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# KORALZ as an Approximate Monte Carlo for $e^+e^- \to \chi\widetilde{G}$ with $\chi \to \gamma\widetilde{G}$ including multiphoton Initial State Bremsstrahlung

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**Abstract**

In this note we explain briefly modifications introduced to KORALZ version 4.02 in order to simulate the process $e^+e^- \to \chi\widetilde{G}$ with $\chi \to \gamma\widetilde{G}$. Input parameters, tests of the program are also presented as well as some numerical results from simulations of the process and its main background $e^+e^- \to \nu\bar{\nu}\gamma$.

# 1 Introduction

In the scenario where the gravitino is the lightest supersymmetric particle (LSP) the process $e^+e^- \to \chi\widetilde{G}$ (see Feynman diagrams in fig.1) with $\chi \to \gamma\widetilde{G}$, where $\chi$ is the lightest neutralino, is maybe the simplest kind of event that could be seen at LEP. Moreover, there are some recently proposed supersymmetric models according to which supersymmetry is dynamically broken at low scale and the gravitino is the LSP and the next to LSP is a neutralino.

At present the Monte Carlo program SUSYGEN [1] generating this kind of processes including ISR up to single bremsstrahlung is being developped, and the corresponding documentation is expected to be available soon [2]. The detailed knowledge of the ISR correction to this process can be important since the only detectable final state particle would be a photon. It is also important to obtain a consistent picture with leading backgrounds such as $\nu\bar{\nu}\gamma(\gamma' s)$.

In what follows we present a Monte Carlo program which simulates $e^+e^- \to \chi\widetilde{G}$, $\chi \to \gamma\widetilde{G}$ with ISR introduced at several levels of approximation. From the SUSY point of view, the program can work in three modes: the most general SUSY scenario, in a less general SUSY scenario where the neutralino mass is computed starting from $\mu$, $tan\beta$ and the SU(2) gaugino mass $M$ assuming the GUT relation between M' and M, and in the Lopez-Nanopoulos-Zichichi one-parameter model [3].

# 2 The Program

We first present the properties of KORALZ which are important for our purpose and then the modifications actually introduced.

## 2.1 The KORALZ Monte Carlo Program

The algorithm of KORALZ for $e^+e^- \to \tau^+\tau^-$ including radiative corrections and $\tau$ decay is described in [4]. Here we will recall only few properties. The program can be run at Born level (`KEYRAD=0`) including order $\alpha$ QED corrections (`KEYRAD=1`), as well as order $\alpha^2$ (or for tests, just $\alpha$) QED corrections including exclusive exponentiation (`KEYRAD=12`). In calculating matrix elements at order $\alpha$ and pragmatic $\alpha^2$, as building block, Born level differential distribution is used.

## 2.2 Modifications to KORALZ

Let us first recall basic factorization properties of QED. In infrared limit as well as for important regions of phase space which give leading log corrections, the matrix element can be written (up to non-leading terms) as a product of the Born level matrix element multiplied by the factors which are independent from the particular hard process under consideration. The same holds for phase space. See e.g. [5] for some introductory presentation and references.

This opens the possibility, if the algorithm for one process is already built and tested, of its fast adaptation to another one, under the assumption that non-leading corrections can be neglected and control over corresponding systematic errors is not important. The present program is such a modification of the KORALZ program [4] where the matrix element taken from [3] replaces the one of $e^+e^- \to \tau^+\tau^-$ (as a function of $s$ and $\cos\theta$).

The final state $\chi\widetilde{G}$ includes a pair of particles of which one is massive with mass $M_\chi$ and the other is virtually massless. For every event we thus generate first a pair of faked $\tau$'s of mass $M_\chi/2$ and in the second step we replace the faked $\tau$'s 4-momenta by means of the simple following algorithm:
The 4-momenta of the faked $\tau$'s are first boosted into the rest frame of the pair (we will denote the invariant mass squared of the pair as s').
Their 4-momenta are then replaced with the 4-momenta of $\chi$ and $\widetilde{G}$, in such a manner that the back to back directions of $\chi$ and $\widetilde{G}$ follow respectively the directions of $\tau^+$ and $\tau^-$. The invariant mass squared of the pair remains $s'$ and the 3-momenta of the two are equal on module.
We perform boost back to the laboratory system.
In the last step of the generation, for the decay of $\chi$, the modified $\tau$ decay library TAUOLA [6] is used. In fact it is the two body decay mode of $\tau \to \pi\nu$ which is in use, (spin effects must be switched off in KORALZ `ISPIN=0`) and PDG identifiers and masses of $\pi$ and $\nu$ were replaced with that of $\widetilde{G}$ and $\gamma$.

The question of how good such an algorithm can be would require careful comparisons of the generated distributions with those of exact matrix element calculations of at least order $\alpha$. This is difficult and not necessary at the moment, but similar tests for the process $e^+e^- \to \nu\bar{\nu}\gamma$'s were performed in [7] and the approximation worked indeed very well[1].

The procedure presented above introduces systematic uncertainties in particle distributions. These uncertainties do not affect Born level contributions and also do not affect leading log content of QED corrections. Distributions of photons in soft regions are correct. We also benefit from the full coverage of the bremsstrahlung photons phase space. Only distributions in some small regions of phase space or corrections to overall normalizations leading to next-to-leading-log contributions of radiative corrections are affected. These are however in general at the level of $\frac{\alpha}{\pi} = \frac{1}{400}$ only.

After these modifications KORALZ can be used for our purpose and radiative corrections can be switched off (`KEYRAD=0`), run at order $\alpha$ (`KEYRAD=3`)[2] or at multiple photon level (`KEYRAD=12`).

Note that the masses of the $\widetilde{G}$ and of the $\gamma$ coming from the neutralino decay are computed, for storage in PDG common block, from the 4-momenta, with `REAL*4` single precision. Thus, they come out small, but non-zero, sometimes negative. Nev-

[1] One may notice that the above process is the main source of background for us.

[2] Special option `KEYRAD=3` differs from `KEYRAD=1` in that only initial state single photon corrections are included.

ertheless, in the cross-section computation the correct gravitino mass is used.

# 3 Tests

A series of tests has been performed on the program. First of all we have checked that we reproduce the results of [3] on the total Born cross-section and the angular distribution of the neutralino. In fact, to get the same numerical results as in [3] we have changed an overall sign in their definition of $N'_{12}$ (eq. (23) of [3]) assuming that there may be a misprint there.

We have also checked that the insertion of the ISR gives consistent results. This was done in the following way. Having divided the range of the sum of the energy carried by the ISR photons in about ten bins, we have looked at the cross-section, the neutralino angular distribution and the forward-backward asymmetry for various c.m.s. energies, neutralino and selectron masses, see Tabs. 1-14.

In particular, figs. 2 and 3 show that when the total energy carried by the ISR photons is small ($\leq 1$ GeV) the neutralino angular distribution is close to the angular distribution of the Born level. They differ mainly by normalization.

Note that as expected (see the tables) the introduction of ISR corrections decreases slightly the cross section; in fact, as it should, the decrease is stronger in the case of single bremsstrahlung than in multiphoton case.

