Los Alamos NATIONAL LABORATORY

pRad PROTON RADIOGRAPHY

# Proton Radiography for Density Movies of Dynamic Exploding Events

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**pRad Project Leader**

AIAA Defense Forum

Laurel, Maryland

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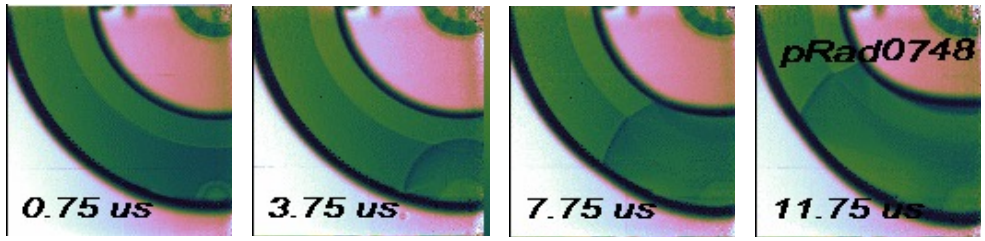
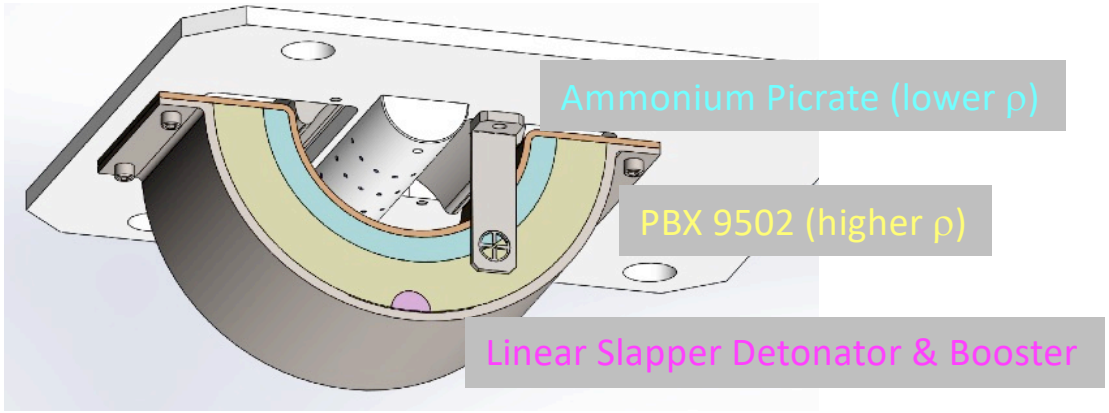
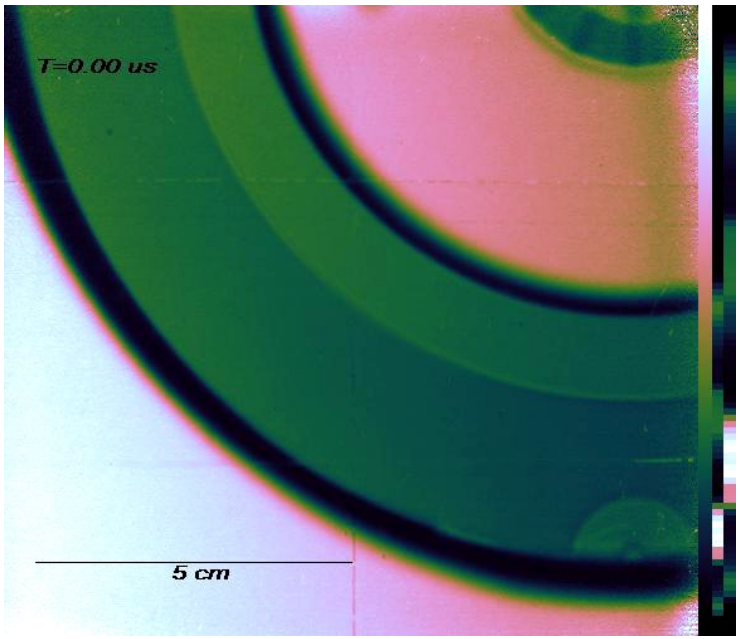
NNSA National Nuclear Security Administration

LA-UR-21-27378

# Proton radiography allows us to see material deformation & explosive detonation front positions and speeds




A density movie of the explosion can be directly compared to simulations to see if we are modeling materials correctly

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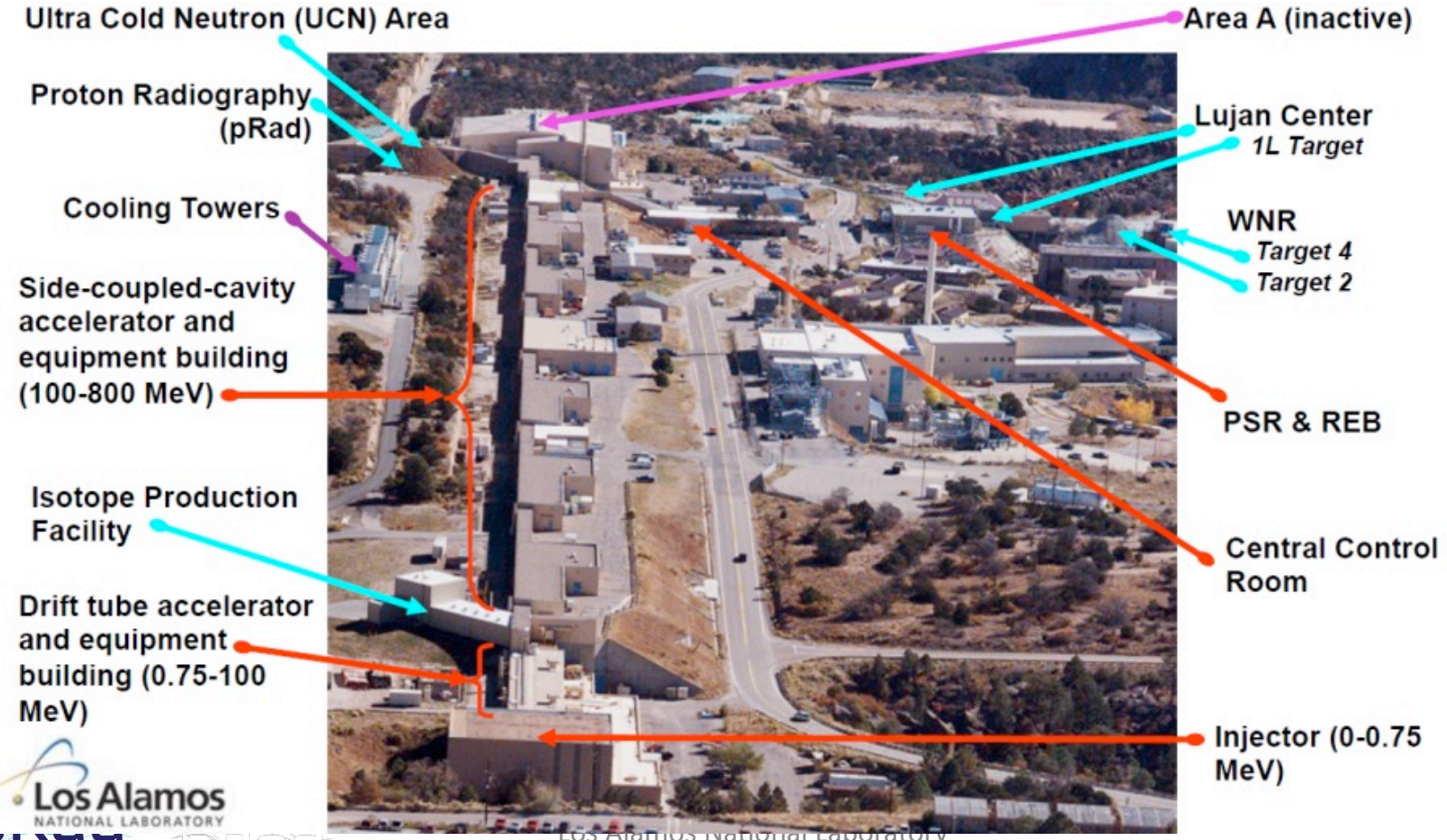
Contact: John Budzinski

