DESY Summer Program 2010

Frozen Showers in the Atlas Calorimeter

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Abstract

The time needed to simulate events in the Atlas detector at LHC with GEANT 4 is mainly spent in the electromagnetic calorimeter, specially for electrons and photons in the electromagnetic Barrel and the electromagnetic endcap calorimeter. To reduce this time, the Frozen Shower technique has been developed. The point of this project is to enhance the Frozen Shower results: we show in this report how we minimized the differences between the FS results and the full G4 simulation.

1 Introduction

In modern High Energy Physics, simulations are as important as data in the analysis process.
Most detectors (BaBar, Atlas, CMS, T2K...) use the Geant 4 platform: for a given detector geometry and structure, G4 uses packages including most known interactions of particles passing through matter (figure 1). It can then simulate all known physical processes happening in the detector.

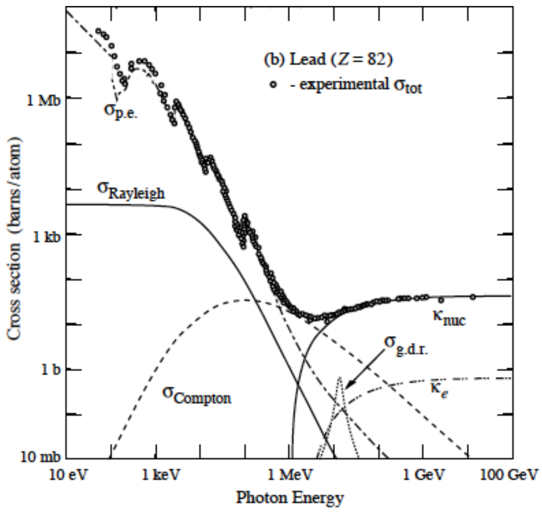


Figure 1 : Photon total cross sections as a function of energy in lead.
$\sigma_{p.e.}$ = Atomic photoelectric effect (electron ejection, photon absorption)
$\sigma_{Rayleigh}$ = Rayleigh (coherent) scattering atom neither ionized nor excited
$\sigma_{Compton}$ = Incoherent scattering (Compton scattering off an electron)
κ_{nuc} = Pair production, nuclear field
κ_{e} = Pair production, electron field
$\sigma_{g.d.r.}$ = Photonuclear interactions, most notably the Giant Dipole Resonance. In these interactions, the target nucleus is broken up.

The informations given by Geant 4 then have to be digitized and reconstructed before being compared to real data. The full chain Monte Carlo production (see figure 2) is not discussed here, for more informations see for example the Atlas Wiki page [1].

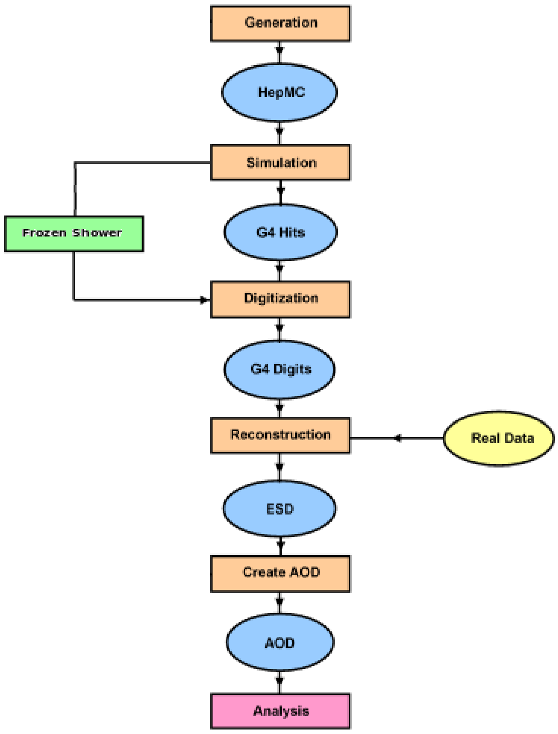


Figure 2 : full chain Monte Carlo production

This so-called Full Simulation takes a lot of time (10 minutes of CPU-time for a 14TeV p-p collision event in average). About 70% of this time is spent in the electromagnetic calorimeter, specially in the ElectroMagnetic Barrel (EMB) and the ElectroMagnetic EndCap (EMEC).
There are techniques to lower this CPU time, used in different energy ranges. Here we will discuss the Frozen Shower technique, used for low energy γ and e^- (below a few GeV).

1.1 Frozen Shower

The principle of Frozen Shower is basically to store events previously simulated via Geant 4 in libraries and to use them instead of full simulation. This technique is used for events below some energy. That way, simple calculations are computed instead of the complex Geant 4 ones [2, 3]. Hence, the CPU-time needed is greatly reduced (see figure 3).

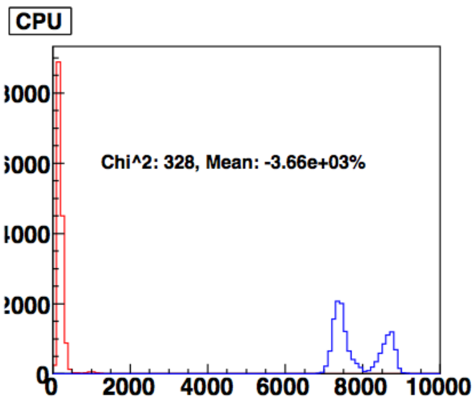


Figure 3 : Number of events for a given CPU-time in seconds; blue = Full Simulation, red = Frozen Shower

Most electromagnetic particles (γ, e^-, π^-, neutrons...) entering the detector (eg: high energy e^-) produce a huge number of lower energy particles via electromagnetic showers. These showers represent a lot of informations and a long CPU-time to be generated.
The Geant 4 simulation is used for deposited energy down to 1GeV, and the rest of the shower, very rich in low energy events (mainly EM γ and e^- showers) is simulated with the Frozen Shower technique.
In order to minimize the additional disk space and memory consumption the Frozen Shower hits are compressed [2].

2 Project

The Frozen Shower technique obviously has to give results as similar as possible to the one from the full simulation. We try here to explain how to have a better agreement between both ways.

2.1 Problem analysis

The first step is to find where the differences are, using the libraries available on Atlas LXR server [4].
For this we generate events, with significant statistics, using some python scripts. We then plot the energy deposit for specific η ranges. We calculate χ^2/ndf, which is a good statistical tool to check the similarity between two curves [5], as well as the mean difference: $(1 - \frac{mean(histogram2)}{mean(histogram1)}) * 100$
The libraries used here have already been shifted by a factor of 1%, it fixes the shifts in most plots. We see that in some regions, agreement is quite good (similar shapes, χ^2/ndf close to 1, small mean difference) , whereas some regions present serious divergences.

2.1.1 good η region

For example (see figure 4), for an electron entering the EMB detector with energy 200 GeV, in the η range 0.5-0.6. We generate this event 5000 times (100*50), for the atlas release 15.6.7, with geometry package ATLAS-GEO-08-00-01.
Here the 1% energy shift might not be sufficient for this region. Nevertheless, the shape is similar, and the bad χ^2/ndf test is due to the shift.

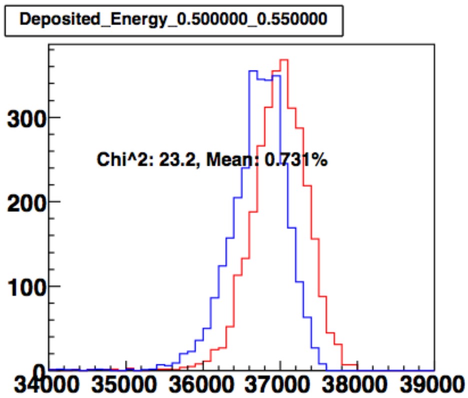


Figure 4 : Deposited Energy for the η range 0.5-0.55, blue = Full Simulation, red = Frozen Shower

2.1.2 problematic η region

The problematic η region are visible in the Appendix A: the main ones are 0.78-0.82, 1.4-1.48, 2.48-2.52. Here (see figure 5), an electron enters the EMEC detector with energy 200 GeV, in the η range 2.4-2.7. We generate this event 15000 times (250*60). We see that some features appear in the Frozen Shower plots that are not present in the Full Simulation ones, and the χ^2/ndf is high.

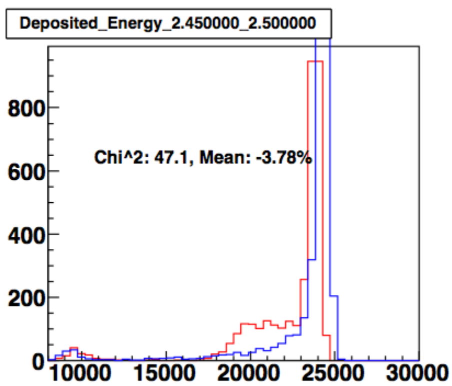


Figure 5 : Deposited Energy for the η range 2.45-2.50, blue = Full Simulation, red = Frozen Shower

We can see that these problematic "crack" regions correspond to the limits between different parts of the detector, or some variations in the structure. See figure 6 and Appendix A.

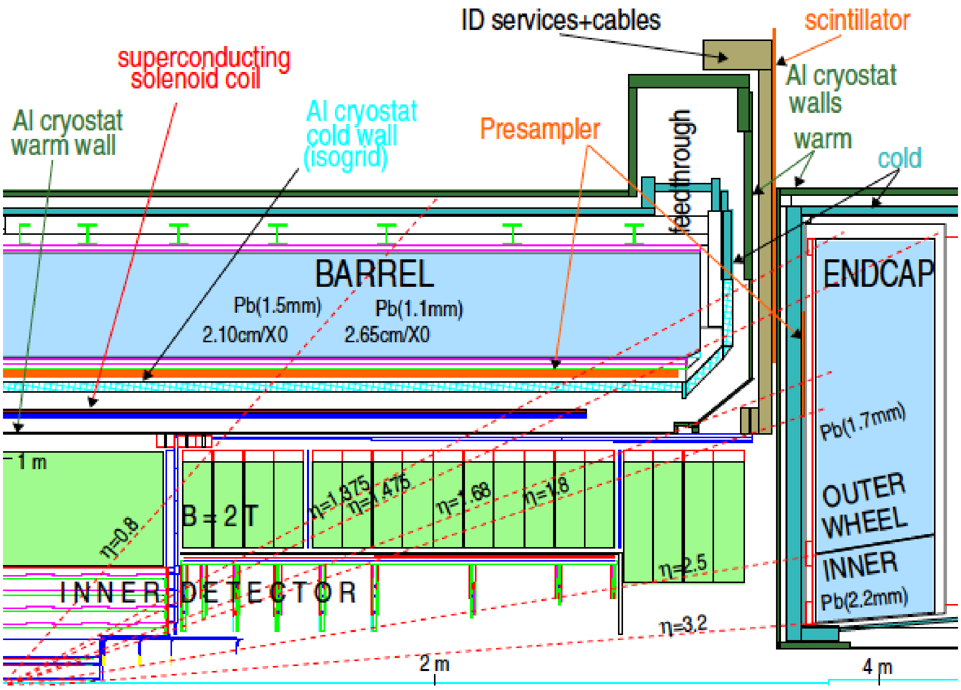


Figure 6 : Layout of ATLAS EM Calorimeter (FCAL not shown)

2.2 Generation of new libraries

Having analysed the old libraries, we can now generate new ones, with Atlas new release (15.6.11) and new geometry (ATLAS-GEO-10-08-00). First, we check that the observed features were not specific to the old release (figure 7): for that we compare the full simulation with old release and the full simulation with new release.

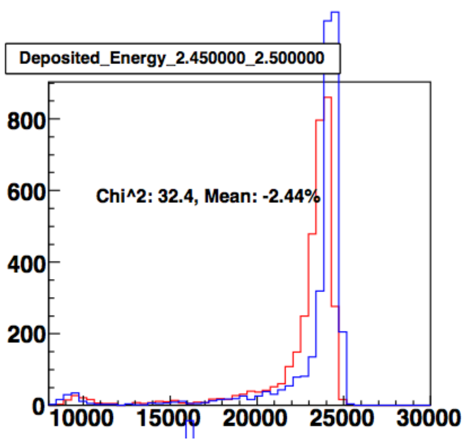


Figure 7 : Deposited Energy for the η range 2.45-2.50, blue = new Full Simulation, red = old Full Simulation

At this crack region, there are some visible differences, but the overall shape is similar.

2.3 Good regions

In the "good regions" we see that there are already some big improvements if we do the same corrections than for old libraries: we need a rescaling of 1% up in energy to have better agreement (figure 8).

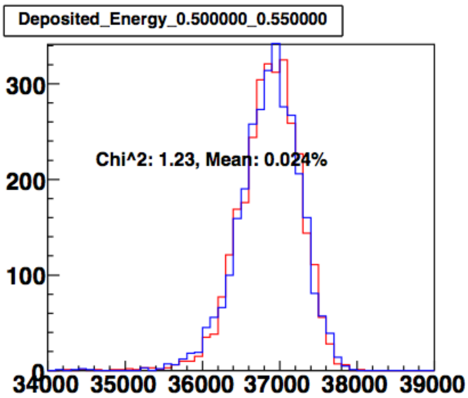


Figure 8 : Deposited Energy for the η range 0.5-0.55, blue = Full Simulation, red = Frozen Shower

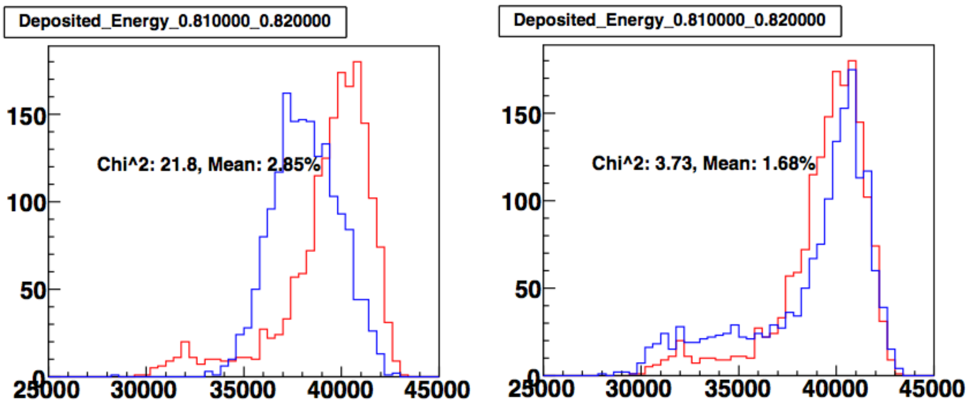
There is no need to tune these parts of the libraries.

2.4 Problematic regions: tuning of the new libraries

The new libraries don't give significantly better results for problematic regions. We can now start to tune the library to have better agreement. The most straightforward ways are to use a new η binning for the libraries (by adding new bins or moving old ones, the latest technique avoids time consumption for generating new libraries and sometimes gives better results, if the variation are too chaotic in the crack region) or to rescale some η bins in energy.
The new libraries are given in annexe B (for photons, we use the same parameters).

2.4.1 New EMB libraries

We generate new libraries trying to fix the problematic region in the EMB crack: $\eta \in [0.78, 0.82]$ (see figure 6 and Annexe A). In the old libraries, the binning was at 0.75, moved at 0.81, and 0.85, moved at 0.83.
The new geometry does not fix the problem (see figure 9.a). We then introduce a new binning at 0.8, right in the crack, and we move the 0.75 library at 0.795, and 0.85 at 0.81. We see that the new energy profile is closer to the full simulation's one (see annexe A), and the χ^2/ndf test is a lot better.

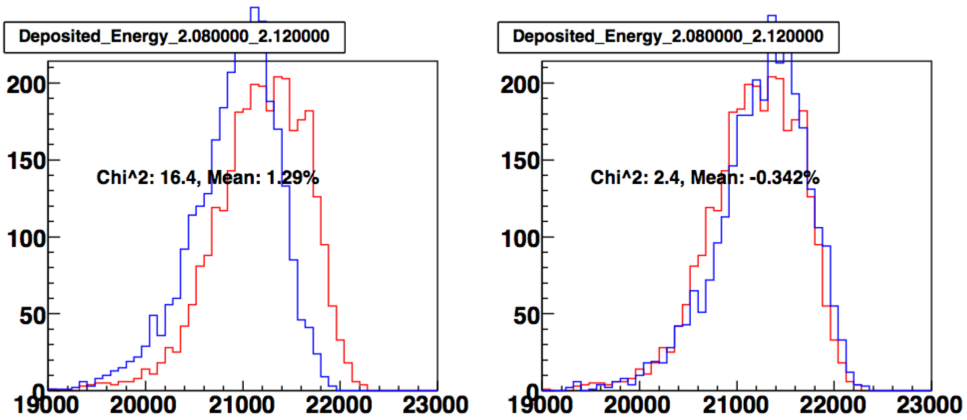


a: new libraries before tuning ; b: new libraries after tuning

Figure 9 : Deposited Energy for the η range 0.81-0.82, red = Full Simulation, blue = Frozen Shower.

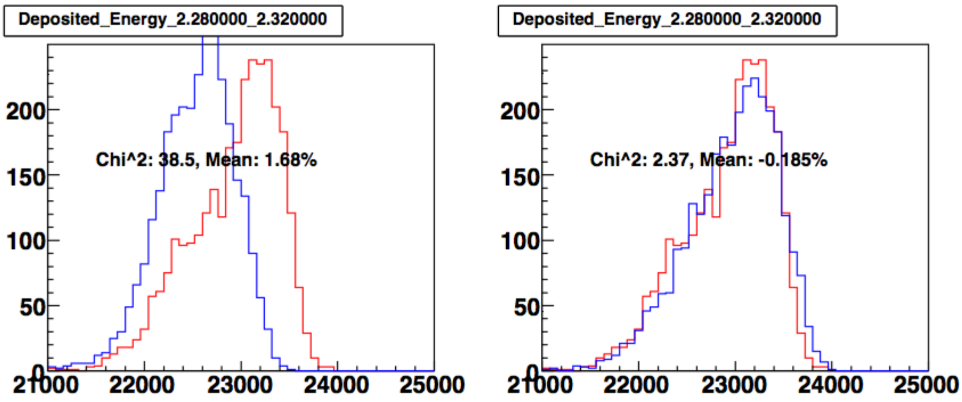
2.4.2 New EMEC libraries

Here we have several region s to fix.
- $\eta \in [2.0, 2.4]$. Some "bumps" appear in the full simulation curve at $\eta \simeq 2.1$ and $\eta \simeq 2.3$. They are not present in the Frozen Shower curve. We then introduce new bins there. After checking, we see that the 1% rescaling is not necessary for η=2.32



a: new libraries before tuning ; b: new libraries after tuning

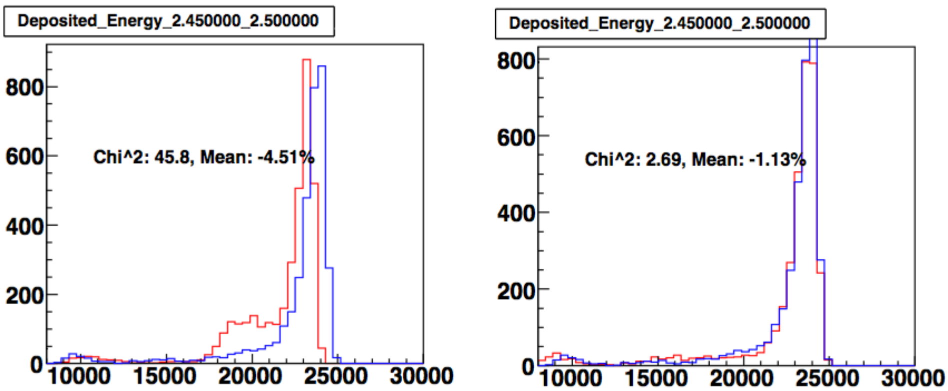
Figure 10 : Deposited Energy for the η range 2.08-2.12: red = Full Simulation, blue = Frozen Shower.



`a: new  libraries before tuning ; b: new libraries after tuning`

Figure 11 : Deposited Energy for the η range 2.28-2.32: red = Full Simulation, blue = Frozen Shower.

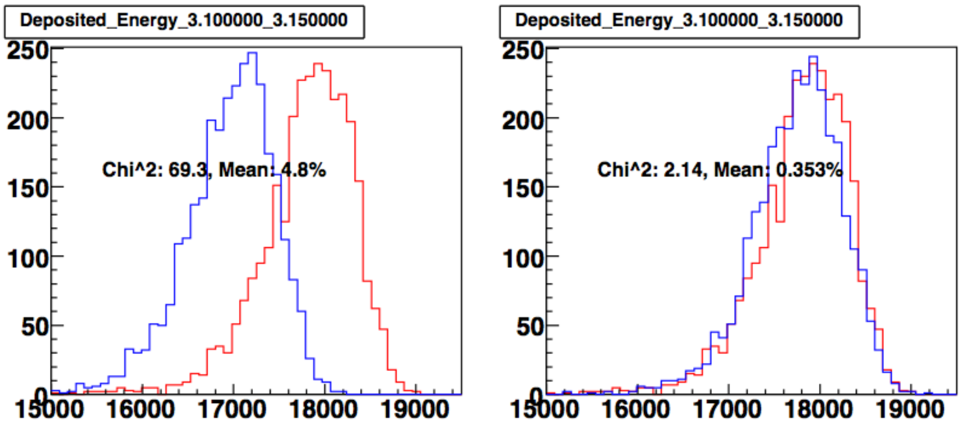
- $\eta \in [2.4, 2.7]$. The η range 2.48-2.52 is the main crack in EMEC, it is due to the transition between the outer wheel and the inner wheel (see figure 6). The libraries released on LXR server [4] have bins at η=2.4 moved at 2.48 and η=2.6 moved at 2.52. For the new libraries, the new geometry package does not fix the problems (see figure 10.a), thus we replace these bins with new ones at η=2.46, 2.49, 2.5, 2.51, 2.52, 2.7, and we rescale some η in energy. 2.46: 3%, 2.49: 3%, 2.5: 4%, 2.51: 4%. For the others we use the usual 1% rescaling.



`a: new  libraries before tuning ; b: new libraries after tuning`

Figure 12 : Deposited Energy for the η range 2.45-2.50: blue = Full Simulation, red = Frozen Shower.

- $\eta \in [2.7, 3.2]$. In this range, we mainly have a shift that is not corrected by the 1% rescaling. We have to introduce 2 bins: 2.9 and 3.05 and rescale: 3.05: 2%, 3.15: 5%.



a: new libraries before tuning ; b: new libraries after tuning

Figure 13 : Deposited Energy for the η range 3.1-3.15: red = Full Simulation, blue = Frozen Shower.

3 Conclusion & Perspectives

We showed that by a simple appropriate tuning of the η binning for the generated libraries, and by the use of energy rescaling, we can have significant improvements.

3.1 Memory consumption

The problem we have by introducing new η bins is the memory they represent, more than the CPU time. For example, the old EMEC library for an electron (with 14 η) is 42.4 MB big, the new one (23 η) is 62.2 MB big. Here, an increasing of 64.3% of η bins induces an increasing of 46.7% in memory. The following hypothetical solutions have not been tested during this project.

3.1.1 number of events

Since we introduce a lot of bins in a narrow η range, we could reduce the number of events generated and keep a constant average number of events in this region: the denser the binning is, the fewer events we could use per η bins.

3.1.2 photon libraries

In the Frozen Shower simulation, libraries are generated for electrons, photons, pions, and neutrons. In this project, we just tuned the libraries for electrons and photons, since they are significantly dominant in the EM showers. We see in figure 1 that the photon pairproduction dominates above a few 10MeV. Thus, when a photon enter the calorimeter with an energy above this threshold, it pair produces. At that point, we could switch to the electron libraries. Then, we could suppress all energy above a threshold (around 10-50 MeV) in the photon libraries.

3.1.3 zeroes

The low energy entering particles usually do not produce interesting showers. Most of the daughter particles are so low in energy that we store zeroes in the libraries. These 0s should also be deleted since they do not provide useful informations.

3.2 Improvement

3.2.1 Tune the EMB-EMEC transition region

The big disagreement in the η region 1.4-1.48 is due to the transition between the EMB detector and the EMEC (see figure 6). Both detectors should detect the shower. Here, new bins don't really fix the problem; a solution might be to generate an η continuous spectrum. An Ad hoc energy rescaling might also fix the problem.

3.2.2 Tune the other particle's libraries

As mentioned before, libraries are created for a few EM interacting particles. We only tuned the electron and photon libraries. A fine tuning for the pion and neutron libraries, might also improve the results.

3.2.3 Tune the FCAL detector

We also skipped the tuning in the Forward CALorimeter (FCAL), which detects particles with high η. For this detector, the η dependence is really weak. The tuning would mainly be at the transition with EMEC. There is no overlap though, so the transition is pretty smooth.

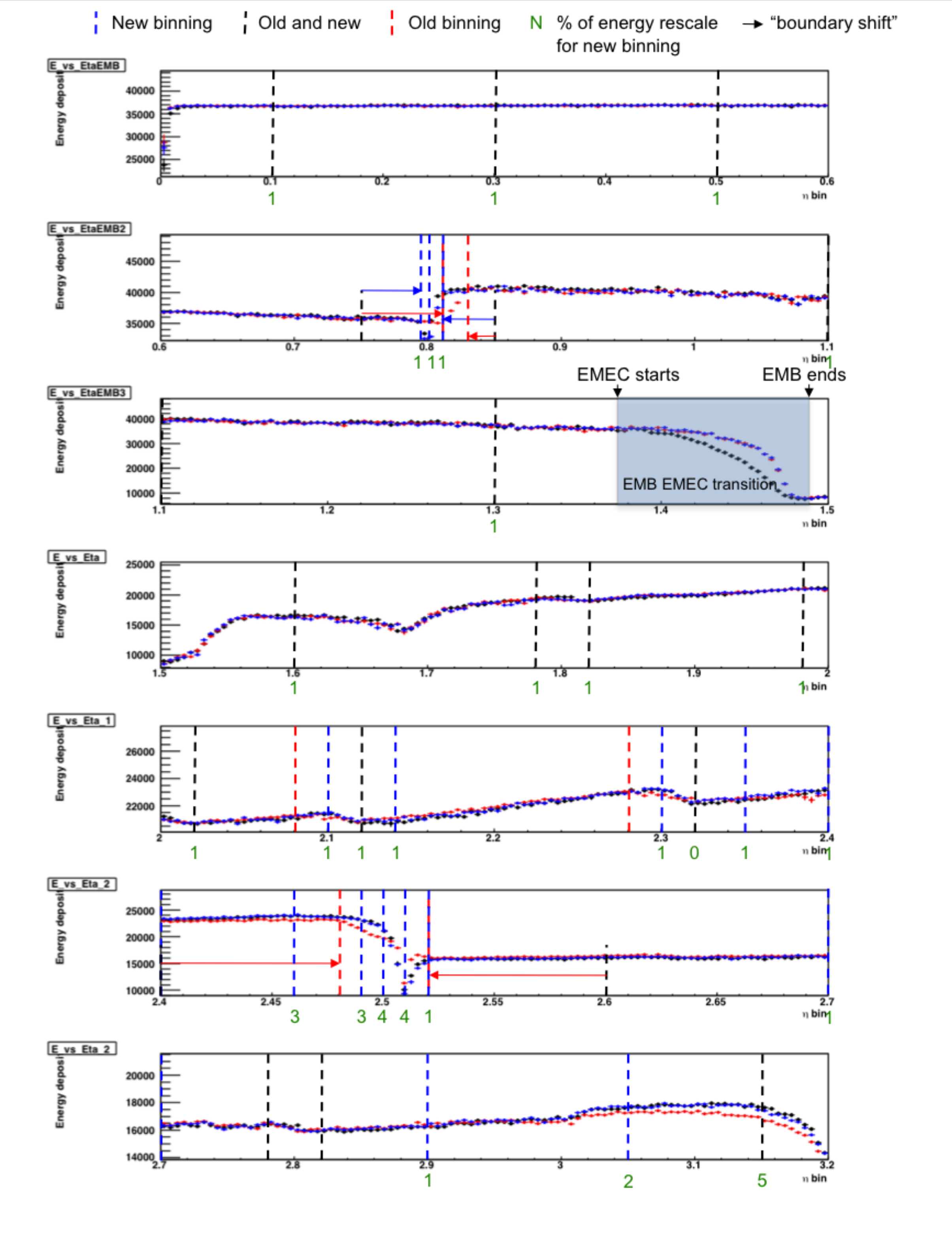
3.2.4 Passive-Active libraries

In the FCAL libraries, the inner structure of the detector is composed of very small active material layers in LAr (LAr gaps within coppers tubes and rods) [3]. The showers won't develop the same way if they start in active or passive materials. For example, showers starting in active materials should give more energy. The result of the simulation in the FCAL thus depends on the distance to the active material. The chosen solution was to generate one library in each material, and merge them with the appropriate ratio. Then, when a particle enter the detector, we also check the distance to the active material. This was ignored in the other part of the detector, but it might induce some significant change, and eventually fix the problem of inducing the artificial 1% energy shift. This is currently being studied by George Sedov.

3.3 More checks

Here we studied the agreement for an electron with energy 200 GeV entering the detector. Different events could be simulated too, for various particles at various energy.
At a final step, the reconstruction level has to be checked.

4 Annexe A: Energy vs. η



blue = new frozen libraries, red = old libraries, black = full simulation

old libraries have rescaling of 1 %

5 Annexe B: new libraries

VERSION: 10005 PARTICLE: e DETECTOR: EMEC

COMMENT: MERGED scaled by ETA2.5=1.04 ETA1.98=1.01 ETA3.15=1.05 ETA2.51=1.04 ETA2.02=1.01 ETA2.32=1.0 ETA3.05=1.02 ETA2.3=1.01 ETA1.78=1.01 ETA2.82=1.01 ETA2.14=1.01

Number of etabins: 23 | Number of ebins 10

etas\ebins	1.0	2.0	5.0	10.0	20.0	50.0	100.0	200.0	500.0	1000.0
1.62	500	500	500	500	500	500	500	500	500	500
1.78	500	500	500	500	500	500	500	500	500	500
1.82	500	500	500	500	500	500	500	500	500	500
1.98	500	500	500	500	500	500	500	500	500	500
2.02	500	500	500	500	500	500	500	500	500	500
2.1	500	500	500	500	500	500	500	500	500	500
2.12	500	500	500	500	500	500	500	500	500	500
2.14	500	500	500	500	500	500	500	500	500	500
2.3	500	500	500	500	500	500	500	500	500	500
2.32	500	500	500	500	500	500	500	500	500	500
2.35	500	500	500	500	500	500	500	500	500	500
2.4	500	500	500	500	500	500	500	500	500	500
2.46	500	500	500	500	500	500	500	500	500	500
2.49	500	500	500	500	500	500	500	500	500	500
2.5	500	500	500	500	500	500	500	500	500	500
2.51	500	500	500	500	500	500	500	500	500	500
2.52	500	500	500	500	500	500	500	500	500	500
2.7	500	500	500	500	500	500	500	500	500	500
2.78	500	500	500	500	500	500	500	500	500	500
2.82	500	500	500	500	500	500	500	500	500	500
2.9	500	500	500	500	500	500	500	500	500	500
3.05	500	500	500	500	500	500	500	500	500	500
3.15	500	500	500	500	500	500	500	500	500	500

VERSION: 10005 PARTICLE: e DETECTOR: EMB

COMMENT: MERGED scaled by ETA0.5=1.01 ETA0.1=1.01 ETA0.8=1.01 ETA0.3=1.01 ETA1.1=1.01 ETA1.3=1.01 ETA0.81=1.01 ETA0.795=1.01

Number of etabins: 8 | Number of ebins 10

etas\ebins	1.0	2.0	5.0	10.0	20.0	50.0	100.0	200.0	500.0	1000.0
0.1	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0.3	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0.5	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0.795	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0.8	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
0.81	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1.1	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1.3	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000

6 Acknowledgements

I would like to thank my instructor Mikhail Karnevskiy for his patience and his help during this project, and congratulate him for his newborn baby girl. I also want to thank George Sedov for his explanations and his really helpful scripts. I wish him good luck for his PhD. Alexander Glazov was also of a great help; his good mood and clear ideas were inspiring.

The DESY summer student program was a great experience, thanks to all the people taking part of its organisation. I would recommend it to any student who has interests in physics, not necessarily future high energy physicists or photon scientists. Meeting new people from all over the world and discovering Hamburg and other cities in Germany in this really instructive but quite relaxed atmosphere is a great opportunity.

References

[1] S Lloyd, *Atlas WIKI Page: workbook*, **online**, Available on: https://twiki.cern.ch/twiki/bin/view/Atlas/WorkBook

[2] E Barberio *et al*, *J. Phys.: Conf. Ser.* **119**, 032008 (2008)

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[4] W. Ehrenfeld, *Atlas LXR Server: frozen shower libraries*, **online**, Available on: http://alxr.usatlas.bnl.gov/lxr-stb4/source/atlas/LArCalorimeter/LArG4/LArG4GenShowerLib/doc/generate_libs.txt

[5] N.Gagunashvili, *root documentation*, **online**, Available on: http://root.cern.ch/root/htmldoc//TH1.html#TH1:Chi2Test

Figures

figure 1 : Particule Data Group, *PDG review 2010*, Figure 27.14 (2010)

figure 3 : Adapted from S Lloyd, *Atlas WIKI Page: workbook*, **online**, Available on: https://twiki.cern.ch/twiki/bin/view/Atlas/WorkBook

figure 6 : E Barberio *et al*, *J. Phys.: Conf. Ser.* **160**, 012082 (2009)