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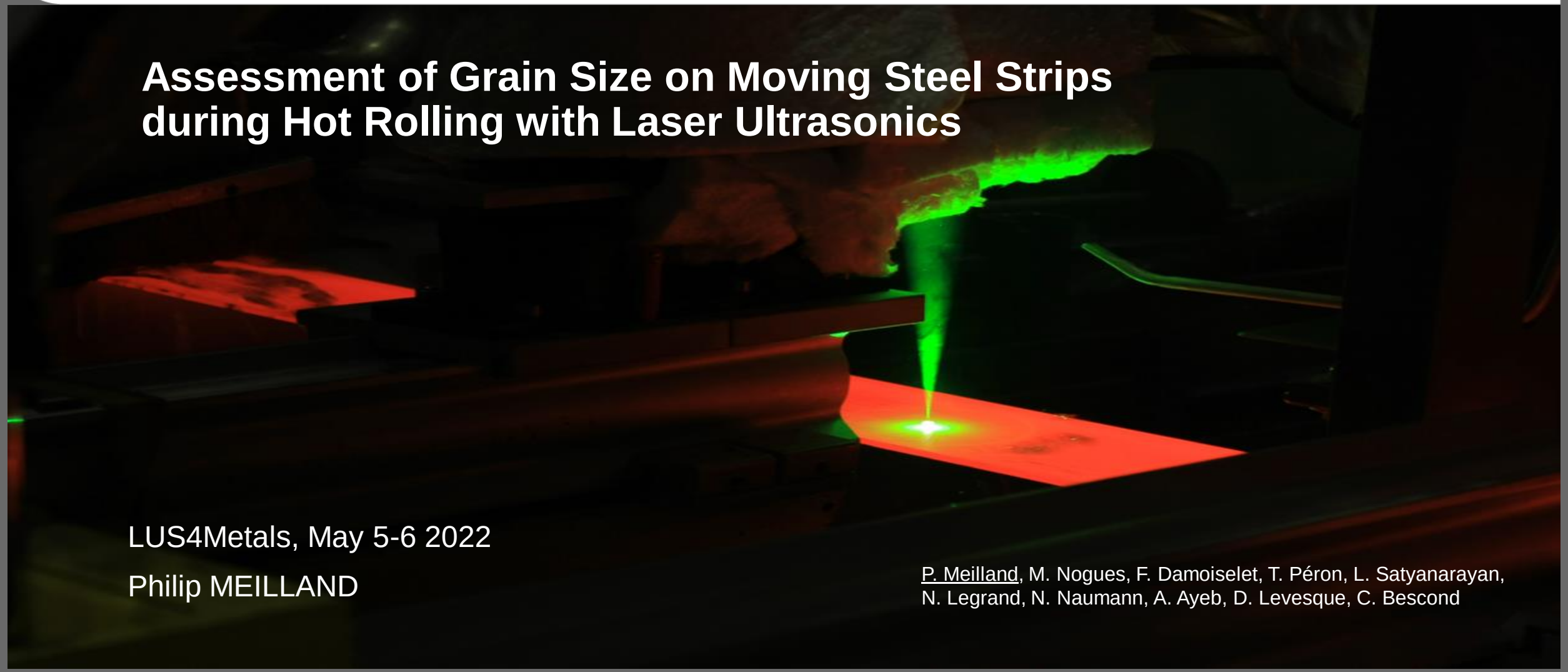
Assessment of Grain Size on Moving Steel Strips during Hot Rolling with Laser Ultrasonics

