Production of four charged leptons in electroweak $\gamma\gamma$ interactions

I. Sotsky

NC PHEP ,BSU, Minsk, Belarus

Abstract

At present paper we performed a detailed numerical analysis of four charged leptons photoproduction in frame of standard theory of electroweak interaction. Total and differential cross sections are obtained by using of the Monte-Carlo method of numerical integration. Different energies of initial photons (60-2000 GeV in c.m.s.), definite and averaged spin states of interacting particles and fixed kinematical cuts are considered.

1 Introduction

In the nearest future are planned to realize high energy experiments on linear collider which will have a possibility to operate in $\gamma\gamma, \gamma e$ mode [1]. This new capability will provide a great advantage in investigation of new physics phenomenon, new particles research, and detailed study of non abelian nature of electroweak interaction. However it is necessary to take in to account several important features, to realize such kind experiments successfully.

First of all, since produced $W^{\pm}$ and Higgs particles ordinarily decay within detector they could be observed via it's decay products only, for example via several pairs of leptons in final state. Because of high accuracy and relatively clean environment provided by leptonic collider, the exact computations of all backgrounds, namely: $\gamma\gamma \rightarrow 2l$, $\gamma\gamma \rightarrow 2l + photons$ and $\gamma\gamma \rightarrow 4l$ processes, are required to study of such type production.

Secondly, since initial high energy γ quantums are produced by Compton backscattering of laser ray on fast electrons, the exact information about polarization state and energy spectrum of obtained photon's beams is necessary to interpret the results of such experiments correctly. This data one can be gathered from measuring of several calibration processes: $\gamma\gamma \rightarrow 2l$, $\gamma\gamma \rightarrow 2l + photons$ and $\gamma\gamma \rightarrow 4l$ for example.

So it is obviously a great importance in precision investigation of processes listed behind. The analysis of $\gamma\gamma \rightarrow 2l$ and $\gamma\gamma \rightarrow 2l + photons$ processes one can find in [2]-[4] for example. The detailed theoretical description of $\gamma\gamma \rightarrow 4l$ reaction, a lot of useful references to the works devoted to same problem and expression of squared matrix element constructed by helicity amplitude method one can find in [5]. At this paper we performed the detailed numerical analysis of two charged leptons pair production in frame of standard theory of electroweak interaction. Different energies, polarization states and definite set of experimental kinematical cuts are considered.

2   Calculation

There are six topologically different Feynman diagrams describing process of $\gamma\gamma \to 4l$ in the lowest order of standard theory of electroweak interaction (see fig.1). Whole set of diagrams can be derived on base of these six ones using C- P- and crossing symmetries.
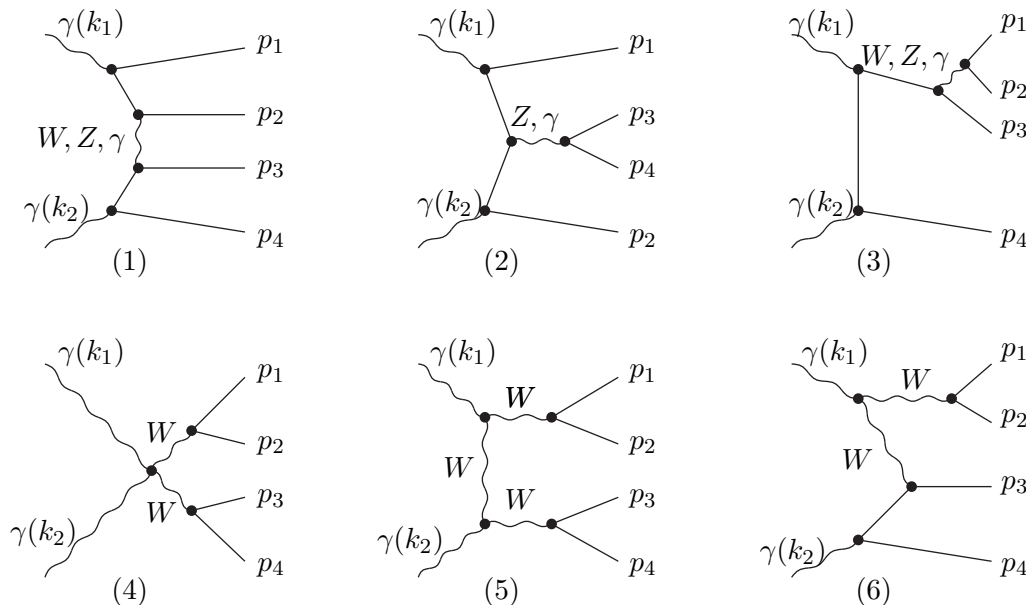

Fig.1. Feynman diagrams for process $\gamma\gamma \to 4l$.

