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Commissioning and Performance of the ATLAS Calorimeter System with proton collision at LHC

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ATLAS is a general purpose detector located on the CERN Large Hadron Collider (LHC) which recorded its first proton-proton collisions at the end of 2009. Its calorimeter, very granular, hermetic in depth and covering 99% of the solid angle around the interaction point, is the central detector used to reconstruct electron, photon, jets, taus and missing transverse energy. The present hardware status is reviewed as well as the first *in situ* performance obtained with collision data.

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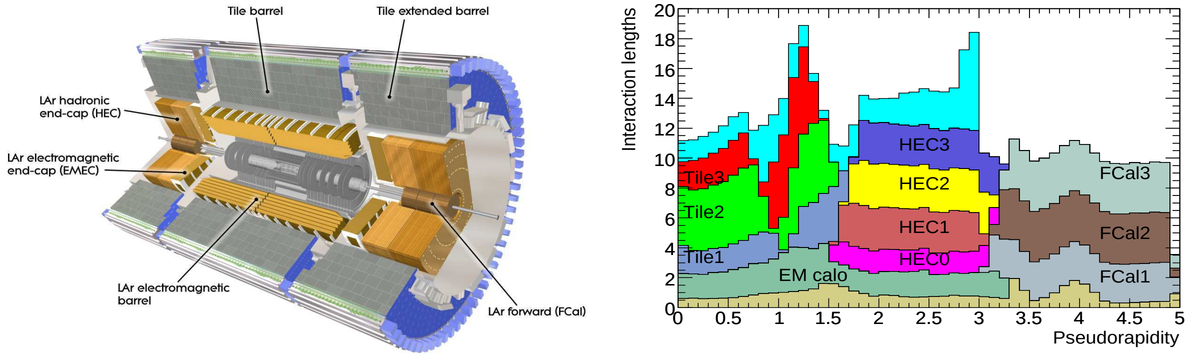

Figure 1: *Left: Cut-away view of the ATLAS calorimeter system, 17 m long and 9 m of diameter. Right: Cumulative amount of material, in units of interaction length λ, as a function of pseudorapidity $|\eta|$, in front, in each layer of the calorimeter system and before the muon spectrometer.*

1. Introduction

ATLAS (A Toroidal LHC Apparatus) [1] is a general purpose experiment located on the CERN proton-proton facility LHC, which starts colliding beams at the end of 2009 at a center of mass energy of 0.9 TeV and 2.36 TeV. Since end of March 2010, the center of mass energy is increased to 7 TeV and about 300 nb^{-1} of data were recorded prior to the beginning of this conference [2]. In the following, the polar angle θ is measured from the beam axis and the pseudorapidity is defined as $\eta = -\ln \tan(\theta/2)$. The azimuthal angle ϕ is measured in the plane orthogonal to the beam axis.

The ATLAS calorimeter is a central detector (Figure 1 left) and consists of a number of samplings sub-detectors with full ϕ symmetry and coverage around the beam axis. The calorimeters closest to the beam-line are housed in three cryostats filled with liquid argon (LAr), one barrel and two end-caps [3]. These cryostats contain respectively the electromagnetic barrel calorimeter (EMB, $|\eta| < 1.475$), the electromagnetic end-cap calorimeter (EMEC, $1.375 < |\eta| < 3.2$), the hadronic end-cap calorimeter (HEC, $1.5 < |\eta| < 3.2$) located behind the EMEC, and the forward calorimeter (FCal, $3.1 < |\eta| < 4.9$) to cover the region closest to the beam. For $|\eta| < 1.8$, a pre-sampler provides a measurement of the energy lost upstream. The three cryostats are surrounded by a Tile calorimeter [4] covering $|\eta| < 1.7$. The very high granularity of the electromagnetic (EM) calorimeter, build from accordion shape lead absorbers and electrodes to have a perfect ϕ hermiticity, is particularly suitable to obtain a very good electron/jet and γ/π^0 separation. The main characteristics of the hadronic calorimeter are its wide coverage (up to $|\eta| < 4.9$), its excellent hermiticity in depth (at least 10 interaction lenghts λ, see Figure 1 right) which provides an optimal jet and missing transverse energy measurement.