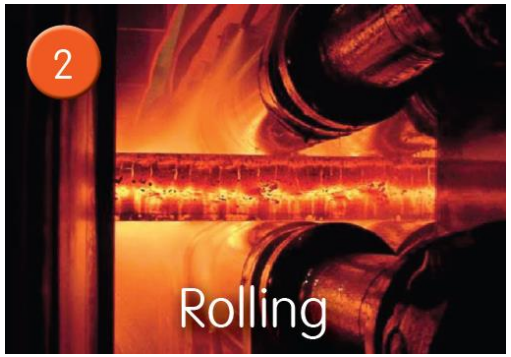


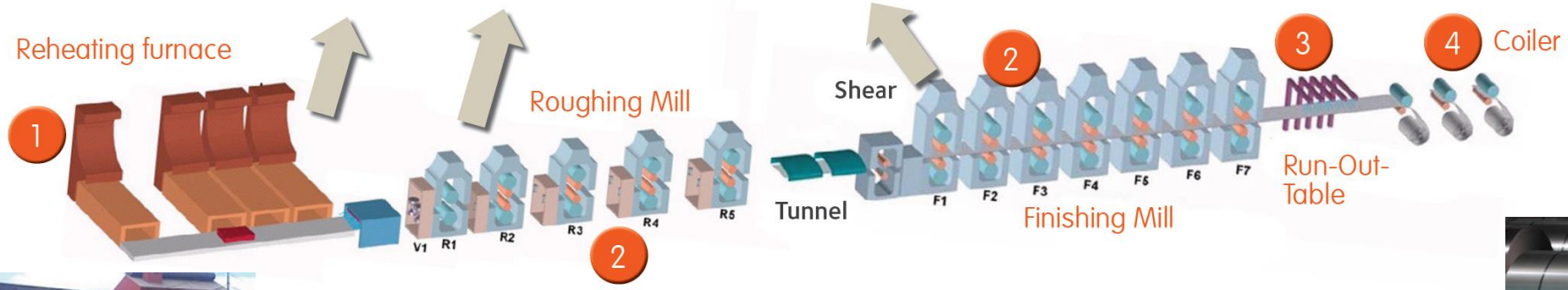
LUS4Metals, May 5-6 2022

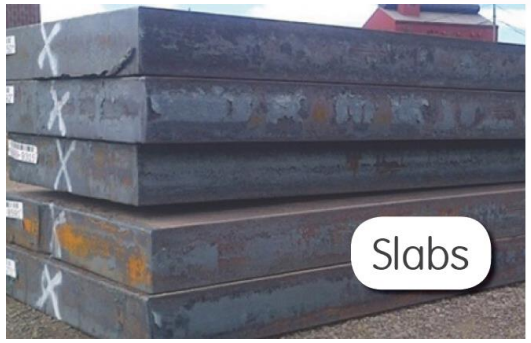
Philip MEILLAND

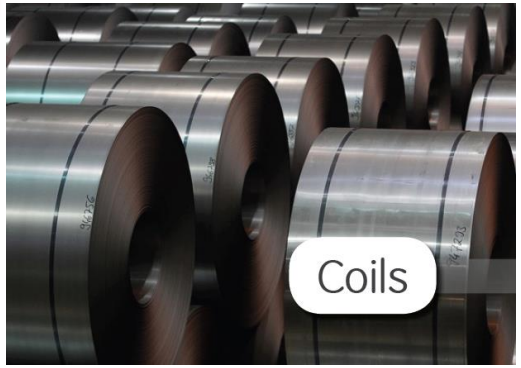
P. Meilland, M. Nogues, F. Damoiselet, T. Péron, L. Satyanarayan, N. Legrand, N. Naumann, A. Ayeb, D. Levesque, C. Bescond

Quick Overview of a Hot Rolling Mill









- A mettre en Anglais

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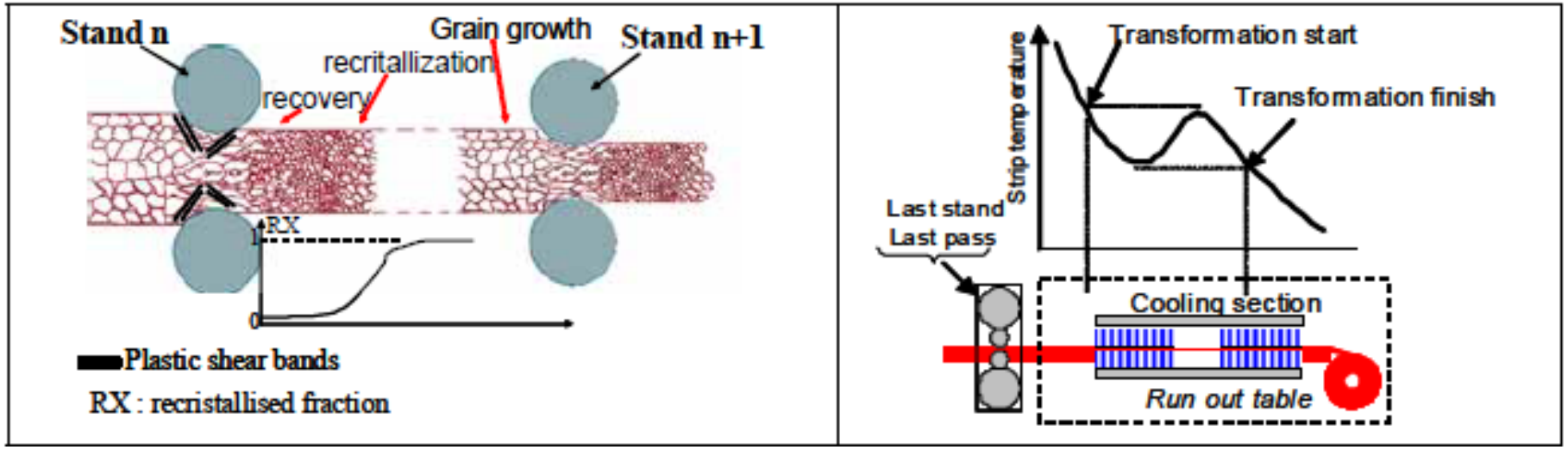
Description of the Project

- Model based assessment of steel microstructural features during Hot Rolling:
  - Roughing / Finishing and Run-Out Table:



- Need to assess actual features with on-line measurement:
  - Roughing & Finishing : Austenitic Grain Size
  - Run-Out-Table : Ferritic Grain Size, Austenitic / Ferritic Phase Proportion

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Project Objectives

- Develop a robust and portable Laser Ultrasonic (LUT) sensor to measure simultaneously the steel microstructure at several points all along a hot rolling mill (austenite recrystallization & austenite grain size in inter stands, phase transformation on the ROT).

