Performance of the ATLAS Tile Calorimeter in pp collisions at the LHC

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on behalf of the ATLAS Collaboration

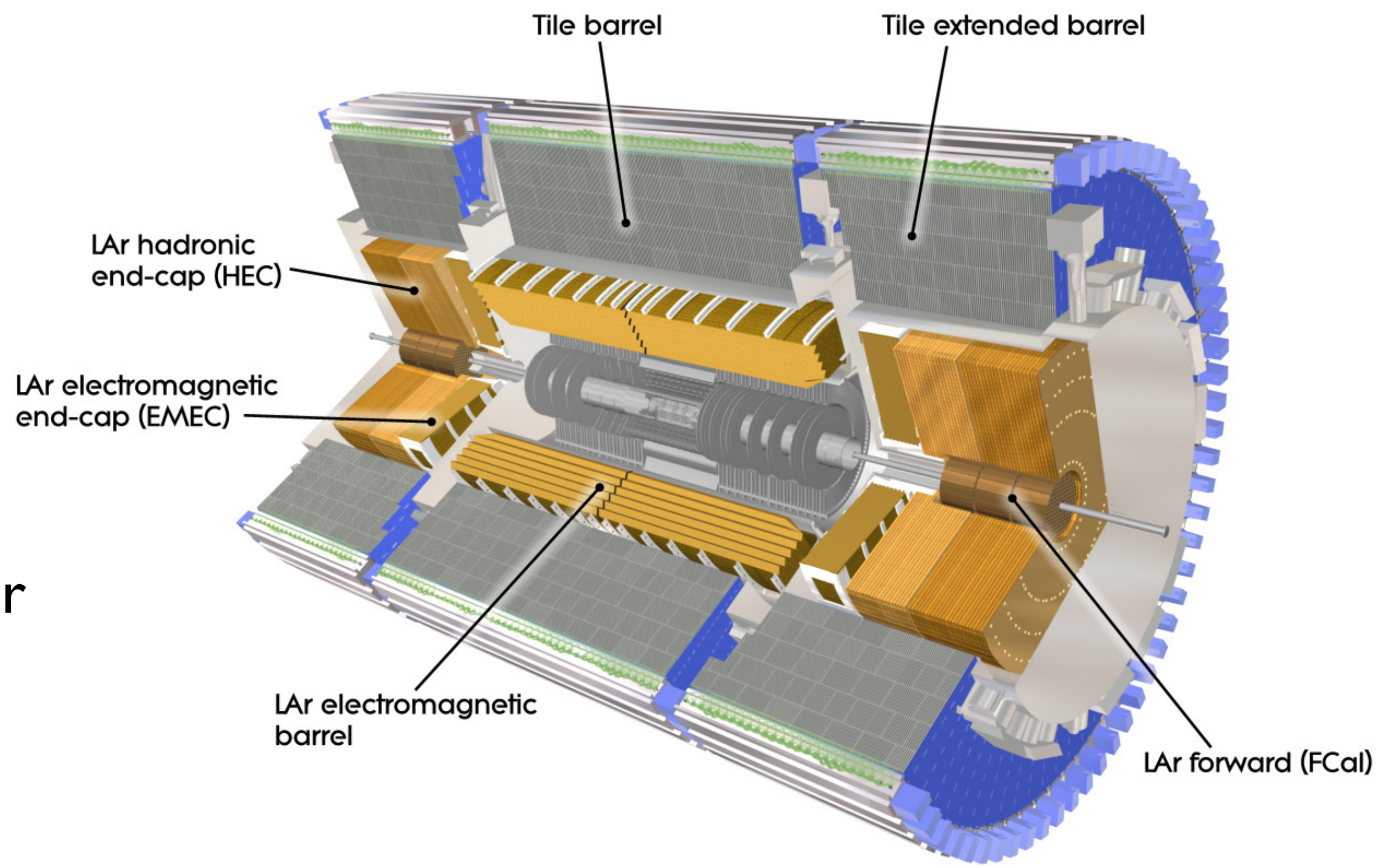
CALOR2014 - Giessen (Germany)
April 7, 2014

The ATLAS Tile Calorimeter

Barrel hadronic calorimeter of the ATLAS detector ($-1.7 < \eta < 1.7$)

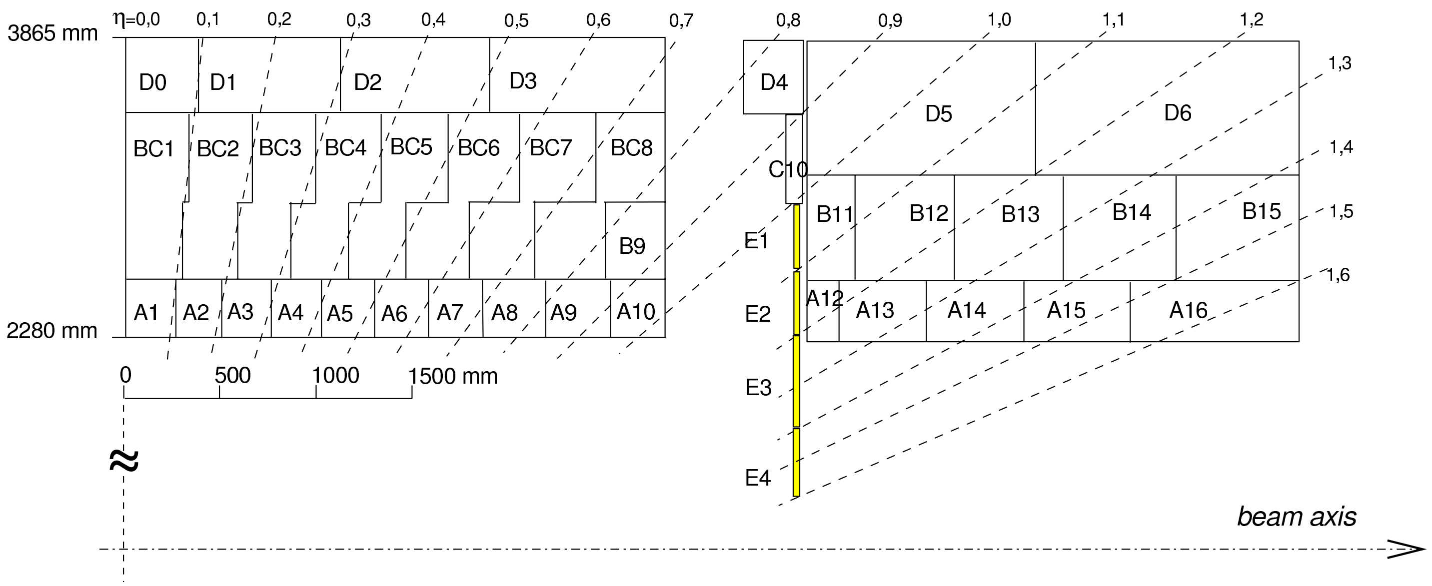
- long barrel (LB): $-1.0 < \eta < 1.0$
  two extended barrels (EB): $1.0 < |\eta| < 1.7$
- 4 x 64 wedges in φ ($\Delta\varphi=0.1$)
- three longitudinal layers, total thickness ~7λ
- pseudo-projective towers for first level trigger

Sampling calorimeter: steel + plastic scintillator

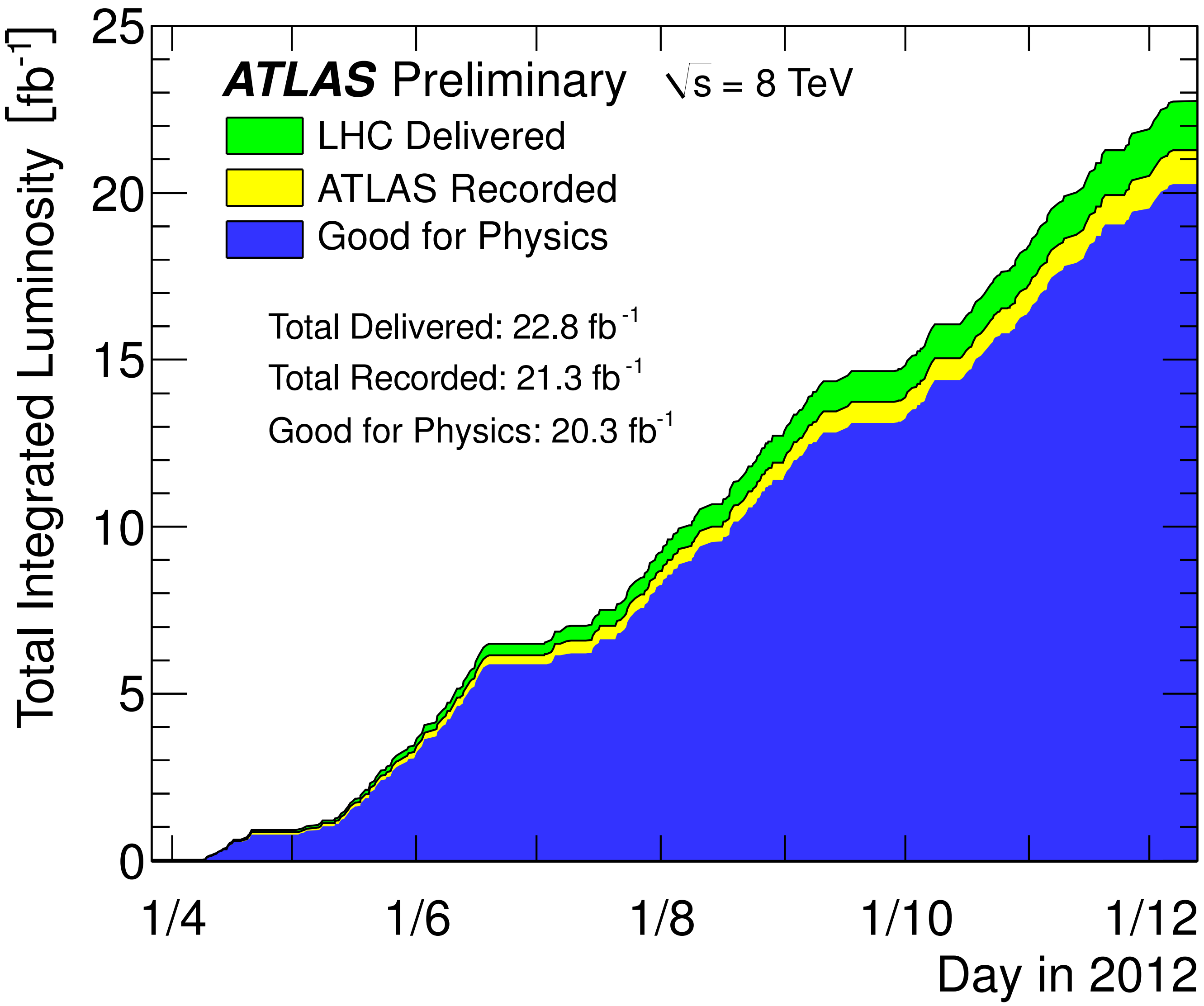


Designed performance requirements

- Jet energy resolution:
  $\sigma(E)/E = 50\% / \sqrt{E(\mathrm{GeV})} \oplus 3\%$
- Jet energy linearity: 1-2% up to ~ 4 TeV
- Accurate missing transverse energy measurement requires full-coverage hadronic calorimeter



2012 pp data-taking



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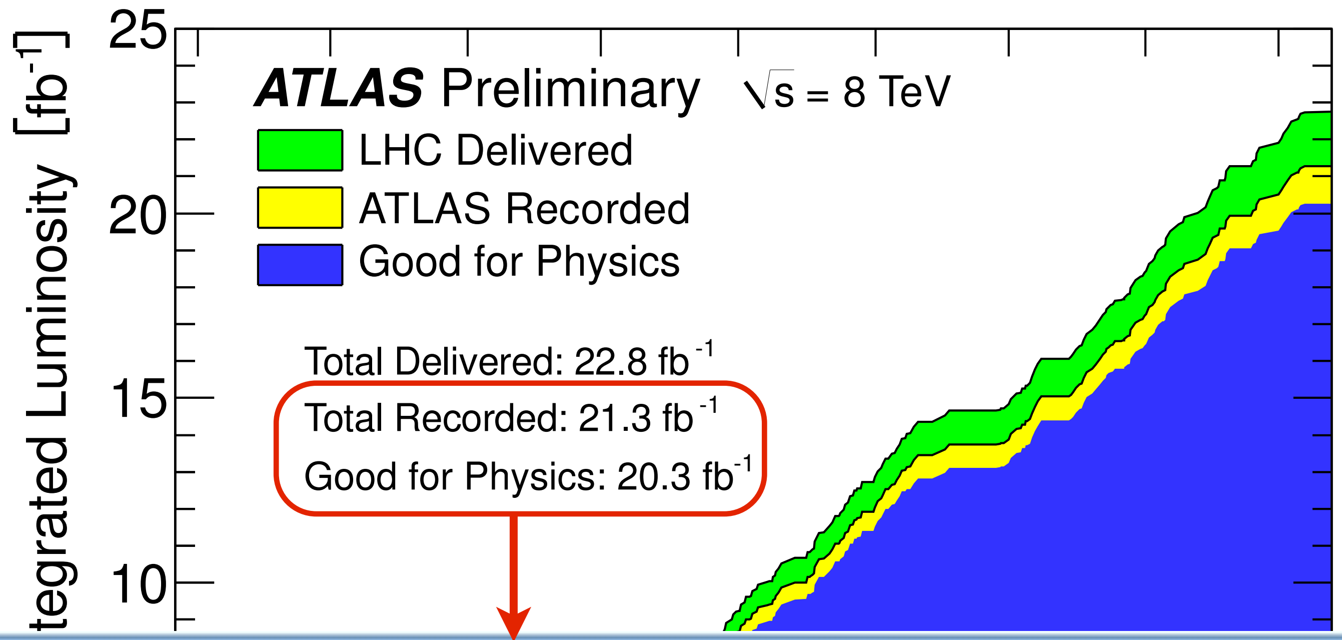
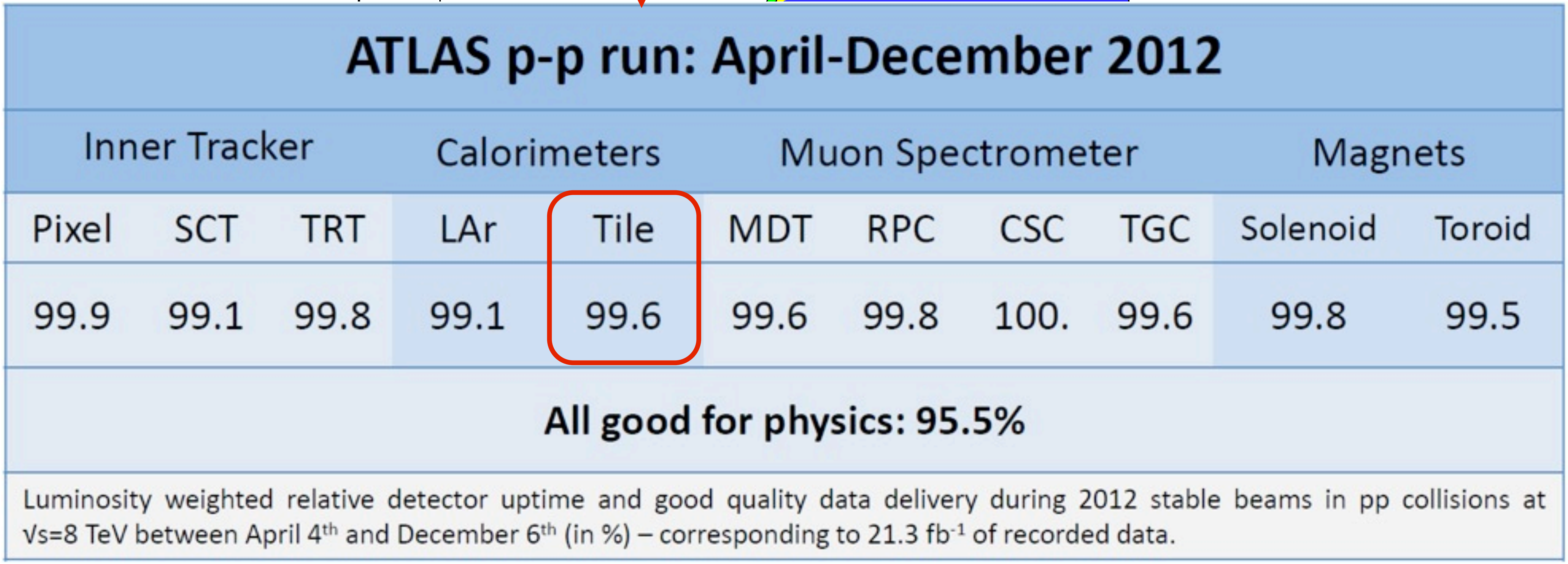




