September 1, 2023

LHCb SciFi - Analysis of service performance

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Abstract

In this project report, the analysis of the service performance in the Scintillating Fibre Tracker (SciFi), part of the LHCb experiment at CERN, is summarised. The considered services are used to prevent condensation appearing in the detector. Condensation occurs due to cooling the readout silicon photomultipliers to reduce dark noise. The monophased cooling liquid $C_6 F_{14}$ is used. The services include dry gas flowing through the detector to reduce humidity in the detector, heating by heating wires and the monitoring of outside temperatures. Additionally, the dew point inside the cavern is observed since it has a relation to monitoring the temperatures. The analysis shows that all services are working as expected and it can be assumed that no condensation occurs in the detector and the operating is thus save. During the dew point measurements in the cavern, a constant offset of 2°C was observed. Furthermore, long-term cooling tests using the monophased cooling liquid *Novec7100* were performed using a prototype C-frame. *Novec7100* has a lower global warming potential is would therefore be preferred. So far, no problems occurred during the tests with several cooling temperatures.

Contents

1 Introduction of the LHCb SciFi tracker **1**

2 Analysis of the SciFi service performance **4**
2.1 Dry Gas Flow 4
2.2 CPS Dry Gas Outlet and Cold Box temperatures 4
2.3 Dew point measurements in the LHCb cavern 6

3 Cooling tests in the LHCb assembly hall **8**
3.1 Preparation of the prototype C-frame 8
3.2 Strategy of long-term cooling tests with *Novec7100* 8

4 Conclusion **10**

1 Introduction of the LHCb SciFi tracker

The Large Hadron Collider beauty (LHCb) experiment, shown in Figure 1, is one of the large experiments at the Large Hadron Colider (LHC) at CERN. It is used to do precision measurements in processes including beauty and charm quarks. Because of the event signature of these processes, LHCb is designed as a single-arm forward spectrometer. The *pp* collisions take place in the Vertex Locator (VELO), from which the particles pass a tracking system and a particle identification (PID) system. The tracking system consists of the upstream tracker (UT), a magnet and the downstream Scintillating Fibre Tracker (SciFi), whose services are the focus of the project. The PID system includes Cherenkov detectors (RICH), electromagnetic (ECAL) and hadronic (HCAL) calorimeters and muon stations.

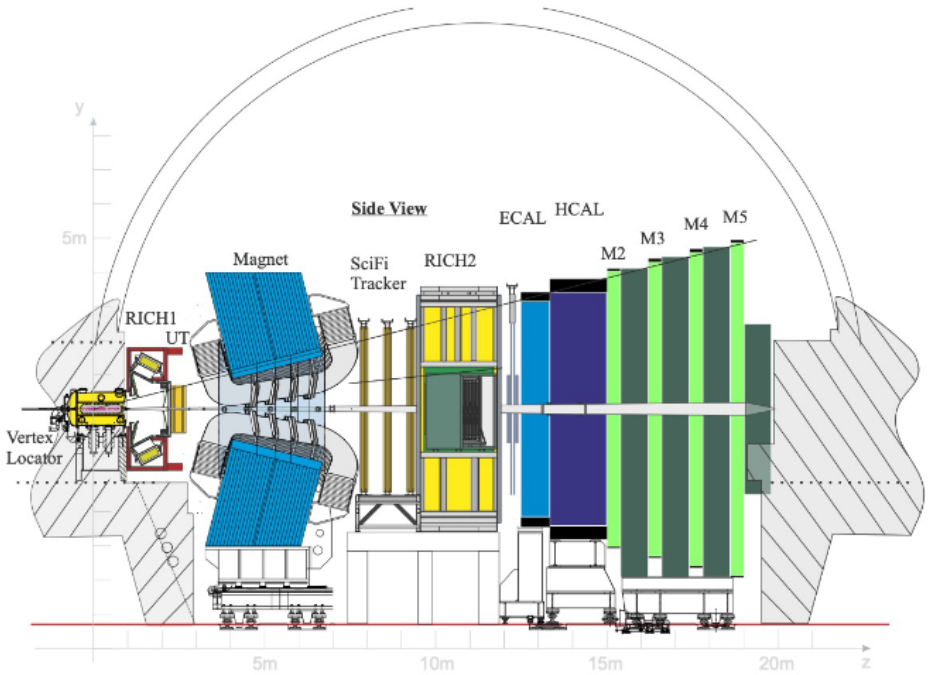


Figure 1: Schematic view of the LHCb experiment at CERN. Taken from [1].

