Mechanical measurements in Superconducting magnets

M. Guinchard – CERN –EN/MME
Mechanical Measurement Lab

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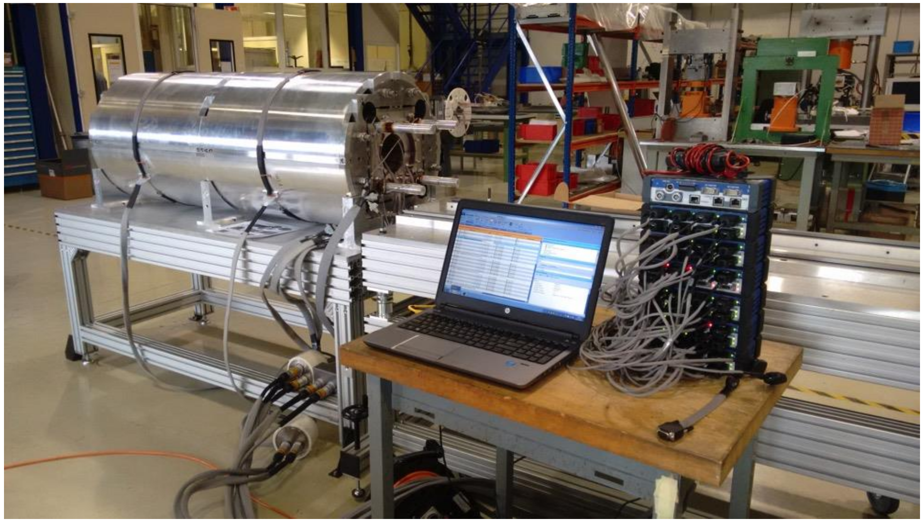
Outine

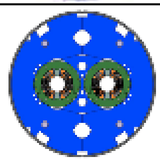
- Introduction
- Overview of mechanical measurement systems :
  - Electrical strain gauges
  - CERN-LARP collaboration results
  - Software and data management
  - Optical fibre strain sensors
- Mechanical testing equipment’s
- Conclusions

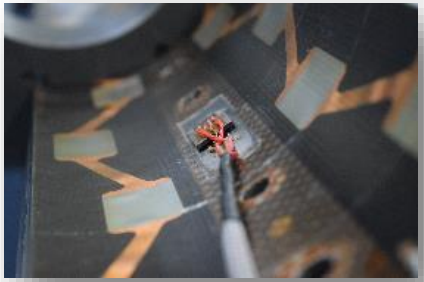
Why mechanical measurements in magnets ?

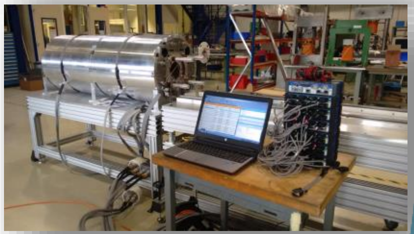
- Validate Finite Element Analysis (FEA) during :
  - Assembly phases;
  - Thermal cycles (down to 1.9K);
  - Powering tests.
- Check the integrity of the structure during assembly phases.



Current situation at CERN

Name	Cross Section	Diameter	Magnetic Field	Nb of Strain gauges	Nb of wires
SMC		540 mm	12.5 T peak field	48	156
RMC		570 mm	16 T peak field	48	148
FReSCa2		1030 mm	13 T bore field	40	116
MQXFS		615 mm	12.1 T bore field	64	104
DS 11T Dipole		580 mm	11.21 T bore field	180	416

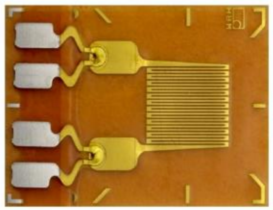




Tools for mechanical measurements

	Electrical strain gauges	Capacitive gauges	Optical fiber sensors	Non contact video systems
Principle	Resistive	Capacitive	Bragg	Image processing
Loading cases	All	Compression	All	All
Magnetic effects	Affected	Non affected	Non affected	-
Cryogenic temp.	Affected	Affected	Affected	Only RT

Electrical strain gauges

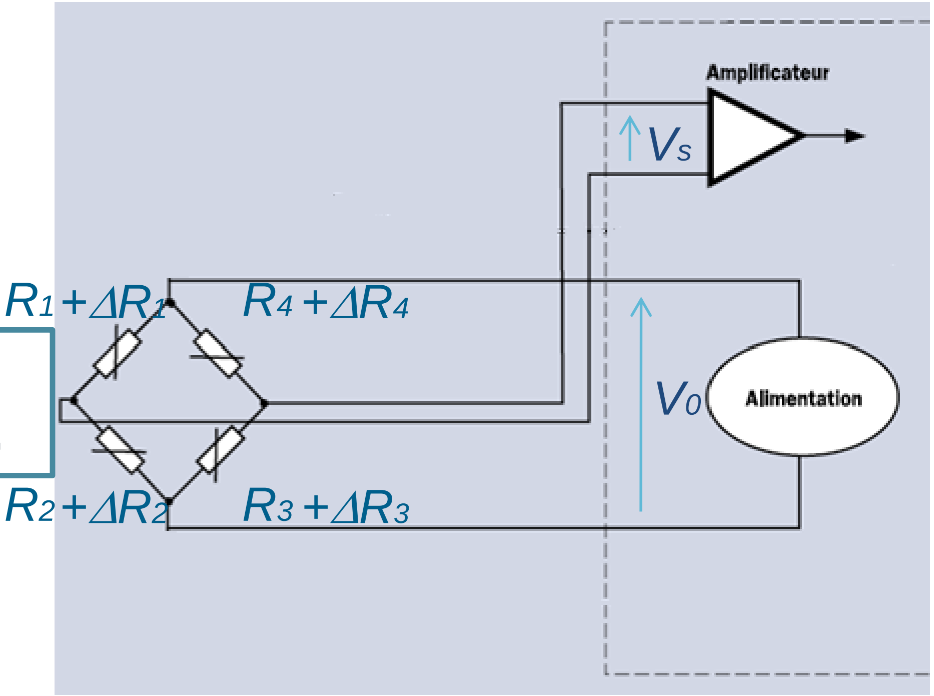


$$\frac{\Delta R}{R} = k\,\frac{\Delta L}{L}$$

with k : Gauge factor

Resistance values : 120, 350, 700 Ω
For 2000 μm/m, **ΔR is equal to 11 μΩ**

➔ Wheatstone bridge !



- Wheatstone bridge equation :

$$\frac{V_0}{V_s} = \frac{K}{4}\left(\frac{\Delta L_1}{L_1} - \frac{\Delta L_2}{L_2} + \frac{\Delta L_3}{L_3} - \frac{\Delta L_4}{L_4}\right)$$

