Studies of the Tile Calorimeter response to muons at Test Beams

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ATLAS EXPERIMENT

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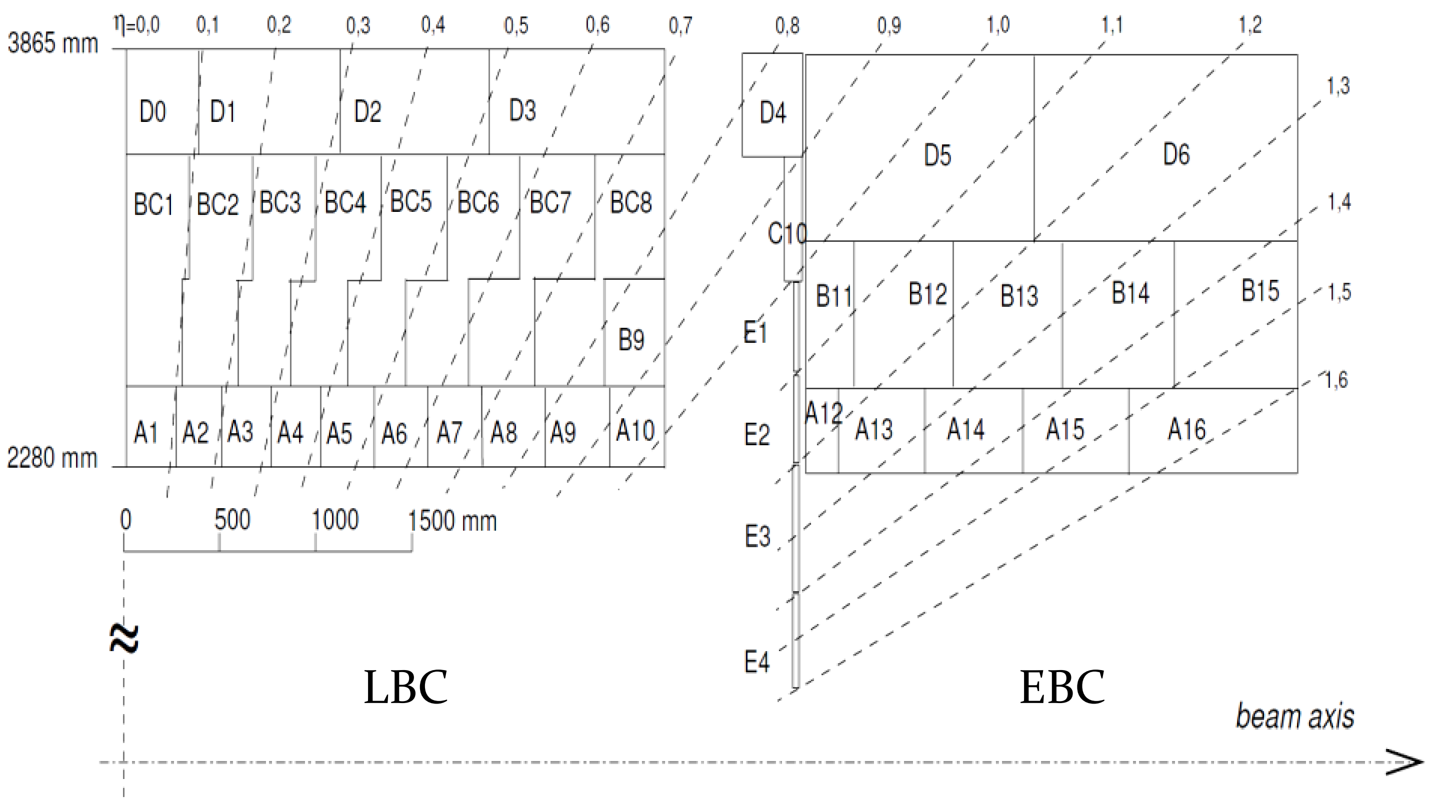
Outline

- Description of the Test Beam setup
- Signal reconstruction methods
- Energy and Timing Response in Demonstrator
  - Noise separation from signal (using 150 GeV muons at -90 °)
    - Timing cut
    - Choosing rec. method
    - Evaluating Electronic noise
    - dE/dX for A layer
  - Noise separation from signal (using 100 GeV muons at 20 °)
    - Selecting muons from an unbiased response in a layer by placing no energy cuts on the layer studied but on energy of remaining layers in the beamline.

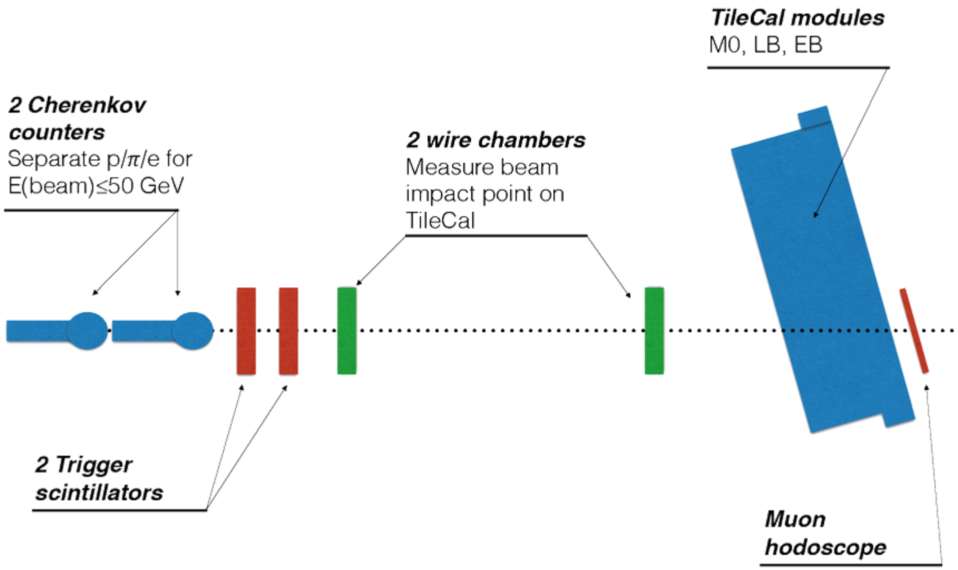
ATLAS Tile Calorimeter

Principle of TileCal:

- Measure light produced by charged particles in plastic scintillator.
- Scint. light from tiles collected by WLS fibers and delivered to photomultipliers (PMTs)
- Tile readout is grouped into projective geometry cells. each cell readout by 2 PMTs except special cells (layer E).
- Each barrel consist of 11 tile rows which form 3 longitudinal layers (A, BC, D).