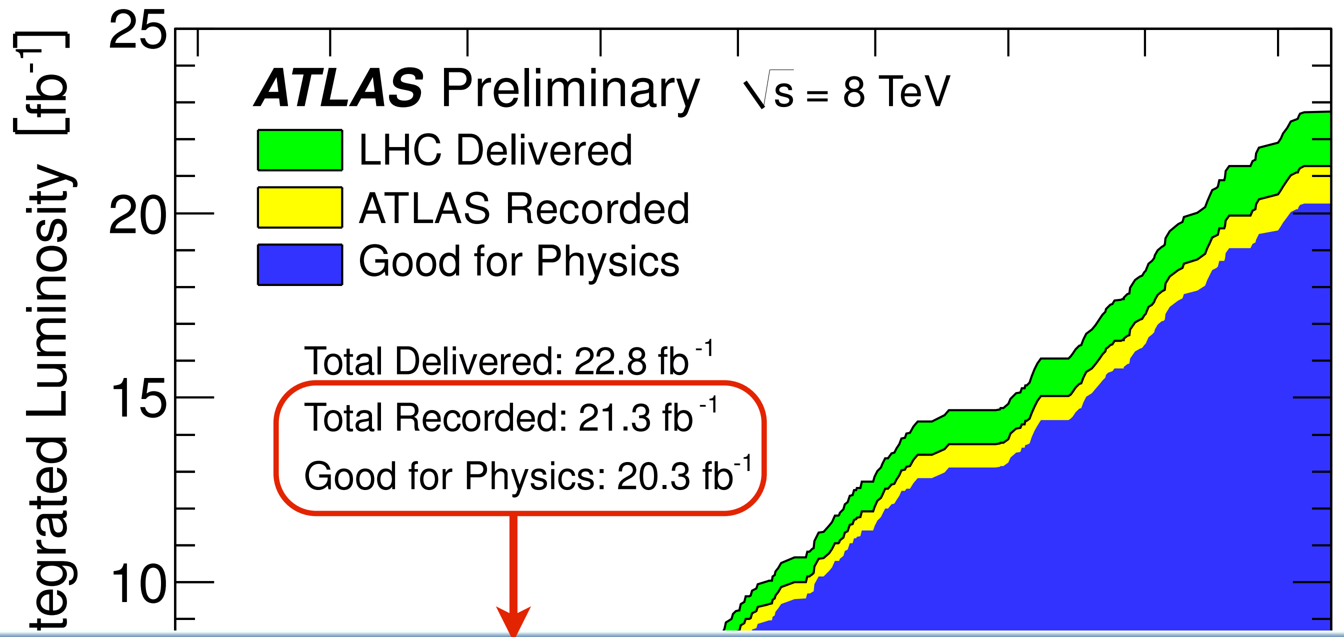
ATLAS p-p run: April-December 2012

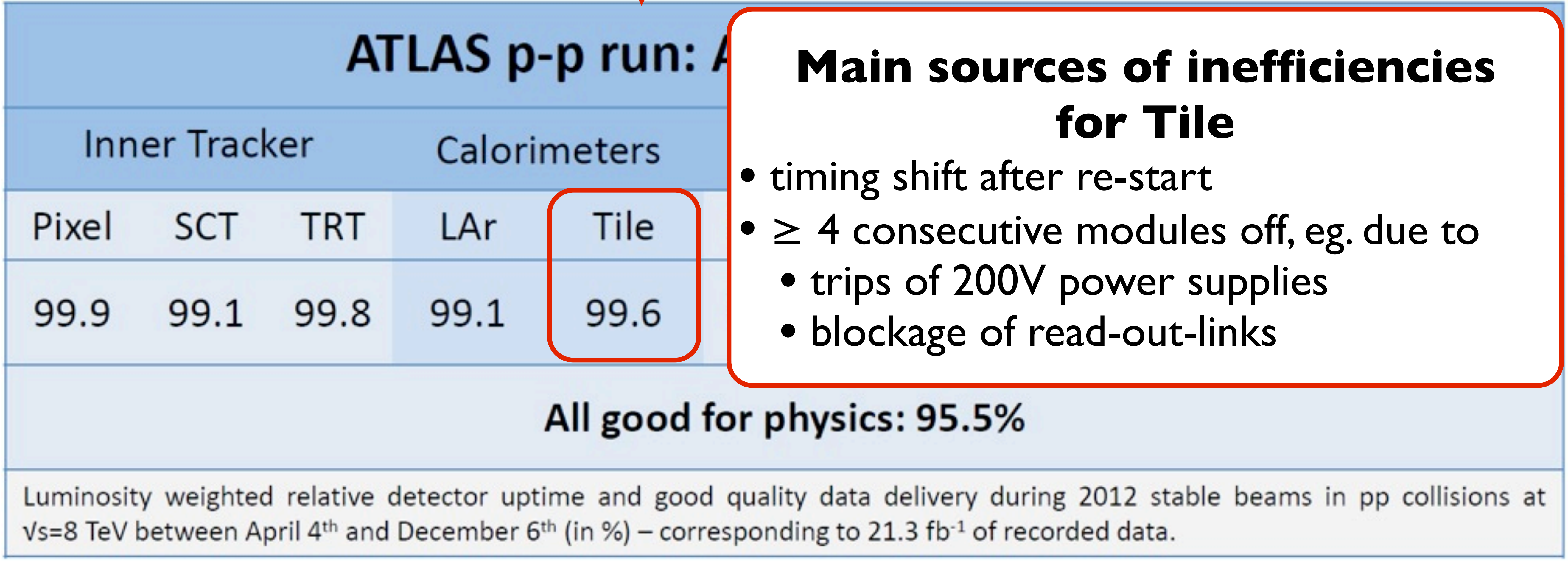
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.1	99.8	99.1	99.6	99.6	99.8	100.	99.6	99.8	99.5

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.

2012 pp data-taking





ATLAS p-p run: A

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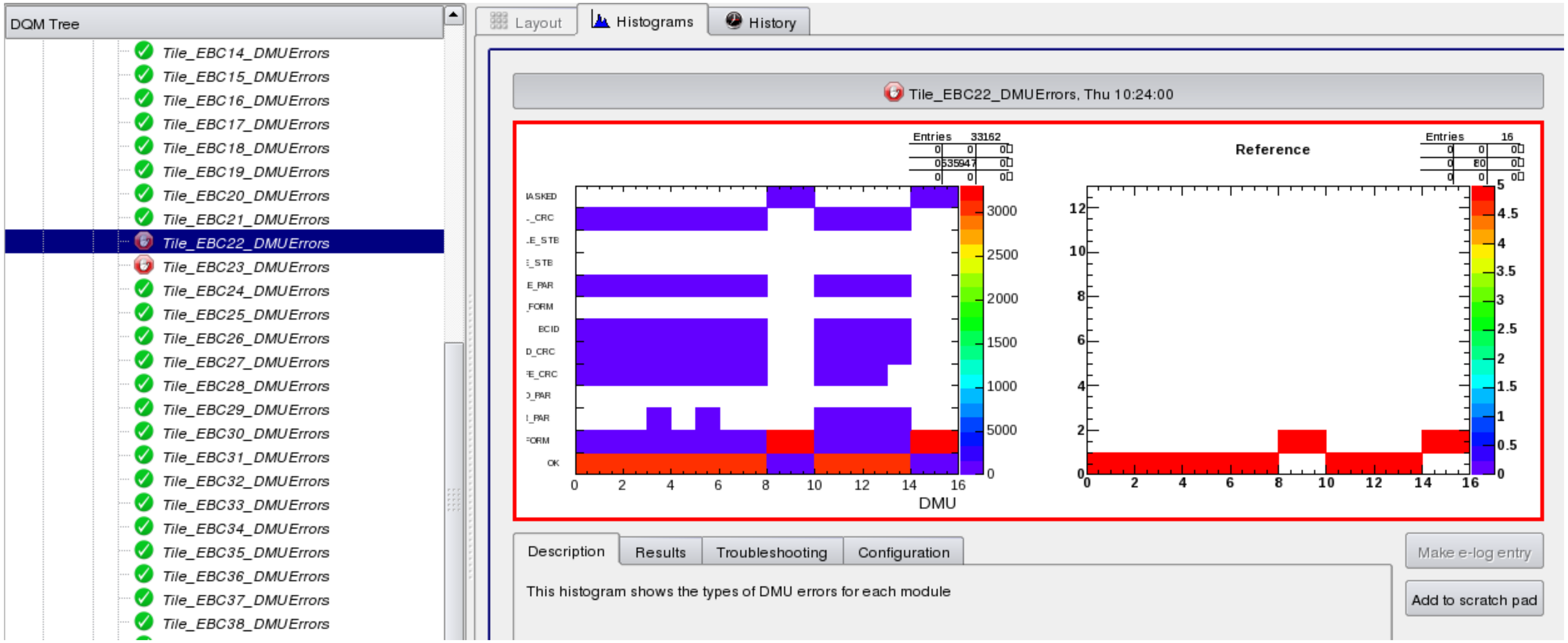
Main sources of inefficiencies for Tile

- timing shift after re-start
- ≥ 4 consecutive modules off, eg. due to
  - trips of 200V power supplies
  - blockage of read-out-links

Tile Data Quality (DQ)

High data-quality efficiency (99.6% in 2012) thanks to an effective monitoring system:

- Data Quality Monitoring Framework (DQMF) collects information about the quality of the data and performs quality checks
- problems flagged automatically + warning/error messages:
  → visual inspection by shifter and immediate action during data-taking
- automatic recovery procedures implemented in the Data Acquisition System (DAQ) and Detector Control System (DCS)
  → minimize the need for manual interventions and the reaction time



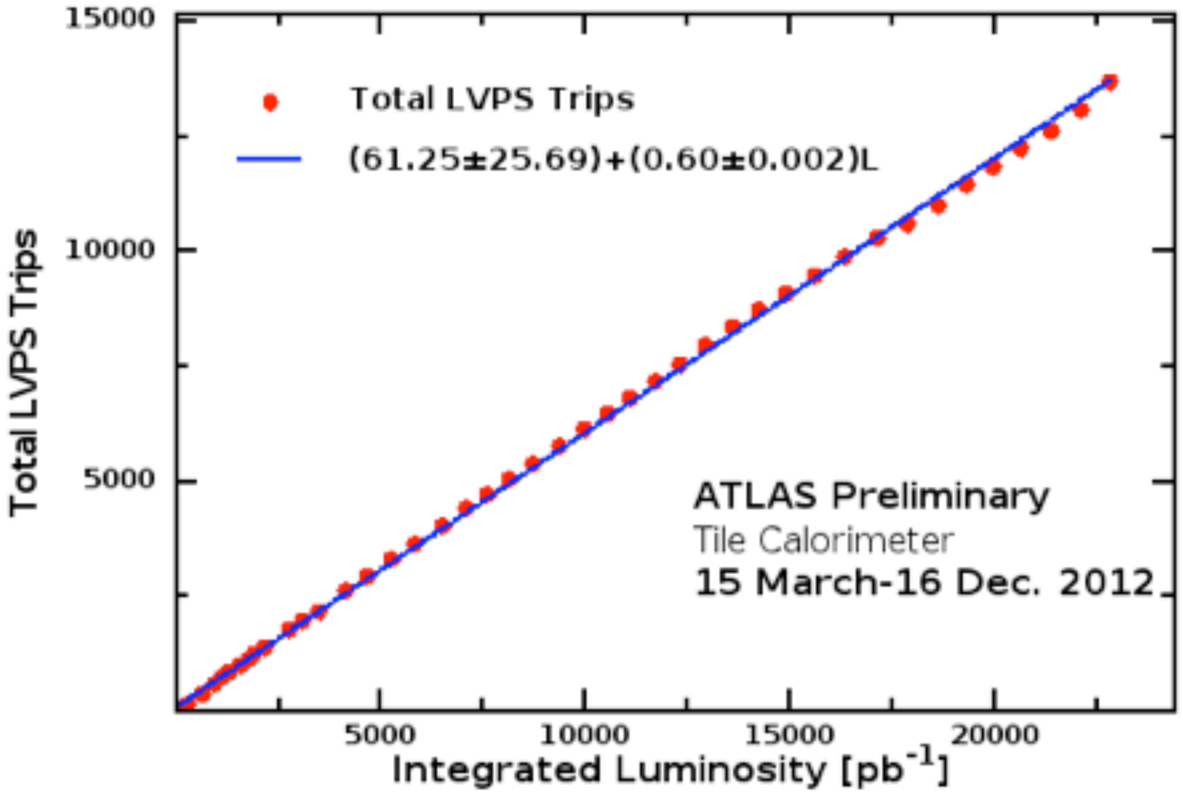
Tile_EBC22_DMUErrors, Thu 10:24:00

This histogram shows the types of DMU errors for each module

Low Voltage Power Supplies (LVPS)

Problems with the LVPS in the front-end electronics during Run1:

- failures of LVPS (full module off)
- frequent trips of LVPS



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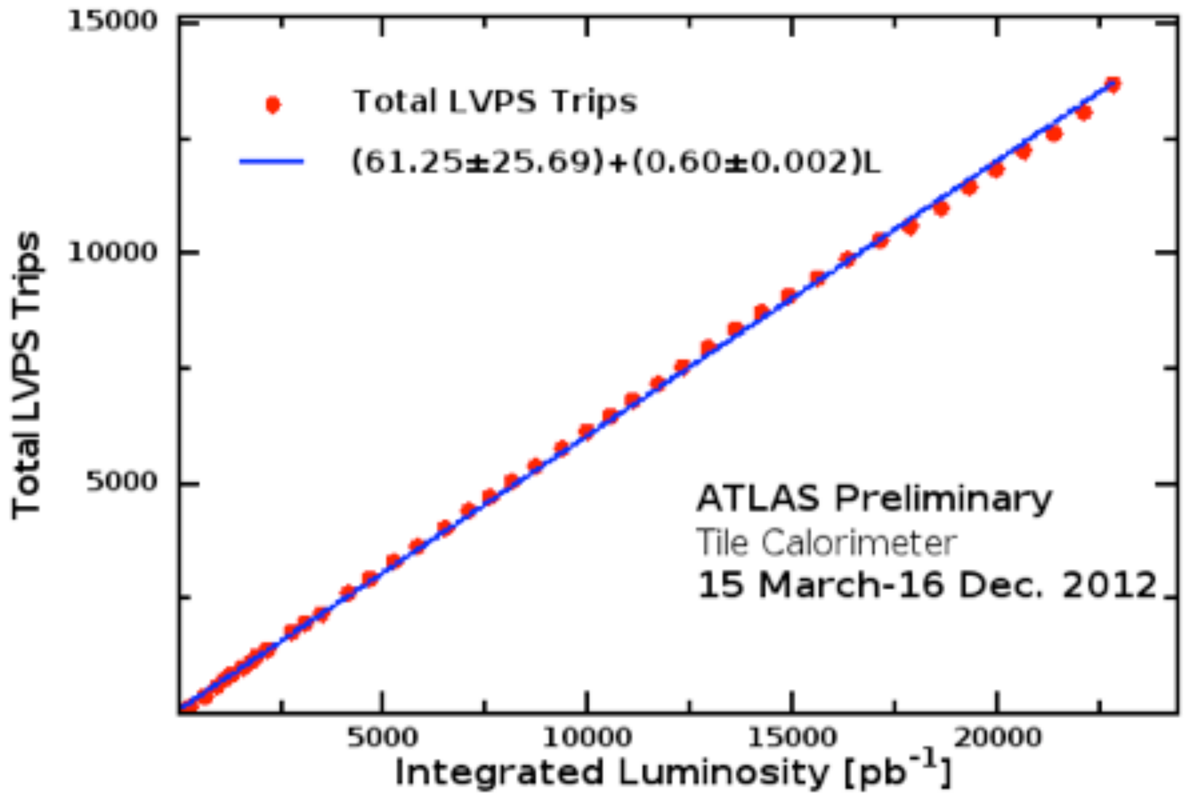

Despite this, achieved **high DQ efficiency**!

