DELPHI 97-89 CONF 75
28 July, 1997

Acoplanar photons background Generators

Preliminary

DELPHI Collaboration

P. Bain & R. Pain
LPNHE, Université Paris VI & VII, France

Abstract

The most important physics background for processes with acoplanar photons and large missing energy comes from the reaction $e^+e^- \rightarrow \overline{\nu}_i\nu_i\gamma\gamma(\gamma)$ (i=e, μ, τ) when two photons are seen in the detector and the third one, if any, stays undetected. We compute the cross-sections of these processes using the CompHEP and GRACE event generators and compare them with calculations done with Pythia.

Paper submitted to the LP'97 Conference
Hamburg, July 28 - August 1st

1 Introduction

The most important physics background for processes with acoplanar photons and large missing energy comes from the reaction $e^+e^- \to \overline{\nu}\nu\gamma\gamma(\gamma)$, once the very large QED background $e^+e^- \to \gamma\gamma(\gamma)$ has been removed by an acoplanarity cut and/or a cut in the maximum photon energy.

In a recent article, Ambrosanio et al. [1], have computed this background in the case where only two photons are produced in the final state using the compHEP[2] program. The purpose of the work reported here was two fold :

- Calculate the contribution arising from final states where a third photon is produced and escapes detection. This could be a potentially big additional background due to the fact that a third photon, often produced at small angle would "help" the radiative return to the Z^0 and therefore enhance this otherwise small cross-section. Radiative return events accompanied with a third undetected photon would then appear in the high missing mass region well above the Z^0 mass.
- Calculate the expected background in DELPHI and compare it with calculations done using similar technics as in GRACE [3] or different ones as in Pythia[4]

In section 2, we briefly describe the three steps of the calculation of the processes $e^+e^- \to \overline{\nu}\nu\gamma\gamma(\gamma)$ where the neutrino can be ν_e, ν_μ or ν_τ : (i) Calculation of $\bar{\nu}_\mu\nu_\mu\gamma\gamma$ final state (ii) calculation of $\bar{\nu}_e\nu_e\gamma\gamma$ final state and (iii) calculation in the case where a third photon is emitted. The missing mass distributions for those three processes and the sum of the contributions are presented. In section 3, we compare the results obtained in section 2 to calculations made with Pythia using two different settings for the latter, and we compute the expected background in DELPHI at 161 and 172 GeV center of mass energies.

2 Calculation with CompHEP and GRACE

Calculations of cross-sections for the processes $e^+e^- \to \overline{\nu}_i\nu_i\gamma\gamma(\gamma)$, $i = (e, \mu, \tau)$ were done using both GRACE and CompHEP packages. These two programs automatically generate Feynman amplitudes given a set of initial and final state particles. Calculation were performed at tree level. Both programs use BASES, a Monte-Carlo phase-space integration program to integrate the cross-sections and SPRING, a generic Monte-Carlo event generator to generate 4-vectors. Some 20000 events were generated for each final state considered and with both programs in order to compare differential cross-sections as well as the total cross-sections integrated in the following acceptance for both photons :

$$|cos\theta_\gamma| < 0.95 \tag{1}$$
$$E_\gamma > 5GeV \tag{2}$$

During preliminary calculations, a factor 2 difference was found when comparing CompHEP and GRACE for the processes $e^+e^- \to \overline{\nu}_i\nu_i\gamma\gamma$. This was due to the fact that, while CompHEP computes the cross-sections taking into account the fact that the 2 photons are indistinguishable, it is a user prerogative to account for this with the GRACE program. This was checked for the simple 2 photons final state as well as for the final state with 3 photons (where the indiscernability of the photons results in a factor 6 difference) and confirmed by the GRACE authors [5].

Once this effect is correctly accounted for, both programs agree within their quoted uncertainties both for total cross-sections and the differential cross-sections. Our calculation also agrees with the results quoted in [1] for the $\overline{\nu}_\mu\nu_\mu\gamma\gamma$ and $\overline{\nu}_\mu\nu_\mu\gamma\gamma$ final states. The following distributions were compared and show perfect agreement : $\frac{d\sigma}{d\theta_+}$, $\frac{d\sigma}{E_+}$, $\frac{d\sigma}{d\theta_{acop}}$ and $\frac{d\sigma}{dM_{inv}}$ where θ_+ and E_+ are the polar angle and energy of the most energetic photon, θ_{acop} is the acoplanarity angle between the two photons and M_{inv} is the invisible or missing mass of the event defined as :

$$M_{inv}{}^2 = (p_{e^+} + p_{e^-} - p_{\gamma_1} - p_{\gamma_2})^2$$

2.1 Final states with 2 photons

The dominant process for two acoplanar photons in the final state is Z^0 annihilation into a pair of neutrinos accompanied by double initial state radiation. This is illustrated in Figure 1(a) which shows the Feynman diagrams taken into account in the calculation of $\overline{\nu}_\mu\nu_\mu\gamma\gamma$ final state. The calculation is identical when ν_τ are produced. In the case of ν_e however, the situation is slightly complicated by W exchange as can be seen in Figure 1(b).

