The CMS Silicon Strip Tracker

Carlo Civinini
INFN Sez. di Firenze*)
For the CMS Silicon Tracker Collaboration

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Abstract

The subject of this presentation is the description of the CMS Silicon Strip Tracker. The project is currently in a well advanced phase: the detector modules and the other tracker components production is finished, the integration of the single active and passive elements into the macroscopic parts of the tracker is underway and the tracker commissioning is about to start.
After a description of the detector layout, modules and electronics a detailed review of the integration activities on the inner barrel part of the tracker (TIB) will be reported.

Introduction

The CMS strip tracker is the first large scale tracker entirely based on silicon detectors technology. A few numbers to clarify the dimensions of this project: active silicon area of 198 m^2, 15148 silicon strip modules, 9.316.352 analogue readout channels, -10^{o}C sensor operating temperature, radiation resistance up to $2x10^{14}$ neutrons/cm^2 for an expected lifetime of about 10 years at the LHC collider.
The realization of this scientific instrument is based on the following key points. Availability of excellent performance, low price, radiation tolerant, frontend chips realized in 0.25 μm technology. Silicon sensor design and construction based on 'P on N' type: in such a way the devices are able to maintain adequate performance after bulk type inversion once operated at high bias voltage; metal over-hang is implemented to obtaining sensors with high breakdown voltage and the <100> crystal orientation minimizes the surface damage. Simple design rules are used for guard ring and strip geometries, obtaining single sided sensors that can be produced in large 6" industrial lines, with high yield and affordable price. The assembly of over 15,000 detector modules has been carried out using automatic machines, saving manpower and producing modules with a high precision and reproducibility. The module testing team has characterize each single strip of the whole production set, probing also early failure at realistic final experiment conditions. Module production yield in the range 95-99% and fraction of bad strips less than 0.1% has been achieved.

The CMS Silicon Strip Tracker Layout

A few words to describe the CMS Silicon Strip Tracker layout (Fig. 1). The Silicon Strip Tracker occupies the radial range, around the LHC interaction point, between 20 cm and 110 cm. The barrel region ($|z| < 110$ cm) is split into an Inner Barrel (TIB) made of four detector layers, and an Outer Barrel (TOB) made of six detector layers. The TIB is shorter then the TOB, and is complemented by three Inner Disks per side (TID) each made of three rings. The forward and backward regions $120 \text{ cm} < |z| < 280$ cm are covered by nine End-Cap (TEC) disks per side, each made of seven rings. The whole tracker region is embedded into the CMS 4 Tesla solenoidal magnetic field aiming at a charged particle transverse momentum resolution of about 1.5% for central muon of 100GeV/c.

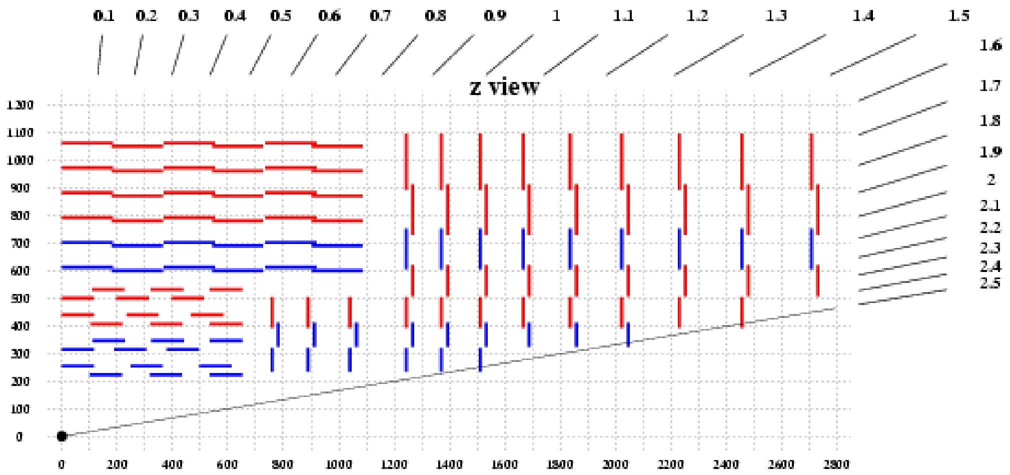

Fig. 1 Sketch of the tracker layout (1/4 of the longitudinal view); red lines represent single sided modules while blue lines double sided ones. Dimensions are in mm, pseudorapidity coverage is also shown.

Detector Modules

Detectors of the TIB, TID, and of the four innermost rings of the TEC have strip lengths of approximately 12 cm and pitch between 80 and 120 μm. These detectors are made of a single sensor of 320 μm thickness. In the outer part of the tracker (TOB and three outermost TEC rings) strip length and pitch are increased by about a factor of two with respect to the inner one. In order to compensate for the noise increase due to the higher inter-strip capacitance, a silicon thickness of 500 μm is chosen for these larger detectors.
All Silicon Strip Sensors are of single sided type. Double sided detectors are realized simply gluing back to back two independent single sided modules: to obtain a coarser but adequate resolution on the longitudinal coordinate the so called 'stereo' module has the sensor tilted of 100mrad with respect to the 'R-Phi' one. The stereo sensor and electronics are identical to the r-phi ones, the only difference is in the support mechanics and pitch adapters. In such a way the number of different sensor types is kept low with obvious advantage in terms of production simplicity and costs.

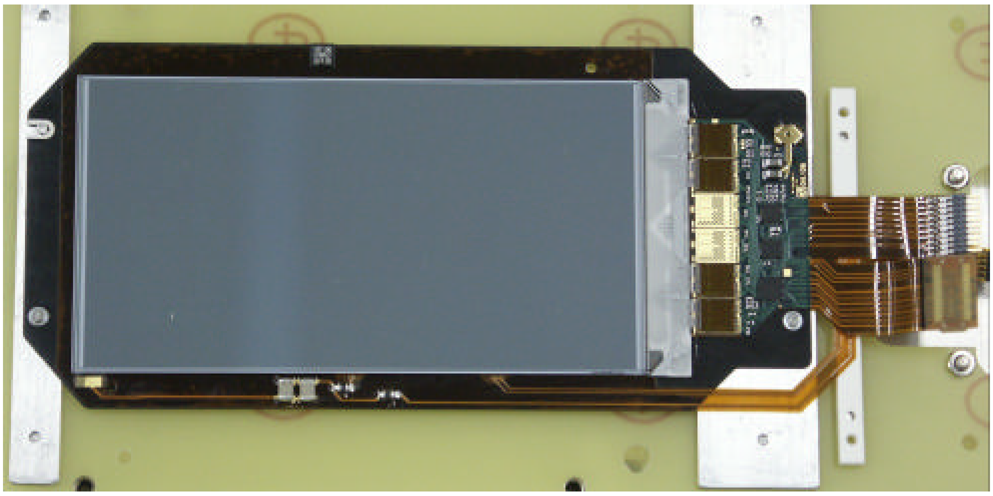

Fig. 2 A single sided TIB Silicon strip module mounted on its test and transport carrier.

Fig. 2 shows a picture of a complete TIB single sided module. The sensor is glued on a carbon fibre support frame which also holds the front-end electronics hybrid. The readout chip pitch (44μm) is matched to the silicon pitch (120μm for the sensor shown in Fig. 2) via a glass fanout circuit (picth adapter). The hybrid circuit (right part on Fig. 2), which houses the frontend chips and ancillary electronics, is realized using kapton multilayer technology. Of the two main kapton tails visible in picture the upper one provides the module with low voltage power, 40MHz clock and trigger, detector control signals, while the other sends strip analog signals to the optoconverter for transmission to the control room.

Tracker Electronics

The signals coming from each silicon strip are processed by frontend readout chips (APV25) mounted on the detector kapton-based hybrid circuit. The APV25 is built in radiation hard 0.25 μm CMOS technology. It is a 128 channel chip which samples at the LHC frequency of 40 MHz and implements a charge-sensitive amplifier with a time constant of 50 ns, a shaper and a 192 column analogue pipeline memory. On a level 1 trigger positive decision useful data are marked after a programmable latency, and held in the pipeline until such a time that they can be read out. A 32 deep FIFO holds the addresses of pipeline columns holding marked data. When data is read from the pipeline it is processed using a filter before being read out through an analogue multiplexer and driven off chip as a differential current.
This frontend chip can be operated in the so called 'deconvolution mode' where three consecutive samples are used to eventually compensate for nearby bunch crossing contributions leading to an effective time constant of 25ns which is important for correct bunch crossing identification in the high luminosity running phase of the LHC.
The electrical signals are then converted to optical signals in dedicated Analog-Opto Hybrids, and transmitted to the counting room by means of multimode optical fibres, where they are digitized. The entire readout chain is able to sustains a level 1 trigger rate of about 100KHz. Data coming from the Silicon strip tracker will also be used by the Global CMS High Level Trigger.

Module Production and Test

The various module components (silicon sensor, support frame, frontend hybrid with pitch adapter and HV bias circuitry) are glued together using automatic 'Gantry' assembly machine. This 'industrial approach' saves an important amount of manpower and assure that the 15000 modules have the requested assembly precision.
After gluing the modules are shipped to the bonding and test centres. There the modules are microbonded using industrial bonding machines. The microbonding quality is monitored measuring, on a sampling base, the pull strength and the characteristics of the bonds.
After this operation the module undergo to a certain number of tests which verify the quality and the reliability of the detector and certify it for integration on the Tracker. In the following a brief description of the tests performed on a TIB module is reported.
First a module is tested at room temperature using a single module test station called 'ARC'. Here the basic module functionality (i.e. frontend chip response to operational parameter download via I2C line, normal low voltage consumption, fast noise and calibration response) is quickly checked preparing the module to a more deep set of measurements. The IV characteristics of the sensor is then measured up to 450V and a limit on the bias current of 10μA is requested to accept a module. Fig. 3 shows the bias current measured at 400V for more than 2200 TIB modules; the 2% modules which do not pass the IV cut are not included in the plot. The module is then biased at 400V and the noise and calibration are performed in the four different frontend operating modes: in such a way dead, shorts or noisy channels are identified. Furthermore an LED device artificially changes the sensor bulk current in order to spot possible implant-readout strip shorts or pinholes.

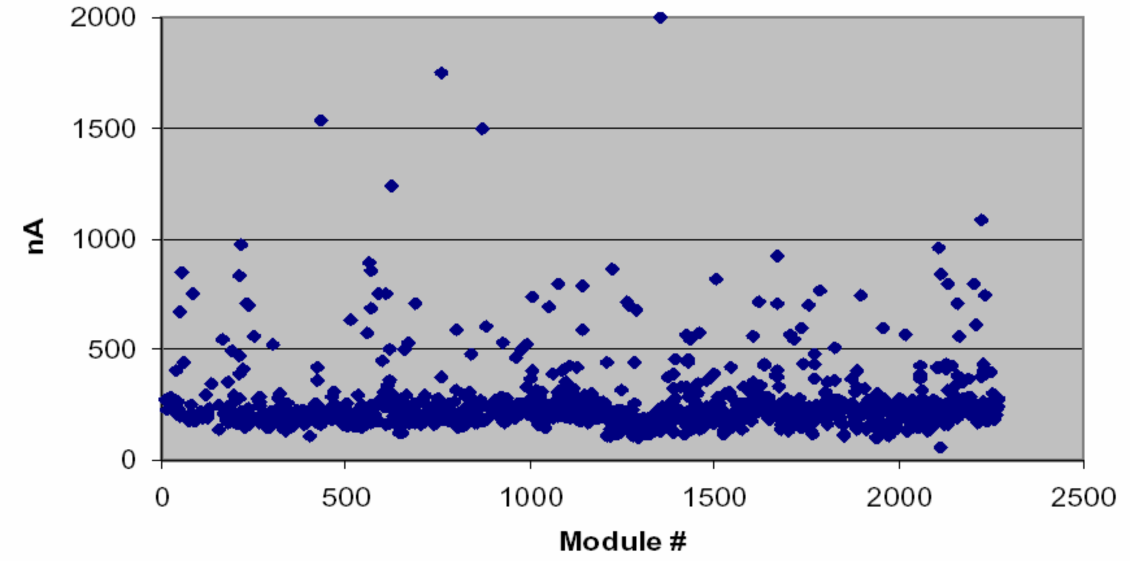

Fig. 3 Reverse bias current, measured at 400V, for TIB modules.

If the ARC test is passed a module is tested in an environment similar to the real detector conditions. Up to nine modules are inserted in a climatic chamber which thermally cycles them between -20^{o}C and +20^{o}C in a dry atmosphere. During these cycles, which for TIB modules lasts for two days, the module is readout performing a noise and calibration measurements. This ‘long term test’ is aim at identify week modules components which can possibly break early in the lifetime of the detector. About 1% of the TIB modules have been rejected because they fail the long term test. Fig. 4 show an example of noise measurements done at -20^{o}C on TIB detectors. Disconnected or ‘dead’ channels are the ones with noise less that 1 ADC count while noisy channel have noise values greater than 1.8 ADC counts.