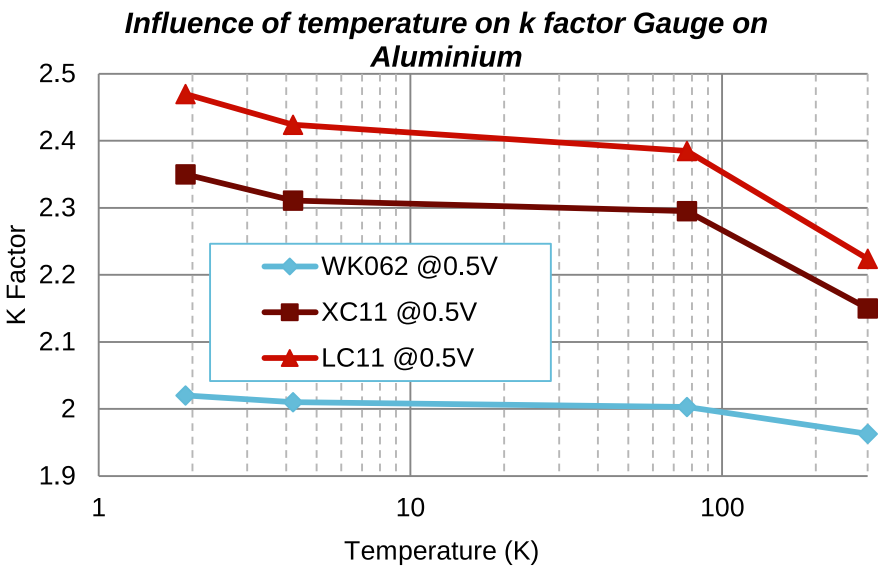
- Wheatstone bridge config. :
  - ¼ Bridge
  - ½ Bridge
  - Full Bridge

Electrical strain gauges

- K factor variation :

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

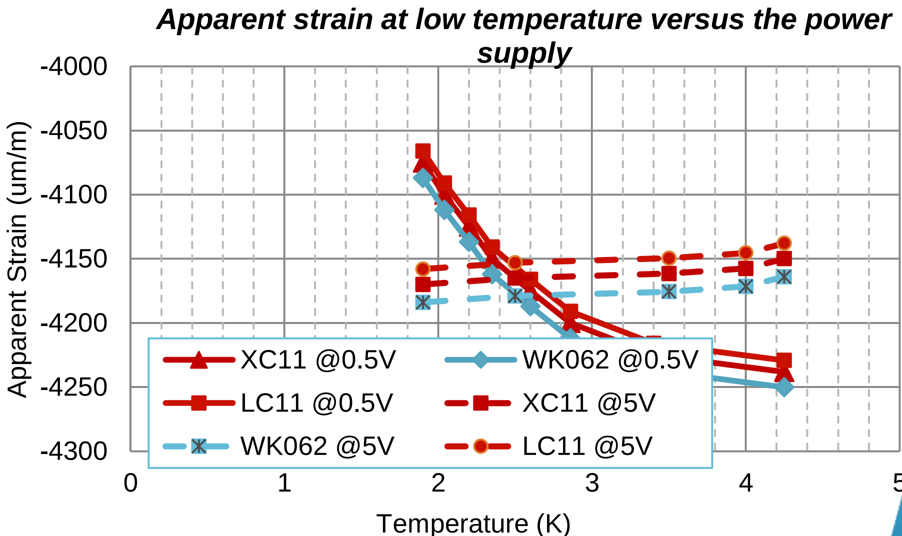
Up to 10 % of variation between 300 K and 1.9 K



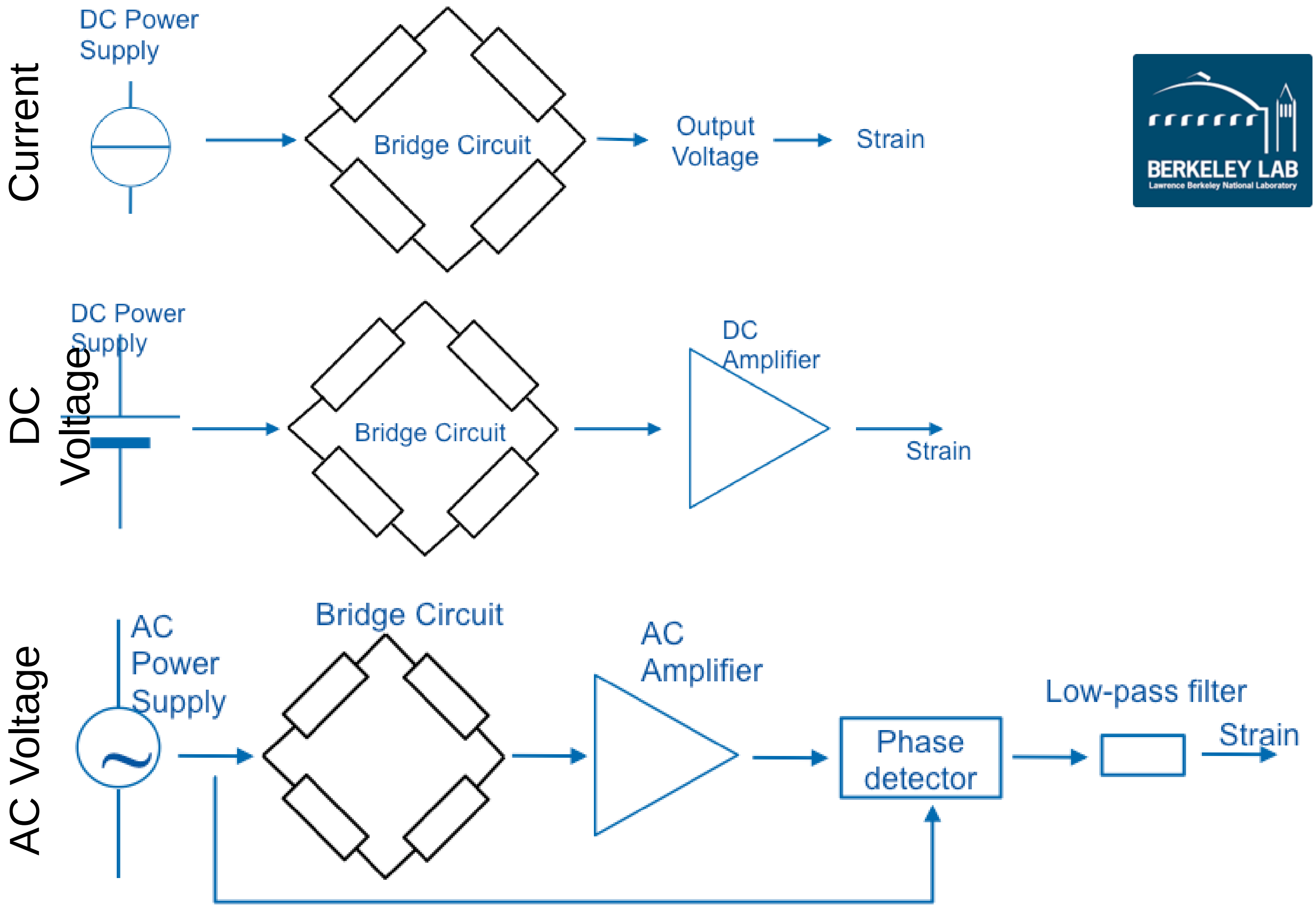
- Apparent strain :

$$\left(\frac{\Delta L}{L}\right)_{Measured} = \left(\frac{\Delta L}{L}\right)_{Real} + \left(\frac{\Delta L}{L}\right)_{ApparentStrain}$$

