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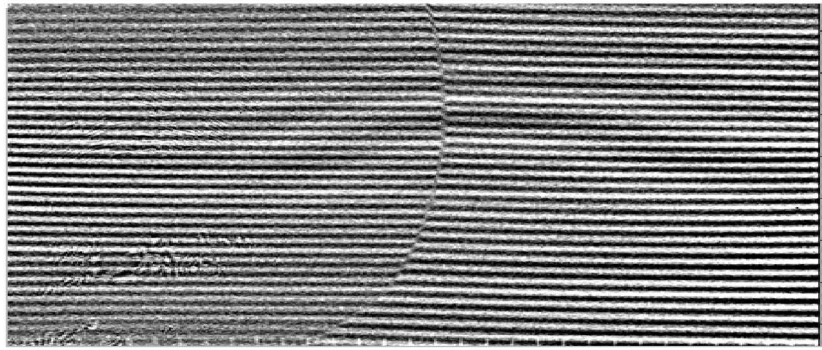

Z Line-VISAR: A Spatially Resolved Load Current Diagnostic at the Z Pulsed Power Facility

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The Z Line VISAR (ZLV) team is a collaboration between Sandia & LLNL.

ZLV commissioning PE & PD: Clayton Myers, Tom Awe and Mark Hess

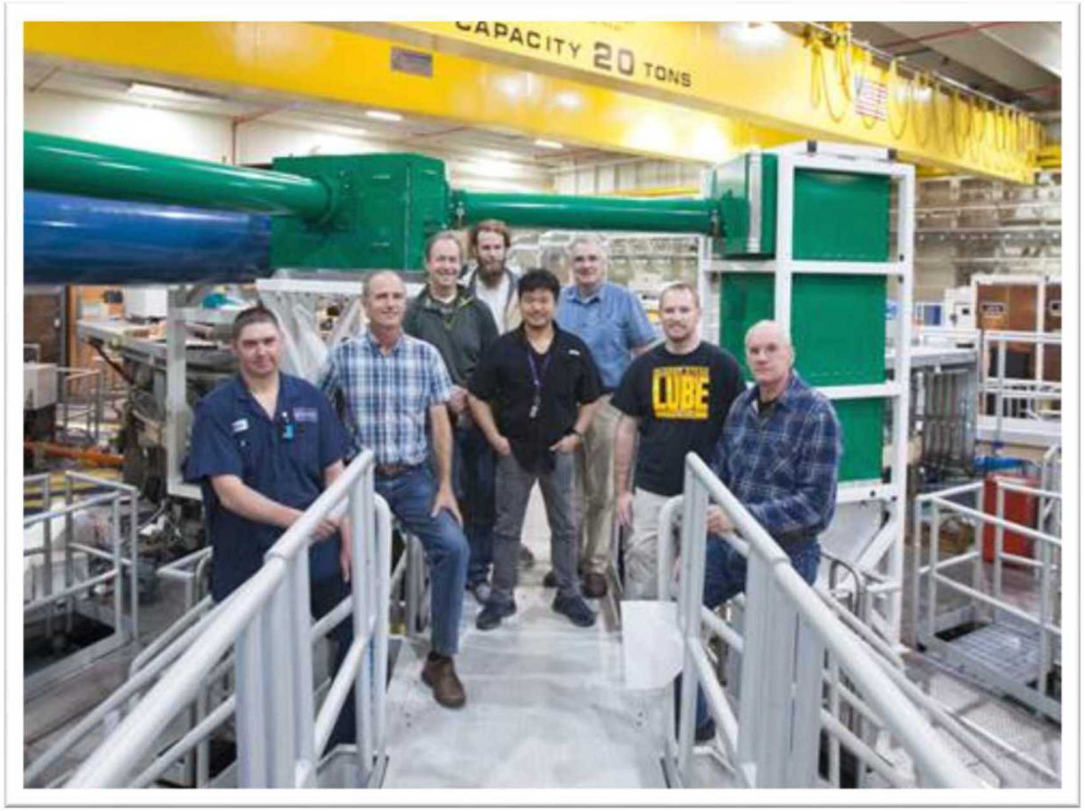
ZLV diagnostic scientists (SNL): Clayton Myers and Dave Bliss

ZLV instrument team (LLNL): Phil Datte, Gene Frieders, Gene Vergel de Dios, Tom McCarville, Michael Crosley, and many more

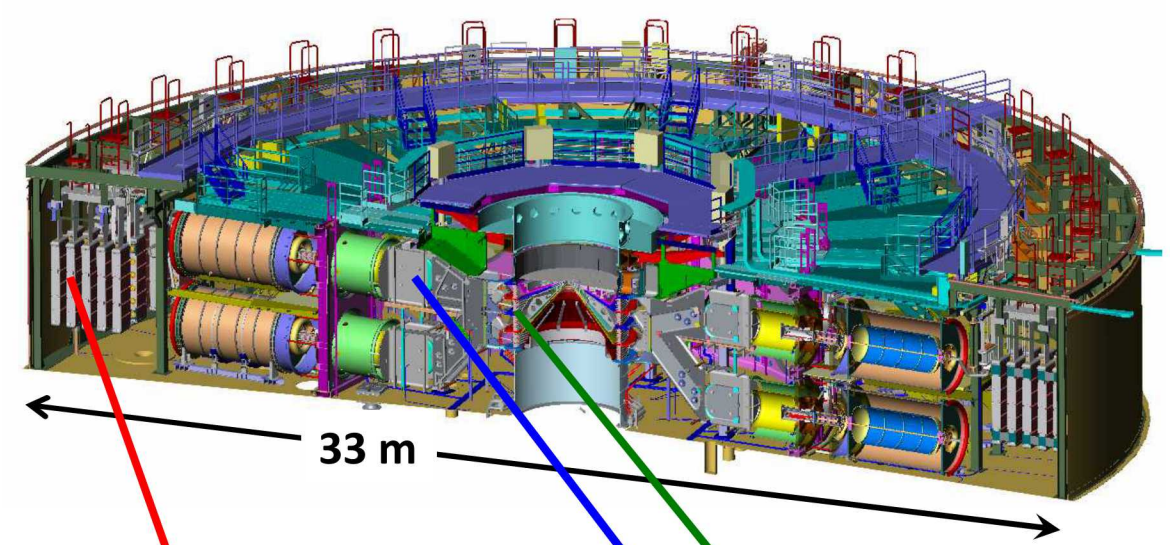
ZLV instrument team (SNL): Michael Jones, Dave Bliss, Drew Johnson, Decker Spencer, Grafton Robertson, and many more

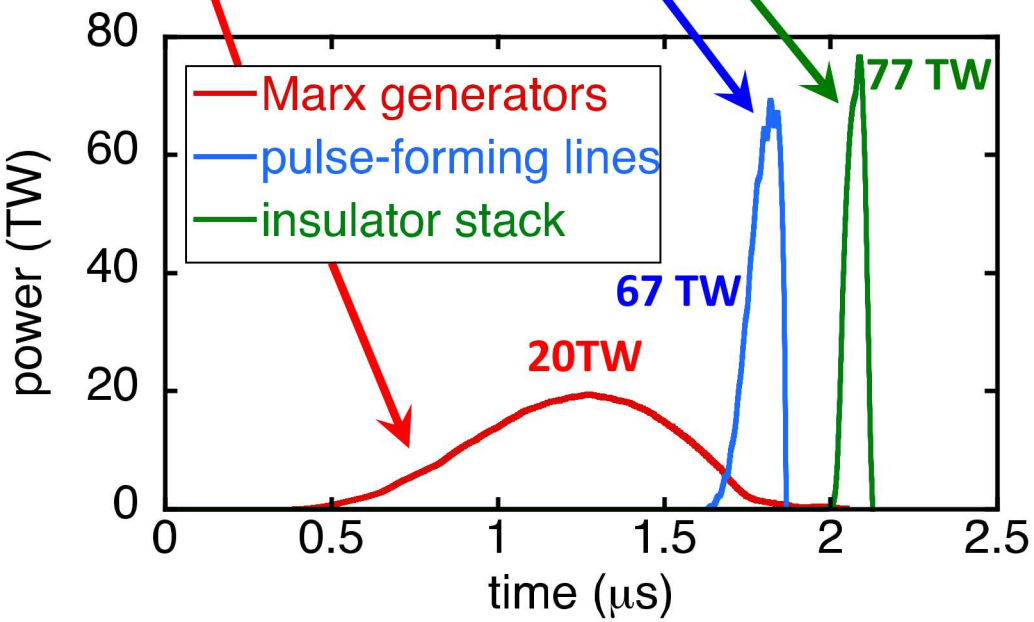
ZLV physics team (LLNL): Peter Celliers, Dave Erskine, and Dayne Fratanduono

Commissioning target modeling: Mark Hess (HYDRA 2D & ALEGRA 1D)
Kumar Raman & Keith LeChien (ARES)
Chris Jennings (GORGON)



Large currents on Z create extreme pressures at the load.

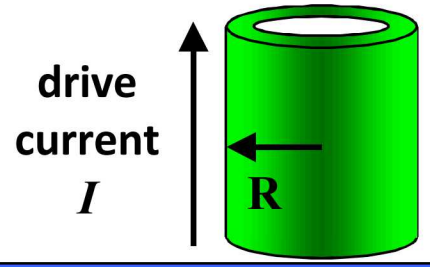




Z capacitors store 22 MJ.
Z couples several MJ to the load hardware at machine center

Magnetically Driven Implosion

$$P = \frac{B^2}{8\pi} = 105\left(\frac{I_{MA}/26}{R_{mm}}\right)^2 \text{ MBar}$$



100 MBar at 26 MA and 1 mm

100 GPa = 1 Mbar ≈ 10^6 atmospheres

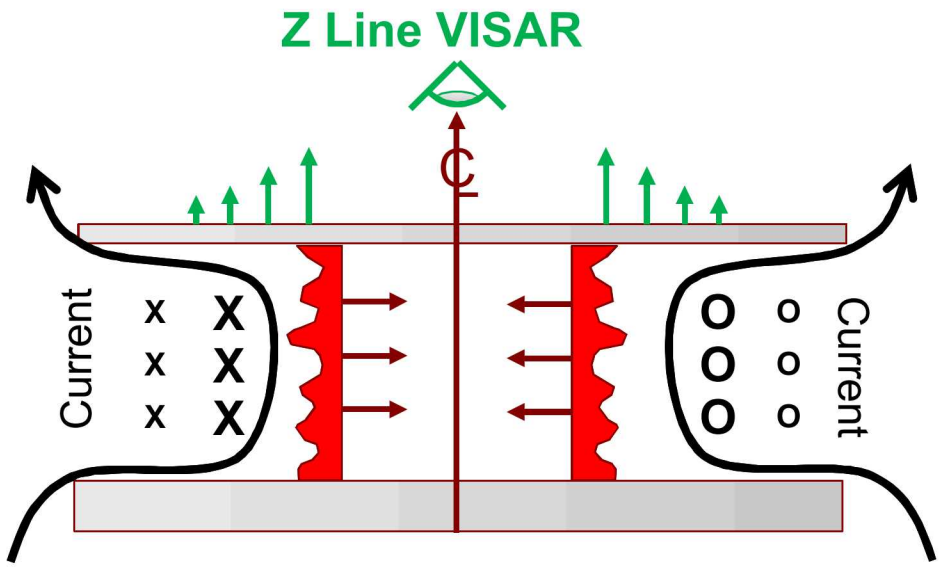
Z Line VISAR will allow us to examine the position and timing of current loss by measuring the spatial and temporal dependence of surface and shock velocities.

