ATLAS Calorimeter Commissioning

Jeremy Ticey

Hampton University

August 13, 2009
Project Goal

Introduction
- ATLAS
- ATLAS Calorimeters

Missing Transverse Energy
- $MissingE_T$ Performance Package

Minimum Bias Events
- Minimum Bias Events Histograms

DiJet Events
- DiJet Events Histograms

Conclusion
- Results
Analyze the performance of the ATLAS calorimeter through the creation of a resolution curve that models the Missing Transverse Energy over different sets of data samples including: Minimum Bias events and DiJet Samples.
ATLAS Project

- A Collaborative experiment of over 2500 scientists, from 37 countries, at the Large Hadron Collider (LHC) at CERN Laboratories
- Collisions between protons that are accelerated around the 27 km accelerator ring to energies of 7 TeV
**ATLAS Project**

- A Collaborative experiment of over 2500 scientists, from 37 countries, at the Large Hadron Collider (LHC) at CERN Laboratories
- Collisions between protons that are accelerated around the 27 km accelerator ring to energies of 7 TeV

- The general purpose detector will aim to uncover the basic forces of the world
- More specifically, the experiment has high interest in:
  - Higgs Boson
  - Unification theories
  - Extra Dimension and many more...
The ATLAS Detector is made up of four main components:

- **Inner Tracker**
  - Responsible for the measurement of the momentum of the particles

- **Magnet System**
  - Bends the charge particles as a part of the measurement of their energies

- **Muon Spectrometer**
  - Detects and measures Muons
The ATLAS Detector is made up of four main components:

- **Inner Tracker**
  - Responsible for the measurement of the momentum of the particles

- **Magnet System**
  - Bends the charge particles as a part of the measurement of their energies

- **Muon Spectrometer**
  - Detects and measures Muons
The ATLAS Detector is made up of four main components:

- **Inner Tracker**
  - Responsible for the measurement of the momentum of the particles

- **Magnet System**
  - Bends the charge particles as a part of the measurement of their energies

- **Muon Spectrometer**
  - Detects and measures Muons
The ATLAS Detector is made up of four main components:

- **Inner Tracker**
  - Responsible for the measurement of the momentum of the particles

- **Magnet System**
  - Bends the charge particles as a part of the measurement of their energies

- **Muon Spectrometer**
  - Detects and measures Muons
Electromagnetic Calorimeter

- Consists of two main components:
  - Electromagnetic end-cap (EMEC)
  - Electromagnetic barrel

Composition

Lead and Copper separated by Liquid Argon
Copper "grid" acts as an electrode to measure the path of particles
Measures the energies of electrons and photons
**Hadronic Calorimeter**

- Consists of three main components:
  - Hadronic end-cap (HEC)
  - Hadronic barrel
  - Forward Calorimeter (FCal)

**Composition**

Made of steel and scintillator "tiles" (Radiate light when exposed to a charged particle)

Measures the energy of Hadrons
Missing Transverse Energy

Definition

Transverse energy that is not detected by the detector but known to exist because of Conservation of Momentum

- Real \( \text{Missing} E_T \) from Neutrinos
Missing Transverse Energy

Definition

Transverse energy that is not detected by the detector but known to exist because of Conservation of Momentum

- Real \( \text{Missing} E_T \) from Neutrinos
- Fake \( \text{Missing} E_T \) can be created from many areas
  - Dead Material
  - Cracks in Detector
  - Noise from electronics
Missing Transverse Energy

Definition

Transverse energy that is not detected by the detector but known to exist because of Conservation of Momentum

- Real $\text{Missing} E_T$ from Neutrinos
- Fake $\text{Missing} E_T$ can be created from many areas
  - Dead Material
  - Cracks in Detector
  - Noise from electronics
- True $\text{Missing} E_T$ signifies possible new particles or Physics
**$\text{Missing } E_T$ Reconstruction**

$$E_{x,y}^{\text{Final}} = E_{x,y}^{\text{Calo}} + E_{x,y}^{\text{Cryo}} + E_{x,y}^{\text{Muon}}$$
**Missing**$E_T$ Reconstruction

$$E_{x,y}^{\text{Final}} = E_{x,y}^{\text{Calo}} + E_{x,y}^{\text{Cryo}} + E_{x,y}^{\text{Muon}}$$

**Calorimeter Term**

- **Cell-Based**
  - **Missing**$E_T$ over all of the cells of the calorimeter
- **Topological Cell Clusters**
  - Utilizes 3-D Topological Calorimeter clusters
Missing $E_T$ Reconstruction

$E_{\text{Final}} = E_{\text{Calo}} + E_{\text{Cryo}} + E_{\text{Muon}}$

Cryostat Term

- Thickness of cryostat between the EM Calorimeter barrel and the Hadronic Calorimeter barrel can attribute to the loss of energy
- Issue addressed by examining the relationship between the energy of the particle when it enters the cryostat and when it leaves

$$E_{\text{jet}}^{\text{cryo}} = w^{\text{cryo}} \cdot \sqrt{E_{\text{EM}} \times E_{\text{HAD}}}$$
**Missing**$E_T$ Reconstruction

\[ E_{x,y}^{\text{Final}} = E_{x,y}^{\text{Calo}} + E_{x,y}^{\text{Cryo}} + E_{x,y}^{\text{Muon}} \]

