

# FIBER-OPTIC DIAGNOSTIC SYSTEM FOR FUTURE ACCELERATOR MAGNETS

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## SUMMARY

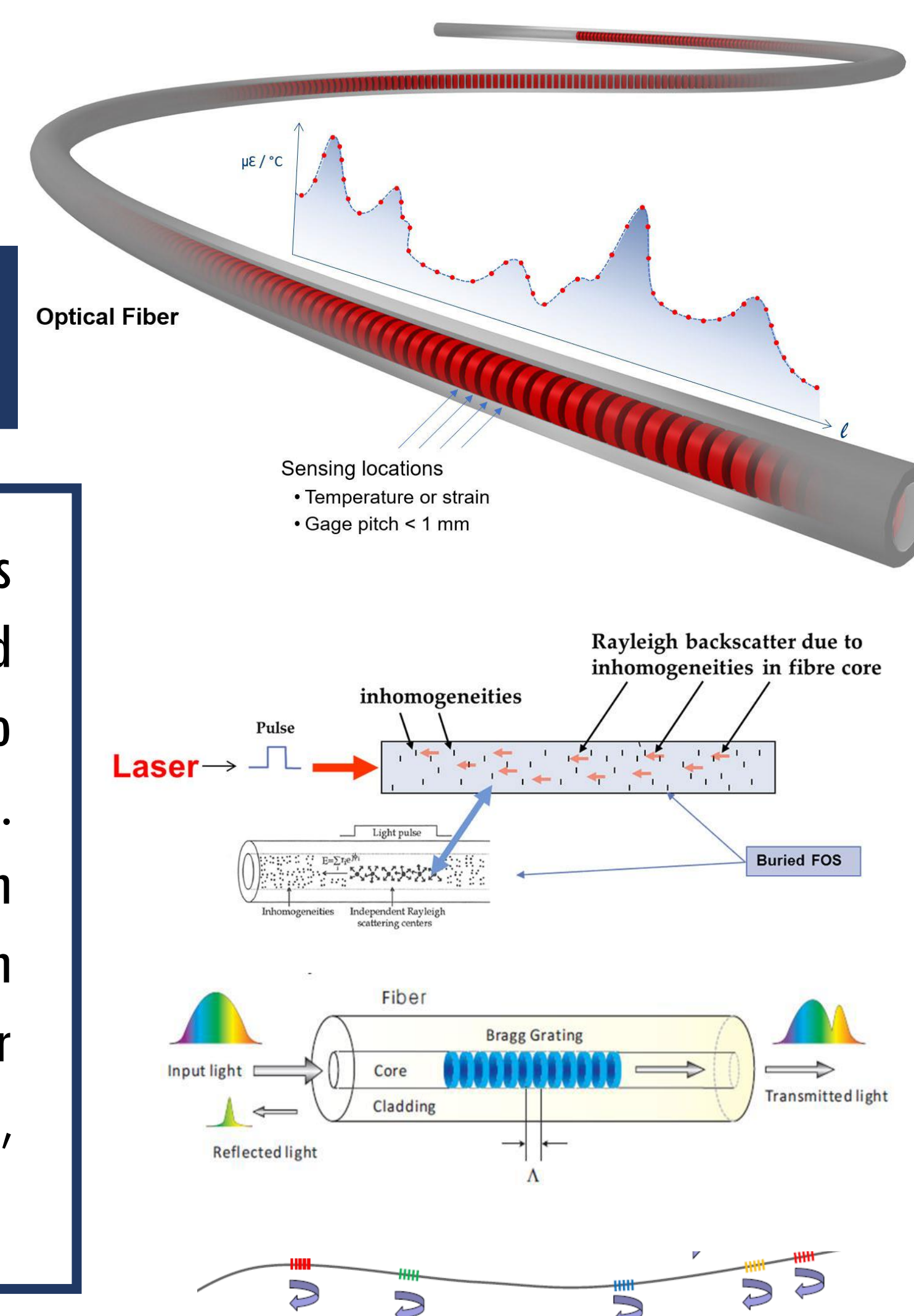
The next generation high energy physics accelerators will require magnetic fields at  $\sim 20$  T. and several efforts are currently dedicated on designing 20 T HTS- LTS hybrid magnets.

