First FBG tests at IFIC laboratory

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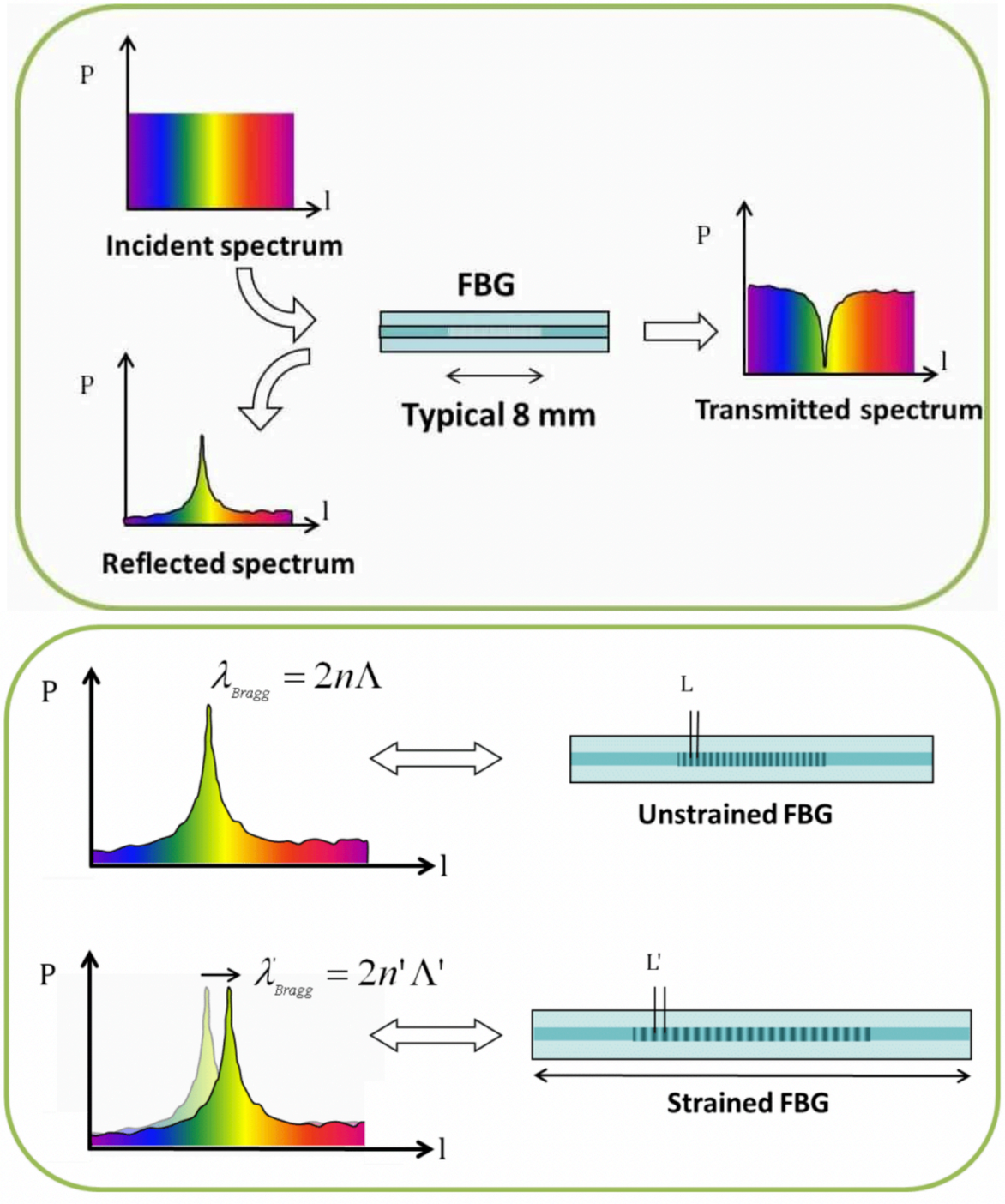
Principle of operation of FBG.