**Muon Term**

- The muon detection component of the detector has good identification and resolution.
- However, sometimes mismeasured or fake muons can be a source of large “fake” Missing$E_T$

\[ E_T^{\text{Muon}} = - \sum_{\text{recMuons}} E_{x,y} \]
Motivation

SUSY Vs. QCD

SUSY: $E_T^{\text{miss}} > 100$ GeV

QCD: jets, low $E_T^{\text{miss}}$
Missing $E_T$ Performance Package

Consolidated code that can be used to evaluate the performance of the detector by studying the Missing Transverse Energy. It is used to produce ROOT files that can be used to analyze the Missing Transverse Energy of the Detector.
Consolidated code that can be used to evaluate the performance of the detector by studying the Missing Transverse Energy. It is used to produce ROOT files that can be used to analyze the Missing Transverse Energy of the Detector

- $E_x$ - The “x” component of the Missing Transverse Energy
- $E_y$ - The “y” component of the Missing Transverse Energy
- $E_\phi$ - The “$\phi$” component of the Missing Transverse Energy
**Missing\(E_T\) Performance Package**

Consolidated code that can be used to evaluate the performance of the detector by studying the Missing Transverse Energy. It is used to produce ROOT files that can be used to analyze the Missing Transverse Energy of the Detector.

- \(E_x\) - The “x” component of the Missing Transverse Energy
- \(E_y\) - The “y” component of the Missing Transverse Energy
- \(E_\phi\) - The “\(\phi\)” component of the Missing Transverse Energy
- \(SUME_T\) - The sum of the Missing Transverse Energy over all of the cells

\[ SumE_T = \sqrt{E_x^2 + E_y^2} \]
There are two different types of Geometries programmed into the Monte Carlo Simulations used by ATLAS physicists to test the performance of the ATLAS detectors:

**“Ideal” Geometry**

Has the dead regions of the detector taken into account, in addition to, the misalignment of the hadronic calorimeter endcaps. This package is normally used in performance studies.

**“Distorted” Geometry**

Does not have the misalignment corrections programmed into it and there is extra material added between the calorimeters and inner detectors. This type contains the programmed hardware failure, that simulates the failure of one component of the detector.
**Eta Rings Tool**

- Tool that is used to determine which part of the detector could possibly be the source of “fake” $MissingE_T$

<table>
<thead>
<tr>
<th>Hadronic Calorimeter</th>
<th>Electromagnetic Calorimeter</th>
<th>Crack Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tile: $</td>
<td>\eta</td>
<td>&lt; 1.7$</td>
</tr>
<tr>
<td>Endcap: $1.5 &lt;</td>
<td>\eta</td>
<td>&lt; 3.2$</td>
</tr>
<tr>
<td>Forward: $3.2 &lt;</td>
<td>\eta</td>
<td>&lt; 4.9$</td>
</tr>
</tbody>
</table>
**Eta Rings Tool**

- Tool that is used to determine which part of the detector could possibly be the source of “fake” $\text{Missing}E_T$
- Plots the $\text{Missing}E_T$ with respect to the Psuedorapidity
  - $\eta = -\ln(\tan(\frac{\theta}{2}))$

<table>
<thead>
<tr>
<th>Hadronic Calorimeter</th>
<th>Electromagnetic Calorimeter</th>
<th>Crack Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tile: $</td>
<td>\eta</td>
<td>&lt; 1.7$</td>
</tr>
<tr>
<td>Endcap: $1.5 &lt;</td>
<td>\eta</td>
<td>&lt; 3.2$</td>
</tr>
<tr>
<td>Forward: $3.2 &lt;</td>
<td>\eta</td>
<td>&lt; 4.9$</td>
</tr>
</tbody>
</table>
Minimum Bias Events

Why Study?

Minimum Bias Events will play a key role verifying the $MissingE_T$ Reconstruction procedure and estimated $MissingE_T$ resolution for low $SumE_T$ events.

Figure: $p_T > 25$ GeV
Minimum Bias Events

Why Study?

Minimum Bias Events will play a key role verifying the $MissingE_T$ Reconstruction procedure and estimated $MissingE_T$ resolution for low $SumE_T$ events.

