SAND2017-9884C

Shock Thermodynamics Applied Research

Ring Fragmentation

Bill Reinhart & Scott Alexander

68th Aeroballistic Range Association

Monterey, California

September 17th – 22nd, 2017

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525

Overall Programmatic Goals

Multi-Laboratory effort to understand the physics of material fragmentation and to benchmark hydrocodes

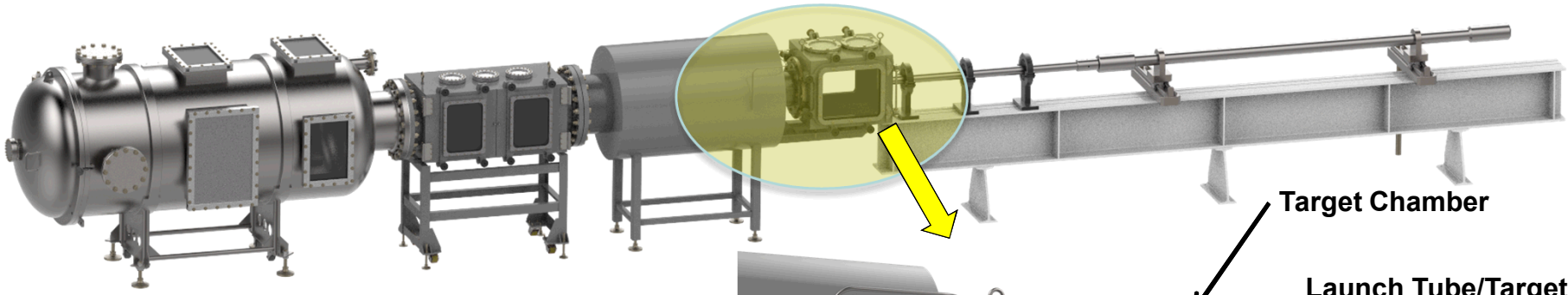
- Investigate failure and fragmentation of metals
- Provide fully predictive capability for fracture properties of materials
- Testing to provide strain rate dependent strain-to-failure data

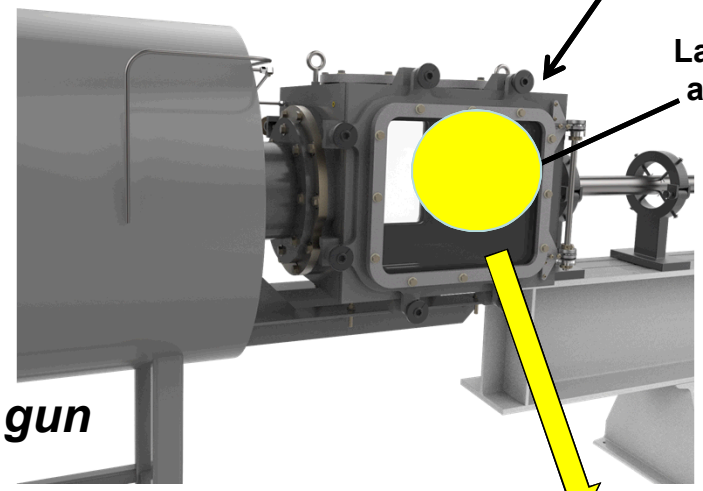
Implement test methodology at higher stress states than previous gun-launched tests

- Rings expanded via expansion of confined polymer
  - Gun launched cylinder impacting stationary cylinder inside metallic tube
- Each individual ring will have unique strain-strain rates
- Large number of statistical observations are obtained in a single experiment
- Complementarity experiments for fragment recovery
  - statistical distribution associated with the fragmentation process and failure mechanisms

Ultimate goal is to provide high precision data, at higher stress states, for calibrating current fracture models