# 4 Numerical results

Let us now go to numerical results which are more realistic than in the case of basic technical tests, i.e. for cross-section in the barrel region of an idealized detector. One can see the influence of the ISR on the cross-section of visible photons. In tables 2, 6, 10 the percentage of events that have at least one photon (irrespective of being an ISR photon or the neutralino photon) of at least 1 GeV in the barrel region ($\mid cos\theta_\gamma \mid \leq 0.7$) is given. From now on, we will call such photons barrel photons. The percentage of events in which it is the photon from the neutralino decay which goes to the barrel region is given in brackets. The contribution of configurations where it is ISR photon rather than the one from $\chi$ decay which triggers is negligible. On the contrary, as we can see from the last lines of our tables 1 and 2, the background from the process $e^+e^- \to \nu\bar{\nu}\gamma$'s selected with the same cuts as defined above is not small; in fact it is several times bigger than the signal and depends rather strongly on the order of perturbation expansion used in the calculation (see Tab 1, 2 and Fig. 8). The statistical analysis of the observables must include analysis of the differences in phase space distribution of photons from $\chi\widetilde{G}$ and $e^+e^- \to \nu\bar{\nu}\gamma$'s final states. See Figs. 4-8, where angular and energy distributions of barrel photons are given. Cuts exluding soft photons as well as photons matching radiative return to $Z$ are probably examples of simple improvements to reduce significantly the background. For more sophisticated analysis one may probably include multivariable cuts and/or distribution moments.

Similar discussion of other potential sources of anomalies in single $\gamma$ events such as anomalous $W - W - \gamma$ coupling will be presented elsewhere [8].

# 5 How to Use the Program

Standard input of KORALZ has to be set as follows:

1. Final state $\tau$
2. $\tau$ decay mode has to be set to $\pi\nu$
3. spin effects switched off.
4. Mass of the $\tau$ has to be set to half of $\chi$.
5. `KEYRAD=0,3,12`
6. `KEYGSW` becomes dummy.

There is additional input which affects Born level matrix element only. It is transmitted from the main program independently from basic KORALZ structure to appropriate routines.

The relevant parameters on which the cross section depends are:

1. The gravitino mass;
2. The neutralino mass;
3. The mass of the superpartner of the right-handed electron;
4. The mass of the superpartner of the left-handed electron;
5. The neutralino composition $(N'_{11}, N'_{12})$.

There are 3 data cards: `LNZMOD,` `LNZINP` and `KORZIN`.
`LNZMOD` is an integer.
If `LNZMOD=1` (explicit input) `LNZINP` takes 6 `REAL*4` values:

1. gravitino mass in electronVolt (NOT GeV);
2. neutralino mass in GeV;
3. mass of the superpartner of the left-handed electron;
4. mass of the superpartner of the right-handed electron;
5. $N'_{11}$;
6. $N'_{12}$.

Note:
Zino: $N'_{11} \sim 0$ and $N'_{12} \sim 1$ ($N'_{11}$ cannot be exactly 0 because there would not be any neutralino decay into photon);
Bino: $N'_{11} = cos\theta_W$ and $N'_{12} = -sin\theta_W$;
Photino: $N'_{11} = 1$ and $N'_{12} = 0$.
If `LNZMOD=2` (Lopez, Nanopoulos, Zichichi one-parameter model) `LNZINP` takes 2 `REAL*4` values:

1. gravitino mass in electronVolt (NOT GeV);
2. neutralino mass in GeV.

If `LNZMOD=3` the neutralino mass and composition computed as a function of $M, tan\beta, \mu$. Like SUSYGEN the GUT relation $M' = 5/3(g'^2/g^2)M$ is assumed. `LNZINP` takes 6 `REAL*4` values:

1. gravitino mass in electronVolt (NOT GeV);
2. M (SU(2) gaugino mass);
3. $\mu$;
4. $tan\beta$;
5. mass of the superpartner of the left-handed electron;
6. mass of the superpartner of the right-handed electron.

`KORZIN` takes 3 input values:

1. the `KORALZ` parameter `KEYRAD` (a new value can be used `KEYRAD=3`);
2. the number of events to be generated;
3. the c.m.s. energy.

All the above input parameters are stored in the new common blocks `/LNZMODE/, /LNZINPUT/, /KORZINP/` which are specific for the neutralino-gravitino process generation (see Appendix for more details on common blocks).
Following SPYTHIA conventions the ID code of the lightest neutralino is 66, whereas for the gravitino 76.

The modifications of KORALZ consist of adding new routines as well as replacing some of them (see appendix A for details). If the rest of KORALZ is loaded as library it is thus sufficient to add new and modified routines to the main program. Otherwise it is necessary to remove duplicate entries from standard KORALZ source code.

The output is coded in the JETSET `/LUJETS/` common block or the standard `/HEPEVT/` one.

The user should use the korzgra.f program available in francoxv/grakor. In the same directory is an example of installation file (korzgra.ins) that links the L3 KORALZ library.
An example of job is the following:

```
korzgra.exe <<!
LNZMOD 1
KORZIN 12 100 91.2
LNZINP 1e-5 25.  300.  300.  1.  0.
END
exit 0
```

# 6 Summary

In this brief note the general properties of the modifications introduced into KORALZ to enable generation of neutralino-gravitino pair with subsequent decay of neutralino into gravitino and photon are given. Performed tests indicate the status of work on theoretical uncertainties of the predictions. Some numerical results of physical interest are also given. In particular the size of the signal and $\nu\bar{\nu}\gamma$ background in case of rather simple cuts and some assumptions on the SUSY model are presented. We could see that the background in all cases is several times bigger than the signal in most regions of the phase space and that its size, for barrel photons, depends strongly on the order of QED calculations. Detailed analysis of phase space distributions for photons from $\chi\widetilde{G}$ and $\nu\bar{\nu}\gamma$ background, is essential to optimize the sensitivity of the measurement. From theoretical point of view the most essential improvements should include discussions of systematic uncertainties of $\nu\bar{\nu}\gamma$ predictions rather than the $\chi\widetilde{G}$.

Improvements introduced recently into the YFS3 generation, in particular those of the leading log content of third order matrix element are not yet included in this project. We expect that the numerical size of effects related to these improvements is by far smaller than precision required for our signal.

Finally, let us note that the amount of practical tests performed on the program has been limited. In particular, possible nonsense combinations of input parameters are not stop protected, more care should be taken than in use of KORALZ for the standard model physics processes.

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Table 1: Total cross-section in pb at $\sqrt{s}$ = 190 GeV, for a neutralino (=photino) of mass 125 GeV, with `KEYRAD=0,3,12` for 3 selectron masses (75, 150, 300 GeV). Within brackets is the error on the last digit (calculation based on 1,000,000 events). Cross section for the background process $\nu\bar{\nu}(\gamma)$ is also given for comparisons.

| $m_{\tilde{e}}$ | KEYRAD=0 | KEYRAD=3 | KEYRAD=12 |
|---|---|---|---|
| 75 | .38308(6) | .32900(5) | .33102(8) |
| 150 | .18792(4) | .15795(3) | .15927(5) |
| 300 | .62125(4) | .51795(3) | .52295(7) |
| $\nu\bar{\nu}$ | .0 | 55.15(1) | 56.24(2) |

Table 2: Percentage of events with at least one photon in the barrel region ($\mid cos\theta \mid \leq 0.7$) with energy greater than 1 GeV (same conditions as in the preceding table). In brackets are the percentages when only the photon from the neutralino decay is looked at.

| $m_{\tilde{e}}$ | KEYRAD=0 | KEYRAD=3 | KEYRAD=12 |
|---|---|---|---|
| 75 | 70.48 | 71.10(70.41) | 71.07(70.49) |
| 150 | 71.05 | 71.65(70.99) | 71.48(70.94) |
| 300 | 69.77 | 70.40(69.74) | 70.34(69.79) |
| $\nu\bar{\nu}$ | .0 | 3.75 | 4.82 |