- during LHC run automatic recovery procedures to power-on the LVPS, configure front-end electronics and resume data-taking
- energy interpolated from neighboring module

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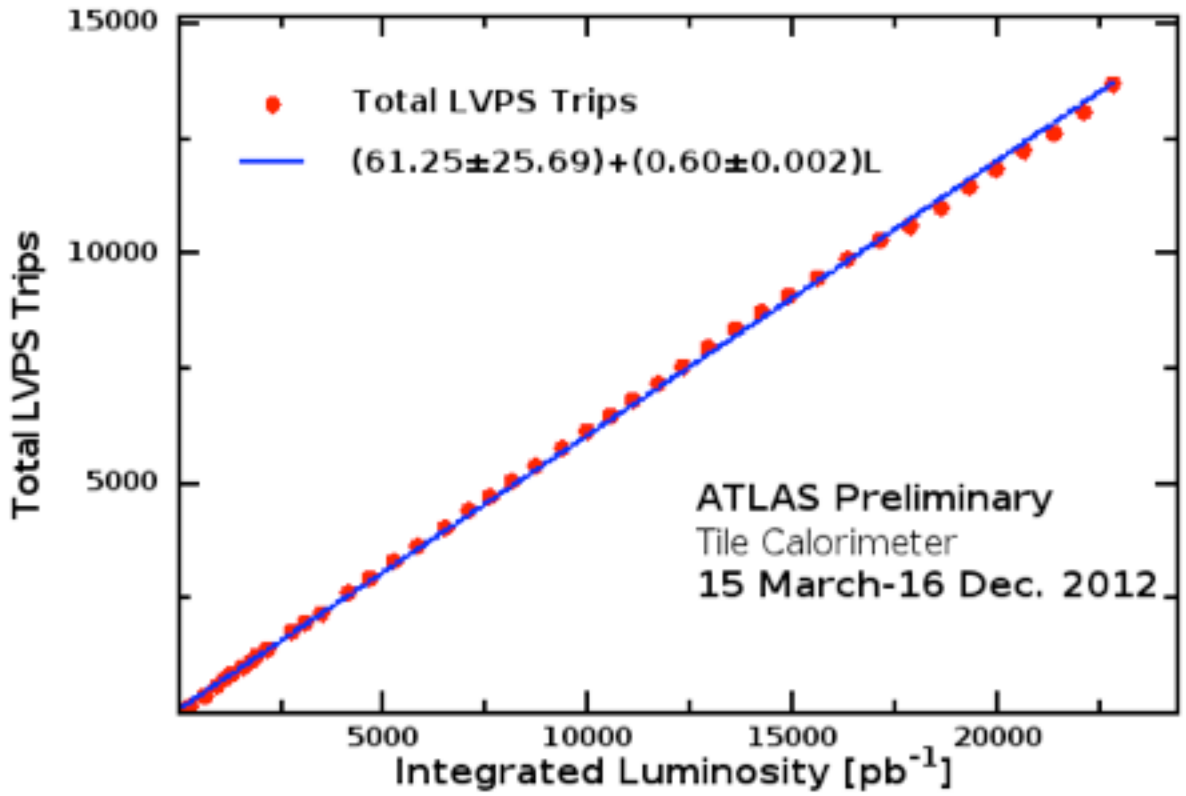
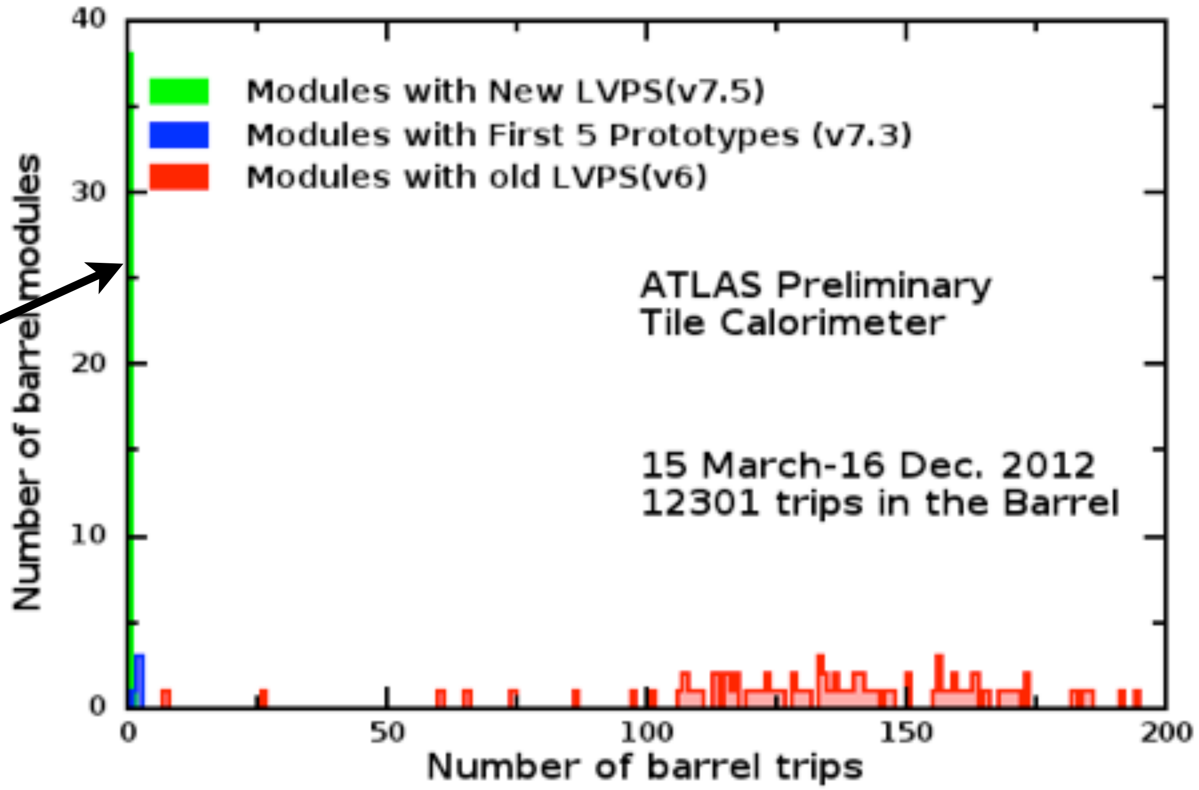
Today: upgraded power supplies

- 40 new LVPS installed in 2012: just one trip
- benefit from lower electronic noise
- full production of new LVPS was installed in 2013 during the shutdown

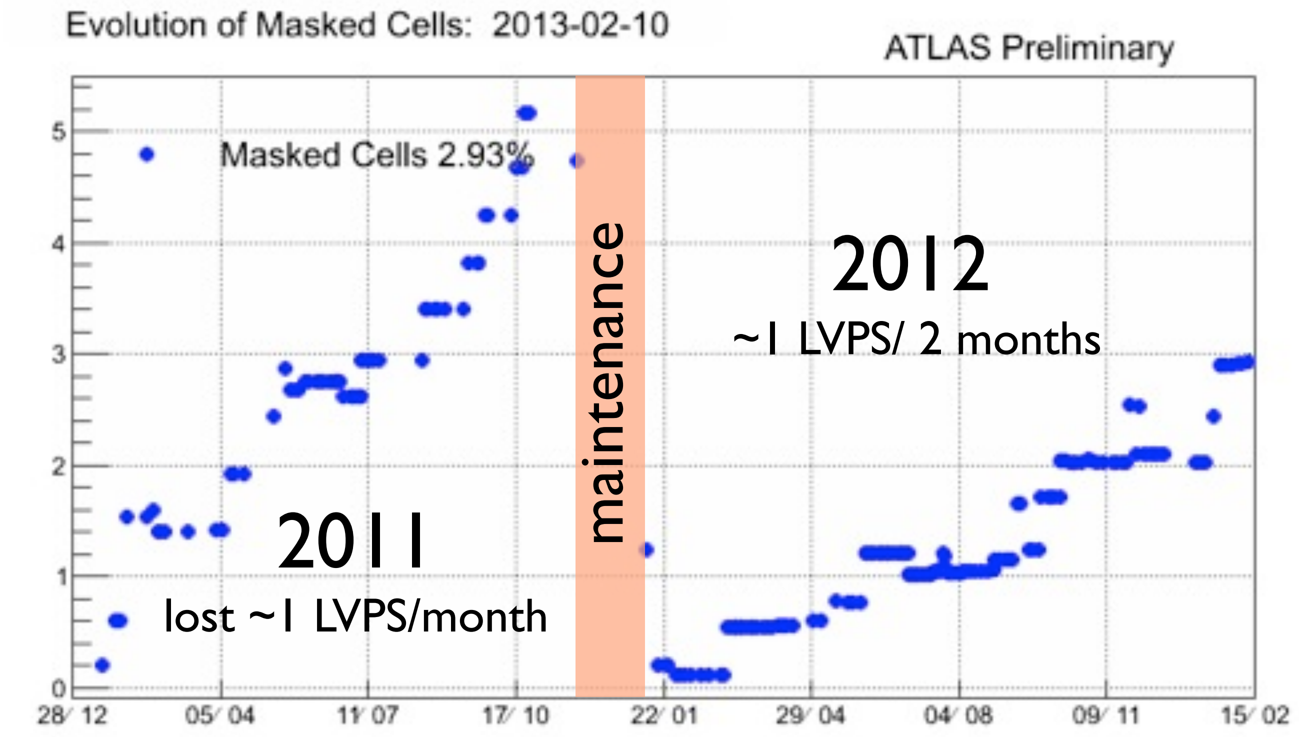


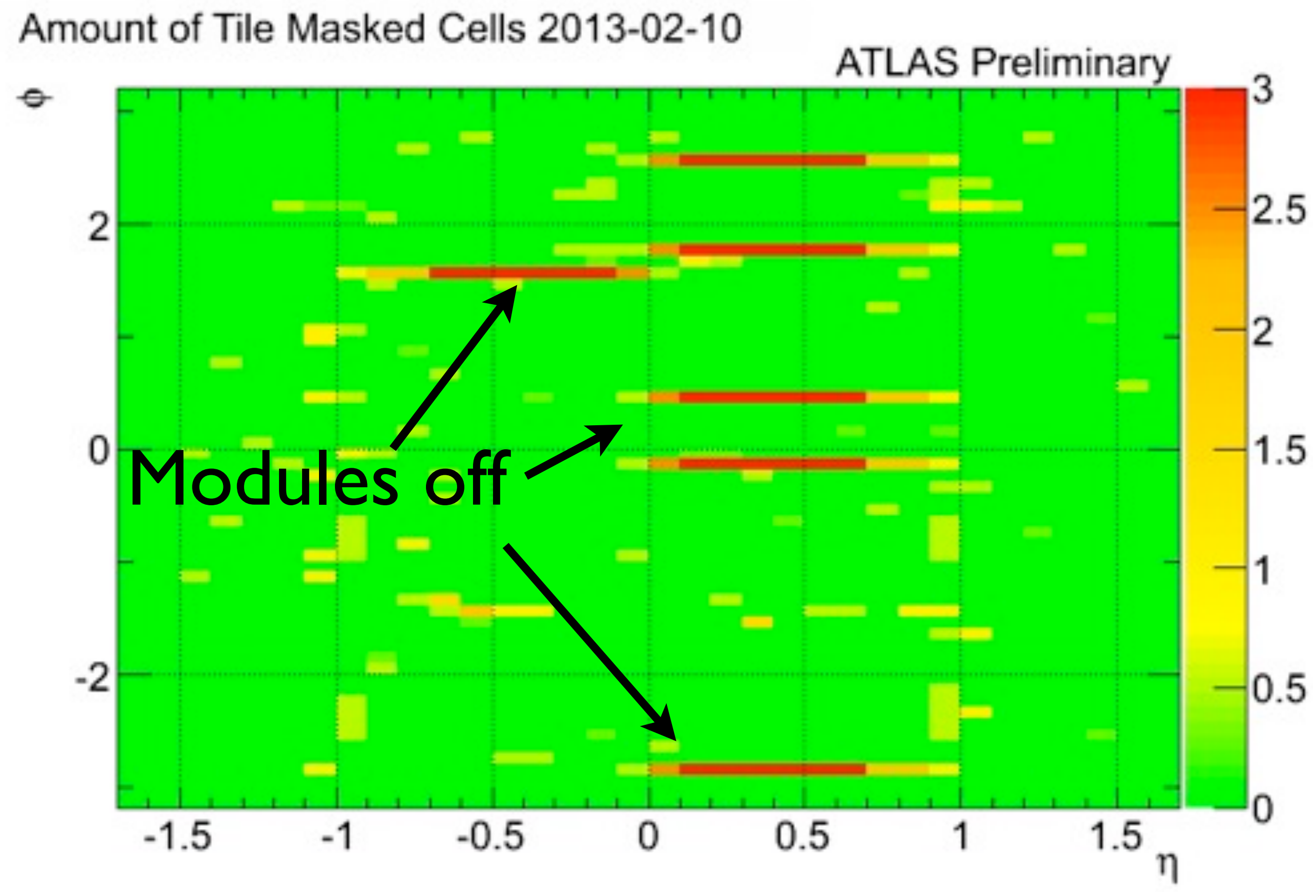


Detector Status - end of LHC Run1

Status at the end of Run1 (Feb. 2013)

- ~ **3%** of masked cells
  - **6** modules off with bad LVPS
  - energy for masked cells is interpolated from neighboring cells





