Calibration of the ATLAS Tile Calorimeter using muons

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School and Workshop "Frontiers of QCD"
Sept. 23-28, 2019, Tbilisi, Georga

Supported by the joint grant of Volkswagen Foundation and SRNSF (Ref. 93 562 & #04/48)

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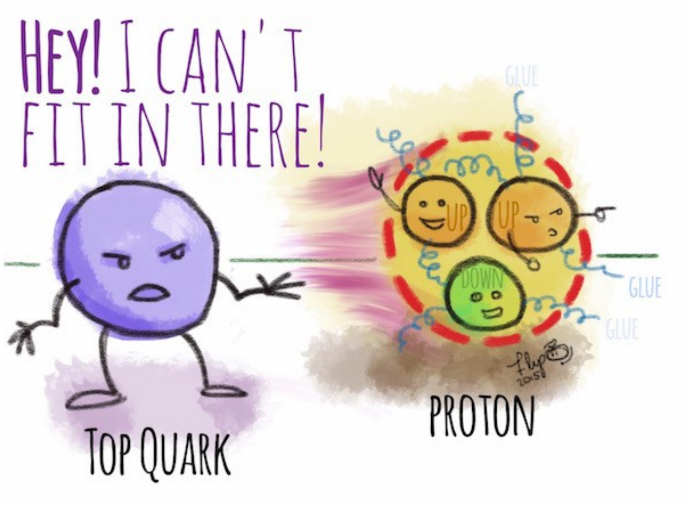
- Test Beam setup
- Use the new TB data collected to:
  - Check the proposed Upgrade phase II electronics
  - To review and improve the detector calibration procedure.
- Summary


Large Hadron Collider
Lake of Geneva
CMS
LHCb
Airport
ALICE
ATLAS

Physics beyond Standard Model



BSM:

- The extra dimensions of space
- Unification of fundamental forces
- Supersymmetry and string theory
- …

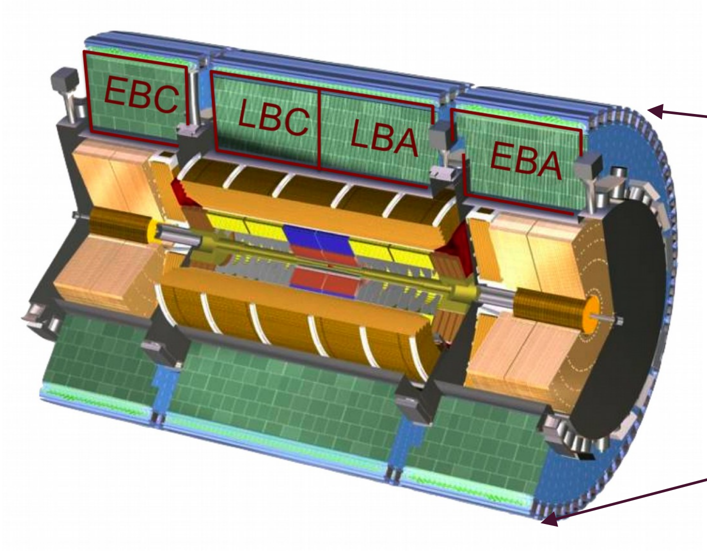
LHC is the machine where top quarks are produced in large numbers, so much so that it is sometimes called the “top factory”.

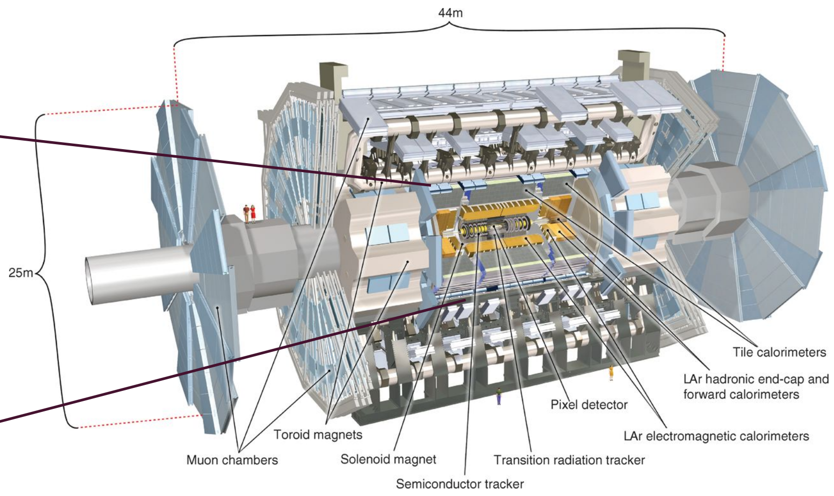
Current studies in Physics field of ATLAS Georgian group of HEPI TSU:

- Search for Flavor Changing Neutral Current (FCNC) top quark decay (t->qZ);
- Study of the production mechanism of the top quark pair in association with a heavy vector quarkonium state and inclusive quarkonium studies.

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.

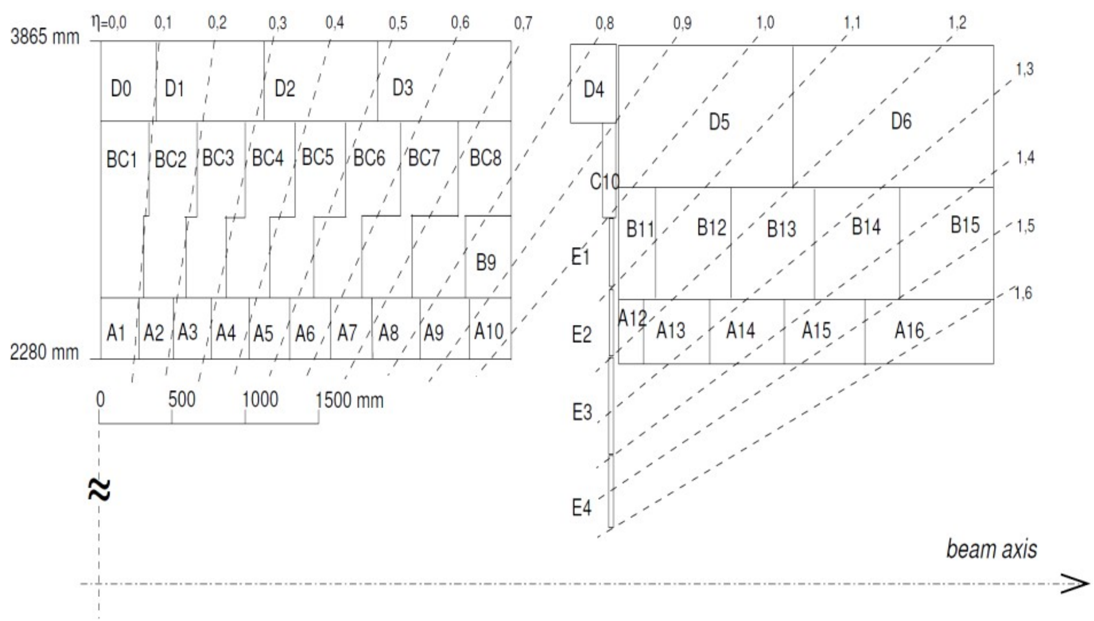


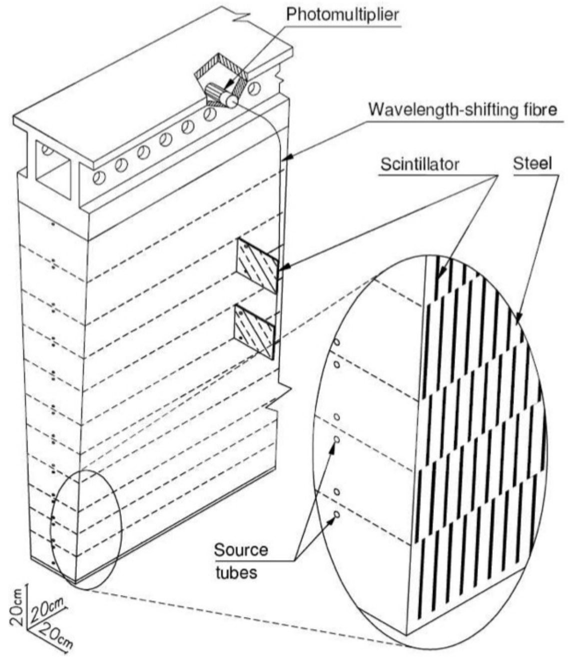


ATLAS Tile Calorimeter

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).

