CERN

ENGINEERING DEPARTMENT

The Expertise and Infrastructure of CERN's Mechanical Measurement Laboratory for Testing of Materials and Components

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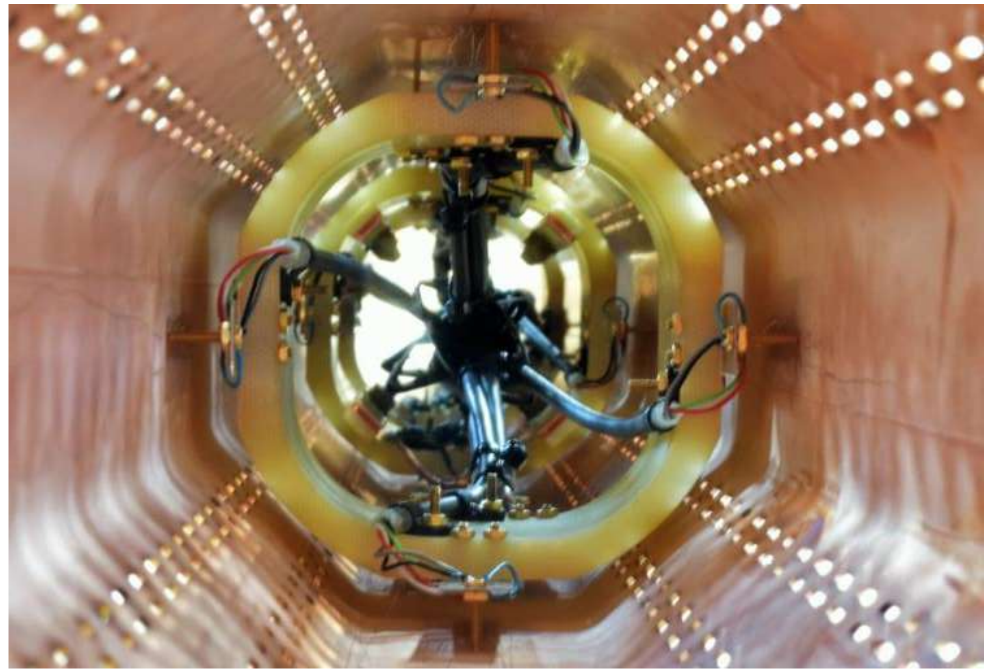
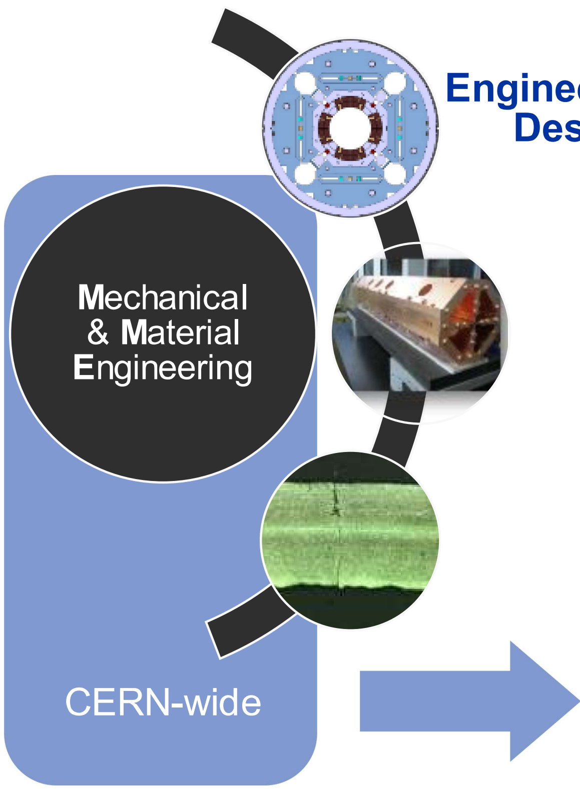
6/22/2023

Outline

- **Mandate and approach**
- **Platforms and expertise**
  - Characterization
  - Experimental Stress Analysis
  - Dynamic Testing



