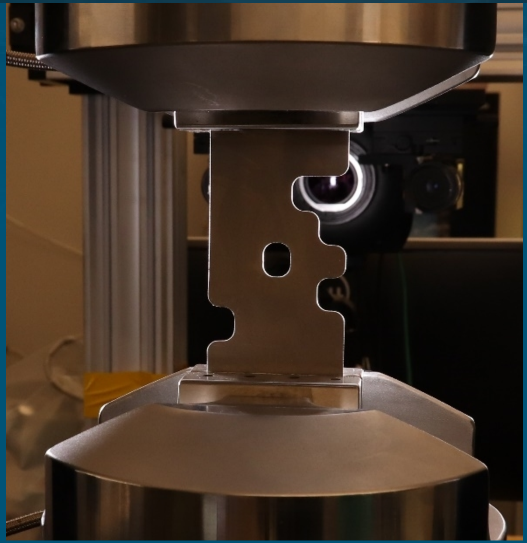
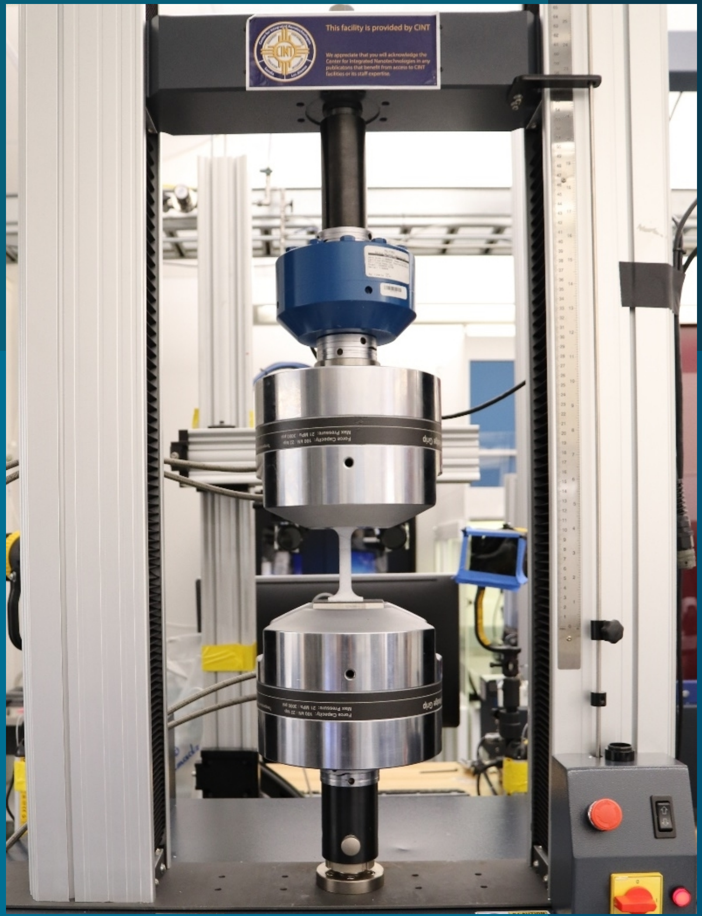
SAND2024-06945C

https://sem.org/dic-challenge

Stereo-DIC Challenge 2.0
The Tensile Experience - Update





PRESENTED BY

Phillip Reu, Waqas Ahmad, Amanda Jones, Elizabeth Jones, Sven Bossuyt, and Mark Iadicola

Special Thanks to Dave Johnson for experimental support

Mission of the DIC Challenge: Improve DIC methods

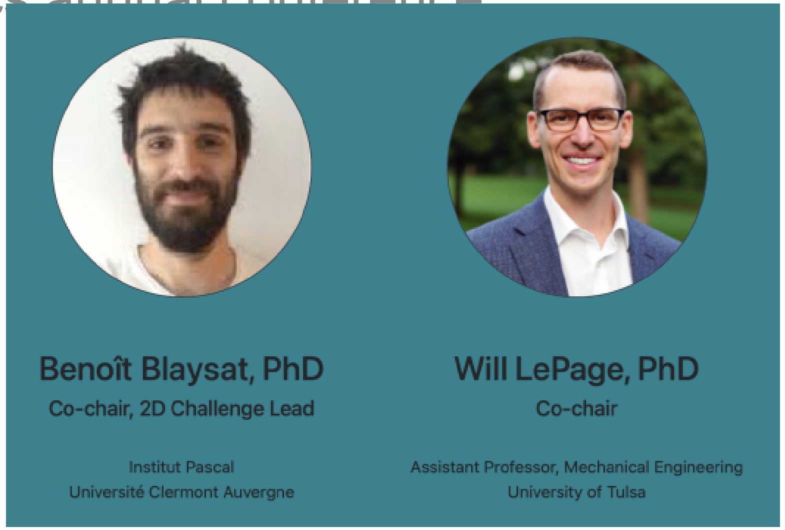
Mission: advance the practice of DIC through collective efforts that point to optimum methodologies

Comprised of industry, government, and academic researchers

Meets twice annually, in sync with Society for Experimental Mechanics annual conference in the summer and the International DIC Society meeting in the fall

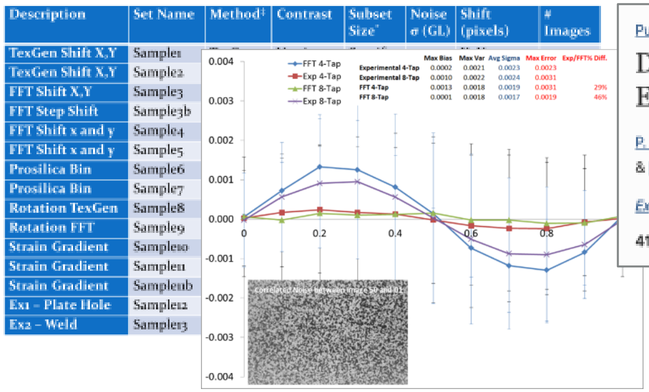
2023 Challenge Board

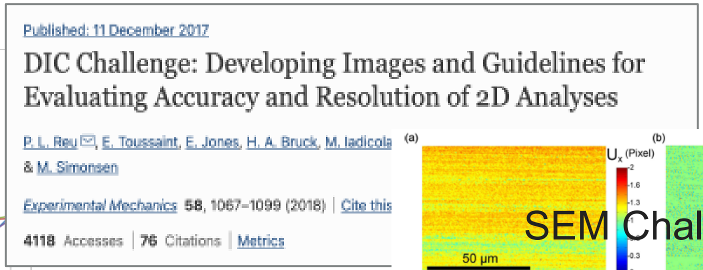
Will LePage (U. Tulsa) – Co-chair
Benoît Blaysat (U. Clermont Auvergne) – Co-Chair
Jin Yang (U. Austin) – Secretary
Hugh Bruck, Jeff Helm, Mark Iadicola – Advisors at Large
Evelyne Toussaint, Elizabeth Jones – Results analysis
Helena Jin (Sandia) – DVC Lead
Phillip Reu (Sandia) – Stereo-DIC Challenges
Victoria Tucker (U Tulsa) – SEM Lead



Challenge image sets should be used for all publications claiming improvements in DIC algorithms.

History of the DIC Challenge




Published: 11 December 2017

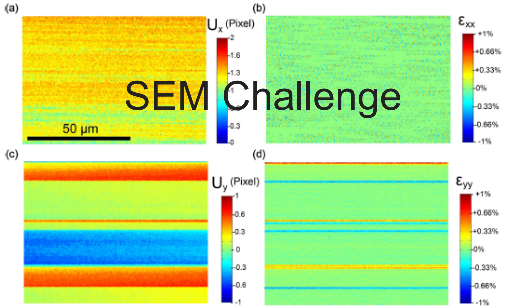
DIC Challenge: Developing Images and Guidelines for Evaluating Accuracy and Resolution of 2D Analyses

P. L. Reu, E. Toussaint, E. Jones, H. A. Bruck, M. Iadicola & M. Simonsen

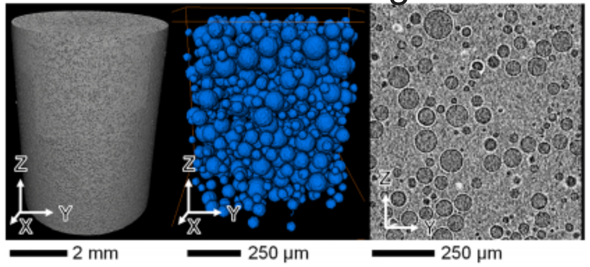
Experimental Mechanics 58, 1067–1099 (2018) | Cite this

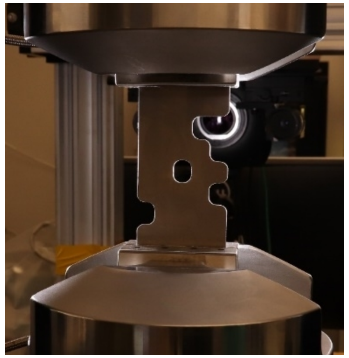
4118 Accesses | 76 Citations | Metrics

SEM Challenge



DVC Challenge

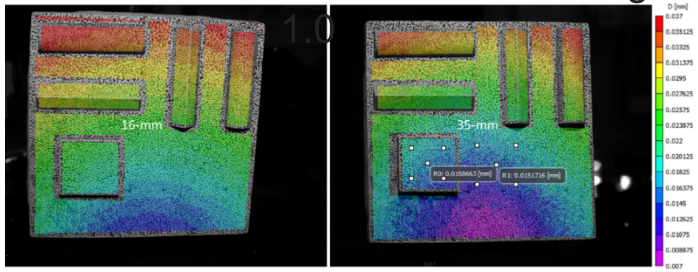




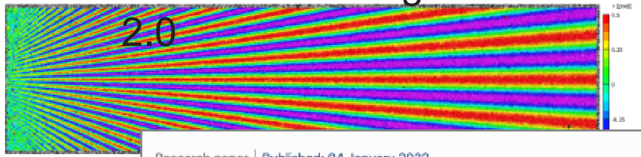
Stereo-DIC Challenge 2.0

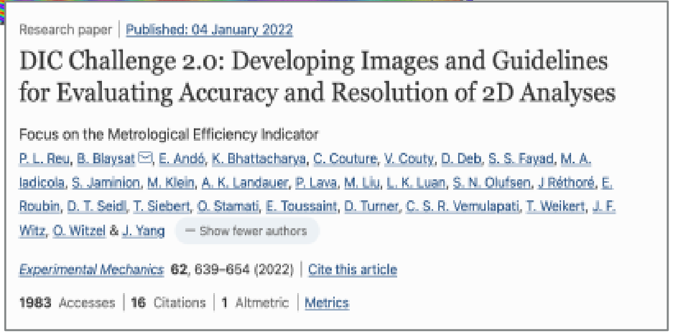
2012 | 2D-DIC Challenge 1.0 | 2015 | 2018 | 2021 | 2023

Stereo-DIC Challenge 1.0



2D-DIC Challenge 2.0




Research paper | Published: 04 January 2022

DIC Challenge 2.0: Developing Images and Guidelines for Evaluating Accuracy and Resolution of 2D Analyses

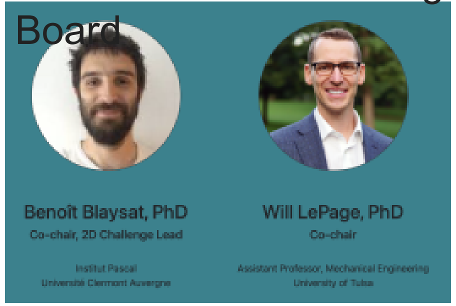
Focus on the Metrological Efficiency Indicator

P. L. Reu, B. Blaysat, E. Andó, K. Bhattacharya, C. Couture, V. Couty, D. Deb, S. S. Fayad, M. A. Iadicola, S. Jaminion, M. Klein, A. K. Landauer, P. Lava, M. Liu, L. K. Luan, S. N. Olufsen, J Réthoré, E. Roubin, D. T. Seidl, T. Siebert, O. Stamati, E. Toussaint, D. Turner, C. S. R. Vemulapati, T. Weikert, J. F. Witz, O. Witzel & J. Yang — Show fewer authors

Experimental Mechanics 62, 639–654 (2022) | Cite this article

1983 Accesses | 16 Citations | 1 Altmetric | Metrics

2020 New DIC Challenge Board



Founded about 2012
DIC Challenge Board

Phillip Reu (Chair – US)
Mark Iadicola (Co-Chair)
Bertrand Wattrisse (EU)
Wei-Chung Wang (Asia)
Laurent Robert (EU)

DIC Challenge Board ca 2017

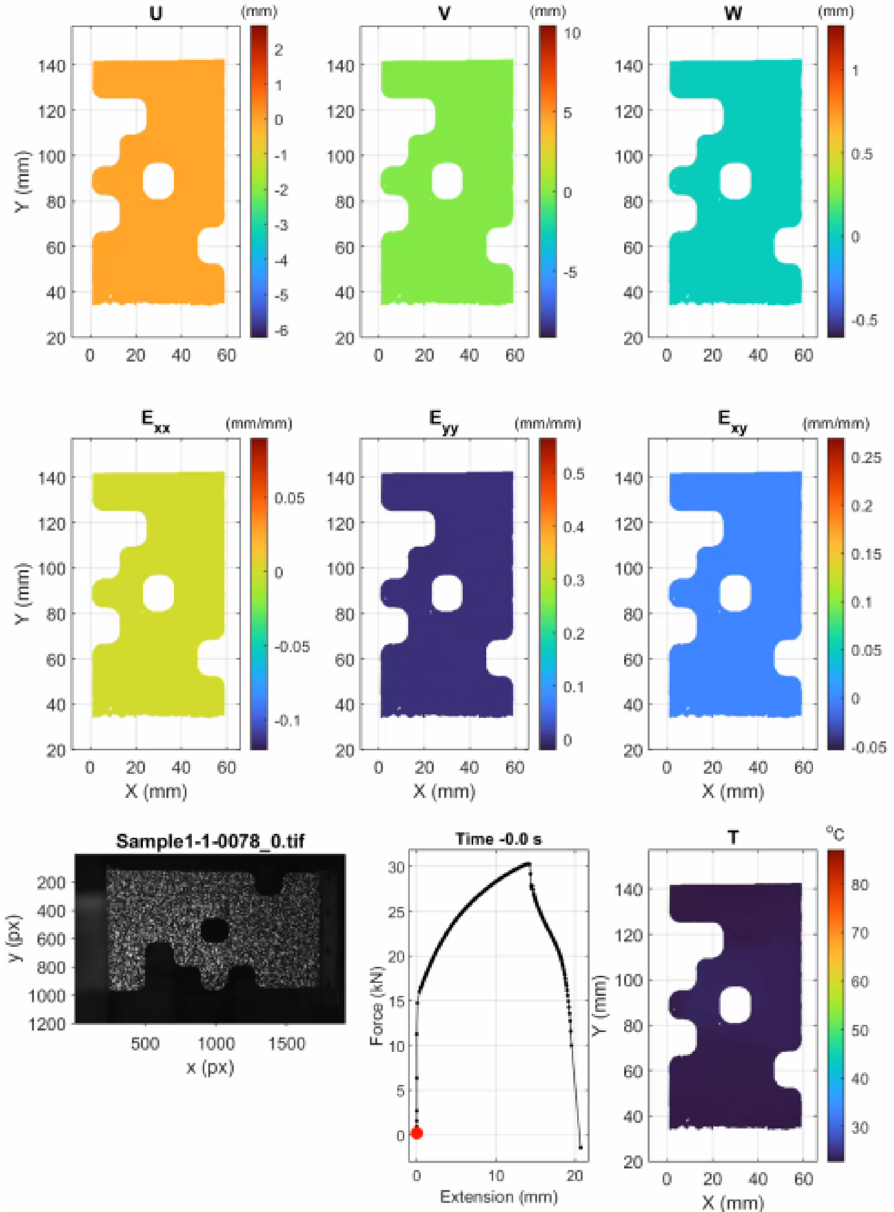
Phillip Reu – Chairman (US – FFT Shifting)
Mark Iadicola (NIST) – co-chair
Will LePage (Univ. Mich.) – SEM challenge Lead
Helena Jin (Sandia) – DVC challenge Lead
Elizabeth Jones (Sandia) – Results analysis
Evelyne Toussaint (University Clermont Auvergne, France)
Ruben Balcaen (PhD Student KU Leuven)
Hugh Bruck (University of Maryland)
In memoriam – Laurent Robert

Current Challenges

- 2-D DIC Challenge 1.0 and 2.0 (Phillip Reu)
- Digital Volume Correlation (DVC) Round Robin 1.0 and 2.0 (Helena Jin)
- Discontinuity DIC Challenge (J.C. Stinville)
- Stereo DIC Challenge 1.0 and 2.0 (Phillip Reu)
- Huge Strain Challenge (Benoît Blaysat)
- Scanning Electron Microscope DIC (SEM-DIC) Round Robin (Will LePage)

iDICs

A thorough data set of DIC+IR full field data for 304L stainless steel sheet metal is publicly available in support of Material Testing 2.0.



