The Tile Calorimeter

QFTHEP 2013

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On behalf of the ATLAS Tile Calorimeter group

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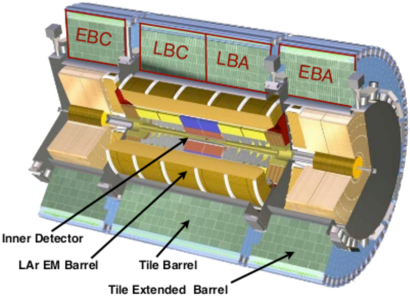
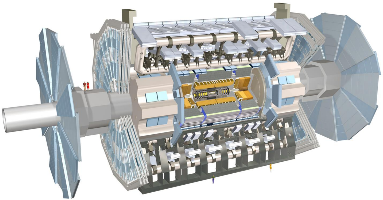
Introduction

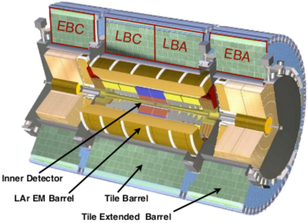




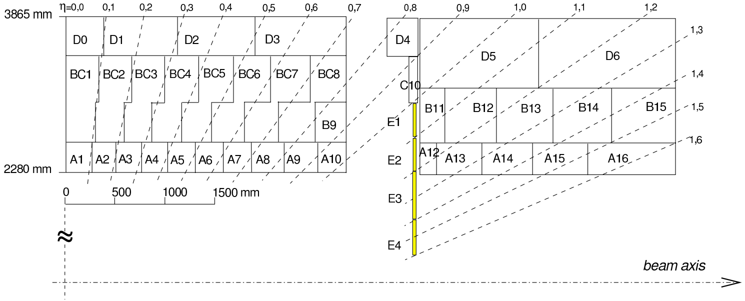
- Central **hadron calorimeter** in ATLAS.
- Measures energy and position of absorbed particles.
- Registers jets, hadronic τ decays, E_T^{miss}, helps identify muons.
- **Jets**: topoclusters around cells with large signal compared to noise.
  - Jet energy resolution: $50\%/\sqrt{E\,[GeV]} \oplus 3.\%$
- $\mathbf{E_T^{miss}}$: theoretically zero from conservation of momentum.
  - A large E_T^{miss} could indicate the presence of neutrinos or WIMPs.

Dimensions

- Mass: 3000 tons
- Inner radius: 228 cm, outer radius: 423 cm.
- One long barrel + 2 extended barrels.
  - Gap of 60 cm between barrels.
  - Long Barrel: 654 cm
  - Extended Barrels: 219 cm.
- Each barrel is segmented in 64 modules azimuthally.

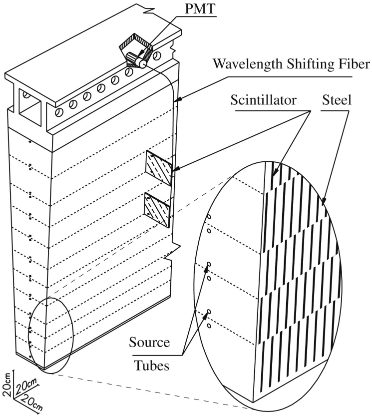


Coverage



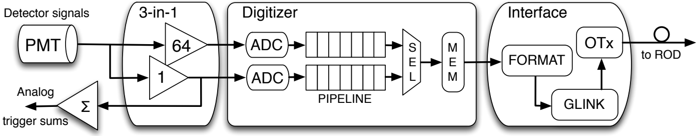
- Central hadronic calorimeter, covering $-1.7 < \eta < 1.7$
- η - solid angle along length of ATLAS, defined as $\eta = -\ln(\tan(\frac{\theta}{2}))$ (θ - polar angle), ϕ - azimuthal angle
- Three longitudinal layers: A, BC and D. 5200 cells in total.
- Gap and crack cells (E cells) in gap between long and end barrels.
- Granularity: $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ in A and BC, 0.2×0.1 in D.