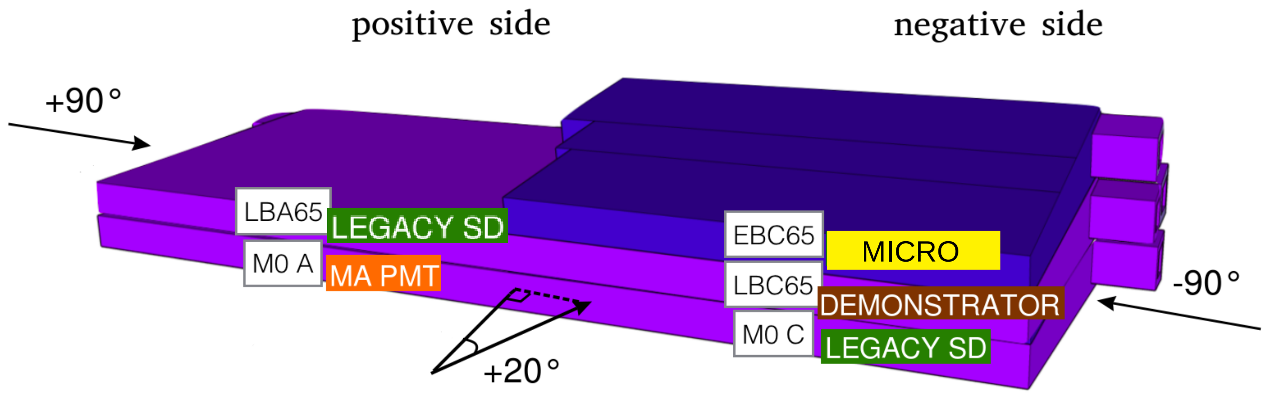




Test Beam setup

Motivation:

- **High Luminosity upgrade of the LHC – increase of instantaneous luminosity by a factor of 5-10.**
- **New electronics - withstand a much higher radiation dose as well as a increased demand for data throughput.**



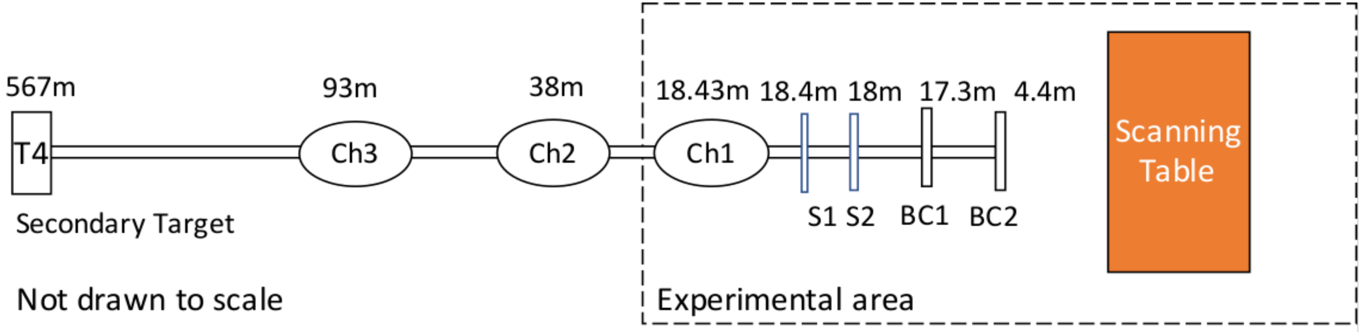
Half-module (LBC65) has been equipped with so-called Hybrid **Demonstrator**. The 3-in-1 front-end option has been mounted in this Demonstrator which provides all the upgrade functionalities but maintaining the analog trigger signals for backward compatibility.

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 results were obtained using Demonstrator data produced by -90° muons in 2018.

Beam line

The beams were produced by extracting 400 GeV protons from the Super Proton Synchro-tron (SPS) machine.



Beam line elements:

- Two wire chambers (BC1/BC2) - The transverse beam profile is monitored by.
- Two scintillators (S1/S2) - an active surface of 5 × 5 cm ^{2}, in coincidence they trigger the data acquisition and provide the trigger timing.
- The Cherenkov counters (Ch1, Ch2 and Ch3) - allow the beam particle identification.

