FIBER BRAGG GRATING SENSORS FOR SMART-TRACKERS

Application to Belle II Vertex Detector

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Outline

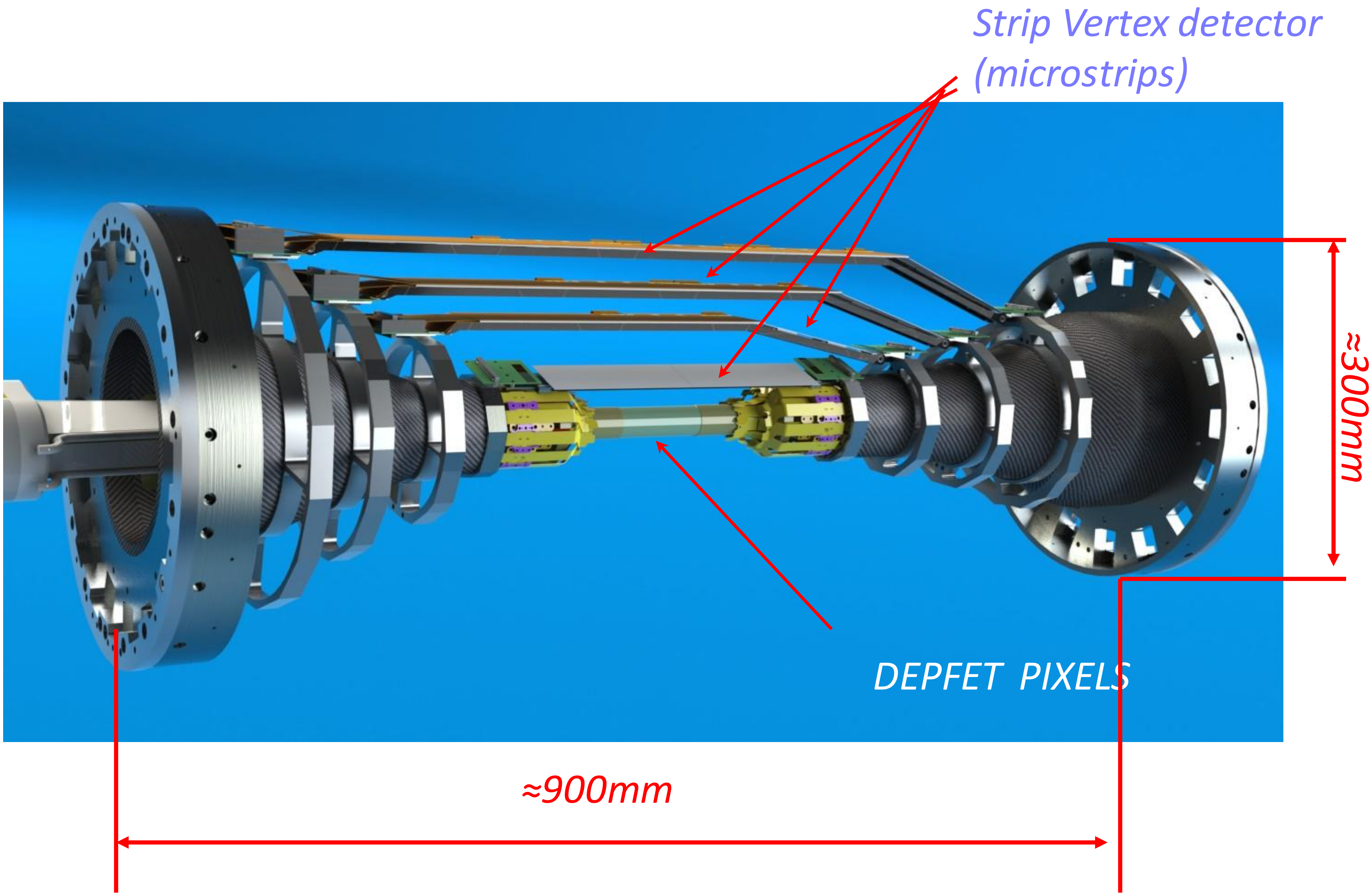
- Introduction to Fiber Bragg Grating (FBG) optical sensors
- The Belle II vertex detector (VXD):
- A FBG-based real time monitoring for VXD.
  - Displacement transducers (omega and L-shape)
    - Manufacturing
    - Thermal and displacement calibration
    - Humidity, Nitrogen sensitivity
  - Environmental measurements on PXD-SVD thermal closure.
- Summary

OFS & FBG advantages

- FBG sensors are strain and temperature sensors inscribed in the core of an optical fiber (length ≈ 10 mm, diameter ≈ 200um). Attributes:
  - Immunity against:
    - High electromagnetic fields, high voltages.
    - High and low temperatures. ((4 K to 1200 K).
  - Characterized up to high radiation dose (1.5 Grads)
  - Small footprint, Light-weight, flexible, low thermal conductivity.
  - Low-loss, long-range signal transmission(“Remote sensing”)
  - Wavelength encoded (multiplexing capability)
  - Embedding in composite materials.
  - Mass producible at reasonable costs.

FOS for environmental and structural monitoring industry driven technology

A FBG-BASED REAL TIME ESTRUCTURAL AND ENVIROMENTAL MONITOR FOR BELLE-II VXD.



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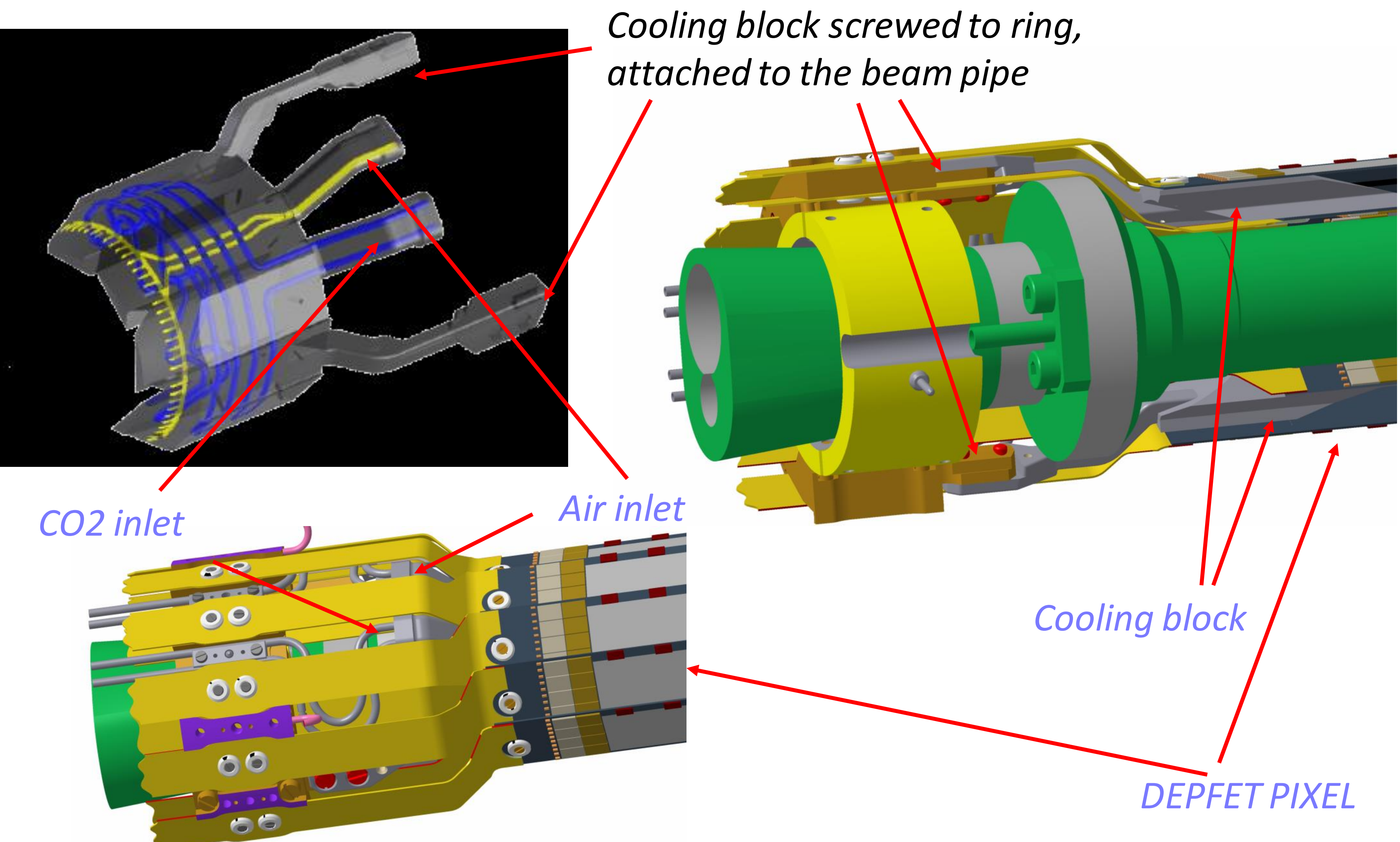


