Remote Sensing & Beam Instrumentation

Lessons learned & future steps for mechanical instrumentation

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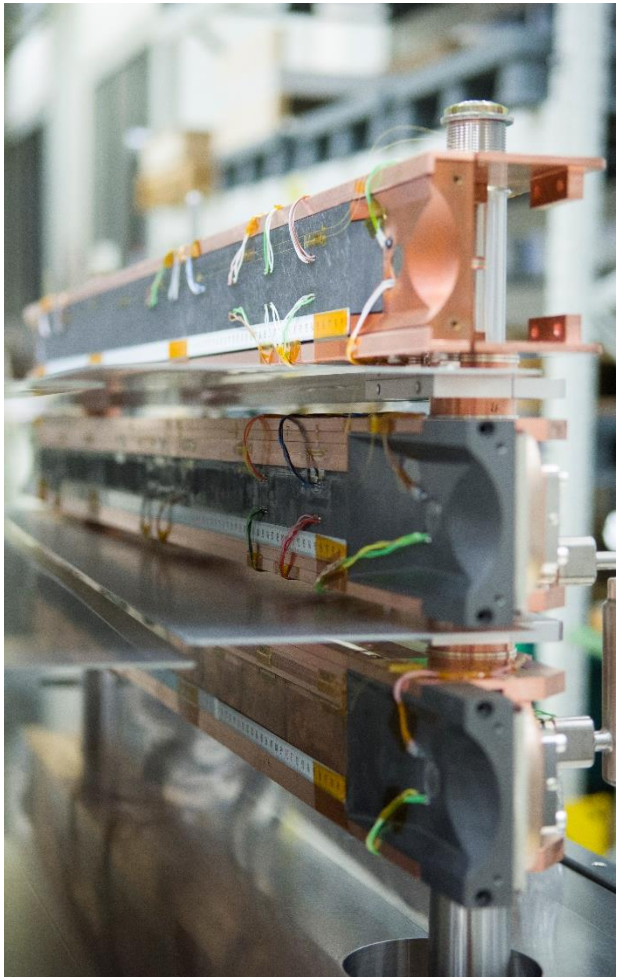
CERN | EN ENGINEERING DEPARTMENT

Outline

- Introduction
- Measurement techniques
- Results and lessons learned
- Future development
- Conclusion

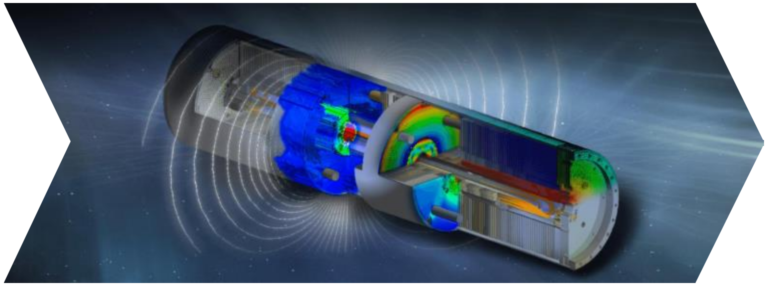


Introduction

- Why perform measurements ?

Inputs for FEA :

- Thermo physical properties
- Mechanical properties



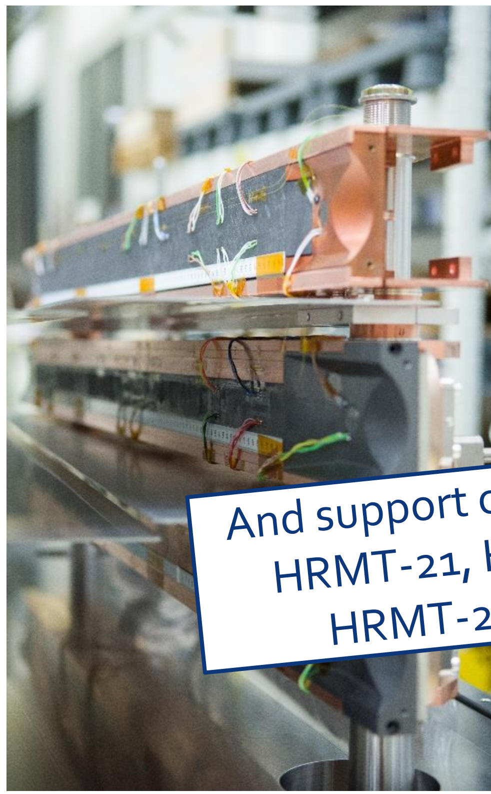
FEA validation & Safety

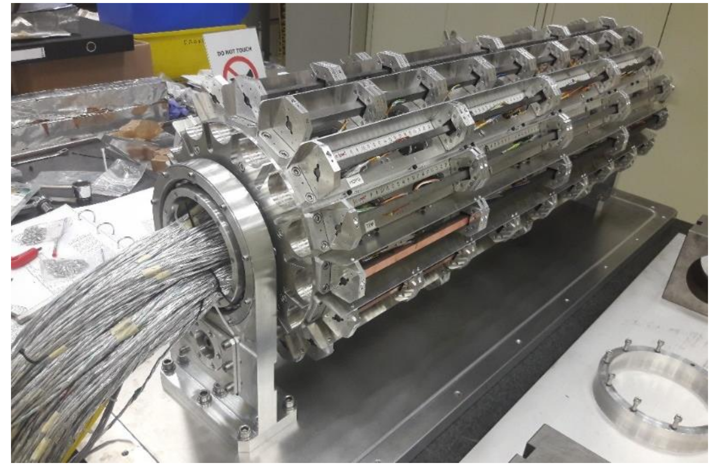
- Why mechanical measurements in HiRadMat experiments ?
  - Collect **data real time**.
  - To **benchmark** advanced numerical simulations, powerful but based on limited and scarce literature data on **material constitutive models**.
  - To optimize **design schedule** by collecting objective data sooner than the post-mortem analysis due to radiation aspect.
  - For **safety reason**, with a complete vision of the integrity of the structures and material under tests.
  - **Beam based alignment** in addition of beam instrumentation

Measurement experiences in HiRadMat

HRMT-14
6 different materials
(Inermet, Glidcop, Mo,
MoCuCd, CuCd, CFC)
Cylindrical and
half-moon samples

HRMT-23
3 different materials
(CFC, MoGr, CuCd)
Collimator Jaws



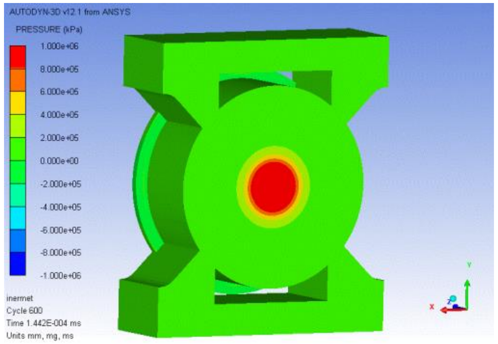


HRMT-36, HRMT-46

And support on HRMT12,
HRMT-21, HRMT-24,
HRMT-26, etc…

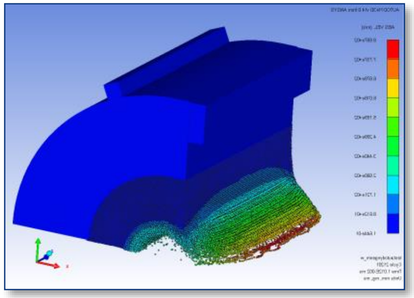
Measurement experiences in HiRadMat

Physical effects		
Physical effects	Expected amplitude	Time response
Mechanical strain	Up to 5000 µm/m	µs scale
Mechanical strain	Up to 5000 µm/m	second scale
Surface velocity	Up to 24 m/s	µs scale
Surface displacement	Up to mm	µs scale
Vacuum level	10-6 mbar	second scale
Temperature	Up to 1000 °C	second scale
Particle Front propagation	Up to 500 m/s	µs scale



Pressure wave propagation pattern

Simulations on Inermet 180
(σ = 2.5 mm, 20 b, 1.5e11)

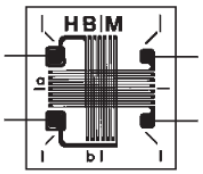


- A real challenge due to the quantity/type of channels and the bandwidth !!!
- Synchronisation of the measurements
- And the environmental conditions (radiation, vacuum, long distances, etc...)