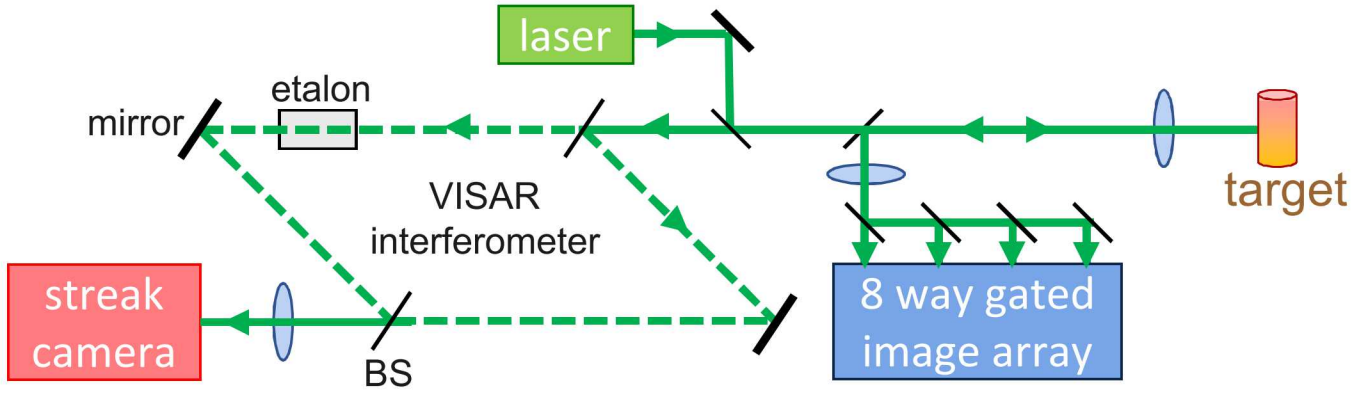
By measuring velocity as a function of radius we can infer the amount of current delivered and the position of current loss.

$$P = \frac{B^2}{8\pi} \sim \frac{I^2}{R^2}$$

$$U_s \sim \sqrt{\frac{P}{\rho}} \sim \frac{I}{R}$$

P – Pressure
B – Magnetic Field
I – Current
R – Radius
U_s – Shock Velocity





Z Line VISAR is a high-performance instrument designed to meet the demands of the harsh Z environment: Shock, EMP, Radiation, Neutrons.

Physics needs

- Measure high shock velocities
- Measure velocity as a function of radius to identify current loss locations
- High f-number to account for titling of the shock front
- Multiple fields of view to examine velocity at large and small radii
- 2D images of shocked surface to assess centering and symmetry

ZLV diagnostic requirements

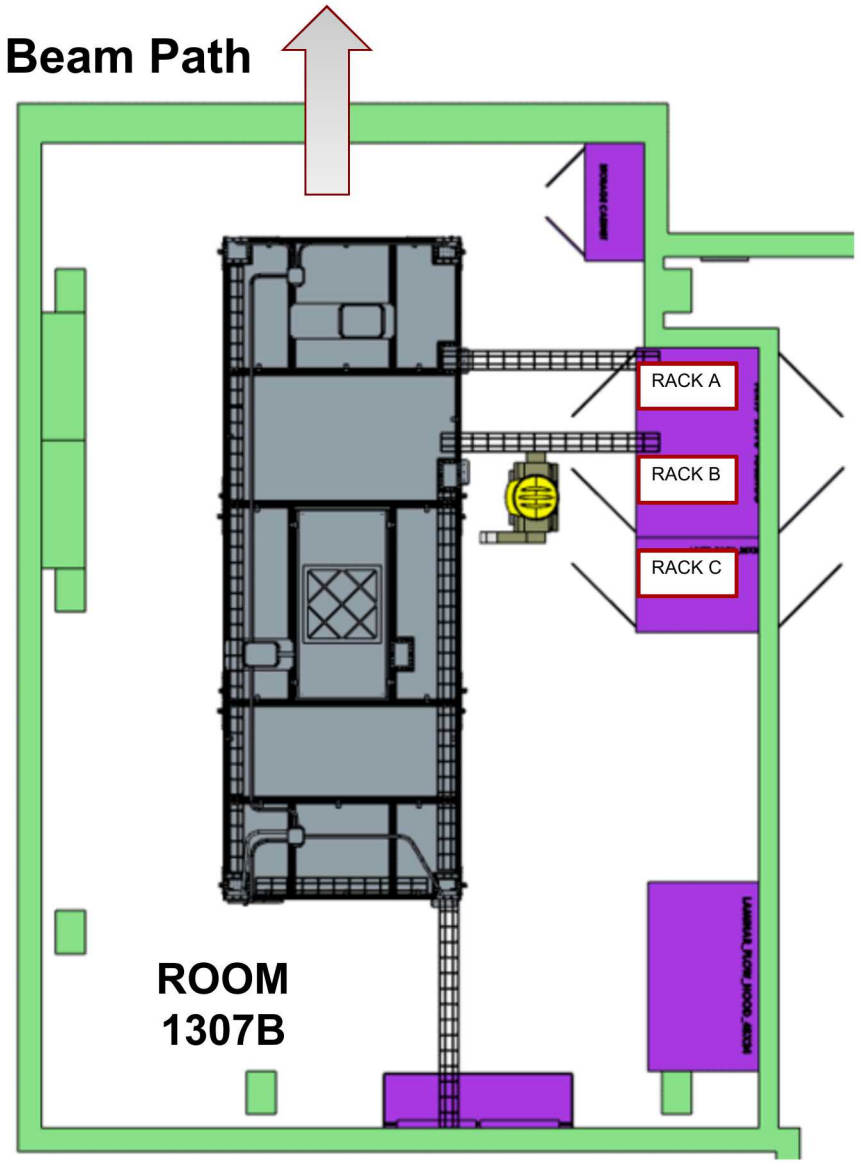
Velocity interferometer

- Spatial resolution better than 10-20 μm
- Timing accuracy better than 20 ps
- 1, 2 and 4 mm FOV
- f/2 (!)
- Two interferometer legs for fringe ambiguities

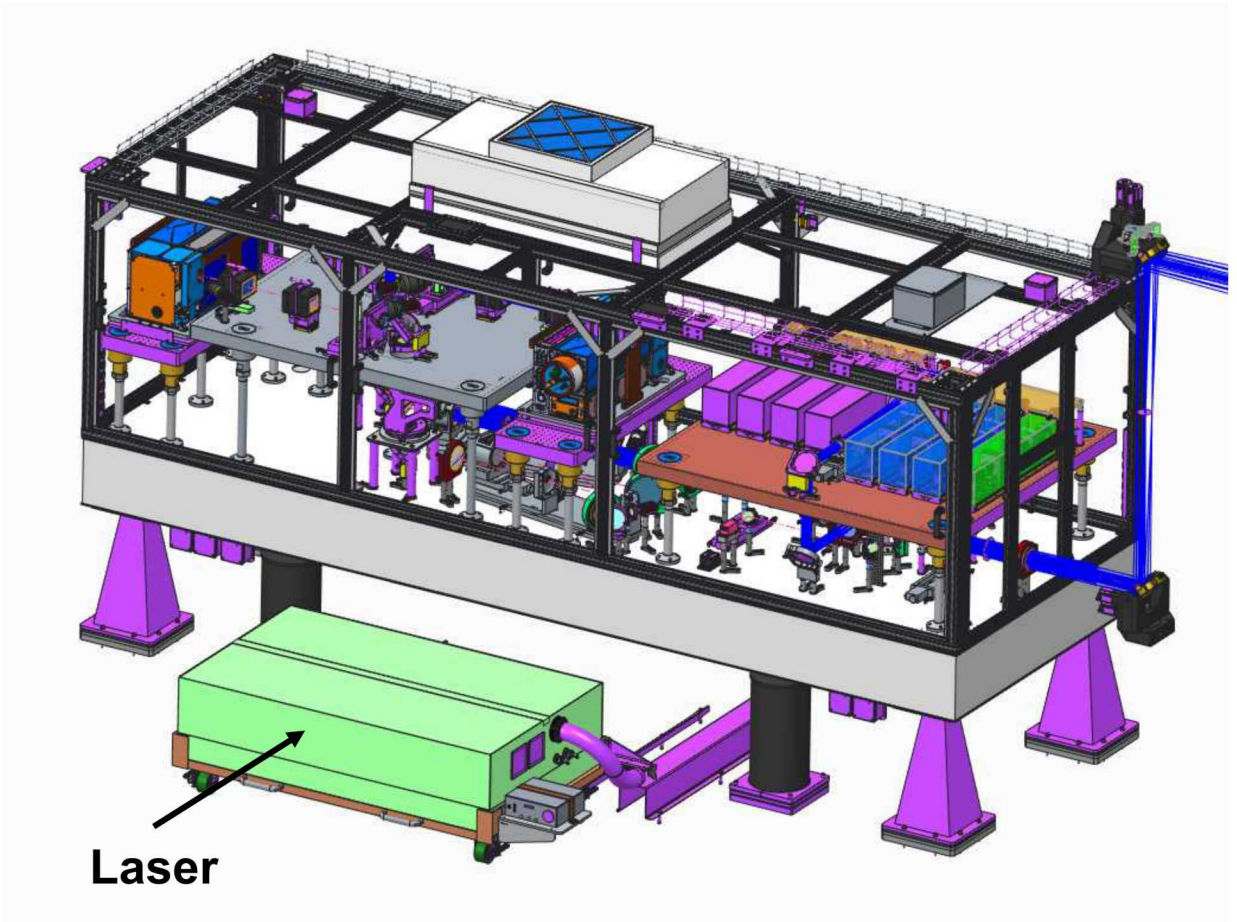
Gated Optical Imager (GOI)

