MODEL-INDEPENDENT LIMITS
ON FOUR-FERMION CONTACT INTERACTIONS
AT LC WITH POLARIZATION

A.A. Pankov

and

N. Paver

29 - 40

United Nations Educational Scientific and Cultural Organization
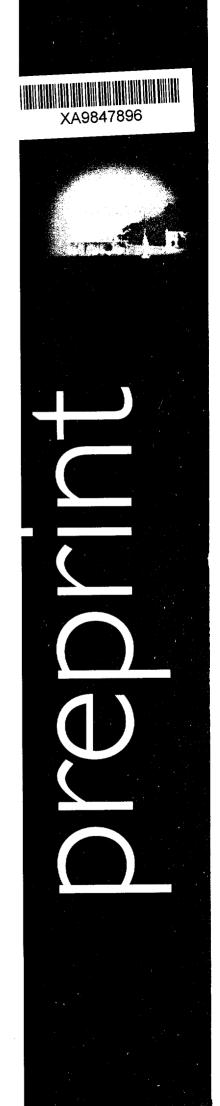and
International Atomic Energy Agency
THE ABDUS SALAM INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

MODEL-INDEPENDENT LIMITS ON FOUR-FERMION CONTACT INTERACTIONS AT LC WITH POLARIZATION

A.A. Pankov[1]

Department of Physics, Polytechnical Institute, Gomel, 246746 Belarus,[2]
Istituto Nazionale di Fisica Nucleare, Sezione di Trieste, Trieste, Italy
and
The Abdus Salam International Centre for Theoretical Physics, Trieste, Italy

and

N. Paver[3]

Dipartimento di Fisica Teorica, Università di Trieste, Trieste, Italy
and
Istituto Nazionale di Fisica Nucleare, Sezione di Trieste, Trieste, Italy.

Abstract

Fermion compositeness, and other types of new physics that can be described by the exchange of very massive particles, can manifest themselves as the result of an effective four-fermion contact interaction. In the case of the processes $e^+e^- \to \mu^+\mu^-, \tau^+\tau^-, \bar{b}b$ and $\bar{c}c$ at future e^+e^- colliders with $\sqrt{s} = 0.5 - 1$ TeV, we examine the sensitivity to four-fermion contact interactions of two new integrated observables, σ_+ and σ_-, conveniently defined for such kind of analysis. We find that, if longitudinal polarization of the electron beam were available, these observables would offer the opportunity to separate the helicity cross sections and, in this way, to derive model-independent bounds on the relevant parameters.

MIRAMARE – TRIESTE

April 1998

1 Introduction

Deviations from the Standard Model (SM) caused by new physics characterized by very high mass scales Λ can systematically be studied at lower energies by using the effective Lagrangian approach. In this framework, by integration of the heavy degrees of freedom of the new theory, an effective Lagrangian which obeys the low energy SM symmetries is constructed in terms of the SM fields. The resulting interaction consists of the SM itself as the leading term, plus a series of higher order terms represented by higher-dimensional local operators that are suppressed by powers of the scale Λ. Consequently, the effects of the new physics can be observed at energies well-below Λ as a deviations from the SM predictions, and can be related to some effective contact interaction. Here, we study the manifestations of such four-fermion contact interactions [1, 2] in high-energy e^+e^- collisions.

In the framework of composite models of leptons and quarks, the contact interaction is regarded as a remnant of the binding force between the fermion substructure constituents. Furthermore, in e^+e^- collisions, many types of new physics, for which the exchanged particles in the s, t, or u channels have mass-squared much larger than the corresponding Mandelstam invariant variables, can be described by an effective $eeff$ contact term in the interaction Lagrangian [3]-[9]. For example, effects of a Z' boson of a few TeV mass scale would be well-represented by a four-fermion contact interaction. The exchange of a leptoquark of a similar mass scale could be described by an effective $eeqq$ contact term in the relevant interaction. At energies much lower than the sparticle masses, R-parity breaking interactions introduce effective $eell$ and $eeqq$ interactions. The concept of contact interactions with a universal energy scale Λ is also used in other processes, such as ep and $p\bar{p}$ collisions, to search for substructure of quarks or new heavy particles coupling to quarks and gluons. Thus, quite generally, the contact interaction is considered as a convenient parameterization of deviations from the SM that may be caused by some new physics at the large scale Λ.

Fermion-pair production in e^+e^- collisions

$$e^+ + e^- \rightarrow \bar{f} + f \tag{1}$$

($f = l$ or q) is one of the basic processes of the SM, and deviations of the measured observables from the predicted values would be a first indication of new physics beyond the SM.

