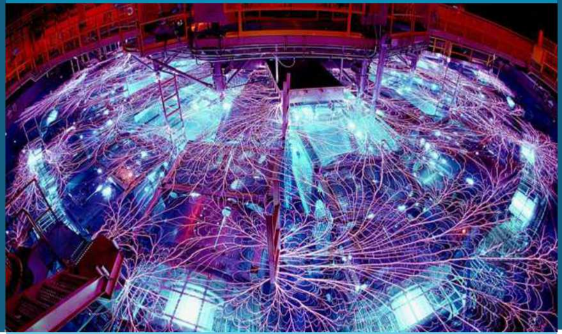
SAND2019-6425C

Z Line VISAR update



PRESENTED BY

Clayton Myers on behalf of the ZLV team

Z Diagnostic Workshop – April 17, 2019

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.

SAND2017-9564 A

The Z Line VISAR (ZLV) team is extensive and multi-institutional

ZLV commissioning PE & PD: Clayton Myers* 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, Neil Butler, 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, Dayne Fratanduono, Kumar Raman, Paul Springer, Jim Hammer, and many more

Commissioning target modeling: Mark Hess (HYDRA 2D & ALEGRA 1D)

Chris Jennings (GORGON)

Kumar Raman and Keith LeChien (ARES)

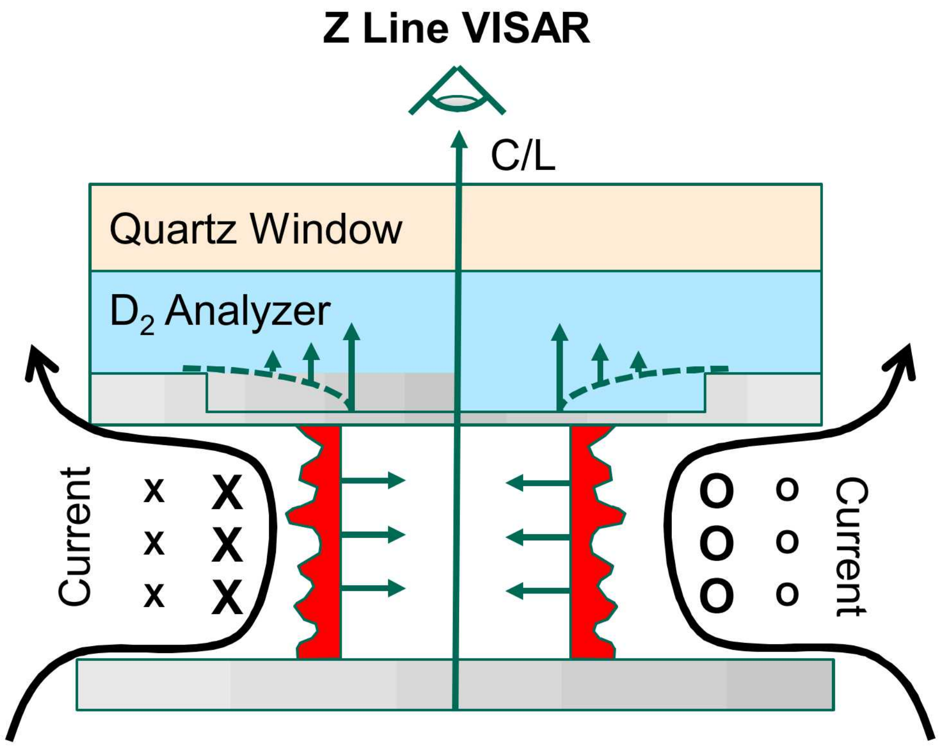
* *Tom Awe conducted much of the design work for the ZLV commissioning load hardware (A0817)*

Z Line VISAR will provide spatially and temporally resolved measurements of the current delivered to a target on Z

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

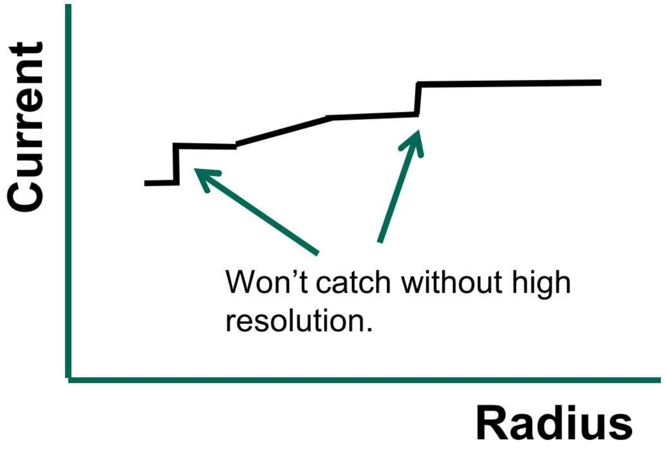
$$U_s \sim \sqrt{\frac{P}{\rho}} \sim \frac{I}{R}$$

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



By measuring velocity as a function of position in a D_2 analyzer, we can infer the current delivery

Current loss cartoon



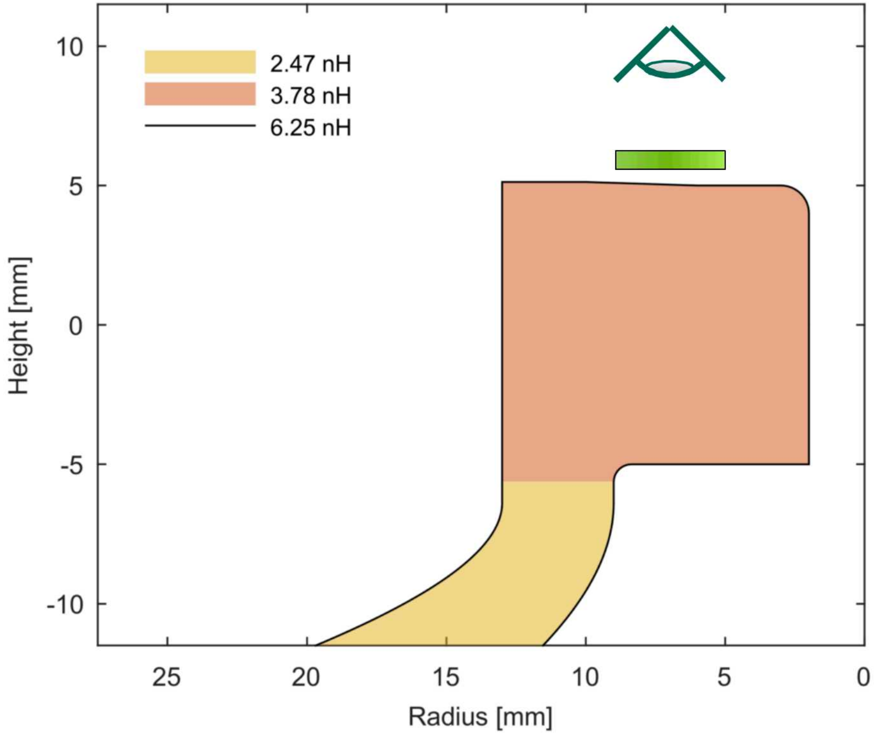
Measuring the loss profile requires high spatial and temporal resolution

Slide courtesy of Dayne Fratanduono (LLNL)

Z Line VISAR can also be used to diagnose power flow and benchmark codes at high current density and electric field stress → Z-Next

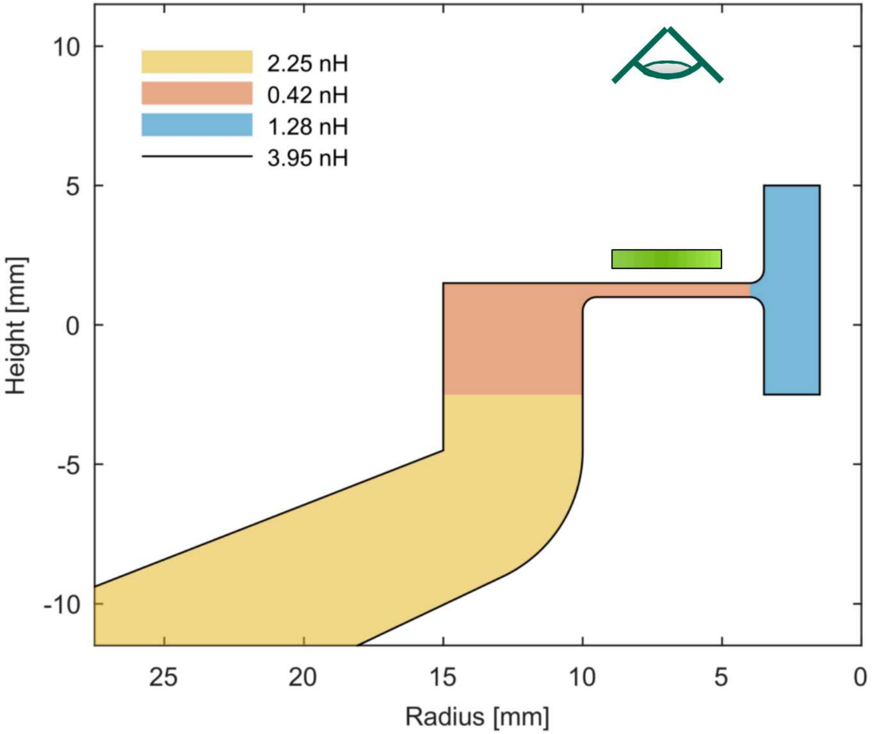
ZLV commissioning experiment (z3337):

- Non-imploding target
- Large feed gaps → low-stress
- Low-voltage (50 kV) → lossless load



Gap closure experiment (proposed):

- Non-imploding target
- Long, narrow feed gap → high-stress
- Losses expected → benchmark codes



We have an ambitious ZLV program scheduled in CY19 and early CY20

17-Dec-2018	Mon	ICF	Line-VISAR Commissioning	A0817A	z3337	Myers, C.	Robertson, G.	**Successful commissioning shot**
May 2019?		ICF	Line-VISAR Commissioning	A0817B		Myers, C.	Robertson, G.	**Hardware on-site**
Shelf		ICF	Line-VISAR Commissioning	A0817C		Myers, C.	Robertson, G.	
Shelf		ICF	Sierra 18d Line-VISAR	A0823B		Myers, C.	Robertson, G.	
28-May-2019	Tue	ICF	Sierra B 19a Line-VISAR	A0851A		Myers, C.	Whittemore, K.	**Hardware on-order**
03-Jun-2019	Mon	ICF	Sierra B 19a Line-VISAR	A0851B		Myers, C.	Whittemore, K.	
19-Aug-2019	Fri	DMP	Alameda 1	A0861A		Porwitzky, A.	Williams, J.	**Additional planned ZLV shots**
04-Sep-2019	Wed	ICF	Sierra DTC 19a (or Sierra B 19b)	A0922A		Myers, C.	Robertson, G.	
06-Sep-2019	Fri	ICF	Sierra DTC 19a (or Sierra B 19b)	A0922B		Myers, C.	Robertson, G.	
22-Nov-2019	Fri	DMP	Alameda 2	A0862A		Porwitzky, A.	Williams, J.	
Jan/Feb 2020		ICF	Sierra B 19b (or Sierra DTC 19a)	A0912A		Myers, C.	Robertson, G.	
Jan/Feb 2020		ICF	Sierra B 19b (or Sierra DTC 19a)	A0912B		Myers, C.	Robertson, G.	

- We hope to field Z Line VISAR on ~10 shots in CY19 and early CY20
- We must complete the ‘physics’ commissioning of the ZLV diagnostic to execute these shots

Z Line VISAR is a high-performance instrument designed to meet the demands of the Z environment

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

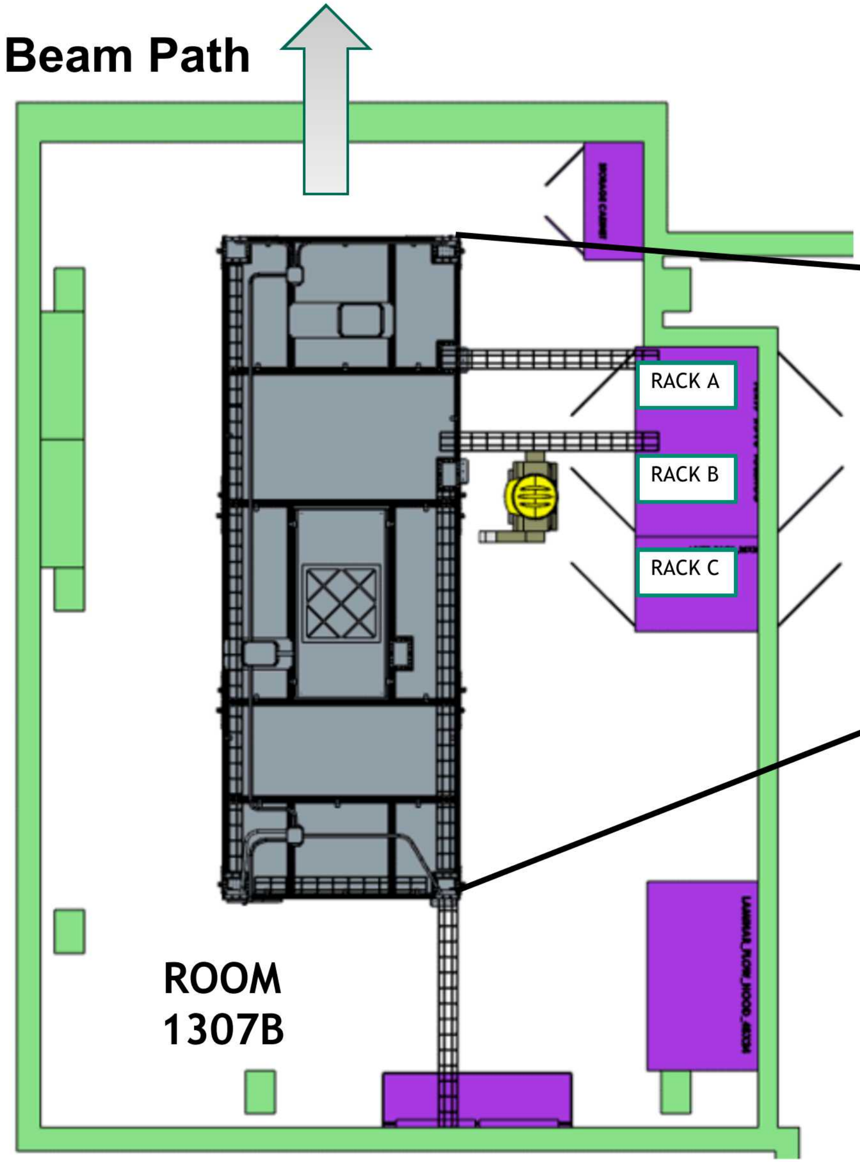
- Spatial resolution better than 10-20 μm
- Timing accuracy better than 20 ps
- 1, 2 and 4 mm FOV
- f/2 (!)
- Two interferometer legs for fringe ambiguities

