Comparisons of EAShower and GEANTShower

Anthony Shoup

Dept. of Physics
University of California
Irvine, CA 92717

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1 Introduction

The email memos by Cristobal Padilla and Matteo Cavalli-Sforza of August 1995 pointed out some differences between air shower Monte Carlo packages and also a problem with the Monte Carlo program EAShower. Specifically, they showed that EAShower and an air shower generation program using GEANT produced significantly different results for several shower characteristics for photon and proton initiated air showers. Simply put, EAShower showers had larger amounts of energy reaching the ground than did GEANT showers. This was manifest by a larger number of photons (the dominant type of secondary reaching the ground) and a larger average photon energy. The problem with EAShower presented by Cristobal and Matteo was that the number of photons reaching the ground varied by a factor of two when the EGS tail threshold was changed from 1 to 100 GeV.

As most of you know, EAShower is a program created by Steve Biller using J. A. Wrotniak's ShowerSim. The ShowerSim package was written to simulate the development of air showers in the Ultra-High Energy region ($>$ 10.0 TeV) produced by various primary species, such as photons, protons, and atomic nucleii. To obtain the impressive "speed" of ShowerSim, the package used several relativistic approximations which are certainly valid for the normal energy range of ShowerSim. However, most of the speed gains of ShowerSim (or EAShower) are due to the processing of electromagnetic tails, either by using the analytical approximations of Approxation B (reference?) and NKG (reference?) or by attaching previously generated EGS4.0 tails (subshowers).

The hadronic models use in EAShower were devised to correspond to ISR and Sp-barpS collider data and also other data where available. Some description of this comparision can be found in the paper by H.T.Freudenreich et al, Phys. Rev. D41, 2732, 1990 and also in J.A.Wrotniak and G.B.Yodh in Proc. of the 19th ICRC in La Jolla, 1985, vol 6, p56. It should be pointed out that many properties of air shower propagation are dominated by large values of Feynman x, where there is a paucity of data at collider energies.

EAShower calculations have been compared with a variety of actual cosmic ray data: High energy muons (Parente et al, Astroparticle Physics, 3, 17, 1995), Muons in air showers (G.B.Yodh et al, Phys. Rev. D29, 892, 1984), Cygnus data (D.E.Alexandreas et al., NIM A311, 350, 1992 and Biller's thesis) and low energy hadrons (J.A.Goodman et. al, Phys. Rev. D26, 1043, 1982 and H. T. Freudenreich et. al , ibid). These comparisions cover the energy range from a few hundred GeV to PeVs and are sensitive to different features of the simulations. None of these comparisions really tested all the properties of showers that are needed in doing the best possible simulation for Milagro, however they do show that EAShower is a pretty good program. EAShower does not deal with hadronic collisions in the detail that Geant probably does, but it has most of the features of shower development which significantly influence air shower experiments.

Instead of "throwing away" the impressive speed acheived by EAShower, not to mention all the hard work put into it, I thought it worthwhile to investigate the why there were differences between the two Monte Carlo packages. More importantly, I wanted to fix the problem which produced different results for different EGS tail threshold values. I also wanted to make a more thorough comparison between results obtained by EAShower and those of GEANT.

In the following sections, I describe how I fixed the tail threshold problem in EAShower and present comparisons of characteristics of secondary particles reaching the ground. I will show that after fixing the tail threshold, problem, the two (very different) Monte Carlo air shower packages actually agree quite well. I also show a comparison between showers generated using a tail library and those using tails generated "on-the-fly". Aside from slightly higher fluctuations in some distributions of secondary characteristics, the agreement is good.

2 EAShower Fixes

The fact that the amount of energy reaching the ground in showers produced by EAShower varied with EGS tail threshold indicated that ShowerSim and EGS were handling the propagation of photons and electrons differently. With a "low" tail threshold, ShowerSim processes most of the shower. With a high tail threshold, EGS processes most (if not all) of the shower. One obvious place to check was the modeling of the atmosphere and how this influenced particle propagation.

ShowerSim has a very robust model (based on the U.S. standard atmosphere) and a straightforward implementation (since particles are stepped in $grams/cm^2$). EGS however was designed for constant density media and thus introducing a density that varies expodentially is rather tricky. The original EAShower version attempted to do this by recalculating the step size requested by the EGS code. The requested step size, S_m (in meters), was converted into gms/cm^2, S_g, based on the air density used by EGS to compute S_m. S_g was then rescaled to S'_g by a rather complicated parameterization which depends on S_g, the particle's Z-direction and the current air density. S'_g is then converted to meters, S'_m, and the current particle's position is changed so that when the EGS code steps the particle by S_m, the particle is really only stepped by S'_m. So EGS thinks it has stepped by S_m and this effects the distance to the next interaction point. In addition, dE/dx losses are also sensitive to the air density and this is not correctly handle by this procedure.

My fix to this was to rescale every step size computed by EGS inside the EGS routines ELECTR and PHOTON which handle the propagation of electrons and photons. This was done by the following algorithm:

1. Compute current atmospheric depth (using Z position and U.S. model)
2. Compute vertical step size in $grams/cm^2$
3. Compute new depth after step and compute new Z position
4. Compute required step size to get to new Z position

Again, this was done for every step calculation in EGS, which, for electrons included the current scattering distance, range (from dE/dx), and interaction distance.

3 Results

Using this new version of EAShower and the air shower program using GEANT written by Cristobal, I call GEANTShower, I generated several sets of vertical showers initiated by photons. I generated 1000 showers at 100 GeV, 500 showers at 500 GeV, and 100 shower at 2000 GeV. The figures and their captions below are a graphical summary of the results. They show direct comparisons of distributions of secondary particle characteristics in addition to shower development curves. Sorry for the large number of graphs, but it is important to look at all aspects of the showers. Even with all the plots, I certainly have not looked at all possible correlations between characteristics.

The plots show that EAShower and GEANTShower agree quite well in all aspects except for a slight difference in lateral distributions of secondaries. This difference is probably caused by differences in GEANTShower's and EAShower's implementation of the U.S. standard atmospheric model. GEANTShower uses 20 constant density layers whereas EAShower trys to implement a continuously varying air density.

4 Final Comments

I plan to compare results from proton and nuclii induced showers as well. Considering the difficulty of simulating the appropriate processes, the results should be interesting.

Hopefully this memo will help us decide which direction to go in our continuing quest for a Monte Carlo package which is "as correct as" possible.

5 Figures

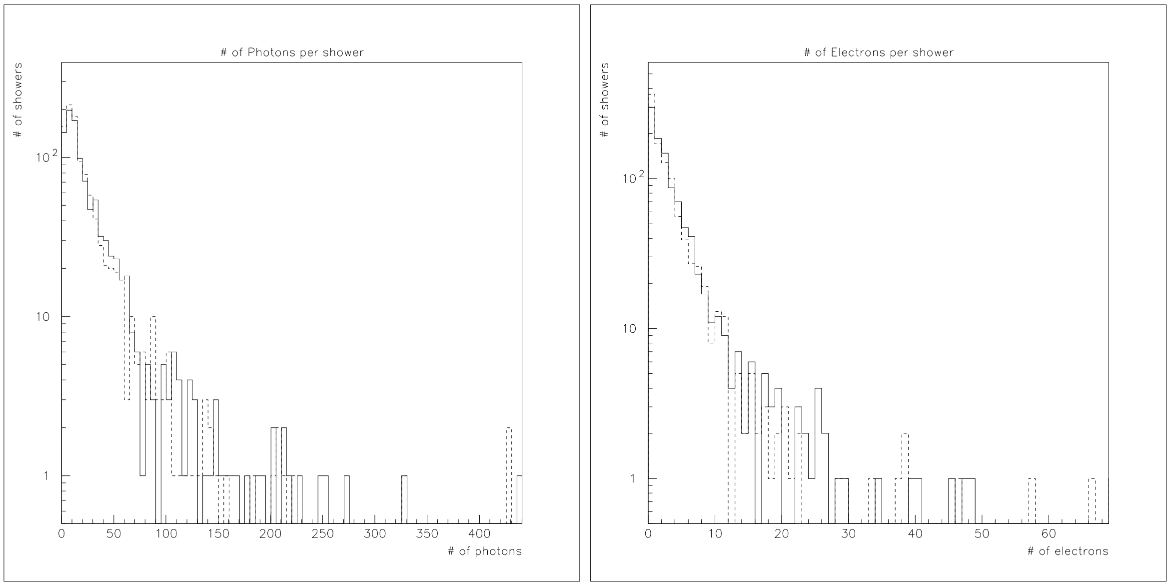

Figure 1: # of photons and electrons at 750g per 100 GeV shower. EAShower is solid line, GEANTShower is dashed line. Mean # of photons in EAShowers (GEANTShowers) is 27.1 (25.6). Mean # of electrons is 3.2 (2.8)

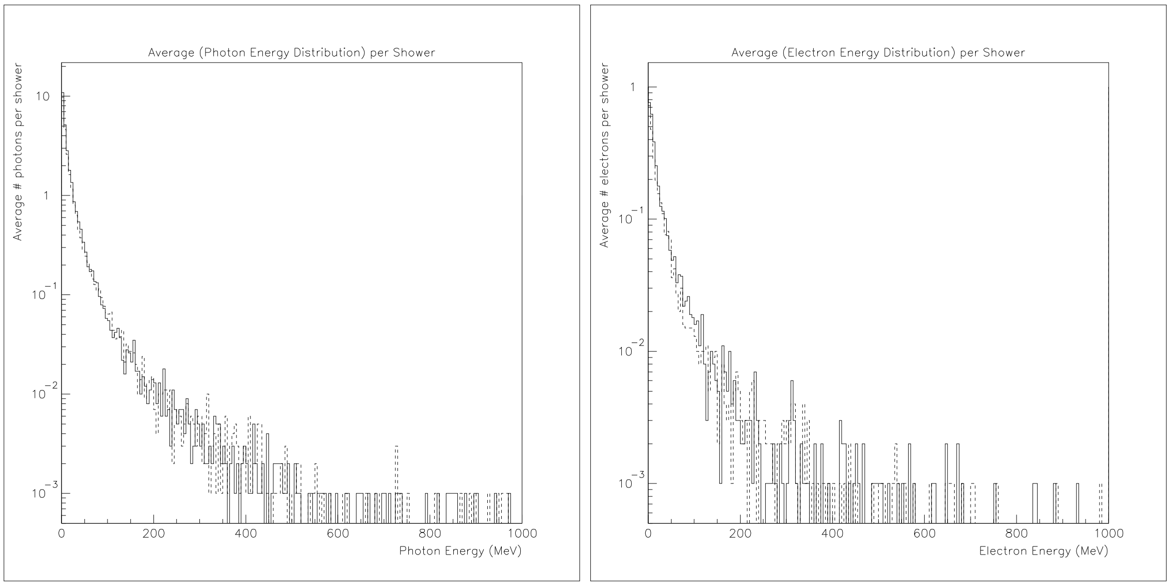

Figure 2: Average "photon and electron energy distributions" per 100 GeV shower. EAShower is solid line, GEANTShower is dashed line.

