In-situ probe of the response of the Tile Calorimeter to isolated hadrons

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The ATLAS Experiment

Comprised of:

1. The **Inner Detector** to measure the momentum of charged particles
2. The **Calorimeters** to measure the energy of electromagnetic and hadronic showers through the Liquid Argon and Tile calorimeters.
3. The **Muon Chambers** to measure the momentum of muons

In-situ probe of Tile Calorimeter response

The Tile Calorimeter

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The Tile Calorimeter

- Tile Calorimeter is divided into one long barrel ($|\eta| < 0.7$) and two extended barrels ($0.7 < |\eta| < 1.7$)
- Symmetric about the beam line in 64 modules in the ϕ direction
- Each module is segmented into 3 layers, A, BC and D. These layers are 1.5, 4.1 and 1.8 interaction lengths thick at $\eta = 0$
- Layers are composed of cells with granularity $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ or 0.1×0.2 for layer D.

Calorimeter Response

- The performance of the Tile Calorimeter system can be probed in-situ, via the response
 - Measured Energy in Tile Calorimeter (E) vs True Energy
- For charged particles, the momentum (p) observed using the Inner Detector can be used as a measure of the True Energy
 - Inner Detector momentum resolution $\sim 1\%$ for the momentum range considered
- By studying the ratio E/p in both simulation and data the integrity of the simulation may be examined
- $\langle E/p \rangle$ is examined in bins of η , p and ϕ

**Particle
Momentum (p)**

Methodology

- Find charged hadrons (usually $\pi^\pm$)
- Extrapolate their trajectory to each layer of the calorimeter system, using the known geometry of the detector and magnetic field strength.
- To remove contributions to the response from other particles, select particles isolated within a cone of $\Delta R=0.4$ from any inner detector track.
- Sum all the energy deposited in a cone around the charged hadron

$$\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2}$$

Choice of Cone Size

- The best choice of cone size is found by comparing the response in:
 - **Single $\pi^\pm$ simulated sample**
(The response to a single particle)
 - **Particles in a simulated minimum bias collision**
(Background sources affect the energy around the isolated hadron)
 - The choice is the best compromise between:
 - Capturing all the energy associated with the charged hadron
 - The $\langle E/p \rangle$ of the **single $\pi^\pm$** is close to its maximum
 - Avoiding energy from background sources in the event
 - Minimising the difference between the **minimum bias** and the **single $\pi^\pm$** radial energy deposition
- $\Delta R < 0.2$ is chosen to best fit these constraints

Datasets Description

- 2010 data events are triggered using the MBTS (Minimum Bias Trigger Scintillator).
- As the rate of minimum bias events is too high, approximately 1 in 500 events are triggered leaving 92 nb^{-1} .
- In 2010 bunch spacing was 150 ns and the average number of interactions per crossing was between 2 and 3.
- 2011 data events are randomly triggered during collisions at a fixed rate.
- 4.7 fb^{-1} is used from this year. The last period is not included.
- In 2011 bunch spacing was 50 or 75 ns and the average number of interactions per crossing was significantly higher, between 10 and 18.

Datasets Description

- The simulated datasets for both 2010 and 2011 contain 20 million minimum bias events, generated using Pythia 6.
- The hadronic interactions were simulated with the QGSP_BERT set of processes in Geant4
- The simulated sample is weighted so that it's pile-up distribution matches that observed in data
- Simulated events are normalised to observed events by deriving weights in bins of pseudo-rapidity and momentum (2010) or transverse momentum (2011).
 - This normalisation does not affect the shape of the E/p distribution.

Particle Selection

- Particles are selected to probe our understanding of Tile Calorimeter
- Particles are selected if no energy deposit associated with them comes from a calorimeter cell which has been flagged as problematic
- Select particles which behave like a MIP in the **Electromagnetic Layers** ($E_{\text{loss}} < 1 \text{ GeV}$)
- In 2010, particles are required to have the maximum energy deposit of any layer be in a **Hadronic Layer**.
- Instead, in 2011, particles are required to deposit $> 70\%$ of their observed energy in a **Hadronic Layer**.

2010 Results

- Overall very good agreement between simulation and observation is measured, within 3%
- Some small discrepancies in the region $0.8 < |\eta| < 1.1$, the transition between barrel and extended barrel ($\sim 5\%$ difference)
- 3 interesting areas stand out at $\phi = -1, 1$ and 2.5 ($\sim 4\%$)

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2010 Results

- Overall very good agreement between simulation and observation is measured, within 3%
- A potentially interesting trend in the Data/MC ratio between 10 and 20 GeV
- Not enough particles are observed above 20 GeV to measure the agreement

2011 Results

- $\langle E/p \rangle$ has increased in the extended barrel with respect to 2010 (~ 0.4 to ~ 0.5)
 - Data/MC agreement has also decreased in this region (5% to 10%)
- This increase in $\langle E/p \rangle$ is attributable to the change in beam conditions. More pile-up and smaller bunch spacing leads to an increase in jets at higher values of η , which increase the baseline cell energy, even for isolated particles.

2011 Results

- Overall, $\langle E/p \rangle$ has increased slightly more for the simulated sample.
 - Simulated showers tend to be longer than observed showers.
 - Thus particles in the simulation deposit more energy in Tile Calorimeter than those observed.
 - This effect is amplified by the higher pileup conditions in 2011

2011 Results

- The increased $\langle E/p \rangle$ is particularly pronounced at low momentum, indicating that perhaps there are more neutrally charged particles contributing hadronic energy.
- Simulation now drastically deviates from observation around 12 GeV and 14 GeV. This corresponds to a transition in the gain of the readout electronics, which may not be well reproduced by simulation. Geant4 is also known to have a poor description of hadronic showers in this region.
- Interesting Data vs MC trend hinted in 2010 results is now more pronounced.

2011 Results

Selecting tracks only for
the Tile Barrel ($\eta < 0.7$)

- Increased statistics allow one bin for each module in ϕ
- Overall the good agreement between simulation and observation is similar to 2010
- The same areas of discrepancy can be identified, -1, 1 and 2.5 (this last is less significant)

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2011 Results

Selecting tracks which deposit their maximum energy in Layer A

- Increased statistics also allow splitting into individual layers
- Focusing on Layer A shows even nicer agreement, particularly in the barrel
- Simulation is no longer consistently higher than observation
 - By requiring the particle to shower early, the longer shower shape in simulation has less effect.

2011 Results

Selecting tracks which deposit their maximum energy in Layer BC

- Layer B has large discrepancies at $|\eta| = 1$. Such particles barely graze the highlighted cells.
- $\langle E/p \rangle$ is also higher than Layer A, for both simulation and observation.
 - Particles which have a maximum deposit in Layer B have showers more contained within the hadronic calorimeter

Conclusions

- This study is a firm validation of the energy scale of isolated hadrons.
- 2010 was proven to have good agreement due to calibration, and tuning simulation, with the test beam studies.
 - A similar level of agreement to the combined calorimeter E/p analysis.
- 2011 shows very good agreement despite a large change in beam conditions.
 - This is a success for the simulation of pile-up and the performance of energy reconstruction techniques.
- Studies such as these are used as feedback to improve the next iteration of simulation.

BACKUP

MBTS

- The Minimum Bias Trigger Scintillator (MBTS) is a set of 32 scintillating plates covering the range $2.1 < |\eta| < 3.8$.
- Fibers from these scintillating plates extend radially to photomultipliers in the TileCal girder
- The MBTS was used to trigger minimum bias events in early data taking.

MBTS

Beam Pipe