Strip Tracker of CMS: Operation and performance in first 7 TeV collisions

Natale Demaria

INFN Torino, v. P.Giuria 1, 10125 Torino, Italy

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The Strip Tracker of CMS has been run in deconvolution mode in 2010 during the first high energy collisions of the LHC. This paper describes the operational state and the detector performance.

1 Introduction

The CMS Tracker [1] is the main tracking detector of the CMS experiment at the CERN Large Hadron Collider. It contains two systems based on silicon sensor technology, one employing pixels and another using silicon microstrips.

The Silicon Strip Tracker (SST), the subject of this paper, surrounds the pixel system and consists of: the Inner Barrel (TIB) with 4 layers, three Inner Disks on each side (TID), an Outer Barrel with 6 layers (TOB) and two End Caps with nine disk each (TEC). It is the largest silicon detector ever built, with 9.3 million sensor channels covering a surface area of $198\,\mathrm{m}^2$. The SST was designed to measure charged particles with high efficiency and spatial resolution over a wide range of momenta, and to operate with minimal intervention for the nominal LHC lifetime of 10 years.

The Tracker was thoroughly tested already before and after the installation in the experimental cavern, using cosmics rays [2]. The first collisions at CMS were recorded in December 2009 at energy of $\sqrt{s} = 900\,GeV$ and 2.36 TeV with the front end electronics configured in *peak mode*, with a 50 ns integration time. In 2010, the SST was commissioned with the front end electronics configured in *deconvolution mode*, characterized by a faster signal, approximately gaussian with a sigma of 11 ns allowing the identification of the LHC bunch: this mode is the baseline for running at higher luminosity where pile-up events start to play a role.

The first section of this paper describes briefly the commissioning and running of SST while the second section illustrates the performance results obtained at the new high energy regime of the LHC.

2 Detector running and commissioning

The SST was proven during 2010 to be a very solid, reliable and stable detector, determining only 0.4% of down time of CMS during LHC collisions and negligible dead time. Important steps have been the commissioning of the detector and achieving good stability of the detector systems.

2.1 Commissioning

The key elements in the front end readout electronics are: the chip (APV25), providing analog readout signal serialized for 128 channels; the multiplexer serializing 256 signals and the Linear Laser Driver (LLD). This sends the data to the back end electronics via a 30 to 50 meters long optical fiber connected to the Front End Detector (FED). The FED digitalizes the signal, subtracts on an event by event basis the common mode noise and makes the zero suppression, sending to the CMS DAQ only the signal for those channels forming clusters well above the baseline.

In order to bring the SST detector into an operational state suitable for data-taking, several commissioning procedures are required to configure, calibrate, and synchronise the various hardware components of the control and readout systems. The full commissioning sequence of the SST is explained in [3]. It is mostly based on calibrations done without an external trigger and consists of the following sequence: internal synchronization of all analog signals from front end chips to the FED; gain equalization of all LLDs transferring out the signal via optical fibers; optimization of the average baseline at the FED; adjustment of the pulse shape of each chip and finally the measurement of the average baseline (pedestal) and of the noise of each channel. The pedestal and noise measured are then uploaded to the FED and used to perform the zero suppression of data. In the absence of a real signal, the SST is very quiet: occupancy due to noise is of the other of 10^{-5} in deconvolution and 10^{-6} in peak mode, to be compared with about 1-4% occupancy during collisions at full luminosity. Gain, pedestal and noise have been monitored by taking periodically timing and pedestal runs and they have been confirmed to be very stable: updates were done only occasionally due to minor hardware interventions done during LHC technical stops.

Detector parts that are malfunctioning are mainly detected during SST commissioning. Only good alive channels are selected to be readout and for the year 2010 they constitute 98.1% of the SST, distributed in: 96.3% (TIB/TID), 98.3% (TOB), 98.8% (TEC+) and 99.1% (TEC-). The major contribution to the bad channels comes from two sets of modules that are sharing, each one, the same power supply line for the digital power to the front end (for trigger, clock and I_2C bus): the cable has a short at the level of a patch panel inside CMS. These two shorts are responsible for 1.1% of the bad channels and will be recovered at the next LHC shutdown in 2012. Other missing parts are due to: HV lines missing (0.1%); HV lines shorts (0.3%); bad fibers and other problems (0.4%).