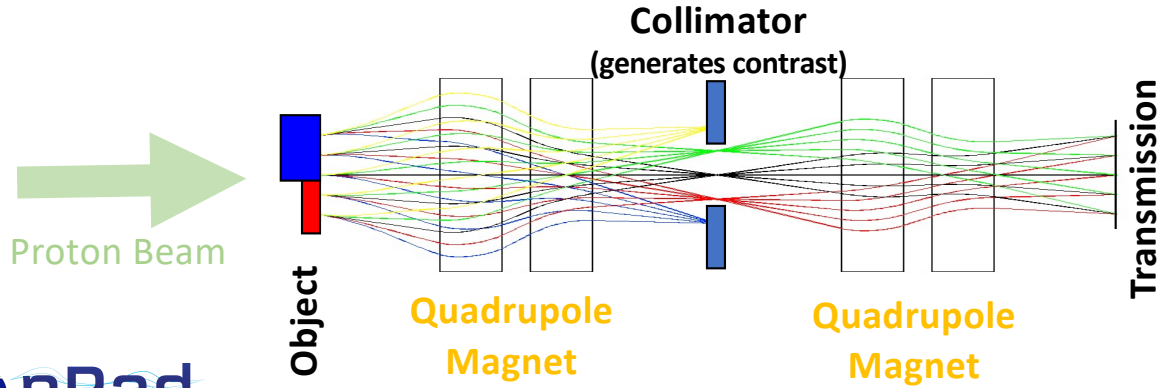
# pRad takes place at the Los Alamos Neutron Science Center (LANSCE, TA 53)






From Nathan Moody, AOT

# The Line C Dome is where all of the dynamic experiments occur




Object thicknesses and densities can be discerned from the multiple coulomb scattering observed at the transmission plane

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# Explosive experiments take place in a vessel

Vessel

x3 quadrupole electromagnets

Image Location


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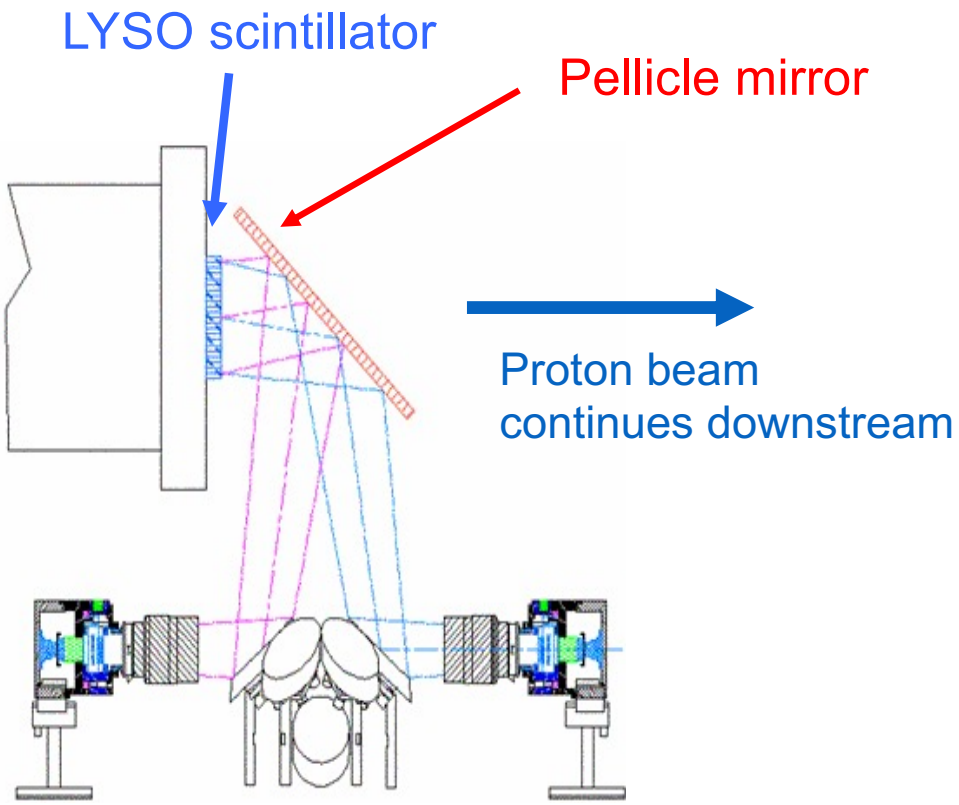
# pRad images are acquired with fast scintillators and high speed framing cameras




LYSO scintillator panel generates visible light with ~50 ns lifetime.

