An Alternative Method for Tilecal Signal Detection and Amplitude Estimation

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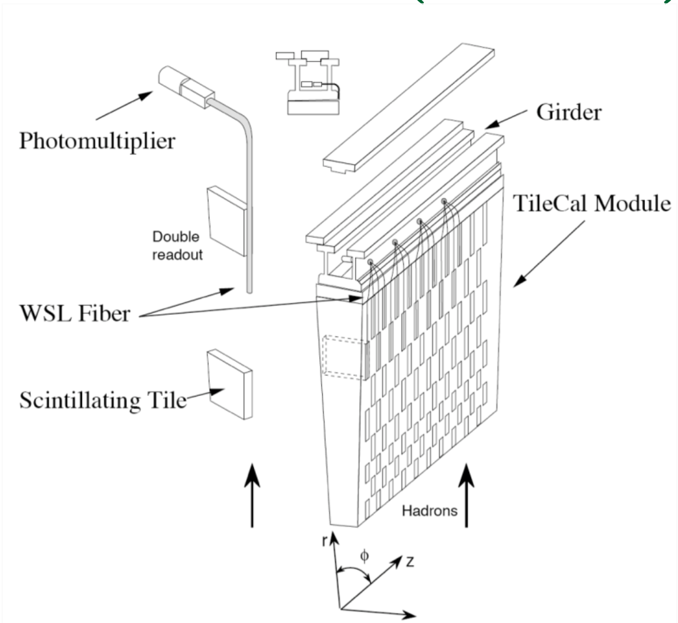
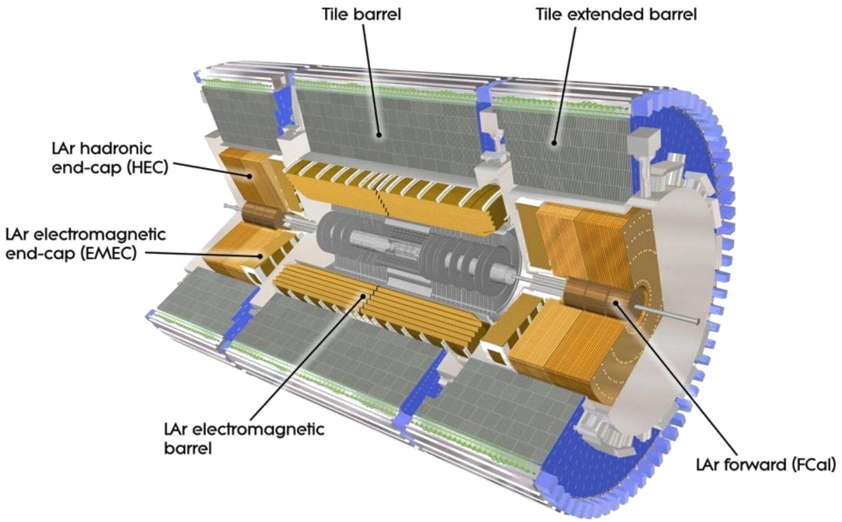
Summary

- Introduction
- Goal and Motivation
- Database
- Tilecal Signals
- Methods for Signal Amplitude Estimation
- Results
- Conclusions

Introduction – The Tile Calorimeter (Tilecal)

- Hadronic calorimeter in ATLAS
- Four logical partitions
- Approximately 10,000 channels
- Tilecal cell has double readout
- Tilecal signal sampled at 40 MHz





- Signal amplitude estimated for each channel
- Channel amplitude estimations from the same cell are summed up to produce the final Tilecal cell energy estimation

Goal and Motivation

Goal:

- To propose an alternative method for signal estimation and improve signal detection (against noise)

