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Dynamic Initiator Experiments using X-Ray Phase Contrast Imaging at the Advanced Photon Source

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N. Sanchez, C. Johnson, B. Jensen, K. Ramos, M. Martinez, A. Iverson, S. Clarke et al.

Our understanding of Initiator-HE interactions is crucial for understanding critical performance parameters in order to develop a predictive capability

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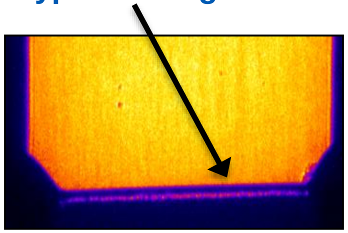
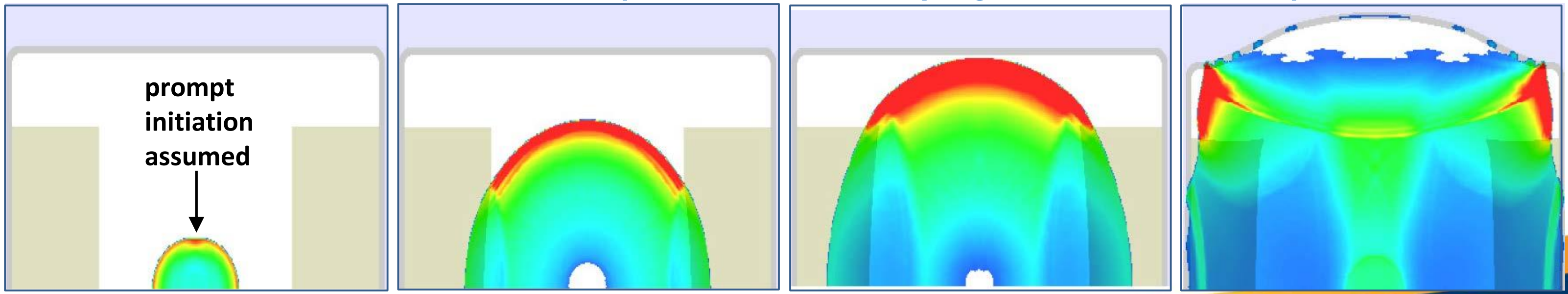
- ***A long-standing question*** in detonator science – What are the initiation mechanisms and key performance parameters for Exploding Bridge Wire (EBW) and slapper detonators?
- ***Current detonator modeling*** capabilities capture performance characteristics, but lack details of initiation mechanics
- ***Understanding*** the initiation mechanisms are important for assessing aging margins and developing new/improved designs (safety, performance, margin)
- ***Our approach –*** Utilize current & future synchrotron sources to better understand the coupling of electrical energy to the high explosives

Typical Bridge Geometry

Typical Bridge Wire



Simulations of EBW detonator performance – JWL programmed burn hemisphere



A.J. Iverson, C.A. Carlson, B.J. Jensen, et al, SCCM (2013)

X-ray phase contrast imaging at the Advanced Photon Source

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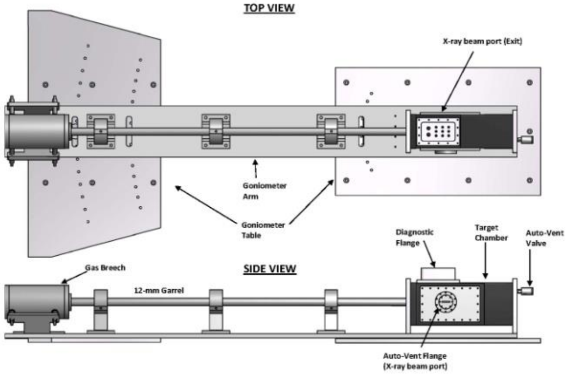
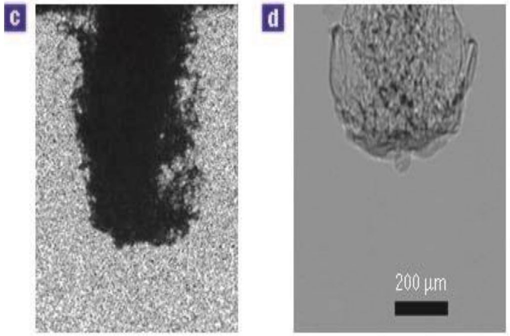


- Propagation based PCI is a phase diffraction effect
- Sensitive to differences in refractive index proportional to density
- Requires spatially coherent beam
- Enhanced contrast brings out features such as edges/voids
- Resolution vs. contrast trade-off

