The TileCal Energy Reconstruction for LHC Run2 and Future Perspectives

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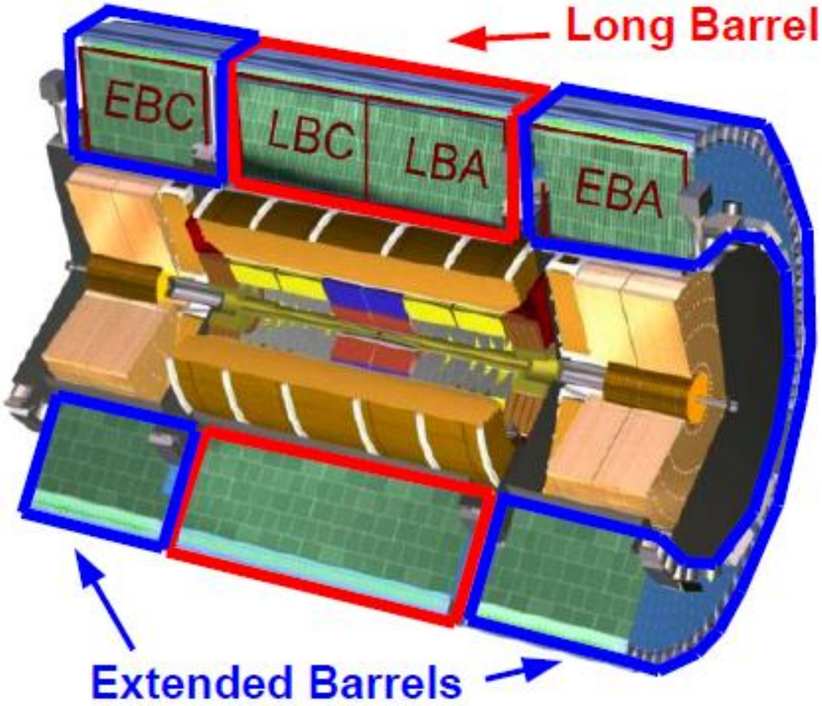
Agenda

- The ATLAS Tile Calorimeter (TileCal)
- Signal Processing Chain
- TileCal Signal Reconstruction
- Performance
- Future Perspectives
- Conclusions

The Tile Calorimeter

- ATLAS central hadronic calorimeter.
- Sampling calorimeter:
  - Steel as absorbing material.
  - Plastic scintillating tile as active material.
- Three Cylinders:
  - Long barrel (covering $|\eta|<1.0$).
  - Extended barrels (covering $0.85<|\eta|<1.7$).
- Total length 12 m, diameter 8.8 m, weight 2900 tons.
- Jet linearity[1] (from data):
  - ~3% in the range 25 GeV to few TeV.
- Jet energy resolution[1] (from data):
  - $\sigma(E[\mathrm{GeV}])/E[\mathrm{GeV}] \sim 60\%/\sqrt{E/\mathrm{GeV}} + 3\%$.



