PROCEEDINGS OF SCIENCE

Jet and $\not{E}_T$ Commissioning in ATLAS

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A reliable reconstruction and calibration of jets and $\not{E}_T$ in ATLAS is crucial to understand Standard Model Physics measurements and to discover new phenomena. This paper describes the step-by-step approach that ATLAS has adopted to reconstruct and calibrate jets and $\not{E}_T$ to guarantee flexibility and robustness with first data. The main techniques are described to establish the energy scale "in-situ", which is the most challenging task for jets and $\not{E}_T$. Measuring jets and $\not{E}_T$ is challenging but ATLAS has developed tools and strategies to be ready for commissioning with real collisions.

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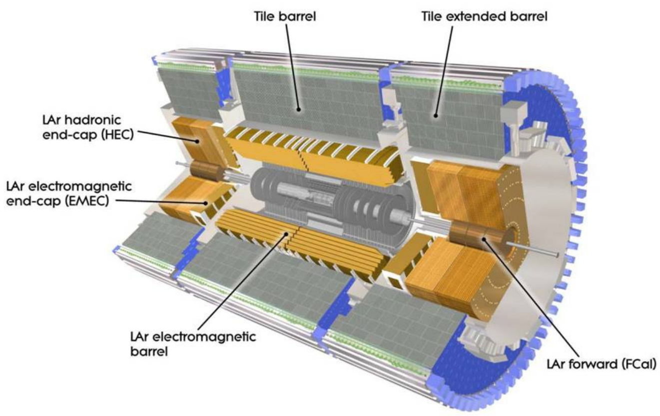


Figure 1: The ATLAS calorimeters

1. Introduction

The most important detector for jet and $\not\!\!E_T$ reconstruction in ATLAS is the calorimeter system, see Figure 1 for its basic components. It provides near hermetic coverage in the pseudorapidity range $|\eta| < 4.9$. The electromagnetic liquid argon/lead calorimeters feature an accordion geometry homogeneous in azimuthal coverage for $|\eta| < 3.2$. The hadronic calorimeters surrounding them are iron with scintillating tile readout in the central region ($|\eta| < 1.7$) and parallel plate liquid argon/copper in the endcap regions ($1.7 < |\eta| < 3.2$). The forward region is covered by liquid argon/copper and liquid argon/tungsten calorimetery. The readout of the calorimeters is highly granular in particular for the electromagnetic devices, the total number of readout cells in the ATLAS calorimeters system is close to 200,000 [1]. Basic features that should be taken into account for jet and $\not\!\!E_T$ reconstruction are the following:

- the calorimeters are non-compensating, their response to hadrons is lower than that for electrons and photons and for that reason specific calibrations have been developed.
- part of the energy is lost because of dead material, cracks and gaps in the calorimeter.
- the solenoidal magnetic field bends low-energy charged particles.

The reconstructed jet energy and $\not\!\!E_T$ must be corrected for these effects to obtain the best measurement as will be explained in the following sections.

2. Jet and $\not\!\!E_T$ reconstruction

Jets and $\not\!\!E_T$ reconstruction start from common basic input signals: the Topological Clusters (TopoClusters), that consist of a group of calorimeter cells with topologically connected signals. Clusters grow dynamically around seed cells based on noise thresholds. The aim of a clustering step before jet and $\not\!\!E_T$ reconstruction is two-fold:

- to suppress noise from electronics and pile-up by reducing the number of cells included in the jets and $\not\!\!E_T$ via noise-driven clustering thresholds.
- to improve the correspondence between clusters and particles in the calorimeters.

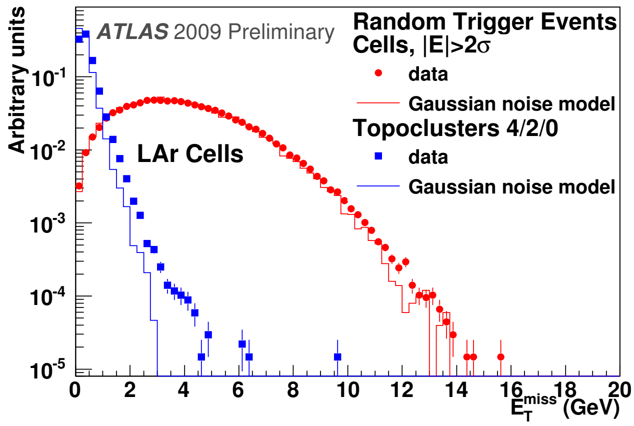


Figure 2: $\not\!\!E_T$ distributions with two noise suppression methods in random trigger events.