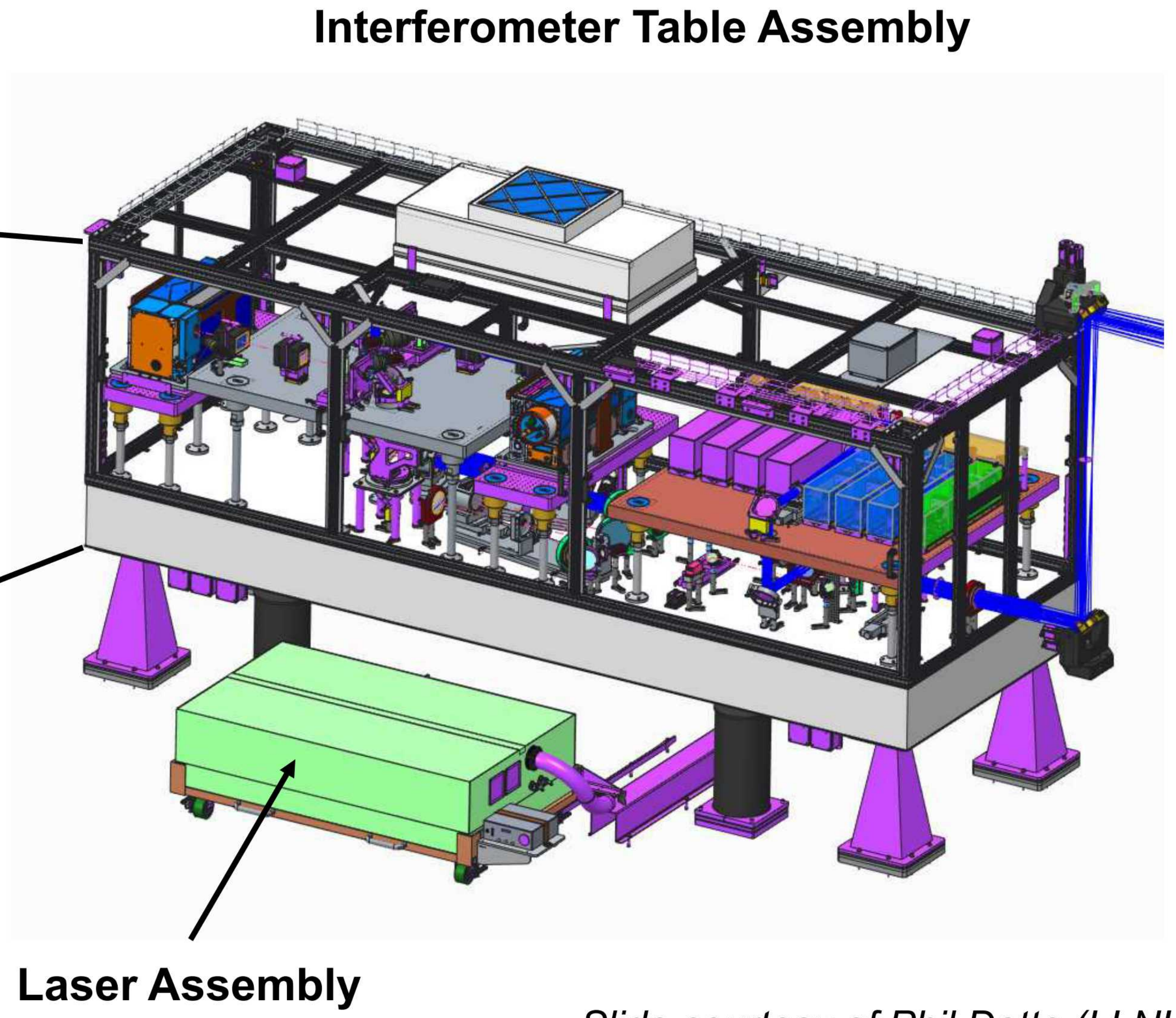
Gated Optical Imager (GOI)

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

Slide courtesy of Dayne Fratanduono (LLNL)

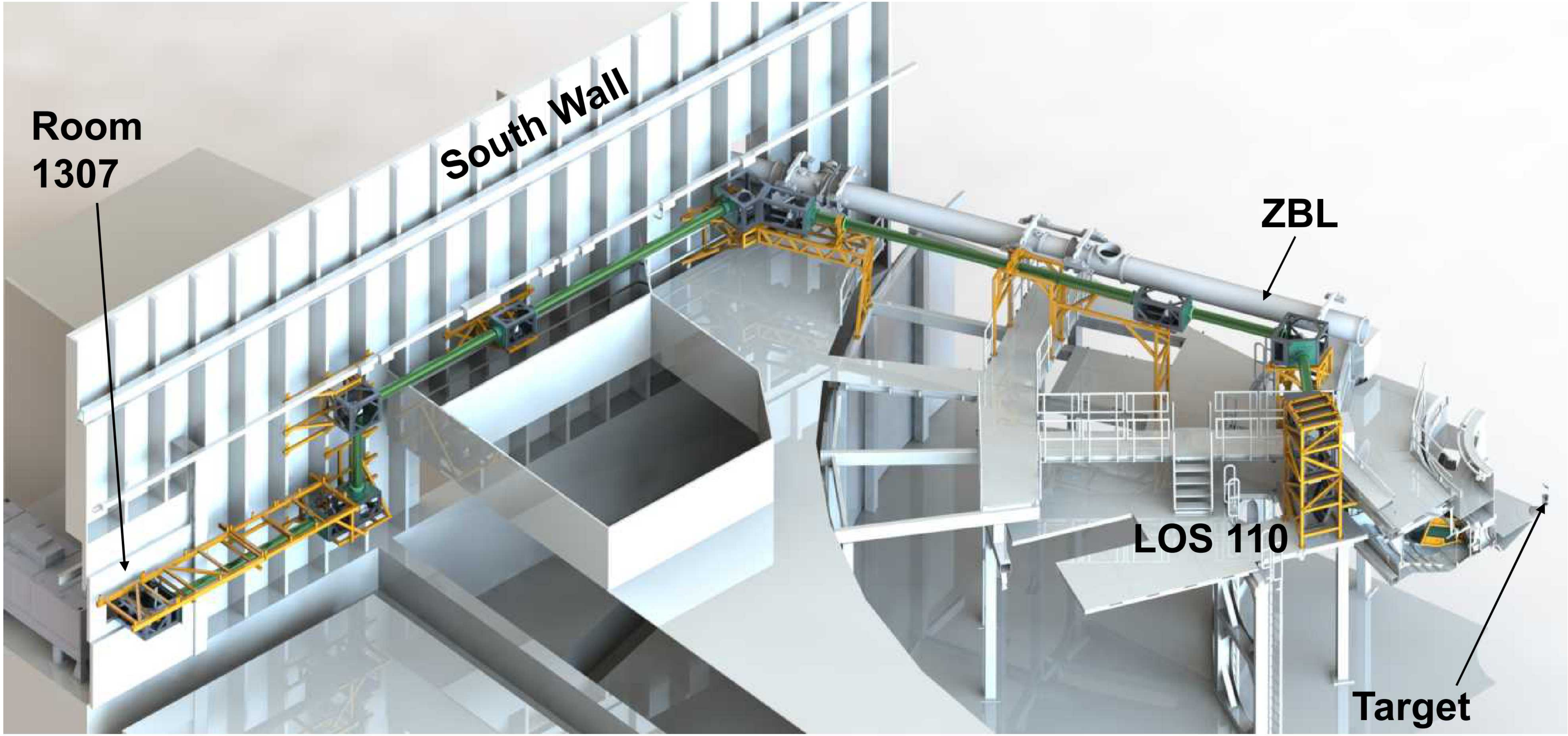
The ZLV optics table and laser system have been installed and brought online in 983/1307 (below the SVS room)





Slide courtesy of Phil Datte (LLNL)

The ~50m ZLV beam transport system (9 lenses, 12 mirrors) has changed the look of the Z high bay



The ZLV beam transport system was completed in November 2018

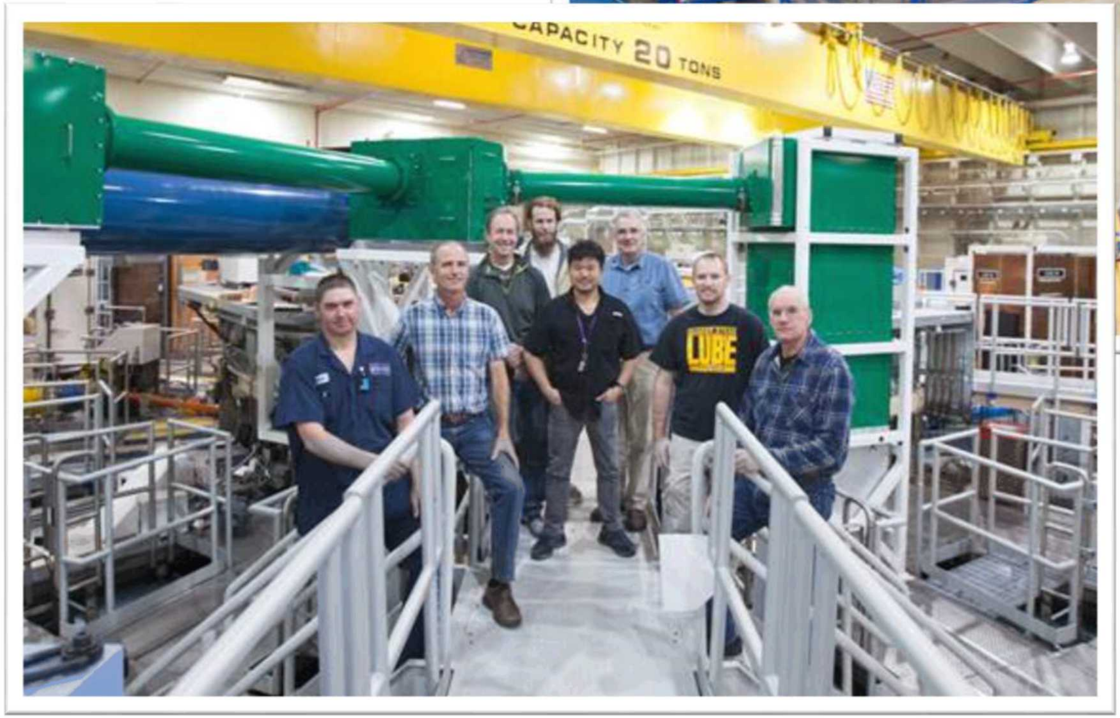
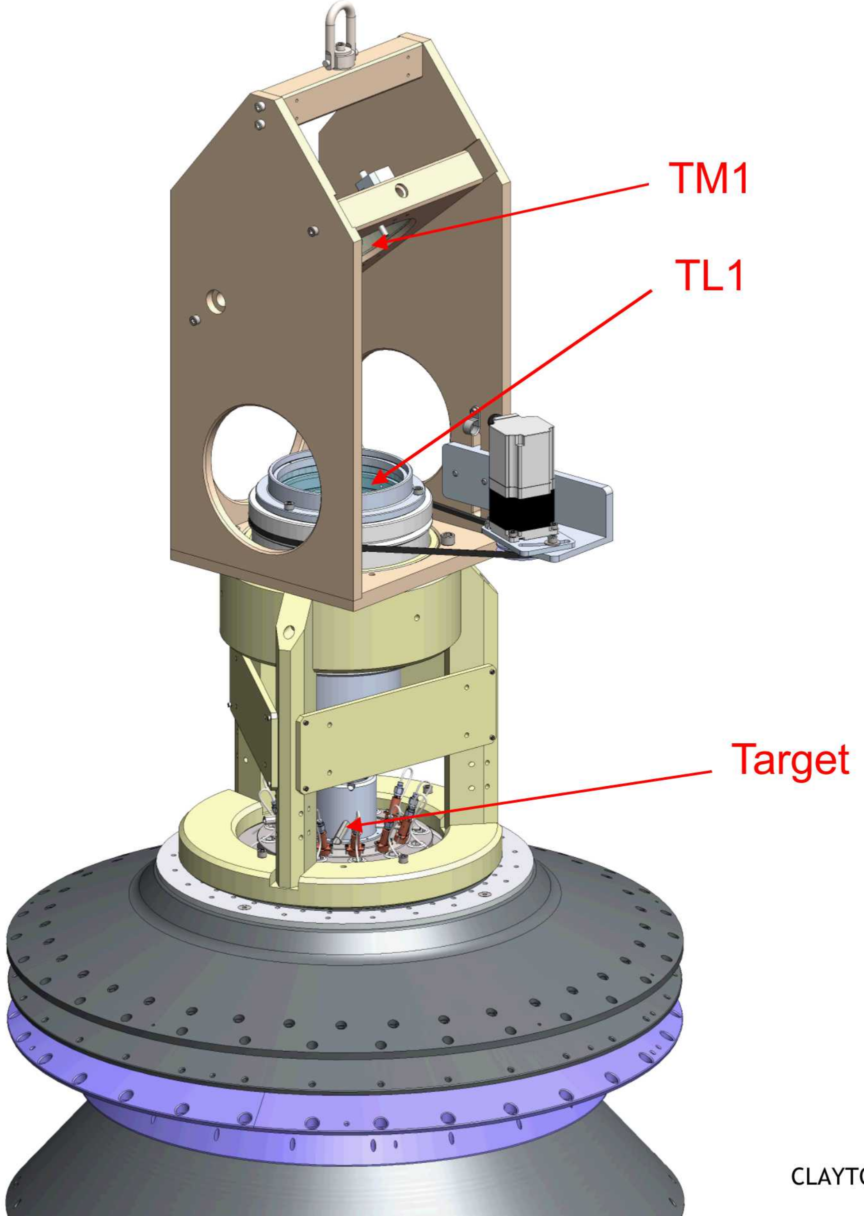
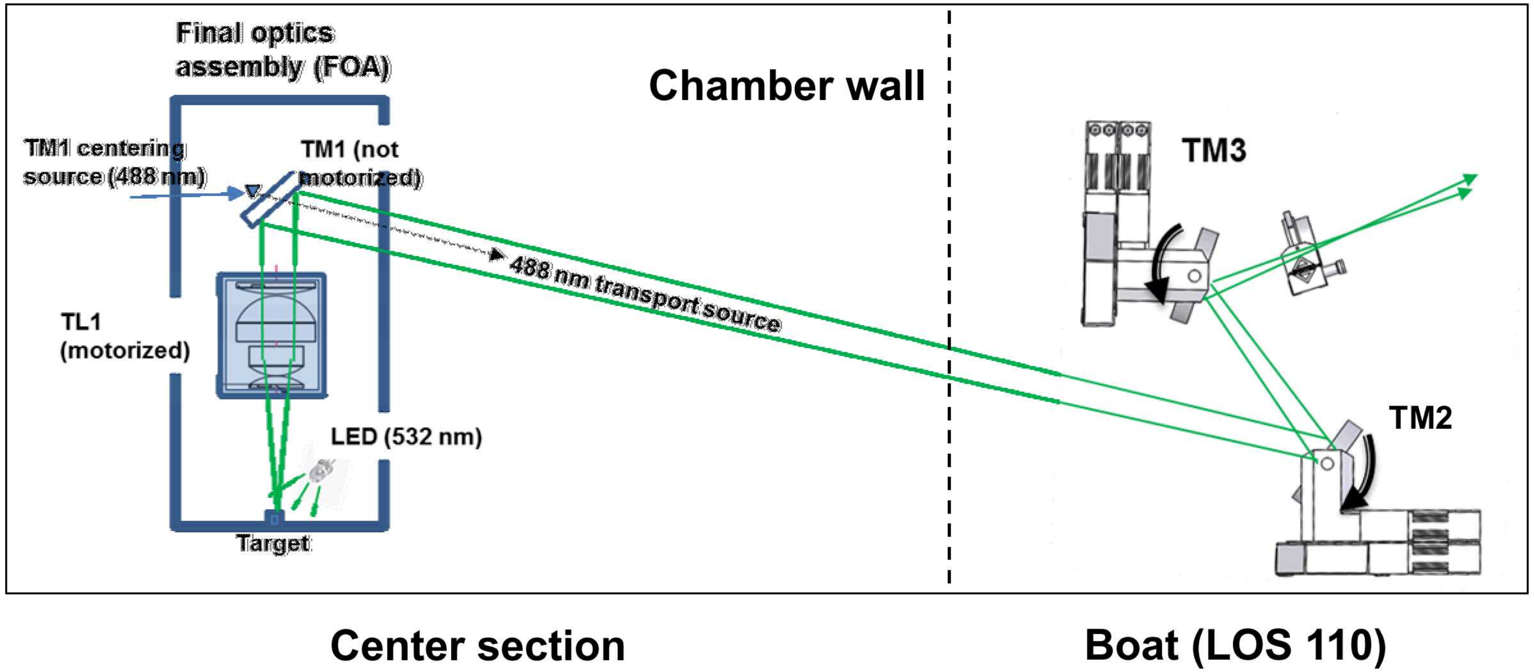