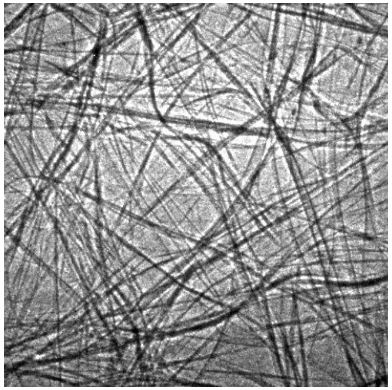
Fuel Injector Flow

Radiography PCI

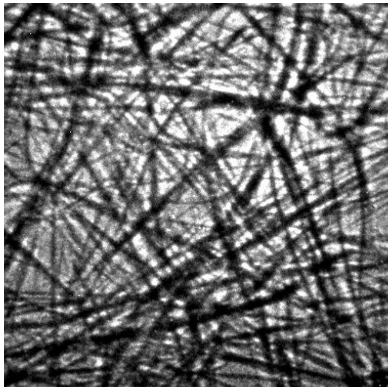


Y. Wang, X. Liu, et al. Nature Physics Vol. 4, p. 305 (2008)

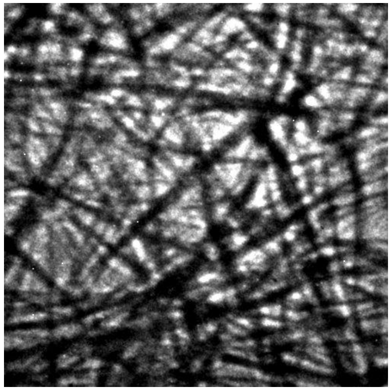
Phase Contrast Images of Polymer Foam



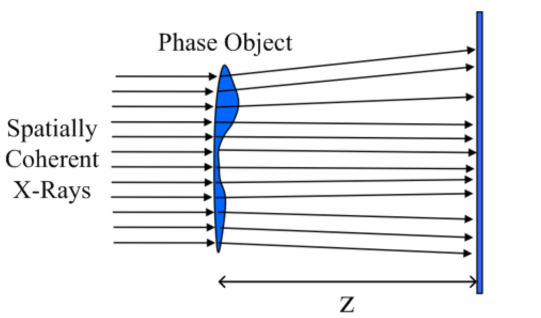
Z = 50 mm



Z = 400 mm



Z = 800 mm



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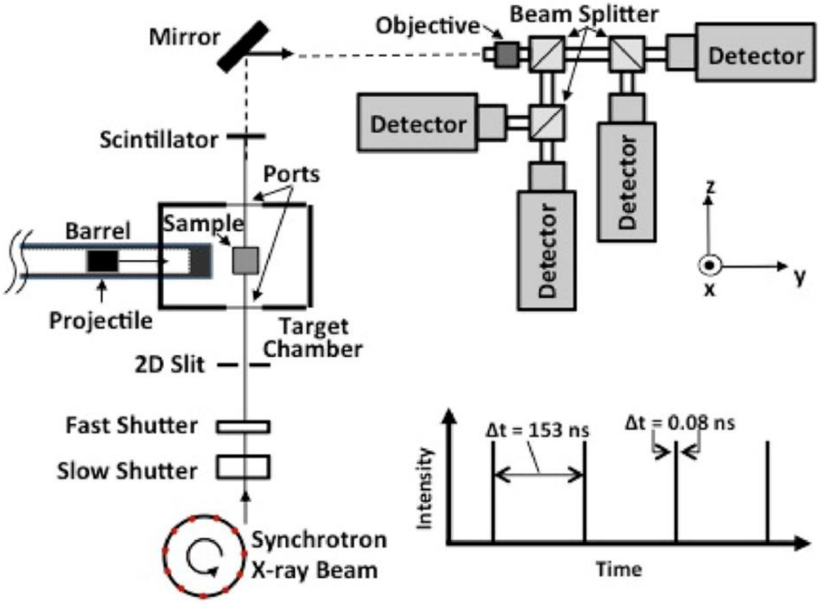
Experimental Configuration (Phase Contrast Imaging)

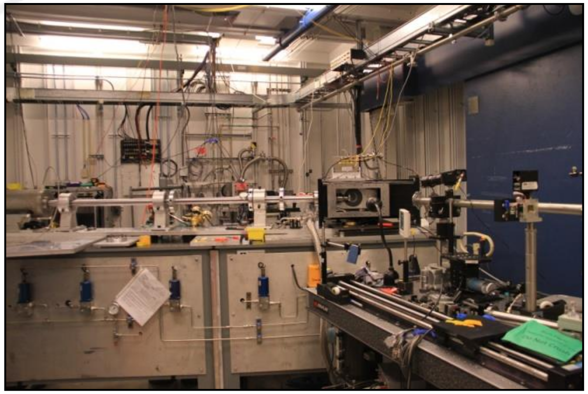
Experiment Configuration for Phase Contrast Imaging (PCI)

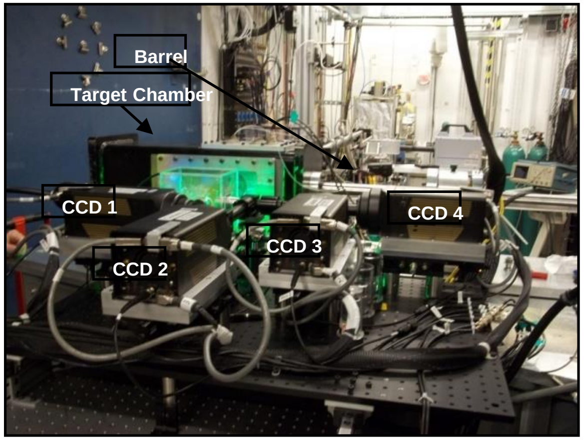


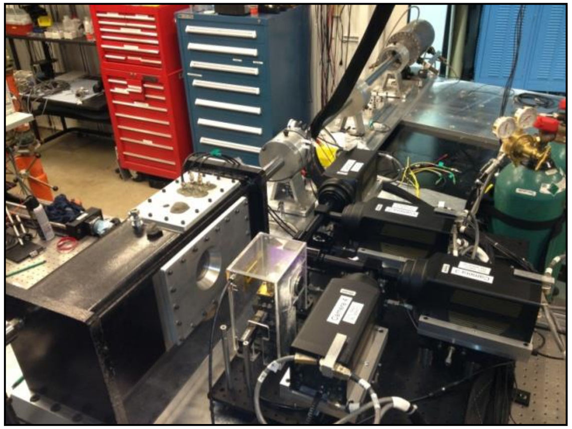
- Beam operated in standard mode with one 80-ps pulse every 153 ns
- Targets designed for quick setup/turn-around resulting in experiments every 1-2 hours

