Commissioning of the ATLAS Liquid Argon Calorimeter

Adam Gibson
University of Toronto
on behalf of the ATLAS Liquid Argon Calorimeter Group

ICATPP 2009, Villa Olmo, Como
October 5, 2009
The Liquid Argon (LAr) Calorimeter of the ATLAS Experiment

- **The ATLAS experiment**
  - general purpose detector at the LHC, at CERN

- **LHC environment**
  - proton-proton collisions ($\sqrt{s} = 14$ TeV) every 25 ns
  - $\sim$900 M inelastic collisions per second at design luminosity
  - high interaction rate
  - high radiation doses

- **Liquid Argon (LAr) Calorimeter**
  - sampling calorimeter
  - intrinsically radiation-hard
  - Very good electromagnetic calorimetry
    - main benchmarks:
      - $H \rightarrow \gamma \gamma$, $Z' \rightarrow ee$
      - identification and measurement over a large dynamic
        (50 MeV $\rightarrow$ TeV : 16 bits)
  - Hermetic jet and transverse missing energy calorimetry
    - Hadronic End-Cap and Forward Calorimeter
- **Hadronic End-Cap [Cu + LAr]**
  - Flat-plate design
  - Coverage: $1.5 < |\eta| < 3.2$
  - Resolution:
    \[ \frac{\Delta E}{E} = \frac{50\%}{\sqrt{E \text{ (GeV)}}} \oplus 3\% \]
  - 4 sampling depths
    - $\sim 11 \lambda$ in total 5,632 channels

- **Electromagnetic Calorimeter [Pb + LAr]** 173,312 channels
  - Accordion geometry providing an uniform $\phi$ coverage without crack
    - Barrel + End-cap: $|\eta| < 3.2$
  - Resolution:
    \[ \frac{\Delta E}{E} = \frac{10\%}{\sqrt{E \text{ (GeV)}}} \oplus 0.7\% \]
  - 3 sampling depths ($|\eta| < 2.5$)
    - $\sim 22-30 X_0$ in total
    - $+ 1$ presampler ($|\eta| < 1.8$)

- **Forward Calorimeter [Cu/W + LAr]**
  - Small LAr gaps between rods and tubes parallel to the beam axis
    - Coverage: $3.1 < |\eta| < 4.9$
  - Resolution:
    \[ \frac{\Delta E}{E} = \frac{100\%}{\sqrt{E \text{ (GeV)}}} \oplus 10\% \]
  - 3 sampling depths 3,524 channels
    - 1 EM (Cu) / 2 HAD (W)
    - $\sim 11 \lambda$ in total
The Hadronic End-Cap Calorimeter

- Hadronic End-Cap [Cu + LAr]
  - Flat-plate design
  - Coverage: $1.5 < |\eta| < 3.2$
  - Resolution:
    $$ \frac{\Delta E}{E} = \frac{50\%}{\sqrt{E\ (GeV)}} \oplus 3\% $$
  - 4 sampling depths
    - ~11 $\lambda$ in total 5,632 channels

- Electromagnetic Calorimeter [Pb + LAr]
  - 173,312 channels
  - Accordion geometry providing uniform $\phi$ coverage without crack
  - Barrel + End-cap: $|\eta| < 3.2$
  - Resolution:
    $$ \frac{\Delta E}{E} = \frac{10\%}{\sqrt{E\ (GeV)}} \oplus 0.7\% $$
  - 3 sampling depths ($|\eta| < 2.5$)
    - ~22-30 $X_0$ in total
    - + one presampler ($|\eta| < 1.8$)

- Forward Calorimeter [Cu/W + LAr]
  - Small LAr gaps between rods and tubes parallel to the beam axis
  - Coverage: $3.1 < |\eta| < 4.9$
  - Resolution:
    $$ \frac{\Delta E}{E} = \frac{100\%}{\sqrt{E\ (GeV)}} \oplus 10\% $$
  - 3 sampling depths
    - 3,524 channels
    - 1 EM (Cu) / 2 HAD (W)
    - ~11 $\lambda$ in total
The Forward Calorimeter

- Hadronic End-Cap [Cu + LAr]
  - Flat-plate design
  - Coverage: $1.5 < |\eta| < 3.2$
  - Resolution:
    $$\frac{\Delta E}{E} = \frac{50\%}{\sqrt{E\,(GeV)}} \oplus 3\%$$
  - 4 sampling depths
    - $\sim 11\,\lambda$ in total  5,632 channels