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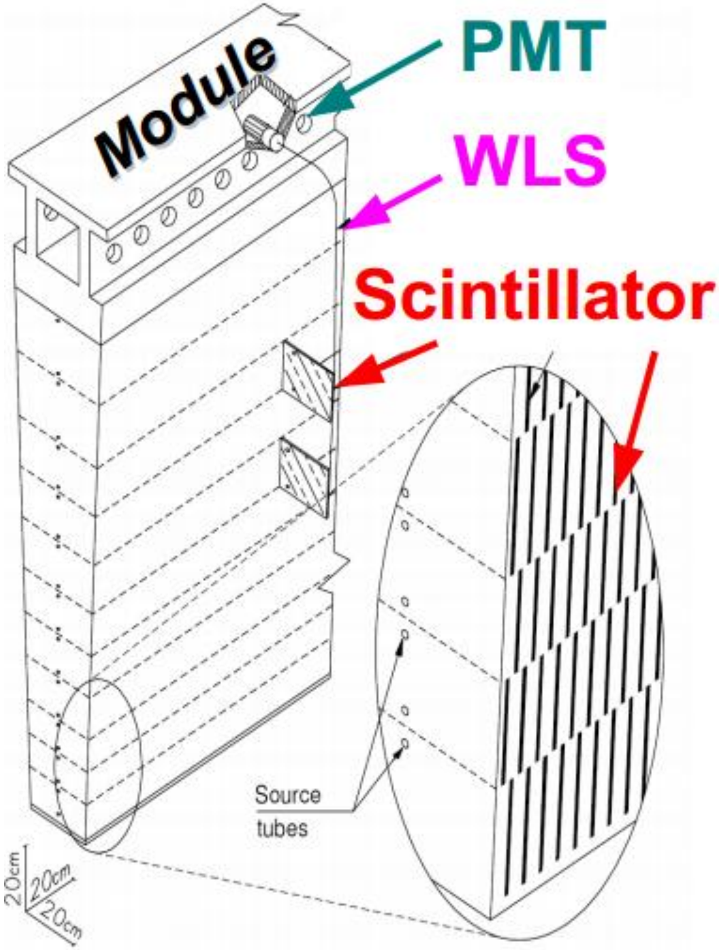
[1] The ATLAS Collaboration, *The ATLAS experiment at the CERN Large Hadron Collider*, JINST 3 S08003, 2008.

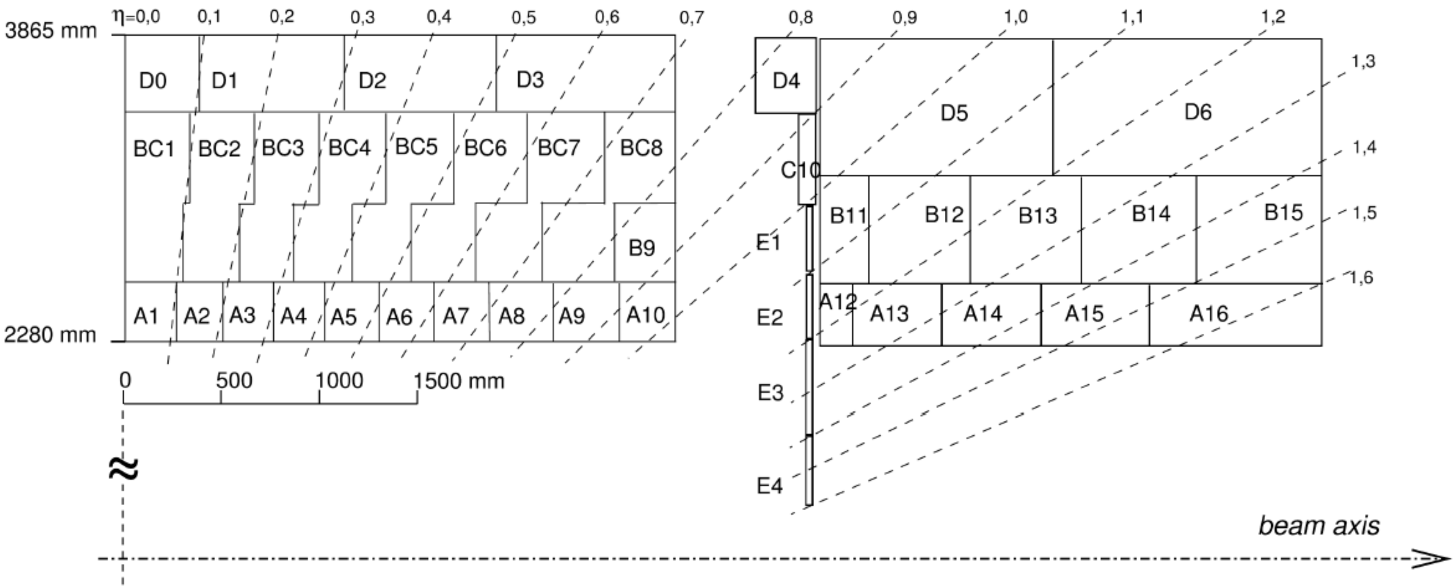
The Tile Calorimeter

- 64 independent modules in each Tile cylinder.
- Scintillator tiles inserted in the iron structure.
- Light produced in scintillators collected by wavelength shifting fibres (**WLS**) and delivered to photomultipliers (**PMT**s - Hamamatsu R7877).
- Approximately 10,000 readout channels (PMTs).