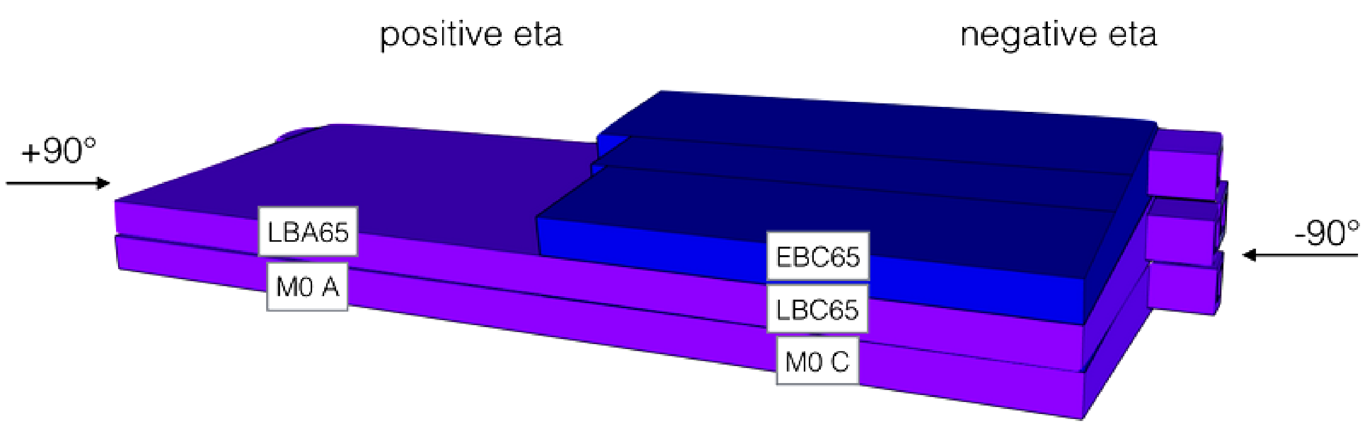


Test Beam Modules Setup



•Half-module (LBC65) has been equipped with so-called Hybrid Demonstrator. The 3-in-1 front-end option has been mounted in this Demonstrator which provides all the upgrade functionalities but maintaining the analog trigger signals for backward compatibility.

•Another half-module (LBA65) has been instrumented with other two front-end electronics options (QIE and FATALIC) which are under evaluation.



- These modules equipped with Phase-II upgrade electronics together with modules equipped with the legacy system where exposed to different particles and energies in three test-beam campaigns during 2015 and 2016.

Introduction

Interest in muons:

- Muons provide a different approach to the calibration procedure and a cross-check of the existing calibration. The advantages to calibrating with muons are:
  - The muon signal is well understood and the deposited energy is more or less proportional to the traversed path length.
  - Muons deposit energy in all calorimeter cells along the path.
  - The energy deposit is less energy dependent than for other particles
- Also muon signals are important for evaluating electronics performance, since they produce a signal that is close to electronics’ noise values.
- Goal is to separate muon signal from the electronics’ noise.

Signal reconstruction

- The analog signal from PMTs is shaped and sampled every 25 ns.
- Several methods exist to reconstruct amplitude (A), time (τ) and quality factor (QF)

● Fit method: fit with $f(t) = Ag(t-\tau) + c$

where g is known normalized pulse shape, A amplitude (Efit) , τ phase (Tfit) , and c pedestal.

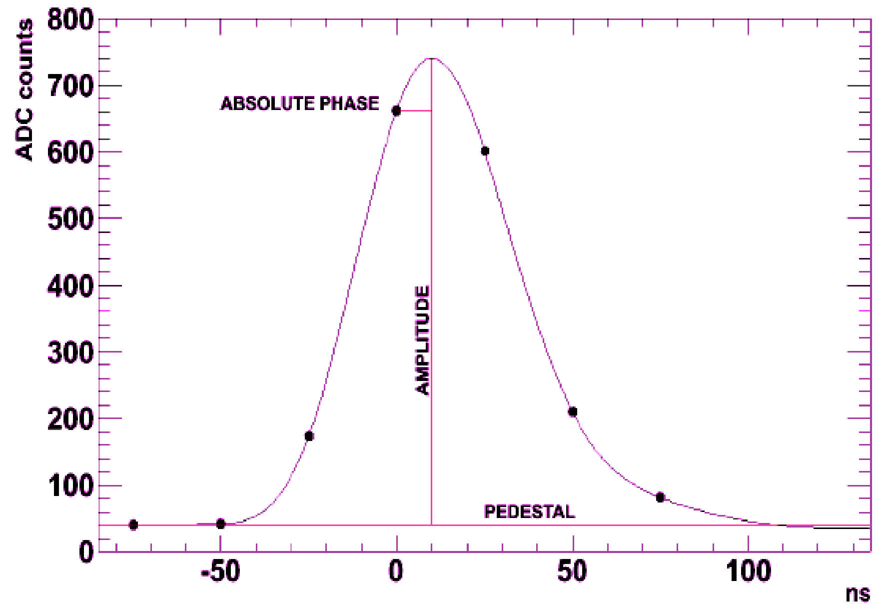
● Optimal Filter: weighted sum of measured samples, designed to minimize the noise:

$$A = \sum_{i=1}^{N} a_i S_i$$

$$A\tau = \sum_{i=1}^{N} b_i S_i$$

$$QF = \sum_{i=1}^{N} \mathrm{abs}(S_i - Ag_i)$$

S_i - i^{th} sample
N - number of samples
A - amplitude of the signal (Eopt)
τ - the phase with respect to the expected samplingtime (Topt)
QF - quality factor of the reconstruction.