- Fibre Bragg Gratings are made by laterally exposing the core of a single-mode fibre to a periodic pattern of intense laser light. The exposure produces a **permanent increase in the refractive index of the fibre's core**, creating a fixed index modulation. This modulation is called **grating**.
- When the **Bragg condition** is fulfilled, **small amounts of reflected light** signals coherently interfere at each periodic refraction change combining into a **large reflection** at a particular wavelength.
- This condition is fulfilled at the so-called **Bragg wavelength** of the grating.
- The **Bragg wavelength varies** when external changes on the fibres are applied, as temperature or strain. The measurement of these Bragg wavelength changes allows to measure the source of the change, i.e. temperature.



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Requirements & Objectives

- The main requirement is to achieve enough precision to **resolve** the expected ~15-20 mK **temperature gradient** inside the DUNE cryostat.

- An additional requirement is to build a **real-time high-precision temperature map** of the LAr.

- The main objective of the R&D team is to achieve **similar resolution as established for the RTD**s: ~2-3 mK.

- An additional objective is to construct a flow **model** based on CFD simulations to **predict the impurities concentration** based on the temperature map.

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Conclusions from the last talk

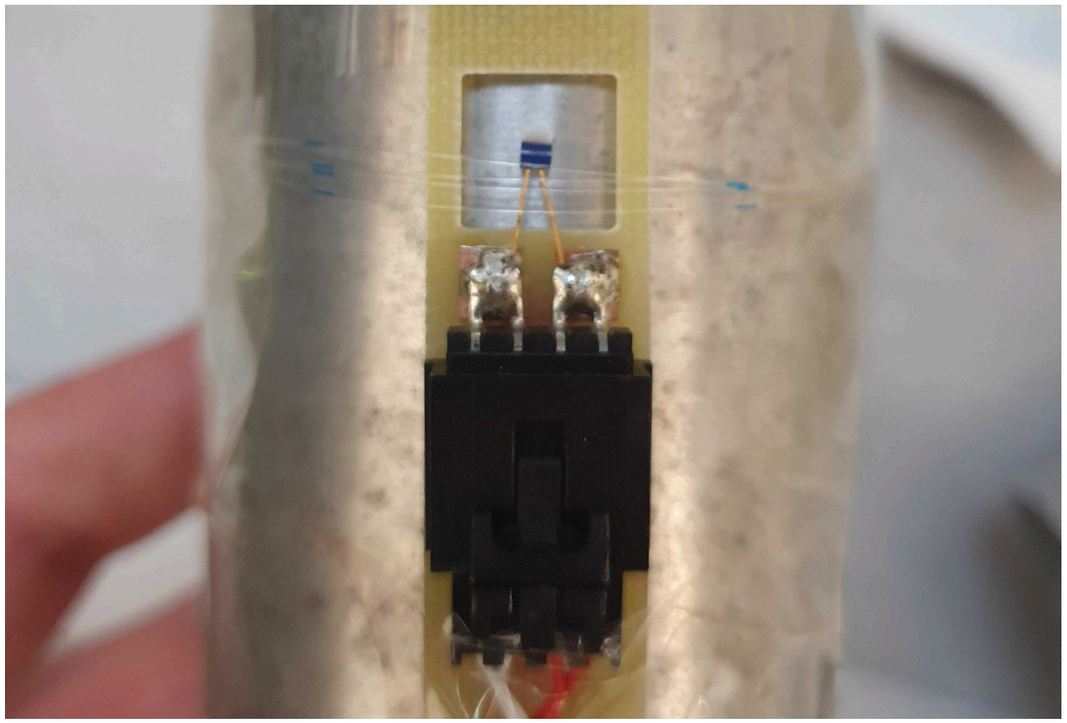
- FBG technology is **suitable** for monitoring temperature at very-low temperatures with enough resolution to **meet the consortium requirements**.
- BELLE-II, other experiments and industry already use this technology to monitor temperature.
- The **long-term sub-mK precision** of large volumes has **not been reported** in the literature. It represents a technical challenge.
- An **R&D plan** has been **agreed** with already two companies (FBGS & OPTICS11) to further increase the sensitivity of the interrogator and the fibres in the coming years.
- The **ProtoDUNE-VD TMS** installation will consist more on a **mechanical installation** than on a detector performance test. Although, some **relevant physical results** may come out of the ProtoDUNE-VD run.