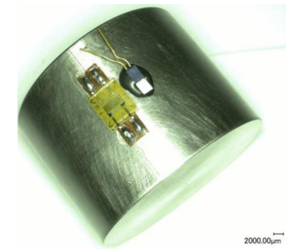
Electrical strain measurement

- Design :
  - Biaxial measurements, same spot
  - Support : Polyimide (≈ 45 μm thickness)
  - Grid : Copper-nickel alloys (5 μm thickness)
  - Twisted and shielded pair cables
  - Bonding process with epoxy glue

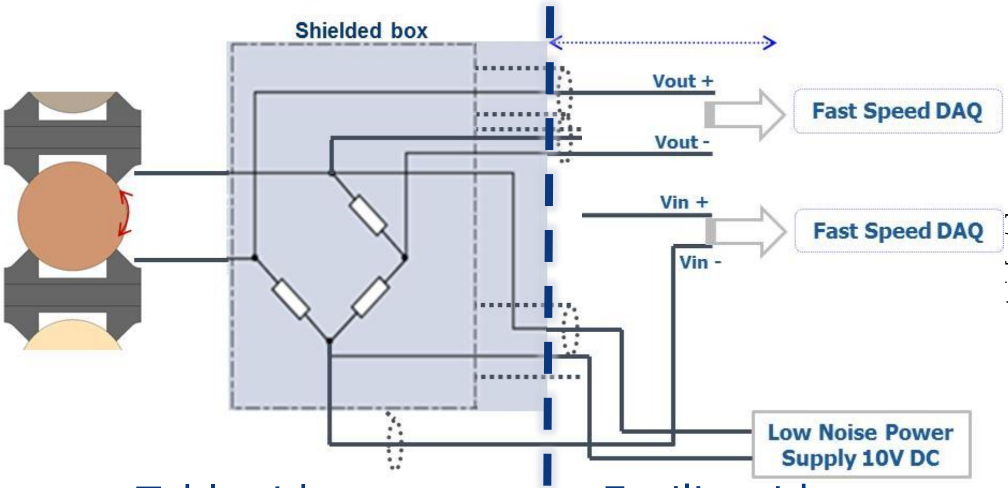
$$\frac{\Delta R}{R} = k\,\frac{\Delta L}{L}$$



with k : Gauge factor



→ For 2000 μm/m, ΔR is equal to 11 μΩ !
→ Measurements inside a Wheatstone Bridge located on the table :



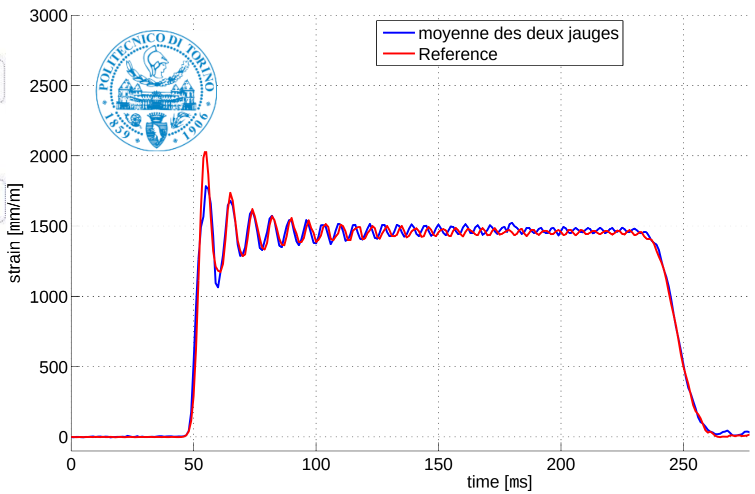
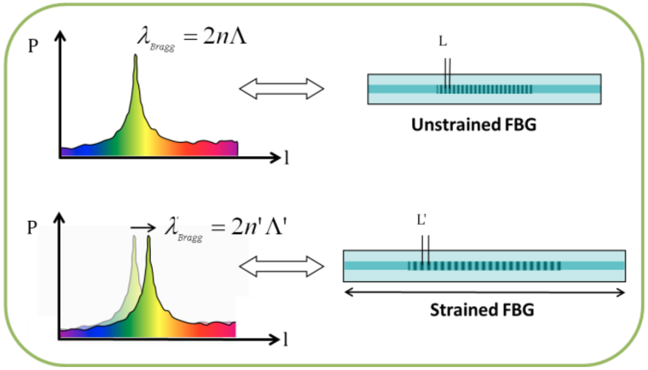
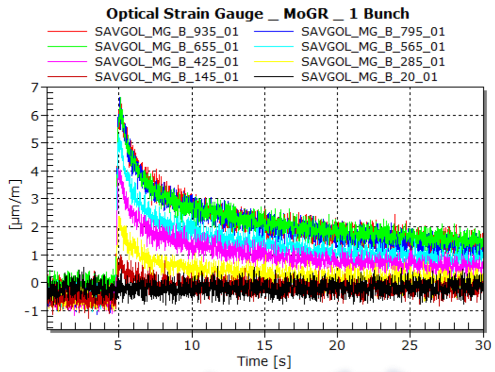


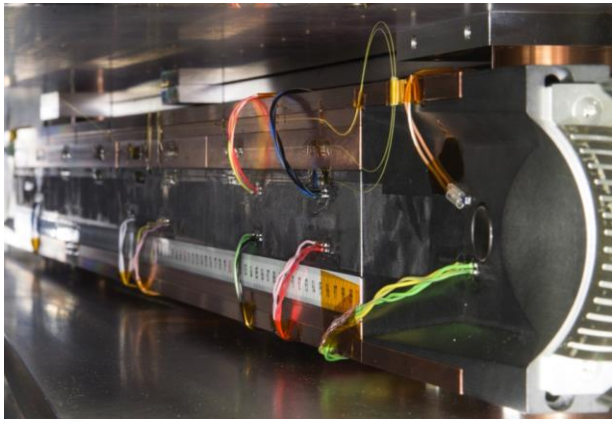
Table side Facility side

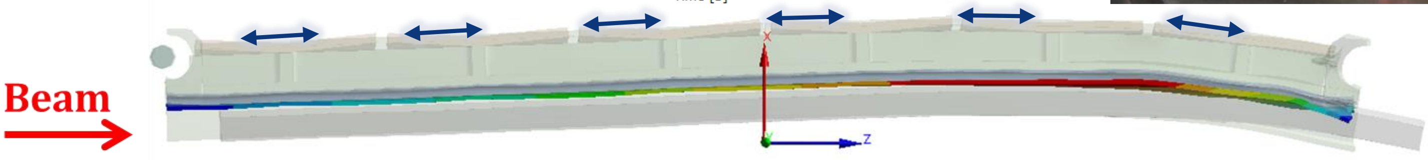
Optical strain measurement

- Bragg technique :
  - Several gratings on the same fiber
  - Less connections, low mass
  - Insensitivity to the particle beam
  - Sampling frequency@ 1 kHz



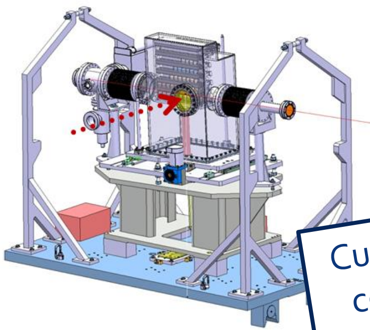






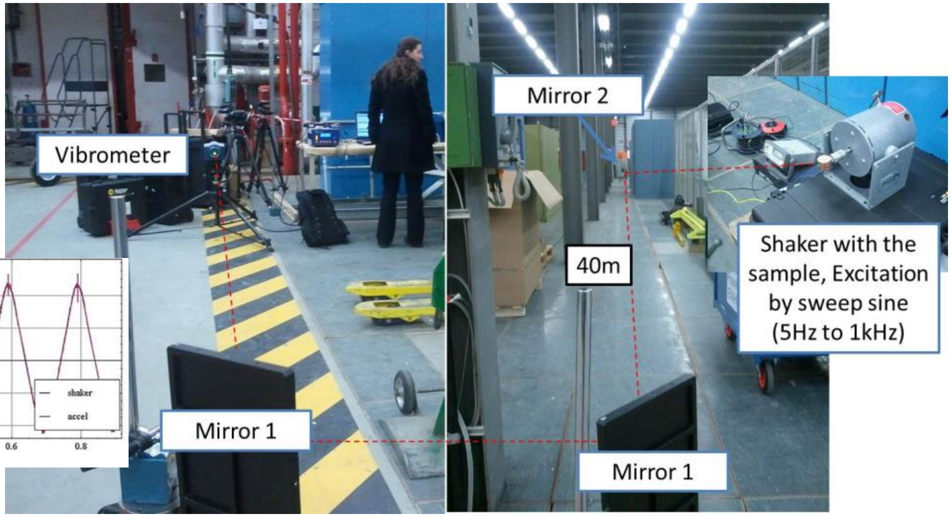
Velocity measurement

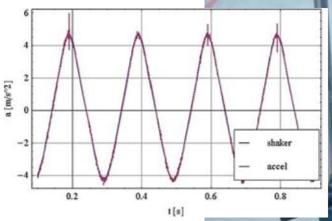
- Laser Doppler Vibrometer equipped with :
  - Targeting laser (green)
  - Infrared laser for measurements
  - Long range lens
  - In line video camera with reticle overlay