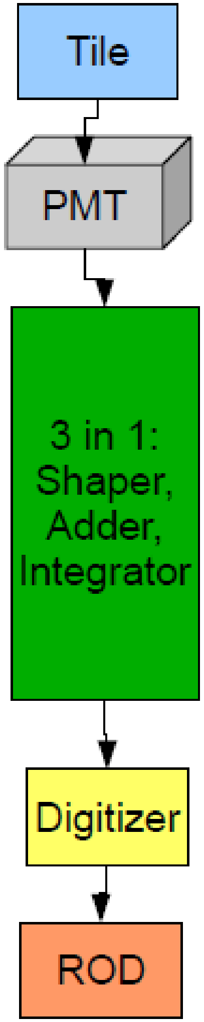
The Tile Calorimeter

- Readout granularity:
  - Three radial layers (λ_{int} =1.5, 4.1 & 1.8).
  - $\Delta\eta$ X $\Delta\varphi$=0.1 x 0.1 (0.2 x 0.1 in outermost layer). Each cell readout by 2 different PMTs except for the special cells (e.g E-cells).



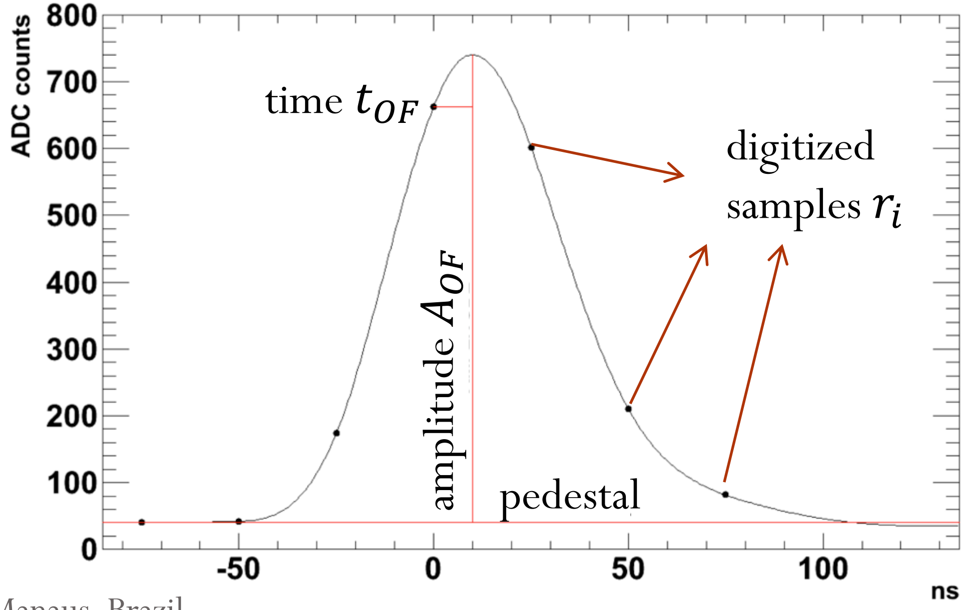
Signal Processing Chain

- Light produced from scintillating tiles is transmitted to PMTs located inside the modules and converted into electric signals.
- PMT output signal is shaped (amplitude proportional to energy) and amplified with two different gains (1:64)
- Signals are sampled at 40 MHz and digitized samples are sent to ReadOut Driver (ROD).
- Digital signal processing is carried out at the ROD level.
- Signal amplitude, time and quality are computed for each cell and recorded.
- Raw data from all signals above certain threshold are recorded for offline analysis.



