ALICE EMCal Reconstructable Energy Non-Linearity From Test Beam Monte Carlo

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1 Introduction

Calorimeters play many important roles in modern high energy physics detectors, such as event selection, triggering, and precision energy measurements. EMCal, in the case of the ALICE experiment provides triggering on high energy jets, improves jet quenching study measurement bias and jet energy resolution, and improves electron and photon measurements [3]. With the EMCal detector in the ALICE experiment taking on so many important roles, it is important to fully understand, characterize and model its interactions with particles. In 2010 SPS and PS electron test beam measurements were performed on an EMCal mini-module [2]. Alongside this, the test beam setup and geometry was recreated in Geant4 by Nico [1]. Figure 1 shows the reconstructable energy linearity for the SPS test beam data and that obtained from the test beam monte carlo, indicating the amount of energy deposit as hits in the EMCal module.

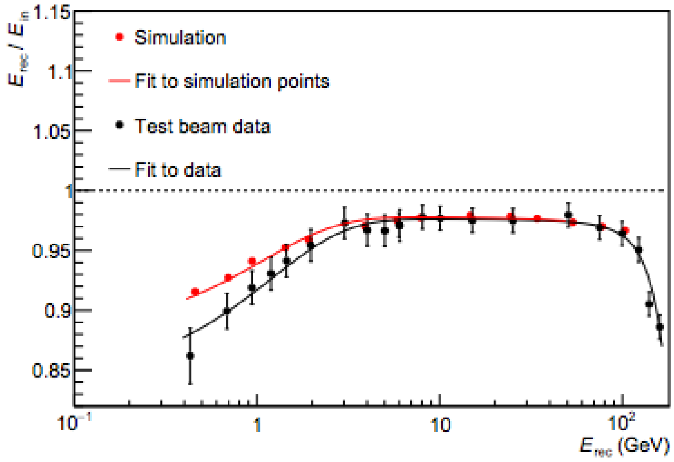

Figure 1: The ratio E_{rec}/E_{in} (non-linearity correction) as a function of E_{rec} calculated from test beam data (weighted average, black points) and simulation (red points) after adjusting the PS and SPS data points to the simulated ones [2].

It can be seen that for energies above $\sim$ 100 GeV there is a significant drop in the reconstructable energy measured in the EMCal module from the test beam, this is due to EM showers not being fully contained longitudinally in the EMCal module, with some proportion of the particles from the shower exiting out its back. When compared with the same results for Monte Carlo data, there seems to be the start of a discrepancy in reconstructable energy at 100 GeV, with the MC overestimating the amount of reconstructable energy deposited in the module. It is thought that the cause of this overestimation is either due to problems in the simulation causing it to predict the loss of a smaller fraction of EM showers out of the back face of the EMCal module, or insufficient modelling of interactions and cross sections by the Monte Carlo generator Geant4. This report aims to investigate these two cases, firstly by comparing longitudinal and radial shower shapes from the Monte Carlo with baseline results from Wigmans [4], and secondly by updating to the more modern version of Geant4 (that used currently in AliRoot) to see if dataset improvements improve MC agreement.

2 Investigations

The test beam Geant 4 Monte Carlo was obtained from Nico, as produced for his PhD thesis [1], was revived. The application was originally built against the Geant 4 version present at the time of its creation (Geant4.9.6.p04), and root5 version corresponding to the same time period (version 5.34/32). In order to investigate the effects of improved MC modelling in newer versions of Geant 4, the simulation was then adapted to be built against the version existent in AliRoot (Geant4.10.01.p03), root6 (version 6.10/04) was used to overcome C++11 compilation errors. Full instructions on how to replicate each build are available in Appendix A.

Within the MC simulation, a beam of electrons was fired towards the front plate of the centre of an EMCal module, traversing 5m of air prior, as to replicate the Test Beam setup. The beam was orientated perpendicularly to the front plate to avoid lateral shower deviation. Module geometries were double checked with the ALICE EMCal TDR [3]. Information required for the following investigations, such as particle ID, track ID, energy deposit, 3d position and 3d momentum were output for each step and each hit (energy deposit in the scintillator medium) in each event simulation. The number of events simulated at each energy was chosen in order to produce enough hits to achieve good statistics (higher energies need less events). Encompassing a whole shower longitudinally was necessary, leading to the arbitrarily large longitudinal module extension from 20.1 X_0 [3] to $60X_0$.

Longitudinal shower profiles were investigated by plotting the hit energy as a percentage of the incoming electron energy vs module depth in X_0. Wigmans [4] produces this same plot for EM showers in copper at energies of 1, 10, 100 GeV and 1 TeV, and gives a shower shape at 10 GeV in lead giving a basis for comparison.

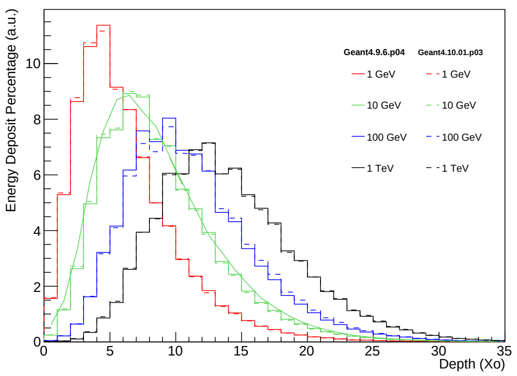

Figure **2.a**

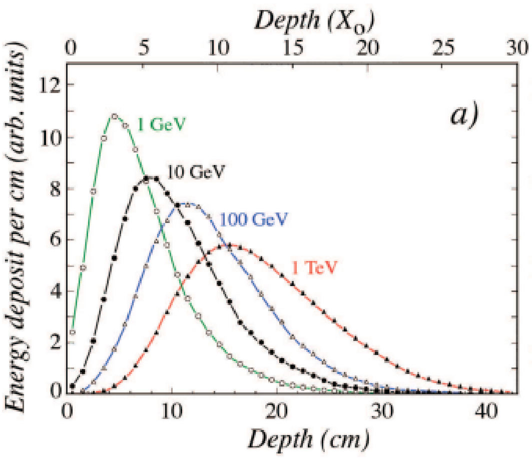

Figure **2.b**

Figure 2: The energy deposited as a function of depth for 1, 10, 100 and 100 GeV electron showers. Curves are nomalised to the same value for comparison. 2.a: Showers developing in the EMCal module of length $60X_0$, green curve is 10 GeV baseline from Wigmans, 2.b: Showers developing in a block of copper.

As shown in figure 2.a we see the longitudinal shower shapes produced in an arbitrarily long module. With increasing incoming electron energy we see a broadening of the energy distribution, with a peak shift to larger X_0. We also see very similar distributions for each Geant version. This distribution broadening and peak shift is the result of a more energetic shower needing more material to be enclosed longitudinally. When comparing to the same profiles for copper (figure 2.b), we see the same broadening effect, however peak positions for each energy exist at smaller values of X_0.

Wigmans [4] gives a longitudinal shower profile for 10 GeV electrons in lead. When superimposing this with what is obtained for that of 10 GeV in the EMCal module (figure 2.a (green)) we see good agreement. Agreement here gives us a basis for explanation of the peak shifts we see when comparing EMCal and copper shower profiles; Wigmans states that these profiles are not independent of X_0, and that it takes more X_0 of lead to enclose and EM shower than of copper. These shower shape shifts are understood by the particle multiplication ranges in different materials; those with higher Z continue with these processes at lower energies [4].

Lateral development of EM showers in the module provided as another cross check. Radial calculations were made about the axis in which electrons were incident on the module. The energy deposit of hits at different X_0 values is plotted against their radial position in Molière radii [3] (figure 3.a), while Wigmans creates the same plot but for copper (figure 3.b). Energy deposits within the interval of $\pm$ 0.5 X_0 were selected to contribute to each distribution. Where values of 2, 6 and 15 X_0 are chosen to represent early, peak and tail positions of the EM shower.

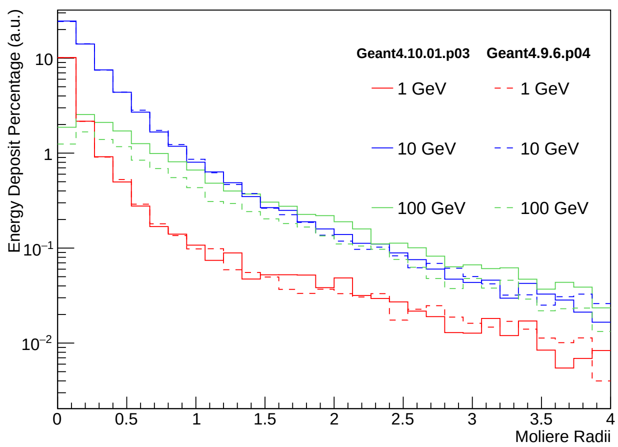

Figure **3.a**

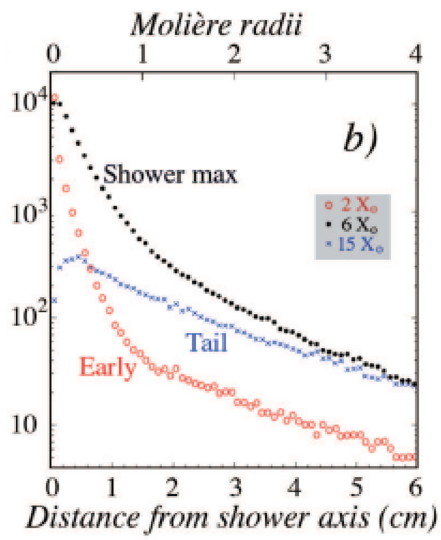

Figure **3.b**

Figure 3: The radial distributions of the energy deposited by 10 GeV electron showers in the EMCal module (3.a) and in a block of copper (3.b), at various depths.

In a side by side comparison we see very similar distributions in the EMCal geometry as we do in Copper. This is to be expected as material differences in lateral shower containment are much smaller. There is also no energy dependence; a 1 TeV EM shower and a 1 GeV EM shower will cover the same lateral area at peak [4]. Taking this into account, when overlaying lateral distributions for the EMCal module and for copper we only see slight disagreement in the distributions for 6 X_0, this is to be expected from the peak shifts seen in figure 4. When varying the selection limits for different X_0 depths we are also most sensitive in this region due to varying near the shower maximum.

Finally Wigmans provides a plot showing the distribution of energy deposit percentage in the first 5 X_0 of EM showers produced by 10 GeV electrons and gammas in lead. Here we reproduce the same plot using the EMCal test beam MC and overlay the results.

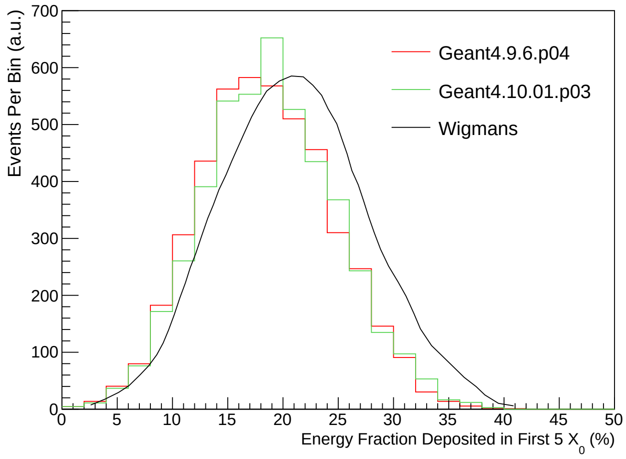

Figure 4: Distribution of the energy fraction deposited in the first 5 radiation lengths by 10 GeV electrons and s showering in the EMCal module and in lead.

Above we see good shape agreement with the distributions obtained from Wigmans. We see that showers produced by electrons, on average, deposit $\sim 20\%$ of their energy in the first 5 X_0 of longitudinal module material. There exists a small shift between that obtained from the EMCal module Monte Carlo and that given by wigmans. This is explained by the presence of scintillator and other foreign layers in the module; having a lower EM shower interaction cross section these would reduce the percentage energy deposit in a specified longitudinal distance.

Energy deposit as hits in the in the MC simulation represents what would be reconstructable energy in the real world EMCal detector scenario. In the following we plot this energy against the incoming electron energy, in the case of the 60 X_0 module, and following this, the ratio of the 20.1 X_0 to the 60 X_0 cases. Each was produced for both Geant4 versions.

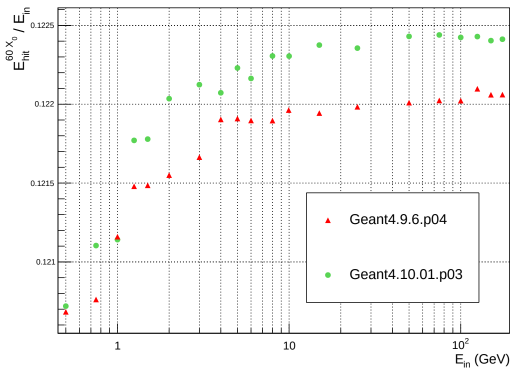

Figure **5.a**

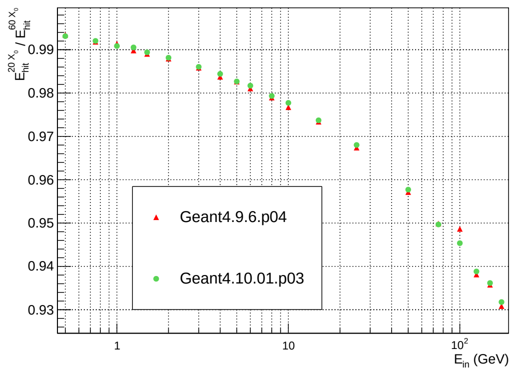

Figure **5.b**

Figure 5: Displaying reconstructable hit energy information in the case of the arbitrarily long module and the realistic case. 5.a: The ratio $E_{rec}^{60\ X_0}/E_{in}$ as a function of E_{in} 5.b: The ratio $E_{rec}^{20\ X_0}/E_{in}^{60\ X_0}$ as a function of E_{in}

When considering the arbitrarily long module (figure 5.a) we see similar distributions for both versions of Geant4, with an overall negligible shift in reconstructable energy of ~ 0.05 % between them. The drop in reconstructable energy at lower incoming electron energy can be explained by energy loss when traversing the medium before entering the module. With the increase in incoming energy we see a flatter distribution, this is as expected due to the long module being able to enclose whole showers longitudinally at these energies. Taking the ratio between 20.1 and 60 X_0 cases shows a decreasing distribution with increasing incoming electron energy, indicating the presence of increasing energy loss in the case of the real 20.1 X_0 module.

Finally when plotting the ratio of rectonstructable hit energy to the incoming electron energy for the case of modelling the EMCal module (20.1 X_0, we reproduce that of the Non-Linearity of from the test beam as in figure 1. By scaling the x-axis of the test beam data to the incoming electron energy we obtain comparable data points. Monte Carlo data is scaled to agree with test beam data at 10 GeV due to this being the point of calibration from SPS [2].

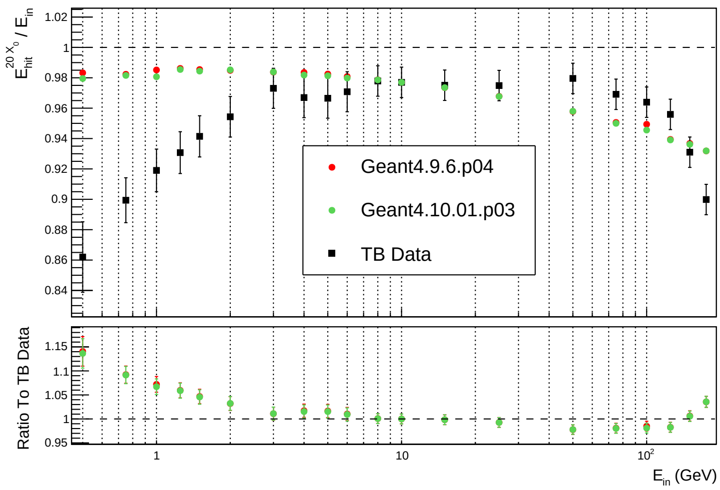

Figure 6: The ratio E_{rec}/E_{in} (non-linearity correction) as a function of E_{in} calculated from test beam data and TB Monte Carlo after adjusting the TB Monte Carlo points to the data.

We see large discrepancies at low and high E_{in} for both Geant4 versions, with any fluctuations between versions being statistical. Both show good agreement with the test beam data in the linear region between energies 3-50 GeV, this was seen in the comparison between Monte Carlo and TB data in figure 1. However at low energies we do not see the drop in reconstructable for the Monte Carlo data energy that we do from the TB data. As we can see from the ratio bar, the Monte Carlo over estimates the amount of reconstructable hit energy deposited in the module in both cases of low (0.5 - 2 GeV) and high ($>$ 100 GeV) incoming electron energy.

3 Conclusions

When comparing shower shape profiles to that given by Wigmans (figure 2) we see good agreement at 10 GeV, and the expected trend in spectrum broadening and peak shift with increasing incoming electron energy. We are therefore led to believe that the test beam geometry is recreated correctly inside the MC framework, servers effects such as double counting would give global disagreement. However due to their only being a 10 GeV reference for lead given by wigeons, we cannot deduce that there is no discrepancy at higher and lower energies due to other effects such as poor interaction modelling by the MC generator. We obtain similar shapes for shower radial distributions, which are less material dependent, further supporting the correct TB geometry being in place. Fractional energy deposit by EM showers initiated by electrons show a shift to lower energy in the MC data, this is put down to the presence of lower cross section scintillator layers being present compared to Wigmans who uses a solid block of lead.

We see the expected flattening of distribution of reconstructable energy in the case for the arbitrarily long module, and and a drop in the ratio between reconstructable energy in the module of real longitudinal length and that of the arbitrarily long module, with increasing incoming electron energy. In the case for both versions of Geant4 we see discrepancies at high and low incoming electron energies to the test beam data when considering the reconstructable energy of the real module. We can therefore deduce that updates to data sets that come with Geant4 updates have not improved Test Beam MC simulation agreement.

The future outlook for this investigation lies in finding more baseline profiles at different incoming electron energies for comparison to Test Beam MC data, this would give a deeper understanding to the reconstructable energy discrepancies displayed in figure 6. For use in AliRoot, ALICE MC geometries have been ported to Virtual Monte Carlo (VMC), within this the ALICE collaboration has developed their own data sets and models for particle interactions, such as "SpecialUrbanMsc". Porting the Test Beam MC geometry to VMC would therefore be a logical next step, to see whether these custom models resolve discrepancies.

References

[1] N. ARBOR and C. FURGET. Etude de la fragmentation des partons par la mesure de corrélations photon-hadron auprès de l'expérience ALICE au LHC, 2013. Presented 19 Sep 2013.

[2] T. A. Awes and P. Ganoti. 3 energy resolution and linearity of the alice-emcal calorimeter. *ALICE*, Feb 2017.

[3] A. Collaboration. Alice emcal tdr. *CERN*, page 7–17, Sep 2008.

[4] R. Wigmans. *Calorimetry: Energy measurement in particle physics.* Clarendon Press, 2000. pages 18–55.

Appendices

A Build Instructions

A.1 Build 1 (Geant4.9.6.p04, root5.34/32)

- Download Geant4: http://geant4.web.cern.ch/geant4/support/source/geant4.9.6.p04.tar.gz
- Extract: tar -xzvf geant4.9.6.p04.tar.gz
- Create Build Directory: mkdir geant4.9.6.p04_build
- Cd Build Directory: cd geant4.9.6.p04_build
- Cmake With Options: cmake -DCMAKE_INSTALL_PREFIX=/path/to/geant4.9.6.p04-install -DGEANT4_INSTALL_DATA=ON -DGEANT4_USE_OPENGL_X11=ON /path/to/geant4.9.6.p04
- Download and Install Root5.34/32.
- Initiate Root Shell.
- Download TB MC Files: https://gitlab.cern.ch/alice-EMC/TestbeamSimulation
- Extract TB MC Files.
- Cd to Geant4 Folder.
- Cd to emcalBeamTest folder.
- Delete CMakeCache.txt
- Edit CMakeLists.txt file, change CMAKE_MODULE_PATH to correct path: set(CMAKE_MODUL $CMAKE_MODULE_PATH /path/to/geant4.9.6.p04/cmake/Modules)
- Cd to Geant4 Folder.
- Create Build Directory: mkdir emcalBeamTest_build
- Cd to Build Directory: cd emcalBeamTest_build
- Create Folder For Root Output: mkdir root_output
- Cmake With Options: cmake -DGeant4_DIR=/path/to/geant4.9.6.p04-install/lib/geant4-9.6.4 –ROOT_INCLUDE_DIR=$ROOTSYS/include ../emcalBeamTest
- Make the Build: make
- Point to Data Files: export G4LEDATA=/path/to/geant4.9.6.p04-install/share/Geant4-9.6.4/data/G4EMLOW6.32/
- Run The Program (Optional Geant4 Macro): ./emcal (run1.mac)

A.2 Build 1 (Geant4.10.01.p03, root6.10/04)

- Download Geant4: http://geant4.web.cern.ch/geant4/support/source/geant4.10.01.p03.tar.gz
- Extract: tar -xzvf geant4.10.01.p03.tar.gz
- Create Build Directory: mkdir geant4.10.01.p03_build
- Cd Build Directory: cd geant4.10.01.p03_build
- Cmake With Options: cmake -DCMAKE_INSTALL_PREFIX=/path/to/geant4.10.01.p03-install -DGEANT4_INSTALL_DATA=ON -DGEANT4_USE_OPENGL_X11=ON /path/to/geant4.10.01.p03
- Download and Install Root6.10/04.
- Initiate Root Shell.
- Download TB MC Files: https://gitlab.cern.ch/alice-EMC/TestbeamSimulation
- Extract TB MC Files.
- Cd to Geant4 Folder.
- Cd to emcalBeamTest folder.
- Delete CMakeCache.txt
- Edit CMakeLists.txt file, change CMAKE_MODULE_PATH to correct path: set(CMAKE_MODUL $CMAKE_MODULE_PATH /path/to/geant4.10.01.p03/cmake/Modules)
- Add Line to CMakeLists.txt: set(CMAKE_CXX_FLAGS "$CMAKE_CXX_FLAGS -std=c++11")
- Add CLHEP units to necessary source files: e.g "using CLHEP::GeV;"
- Remove Unecessary Header Include Lines in Source Files: e.g. in emcal.cc remove line #include "QGSP.hh"
- Cd to Geant4 Folder.
- Create Build Directory: mkdir emcalBeamTest_build
- Cd to Build Directory: cd emcalBeamTest_build
- Create Folder For Root Output: mkdir root_output
- Cmake With Options: cmake -DGeant4_DIR=/path/to/geant4.10.01.p03-install/lib/geant4-10.01.3 –ROOT_INCLUDE_DIR=$ROOTSYS/include ../emcalBeamTest
- Make the Build: make
- Point to Data Files: export G4LEDATA=/path/to/geant4.10.01-install/share/Geant4-10.1.3/data/G4EMLOW6.41
- Run The Program (Optional Geant4 Macro): ./emcal (run1.mac)