ATLAS: Status and First Results

Dan Tovey, University of Sheffield, on behalf of the ATLAS Collaboration
• Overview of the ATLAS detector
• Status of the experiment
• Performance and physics results in the first six months
• Future milestones
~3000 physicists
37 countries
173 institutes

ATLAS Collaboration
The ATLAS Detector

**Inner Detector (|\eta|<2.5, B=2T):**
- Si Pixels, Si strips, Transition Radiation detector (straws)
- Precise tracking and vertexing, e/\pi separation
- Momentum resolution (\eta=0): \( \sigma/p_T \approx 3.8 \times 10^{-4} p_T \text{(GeV)} \oplus 0.015 \)

**Muon Spectrometer (|\eta|<2.7):** air-core toroids with gas-based muon chambers
- Muon trigger and measurement with momentum resolution < 10% up to \( E_\mu \approx 1 \text{ TeV} \)

**EM calorimeter:** Pb-LAr Accordion
- e/\gamma trigger, identification and measurement
- E-resolution: \( \sigma/E \approx 10\%/\sqrt{E} \)

**HAD calorimetry (|\eta|<5):**
- Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
- Trigger and measurement of jets and missing \( E_T \)
- E-resolution: \( \sigma/E \approx 50\%/\sqrt{E} \oplus 0.03 \)

**3-level trigger reducing the rate from 40 MHz to \sim200 \text{ Hz}**

**Dimensions:**
- Length : \sim 46 \text{ m}
- Radius : \sim 12 \text{ m}
- Weight : \sim 7000 \text{ tons}
- \sim10^8 \text{ electronic channels}
- 3000 km of cables
First Six Months of Operation

- **20 Nov – 23 Dec:**
  - First physics run at $\sqrt{s} = 900$ GeV (few hours $\sqrt{s} = 2.36$ TeV)
  - ATLAS recorded $\sim 12 \mu$b-1, 0.5M events

- **16 Dec – 28 Feb:**
  - Winter technical stop

- **Since 30 March:**
  - LHC running at $\sqrt{s} = 7$ TeV
Data-Taking Status

Absolute luminosity uncertainty ~ 20% (MC-based cross-section and acceptance of luminosity detectors) ➔ <10% soon (Van der Meer scans)
## Detector Status

<table>
<thead>
<tr>
<th>Subdetector</th>
<th>Number of Channels</th>
<th>Approximate Operational Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixels</td>
<td>80 M</td>
<td>97.5%</td>
</tr>
<tr>
<td>SCT Silicon Strips</td>
<td>6.3 M</td>
<td>99.3%</td>
</tr>
<tr>
<td>TRT Transition Radiation Tracker</td>
<td>350 k</td>
<td>98.0%</td>
</tr>
<tr>
<td>LAr EM Calorimeter</td>
<td>170 k</td>
<td>98.5%</td>
</tr>
<tr>
<td>Tile calorimeter</td>
<td>9800</td>
<td>97.3%</td>
</tr>
<tr>
<td>Hadronic endcap LAr calorimeter</td>
<td>5600</td>
<td>99.9%</td>
</tr>
<tr>
<td>Forward LAr calorimeter</td>
<td>3500</td>
<td>100%</td>
</tr>
<tr>
<td>LVL1 Calo trigger</td>
<td>7160</td>
<td>99.8%</td>
</tr>
<tr>
<td>LVL1 Muon RPC trigger</td>
<td>370 k</td>
<td>99.7%</td>
</tr>
<tr>
<td>LVL1 Muon TGC trigger</td>
<td>320 k</td>
<td>100%</td>
</tr>
<tr>
<td>MDT Muon Drift Tubes</td>
<td>350 k</td>
<td>99.7%</td>
</tr>
<tr>
<td>CSC Cathode Strip Chambers</td>
<td>31 k</td>
<td>98.5%</td>
</tr>
<tr>
<td>RPC Barrel Muon Chambers</td>
<td>370 k</td>
<td>97.3%</td>
</tr>
<tr>
<td>TGC Endcap Muon Chambers</td>
<td>320 k</td>
<td>98.8%</td>
</tr>
</tbody>
</table>

- **Overall data taking efficiency:** ~ 92%
- **Recorded with all detectors at nominal voltage (including Pixels):** ~ 88 %
Trigger Status

