

Optical Fiber Sensors for Cryogenic applications

Presented by:

Daniele Inaudi, CTO SMARTEC

daniele.inaudi@smartec.ch

www.smartec.ch

Contents

- Fiber Optic sensors
- Sensing in Extreme Environments:
 - Cryogenic temperatures
 - Radiation environments
 - Vacuum
 - Strong magnetic fields and EM interferences
- Application Examples

Fiber optic Sensors: Why?

- Small size of sensors and cables
- Great variety in the measurable parameters
- Insensitive to EMI (Electro-Magnetic Interference)
- Distributed and Multiplexed topologies
- Can work reliably in demanding environments, including extreme temperatures, radiation and vacuum

Main FOS Technologies

Fabry-Pérot

Strain, T, pressure, displacement

Fiber Bragg Gratings

Strain, Temperature, acceleration, tilt

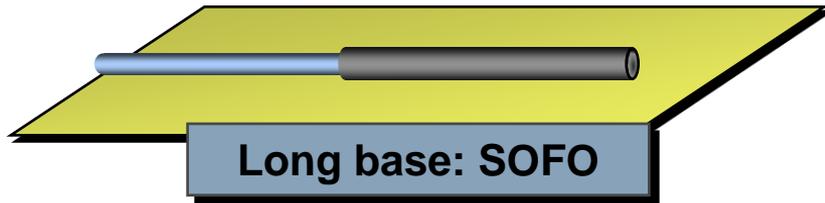
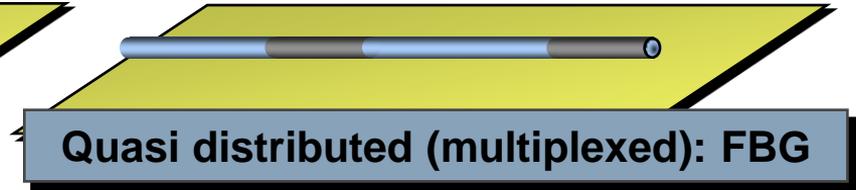
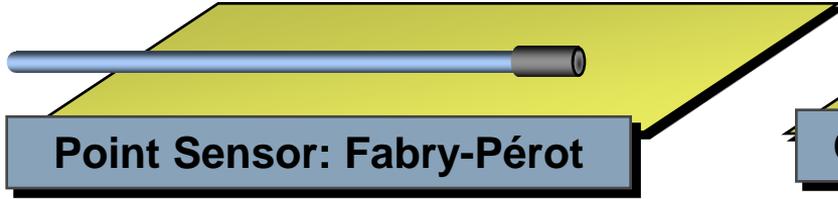
SOFO

Deformations, curvature

Brillouin/Raman

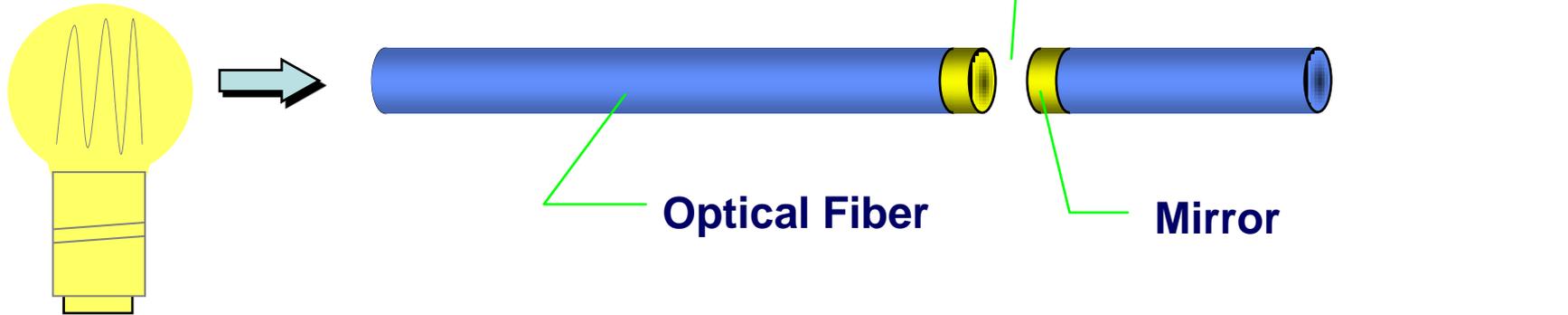
Distributed strain and temperatures

Fiber Optic Sensor Types

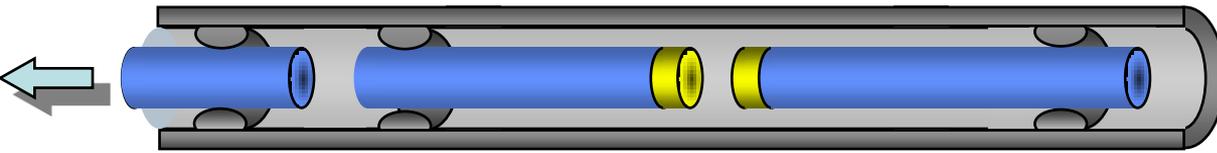


Fabry – Pérot Principle

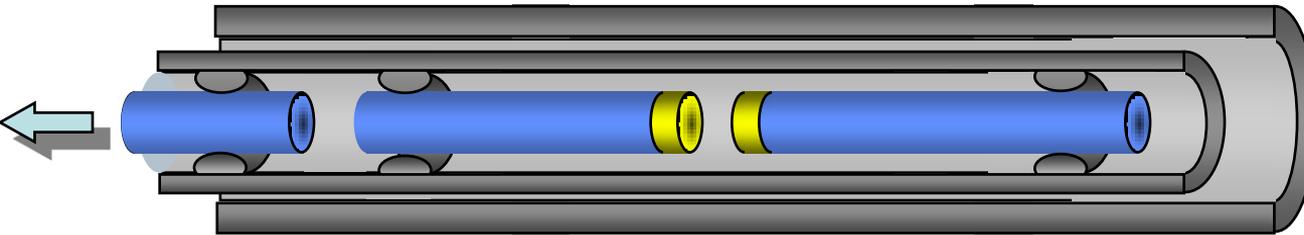
Measurement is achieved by measuring the Fabry-Perot cavity length using white light interferometry



