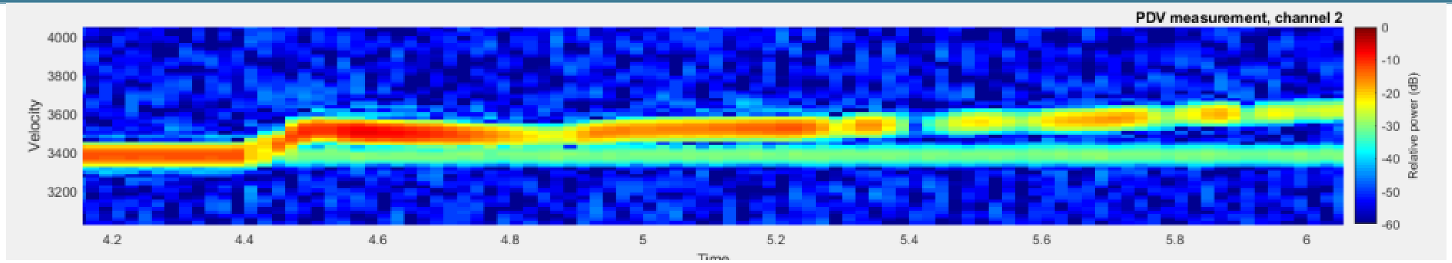
This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

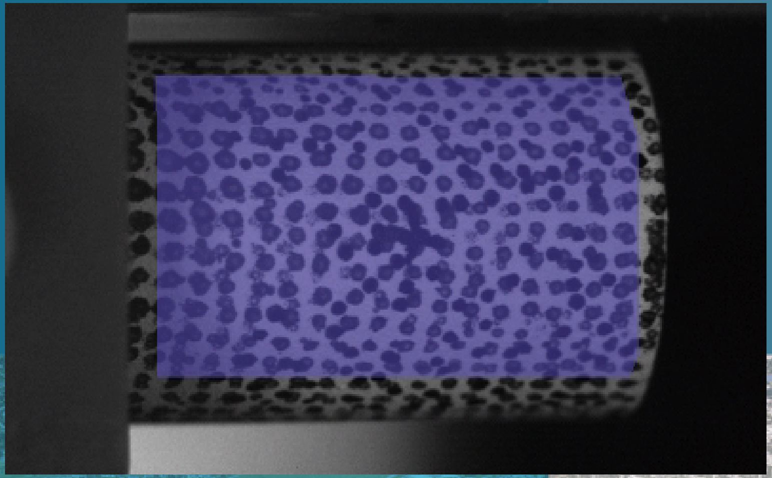
SAND2022-8105C

Sandia National Laboratories

A Study in Paint Failure in Explosively Driven DIC Testing

High-rate testing and leveling





Phillip L. Reu,

Elizabeth Jones, Daniel Guildenbecher, Elise Hall, Mike Bejarano, and Patrick Ball

Society for Experimental Mechanics (SEM)

June 2022, Pittsburgh, USA

U.S. DEPARTMENT OF ENERGY NNSA

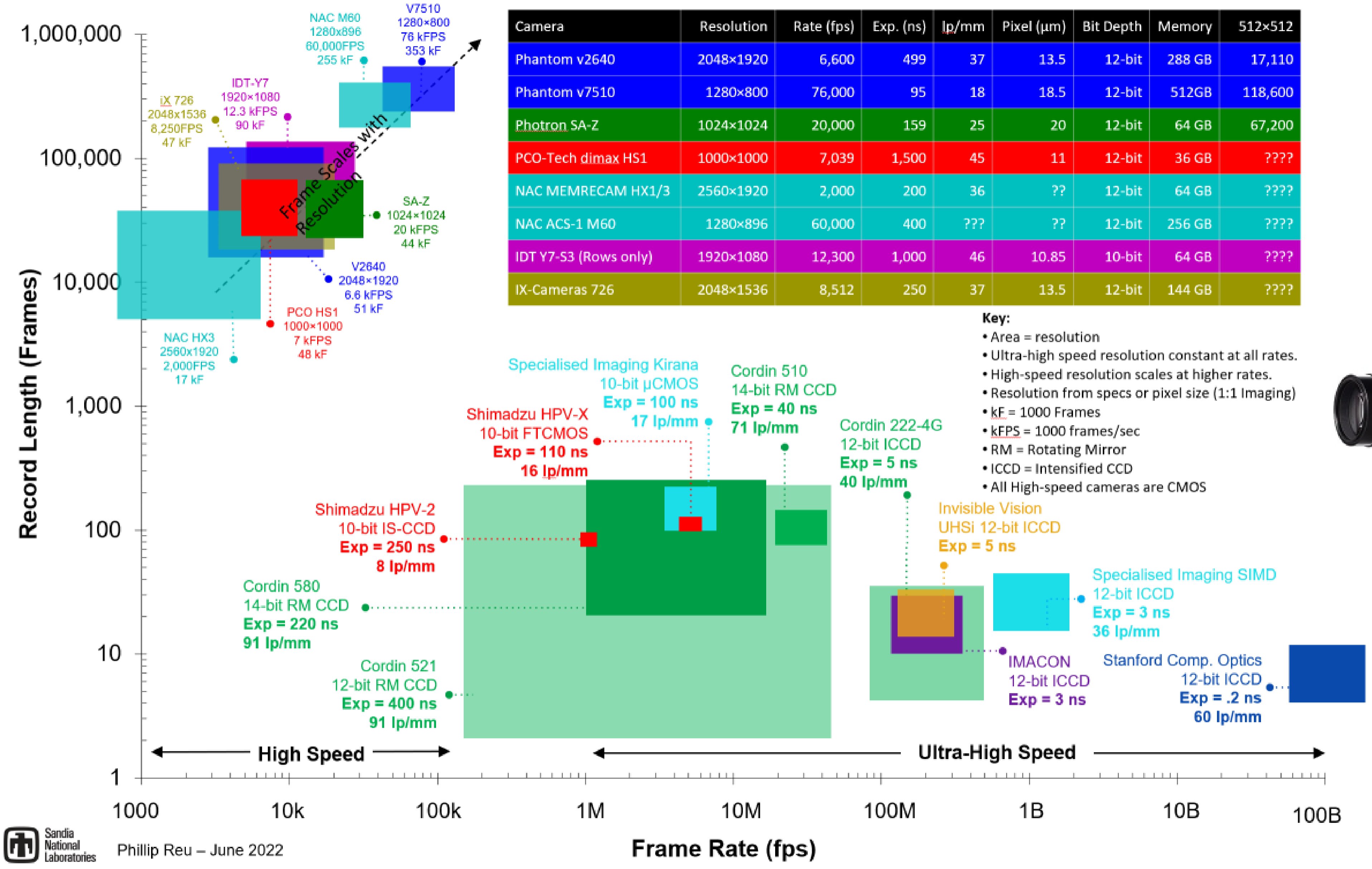
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & 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.

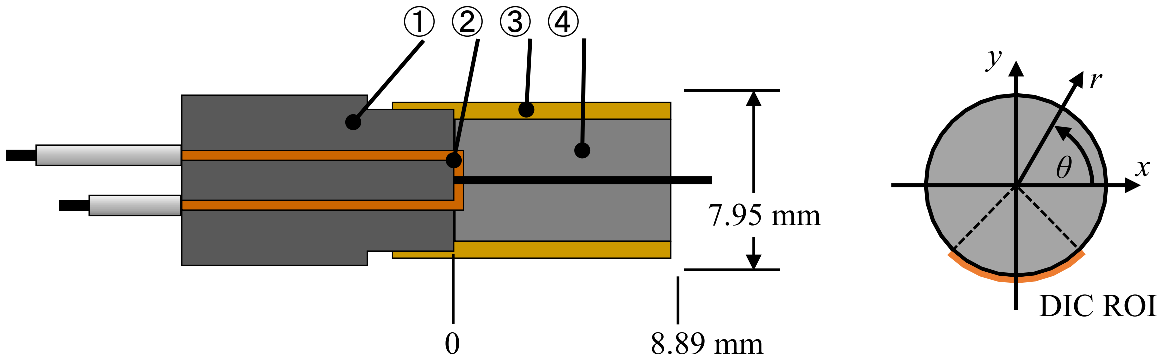
High-Speed and Ultra-high Speed cameras have opened up explosive testing regimes for DIC.

Camera	Resolution	Rate (fps)	Exp. (ns)	lp/mm	Pixel (µm)	Bit Depth	Memory	512×512
Phantom v2640	2048×1920	6,600	499	37	13.5	12-bit	288 GB	17,110
Phantom v7510	1280×800	76,000	95	18	18.5	12-bit	512GB	118,600
Photron SA-Z	1024×1024	20,000	159	25	20	12-bit	64 GB	67,200
PCO-Tech dimax HS1	1000×1000	7,039	1,500	45	11	12-bit	36 GB	????
NAC MEMRECAM HX1/3	2560×1920	2,000	200	36	??	12-bit	64 GB	????
NAC ACS-1 M60	1280×896	60,000	400	???	??	12-bit	256 GB	????
IDT Y7-S3 (Rows only)	1920×1080	12,300	1,000	46	10.85	10-bit	64 GB	????
IX-Cameras 726	2048×1536	8,512	250	37	13.5	12-bit	144 GB	????