- Trigger output rate: typically 200-300 Hz (up to ~350 Hz)
- $L < \text{few } 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$:
  - (un-prescaled) minimum-bias LVL1 trigger based on hits in scintillator counters (MBTS) located at $Z=\pm 3.5$ m from collision centre
  - LVL1 muon and calo (EM, jets, ..) triggers also active
  - HLT (LVL2+EF) commissioned by running mostly in pass-through mode
- $L > \text{few } 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$: MBTS trigger pre-scaled
- $L > 10^{29} \text{ cm}^{-2} \text{ s}^{-1}$: e/γ HLT chain activated in rejection mode to be able to run with lowest-threshold EM LVL1 item (3 GeV)
Many more results than I can possibly hope to show in 30 minutes … 

More results and more details at: https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasResults
6 Jet Event in 7 TeV Collisions

Maximum jet $p_T$ 70 GeV
• Jets reconstructed with Anti-kT algorithm, calibrated with simple $\eta/p_T$-dependent corrections from test-beam, track E/p, MC $\rightarrow$ 7% scale uncertainty
• Good agreement with LO+PS MC
$\pi^0 \rightarrow \gamma\gamma$ Reconstruction

- Key benchmark for EM reconstruction
- Tool for measuring calorimeter scale and uniformity
- Energy scale measured to $\sim 2\%$

Mass peak: $135.05 \pm 0.04$ MeV (PDG: 134.98)
Width: $\sim 20$ MeV
Systematics: m: 1%; $\sigma \sim 10\%$

\[ \pi^0 \rightarrow e^+e^- \]
Minimum Bias with Tracks

• Inclusive, model-independent measurement from inelastic events:
  – Well-defined kinematic region: $\geq 1$ charged particle $p_T > 500$ MeV, $|\eta| < 2.5$
  – Single-arm scintillator trigger with high acceptance in above phase-space
  – No removal of single/double diffractive components
  – Distributions corrected back to hadron level

• Results at $\sqrt{s} = 900$ GeV published in Phys. Lett. B688 (2010) 1
• Excess above MC observed $\rightarrow$ new tune (ATLAS-CONF-2010-031)
Primary Vertex Reconstruction

- ~10-45 tracks with $p_T > 150$ MeV per vertex
- Vertex z-positions: $-3.2, -2.3, 0.5, 1.9$ cm (vertex z-resolution better than ~200 μm)
- Expect handful of 4-vertex events in this run
Run 152166
Event 817271

b-tagged jet in 7 TeV collisions

jet $p_T = 19$ GeV (measured at electromagnetic scale)

4 b-tagging quality tracks in the jet
Flavour Tagging

- **Track counting:** simple, robust
- **Jet probability tagger:**
  - Construct combined probability of tracks to be associated with PV
- **Secondary vertex tagger:**
  - Reconstruct SVX and cut on decay length significance
- **Data/MC agreement very encouraging** at such an early stage: bodes well for b-jet physics

![Graph](image)

Cut at $P_{\text{jet}} = 0.055$

- yields:
  - 6213 (6230) jets in data (norm MC)
  - 60\% (24\%) eff. for b(c)-jets in MC

![Graph](image)

**Vertex mass in events with $L/\sigma(L) > 7$**

- Normalized to data
- Stat errors only

![Graph](image)

**Decay length significance $L/\sigma(L)$**

ATLAS-CONF-2010-041
ATLAS-CONF-2010-042
Hadron Spectroscopy

**Early $K^0_s \rightarrow \pi^+\pi^-$ observed in Dec 2009, a few days after first collisions**

**ATLAS**
- $K^0_s$ Invariant Mass

- Data
- Simulation
- Gauss (+poly) fit
  - $\mu = 497.5 \pm 0.1$ (stat) MeV
  - $\sigma = 8.2 \pm 0.1$ (stat) MeV
- PDG (2009) $m_{K^0_s} = 497.614 \pm 0.024$ MeV

Normalized to data
Stat errors only

**$\Phi \rightarrow K^+K^-$**

**PDG: 1321.32 GeV**

**$\Xi \rightarrow \Lambda\pi$**

**$\sqrt{s}=7$ TeV data**

$\Xi(1320) \rightarrow \Lambda\pi$

$\sim 250 \mu$b$^{-1}$

**Normalized to data**
**Stat errors only**

**$\Lambda$**

**$\pi$**

**$\Xi$**

**$\Phi$**

**$\sqrt{s}=900$ GeV**

**Normalized to data**
**Stat errors only**

**$\phi \rightarrow \pi^+\pi^-$**

**$\mu = 1322.2 \pm 0.07$ (stat) MeV**

**$\sigma = 3.8 \pm 0.08$ (stat) MeV**
D(*) Meson Reconstruction

For more details see Eleni Mountricha’s talk
**J/ψ \rightarrow \mu^+\mu^-**

- **Key milestone for commissioning and physics**
  - QCD test with J/ψ differential cross section, polarization...
  - Crucial to understand detector performance
  - Crucial for B-physics