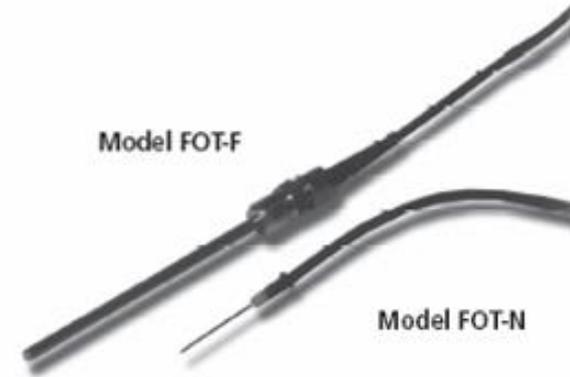
Fabry-Pérot Sensors



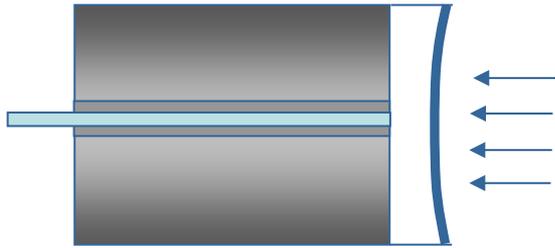
Strain



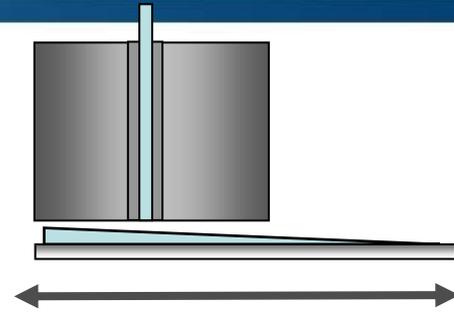
Temperature



Fabry-Pérot Sensors



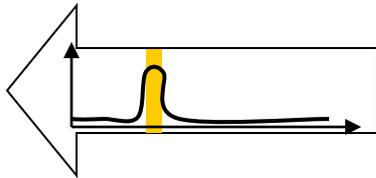
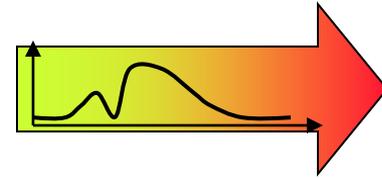
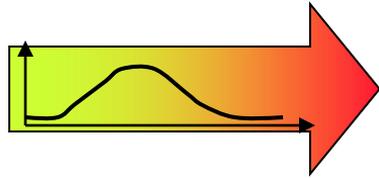
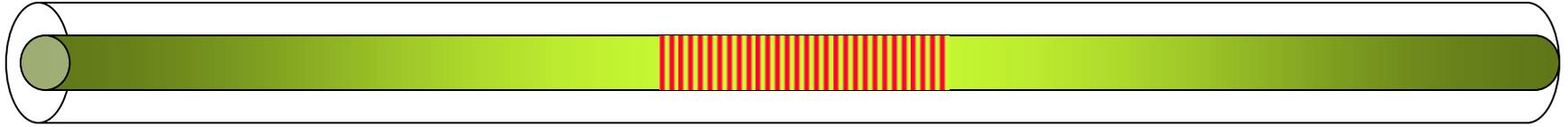
Pressure