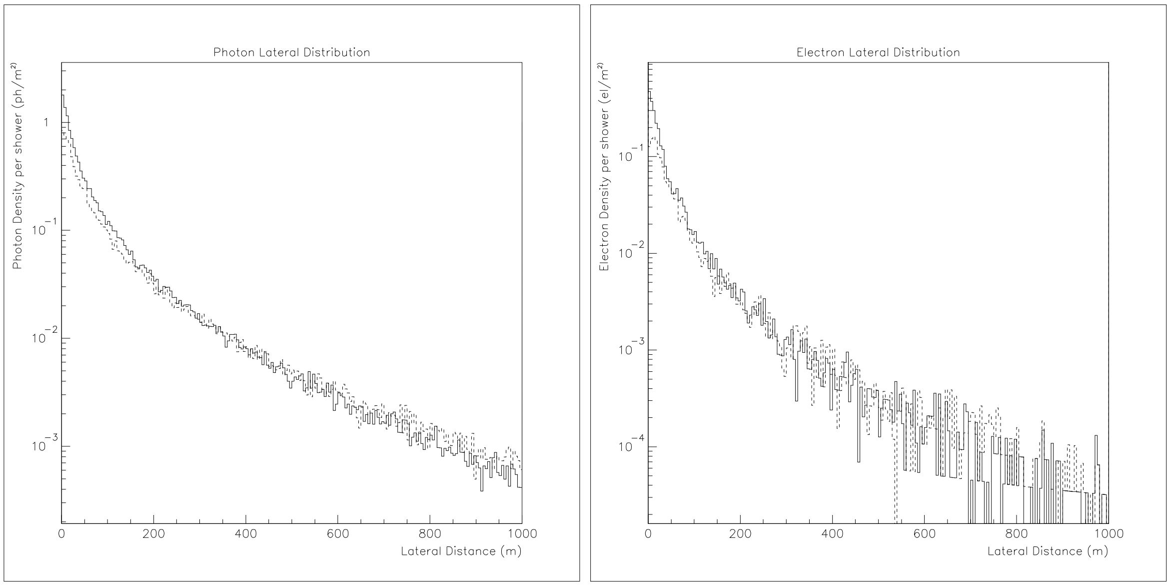

Figure 3: Average "photon and electron lateral distributions" per 100 GeV shower. EAShower is solid line, GEANTShower is dashed line.

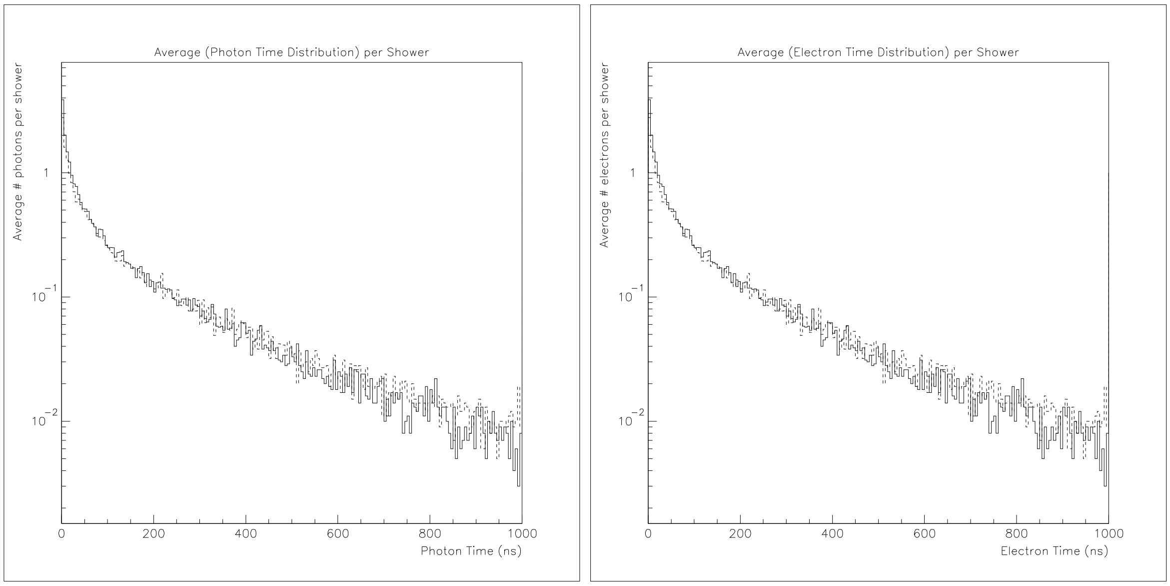

Figure 4: Average “photon and electron time distributions” per 100 GeV shower. EAShower is solid line, GEANTShower is dashed line.

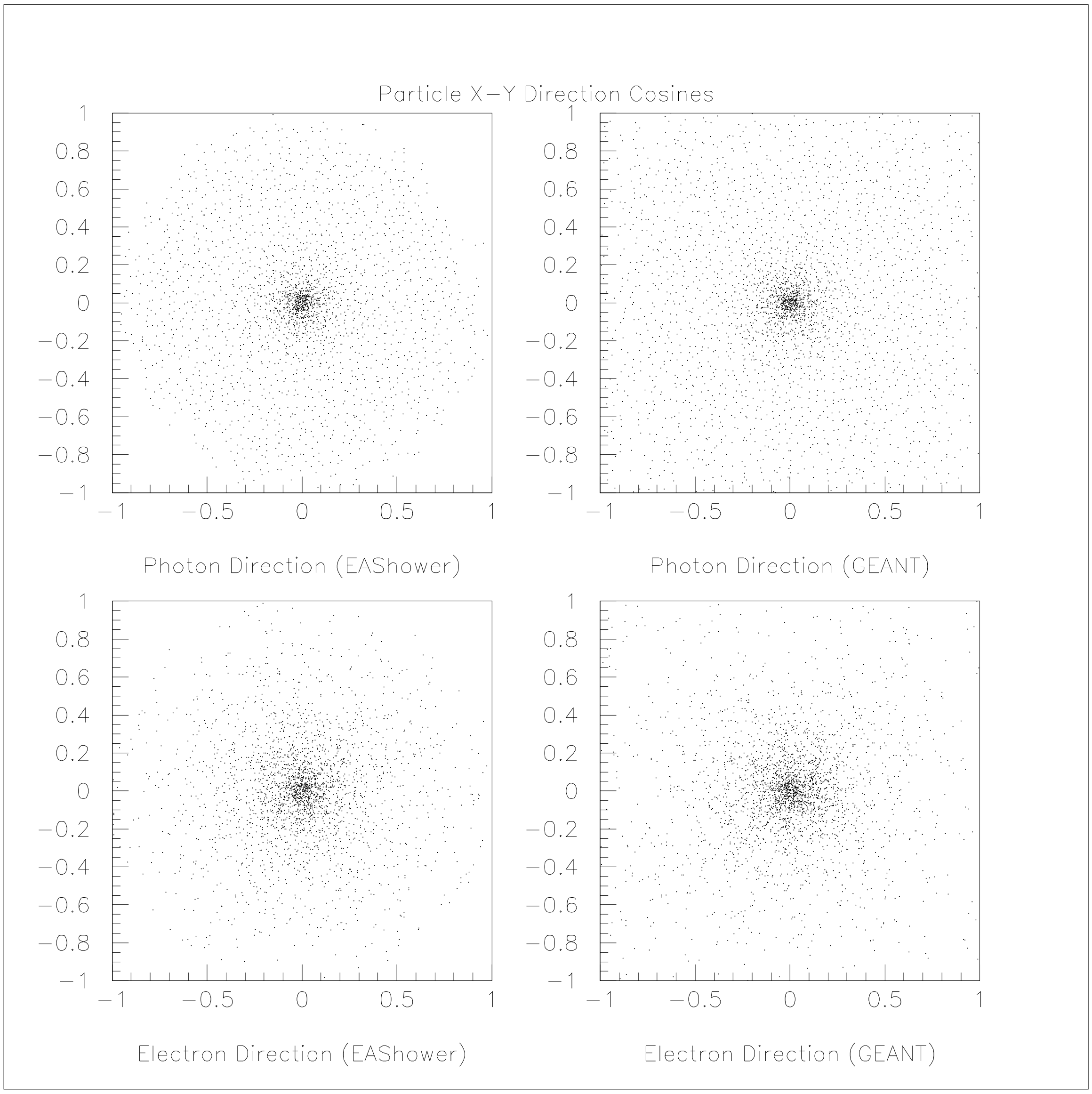

Figure 5: Photon and electron direction cosines for 100 GeV showers.

