The ATLAS experiment: from calibrations & cosmics to first beams

Manuella G. Vincter (Carleton University) on behalf of the ATLAS Collaboration
Commissioning of the ATLAS experiment

- ATLAS detector commissioning
- Subsystems and their performance
  - Trigger
  - Inner detector
  - Calorimeters
  - Muon system
- In-situ commissioning since 2005

ATLAS proposal


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

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Commissioning runs

In-situ detector commissioning
- System-specific stand-alone calibration runs
  - Noise measurements
  - Calibration pulses
- Stand-alone cosmics runs
- Combined cosmics runs
  - Trigger at Level 1 with:
    - Calorimeters (LAr&Tile)
    - Muon system (RPC&TGC)
    - Minimum bias scintillators
  - Detector subsystems have joined combined runs as they came online
Trigger

Level-1
- Custom-made electronics
- Reduced granularity info from calorimeter and muon systems
- Signatures from high $p_T$ muons, $\gamma/e$, jets, $\tau$, events with large $E_T^{\text{miss}}$

High-Level Trigger
- Software and mainly commercially available equipment
- Level-2: seeded by Regions of Interest (RoI) provided by Level-1, full detector granularity in RoI (tracking information used)
- Event Filter: uses offline analysis procedures to further select events, potential full access to event

Event rate reduced 40MHz $\Rightarrow$ 200Hz
Inner detector

Inner detector system: 87 million readout channels

- **Silicon pixel**
  - Discrete space points, 3 layers, $|\eta| < 2.5$

- **Silicon microstrip (SCT)**
  - Stereo pairs, 8 layers (4 space points), $|\eta| < 2.5$

- **Straw tube transition radiation tracker (TRT)**
  - Typically 36 hits per track, $|\eta| < 2.0$

**Goals:**

<table>
<thead>
<tr>
<th>Intrinsic accuracy</th>
<th>R- $\phi$</th>
<th>R or z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel</td>
<td>10 $\mu$m</td>
<td>115 $\mu$m</td>
</tr>
<tr>
<td>SCT</td>
<td>17 $\mu$m</td>
<td>580 $\mu$m</td>
</tr>
<tr>
<td>TRT</td>
<td>130 $\mu$m</td>
<td></td>
</tr>
</tbody>
</table>

**2008 commissioning:**

- 2.5% lost due to cooling leaks and heater problems in endcap (much can be recovered in shutdown)

- $\sigma/p_T \sim 0.05\% \ p_T \oplus 1\%$
Silicon ID with cosmics events

First cosmic runs with pixels: mid-September!
- 7 pixel hits and 16 SCT hits: one hit in every layer!

Initial alignment of SCT and pixel with cosmics:
- Number of pixel hits seen per event in cosmics runs
- Cosmic track crossing TRT endcap, SCT and pixel barrel+endcap
- Important for alignment
TRT with cosmic events

- TRT hit resolution already close to design requirements (130$\mu$m)
- In September, TRT switched to Xenon gas mixture
- First in-situ transition radiation probability curve with cosmic muons
  - Track $p_T$ 1-400 GeV
  - Comparison with barrel TB results

$\sigma = 174\mu$m

![Graph showing residual distribution and high-threshold probability against Lorentz gamma factor with legend for negative and positive cosmic muons and combined testbeam results. Preliminary Runs 90272, 90275]
Sampling calorimetry

~200k readout channels

Electromagnetic:
- 3 sampling depths in precision region $|\eta| < 2.5$
- Presampler $|\eta| < 1.8$

Hadronic:
- Barrel: $|\eta| < 1.7$, 3 sampling depths
- Endcaps: $1.5 < |\eta| < 3.2$, 4 sampling depths
- Forward: $3.1 < |\eta| < 4.9$
- 3 sampling depths (1 for electromagnetic and 2 for hadronic measurements)

Goals:
- Fine granularity in overlap region with inner detector for precision measurements of $e/\gamma$
  - $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.7\%$
  - Linearity to $\sim 0.1\%$
- Coarser granularity in the other regions sufficient for jet reconstruction and $E_T^{\text{miss}}$ measurements
  - $\sigma/E \sim 50\%/\sqrt{E} \oplus 3\%$ (barrel/endcap)
  - $\sigma/E \sim 100\%/\sqrt{E} \oplus 10\%$ (forward)
Calorimeter performance

