© 2008 Proceedings of the "Foundations & Advances in Nonlinear Science" Conference-School

Effects of new physics and gauge theory construction in polarized lepton annihilation on ILC

Tatyana Shishkina*
Faculty of Physics, Belarusian State University, 4, Nezalezhnasti av., 220030, Minsk, Belarus

Vasili Andreev†
Gomel State University, Sovetskay street, 102, Gomel, 246699, Belarus

The matrix element of the annihilation process was obtained in the lowest order of perturbative theory of electroweak interaction. Additional diagram which corresponds to possible Z'- exchange was included. Matrix element was reduced to scalar functions using method of basis spinors. Differential and total cross sections, polarization and other additional types of observables were calculated and analyzed. Several non-minimal gauge models were considered and analyzed. Probable kinematic and energy regions of deviations from Standard Model were investigated and possible directions of deviations were suggested.

Keywords: Z'-boson, additional types of observables, method of basis spinors

1. Introduction

The investigation of effects beyond Standard Model will hold a significant part of research programme at future experiments on International Linear Collider (ILC). The analysis of non-minimal gauge models can provide some important information useful for future experiments. This paper is devoted to the consideration of gauge models with additional Z'-boson. Therefore we analyze the expansions of Standard Model (SM) that include Z' as the only additional gauge vector boson. Various gauge models which can be the expansion of $SU(2) \times U(1)$ were suggested [1]-[12]. We analyze several most popular models in modern physics and differentiate them in order to choose few ones which are more suitable for future experimental research. Obviously we need the theoretical calculations of considered processes to be of high precision. Methods which give precise Lorentz-invariant expressions will be of great importance. Also it should be noted that the analysis of particles polarization gives additional opportunity for new physics searching.
In this paper the process $e^- + e^+ \longrightarrow f + \bar{f}$ is considered in frame of a set of gauge models including additional Z'- exchange. Cross sections and asymmetries in frame of several non-minimal gauge models are calculated and analyzed. Kinematic and energy regions appropriate for physics beyond Standard Model research are suggested.

2. Matrix element and cross sections

There are two Feynman diagrams of process $e^- + e^+ \longrightarrow f + \bar{f}$ in the lowest order of perturbative theory. One corresponds to electromagnetic interaction, another — to weak interaction. Additional

*E-mail: tshishkina@tut.by
†E-mail: selfdenied@tut.by

diagram including Z' appears in different expansions of SM. We include it in consideration in frame of nonminimal gauge theories of electroweak interaction. We consider p_1 and p_2, k_1 and k_2 to be four-

FIG. 1. Diagrams of the process with γ and Z,Z'-exchange .

momenta of initial and final particles respectively, λ_{p_1} and λ_{p_2}, λ_{k_1} and λ_{k_2} — helicity of initial and final particles respectively.

In accordance with the Feynman rules one can obtain matrix element of the process:

$$M = M_\gamma + M_Z + M_{Z'}, \tag{1}$$

where

$$M_\gamma = i\ N_{k_1} N_{k_2} N_{p_1} N_{p_2} e^2 (2\pi)^4 \bar{U}(k_1,\lambda_{k_1})\ \gamma_\nu\ V(k_2,\lambda_{k_2}) \frac{1}{q^2}\ \bar{V}(p_2,\lambda_{p_2}) \times \\ \gamma^\nu U(p_1,\lambda_{p_1})\ \delta(k_1+k_2-p_1-p_2), \tag{2}$$

$$M_Z = i\ N_{k_1} N_{k_2} N_{p_1} N_{p_2}\ \frac{g^2}{4\cos^2\theta_W}\ (2\pi)^4 \bar{U}(k_1,\lambda_{k_1})\ \gamma^\mu\ (g_V + g_A\gamma_5)\ V(k_2,\lambda_{k_2}) \times \\ \frac{g_{\mu\nu} - \frac{q_\mu q_\nu}{m_Z^2}}{q^2 - m_Z^2}\ \bar{V}(p_2,\lambda_{p_2})\ \gamma^\nu\ (g_V + g_A\gamma_5) U(p_1,\lambda_{p_1})\ \delta(k_1+k_2-p_1-p_2), \tag{3}$$