Laboratory Approach

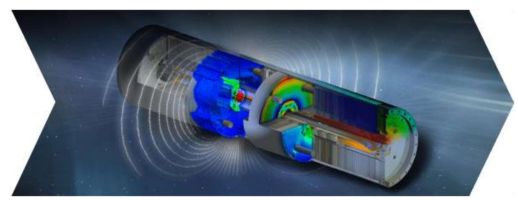


Design

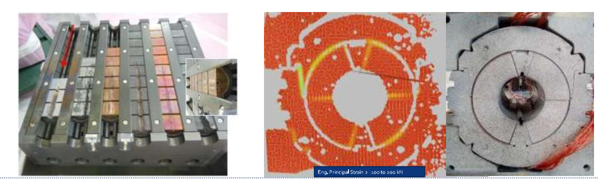
Simulations & Analyses

Mechanical Measurements

Inputs for FEM :
Mechanical properties
Thermo-physical properties



FEM Validation



Thermal and Mechanical Characterization

Thermal Analysis

Mechanical Testing

Components and Materials Testing

Furnace up to **1200 °C**

Cryostat down to **-196 °C**

Digital Image Correlation (DIC)

Impulse Excitation Technique (IET)

Thermal Expansion: 1.8 K to 2000 °C

Thermal Diffusivity: -140 to 2000 °C

Thermal Conductivity: -140 to 2000 °C

Specific Heat: -160 to 2000 °C

MATERIALS TESTING FROM 1.8 K UP TO 2000°C

Closed Cycle Cryostat down to 1.8 K Dilatometry + Sensors Development

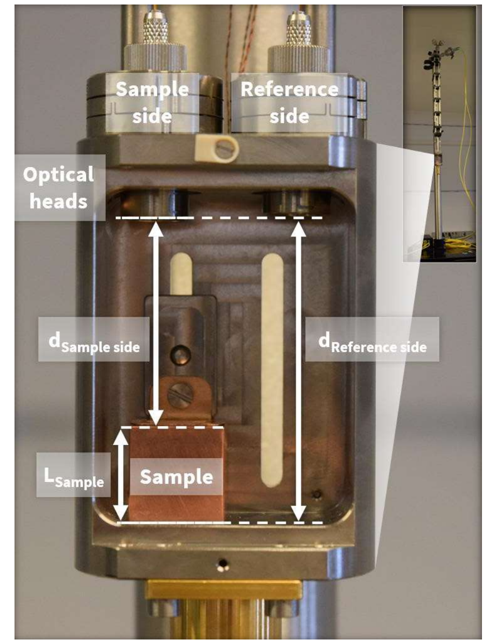
- **Temperature controllable in a range from 300 K down to 1.8 K**
  - **Dynamic** and **steady-state** measurements
  - High temperature stability in steady-state conditions ($\Delta T \leq 10$ mK for $T < 10$ K)
- **Cooling without liquid helium supply by using a closed-cycle cryocooler**
  - **Insignificant cryogenic hazard**
  - Cost effective
- **Integrated 9T Magnet**
  - Magnetostriction tests
  - Sensors validation against magnetic fields

CTE Measurement Insert

Joint Development

CERN

attocube WITTENSTEIN Group



Thermal contraction determination

$$\frac{dL}{L_0}(T) = \frac{\Delta L_{Sample}(T)}{L_0(T_{Ref})} = \frac{\Delta d_{Ref\ side}(T) - \Delta d_{Sample\ side}(T)}{L_0(T_{Ref})}$$