≅ 1500 µm/m between 293 K and 77 K



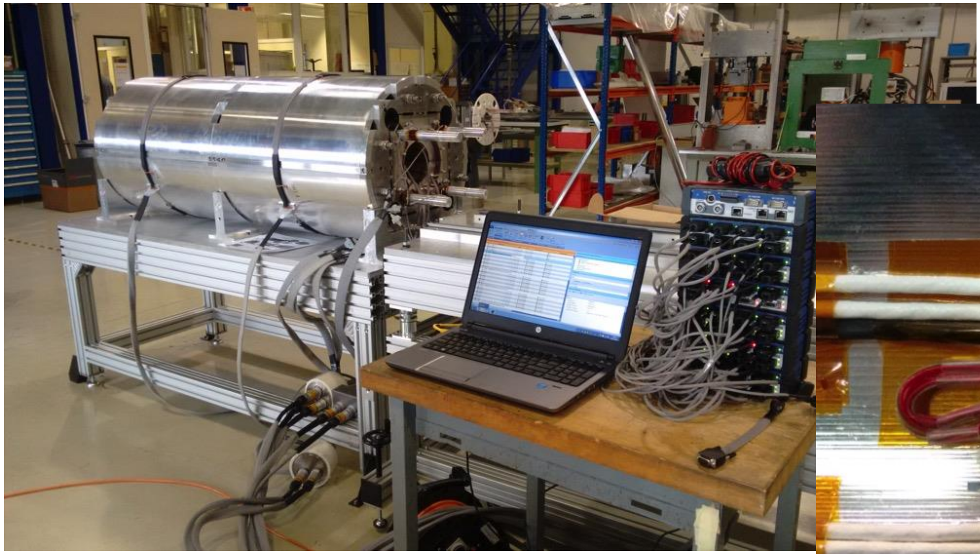
Electrical strain gauges

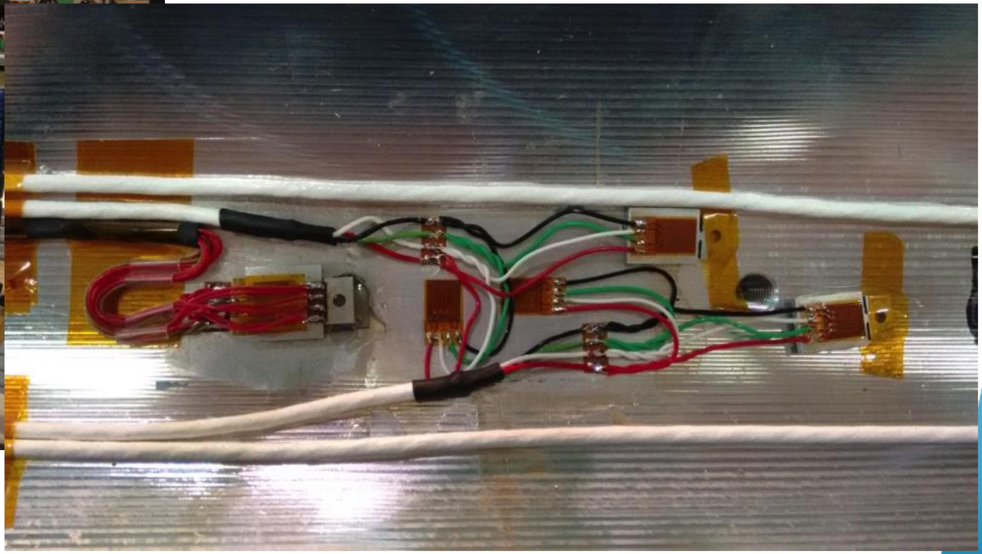


Electrical strain gauges – LARP Collaboration

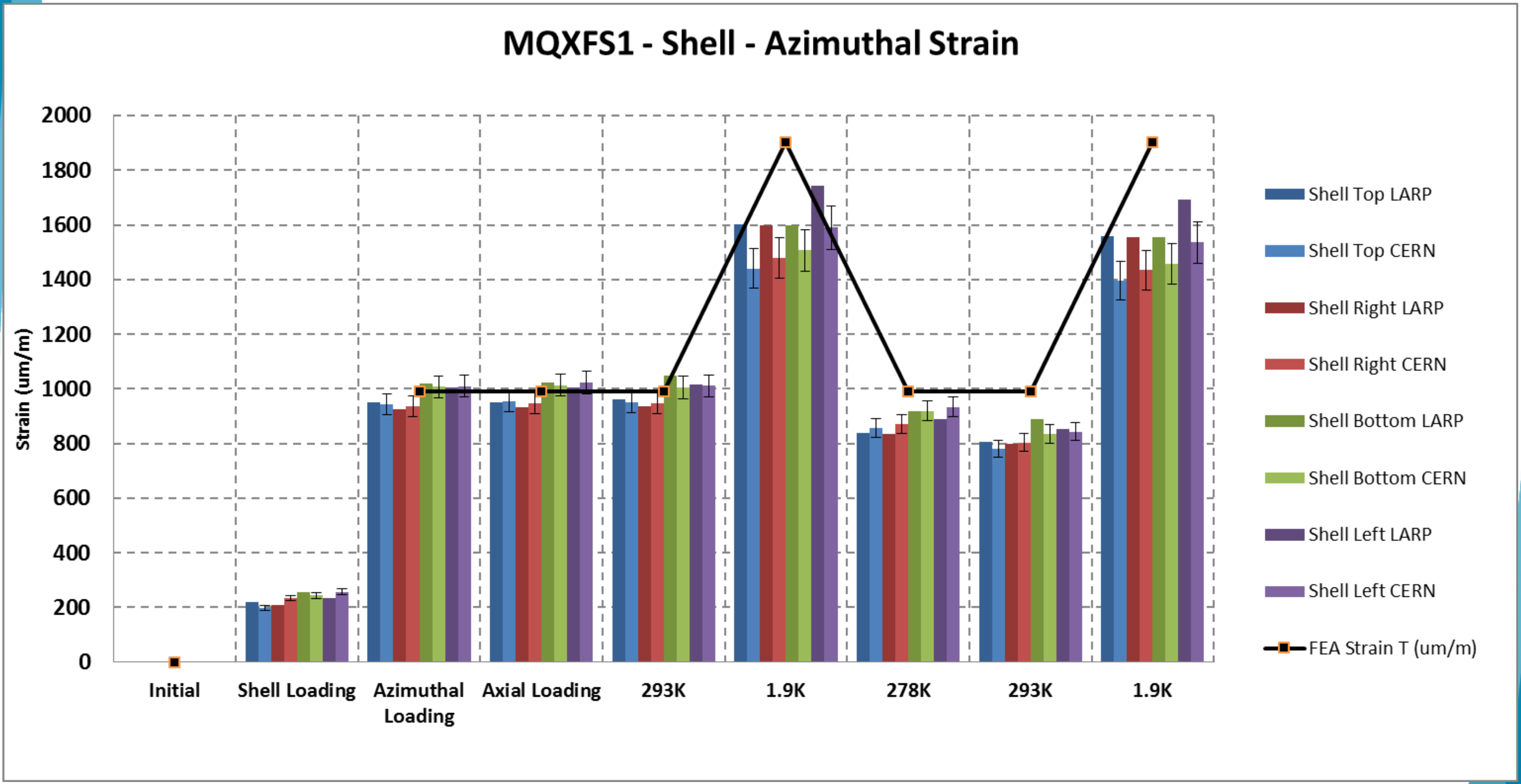
MQXFS magnet was equipped with LARP & CERN stations:

- 4 biaxial stations on the shell
- 4 biaxial stations on the 4 coils

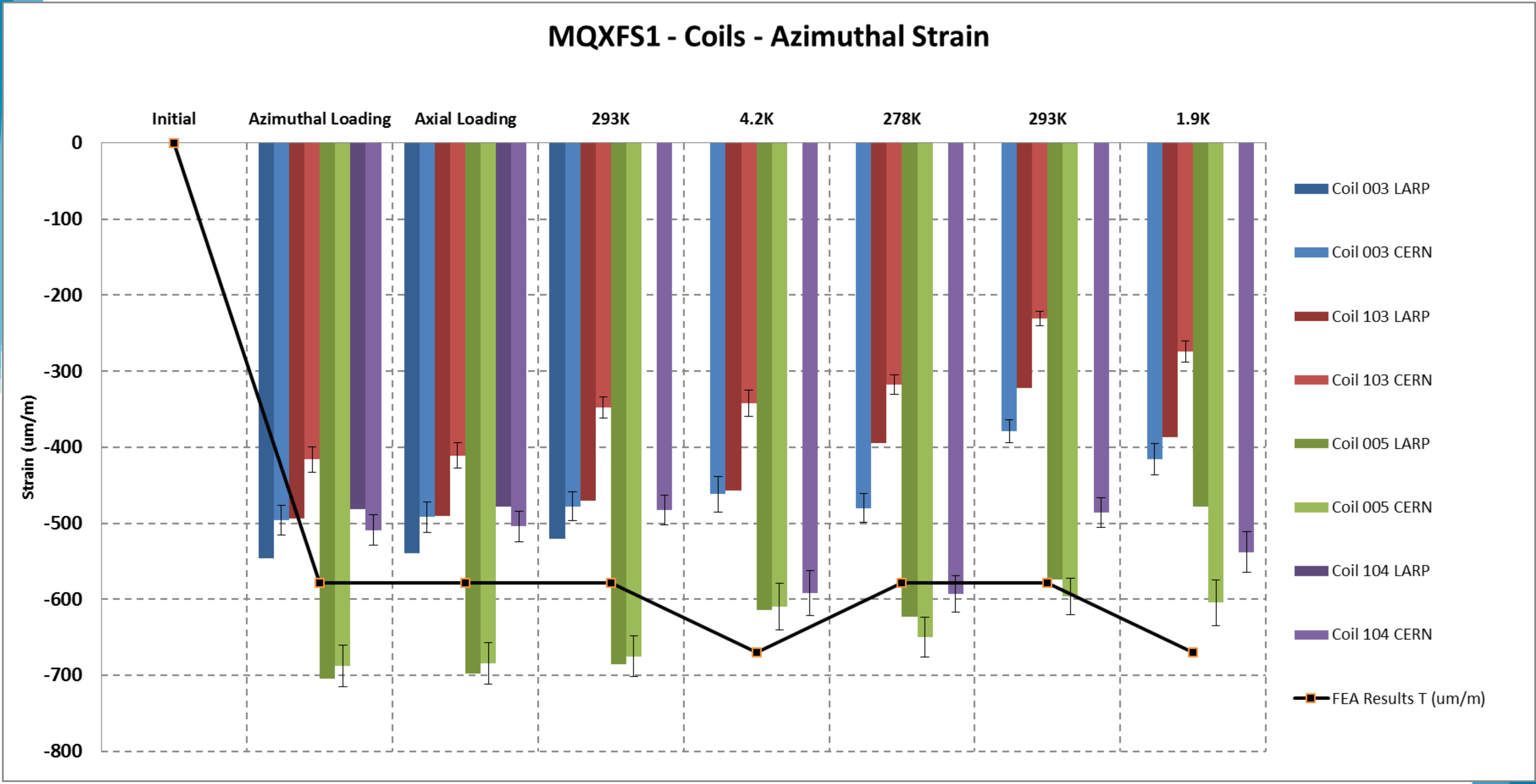




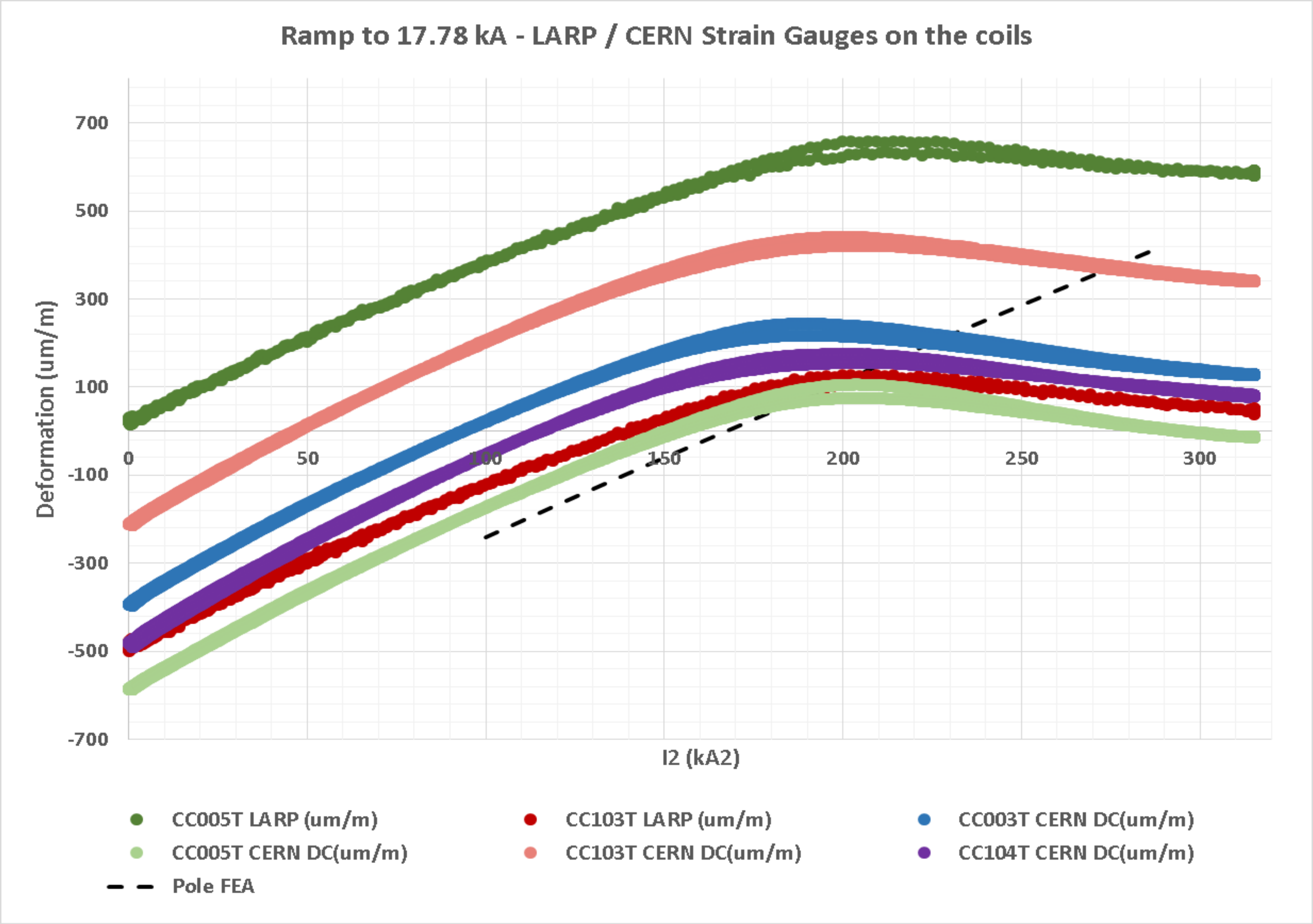
Electrical strain gauges: LARP Collaboration



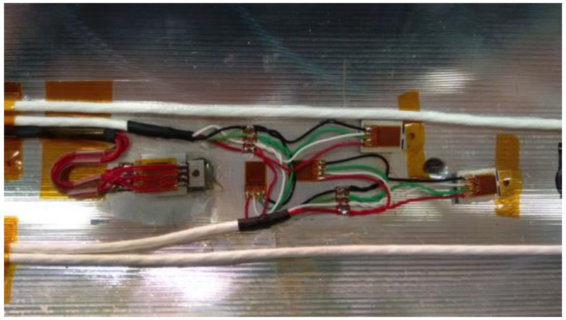
Electrical strain gauges: LARP Collaboration



