Studies on muon simulation with ATLAS TileCal calorimeter

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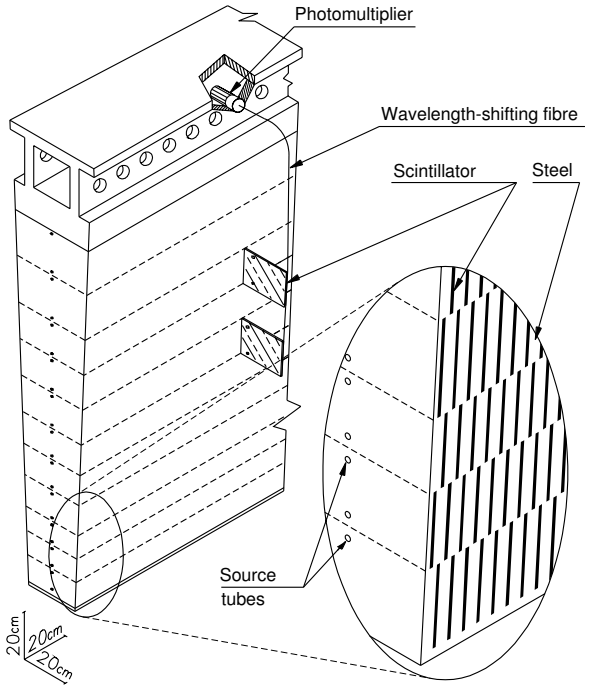
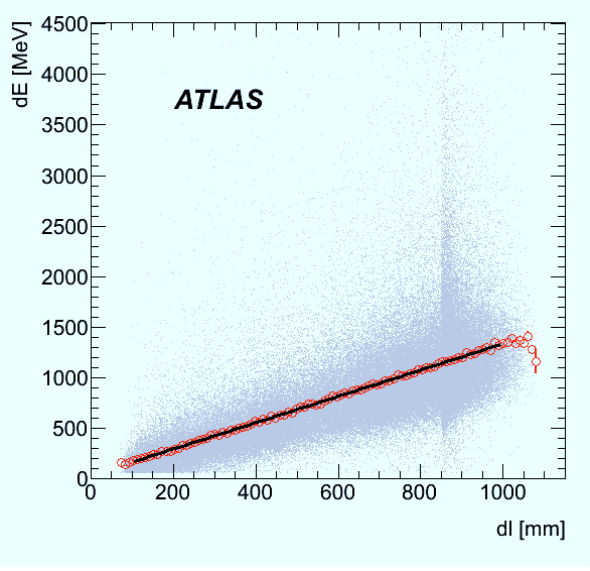
Outline

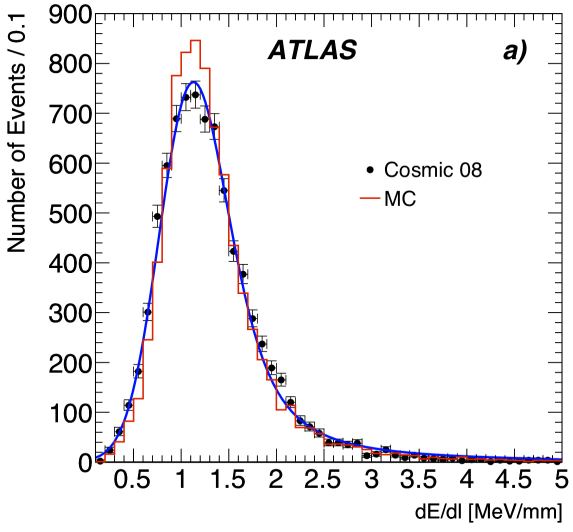
Cosmic Analysis in TileCal, ATLAS



- Hardronic Calorimiter of ATLAS: TileCalorimiter is a sampling plastic-scintillator/iron detector, with 64 Phi-module, each with 81 Cells
- Cosmic ray data is used to validate the inter-calibration status, and also provide a tool to check the EM scale set from the TestBeam using electron.
- In Cosmic analysis, response of TileCal is characterized by dE/dl: the ratio between the energy deposited in a calorimeter cell (dE) and the length of the path of the track in the cell(dl).

