Studies of the assembled CMS tracker.

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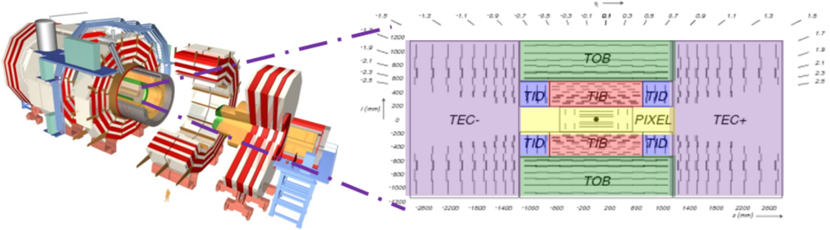
Summary

StripTracker Overview



5.4m x 2.4m
210m2 of active silicon
15148 modules
75000 APV FE chips
9.6M readout channels

Tracker Endcaps (TEC)
2x9 disks, 6400 modules
Grouped into Petals

Tracker Inner Barrel (TIB)
4 layers, 2724 modules
Grouped into Strings

Tracker Outer Barrel (TOB)
6 layers, 5208 modules
Grouped into Rods

Tracker Inner Disks (TID)
2x3 disks, 816 modules
Grouped into Strings

Largest, most complicated tracker ever built. Very well-designed but the complexity requires extreme care and investigations.

Tracker Overview: DAQ chain

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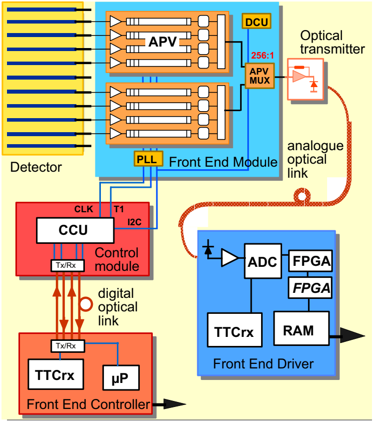
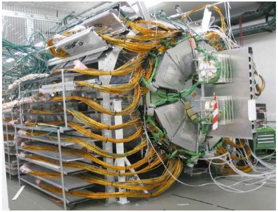
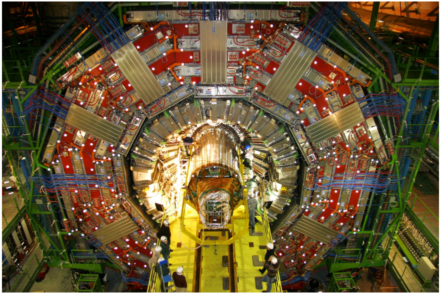


- Control Path
  - FEC (Front-End-Controller): Clock/trigger distribution and FE control
  - DOHM (Digital Opto-Hybrid Module): Optical-digital electrical conversion
  - CCU (Communication and Control Unit): distribution of electrical control signals
- Data Path
  - FE (APV) does analogue pulse shaping, local storage, optical conversion/transmission
  - FED (Front End Driver) Digitization, Data processing/Zero suppression, Clusterization, and transmission to upstream DAQ

Tracker Overview: TIF and Point 5

- Tracker subdetectors integrated at Tracker Integration Facility (TIF) Oct 06 till Jul 07
- During TIF, Tracker used in a 'Sector Test' with cosmics
  - 4.7 M cosmic triggers recorded
  - $\approx$ 25 % of the StripTracker readout using final DAQ electronics
  - Operated at range of temperatures: between +15 and -15 C

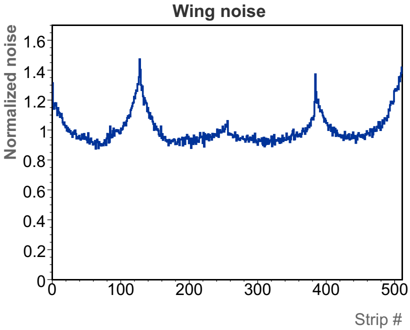


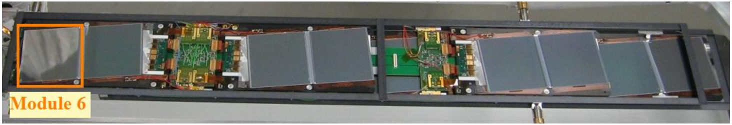


- Installation at Point 5 in December 07
  - Connections: December-March
  - Commissioning: Mid June - August
- First large-scale tests!