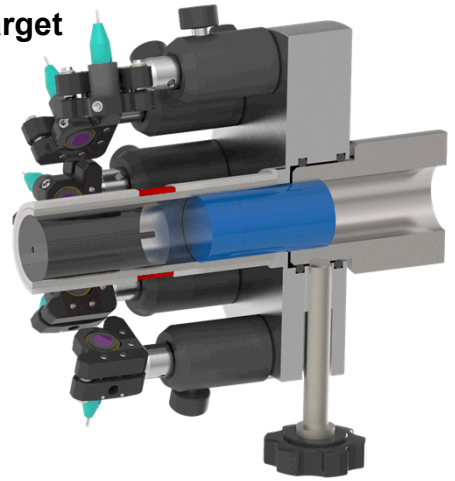
Facility: Terminal Ballistic Facility



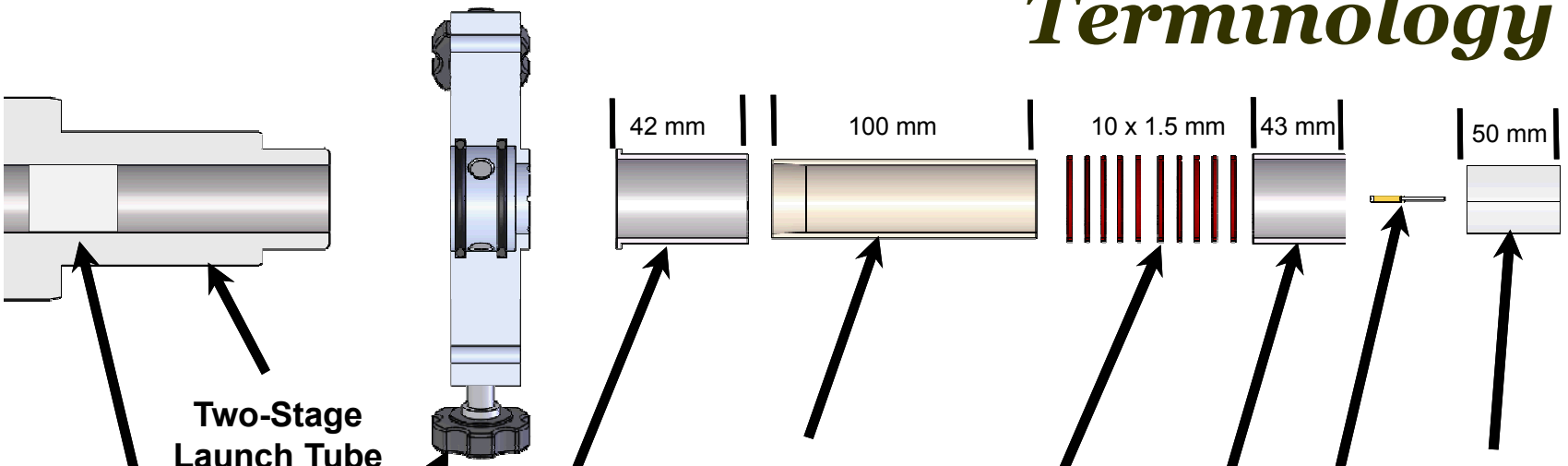


Two stage, smooth bore, light gas gun
Helium drive gas
25 mm bore diameter
1.8 m length
30 gm projectile mass
2 km/s (5GPa impact pressure)

Launch Tube/Target assembly



Ring Expansion Configuration: Terminology



Two-Stage Launch Tube
(25 mm Bore)

Projectile
Nominal Dimensions
OD: 25 mm
Length: 50 mm
Mat: Polycarbonate

Muzzle Cap
(Instrumentation Mount)

Outer Cylinder #1:
Nominal Dimensions
OD: 33.9 mm
Wall: 2.3 mm
Length: 41.7 mm
Mat: SS2169

Inner Sleeve:
Nominal Dimensions
OD: 29.5 mm
Wall: 2.0 mm
Mat: SS2169, SS304L

Rings (10)
Nominal Dimensions
OD: 32.5 mm
ID: 29.5 mm
Width: 1.5 mm
Mat: Al6061, SS304L, SS2169

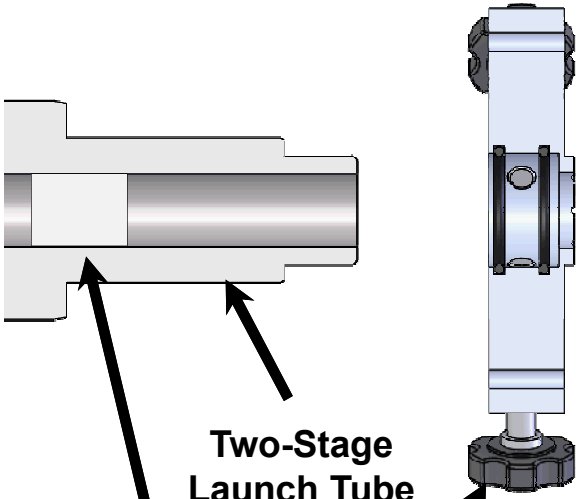
Outer Cylinder #2:
Nominal Dimensions
OD: 33.9 mm
Wall: 2.3 mm
Length: 43.3 mm
Mat: SS2169

Projectile Motion PDV (Het-V) Probe
AC Photonics collimator

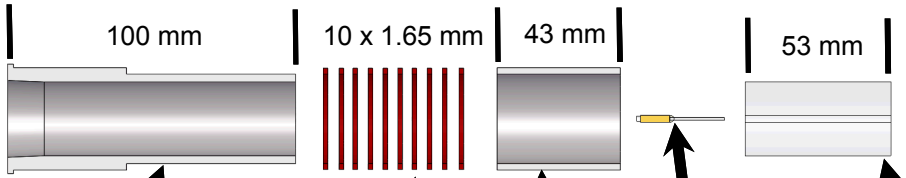
Infill
Nominal Dimensions
OD: 25 mm
Length: 50 mm
Mat: Polycarbonate

Total target length ~ 100 mm

Ring Expansion: Updated Configuration



Two-Stage Launch Tube
(25 mm Bore)



Sleeve:
Nominal Dimensions
OD: 30.89 mm
Wall: 2.71 mm
Mat: AreMet 100

Infill
Nominal Dimensions
OD: 25.4 mm
Length: 50.75 mm
Mat: Polycarbonate

Projectile Motion
PDV (Het-V) Probe
AC Photonics collimator

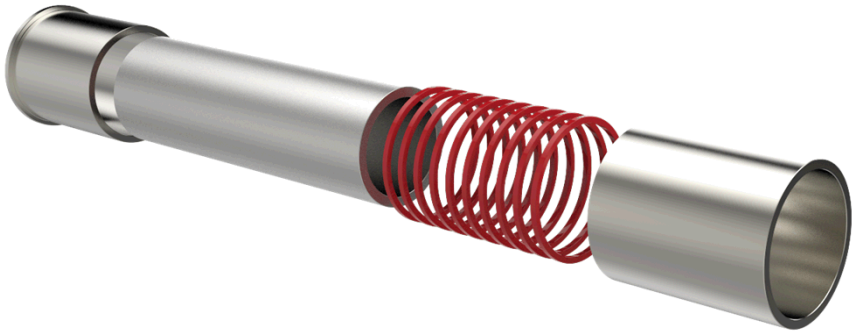
Muzzle Cap
(Instrumentation Mount)

Rings (10)
Nominal Dimensions
OD: 34.91 mm
ID: 30.92 mm
Width: 1.65 mm
Mat: Al6061, SS304L, SS2169, Tantalum

Outer Cylinder:
Nominal Dimensions
OD: 35.31 mm
ID: 30.92 mm
Wall: 2.18 mm
Length: 43.3 mm
Mat: AreMet 100