The diagrams containing charged current exchange are excluded because only processes with four charged leptons in final state are considered at present work.

The construction of squared matrix element is realized both using helicity amplitude method [6]-[9] and precision covariant one [10],[11]. Helicity amplitude method is used to obtain cross sections in massless limit at each possible polarization state. Simple form of final expression allow to perform numerical integration with high enough accuracy for a short interval of computing time. The explicit view of matrix element constructed by using helicity amplitude method one can find in [5].

The precision covariant method allow to construct squared matrix element without any approximations at averaged polarization state of interacting particles. It is applied to verify of received data, to estimate error of massless approximation and to investigate heavy leptons production processes.

The investigation of differential and total cross sections is realized by using of the Monte-Carlo method of numerical integration.

3   Results and Conclusion

We have calculated the differential and total cross sections of $\gamma\gamma \to 4l$ process in frame of standard theory of electroweak interaction at various sets of energies, polarization states and kinematical cuts.

The values of total cross sections at different kinematical conditions are presented in the Table. The differential cross section dependences on cosine of polar angle are shown on figs.2-9. The case of averaged polarization state of interacting particles as well as fixed ones is considered. The total cross section dependence on energy of initial particles one can see on fig.10.

Presented results demonstrate the cross section's pronounced dependence on cosine of polar angle: cross section is almost equals to zero in the middle part of kinematical region (the kinematical region where final particles have large $p_\perp$) and extremely increase in the part close to the borders (the kinematical region with small $p_\perp$) (see figs.2-9). Also, the total cross section strongly increase with decreasing energy of interacting photons (see the Table and fig.10). Such behavior causes because an expression of cross section contain $\frac{1}{k_1 k_2}$ phactor, where k_1 and k_2 are four momenta of initial photons.

The assymetry of differential cross section (figs.4,5) occurs because the probability of lepton scattering into direction close to direction of initial photon is larger in case of different signs of photon polarization and scattering lepton helicity then in case of equal ones.

As one can see on figs.6,7 the differential cross section has symmetric form since initial photons have the similar polarization signs, but the cross section's value is larger in case when lepton's helicity sign is different from polarization signs of interacting photons. The total cross section of lepton photoproduction with fixed polarization states is larger in case of different polarizations of initial photos then in case of similar ones (see fig.8,9).

The comparison of results obtained by helicity amplitude method and precision covariant one indicates that electron and positron mass contributions have vanishingly small value at investigated kinematical region. Also, as one can see in the Table, the distinguish between $\gamma\gamma \to 4\mu$ cross section and $\gamma\gamma \to 4e$ one at the energy of initial particles $0.5Tev$ (in c.m.s.) is less then Monte-Carlo statistical error. So, at the energy of initial photons $0.5Tev$ (in c.m.s.) and higher one could neglect muon mass contribution without precision losing. As well, we could perform the same neglect in $\gamma\gamma \to e^+e^-\mu^+\mu^-$ reaction with interacting energy $0.5Tev$ (in c.m.s.) and higher by the similar reason.

The squared matrix element, constructed by precision covariant method, is obtained for unpolarized interacting particles only, so one could't investigate cross sections at definite spin states in case of heavy particles production (μ and τ leptons). However, if the interacting energy is larger then value indicate above (0.5 Tev for $\gamma\gamma \to \mu^+\mu^-\mu^+\mu^-$ and $\gamma\gamma \to e^+e^-\mu^+\mu^-$ reactions), one could apply the expression of matrix element constructed by helicity amplitude method for massless particles and obtain cross section at each possible spin states.

The relative error of obtained results ($\sim$ 0.5%-0.9%) is less then expected experimental error in future high energy experiments on linear collider [1].

Table.

The total cross sections dependences on energy of initial particles. Here the following notation (α, β) is used to describe kinematical cuts, where α is minimal angle between any two final particles, $\beta-$ minimal polar angle. Minimal admissible energy of any final particle is $1Gev$.

