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Production of the CMS Tracker End Cap sub-structures

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Abstract

The production and qualification of the 288 petals needed to build both CMS Tracker End Caps (TECs) is summarized. There will be first a description of a petal, integrating many components, the most important ones being the silicon modules. The organization of the production, involving 7 Institutes all over Europe, will then be explained. The petal assembly and testing procedure will be quickly described. The quality assurance put in place at each production step has resulted in a very high petal quality, as some overall plots will attest. Finally some details about part failures will be given.

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1 Introduction

The new CERN accelerator, Large Hadron Collider, will start to deliver the first beams in 2007. CMS is one of the four experiments installed at the LHC. The Tracker houses pixels in the innermost part and the Silicon Strip Tracker (SST) in the outer one. The SST basic element is a module, made of 1 or 2 silicon sensors connected to a front end hybrid [1]. The SST contains 15000 modules and is divided into four sub-detectors: the Inner Barrel, the Inner Disks, the Outer Barrel and the 2 End Caps (TECs) as shown in Fig. 1. The TEC diameter is 2.4 m for a length of 1.6 m. Each TEC consists in 9 disks, each disk supporting 16 wedge shaped structures called petals (8 on each side of the disk) (Fig. 1).

The petal is the TEC sub-structure housing the silicon modules (also wedge shaped). The 9 TEC disks are not identical, so that 8 different types of petal are needed to build the End Caps. The 288 petals built contain 6400 silicon modules. The petals have been directly integrated into the TEC body (housing the empty disks), sector by sector.

Due to significant delays in front-end hybrid production, petal integration had to run in parallel with both module production and End Cap integration, inducing strong logistics constraints.

2 Petal description

A petal is a complex stand-alone device which can be fully tested before integration into the TECs. The design idea has been guided by the TEC structure geometry where access to the inner components is impossible without dismounting. A petal integrates between 17 to 28 silicon modules, according to its type, for an average number of channels close to 14 000 (Fig. 2). The modules are arranged in seven rings of increasing radial distance from the beam line and placed such that the odd number rings are put in one side of the petal, while the even rings in the opposite. There are front and back petals (two sides of the disk). Petals belonging to different disks have different lengths, as shown in Fig. 1. Each module is read out by an Analog Optohybrid (AOH), which converts electrical to optical read out signals. Finally two Communication and Control Units (CCU) are dedicated to the control signals distribution within the petal. All these components are plugged in the motherboards which also include low and high voltage distribution. A cooling circuit is implemented inside the honeycomb of the petal mechanical structure.

3 Petal integration

The petal integration has been divided into three steps: manufacturing of the mechanics, AOH integration, and finally module integration. Due to the large number of petals, their integration has been shared between 7 institutes in Europe.

Aachen 1 has produced all the mechanics, including the mounting of the motherboards. The quality assurance consisted of metrology measurements and a test of the cooling loop tightness.

In order to optimize the production chain, a single center, Hamburg, was in charge of the AOH integration. The fiber routing of many fiber types (8) is indeed a very delicate operation and a well trained team carried out this task. After integration, each fiber transmission level was cross-checked (50 fibers per petal in average).

The module integration has been done by five institutes, namely Aachen 3, Brussels, Karlsruhe (2 lines), Louvain

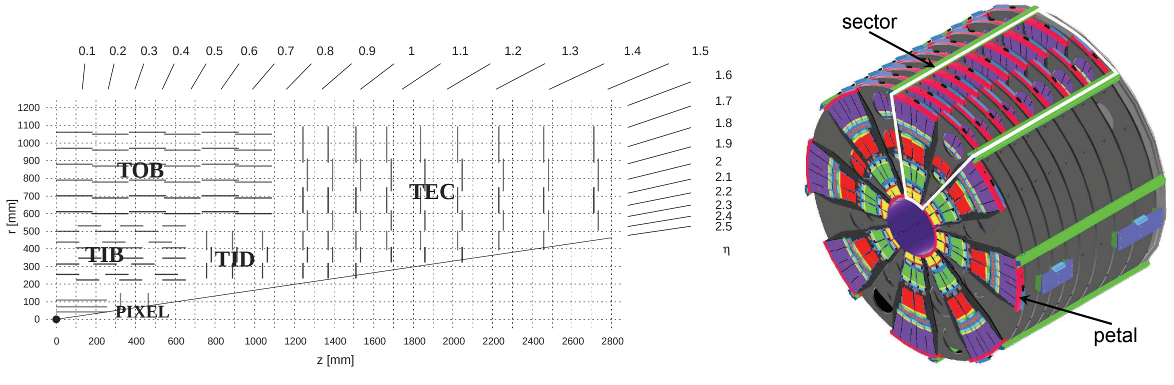

Figure 1: r-z view of a quarter of the Tracker (left) and schematic view of an End Cap (right)

