The CMS Silicon Strip Tracker

Marco MUSICH – University and INFN Torino

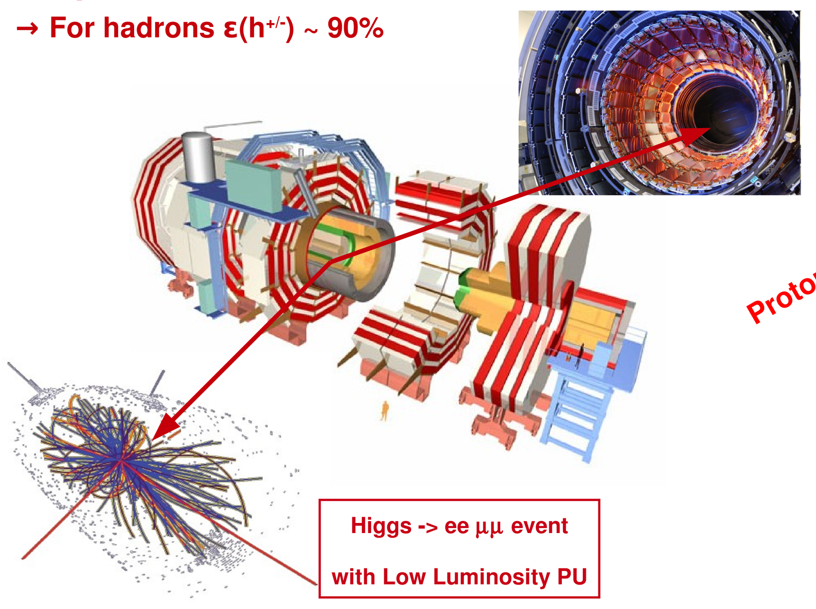
On behalf of the CMS Tracker Collaboration

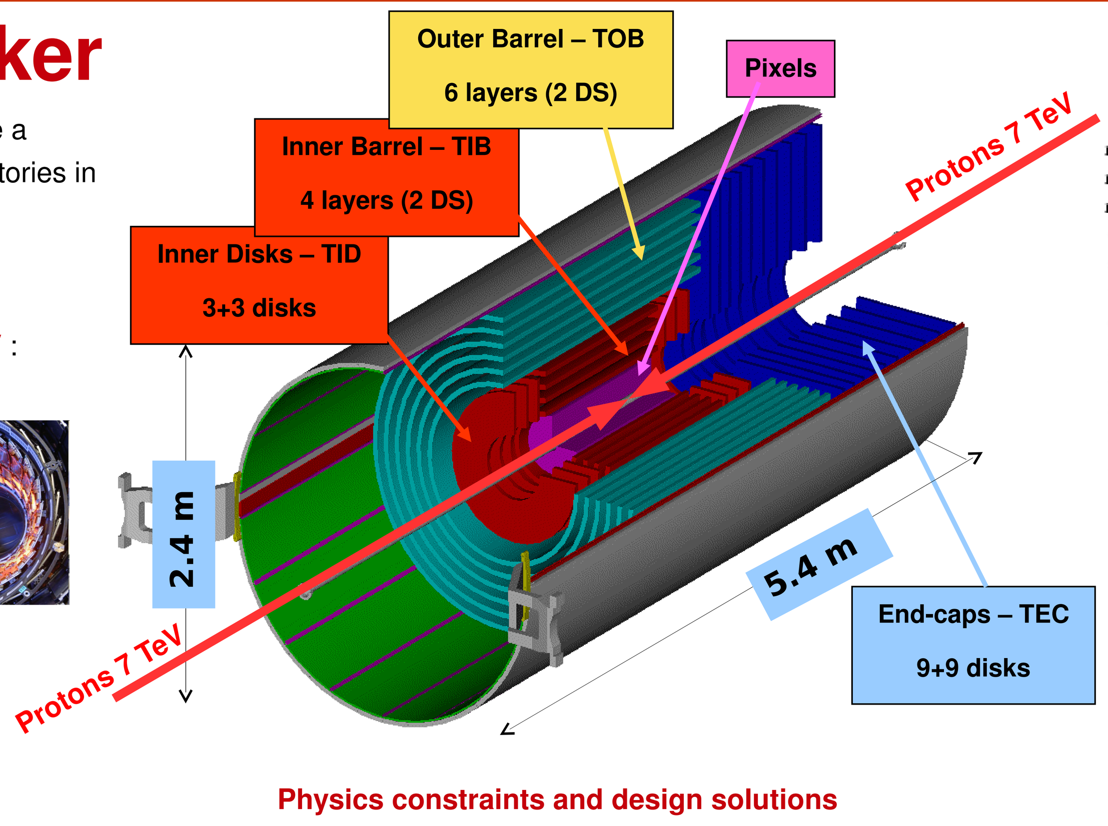
The CMS Silicon Tracker

The CMS tracking system [2,3] has been designed to provide a precise and efficient measurement of charged particles trajectories in the LHC collisions.

