ON THE USE OF FIBER OPTIC SENSORS FOR STRUCTURAL AND ENVIRONMENTAL MONITORING OF THE BELLE II VERTEX DETECTOR

Forum on Tracking Detector Mechanics, June 2014

D. Moya, I. Vila, A. L. Virto, E. Currás , A.Ruiz

Instituto de Física de Cantabria

M. Frovel, J.G. Carrión

Instituto Nacional de Técnica Aeroespacial

A. Oyanguren, C. Lacasta, P. Ruiz

Instituto de Física Corpuscular

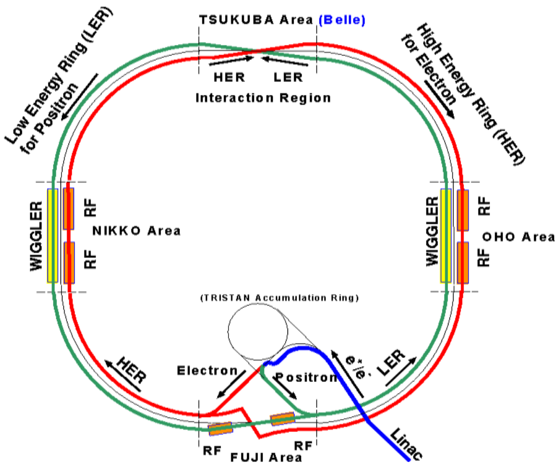
David Moya Martín, IFCA (CSIC-UC)

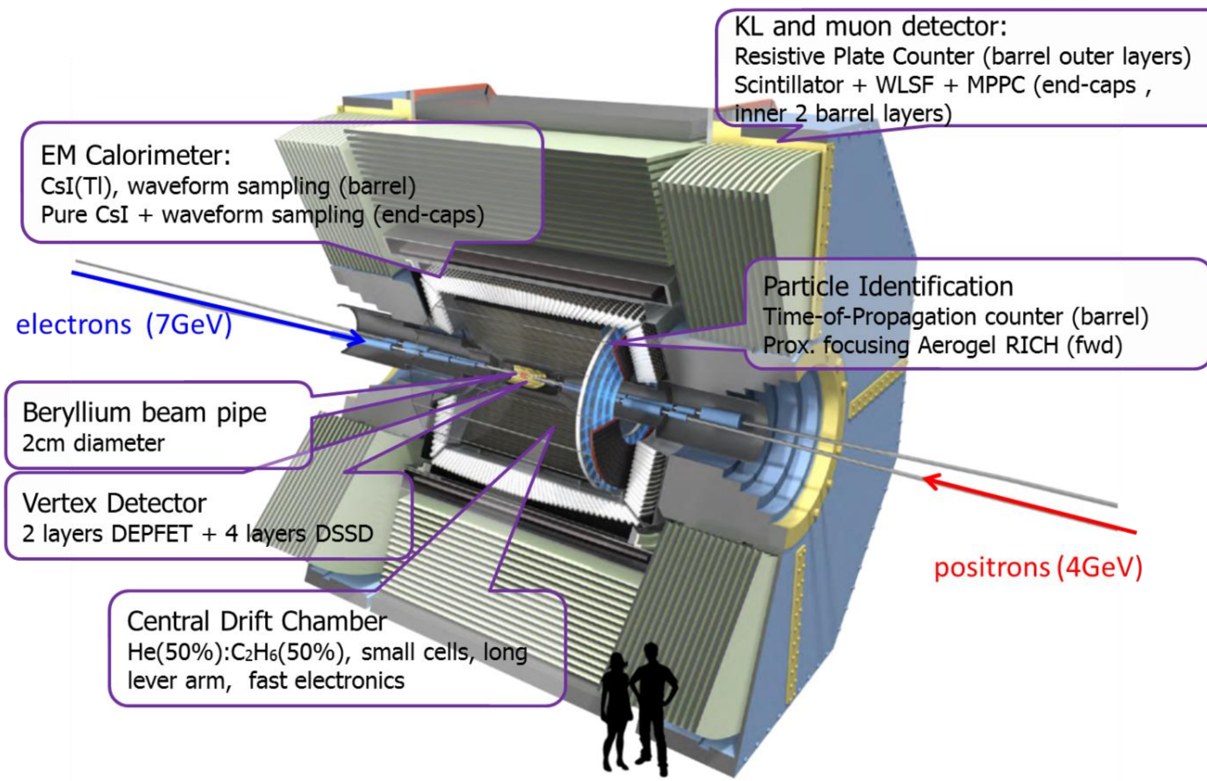
Outline

- Introduction Belle II Vertex detector
- FBG monitoring system for Belle II vertex detector
- Introduction to FBG sensors
- Environmental sensor characterization
- Displacement transducers
- Belle II PXD/SVD common test beam environmental and structural monitoring.
- Summary and Outlook

Introduction to Belle

- Belle II is an experiment for flavor physic studies expected to be commissioned at KEK in 2016





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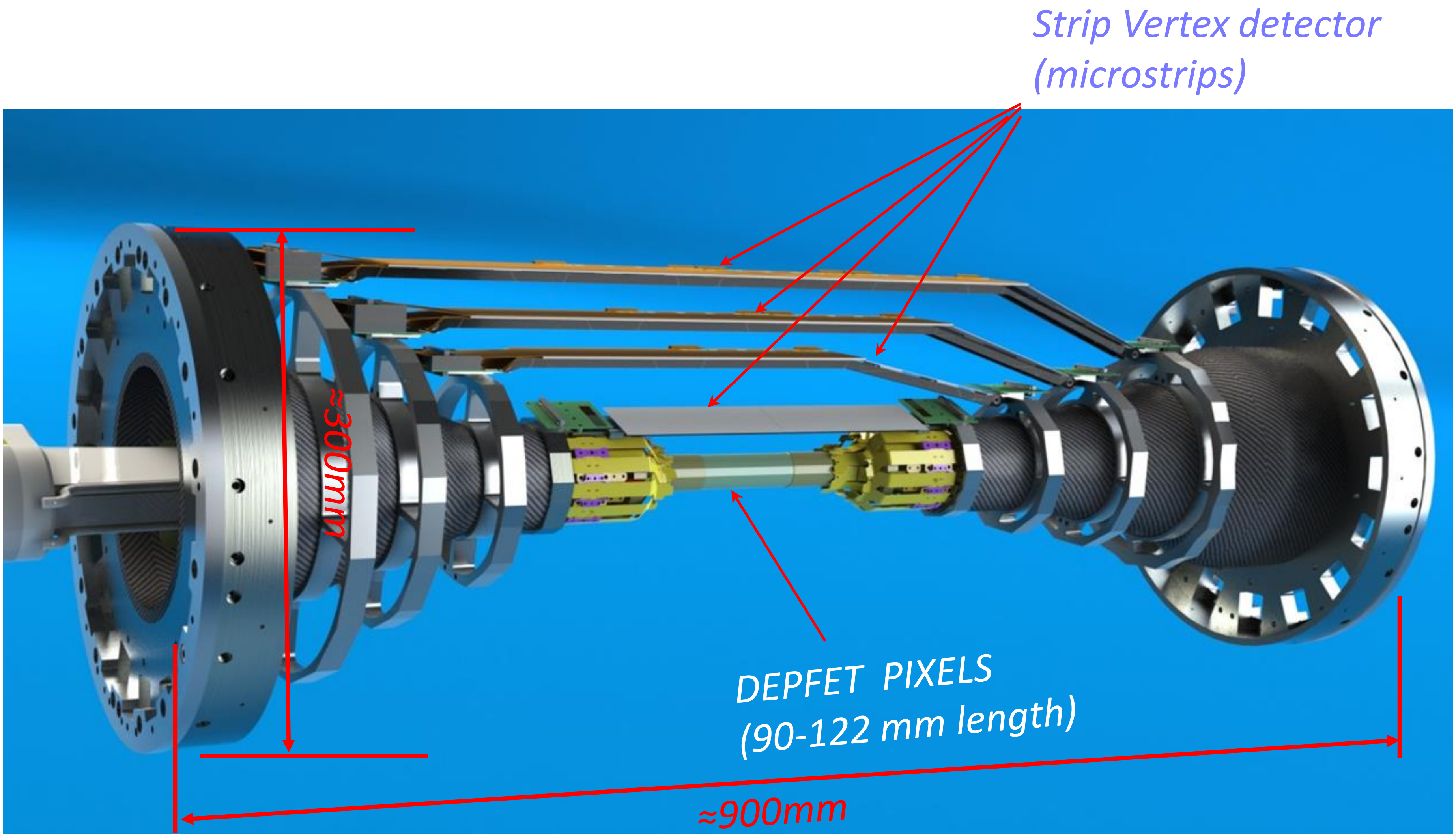
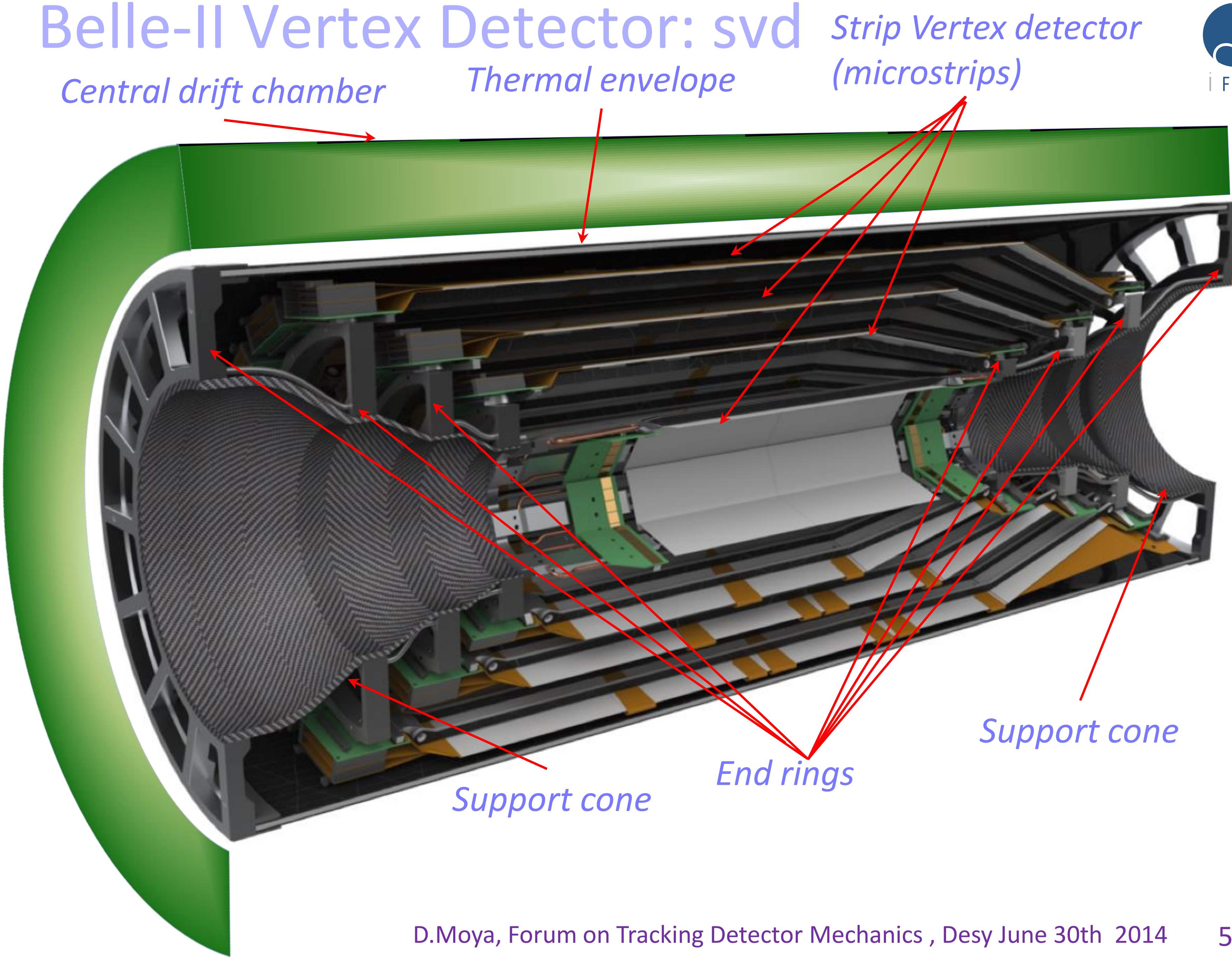
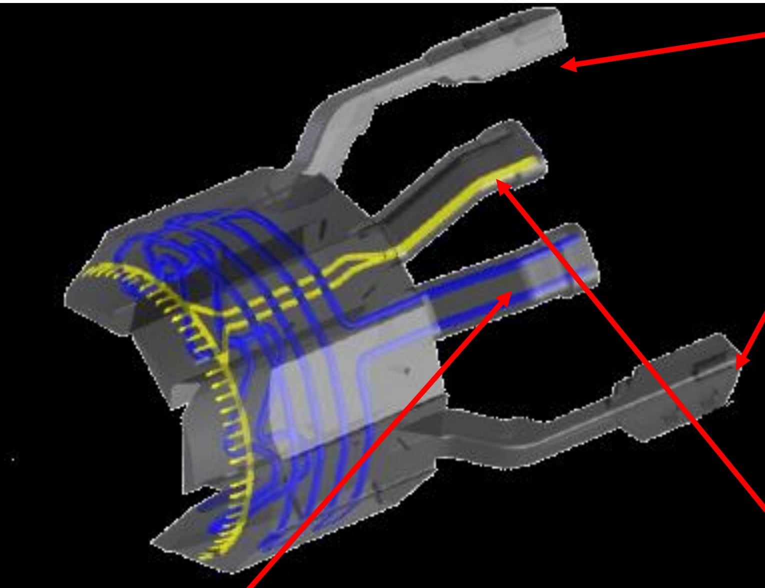
Belle-II Vertex Detector



