Calibration and performance of the ATLAS Tile Calorimeter during the Run 2 of the LHC

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ATLAS Tile Calorimeter

- Hadron non-compensating sampling calorimeter with steel as radiator and scintillating tiles as active medium. 3 mm thick scintillating tiles (PSM or BASF polystyrene + dopants) oriented perpendicular to beam axis, wrapped in Tyvek paper.
- Readout via green WLS fibres (Kuraray Y11) connected to both short edges of scintillating tiles.
- 10k Hamamatsu R7877 PMTs, located in a module’s girder, collect light from the fibre bundles.
- 3 cylinders: one Long Barrel (with two readout regions LBA, LBC) and two Extended Barrels (EBA, EBC), 64 modules in a cylinder, 12 m overall length with 4.25 m outer radius.
• Long barrel $|\eta|<1.0$, extended barrel $0.8<|\eta|<1.7$, three longitudinal layers (A,BC,D), total thickness of about $7.4\lambda$.
• WLS fibre routing defines 5200 calorimeter cells: $0.1\times0.1$ $\Delta\eta\times\Delta\phi$ cell granularity ($0.2\times0.1$ for D layer cells)
• Hermetic coverage, pseudo-projective towers for first level trigger
• Dynamic range of PMTs: 10 MeV to 750 GeV
• Design resolution for jets $\Delta E/E = 50%/\sqrt{E}\oplus3\%$, linear within 2% for up to 4 TeV jets
Calorimeter in the cavern
To provide correct energy and time for data reconstruction, an elaborate chain of calibration systems is used:

- Charge injection system (CIS) to calibrate the response of the ADC
- Laser calibration system to measure the performance of the PMTs
- Cesium radioactive source system (Cs) to calibrate the full optical path from scintillating tiles and WLS fibres down to integrated current of the PMTs
- Minimum bias monitoring system (MBM) to monitor the response of the calorimeter online via integrated currents of PMTs

About 11% of 192 Tile calorimeter modules were calibrated at the test beams and the EM scale (1.05 pc/GeV) was transferred to the final detector with the help of calibration systems.
Charge injection system (CIS)

- Charges of known values, spanning the full range of ADC (0-800 pC) are injected by a 5.2 pF (±2%) or more precise 100 pF capacitor (±1%)
- The passive pulse shaper produces a pulse with a Gaussian shape (∼50ns), then the pulse is split and sent through 2 different amplifiers separated by a gain of 64
- The injection timing with respect to the ADC clock can be varied
- This allows to simulate a physics pulse from PMT and to calibrate both high and low gain ADCs (although the CIS pulse is shorter and has a leakage part)
- Also used to calibrate analog L1 calorimeter trigger
The charge of varying amplitude is injected and the slope of the response vs. injected charge gives the CIS constant for that ADC.

- Calibration is usually performed twice a week (few minutes)
- Typical uncertainty is 0.7%
- Stable within 0.04% overall in 2016
Laser system

- PMT gain drift affects the detector response and calibration
- Laser system delivers 532 nm green light via 400x 100m long clear fibres to all PMTs
- Upgraded optics box and control electronics for Run 2
- Better laser light monitoring with more diodes, rack vibration isolation
- Precision on the gain variation measurement is better than 0.5%
- New integrated 6U VME control card
Laser calibration

- Laser is used to monitor the gain and stability of the PMTs
- To cross-check problematic channels (unstable HV or bad CIS)
- To set-up and cross-check timing, provide correction for “timing jumps”
- Two calibration runs per week, special long sequence of runs (1 hour)

Map of PMT response variation during pp run of 2016

“Timing jump”
Cs system

- Powerful (10 mCi) and stable ($t_{1/2}$ of 30 years) $^{137}$Cs gamma-source (0.662 MeV) in dumb-bell shaped capsule
- Movable by flow of water inside calibration tubes through all of the 463000 of calorimeter scintillating tiles, with the speed of 30 cm/s
- PMT integrated currents readout during the source movement
- Allows to have calibration of complete optical chain and monitoring of the calorimeter response over time
Cs calibration