Current Devices & Sensors

- **Lab-Test fibres**: we have 4 fibres with different number of sensors (3x#4 + 1x#19), lengths (4 - 10 m) and coating materials (Ormocer + OrmocerT). During the first mechanical tests, one of the fibres broke because of contact with sharp surfaces -> **Lesson learned**

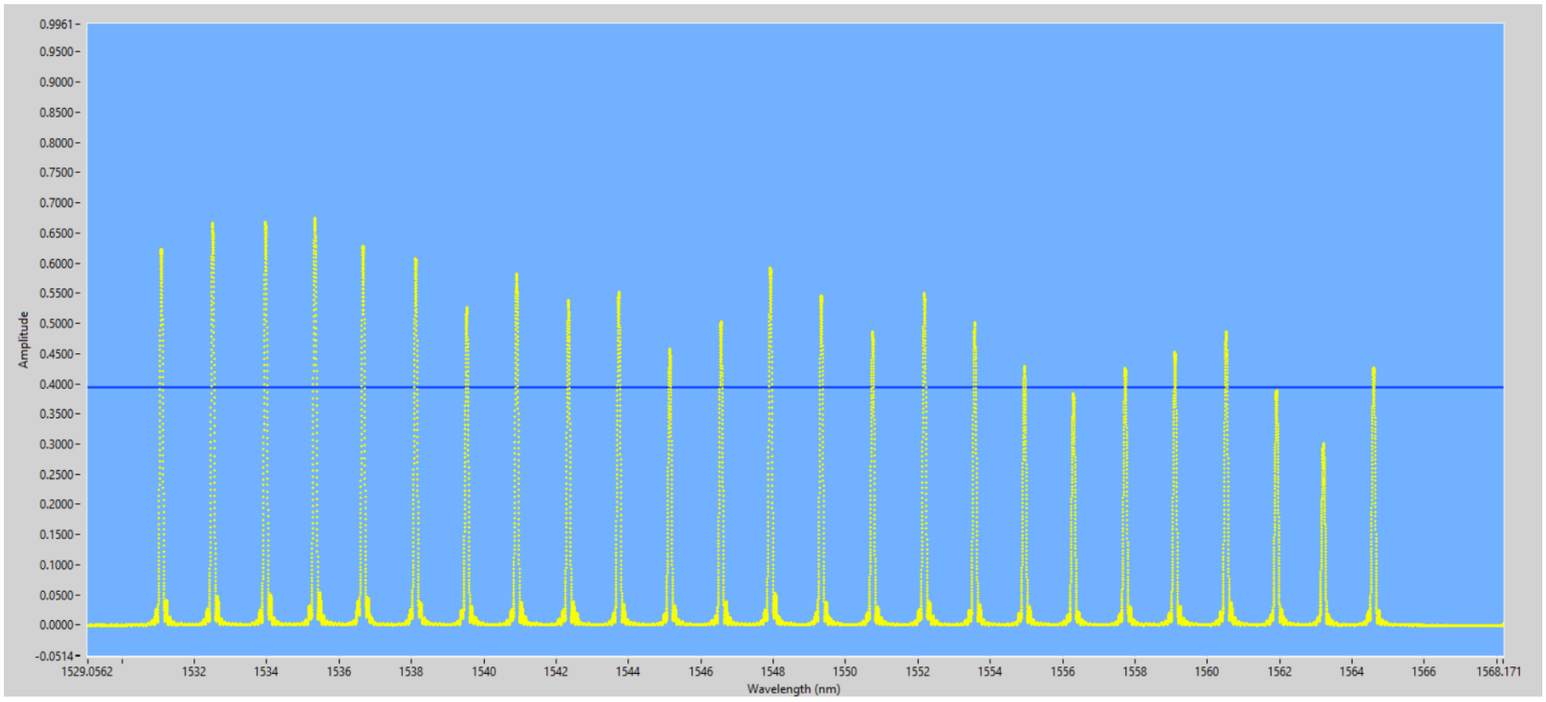
- **Installation Fibres**: the 3 fibres to be installed in ProtoDUNE-VD are already at IFIC and the characteristics validated

- **Interrogators**:
  - I4G-16 from OPTICS11
  - FBGS borrowed interrogator for comparison