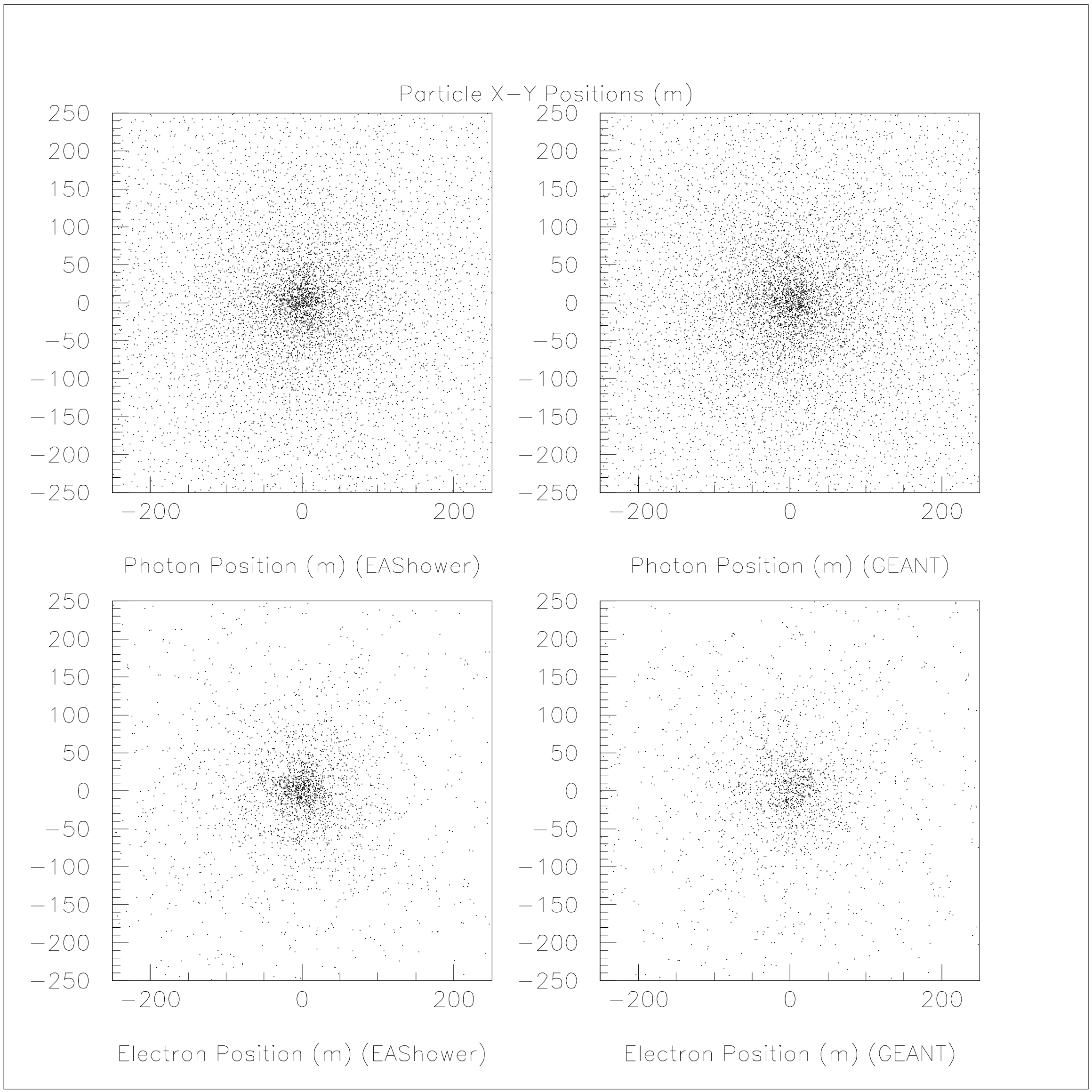

Figure 6: Photon and electron X vs. Y positions from core for 100 GeV showers.

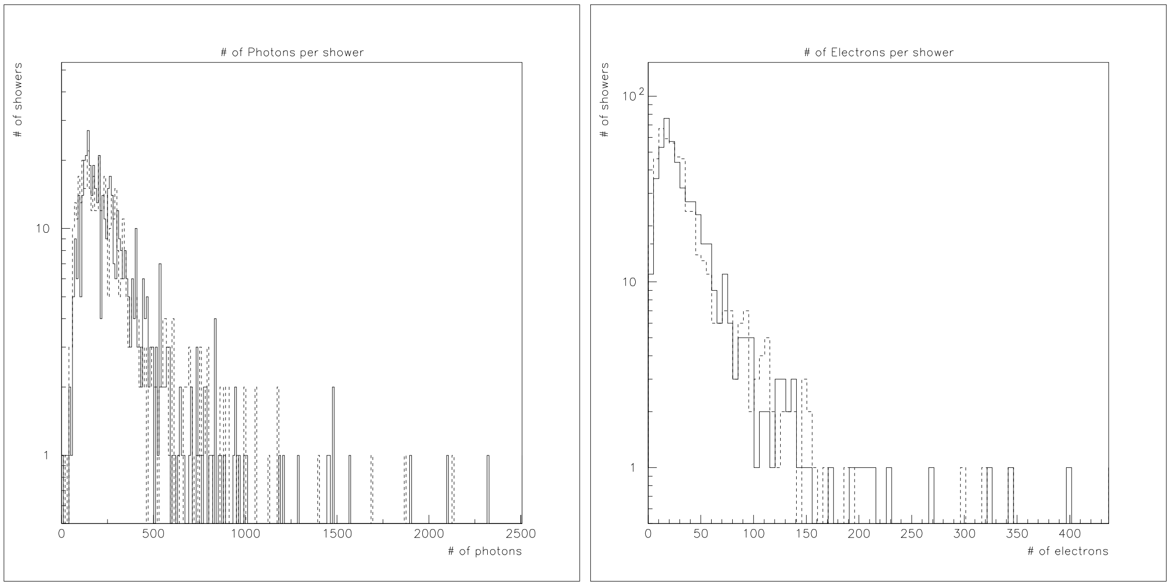

Figure 7: # of photons and electrons at $750g$ per 500 GeV shower. EAShower is solid line, GEANTShower is dashed line. Mean # of photons in EAShowers (GEANTShowers) is 316 (298). Mean # of electrons is 41.4 (37.8)

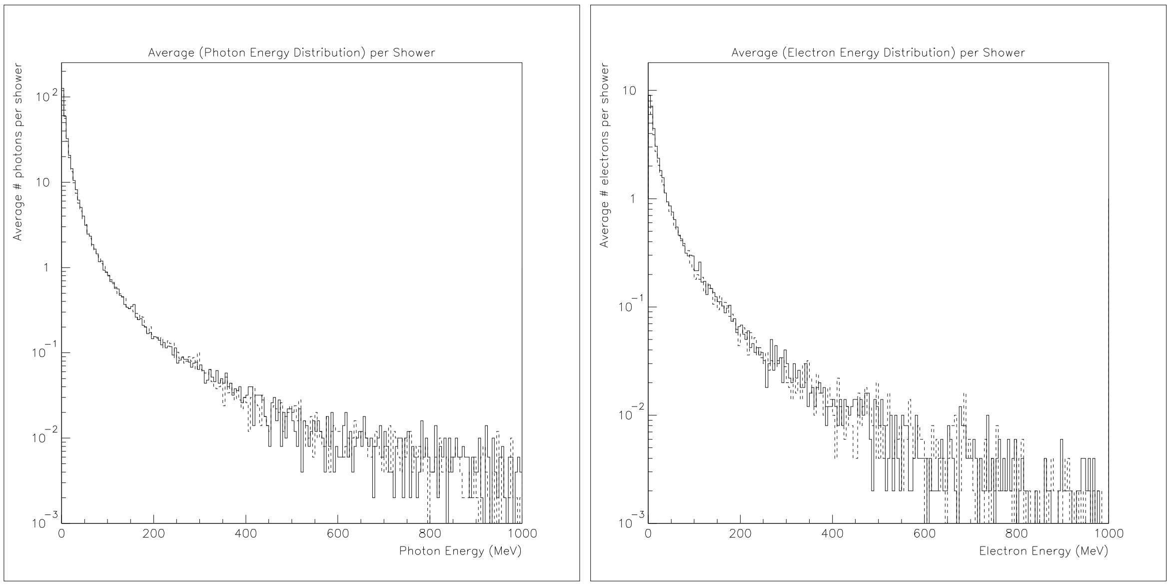

Figure 8: Average "photon and electron energy distributions" per 500 GeV shower. EAShower is solid line, GEANTShower is dashed line.

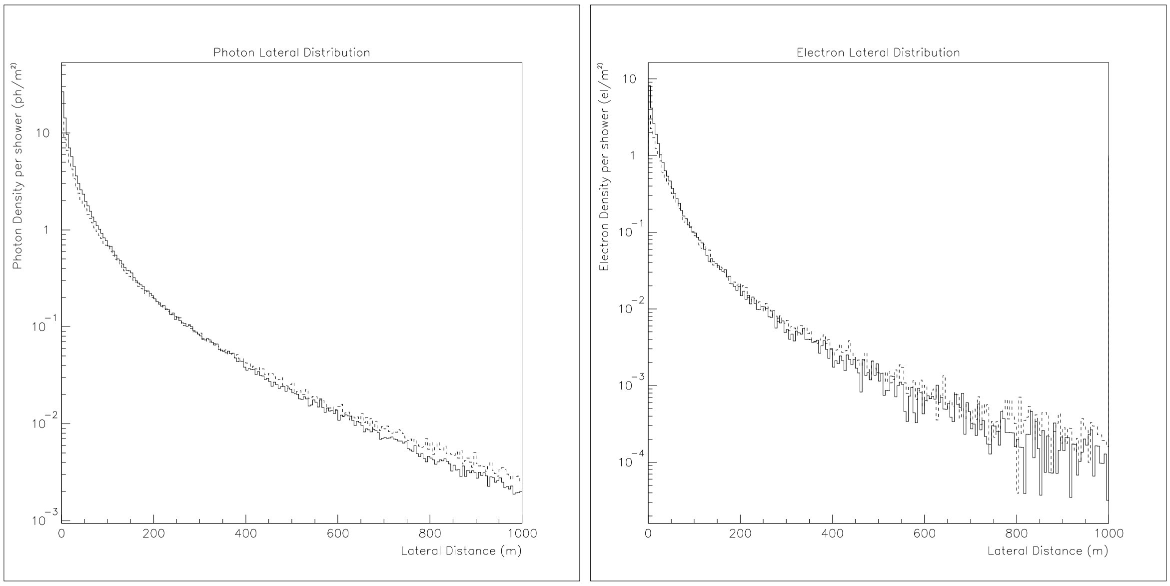

Figure 9: Average "photon and electron lateral distributions" per 500 GeV shower. EAShower is solid line, GEANTShower is dashed line.

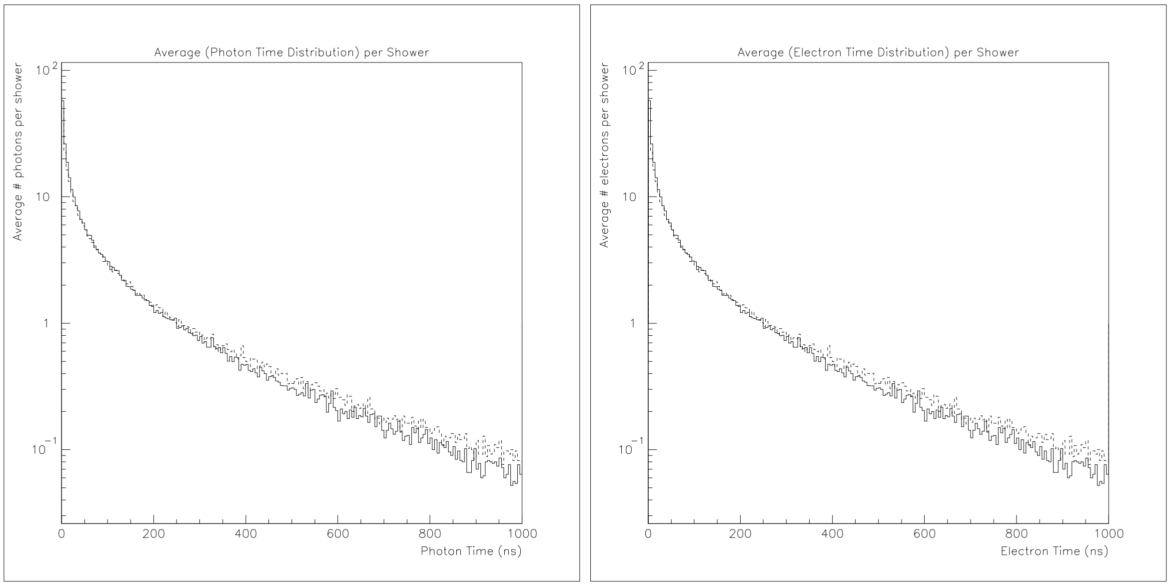

Figure 10: Average "photon and electron time distributions" per 500 GeV shower. EAShower is solid line, GEANTShower is dashed line.