Among the existing challenges:

- lack of a robust quench detection system for hybrid magnet technology.
- high number of training quenches required by Nb3Sn magnets to reach performance level.

We need a tool that allow local real-time monitoring of magnet strain and temperature. We propose the use of fiber optics sensors for diagnostic and quench detection in future accelerator superconducting magnets.

## FIBERS



The working principle of those sensors is very simple: the spectral shift observed in the fiber can be directly connected to strain and temperature variations [1]. Those sensors can be divided in two main categories: discrete sensors based on Bragg grating principle (FBG) or distributed sensors based on Rayleigh, Raman or Brilluoin backscattering.

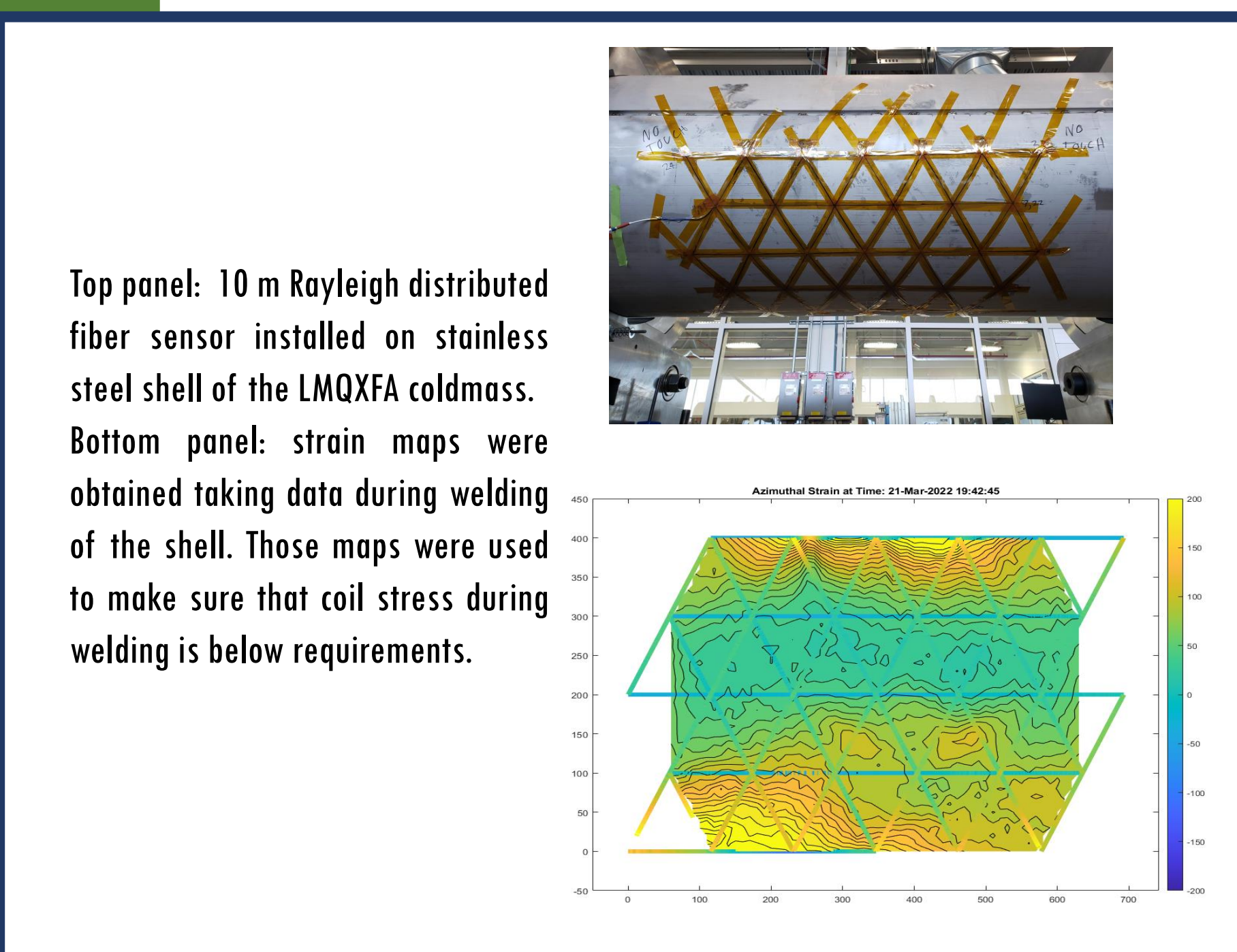
## GOALS

- To instrument hundreds of accelerator superconducting magnets and to move beyond the proof-of-concept level.
  - to improve mechanical properties and fabrication processes in order to produce hundreds of meters of fiber
- to make those sensors a robust and reliable diagnostic tool for accelerator superconducting magnets over the next 10 year.
  - increase of sample rate and sensitivity. Close collaboration with vendors will be necessary.

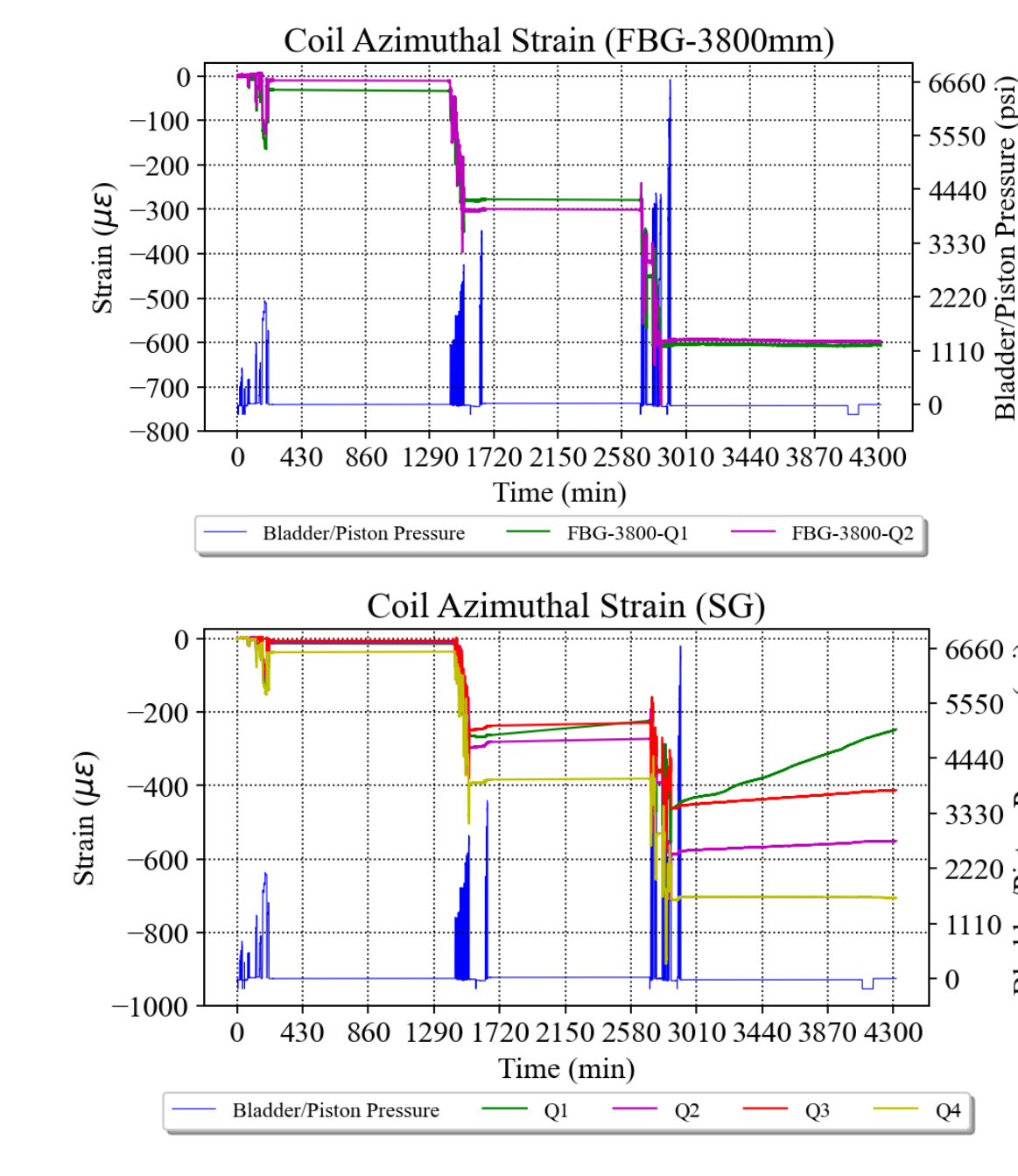
Close collaboration with vendors will be necessary. Those R&D efforts will last up to 10 years with a founding level that spans between 5-10 M\$.