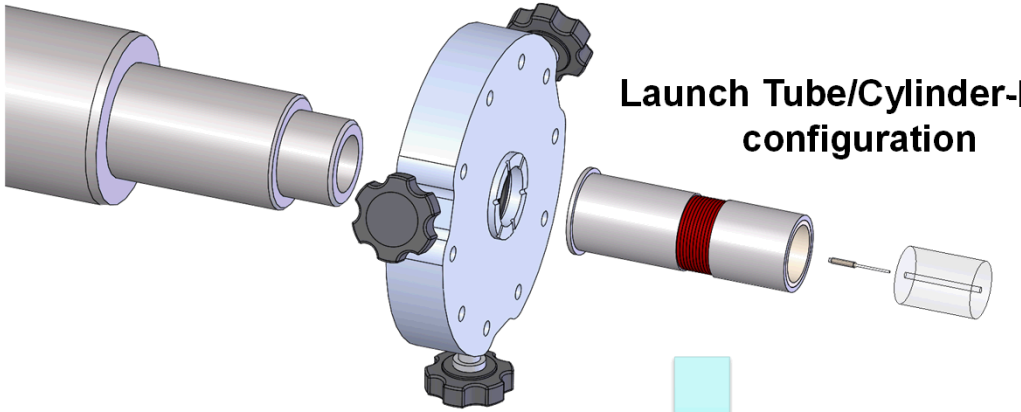
Total target length ~ 100 mm

Assembly



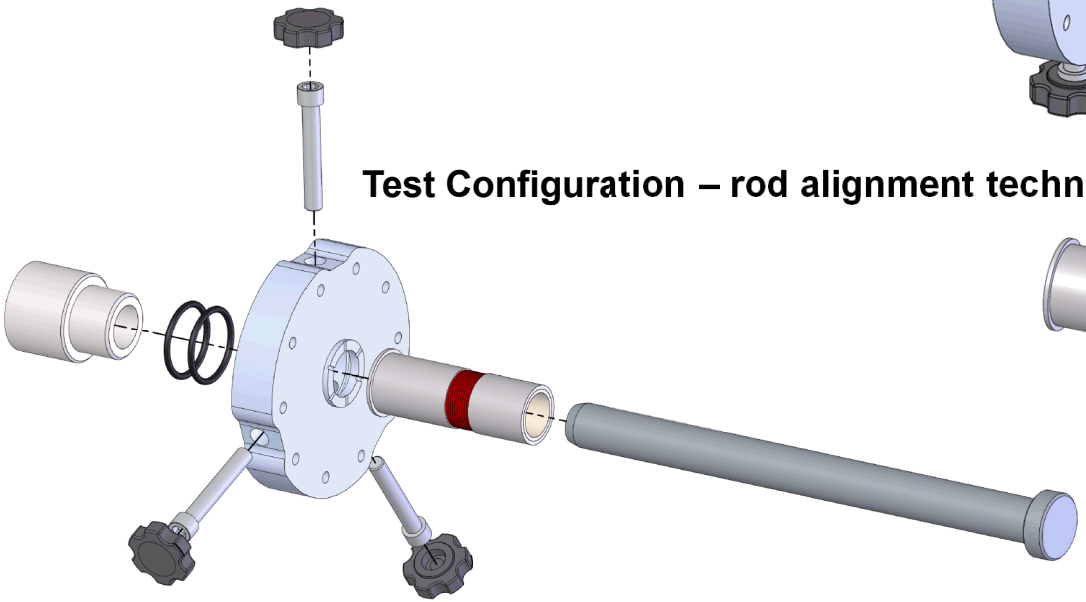
Experimental Test Setup/Alignment:

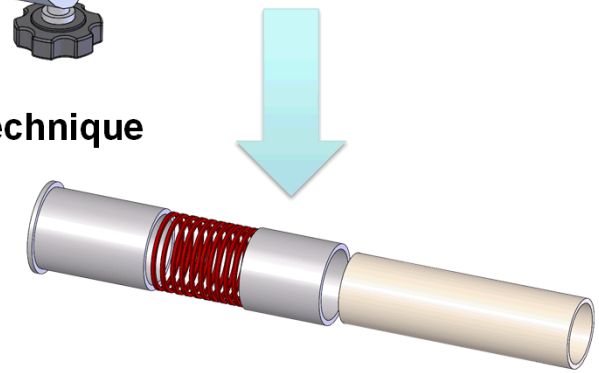
- ***Tube, infill, rings on instrumentation Cap***
  - *Precision Alignment rod*