- Design and Fabrication of a more robust nomad LUT system :Hardware and Software
- Simplification of safety procedures
  - Easy applicability for industrial trials
- Industrial trials on different grades
  - Inter-stands,
  - run out table
  - and before coiling

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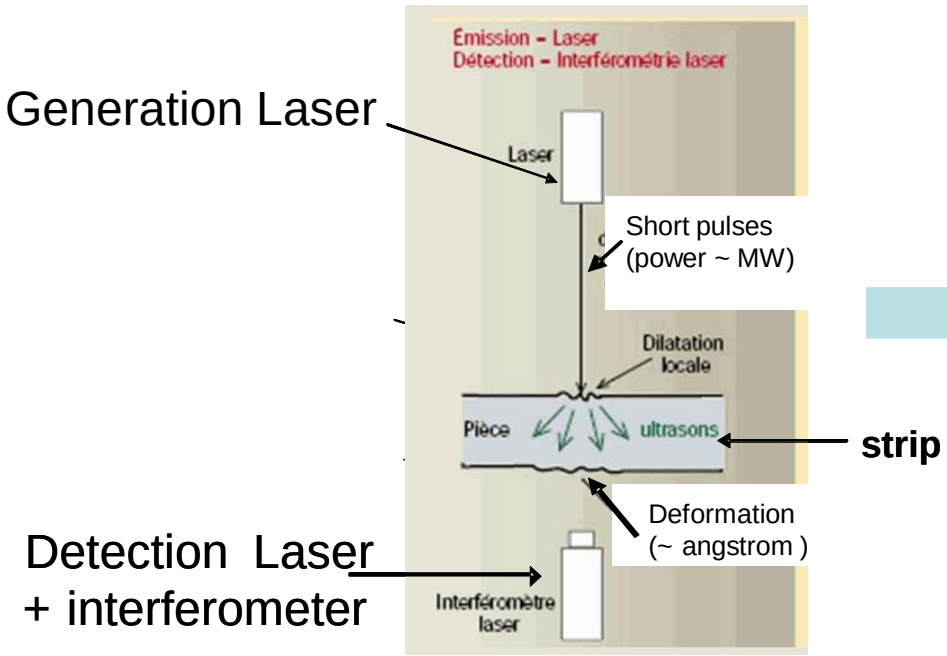
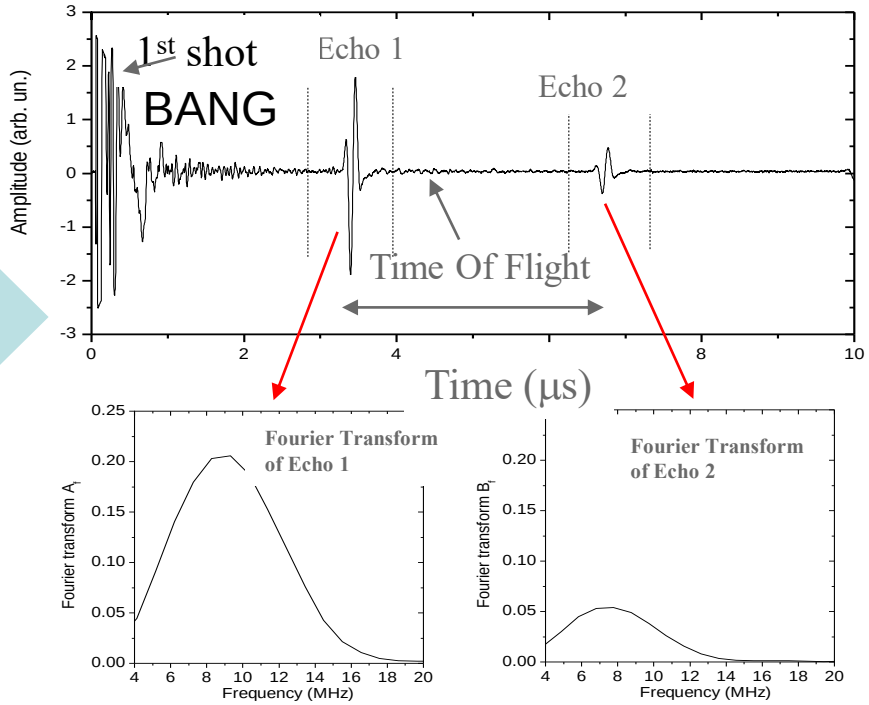
LUT Principle

- 1 Hit with generation laser, then listen with detection laser => succession of backwall echoes
- Evolution of spectral content of echoes => linked to grain size (Lord Rayleigh, early 1900's)
- Velocity (time of flight between echoes) => Phase fraction, Recrystallisation