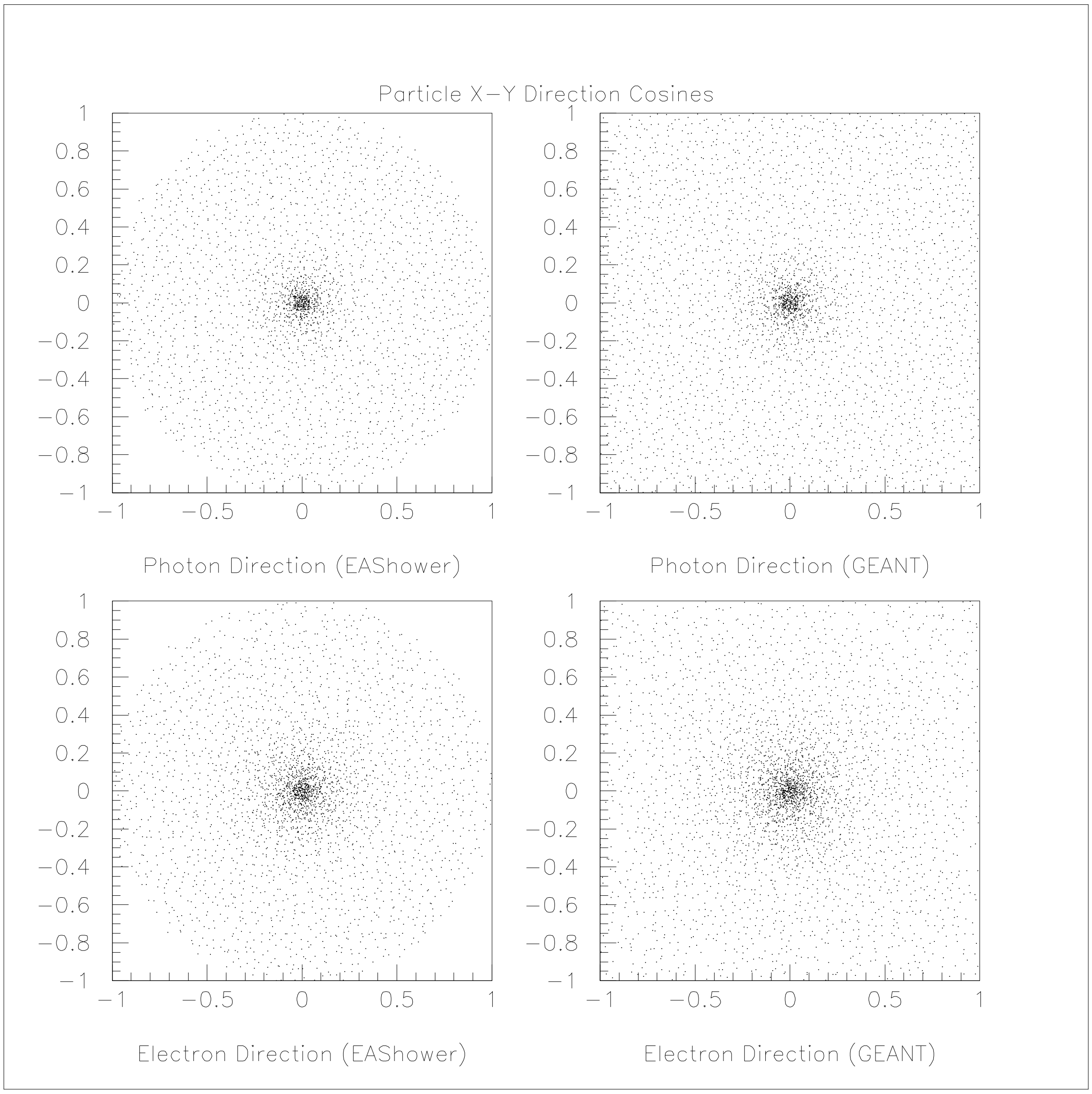

Figure 11: Photon and electron direction cosines for 500 GeV Showers

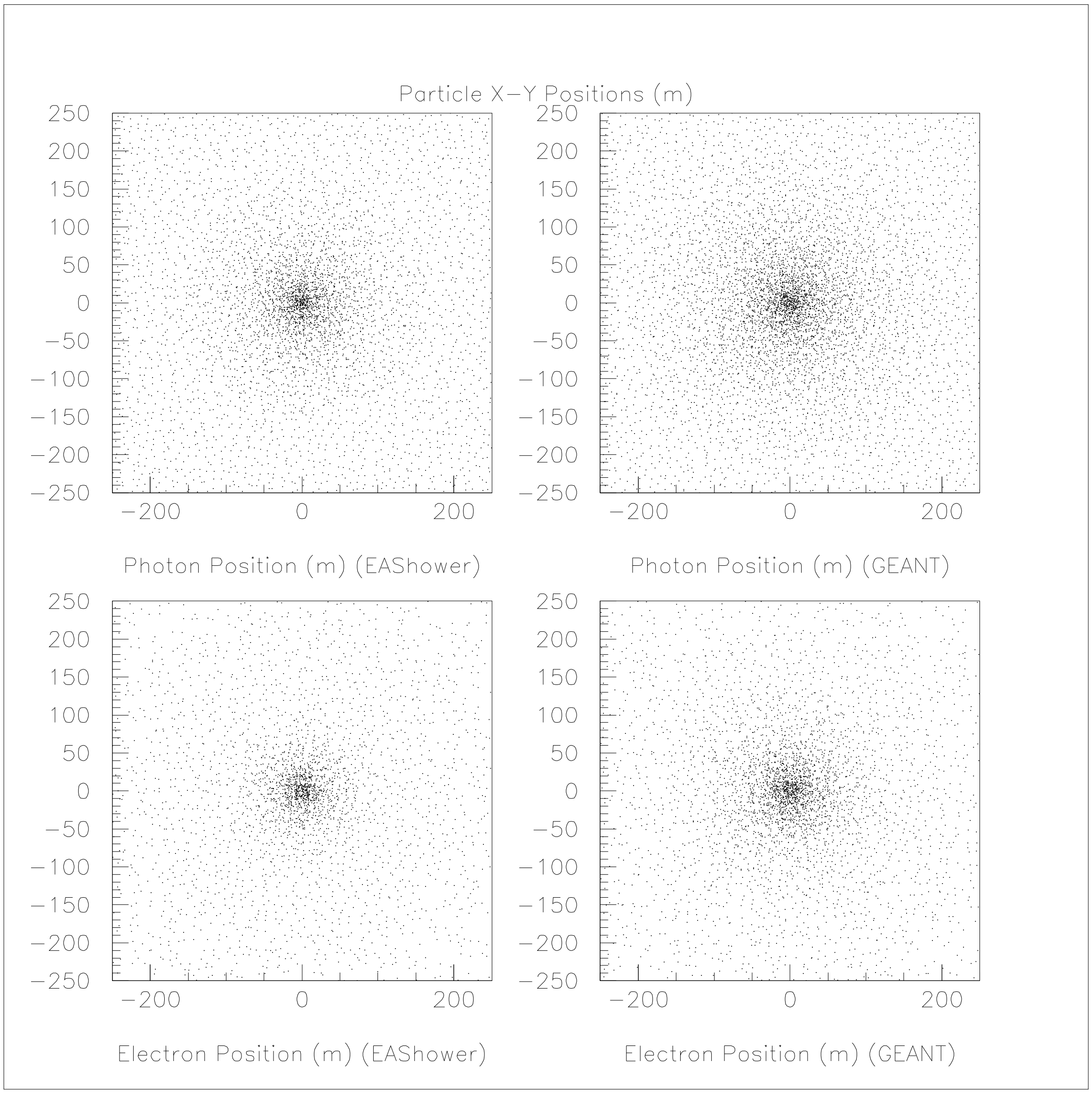

Figure 12: Photon and electron X vs. Y positions from core for 500 GeV Showers.

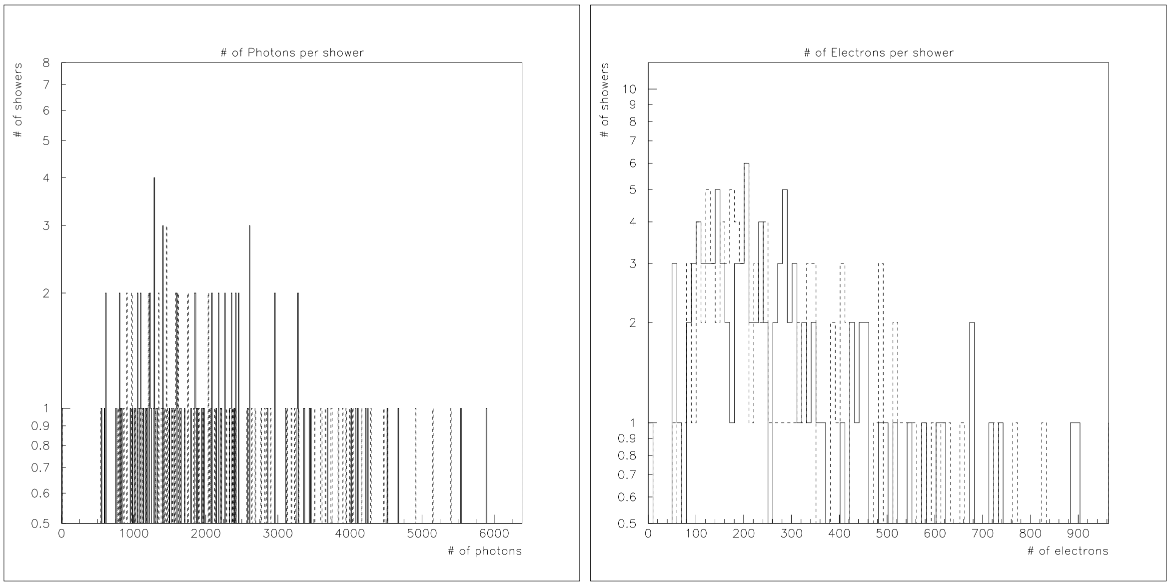

Figure 13: # of photons and electrons at $750g$ per 2000 GeV shower. EAShower is solid line, GEANTShower is dashed line. Mean # of photons in EAShowers (GEANTShowers) is 2116 (2180). Mean # of electrons is 286 (289)