Wing noise: Phenomenon

- Tracker Outer Barrel (TOB) rods show unusual wing-like noise distribution.
- Large enough to affect tracker performance.
- Predominantly on module 6, layers 3 and 4 most affected.

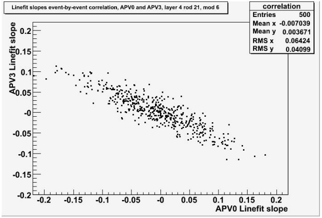


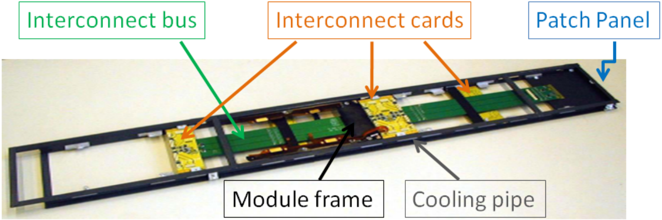


Wing noise: Investigation

TIF investigations with the assembled TOB and testbench Rods

- Sheet of copper clad Kapton between interconnect bus and sensor.
  - Wings disappear, even when sheet is not grounded.
  - Ungrounded ⇒ Not electrical, but magnetic coupling.
- Similar sheets between sensor and hybrid or fiber frame ⇒ no effect.
- Pedestal slopes on first chip and last chip of module anti-correlated.





Wing noise: Investigation

- Cause of wing noise: connection between CCU on rod and DOHM
  - Currents runs on top and bottom of interconnect bus and returns through common ground in the middle.
  - DOHM receives control signals over optical link and converts them to diff. electrical signals sent over copper link.
  - Differential signals are never perfectly in balance, so imbalance current returned to DOHM via ground.
  - Return from control circuit board to power bus.
  - Then via power cables and control power cables back to DOHM.
  - Cooling pipes also provide an adequate path for noise current.
- Loop that creates signal voltage: alum. sense lead on top, HV bias plane on bottom and capacitance of reverse biased diodes at sides.
- Reverse bias increases $\Rightarrow$ lower capacitance $\Rightarrow$ smaller current.
- Capacitance $\propto$ width strips
  $\Rightarrow$ Layer 3 and 4 (widest) have highest noise.

Wing noise: Solution

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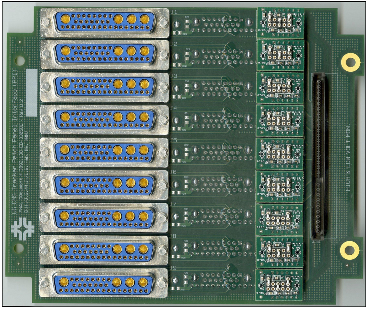
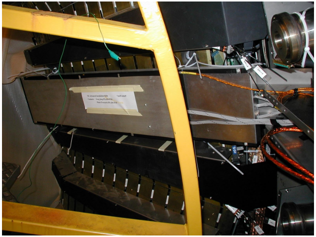
- Solution: High quality ground at common point for cooling pipes, rod power and control power.
  - At cable patch panel mounted on large cryostat of CMS magnet.
  - Designed daughtercards to address the problem.

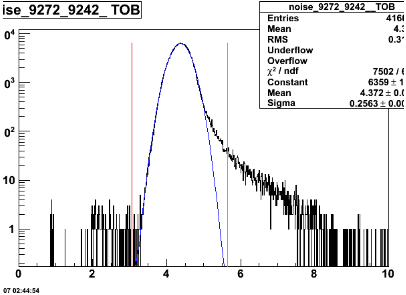




- RIB (Rod-In-a-Box):
  - TOB Rod installed at Point 5 before Tracker arrival
  - First test of wing noise in final P5 environment.
  - Daughtercard scheme proven to work.