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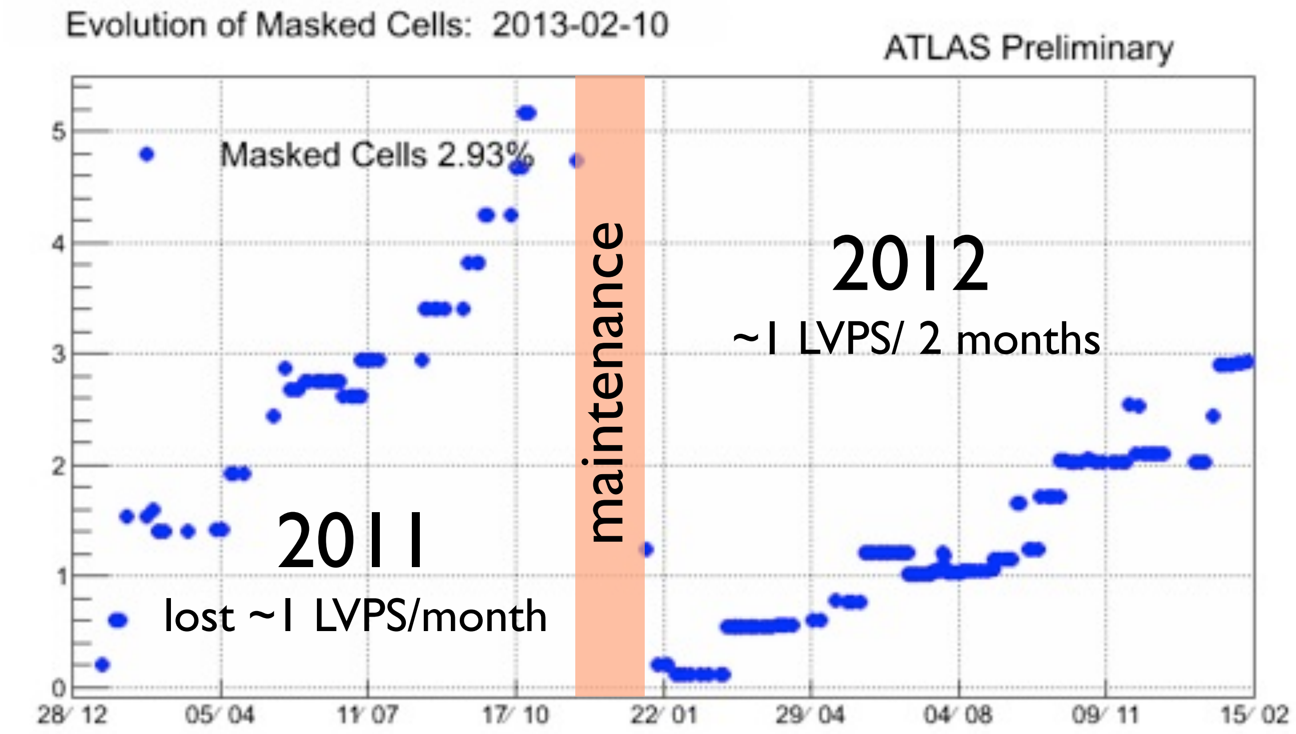
  - HV cannot be adjusted to optimum value
  - The EM scale is restored with Cs-137 and laser calibration systems



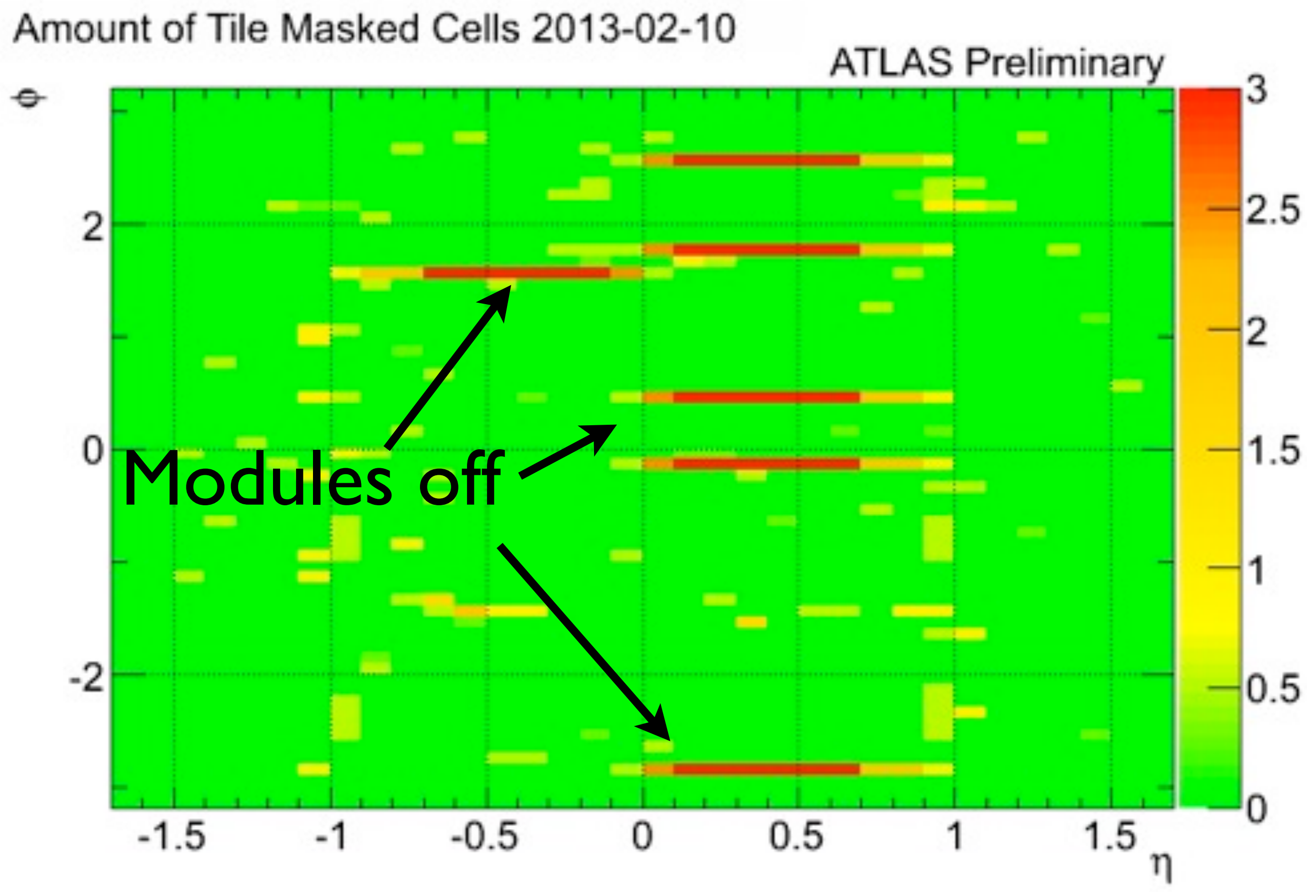
maintenance

2011

lost ~1 LVPS/month

2012

~1 LVPS/ 2 months



Modules off

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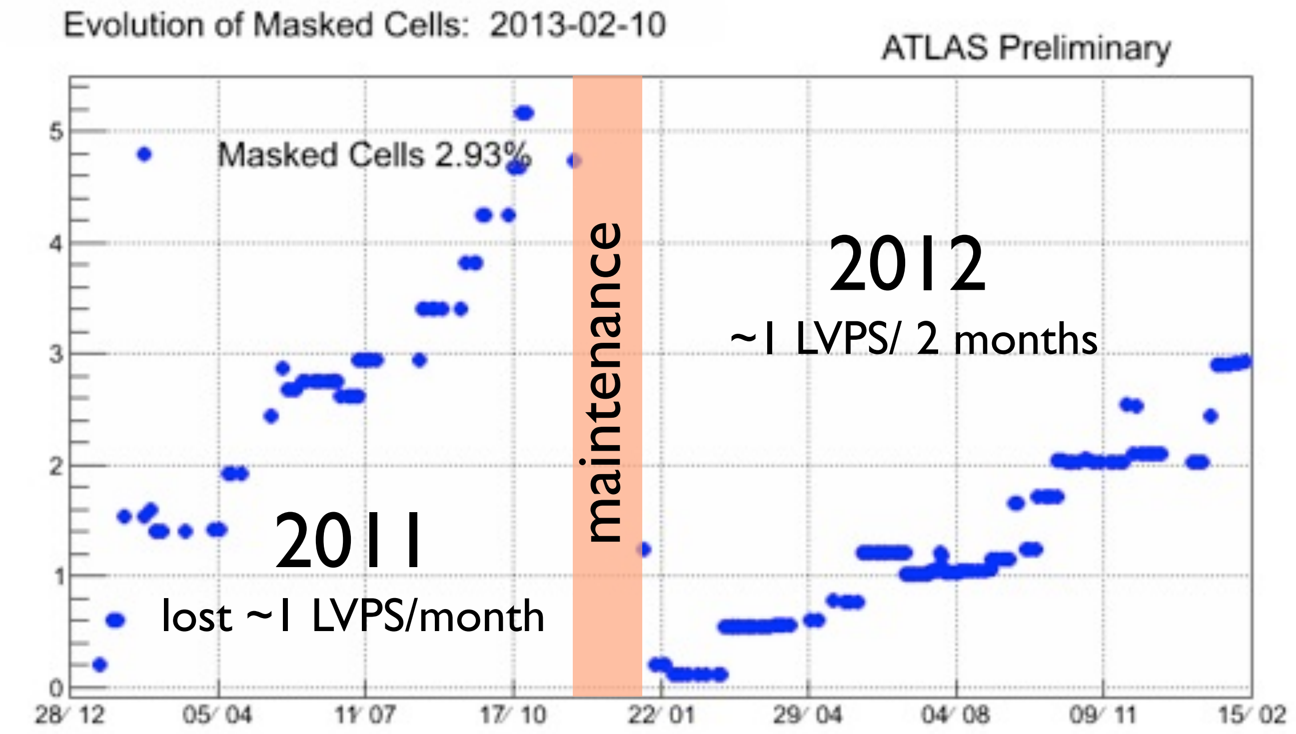
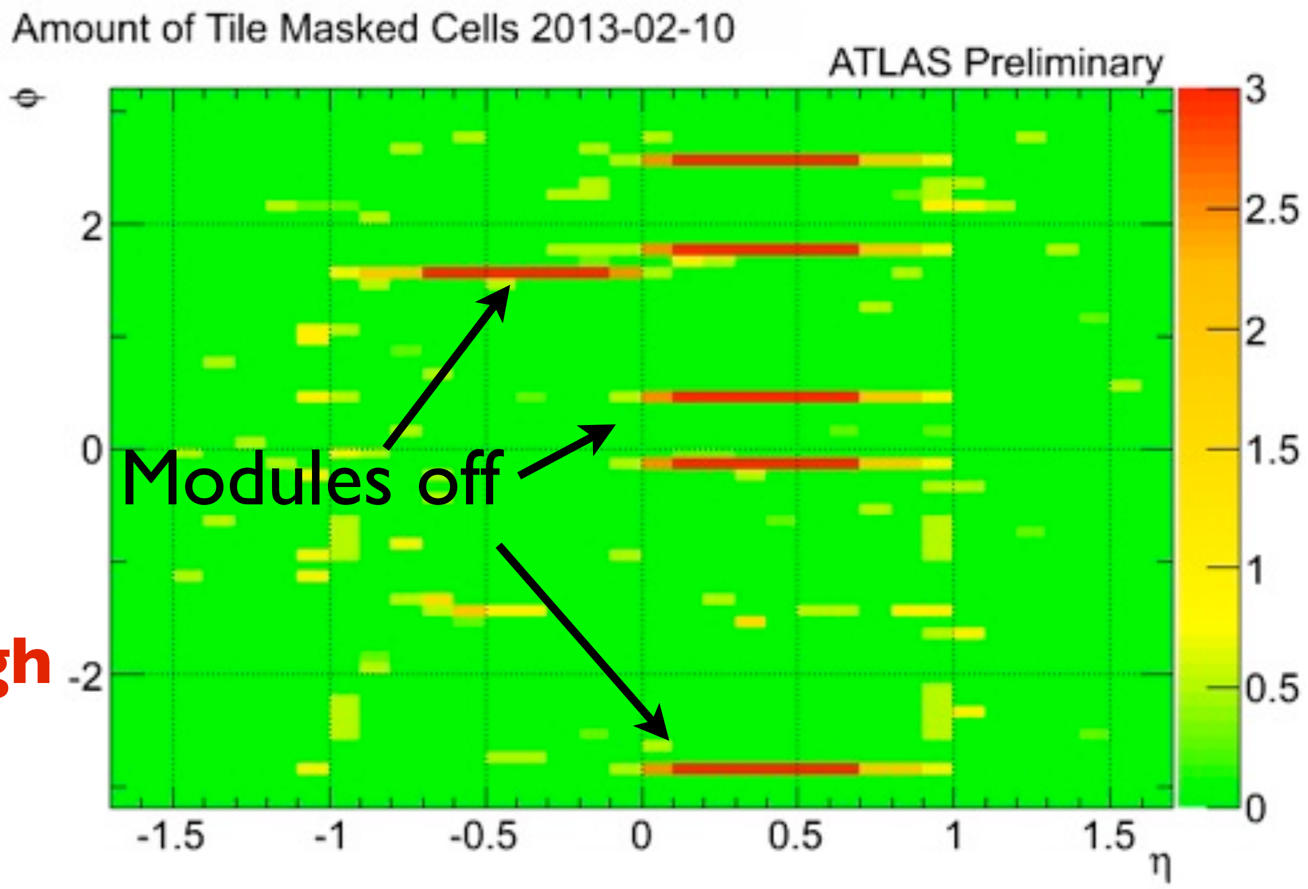
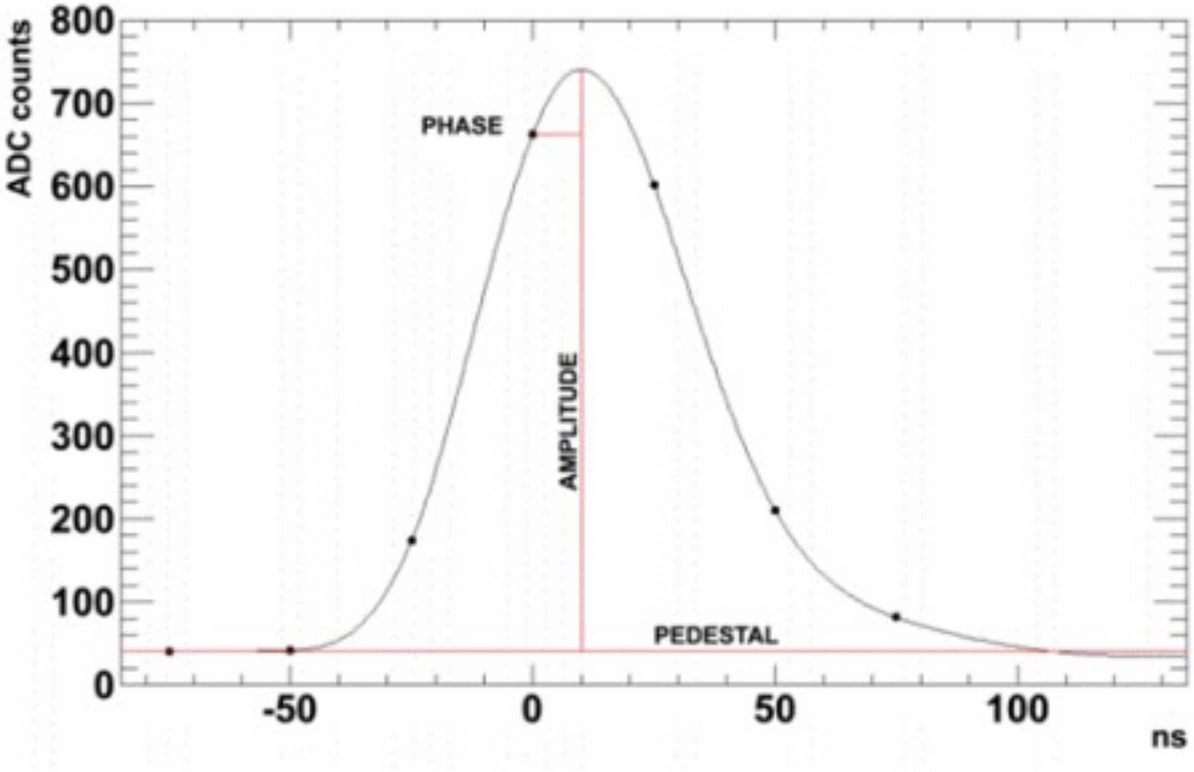
Most bad channels are recovered during maintenance periods, when front-end electronics are accessible.

