Response of the ATLAS Tile Calorimeter at Test Beams using Phase II upgrade readout

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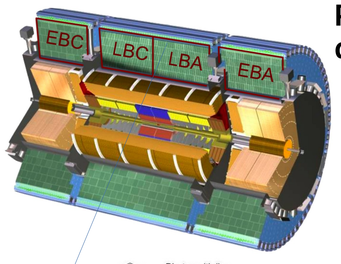
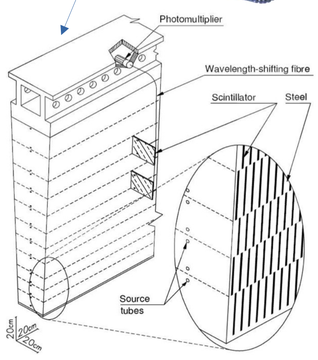
The 41st International Symposium on Physics in Collision
5-9 September, 2022 | Tbilisi, Georgia

Motivation:

- High Luminosity upgrade of the LHC – increase of instantaneous luminosity by a factor of 5-10.
- Test out new electronics, which should withstand a much higher radiation dose as well as a increased demand for data throughput.

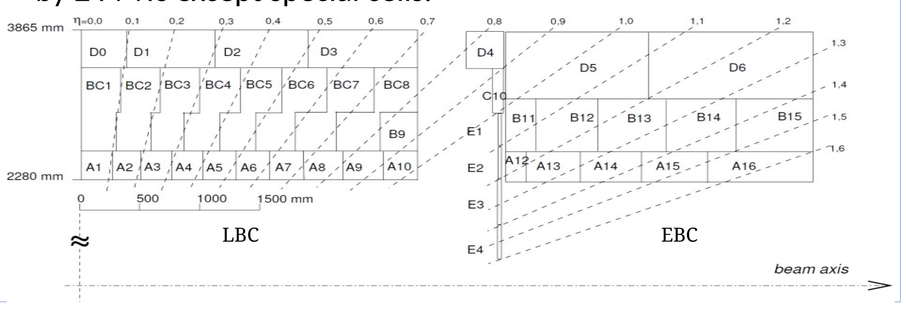
ATLAS Tile Calorimeter





Principle of Tile Calorimeter [1] – hadronic calorimeter of the ATLAS detector

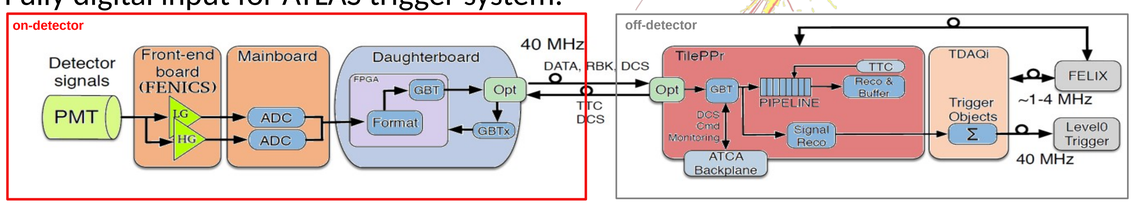
- The defining role of hadron calorimetry is to measure the energies of jets and missing transverse momentum in the event.
- Measure light produced by charged particles in plastic scintillator.
- Scint. light from tiles collected by WLS fibers and delivered to PMTs.
- Tile readout is grouped into projective geometry cells. Each cell readout
  by 2 PMTs except special cells.



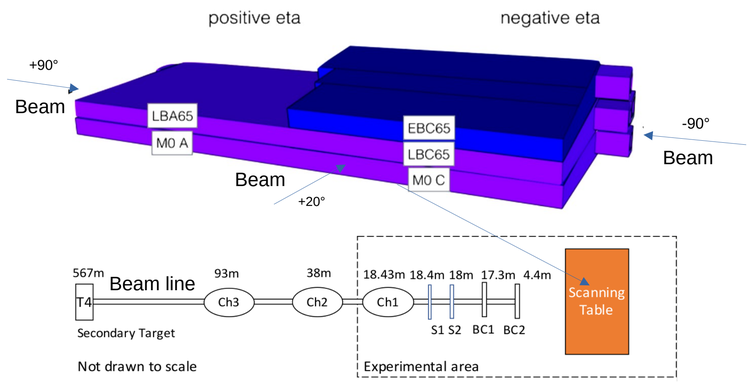
TileCal Test Beams: testing Phase II upgrade readout

New TileCal electronics [2] should withstand:
- Higher ambient radiation,
- The high luminosity environment (~200 collisions per bunch crossing).