- Electromagnetic Calorimeter
  [Pb + LAr]  173,312 channels
  - Accordion geometry providing a uniform $\varphi$ coverage without crack
    - Barrel + End-cap: $|\eta| < 3.2$
  - Resolution:
    $$\frac{\Delta E}{E} = \frac{10\%}{\sqrt{E\,(GeV)}} \oplus 0.7\%$$
  - 3 sampling depths ($|\eta| < 2.5$)
    - $\sim 22$-30 $X_0$ in total
    - + one presampler ($|\eta| < 1.8$)

- Forward Calorimeter [Cu/W + LAr]
  - Small LAr gaps between rods and tubes parallel to the beam axis
    - Coverage: $3.1 < |\eta| < 4.9$
  - Resolution:
    $$\frac{\Delta E}{E} = \frac{100\%}{\sqrt{E\,(GeV)}} \oplus 10\%$$
  - 3 sampling depths  3,524 channels
    - 1 EM (Cu) / 2 HAD (W)
    - $\sim 11\,\lambda$ in total
Detector Status
(from September 26, 2009)

• ~182k total channels
• Only 36 (<0.02%) permanently dead
  – E.g. problem inside cryostat
• ~1.2% with dead readout
  – Mostly bad optical transmitters on front end boards
  – To be fixed at next access
• <0.4% with broken calibration lines (calibration degraded by ~2%)
• <0.1% with large noise
• Channels exercised with regular calibration and cosmic runs.

October 5, 2009    A. Gibson, Toronto; Villa Olmo 2009; ATLAS LAr Commissioning
Ionization and Signal Processing

- Shower develops in absorber
- LAr ionization electrons collected with ~1 kV/mm HV

- Front End Boards, on detector, receive ionization signals and
  - Amplify them, give them a bipolar shape (3 gains, ~1:10:100)
  - Sample and store them (~2.5 μs) while awaiting a L1 trigger decision
  - Select the gain, digitize, and transmit the signal upon L1 accept
  - Energy is calculated in back-end, off-detector, electronics
Energy Reconstruction and Calibration

• Electronic calibration runs taken regularly
  – Calibration board delivers precise current to injection resistors at cell input (for EM calorimeters)
  – Pedestal runs, ramp runs to measure gain (ADC to DAC), delay runs to measure pulse shape
  – Exponential calibration input vs. triangular input from ionization
• Optimal Filtering Coefficients from ionization pulse prediction, using delay runs as input
• Sampling fraction from test beam and simulation
• DAC $\rightarrow \mu A$ property of calibration board
• Cell energies computed in back-end electronics or offline

Cell energy
Sampling fraction
Calibration board

ADC to DAC (Ramps)

Pulse Samples

Optimal Filtering Coefficients
Pedestals

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

- Calibration runs planned between every LHC fill
- If significant changes are seen, calibration database is updated
- Pedestals are stable at the few MeV level over a period of months, here for one Front End Board (128 channels)
- Electronic noise for this layer ~25 MeV

- Amplitude of calibration pulses in delay runs stable at the 0.1% level
- Here comparing two calibration runs for whole LAr Barrel (~100k channels)
- Sensitive to stability of calibration pulse, shaper, pedestals, etc.
In Situ Commissioning ongoing since 3 years


ATLAS proposal
Detector and physics Technical Design Report
Stand-alone beam tests Construction CBT Installation Cosmic data taking LHC

1 2 3 4 5 6 7 8 Milestone weeks

Cosmic muons
Recorded in the LAr calorimeter since 2006

LHC Single beams (Sept. 2008)

140 m

closed collimator as fixed target

October 5, 2009
LAr (Online) Monitoring and Data Quality

- Extensive suite of monitoring plots and data quality checks for online and offline use
- Energy-weighted pulse shape gives quick check of timing, by trigger and subdetector, and evidence of signal
- Sporadically noisy cells from damaged amplifiers repaired with front end board refurbishment

Energy-weighted average pulse shape.