Fast cameras gated on different proton pulses take individual frames that are then stacked to make a movie.

| Camera | 10-frame | 3-frame |
|---|---|---|
| Min integration time | 50 ns | 150 ns |
| Min inter-frame time | 150 ns | 358 ns |
| Dynamic Range | 3430 | 1330 |
| Read Noise ($e^-$) | 79 | 216 |
| Pixel array | 1100 x 1100 | 720 x 726 |
| Pixel pitch | 40 µm | 26 µm |
| Sensitivity ($e^-/J/cm^2$) | 3.0 x $10^{12}$ | 1.9 x $10^{13}$ |
| Sensor size | 44 x 44 mm | 21 x 22 mm |
| Well Depth | 272 | 180 |

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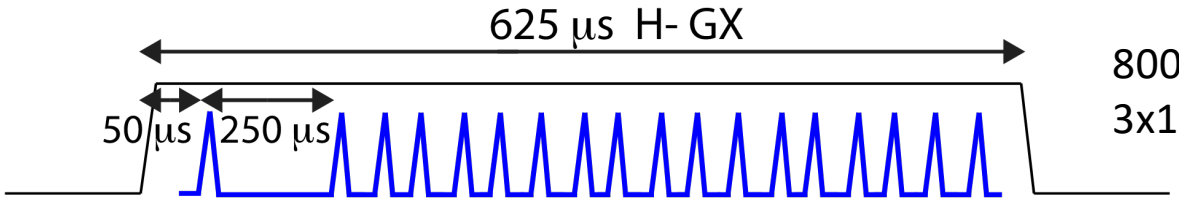
# Temporal resolution allows capture of shock waves and detonation fronts in objects

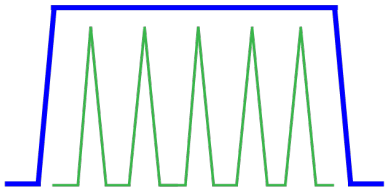



800 MeV Protons
$3x10^8$ protons per micropulse

**Camera Pulses**

**~60 ns Precursor Pulse Triggers Hardware**

**Single Pulse Composition**



**Micropulses**
f=201.25 MHz ~ 5ns
width=100 ps

**Camera Pulse Structure**
Minimum frame spacing: 200 ns
Exposure time: 50-100 ns
Number of frames: 22 (10-frame + 4 3-frames)

The pRad imaging pulse structure and timing is customizable, depending upon the experiment needs.

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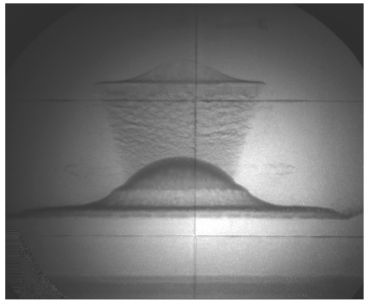
# Going from raw radiograph to areal density

"Raw" Radiograph



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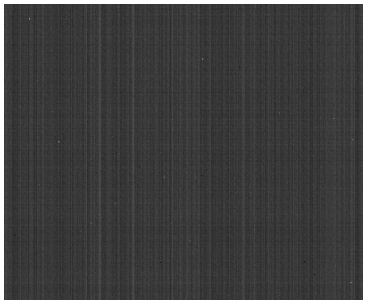
Dark Field



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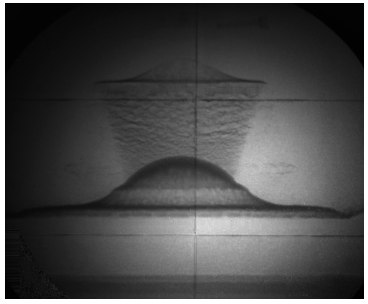

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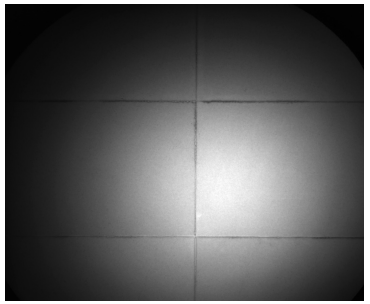
Beam Picture



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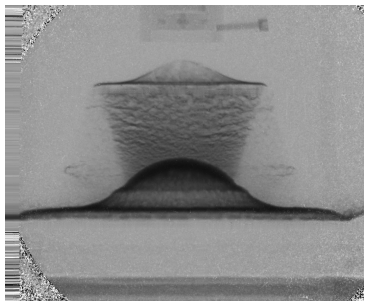
Transmission



➡

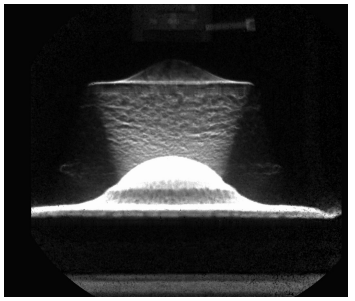
$$T = e^{-x/\lambda}\left(1 - e^{-\left(\frac{\theta_c p\beta}{14.1\,MeV}\right)^2 \frac{x_o}{2x}}\right)$$

Nuclear attenuation

Multiple Coulomb Scattering

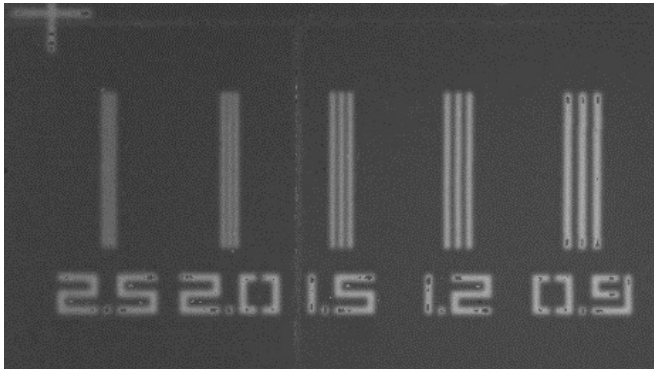
➡

Areal Density (g/cm$^2$)

