Report on the TEC X5 Beam Test 2004

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Outline

• The TEC setup
• Hardware performance
  - I²C performance
  - Problematic modules
  - Experience with cooling
• Analysis results:
  - Noise performance
  - Effect of petal transport on number of bad strips
  - S/N
  - ENC noise and its temperature dependence
  - High voltage scans
  - Performance of modules with common mode noise
  - Study of zero suppression
  - Comparison of noise with CAEN/Delphi PS
• Summary and outlook
The TEC test beam team

- **TEC test beam coordinator: Nick Lumb (Lyon)**
- **Aachen 1: Richard Brauer, Katja Klein**
- **Aachen 3: Benedikt Hegner, Thomas Hermanns, Stefan Kasselmann**
- **Antwerp: Wim Beaumont**
- **Brussels: Jan Heyninck, Lionel Neukermanns**
- **Hamburg: Markus Stoyle**
- **Karlsruhe: Javier Fernandez Menendez, Valery Zhukov**
- **Lyon: Michel Ageron, Didier Contardo, Antoine Le Carpentier, Laurent Mirabito, Benjamin Trocme**
- **Strasbourg: Abdenour Lounis**

Many thanks to all of you for the help!
Introduction

Beam

TOB cosmic rack

trigger scintillator

A≈8x8cm²

Electronic hut

TEC box

Pions with p=120 GeV

and/or

muons with 70 GeV < p < 120 GeV

Program: May 27th to June 8th: normal beam

June 14th to 21st: LHC-like beam: particle bunches spaced by 25ns

SPS cycle=12s, spill length =2.2 s, T=23 μs, 48 bunches a 25 ns=1.2 μs per revolution

Trigger rate on scintillator: ≈ 2000 muons/spill or ≈ 600000 pions/spill (with A=4cm²)

⇒ Smeared over spill, rates of 15 Hz/cm² for muons and 70 kHz/cm² for pions
The TEC setup

- **One TEC control loop**, consisting of one front and one back petal
- Both petals were fully equipped: **51 modules** $\Delta$ 124 readout channels
  - Front petal (FP) prepared in Lyon
  - Back petal (BP) prepared in Aachen 1
The TEC setup

- Petals mounted in stacked transport frames (no precision mounting)
- Petals were kept in a thermally insulated metallic box

The box was placed on an xy-table → scan of whole petal area possible
Petal Cooling

- The two petals were cooled with the Louvain cooling plant (typical flux=0.7l/min)
- Box flushed with cold dry Nitrogen
- Typical cooling plant outlet temperature: -25°C
- Typical air temperature: -10 °C
- Relative humidity ≈ 4%

Final configuration:

A copper plate provided active cooling of the box
Hardware configuration

- Six Delphi power supplies for low voltage
- Two ISEG power supplies for high voltage
- Mostly laboratory PS used to power the ring (DOHM & CCUs)
  → all PS floating
- 20 - 40 m long Multi Service cables

• Optical ring consisting of optical PCI FEC, DOHM prototype (mounted on the front petal) and 2 DOHs

• 124 readout channels in the DAQ
• Readout via VME FED9U:
  - two VME FED9Us in one crate
• one petal per FED9U
DAQ aspects & slow control

• Readout via Laurent's DAQ software (2004 version):
  - based on XDAQ V2.0
  - DAQ processes running on five ports on four PCs
  - run control via xdaqWin

• Low readout rate due to slow data processing: ca. 200 events/spill

• FEC data base tested, including DCU readout and monitoring tool

→ DAQ reasonably stable
→ DAQ relatively easy to use (managed even by newcomers after 1h of training)
→ Commissioning (e.g. tuning of opto-hybrid settings, timing) of 51 detectors requires a lot of editing of xml files by the user, automation required

• Slow control: continuos readout of temperature and humidity sensors with PLC, all values displayed on screen
• Status of cooling plant monitored
• From these informations: interlock of low voltage power supplies
I²C communication

Configuration:

- InterConnect Boards (ICBs) modified for the final I²C design:
  2.2 nF capacitor in parallel to 470 Ω current limitation resistor in serial clock line.
  - Unfortunately, on 3 positions (7.2, 7.3, 7.4) on the front petal, the capacitor was forgotten → I²C unstable on these positions
  - On position 5.6 BP a wrong resistor was mounted on the ICB → reset not working properly, I²C unstable for this position
  - In addition, capacitors forgotten on ring 1 on the FP on one of two ICBs → stable, but problem with higher I²C frequency

Running experience @ nominal I²C frequency (100kHz):

