Status of the Atlas Liquid Argon Calorimeter and its Performance after three years of LHC operation

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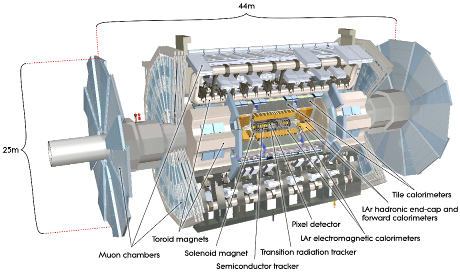
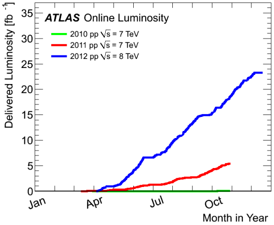
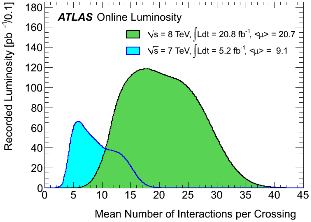
Three Years of ATLAS and LHC operation

Proton-Proton Physics: $\sim 5.3\ fb^{-1}$ *at* $\sqrt{s} = 7\ TeV$ *and* $\sim 21.7\ fb^{-1}$ *at* $\sqrt{s} = 8\ TeV$



- 93.5% of the delivered luminosity is recorded by ATLAS.
  - No loss due to Liquid argon calorimeter.
- Only good quality data (95.8%) are used for Physics.





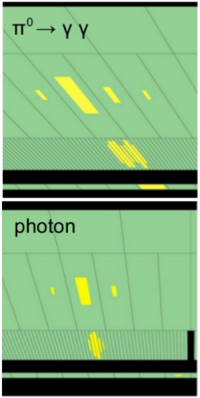
Design requirements for the ATLAS EM calorimeter.

Requirements mainly driven by the characteristics of few benchmark channels

- $H \rightarrow \gamma\gamma, H \rightarrow ZZ \rightarrow 4e\pm, H \rightarrow WW \rightarrow e\nu e\nu$
- Discovery of physics beyond the standard Model with masses up to $6\ TeV$

Design Requirements for the EM calorimeter

- Large dynamic range: $10\ MeV - 3\ TeV$
- Energy resolution: $\sigma_E = \frac{10\%}{\sqrt{E}} \oplus 0.7\%$
- Linearity: 0.1%
- Position and angular measurements: $\frac{50 mrad}{\sqrt{E}}$, necessary for precise vertex identification.
- Time resolution: $O(100\ ps)$ to allow identification of heavy exotic particles with slow decay.
- Fast shaping: Needed to cope with $40\ Mhz$ bunch crossing rate.
- Minimal coherent noise: $< 5\%$ of incoherent noise.
- Minimal dead time.
- Particle ID: $e^{\pm}/jets, \gamma/\pi_0, \gamma/jets$
  - fine strips, lateral and longitudinal segmentation.



Full details on Performance on e/gamma talk by Quentin Buat.

The ATLAS Liquid Argon Calorimeter

- Liquid Argon chosen because:
    - Linear behaviour.
    - Stability and radiaction tolerance.

Electromagnetic calorimeter (EMB and EMEC)

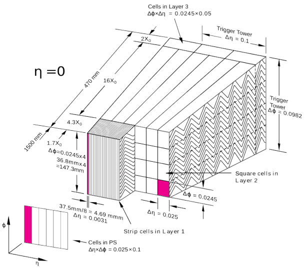
- Pb absorber, accordion geometry, $|\eta| < 3.2$.
- 173312 channels, 0.04% non operational.
- 3 longitudinal layers. (2 for $|\eta| > 2.5$). Presampler for $\eta < 1.8$.
- Accordion geometry chosen because:
    - High granularity and longitudingal segmentation.
    - Good hermeticity and good uniformity in Φ
    - Very fast response.

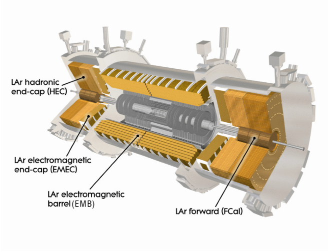
Hadronic Endcap (HEC)

- Cu Absorber, flat plate, $1.5 < |\eta| < 3.2$.
- 5632 channels, 0.39% non operational.
- 4 longitudinal layers.

