The CMS Silicon Strip Tracker - Overview and Status

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Overview

• The CMS silicon strip tracker
• Mass production and quality control
  - silicon sensors
  - front-end hybrids
  - silicon strip modules
  - integrated substructures (petals)
• Tracker integration
• Performance of substructures in test beams
• Summary

All results are preliminary!
The CMS Detector at the Large Hadron Collider

The LHC at CERN: pp collisions @ $\sqrt{s}=14$TeV from 2007 onwards

The Compact Muon Solenoid detector:

- pixel detector and silicon strip tracker
- electromagnetic calorimeter
- hadronic calorimeter
- superconducting solenoid, B=4T
- muon chambers

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The CMS Silicon Strip Tracker

Silicon strip tracker:
• 15148 silicon strip modules
• $\approx 200\text{m}^2$ active silicon area
• $\approx 10$ million readout channels (strips)
• high radiation level: 10 LHC years \(\equiv 1.6 \times 10^{14} \text{n}(1\text{MeV})/\text{cm}^2\)
  \(\rightarrow\) operating temperature below -10° C
The CMS Silicon Strip Tracker

Cross section of one quarter of the tracker:

- single-sided modules
- double-sided modules (stereo angle = 5.7°)
  → position information along the strips

TOB:
- 6 layers
- 5208 modules

TID:
- 2 x 3 disks
- 816 modules

TIB:
- 4 layers
- 2724 modules

TEC:
- 2 x 9 disks
- 6400 modules

thick sensors: 500µm
high resistivity

thin sensors: 320µm
low resistivity

Interaction point
The Silicon Strip Modules

A TEC ring 5 module:

- 1 or 2 silicon sensors
  - p-type strips on n-type bulk
  - pitch 80-205\(\mu\)m, width/pitch = 0.25

- support frame
  - graphite and carbon fiber (CF)

- front-end (FE) hybrid

- pitch adapter

- micro bonds

- Kapton circuit
  - bias voltage
  - back plane isolation
  - temperature sensor

≈10cm

29 module types: 512 or 768 strips, 1 or 2 sensors, rectangular or wedge-shaped sensors, geometry .....
The Front-end Hybrid

4-layer Kapton substrate (flex) laminated onto ceramic carrier

4 or 6 APV25 readout chips
- radiation hard commercial 0.25µm CMOS technology
- 128 strips per APV, multiplexed to one analog output
- per channel: pre-amplifier, CR-Rc shaper, 4.8 µs pipeline

2 readout modes:
- **Peak mode**: 1 sample (τ≈50ns)
- **Deconvolution mode** (high lumi): weighted sum of 3 samples, τ≈25ns, but higher noise

2:1 multiplexer
- 2 APVs multiplexed to one readout channel

PLL chip
- decodes clock & trigger signals

Detector Control Unit (DCU)
- 12-bit ADC
- 8 channels:
- hybrid and sensor temperatures
- leakage current
- low voltages

Analog & optical readout!

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Sensor Production

- Suppliers deliver 24244 tested silicon sensors (6" technology)
- 320μm thick sensors: HPK; 500μm thick sensors: 85% HPK, 15% STM (since 2004)

STM → CERN distribution → quality control
5%: IV, CV, pinholes, $I_{\text{strip}}$, $R_{\text{poly}}$, $C_{\text{coup}}$, ...

1% → radiation tests (p, n) → module production

5% → process control longterm behaviour

Problems with STM sensors during mass production (unstable leakage current, oxidation, high common mode, ...)
→ bulk of thick sensor production shifted to HPK

HPK monthly plan and delivery

Status (mid July):
- HPK: 100% of thin and 70% of all thick sensors delivered, excellent quality
- STM: 15% of all thick sensors delivered and qualified

prod. completed: October 05
Front-end Hybrid Production

- Flex circuits produced by Cicorel, assembly done by Hybrid SA
- Quick & easy test of > 15000 hybrids: Front-end Hybrid Industrial Tester
  - connectivity, electrical test, readout test within 1 minute

Several problems, e.g.:
- Lines broken at connector (Ni/Au pads on Kapton) → FR4 stiffener
- 100μm vias developed bad contact → additional Kapton layer

