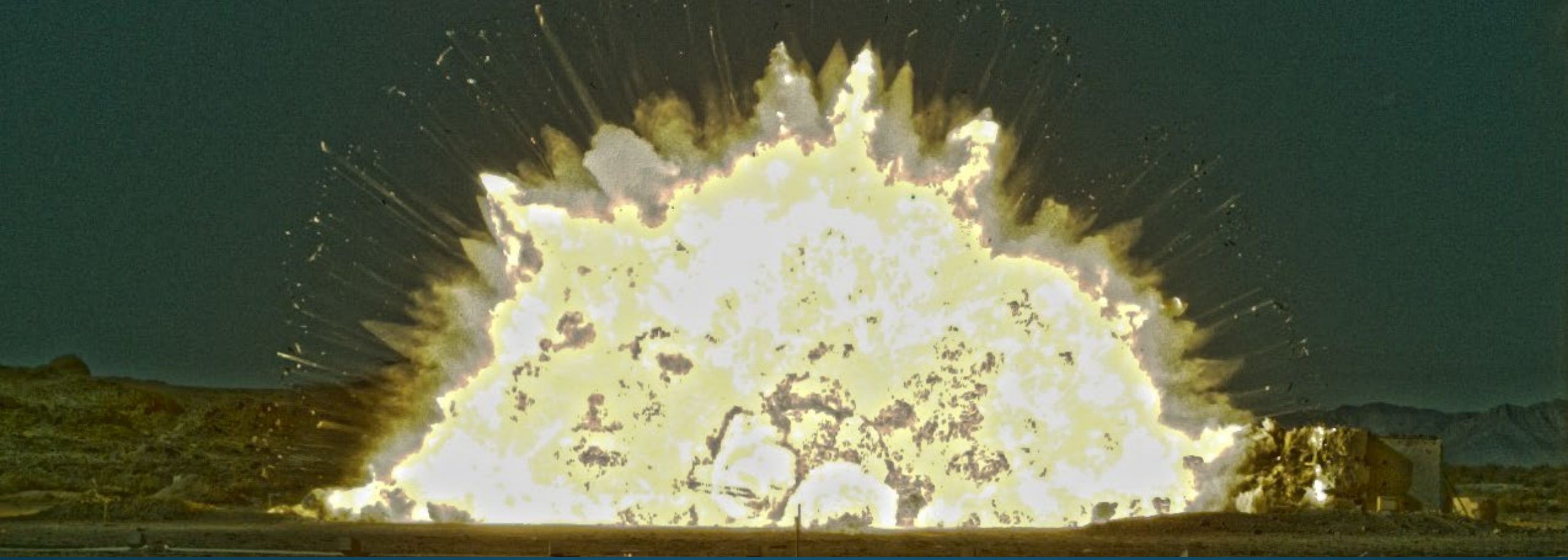

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USAF – Explosive Ordnance Test Lab

Overview of Full-Scale Arena Testing of Munitions with Optical-Tracking Diagnostics

Presentation Overview

- BLUF
- Traditional Arena Testing
- Advanced Arena Testing – 60,000 ft View
  - Digital Image Correlation – Munition Case Strain/Displacement
  - Optical Tracking of Fragments
- Issues/Errors
- Observed Detonation Phenomena
- Summary/Benefits

BLUF

- The application of optical-tracking methods represents an enormous leap forward for testing large, cased munitions
- Improvements across the spectrum:
  - Drastically decreased test timeline
    - Enables increased throughput
    - Enables testing of larger population samples
  - Increased quantity and quality of data per test
    - Correlated individual fragment mass and velocity
    - Richer understanding of detonation phenomena
- Methods developed in partnership between
  - Bombs Section within the US Air Force Armament Directorate (AFLCMC/EBHCB)
  - Sandia National Labs
  - US Air Force Explosive Ordnance Test Lab (309 MMXG)

Traditional Arena Test Methods

Traditional Arena Test Methods

Example: 2000 lb warhead tested at Eglin AFB in 2008

- 6 Pressure Transducers
- 74 16-ft soft-catch fiberboard bundles
  - Fragment mass and location – 180° coverage
  - Months of manual labor to sort through
- Velocity screens
  - Uncorrelated with mass

Typical Pressure Transducer

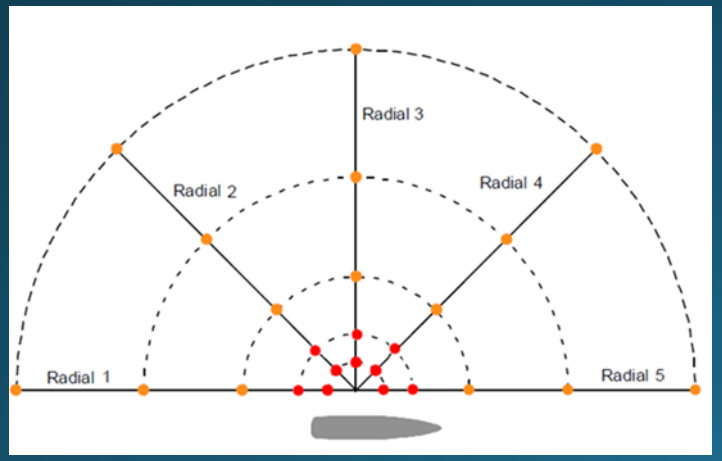
Image Credit: U.S. Air Force/Airman 1st Class Anthony Jenning

