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ATLAS DETECTOR WITH COSMIC RAYS AND EXPECTED PERFORMANCE WITH EARLY LHC DATA

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Cosmic muons have helped to understand the ATLAS detector in terms of DAQ, trigger, alignment and calibration. The performance of the ATLAS Inner Detector, Calorimeters and Muon Spectrometer systems with cosmic rays is briefly reviewed. The expected performance with first LHC collisions will also be described.

1 The ATLAS detector design

The primary purpose of the ATLAS experiment is to find the Higgs boson in the mass range from 100 GeV to 1 TeV, and supersymmetry, the most studied theory beyond the Standard Model.

Two basic facts influenced the detector design and optimization[1]. First, the signal production is below the total LHC interaction rate by up to $14 - 15$ orders of magnitude. Second, as the LHC is essentially a gluon-gluon collider, the QCD production is dominant over all the other processes.

The first fact implies the necessity of a high instantaneous luminosity. For ATLAS it means radiation-hard technology choice, fast trigger decision and readout and powerful Grid computing. The solution to the second challenge is high jet rejection. At transverse momentum $p_T = 20$ GeV for example, there are about 10^5 hadronic jets produced per electron or muon. The electron and muon reconstruction and identification algorithms must therefore be able to reject jets by the same factor 10^5.

The main design choices of the ATLAS detector are therefore[2]:

- Excellent electromagnetic calorimetry for electron and photon identification, completed by thick and hermetic hadronic calorimetry for jet and missing transverse energy measurements.

- Efficient tracking for lepton momentum measurements, enhanced electron and photon identification and, at low luminosity, excellent b-tagging capability.

- Standalone and precise muon measurements over a wide polar range coupled with low momentum trigger capability with toroid magnets.

Table 1 summarizes the required performance of each ATLAS subdetector and the respective η coverage.

Table 1: Required performance of the ATLAS subdectors.

Subdetector	Required resolution	η coverage	
		Measurement	Trigger
Tracking	$\sigma_{p_T}/p_T = 0.05\% p_T \oplus 1\%$	± 2.5	
EM calorimetry	$\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$	± 3.2	± 2.5
Hadronic calorimetry (jets)			
Barrel and Endcap	$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$	± 3.2	± 3.2
Forward	$\sigma_E/E = 100\%/\sqrt{E} \oplus 10\%$	$3.1 - 4.9$	$3.1 - 4.9$
Muon spectrometer	$\sigma_{p_T}/p_T = 10\%$ at $p_T = 1$ TeV	± 2.7	± 2.4

2 Performance with cosmic rays

Since the ATLAS calibration and reconstruction procedure relies essentially on Monte Carlo data, it has to be validated by various test beams and cosmic runs. The rest of this proceeding contribution describes the performance of the ATLAS detector with cosmic rays[3].

2.1 Inner Detector

More than 99% of the readout modules are active. A reasonable preliminary set of alignment and calibration constants for the Silicon Pixel detector (Pixels), Semi-Conductor Tracker (SCT) and Transition Radiation Tracker (TRT) can already be obtained using cosmic muons. The respective hit position resolutions are 24, 30 and 187 μm. These values are still $30 - 50\%$ higher than the expected ones due to the specificity of cosmic muons: the trigger is asynchronous with respect to the muon arrival, and tracks and clusters are often non-projective.

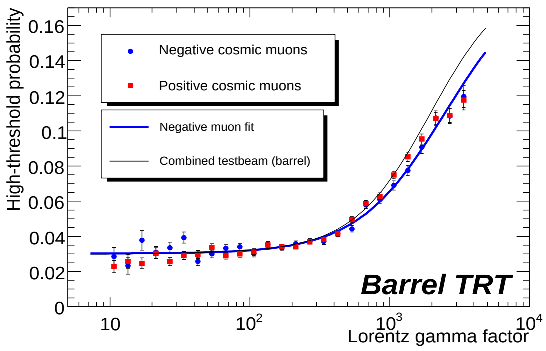

Figure 1: The TRT Transition Radiation turn-on as function of the Lorentz boost.

