VELO Upgrade module characterization

CERN Summer Student Programme 2019 Report
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Summary

During Run I and II, the Large Hadron Collider Beauty (LHCb) Experiment acquired proton-proton collisions data with an instantaneous luminosity of $4 \times 10^{32} \text{ cm}^{-2} \text{s}^{-1}$. Through the long-shutdown two (LS2), most of the LHCb sub-detectors are being upgraded due to the new data-taking conditions which include an increase of factor 5 on the instantaneous luminosity. VErtex LOcator (VELO) is a detector designed surrounding to the interaction point. Its main purpose is the reconstruction of tracks of p-p collisions and decay vertices. The new hybrid pixel vertex detector will feature modules based on microchannel cooling substrates and $55 \times 55 \mu m^2$ pitch pixel detectors bump bonded to ultra high speed ASICs which operates at 40 MHz called the Velopix.

CERN VELO Lab has the important role of testing and debugging VELO module prototypes. My contribution related to the operation of a setup for testing the modules during the Summer Program is reported.
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1 Introduction

The LHCb experiment searches for new physics measuring CP violation and rare decays of heavy flavour hadrons. The detector is optimized to the study of particles containing b and c quarks and is composed by two RICH detectors for particle identification, electromagnetic and hadronic calorimeters and a muon system [2]. During Long Shutdown 2 (LS2), LHCb will be upgraded in a way that new precision measurements of rare decays will be possible. During LS2, LHCb ran at a luminosity (number of collisions produced in the detector per $cm^2$ and per second) of $4 \times 10^{32} \, cm^{-2} \, s^{-1}$ and is expected to increase to $2 \times 10^{33} \, cm^{-2} \, s^{-1}$.

The luminosity is limited by the trigger on both hardware and software level. The former VELO has a readout limit of 1 MHz, but to run at a higher luminosity, the hardware trigger will be replaced with a full software trigger readout system of 40MHz. To achieve this, the current VELO detectors will be replaced by hybrid pixel detectors with 200 $\mu m$ thick n-on-p silicon sensor bump-bonded to new VeloPix readout chips designed for the 40MHz readout rate. VeloPix is based on the Timepix3 and consists of $256 \times 256$ pixels with a pixel pitch of 55 $\mu m$.

CERN VELO Lab is responsible for testing and debugging VELO modules prototypes. They are sent to CERN from both production sites in Amsterdam and Manchester to cross-check its performances and make sure they meet the operation requirements.

1.1 Electronics

The new module layout has a L shape geometry with 4 sensors, two on each side, and 2 transceivers (GBTx), one of each side. Each sensor consists of 3 VeloPix ASICs connected to the same silicon sensor (see Fig. 8). To minimize the amount of material close to the beam, the electronics (sensor + ASIC) exceed the cooling substrate by 5 mm.

![Back Hybrid and Front Hybrid](image)

Figure 1: Back side and Front side of the hybrid. The black bigger squares represent the GBTx transceivers.
1.1.1 MiniDAQ read-out system

MiniDAQ (Mini-Data Acquisition) is the data acquisition module, prototype of the LHCb DAQ system. The LHCb upgrade will use a common board for all its electronic components called PCIe40, which is based on the Altera Arria 10 FPGA. The FPGA and the server together make up the system composed by the boards SOL40 and TELL40, whose functions are determined by the firmware which is controlled via WinCC OA. [4]

- **SOL40**: uses the LHCb standard communication protocol (GBT) to communicate with the GBTx ASIC as distribute the control signals to all front-ends chips and keep the whole experiment synchronous.

- **TELL40**: uses the VELO specific communication protocol (GWT) to receive data from the VeloPix ASIC. the TELL40 is responsible for the high speed data acquisition

The MiniDAQ communicates to the experimental setup through optical fibre links. In the test setup they are less than one meter in length, but the final system will be more than 100m for the final detector.

1.1.2 OPB

The Opto Power Board (OPB) is placed outside the VELO tank and converts the electrical data and control signals from the hybrid module to optical data over the fibre links to the MiniDAQ, and vice-versa.

1.1.3 GBTx

The processing and translation of differential signals from Velopix into optical signals is done via the GBTx ASIC.

2 The experimental setup

To simulate the operational conditions of LHCb, such as pressure and temperature of new VELO modules, a setup was commissioned, which was called MiniVELO. This setup consists mostly of the VELO module inside a chamber evacuated (see Fig. 3), a CO$_2$ pumping unit TRACI V3 $^1$(see Fig. 4) along with all the piping necessary to feed the module and sensors for measuring features such as temperature, pressure, and CO$_2$ flow.

For testing purposes, a LabVIEW remote user control interface was created. With the LabVIEW program, it is possible to control heaters, power the OPB, control and monitor the temperature and flow of TRACI and monitor the pressure of the chamber. The live status of TRACI is published on a webpage. LabVIEW can access this webpage, retrieve the information and display it on the front panel.

The modules are being cooled with an evaporative method to keep the sensors below -20 $^\circ$C, so it is necessary to fine-tune the boiling point of the CO$_2$. That is why heaters on the CO$_2$ pipes are necessary. Boiling too early could lead to a system dry-out, and not boiling

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$^1$Multipurpose Refrigeration Apparatus for CO2 Investigation [1]
properly inside the could lead to an ineffective cooling. The heaters are powered individually
by a pair of power sources and are controlled by LabVIEW as well.