Customized system developed in collaboration with Polytec® for this application !

- Validation results:
  - Test performed in BA7, same configuration as HiRadMat facility
  - Same components as for the final measurement





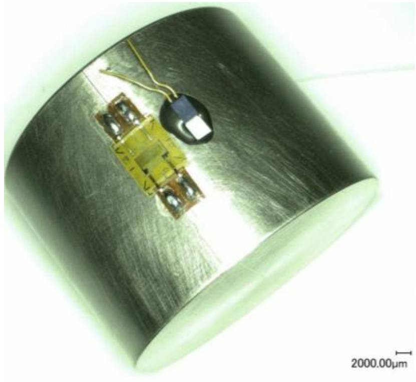
Position measurement

- Fiber optic based interferometer :
  - Sensor resolution : 1 pm
  - Sensor repeatability : 2 nm (at 10 mm working distance in vacuum conditions)
  - Max. target velocity : 2 m/s
  - Measurement bandwidth : 10 MHz

HRMT-44 :
Jaw deflection measurements

Temperature measurement

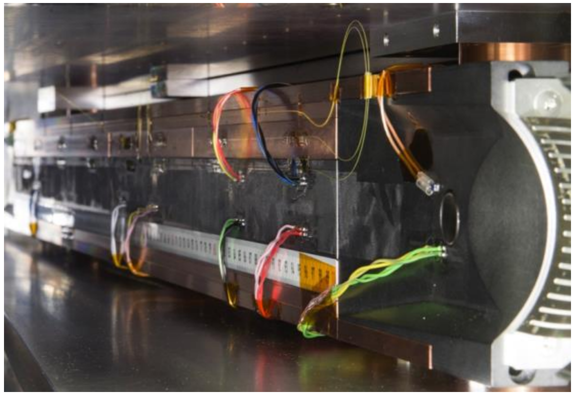
- Pt 100 probes :
  - Slow acquisition : ≈100 S/s
  - Intermediate temperature : < 200°C
  - Bonding process with an high thermal conductivity glue.



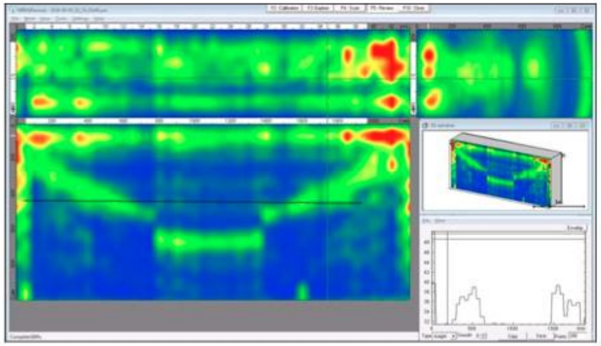
- Thermocouples probes :
  - Slow acquisition : ≈1 S/s
  - High temperature : >600 °C
  - High temperature ceramic glue with operating temp of 1650°C

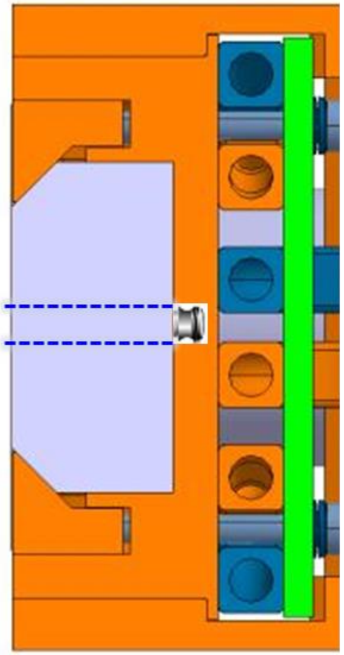
Crack investigation

- Ultrasound investigation for :
  - Cracks and phase modifications in the jaws
  - Modification of the structure (melted area)
  - Probe compatible with 1000 kGy and 350°C
- Outcomes :
  - Issue with the coupling between the probe and the material itself
  - Not online… checking between impacts



Ultrasonic Pulse Echo Scans Produced By the MIRA

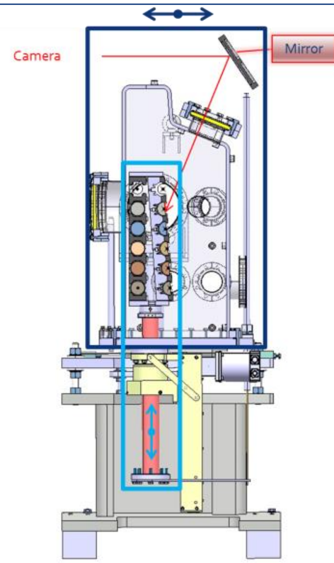




Visual inspection

- High Speed Camera:
  - Observable area at 42 m: ~100x100 mm,
  - Optical Circuit: 3 mirrors + 1 window,
  - Frame rate: 20000 fps,
  - Shutter time: 5 µs.
- Radiation resistant video camera:
  - 30kGy gamma, <30kGy mixed field…
  - 20 fps
  - Not HD but reliable!
- Lighting systems:
  - Vintage Xenon Flash Light with a customized electronic circuit