Physics requirements[1]:

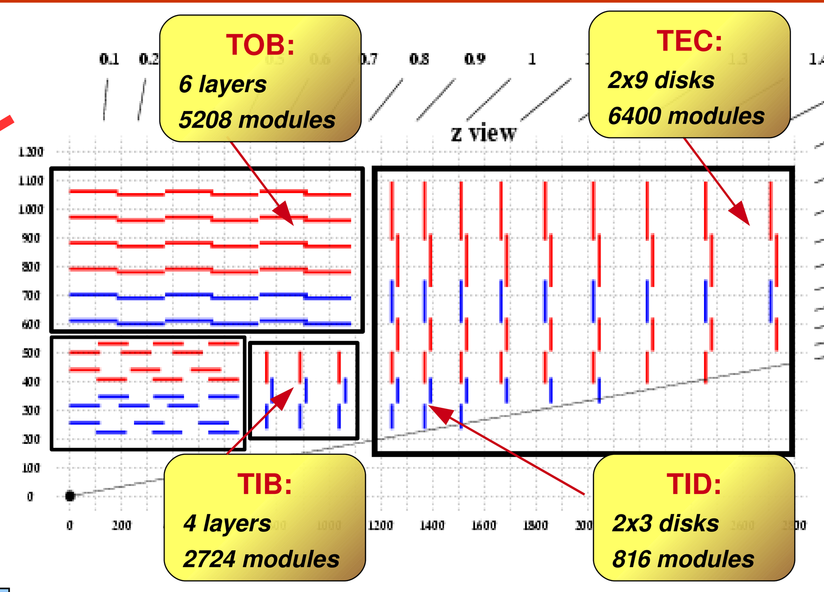
- Momentum resolution: $\delta p_T/p_T \sim 1/2\%$ ($|\eta|<1.6$)
- Very high tracking efficiency for tracks with p_T > 500 MeV :
  - → $\varepsilon(\mu) \sim 99\%$ for muons
  - → For hadrons $\varepsilon(h^{+/-}) \sim 90\%$





Physics constraints and design solutions

Physics Enviroment	Design features
High particle fluence	Radiation hardness
High particle density	High granularity
BX time = 25 ns	Very fast read-out



- Strip length: from ~10 cm in the inner layers to ~ 20 cm in the outer layers.
- In some regions different modules overlap: 2 or more measurements per layer per track

Blue = "double" sided modules

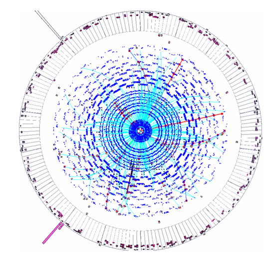
Red = single sided modules

The challenges

- The SST is the main tracking devices of CMS and will have to face the demanding environment of LHC collisions:

p – p collisions at design luminosity ($10^{34}cm^{-2}s^{-2}$, 14TeV)

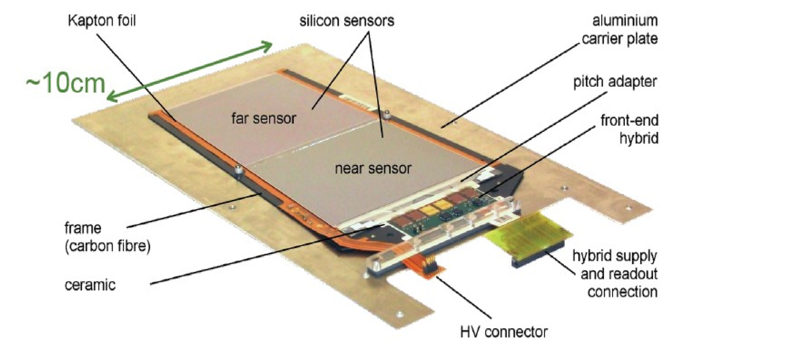
- 40 MHz crossing rate
- O(20) superimposed pileup (PU) events / crossing
- O(2000) charged tracks / crossing
- Trigger Levels 2/3 (HLT) include track reconstruction: reduction from 100 kHz to ~300Hz