TileCal signal reconstruction

- The shaped signal is digitized at 40 MHz.
- Electronic noise is usually modeled by a Gaussian distribution.
- An Optimal Filter (OF) algorithm, based on a variance minimization procedure, is used to extract signal parameters – amplitude ($\hat{A}_{OF}$), time (t_{OF}) and quality – from the received digitized samples r_i.



Optimal Filter Algorithm

- Goal is to estimate the amplitude $\hat{A}_{OF}$ and time t_{OF} from the 7 digitized samples, through a weighted sum of the received digitized samples r_i:

$$\hat{A}_{OF} = \sum_{i=1}^{7} w_i r_i \qquad t_{OF} = \frac{1}{\hat{A}_{OF}} \sum_{i=1}^{7} b_i r_i$$

where w_i are the OF weights.

- OF weights w_i and b_i are computed from the following parameters using the Lagrange multipliers:
  - Channel pulse shape
  - Noise covariance matrix
  - Expected signal phase

- Simple and fast
- Suitable to be used on digital signal processors

- A set of constraints can also be added to the optimization procedure.

TileCal Signal Reconstruction (Run1)

- The OF version used during LHC Run1 is called OF2.
- The noise covariance was approximated by the identity matrix (white Gaussian noise) and the following three constraints were used:

$$1)\sum_{i=1}^{7} w_i g_i = 1, \qquad 2)\sum_{i=1}^{7} w_i {g'}_i = 0, \qquad 3)\sum_{i=1}^{7} w_i = 0$$

where ***g*** e ***g***' correspond to the normalized reference pulse shape (output from shaping circuit) and its derivative, respectively.

- Constraint 1 implements the energy scale factor. Constraints 2 and 3 make the estimator robust against phase and baseline deviations, respectively.

TileCal Signal Reconstruction (Run2)

- For LHC Run2, constraint 3 ($\sum_{i=1}^{7} w_i = 0$) is removed from both computation of w_i and b_i, as it increases the variance of the OF estimator. This version of OF is called OF1.
- Therefore, OF1 relies on the pedestal stability.
- In the OF1 version, the pedestal value is subtracted from each received digitized sample r_i when computing $\hat{A}_{OF}$ and t_{OF}:

$$\hat{A}_{OF} = \sum_{i=1}^{7} w_i (r_i - ped) \qquad t_{OF} = \frac{1}{\hat{A}_{OF}} \sum_{i=1}^{7} b_i (r_i - ped)$$

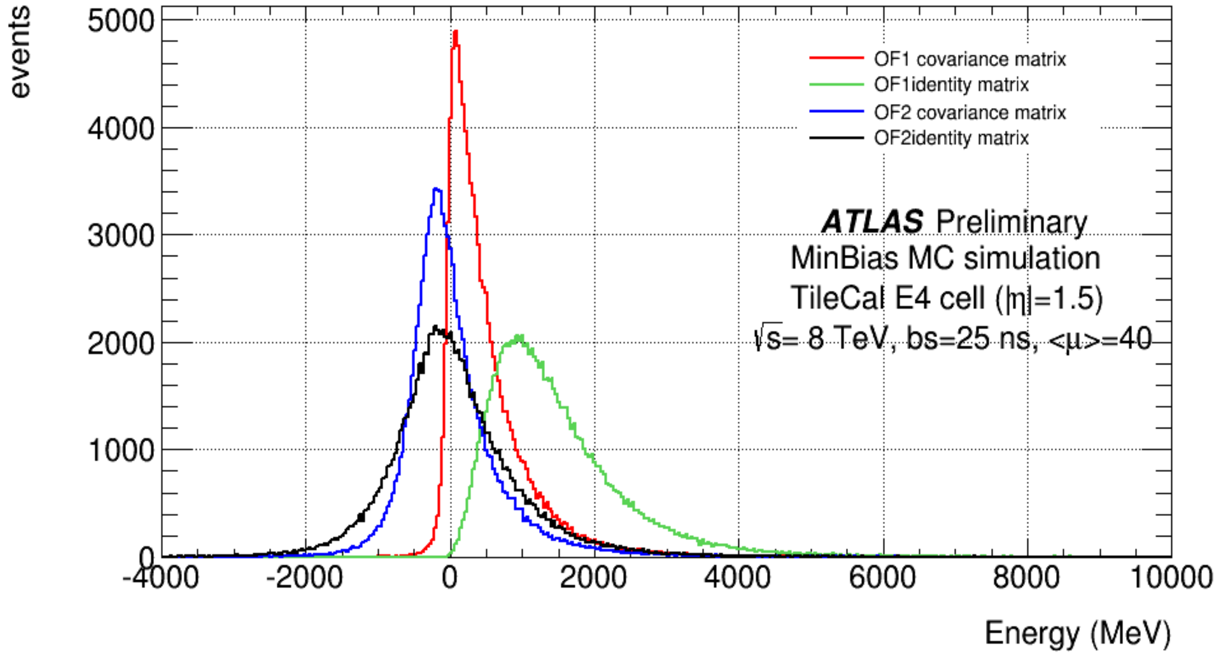
where ped is the pedestal value. This value is measured through periodic calibration runs and stored in data base for online and offline use.