For each channel, fraction of events $3\sigma$ (DB) away from pedestal

For each event, fraction of cells $3\sigma$ (DB) away from pedestal
Noise and $E_T^{\text{Miss}}$

- Electronic noise is measured in pedestal runs, but also in physics runs (random triggers) using the full reconstruction of the cell energy and recorded in the calibration database
  - Varies with layer, $\eta$, and subdetector across almost two orders of magnitude

- $E_T^{\text{Miss}}$ reconstructed with cells, and with calorimeter clusters with additional noise suppression
- One faulty HV cable contributes significant coherent noise (now replaced)
- Aside from this, distribution is reasonably consistent with incoherent Gaussian noise
• Electronic noise is measured in pedestal runs, but also in physics runs (random triggers) using the full reconstruction of the cell energy and recorded in the calibration database
  – Varies with layer, $\eta$, and subdetector across almost two orders of magnitude

- $E_T^{\text{Miss}}$ reconstructed with cells, and with calorimeter clusters with additional noise suppression
- One faulty HV cable contributed significant coherent noise (now replaced)
- Aside from this, distribution is reasonably consistent with incoherent Gaussian noise
Cosmics as MIP’s to Test Response Uniformity

- Cosmic $\mu$’s approximate minimum ionizing particles (MIP’s)
- Projective muons, passing through center of ATLAS, leave a clear signal in LAr
- Tests calorimeter simulation and calibration
  - Probes non-uniformity of calorimeter response at 1% level

Energy in cluster described by Landau + Gaussian

Peak of Landau distribution vs. $\eta$

Response uniformity in $\eta$
Testing Our Pulse Prediction With Cosmics: Measuring the Drift Time

- Some cosmic runs taken with 32 sample LAr readout (instead of nominal 5)
  - Large event size limits ATLAS trigger rate
  - But, allows detailed studies of signal shape
- Drift time of the freed electrons relates directly to the pulse undershoot
  - Allows in situ measurement of drift time
  - Tests ionization pulse model and detector simulation
  - In barrel, allows us to estimate gap uniformity (0.3%) and overall calo uniformity (0.4%)

![Example pulse shape from cosmic run](image)

![Drift time measurement in EM endcap](image)

Example pulse shape from cosmic run

Drift time measurement in EM endcap

October 5, 2009

A. Gibson, Toronto; Villa Olmo 2009; ATLAS LAr Commissioning
Test of Cell Timing With Single Beam Events

- Single beam and collimator “splash” events
  - Large energy deposit in (nearly) every cell
  - Allows another pulse prediction quality check
  - Also, shown here, we check the time calibration
- Time computed with optimal filtering coefficients
  - Corrected for assumed time of flight
  - Prediction from calibration runs, and known calibration vs. signal path differences
- Agrees at ~2 ns level, except for presampler (and this artifact is now understood)
“Jets” in Cosmic Ray Events

- Cosmic rays can deposit significant energy in the EM and hadronic calorimeters
  - Either via hard *bremsstrahlung* events, or spectacular air showers
  - Good agreement with MC, aside from a few events in the tail (perhaps from air showers, unmodeled in the cosmic MC)

- With cosmics we can commission reconstruction software that will be used for collisions
- And look for unusual phenomena, like TeV jets

October 5, 2009
Rejecting “Jets” from Cosmic Ray Events

• These “jets” will be a significant background for some physics measurements (e.g. searches for beyond the Standard Model production of monojets + $E_T^{\text{Miss}}$)

• Jets from collisions deposit energy throughout the calorimeter

• “Jets” in cosmic ray events are often single hard brem interactions in either the EM or hadronic calorimeter

• Simple cleaning cuts can almost completely eliminate the background
Electrons from Ionisation in Cosmic Muons [1/2]

Muon track

Use tracker to measure the momentum $p$

Pixel, Semiconductor Tracker

Transition Radiation Tracker

transition radiations produce higher signal for electrons

red/blue points are for high/low TRT threshold

color ratio red/blue is a reliable discriminant variable for electron identification

Electron

Calorimeter

Use calorimeter to measure the energy $E$

muon chambers

inner detector and calorimeters
EM cluster ($E_T > 3$ GeV) + loose (downward) track match + electron like shower shape

- 1314 events

1229 events with only 1 track: muon bremsstrahlung candidates

85 events with 2 tracks: ionisation electron candidates

Expected background shape from muon bremsstrahlung candidates

First observation of electrons in the ATLAS detector
Conclusions and Outlook

• The ATLAS Liquid Argon calorimeter is completely installed
  – Extensively commissioned with calibration, cosmic, and LHC single beam runs
  – Data Acquisition, reconstruction, monitoring and data quality infrastructure well developed

• Calibration system, including ionization pulse model, well understood
  – Regularly exercised, with stable calibration constants

• Cosmic ray events extensively studied
  – Gain confidence in reconstruction, calibration, detector simulation
  – Test detector uniformity and drift time, understand bad channels and noise, possible backgrounds to physics

• Ready and waiting for LHC collisions!
  – ATLAS Global cosmic run starts next Monday with 24-7 operation and shift crews
  – LHC beam anticipated in mid-November
  – LHC collisions would be an excellent Christmas present!