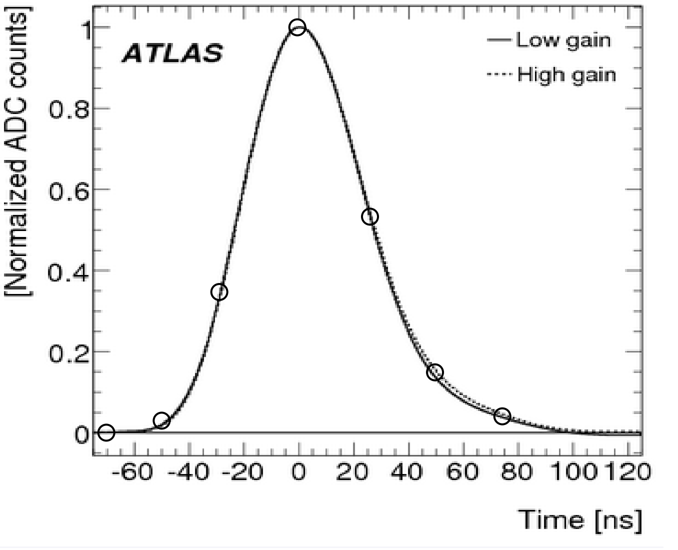
- To analyse the impact on both detection efficiency and amplitude estimation when signals from a given cell are added before amplitude estimation is performed

Motivation:

- Noisy channels may be discarded during event reconstruction

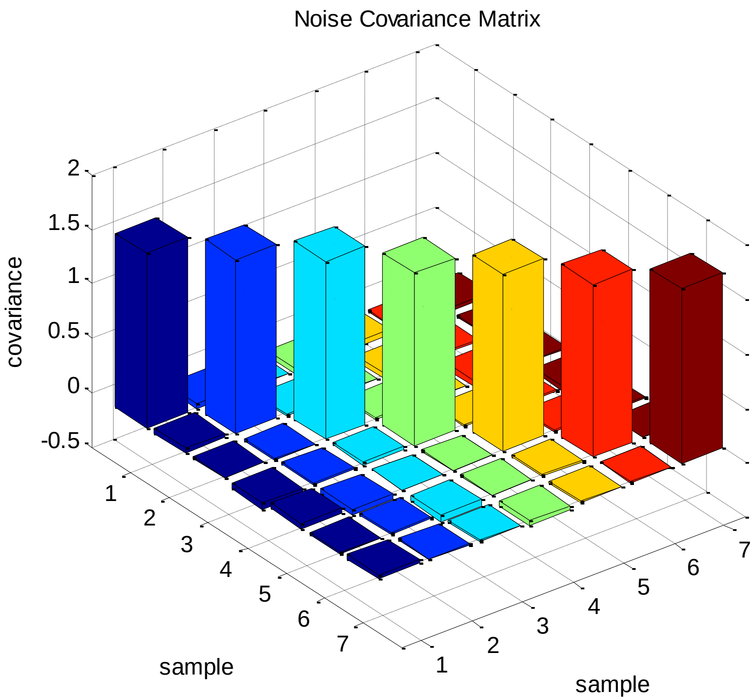
Database

- Comprises two data sets:
  - Noise
    - 5,016 pedestal signals taken from a single Tilecal channel (no collisions)
  - Signal
    - 5,016 event signals generated by summing noise signals to normalized Tilecal reference pulse shape with known amplitude distribution
    - Signal Parameters:
      - Amplitude 1<A<5 counts
      - Signal shifting [-7,7] ns as time jitter
      - Sampled and digitized 7 times in 25 ns intervals



Tilecal Noise Characterization

- Noise distribution: approximately Gaussian (previous work)



$$CT(\%) = \frac{\sum_{i=1}^{7}\sum_{j=1}^{7} c_{ij} - \sum_{k=1}^{7} c_{kk}}{\sum_{k=1}^{7} c_{kk}} \cdot 100$$

$$CT = 8.59\%$$

Where c_{ij} is the covariance between samples i and j

Current Tilecal Amplitude Estimation Method

- It makes use of an optimal filtering (OF) algorithm to estimate the signal amplitude
- OF output (in ADC counts) computed by an inner product of the input signal and the OF coefficients
- Coefficients are defined by the Tilecal reference pulse shape from particle energy depositions