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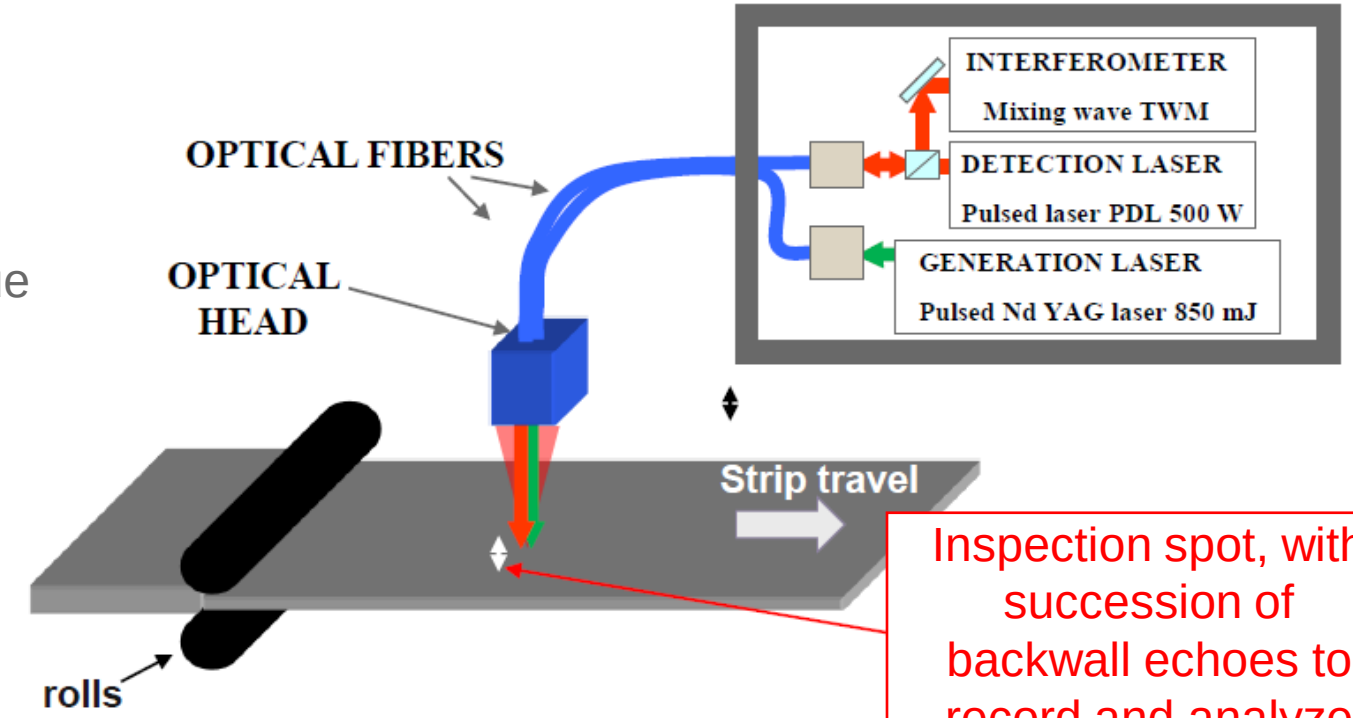
Challenge for on-line trials : Single Side Detection & Vibration Handling

- Single side:
  - Avoid blinding detection
  - Need for different wavelengths
- Vibrations, fluttering :
  - Classical interferometric devices not suited
- Use of long pulse detection laser, with non-linear optics two wave mixing (TWM) technique
  - Generation Laser and PDL lasers wavelength 1064 nm
  - Effective detection wavelength 532 nm
- Avoid cobbling collision
  - Working distance 1 m
- Safety Aspects
  - Minimize Safety Perimeter by design
  - Add conditions for laser firing to ease safety procedures
    - Product presence detection (pyrometry) to open shutters
- Not to forget : Heat Shielding!



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Main Achievements

Construction of Laser Ultrasonic Trolley

- Optical fibres linking Main Body to Optical Head

- On Main Trolley Body:
  - Lasers
  - Detection Module
  - Data acquisition
  - Control panel

- At beam extremity:
  - Optical head
  - Pyrometers

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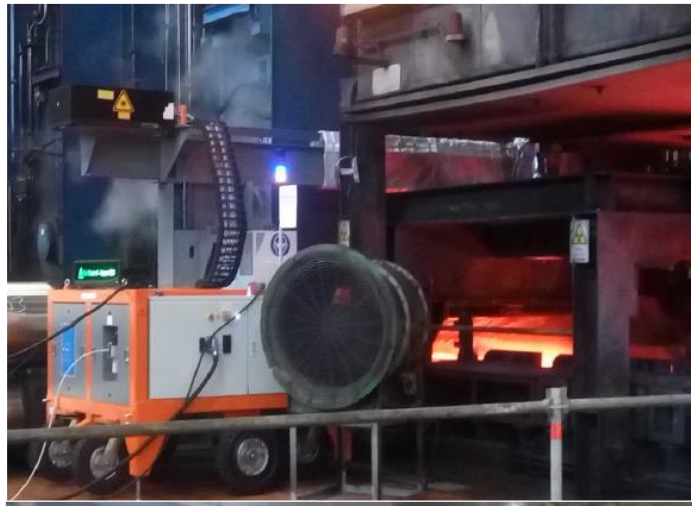
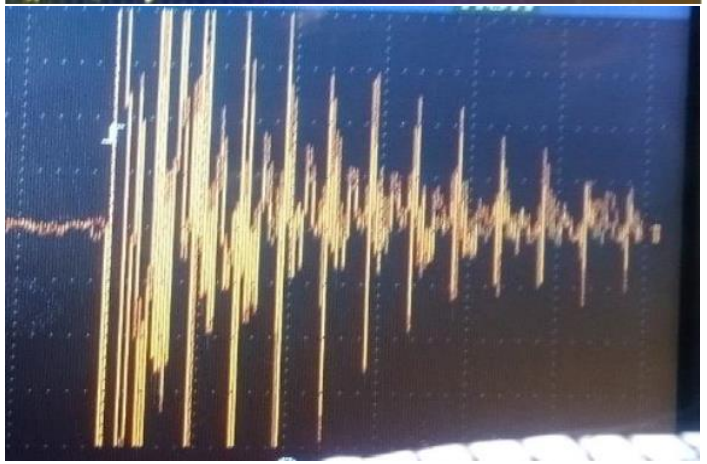
Action!... with real-time visualisation of on-line A-scans