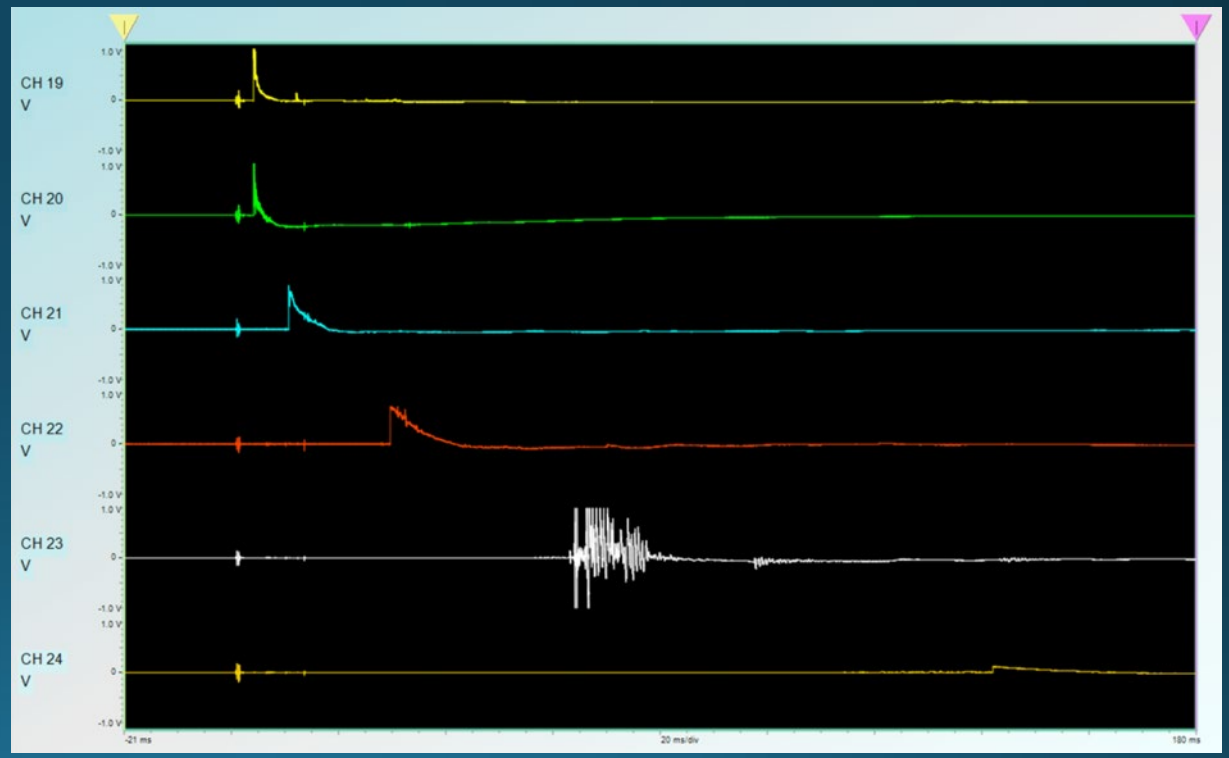
Bundle Picking

Pressure Gage Data Analysis

Convert pressure gage data to a single Equivalent Explosive Weight

- Follows the process outlined in the 61 JTCG/ME 1-9 recommendations (Section 4.8).
- Useful for making comparisons between lots or as munitions age
- Complicated by data loss caused by line cuts or by disturbances in the air caused by reflected shock waves or passing fragments.

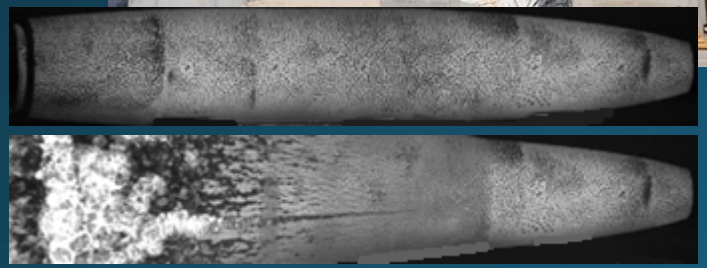




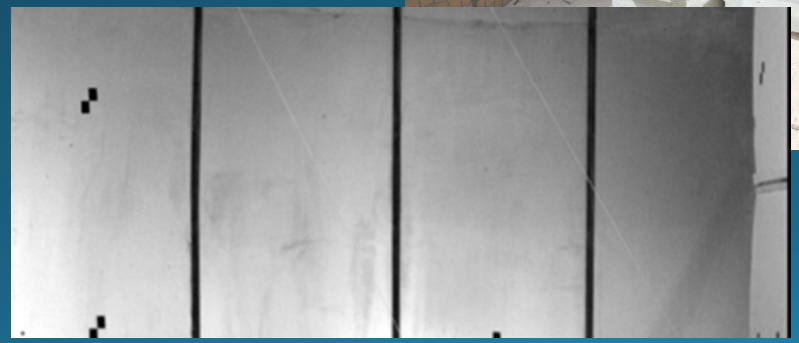
Advanced Arena Test Methods

Advanced Arena Test Methods

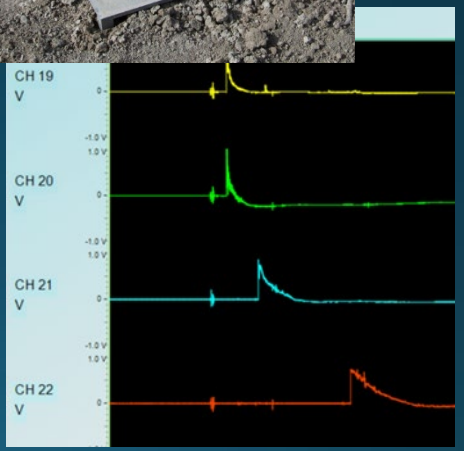
Digital Image Correlation (DIC)