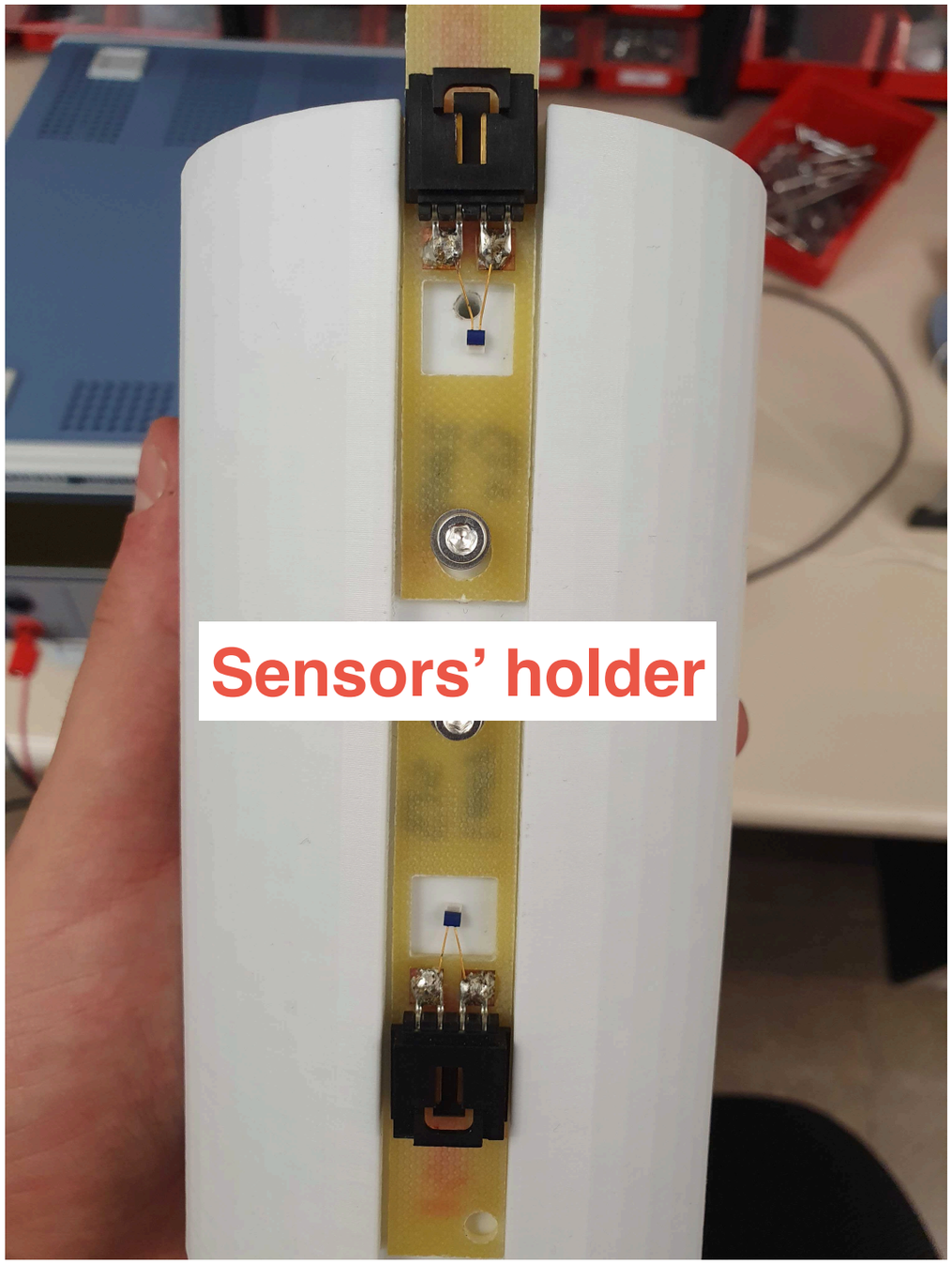
First Experimental Tests: Purpose

- Compare the performance between I4G-16 and FBGS interrogators.
- Test the integrity of the installation fibres for ProtoDUNE-VD.
- Roadmap:
  - **Warm** tests from 20ºC to 40ºC with a dedicated setup.
  - Cool tests from -70ºC to 40ºC using a **climatic chamber** available at the IFIC facilities.
  - **Cryogenic** tests in LN2 and LAr.