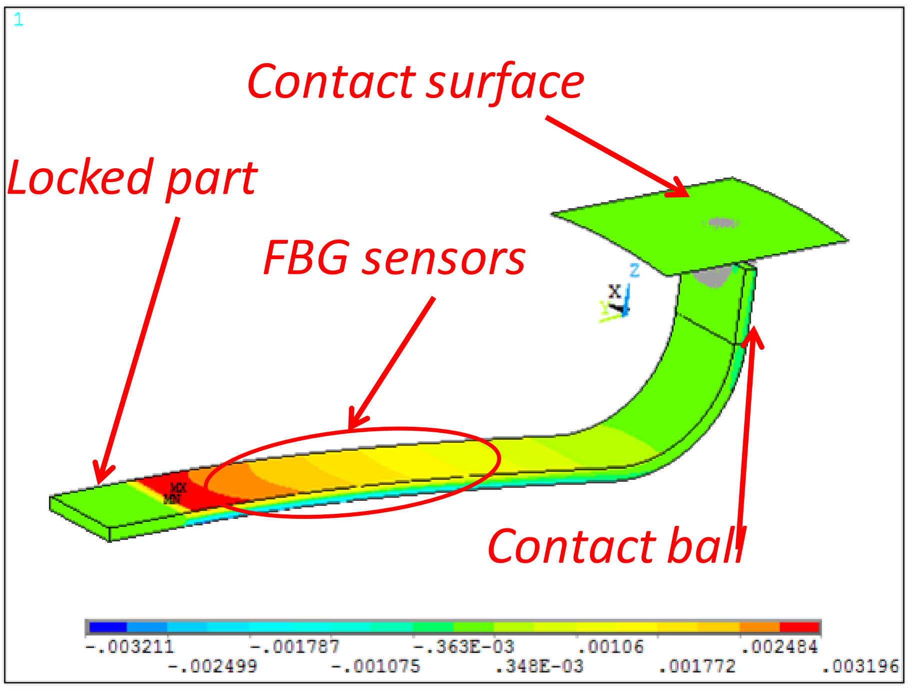
FBG Real time monitor for VXD

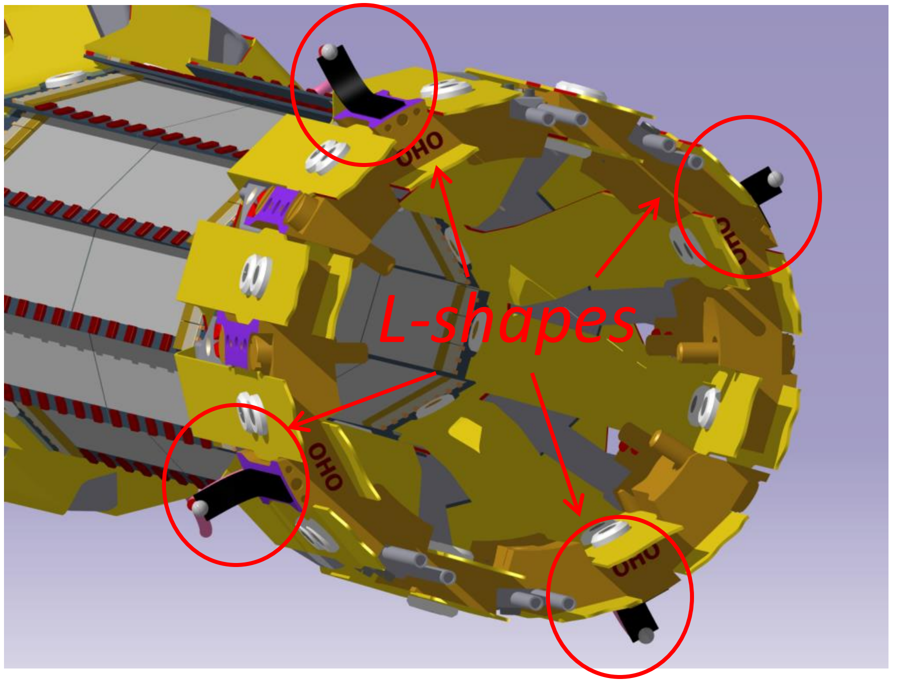
- Relative PXD-SVD radial positioning.
  - Using displacement FOS-based custom made transducers (Omega and L-shape)
  - Radial compressions and expansions (PXD and SVD are mechanically independent) are a mode to which track-based alignment has a poor sensitivity.
- Environmental measurement inside the PXD-SVD thermal envelope
  - PXD & SVD cooled with CO2 and forced air; inside the thermal envelop we will have a dry atmosphere (Dry air or Nitrogen).
  - Distributed FBG network for temperature and humidity monitoring.

_Displacement-Strain transducers

- The idea is to monitor online PXD-SVD relative displacement using a tiny CFRP structure with FBG sensors embedded.
- Four Omega Shapes($\Omega 1$, $\Omega 2$, $\Omega 3$ and $\Omega 6$) and three L shapes (L-1,L-2,L-3) have been manufactured and calibrated with temperature and displacement

L-shapes attached to Belle II PXD

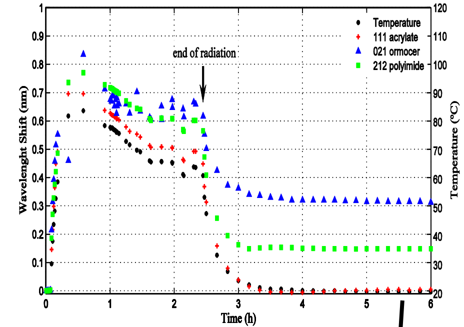


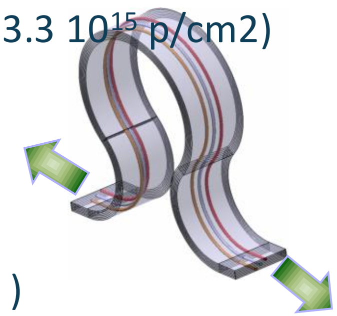


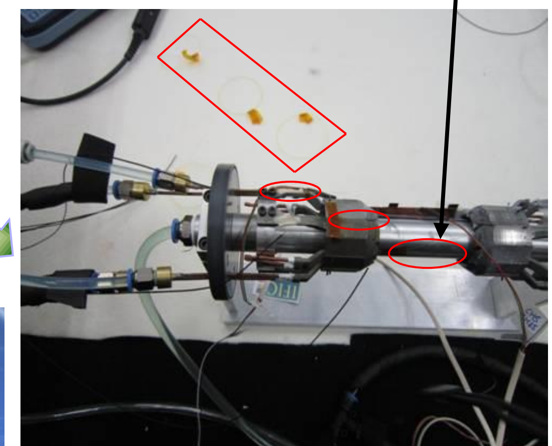
VXD FOS Monitor Timeline

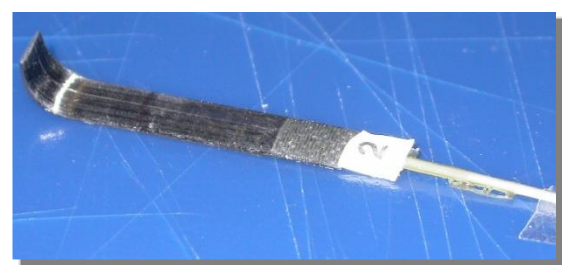
- ☑ 2009 Oct FOS Monitor proposal
- ☑ 2010 Jan Omega-shape proposal
- ☑ 2010 Oct. FOS radiation hardness study (1.5 GRads ,3.3 10^{15} p/cm2)
- ☑ 2011 January First omega mechanical dummies
- ☑ 2011 March Test in depfet mock-up at IFIC
- ☑ 2011 Sept. FOS radiation hardness study (10 Mrads)
- ☑ 2011 Dec Proof-of-comcept-prototype omega
- ☑ 2012 Feb Omega calibration.
- ☑ 2012 March New transducer design L-shape
- ☑ 2012 May Test in depfet mock-up at IFIC
- ☑ 2012 October L –shape calibration