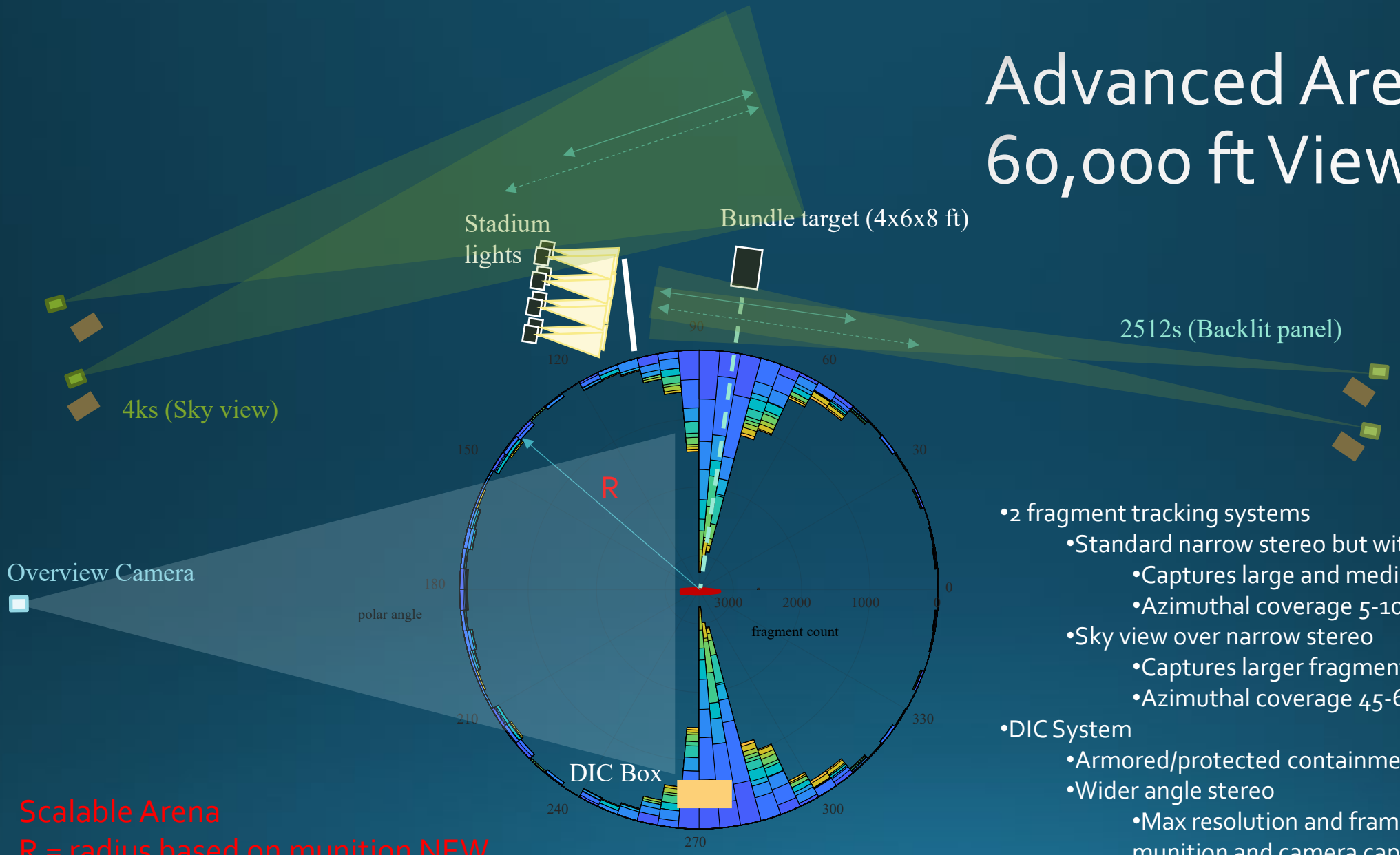
Fragmentation Tracking



Blast Pressure



Advanced Arena 60,000 ft View

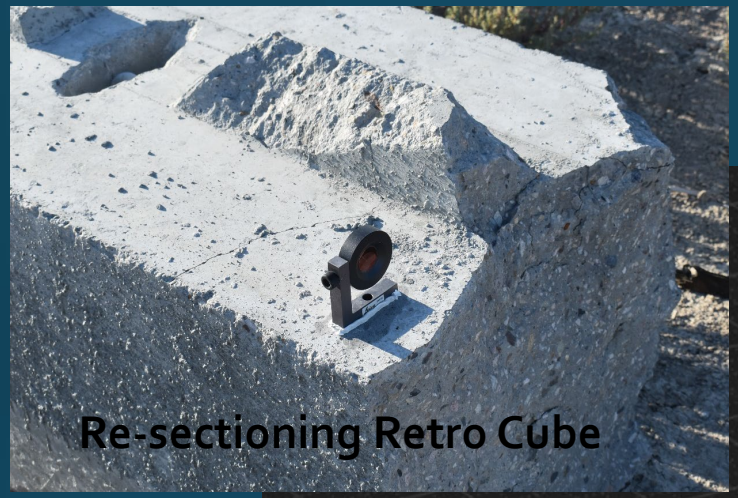


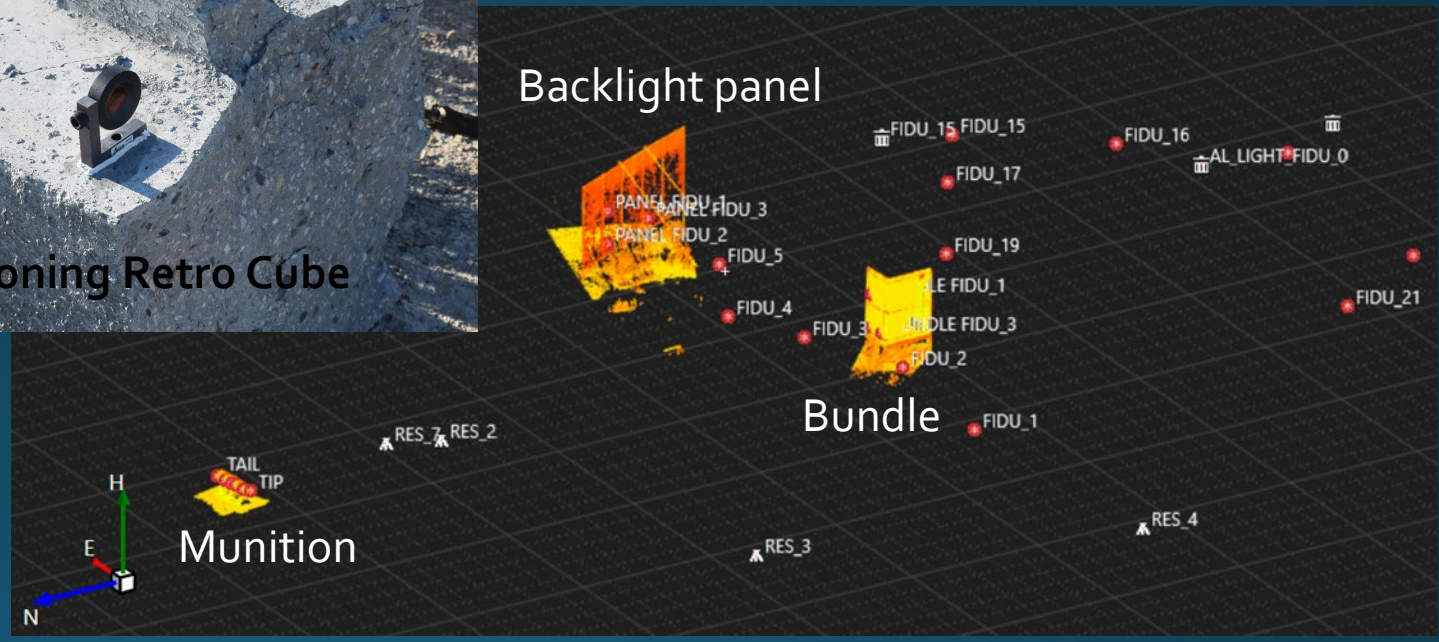
Scalable Arena
R = radius based on munition NEW

- 2 fragment tracking systems
  - Standard narrow stereo but with backlighting
    - Captures large and medium fragments
    - Azimuthal coverage 5-10 degrees at R radius
  - Sky view over narrow stereo
    - Captures larger fragments
    - Azimuthal coverage 45-60 degrees at R radius
- DIC System
  - Armored/protected containment unit at 50 ft radius
  - Wider angle stereo
    - Max resolution and frame rate based on size of munition and camera capability
- Overview Camera
  - Blast Overview
  - Not used to track fragments