The SciFi tracker consists of three tracking stations (T1-T3) with four layers each (L0-L3). The tracking stations are divided in two halves which enclose the beam pipe from both sides. One half is called A-side, the other C-side. Each layer is divided into four quadrants, two on the C-side (Q0, Q2) and two on the A-side of the detector (Q1, Q3). There are five to six modules of 5 m in each layer (M0-M4(M5)), which are based on scintillating fibres with a diameter of 250 μm. When a particle hits a module, light is produced and guided to either end of the modules via the fibres. At the corresponding end, the signal is read out using silicon photomultipliers (SiPM). A C-frame is defined as one half of a tracking station including two quadrants and two layers, whereby the inner layer is rotated by $\pm 5°$ to provide an optimal reconstruction of the location where the particle hit the detector and therefore a good reconstruction of the track. The resolution of SciFi is thereby $< 100\,\mu\text{m}$.

The silicon photomultipliers need to be cooled to reduce noises and thus background.

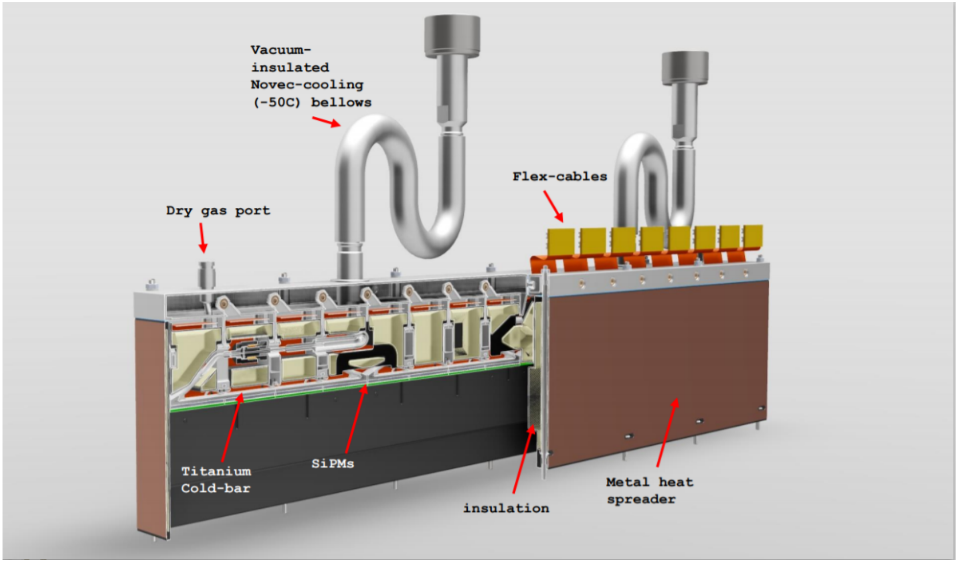


Figure 2: Construction of the cooling system used in SciFi to reduce noise in the silicon photomultipliers. Taken from [2].

