The CMS pixel luminosity telescope

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The Pixel Luminosity Telescope (PLT) is a new complement to the CMS detector for the LHC Run II data taking period. It consists of eight 3-layer telescopes based on silicon pixel detectors that are placed around the beam pipe on each end of CMS viewing the interaction point at small angle. A fast 3-fold coincidence of the pixel planes in each telescope will provide a bunch-by-bunch measurement of the luminosity. Particle tracking allows collision products to be distinguished from beam background, provides a self-alignment of the detectors, and a continuous in-time monitoring of the efficiency of each telescope plane. The PLT is an independent luminometer, essential to enhance the robustness on the measurement of the delivered luminosity and to reduce its systematic uncertainties. This will allow to determine production cross-sections, and hence couplings, with high precision and to set more stringent limits on new particle production.

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1. Introduction

Before the end of Long Shutdown 1 (LS1), the first major maintenance and upgrade period for the LHC and its experiments, the Pixel Luminosity Telescope (PLT) was installed in the CMS experiment. Positioned close to the beam pipe, directly behind the Forward Pixel detector, its purpose is to measure the instantaneous luminosity at the highest energies and highest collision rates foreseen at the LHC. The PLT is the only sub-detector in CMS, whose sole function is to measure the delivered instantaneous luminosity. It must do this with a high precision and in real-time. The high precision is essential since the luminosity is a key quantity for many physics measurements at the LHC, where data collected under different beam conditions has to be combined. Simultaneously the luminosity measurement needs to be directly available to the LHC operators in order to optimise the beam conditions for the experiment.

2. The PLT Detector

The PLT is built using the same hybrid pixel sensor and readout technology already used in the current CMS Pixel detector [1]. The detector is separated in quarters where each quarter, or ‘cassette’, is a separate structure that houses 4 beam telescopes, placed in a half circle around the beam pipe. On each end of CMS two quarters were placed at a distance of 1.75 m from the interaction point (IP) ($\eta \approx 4; 1.55^\circ$ viewing angle towards the IP). Each telescope consists of three hybrid boards equipped with a single pixel sensor, where the pixel sensor consists of an array of 4160 pixels, arranged in 80 rows and 52 columns, totalling to 200 k channels in the entire PLT system. Each pixel is 100 $\mu$m by 150 $\mu$m and has a depletion depth of 285 $\mu$m. The sensor is bump bonded to the PSI46v2 CMS pixel readout chip (ROC) [2] which provides data in two different formats [3]:

1. \textbf{Pixel data}: If one pixel of the sensor is hit and a charge higher than a previously programmed threshold is detected, a pixel hit is created. The pulse height and pixel address are saved together with a time stamp in a buffer and read out on an external trigger signal. The maximum trigger rate for pixel data is 100 kHz. Since the pixel data can be used to reconstruct tracks it is possible to separate particles coming from the interaction point from background particles of the beam halo, a powerful tool to determine systematic corrections and to measure pixel efficiencies [4].

2. \textbf{Fast-OR data}: Whenever a pixel hit above threshold is detected, the ROC will set a fast-OR signal with a pulse height proportional to the number of double columns hit in a specific bunch crossing (25 ns window). The Front End Driver (FED) especially

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developed for the PLT, dedicated to record the Fast-OR signals, counts triple coincidences between the three planes of a telescope, which then can be translated into a luminosity value for each bunch crossing (40 MHz readout rate). This readout mode of the ROC is not used in the current CMS Pixel detector and finds its first application in the PLT.

A schematic of the PLT control and readout logic for a single quarter is given in Fig. 1.

2.1. PLT mechanics and cooling

The silicon sensors and readout chips of the PLT need to be cooled to create a stable operating temperature for the detector, and to reduce the leakage current and prevent a thermal runaway of the sensor material after irradiation. The PLT cooling and mechanical structure was manufactured in a novel production process called Selective Laser Melting (SLM). This process allows to create metal structures with complex geometries, thin walls, and hidden voids or channels, and is perfectly suited for small production batches. Printed as a single piece of titanium alloy, the cooling structure is built as a meandering tube of 2.8 mm diameter. The coolant liquid, C6F14, comes from the CMS Tracker cooling plant at a temperature of $\pm 15$ C. Not only the sensors and Front-End readout chips are cooled, but also the Optohybrid motherboard electronics.

2.2. Installation and calibrations

Just before the end of Long Shutdown 1 the Pixel Luminosity Telescope was installed in the CMS experiment. The connection of all low voltages, high voltages and optical fibres was verified and the correct mapping of all channels certified. A pressure test of the cooling loops was successfully performed. The detector had to be calibrated to have a uniform response at its operating temperature of $\pm 15$ C. This means that all $\approx 200$ k readout channels need to be calibrated to the same pixel hit threshold of 3000 e$^-$. In the PSI46v2 readout chip this is done by using a configurable internal calibration charge. By varying the amount of charge injected into a single pixel, the hit detection efficiency can be measured. The pixel threshold is defined as the crossing point of the measured hit efficiency with a horizontal line at 0.5. Global voltages for the ROC and pixel unit cell specific parameters, influencing the comparator voltage, are tuned until a chosen target threshold value is reached for all pixels. In Fig. 2 the measured thresholds of 41 calibrated ROCs are shown, a target value of 60 Vcal was used. Vcal is a ROC internal DAC to set the calibration charge.

2.3. First collision data

On May 5th the LHC produced the first collisions during tuning at a beam energy of 450 GeV. This was the first time the PLT detector saw particles coming from the interaction point of CMS. The first measurements show that the detector is in an operational
stage. Tracks, obtained with a very preliminary calibration, can be seen in all telescopes and the measurement of triple coincidences in the telescopes correlates very well with the measurements of the already established luminometers, the Hadron Forward Calorimeter (HF) and the Beam Conditions Monitors (BCM), as shown in Fig. 3.

3. Conclusions

The Pixel Luminosity Telescope has been successfully installed in the CMS experiment and first measurements show that it is working as expected. The calibration of the detector will have to be finalised. During the first collisions with nominal beam energy of 6.5 TeV the detector will be further tested. A Van Der Meer scan is needed to obtain an absolute calibration between the number of counted triple coincidences and the luminosity provided by the Large Hadron Collider to CMS.

References