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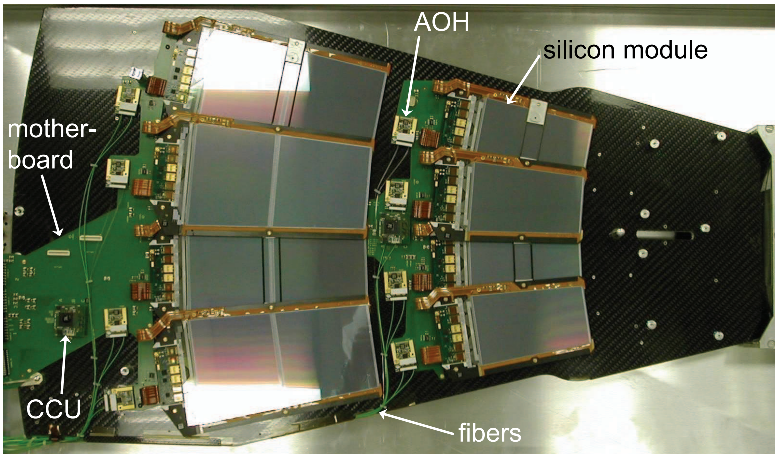

Figure 2: Photograph of a front disk 9 petal - side where modules from even rings are mounted

and Strasbourg (2 lines). This operation was delicate, as many modules were very close to each other. In some positions, modules were mounted back to back to get radial hit position information [2]. During integration, the communication between AOH and module was checked for each position. This integration was followed by a more exhaustive test, as described in the next section.
Due to the large number of pieces to be mounted (there were many spacers and screws of different types), a dedicated assembly computer program was developed. This served mainly as a visual help, but an initial test (after AOH as well as after module integration) was also included. To manage the module flow and to optimize their pairing, according to the depletion voltage, another computer program was used. Each important part, module, AOH, CCU, motherboard and petal mechanics was individually referenced into the central construction database.

4 Petal long term test

This test was meant as a full functionality test which also aimed to reveal weak components. For this reason, the test included three to five thermal cycles between 16°C and -25°C to stress both components and connections during a significant amount of time (around 40 hours). The petal was installed in a fridge and the cooling loop was supplied to go down to -25°C (Fig. 3).
The test was done using dedicated software, while another PC ran the slow control program. The first part of the test was a so-called "connectivity test". On average, connecting a petal implies around 50 optical, 22 high voltage and 45 low voltage connections, in addition to the control signals. The heart of the test was a repetition, alternatively in warm and in cold, of a basic sequence consisting of : opto-scan, pedestal and calibration runs, IV of individual modules. The read out data were saved in files together with some slow control informations.
After the test, the files were processed to find failing or weak components, to flag the bad channels and finally to grade the petal. When needed, components were replaced and the test was repeated.

5 Petal overall quality

In addition to the existing quality control at each production step, an overall cross-check of the petal behaviour has been implemented. An analysis of the module behaviour before and after the petal integration has been performed together with a comparison of several relevant quantities. Figure 4 shows the behaviour of the leakage current distribution at 450V before and after petal integration. It should be noticed that most of the currents stay below 2 μA before as well as after integration. For further information, the ratio of the leakage current after/before integration is also plotted. The mean value is close to 1, indicating no significant degradation coming from the integration.

As far as the strip behaviour comparison is concerned, channels are flagged as bad if the values of the noise, rise time and pulse height (measured using a calibration signal at the APV channel input) are outside of given acceptance cuts (see Fig. 5). The cuts are defined so that any of the usual defects like short, pinhole, broken bond, short or noisy strips and dead APV channel are detected. It should be noticed that only 0.2 % of the channels are flagged. Most of the ones flagged both before and after integration are really defective. The rest is mainly noisy strips, close to the limit. Due to the improved statistics for Long Term (LT) compared to initial validation, the