The lowest order four-fermion contact terms have dimension 6, which implies that they are suppressed by g_{eff}^2/Λ^2, with g_{eff} an effective coupling constant. The fermion currents are restricted to be helicity conserving and flavor diagonal. The general, $SU(3) \times SU(2) \times U(1)$ invariant, contact four-fermion $eeff$ interaction Lagrangian with dimension 6 can be written as [1, 2], [10]-[11]:

$$\begin{aligned} \mathcal{L} = \frac{g_{eff}^2}{2\Lambda^2} \big[&\eta_{LL} \left(\bar{e}_L \gamma_\mu e_L \right) \left(\bar{f}_L \gamma^\mu f_L \right) + \eta_{LR} \left(\bar{e}_L \gamma_\mu e_L \right) \left(\bar{f}_R \gamma^\mu f_R \right) \\ + &\eta_{RL} \left(\bar{e}_R \gamma_\mu e_R \right) \left(\bar{f}_L \gamma^\mu f_L \right) + \eta_{RR} \left(\bar{e}_R \gamma_\mu e_R \right) \left(\bar{f}_R \gamma^\mu f_R \right) \big], \end{aligned} \tag{2}$$

2

where generation and color indices have been suppressed. The subscripts L, R indicate that the current in each parenthesis can be either left- or right-handed, and the parameters $\eta_{\alpha\beta}$ ($\alpha, \beta = R, L$) determine the chiral structure of the interaction. They are free parameters in these models, but typical values are between -1 and $+1$, depending on the type of the assumed theory [3]. It is conventional to define $g^2_{eff} = 4\pi$, and the interaction is defined to be strong when $\sqrt{s}$ approaches Λ.

Constraints on the parameters characterizing contact interactions can be derived phenomenologically, by comparing the SM prediction for the observables that can involve such interactions with the relevant experimental data. In principle, cross sections simultaneously depend on all four-fermion effective coupling constants in Eq. (2), which therefore cannot be easily disentangled *a priori*. Therefore, such analyses are usually performed by assuming a non-zero value for only one parameter at a time, and all the remaining ones equal to zero. By this procedure, limits on *eeqq* contact interaction parameters have recently been derived from a global analysis of the data [11], including deep inelastic scattering from ZEUS and H1, atomic physics parity violation in Cesium from JILA, scattering of polarized e^- on nuclei at SLAC, Drell-Yan production at the Tevatron, and the e^+e^- total cross section into hadrons at LEP1, LEP2 and SLD.[4] The obtained constraints exclude, at the 95% C.L., contact interactions among leptons and *up* or *down* quarks with scale $\Lambda < 7.2 - 15.4$ TeV. The analogous bounds on the scale Λ of the four-lepton contact interactions *eell* from LEP2 ($\sqrt{s} = 130 - 183$ GeV) are in the range $5.2 - 6.5$ TeV, depending on the various helicity combinations [13]-[16]. Also, the constraints on lepton-heavy quark (*eebb*) contact parameters derived from LEP2 are slightly less stringent, and the bounds on the corresponding mass scale are $1.8 - 5.9$ TeV [13]. Compositeness scales of $3.0 - 6.3$ TeV have been probed at the Tevatron [17].

In the near perspective, run II of the Tevatron is expected to improve these limits to 10 TeV while, in the more distant future, a search limit for Λ in the range $15 - 20$ TeV is expected at the LHC [18]. The next linear e^+e^- collider (LC) with $\sqrt{s} \geq 500\,GeV$ will provide the best opportunities to analyse *eell*, *eebb* and *eecc* contact interactions with significant accuracy from process (1), due to the really high sensitivity of this reaction at such energies, in particular if initial beam polarization will be available. A detailed analysis of the potential of lepton colliders along these lines was performed in [10] and [19].

The aim of this paper is to outline an analysis of *eeff* contact interactions at the LC with longitudinally polarized beams, on a somewhat different basis that allows the various effective couplings to be taken into account as free parameters simultaneously. To this purpose, we consider two particularly helpful integrated observables, σ_+ and σ_-, that could directly distinguish the relevant helicity cross sections and, correspondingly, exhibit the dependence on a single effective coupling. As the outcome of such a procedure, one should obtain disentangled, model-independent, constraints on the *eell*, *eecc* and *eebb* couplings. In Sec. 2, the separation

---

[4]Effects of contact interactions at $\sqrt{s} = M_Z$ were considered in [12].

of the helicity cross sections by means of the observables σ_+ and σ_- is discussed. In Sec. 3, we present the corresponding analysis of the four-fermion couplings, as well as the numerical results for the expected bounds at the LC with some conclusive remarks.

2 Separation of the helicity cross sections

In Born approximation including γ, Z exchanges and the four-fermion contact interaction term (2), and neglecting m_f with respect to the CM energy $\sqrt{s}$, the differential cross section for the process $e^+ e^- \rightarrow \bar{f} f$ ($f \neq e, t$) with longitudinally polarized electron-positron beams can be written as

$$\frac{d\sigma}{d\cos\theta} = N_C \, \frac{\pi \alpha_{e.m.}^2}{2s} \left[(1 + \cos^2\theta) \, F_1 + 2\cos\theta \, F_2 \right], \tag{3}$$

where θ is the angle between the initial electron and the outgoing fermion in the CM frame, and N_C is the color factor ($N_C = 3$ or 1 for final quarks or leptons, respectively). The functions $F_{1,2}$ can be expressed in terms of helicity amplitudes as

$$
\begin{aligned}
F_{1,2} = \frac{1}{4} \Big[&(1 + P_e)(1 - P_{\bar{e}}) \left(|A_{RR}|^2 \pm |A_{RL}|^2 \right) \\
&+ (1 - P_e)(1 + P_{\bar{e}}) \left(|A_{LL}|^2 \pm |A_{LR}|^2 \right) \Big],
\end{aligned}
\tag{4}
$$

where P_e and $P_{\bar{e}}$ are the degrees of longitudinal electron and positron polarizations, respectively. The helicity amplitudes $A_{\alpha\beta}$ ($\alpha, \beta = L, R$) can be written as

$$A_{\alpha\beta} = (Q_e)_\alpha (Q_f)_\beta + g_\alpha^e \, g_\beta^f \, \chi_Z + \frac{s \eta_{\alpha\beta}}{2\alpha_{e.m.}\Lambda^2}, \tag{5}$$

where the gauge boson propagator is $\chi_Z = s/(s - M_Z^2 + iM_Z\Gamma_Z)$, the left- and right-handed fermion couplings are $g_L^f = (I_{3L}^f - Q_f s_W^2)/s_W c_W$ and $g_R^f = Q_f s_W^2/s_W c_W$ with $s_W^2 = 1 - c_W^2 \equiv \sin^2\theta_W$, and Q_f are the fermion electric charges.

Our discussion of the effects of the four-fermion contact interaction in the annihilation process (1) will be based on the 'new' observables σ_+ and σ_-, defined as the differences of integrated cross sections:

$$\sigma_+ \equiv \left(\int_{-z^*}^1 - \int_{-1}^{-z^*} \right) \frac{d\sigma}{d\cos\theta} \, d\cos\theta, \tag{6}$$

$$\sigma_- \equiv \left(\int_{-1}^{z^*} - \int_{z^*}^1 \right) \frac{d\sigma}{d\cos\theta} \, d\cos\theta, \tag{7}$$

with $z^* > 0$ such that

$$\int_{-z^*}^{z^*} (1 + \cos^2\theta) \, d\cos\theta = \left(\int_{z^*}^1 - \int_{-1}^{-z^*} \right) 2\cos\theta \, d\cos\theta. \tag{8}$$

This condition implies same coefficients multiplying F_1 and F_2 after integration of Eq. (3) over $\cos\theta$ in the indicated ranges, and determines the value of z^* via a cubic equation with solution

$z^* = 2^{2/3} - 1 = 0.5874$, corresponding to $\theta^* = 54°$. In the case of a reduced angular range, e.g., $|\cos\theta| < c$, one has $z^* = (1 + 3c)^{1/3} - 1$. One should notice that, in the approximation of neglecting m_f as in (3), the value of z^* is independent of $\sqrt{s}$. This would not be the case for $\bar{t}t$ pair production, where the expression of the differential cross section is such (see, e.g., [20]) that the relevant z^* would have a non-negligible dependence on $m_t/\sqrt{s}$, so that a separate treatment would be needed for this channel. Also, in the case of Bhabha scattering, condition (8) could not be satisfied, and the corresponding z^* could not be determined, because in this case the decomposition of the cross section into fully symmetric and antisymmetric parts as in (3) does not occur due to the presence of the additional t-channel γ- and Z-exchange amplitudes.

In terms of F_1 and F_2 of Eq. (3), and of $\sigma_{\rm pt} \equiv \sigma(e^+e^- \to \gamma^* \to \mu^+\mu^-) = (4\pi\alpha_{e.m.}^2)/(3s)$:

$$\sigma_\pm = N_C\, \sigma_{\rm pt}^* \,(F_1 \pm F_2), \tag{9}$$

where numerically, to a very good approximation:

$$\sigma_{\rm pt}^* = \frac{3}{4}\left(1 - z^{*2}\right)\sigma_{\rm pt} = 0.5\,\sigma_{\rm pt}. \tag{10}$$

Introducing the helicity cross sections

$$\sigma_{\alpha\beta} = N_C\,\sigma_{\rm pt}\,|A_{\alpha\beta}|^2, \tag{11}$$

and using Eqs. (9), (10) and (4), the observables σ_+ and σ_- can be expressed as:

$$\sigma_+ = \frac{1}{4}\left[(1 + P_e)(1 - P_{\bar{e}})\,\sigma_{RR} + (1 - P_e)(1 + P_{\bar{e}})\,\sigma_{LL}\right], \tag{12}$$

$$\sigma_- = \frac{1}{4}\left[(1 + P_e)(1 - P_{\bar{e}})\,\sigma_{RL} + (1 - P_e)(1 + P_{\bar{e}})\,\sigma_{LR}\right]. \tag{13}$$

Eqs. (12) and (13) show that σ_+ and σ_- provide a convenient tool to separate cross sections with different combinations of helicities by different choices of the initial beams polarizations, and actually, in this regard, they should be interesting by themselves. Indeed, corresponding to the different initial electron right- and left-handed longitudinal polarizations in Eq. (4), one has:

$$P_e = \pm 1, \quad P_{\bar{e}} = 0 \quad : \qquad \sigma_+^{R,L} \propto \sigma_{RR},\ \sigma_{LL}$$

$$P_e = \pm 1, \quad P_{\bar{e}} = 0 \quad : \qquad \sigma_-^{R,L} \propto \sigma_{RL},\ \sigma_{LR}. \tag{14}$$

For reference, we quote also the 'conventional' observables for the analysis of process (1), namely, the total cross section

$$\sigma = \int_{-1}^{1} \frac{d\sigma}{d\cos\theta} d\cos\theta = N_C\,\sigma_{\rm pt}F_1$$

$$= \frac{1}{4}\left[(1 + P_e)(1 - P_{\bar{e}})(\sigma_{RR} + \sigma_{RL}) + (1 - P_e)(1 + P_{\bar{e}})(\sigma_{LL} + \sigma_{LR})\right], \tag{15}$$

and the forward-backward asymmetry

$$A_{\rm FB} = (\sigma^{\rm F} - \sigma^{\rm B})/\sigma = 3F_2/4F_1, \tag{16}$$

5

where $\sigma^{\mathrm{F}} = \int_0^1 (d\sigma/d\cos\theta)d\cos\theta$ and, similarly, $\sigma^{\mathrm{B}} = \int_{-1}^0 (d\sigma/d\cos\theta)d\cos\theta$.

The independent observables σ_+ and σ_- are simply related to the, also independent, σ and A_{FB} by the relation

$$\sigma_{\pm} = 0.5\,\sigma\left(1 \pm \frac{4}{3}A_{\mathrm{FB}}\right). \tag{17}$$

Therefore, σ_+ and σ_- can be measured either by direct integration of the differential cross section according to Eqs. (6) and (7), or by the particular combination of σ and A_{FB} on the right-hand side of Eq. (17), which carries the same kind of information.

From Eqs. (12) and (13), only σ_+ and σ_- allow to directly disentangle the helicity cross sections, by combining measurements at two different electron polarizations. From Eqs. (15) and (16), σ and A_{FB} give information only on linear combinations of helicity cross sections even for polarized electrons, and therefore do not allow such a direct separation by themselves. The above mentioned distinctive features with regard to the determination of the helicity cross sections make σ_+ and σ_- potentially more convenient, in order to study the deviations from the SM due to the four-fermion contact interactions. The role of these observables also for other types of new physics to be studied in e^+e^- collisions such as, e.g., a new heavy neutral gauge boson Z' or the anomalous gauge boson couplings, has previously been emphasized in [21, 22].

The previous formulae continue to hold to a very good approximation with the inclusion of one-loop SM electroweak radiative corrections, in the form of improved Born amplitudes. Basically, the parameterization that uses the best known SM parameters G_{F}, M_Z and $\alpha(M_Z^2)$ is obtained by the following replacements in the above equations [23, 24]:

$$\alpha_{e.m.} \;\Rightarrow\; \alpha_{e.m.}(M_Z^2)$$

$$g_L^f \;\Rightarrow\; \frac{1}{\sqrt{\kappa}}\left(I_{3L}^f - Q_f\sin^2\theta_W^{\mathrm{eff}}\right), \qquad g_R^f \;\Rightarrow\; -\frac{Q_f}{\sqrt{\kappa}}\sin^2\theta_W^{\mathrm{eff}}$$

$$\sin^2\theta_W \;\Rightarrow\; \sin^2\theta_W^{\mathrm{eff}}, \qquad \sin^2(2\theta_W^{\mathrm{eff}}) \equiv \kappa = \frac{4\pi\alpha(M_Z^2)}{\sqrt{2}G_{\mathrm{F}}\,M_Z^2\rho}, \tag{18}$$

with

$$\rho \approx 1 + \frac{3G_{\mathrm{F}}m_{top}^2}{8\pi^2\sqrt{2}}. \tag{19}$$

Moreover, for the Z-propagator: $\chi_Z(s) \Rightarrow \dfrac{s}{s - M_Z^2 + i(s/M_Z^2)M_Z\Gamma_Z}$.

3 Model independent analysis and results

According to Eq. (14), by the measurements of σ_+ and σ_- for the different initial electron beam polarizations one determines the cross sections $\sigma_{\alpha\beta}$ related to definite helicities. From Eq. (5), one can observe that the contact interaction contributes to these amplitudes the term $s\eta_{\alpha\beta}/2\alpha_{e.m.}\Lambda^2$. To the same leading order in s/Λ^2, interference between the contact terms and the usual gauge interactions can affect the observables of process (1) and lead to deviations from the SM predictions at energies much below Λ, that in principle might be observed. The size of such interference term relative to the SM prediction is given by $s/\alpha_i\Lambda^2$, where α_i represents the

6

strength of the relevant gauge couplings, and to this order one may neglect modifications of the gauge couplings due to form factors [10].

Accordingly, in the considered situation $\sqrt{s} \ll \Lambda$, where only the interference term in the relevant observables is expected to be important, the deviation of each of the helicity cross sections from the SM prediction is given by the following expression:

$$\Delta \sigma_{\alpha\beta} \equiv \sigma_{\alpha\beta} - \sigma_{\alpha\beta}^{SM} = N_C \, \sigma_{\rm pt} \, 2 \left(Q_e \, Q_f + g_\alpha^e \, g_\beta^f \, \chi_Z \right) \cdot \frac{s \eta_{\alpha\beta}}{2\alpha_{e.m.} \Lambda^2}, \tag{20}$$

and depends on a single 'effective' non-standard parameter. Therefore, in an analysis of experimental data for $\sigma_{\alpha\beta}$ based on a χ^2 procedure, a one-parameter fit is involved and we may hope to get slightly better sensitivity to contact interactions with respect to the other observables, such as σ and $A_{\rm FB}$, which depend on sums of different helicity cross sections and, consequently, involve more then one free parameter at the same time. Moreover, in these cases, cancellations among the different independent parameters in interference terms cannot be excluded a priori.

In the case where no deviations are observed, one can make an assessment of the sensitivity of process (1) to the contact interaction parameters, based on the expected experimental accuracy on the observables σ_+ and σ_- introduced above. To this purpose, we adopt a χ^2 procedure which starts from a χ^2 function defined, for any observable $\mathcal{O}$, as follows:

$$\chi^2 = \left(\frac{\Delta \mathcal{O}}{\delta \mathcal{O}} \right)^2. \tag{21}$$

Here, $\delta \mathcal{O}$ is the expected uncertainty on the considered observable, and combines both statistical and systematic uncertainties. As a criterion to constrain the values of the contact interaction parameters to the domain allowed by the non-observation of the corresponding deviations within $\delta \mathcal{O}$, we impose that $\chi^2 < \chi_{\rm crit}^2$, where the actual value of $\chi_{\rm crit}^2$ specifies the desired 'confidence' level. The numerical analysis has been performed by means of the program ZEFIT adapted to the present discussion, which has to be used along with ZFITTER [25], with input values $m_{top} = 175$ GeV and $m_H = 300$ GeV. In order to reach the full sensitivity to contact interaction effects, a cut on the energy of photons emitted in the initial state, $\Delta = E_\gamma/E_{beam}$, is applied. For instance, at $\sqrt{s} = 0.5$ TeV a radiative return to the Z peak is avoided by choosing $\Delta = 0.9$.

In practice, referring to Eq. (14), polarization will not be exact, i.e., $|P_e| < 1$. Therefore, the measured σ_+ of Eq. (12) will involve a linear combination of σ_{LL} and σ_{RR}, which have to be disentangled from the data by solving the system of two equations corresponding to both signs of the electron longitudinal polarization, and the same is true for the determination of σ_{RL} and σ_{LR} from σ_-. For a quantitative discussion, we assume in the sequel $P_e = \pm P = \pm 0.8$ ($P_{\bar{e}} = 0$) at the LC [26].

For definiteness, we present in detail the case of σ_+. The solutions of the system of two equations corresponding to $P_e = \pm P$ in Eq. (12), can be written as:

$$\sigma_{RR} = \frac{1+P}{P} \sigma_+(P) - \frac{1-P}{P} \sigma_+(-P), \tag{22}$$

7

$$\sigma_{LL} = \frac{1+P}{P}\sigma_+(-P) - \frac{1-P}{P}\sigma_+(P). \tag{23}$$

From these equations, one can easily see that this procedure to extract σ_{LL} and σ_{RR}, by the two independent measurements of $\sigma(\pm P)$, is efficient as long as the values of $\sigma_+(P)$ and $\sigma_+(-P)$, as well as their experimental uncertainties, are comparable. In general, the statistical uncertainty on a indirectly measured quantity such as, e.g., σ_{RR} via $\sigma_+(P)$ and $\sigma_+(-P)$, is given by

$$\delta\sigma_{RR}^{stat} = \sqrt{\left(\frac{1+P}{P}\right)^2 (\delta\sigma_+(P))^2 + \left(\frac{1-P}{P}\right)^2 (\delta\sigma_+(-P))^2}, \tag{24}$$

where $\delta\sigma_+(\pm P)$ is the statistical uncertainty on $\sigma_+^{SM}(\pm P)$:

$$\delta\sigma_+(\pm P) = \sqrt{\frac{\sigma^{SM}(\pm P)}{\epsilon \mathcal{L}_{int}}}. \tag{25}$$

Here, $\mathcal{L}_{int}$ is the integrated luminosity, ϵ is the efficiency for detecting the final state under consideration and $\sigma^{SM}(\pm P)$ is the polarized cross section defined by Eq. (15). Eq. (25) has been obtained under the assumption that $\sigma_+^{SM}(\pm P)$ is measured directly as the difference of integrated cross sections defined in Eq. (6). Replacing Eq. (25) into Eq. (24) one can easily find:[5]

$$\delta\sigma_{RR}^{stat} = 2\sqrt{\frac{\sigma_R^{SM}}{\epsilon \mathcal{L}_{int}}\left[1 + \frac{1-P^2}{4P^2}\left(1 + \frac{\sigma_L^{SM}}{\sigma_R^{SM}}\right)\right]}, \tag{26}$$

where we introduced the following notations:

$$\sigma_R^{SM} = \frac{1}{2}\left(\sigma_{RR}^{SM} + \sigma_{RL}^{SM}\right), \quad \sigma_L^{SM} = \frac{1}{2}\left(\sigma_{LL}^{SM} + \sigma_{LR}^{SM}\right). \tag{27}$$

One should notice that the expression for $\delta\sigma_{RL}^{stat}$ is the same as Eq. (26), whereas the expression for $\delta\sigma_{LL}^{stat}$ ($=\delta\sigma_{LR}^{stat}$) can be obtained from $\delta\sigma_{RR}^{stat}$ by changing $L \leftrightarrow R$. The right-hand side of Eq. (26) has a non-trivial dependence on the value of the polarization P. In the numerical analysis presented below, we take three different values of the polarization, $P =1$, 0.8, 0.5, in order to test this dependence.

It turns out that, to a reasonable approximation, in the 'linear' approximation where, as anticipated, only the interference term is taken into account in the observable quantities,[6] the sensitivity of $\sigma_\pm$ to the contact interaction parameters can be simply expressed by the bounds directly following from Eqs. (20) and (21):

$$\Lambda_{(\alpha\beta)}^{-2} < \sqrt{\chi_{crit}^2}\,\frac{\alpha_{e.m.}}{s}\,\frac{\delta\sigma_{\alpha\beta}}{N_C\sigma_{pt}|A_{\alpha\beta}^{SM}|}. \tag{28}$$

Numerically, for σ_+ and σ_- we take into account the expected identification efficiencies [27] and the systematic uncertainties on the various fermionic final states, for which we assume: $\epsilon = 100\%$ and $\delta^{sys} = 0.5\%$ for leptons; $\epsilon = 60\%$ and $\delta^{sys} = 1\%$ for b quarks; $\epsilon = 35\%$ and

---

[5] The same level of statistical uncertainty would obtain from the combination of σ and A_{FB} in Eq. (17).

[6] For consistency, including quadratic terms in $1/\Lambda^2$ would require consideration of the dimension 8 operators in the effective Lagrangian.

Table 1: 95% C.L. model-independent compositeness search reach in TeV at e^+e^- linear collider with $E_{c.m.} = 0.5\,TeV$ and $\mathcal{L}_{int} = 50\,fb^{-1}$.

process	P	Λ_{RR}	Λ_{LL}	Λ_{RL}	Λ_{LR}
$e^+e^- \to \mu^+\mu^-$	1.0	30.1	30.1	21.7	21.0
$e^+e^- \to \mu^+\mu^-$	0.8	28.4	28.7	20.3	19.8
$e^+e^- \to \mu^+\mu^-$	0.5	24.2	24.8	17.1	16.9
$e^+e^- \to \bar{b}b$	1.0	34.8	32.8	26.2	17.4
$e^+e^- \to \bar{b}b$	0.8	30.6	32.0	22.8	16.7
$e^+e^- \to \bar{b}b$	0.5	23.8	29.5	17.6	14.7
$e^+e^- \to \bar{c}c$	1.0	28.6	26.1	15.8	19.1
$e^+e^- \to \bar{c}c$	0.8	27.1	25.6	14.4	18.2
$e^+e^- \to \bar{c}c$	0.5	23.2	23.7	11.7	15.8

Table 2: 95% C.L. model-independent compositeness search reach in TeV at e^+e^- linear collider with $E_{c.m.} = 1\,TeV$ and $\mathcal{L}_{int} = 100\,fb^{-1}$.

process	P	Λ_{RR}	Λ_{LL}	Λ_{RL}	Λ_{LR}
$e^+e^- \to \mu^+\mu^-$	1.0	51.4	51.6	36.9	35.6
$e^+e^- \to \mu^+\mu^-$	0.8	48.4	48.9	34.5	33.6
$e^+e^- \to \mu^+\mu^-$	0.5	40.9	42.0	29.0	28.6
$e^+e^- \to \bar{b}b$	1.0	59.6	58.6	43.1	29.6
$e^+e^- \to \bar{b}b$	0.8	52.2	56.9	37.6	28.5
$e^+e^- \to \bar{b}b$	0.5	40.4	51.5	28.9	25.2
$e^+e^- \to \bar{c}c$	1.0	51.1	47.9	27.3	32.5
$e^+e^- \to \bar{c}c$	0.8	47.7	46.5	25.0	31.0
$e^+e^- \to \bar{c}c$	0.5	40.0	42.1	20.3	27.0

$\delta^{sys} = 1.5\%$ for c quarks. Also, $\chi^2_{crit} = 3.84$ as typical for 95% C.L. with a one-parameter fit. The 95% C.L. lower bounds on the mass scales Λ relevant to the four pieces of the contact interaction (2) are reported in Tables 1 and 2, corresponding to $\sqrt{s} = 0.5$ TeV, $\mathcal{L}_{int} = 50\ fb^{-1}$, and $\sqrt{s} = 1$ TeV, $\mathcal{L}_{int} = 100\ fb^{-1}$, respectively. Also, for polarized beams, we assume $1/2$ of the total integrated luminosity quoted above for each value of the electron polarization, $P_e = \pm P$. Tables 1 and 2 show that the 'new' integrated observables σ_+ and σ_- are quite sensitive to contact interactions, with discovery limits ranging from 30 to 60 times the CM energy at the maximal planned value of degree of the electron longitudinal polarization $P = 0.8$. The best sensitivity occurs for the $\bar{b}b$ final state, while the worst one is for $\bar{c}c$. Decreasing the electron polarization from $P = 1$ to $P = 0.5$ results in worsening the sensitivity by $20 - 30\%$, depending on the final channel, which is not dramatic. Regarding the role of the assumed uncertainties on the observables under consideration, in the cases of Λ_{RL} and Λ_{LR} the expected statistics are such that the uncertainty turns out to be dominated by the statistical one, and the results are almost insensitive to the value of the systematic uncertainty. Conversely, in the cases of Λ_{LL} and Λ_{RR} the results depend more sensitively on the chosen value of the systematic uncertainty. Moreover, one should remark that, as evident from Eqs. (12) and (13), a further improvement

on the sensitivity to the various Λ-scales in Tables 1 and 2 would be obtained if both initial e^- and e^+ longitudinal polarizations were available [26].