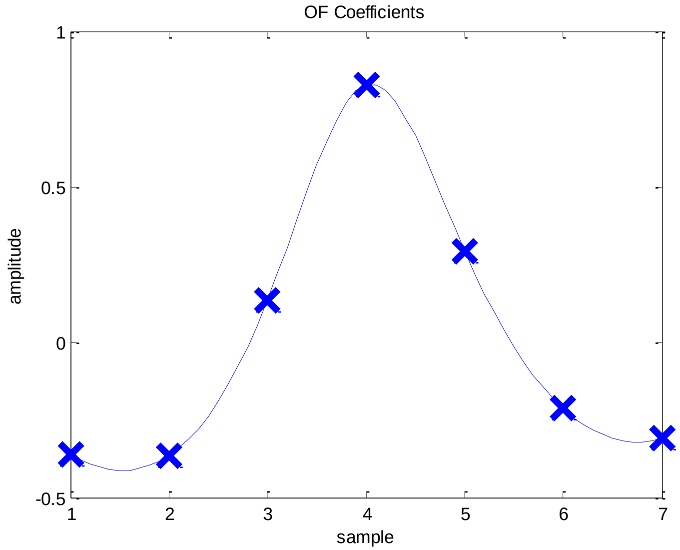
Amplitude estimation by OF:

$$A = \sum_{k=1}^{7} s[k] \cdot a[k]$$

$s[k]$ → incoming signal

$a[k]$ → OF coefficients

Particularity: Sum of the OF coeficients is equal to zero (pedestal immunity)



Alternative Method: Signal Detection and Amplitude Estimation (MF)

- Matched Filter approximation (optimum signal detection with respect to signal-to-noise ratio – SNR)
- Filter matched to the Tilecal reference pulse shape from particle energy depositions

