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Laser-Ultrasound-Based Grain Size Gauge for the Hot Strip Mill

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Anton Jansson



Peter Lundin



Hans Magnusson



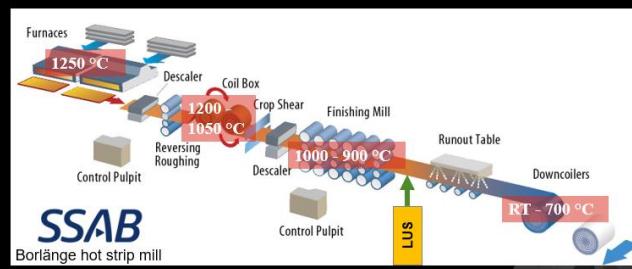
Bevis Hutchinson



Tuomo Nyssönen

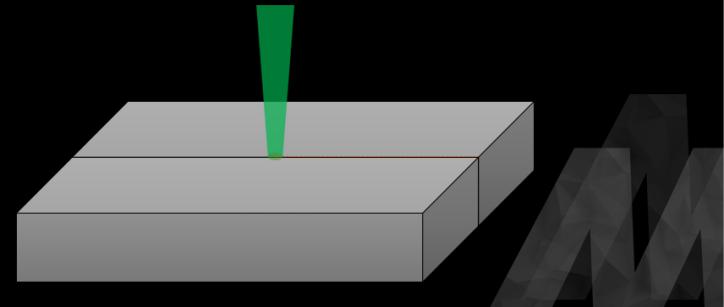


Johan Lönnqvist



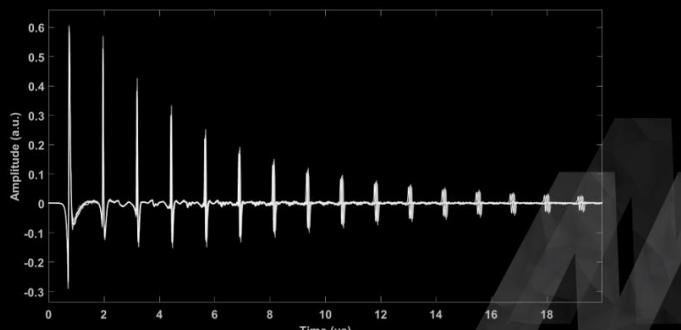
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Laser ultrasonics – LUS Generation and pulse propagation



P. Bate et al. "Application of laser-ultrasonics to texture measurements in metal processing," *Acta Materialia*, vol. 123, pp. 329–336, Jan. 2017, doi: 10.1016/j.actamat.2016.10.043.

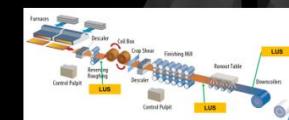
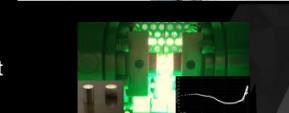
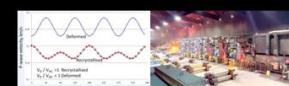
Typical measurements with new grain size gauge



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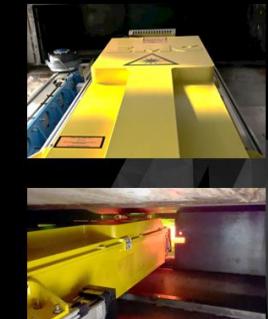
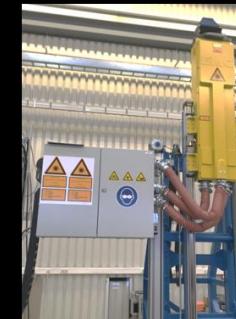
Future for the LUS grain size gauge

- LUS grain size gauge
Further develop recrystallized fraction calculation
- GLUS® trials assisting product development and material behavior online
- Desire to test several locations in the mill



New grain size gauge

New grain size gauge

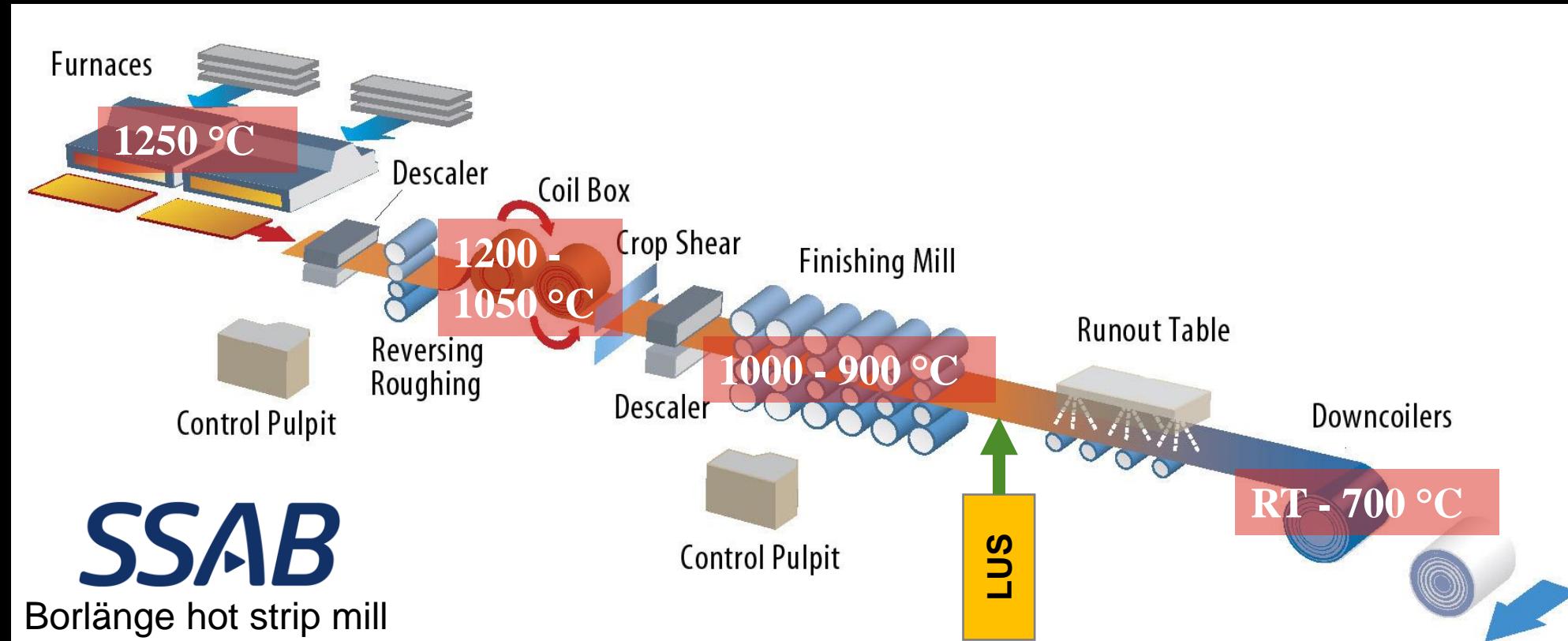


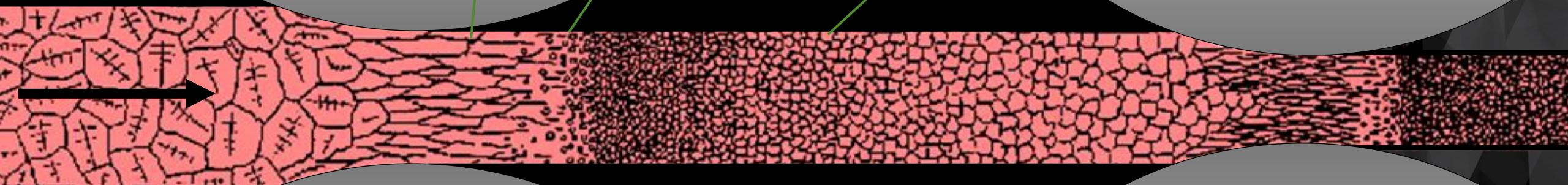
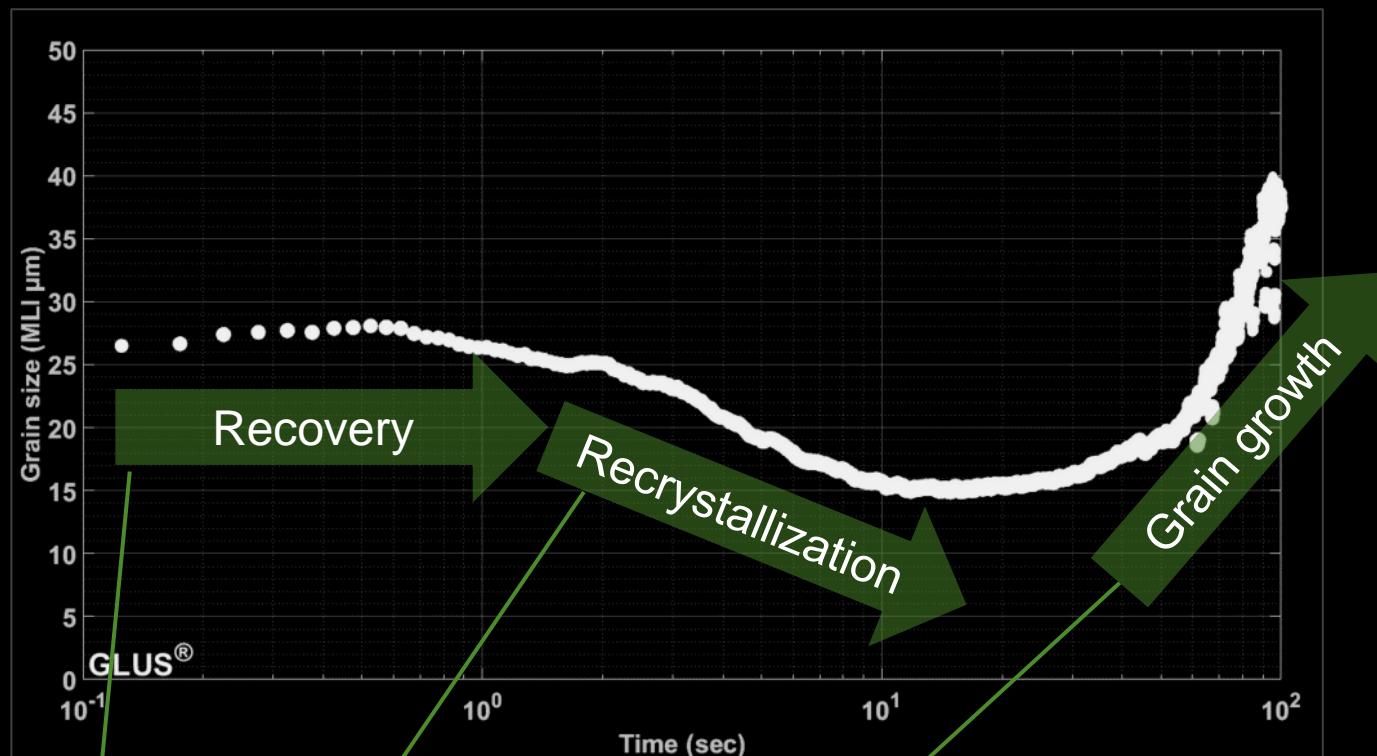
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More LUS / GLUS® / LUS-online info:

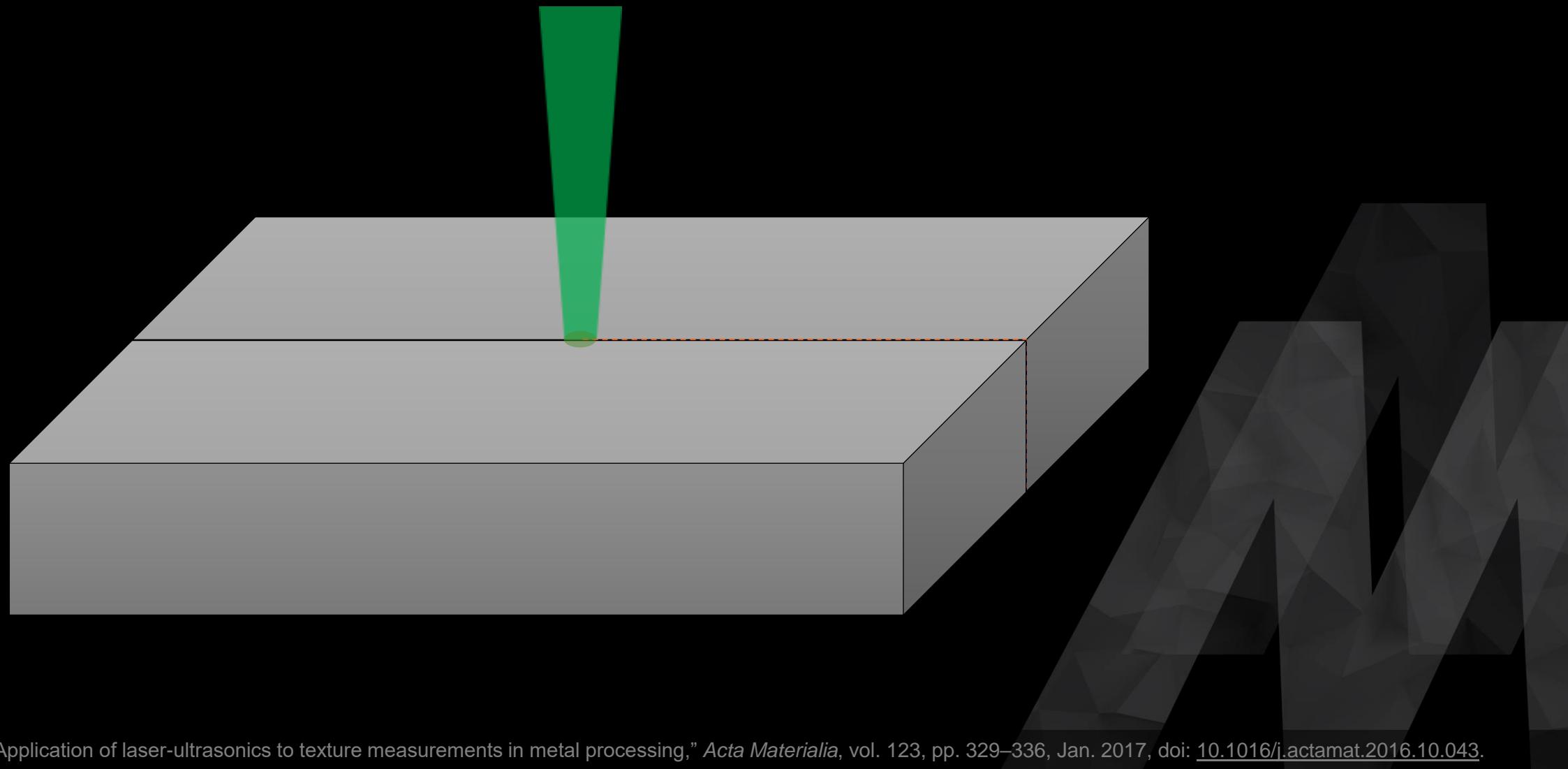
<https://www.swerim.se/en/services/material-analysis-process-monitoring/laser-ultrasonics-lus/glusr-gleebble-lus>
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<http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-300906> (recorded presentation)
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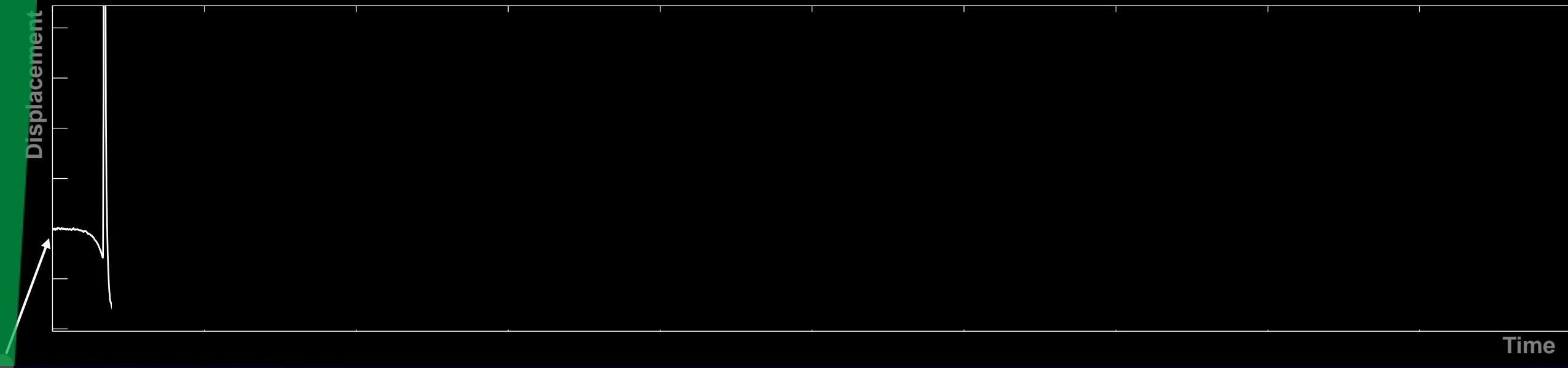