Cosmic Analysis in TileCal, ATLAS





- The ATLAS Monte Carlo (MC) is based on the Geant4 toolkit, Cosmic Muon spectrum well simulated.
- Muon P range [10GeV, 30GeV], MIP signal. dE/dl shape follows Landau$\oplus$Gaussian distribution, good agreement between Data/MC
- The estimator of the muon response is defined as the mean of the dE/dl distributions, truncated to the lower region containing 99% of events,to reduce the effect from rare high energy-loss processes.

Check for the EM Scale
Uncertainty on MC

$$E_{rec}^{\mu data} = E_{pC}^{\mu data} \times \left(\frac{E_{beam}^{eTB}}{E_{pC}^{eTB}}\right) \quad (1)$$

$$E_{rec}^{\mu MC} = E_{vis}^{\mu MC} \times \left(\frac{E^{e}}{E_{vis}^{eMC}}\right) \times R_{instr} \quad (2)$$

- For Data, EM scale set by test beam with Electron(20GeV,100GeV,180GeV)
- For MC, EM scale set by similar process by making ratio between particle energy and visible energy in scintilator.
- EM process "well known", expected muon response(MIP signal) ratio $\frac{E^{\mu data}}{E^{\mu MC}}$ to be 1.
- R_{instr} take into account implementation of Birk's law,light attenuation (uncertainty estimated to be $< 0.6\%$)
- Uncertainty from MC: uncertainty on $\frac{E_{vis}^{\mu MC}}{E_{vis}^{eMC}}$ ratio

Check for the EM Scale
Uncertainty on MC

Simulation for MC Uncertainty study

- Simulation using standard ATLAS Geometry, geant4.9.3.patch01
- Muon/Electron shoot right in front of TileCal, also checked with Pion

MC Uncertainy source

- Change physics list to investigate different treatment toward multiple scattering(Trade off between high presicion and CPU time)
- Change geant4 range cut (production cut relating to energetic δ-rays and bremsstrahlung)
- Other systematic soruce estimated to be no larger than 0.4% (gamma-nuclear and lepto-nuclear

Method

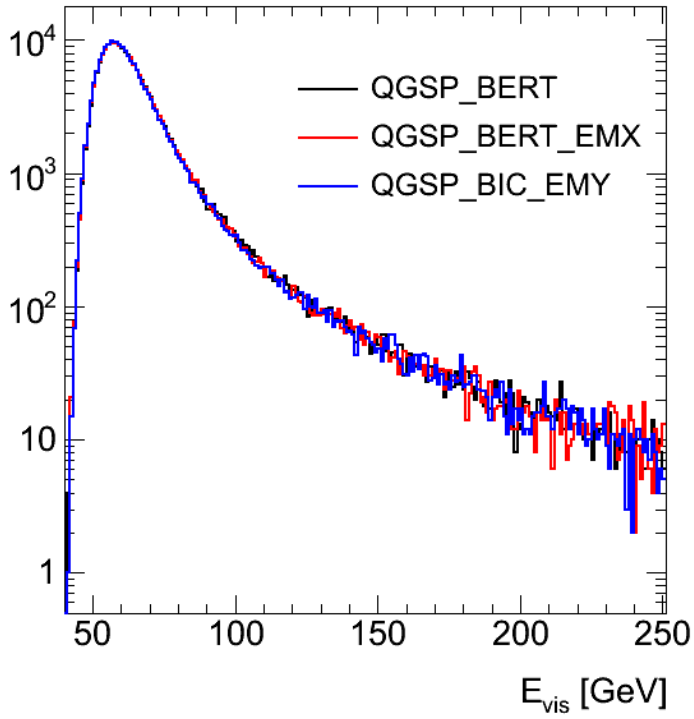
Physics List

- Based on ATLAS avilable option, focus on EM process
- QGSP_BERT :
  Default in ATLAS, standard EM processes
- QGSP_BERT_EMX:
  StandardEM, Apply production thresholds on secondary particles produced by Geant4 gamma processes, better speed performance, strong dependence of the visible energy on the cut.
- QGSP_BIC_EMY:
  Standard EM , Precise description of low-energy effects(UseDistanceToBoundary, closest to the data.)