## SUPERCONDUCTING MAGNET DIAGNOSTIC

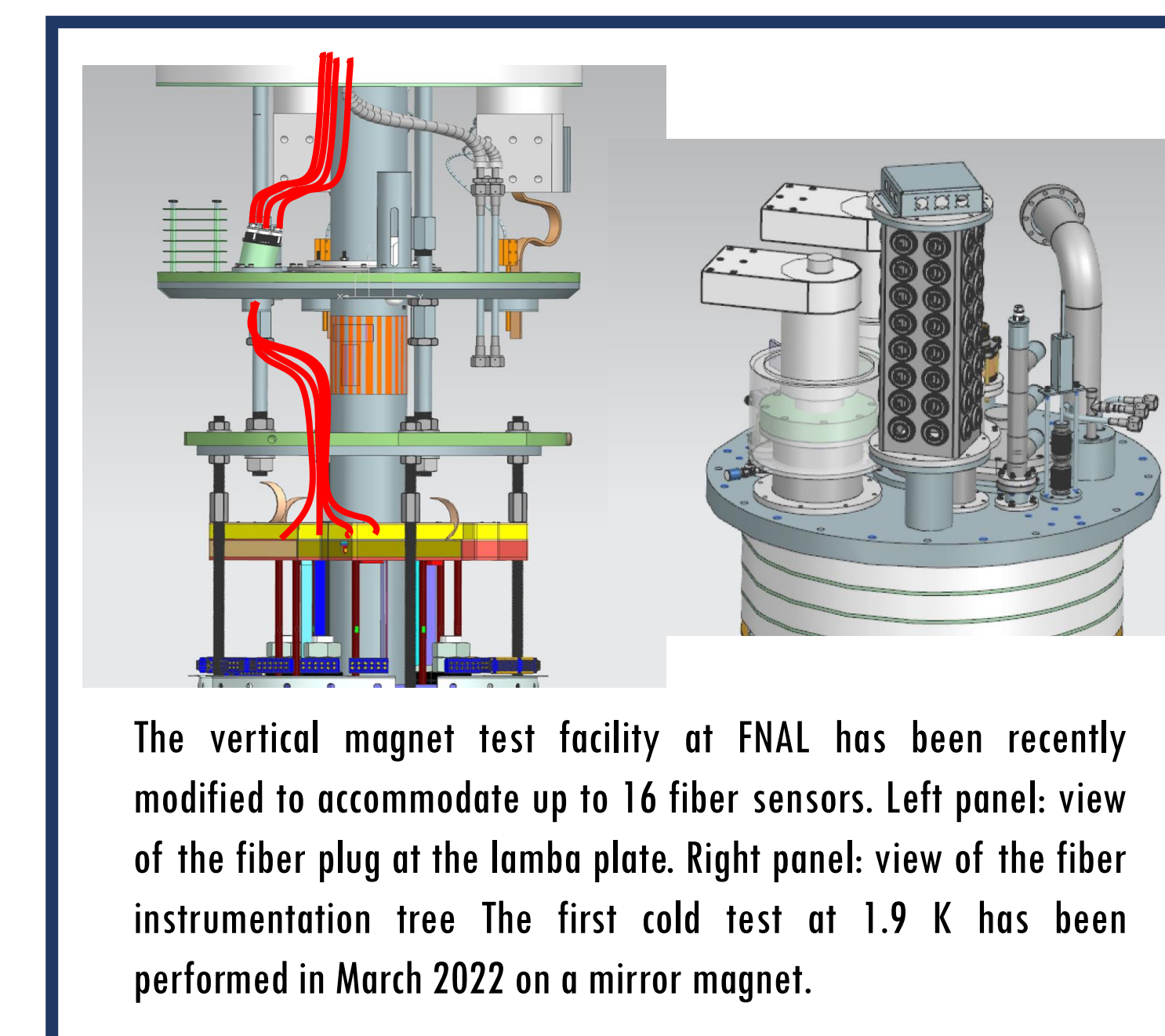
- The Nb3Sn MQXFA superconducting magnets fabricated through the HL-LHC Accelerator Upgrade project (AUP) are currently being instrumented with FBG fibers.
  - measuring strain during magnet preload and training
  - Measure coil strain during the LMQXFA coldmass shell welding. Optical fibers are extremely thin ( $< 200$   $\mu$ m diameters) so they can survive the insertion of the magnet bore.