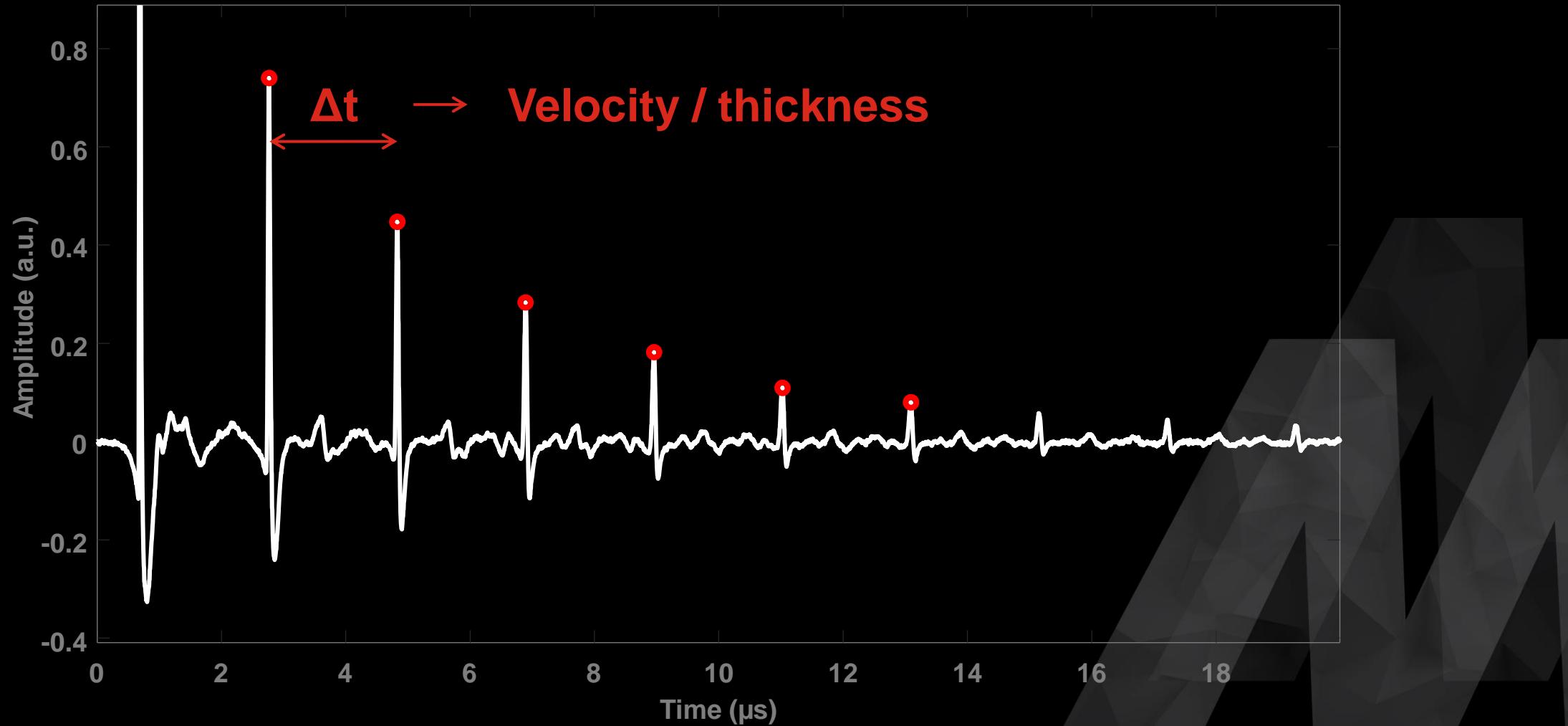
Laser ultrasonics – LUS

Generation and pulse propagation





Laser ultrasonics – LUS the A-scan



LUS equipment in industry

Wall thickness of seamless pipes

tecnar

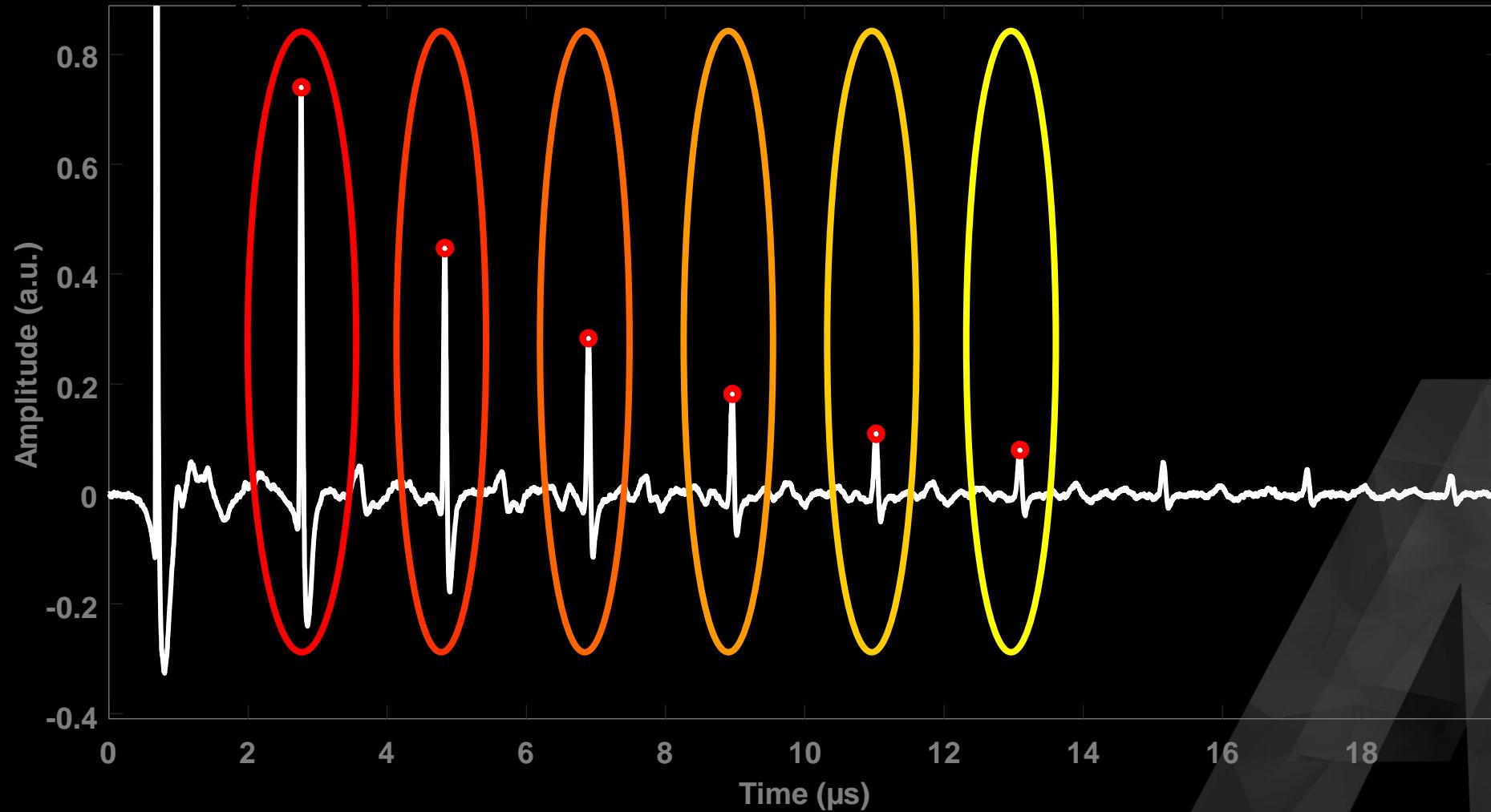


@ Baosteel, Shanghai

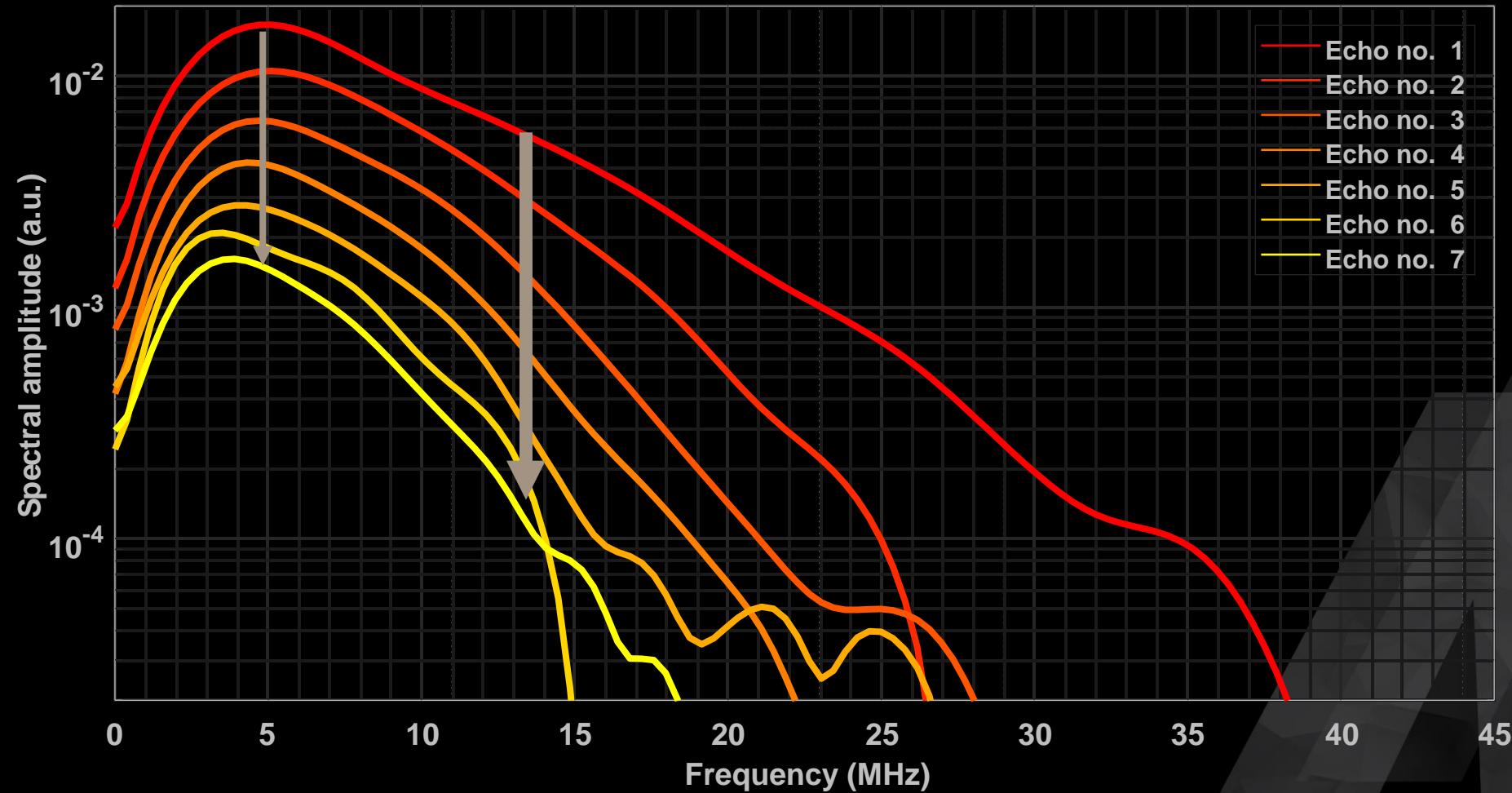


@ Ovako, Hofors

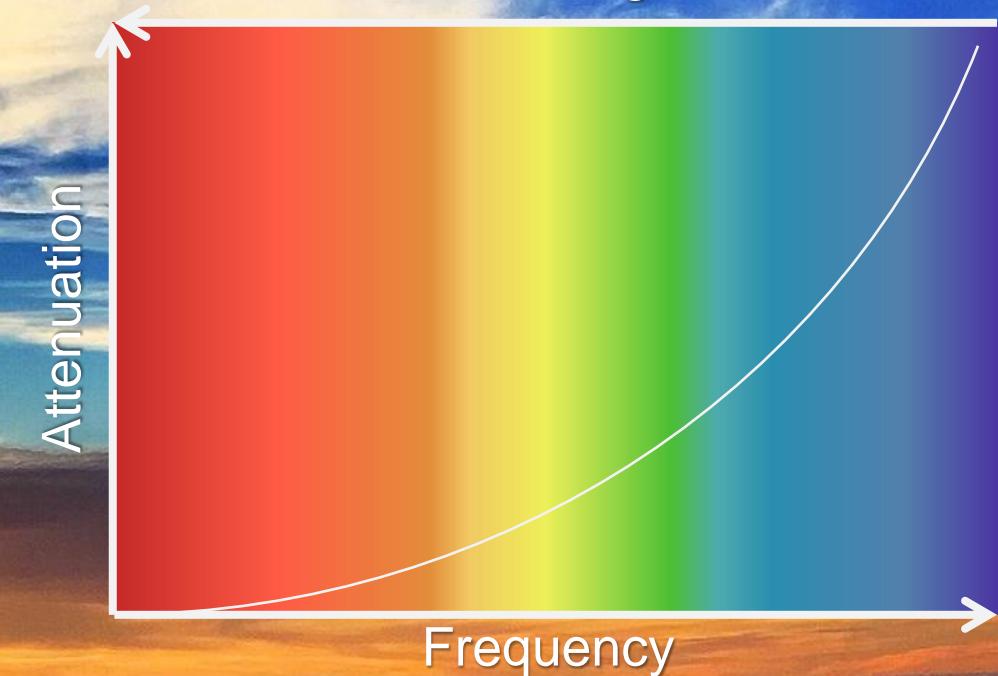
Frequency content of echoes



Spectral content of echoes

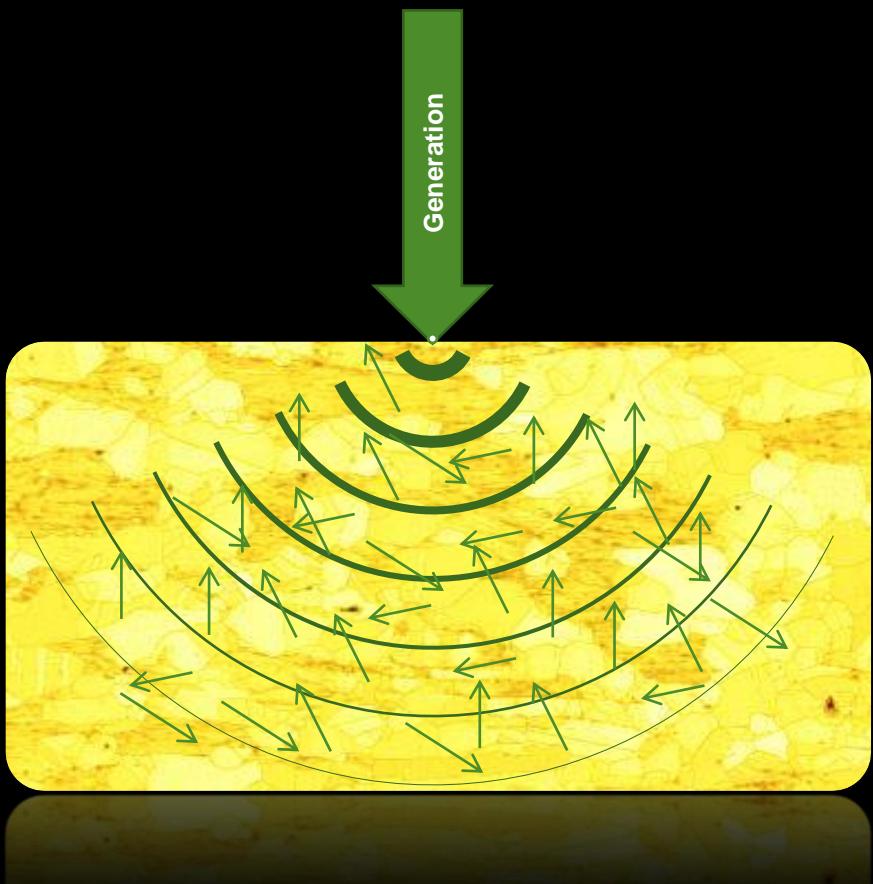


Spectral attenuation in scattering media