- Spatial resolution of ~100 μm
- Multiple images (8) to account for physics and facility jitter

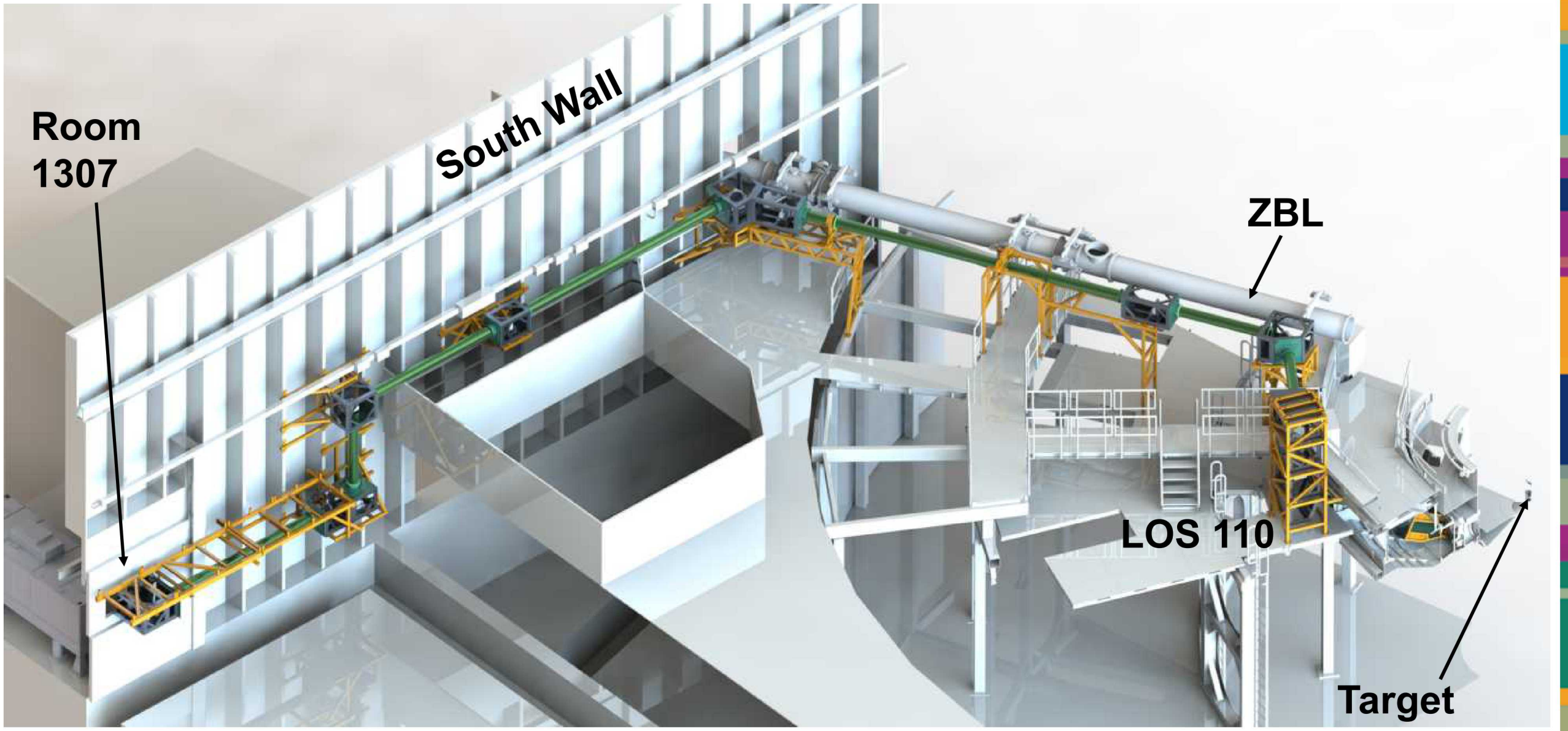
The ZLV optics table and laser system form a compact assembly away from the Z high bay environment.



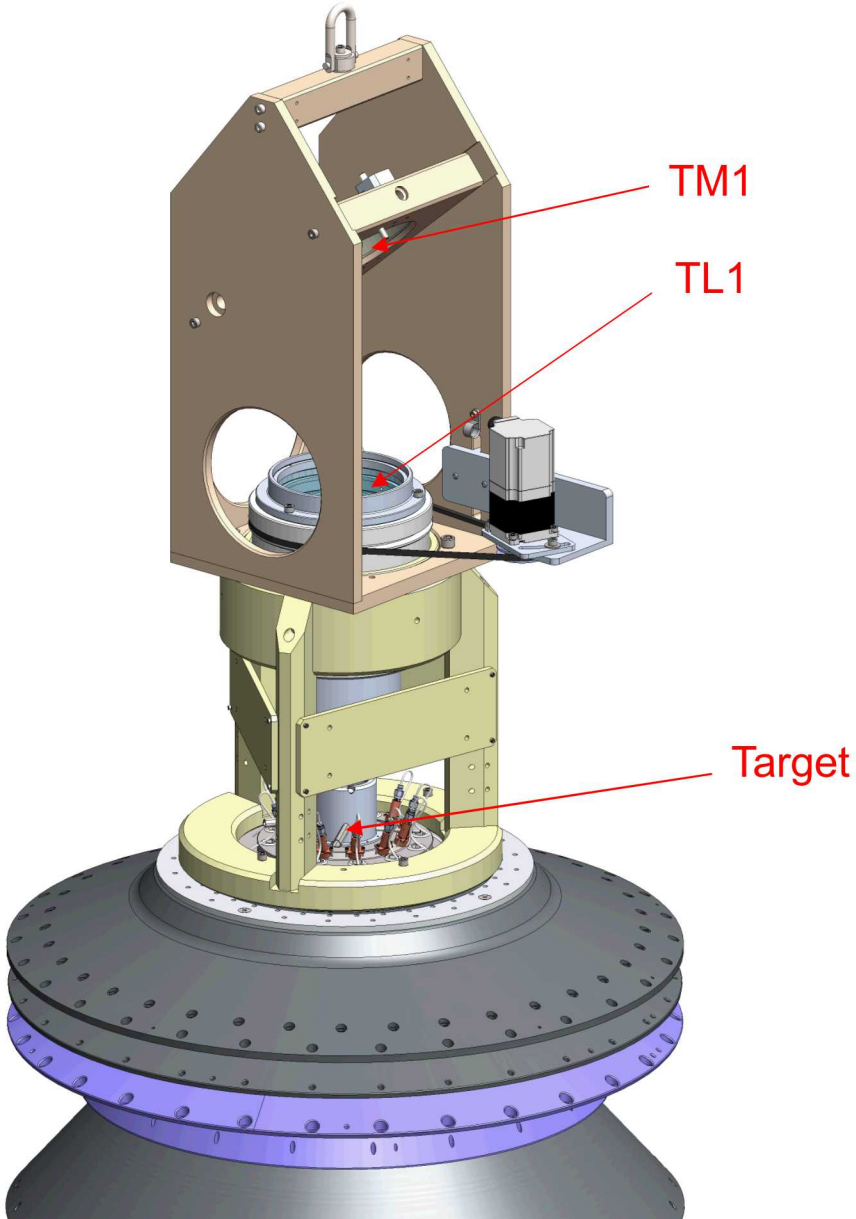
Interferometer and GOI Table

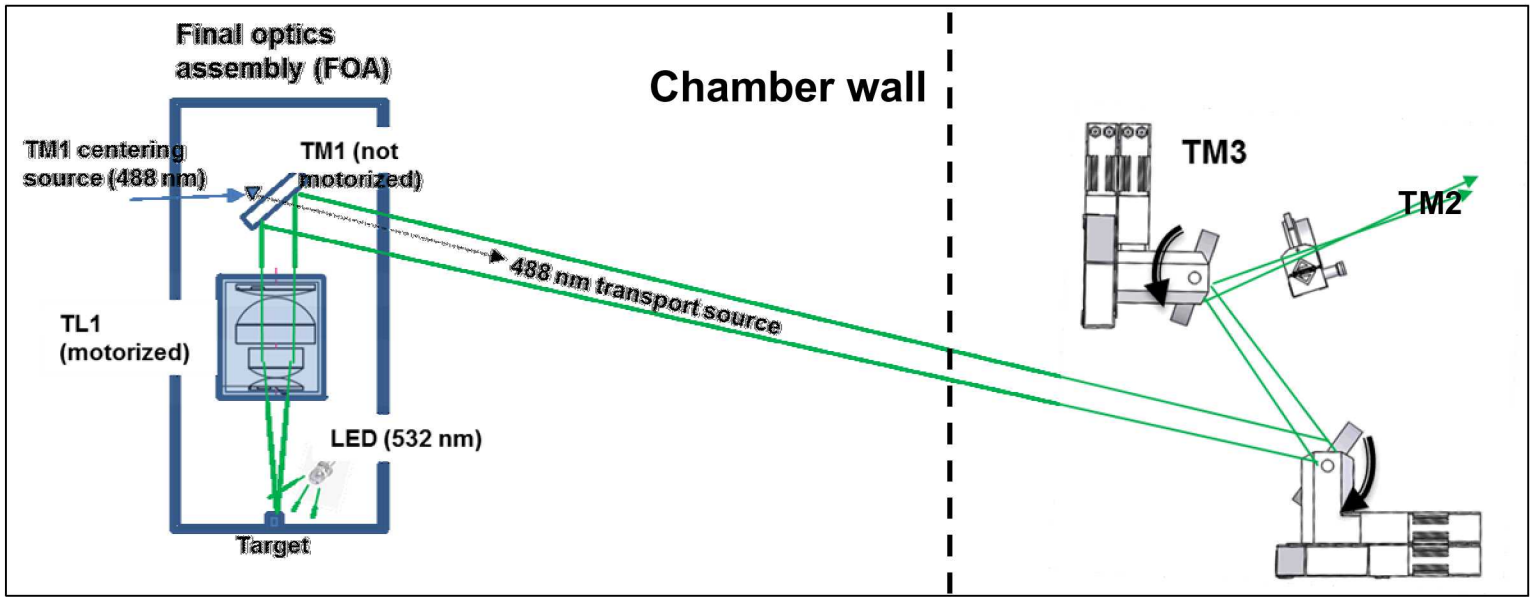


The ~50m enclosed optical system (9 lenses, 12 mirrors) transports the laser beam to the target and relays the reflected image back to ZLV.