Global Coordinate System

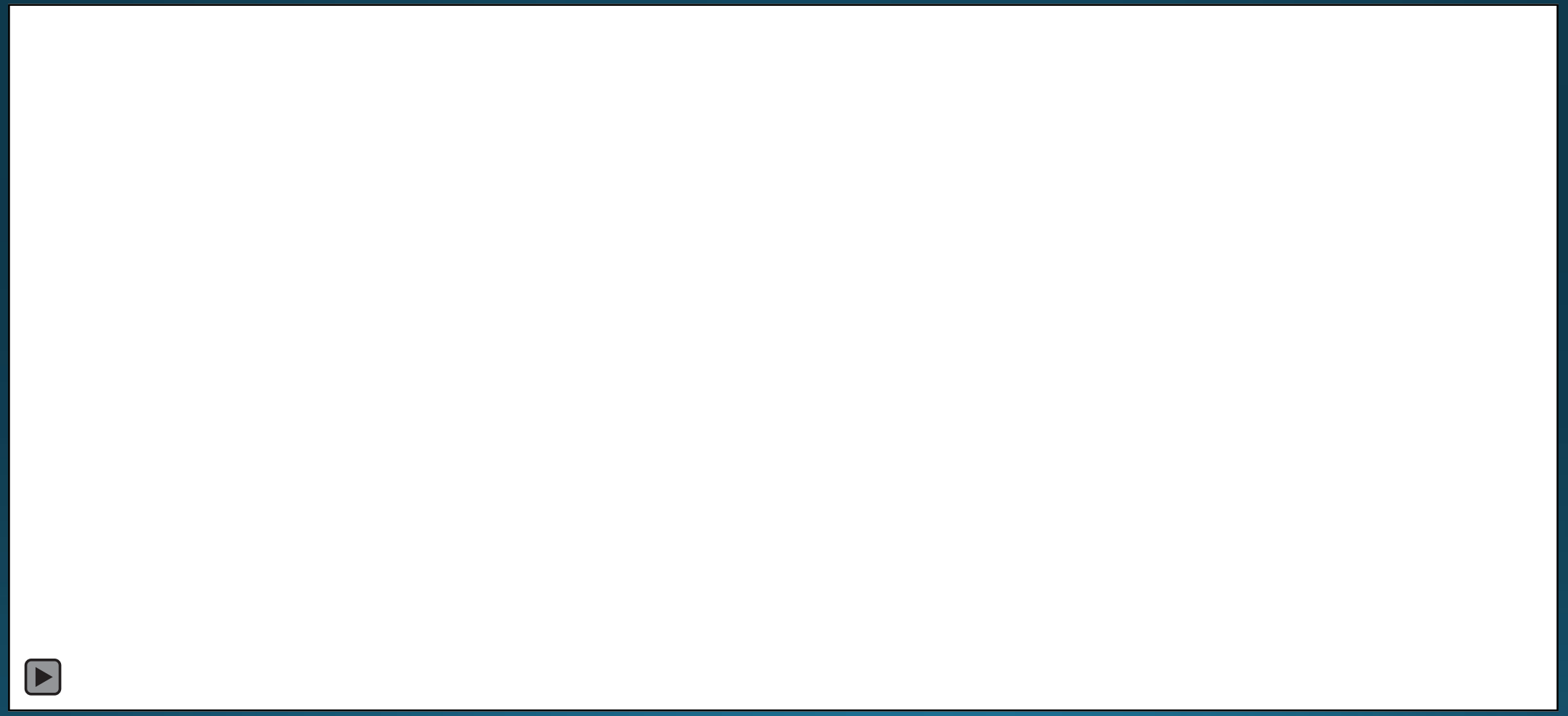
Leica MS60





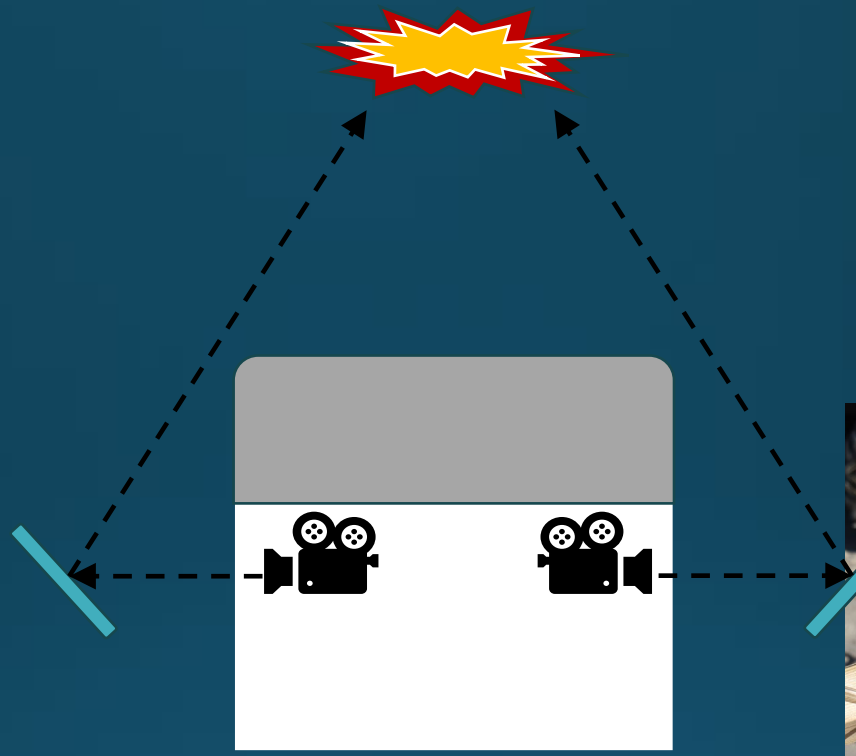
- Leica MS60 can survey and laser scan the arena
- Re-sectioning (×3) retro points are needed for moving the Leica to different locations in the arena. These need to be surveyed in for each test series.
- KEY POINT: Surveying allows the exact Polar Zones to be known relative to the bundles and the Fragment tracking systems

Overview Camera



Digital Image Correlation

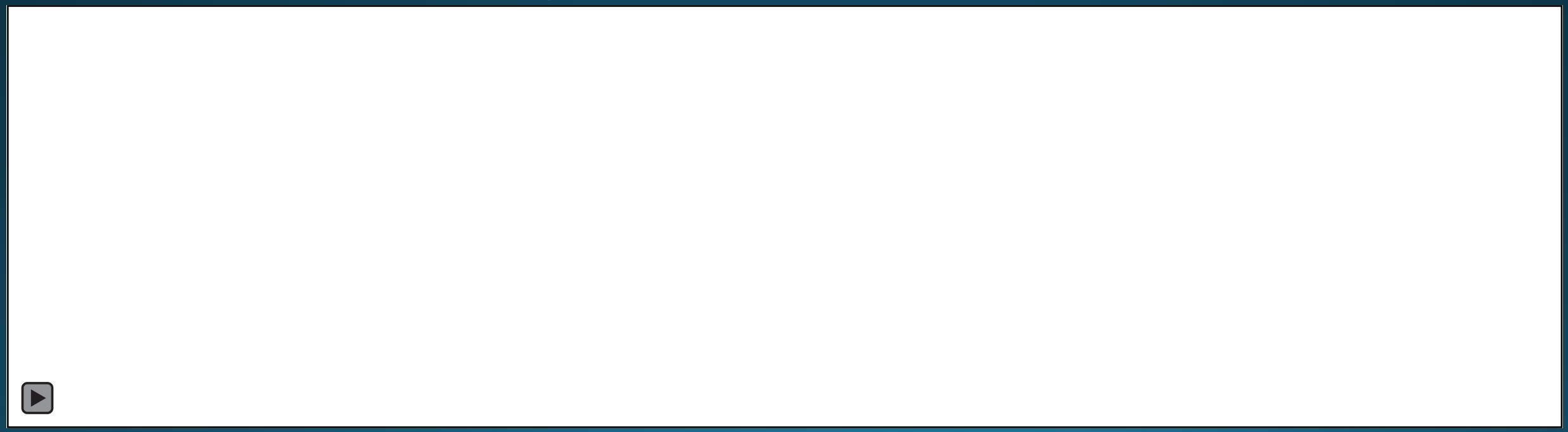
DIC Setup



- Turning mirrors to view the bomb
- Argon flash bulbs for lighting – Megasun capacitor banks
  - ~700 msec of good light
- Used two Phantom TMX7510 camera.
  - >200,000 fps
- Timing/Triggering
  - Tight time constraints

