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The CMS Pixel Luminosity Telescope

Frontier Detector for Frontier Physics – 13th Pisa Meeting on Advanced Detectors, May 24 – 30, 2015, La Biodola, Isola d'Elba (Italy)
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A dedicated luminometer for CMS

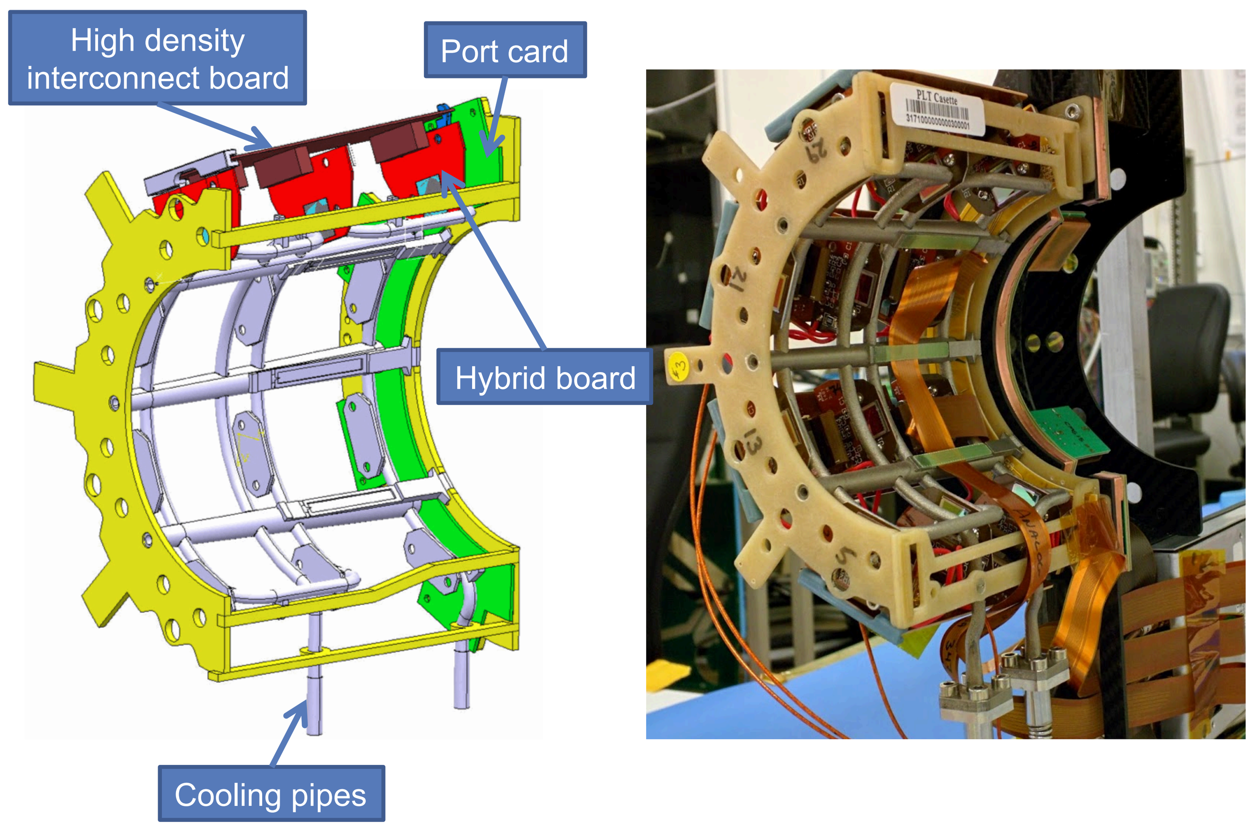
Just before the end of Long Shutdown 1 (LS1), the first major maintenance and upgrade period for the LHC and its experiments, the **Pixel Luminosity Telescope (PLT)** was installed in the CMS experiment. Positioned close to the beam pipe, directly behind the Forward Pixel detector its purpose during the next running period will be to **measure the instantaneous luminosity** at the highest energies and highest collision rates foreseen at the LHC.