$$M_{Z'} = i\ N_{k_1} N_{k_2} N_{p_1} N_{p_2}\ \frac{\widetilde{g}^2}{4\cos^2\theta'_W}\ (2\pi)^4 \bar{U}(k_1,\lambda_{k_1})\ \gamma^\mu\ (\widetilde{g}_V + \widetilde{g}_A\gamma_5)\ V(k_2,\lambda_{k_2}) \times \\ \frac{g_{\mu\nu} - \frac{q_\mu q_\nu}{m_{Z'}^2}}{q^2 - m_{Z'}^2}\ \bar{V}(p_2,\lambda_{p_2})\ \gamma^\nu\ (\widetilde{g}_V + \widetilde{g}_A\gamma_5) U(p_1,\lambda_{p_1})\ \delta(k_1+k_2-p_1-p_2), \tag{4}$$

Here $N_p = 1/\left((2\pi)^{\frac{3}{2}}\sqrt{2p_0}\right)$, $p_0 = \sqrt{p^2+m^2}$, $q = p_1 + p_2 = k_1 + k_2$, $g_V = -\frac{1}{2} + 2\sin^2\theta_W$, $g_A = -\frac{1}{2}$, θ_W — Weinberg angle, U and V — Dirac bispinors, $\widetilde{g}, \widetilde{g}_A, \widetilde{g}_V$ — additional coupling constants, which depend on the model considered.

As one can see matrix element (1) includes additional term connected with Z'-exchange. That is why the reduction of matrix element to scalar functions in frame of the method of basis spinors (MBS) was used.

This method allows to reduce matrix element itself using no traces. Due to its block structure, this method can be easily programmed using a computer.

When evaluating a Feynman amplitude involving fermions, the amplitude is expressed as a sum of terms which have the form

$$\mathcal{M}_{\lambda_p,\lambda_k}(p, s_p,\ k, s_k\ ;Q) == \bar{u}_{\lambda_p}(p, s_p)\, Q\ u_{\lambda_k}(k, s_k)\,, \tag{5}$$

where λ_p and λ_k are helicities of particles with four-momentum p, k and arbitrary polarization vectors s_p, s_k. The operator Q can be expressed as a sum of products of Dirac γ-matrices. The operator Q is equal to γ_ν in case of matrix element M_γ, $\gamma^\mu(g_V + g_A\gamma_5)$ in case of M_Z and $\gamma^\mu(\widetilde{g}_V + \widetilde{g}_A\gamma_5)$ in case of $M_{Z'}$.

The matrix element (5) with Dirac spinors should be expressed in terms of scalar functions formed from spin and momentum four-vectors of Dirac spinors, including p, s_p, k, s_k and operator Q. We use MBS based on spinors which are connected with vectors of isotropic tetrad.

We investigate the expressions for differential and total cross sections in the center-of-mass system. This system was chosen to obtain simple expressions for cross sections in accordance with the kinematics of future experiments on linear colliders (ILC, for example).

The differential cross section in the center-of-mass system can be written as:

$$\frac{d\sigma}{d\theta} = \frac{\beta_f}{\beta_e}\ \frac{|R|^2}{16(2\pi)^2 s}, \tag{6}$$

where θ is the scattering angle between the direction of initial and final particle.
Total cross section can be written as:

$$\sigma = 2\pi \int_0^\pi \frac{d\sigma}{d\theta} \sin\theta\ d\theta. \tag{7}$$

The next section is devoted to numerical analysis of differential and total cross sections, asymmetries for a set of gauge models.

3. Asymmetries and discussion

In this paper forward-backward, polarization asymmetries and other additional types of observables are considered.