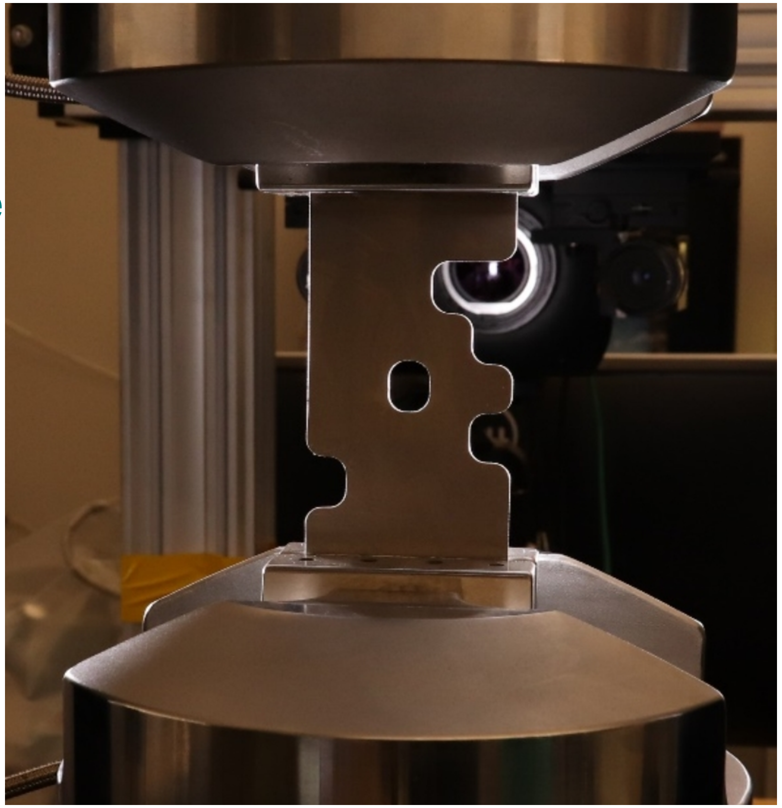
- Seven unique geometries (including the one from the stereo DIC Challenge 2.0)
- Full-field DIC+IR data, plus force, global extension, and time
  - Two nominal grip velocities for rate-dependence characterization
  - Three material orientations (transverse, rolling, diagonal) for anisotropy characterization
  - Infrared (IR) temperature measurements for temperature-dependence characterization
- Both post-processed data AND raw images included (so you can either immediately use spatially and temporally synchronized data, or reanalyze with your own software)
- Tensile dog bone stress-strain data also included
- EMC Jones, PL Reu, SLB Kramer, AR Jones, JD Carroll, KN Karlson, DT Seidl, DZ Turner. "Digital Image Correlation and Infrared Thermography Data for Seven Unique Geometries of 304L Stainless Steel", submitted to *Scientific Data*, April 2024.
- Data will be hosted on Figshare+ repository, https://doi.org/10.25452/figshare.plus.25483534

Stereo-DIC Challenge 2.0: The Tensile Experience

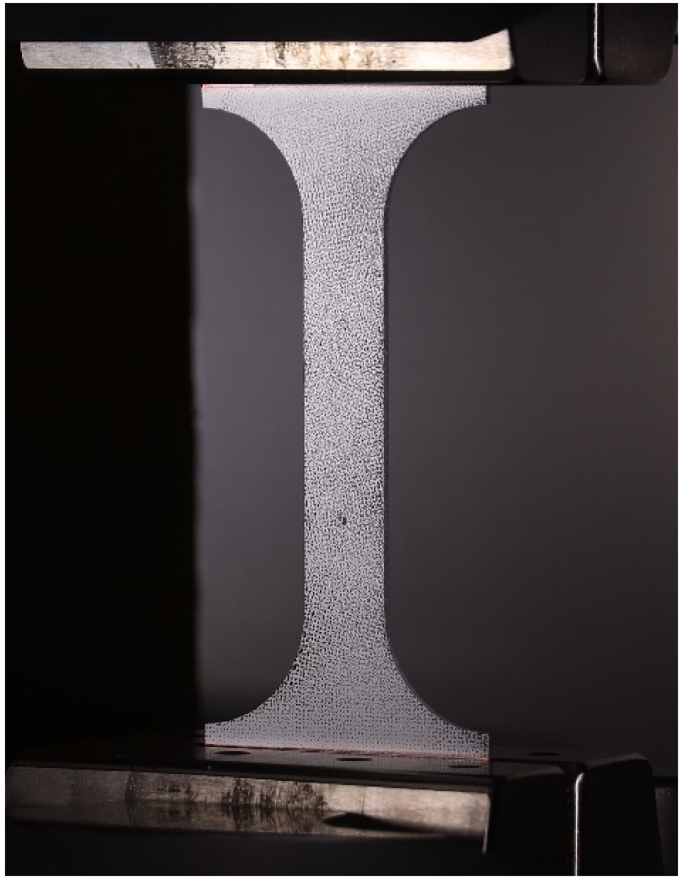
Why a Stereo-DIC Challenge 2.0?
Strain!

- Comparison of strain calculations – there are multiple paths to calculation of strain that vary greatly between codes.
- Comparison of strain spatial resolution vs noise
- Complex specimen geometry
- Standard tensile specimen
- Use data for the Good Practices Guides
- Possible extension to a material property challe

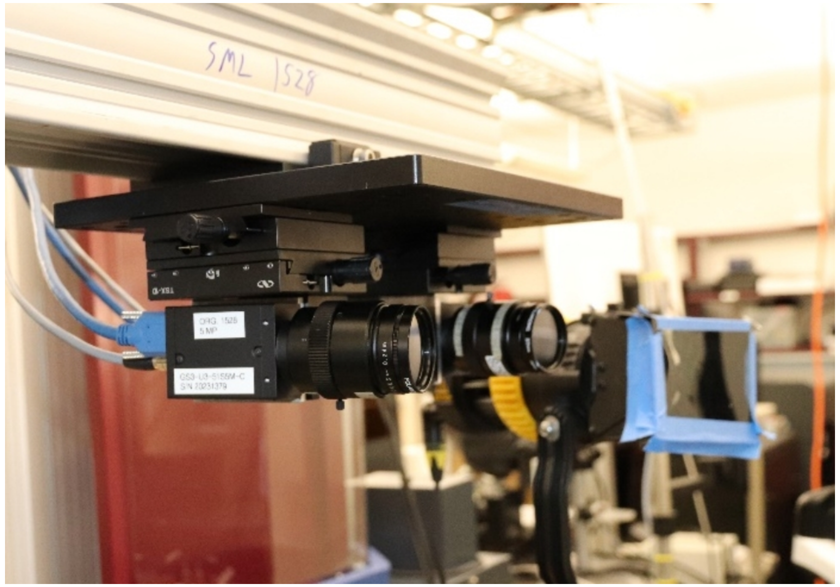
Bespoke Specimen ×1



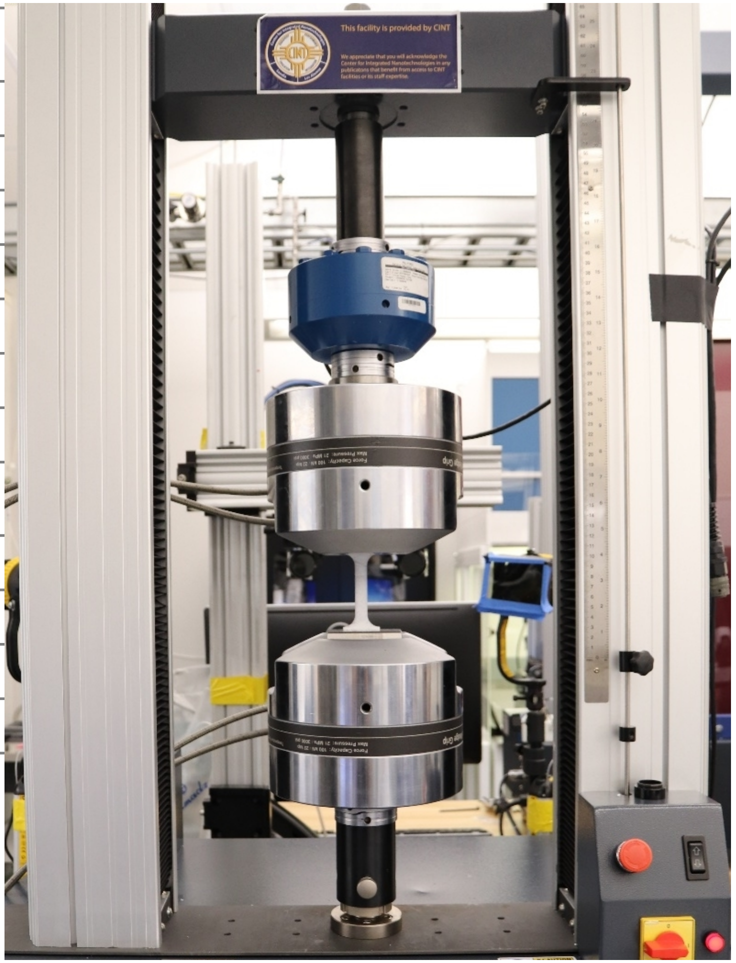
Standard Tensile Specimen ×2



Experimental Setup: Very stable throughout the day

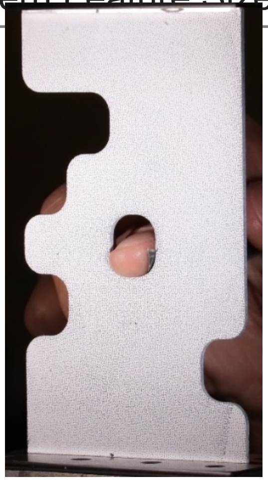


Camera	Grasshopper 2 (Gras-50S5M)
Image Size	2448×2048 pixels
Aperture	≈$f/8$
Field-of-view	≈125 mm
Focal Length	35-mm
Image Scale	19.7 px/mm
Stereo-Angle	19.4˚
Stand-off Distance	600 mm
Image Acquisition Rate	1 Hz
Exposure Time	< 2 ms
Paint	Rust-oleum flat enamel
Patterning Technique	Roller 0.007-inch pattern
Pattern Feature Size	≈ 7 pixels



Ideal Experimental Setup

- Low distortion 35-mm lens
- Cross-polarized lighting to remove glare
- Minimal heat waves
- Rigid camera mounting – stable stereo-rig



Load Frame	313 Series Frame, 313XHD
Load Cell	12.5 kip, 1020ACK-12.5k-B

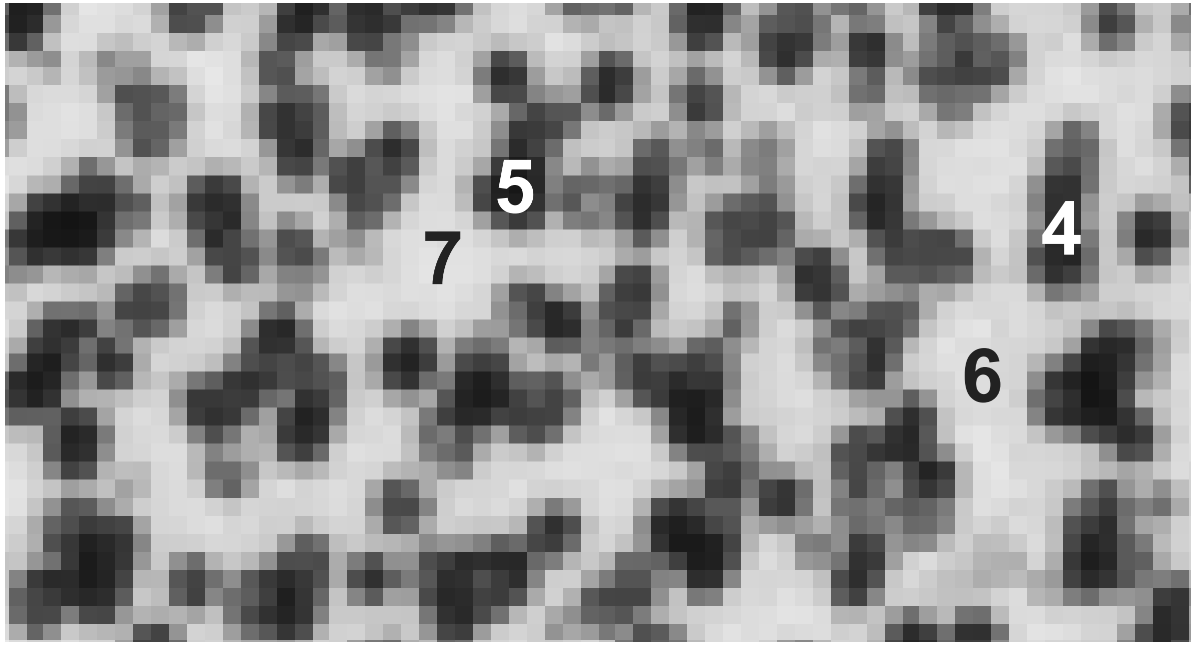
Test Conducted
June 2023

iDICs

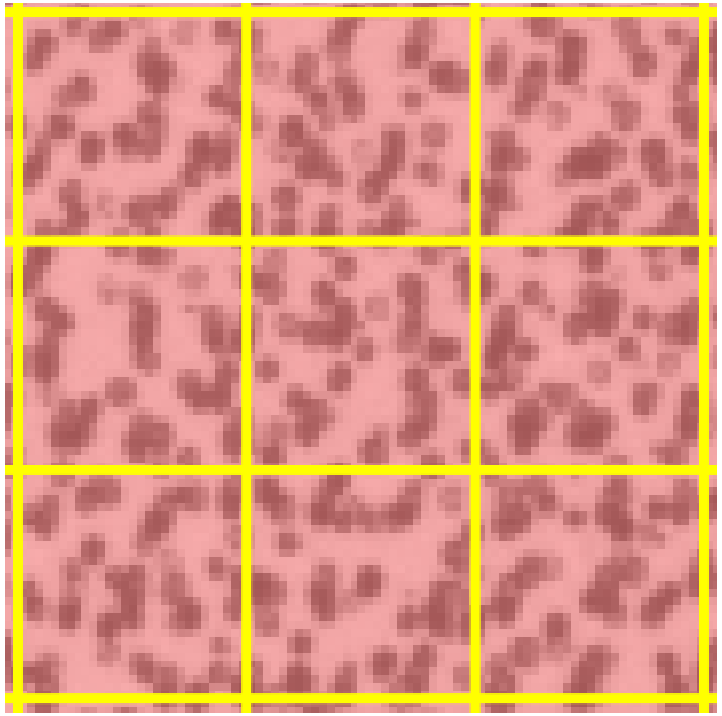
Speckle Pattern nearly ideal using a multi-pass roller on white base-coat

Ideal Speckle pattern

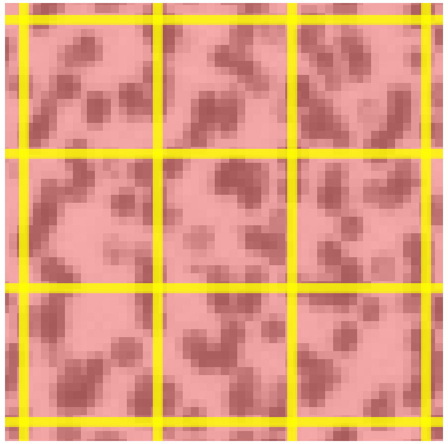
- White base coat (no evidence of failure)
- Black ink roller with multiple passes
- Very uniform pattern with approximately 5-pixel speckles
- Should support subset sizes down to 17 or maybe 15



Subset 29×29



Subset 17×17



DIC Analysis

- Subset 29 pixels
- Step 1 pixel
- SW = 15
- Affine shape
- ZNSSD
- 8-tap interpolant

VSG = 43 pixels

Virtual Strain Gage (VSG) and Examples of Strain Gage Calculation Methods Sec. 5.3.1 and Sec. 5.3.2

VSG size:

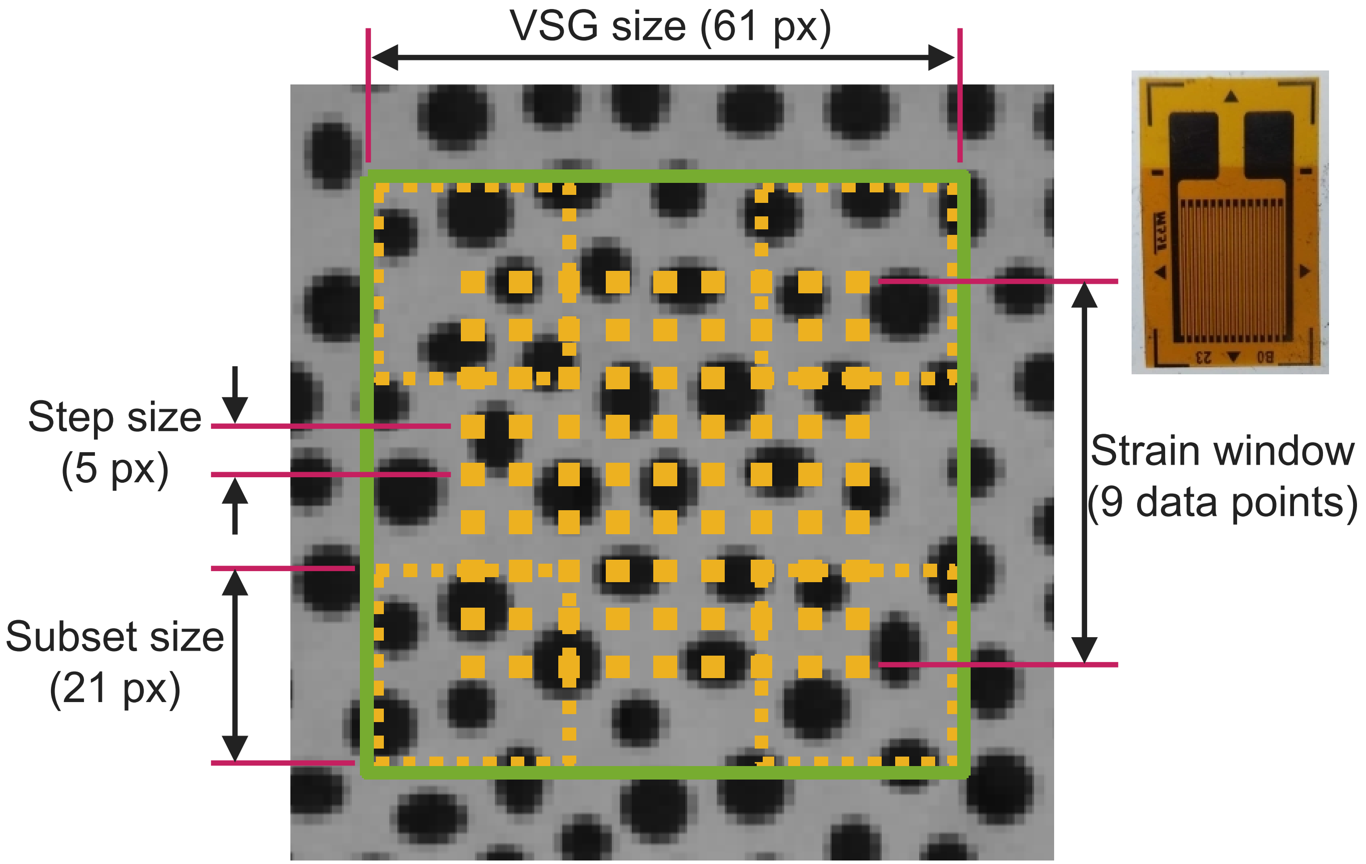
- Local region of the image that is used for strain calculation at a given location
- Analogous to, but not exactly, the size of a physical strain gage
- Participants submitted VSG sizes of 23, 33, 43, 53, and 63 pixels

Strain computation methods:

- Many methods, such as:
  - Subset Shape Function
  - Finite Element Shape Function
  - Strain Shape Function
  - Spline Fit
- See software manual for details

For subset based codes – This is the definition of VSG s

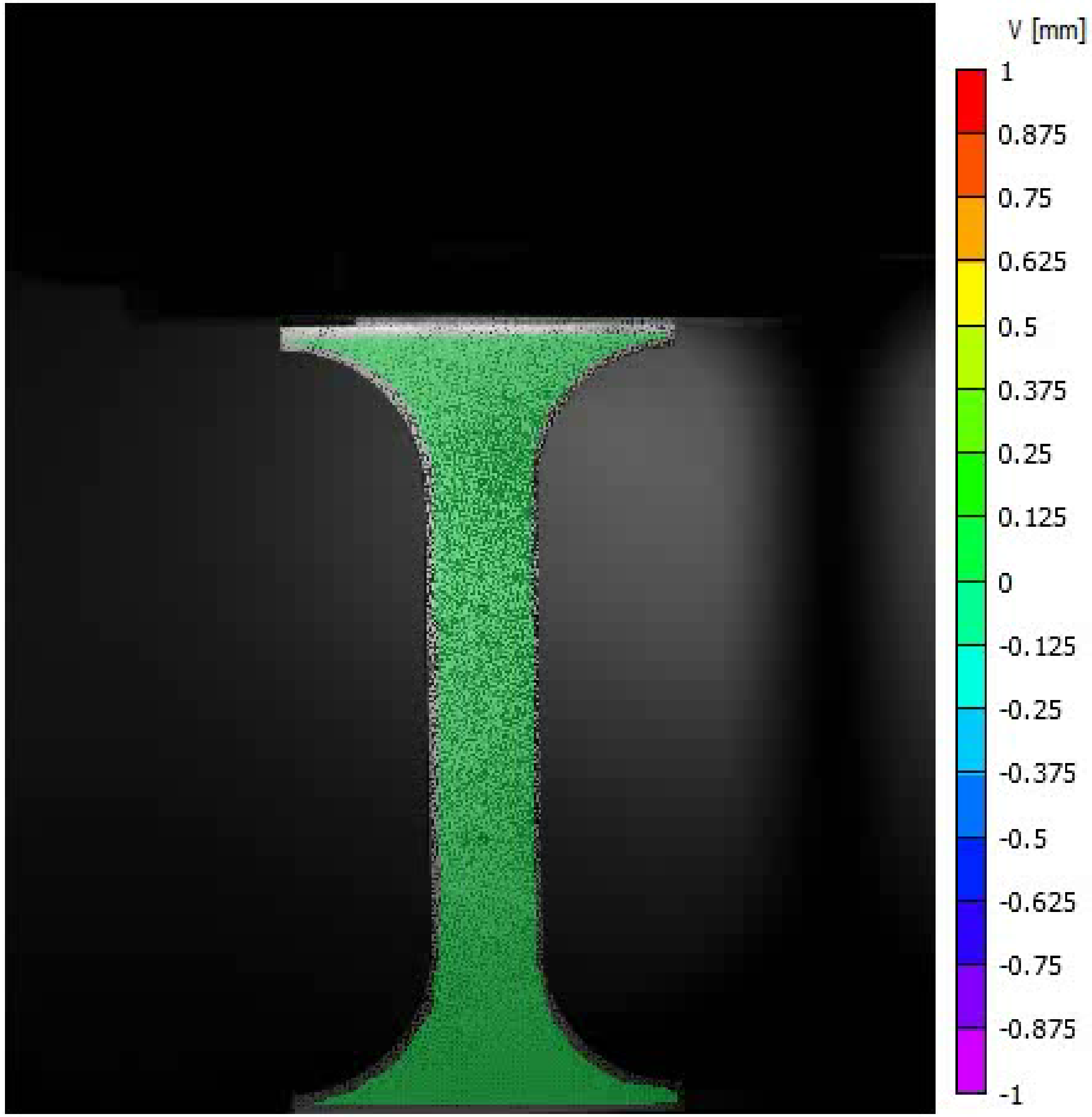
$$L_{VSG} = (L_{window} - 1)L_{step} + L_{subset}$$



Participants joined via online meeting to approve the calibrations

Live Event Participants
- Dantec,
- LaVision,
- DICe,
- Eikosim,
- MatchID
- Correlated Solutions

Invited to Participate
- GOM
- Image Systems,
- CorreliSTC,
- ALDIC,

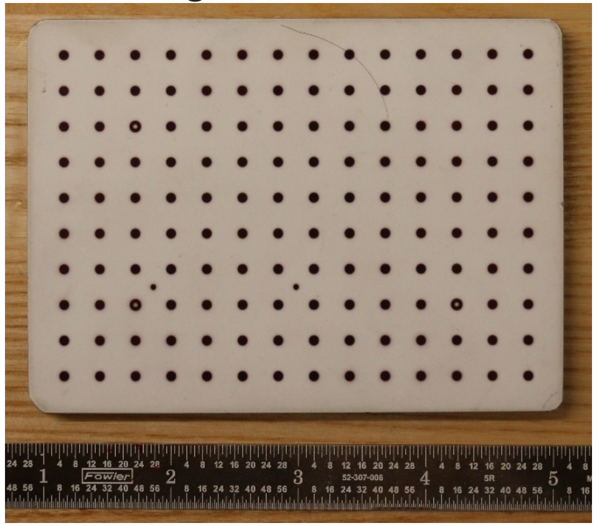


Participation during experiment to validate setup

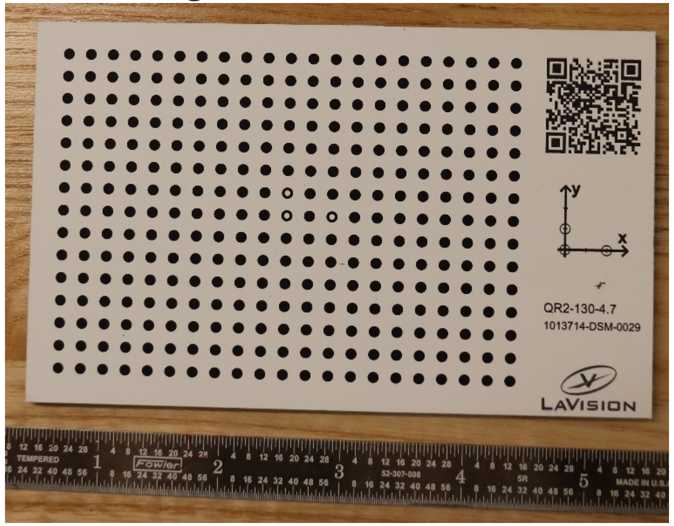
- Nearly all vendors participated in the live calibration event. Feedback was provided until all participants happy with calibration
- Data collected immediately after calibration. Projection error remained small the remainder of the day
- Data available to all participants by invitation to the Google Drive. Email: plreu@sandia.gov

Calibration targets: Something for everyone.

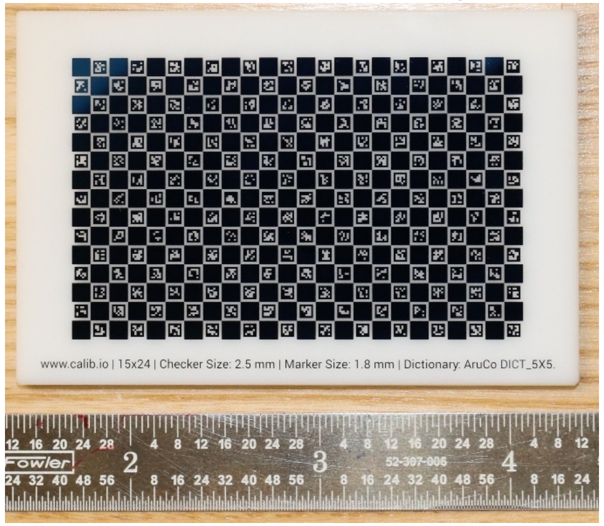
CSI 7mm Dot Grid (H95-00-04)
113 Images



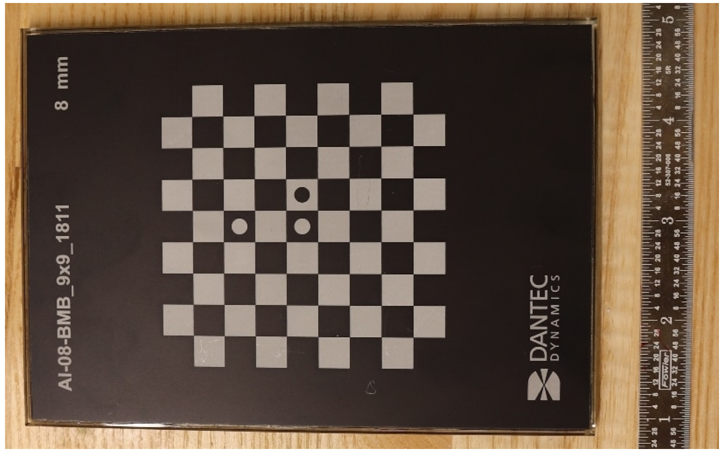
LaVision Dot Grid (QR2-130-4.7)
169 Images



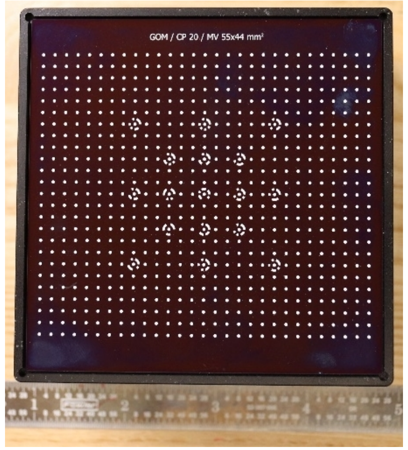
Eikosim OpenCV 15×24 Checker =2.5m
Marker=1.8mm 188 Images



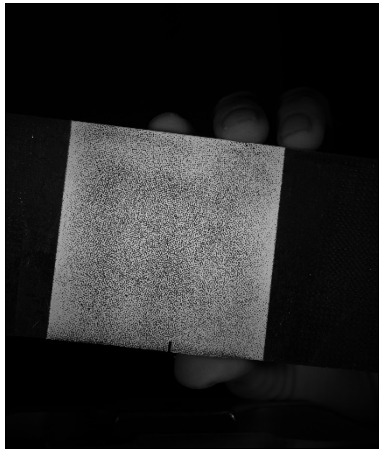
Dantec 8-mm Grid (AI-08-BMB-9×9_1811)
125 Images



GOM 55×44 mm^2 (CP20)
201 Images

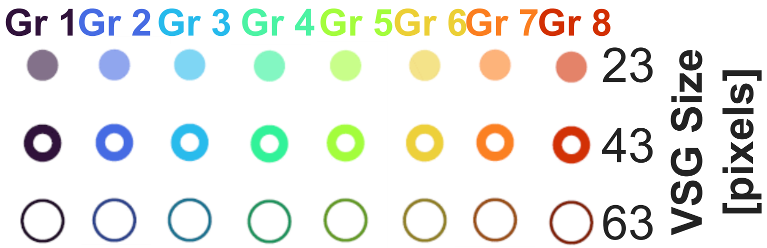


Rigid Plate
78 Images



Participants to the DIC Challenge Analysis

Participant	Type of Code	Strain Description
DICe	Subset Based	
LaVision	Subset Based	Provided
Dantec Dynamics	Subset Based	Provided
Correlated Solutions	Subset Based	
Eikosim	Global Code	
MatchID	Subset Based	
ALDIC	Subset/Global Hybrid	Provided
CorreliSTC	Global Code	
	Your Name Here	



Missing Codes from the Challenge

- GOM
- Image Systems
- SeptD
- IIT

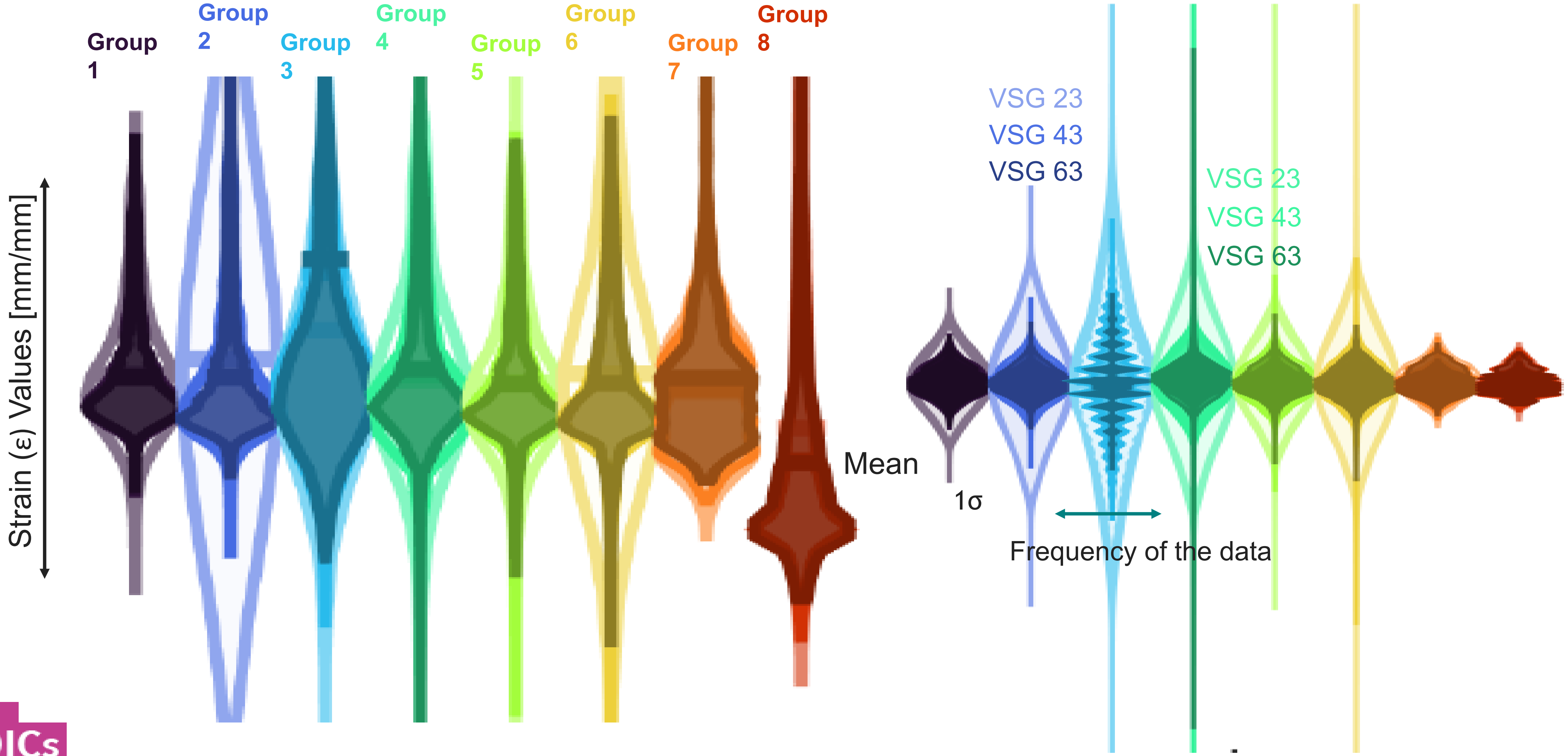
Why participate in the challenge?