Other basic input signals, mostly used in jet reconstruction, are cell signals collected into projective (in η and ϕ) towers with $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$. Here either all cells are used (Tower), or only cells with significant signal, as defined by the topological clustering are used (Topo-Towers).

The jet reconstruction is a sequential process starting from the input signals, as explained above, to which a jet finding algorithm is applied that groups the collection of clusters(towers) according to geometrical and/or kinematic criteria. Many algorithms have been studied in ATLAS and recently the main focus has been on the AntiKt algorithm [2], which has been shown to be the most promising. The final steps of the reconstruction procedure consist of the jet calibration that will be described in section 4.

The $\not\!\!E_T$ reconstruction is a complex procedure that adds significant signals from all detectors: calorimeter input signals (Cells, TopoClusters) in physics objects but also not used in physics objects reconstruction, muons, and tracks in regions where calorimeter or muon spectrometer are inefficient. Moreover, a specific correction for energy lost in dead material is also applied.

3. Commissioning jets and $\not\!\!E_T$ with cosmic rays and random trigger events

During the years 2008 and 2009 the ATLAS calorimeters recorded over 200 million cosmic ray and random triggered events that were used to study the performances of $\not\!\!E_T$ and jets and for the optimization of cleaning criteria to suppress signals from cosmic rays in collision events. In particular, concerning studies of $\not\!\!E_T$ with random trigger events, two methods have been studied to reconstruct a basic $\not\!\!E_T$ in the calorimeters:

- The Cell-based method, in which all cells with energies above a noise threshold of two standard deviations are used in the $\not\!\!E_T$ computation.
- The TopoCluster-based method, in which all Topological Clusters measured in the calorimeter are used in the $\not\!\!E_T$ computation.

As shown in Fig. 2, the second approach provides a better noise suppression for $\not\!\!E_T$, since for random triggers no real energy is expected to be deposited in the calorimeters, so the only contribution to $\not\!\!E_T$ is given by electronic noise [3].

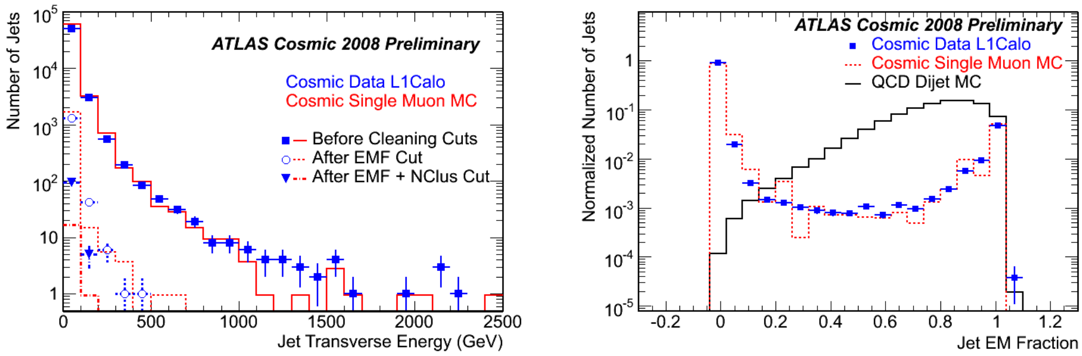


Figure 3: (a) Distribution of the jet transverse energy before and after the cleaning cuts is shown, the cuts applied are: 0.2 < EMF (jet EM fraction) <0.97 and NClus (number of clusters) >=7 (b) Distribution of jet EM fraction is shown. In both cases the comparison with Monte Carlo (in red) is shown

The studies with cosmic rays have shown that "fake" jets and large $\not\!\!E_T$ can originate from high energy cosmic muons passing through the ATLAS calorimeter and undergoing hard bremsstrahlung. A good agreement with single muon Monte Carlo simulation is shown in Fig. 3. Jets and $\not\!\!E_T$ from cosmics can be a background for many physics channels. A set of variables has been used to largely suppress this contribution (Fig. 3a), including the jet energy fraction in the electromagnetic calorimeters (Jet EM fraction, see Fig. 3b), which is very close to 0 or 1 for muons undergoing bremsstrahlung. Additional event variables are the total EM energy fraction, and the number of clusters, together with some tracking based criteria [4].