Displacement

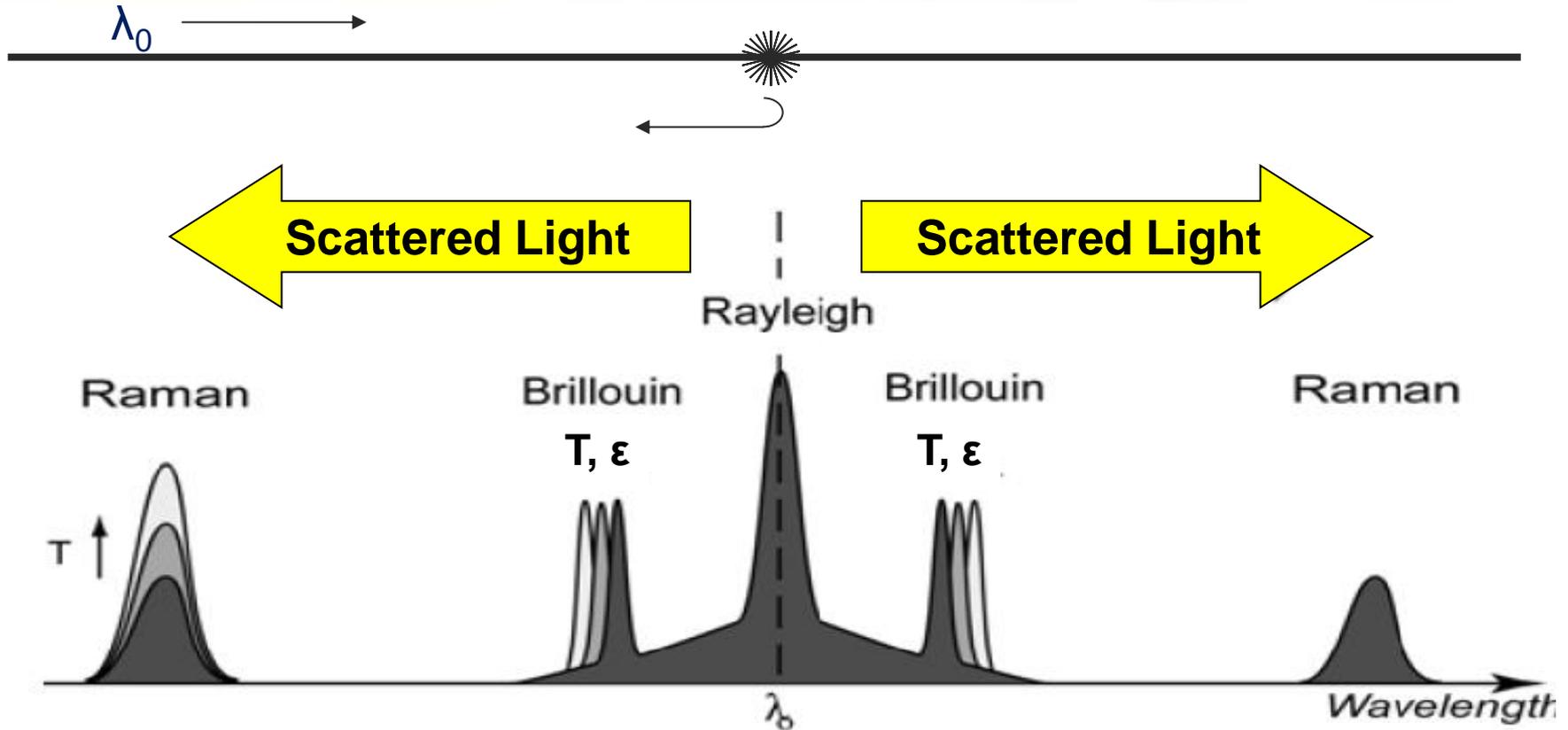


Fiber Bragg Grating Sensors



The reflected wavelength depends on the strain and temperature of the fiber

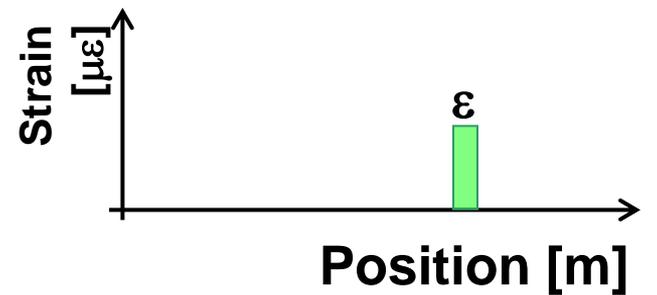
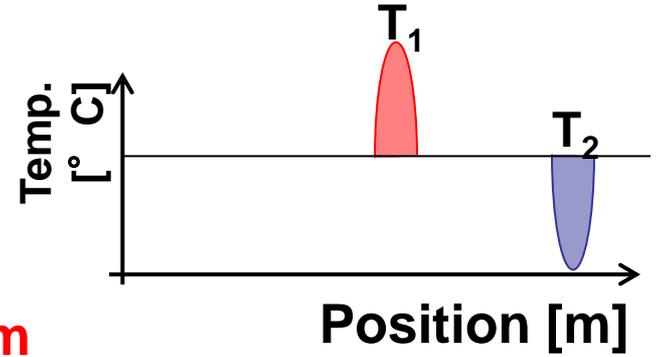
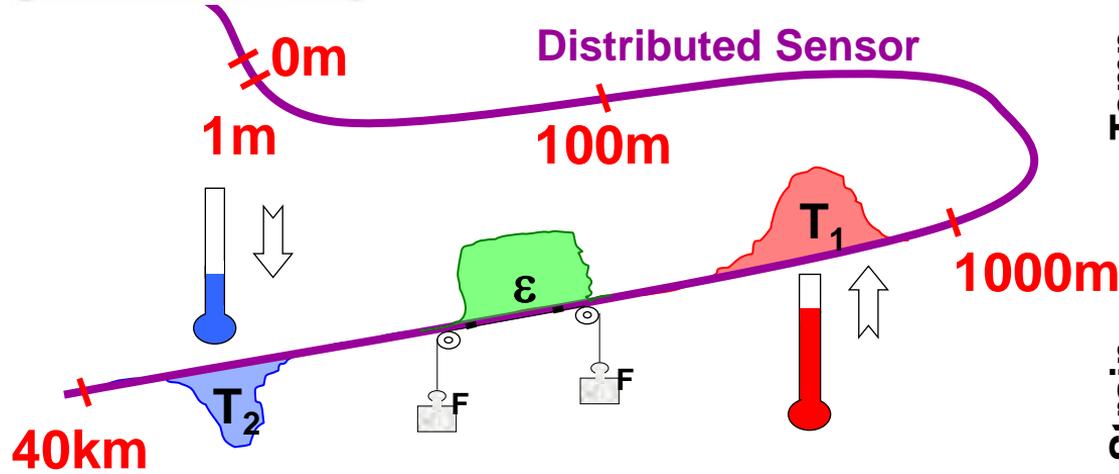
Optical scattering in silica fibers