Calibration procedure in Tile Calorimeter

$$E_{channel}\,[\mathrm{Gev}] = A\,[\mathrm{ADC}] \cdot C_{ADC \to pC} \cdot C_{pC\text{->}GeV} \cdot C_{Cs} \cdot C_{Las} \cdot C_{\mu}$$

- A [ADC] - Signal amplitude obtained using the Optimal filter reconstruction method.
- $C_{ADC \to pC}$ - Charge injection system (CIS) : Charges in Pico Coulomb of known values are injected into read out electronics. The CIS constant gives the relation between the value of a charge and the signal amplitude.
- $(1/C_{pC \to GeV})$ - Conversion factor (EM scale calibration constant) between the measured charge in pC and the energy of the incident electron.
- C_{Cs} - Cesium system (Cs) : ^{137}Cs γ – source embedded in a capsule, moves with a constant speed inside the stainless steel tubes through all the calorimeter volume exiting all the scintillating tiles. It is the main tool to equalize the calorimeter cells responses.
- C_{las} - Laser system: Sends laser pulses of known intensities into the photocathodes of PMTs. It's aim is to monitor the response of PMTs and provide additional calibration factor.
- C_{μ} – Correction of the EM scale, due to the different sizes of the cells and the position of the CS stainless steel tubes.

A similar procedure has been used to reconstruct the energy in the simulation.

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.

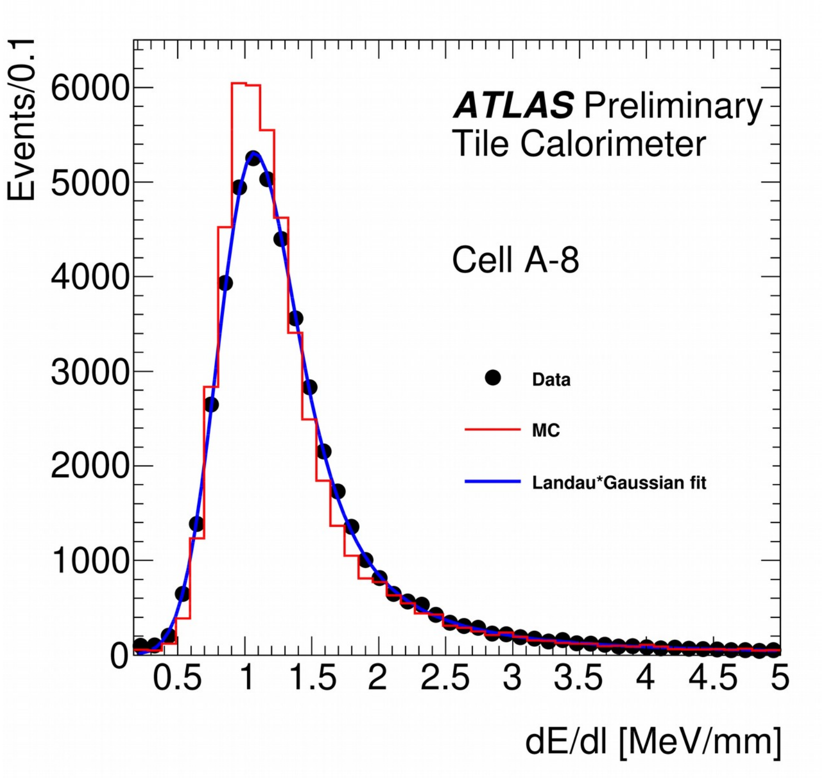
The energy deposited in the calorimeter by high energy muons is much smaller by the one deposited by electrons and pions with the same energy.

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 review and improve the detector calibration procedure:

- Measurement of the response of cells as a function of radial depth allows setting the EM scale obtained with electron beams in the first radial compartment in the other two compartments (the factor C_μ).

Identification and energy reconstruction of muons



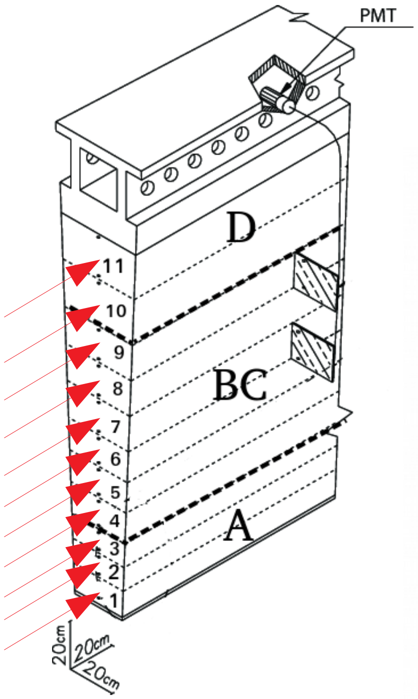
The TileCal response to high energy muons follows a Landau type distribution with characteristically long tails at high energies.