![Figure 2: VELO module positioned on the chamber support.](image)

![Figure 3: Experimental setup with the module and the vacuum pump.](image)

![Figure 4: Opposite side of the setup with TRACI (the green box).](image)

2.1 **LabVIEW interface**

LabVIEW is a platform and development environment for a visual programming language
developed by National Instruments. LabVIEW routines are defined by virtual instruments (VIs). It integrates the creation of user interfaces (front panel) into the development interface (block diagram).
2.1.1 MiniVELO LabVIEW control interface

On Fig. 5 is the front panel of the main program to control the setup.

![Figure 5: VELO module positioned on the chamber support.](image)

To ensure the safety of the equipment and the module, security features ought to be implemented to the code. These features are software level interlocks that when triggered, turn off the heaters and the module power.

Fig. 6 shows the tab in the program that monitors the interlocks. Each interlock follows security mechanisms for several features of the setup. On the bottom left, there is a new piece of code I developed to alert any loss of connection between LabVIEW and TRACI. If the connection is lost, it is possible to enable interlock after a defined time and email the user to warn about the loss and/or recovery of connection, and in case of activation of interlock.

Other configurations were modified. One of the changes was enabling security checks of the NTCs temperatures and for the flow as default. A pop-up window appears to alert the user that these conditions would enable interlock if the conditions are met. To avoid burning a piece of the setup when the heaters are on, I added an automatic TRACI minimum flow change after it reaches a certain value. Thus, the heaters are turned off if there is no cooling on the system.
2.1.2 IV Curve

After the upgrade, LHCb sensors will receive highly non-uniform radiation such that the sensors are expected to retain a 99% hit efficiency at up to 1000 V bias voltage without suffering breakdown [3]. In this way, the current versus voltage (IV) curve of the sensor is important to characterize the electrical stability and power dissipation of sensors tolerance.
at this high bias voltage.

Until June 2019, an old program was being used to control two Keithley Voltage sources (one for each side of the module), but this LabVIEW code was not user-friendly and made troubleshooting and inserting new features very difficult and time-consuming.

To study the behavior of the module, IV curves are performed for each chip (VP0, VP2 and VP3, as seen in Fig. 8). It is now possible to control both sources in the same VI, which was not allowed with the previous code.

Figure 8: Screenshot of the LabVIEW program developed during the Summer Program.

Figure 9: Comparison of the old block diagram (left) and the new one (right) for controlling one Keithley power supply.
3 Data Controlling

For the many experiments at CERN, all the data monitoring and development is being implemented using WinCC Open Architecture (WinCC OA), which is a tool for building SCADA\(^2\) applications chosen by the Joint Control Projects Framework (JCOP).

CERN developed JCOP Framework to support the creation of controlling systems for its experiments, particle accelerators, and infrastructure. JCOP was created to simplify the access do SCADA and aims to reduce the overall manpower cost required to produce and run the experiment control system.

3.1 VeloPix Communication and Power Modes

For the Mini VELO experiment, there are some panels available, and in order to facilitate the analysis process, two of them were merged. The right side of the panel on Fig. 10 will monitor the communication with all ASICs. On the right side, it is possible to choose the Power Modes, in which you can set different power scenarios to the Velopix ASIC that increases in potency from 1 to 5.

The results are stored in a log file containing the power mode, the chip IDs of the ASICs (wich corresponds to the ASICs seen on Fig. 8) and the digital and analog supply voltages.

3.2 NTC Temperatures monitoring

As during the LHCb Run, all the experiment will be controlled by WinCC OA, the tendency is to adapt Mini VELO to be monitored and controlled mostly, if not completely, by this system.

\(^2\)Supervisory Control and Data Acquisition
There are 6 NTCs on the module, one for each ASIC and one for each GBTx. At the Lab, different computers control the experiment. I created a new panel (Fig. 11) that takes the NTC temperatures values displayed on LabVIEW (Fig. 5) using TCP/IP (Transmission Control Protocol/Internet Protocol).

The Fig. 12 shows the piece of code added to the MiniVELO LabVIEW control program. The code opens a TCP session and sends the information using an available port. On the computer responsible for controlling the ASICs with WinCC, I wrote a python script to read these values and update it repeatedly creating a text file. Then, the panel opens this file and reads these values potting them.

Figure 11: NTC monitoring panel on WinCC.

Figure 12: Block diagram with the TCP connection on LabVIEW
4 Conclusion

I participated in the VELO upgrade tests at VELO Lab by updating the experiment control interface as seen in section 2.1.1 and created a new one for controlling the high voltage sources on the sensors (section 2.1.2). Also, a WinCC panel was updated to improve the analysis (section 3.1) and a new panel was created following the necessity of transition from LabVIEW to WinCC. My scripts and panel can now be used by the group to test the modules.

Furthermore, other laboratory routines were performed and data collection was followed up. All the activities performed provided me a great learning experience and I hope it makes good use for the team.
References