2. Commissioning of the ATLAS Calorimeter

The commissioning of the calorimeter started about 10 years ago with the test beam of the ATLAS sub-detector modules [1]. Since early 2008, the calorimeter installation is completed in the experimental hall and intensive commissioning activities are going on [3, 4], helping to settle a close to 100% working detector for the first collisions, end 2009. Beginning of July 2010, 98.5%

and 97.3% of the LAr and Tile calorimeter cells were functionning and only few per mill of these cells where masked because of (sporadically) noisy behaviour. With first millions of minimum bias events it was possible to check that only 0.4% working EM cells behaved unexpectedly in physics mode [5]. This was traced back to detector cabling inversion and corrected for the 2010 run.

3. Performance of the ATLAS Calorimeter

The first level (L1) calorimeter trigger is crucial in hadronic collider experiment. It searches for signatures from high-pT electrons/photons, jets, τ-leptons decaying into hadrons as well as large missing transverse energy ($\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$). To meet the demands of the trigger latency envelope, it uses reduced-granularity information collected on a predefined grid of typical size $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ (corresponding to few tens of calorimeter cells). Turn-on curves for the EM and Jet triggers obtained on data, presently for p_T threshold lower than 10 GeV because of limited data set, are in fair agreement with Monte Carlo expectations [6].

In ATLAS, the electron/γ identification benefits from the fine lateral and longitudinal granularity of the EM calorimeter. With 15 nb^{-1} of 7 TeV center-of-mass energy data, around 10,000 electrons were selected with a transverse energy, $\mathrm{E}_T > 7$ GeV and a signal-to-background ratio of 0.15 [7]. Similarly, about 620 photons with $\mathrm{E}_T > 20$ GeV and a purity of 70% were extracted [7]. With first 0.5 nb^{-1} of data, more than one million of π^0 were reconstructed. A ± 2 % agreement between data and Monte Carlo simulation mass peak position is obtained over $|\eta| < 2.5$ (Figure 2 left) giving a first flavour of the EM calorimeter energy scale. From the same study, the present EM calorimeter response uniformity in ϕ is around 0.7%, prior any $Z \rightarrow ee$ intercalibration.

One of the main calorimeter task is to calibrate the cell energy deposit (E^{cell}) taking into account non-compensation. For this, 3 dimensionnal clusters are reconstructed around $|E^{\mathrm{cell}}|$>4 σ_{noise} seeds (σ_{noise} is the electronic noise) by iteratively gathering neighboring cells with $|E^{\mathrm{cell}}|$>2 σ_{noise} and finally adding direct neighbors of the accumulated secondary cells [9]. This algorithm allows to be closer to particle level and suppresses efficiently the noise contribution. Using the moments of the reconstructed cluster, it is classified as EM-like or hadronic-like cluster, and weights based on the cluster energy density are applied [10]. Finally, out of cone and loss in inner detector/cryostat material are corrected for, presently using the Monte Carlo. Over the full calorimeter coverage, an agreement between data and Monte Carlo of ± 5% is reached for the topocluster energy entering p_T >20 GeV jets [8].

The transverse missing energy is of outmost importance for new physics searches and is mainly based on calibrated cluster transverse energy [8]. Figure 2 right shows a very good agreement between data and Monte Carlo simulation for the $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ distribution in minimum bias events. Moreover there is no high energy tail, demonstrating the very good performance of the calorimeter.