DIC Data

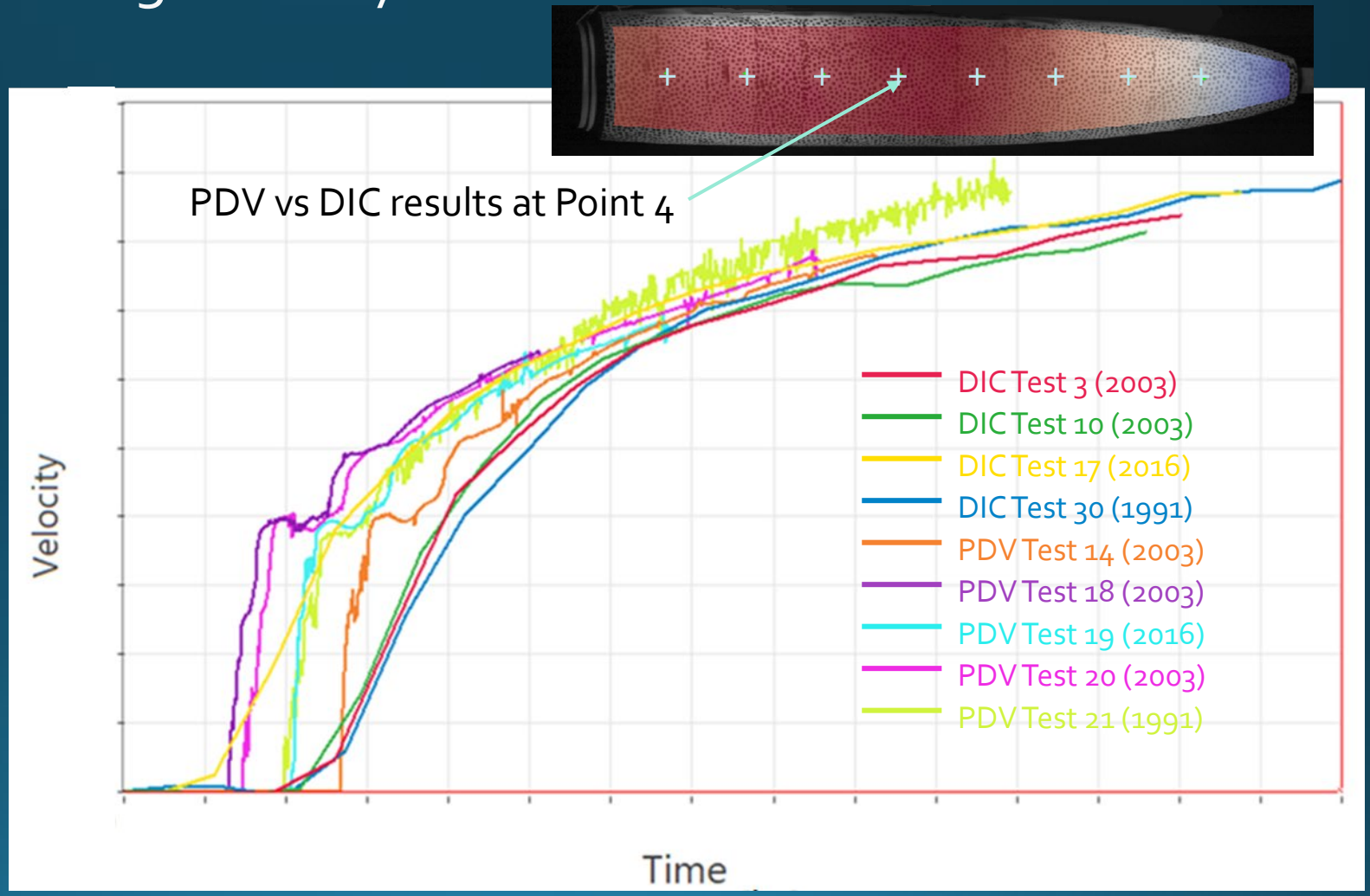
- Calibration required – measurement verification suggested
- Computed test data
  - Case Displacement (strain), Velocity, Acceleration
  - Detonation Velocity



Photonic Doppler Velocimetry (PDV)

- Used on a subset of testing to verify DIC results

- Uses the Doppler shift in a laser beam to measure the velocity of the reflecting surface.
- Multiple fiber ends were placed in a test rig along the bomb surface
- A laser power system and oscilloscope are used to measure the surface motion during detonation.



