Cryogenic Applications of Sensors based on Optical Fiber Technology

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Goals of the experiments

- The **feasibility** of the measurements at low temperature: very first experiments to check the capability of the fibers and the sensors to stand the liquid Nitrogen LN and Liquid Helium LHe temperature (77K and 4.2K respectively).

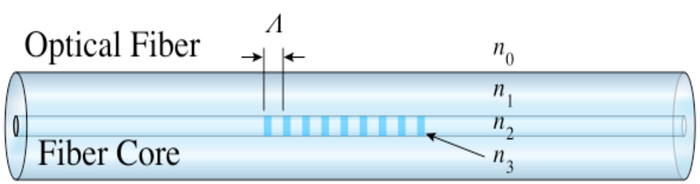
- To profit of the occasion of a prepared test of a magnet at low temperature: test **strain and temperature** probes (eventually also @ 1.9K)

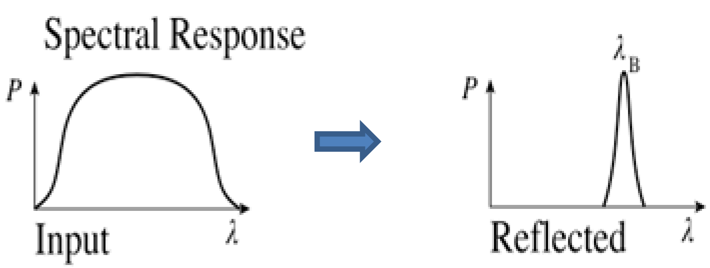
Experiments

Date	Test
August 20th , 2010	Temperature measurements with LN at 77 K
August 25th , 2010	Temperature measurements with LHe at 4.2 K
September 17th , 2010	Temperature measurements with LN at 77 K
September 22nd , 2010	Temperature measurements with LN at 77 K
September 24th , 2010	Temperature and Strain measurements with LHe at 4.2 K
September 30th , 2010	Temperature measurements with LHe at 4.2 K
October 4th , 2010	Temperature and Strain measurements with LHe at 4.2 K and 1.9 K

What we measure

Each “Fiber Bragg Grating” (FBG) reflects a single Bragg wavelength λ_B. Changes in the **temperature** and **strain** state of the fiber change the λ_B.





Obtaining the lambda-shift from measured λ_B, the following measurements are obtained in

- **Temperature** $$\Delta\lambda_{BT} = \lambda_B(\alpha + \xi)\Delta T$$
- **Strain** $$\Delta\lambda_{BS} = \lambda_B(1 - \rho_\alpha)\Delta\varepsilon$$

$\Delta\lambda_{BT}$, $\Delta\lambda_{BS}$: temperature and strain induced Bragg wavelength shifts

α : coefficient of thermal expansion

ξ : thermo-optic coefficient

ρ_α: photo elastic coefficient of the fiber

Overview

Sensors

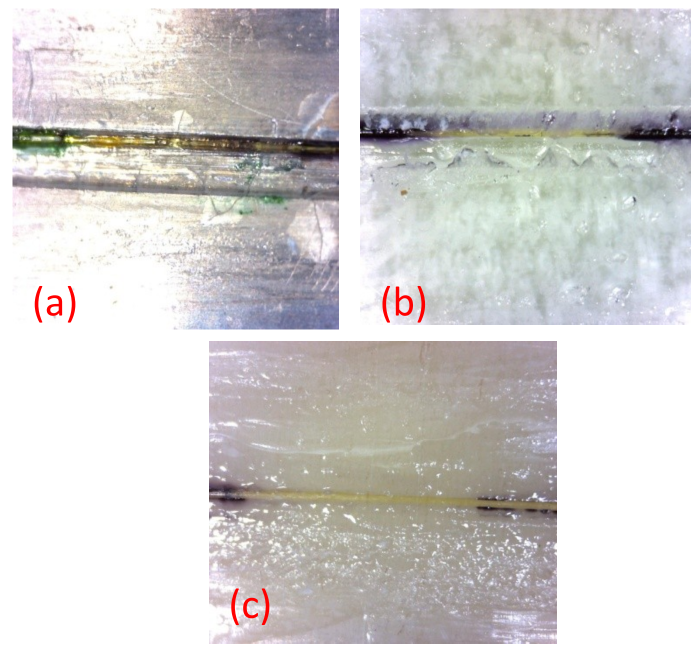
- Polymide coated and un-coated FBGs
- Reference sensors :
  - *Temperature*: PT100 and Allen Bradley
  - *Strain*: resistive gauges XC11-3-350 in half bridge configuration

Host materials

- Aluminium
- Ryton
- Lead (a)
- Plexiglass (PMMA) (b)
- Teflon (c)
- Aluminium shell of the magnet

Devices

- Open dewar with LN
- Cryostat filled with LHe
- Sm125 Optical Sensing Interrogator