Distributed Sensing

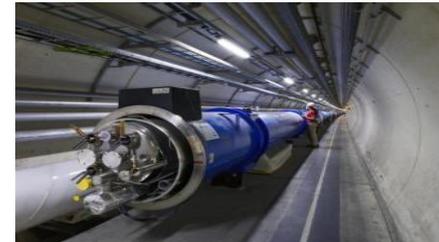
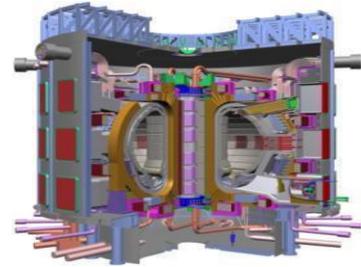


Reading Unit



Structures at Cryogenic Temperature

- LNG Pipelines
- LNG Tanks
- Superconducting Magnets
 - Physics (ITER)
 - Particle physics (CERN)
 - Bio-chemistry (spin-resonance)
- Space-like condition testing



Cryogenics: Key features

- Sensors for Cryogenic temperatures must exhibit the following features:
 - Use of appropriate materials to control differential thermal expansion coefficients
 - Ability to operate reliably even during fast temperature changes, e.g. shock immersion in liquid nitrogen
 - Survive multiple temperature cycles. SMARTEC sensors are cycled 10 times in liquid nitrogen
 - Low sensitivity to very large temperature changes



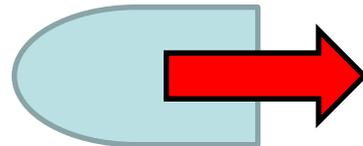
Radiation: Key features

- Sensors for Radiation environments must exhibit the following features:
 - No degradation of materials due to radiation
 - No drift of measurements due to radiation effects: SMARTEC sensors tested at 5 MGray dose
 - No significant increase in fiber optical losses due to radiation: use of rad-hard fibers



Vacuum: Key features

- Sensors for vacuum environments must exhibit the following features:
 - No degradation of materials due to vacuum
 - No drift of measurements due to vacuum
 - Availability of vacuum feed-through to connect optical fibers to atmospheric environment
 - No de-gassing from sensors
 - Ability to sustain multiple vacuum cycles and rapid pressure changes



Magnetic and EMI: Key features

- Sensors for Strong magnetic fields and EMI environments must exhibit the following features:
 - No drift or noise on measurements due to EMI
 - Use of non magnetic materials: SMARTEC sensors have magnetic permeability < 1.05
 - Use of non-metallic cables to avoid induced currents and allow electrical isolation of the sensors



SMARTeC Extreme Sensors

Measurements:

- Displacement:
 - Short range
 - Long range
 - Non-contact
- Strain
- Temperature
 - Local
 - Distributed

Technologies:

- Fabry-Perot (FISO)
- FBG (MuST)
- SOFO (low-coherence interferometer)
- Laser Distance Meter
- Raman (DiTemp)