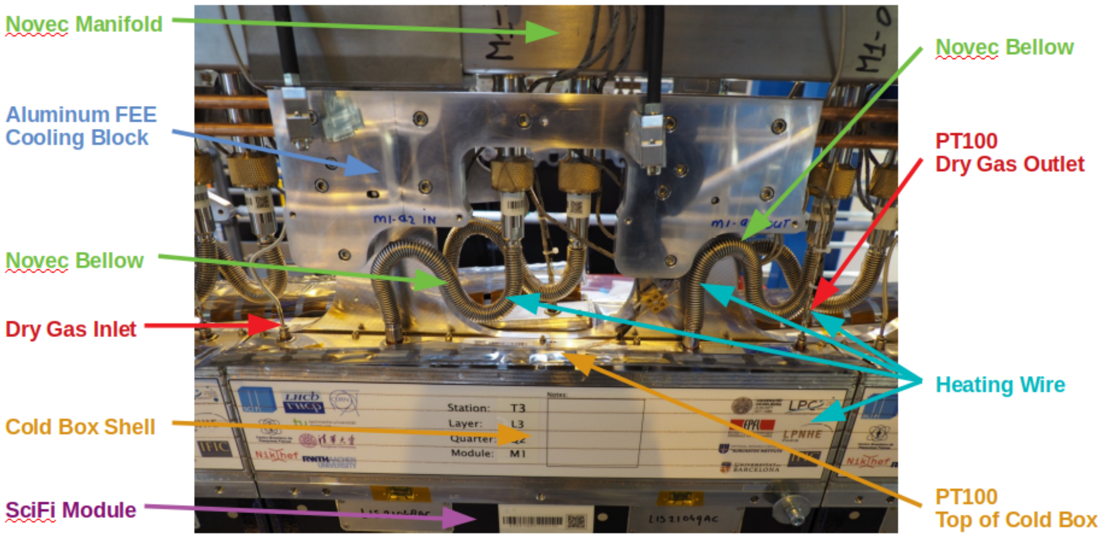


Figure 3: Location of temperature sensors and heating wires on the modules to prevent condensation in the detector. Taken from [2].

To achieve this, several services are installed in the SciFi tracker. The cooling of the photomultipliers is done at both ends of the modules, using a monophased cooling liquid. It's system is shown in Figure 2. More information about the construction, the used elements and the cooling process can be found in [2]. The cooling of the modules leads to condensation in the detector. To prevent condensation on the outside of the detector, heating wires are used, as well as a monitoring of the temperatures with sensors in several positions at the cooling system and the module. This is shown in Figure 3. Furthermore, dry gas is flowing through the detector to reduce the humidity inside the detector. The dry gas flow is monitored.

The currently used cooling liquid is $C_6\,F_{14}$. The before used cooling liquid *Novec649* was removed, since it potentially caused damage in the detector which would be difficult to monitor. In the course of this project, the performance of the described services for the currently used cooling liquid is analysed. Furthermore, another cooling liquid *Novec7100* is tested utilising a prototype of a C-frame, located in the LHCb assembly hall in building 3852. Here, long-term tests are planned to analyse the services' performance with using the *Novec7100* cooling liquid. This is done, since the global warming potential of the currently used $C_6\,F_{14}$ has a value of 9300, while *Novec7100* has a global warming potential of 320 and would therefore be preferred.

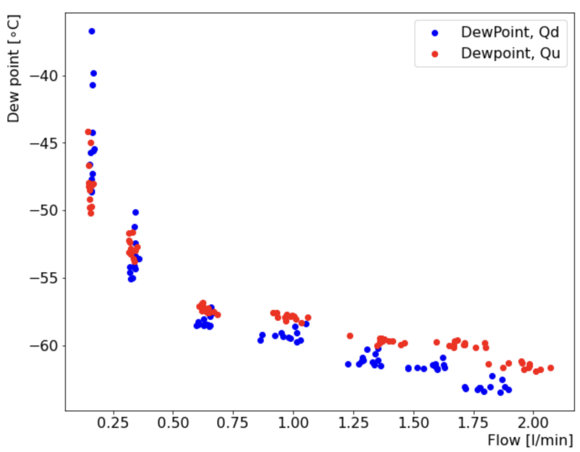
The analysis of the services' performance with the currently used cooling liquid $C_6\,F_{14}$ is described in section 2. In section 3, a description of the preparation work on the prototype C-frame is given, as well as an overview over the planned long-term cooling tests. Both parts of the project are summarised in section 4.

