compaction-to-detonation process or thermal initiation at the wire?
- *Current detonator modeling* capabilities capture performance characteristics, but lack details of initiation mechanics.
- *Understanding* the initiation mechanisms is important for assessing aging margins and developing new/improved designs (Life Extension Programs (LEP), safety, performance).

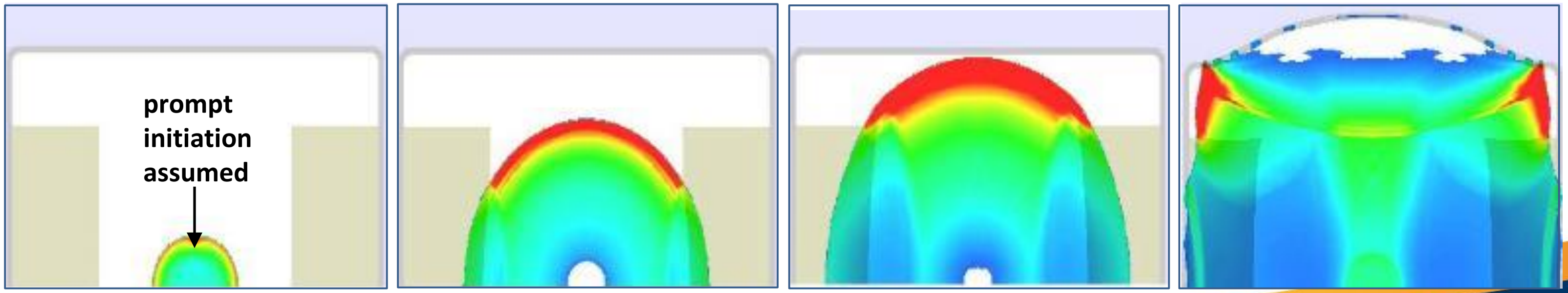
An SE-1 EBW Detonator Schematic



Slapper Initiator



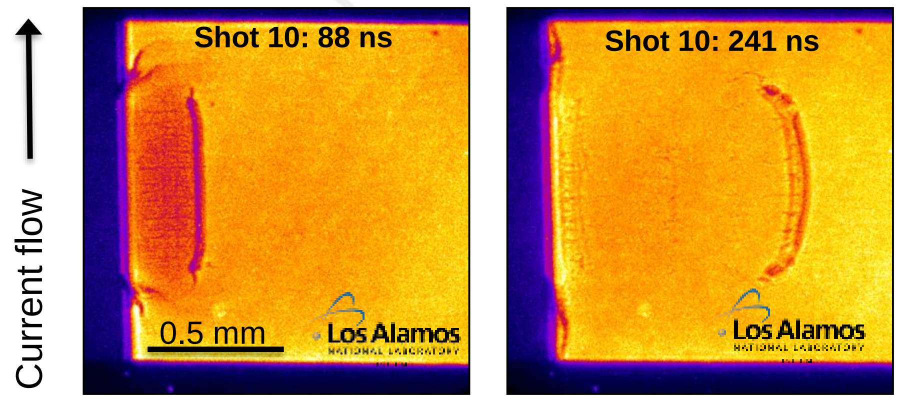
Simulations of EBW Detonator Performance – JWL Programmed Burn Hemisphere



Dynamic Imaging of Slapper Initiators dynamics and plasma instabilities Utilizing X-Ray PCI for Stockpile Stewardship

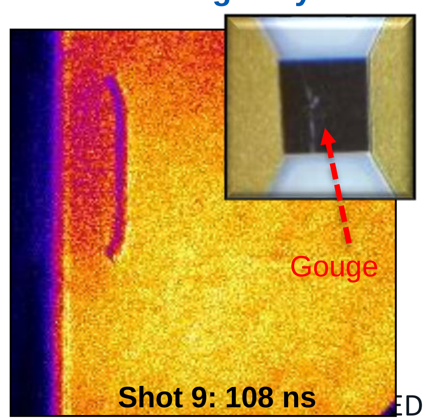
- Understanding the effects of defects and radiation on slapper initiator performance is key for weapon certification.
- Data will aid in understanding critical performance parameters required for stockpiled systems and inform future design.
- Recent experiments performed on AWE slappers – flexible foil Cu/Kapton slappers
- Collaborative effort between LANL, LLNL, AWE