Why does CMS need the PLT?

The PLT is the only sub-detector in CMS, whose sole purpose it is to measure the delivered instantaneous luminosity. It must do this with a high precision and in real-time.

The **high precision** is needed since the luminosity is an important ingredient to many physics measurements done at the LHC, for example the measurement of the Higgs cross section.

Simultaneously the luminosity measurements have to be **directly available** to the LHC operators to tune the beams according to CMS requirements.



A design drawing of a PLT carriage equipped with a single telescope and a picture from the final detector quarter with all four telescopes and electrical connections in comparison

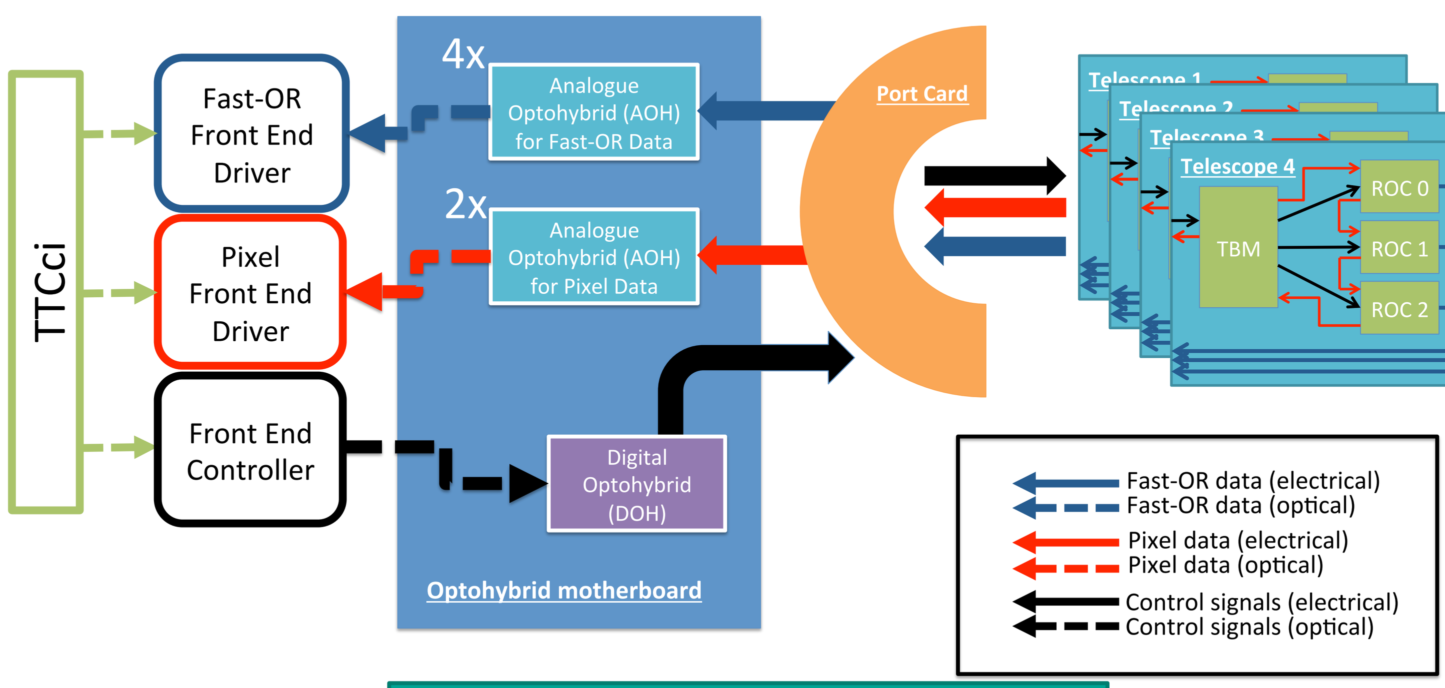
What is the PLT? And how does it work?