General Features

- Volume: 24 m³ - covered *Si* area: 210 m²
- Running temperature: -10°C
- Inside the CMS Solenoid (4 T bending magnetic field)
- STRIP detector:
  - 15148 modules (pitch: 80 – 205 μm)
  - Single point resolution of 20 – 60 μm
  - 2-D measurement with double sided (= DS) modules: mounted back to back with a tilt angle of 100 mrad
  - High Granularity and radiation hardness is obtained by means of a "heavy" tracker (up to 1.8 X_0)

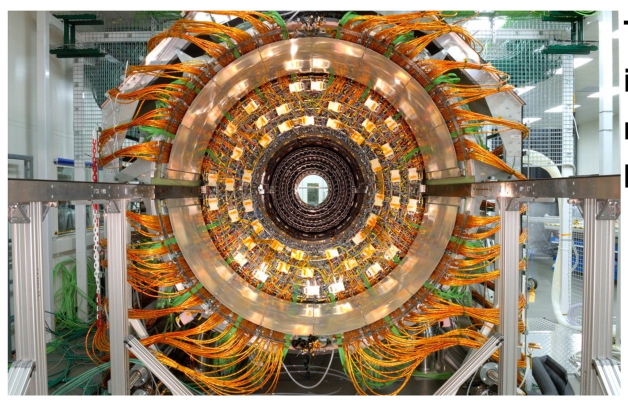
A CMS Silicon Strip Module:



The Tracker Slice Test

At CERN Tracker Integration Facility [4] (TIF) all SST subsystems were assembled into the Tracker support tube since fall '06 to March '07.

Integration did not result in new defects, only a few per mil bad channels (0.2%)



The TIF Slice Test consisted in cooling, powering and reading-out ~ 15% of the SST

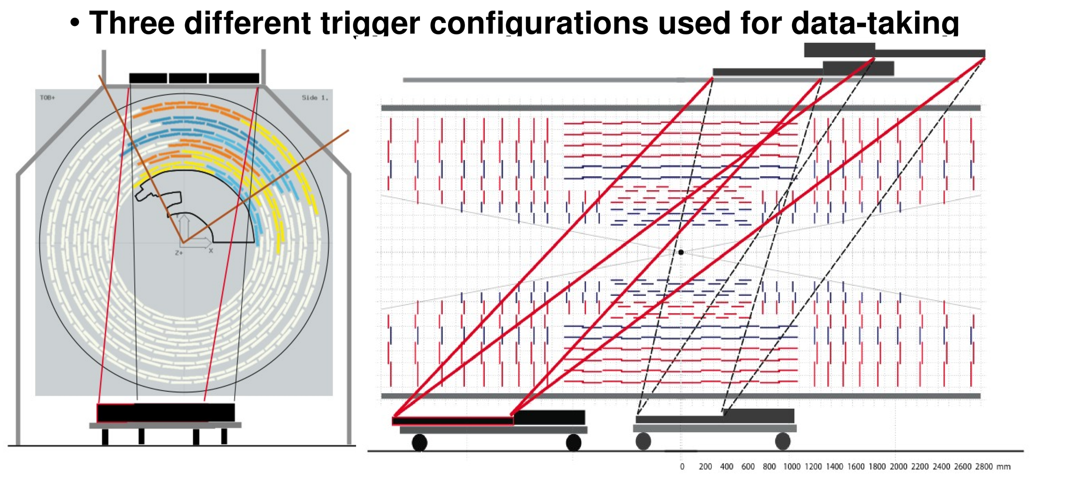
Important exercise on:

- Commissioning
- Monitoring
- Data Management
- *Tracking & Alignment*

Slice Test Layout

Scintillator based system used to trigger on cosmic events.

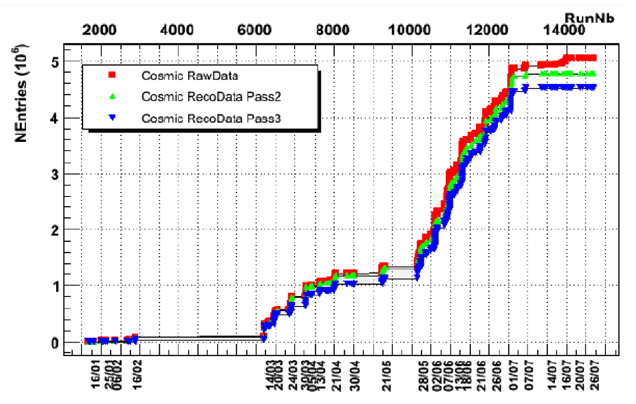
- Trigger Rate ~5 Hz
- Three different trigger configurations used for data-taking