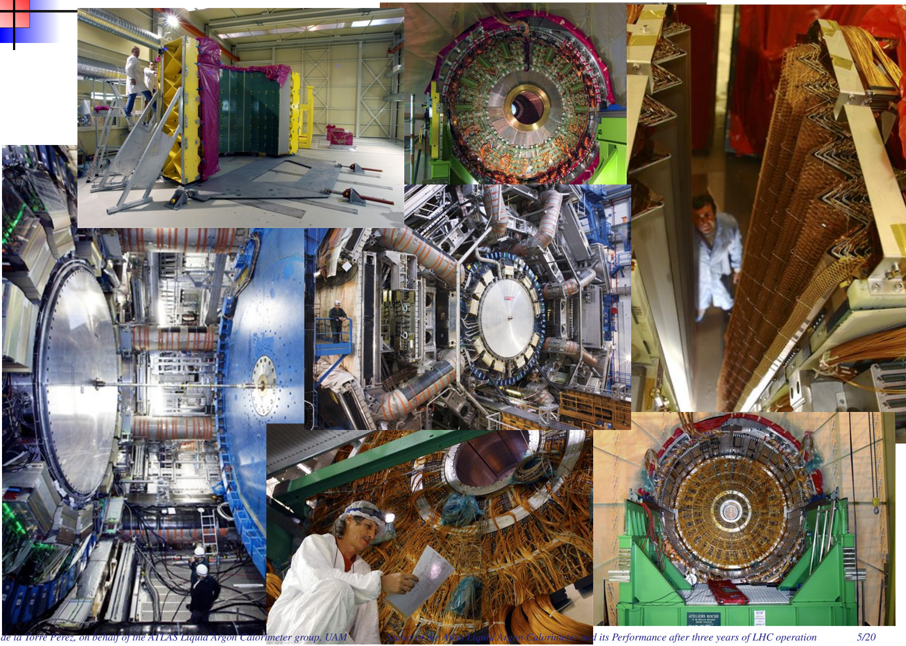
Forward Calorimeter (FCal)

- Cu/W absorber, rod matrix geometry, $3.2 < \eta < 4.9$.
- 3524 channels, 0.23% non operational.
- 3 longitudinal layers (1 EM, 2 HAD).





A long road since construction started



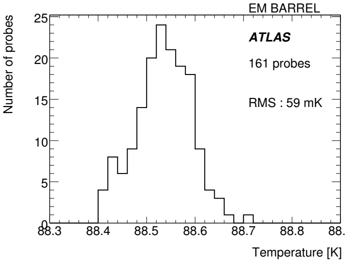
Liquid Argon Monitoring

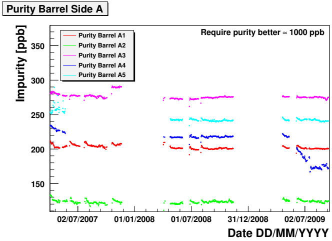
LAr Temperature

- 508 PT100 probes immersed in liquid argon.
- Require temperature stability and uniformity of liquid argon $< 100mK$.
    - Overall temperature homogeneity for the Barrel, $\sim 59mK$. Time stability $\sim 1.5mK$
- Average LAr Temperature is $\sim 88.5\,K$.
- $-2\%/K$ effect on the calorimeter signal.

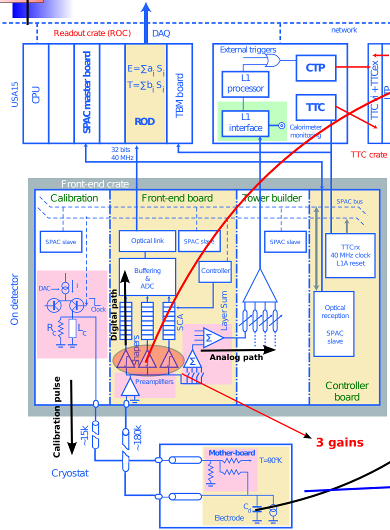
LAr Purity

- Electronegative impurities would lead to a reduction of the signals.
- 30 purity monitors, read out every 10-15 min.
- Impurity required to be below $1000\ ppb$.