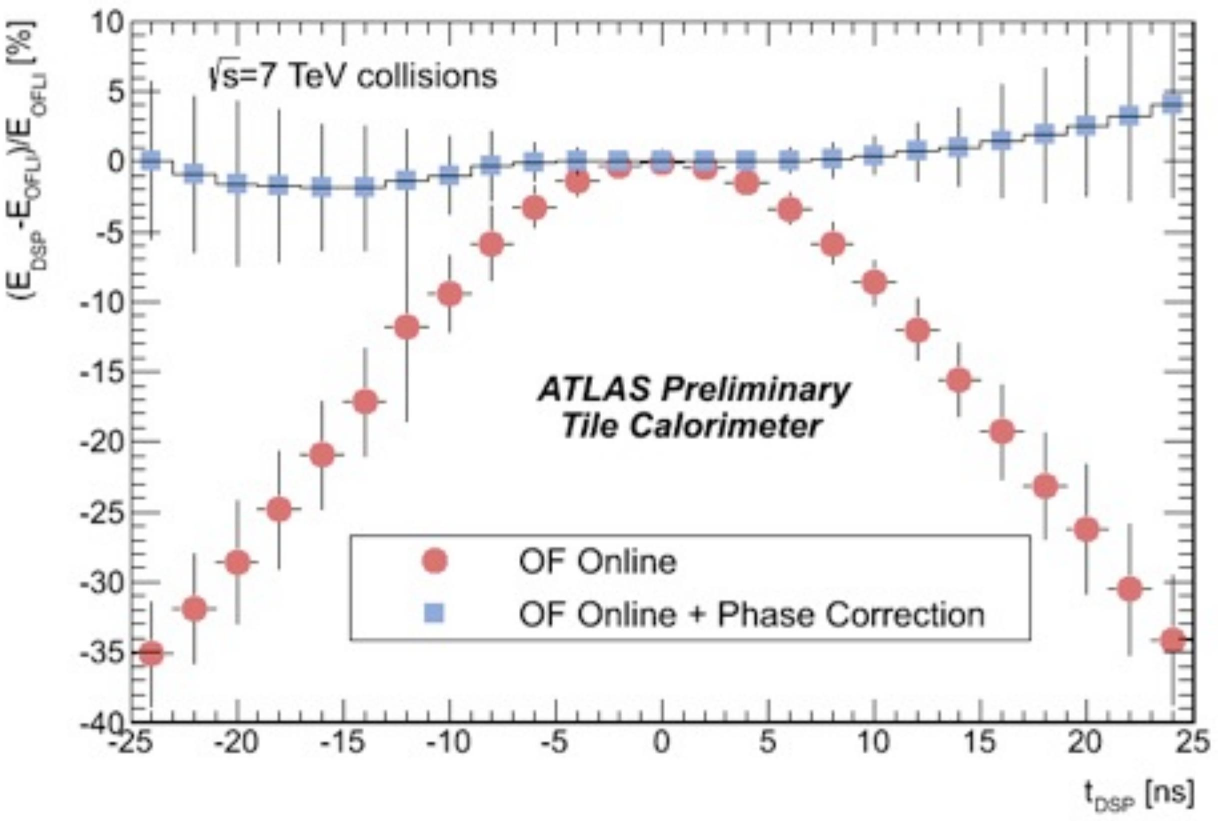
During LS1 (2013-2014): major maintenance activities to ensure **high performance**, **high quality** and **robust operations** in Run2.





Signal Reconstruction





Signal properties reconstructed with Optimal Filtering from 7 digitized samples spaced by 25 ns:

- extract amplitude (A) and time (τ)

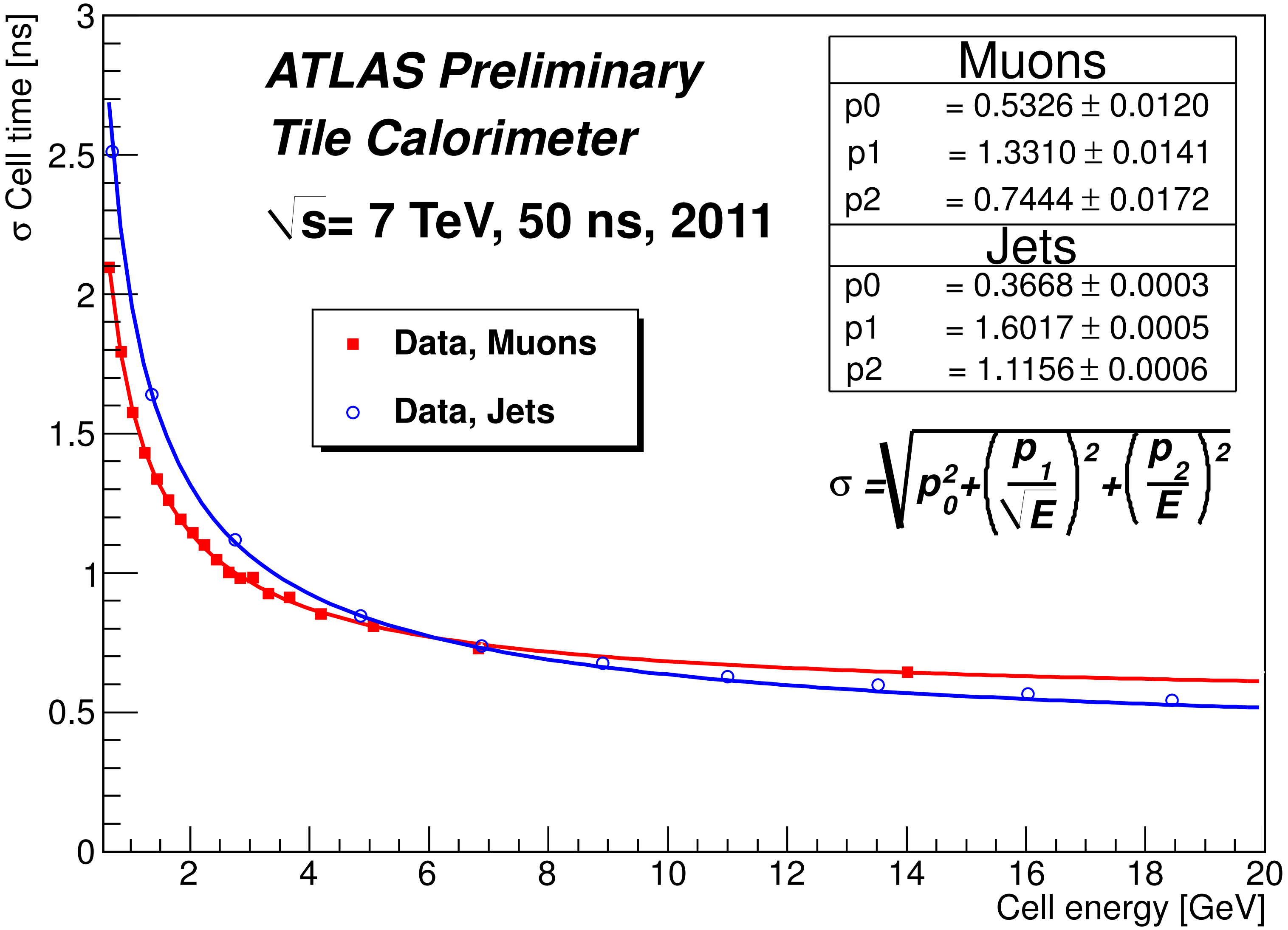
$$A = \sum_{i=1}^{n=7} a_i S_i , \qquad \tau = \frac{1}{A} \sum_{i=1}^{n=7} b_i S_i ,$$

- energy proportional to A
- weights defined by pulse shape and noise autocorrelation matrix
- requires initial knowledge of signal phase

Difference between online and offline energy reconstruction:
bias due to phase of the signal can be corrected online

Timing

Synchronization of all 10 000 Tile channels performed with laser calibration, cosmic events, single beam events and collision events.

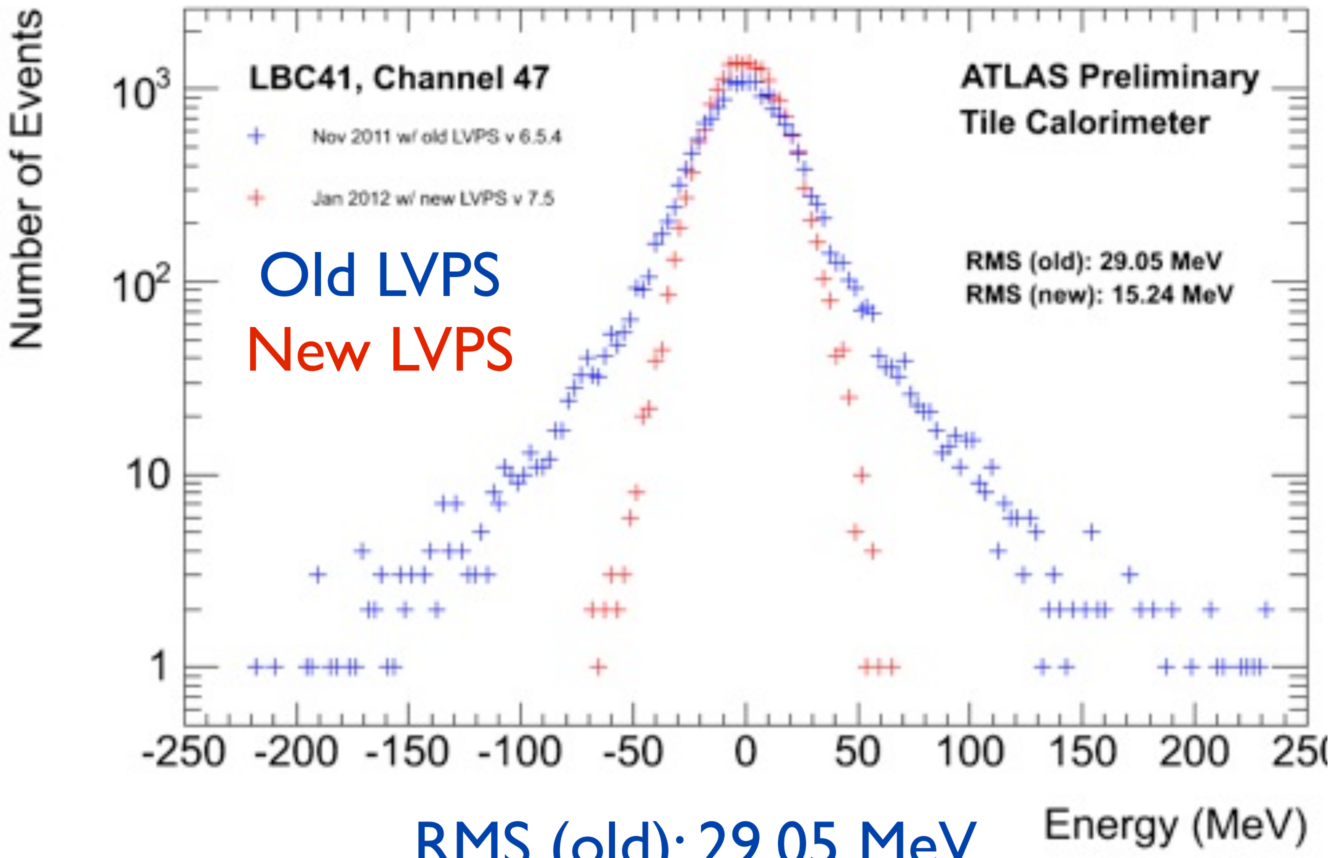


Cell time resolution:

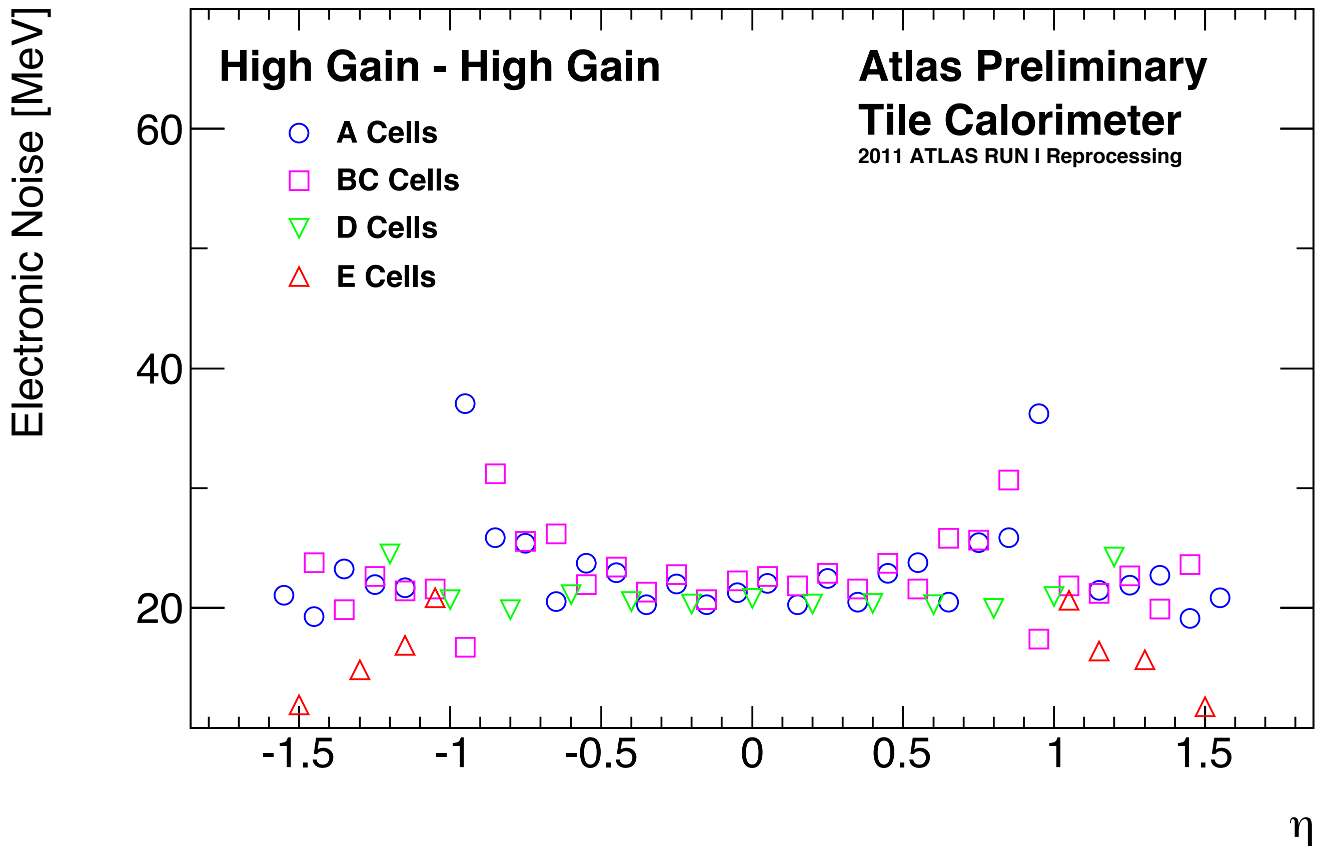
1.15-1.3 ns at E ~ 2 GeV (muons)