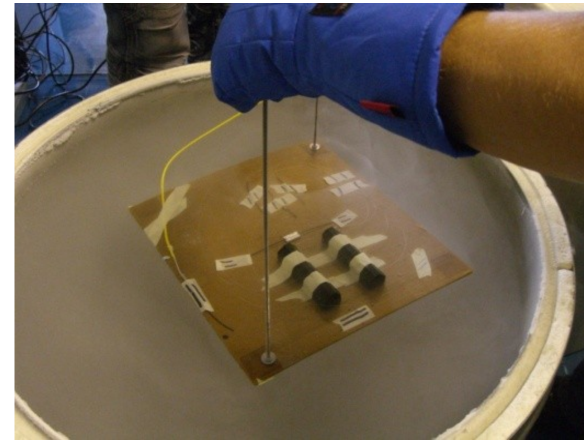


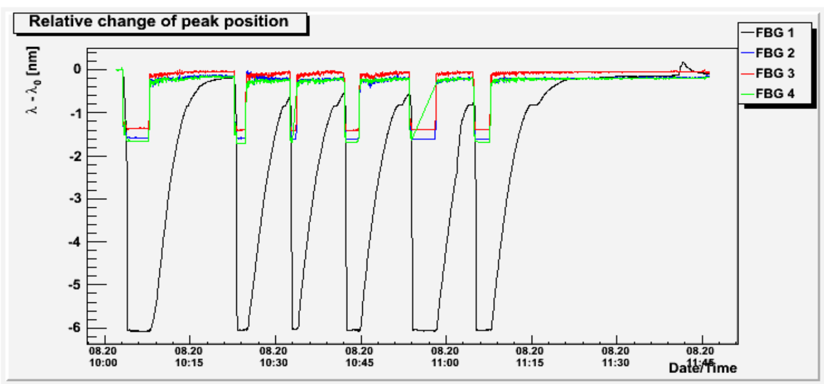
FBGs glued on the samples with Loctite Super Attack Precision Glue

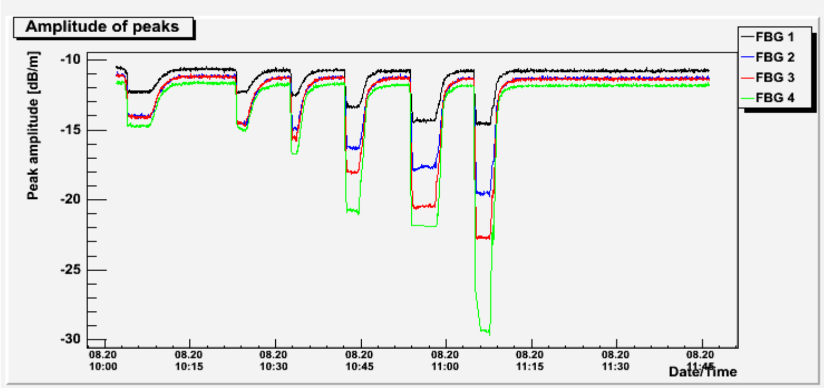
Feasibility Test at 77 K

August 20th, 2010

- An array of 4 FBG fixed on a carton support:
    1. Polymide coated FBG glued on Al plate
    2. Polymide coated free FBG
    3. Uncoated free FBG
    4. Polymide coated free FBG







- 6 cycles of immersions in the LN at **77 K**

Conclusions of the test:

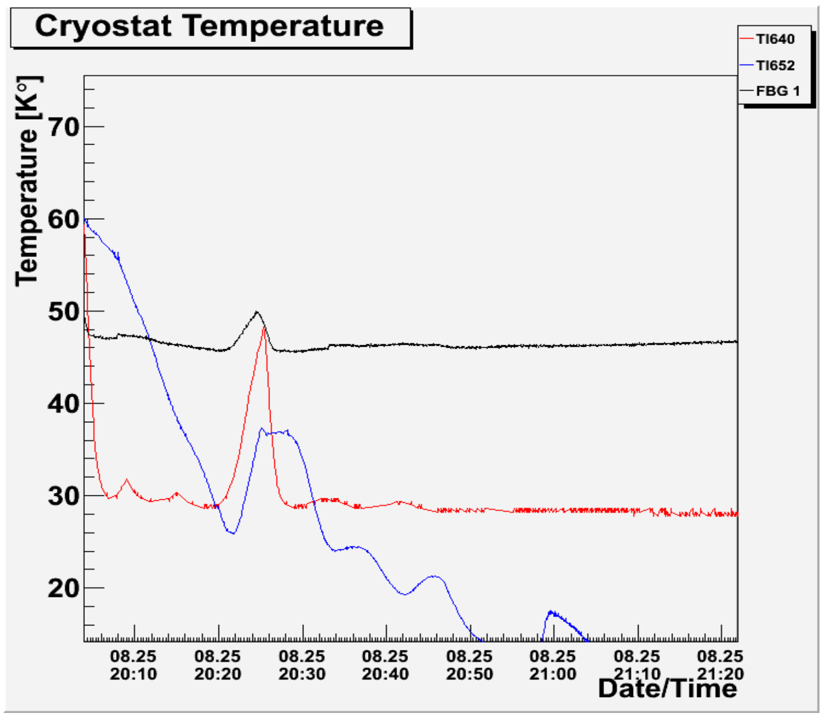
- reproducible peak positions
- glued FBG on AL shows the biggest lambda-shift
- degradation of low temperature peak amplitudes probably due to a bad sensors configuration