incoming signal

Filter output: $$y = \sum_{k=1}^{7} s[k] \cdot s_{ref}[k]$$

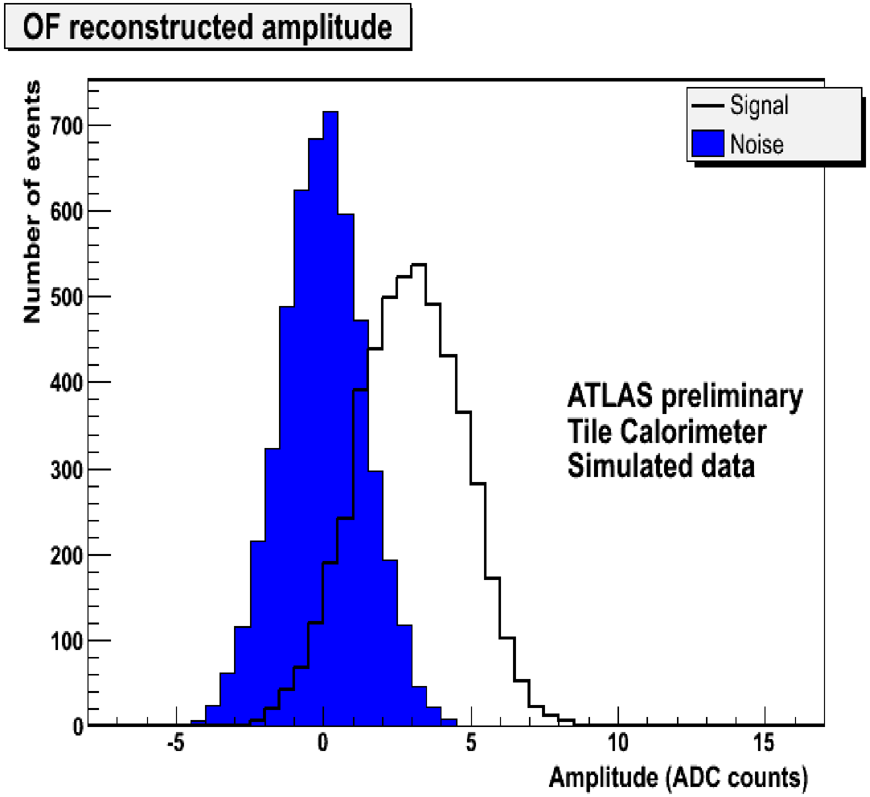
MF coefficients

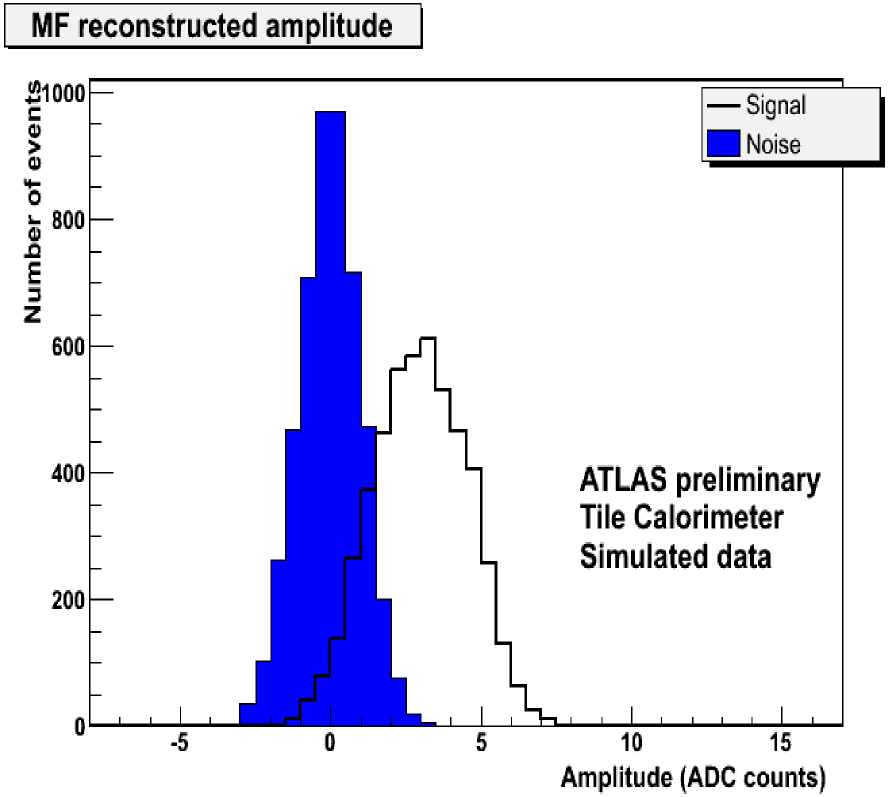
Amplitude estimation: $$A = \frac{y - ped \cdot \sum_{k=1}^{7} s_{ref}[k]}{\sum_{k=1}^{7} {s_{ref}}^2[k]}$$

Where:

- s[k] is the input signal
- $s_{ref}[k]$ is the Tilecal reference pulse shape
- ped is the mean value of the first sample