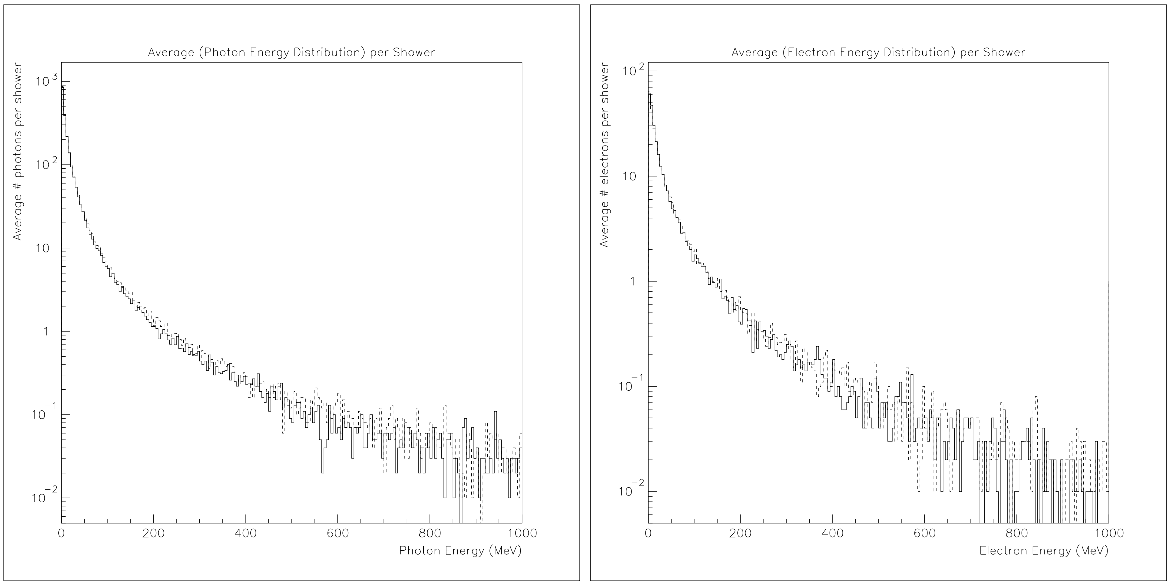

Figure 14: Average "photon and electron energy distributions" per 2000 GeV shower. EAShower is solid line, GEANTShower is dashed line.

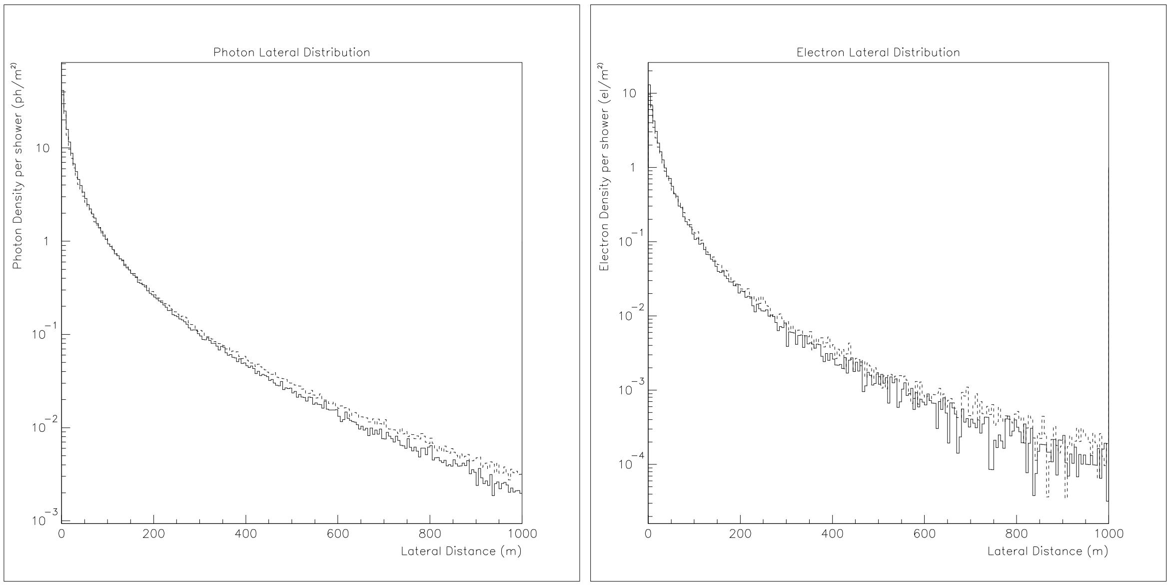

Figure 15: Average "photon and electron lateral distributions" per 2000 GeV shower. EAShower is solid line, GEANTShower is dashed line.

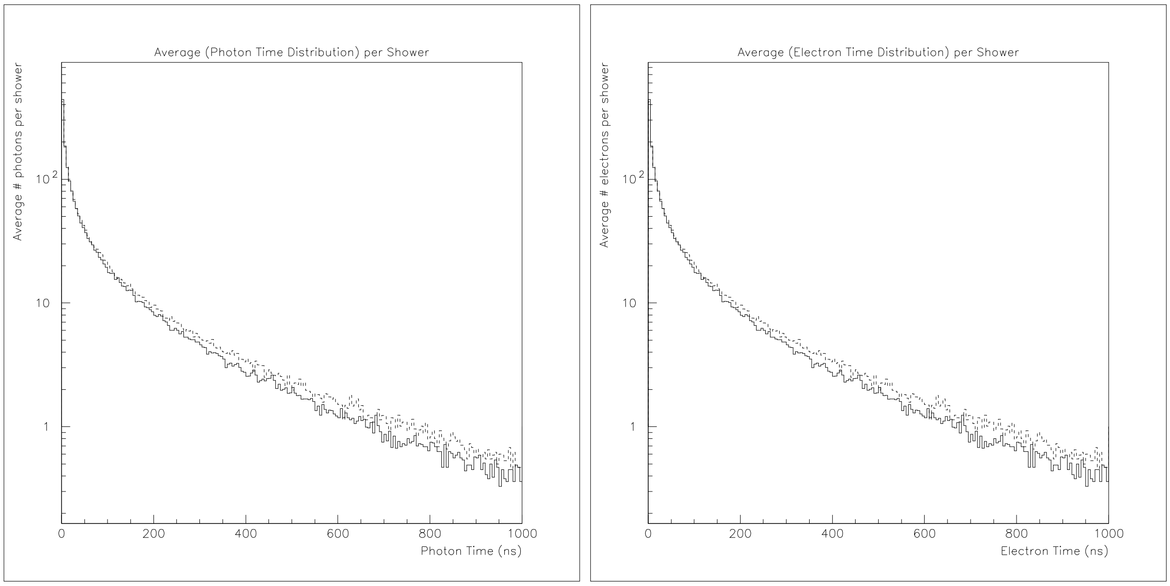

Figure 16: Average "photon and electron time distributions" per 2000 GeV shower. EAShower is solid line, GEANTShower is dashed line.

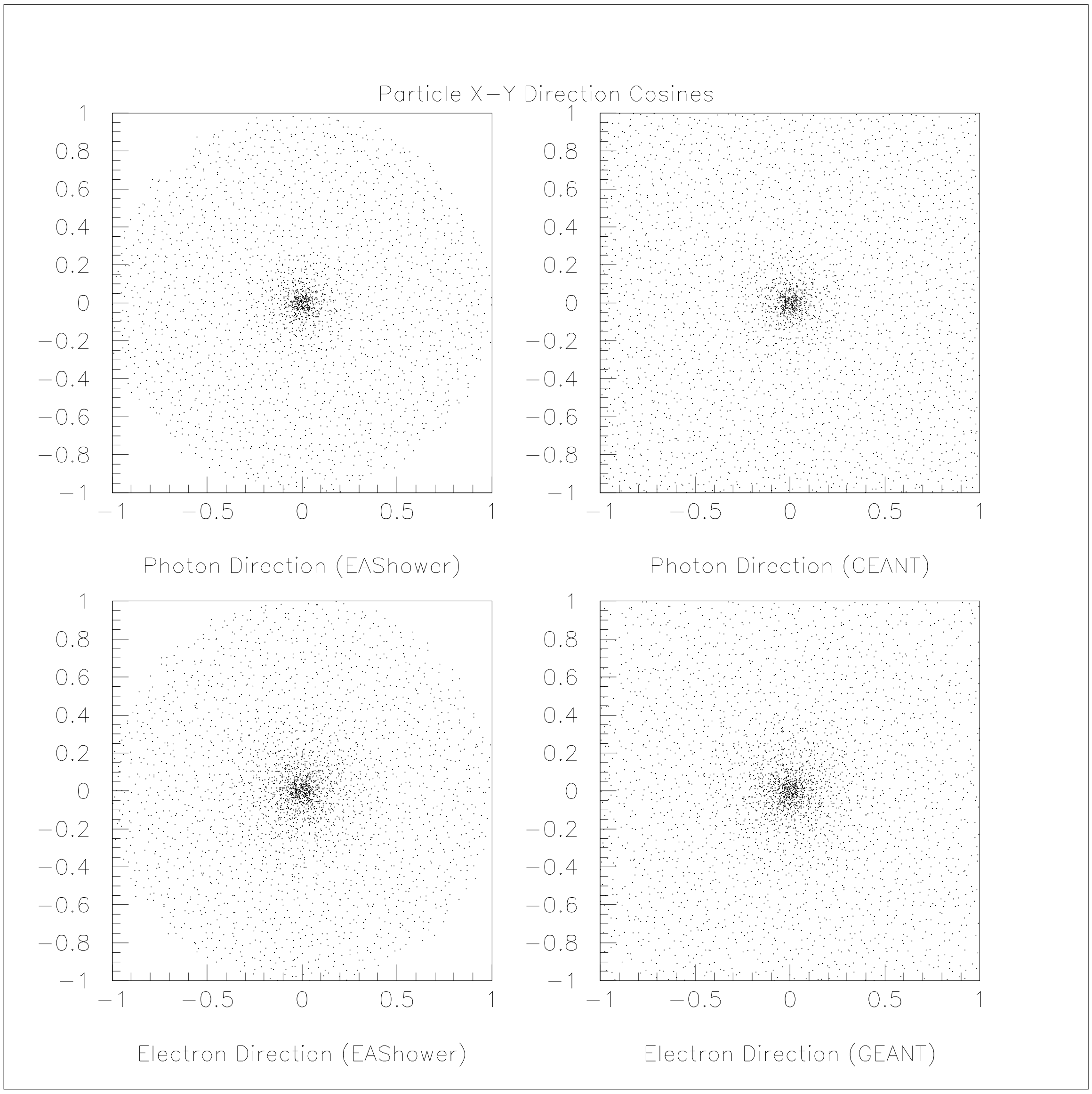

Figure 17: Photon and electron direction cosines for 2000 GeV showers.