2 Analysis of the SciFi service performance

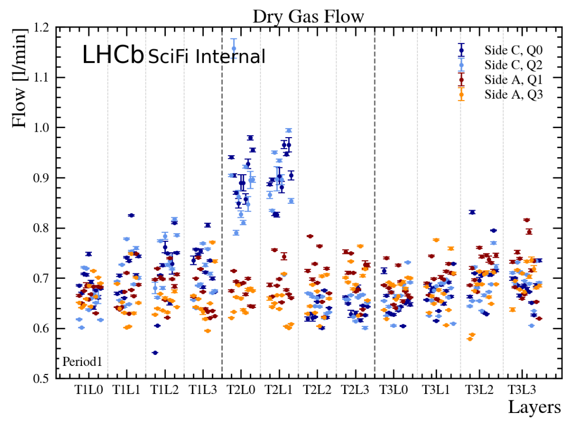
In the following, the performance of the different services, introduced in section 1, is analysed. The focus lies hereby on making sure that all services work optimal as expected to prevent condensation. Therefore, it is important that all services operate above the dew point.

2.1 Dry Gas Flow

The dry gas flowing through the detector is used to prevent condensation inside the detector. In a previous analysis [2], the relation between the dry gas flow and the dew point inside the cold box was considered. This is shown in Figure 4a. From a value of



(a) Dew point inside the cold box in dependency of the dry gas flow. A value 0.6 l/min is chosen as a lower limit of the dry gas flow. Ref.: [2].



(b) Distribution of the dry gas flow in all 12 C-frames on the 28th of June 2023. A cooling temperature of −40°C was set for the SiPMs. Almost all sensors are above the chosen limit.

Figure 4: Overview of dry gas flow in full SciFi (right) and relation between dew point and dry gas flow to determine a valid lower limit (left).

0.6 l/min on, the dew point does not change so much with varying flow. This value was therefore set as a lower limit of the flow and the flow meter was adjusted correspondingly. Also, the dew point is low enough compared to the cooling temperature. Now, the dry gas flow in all 12 C-frames is considered on the 28th of June 2023 with a cooling temperature of −40°C applied on the SiPMs. The distribution of the dry gas flow measured by all sensors in SciFi is shown in Figure 4b. One can see that the values of almost all sensors are above the chosen limit of 0.6 l/min.

2.2 CPS Dry Gas Outlet and Cold Box temperatures

To make sure the temperature on the outside parts of the detector is above the dew point in the experimental cavern, a condensation prevention system (CPS) is used. This includes heating wires on which a power is applied to heat the detector from the outside. In order to see whether the operating temperature is save, the temperature of the corresponding sensors is considered on all C-frames. The sensors are located on the Dry Gas Outlet and the top of the cold box. Both temperatures are observed in two different periods. 'Period 1' denotes the 28th of June 2023 with a SiPM cooling temperature of $-40°C$ as in the analysis of the dry gas flow and 'Period 2' denotes the time from the 13th of April, 17:00 to 14th of April, 07:00 with a SiPM cooling temperature of $-50°C$. To get a better overview over the temperature distribution, the average of all sensors in each quadrant is used, together with the maximum and minimum value of each quadrant as error bars. The distribution of the CPS temperatures for the Dry Gas Outlet and Cold Box sensors are given in Figure 5 and Figure 6. As the temperature of all sensors is above the dew point for both SiPM cooling temperatures, it can be assumed that no condensation occurs on the detector and the operation is save. In comparison of the CPS temperature in both periods, one can see that the temperatures are slightly higher when applying a higher cooling temperature on the photomultipliers.

