Studies of the ATLAS hadronic Calorimeter response to different particles at Test Beams

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ATLAS EXPERIMENT

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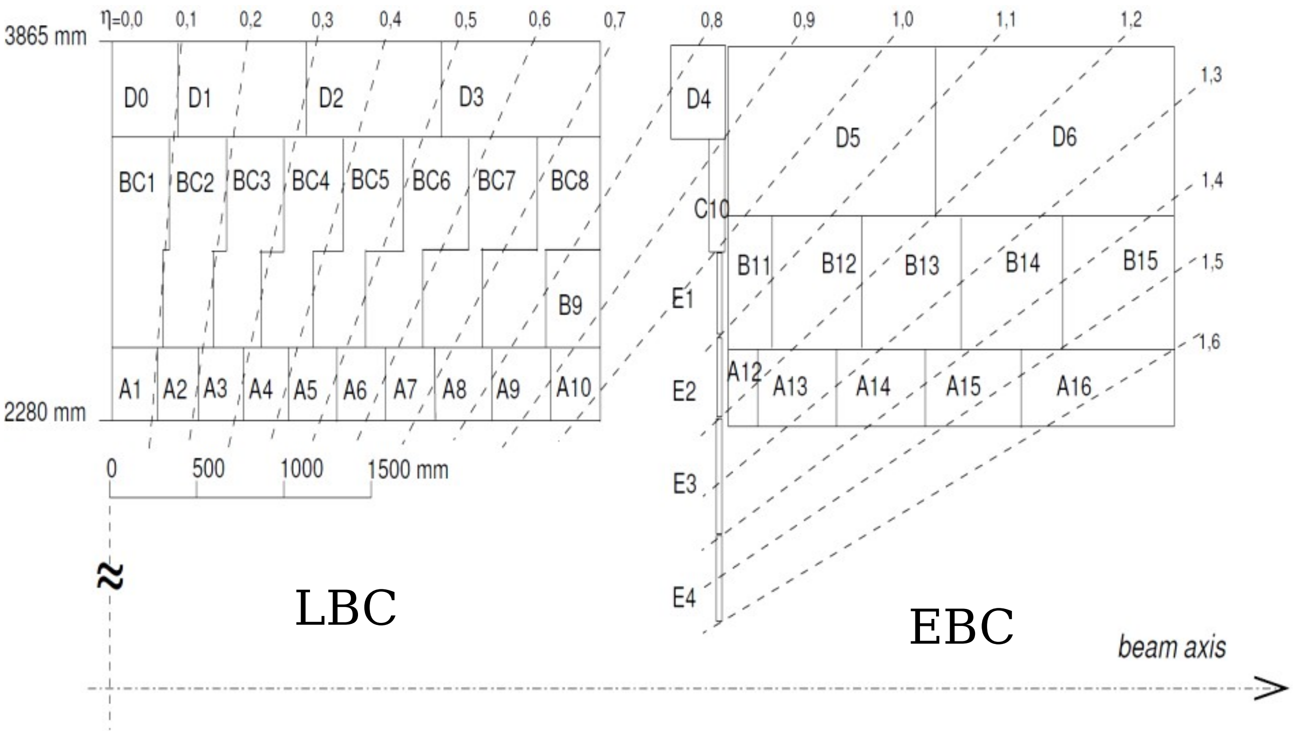
Outline

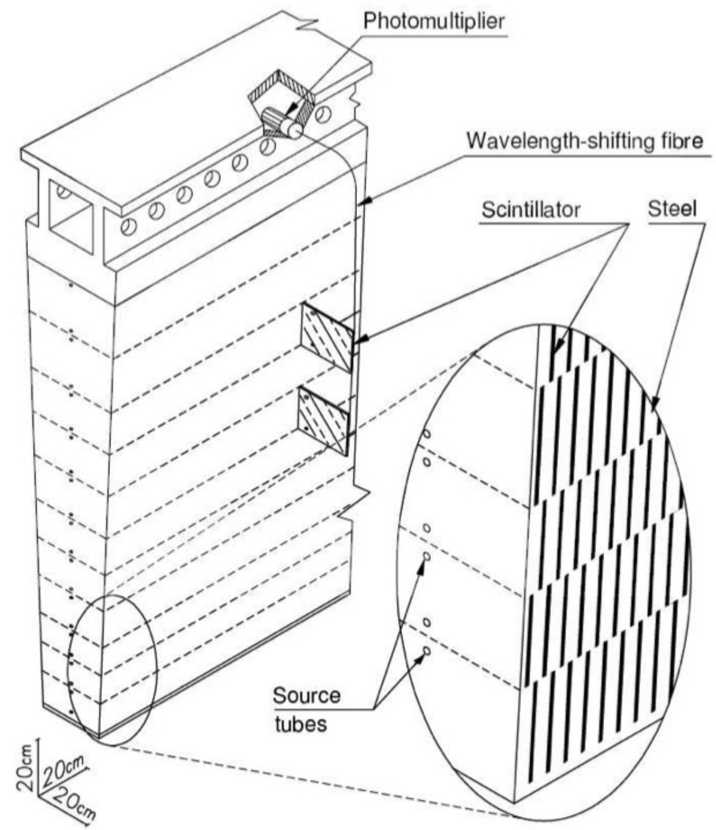
- ATLAS Tile Calorimeter
- Test Beam setup
- The results obtained using:
  - Muons
  - Electrons
  - Hadrons
- Summary