4. Conclusions

The ATLAS calorimeter has been designed to provide optimal measurement for electron, photon, jet and $\mathrm{E}_{\mathrm{T}}^{\mathrm{miss}}$ taking profit of its very high granularity (187 000 cells), very good hermiticity in depth ($> 10\lambda$) and very large angular coverage ($|\eta| < 4.9$). Intensive test beam programs in the first half of the 2000 decade as well as *in situ* training of the full system in 2008-2009 allows to

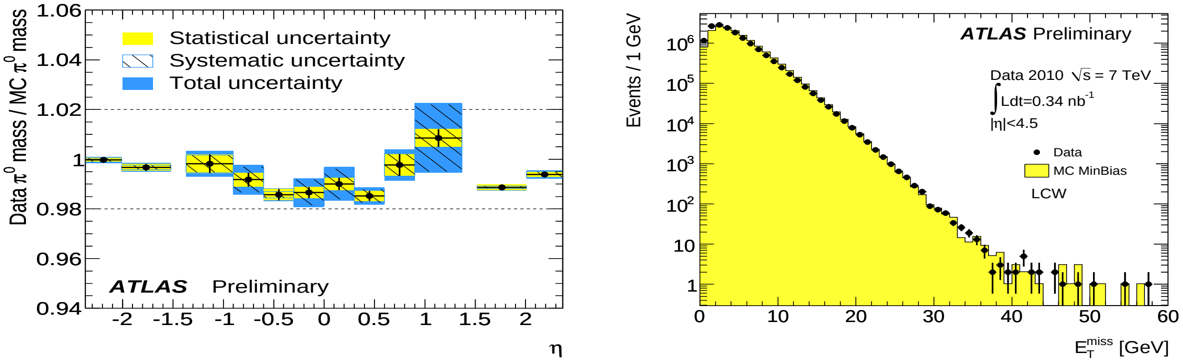

Figure 2: *Left: Ratio of pi^0 mass reconstructed in data and Monte Carlo simulation as a function of η. Right: Missing transverse energy in 7 TeV center of mass energy minimum bias events.*

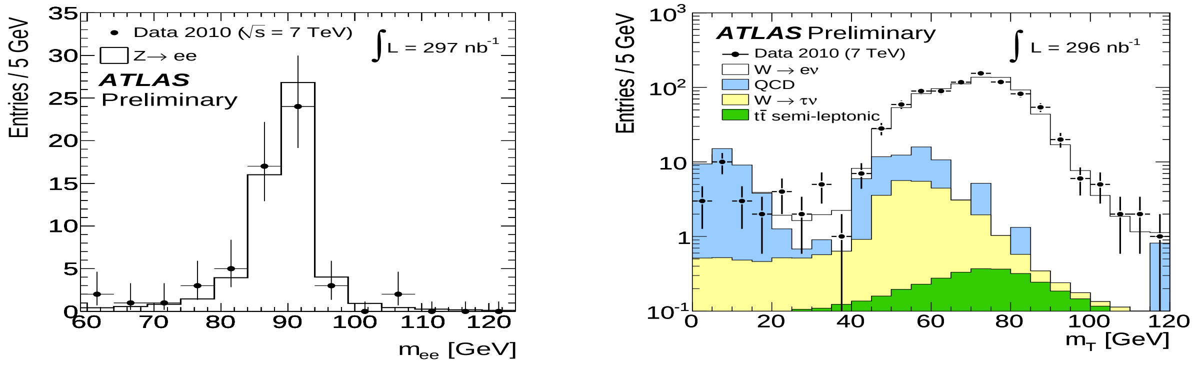

Figure 3: *Left: Mass peak of the reconstructed $Z \to ee$. Right: Transverse mass of $W \to e\nu$. Both plots use 300 nb^{-1} of data from proton-proton collisions at 7 TeV in the center of mass energy. The number of entries of Monte Carlo is normalised to data.*

have already an almost fully operationnal calorimeter for first LHC collisions, close to nominal performance. The mass distributions of the first hundreds of $W \to e\nu$ and tens of $Z \to ee$, compared to Monte Carlo expectations, are shown in Figure 3. A good agreement is observed illustrating again the very good behaviour of the calorimeter only 6 months after the collision recording in ATLAS.

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