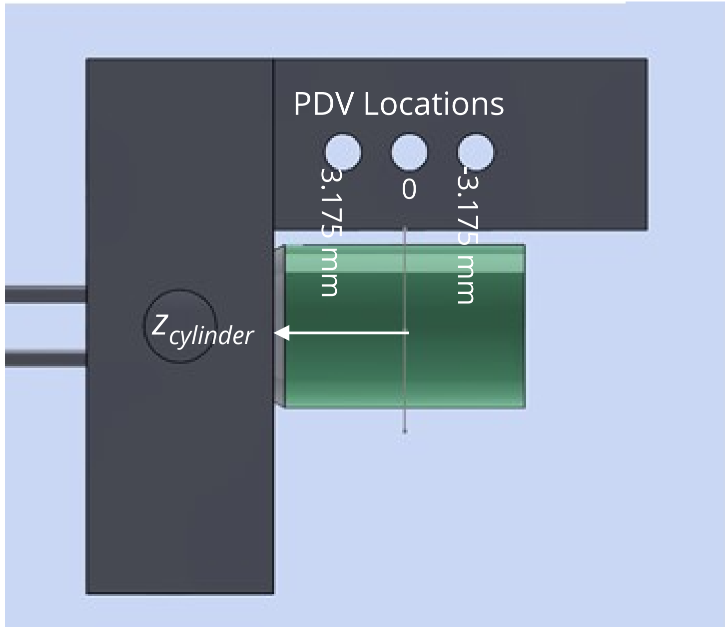
Key:
- Area = resolution
- Ultra-high speed resolution constant at all rates.
- High-speed resolution scales at higher rates.
- Resolution from specs or pixel size (1:1 Imaging)
- kF = 1000 Frames
- kFPS = 1000 frames/sec
- RM = Rotating Mirror
- ICCD = Intensified CCD
- All High-speed cameras are CMOS



The bespoke EBW detonator. Can we measure this with DIC?

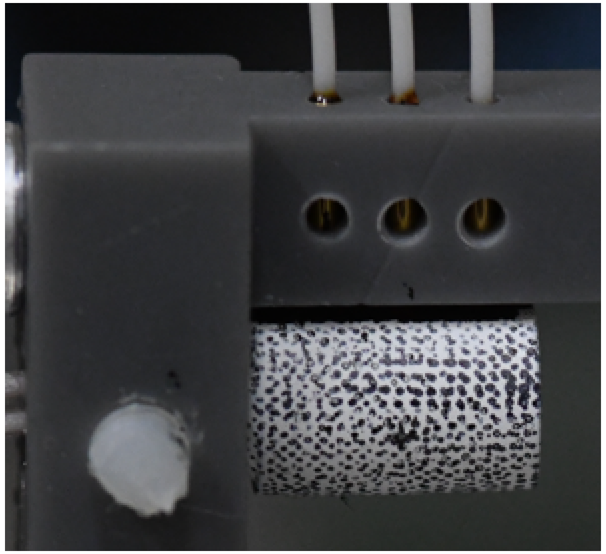


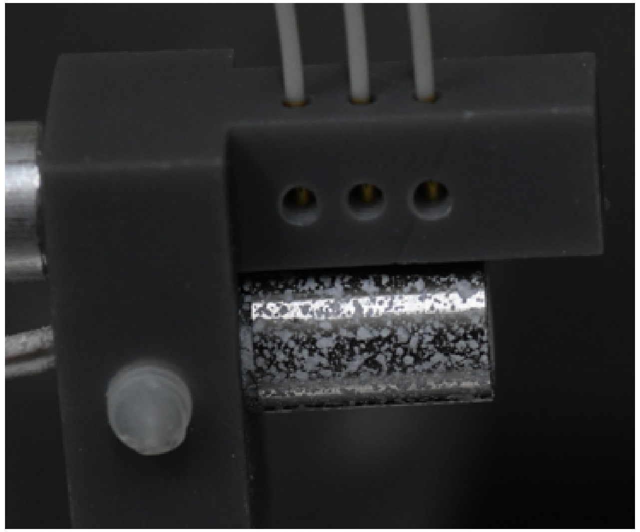
Simplified schematic of the Explosive Bridge Wire (EBW) detonator, where main components include (1) plastic molded header, (2) bridge wire (gold), (3) Stainless Steel cylinder 1.4 mm thick, and (4) 214 mg PETN



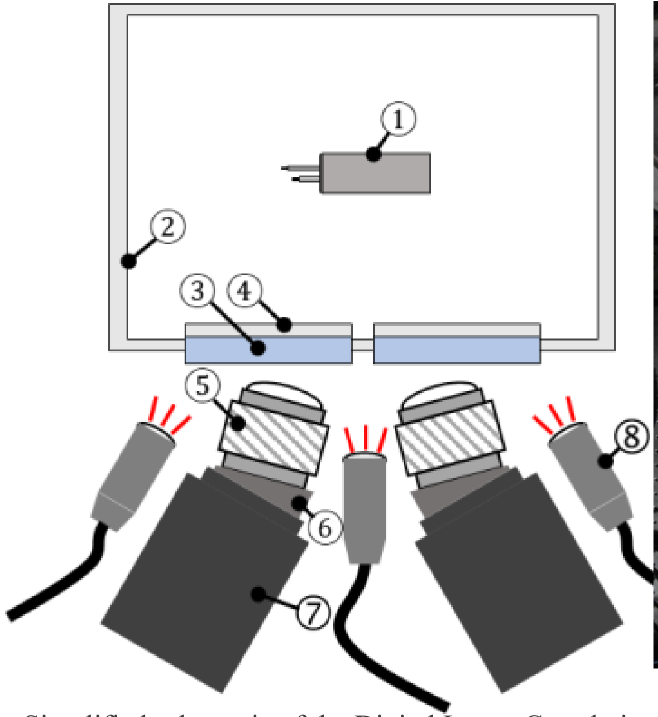
Important questions to answer

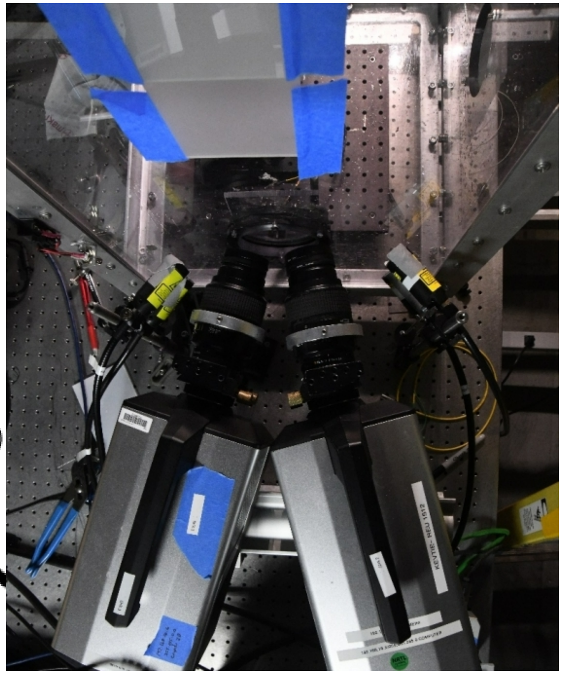
- Does the paint fail?
- Can we measure case velocity?
  - Compare with Photonic Doppler Velocimetry (PDV)
- Can we measure detonation velocity?
- Can we measure case strain?