- For positions with capacitors mounted, the I²C communication was very stable, both in the warm and cold environment
- But: - sensitivity to grounding: stable only for connection to X5 ground, unstable if setup was left completely floating
  - sensitivity to cable routing (noise pickup on digital power cables?)
  - to be investigated in Lyon or Aachen

I²C Speed test: successful (1 module failed at 1MHz)
Three ring 5 modules have single strips with very high noise (50-100 ADC counts), associated with high CMN of whole APV

Problem appears at 100-150 V for 5.1, 5.2 FP and 450V for 5.5 BP

Modules have not been built on the gantry

Raw noise - deconv.
Cms noise - deconv.
Raw noise - peak
Cms noise - peak

Not recovered by common mode subtraction (constant CM) in peak mode
Modules with problems

Modules with HV problems:
- One module (FP 2.4) did not hold HV from the beginning
  Trip at very low voltage - to be investigated by Benjamin
- One module (BP 2.1) lost HV in the cold
  Investigation in Aachen showed that bias Kapton had lost glue connection to backplane. Very small glue dots → will be improved at module production center

Modules with other problems:
- One module (BP 5.5) had no signal on one readout channel
  Reason unknown. Strange behaviour also seen in single module test
- One module (FP 3.2) showed high common mode on one APV
  Reason unknown. Also seen in single module test.

Raw noise - deconv.
Cms noise - deconv.
Raw noise - peak
Cms noise - peak
Cooling performance

No realistic cooling test, since
- sensors not irradiated
- T of Nitrogen not known
- Electrical insulation of modules against cooling pipe by Kapton washers (later anodisation layer)
- bad thermal insulation of box etc.

- Relative measurements possible
- DCUs readout by the DAQ
- Silicon temperatures calculated using DCU calibration constants by Th. Hermanns and T. Franke

Cooling performance

Temperature Correlations

![Graph showing correlation between hybrid and silicon temperature with markers for 4 and 6 APVs]
Experience from running cold

- In general, system was **running stable at low temperature**
- But: on four modules, for some time no signal observed in the cold: observed a few times for BP 5.6, once for BP 2.1, FP 7.2 and FP 6.2

Some attempts to study this in a systematic way at the end of testbeam
(even spend one night for thermocycling to provoke the effect)

→ **In case of 5.6, associated to I²C problems with AOH (known problem, identified as being due to wrong resistor on board)**

→ For other modules, behaviour did not occur anymore → we don't know.
Experience with running cooled

Clearly, further investigation is needed:

- **Back petal** has been given to Aachen 3 (Alexander Flossdorf and Alexander Linn) for thermocycling
  Status: commissioning of test setup: fridge, software, ...
  Good progress, first thermocycling run performed this week.

- **Front petal** will be investigated by Benjamin (at room temperature)
Analysis code by Richard Brauer used for analysis of test beam data (Documentation on http://brauer.home.cern.ch/brauer/Apa/index.html)

- Constant common mode subtracted (median)
- Bad strips are masked out (three iterations, first and last strip per APV excluded)
- Cluster finding: S/N > 5 for seed; S/N>3 for neighbour
- Cluster noise = seed noise
- Mostly, bias voltage set to 300V

Most of the plots prepared by Richard.

All results are preliminary!!
**Remember:**
- Test beam May 2003: strange noise observed on some positions on the petal
- Investigated in the system test in Aachen and Lyon
- Solved by placing shielding foils (18 μm of copper) between Interconnect Board (ICB) and modules
- Affected positions: FP 6.3, 4.3; BP 6.2, 4.2

⇒ both petals were equipped with the shielding foils
Front petal noise

Raw noise - deconv.
Cms noise - deconv.
Raw noise - peak
Cms noise - peak

FP 1.4
FP 6.3
BP 4.3
BP 6.2
Back petal noise

Raw noise - deconv.
Cms noise - deconv.
Raw noise - peak
Cms noise - peak

Pos. 1.1
Pos. 4.3
Pos. 6.2
Pos. 7.5
Number of bad strips

- Bad strips have been identified using pedestal runs in peak & deconvolution mode as well as calibration runs.
- A strip is classified as "bad" if identified as noisy or dead in at least two run types (excluding the first and last strip per APV).
- One bad readout channel not included in numbers.