ATLAS Tile Calorimeter

Principle of TileCal:

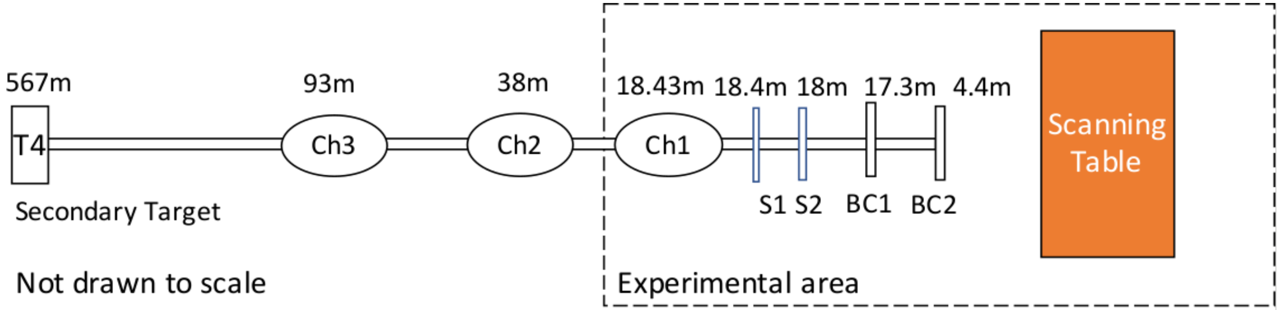
- The defining role of hadron calorimetry is to measure the energies of jets.
- Measure light produced by charged particles in plastic scintillator.
- Scint. light from tiles collected by WLS fibers and delivered to PMTs.
- Tile readout is grouped into projective geometry cells. each cell readout by 2 PMTs except special cells (layer E).
- Each barrel consist of 11 tile rows which form 3 longitudinal layers (A, BC, D).



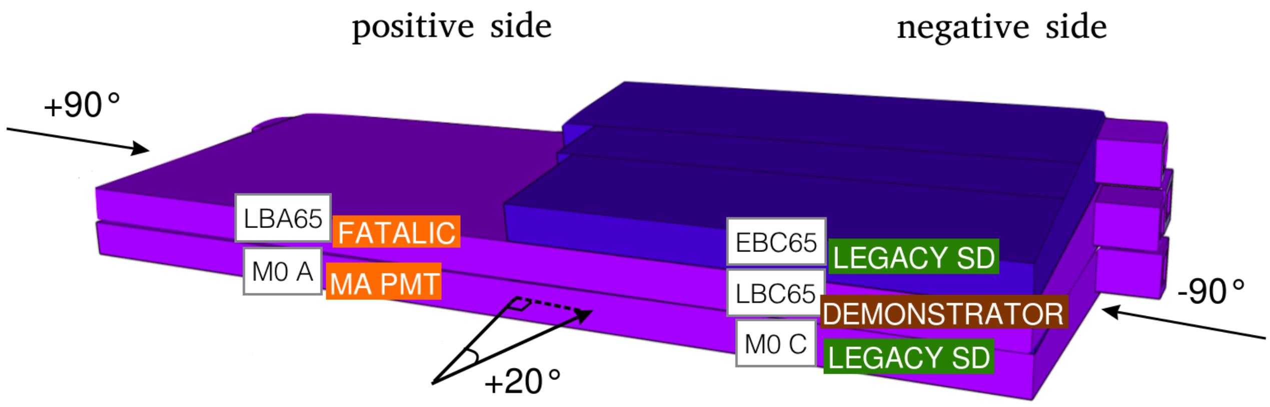


Test Beam setup

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.



- Half-module (LBC65) has been equipped with so-called Hybrid **Demonstrator**. The 3-in-1 front-end 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) has been instrumented with other front-end electronics options FATALIC and M0 A was equipped with Multi-Anode PMT.



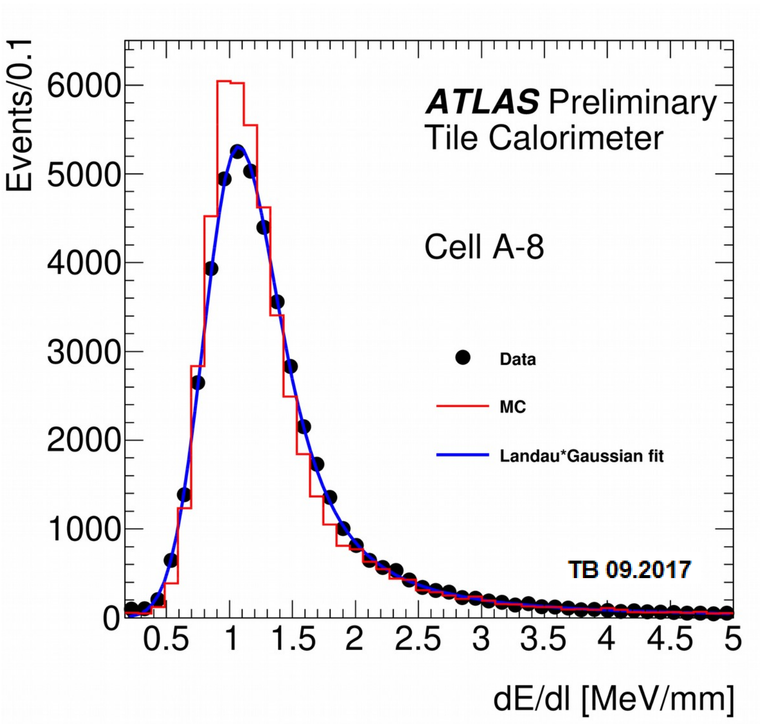
- These modules equipped with Phase-II upgrade electronics together with modules equipped with the legacy system where exposed to different particles and energies, coming from SPS accelerator, in the test-beam campaigns during 2015 – 2017. **Following work is done using Demonstrator data.**