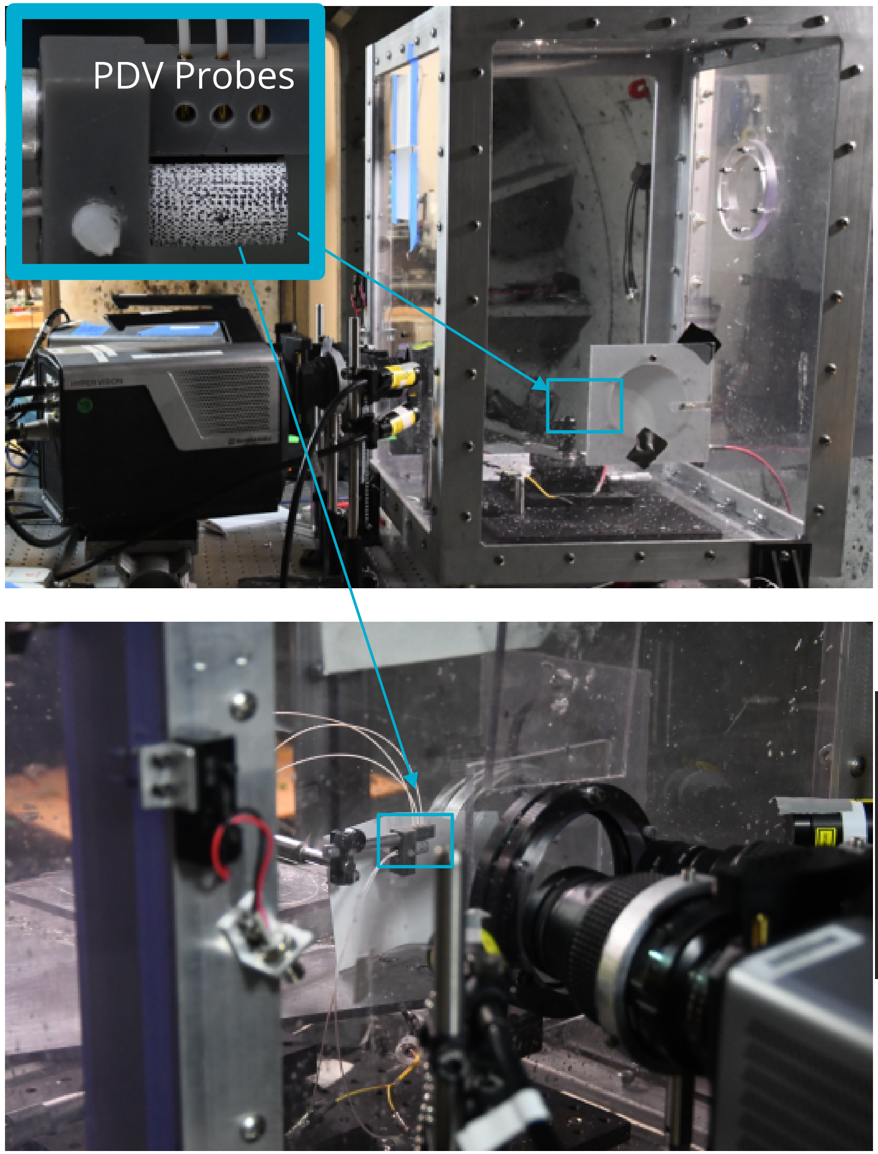


A lab scale test bed for cased explosives. This is appropriate for small explosives (gms)





Simplified schematic of the Digital Image Correlation (DIC) experimental configuration. Top-down view showing the (1) Detonator in a (2) polycarbonate containment box. (3) 12 mm thick optically flat BK7 glass protected by (4) 6 mm thick polycarbonate sheets. Matched (5) lenses, (6) Scheimpflug mounts, and (7) Shimadzu HPV-X2 cameras. Illumination provided by (8) four Cavilux Smart UHS lasers. Schematic is not to scale.

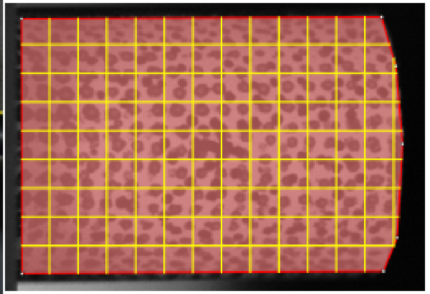


DIC Experimental Setup

- Shimadzu HPV-X2
- 400×250 pixels
- 5 MHz rate
- 200 ns exposure
- 10 ns Synchronization
- Nikon 105mm Macro
- Scheimpflug mount
- 25.2 pixel/mm scale
- FOV 16 mm × 10 mm
- Polarizers on lights and lens
- Notch filter at laser λ

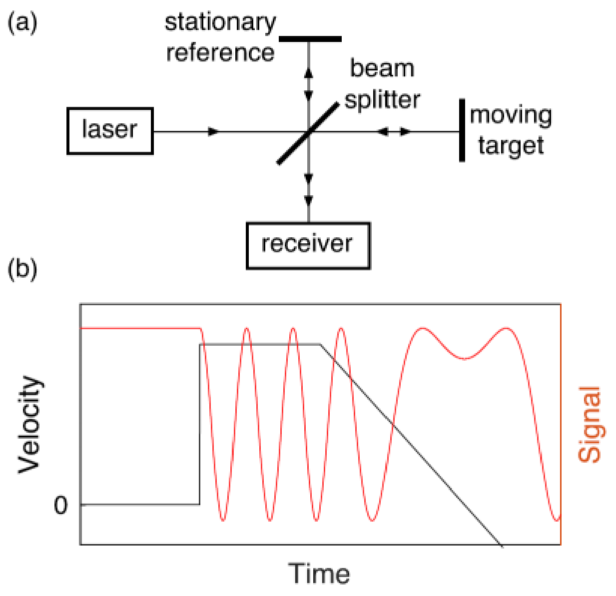
DIC Analysis

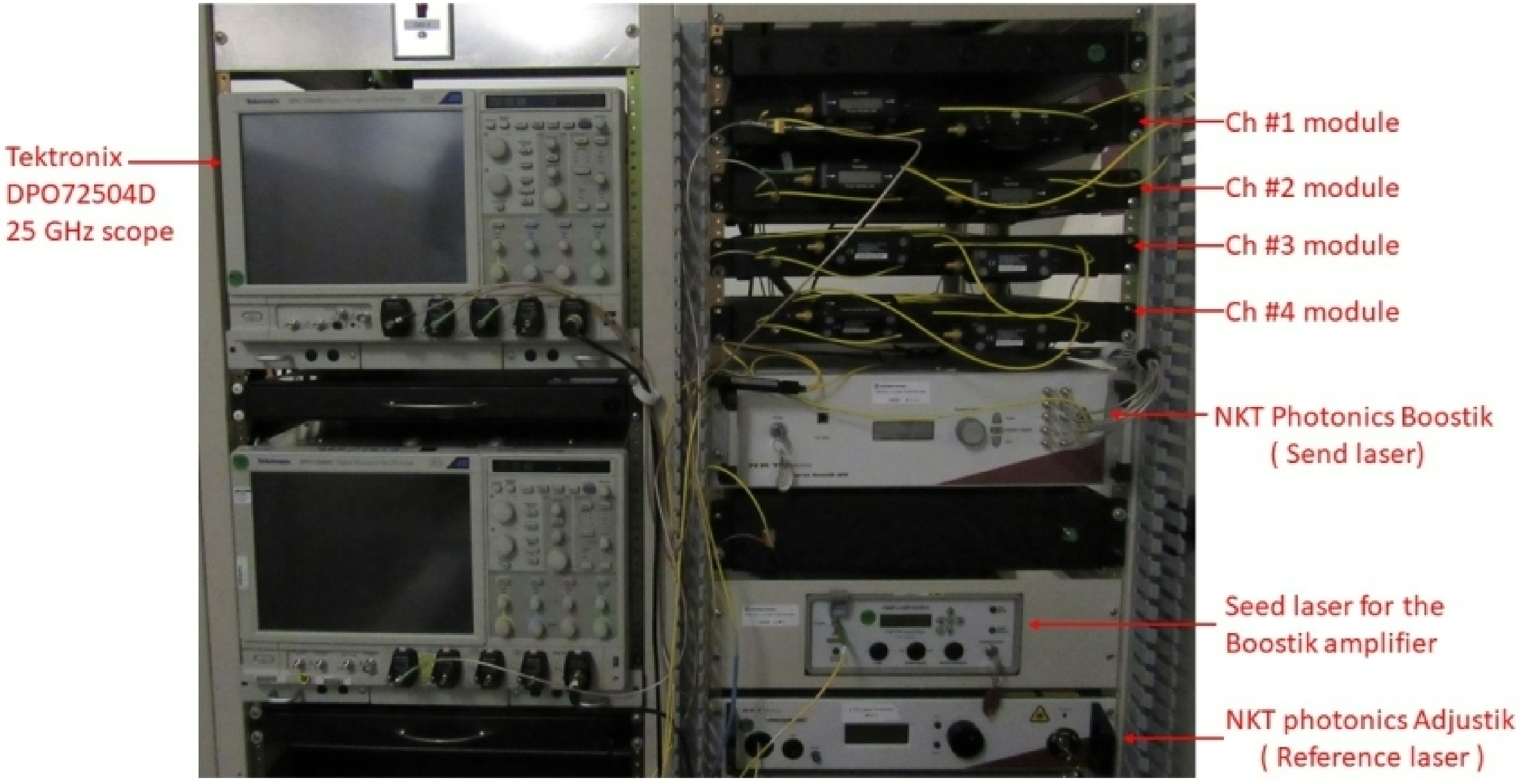
- Subset 21 pixels
- Step 1 pixel
- Affine shape
- ZNSSD
- 8-tap interpolant