Ultrasonic attenuation due to scattering

$$\alpha = k_1 D^3 f^4 \text{ for:}$$



$$\alpha = k_2 D f^2 \text{ for:}$$

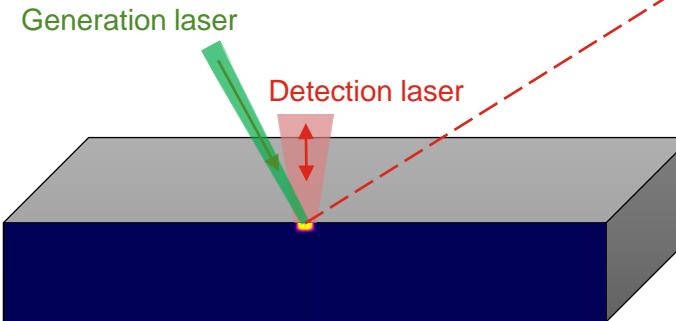
f	\sim	30 - 6 MHz
λ	\sim	0.2 - 1 mm
Hexagon	\sim	0.01 - 0.1 mm

Approximation

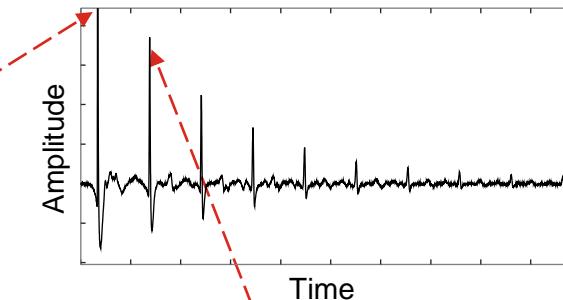
$$\alpha \sim \overline{G} S^2 f^3$$



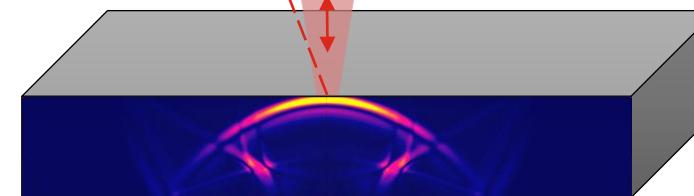
Grain size measurement with LUS



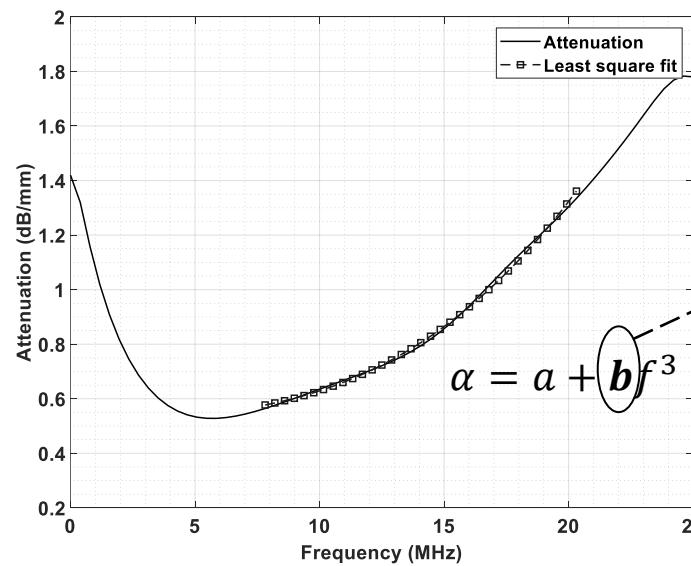
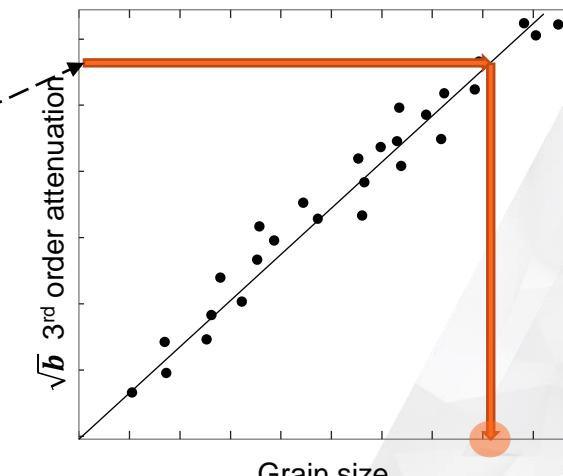
(1) Generate ultrasound