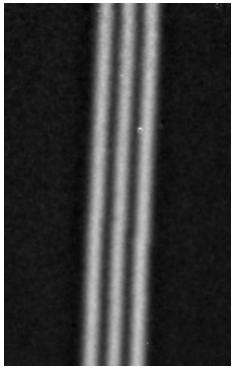


# Several magnification systems are available for changing spatial resolution and FOV

**Identity Lens –I**
**120 mm FOV**




**X3 Lens**
**44 mm FOV**



2.5 lp/mm

**X7 Lens**
**17 mm FOV**


Ideal Spatial Resolution

| 178 μm | 45 μm | 25 μm |
|---|---|---|

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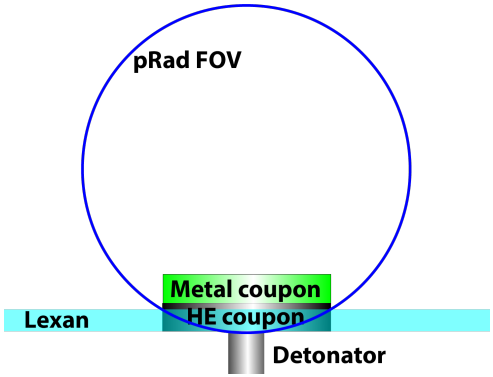
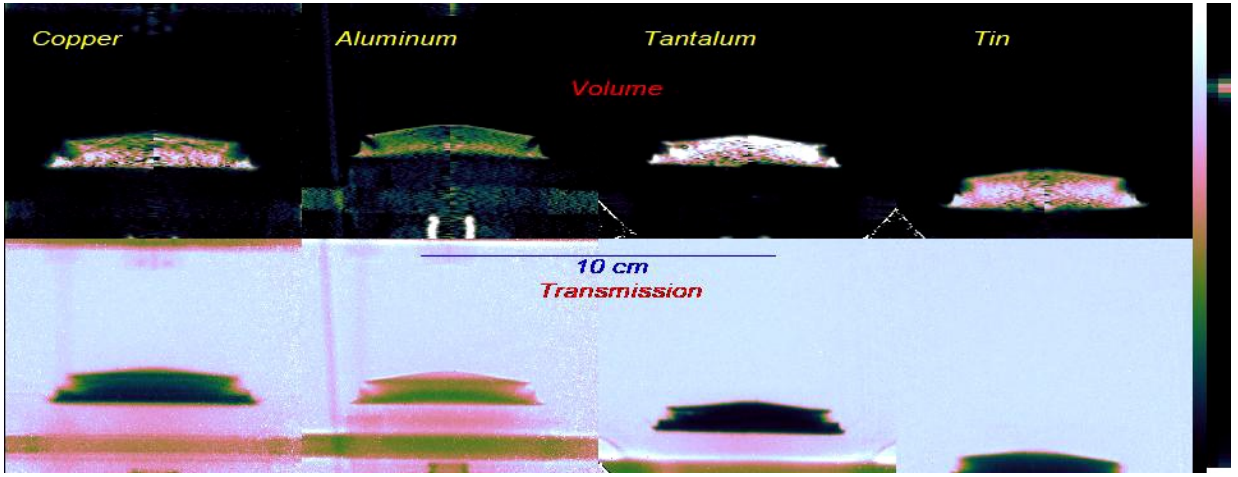
# Dynamic material strength experiments show the structure in material failure




pRad 84 (copper) pRad 85 (aluminum) pRad 89 (tantalum) pRad 90 (tin)

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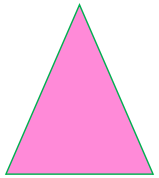
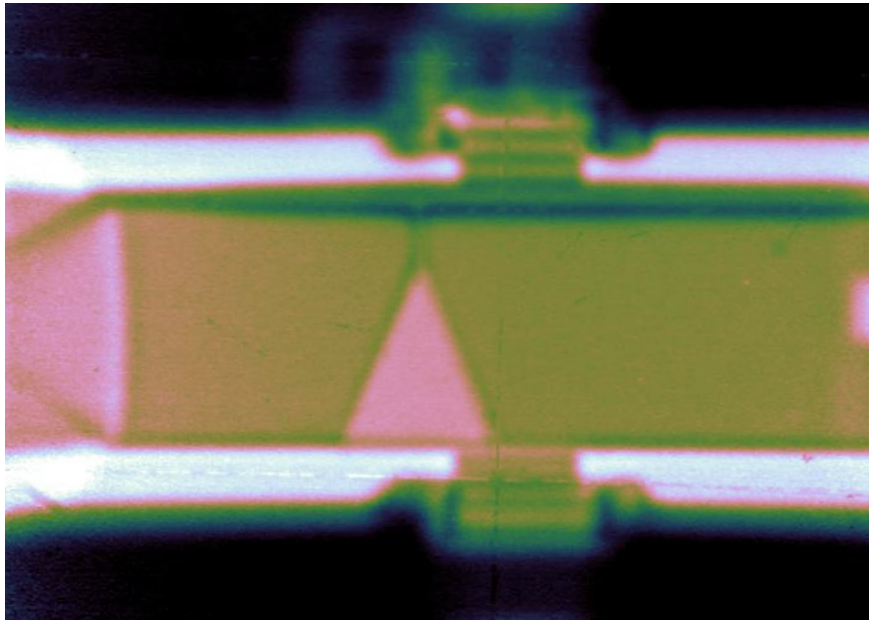
Contact: Chris Morris

# WRX experiments study how inert materials can disrupt a detonation front

Detonation front moves left to right through HE slab

Polycarbonate wedge (starting proportions)