→ Contraction of sample housing requires **reference**

Next Steps

- Specific heat
- Thermal conductivity

Measurements on non–standard materials

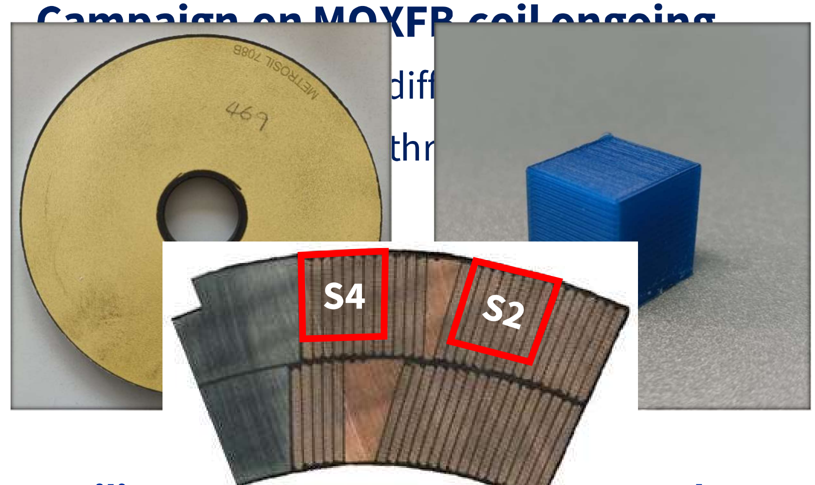
Various materials tested

- Ceramics, 3D printed parts, composites
- dL/L_0 from 0.04 up to 2 %

- Campaign on MOXFR coil ongoing

dif…

thr…



Silic… (disc)

…mple (3D printed)

Incipient Collaboration on Low T CTE Measurements

- **Validation campaign revealed certain differences with respect to commonly accepted literature values (< 5 %)**
- **Insignificant for most engineering applications, yet relevant in some cases (alignment, aerospace, etc.)**
- **Most literature values date from more than 20 years ago, and don’t go below 20 K**

Interlaboratory Benchmarking Campaign	Workshop on CTE Measurements
First discussions with KIT CryoMak ongoing	Host by CERN in autumn 2023
Please see “CryoMaK – The Cryogenic Material Test Lab Karlsruhe” by Dr Klaus-Peter Weiss Tomorrow	Get together the relevant actors
Actively searching for more partners to join the exercise	Provide momentum to the benchmarking exercise

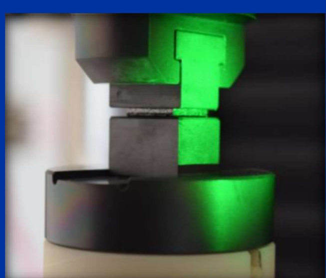
Application: Extreme Thermal Management Materials

Ceramic Matrix Composites Development

Choice of components (materials, topology, dopants)

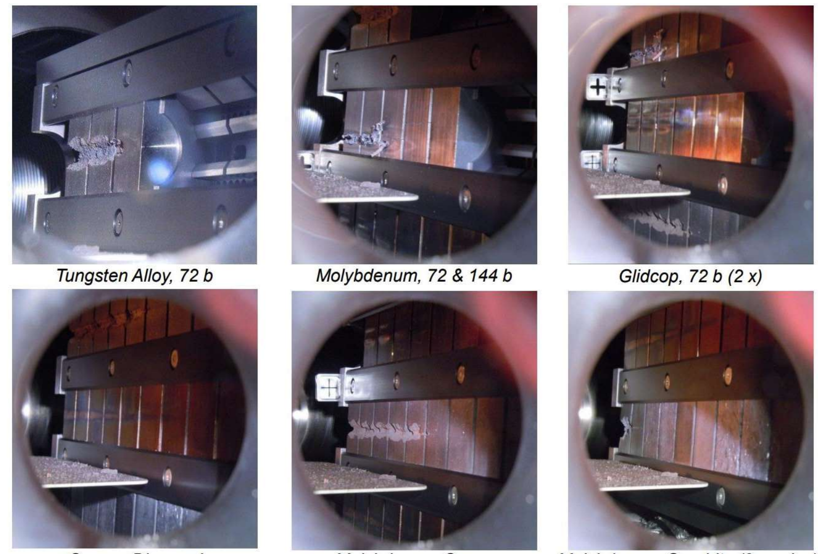
High temperature manufacturing (SPS, RHP)