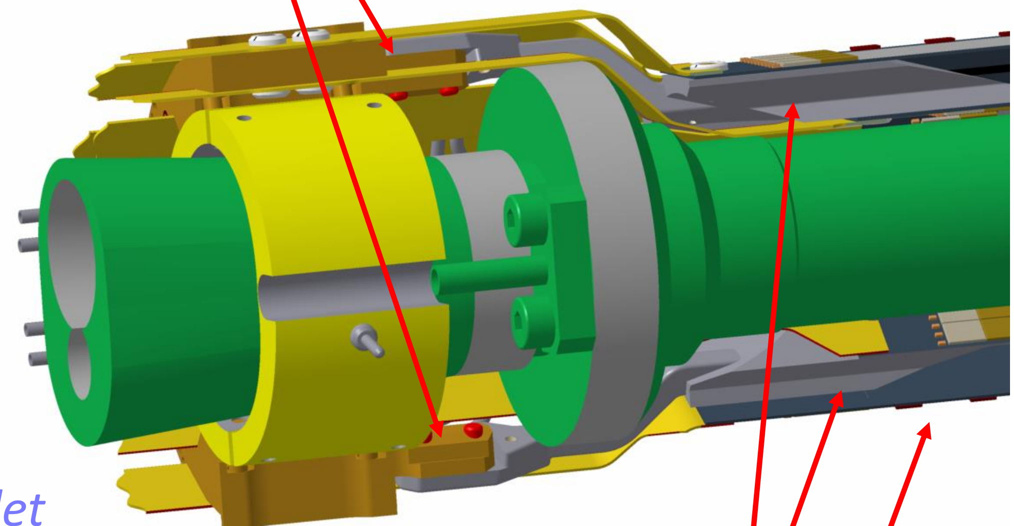
Belle-II Vertex Detector: svd



PXD Cooling Strategy

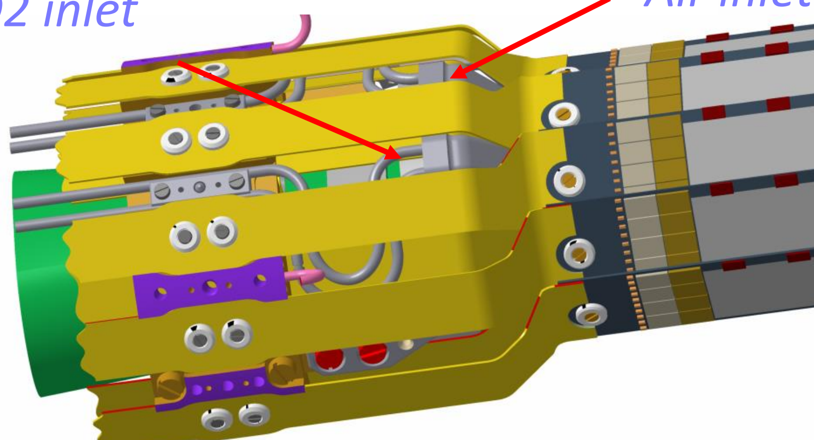


Cooling block screwed to ring, attached to the beam pipe



CO2 inlet

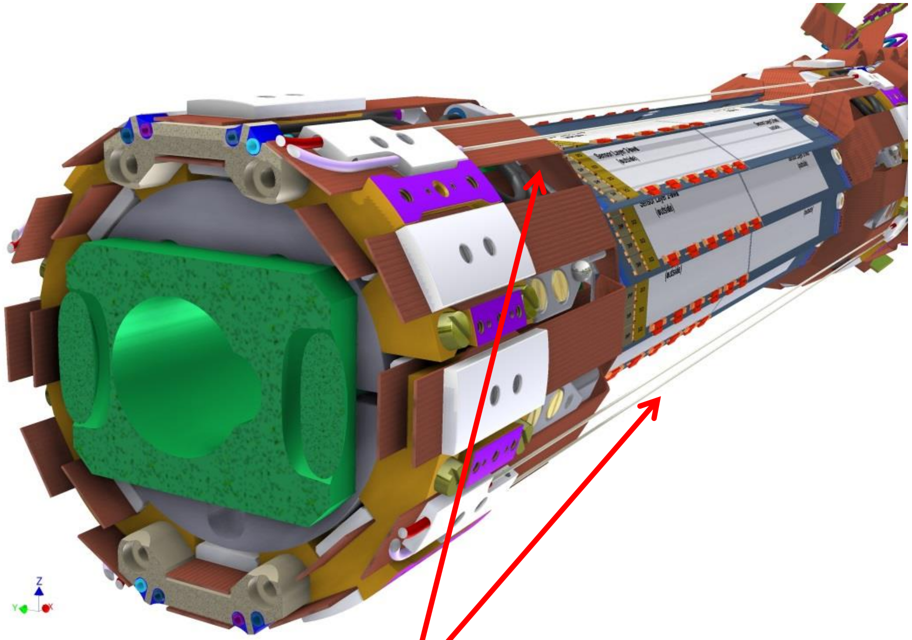
Air inlet

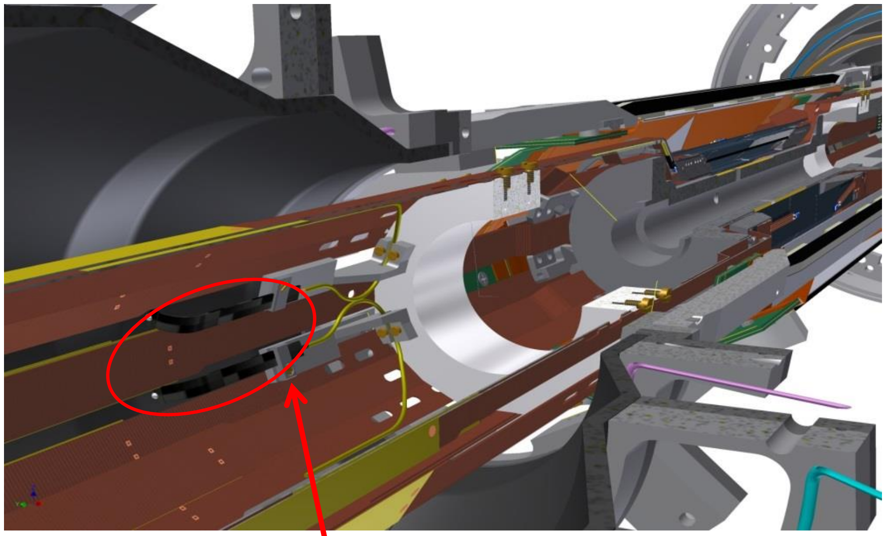


Cooling block

DEPFET PIXEL

Solution: FOS Monitor system





Eight fibers for environmental monitoring (4 for temperature and 4 for RH% measurement)

Four L-shapes per side in order to measure relative PXD - SVD radial displacements or relative displacements in Z direction

		Total Nº of fibers	#Nº of fibers (NIKKO SIDE)	#Nº of fibers (OHO SIDE)	Diameter in sensing area (mm)
PXD	Relative displacement measurement (L-shape)	16	8	8	0.16
	Measures temperatura (2nd/3rd layer)	4	2	2	1
	Measures Humidity (2nd/3rd layer)	4	2	2	0.16

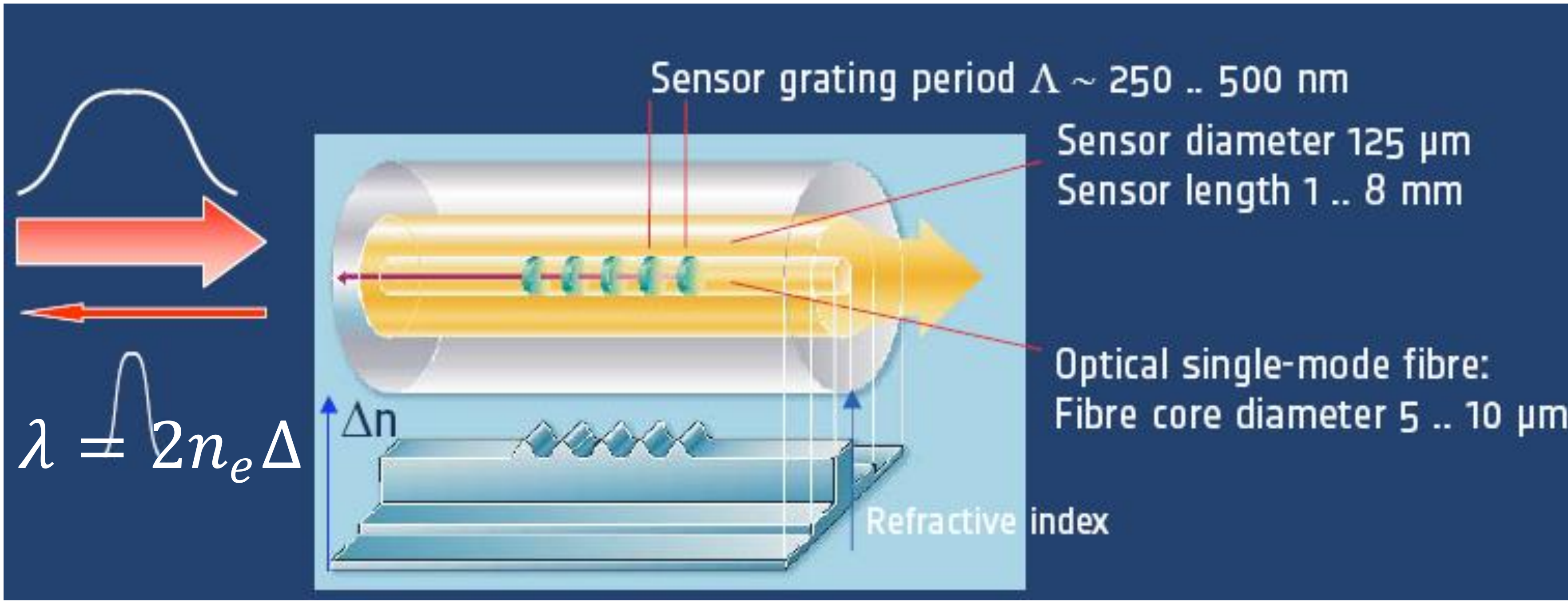
Introduction to FBG sensors

FOS for environmental and structural monitoring industry driven technology

- Main advantages for particle physics:
  - Immunity against:
    - High electromagnetic fields, high voltages.
    - Nuclear radiation environments
    - High magnetic fields
  - Small footprint, Light-weight
  - Low-loss, long-range signal transmission
  - Multiplexing capability (sensor network) and fast readout (1kHz)
  - **Embedding in composite materials.**
  - Wavelength encoded (neutral to intensity drifts)
  - Mass producible at reasonable costs.

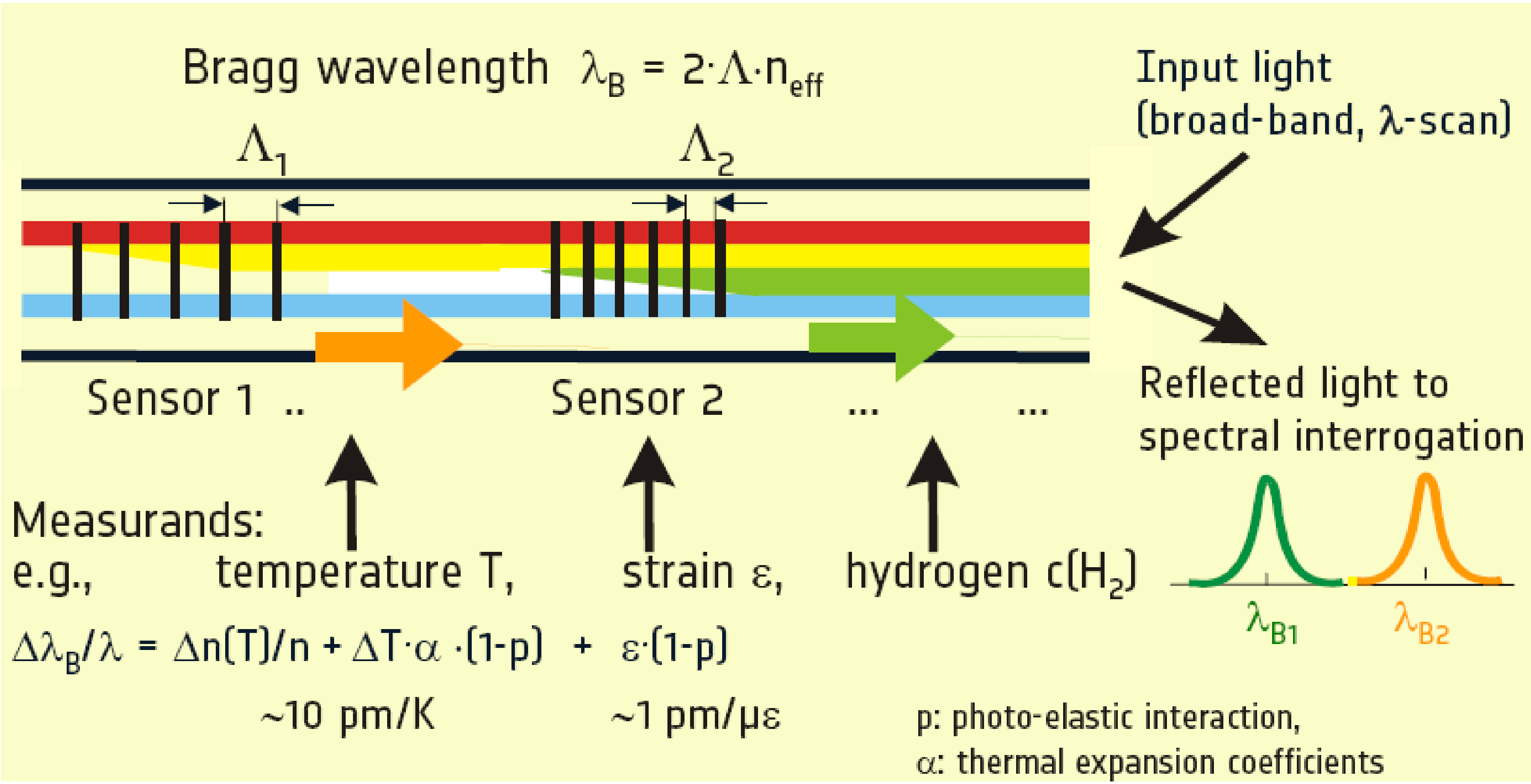
_Bragg grating sensor basics

- 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



FBG Environmental sensor development

Radiation Resistance Assessment

- Sensors resistance to irradiation must be Checked. (Two irradiation with protons up to 1500 and 10 Mrads)

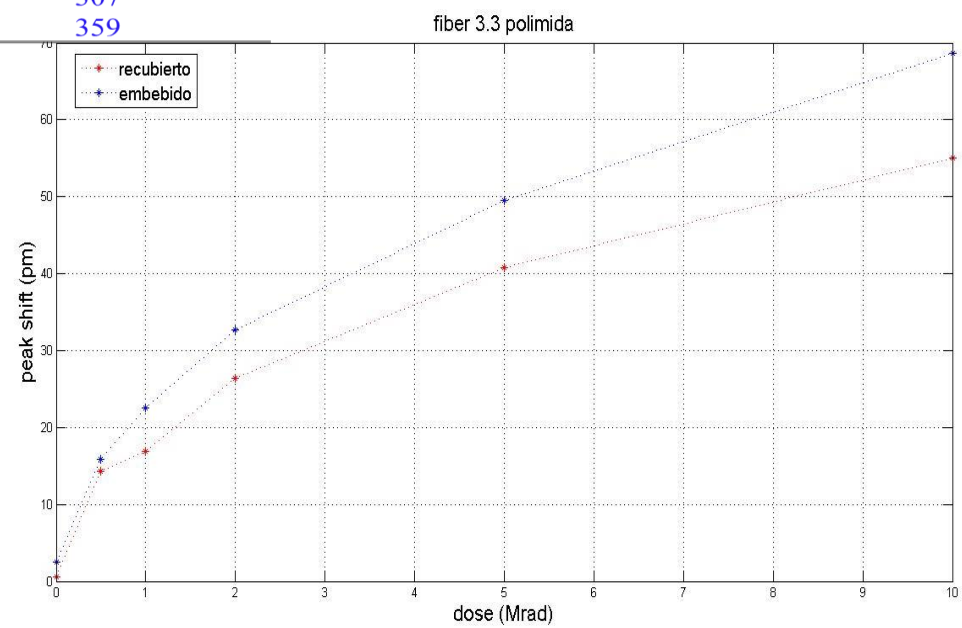
Sensor code	Coating	Amp. Change, dB	Peak Shift, pm
111	acrylate	-0.42	-3
112	acrylate	-0.15	-14
212	polyimide	-6.05	140
213	polyimide	-6.26	173
214	polyimide	-7.16	175
221	polyimide	-7.56	158
222	polyimide	-6.92	175
223	polyimide	-6.92	173
021	ormocer	-6.23	308
022	ormocer	-8.80	379
023	ormocer	-5.00	334
03	ormocer	-0.01	206
04	ormocer	-0.03	307
05	ormocer	-0.21	359

Irradiation up to 1.5Grads:

- *Acrylate coated sensors less peak shift (not sesible at all)*
- *Fiber type (Ge doped, H_2 loaded…) main parameters affecting the attenuation*

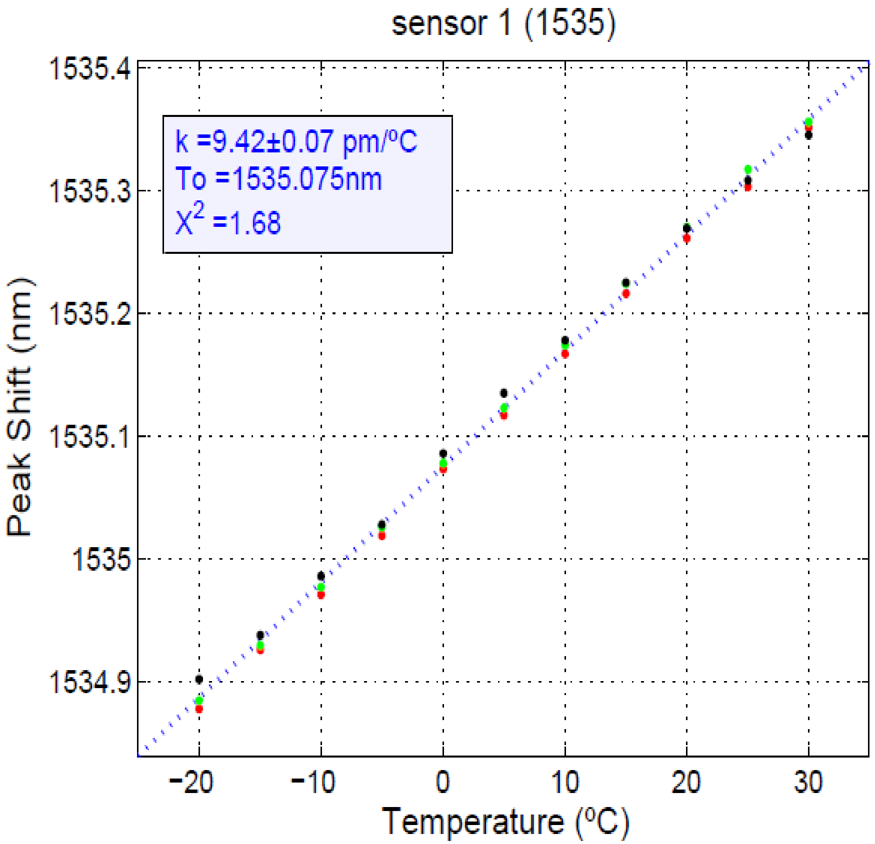
Irradiation up tu 10 Mrads (expected dose at Belle II after 10 years):