Polarization asymmetry can be presented as:

$$A_{LR} = \frac{d\sigma_{+-} - d\sigma_{-+}}{d\sigma_{+-} + d\sigma_{-+}}\ , \tag{8}$$

where $d\sigma_{+-} = d\sigma/d\theta\ (\lambda_{p_1} = 1;\ \lambda_{p_2} = -1)$, $d\sigma_{-+} = d\sigma/d\theta\ (\lambda_{p_1} = -1;\ \lambda_{p_2} = 1)$.

Forward-backward asymmetry can be introduced as:

$$A_{FB} = \frac{\int_0^{\pi/2} d\sigma - \int_{\pi/2}^{\pi} d\sigma}{\int_0^{\pi/2} d\sigma + \int_{\pi/2}^{\pi} d\sigma}\ . \tag{9}$$

But the main purpose of this paper to investigate additional observables:

$$A_1 = \frac{\int_0^{\pi/2} d\sigma_{+-} - \int_{\pi/2}^{\pi} d\sigma_{-+}}{\int_0^{\pi/2} d\sigma_{+-} + \int_{\pi/2}^{\pi} d\sigma_{-+}}\ , \qquad A_2 = \frac{\int_0^{\pi/2} d\sigma_{-+} - \int_{\pi/2}^{\pi} d\sigma_{+-}}{\int_0^{\pi/2} d\sigma_{-+} + \int_{\pi/2}^{\pi} d\sigma_{+-}}\ ,$$

$$A_3 = \frac{\int_0^{\pi/2} d\sigma_{-+} - \int_{\pi/2}^{\pi} d\sigma_{+-}}{\int_0^{\pi/2} d\sigma_{+-} + \int_{\pi/2}^{\pi} d\sigma_{-+}}\ , \qquad A_4 = \frac{\int_0^{\pi/2} d\sigma_{+-} - \int_{\pi/2}^{\pi} d\sigma_{-+}}{\int_0^{\pi/2} d\sigma_{-+} + \int_{\pi/2}^{\pi} d\sigma_{+-}} \tag{10}$$

We consider a set of gauge models:

a) Sequential Standard Model (SSM) based on the group $SU(2)_L \times U(1)_Y \times U'(1)_{Y'}$;
b) Two Left-Right Symmetric Models (LR) based on the group $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, both with certain value of free parameter α;
c) Three grand-unified E_6-motivated models (E_6) (λ, ψ, η models);
d) $SU(3)_C \times U(1)_Y$-motivated model.

Differential and total cross sections were calculated for the considered set of gauge models (see Figs. 2,3). As an example of final fermions a pair of muon - antimuon was considered. As a possible value of Z' mass 1000 GeV was taken. As one can see the behavior of differential cross section is

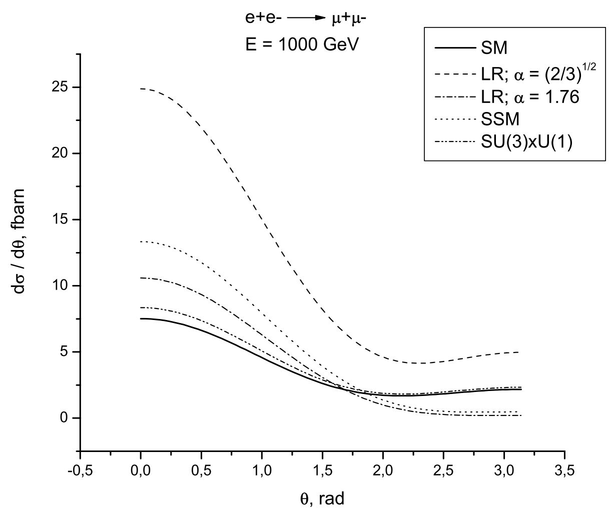

FIG. 2. Differential cross sections for SSM, LR and $SU(3)_C \times U(1)_Y$-motivated gauge models

similar for all models considered. In the case of λ model and LR model with free parameter $\alpha = \sqrt{2/3}$ the value of differential cross sections is 2-3 times greater than that of Standard Model (SM). So one can draw a conclusion that in the case when above mentioned models are realized, the deviations from SM could be easily found in the forward kinematic region ($0 \leq \theta \leq \pi/2$).