The PLT is built using the same sensor and readout technology already used in the current **CMS Pixel detector**[1]. The detector is separated in **quarters**. Each quarter or cassette is a separate structure that houses **4 telescopes**, placed in a half circle around the beam pipe. On each side of CMS two quarters are placed at a distance of **1.75m from the interaction point (IP)** (η ≈ 4; 1.55° viewing angle towards the IP).

Every telescope consists of three hybrid boards, each equipped with a single pixelated silicon sensor that is read out by a PSI46v2 readout chip (ROC). This chip is able to provide two different kind of data:

1.) Pixel data:
If one pixel of the sensor is hit and a charge higher than a previously programmed threshold is read out by the ROC, a pixel hit is created. The pulse height is saved together with a time stamp in a buffer and read out by an external trigger signal. The maximum trigger rate for pixel data is **100kHz**. The pixel data is used to reconstruct tracks and allows to differentiate particles coming from the IP from beam halo particles.

2.) Fast-OR data:
Whenever a pixel hit above threshold is being detected, the ROC will send out a fast-OR signal. The fast-OR signal height is proportional to the number of double columns hit in a specific bunch crossing (25ns window). In the Front End Driver (FED) dedicated to the fast-OR signals the **triple coincidences** between the three planes of a telescope are counted and can be translated into a **luminosity value for each bunch crossing (40MHz 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.

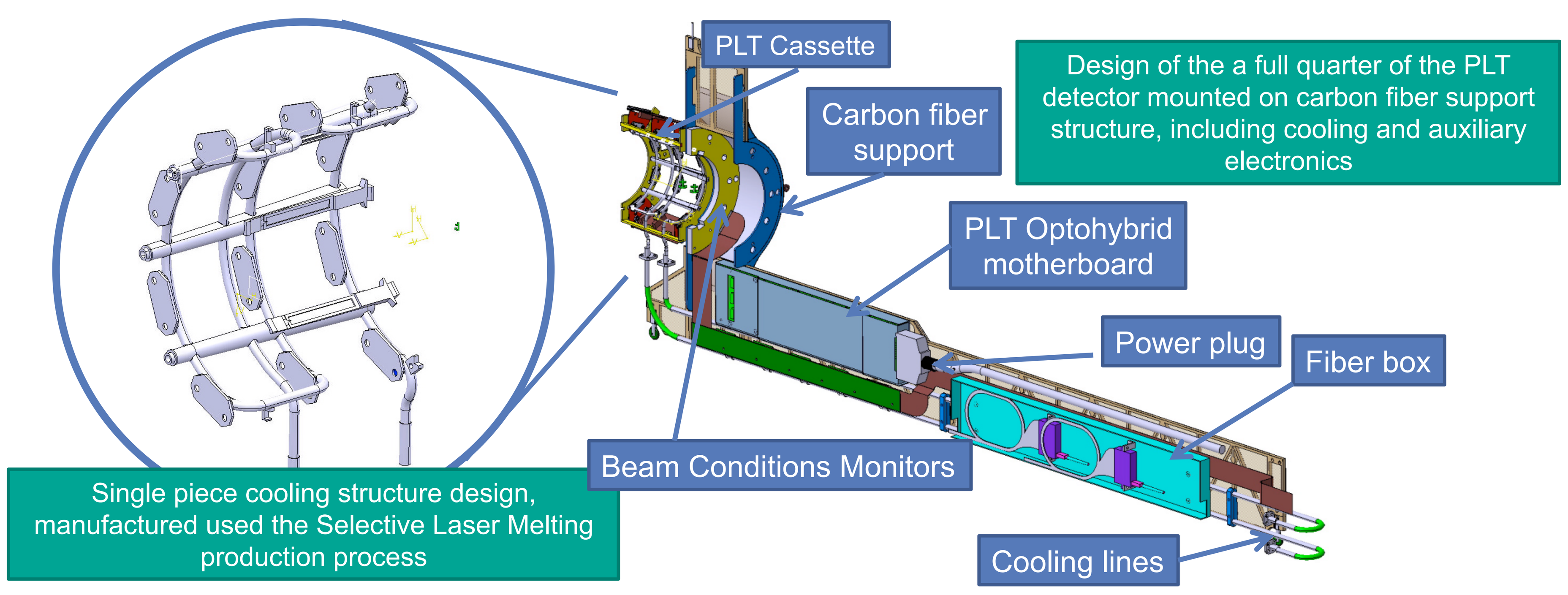


Control and readout logic of a single PLT quarter

Unique mechanics for a unique detector

The silicon sensors of the PLT need to be cooled to counter the negative effects of radiation damage. 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.