Time

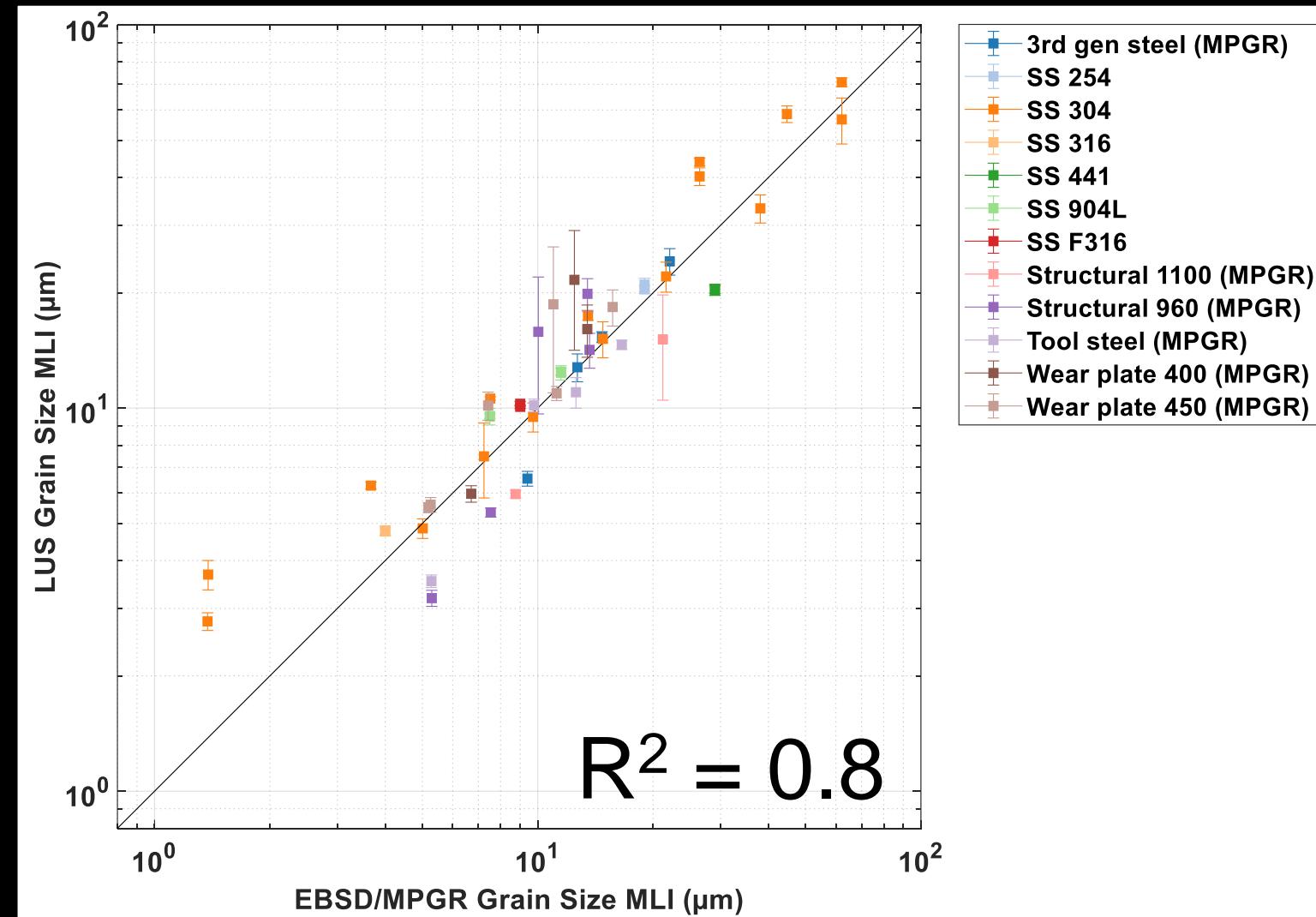
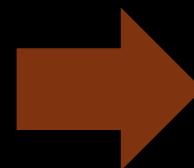
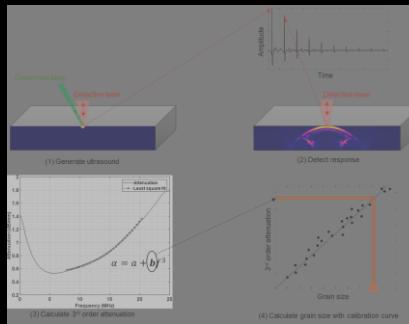


(2) Detect response

(3) Calculate 3rd order attenuation

(4) Calculate grain size with calibration curve

LUS grain size vs EBSD/MPGR grain size from RT to > 1100 °C

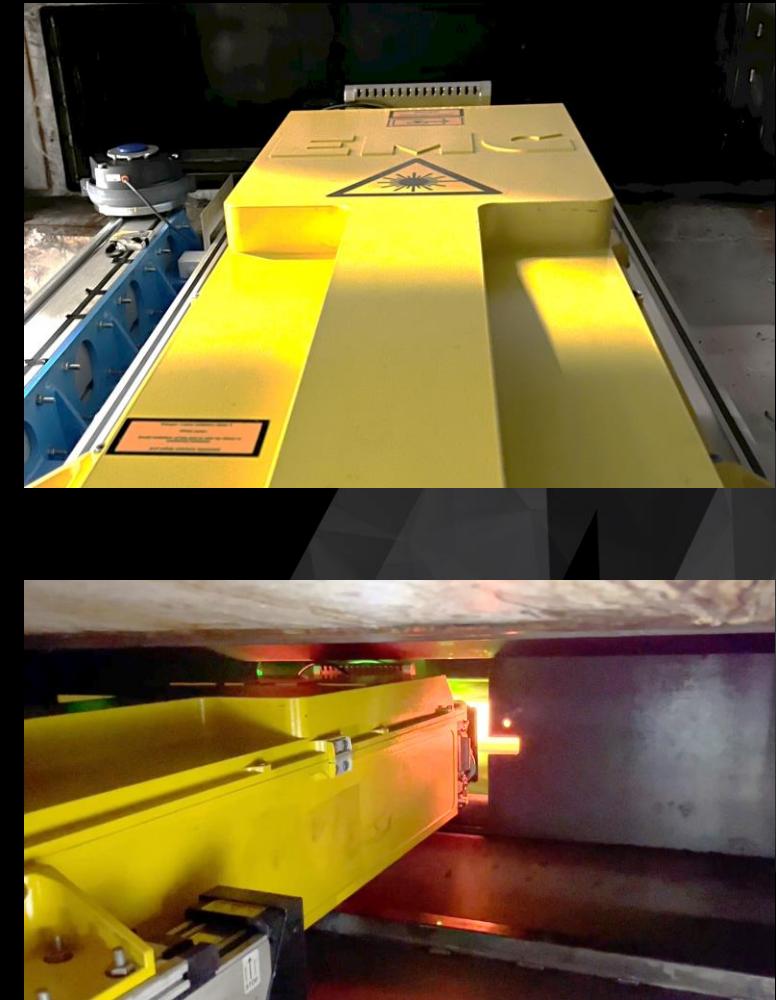
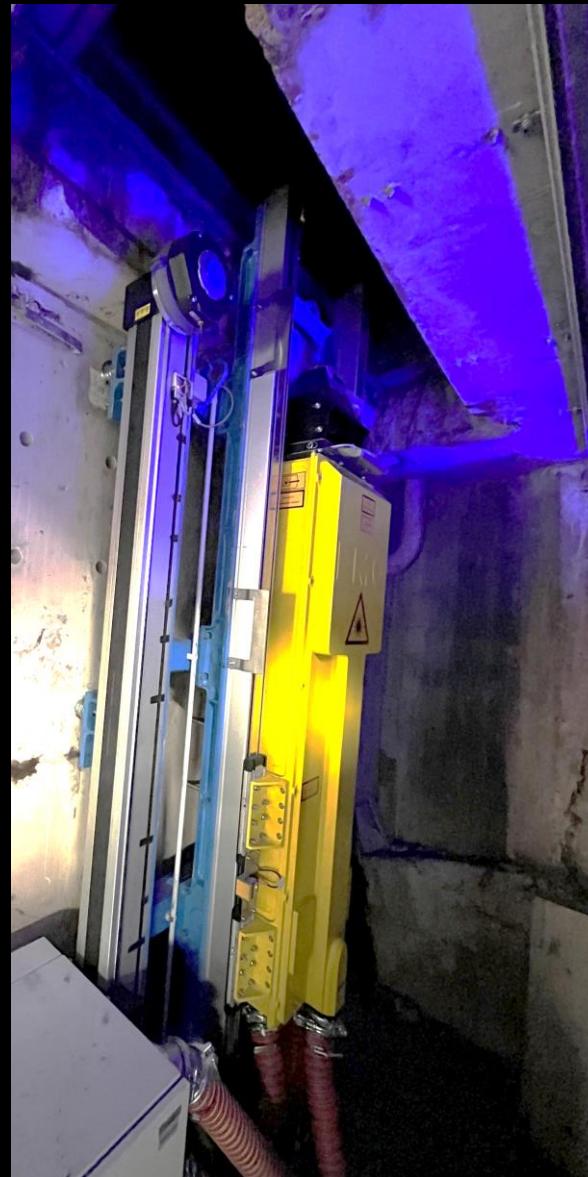