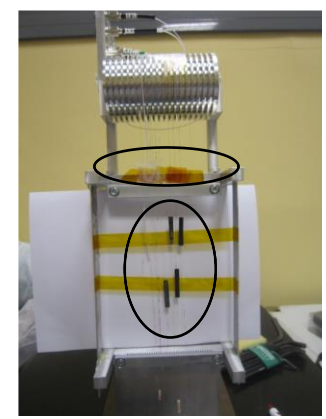
  (resolution less 1 um ,accuracy≈10 um)
- ☑ 2013 May Test in deftet mock-up at IFIC (N_2 atmosphere)
- ☐ 2013 June-July Omegas and L-s irradiation ELSA
- ☐ 2014 January commissioning at PXD-SVD common test beam









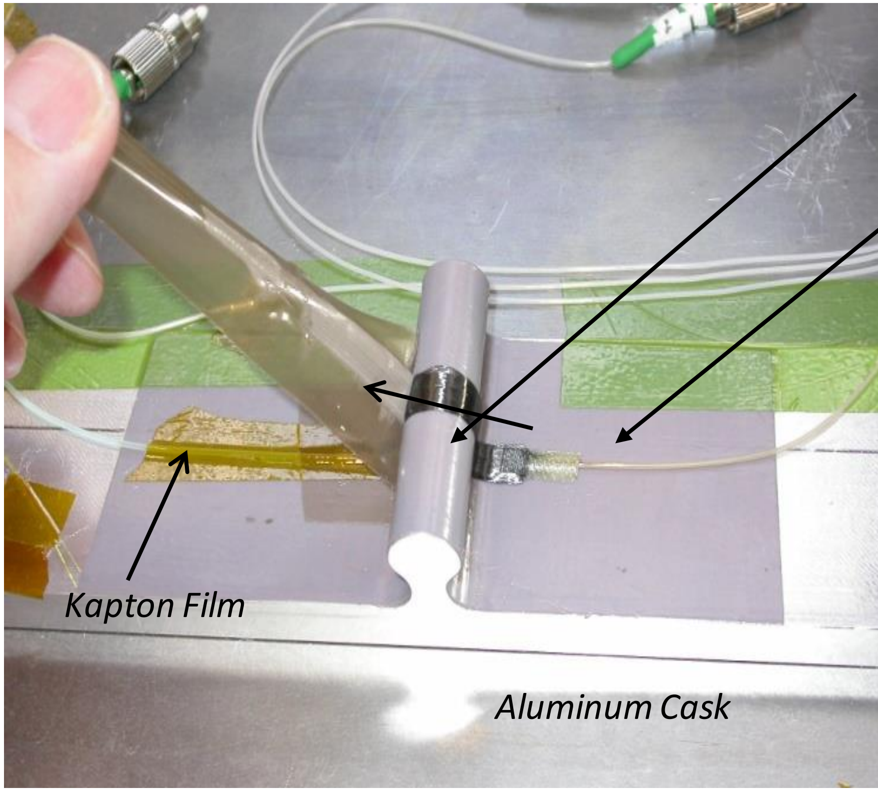


Omega Shapes & L-shapes Manufacturing

Omega Shape

Omega CFRP layout

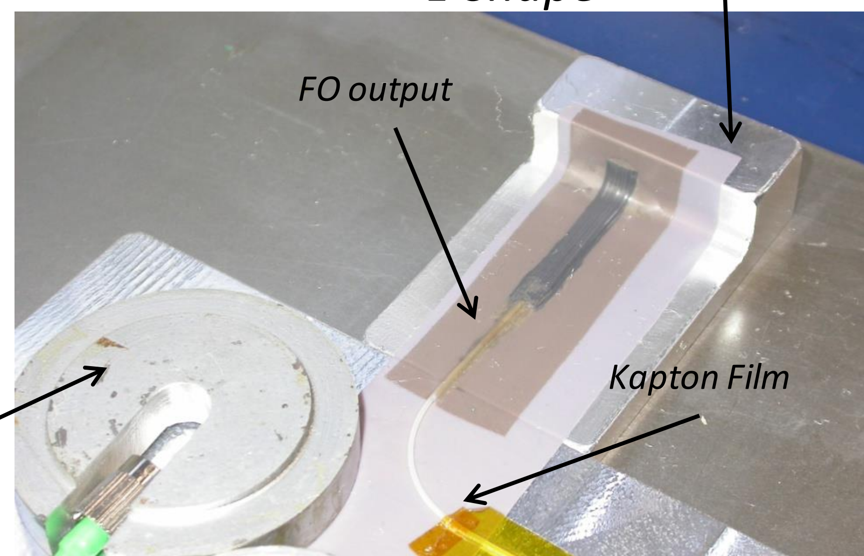
FO output



Aluminum support base

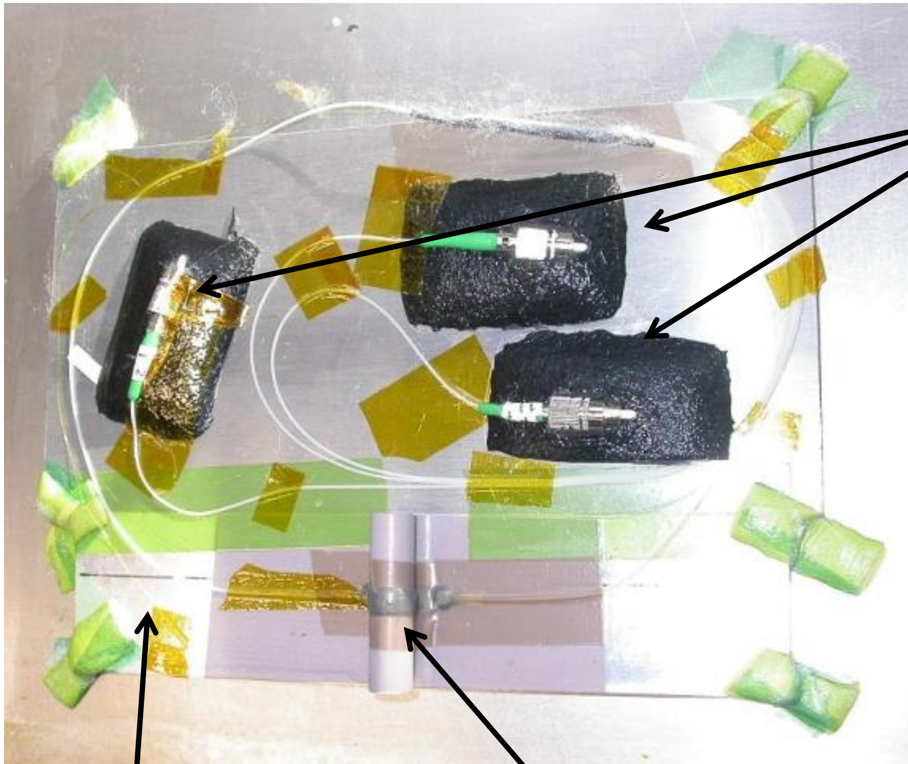
Aluminum Cask

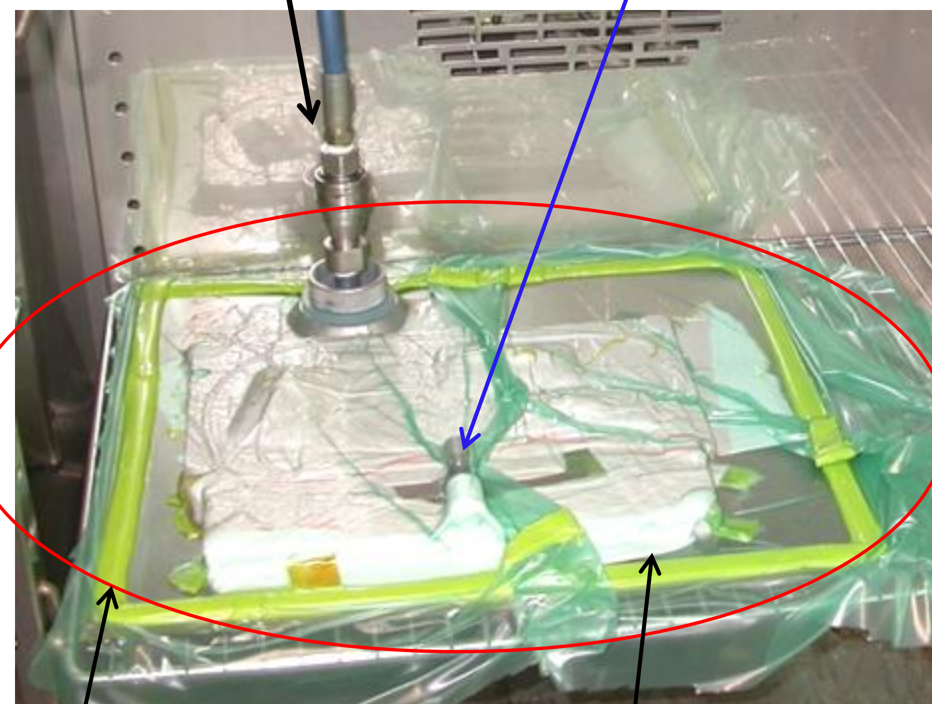
L-Shape