2.2 Final states with three photons

In the previous section, we study the cases where the two photons are produced and detected at angle in the forward and/or barrel electromagnetic detectors. It is however interesting to ask whether processes resulting in final state with three photons, with the third photon escaping detection, could give a sizeable contribution. The reason is that the reduction of the cross-section caused by the emission of a third photon, most of the time along the beam direction, could be largely compensated, at large center of mass energies, by the induced additional return to the Z^0 resonance.

We therefore attempted to calculate this contribution using CompHEP and GRACE programs. This could not be done, as previously, by simply specifying all final state particles as current versions of CompHEP and GRACE cannot handle final states with more than 4 particles. Instead, we approximated processes with 3 photons and two neutrinos in the final state as resulting from the production of a real Z^0 and 3 photons as shown in Figure 2, followed by subsequent decay of the Z^0 into neutrinos.

The decay into neutrinos simply resulting in a reduction by a factor 5 of the $e^+e^- \to Z^0\gamma\gamma\gamma$ cross-section as the Z^0 branching ratio into neutrinos is 20%.

2.3 Invisible mass distributions

Figure 3 (a)(b)(c) show the invisible mass distribution of respectively, $\overline{\nu}_\mu\nu_\mu\gamma\gamma$, $\overline{\nu}_e\nu_e\gamma\gamma$, and $e^+e^- \to Z^0\gamma\gamma\gamma$ processes. The sum of all contributions, including the one with ν_τ in the final state, identical to the ν_μ contribution, is shown in figure 3 (d). These plots were obtained using cuts (1) and (2) on both photons and requiring the third photon, if any, to escape detection ($\theta_\gamma \leq 2.3^o$ or $\theta_\gamma \geq 177.7$ for $E_\gamma \geq 1GeV$).

Although, as expected, the Z^0 annihilation into neutrinos largely dominates the cross-sections, the high invisible mass tail is significantly larger in the ν_e case. A full calculation of the W exchange contributions and interference terms are therefore needed for a good description of the high invisible mass region.

As expected, the missing mass distribution of processes with a third photon contributes to large missing masses due to the emission of an additional photon which stays undetected. The overall effect is small although of the same order of magnitude as the contribution of $\overline{\nu}_e \nu_e \gamma\gamma$ for missing masses above 120 GeV.

3 Comparison with Pythia

It is interesting to compare the above results with the widely used PYTHIA Monte-Carlo event generator. Unlike COMPHEP and GRACE, PYTHIA uses a "Parton Shower" (PS) formalism to describe initial state radiation (ISR). This description is well adapted at the Z^0 resonance but may be less suitable at higher center of mass energies.

Technically, there are two different possibilities to generate $\overline{\nu}_i \nu_i \gamma\gamma(\gamma)$ final states with PYTHIA :

- Selecting the "process" : ISUB=1 to describe the $e^+e^- \to \nu\bar{\nu}$ processes and switching the "Parton Shower" radiative corrections on (MSTP(11)=1). In that case, both photons originate from PS radiations from electron and positron lines. A third photon (or more), can also be produced through the same mechanism.

- Selecting the "process" : ISUB=19 to describe the $e^+e^- \to Z^0\gamma \to \nu\bar{\nu}\gamma$ processes and switching the "Parton Shower" initial states radiation on. In that case, one of the final state photons is a PS photon, produced by ISR from either the positron or the electron line and the other is the "Matrix Element" (ME) photon which originates directly from the annihilation process. A third photon (or more) can also be produced via the PS formalism.

About 20000 events were generated in the acceptance defined by (1) and (2) using both realisations of PYTHIA and compared with COMPHEP. A comparison of the differential cross-sections : $\frac{d\sigma}{d\theta_+}$, $\frac{d\sigma}{E_+}$, $\frac{d\sigma}{d\theta_{acop}}$ and $\frac{d\sigma}{dM_{inv}}$ was also performed. Total cross-sections are presented in the following table. The ratios are computed with respect to COMPHEP. Note that $\alpha^{-1} = 128$ was used in COMPHEP. Using $\alpha^{-1} = 137$ results in a reduction of the quoted value by 13%. The default value for α was used in PYTHIA.

Program	σ (fb)	ratio
COMPHEP, $\alpha^{-1} = 128$	194.8	-
PYTHIA, ISUB=1	116.8	0.60
PYTHIA, ISUB=19	321.8	1.65

Very large discrepancies are visible, both when comparing PYTHIA with COMPHEP but also between both PYTHIA calculations.

In order to ease the comparison of the differential cross-sections, all PYTHIA distributions were rescaled to the COMPHEP values using the above ratios. The distributions are shown in figure 5 and 6 for PYTHIA(ISUB=1) and PYTHIA(ISUB=19) respectively. For comparison, distributions obtained with COMPHEP are shown in Figure 4.

Apart from a 60% difference in absolute normalisation, the main discrepancy when comparing COMPHEP with PYTHIA(ISUB=1) lies in the photon angular distribution, which is significantly steeper in PYTHIA as expected for a PS description of the ISR. There is also a sizeable difference in the high missing mass region of the missing mass distribution. This could be due to the neglection of interference terms in the PYTHIA calculation for final states with electron neutrinos.

When comparing COMPHEP with PYTHIA(ISUB=19) however, the difference in absolute normalisation is reversed as PYTHIA now lies above COMPHEP. In addition, a dramatic difference is visible in the acoplanarity distribution. Clearly, the PYTHIA(ISUB=19) acoplanarity distribution cannot be real as no physical explanation is likely to account for such a peak in the $\theta_{acop} = 180^o$ region.