Instrumentation



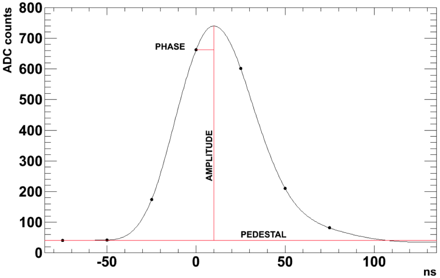
- Each cell: dozens of **scintillating tiles** embedded in steel absorber plates.
- **Wavelength shifting fibres** connected to tiles transport light to PMTs.
- Each cell read out by **two PMTs** from both ϕ sides for uniformity and redundancy.
- Plates are perpendicular to the beam axis.

Readout

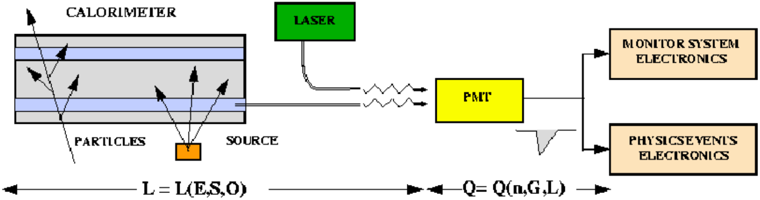


- A shaper widens the sharp peak from the PMT for better sampling.
- Pulse is amplified in high/low gain branches with gain ratio 64.
- Analog signals provided to level 1 trigger.
- **Digital samples** are stored in front end pipeline memories.

- Signals given level 1 trigger accept are transported to back end electronics for **reconstruction**.
  - Signal: 7 samples 25 ns apart.
  - Amplitude of pulse $\propto$ energy
  - Position of peak gives the timing.



Calibration



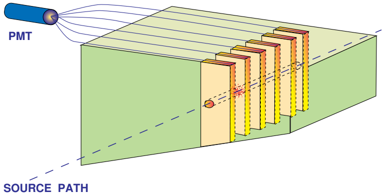
Calibration constants

Calibration constants needed to relate the induced charge to digital pulse and to cell energy.

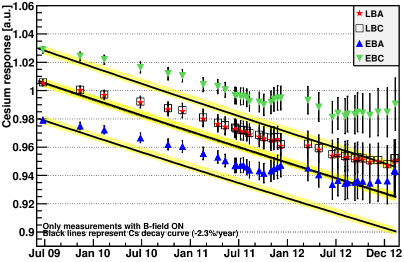
- Constants derived from charge injection system (**CIS**) relate ADC counts to a charge.
- Conversion factors from testbeams relate charge to cell energy.
- Calibration with **cesium source**: monitor response of scintillators, PMTs.
- Irradiation of PMTs with **laser** monitor response of PMTs.
- $E = A \cdot C_{ADC \to pC} \cdot C_{pC \to MeV} \cdot C_{Cs} \cdot C_{laser}$

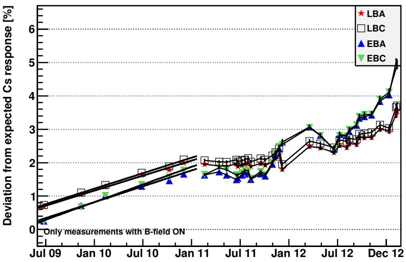
Cesium calibration

- Monthly calibrations of optics and PMTs.
- Tubes with $_{137}\mathrm{Cs}$ pushed through the scintillators using hydraulics.

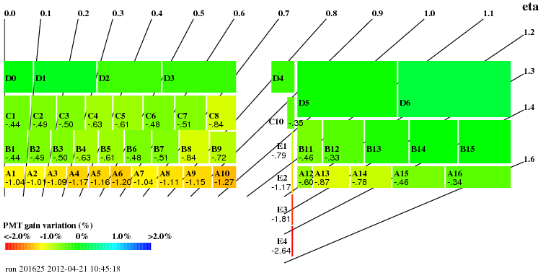


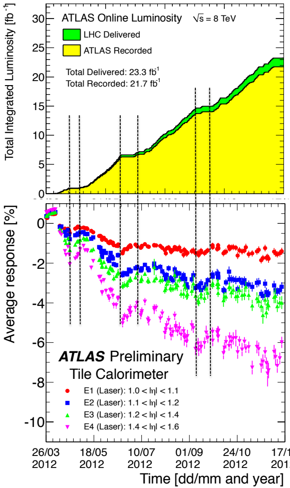
  - Calibration precision: 0.4%.
  - Some decrease in response expected from ageing.
  - Deviation from expected response increases during data taking.





