Energy response of ATLAS Tile Calorimeter to isolated muons

Tadeas Petru [1] on behalf of the ATLAS Collaboration

[1]Charles University, Czech Republic

Introduction

ATLAS Tile Calorimeter

- The Tile Calorimeter (TileCal) is a hadronic calorimeter of the ATLAS detector
- TileCal is a sampling calorimeter consisting of scintillating tiles and steel plates
- Light produced in the scintillating tiles is collected by wavelength-shifting (WLS) fibres and transported to the photomultiplier tubes (PMTs)
- The signal is shaped and digitised in the front-end readout electronics

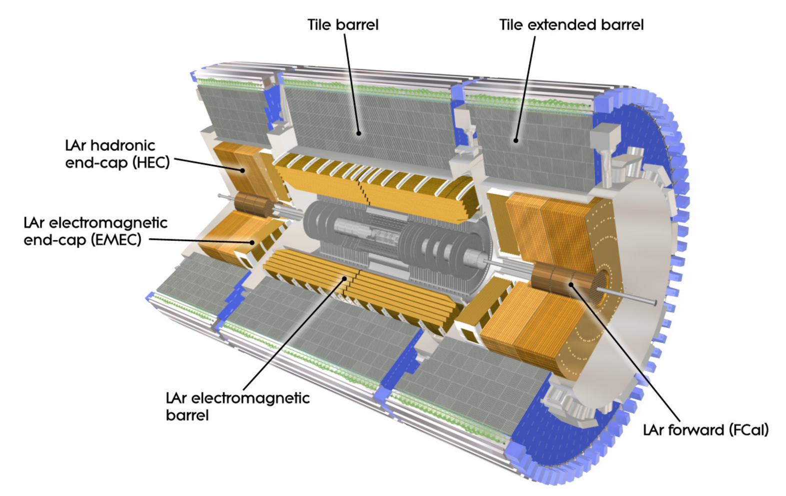

Figure 1. Cut-away view of the ATLAS calorimeter system

- The amplitude of the signal is then reconstructed in units of ADC counts
- TileCal is divided into one central long barrel (LB) and two extended barrels (EB)
- Each barrel is composed of 64 azimuthal modules
- The WLS fibres from individual tiles are grouped together to a given PMT creating a readout cell geometry
- In the longitudinal direction the readout cells are divided into three layers in LB and three layers in EB

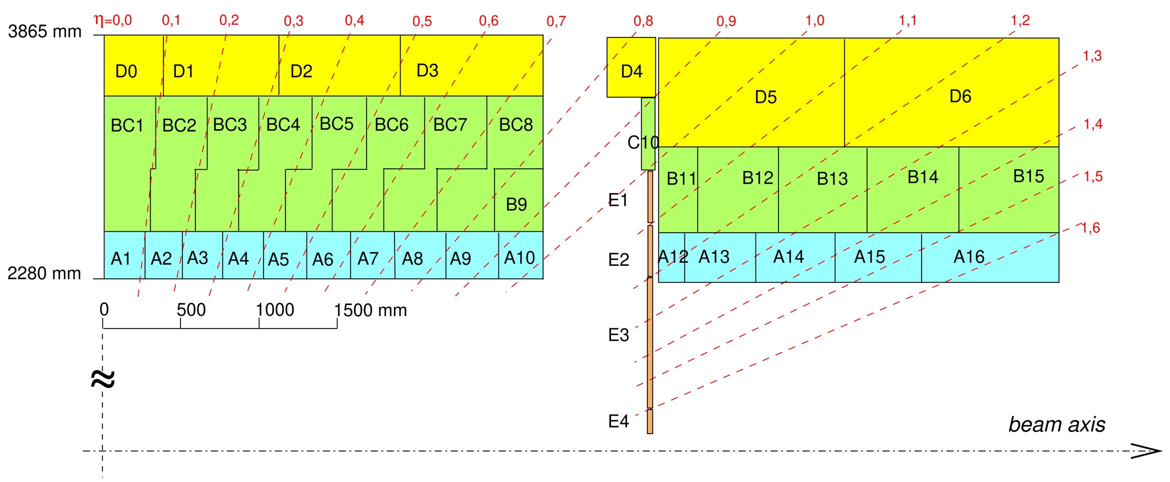

Figure 2. TileCal segmentation for LB (left) and EB (right) in Run 3

Calibration

- Several calibration systems are installed to calibrate each step of the TileCal cell energy reconstruction
- The caesium system allows the equalisation of the cells' response
- The laser calibration system measures the variation in the response of the PMTs
- The charge injection system probes the calibration of the front-end electronics (ADC counts to pC units)
- Integrator readout of minimum-bias (MB) measures the variations of the TileCal response in MB pp events
- The energy in GeV is obtained as:

$$E[\mathrm{GeV}] = \frac{A[\mathrm{ADC}]}{C_{ADC\to pC} \times C_{pC\to GeV} \times C_{Cs} \times C_{MB} \times C_{Las}} \quad (1)$$

