Performances comparison of a laser ultrasonic system using 10.6 µm infrared or 532 nm visible generation beam for the investigation of CFRP

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Context and introduction

- **Composite samples**
  - From aerospace industries
  - Fully made of CFRP
  - Generally ~ 1 m² size
  - Complex shapes

- **Develop a medium cost industrial LU system**
  - Flexible lightweight optical head
  - Based on two-wave mixing
  - Compact optical head
  - Interfaced to a 6-axis robot for scanning

- **Analysis of two system with the same detection system**
  - Influence of the generation system
  - Impact on the usability of the whole LU-system

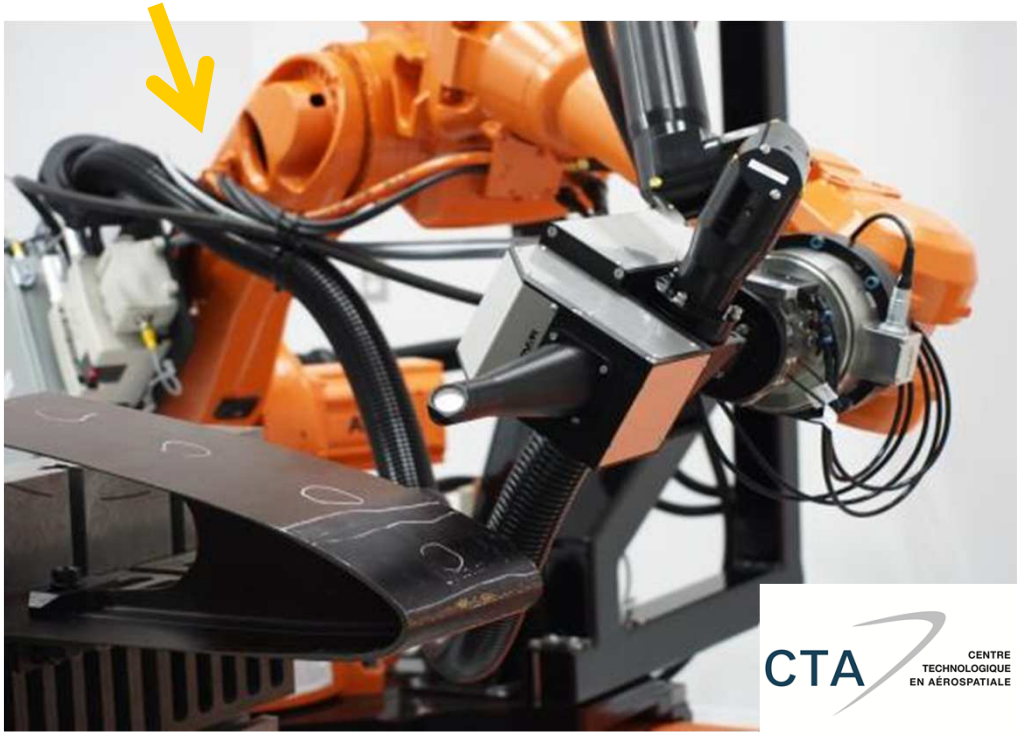
Comparison of two LU systems

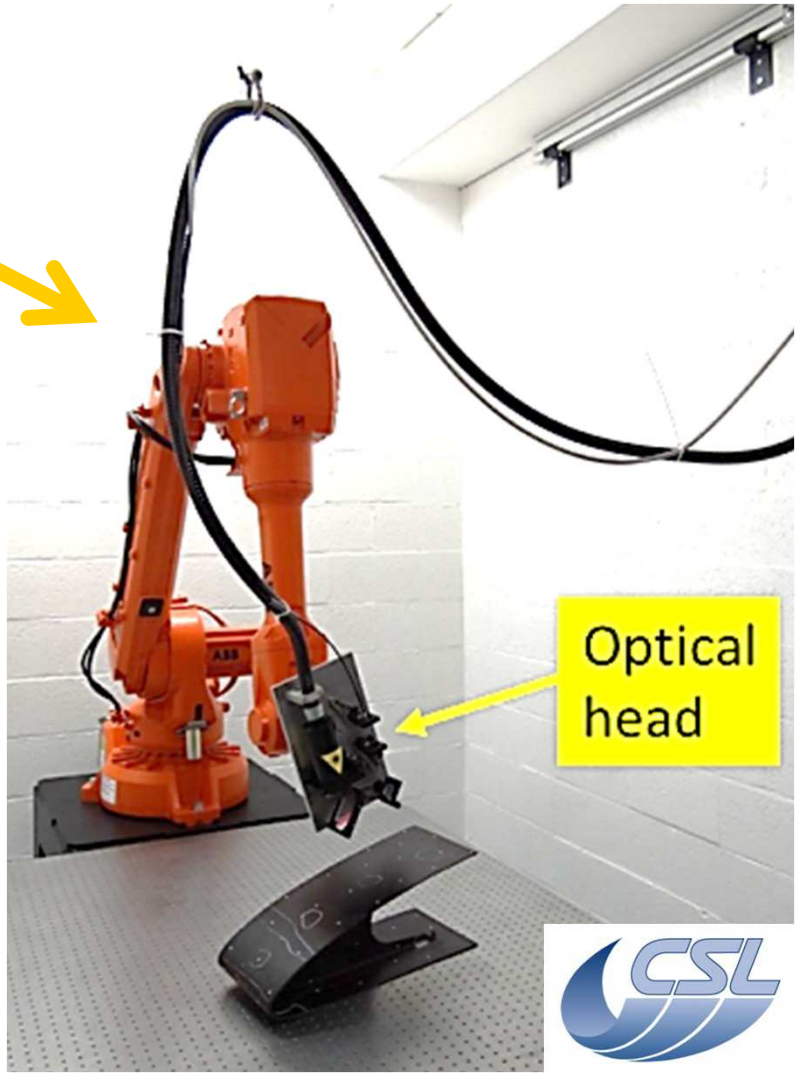
- **Detection**
  - PDL laser Tecnar with TWM detection probe
  - flexibility → 10 meter robust flexible conduit
  - Working @ 1.06 µm
  - Interfaced to a 6-axis robot for scanning

- **Generation**
  - CO_2 lasers (10.6 µm)
    - LUIS system @ CTA (Montréal, Canada)
    - More generally used
    - No optical fiber → less flexible (mirror reflection system)
  - Best wavelengths: 3.3 and 4 µm
    - No commercial and cost-effective solution currently available
  - YAG Q-switched lasers (532 nm)
    - CSL system (Liège, Belgium)
    - Ultra 50 from Quantel @ 532 nm
    - 30 Hz repetition
    - 30 mJ at the output power