- **Makes use of matched ID and MS tracks**

- **Mass consistent with PDG, width well modelled by simulation**

- **For more details see Maria Smizanska’s talk**

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**Very loose selections:**
- min-bias trigger at LVL1 plus HLT muon (\(\rightarrow\) sensitive to \(p_T(\mu)\) as low as \(\sim 1\) GeV)
- 2 muons with opposite sign fitted to common vertex
- \(p_T(\text{ID track}) > 0.5\) GeV

**Signal** : \(612 \pm 34\) events

**Background** : \(332 \pm 9\) events

**Mass peak** : \(3.095 \pm 0.004\) GeV (PDG: 3.097)

**Mass resolution** : \(82 \pm 7\) MeV (MC: 74\pm0.4)
Missing Transverse Energy

- Sensitive to calorimeter performance (coherent noise, dead/hot cells, miscalibration, cracks etc.) and non-collision backgrounds \(\Rightarrow\) strong test
- Calibrated at EM scale currently
- Clean and stable

![Graph showing stability of \(E_T^{\text{miss}}\) distribution vs time over 1 month: < 3%]

\(\begin{align*}
\text{Data} & \quad \text{fit } 0.41 \sqrt{\Sigma E_T} \\
\text{MC} & \quad \text{fit } 0.43 \sqrt{\Sigma E_T}
\end{align*}\)
Muon: 3 Pixel hits, 8 SCT hits, 17 TRT hits, 14 MDT hits, $Z \sim 0.1$ mm from vertex, ID-MS matching within 1 GeV, $E_T^{\text{miss}}$ (calorimeter only) $\sim 3$ GeV

$p_T(\mu^-) = 40$ GeV
$\eta(\mu^-) = 2.0$
$E_T^{\text{miss}} = 41$ GeV
$M_T = 83$ GeV

$W \to \mu \nu$ candidate in 7 TeV collisions
**W → μν Signal**

- **Event Selection**
  - Level 1 muon trigger (no $p_T$ threshold)
  - One PV with 3 tracks, consistent with BS
  - 1 combined MS+ID muon, $p_T$(combined)$>$ 15 GeV, $p_T$(MS)$>$10 GeV
  - $|p_T$(combined)$-p_T$(MS)$|< 15$ GeV
  - $|z_\mu - z_{PV}|<1$cm, $|\eta|<2.4$
  - Any jets must pass quality cuts

- **Tight selection**
  - $p_T>20$ GeV and relative track isolation<0.2 in $\Delta R=0.4$

**Preselected sample**

Data driven fake background

Tight sample no $E_T^{miss}$

$\sigma_{NNLO}(W \rightarrow l\nu) = 10.45$ nb

$E_T^{miss} > 25$ GeV, $m_T > 40$ GeV

<table>
<thead>
<tr>
<th></th>
<th>Observed</th>
<th>Expected</th>
<th>Signal</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$28.7\pm0.5$(stat)$\pm3.9$(syst) $\pm5.7$(lumi)</td>
<td>$25.9\pm3.6$(syst)$\pm5.2$(lumi)</td>
<td>$2.8\pm0.5$(stat)$\pm0.8$(syst)$\pm0.6$(lumi)</td>
</tr>
</tbody>
</table>

**ATLAS-CONF-2010-044**
$W\nu$ candidate in 7 TeV collisions

$p_T(e+) = 23$ GeV
$\eta(e+) = -0.64$
$E_T^{\text{miss}} = 31$ GeV
$M_T = 55$ GeV
**W→ eν Signal**

### Event Selection
- Level 1 EM trigger (≈ 2 GeV $E_T$ threshold)
- One PV with 3 tracks, consistent with beam spot
- One loose electron with: ID track matching EM calo cluster, selection on the shower shape in the 2nd calo layer, energy in 1st had layer, cluster $E_T > 20$ GeV
- Any jets must pass quality cuts