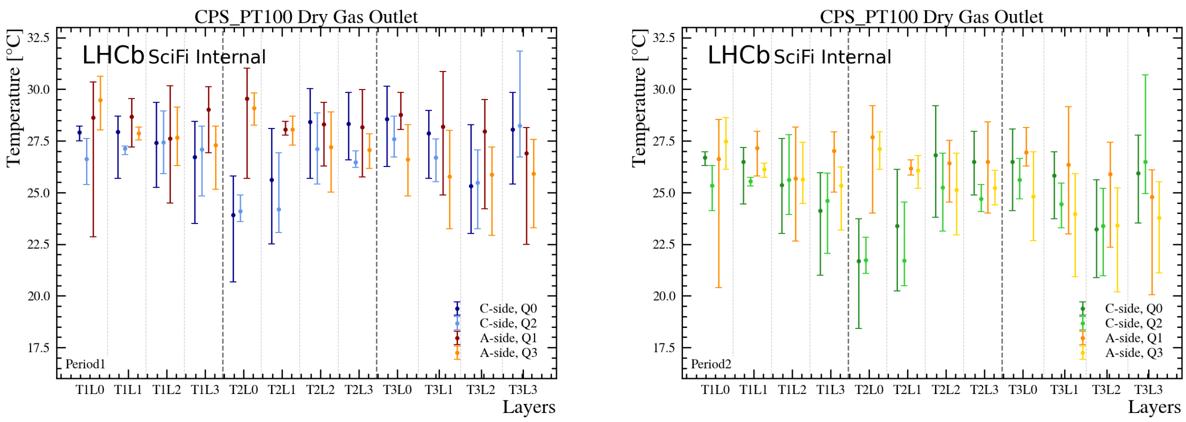


Figure 5: CPS Dry Gas Outlet temperature distribution in full SciFi with a SiPM cooling of $-40°C$ (left) and $-50°C$ (right). All temperatures are above the dew point.

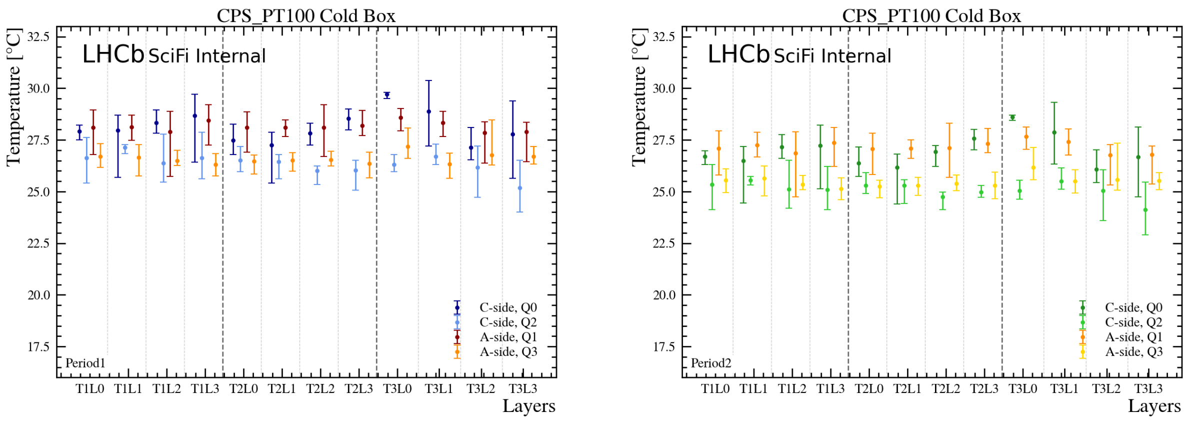
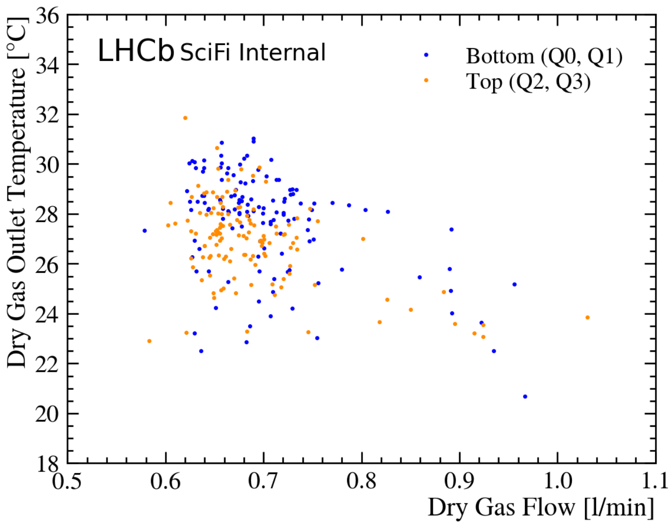


Figure 6: CPS Cold Box temperature distribution in full SciFi with a SiPM cooling of $-40°C$ (left) and $-50°C$ (right). All temperatures are above the dew point.