Photo credit: Michael Jones

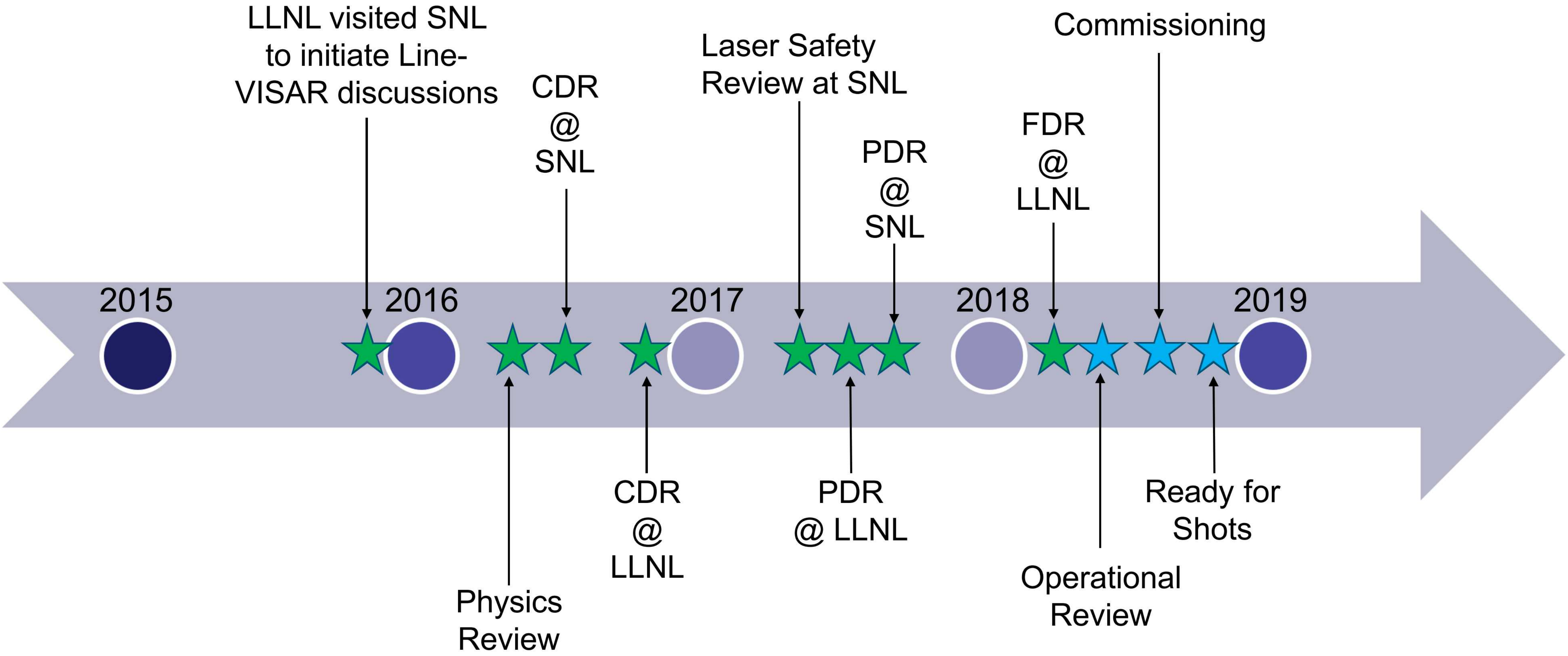
Each Z Line VISAR experiment must field a consumable final optics assembly that precisely images the top of the target





Slide courtesy of Phil Datte (LLNL)

The design and construction phases of the Z Line VISAR project have required a multi-year, multi-institutional effort



Slide courtesy of Michael Jones

Seven machine days (+weekends) were dedicated to ZLV in Q4 of CY18

09-Nov-2018	Fri	ICF	Line-VISAR Commissioning	A0817A		Myers, C.	Robertson, G.
10-Nov-2018	Sat	ICF	Line-VISAR Commissioning	A0817A		Myers, C.	Robertson, G.
12-Nov-2018	Mon	ICF	Line-VISAR Commissioning	A0817A		Myers, C.	Robertson, G.

Beam transport to machine center
Initial target alignment
White-light fringes

30-Nov-2018	Fri	ICF	Line-VISAR Commissioning Setup	A0817A		Myers, C.	Robertson, G.
01-Dec-2018	Sat	ICF	Line-VISAR Commissioning Setup	A0817A		Myers, C.	Robertson, G.
03-Dec-2018	Mon	ICF	Line-VISAR Commissioning	A0817A		Myers, C.	Robertson, G.
04-Dec-2018	Tue	ICF	Line-VISAR Commissioning	A0817A		Myers, C.	Robertson, G.

Additional target alignment
First streaked fringes
ZLV diagnostic milestone
Vacuum pumpout test

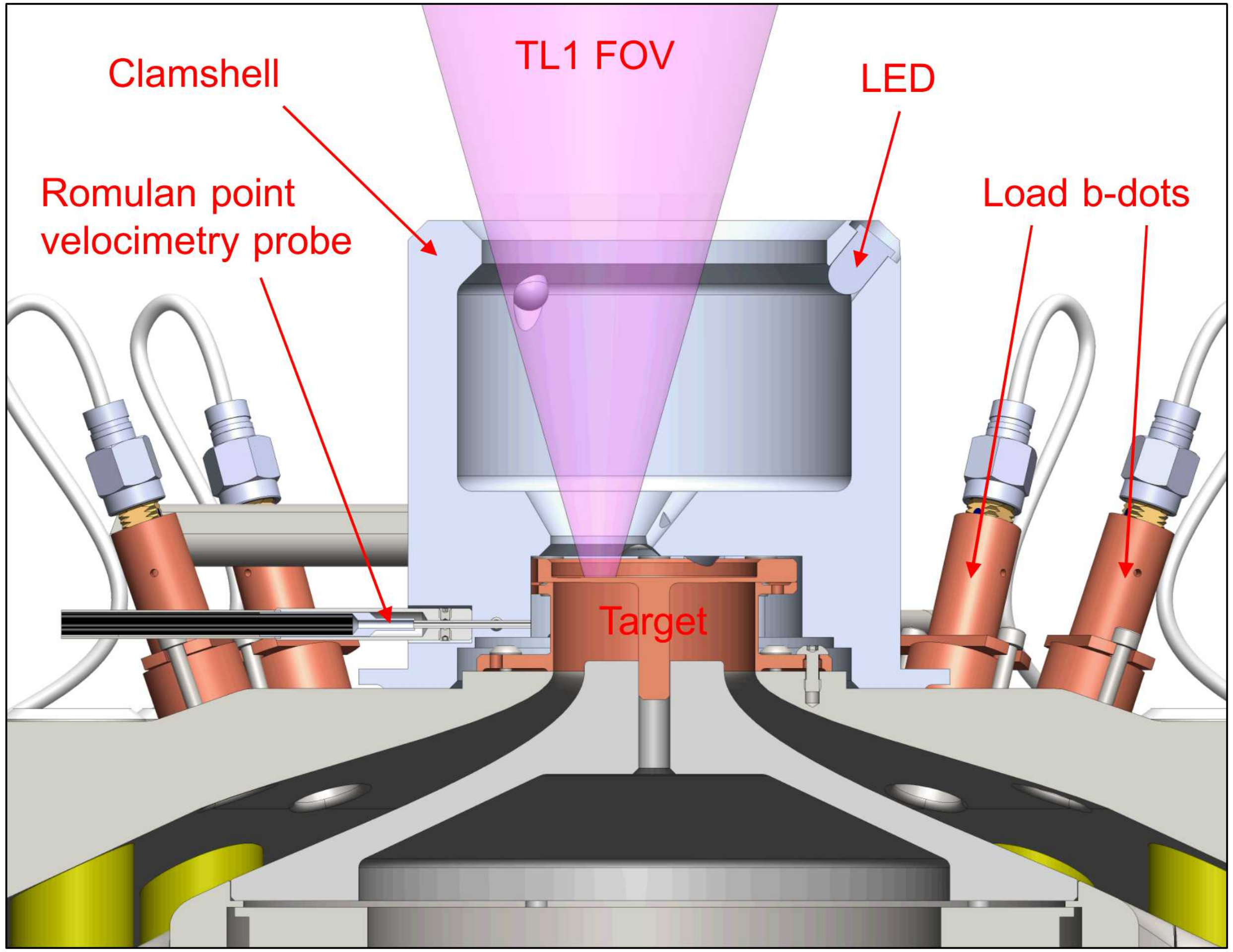
14-Dec-2018	Fri	ICF	Line-VISAR Commissioning Setup	A0817A		Myers, C.	Robertson, G.
17-Dec-2018	Mon	ICF	Line-VISAR Commissioning	A0817A	z3337	Myers, C.	Robertson, G.