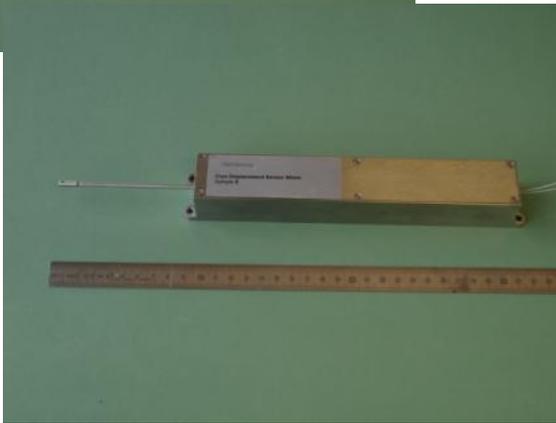
Displacement: Long/short range



Fabry-
Perot



Fabry-
Perot

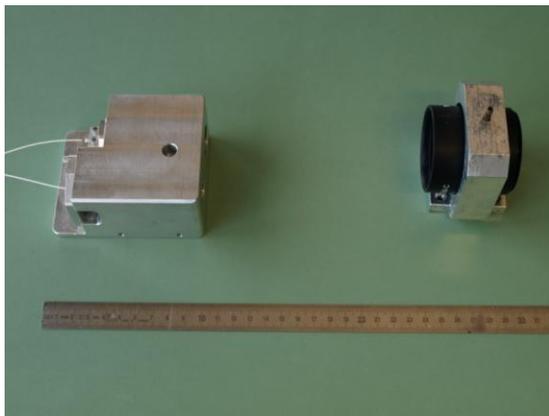


FBG

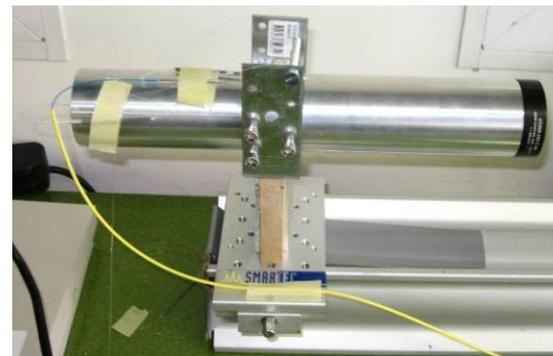


FBG

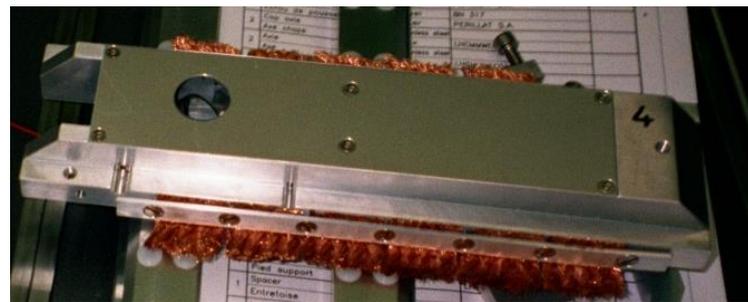
Non-contact Distance Meter



Laser distance Meter



SOFO



SOFO

Strain



Fabry-Perot



FBG

Temperature



Fabry-
Perot



FBG

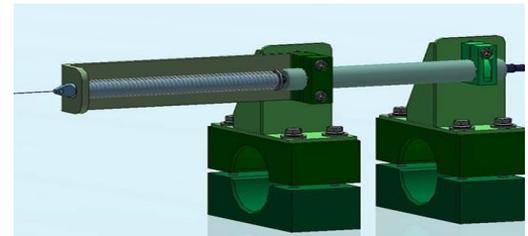
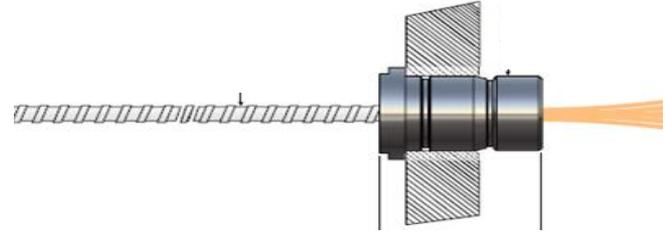


Distribut
ed
Raman

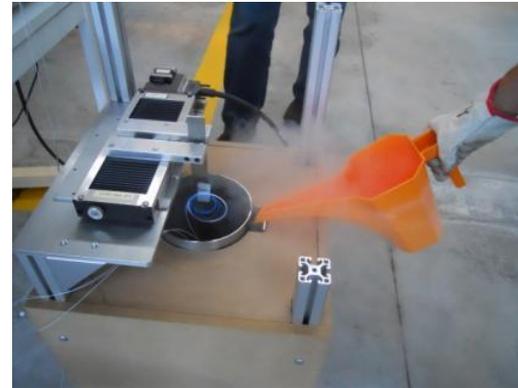
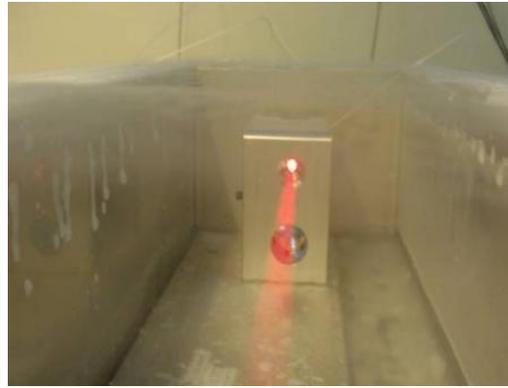
SMARTEC Extreme Sensors

Accessories:

- Vacuum feed-through
- Cables:
 - Rad-hard fibers
 - PEEK coating
 - Non Metallic
 - Fiber bundles
- Sensor covers and mounting



Qualification and Testing



Summary of testing specs

- Temperature: 4.2K (-269°C) to 80 °C
 - Temperature sensors: 10K to 80°C
 - Distributed T sensors: 80K to 300°C
- Radiation: SMARTeC sensors were tested at 5 MGray (gamma)
- Vacuum: 10^{-8} Torr
- Magnetic Fields: 6 Tesla

SMARTEC Experience/Partners

Reference Projects:

- ITER (International Thermonuclear Experimental Reactor)
- CERN (European particle research center) LHC magnets
- Oak Ridge Spallation Neutron Source, USA
- LNG Tanks and pipelines
- CryoBragg EU Project
- Other (confidential)

