PROCEEDINGS OF SCIENCE

The LHCb VELO upgrade

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The upgrade of the LHCb experiment is planned for beginning of 2019 unitl the end of 2020. It will transform the experiment to a trigger-less system reading out the full detector at 40 MHz rate. The Vertex Locator (VELO) surrounding the interaction region is used to construct primary and secondary vertices, and the flight distance of long-lived particles. The upgraded VELO will be a hybrid pixel detector read out using the VeloPix ASIC. The vacuum of the detector modules is separated from the beam vacuum by a thin custom made foil. The detector halves are retracted when the beam is injected and closed during stable beams. When closed the first sensitive pixel is 5.1 mm away from the beam. The use of evaporative CO_2 coolant in micro-channels decreases the material budget. Micro-channel cooling brings advantages: very efficient heat transfer with almost small temperature gradients across the module, no CTE mismatch with silicon components, and low material contribution. The current status of the VELO will be described together with a presentation of recent test beam results.

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1. Introduction

The LHCb experiment [1] located at CERN is a single arm spectrometer covering a forward pseudorapidity region of $2 \leq \eta \leq 5$. It currently operates at 4×10^{32} cm^{-2}s^{-1}. It has collected 3 fb^{-1} of data during the first run of the LHC. LHCb is focussing on the study of CP violation and rare decays of beauty and charm particles. The Vertex Locator (VELO) is a silicon strip detector operating in a secondary vacuum around the interaction point. The secondary vacuum is separated from the beam vacuum by an RF-foil, which is a thin aluminium box. The modules of the VELO are mounted on two retractable halves, which move towards the interaction point when the beam is stable. When moved in the detector is 8.1 mm away from the beam.

The Large Hadron Collider will be upgraded in 2019. The upgraded LHCb detector will have to deal with a higher luminosity of 2×10^{33}cm^{-2}s^{-1} and will collect 50 fb^{-1} of data. The plan of this upgrade in luminosity is to get a higher beauty and charm yield. All of the sub-detectors need to be upgraded to cope with the data bandwidth that is going to be collected.

2. The Upgraded Vertex Locator

The detector modules and other major parts of the Vertex Locator are going to be replaced for the upgrade [2]. The silicon strip detector is going to be replaced by a hybrid pixel detector. The pixel sensors have a 1.4×1.4 cm active area with 256×256 pixels. Each pixel measures 55×55 μm. The VeloPix ASIC is bump bonded to a 200 μm silicon detector. The upgraded VELO will have 52 modules divided over the two retractable halves. When the halves are closed around the interaction point the closest point of the detector will be 5.1 mm away from the beam. This will improve the impact parameter resolution, the primary vertex and proper time resolution. The cooling of the module is done by evaporative CO_2 cooling through micro-channels etched into the silicon substrate. The upgraded VELO is separated from the beam vacuum by an upgraded RF foil.

2.1 Module and RF-foil

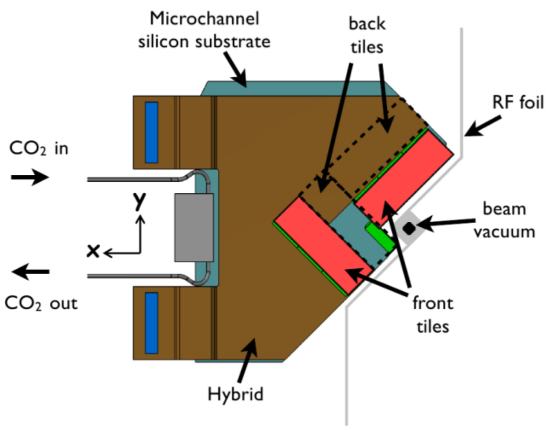

Figure 1: Module design of VELO upgrade

The latest design of the module is shown in figure 1. Three ASICs are bump bonded to a single silicon sensor, which makes up one tile. Each module consists of four tiles. The tiles lay next to the hybrids; which are the printed circuit boards and high voltage connectors and also have the HV, LV, and data signals out of the vacuum tank. The CTE mismatch between the module substrate and the sensor tiles is avoided by having the substrate made out of silicon.

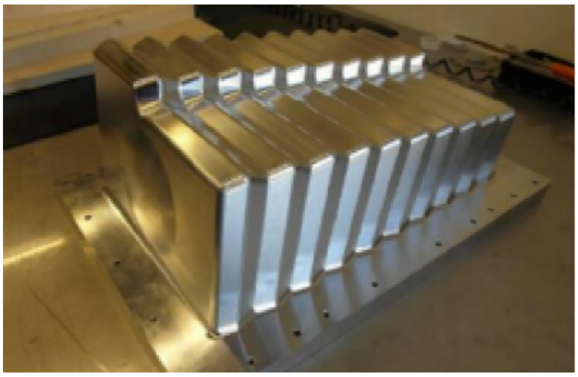

Figure 2: RF Foil

The RF foil is a 250 μm piece of milled aluminium that separates the detector vacuum from the beam pipe vacuum. The RF foil also protects the detectors from beam interference and guides mirror currents away. The foil is one of the main contributors to the material budget of the detector. This is because it is relatively thick metal layer, and it sits directly between the collisions and the detector. The corrugations, as seen in figure 2, should ensure that particles pass through the foil at a more perpendicular angle. Chemical etching to make the RF foil even thinner is being investigated.