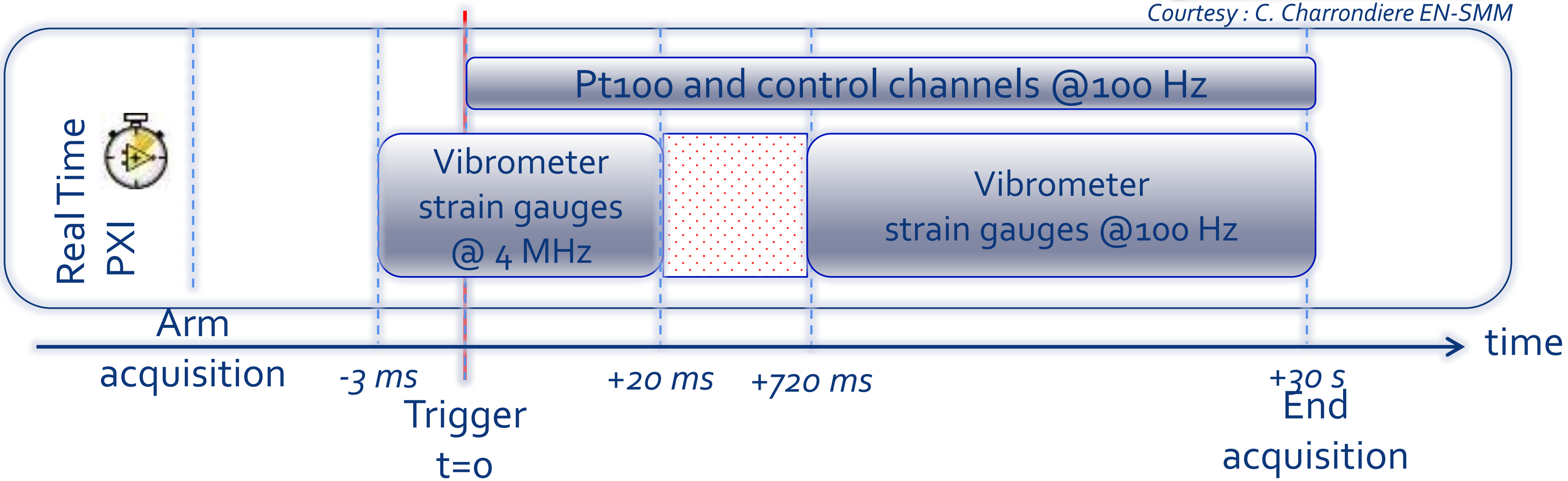
  Or
  - Remote operated LED arrays



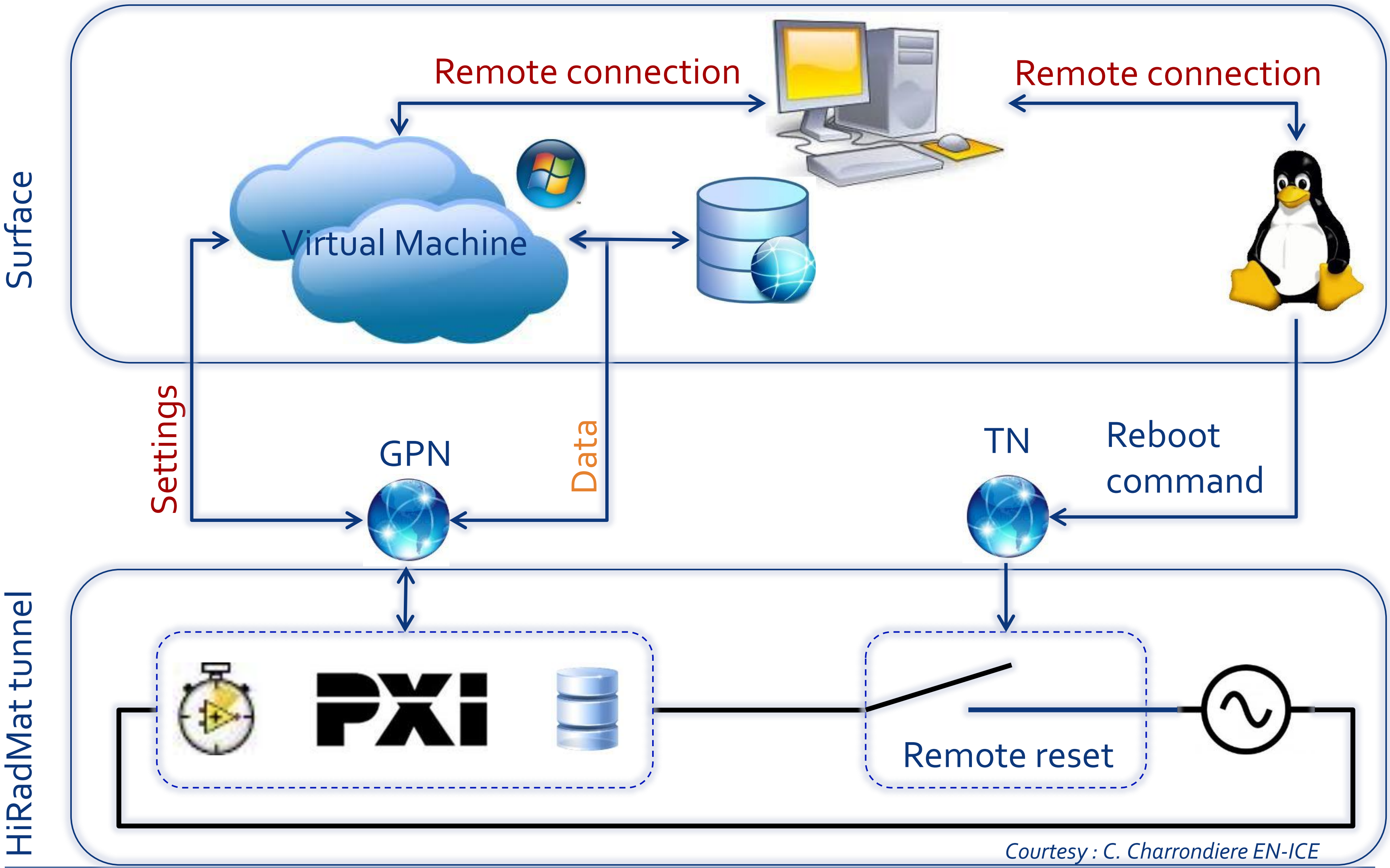
DAQ & Software

- Labview based data acquisition system, fully configurable :
  - 48 fast channels (PXIe-6124), 4 MS/s per channel, 16 bits, 1V
  - 20 Pt100 channels at 100 S /s/ch
  - 10 0-10V channels for system monitoring (Power supply, etc…)
  - 32 Thermocouple channels at 90 S /s per channel
  - 24 Wheatstone bridge channels 25.6 kS /s per channel
  - One FPGA card for interferometer acquisition