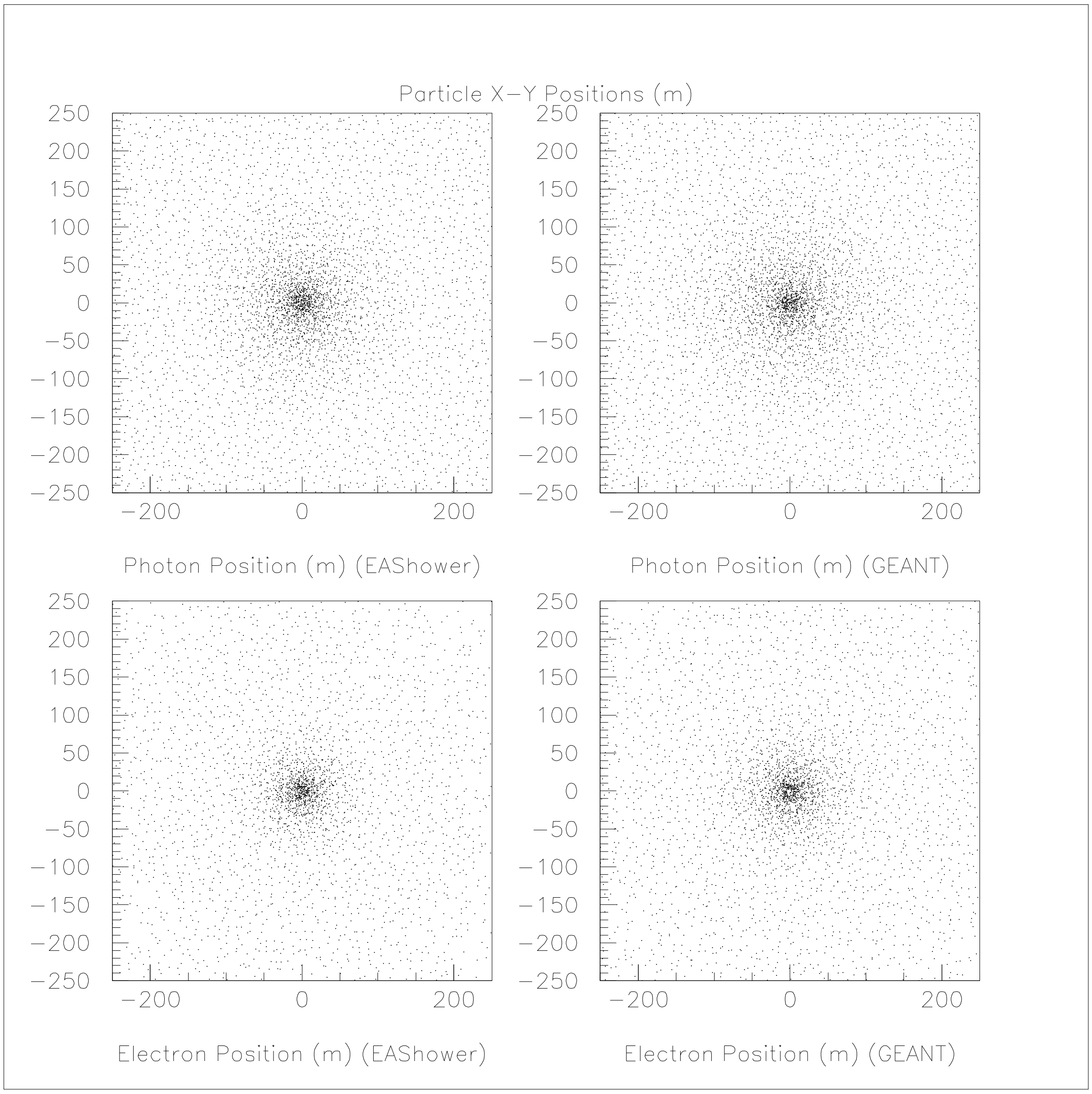

Figure 18: Photon and electron X vs. Y positions from core for 2000 GeV Showers.

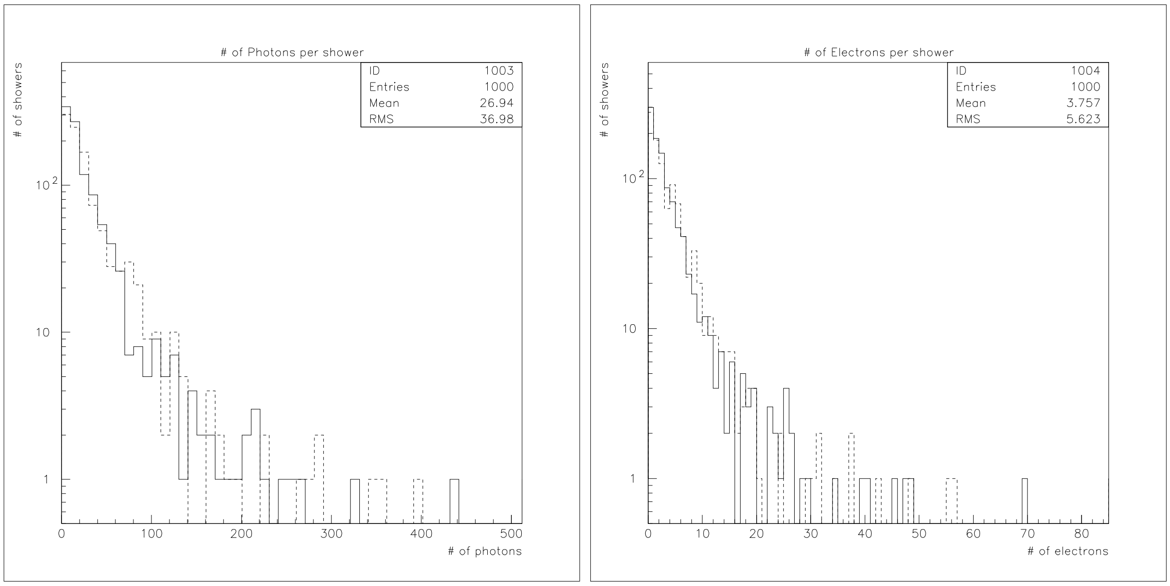

Figure 19: # of photons and electrons at 750g per 100 GeV shower. "Fly" is solid line, "Lib" is dashed line. Mean # of photons in "Fly" ("Lib") is 27.1 (30.4). Mean # of electrons is 3.2 (3.4)

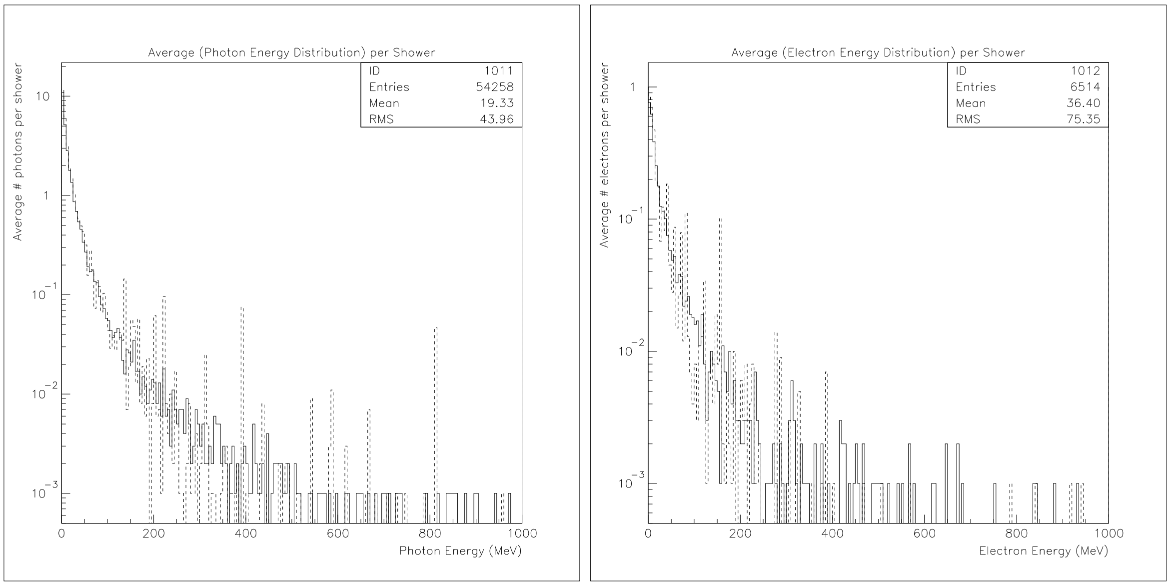

Figure 20: Average "photon and electron energy distributions" per 100 GeV shower. "Fly" is solid line, "Lib" is dashed line.

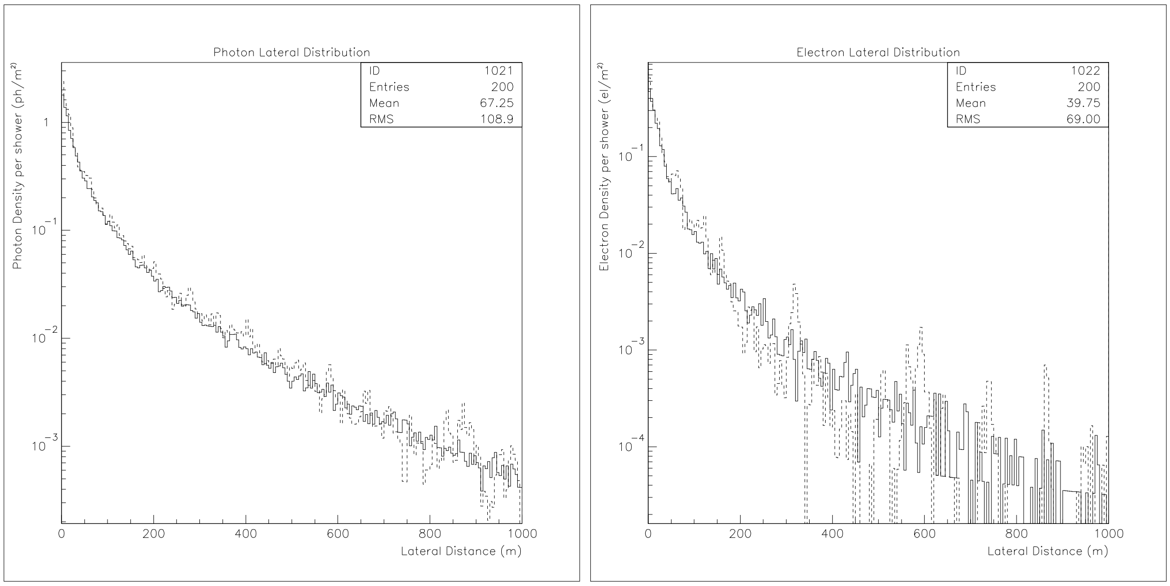

Figure 21: Average "photon and electron lateral distributions" per 100 GeV shower. "Fly" is solid line, "Lib" is dashed line.