Comparing the sensor entries in the different layers in the distribution of the dry gas flow and the CPS Dry Gas Outlet temperature, a relation between the amount of flow and the temperature is clearly visible in the C-side quadrants of T2L0 and T2L1. There seems to be a cooler temperature in the parts of SciFi, where a higher flow was measured. To observe this further, both observables were plotted against each other. This is shown in Figure 7. No correlation is visible. A possible explanation is given by the close positioning of the temperature sensor to the heating wires, so this influence dominates.



(a) Relation between the dry gas flow and the CPS Dry Gas Outlet temperature at a SiPM cooling of $-40°$C.

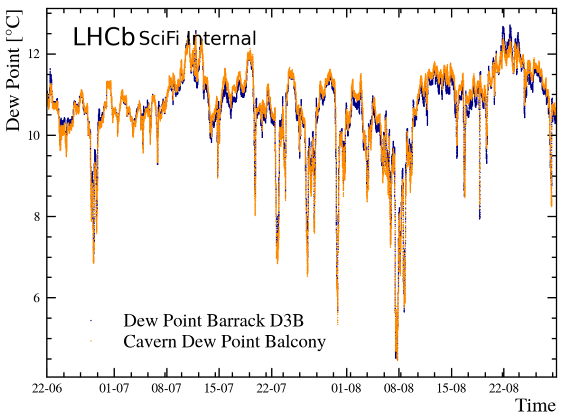
(b) Positioning of the CPS Dry Gas Outlet temperature sensor on the dry gas wire next to heating wires.

Figure 7: Relation between dry gas flow and outlet temperature. No correlation is visible. The correlation is probably dominated by the position of the temperature sensor compared to the heating wires.

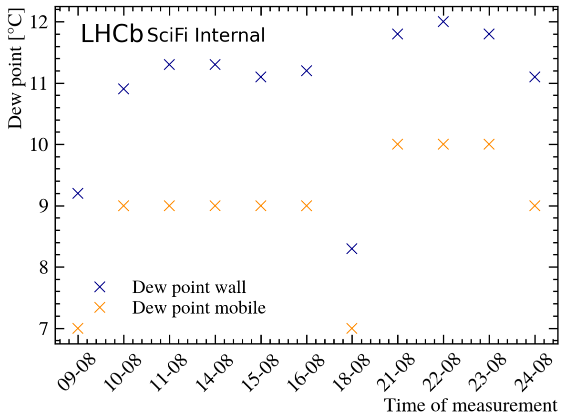
2.3 Dew point measurements in the LHCb cavern

As said in the previous chapters, the optimal heating power depends on the dew point in the LHCb cavern. Therefore, the distribution of the dew point is considered. The data is only available since the end of June. The dew point sensors are located at different positions in the cavern: one in the cavern close to the detector, the other one on the other side of the concrete wall. Both distributions of the sensors are given in Figure 8a. They agree well.

Additionally, a current measurement of the dew point in the cavern is done by taking values from a measurement device located on the wall next to the detector and a mobile device, located on the floor below the device on the wall, to gain confidence in the measurement. The distribution of the measured values is shown in Figure 8b. A constant offset of about 2°C between the values from the device on the wall and the mobile device is visible. The measured values from the device on the wall correspond to the cavern balcony sensor in Figure 8a.



(a) Distribution of the dew point measured in two different locations in the LHCb cavern. Both distributions agree.



(b) Measured values of the dew point from the measurement device on the wall next to the detector and a mobile device. A constant offset is visible.

Figure 8: Measurements of the dew point in the LHCb cavern.

3 Cooling tests in the LHCb assembly hall

To test the performance of the services using the new cooling liquid *Novec7100*, a prototype is used which is located in the assembly hall at point 8. The prototype includes one C-frame with two modules. In order to do long-term cooling tests, the prototype C-frame had to be prepared and a strategy had to be created.

3.1 Preparation of the prototype C-frame

To prepare the prototype C-frame, the corresponding temperature sensors of the services had to be installed. This includes the sensors for the cooling of the silicon photomultipliers, as well as the sensors for the CPS. Additionally, there are sensors to observe the room temperature in the assembly hall. Furthermore, the heating wires and power supplies were installed. The work on the prototype for installing the temperature sensors is shown in Figure 9.