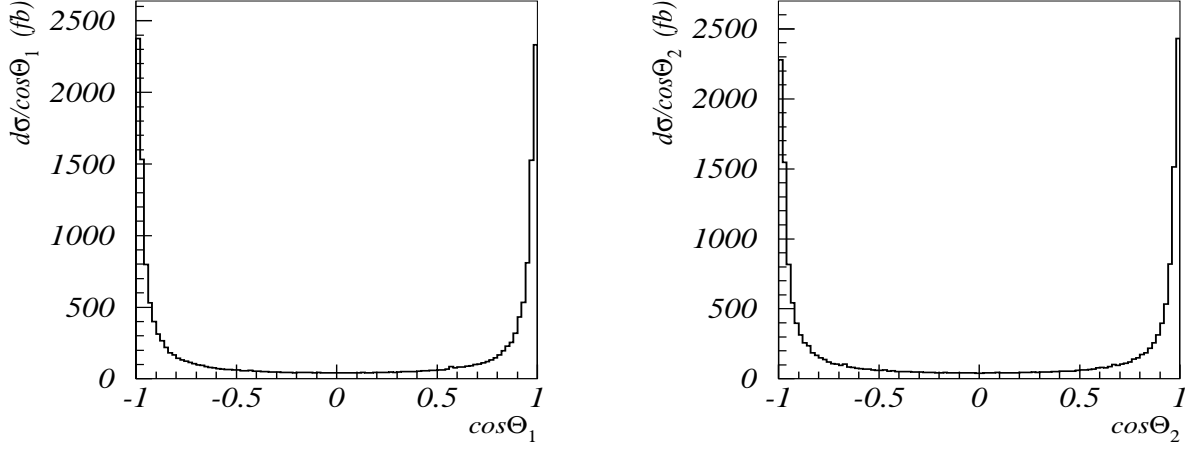| cut	$(3^o, 7^o)$		
energy (Gev)	$e^+e^-e^+e^-$	$\mu^+\mu^-\mu^+\mu^-$	$e^+e^-\mu^+\mu^-$
60	1254.36 ± 6.73	1210.99 ± 8.90	630.20 ± 5.49
120	379.86 ± 1.87	370.37 ± 2.48	189.41 ± 1.55
200	154.94 ± 0.81	152.87 ± 1.25	78.12 ± 0.54
300	76.41 ± 0.47	75.36 ± 0.44	38.77 ± 0.23
400	46.97 ± 0.30	46.67 ± 0.35	23.95 ± 0.17
500	32.15 ± 0.15	32.14 ± 0.27	16.43 ± 0.14
1000	9.90 ± 0.07	9.97 ± 0.12	5.03 ± 0.04
1500	5.05 ± 0.04	5.07 ± 0.11	2.55 ± 0.01
2000	3.04 ± 0.03	3.03 ± 0.03	1.52 ± 0.01