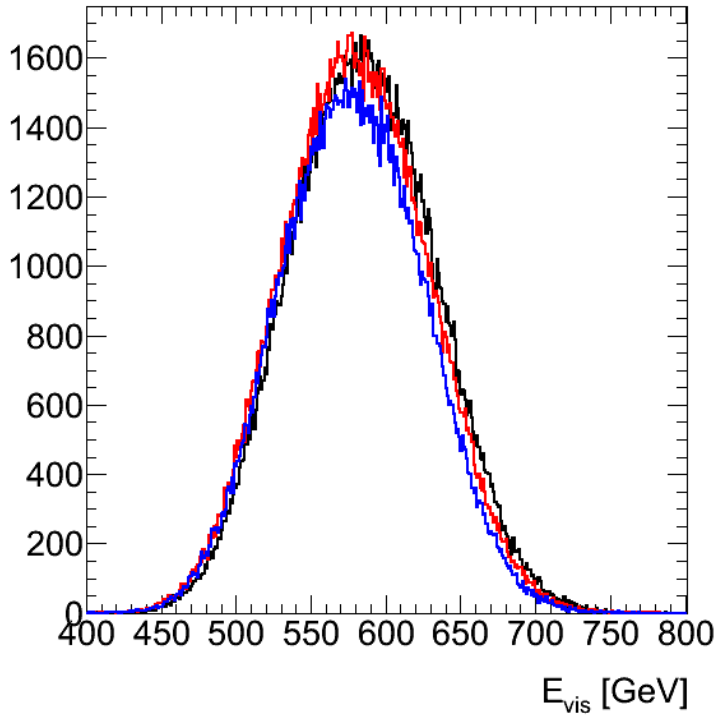
MC Points

- Electron: 20GeV, 30GeV,...100GeV,... 180GeV (20°), "Test Beam Setup"
- Muon: 20GeV (20°, 30°, 40°,.....),"Cosmic in the analysis"