- Events that are selected with “Minimum Bias”
  - Concrete definition varies depending on the experiment being conducted

- Will provide the first description of an average inelastic proton-proton collision
  - Totally Inclusive Trigger

- Minimum Bias events are dominated by “soft” partonic interactions with low transverse energy
Minimum Bias Event Histograms

No Energy Cuts

\[ E > 2\sigma \]

- **h_Base0_METx**
  - Entries: 10000
  - Mean: -0.0766
  - RMS: 6.78
  - \( \chi^2 / \text{ndf} \): 35.07 / 52
  - Constant: 590.1 ± 7.3
  - Mean: -0.05029 ± 0.06764
  - Sigma: 6.74 ± 0.05

- **h_Base0_METy**
  - Entries: 10000
  - Mean: -0.1017
  - RMS: 6.794
  - \( \chi^2 / \text{ndf} \): 40.89 / 46
  - Constant: 586.5 ± 7.2
  - Mean: -0.0681 ± 0.1099
  - Sigma: 6.777 ± 0.049

- **h_Base_METx**
  - Entries: 10000
  - Mean: -0.0265
  - RMS: 3.981
  - \( \chi^2 / \text{ndf} \): 55.57 / 33
  - Constant: 1015 ± 12.8
  - Mean: 0.03922 ± 0.05088
  - Sigma: 3.91 ± 0.03

- **h_Base_METy**
  - Entries: 10000
  - Mean: 0.007653
  - RMS: 4.004
  - \( \chi^2 / \text{ndf} \): 43.76 / 32
  - Constant: 999.6 ± 12.6
  - Mean: 0.03984 ± 0.00195
  - Sigma: 3.974 ± 0.030

Jeremy Ticey (Hampton University)
DiJet Event Sample

- Ran the $\text{Missing}E_T$ Performance Package on DiJet events ranging from J0-J3

- DiJet Events are divided into different subgroups according to their $p_T$

- Takes into account the decreasing cross sections of the increased energies

<table>
<thead>
<tr>
<th>Dijet $p_T$ Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>J0</td>
</tr>
<tr>
<td>J1</td>
</tr>
<tr>
<td>J2</td>
</tr>
<tr>
<td>J3</td>
</tr>
</tbody>
</table>
DiJet Event Histograms

No Energy Cuts

\[ E > 2\sigma \]

**h_Base0_METx**
- Entries: 925170
- Mean: -0.5132
- RMS: 6.897
- \( \chi^2 / \text{ndf} \): 193.7 / 63
- Constant: 69 ± 5.35e+04
- Mean: 0.007 ± -0.511
- Sigma: 0.005 ± 6.898

**h_Base_METx**
- Entries: 925170
- Mean: -0.4729
- RMS: 4.552
- \( \chi^2 / \text{ndf} \): 1552 / 47
- Constant: 107 ± 8.128e+04
- Mean: 0.005 ± -0.464
- Sigma: 0.004 ± 4.534

**h_Base0_METy**
- Entries: 925170
- Mean: -0.8489
- RMS: 6.915
- \( \chi^2 / \text{ndf} \): 282.9 / 64
- Constant: 68 ± 5.336e+04
- Mean: 0.0072 ± -0.8481
- Sigma: 0.005 ± 6.914

**h_Base_METy**
- Entries: 925170
- Mean: -0.7786
- RMS: 4.564
- \( \chi^2 / \text{ndf} \): 1856 / 43
- Constant: 106 ± 8.107e+04
- Mean: 0.005 ± -0.764
- Sigma: 0.004 ± 4.543
Resolution

Contained in the \( \text{Missing}_E T \) Performance Package is a macro that plots the Reconstructed \( \text{Missing}_E T \)

- Resolution is estimated from the width of the X and Y component distributions in bins of the total transverse energy deposited in the Calorimeters
- The core of each distribution is fitted with a Gaussian shape to estimate the width
Resolution

Contained in the $\text{Missing}_TE_T$ Performance Package is a macro that plots the Reconstructed $\text{Missing}_E T$

- Resolution is estimated from the width of the $X$ and $Y$ component distributions in bins of the total transverse energy deposited in the Calorimeters
- The core of each distribution is fitted with a Gaussian shape to estimate the width
- Plot is created with $\sigma$ vs. $\text{Missing}_E T$
- The resolution curve is fitted with a function:
  $$\sigma \approx a \cdot \sqrt{\sum E_T}$$
  - "$a$" quantifies the $\text{Missing}_E T$ Resolution
Resolution Curve

Resolution curve plotting Minimum Bias Events covering the $SumE_T$ ranges of 0 - 200 GeV

- Both follow the same fit and the maximum amount of $SumE_T$ occurs around 200 GeV
- Expected calorimeter performance: $\approx \frac{50\%}{\sqrt{\sum E_T}}$
- My produced calorimeter performance: $\approx \frac{43\%}{\sqrt{\sum E_T}}$
Future Work

- In order to complete the Resolution curve, it is necessary to understand the binning procedure of the Missing ET Performance Package for DiJet events
  - Project will be continued by Travis Bain (University of Toronto)
- Produce a resolution curve that accurately models the ATLAS calorimeter’s performance in order to prepare for the initial start up of the LHC in Fall ’09
Cultural Experiences
Cultural Experiences
Acknowledgements

- Dr. Richard Teuscher
- Mr. Travis Bain
Acknowledgements

- Dr. Richard Teuscher
- Mr. Travis Bain
- Dr. Homer Neal
- Dr. Jean Krisch
- Dr. Myron Campbell
- Mr. Jeremy Herr
Acknowledgements

- Dr. Richard Teuscher
- Mr. Travis Bain
- Dr. Homer Neal
- Dr. Jean Krisch
- Dr. Myron Campbell
- Mr. Jeremy Herr
- REU Students
Questions?