Results with:

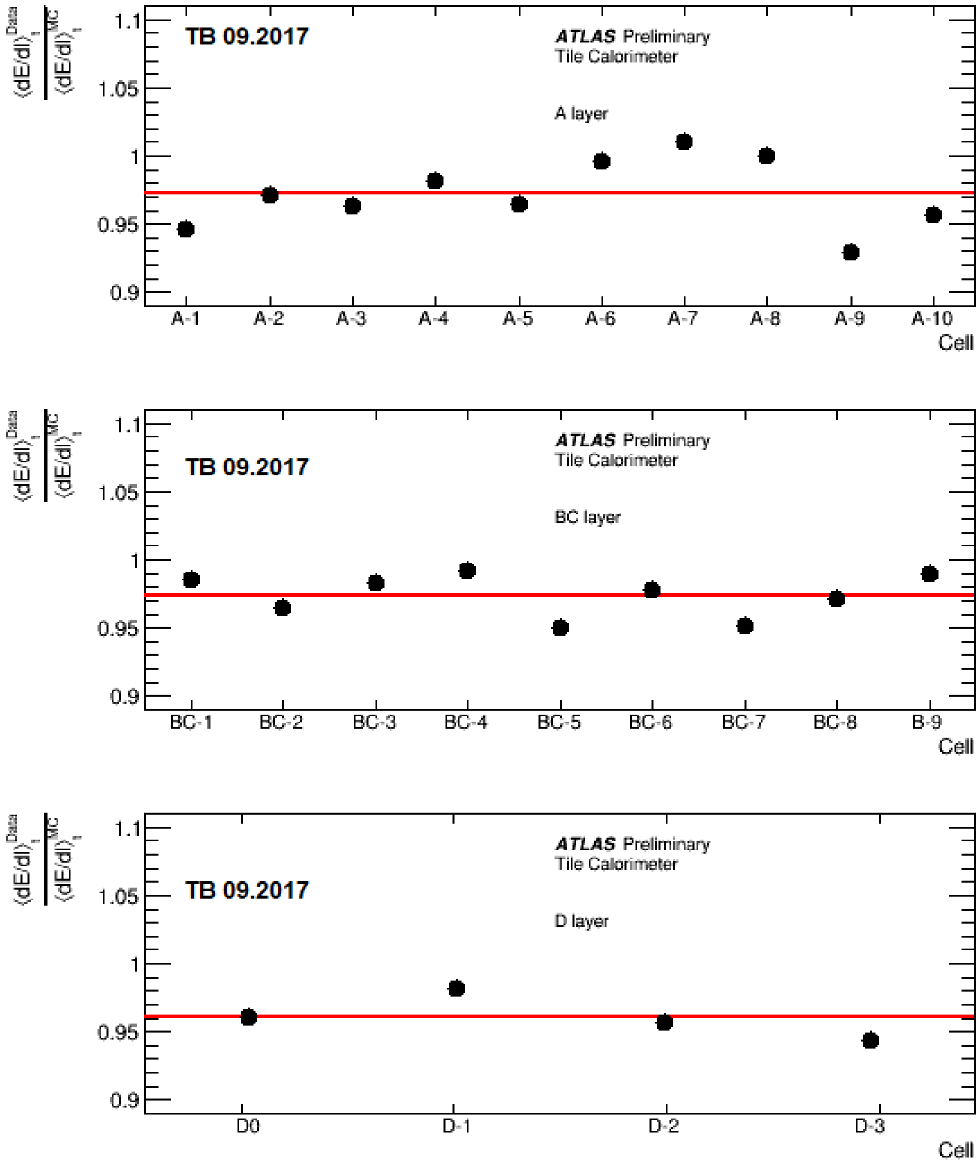
- Muons
  - The high energy muons traverse the entire TileCal modules for any angle of incidence, thereby allowing a study of the module response in great detail through their entire volume.
  - The interaction of muons with matter is well understood. The dominant energy loss process is ionization and the energy loss is essentially proportional to the muon track path length.
  - Muon data allows us to:
    - **verify the new electronics performance by checking the equalization of the cell response.**
- Electrons
- Hadrons

Results with muons: strategy

- The TileCal response to high energy muons follows a Landau type distribution with characteristically long tails at high energies.
- The most obvious definition, namely the most-probable (peak) value of the signal divided by the muon path length, displays a significant residual dependence on the path length.
- Instead, **the mean value of the measured muon energy loss spectrum truncated at 97.5% of the total number of entries was adopted.**
- The truncated mean was preferred to the full one because it is less affected by rare high energy loss processes.