Improved streaked fringes
Full target alignment
Downline commissioning shot

- The ZLV instrument was brought online in three separate commissioning schedule blocks
- Remarkable progress: first target alignment → first streaked fringes → first downline shot

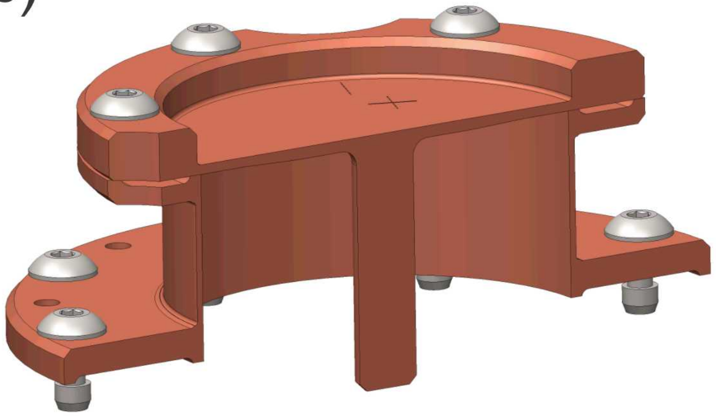
ZLV commissioning load hardware (A0817)

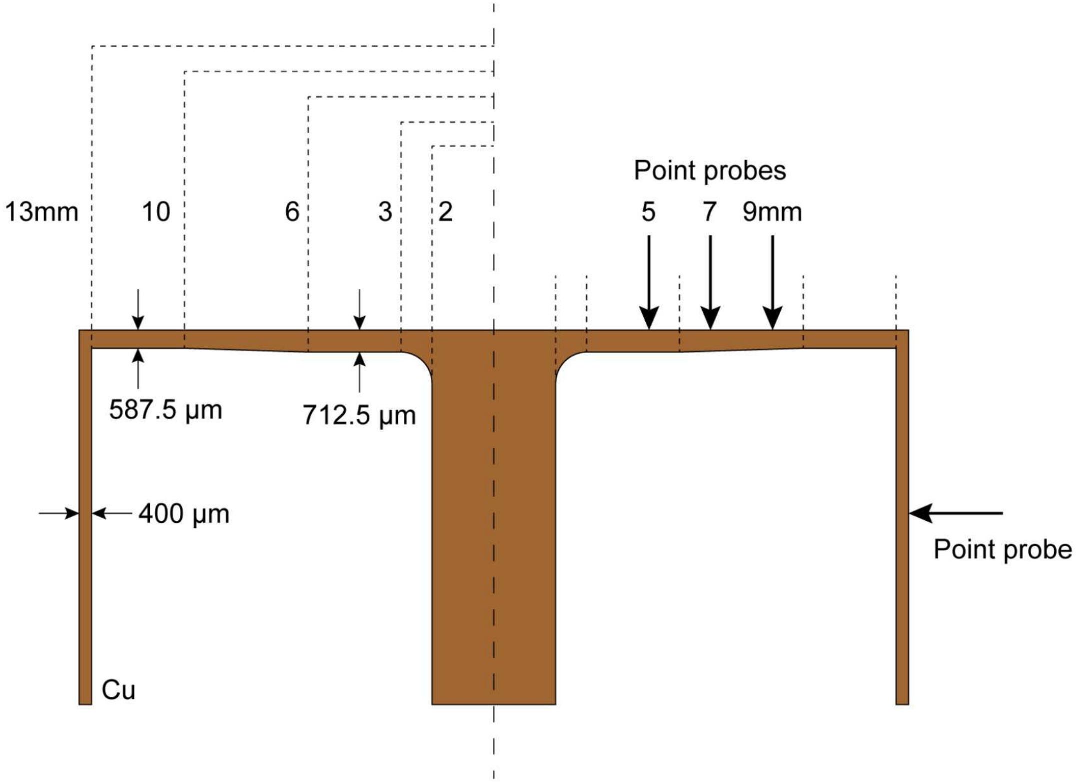
- The TM1/TL1 optics assembly mounts to the top anode → alignment tolerance
- The only in-chamber adjustment is the TL1 focus (no tip/tilt)
- For commissioning, the TL1 FOV is offset from machine center by 7 mm
- Ten load B-dots are fielded to assess the current delivered to the inner MITL
- Nine Romulan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



ZLV commissioning target (PD: Mark Hess)

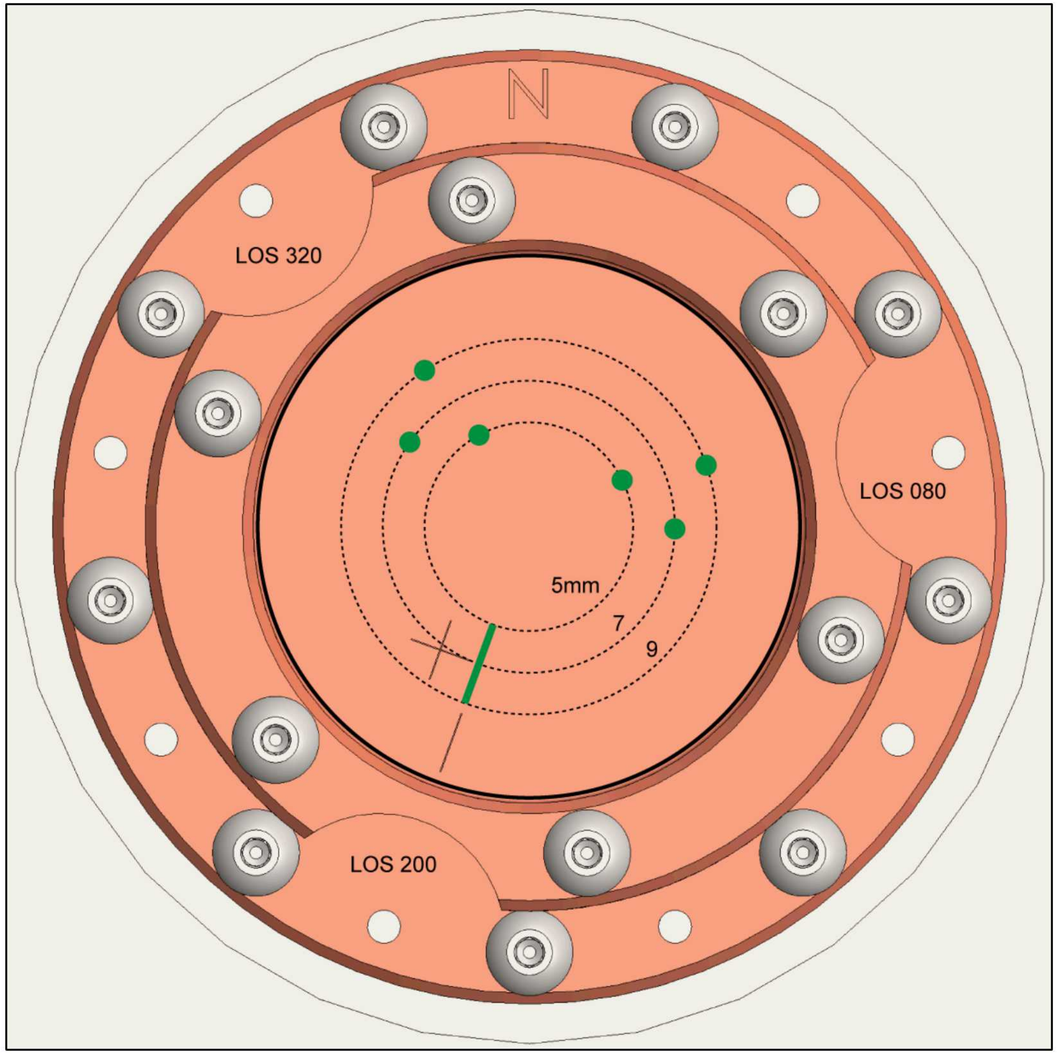
- The commissioning target is a non-imploding copper target with a shimmed top cap
- The top cap thins linearly from 712.5 μm to 587.5 μm between r = 6 mm and r = 10 mm
- A 1-mm radius on the inner corner is included to suppress breakthrough due to high magnetic pressure on the inboard side
- A 400-μm-thick return can enables standard side-on load current velocimetry



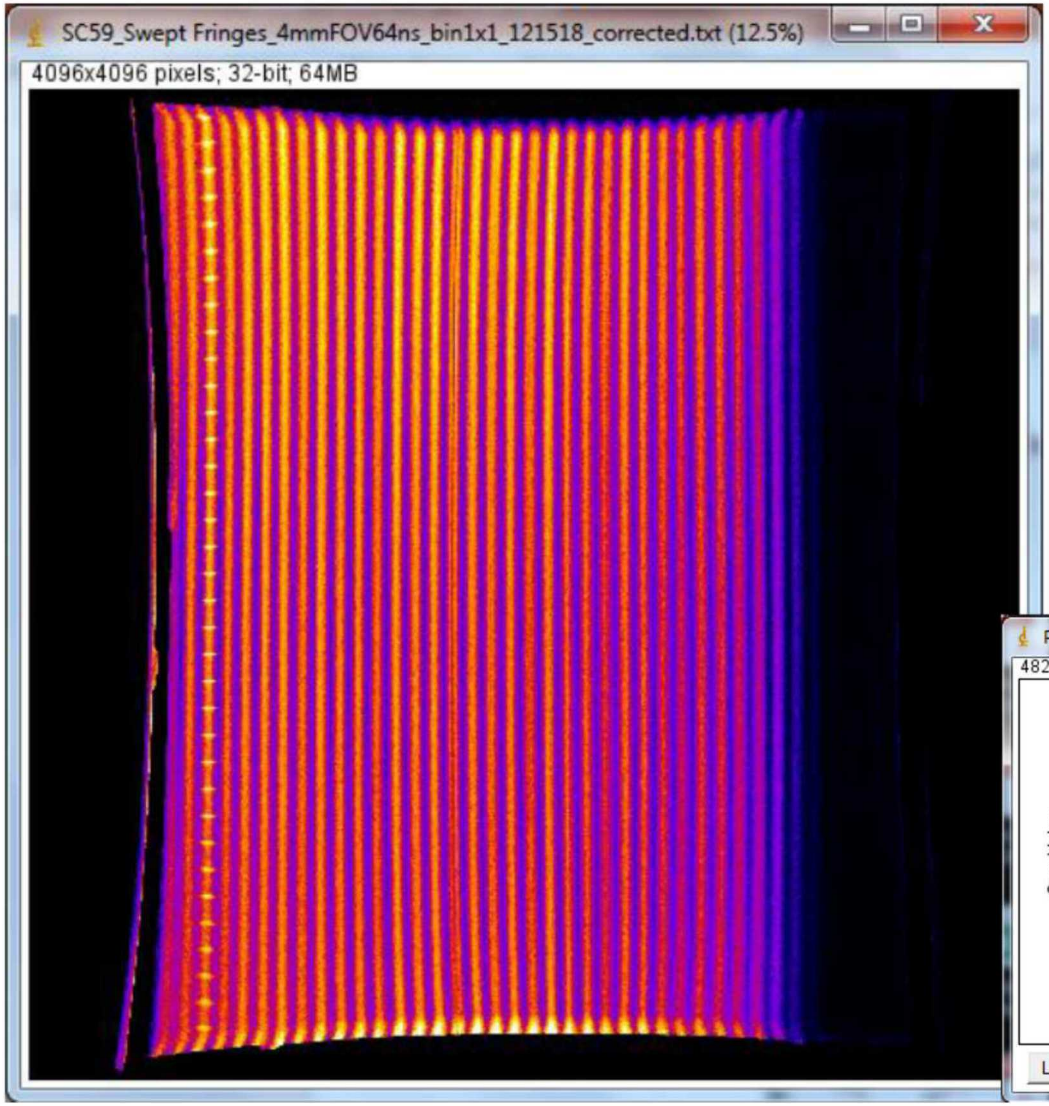


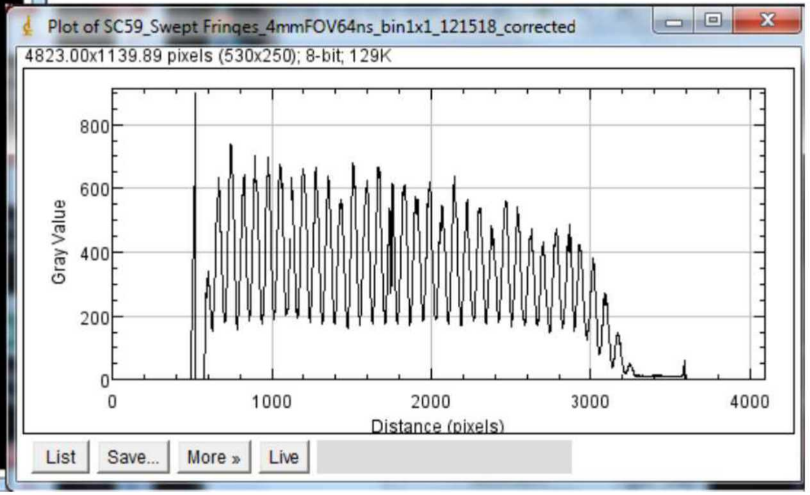
ZLV commissioning target (PD: Mark Hess)

- The commissioning target is a non-imploding copper target with a shimmed top cap
- The top cap thins linearly from 712.5 μm to 587.5 μm between r = 6 mm and r = 10 mm
- A 1-mm radius on the inner corner is included to suppress breakthrough due to high magnetic pressure on the inboard side
- A 400-μm-thick return can enables standard side-on load current velocimetry
- Six point probes are clustered into sets of three on top of the target at 5, 7, and 9mm
- Line VISAR spans the same distance at a different azimuth



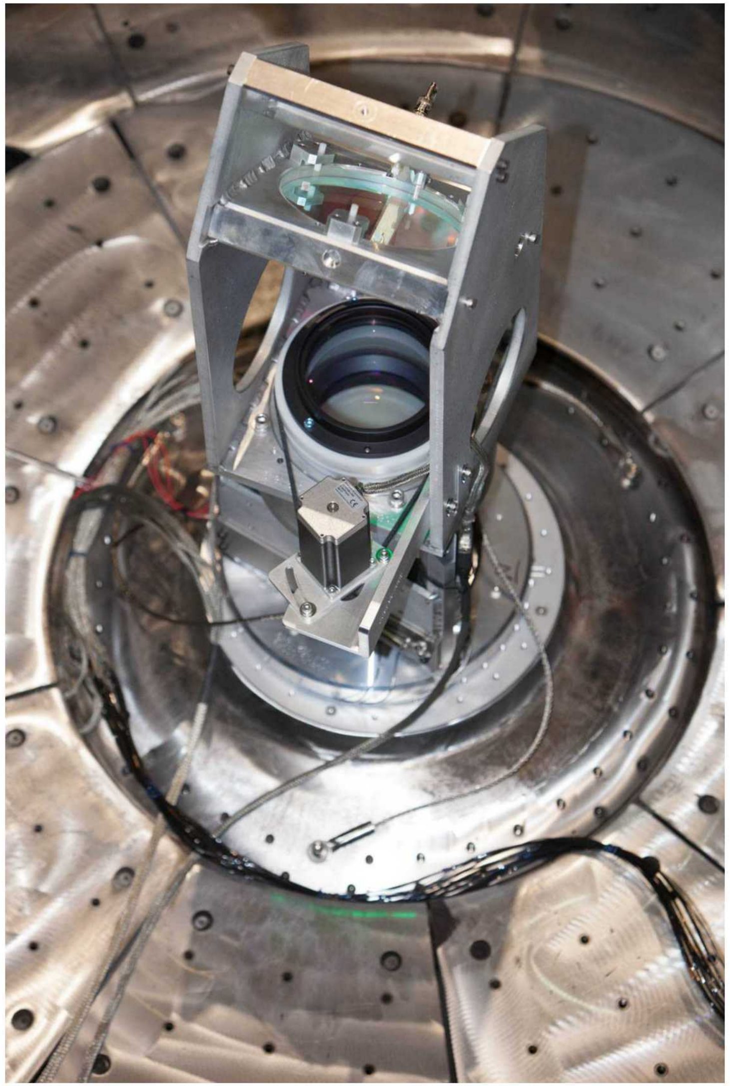
By the third ZLV commissioning schedule block, we were obtaining shot-quality streaked fringes from an aligned commissioning target