0.5-0.6 ns at E~20 GeV (jets)

Electronic Noise



RMS (old): 29.05 MeV
RMS (new): 15.24 MeV



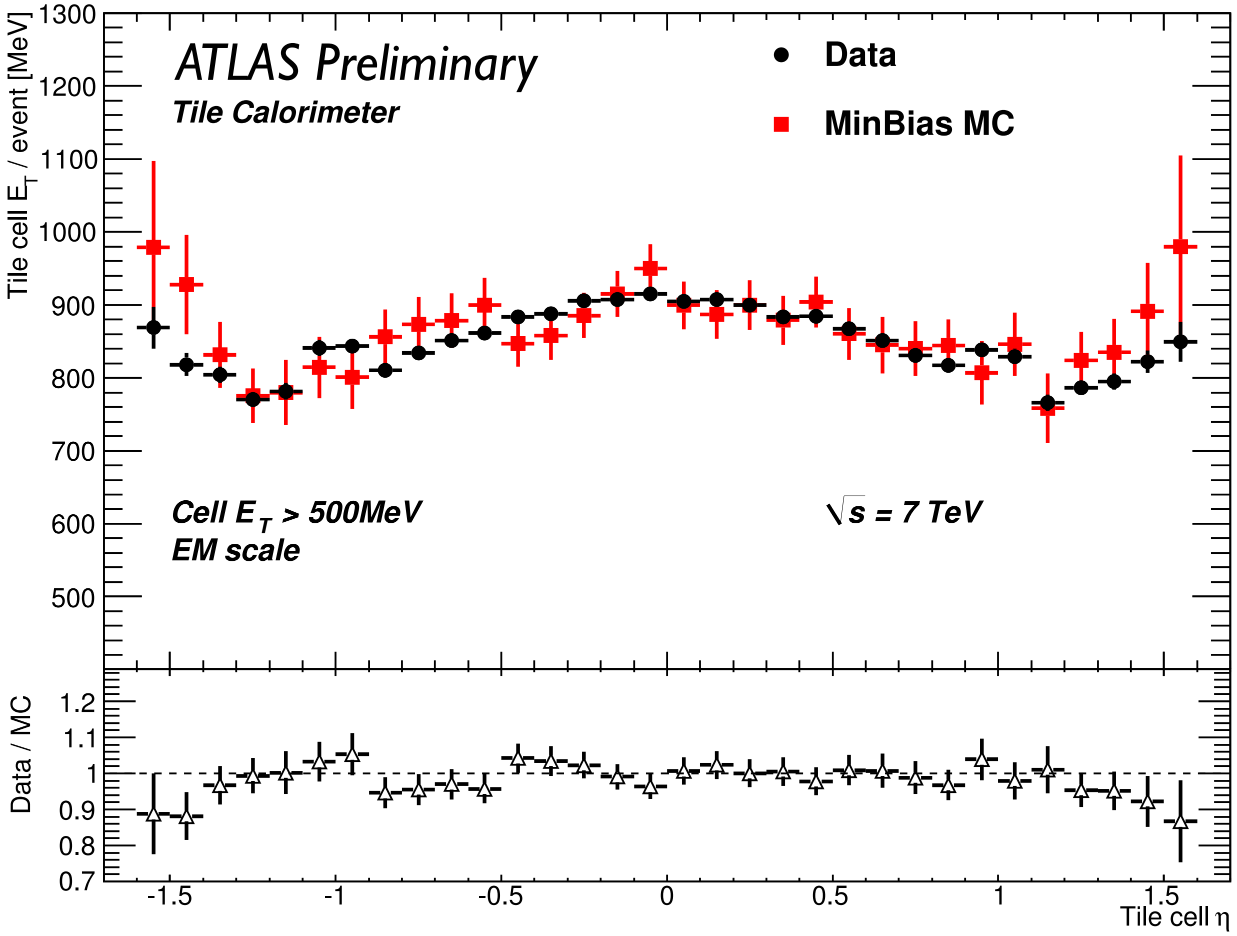
Electronic noise measured in pedestal calibration runs without colliding beams.

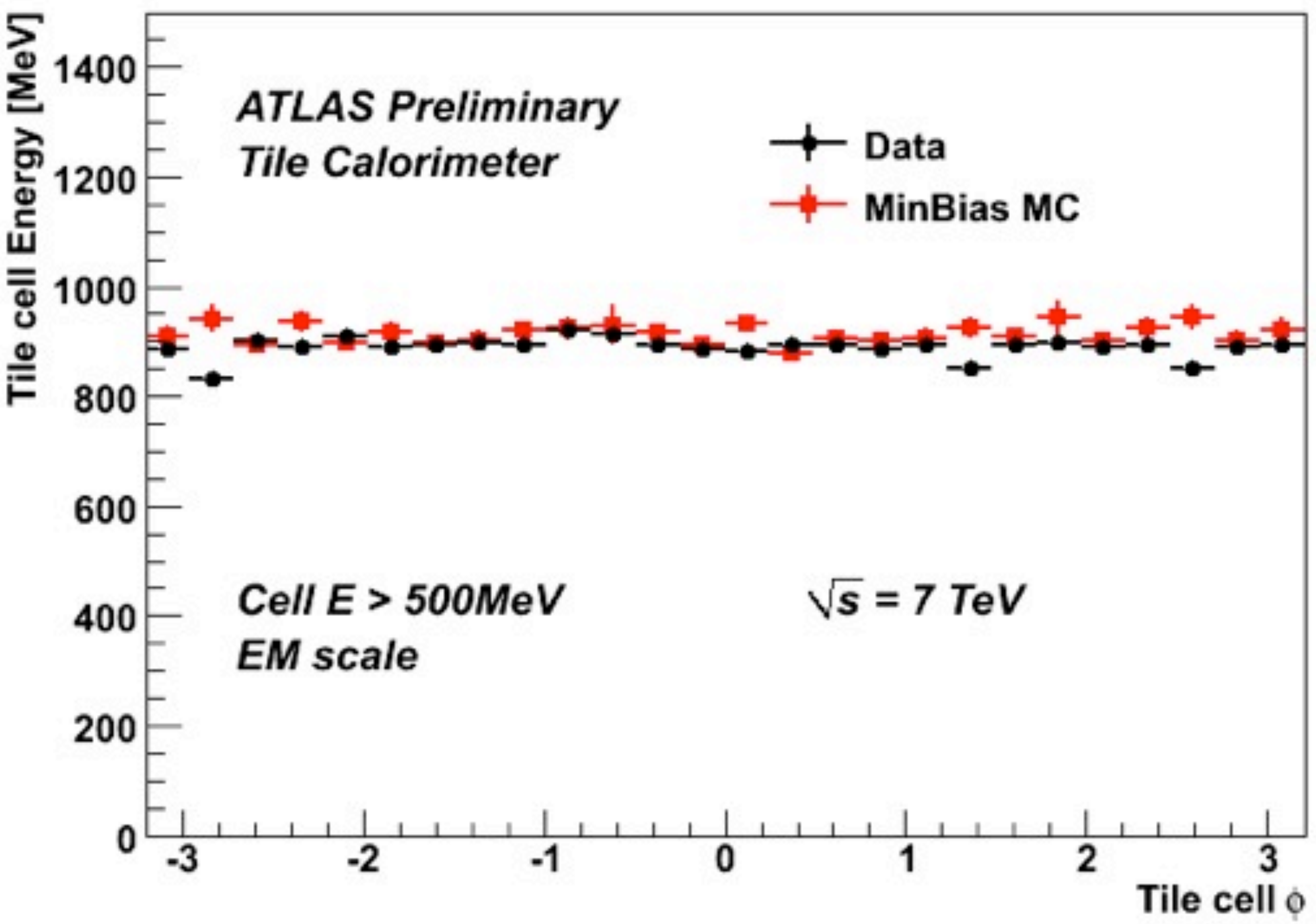
Noise affected by the Low Voltage Power Supplies:

- with old LVPS: deviation from single Gaussian due to instabilities in the LVPS
- with new LVPS: lower noise and reduced tails

Energy response

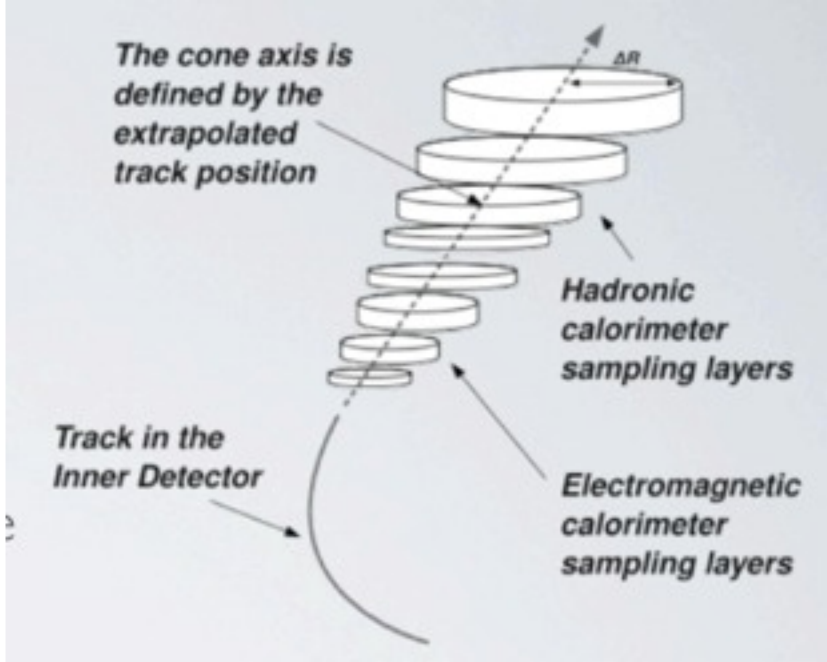
Inclusive energy response at EM scale in collisions at $\sqrt{s}$ = 7 TeV





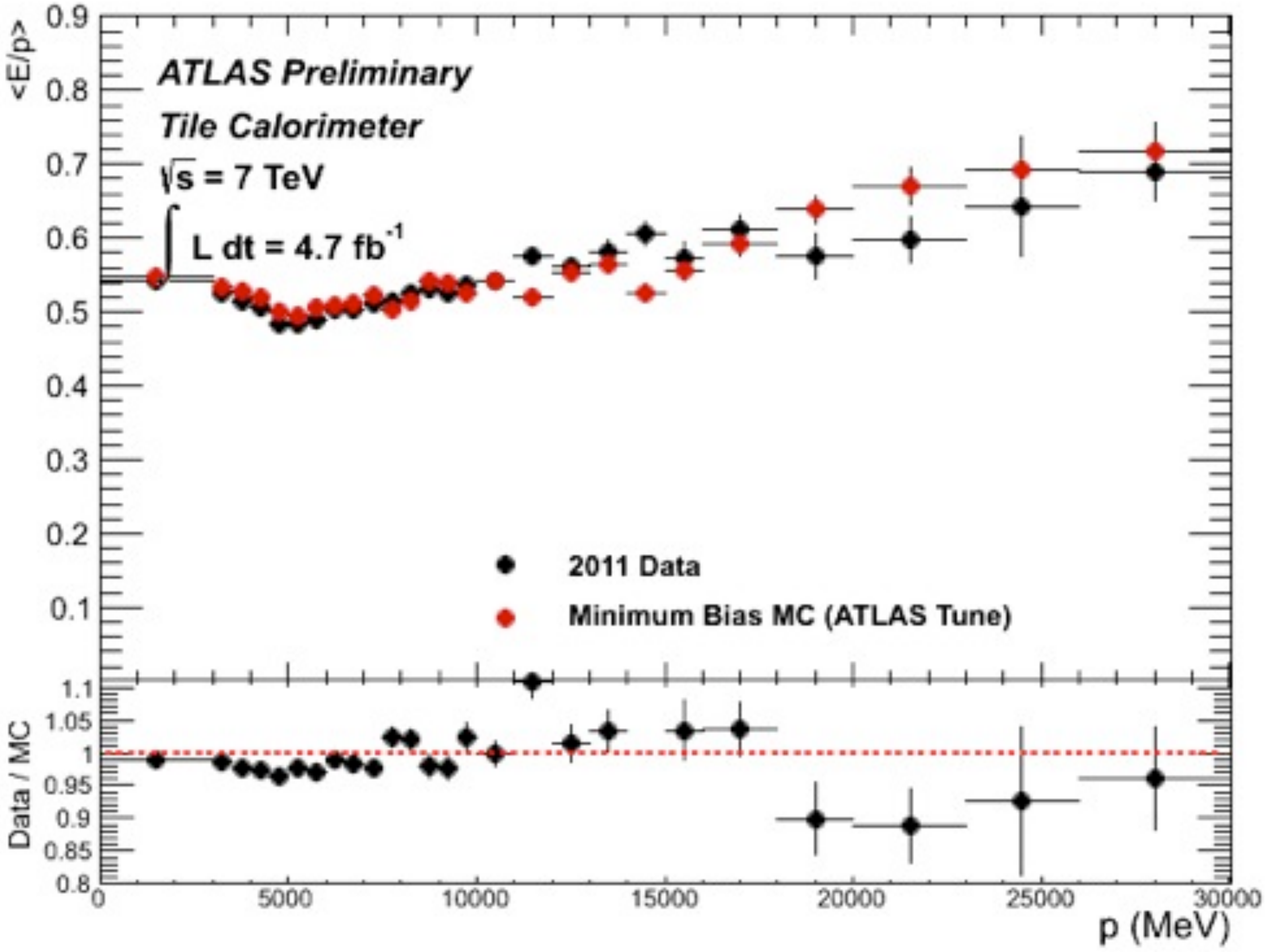
- cut E_T > 500 MeV to probe well into the range of energies deposited by particles in min. bias
- response uniform in φ
- follows the shape of MC in η

