Overview of test beam campaigns for readout electronics of the upgrade Tile Calorimeter of the ATLAS Detector

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Outline

• ATLAS Tile Calorimeter

• The phase-II Front-End electronics

• Test Beam Setup

• The Result obtained using Electrons:

• Summary
The ATLAS Tile Calorimeter (TileCal) is the central hadronic calorimeter for the experiment. A cross-sectional view of the detector is shown on Figure 1. The calorimeter is partitioned into 4 cylindrical sections (EBA, LBA, LBC, and EBC), each containing 64 wedged-shaped modules as shown on Figure 2.

The TileCal is a sampling calorimeter constructed of steel and plastic scintillators. The steel acts as an active absorber, and when high energy particles interact in the steel, showers of low energy particles are produced, which then interacts with the scintillators to produce light. This light is then collected using wavelength-shifting (WLS) fibres to the on detector electronics, the front-end system.

At the front-end electronics system the light signal is converted the to electrical signals and digitized, and then processed as first level (L0/L1) trigger events. Data from the FE electronics is further transferred to the off-detector back-end (BE) for further processing and readout to permanent storage.
The phase-II Front-End electronics

• The phase-II Front-End (FE) readout design relies on the use of high reliability components, with a strong emphasis on radiation tolerance that satisfies the HL-LHC criteria of 10 kRad over the period of 10 years.
• The FE electronics will be housed in independent mechanical structures called mini-drawers. Four mini-drawers comprises a super-drawer in contrast to the current configuration of two-drawers, and 256 super-drawers will constitute the full detector in 4 barrels of 64 wedges each, see figure 6 and 7.
• There are three proposed options for the redesign of the FE cards:
  1. The optimized redesign of the current 3-in-1 cards.
  2. FATALIC which uses shaping just like the 3-in-1 but with a different pulse.
  3. The QIE ASIC developed by the Argonne National Lab.
The Demonstrator program

- The Demonstrator project aims at testing the long term performance of the upgrade system without compromising data taking.
- The Demonstrator is a prototype phase-II super-drawer composed of 4 independent mini-drawers. If it is verified to perform according to the requirements, it will be inserted into the real ATLAS detector during the long shutdown.
- The data is readout through the Pre-Processor (PPr) board which formats and transmits it to the legacy readout drivers (RODs) for backward compatibility with the current system and to the Front-End Link exchange (FELIX).
- The Demonstrator will house the redesigned 3-in-1 cards.

*Figure 8:* The Scanning table of the Test beam

- [Image of the scanning table](image-url)
Test Beam Setup

Motivation:
The Phase II Upgrade of the LHC – increase of instantaneous luminosity by a factor of 5-10. Electronics will need to withstand a much higher radiation dose as well as a increased demand for data throughput.

- As of 2016 test beams, 3 Cherenkov Counters were used to separate the electrons, muons, and protons for energies below 50 GeV, and a muon hadoscope (Muon wall) located behind the modules was used to detect muons.

- Half-module (LBC65) C side has been equipped with so-called Hybrid Demonstrator. The 3-in-1 FE option has been mounted in this Demonstrator, which provides all the upgrade functionalities but maintaining the analog trigger signals for backward compatibility. Another half-module (LBA65) A side has been instrumented with other FE electronics options FATALIC & QIE.

- These modules equipped with Phase-II upgrade electronics together with modules equipped with the legacy system where exposed to different particles and energies, coming from SPS accelerator, in the test-beam campaigns during 2015 – 2018. Following work is done using Demonstrator data.
The Results Obtained using Electrons:

• Electron beams provide perfect tool to:
  • Determine the electromagnetic (EM) scale – it does so by measuring signals of beam particles at known energies and calculating the average Charge-to-Energy conversion factor, in pC/GeV.
  • Verify the linearity of the response vs energy to test the detector uniformly and its energy resolution.

• Test beam is a mixture of electrons, hadrons and muons:
  • muons were rejected by requiring the total measured energy to be $E_{\text{tot}} > 5\text{GeV}$.
  • For electron/hadron separation, two shower profile criteria were used (C-method): $C_{\text{long}}$ and $C_{\text{tot}}$ exploiting the difference of electromagnetic and hadronic shower profiles in the calorimeter.

• $C_{\text{long}} = \sum_{i=1}^{2} \sum_{j=1}^{3} \frac{E_{ij}}{E_{\text{beam}}}$
  • The variable $C_{\text{long}}$ represents the fraction of energy deposited in the first two longitudinal layers of the demonstrator module: Where $j$ runs over 3 adjacent cells of the layer $i$ centered around the beam and $E_{ij}$ stands for the energy measured in a cell.

• $C_{\text{long}} = \frac{1}{\sum_{c} E_{c}^{\alpha}} \sqrt{\sum_{c} \left( \frac{E_{c}^{\alpha} - \sum_{c} E_{c}^{\alpha}}{N_{\text{cell}}} \right)^{2}}$
  • The variable $C_{\text{tot}}$ measures the spread of the energy deposited in the calorimeter cell $c$: where $E_{c}$ represents the energy in cell $c$ and $N_{\text{cell}} = 9$ stands for the total number of cells considered. The exponent $\alpha = 0.6$ was tuned using a Monte Carlo simulation to achieve maximum electron/hadron separation.
The Results Obtained using Electrons:

- The combination of the quantities $C_{\text{long}}$ and $C_{\text{tot}}$ are used for electron/hadron separation.
- The region on the right/top corresponds to electrons, the other to hadrons.

- The cut on $C_{\text{long}}$ ($C_{\text{tot}}$) depends on the beam energy, it ranges from 0.75 (2.1) at 20 GeV to 0.88 (6.5) at 100 GeV.
- At energy $E_{\text{beam}} = 20$ GeV the purity of the electron sample is improved requiring signals of the Cherenkov counters 1 and 3 of the beam line larger than 500 ADC counts.
The Results Obtained using Electrons:

Electron Analysis is done to compare the electron signals with the required electron data. The analysis was done at energies 20, 50 and 100 GeV. Electron data is compared with data from the old electronics. The distributions obtained using experimental data in the case of beams incident in the A-3 cell are shown.
The Results Obtained using Electrons:

- The linearity of the calorimeter response to electrons was checked in the range of 20-100 GeV.
Summary

• **Motivation:** The Phase II Upgrade of the LHC plans to increase instantaneous luminosity by a factor of 5-10. Electronics will need to withstand a much higher radiation dose as well as an increased demand for data throughput.

• A stack of three modules of the hadronic calorimeter of the ATLAS experiment (TileCal) equipped with the updated front-end electronics has been exposed to the beams of the SPS at CERN.

• More analysis done on hadrons and muons.

• The results obtained using electrons are in agreement with the calibration settings obtained using the old electronics and with the expectations obtained using simulated data.

• The Results confirm good performance of the new electronics
Thank You!