Status (mid July):
- Improved QA & C
- Production rate: ≈ 400 hybrids/week
- 70% of hybrids delivered and accepted
- Expected end of production: November 05
- Back-up line being set up
Module Production

- **Assembly**: gluing of sensor(s) and hybrid to the frame
  - 15,148 modules need to be assembled with high precision
    - (e.g. coordinate \( \perp \) strips: 39\( \mu \)m)
  - \Rightarrow fully-automatic gluing robots: “gantry”
    - 6 gantries in operation
    - Issues: precision, calibration
    - 99% of modules within specs
    - Up to 20 modules/gantry/day

- **Bonding**: 23 automatic bonding machines (> 5 modules/machine/day)
- **Single module test** (warm & cold): noise, bad strips, IV, pipeline errors, ...

- Typically 0.1-0.3% of bad strips per module
- Yield > 95%

**Status (mid July):**
- 5348 production modules built = 35%
- Expected end of production: January 06
Substructure Production (Example: TEC Petals)

- Per end cap (TEC): 9 CF disks
- Modular design: 16 removable CF structures (petals) per disk
- Up to 28 modules per petal, arranged in 7 radial rings

- 40% of petal mechanics with motherboards produced
- Mounting of optical converters (AOHs), routing of fibers
- Assembly of modules and functional test (7 prod. lines in 5 centers)
- Longterm test of assembled petals: started in May 05
  - 6 cooling cycles between room temp. and -20°C → 3 days
  - grading: # of bad strips, noise, longterm stability, IV
  - petals have only 0.1-0.4% of bad strips
  - ramp-up phase, expected rate 1 petal/week/line

Status (mid July): 22/288 petals built; 12 fully characterized
Tracker Outer Barrel (TOB) Integration

Modules mounted onto rods:

- 3 single- or double-sided modules per side

CF frame (rod)

• 100% of rod frames produced
  (precision of positioning pins: $\sigma = 40\mu m$)
• 60% of rods cabled
• rod assembly has started
  24/344 rods assembled and longterm tested
• TOB integration starts in August

Mechanical support structure (“wheel”) is ready:

inner & outer cylinder

6 layers, two rods in z

4 disks with slots for rods
• Strings of 3 modules mounted inside & outside of the barrel cylinders
• Cylinders of layers L2+, L3+, L4+ completed
• **First single-sided layer (L3+) fully integrated**
• Readout test and burn-in of L3+ ongoing
• >99% of good strips, noise level as in test beams
• Grounding/shielding/x-talk under study

### Noise of strips of 15 modules at room temperature

- **Peak mode**
  - \( \tau = 50 \text{ns} \)

- **Deconvolution mode**
  - \( \tau = 25 \text{ns} \)
• First end cap assembled, ready for petal insertion
• Assembly of second end cap far advanced
• TEC integration starts in August
TEC Petals in the Test Beam

Setup: 2 petals (1% of the TEC), operated at CMS temperature ($\approx -10^\circ$C)

Excellent system behaviour:
- stable communication and readout at all temperatures
- uniform noise distributions, small common mode
- signal/noise > 20
- equivalent noise charge consistent with expectation from measurements with single APVs

May 2004 CERN X5

pions (120GeV)
muons (70GeV-120GeV)
**TOB Rods in the Test Beam**

**Setup: TOB cosmic rack with 6 rods**
Precision support structure with integrated cooling

- stable readout at all temperatures
- uniform noise
- S/N≈ 24 in deconvolution mode
- tracking with expected spatial resolution

\[
\begin{array}{c|c|c}
   & \perp & \parallel \\
\hline
   DS & 45 & 29 \\
   SS4 & 45 & 23 \\
   SS4 & 42 & 38 \\
   SS6 & 35 & 28 \\
   SS4 & 54 & 33 \\
   DS & 50 & 30 \\
\end{array}
\]

pitch/√12=35µm (SS6) and 53µm (DS, SS4)
Summary

- Excellent performance of components proven in system tests and test beams
- Technical problems with sensors and hybrids seem to be overcome
- 35% of modules built with high quality, production completed early 2006
- Integration of modules on petals, rods and shells has started
- Integration of large structures until spring 2006
- Readout test of 25% of the tracker with final DAQ system

Integration into the CMS detector in autumn 2006