Will provide:
- Low-latency,
- High-frequency (40 MHz),
- Fully digital input for ATLAS trigger system.



TileCal modules equipped with Phase-II upgrade electronics together with modules equipped with the legacy system were tested in several test beam campaigns at SPS during 2015-2018 and 2021-2022,using:
- Muon beams
- Electron beams
- Hadron beams



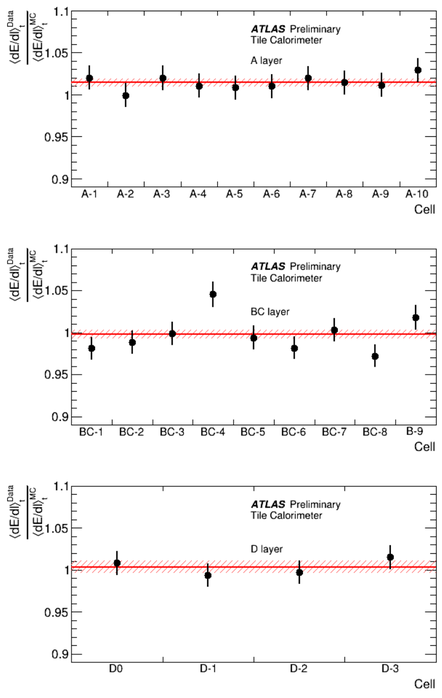
Muon beams

- 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.**
- The response of the detector in each layer and in each cell 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 160GeV muons at an incident angle of -90° [3].
- The ratio of experimental and simulated dE/dl values was defined for each calorimeter cell:

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

The red horizontal lines on the plot represent the mean values of dE/dl for each layer:

Layer	Mean	Uncertainty
A	1.014	0.005
BC	0.998	0.005
D	1.004	0.007

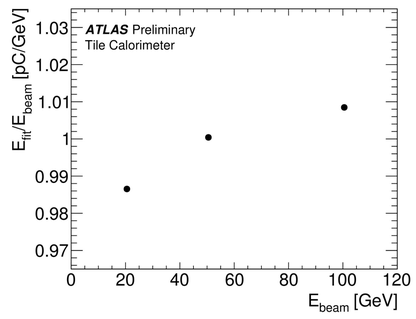


- The data show a layer uniformity within 1%.
- An offset of max 1.4% is observed for Data/MC.

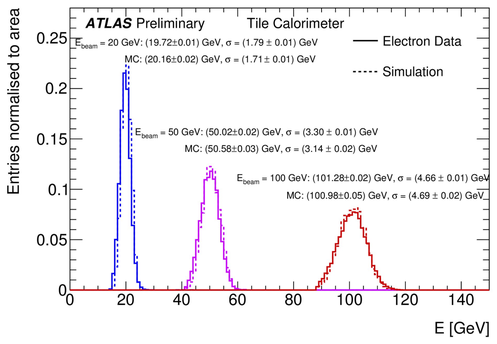
Electron beams

Since electron's response is well understood, electron beams provide perfect tool to **verify the linearity of the response vs. energy and to test the detector uniformity and its energy resolution [2,4].**