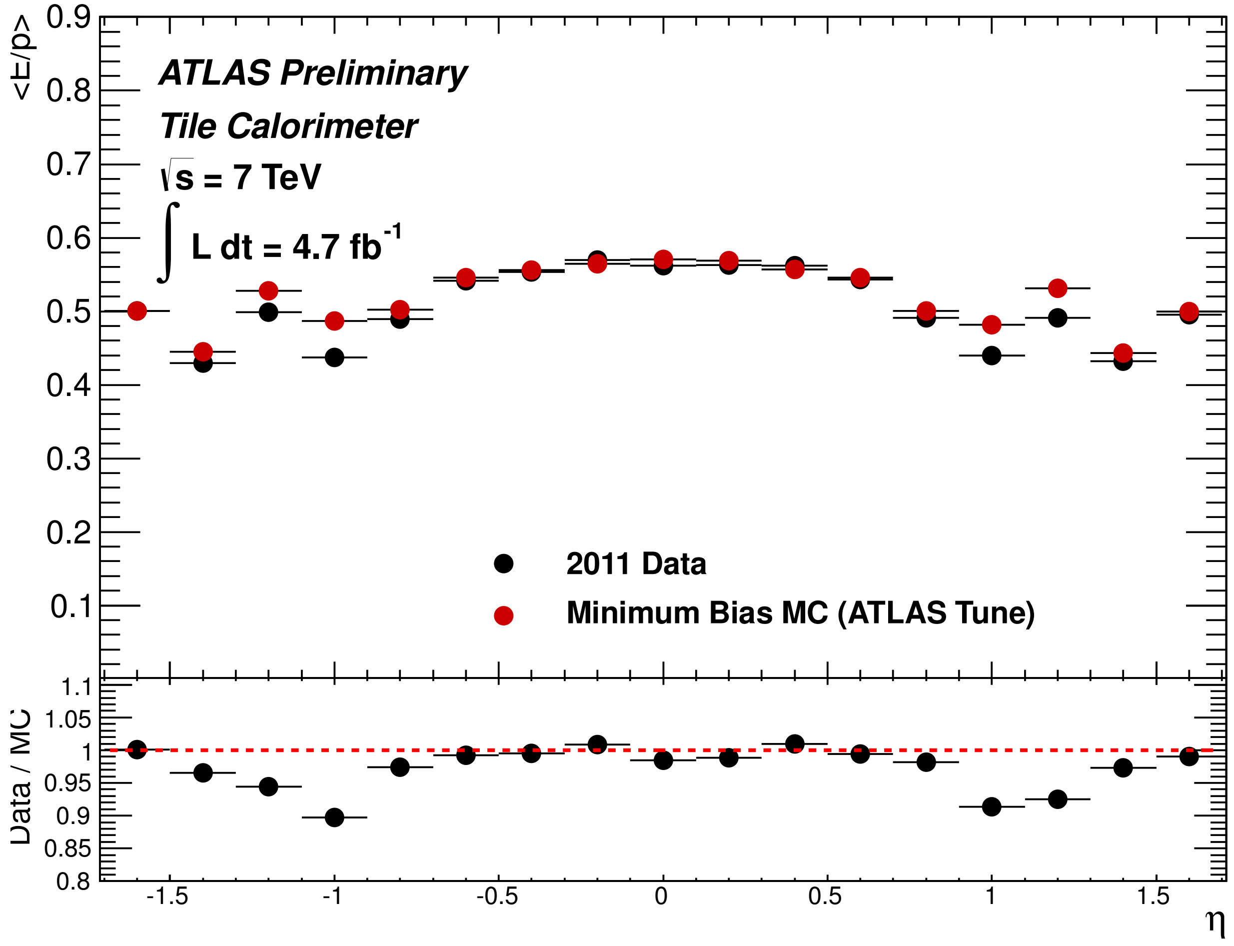
Single hadron response



In-situ method to probe the calorimeter response using energy deposited by **isolated charged particles** that shower in TileCal:

- momentum (p) measured in the inner detector with high accuracy
- measure energy (E) of topological clusters around the track extrapolated to the calorimeter
- response is characterized by **E/p**



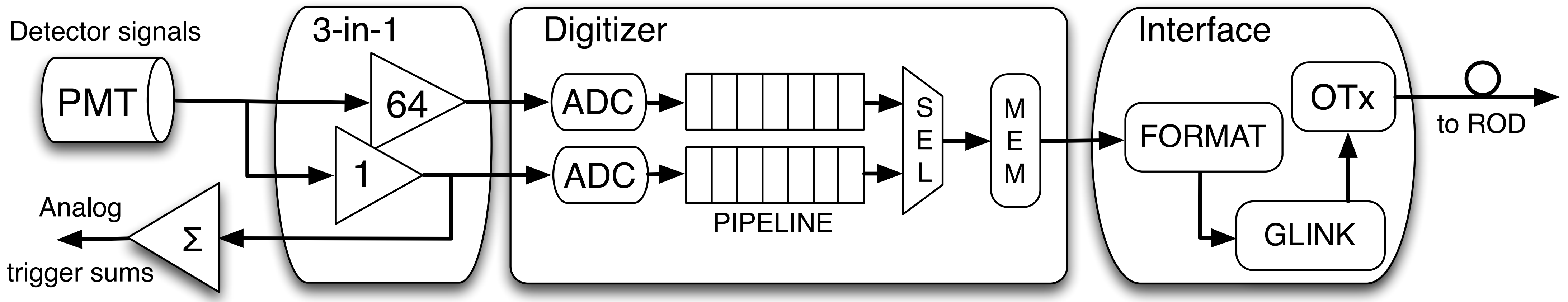


Conclusions

- The Tile Calorimeter has performed very well during the LHC Run1
- Achieved high data-quality efficiency of 99.6% despite the frequent problems with the LVPS
- 3% of masked cells by the end of Run1 in 2013 (was >5% in 2011)
- Improvements for Run2 are underway: upgraded LVPS and consolidations to guarantee robust operations and high performance
- Achieved time synchronization and time resolution below 1ns
- Studied the response with minimum bias data, single hadrons: good agreement between data/MC
- More information on calorimeter calibration and simulation/validation in the talks from Djamel Boumediene and Jana Faltova

EXTRA

Front-end electronics



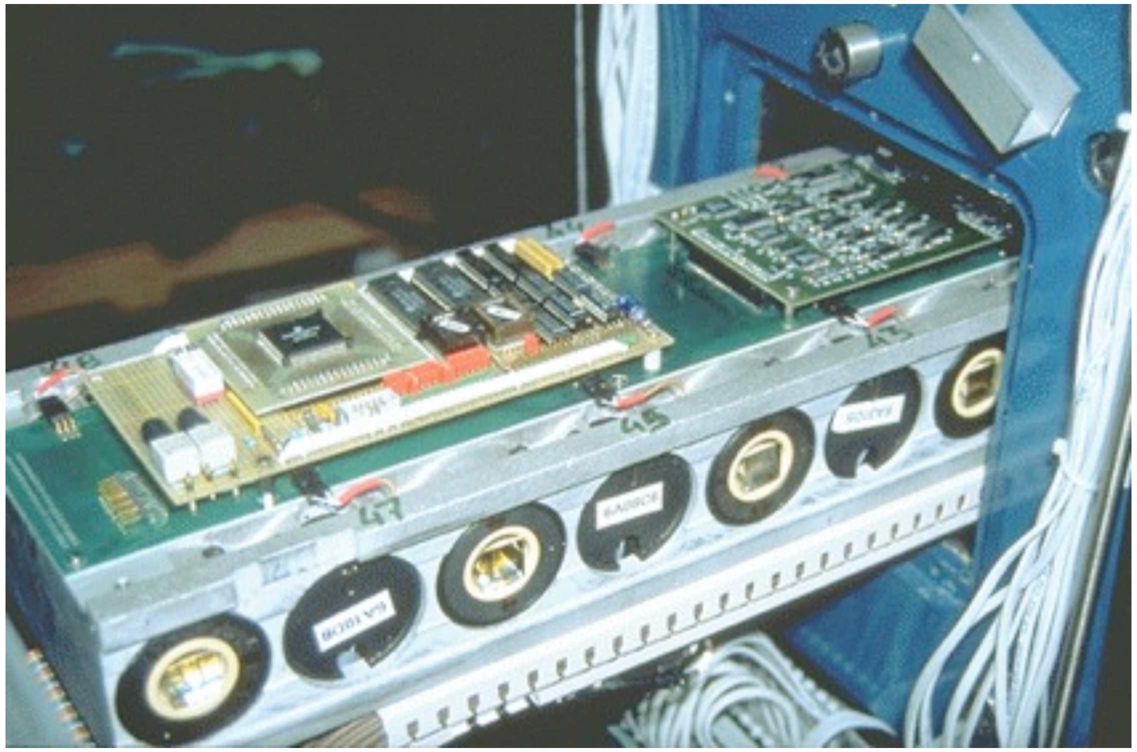
- PMT signals are shaped and amplified in two gains (relative ratio 1:64)
- analog tower sums provided for the level one trigger
- both gains are sampled at 40 MHz using 10-bit ADCs
- digitized samples stored in pipeline memories
- upon level-1 accept, data from one of the gains are selected, formatted and sent to the back-end electronics via optical fibers

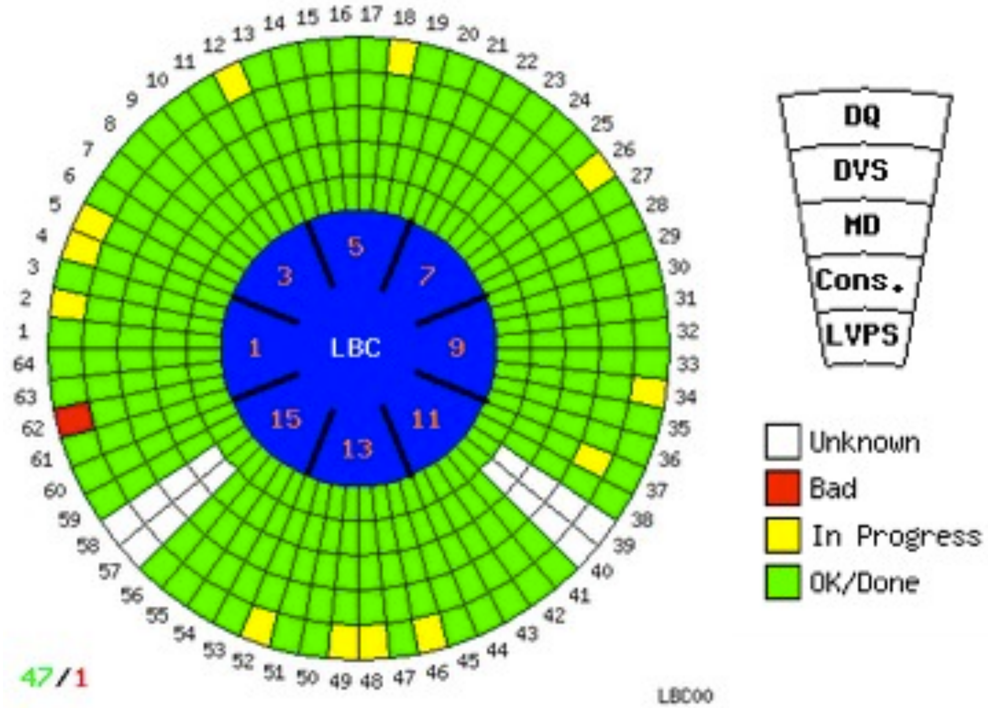
Detector maintenance

Maintenance activities aim to ensure high performance, high quality and robust operations during Run2

Maintenance activities during the LHC shutdown (2013-2014):

- replacement of all LVPS with new ones
- fix problems identified by experts in physics and calibration data
- consolidations to prevent data loss and corruption





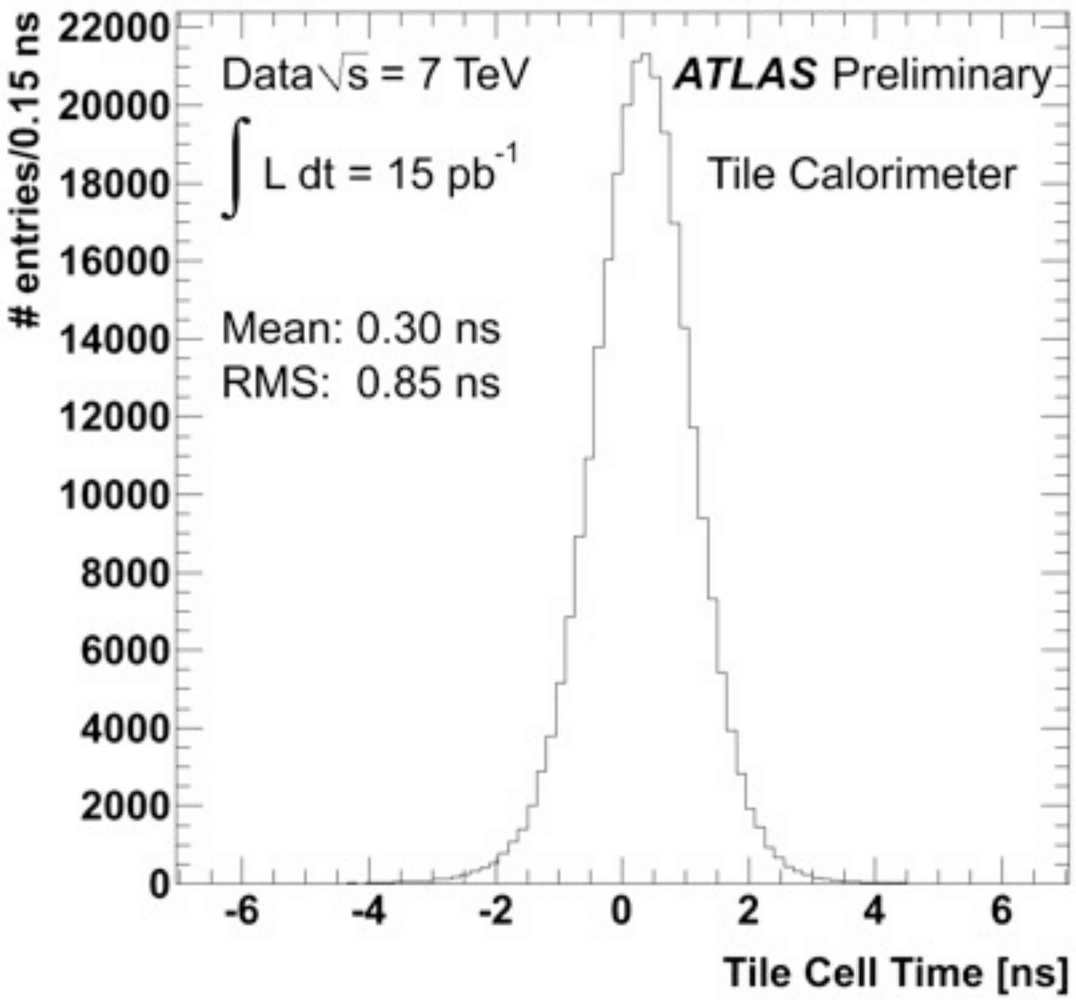
Thorough test and data-quality checks are performed to certify the consolidations

Current status:

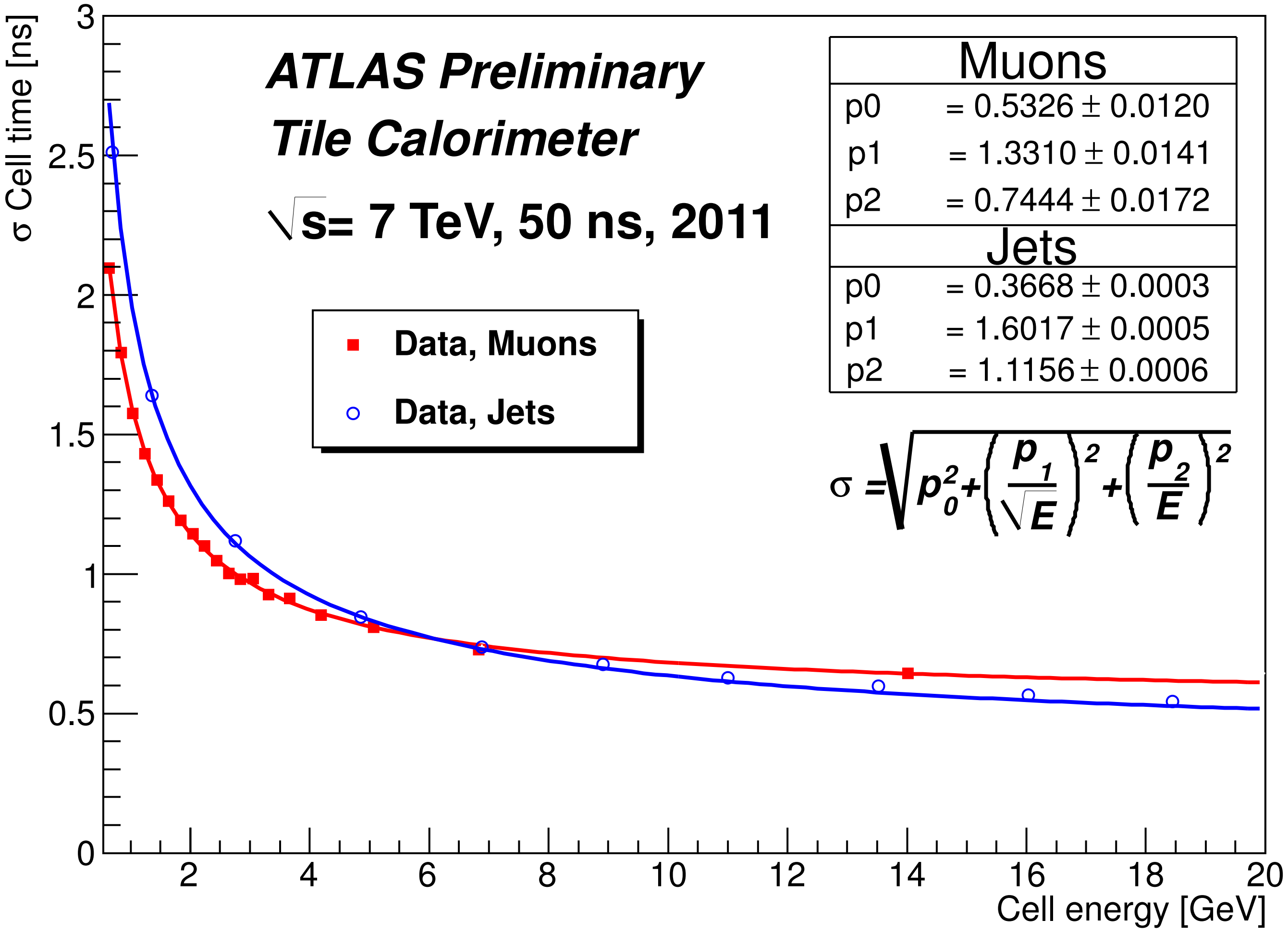
- all new LVPS installed
- > 90% of the detector consolidated
- some modules to be re-opened

Timing

Synchronization of all 10 000 Tile channels performed with laser calibration, cosmic events, single beam events and collision events.