- At Last Stand,



- Before Down Coiler



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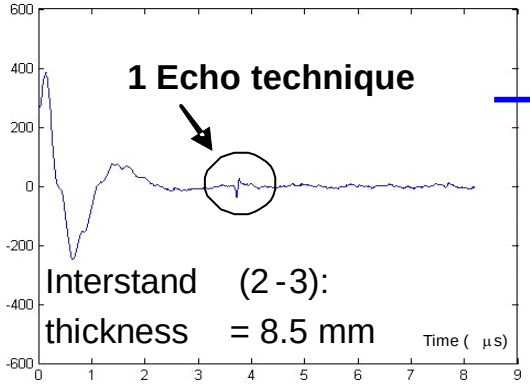
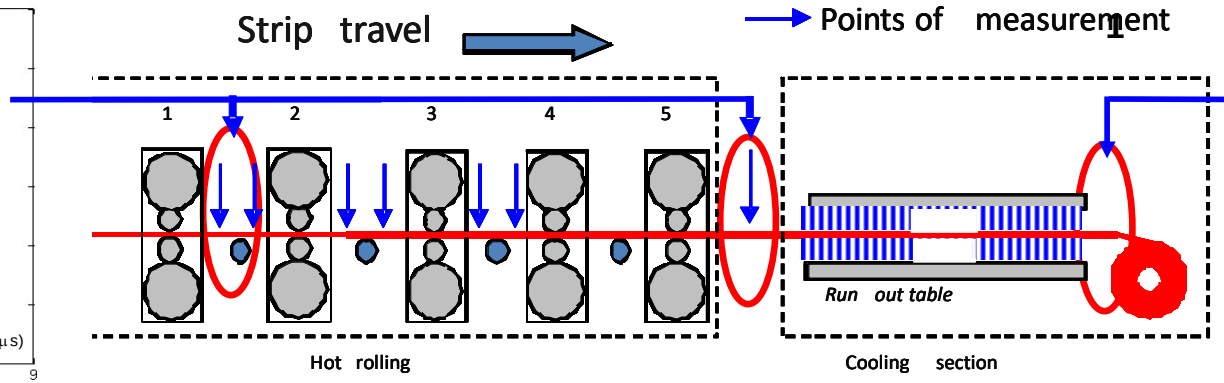
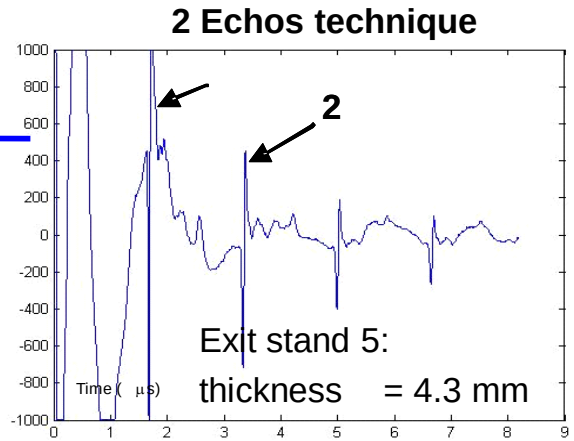
Summary of Plant Trials (Sept. & Nov 2019)

- **Trials at 3 locations: stand 1, stand 5, coiler**
- Measurements along ~80 coils
  - Low-Carbon grades
  - A-scans analysis to derive Grain Size