Systematic from Multiple Scattering



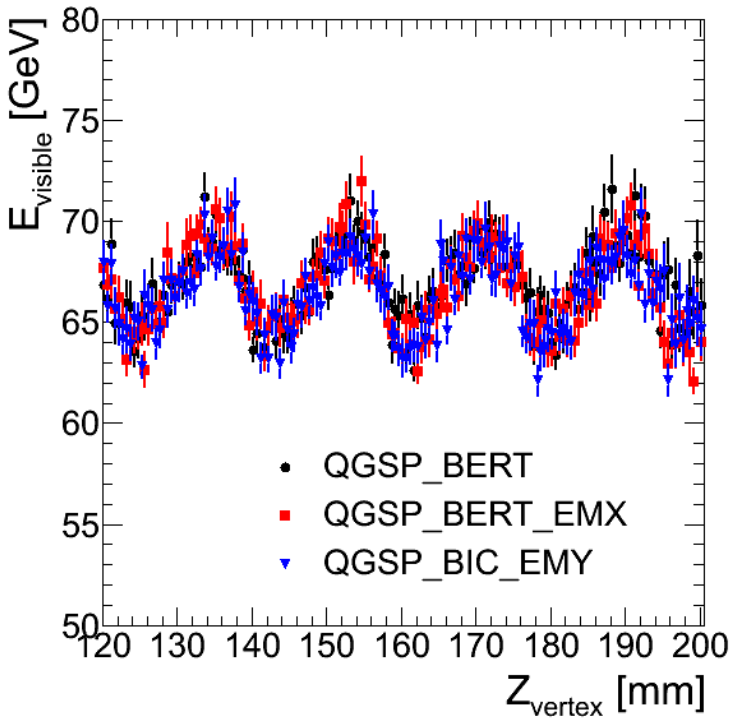
(a) Muon,20GeV, 20°



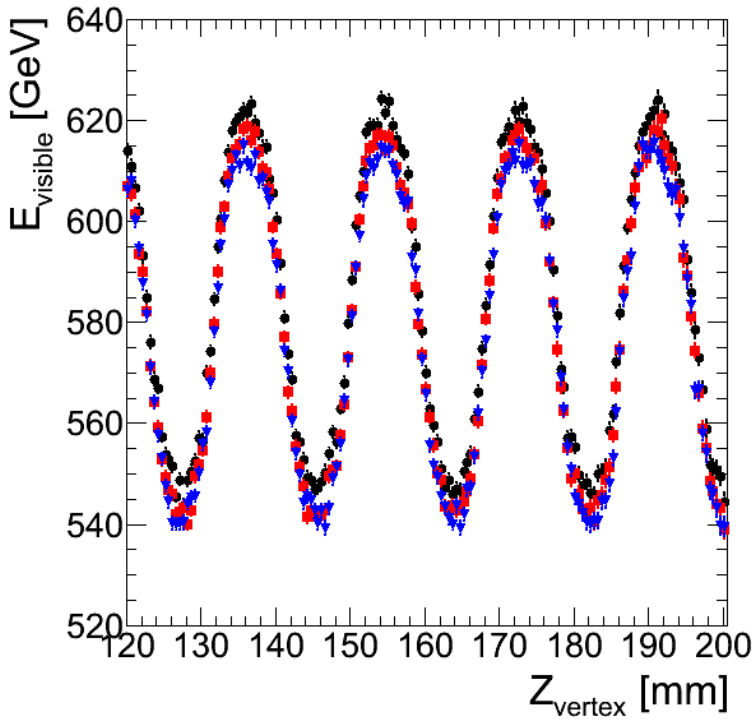
(b) Electron,20GeV, 20°

- Different physics list have the same shape on visible energy
- Slightly shift in Electron E_{vis} distribution

