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Effects of "new physics" in processes of photons scattering on linear colliders of next generation

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The main possibilities of "new physics" effects using polarized gamma beams of linear colliders are considered. It is discovered that processes of several bosons production in processes of photons scattering is the best place to search directly for any anomalous behaviour of quartic couplings (a_0, a_e and a_n). A set of anomalous quartic boson operators are considered in the paper. Compton scattering of polarized photons by polarized electrons is investigated. Numerical analysis is realized at energy and kinematic conditions of ILC. Radiative effects in processes of $\gamma\gamma$ and γe interaction are calculated and analyzed. It is discovered the importance of radiative correction procedure for study of the effects beyond Standard Model of electroweak interaction. Different methods of "new physics" search are discussed.

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1. Introduction

The Standard Model (SM) has possibility to describe all experimental data up to now with typical precision around one per mil. Nevertheless the Model is not the final theory valid up to very high scales and at linear collider that can run at center of mass energies around 1 TeV one can hope to see finally deviations in precision measurements occur typically for two reasons.

Linear lepton colliders will provide the opportunity to investigate photon collisions at energies and luminosities close to these in e^+e^- collisions [1].

The possibility to transform the future linear e^+e^--colliders into the $\gamma\gamma$ and γe -colliders with approximately the same energies and luminosities was shown. The basic e^+e^--colliders can be transformed into the $e\gamma$- or $\gamma\gamma$-colliders. The intense γ -beams for photon colliders are suggested to be obtained by Compton scattering of laser lights which is focused on electrons beams of basic e^+e^--accelerators.

The electron and photon linear colliders of next generation will attack unexplored higher energy region where new behaviour can turn up. In this area the photon colliders have a number of advantages.

– The first of the above advantages is connected with the better signal/background ratio at both e^+e^-- and $e\gamma/\gamma\gamma$-colliders in comparison with hadron ones.

– The production cross sections at photon colliders are usually larger than those at electron colliders.

– The photon colliders permit to investigate both of the problems of new physics and those ones of "classical" hadron physics and QCD.

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2. $\gamma\gamma$-interactions on linear colliders

Future high-energy linear e^+e^- colliders in γe and $\gamma\gamma$ mode could be a very useful instrument to explore mechanism of symmetry breaking in electroweak interaction using self couplings test of the W and Z bosons in non-minimal gauge models. WW-production would be provided mainly by $\gamma\gamma$-scattering [2]. The Born cross section $\sigma(\gamma\gamma \to W^+W^-)$ is about 110pb at 1 TeV on unpolarized γ-beams. Corresponding cross section of WW-production on electron colliders is an order of magnitude smaller and amounts to 10pb. One needs to consider a reaction $\gamma\gamma \to W^+W^-Z$ since its cross section becomes about 5%-10% of the cross section WW-production at energies $\sqrt{s} \geq 500$ GeV. The anomalous three-linear [3] γWW and ZWW and quartic [4] $\gamma\gamma WW$, γZWW, $ZZWW$ etc. couplings induce deviations of the lowest-order cross section from the Standard Model.

In order to evaluate contributions of anomalous couplings a cross section of $\gamma\gamma \to W^+W^-$ must be calculated with a high precision and extracted from experimental data. Therefore one needs to calculate the main contribution of high order electroweak effects: one-loop correction, real photon and Z emission.

Lagrangian of three-boson ($WW\gamma$ and WWZ) interaction in the most general form can be presented as

$$\begin{aligned} L_{WWV} = -g_{WWV} i[g_1^V \left(W^+_{\mu\nu} W^\mu V^\nu - W^+_\mu V_\nu W^{\mu\nu}\right) \\ +k_V W^+_\mu W^\nu V^{\mu\nu} + i\lambda_V/m_W^2 W^+_{\lambda\mu} W^\mu V^{\nu\lambda} - \\ -g_4^V W^+_\mu W^\nu \left(\partial^\mu V^\nu + \partial^\nu V^\mu\right) + \\ + g_5^V \epsilon^{\mu\nu\rho\sigma} \left(W^+_\mu \overleftrightarrow{\partial}_\rho W_\nu\right) V_\sigma + \\ +i k_V W^+_\mu W_\nu \tilde{V}^{\mu\nu} + i\tilde{\lambda}_V/m_W^2 W^+_{\lambda\mu} W^\mu_\nu V^{\nu\lambda}]. \end{aligned} \tag{1}$$

