ATLAS Tile Calorimeter Signal Reconstruction and Performance

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**ATLAS TileCal**

- TileCal is the ATLAS central hadronic calorimeter detector:
  - Sampling calorimeter: scintillator as active material (tile scintillators) and iron as absorbing material (iron plates).
  - Cover wide range of energy from MIP particles to TeV hadronic shower in $|\text{eta}| < 1.7$
The role of TileCal

- Important system in jet measurements → critical for QCD physics results.

![Graph showing inclusive jet multiplicity and comparison with Monte Carlo predictions](image)

TileCal signal processing sequence

Sampling the signal (7 samples) by digitizer

Reconstruct the signal amplitude, phase and pedestal from 7 ADC samples (at real time and offline)

Reconstruction algorithms: optimal filter (OF2, used in Run 1), match filter (MF, new development)
Signal reconstruction performance

- OF2 signal is broader near noise dominant regions (below ~200 MeV)
- Amplitude bias for out-of-time pile-up signals
Calibration systems

Figure: $E_{PMT} = \text{Amplitude} \times C_{ADC \rightarrow pC} \times \xi_{\text{laser}} \times \xi_{\text{Cs}} \times C_{pC \rightarrow \text{MeV}}$

- Derive the calibration constants and monitor the system stability
- Three calibration systems:
  - Cesium: using Cesium-137 radiation source to maintain same cell responses.
  - Laser: monitor PMT gain and timing of channels
  - Charge injection: monitor electronic stability, ADC to pC conversion.
Average cell energy and single particle response

ATLAS-PLOT-TILECAL-2011-001

- EM scale: the scale to give correct energy of EM shower
- Good agreement between data and simulation
TileCal noise

- Combination of electronic noise and pile-up noise
  - Pile-up noise caused by energy fluctuation due to pile-up condition → increase with pileup

\[ \sigma_{el\text{-}noise+pile\text{-}up} = \sqrt{\sigma_{el\text{-}noise}^2 + \sigma_{pile\text{-}up}^2} \]

### Table 7

<table>
<thead>
<tr>
<th>Sample</th>
<th>No. of events</th>
<th>( &lt;\mu&gt; )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period F8</td>
<td>2011 Data, s = 7 TeV</td>
<td>0.06</td>
</tr>
<tr>
<td>Period G8</td>
<td>data, s = 7 TeV, 46.7-96.8 physics ZeroBias4recon4ESD4f9-7</td>
<td>-9.9</td>
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<tr>
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<tr>
<td>Period M0</td>
<td>data, s = 7 TeV, 46.7-96.8 physics ZeroBias4recon4ESD4f079</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Monte Carlo mc valid 76, 8994 singlepart mu 76, 8994 e-.6 s 7998 r 9609

Data 2011 \( s = 7 \) TeV

- \( p_T \) value
- Jet kinematics
- EM+JES calibration

### Figure 8

- ATLAS Preliminary Tile Calorimeter
- Pedestal (HG)
  - with old LVPS (v.6)
  - with new LVPS (v.7)
- LBA47 ch 47 (pmt 46) Energy [MeV]
- RMS = 25.667 MeV
- RMS = 17.927 MeV

Looking into future

- The electronic is aging requiring maintenance and consolidation during phase-0 and phase-1
- Major upgrade during phase-2 to prepare for LHC high luminosity runs
  - Improve the reliability of the system (independent configurations and redundancy systems)
  - Upgrade the front-end electronics for better handling signal at high pile-up.
  - New readout electronics: signal samples will be sent out of detector at 40 MHz speed for further processing

![Diagram of signal processing and digitization](image-url)
Conclusions

- The basic performances of ATLAS TileCal detector are presented: signal reconstruction, energy response, noise.
  - Good performances in LHC Run 1
  - Increasing pile-up affects the TileCal signal reconstruction in high rapidity cells.

- Preparations for TileCal upgrade in phase-2 are ongoing with activities to develop and test innovative solutions for TileCal electronics and mechanical.
  - A tile demonstrator drawer (container of near detector TileCal electronic) is being built and will operate during Run 2 (2015) to study the performance of upgrade electronics.
Backups
- 64 divisions to cover azimuthal radius $\rightarrow$ 4x64=256 modules
- Each module is segmented in three layer of double read out cells (23 cells in LB modules and 18 cells in EB modules)
**Signal reconstruction**

- Reconstruct the amplitude from 7 samples ($s_k$) using a set of weights ($a_k$)
  $$\hat{A} = \sum_{k=0}^{N-1} a_k s_k$$

- In OF2, the weights is found by
  - Requiring that the amplitude is phase and pedestal independent
    $$\sum_{k=0}^{N-1} a_k g_k = 1 \quad \sum_{k=0}^{N-1} a_k g'_k = 0 \quad \sum_{k=0}^{N-1} a_k = 0$$
  - Minimizing the variant of amplitude due to noise with above constraint
  $$var(\hat{A}_{OF}) = a^T C a$$

- In MF: Signal detection and amplitude estimator based on hypothesis testing
  $$\hat{A}_{MF} = \frac{(s - ped)^T C^{-1} g}{g^T C^{-1} g}$$
Timing

- Good timing performance: low bias and resolution less than 1 ns
On-line and off-line time and energy reconstruction

- Non-iteration OF implemented in DSP fails to reconstruct late and early signals
- Iterative OF algorithm is intensive → available at off-line analysis
Data quality for 2012: 99.6%

Data is rejected if more than 4 consecutive modules are not recorded.

DQ inefficiency is greatly reduced by automatic recovery of Read-Out Link removal.

Loss from timing shifts was corrected in offline software.