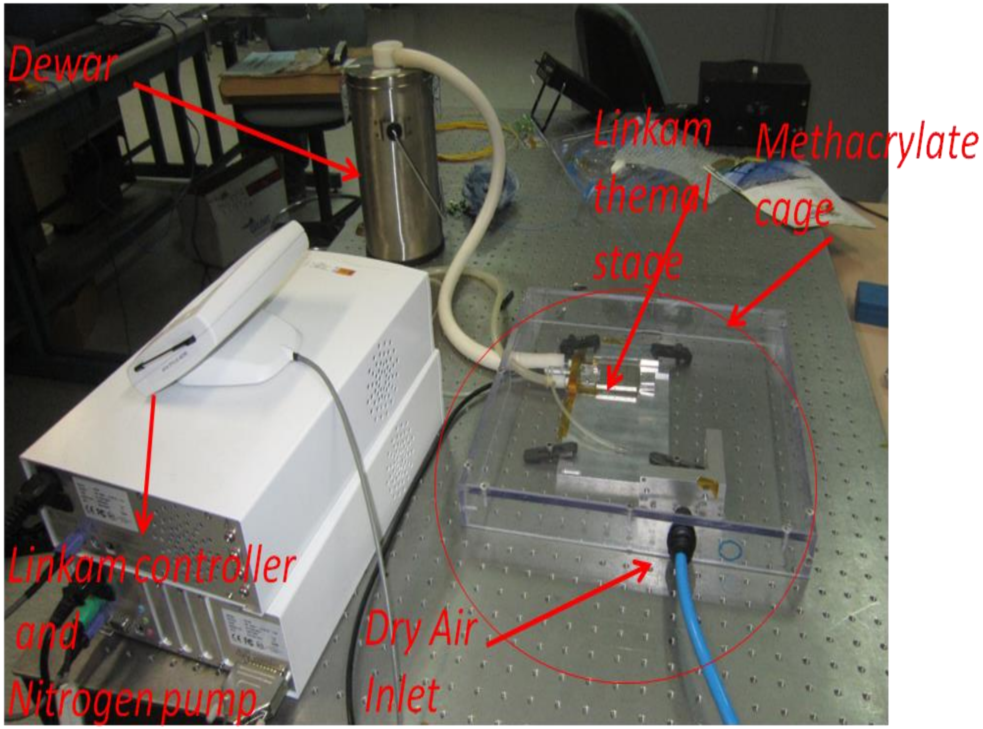
- FBGs sensitivity to radiation seems to saturate at higher absorbed doses.
- *After two weeks we saw an annealing effect an the sensors (nearly recovered initial wavelength value)*



Thermal Sensivitity: calibration

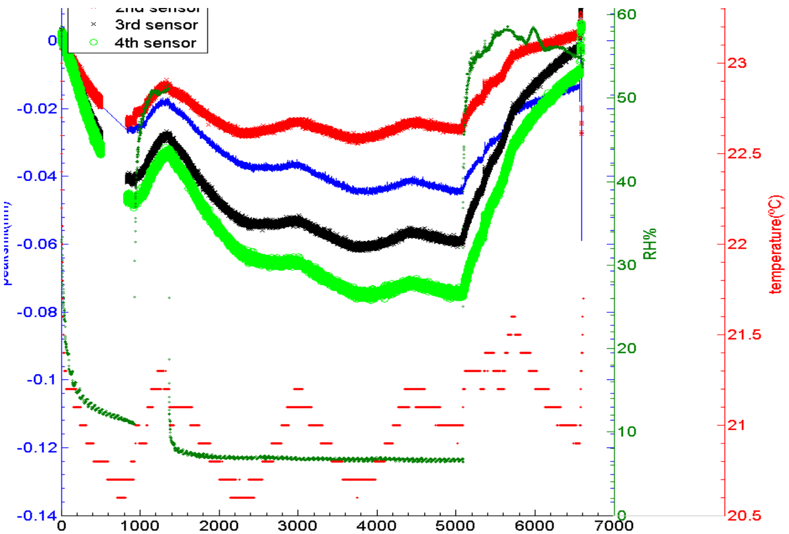
- Thermal sensitivity is measured in a custom set-up. A thermal stage (peltier + nitrogen pumping system) is used for the calibration. All the system is inside a methacrylate cage with dry air injection system.
- The temperature sensitivity is measured at ambient humidity (is not humidity dependant).





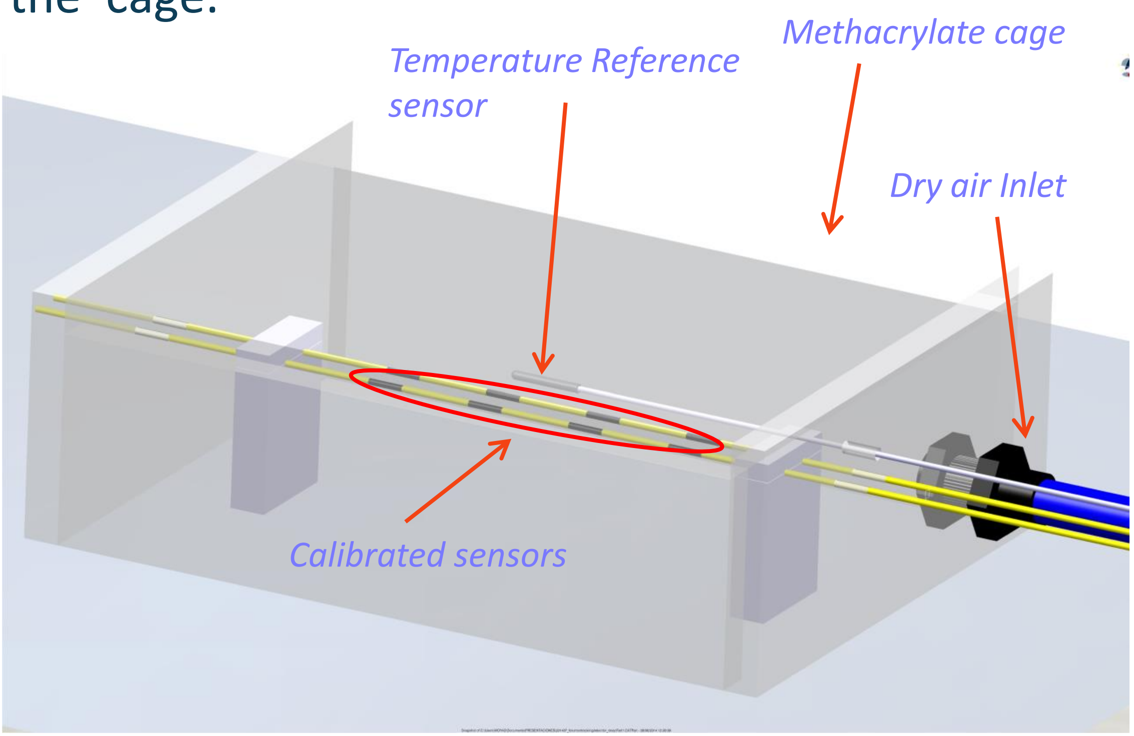
Residual dependence with Humidity

- Ormocer/Polyimide coated fibers are sensitive both to humidity and temperature.
- To avoid humidity sensitivity, sensors are protected with a jacket (polyethylene, teflon or metallic)
- Still a residual humidity sensitive remains (tested inside a air dry atmosphere during several days)
- The residual humidity sensitivity depends on jacket material and its internal diameter.
    - The humidity sensitivity has a large latency response (not sensitive to fast humidity changes)
- Bottom line: the humidity effect should be accounted as an off-set and be taking into account during the FBGs calibration.



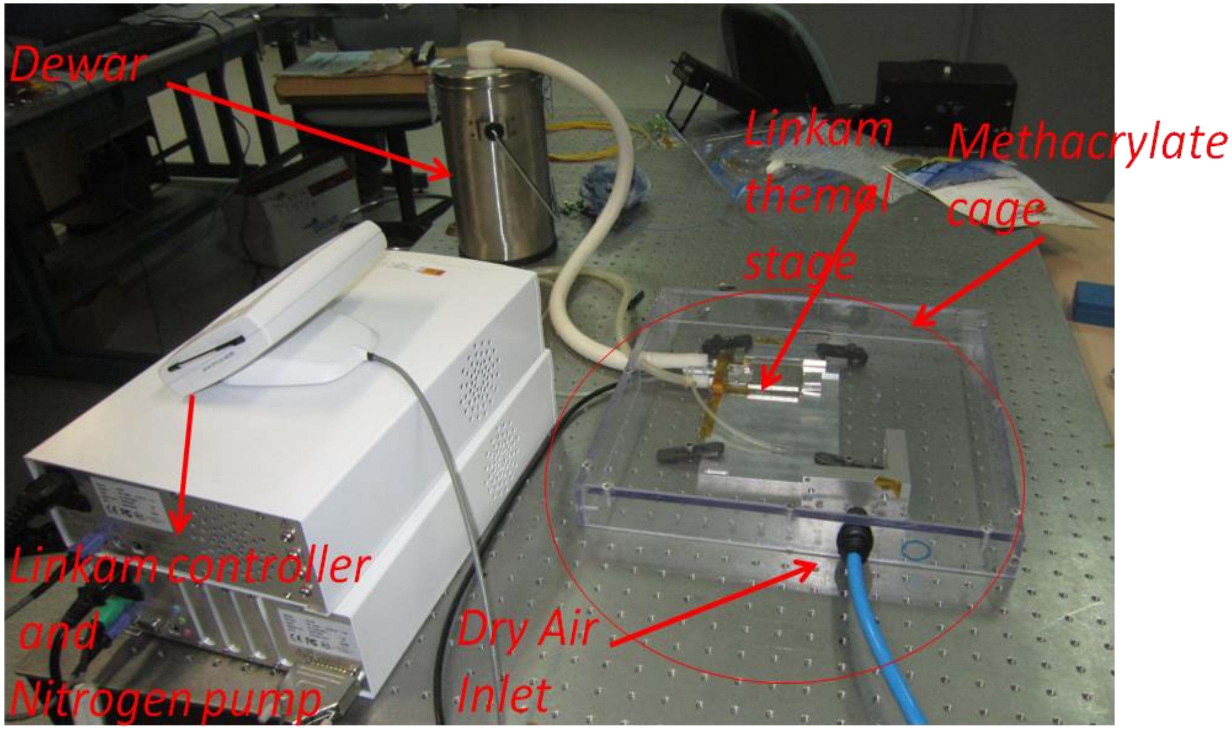
Temperature Offset calibration

- For the case of Belle II (and generally in most of detector trackers) there will be a low humidity environment (below 10%) while the detector is working.
- For the offset calibration a mechanical set-up inside the methacrylate cage will be used. The fibers sensors will be positioned mechanically in a similar way as in the final application. A temperature reference sensor (non sensitive to humidity) will be positioned near the sensors in order to measure temperature inside the cage.
- The environmental humidity will be reduced up to the humidity expected for real application (10 %) and maintain during 2-3 days (until the sensor signal became stable).
- The sensors measured value will be taken as the offset value at the temperature measured with the reference sensor.



Humidity sensitive sensors calibration

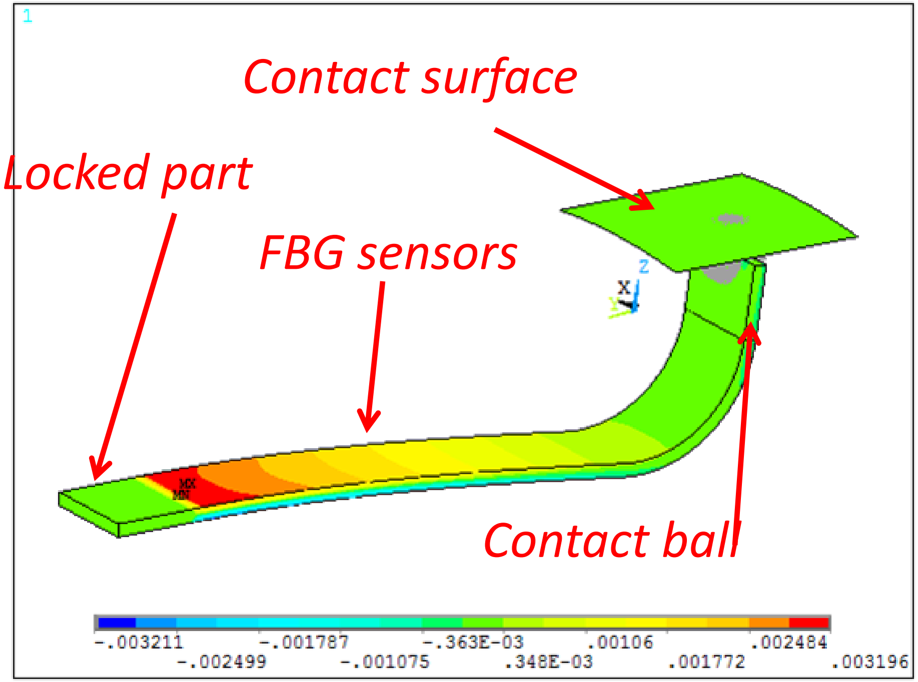
- For the humidity + temperature sensors the process will be slightly different
- Using the thermal sensitivity calibration set-up, the sensors will be calibrated with temperature at three different humidity's (10% ,25% and 50%)
- At this three different humidity's thermal sensitivity and offset will be measured.
- During operation, the temperature will be compensated with near positioned temperature sensors.

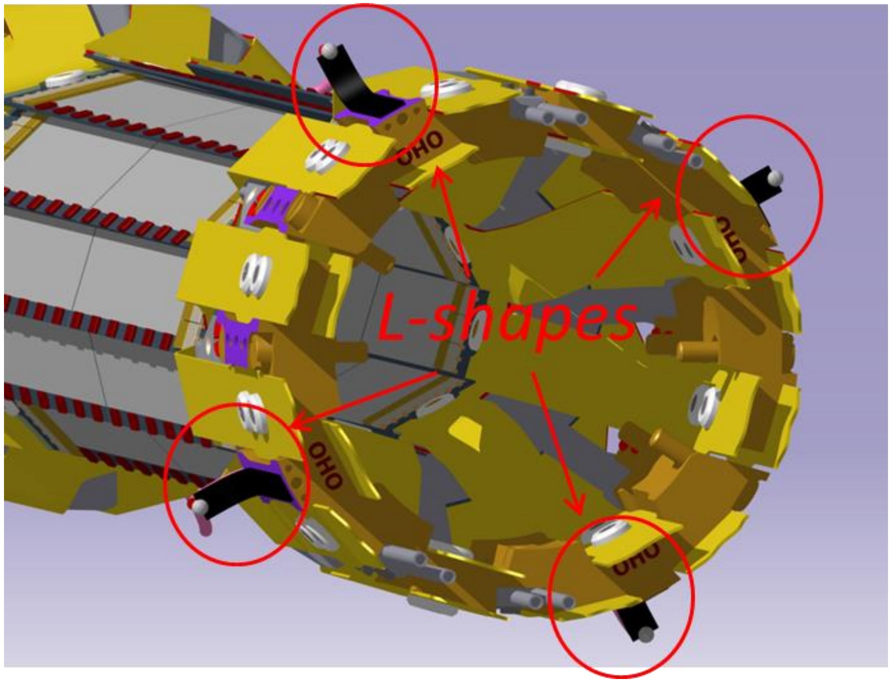


Strain Displacement transductor : L-shape.