Thermophysical and mechanical characterization



Microstructural characterization

Data analysis, investigation, new proposal



Tungsten Alloy, 72 b — *Molybdenum, 72 & 144 b* — *Glidcop, 72 b (2 x)*

Copper-Diamond 144 b — *Molybdenum-Copper-Diamond 144 b* — *Molybdenum-Graphite (3 grades) 144 b*

- Understanding of the behavior and manufacturing process of complex materials
- Robust materials constitutive models
- Increased confidence in FEM
- Material procurement contractual qualification

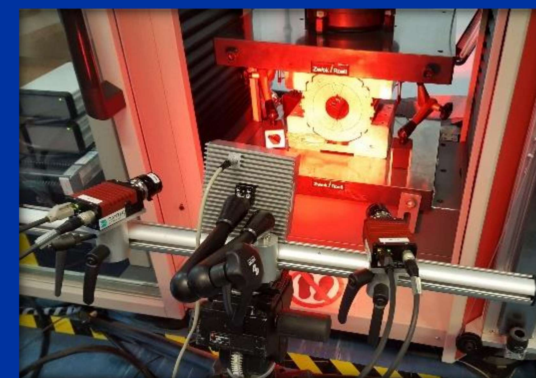
Experimental Stress Analysis

Experimental stress analysis is performed in several types of components: superconducting magnets, dumps and detectors, in different conditions as electro-magnetic fields, highly turbulent water, vacuum, radiation, etc.

- Online control of the mechanical integrity of the structures during their whole lifetime
- Validation of the FEM models for increased confidence
- Acceleration of the prototyping phase of the projects

FEM Benchmarking

11T Mockup



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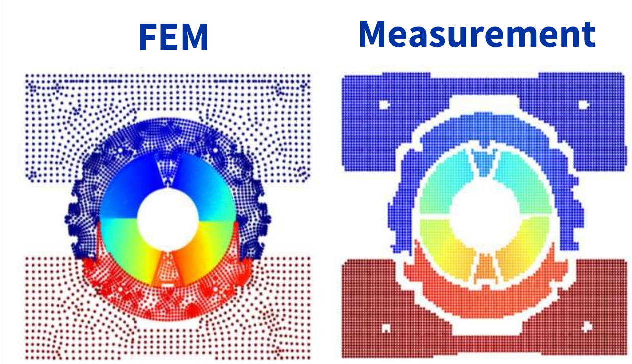
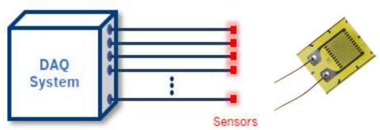


Strain Sensing Techniques

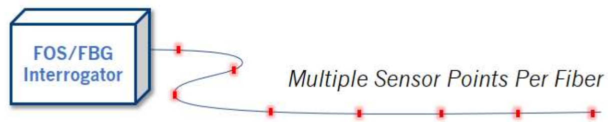
80's | 2011 | 2021

Electrical Strain Gauge (ESG)

Multiple Copper Wires Per Sensor

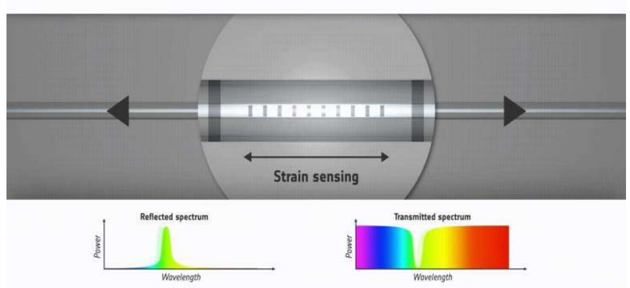


Fiber Bragg Grating (FBG)



Discrete

- Single optical fiber
- Challenging bonding process for cryogenic temperatures



Source: FBGS

Rayleigh Backscattering (RBS)

Distributed

- Single optical fiber
- Sub mm spatial resolution
- Challenging bonding process for cryogenic temperatures

New Develoment!!