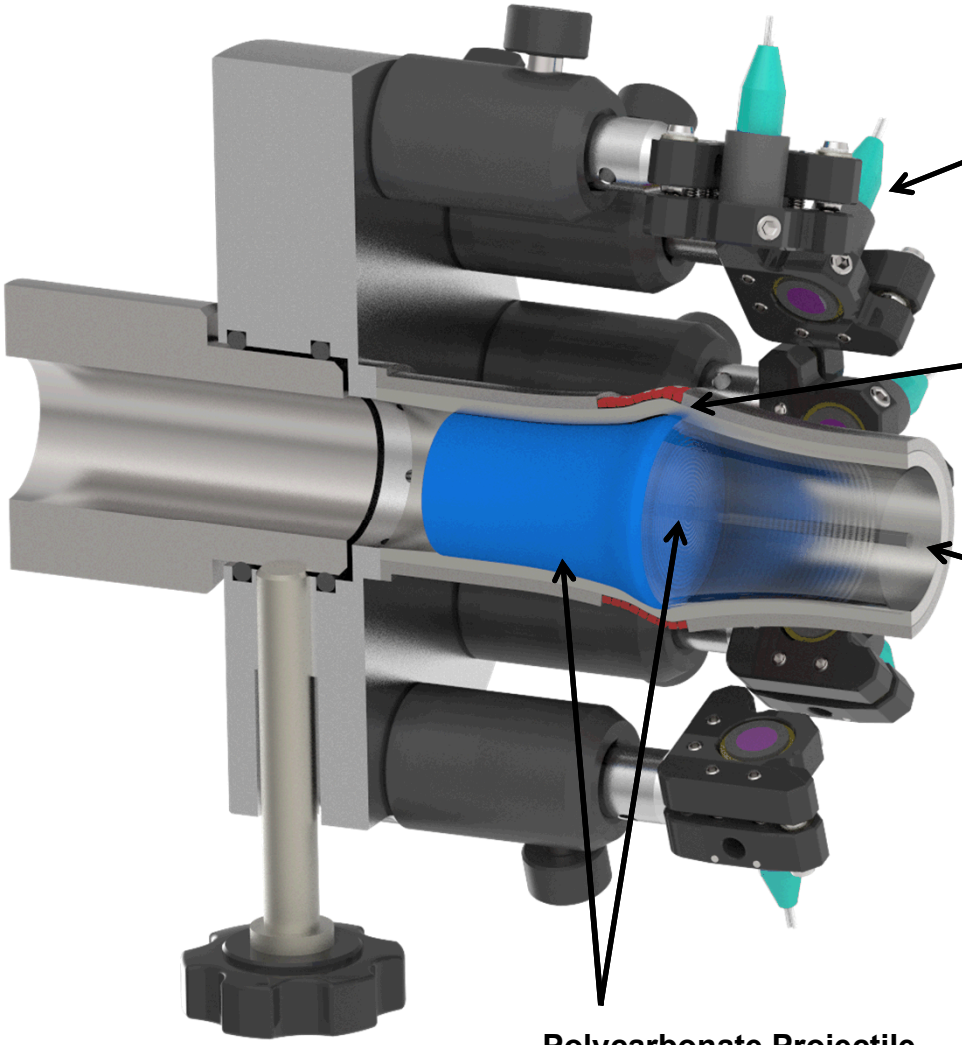
Launch Tube/Cylinder-Ring configuration

Test Configuration – rod alignment technique





Experimental Approach

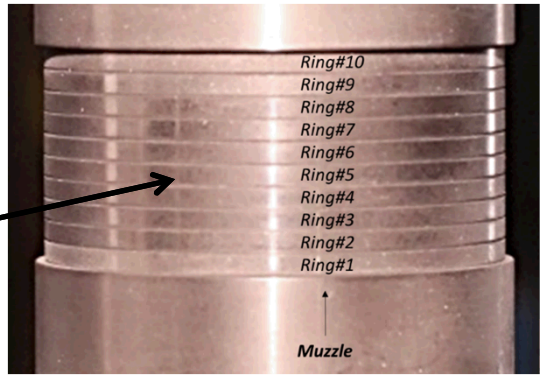


VISAR and HetV (PDV)

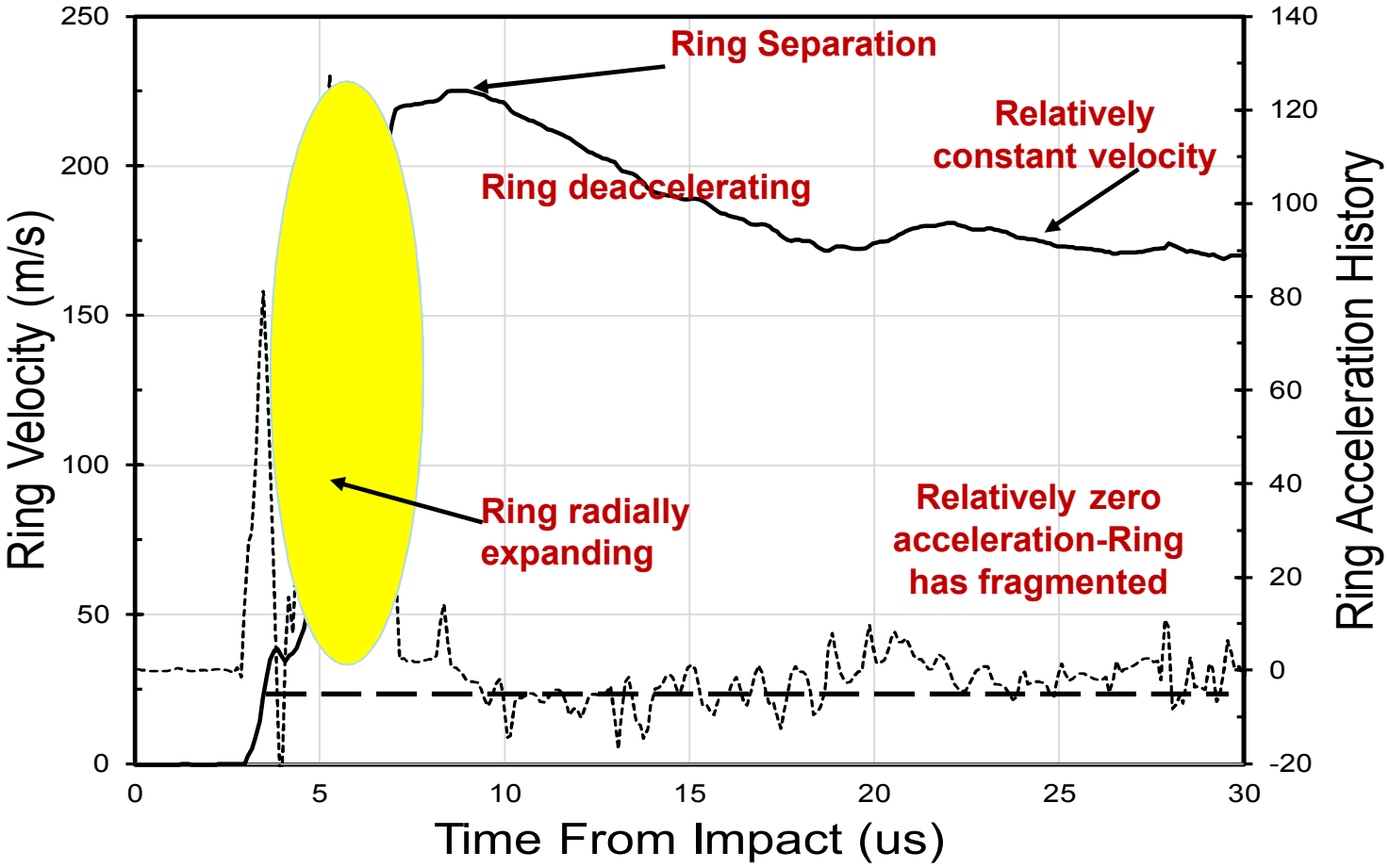
well controlled and repeatable loading conditions allows uniform symmetric expansion of thin rings at high strain rates

Accurate projectile velocity and impact time measurements from HetV (PDV) probe

Polycarbonate Projectile Impacts stationary infill on (polycarbonate). Impact at Ring 5 on all tests