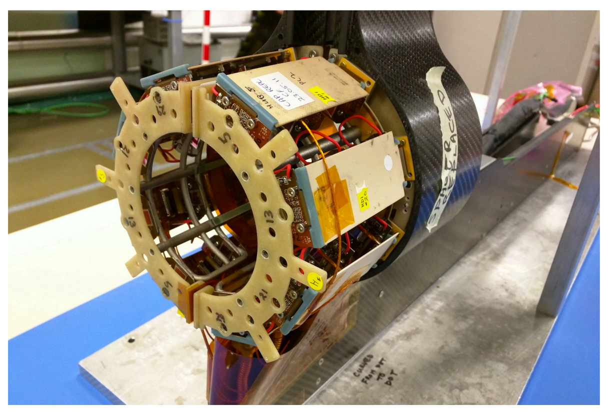
Printed as a **single piece of titanium alloy**, the cooling structure is built as a meandering tube of 2.5(+0.3)mm diameter. The coolant, liquid C_6F_{14}, comes from the CMS Tracker cooling plant at a temperature of -15°C. Not only the sensors and Front-End readout chips are cooled, but also the Optohybrid motherboard electronics.



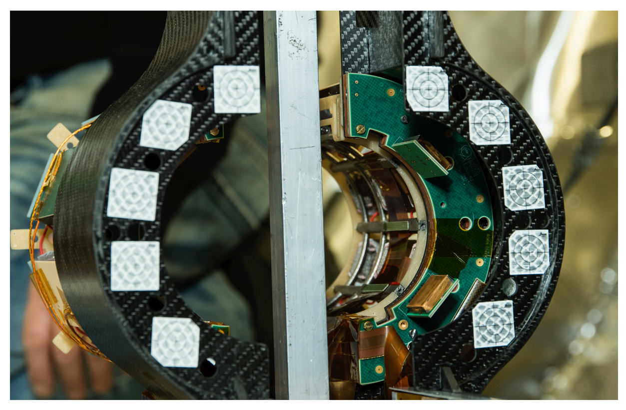
Design of the a full quarter of the PLT detector mounted on carbon fiber support structure, including cooling and auxiliary electronics

Single piece cooling structure design, manufactured used the Selective Laser Melting production process

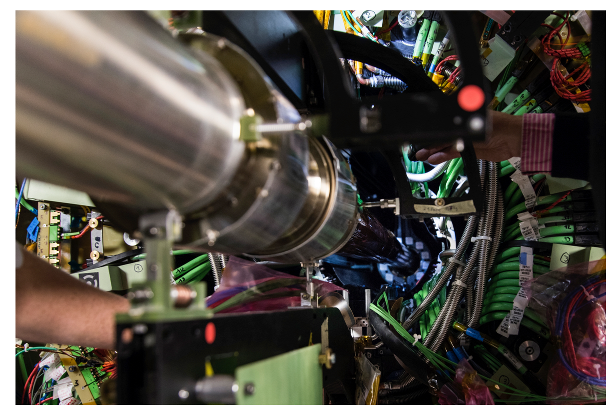
The Big Day, Installation in CMS



PLT detector half in the cleanroom



PLT detector half after transport to CMS bulkhead.
Alignment markers for survey applied



PLT detector half at final position in CMS

Getting ready for first collisions: Tests and calibrations

After the installation of the PLT detectors in the CMS experiment tests were made to check if everything was working as expected and all of the **low voltage**, **high voltage** and **optical fiber** connections were routed correctly. All readout chips were addressed and they responded to external signals. By measuring the noise of a pixel the high voltage connection to the silicon sensors was checked. The last test checked the cooling loops for leaks but did not find any.