- The background covariance matrix will also be used in the computation of w_i, aiming at reducing the incertainties introduced by the signal pile-up.

Performance

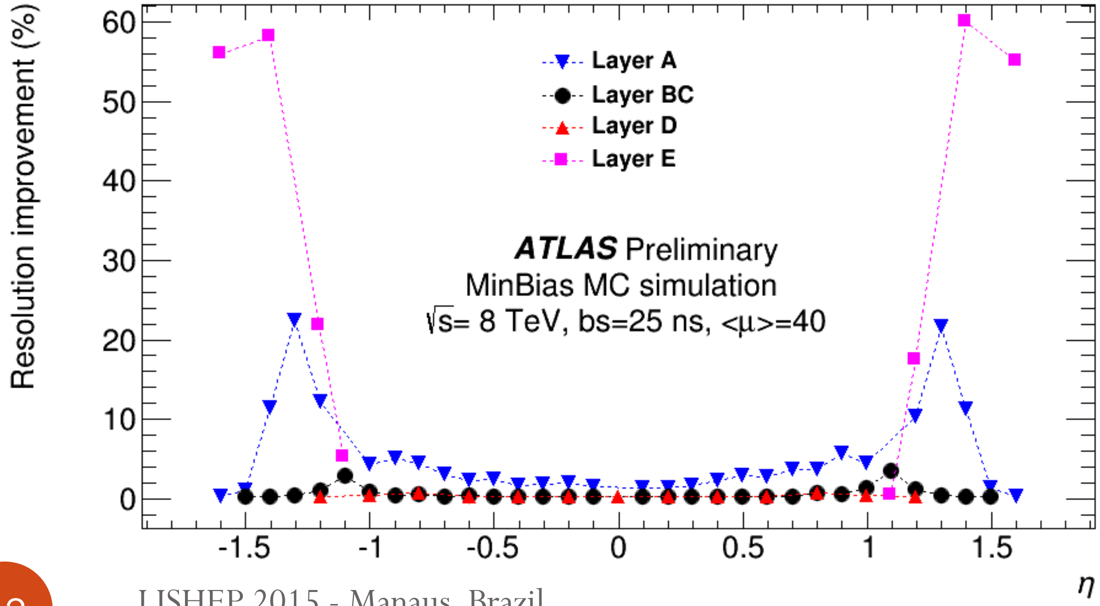
- Evaluation for the highest occupancy cell in TileCal (E4).
- A simulation containing only noise (electronic+pile-up) is used to evaluate the improvement when using the correct noise covariance matrix with respect to the identity matrix.
- The OF2 (used in Run1) presents long negative tail due to the presence of Out-Of-Time (OOT) signals.