Calorimeter commissioning

- “Dead” channels:
  - EM: ~0.01% (+0.5%, most can be recovered at next shutdown via frontend board replacement)
  - HEC: ~0.1% (+LVPS impacting ¼ of an endcap, to be resolved next shutdown)
  - FCal: none
  - Tile: ~1.5% (all should be recoverable next shutdown!)
- LAr: Some channels require special corrections e.g. high voltage
- Tile: Cs source used to set HV and equalise PMT gains to <1%
- Tile timing corrections: can intercalibrate to 0.5ns
- Effort is now more focused on performance
  - Long term stability
  - Prediction of the signal
  - Calibration constants

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Calorimeter performance

- Energy reconstruction
  - LAr EM: Reconstruct E with 3x3 calorimeter cells, comparison to Landau
    - energy $\eta$ dependence agreement, though there is a 5% systematic uncertainty on the MC prediction
  - Tile: energy deposited by $\mu$ vs. $\eta$, normalised by distance traveled in tile
    - energy scale&uniformity tested to 2-3%

<table>
<thead>
<tr>
<th>Tile Cal MuonFit Energy Density</th>
<th>Tile Muon Energy Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
<td>3851</td>
</tr>
<tr>
<td>Mean</td>
<td>1.739</td>
</tr>
<tr>
<td>RMS</td>
<td>0.0469</td>
</tr>
<tr>
<td>Landau width</td>
<td>0.1630</td>
</tr>
<tr>
<td>MPV</td>
<td>1.35</td>
</tr>
<tr>
<td>Norm factor</td>
<td>743 × 12.5</td>
</tr>
<tr>
<td>Gaussian Sigma</td>
<td>0.015</td>
</tr>
</tbody>
</table>

<p>| LAr EM Cluster Energy (0.3 &lt; | Cluster Energy (0.3 &lt; |</p>
<table>
<thead>
<tr>
<th>$l &lt; 0.4$)</th>
<th>$l &lt; 0.4$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
<td>2295</td>
</tr>
<tr>
<td>$\chi^2$/ndf</td>
<td>35.5 / 37</td>
</tr>
<tr>
<td>Prob</td>
<td>0.5385</td>
</tr>
<tr>
<td>Width</td>
<td>11.77 ± 1.10</td>
</tr>
<tr>
<td>MPV</td>
<td>280.0 ± 2.3</td>
</tr>
<tr>
<td>Area</td>
<td>4.528e+04 ± 974</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>60.78 ± 2.35</td>
</tr>
</tbody>
</table>

- Data
- MC

- Tile muon cosmics

- Tile

- Normalised energy

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Calo/trigger performance

- Correlation between energy as measured in calorimeter and as seen in L1 trigger
- Impact of air showers as sources of non-IP jets: reduced though timing cuts

\[ E_T = \sqrt{\sum E_{T,x}^2 + \sum E_{T,y}^2} \]
Muon spectrometer

Air-core toroid magnet system

Precision tracking chambers
- 3 barrel layers, 3 endcap wheels
- ~370k readout channels
- Monitored Drift Tubes (MDT)
  - $|\eta| < 2.7$ (innermost layer $|\eta| < 2.0$)
- Cathode Strip Chambers (CSC)
  - innermost layer $2.0 < |\eta| < 2.7$

2008 commissioning: MDT
- 99.8% of chambers readout
  - 2 endcap chambers with no access
- 1.5% of channels dead (should be reduced to 0.2% after shutdown)

2008 commissioning: CSC
- All chambers operational
- <0.1% dead channels

Trigger chambers
- ~680k readout channels
- Resistive Plate Chambers (RPC)
  - $|\eta| < 1.05$
  - 3 double layers
- Thin Gap Chambers (TGC)
  - $1.05 < |\eta| < 2.7$ (2.4 for triggering)
  - 4 wheels
Muon status and performance

**Goal:** stand-alone $p_T$ resolution $\sim 10\%$ for 1TeV tracks
- sagitta along the beam axis of $\sim 500\mu m$ for 5m track, to be measured with resolution of $50\mu m$

**Status:** All chambers installed & services connected
- Noise rates are under control
- Integrated into the DAQ
  - MDT tested to 100kHz, TGC and RPC to 40kHz
  - CSC: rate issues related to programming of FPGA
    - Under investigation

<table>
<thead>
<tr>
<th>Chamber resolution</th>
<th>$z/R$</th>
<th>$\phi$</th>
<th>time</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDT</td>
<td>35 $\mu m$ (z)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>CSC</td>
<td>40 $\mu m$ (R)</td>
<td>5 mm</td>
<td>7 ns</td>
</tr>
<tr>
<td>RPC</td>
<td>10 mm (z)</td>
<td>10 mm</td>
<td>1.5 ns</td>
</tr>
<tr>
<td>TGC</td>
<td>2-6 mm (R)</td>
<td>3-7 mm</td>
<td>4 ns</td>
</tr>
</tbody>
</table>