In order to understand the differences between PYTHIA(ISUB=1) and PYTIA(ISUB=19), one should keep in mind that, in PYTHIA(ISUB=19) each event is produced with a PS photon and a ME one. No cuts are applied on the photons' transverse momenta which can lead, in some cases, to final states where the PS photon has higher transverse momentun that the ME one. In order to "cure" this problem, T. Sjostrand suggested that we remove such events from the generated sample. We therefore generated another set of 20000 events in that modified configuration and obtained : σ(PYTHIA, ISUB=19, PTME>PTPS) = 138.9 fb, a reduction by almost a factor 3 in the total cross-section and a value slightly above the PYTHIA(ISUB=1) value. The acoplanarity distribution although slightly steeper than the COMPHEP one, no longer exhibits the 180^o peak as can be seen in Figure 7.

4 Expected background at 161 and 172 GeV

As an exercise, we computed the expected background cross-sections within the DELPHI detector at center of mass energies of 161 and 172 GeV. Cuts simulating the DELPHI acoplanar photon analysis were applied at "generator level". This analysis requires two and only 2 photons to be detected. The most energetic photon has to be detected in the HPC ($40^o < \theta < 140^o$) with an energy greater that 10 GeV whereas the second one can be detected in the FEMC ($25^o < \theta < 155^o$) and have a minimal energy of 5 GeV. The additional photons, if any, have to escape detection ($\theta < 2.3^o$ or $\theta > 177.3^o$ for $E_\gamma > 1$ GeV) and the photons acoplanarity must be greater than 3^o to remove the QED background.

Cross-sections were computed within these cuts (σ_1) and with an additional cut on the missing mass (σ_2) to estimate the background far from the region where the Z^o decay into neutrinos dominates. The results are given in the following table :

	161 GeV		172 GeV	
Process	σ_1 (fb)	σ_2 (fb)	σ_1 (fb)	σ_2 (fb)
$e^+e^- \to \nu_e\nu_e\gamma\gamma$	36.9	6.2	32.8	8.1
$e^+e^- \to \nu_\mu\nu_\mu\gamma\gamma$	29.8	0.8	24.1	1.0
$e^+e^- \to Z_0\gamma\gamma\gamma$ ($\times 0.2$)	8.7	1.6	6.6	1.2
Total (ν_e, ν_μ, ν_τ)	105.3	9.4	87.6	11.3

As can be seen from these figures, about 10% of the events have missing masses above 120 GeV, a fraction which rises significantly with energy. With about 10 pb^{-1} collected at both energies and neglecting efficiencies, we expect about one event at each energy and 0.1 for missing masses above 120 GeV.

5 Conclusion

We have computed cross-sections for the processes $e^+e^- \to \nu_i\nu_i\gamma\gamma(\gamma)(i = e, \mu, \tau)$ at center of mass energies of 161 and 172 GeV using the CompHEP program. The contribution arising from the three photons final states amounts to less than 10% of the total.

Calculation with the GRACE program shows excellent agreement both in normalisation and for the differential cross-sections provided one takes into account the fact that the final state contains identical particles (divide by n!). This factor is already accounted for in the CompHEP program.

Calculation with process 1 of Pythia (ISUB=1) together with the "Parton Shower" approximation for both photons gives a cross-section significantly *lower* than that calculated with CompHEP. The missing mass, photon energy and acoplanarity distributions are in good agreement but the photon angular distributions are more peaked as expected from a *Parton Shower* approximation.

Calculation with process 19 of Pythia (ISUB=19) together with the "Parton Shower" approximation for the second photon gives a cross-section significantly *bigger* than with CompHEP. The photon angular distribution improves with respect to the case ISUB=1, but the acoplanarity distribution exhibits a peak at 180^o. Better agreement is found, however, for both the cross-section and the acoplanarity distribution when events with "Parton Shower" photon transverse momentum greater than the "Matrix Element" photon transverse momentum are rejected.

Our conclusion is that acoplanar photon background calculations and event generation should now be performed with either CompHEP or GRACE Monte-Carlo event generators.

References

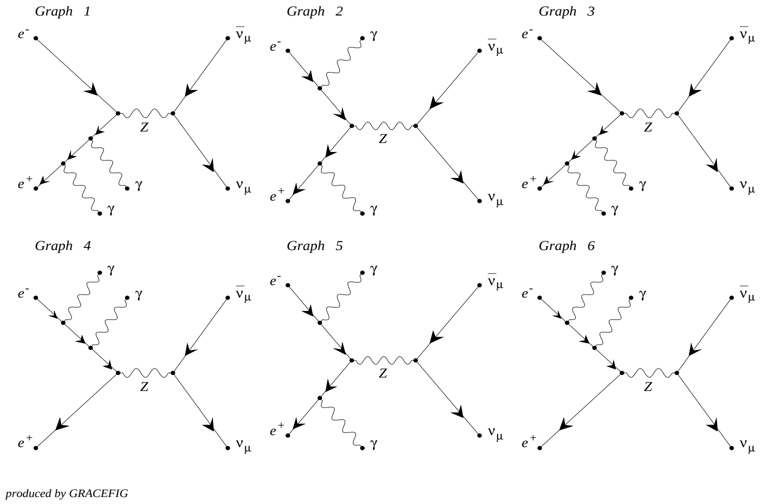
[1] S.Ambrosanio et al., hep-ph/9605398

[2] E.E.Boss, M.N.Dubinin, V.A.Ilin, A.E.Pukhov, V.I.Savrin, "CompHEP: Specialized package for automatic calculation of elementary particule decay and collisions", hep-ph/9503280