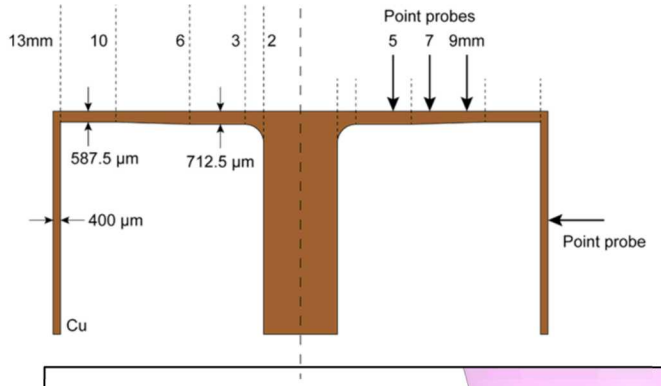
Each Z Line VISAR experiment must field a consumable final optics assembly that precisely images the top of the target.

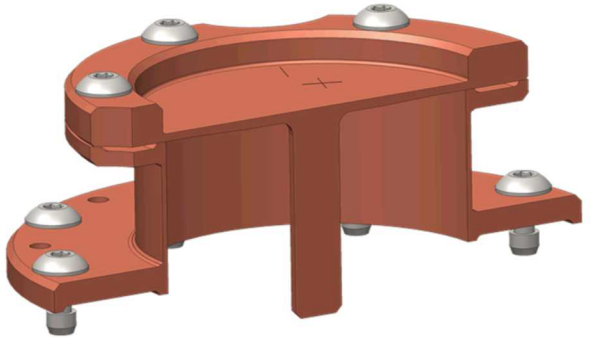


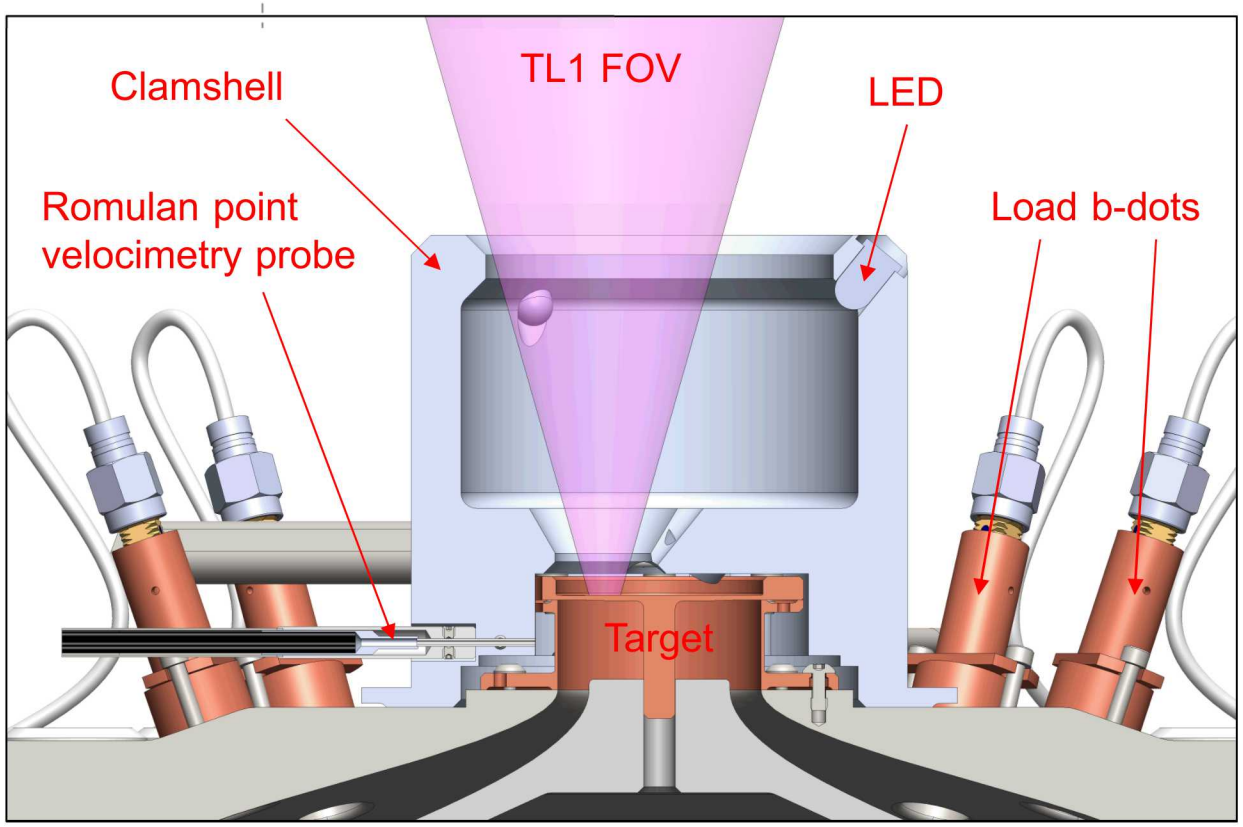


ZLV commissioning load hardware was designed to be a lossless non-imploding copper cylinder with extensive diagnostics to characterize current at various locations near the load.

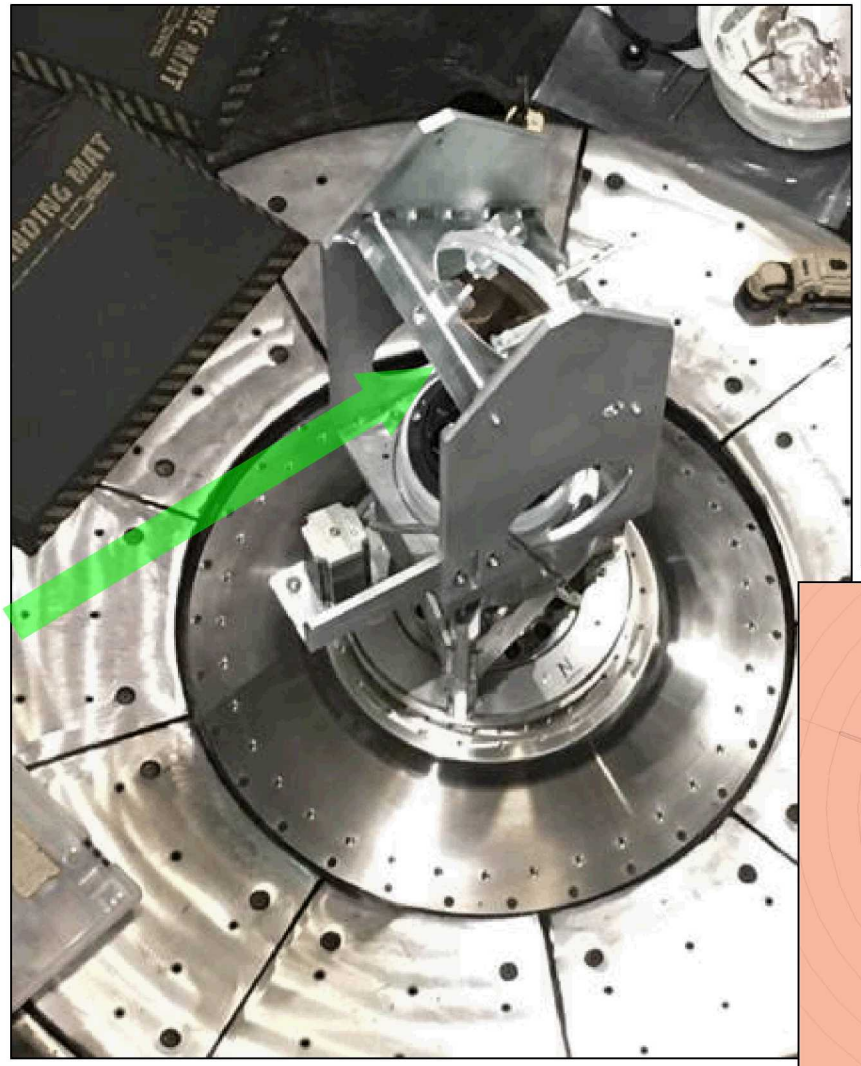
- The TM1/TL1 optics assembly mounts directly to the top anode to provide alignment precision.
- The only in-chamber adjustment is the TL1 focus (no tip/tilt).
- For commissioning, the TL1 FOV is offset from machine center by 7 mm.
- Ten load B-dots are fielded to assess the current delivered to the inner MITL.
- Nine Romulan point velocimetry probes are mounted in a clamshell clamped to the target.
- Three LEDs in the clamshell illuminate the top of the target for ZLV alignment.