- Transfers EM scale from test beam measurements to all modules
- Provides pC->MeV calibration constants
- Allows to adjust PMT gain (changing high voltage) to restore calorimeter response uniformity
- Precision of the measurement is better that 0.3%
- Full calibration scans at the beginning and end of the year, monthly scans in between
- Scans are taken in parallel in 3 detector cylinders, 8 hours per scan
Integrated currents monitoring

- Integrated currents (~10 ms) from PMTs are measured and stored by minimum bias monitoring system via separate slow data path (CANbus)
- Provides additional luminosity measurements and cross-check of other luminometers
- Tracks overall calorimeter response behaviour between Cs source scans
Calibration in empty bunches

- LHC beam abort gap (~3 us) used for calibration “in parallel” with collisions
- Laser and minimum bias (currents) monitoring
- SHAFT 6U VME board with pattern memory to control, time in and arbitrate calibration pulses and calibration trigger requests
- Laser pulses at the rate of 3 Hz during physics runs
48/256 (~19%) modules were opened in the last shutdown of 2016-2017

Fixed all high priority problems and many low priority ones

Typical problems:
- Digital errors
- HV off for ¼ of module’s channels
- Cooling air leaks
- Integrator failures (FEB latch-up)
- Cold soldering in power connector
- Trigger tower low or no signal
Electronics noise stays at the level below 20 MeV for most of the cells. Pedestal and noise are measured regularly with calibration runs.

New power supplies (fLVPS), installed in long shutdown (2014), have better performance and more Gaussian noise.

Total noise is increasing with pile-up, especially for the inner layer.
Time calibration

- Initially set with splashes (high-energetic muons from beam-collimator hits at the start of data taking period, few events)
- Tuned later with muons and jets
- Resolution is better than 1 ns for $E_{\text{cell}} > 4$ GeV
- Monitored during physics data taking with laser, eventual corrections
**Detector response variation**

- Cell response is not constant in time due to the PMT gain variation and scintillator degradation, and the recovery of them.
- Tracked with calibration systems.
- Laser vs. Cs and minimum bias allows to derive irradiation effect.
- Effect is more pronounced at higher integrated luminosity.
- PMT gain can be recovered by raising the high voltage, while scintillator degradation is compensated by calibration constants.
Single particle response

- An important Tile Calorimeter characteristic is the ratio of energy to track momentum \((E/p)\) for isolated, charged hadrons in minimum bias events, is used to evaluate calorimeter uniformity and linearity during data taking.

- Data and simulation do agree, showing linearity and uniformity in detector response.

- \(dE/dx\) of minimum ionizing muons (near noise threshold) show data/MC within 3%.

\[\langle E/p \rangle = 0.67\]
Muons

- Muons from cosmic rays, beam halo and collisions are used to study in-situ the electromagnetic energy scale
- 1% response non-uniformity in $\eta$ in Long Barrel with cosmic muons
- A good energy response uniformity in all calorimeter layers
- The data/MC agreement is within 3%
Jet performance

- Good agreement in Tile cell energy distribution
- Consistent overall jet energy scale
- Jet energy resolution is below 10% at $p_T > 100$ GeV
- Constant term is within expected 3%
Luminosity measurements

- Tile Calorimeter contributes to the ATLAS luminosity measurement
  - Calibration transfer from low to high luminosity conditions
  - Long term luminosity monitoring
- Dedicated readout of the anode currents in every channel
  - Fully decoupled from trigger
  - Intrinsically independent from pileup
- Allows to cross-check other luminometers
Summary

• Tile Hadron Calorimeter is a key detector to measure jet and missing $E_T$ energy in ATLAS experiment at LHC

• To calibrate and monitor the calorimeter response a set of calibration systems is used

• Calibration systems allowed to achieve great performance of Tile Calorimeter in LHC Run 2 with better than 1% precision

• Getting ready for HL-LHC upgrade

Calorimeters (4) Fukun TANG
Two 3.79 TeV jets
Invariant mass of 8.12 TeV!

TileCal
Central dijet event with $m(jj) = 8.2$ TeV

Run: 305777
Event: 4144227629
2016-08-08 08:51:15 CEST
Thank you for your attention!