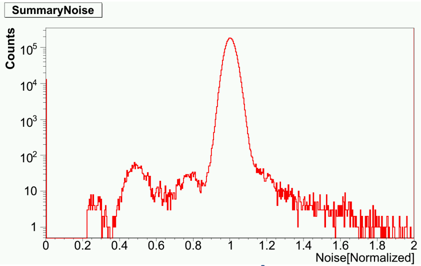
Wing noise: Results assembled tracker

Before



TIF Results

After

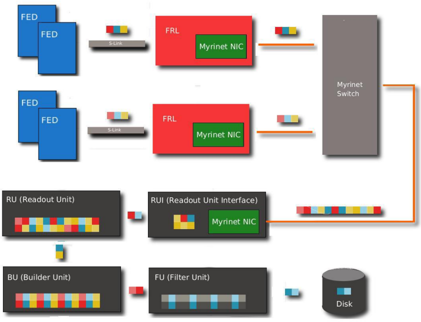


P5 Results

- Distributions look better:
  - High noise shoulder reduced by two orders of magnitude
  - 9 wingy modules left on 7 rods (out of 688 rods).
  - Point 5 results normalized (dead strips at low end)

High Rate Noise: DAQ read-out chain.

- Cosmics at TIF were low trigger rate, but CMS collisions will be at high trigger rate
- VME read-out only works for cosmics
- Needed extra hardware to test DAQ at collision rates
- No real signal, just noise and pedestals



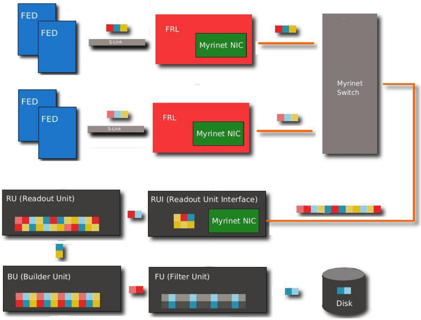
DAQ at 100 kHz very difficult with limited resources,not using full-scale CMS DAQ!

- Available bandwidth limited us to running ZeroSuppression only
  - ZeroSuppression: Only see fraction of data over specified threshold
  - Can only recognize the effect, difficult to investigate it.

High Rate Noise: DAQ Adaptations

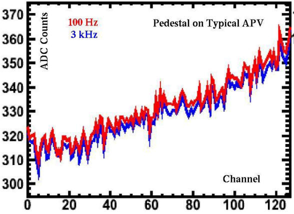
DAQ at 100 kHz very difficult with limited resources, not using full-scale CMS DAQ!

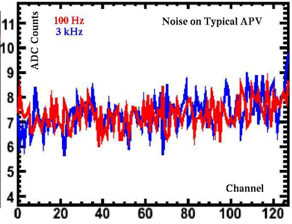
- Prescale at the PC input
  - First: no info about previous event
  - Modified to take consecutive events (determining event correlations)
- Extra Myrinet RUI to increase bandwidth
- Prescale also implemented in FED Firmware
  - Possible to run in VirginRaw-mode at high rate
    - VirginRaw: data from all channels
  - Measure high-rate pedestals and noise

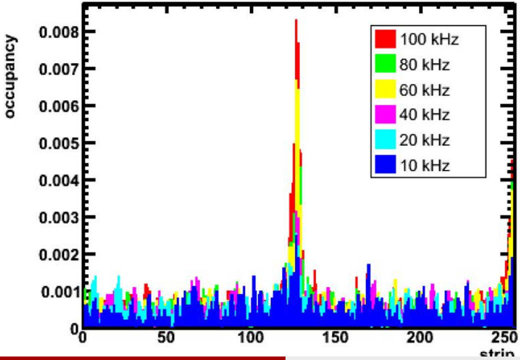


What is high-rate noise?

- Investigate noise vs. trigger rate
- At low rate, expected behavior, no differences between 100 Hz and 3 kHz

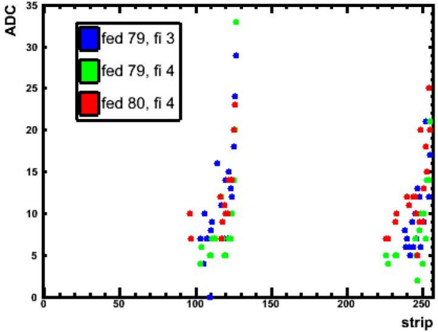






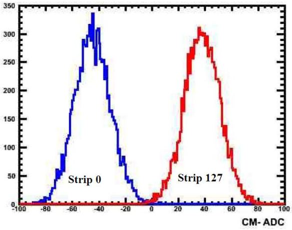
- At high rate (>30kHz) considerable growth in occupancy
- At edge strips of chip.

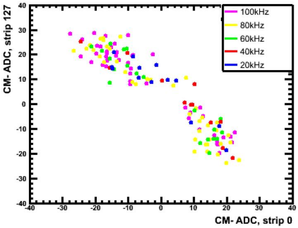
Characteristics of high-rate noise.