Outcomes of the last years of development disseminated in

27th International Conference on Optical Fiber Sensors
OFS 2022
August 29–September 2, 2022 | The Westin Alexandria | Alexandria, Virginia, USA

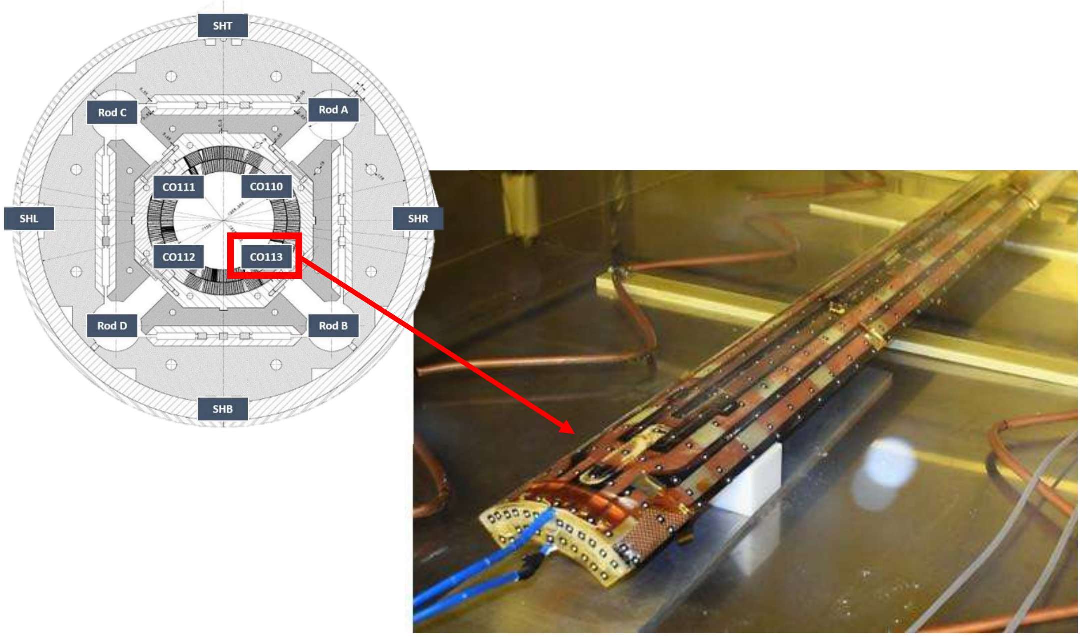
90 min tutorial talk

Distributed and Discrete Optical Strain Measurements down to Cryogenic Temperatures. K. Kandemir

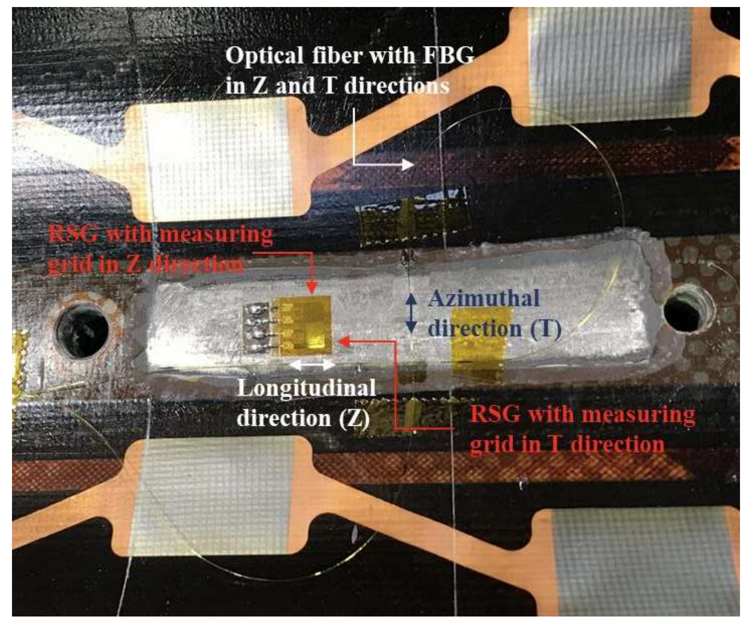
Strain monitoring of prototypes is crucial to confirm the mechanical response of structures and validate Finite Element Analysis. Optical fiber-based strain sensors offer many advantages with respect to electrical strain gauges, such as being less invasive and intrinsically immune to electromagnetic fields [1,2].