It has to be remembered that the SST was designed with very high redundancy and can accept a high level of dead channels before tracking performance is affected.

2.2 Detector systems

The SST is cooled by two cooling plants distributing C_6F_{14} liquid at 4 °C via 180 lines. Only 2 lines (for 0.6% of front end) are closed due to substantial leaks, but the associated detector modules are powered on and fully working, despite a nearly 20% higher temperature. Still one cooling plant is leaking at a non negligible level in other two lines and further investigations are under way.

The SST uses 2000 power supply units and has reached a failure rate of 1% per year. During 2010 the replacement of the power supply unit was normally done at the first opportunity of down time of the LHC.

The SST readout has been running stably. The only interventions required have been: the early replacement of 5% of VME-PCI boards due to failures in the opto-receiver; the recent replacement of one FED out of 440 due to a bad temperature probe that was causing one FED to eventually stop working.

2.3 Detector running with beams

The SST was included in the readout of CMS at all times, but was giving sensible data only during Stable Beams: as a safety precaution the high voltage needed to deplete the silicons was switched on only when LHC declared stable beams and they were switch off again when LHC was declaring a handshake to go to other states like beam dump or adjust. In order to send little or no data to CMS when the high voltage was off, the FEDs were set automatically by the DAQ with a high threshold.

Recently the SST spy channel readout has been introduced in the standard running during stable beams. It allows to readout synchronously from VME all the FED data at a frequency of about 0.1 Hz. This will allow to monitor on-line the data and therefore measure pedestals and noise while taking collisions data.

3 Performance

The signal in deconvolution mode is very fast and therefore a precise timing with respect the trigger is necessary. A preliminary scan with 20 steps of 2 ns each was done already during 2009 with 2.36 TeV collisions but was repeated in early April 2010 scanning in each subdetector separately. Only one layer per subdetector is scanned while the other layers are set in peak mode and used as a telescope to extrapolate tracks to the measured layer. Results of this scan are shown on left of Fig. 1: the line indicates the settings found in 2009; a difference of up to 4 ns was found and new settings have been used since then. In the figure is visible the quick signal provided by the deconvolution mode of the front end chip. The signal over noise ratio of

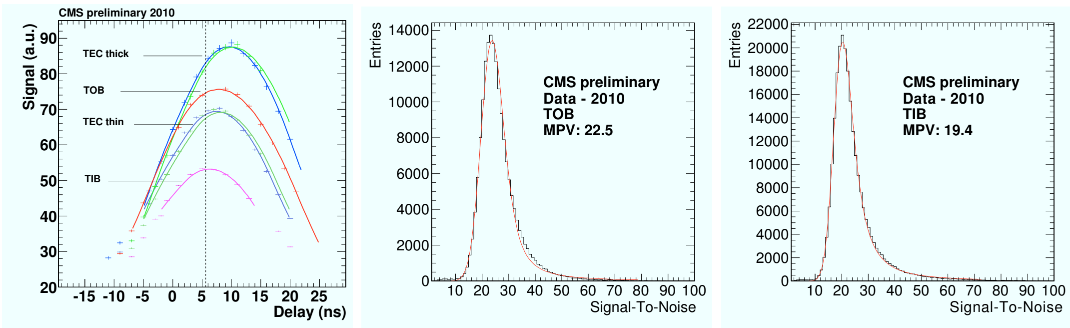

Figure 1: Results in deconvolution mode: on left the signal versus the delay of trigger; in the middle and right plots, the ratio of signal over noise for the TOB and TIB respectively.

the SST in deconvolution mode is very good and fits with expectations. The value normalized to tracks perpendicular to the silicon sensor of the most probable value of the Landau has been measured of 18.5, 19.4, 23.9, 19.4 and 22.5 respectively for TID, TEC thin, TEC thick, TIB and TOB subdetectors modules. Results for TOB and TIB are shown respectively in the center and right plots of Fig. 1.