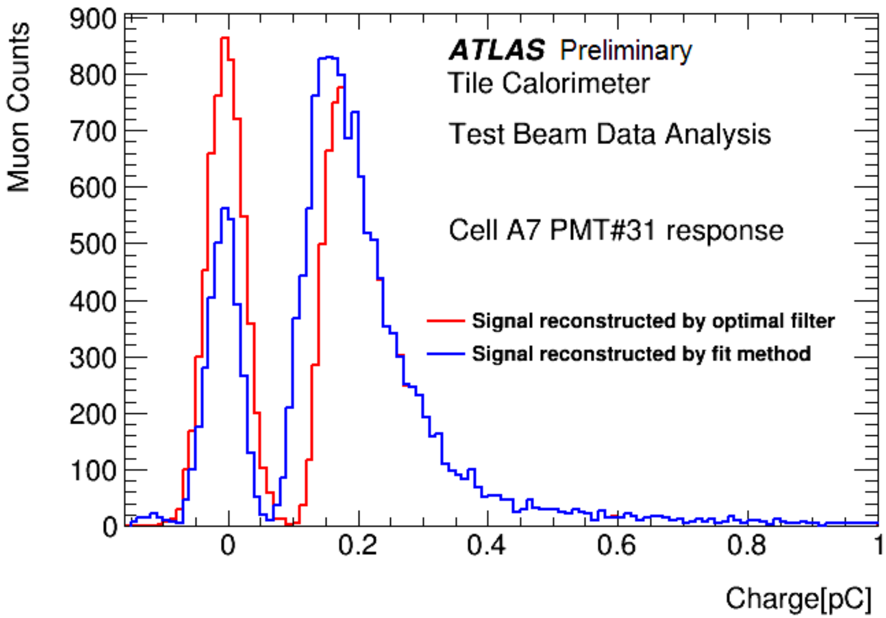


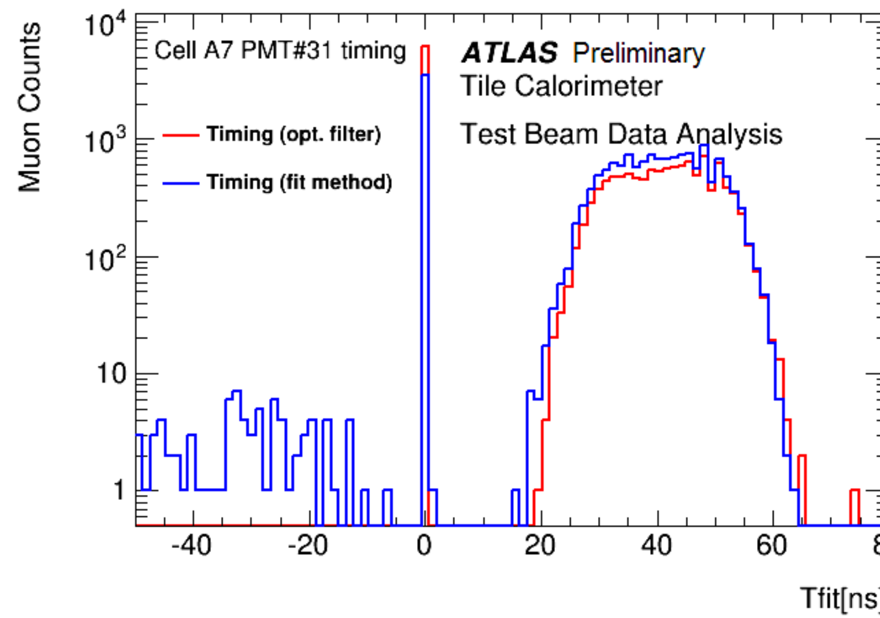
Iterative optimal filter: multiple iterations to find correct position of the peak.

if (max_sample - ped) <= threshold - no iterations in both methods, phase=0 is assumed.
threshold:
- 5 ADC counts hard-coded value in opt. filter (optimized cut for legacy system)
- adjustable parameter in fit method

Energy and Timing Response in Demonstrator

- These are the results of the analysis of 150 GeV muons hitting LBC module at -90°.
- Left plot – Amplitude reconstructed using both methods (cell A7 PMT#31).
- Right plot - Timing reconstructed using both methods (cell A7 PMT#31).





- Optimal filter and Fit method give identical results for good signals above noise threshold
- Behavior for small signals is different because different noise thresholds used:
  - 5 ADC counts in Optimal filter
  - 3.2 ADC counts in Fit method
- When Tfit leaves time window (range where most of the events are), reconstructed amplitude with fit method might be negative (small bump at the left plot on the negative side of x axis).
- Peak at zero on the right plot represents noise events reconstructed without iterations.

Determining reconstruction method and timing for each event to separate signal from noise

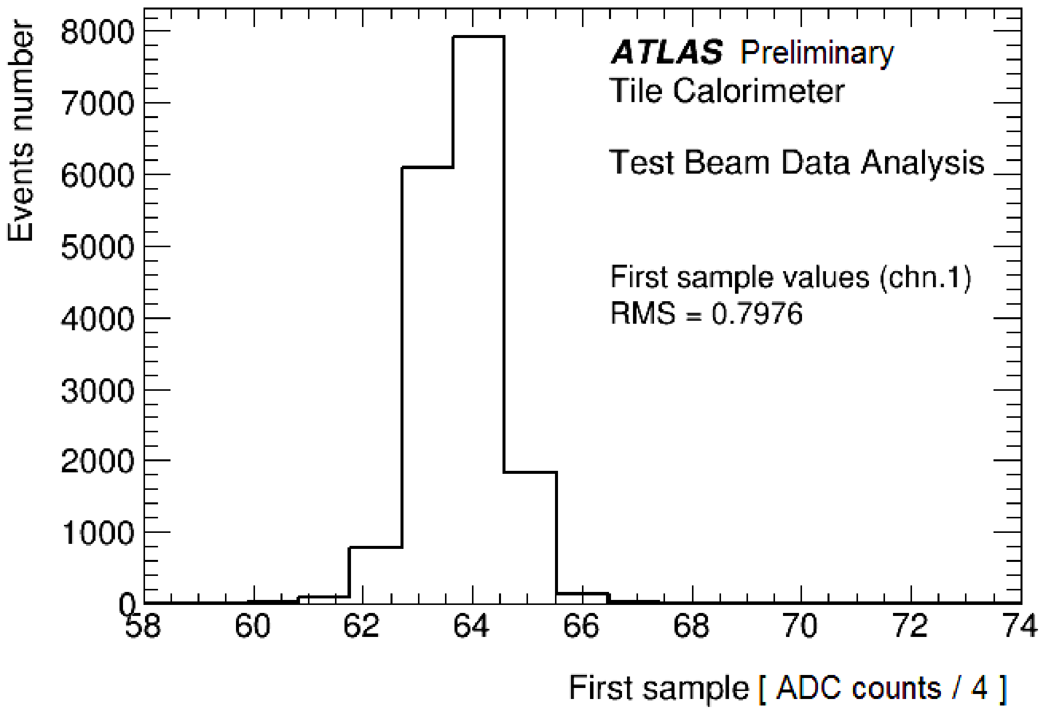
- Keep only signals after iterative reconstruction method:
  - Time!=0 cut (indication of iterative method) effectively selects events which have some signal above noise threshold.
- Apply more strict cut on time window:
  - To remove noise from fake signals, reconstructed time was required to be compatible with triggering time (to be in 50 ns time window where all the signals with big amplitudes are).

- Optimization of the noise threshold:
  - Initial thresholds values of 5 ADC counts (in Optimal filter) and 3.2 ADC counts (In Fit method) were found to be non-optimal.
  - Smaller noise in new electronics allowed to keep smaller muon signals for analysis.
  - Instead of single threshold value for all the channels, different values of noise thresholds proportional to electronic noise RMS in given channel were studied:

threshold = C * sampleRMS, where C=2,3,4

Electronic noise evaluation

- Electronic noise RMS was evaluated using amplitude of the first sample (which never contains signal).
- Noise in PMT#2 connected to cell A1 is shown on the plot.