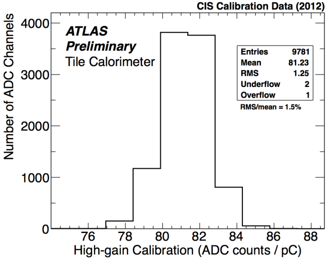
Laser calibration

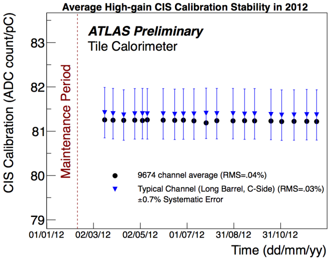




- Monitor gains of PMTs by irradiating them with laser weekly. Precision: 0.3%.
- Correct for nonlinearity of response.
- Mean down-drift of PMT response below 1.3% a year, except E cells.
- Periods of data taking visible as up drift.

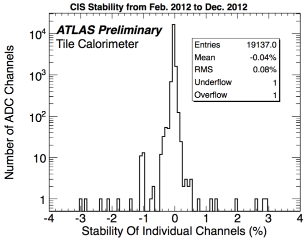
Charge injection



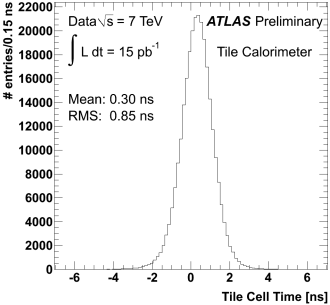


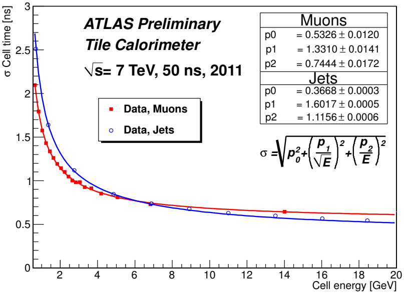
- Conversion from amplitude in ADC counts to a charge.
- Weekly runs for calibration of front-end electronics.

- Very stable: constants updated twice a year.
- RMS of variation 0.08% over 2012.
- Channels with variations > 1% recalibrated.



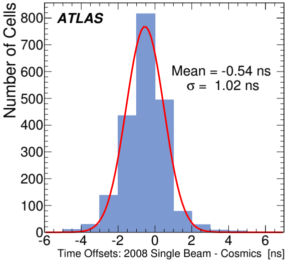
Timing



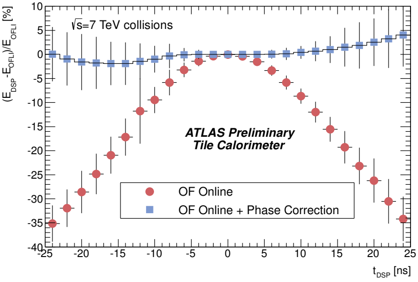


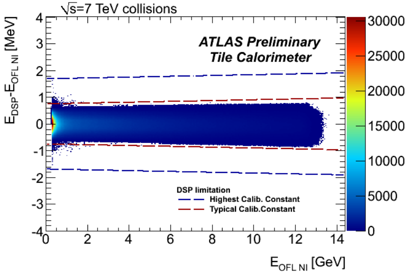
$$\sigma = \sqrt{p_0^2 + \left(\frac{p_1}{\sqrt{E}}\right)^2 + \left(\frac{p_2}{E}\right)^2}$$

- Time between consecutive bunch crossings: 50 ns.
- Timing from collisions: $0.30 \pm 0.80\,\mathrm{ns}$.
- Cell time resolution: 1 ns for $> 4\mathrm{GeV}$.
- Difference in time offsets for single beam - cosmics: $-0.54 \pm 1.02\,\mathrm{ns}$.



