ATLAS TILE CALORIMETER CALIBRATION
AND PMT RESPONSE

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The ATLAS detector

- ATLAS is a detector installed at the LHC at CERN.
- Composed of several sub-detectors:
  - Inner detectors for the measurement of the trajectory of charged particles.
  - Calorimeters for the energy measurement
  - Muon chambers.
  - Inner detectors and muon chambers immersed in magnetic fields.
The Tile Calorimeter (TileCal) contributes to the measurement of hadrons, jets, hadronically decaying $\tau$ and missing transverse energy. TileCal can help in $\mu$ identification and measurement.

TileCal covers the central region $|\eta| < 1.7$ composed of 3 cylinders (one barrel, two extended barrels), 64 modules in each cylinder, 3 longitudinal layers (named A, B/C, D), 1 additional layer (E) covers gap and crack regions.

Sampling Calorimeter: iron plates and scintillating tiles. About 5000 cells. Energy measured with 9875 channels.
The Tile Calorimeter

- Light produced in scintillating tiles is converted into electric currents by Photo Multiplier Tubes (PMTs).
- The signal from the PMTs is shaped and amplified using two gains (with a ratio of 1:64) with 10-bit ADC digitizers. Signals are sampled and digitized at 40MHz.
- If event passes Level 1 Trigger (40 kHz) → digitized signals are collected and processed by the Read-Out Drivers.
- Integrator measures the integrated current from the PMTs.
TileCal PMTs

- PMTs are customised 8-stage Hamamatsu model R5900/R7877.
- PMTs were qualified 15 years ago using dedicated test benches.
- Intrinsic properties were measured before installation:
  - Nominal High Voltage, $HV_{\text{nom}}$
  - $\text{Gain}(HV_{\text{nom}}) = 10^5$
  - Quantum efficiency.
  - Amplification: $\beta$
    
    $\text{Gain}(HV) \propto HV^\beta$
  - PMTs deployed taking into account their properties.
  - High Voltage set in order to equalise PMTs response to Cesium source.

$5 \text{ Gain}(HV) \propto HV^5$
Energy Calibration in TileCal

- Relation between deposited energy and channel signal has to be known and monitored.
- It can be affected by HV instability, PMTs stress, read-out failures, optic ageing...

**Cesium System:** calibration of the optical components and PMTs.

**Laser System:** calibration of photomultiplier gains and readout electronics.

**Charge Injection system (CIS):** calibration of the readout electronics.

**Integrated** currents from **Minimum Bias** event monitor optical components, PMTs and beam conditions.
Energy Calibration in TileCal

- Relation between deposited energy and channel signal has to be known and monitored.
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The Charge Injection System

- CIS system injects a signal of known charge and measures the electronic response.
- Calibration checks full ADC range: 2 gains for each PMT.
- CIS calibration is taken twice a week.
- Aim is to measure the pC/ADC conversion factor and correct for non-linearities in low-gain.

Precision on single channel response < 0.7%
Constant in time at the level of 0.03%
The Cesium System

- A moveable radioactive source of $^{137}\text{Cs}$ passes through the calorimeter body.
- The source emits $\gamma$-rays with well-known energy (662 keV) and activity.
- Electronic read-out is not the same as for physics, treated by an integrator circuit.
- Check the quality of the optical component response, equalize the response of all read-out cells and monitor the cell electromagnetic scale in time.

Precision on single channel response better than 0.5%
Integrator System

- Integrated PMT signals over a large time window (\(\sim 10 \, \mu s\)).
- Integrator system monitors and measures the response to the source during Cesium scans.
- During physics runs, measure the detector response to the minimum bias events, a way to monitor the instantaneous luminosity in ATLAS.
- Use of the response stability to produce calibration constants in absence of Cesium calibration.

Stability of each channel better than 0.05%
Average stability better than 0.01%
The Laser System

- Send light pulses to the PMTs with a wavelength close to the one of physical signals.
- Controlled amount of light sent to the PMTs through 400 fibres.
- Laser pulses are also sent to TileCal during empty bunch crossings (1-2Hz frequency).
- The relative gain variation is measured between two Cesium scans.

Precision on single channel response better than 0.5%
Laser system measures the gain variation during data taking.

The maximal drift is observed in E and A cells which are the cells with highest energy deposits.

This behaviour is confirmed by Cesium and Minimum Bias measurements: expected and attributed to the PMTs.
Spread of Gain variation versus luminosity

- Gain variation correlated to luminosity.
- Different channel to channel behaviour → Spread larger than precision of measurements.
- Gain variation can be compared to intrinsic properties of PMTs.
Effect of the amplification

- Average Gain variation of PMTs in A Cells as a function of $\beta$ ($\text{Gain(HV)} \propto \text{HV}^\beta$).
- Gain variation measured in 2018 at the end of proton data taking.
- No dependence to the $\beta$ amplification factor is observed within the tested range.
Effect of the Quantum efficiency

- Average of relative variation of A cells as a function of the Quantum Efficiency of the PMTs.
- PMT stress that induces the gain variation is more important when Quantum Efficiency is high.
- Trend is independent from the HV bias → small HV changes does not change the relative gain variation.

\[ \text{trend} = -0.36 \pm 0.11 \]
Effect of the Quantum efficiency

- Average gain variation of A13 cells versus time.
- Comparing two family of PMTs: High and low Quantum Efficiency.
- Systematic difference induced by Quantum Efficiency, scales with luminosity.
- Similar effect observed on other TileCal cells.
Summary

* The Tile calorimeter is a sub-detector of ATLAS at LHC, the control of its energy scale is essential to measure the energy of jets and the missing energy.

* During LHC Run 2, several calibration systems were used in conjunction: Cesium, LASER, Charge Injection and Integrator systems.

* The stability of the absolute energy scale at the cell level was maintained to better than 1% during LHC data-taking.

* This performance is possible through regular calibration of each single channel.

* Better understanding of channels behaviour, optics, Photomultiplier Tubes... Inputs for the upgrade

* Performances of TileCal also monitored with cosmic muons, charged hadrons and data quality analysis.

* cf. talk by P. Klimek
Additional Material
Gain variations measured with Laser

Gain variation measured with the laser system during data taking, from May to Octobre 2016