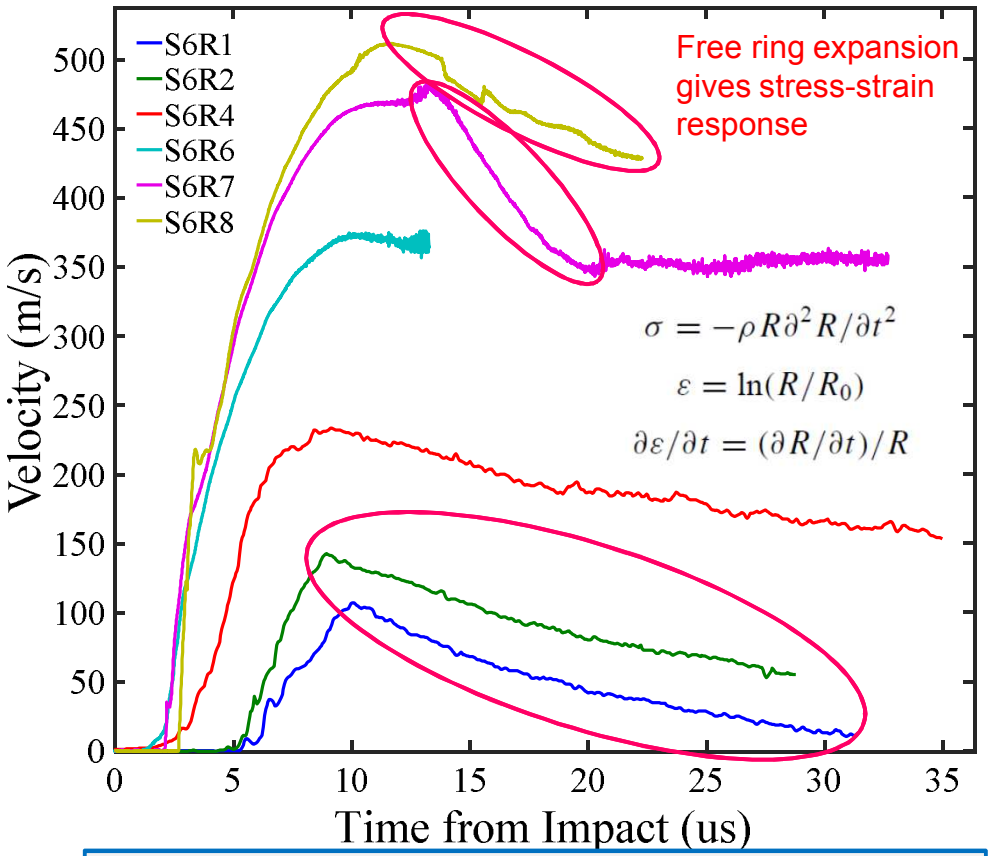
(S2R4)

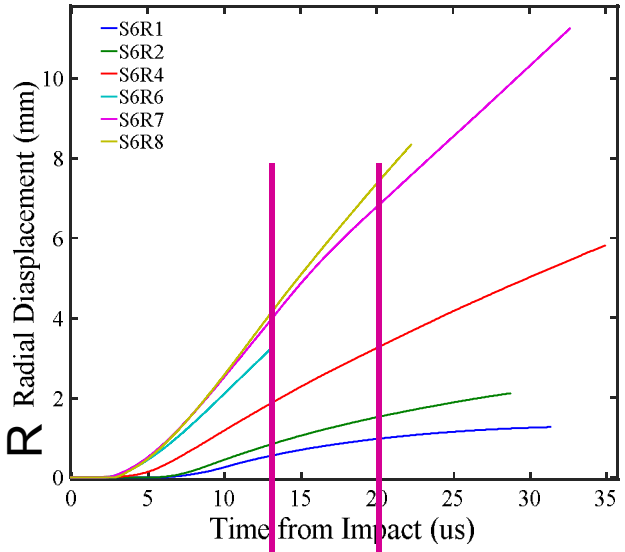


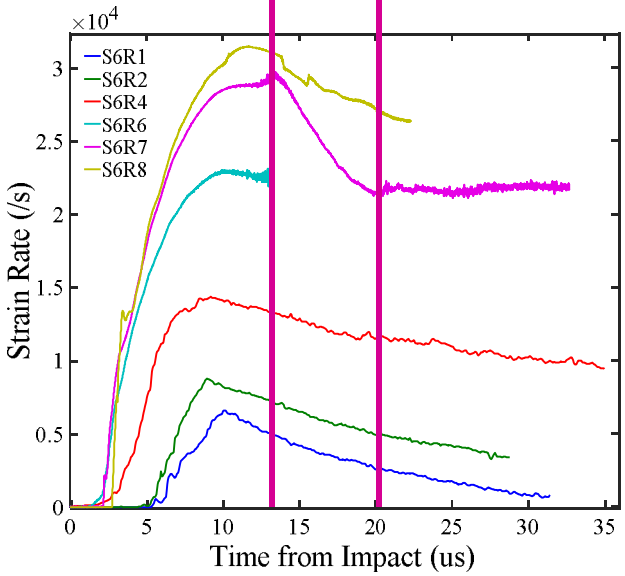
Velocity history of the ring is determined from time resolved interferometric measurements (PDV/VISAR) of the motion at one point on each ring. Free flight of the test ring is allowed through onset of fracture and fragmentation.
Ring accelerates and separates from inner sleeve, continues to expand from its own inertia, deaccelerates by radial component of hoop stresses. Wave profiles from each ring provide accurate determination of:

- region of ring separation
- measured deceleration of the expanding ring prior to fragmentation
  - Used to calculate tensile flow stress
- % of expansion at failure and velocity at failure
- strain rate dependent strain-to-failure data