We leveraged multiple DOE programs to purchase new cameras that allow additional frames and will allow density to be extracted via two scintillator distances

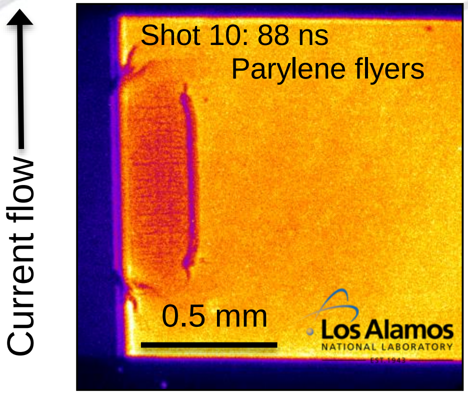
Diagnostics are located in the Sector 32 Experimental Hutch:

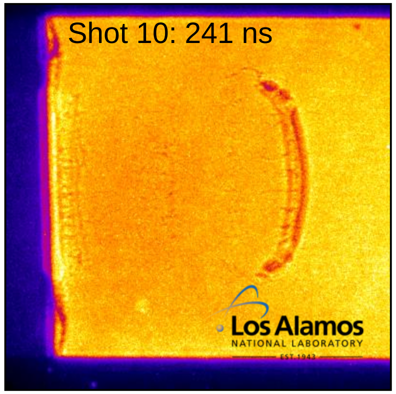


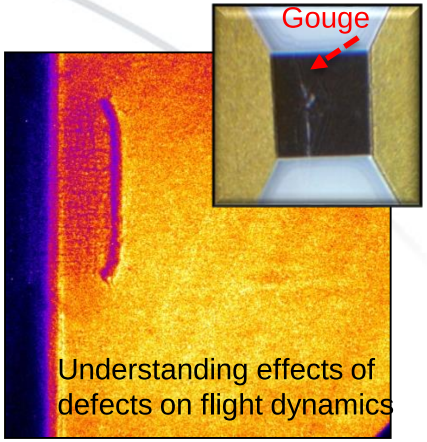


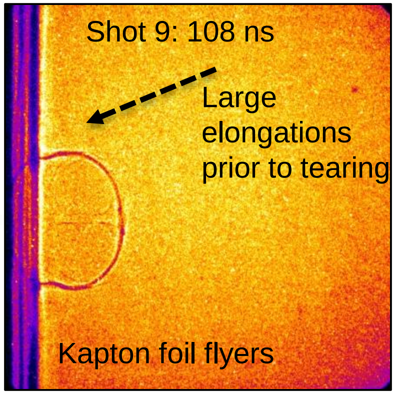


Dynamic Imaging of Slapper Initiators Utilizing X-Ray Phase Contrast Imaging for design optimization









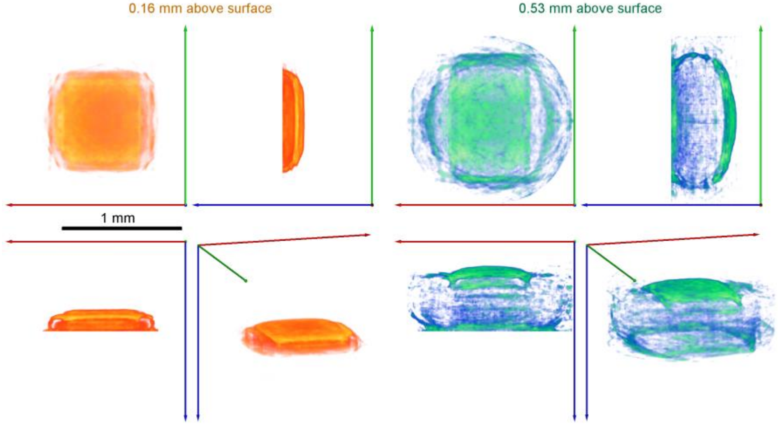


Figure 3: 3D renderings of LTT reconstructed in-flight slappers reconstructed from 7 real views each. are designated with red, green, and blue, respectively.

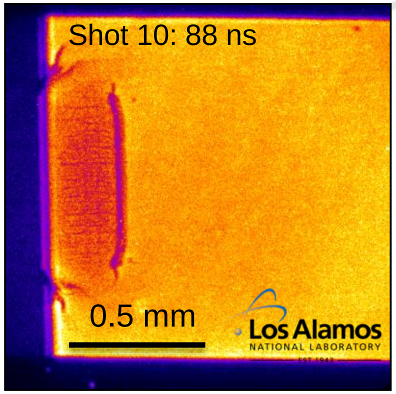
- Phase Contrast Imaging has allowed direct observation of slapper flight dynamics and plasma instabilities
- This work lends insight to initiator performance in stockpiled systems and has provided key data for future designs.
- Understanding the effects of defects and radiation on slapper initiator performance are key for weapon certification.

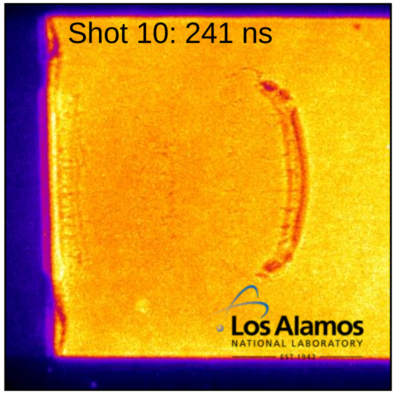
This data will aid in understanding critical performance parameters of slapper initiators for stockpiled systems and inform future designs

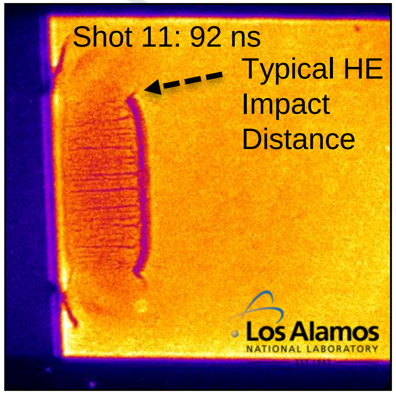
Dynamic Imaging of Slapper Initiators Utilizing X-Ray Phase Contrast Imaging

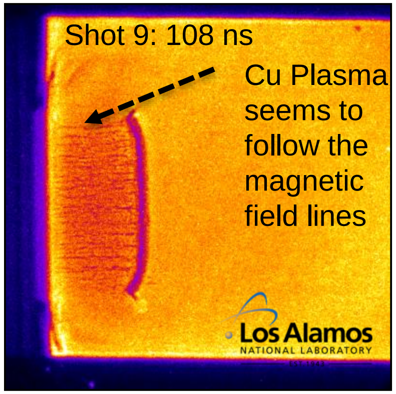
Current flow

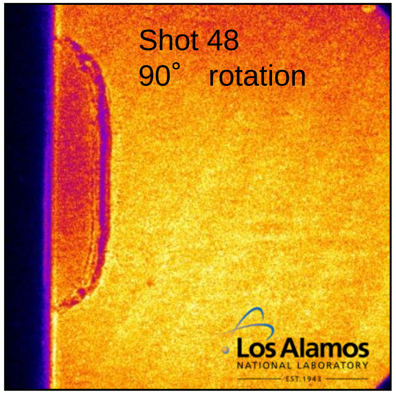
X







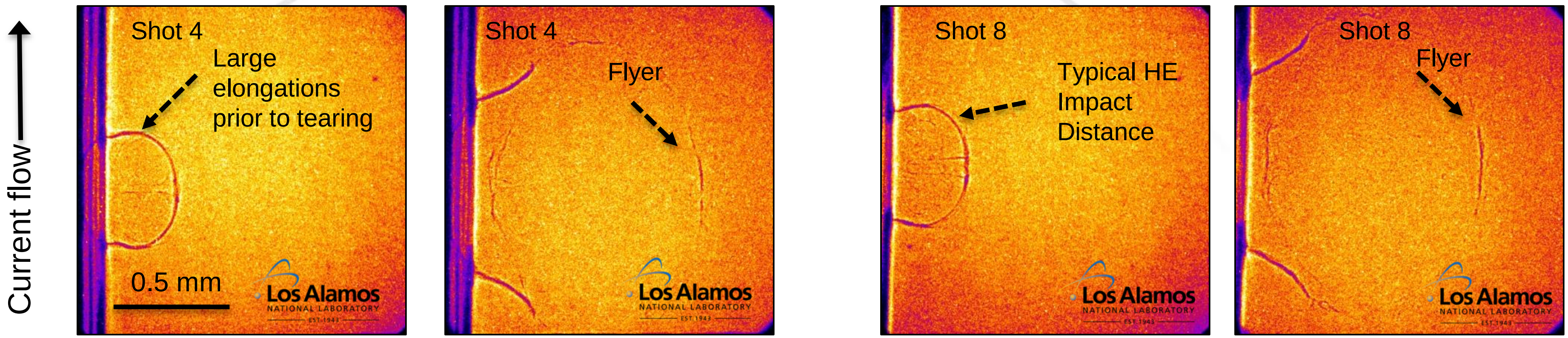


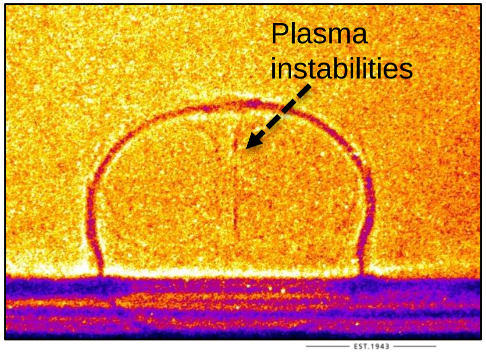


- Phase Contrast Imaging has allowed direct observation of slapper flight dynamics and plasma instabilities
- Planar flight suggests previous 1-D assumption is correct.
- Plasma instabilities likely due to random density perturbations. The plasma appears to align with the magnetic field produced from the high current.
- Parylene is robust enough for flyer applications, but radiation or extreme temperature differences must be evaluated.

This data will aid in understanding critical performance parameters of slapper initiators

Dynamic Imaging of Microclad Slappers Initiators Utilizing X-Ray Phase Contrast Imaging





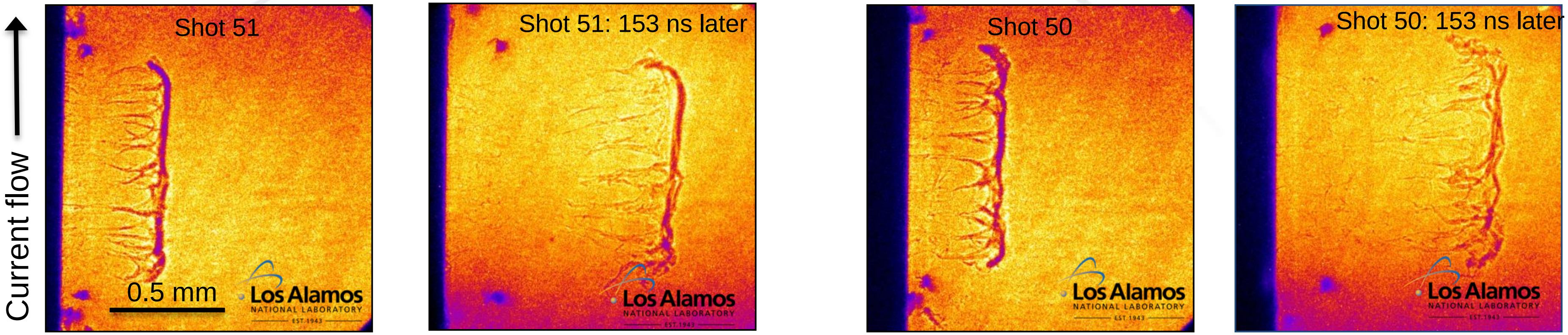
- 203 micron radiused bridges with 25 microns of Kapton.
- Data suggests that kapton "bubbles" & impacts the high explosive pellet instead of tearing. This defines the region undergoing impulsive loading and answers the long standing question whether the kapton bubbles or tears prior to impact.
- Multiple experiments showed consistent behavior of large percentage elongations prior to tearing. This causes thinning of the flyer by ~40% leading to a 16 micron flyer upon impact.

This data will aid in understanding Initiator-HE interactions and lend insight to slapper formation & flight dynamics

Understanding Radiation Effects on Dynamic Behavior of Parylene C Flyers Utilizing X-Ray Phase Contrast Imaging

Pristine 40x40 mil bridge with 0.5 mils Parylene C

Radiated to 4800 Gy



- Radiation does appear to negatively affect Parylene C flyer characteristics.
  - This effect appears to be minimal at relevant flight distances and time, but is more pronounced at later times as seen in shot 50 with flyer break up.
- Future experiments are needed to completely elucidate the effects of radiation on initiators with Parylene C. This is still an open question in the community.

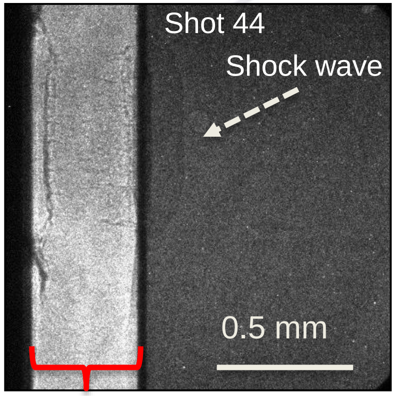
This data will aid in understanding slapper performance and margin in radiation environments

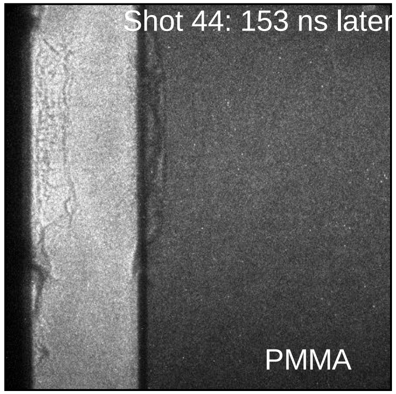
Dynamic Imaging of Slapper Impacts on Inert & Energetic Materials Utilizing X-Ray Phase Contrast Imaging

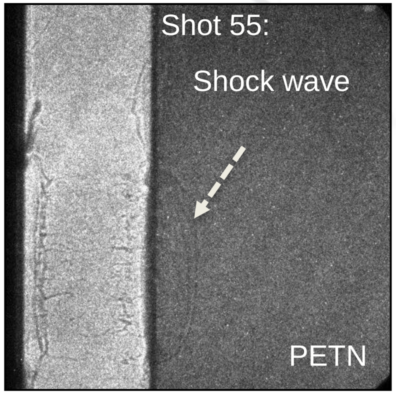
Slapper impact on PMMA

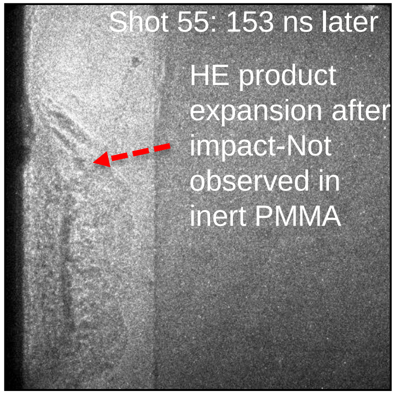
Slapper impact on PETN

Current flow

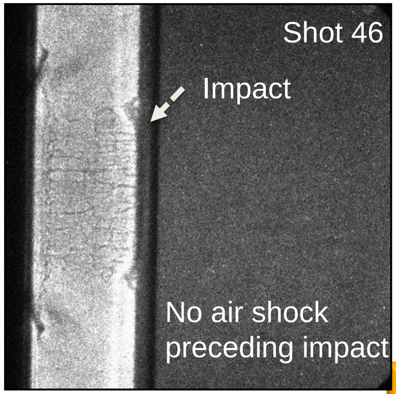








Barrel/flight distance



- Captured a well defined shock wave in PMMA from slapper initiator impacts.
- Shock wave was observed in PETN.
  - Broadening of shock front likely indicates prompt reaction.
- Product expansion was observed in PETN impacts