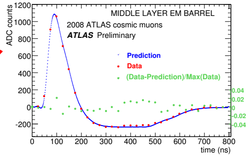


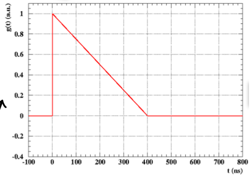


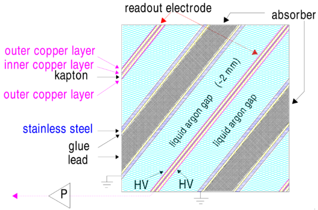
Signal Readout



3 gains

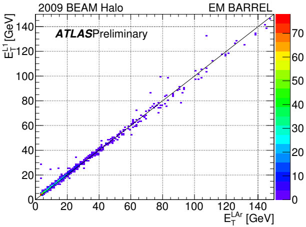


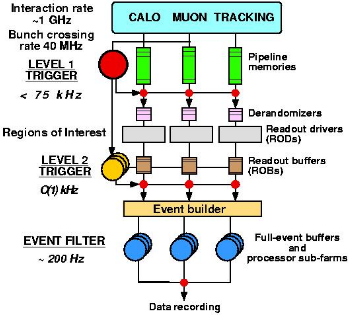




Calorimeter Trigger

- Calorimeter cells (Both from LAr and Tile) seed L1 Calorimeter Towers.
- Granularity of 0.1×0.1 in $\Delta\phi \times \Delta\eta$ for $|\eta| < 2.5$.
- Signal splits in the Front End Board(Digital path), going into the Tower Builder Boards (Analog path). Decision time $\sim 2\mu s$





Very good agreement between analog and Digital paths

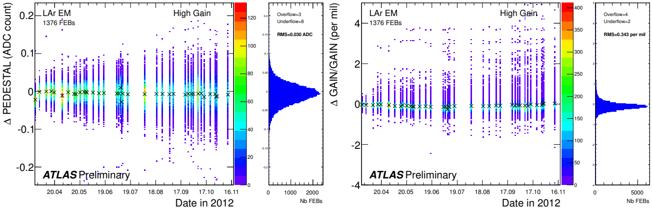
Electronic Calibration

Idea is to inject a well known exponential pulse as close as possible to the point where the ionisation pulse is created and read it back with the regular readout chain.

Pedestal runs	Noise and Pedestal constants, taken daily.
Ramp Runs	Gain Constants, taken daily.
Delay Runs	Monitor stability of pulse shapes, used to calculate Optimal filter coefficients, taken weekly.

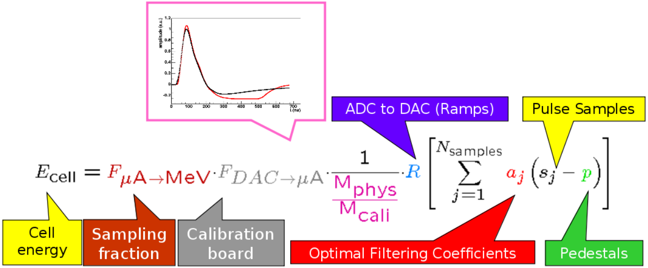
- Runs taken in fixed gain for three gains (Low, Medium,High).

Update of the calibration constants done roughly once a month, more if needed because of change in conditions



Pedestal and Gain stability on the per mil level

Energy reconstruction



$$E_{\text{cell}} = F_{\mu\text{A}\rightarrow\text{MeV}} \cdot F_{DAC\rightarrow\mu\text{A}} \cdot \frac{1}{\frac{\text{M}_{\text{phys}}}{\text{M}_{\text{cali}}}} \cdot R \left[\sum_{j=1}^{N_{\text{samples}}} a_j \left(s_j - p \right) \right]$$

Cell energy

Sampling fraction

Calibration board

ADC to DAC (Ramps)

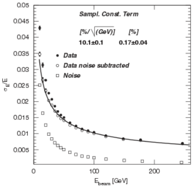
Pulse Samples

Optimal Filtering Coefficients

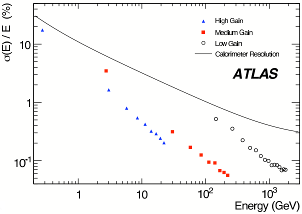
Pedestals

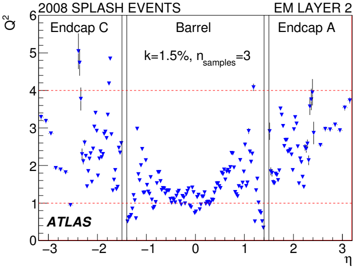
- Number of samples usually five for Phyisics data taking.
    - Considered to move to 4 for 14 TeV to be able to reach L1 rate of 100KHz.
- Sampling Fraction coefficient obtained from test beam.
- ADC to DAC obtained from Ramp calibration runs.
- ADC Pedestals obtained from Pedestal calibration runs.
- OFCs obtained from Delay runs + electronic noise + pileup noise from Monte Carlo.