Results with muons: dE/dl VS cell



- The response of the detector has been studied determining the ratio between the energy deposited in a calorimeter cell (dE) and the track path-length in the cell (dl) using 165GeV muons at an incident angle of -90°.
- The ratio of experimental and simulated dE/dl values was defined for each calorimeter cell:

$$R = \frac{\langle dE/dl \rangle_t}{\langle dE/dl \rangle_t^{MC}}$$

- The red horizontal lines - the mean values of dE/dl for each layer.
- The data show a layer uniformity at 1%. An offset of max 4% is observed for Data/MC.

Results with:

- Muons
- Electrons
  - electron beams provide perfect tool to:
    - Determine the electromagnetic scale— 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 and to test the detector uniformity and its energy resolution.
- Hadrons

Electron identification

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

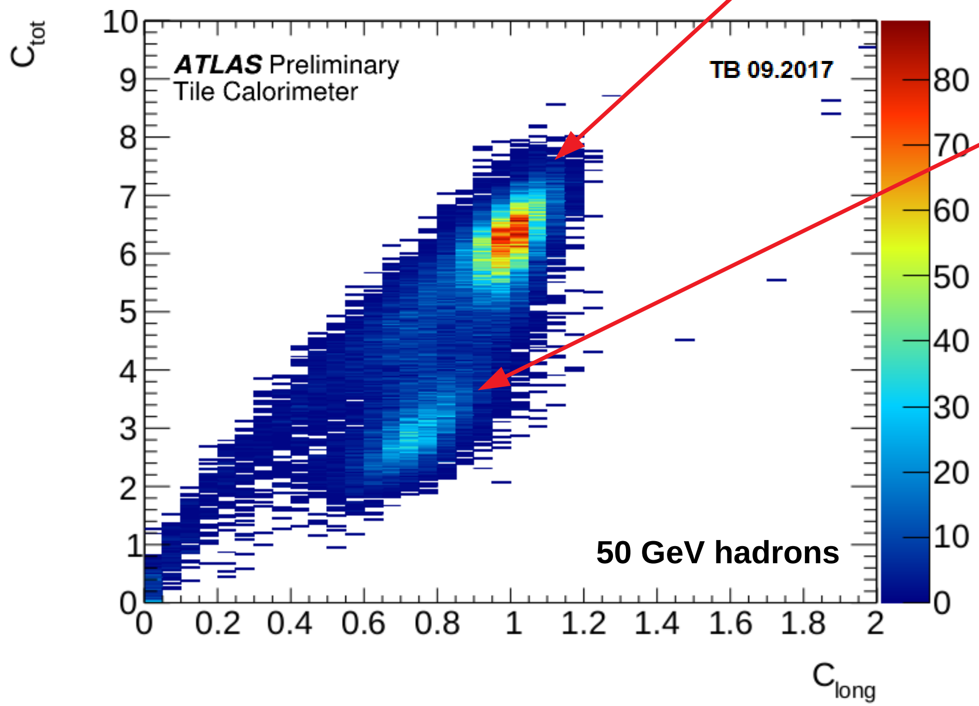
$$C_{long} = \sum_{i=1}^{2} \sum_{j=1}^{3} \frac{E_{ij}}{E_{beam}}$$

$$C_{tot} = \frac{1}{\sum_c E_c^\alpha} \sqrt{\sum_c \frac{\left(E_c^\alpha - \sum_c E_c^\alpha / N_{cell}\right)^2}{N_{cell}}}$$

- The variable C_{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.
- The variable C_{tot} measures the spread of the energy deposited in the calorimeter cell c:
  where E_c represents the energy in cell c and N_{cell} = 9 stands for the total number of cells considered. The exponent α = 0.6 was tuned using a Monte Carlo simulation to achieve maximum electron/hadron separation.