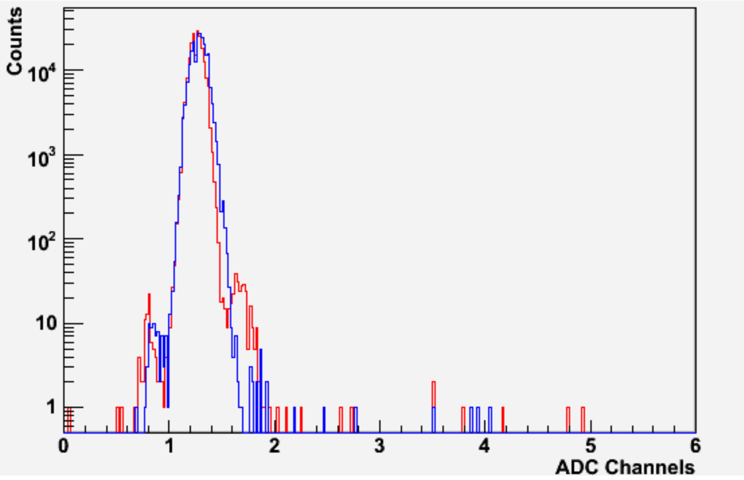

Fig. 4 Cumulative noise distribution for TIB modules measured at -20^{o}C during long term test (blue: four chip modules, red: six chips modules).

TIB Shells Integration

The module and other Silicon strip tracker components production is now finished. The integration of module, electronics, mechanics and services all together to finally arrive to the construction of a working scientific instrument has started last year and it is now to a well advanced stage. This presentation will review the TIB integration activities and results.

The TIB and TID modules are assembled into large structures each of them containing several hundreds of different components: TIB structures are half-shell shaped, four for each layers, while TID ones are disks.

The integration starts from the carbon fibre based mechanics, which already contains the aluminium cooling pipes and precision ledges for modules mounting and cooling (Fig. 5).

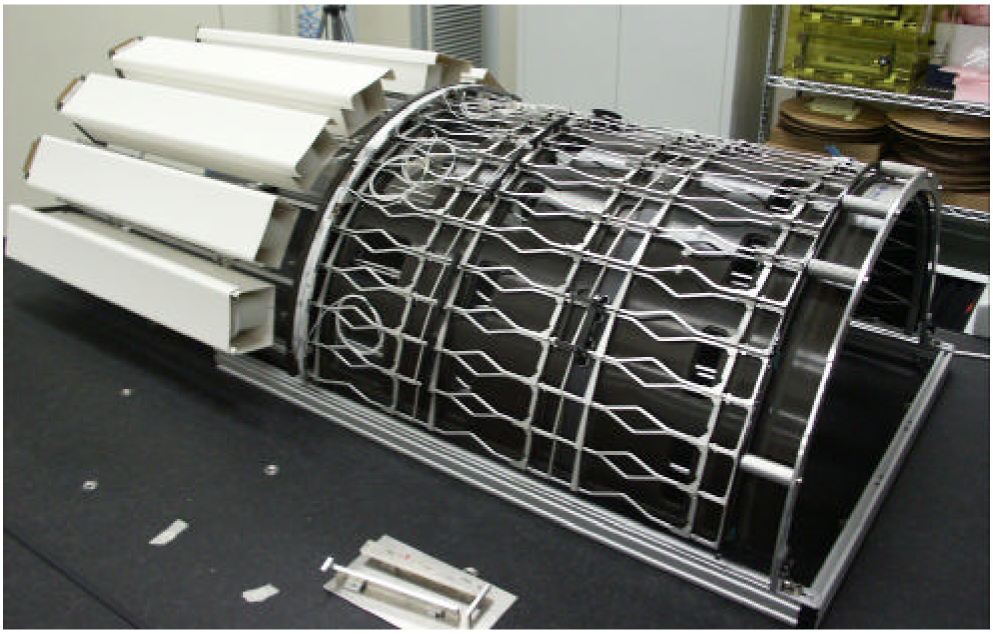

Fig. 5 TIB layer 2 carbon fibre mechanical structure with cooling pipes and temporary optical fibre holders (left).

Then the analogue opto-hybrids, with two metres long optical fibres tails attached to them, are mounted on the structure routing the fibres outside the half shells to temporary fibre holders (Fig. 6).