In conclusion, we have studied the sensitivity to four-fermion contact interaction effects at linear colliders of two 'new' polarized observables, σ_+ and σ_-, leading to an analysis that enables to directly disentangle the four effective couplings relevant to the Lagrangian of Eq. (2). This feature can be realized by extracting individual helicity cross sections from the combination of observables measured at two different values of the electron polarization. Depending on the specific final state flavor and the helicity of fermions involved in process (1), contact interactions can be probed up to vales of the corresponding mass scales Λ of the order of $30 - 60$ times the CM energy.

Acknowledgements

References

[1] E. Eichten, K. Lane and M.E. Peskin, Phys. Rev. Lett. **50** (1983) 811.

[2] R.J. Cashmore, et al., Phys. Rept. **122** (1985) 275; R. Rückl, Phys. Lett. **B129** (1983) 363.

[3] P. Haberl, F. Schrempp, and H.U. Martyn, in Proceedings of *Physics at HERA*, Vol. 2 (1991) p.1133.

[4] G. Altarelli, J. Ellis, G.F. Giudice, S. Lola, and M.L. Mangano, preprint CERN-TH/97-040.

[5] K.S. Babu, G. Kolda, J. March-Russel, and F. Wilczek, Phys. Lett. **B402** (1997) 367.

[6] C.J. Burges and H.J. Schnitzer, Phys. Lett. **B134** (1984) 329.

[7] V. Barger, K. Cheung, K. Hagiwara, and D. Zeppenfeld, Phys. Lett. **B404** (1997) 141.

[8] N. Di Bartolomeo and M. Fabbrichesi, Phys. Lett. **B406** (1997) 237.

[9] J. Kalinowski, R. Rückl, H. Spiesberger, and P.M. Zerwas, Phys. Lett. **B406** (1997) 314; Z. Phys. **C 74** (1997) 595.

[10] K. Cheung, S. Godfrey, and J. Hewett, preprint SLAC-PUB-7373, 1996.

[11] V. Barger, K. Cheung, K. Hagiwara, and D. Zeppenfeld, Phys. Rev. D **57** (1998) 391.

[12] J. Erler, Phys. Rev. D **52** (1995) 28.

[13] ALEPH Collaboration, preprint ALEPH 98-021, 1998.

[14] L3 collaboration, preprint CERN-EP/98-31, 1998.

[15] OPAL Collaboration, K. Ackerstaff et al., preprint CERN-PPE/97-101, 1997.

[16] DELPHI collaboration, A. Behrmann et al., preprint DELPHI 97-132 CONF 110, 1997.

[17] R.G. Wagner, preprint FERMILAB-Conf-97/293-E, 1997.

[18] US ATLAS and CMS Collaborations, ed. by I. Hinchliffe and J. Womersley, LBNL-38997, 1996.

[19] K. Cheung and R.M. Harris, preprint UTEXAS-HEP-96-20, 1996.

[20] B. Grzadkowski, Z. Hioki and M. Szafranski, Warsaw preprint IFT-16-97 (1997).

[21] P. Osland and A.A. Pankov, Phys. Lett. **B403** (1997) 93; **B406** (1997) 328.

[22] A.A. Babich, A.A. Pankov, and N. Paver, Phys. Lett. **B426** (1998) 375.

[23] M. Consoli, W. Hollik and F. Jegerlehner, *in* Z physics at LEP1, ed. G. Altarelli, R. Kleiss and C. Verzegnassi, vol.1, p.7, 1989.

[24] G. Altarelli, R. Casalbuoni, D. Dominici, F. Feruglio and R. Gatto, Nucl. Phys. **B342** (1990) 15.

[25] S. Riemann, FORTRAN program ZEFIT Version 4.2;
D. Bardin et al., preprint CERN-TH. 6443/92, CERN, 1992.

[26] E. Accomando, et al., hep-ph/9705422, to appear in Phys. Rept.

[27] C. Damerall and D. Jackson, in *Proceedings of the 1996 DPF/DPB Summer Study on New Directions for High Energy Physics - Snowmass96,* Snowmass, CO, 25 June - 12 July, 1996.