The use of the covariance matrix improves significantly the OF1 performance, and it shows the smaller dispersion with respect to other methods.



Performance

- Although the signal pile-up introduces non-Gaussian components to the background, the covariance matrix can be used to improve performance, for extended barrel cells (|η|>1), which suffer more from the OOT signals.
- The plot shows the percentage improvement in the RMS of the estimation error distribution by using the covariance matrix with respect to the identity matrix.



The cells in barrel region (|η|<1) are less affected as the noise is mainly electronic noise (approximated by an identity matrix).

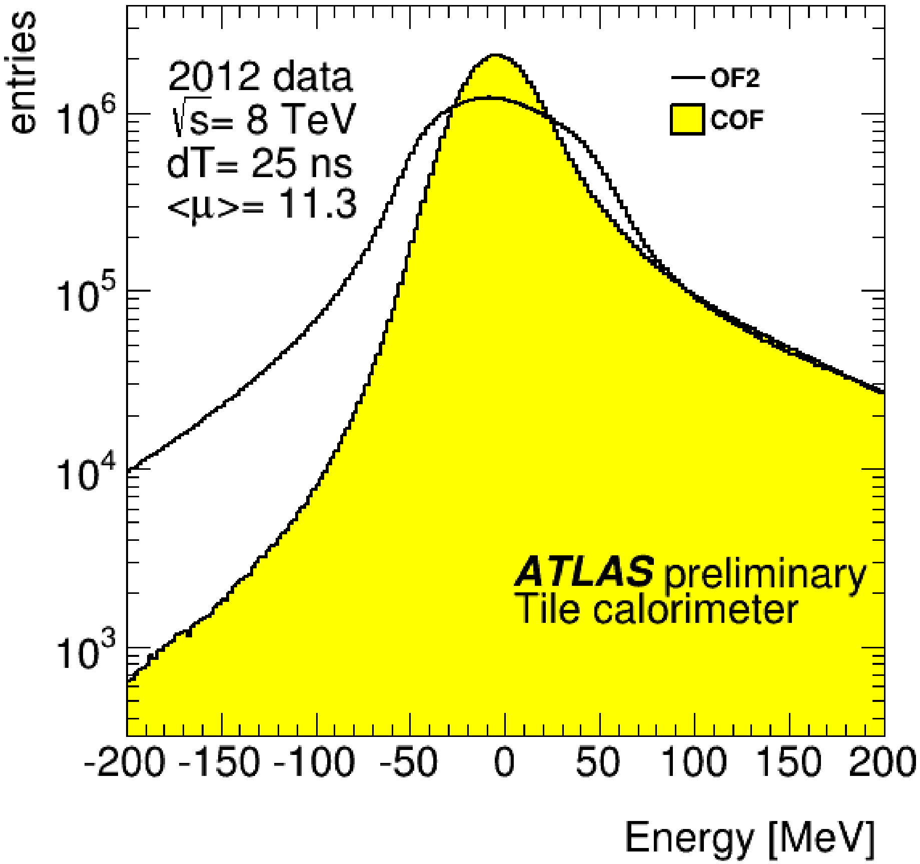
Future Perspectives

Future Perspectives (motivation)

- The OF method is designed for Gaussian noise only.
- With the increase of pile-up, the background noise comprises the electronic (Gaussian like) convoluted with the pile-up (log-normal like), therefore OF becomes no longer optimum.
- A more sophisticated approach has been proposed, namely the Constrained Optimal Filter (COF).
- Unlike OF, COF considers the pile-up as additional signals, and it estimates a linear deconvolution matrix (based on the reference pulse shape) to recover the signal within the readout window
- Therefore, the noise comprises only the usual electronic noise (WG noise) and the designed becomes luminosity independent.