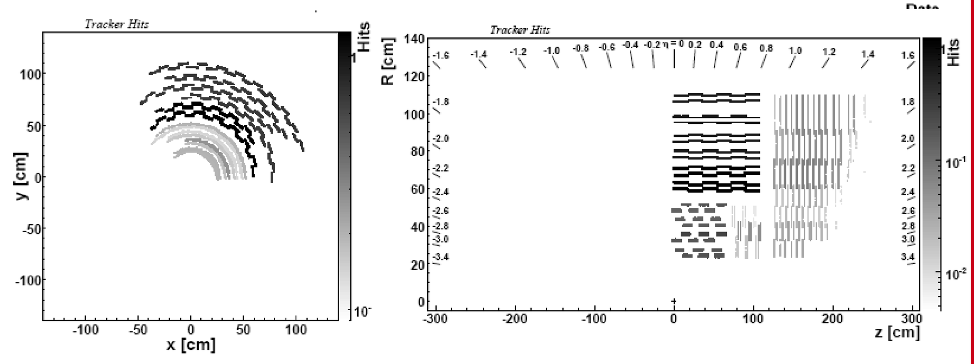


- 5 cm of lead on the bottom scintillator to reject soft muons

Slice Test Highlights

- 5 million cosmic events collected (cosmic muons with p> 200 MeV/c).
- No p_t measurement (B=0T)
- The Silicon Strip Tracker operating with ranging from +15° and – 15° C.
- Up to 15% of the SST was read-out
  - 16% of TIB
  - 25% of TID
  - 13% of TOB
  - 13% of TEC

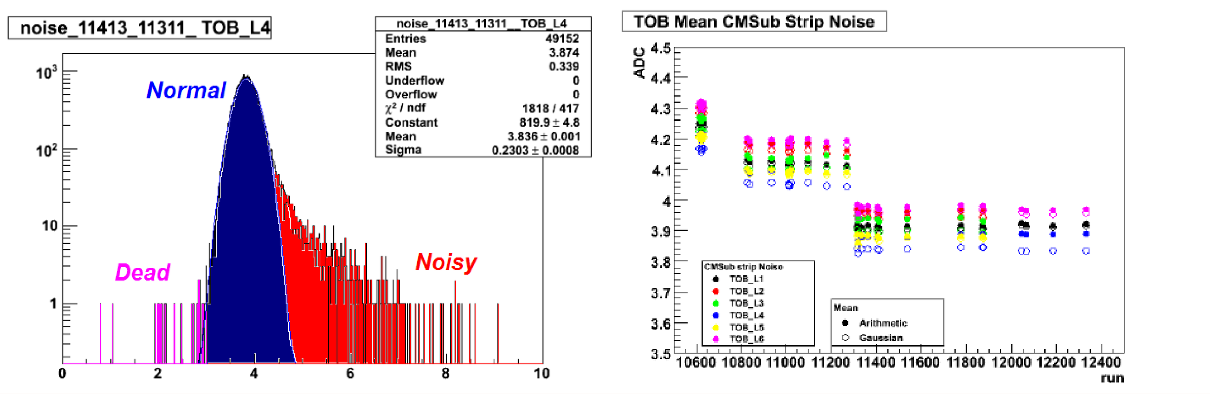




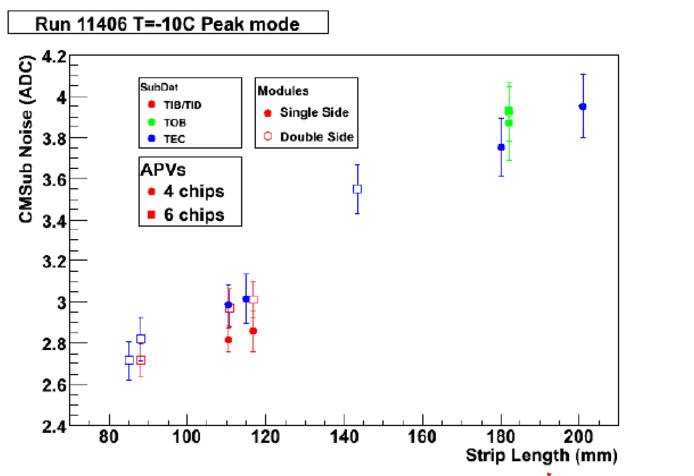
Noise Studies

Determination of noise profiles (in ADC counts) with Gaussian fit, of noisy channels in non-Gaussian tails at high values and of dead channels.

- Stability of noise performance studied taking pedestals and noise runs at different times when running in stable configuration (T=-15,-10,0,10°C).
- For constant temperature noise is stable better than ±0.5%.