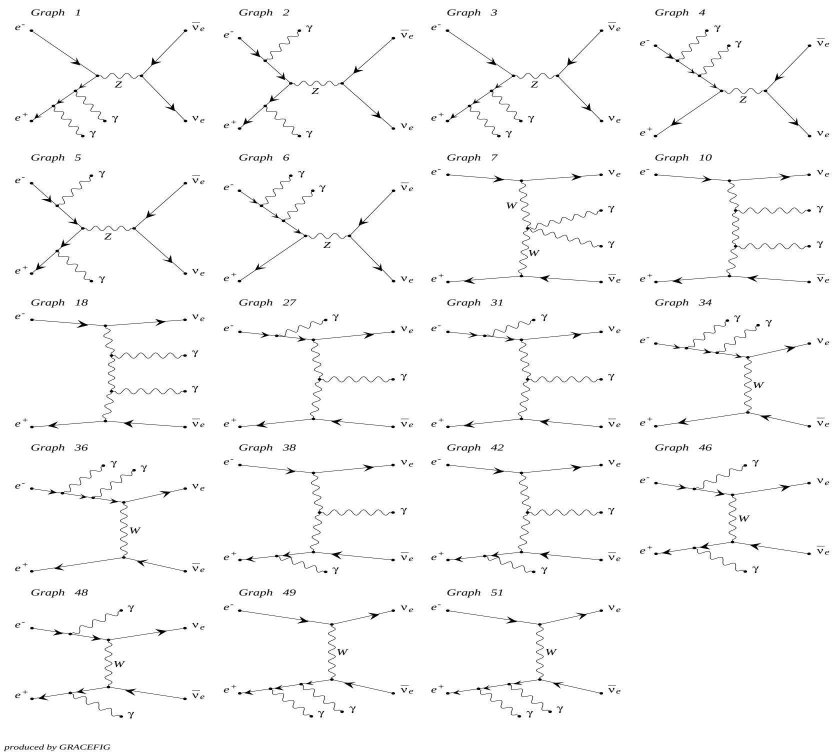
[3] MINAMI-TATEYA group, "GRACE" manual, KEK Report 92-19, Feb. 1993

[4] T.Sjostrand, Comp. Phys. Comm. 39 (1986) 347
T.Sjostrand, "Pythia 5.7 and Jetset 7.4, Physic and Manual", CERN-TH.7112/93

[5] D. Perret-Gallix, private communication



(a) *Feynman diagrams for* $e^+e^- \to \overline{\nu}_\mu\nu_\mu\gamma\gamma$ *or* $e^+e^- \to \overline{\nu}_\tau\nu_\tau\gamma\gamma$ *process*



(b) *Feynman diagrams for* $e^+e^- \to \overline{\nu}_e\nu_e\gamma\gamma$ *process*

Figure 1: *Feynman diagrams for final states with 2 photons and 2 neutrinos (some graphs appear identical because the photons are not numbered in this display produced by* GRACE *software).*