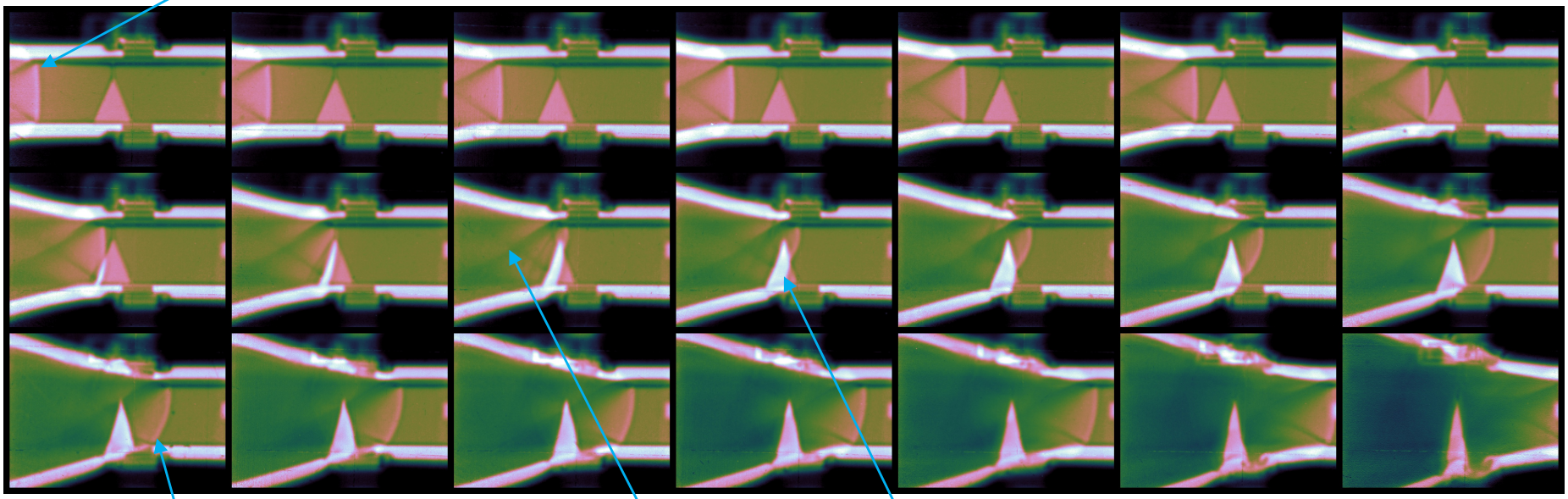




pRad images the **speed and shape** of the detonation shock waves through the HE and the det products, plus **pre- and post-shock densities**, giving strong constraints to equations of state

# WRX experiments study how inert materials can disrupt a detonation front

Flat detonation front



Curved det front

Reflected shocks in det products

Shock speed/position through polycarbonate wedge

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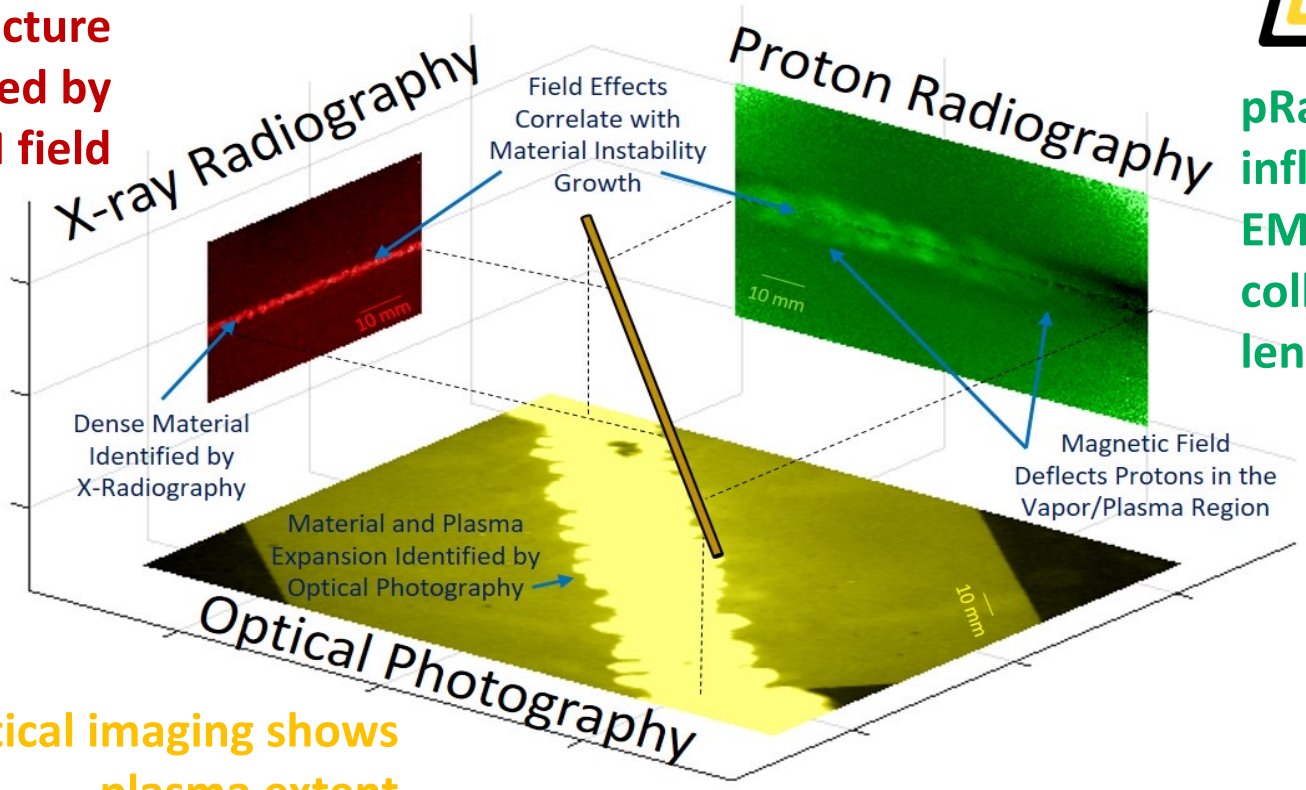
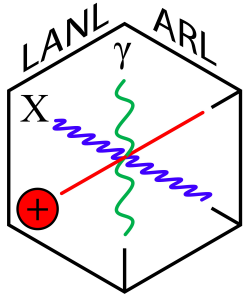
# ARL shots demonstrated a new way to use pRad to look at magnetic field effects in plasmas