This data will aid in understanding Initiator-HE interactions and lend insight to initiation mechanisms

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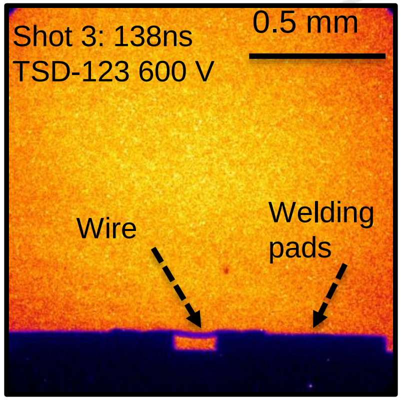
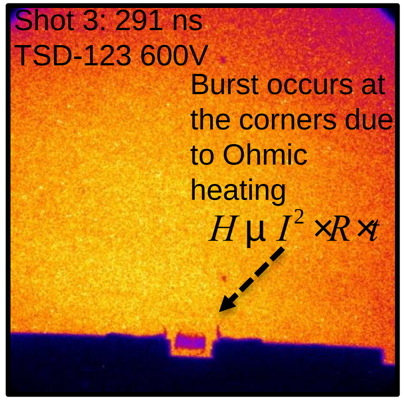
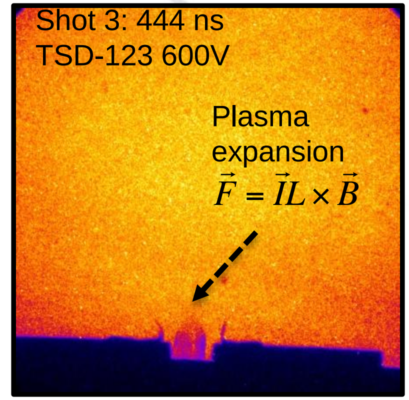
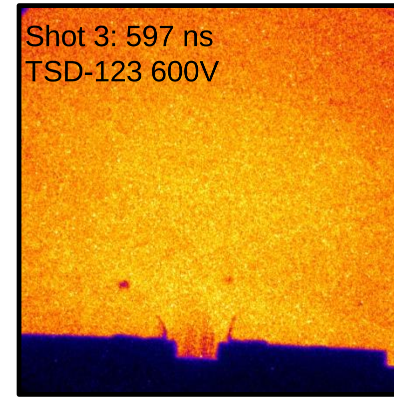
Dynamic Imaging of Low Voltage Exploding Bridgewires Utilizing X-Ray Phase Contrast Imaging

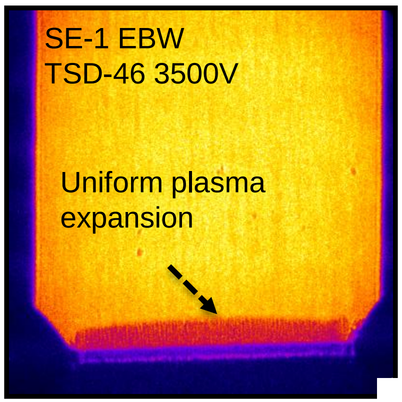
Nate Sanchez (LANL) and Brian Jensen (LANL), Will Neal (AWE), J. Gibson, M. Martinez, C. Owens (LANL), A. Iverson, C. Carlson , M. Teel (NS Tech), A. Derry (APS)

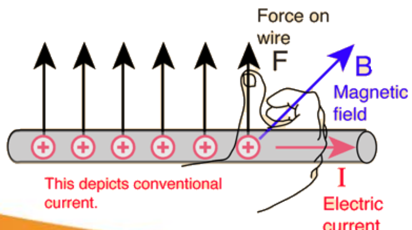












- Phase Contrast Imaging has allowed direct observation of low voltage exploding bridgewires and plasma instabilities
- Data suggests the welding pads disturb the current flow excessively, causing ohmic heating at the corners and non-uniform burst.
  - Does this rob sufficient energy from the system and reduce margin?
- There are substantial differences between a high voltage EBW and a low voltage EBW.
  - Is this due to differences between large welding pads and soldering bumps or the actual physics of plasma expansion at various voltages?