Number of bad strips at X5:
- Back petal: 54 / 14336 = 0.38 %
- Front petal: 75 / 17408 = 0.43 %

Quality ok, considering that:
- About half of the modules have been used in the system test.
- For some geometries these were the only modules available.
Effect of petal transport

- Back petal has been transported to CERN by car (800km)
- Petal mounted in transport frame and kept in vertical position (as in the tracker)
- Foam for damping

Number of bad strips:
- at Aachen: 52
- after transport to X5: 51
- back in Aachen: 47

Very encouraging: within uncertainty, no strips lost!

But: back in Aachen, one module (7.2) had a dead APV.
(this APV is not included in above numbers)
Investigations showed no apparent defect, module will be given to hybrid experts.
Beam profile and cluster width

Clusters Versus Strips Back petal 1 CCU 12 ring 3 detector 2 run 51033

Pions

Clusters Versus Strips Back petal 1 CCU 12 ring 4 detector 1 run 50436

Muons

Module 4.1

Module 4.2

Module 4.3

Cluster width BP pos 5.6

Entries

0 500 1000 1500 2000 2500 3000

Cluster width [strip]

1 2 3 4 5 6 7 8 9 10

Pions

Muons
Landau distributions - peak mode

Muons in peak mode, room temperature

Ring 1
320 µm
S/N = 29.6

Ring 5
500 µm
S/N = 38.7
Landau distributions - deconvolution mode

Muons in deconvolution mode, room temperature

Ring 2
320 µm
S/N = 18.2

Ring 6
500 µm
S/N = 21.3
Noise in electrons

Assuming that 1 MIP creates 24000 electrons in 300 μm silicon (TDR Add.)

Example: BP Ring 4.2

ARCS single module test:
≈780 e⁻ in peak
≈1070 e⁻ in deconvolution
(Markus Axer 2003)
Mean ENC noise per APV → mean ENC noise per geometry calculated from 5-20 APVs

- Linear dependence on strip length (or capacitance)
- Difference between room temperature and cold environment: ≈5-15%
- Expectation in deconvolution mode: ≈1130-2090 e⁻
  (from ENC[e⁻] = 425 e⁻ + 64 e⁻/pF*C[pF] (A.Honma 2002, Temperature?))
HV scan on rings 1 & 2 (thin sensors)

No hysteresis effect observed!
(Humidity ≈ 4%)

⇒ Saturation at 125-155V
HV scan on ring 5 (thick sensors)

⇒ Saturation at 180-215V
Effect of CMN?

- Common mode noise increases with HV
- HV scan shows no "unomalies" in S/N
- No increase in # of fake clusters
- S/N not significantly lower in affected APV? (further study needed)
Zero suppression

The VME FED9U implements different readout modes:
- "virgin raw": raw data of all strips are stored
- "zero suppression": pedestal subtraction & cluster finding, only clusters are stored

Example:

Study on eight ring 5 modules, using data from HV scan:
Comparison CAEN PS - Delphi PS

- After end of beam, the CAEN PS (barrack type) were tested with the petals by the CAEN experts
- PS tuned for capacitive load of a TOB rod
- Both with the front and the back petal, the PS worked immediately
- 2 PSM available → one petal powered with CAEN PS, the other with Delphi PS
- Higher common mode observed in runs with the CAEN PS
- More measurements are needed!
Comparison CAEN PS - Delphi PS

Peak mode, CAEN PS connected to back petal:

- BP group 2
- BP group 1(!)
- BP group 3
- Raw - BP: CAEN; FP: Delphi
- Cms - BP: CAEN; FP: Delphi
- Raw - all Delphi
- Cms - all Delphi
- FP group 2
We had excellent support from a lot of people:

- Coordination: Patrice Siegrist
- DAQ: Laurent Mirabito
- FEC support: Frederic Drouhin, Laurent Gross, Damien Vintache
- FED support: Matthew Noy, Jonathan Fulcher et al.
- Opto support: Stefanos Dris, Jan Troska et al.
- Slow control & interlocks: Enzo Carrone, Andromachi Tsirou et al.
- TOB colleagues for loan of cables and for copying or data to Castor
- ... plus all others that I might have forgotten...

Many thanks to all of you!!!
For the first time, a complete TEC control loop was operated and tested in a particle beam
System was running stable
Good performance of the system observed
S/N=15-28 in deconvolution mode, 25-40 in peak mode
ENC noise = 800-1100 e\textsuperscript{-} in peak mode, 1200-1700 e\textsuperscript{-} in deconvolution mode

Some open questions (e.g. “dead” modules in the cold) under investigation
ORCA based analysis planned by Benedikt Hegner and Abdenour Lounis (S/N vs. strip length, efficiency, tracking, ...)

Summary & outlook