**X-ray structure not influenced by local EM field**



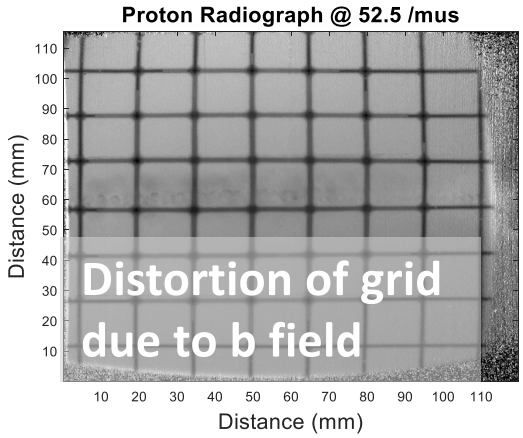

**pRad structure influenced by EM fields collimators + lenses**

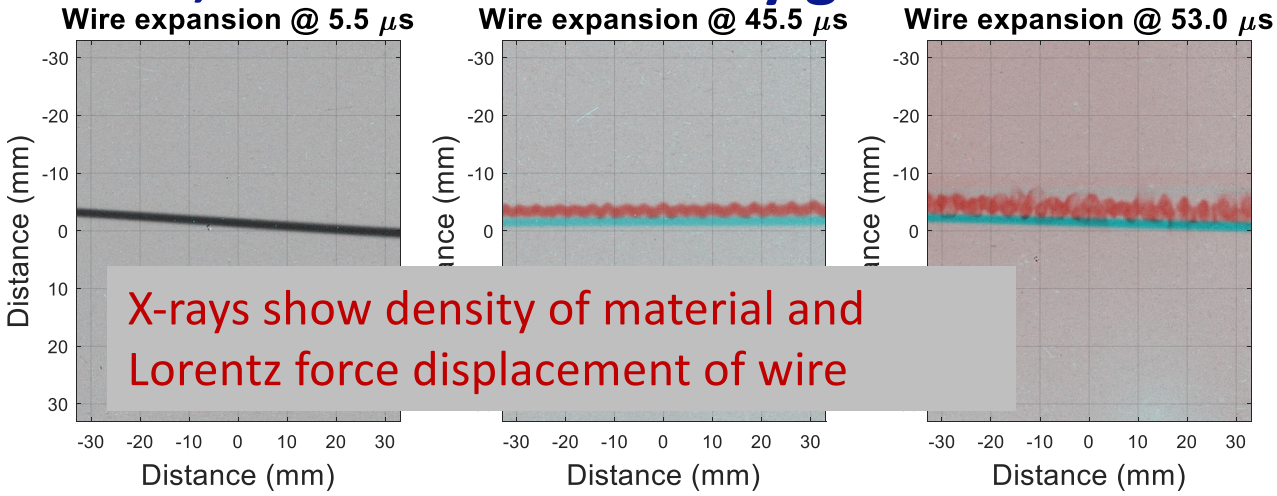
**Optical imaging shows plasma extent**

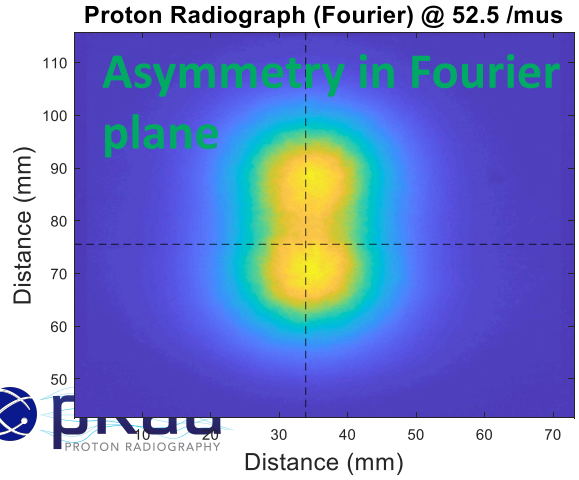



Contacts: Mike Zellner, ARL; Neukirch + Freeman

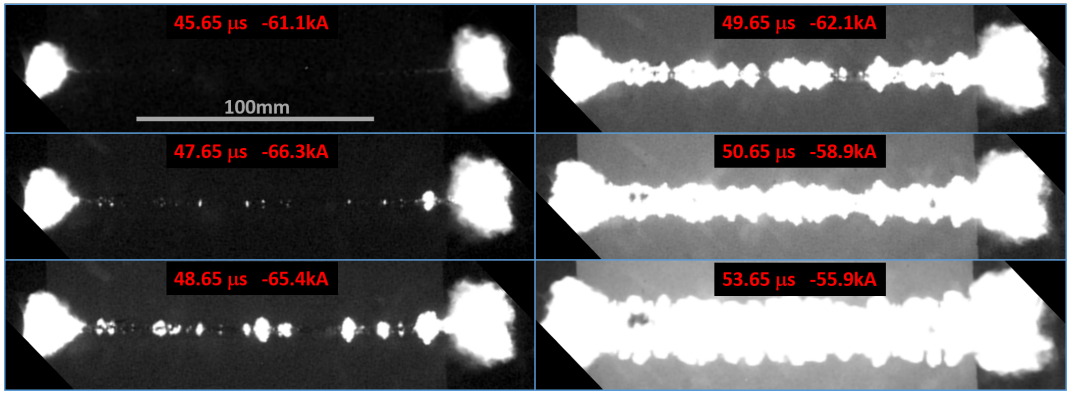
# ARL experiments studying plasma behavior, conduction pathways in material mixtures, and MHD instability growth