The energy is obtained as the sum of the reconstructed energy in the each PMT of a cell.

As a cell response **the mean value of the measured muon energy loss spectrum truncated at 95% of the total number of entries is adopted.**

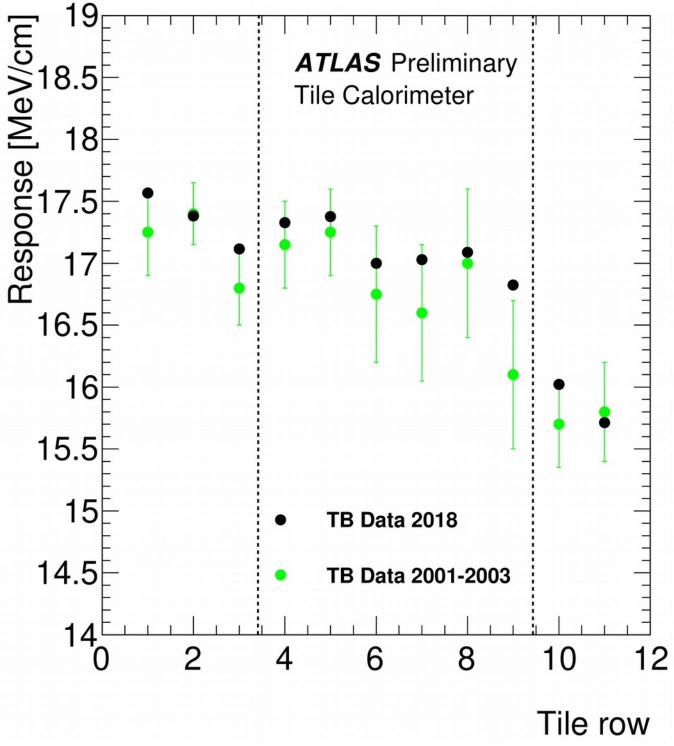
Used cuts to purify muon beam:

- BeamChamber cuts: selecting correct region for response.
- Total E cut (< ~ 16 GeV): rejecting other particles in the beam.
- At least in one PMT high signal (> ~ 0.06 GeV): to reject false trigger muons.



Tile

Muon results: E vs Tile row



The signal per unit path length produced by -90° muons incident on individual tile-row's center.

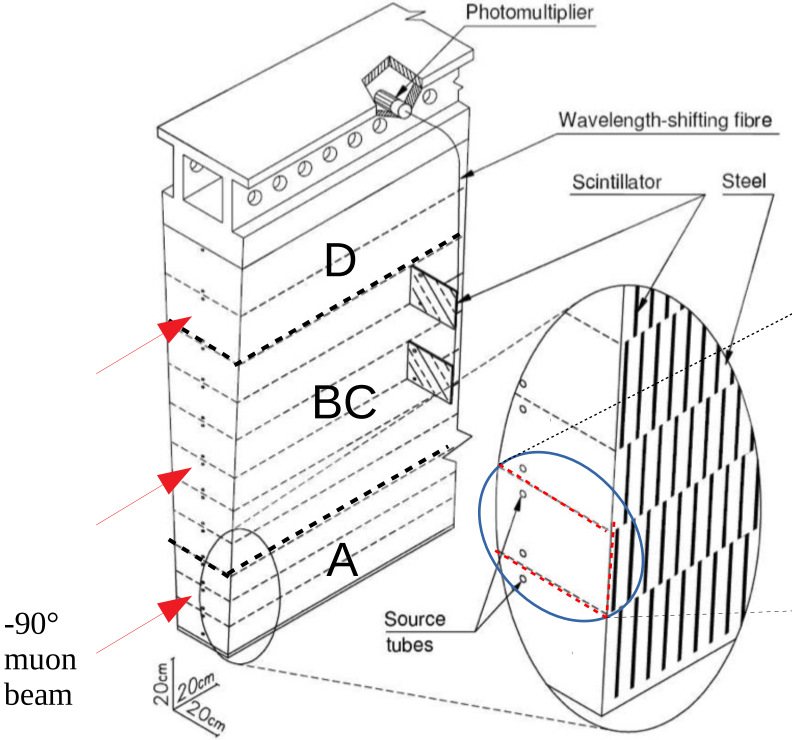
After Cs equalization is performed, the correction for the cell dimension in the reconstruction of the energy (C_μ) is obtained using the response of 300 GeV muons hitting at -90° in the middle of the cells tile rows.