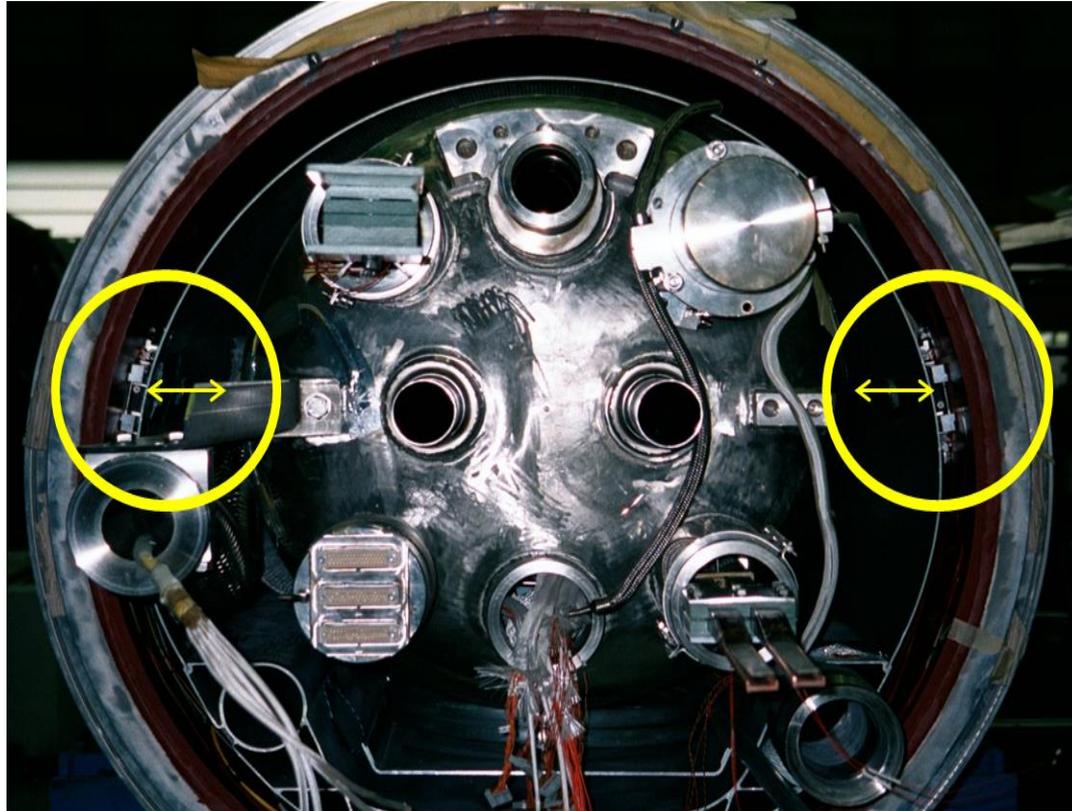
CERN-LHC Dipoles



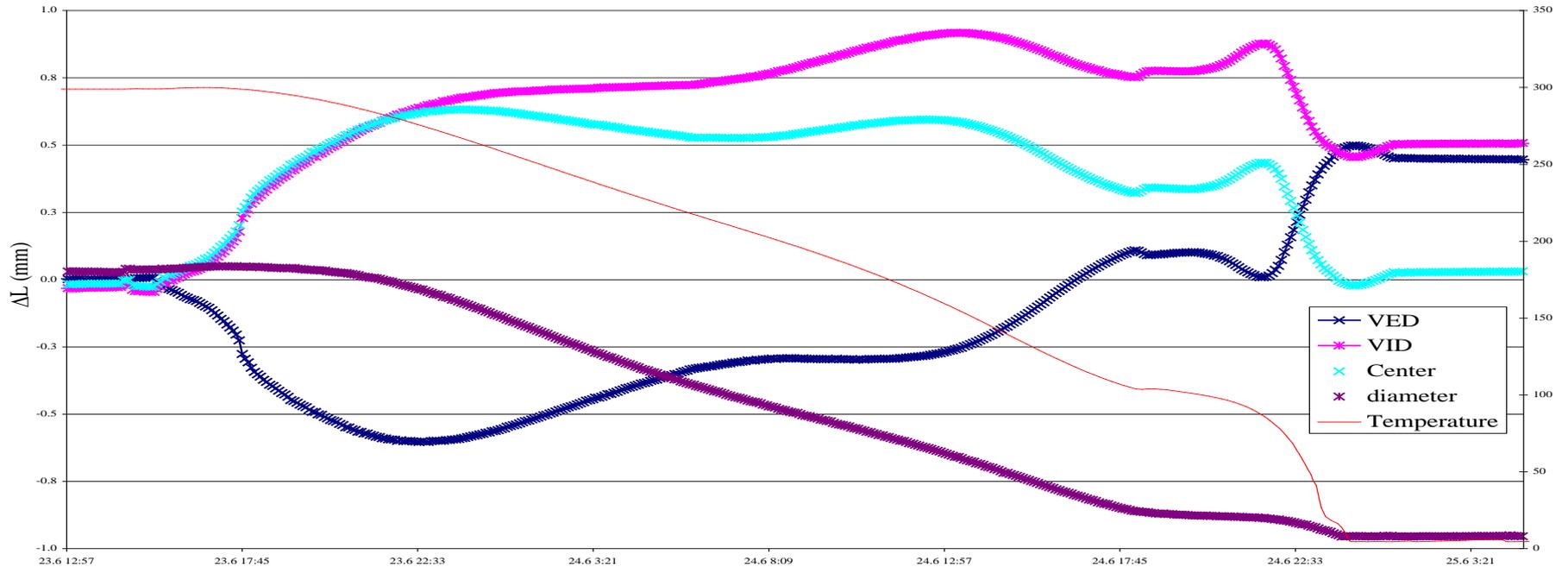
Measurement Aims

- Measure the relative displacements of the cord-mass and the vacuum tube
- Measurement base: 150-200 mm
- Measurement base: 1.5 to 300 °K
- Cold mass contracts about 20 mm during cool-down: lateral displacement
- Cold mass rotates
- Measurement in vacuum
- No direct optical access to the measurement zones

Sensor installation

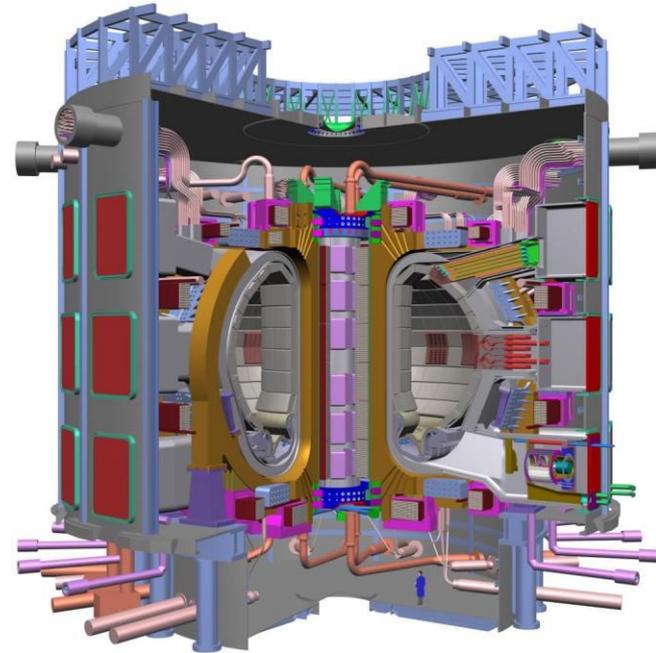


Results: Cool down



ITER

- International project for new Fusion Reactor
- Under construction in Cadarache (France)
- Thermo-Mechanical instrumentation: 1000+ sensors, 80% fiber optics
- Contract awarded to SMARTeC / FiberSensing Consortium