Cosmic rays are not the only source of "fake" $\not\!\!E_T$ that can be caused also by many other problems, including failures in detectors like i.e. dead, hot, noisy channels, problems in HV sectors, noise from pile-up, energy lost in dead materials (cracks, cryostats), backgrounds like beam halo, beam gas, cosmic rays and mis-measurements of muons and jets.

Keeping all these effects under control with first data is a real challenge for the $\not\!\!E_T$ reconstruction. In the past years ATLAS has developed a set of algorithms to suppress these contributions, including fake muon, muon detection inefficiencies and event topology based indication of jet mis-measurements [1].

4. Strategy for Jet calibration

The strategy for jet calibration is based on a factorized multi-step approach to provide the flexibility in understanding corrections individually and use different techniques, as they become validated with data within a same framework. The idea is to apply a combination of 'in-situ' and Monte Carlo (MC) corrections as explained below:

• "Hadronic calibration", allowing corrections for calorimeter effects like non-compensation and dead material energy losses. Two different strategies have been developed: the "global cell energy density calibration (GC)" and the "local hadron calibration (LC)" based on TopoClusters as jet constituents. They give similar performance in MC simulations. Figure 4 shows the jet energy response linearity and resolution for the GC case [1].

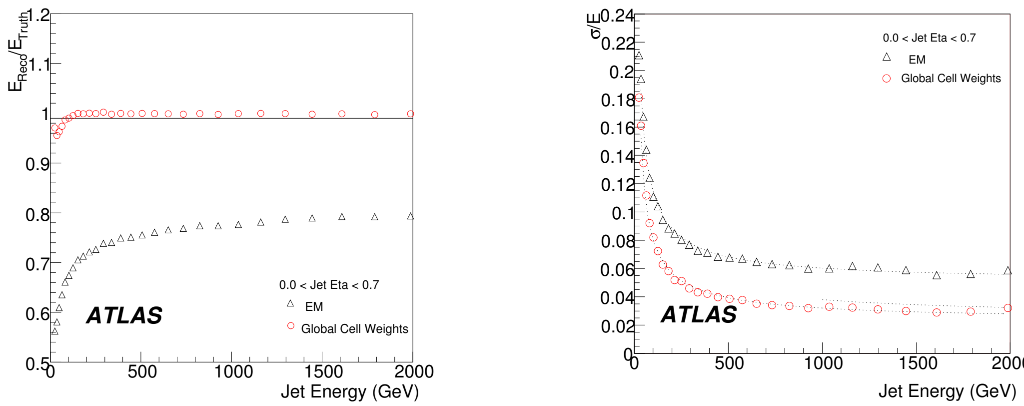


Figure 4: Performance of the global cell energy density calibration (red points) for jets with $|\eta|$< 0.7. (a) The energy dependence of the calibrated response is compared to the uncalibrated response. (b) The resolution improvements due to calibration are indicated

• Jet energy scale calibration, including an offset correction for pile-up, based on the subtraction of the average contribution to the jet energy not originating from the primary interaction, and a response correction calibrating the calorimeter jet to the particle jet. The following "in-situ" processes have been studied:

- QCD di-jet events to equalize the jet response in η with di-jet p_T balance techniques.
- gamma/Z-jet events to set the absolute energy scale, with the basic idea that jet energy scale is determined by the p_T balance between the jet and a well measured electromagnetic system.

Further optional corrections based on the energy sharing between calorimeter segments in the jet and tracks associated with the jet are under study.