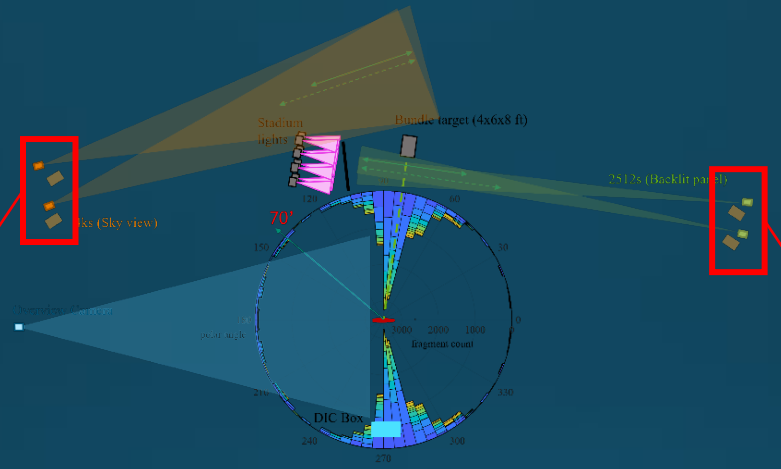
Fragment Tracking Cameras

Fragment Tracking Cameras - Setup photos

Narrow stereo system 1

Wide view system 2

Fragment Tracking Example Results

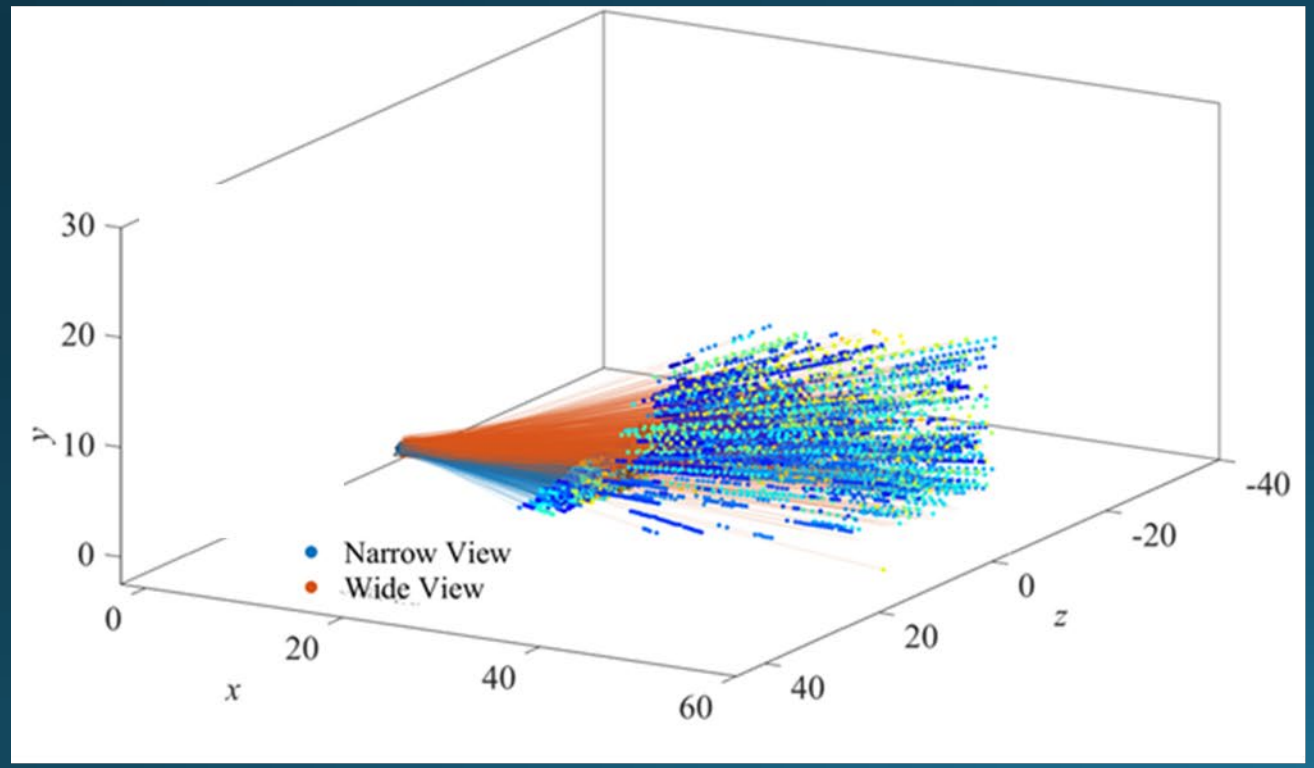


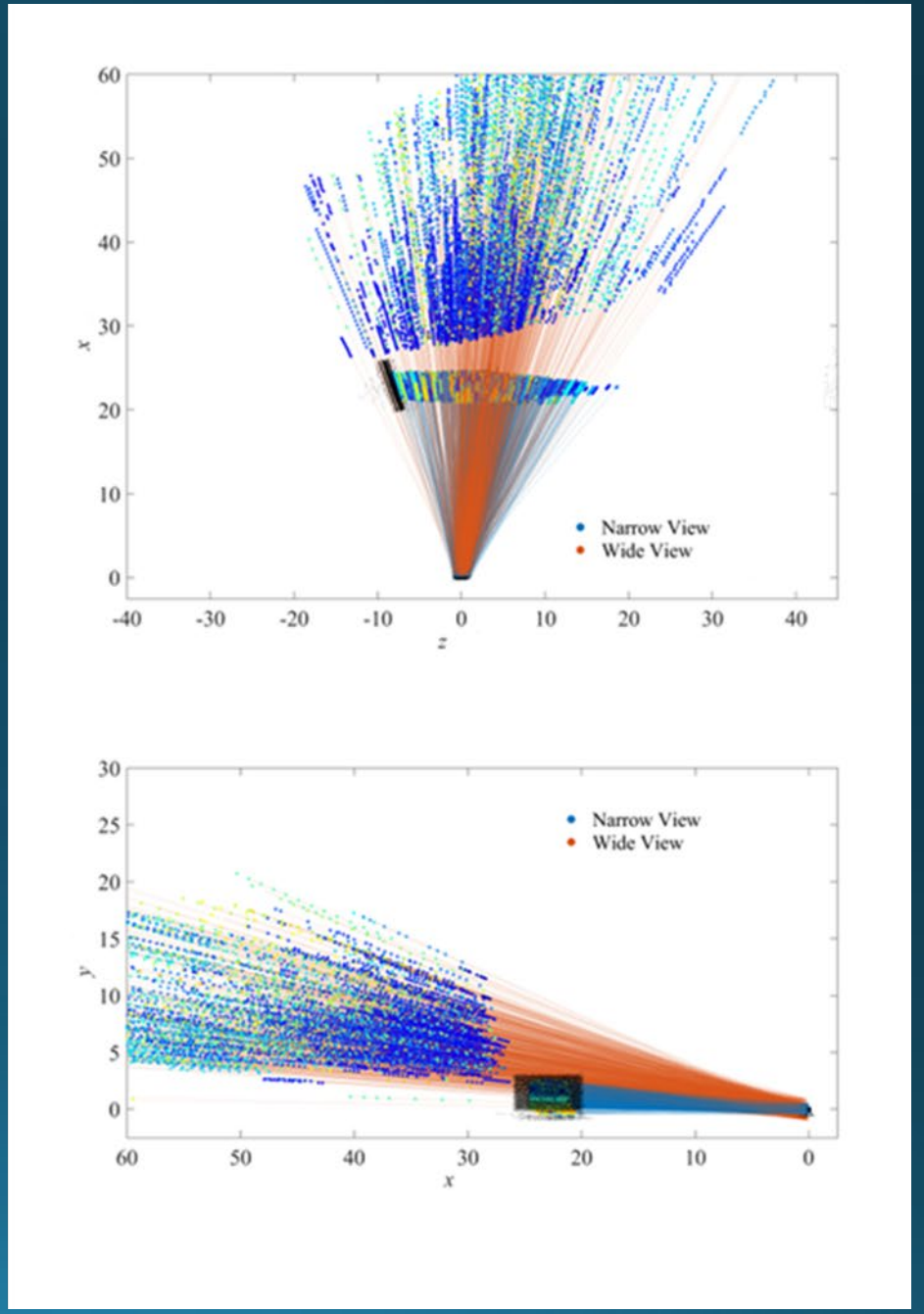
Wide FOV Results

Narrow FOV Results

Trajectory Analysis

Data from all tests of one particular lot overlaid

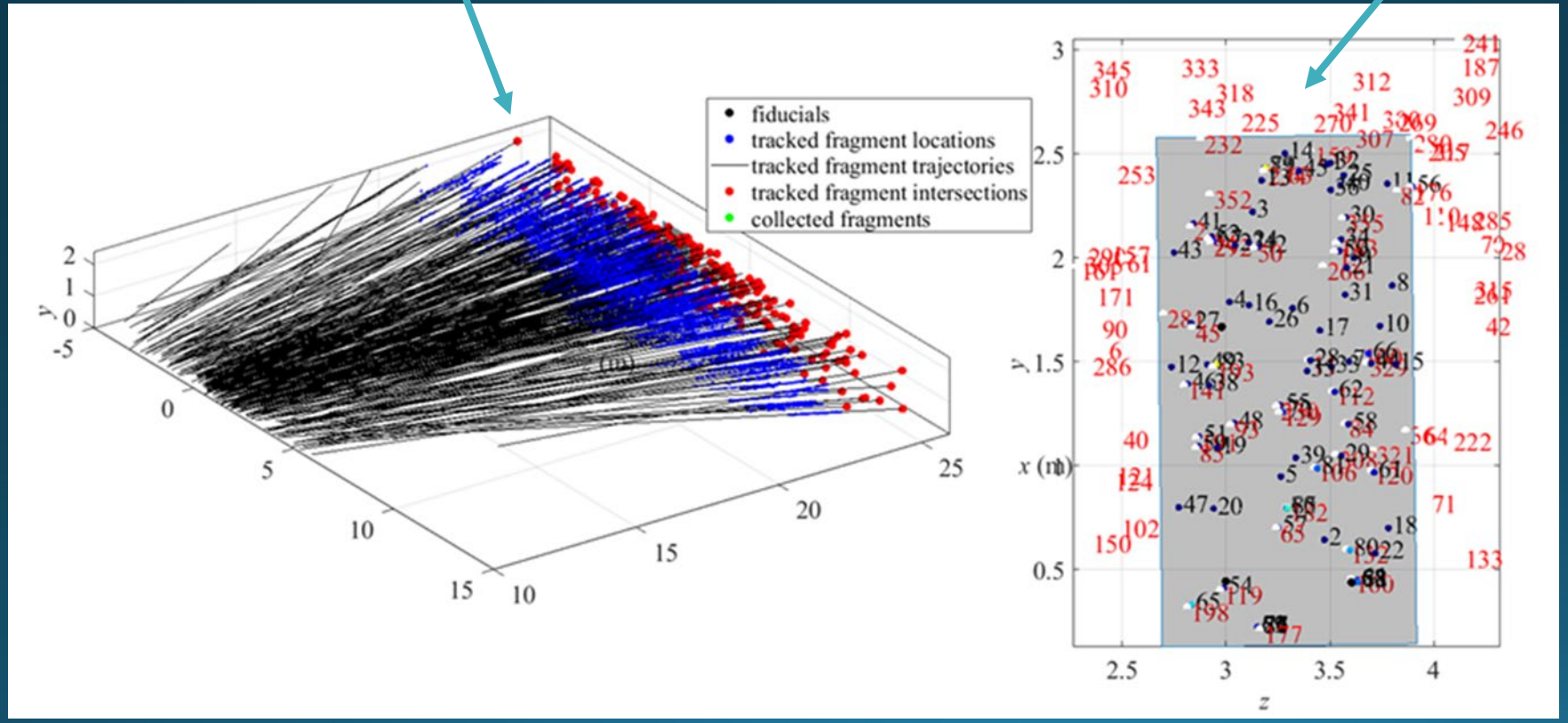




Trajectory Analysis

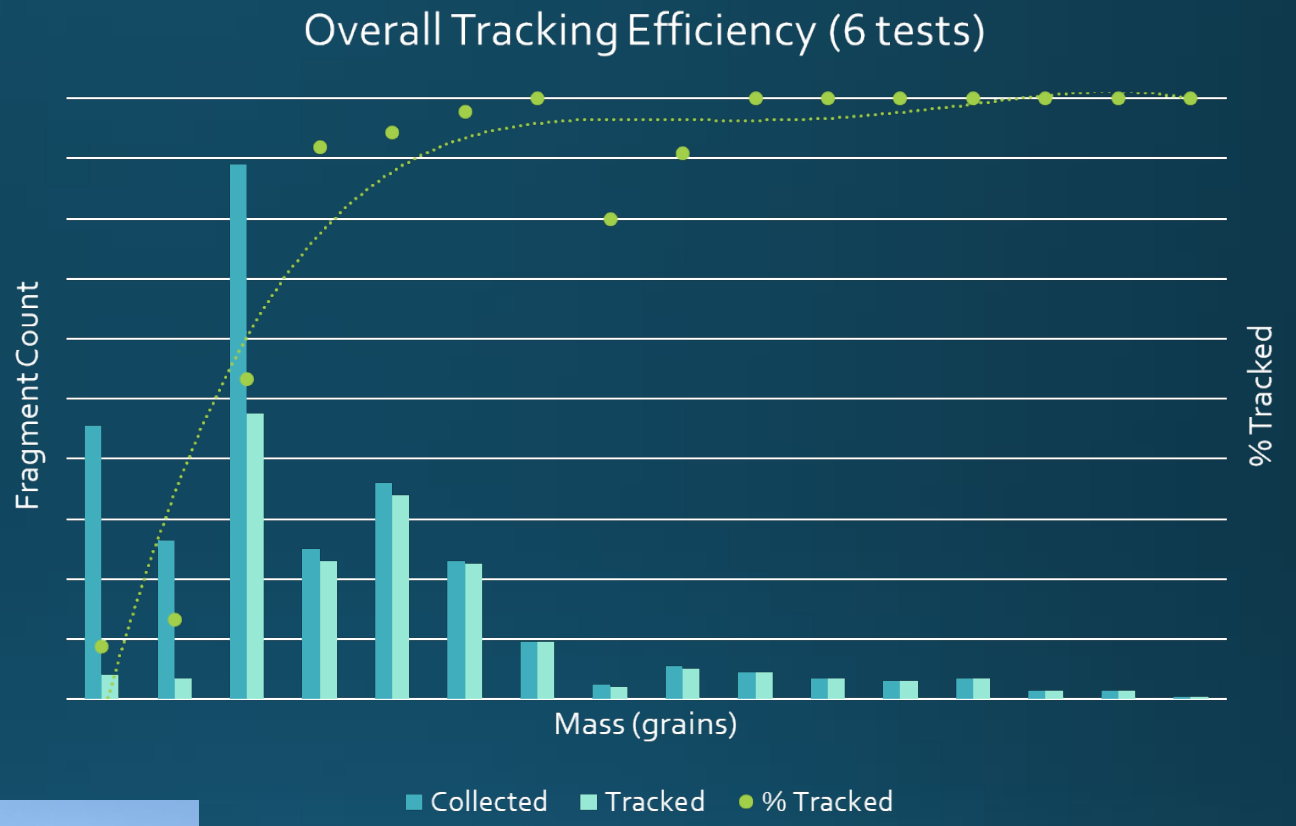
Trajectories fit to optical tracks to identify intersection points with the bundle

Soft catch collected and optical track intersections overlaid to identify matches

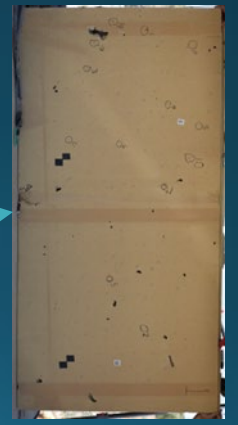


Tracking Efficiency

- Nearly 100% tracking efficiency over a certain size