Mean values of strip noise obtained from Gaussian fit for each different type of module has been correlated with strip length, obtaining as expected a linear correlation, since noise scales with detector volume. Deviations form this behavior are explained by different supply voltages.



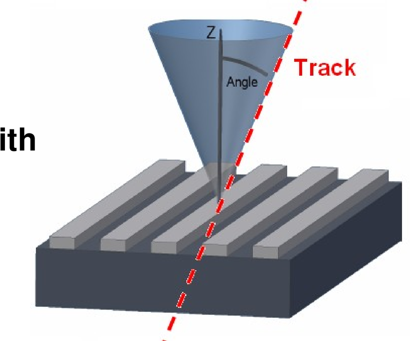
Signal Parametrization

- Energy deposited in Tracker modules can be parametrized as:

$$S_{Tot} = K \cdot \frac{dE}{dx} \cdot t \quad K = \frac{1}{\cos\theta_{3D}}$$

with $\cos\theta_{3D}$ cosine of the angle of incidence of the track with respect to the silicon normal. Thickness normalized signal is defined as:

$$S_{Norm} = \frac{dE}{dx} \cdot t = \frac{S_{Tot}}{K}$$

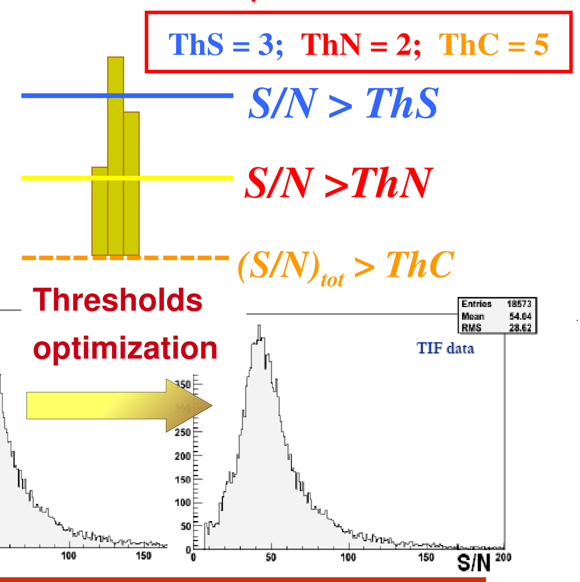


Cluster Thresholds Optimization

The Silicon Strip Cluster building provides a fast and powerful rejection of fake hits (~1000) .

Applied conditions:

- Noise evaluated trough pedestal studies
- Three different thresholds on S/N:
- Find seed with S/N > T_s
- Clusterize and check neighbors S/N > T_n
- Check cluster threshold $\sum$(S/N) >T_c



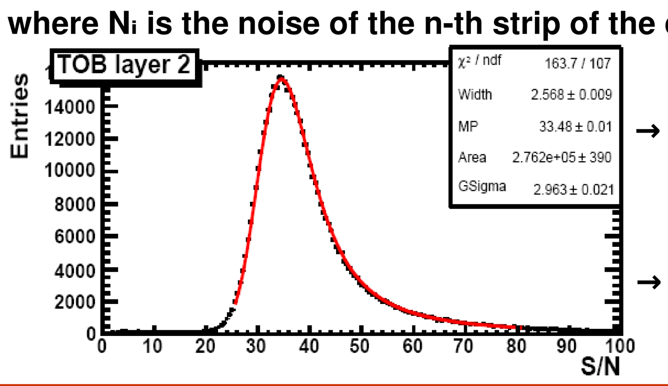
Signal to Noise Ratio

Signal to Noise ratio normalized to detector *effective* thickness was evaluated layerwise allowing a more accurate result from modules of the same layer at operation temperature T =-10°C.

- S/N Ratio is defined as:

$$S/N = \frac{S_{Norm}}{\langle N \rangle} = \frac{S_{ren}}{\sqrt{\sum_i N_i^2 / n_{strips}^{cluster}}}$$

where N_i is the noise of the n-th strip of the cluster and nstrips number of strips in a cluster



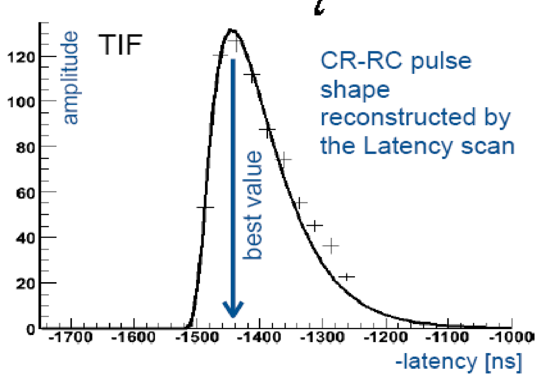
→ Distributions were fitted with a Landau convoluted with a Gaussian (4 parameters) with an excellent χ^2/ndof.

