Performance and calibration of the ATLAS Tile Calorimeter

Tomas Davidek (Charles University),
on behalf of the ATLAS Collaboration
Tile Calorimeter (1)

- Hadronic sampling calorimeter (steel/scintillator) in ATLAS covering $|\eta| < 1.7$
- Measures energy & direction of jets, taus, missing $E_T$, assists in muon identification and provides input to L1-trigger
- Central Long Barrel and two Extended Barrels
- Signal collection & processing
  - charged particles produce scintillating light absorbed in WLS fibres, re-emitted and transmitted to PMTs
  - PMT signal shaped, amplified (two gains, 64:1) and digitized @ 40 MHz frequency with 10-bit ADCs
  - data sent off-detector for further processing upon L1-trigger accept
  - amplitude $A$ and time $t_0$ reconstructed with Optimal Filtering algorithm
  - most cells readout with 2 PMTs (one on each side), ~5000 cells in total
Tile Calorimeter (2)

- Pseudo-projective cell geometry
  - 3 radial layers, $\Delta \eta \times \Delta \phi = 0.1 \times 0.1$ (0.2 $\times$ 0.1 in the outermost layer)
Overview of the calibration systems

• Three dedicated systems cover different parts of the readout chain
  • Cs – optics, PMT $\rightarrow C_{Cs}$
  • Laser – PMT, fast readout electronics $\rightarrow C_{las}$
  • Charge Injection System (CIS) – fast readout electronics $\rightarrow C_{CIS}$

• Energy reconstructed at the EM scale

$$E[GeV] = \frac{A[ADC\ counts]}{C_{Cs} \cdot C_{las} \cdot C_{CIS}[ADC\ counts/pC] \cdot C_{TB}[pC/GeV]}$$

• $C_{TB}$ determined at dedicated beam tests
Cesium system

- Radioactive $^{137}\text{Cs}$ source hydraulically driven through all calorimeter tiles
  - calibrates the whole readout chain (optics, PMTs)
  - readout through integrator system ($\tau = 10-20$ ms)
  - allows for PMT response equalisation through PMT HV settings at high precision (~0.3%)
- Deviations of the response caused by optics degradation (due to radiation dose) and PMT gain variations
  - largest drift during Run-2 period observed in the innermost radial layer, closest to the interaction point
Laser system

- Controlled short laser pulses sent simultaneously to all PMTs, used to monitor PMT gain and to measure possible PMT non-linearity
  - PMT response determined w.r.t. last Cesium scan
  - standalone laser runs (performed daily, constants updated ~weekly) as well as laser-in-gap events (collected during collision runs in LHC empty bunches, used also for time calibration monitoring)
  - precision of the system at the level of 0.5%
- Largest drifts observed for PMTs reading the innermost cells
  - down-drift during collisions
  - recovery during beam-off periods
Charge Injection and Minimum Bias systems

- CIS injects well-defined charge into fast readout electronics, spanning the whole dynamic range in both gains
  - determines the amplitude [ADC counts] to charge [pC] conversion and electronics non-linearities, also used to calibrate analog L1 trigger
  - precision ~0.7%, very good stability in time
- Minimum bias system measures response to soft inelastic interactions
  - shares readout path with Cs, integrates signal over ~ 10-20 ms
  - also calibrates special cells (E-cells and Minimum Bias Trigger Scintillators) where Cs is not available
  - signal proportional to instantaneous luminosity → used in luminosity measurements
Combined calibration

- Combination of individual systems allows to disentangle between various effects
  - Cs and minimum bias results are in good agreement
  - difference between laser and Cs (minimum bias) is due to tile and WLS fibre degradation
  - ~10% optics degradation seen in cell A13 during Run 2 (most irradiated standard cell)
Time calibration & monitoring

- Measured time $t_0$ is the phase of signal pulse w.r.t. readout window centre
- Goal: particles from IP travelling at speed of light give $t_0 \sim 0$, important for time-of-flight measurements and Optimal Filtering energy reconstruction
- Calibration performed with splash events and initial pp collisions
- Timing is monitored with laser-in-gap and pp collision data. Examples of problems during Run 2:
  - intermittent events with +25 ns offset
  - sudden changes in time calibration
  These problems are corrected in (re)processed data
Isolated muons

- **Check of the EM scale and uniformity with isolated muons from W decay**
  - momentum range 20-80 GeV (ionization dominates, $\Delta E$ scales with path length $\Delta x$)
  - evaluate truncated mean $\Delta E/\Delta x$ (remove 1% of events with highest values) in every cell
  - look at $R = (\Delta E/\Delta x)_{\text{data}}/(\Delta E/\Delta x)_{\text{MC}}$ to avoid residual non-linearity of the truncated mean

- **Results**
  - cell uniformity 2.4% across azimuth, consistent between different cell types
  - all layers consistent with $R=1$ within 2%
  - comparison of 2015+2016 vs 2017 vs 2018 shows very good stability in time, at the level of few percents
Single isolated hadrons

- Isolated tracks with EM calorimeter MIP-like signal
  - calorimeter clusters ($\Delta R=0.2$) associated to tracks, cluster energy measured in TileCal, track momentum in Inner Detector
  - muons and neutral particles removed with further calorimeter cuts
- Compare $E/p$ for data and MC
  - non-compesated calorimeter $\rightarrow E/p < 1$
  - good agreement data/MC for low pile-up ($\langle \mu \rangle \approx 2$)
  - for higher pile-up ($\langle \mu \rangle \approx 15$) differences $\sim 3\%$ due to pile-up mismodelling
  - systematic uncertainties:
    - residual contribution from neutral particles ($\sim 1\%$)
    - upstream dead material for $|\eta| > 0.7$ (few %)
Timing performance

- Measured with jets using associated cells
- Mean cell time is very stable across Run 2 period
  - slightly depends on the deposited energy due to neutrons/slow hadronic component of the shower
- Time resolution
  - affected by pile-up at small energies, best in 2015 (lowest pile-up)
  - benefits from improved calibration procedure at higher energies since 2016
Tile-Muon trigger

- Special Tile-Muon trigger improves the background rejection in L1 trigger (new in Run 2)
  - coincidence of the 3rd (outermost) TileCal layer and TGC in the region $1.0 < |\eta| < 1.3$
- Total rate is reduced by 6%, but significantly in the corresponding region
- Inefficiency of 2.5% measured with $Z \rightarrow \mu\mu$, compatible with thin gaps between Tile modules
Conclusions

- All Tile Calorimeter calibration systems have precision below 1%, combined energy calibration guarantees very good response stability
- Good stability of timing due to extensive monitoring
- Tile Calorimeter performance assessed with muons, single hadrons and jets
  - verified EM scale settings and the response uniformity
  - time resolution measured and understood
  - new Tile-muon trigger improved the first level trigger
- In parallel working on upgrade for HL-LHC, see the dedicated talk on Thursday morning
BACKUP