Fig.2. The differential cross section dependence of $\gamma\gamma \to e^+e^-e^+e^-$ process on cosine of polar angle at averaged polarization state of interacting particles. Here energy of $\gamma\gamma-$ beam is $120 GeV$ in c.m.s, $\theta_{1(2)}$ is the angle between the first(second) photon and one of the final electron. The values of polar angle cut and cut on angle between any two final particles are 7° and 3° respectively. Minimal admissible energy of any final particle is $1 Gev$
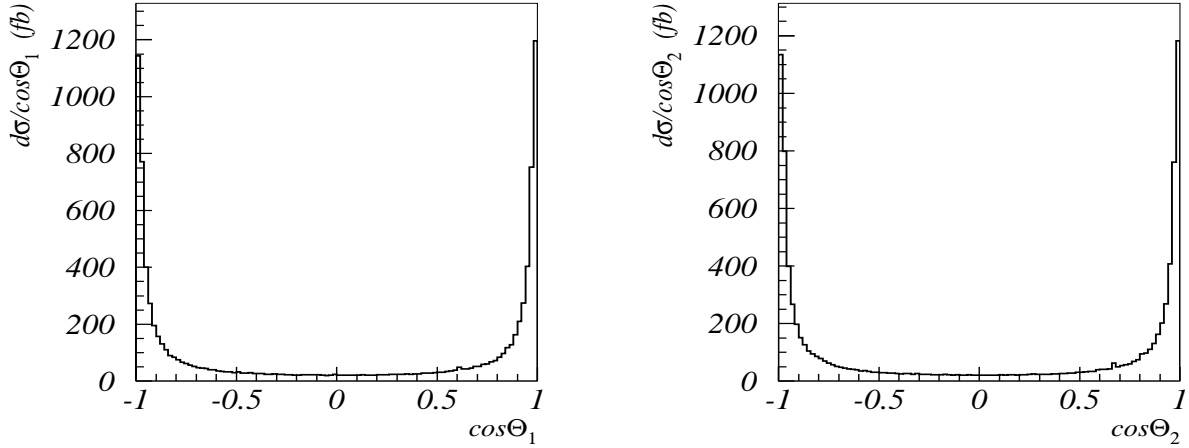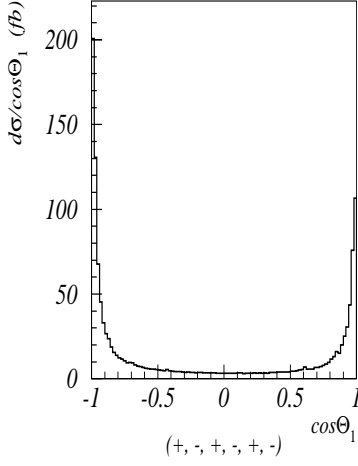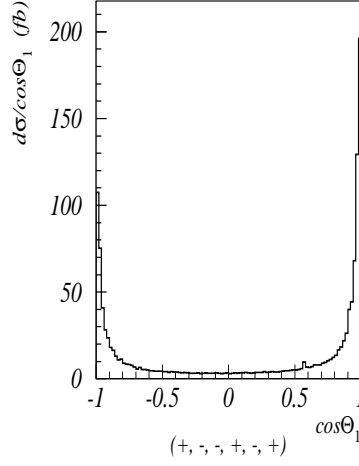

Fig.3. The differential cross section dependence of $\gamma\gamma \to e^+e^-\mu^+\mu^-$ process on cosine of polar angle at averaged polarization state of interacting particles. Here energy of $\gamma\gamma-$ beam is $120 GeV$ in c.m.s, $\theta_{1(2)}$ is the angle between the first(second) photon and one of the final electron. The values of polar angle cut and cut on angle between any final two particles are 7° and 3° respectively. Minimal admissible energy of any final particle is $1 Gev$
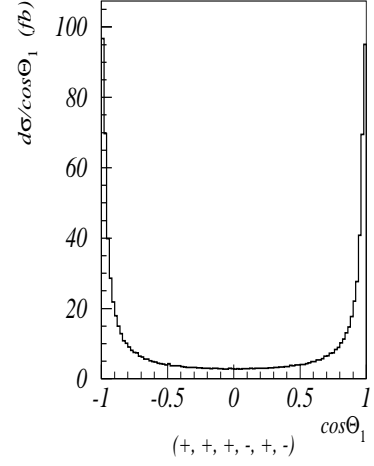
Fig.4. $(+, -, +, -, +, -)$

Fig.6. $(+, -, -, +, -, +)$

Fig.6. $(+, +, +, -, +, -)$

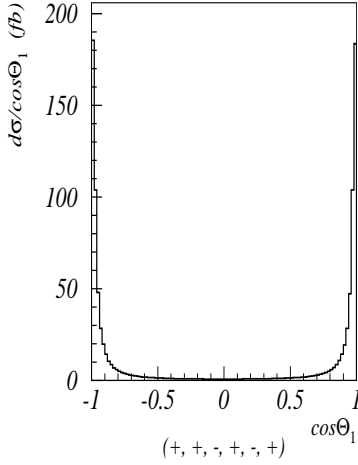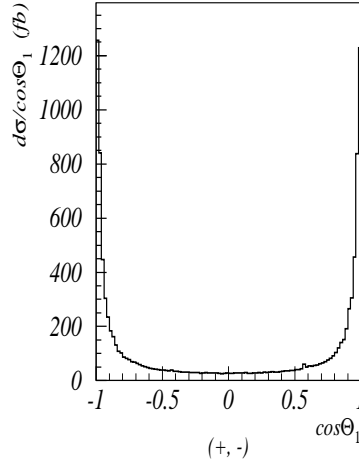Fig.7. $(+, +, -, +, -, +)$