→ Stability vs time was also checked.

Latency scan

The response of CMS silicon modules has the analytical form of the transfer function in the time domain of a CR-RC circuit:

$$S_{peak}(t) \propto \frac{t}{\tau} e^{-t/\tau}$$



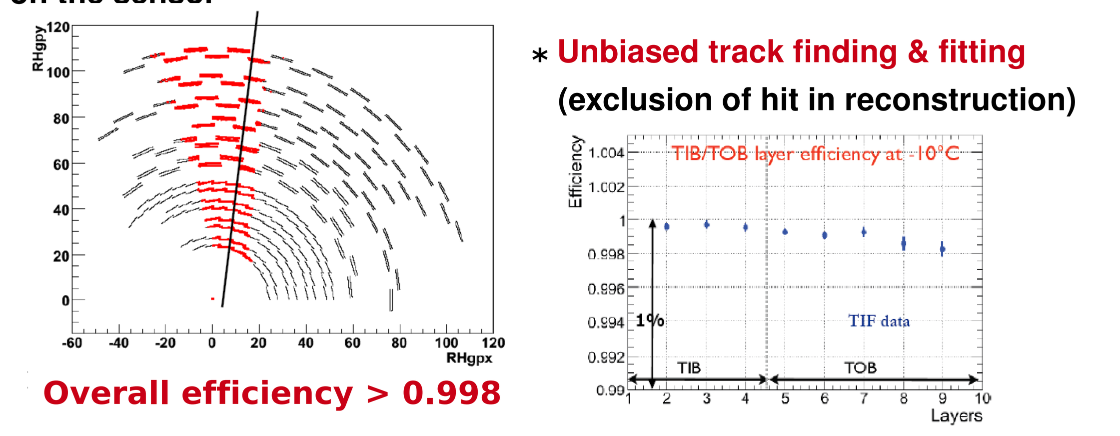
Since the rise time of signal of front-end electronics lasts several bunch crossings, a voltage proportional to the input charge is stored in a pipeline memory. During the slice test a latency scan in peak mode was performed to determine the best trigger latency in order to maximize the signal peak amplitude sampling.

Hit reconstruction efficiency

- Efficiency measurement module by module

Check presence of hit on a module given a track within a fiducial area on the sensor

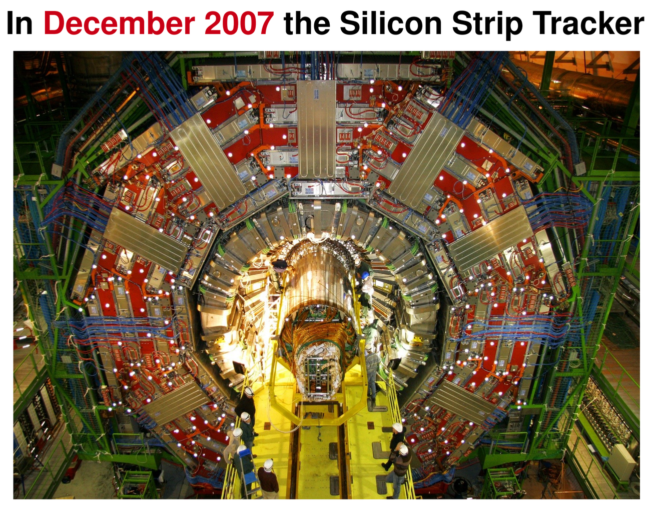
- Unbiased track finding & fitting (exclusion of hit in reconstruction)



Overall efficiency > 0.998

SST Performance at Global Runs

In December 2007 the Silicon Strip Tracker was inserted inside CMS

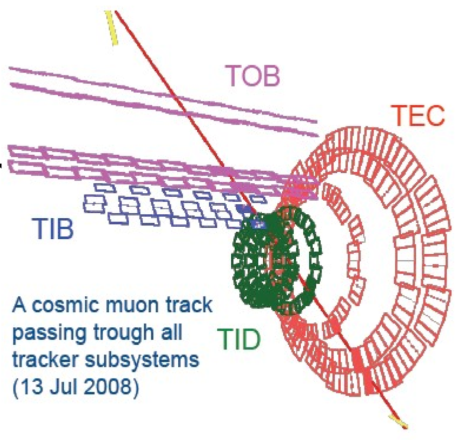


→Full cabling and piping completed in March '08

→Some accidents at the Tracker Cooling prevent completion of checkout activities until June '08.