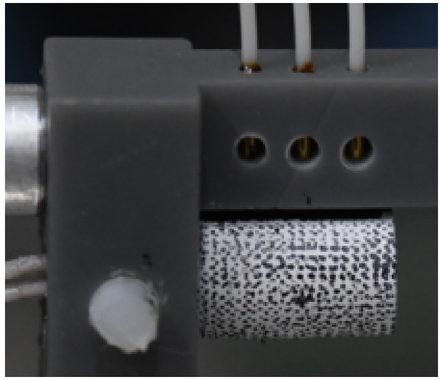


Guildenbecher, D. R., Jones, E.M., Reu, P.L., et al. (2022). "3D optical diagnostics for explosively driven deformation and fragmentation." International Journal of Impact Engineering **162: 104142.**

Photonic Doppler Velocimetry (PDV)







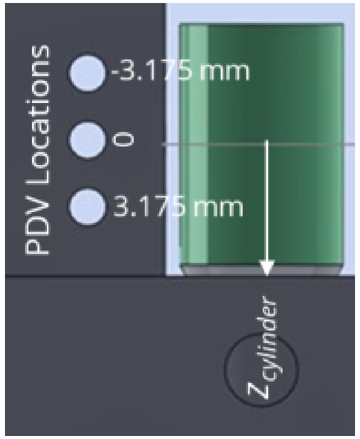
PDV Basics

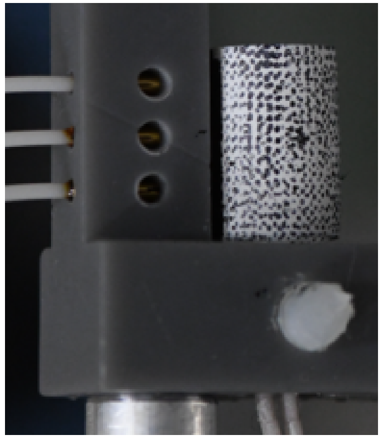
- GHz Sample rates
- Excellent sensitivity
- Low velocity uncertainty
- Single point measurement

Dolan, D. (2020). "Extreme measurements with photonic Doppler velocimetry (PDV)." Review of Scientific Instruments **91(5): 051501.**

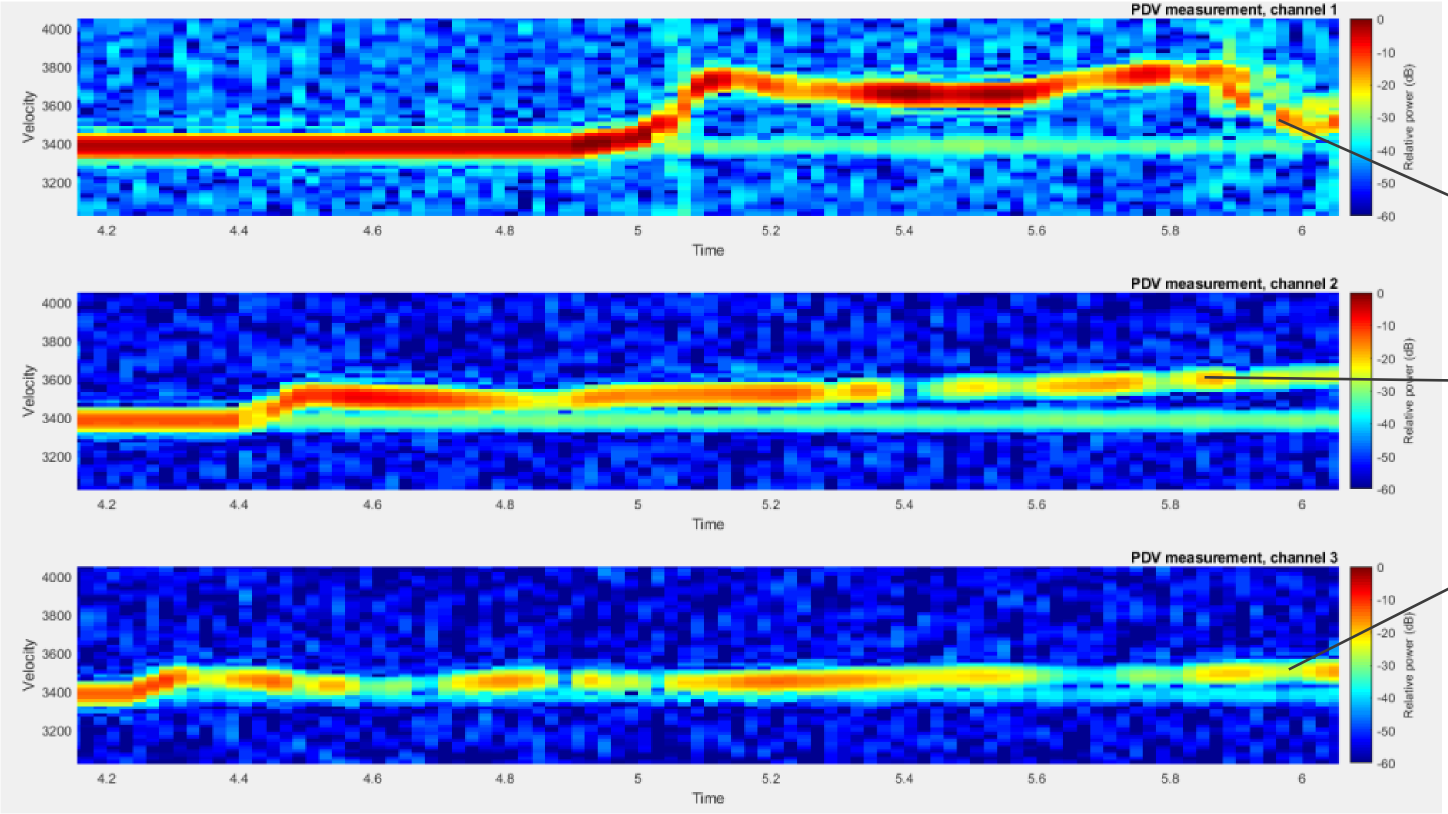
PDV measurements will be compared with DIC at the same location along the cylinder length

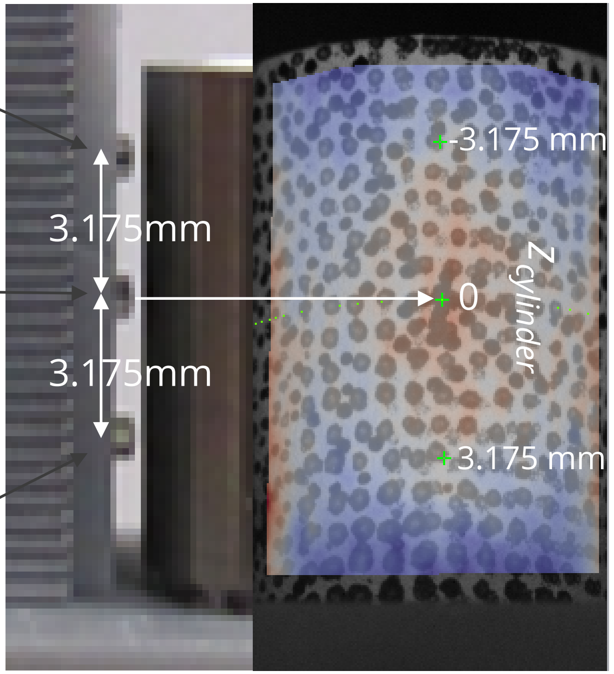
- 3 PDV locations measured
- Corresponding DIC points extracted at 90˚



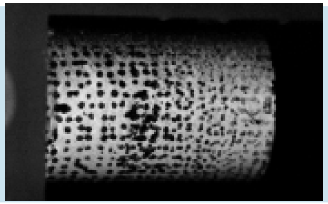
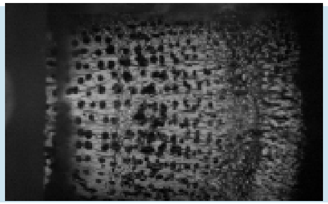
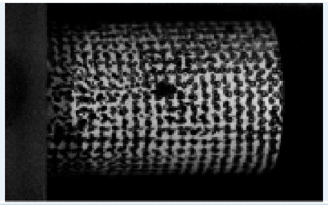
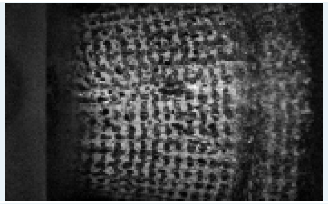
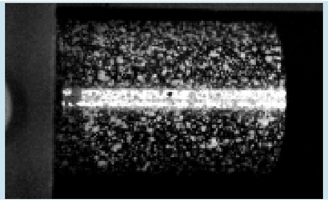
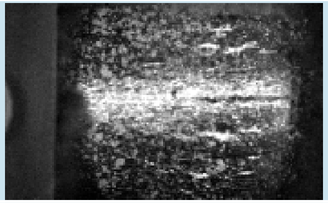
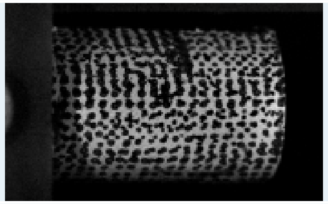
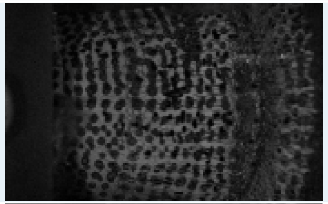
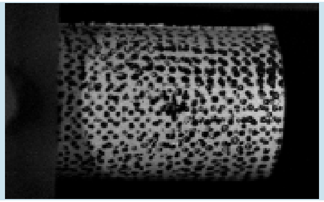
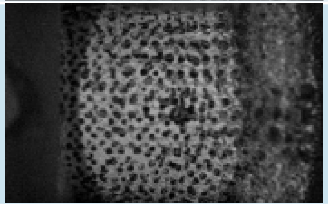
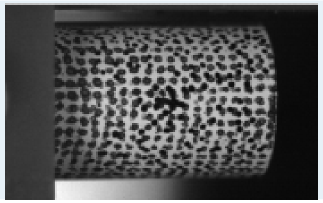
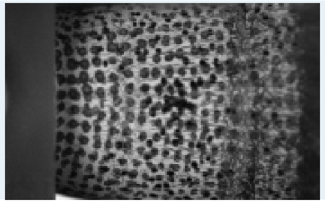


