First Measurement of Jets and Missing Transverse Energy with the ATLAS Calorimeter at
\[ \sqrt{s} = 900 \text{ GeV and } \sqrt{s} = 7 \text{ TeV} \]

David W. Miller
on behalf of the ATLAS Collaboration
13 May 2010
CALOR 2010, Beijing, China
What I will try to convey

• You have heard (quite a bit) about:
  – How we collect data with the **missing transverse energy, \( \tau \) (next!)** and \( e/\gamma \) **trigger systems** at both Level-1 and the HLT.  (H. Beauchemin, V. Dao, T. Childers, A. Sfyrla)
  – How ATLAS has used the test beams to develop extensive understanding of the **hadronic showers and calibrations**.  (M. Simonyan and G. Pospelov)
  – How the **hadronic, EM and forward calorimeters** perform in the first data.  (D. Gillberg, H. Zhang, C. Gabaldon, V. Rossetti, G. Usai)
  – How these calorimeters respond to **single pions and the use of topological cluster calibration** in the very first collision data.  (M. Simonyan and P. Giovannini)
  – How the **ECAL is used to reconstruct e/\( \gamma \)** in the very first collision data  (D. Banfi)

*I will try to convey to you how all of this hard work has translated into the first measurements of jets, jet properties, calibrations and missing transverse energy at several center-of-mass energies.*
The 2009 and 2010 Data Sample

Almost 1 million events collected in 2009 at $\sqrt{s} = 900$ GeV

More than 2.5 nb$^{-1}$ accumulated to date in 2010 at $\sqrt{s} = 7$ TeV

- **Peak luminosity:** $\sim 7 \times 10^{26}$ cm$^{-2}$s$^{-1}$
- **Integrated luminosity:** 12 µb$^{-1}$
  
  *(stable beams, 30% syst)*

- **Peak luminosity:** $\sim 2 \times 10^{28}$ cm$^{-2}$s$^{-1}$
- **Integrated luminosity:** 2.5 nb$^{-1}$
FIRST OBSERVATION OF JETS AND MEASUREMENTS OF MISSING ET
Observation of jets at $\sqrt{s} = 0.9, 7$ TeV

- Infrared and collinear safe jet algorithm: \textit{anti-}k_t (R=0.6)
- All jets and MET uncalibrated (“EM-scale”)
  - validate calibrations first

- Kinematic distributions are well described by the MC

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Di-jet production at $\sqrt{s} = 0.9$, 7 TeV

QCD di-jet production observed within days of the first collisions

Kinematic balance ("back-to-back") well described at both 0.9, 7 TeV
Missing transverse energy at $\sqrt{s} = 0.9, 2.36, 7$ TeV

Well understood cell-level energy response directly impacts MET measurements

Well understood tails

Uncorrected, calorimeter based MET

ATLAS-CONF-2010-008
Missing transverse energy resolution

- A very good agreement between data and Monte Carlo at **900 GeV and 2.36 TeV**
- Tails are **well-under control**
- MET measurements **stable to within 3%** over the full 900 GeV running period
JET RECONSTRUCTION AND CALIBRATION SCHEMES
Inputs to jet reconstruction

The performance and physics potential of jet-based analyses depends crucially on the calorimeter performance and the understanding of the inputs to jet reconstruction.

- **ATLAS uses two primary jet inputs**
  - Topological clusters
    - nearest neighbor energy significance
  - Noise suppressed towers using cells in clusters

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**ATLAS-CONF-2010-016**

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ATLAS Jet and EtMiss First Results - CALOR2010
Jet calibration schemes in ATLAS

- ATLAS has developed several calibration schemes with different levels of complexity and sensitivity to systematic effects
- Complementary in how they contribute to the understanding of the jet energy measurement

(Talk by M. Simonyan on in-situ techniques)

<table>
<thead>
<tr>
<th>Calibration Scheme</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td><strong>EM+JES</strong></td>
<td>Simple $p_T$ and $\eta$-dependent calibration (MC or data)</td>
</tr>
<tr>
<td><strong>GS</strong></td>
<td>Global sequential calibration using jet properties (MC or data)</td>
</tr>
<tr>
<td><strong>GCW</strong></td>
<td>Cell energy-density-based weighting (MC-based)</td>
</tr>
<tr>
<td><strong>LCW</strong></td>
<td>Cluster property-based weighting (MC-based)</td>
</tr>
</tbody>
</table>

Derived using MC at $\sqrt{s} = 10$ TeV

ATLAS Preliminary
- EM+JES Calibration
- GS Calibration
- GCW Calibration
- LCW Calibration
Topo-cluster jets
MC Simulation
Inputs to calibration schemes at $\sqrt{s} = 900$ GeV

Energy in 2nd EM layer in data vs MC

Cell energy density weights in data vs MC

Cluster property-based weights in data vs MC

(A) A good agreement between MC and data for long. layer energies in jets.