Applications: Superconducting magnet prototypes

CERN’s High-Field Low temperature superconducting magnet prototype coils instrumented with FBGs;
Measurements from its assembly at rom temperature to its powering tests at 1.9 K and up to 16.23 kA.



LTS magnet’s coil.

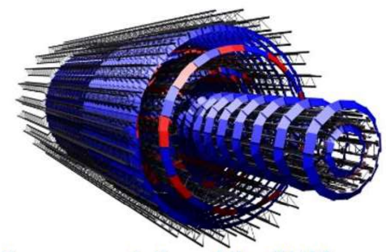


Sensors bonded on Superconducting Magnet’s coil on a Ti-alloy pole.

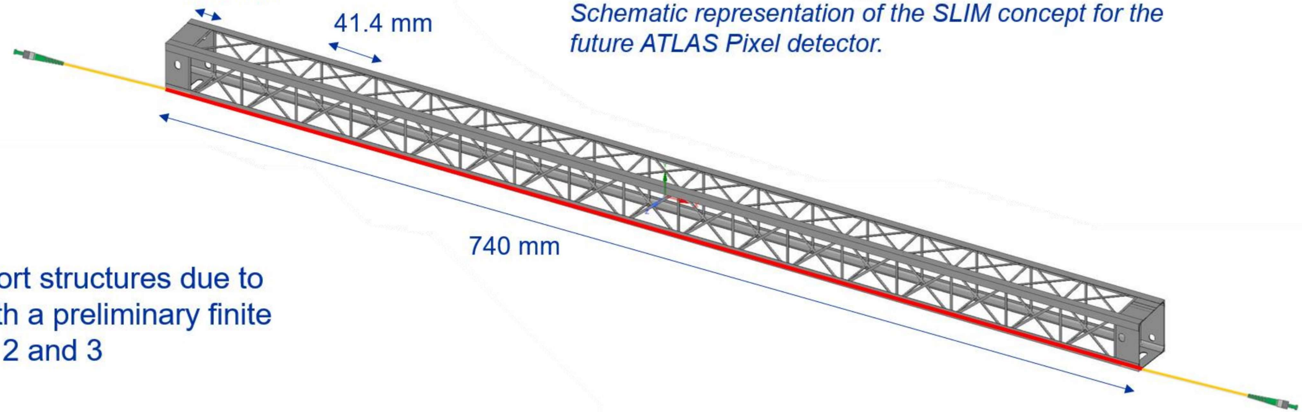
Lightweight Embedded Strain Sensors

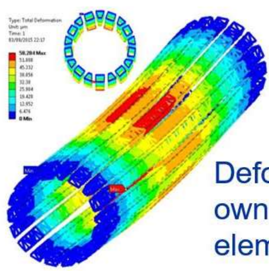
- SLIM concept (A Stiff Longeron for ITk Modules) for the outer layers of the future ATLAS pixel detector;
- Experimental tests to embed FBG sensors inside the structure;
- FBG sensors and distributed optical fiber installed all along the specimen in one side.

Detail of a prototype of the carbon fibre reinforced plastic (CFRP) truss to be used as a support structure



Schematic representation of the SLIM concept for the future ATLAS Pixel detector.

