CMS Forward Pixel Phase I Upgrade and Commissioning

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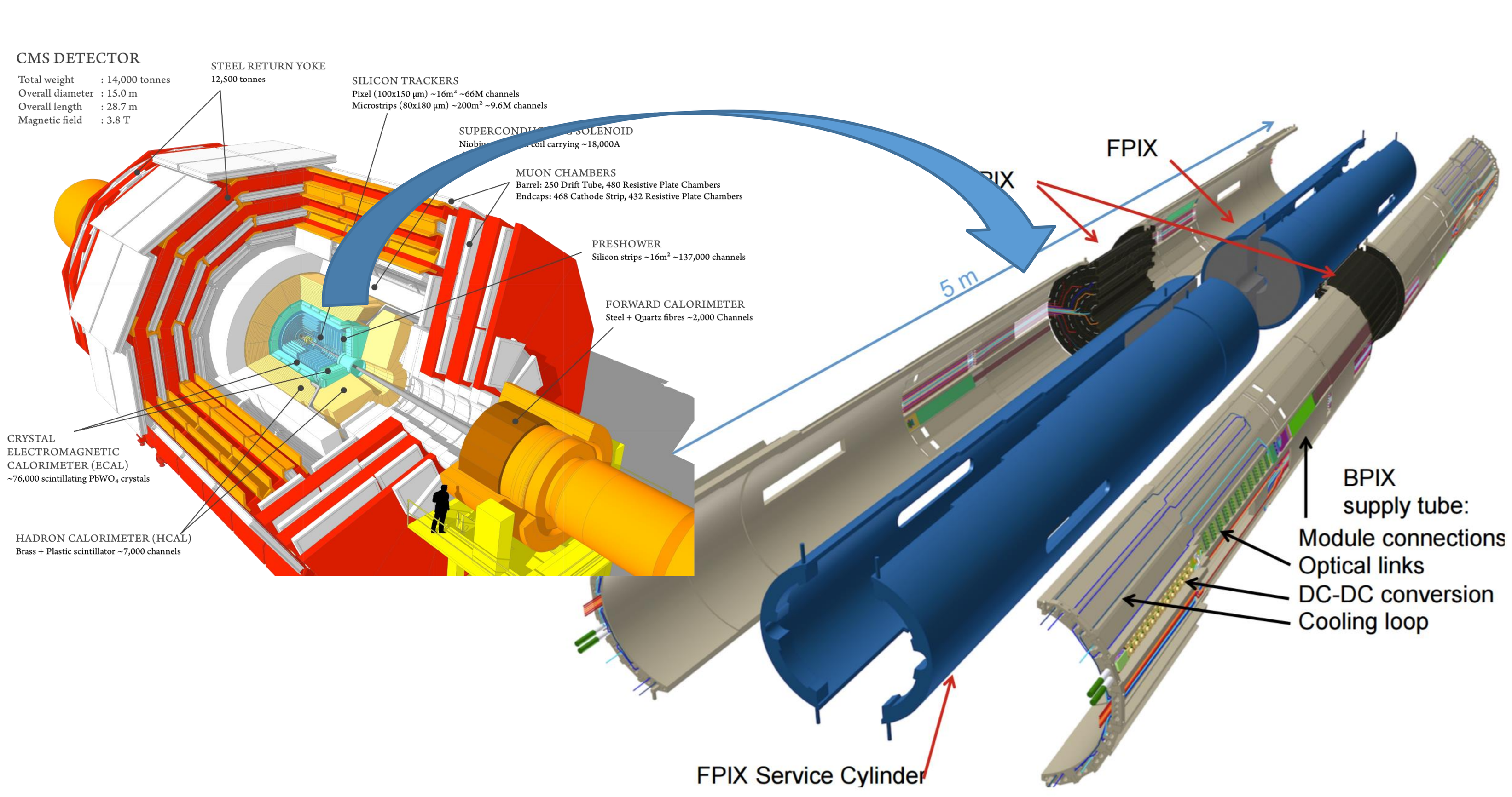
Overview

The innermost layers of the CMS tracker are built out of silicon pixel detectors that provide space points that are used as seeds in track finding and that are crucial for resolving track ambiguities in high occupancy environments and for tagging products of the decay of heavy flavor quarks. The original CMS pixel detector was designed to operate at a maximum instantaneous luminosity of $10^{34} cm^{-2} s^{-1}$. The CMS pixel detector is being replaced during this extended end of year shutdown to handle even higher luminosities. We describe the construction, testing and commissioning of the forward part of the detector (FPIX) , three disks in each of the two end cap. The FPIX detector was built in the United States and has been transported to CERN in Fall 2016. **The detector has been fully commissioned and it is ready for the installation that will take place at the beginning of March.**