- Conversion from pC to GeV is determined by measuring the response of the calorimeter to electrons in a test beam campaign

Analysis with collision muons

- The performance of the reconstruction and calibration methods mentioned above is verified by several dedicated studies (see the Run 2 operation and performance paper [arXiv:2401.16034])
- The goal of this study is to determine the uniformity and stability of the ATLAS TileCal cells' response and the EM scale setting with the use of isolated muons produced in $W \to \mu\nu$ decays from pp collisions
- As low energy muons are minimum ionizing particles they can traverse the calorimeter without losing much of their initial energy, which makes them ideal for probing the TileCal's response
- This analysis is a continuation of a study that was done in Run 2 [arXiv:2401.16034] and Run 1 [Eur. Phys. J. C78 (2018) 987]

- Events are selected with the lowest unprescaled single muon trigger
- We then apply several event cut-flow criteria to select isolated muons originating from the $W \to \mu\nu$ decay and to suppress background processes
- Only muons in a tight momentum range of 20 to 80 GeV are accepted to ensure their energy loss is predominantly via ionization process

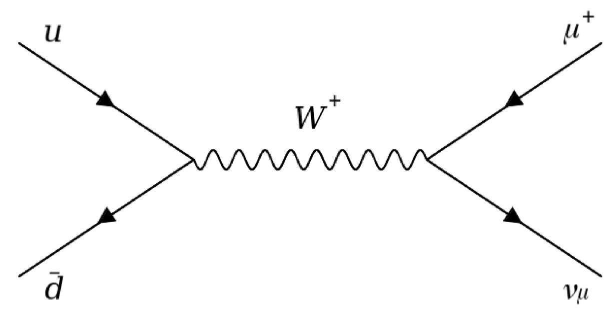

Figure 3. Feynman diagram of a dominant W^+ boson production in pp collisions and its leptonic decay to a muon and a neutrino (similiar diagram for W^- with the charges being flipped)

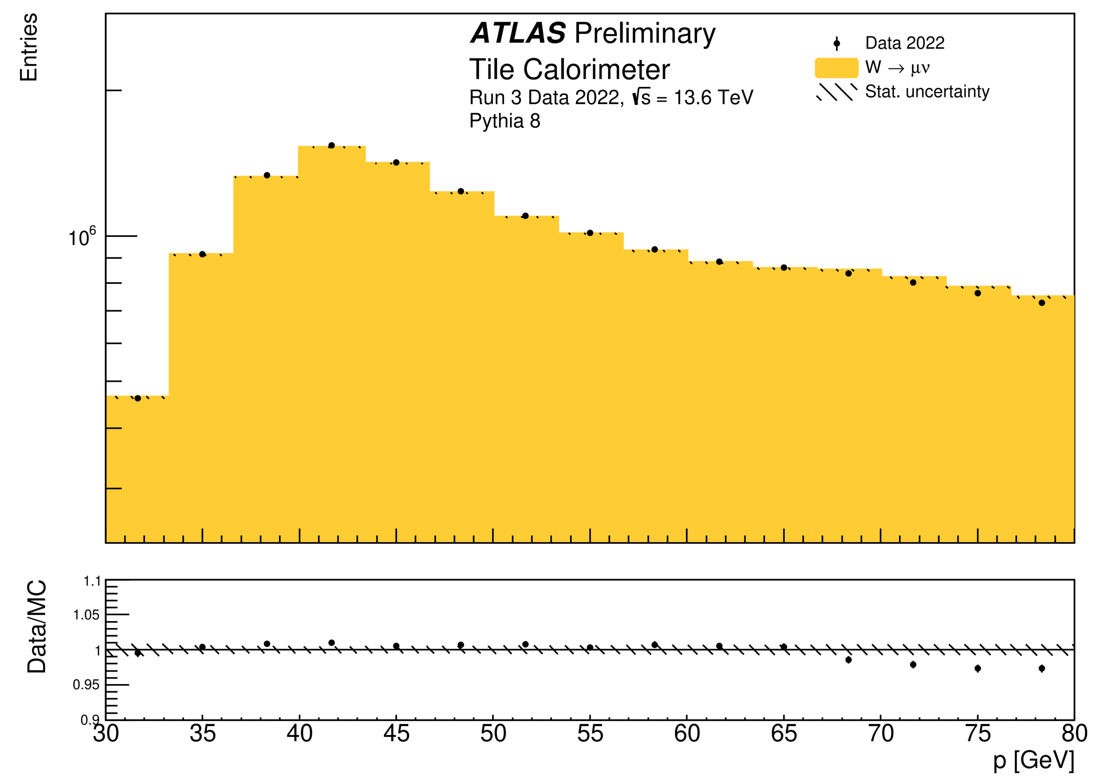

Figure 4. Momentum distribution of muons originating from the $W \to \mu\nu$ decay process