In the case of other gauge models such deviations are much more difficult to found because the difference between values of differential cross sections is less than 5 fb.

The situation for total cross sections is quite similar. It's evident that in contrast to SM, all models considered possess a Z' peak near 1000 GeV (Z' mass). It should be easily found during experiments. The only problem is that the mass of Z'-boson can be greater than $2,3$ or even more TeV.

The other feature that can be noticed is connected with the behavior of total cross sections before Z' peak. One can see that total cross section behavior in λ, η models, LR model with $\alpha = \sqrt{2/3}$ and $SU(3)_C \times U(1)_Y$-motivated model differs from that of the others. For example, in the case of λ model deviations from SM can be found in the energy region from 600 GeV to 1000 GeV. In the behavior of the function one can see a downward excursion and the minimal value is near 840 GeV. For LR model the situation is almost similar. The only difference is that minimum of the function is near 800 GeV. For $SU(3)_C \times U(1)_Y$-motivated model this minimum is close to Z' peak and can be detected in the region from 900 GeV to 1 TeV. For η model the location of minimum is situated in the similar region as that of the latter model, but it's not so expressed.

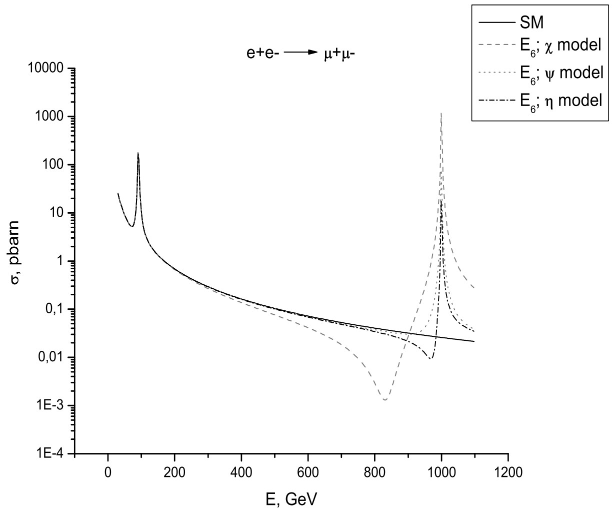

FIG. 3. Total cross sections for E_6-motivated gauge models

So it's very difficult to differentiate all the models considered judging only by differential and total cross section. In order to succeed one has to look for some other magnitudes.

Additional extremely important information may be provided by additional types of observables (10). On Figs. 4 one can see values of A_1 and A_2 observables for E_6-motivated models. It's obvious that the results obtained during the experiment may indicate that deviations from SM occur according to one or another model. Some model predictions are very close and hard to differentiate. That's why we need many observables to discriminate such models.

(a) (b)