Top panel: Coil azimuthal strain measured with a FBG fiber sensors. Two coils have been instrumented with FBG optical fibers. The bladder pressure is also displayed in the plot (right y axis).  
Bottom panel: Coil azimuthal strain measured with a strain gauges. Four coils were instrumented with strain gauges. The bladder pressure is also displayed in the plot (right y axis). Results obtained with fibers are in good agreement with what has been observed with strain gauges



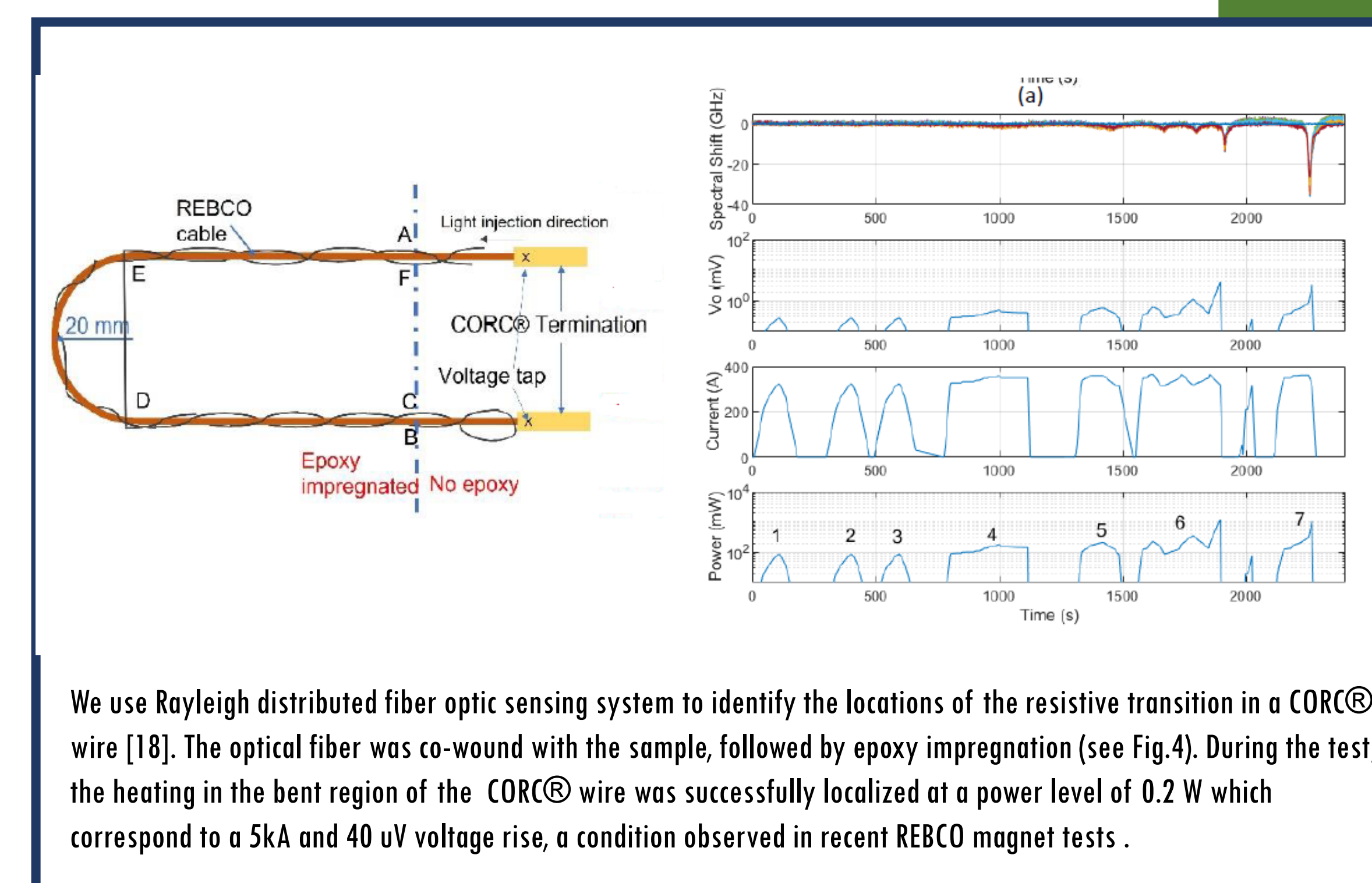
Distributed Rayleigh fiber sensors can be used to obtain strain maps during coil, magnet or cold mass fabrication/ or to measure temperature during epoxy impregnation. There are 30000 sensing regions in a 20 m fiber.