- On *every* APV simultaneously
- Not just some faulty components, really affects the whole tracker.

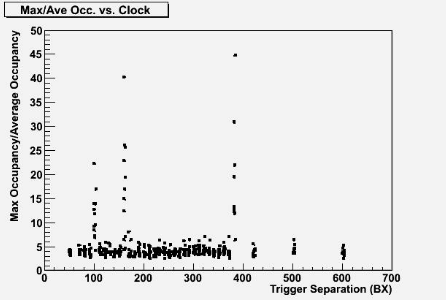
- Anti-correlation in strips 0 and 127 in common mode subtracted Pedestal





Characteristics of high-rate noise.

- Shielding has no impact at all.
- Fixed-frequency trigger shows no effect.
  - Check trigger hardware for pathological effects: none found
- Not correlated with pipeline location in APV.



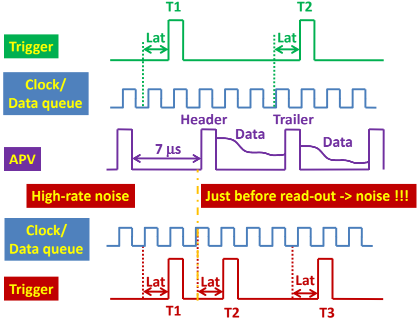
- Discovered certain trigger intervals (T2-T1) with Spikes in Maximum Occupancy (380, 160 and 100)
- Animation at `http://www.mit.edu/~khahn/interval/loopBX.gif`
- Jumps up for all fibers

How is the high-rate noise generated?

Simultaneous look at trigger and data at the APV chip with a scope caused the breakthrough.

- Trigger arrives
- Queued data buffered for read-out (latency)
- DAQ occurs just before read-out
  $\Rightarrow$ current rise due to read-out affects noise behaviour.
- $\Rightarrow$ High Rate Noise

Cross-talk between read-out and acquisition



Confirmed by simulation

How to deal with high-rate noise in tracker?

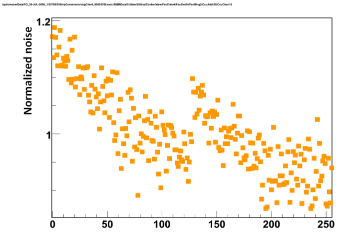
- Tracking problematic with high-rate noise:
  - With abnormally high thresholds tracking still slow and lots of ghost tracks.

Possible solutions:

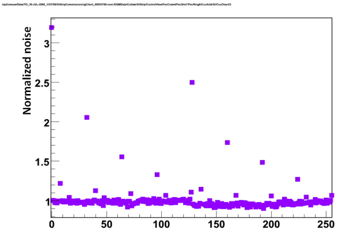
- Offline ID of high-rate noise (lose 1%)
- Change the trigger rules to reject events
  - High dead-time.
- Further down the DAQ chain: hardware veto for bunch-crossings that align with data-read-out
  - Not easy to implement in firmware and still dead-time (but less).
- Use anti-correlation to flag or reject events in FEDs
  - Rejection risky with non-optimized algorithm.
  - Difficult to implement in firmware.
  - Extra bit in FED header needed for flagging.

Commissioning Results: Still Discovering details

- At subpercent level!
- 71 modules out of 15148 show noise problems (0.5%)
- New phenomena:
  - MUXing problem on 18 modules.
  - Mysterious noise behaviour on 25 modules.
  - Show correlation with bad supply of power or control signals.



Mysterious noise



MUX noise

Conclusions

- **In general tracker performs extremely well.**
- Two problems found and understood:
  - Wing noise: in control path, solution found and implemented.
  - High Rate Noise: in read-out path, solution under development.
- Tracker Integration Facility showed its merit as a testbench.
  - Problems found and solved there.
  - In time to change final design slightly (daughtercards).
- Remain vigilant for future problems
  - Already seen some new syndromes during commissioning
  - What will happen with first pp collisions?

- Acknowledgments:
  - Wing Noise: F. Arteche, P. Harris, M. Johnson, J. Lamb, S. Tkaczyk, E. Zverev
  - High Rate Noise: K. Hahn, S. Nahn, K. Sung, S. Tkaczyk, M. Johnson, G. Hall, N. Cripps, J. Fulcher, M. Raymond, Q. Morrissey