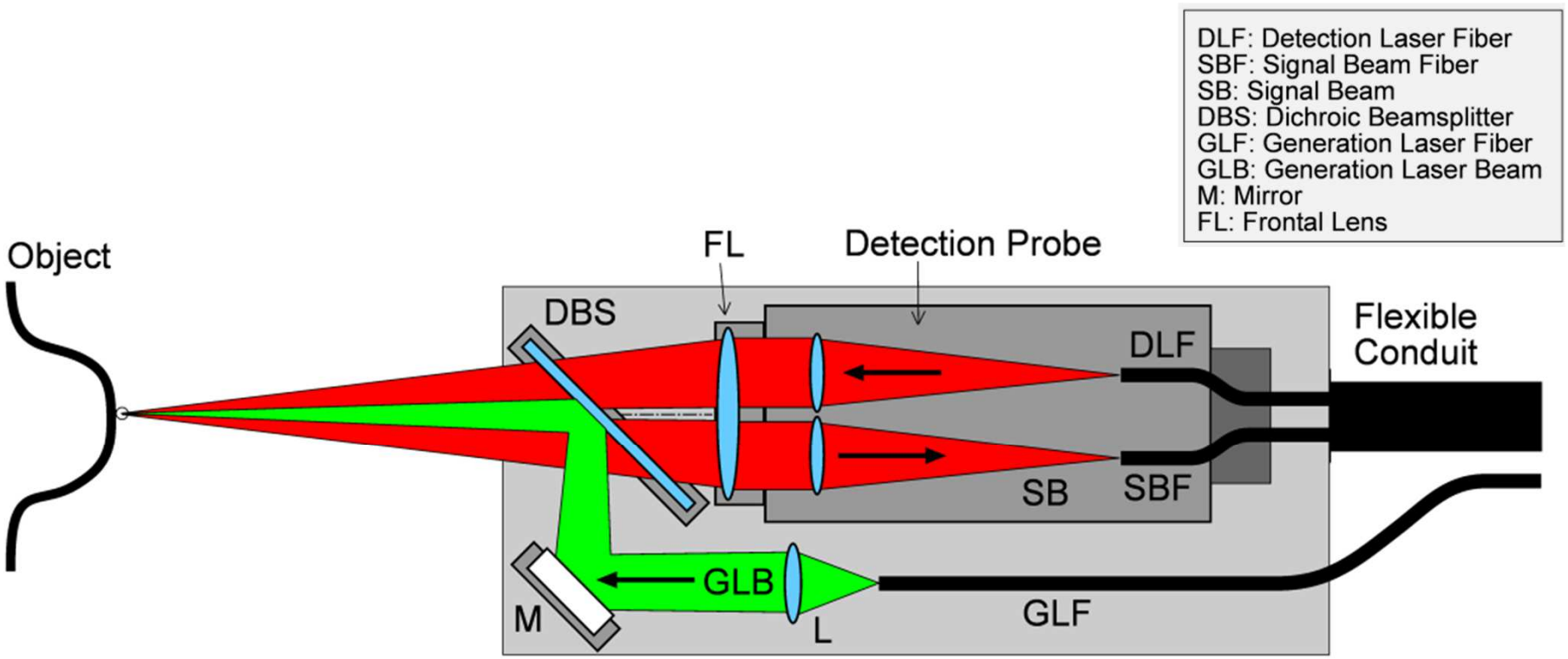
Two tools compared

- **CSL system**
  - Visible generation: 532 nm
  - All-fibered system
- **LUIS**
  - Infrared generation: 10µm
  - Periscope system



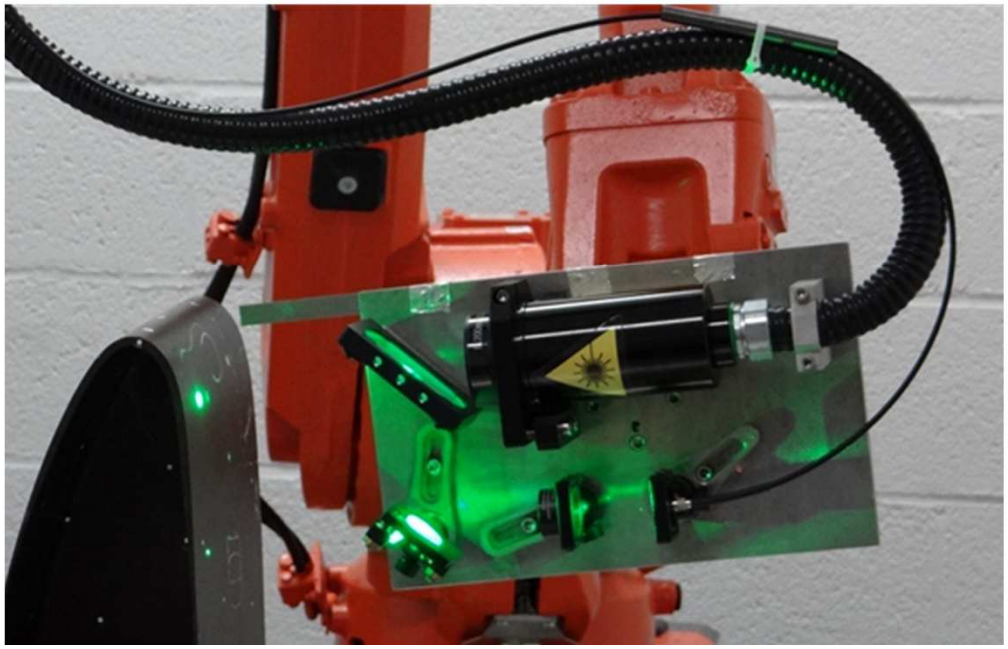


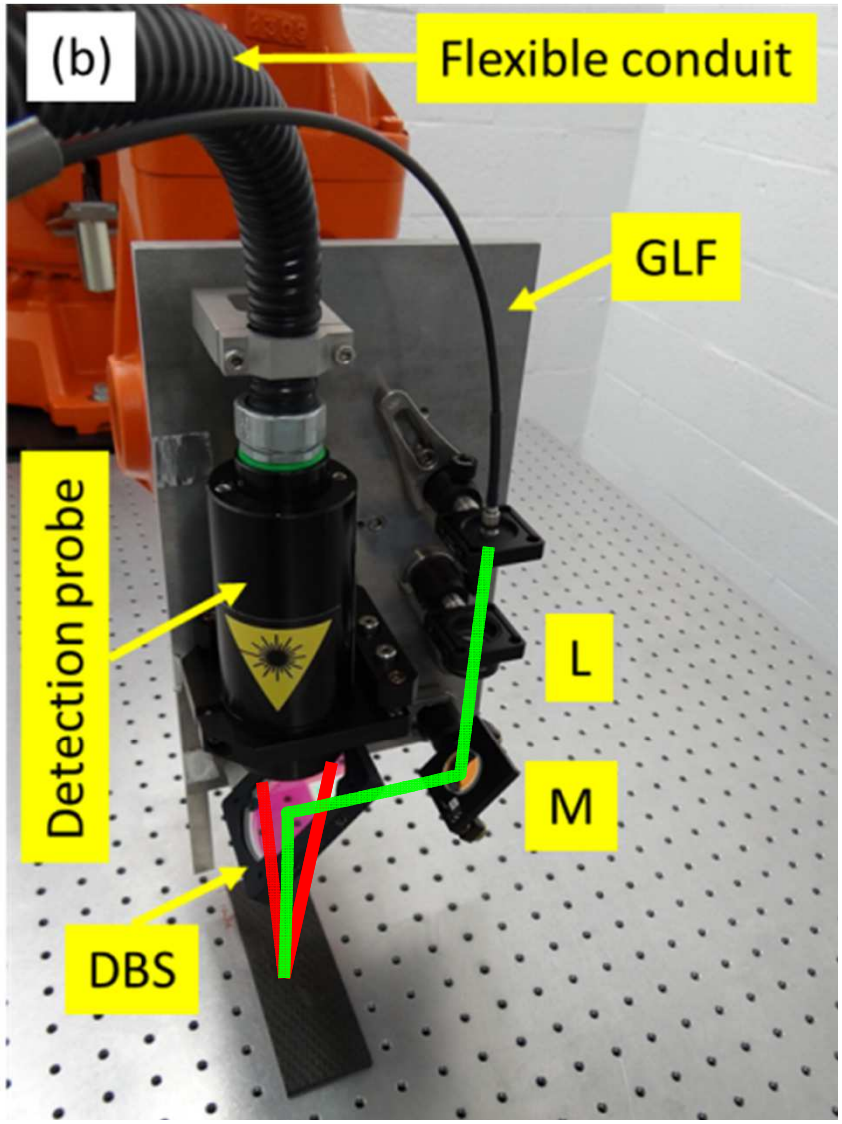
TECNAR probe



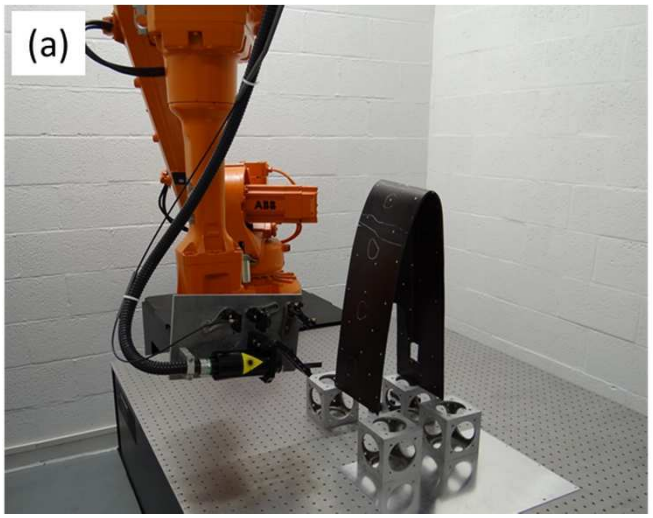
CSL system

- Fully fiber-coupled system
  - Detection by Two-Wave Mixing
    - fiber-coupled system by Tecnar
  - Generation by YAG laser (green)
    - fiber-coupling by CSL
  - Lightweight optical head on robot-arm