Here V_μ is the photon or Z-boson field (correspondingly, $V = \gamma$ or $V = Z$), W_μ – W^--boson field,

$$W_{\mu\nu} = \partial_\mu W_\nu - \partial_\nu W_\mu, \;\; V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu, \tag{2}$$

$\tilde{V}_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\rho\sigma}V^{\rho\sigma}$ and $A \overleftrightarrow{\partial}_\mu B = A(\partial_\mu B) - (\partial_\mu A)B$. The parameter of interaction g_{WWV} are fixed as follows:

$$g_{WW\gamma} = e, \;\; g_{WWZ} = e\cos\theta_W. \tag{3}$$

In case of $WW\gamma$-interaction the first term corresponds to the minimal interaction (in case of $g_1^\gamma = 1$). The parameters of the second and third terms are connected with magnetic momentum and quadrupole electric one of W-boson correspondingly as

$$\mu_W = \frac{e}{2m_W}(1 + k_\gamma + \lambda_\gamma), \;\; Q_W = \frac{e}{m_W^2}(\lambda_\gamma - k_\gamma). \tag{4}$$

The last two operators parameters are connected with electric dipole moment d_W as well as quadrupole magnetic moment $\tilde{Q}_W$:

$$d_W = \frac{e}{2m_W}(\tilde{k}_\gamma + \tilde{\lambda}_\gamma), \;\; \tilde{Q}_W = \frac{e}{m_W^2}(\tilde{\lambda}_\gamma - \tilde{k}_\gamma). \tag{5}$$

In frame of the SM $WW\gamma$- and WWZ-vertices are determined by gauge group $SU(2)\otimes U(1)$. In the lowest order of perturbative theory only C- and T-invariant corrections exist (in this case $k_V = 1$, $\lambda_V = 0$). However electroweak radiative corrections (loop diagrams with heavy charged fermions) can give significant contribution in k_V and λ_V as well as C- and T-violate interaction.

There are four-boson vertices giving additional independent information about gauge structure of electroweak interaction. The corresponding cross sections give contribution in cross section of boson production in $e\gamma$- and $\gamma\gamma$-scattering.

If we will consider only the interactions which conserve P- and C-symmetry, Lagrangian four-boson interaction includes two 6-dimension operators

$$L_Q^{(6)} = -\frac{\pi\alpha}{4m_W^2}\left[a_o F_{\alpha\beta}F^{\alpha\beta}\left(\vec{W}_\mu \cdot \vec{W}^\mu\right) + a_c F_{\alpha\mu}F^{\alpha\nu}\left(\vec{W}^\mu \cdot \vec{W}_\nu\right)\right], \tag{6}$$

where $F_{\alpha\beta}$ – tensor of electromagnetic field, $\vec{W}_\mu$ represent W-triplet, a_0 and a_c – anomalous constants. The first term corresponds to neutral scalar exchange. One-loop corrections due to charged heavy fermions give contributions with four-boson vertices to the both terms of the Lagrangian (7).

Charged scalars give contribution proportional to a_0 only.

Since cross section of photoboson production rises to constant value and cross section of electron-positron interaction decreases with energy growth as reverse proportional dependence s^{-1} when central mass is equal to 500 GeV, the photoproduction of boson cross section is an order bigger than e^+e^- interaction cross section and is the most important source of information about anomalous boson couplings.

We have considered the anomalous quartic boson vertices. For this purpose the following 6-dimensional $SU(2)_C$ Lagrangian [4, 5] have been chosen:

$$\begin{aligned} L_0 &= -\frac{e^2}{16\Lambda^2} a_0 F^{\mu\nu} F_{\mu\nu} \vec{W}^\alpha \cdot \vec{W}_\alpha, \\ L_c &= -\frac{e^2}{16\Lambda^2} a_c F^{\mu\alpha} F_{\mu\beta} \vec{W}^\beta \cdot \vec{W}_\alpha, \\ \tilde{L}_0 &= -\frac{e^2}{16\Lambda^2} \tilde{a}_0 F^{\mu\alpha} \tilde{F}_{\mu\beta} \vec{W}^\beta \cdot \vec{W}_\alpha. \end{aligned} \tag{7}$$