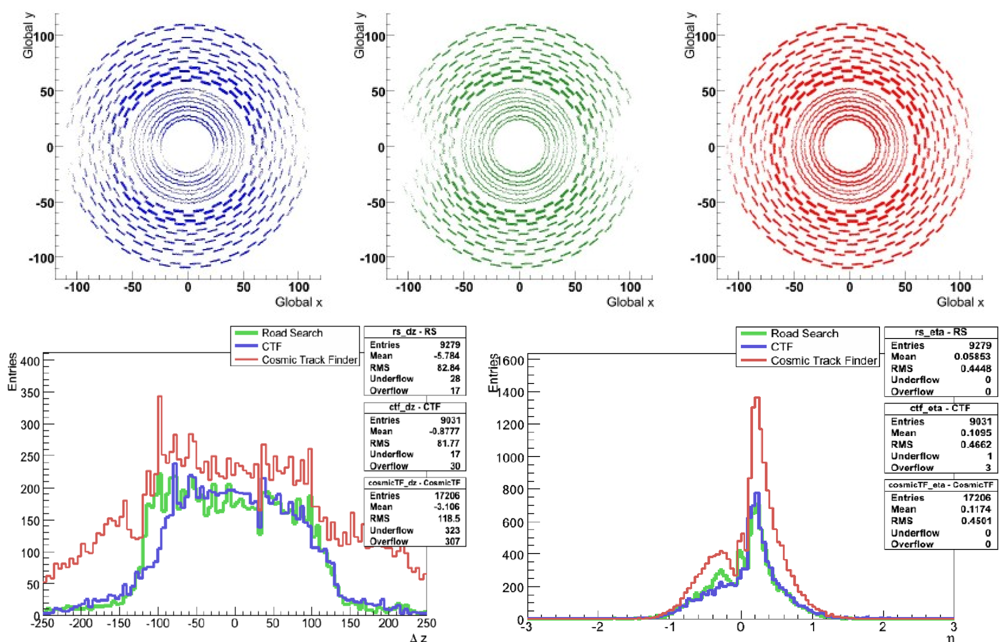
Since July 2008 the Silicon Strip Tracker joins CMS operations. Tracker operated in the final conditions: same data processing chain as expected for collision data.

A cosmic Global Run without magnetic field took place in July and August. The test was very important for CMS: the engages for the first time the entire DAQ system. More than half a million tracks were recorded out of 50 million events.



Tracking at the Global Run

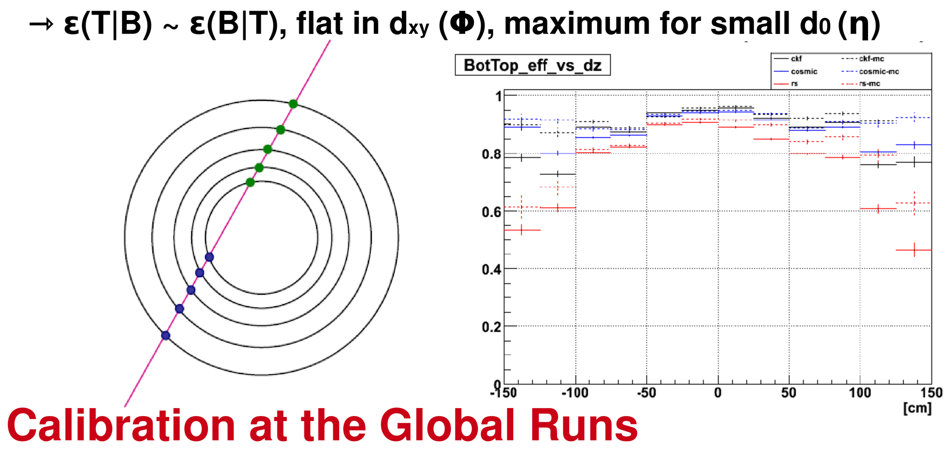
CMS collaboration deploys three tracking algorithms for reconstruction of cosmic muon tracks: Combinatorial Tack Finder (CTF), Road Search and Cosmic Track Finder, the former two developed for p-p collisions and the latter specialized to reconstruct single track cosmic events. Algorithm performances together with stability in time were tested.



Top-Bottom track matching in the two halves of the SST was tested too at global runs.