Energy reconstruction

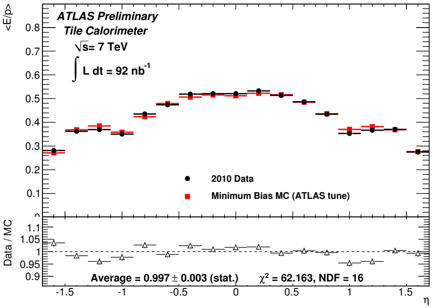


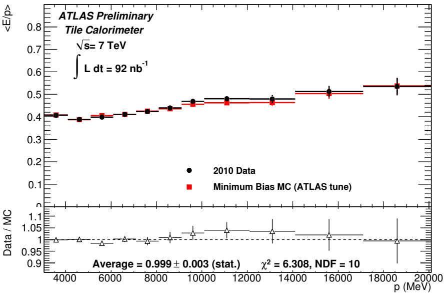


- Timing crucial for energy reconstruction.
- Corrections for timing applied offline.
- Validation of energy reconstruction by comparison of two different methods (noninterative and offline).
- Maximum expected difference proportional to calibration constants.
- 99% of channels within maximum expected precision of ± 1 MeV.

Single particle response

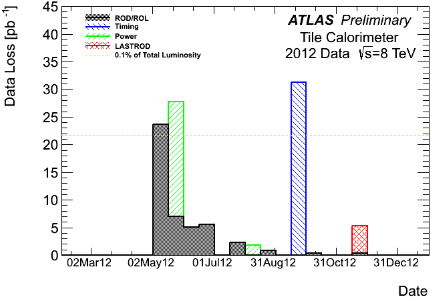
- An in-situ method to probe the calorimeter response that can be performed on isolated hadrons.
- Based on ratio of energy E measured in the calorimeter over the momentum p measured by the inner tracking system.
- η dependence is understood and overall **E/p** is well modelled in MC.





Data quality efficiency

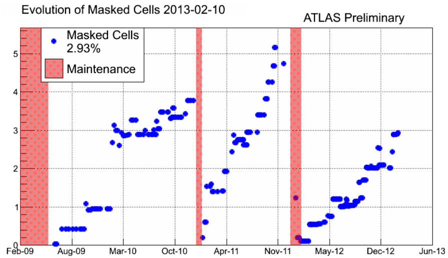
- Data loss below 0.1% of luminosity.
  - Problem with readout datataking process in spring 2012 - solved.
  - Problem with timing in September.
- Tile is 99.6% efficient.

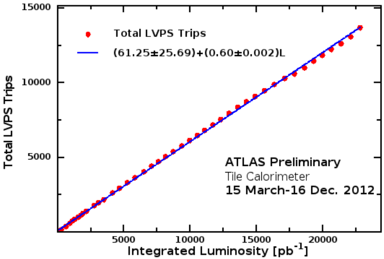


ATLAS p-p run: April-December 2012										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.1	99.8	99.1	99.6	99.6	99.8	100.	99.6	99.8	99.5
All good for physics: 95.5%										

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at √s=8 TeV between April 4th and December 6th (in %) – corresponding to 21.3 fb^{-1} of recorded data.

Masked cells and LVPS



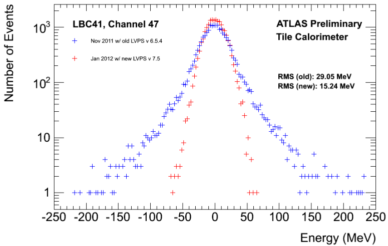


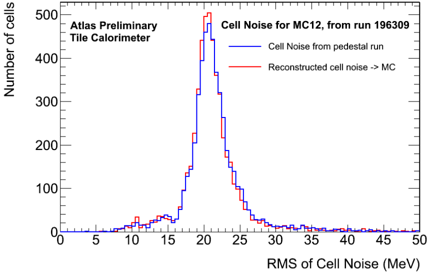
Masked cells

- Cells with corrupted data are **masked**, 2.93% at end of data taking.
- Each maintenance period brought fraction of masked cells to ‰ level.
- Sharp increase of masked cells: loose halves of modules, e.g. breakdown of low voltage power supplies (LVPS) or power connectors.

- **Trips** in **LVPS** $\propto$ integrated luminosity; caused by radiation.
  - 14 000 trips in 2012.