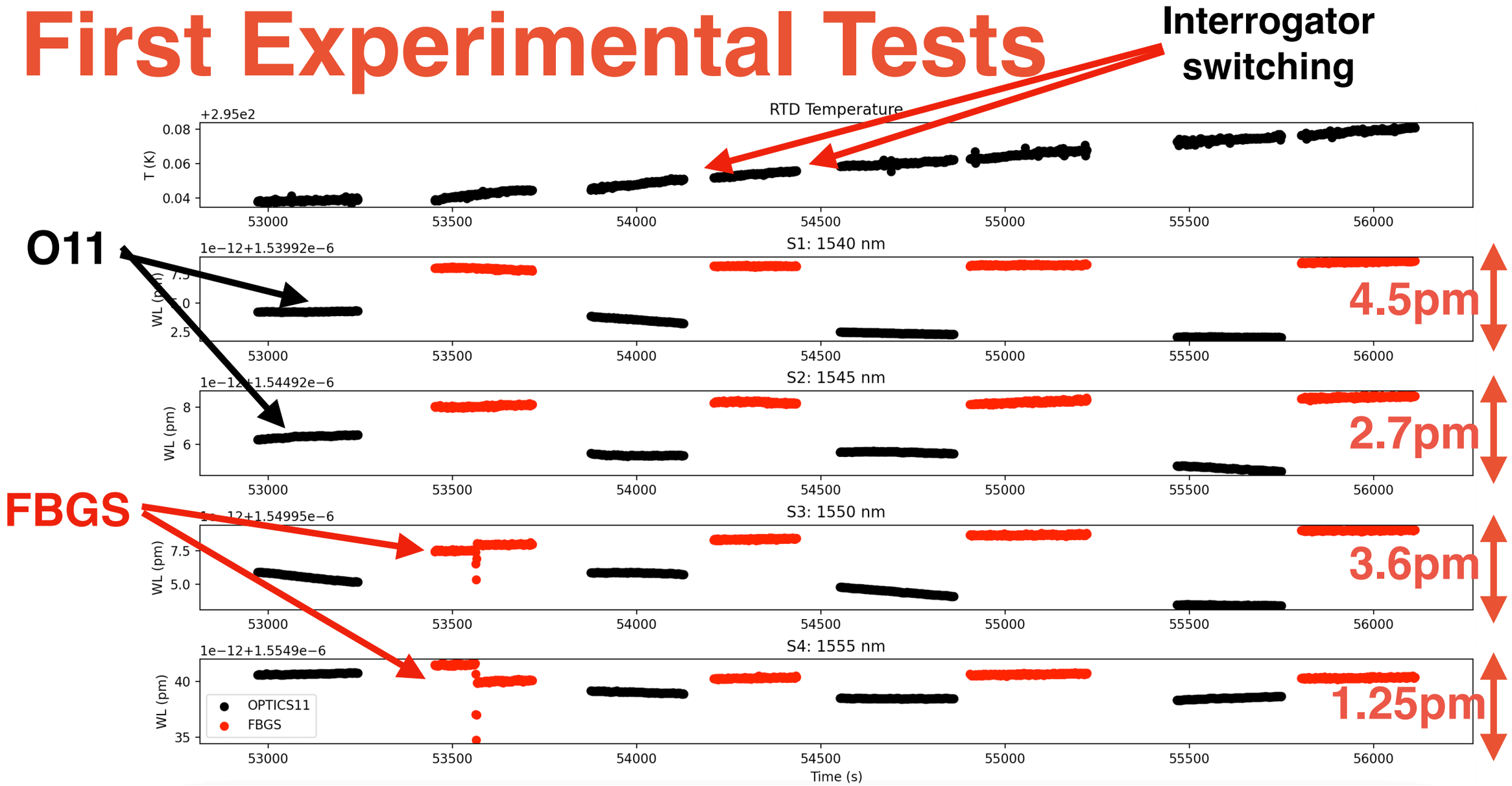


First Experimental Tests

We tried to keep the conditions stable for a single fibre while connecting it iteratively to one and the other interrogator.