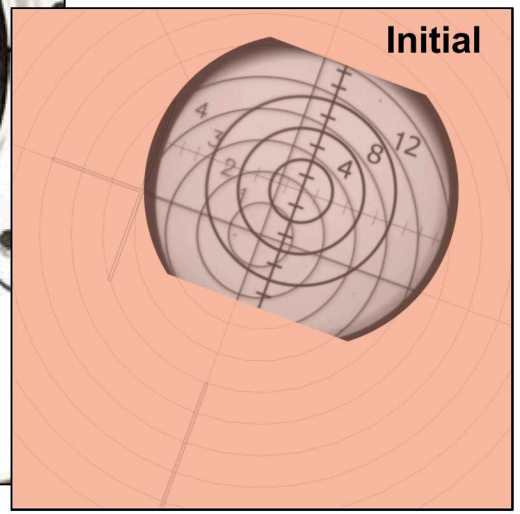


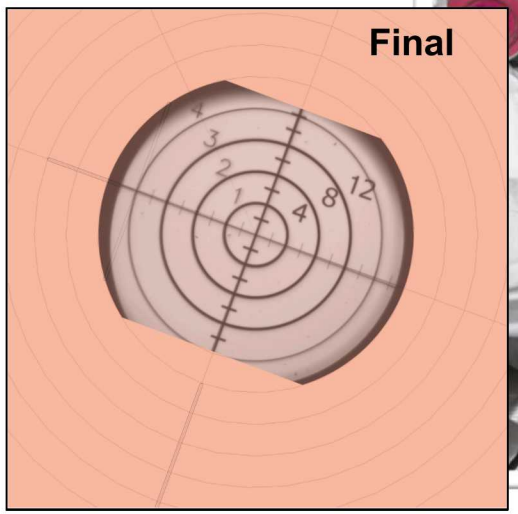


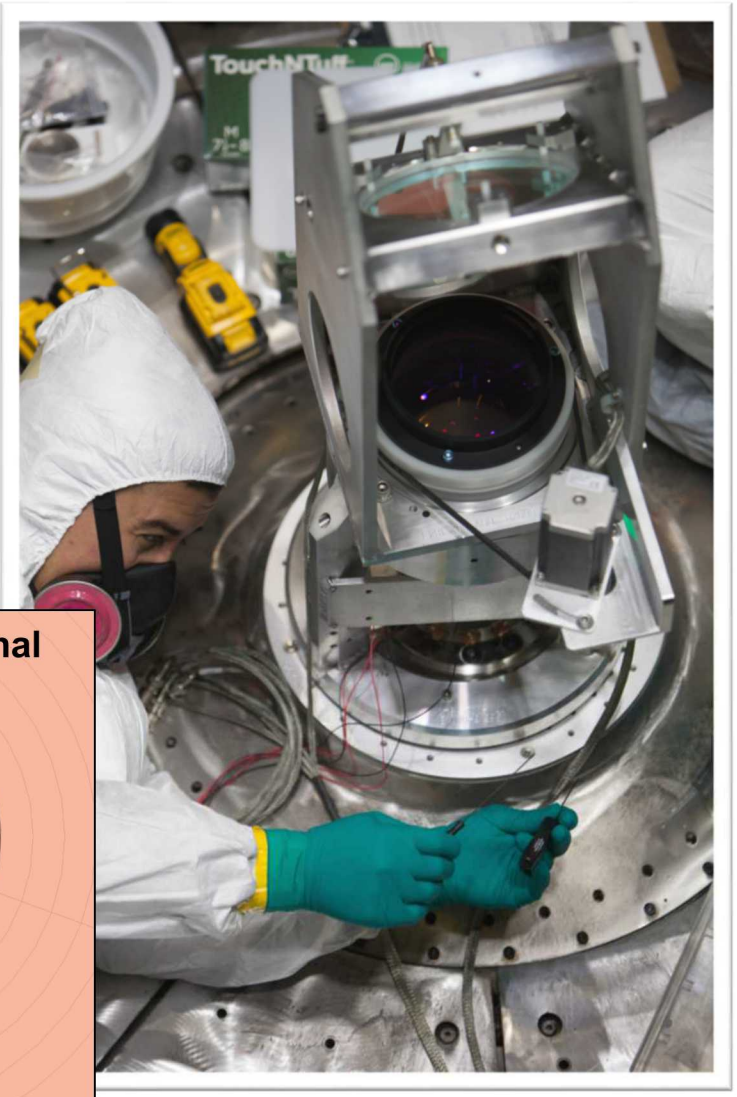


The ZLV commissioning hardware was first installed and tested for alignment on November 9, 2018



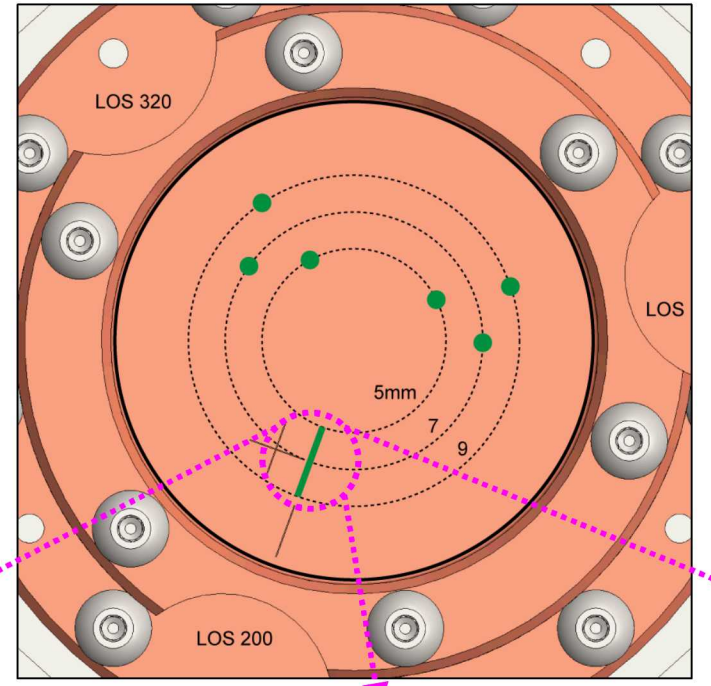






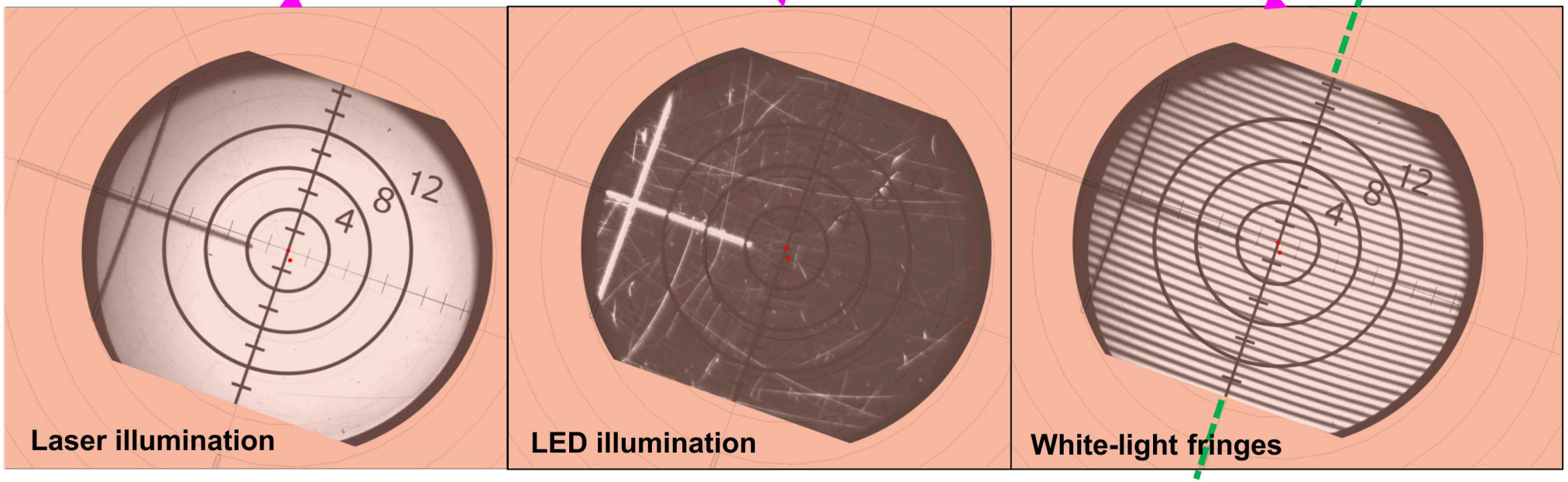
The numbers 1-2-3-4 are in chamber on the reticle target,
while 4-8-12 are at an intermediate image plane in ZLV room.

A selection of cameras and illumination sources aids in the focusing and alignment of the ZLV system to the copper downline target.

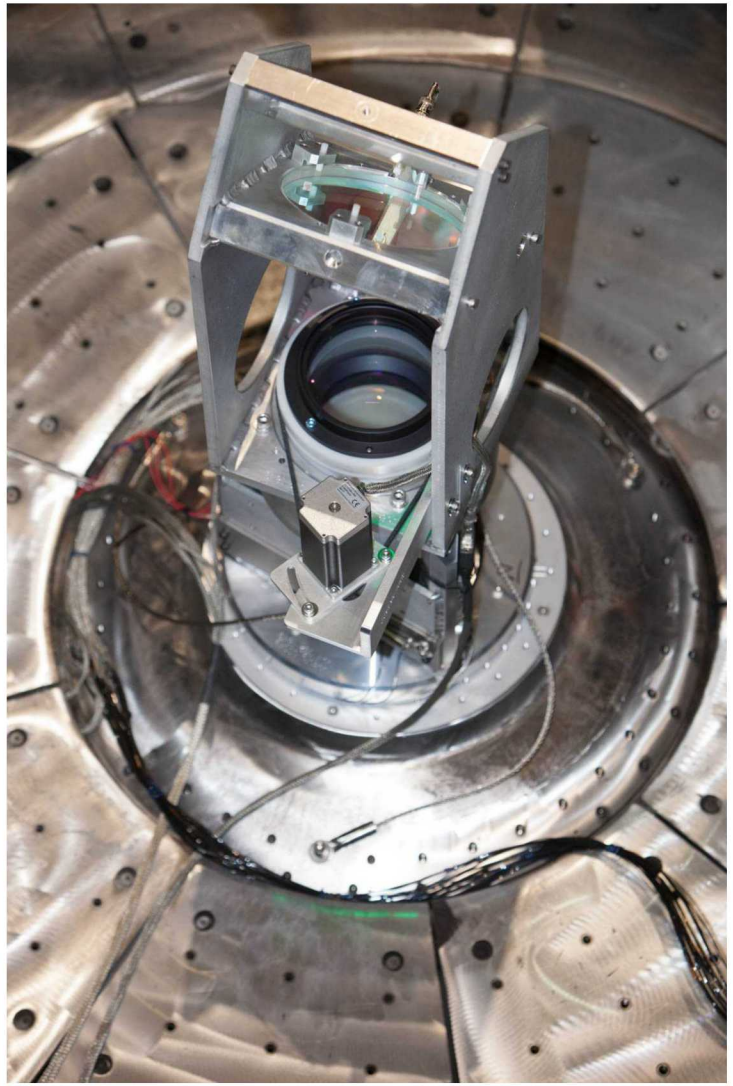


- Alignment and focusing of ZLV to the Cu target was achieved using the + fiducial mark scribed on the target.
- The – fiducial mark was just outside the field of view.

