Granularity of ATLAS Tile Calorimeter studied through simulations

Anabel Cristina Romero Hernandez
Supervisor: Irene Vichou

Project report for CERN Summer Student Programme 2015

Abstract

A small study, done through simulations, of the energy resolution of ATLAS Tile Calorimeter dependence on granularity is presented. The results could indicate that finer granularity of the calorimeter gives better energy resolution, although it would require better statistics to be sure.

1. Introduction

The Tile Calorimeter is the hadronic calorimeter of the ATLAS detector of LHC. It has three parts, the barrel and two extended barrels, and each barrel is composed of 64 modules (Figure 1). A module is an iron structure that has several slots for scintillators; it has 11 rows and each row contains 307 scintillators (Figure 2).[1] Scintillators are also called *tiles*.

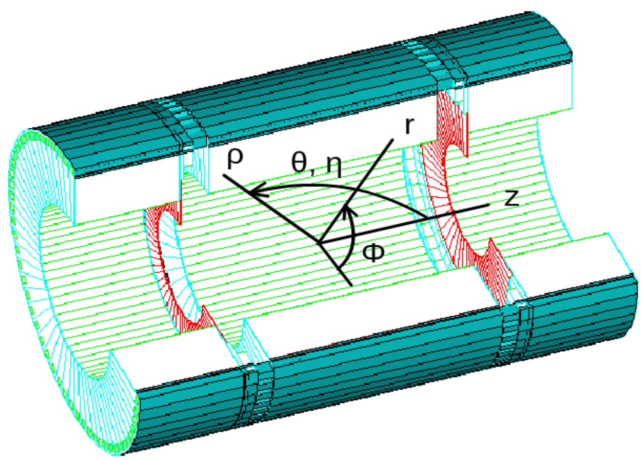

Figure 1. Section of the Tile Calorimeter showing the barrel, extended barrels, and coordinates.

The coordinates used in the ATLAS detector are Z, the direction of the beam, Φ, the polar angle measured in a perpendicular plane to the beam direction, and the pseudo-rapidity η, defined as $\eta = -\ln(\tan(\theta/2))$, where θ is the angle between a certain position and the direction of the beam (Figure 1). The quantity $\Delta R = \sqrt{\Delta\eta^2 + \Delta\Phi^2}$ is Lorentz invariant, and it represents a distance in the Φ – η space. ΔR is an important parameter used in jet clustering algorithms.[3]

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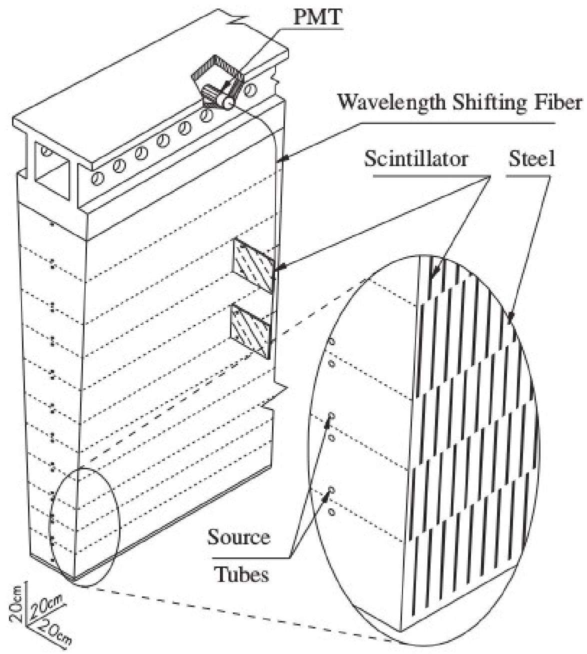

Figure 2. Mechanical structure of a TileCal module, showing the slots in the iron for scintillating tiles and the method of light collection by WLS fibers to PMTs. The hole for radioactive source tubes that traverse the module parallel to the colliding beams are also shown. Taken from [2].

Every time a particle passes through the calorimeter, it looses energy in the tiles, and the energy is collected from groups of tiles called *cells*. Cells are defined in such a way that the granularity in η is 0.1. Also, since there are 64 modules in a barrel, the granularity in Φ is $2\pi/64 = 0.1$. The current granularity of the Tile Calorimeter is $\Delta\eta \times \Delta\Phi = 0.1 \times 0.1$ (0.1×0.2 in last segment), both for barrel and extended barrel.[2]

If this granularity was finer, one would expect the energy resolution to be better, and making this granularity finer could be a project for the next upgrade of the Tile Calorimeter. Note that the granularity in η is the easiest to change since it depends on the grouping of tiles to form cells; changing the granularity in Φ would require new tiles. Therefore, the aim of this work is to study the granularity in η and its relation to the energy resolution of the Tile Calorimeter, and this is done through simulations.

2. Simulations

Simulations were done using ATLAS software release 17.7.3.1, which uses Geant4 version 9.6.p2, with a geometry of five barrel modules, and pions of 100 GeV impinging on the central module, which corresponds to $\Phi = 0.2$, and at an angle $\theta = 20°$, which corresponds to $\eta = 0.35$. A scheme of the simulation is shown in Figure 3.

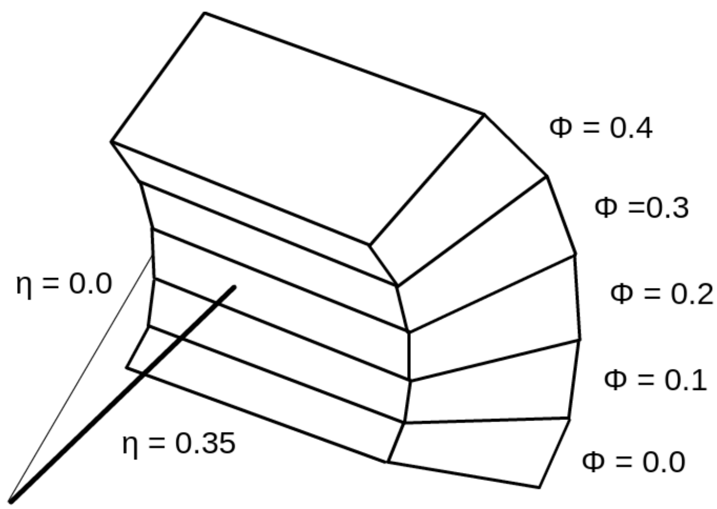

Figure 3. Scheme of the simulation. 100 GeV pions impinging on the central module ($\Phi = 0.2$) of a five barrel modules configuration, and at an angle $\theta = 20°$ ($\eta = 0.35$).

In the simulations, one event represents one pion going through the calorimeter, and each time it leaves a certain amount of energy in one of the scintillators, this is called a *hit*. Then, each event has a corresponding number of hits.

The output of the simulation is an n-tuple (a collection or list of numbers) that contains the information of each hit: event number, module number, tile number, row number, and energy. For one hit, the Φ value can be obtained directly from the module number (because each module represents $\Phi = 0.1$), but for the η value, the information is contained implicitly in the tile number and row number since it depends on how cells are defined.

A script was wrote in which different groupings of tiles were made, corresponding to granularities $\Delta\eta$ of 0.2, 0.1, 0.05 and 0.025 (in principle it wouldn't make sense to use $\Delta\eta = 0.2$ because the current granularity of the Tile Calorimeter is $\Delta\eta = 0.1$, and one would not want a coarser granularity, but $\Delta\eta = 0.2$ was useful to see the behavior of the simulations). The grouping of tiles was done assigning certain tiles in certain rows to its corresponding value of η depending on the granularity; for example: for a granularity of $\Delta\eta = 0.1$, and for the first row, tiles 1 to 13 correspond to $\eta = 0.1$, tiles 14 to 26 correspond to $\eta = 0.2$, and so on. This script was used to analyze the n-tuple and get the total energy per Φ and η within a radius $\Delta R = \sqrt{\Delta\eta^2 + \Delta\Phi^2}$.

Simulations were of 2500 events and energy histograms were obtained for the different granularities used and for different radii ΔR. Radii used were those corresponding to $\Delta R = \sqrt{\Delta\eta^2 + \Delta\Phi^2}$ with $\Delta\eta = \Delta\Phi = d$, where d took the same values as the granularities simulated, namely: 0.2, 0.1, 0.05 and 0.025.

3. Results

The energies presented here are only the energies deposited in the scintillators. To get total the total energy including the iron, the sampling fraction must be considered. Sampling fraction is defined as: $SF = E_{scintillators}/E_{beam}$. In the simulations, the inverse of the sampling fraction was: $1/SF = 33.87 \pm 0.01$.

The energy (of each hit of the 2500 events) per tile, row and Φ is shown in Figure 4. This is basically a graph of the content of the n-tuple. Note that the energy is mostly deposited in Φ = 0.2, that means that the shower of the pions is almost completely contained in the middle module.

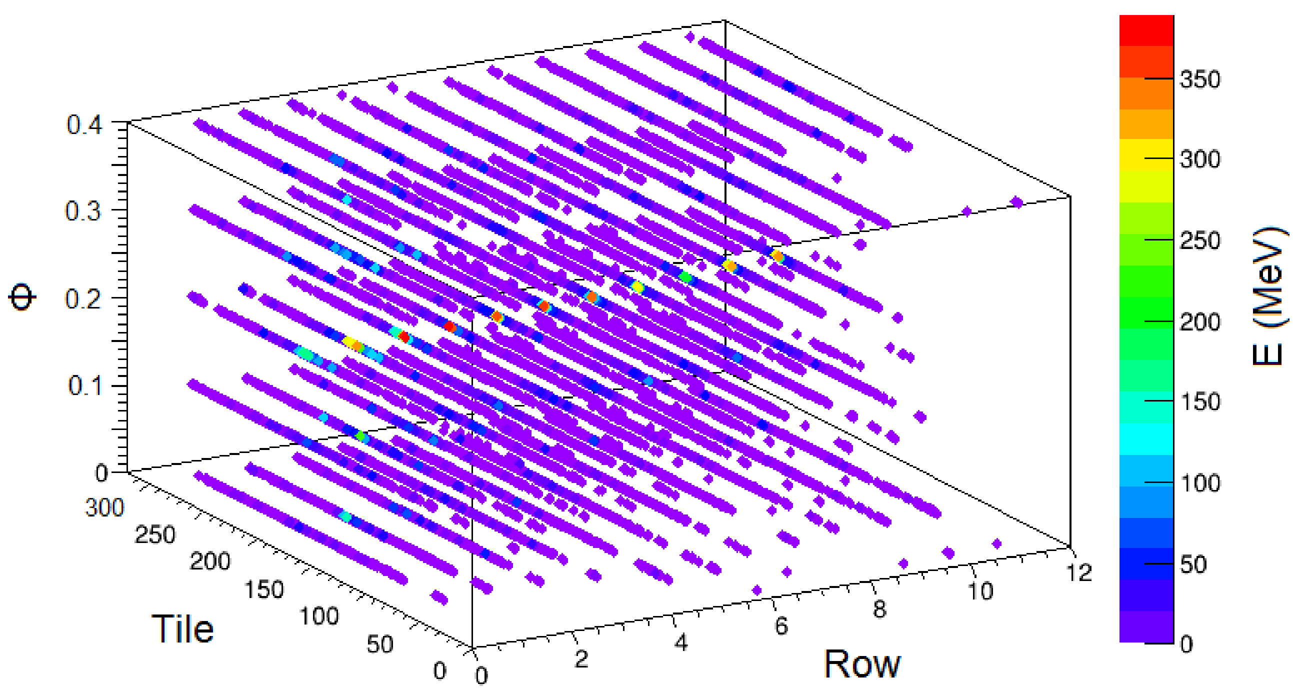

Figure 4. Energy per tile, row and Φ for each hit of the 2500 events simulated.

Figure 5 shows the energy of each hit of the 2500 events per tile and row only. This corresponds to the five modules, but since almost all the energy is deposited in the middle module, it can be thought of as the middle module only. The track of the pions can be seen, it starts at around tile 200 in the first row and finishes at around tile 250 in the last row (it's a “straight” line, but at an angle with respect to $\eta = 0$ because pions were impinging on the middle module with $\eta = 0.35$).

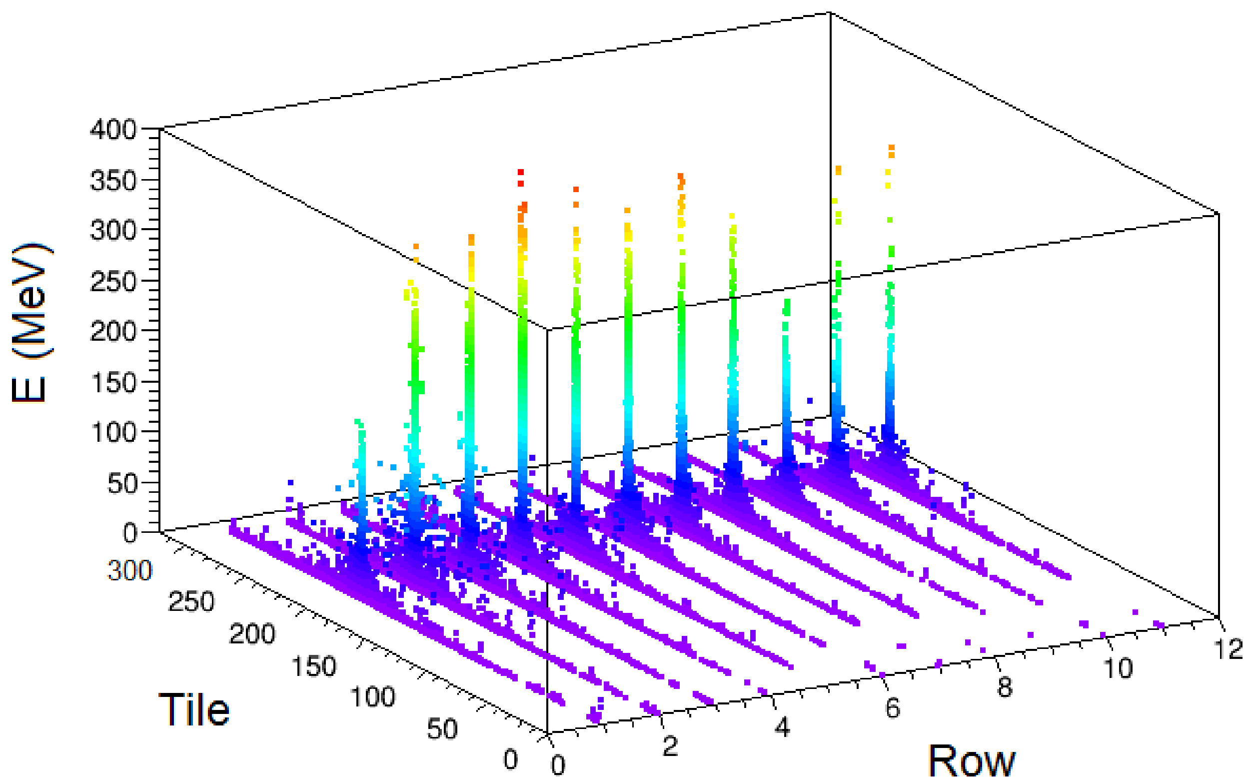

Figure 5. Energy per tile and row for each hit of the 2500 events simulated.

The total energy per Φ and η, and for the different granularities used, is shown in Figure 6. Note that the center of the energy deposited depends on the granularity in η. For the finest granularity $\Delta\eta = 0.025$, the center is in $\eta_c = 0.65$, but for granularity $\Delta\eta = 0.2$, the center is 0.8. That happens because a granularity of $\Delta\eta = 0.2$ means that any energy deposited in $0.6 < \eta < 0.8$, is going to be regarded as having $\eta = 0.8$. The same happens for a granularity of $\Delta\eta = 0.1$, because $0.6 < \eta_c < 0.7$.

Figure 7 is an example of a histogram of the energy deposited within a radius ΔR. Several histograms like this were obtained for different granularities and radii, and were all fitted with Gaussian distributions. Table 1 shows for different granularities $\Delta\eta$ and different radii ΔR, the energy E and standard deviation σ of the Gaussian fits of the histograms, and the corresponding resolution R calculated from E and σ.

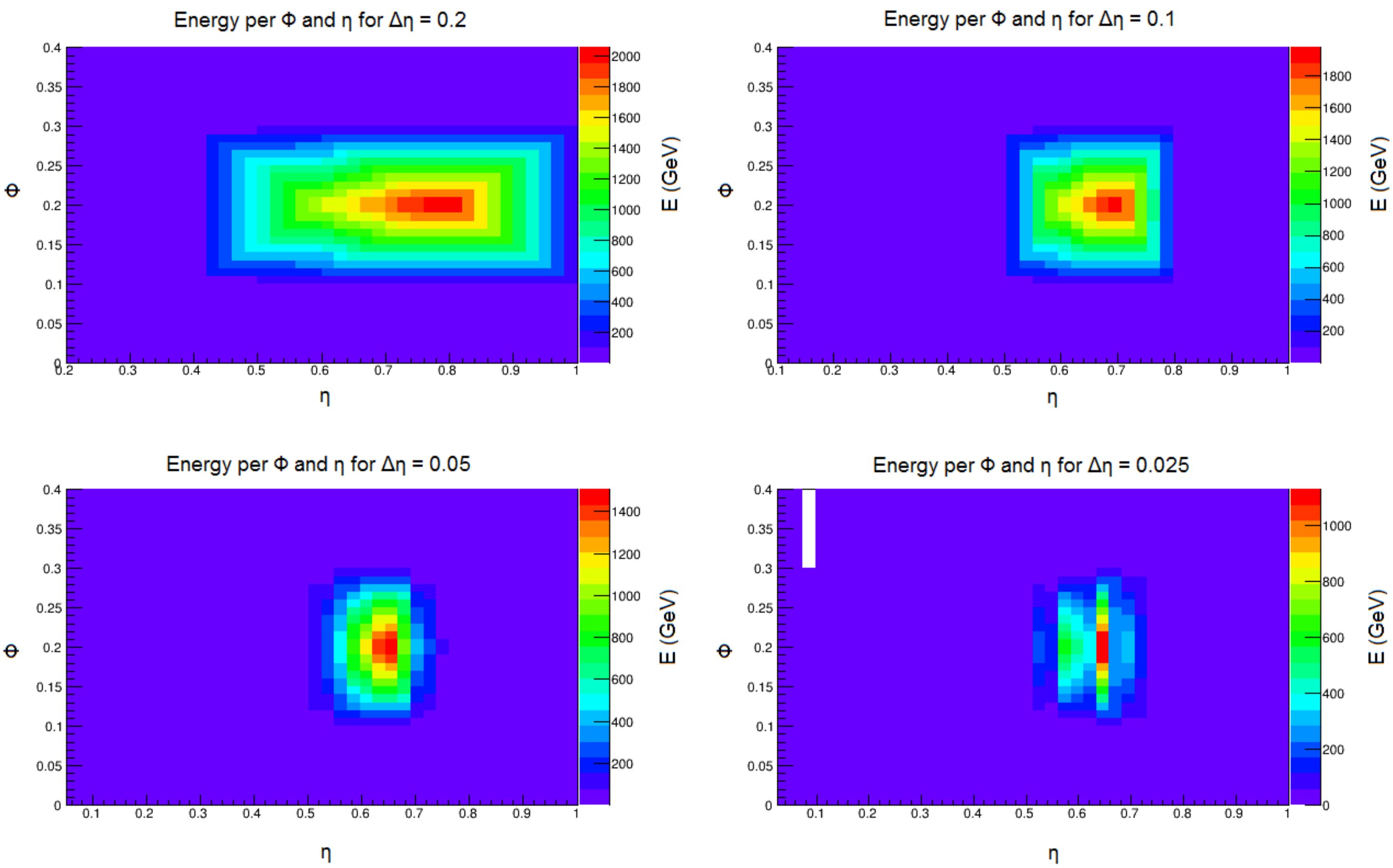

Figure 6. Total energy per Φ and η for different granularities, and for all 2500 events.

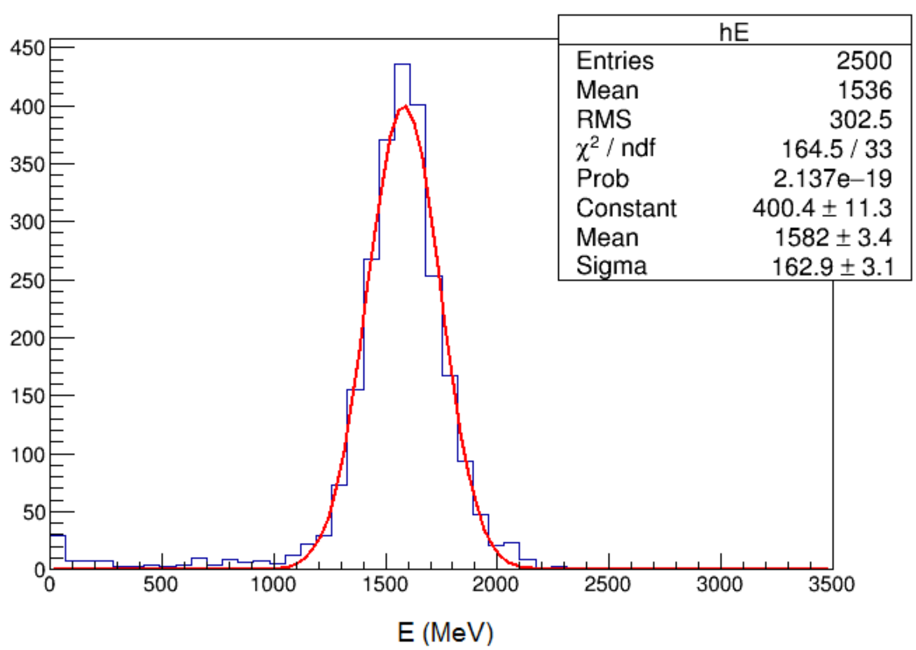

Figure 7. Histogram of energy deposited within a radius $\Delta R = 0.1414$ or $d = 0.1$, for a granularity of $\Delta\eta = 0.1$.

Table 1. Fit parameters energy E and standard deviation σ for histograms of energy within a radius ΔR, and resolution R, for different granularities Δη and different radii ΔR				
	Δη	E (MeV)	σ (MeV)	R
ΔR = 0.2121 d = 0.15	0.025	1659 ± 3.3	157.4 ± 4 3	0.0949 ± 0.0020
	0.05	1659 ± 3.3	158.1 ± 3.1	0.0953 ± 0.0020
	0.1	1654 ± 3.3	158.6 ± 3.1	0.0959 ± 0.0021
	0.2	1599 ± 3.4	163.9 ± 3.2	0.103 ± 0.002
ΔR = 0.1768 d = 0.125	0.025	1650 ± 3.3	158.6 ± 3	0.0961 ± 0.002
	0.05	1650 ± 3.3	158.4 ± 3	0.0960 ± 0.002
	0.1	1641 ± 3.3	158.2 ± 3	0.0964 ± 0.002
	0.2	1084 ± 13.8	353 ± 9	0.33 ± 0.1
ΔR = 0.1414 d = 0.1	0.025	1619 ± 3.3	160.9 ± 3.1	0.099 ± 0.002
	0.05	1615 ± 3.4	162.2 ± 3.1	0.100 ± 0.002
	0.1	1582 ± 3.4	162.9 ± 3.1	0.103 ± 0.002
	0.2	1084 ± 13.8	353 ± 9.0	0.33 ± 0.1
ΔR = 0.1061 d = 0.075	0.025	1503 ± 4.5	201.7 ± 4.5	0.134 ± 0.002
	0.05	1571 ± 3.4	164.3 ± 3.0	0.105 ± 0.002
	0.1	1582 ± 3.4	162.9 ± 3.1	0.103 ± 0.002
	0.2	1084 ± 13.8	353 ± 9.0	0.33 ± 0.1
ΔR = 0.0707 d = 0.15	0.025	1087 ± 10.1	321 ± 8	0.30 ± 0.01
	0.05	1378 ± 5.2	228.6 ± 5.4	0.166 ± 0.005
	0.1	987.2 ± 12.2	357.9 ± 9.8	0.36 ± 0.01
	0.2	1030 ± 13.2	365.2 ± 9.9	0.35 ± 0.01

Table 1 shows some behaviors that were expected:

- For the same granularity, the energy within a radius ΔR increases with the radius.
- For the largest radius $\Delta R = 0.2121$, the energies for different granularities are similar because all the energy is almost completely contained within this radius, as it can be seen in Figure 6.
- Granularity $\Delta\eta = 0.2$ is so coarse, that energy within radii $\Delta R = 0.1768$, $\Delta R = 0.1414$ and $\Delta R = 0.1061$ is the same. This happens because the difference between these radii is smaller than the granularity, and basically the detector is blind to such small changes in radius.

Regarding the resolution dependence on granularity, it could be that the resolution gets better by decreasing granularity, but we can't be completely sure because the errors are not small enough. It would require simulations with more events and better statistics to be sure. The only cases in which this is not true is for granularity $\Delta\eta = 0.025$ and radii $\Delta R = 0.0707$ and $\Delta R = 0.1061$, but this could be because the total energy per η and Φ for this granularity had a strange distribution, as it can be seen in Figure 6.

4. Conclusions

Simulations with better statistics are required to ensure that the resolution gets better with finer granularity, 2500 events were not enough.

It would be interesting to repeat this study for different incident energies of the pions.

5. References

[1] ATLAS Collaboration, ATLAS Tile Calorimeter Technical Design Report, CERN/LHCC/96-42, 1996.
[2] ATLAS Collaboration, Testbeam studies of production modules of the ATLAS Tile Calorimeter, Nuclear Instruments and Methods in Physics Research A 606 (2009) 362–394.
[3] ATLAS Collaboration, The ATLAS Experiment at CERN Large Hadron Collider (2008), Institute of Physics Publishing and SISSA.