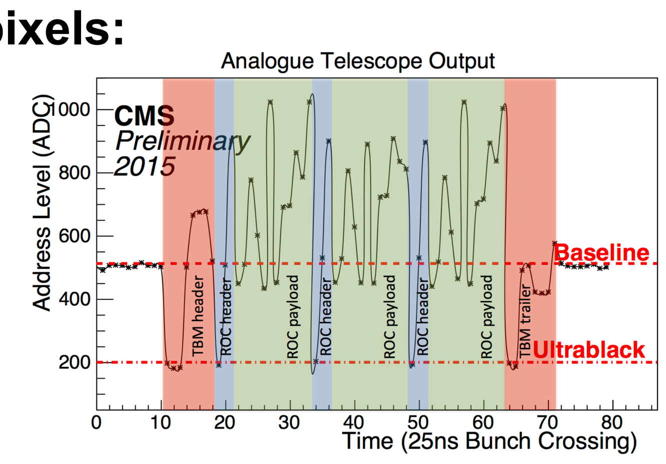
The installation of the PLT was a success!

As a next step the detector had to be **calibrated at its operating temperature**. These calibrations have to be done for every telescope, every ROC and even for every pixel. The goal is that all **~200k readout channels** have a similar response behavior for charge deposited in the sensor material and are able to transmit pixel and fast-OR data with an error rate as low as possible.

How to unify the response threshold for ~200k pixels:

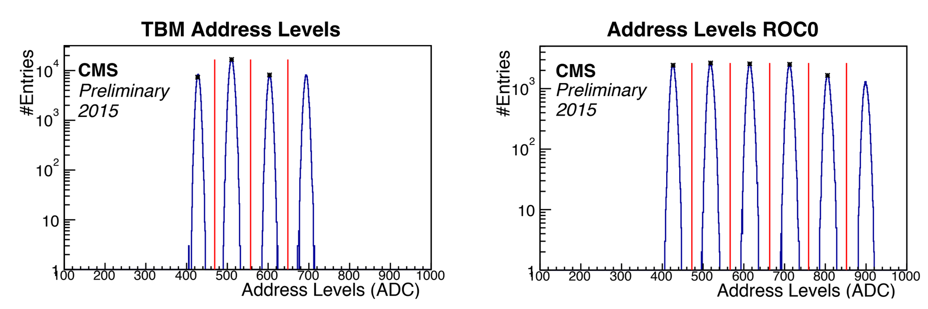
Step 1) Find optimal sampling time for analogue telescope data output

- Correct decoding of header and trailer information



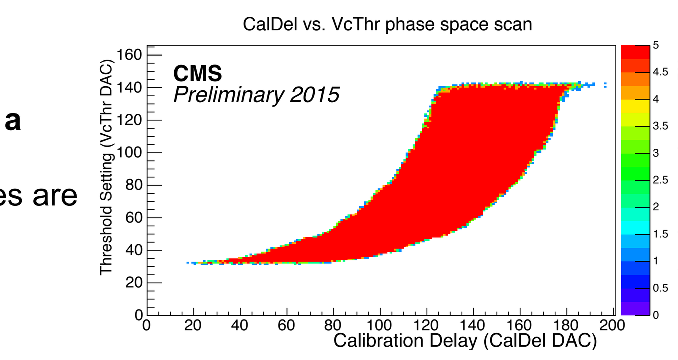
Step 2) Find correct address levels for every telescope