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



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



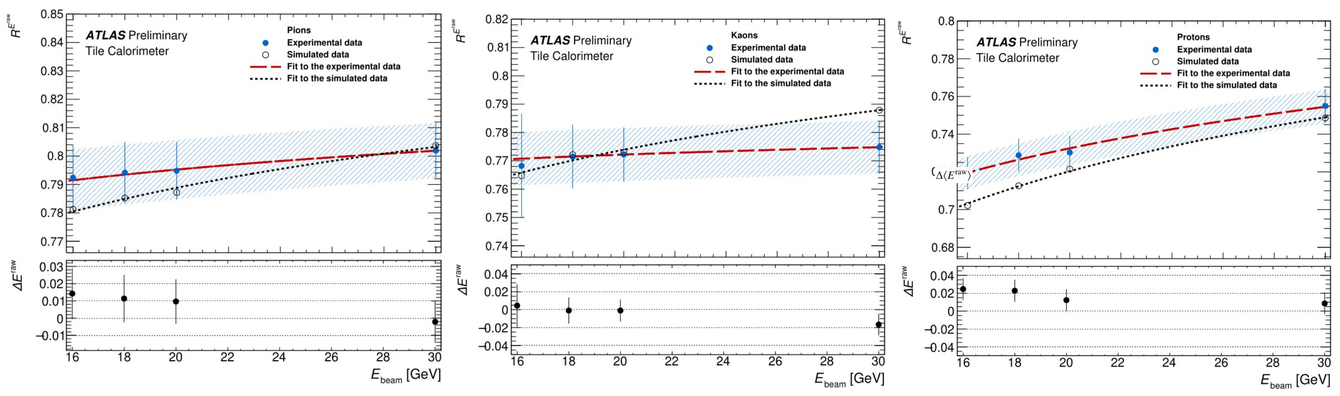
Hadron beams

- The role of the hadron calorimetry is to measure the energy and the direction of isolated hadrons and jets.
- To achieve good performance, the study of the sub-detector response to isolated hadrons is important.
- The characterization of the response of the ATLAS calorimeter to hadrons[5] is **important to probe and validate and to improve the modeling of the jets energy characterization of the ATLAS simulation using the GEANT4 toolkit.**

The energy response ratio:

$$R^{\langle E^{\mathrm{raw}} \rangle} = \frac{\langle E^{raw} \rangle}{E_{\mathrm{beam}}}$$

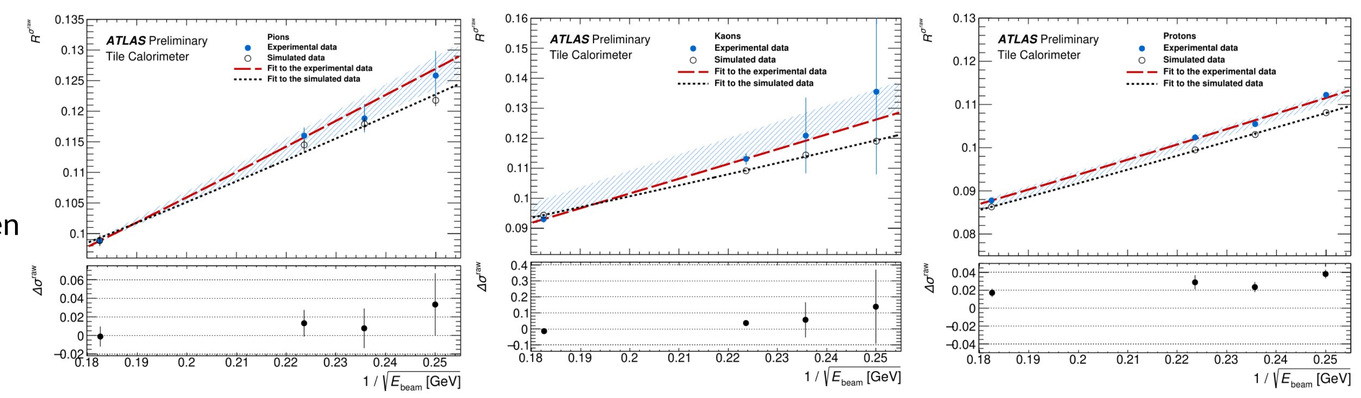
Max. difference between data and MC:
- Pions – 1.4%
- Kaons – 1.7%
- Protons – 2.5%



The fractional resolution:

$$R^{\sigma^{\mathrm{raw}}} = \frac{\sigma^{\mathrm{raw}}}{E_{\mathrm{beam}}}$$

Max. difference between data and MC:
- Pions – 3.3%
- Kaons – 13.8%
- Protons – 3.8%



Summary

- The ATLAS Phase-II Upgrade of the LHC (HL-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:
  - 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.
  - Further goals: perform standard calorimeter measurements mentioned above, at the future test beams with the final Phase-II read-out electronics.
- All TileCal on- and off-detector electronics will be replaced in 2026-2028 during ATLAS Phase-II upgrade for the HL-LHC:
  - R&D is done, test beams demonstrate good performance.

References

[1] CERN-LHCC-96-42 (1996)
[2] CERN-LHCC-2017-019 ; ATLAS-TDR-028 (2017)
[3] ATL-TILECAL-SLIDE-2022-241
[4] JINST 15 C09003 (2020)
[5] The Eur. Phys. J. C 81, 549 (2021)

The author was funded by the grant #04/48 through Shota Rustaveli National Science Foundation, and The Volkswagen Foundation Ref.: 93 562