This data will aid in understanding critical performance parameters and margin in low voltage EBWs

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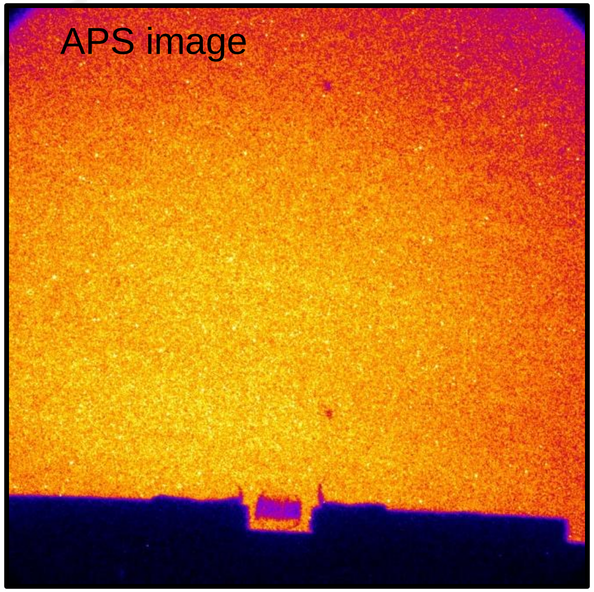
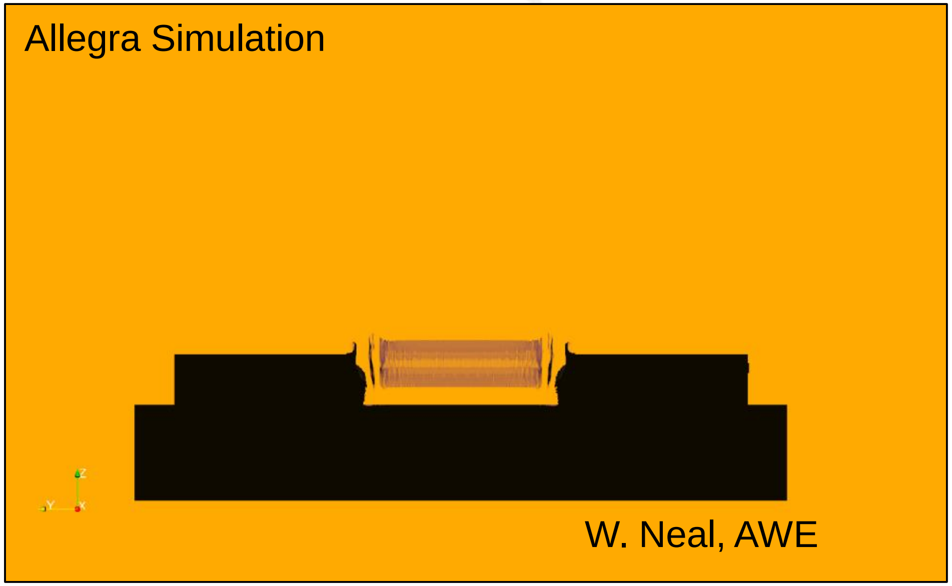
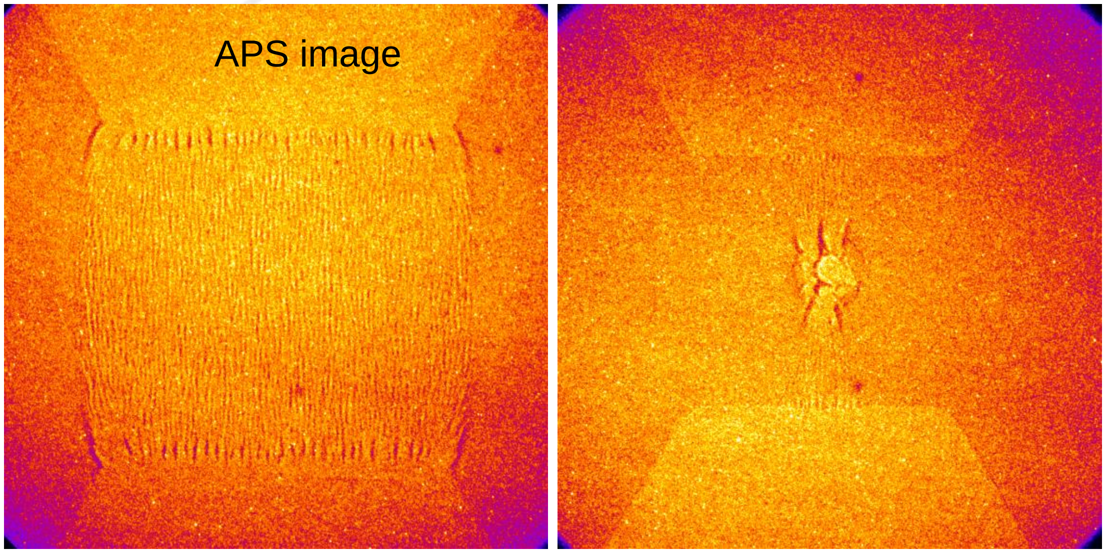
Pre-shot Predictions with similar geometry from Allegra Models Match the PCI Image Well





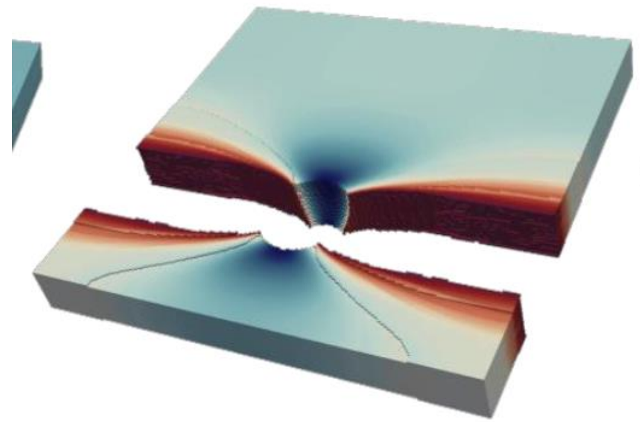
- Allegra modeling could prove to be a guide for design decisions, while PCI will serve as a good validation tool.