TileCal response

- The response is quantified by the truncated mean of the $\Delta E/\Delta x$ (deposited energy per path length) distribution for both data and MC, calculating the double ratio

$$R = \frac{\langle \Delta E/\Delta x \rangle^{Data}_{F=1\%}}{\langle \Delta E/\Delta x \rangle^{MC}_{F=1\%}} \quad (2)$$

- Taking the ratio between experimental and simulated data cancels out various sources of systematic uncertainties

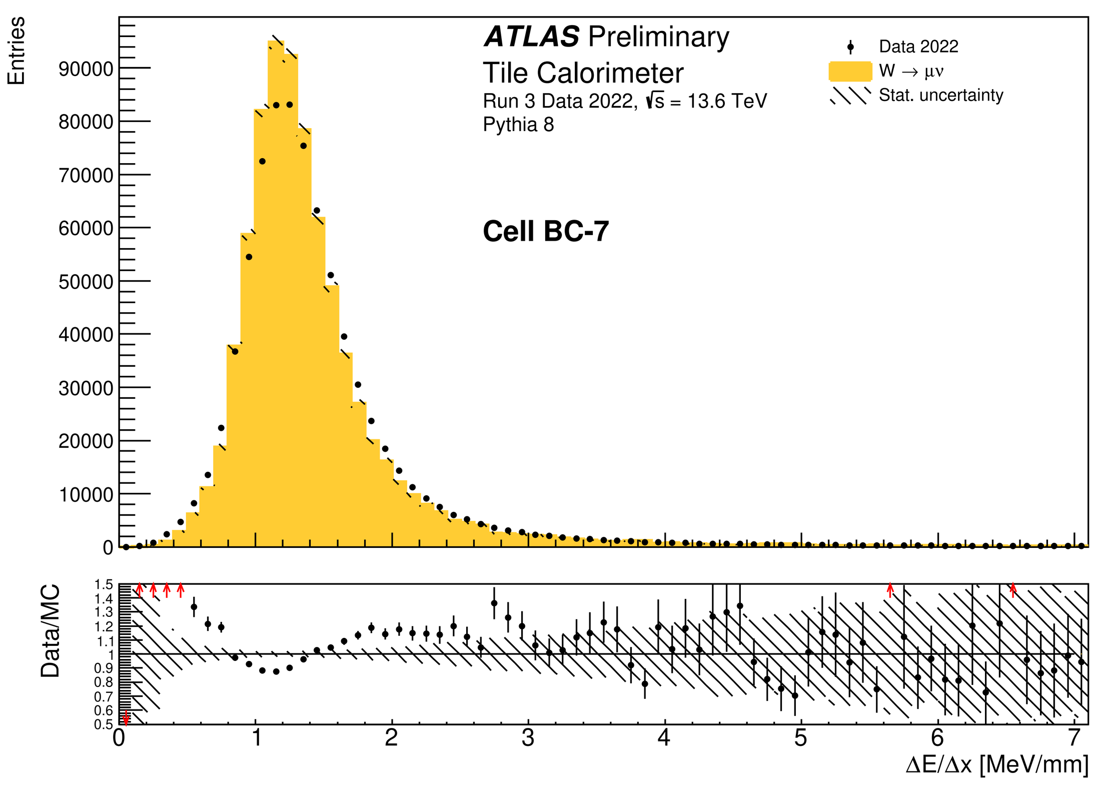

Figure 5. The $\Delta E/\Delta x$ (deposited energy per path length) spectrum in cell BC-7 of the ATLAS Tile Calorimeter (TileCal)

Cell response uniformity

- For each cell of the TileCal we plot the double ratio distribution over the 64 azimuthal modules and fit it with the Gaussian likelihood function:

$$\mathcal{L} = \prod_{m=1}^{64} \frac{1}{\sqrt{2\pi}\sqrt{\sigma_m^2 + \hat{s}^2}} \exp\left[-\frac{1}{2}\frac{(R_m - \hat{\mu})^2}{\sigma_m^2 + \hat{s}^2}\right] \quad (3)$$