The Determination of C_μ:

Layer	Corr. Factor (TB 2001-2003)	Corr. Factor (TB 2018)
A	1.000	1.000
BC	1.025 ± 0.002	1.014 ± 0.008
D	1.088 ± 0.005	1.094 ± 0.010

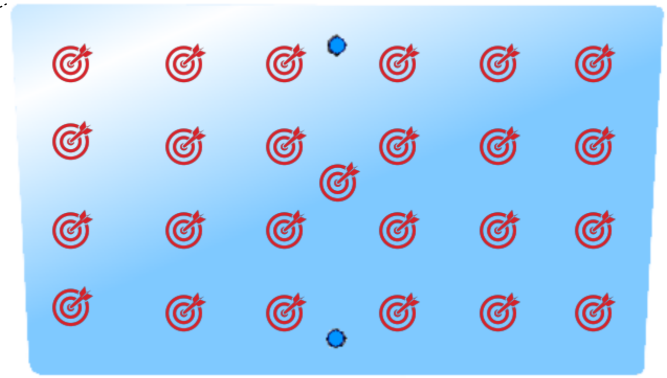
The weights in the second and third radial compartments are evaluated as the inverse ratio of the mean muon responses in the respective tile-rows to the mean responses of the three A-layer tile-rows.

Justification of the method



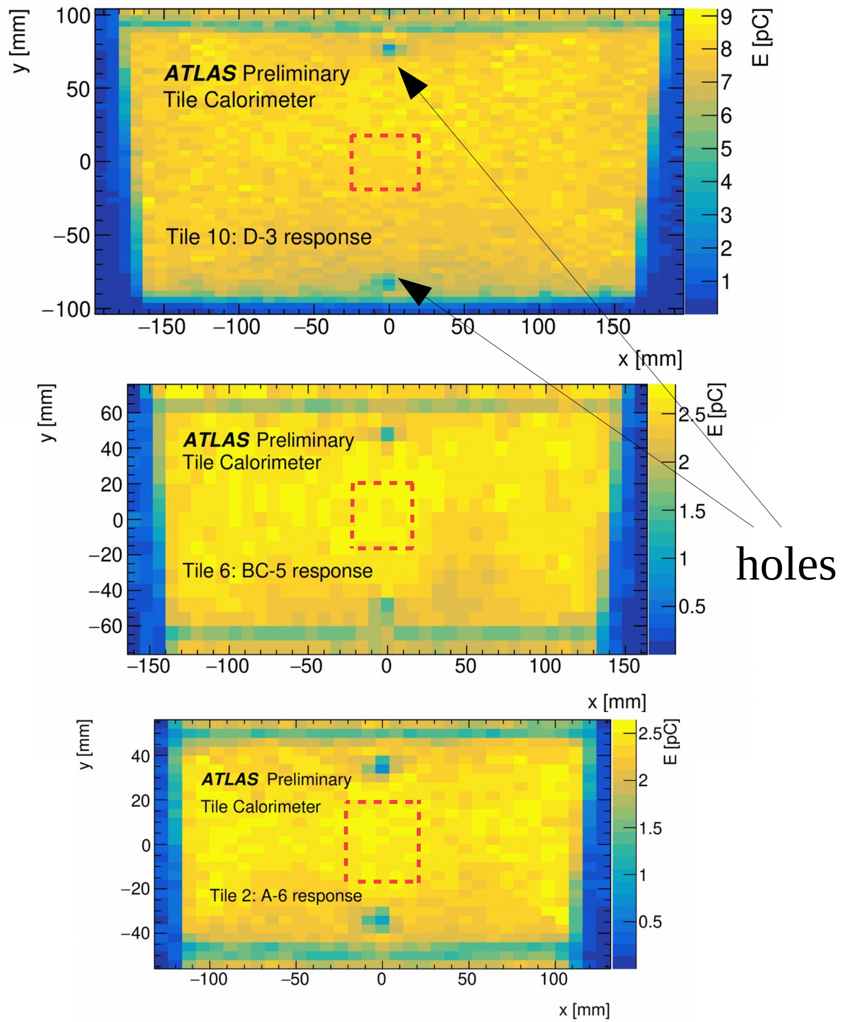
The ratio R of the central region average response over the full region average response of the tile is tile size independent. In the past this ratio was estimated using a Sr source scanning.

