Performance of the ATLAS Liquid Argon calorimeter

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- ▶ The ATLAS Liquid Argon calorimeter
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 - ▶ Signal reconstruction
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 - ▶ Timing alignment
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The ATLAS detector

1997

Start of construction, test beams

2003-2009

Installation in the experimental cavern, cosmic data

September 2008

First LHC beam

November 2009

First collisions @ 900GeV

March 2010

First collisions @ 7 TeV

Structure

- Tracking : Pixel, Silicon detector, Transition Radiation Tracker ; in a solenoidal magnetic field
- Calorimetry : Liquid Argon + Scintillators
- Muon spectrometer : Drift Chambers, Resistive Plate Chambers ; in a toroidal magnetic field

Physics

Standard Model, Higgs, SUSY, ...
Signatures : leptons, jets, missing transverse energy, ...

➔ Need for a good calorimetry!

The ATLAS LAr Calorimeter (1/2)

Electromagnetic Calorimeter (EM)

- Absorbers : Pb
- Active Medium : LAr
- Accordion geometry : full ϕ coverage
- Coverage : $|\eta| < 3.2$
- Segmentation in η and in depth
- 3 layers up to $|\eta| = 2.5$; 2 up to $|\eta| = 3.2$
 - Layer 1 : $\Delta\eta \times \Delta\phi = 0.0031 \times 0.1$
 - Layer 2 : $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$
- Presampler up to $|\eta| = 1.8$
- 173312 readout channels(98.5% operational)

- Design resolution : $\frac{\Delta E}{E} = \frac{10\%}{\sqrt{E(\text{GeV})}} \oplus 0.7\%$
(from test beam)

- Photon angular resolution : $\approx \frac{50\mu\text{rad}}{\sqrt{E(\text{GeV})}}$

The ATLAS LAr Calorimeter (2/2)

Hadronic Endcap (HEC)

- Absorbers : Cu
- Active medium : LAr
- Coverage : $1.5 < |\eta| < 3.2$
- 4 layers ($\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ or 0.2×0.2)
- 5632 readout channels (99.9% operational)

- Design resolution :
$$\frac{\Delta E}{E} = \frac{50\%}{\sqrt{E(\text{GeV})}} \oplus 3\%$$

Forward Calorimeter (FCal)

- Absorbers : Cu/W
- Active medium : LAr
- Coverage : $3.1 < |\eta| < 4.9$
- 1 EM + 2 Hadronic layers
- 3524 readout channels (100% operational)

- Design resolution :
$$\frac{\Delta E}{E} = \frac{100\%}{\sqrt{E(\text{GeV})}} \oplus 10\%$$

FCal

HEC

Signal reconstruction

$$E = \sum_{i=1}^{N_s} a_i (s_i - p)$$

$$\tau = \frac{1}{E} \sum_{i=1}^{N_s} b_i (s_i - p)$$

 N_s : number of samples

s_i : sample ADC counts

a_i, b_i : Optimal Filtering Coefficients

p : pedestal

Shaped signal, digitized
Sampled at 40MHz

ionization
pulse

Stability of calibration

Stability of calibration constants

- Calibration runs are taken between every LHC fill
- Calibration constants are updated every few weeks
- Stability of constants are monitored over long periods (here 6 months in 2009)
- Pedestals : < 0.03 ADC counts for all calorimeters
- Gains : < 0.1 % for all calorimeters

→ Robust calibration procedure
→ Good electronics stability

Timing alignment

Goal : align all the readout electronics in time
Prediction : time of flight, cabling length, ...
Time is calculated with collision data along with energy
Above : offset between calculated time and prediction

→ Achieved so far : 1ns per front-end board (128 readout channels)
→ Goal : 100ps per readout channel

Trigger performance

- Energy is summed over neighboring cells in trigger tower
- Typical size : $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ (approx. 60 readout channels)

- Trigger energy can be used to correct energy when digital readout is missing

Resolution of $E_T(\text{L1Calo}) < 5\%$ for $E_T(\text{LAr}) > 10\text{GeV}$

Physics results (1/2)

Photon identification results

Signal purity > 80% for $E_T > 30 \text{ GeV}$ using data-driven measurement of background using the calorimeter segmentation

Physics results (2/2)

Transverse energy of electron candidates

→ Good agreement between data and Monte-Carlo for variables related to physics objects

Above : missing transverse energy for $W \rightarrow e\nu$ candidates (left) and invariant mass of $Z \rightarrow ee$ candidates (right)

→ Well understood calorimeter variables allow interesting rediscoveries!

Summary

- The ATLAS Liquid Argon Calorimeter is installed in the cavern since 2006
 - Intense commissioning with cosmic muons until first LHC collisions in 2009
- Calibration
 - Procedure is robust, constants are stable over long periods
 - Updates every few weeks if necessary
- Timing alignment
 - Achieved : a few 100 ps
 - Goal : 100 ps
- Basic calorimeter variables are well understood and under control
 - Electrons, photons, missing transverse energy
- First physics results very promising
 - W, Z, jets cross-section measurements

LAr Calorimeter is well understood
Performance is very close to design

Thank you

ATLAS design resolutions

Detector component	Required resolution	η coverage	
		Measurement	Trigger
Tracking	$\sigma_{p_T}/p_T = 0.05\% p_T \oplus 1\%$	± 2.5	
EM calorimetry	$\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$	± 3.2	± 2.5
Hadronic calorimetry (jets) barrel and end-cap forward	$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$	± 3.2	± 3.2
	$\sigma_E/E = 100\%/\sqrt{E} \oplus 10\%$	$3.1 < \eta < 4.9$	$3.1 < \eta < 4.9$
Muon spectrometer	$\sigma_{p_T}/p_T = 10\%$ at $p_T = 1$ TeV	± 2.7	± 2.4

Table 1. General performance goals of the ATLAS detector. Note that, for high- p_T muons, the muon-spectrometer performance is independent of the inner-detector system. The units for E and p_T are in GeV.

LAr in numbers

Granularity

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

Design channel count

Layer	Number of channels
EM Barrel	
Presampler	7808
Layer 1	57216
Layer 2	28672
Layer 3	13824
Barrel end	2048
Calibration	8192
EM Endcap	
Presampler	1536
Layer 1	28544
Layer 2	23424
Layer 3	10240
Calibration	5952

Total EM Barrel
109568

Total EM Endcap
63744

HEC module and section	Total number of channels	Module	Total number of channels
HEC1 (first section)	1536	FCal1 (side A)	1008
HEC1 (second section)	1472	FCal2 (side A)	500
HEC2 (first section)	1344	FCal3 (side A)	254
HEC2 (second section)	1280		
Calibration	1024		
		FCal1 (side C)	1008
		FCal2 (side C)	500
		FCal3 (side C)	254

Total HEC
5632

Total FCal
3524

Grand Total LAr
182468

Energy reconstruction

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

Cell energy Sampling fraction Calibration board ADC to DAC (Ramps) Pulse Samples Optimal Filtering Coefficients Pedestals

The above formula describe the LAr electronic calibration chain (from the signal ADC samples to the raw energy in the cell. Note that this version of the formula uses the general M_{ramps} -order polynomial fit of the ramps. Actually we just use a linear fit (electronic is very linear, and additionally we only want to apply a linear gain in the DSP in order to be able to undo it offline, and apply a more refined calibration). In this case, the formula is simply:

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