Electron identification

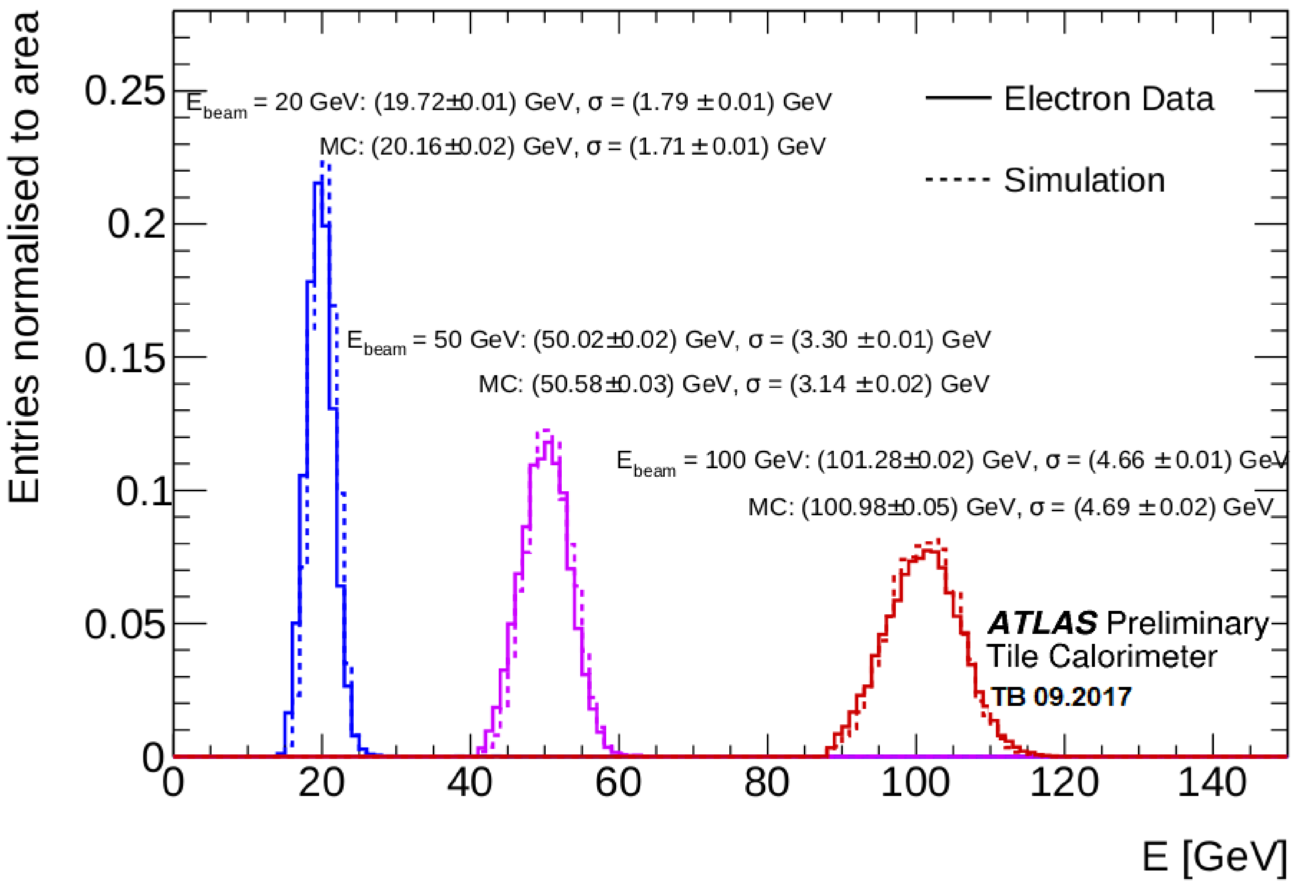
- The combination of the quantities C_{long} and C_{tot} are used for electron/hadron separation.
- The region on the right/top corresponds to electrons, the other to hadrons.



- The cut on C_{long} (C_{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_{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.

Electron data MC comparison

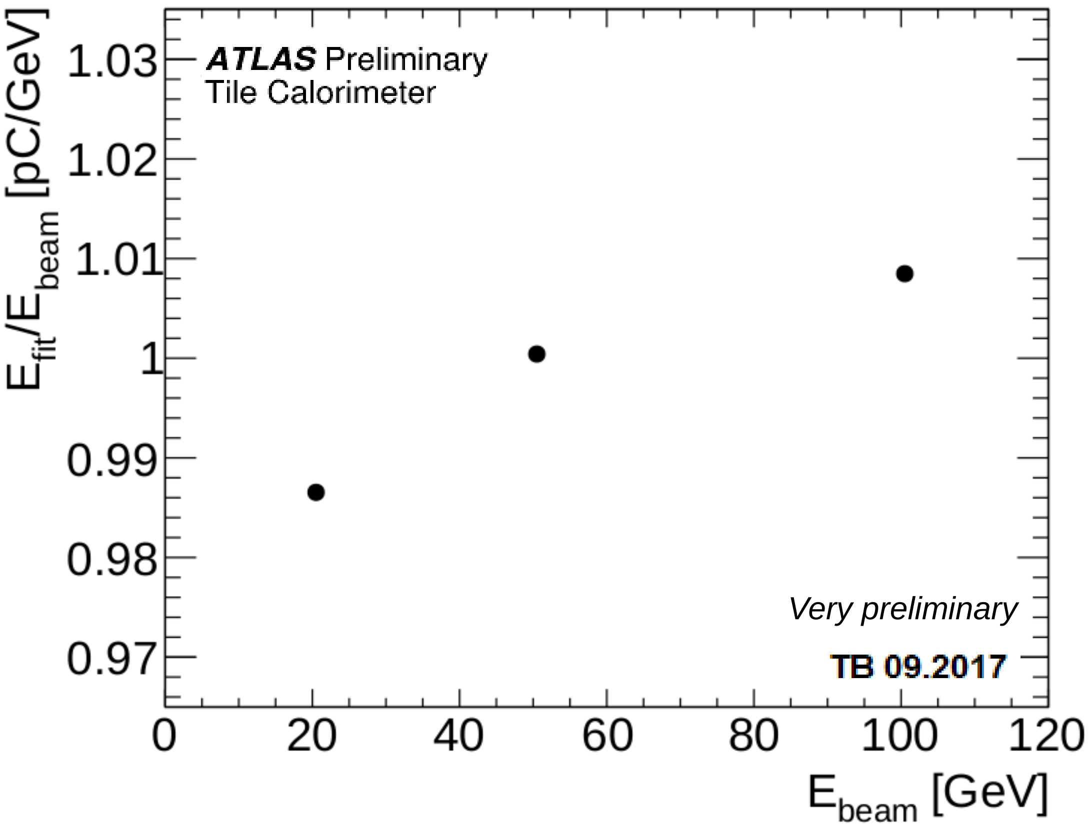
- The distributions obtained using experimental and simulated data in the case of beams incident in the A-4 cell at 20° are shown.
- For a given beam energy the experimental and the simulated shapes are very similar proving the purity of the selected experimental electron samples.
- The solid (dashed) distribution corresponds to experimental (simulated) data.



