Identification of Pile-up Using the Quality Factor of Pulse Shapes in the ATLAS Tile Calorimeter

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Overview

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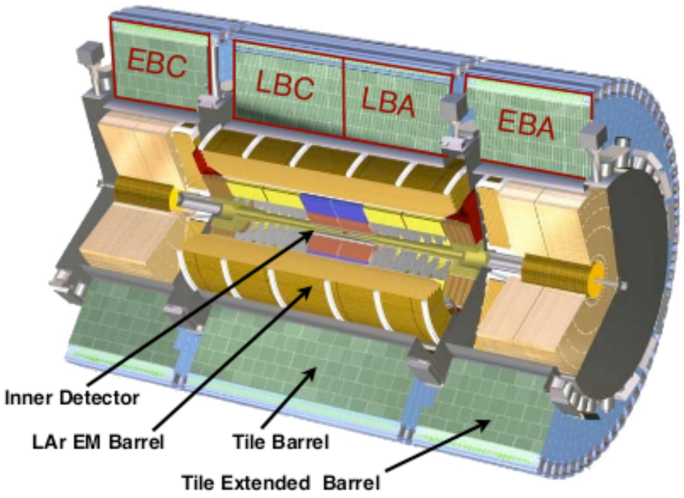
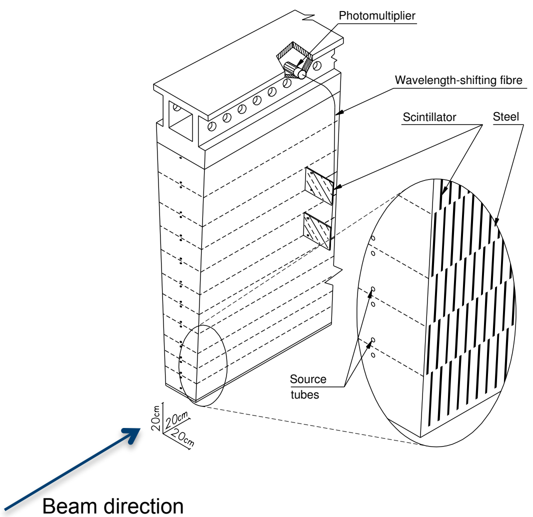
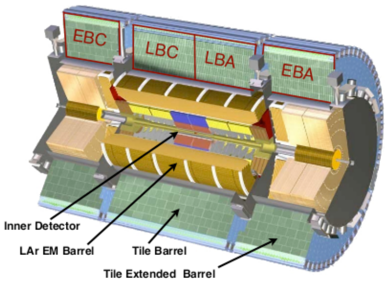
ATLAS Tile Calorimeter

- Tile Calorimeter is the central hadronic calorimeter (|η|<1.7).
- Identify and measure hadrons, jets, taus, missing energy and trigger.
- Cover dynamic range (energy per channel between ~30 MeV and ~1.6 TeV) with 2 outputs: high and low gain
- Sampling calorimeter (steel/scintillators), PMT readout using wave length shifting fibers.

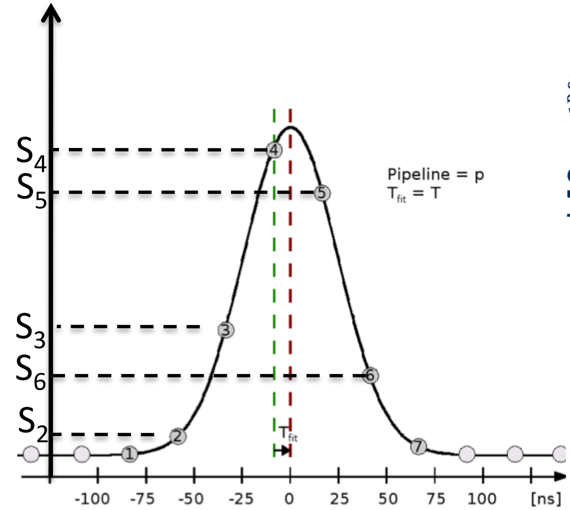




Introduction



S_i



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Study of Quality Factor

- Understand the distribution of QF w/o pile-up.
- Develop pulse simulator that reproduces QF distribution in data.
- Implement and study QF with pile-up using developed pulse simulator.
- Goal is to use QF to flag channels with pile-up (both online and offline).