First Experimental Tests



- There exists a **clear difference** in the measurements taken using O11 and FBGS interrogators. O11 is more sensitive to changes than FBGS.

First Experimental Tests: Conclusions

- According to the **specifications**, the WL drift as a function of temperature is of the order **~10pm/K**.
- Within **~40mK** temperature variation the wavelength is shifting by **~2pm** (~50 pm/K) -> The effect is much **larger than expected** (*~10 pm/K*).
- Further studies are needed to understand our systematic errors, we are still learning how to perform reliable measurements with the interrogator (many parameters to tune).

OPTICS

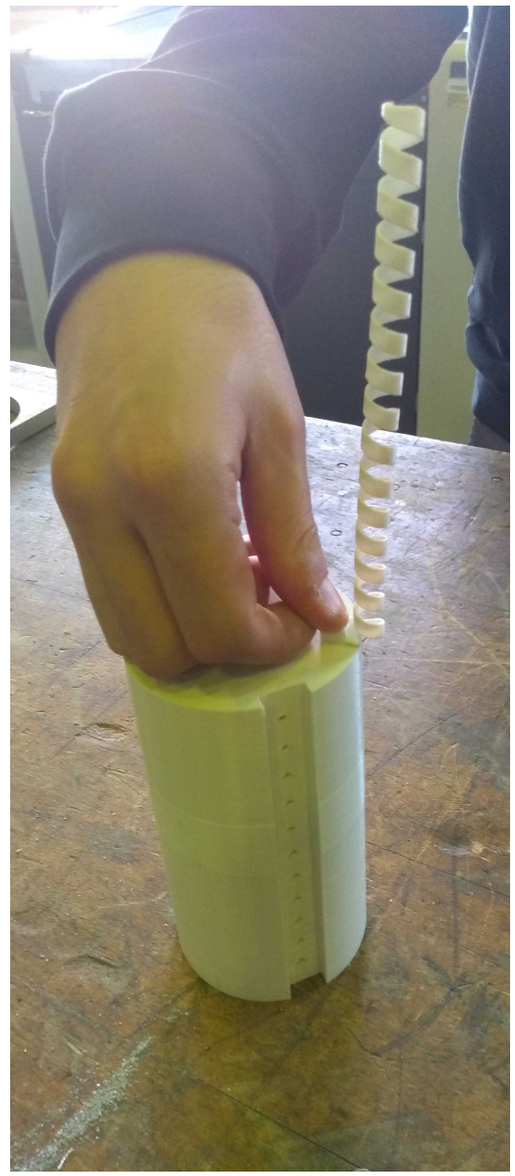
Run	Temp(mK)	S1 (pm): 1539.924nm	S2 (pm): 1544.926nm	S3 (pm): 1549.956nm	S4 (pm): 1554.941nm
Run1	0.0 +- 0.565	0.0 +- 0.03	0.0 +- 0.072	0.0 +- 0.229	0.0 +- 0.056
Run2	9.619 +- 1.732	-0.709 +- 0.175	-1.0 +- 0.029	0.316 +- 0.04	-1.642 +- 0.073
Run3	21.483 +- 1.137	-1.876 +- 0.063	-0.838 +- 0.035	-1.082 +- 0.202	-2.206 +- 0.018
Run4	35.316 +- 1.147	-2.211 +- 0.02	-1.716 +- 0.091	-2.084 +- 0.026	-2.172 +- 0.097