In this analysis the scanning was performed using -90° muons.



- At test beam surface of three type of tiles were irradiated by muon beam at different points: Tile 2 (165 GeV), Tile 6 (300 GeV), Tile 10 (300 GeV).
- Impact point was calculated using the two Beam Chambers of the beam line.

Muon results: Tile response



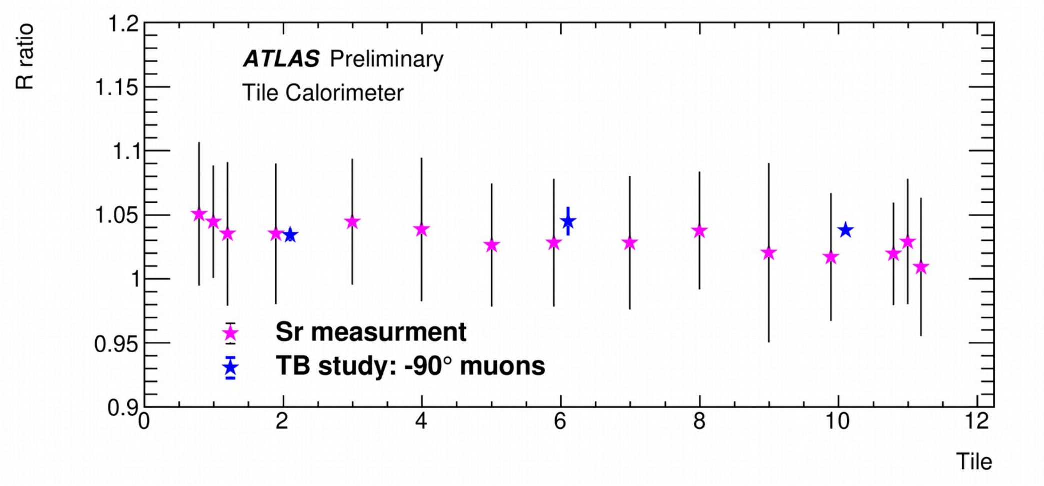
R - ratio of Central region (4 cm x 4 cm) average response to whole tile surface average response:

$$R = \langle E_C \rangle / \langle E_W \rangle$$

Tile row	R ± RMS
T2	1.034 ± 0.005
T6	1.045 ± 0.011
T10	1.038 ± 0.002

Central region average response is ~ 3.9% bigger than the total tile surface average response for tile rows studied. It is tile size independent within 5‰.

Comparison with previous results obtained using a Sr source



R ratio - the ratio of the central region average response over the full region average response of the tile is tile size independent.

$\langle R_{Sr} \rangle = 1.035$ with $RMS_{Sr} = 1.4\%$ using Sr source,
$\langle R_{Sr} \rangle$ - average of 30 tile R value measurments,
RMS_{Sr} - spread of measurments.

$\langle R_{\mu} \rangle = 1.039$ with $RMS_{\mu} = 0.5\%$ using -90° muon beam.
$\langle R_{\mu} \rangle$ - average of 3 tile R value measurments,
RMS_{μ} - spread on measurments.

- Violet stars: Sr measurements of individual tiles.
- Blue stars: is new measurements at the test beam, average behavior of many tiles in a module.
- Error bars: RMS values.

Summary

- **Motivation of the new front-end electronics:** High Luminosity 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.
- Dependence of the cell response on the impact point of the beam was studied using muon beam hitting the calorimeter at 90°. The results are in agreement with the calibration settings obtained using the old electronics.
- The results confirm good performance of the new electronics, which was inserted in one of the modules of ATLAS Tilecal calorimeter in Spring, 2019.

Thank you!