- Benchmark your code against others
- Ensure that DIC results are reliable industry wide
- Validate your code against the best available experimental data

Strain Calculation Methods are needed

- Error estimates for the lens distortions
- Need to provide calibration parameters for the calibration
- May need to resubmit results to correct coordinate systems
- We are looking for a way to check if everyone is in the same coordinate system

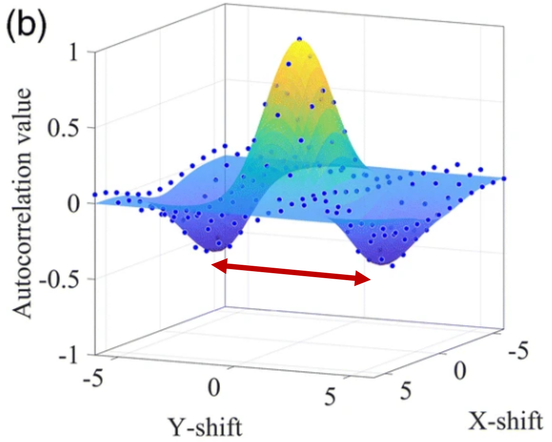
Data plotting description – Violin Plots

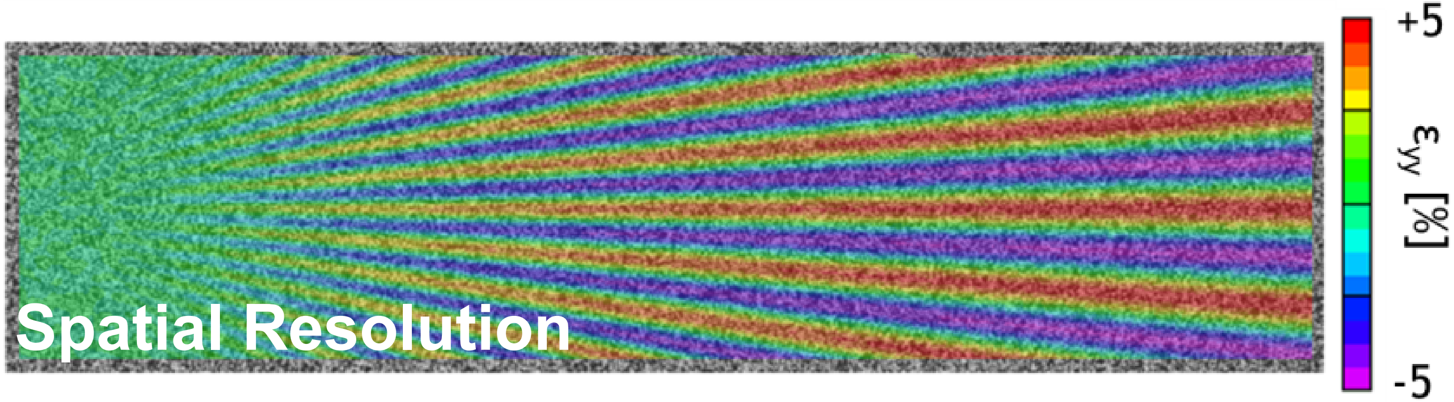


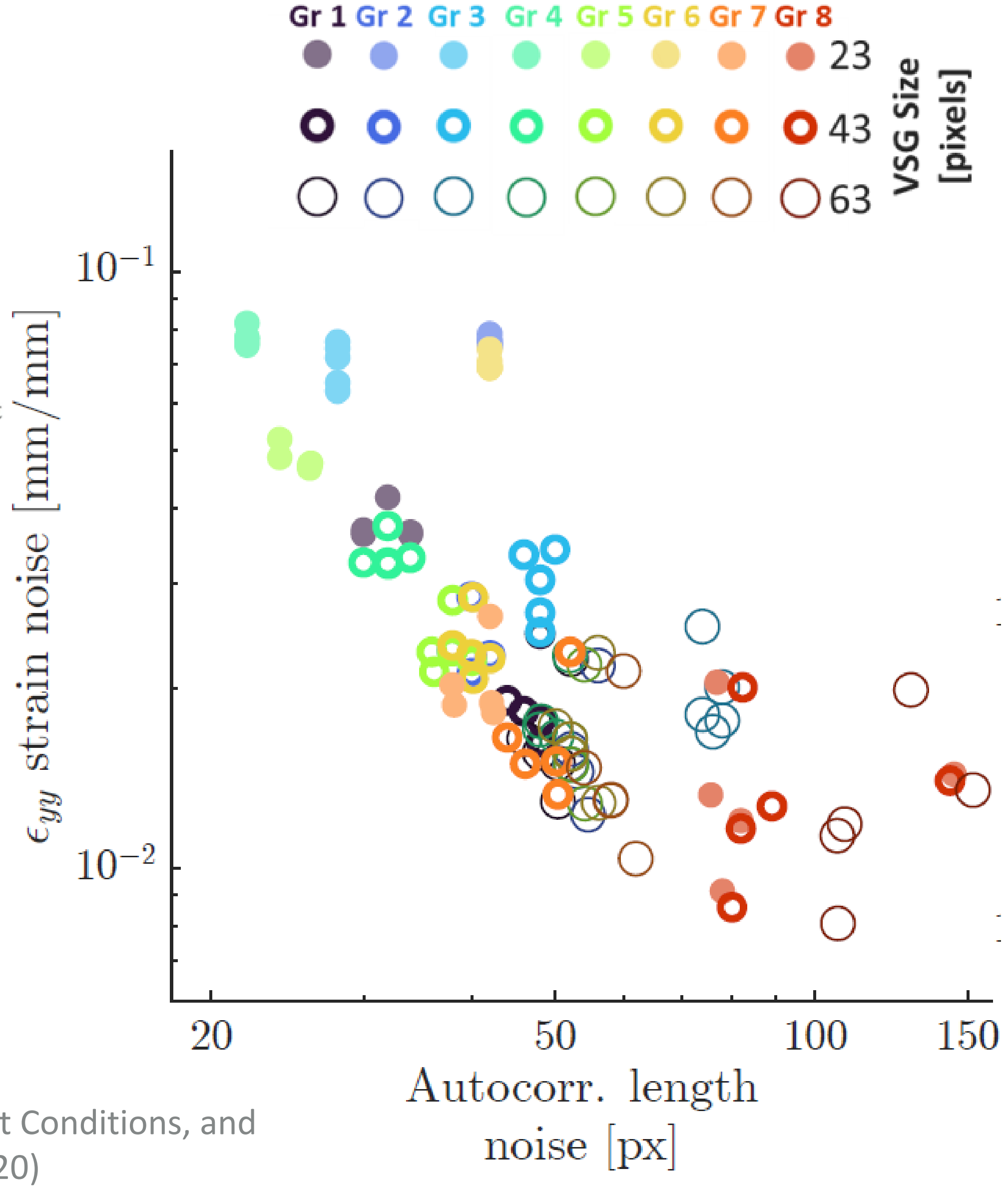
First Item: Static Noise Floor: Noise vs Spatial Resolution (ε_{yy} shown here)

Notes

- Spatial resolution is a measure of the maximum gradient DIC can measure
- Autocorrelation length used to estimate the strain resolution
- Distance between the peaks estimates the spatial resolution
- All 8 Groups plotted
- Note the log/log scaling
- Some data is hidden but all is plotted.





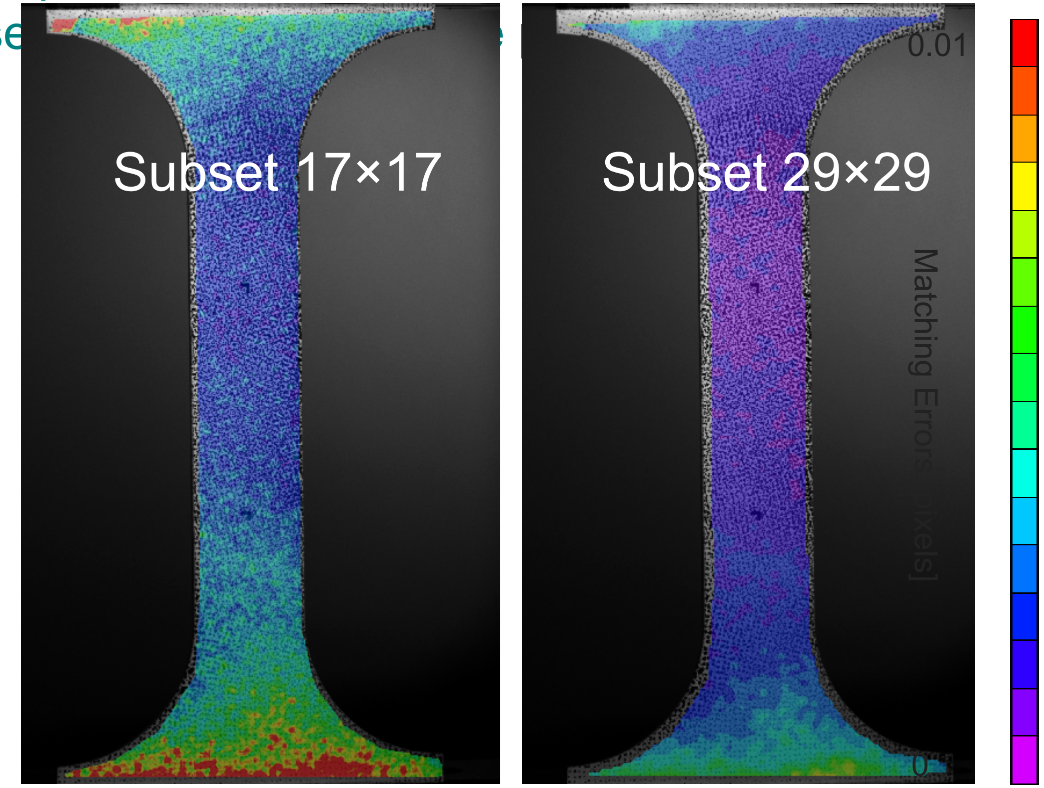


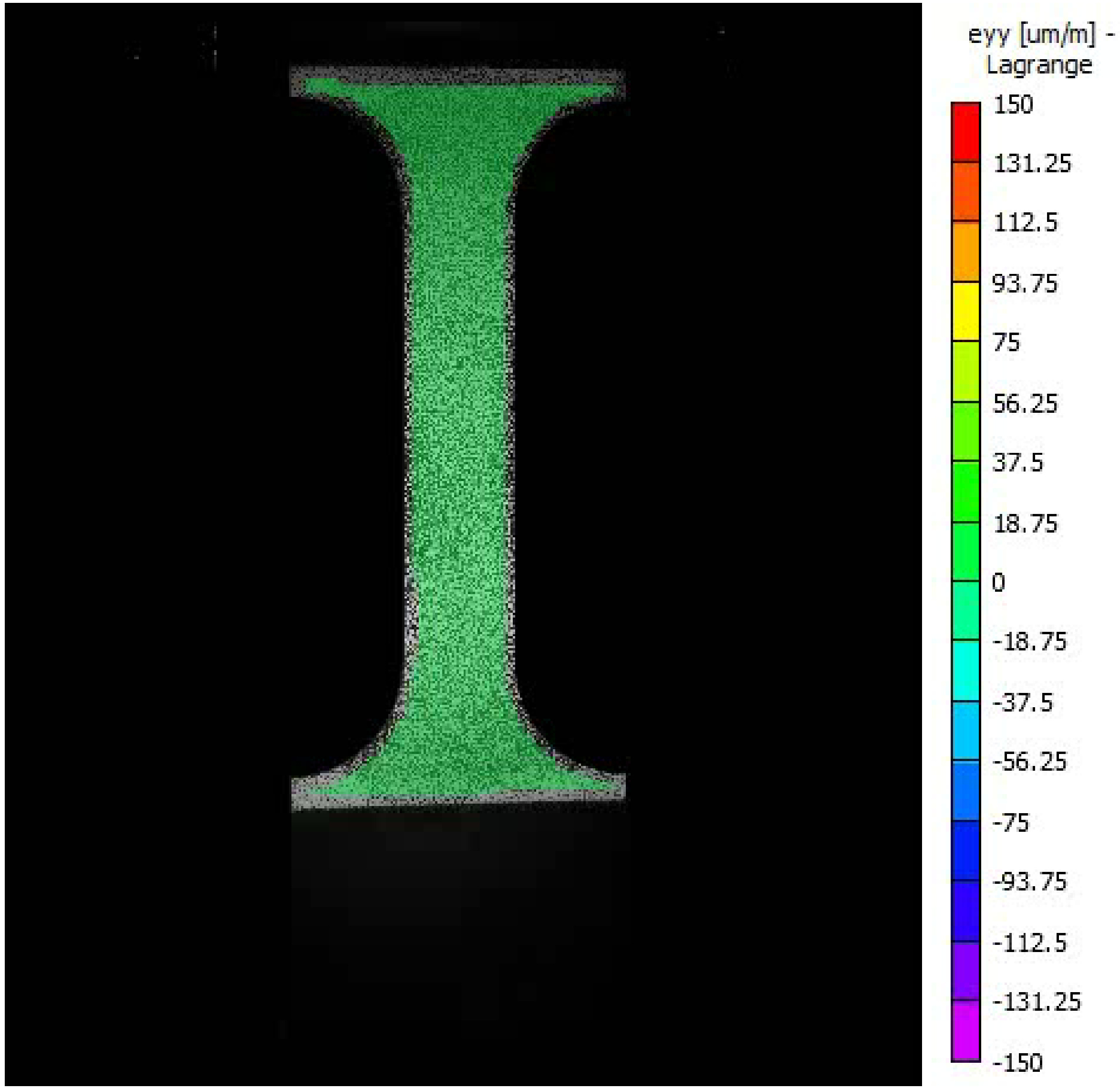
Forsström, A., Bossuyt, S., Scotti, G. *et al.* Quantifying the Effectiveness of Patterning, Test Conditions, and DIC Parameters for Characterization of Plastic Strain Localization. *Exp Mech* **60**, 3–12 (2020)

Better uncertainty estimate is the: Rigid-body zero-value test

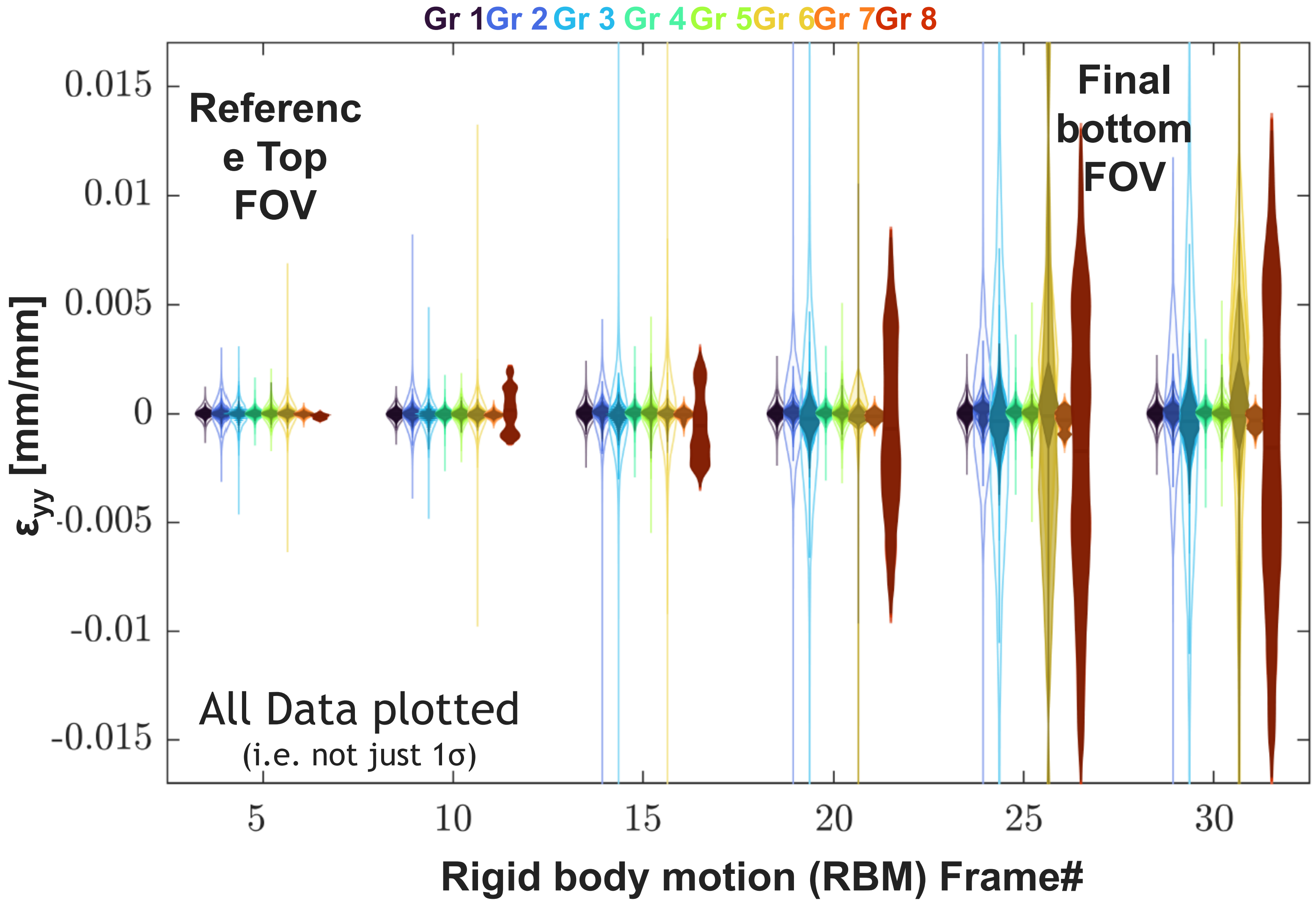
Rigid-body zero-value – Tensile specimen

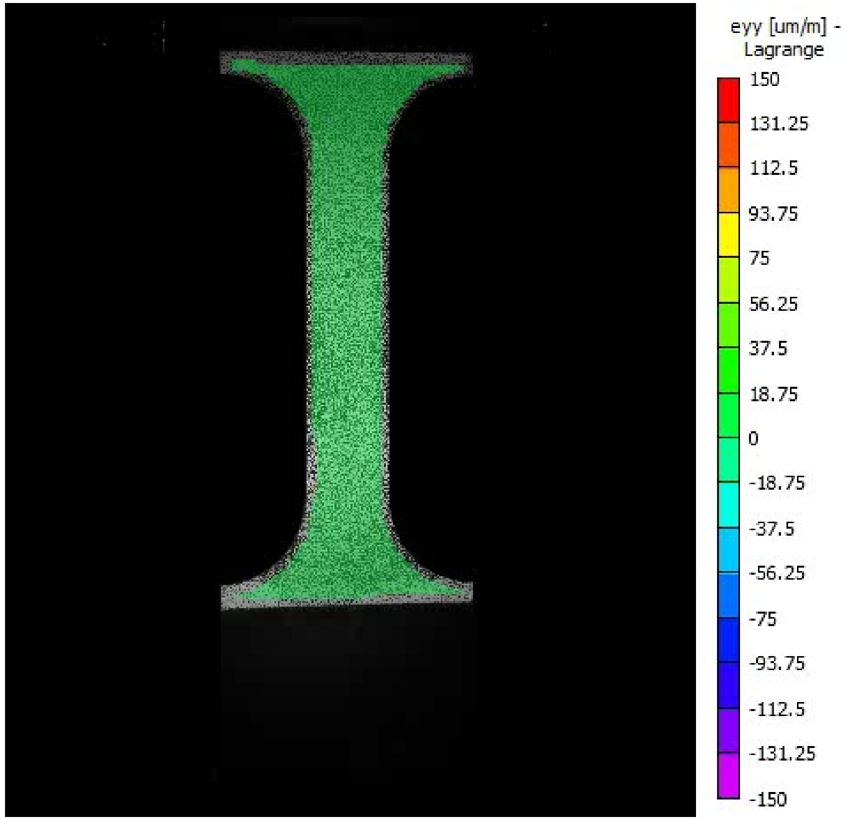
- Test sample used and translated unloaded through FOV
- Some hints of air turbulence (SS = 29)
- No drop-outs with even a subset = 17
- Subse





RBM Strain Results – The errors are growing!





What do the growing errors (for some codes) indicate?

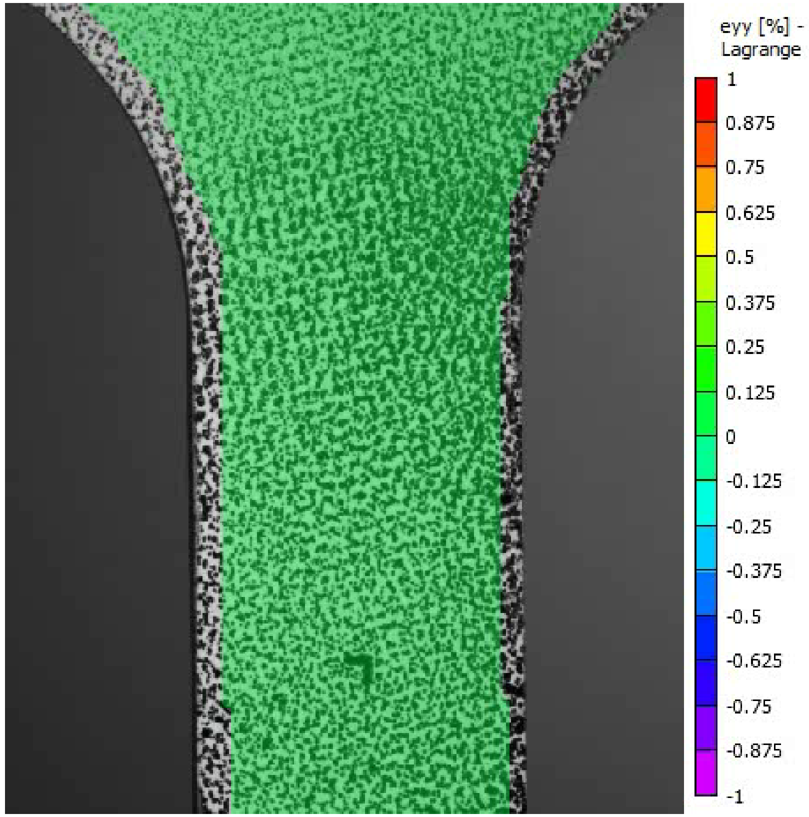
Notes

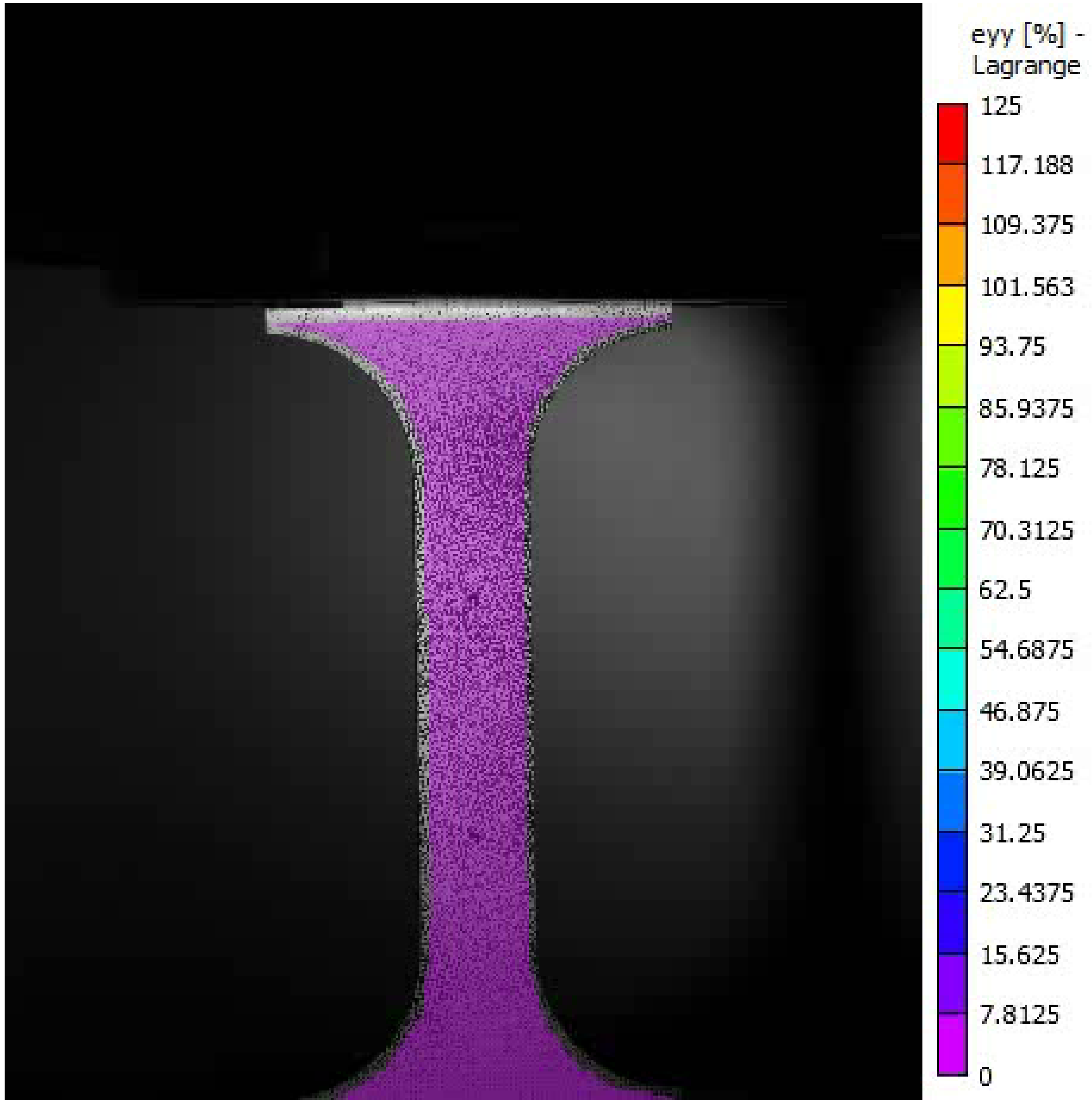
- All 8 Groups plotted
- VSG 23, 43 and 63 plotted in different shades
- All groups had more noise
- Group 2 and Group 7 Performed badly

Tensile data provides a rich data set to explore DIC code implementations

Tensile Specimen goes to failure

- Paint held up well.
- Pattern is ideal.
- Very clean experimental data set.



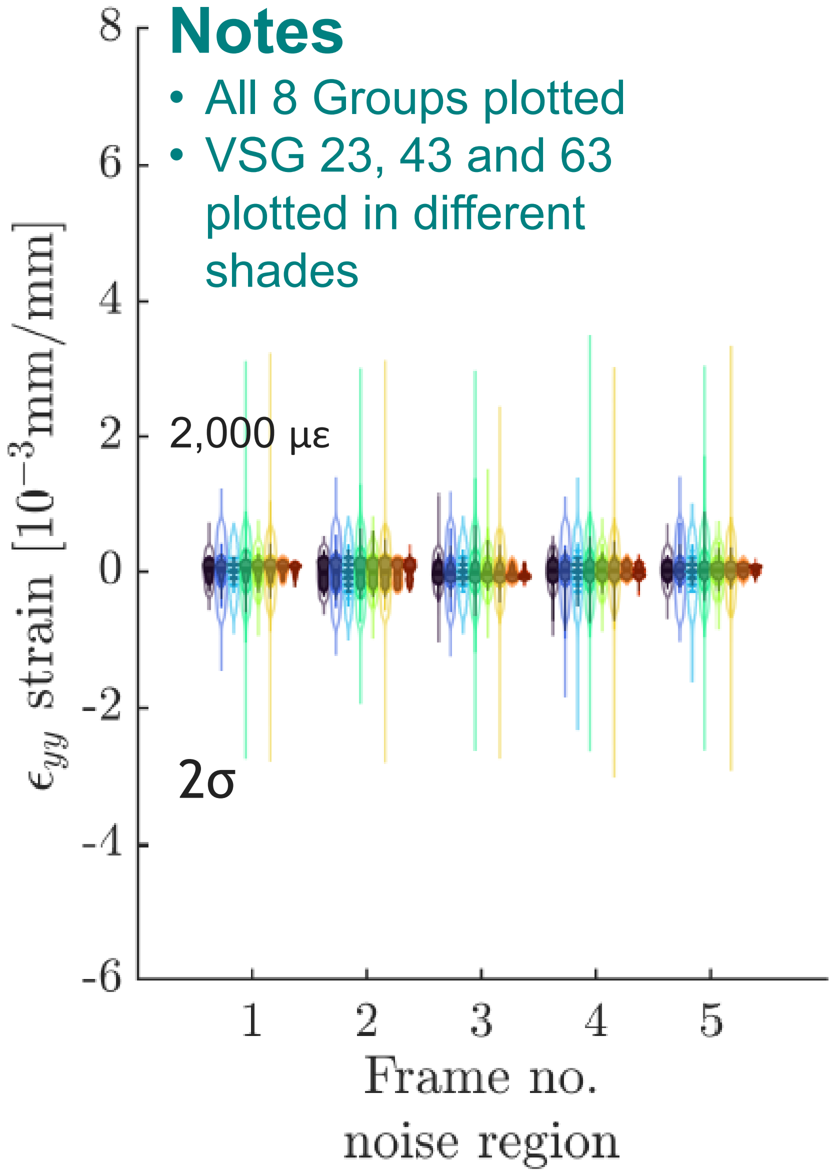


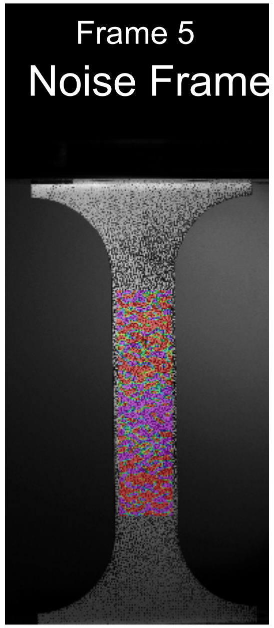
iDICs

Overview of the strain for the region before localization ε_{yy}

Notes

- All 8 Groups plotted
- VSG 23, 43 and 63 plotted in different shades

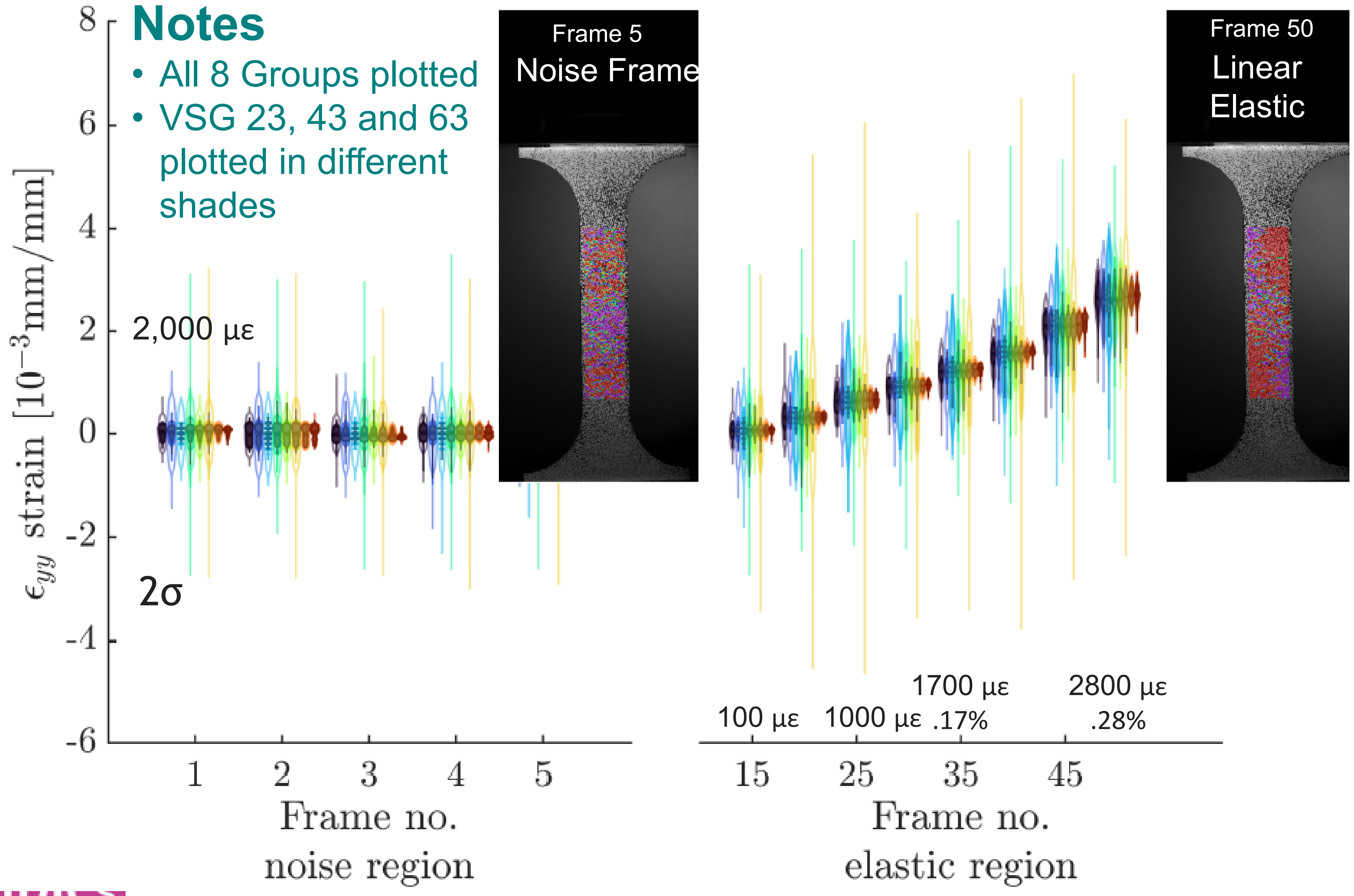




Overview of the strain for the region before localization ε_{yy}

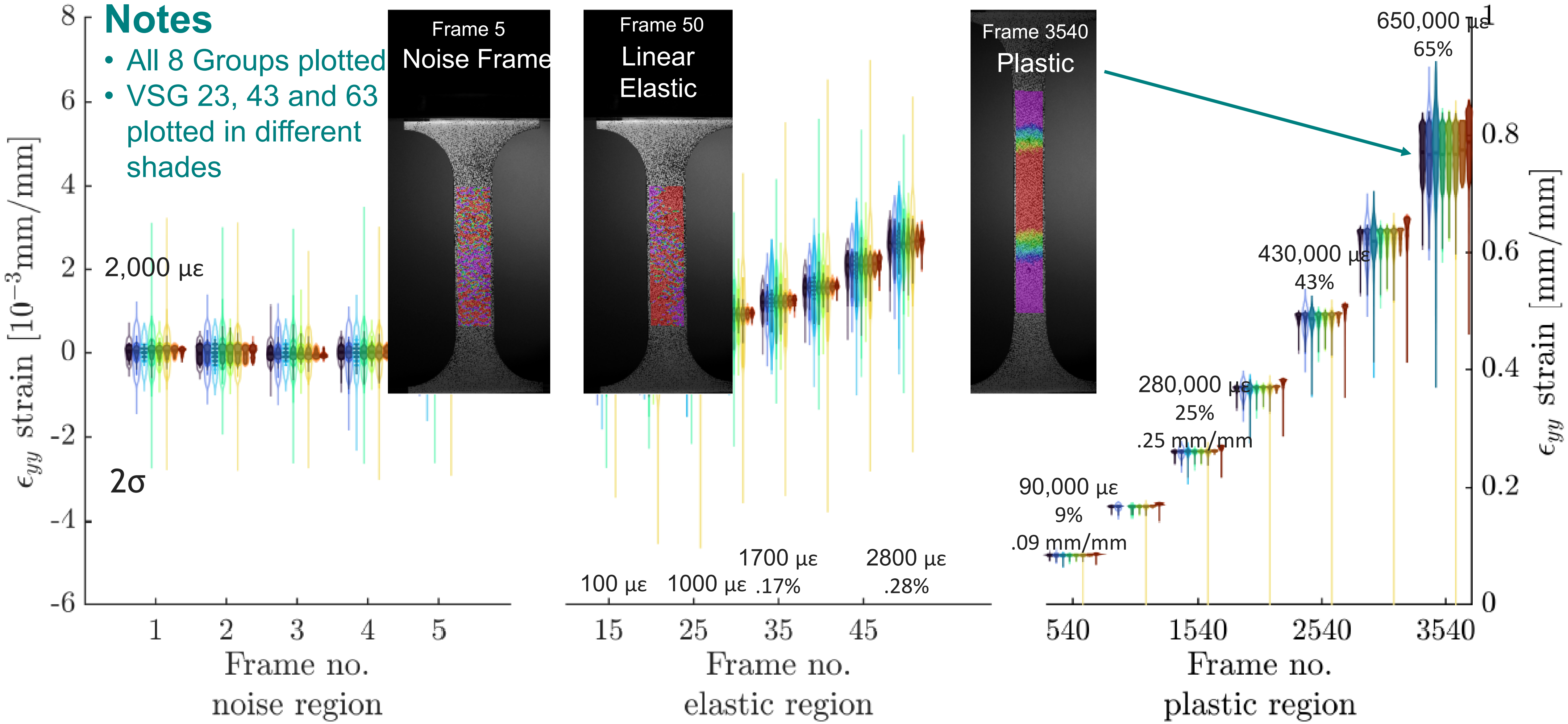
Notes

- All 8 Groups plotted
- VSG 23, 43 and 63 plotted in different shades

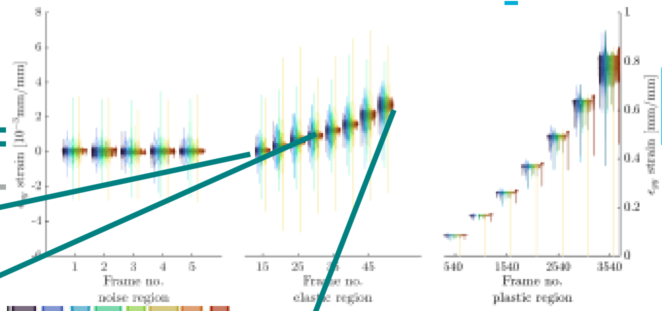


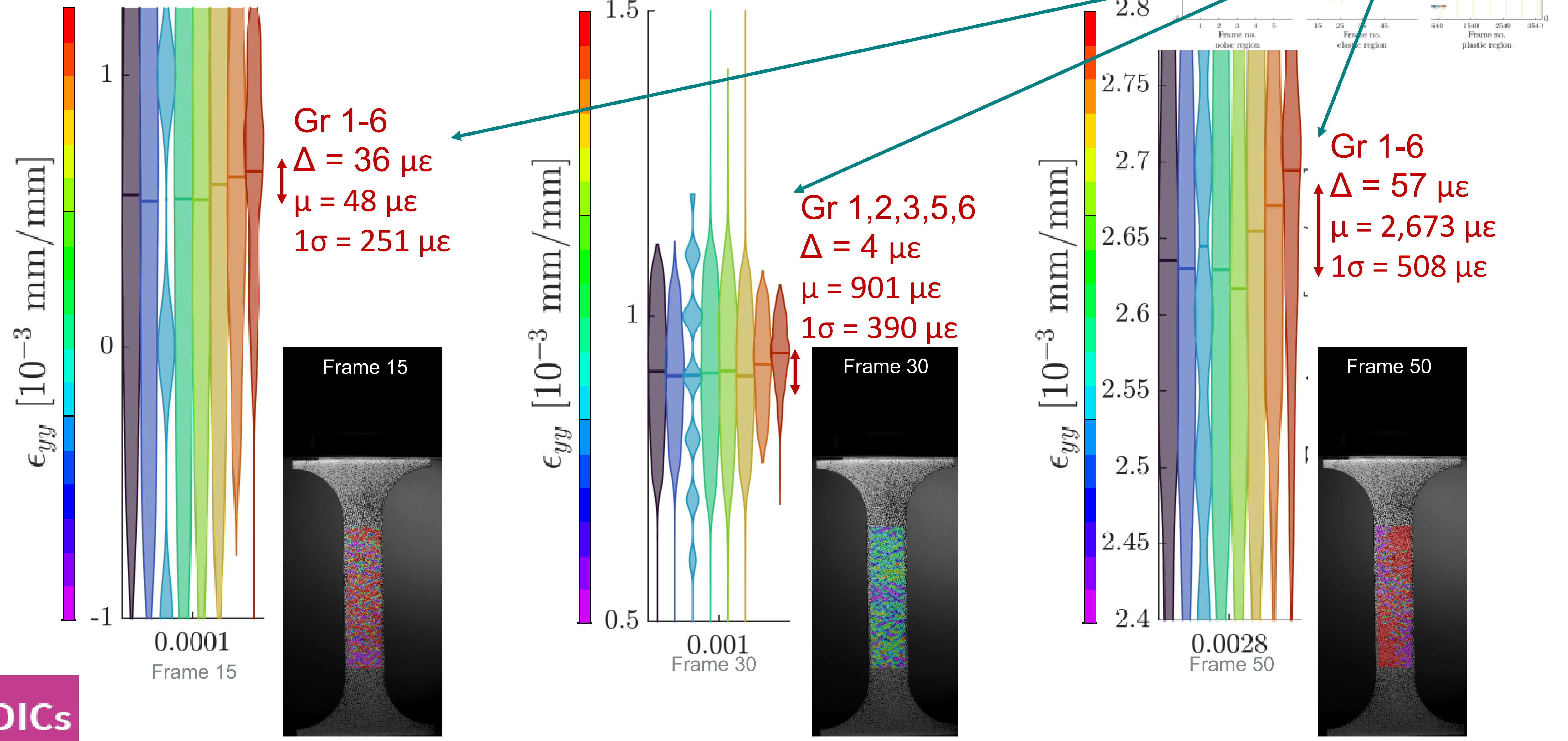
Overview of the strain for the region before localization ε_{yy}

Notes
- All 8 Groups plotted
- VSG 23, 43 and 63 plotted in different shades



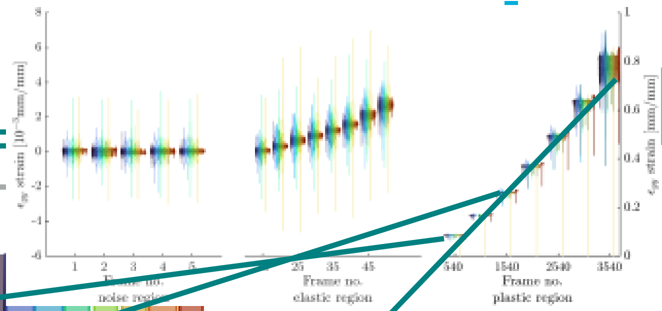
A closer look at the differences between the codes for ε_{yy} (VSG =

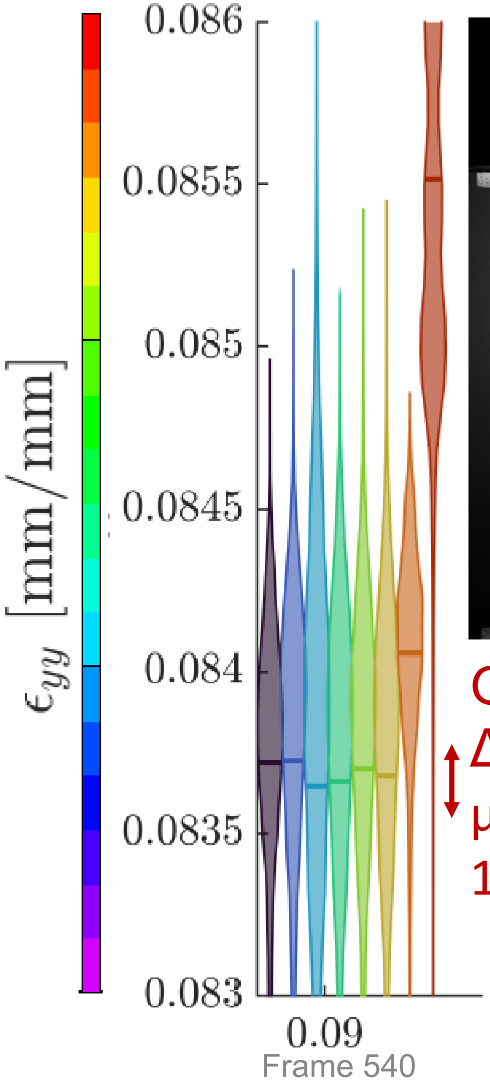


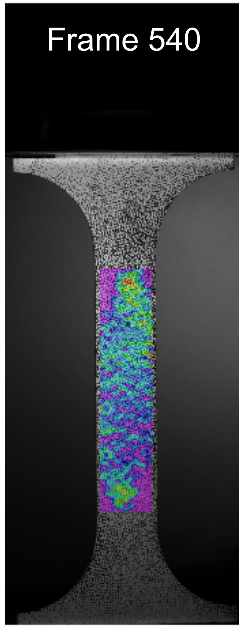


iDICs

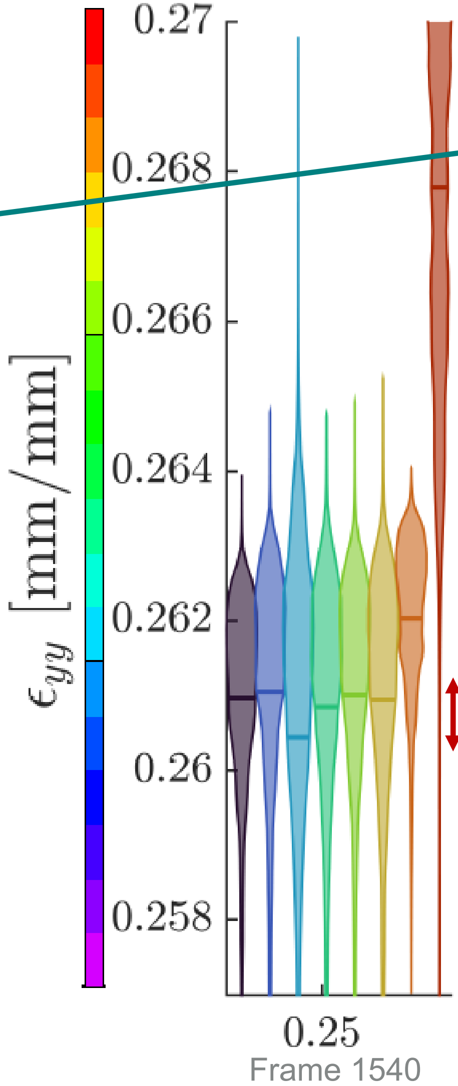
A closer look at the differences between the codes for ε_{yy} (VSG =

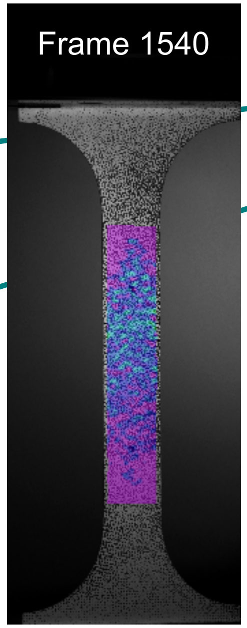




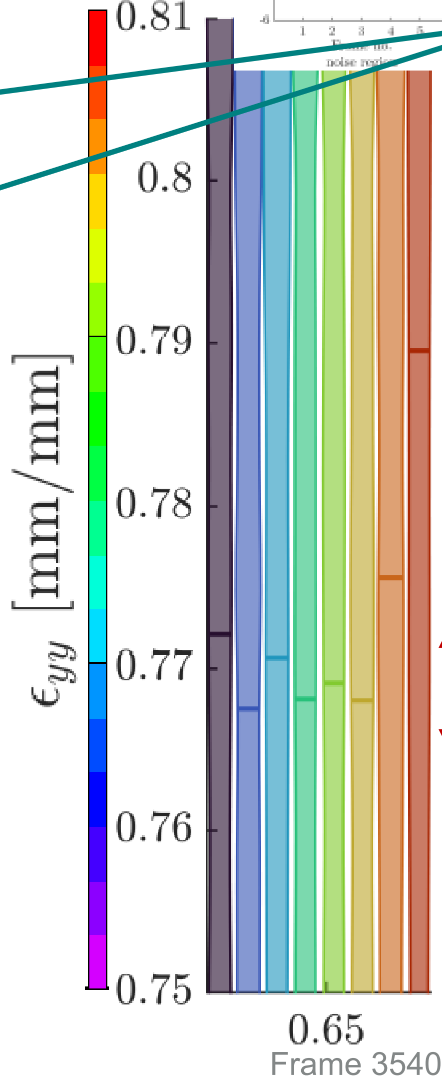


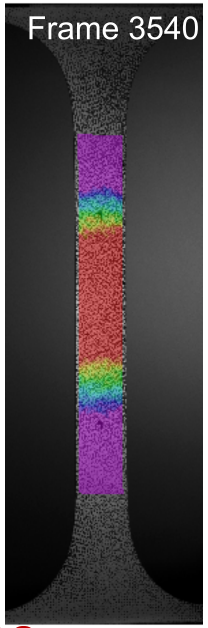
Gr 1-6
Δ = 509 με
μ = 85,000 με
1σ = 1,757 με





Gr 1-6
Δ = 1,727 με
μ = 259,749 με
1σ = 5,247 με





Gr 1-6
Δ = 8,482 με
μ = 761,091 με
1σ = 64,515 με

Gr 1 Gr 2 Gr 3 Gr 4 Gr 5 Gr 6 Gr 7 Gr 8

iDICs

Verification and classification of extensometer systems ASTM E83 and ISO 9513
Where does DIC fit into this standard?

Notes

- ASTM E83/ISO9513 Extensometer verification
- Checks the extensometer against a special caliper
- Three classes of accuracy are allowed, A, B-1 and B-2
- We are going to do a similar calculation. but using the displacement from I displacement

MTS 1 µm
ASTM B2
Standard?