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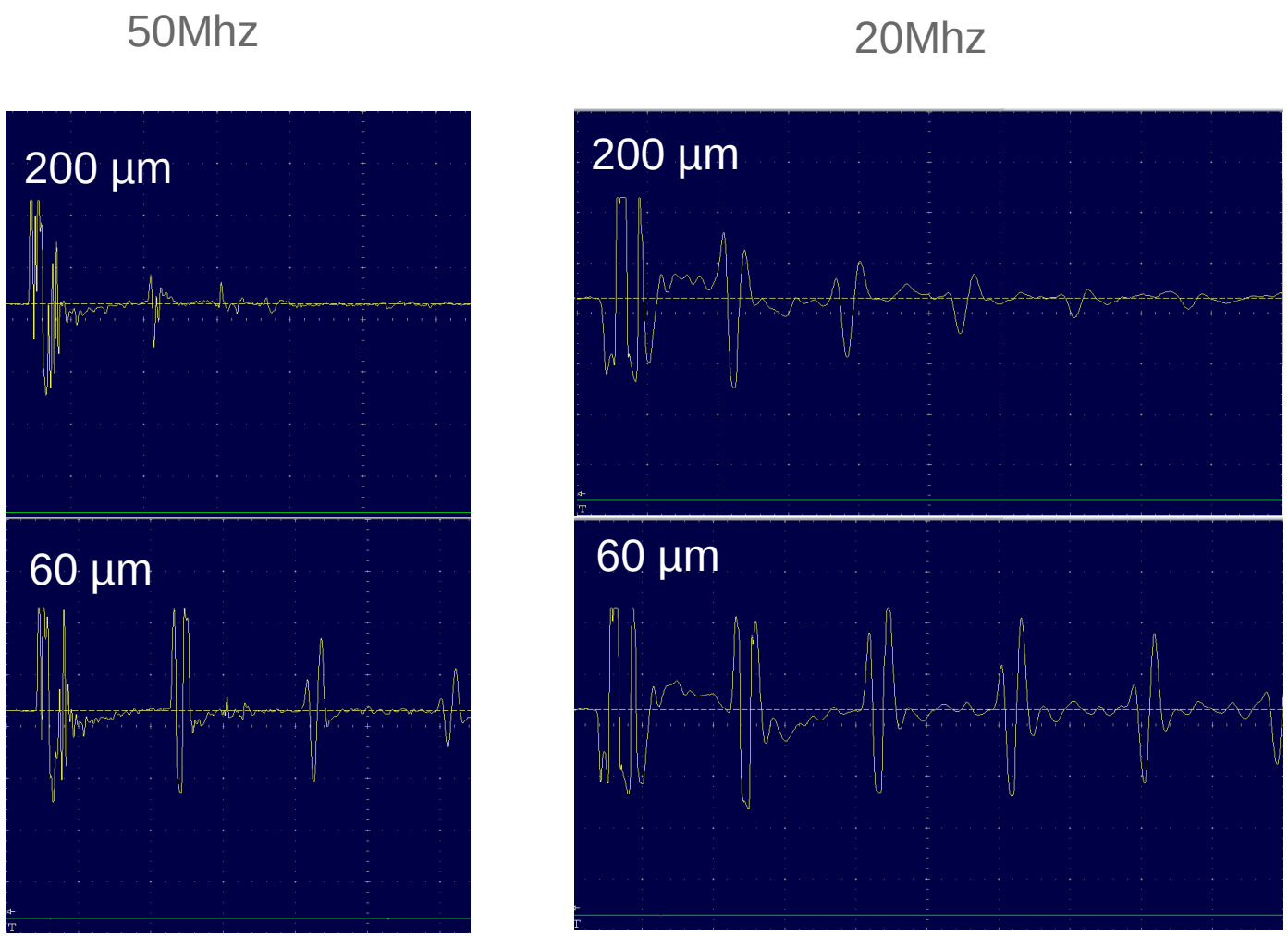
Effect of Grain Size on Attenuation

- Example from work
  - 2.5 mm samples, GS 60 and 200 µm
  - Single frequency PZT transducers
- Attenuation of Echoes with time
  - Increases with grain size
  - Increases with frequency
- Spectral content of consecutive echoes allows deriving grain size related information