- Well separated analogue readout levels guarantee low number of readout errors



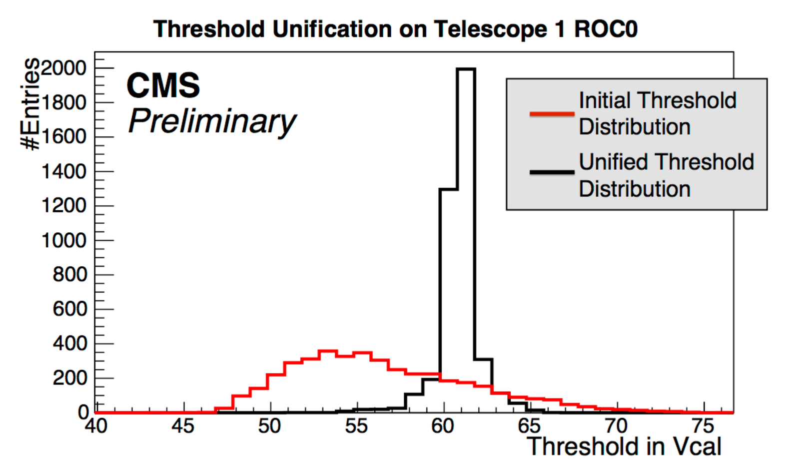
Step 3) Find a working point for every ROC where all pixels see a calibration signal

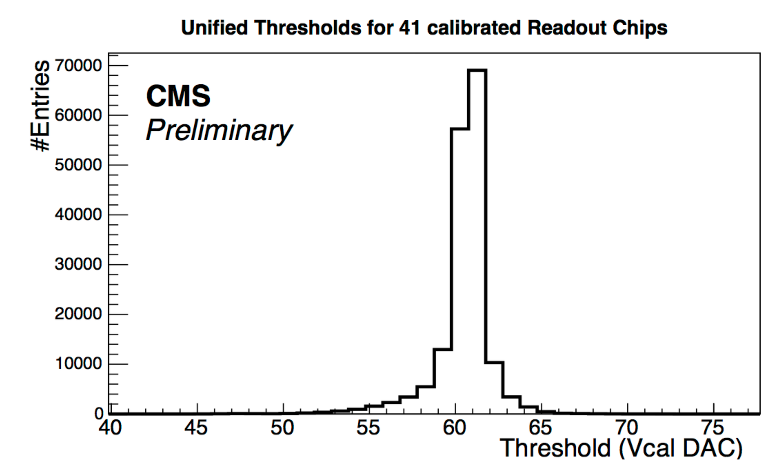
- Threshold setting and delays have to adjusted to all calibrate pulses are found in the correct bunch crossing



Step 4) Measure thresholds and adjust trim bits of every pixel to unify response to calibration charges

- The threshold of a pixel is defined as the 50% point in the response efficiency towards an increasing calibration charge controlled by Vcal
- Measure all thresholds
- Adjust trim bits to match thresholds over all pixels (Vcal 60 chosen as a target here)