EBSD
Electron Back-Scattering Diffraction

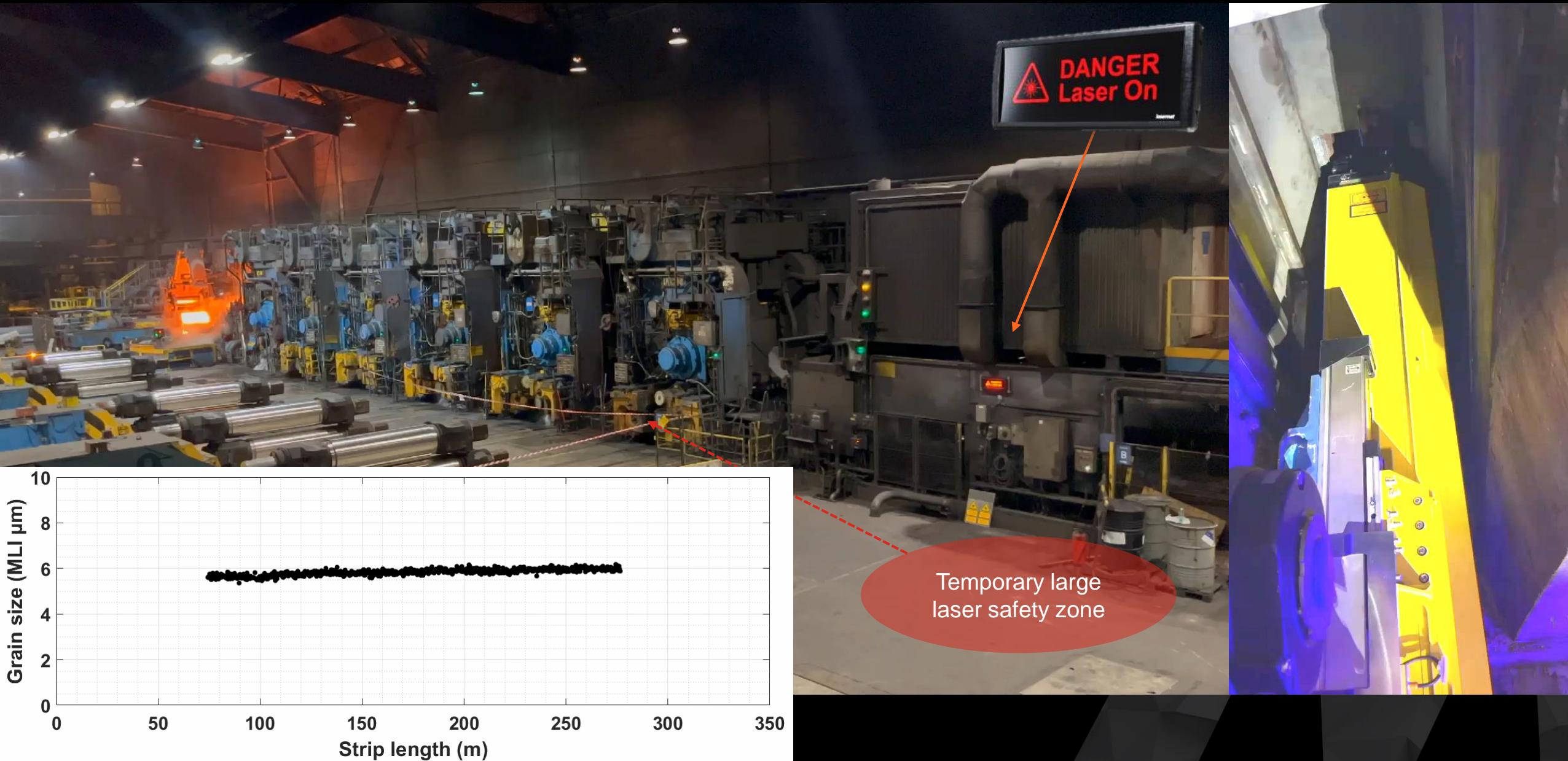
MPGR
Martensite Parent Grain Reconstruction

T. Nyssönen et al., "Significance of Annealing Twins in Laser Ultrasonic Measurements of Grain Size in High-Strength Low-Alloy Steels," *Applied Sciences*, vol. 13, no. 6, p. 3901, Jan. 2023, doi: [10.3390/app13063901](https://doi.org/10.3390/app13063901).

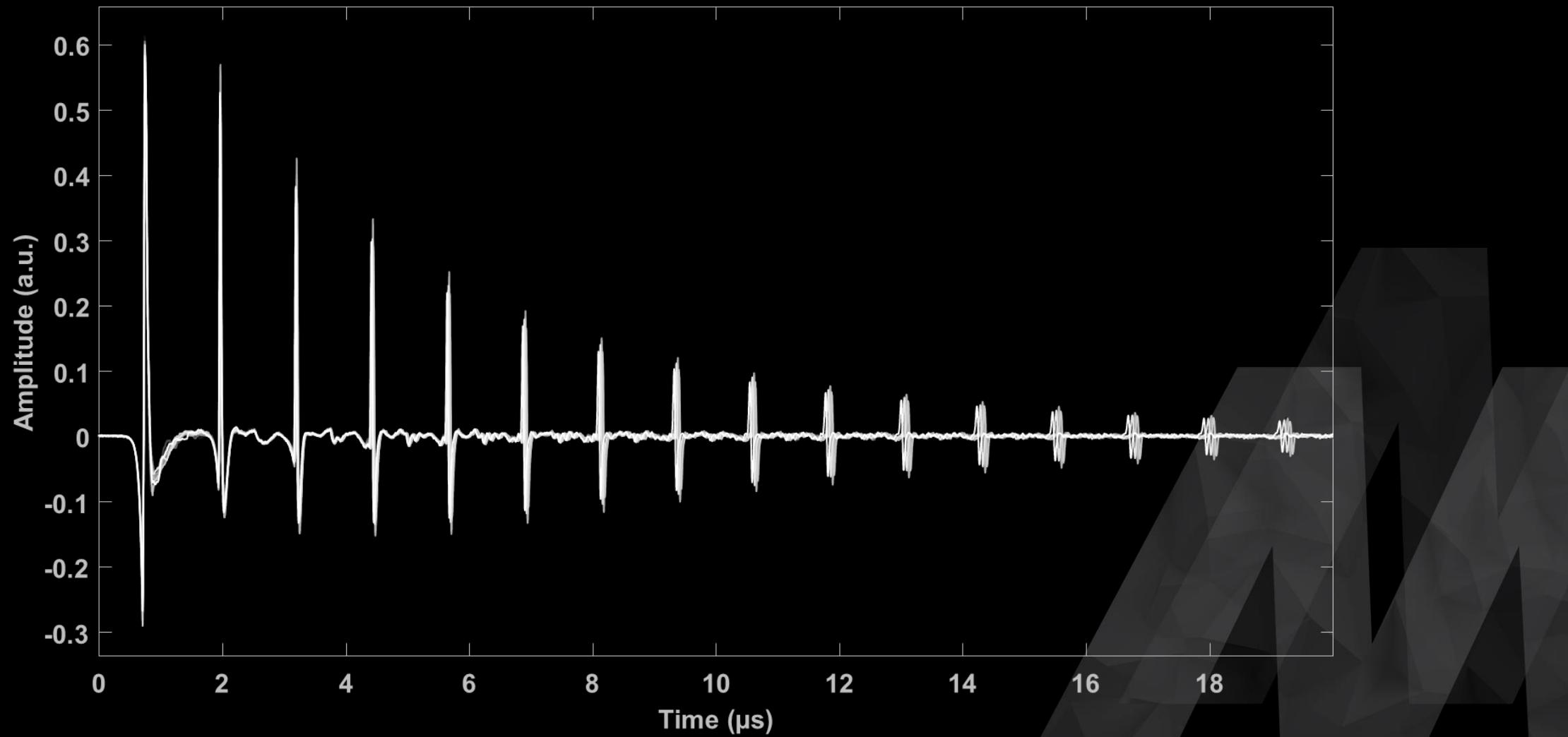
New grain size gauge



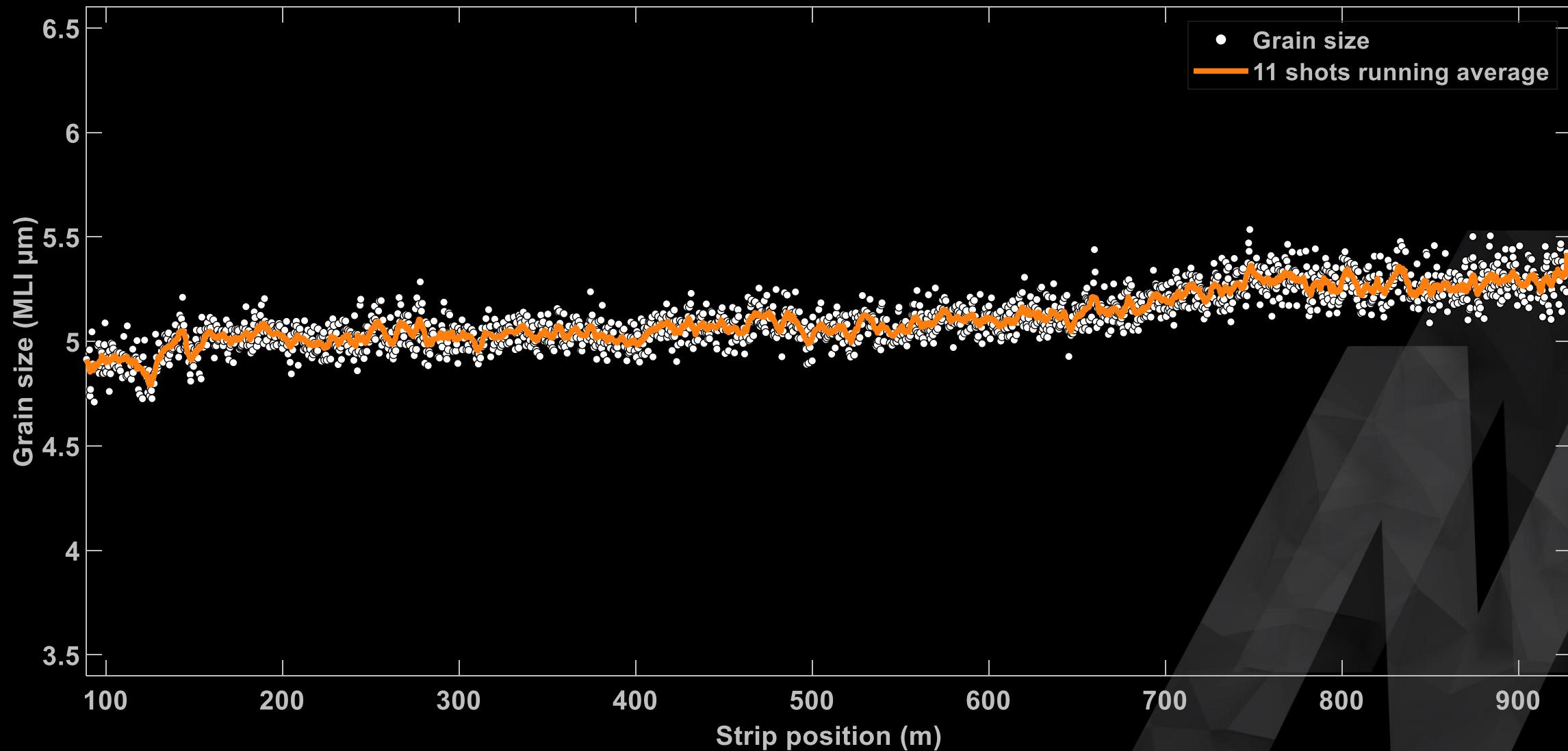
Laser ultrasonic grain size measurement in HSM