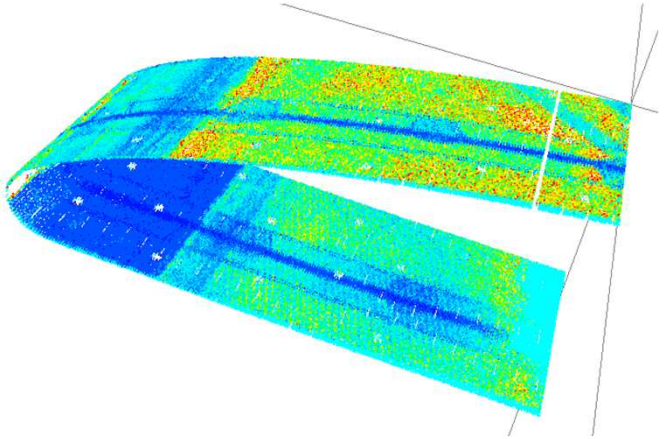




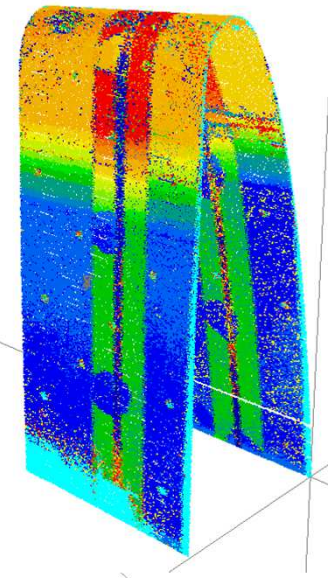
CSL system: Complex-shape object

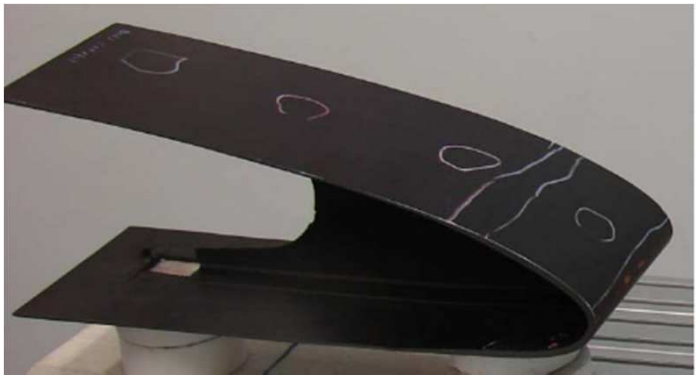


C-Scan Amplitude

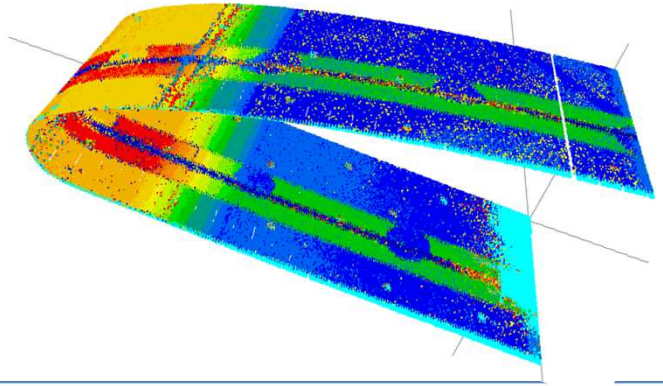


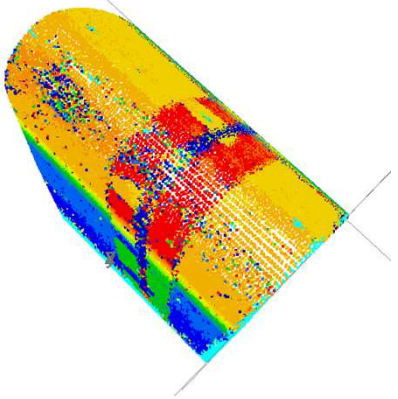
Defects seen at different angles





C-Scan Time of Flight



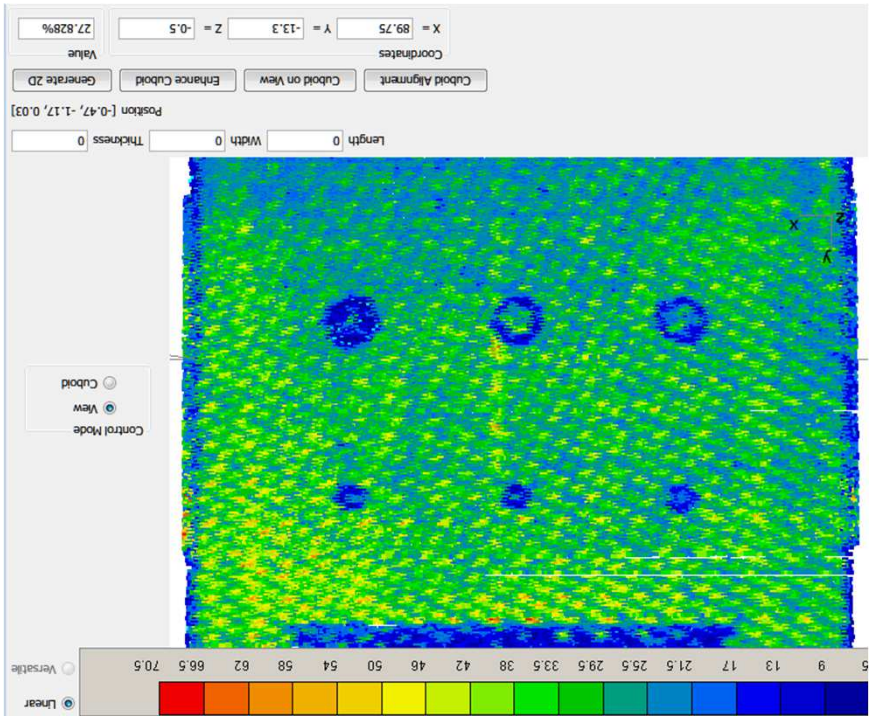


LUIS

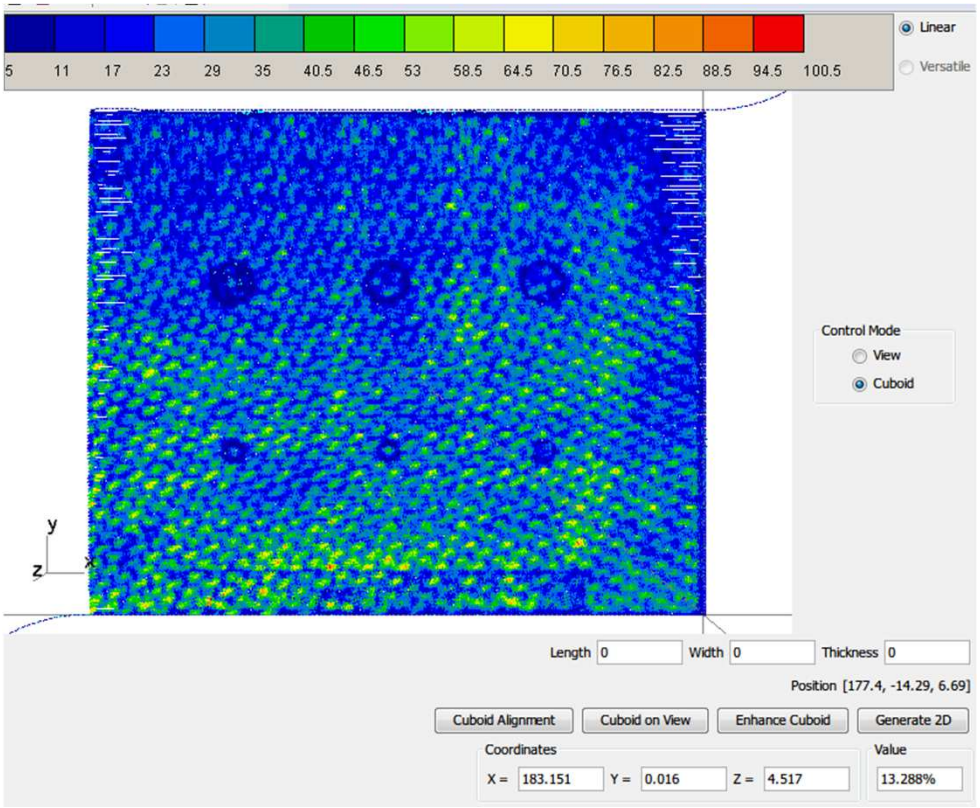
- **Same detection system**
  - PDL and TWM by Tecnar
- **Generation by CO_2 laser (10 µm)**
  - Laser illumination brought by a complex articulated arm with mirror and protection tube