Instron 0.1 µm
ASTM B1 Standard

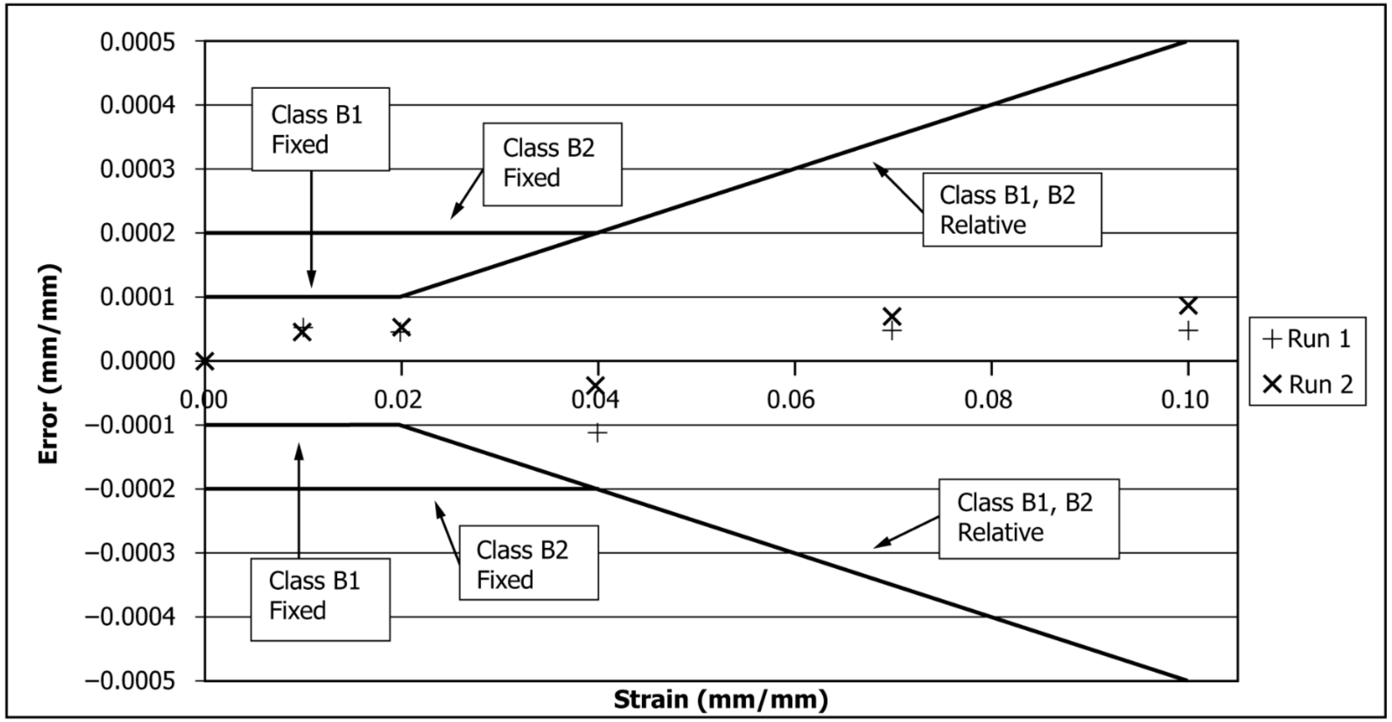


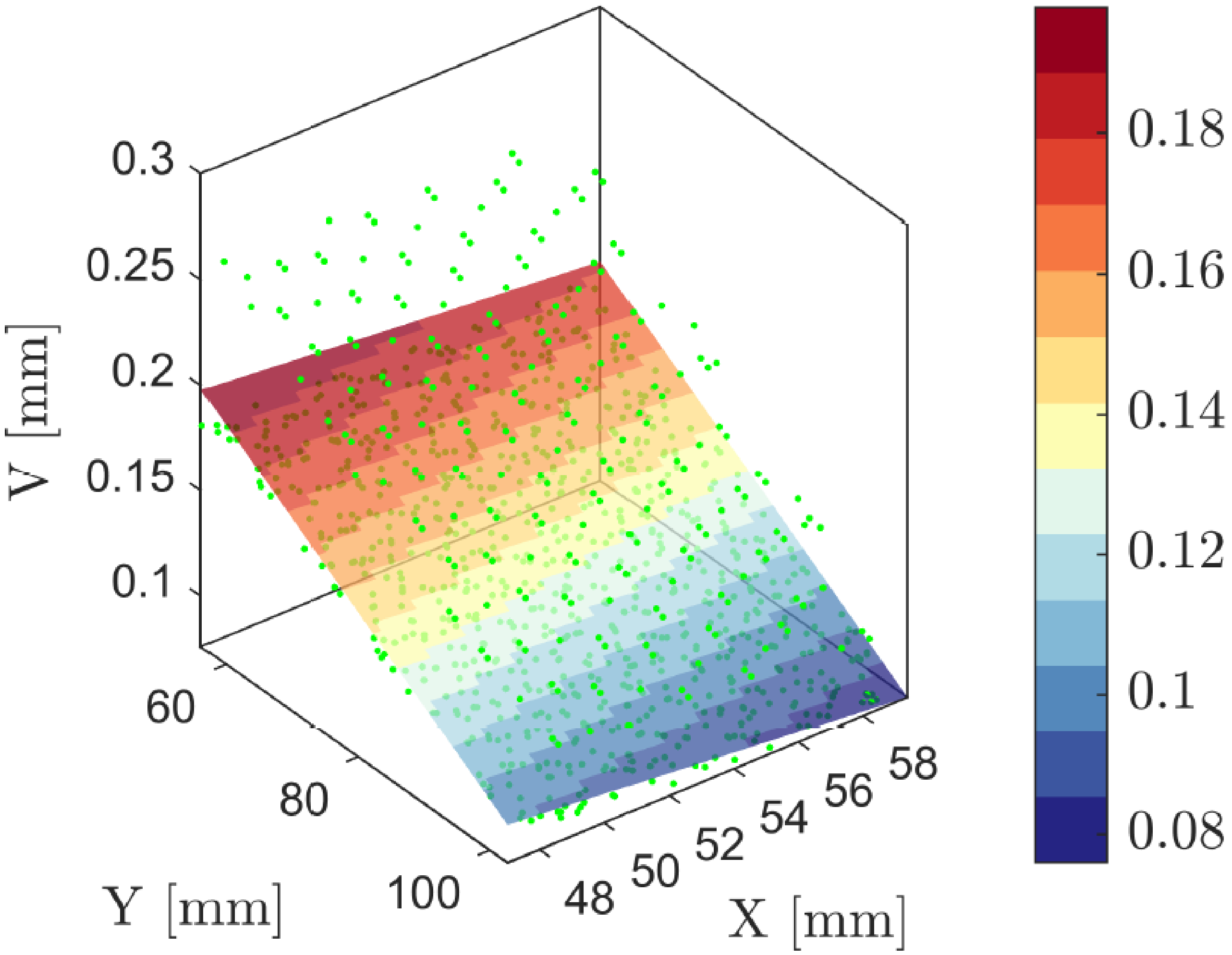
FIG. X1.4 Extensometer Errors and Specifications 25 mm, 100% Extensometer (10% Range, Fig. X1.2)

Calculation of the strain for the ASTM E83 comparison

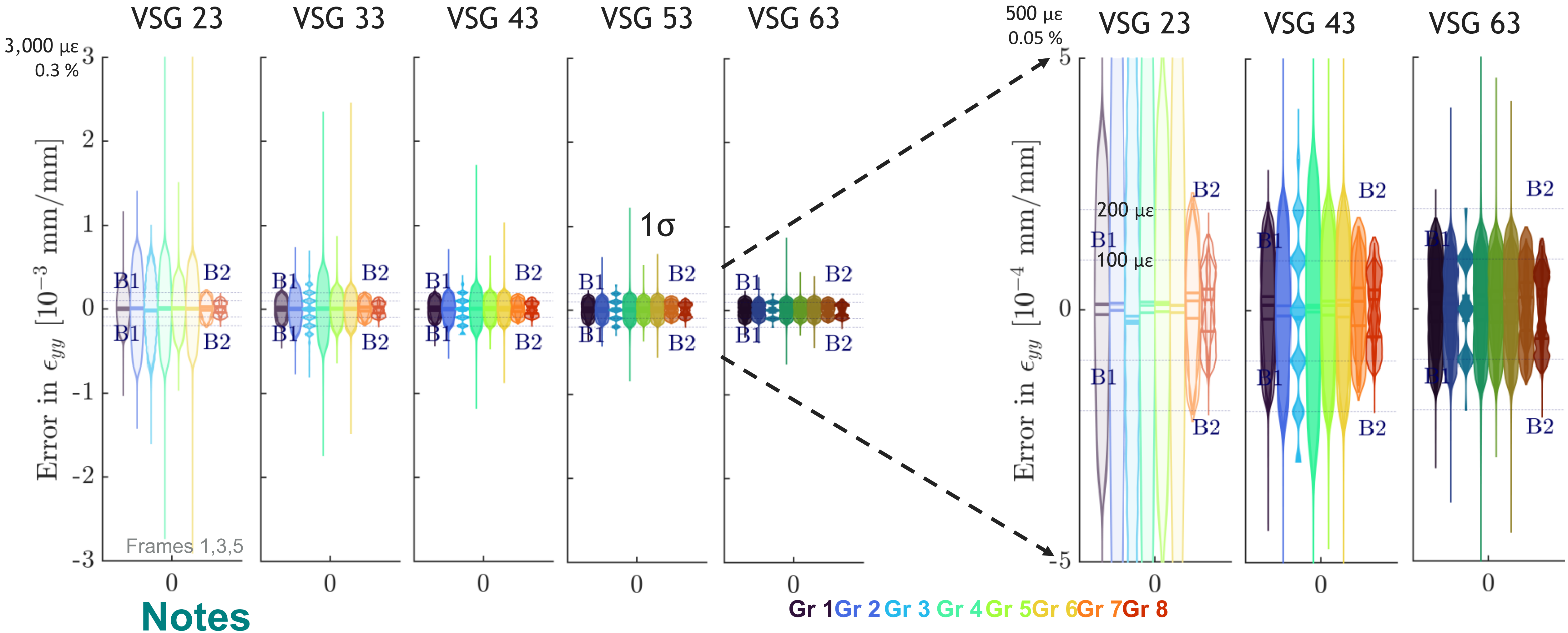
Notes

- Method is still in process of being developed
- 3 Groups had coordinate system errors and were not used for calculating the displacement/strain
- Pixel locations rather than X,Y locations used and then scaled (again due to coordinate issues)
- 5 Groups & 5 VSG sizes with a weighted average were combined together to get U, V and W planes. May have had the same subset size. Weights were determined from noise floor images.
- Displacement fields were then fit with a plane to calculate the ε_{xx}, ε_{yy}, and ε_{xy}
- The average strains were then subtracted as the "ground truth" for the following "ASTM" plots.
- Errors may grow in the plastic regions, but are thought to be small at this point.

V- Displacement field (Data and average plane)



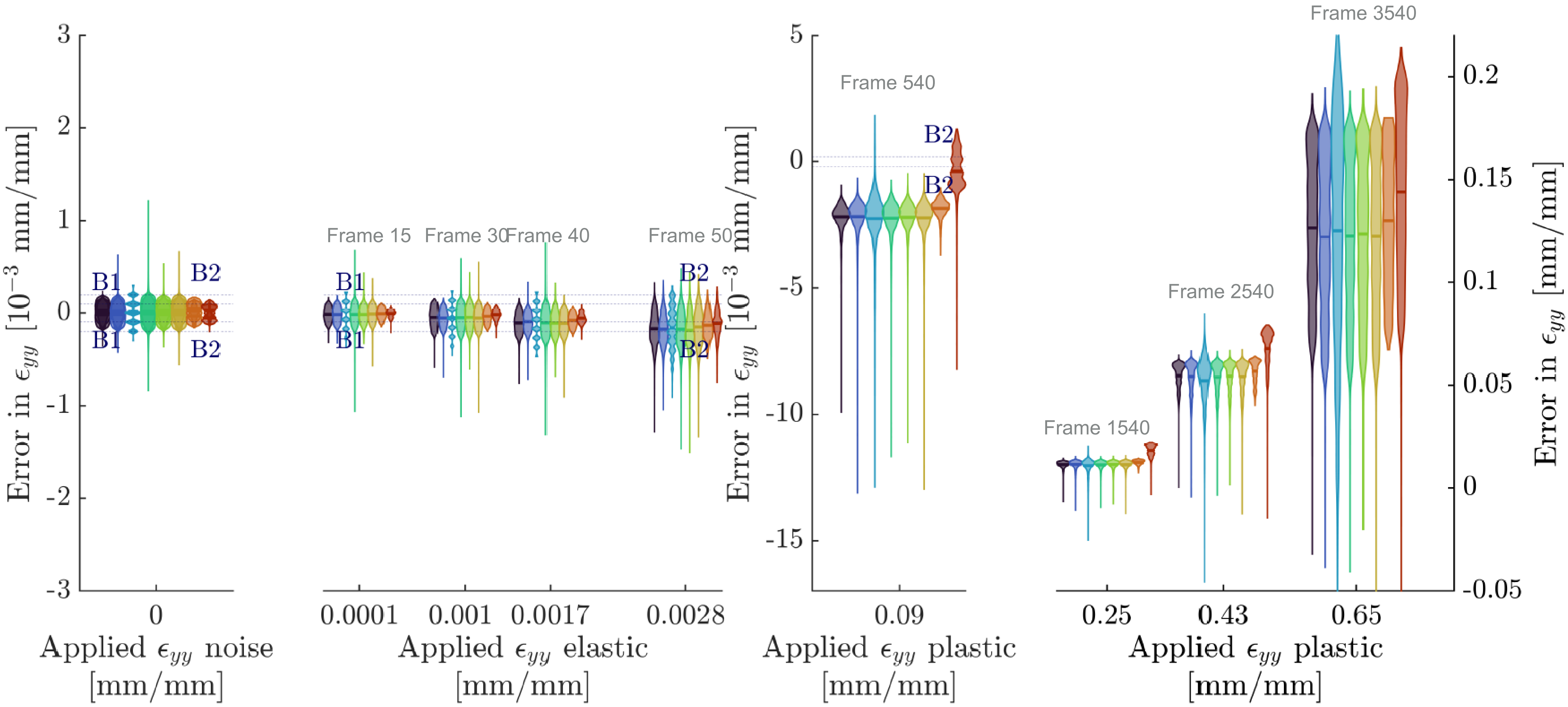
ASTM Noise floor image comparisons ε_{yy}



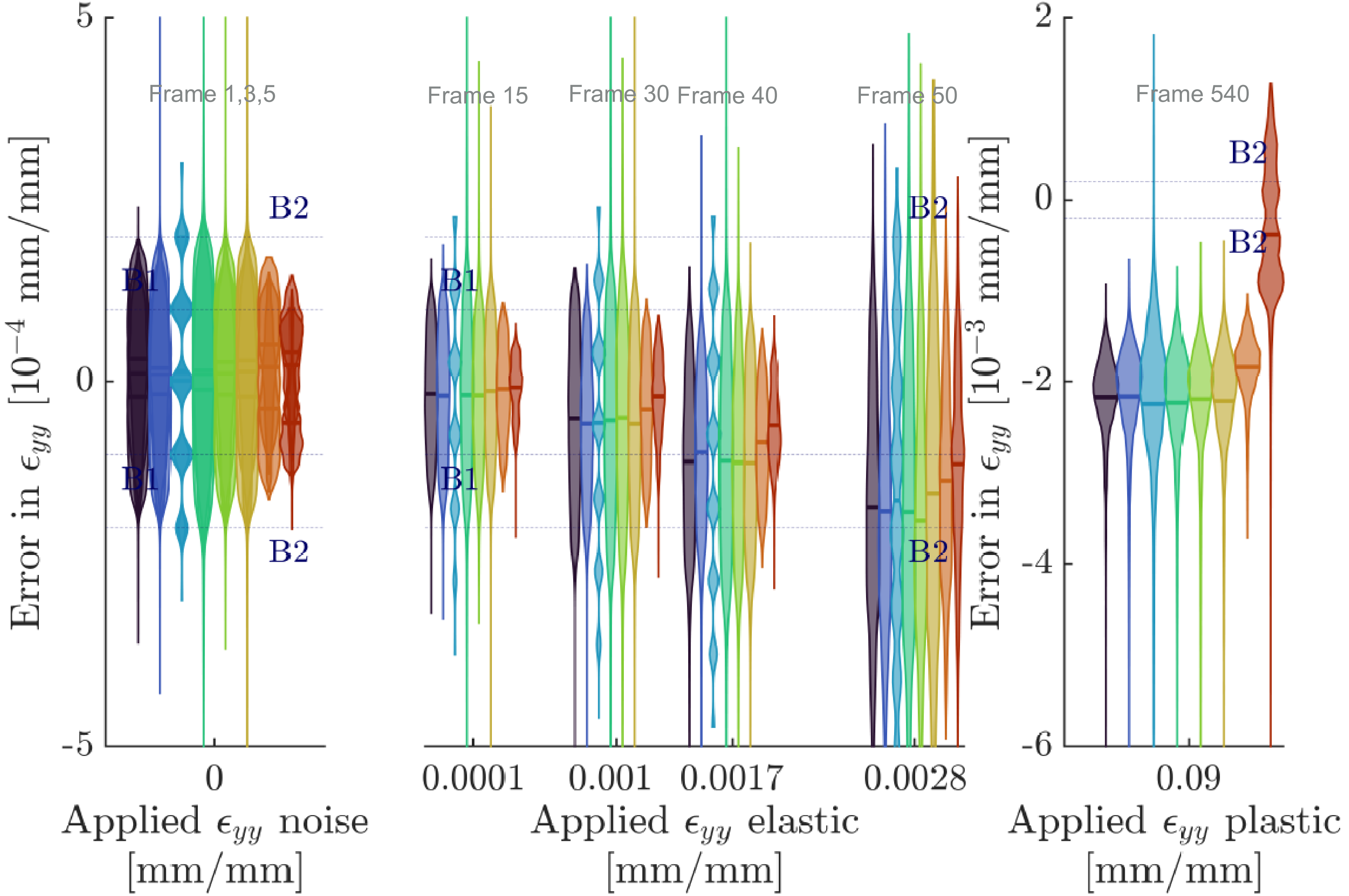
Notes

- VSG 43 seems to be the optimum size
- In the noise region we meet the ASTM B1 standards