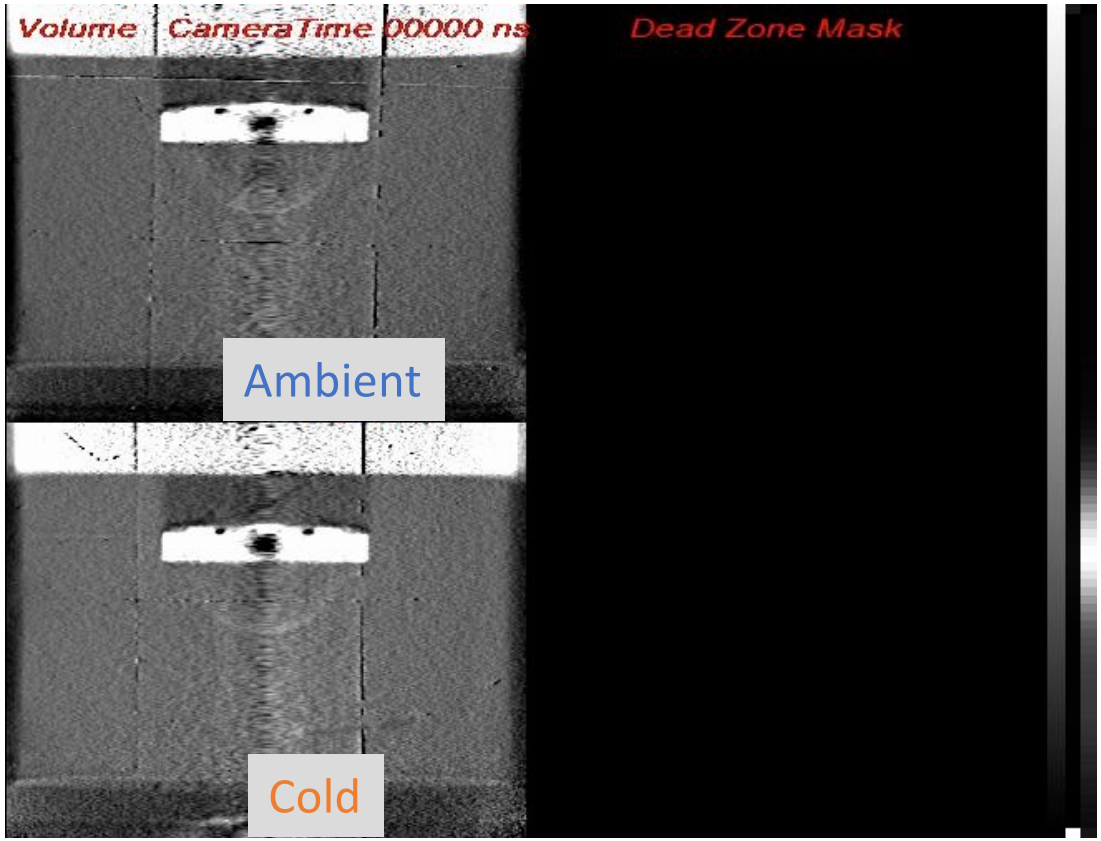



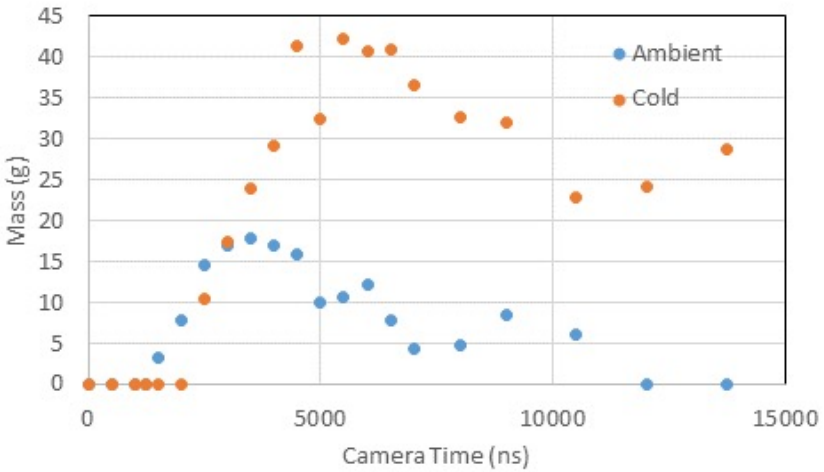

## Development and extent of plasma



# Explosives exhibit different dead zone behavior depending upon temperature

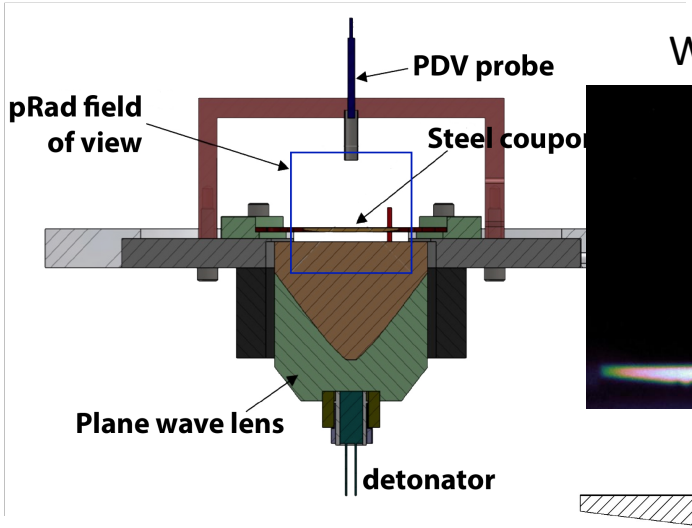


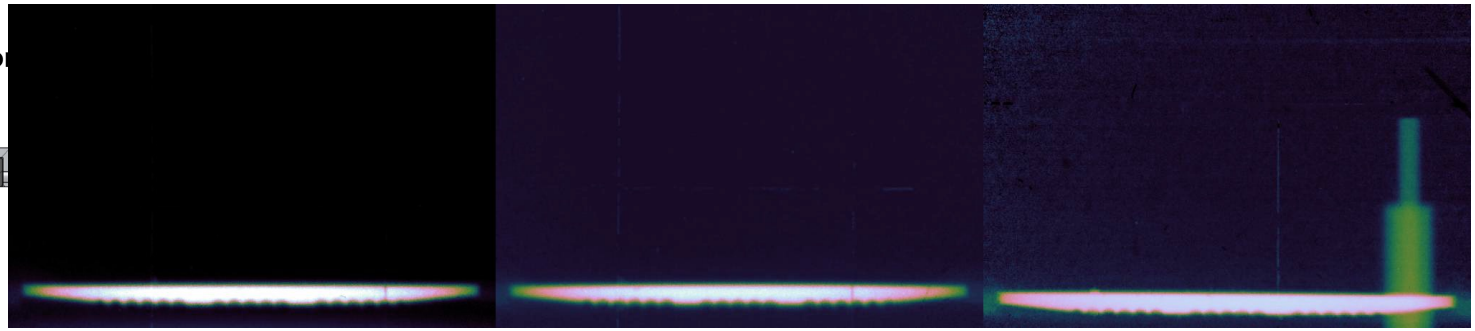

Dead zone masses are estimated from pRad density images and compared to pre-shot calculations