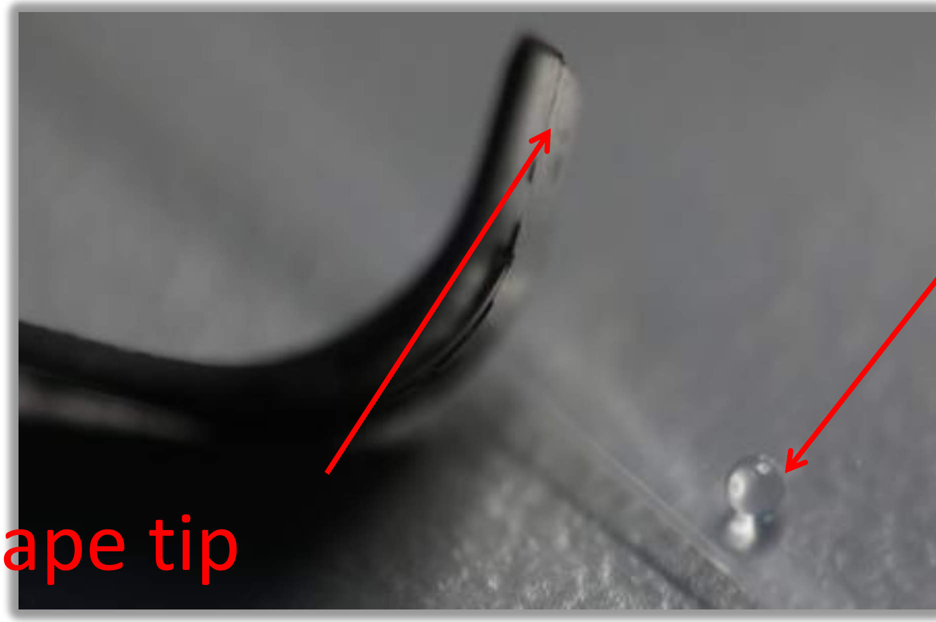
Position transducer: The L-shape

- Temperature & strain to displacement transducer with custom geometry for integration in PXD
- Readout speed from zero to 1KHz (vibrations)
- Currently eight demonstrators manufactured



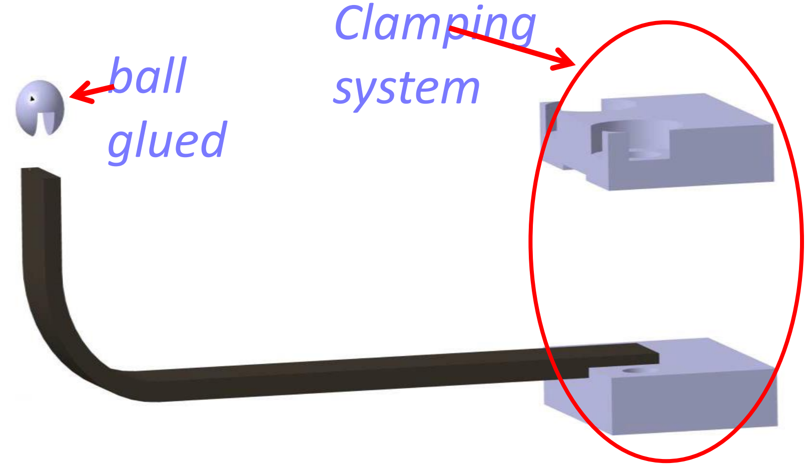


L-Shape Demostrators



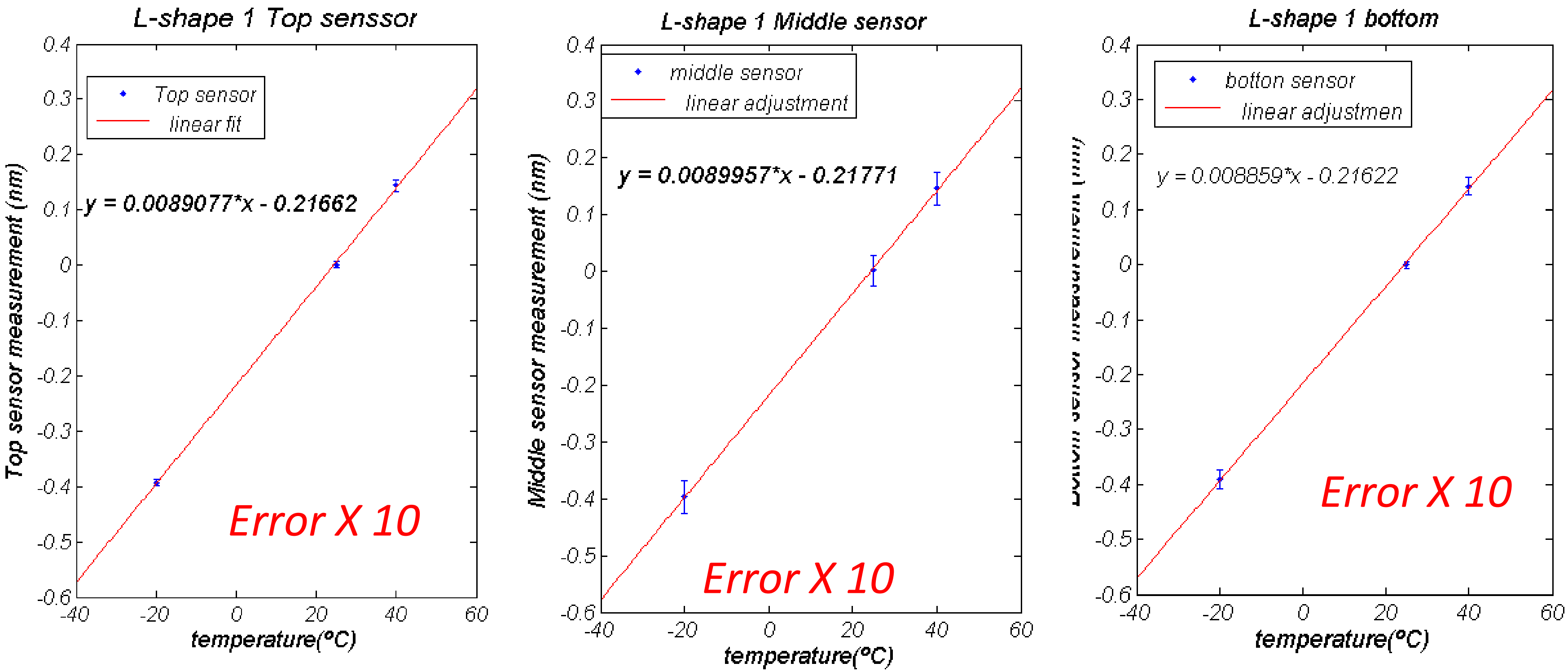
One millimiter Diameter
Quartz contact ball

hape tip



Thermal calibrations & temperature compensation

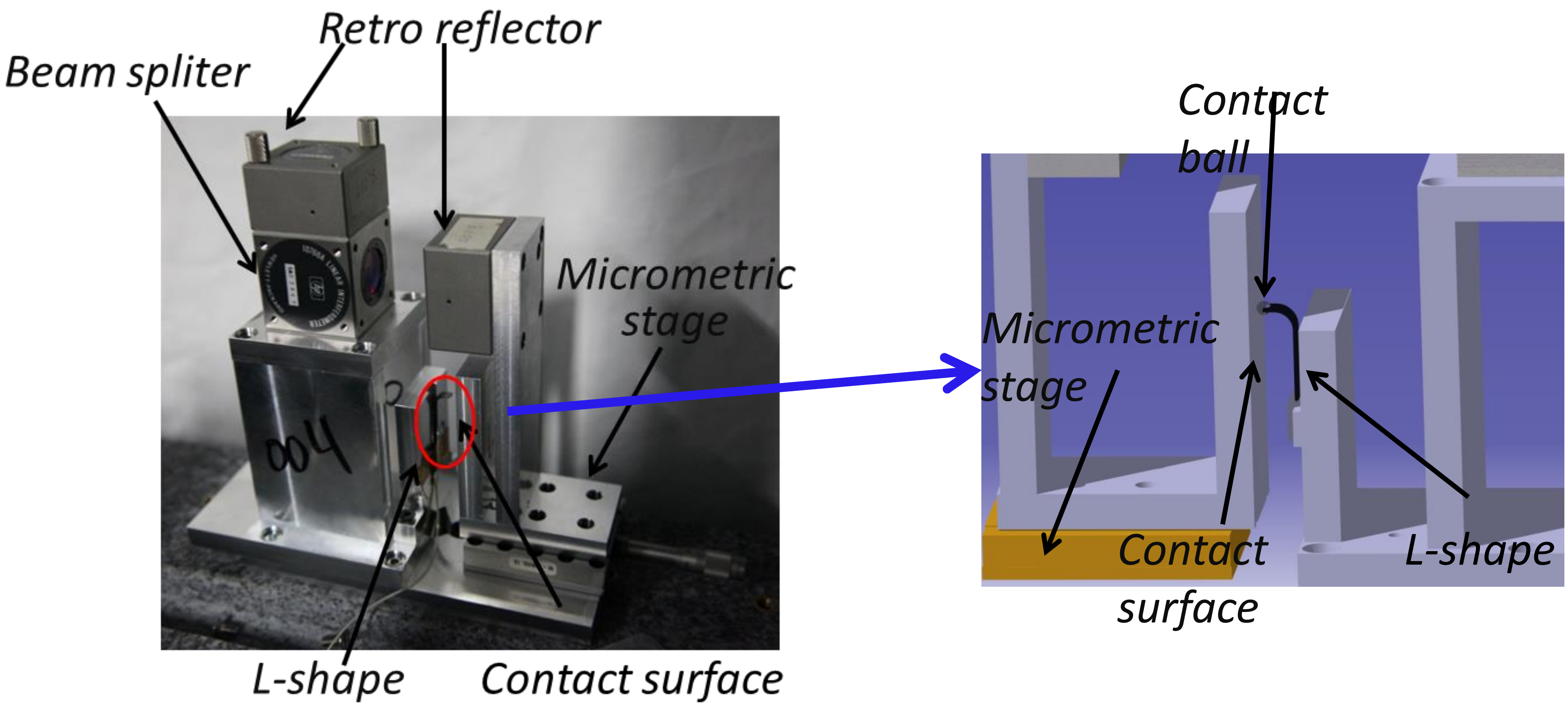
- Calibration using a SIKA thermocouples calibrator.
- The temperature sensitivity of three sensors was constant and near the same (difference<0.6%) *Maximum deviation < 3 pm (0.3 ºC)*



– Trivial approach to temperature compensation

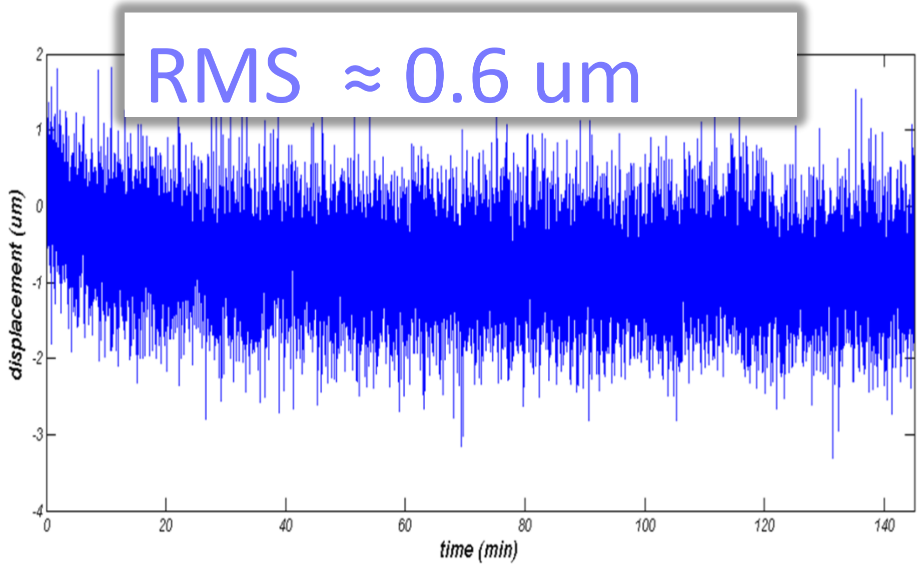
Displacement Calibration

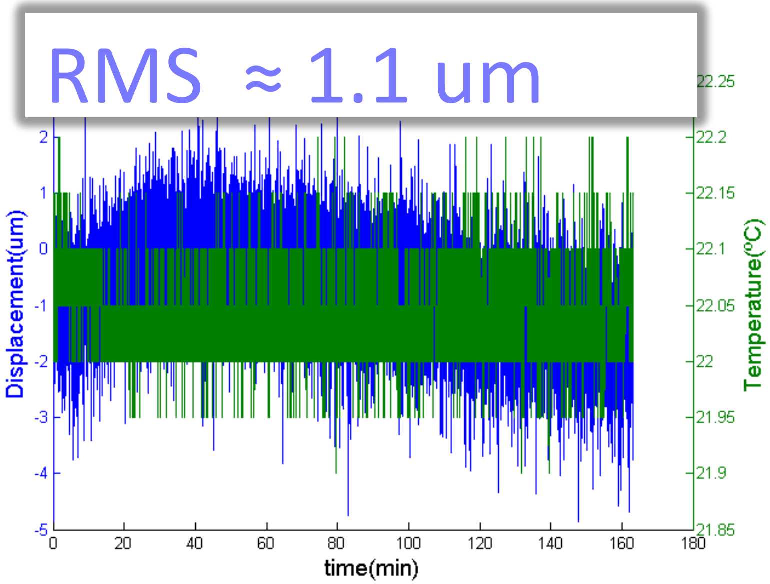
– Displacement measured with Michelson interferometer for high precision calibration (tenth of a micron)
– Readout of L-shape compared with true position (interferometer)



L-shape Output Stability

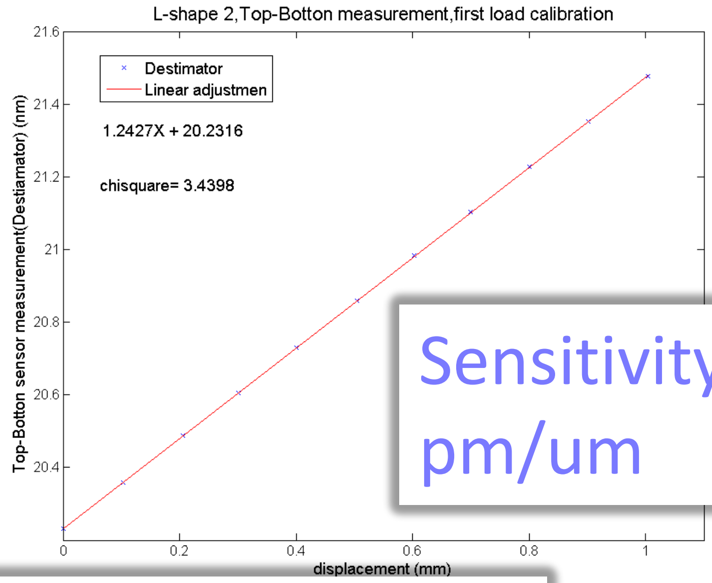
- Short term studies (temperature constant ± 0.1°)
- Continuous readout of the sensor output.
- Stabilities below or about 1um (convolution with mechanics stability)

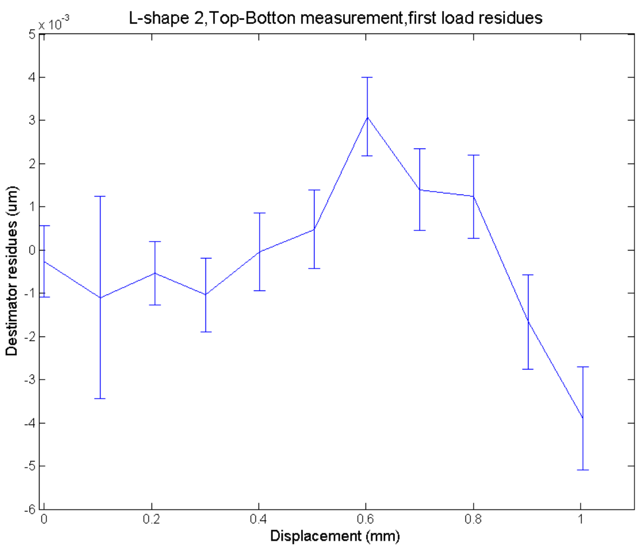




L-shape Linearity vs. Displacement

- Calibration over a range of 1mm
- Resolution (readout resolution) 0.5 um.
- Accuracy (diff. Between inter & L-shape) ≈ 2 um