C-scan: Amplitude

CSL system (532 nm)

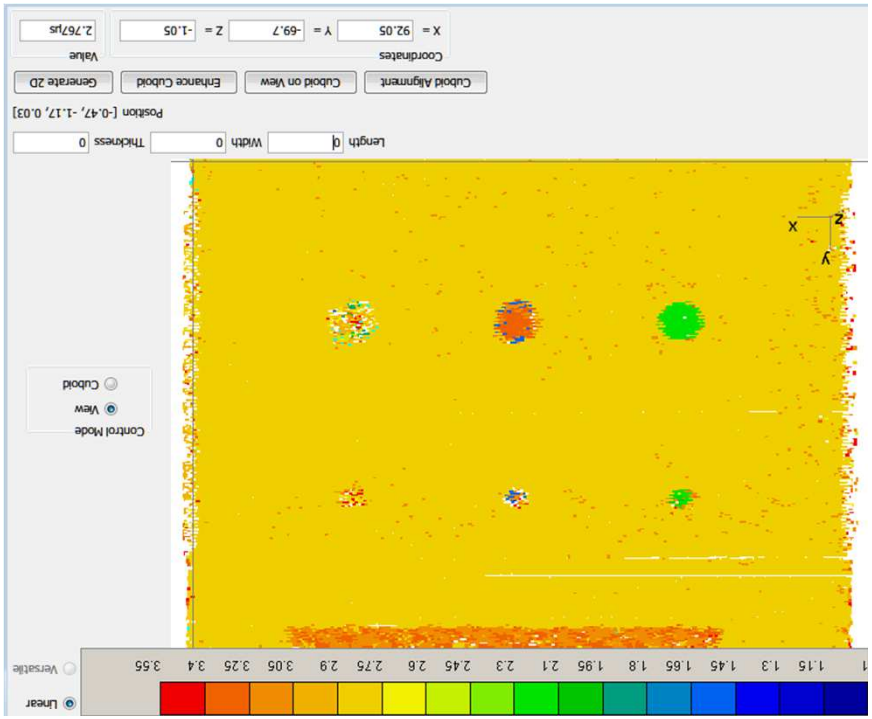


LUIS (10 µm)

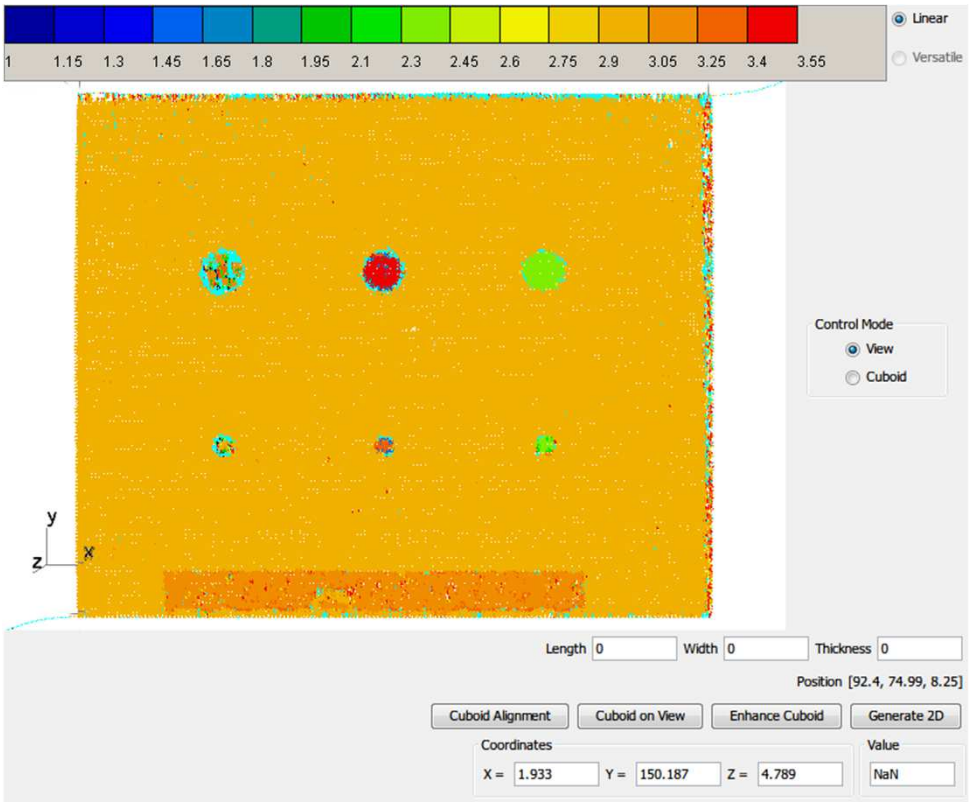


C-scan: Time of Flight

CSL system (532 nm)



LUIS (10 µm)



Comparison of two LU systems

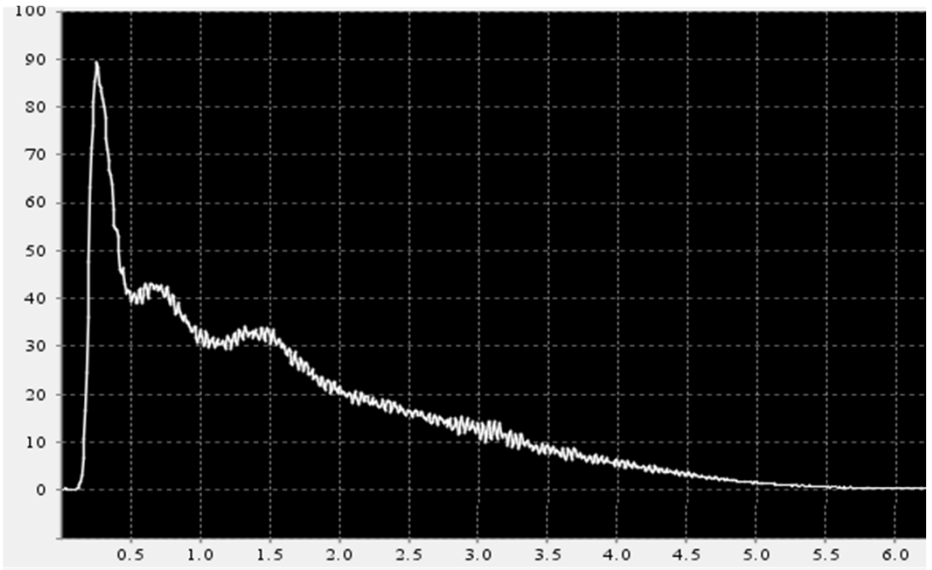
- **Generation signal**
  - Shape and duration of the pulse
  - How to bring laser pulse to the sample

- **Absorption physic difference**
  - How does it affects the A-scan produced
  - Surface damaging