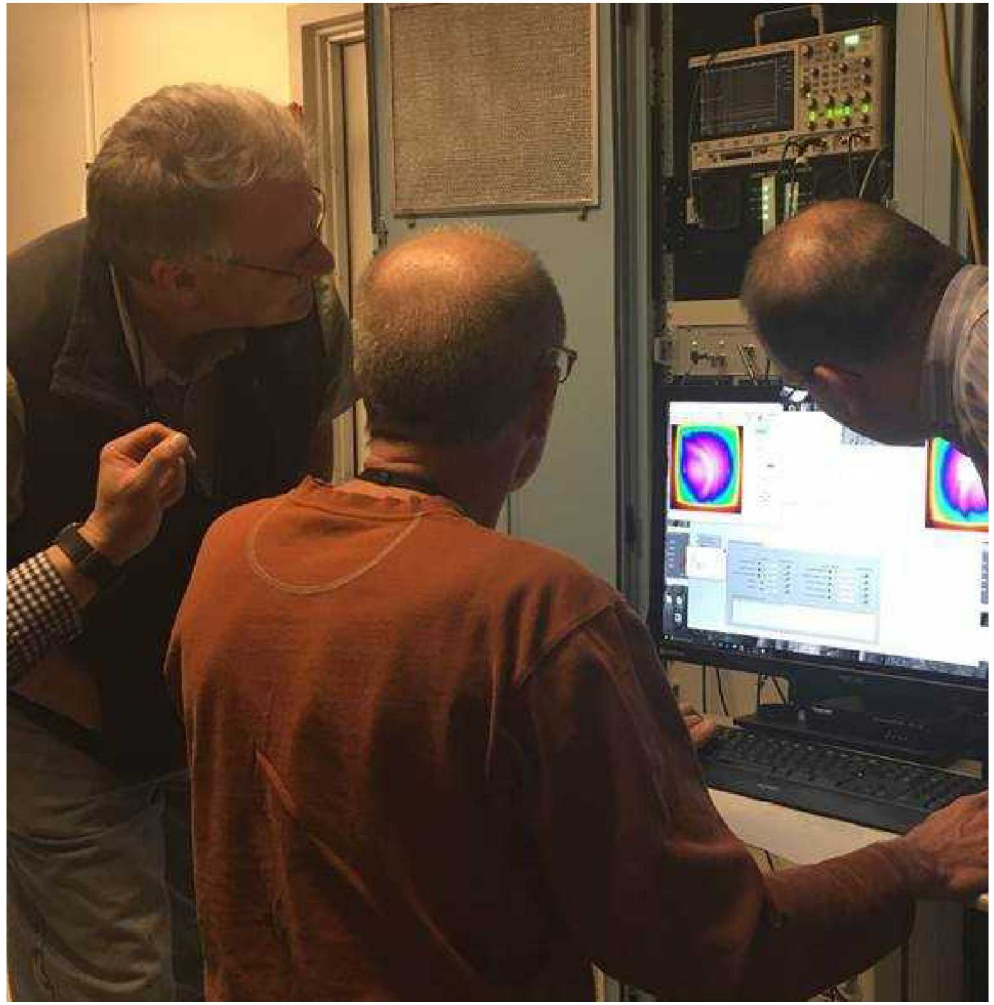
Orientation of the Streak camera slit

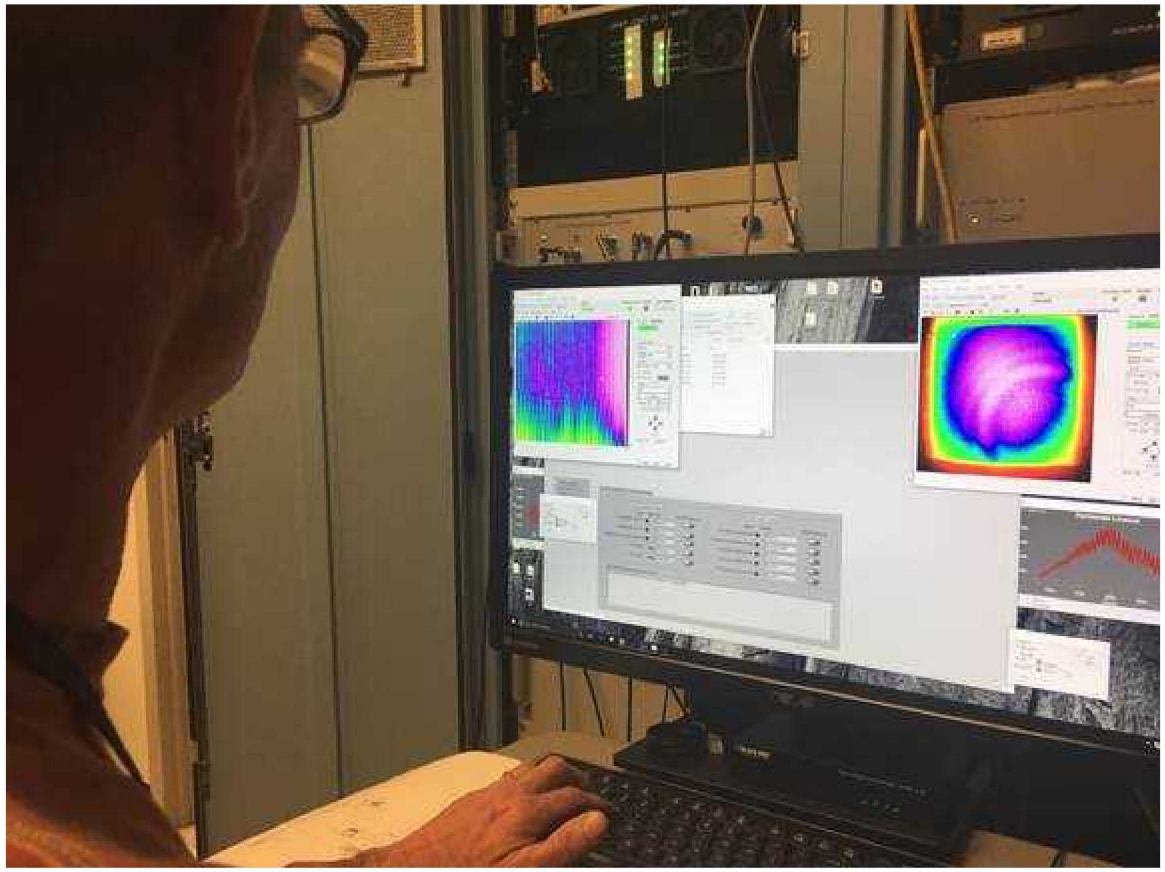


Effect of downline current on the ZLV commissioning hardware! (z3337)