Velocimetry data indicate deformation at a range of strain rates

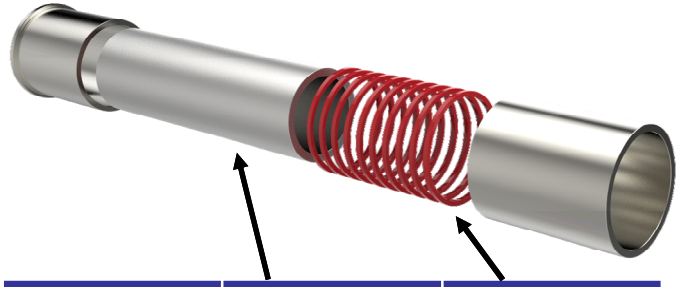




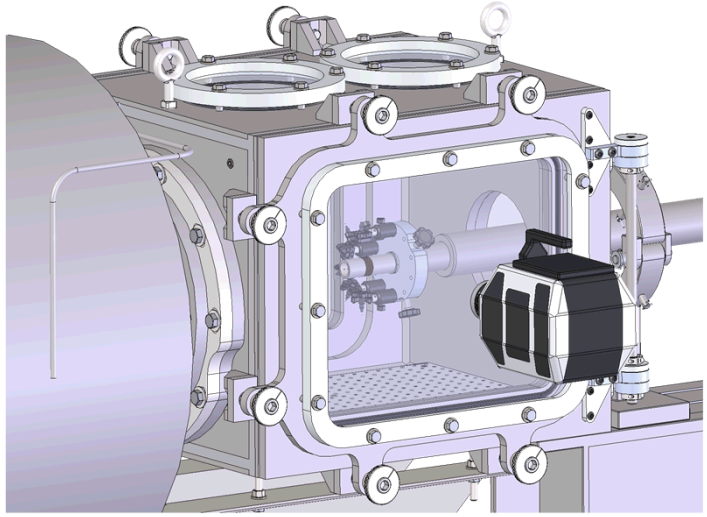


- Motion is tracked over 12-35 mm of radial displacement
- Strain rates up to 3 x10^4 s^{-1}
- Some indication of ring failure in high numbered rings
- Low numbered rings show deformation but not failure

The whole shebang: fully integrated test combines velocimetry and high speed video

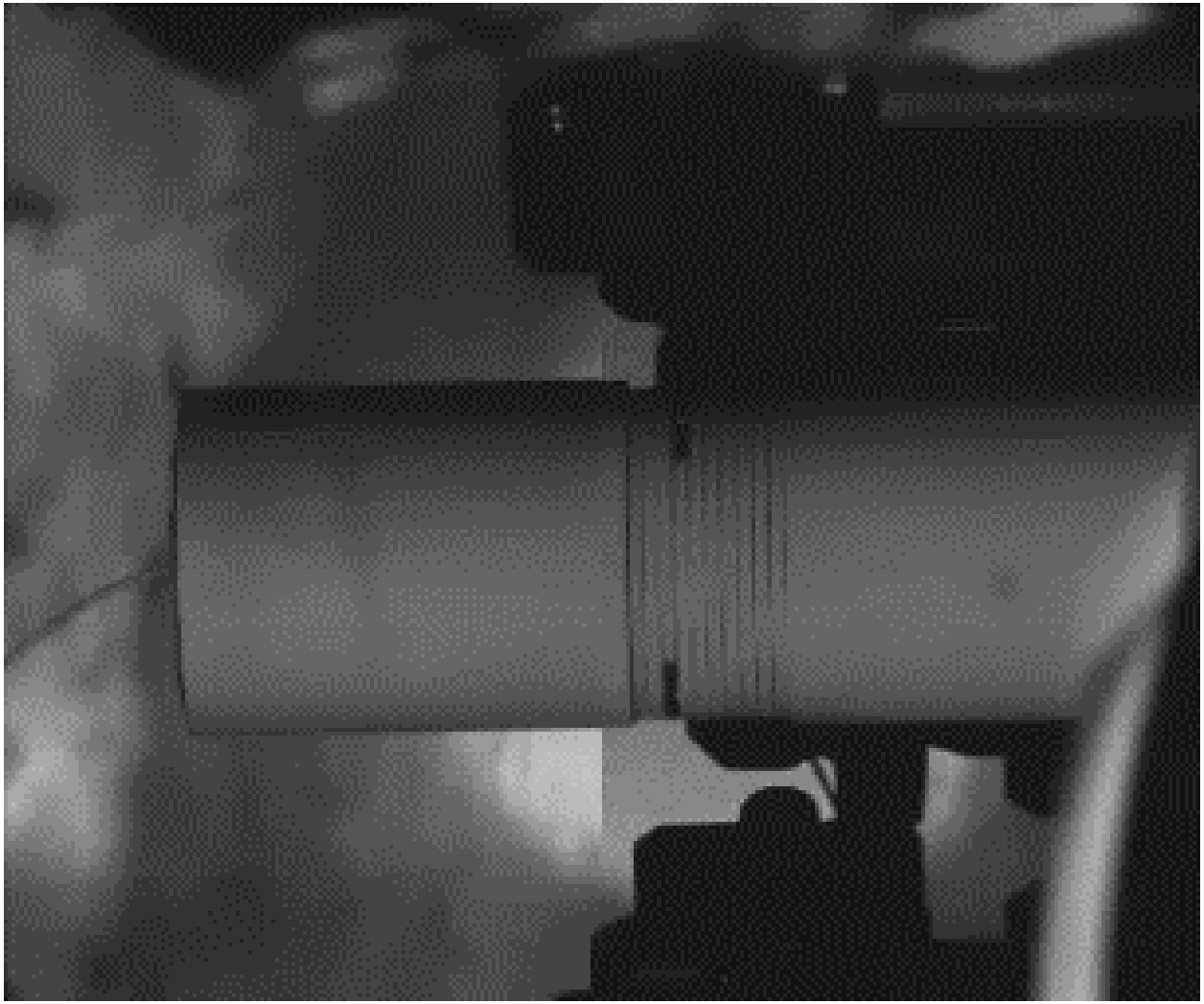


	Inner Sleeve	Rings
Shot 6	SS 304	SS 304



- Goal of this test was to confirm capability to conduct a fully integrated test
  - Simultaneous velocimetry and photography
- Rings and inner sleeve were 304 stainless steel

