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Study of the response of ATLAS electromagnetic liquid argon calorimeters to muons

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ABSTRACT

The response of the ATLAS electromagnetic calorimeter to muons has been studied in this paper. Results on signal over noise ratio, assessment of the detector response uniformity, and position resolution are presented. The possibility to study fine details of the structure of the detector through its response to muons is illustrated on a specific example. Finally, the performance obtained on muons in test-beam is used to estimate the detector uniformity and time alignment precision that will be reachable after the commissioning of the ATLAS detector with cosmic rays.

1. Introduction

The CERN Large Hadron Collider (LHC) is a proton–proton collider with 14 TeV centre of mass energy and design luminosity of $10^{34}\,\mathrm{cm^{-2}\,s^{-1}}$. ATLAS is one of the experiments that will take data at LHC. It has been optimized for the discovery of new particles like the Standard Model Higgs boson or supersymmetric partners of Standard Model particles, and also for the measurement and detailed study of known objects like heavy quarks or gauge bosons.

The electromagnetic calorimeter of ATLAS is a lead-liquid argon sampling calorimeter with accordion shaped absorbers and electrodes. ATLAS has chosen liquid argon calorimetry for its stability, intrinsic linear behaviour and radiation tolerance. The electromagnetic calorimeter has been particularly optimized for the detection of the $H \rightarrow \gamma\gamma$ decay. The possible observation of this channel has placed stringent requirements on the detector in terms of energy resolution, angular measurement and particle identification capability.

In comparison to electrons, muons deposit a small amount of energy, but can nevertheless give complementary information on an electromagnetic calorimeter, provided they can be detected with a sufficient signal over noise ratio. For muons interacting with lead, the critical energy is about 140 GeV.[7] For muon momenta significantly above the critical energy, radiative energy loss processes are more important than ionization, and muons will behave in the calorimeter like electrons at very high energies, i.e. produce electromagnetic showers. If the muon momentum is of the order or below the critical energy, radiative energy loss is not dominant and the energy deposit corresponding to the muon is very localized in the calorimeter compared to electrons. Such muons can be used as a probe to understand fine details of the detector cells' response. This can be important in the future, to help understanding the electron signal and also to prepare the commissioning of the liquid argon electromagnetic calorimeter. The study of muon signal can also be useful to identify the source of residual non-uniformities [2].

The present study has been done on ATLAS barrel and end-cap series modules. The detailed geometrical description of these detectors is presented in Ref. [3]. Only the aspects relevant for the studies performed here will be recalled.

2. Experimental setup

The test beams of the production modules whose data have been used in the present analysis have been carried out on CERN's H8 beam line for the barrel modules, and on CERN's H6 beam line for the end-cap modules. Both setups are very similarly organized (Fig. 1, and Refs. [2,4–7]), using several scintillator counters in coincidence in front of the cryostat to trigger the readout system and define the detector region under study, complemented by MWPCs [8], used here as beam chambers to measure event by event the position of each particle impinging the detector. Some additional scintillator counters placed after the detector are used to tag pions or muons in the beam.

The barrel and end-cap preproduction modules (modules 0), four series barrel modules and three series end-cap modules have been studied mainly under electrons beams of various energies between 10 and 300 GeV. In addition, some spots of the detectors have been studied under pure muon beams. The results obtained from the analysis of the electron and photon data can be found in Refs. [2,4–7]. Results obtained from series modules using the muons that are present in standard 245 GeV electron beams are presented in the present paper. These muons originate from pion decays along the beam line, and their energy is less than the beam energy. Since the exact spectrum of the muon momentum is not known, comparisons between muons produced in association with electrons of different beam energies could not be done. Most of the studies presented here rely only on comparisons between different cells in the calorimeter using the same 245 GeV electron beam setup. Some specific studies using 120 GeV pure muon beam data taken on the preproduction module are also described. The available data represent typically 10 000 muons per calorimeter cell studied.

3. Detector description

Fig. 2 shows the accordion structure of the lead absorbers. The spacing between two consecutive absorbers defines a liquid argon gap. Each liquid argon gap contains a readout electrode. The electrodes are positioned in the middle of the gap by honeycomb spacers. Each electrode is made of three copper layers separated by polyimide insulating layers. The two outermost copper layers are connected to the high voltage, and create an electrical field of 1 kV per mm between the electrode and the absorbers that are connected to the ground. The third layer, sandwiched between the two outer layers, is used for signal collection. Due to the accordion structure of the readout electrodes and absorbers, the physical boundary between two readout cells also follows this geometry, so that a particle crossing a calorimeter along a straight track will deposit energy in two adjacent readout cells in φ (see Fig. 2). The end-cap geometry is similar. An important consequence of this geometry is that muons behaving as minimum ionizing particles deposit their energy in two adjacent cells in φ.

Electrons induced by the development of showers in the calorimeter drift in the electrical field, and induce by capacitive coupling a current on the signal layer. This current is collected and processed by the front-end electronics.

[7] The critical energy is given by $5700\,\mathrm{GeV}/(82+1.47)^{0.828}$, see Ref. [1].