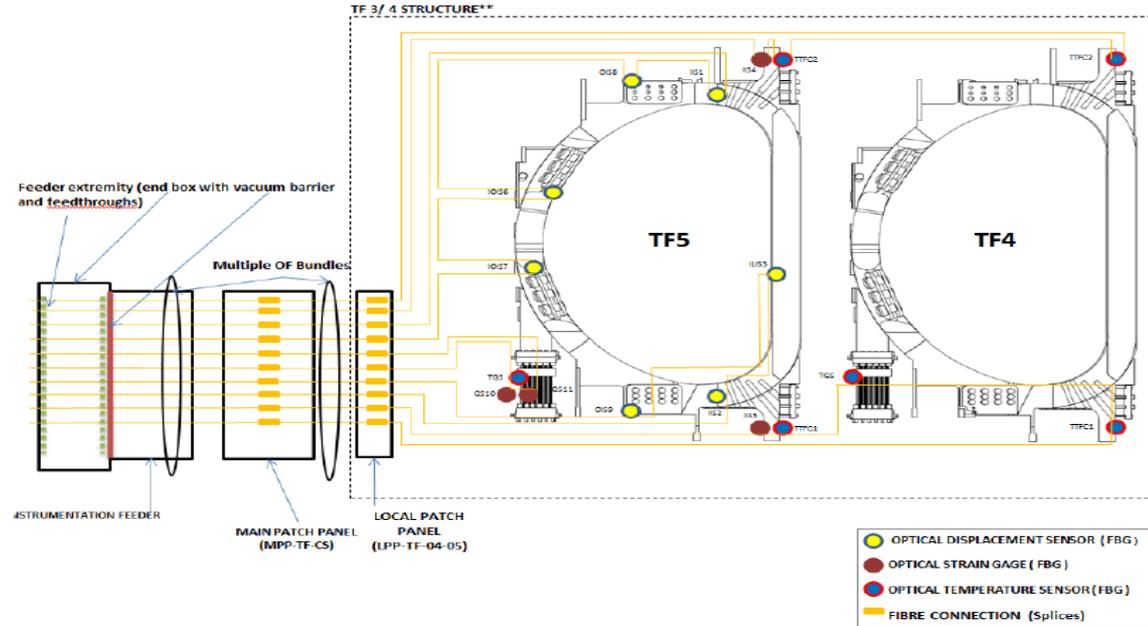
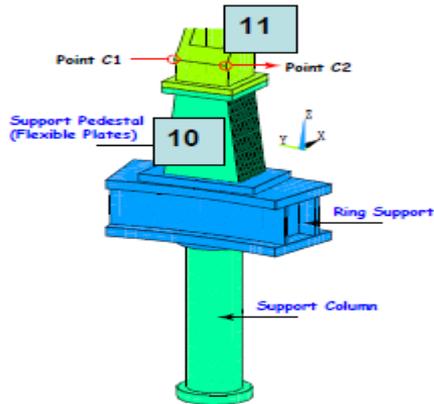
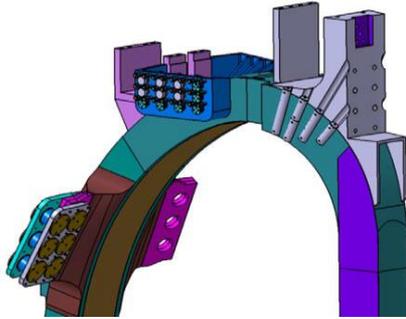
ITER

- Phase II contract for delivery of 700 sensors (strain, displacement, temperature)
- 3-year qualification program
- Monitoring of superconducting magnets and support structures