Steel cask for connectors protection

Omega Shapes an L-shapes Manufacture Process

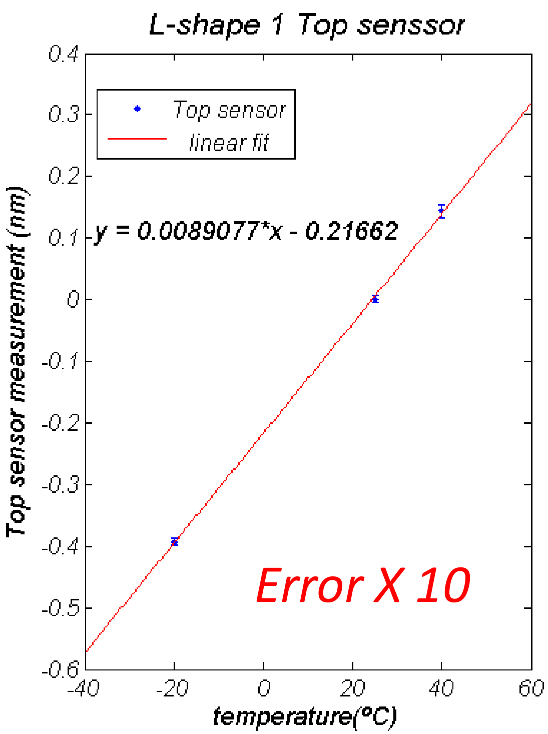


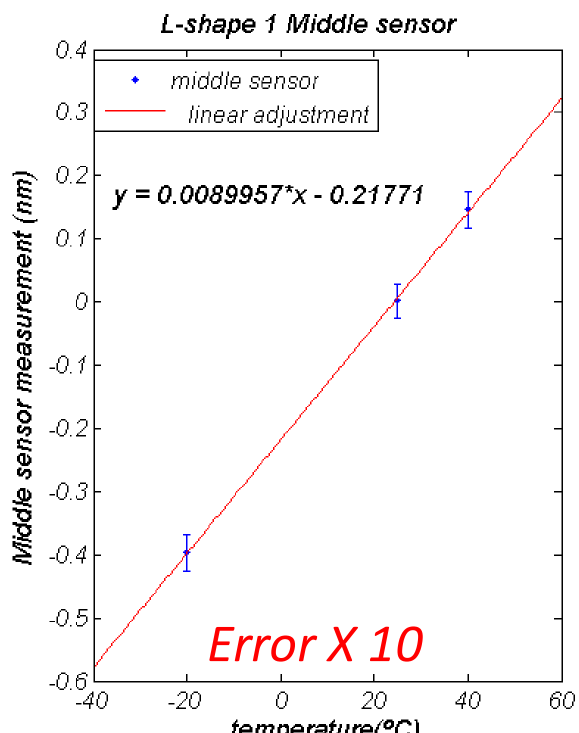


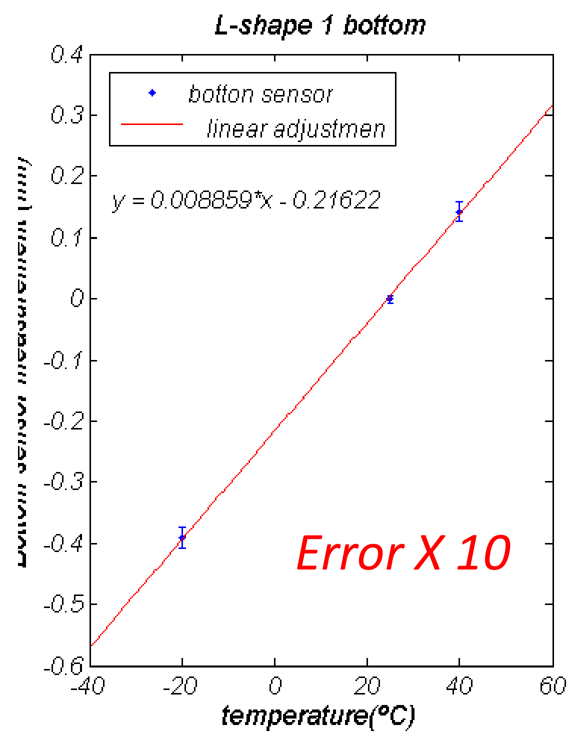
Thermal calibrations and temperature compensation

- Omega and L-shapes were calibrated using a thermocouples calibrator. They were calibrated to three different temperatures, and the calibration was repeated three times.
- The sensitivity of three sensors was constant and near the same (difference<0.6%)

Maximum error < 3 pm (0.3 ºC)