Table 3: Fraction of events with the sum of all ISR photon energies in respective bins. The $\sqrt{s}$ = 190 GeV, neutralino(=photino) mass=125 GeV, $m_{\tilde{e}}$ = 75 GeV, `KEYRAD=12` (total nr. of events 25000).

| Bin range in GeV | nr. of events | fraction of the total nr. of events |
|---|---|---|
| $[0,1]$ | 18476 | 0.739 |
| $(1,5]$ | 3537 | 0.141 |
| $(5,10]$ | 1420 | 0.0568 |
| $(10,15]$ | 623 | 0.0249 |
| $(15,20]$ | 405 | 0.0162 |
| $(20,25]$ | 270 | 0.0108 |
| $(25,30]$ | 147 | 0.0059 |
| $(30,35]$ | 69 | 0.0028 |
| $(35,40]$ | 40 | 0.0016 |
| $(40,45]$ | 9 | 0.0004 |
| $(45,50]$ | 4 | 0.0002 |
| $> 50$ | 0 | 0.0000 |

Table 4: Fraction of events with the sum of all ISR photon energies in respective bins. The $\sqrt{s}$ = 190 GeV, neutralino (=photino) mass=125 GeV, $m_{\tilde{e}}$ = 150 GeV, `KEYRAD=12` (total nr. of events 25000).

| Bin range in GeV | nr. of events | fraction of the total nr. of events |
|---|---|---|
| $[0,1]$ | 19081 | 0.763 |
| $(1,5]$ | 3382 | 0.135 |
| $(5,10]$ | 1315 | 0.053 |
| $(10,15]$ | 585 | 0.023 |
| $(15,20]$ | 308 | 0.012 |
| $(20,25]$ | 175 | 0.007 |
| $(25,30]$ | 89 | 0.0036 |
| $(30,35]$ | 40 | 0.0016 |
| $(35,40]$ | 20 | 0.0008 |
| $(40,45]$ | 3 | 0.0001 |
| $(45,50]$ | 2 | 0.0001 |
| $> 50$ | 0 | 0.0000 |

Table 5: Total cross-section in pb at $\sqrt{s}$ = 190 GeV, for a neutralino (=photino) of mass 25 GeV (1,000,000 events).

| $m_{\tilde{e}}$ | KEYRAD=0 | KEYRAD=3 | KEYRAD=12 |
|---|---|---|---|
| 75 | .37501(6) | .38377(6) | .3829(1) |
| 150 | 2.1681(2) | 2.1270(2) | 2.1223(4) |
| 300 | 5.8941(3) | 5.5817(3) | 5.5787(7) |

Table 6: Percentage of events with at least one photon in the barrel region ($|\, cos\theta \,| \leq 0.7$) with energy greater than 1 GeV (same conditions as in preceding table). In brackets are the percentages when only the photon from the neutralino decay is looked at.

| $m_{\tilde{e}}$ | KEYRAD=0 | KEYRAD=3 | KEYRAD=12 |
|---|---|---|---|
| 75 | 76.25 | 75.96(75.22) | 75.89(75.12) |
| 150 | 70.96 | 71.25(70.41) | 71.25(70.42) |
| 300 | 66.37 | 67.06(66.15) | 67.11(66.24) |

Table 7: Fraction of events with the sum of all ISR photon energies in respective bins. The $\sqrt{s} = 190$ GeV, neutralino (=photino) mass =25 GeV, $m_{\tilde{e}} = 75$ GeV, `KEYRAD=3` (total nr. of events 25000).

| Bin range in GeV | nr. of events | fraction of the total nr. of events |
|---|---|---|
| $[0, 1]$ | 13877 | 0.555 |
| $(1, 5]$ | 4475 | 0.179 |
| $(5, 10]$ | 1869 | 0.075 |
| $(10, 15]$ | 1024 | 0.041 |
| $(15, 20]$ | 701 | 0.028 |
| $(20, 25]$ | 522 | 0.021 |
| $(25, 30]$ | 408 | 0.016 |
| $(30, 35]$ | 363 | 0.014 |
| $(35, 40]$ | 307 | 0.012 |
| $(40, 45]$ | 232 | 0.009 |
| $(45, 50]$ | 228 | 0.009 |
| $> 50$ | 998 | 0.040 |

Table 8: Fraction of events with the sum of all ISR photon energies in respective bins. The $\sqrt{s} = 190$ GeV, neutralino (=photino) mass =25 GeV, $m_{\tilde{e}} = 75$ GeV, `KEYRAD=12` (total nr. of events 25000).

| Bin range in GeV | nr. of events | fraction of the total nr. of events |
|---|---|---|
| $[0, 1]$ | 15900 | 0.636 |
| $(1, 5]$ | 3000 | 0.120 |
| $(5, 10]$ | 1515 | 0.06 |
| $(10, 15]$ | 924 | 0.04 |
| $(15, 20]$ | 626 | 0.025 |
| $(20, 25]$ | 499 | 0.020 |
| $(25, 30]$ | 420 | 0.017 |
| $(30, 35]$ | 314 | 0.013 |
| $(35, 40]$ | 301 | 0.012 |
| $(40, 45]$ | 225 | 0.009 |
| $(45, 50]$ | 219 | 0.009 |
| $> 50$ | 1057 | 0.042 |

Table 9: Total cross-section at $\sqrt{s} = 91.2$ GeV, for a neutralino (=photino) of mass 25 GeV (1,000,000 events).

| $m_{\tilde{e}}$ | KEYRAD=0 | KEYRAD=3 | KEYRAD=12 |
|---|---|---|---|
| 75 | .40881(5) | .38841(4) | .39091(7) |
| 150 | 1.09750(5) | 1.01708(5) | 1.0236(1) |
| 300 | 1.56195(3) | 1.43228(3) | 1.4411(2) |

Table 10: Percentage of events with at least one photon in the barrel region ($\mid cos\theta \mid \leq 0.7$) with energy greater than 1 GeV (same conditions as in preceding table). In brackets are the percentages when only the photon from the neutralino decay is looked at.

| $m_{\tilde{e}}$ | KEYRAD=0 | KEYRAD=3 | KEYRAD=12 |
|---|---|---|---|
| 75 | 71.00 | 71.35(70.72) | 71.33(70.74) |
| 150 | 67.74 | 68.17(67.52) | 68.25(67.76) |
| 300 | 66.37 | 66.98(66.32) | 66.98(66.38) |

Table 11: Fraction of events with the sum of all ISR photon energies in respective bins. The $\sqrt{s}$ = 91.2 GeV, neutralino (=photino) mass =25 GeV, $m_{\tilde{e}}$ = 75 GeV, `KEYRAD=3` (total nr. of events 25000).

| Bin range in GeV | nr. of events | fraction of the total nr. of events |
|---|---|---|
| $[0, 1]$ | 17513 | 0.70 |
| $(1, 5]$ | 4255 | 0.17 |
| $(5, 10]$ | 1541 | 0.06 |
| $(10, 15]$ | 795 | 0.03 |
| $(15, 20]$ | 409 | 0.016 |
| $(20, 25]$ | 265 | 0.010 |
| $(25, 30]$ | 145 | 0.006 |
| $(30, 35]$ | 66 | 0.003 |
| $(35, 40]$ | 11 | 0.0004 |
| $> 40$ | 0 | 0.0 |

Table 12: Fraction of events with the sum of all ISR photon energies in respective bins. The $\sqrt{s}$ = 91.2 GeV, neutralino (=photino) mass =25 GeV, $m_{\tilde{e}}$ = 75 GeV, `KEYRAD=12` (total nr. of events 25000).