Energy resolution and Q factor



- Calorimeter resolution is parametrised with the formula:
  - $\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$
- Where a is the sampling term, b is the noise term and c is the constant term. Sampling and Constant terms were measured during test beam, Noise measured using calibration data. They are η dependent





$$Q^2 = \frac{1}{nDoF} \sum_{i=1}^{n_{samples}} \frac{(A_i^{data} - A_i^{pred})^2}{\sigma_{noise}^2 + \sigma_{pred}^2}$$

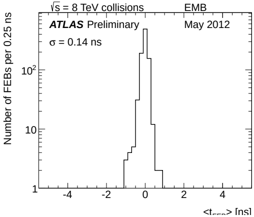
Quality factor

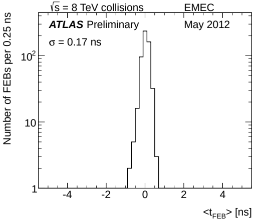
- Allows to check the signal reconstruction.
- $Q^2 = 1$: E_{cell} predicted at 1.5%,
- $Q^2 = N$: Accuracy degraded by $\sqrt{N}$.
- Over η range, prediction degraded by at most a factor ~ 2.

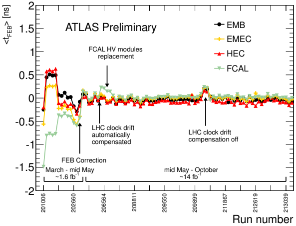
Signal reconstruction under control over the full EM calorimeter coverage.

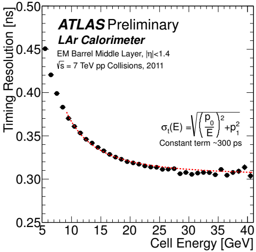
Timing

- Clock adjusted for each Front End Board (128 channels). Minimal adjustment: *0.104 ns*
- Cell level corrections are also applied, but only offline.







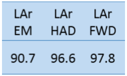


Precision timing has several advantages

- Veto cosmic events.
- Rejecting beam induced background.
- Identify heavy exotic particles with slow decay.

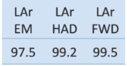
Data Quality evolution

2010

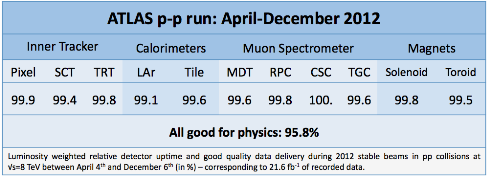


LAr EM	LAr HAD	LAr FWD
90.7	96.6	97.8

2011



LAr EM	LAr HAD	LAr FWD
97.5	99.2	99.5



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	99.4	99.8	99.1	99.6	99.6	99.8	100.	99.6	99.8	99.5

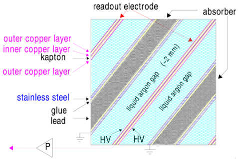
All good for physics: 95.8%

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 21.6 fb^{-1} of recorded data.

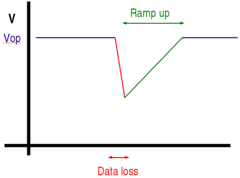
Clear improvement on the Data Quality, thanks mainly to the work on the HV system and the treatment of the noise bursts.