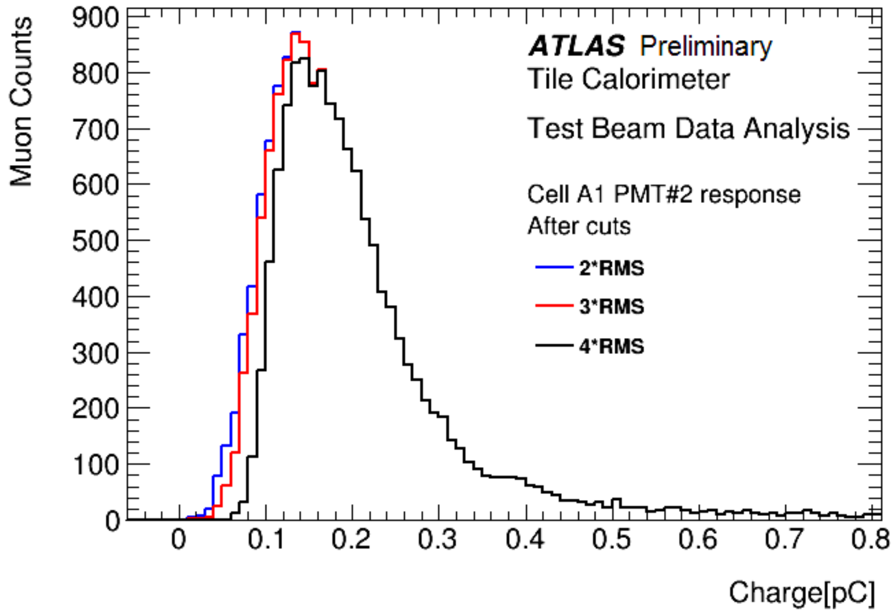
- Noise is about 0.75 counts for most of the channels (see table in the backup).
- N.B: In this part of the analysis true 12-bit ADC readout of new system was converted to 10 bits range, to be compatible with 10-bit readout in legacy system (i.e. actual signal in ADC counts is 4 times bigger)

Electronic noise evaluation

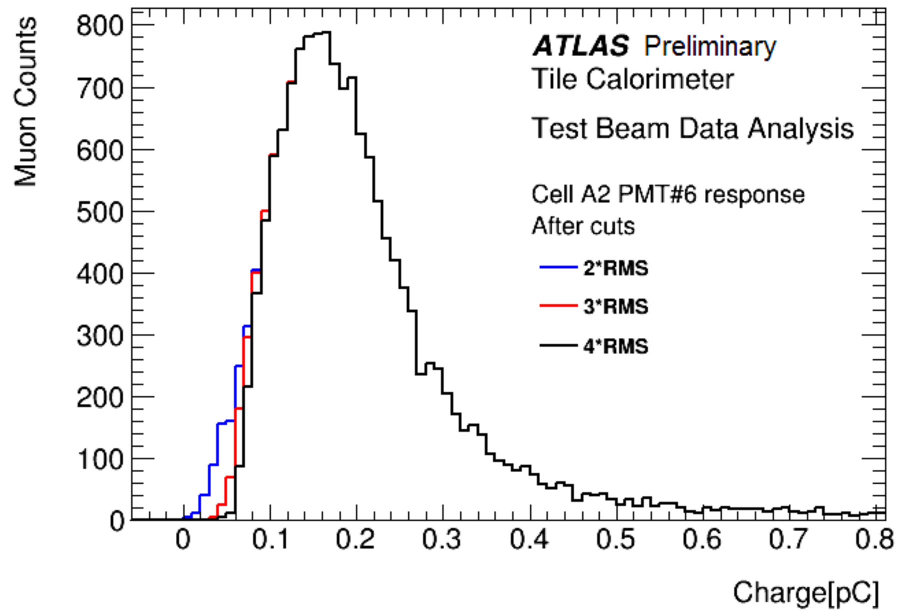
- After applying cuts on time and determining reconstruction method for each event, for noise evaluation several thresholds were considered:

C * sampleRMS , where C=2, 3, 4

Cell A1 PMT#2 response



Cell A2 PMT#6 response

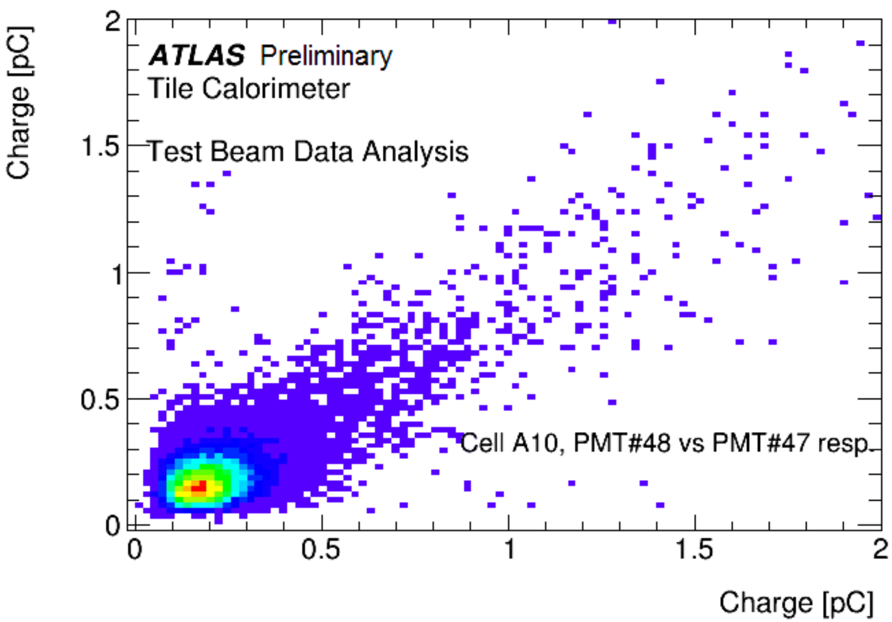


As a noise threshold 3*RMS is selected!
Distribution behavior in low signal range is more like landau distr.
(Logy scale in backup)

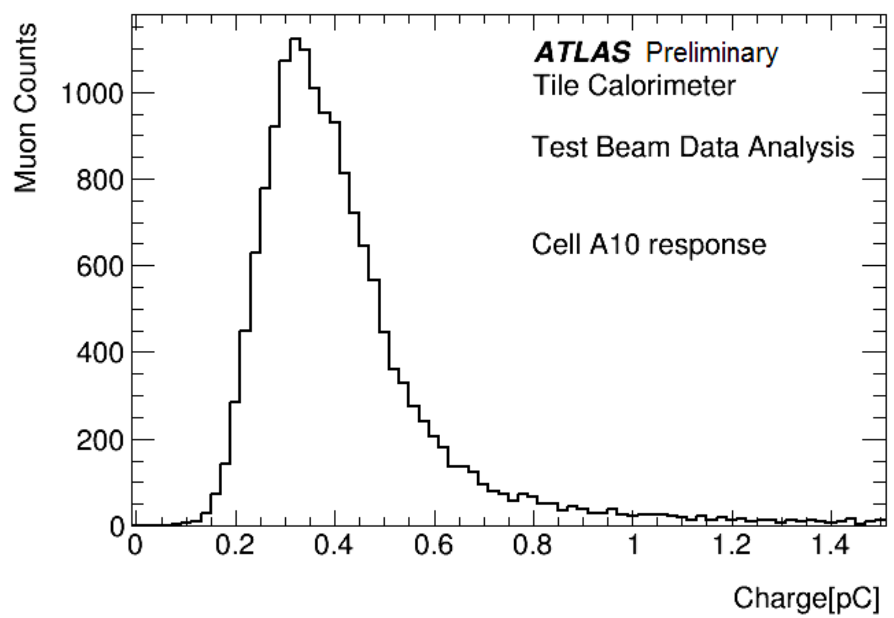
Evaluating cell signal

- To obtain a cell response corresponding two PMTs' signals are summed up (amplitude and timing cuts applied).