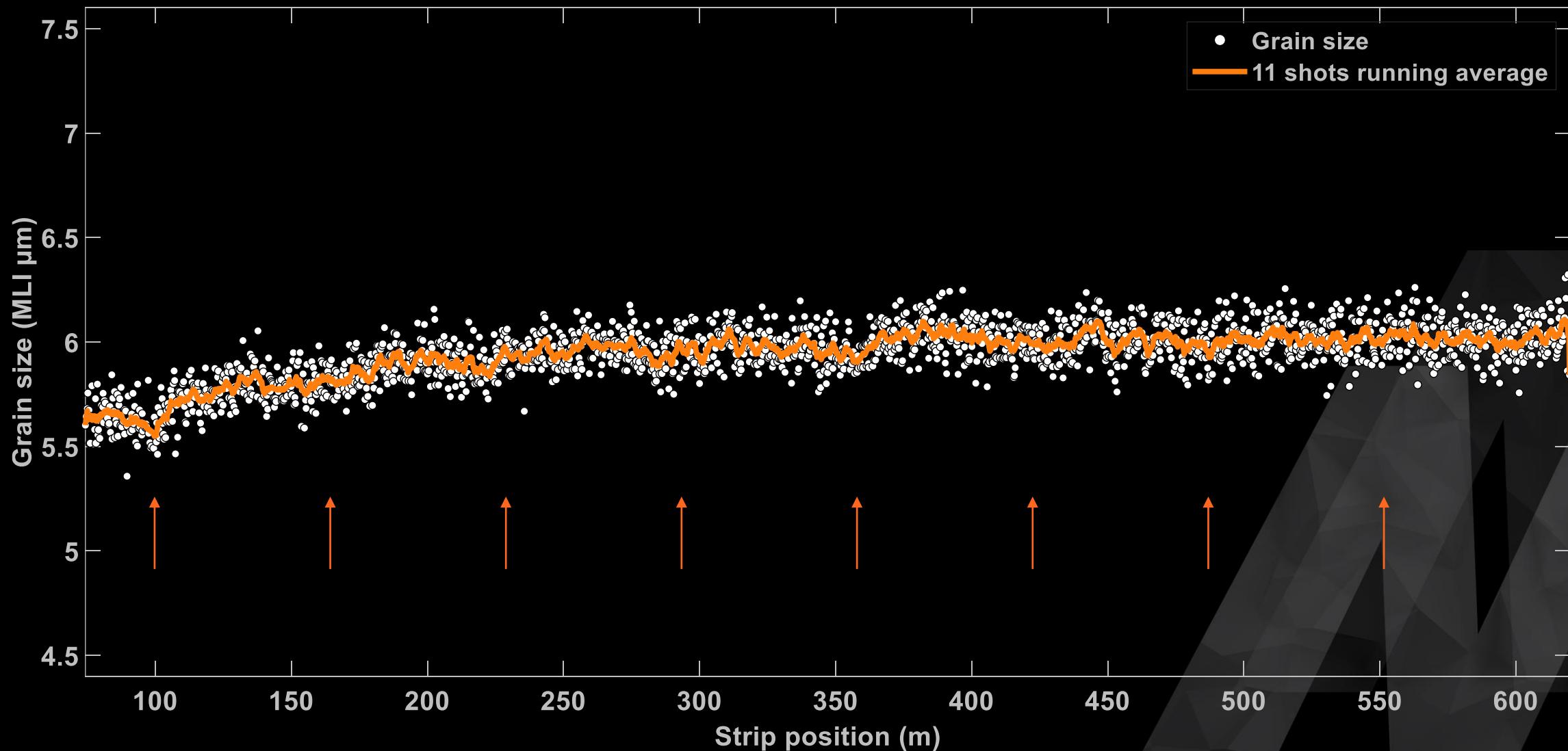
Typical measurements with new grain size gauge



LUS measured grain size of hot strip



LUS measured grain size of hot strip

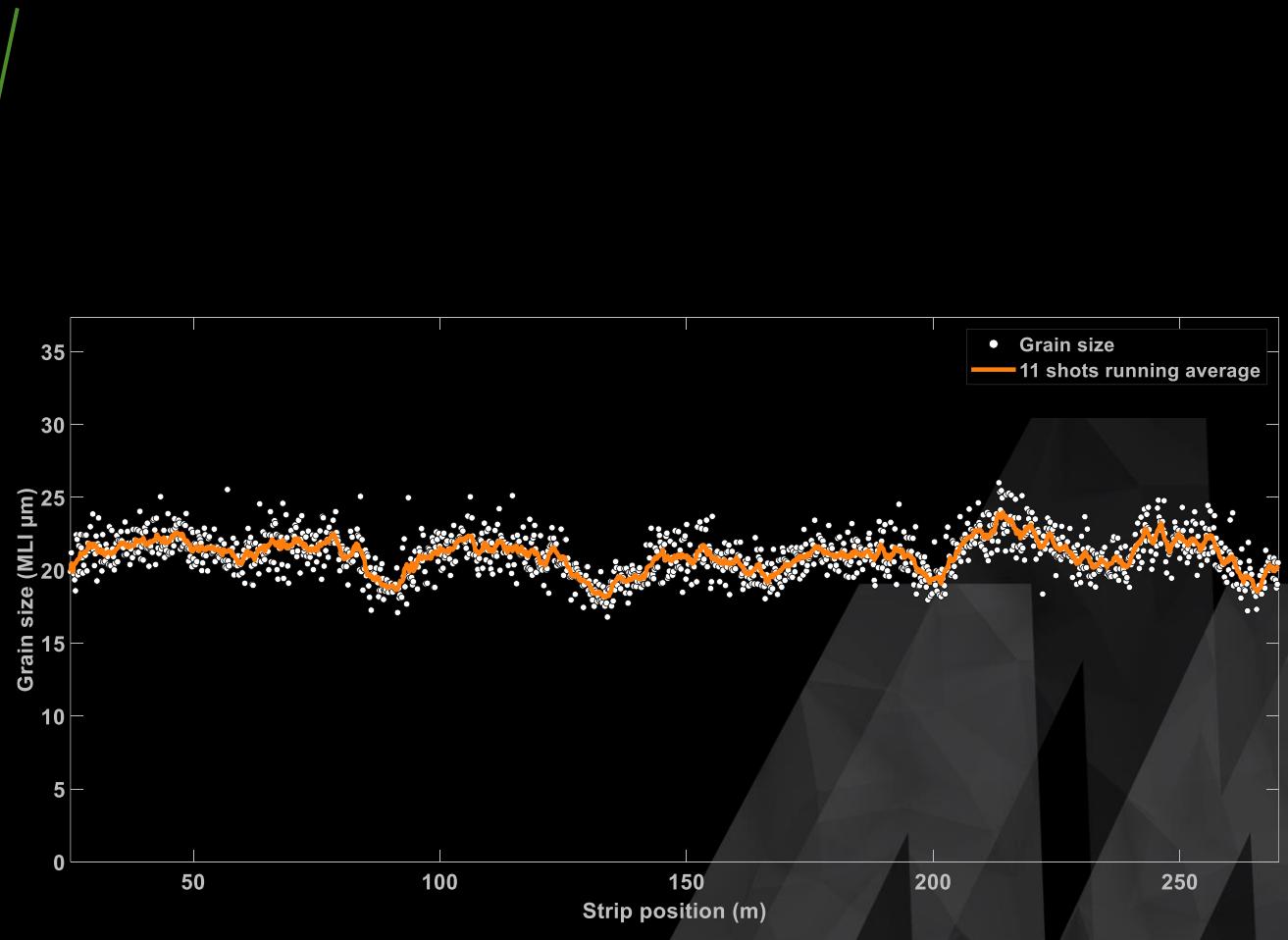
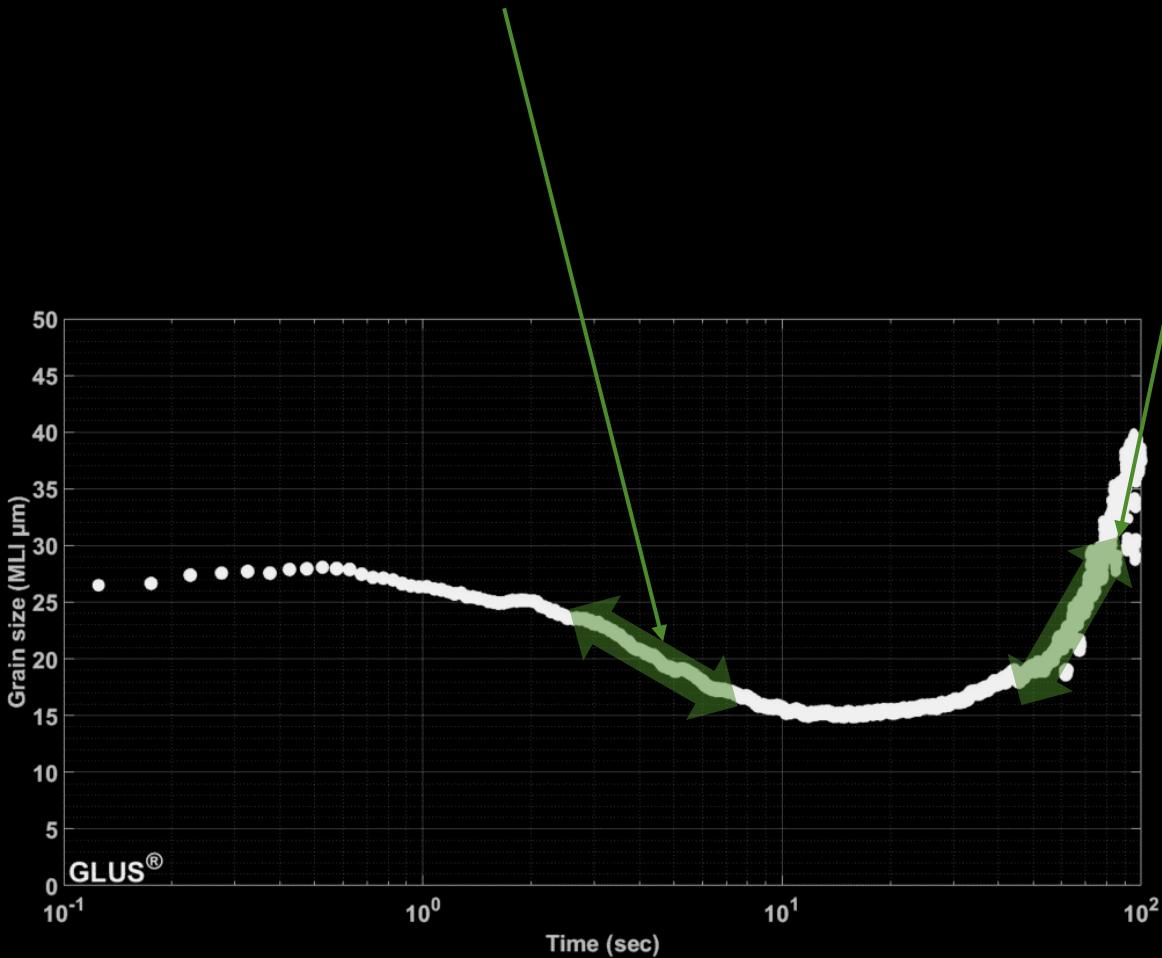