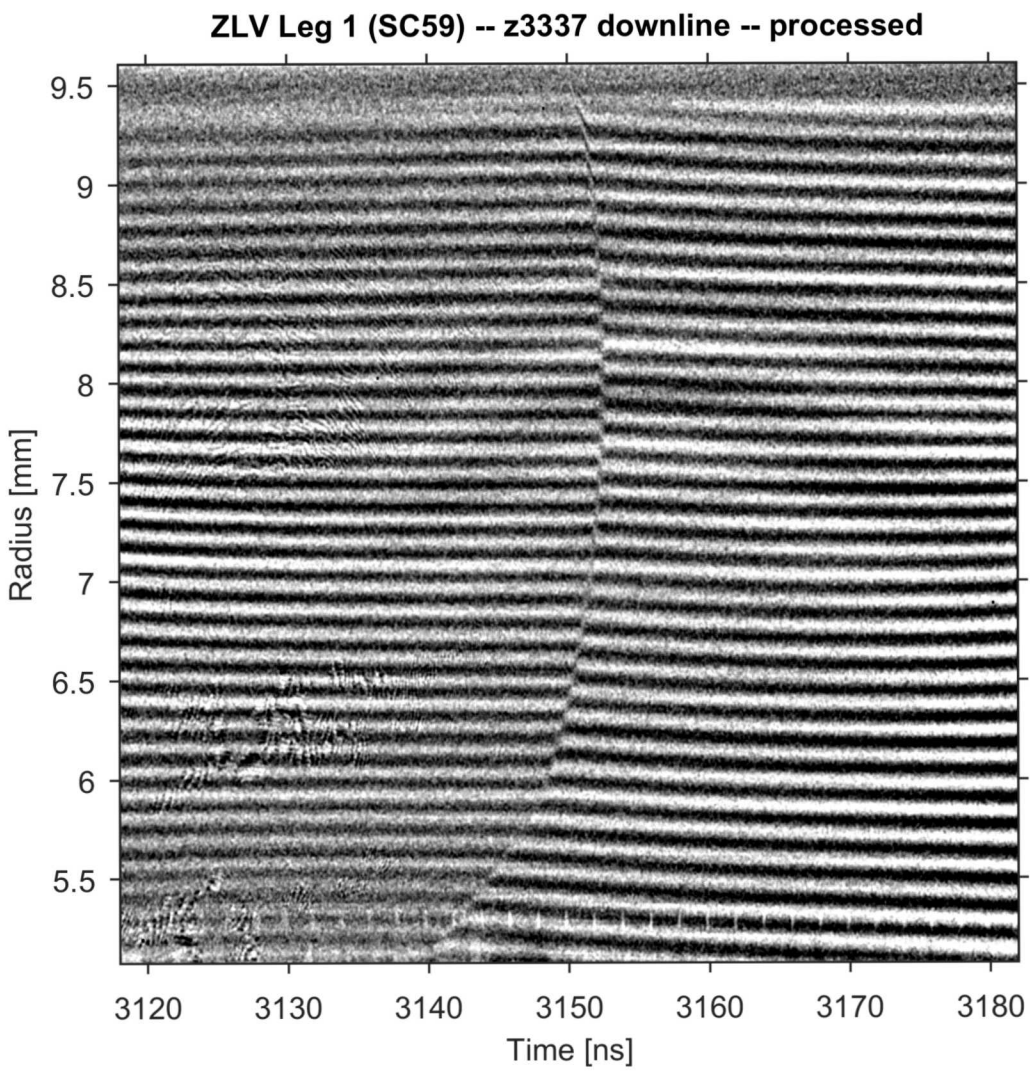


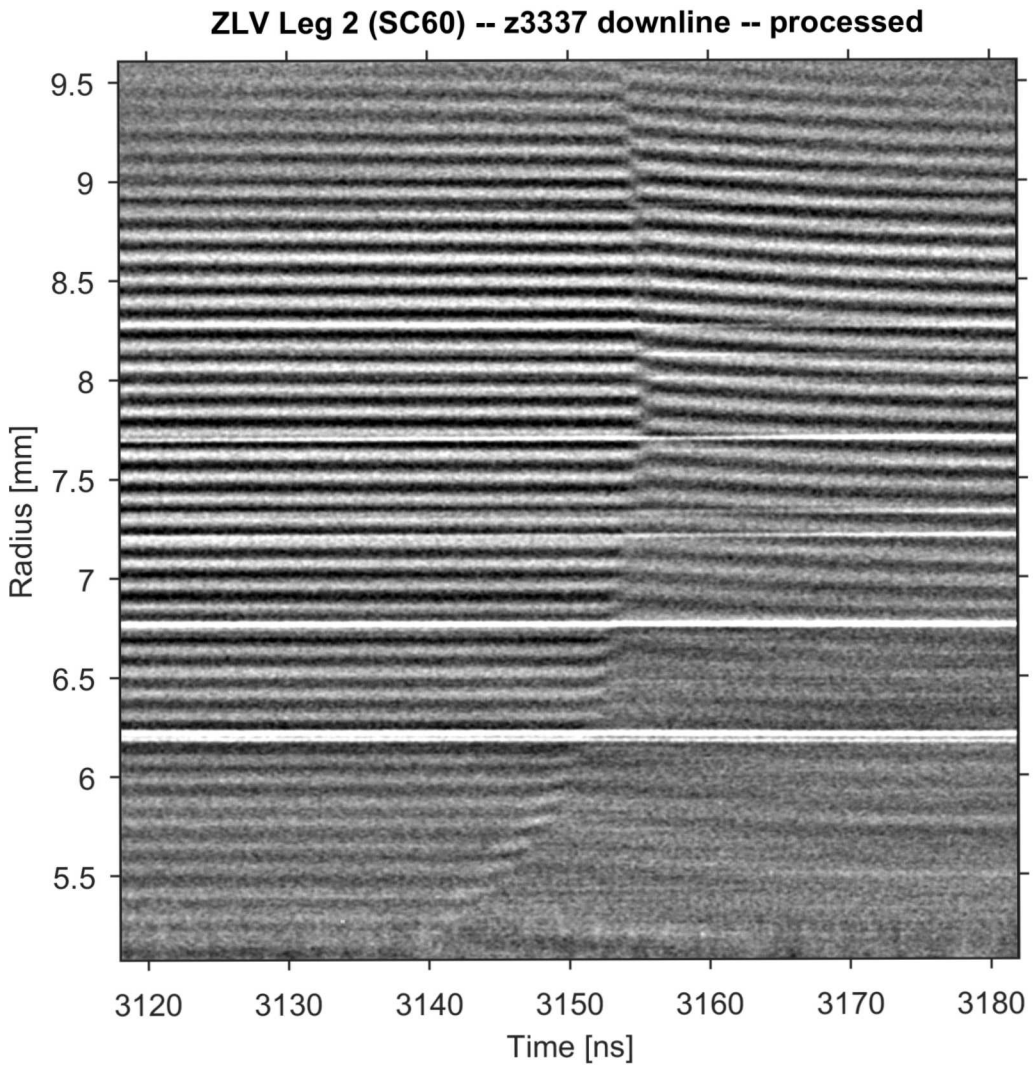
As the ZLV team looks on intently, the data is calmly saved …



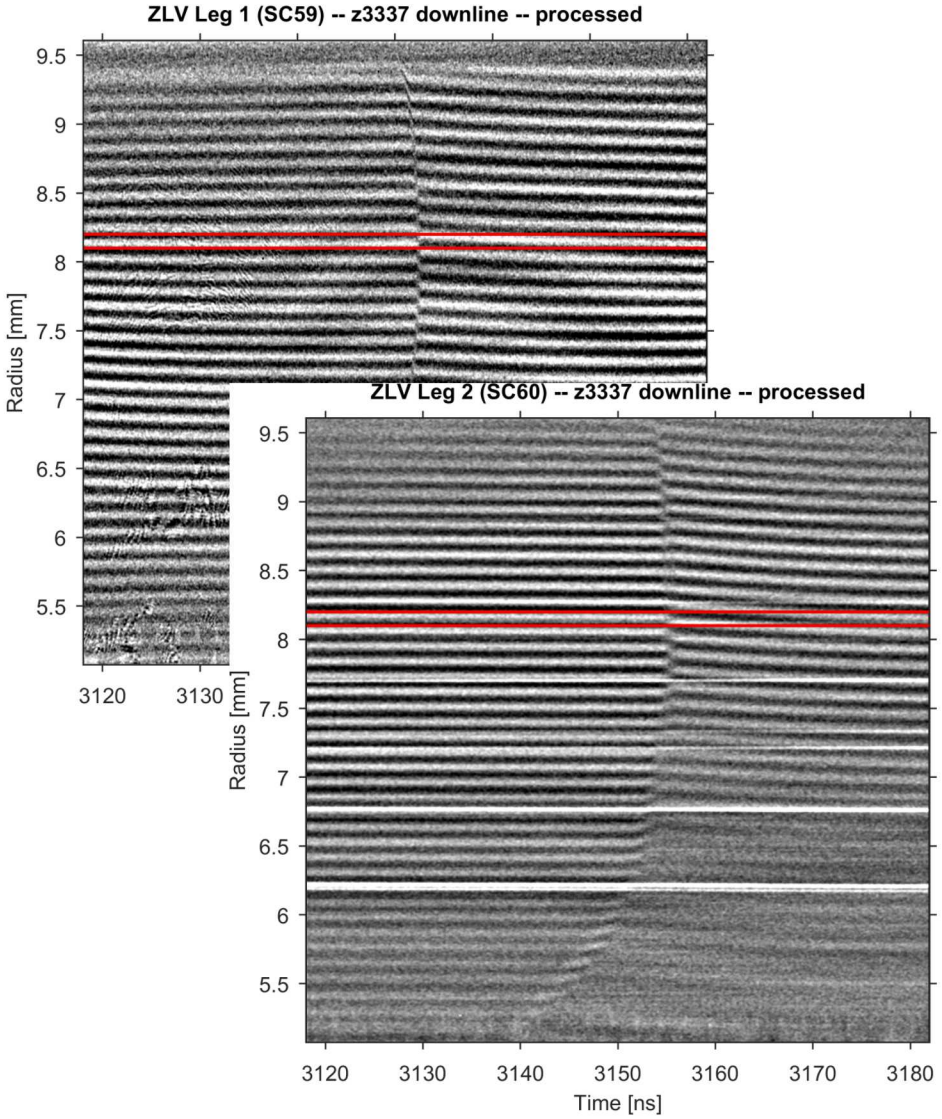


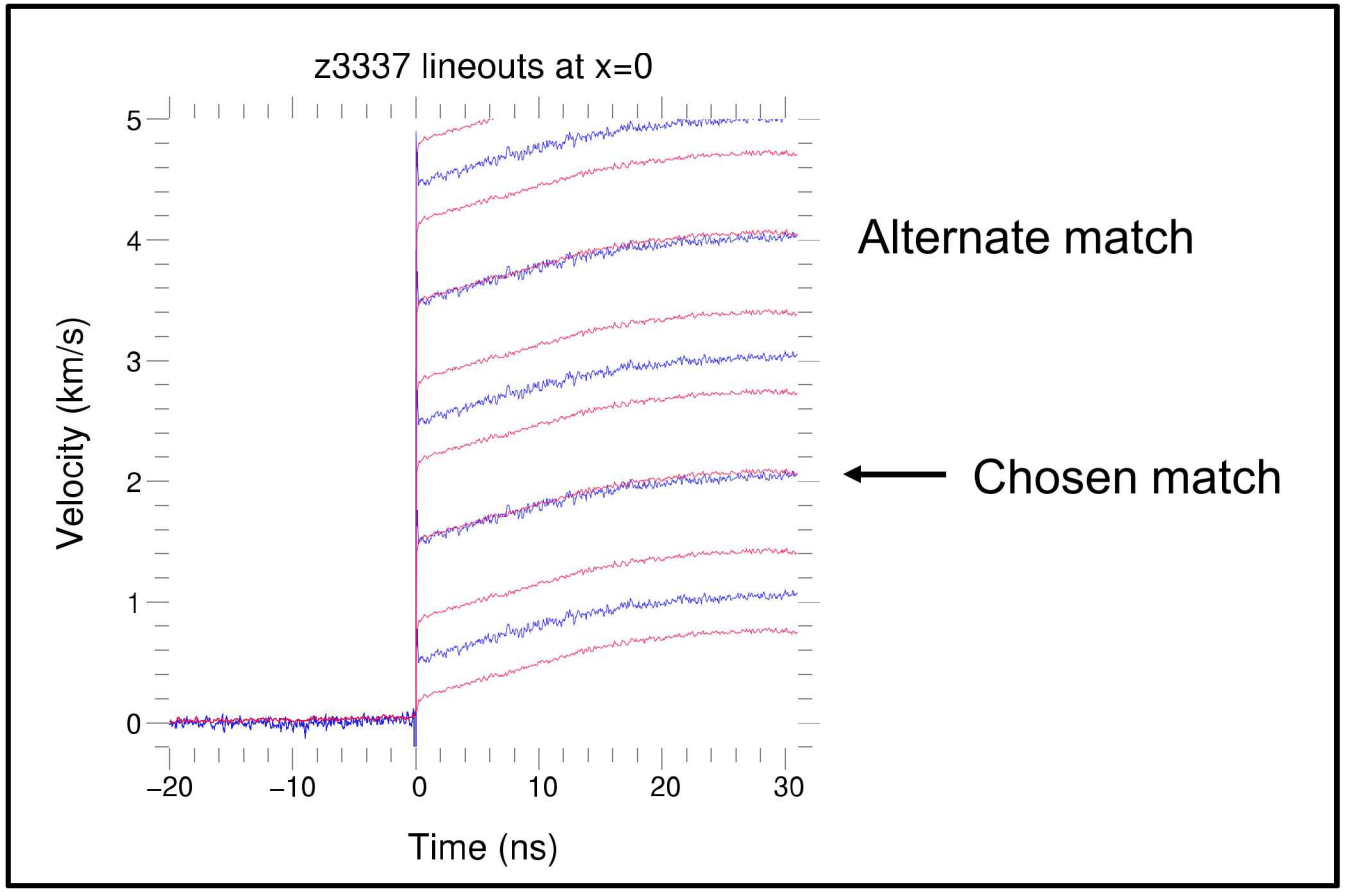
… and to the relief of all, the shock feature is clearly visible along with velocity fringe shifts visible post-shock!