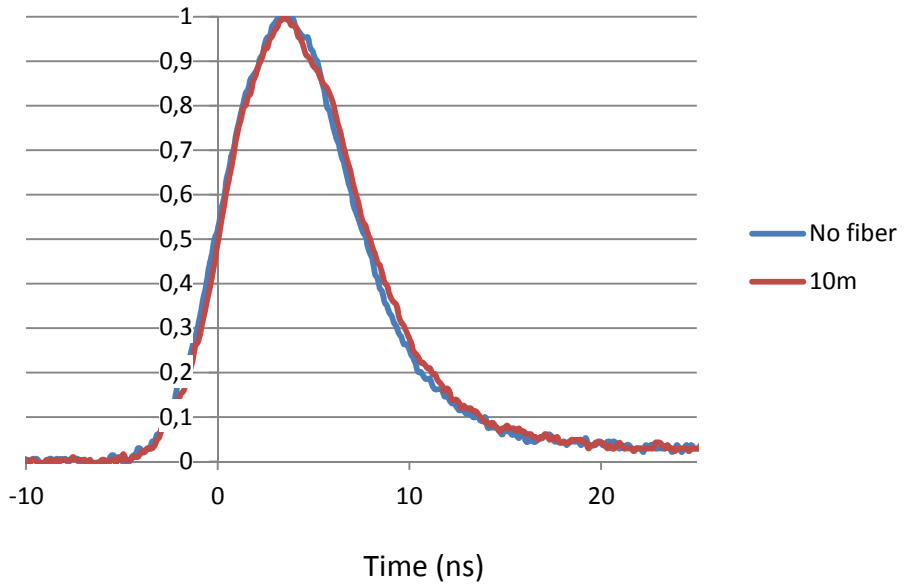
Shape of the pulses are different

- CO_2 pulse energy ratio between peak and trail is not constant between each pulses
- High repeatability of the 532 nm laser pulse

Normalized pulse shape (10 µm)



Normalized pulse shape (532 nm)



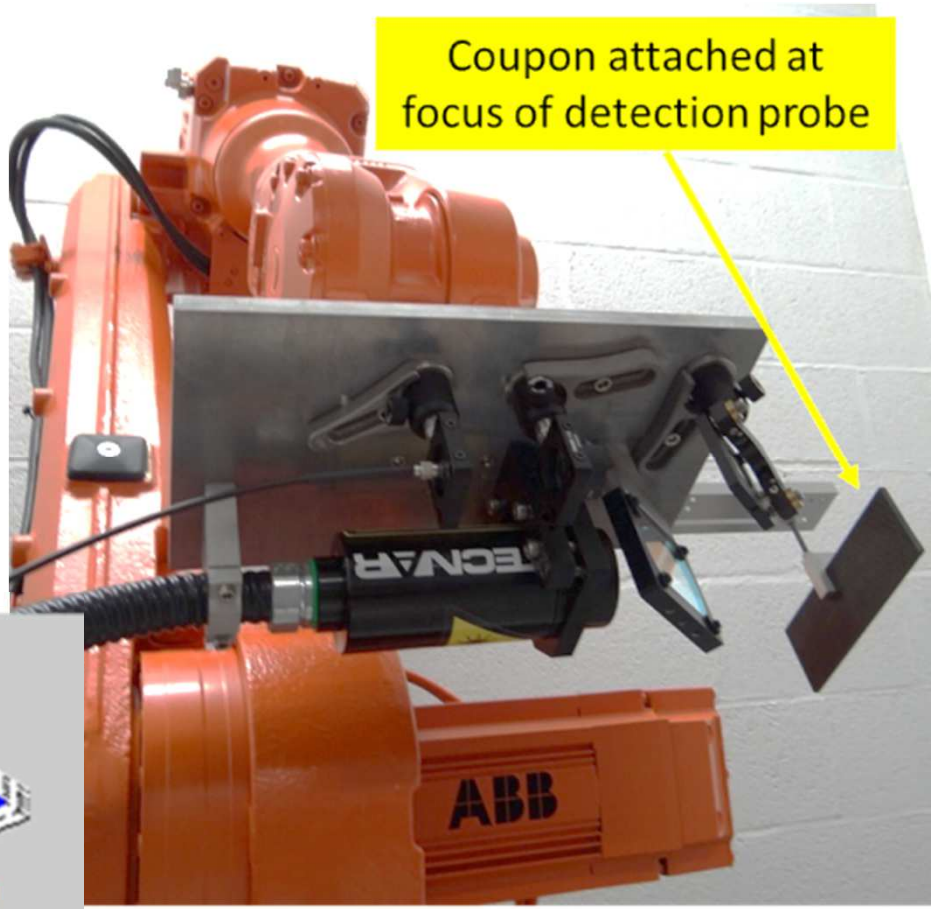
Bring laser pulse to the sample

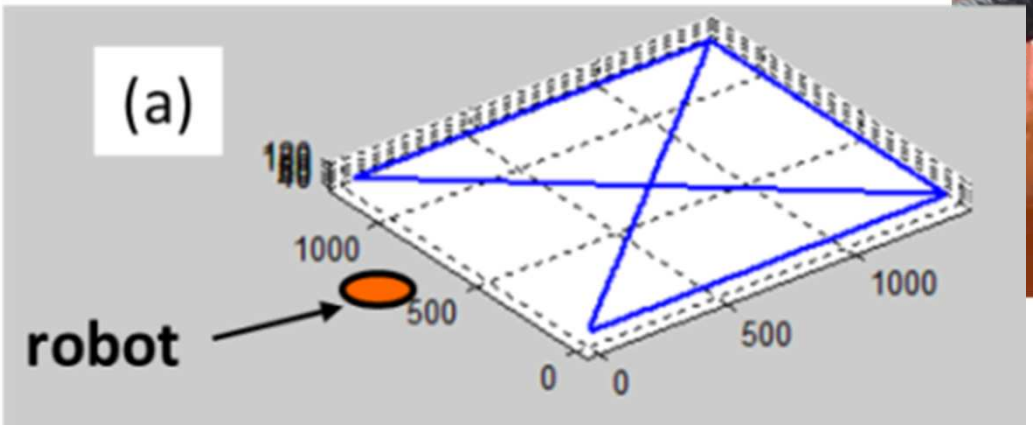
- **10 µm: periscopic system**
  - Less flexible
  - More restriction on the movement of the robot arm
  - Safety restriction due to high power invisible light

- **532 nm: optical fiber**
  - Highly flexible
  - Few restriction on the movement of the robot arm
  - Effect of the fiber on the generation pulse