ONLINE

High Level trigger

OFFLINE

Non-iter OF

Iterative OF

A, τ, QF

S_i

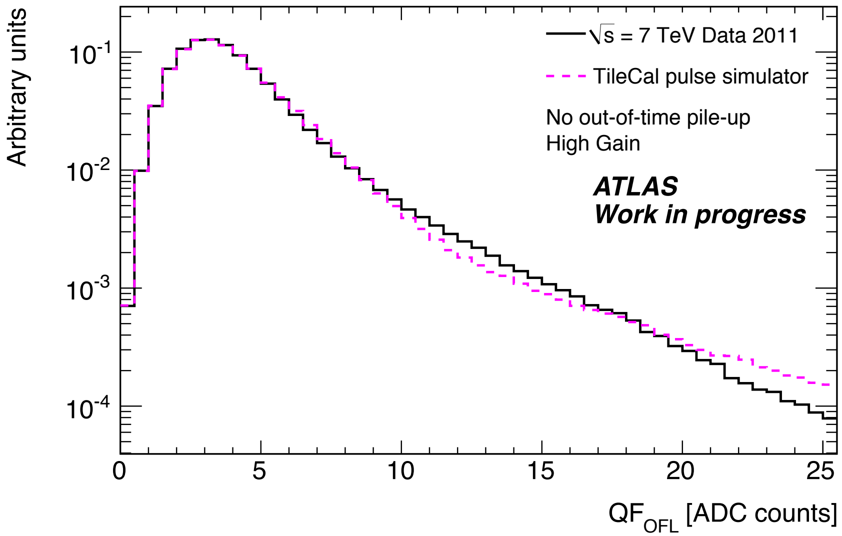
Read Out Driver
Non-iter Optimal Filtering Method

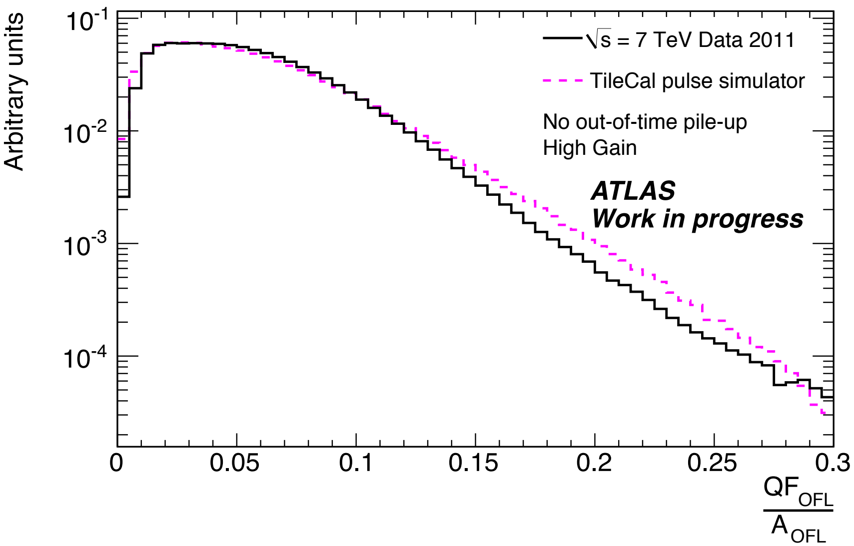
$$A = \sum_{i=1}^{7} a_i \cdot S_i \qquad \tau = \frac{1}{A}\sum_{i=1}^{7} b_i \cdot S_i \qquad P = \sum_{i=1}^{7} c_i \cdot S_i$$

$$QF = \sqrt{\sum_{i=1}^{7} (S_i - (A \cdot g_i - A \cdot \tau \cdot g'_i + P))^2}$$