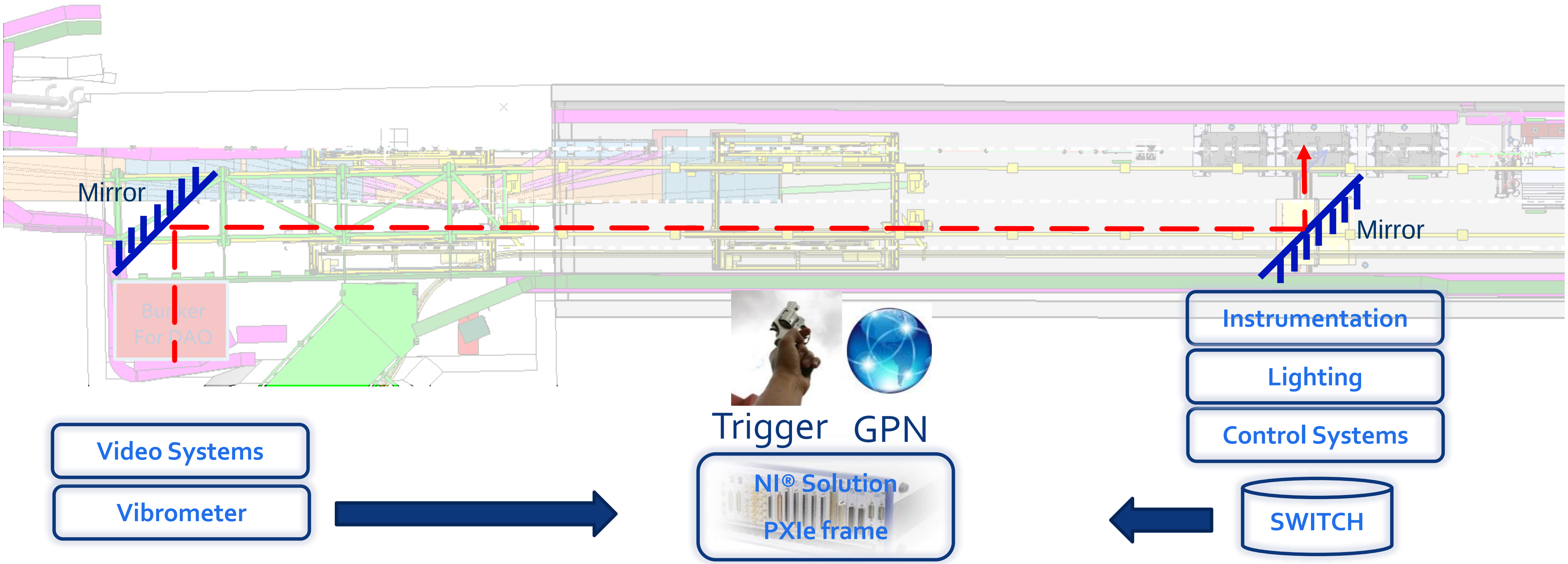
Courtesy : C. Charrondiere EN-SMM



DAQ & Software



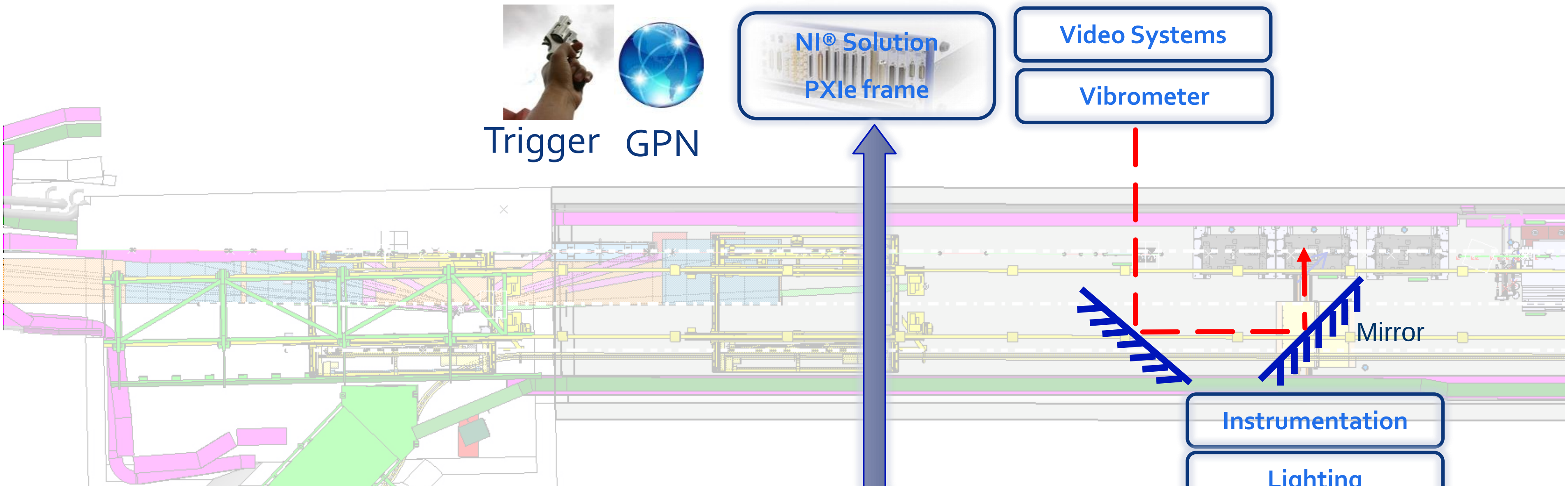
Implementation (TNC-TJ7)

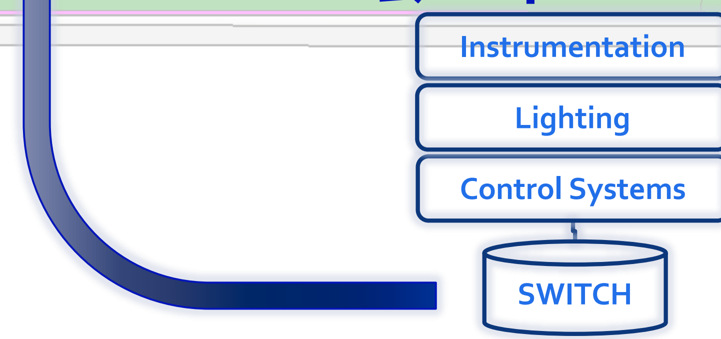


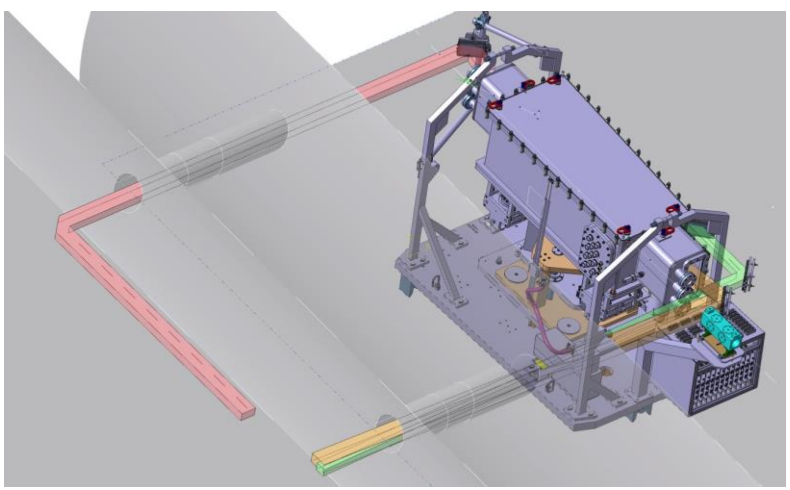
Hardware Control from the surface (+60 m):

- Switch positions depending of the materials tested
- Control / Activation of the flash system
- Positioning of the sample holder

Implementation (TNC-TT61)





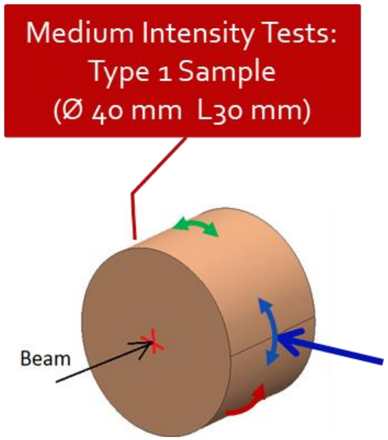


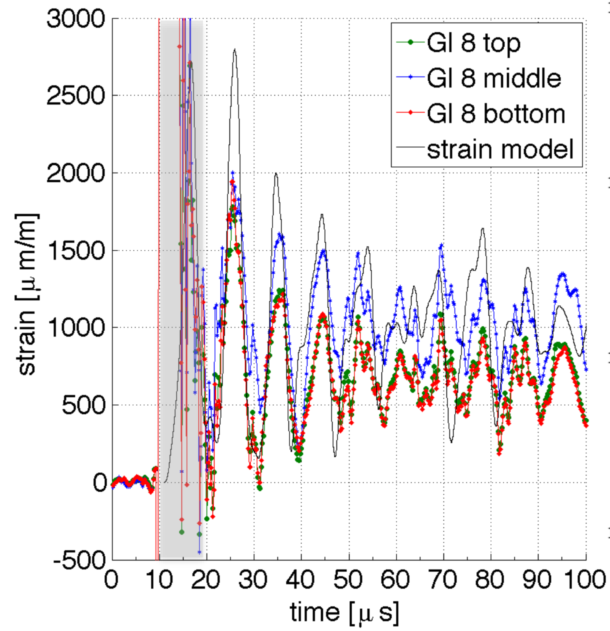
Hardware Control from the surface (+60 m):

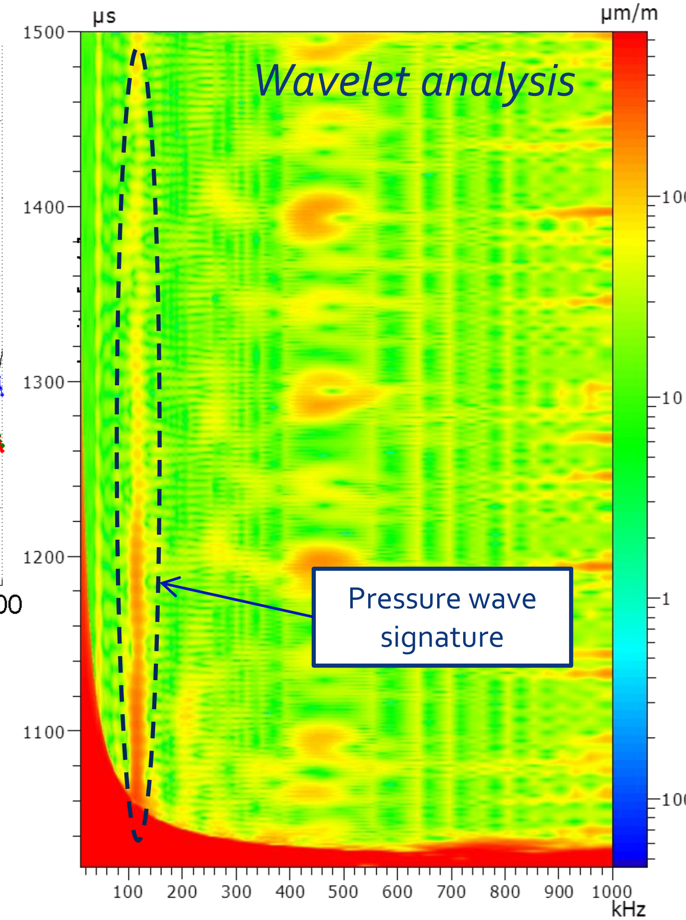
- Switch positions depending of the materials tested
- Control / Activation of the flash system
- Positioning of the sample holder