Electrical strain gauges: LARP Collaboration



DAQ, Software and data management



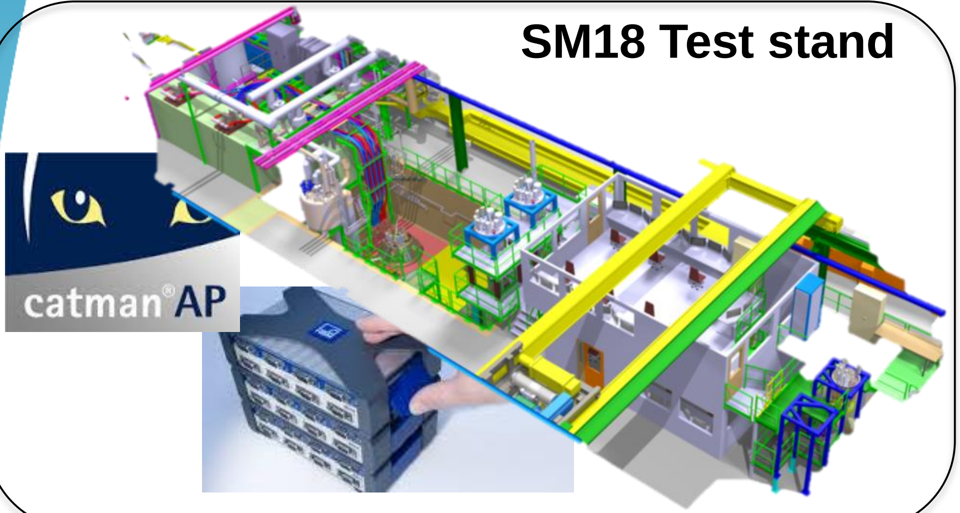
Electrical strain gauges
Optical Fiber strain sensors
Capacitive gauges
Current
Temperature

8 channels/module
¼, ½ and full bridge
24 bits, firewire synch.
Fs : 0,1Hz up to 20kHz
Synchronous measurement

Settings of the DAQ
Online vizualisation
Online calculation
Data storage management
Measurement on trigger

DAQ, Software and data management

SM18 Test stand



Ascii files
Updated every 10 minutes / quench

SM18 Test Server

Catman files
Continuous storage

Mechlab Server

Mechlab Team

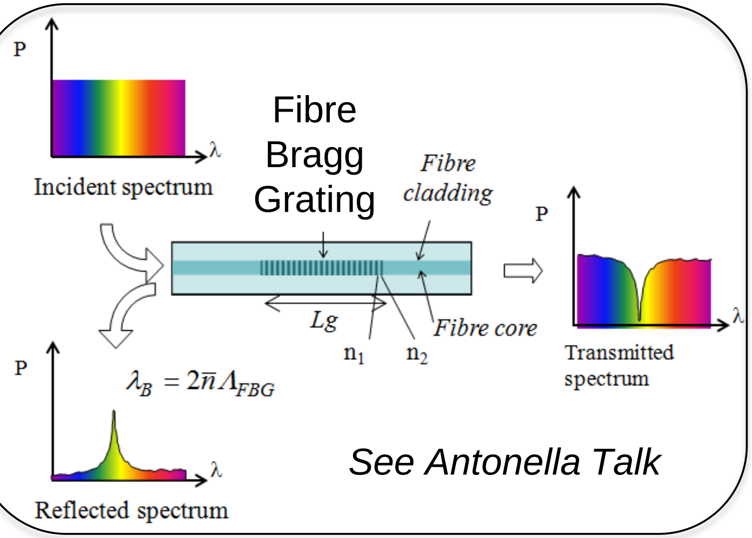
- Measurement validation
- K factor & AS corrections

EDMS

Optical Fiber Strain Sensors

Strain Measurements → Fibers Selection → Bonding Process → Validation tests → Protection issues

KT Agreement KN2480/KT/EN/223C



See Antonella Talk

Due to the temp sensitivity, we need to perform an R&R evaluation of the bonding process.
Before field implementation, we need to determine the accuracy class.

Optical Fiber Strain Sensors

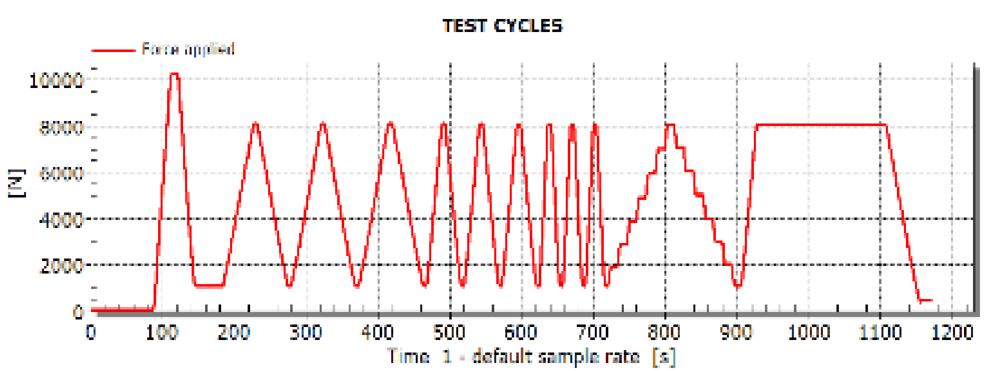
- Validation procedure:

10 Thermal Cycles at 77K → Tensile Tests at Room temp. → Tensile Tests at 77K → Tensile Tests at 4.2K → Tensile Tests at Room temp. → 10 Thermal Cycles at 77K

Precision (repeatability & reproducibility)

