STUDY OF THE ANOMALOUS COUPLINGS AT NLC WITH POLARIZED BEAMS

R. Casalbuoni[(a,b)], S. De Curtis[(b)] and D. Guetta[(a,c)]

(a) - Dipartimento di Fisica, Università di Firenze, Italy
(b) - I.N.F.N., Sezione di Firenze, Italy
(c) - Department of Physics, Technion, Haifa, Israel.

LC note: LC-TH-1999-013

1 Introduction

The experimental confirmation of the Standard Model (SM) is presently limited to the sector of fermion interactions with gauge vector bosons, however a precise measure of the vector boson self coupling is needed to test the non abelian structure of the SM. In fact indirect tests via loop effects must be confirmed by direct exploration of the interactions of the vector bosons among themselves via production and scattering experiments. Next linear colliders will provide the right framework where to study the $SU(2)_L \otimes U(1)_Y$ gauge structure [1]. Future experiments at these colliders may be used to confirm the SM predictions as well as to probe for new physics. In particular it is possible that signals of new physics will appear in the gauge boson sector through the discovery of anomalous vertices.

Among the various possible reactions, where to test the trilinear gauge boson couplings we choose the reaction $e^+e^- \to W^+W^-$ [2] with the W-pair decaying into a lepton pair plus jets. We consider possible deviations from the SM coming both from anomalous gauge vector boson trilinear couplings and from non standard couplings of gauge bosons to fermions [3]. Both of them can be due to the physics responsible of the electroweak symmetry breaking. Moreover we will see that the trilinear and the fermionic couplings are strongly correlated, therefore it is not justified to neglect the latter in a phenomenological analysis.

We assume the experimental possibility of reconstructing the polarization of the final W's and we consider the effects of having both the electron and the positron beams polarized [4]. This would be of particular interest in order to increase the sensitivity to the anomalous couplings [5]. The observables on which we concentrate to bound new physics are the differential cross sections for the $e^+e^- \to W^+W^-$ for the various channels of final W and initial beams polarization. Theoretically, this program is carried out by evaluating the helicity amplitudes $F^{\lambda\lambda'}_{\tau\tau'}$, where λ (λ') are the e^- (e^+) helicities ($\lambda' = -\lambda = \pm 1/2$), and τ (τ') $= \pm 1, 0$ are the W^- (W^+) helicities. From the study of the high-energy behaviour of the observables [3] we concluded that terms proportional to the square of the anomalous couplings are not negligible and then it is not justified to make any approximation in the deviations from the SM. For this reason we have used the exact expressions in our calculation. We analyze various models at energy ranges relevant to next linear colliders and for various degree of longitudinal polarization of the incoming beams.

In Section 2 we will write the general parametrization of the gauge boson trilinear anomalous couplings and of the non-standard fermionic couplings and we will introduce the observables considered in our analysis. The phenomenological analysis is given in Section 3. Although a general fit could be possible, we have limited our analysis to the case of two free parameters by considering particular models. The constraints on the anomalous couplings from future e^+e^- colliders are shown in Section 4. The options we will consider are for c.m. energies of 300, 500 and 1000 GeV, with corresponding integrated luminosities of 200, 300 and 500 fb^{-1}. In this section we will also study the effect of the polarization of the electron and positron beams and we will see that a more restricted region for the anomalous parameters can be obtained. Conclusions and comparison with the reaches of other collider machines are given in Sect. 5.

2 Helicity amplitudes and polarized cross sections

The CP invariant effective Lagrangian for the gauge boson self-interactions in terms of the anomalous couplings can be expressed as follows: [6]

$$\begin{aligned}\mathcal{L}^3_{eff} &= -ie[A_\mu(W^{-\mu\nu}W^+_\nu - W^{+\mu\nu}W^-_\nu) + A^{\mu\nu}W^+_\mu W^-_\nu] - iex_\gamma A^{\mu\nu}W^+_\mu W^-_\nu \\ &\quad -ie(ctg\theta + \delta_Z)[Z_\mu(W^{-\mu\nu}W^+_\nu - W^{+\mu\nu}W^-_\nu)] - iex_Z Z^{\mu\nu}W^+_\mu W^-_\nu \\ &\quad +ie\frac{y_\gamma}{M_W^2}A^{\nu\lambda}W^-_{\lambda\mu}W^{+\mu}_\nu + ie\frac{y_Z}{M_W^2}Z^{\nu\lambda}W^-_{\lambda\mu}W^{+\mu}_\nu \end{aligned} \tag{2.1}$$

where $V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu$ for $V = A,\ Z,\ W$. x_γ and x_Z parametrize deviations in weak and electromagnetic dipole coupling from their SM values; y_γ and y_Z indicate the intensity of the non-standard quadrupole interactions of $W^\pm$ and δ_Z describes a deviation overall of the ZW^+W^- coupling from its standard value. The relations of the above parameters to those directly connected with W static properties are (se e.g. [7])

$$\Delta g_1^Z = \delta_Z \tan\theta, \qquad \Delta\kappa_\gamma = x_\gamma, \qquad \lambda_\gamma = y_\gamma \tag{2.2}$$

$$\Delta\kappa_Z = (x_Z + \delta_Z)\tan\theta, \qquad \lambda_Z = y_Z \tan\theta \tag{2.3}$$

We will assume that the energy relevant to the problem (i.e. the energy of the electron-positron beams) is much lower than the energy scale of the new physics. As a consequence we will consider all the anomalous couplings as constant ignoring their possible energy dependence.

The fermionic Lagrangian relevant to our process is:

$$\mathcal{L}^{neutral} = -eZ_\mu \bar{\psi}_e[\gamma^\mu a_e^Z - \gamma^\mu \gamma_5 b_e^Z]\psi_e - eA_\mu \bar{\psi}_e Q_e \psi_e \tag{2.4}$$

$$\mathcal{L}^{charged} = ea_w \left(\sum_\ell \bar{\psi}_{\nu_\ell} \gamma^\mu (1-\gamma_5)\psi_\ell W_\mu^+ + \sum_{i=1}^{3} \bar{\psi}_i \gamma^\mu (1-\gamma_5)\tau_+ \psi_i W_\mu^+ + h.c. \right) \tag{2.5}$$

In these expressions ψ_e is the electron field, $\ell = e, \mu, \tau$, and the sum over $i = 1, 2, 3$ is on the quark charged current eigenstates. In the following we will consider the possibility of deviations of the parameters a_e^Z, b_e^Z and a_W from their SM values. We define

$$f = f(SM) + \delta f \tag{2.6}$$

with $f = a_e^Z, b_e^Z, a_W$, and

$$a_e^Z(SM) = \frac{1}{2s_\theta c_\theta}(-\frac{1}{2} + 2s_\theta^2), \qquad b_e^Z(SM) = -\frac{1}{4s_\theta c_\theta}, \qquad a_W(SM) = \frac{1}{2\sqrt{2}s_\theta} \tag{2.7}$$

where s_θ is defined through the input parameters G_F, $\alpha(M_Z)$, M_Z:

$$s_\theta^2 = \frac{1}{2} - \sqrt{\frac{1}{4} - \frac{\pi\alpha(M_Z)}{\sqrt{2}G_F M_Z^2}} \tag{2.8}$$

Finally we put

$$M_W = M_W(SM) + \delta M_W, \qquad M_W(SM) = c_\theta M_Z \tag{2.9}$$

The differential cross-section for initial $e^+_{\lambda'}$, e^-_λ, and final $W^+_{\tau'}$, W^-_τ, where λ, λ', τ and τ' are the helicities of the various particles, is given by

$$\frac{d\sigma_{\tau\tau'}^{\lambda\lambda'}}{d\cos\phi} = \frac{|\vec{p}|}{4\pi s\sqrt{s}} |F_{\tau\tau'}^{\lambda\lambda'}(s, \cos\phi)|^2 \tag{2.10}$$

where

$$|\vec{p}| = \beta_W \frac{\sqrt{s}}{2}, \qquad \beta_W = \sqrt{1 - \frac{4M_W^2}{s}} \tag{2.11}$$

and ϕ is the angle between the incoming electron and W^-.
The expression of the helicity amplitudes in terms of the anomalous couplings are given in the first of ref. [3]. In this paper we give the helicity amplitudes in a form where the contribution of the SM and of the anomalous part is explicit

$$F_{\tau\tau'}^{\lambda\lambda'} = F_{\tau\tau'}^{\lambda\lambda'}(SM) + \delta F_{\tau\tau'}^{\lambda\lambda'} \tag{2.12}$$

In the helicity basis the transition probability is given by [8]:

$$|F|^2 = \frac{1}{4}\left[\Big(1 - P_L(e^-)\Big)\Big(1 + P_L(e^+)\Big)|F_-|^2 + \Big(1 + P_L(e^-)\Big)\Big(1 - P_L(e^+)\Big)|F_+|^2\right] \tag{2.13}$$

where $F_\pm$ correspond to $\lambda = -\lambda' = \pm 1/2$ and $P_L(e^-)(P_L(e^+))$ is the degree of longitudinal polarization of the $e^-(e^+)$ beam. Then the differential cross-sections are given as [8]

$$\frac{d\sigma_{\tau\tau'}}{d\cos\phi} = \frac{1}{4}\left[(1+P_L(e^-))(1-P_L(e^+))\frac{d\sigma^{(+1/2,-1/2)}_{\tau\tau'}}{d\cos\phi} \right. \\ \left. + (1-P_L(e^-))(1+P_L(e^+))\frac{d\sigma^{(-1/2,+1/2)}_{\tau\tau'}}{d\cos\phi}\right] \tag{2.14}$$

We consider the experimental possibilities of reconstructing the polarization of the final W^+W^- and then we have three different differential cross sections as observables:

$$\frac{d\sigma_{TT}}{d\cos\phi};\quad \frac{d\sigma_{LL}}{d\cos\phi};\quad \frac{d\sigma_{LT}}{d\cos\phi}\;. \tag{2.15}$$

For the standard $SU(2)_L \otimes U(1)_Y$ couplings the asymptotic behaviour in the high-energy limit of these observables is:

$$\frac{d\sigma_{TT}}{d\cos\phi} \sim \frac{1}{s};\quad \frac{d\sigma_{LL}}{d\cos\phi} \sim \frac{1}{s};\quad \frac{d\sigma_{LT}}{d\cos\phi} \sim \frac{1}{s^2}\;. \tag{2.16}$$

In fact within the SM the $e^+e^- \to W^+W^-$ cross-section has a good behaviour at high-energy due to the cancellations required by the gauge invariance. In the actual case, however, this is not true. However we should remember that we are dealing with an effective theory and that we are allowed to use it only up to energies smaller than the new physics scale. The complete analysis of the high-energy behaviour of the helicity amplitudes in presence of the anomalous couplings is given in [3]. The main result is that the terms linear in s, which are the most important ones at high-energy, turn out to be quadratic in the anomalous couplings. Since the expansion parameter is s/M_W^2, it is a bad approximation to neglect the quadratic terms in the anomalous parameters when one is discussing the cross-sections at energies of the order 10 M_W or more (we are assuming a size for the anomalous parameters comparable to the size of the radiative corrections within the SM). From the explicit expressions in [3] it turns out that the contribution of the dipole interactions $x_\gamma, x_Z \neq 0$ and the deviation from universality $\delta_Z \neq 0$ lead to $\sigma_{LL} \sim s$; quadrupole interactions $y_\gamma, y_Z \neq 0$ imply that $\sigma_{TT} \sim s$ and that the leading term in the high-energy expansion of $d\sigma_{LT}$ depend on $x_\gamma + y_\gamma$, $2\delta_Z + x_Z + y_Z$, δa_e^Z, δb_e^Z, δa_W. This study suggests that an analysis of the differential cross-sections at various energies should be useful in order to discriminate among various anomalous parameters.

3 Phenomenological analysis

As a procedure to quantitatively assess the sensitivity of the differential cross sections to the anomalous gauge couplings and to the non-standard fermionic couplings, we divide the experimentally significant range of the production angle $\cos\phi$ ($-0.95 \le \cos\phi \le 0.95$) into 6 bins. For each differential cross-section we evaluate the differences

$$\sigma_{i,a}^{AN} = \sigma_{i,a} - \sigma_{i,a}(SM), \qquad i = 1, \cdots, 6, \quad a = LL, LT, TT \tag{3.1}$$

where $\sigma_{i,a}$ and $\sigma_{i,a}(SM)$ are respectively the full and the SM differential cross-sections integrated over the bin i. From these differences we can evaluate the χ^2 function for each differential cross-section

$$\chi_a^2 = \sum_{i=1}^{6} \frac{(\sigma_{i,a}^{AN})^2}{(\delta\sigma_{i,a})^2}, \qquad a = LL, LT, TT \tag{3.2}$$

We assume the errors $\delta\sigma_{i,a}$ as follows

$$\delta\sigma_{i,a} = \sqrt{\frac{\sigma_{i,a}}{BR \cdot L} + \sigma_{i,a}^2 \Delta_{\rm sys}^2} \tag{3.3}$$

where $\Delta_{\rm sys}$ is the systematic error taking into account the relative errors on the luminosity, on the branching ratio of the decay of W's into a lepton pair plus jets, on the acceptance and on the longitudinal polarization of the beams. We assume $\Delta_{\rm sys} = 1.5\%$. We take into account the efficiency in reconstructing the W pairs from their decays into a lepton pair plus jets by reducing the true branching ratio from 0.29 to 0.10 (see [9]). This is the effective branching ratio BR that we use in eq. (3.3). There is a delicate point about the branching ratio. In fact we are assuming that the coupling $We\nu$ may differ from its SM value. This could modify the branching ratios of W's into fermions. However, for deviations respecting the universality, it is easy to see that neglecting, as usual, mixed terms in the radiative and in the anomalous corrections, the branching ratios are the same as in the SM up to 1-loop level.

Let us now consider the bounds on the anomalous couplings coming from the minimization of the χ^2-function given in eq. (3.2). We will not attempt to make a general analysis in all the parameters expressing the deviations from the SM (5 anomalous trilinear couplings, 3 non-standard fermionic couplings and the M_W deviation), but rather we will concentrate on a few models depending only on 2 parameters. The first simplifying hypothesis we will make is that all the fermionic deviations can be expressed in terms of the ϵ_i, $i = 1, 2, 3$, parameters [10]. By using the definitions of the ϵ_i in terms of the observables one gets

$$\begin{aligned}
\delta a_e^Z &= -\frac{\epsilon_1}{8 s_\theta c_\theta} - \frac{1}{c_{2\theta}} \frac{s_\theta}{c_\theta} \left(\frac{\epsilon_1}{2} - \epsilon_3 \right) \\
\delta b_e^Z &= \frac{\epsilon_1}{8 s_\theta c_\theta} \\
\delta a_W &= \frac{1}{2\sqrt{2} s_\theta} \left(\frac{c_\theta^2}{2 c_{2\theta}} \epsilon_1 - \frac{\epsilon_2}{2} - \frac{s_\theta^2}{c_{2\theta}} \epsilon_3 \right) \\
\frac{\delta M_W^2}{M_W^2} &= \frac{c_\theta^2}{c_{2\theta}} \epsilon_1 - \epsilon_2 - 2 \frac{s_\theta^2}{c_{2\theta}} \epsilon_3
\end{aligned} \tag{3.4}$$

We will restrict our analysis to models of new physics with no isospin violation. In such a case one has $\epsilon_1 = \epsilon_2 = 0$. Therefore all the non-standard fermionic couplings and δM_W are parametrized in terms of ϵ_3. The experimental bound on ϵ_3 coming from LEP1, LEP2, Tevatron and low-energy measurements is [11]

$$\epsilon_3^{\rm exp} = (3.55 \pm 0.96) \times 10^{-3} \tag{3.5}$$

Notice that the ϵ_3 appearing in our equations is only the contribution due to new physics, so in order to get an useful bound for it one has to subtract from $\epsilon_3^{\rm exp}$ the contribution from the SM radiative corrections which, for $m_{top} = 175\ GeV$, are the following [12]

$$\begin{array}{rl} m_H = 100\ GeV & \epsilon_3^{\rm rad} = 5.11 \times 10^{-3} \\ m_H = 300\ GeV & \epsilon_3^{\rm rad} = 6.115 \times 10^{-3} \\ m_H = 1000\ GeV & \epsilon_3^{\rm rad} = 6.65 \times 10^{-3} \end{array} \tag{3.6}$$

The 90% C.L. bound we get (in the case of two degrees of freedom) is then

$$-(4.6^{-1.0}_{+0.5}) \times 10^{-3} \leq \epsilon_3 \leq (-0.5^{+1.0}_{-0.5}) \times 10^{-3} \tag{3.7}$$

The upper and lower bounds correspond to $m_H = 100\ GeV$ and $m_H = 1\ TeV$ respectively. The central value is obtained for $m_H = 300\ GeV$.

As far as the anomalous trilinear gauge couplings are concerned we will also consider some particular models. In order to reduce the number of free parameters we will examine the Lagrangian (2.1) in terms of its underlying symmetries.

MODEL A

First we consider the case in which one assumes a global $SU(2)_L$ symmetry for the Lagrangian (2.1) [13]. This gives rise to the following correlations between the anomalous parameters

$$\delta_Z = x_\gamma = x_Z = 0 \tag{3.8}$$

and

$$y_Z = \frac{c_\theta}{s_\theta} y_\gamma \neq 0, \tag{3.9}$$

Assuming again $\epsilon_3 \neq 0$ we get a two parameter space (ϵ_3, y_γ).

MODEL B

This is an effective model in which the existence of a new triplet of vector fields $\vec{V}_\mu$ is assumed (BESS model [14]). These are the gauge fields associated to a spontaneously broken local symmetry $SU(2)_V$. The new vector particles mix with W and Z. As a consequence at energies well below their mass (assumed to be around the TeV scale), effective anomalous fermionic and trilinear couplings are generated [15]. The parameters

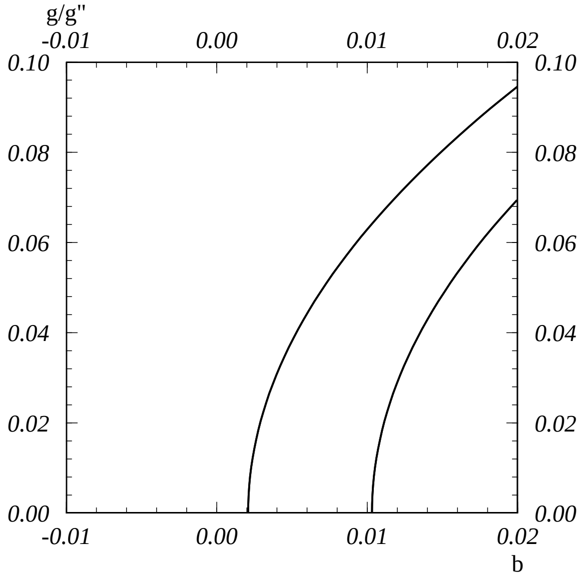

Figure 1: 90% CL bounds on the parameter space $(b, g/g'')$ in the case of model B (BESS model), as obtained from the experimental data fit to the ϵ_3 parameter.

characterizing this model are the gauge coupling of the $\vec{V}_\mu$, g'', and their direct coupling to the fermions, b. Only ϵ_3 and δ_Z are different from zero and they are given by

$$\epsilon_3 = -\frac{b}{2} + (\frac{g}{g''})^2, \qquad \delta_Z = \frac{c_\theta}{2 s_\theta c_{2\theta}}(b - \frac{1}{c_\theta^2}(\frac{g}{g''})^2) \tag{3.10}$$

where g is the standard coupling of $SU(2)_L$. The BESS model is a generalization of a non-linear σ-model and it is not renormalizable. However at 1-loop level it is equivalent to a heavy Higgs model with the Higgs mass playing the role of a cut-off. Assuming the cut-off of the order of 1 TeV we can evaluate $\epsilon_3^{\rm rad}$ with a Higgs mass equal to 1 TeV. In Fig. 1 we give the bounds obtained in this way on the parameter space arising from LEP1, LEP2, Tevatron and low-energy experiments.

MODEL C

Finally we consider a model with two trilinear anomalous couplings and no fermionic one. In particular we consider the case in which one adds to the SM Lagrangian the most general operator of dimension 6 invariant under $SU(2)_L \otimes U(1)_Y$ (see ref. [13]). The general form of this term is

$$\frac{ie}{2M_W^2}\left[\frac{f_B}{c_\theta} B_{\mu\nu}\,(D_\mu\phi)^\dagger\,(D_\nu\phi) + \frac{f_w}{s_\theta}\vec{w}_{\mu\nu}\cdot(D_\mu\phi)^\dagger\,\vec{\tau}\,(D_\nu\phi)\right] \tag{3.11}$$

where $B_{\mu\nu}$ is the weak hypercharge field strength, $\vec{w}_{\mu\nu}$ is the non-abelian field strength associated to $\vec{W}_\mu$ and D_μ the covariant derivative operating on the Higgs field ϕ. The interaction generated by this operator is non-renormalizable but the symmetry of the non-standard interaction (3.11) at one-loop level is expected to assure logarithmic divergences only. For example for $f_B = fw$ one obtains the HISZ model [16] analyzed at the NLC in [17]. Here we consider the case $f_B = 0$ leading to the following relations

$$x_Z = -\frac{s_\theta}{c_\theta} x_\gamma, \quad \delta_Z = \frac{1}{s_\theta c_\theta} x_\gamma, \quad y_Z = \frac{c_\theta}{s_\theta} y_\gamma \tag{3.12}$$

Assuming $\epsilon_3 = 0$ we get a two parameter space (x_γ, y_γ).

4 Bounds on the anomalous couplings

We first analyze the models for various observables, namely the unpolarized cross-sections for different final W's polarization, σ_{LL}, σ_{LT}, σ_{TT} and the total one.

The 90% CL bounds for the model A are given in Fig. 2, together with the bounds coming from combining the χ^2 for the final state polarized observables ($\sigma_{\rm comb}$), for a NLC machine with a center of mass energy of 500 GeV and an integrated luminosity of 300 fb^{-1}. The figure shows the independence of σ_{LL} on y_γ. We notice that we can obtain a good restriction in the parameter space just combining the total σ with σ_{LL}. In Fig. 3 we give the 90% CL bounds arising from $\sigma_{\rm comb}$ at various energies and luminosities, namely: $E = 300,\ 500,\ 1000\ GeV$ with $L = 200,\ 300,\ 500\ fb^{-1}$ respectively. We see that, for this model, one needs to reach at least 500 GeV in energy in order to get bounds on ϵ_3 better that the present ones (see eq. (3.7)). Notice that the bound at $E = 1000\ GeV$ includes a region which is not connected with the SM point. This means that there is the possibility of having an ambiguity at this energy. However this is already resolved by the present data. It is also interesting to notice that there are strong correlations among y_γ and ϵ_3. This means that going at values of ϵ_3 different from zero, the bounds on y_γ can change considerably.

The analysis at the NLC of the bounds on the BESS model parameter space at fixed energy and different observables shows that the most restrictive ones comes from σ_{LL}. In fact the new resonances are strongly coupled to $W_L W_L$ leading to an enhancement in this channel. In Fig. 4 we give the 90% CL bounds from $\sigma_{\rm comb}$ at various energies for unpolarized beams. The comparison with Fig. 1 shows that already at 500 GeV with the high luminosity option we are considering, we can achieve a real improvement. Fig. 5 is the analogous of Fig. 3 for the model C. We see that, even for unpolarized beams, the NLC configuration corresponding to an energy of 500 GeV and $L = 300\ fb^{-1}$ can put very stringent bounds: $|x_\gamma| < 1 \times 10^{-3}$, $|y_\gamma| < 4 \times 10^{-3}$ and a strong correlation between the two.

POLARIZED BEAMS
An interesting question is whether the use of polarized beams significantly improves the

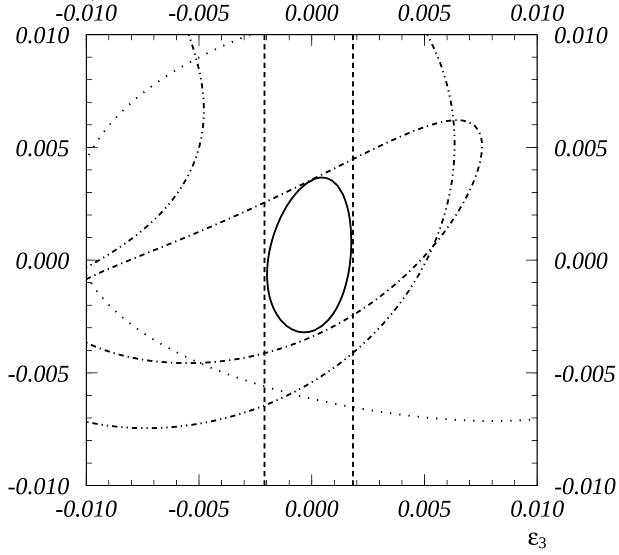

Figure 2: 90% CL bounds on the parameter space (ϵ_3, y_γ) in the case of model A. The dot line represents the bounds from σ_{TT}, the dash-dot from σ_{LT}, the dash from σ_{LL}, the dash-doubledot from $\sigma_{\rm total}$, and the continuous one from $\sigma_{\rm comb}$. Here the parameters of the NLC are $E = 500\ GeV$, $L = 300\ fb^{-1}$, and $P_L(e^-) = P_L(e^+) = 0$.

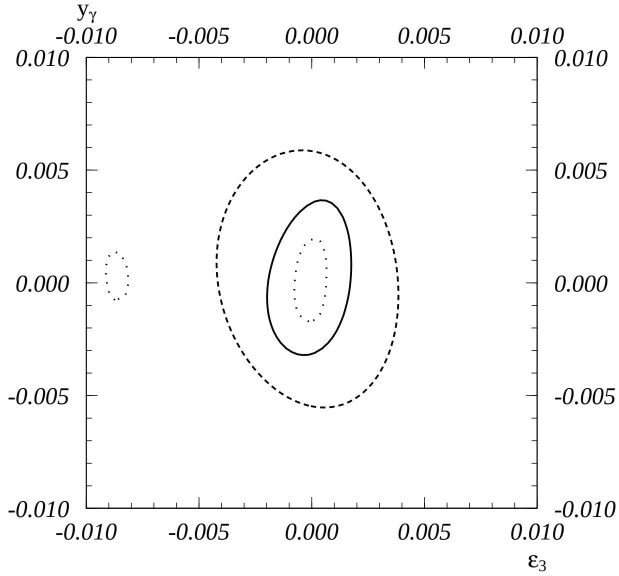

Figure 3: 90% CL bounds on the parameter space (ϵ_3, y_γ) in the case of model A. The bounds are obtained from $\sigma_{\rm comb}$ and $P_L(e^-) = P_L(e^+) = 0$ at various energies and luminosities. The dash line corresponds to $E = 300\ GeV$ and $L = 200\ fb^{-1}$, the solid to $E = 500\ GeV$ and $L = 300\ fb^{-1}$, and the dot one to $E = 1000\ GeV$, $L = 500\ fb^{-1}$.

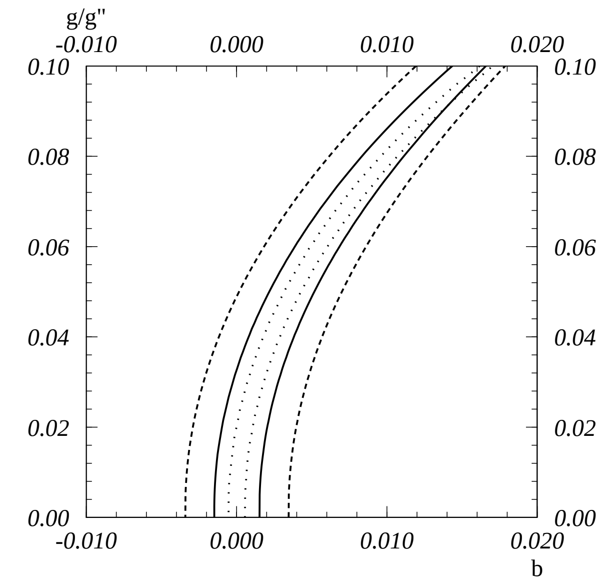

Figure 4: Same of Figure 3 for the parameter space $(b, g/g'')$ in the case of model B (BESS model).

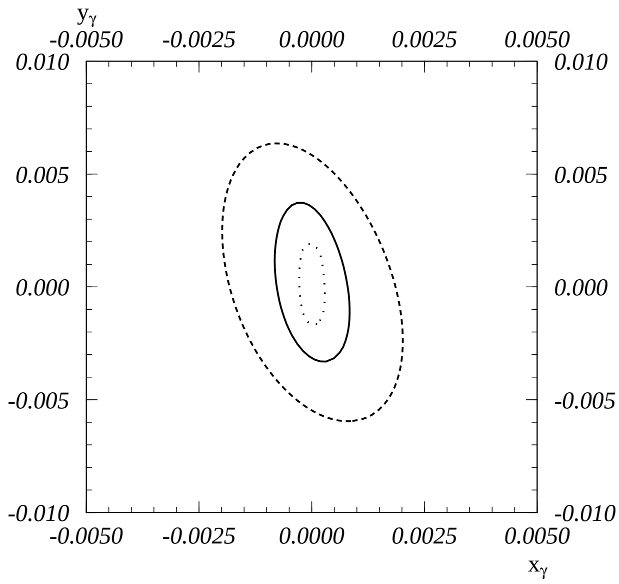

Figure 5: Same of Figure 3 for the parameter space (x_γ, y_γ) in the case of model C.

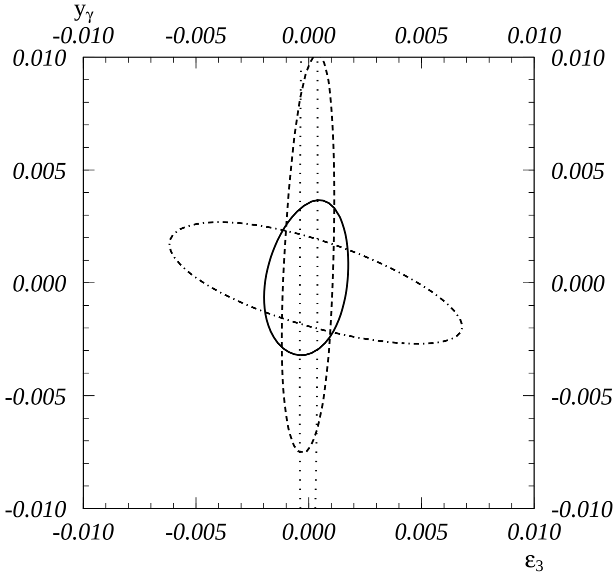

Figure 6: 90% CL bounds on the parameter space (ϵ_3, y_γ) in the case of model A. The bounds are obtained from $\sigma_{\rm comb}$ at $E = 500\ GeV$, $L = 300\ fb^{-1}$ and different degrees of polarization $(P_L(e^-), P_L(e^+))$: the dash line corresponds to (0.9,0.6), the dot one to (0.9,-0.6), the dash-dot to (-0.9,0.6) and the solid one to (0,0).

bounds that can be placed on the anomalous couplings. In ref. [3] we included in the analysis a longitudinal polarization for the electron beam only. The result was encouraging since the general effect of the polarization is to select different combinations of the anomalous parameters producing, as a consequence, a rotation of the allowed region. Here we consider the possibility of longitudinally polarized electron and positron beams. Depending on the mechanism used to polarize the beams it should be possible to achieve various degrees of polarization. A reasonable possibility [18] seems to be $(P_L(e^-), P_L(e^+)) = (0.9, 0.6)$. We have considered also the options with electron and positron beams polarized with opposite sign. In Fig. 6 we give the 90% CL bounds for the model A arising from combining the final state polarized differential cross-sections at the energy of 500 GeV and luminosity of 300 fb^{-1}, for different longitudinal degrees of polarization of the incoming beams. We see that any degree of polarization leads to an improvement of the bounds. However, the most efficient ones are the case with $(P_L(e^-), P_L(e^+)) = (\pm 0.9, \mp 0.6)$. For example, for this model an increasing of the bounds on y_γ with respect to the unpolarized case, requires negative longitudinal polarization for the electrons while the best for limiting ϵ_3 is obtained with negative longitudinal polarization for the positrons. We have not combined the bounds coming from different polarizations, just to illustrate the achievements of the different options. In Fig. 7 the same analysis is performed for the BESS model. We see that, also in this case, it is much more efficient to consider polarizations with opposite signs. A negatively polarized

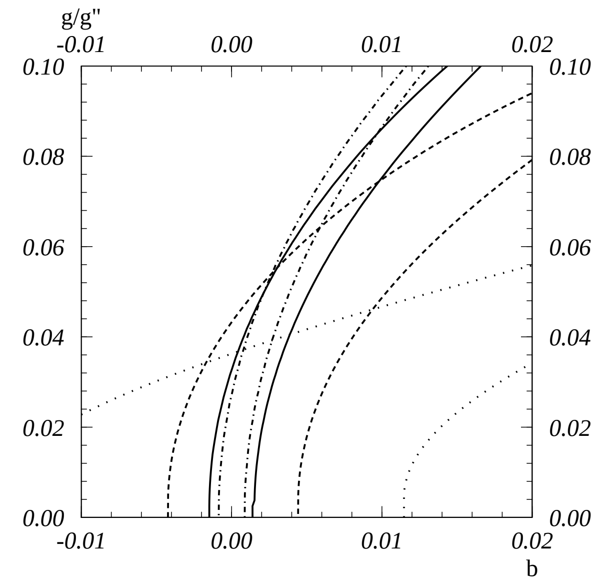

Figure 7: Same of Figure 6 for the parameter space $(b, g/g'')$ in the case of model B (BESS model).

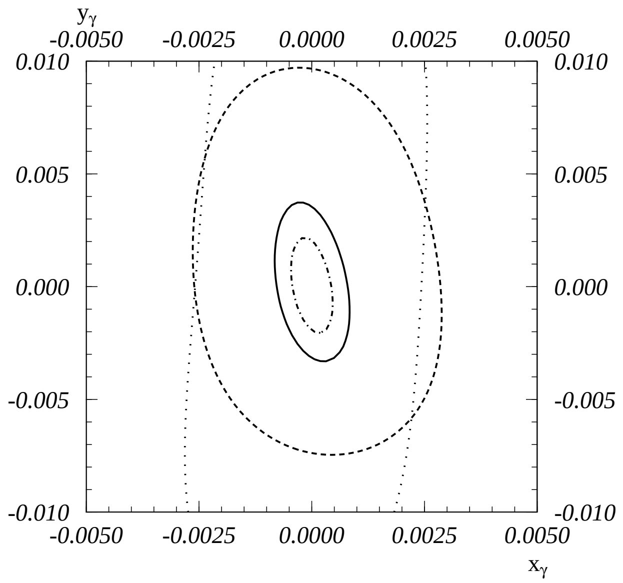

Figure 8: Same of Figure 6 for the parameter space (x_γ, y_γ) in the case of model C.

positron beam can put a very stringent bound on the gauge coupling constant g'' of the new resonances. For the model C in Fig. 8 we plot the analogue of Figs. 6 and 7 and we notice that, in this case, the polarization of the initial beams does not give a bigger constraint except for the case of a high degree of negative polarization for the incoming electrons.

A general conclusion is that polarization of the initial beams is very useful to constrain the anomalous parameters. In addition, for any of the options we have considered, we find that, by combining polarized and unpolarized differential cross-sections, one is able to get significantly more restrictive bounds, showing the complementarity of polarized and unpolarized measurements.

5 Conclusions

In this contribution we have considered the cross sections of $e^+e^- \to W^+W^-$ in various channels of W's polarizations as our observables to test non-standard gauge and fermionic couplings at the various options planned for the Next Linear Colliders. We found that the longitudinal cross section gives the most restrictive bounds on the anomalous parameters. We considered the contribution of the anomalous fermionic couplings because they can be present in a new physics scenario on the same footing of the trilinear anomalous gauge couplings. Also, from the high-energy behaviour of the observables, it is easy to show that terms proportional to the square of the anomalous couplings are not negligible. So we performed all the calculation without making any expansion in these parameters.

We studied the effect of the polarization of the electron and positron beams to the differential cross sections. The general effect of the polarization is to extend the reach of the colliders allowing experiments to probe different directions in parameter space. In this way, combining bounds from different polarization options, we obtain a much more restricted region for the anomalous parameters. Our conclusion is that, for the particular models we have considered, the most efficient option would be to have both beam polarized but with opposite sign.

In summary we have seen that the NLC (already with a c.m. energy of 500 GeV with the high-luminosity option) can give very stringent bounds on the anomalous parameters also improving our knowledge of the fermionic couplings which are very much constrained yet from LEP. Furthermore, if polarized beams will be available, the bounds will increase dramatically. So the final result is that polarized beams with adjustable degrees of polarization would constitute a very significant tool in the search for new physics.

Just to qualitatively compare these results for NLC with the sensitivity to the anomalous couplings of the present and planned accelerators we can refer to Fig. 5 of ref. [17]. Pre-LHC experiments will not probe these couplings to precision better than $\mathcal{O}(10^{-1})$. The present direct measurements of WWV couplings come from hadron collider experiments at Tevatron and from LEP2. For example, the most restrictive 95% CL limits on anomalous $WW\gamma$ and WWZ couplings from the $D0$ collaboration at Tevatron given in [19], assuming HISZ [16] equations (see eq. (2.3)), are $-0.18 \leq \lambda_\gamma \leq 0.19$ ($\Delta k_\gamma = 0$) and $-0.29 \leq \Delta k_\gamma \leq 0.53$ ($\lambda_\gamma = 0$) for $\Lambda = 2\ TeV$ (the momentum scale at which in these couplings are calculate). Similar bounds come from LEP2 analysis. The results presented at the Tampere conference [20] gives 95% CL one-parameter limits on Δk_γ, λ_γ, Δg_1^Z in the range 0.1-0.5. Limits will improve at the Tevatron Upgrade and at the LHC. The analysis done at the LHC shows that there is a strong dependence upon the assumed form factor scale Λ. Anyway the various estimates are in the range $5 - 10 \times 10^{-3}$. For the most recent analysis combining both CMS and ATLAS results, see [21].