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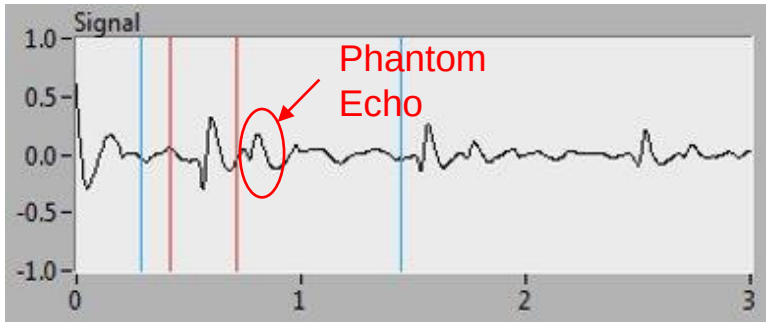
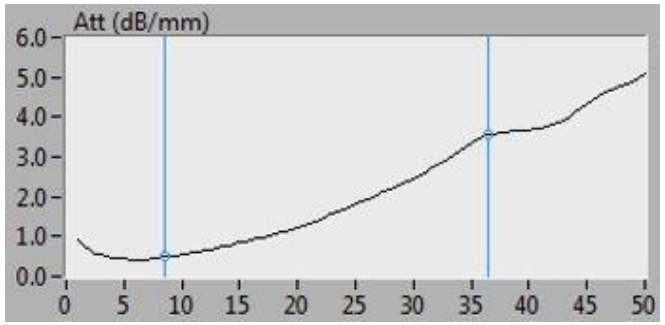
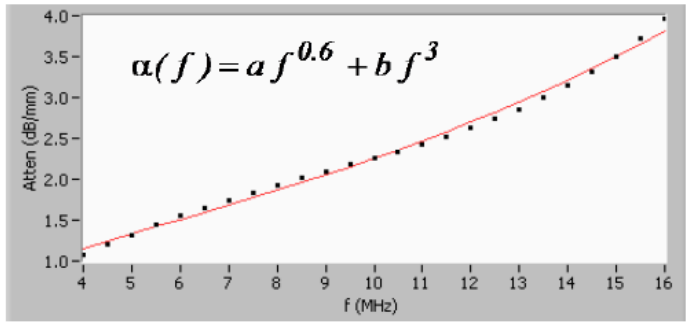
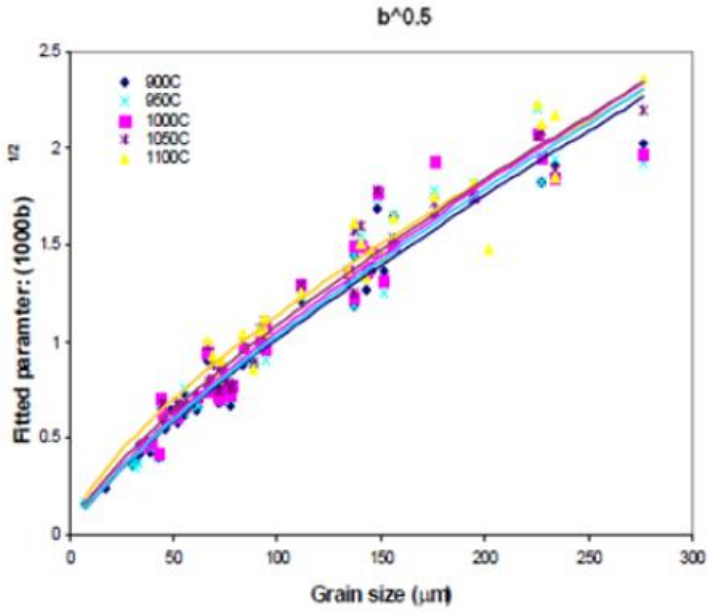
Spectral attenuation and calibration curve for EHN Trials







- From A-scan segment around backwall echoes
  - Derive spectral attenuation with FFT
  - Fit parametric model in given frequency range
  - Derive grain size from parameter b
- Review of method
  - FFT not optimal for pulses
  - HSM steel grain sizes at low end of ranges (accuracy of model?)
- Issue with «Phantom Echo »
  - Ongoing identification of source
  - Degrades FFT estimation



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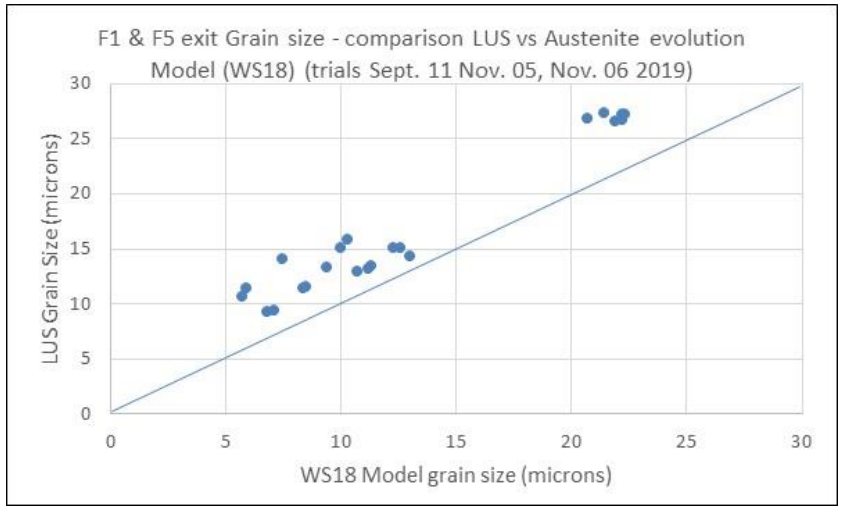
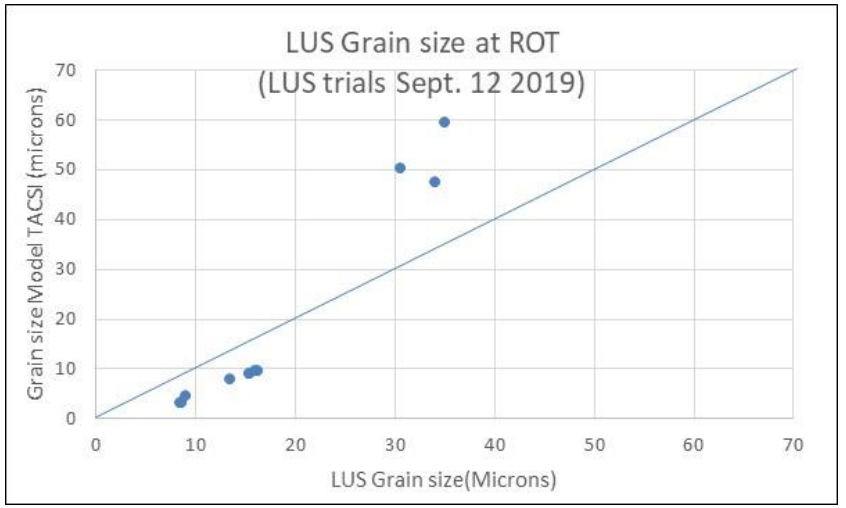
Grain size estimation : LUT vs Models (N. Legrand)