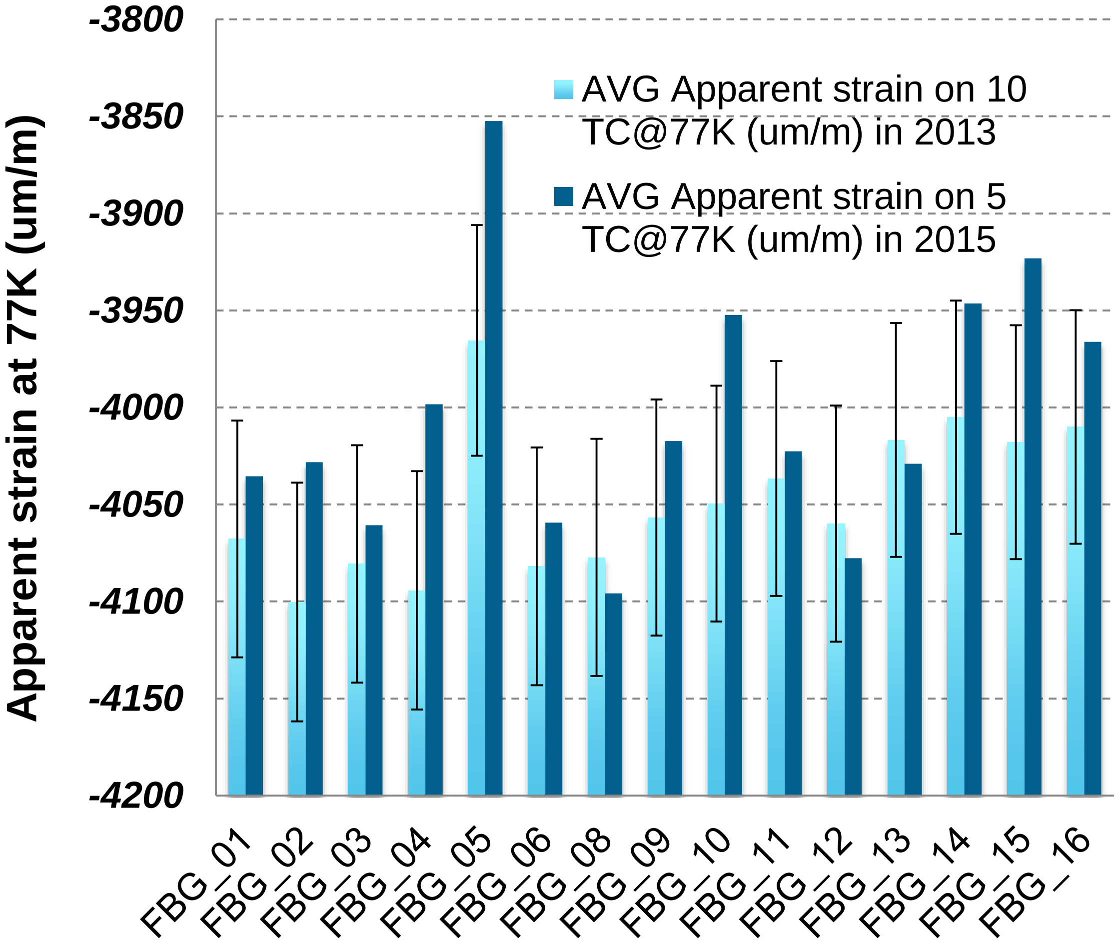
Trueness

ACCURACY (Following ISO5725)



Optical Fiber Strain Sensors

- Repeatability & Reproducibility:

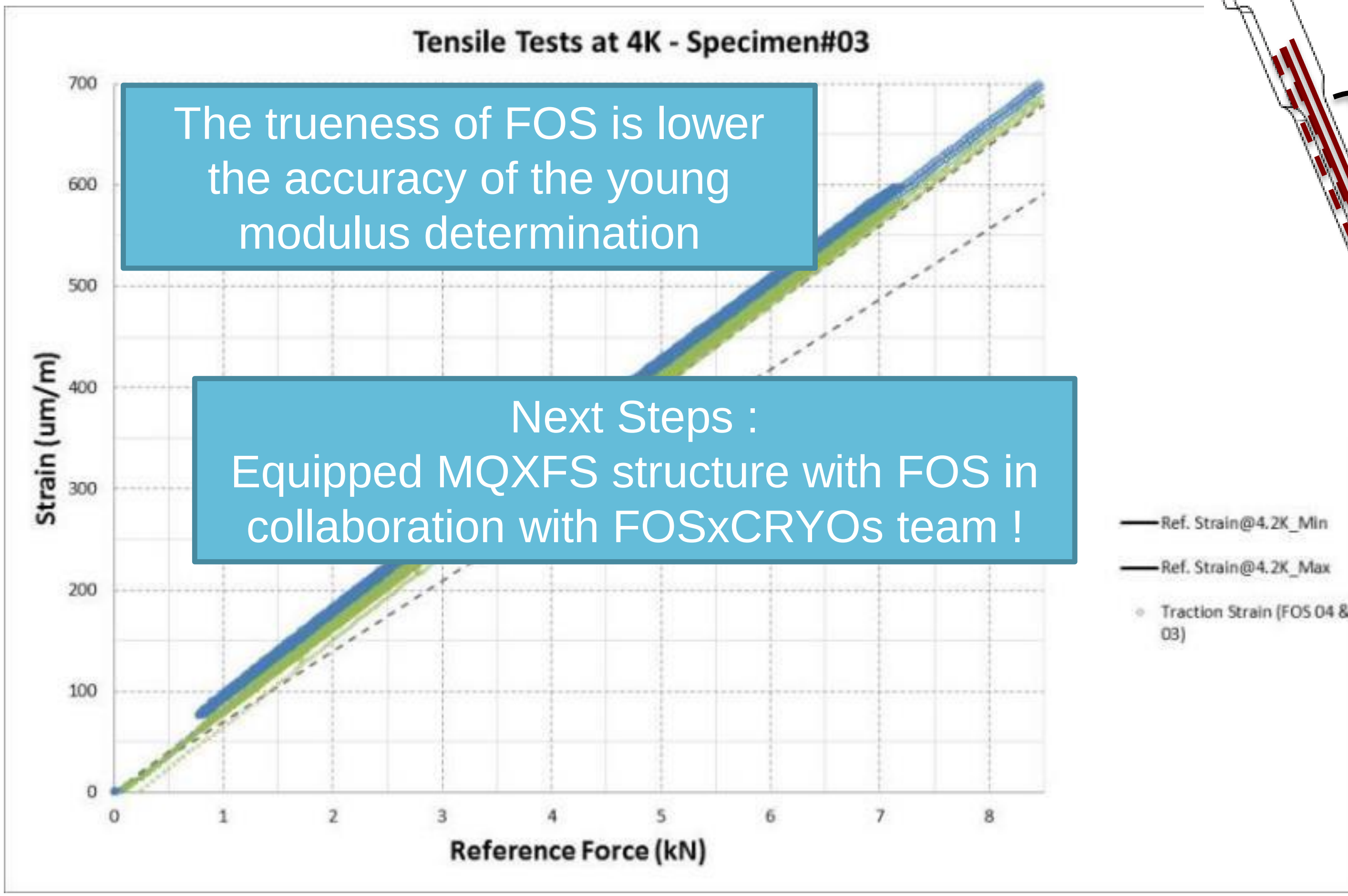


20 FBG's glued on 5 tensile specimens :

- 10 thermal cycles at 77K
  Repeatability : +/- 1,5%
  Reproducibility : +/- 2,5%

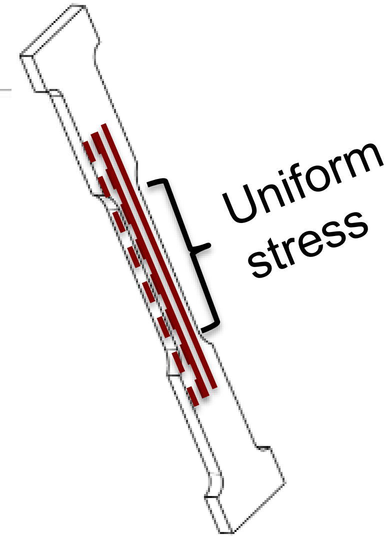
Optical Fiber Strain Sensors

- Trueness:



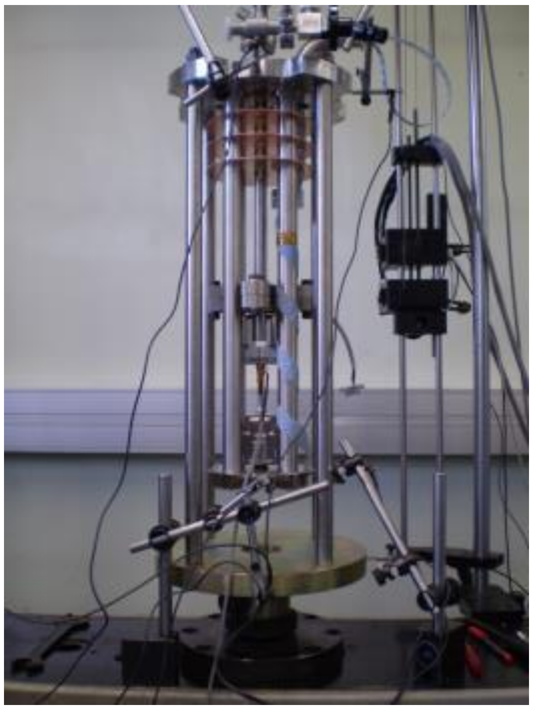
The trueness of FOS is lower the accuracy of the young modulus determination