Quality factor in 2011 data and pulse simulator

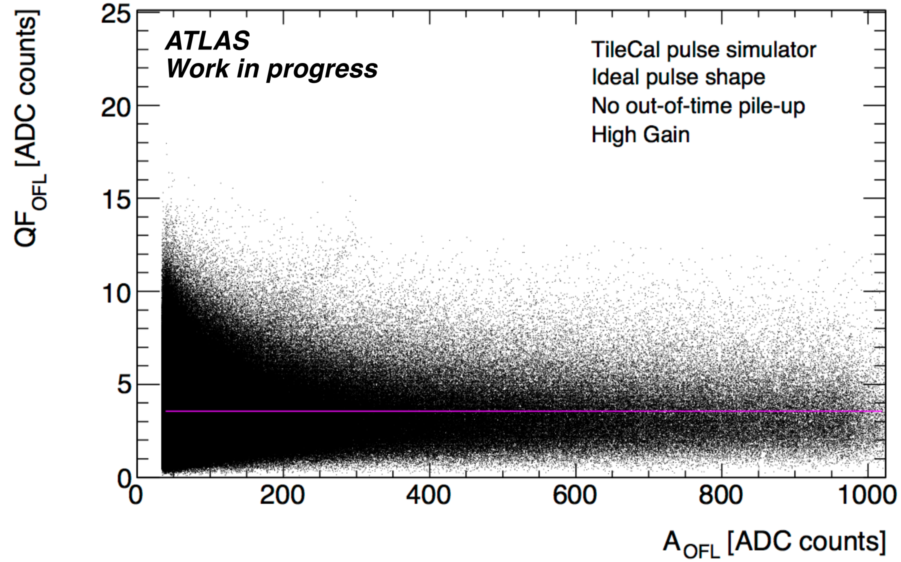
- Data collected with jet or missing energy trigger.
- Developed and tuned pulse simulator that covers whole amplitude range, 34 – 1024 ADC.
- Effects taken into account: electronic noise, energy distribution, pulse shape deviations, channel to channel phase variations.
- Offline iterative Optimal Filtering method, high gain.
- Fair agreement between data and pulse simulator in the case of no out-of-time pile-up.

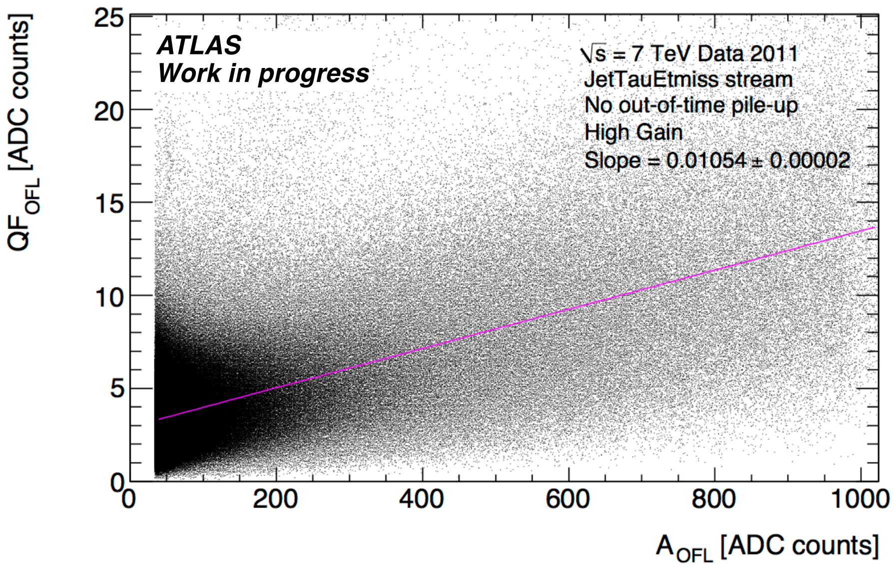


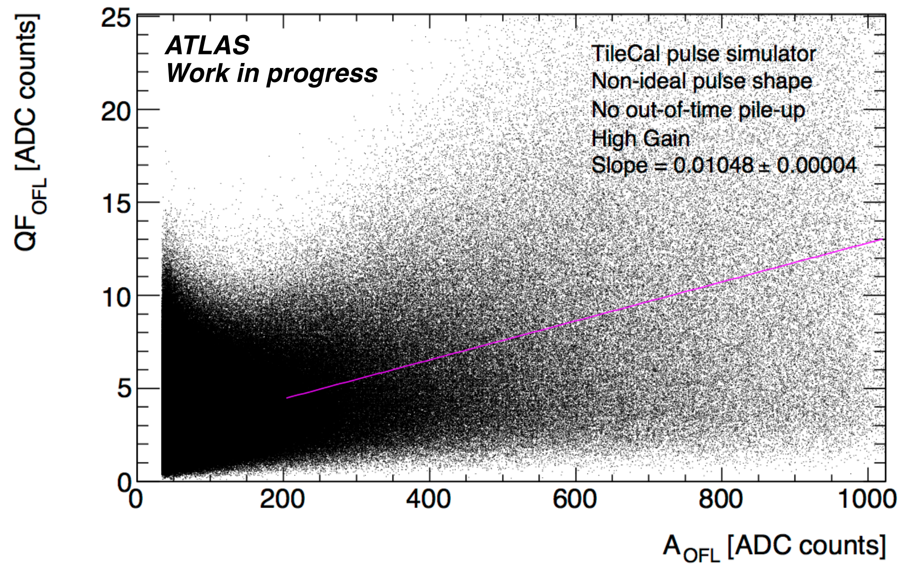


Amplitude dependence of quality factor

- Demonstrated that the non-ideal pulse shapes in the detector cause energy dependence of quality factor.
- The simulator can reproduce energy dependence if non-ideal pulse shapes are assumed.