| Bin range in GeV | nr. of events | fraction of the total nr. of events |
|---|---|---|
| $[0, 1]$ | 18651 | 0.746 |
| $(1, 5]$ | 3304 | 0.132 |
| $(5, 10]$ | 1386 | 0.055 |
| $(10, 15]$ | 734 | 0.029 |
| $(15, 20]$ | 414 | 0.0166 |
| $(20, 25]$ | 258 | 0.0103 |
| $(25, 30]$ | 159 | 0.0064 |
| $(30, 35]$ | 70 | 0.0028 |
| $(35, 40]$ | 19 | 0.0008 |
| $(40, 45]$ | 3 | 0.0001 |
| $(45, 50]$ | 2 | 0.0001 |
| $> 50$ | 0 | 0.0000 |

Table 13: Neutralino Forward-backward asymmetry with the sum of all ISR photon energies in respective bins. The $\sqrt{s}$ = 190 GeV, neutralino(=photino) mass=125 GeV, $m_{\tilde{e}} = 75$ GeV, `KEYRAD=3` (total nr. of events 25000).

| Bin range in GeV | $A_{FB}$ |
|---|---|
| $0 - \infty$ | 0.0058 |
| $[0, 1]$ | 0.0039 |
| $(1, 5]$ | 0.0059 |
| $(5, 10]$ | 0.0113 |
| $(10, 15]$ | 0.0465 |
| $(15, 20]$ | $-0.0074$ |
| $(20, 25]$ | 0.0296 |
| $(25, 30]$ | 0.0068 |
| $(30, 35]$ | 0.0725 |
| $(35, 40]$ | $-0.1$ |
| $(40, 45]$ | $-0.1$ |
| $> 45$ | 0.0 |

Table 14: Neutralino Forward-backward asymmetry with the sum of all ISR photon energies in respective bins. The $\sqrt{s}$ = 190 GeV, neutralino(=photino) mass=125 GeV, $m_{\tilde{e}} = 75$ GeV, `KEYRAD=12` (total nr. of events 25000).

| Bin range in GeV | $A_{FB}$ |
|---|---|
| $0 - \infty$ | 0.0074 |
| $[0, 1]$ | 0.0205 |
| $(1, 5]$ | $-0.0202$ |
| $(5, 10]$ | $-0.0179$ |
| $(10, 15]$ | $-0.0280$ |
| $(15, 20]$ | $-0.0586$ |
| $(20, 25]$ | 0.0940 |
| $(25, 30]$ | 0.0075 |
| $(30, 35]$ | $-0.0976$ |
| $(35, 40]$ | 0.3953 |
| $(40, 45]$ | 0.0 |
| $> 45$ | 1.0 |

# Appendix

To run KORALZ as generator for $\tilde{G}\chi$ final state it was sufficient to introduce the following new routines as explained above:
`SUBROUTINE LNZINI`
`Initialization of the neutralino-gravitino generator`
`SUBROUTINE LNZINOUT(MODE,XPAR,NPAR)`
`Interface routine to transfer data from/to KORALZ`
`to/from the neutralino-gravitino routines.`
`FUNCTION LNZBORN(S,CTHETA)`
`Differential Born cross-section.`
`SUBROUTINE LNZNMASS(M,MU,TANB,RMCHI0,RNP11,RNP12)`
`Computation of the neutralino mass and composition when LNZMOD=3.`
`SUBROUTINE LNZ1PARM(XN,MSELR,MSELL,NP11,NP12)`
`Computation of the selectron masses and neutralino composition according to the LNZ one-parameter model (LNZMOD=2) once the neutralino mass XN is given.`

In addition the following routines of KORALZ were modified:
In tauola.f: `DWLUPI`
In bufor.f: `INIMAS` (change of masses and call to `LNZINOUT`); `INIREA`, `BORNS`.
In koralz.f: `KORALZ` (introduction of option `KEYRAD=3` that corresponds to set `KEYRAD=1` with `KBRFIN=0`), `ZTOHEP`, `TRALO4`, `EVENTM`, `WEIGHT`.
In yfsface.f: `EVENTE`.

To run the program it is thus enough to supplement the main program with the additional file `francoxv/grakor/korzgra.f` which can be obtained from Franco.Anselmo@cern.ch, if the standard KORALZ is loaded as library. Otherwise it may be necessary to remove from the KORALZ source the duplicated entries to avoid corresponding fatal loader errors.

The file francoxv/grakor/korzgra.f contains new routines specific to our purpose and the replacement routines for KORALZ. The second part is separated from the first one by:

```
C==================================================================C
C====
C====
C==== KORALZ G x replacement routines
C====
C====
C==================================================================C
```

The following new common blocks have been introduced into the KORALZ structure. Three common blocks are for storing the input parameters from the data cards and have to be filled for the FFREAD CERN library program (see above, sect. 5):

```
REAL ROOTS
INTEGER IKEYRAD,INEVTS
COMMON/KORZINP/IKEYRAD,INEVTS,ROOTS
```

```
INTEGER LNZMOD
COMMON/LNZMODE/LNZMOD
```

```
REAL RMGINOEV,R1,R2,R3,R4,R5
COMMON/LNZINPUT/RMGINOEV,R1,R2,R3,R4,R5
```

`R1,R2,R3,R4,R5` take different meaning depending on `LNZMOD` (see sect. 5).

The following four common blocks are used for internal purposes.

```
DOUBLE PRECISION M2SELL,M2SELR,MCHI0,M2CHI0,MGINO
COMMON/LNZMASS/M2SELL,M2SELR,MCHI0,M2CHI0,MGINO
```

These are the squared masses of $\widetilde{e}_R$ and $\widetilde{e}_L$, the mass and the squared mass of the lightest neutralino and the gravitino mass.

```
DOUBLE PRECISION ZMASS,M2Z,GZ,SIN2TW
COMMON/LNZPAR1/ZMASS,M2Z,GZ,SIN2TW
```

Z mass, Z mass squared, Z width and squared sine of Weinberg angle.

In the following two common blocks /LNZPAR2/ and /LNZPAR3/ parameters defining couplings are stored. See the source of the program for more details.

```
DOUBLE
PRECISION NP11E,NP12GC,CR,CL,XR,XL
COMMON/LNZPAR2/NP11E,NP12GC,CR,CL,XR,XL
```

```
DOUBLE PRECISION NP11,NP12
COMMON/LNZPAR3/NP11,NP12
```

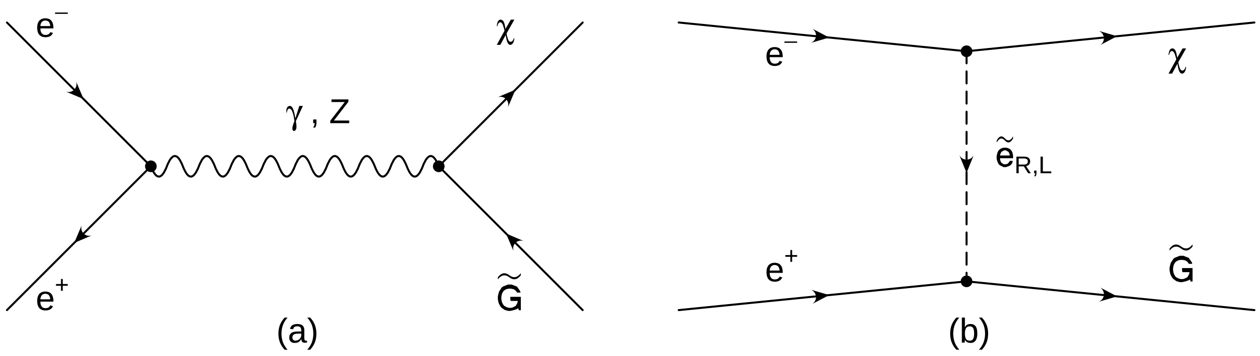


Figure 1: Feynman diagrams contributing to the process at the Born level.