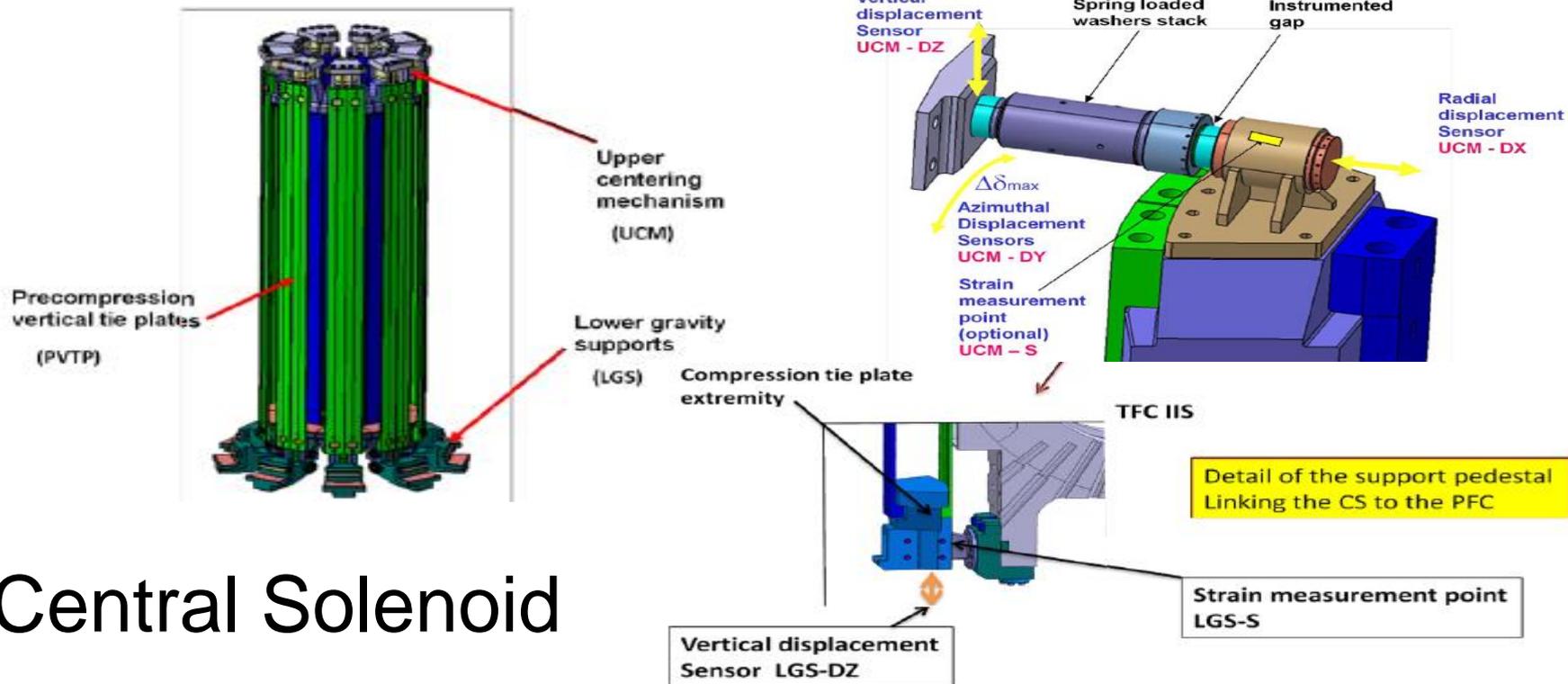


ITER Magnets instrumentation

Toroidal Field Coils

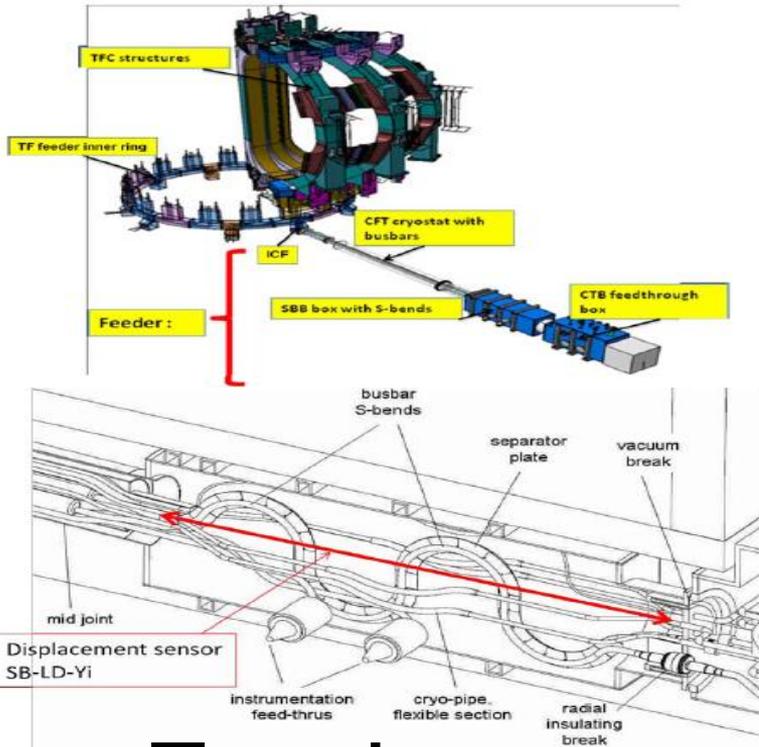


ITER Magnets instrumentation

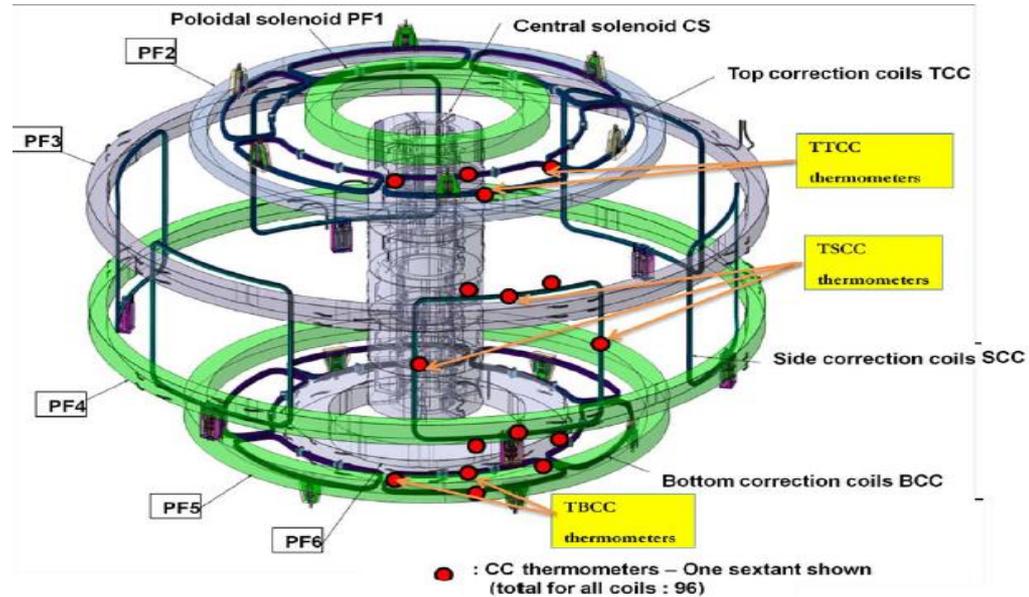


Central Solenoid

ITER Magnets instrumentation



Feeders



Correction Coils