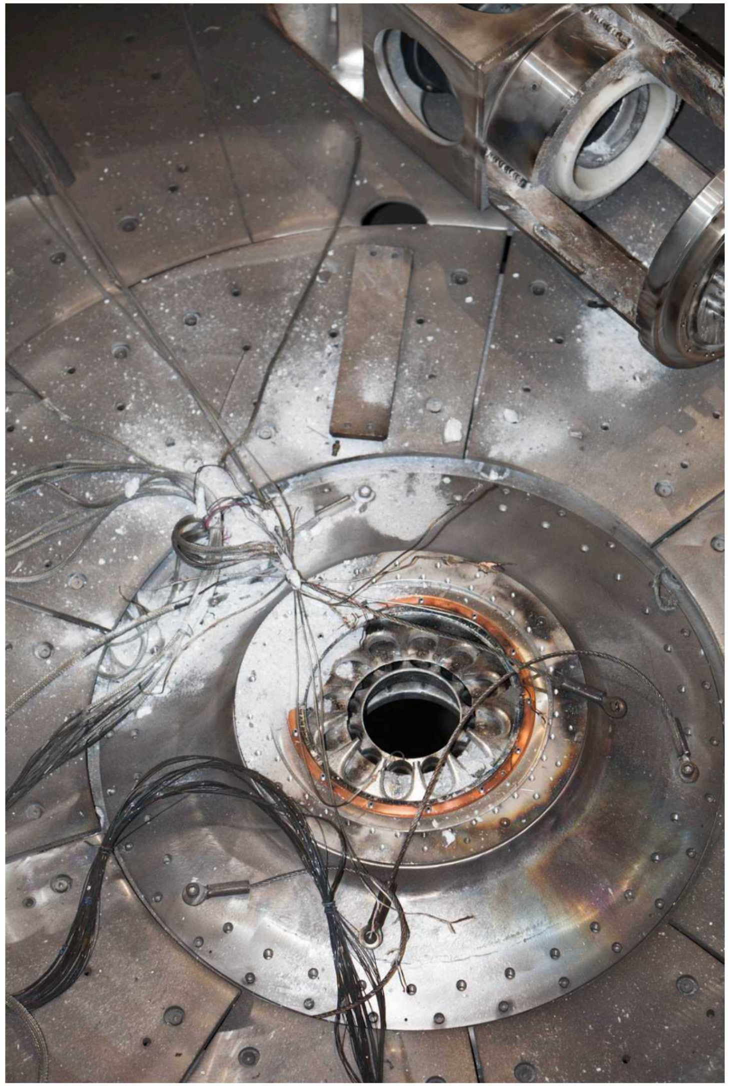




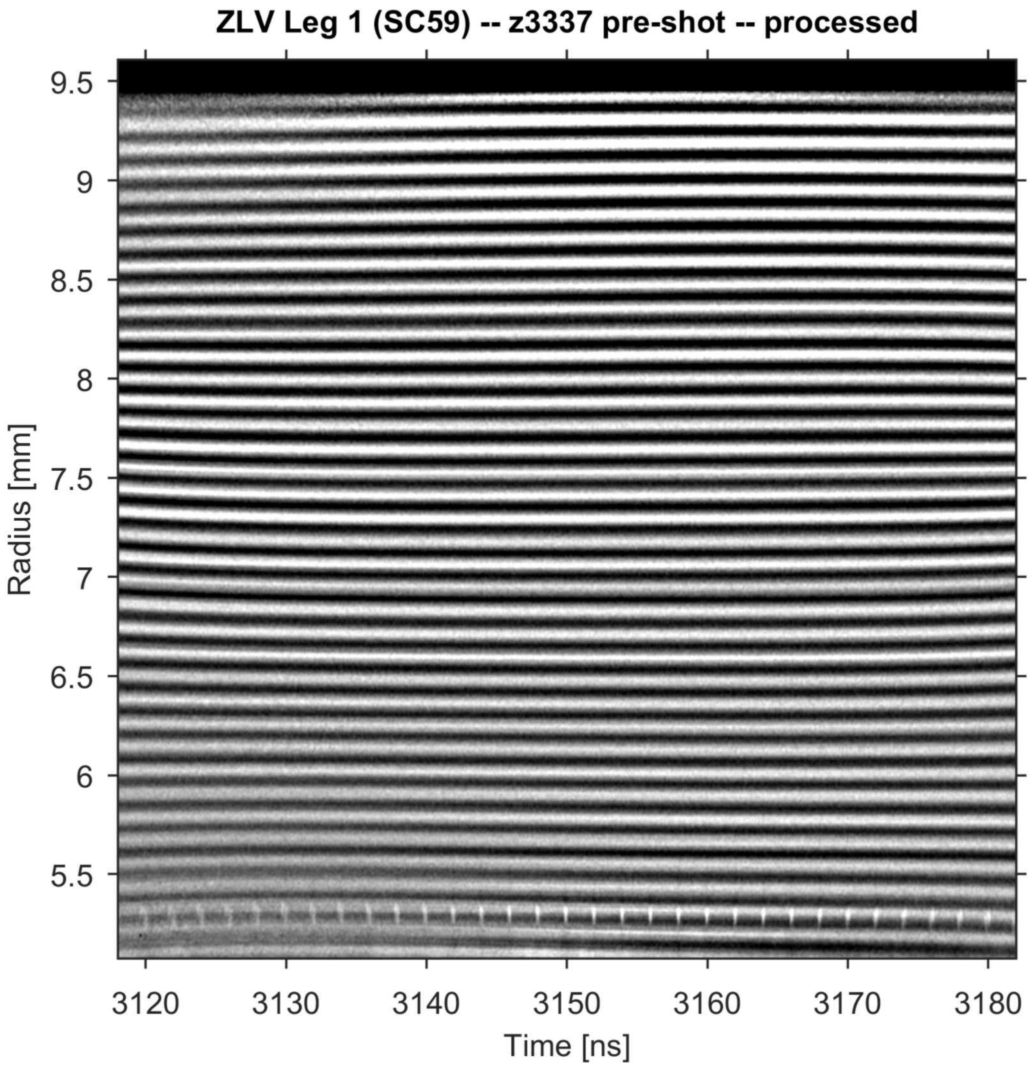
Fringes set with pico-motors, speckling and illumination much improved

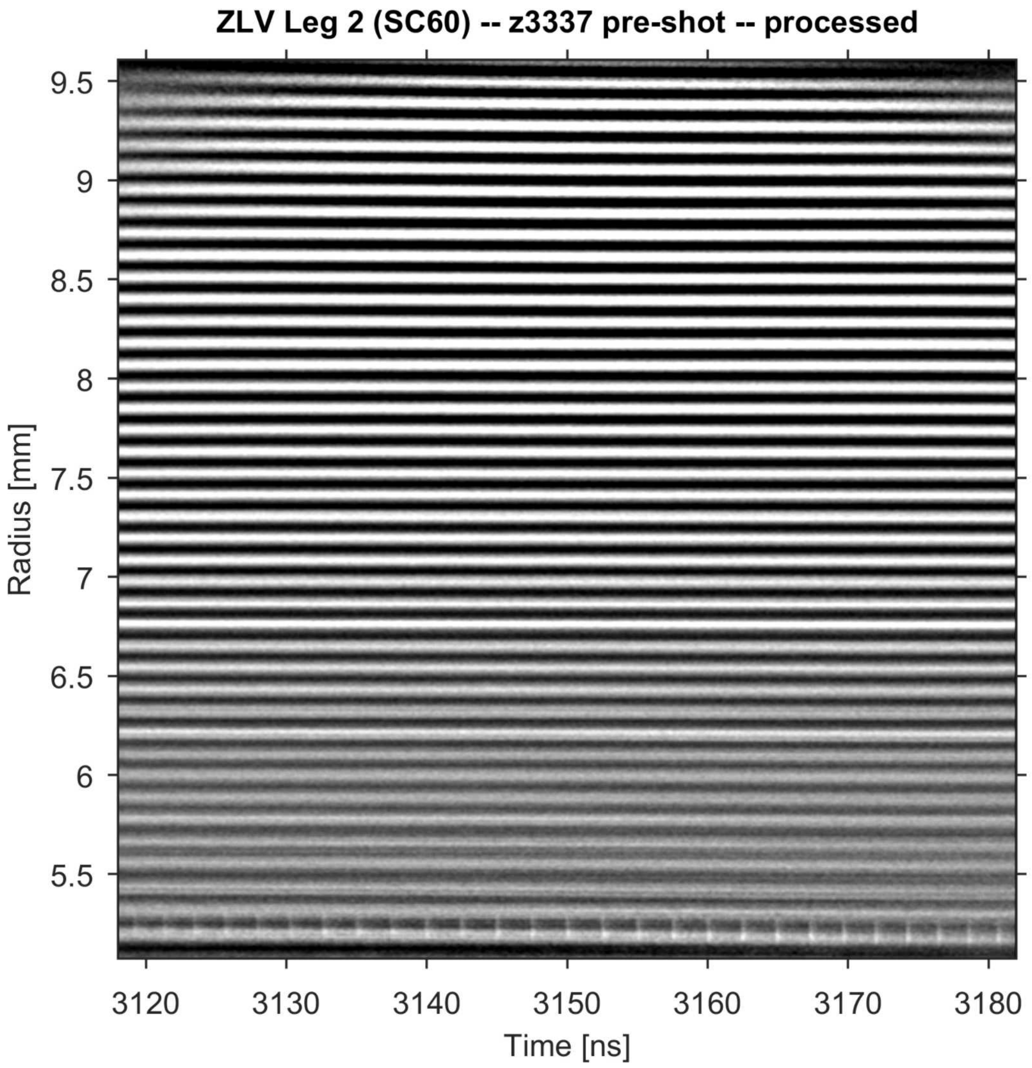
At 4:52p on December 17th, the first ZLV shot went downline (z3337)