where the triplet gauge boson $\vec{W}_\mu$ and the field-strength tensors

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu,\ W^i_{\mu\nu} = \partial_\mu W^i_\nu - \partial_\nu W^i_\mu,\ \tilde{F}_{\mu\nu} = \frac{1}{2}\varepsilon_{\mu\nu\rho\sigma}F^{\rho\sigma}$$

are introduced. As one can see the operators L_0 and L_c are C-, P- and CP-invariant. $\tilde{L}_0$ is the P- and CP-violating operator.

The dependence of total cross section $\sigma(W^+W^-)$ on anomalous parameters was investigated at the following experimental conditions:

– The center-of-mass energy of $\gamma\gamma(\sqrt{s})$ in $\gamma\gamma \to W^+W^-$ is fixed at 1 TeV;

– Photon luminosity L is supposed to be 100 fb^{-1}/year;

– In ILC experiments for $\gamma\gamma$-scattering polarization states of the photon beams will be fixed by $J = 0$ or $J = 2$ states;

– In addition it is assumed that the final W-bosons will be detected with certain polarization states.

It was discovered that minima of the curves are close to the Standard Model point $a_i = 0$ since the interference between anomalous and standard part of cross section is very small. Through the region of a_i is small (about 0.05) the cross section with anomalous constants may reach values of 1.6σ. Taking into account a luminosity of photons and beams energy statistical error will be equal to 0.05 %. Therefore for precision analysis of experimental data it is important to calculate radiative corrections. We calculate $\mathcal{O}(\alpha)$ radiative correction giving maximal contribution to cross section value. It includes real photon emission as well as a set of one-loop diagrams. Since of ILC-beams energy exceeds the threshold of three boson production this process must be considered as radiative effect too.

FIG. 1: Contour plots on (a_0, a_c) for $+2\delta$ deviations of $\sigma(W^+W^-)$

Fig. 1 demonstrates radiative correction has significant magnitude and its calculation increases the precision of anomalous couplings measurement.

It must be noted that consideration of $W^+W^-\gamma$, $ZZ\gamma$, $Z\gamma\gamma$ processes in electron-positron annihilation gives additional information about a_0 and a_e, but the precision is two orders worse [6]. But e^+e^- beams open possibility to measure four-boson connections [6-8] such as $W^+W^-W^+W^-$-, W^+W^-ZZ-, $ZZZZ$-production that it's impossible for $\gamma\gamma$-physics. Corresponding four-boson anomalous weak interaction are presented by the Lagrangian with two four-dimension operators:

$$L_Q^{(a)} = \frac{1}{4} g_w^2 \left[g_o \left(\vec{W}_\mu \cdot \vec{W}^\mu \right)^2 + g_c \left(\vec{W}_\mu \cdot \vec{W}^\nu \right) \left(\vec{W}^\mu \cdot \vec{W}_\nu \right) \right]. \tag{8}$$

Here the first operator describes the exchange of neutral scalar particle with very high mass, but the second one corresponds to triplet of massive scalar particles. If four neutral boson vertex ($ZZZZ$) is absent (e.g. $g_0 = g_c$), interaction can be realized by massive vector boson exchange.

3. γe-interactions on linear colliders

The new generation electron and photon colliders provide a number of essential advantages. The advance of experimental tools such as highly polarized photon beams, polarized targets and more powerful accelerators, makes it feasible to study polarized Compton scattering in detail.

Therefore necessity appeared to calculate basic characteristic of polarized particle interactions such as cross sections, decay properties, asymmetries etc.