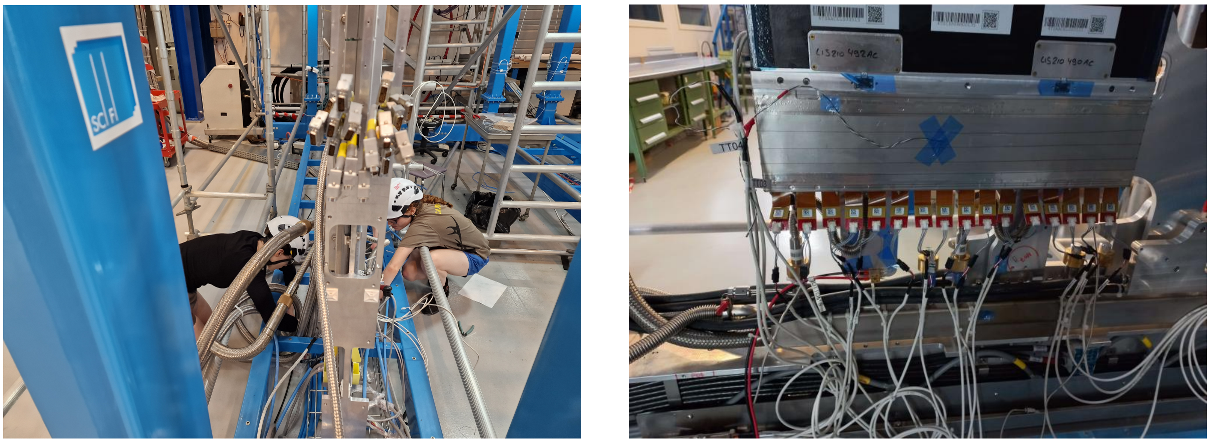


Figure 9: The preparation of the prototype C-frame included the installation of temperature sensors and heating wires.

3.2 Strategy of long-term cooling tests with *Novec7100*

To see how everything behaves in a long term usage of *Novec7100*, long-term cooling tests are done. Several settings regarding the cooling temperature of the SiPMs, as well as the applied heating power are tested. These settings are listed in Figure 10. Figure 11 shows an overview of the currently measured temperatures in the prototype. This overview was created by technical student Annabelle Parry who is also working on this project. The first setup was used to measure a baseline at room temperature with an applied dry gas flow of 0.6 l/min, the same value as used in the cavern. This flow-value was not changed during the tests. Afterwards, several amounts of heating power were applied, whereby the values given in Figure 10 correspond the applied heating power per cold box. Since there are four cold boxes included in the prototype, the given value has to be multiplied by four. The aim of the several tests is to measure the stability of the temperatures for different cooling temperatures. The analysis of these stability measurements is pending and not included in this report.

Cooling set point [°T]	Power [Watts]		0	5	10	15	20	25	30	35	
											finished
		0.3									pending
20	Dry gas flow [l/mi	0.6	1								ongoing
		0.9									
		0.3									
-50	Dry gas flow [l/mi	0.6			4	6	3	5	2		
		0.9									
		0.3									
-25	Dry gas flow [l/mi	0.6		11	10	9	8	7			
		0.9									
		0.3									
0	Dry gas flow [l/mi	0.6	12	13	14						
		0.9									

Figure 10: Overview of the different set points for the long-term cooling tests using *Novec7100*.

