Performance of the ATLAS Tile Calorimeter in pp collisions at the LHC

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on behalf of the ATLAS Collaboration
CALOR2014 - Giessen (Germany)
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The ATLAS Tile Calorimeter

Barrel hadronic calorimeter of the ATLAS detector (-1.7 < \( \eta \) < 1.7)

- long barrel (LB): -1.0 < \( \eta \) < 1.0
- two extended barrels (EB): 1.0 < |\( \eta \)| < 1.7
- 4 x 64 wedges in \( \phi \) (\( \Delta \phi = 0.1 \))
- three longitudinal layers, total thickness \( \sim 7\lambda \)
- pseudo-projective towers for first level trigger

Sampling calorimeter: steel + plastic scintillator

Designed performance requirements

- Jet energy resolution: \( \sigma(E)/E = 50\% / \sqrt{E(\text{GeV})} \oplus 3\% \)
- Jet energy linearity: 1-2% up to \( \sim 4\text{ TeV} \)
- Accurate missing transverse energy measurement requires full-coverage hadronic calorimeter
2012 pp data-taking

\[ \sqrt{s} = 8 \text{ TeV} \]

**ATLAS Preliminary**

- **LHC Delivered**
- **ATLAS Recorded**
- **Good for Physics**

Total Delivered: 22.8 fb\(^{-1}\)
Total Recorded: 21.3 fb\(^{-1}\)
Good for Physics: 20.3 fb\(^{-1}\)
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### ATLAS p-p run: April-December 2012

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**All good for physics: 95.5%**

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at \( \sqrt{s}=8 \text{ TeV} \) between April 4^{th} and December 6^{th} (in %) – corresponding to 21.3 fb^{-1} of recorded data.
### Main sources of inefficiencies for Tile

- timing shift after re-start
- $\geq 4$ consecutive modules off, eg. due to
  - trips of 200V power supplies
  - blockage of read-out-links

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Tile Data Quality (DQ)

High data-quality efficiency (99.6% in 2012) thanks to an effective monitoring system:

- **Data Quality Monitoring Framework (DQMF)** collects information about the quality of the data and performs quality checks
- problems **flagged automatically** + warning/error messages:
  → visual inspection by shifter and immediate action during data-taking
- **automatic recovery procedures** implemented in the Data Acquisition System (DAQ) and Detector Control System (DCS)
  → minimize the need for manual interventions and the reaction time
Problems with the LVPS in the front-end electronics during Run1:

- failures of LVPS (full module off)
- frequent trips of LVPS
Low Voltage Power Supplies (LVPS)

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Despite this, achieved **high DQ efficiency**!

- during LHC run automatic recovery procedures to power-on the LVPS, configure front-end electronics and resume data-taking
- energy interpolated from neighboring module
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**Today:** upgraded power supplies

- 40 new LVPS installed in 2012: just one trip
- benefit from lower electronic noise
- full production of new LVPS was installed in 2013 during the shutdown
Detector Status - end of LHC Run 1

Status at the end of Run 1 (Feb. 2013)

- ~ 3% of masked cells
- 6 modules off with bad LVPS
- energy for masked cells is interpolated from neighboring cells
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- The EM scale is restored with Cs-137 and laser calibration systems
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Most bad channels are recovered during maintenance periods, when front-end electronics are accessible.

During LS1 (2013-2014): major maintenance activities to ensure high performance, high quality and robust operations in Run2.
Signal properties reconstructed with **Optimal Filtering** from 7 digitized samples spaced by 25 ns:

- extract **amplitude** \((A)\) and **time** \((\tau)\)

\[
A = \sum_{i=1}^{n=7} a_i S_i, \quad \tau = \frac{1}{A} \sum_{i=1}^{n=7} b_i S_i,
\]

- energy proportional to \(A\)
- weights defined by pulse shape and noise autocorrelation matrix
- requires **initial knowledge of signal phase**

**Difference between online and offline energy reconstruction:**

**bias due to phase** of the signal can be **corrected online**
Synchronization of all 10 000 Tile channels performed with laser calibration, cosmic events, single beam events and collision events.