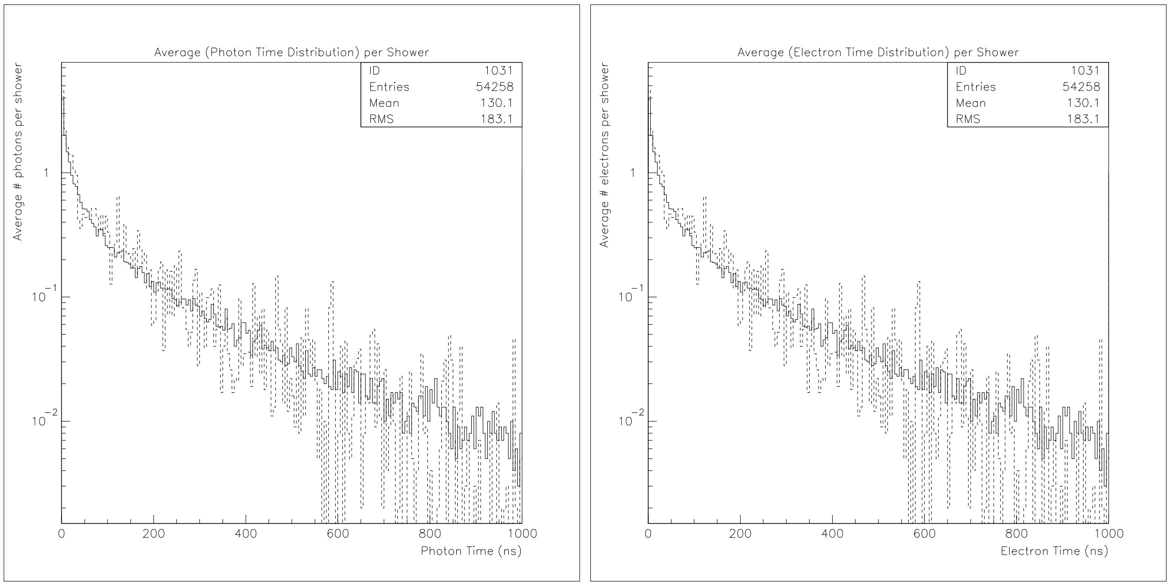

Figure 22: Average "photon and electron time distributions" per 100 GeV shower. "Fly" is solid line, "Lib" is dashed line.

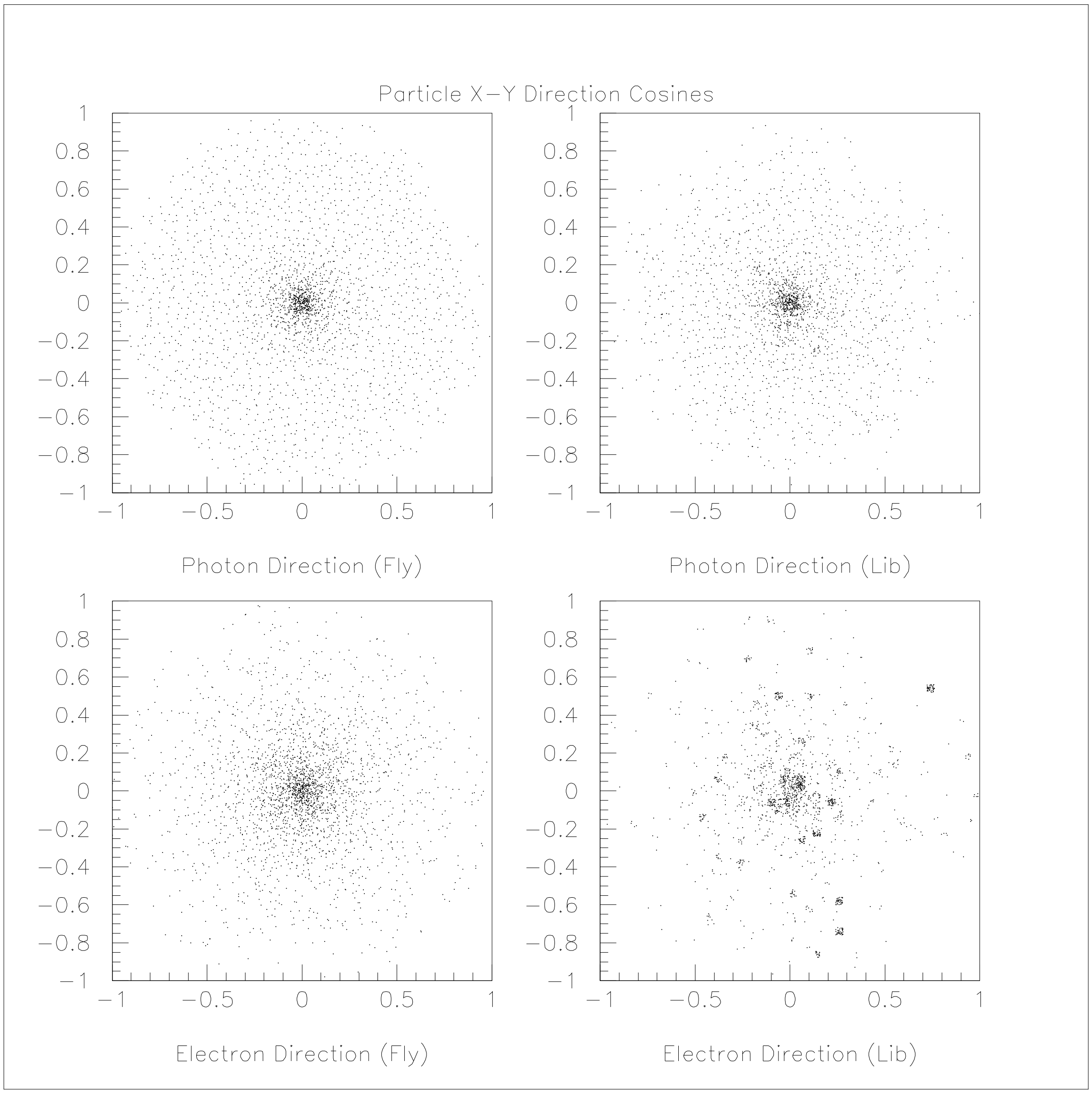

Figure 23: Photon and electron direction cosines for 100 GeV showers.

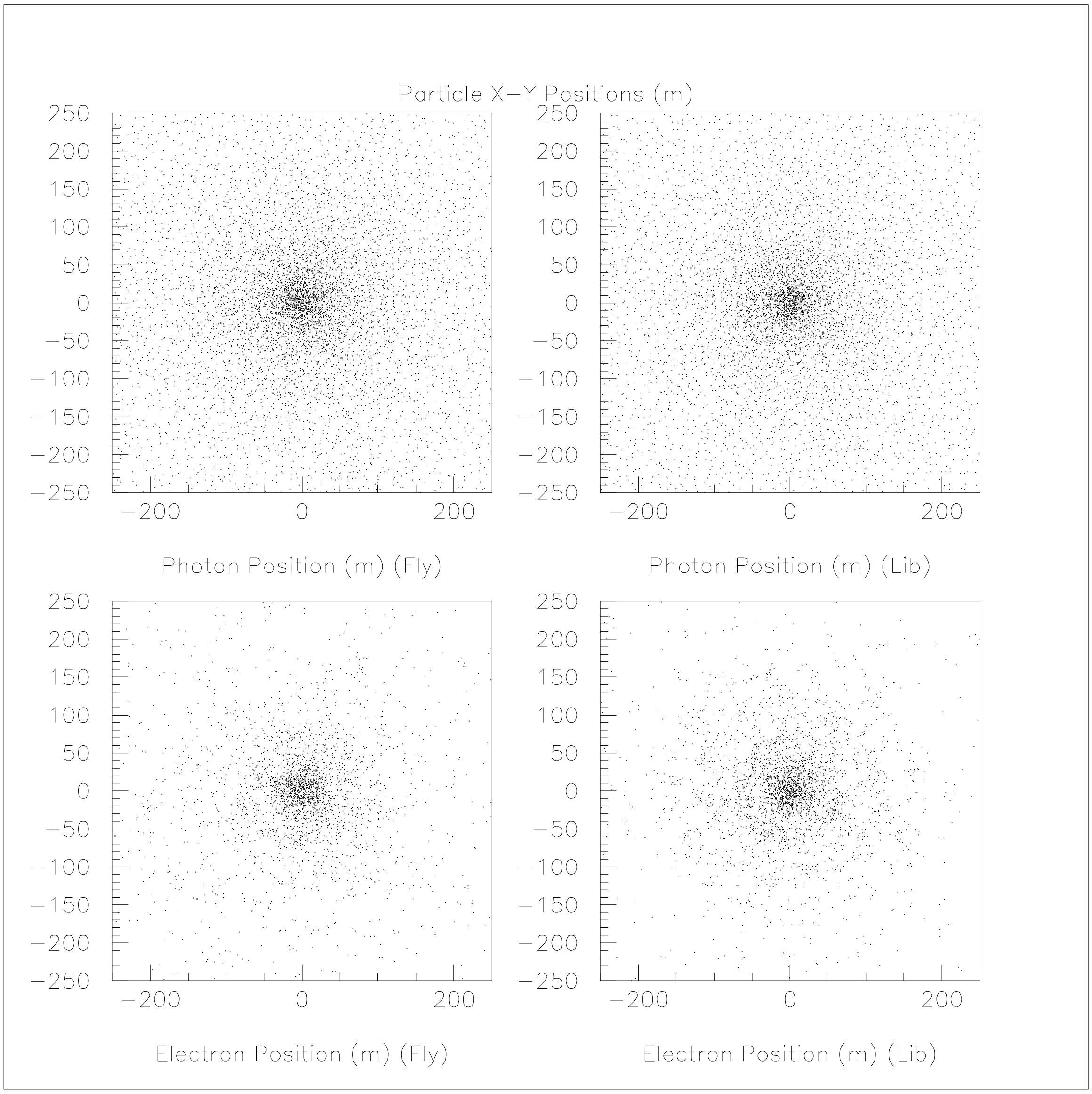

Figure 24: Photon and electron X vs. Y positions from core for 100 GeV showers.