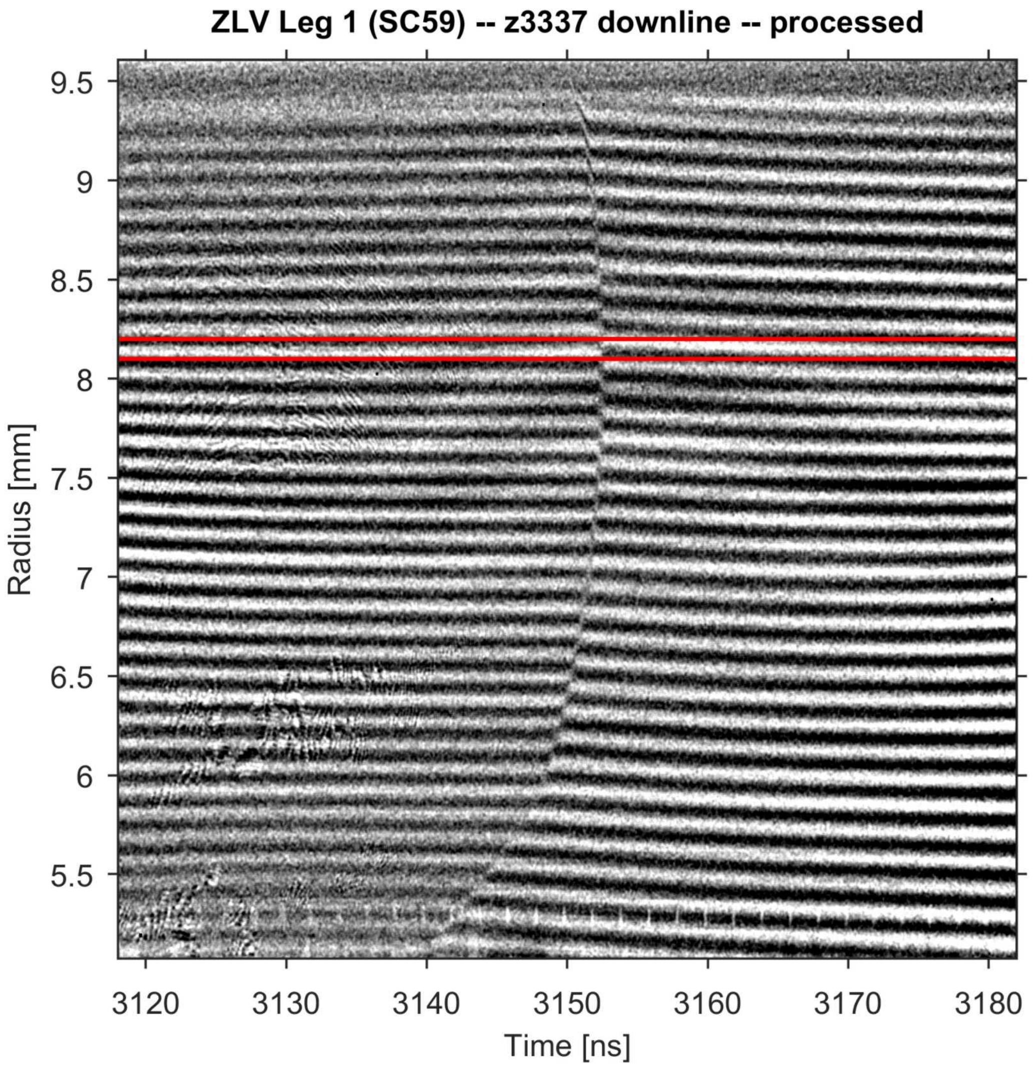


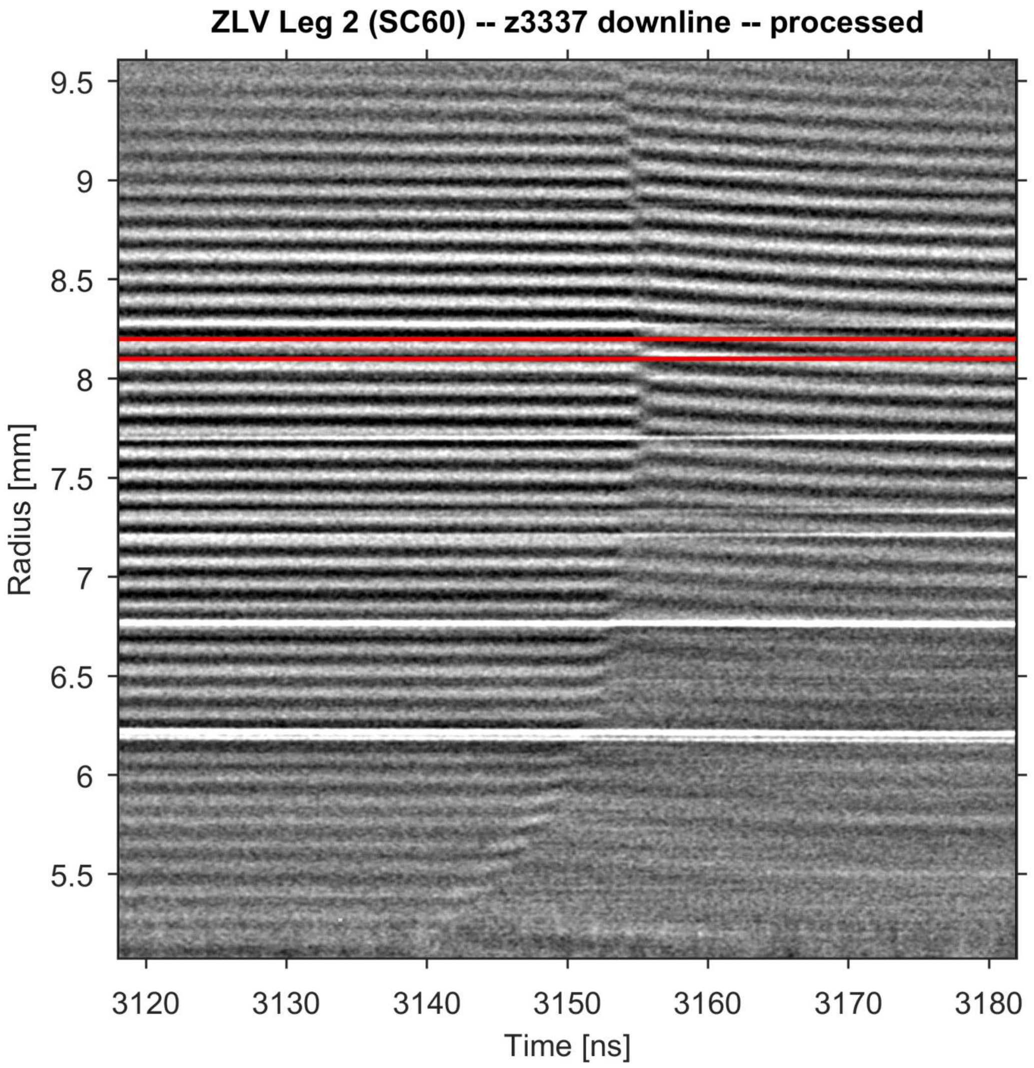
The pre-shot fringe contrast was good across most of the field of view of each of the two ZLV interferometer legs



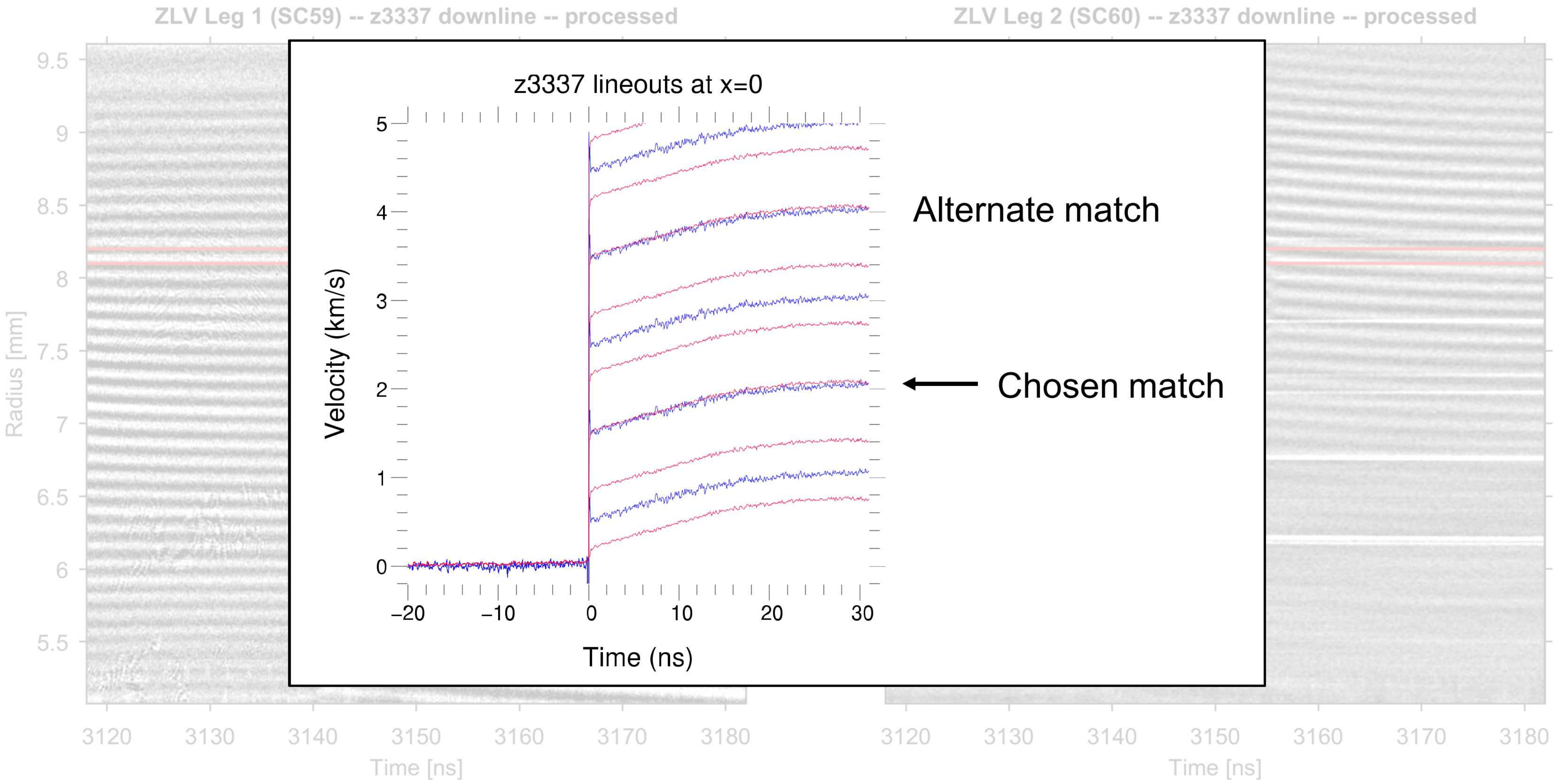


Despite substantial background light, we observed a curved shock breakout on both ZLV legs at the expected time of ~3150 ns!

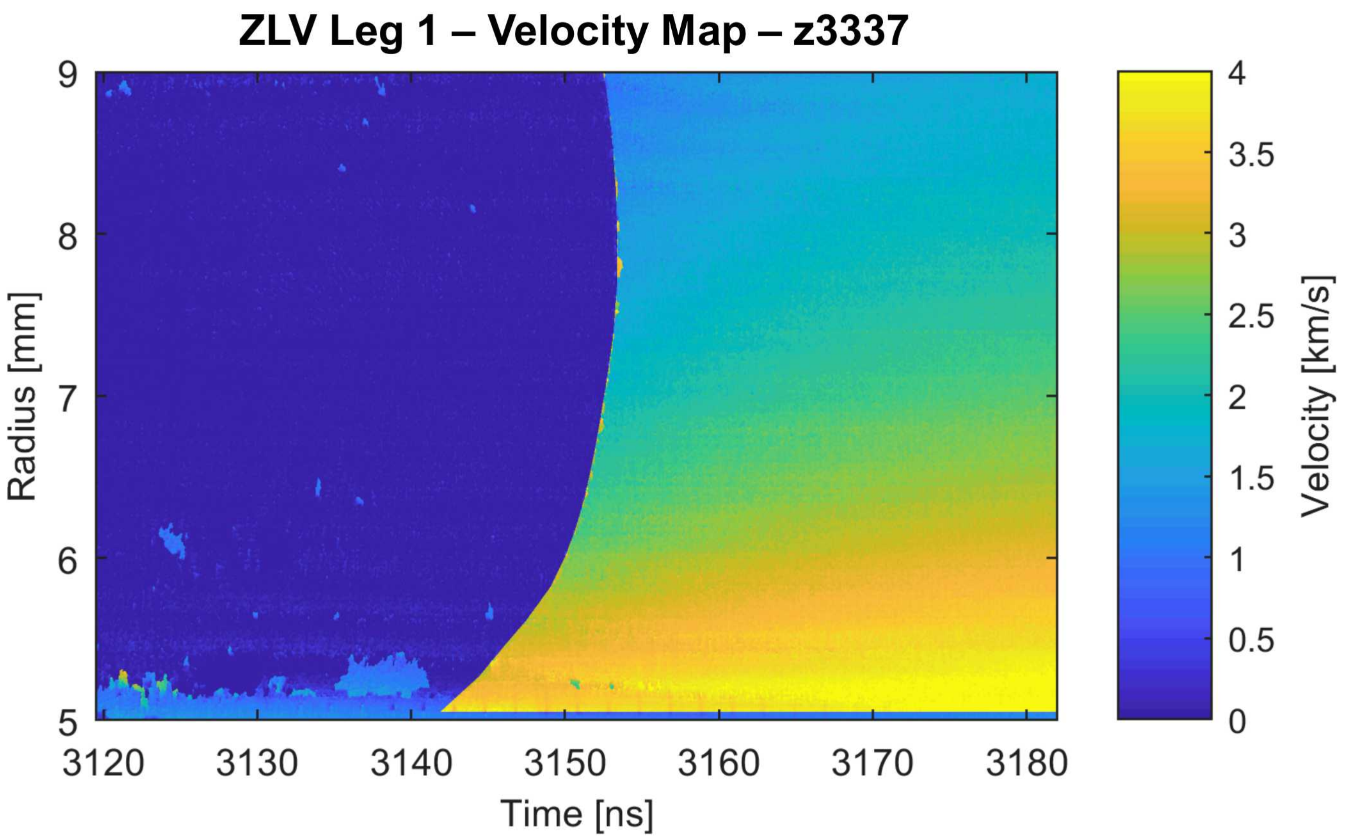




Taking lineouts at 8.1–8.2mm provides an assessment of the fringe jump condition required to match the two ZLV interferometer legs



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



Line VISAR unfolds:

Peter Celliers and Dave Erskine

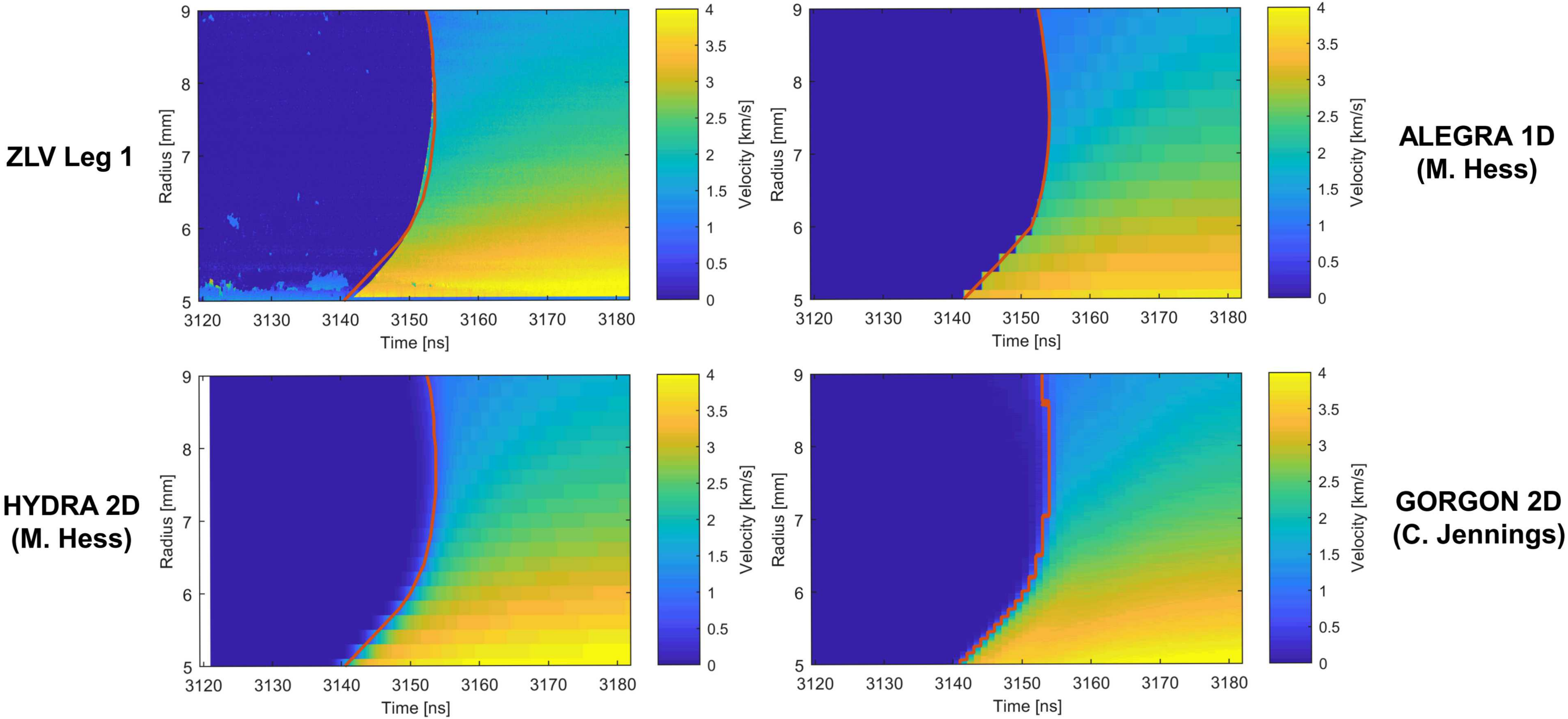
Streak image registration:

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

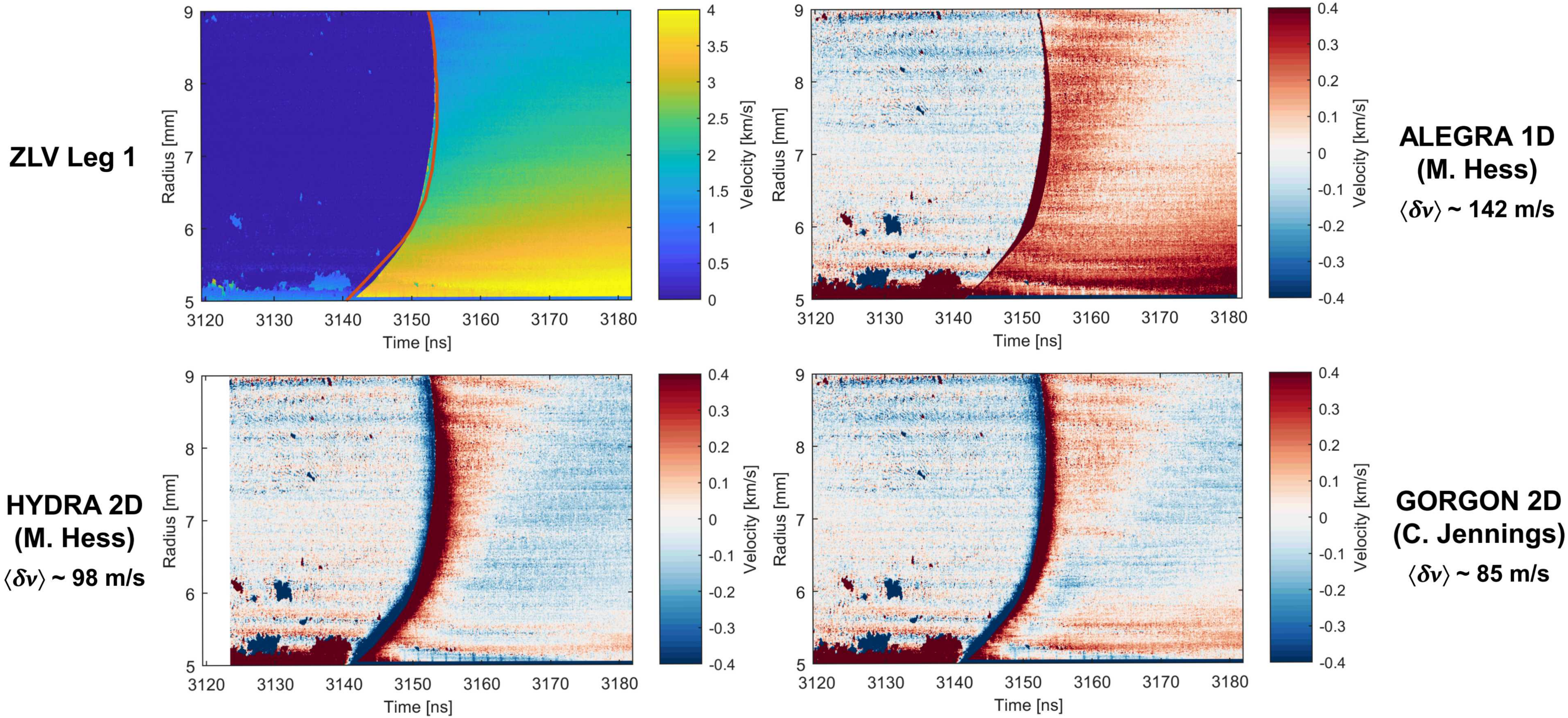
Comments:

- The team had to resolve a directional ambiguity in the fringe motion (point probes)
- The timing combs will not be fielded on future downline shots to improve data quality on the inboard side

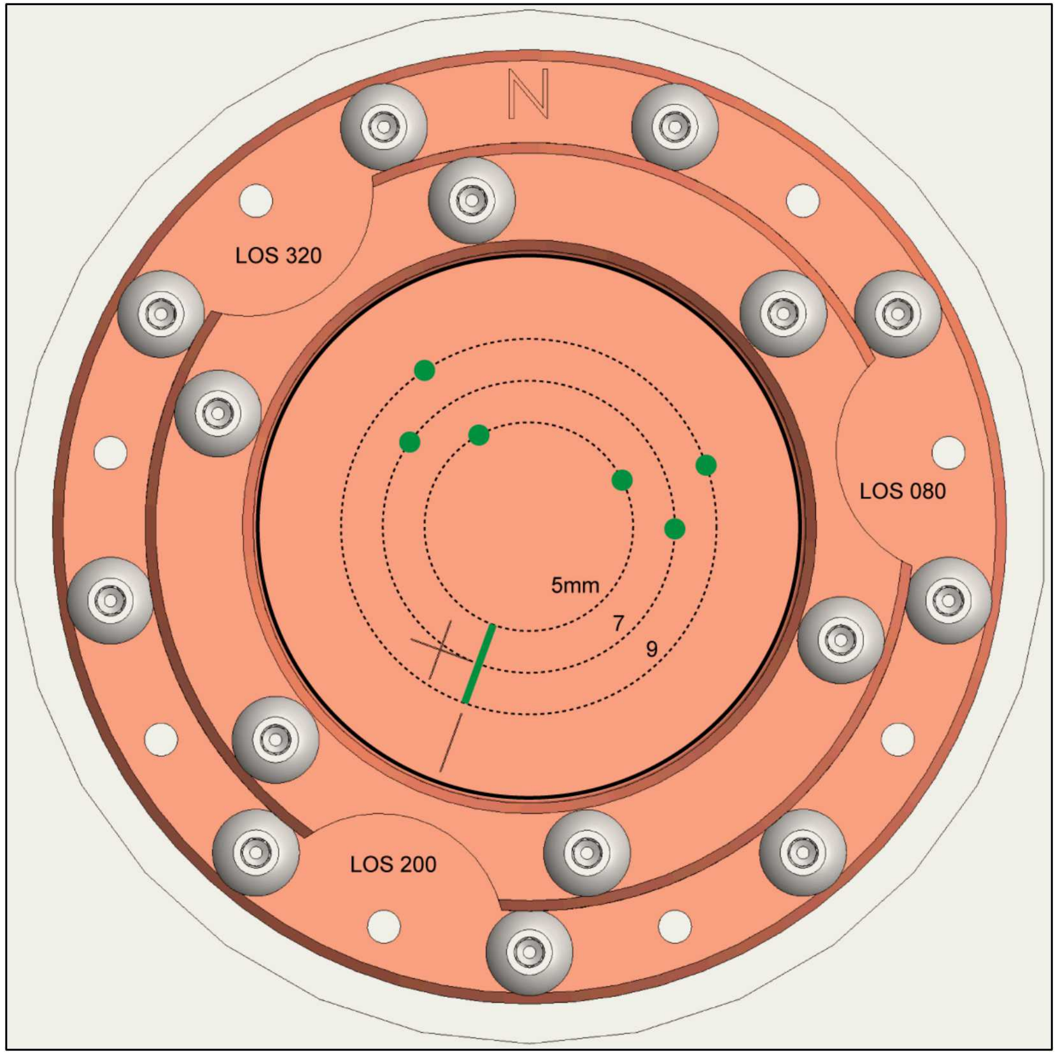
ALEGRA, HYDRA, and GORGON simulations driven by the measured load current waveform all show remarkable agreement with the ZLV data

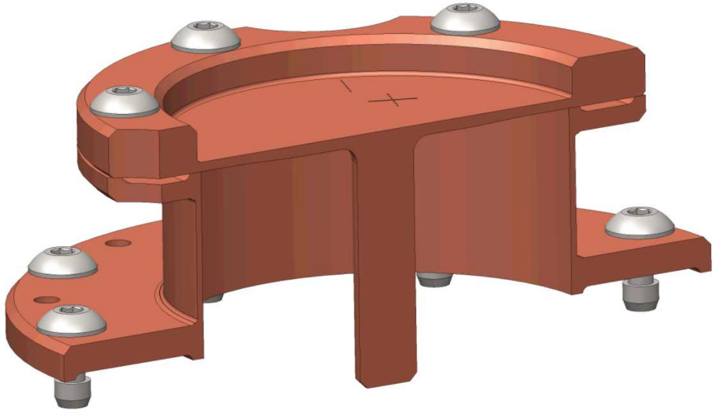


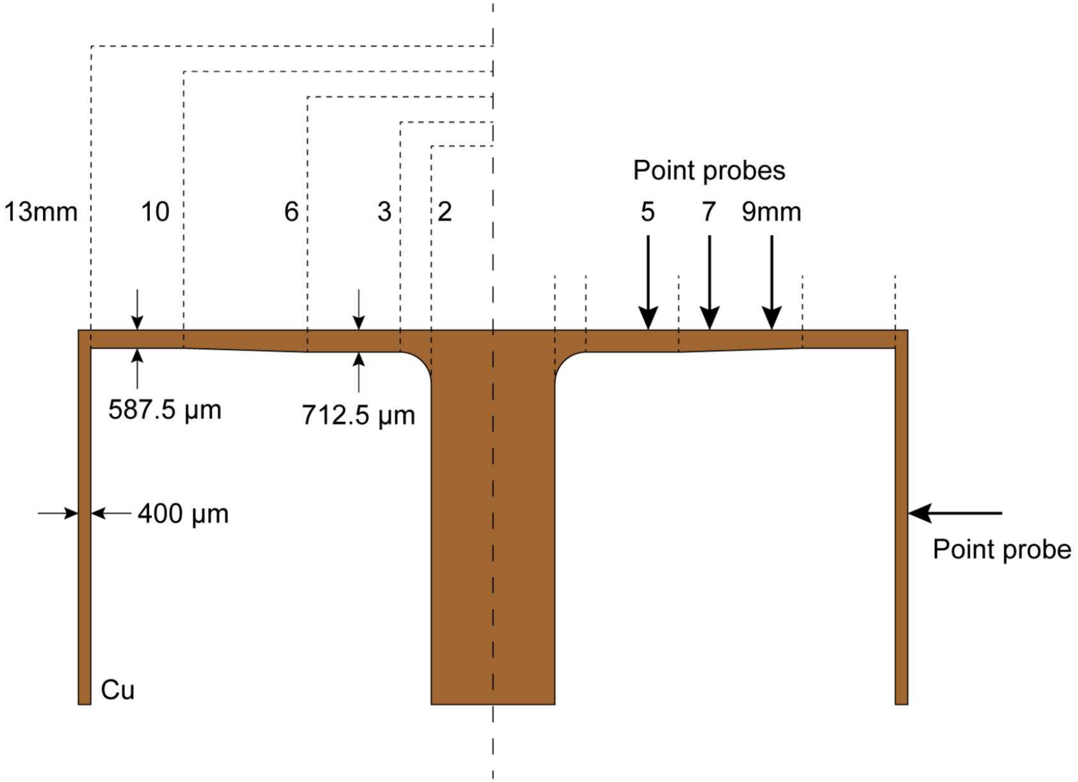
Differencing the simulations from the ZLV data reveals that the RMS differential is ~100 m/s in the 2D calculations → the target is lossless



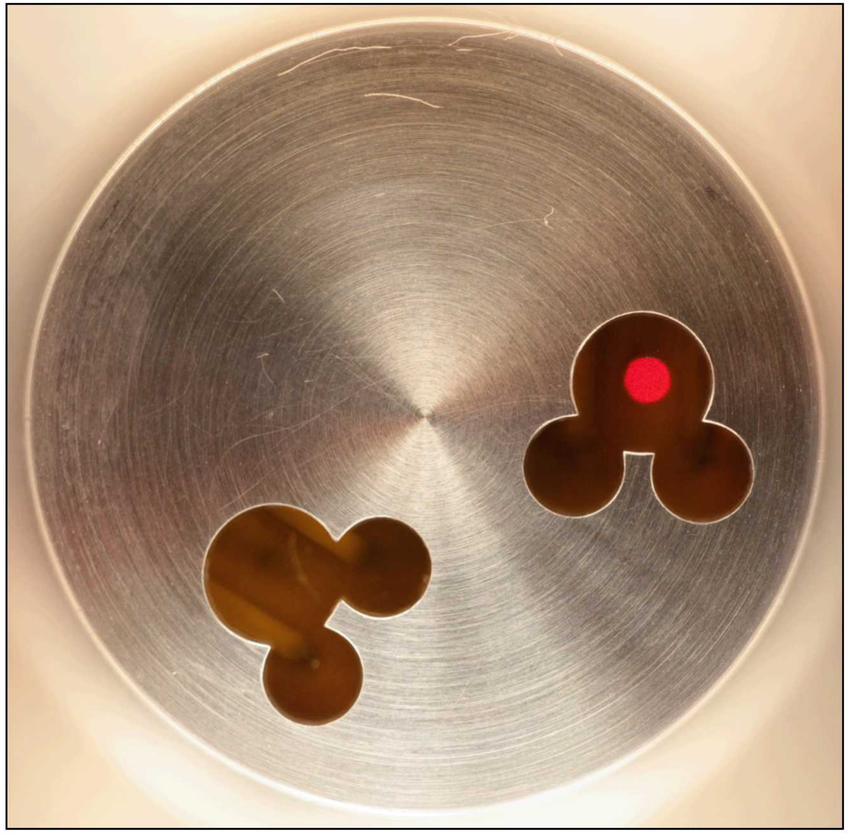
What about the point probe data?