**ATLAS Preliminary Tile Calorimeter**

$\sqrt{s} = 7$ TeV, 50 ns, 2011

Cell energy [GeV]

<table>
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<tr>
<th></th>
<th>Muons</th>
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<th>Jets</th>
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<tr>
<td>$p_0$</td>
<td>$0.5326 \pm 0.0120$</td>
<td></td>
<td>$0.3668 \pm 0.0003$</td>
</tr>
<tr>
<td>$p_1$</td>
<td>$1.3310 \pm 0.0141$</td>
<td></td>
<td>$1.6017 \pm 0.0005$</td>
</tr>
<tr>
<td>$p_2$</td>
<td>$0.7444 \pm 0.0172$</td>
<td></td>
<td>$1.1156 \pm 0.0006$</td>
</tr>
</tbody>
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Cell time resolution:

- 1.15-1.3 ns at $E \sim 2$ GeV (muons)
- 0.5-0.6 ns at $E \sim 20$ GeV (jets)
Electronic noise measured in pedestal calibration runs without colliding beams.

Noise affected by the Low Voltage Power Supplies:

- with old LVPS: deviation from single Gaussian due to instabilities in the LVPS
- with new LVPS: lower noise and reduced tails
Inclusive energy response at EM scale in collisions at $\sqrt{s} = 7$ TeV

- cut $E_T > 500$ MeV to probe well into the range of energies deposited by particles in min. bias
- response uniform in $\phi$
- follows the shape of MC in $\eta$
Single hadron response

In-situ method to probe the calorimeter response using energy deposited by isolated charged particles that shower in TileCal:

- momentum \( (p) \) measured in the inner detector with high accuracy
- measure energy \( (E) \) of topological clusters around the track extrapolated to the calorimeter
- response is characterized by \( E/p \)

\begin{align*}
\text{ATLAS Preliminary} \\
\text{Tile Calorimeter} \\
\sqrt{s} = 7 \text{ TeV} \\
\int L \, dt = 4.7 \text{ fb}^{-1}
\end{align*}
Conclusions

• The Tile Calorimeter has performed very well during the LHC Run1

• Achieved high data-quality efficiency of 99.6% despite the frequent problems with the LVPS

• 3% of masked cells by the end of Run1 in 2013 (was >5% in 2011)

• Improvements for Run2 are underway: upgraded LVPS and consolidations to guarantee robust operations and high performance

• Achieved time synchronization and time resolution below 1ns

• Studied the response with minimum bias data, single hadrons: good agreement between data/MC

• More information on calorimeter calibration and simulation/validation in the talks from Djamel Boumediene and Jana Faltova
EXTRA
Front-end electronics

- PMT signals are shaped and amplified in two gains (relative ratio 1:64)
- analog tower sums provided for the level one trigger
- both gains are sampled at 40 MHz using 10-bit ADCs
- digitized samples stored in pipeline memories
- upon level-1 accept, data from one of the gains are selected, formatted and sent to the back-end electronics via optical fibers
Detector maintenance

Maintenance activities aim to ensure high performance, high quality and robust operations during Run2

Maintenance activities during the LHC shutdown (2013-2014):

- replacement of all LVPS with new ones
- fix problems identified by experts in physics and calibration data
- consolidations to prevent data loss and corruption

Thorough test and data-quality checks are performed to certify the consolidations

Current status:

- all new LVPS installed
- > 90% of the detector consolidated
- some modules to be re-opened
Timing

Synchronization of all 10 000 Tile channels performed with laser calibration, cosmic events, single beam events and collision events.

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Time distribution for cells belonging to topological clusters of jets with pt > 20 GeV

Cell time resolution:
1.15-1.3 ns at E ~ 2 GeV (muons)
0.5-0.6 ns at E~20 GeV (jets)
Pile-up noise

“Pile-up” refers to the effect of additional pp collisions in the same or neighboring bunch crossings.

Cell noise depends on both electronic and pile-up noise.

Good noise description important for topological clustering algorithms to distinguish between signal and noise.

Pile-up noise measured in pp collisions using zero bias trigger.

Noise level depends on layer:

- higher pile-up noise in layer A (closer to the beam pipe) than in layers BC and D
- highest noise in gap/crack cells
Response to single muon

EM scale and cell-to-cell uniformity is validated using muons from cosmic data. Response is probed estimating energy loss per unit length of detector material (dE/dx)

- **Good cell-to-cell uniformity** within a longitudinal layer
- Differences up to **4%** between layers
- Successfully validate propagation of EM scale from testbeam to ATLAS

Muon signal and noise well separated (S/N=29)
Jet and Missing $E_T$ Performance

Good performance of jet and missing transverse energy resolution