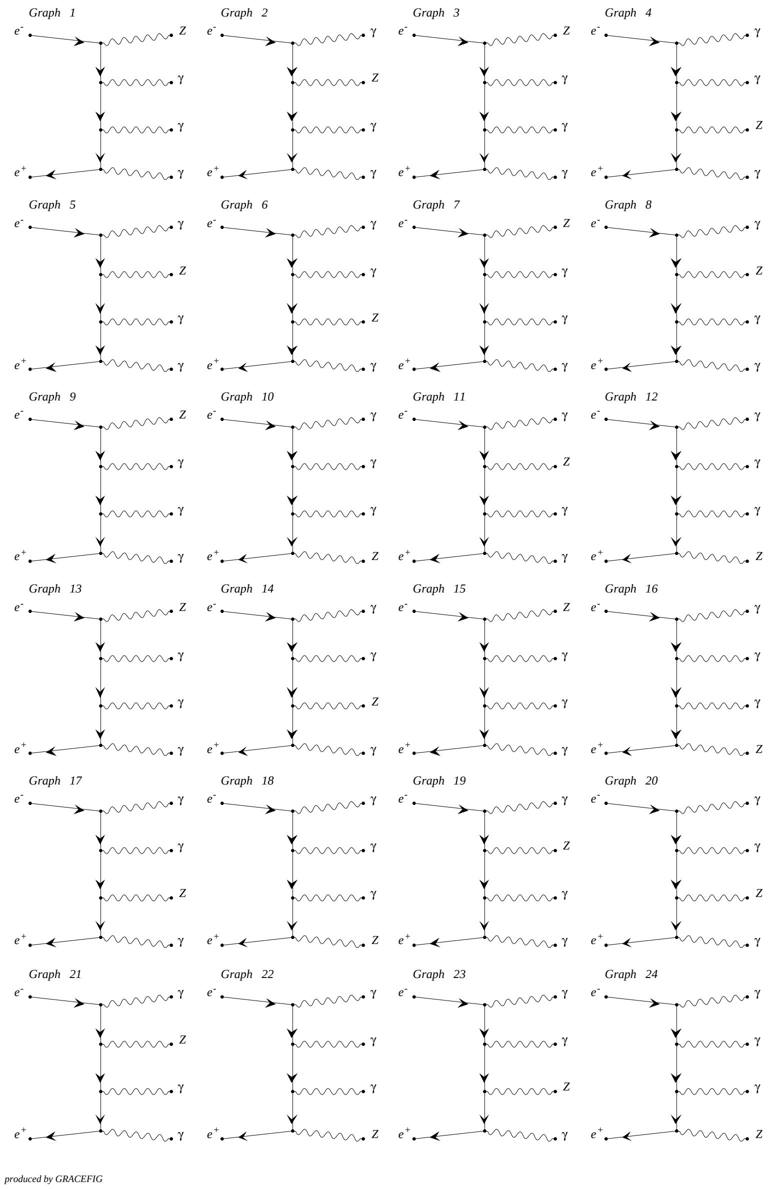


Figure 2: *Feynman diagrams for* $e^+e^- \to Z^0\gamma\gamma\gamma$ *process (some graphs appear identical because the photons are not numbered in this display produced by* GRACE *software).*

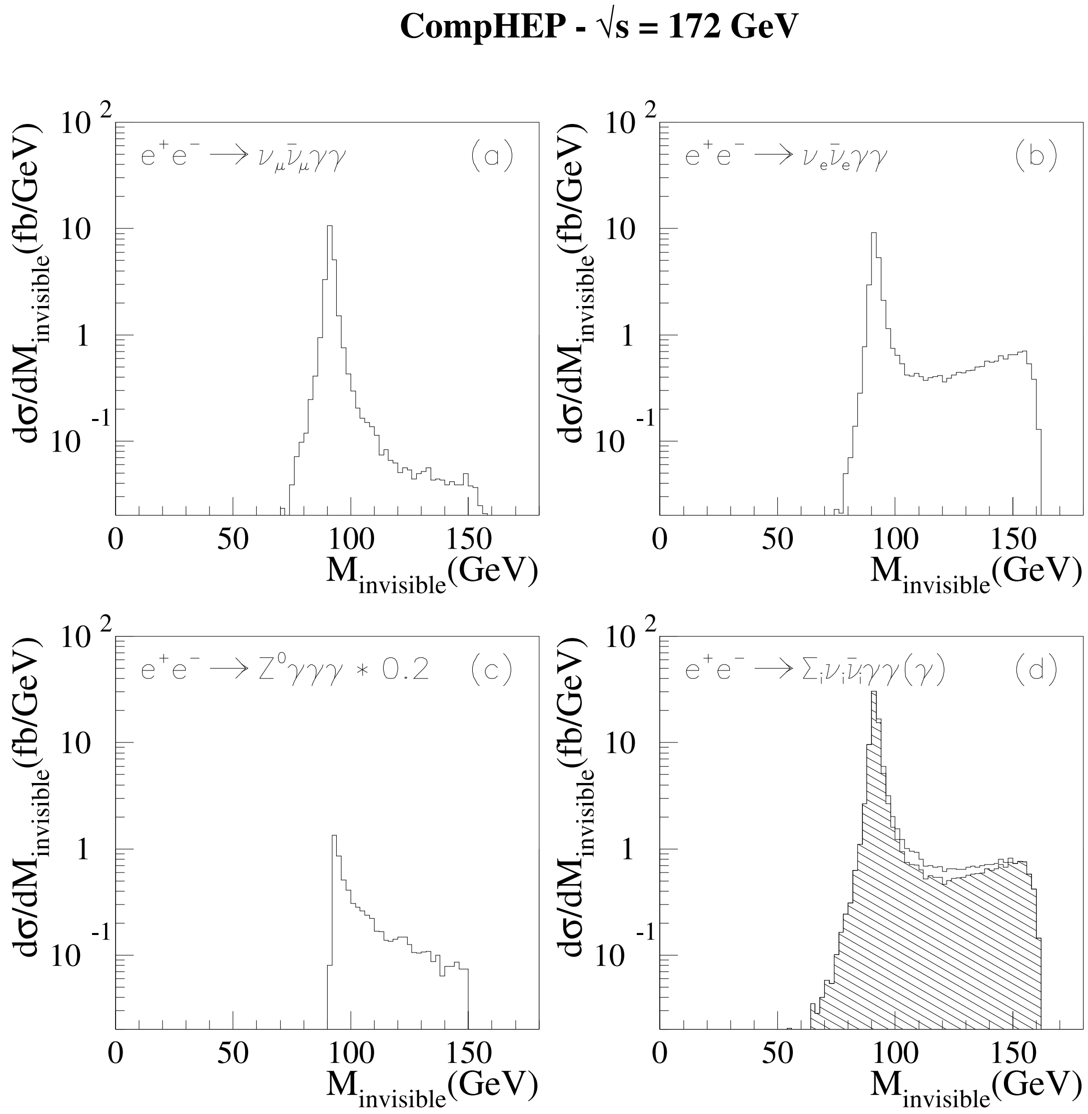


Figure 3: *Missing mass distributions. Indivudals contribution are shown in (a), (b) and (c) whereas the total contribution is given in (d). The contribution from the emission of a third photon is shown as unshaded.*