Slapper Initiators with Parylene Flyers

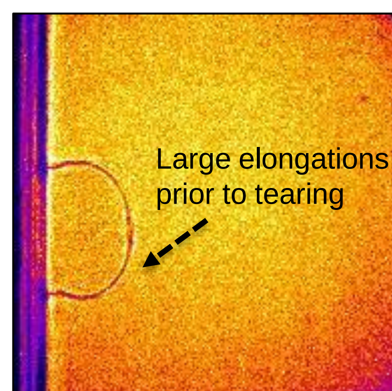


Typical Bridge Geometry

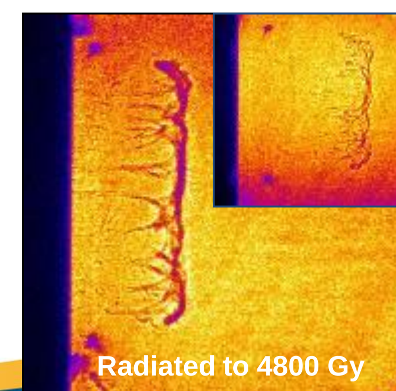
Understanding Effects of Defects on Flight Dynamics



Kapton Foil Flyers

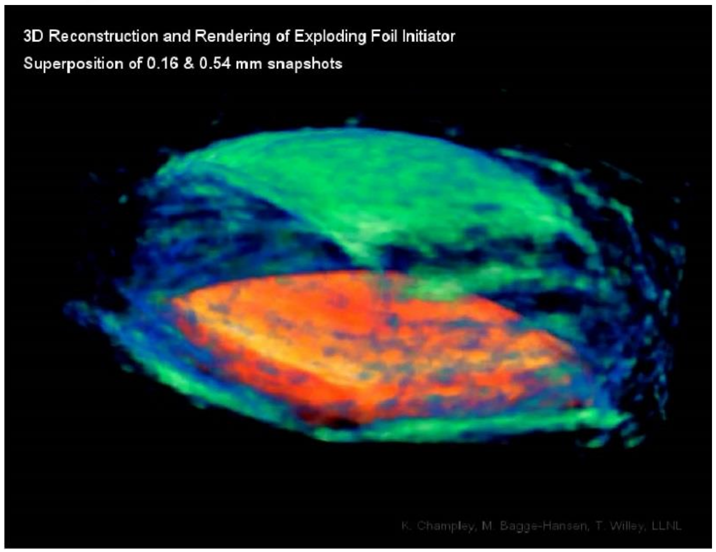


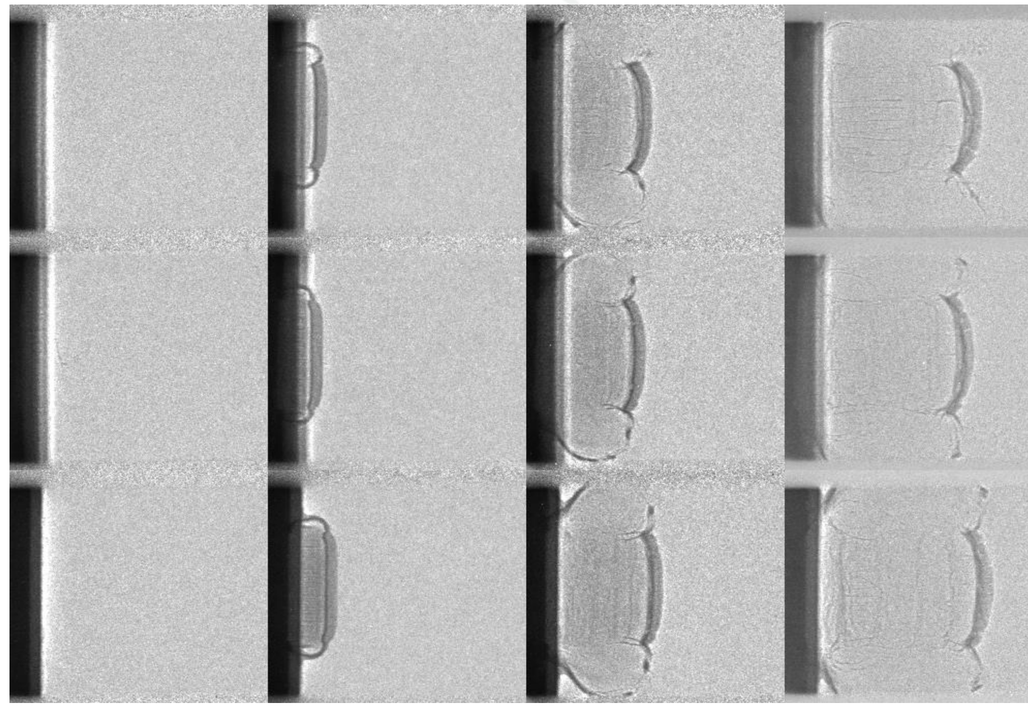
Radiation Effects



T. M. Willey, K. Champley, R. Hodgin, L. Lauderbach, M. Bagge-Hansen, C. May, N. Sanchez, B.J. Jensen, A. Iverson, T. van Buuren.