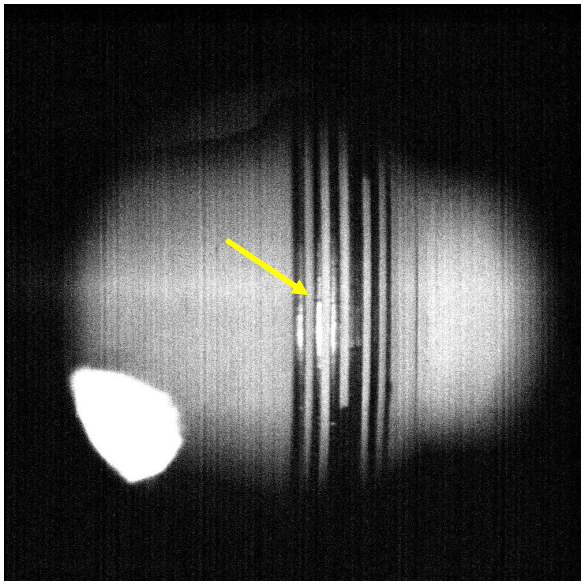
Failure of inner sleeve and rings is evident in high speed video



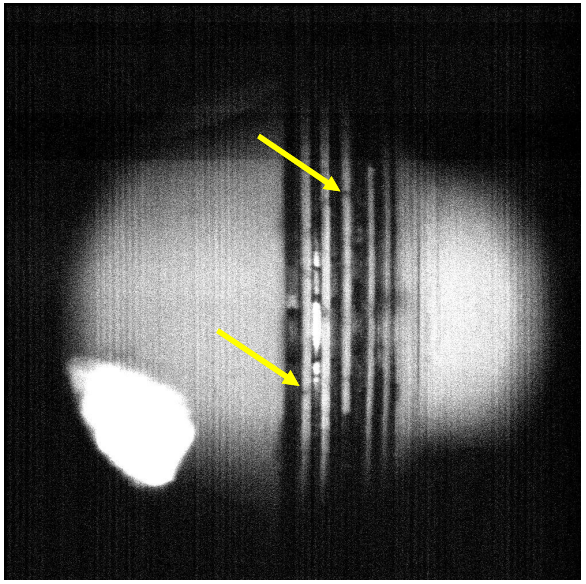
impact

cracking of sleeve and rings

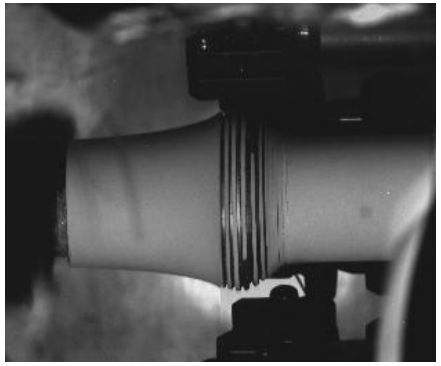
High resolution Cordin images indicate onset of failure in sleeve and rings



Cracks evident in inner sleeve
19 us after impact

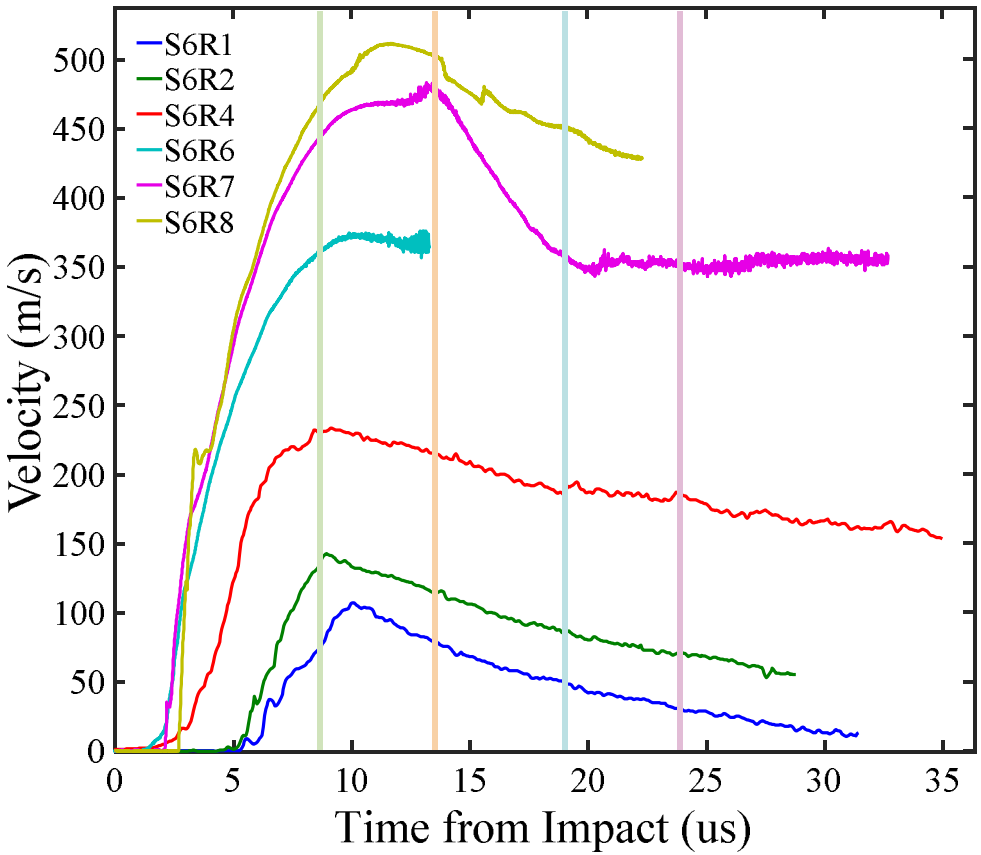


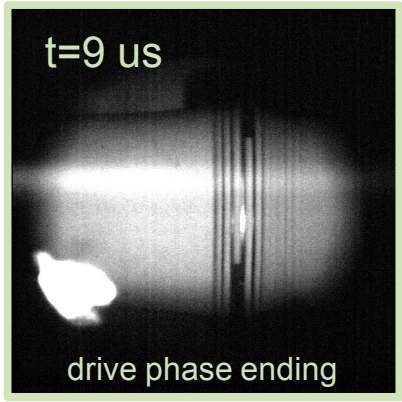
Cracks evident in rings
24 us after impact