TotalE vs. Z



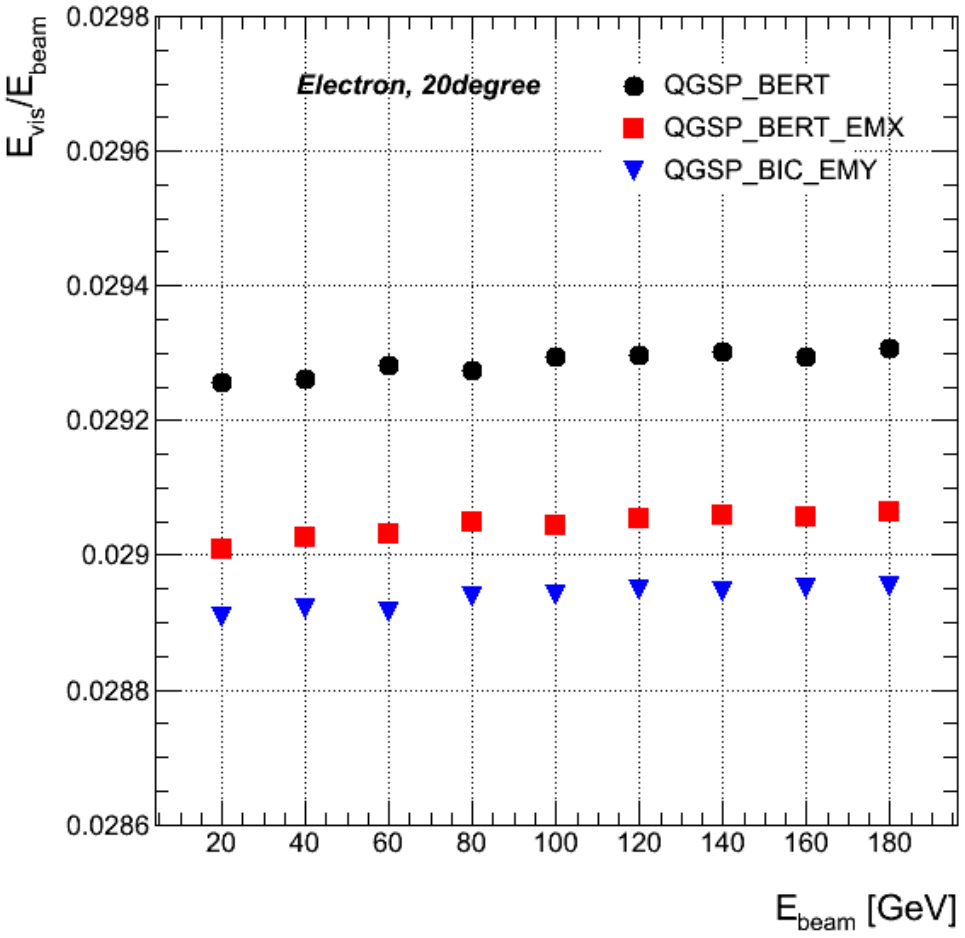
(c) Muon,20GeV, 20°



(d) Electron,20GeV, 20°

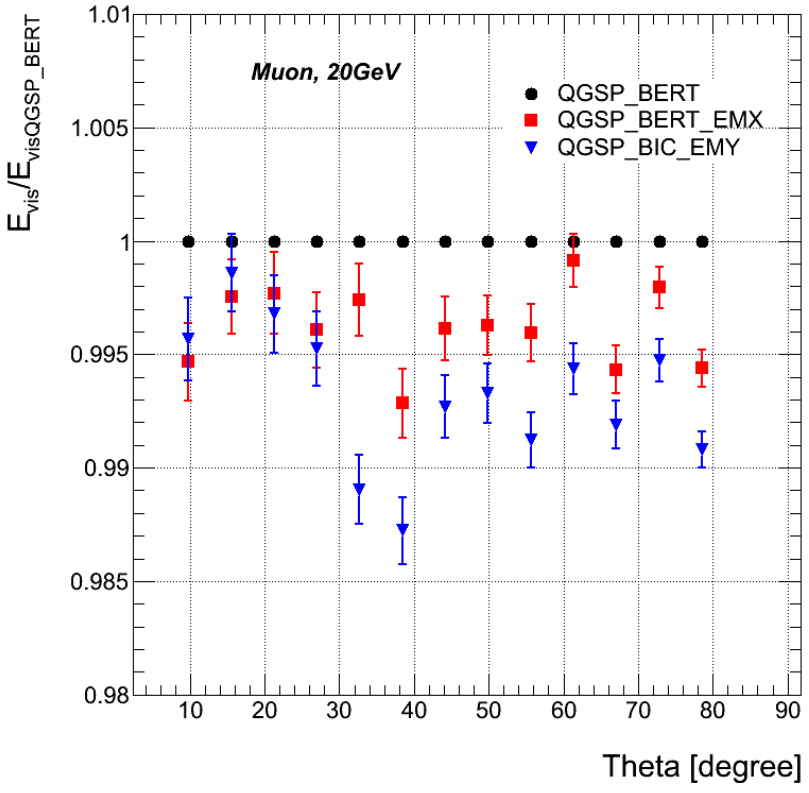
- Occilation effect due to periodic structure of Tiles, confirm with TB results
- For Electron response, systematic shift between different physics lists, no position dependence