→ High quality track selection, and independent reconstruction in the two halves

→ $\varepsilon(T|B) \sim \varepsilon(B|T)$, flat in d_{xy} (Φ), maximum for small d_0 (η)



Calibration at the Global Runs

- At the Global Runs it was possible for first time to calibrate the full SST repeating with the 100% of modules the calibration measurements performed at TIF Tracker Slice Test, such as S/N, optimization of cluster thresholds, hit efficiencies, latency scans and signal synchronization.

Alignment at the Global Runs

- With O(100k) independent d.o.f., alignment of CMS Silicon Strip Tracker poses a major challenge.
- The Global Runs were also the first opportunity to test the full scale alignment of the Silicon Strip Tracker, using in-situ track based alignment.
- Together with the Laser Alignment System and Detector Surveys, track based alignment algorithms are used to align the SST.

Two alignment algorithms (HIP and MillePede) were used, both aiming to minimize the global χ^2 function:

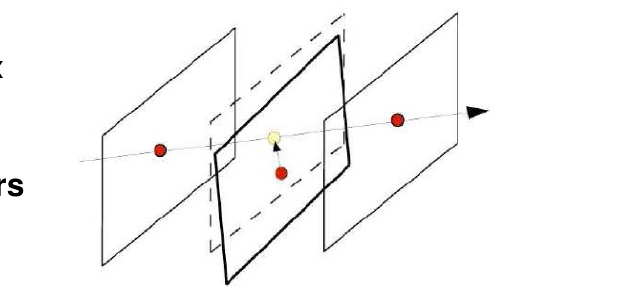
$$\chi^2 = \sum_k^{hits} r_k^T(p,q) V_k^{-1} r_k(p,q)$$

$$r_k = u_k^{hit} - u_k^{fit}(p,q)$$

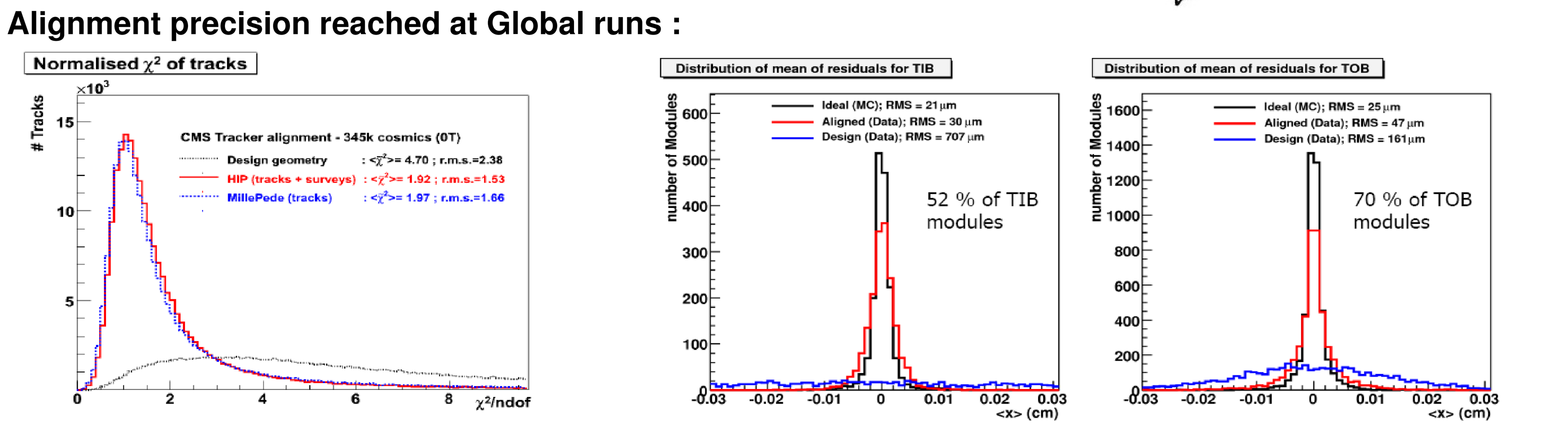
V = fit covariance matrix

r = hit residual

p = alignment parameters



Alignment precision reached at Global runs :



References:

[1] CMS COLLABORATION, *Physics TDR vol. 1* – CERN/LHCC 2006-001

[2] CMS COLLABORATION, *The CMS Tracker System Project: Technical Design Report*, CERN/LHCC 98-006

[3] CMS COLLABORATION, *The CMS Tracker: addendum to Technical Design Report*, CERN/LHCC 2000-016

[4] CMS Note 2008/xxx (in preparation): *Silicon Strip Detector Performance with Cosmic Ray Data at the Tracker Integration Facility*