Filter output (amplitude) in ADC counts for single channel

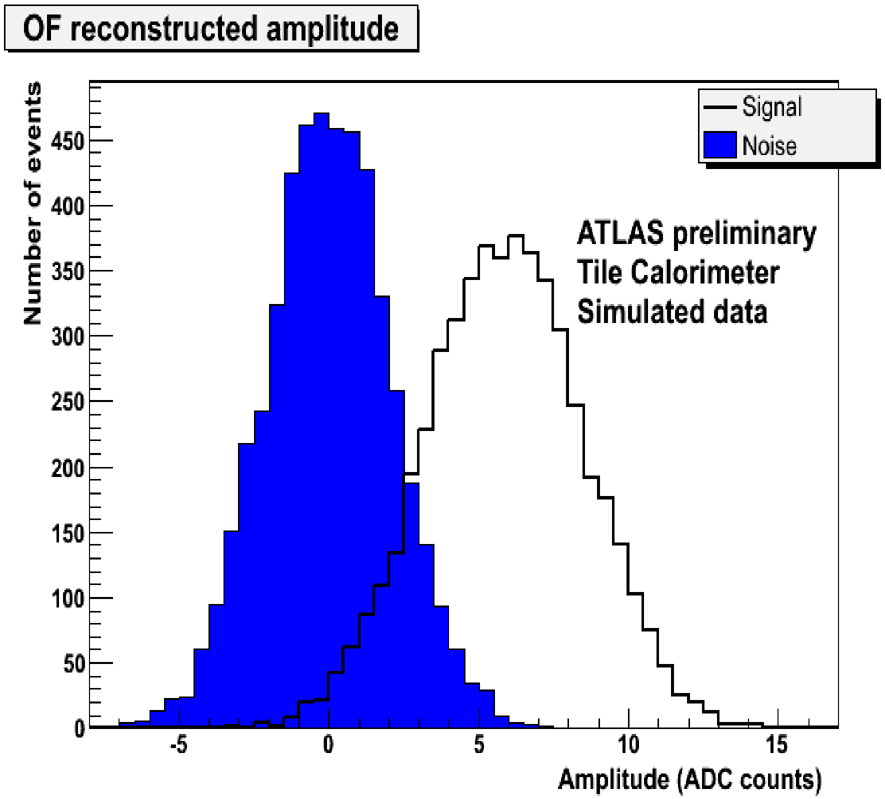


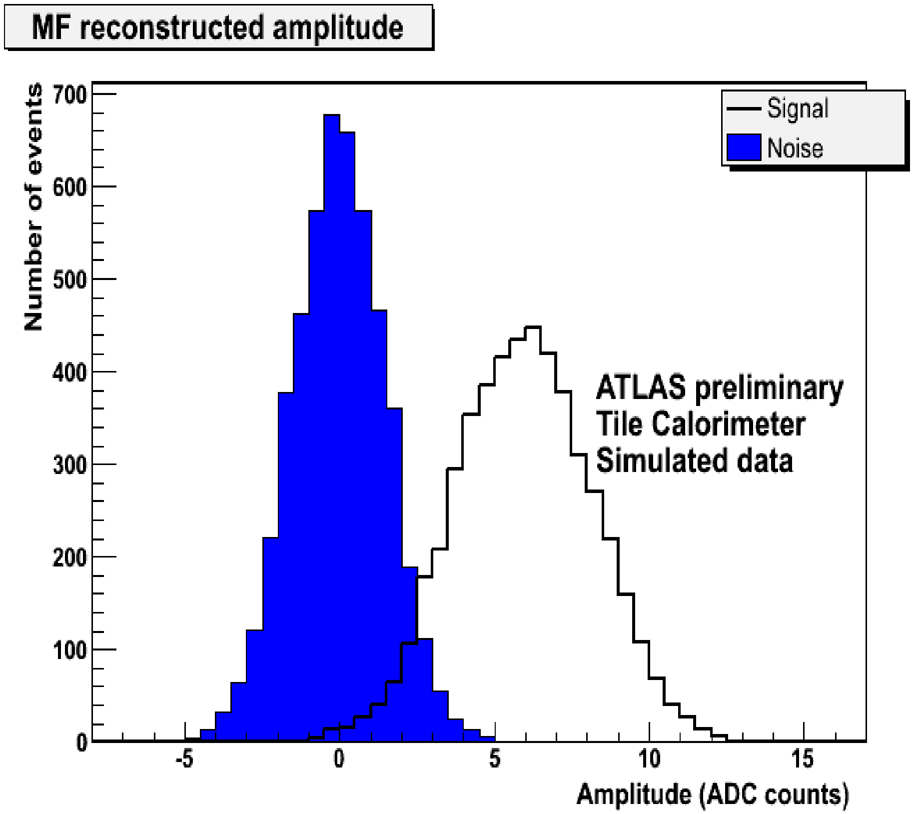


Noise standard deviation:
1.4149 ADC counts

Noise standard deviation:
1.0116 ADC counts

Filter output (amplitude) in ADC counts for cell (adding channels)