Results and lessons learned

- HRMT-14 : Electrical strain gauges and LDV measurements



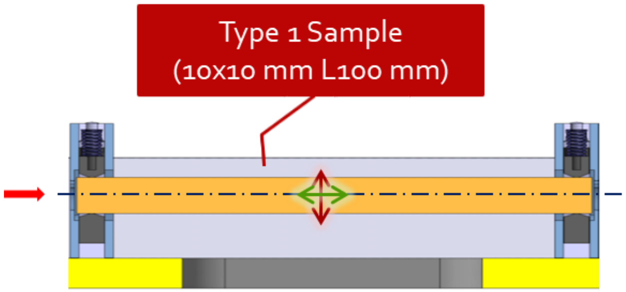


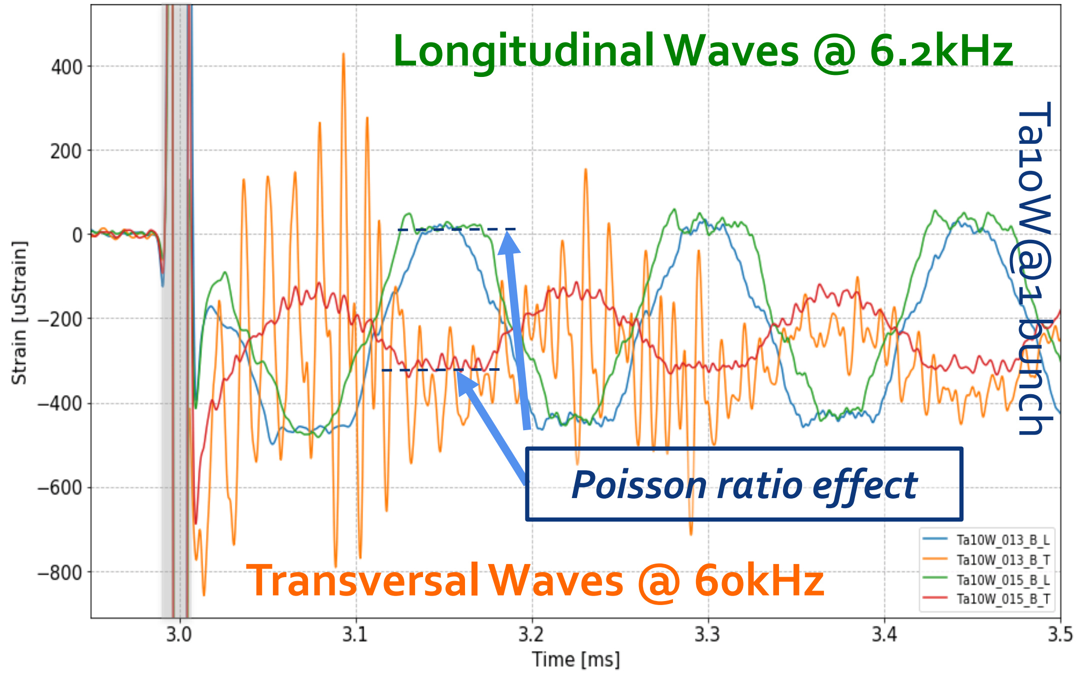


→ Beam/Strain gauge distance : 20 mm
→ Black-out during 10 μs after the beam on the electrical strain gauge
→ Noise level : +/- 50 μm/m @4 MHz /42 m
→ High stability of the LDV signal

Results and lessons learned

- HRMT-36 : Electrical strain gauges

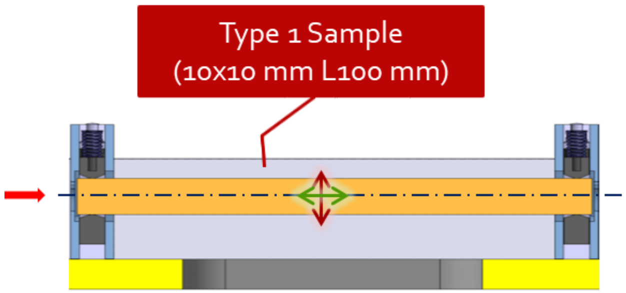


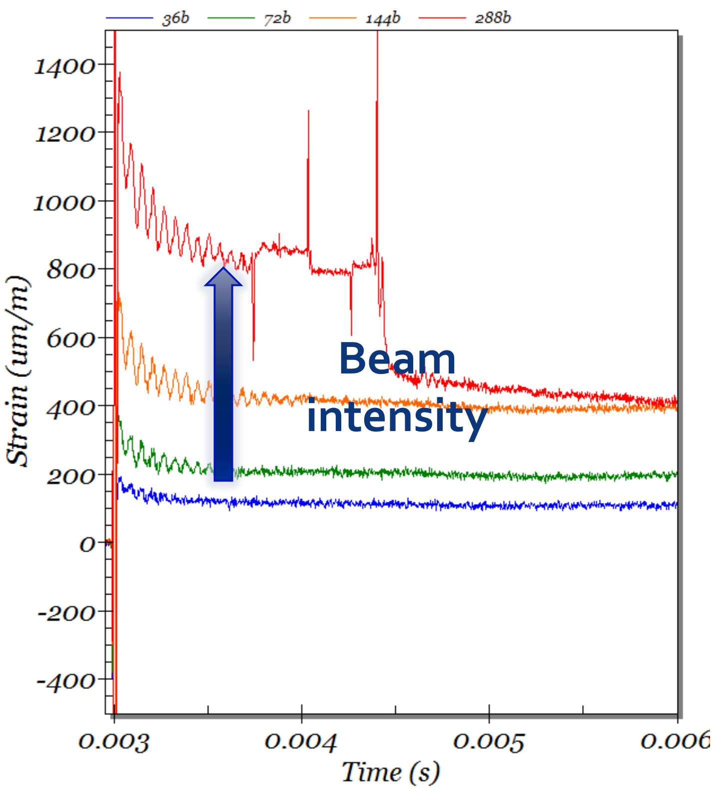


→ Beam/Strain gauge distance : 5 mm
→ Black-out during 25 µs after the beam on the electrical strain gauge
→ Noise level : +/- 50 µm/m @4 MHz /42 m