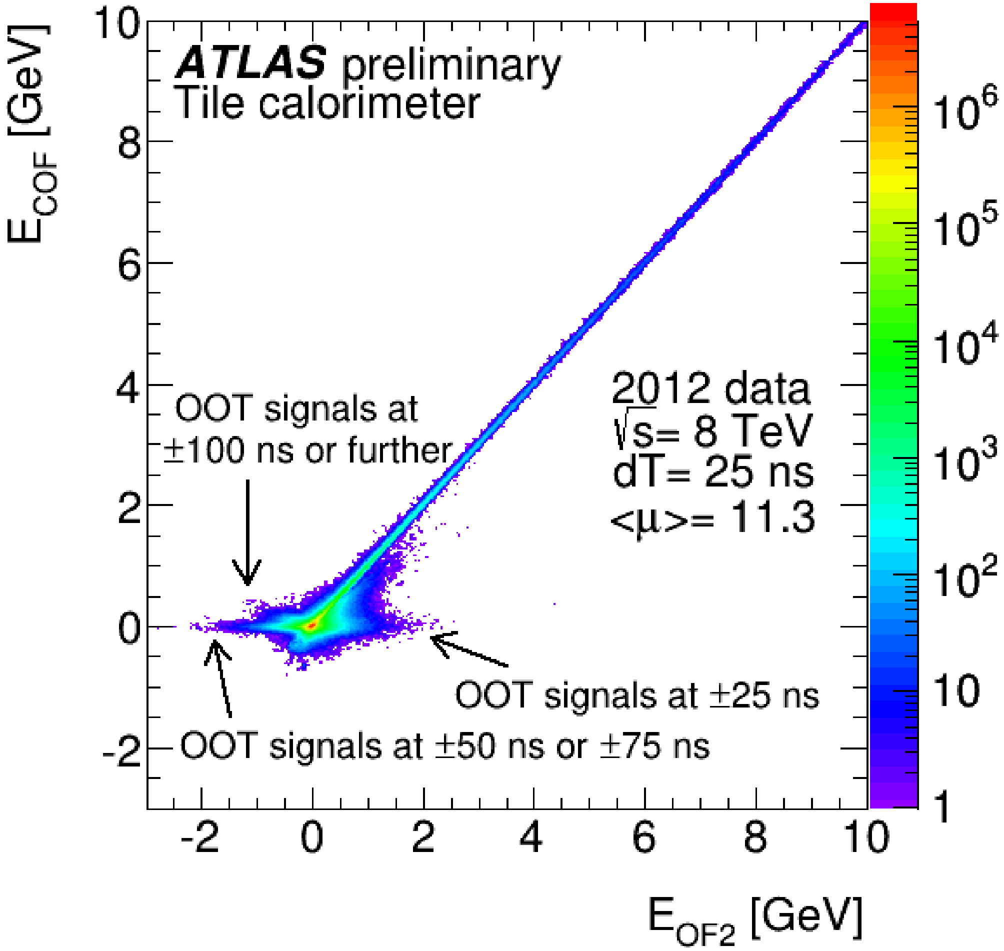
Future Perspectives (COF method)

- Cell energy distributions for COF and OF2 (used in Run1).
- The noise range (±200 MeV) is highlighted to illustrate the estimation error using real data.
- Due to the pedestal constraint imposed by OF2 ($\sum_{i=1}^{7} w_i = 0$), the method tends to estimate negative energies in the presence of OOT signals.
- The COF method is resilient to OOT signals, therefore, it presents better energy resolution than OF2.



Future Perspectives (COF method)

- Cell energy correlation between COF and OF2.
- Under pile-up conditions, OF2 tends to estimate negative or positive energies, depending on the position of the OOT signals.
- A small contribution from signals outside the readout window (±100 ns or further) is also seen.