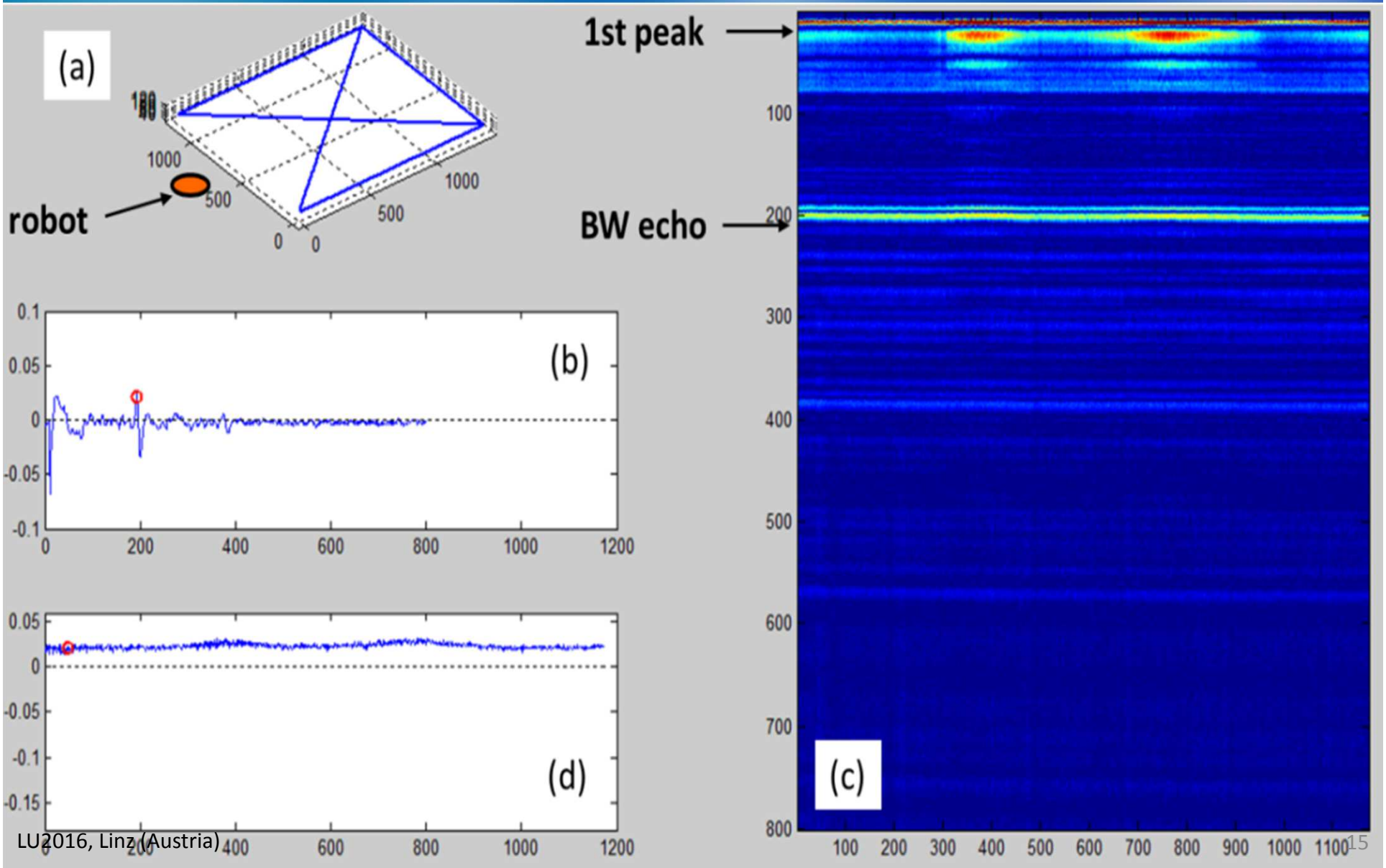
Effect of the optical fiber

- **CFRP coupon**
  - Attached on the optical head
  - Position of best detection
  - Move the optical head all along the workbench (1.8 x 1.2 m²)





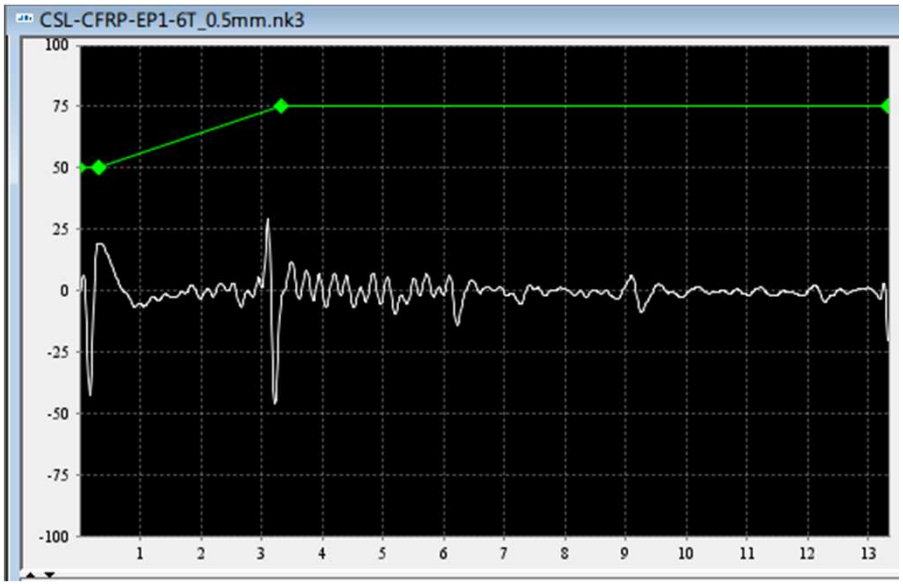
Effect of generation fiber curvature



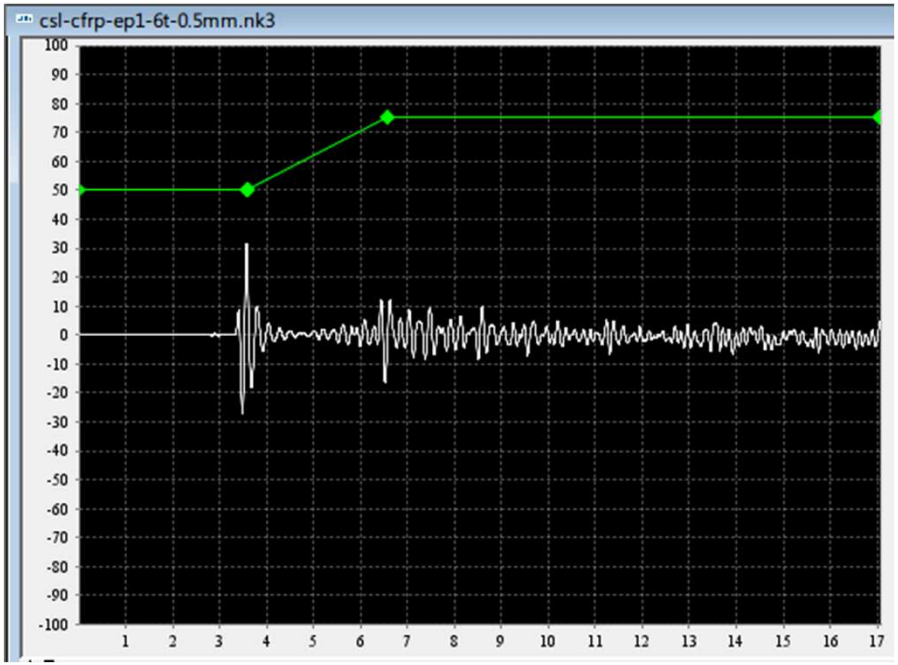
A-scan comparision

- **Flat CFRP plate**

CSL system (532 nm, 30 mJ)



LUIS (10 µm)