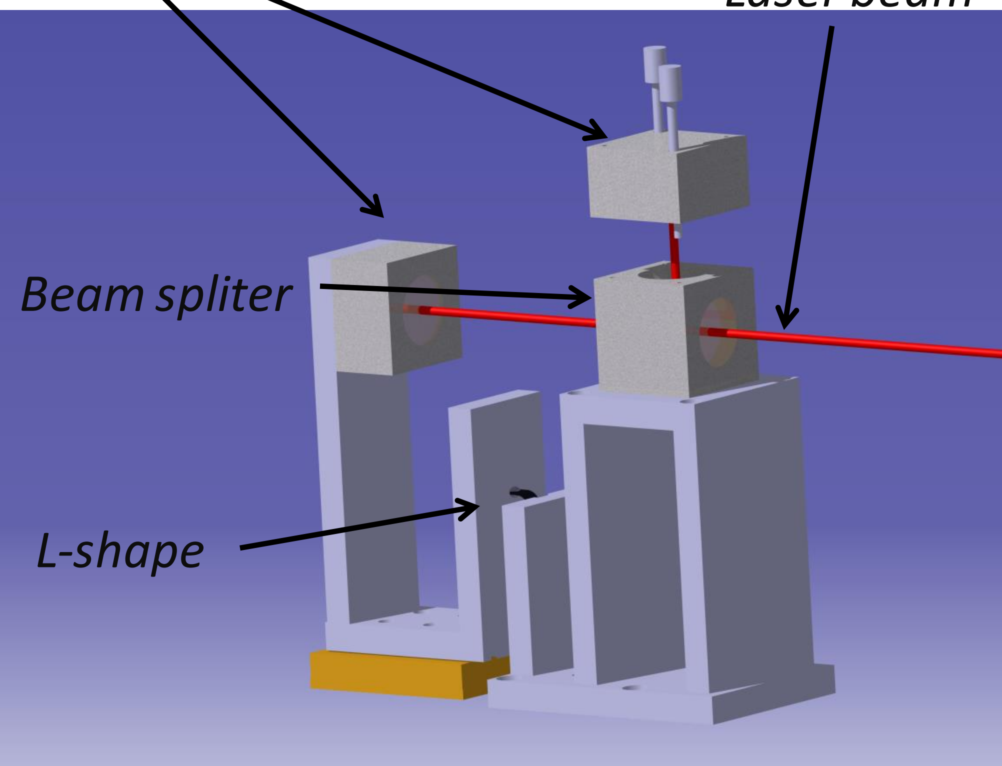


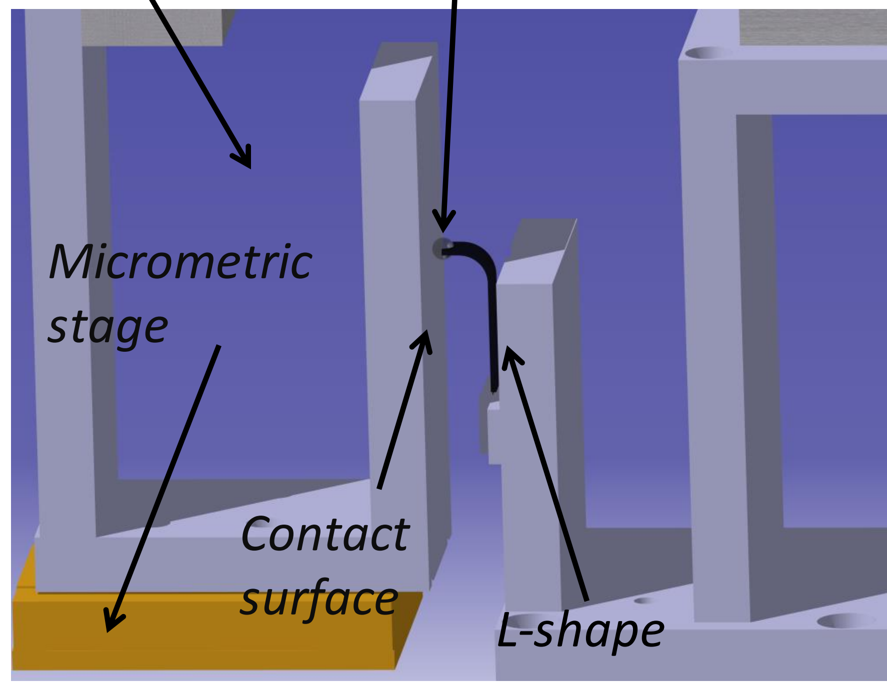


  – Trivial approach to temperature compensation with subtraction of top and bottom sensor readout (Destimator)

Interferometric calibration set-up

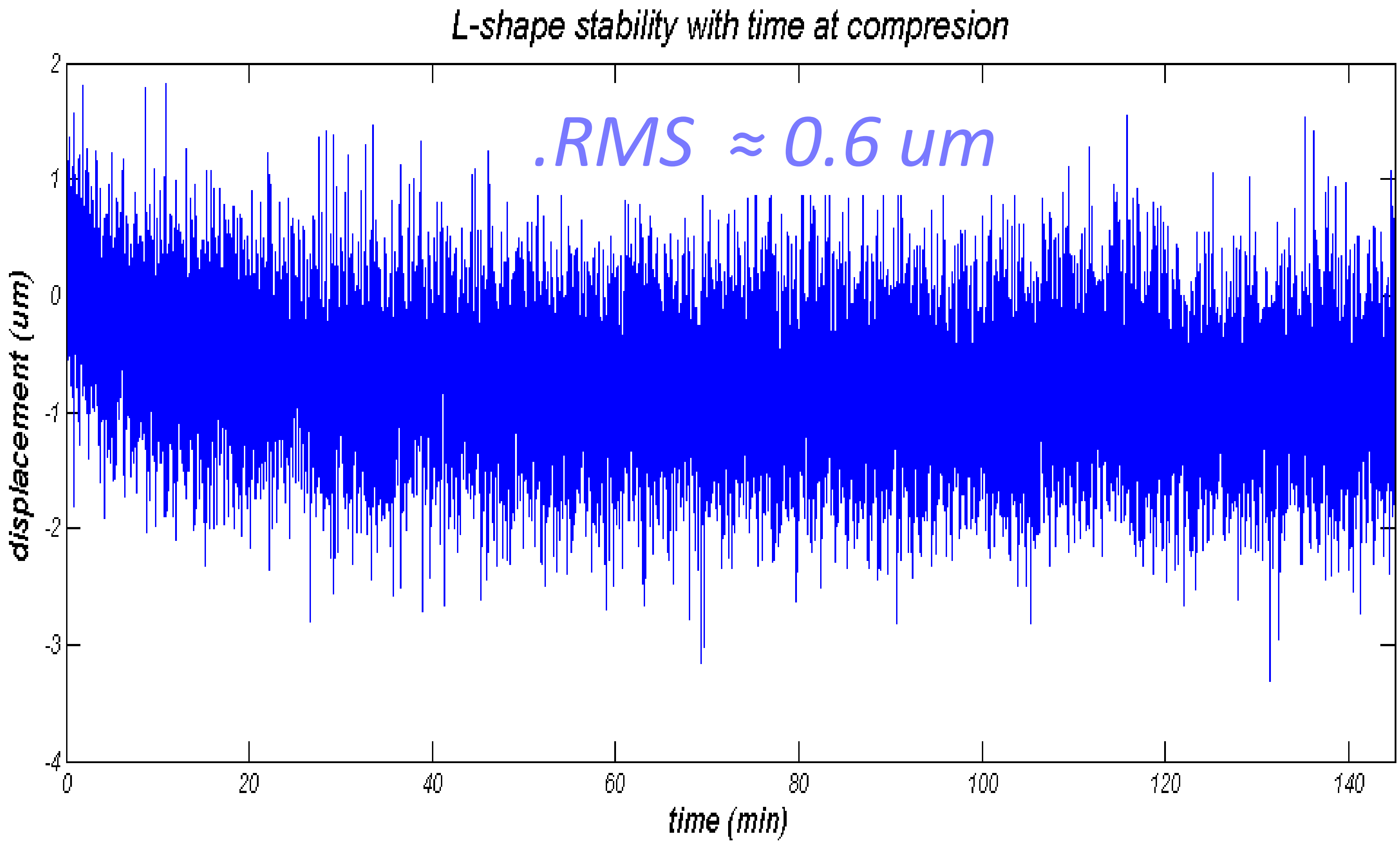
- We have setup a Michelson interferometer for the L-shape calibration
- The use of the Interferometer allow us to measure the displacement with a resolution and an stability below the micron.





L-shape stability study

- The stability of the L shape was measured during near two and a half hours at a compression of near 0.2 mm.



L-shape repeatability study

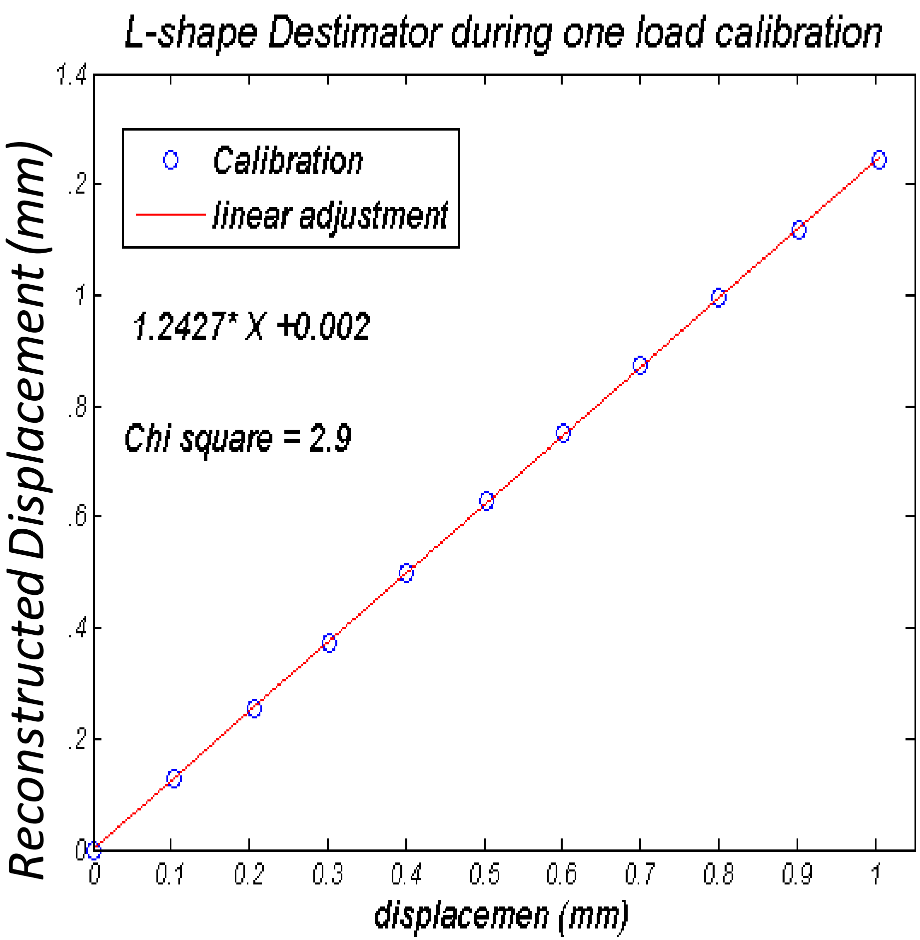
- Repeatability measurements done with the interferometer
- The L-shape was compressed between 0.3 mm and 1.1 mm and this process was repeated seven times with a repositioning better than 1 um according to the interferometer readout.
- Tables show the deviation with respect to the initial position