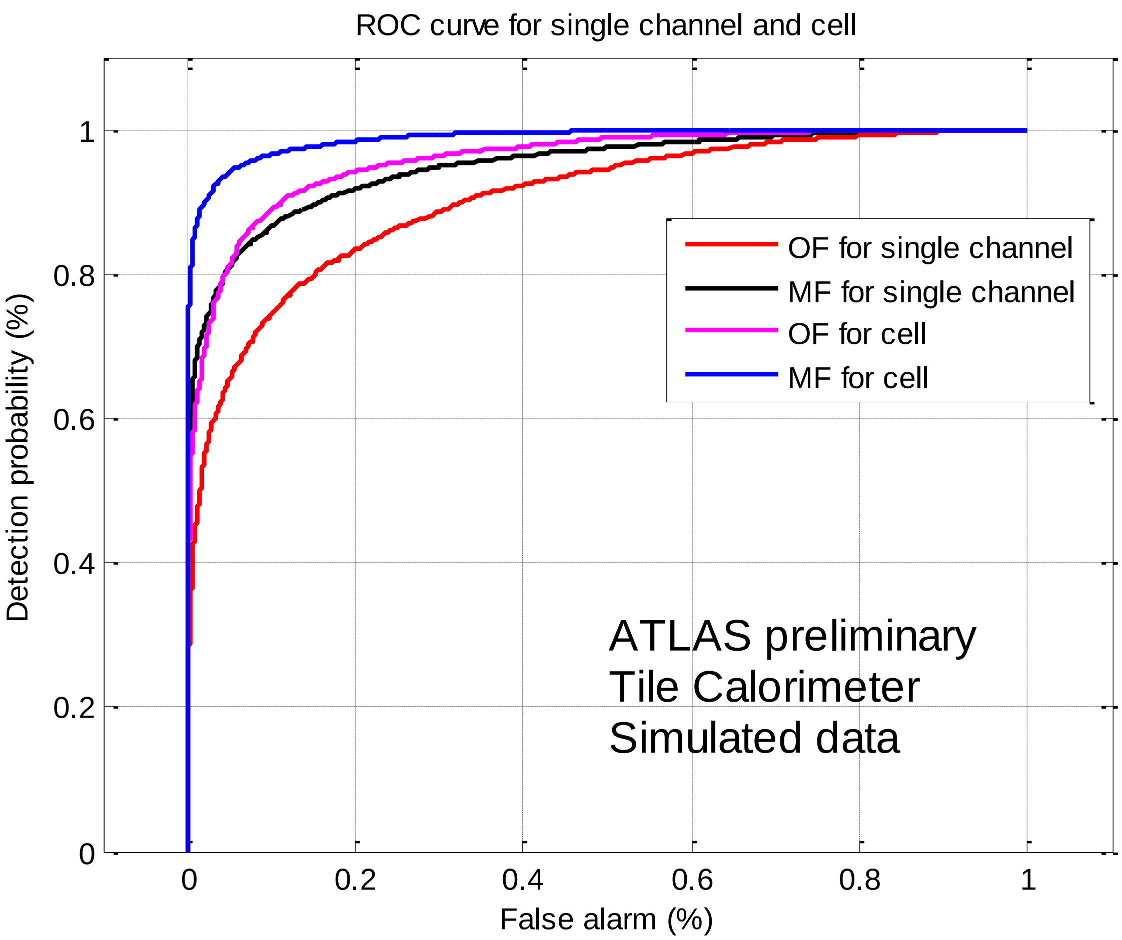




Noise standard deviation: 2.0834 ADC counts

Noise standard deviation: 1.4917 ADC counts

Comparison OF x MF - Detection efficiency



For 0.01% of False Alarm, Detection Efficiency is:

Single channel:

- MF: 66.23%
- OF: 43.36%

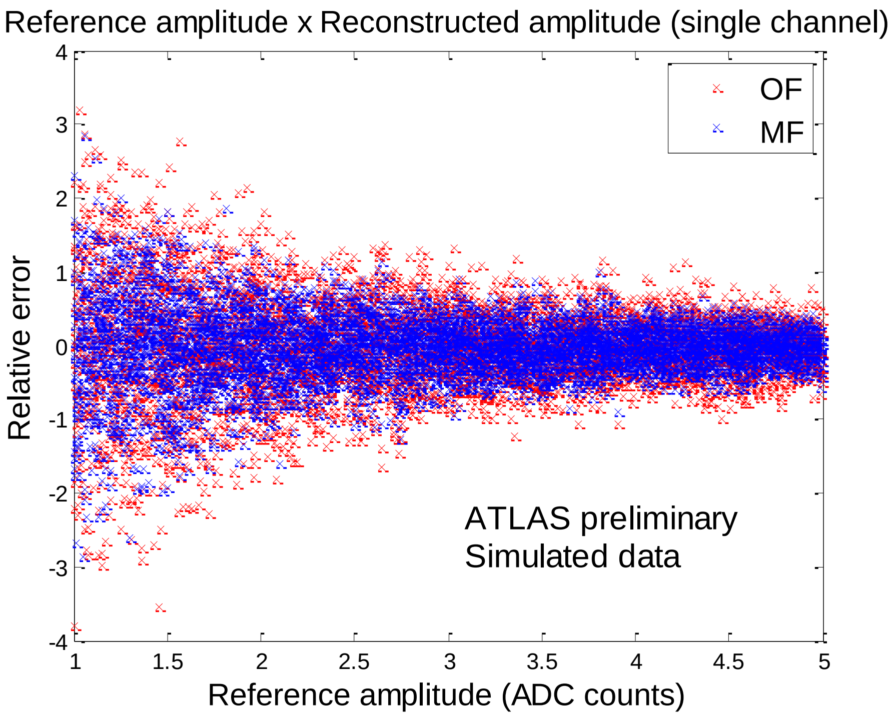
Cell:

- MF : 86,30%
- OF : 60,55%

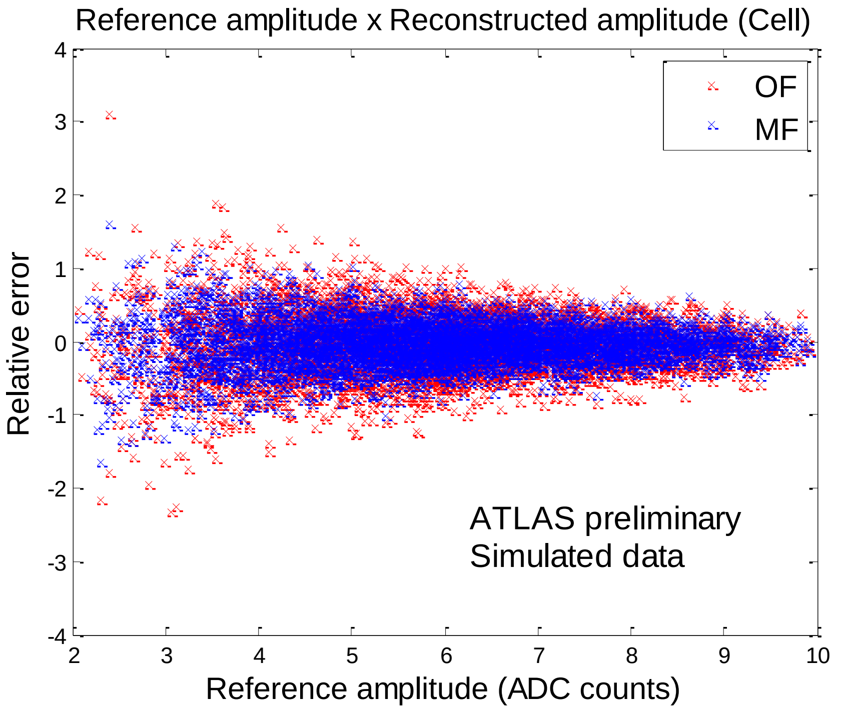
Comparison OF x MF – Linearity

Relative error in ADC counts with respect to the reference amplitude

Single channel



Cell



Summary of Error Estimation

- Error estimation in ADC counts

	Single channel	Cell
OF	1.4149	1.0417
MF	1.0116	0.7459

Motivation for summing the cell signals before estimating the amplitude:

For uncorrelated Gaussian channels, the noise standard deviation of the sum of the two signals increases by a factor of $\sqrt{2}$ while the final amplitude is doubled (considering channel amplitudes approximately the same for a given cell). Therefore, this procedure increases the SNR.

Conclusions

- An alternative method (Matched Filter) for Tilecal signal detection and amplitude estimation was presented
- Under conditions where the pedestal could be considered stationary and its value estimated by the mean of the first input signal samples, it was shown that the MF method surpasses the OF algorithm in terms of both detection efficiency and better amplitude estimation (smaller errors)
- Summing cell signals before amplitude estimation increases considerably the performance of both methods
- Since the MF makes only usage of the Tilecal pulse shape, which comprises 7 coefficients, it is suitable for DSP implementation as well as the OF is currently implemented
- In case of significant noise sample correlation, a whitening filter can be designed

Ongoing Work

- Perform same analysis with collision data
- Apply a pre-processing step (PCA) in order to remove cross-correlation between the two channels from the same cell before summing them
- Analyse the MF performance under pile-up conditions