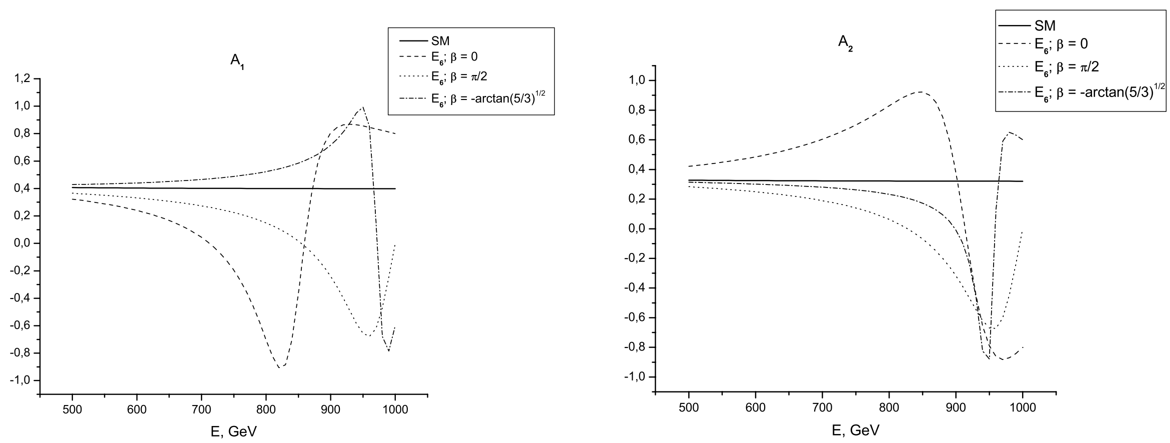

FIG. 4. Additional observable A_1 and A_2 for E_6-motivated gauge models

In the case of λ model A_1 observable deviates at most from SM in the energy region between 750 and 850 GeV. In addition, it has the opposite sign than that of SM. But very close results are provided by ψ and SSM models as well. So one have to look at A_2 observable. For λ model A_2 observable has the same sign as that of SM on the most part of energy region while the behavior of function for ψ and SSM models almost hasn't changed. That is, calculation of different types of observables and their further analysis provides us quite good method of gauge models discrimination.

In this paper calculations of differential and total cross sections, polarization and other types of observables were made. Corresponding graphs were constructed and analyzed. As a result one can see several problems in searching physics beyond Standard Model. It is clear that many non-minimal gauge models provide very small deviations from Standard Model, so it's difficult to register them. To overcome this problem somehow one should investigate special observables where effects beyond Standard Model are more essential. Additional types of observables presented and investigated in this paper may be a useful tool for solving this problem.

References

[1] V.V. Andreev. Analytical calculation of feynman amplitudes. *Nucl. Phys.*, 66:410–420, 2003.

[2] Vernon D. Barger, W. Y. Keung, and Ernest Ma. Doubling of weak gauge bosons in an extension of the standard model. *Phys. Rev. Lett.*, 44:1169, 1980.

[3] Vernon D. Barger, K. Whisnant, and Ernest Ma. Weak gauge bosons above or straddling the standard model masses. *Phys. Rev.*, D25:1384, 1982.

[4] M. Cvetic and B. W. Lynn. Gauge structures beyond the standard model and slc / lep physics. *Phys. Rev.*, D35:51, 1987.

[5] E. H. de Groot, G. J. Gounaris, and D. Schildknecht. Possible structures of the neutral current within a gauge theory framework. *Zeit. Phys.*, C5:127, 1980.

[6] Harald Fritzsch and Peter Minkowski. Parity conserving neutral currents and righthanded neutrinos. *Nucl. Phys.*, B103:61, 1976.

[7] M. Hayashi, K. Katsuura, and S. Homma. Neutral current effects in the standard and extended gauge models for spin polarization effects in e+e- into mu+ mu-. *Nuovo Cim.*, A77:76–98, 1983.

[8] Kenzo Inoue, Akira Kakuto, Hiromasa Komatsu, and Yoshimasa Nakano. Su(2) x u(1) x u(1) gauge theory of weak and electromagnetic interactions in a unified su(6) scheme. *Prog. Theor. Phys.*, 58:1914, 1977.

[9] Benjamin W. Lee and Steven Weinberg. Su(3) x u(1) gauge theory of the weak and electromagnetic interactions. *Phys. Rev. Lett.*, 38:1237, 1977.

[10] Liao-Fu Luo and Gang Zhao. The phenomenology of su(2)-l x su(2)-r x u(1)-(l+r) gauge theory. *Lett. Nuovo Cim.*, 44:319–325, 1985.

[11] Rabindra N. Mohapatra and Deepinder P. Sidhu. Implications for gauge theories if search for parity violation in atomic physics fails. *Phys. Rev. Lett.*, 38:667, 1977.

[12] Jogesh C. Pati, Subhash Rajpoot, and Abdus Salam. Complexions of neutral current phenomena within the left-right symmetric unified theory of quarks and leptons. *Phys. Rev.*, D17:131–150, 1978.