Response linearity

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

The values of E_{fit}/E_{beam} obtained with electron beams with different energies, 20, 50 and 100 GeV

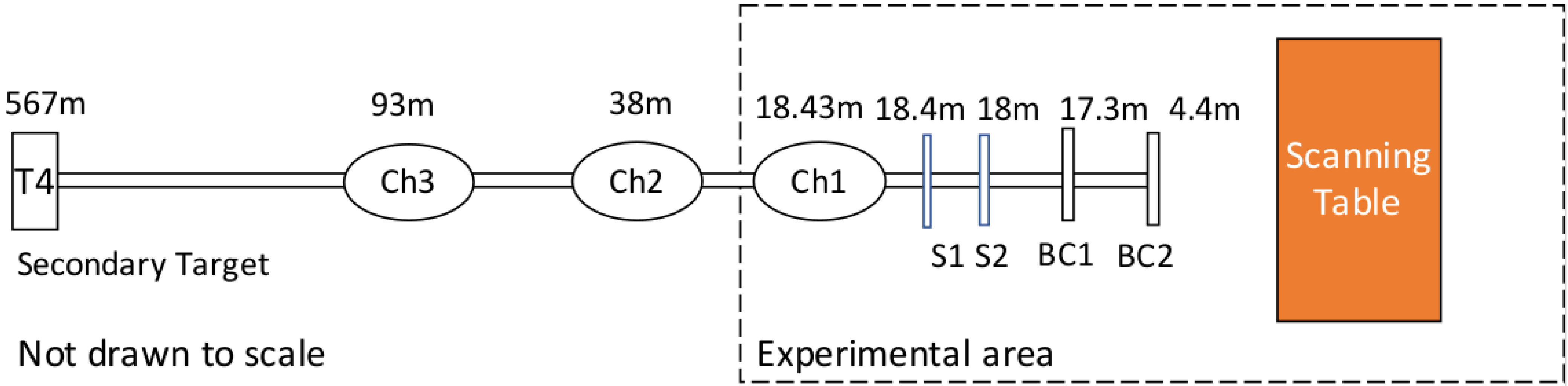


Results with:

- Muons
- Electrons
- Hadrons
  - The defining role of hadron calorimetry is to measure the energies of jets.
  - It is important to determine response from different hadrons.

Separation of hadrons

- Test beam is a mixture of: p, π, K, e, μ
- Particles of the beam were identified mainly by the calorimeter’s response and three beam-line Cherenkov counters, which were tuned for p,K separation:
  - Cherenkov 3 (Helium at 0.3 bar): separation of p/K from the rest
  - Cherenkov 2 (CO_2 at 2 bar): separation of p from the rest
  - Cherenkov 1 (CO_2 at 2.6 bar): separation of p/K from the rest



Separation of hadrons

The selection criteria chain applied for 18 GeV beam is visualized in figures.

p/K particles are separated from π/e requiring:

- Cher1 < 400 and

  Cher3 < 420 ADC counts

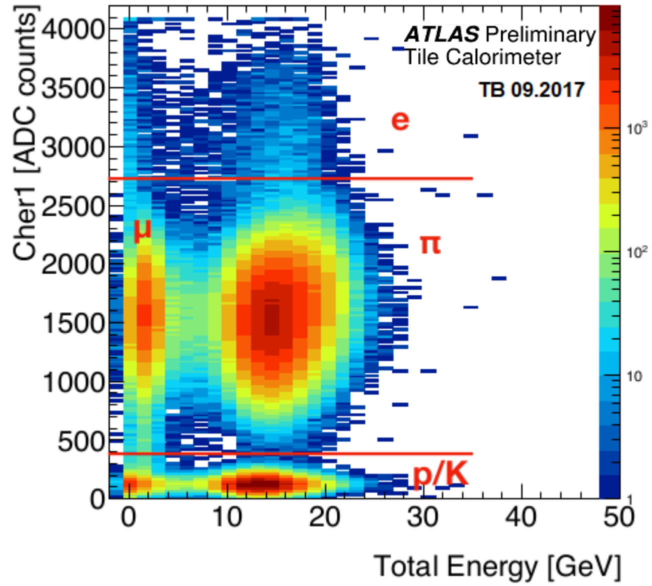
Pions from electrons:

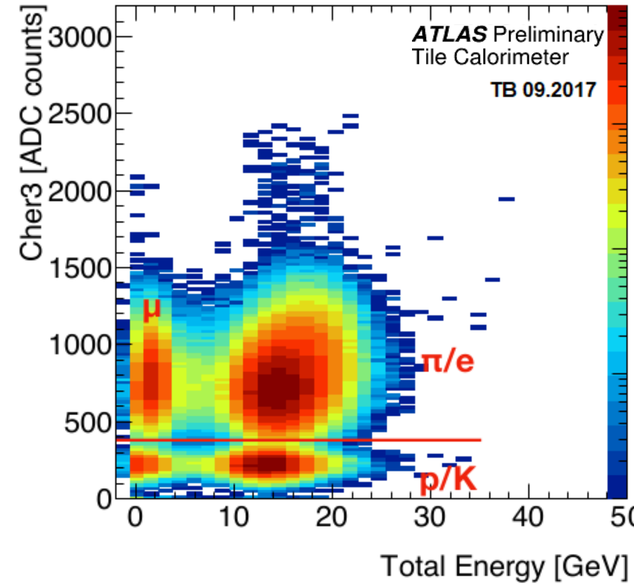
- Cher1 < 2600 and

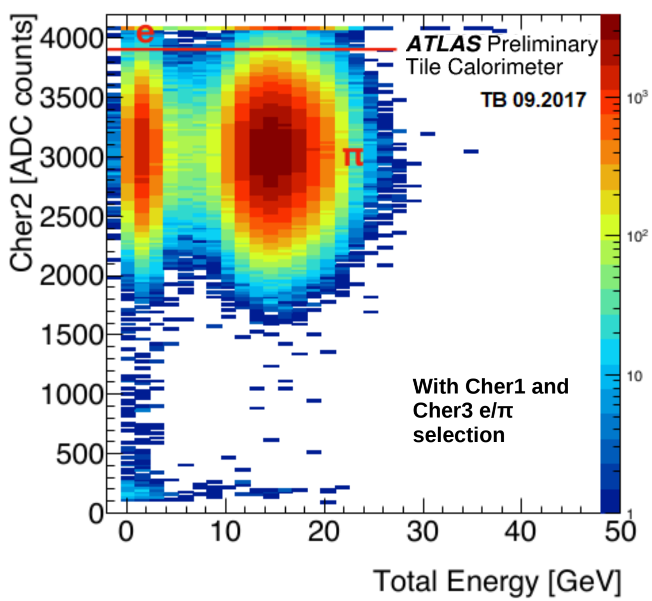
  Cher2 < 3900 ADC counts

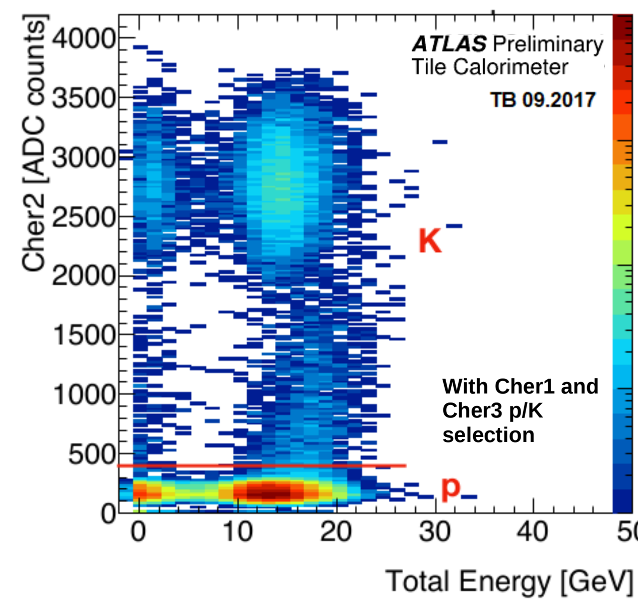
Kaons from the protons:

- Cher2 < 460 ADC counts



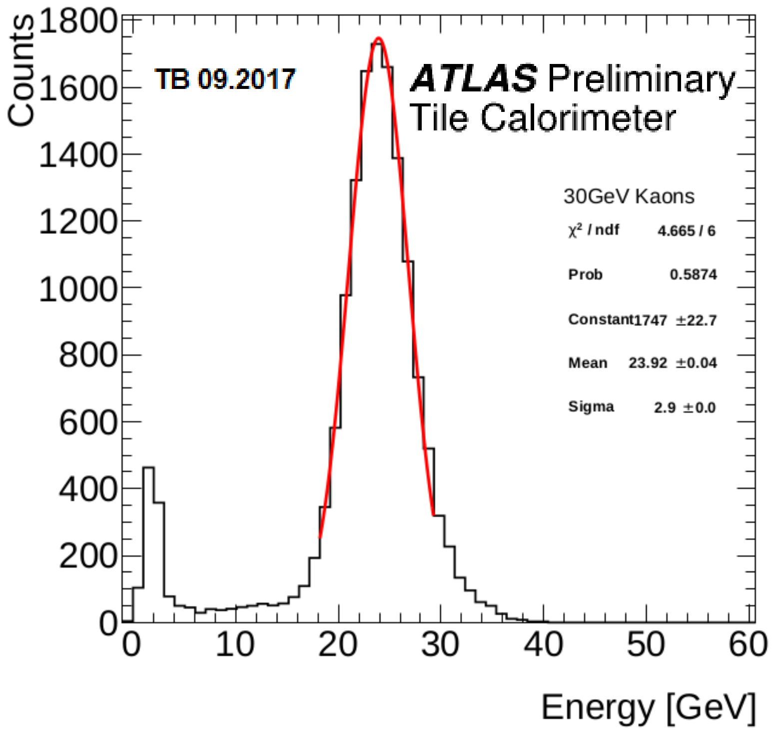






Response of hadrons

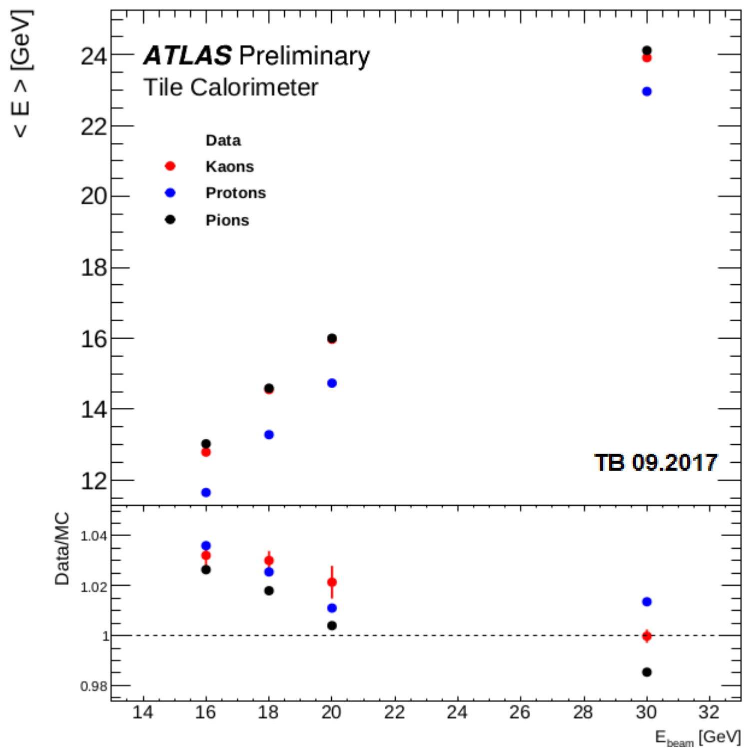
Distribution of the measured energy
for 30 GeV kaons.

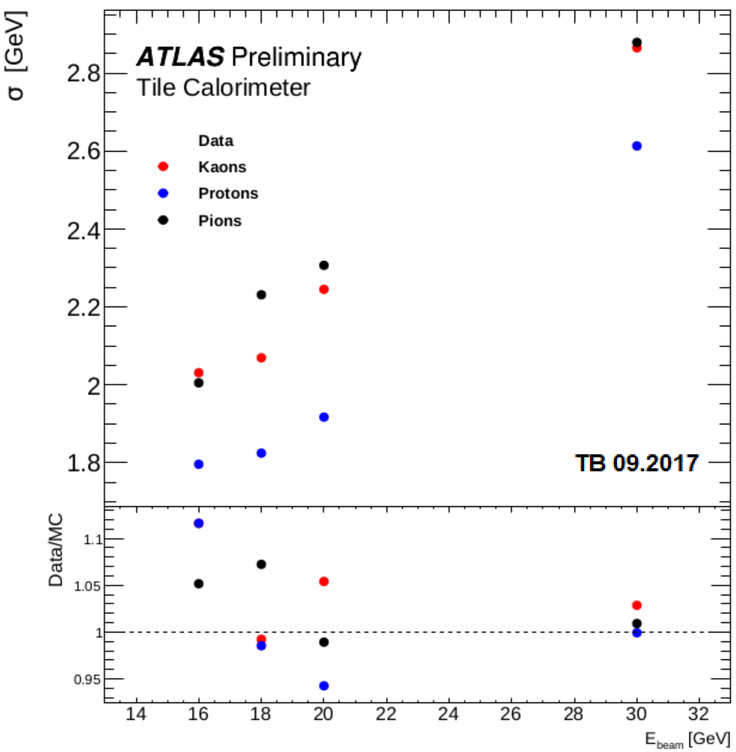


- For all the beam energies, the responses < E > are extracted as the mean values of a Gaussian fitted in the range $\pm 2\sigma$ centered on the peak.
- The width of the distributions are extracted as the σ of the fit function.
- The low energy peak is due to muons coming from kaons decays.

Results with hadrons

- Left figure shows the measured response < E > as function of the beam energy.
  - The agreement with the simulated results obtained using the Geant 4.10.1 (FTFP_BERT_ATL physics list) improves with increase of the beam energy.
- Right figure shows the width σ as a function of the beam energy.
- In the considered range, the response is larger for pions and kaons than for protons.
- The agreement Data/MC is better than 5% for measured response < E > and better than 12% for measured width (ratio is shown at the bottom of each plot).





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 a 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.
- The results obtained using muons, electrons and hadrons 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 for your attention!

Backup

ATLAS detector

- The TileCal is the central hadronic calorimeter within the ATLAS at the LHC situated at CERN, Geneva.
- The TileCal is composed of four barrel sections (two central and two extended barrels), each containing 64 azimuthal slices.
- The Phase II Upgrade of the LHC plans to increase the present instantaneous luminosity by a factor of 5-10. will need to withstand a much higher radiation dose as well as a increased demand for data throughput.