Given a good track crossing a layer, the presence or absence of a hit in that layer measures its hit detection and reconstruction efficiency. Cuts have been applied, avoiding crossing the layer at the border of the acceptance region, given the extrapolation error of the track and known bad modules have been excluded. The overall measured efficiency is 99.9%: this analysis has revealed eight additional inefficient modules that are currently under investigation.

The hit resolution was measured using tracks crossing overlaps regions. The small distance and amount of material between the overlapping modules makes the comparison of local coordinates of the two modules a good estimate of the hit resolution. The measurement is almost insensitive to local misalignment, except for uncertainties on the relative angles between the two modules that have a negligible contribution to first order. The study has been done for different track inclinations with respect the module surface and results are in good agreement with simulation. For example a resolution of 14, 18 and 28 μm was measured for pitches of 80, 120, 180 μm and a track crossing angle of 10-20^o with respect to the normal to the module. For each track the SST provides not only a measurement of momentum, but also a multiple

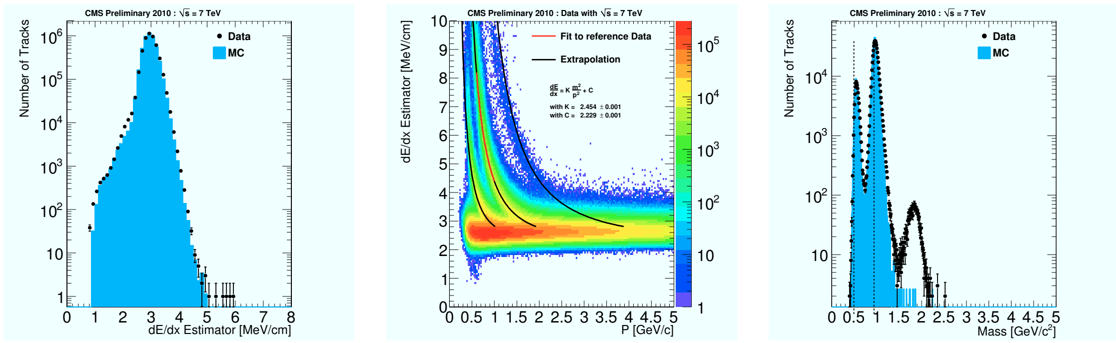

Figure 2: Left: dE/dx; center: dE/dx vs momentum; right: mass plot for $p < 2\,\mathrm{GeV/c}$, $\mathrm{dE/dx} > 5\,\mathrm{MeV/cm}$ (see more in text).

measurement of dE/dx and therefore provides some particle identification capabilities. A barrel track can count on at least 10 independent measurements from the SST: a harmonic mean with power -2 has been preferred instead of the median or the truncated mean and is therefore reported here. Data and simulation are in very good agreement as is shown on the left of Fig. 2. The results of dE/dx versus the momentum can be seen in the middle of Fig. 2: the lines of kaons, protons and deuterons are visible. The lines reported are a fit to an approximated formula as shown in the picture. For small momentum this formula can be reversed, so the mass can be computed from the dE/dx and the momentum. The plot of the mass abundance on the right of Fig. 2, together with simulation expectations, shows how well the presence of protons and kaons is described by simulation, whereas deuterons are not well reproduced.

4 Conclusions

The Silicon Strip Tracker of CMS was running during 2010 collisions in deconvolution mode, showing excellent S/N, cluster reconstruction efficiency and resolutions, dE/dx performances, achieved thanks to the detector commissioning and the calibration procedures. The detector ran efficiently with almost no downtime thanks to the stability of all detector systems, in particular cooling, power supply and back end electronics linked to DAQ.

This results are an excellent milestone for the 2010-2011 long physics data taking with LHC collisions at 7 TeV center of mass energy.

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