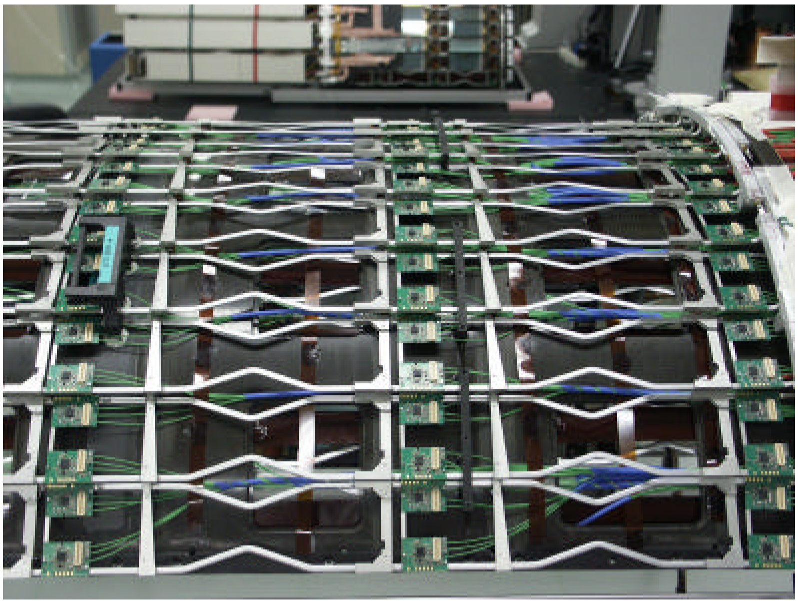

Fig. 6 Analog optohybrids mounted on the mechanical structure.

Then kapton circuits, which provide the modules with clock, trigger and control signals as well as LV and HV power lines, are inserted below the supporting ledges. Modules (Fig. 7) are mounted on the precision ledges (on both inner and outer surfaces of the shell) and tested, together with the opto-hybrids, for communication and full functionality (high voltage test at 400V and noise measurements).

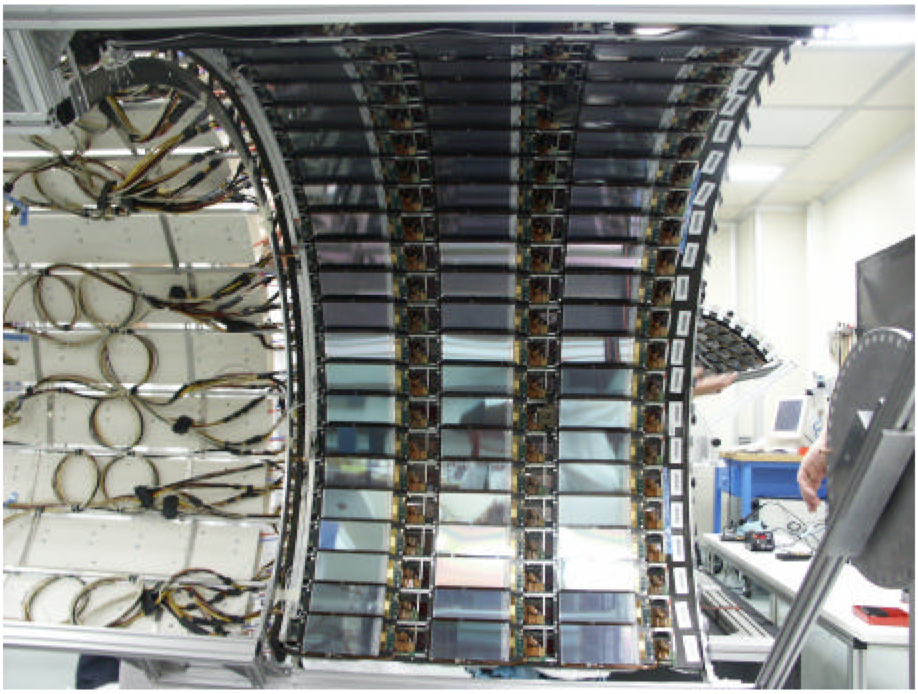

Fig. 7 TIB layer 4, inner part, completely assembled with modules.

Finally the control electronics are mounted and cabled on the shell (Fig. 8) and everything is fully tested again. Fig. 9 shows a cumulative strip noise distribution of the modules mounted in a TIB layer 4 half-shell. This distribution matches very well the one shown in Fig. 4 if a small difference in normalization between the two completely different readout systems is taken into account. This means that no degradation on noise performances is observed when modules are readout together after integration in a completely assembled shell.