Results and lessons learned

- HRMT-36 : Electrical strain gauges

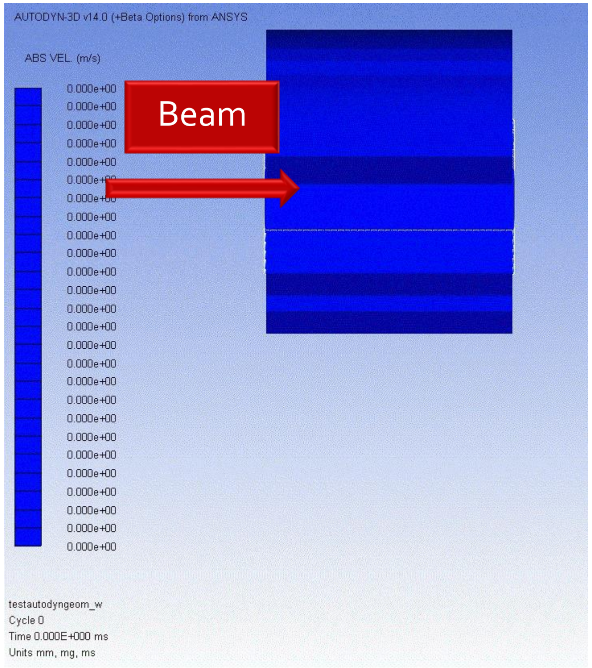


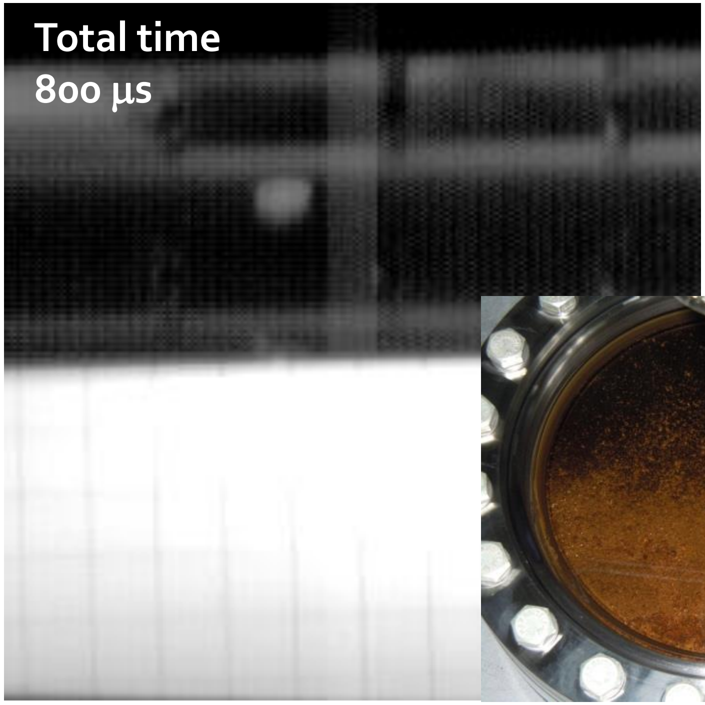


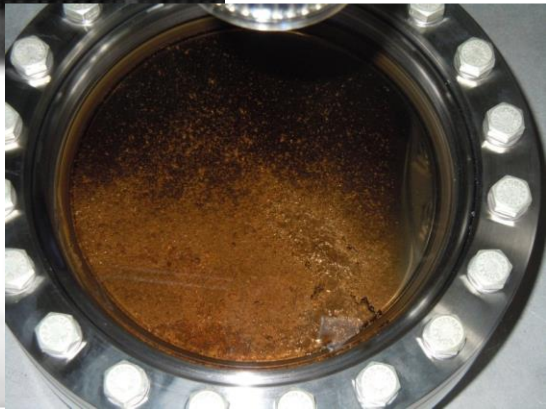
➔ Temperature effects expected on the tin connection pad induced by the particle shower, not by the materiel itself (<160°C)

Results and lessons learned

- HRMT-14 : Fast speed camera – Inermet sample







➔ Camera/Sample distance : 42 m with 3 mirrors
➔ Tungsten and Molybdenum vapours generated during beam impact expanded inside the vacuum tank and condensed on viewports limiting video acquisition.

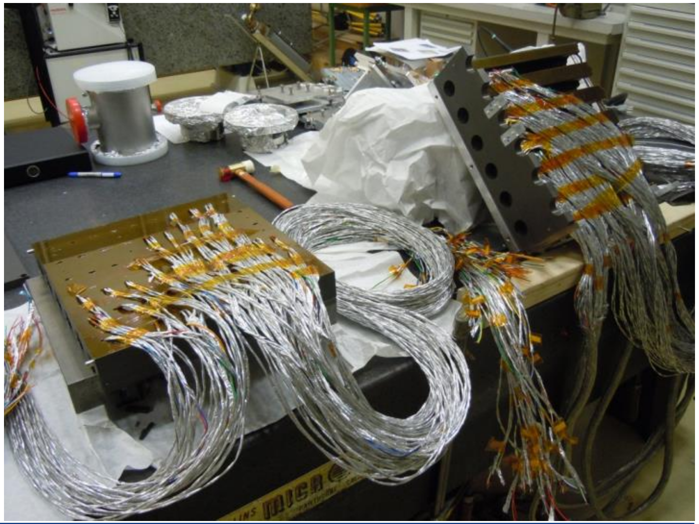
Results and lessons learned

- HRMT-23 : Fast speed camera – Copper Diamond jaw

➔ Camera/Sample distance : 42 m with 3 mirrors
➔ HRMT-23 equipped with protective windows

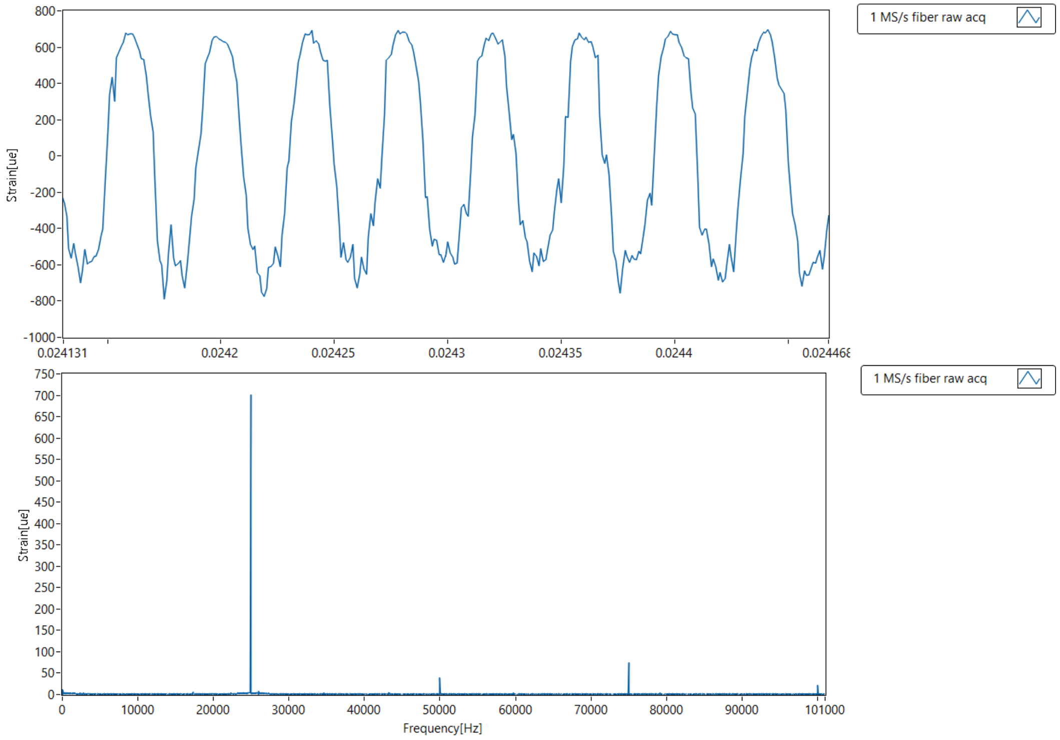
Results and lessons learned

- No non-radhard electronics should be installed in TNC;
- Even with deported electronics, expect 'blackouts' during beam impacts due to electromagnet interference on electrical gauges;
- Pay attention to electrical shielding and cable routing to get acceptable noise levels;
- Include remote electrical rebooting for all instrumentation, and monitoring where possible;
- Consider redundancy in measurements;
- Make data visualization efficient to take decisions between shots;
- Cables need to be considered from the design phase.



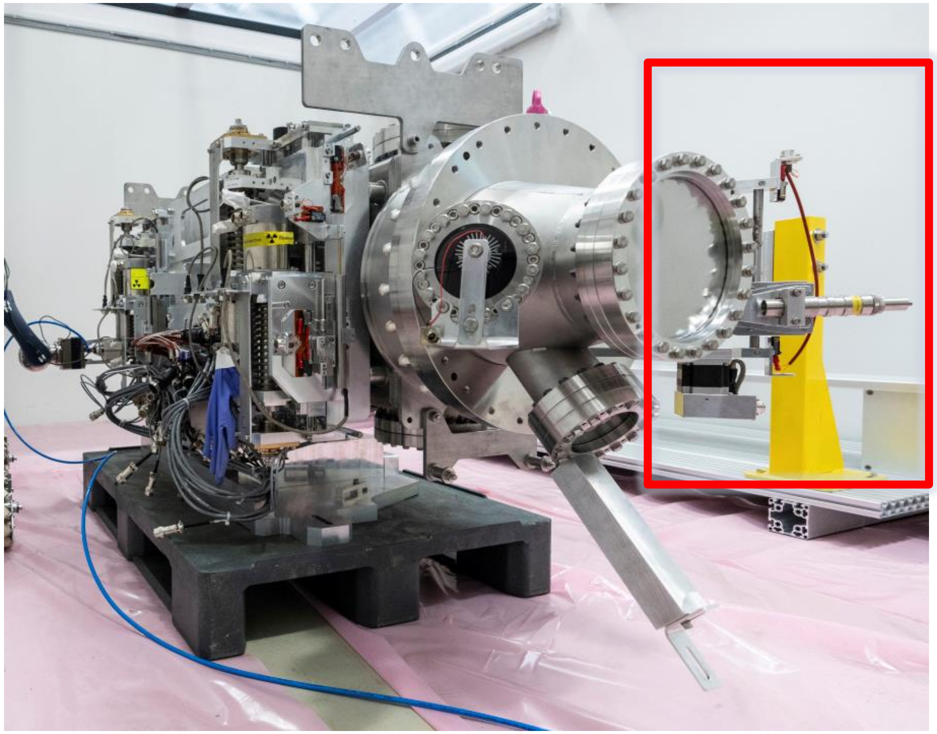
Future developments

- Fast optical strain measurements up to 2 Ms/s
  - Based on Micron optics SM690 - 4 channels (not multiplexed)
  - NI PXI compatible
  - Collaboration SMM (DAQ) & MME (fiber and bonding technology)