Time distribution for cells belonging to topological clusters of jets with pt > 20 GeV



Cell time resolution:
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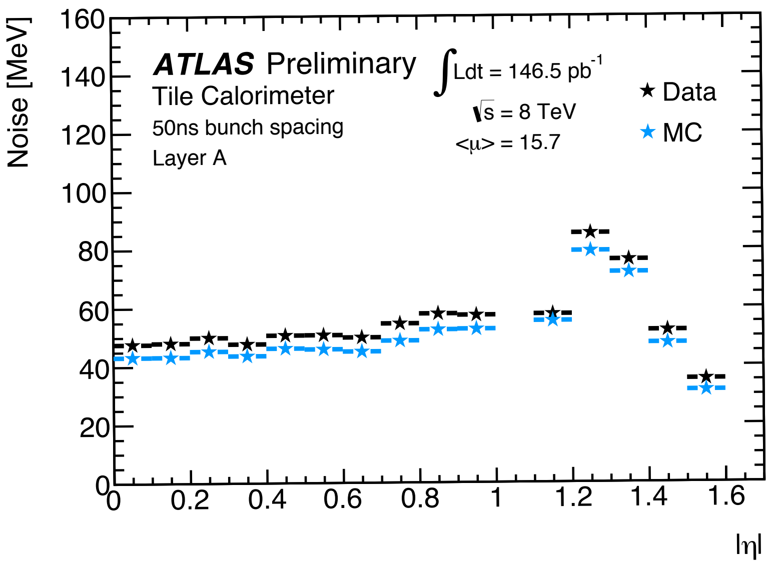
0.5-0.6 ns at E~20 GeV (jets)

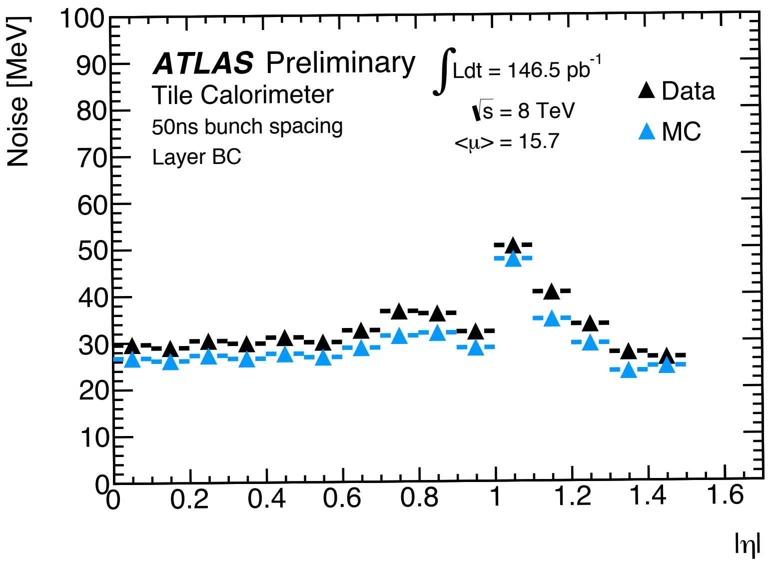
Pile-up noise

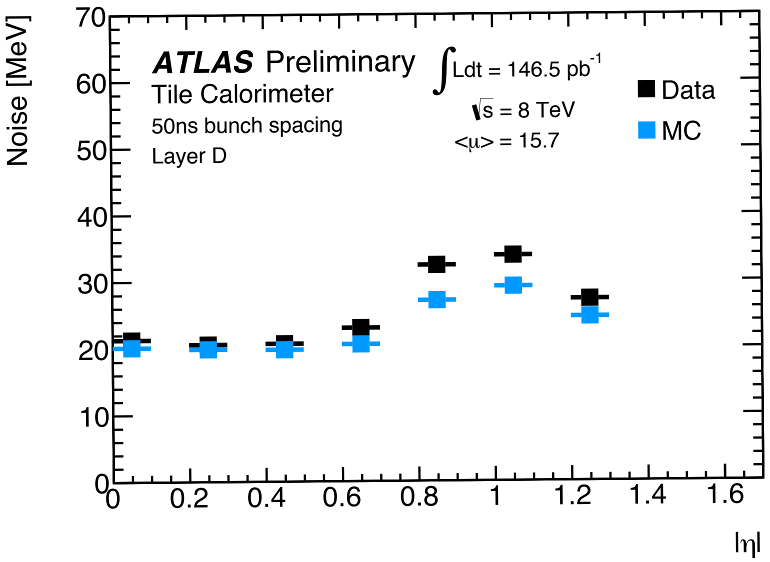
“Pile-up” refers to the effect of additional pp collisions in the same or neighboring bunch crossings

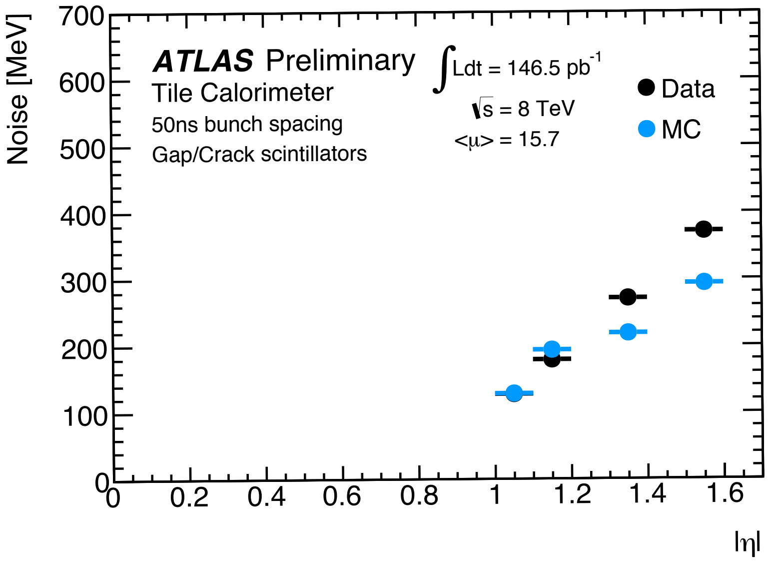
Cell noise depends on both electronic and pile-up noise

➡ Good noise description important for topological clustering algorithms to distinguish between signal and noise









Pile-up noise measured in pp collisions using zero bias trigger

Noise level depends on layer:

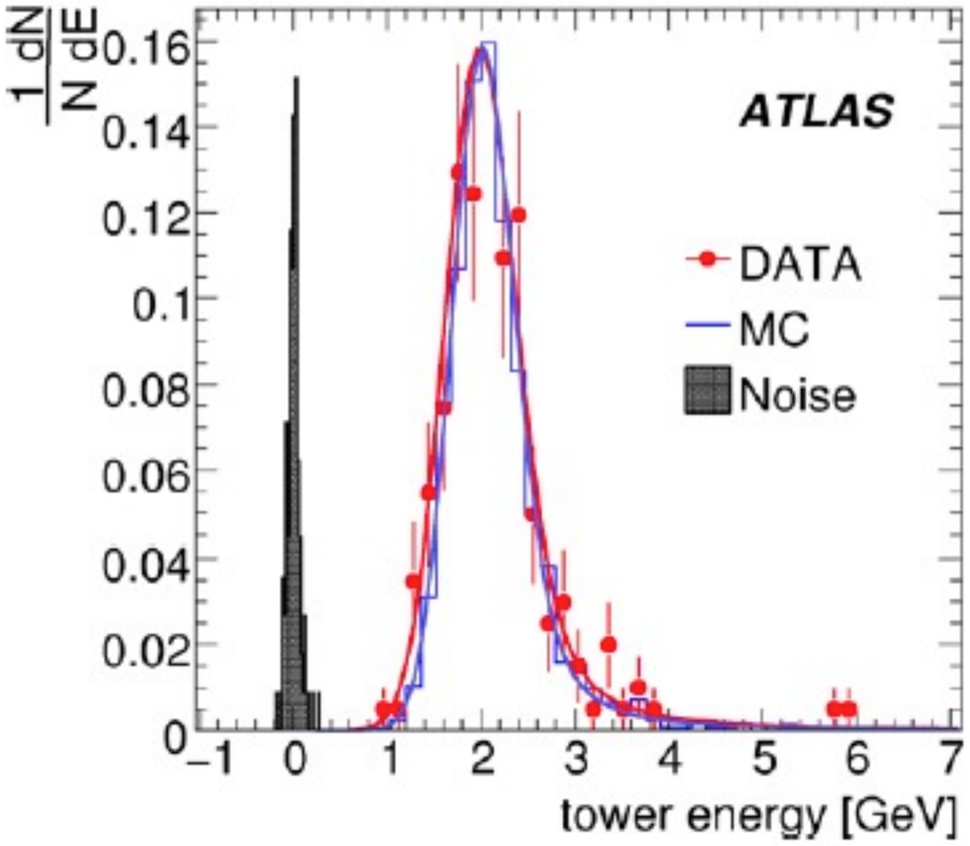
- higher pile-up noise in layer A (closer to the beam pipe) than in layers BC and D
- highest noise in gap/crack cells

Response to single muon

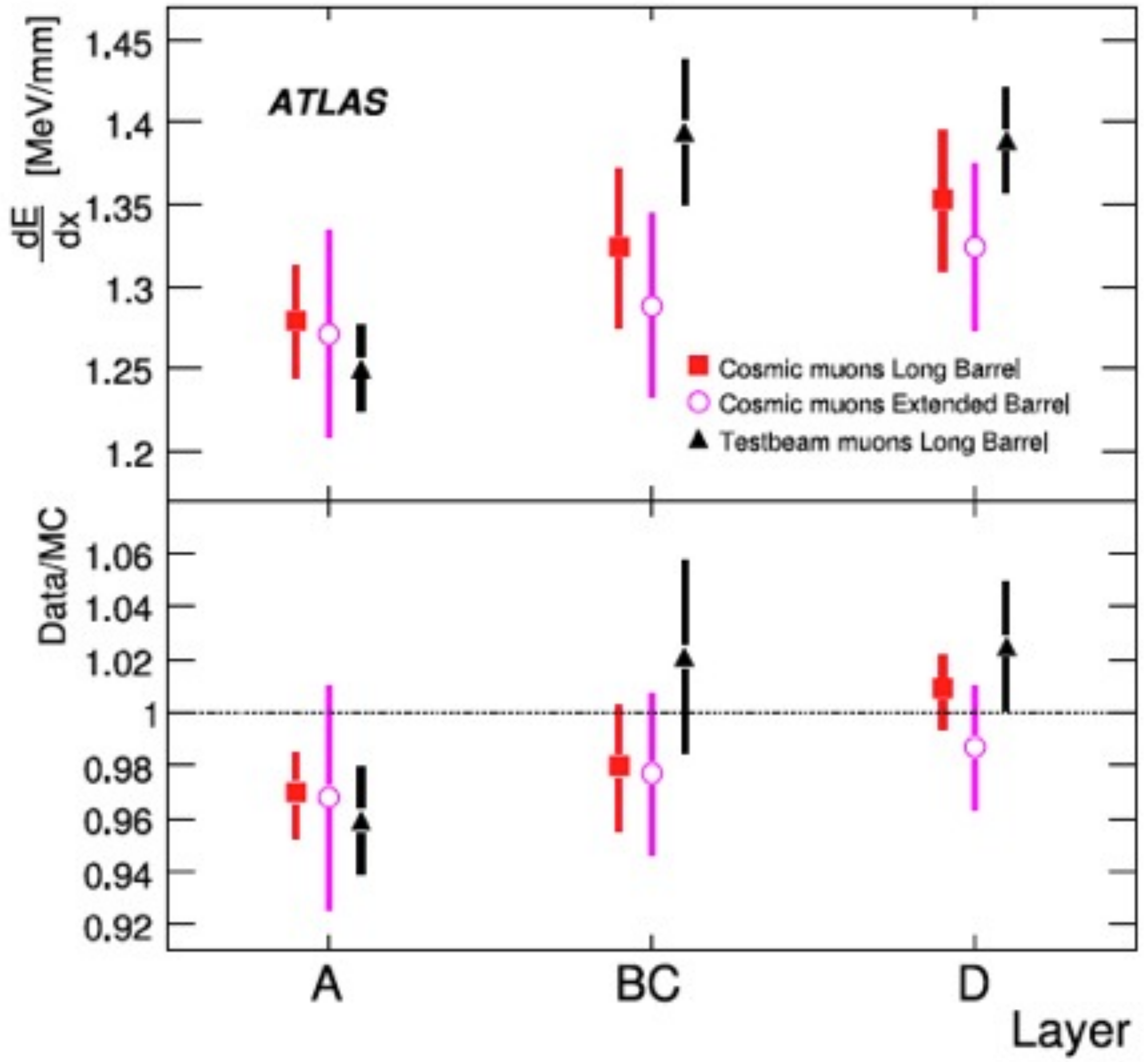
EM scale and cell-to-cell uniformity is validated using muons from cosmic data

Response is probed estimating energy loss per unit length of detector material (dE/dx)

- Good cell-to-cell uniformity within a longitudinal layer
- Differences up to 4% between layers
- Successfully validate propagation of EM scale from testbeam to ATLAS



Muon signal and noise well separated (S/N=29)



Jet and Missing E_T Performance

Good performance of jet and missing transverse energy resolution