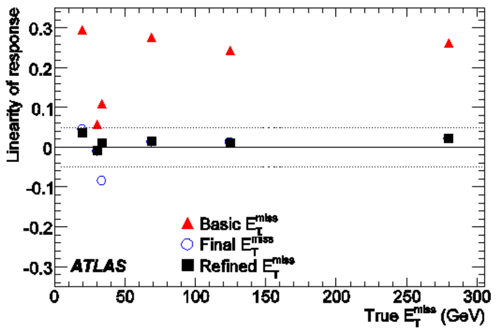
5. Strategy for $\not\!\!E_T$ reconstruction and calibration

The strategy for $\not\!\!E_T$ reconstruction and calibration is based on a step-by-step procedure of increasing complexity to guarantee robustness with first data. Several calculation and calibration schemes are available to allow for a maximum degree of flexibility and different sensitivity to systematic effects. The first step of this procedure consists of a "Basic $\not\!\!E_T$" calculation from all calorimeter cells applying the cell and cluster based selections discussed in section 3.

The second step is the calculation of the so-called "Final $\not\!\!E_T$" applying the hadronic calibration to all cells entering the $\not\!\!E_T$ calculation. Alternatively, both the global cell energy density method and the local hadronic calibration can be applied here. The contribution from muons plus the correction for energy lost in cryostat between electromagnetic and hadronic calorimeters are added to complete the "Final $\not\!\!E_T$" computation.

The third and most complex step is the refinement of the $\not\!\!E_T$ calibration ("Refined $\not\!\!E_T$"). For this, ATLAS has developed a new approach to resolve the calorimeter signal ambiguities in the event reconstruction:

• sequential decomposition of reconstructed objects: electrons, photons, taus, jet, muons into



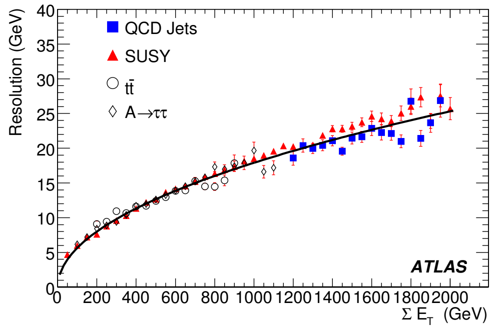


Figure 5: (a) Mean value of the linearity of response as a function of the True $\not\!\!E_T$ for various physics processes and for the three steps of $\not\!\!E_T$ reconstruction, (b) Resolution of the two $\not\!\!E_T$ components as a function of the total transverse energy in the "Refined $\not\!\!E_T$" case

basic constituents (calorimeter cells or TopoClusters) and veto of multiple contributions to guarantee no double counting in $\not\!\!E_T$ calculation

- calibration weights applied to basic constituents depending on reconstructed object type
- also TopoClusters not associated with any reconstructed objects are taken into account.

This "Refined $\not\!\!E_T$" provides the best performance in terms of linearity of response and energy resolution, Fig. 5 shows the comparison with the Basic and Final $\not\!\!E_T$.

Finally a specific road-map for $\not\!\!E_T$ commissioning with first data has been studied starting with Minimum Bias and QCD di-jets events, which will be the first control samples to test $\not\!\!E_T$ resolution in-situ. With increasing integrated luminosity it will be possible to test the calibration and scale of $\not\!\!E_T$ with Z $\to$ ll events, and with an integrated luminosity of 10-100 pb^{-1} it will be possibile to determine the "in-situ" $\not\!\!E_T$ scale from the W $\to e\nu$ transverse mass and the Z $\to \tau\tau \to$ lepton-hadron invariant mass [3].

6. Conclusion

Based on simulations, empty and cosmic events ATLAS has developed techniques and strategies for the commissioning of jet and $\not\!\!E_T$ reconstruction with first collisions. A highly modular jet energy scale calibration based on simulations and in-situ assessments is available, with expectations for a jet reconstruction performance meeting the physics analysis requirements. $\not\!\!E_T$ can be reconstructed using various signal definitions and refinements, including a new event signal ambiguity resolution technique with a very promising performance.

References

[1] CERN-OPEN-2008-020, chapter 6 "Jets and Missing Transverse Energy"

[2] Cacciari, Matteo and Salam, Gavin P. and Soyez, Gregory, JHEP 04 (2008) 063.

[3] *https://twiki.cern.ch/twiki/bin/view/Atlas/ApprovedPlotsLAr*

[4] *https://twiki.cern.ch/twiki/bin/view/Atlas/ApprovedCosmicPlotsJetEtMiss*