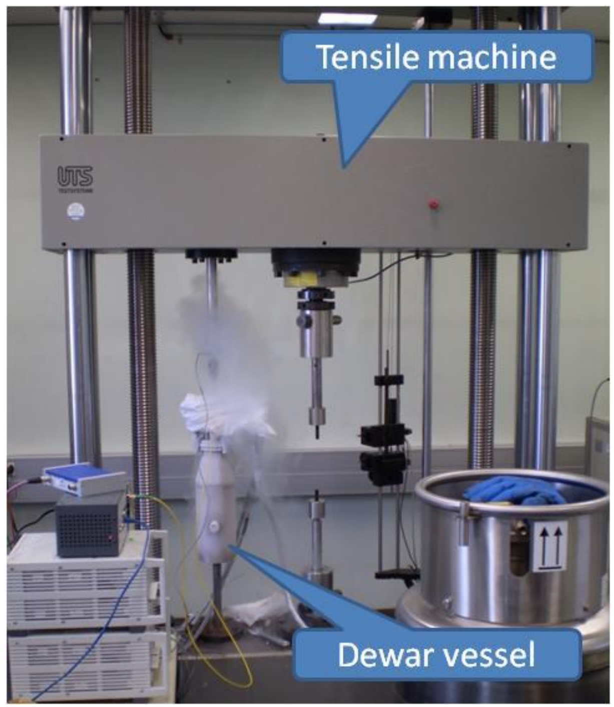
Next Steps :
Equipped MQXFS structure with FOS in collaboration with FOSxCRYOs team !



Mechanical testing at RT, 77K and 4.2K

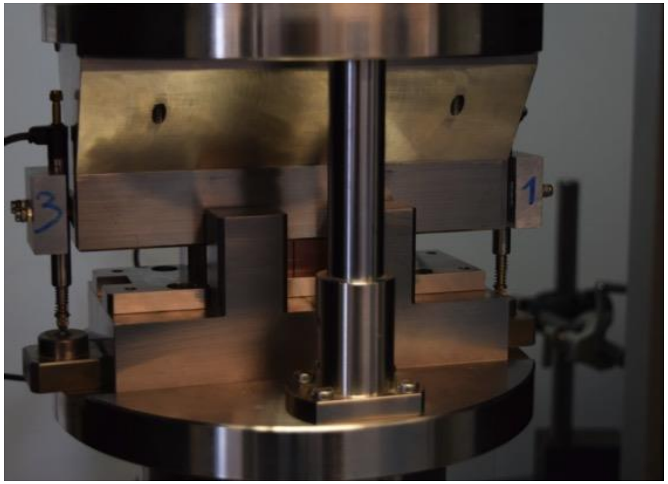
- ZWICK Tensile machine (400kN) – UTS Tensile Machine (200kN)
- Cryostat for tests up to 25kN – Temperature Range : 4.2K - 293K in the bath
- Cryostat for tests up to 100kN – Temperature Range : 4.2K - 293K in the bath
- Compression tools up to 400kN – Temperature Range : 77K - 293K in the bath