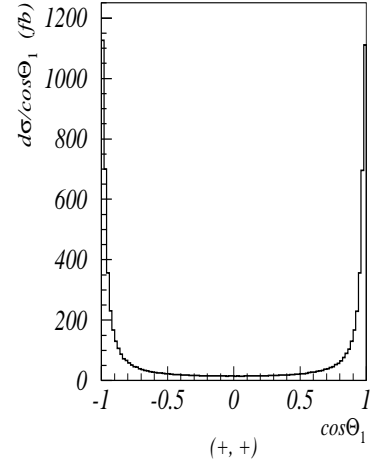Fig.8. $(+, -)$

Fig.9. $(+, +)$

Figs.4-8. The dependence of the $\gamma\gamma \rightarrow e^{+}e^{-}e^{+}e^{-}$ differential cross section on cosine of polar angle at fixed polarization states of interacting particles. Here energy of $\gamma\gamma-$ beam is $120 GeV$ in c.m.s, θ_1 is the angle between the first photon and one of the final electron. The values of polar angle cut and cut on angle between any two final particles are 7° and 3° respectively.

Minimal admissible energy of any final particle is $1 Gev$ For identification of particle polarizations is used following notation: $(+, -, +, -, +, -,) = (\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6)$, where $\lambda_{1(2)}$ corresponds to polarization state of photon with four momentum $k_{1(2)}$, $\lambda_{3,4,5,6} -$ helicity of lepton with four momentum $p_{1,2,3,4}$. Notations of $(+, -)$ and $(+, -)$ mean spin states with definite photon's and averaged lepton's polarizations.
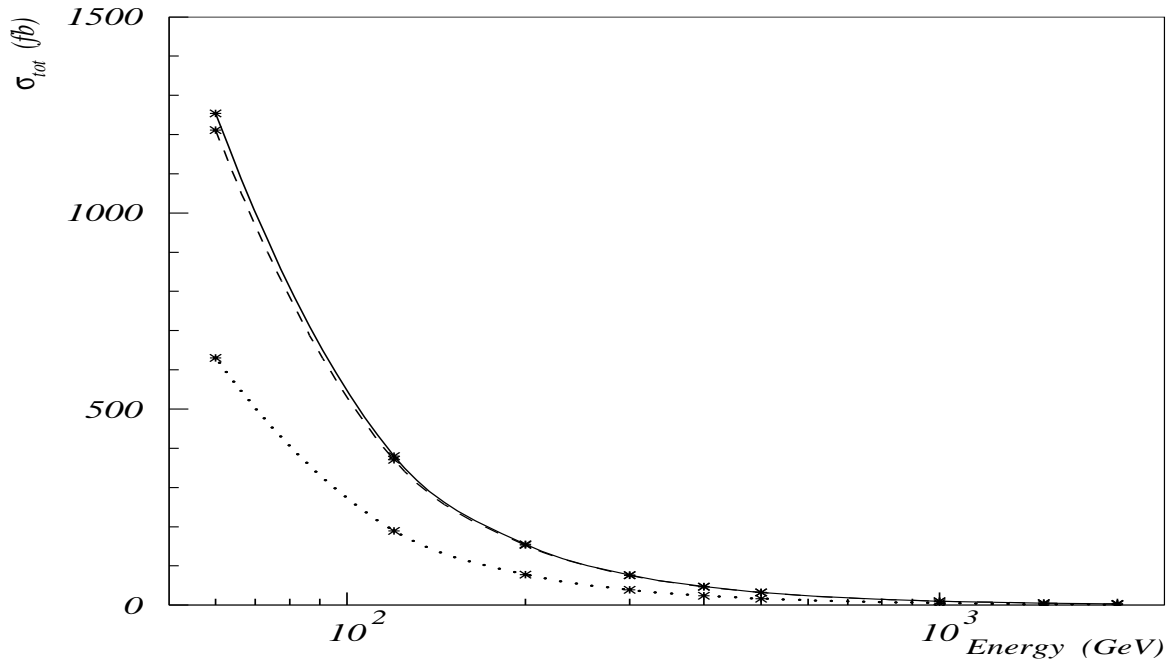
Fig.10. The total cross sections dependences on energy of interacting particles. Solid line corresponds to cross section of $\gamma\gamma \to e^+e^-e^+e^-$ process, dashed line to $\gamma\gamma \to \mu^+\mu^-\mu^+\mu^-$ process and dotted line to $\gamma\gamma \to e^+e^-\mu^+\mu^-$ process.

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