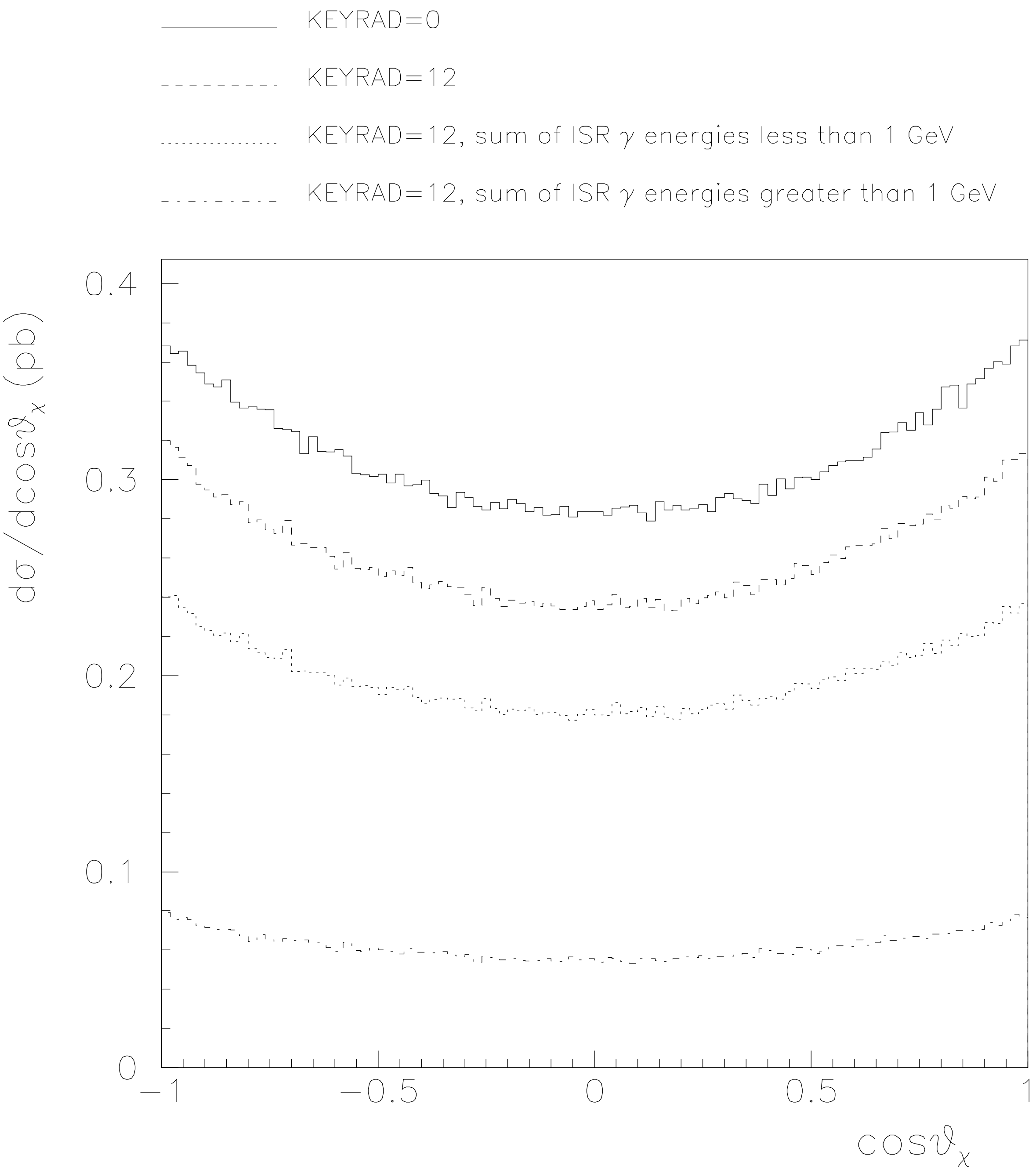


Figure 2: Neutralino (=photino) $cos\theta_\chi$ distribution without ISR (full line) and with multiphoton ISR (dotted line). Also plotted are the distributions when the sum of the ISR photon energies is less than 1 GeV and when it is bigger than 1 GeV ($\sqrt{s} = 190GeV, m_\chi = 125GeV, m_{\widetilde{G}} = 10^{-5}eV, m_{\widetilde{e}} = 300$ GeV).