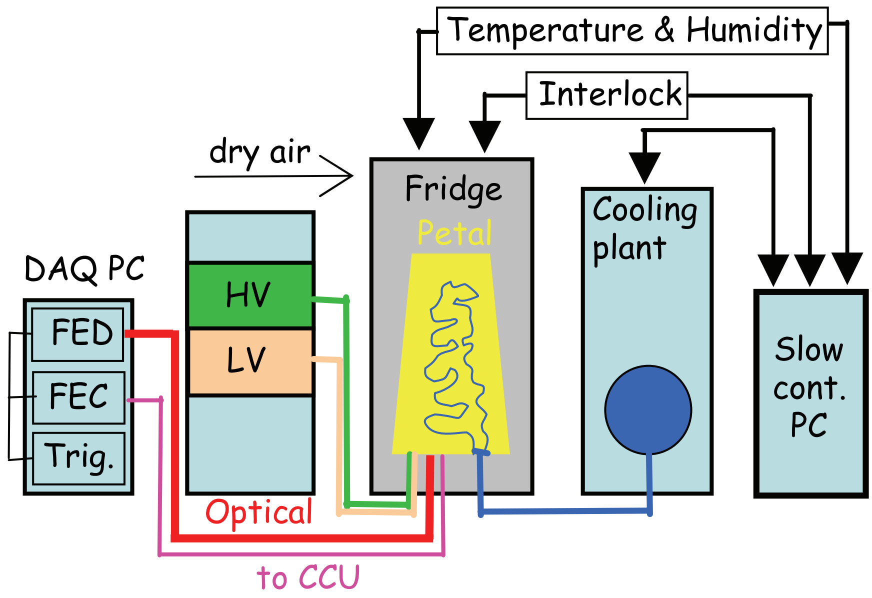

Figure 3: Schematic view of the long term setup with connections to the petal

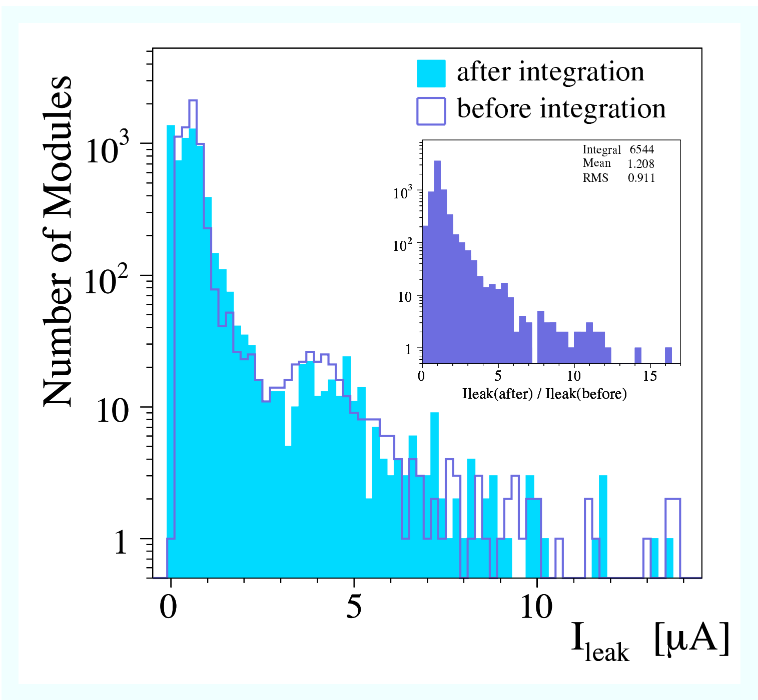

Figure 4: Leakage current comparison before and after petal integration

flagging is more stringent for LT, despite the noisier environment. Considering anyway only the channels flagged as bad in the LT as real defective ones, one can conclude that the integration process induces marginal degradation of modules (0.025 %), which does not fully reflect reality, as explained in the next section.

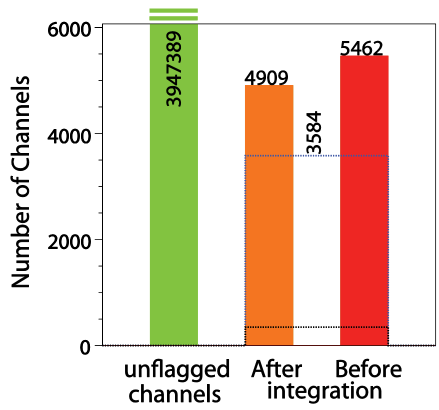

Figure 5: Overview of channels flagging before and after integration

The noise flatness after bad channel removal is a way to show how efficient the channel flagging is. Due to the large number of channels involved here (about 4 millions), the APV noise, which gathers 128 channels, has been chosen as a relevant parameter to be plotted. To make the view easier, the plot is restricted to the front petals (Fig. 6). Starting from 80 noisy APVs before bad channel removal (not shown on the plot), only about 20, meaning 0.13 %, are still noisy at the end. In most cases, these high levels are explained by few channels which were not noisy enough to be flagged. The situation is quite similar for the back petals.