Feasibility Test at 4.2 K

August 25th, 2010

- Glued FBG on Al fixed on a tube
- Two reference temperature sensors

The sensors were dipped into the cryostat at **4.2 K**



Conclusions of the test

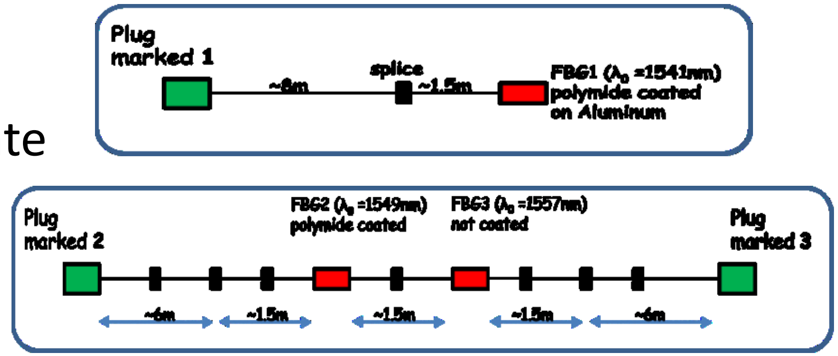
- glued FBG on AL becomes insensitive at around 50K

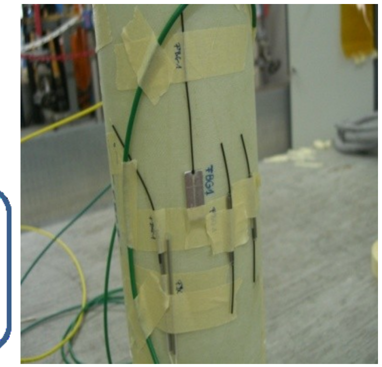
To be remarked that the reference sensor TI640 is not sensitive below 30K and TI652 is not sensitive on high temperate