A10 cell PMT#48 vs PMT#47 signal resp.

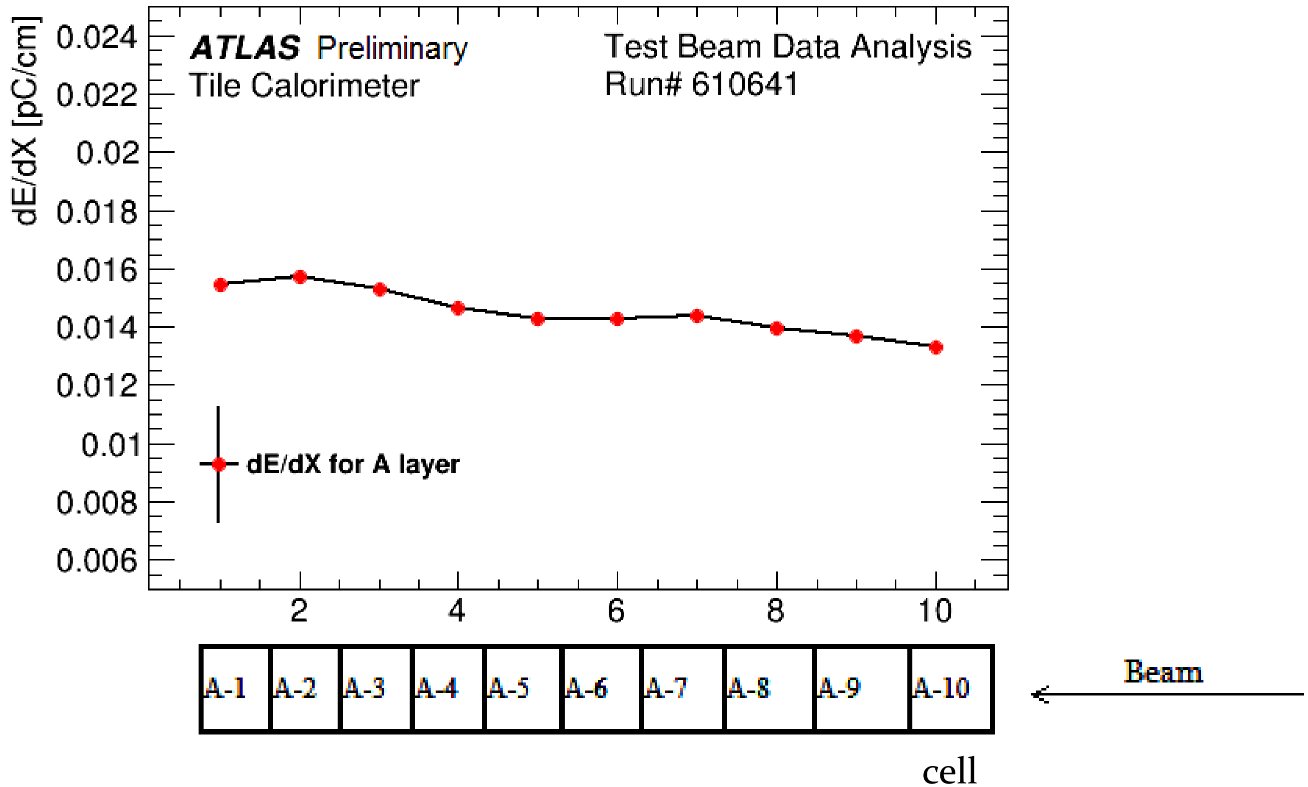


A10 cell signal response



dE/dX for A layer

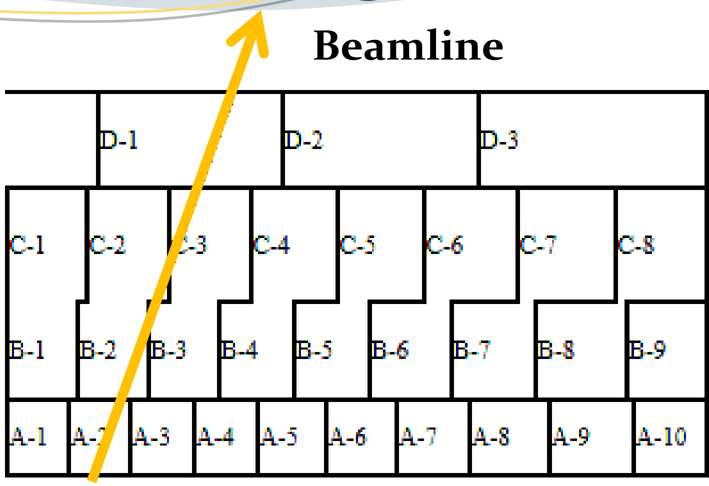
- dE - signal truncated mean (95%) value in the range of [0,1.5]pC in each cell.
- dX - length of a cell
- Maximum difference between cell's dE/dX is around 15%