Figure 1 shows the Transition Radiation probability of the charged particle as function of its Lorentz boost factor. The radiator simulation, particularly difficult in the TRT barrel, is tuned based on ATLAS 2004 Combined Test Beam. Its agreement with the cosmic observation illustrates the importance of using test beam and cosmic results to improve the detector simulation.

2.2 Muon Spectrometer

Like in the Inner Detector case, cosmic rays provide a first set of alignment constants to the Muon Spectrometer. Track-based results show that the aligned sagitta is about 22 μm, well within the design specification. The Muon Spectrometer and the Inner Detector are aligned to each other within about 4 mm.

2.3 Combined performance studies

The muon m.i.p signal in the electromagnetic compartment is reconstructed using both fixed size and variable size algorithms. In the variable size algorithm, only cells with deposited energy above a certain threshold are used. Even at the m.i.p energy scale (about 300 MeV), the Monte Carlo reproduces the data observation to the level of $3-4\%$.

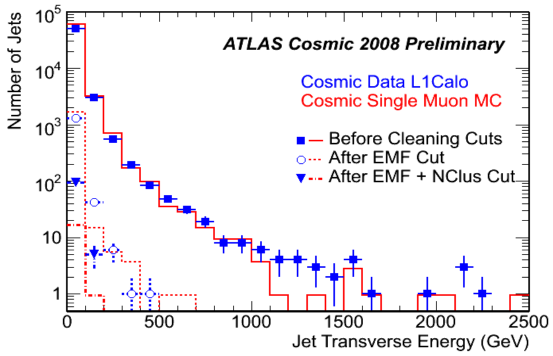

Figure 2: Jets created by locally large muon energy deposit in the calorimeter.

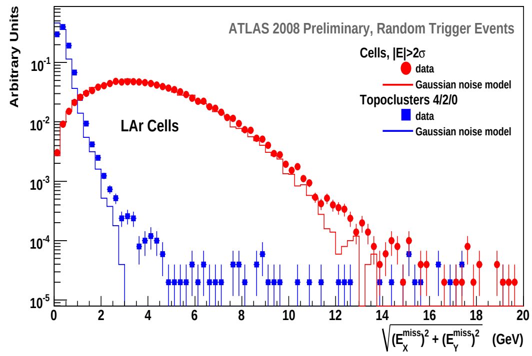

Figure 3: Missing tranverse energy reconstructed by the Liquid Argon calorimeter using random triggers.

Muons sometimes deposit locally large amount of energy in the calorimeters and thus produce jets. These cosmic origin jets can be removed by using the fraction of the energy deposited in the electromagnetic calorimeter and the number of constituent clusters in the jet. Figure 2 shows an excellent agreement between the Monte Carlo prediction and data observation, except for the tail due mainly to limited Monte Carlo statistics and to the absence of the cosmic air shower simulation.

Figure 3 shows the distribution of the missing transverse energy in the Liquid Argon calorimeter (LAr) using random triggers. The energy recorded by each cell is dominated by noise. The missing transverse energy is reconstructed either by using cells or topological clusters as basic input energy vectors. Topological clusters are produced by a variable topology clustering algorithm including noise suppression. The Monte Carlo agrees with data except for the tail due to local coherent noise of the LAr barrel presampler. This agreement shows that the calorimeter noise is low and well understood.

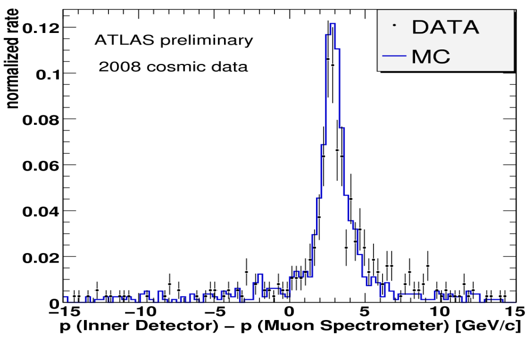

Figure 4: Inner Detector and Muon Spetrometer momenta difference.