Chan 1
Chan 3
Chan 4



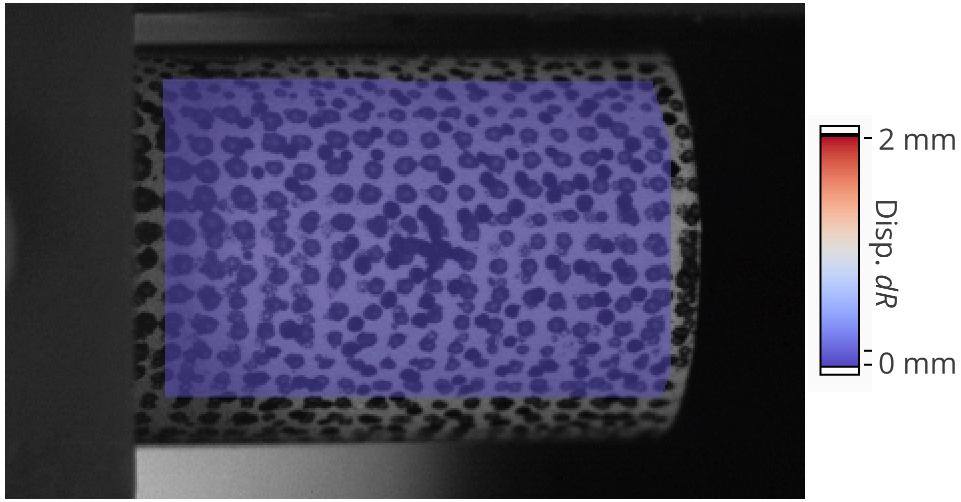


A variety of painting schemes were tried.

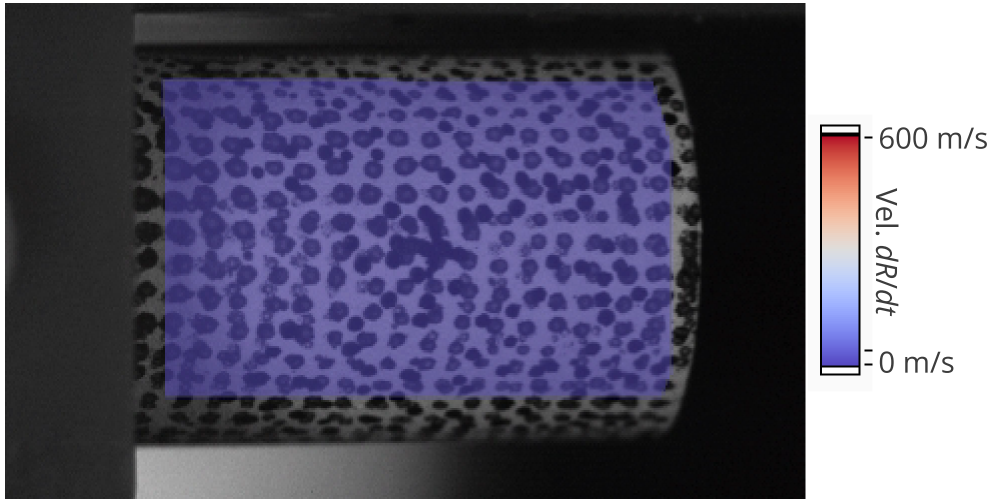
Paint Scheme	#Tests	Lighting	First Frame	Failure (Frame 44)
SEM Same Day/Ink stamp	3 (Shot 1)	Cavilux/Polarizer/λ-filter		
7 Day old SEM	2 (Shot 5)	Cavilux/Polarizer/λ-filter		
White SEM bare	3 (Shot 7)	Cavilux/Polarizer/λ-filter		
VHT/Scuffed/Stamp	2 (Shot 9)	Cavilux/Polarizer/λ-filter		
Rustoleum/Scuffed/ Stamp	2 (Shot 13)	Cavilux/Polarizer/λ-filter		
SEM/Scuffed/Stamp	5 (Shot 17)	Norman Flash/Polarizer Various arrangments		