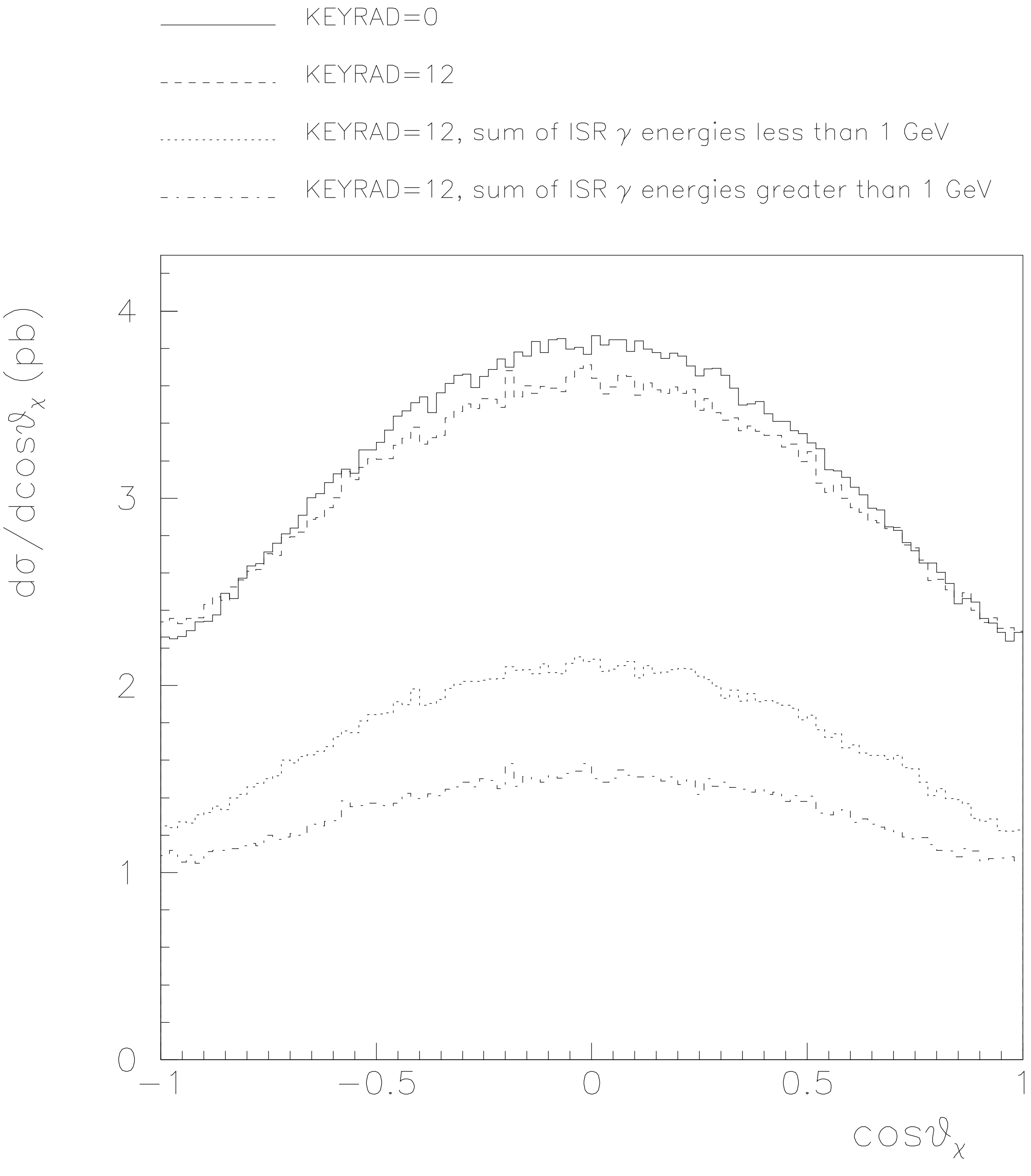


Figure 3: Same as fig. 1 but for $\sqrt{s} = 500$ GeV.

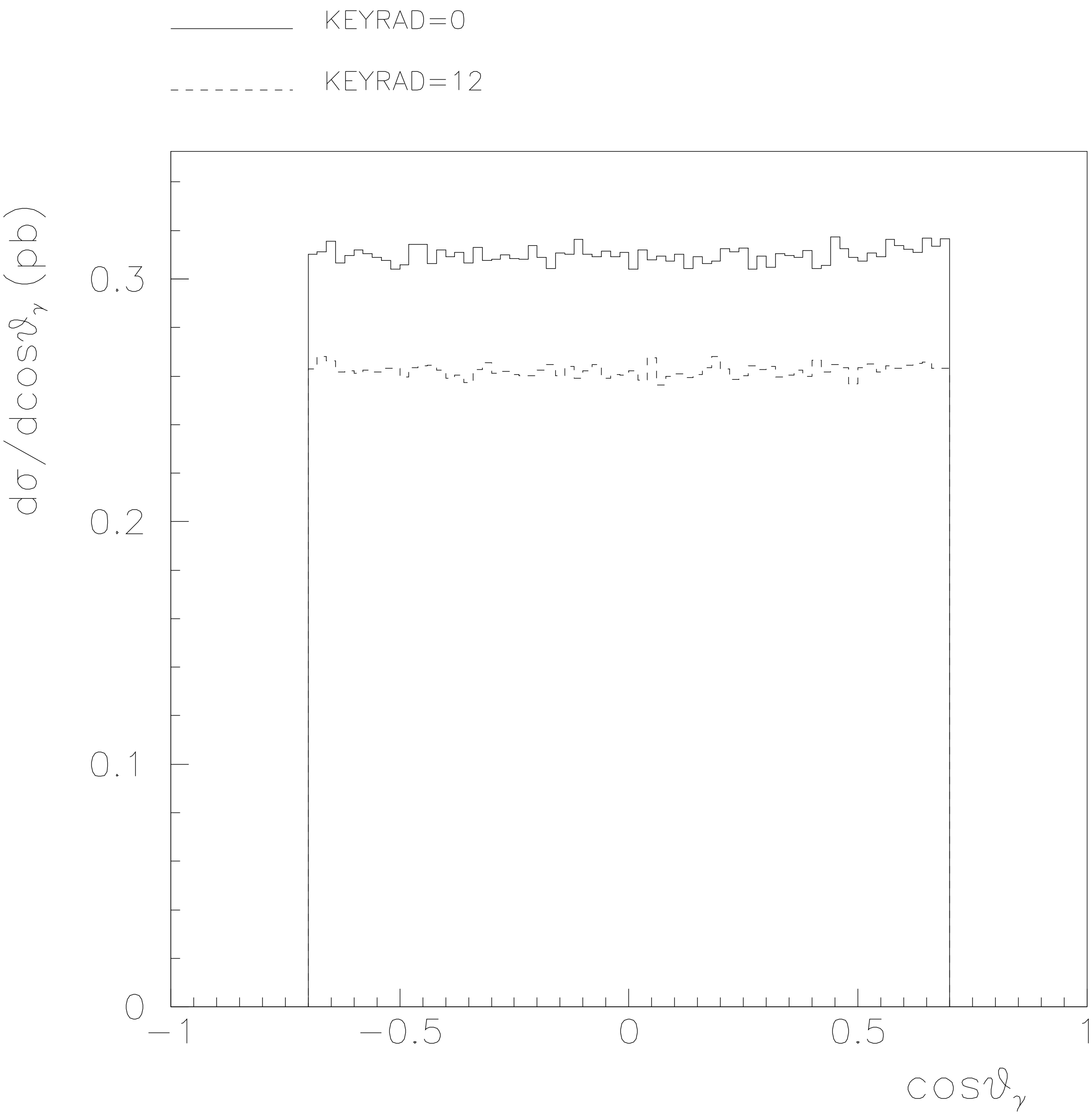


Figure 4: The $cos\theta$ distribution of the highest-$p_t$ barrel photon without ISR (full line) and with multiphoton ISR (dashed line) for $\sqrt{s}$ = 190 GeV ($m_\chi = 125GeV, m_{\widetilde{G}} = 10^{-5}eV, m_{\widetilde{e}} = 300$ GeV).