The expression of the Compton scattering differential cross section can be written as follows:

$$d\sigma = \alpha^2 \frac{k'^{0\,2} d\Omega}{(2pk)^2} |M^2|. \tag{9}$$

Here $\alpha = e^2/4\pi$ and k'^0 is the energy of scattered photon: $k' = (\vec{k}', ik'^0)$; $pk = \vec{p}\vec{k} - p^0k^0$; and the total cross section considering process

$$\sigma = \frac{e^2}{2(pk)} \int |M|^2 d\Gamma, \tag{10}$$

where

$$d\Gamma = \frac{d^3p'}{(2\pi)^3 2p'^0}\frac{d^3k'}{(2\pi)^3 2k'^0}(2\pi)^4\delta(p+k-p'-k').$$

The squared matrix element $|M|^2$ can be presented as the sum:

$$|M|^2 = |M_u|^2 + |M_p|^2, \tag{11}$$

where

$$\begin{gathered}|M_u|^2 = 2m^4\left(\frac{1}{pk'}-\frac{1}{pk}\right)^2 + 4m^2\left(\frac{1}{pk'}-\frac{1}{pk}\right)+ \\ +2\left(\frac{pk}{pk'}-\frac{pk'}{pk}\right),\end{gathered} \tag{12}$$

$$\begin{gathered}|M_p|^2 = \varepsilon(ee'\nu p)\left[\frac{m}{(pk)}+\frac{m}{(pk')}\right]+ \\ +\varepsilon(ee'pk)\left[\frac{m(k\nu)}{(pk)^2}-\frac{m(k'\nu)}{(pk')^2}+\frac{m(k\nu+k'\nu)}{(pk)(pk')}\right]+ \\ +\varepsilon(ee'\nu k)\left[\frac{2m^3}{(pk)^2}-\frac{m^3}{(pk')^2}-\frac{m}{(pk)}+\frac{m}{(pk')}+\right. \\ \left.+\frac{m^3}{(pk)(pk')}\right]+\varepsilon(ee'k'\nu)\left[\frac{m}{(pk)}+\frac{m}{(pk')}\right]+ \\ +\varepsilon(ee'kk')\left[\frac{m(k\nu)}{(pk)^2}-\frac{m(k'\nu)}{(pk')^2}+\frac{m(k\nu+k'\nu)}{(pk)(pk')}\right],\end{gathered} \tag{13}$$

where, for example, $\varepsilon(ee'pk) = \varepsilon_{\alpha\beta\gamma\tau}e_\alpha e'_\beta p_\gamma k_\tau$. Here M_u is the amplitude for unpolarized particles scattering. The total and differential cross section of longitudinally polarized initial and final electrons are shown in Fig. 2.

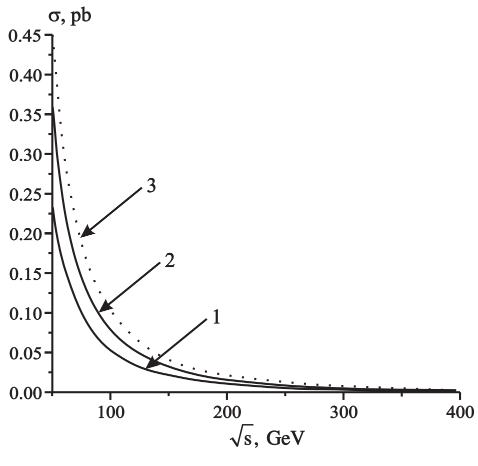

FIG. 2. Total cross section in the energy range of ILC. 1 - the γe - scattering of unpolarized particles; 2 - the initial and final electrons are longitudinally polarized; 3 - the initial electron is longitudinally polarized and the initial photon is circularly polarized.

Present and planned experiments on linear collider (ILC) open additional possibilities to study $e\gamma$ scattering of polarized particles. At the energy of new generation of experiments ($\sqrt{s} \geq$ 500GeV), the corresponding polarized contribution has significant influence to be measured and thus this process will be an important source of new information. For example, by evaluating the polarized asymmetry it is possible to test the Standard model parameters with greater precision than in case of unpolarized beams scattering.

It is convenient to analyze polarization effects using polarized left-right asymmetry:

$$A_{LR} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}. \tag{14}$$

Here σ_+ and σ_- is the total cross sections for left and right polarized scattered photons. The polarized asymmetry as a function of initial electron energy is given in Fig. 3.

FIG. 3. Polarized asymmetry as a function of initial central mass energy (a) and as a function of scaling variable y (b) at the energy of interacting particles $\sqrt{s} = 120$ GeV.

