The CMS Silicon Strip Tracker: System Tests and Test Beam Results

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On behalf of the CMS collaboration.
Outline

• Introduction

• Results from the system tests:
  □ the May 2003 test beam:
    → general DAQ
    → tracker end cap (TEC)
    → tracker inner barrel (TIB)
  □ tracker outer barrel (TOB)

• Summary

All results are preliminary!
FE-hybrid:
- APV25 readout chip: 128 strips, shaping, pre-amplification, 192 cell pipeline
- MUX: 256:1
- PLL: trigger/timing
Purpose of the system test

- Integration of a complete system substructure (rod, petal, ...)
- All hardware components (mechanical structure, electronics, ...) as final as possible
- Qualify overall design/compatibility of components, and optimise before start of mass production, if necessary
- Use hardware together with most recent CMS DAQ software
- Test noise performance etc.
- Integrate auxiliaries: final power supplies, cooling facilities, ...
- Test cooling performance of the substructure

Hardware components / modules / expertise spread in different labs ⇒ test beam used to test the system in its most complete configuration
Tracker test beam May 2003

- **when:** two weeks in May 2003
- **where:** X5 test beam in the CERN west area
  - SPS protons → primary target → hadrons (→ muons)
- **what:** muons or pions (p = 120 GeV for pions)
- **how:** 25 nsec bunched time structure

- **TEC petal in cooling box**
  - 10 modules
  - T = 0°C

- **TOB setup**
  - 6 modules kept at room temp.

- **TIB part of half shell**
  - 6 modules kept at room temp.

- **the beam traversed all three setups**

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Counting room

Opto-electrical converter

External PCI-boxes with PMC FEDs & trigger/sequencer card

PCI-boxes connected to PCs

Particle trigger & external clock

Optical data from beam area

Trigger/clock/I2C optical signals to beam area

PCs with FECs
DAQ performance

- Readout software based on XDAQ
- Successful test of new run control
- Java based online monitoring
- Fast commissioning (~2 hours):
  - tuning of readout (FED) sampling
  - adjustment of opto-hybrid parameters
  - latency & PLL timing scans to find the signal (best working point)
- Mostly three systems (TOB, TIB, TEC) readout in parallel
- First integration of TIB & TOB (coherent readout of two subdetectors) within a few hours shows scalability & commissioning capability of DAQ software
- Offline reconstruction within 30min → data quality checks possible
- 220 GB of data taken → analyses are ongoing
The TEC test beam setup

- First time a petal prototype was put in the testbeam
- Petal equipped with 10 modules plus 12 hybrids

- Slow control (temperature, humidity, LV)
- Electronics: 3 FEDs, 1 FEC (PMC versions)
**TEC test beam setup**

- First test of mounting procedure → difficult but feasible
- First double-sided TEC module under test → working fine
- Prototype of Interconnect Board → software compatibility checked
- Optical control & readout link
- Final cable type (45m)
- Petal cooled to 0°C → optimisation of mechanics well advanced

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Software implementation of all commissioning tasks (automatised):

→ tuning of FED sampling time
→ synchronisation of channels (optimisation of PLL delay):

→ optimisation of opto-hybrid parameters (bias current for given laser gain): working well (to be re-done whenever temperature is changed).
TEC results: Signal/Noise

Sensor results:

- Cluster seed: \( S/N > 4 \)
- Cluster strip: \( S/N > 3 \)
- Total cluster:
  \[ S/N = \frac{\sum S_i}{\sqrt{\langle N^2 \rangle}} > 5 \]

\( S/N \) for 500 \( \mu \)m and 320 \( \mu \)m sensors
T \( \approx \) 0°C, peak mode, U=350V

\( S/N = 38.8 \)
\( S/N = 27.3 \)
preliminary

\( S/N \) for T \( \approx \) 0°C and room temperature
500 \( \mu \)m, peak mode, U=350V

\( S/N = 38.8 \)
\( S/N = 33.5 \)
preliminary

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Reconstruction of the longitudinal coordinate for a double-sided module:

**muon beam profiles:**

- Stereo module sensor up
- Normal module sensor down

100 mrad stereo angle (trapezoidal shape not yet taken into account)

Sensor B bonding gap sensor A

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TEC results: bias voltage scan

Depletion voltage is smaller by a factor of 1.5 (charge collection effect).

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TIB test beam setup

- 6 modules (320µm thick, 120µm pitch) mounted on layer-3 mechanical structure
- Thermally stabilised at room temperature

- Completely assembled structure transported from Italy to CERN by car → not a single strip lost
- Test of counting room power supply prototypes
- 125 m of power cables, noise pick-up studies done
Pulse shape in peak mode

Muon beam, 300V bias voltage
noise ~ 1 ADC count

Pulse shape in deconvolution mode

Rise time = 55ns (slightly adjustable)

Deconvolution algorithm: reweighted sum of 3 consecutive samples of the signal leads to a much shorter pulse.
TIB results: S/N

- signal/noise in peak mode: S/N = 25.85
- signal/noise in deconvolution mode: TIB: S/N = 18.02