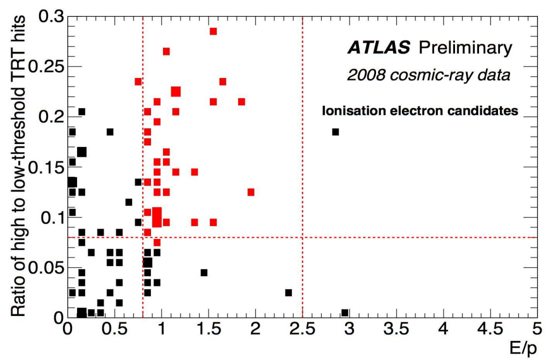

Figure 5: Observation of δ-ray electrons created by cosmic muons within the Inner Detector volume.

The energy deposited in the calorimeter is a measure of the total calorimeter thickness, approximately 11 interaction lengths at $\eta = 0.0$. This energy loss is reflected in the momenta difference between the Muon Spectrometer and the Inner Detector, as shown in Figure 4.

The muon interaction with the Inner Detector material can create $\delta-$ray electrons. These electrons are identified by applying a minimum cut on the ratio between the calorimeter energy and the tracker momentum E/p, and on the Transition Radiation given by the TRT, as shown in Figure 5.

3 Expected performance with early LHC data

The LHC will operate at $3.5 - 5.0$ TeV per proton beam in the first 2009-2010 run. ATLAS expects collecting few hundreds pb^{-1} of data by the end of 2010. With this sample, the first data analyses will focus mainly on basic Standard Model processes with two goals: to calibrate and align the detector, and to measure the processes cross section to compare with theory[4].

For each 100 pb^{-1} of collected luminosity, there will be 250k J/ψ, 300k W and 30k Z reconstructed in the electron channel. The muon channel offers the same statistics for W and Z, but five times more J/ψ due to lower trigger threshold and better muon identification at low energy. These samples provide sufficient statistics for first E/p scale study, trigger and individual detector performance, from low to high energies.

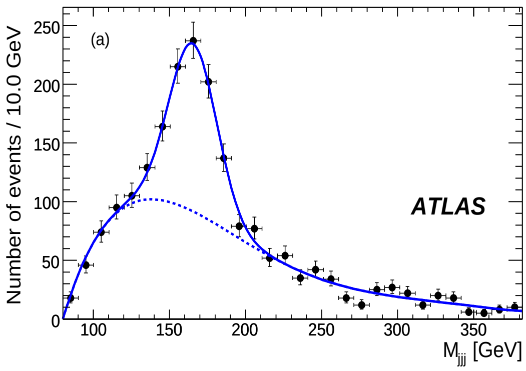

Figure 6: Reconstructed top mass peak in the single muon channel from simulated data for 100 pb^{-1} of luminosity.

For 100 pb^{-1} of integrated luminosity, about 500 $t\bar{t}$ events will be reconstructed in the single muon channel. As shown in Figure 6, signal can be extracted even with pessimistic background estimation. These $t\bar{t}$ events provide an unbiased sample to study the b-tagging efficiency and to understand the jet energy scale.

4 Conclusions

Like any other test beam that ATLAS has undertaken, the cosmic run allows only a partial validation of the detector in terms of DAQ, online, offline and physics performance. However, based on first cosmic results, the detector performs as well as expected: dead channels representing less than 1% of the total readout channels, low and well understood noise, and a reasonable set of first alignment and calibration constants derived from muon tracks. The ATLAS detector is therefore ready for the LHC startup in November 2009.

References

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3. ATLAS physics results https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasResults
4. Expected performance of the ATLAS Experiment, Detector, Trigger and Physics, CERN-OPEN-2008-020