**CSC small wheel**
- Filters missing on LV cables

**MDT TDC signal**
- $\mu$ close to wire
- $\mu$ close to tube

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Muon performance with cosmics

MDT sees cosmic muon tracks very well!
- ~6 hits per layer per track

RPC’s can see footprint of access shafts

Number of MDT hits per muontrack

8 middle + 6 inner + 6 outer hits
Muon performance with cosmics

- Good correlation between MDT and RPC
- Distance between MDT centre & projection by TGC (inner, middle, outer layers)
Joint ID-muon performance

Early cosmic rays for ID in March 2008:
- difference in track ($\theta, \phi$) using ID (SCT+TRT) and muon (MDT) hits
- Resolution at the 10mrad level in $\theta, \phi$

August 2008 cosmics run with magnetic field “on”:
- Correlation between momentum in ID (TRT only) and muon spectrometer
- Note: muon charge wrong for downward tracks in upper detector
Muon alignment

- **Goal:** 10% accuracy for a 1TeV muon track requires a resolution on the reconstructed sagitta of 50\(\mu\)m. Intrinsic resolution of the muon chambers: \(~35\mu\)m
  - relative alignment of the 3 chambers per towers should be known to 30\(\mu\)m
- For needed sagitta accuracy: track-based alignment algorithms used in combination with optical system (\(~12000\) optical sensors)
- Geometer survey: positioning accuracy of the 1100 MDT chambers: \(~5\)mm
- Barrel alignment fit in sector 5: precision of 200-300\(\mu\)m (absolute mode, without straight tracks)
  - best that could be achieved is 100-200\(\mu\)m
- Monte Carlo of optical alignment only where e.g. sector 5 alignment error is propagated to muon sagitta
  - 50\(\mu\)m in the odd sectors
  - 400\(\mu\)m in the even ones
  - Track alignment with curved tracks needed to connect the even sectors to the odd ones

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Magnet runs

- Barrel and endcap toroid magnets (4T, 20.5kA) have been run at full current, in combination with the solenoid magnet (2T, 7.7kA)
- Impact of barrel toroid field on endcap calorimeter low voltage power supplies solved with extra shielding

3 weeks

First TRT cosmic events with solenoid “on”

July-Aug 2008
First beams in LHC!

- Sept 10, 2008! First LHC beams went sector by sector: stop beams on collimators, realigning beam and move to next sector
- Beam splash events depositing TeV’s of energy in the detector
- Beam pick-ups (BPTX) at 175m used as reference for timing-in of experiment
  - Timing evolved quickly!
First LHC beam: inner detector

- Distribution of SCT space-points
  - SCT endcaps at 20V during first beam
- Beam halo event in TRT
  - Magnet off
  - Beam from left to right
  - Hits in barrel and endcap!
Through the calorimeters...

- Beam 2 (C-side) in the calorimeters
- Flow of $\pi, \mu$ running through the experiment
- Can observe
  - Lower energy deposit at $\phi \sim -\pi/4$ to $-3\pi/4$ (probably protected by supports of upstream infrastructure?)
  - 8/16-fold structure due to the endcap toroids and forward shielding
  - Pions attenuated as they go through the experiment?
    - Attenuation of C-side vs A-side?

Barrel EM (2nd layer)
ATLAS commissioning and first beam: summary

- Already 3 years of in-situ commissioning!
  - Essentially the entire detector has been fully tested (in some cases, multiple times!) with calibration runs
  - Most subsystems have joined the ATLAS combined cosmics runs, with the pixels joining just over a month ago!
  - Have a good overview of the status of the subsystems for early running
    - Some intervention required during 2008-9 winter shutdown, which will give us back most of the ailing channels (e.g. some of those due to cooling leaks, LVPS, frontend readout problems)
    - Inaccessible problems at a very low level
  - Establish the initial calibration constants for early running
    - Have already some preliminary alignments, energy scale calibrations, timing from cosmics (but nothing beats real collision data!)
- ATLAS saw first beams!
  - Did wonders for timing-in the detector
  - Can see detector geometry through energy deposit and attenuation
- Near future activities centre on further commissioning the detector with cosmics and winter shut-down activities in preparation for first collisions next spring!