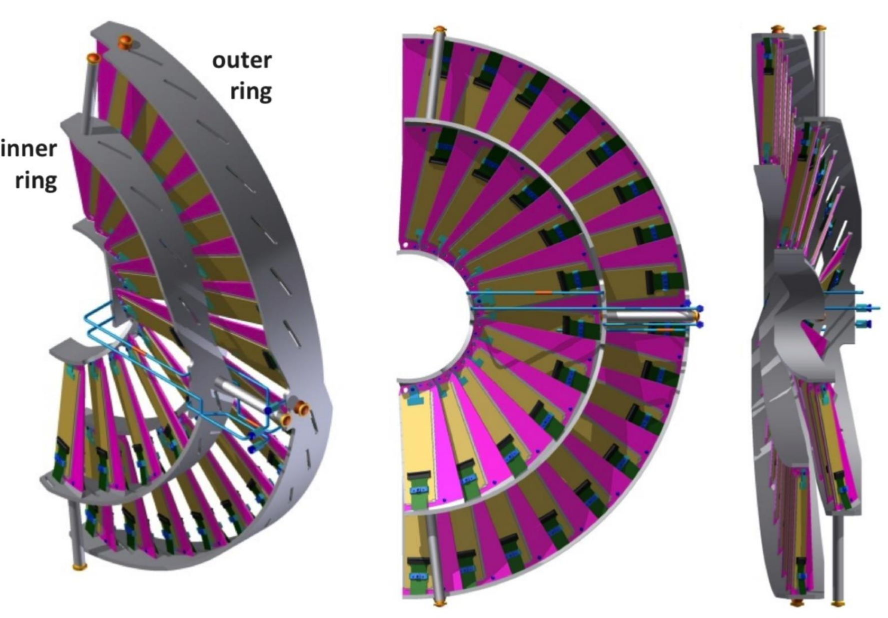
Design and assembly

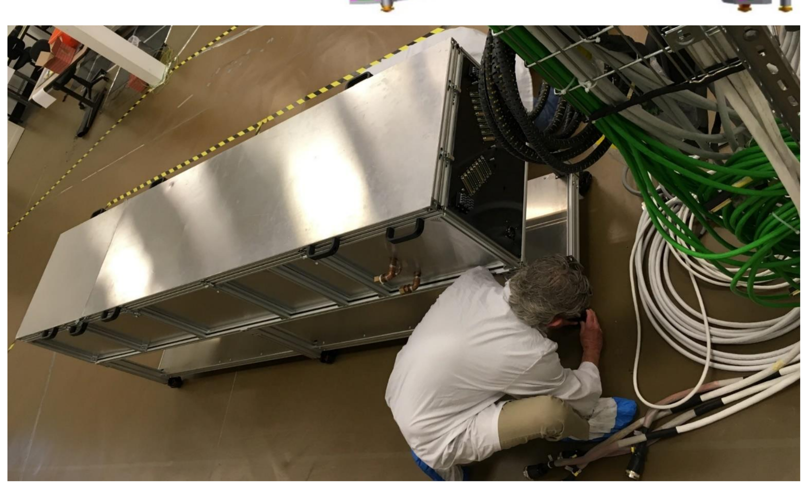
The FPIX detector contains a total of 672 modules, each made of 300 μm tick pixelated silicon sensor, comprising 66,560 pixels, each with size 100 μm times 150μm, read out via sixteen readout chips (ROCs), for a total of 45 M channels. To overcome the limitations of the current detector, the data bandwidth from the ROCs is increased by using two interspersed channels for each module, both running at 160 Mbit/s and **larger data buffers**.

The modules are mounted on carbon fiber light weight support structures that are integrated with a two phase CO_2 **cooling system**. This results in an overall reduction of the material seen by particles traversing the tracker, despite the increase in the number of layers in the pixel detector (three disks in FPIX compared with 2 in the current detector). Each disk in the FPIX detector is split in two parts with modules installed on the blades of turbine shaped supports. **The tilt of the blades is optimized** to avoid gaps in the sensitive area and to optimize the single hit resolution of the detectors.