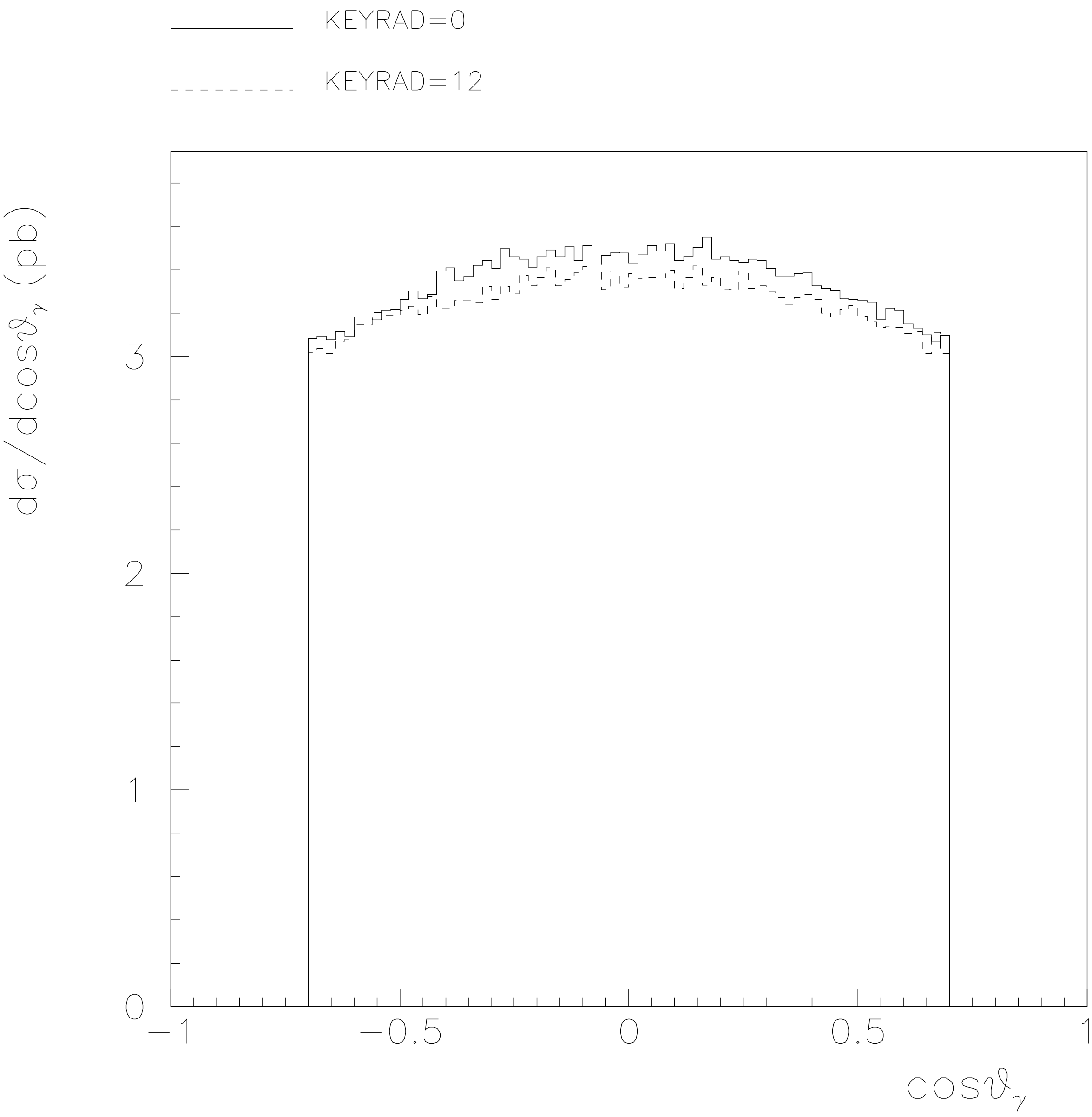


Figure 5: The $cos\theta$ distribution of the highest-$p_t$ barrel photon without ISR (full line) and with multiphoton ISR (dashed line) for $\sqrt{s}$ = 500 GeV ($m_\chi = 125GeV, m_{\tilde{G}} = 10^{-5}eV, m_{\tilde{e}} = 300$ GeV).

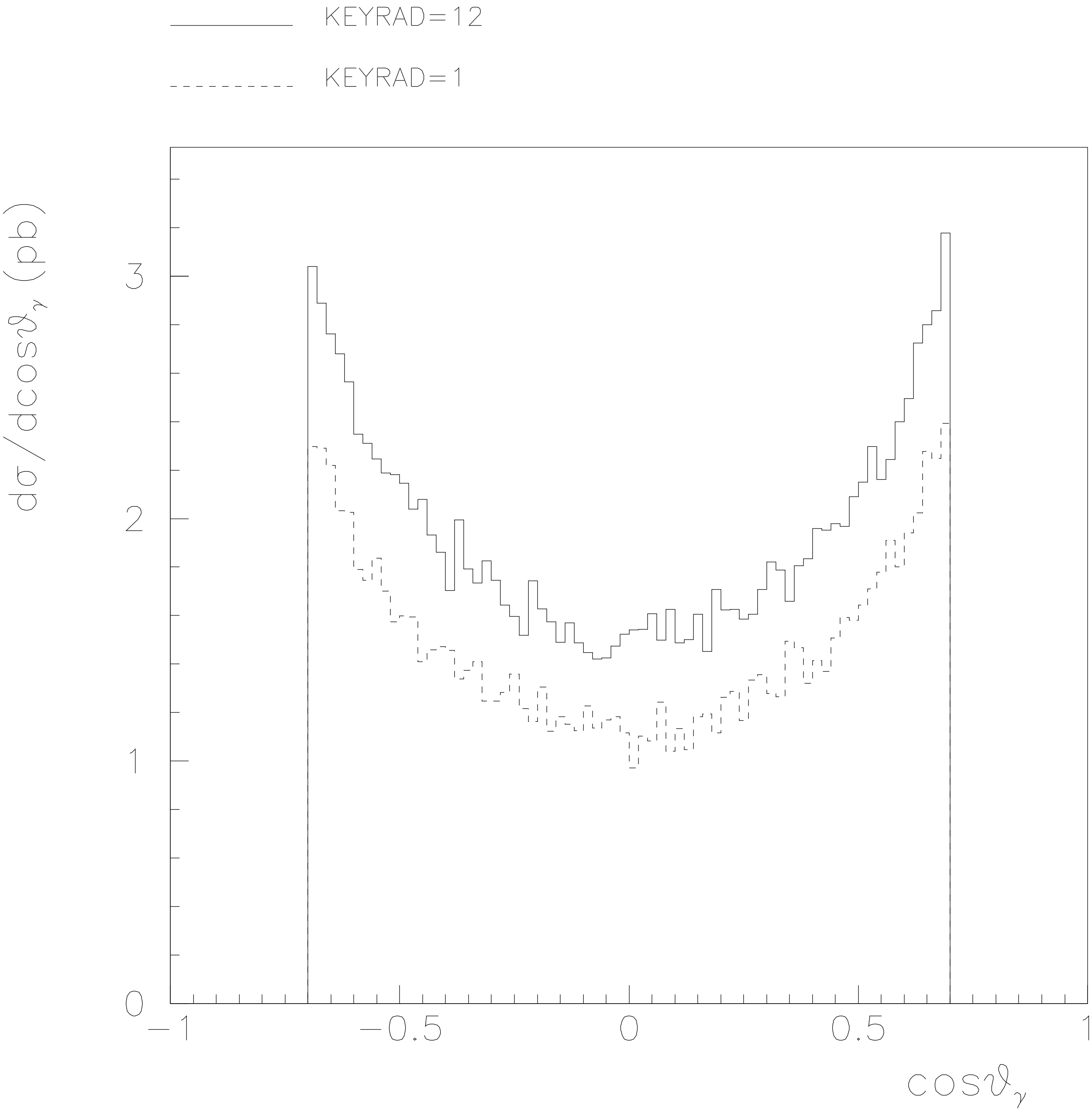


Figure 6: The $cos\theta$ distribution of the highest-$p_t$ barrel photon for the background process $e^+e^- \to \nu\bar{\nu}$ with multiphoton ISR (full line) and with single-photon ISR (dashed line) for $\sqrt{s} = 190$ GeV ($m_\chi = 125 GeV, m_{\tilde{G}} = 10^{-5} eV, m_{\tilde{e}} = 300$ GeV).