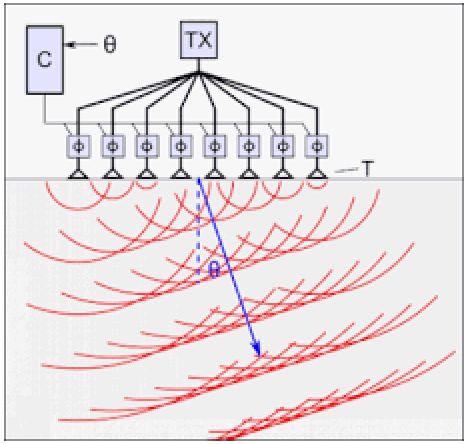
Future developments

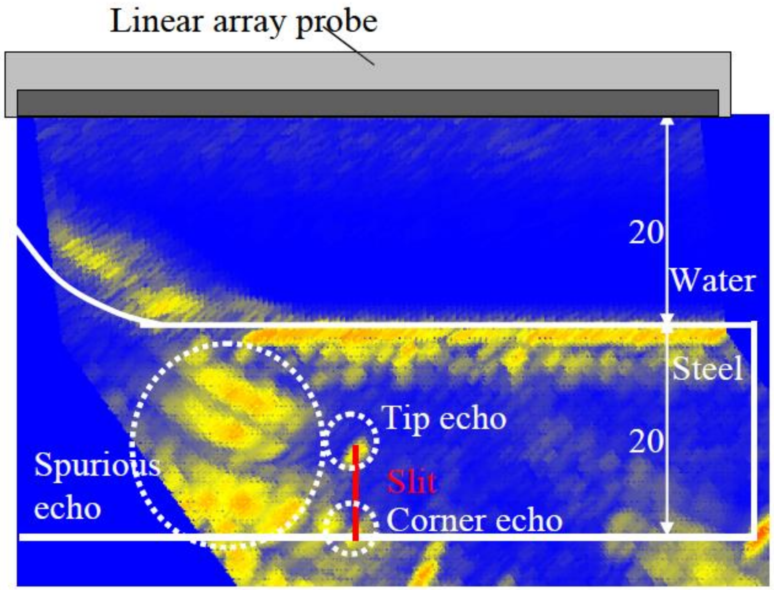
- Reliable fiber optic based fast pyrometer measurements
  - Previously used in HRMT27 and HRMT45 but results not conclusive



Future developments

- Ultrasound techniques based on Phased Array
- Coupling between probes and material need to be study according to high acceleration in HRMT experiments





Conclusion

- After several year's of HiRadMat experiences, all the mechanical measurements based on strain gauges, LDV, interferometer, pt100 and thermocouples successfully worked in spite of the very harsh environment and the technological challenges;
- A huge quantity of data was produced to derive constitutive models for the less known materials described in many publications;
- HiRadMat Facility allows to improve new techniques as ultrasound techniques, pyrometer and fast optical stain measurements for future applications;
- Design, FEA and Measurement teams should work together from the beginning of the design of the experiment to compromise the sample shapes (also shape ratio) and the instrumentation capabilities.

Thank you !
Questions ?

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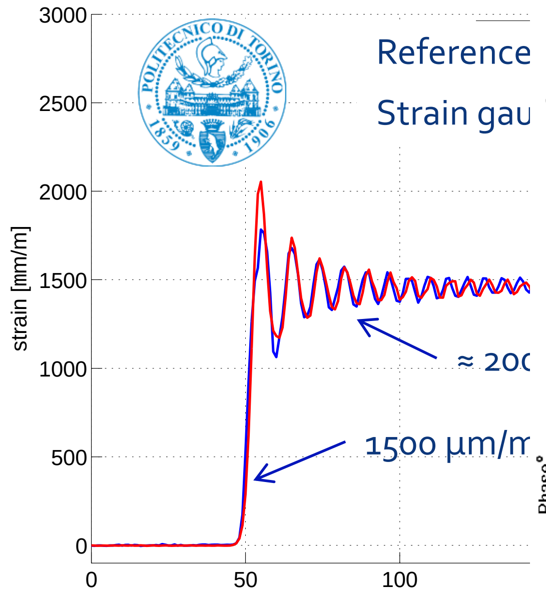
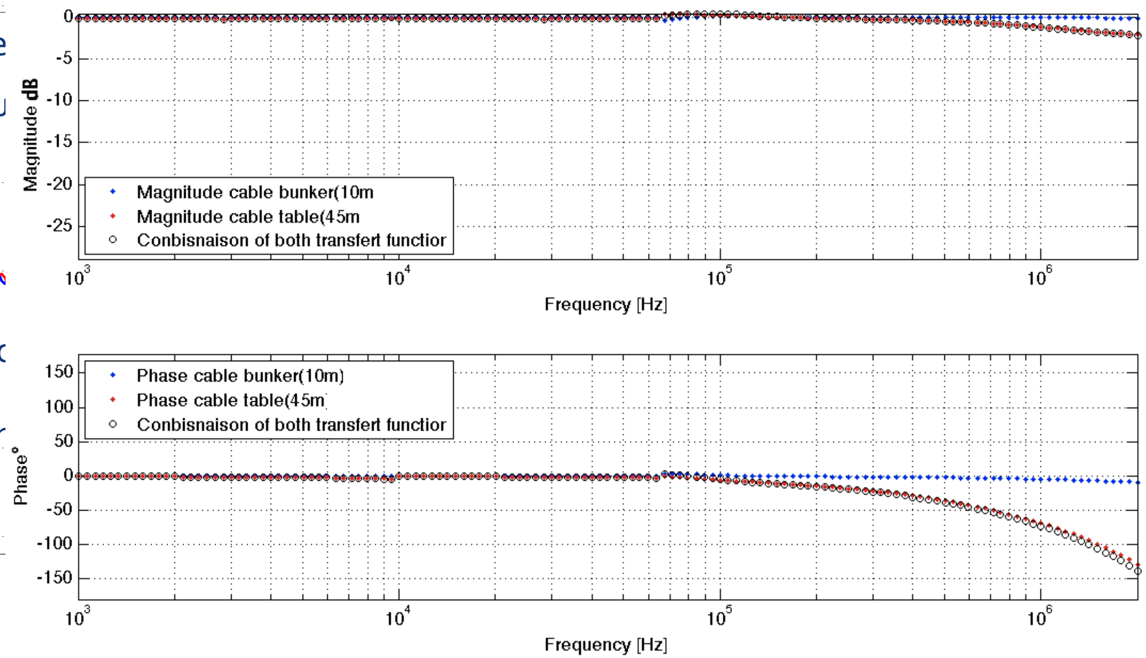
Electrical strain measurement

- Dynamic response of the strain gauges (Typically around 50 kHz) ?
- Hopkinson bars test bench to :
  - Increase our knowledge for this bandwidth (higher than 50 kHz) ;
  - Check the dynamic response of the gauges and the glue ;
  - Evaluate the signal to noise ratio and the accuracy of the measurements





Accessories

- Home made radiation hard switch :
  - 48 Channels over 8 positions (384 Channels)
  - Wheatstone bridge integrated
  - Radiation Hard Components
  - Electrical Consumption : 90 Watts (Air cooling)
  - Special design for low noise level signals
- Mirrors :
  - First reflective layer
  - High flatness

Courtesy : B. Magnin TE-MPE