- Encouraging results :
  - Grain sizes in the same range, yet with discrepancies
  - Issue with Phantom Pulse and quality of FFT approach
  - Possible lack of accuracy of link between fit parameter and grain size
  - TACSI model possibly not properly tuned for large grain sizes

Metallographies only allow confirming predictions Be it models or LUT data

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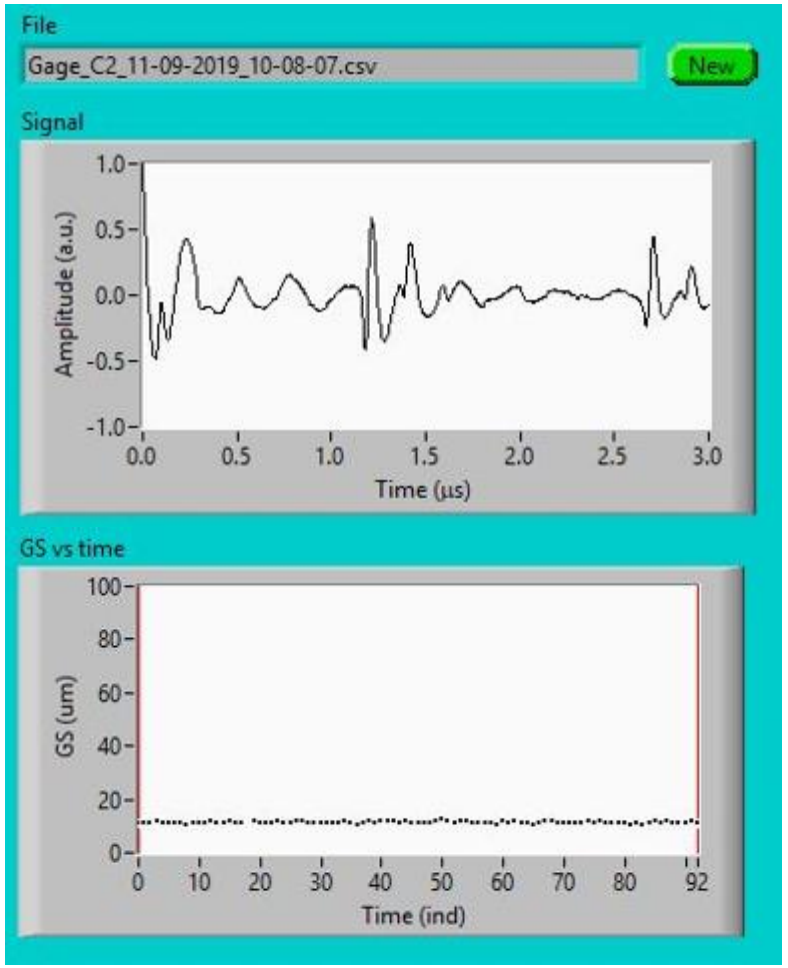
Evolution of Grain Size along coil length - example

- Need for ascertained product presence when laser firing:
  - On- spot product presence
  - Lead time to re-ignite laser at coil head
  - Loss of initial length

  Laser must be turned off before coil end => again slight loss

- No available signals at extremities => constant features in recorded segment of strip



1st A-scan

Grain Size with Time

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Conclusions & Prospects

General conclusions

- Design and Construction of a Transportable Laser Ultrasonic System
  - For monitoring steel microstructural features during hot rolling of strips

- Industrial Trials in EisenHuettenStadt
  - 3 campaigns, sept. Nov 2019
  - Exits of F1, F5 stands, and of ROT
  - 3 grades : S420 ; S460 and DP780

- Signal analysis routines to derive grain size
  - Encouraging results obtained with on-line signal recordings
  - « Phantom Echo » to understand and mitigate
  - Improvements to consider on signal processing approach

=> Compliance with Project Objectives

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Prospects

- Nomad LUT Instrument ready for application in HSM
  - Process Snapshots, with required validation via metallographies, for all HSMs?
  - Tuning/Validation of metallurgical models

- Preparation of Laser Ultrasonics application in CAL / CGL furnaces
  - Monitor & help control metallurgical transformations during thermal cycle
  - Phase transformation for AHSS
  - Recrystallisation for HSLA (µ alloyed)
  - Possible interest of a dual-head system

- Monitor phase transformation during hot rolling of heavy beam blanks
  - Re-ignite contacts with Differdange
  - Interest of dual head (« multiplexed ») system for central web and flange

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The End – Ready for Questions