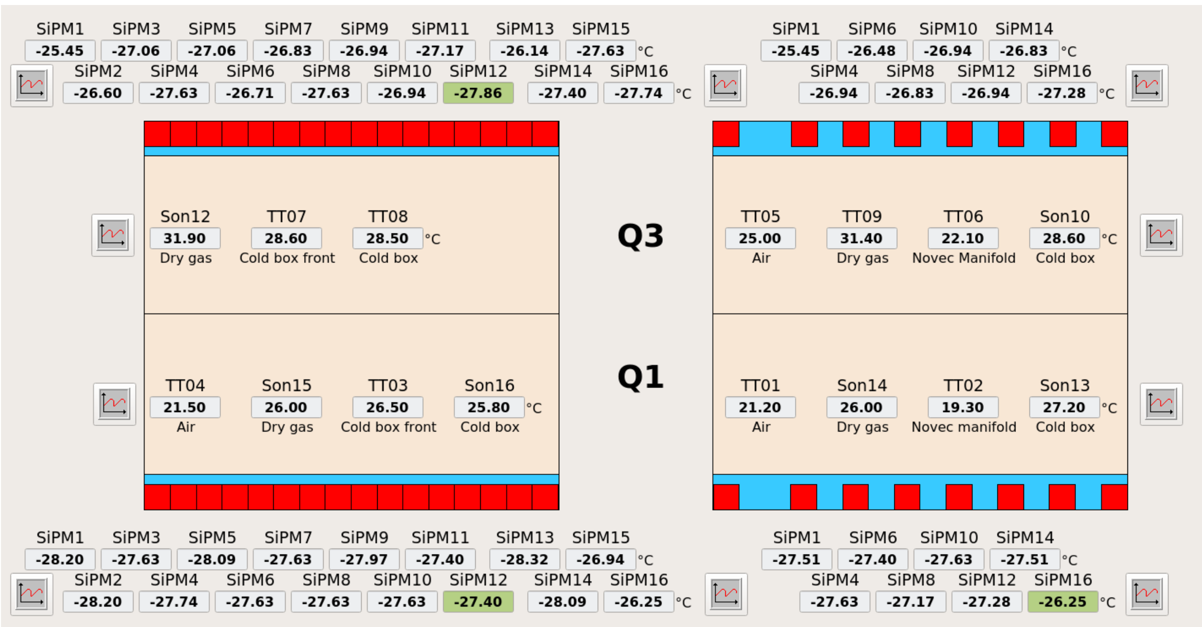


Figure 11: Overview of the SiPM and CPS temperatures measured by sensors on the C-frame prototype. Created by Annabelle Parry.

4 Conclusion

In this project, the performance of the services in the Scintillation Fibre Tracker (SciFi) in the LHCb experiment was analysed. The services are needed to prevent condensation in the detector which occurs due to cooling the silicon photomultipliers (SiPMs) to reduce noise. This is currently done using the monophased cooling liquid C_6F_{14}. The services include dry gas flowing through the detector, as well as a Condensation Prevention System (CPS), based on heating wires wrapped around the cold parts of the detector and monitoring the corresponding temperatures.

First, the amount of dry gas flowing through the detector was considered. An analysis of the flow sensors in full SciFi showed that there is almost no flow below a set lower limit of 0.6 l/min, which was shown to be an amount of flow for which the dew point inside the cold box is low enough in a previous analysis. Afterwards, the temperatures of the CPS were considered, measured by temperature sensors located on the Dry Gas Outlet and the Cold Box. This analysis showed that all temperatures were above the dew point in the experimental cavern, so it can be assumed to have no condensation on the detector and the operating therefore to be save. An overview of the temperature sensors in full SciFi showed a relation between the amount of dry gas flow and the CPS temperature, but no correlation was visible, the relation is assumed to be dominated by the location of the temperature sensors compared to the heating wires. Additionally, the dew point in the cavern was considered since the optimal heating power depends on the dew point. The distribution of the dew point measured by two sensors installed this year was analysed. Both agree well. Furthermore, another measurement of the dew point was taken using a measuring device located next to the detector and a mobile device below to gain confidence in the measurements. A constant offset of about 2°C was observed.

Since the currently used cooling liquid C_6F_{14} has a high global warming potential, the possibility to replace it with *Novec7100*, which global warming potential is lower, is tested. For this, a prototype of a C-frame located in the assembly hall at LHCb is used. The prototype was prepared by installing the needed temperature sensors and the heating wires and a set of cooling and stability tests was done and is still ongoing. So far, no problems occurred for cooling temperatures of +20°C, −50°C and −25°C.

In summary, the services perform well and as expected using the cooling liquid C_6F_{14} and no problems occurred in long-term cooling tests with *Novec7100*, which would be preferred due to it's lower global warming potential.

References

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[2] Jan De Boer. “Forward Physics and Scintillating Fibre Trackers at the Large Hadron Collider”. Masterthesis. 2020. URL: https://cds.cern.ch/record/2753606.