  - 2 larger missed fragments due to fragment overlap and possible ricochet
- Over 90 % tracking efficiency for very small fragments
- Drop off in tracking efficiency to nearly no fragments tracked for fragments that are extremely small

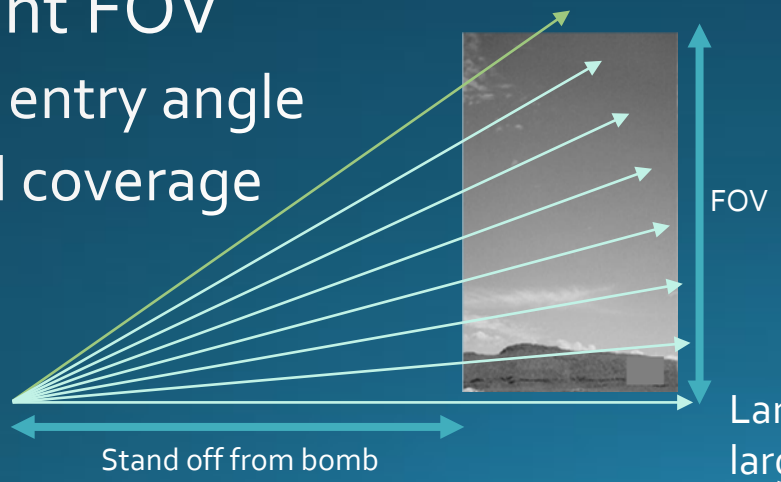


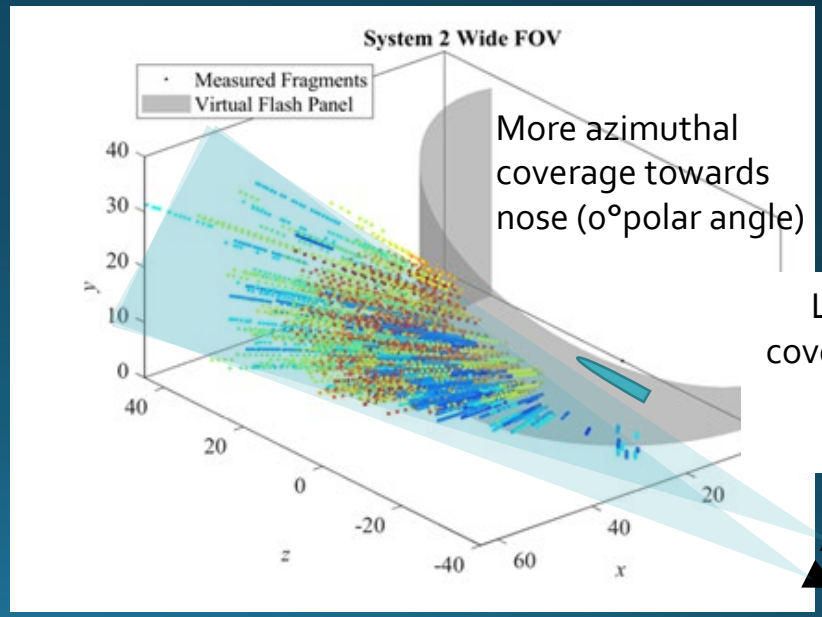
Bundle deconstructed in field



Fragment Tracking Issues/Errors

- Overall accuracy affected by camera setup and configuration
- Very small fragments are hard to track
- Deficiencies in background can make it difficult to track fragments
  - Sky (clouds), contrast at higher elevation LOS, fiducials
- Test to test variation
  - Focus, Aperture, Exposure
- Measurement FOV
  - Fragment entry angle
  - Azimuthal coverage