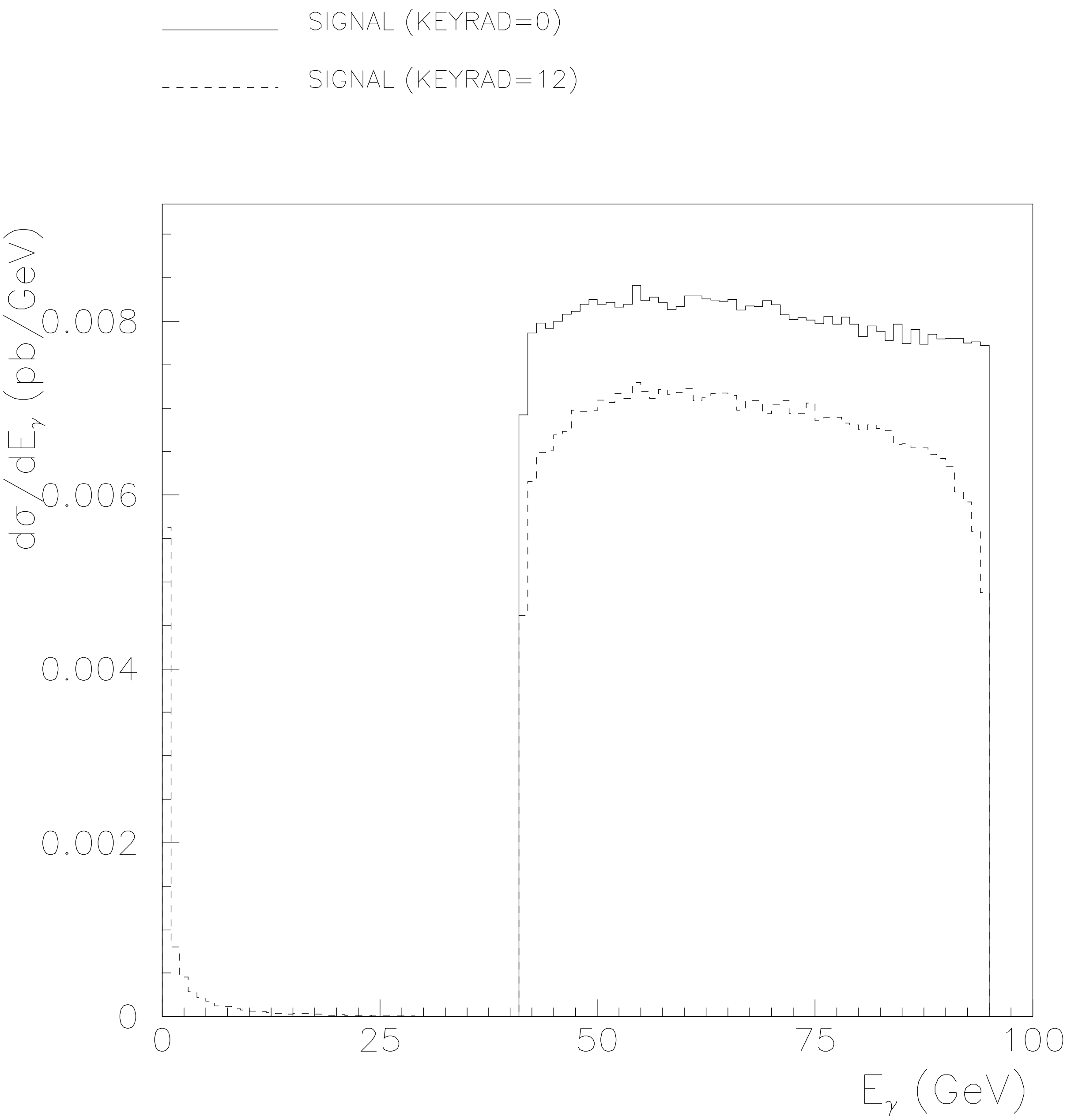


Figure 7: Energy distribution of the highest-$p_t$ barrel photon for the signal with multiphoton ISR (full line) and with single-photon ISR (dashed line) for $\sqrt{s} = 190$ GeV ($m_\chi = 125 GeV, m_{\tilde{G}} = 10^{-5} eV, m_{\tilde{e}} = 300$ GeV).

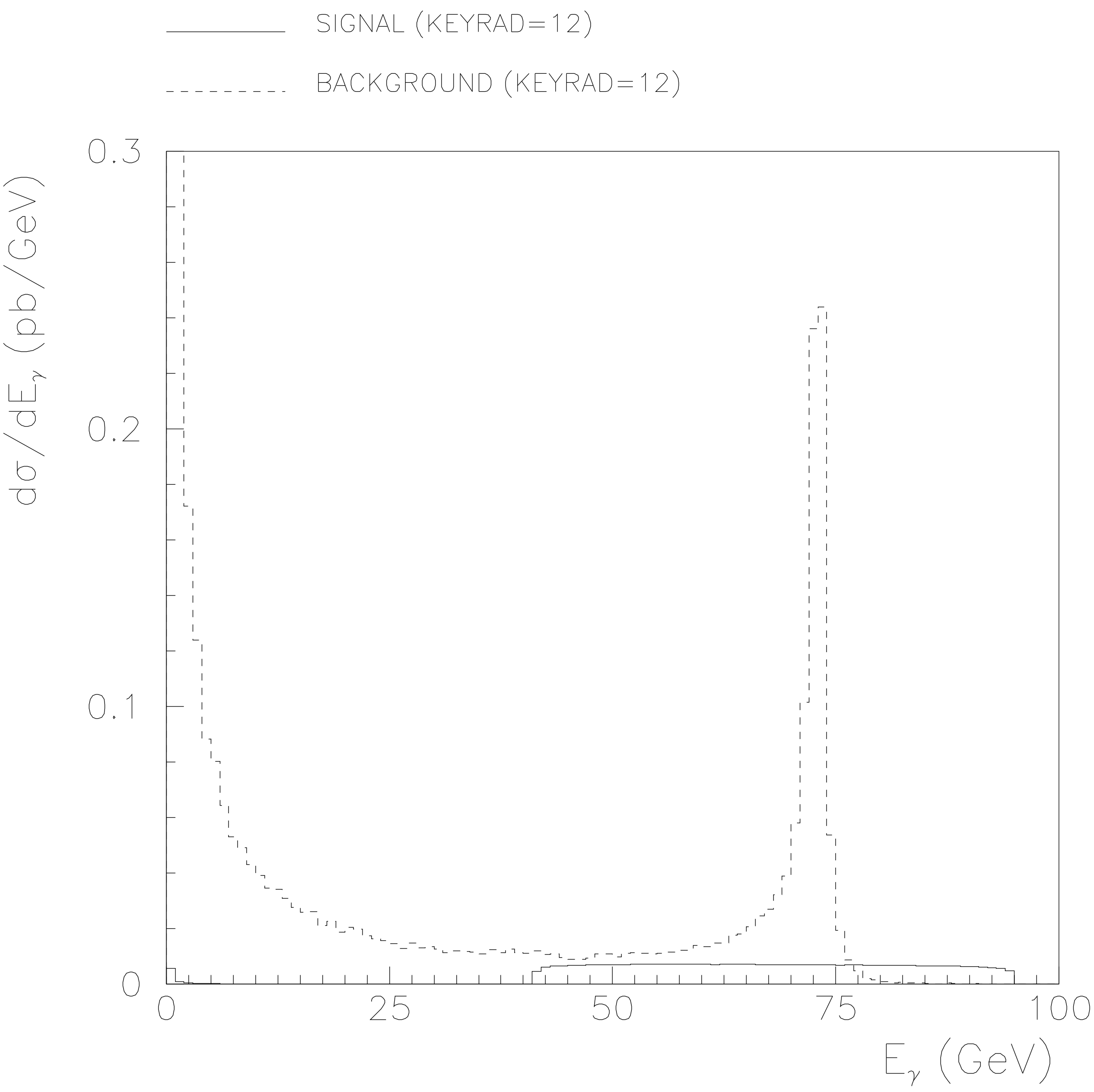


Figure 8: Energy distribution of the highest-$p_t$ barrel photon for the background process $e^+e^- \to \nu\bar{\nu}$ with multiphoton ISR (dashed line) and the signal with multiphoton ISR (full line) for $\sqrt{s} = 190$ GeV ($m_\chi = 125 GeV, m_{\tilde{G}} = 10^{-5} eV, m_{\tilde{e}} = 300$ GeV).

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