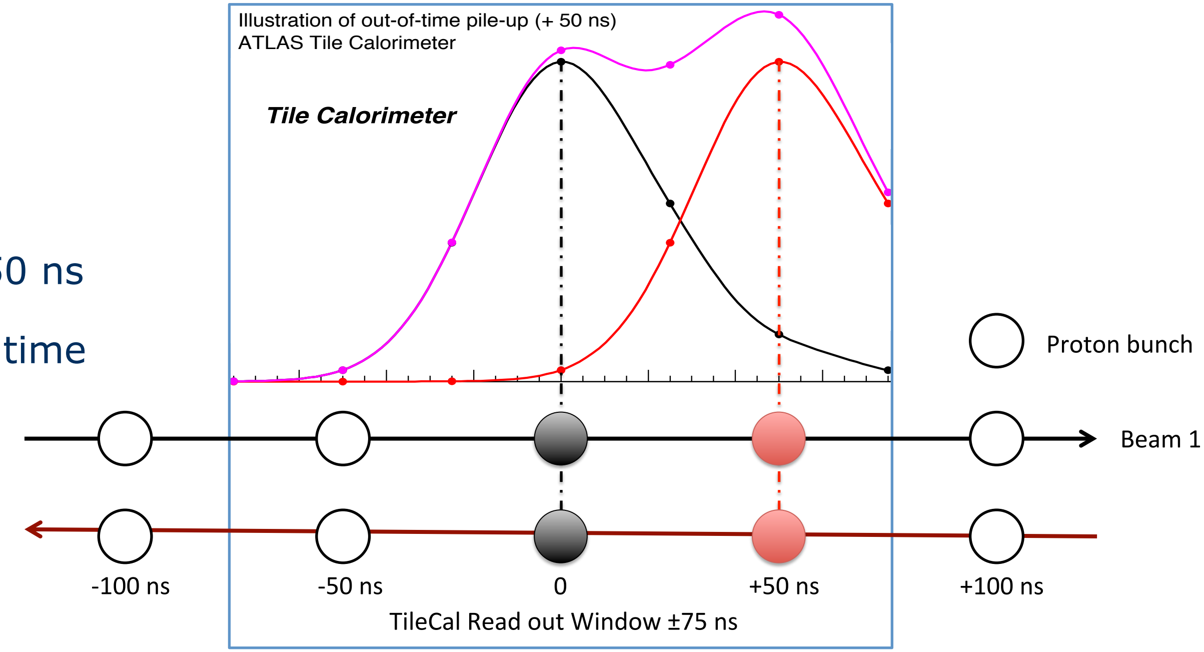


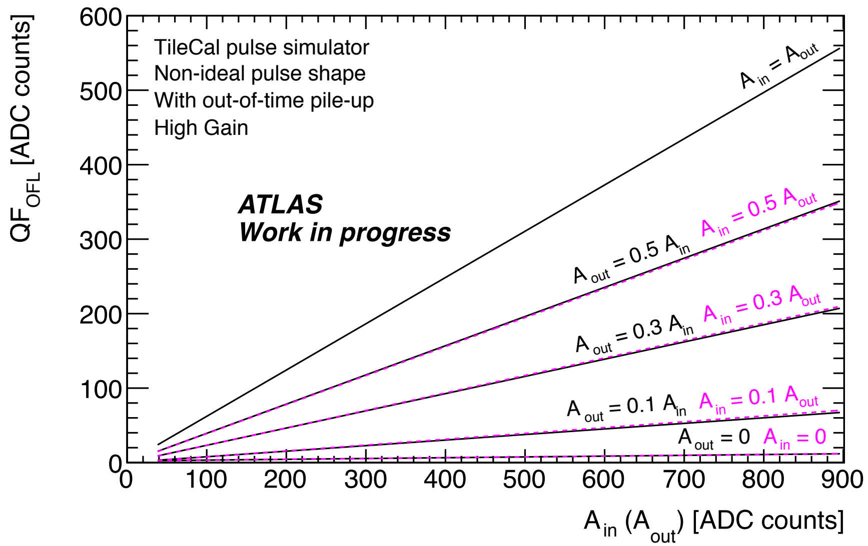




Out-of-time pile-up

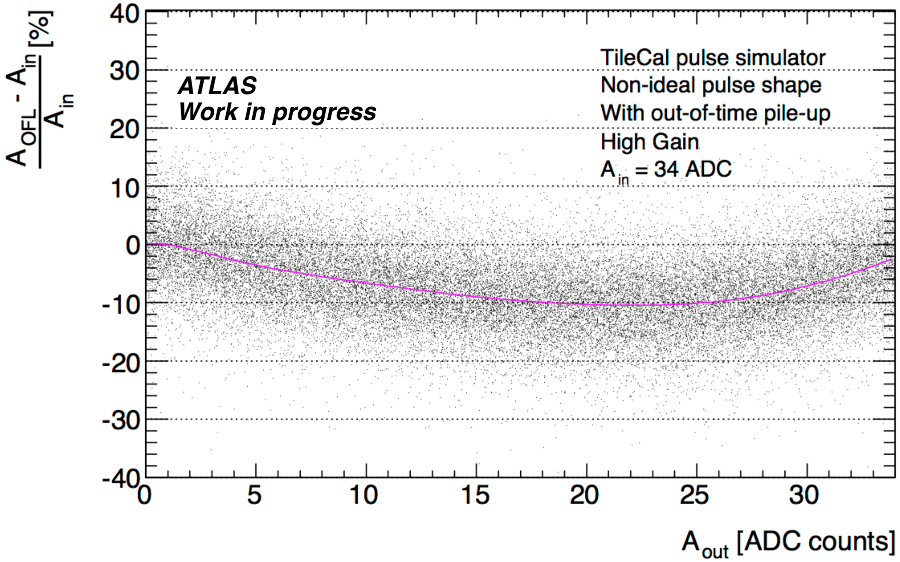
- Currently LHC operates with 50 ns bunch spacing causing out-of-time pile-up signals.

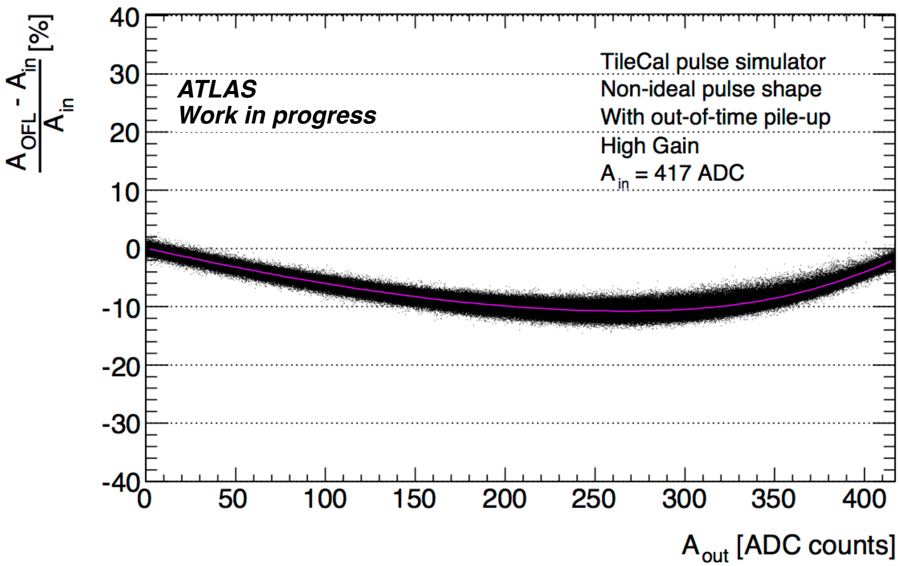




- Quality factor is very sensitive to the difference between expected and real pule shape in the detector.
- Scales linearly with the pile-up amplitude.
- Can be used to flag cells with presence of out-of-time pile-up.