The disks are housed in support half cylinder that also house the readout, control and powering electronics boards that are cooled by the same cooling system used for cooling the sensors and the ROCs. The control and powering electronics is moved to large rapidities, $|\eta| > 2.5$, to reduce the amount of material seen by the tracker. The control signals (clock, trigger, detector configuration) are transmitted from the electronics cavern via optical fiber and distributed to each individual module. The signals from the modules are converted from electrical to optical using opto-hybrids that are mounted inside the service cylinder, and then transmitted to the DAQ backend.

The detector has been assembled at Fermilab, where initial tests have been performed, and then transported to CERN. After the reassembly at the tracker integration facility (building 187) the FPIX detector has been tested both at room temperature and with the cooling set to -23$°C$, and then transported to the surface laboratory at CMS for a final check prior to installation.

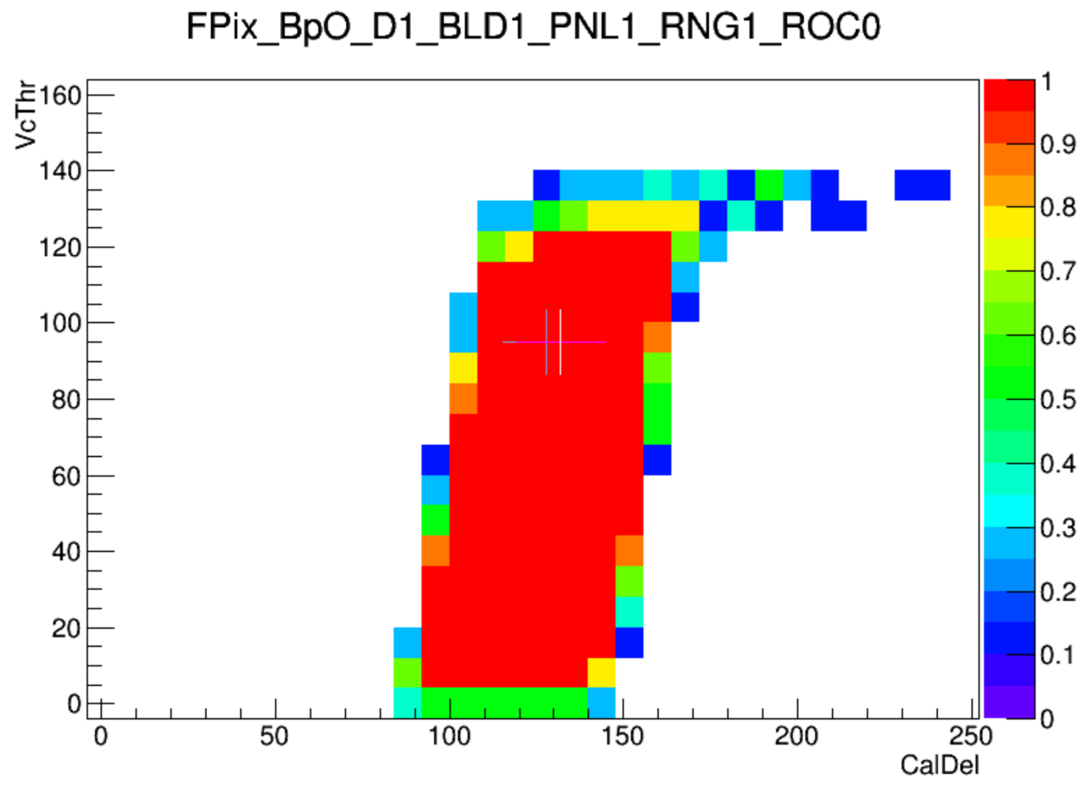




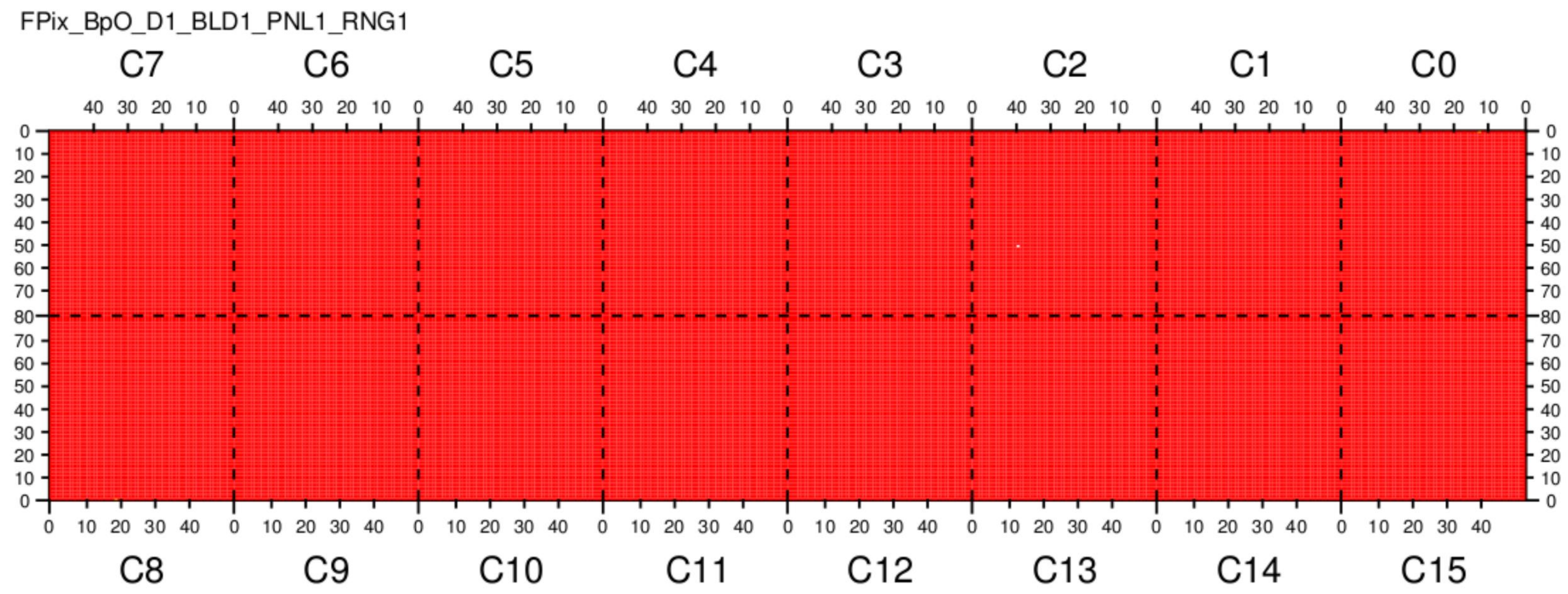
Commissioning at CERN

The operating parameters of all the **672 FPIX modules** have been determined again at two temperatures in the tests at CERN. First the functionality of the entire readout chain has been established, and the parameters controlling the light yield from the opto-hybrids and the timing of all the modules have been optimized. Using injected signals the functionality of each pixel readout has then been tested. First we have optimized for each ROC the threshold as a function of the delay between calibration signal and the clock sent to the detector, and then we have checked that all the pixels in a module respond to the calibration signals.

Optimize threshold



- X-axis: delay in sending out calibration pulse with respect to the clock signal