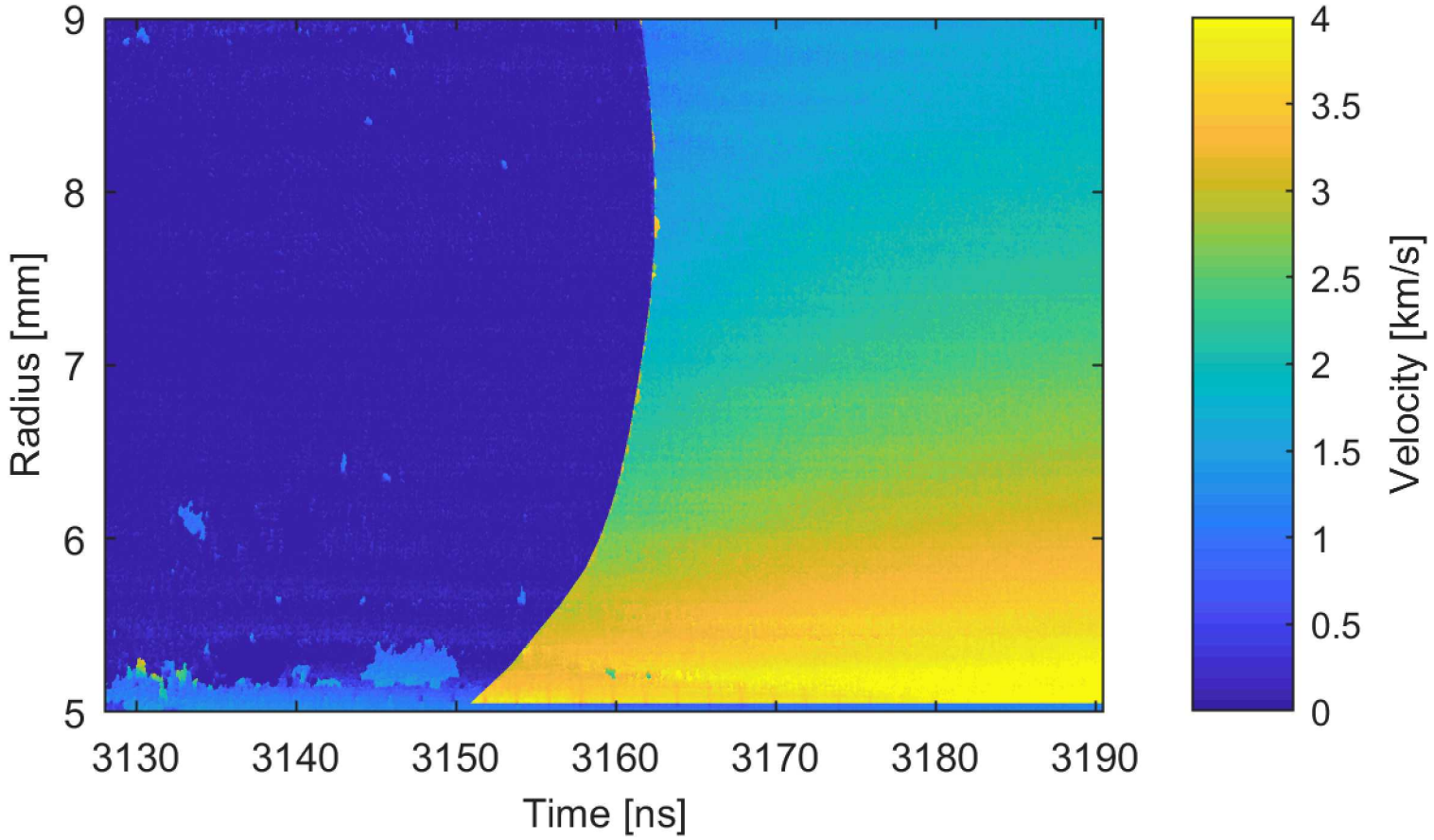
Taking lineouts at 8.1– 8.2mm provides an assessment of the fringe jump ambiguity required to match the two ZLV interferometer legs.





SLIDE COURTESY OF CLAYTON MYERS — Z LINE VISAR — PPPS 2019 — JUNE 28, 2019

The unfolded ZLV velocity map is a remarkable achievement after a single commissioning shot!



Line VISAR unfolds:

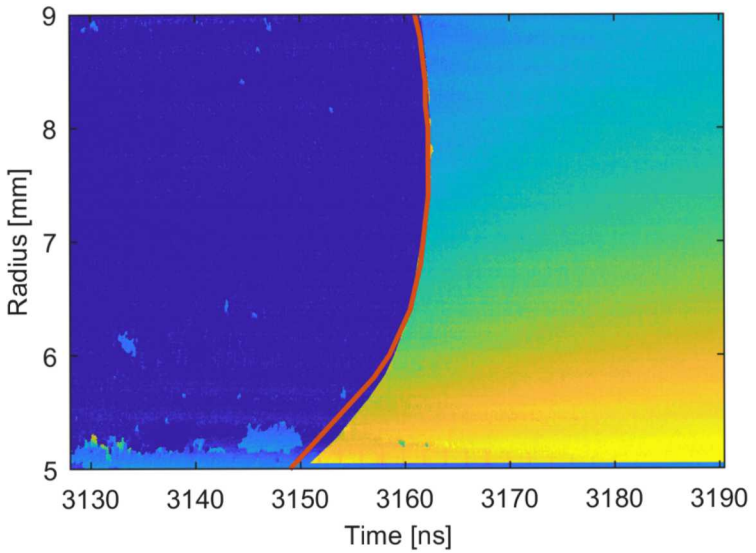
Peter Celliers and Dave Erskine

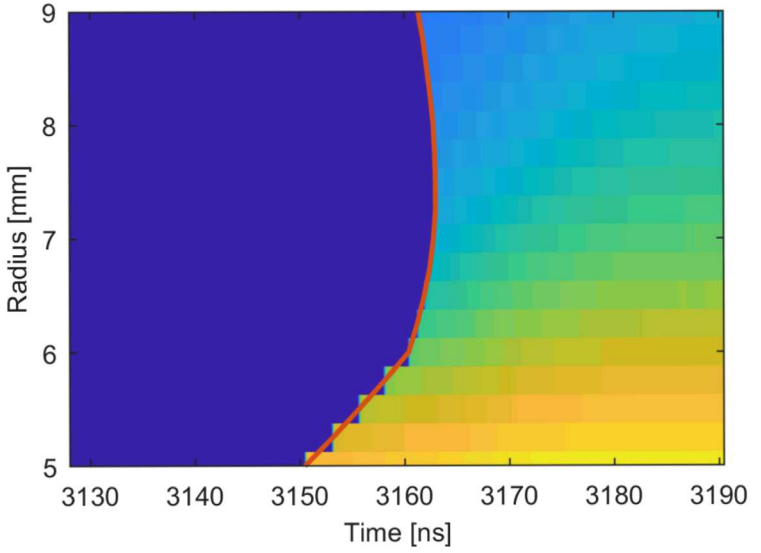
Streak image registration:

Dave Bliss, Peter Celliers, Gene Vergel de Dios, and the ZLV team

Comparison of ZLV data with ALEGRA, HYDRA, and GORGON simulations all show excellent agreement.

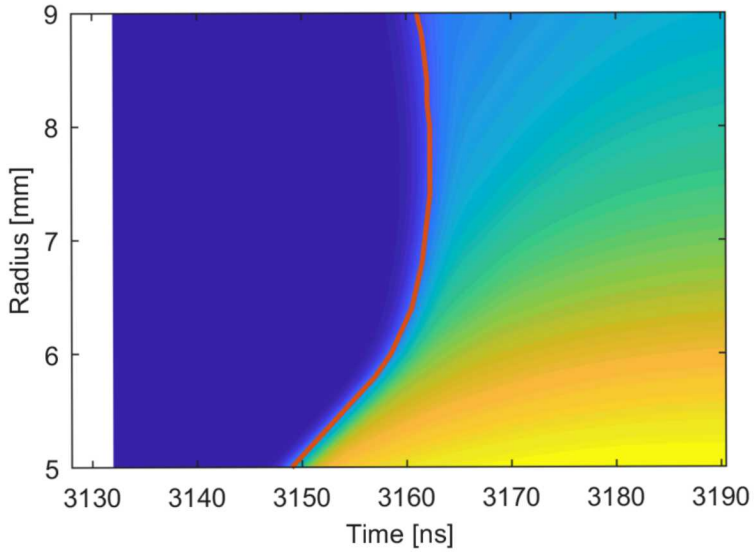
ZLV Leg 1

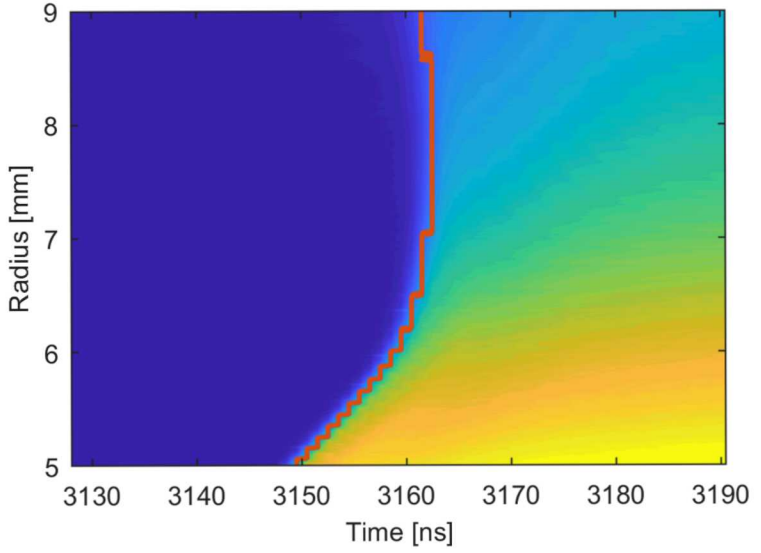




ALEGRA 1D (M. Hess)

HYDRA 2D (M. Hess)





GORGON 2D (C. Jennings)

Summary of Results:

- The Z Line VISAR diagnostic has delivered the first spatially and temporally resolved load current measurements on Z the first time it was fielded!
- The z3337 ZLV data produced a high quality 2D velocity map – $v(r, t)$

Conclusions:

- Comparisons to simulations from multiple codes show consistent shock breakout profiles as well as post-shock velocities that agree to better than 5% (~80 m/s)
- The ZLV velocity data indicates that current delivery across the top flyer plate was lossless as designed to within ~2% uncertainty → ~300 kA out of 14+ MA.
- Spatial and temporal characterization of current delivery in more aggressive loads with current loss looks extremely plausible. This capability will rigorously test the ability of power flow simulations to predict measured current loss at the load.

Future Work:

- Demonstrate improved fringe contrast and signal-to-noise (bandpass filters)
- Commission the gated optical imager (GOI)
- Conduct experiments where current loss is suspected and/or expected