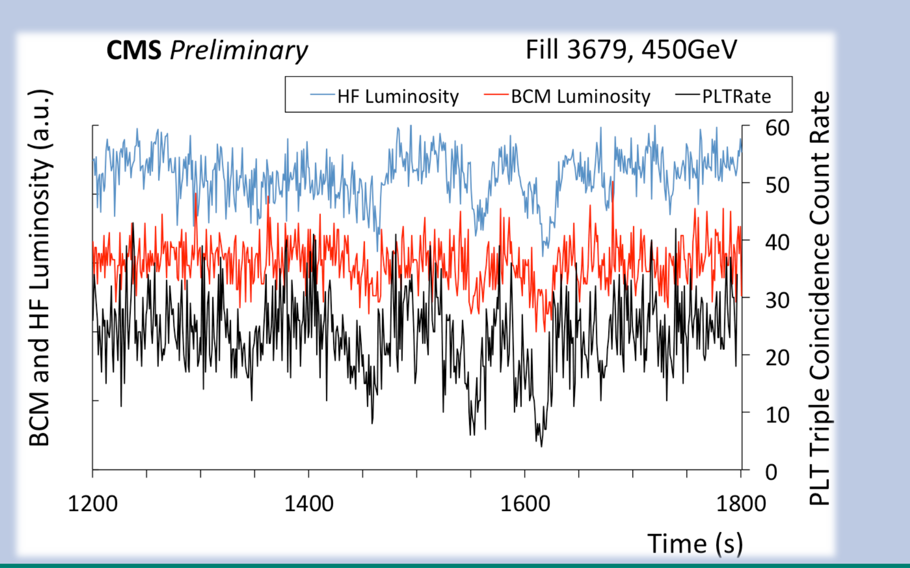




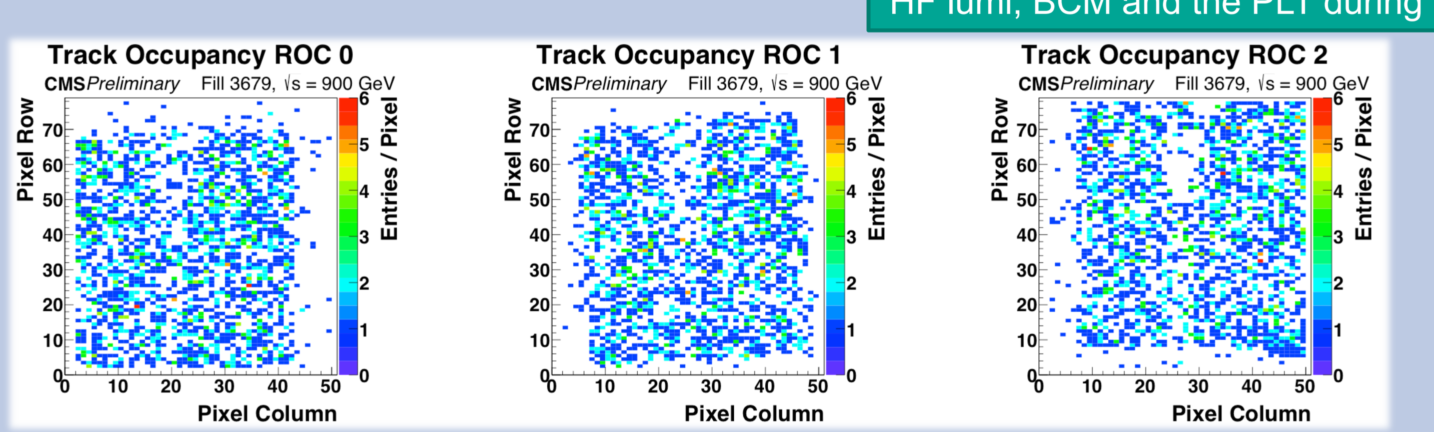
First data from collisions

On May 5th the LHC produced the first non-stable collisions at a beam energy of 450GeV. This was the first time the PLT detector saw particles coming from the interaction point of CMS.

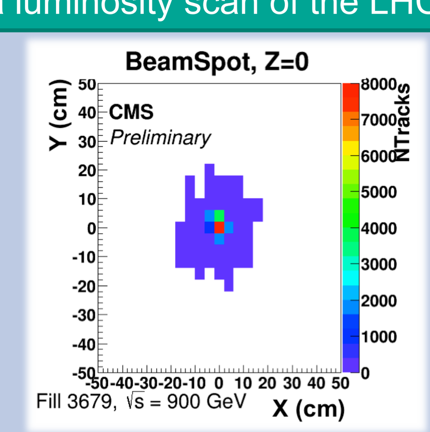
First measurements show that the detector is in an operational stage. Tracks, obtained with a very preliminary calibration, can be seen in all telescopes and the measurement of **triple coincidences** in the telescopes correlates very well with the measurements of the already established luminometers (the **Hadron Forward Calorimeter** (HF) and the **Beam Conditions Monitors** (BCM))



Qualitative comparison of luminosity measurements done by HF lumi, BCM and the PLT during a luminosity scan of the LHC



Track occupancy plots from a single PLT telescope from reconstructed tracks measured during non-stable collisions in CMS



Measured beam spot

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University of Wisconsin, USA
Vienna Institute for High Energy Physics, Austria

References:
[1] "Design and Performance of the CMS Pixel Detector Readout Chip", H.Chr. Kaestli et al., NIM A 565 (2006) 188-194