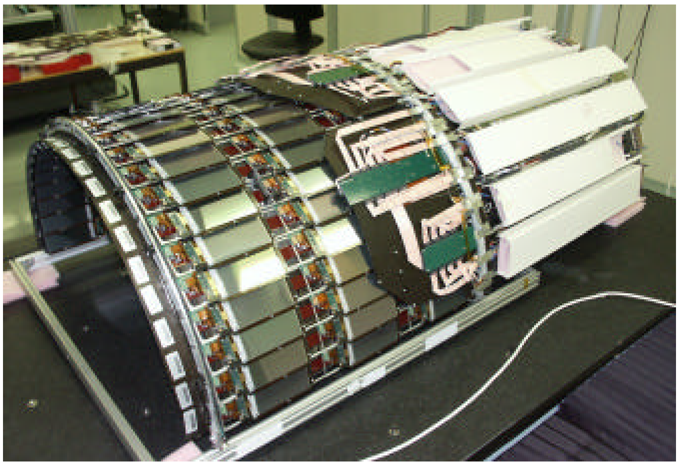

Fig. 8 TIB layer 3 with modules and control electronics mounted on carbon fibre supports on the external part of the shell.

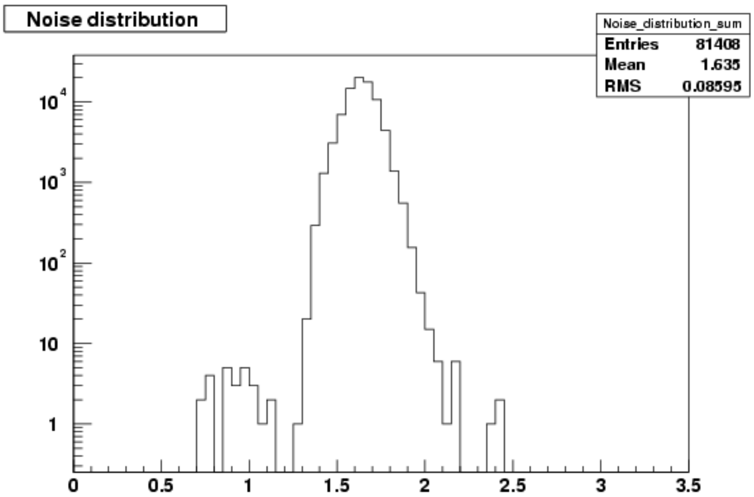

Fig. 9 TIB layer 4 cumulative strip noise distribution (ADC counts).

Then the half shells are sent to the burn-in cold room to be tested at the tracker nominal working temperature. Here a final check of the structures performances (components functionalities, module cooling, noise) before assembling the structures together is performed (Fig. 10).

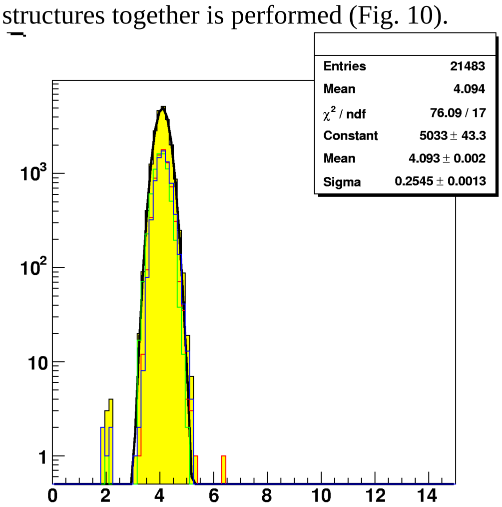

Fig. 10 Cumulative strip noise distribution (ADC counts) of one forth of TIB Layer 4 performed during a burn-in run using cooling fluid at -25^{o}C. The absolute value of the noise is not normalized to the scale of neither Fig. 4 nor Fig. 9.

Finally the structures are assembled together to form a barrel (TIB) and a series of three disks (TID), with the services (cooling pipes, optical fibres and power and HV cables) packed on a ‘service cylinder’ and connected to a main patch panel. The entire TIB-TID is done by two of this macro structures, called ‘plus’ and ‘minus’ from their location on the two sides of the LHC interaction point, which are joined together directly in the tracker support tube. The support tube hosts also the outer barrel (TOB) and the two endcaps (TEC) to complete the CMS Silicon strip tracker.

*) Via G. Sansone, 1
I-50019 Sesto Fiorentino (FI)
ITALY

E-mail: Carlo.Civinini@fi.infn.it
Tel: +39 055 4572232
Fax: +39 055 4572346