CompHEP - √s = 172 GeV

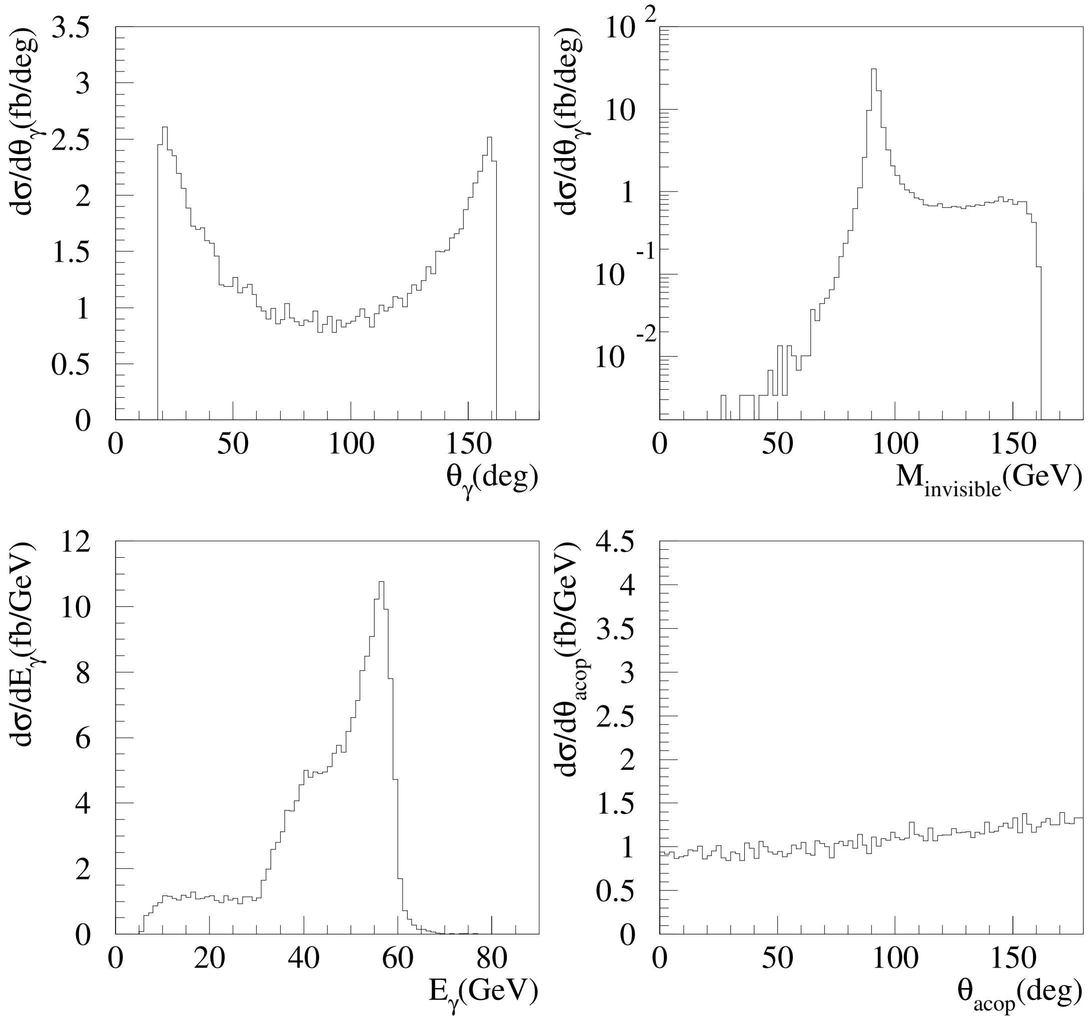


Figure 4: *CompHEP distributions*

Pythia(isub=1)*1.67 - $\sqrt{s}$ = 172 GeV