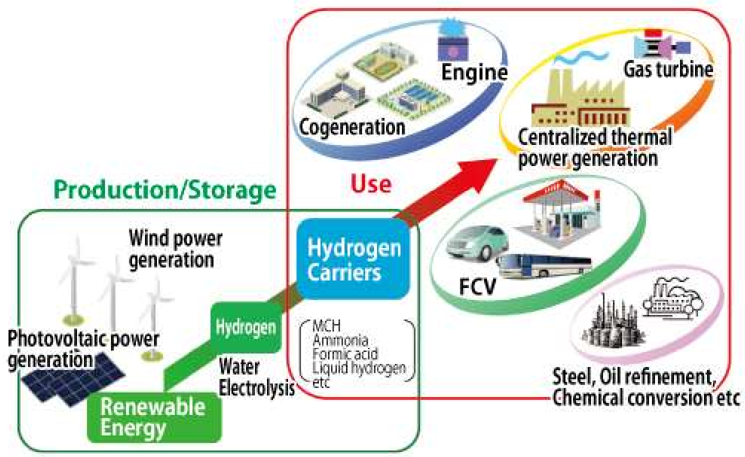




Deformation of the support structures due to own weight, obtained with a preliminary finite element model of layers 2 and 3

Strain sensing at cryogenic temperatures

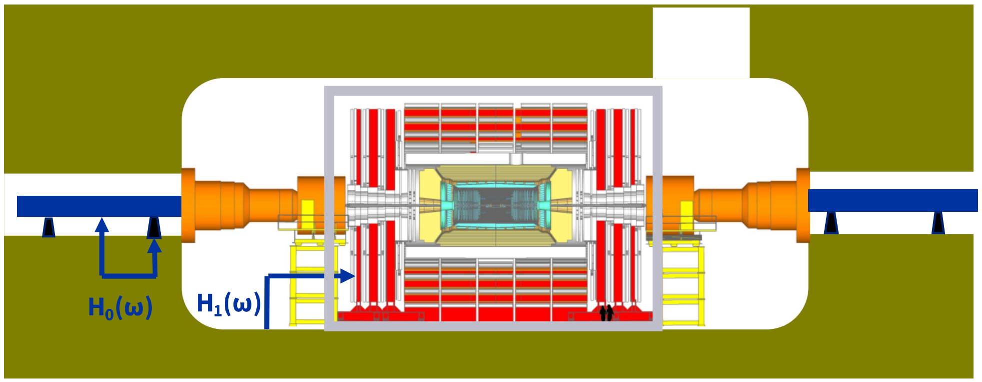
- A perhaps surprising property of optical fibers is that they remain flexible at cryogenic temperatures [12];
- Zirconia ferrule has a very low thermal expansion coefficient, which reduces material stresses caused by temperature gradients; and is also very close to that of the fiber.



Production and utilization of hydrogen from renewable energy

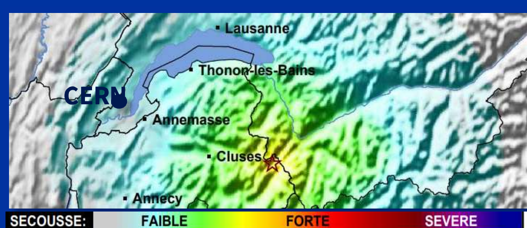
- Hydrogen liquid is seen as one of the energy vectors of the future;
- H_2 must be cooled to 20.28 K to be in liquid state;
- Future emerging research with strain sensing at cryogenic temperatures.

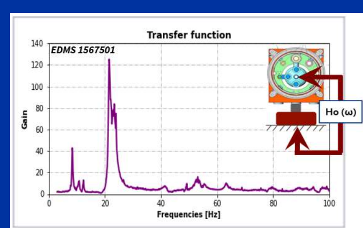
Dynamic Measurements



Ground Motion Measurements

CERN Seismic Network

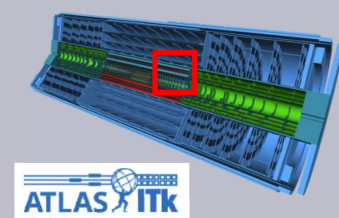




Study of seismicity and cultural noise in the accelerator complex dynamic behavior

Experimental Modal Analysis

Laser Doppler Vibrometry



Determination of the natural frequencies and mode shapes

Measurement of the damping

Evaluating the overall dynamic behavior of the structure prior to commissioning

Online Vibrations Monitoring

Observation of the transport-induced dynamic loads in delicate equipment

Detection of anomalies

Digital Transformation

Increasing complexity of our measurement equipment ecosystem
In order to keep up with state-of-the-art technology