A-scan comparison

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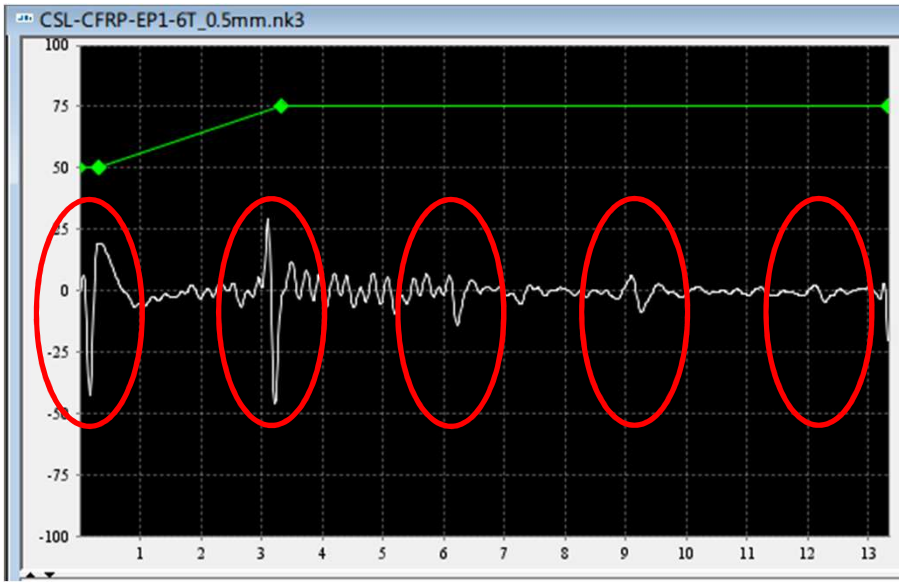
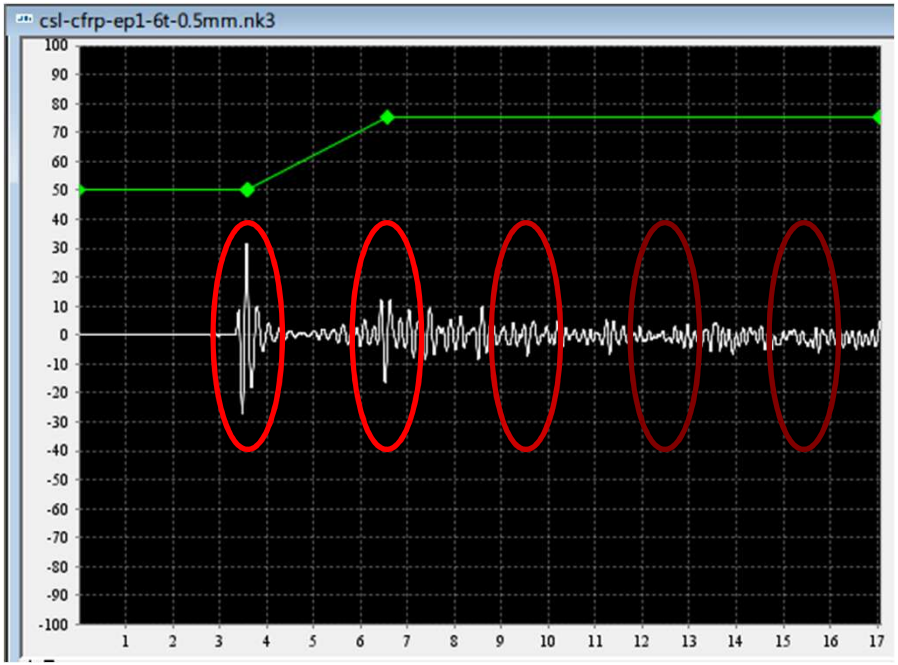
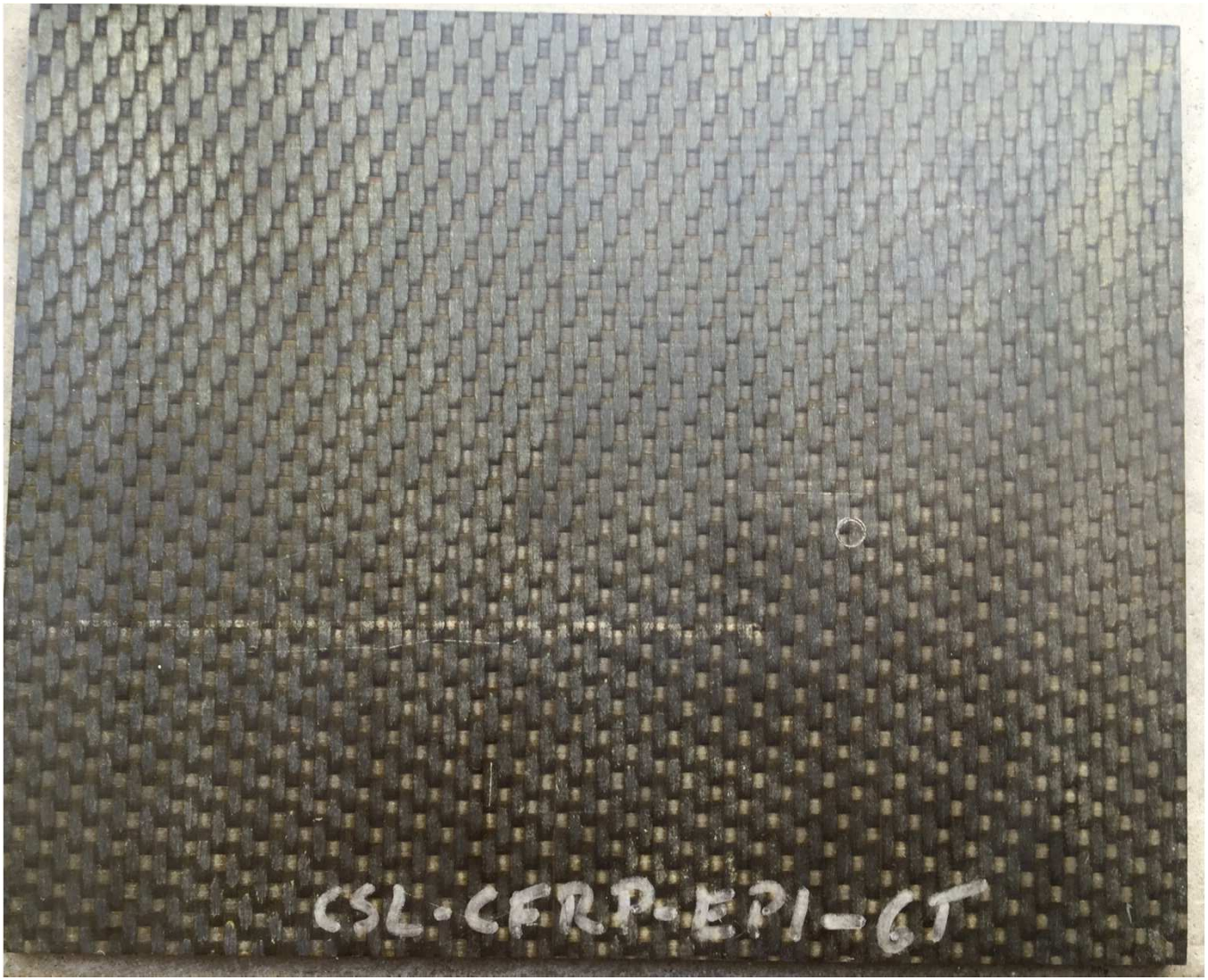


LUIS (10 µm)



Visible generation: surface damaging



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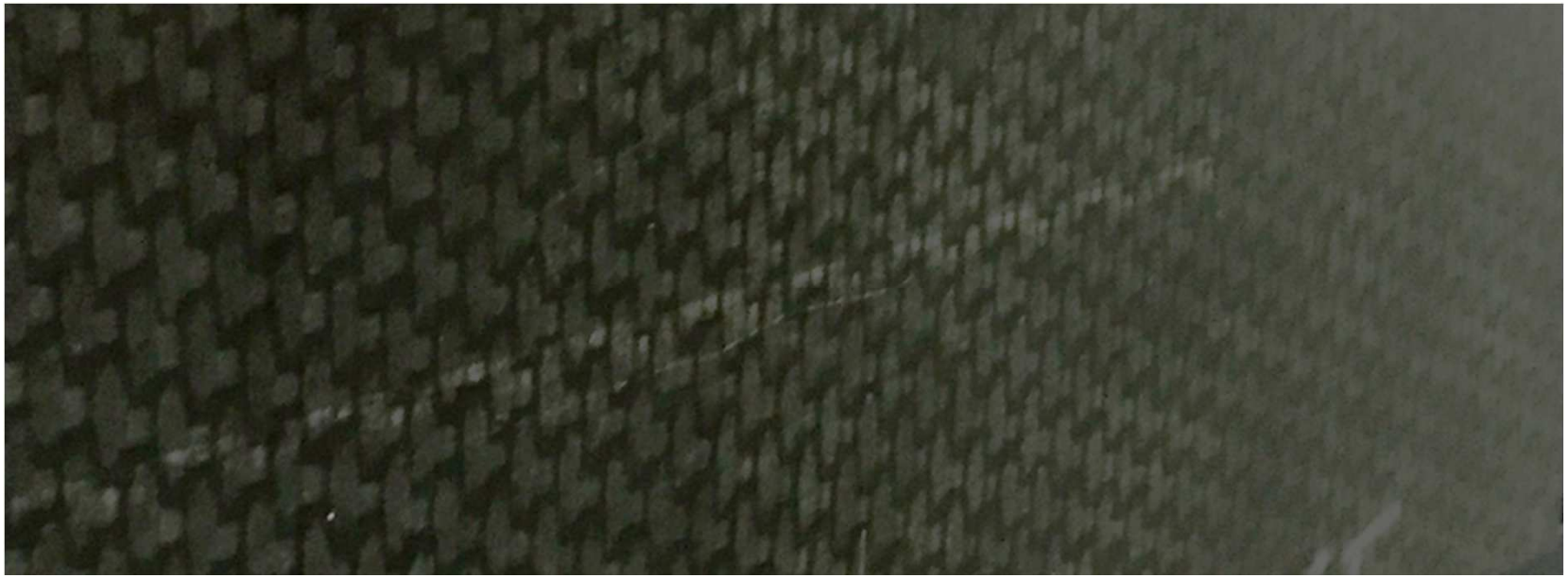
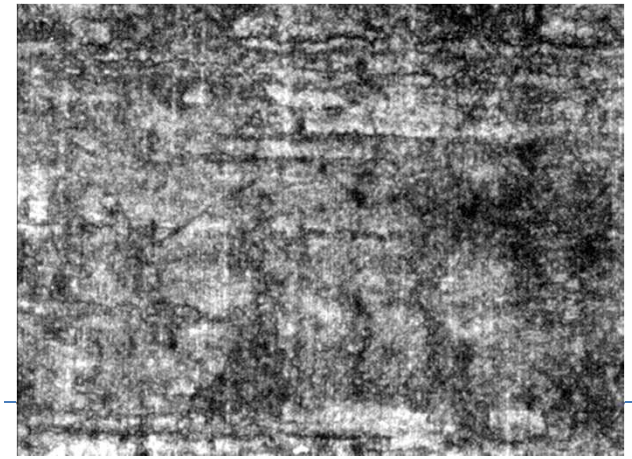
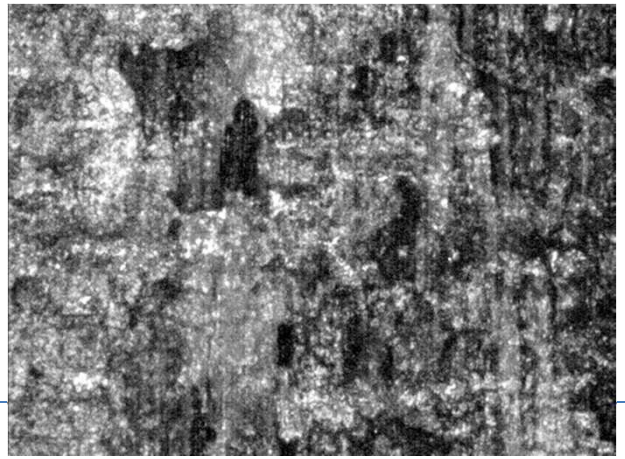