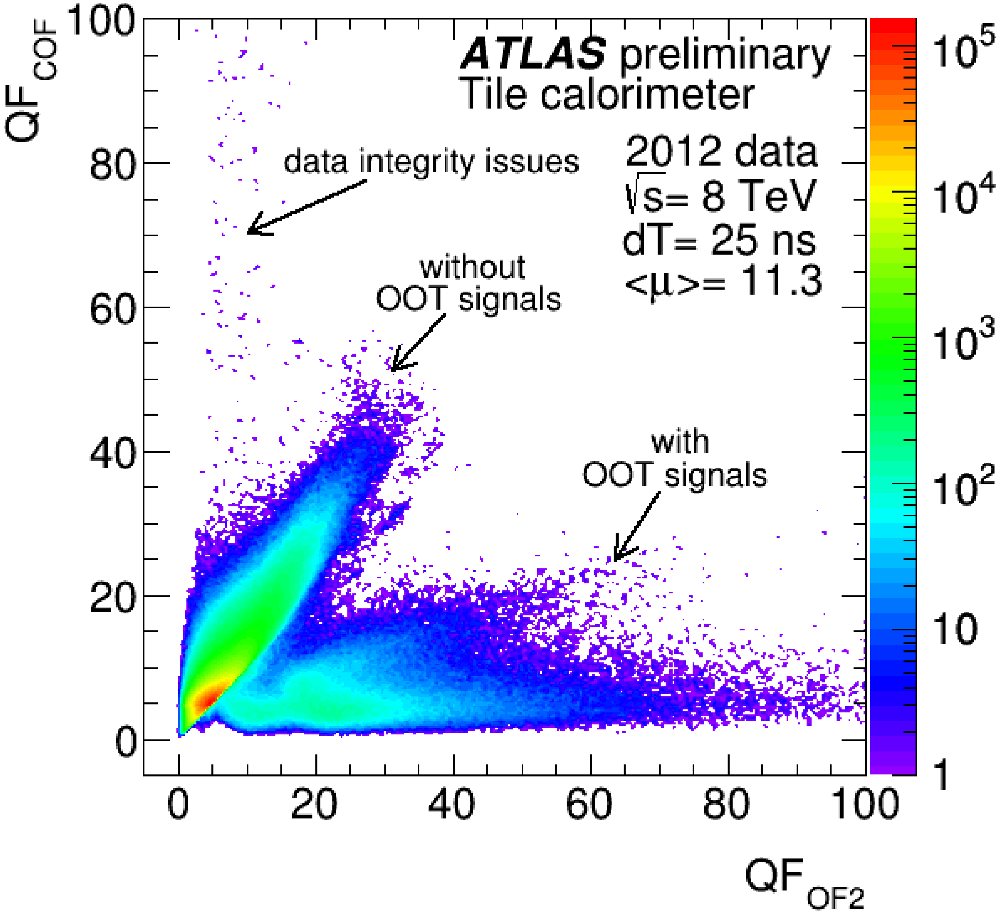
Future Perspectives (COF method)

- The quality factor (QF) is a measure of signal reconstruction goodness, defined by:

$$QF = \sqrt{\sum_{i=1}^{7}(r_i - s_i)^2}$$

where r_i and s_i are the received and reconstructed signal samples, respectively.

- Since COF estimates the amplitudes of in-time and OOT signals, its reconstructed signals presents higher accuracy then OF2.
- In the presence of OOT signals, OF2 presents large values of QF.
- Large values of QF_{COF} can be also used to flag data integrity issues.



Conclusions

- The Optimal Filter (OF) algorithm for TileCal energy reconstruction algorithm was presented.
- The OF design was revised and a new version (OF1) is planned to operate during Run2, where the pedestal value is estimated offline through calibration runs and subtracted online from the digitized samples
- As LHC luminosity increases, the effect of the pile-up deteriorates the signal reconstruction performance.
- The information from the background second order statistics will be used in LHC Run2 to reduce incertainties due to OOT signals in high occupacy cells.

Conclusions

- A promising approach (COF) has been implemented and evaluated offline in cell level and it is currently under validation for future use.
- COF is unfiaseable for current TileCal online electronics setup (based on DSP devices).
- However, it can be tested for offline and future upgrades.

Thank you!