Fast paced development cycle
Increasing need of concurrent real time data availability for swift decision making

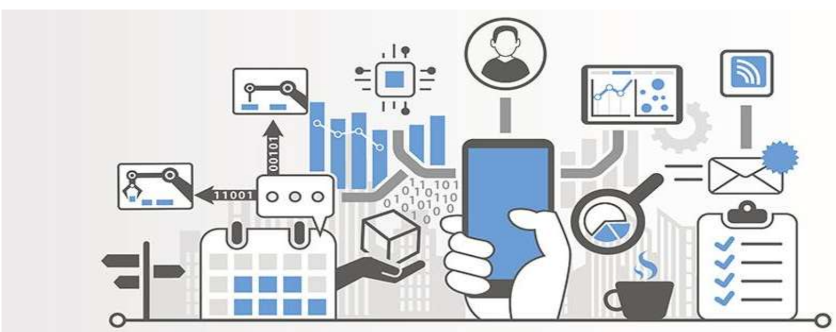
Increased international collaboration
Development team does not forcibly in the same place where assembly and test happen

Technologies available to push forward digital transformation in the laboratory
Not only from measurements industry, but the Internet of Things, cloud computing, etc.

Digital Transformation

The Digital Transformation Revolution occurs everywhere, also in the Test and Measurement Field!

- Measurements ≈ Internet of things
- New ways to perform measurements, archive, share and visualize data
- Increasing complexity of our own developments



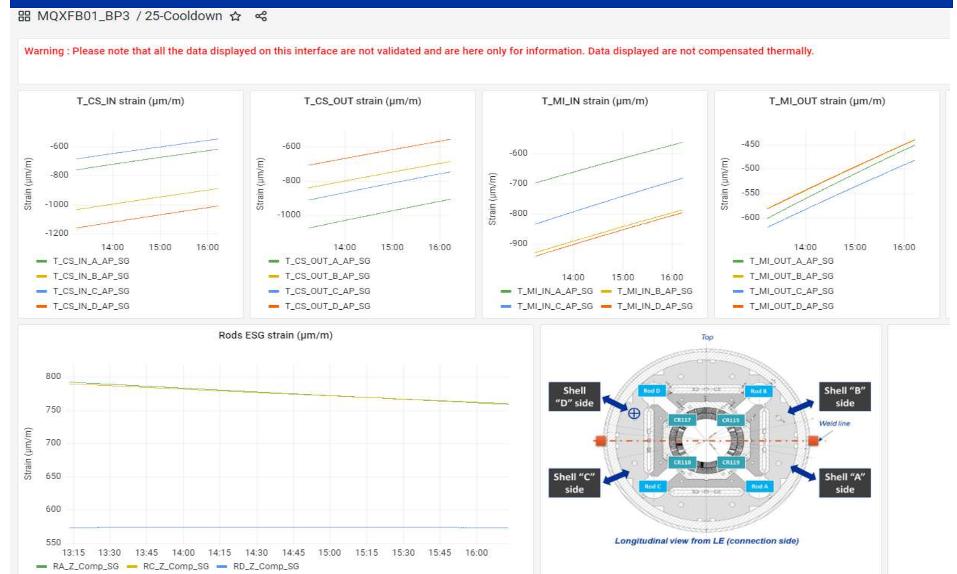
Enormous opportunities but also challenges

- Traceability and documentation of our activity (**Not negotiable**)
- Interoperability of the measurement electronics
- Open and quick access to measurement data by external collaborators

Digital Transformation – Our Answers

Data from every system are continuously streamed and/or stored on the Cloud/DFS

Worldwide real time access to our data through the laboratory dedicated panels



Efficiency | **Transparency** | **Collaboration**

A few takeaways

Rigorous methodologic approach, traceability to international standards, calibration and validation of the techniques

Strong synergy with design and engineering units

Focus on our key expertise: mechanical measurements. Technology scouting and collaboration with industrial partners

Compelling development program for the coming years (sensing technologies, cryogenic thermal measurements, digital transformation)

Thank you for your attention!

Questions?

Engineering Department

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