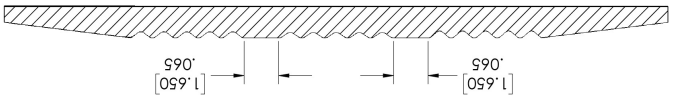



Contacts: Clif Mortensen, LLNL; Chris Morris

# High strain rate drive (~225 kbar) shows how manufacturing processes affect strength




Perturbations to seed deformation

Manufacturing method (wrought vs AM) affects material strength

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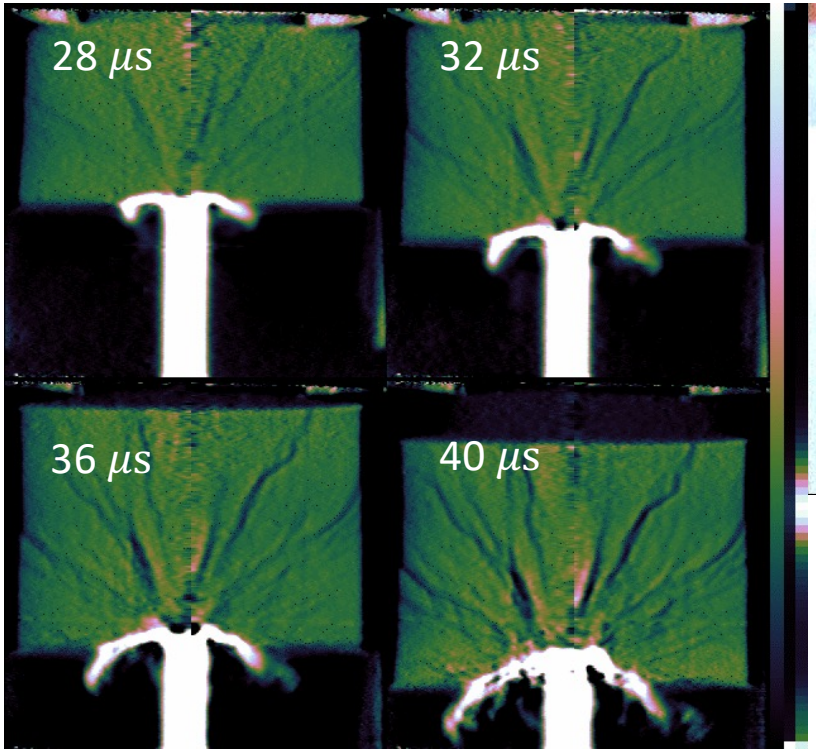
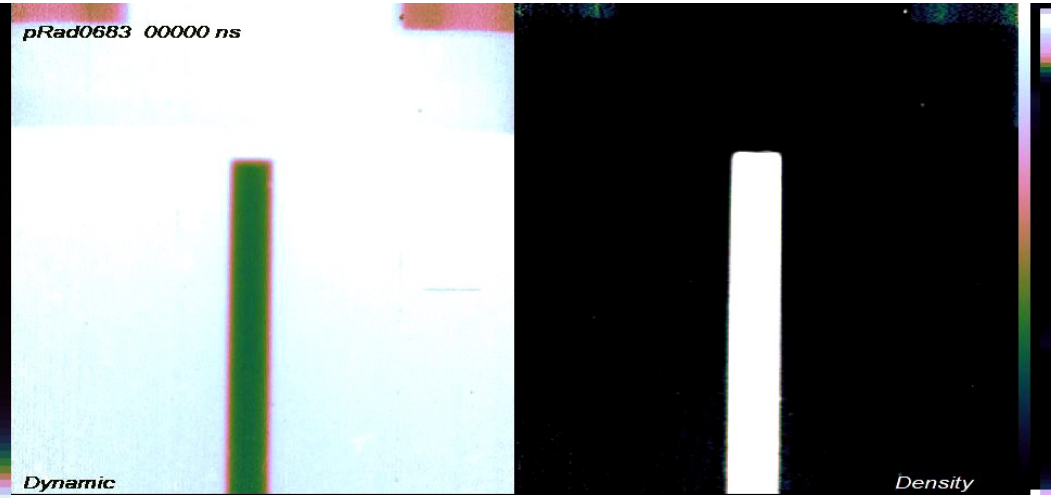
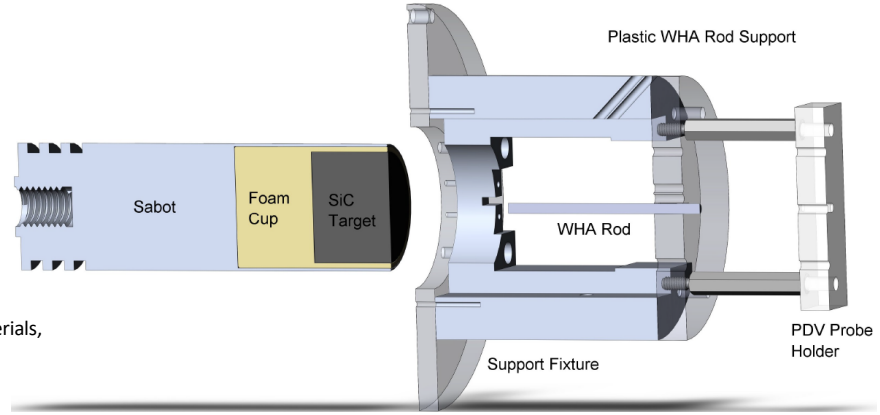
Contact: Anna Llobet

# Army Research Lab reverse flyer series to examine armor failure using the pRad powder gun




Density reconstruction of SiC fracture




Aydelotte B. et al. (2019) Proton Radiography of Reverse Ballistic Impacts. In: Dynamic Behavior of Materials, Volume 1. Conference Proceedings of the Society for Experimental Mechanics Series.

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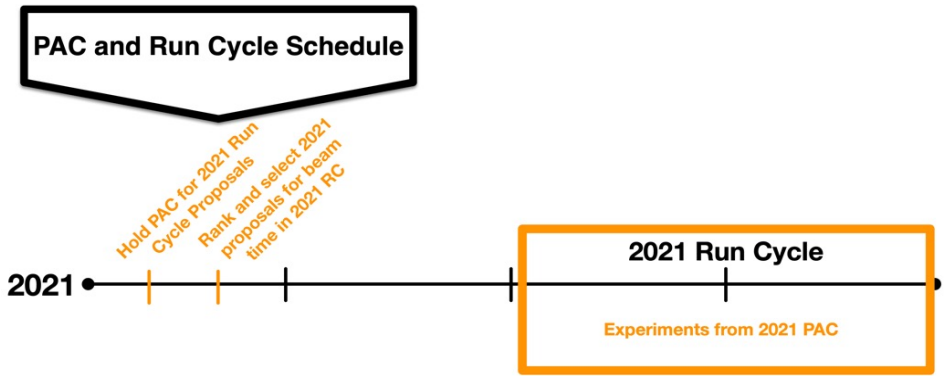
Contact: Brady Aydelotte

# All experiments for pRad must be approved by a Proposal Advisory Committee




**Submitted proposals should address these ranking criteria:**

1. Quality of the science being proposed (What is the problem, and why are experiments needed?)
2. Impact to programs (How will the data be used?)
3. Appropriateness of the use of the pRad diagnostic for the experiments (Why can't this be done somewhere else?)
4. Readiness of the experiments, feasibility with stated resources, and requested time (Has other work been done informing the pRad experiments?)

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# What are the characteristics of highly-ranked experiments?

- Time and density resolution are needed
  - Justify time-resolved areal density measurements
- Thickness/transmission is optimized for pRad
  - Is this an experiment that will image well with 800 MeV protons?
- Facilities/Drivers
  - Are you using an existing capability, such as the powder gun or 6' vessel?
  - Will the proposal require significant investment?
- Materials
  - Are the proposed materials allowed? How will you know?

The best practice is to talk to a pRad team member.
Your proposal should address the above concerns.

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# More info about pRad is online

- The call for proposals for the 2022 Run Cycle comes out in December
- The LANSCE Website has the **User Manual** https://lansce.lanl.gov/facilities/pRad/index.php
- I will put you in contact with someone whose expertise can best assist you with experiment planning.