Shot 17 DIC data: Displacement, Velocity and Acceleration

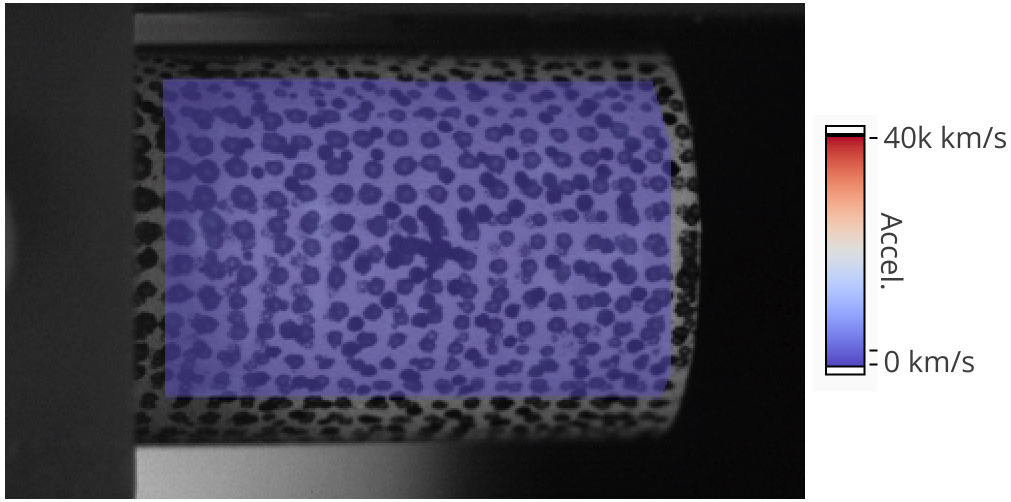
Shot 17 Case Displacement



Shot 17 Case Velocity



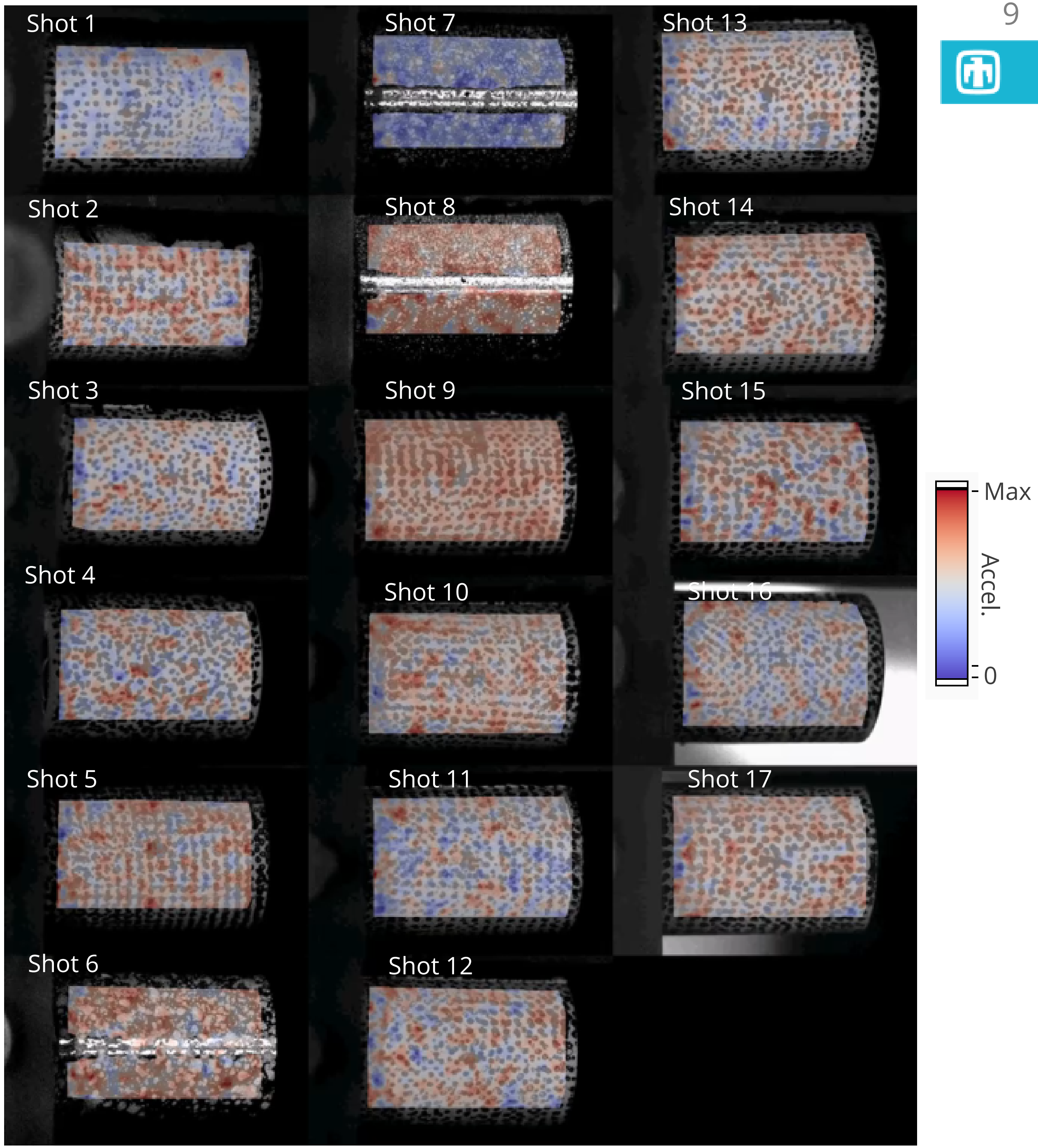
Shot 17 Case Acceleration



Case acceleration. Shows the detonation front.

Quick conclusions

- Paint prep mattered a little bit
- Lighting was more critical
- Polarizers helped a little, but with cylinders it is hard to get it right

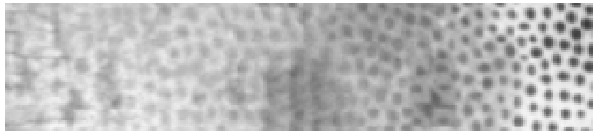


Evidence of paint failure can be seen in the raw video.

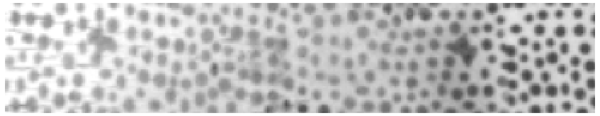
Quick conclusions

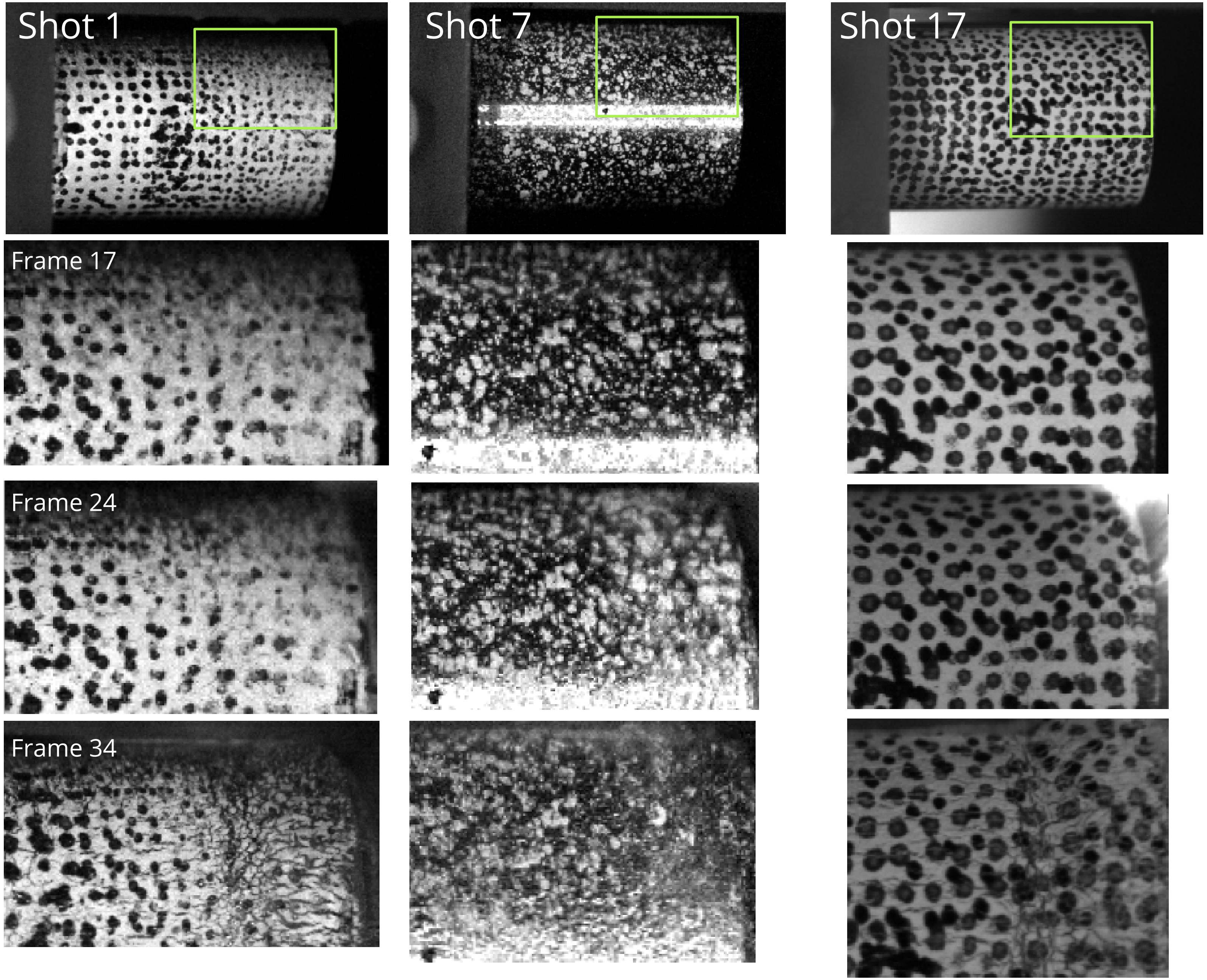
- Paint prep mattered. Scuffing helped.
- Bare metal with polarizers wasn't better.
- Lighting is important
- Detonation velocity matters