Temperature Tests at 77 K

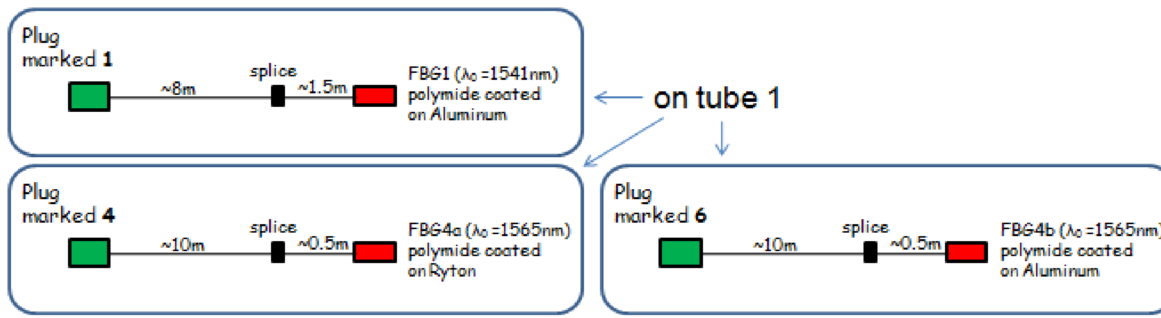
September 17 th, 2010

1. coated FBG1 on Al plate
2. coated free FBG2
3. free FBG3



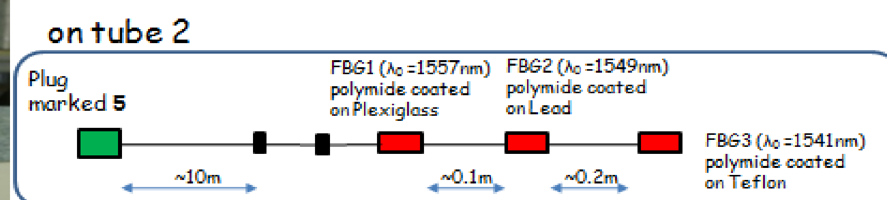


The sensors and the samples where glued on Vetronite tubes



September 22 nd, 2010

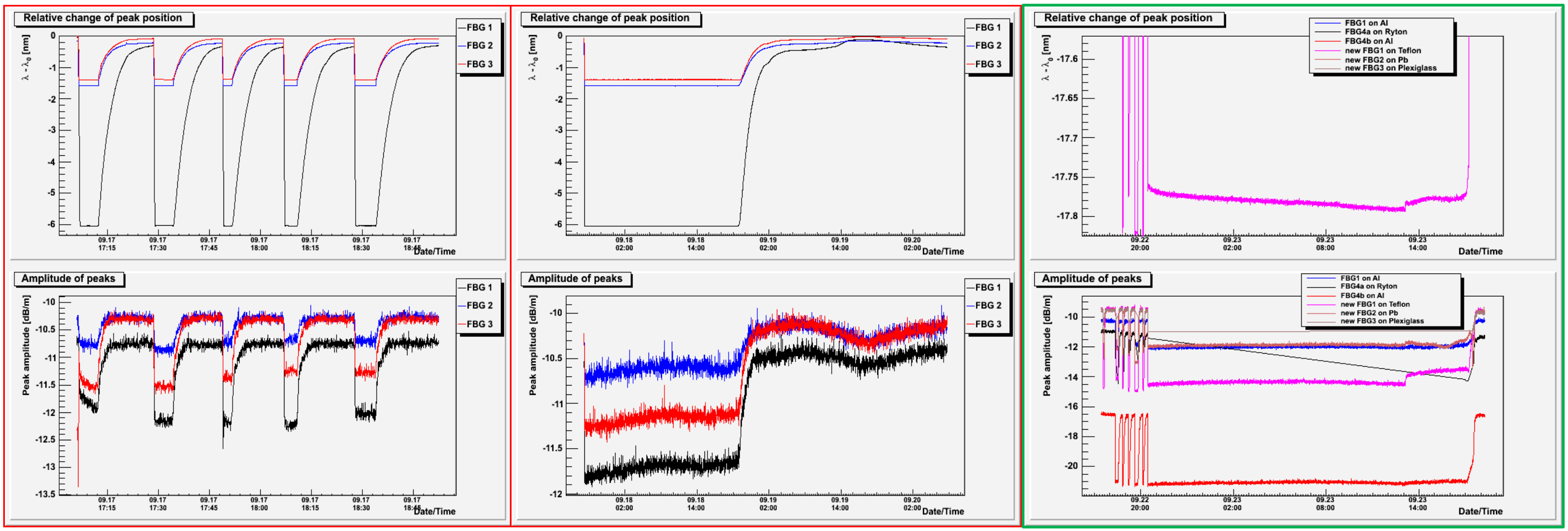
1. coated FBG4a on Ryton
2. coated FBG4b on Al
3. coated FBG1 on PMMA
4. coated FBG2 on Lead
5. coated FBG3 on Teflon