Exploiting the synergies among the HL-LHC Accelerator Upgrade project (AUP), the Magnet Development Program (MDP) and Lab Directed R&D (LDRD) funds, fiber technology is being currently implemented across several US National Laboratories. We expect for FBG discrete sensors to become a stable diagnostic probe for superconducting magnets over the next 3 to 5 years.

## QUENCH DETECTION

The greatest potential of Rayleigh sensors relies on the possibility of using them for quench detection in HTS magnets. Indeed, those sensors could provide significant advantages over traditional techniques for detecting normal zones in HTS. Fibers can be integrated into a REBCO conductor architecture. Preliminary studies demonstrated strain sensing capabilities as well as thermal perturbation detection and localization with higher spatial resolution than taps .



We use Rayleigh distributed fiber optic sensing system to identify the locations of the resistive transition in a CORC® wire [18]. The optical fiber was co-wound with the sample, followed by epoxy impregnation (see Fig.4). During the test, the heating in the bent region of the CORC® wire was successfully localized at a power level of 0.2 W which correspond to a 5kA and 40 uV voltage rise, a condition observed in recent REBCO magnet tests .

## DISCUSSION

**IMPROVE SENSITIVITY:** Fiber optics have very low sensitivity to temperature below 50 K and future machines will probably work at relative low temperature ( $T < 4.5$  K). More robust and reproducible solutions need to be found to separate strain and temperature effects sthe two effects and to make sure those sensors can separately detect small temperature and strain variations.

**IMPROVE RESOLUTION:** At moment, distributed fibers can be as long as 50 m. However, the length of the fiber affects the sample rate. One of the most urgent need is to have long fibers ( $> 100$  m) with the highest sample rate ( $> 1$  kHz) and highest spatial resolution (pitch  $< 1$  mm). This is a necessary step if we want to use those sensors for diagnostic or quench detection during a quench.

**INSTALLATION and SCALING UP:** Fibers are fragile and can be fabricated with several coating materials. We need to be able to fabricate hundreds of meters of coated fibers. Mechanical properties, fabrication and installation processes need to be scaled up to industrial level in order to instrument a large number of accelerator superconducting magnets

## CONCLUSIONS

Fibers have proven to be a promising tool at the level of proof of principle experiments. Over the next 5 years, we expect fiber optic sensors to become a robust and standard diagnostic tool for measuring strain and temperature variation during the life of superconducting R&D accelerator magnets. Hybrid magnets prototype will be fabricated over the next 5-10 years. Spatial/temporal resolution of distributed optical sensors can be tuned and modified according to the needs, making those fibers the most promising quench detection system for LTS-HTS hybrid magnets where integration is the major challenge. The long-term goal would be to integrate fibers in above 20 T hybrid magnets making them a solid quench detection system for future HEP machines.