Reheating furnace at SSAB

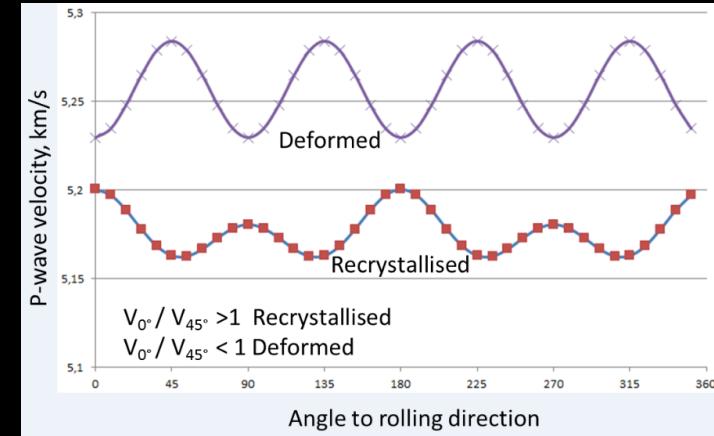
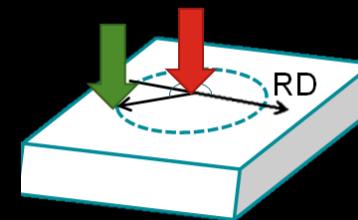
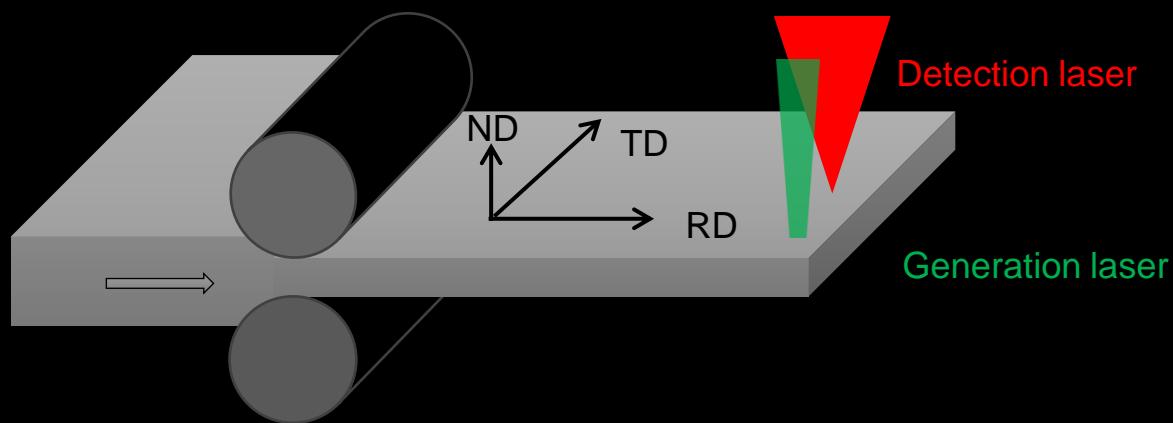


Walking beams are the cause of the skidmarks

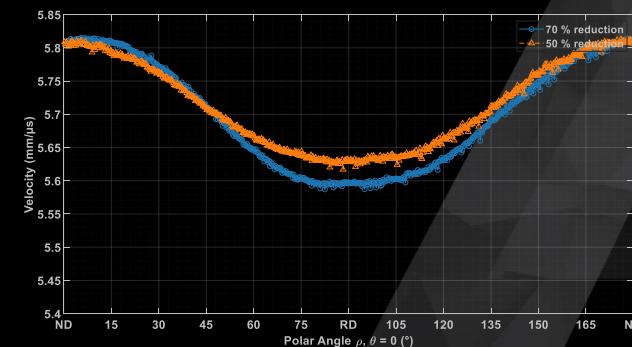
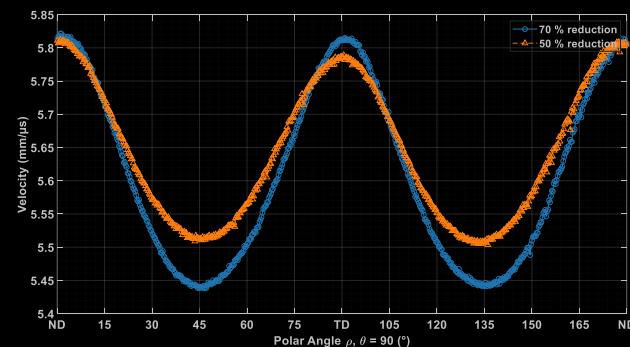
Recrystallization or grain growth?



Use anisotropy for recrystallized fraction estimation

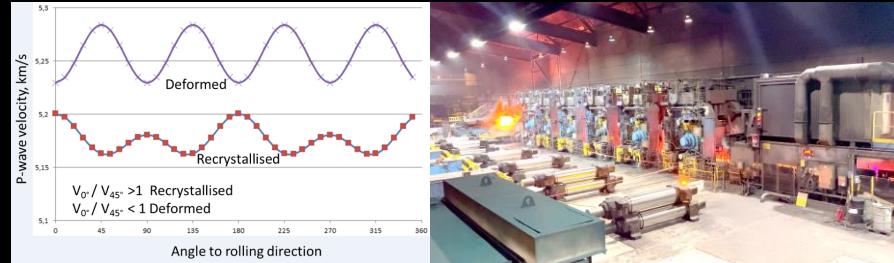


Lena Mauritzson, Bevis Hutchinson, Pete Bate, Peter Lundin, Mikael Malmström, and Eva Lindh-Ulmgren. "Texture Studies Using Laser Ultrasonics (LUS) in Metal Processing." Warwick: IOM Communications, 2017.
<http://www.fems.org/event/line-measurement-and-control-metals-processing>.

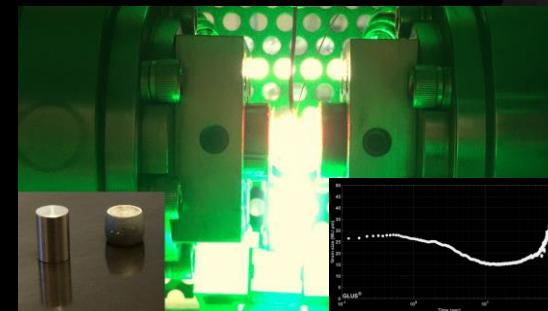


Future for the LUS grain size gauge

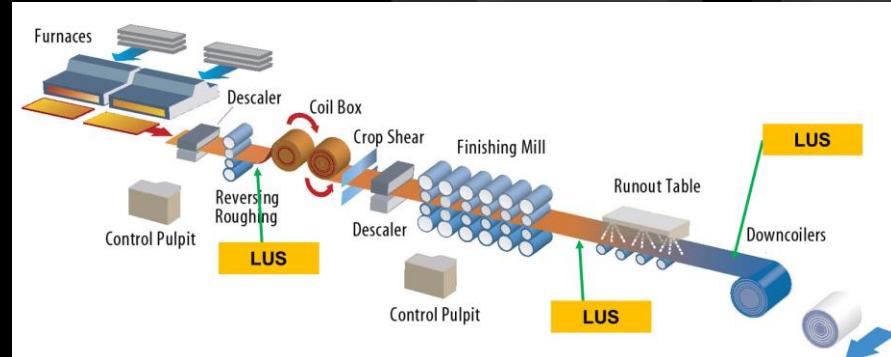
- LUS grain size gauge
Further develop recrystallized fraction calculation



- GLUS® trials assisting product development and material behavior online



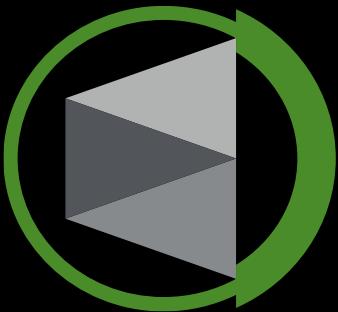
- Desire to test several locations in the mill



Future for the LUS grain size gauge

- Verify microstructure of **pristine vs recycled** material
- Later verify microstructure of
- **Hydrogen reduced** material and the mini-mills





SWERIM

More LUS / GLUS® / LUS-online info:

<https://www.swerim.se/en/services/material-analysis-process-monitoring/laser-ultrasonics-lus/glusr-gleble-lus>

<https://www.swerim.se/en/services/material-analysis-process-monitoring/laser-ultrasonics-lus>

<http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-300906> (Recorded presentation)

<http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-259955>