Electron Response



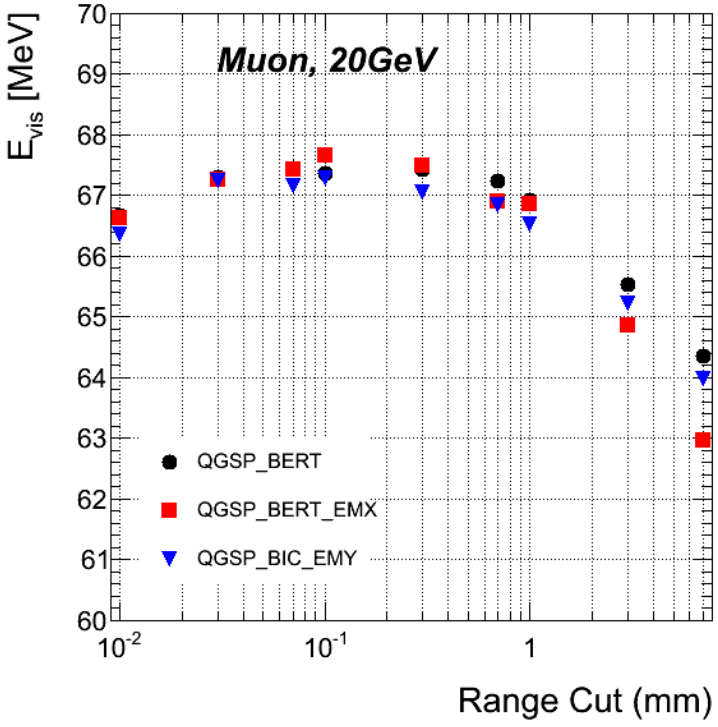
- Same behavior: QGSP_BERT > QGSP_BERT_EMX > QGSP_BIC_EMY
- Normalized Response flat within TestBeam ranges
- Maximum Difference: 1.1%

Muon Response

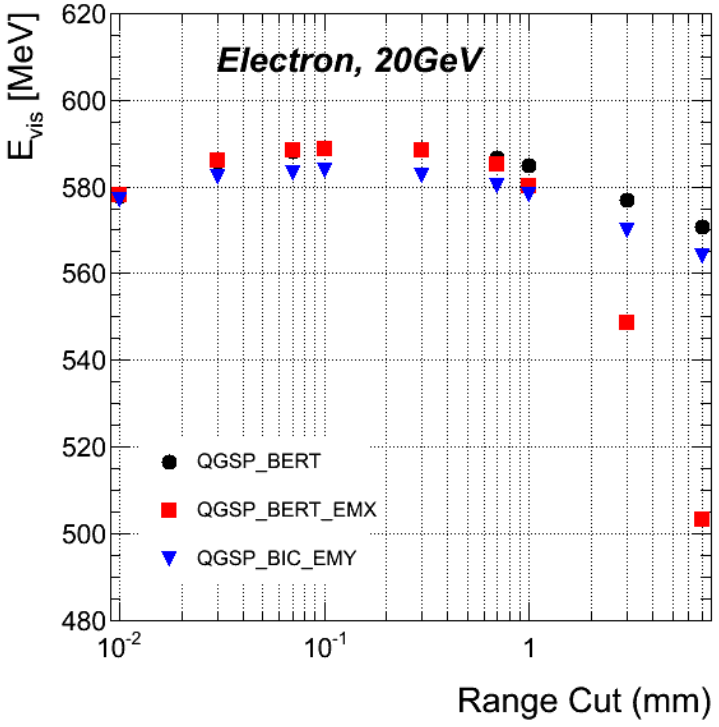


- Theta: Incident angle wrt. normal direction of cell facing beampipe
- Normalized response have no strong
- Change in the same direction wrt. Electron
- Averaged maximum difference: 0.6%
- uncertainty on $\frac{\mu}{e}$ ratio: 1.1%-0.6% = 0.5%