Detailed numerical analysis of the $e\gamma$ cross section and polarized asymmetry demonstrates the contribution of polarization term decreases with increase of initial electron energy. The contribution of the cross section for extremely high energies ($\sqrt{s} \geq 200$GeV) proves to be negligible. The cross section is almost completely determined by unpolarized term and therefore it is clear that the high-energy experiments with polarized particles are excellent instrument for the research of electroweak interaction. Since the cross sections and polarized asymmetry have significant value it is evident it is important to include in consideration the higher order effects (radiative effects). We calculate them using Helicity Amplitudes Method. The corresponding corrections are evaluated for two different values of the central mass energy interacting particles ($\sqrt{s} = 500$GeV and 1000 GeV). The correction to the unpolarized differential cross section is very small and varies between 0.5% and 1%. The correction is totally negligible at the lower end of the spectrum. At the other end of the spectrum it seems that the correction becomes quite large, around 10%. The reason for this is that the lowest-order value is already small.

The considered polarized asymmetry is significant ($\geq$ 90%) when the energies of initial particles occupy the same diapason and it gradually decline with the growth of electron energy compared to the energy of a photon. The radiative correction would not very meaningful in significant part of the kinematic region.

Thus, high polarized $e\gamma$ processes are good instrument for calibration of high energy accelerators and preparation of polarized electron beams with high degree of polarization.

Using $e\gamma$ modes of two-boson production, W^+W^-e, $Z\gamma e$, ZZe, $W^-\gamma\nu$, $W^-Z\nu$, one can consider additional four-boson vertex $WWZ\gamma$ [9]:

$$L_n^{(6)} = i\frac{\pi\alpha}{m_V^2} a_n \vec{W}_\alpha \left(\vec{W}_\nu \cdot \vec{W}_\mu^\alpha\right) \vec{F}^{\mu\nu}. \tag{15}$$

This Lagrangian conserves $U(1)_{EM}$, C-, P- and $SU(2)_C$-symmetry, but violates $SU(2)_L \otimes U(1)_Y$ symmetry.

From all above mentioned processes the most sensitive reactions for a_0 and a_e investigation are ZZe and WWe-production. The bounds of these constants magnitudes are one order better than in e^+e^--process, but about 5 times worse than in $\gamma\gamma$-mode. The vertices $\gamma\gamma\gamma Z$ and 4γ are absent on tree level. One-loop contribution contain both fermion loops and W-boson loops. The last ones give contribution to be measured on photon collider [10].

4. Conclusion

The investigation of polarized photon interaction for analysis of gauge structure of electroweak interaction have been analyzed.

The theoretical analysis demonstrates that investigation of boson anomalous weak interaction in frame of a set of anomalous Lagrangian of $\gamma\gamma$ scattering as well as in frame of $e\gamma$ modes of boson production have great importance for reconstruction gauge group of electroweak interaction beyond the Standard theory and search for "new physics" effects in experiments with photon beams of new generation.

References

[1] I.F.Ginzburg, G.L.Kotkin, S.L.Panfil, V.G.Serbo and V.I.Telnov, Nucl. Instr. Meth. **219**, 5 (1984).
[2] K. Hagiwara et al. Nucl. Phys. B**282**, 253, (1987).
[3] G. Belander et al. Eur. Phys. J. C**283**, 376 (2006); hep-ph/9908254.
[4] I. Marfin, T. Shishkina. Nonlin. Phen. in Compl. Syst. **8**, 4 150 (2005); Elem. Part. and Field **69**, 4 710 (2006).
[5] A. Denner et al. Eur. Phys. J. C**20**, 201 (2001); hep-ph/0104057.
[6] G. Belander, F. Boundjema. Phys. Lett. B**288**, 201 (1992).
[7] V. Barger, T. Han, R.J.N. Phillips. Phys. Rev. D**39**, 146 (1989).
[8] C. Grosse-Knetter, D. Schidknecht. Phys. Lett. B.**302**, 309 (1993).
[9] O.J.P. Eboli, H.C. Gonzalez-Garcia, S.F. Novaes. Nucl. Phys. B**411**, 381 (1994).
[10] G. Jikia, A. Thahbladze. Phys. Lett. B**332**, 441 (1994); Phys. Lett. B**223**, 453 (1994).