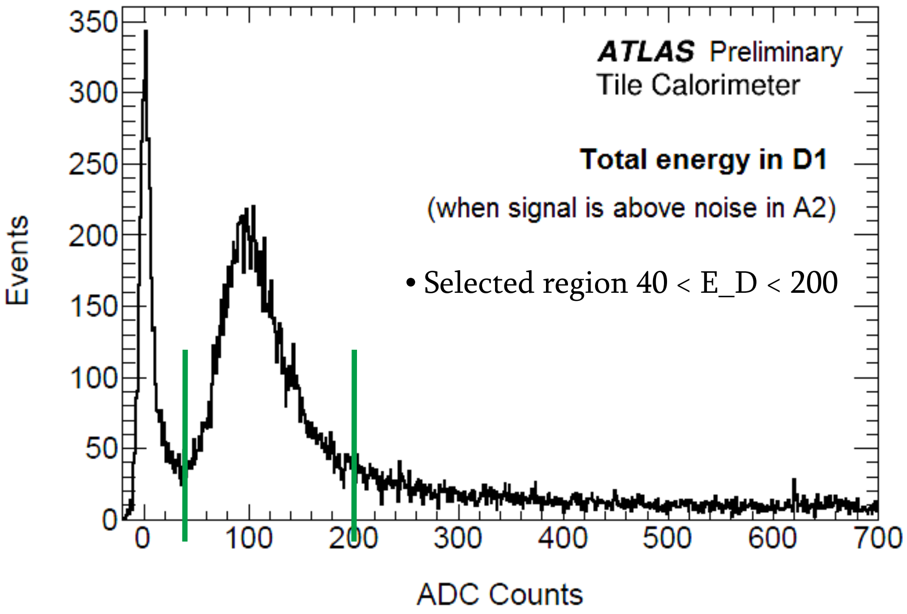


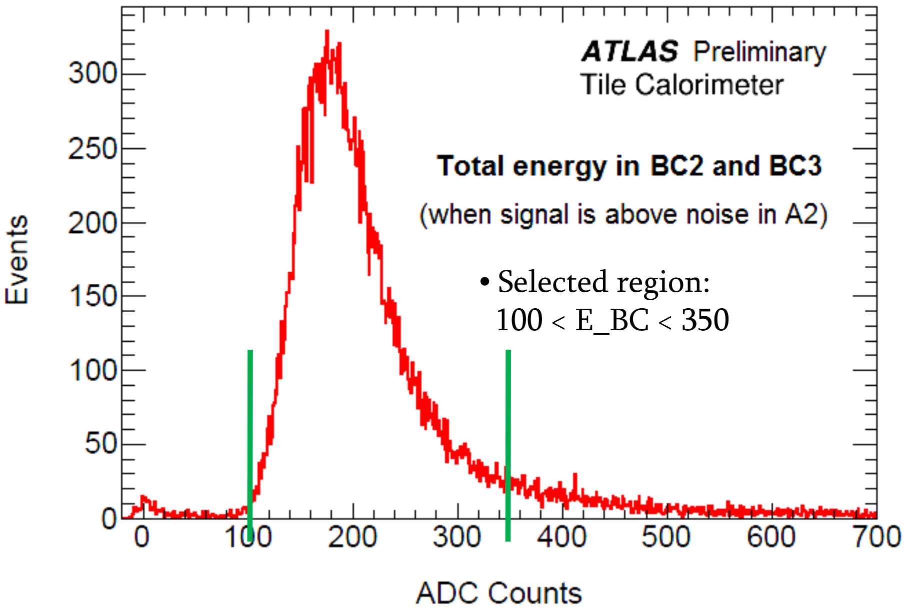
One expects a flatter behavior. Further studies are necessary.

Noise separation from signal using 20° muons

- When there is an "event" in layer A (above noise), total energy in BC2 and BC3 and total energy in D1 are found.
- By looking at those two distributions separately, region of signal is determined.
- As a signal region for tot. E of D1 is chosen [40,200]adc counts.
- As a signal region for tot. E of BC2 and BC3 is chosen [100,350]adc counts.

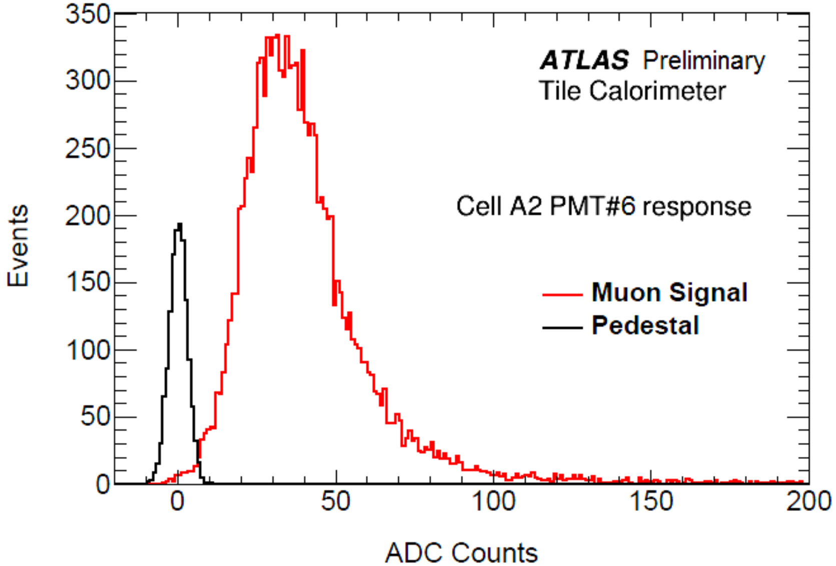


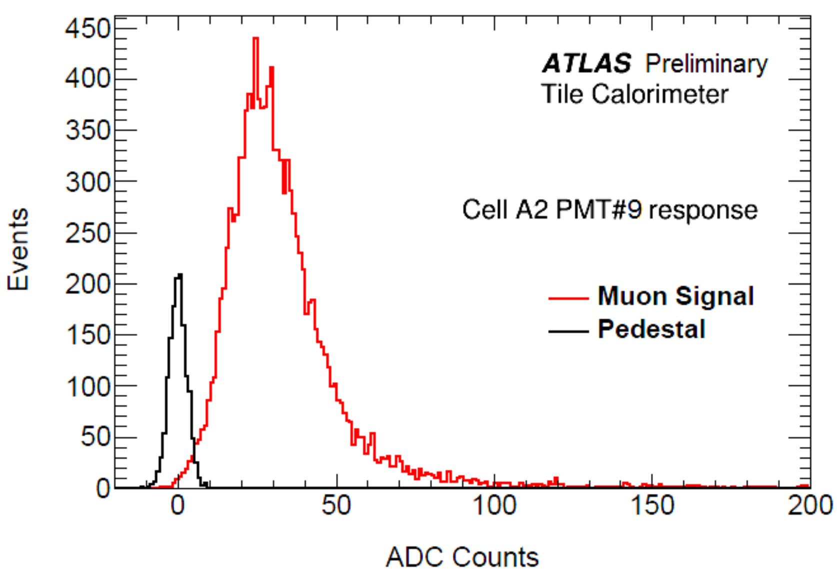




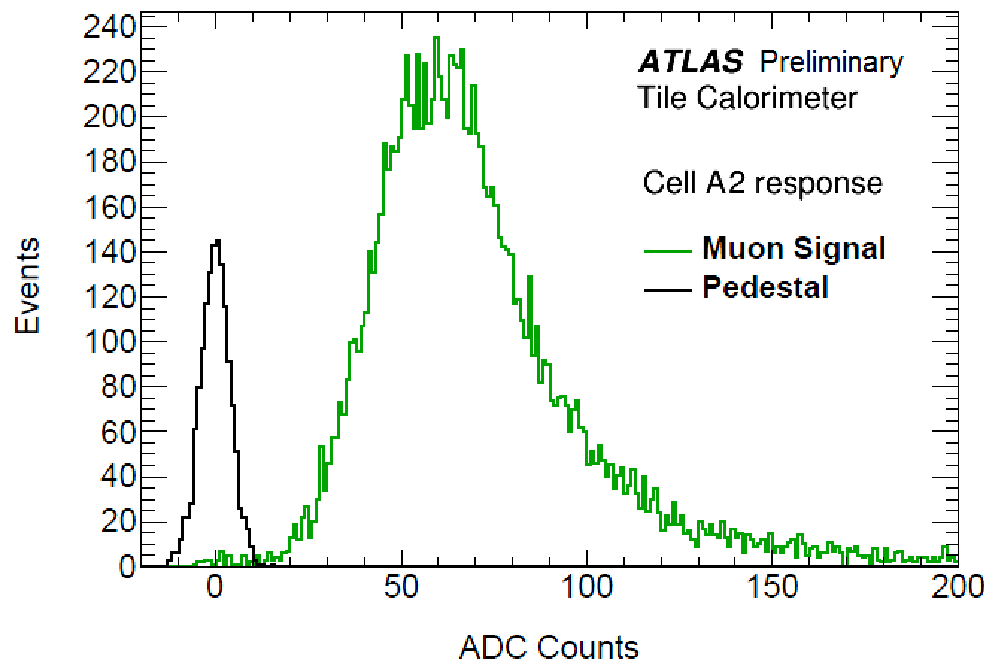
Noise separation from signal using 20 ° muons