### Tight selection
- Full electron ID with TRT HT hits,
- Conversion veto, detailed shower shape, impact parameter requirements

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**Preselected sample**

![Graph](image)

**Normalized to data Stat errors only**

**σ^{NNLO} (W → lν) = 10.45 nb**

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**Observed**

<table>
<thead>
<tr>
<th></th>
<th>17</th>
</tr>
</thead>
</table>

**Expected**

| | 23.1±1.2(stat)±1.7(syst) ±4.6(lumi) |

**Signal**

| | 20.7±1.5(syst)±4.1(lumi) |

**Background**

| | 2.4±1.2(stat)±0.4(syst) ±0.5(lumi) |

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**ATLAS CONF-2010-044**
$p_T(\mu^-) = 27\text{ GeV} \quad \eta(\mu^-) = 0.7$

$p_T(\mu^+) = 45\text{ GeV} \quad \eta(\mu^+) = 2.2$

$M_{\mu\mu} = 87\text{ GeV}$

**Z$\rightarrow$$\mu\mu$ candidate in 7 TeV collisions**
Run Number: 154817, Event Number: 968871
Date: 2010-05-09 09:41:40 CEST

$M_{ee} = 89$ GeV

$Z\rightarrow ee$ candidate in 7 TeV collisions
# Z⁰ Candidates

<table>
<thead>
<tr>
<th></th>
<th>Z→ e⁺e⁻</th>
<th>Z→ μ⁺μ⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysed Integrated Luminosity</td>
<td>6.7nb⁻¹</td>
<td>7.9nb⁻¹</td>
</tr>
<tr>
<td>Observed 80 GeV – 100 GeV</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Observed outside 80 GeV – 100 GeV</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total expected</td>
<td>1.6 ±0.1(syst)±0.3 (lumi)</td>
<td>3.2 ±0.7(syst)±0.6 (lumi)</td>
</tr>
<tr>
<td>Background</td>
<td>&lt;0.2 events From combination of MC and data driven technique</td>
<td>&lt;0.01 events From Monte Carlo</td>
</tr>
</tbody>
</table>

- **Main systematic uncertainties on prediction:**
  - Luminosity (20%), Acceptance (5%), Trigger efficiency (4-7%), electron ID (5%), muon ID (10%)
Prospects for 2010/11

In 2010/11 we expect to record up to 1 fb\(^{-1}\) of integrated luminosity at 7 TeV

**Standard Model**
- \(W \rightarrow l^+\nu\) (4M events)
- \(Z \rightarrow ll\) (400k)
- \(t\bar{t} \rightarrow l + \text{jets}\) (6k)
- \(t\bar{t} \text{ dilepton}\) (2.5k)

**Discovery Potential**
- Susy 5\(\sigma\) discovery above Tevatron limit with a few 100 pb\(^{-1}\)
- \(Z' \rightarrow \mu\mu\) : sensitive up to 1.5 TeV
- Higgs: 3\(\sigma\) evidence in the mass range 145-180 GeV

**Further Detector Commissioning**

Standard Model measurements
Conclusions

• ATLAS detector commissioning with 7 TeV data is ongoing
  – First 16 nb\(^{-1}\) of recorded luminosity.
  – Profound thanks to the machine for such rapid progress

• All detectors are performing remarkably well
  – Performance confirmed to match simulation in most cases
  – Excellent stability

• Physics analysis progressing to progressively heavier / more challenging signals
  – Min bias and underlying event studies
  – Resonances and hadron spectroscopy
  – J/ψ in electron and muon channels \(\rightarrow\) flavour programme
  – First W and Z candidates in both electron and muon channels

• ATLAS is ready for the exciting discoveries to come!
BACK-UP
More challenging due to large background and signal electron bremsstrahlung

Mass from tracks, currently uncorrected for brems effects

For more details see Maria Smizanska's talk

Quite strong selections:
- LVL1 EM2 trigger (3 GeV threshold)
- $p_T$ (clusters) > 4, 2 GeV
- 2 EM clusters matched to tracks
- Track quality, calo shower shapes
- Key handle: large transition radiation in TRT

Signal:
- $52 \pm 8$ events

Background:
- $6 \pm 4$ events

Mass peak:
- $3.052 \pm 0.006$ GeV

$\int L dt \sim 1 \text{nb}^{-1}$

Normalized to data

Stat errors only

$6.3 \text{nb}^{-1}$