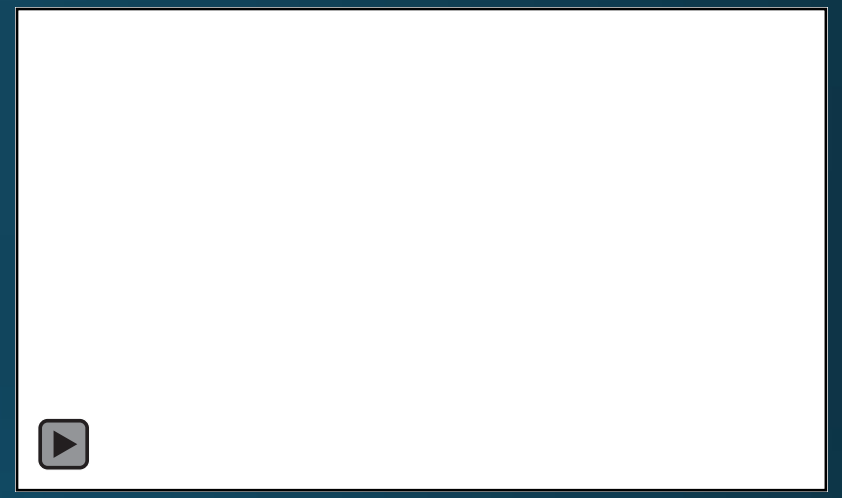


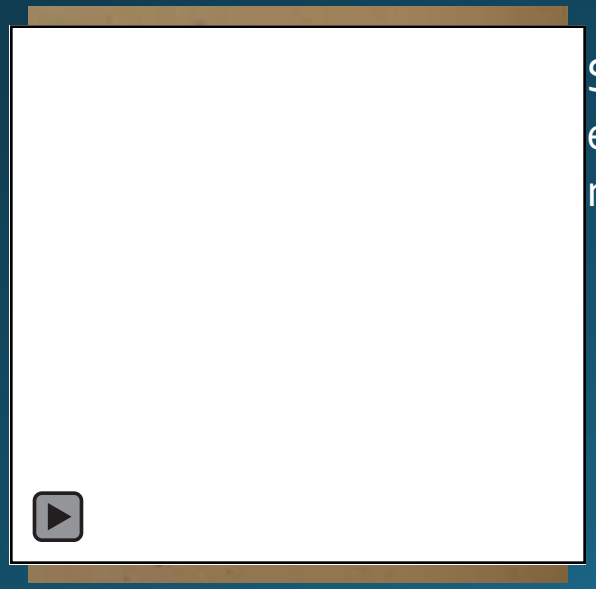
Large change in azimuthal coverage due to relatively large FOV to standoff ratio.

Detonation Phenomena

- "Unzipping" – material specific
  - Observed in the DIC and Fragment Tracking data
- Fragment Breakup

Large high aspect ratio enters bundle



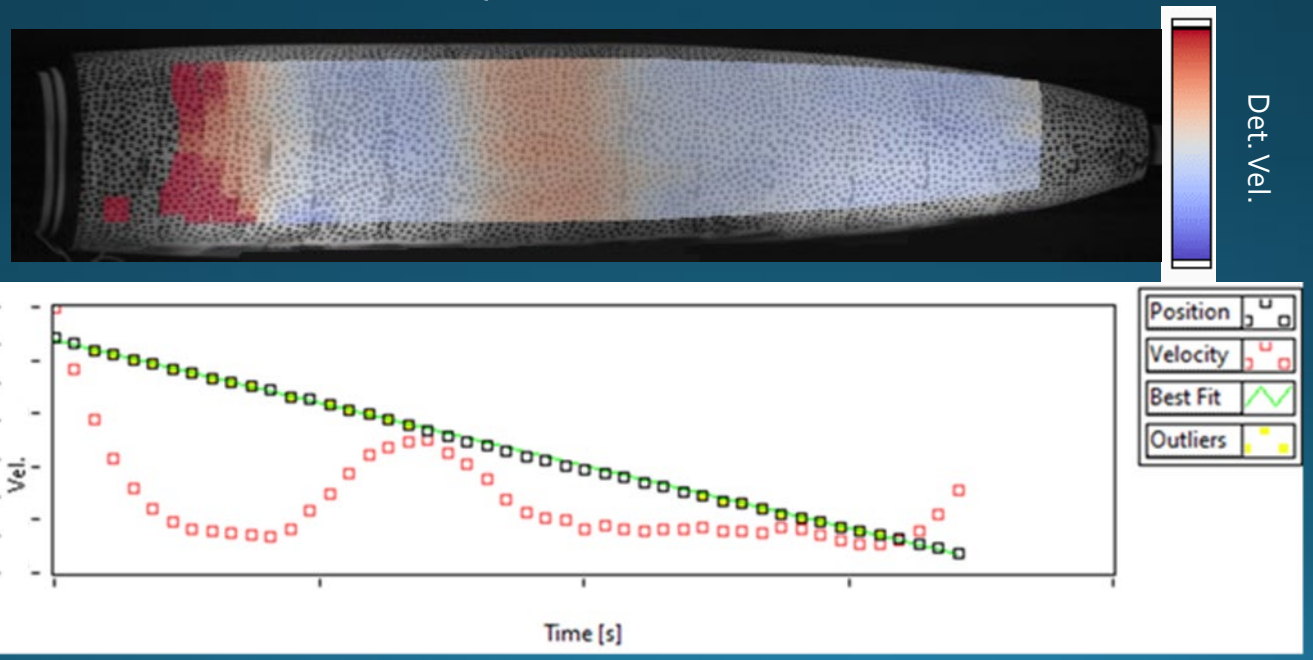


Single fragment entry separates into multiple burrows

4 fragments recovered from single entry

Detonation Phenomena

- Effect of the charging tube and other voids in the explosive fill
  - Tube connecting the FZU from the middle of the munition to the fuze
    - Provides electrical power
  - Cable not present for some of the tests
    - Caused "jetting" that changed the detonation velocity and the frag trajectories
      - Proof that small variations in performance are detectable



Summary

- Benefits of moving to optical-tracking test methods
  - Faster Test Rate: 3-4 tests/week
    - Cost/test is significantly cheaper; ~10x cheaper after initial investment in cameras
      - Lifecycle cost savings
    - Data-informed Aging/Surveillance test programs are now feasible
      - Service life assessments
      - Subtle differences are detectable
  - Increased insight → Increased safety
    - Planning tools and models are not always accurate (TP-16).
    - Storage and handling implications
  - Improvements in modeling
    - Applications in weaponeering – better data set (possibility 3D Z-Data files)
    - Munition development
      - Potential for shorter (and cheaper) development cycle

Questions?

- Special Thanks to
  - Dr. Phillip Reu – Sandia National Laboratories
  - Dr. Elise Hall – Sandia National Laboratories

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