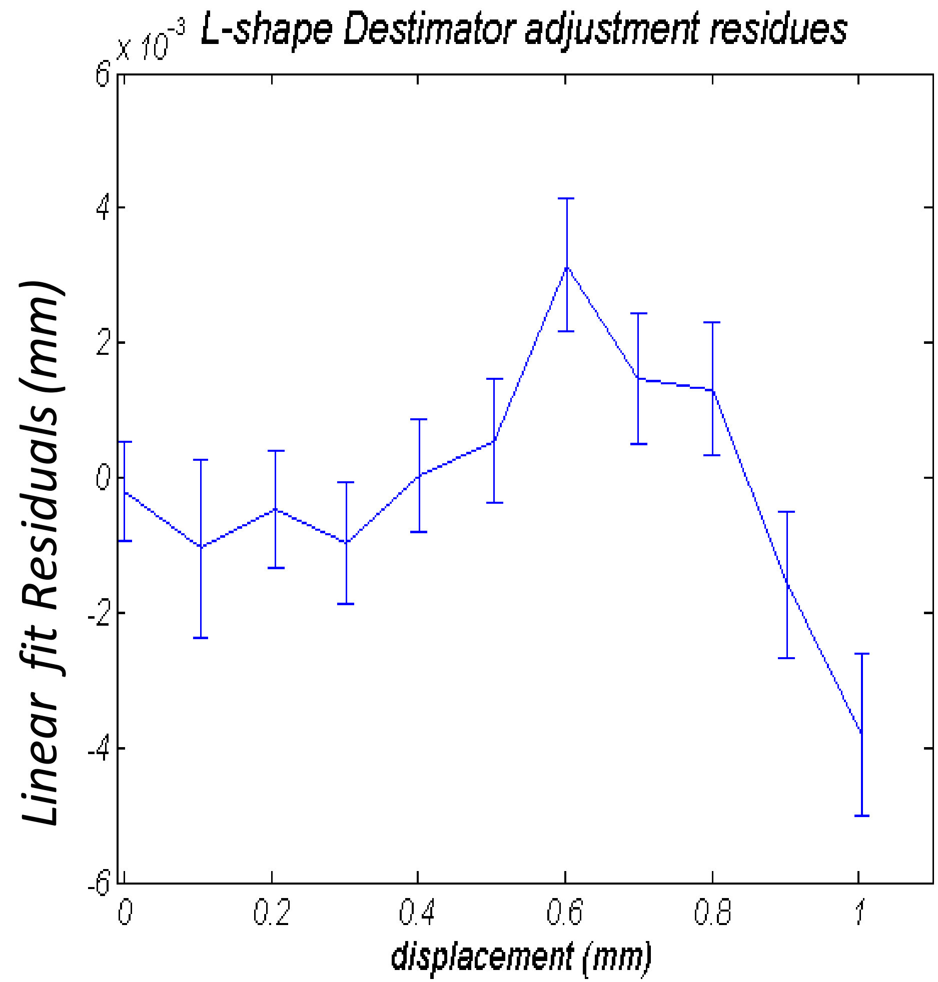
0.3 mm displacment	
Nº of measure	Destimator desviation (um)
1	1.77
2	5.08
3	6.85
4	6.61
5	7.02
6	8.39
7	9.35
rms(um)	2.46 um

1.1 mm displacment	
Nº of measure	Destimator desviation (um)
1	-16.94
2	-9.11
3	11.21
4	11.45
5	5.65
6	-12.34
rms	12.60 um

L-shape Calibration: Response vs. displacement

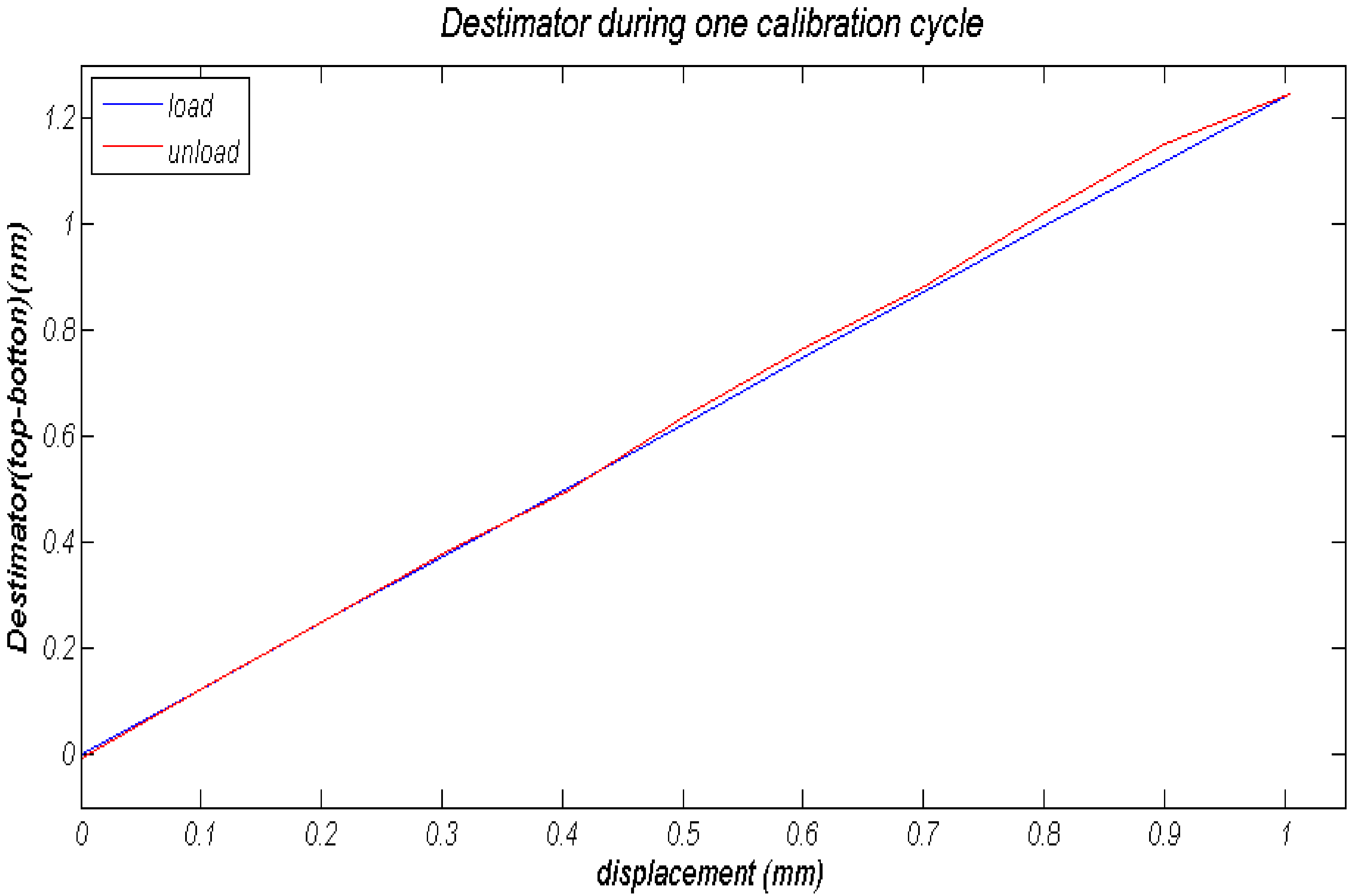
- The L-shapes have been compressed in steps of 0.1 mm up to a total compression of 1 mm
- The L-shape has a resolution below one micron.