Paint Failure



Reduced Paint Failure

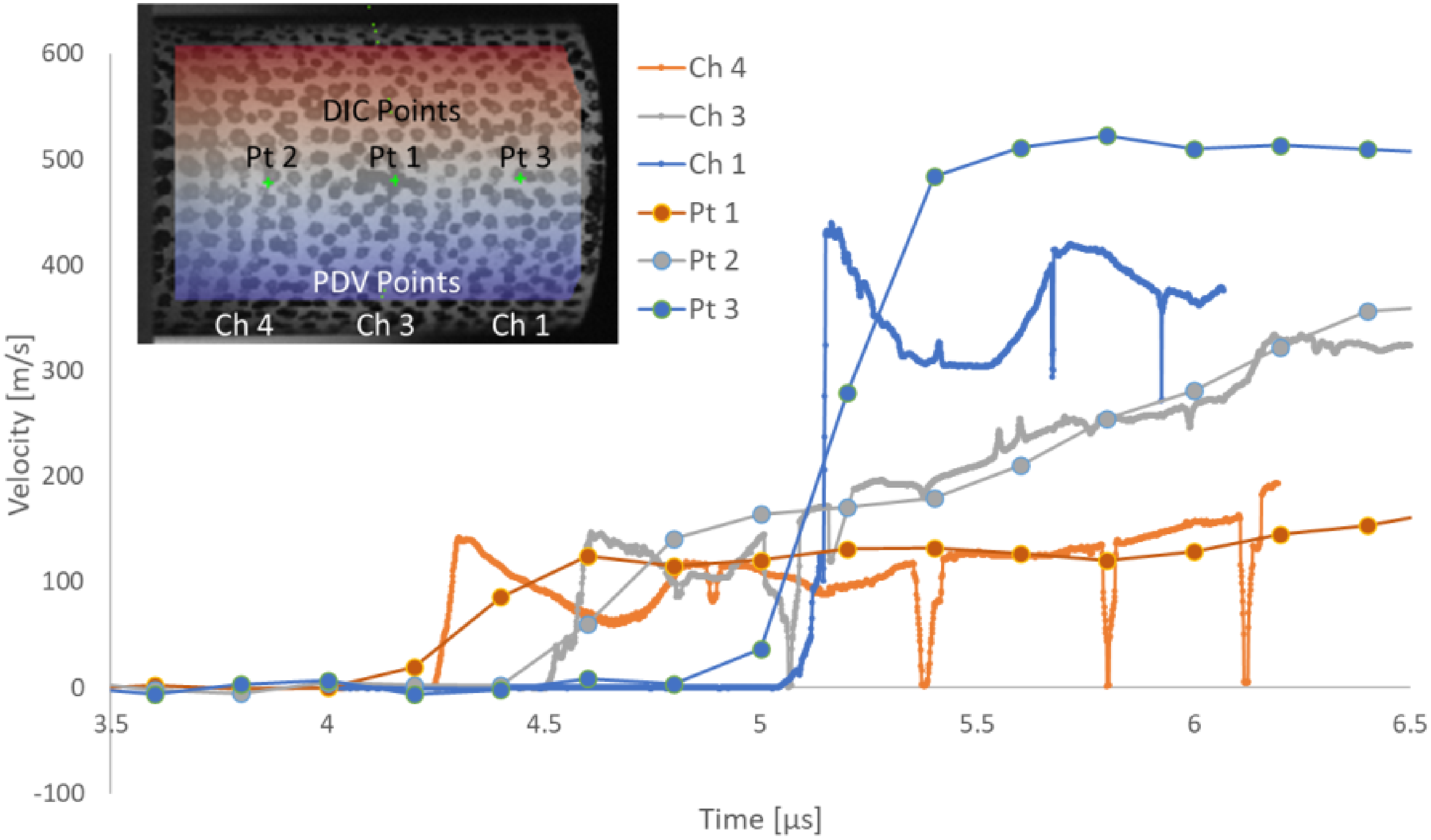




Case velocity: DIC vs PDV

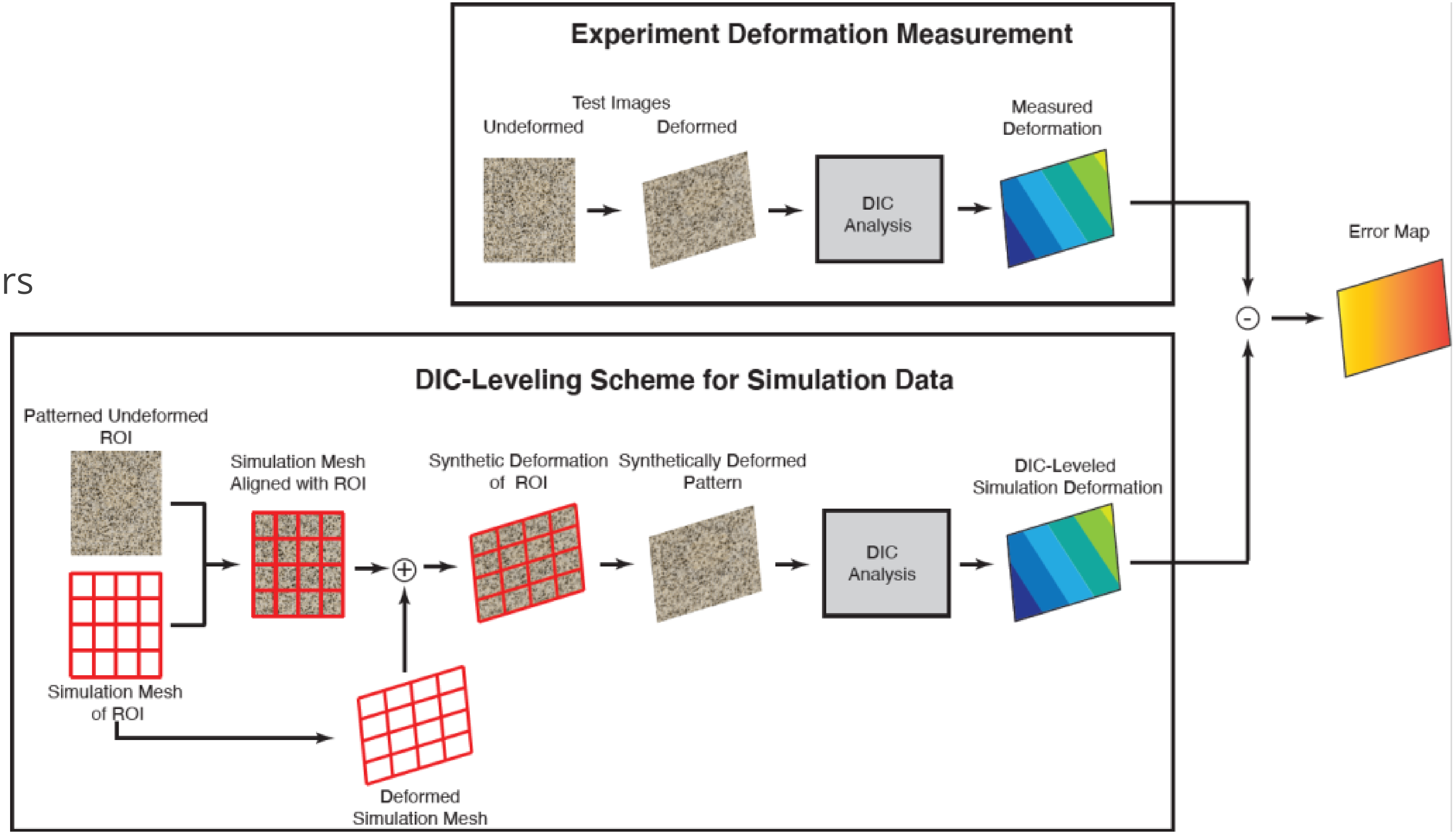
Quick conclusions

- Case velocity rise time is on the order of nanoseconds
- DIC sample rate is too slow
- 1st derivative "temporally filters" the results
- For comparison with FE modeling we need "Leveling"



One-slide overview of leveling

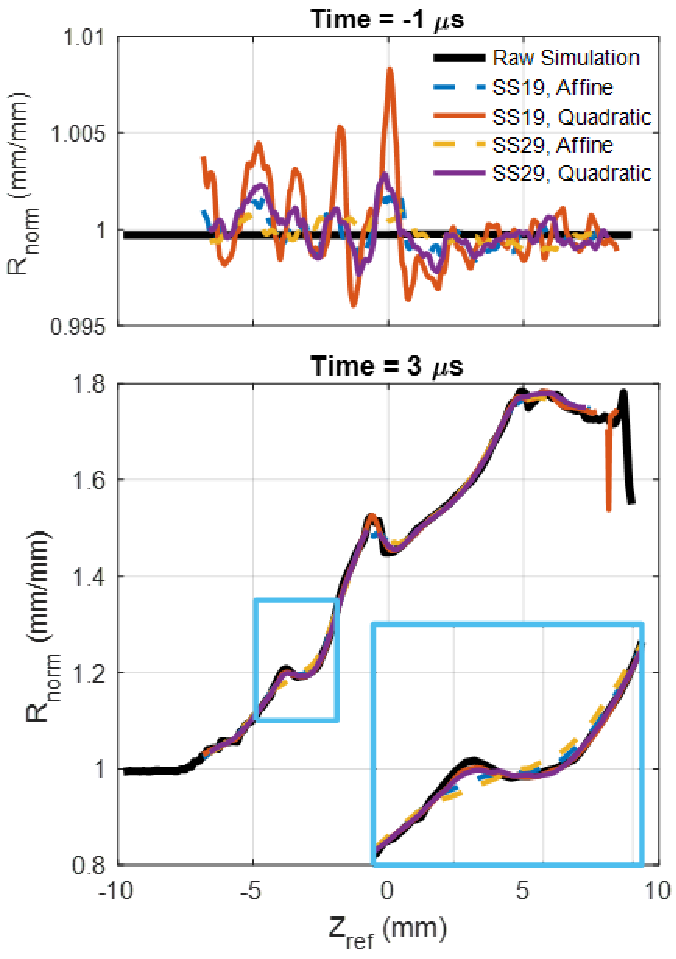
- Temporal Leveling
  - Speed matters
- Spatial Leveling
  - Number of pixels matters



P. Lava, E.M.C. Jones, L. Wittevrongel, F. Pierron, Validation of finite-element models using full-field experimental data: Levelling finite-element analysis data through a digital image correlation engine, Strain, 56 (2020) e12350.