Temperature Tests at 77 K

- 5 cycles of immersions and a long cycle test in the LN

September 17 th **September 22 nd**

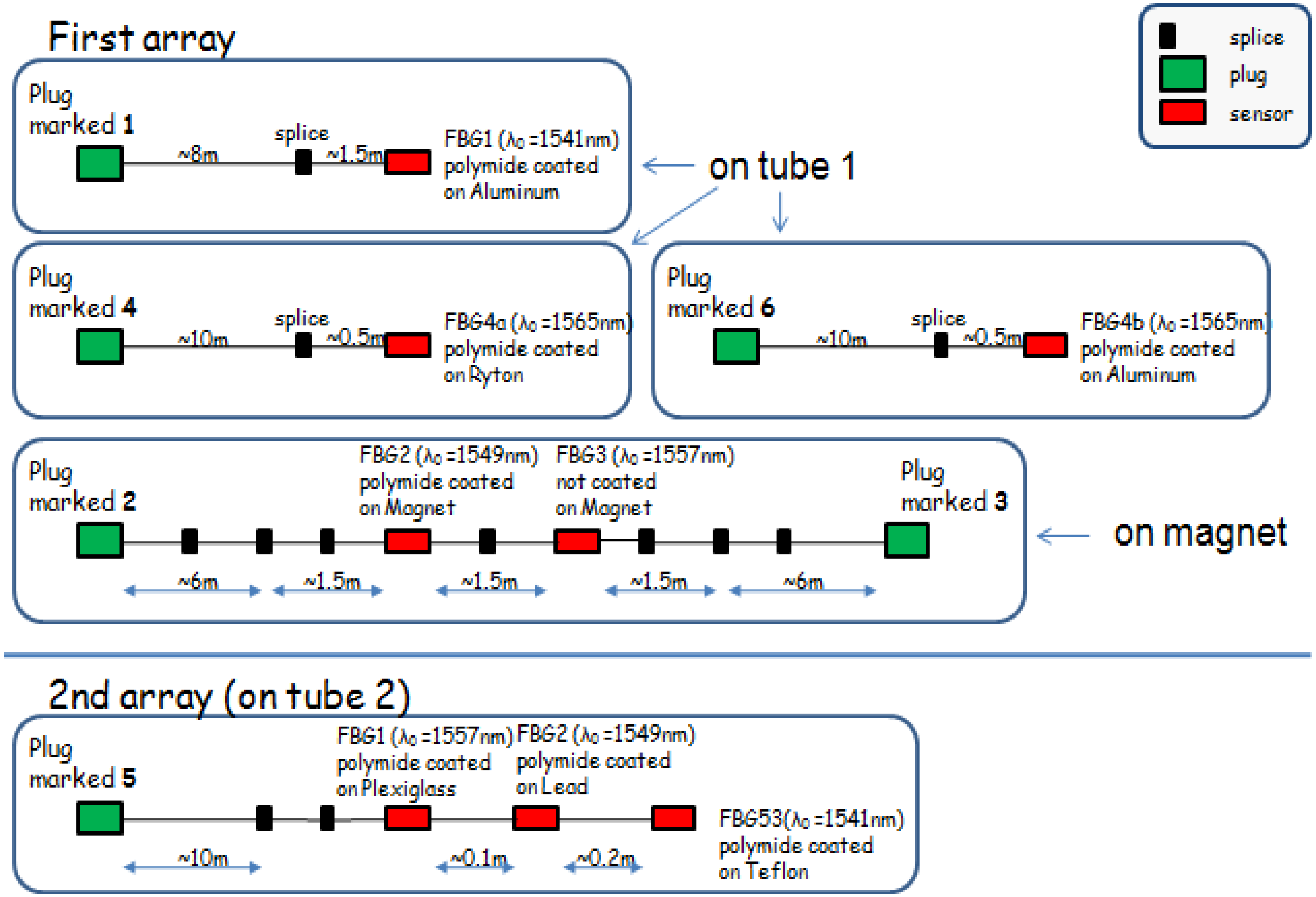


Conclusions of the tests

- On the 17th the sensors show to be stable at 77K and there is no degradation of amplitudes. FBG on ***Al* shows the biggest wavelength change** .
- On the 22nd the sensors show to be stable at 77K and the FBG on ***Teflon* performs the biggest wavelength change**.

Temperature and Strain Tests at 4.2 K and 1.9 K

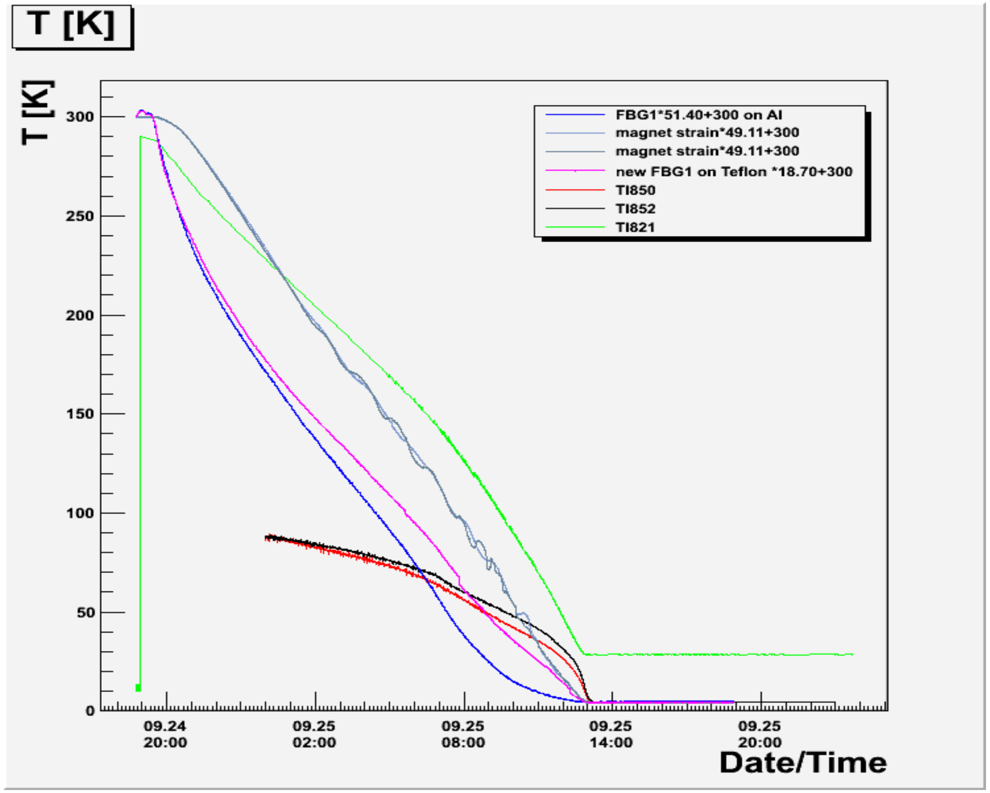
From September 24th to October 4th



Magnet and tubes were dipped into the cryostat

Temperature Tests at 4.2 K

• Comparison between the optical fiber sensors and the reference Temperature sensors fixed into the cryostat during the cool down