(B) Cell energy densities described well at low energy density with a slightly lower average cell-energy density

(C) Cluster property-based weighting agrees to within 4% across all $\eta$ for the combined dead material, hadronic response and out-of-cluster corrections. (see talk by P. Giovannini)
JET PROPERTIES AND INTERNAL STRUCTURE
Jet properties at $\sqrt{s} = 900$ GeV

- Tracks and energy distributions within jets will form a basis for understanding the process of jet production and internal jet structure at higher $\sqrt{s}$
- Describing these properties constitutes a crucial step towards the precise determination of the jet energy scale
Jet properties using tracking at $\sqrt{s} = 900$ GeV

- Our MC offers a good description of the charged particle properties of jets
  - Track multiplicity in jets very close to expectations
  - Dependence of track multiplicity on jet $p_T$ agrees quite well (sensitive to fragmentation)

- Important for jet energy scale and resolution (as well as systematics)
  - $f_{\text{track}}$ has been demonstrated to help improve the jet energy resolution
Jet width at $\sqrt{s} = 900$ GeV

- **Width**: First moment of the radial energy distribution in the jet
  - Reduce sensitivity to quark vs. gluon jets
  - Has been shown to aid in improving the jet energy scale
    - Wider jets typically affected more by non-compensation
- Shape of the width distribution described well by MC
- …but jets in data are “wider”

\[
\text{width} = \frac{\sum (\Delta r \times E_{T_{\text{constituent}}})}{\sum E_{T_{\text{constituent}}}}
\]

$|\eta| < 2.6$
• The more detailed “jet profile” has been measured at multiple colliders.
• It is sensitive to a proper understanding of the jet fragmentation process, the detector response to low energy particles, underlying event and more.
• We find that our MC provides a good description of the jet profile, although here we also see wider jets in the data (less energy in core, more in periphery).
USING MISSING ET AT
\[ \sqrt{s} = 7 \text{ TeV} \]
Observation of $W \rightarrow e\nu$ at $\sqrt{s} = 7$ TeV

Candidate for $W \rightarrow e\nu$ decay, collected on 5 April 2010.
Summary and Conclusions

• The ATLAS detector has been operating and collecting data at high efficiency at both 900 GeV and 7 TeV center-of-mass energy since November 2009.

• Calorimeter performance meets expectations and is well modeled by the Monte Carlo simulation.

• Jet production, missing transverse energy measurements and kinematic distributions are in excellent agreement with predictions.

• Jet reconstruction and calibration are studied with multiple schemes and inputs within ATLAS and the performances are very close to that expected from MC.

• Jet properties and shapes studies indicate important differences with respect to MC that are likely related to a combination of detector and physics effects.
ADDITIONAL MATERIAL
The ATLAS Detector
The ATLAS Calorimeters

- **Cu-LAr structure**
  - $1.5 < |\eta| < 3.2$

- **Pb-LAr accordion**
  - $|\eta| < 2.5$

- **Fe-Scintillating Tile structure**
  - $|\eta| < 1.7$

- **Cu/W-LAr structure**
  - $3.2 < |\eta| < 4.9$

Cryostat (dead material)

Min. bias trigger scintillators (MBTS)
Stability of MET over time at $\sqrt{s} = 900$ GeV
The anti-$k_t$ jet algorithm

- Infrared and collinear safe algorithm
- Use exactly the same algorithm for theory calculations and experimental measurements

Primary algorithm for ATLAS

- Common choice between ATLAS and CMS
- Shows best stability and performance even at high luminosities

Using AntiKt algorithm of the fastjet [1] library

Use clusters or towers as proto-jets and define a distance measure:

$$d_{ij} = \min \left( \frac{1}{p_{T_i}^2}, \frac{1}{p_{T_j}^2} \right) \frac{\Delta_{ij}^2}{R^2}$$

$$d_{i\ell} = \frac{1}{p_{T_i}^2}$$

where:

- $\Delta_{ij} = (\phi_i - \phi_j)^2 + (y_i - y_j)^2$
- $p_{T_i}, y_i, \phi_i$ are the transverse momentum, rapidity and azimuth of proto-jet $i$
- $R = 0.6 (0.4)$ in ATLAS reconstruction

Until no proto-jet are left compute all $d_{ij}$ and take smallest $d_{ij}$:

1. $i \neq j$ Remove proto-jet $i$ and $j$ and add 4-vector sum as new proto-jet
2. $i = j$ Remove proto-jet $i$ and call it a final jet
Jet shapes using tracking

- Can also measure jet profile using tracks
- See the same effects: jets are wider in data than in MC
- Measurement only possible in fiducial tracking volume (|\eta|<2.5, so |\eta^{jet}|<1.9 for R=0.6 jets)
More on inputs to jet reconstruction

**Topological cluster jets**

- Data 2009 \( \sqrt{s} = 900 \) GeV
- MC non-diffractive minimum bias

**Tower jets with topo. noise suppression**

- Data 2009 \( \sqrt{s} = 900 \) GeV
- MC non-diffractive minimum bias

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**Topological noise suppression**

- Seed, Neighbor, and Perimeter cells \((S, N, P)\)
  - Seed cells with \( |E_{\text{cell}}| > S \cdot \sigma_{\text{noise}} \) \((S = 4)\)
  - Expand in 3D adding neighbors with \( |E_{\text{cell}}| > N \cdot \sigma_{\text{noise}} \) \((N = 2)\)
  - Add perimeter cells with \( |E_{\text{cell}}| > P \cdot \sigma_{\text{noise}} \) \((P = 0)\)
  - \((S, N, P) = (4, 2, 0)\) for good results in beam tests

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13 May 2010

ATLAS Jet and EtMiss First Results - CALOR2010
• \( f_{\text{track}} \): Using the ratio of track-to-calo momentum measurements to improve jet resolution at 14 TeV (MC)

Charged particle analyses at both CoM energies indicate very good description of tracking in MC.