Effect of pile-up on reconstructed amplitude

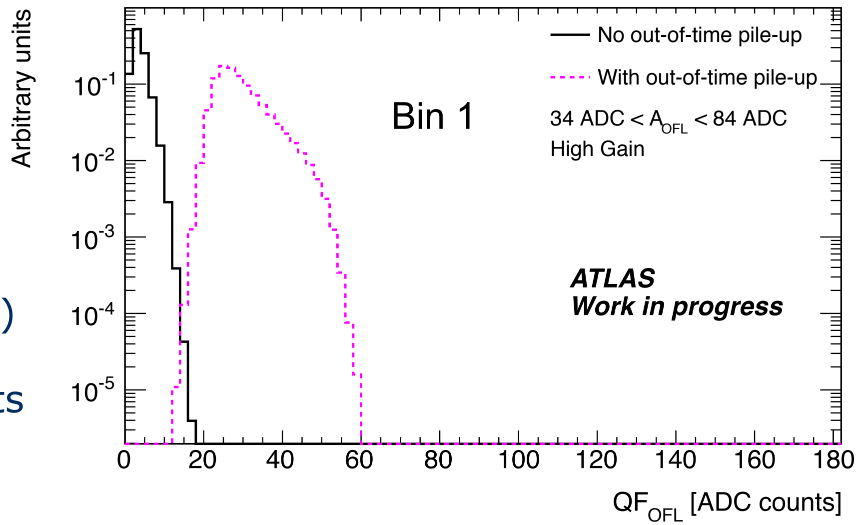




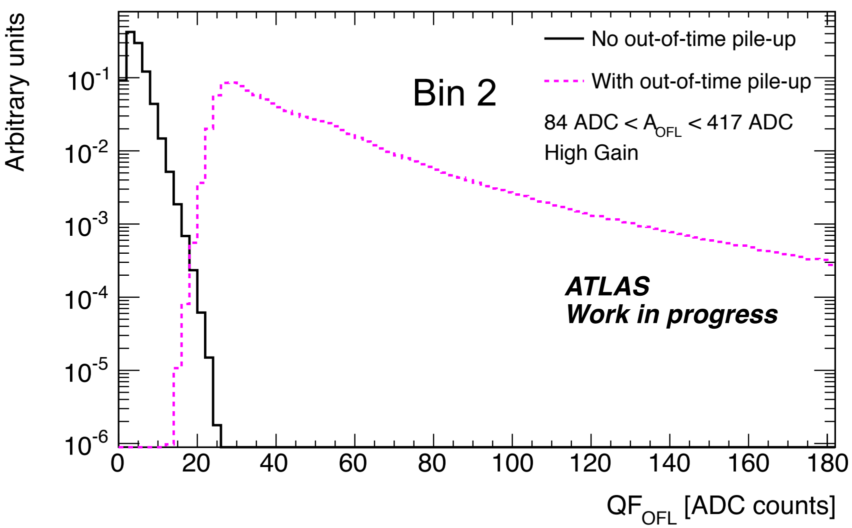
- Deviation of reconstructed amplitude A_{OFL} from the true in-time amplitude A_{in} as a function of the true amplitude of out-of-time pulse A_{out}.
- The purple line corresponds to mean value of relative difference.
- Maximal average effect on the reconstructed amplitude is 11% in all A_{in} bins if $A_{out}<A_{in}$.
- “significant” out-of-time pulses are those with amplitude above 34 ADC.

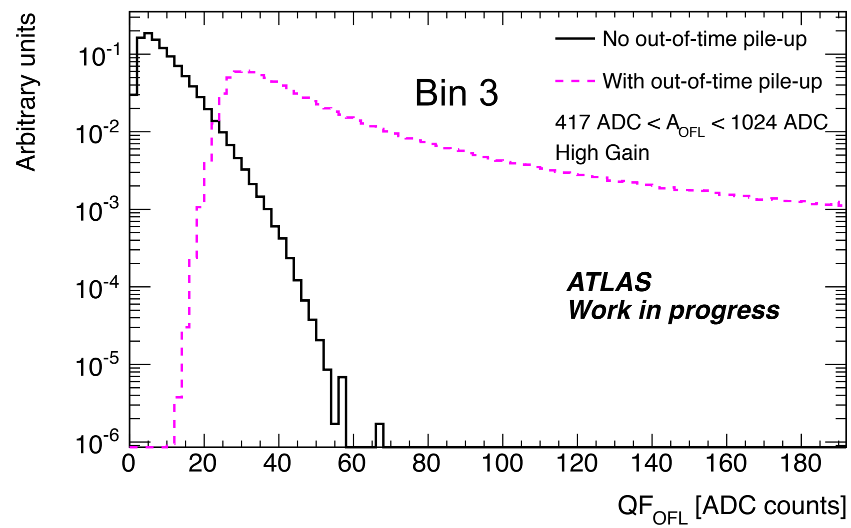
Quality factor with out-of-time pile-up

- Amplitude of in-time-pulse follows amplitude distribution in data (jet, missing energy trigger)
- 3 energy bins:
  - Bin 1: 34 ADC – 84 ADC (400 MeV – 1 GeV)
  - Bin 2: 84 ADC – 417 ADC (1 GeV – 5 GeV)
  - Bin 3: 417 ADC – 1024 ADC (5 GeV – 12 GeV)
- Amplitude of out-of-time-pulse follows amplitude distribution in data (zero bias trigger)
- Out-of-time pulses (50 ns) above 34 ADC counts (400 MeV)
- Good separation between pile-up and non-pile-up cases



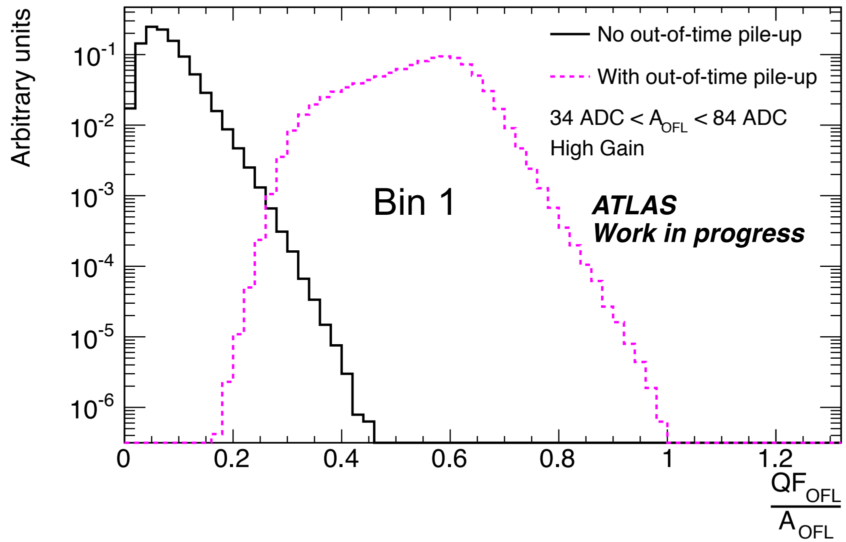
Quality factor with out-of-time pile-up

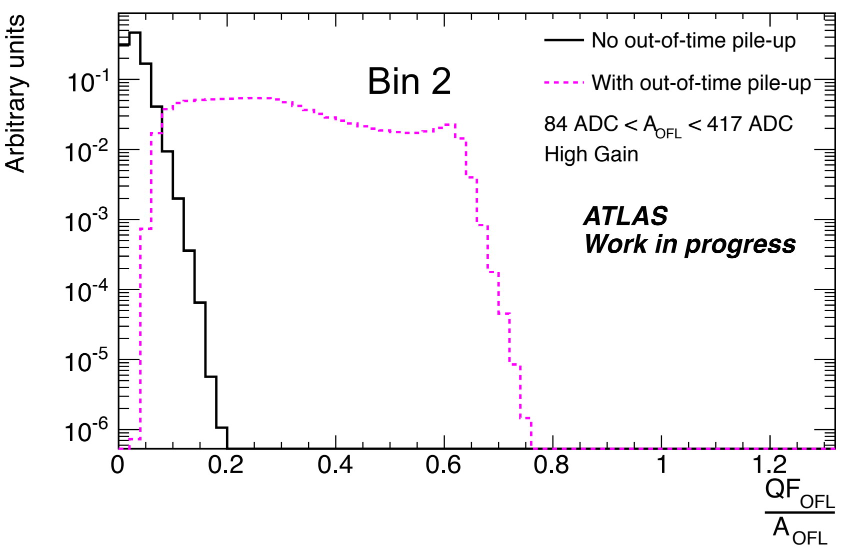


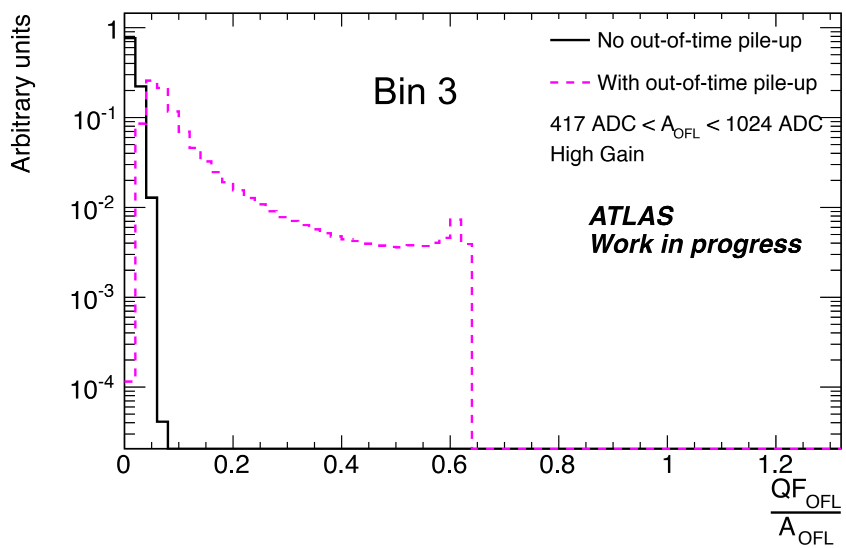


QF/Amp with out-of-time pile-up

- The same studies performed for QF/Amp.
- The observed separation between pile-up and non-pile-up cases is worse.







Detecting pile-up with quality factor

- Since there is a linear dependence of the out-of-time pulse amplitude on quality factor, three different selection criteria are defined for three different amplitude bins.
- The level of pile-up rejection can be adjusted depending on the available bandwidth.
- The fake rate is defined as a fraction of non-out-of-time pile-up events wrongly selected as a pile-up events.
- The efficiency is defined as a fraction of out-of-time pile-up events correctly selected as pile-up events.

A_{OFL} [ADC]	E_{OFL} [GeV]	QF_{OFL} cut [ADC]	Fake rate [%]	Efficiency [%]
34 — 84	0.4 — 1	8.8	0.973 ± 0.004	100.0 (> 99.9% at 95% CL)
84 — 417	1 — 5	11.6	0.985 ± 0.006	100.0 (> 99.9% at 95% CL)
417 — 1024	5 — 12	29.7	0.99 ± 0.01	85.03 ± 0.03
417 — 1024	5 — 12	22.9	3.75 ± 0.03	99.04 ± 0.01
417 — 1024	5 — 12	11.7	26.55 ± 0.06	100.0 (> 99.8% at 95% CL)

Summary

- The simulator of the ATLAS Tile Calorimeter pulses has been developed.
- Using this model, the distribution of the quality factor in the presence of out-of-time pile-up is calculated.