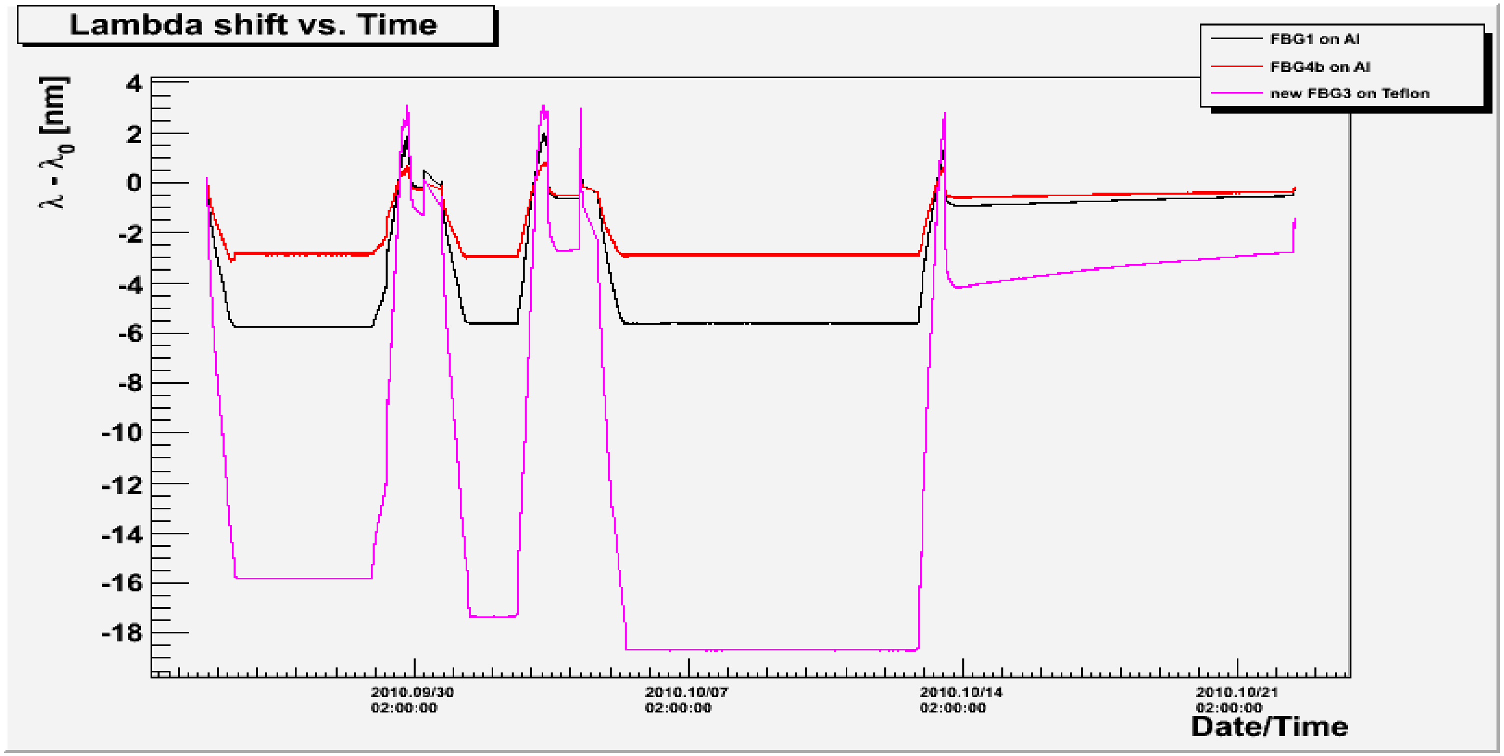
To be remarked that the reference sensor TI821 is sensitive from 300K to 20K and the TI850 and the TI852 are sensitive from 20K to 1.8K

• FBG on Teflon and strain FBGs change until 4.2 K is reached.

• FBG1 on the Al plate starts to change its slope at around 30K.