- After cut is placed on tot. E of D1 and on tot. E of BC2 and BC3 signal in A layer looks like:





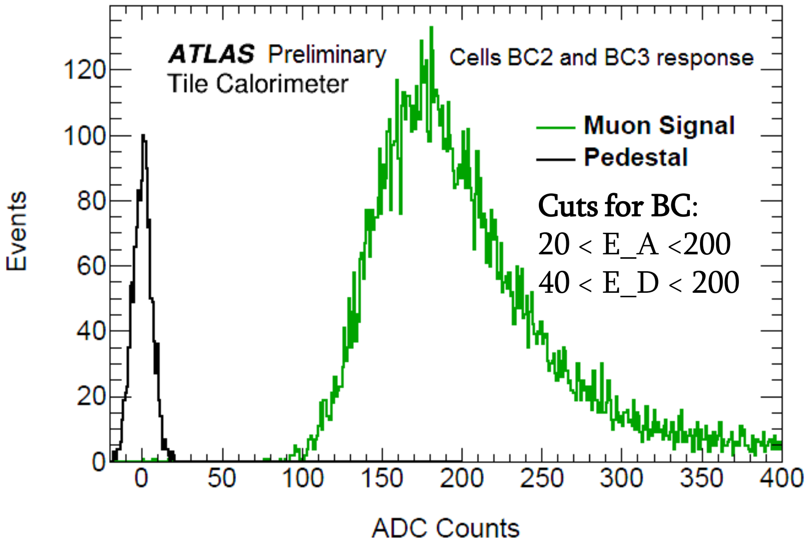
pedestal - reconstructed signal in a given cell from a run when beam doesn't hit Demonstrator.

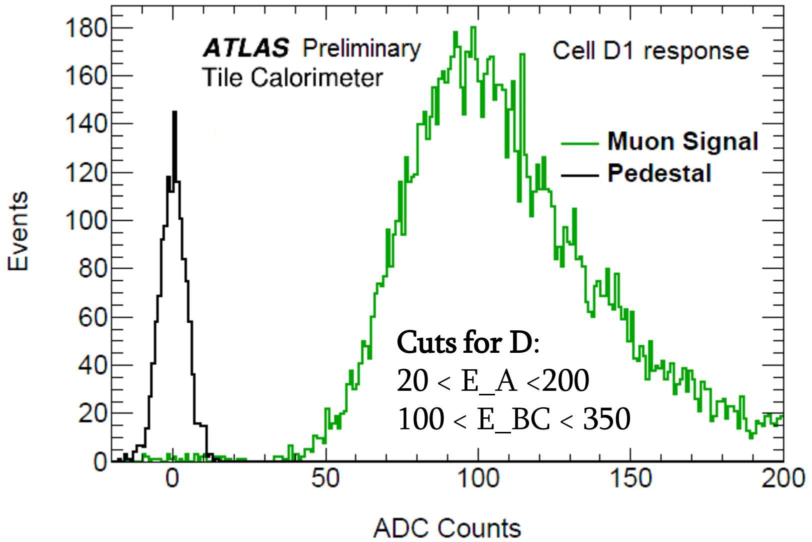


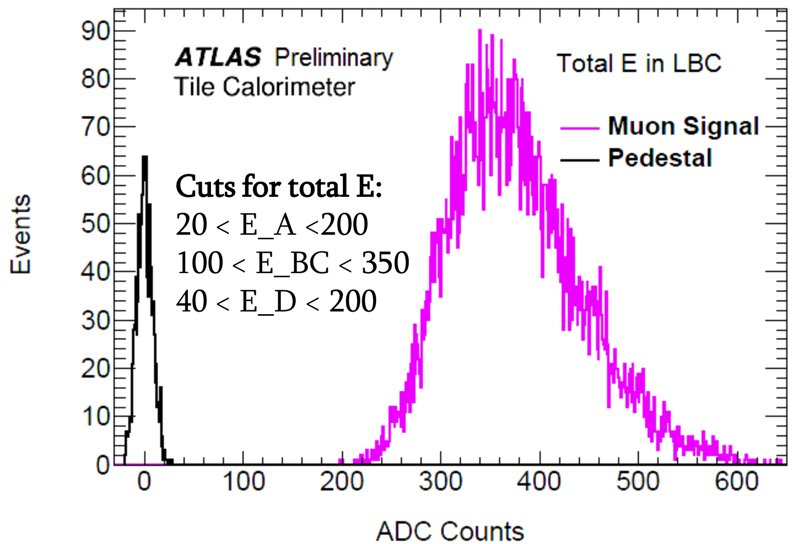
Clean muon signal after this cut!

Noise separation from signal using 20 ° muons

- This process is repeated for BC layer and D layers' cells and final results are:







Summary

- Two sets of 2016 testbeam muon data were analyzed:
  - 150 GeV muons at -90 °.
  - 100 GeV muons at 20 °.
- Two different approaches to separate muon signal from noise were studied:
  - Require signal to be above noise in every channel.
  - Consider signal in given cell requiring signal to be above noise in other cells along muon path.
- For the first approach several noise thresholds were considered (C * sampleRMS, C=2, 3, 4) and 3 * sampleRMS was chosen for analysis.
- Very preliminary results of dE/dX for muons passing calorimeter at different angles were obtained.

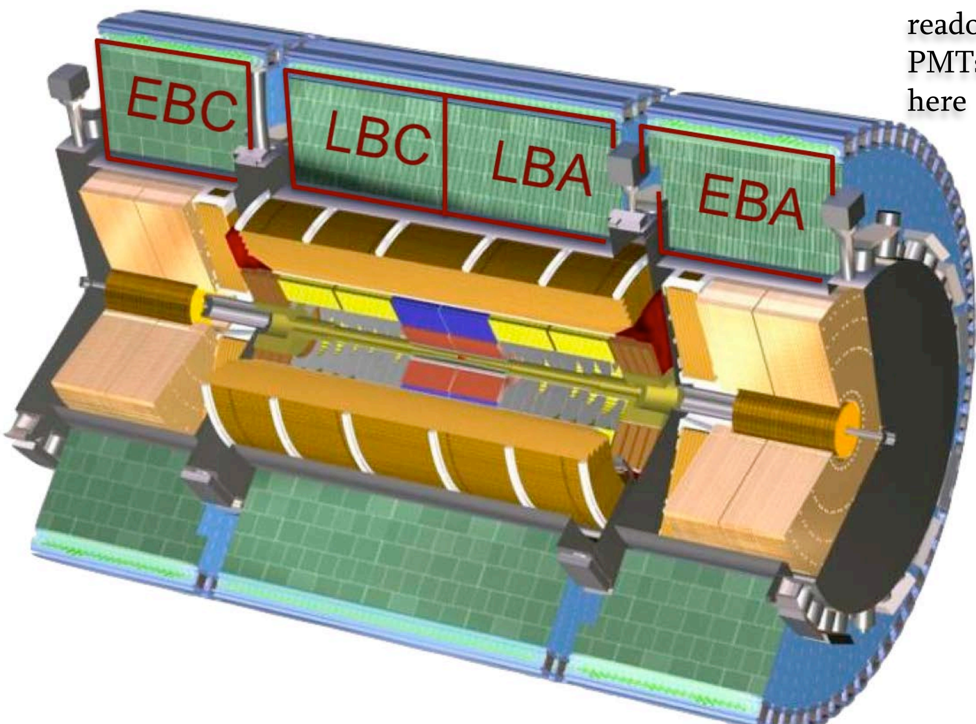
- Future plans:
  - Further study of dE/dX distribution.
  - Two campaigns of Test Beam 2017 will be held.