- muon beam
- 300V bias voltage
- sensor thickness 320µm
- \( \frac{S/N(\text{peak})}{S/N(\text{deconv})} \approx 1.4 \)
TIB results: noise

Number of noisy strips is stable.
(strip i is noisy $\iff N_{i}^{CMS}$ more than $5\sigma$ above truncated mean in $> 80\%$ of all calculations)

Low common mode subtracted noise.

$$N_{i}^{CMS} = \sqrt{\langle (v_{i} - p_{i} - CMN)^2 \rangle_{n=1...500}}$$

$i = \text{number of strip}$

$n = \text{number of event}$

$v_{i} = \text{raw data of strip i}$

$p_{i} = \langle v_{i} \rangle_{n=1...500} = \text{pedestal of strip i}$

$CM_{n} = \langle (v_{i}^{n} - p_{i}) \rangle_{i=1...128} = \text{common mode of event n}$

$CMN = \sqrt{\langle (CM^{2}) \rangle_{n=1...500}} = \text{common mode noise}$
response (\(\eta\)-) function in peak and deconvolution mode

\[ \eta = \frac{Q(l)}{[Q(l) + Q(r)]} \]

\(Q(l/r)\) = charge left/right of reconstructed hit position

More pronounced \(\eta\)–function in peak mode due to higher S/N.
25ns bunched beam structure: select special trigger conditions and study pileup

- trigger condition: particles in two consecutive bunches ('0110')
- trigger on the second event
- measure pileup = clusters from previous event, depending on APV parameter settings (deconvolution mode)

APV Parameter (VFS) responsible for signal rise time varied

→ the shorter the rise time, the cleaner the signal
- Test on single-sided rod: 6 modules → finished, design validated
- Test on **double-sided rod**: 6 double-sided modules (all r-φ) → ongoing
Common mode noise: mod. vs. rod

Noise comparison: single mod. vs. rod

⇒ Noise behaviour compatible with single module setup
TOB system test: cosmic muons

Cosmic muon signal on TOB modules:

- Beam profile: S/N = 26
- S/N in deconvolution mode
- Trigger rate ~ 0.5Hz

500 μm sensor
- Cluster finding: cluster seed: S/N > 5
- Cluster strip: S/N > 2
- Total cluster: S/N = \( \sum S_i / \) seed

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TOB system test: β source

Beam profile

- $^{106}_{44}$ Ru β-source
- Trigger rate ~ 500Hz
- Q=3.5 MeV

S/N in deconvolution mode

S/N in peak mode

S/N = 33

S/N = 21

Efficiency:

$\frac{N_1 + N_2}{N_2} \sim 99.8\%$

$N_i = \# \text{ of hits in Mod. } i$
• Increasingly larger silicon tracker substructures are being studied in system tests in laboratory as well as in test beam environment
• Critical phase - components have to be released for mass production
• Up to now the design is working and no major re-design is necessary
• System tests in the laboratories are ongoing
• Mass production is ramping up
• TOB beam test just finished a few days ago - stay tuned!

We are looking forward to two busy but exciting years: detector integration in CMS in only two years from now!

Many thanks to all involved CMS colleagues, esp. the test beam crew and all analysis people.
The CMS silicon strip tracker:

- silicon area: 210 m²
- 15148 single modules
- $10^7$ strips
- cooled to $T=-10^\circ$C

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The CMS silicon strip tracker

Side view of one quadrant of the silicon strip tracker:

Tracker outer barrel: 5208 modules, 6 layers
Tracker inner barrel: 2724 modules, 4 layers
Tracker inner disks: 816 modules, 3 disks/side
Tracker end cap: 6400 modules, 9 disks per endcap

Interaction point
- Single-sided modules
- Double-sided modules

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The tracker end cap (TEC)

9 disks per endcap

Per disk:
- 8 front petals
- 8 back petals

Petals = TEC substructures with up to 28 modules arranged in 7 rings
e.g. front petal (disk 1):
A side
B side

carbon fiber support structure

b.p.
f.p. (A side)

ring 7
ring 5
ring 3
ring 1
double-sided

ring 6
ring 4
ring 2

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Tracker inner barrel (TIB) & disks (TID)

TIB: 4 cylindrical layers, each layer consisting of two half-shells in z
Layer 1 & 2: double-sided modules

Strings of 3 modules are mounted inside and outside the half-shells

TID: 3 disks with 3 rings
rings 1&2 double-sided
Tracker outer barrel (TOB)

6 cylindrical layers, each consisting of two rods in z

- layers 1 & 2: **double-sided rods:**
  - 6 double-sided modules (6 r-φ, 6 stereo)

- layers 3-6: **single-sided rods:**
  - 6 single-sided r-φ modules

1.10 m

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Silicon module zoo

Thin sensors: 320µm, (TIB/TID, TEC R1-4)
Thick sensors: 500µm (TOB, TEC R5-7)

Different module geometries:
- rectangular (barrel) / wedge-shaped (disks)
- one (thin) / two (thick) wafers daisy-chained
- normal / stereo (100 mrad stereo angle)
⇒ wealth of module types (10 for TEC)!

- single-sided modules (512 strips)
- double-sided modules (768 strips): normal and stereo module mounted back-to-back

e.g. TEC ring 6: