DESY Summer Student Programme
Project Report

Pion Frozen Showers in the Forward ATLAS Detector FCAL

Ömer Can Gürdoğan
Ringailė Plačakytė
Alexander Glazov

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Abstract

Frozen showers, which are precalculated shower libraries, are being used to gain CPU time in the simulations of the electromagnetic (EM) showers in the ATLAS EM detectors[1]. In this work we applied the frozen showers technique to the forward ATLAS calorimeter FCAL for pions and it resulted in additional 14% speed increase in $Z \rightarrow e^+e^-$ event simulations.

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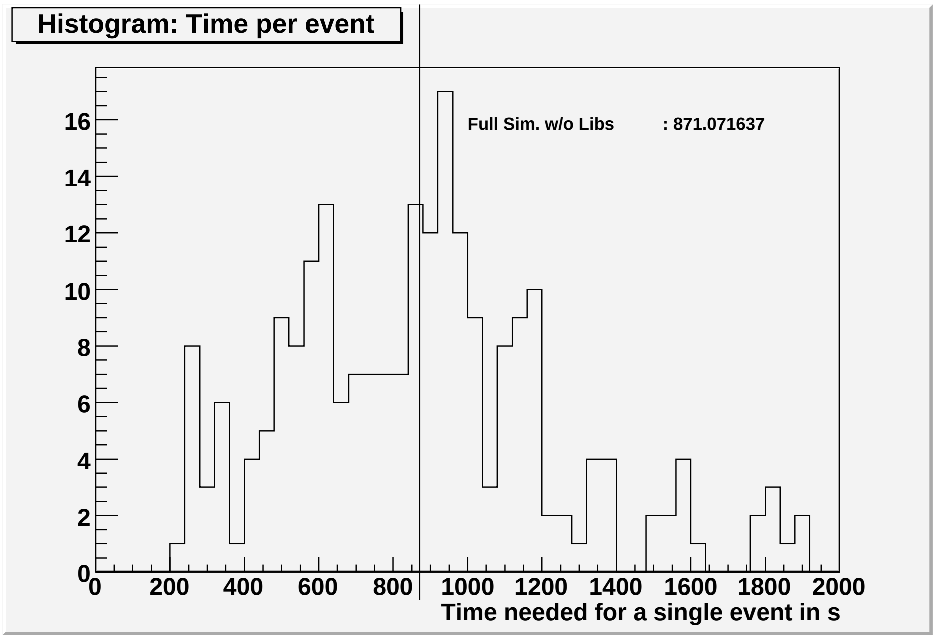


Figure 1: Simulation time of 250 $Z \to e^+e^-$ events

1 Introduction

Simulations of one pp event in the ATLAS detector at the LHC requires a significiant amount of time. For example the simulation of one $Z \to e^+e^-$ event requires 871 seconds in average as seen in Figure 1. The idea of frozen showers is to have readily generated shower libraries that store precalculated shower profiles and use them in the simulation instead of calculating the shower profiles every time. The technique of frozen showers is already being used for EM showers in ATLAS [1].

2 Pion Frozen Showers in the ATLAS Forward Calorimeter FCAL

FCAL is a good candidate to implement frozen showers because it takes a significiant percent of the simulation time and has a geometry rather uniform in particle rapidity η. Table 1 below shows the fractions of the simulation time that takes each ATLAS subdetector for four physics event classes . From Table 1 can be seen that FCAL takes the longest time over the other calorimeters. One can also see that use of frozen showers (here EM showers only) reduces this percentage by approximately 50%.

A second reason for choosing FCAL is its geometry. FCAL stands in the $\eta = 3.1 - 4.9$ range. It consist of three parts placed behind each other, namely FCAL1, FCAL2 and FCAL3. While FCAL1 is an electromagnetic calorimeter, FCAL2 and FCAL3 are hadronic calorimeters. FCAL1 uses copper plates as

	Di-jets		SUSY		Z to ee		Z to tt	
	Fast	Full	Fast	Full	Fast	Full	Fast	Full
EMB	1,83	1,44	4,04	4,50	1,50	1,39	1,95	1,62
EMEC	16,69	23,87	16,21	28,24	15,29	28,61	15,78	24,77
FCAL	18,83	39,35	13,46	24,30	18,22	37,07	17,56	36,42
HEC	5,28	2,39	6,41	2,62	4,44	1,72	4,95	2,20
Tile	1,20	0,47	8,97	3,29	0,72	0,25	1,56	0,66
Tracker	24,65	10,48	20,31	7,97	26,85	9,70	25,44	10,75
Muons	8,25	3,23	5,96	2,20	9,26	3,24	8,73	3,56
Others	23,48	16,76	25,64	26,88	23,72	18,03	24,04	20,02

Table 1: Fraction of the total time that each subetector takes for four different physics event classes

absorbers whereas mainly tungsten was used in FCAL2 and FCAL3 [2].

3 Pion Libraries

The shower libraries have to contain different energy bins to accomodate the showers with different energies. To determine the energy bins of the pion libraries a set of $Z \rightarrow e^+e^-$ simulations was made. The energy distribution of π^+ and π^- particles is shown in Figure 2. Most of the particles are located in the 0-15000 MeV range, therefore the libraries were chosen to consist of the following energy bins :

- 150 MeV
- 500 MeV
- 1000 MeV
- 5000 MeV
- 10000 MeV
- 15000 MeV

There are 2000 events for each energy bin. These libraries, each consisting of 6 (number of energy bins) x 2000 events, have a filesize of 44MB.
The libraries were created for both π^+ and π^- particles. Since there were no differences observed between them (Appendix A) the π^+ library was chosen to be used for simulations for both particles.

4 Simulations in FCAL with Pion Libraries

After modifiying the simulation code to use pion libraries, simulations of single electron and π^+ have been used to validate pion libraries. The η range was chosen to be 3.2 to 4.7 to keep the showers within the FCAL. The following table shows the average times spent per event:

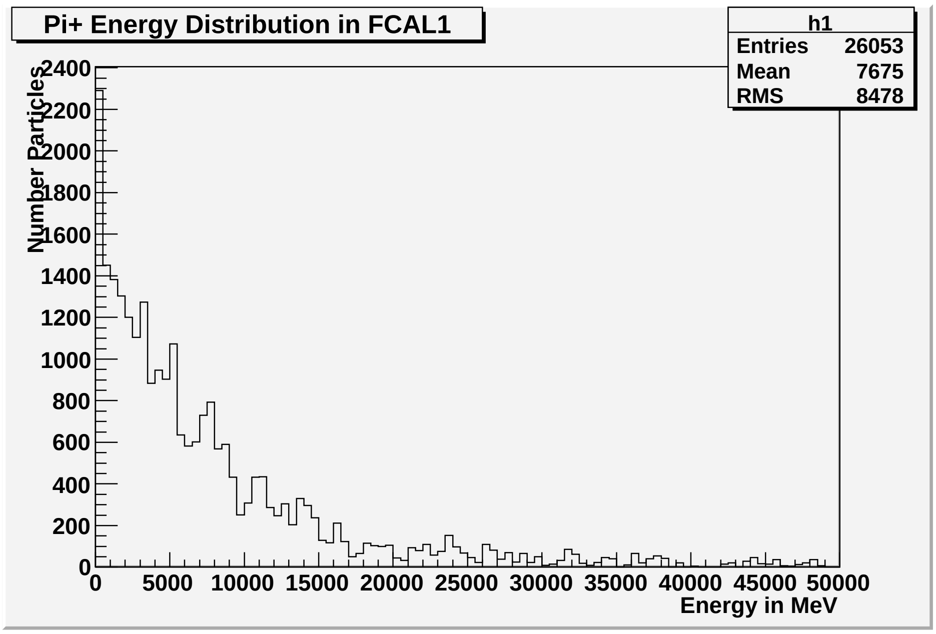


Figure 2: Energy distribution of pions in FCAL (full simulation)

	Full Sim.	Frozen Showers
e^-	14 +- 0.048	14 +- 0.053
π^+	12 +- 0.11	8.4 +- 0.13

Detailed comparisons of full simulations and simulations with frozen showers for electrons and pions can be found in appendices B and C, respectively. As expected, there is no change in electron simulations using pion libraries. However, there is the improvement in CPU time for pions as shown in Appendix C. Despite of the improvement in CPU time, the profile of the total deposited energy is not in agreement with full simulations. To understand this disagreement one can look at the collected energies in individual detector parts FCAL1 and FCAL2, which are EM and hadronic detectors, respectively. It can be seen that the energy profile is well described in FCAL1. For the showers that penetrate into FCAL2, however, the profiles do not match. The reason behind this is that the libraries are created for FCAL1 and they are not applied for events in FCAL2.

Several additional checks for simulations with pion libraries were done. Those checks include simulations with

- 50GeV instead of 100GeV particle energy
- fixed $\eta = 3.4, 3.7, 4.0, 4.4$
- only high (150 to 5000 MeV) / low (5000 to 15000 MeV) energy libraries

All studies show good acceptance in FCAL1 energy profiles but poor in FCAL2. However the disagreement in FCAL2 is less pronounced in simulations that use

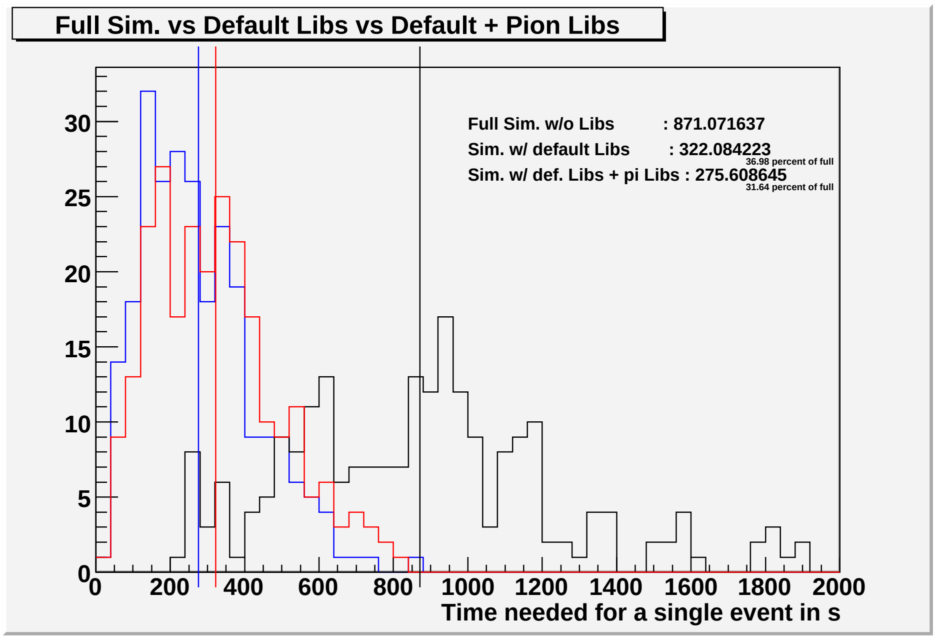


Figure 3: Simulation times of $Z \to e^+e^-$ events with libraries

only low energy libraries. This is an expected result since the low energy showers are more likely to stay within FCAL1.

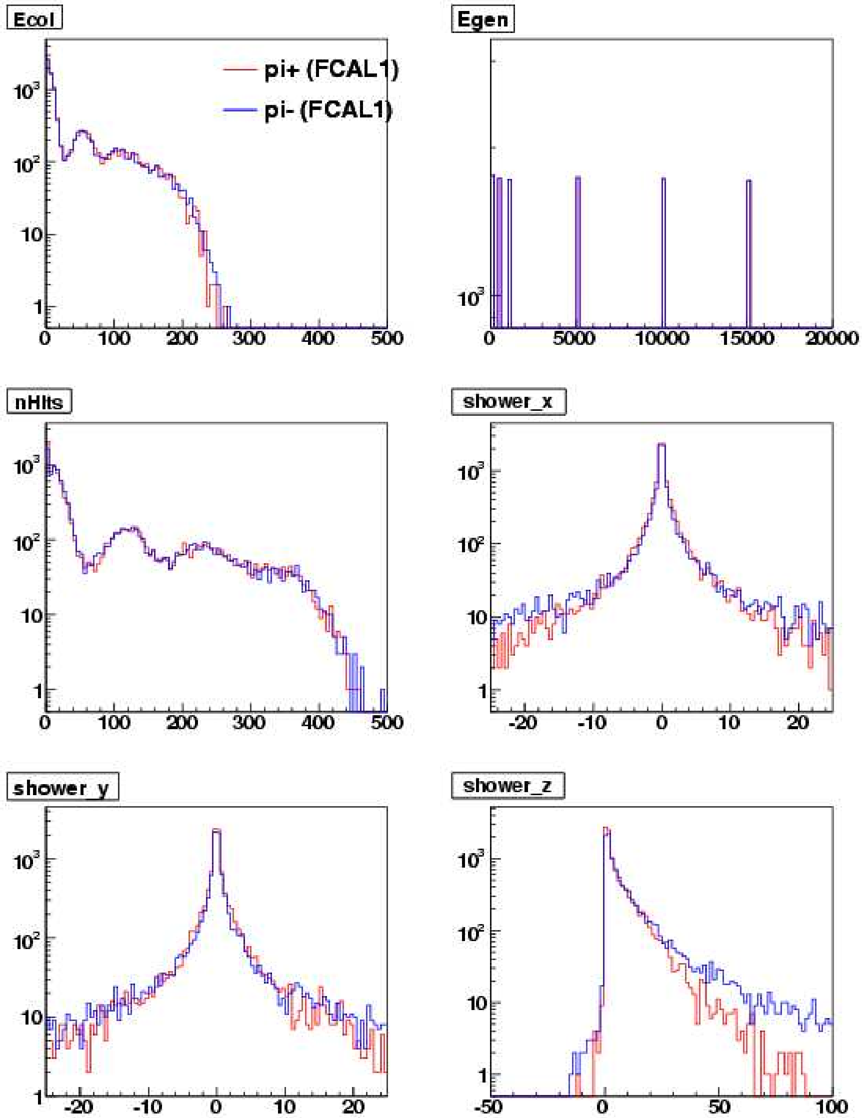
5 Simulations of $Z \to e^+e^-$ Events with Pion Libraries

In addition to the full simulation shown in Figure 1, two more simulations were made for the same $Z \to e^+e^-$ events. For this study a sample of 250 $Z \to e^+e^-$ events was generated using Pythia Monte Carlo. The same generated events were then simulated with different simulation options. One simulation includes only the default frozen showers (electromagnetic showers), the other one includes pion frozen showers in addition to the default libraries. The resulting simulation time for all cases are shown in Figure 3. The default libraries decrease the average simulation time to 322 seconds. The addition of pion libraries decrease this number to 276 seconds (blue plot).

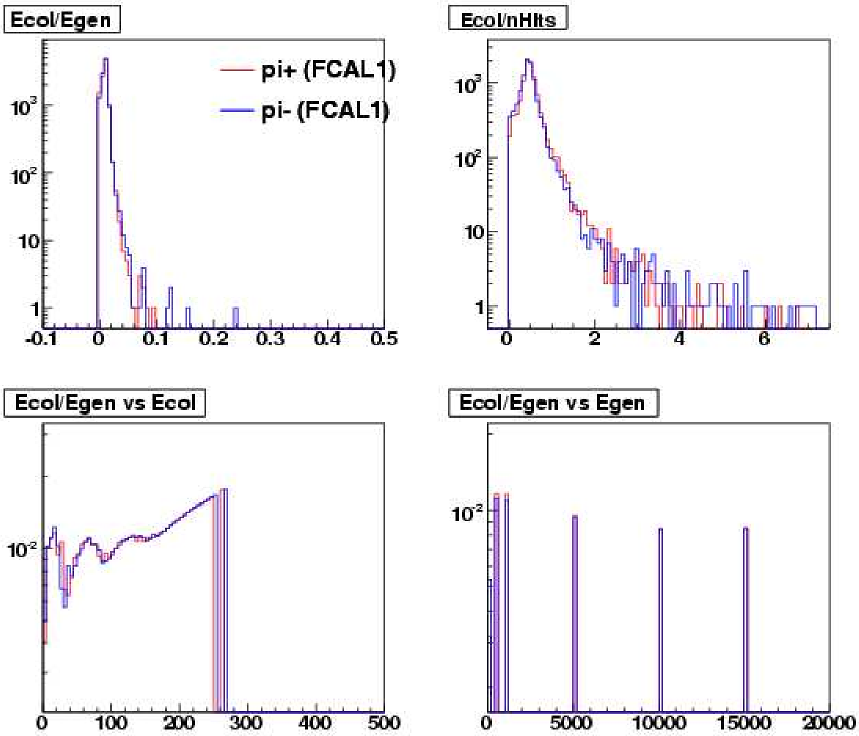
6 Conclusion

It was alreadily possible to use frozen showers to reduce simulation time in ATLAS EM calorimeters. Although the present study showed that pion libraries bring a quite significiant improvement in simulation time, they cannot yet be used. This is due to shower leekage to hadronic calorimeters resulting in the energy loss. The energy loss can be fixed by adding frozen showers to hadronic calorimeters or, for example, limiting the pion showers within FCAL1.

A π^+ Libraries vs π^- Libraries

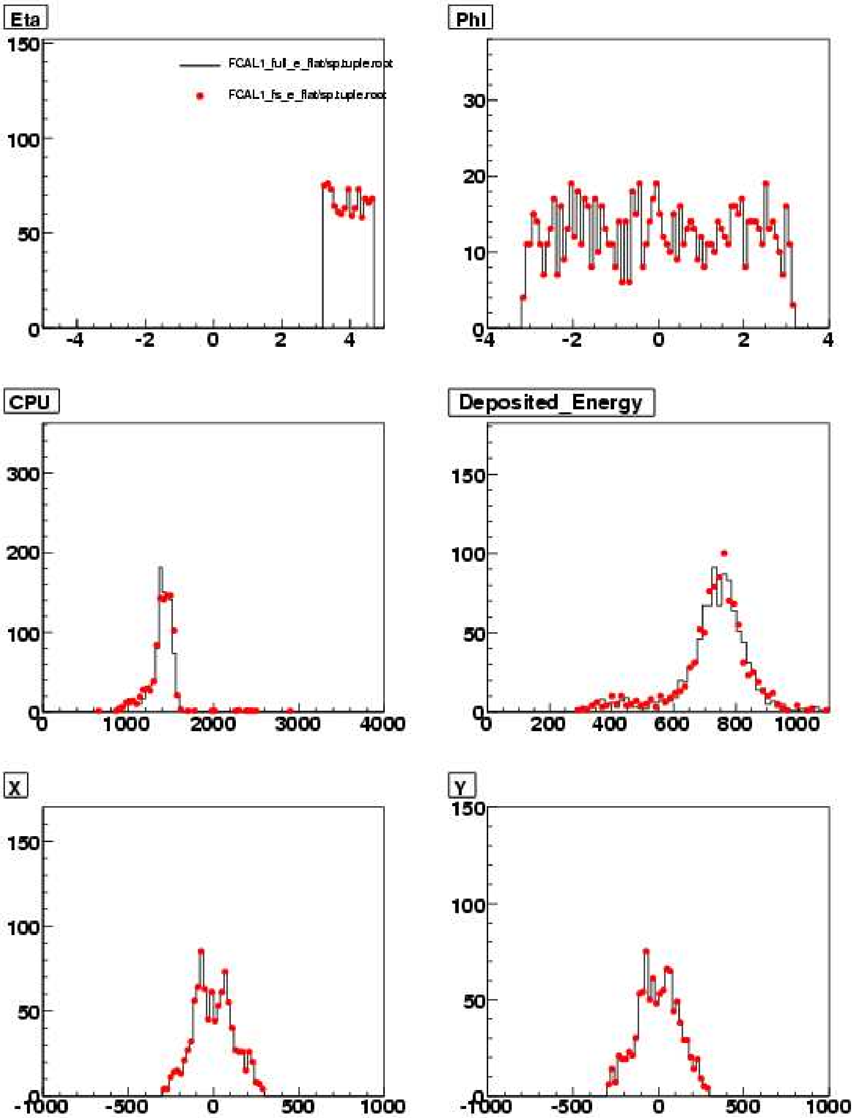


The comparison of π^+ and π^- libraries

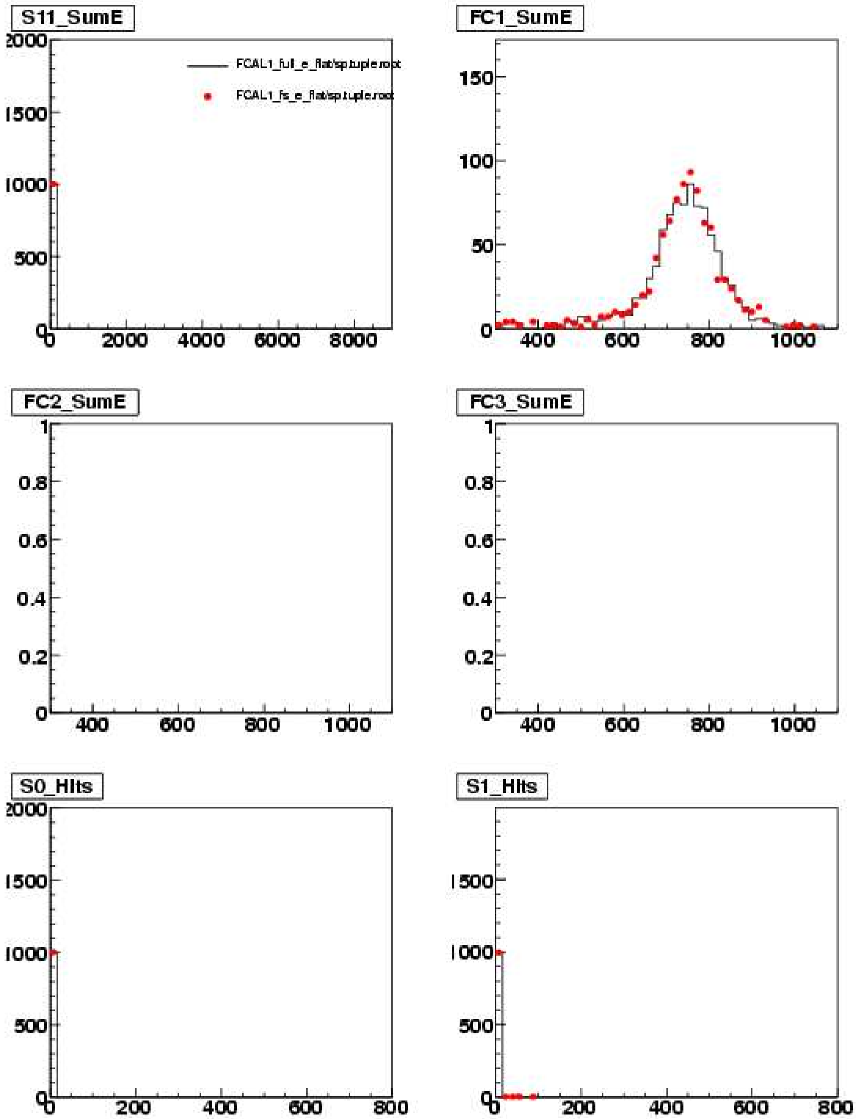


The comparison of π^+ and π^- libraries

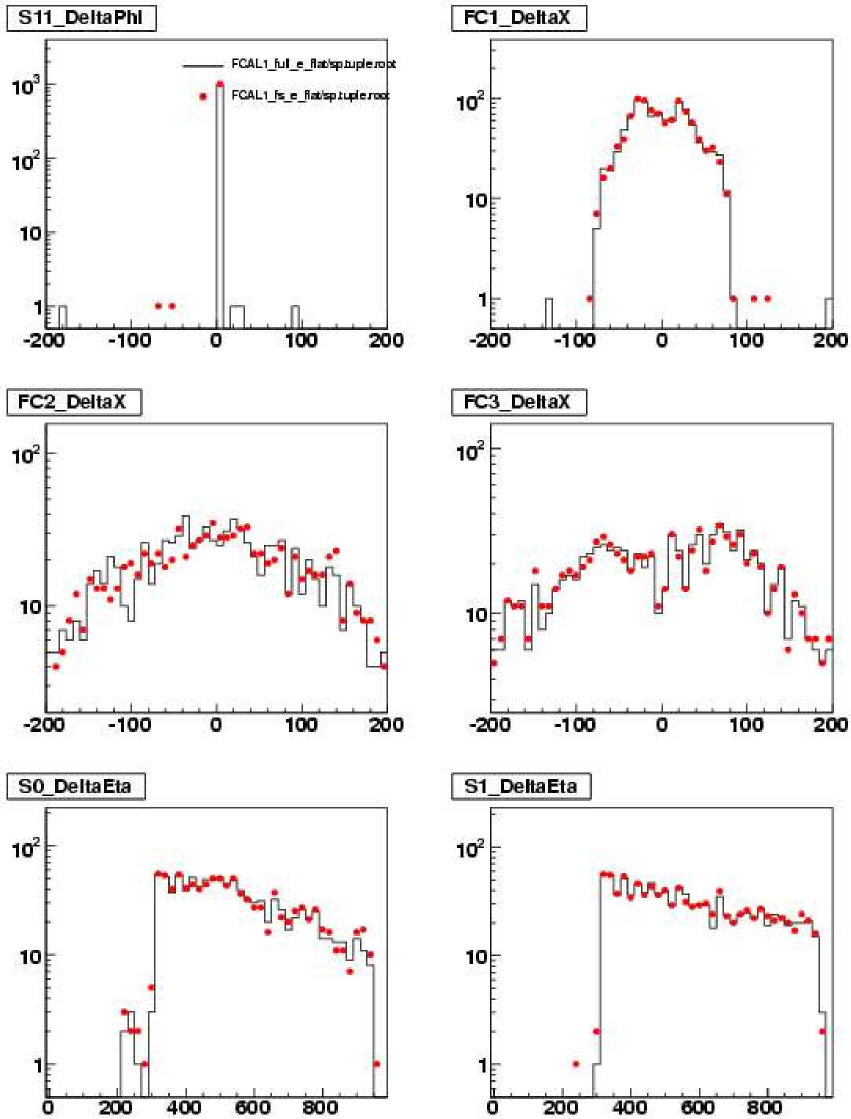
B e^- Simulations



Comparison of full e^- simulation (E=100 GeV, $\eta = 3.2 - 4.7$) with e^- simulation that uses π^+ frozen shower library

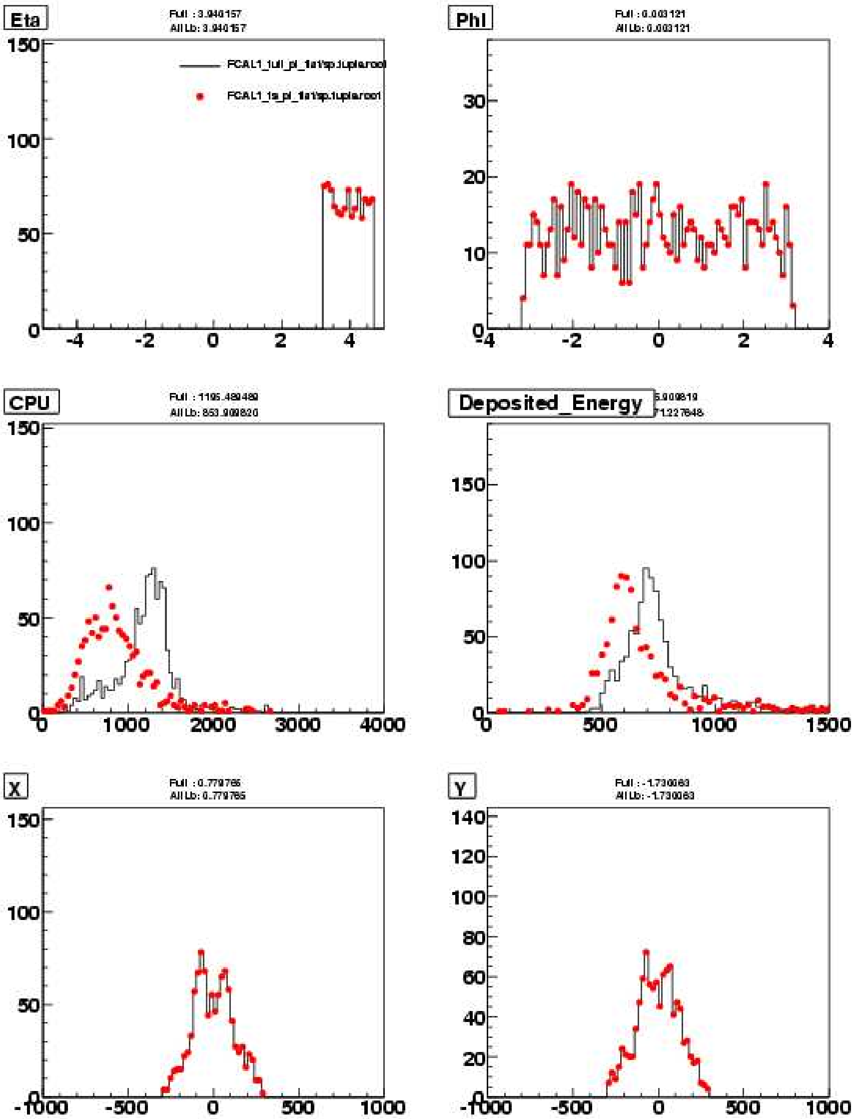


Comparison of full e^- simulation (E=100 GeV, $\eta = 3.2 - 4.7$) with e^- simulation that uses π^+ frozen shower library

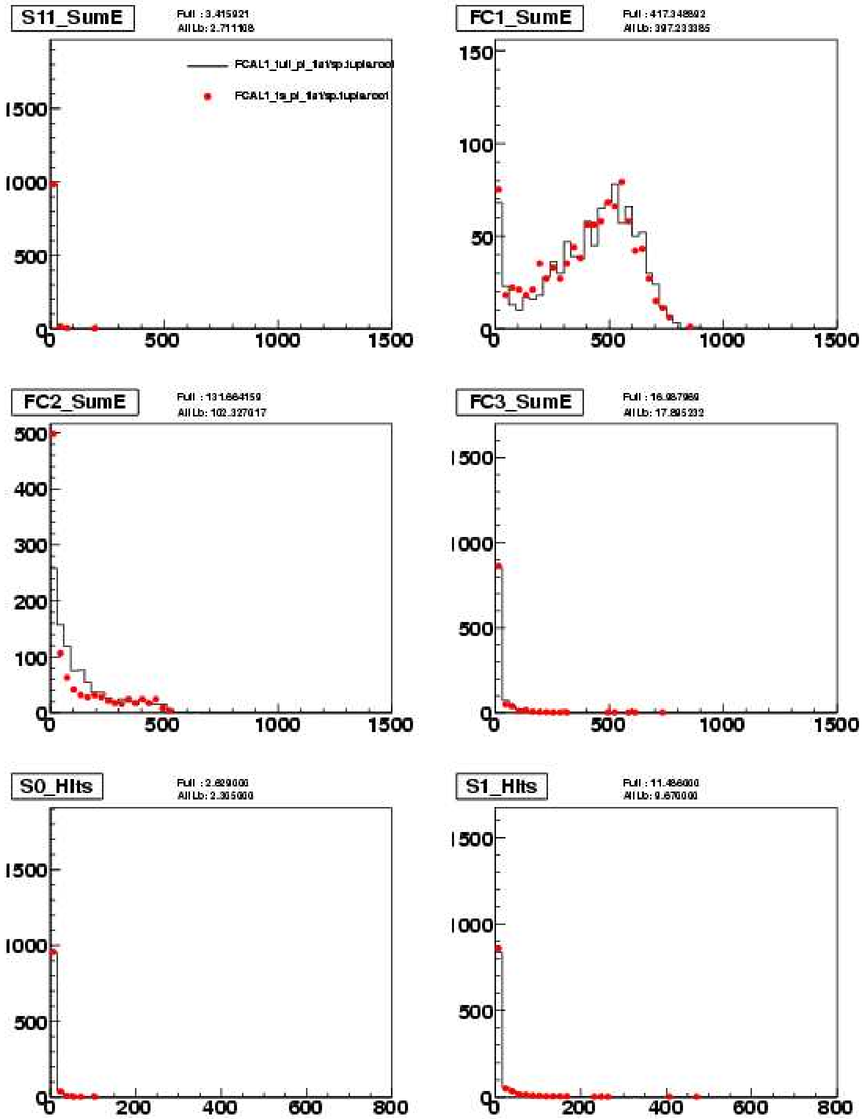


Comparison of full e^- simulation (E=100 GeV, $\eta = 3.2 - 4.7$) with e^- simulation that uses π^+ frozen shower library

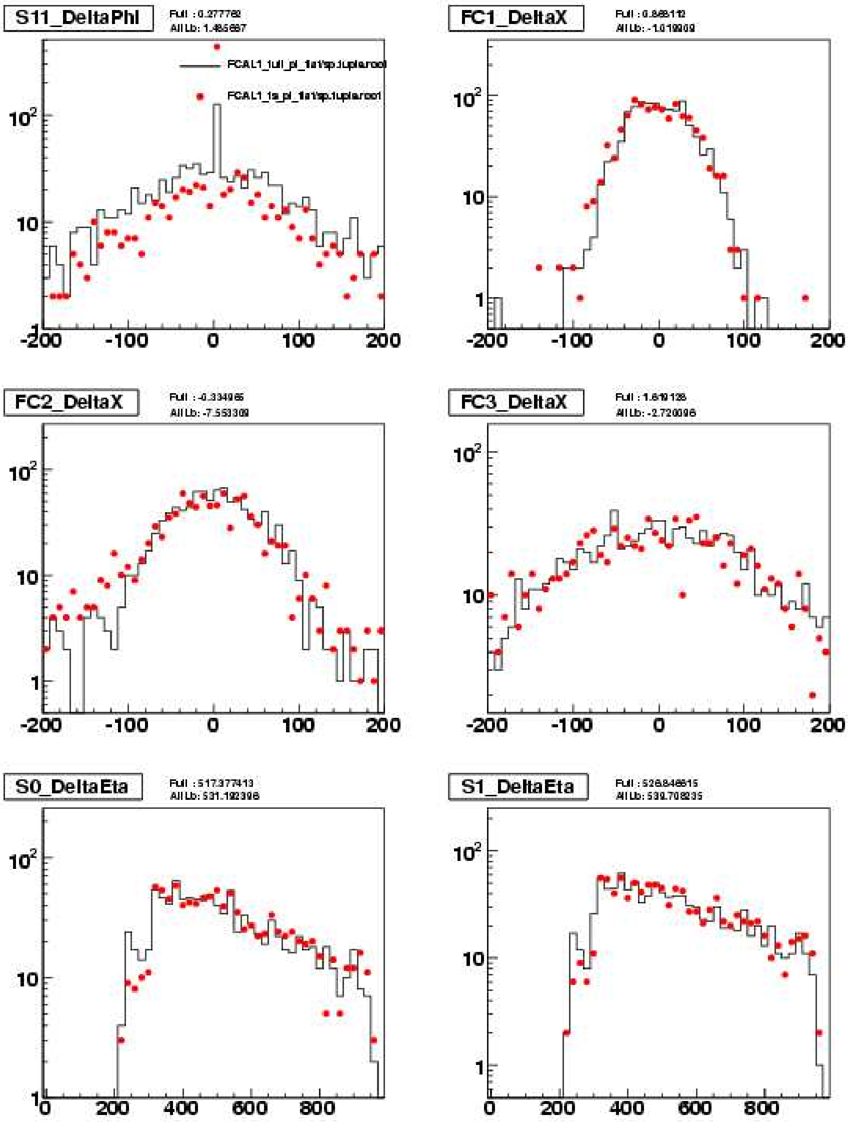
C π^+ Simulations



Comparison of full π^+ simulation (E=100 GeV, $\eta = 3.2 - 4.7$) with e^- simulation that uses π^+ frozen shower library



Comparison of full π^+ simulation (E=100 GeV, $\eta = 3.2 - 4.7$) with e^- simulation that uses π^+ frozen shower library



Comparison of full π^+ simulation (E=100 GeV, $\eta = 3.2 - 4.7$) with e^- simulation that uses π^+ frozen shower library

References

[1] Ehrenfeld W. *Fast Shower Simulation in the ATLAS calorimeter.* contributed paper to International Conference on Computing in High Energy and Nuclear Physics (CHEP07), Victoria BC Canada, 2007.

[2] The ATLAS Collaboration G Aad et al. *The ATLAS Experiment at the CERN Large Hadron Collider.* 2008.