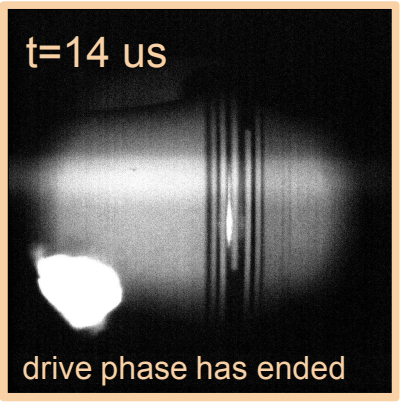


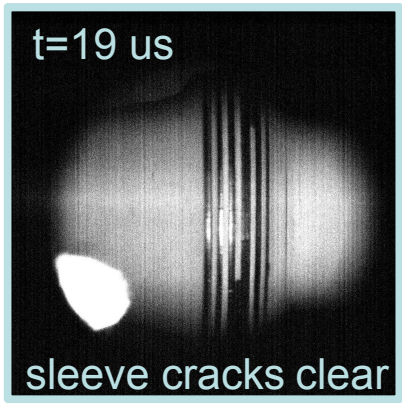
Recovered rings (1-4) and fragments

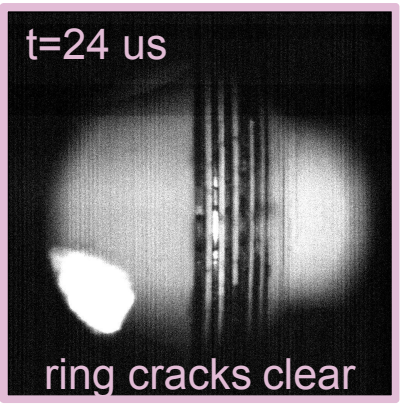
Experiments generate multiple data sets which will be used to calibrate failure models

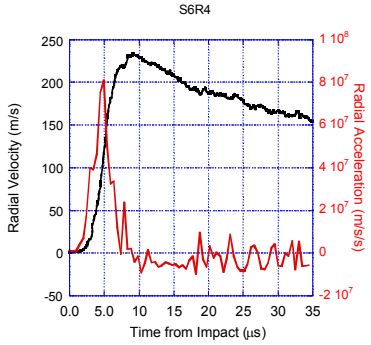


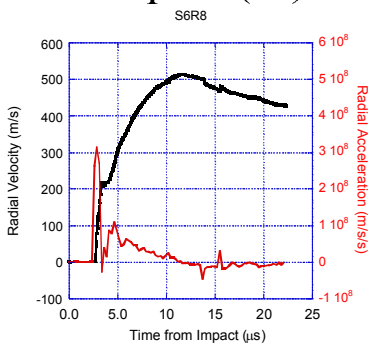








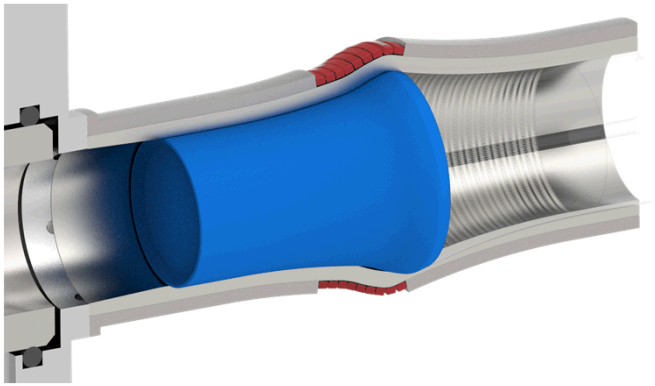


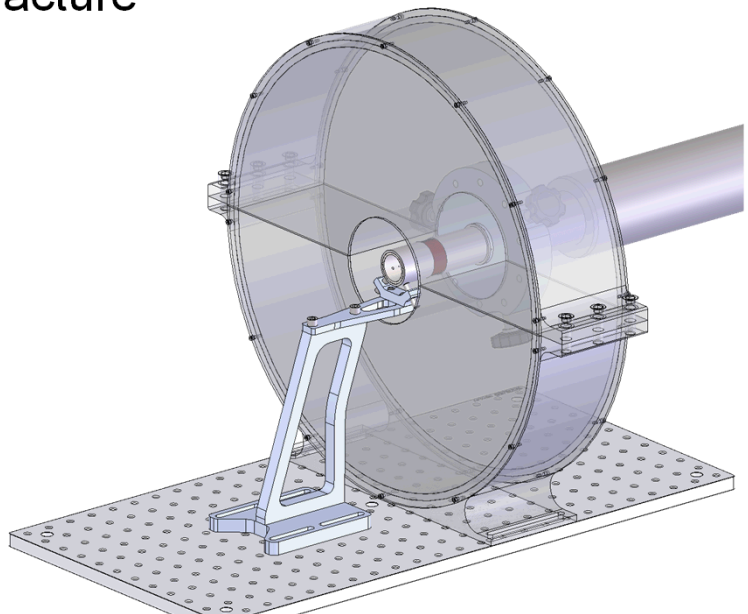


Time correlated combination of velocimetry and imagery provide a plethora of information to inform failure models at multiple strains and strain rates

Material and Recovery:

- Customer will need to supply additional information on the material
- Pre-test sample analysis (LANL)
  - Should know phase of material as results can vary significantly as the alpha (more ductile) phase will be significantly different than the gamma (more brittle) phase
  - Phase will be evident
- Post-Test: LANL will look at recovered fragments
  - Inspection of fragments will reveal necking regions which occurs through local deformation
    - failure in these materials proceeds first through deformation localization and ductile necking, and subsequently by extension fracture





Future:

- Should investigate different geometries of ‘material’ to observe the failure mechanisms
  - Are they different?