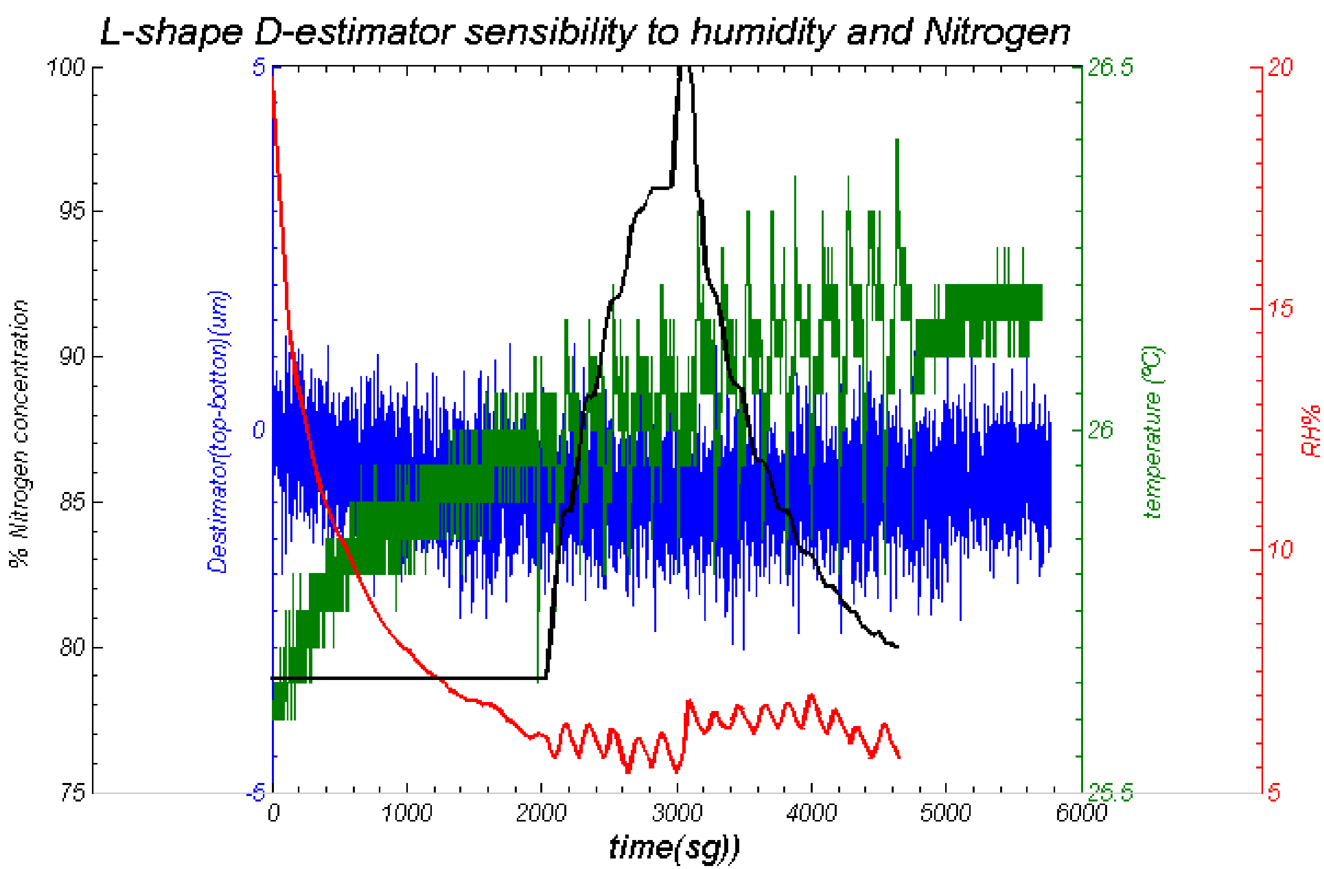


Sensitivity 1.2 pm/um

Difference load-unload cycle 2 %

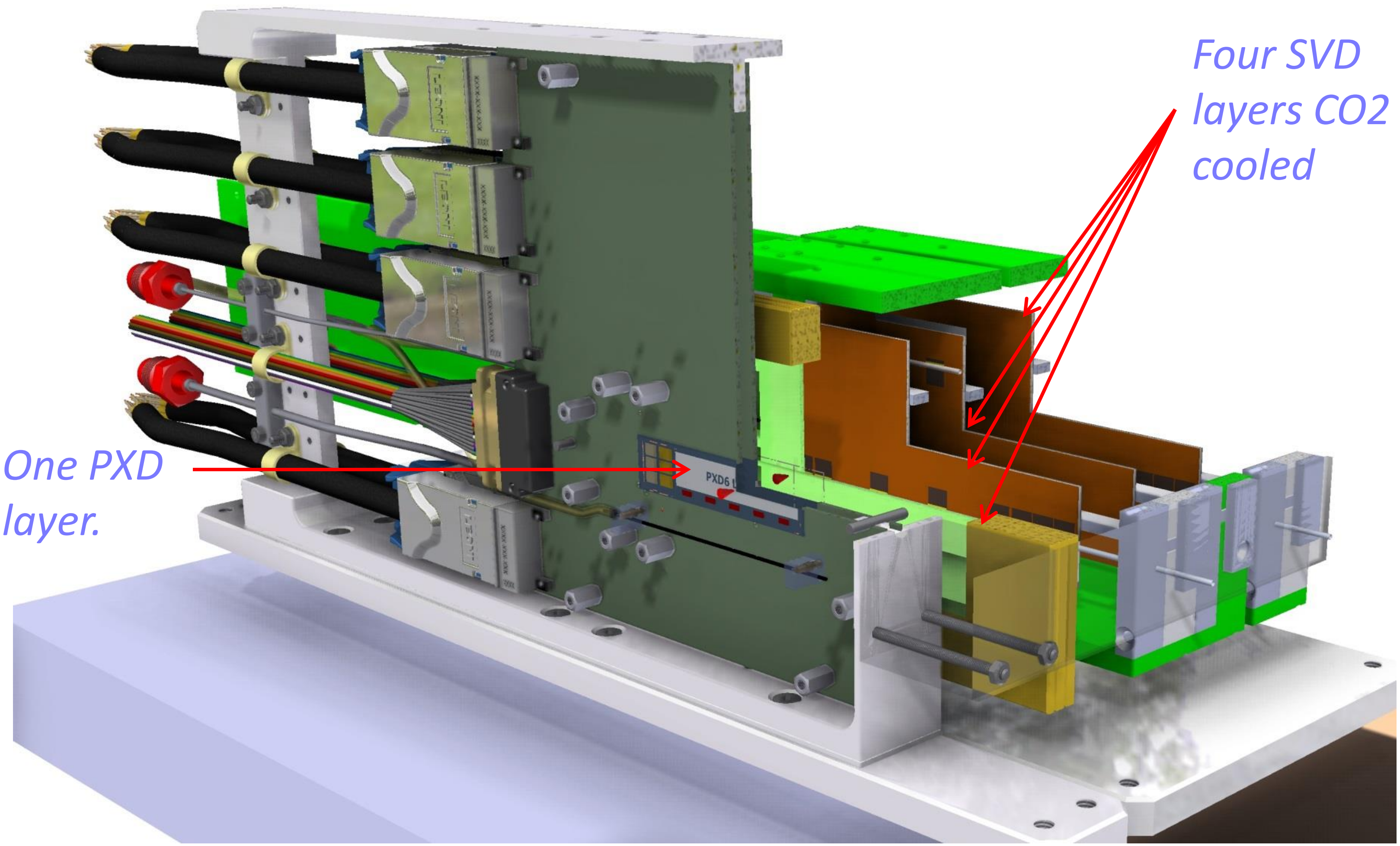
L-Shape sensitivity to enviromental conditions: HR%, T, N_2

No sensitivity to environmental conditions



PXD-SVD common test beam environmental and structural monitoring.

PXD-SVD common test-beam monitoring.



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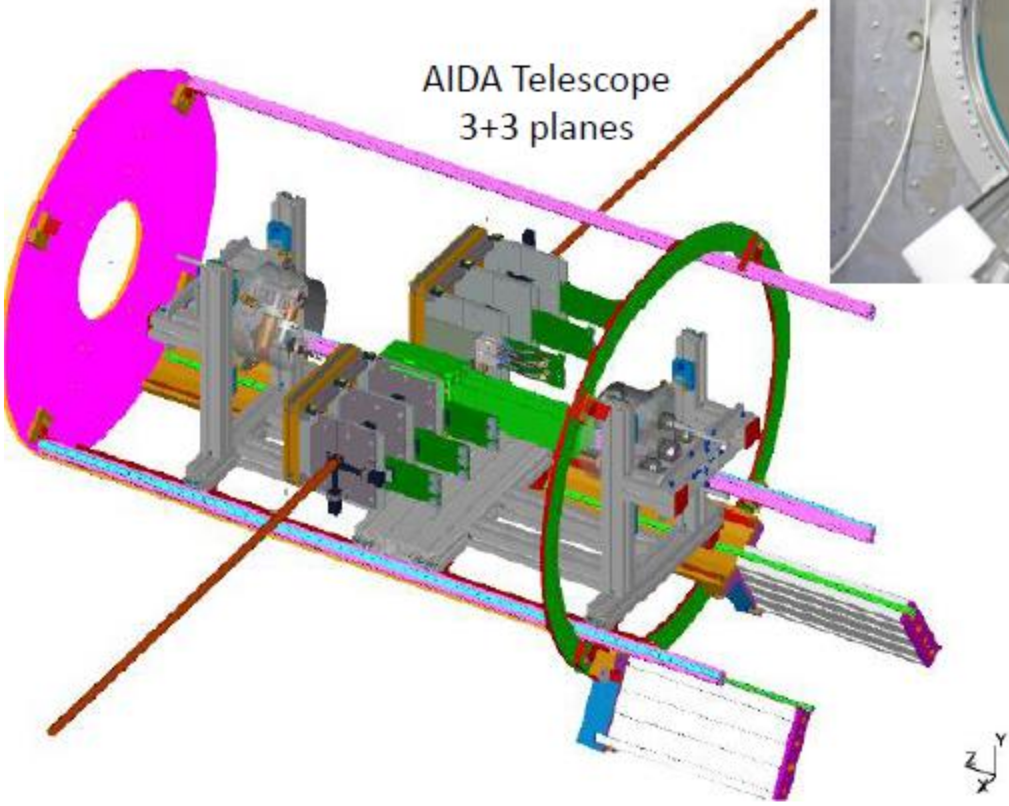
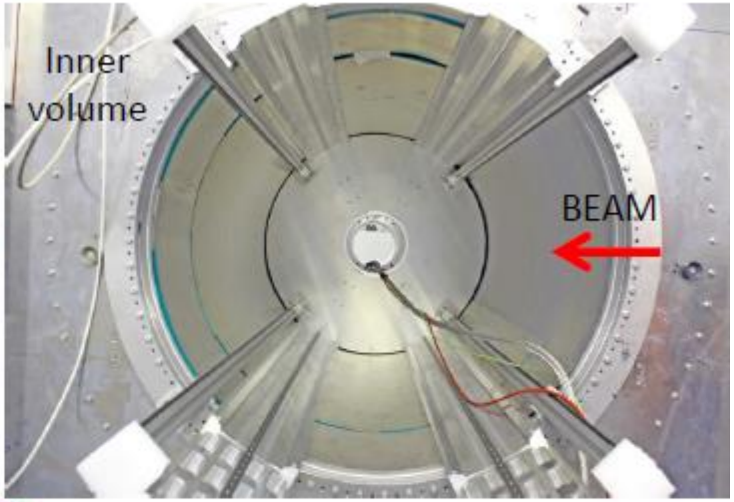
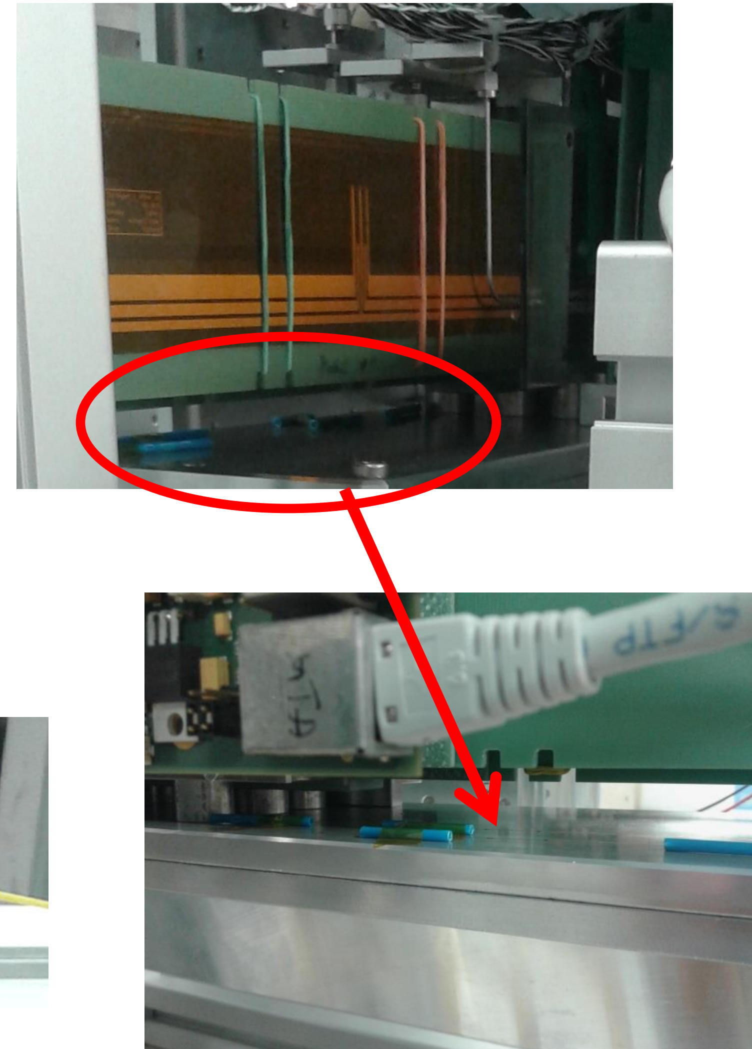
PXD – SVD Integrated test beam set-up