Sane surface

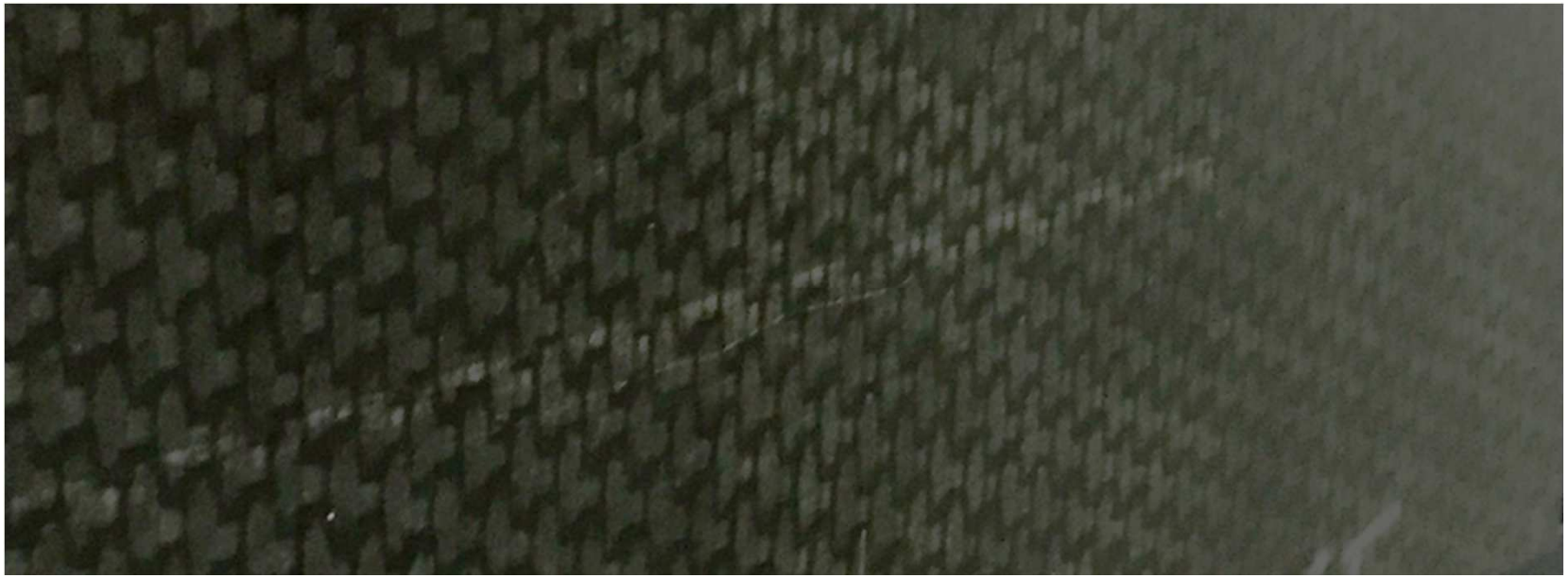


Decolorized surface

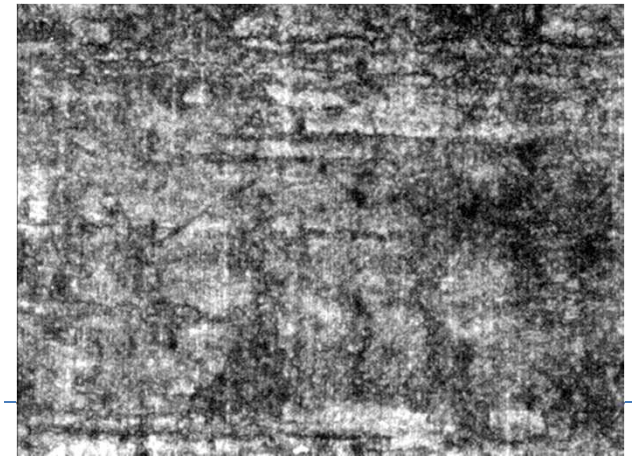


Heavily decolorized surface

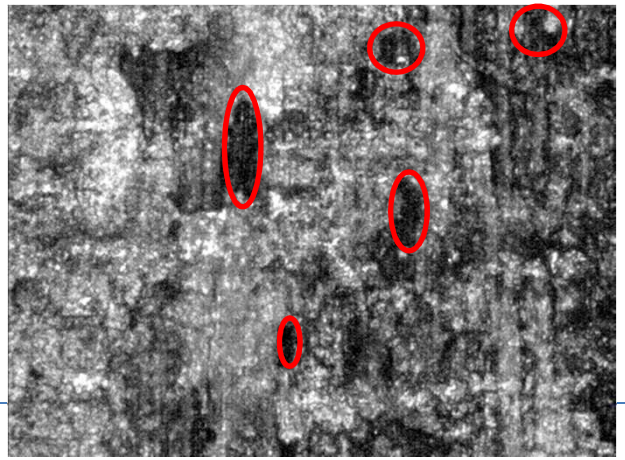
Visible generation: surface damaging



Sane surface



Decolorized surface



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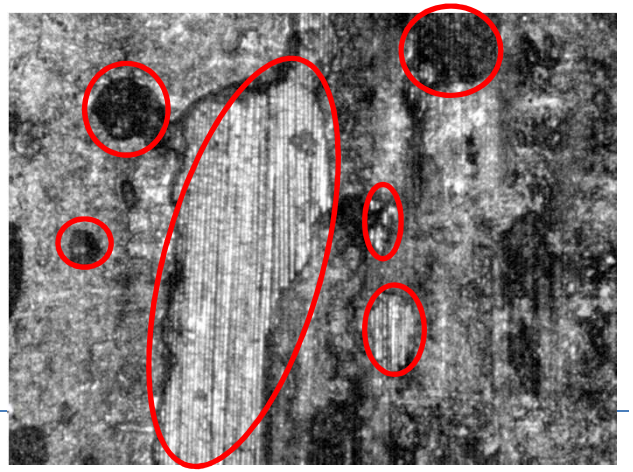

Visible generation: surface damaging

- **Observations**
  - Impact seems to remove resin first
  - Damage fibers afterward
  - Multiple scan of the same surface increases the damage observed

- **Vary from samples to samples**
  - All CFRPs are not equals
    - Some sample present no damaging and not decolorization at all
    - Others present decolorization at very low pulse energy
  - Resin recipes are not provided (!)

- **Not the visible laser only**
  - 1064 nm probe can also damage surfaces

Conclusion

- **Preliminary study**
  - No clear conclusions can be made yet
- **Noticeable differences**
  - Pulse shape and duration
  - Fiber effect on the visible generation
  - Echoes visibility in the A-scans
- **First observation**
  - Visible generation is competitive with CO_2 generation
  - Decolorization of the sample is the main drawback