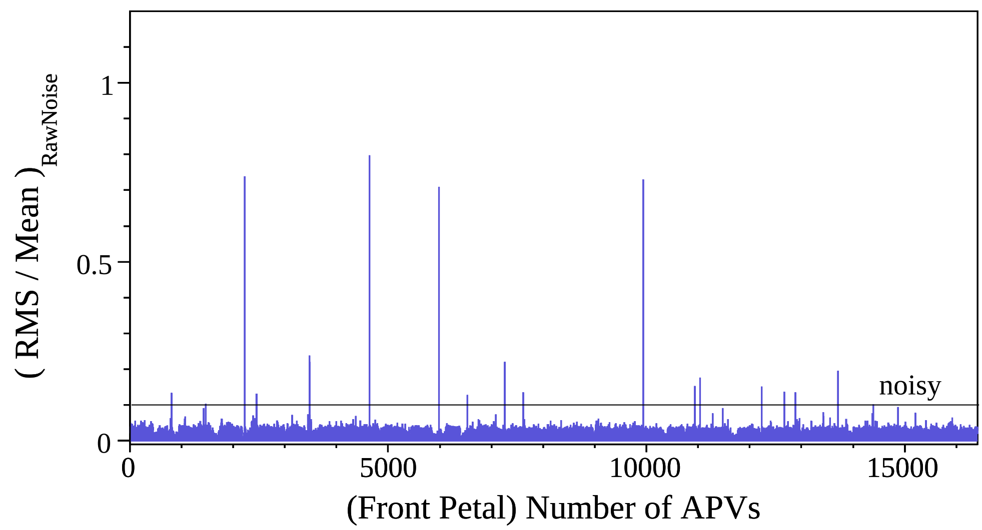

Figure 6: RMS of the raw noise divided by the mean of the raw noise distribution per APV (128 channels), after bad channels removal, for all front petals

Another important aspect of the quality assurance is the part failure follow-up. The aim was to trace back any systematic mistake in the integration process and to have an idea of the induced damaging. Any possible component failures were identified and some systematic problems have been spotted at different places and solved in a common way. This is the case for example with the AOH/module connection. Such a problem has been reported 25 times, corresponding to a small fraction of the modules integrated (0.36 %). In many cases, the problem was only visible in the cold test. This has been identified to be due to a mechanical stress in either the AOH or the module connector. The cure found for this problem was first a disconnection/reconnection of both module and AOH, followed, in a few cases, by a removal of the AOH screw.

The main problem faced during the petal integration was the dismounting of a significant fraction of the petals built (67 among the 288 needed) due to an extensive module retrofitting. The reason of this retrofitting was a possible

weakness of the contact between the silicon backplane and high voltage connection. The problem is detailed in ref. [1]. A special team was dedicated to this dismounting task, but this exercise has anyway induced damages as the petal is a structure not meant to be dismounted, at least on a large scale.
The overall numbers of damaged components are summarized in table 1. These numbers are significantly high but should be viewed with caution. Considering the damaged modules for example, one should keep in mind that many modules have been set to faulty doing the final check just before petal integration. At least at the beginning of the integration, when many modules were already available, it was impossible to identify where the modules were damaged. To avoid any underestimate, they have been kept in the overall loss calculation.

Table 1: Number of parts damaged during petal integration.

Component	**Quantity**
Module	133 (2%)
AOH	72 (1%)
CCU	12 (4%)

6 Conclusion

The integration of 288 petals (plus some spares) has been completed during summer 2006. The quality is excellent as shown by the few selected plots. A very small fraction (0.2 %) of the 4 millions channels are bad. The number of damaged component is significant, typically at a level of a few %. This value should be considered as an upper limit, taking into account the extensive petal dismounting that occurred and the possible overestimate due to the mixing with other operations (packaging, shipment, handling). It should also be noticed that all these components have been replaced so that no bad petal has been delivered. The petals are now integrated into the End Caps. The exhaustive tests of the End Caps have confirmed the excellent quality of the petal production.

7 Acknowledgements

The petal integration has been a huge task involving many people from the seven centres over a period of more than two years. I would like to thank them for the quality of their work. A special thanks to Aachen 3 (Oliver Pooth, Dirk Heydhausen, Gordon Kaussen, Alexander Linn and Marc Henning Zoeller) for the plots shown in section 5.

References

[1] M. Krammer, CMS Conference Report 2006/095.

[2] J.-L. Agram et al., Nucl. Instr. and Meth. A 517 (2004) 77.