As we have seen, a NLC collider at 500 GeV c.m. energy would reach $\mathcal{O}(10^{-3})$ with unpolarized beams (if polarization will be available the bounds could be pushed to $\mathcal{O}(10^{-4})$. This because the e^+e^- colliders allow precision measurement of helicity amplitudes at well determined c.m. energy and this is crucial to improve our understanding of the gauge boson self-interactions and of the fermionic couplings.

References

[1] See e.g. H. Murayama and M.E. Peskin, Ann. Rev. Nucl. Part. Sci. **46** (1996) 533, hep-ex/9606003.

[2] K. Hagiwara, R. Peccei, D. Zeppenfeld and K. Hikasa, Nucl. Phys. **B282** (1987) 253; for a review see: H. Aihara *et al.*, Summary of the Working Group on Anomalous Gauge Interactions of the DPF Long-Range Planning Study, in *"Electroweak Symmetry Breaking and new physics at the TeV scale"*, p. 488, eds. T. Barklow, S. Dawson, H. Haber and J. Siegrist, hep-ph/9503425.

[3] R. Casalbuoni, S. De Curtis and D. Guetta, Phys. Rev. **D55** (1997) 4203; and *ibidem* Proceedings of the Workshop *"e^+e^- Linear Colliders: Physics and Detector Studies"* ed. R. Settles (1997), DESY 97-123E, p. 205.

[4] A. Blondel *et al.*, Proceedings of the ECFA Workshop on LEP 200, Aachen, 1986, eds. A. Böhm, and W. Hoogland, CERN Report 87-08 (1987), Vol. I, p. 120; M. Frank, P. Mättig, R. Settles and W. Zeuner, Proceedings of the Workshop *"e^+e^- Collisions at 500 GeV: the Physics Potential"*, ed. P.M. Zerwas (1992), DESY 92-123A, p. 223; M. Bilenky , J.L. Kneur, F.M. Renard and D. Schildknecht, Nucl. Phys. **B409** (1993) 22.

[5] V.V. Andreev, A.A. Pankov and N. Paver, Phys. Rev. **D53** (1995) 2390, hep-ph/9511300; A.A. Likhoded, T. Han and G. Valencia, Phys. Rev. **D53** (1996) 4811.

[6] See: K. Hagiwara *et al.* in [2], and M. Bilenky *et al.* in [4].

[7] G. Gounaris, J.L. Kneur, J. Layssac, G. Moultaka, R.M. Renard and D. Schildknecht, Proceedings of the Workshop *"e^+e^- Collisions at 500 GeV: the Physics Potential"*, ed. P.M. Zerwas (1992), DESY 92-123B, p. 735.

[8] A.A. Pankov, N. Paver and C. Verzegnassi, Int. J. Mod. Phys. **A13** (1998) 1629, hep-ph/9701359.

[9] M. Frank *et al.* in [4]; R.W. Forty, J.B. Hansen, J.D. Hansen and R. Settles, Proceedings of the Workshop *"Collisions at 500 GeV: the Physics Potential"*, ed. P.M. Zerwas (1993), DESY 93-123C, p. 235; R. Settles, *ibidem*, p. 591; H. Anlauf, A. Himmler, P. Manakos, T. Mannel and H. Dahmen, Proceedings of the Workshop *"Physics and Experiments with Linear e^+e^- Colliders"*, Waikoloa, Hawaii, p. 708, eds. F.A. Harris, S.L. Holsen, S. Pakvasa and X. Tata, World Scientific, Singapore (1993).

[10] G. Altarelli and R. Barbieri, Phys. Lett. **B253** (1991) 161; G. Altarelli, R. Barbieri and S. Jadach, Nucl. Phys. **B369** (1992) 3.

[11] G. Altarelli, talk given at the Blois Conference, June 1999.

[12] G. Altarelli, B. Barbieri and F. Caravaglios, Int. J. Mod. Phys. **A13** (1998) 1031.

[13] M. Bilenky *et al.* in [4].

[14] R.Casalbuoni, S.De Curtis, D.Dominici and R.Gatto, Phys. Lett. **B155** (1985) 95; and Nucl. Phys. **B282** (1987) 235.

[15] L. Anichini, R. Casalbuoni and S. De Curtis, Phys. Lett. **B348** (1995) 521, hep-ph/9410377.

[16] K. Hagiwara, S. Ishihara, R. Szalapski and D. Zeppenfeld, Phys. Lett. **B283** (1982) 535; and Phys. Rev. **D48** (1993) 2182.

[17] T. Barklow *et al.*, in *"New Direction For High-Energy Physics"*, Proceedings of DPF/DPB Summer Study (Snowmass 96, p. 802. Edited by D.G. Cassel, L. Trindle Gennari, R.H. Siemann, SLAC-PUB-7366, hep-ph/9611454.

[18] R. Rückl, private communication.

[19] D0 Collaboration, Phys. Rev. **D60** (1999) 072002, hep-ex/9905005.

[20] ALEPH, DELPHI, L3, OPAL Collaborations, contributions to *International Europhysics Conference in High-Energy Physics 99*, Tampere, July 15-21,1999.

[21] See e.g. W.H. Thümmel, talk given at the *"Workshop on the SM Physics (and more) at the LHC"*, CERN, October 14-15, 1999; F. Gianotti, talk given at the *"ECFA/DESY Linear Collider Workshop"*, Obernai, October 16, 1999.