Systematic from Geant4 Range Cut



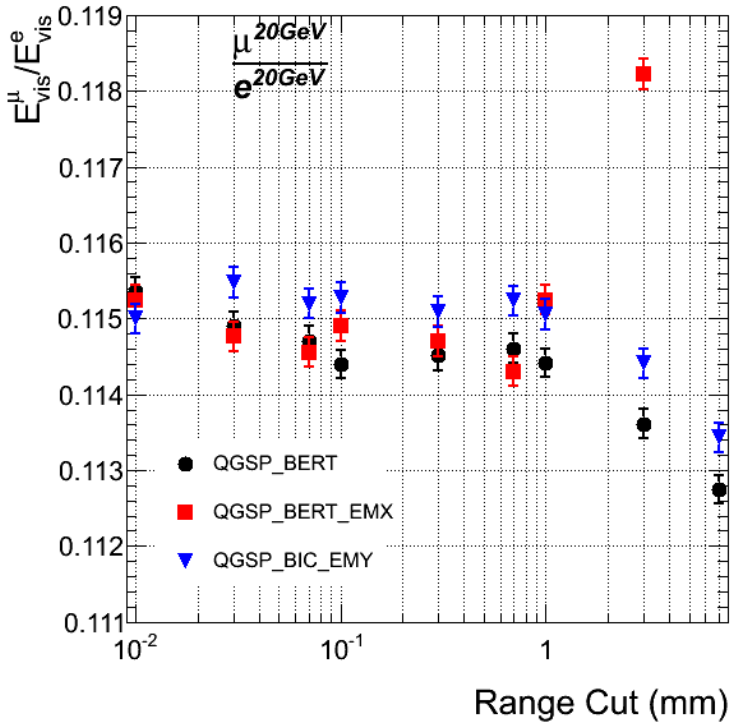
(a) 20GeV Muon Response



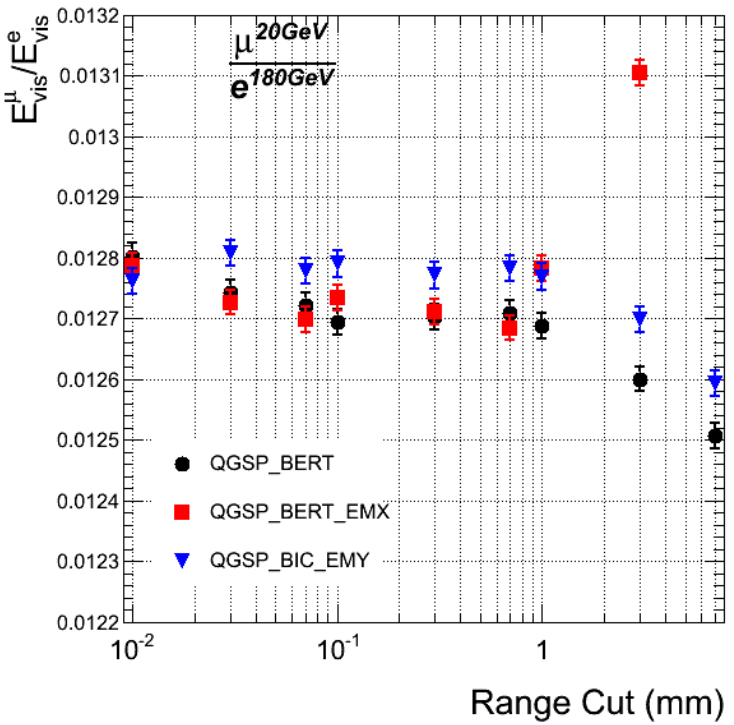
(b) 20GeV Muon Response

- ATLAS default: 1mm, Different physics list follow the same trend
- Range Cut larger than 3mm: comparible with typical size of tiles, not physical result
- For Electron, QGSP_BERT_EMX have strong dependency on range cut

Systematic from Geant4 Range Cut



(a) 20GeV/20GeV Response Ratio



(b) 20GeV/180GeV Response Ratio

- Compare within same physics list
- exclude 3mm, 7mm point for geometrical reason
- For different physics list, maximum difference in $\frac{\mu}{e}$ ratio is similar : 1%

Summary

- Cosmic muons have been used to check the calibration and EM scale of Tile Calorimeter in ATLAS
- $\frac{E_{MIP}^{\mu Data}}{E_{MIP}^{\mu MC}}$ expected to be 1
- Uncertainty on $\frac{E_{MIP}^{\mu Data}}{E_{MIP}^{\mu MC}}$ from MC(Geant4) depends on EM scale setting procedure:
  - Determined by the uncertainty of $\frac{E_{vis}^{\mu MC}}{E_{vis}^{eMC}}$ ratio
  - Considered to be comes from multiple scattering, range cut, and gamma-, lepton-nuclear process
  - Estimated to be $0.5\% \oplus 1\% \oplus 0.4\% = 1.2\%$