2.2 Sensors and VeloPix ASIC

The sensor tiles are 200 μm thick n-on-p type silicon with a conservative $400-450$ μm wide guard ring. A sensor tile measures 1.4 $\times$ 4.2 cm, large enough to cover the surface of all three VeloPix ASICs. The doping type and guard ring final design are not defined yet, and an extensive test-beam campaign is ongoing to characterise the different options. Some of the sensors are also being non-homogenously irradiated so that they mimic the irradiation profile in the VELO. The sensors must be radiation hard up to 8×10^{15} 1 MeV n_{eq}/cm^2. There is approximately a factor of 40 difference in radiation damage between the hottest and the coldest point on module.

VeloPix [3] is a readout ASIC especially designed for the Velo based on the existing Timepix family. The ASIC currently used for testing is TimePix3. One VeloPix comprises of 256 $\times$ 256 pixels which measure 55 $\times$ 55 μm. The VeloPix is designed in 130 nm CMOS technology. The VeloPix has zero suppressed binary readout. Pixels are grouped in 2$\times$4 SuperPixels, sharing the address and the BCID to reduce the data bandwith.' The ASIC should be able to cope with a hit rate of 900MHits/s and the ASIC must be radiation hard up to 400 MRad.

2.3 Microchannel cooling

Evaporative CO_2 cooling is currently being used in the LHCb experiment [4]. The upgraded modules will use evaporative CO_2 cooling using micro-channels. These micro-channels are going to be in the 400 μm thick silicon substrate. There are 19 channels per module with dimensions of 120 $\times$ 200 μm. These channels are etched into one silicon wafer and then another wafer is bonded on top. They must perform well under high pressures; the system will be qualified up to 170 bar. These micro-channels are going to be keeping the sensors at -20 degrees Celsius. The heat dissipation is expected to be 3 W/ASIC and 36 W/module.

3. TestBeam Results

A new telescope using TimePix3 ASICs was commissioned in July 2014. It is based on the existing TimePix telescope [5]. The telescope is comprised of 8 telescope planes divided between

Figure 3: TimePix3 Telescope

two arms with a Device-under-Test (DUT) in the centre. This is shown in figure 3. The pointing resolution is less than 2 μm for a 180GeV beam. Whenever one of the telescope planes is hit a simultaneous measurement of deposited charge and arrival time is possible because of the trigger-less data driven readout of the TimePix3. The TimePix3 ASIC has a high pixel hit rate, allowing reconstruction of 10 Mtracks/second. The TimePix3 telescope has been well tested at both the PS and SPS facilities at CERN. A large sensor testing programme is still on going. These tests include bias, angle, threshold, efficiency and high rate tests with with irradiated and non-irradiated sensors. The base line sensor is a 200 μm thick p-on-n silicon bump bonded to a TimePix3 ASIC. Parameters like the thickness, silicon type and manufacturer are also varied.

From July 2014 to May 2015 fourteen devices were tested. Out of these fourteen, eight were irradiated to different fluences. Some were uniformly irradiated while others were non-uniformly irradiated. The non-uniform irradiation is more similar to the irradiation that will happen in the upgraded VELO. One of the tests that was performed with all of the data from the beam tests was looking at the charge collection efficiency (CCE) over different biases.

The preliminary results that are shown in figure 4 are from a 200 μm thick p-on-n silicon sensor produced by Hamamatsu bump bonded to a TimePix3 ASIC. It was non-uniformally irradiated with a maximum fluence of 2 $\times$ 10^{15} 1 MeV n_{eq}/cm^2. The CCE was measured in two different sections of the sensor. The CCE of the most irradiated region is shown in figure 4.

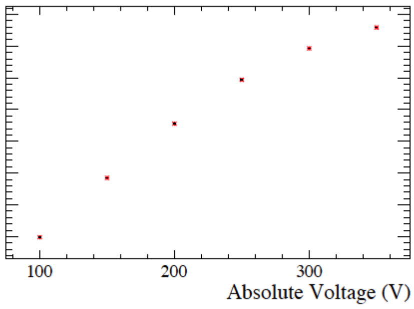

Figure 4: Preliminary CCE of Highest Irradiated Area, no Y-axis because preliminary results are being shown

4. Conclusions

The LHCb detector will have to cope with more luminosity and more data than in Run II. The upgrade requires all sub-detectors to be updated. The Vertex Locator is being redesigned as a hybrid pixel detector. It will be a full silicon module using a new pixel ASIC called VeloPix; they have to be radiation hard up to 8×10^{15} 1 MeV n_{eq}/cm^2. It will use evaporative CO_2 micro-channel cooling. There have been extensive tests on the prototype sensors and ASICs. This testing has been carried out at CERN PS and SPS facilities using the TimePix3 telescope. Testing has started on irradiated sensors and some results are shown here. The module production is scheduled for 2016 and all of the components will be installed in the long shutdown in the beginning of 2019.

References

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