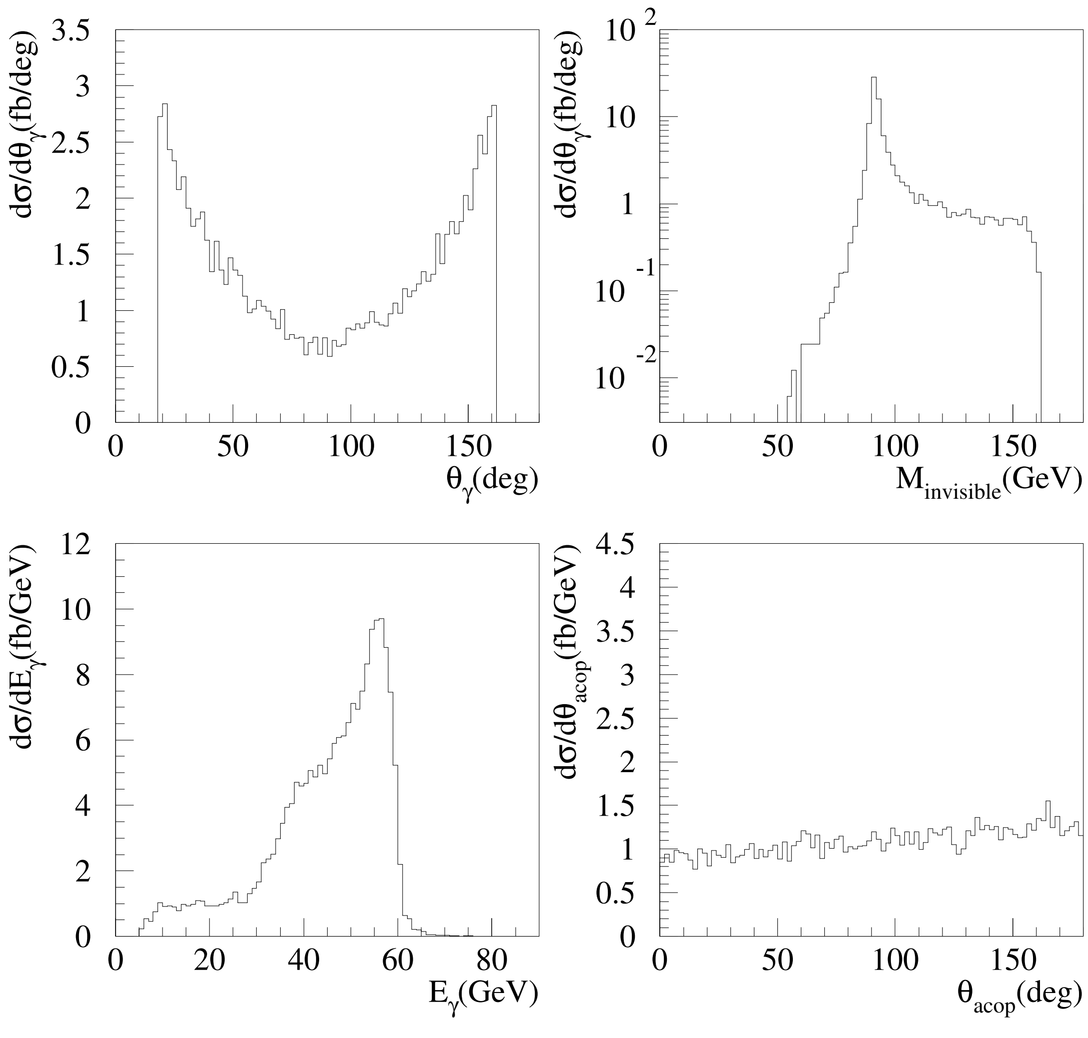


Figure 5: *Pythia(isub=1) distributions*

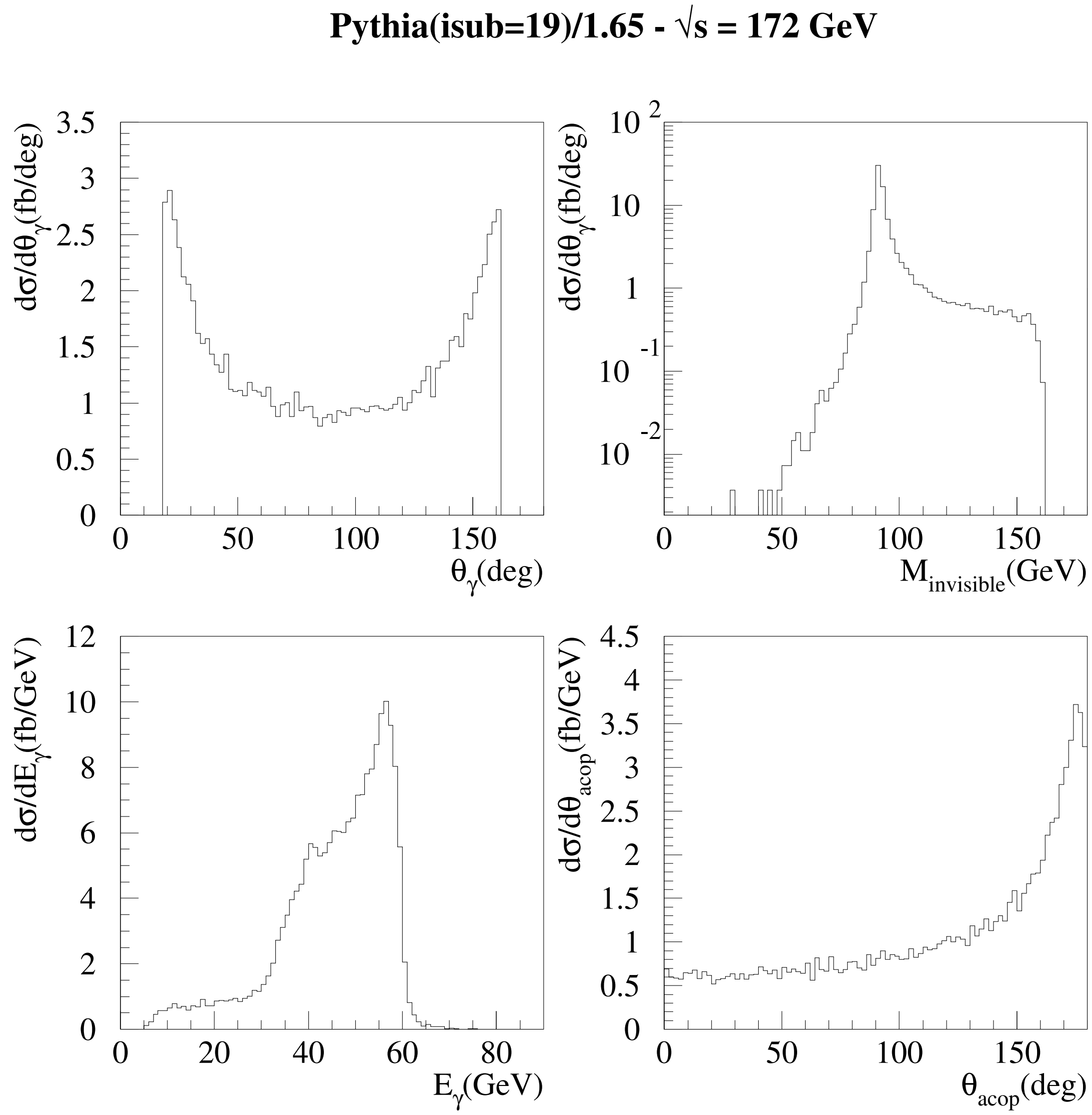