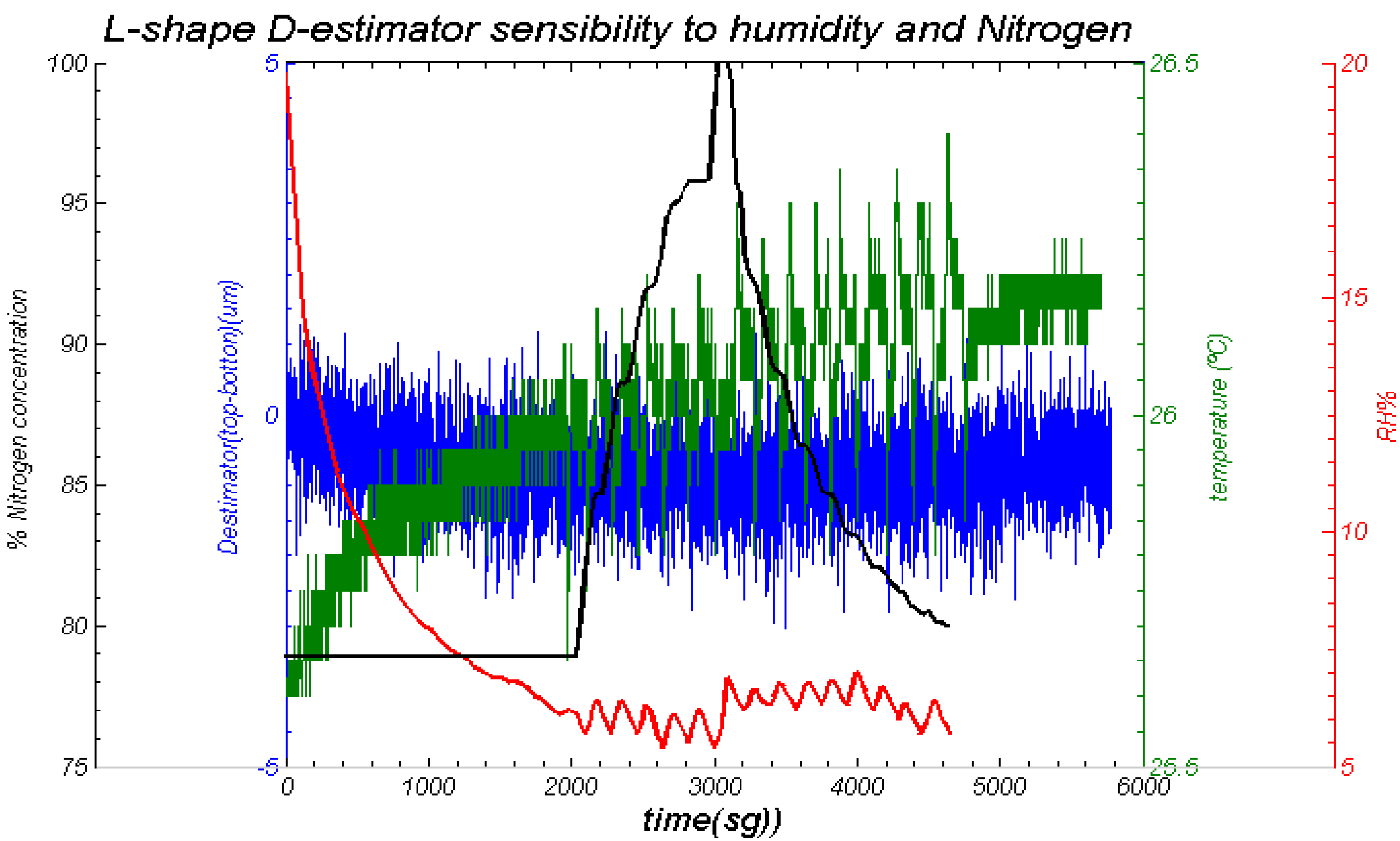
L-shape Calibration problem

- Some problems due to contact roughness surface on the uncompressing displacement.

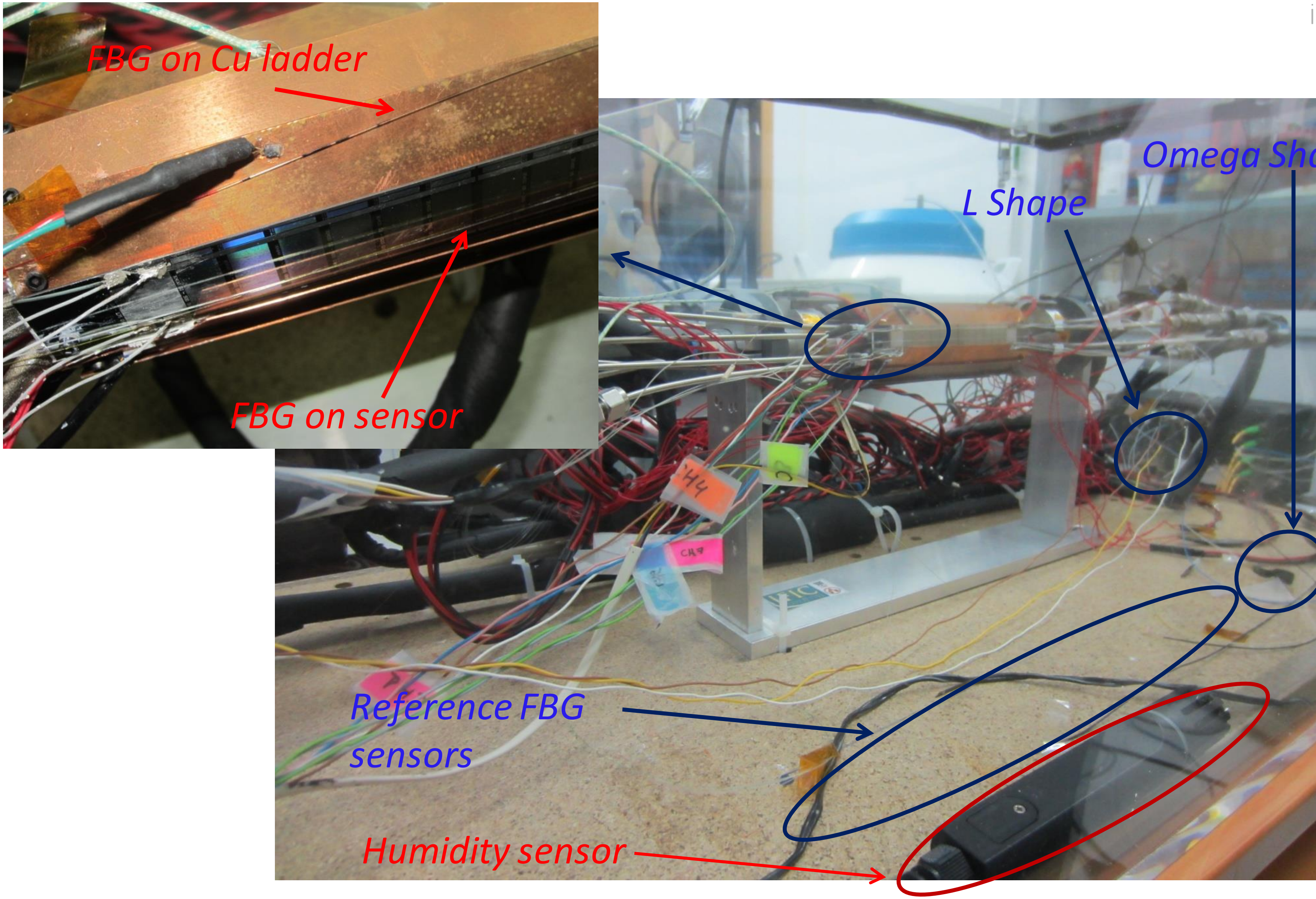


L-shape humidity and Nitrogen sensitivity

- The L-shape was introduced in IFIC PXD mockup and some humidity and Nitrogen cycles where done
- We concluded that the L-shape is not sensitive to humidity changes or Nitrogen concentration.