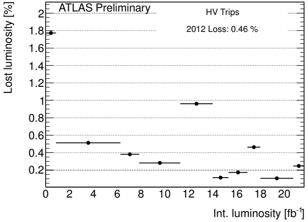
Two main sources of Data loss for 2012 are HV Trips (0.46%) and Noise Bursts (0.2%)

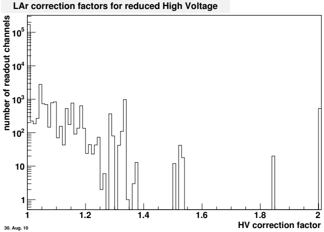
Data Quality (High voltage)



- If a line trips during stable beams, some data is lost (HV is varying too quickly to correct properly).
  - Autorecovery system implemented (Not in sensitive lines).
  - Data taking during Ramp-up are usable after appropriate corrections.
- Steps taken to minimise the impact on data quality:
  - More robust modules installed in the EM End-cap inner wheel → Able to switch to current controlled mode during a ”trip”, avoiding the voltage drop.
  - Reducing the HV on problematic lines (If they trip regularly) → Need to apply a correction.



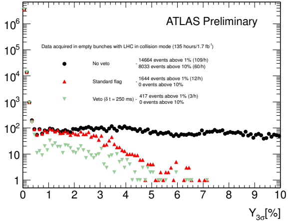


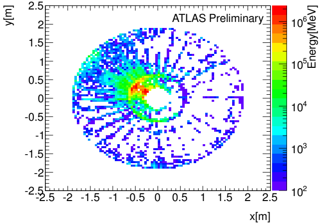


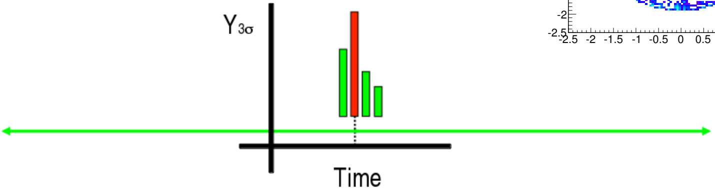
Training effect: *HV trips rate reduced when luminosity stable.*

Data Quality (Noise Bursts)

- Many cells in a region of the calorimeter give large signals with distorted shapes for a very brief period of time (mostly below $5 \mu s$).
- Observed only in presence of collisions.
- Yield increases with luminosity but length remains constant.
- Identified looking into empty bunches:
  - $Y_{3\sigma}$: Yield of channels per event in positive 3σ tails, $\sim 0.13\%$ expected, higher for noise bursts.
- Attempt to reject the events using Quality based flag (on colliding bunches):
  - Uses dedicated triggers on collision stream. Not efficient enough.
- Use a Time window veto to reject potential background events.
  - Vetoing a $250\ ms$ window around the noise burst events has a low inefficiency of 0.2%





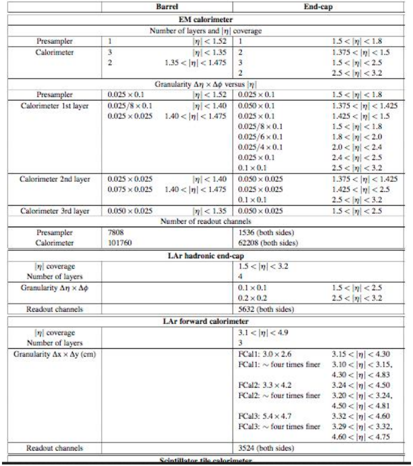


Summary

- LAr Calorimeter has performed wonderfully during the three years of operation.
- No major data-taking stopping issue and excellent stability.
- Data quality in constant improvement, achieved $> 99\%$ during 2012 proton-proton physics campaing.
- These results are impossible without the hard work from all the people involved in operations, data quality and data analysis → Thanks to all of them!!!.