Temperature Tests at 4.2 K

• Comparison between FBGs on Al and the FBG on Teflon over the whole period: different cooled down values in the different cycles but the lambda-shift seems to be the same

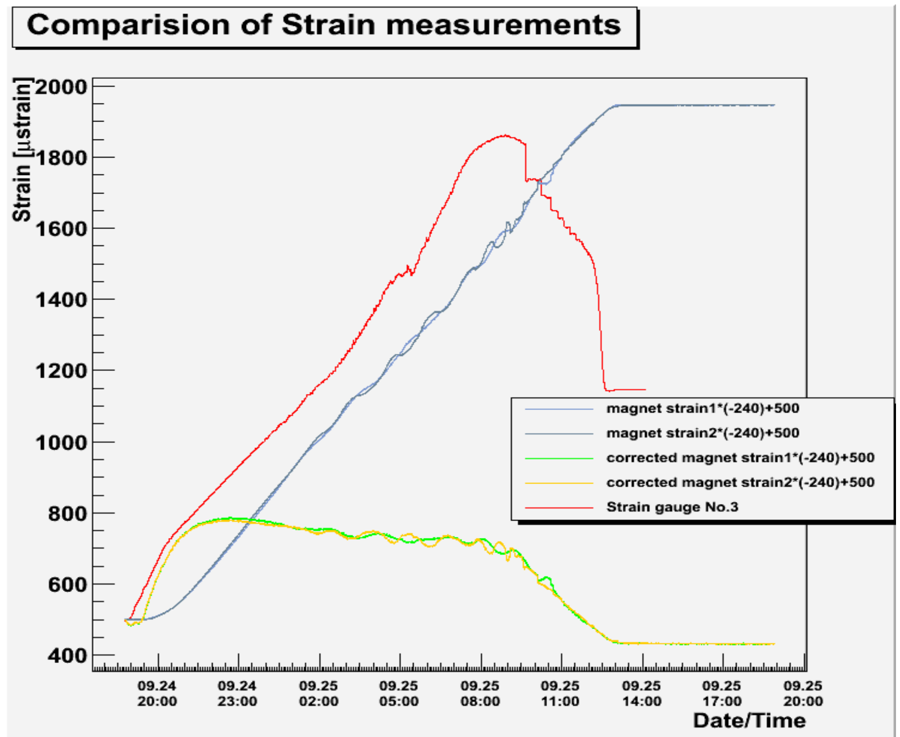


Conclusions of the tests

• Teflon gives sensitivity to the FBG sensor at low temperature but glue and geometry of the sample might effect it's behavior.

Strain Tests at 4.2 K

• Comparison between the optical fiber sensors and the electrical strain gauge closer to the optical fiber sensors and fixed on the magnet.



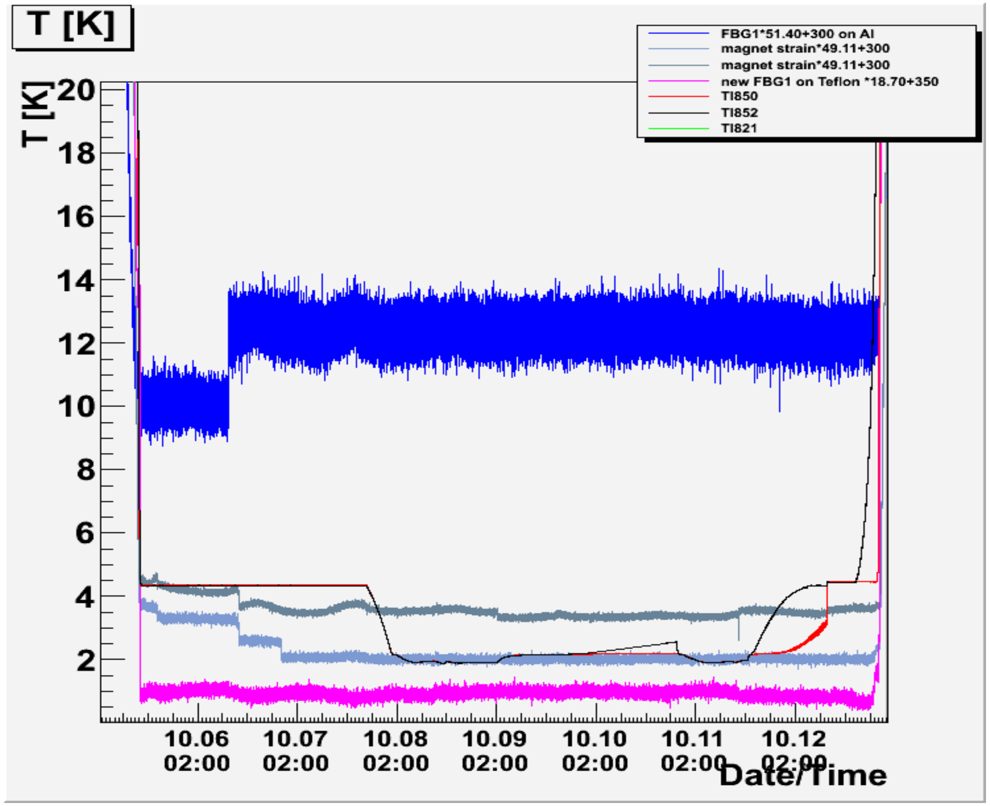
To be remarked that FBG1 on Al was about half meter below the magnet and was not attached to the magnet's mass

Conclusions of the tests

• Quite large 'discrepancy' between FBG strain sensors and magnet strain gauge.
• Strain measurements were not correctly set up (no temperature compensation).