- With R_m being the observed double ratio for a given azimuthal module and σ_m its statistical uncertainty
- The $\log \mathcal{L}$ function is maximized with parameters $\hat{\mu}$ and $\hat{s}$
- Obtained parameter $\hat{\mu}$ represents the average response data-MC agreement and $\hat{s}$ quantifies the non-uniformity across azimuthal modules

Radial layer calibration

- Study of the layer response verifies the layer calibration and the determination of the EM scale
- The response of the six TileCal layers is quantified by calculating the double ratio R from the $\Delta E/\Delta x$ spectrum in a given layer
- For this study we also need to consider systematic uncertainties from the choice of analysis selection criteria
- This part of the analysis is still a **work in progress**

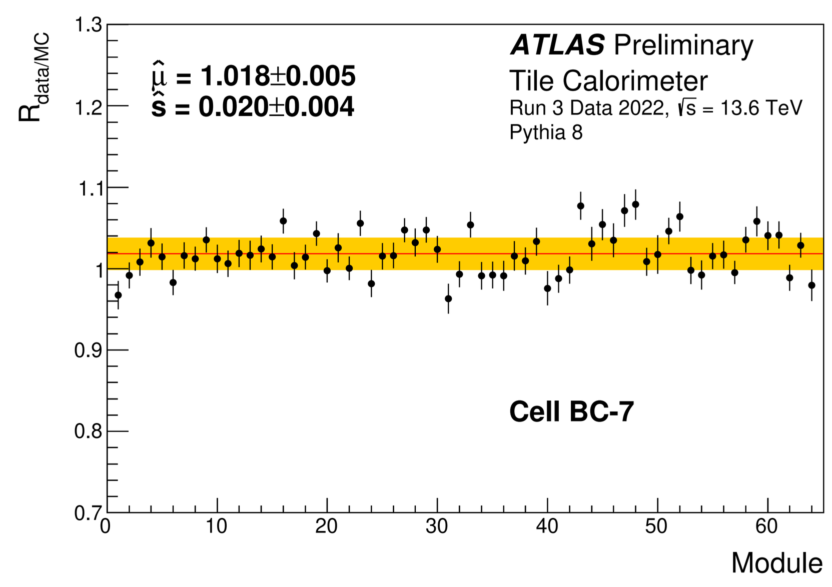

Figure 6. This plot displays the distribution of the ratio R between data and MC for the cell BC-7 of the TileCal long barrel

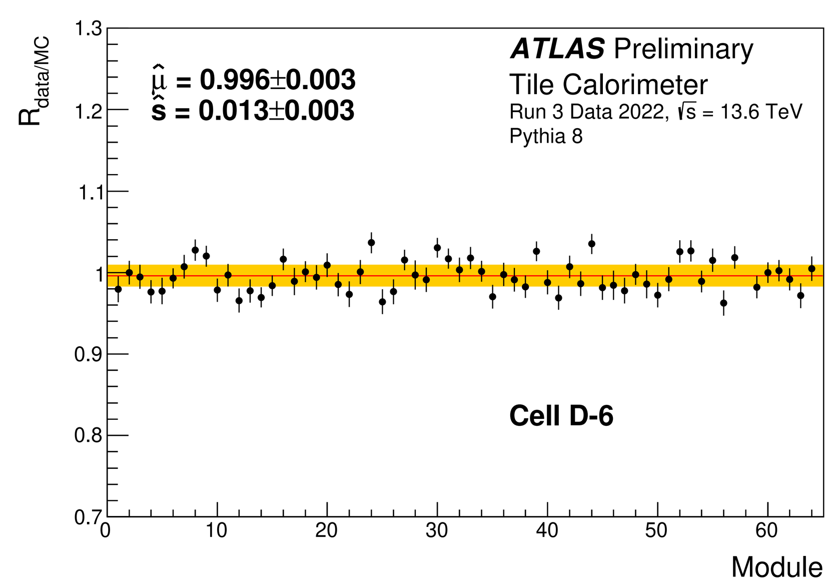

Figure 7. This plot displays the distribution of the ratio R between data and MC for the cell D-6 of the TileCal extended barrel

Conclusions

- We are studying TileCal response with isolated collision muons in Run 3
- Study of the cells' response shows the mean of $\hat{s}$ (systematic error due to ϕ non-uniformity) is determined to be around ~ 0.026 for 2022 data and ~ 0.022 for 2023 data
- Analysis of the layer calibration and EM scale determination is in progress
- All approved public plots for this analysis are available at: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsTileSingleParticleResponse

tadeas.petru@cern.ch