- Y-axis: threshold, Color indicates efficiency.
- We **optimized choice of threshold and delay setting by scanning over a range of configurations.**



- C0 to C15 are 16 ROCs on one module, efficiency marked in color, and Red is 100%
- Pixel hits, when exceeding a **set threshold**, stored and output through ROC.
- By doing charge injections, we mimic real detector environment, and see how many response we get. Above is 100% efficiency plot.

Next, we check the validity of calibration performed on individual modules and measure the noise level in each pixel by measuring the width of the turn-on curve of the calibration pulse. Finally we check the bump bonding connections for each pixel by inducing via capacitative coupling a charge in the sensor and reading it out. Further calibrations, like the optimization and trimming of the thresholds, the calibration of the gain in the amplifiers and the optimization of the pulse height response have also been tested on subsets of the detector. Overall the fraction of non-functioning channels is 1.2%

Overall it is expected that the installation of the new detector will entail only a minimal loss of high quality physics data, which will be compensated with time with all the performance gains compared to the current detector.

Results

The CMS Forward pixel phase I detector has been fully commissioned prior to installation in March, 2017. Calibration has been performed to ensure all 672 modules provide optimal performance. The modules, portcards, CCU, and Front End drivers/Controllers communicate with each other correctly. This has been made possible after a dedicated period of script and software development, delicate engineering, and hard shift work.

Acknowledgement and Reference

[1]Photo credit Reidar Hahn, Satoshi Hasegawa.

[2] CMS Technical Design Report for the Pixel Detector Upgrade , Gill, Karl; Ball, Austin