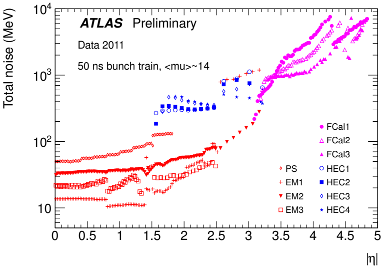
BACKUP

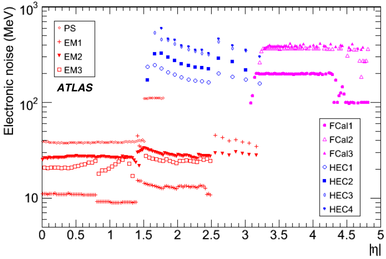
Segmentation

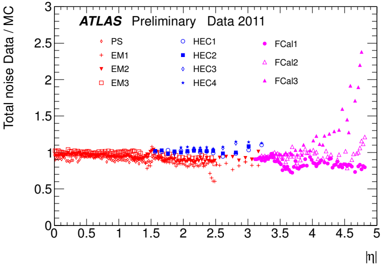


	Barrel		End-cap	
EM calorimeter				
Number of layers and $\|\eta\|$ coverage				
Presampler	1	$\|\eta\| < 1.52$	1	$1.5 < \|\eta\| < 1.8$
Calorimeter	3 2	$\|\eta\| < 1.35$ $1.35 < \|\eta\| < 1.475$	2 3 2	$1.375 < \|\eta\| < 1.5$ $1.5 < \|\eta\| < 2.5$ $2.5 < \|\eta\| < 3.2$
Granularity $\Delta\eta \times \Delta\phi$ versus $\|\eta\|$				
Presampler	0.025×0.1	$\|\eta\| < 1.52$	0.025×0.1	$1.5 < \|\eta\| < 1.8$
Calorimeter 1st layer	$0.025/8 \times 0.1$ 0.025×0.025	$\|\eta\| < 1.40$ $1.40 < \|\eta\| < 1.475$	0.050×0.1 0.025×0.1 $0.025/8 \times 0.1$ $0.025/6 \times 0.1$ $0.025/4 \times 0.1$ 0.025×0.1 0.1×0.1	$1.375 < \|\eta\| < 1.425$ $1.425 < \|\eta\| < 1.5$ $1.5 < \|\eta\| < 1.8$ $1.8 < \|\eta\| < 2.0$ $2.0 < \|\eta\| < 2.4$ $2.4 < \|\eta\| < 2.5$ $2.5 < \|\eta\| < 3.2$
Calorimeter 2nd layer	0.025×0.025 0.075×0.025	$\|\eta\| < 1.40$ $1.40 < \|\eta\| < 1.475$	0.050×0.025 0.025×0.025 0.1×0.1	$1.375 < \|\eta\| < 1.425$ $1.425 < \|\eta\| < 2.5$ $2.5 < \|\eta\| < 3.2$
Calorimeter 3rd layer	0.050×0.025	$\|\eta\| < 1.35$	0.050×0.025	$1.5 < \|\eta\| < 2.5$
Number of readout channels				
Presampler Calorimeter	7808 101760		1536 (both sides) 62208 (both sides)	
LAr hadronic end-cap				
$\|\eta\|$ coverage Number of layers			$1.5 < \|\eta\| < 3.2$ 4	
Granularity $\Delta\eta \times \Delta\phi$			0.1×0.1 0.2×0.2	$1.5 < \|\eta\| < 2.5$ $2.5 < \|\eta\| < 3.2$
Readout channels			5632 (both sides)	
LAr forward calorimeter				
$\|\eta\|$ coverage Number of layers			$3.1 < \|\eta\| < 4.9$ 3	
Granularity $\Delta x \times \Delta y$ (cm)			FCal1: 3.0×2.6 FCal1: $\sim$ four times finer FCal2: 3.3×4.2 FCal2: $\sim$ four times finer FCal3: 5.4×4.7 FCal3: $\sim$ four times finer	$3.15 < \|\eta\| < 4.30$ $3.10 < \|\eta\| < 3.15$, $4.30 < \|\eta\| < 4.83$ $3.24 < \|\eta\| < 4.50$ $3.20 < \|\eta\| < 3.24$, $4.50 < \|\eta\| < 4.81$ $3.32 < \|\eta\| < 4.60$ $3.29 < \|\eta\| < 3.32$, $4.60 < \|\eta\| < 4.75$
Readout channels			3524 (both sides)	
Scintillator tile calorimeter				

Noise plots


ATLAS Preliminary
Data 2011
50 ns bunch train, <mu>~14
Total noise (MeV)
10
10^2
10^3
10^4
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
|η|
FCal1
FCal2
FCal3
PS
EM1
EM2
EM3
HEC1
HEC2
HEC3
HEC4


Electronic noise (MeV)
10
10^2
10^3
ATLAS
PS
EM1
EM2
EM3
FCal1
FCal2
FCal3
HEC1
HEC2
HEC3
HEC4
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
|η|


ATLAS Preliminary Data 2011
Total noise Data / MC
0
0.5
1
1.5
2
2.5
3
PS
EM1
EM2
EM3
HEC1
HEC2
HEC3
HEC4
FCal1
FCal2
FCal3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
|η|

HEC and FCal geometry