Pre-shot Predictions from Allegra Models Match the PCI Image Well



PCI images at burst and prior to flyer formation

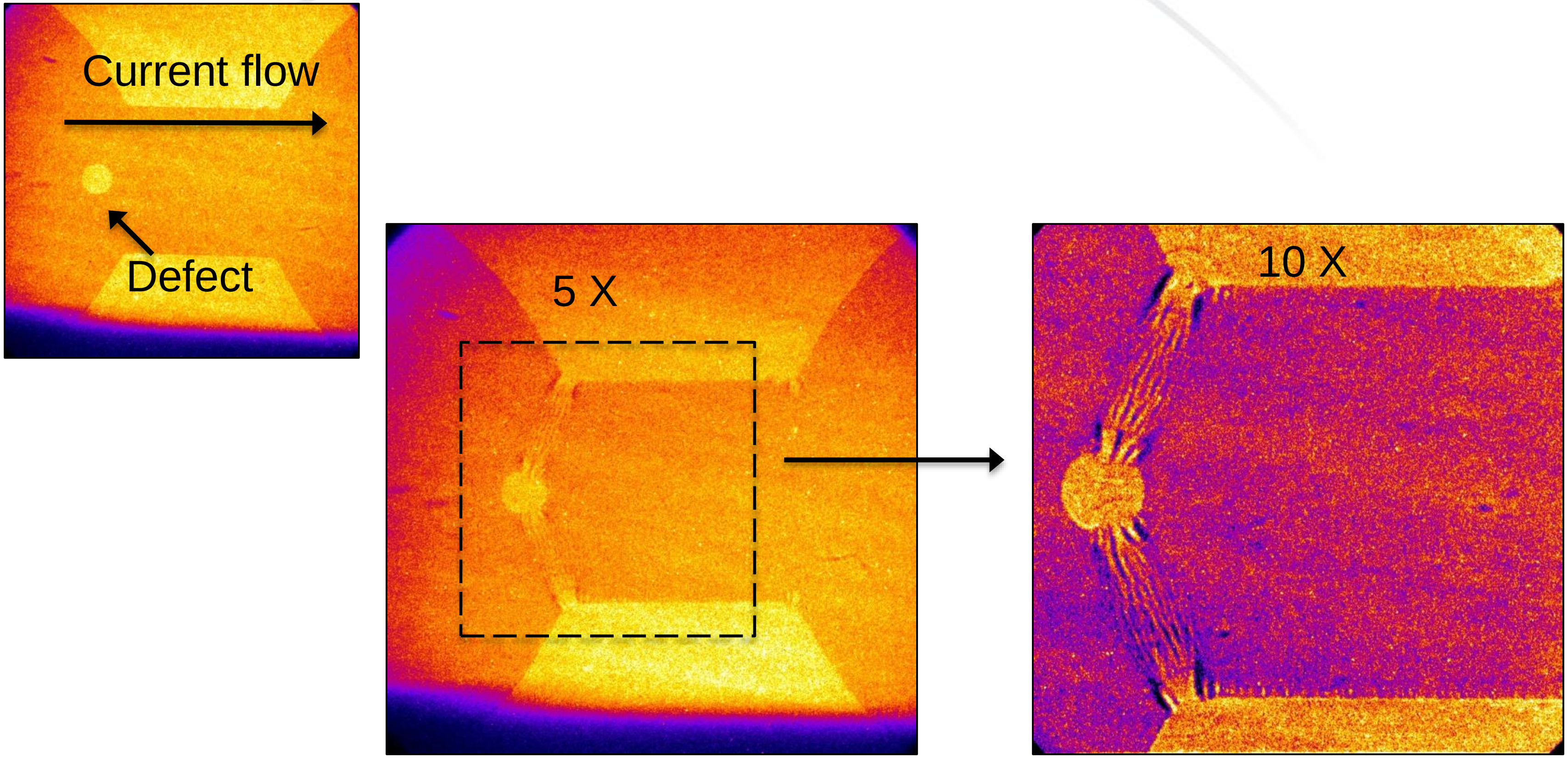
Allegra Simulation



W. Neal, AWE

- Allegra modeling could prove to be a guide for design decisions, while PCI will serve as a good validation tool.
- Future experiments will march through the burst phenomena at 10ns intervals to better understand the evolution of burst
- Future experiments will include multiple holes and holes by the lands to push the model to the limit.

Capability improvement now allows us to zoom in and obtain better resolution



Summary:

- LANL in conjunction with NSTec has developed a new capability for dynamic imaging of detonators at The Advanced Photon Source in Argonne.
- PCI at APS will allow us to answer many questions that remain in the understanding of detonator behavior allowing us to improve upon our predictive capability of models.
- The IMPULSE team gets larger every beam run and we are continuing to evolve our experimental designs as we increase the user knowledge base.
- Future experiments will continue to push diagnostic development and integration.
- Collaboration has allowed us to leverage several funding resources to optimize the amount of science performed relative to funding levels.
- Every year we receive an increase in beam time, while our working groups keep increasing the amount of experiments

Questions?

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