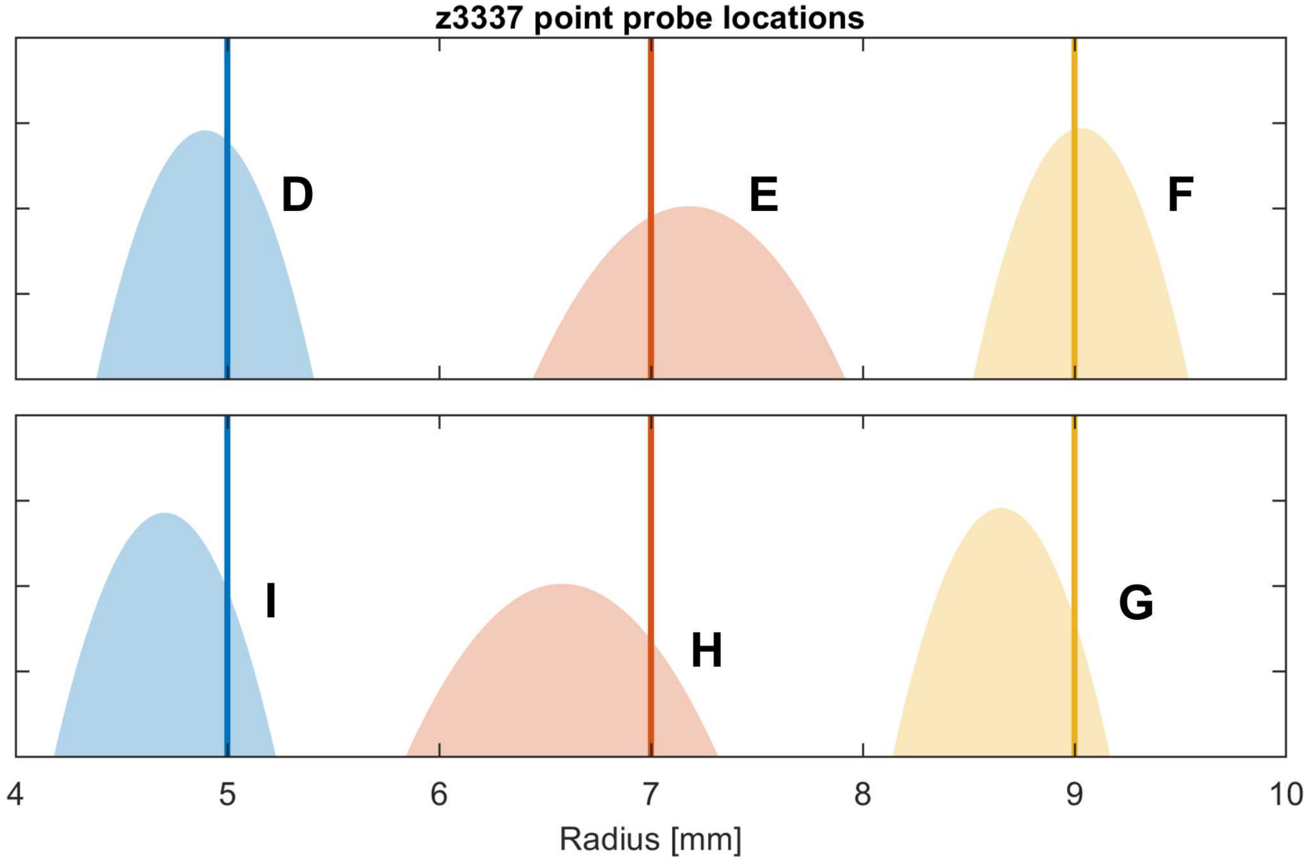






Using the machined features on a surrogate target, we are able to identify the radius and spot size of each point probe fiber → 1–1.5mm spot size



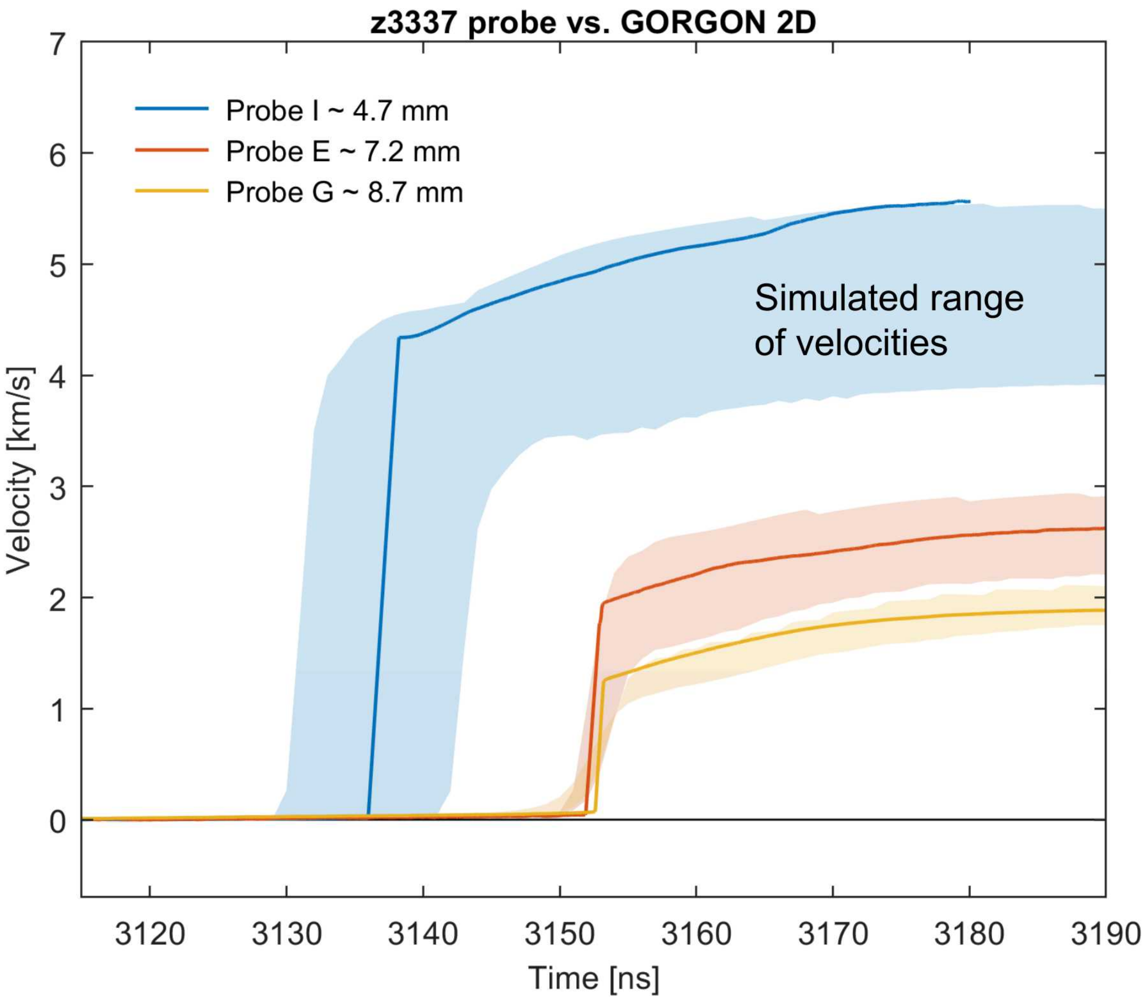


Difficult to compare inboard and outboard probes to ZLV with the FOV limited to [5mm, 9mm]

The large spot size on the point probes means that a wide range of velocities could be observed → not highly constraining on the ZLV results

Summary of point velocimetry results:

- The velocity measured at the r ~ 9mm location is reasonably close to 1D simulations
- The lack of PDV to constrain the shock height at r ~ 7mm prevents a robust comparison
- The r ~ 5mm location registers velocities that are on the high end of the simulations
- It’s difficult to ascertain what radius each probe is sampling → the most prominent reflecting surface could evolve during the shot
- The difficulty of measuring spatially resolved velocities with point probes, even on a simple commissioning target, highlights the transformative nature of Z Line VISAR



Summary of ZLV commissioning progress

We achieved 90% of our commissioning goals on the first shot:

- ZLV data was obtained on both ZLV interferometer legs
- We were able to convert that data to a 2D velocity map – $v(r, t)$
- Comparisons to simulations from multiple codes show consistent shock breakout profiles as well as post-shock velocities that agree to better than 5%
- The ZLV data is also consistent with point velocimetry data, but the large spot size of the point probes limits the ability to constrain the ZLV results

We are pursuing a follow-on commissioning shot before the Sierra B 19a series in May:

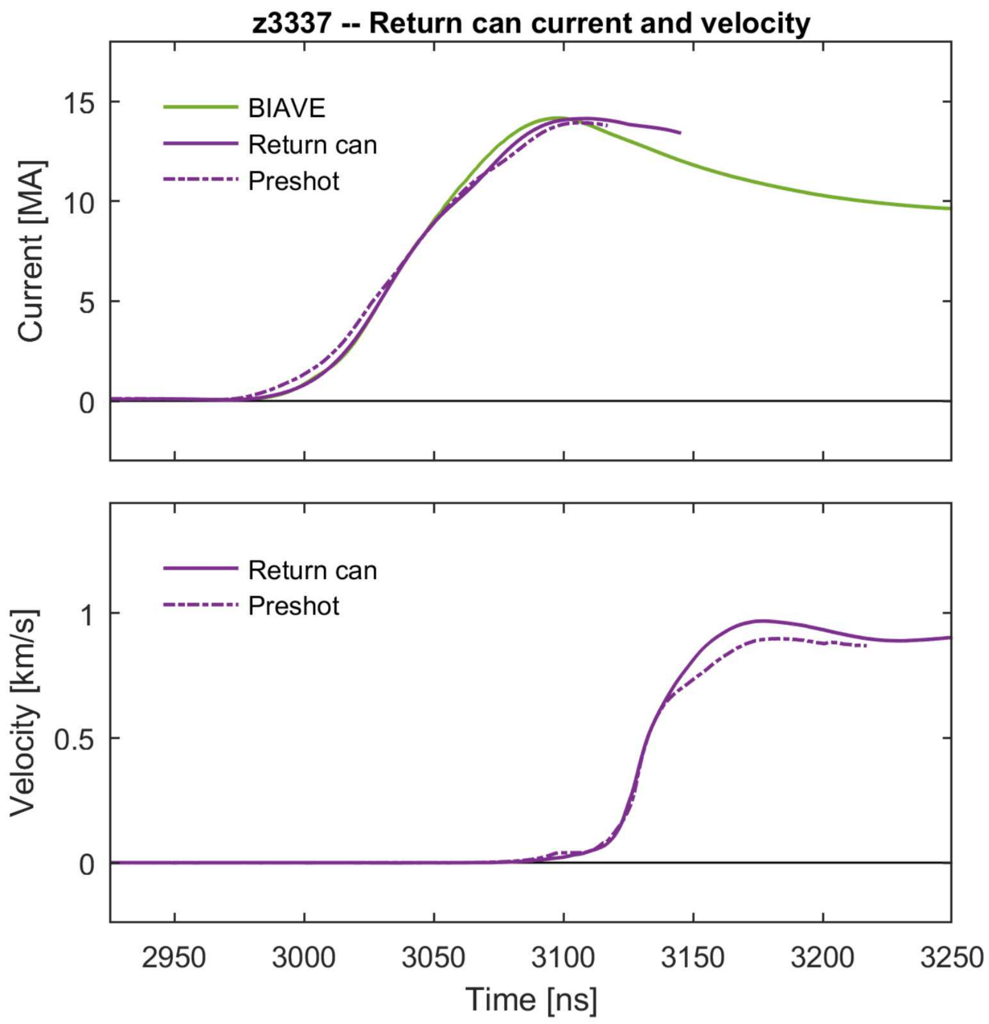
- Demonstrate improved fringe contrast (realign optics) and signal-to-noise (bandpass filters)
- Commission the gated optical imager (GOI)
- Demonstrate robust shot-day procedures and operations

We had excellent success on the first ZLV commissioning shot. Let’s prove that we can do it again, and let’s improve the performance of the instrument in the process.

BACKUP

A load current waveform unfolded from the return can velocimetry is being used to drive numerous post-shot simulations

- All three point VISAR channels from each of the three probes returned good data
- Good PDV only obtained from Probe C
- Consistent velocities at all three azimuthal locations indicate that the target was driven symmetrically in this 50 kV shot
- A load current unfold from the velocimetry data (Jennings) indicates some loss in the inner MITL
- Peak load current ~ 14.1 MA
- The pre-shot current prediction (Hutsel) is slightly more lossy, but it is reasonably close to the downline waveform (after a 17ns shift)



Goals of the follow-on commissioning shot

ZLV modifications/improvements:

- High fringe contrast on both interferometer legs → realign interferometer optics
- Improved signal-to-noise on the downline shot → install bandpass filters
- Commission the gated optical imager (GOI)
- Robust pre-shot procedures for spatially and temporally registering the streak images

Non-ZLV modifications/improvements:

- Seek better PDV data return (especially to remove shock height ambiguity at 7mm)
- Reconfigure the point VISAR VPFs for known target behavior
- Seek stack electrical data return (the stack B-dots clipped on this shot)

We had excellent success on the first ZLV commissioning shot. Let's prove that we can do it again, and let's improve the performance of the instrument in the process.

What are the completion criteria for ZLV physics commissioning?

The second commissioning shot will hopefully give:

- Improved ZLV data quality
- Improve point probe comparisons with better PDV return, better VISAR VPFs

The second commissioning shot will not give:

- Smaller spot sizes or better locations for the point probes
- A better-behaved target on the inboard side

As a practical matter, physics commissioning is complete with a successful second commissioning shot, in spite of its limitations.

To better quantify the precision of the ZLV diagnostic, we could execute of a future commissioning experiment where we image a ~1D split flyer with two thicknesses:

- Eliminates the point probe spot size issue
- The split flyer behavior would be much more predictable