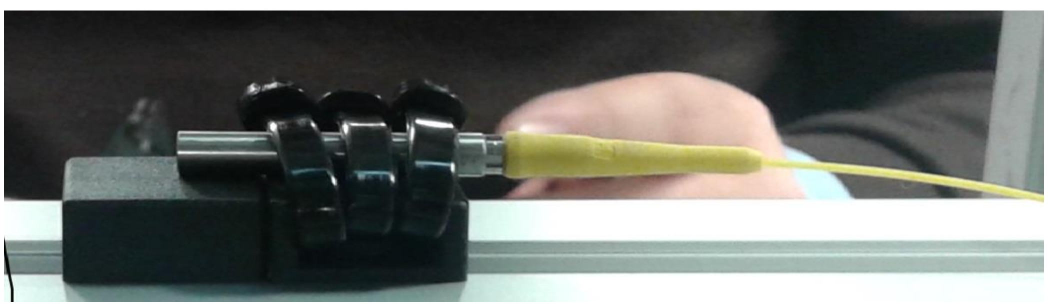
Integration into the PCMAG





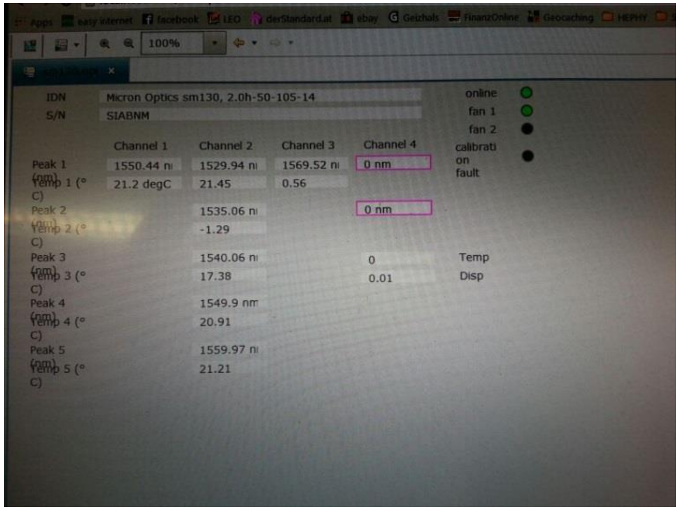
FOS Monitor: FOS Packing



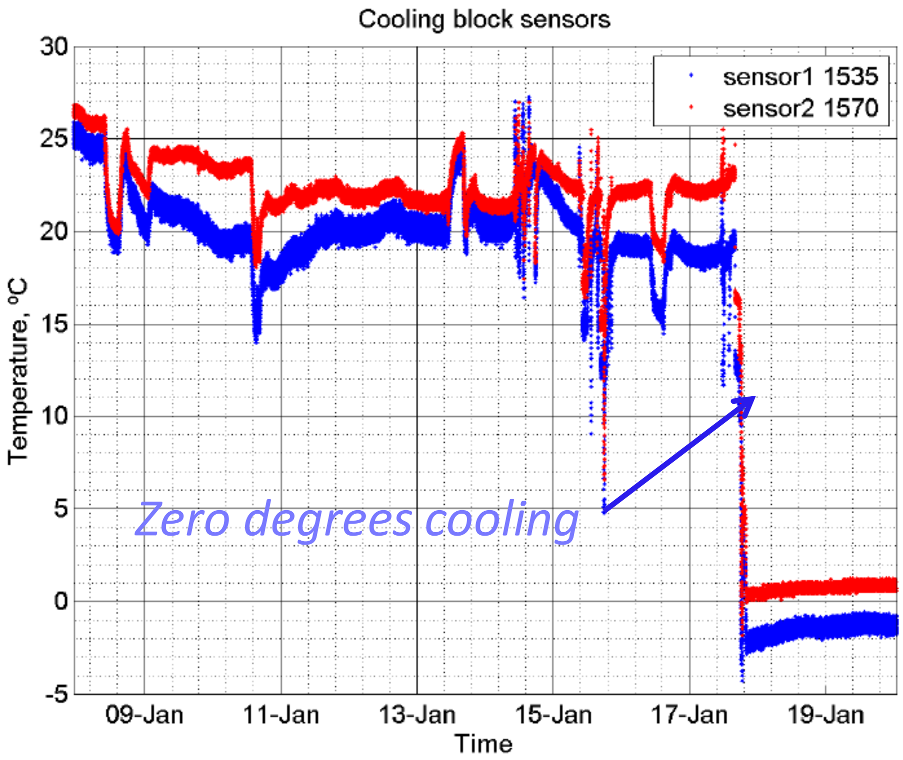


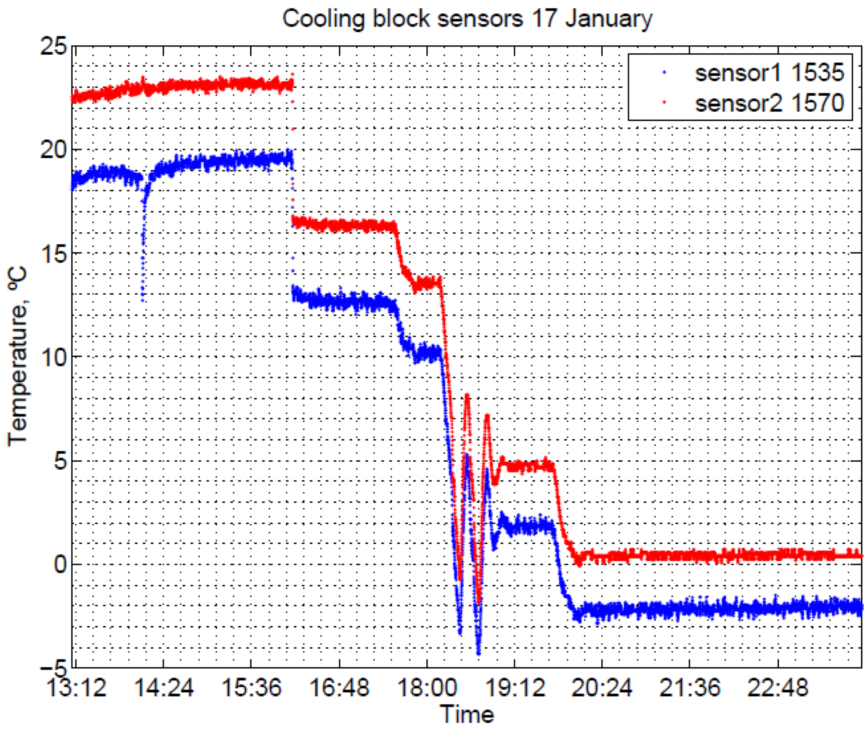
FOS Monitor: DAQ – SC integration

- Optical routing of the sensors up to the interrogating units
- Readout integrated in EPICS (dedicated driver over Ethernet). The integration went very smooth ready since the January 6^{th}

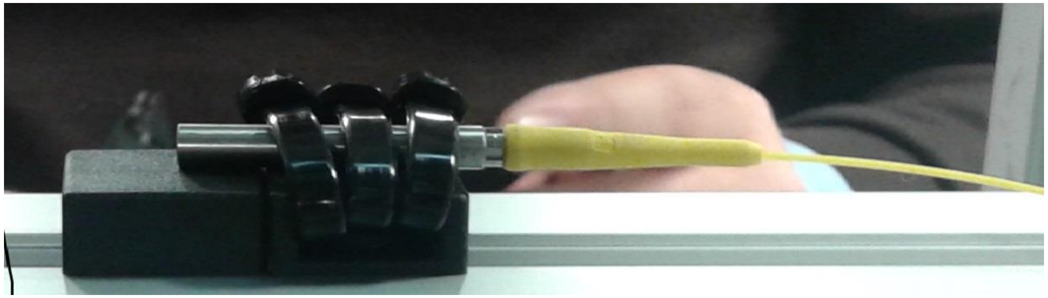


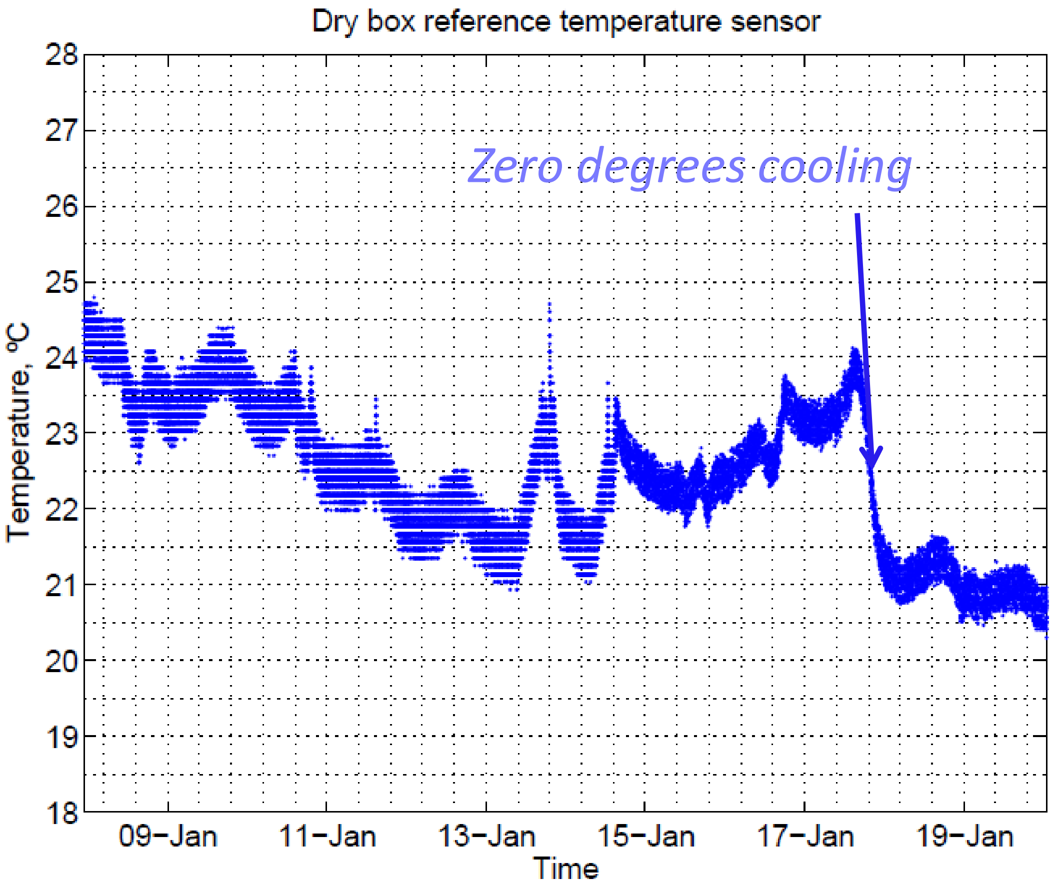
FOS Monitor: Data: MARCO in-let & out-let lines





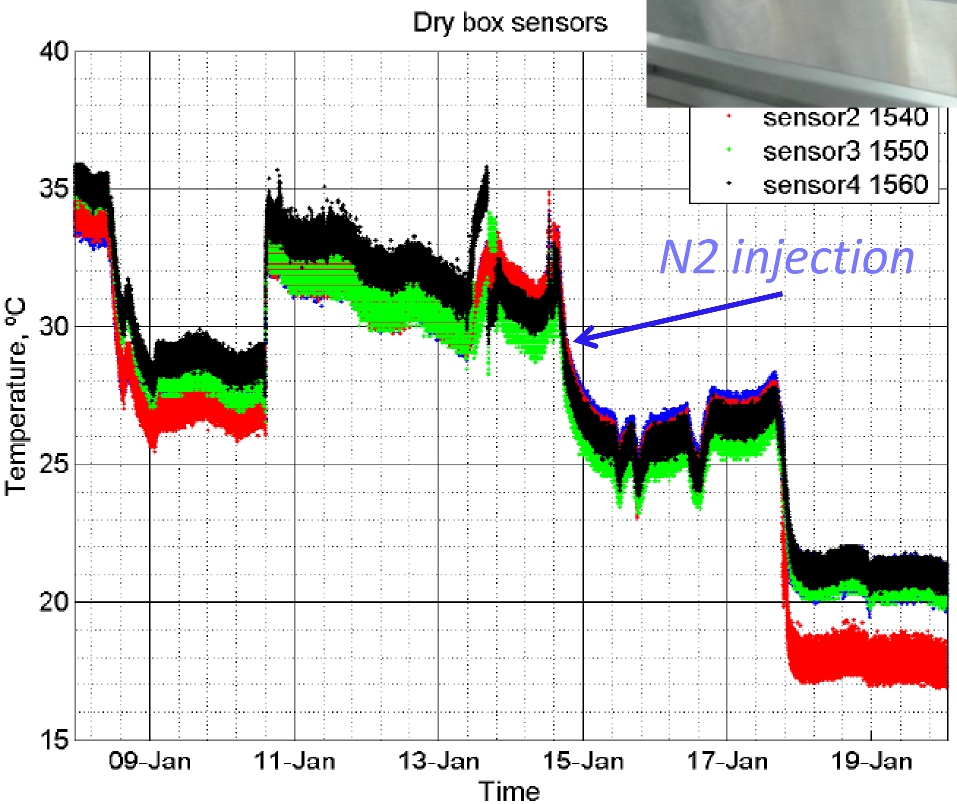
FOS Monitor Data: Ambient Temp

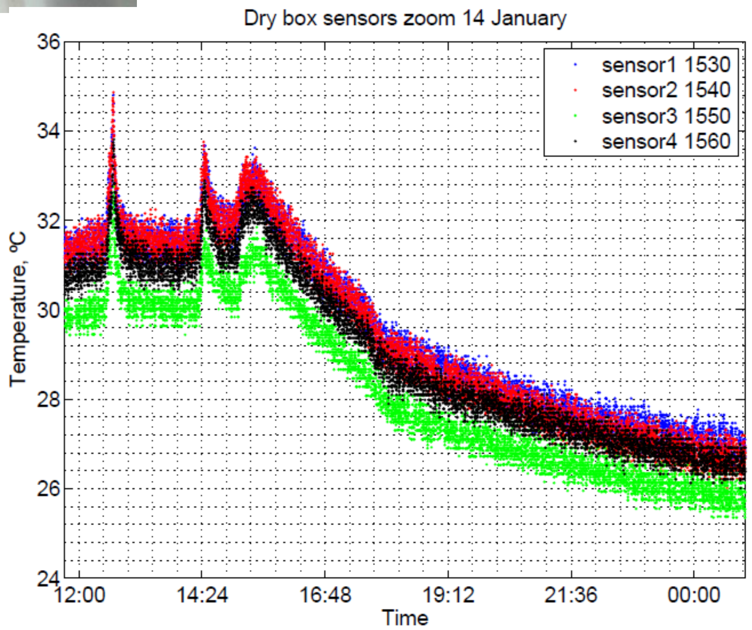




- All FBG temperature sensors worked out of the box (In contrast, there was a problem with standard electric sensors)

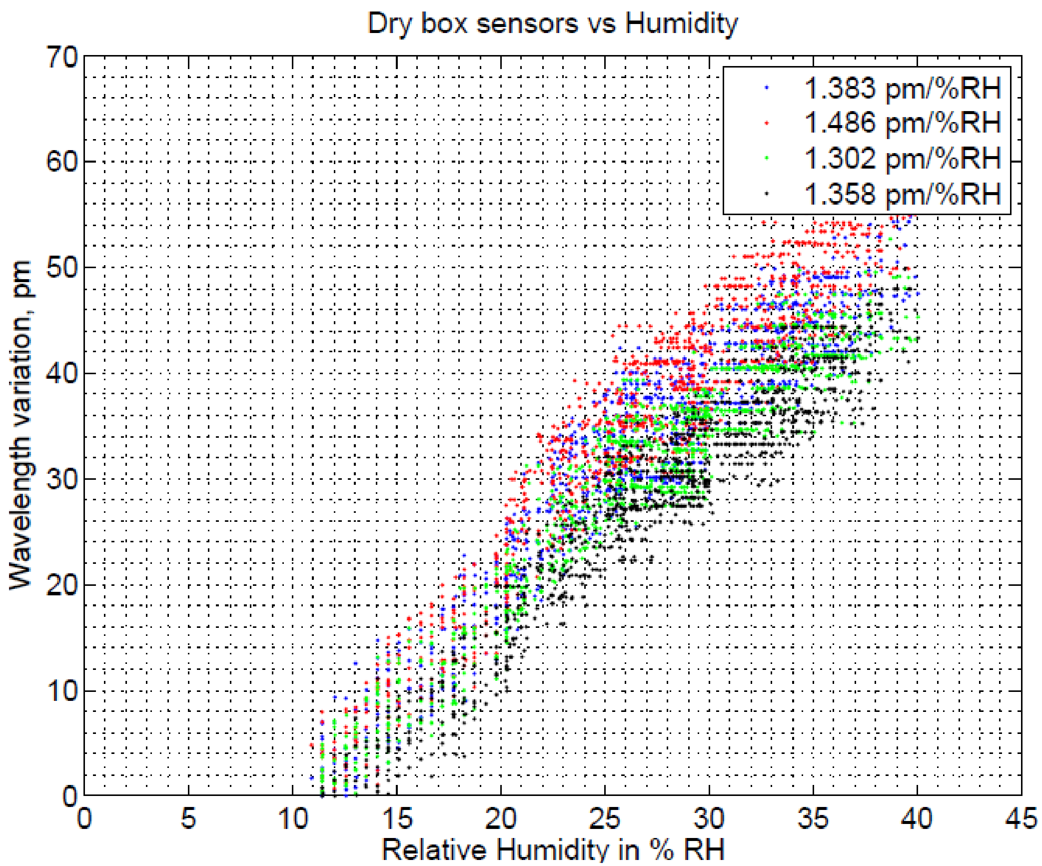
FOS Monitor: Ambient Temp+%RH





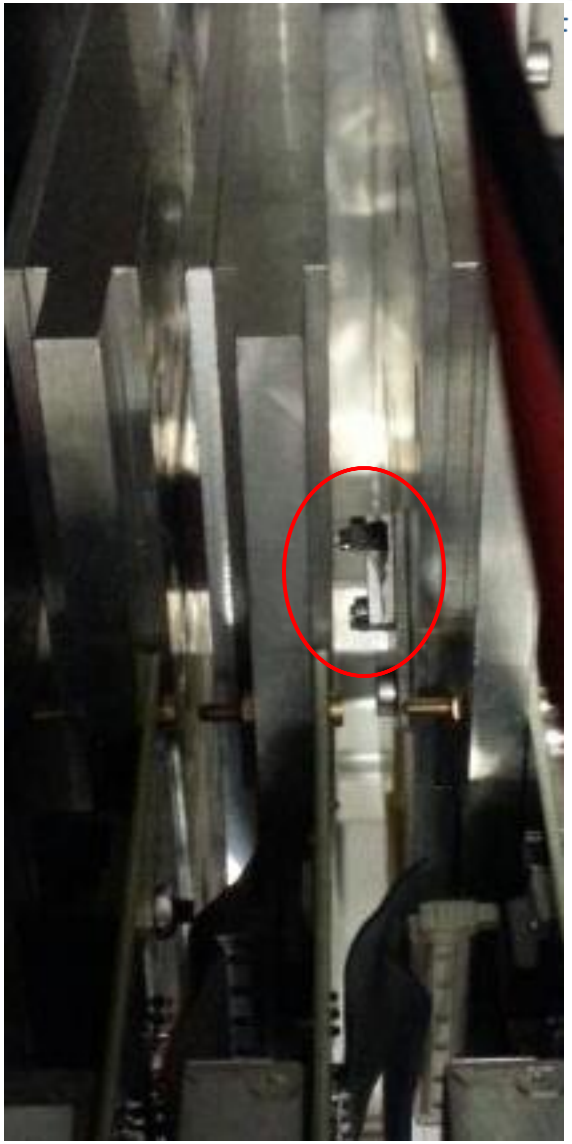
FOS Monitor:Humidity measurements

- Comparing the wavelength shift of ambient sensors (naked fibers) vs. commercial Humidity sensors inside the dry box.
- Excellent linearity and sensibility after temperature compensation