- It shows that when amplitude of the out-of-time pile-up is large enough to affect the amplitude measurement, significant discrimination between the presence and the absence of out-of-time pile-up can be achieved thanks to the the quality factor.
- Adequate cuts on quality factor in three various reconstructed amplitude bins are proposed in order to identify channels with out-of-time pile-up.

- ATLAS INT Note: ATL-COM-TILECAL-2012-025
- 2011 IEEE NSS-MIC proceedings: 10.1109/NSSMIC.2011.6154599
- 2012 CALOR proceedings: ATL-TILECAL-PROC-2012-007

Backup

Amplitude dependence of quality factor

- Formula for quality factor: $QF_{OFL} = \sqrt{\sum_{i=1}^{7}(S_i - A_{OFL} \cdot g_i - P_{OFL})^2}$
- Actual pulse shape is: $h_i = g_i + \delta_i$
- Each sample is: $S_i = A \cdot h_i + P = A \cdot g_i + A \cdot \delta_i + P$
- Therefore, quality factor becomes: $QF_{OFL} = \sqrt{\sum_{i=1}^{7}(A \cdot g_i + A \cdot \delta_i + P - A_{OFL} \cdot g_i - P_{OFL})^2}$
- In absence of the noise and with pedestal perfectly reconstructed: $A_{OFL} = A.$ $P_{OFL} = P$
- Therefore, quality factor formula reduces to: $QF_{OFL} = A_{OFL} \cdot \sqrt{\sum_{i=1}^{7}(\delta_i)^2}$
- In presence of the noise quality factor become: $Q_{OFL} = Q^0_{OFL} + A_{OFL} \cdot \sqrt{\sum_{i=1}^{7}(\delta_i)^2}$
- Imperfect pulses shapes are obtained by warring the width of pulse shape function: $h(t) = g(\alpha t)$

Effect of pile-up on reconstructed amplitude