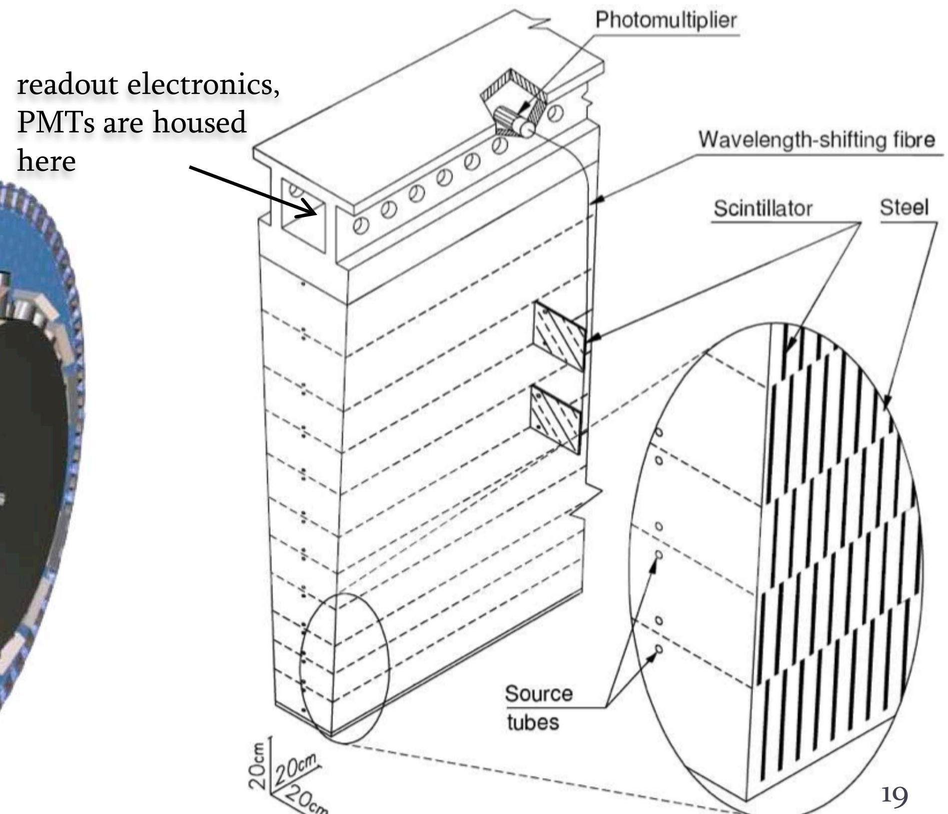
Thanks for attention!

Backup

ATLAS Tile Calorimer

- The TileCal is the central hadronic calorimeter within the ATLAS at the LHC situated at CERN, Geneva.
- The TileCal is composed of four barrel sections (two central and two extended barrels), each containing 64 azimuthal slices.
- The Phase II Upgrade of the LHC plans to increase the present instantaneous luminosity by a factor of 5-10.
- will need to withstand a much higher radiation dose as well as a increased demand for data throughput.





Electronics' noise response

RMS value obtained from the first sample distribution for each channel (corresponding PMT#) :

A layer		BC layer		D layer	
PMT #	RMS	PMT #	RMS	PMT #	RMS
2	0.78498	3	0.783039	1	0.779694
5	0.991726	4	0.72883	14	0.807068
6	0.721143	7	0.769982	15	0.788244
9	0.73934	8	0.731003	27	0.753645
10	0.725907	12	0.731869	26	0.78456
11	0.74707	13	0.770013	40	0.746015
16	0.730422	17	0.908091	43	0.820798
19	0.772104	18	0.74048		
20	0.751312	22	0.781183		
21	0.802576	23	0.826634		
24	0.825841	30	0.735548		
25	0.757607	29	0.743319		
28	0.733694	36	0.775597		
31	0.725758	35	0.746649		
34	0.747074	42	0.719096		
37	0.717232	41	0.734265		
39	0.710739	45	0.720834		
38	0.755751	46	0.712921		
48	0.718566				
47	0.730544				

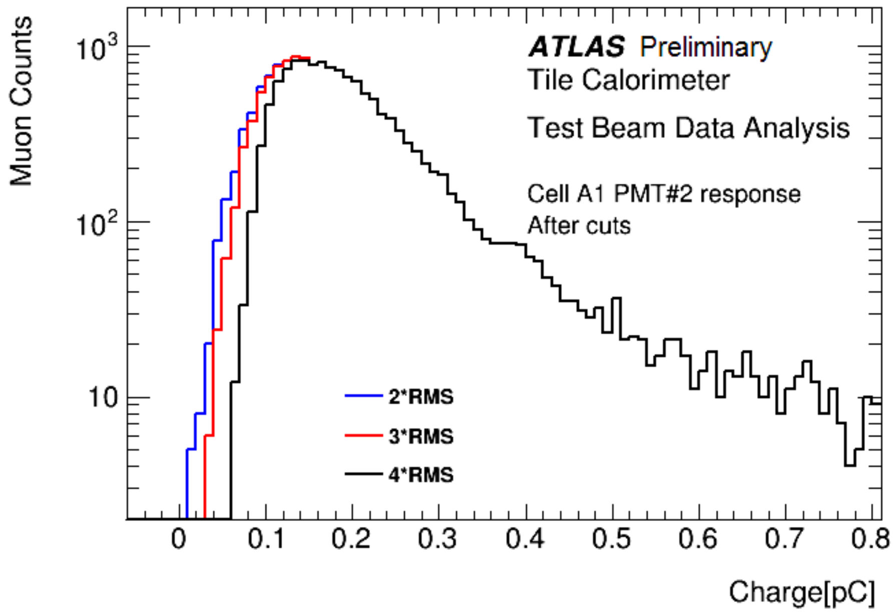
Electronic noise evaluation

- Used cuts:
- if Topt ! = 0 then Eopt is used.
- if Topt = = 0 and Tfit ! = 0 and Tfit is in corresponding time window then Efit is used.

- After applying cuts on time and determining reconstruction method for each event, for noise evaluation several thresholds were considered:

C * sampleRMS , where C=2, 3, 4

Cell A1 PMT#2 response



Cell A2 PMT#6 response