Recent Highlight: "X-ray imaging and 3D reconstruction of in-flight exploding bridge wires" accepted for publication in J. Appl. Phys. (5/2016)



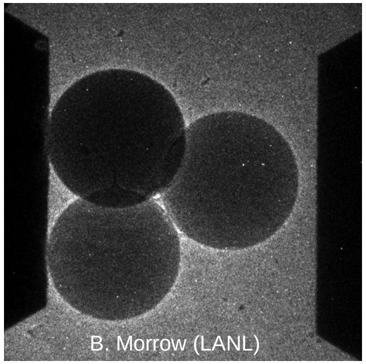


Supplemental Figure 2: Three different shots, all acquired perpendicular to the current direction. These show shot-to-shot reproducibility. For input into reconstruction algorithms, the radiographs were normalized and aligned to the center-of-mass of the flyer in each image.

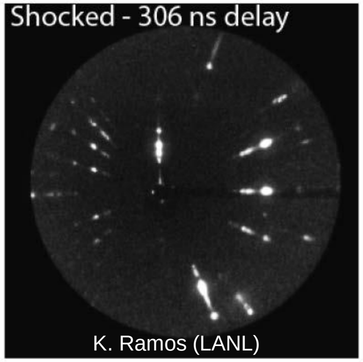
New X-ray diagnostics are providing insight into long-standing scientific questions

- Investments in IMPULSE and DCS are already providing new and exciting data that utilize X-ray techniques to examine dynamic response of materials
- Numerous phenomena have been studied that span length scales/time scales from fundamental to applied science
- We are building a diverse knowledge base of scientists that can utilize/develop these techniques

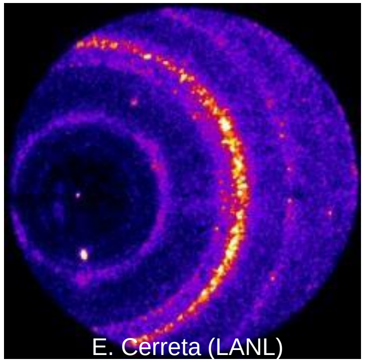
Sphere Compaction



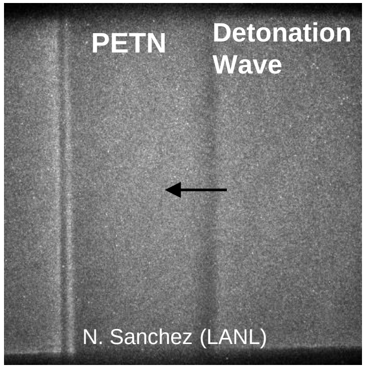
XRD on RDX



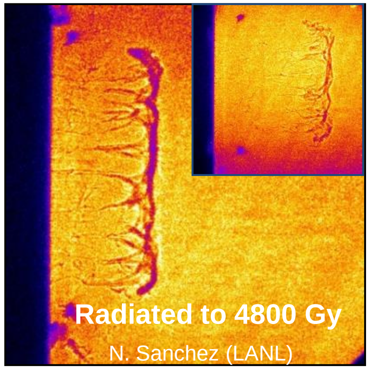
XRD on Shocked Ti



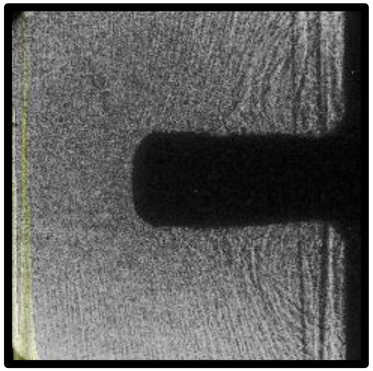
Det-Waves in HE



Initiators



Penetrator into Dyneema



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Questions?

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