Noise description



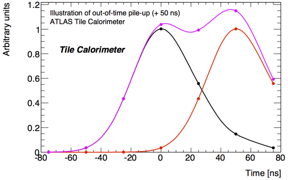


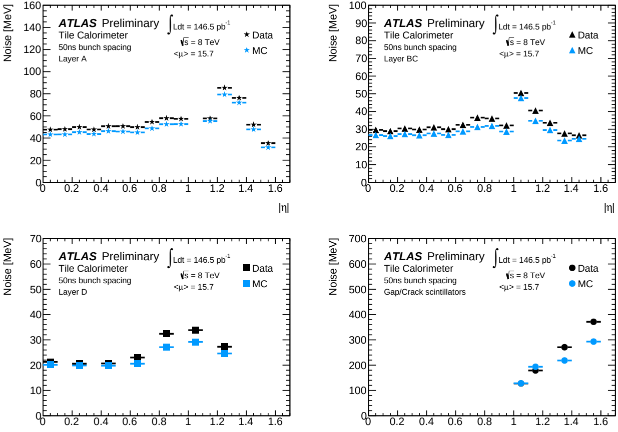
Noise

- Electronic noise: random fluctuations in electronics.
- Conversion from ADC counts to MeV using calibration constants.
- Modelled by a **double Gaussian**, partly due to old LVPS.
- Long tails in noise taken into account when defining jet algorithms.
- Good agreement between data and MC simulations.
- A new version of LVPS results in noise that looks more Gaussian.

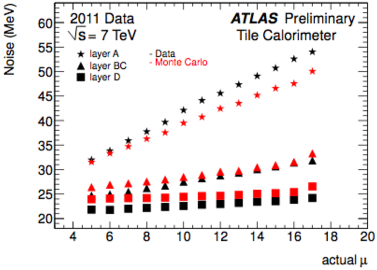
Pileup (1)

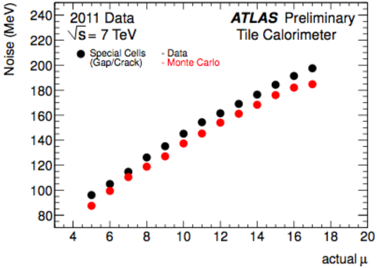
- Elevation of noise - two events interfering.
- Pileup noise at 50 ns bunch spacing and 15.7 interactions per bunch crossing shown below.
- Even larger effect for 25 ns bunch spacing.





Pileup (2)

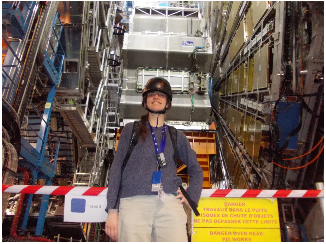




- The pileup varies as a function of μ, the number of interactions per bunch crossing.

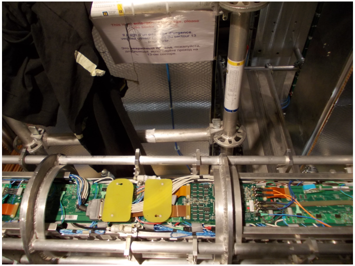
Outlook

- Long shutdown 1: Feb 2013 - April 2015 for consolidation of electronics.
- Perfect time to visit CERN!
- After consolidation, continue operation until phase 2 upgrade.



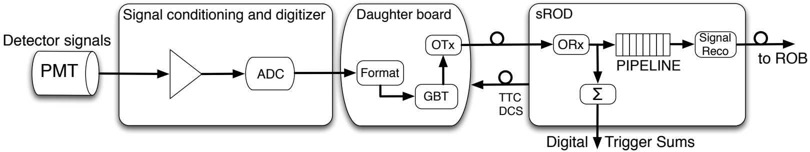
Consolidation work

- Switch LVPS to reduce power trips and noise.
- Switch connector collars.
- Glue together components.



Upgrade

- An upgrade of the hardware is planned in 10 years.
  - **Digitize signal** before sending it to the trigger.
  - **Move** the pipeline memories **to back-end electronics** to be more radiation tolerant.
  - Digitize all signals at 40 MHz in the front-end and transmit all samples to back-end.
  - Remove the single point failures of the current system and increase the redundancy in the front-end electronics.
  - Demonstrator super-drawer, compatible with current analog Level 1 trigger, to be installed by the end of the LS1.