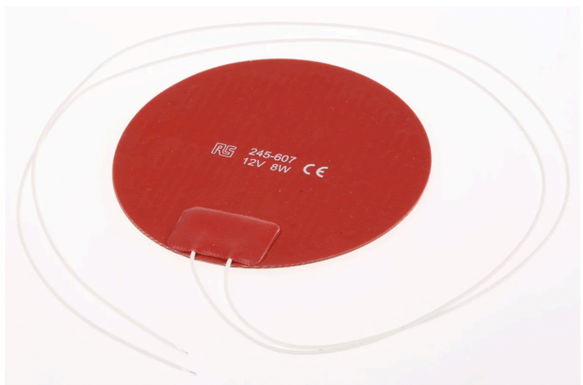
FBGS

Run	Temp(mK)	S1 (pm):1539.928nm	S2 (pm):1544.928nm	S3 (pm):1549.957nm	S4 (pm):1554.942nm
Run1	0.0 +- 1.812	0.0 +- 0.084	0.0 +- 0.053	0.0 +- 0.289	0.0 +- 0.863
Run2	11.532 +- 1.2	0.231 +- 0.029	0.208 +- 0.044	0.617 +- 0.042	-0.294 +- 0.057
Run3	23.088 +- 1.768	0.312 +- 0.038	0.21 +- 0.073	0.923 +- 0.042	0.038 +- 0.062
Run4	36.314 +- 1.461	0.586 +- 0.054	0.479 +- 0.048	1.278 +- 0.037	-0.279 +- 0.055

Warm Setup: Overview

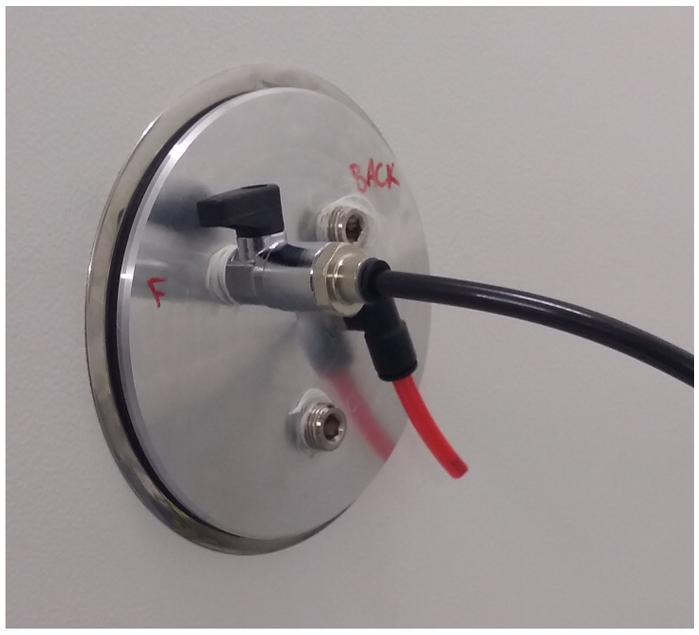
- **Objective**: develop a system able to keep ***stable and uniform temperature*** on all sensors and get the sensitivity curves.
- The setup will consist on three main parts:
  - Isolation based on polystyrene box.
  - Copper vessel instrumented with electric heaters.
  - 3D-printed sample holder for the fibres and RTDs.





Climatic Chamber Setup: Overview

- **Objective**: to carry out measurements in [-70,+40]ºC.
- In January we will study the behaviour of the chamber at temperatures as low as -70ºC to characterise and understand the system.
- One of the major issues is water condensation inside the chamber. The idea is to pump in dry air or GN2 to purge the chamber before going down in temperature.
- In February we have a 2 weeks time slot for our measurements.
- We need to design and construct the flange with the needed feedthroughs adapted to our necessities.



Summary

- FBGs for laboratory tests and installation are available at IFIC and they perform properly (*preliminary*).
- We are learning how to use the interrogator.
- We have set a working plan to carry out temperature measurements at different temperature regimes:
  - Ambient conditions with a small warm setup.
  - Cryogenic conditions in a climatic chamber.
  - LN2/LAr temperature as a final goal

Backup

Why is it necessary to change the technology?

- As it is well-known, for the **HD configuration** the TMS is based on standard **RTD**s for the temperature mapping of the liquid inside the cryostat: sensors on the APA, ullage, inlets, pipes, pump, PrMs, walls…
- Due to the **HV in the VD configuration**, copper wires cannot be used to read out the signal of the sensors -> One solution is to **use optical fibres** instead.
- This is the same motivation as it is for the SoF and PoF that will be tested in ProtoDUNE-VD soon.
- During the last decades, a new technology emerged: **Fibre Bragg Grating** (FBG) technology which has been widely used to measure extensive quantities (Temperature, Strain, Pressure…) over long **long distances** and/or large volumes.
- It has been used mostly in large infrastructures as **oil pipes** or new **buildings** to monitor the status of the structure: the flow in the pipe, the tilt of the building, stratification of natural gas…

https://technicasa.com/application/