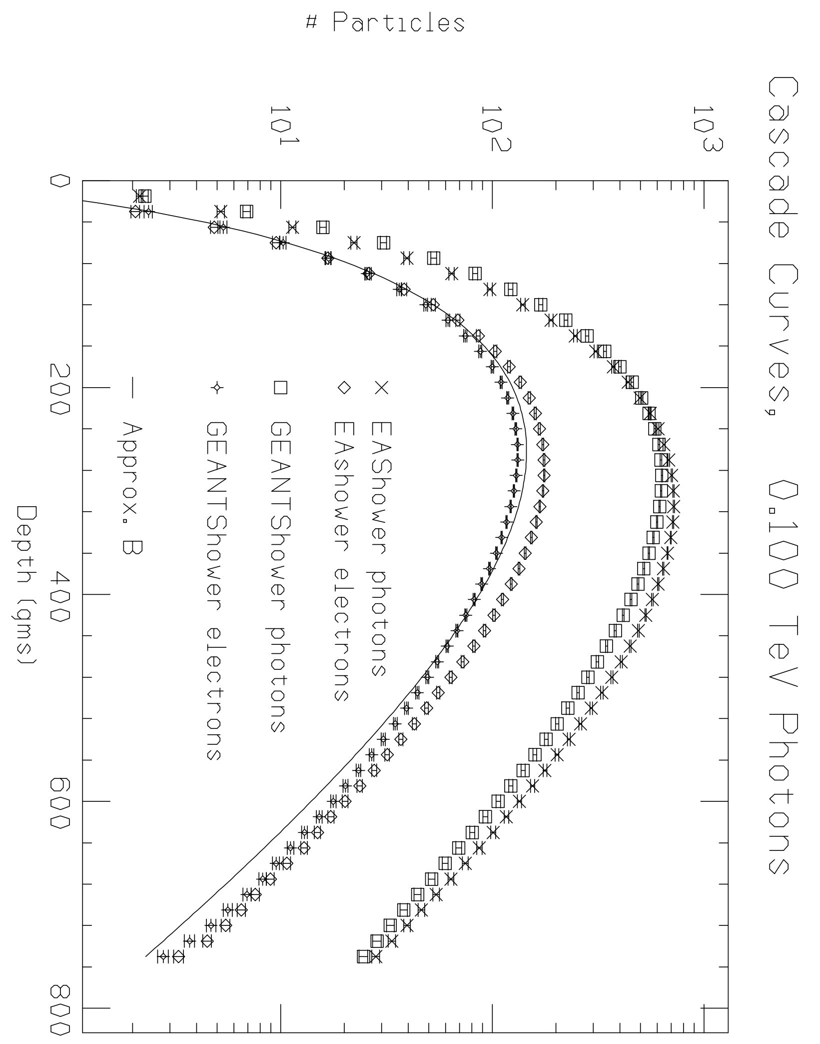

Figure 25: Average shower cascade curves for 1000 100 GeV vertical showers. Approximation B used was with $E_{crit} = 80MeV$ and a $36.7grams/cm^2$ radiation length.

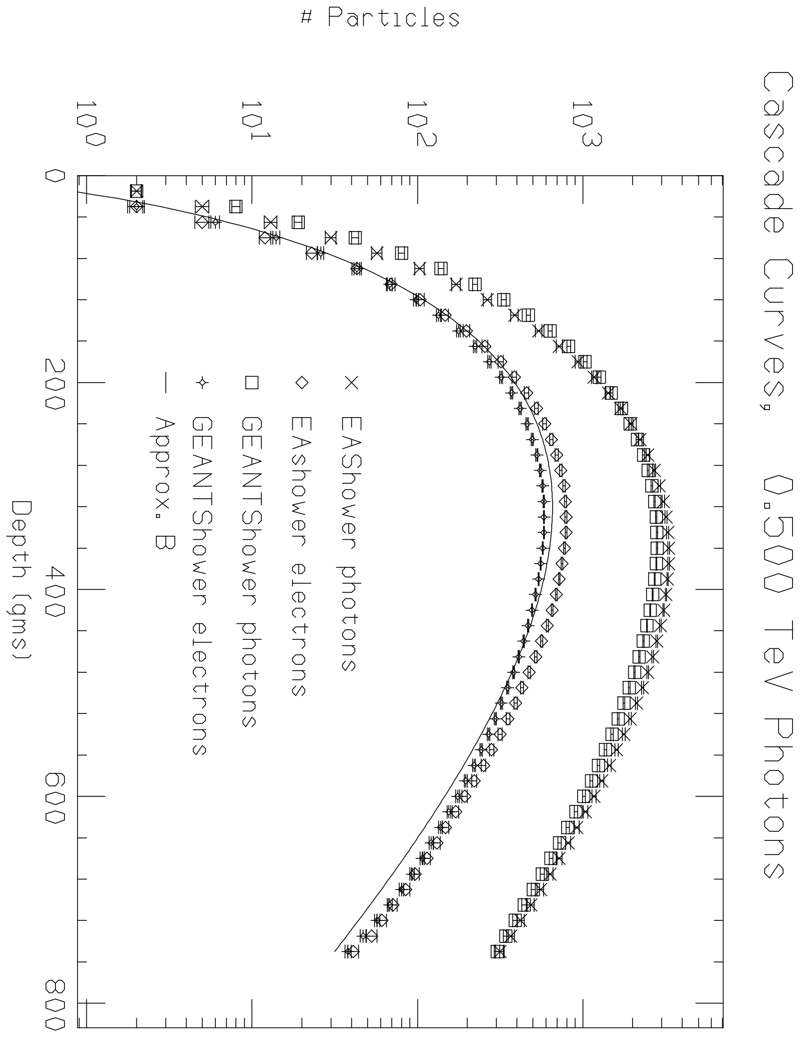

Figure 26: Average shower cascade curves for 500 500 GeV vertical showers. Approximation B used was with $E_{crit} = 80MeV$ and a $36.7grams/cm^2$ radiation length.

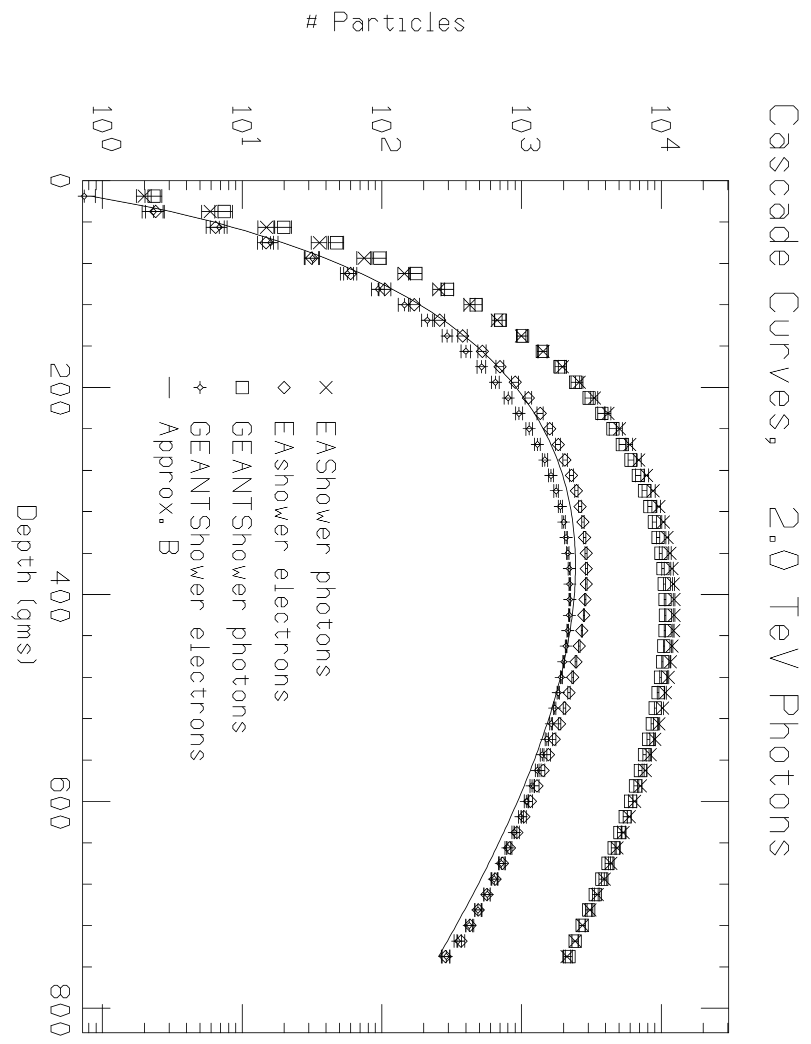

Figure 27: Average shower cascade curves for 100 2000 GeV vertical showers. Approximation B used was with $E_{crit} = 80 MeV$ and a $36.7 grams/cm^2$ radiation length.

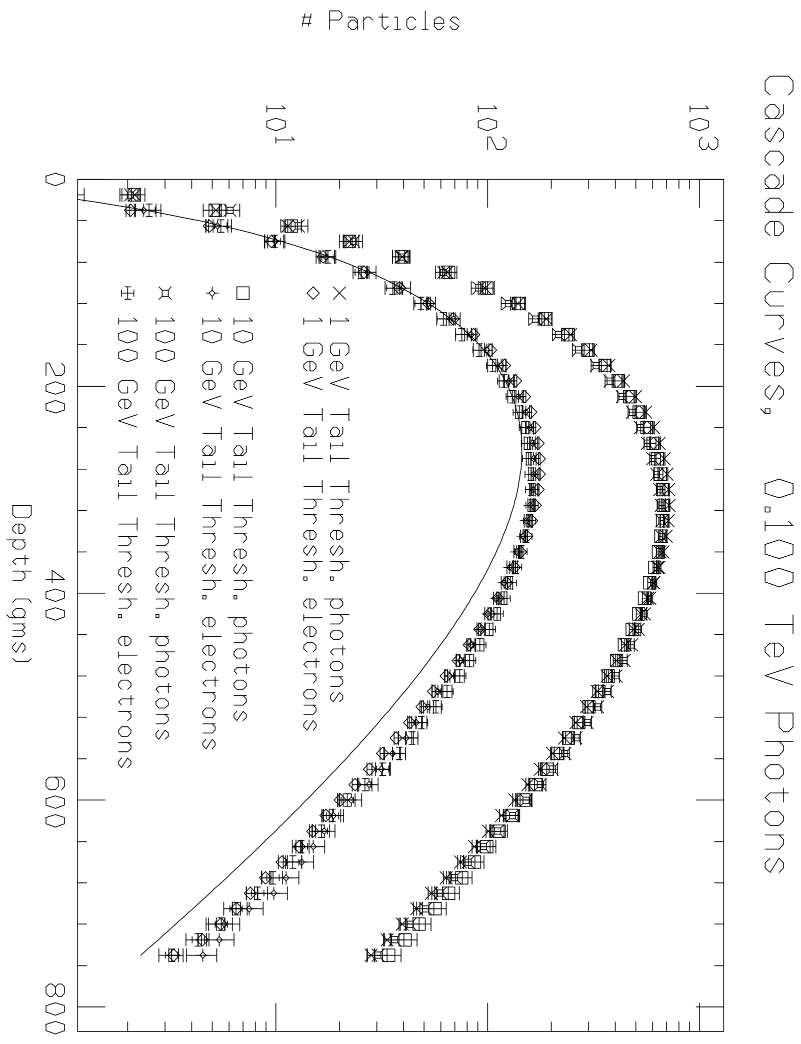

Figure 28: Average shower cascade curves for 1000 100 GeV vertical showers with varying EGS tail threshold values. Approximation B used was with $E_{crit} = 80MeV$ and a $36.7grams/cm^2$ radiation length.