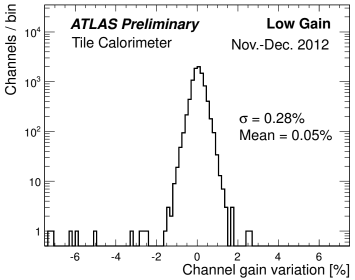
Summary and conclusions

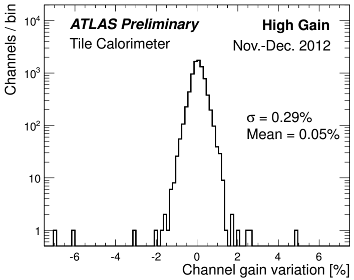
Tile

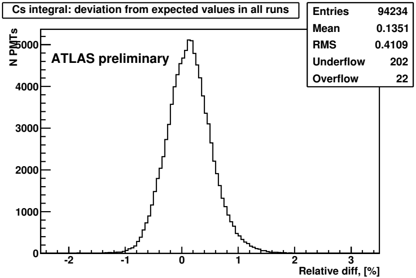
- The calibration systems have a remarkable precision and follow the design requirements.
- More than 99.9% of delivered luminosity was recorded.
- Before LS1, 97.1% of cells were operational.
- The noise has a non-Gaussian component at the moment.
- During long shutdown 1, massive consolidation work to reduce variations and prevent data loss.
- Tile performs well, making physics analysis possible.

Backup slides

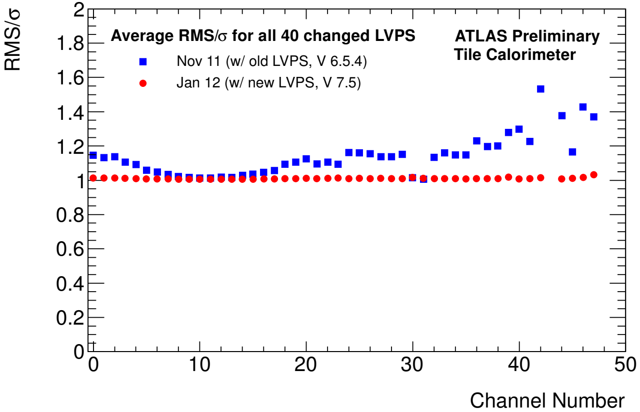
Laser and cesium calibration precision





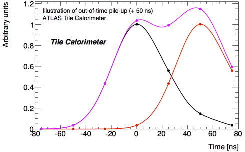


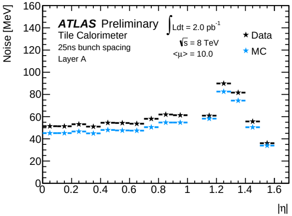
Noise parameters: new vs old LVPS

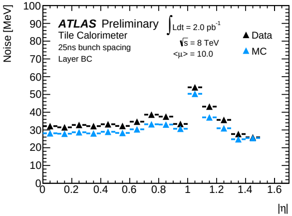


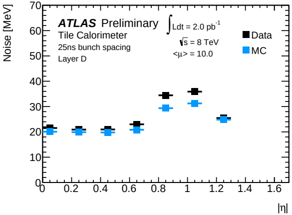
- A parameter to test the Gaussianity of noise is RMS/σ.
  - σ: parameter from optimal filtering.
  - For a Gaussian distribution, $\mathrm{RMS}/\sigma = 1$
  - Channels closest to LVPS have highest deviation from 1 for old LVPS.

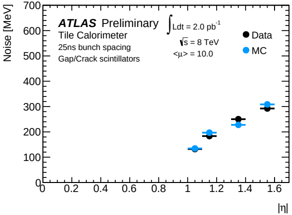
Pileup, 25 ns BX



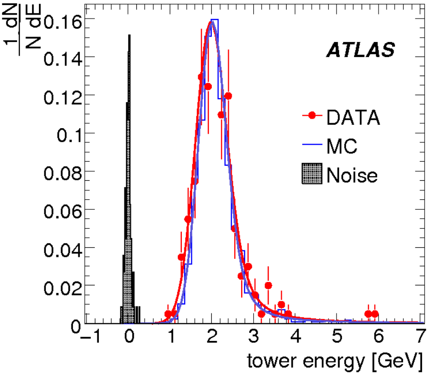








Signal to noise from comsics



- TileCal readout system designed so that even small signals from muons is well separated from noise.
- Signal to noise ratio from fits to data with cosmic muons: $S/N = 29$.
- Muons are least energetic particles measured by TileCal.