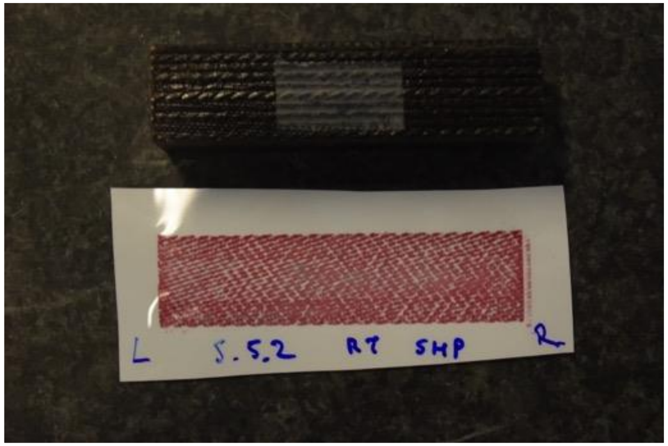


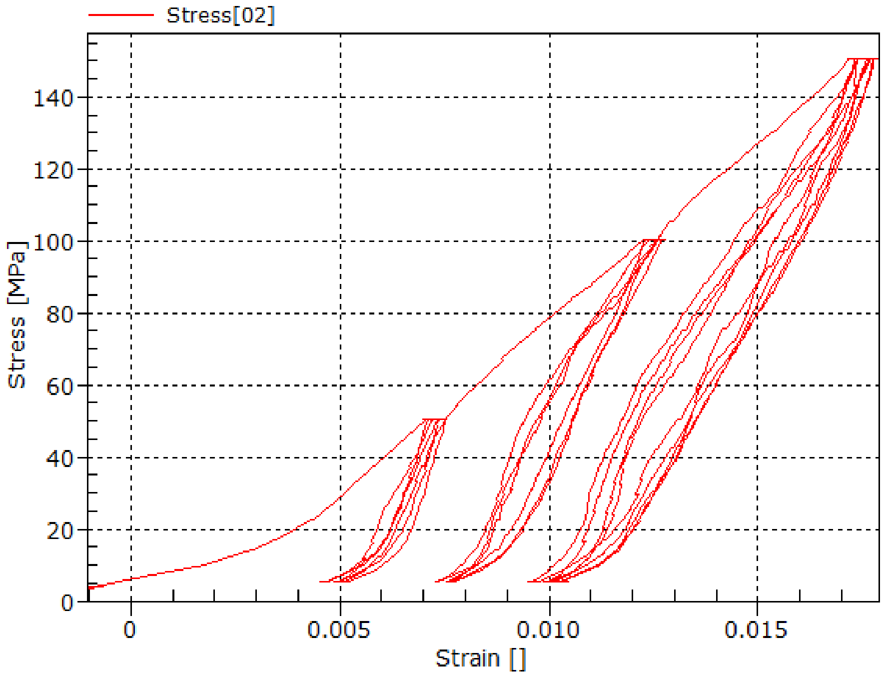


Mechanical testing at RT, 77K and 4.2K

- Stiffness determination of Nb3Sn cable stack



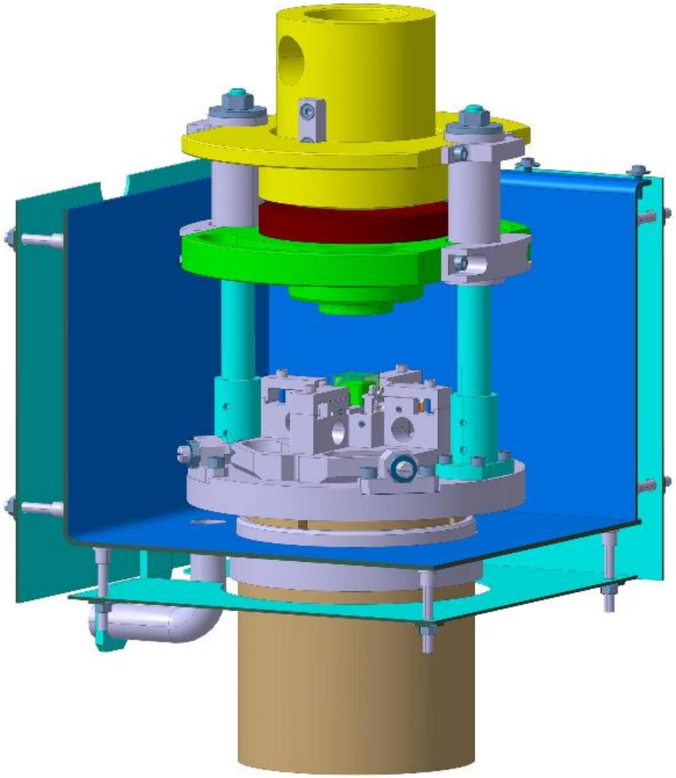


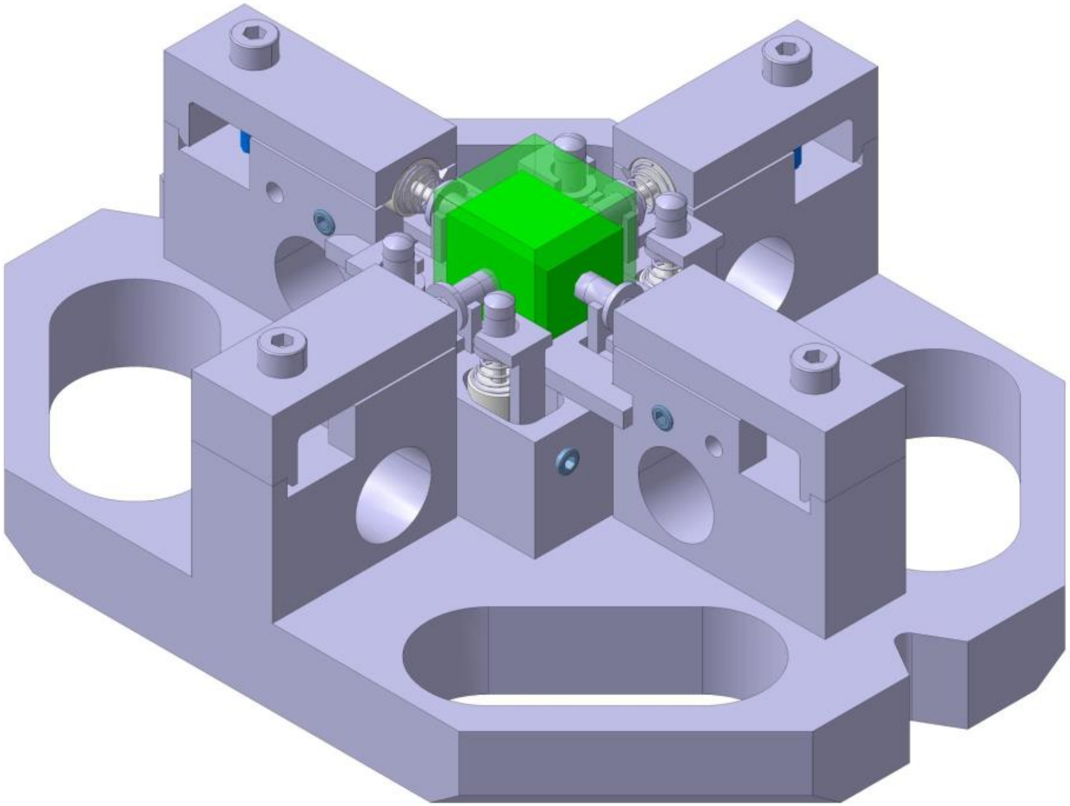


Tests performed at RT and 77K
New setup is under fabrication !

Mechanical testing at RT, 77K and 4.2K

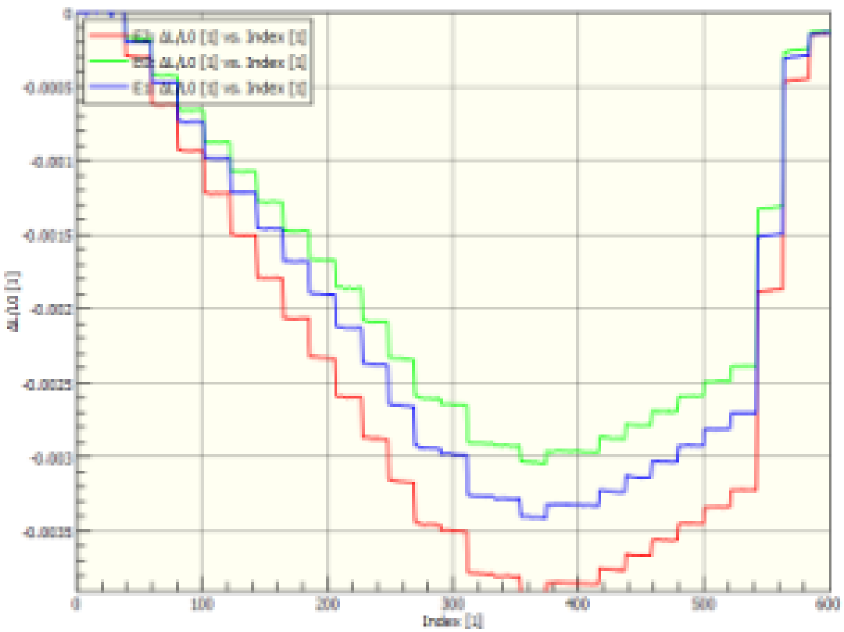
- Stiffness determination of Nb3Sn cable stack

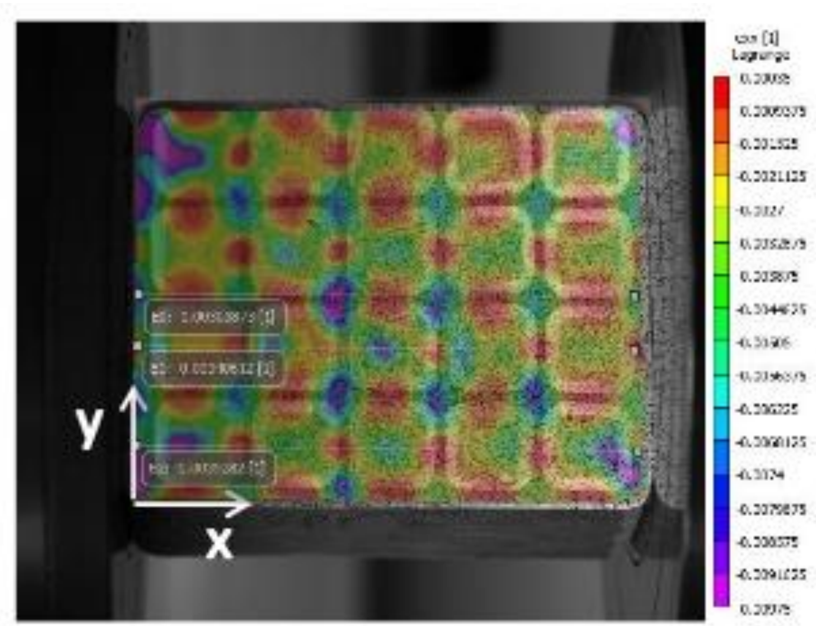




Mechanical testing at RT, 77K and 4.2K

- Digital Image Correlation (under evaluation)





System interesting for relative measurements, poor resolution

Conclusion

- Several tools for mechanical measurements are available for low temperature and powering tests. These equipment's are validated;
- Collaboration between labs is crucial to increase our measurement confidence;
- Collaboration with LARP to check electrical strain gauges was successfully done;
- We expect to use FOS in the field in 2017;
- See you this afternoon at SM18 in front of the equipment's !

Thanks !
Questions ?