Environmental monitoring at IFIC Defpet Set-up



Summary …

- A displacement and environmental monitor for the Belle II vertex detector based on Fiber Bragg Grating optical sensors was introduced.
- A miniaturized, application specific, displacement transducer (L-shape) was designed, developed and (almost) fully characterized with a displacement resolution of about 1 um.
- L-shape experimentally proven not sensible to the environmental conditions of Belle-II thermal envelope: changes in HR%, temperature and N_2 concentration.

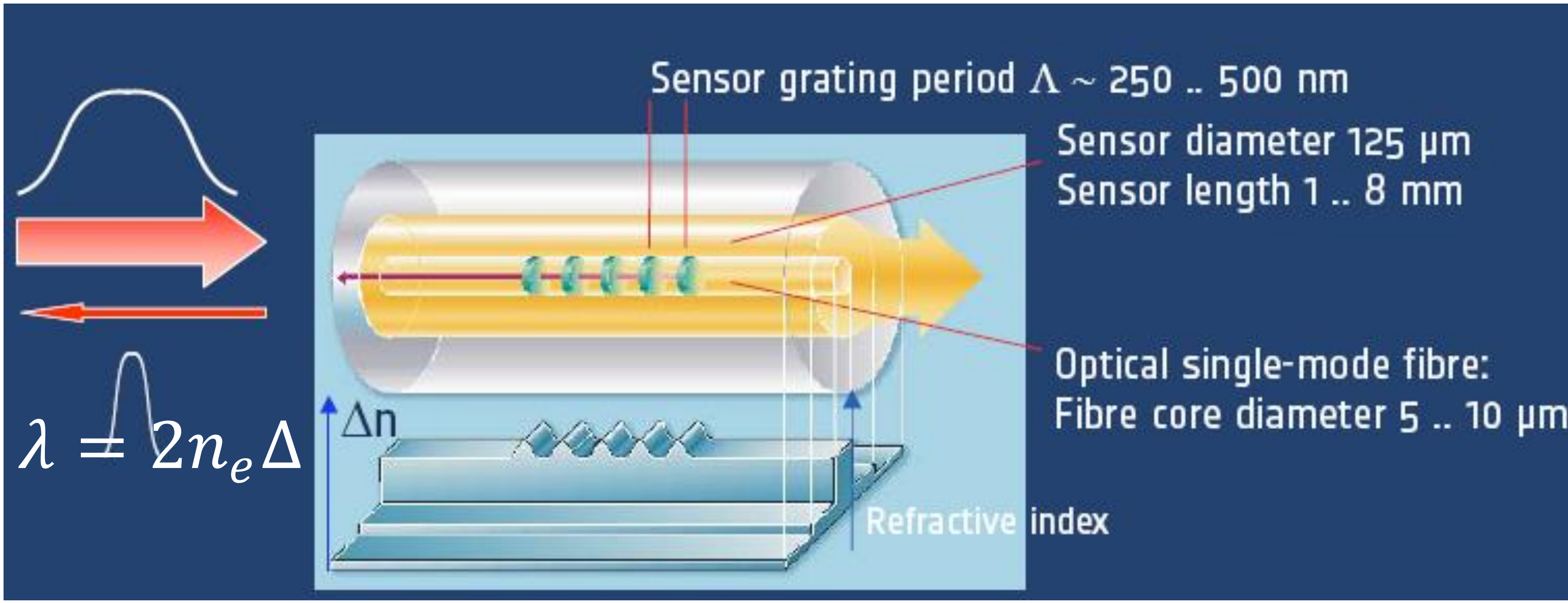
… and work in progress

- Roughness of the contact surface with the sensor tip limits sensor precision (repeatability) and accuracy (few tens of microns). Optimize the L-shape tip and contact surface
- 2013 June-July, new Irradiation at Elsa with electrons up to 10 Mrads
- 2014 January, partial of the system commissioning at PXD-SVD common test beam @ DESY.

BACK - UP

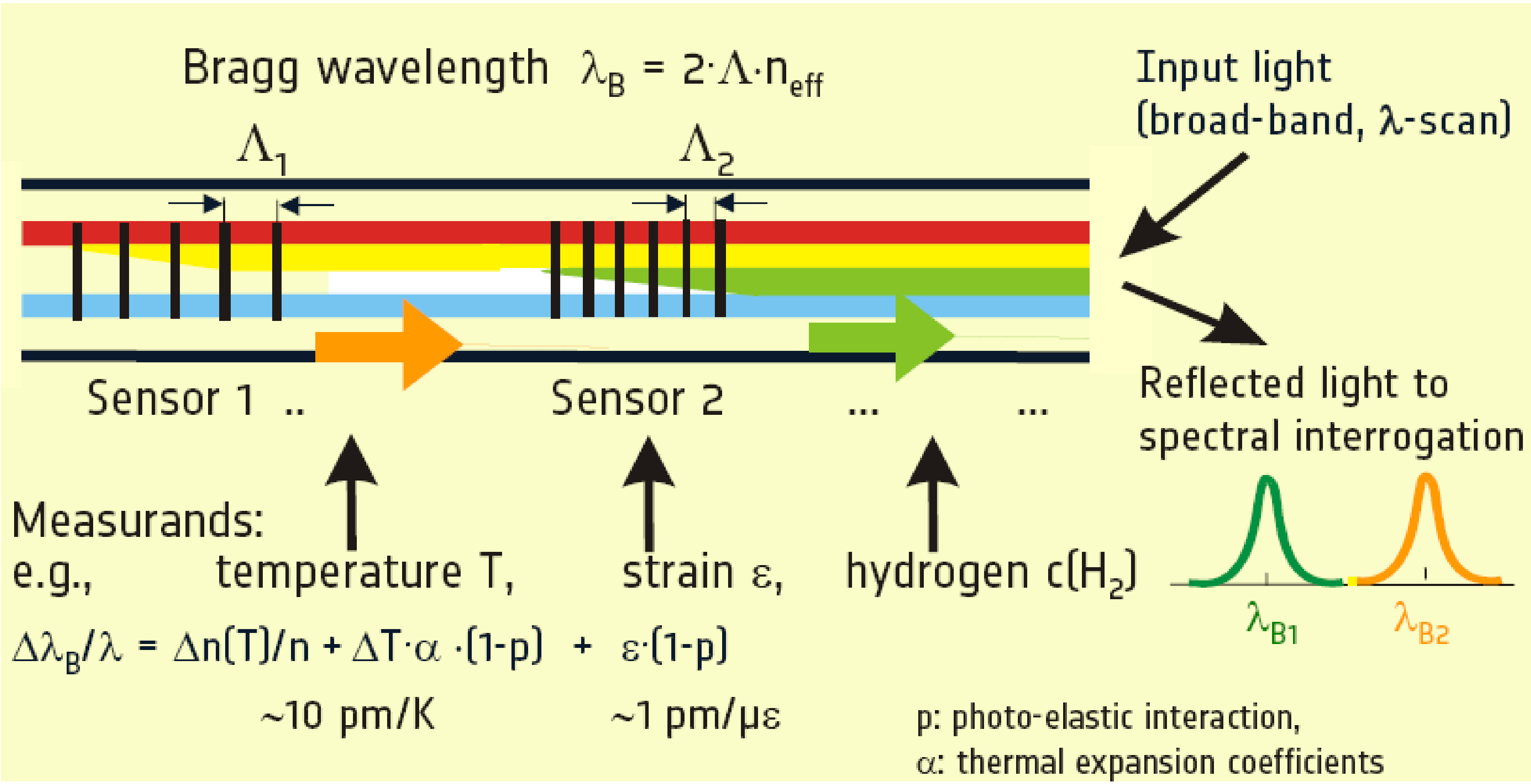
_Bragg grating sensor basics

- FOS monitoring is an standard technique in aeronautic and civil engineer



- Mechanical sensitivity $\Delta\lambda_B/\lambda = \varepsilon\cdot(1-p)$
- Thermal sensitivity $\Delta\lambda_B/\lambda = \Delta n(T)/n + \Delta T\cdot\alpha\cdot(1-p)$

_Bragg grating Multiplexing



_Basic Interrogating Unit

The number of different Braggs is more than 100; moreover by using an optical switching we can use tens of sensing fiber