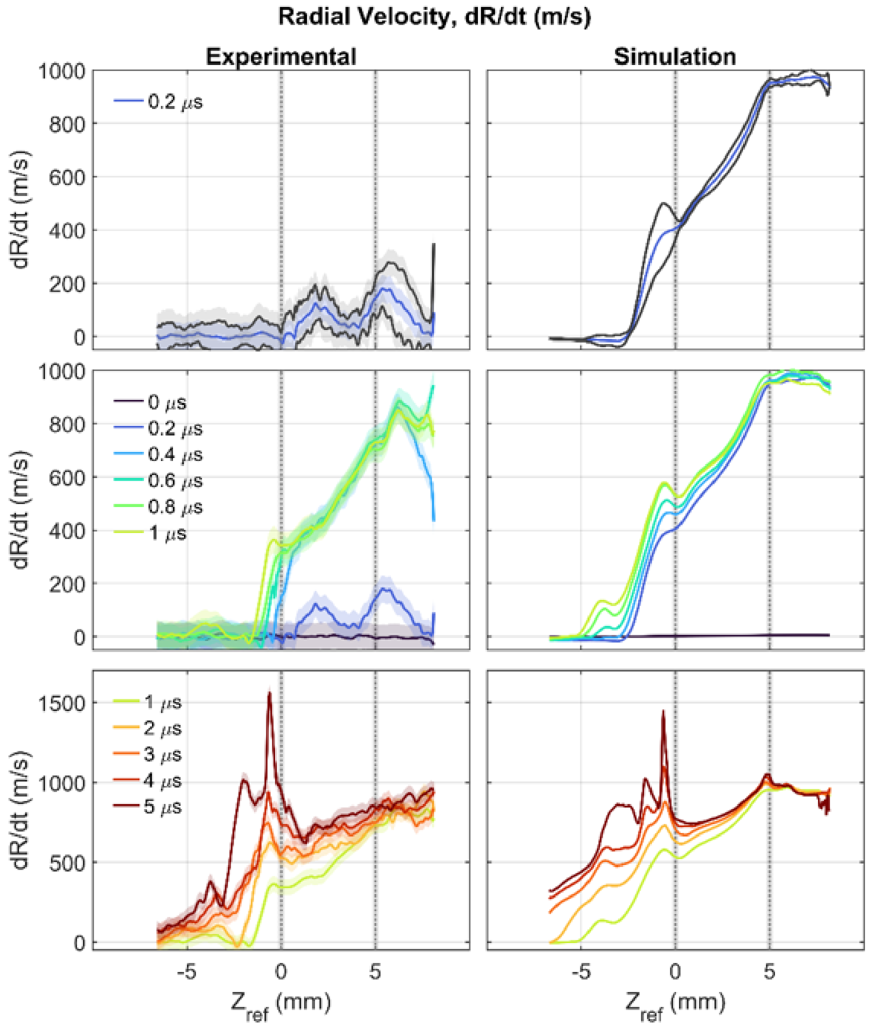
E.M.C. Jones, E. Corona, A.R. Jones, W.M. Scherzinger, S.L.B. Kramer, Anisotropic plasticity model forms for extruded Al 7079: Part II, validation, International Journal of Solids and Structures, 213 (2021) 148-166.

Spatial leveling is required when you don't have enough pixels in the image to capture the displacement results.



Quick conclusions

- Without spatial leveling, the subset size and the shape function matter!
- Leveling can remove these effects when comparing between models and experiments



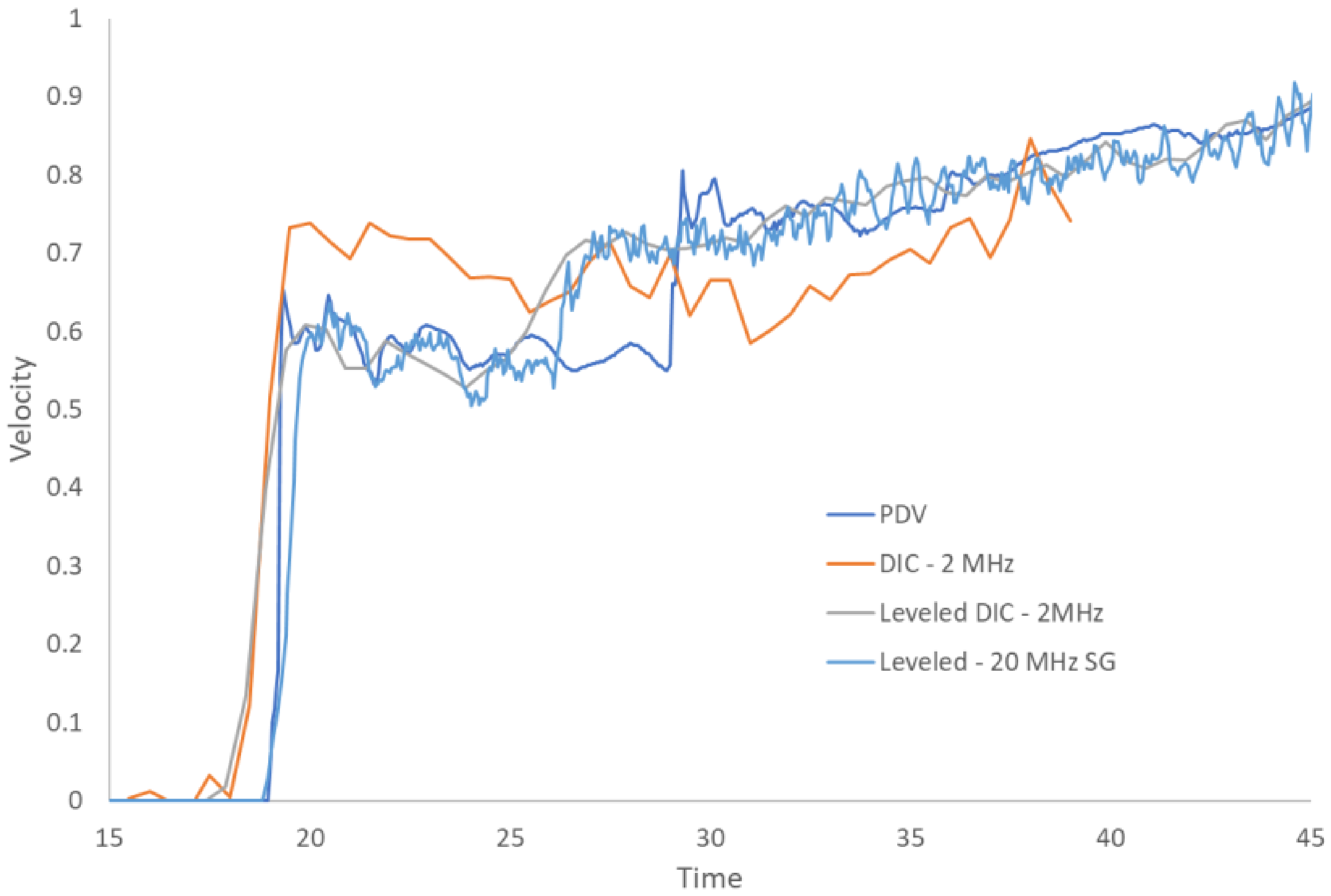
CTH Simulation and MatchID synthetic images and analysis.

Guildenbecher, D. R., Jones, E.M., Reu, P.L., et al. (2022). "3D optical diagnostics for explosively driven deformation and fragmentation." International Journal of Impact Engineering **162: 104142.**

Temporal leveling is needed when the camera rate isn't fast enough for the case jump. (Which is always?)

Quick conclusions

- Camera rate at 2 MHz too slow to capture rise time
- PDV at 20 GHz can capture rise time
- DIC-Leveled simulation data at 2 MHz matches the model
- DIC-Leveled simulation data at 20 MHz closer to the PDV



Zapotec FE Simulation. Synthetic images by Blender (D. Rohe). DIC Analysis Vic3D

Rohe, D. P. and E. M. C. Jones (2021). "Generation of Synthetic Digital Image Correlation Images Using the Open-Source Blender Software." Experimental Techniques.

Don't miss iDICs! Contribute to the HS-DIC Guide!

iDICs INTERNATIONAL DIGITAL IMAGE CORRELATION SOCIETY

SEM

www.idics.org and www.sem.org/idics

Annual International DIC Society Conference
November 7 – 10, 2022 in Boston, MA, USA

General Call

The International Digital Image Correlation Society (iDICs) is inviting your participation in its annual conference in Boston, MA, USA. Please join us to hear from cutting edge DIC researchers and present your own DIC research and applications.

All Digital Image Correlation topics are welcome, including:

- Algorithms and computation methods
- Global and adaptive methods
- High-speed and modal analysis
- Infrastructure and full-scale testing
- Materials testing and constitutive models
- Novel imaging modalities
- Energy systems and materials
- Standardization and uncertainty
- Digital Volume Correlation
- Aerospace and automotive
- Biomaterials and medical devices
- Microscale measurements
- Advanced manufacturing monitoring
- Petroleum and geosciences

iDICs Classes (Monday, November 7)

AM
- **DIC 101** – pt. 1 (Level 1 certification topics)
- **Patterning** (how to speckle anything)
- **High-Speed** Digital Image Correlation

PM
- **DIC 101** – pt. 2 (Level 1 certification topics)
- **Advanced DIC** (intro to Level 2 certification)
- **Modal Analysis** with Digital Image Correlation

iDICs INTERNATIONAL DIGITAL IMAGE CORRELATION SOCIETY

High-Speed Digital Image Correlation (A Good Practices Guide)

Draft document for review purposes.

October 202x