ASTM Comparisons ε_{yy} – All Frames VSG=43



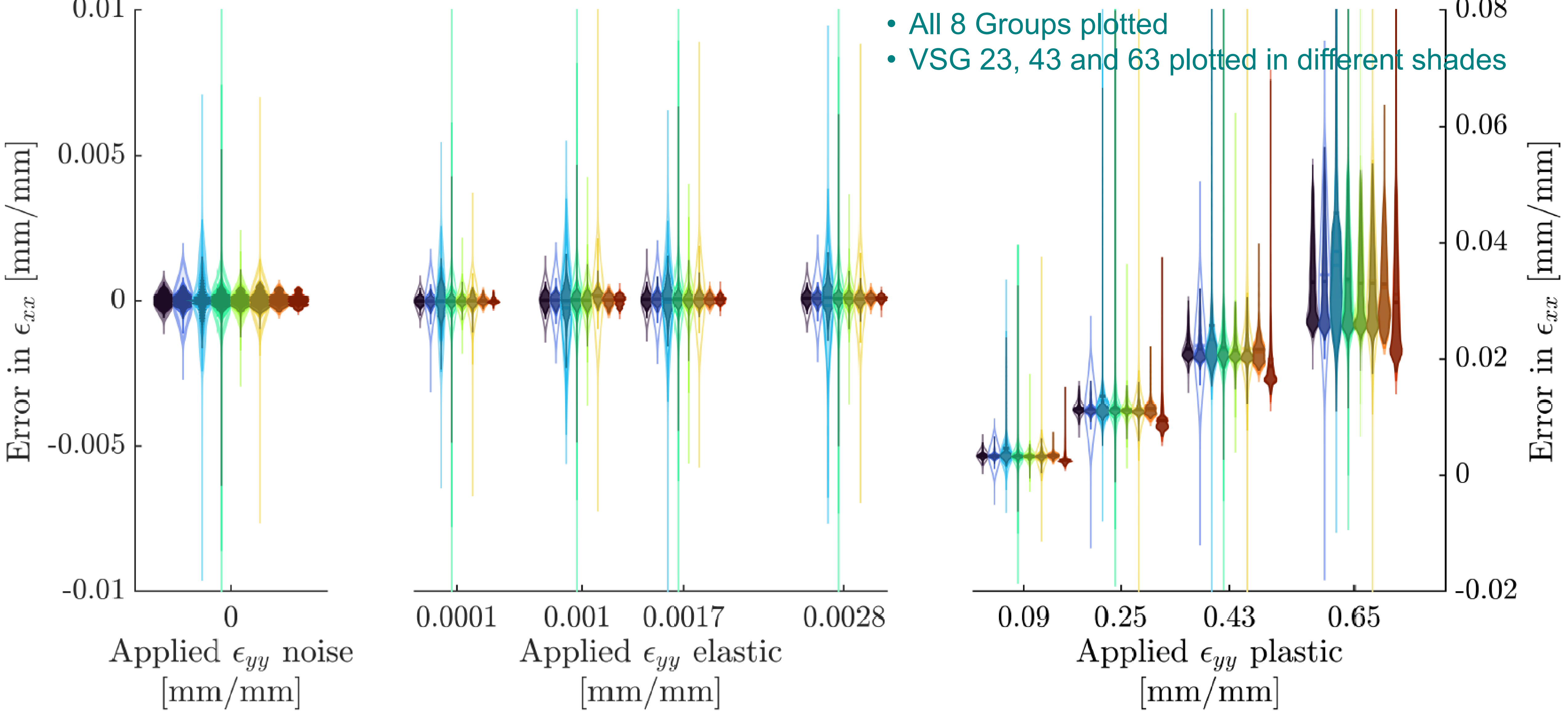
ASTM Comparisons ε_{yy} – All Frames VSG=43



ASTM Comparisons (zoomed) ε_{xx}

Notes

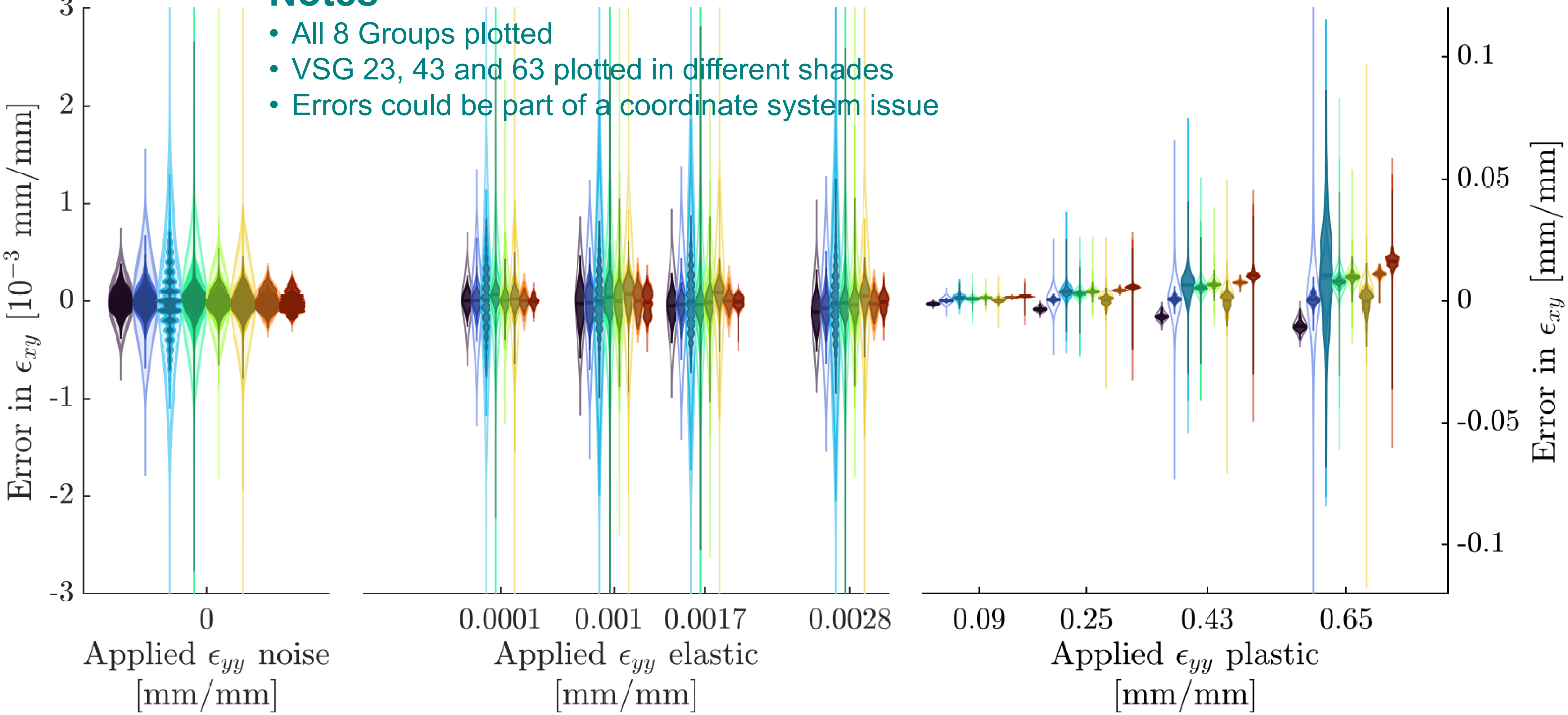
- All 8 Groups plotted
- VSG 23, 43 and 63 plotted in different shades



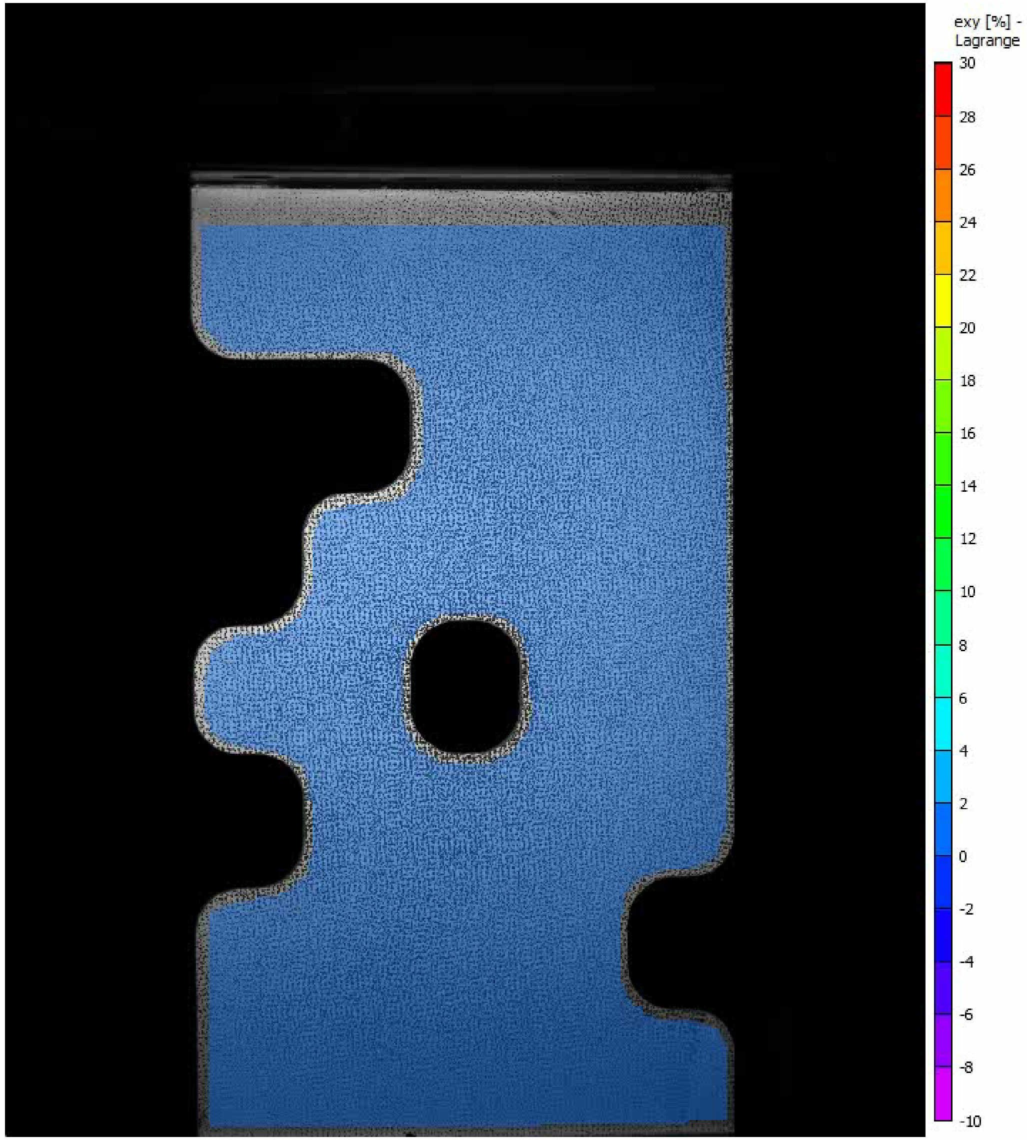
ASTM Comparisons (zoomed) ε_{xy}

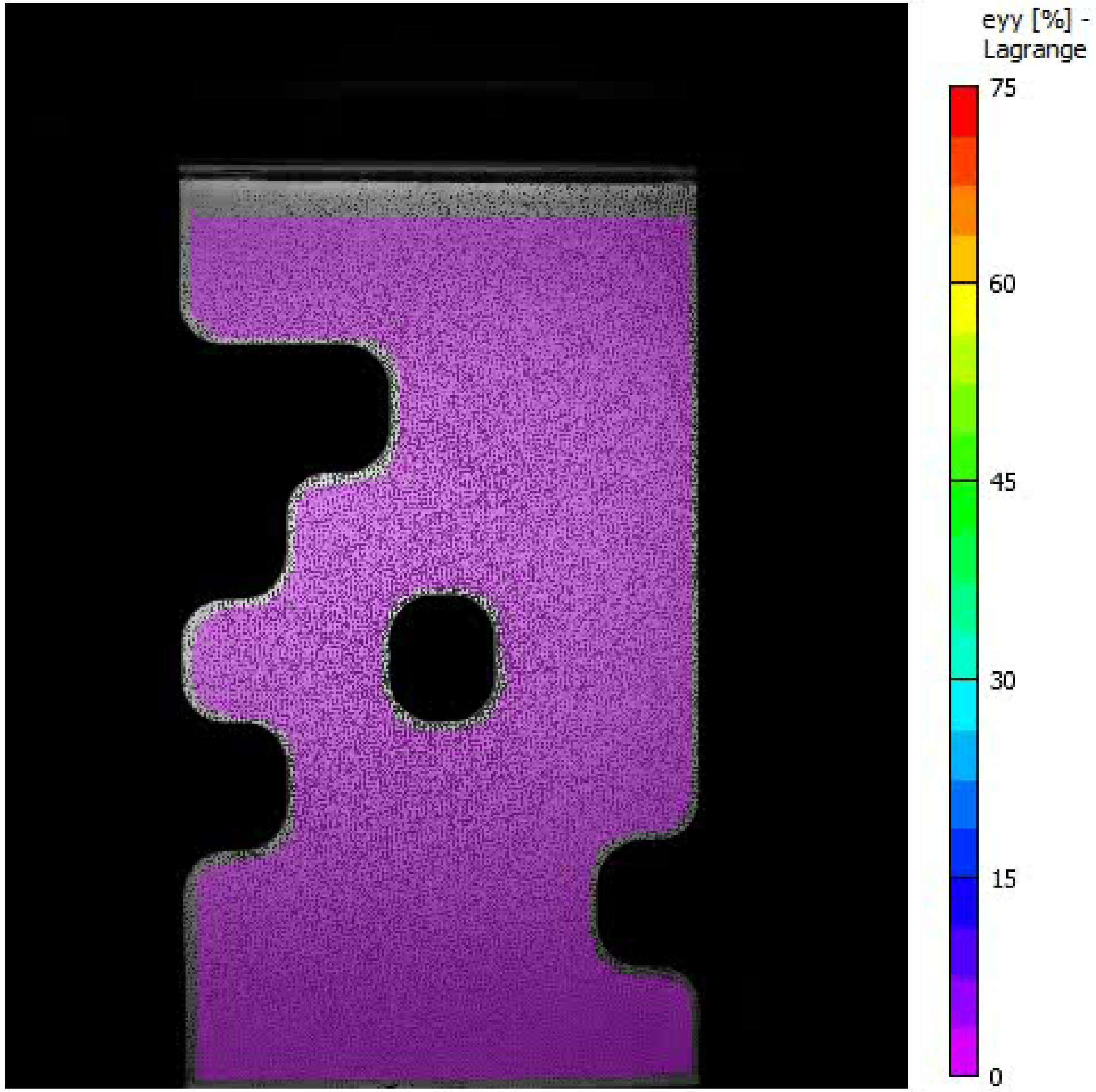
Notes

- All 8 Groups plotted
- VSG 23, 43 and 63 plotted in different shades
- Errors could be part of a coordinate system issue



Example data for the bespoke specimen





Invitation to help with the analysis

Participant	Type of Code	Strain Method
DICe	Subset Based	
LaVision	Subset Based	Provided
Dantec Dynamics	Subset Based	Provided
Correlated Solutions	Subset Based	
Eikosim	Global Code	
MatchID	Subset Based	
ALDIC	Subset/Global Hybrid	Provided
CorreliSTC	Global Code	
Your Name Here		

Missing Codes from the Challenge

- GOM
- Image Systems
- SeptD
- IIT

Future Analysis Ideas (There are multiple papers in this data)

- A participant to run the “missing” codes and submit results
- A study of the effect lens distortion correction on the results
- Improvement on the ASTM analysis
- A comparison of the **displacement** fields for each code
- Bespoke sample data comparisons
- Material 2.0 comparisons

iDICs 2024 is in France – come join us October 29th

Classes

- DIC201 – Updated and new full day

In association with Photomechanics

iDICs