Temperature Tests at 1.9 K

- Comparison between the optical fiber sensors and the reference Temperature sensors fixed into the cryostat



To be remarked that the reference sensor TI821 is sensitive from 300K to 20K and the TI850 and the TI852 are sensitive from 20K to 1.8K

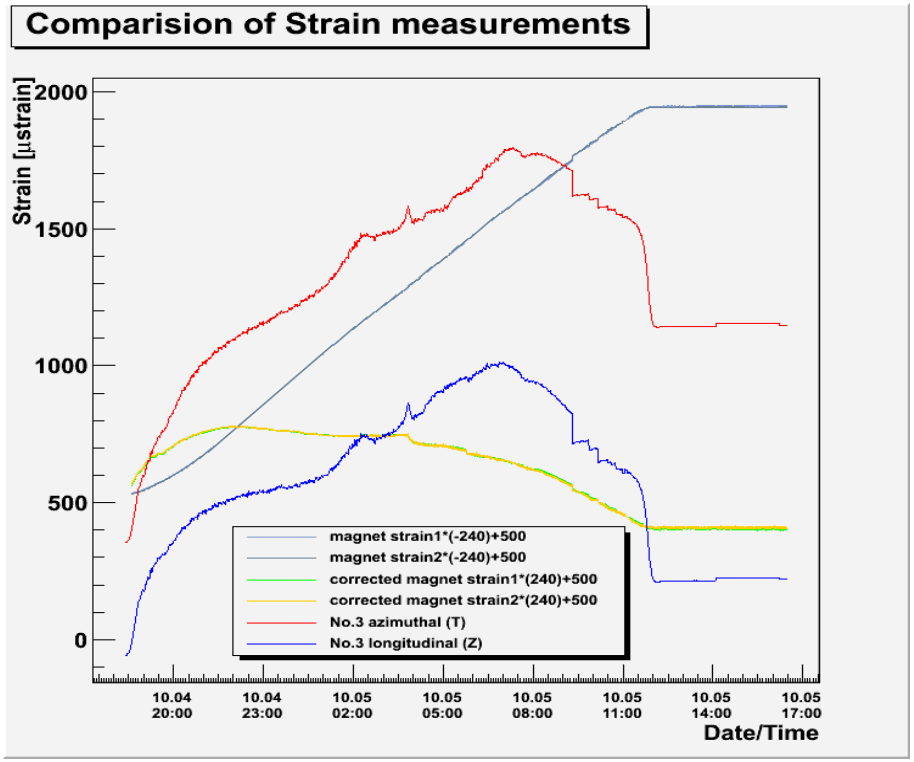
Conclusions of the tests

- No Sensitivity for very low temperature is seen on Teflon.

To be remarked: very low amplitude for the FBG glued on Teflon

Strain Tests at 1.9 K

• Comparison between the optical fiber sensors and the electrical strain gauge closer to the optical fiber sensors and fixed on the magnet.



To be remarked that FBG1 on Al was about half meter below the magnet and was not attached to the magnet's mass

Conclusions of the tests

• Quite large 'discrepancy' between FOS strain sensors and magnet strain gauge.

Conclusions

The **<u>feasibility</u> o**f the low temperature sensoring up to 77K **<u>was proven</u>** of the FBG based FOS based on measurements.

Sensors can survive up to 1.9K temperature but no sensitivity under 50K. Amplification of the Λ shift is efficient with some base materials but still limitations are seen below 50 K for most of them.

Some materials can give the sensitivity up to 4.2 K. The glue between the fiber and the base material has an impact on the results at low temperature. The interface between the fiber and a base material (glues and techniques of gluing) has to be studied.

Measurements of strain is more a question of the set up (similar as for resistive gages). Measurements have been done recently by an other team at CERN EN-MME and the feasibility was demonstrated.

Statistics with different base materials and glues has to be made to prove the principle of measurements at low temperature based on FBG technique. An adequate database and data analysis technique has to be agreed. Procedure of measurements and documentation of each of them is crucial.

Next steps

Temperature

Measurements on the exiting fibers (and specially the one on Teflon)

- at warm to test the data acquisition and data base connection
- at low temperature
  a. In a LN up to 77 K
  b. In the cryopump up to 12K
  c. In LHe

Measurements on the new sensors glued on Teflon and Plexliglass

- Thermal cycles in LN
- Measurements at warm, at 77K, at 12K and only if those measurements gives a consistent and good results we would go to LHe

Strain

Measurements on the new sensors

- Thermal cycles in LN
- Installation in a cryo-traction machine and make the cool down

Thank you for your attention!

Grazie!

Köszönöm!

Merci!