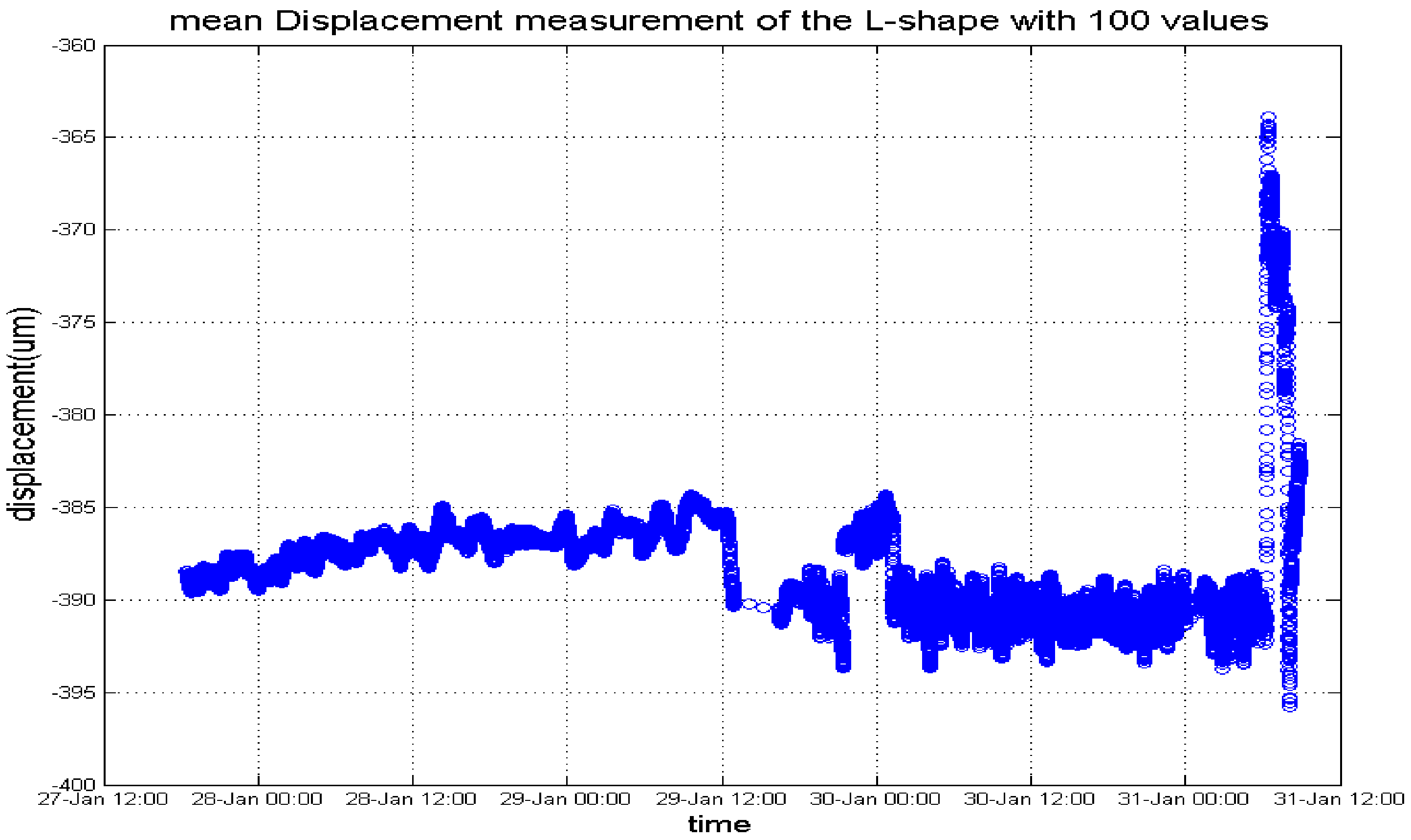
Structural monitoring

- Structural monitoring done during the Test-beam
- The L-shape was positioned between two telescope planes (outside the dry cage) in order to measure relative displacements on beam direction.
- The displacement was measured during Test Beam last three days.
- Some vibration measurements done at 100 Hz and 1000 Hz speed.



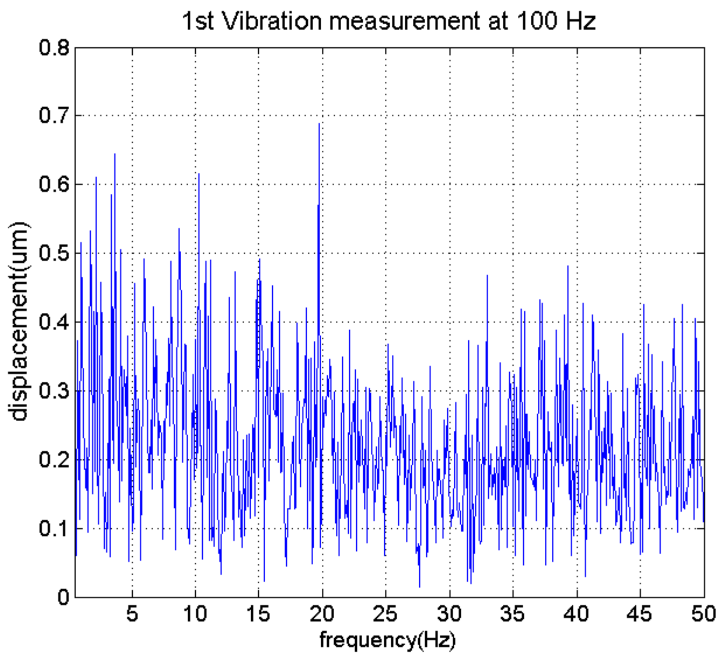
Relative displacement between telescope planes

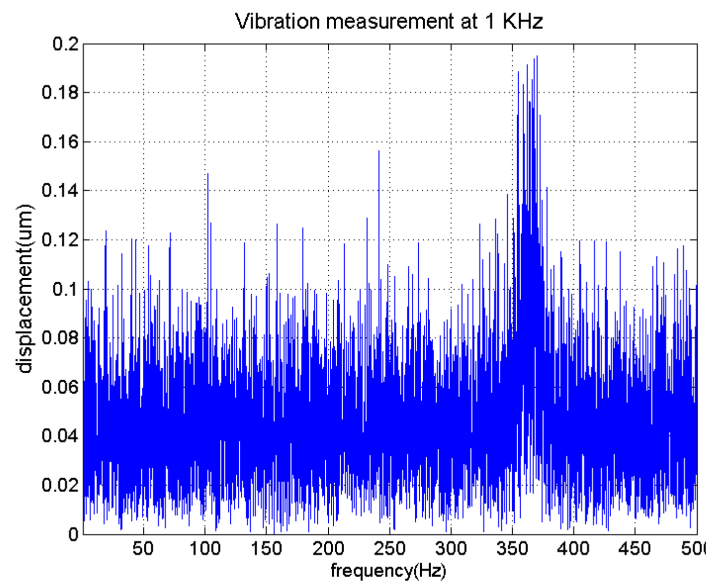
- The relative displacement measured < 10 um
- Big displacements on 31th of January morning are due to the dismounting of the system



Vibration measurements between telescope planes

- Two measurements done at interrogation speed of 0.1 and 1 Khz. In the pictures can be seen that at low frequencies there is no any vibration but it seems to be an small vibration between 300 and 450Hz.

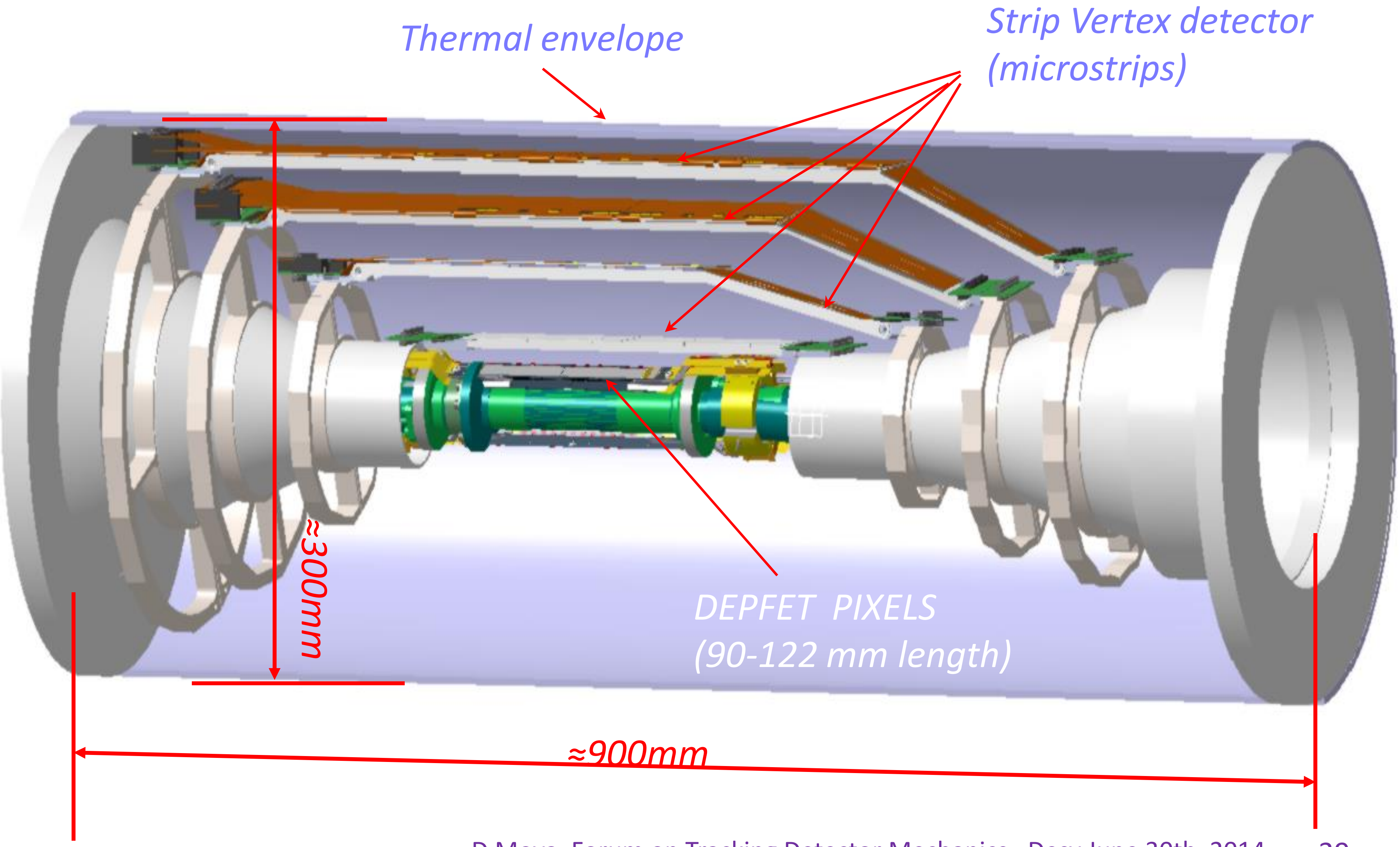




Summary & Outlook

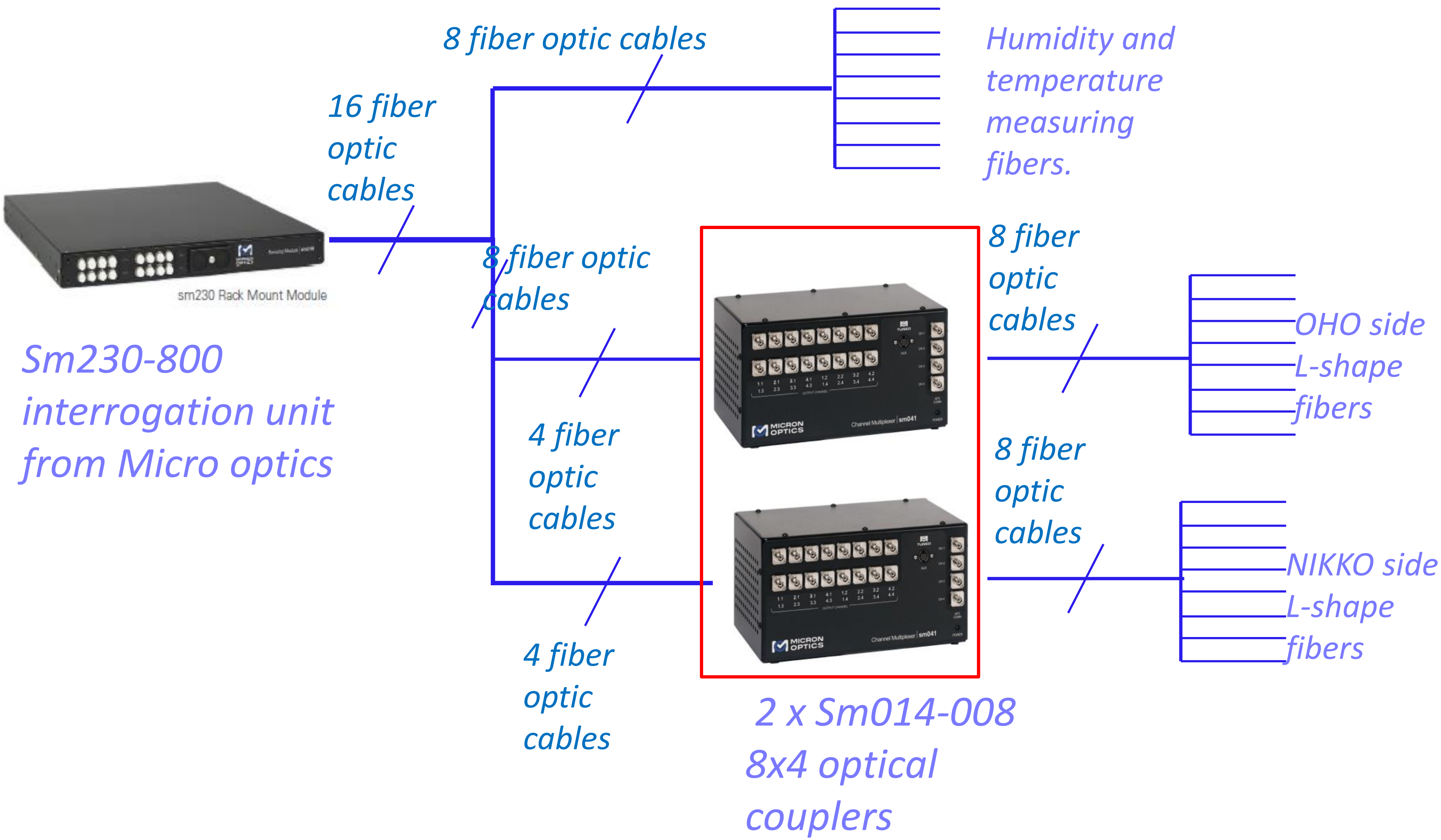
- FBG sensors a very attractive monitoring technology for particle physics: radiation resistance, electromagnetic immunity, small footprint and embedding in CFRP
- Case of use: FOS monitor for Belle II vertex detector
  - Environmental (temperature, humidity) and structural (vibrations, deformations and displacement) monitoring system
  - Miniature, application specific displacement transducer (L-shape) developed for PXD-SVD relative displacement monitoring in real time.
- Started the study of FBGs for humidity sensing.

Belle-II Vertex Detector reminder



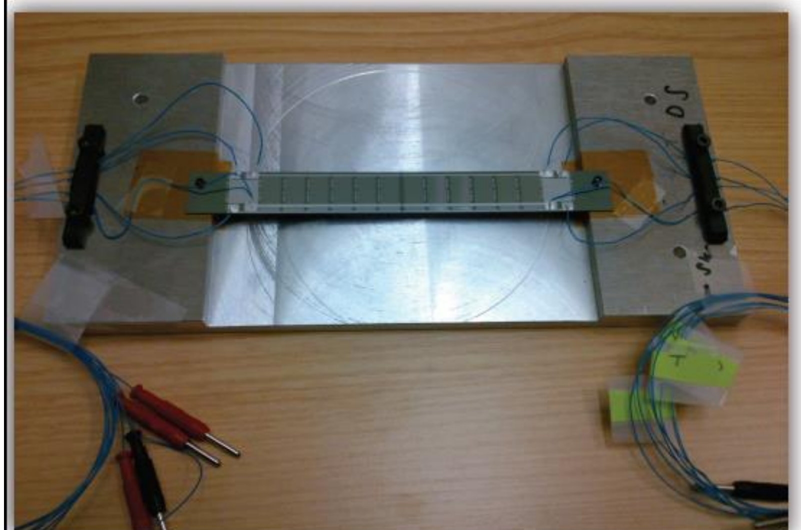
PXD-DAQ system

- DAQ system total cost: around 34.000€

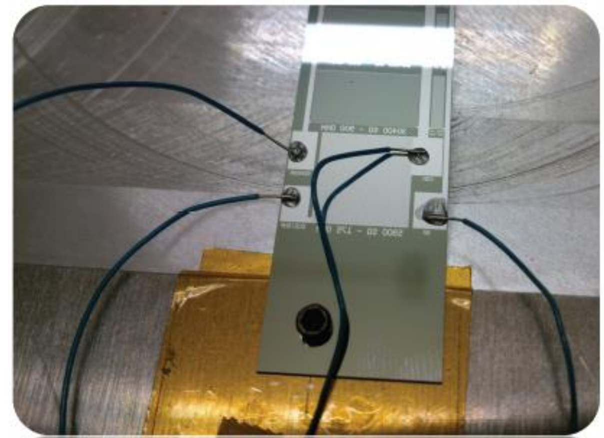


ILC-like power pulsed Depfet sensor temperature measurement.