Figure 6: *Pythia(isub=19) distributions*

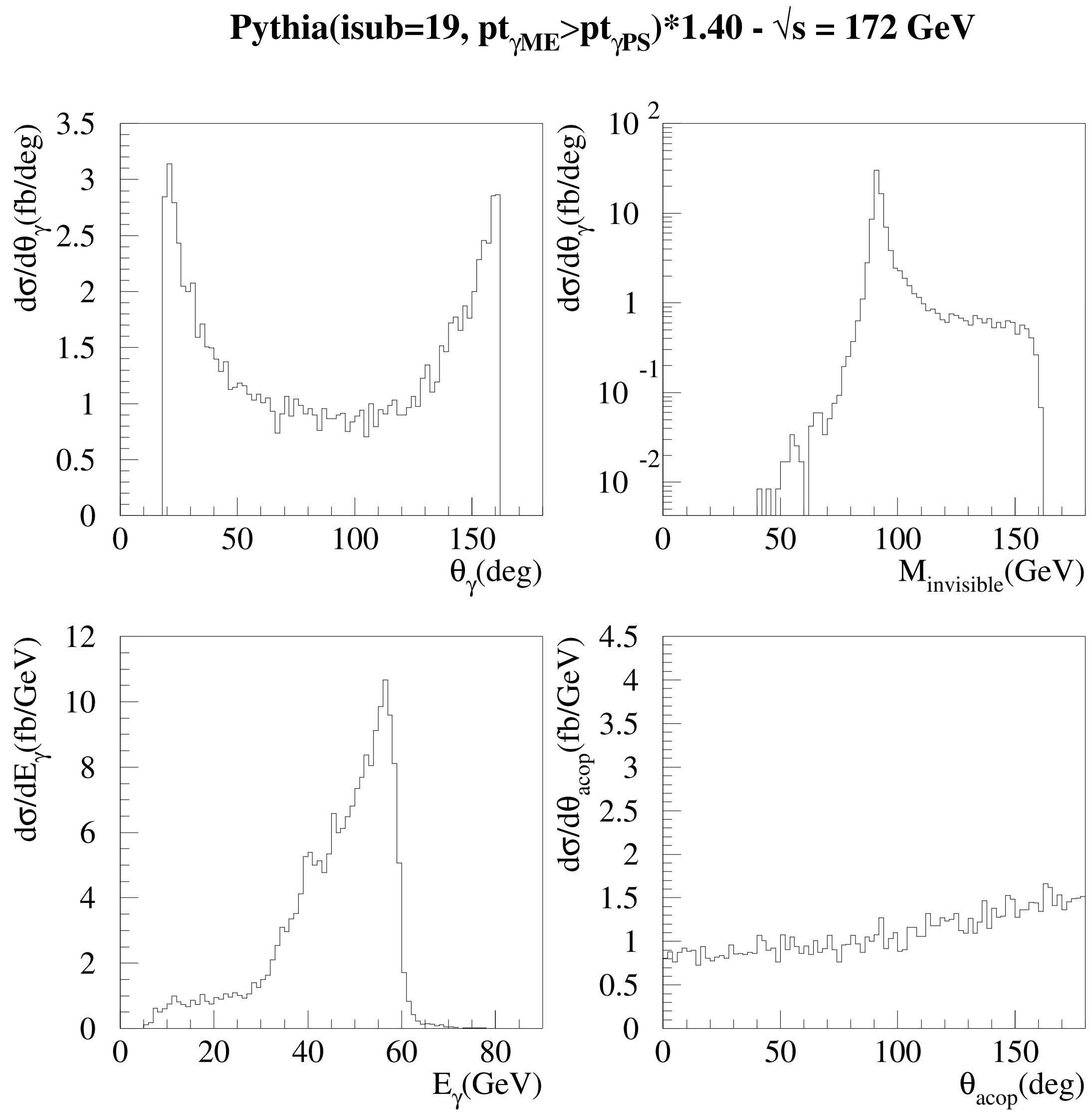


Figure 7: *Pythia(isub=19) modified distributions*