ILC-like power pulsed Depfet sensor temperature measurement.

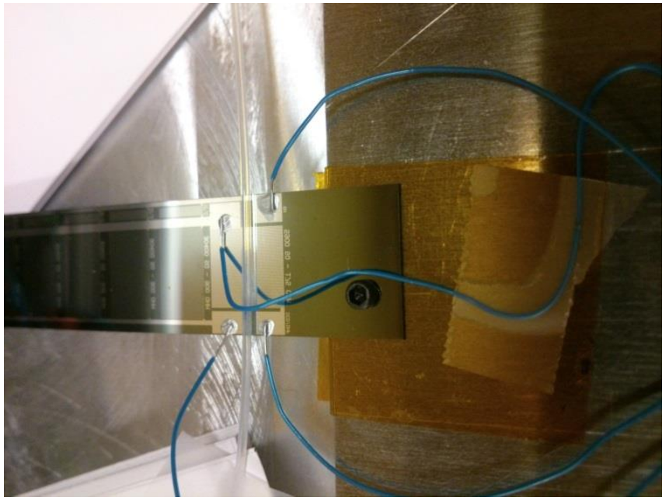


Entire setup: Aluminium with the set ladder

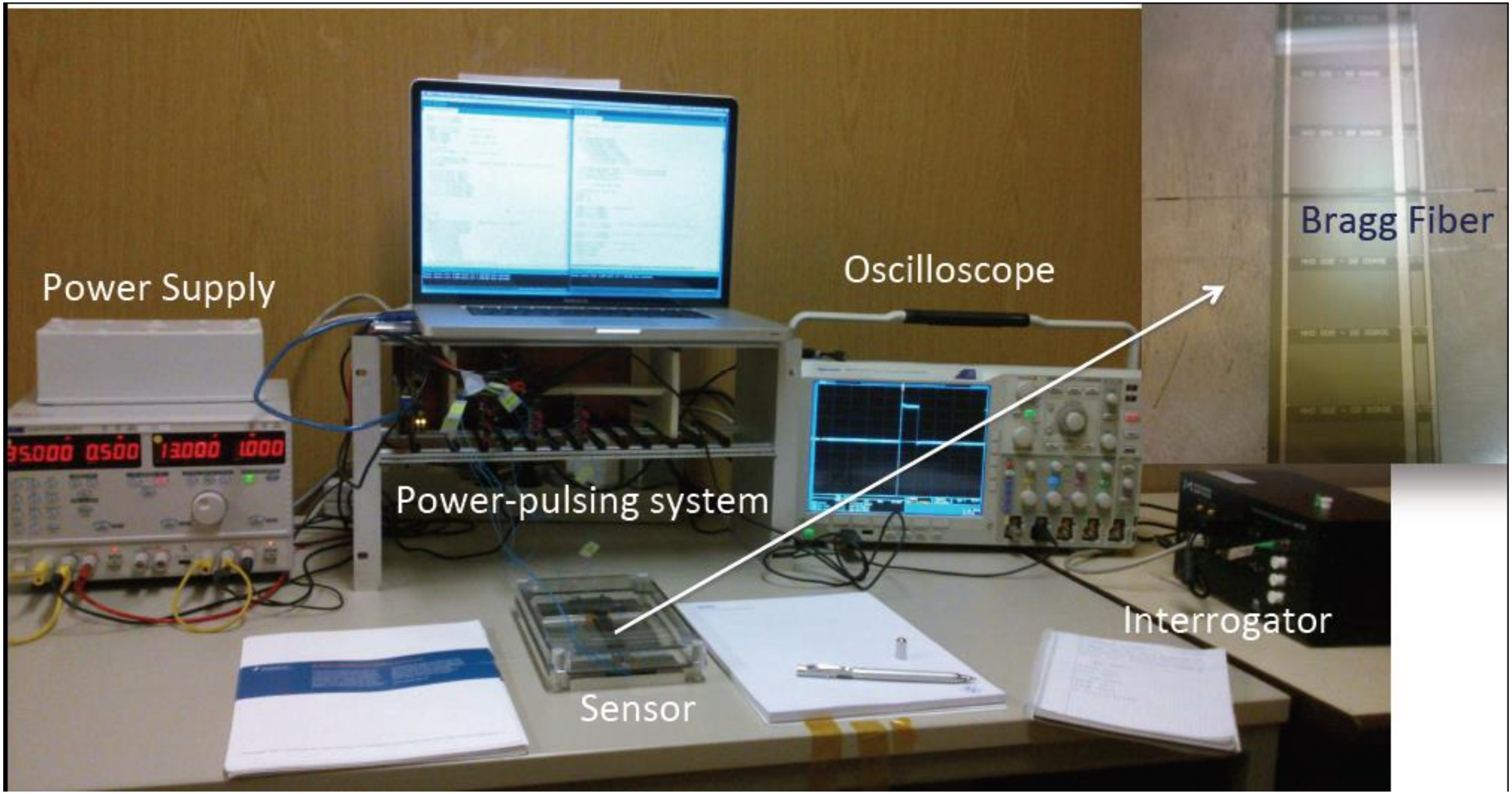


Ladder pads and wires

- A silicon depfet mock-up ladder with build in heaters
- Sensor temperature measured with FBG sensors at 1KHz

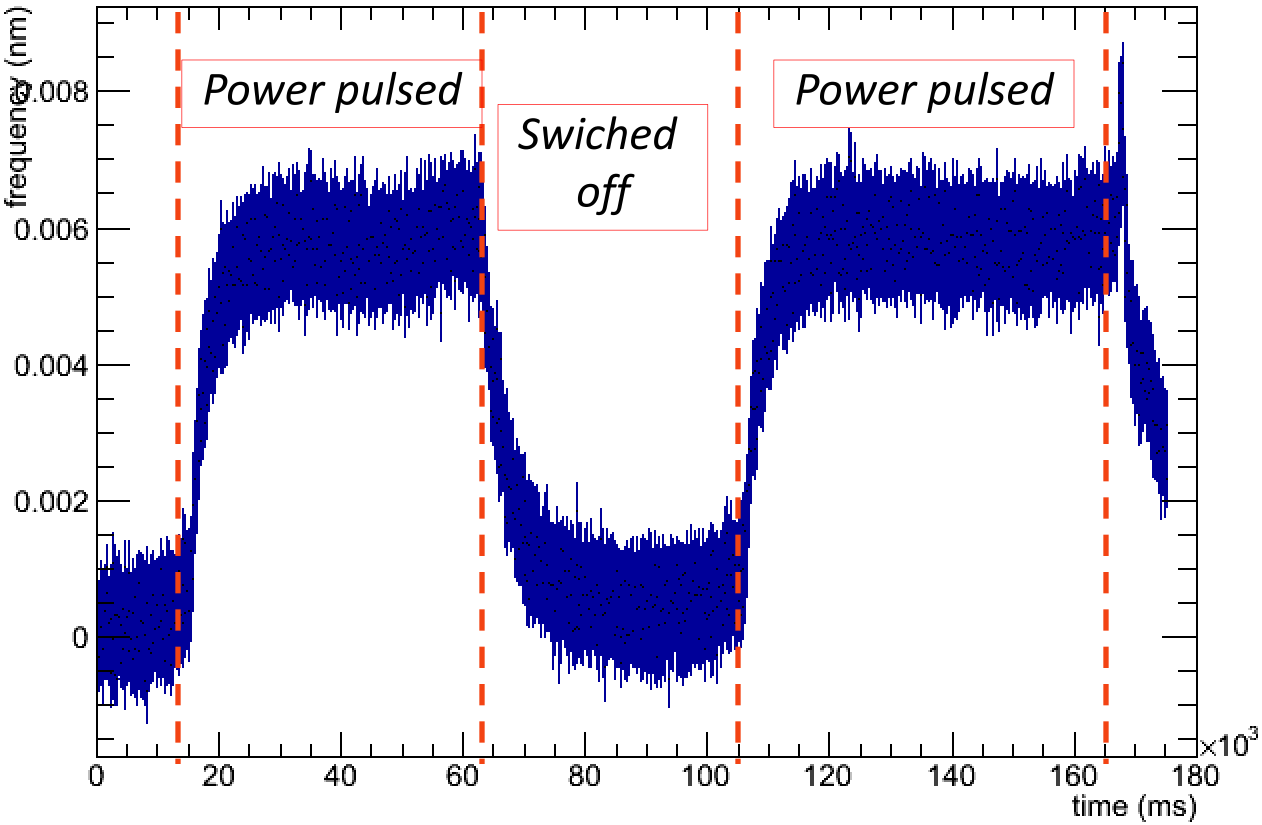


Measurement set-up.



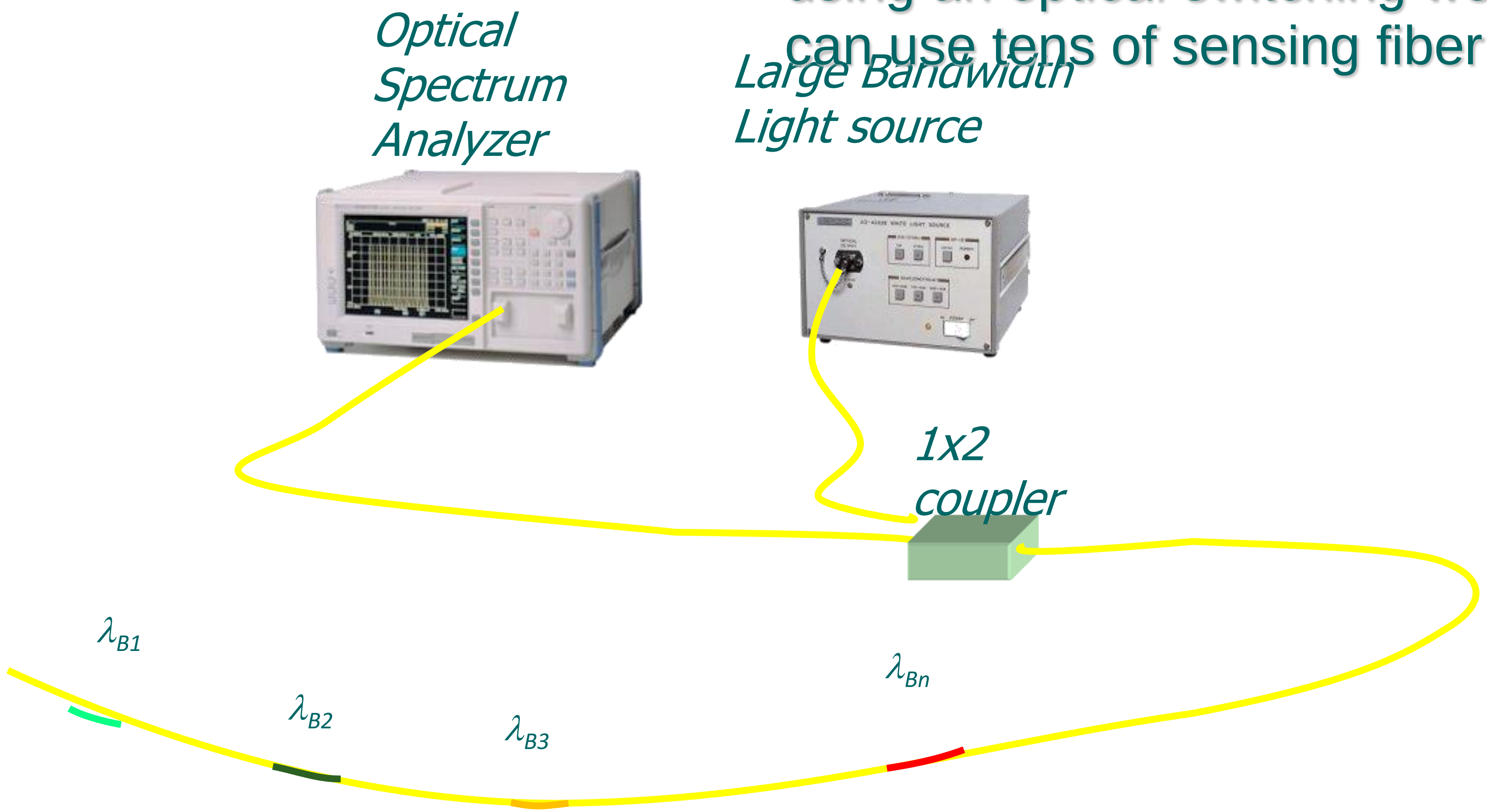
ILC-like power pulsed Depfet sensor temperature measurement: results.

- 1 ms of high consumption followed by 200 ms of no powering.
- The temperature change is limited by the thermal inertia of the ladder, becoming constant in seconds.



_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

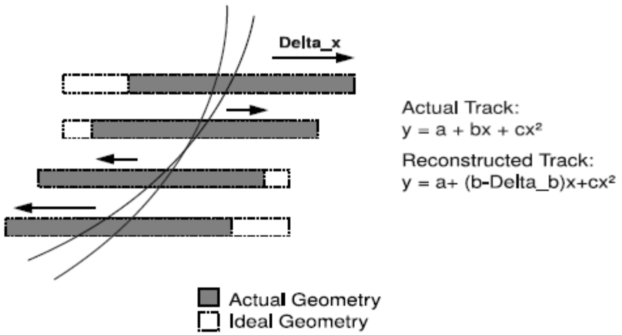


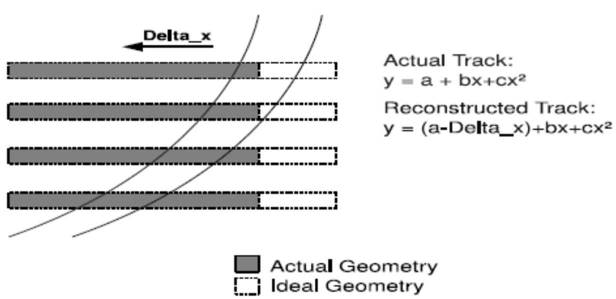
_ Monitoring requirements for Si-Trackers

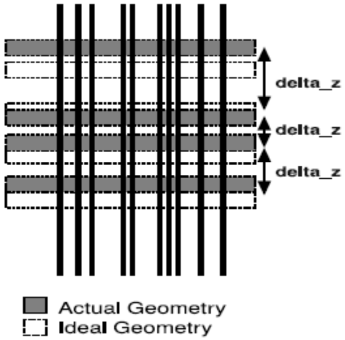
- Current and future silicon systems need for:
  - Real-time monitoring of environment variables: temperature, humidity, CO_2, magnetic field, etc.
  - Real time structural monitoring: deformations, vibrations (push & pull operation), movements.
- Conventional monitoring technologies based on electric relatively bulky transducers with low multiplexing capability, low granularity, and cooper readout and powering lines (conductive EM noise propagation lines).

_Monitoring requirements: Weak Modes

- First lesson from LHC detectors: position and deformation monitors must cover the weak modes of software (track-based) alignment algorithms.







L-shape Linearity (2)

– L-shape sensibility presents a small dependence depending of the direction of movement (L-shape specific effect due to its shape)

	Sensitivity	offset	Chi square
1st load	1.243	20.232	3.440
1st unload	1.268	20.227	107.783
2nd load	1.253	20.219	3.442
2nd unload	1.268	20.226	96.436
3rd load	1.247	20.224	99.450
3rd unload	1.272	20.227	76.313
4th load	1.245	20.226	23.614
4th unload	1.277	20.223	49.120

Sensitivity reproducibility 0.4 %

Difference load-unload cycle 2 %

L-Shape Linearity (3)

– Investigate the effect of the roughness of the contact surface on the asymmetric load-unload behavior.

POLISHING

Still sensitivity asymmetry 2 %
More studies in progress
(harder materials than Al)