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Testing the hypothesis of strongly interacting longitudinal weak bosons in electron-positron collisions at TeV energies

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ABSTRACT

In a previous paper, we presented a phenomenological model based on a chiral Lagrangian expansion to order s^2 for the scattering amplitudes of the longitudinally polarized W_L and Z_L gauge bosons in the case of a generic strongly interacting symmetry breaking sector. Here we apply this model in order to study the viability of testing the strongly interacting hypothesis within the next generation e^+e^- colliders at TeV energies. The different patterns expected for strong $V_L - V_L$ ($V_L = W_L^+, W_L^-$ and Z_L) scattering that come from different underlying theories describing the symmetry breaking sector are also examined. In particular we compare in detail the predictions for two different plausible models: Higgs-like models such as the Standard Model with a heavy Higgs, and QCD-like models such as technicolour models.

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Although the several scenarios proposed in the literature for the Symmetry Breaking Sector (SBS) of the Standard Model (SM) differ very much from each other in the details, they may be, however, roughly classified into two types depending on the strength of their interactions, namely, theories with weakly interacting SBS and theories with strongly interacting SBS. From a phenomenological point of view a weakly interacting SBS is characterized by the appearance of just a few light modes apart from the longitudinal components of the weak bosons (LWB). On the opposite side, a strongly interacting SBS is characterized by the absence of light quanta other than the LWB themselves, while all the new resonances typically belong to the TeV scale. In this last case, the relative low mass of the gauge bosons may be understood on the basis of a certain approximate global symmetry G of the unknown SBS dynamics which is spontaneously broken to another lesser symmetry H ($H \subset G$). Within this approach, the LWB may be interpreted as the Goldstone bosons associated to this symmetry breaking, this being the reason why they are light when compared to the TeV scale. The precise relationship between the Goldstone bosons mentioned above and the LWB is given by the Equivalence Theorem [1]. This theorem asserts that the LWB scattering amplitudes are equal to the Goldstone bosons scattering amplitudes if the weak boson masses are neglected. Combining this result with the available experimental information on the SBS (namely, $\rho \sim 1$ and $v = 250 GeV$), it is possible to derive the so-called Low Energy Theorems (LET) for the LWB scattering amplitudes [2] which are independent of the SBS dynamics.

In a previous paper [3] we introduced a phenomenologically viable model for the one-loop scattering amplitudes of the LWB in the case of strongly interacting SBS that is based on a chiral Lagrangian expansion [4] up to order s^2 . The model is built up from the simplest possible choice of the groups G and H , namely, $G = SU(2)_L \times SU(2)_R$ and $H = SU(2)_{L+R}$ and it is renormalizable up to order s^2 . At order s it reproduces the LET results but at order s^2 the one-loop scattering amplitudes depend on two new parameters that make the model dependent on the underlying unknown SBS dynamics. From the phenomenological point of view it is very important to know what are the chances of measuring these parameters in the future, since, after all, they are the only pieces of the model that depend on the SBS dynamics. In particular, concerning the next generation colliders, it is still an open question which of the projected machines is the most appropriate, if any, for testing the strong interacting SBS hypothesis and how efficient they will be in the measurement of these parameters. The experimental yields for strongly interacting $W_L^\pm$ and Z_L have been previously estimated in the case of pp colliders [5] and e^+e^- colliders [6]. Most of the work was dedicated to the most promising accelerators namely, SSC and CLIC machines, with nominal parameters: $\sqrt{s} = 40 TeV$, $L = 10^{33} cm^{-2} sec^{-1}$ and $\sqrt{s} = 2 TeV$, $L = 10^{33} - 10^{34} cm^{-2} sec^{-1}$ respectively. These previous estimates are based on the LET predictions and therefore they do not differentiate among the various possible scenarios for the strongly interacting SBS.

In this letter we will present the numerical results of our model in [3] for the scattering amplitudes of the strongly interacting $W_L^\pm$ and Z_L in terms of the two parameters that, when properly defined, will allow us to compare the different predictions coming from the

various scenarios for the strongly interacting SBS. For definiteness we have chosen in this note to start by studying the specific predictions for some hypothetical e^+e^- machines with centre-of-mass energies of $\sqrt{s} = 2 TeV$ and $\sqrt{s} = 3 TeV$ and with luminosities of $L = 10^{33}$ to $10^{34} cm^{-2} sec^{-1}$, such that they can also be applied to the future CLIC collider.

The starting point in studying possible strong interaction effects in e^+e^- collisions is to realize that in the presence of strongly interacting SBS the production of gauge bosons pairs at high energies ($\sim 0(TeV)$) is dominated by the so-called fusion process (see fig.1) with the weak boson degrees of freedom that are involved being predominantly longitudinally polarized. Moreover, the fusion diagram is dominated by the region in which the virtual $W^\pm$ and Z are close to their mass-shell, which, in turn, results in the relevant subprocesses for pair production of LWB accounting for strong interaction effects being the processes of the type $V_{L1} V_{L2} \rightarrow V_{L3} V_{L4}$ with $V_{L1,2,3,4}$ being $W_L^\pm$ or Z_L .

In order to compute the rates for $W_L^+ W_L^-$, $Z_L Z_L$ and $W_L^\pm Z_L$ production we have used firstly the effective W-approximation, analogous to the more familiar Weizsacker-Williams approximation for the photon-photon scattering. It allows us to derive the total cross-section for $V_{L3} V_{L4}$ production coming from the fusion process $e^+ e^- \rightarrow V_{L1} V_{L2} X \rightarrow V_{L3} V_{L4} X$ in terms of the cross-section for the subprocess $V_{L1} V_{L2} \rightarrow V_{L3} V_{L4}$ where the initial LWB are taken to be real. More precisely, the total cross-section is obtained from :

$$\frac{d\sigma}{d\hat{s}} = \int_0^1 dx_+ \int_0^1 dx_- \hat{\sigma}(V_{L1} V_{L2} \rightarrow V_{L3} V_{L4}) \delta(\hat{s} - x_+ x_- s) (F_1(x_+) F_2(x_-) + F_1(x_-) F_2(x_+)) \quad (1)$$

where $\hat{\sigma}$ is the cross-section for the subprocess $V_{L1} V_{L2} \rightarrow V_{L3} V_{L4}$ and $\sqrt{\hat{s}} = M_{VV}$ is the corresponding centre-of-mass energy. Here $F_i(x_\pm)$ is the distribution function for the gauge boson V_{L_i} and gives the probability of finding it with a fraction $x_\pm$ of the energy of the parent $e^\pm$. The expressions that have been used here are the following [7]:

$$F_{W_L}(x) = \frac{\alpha}{4\pi s_W^2} \frac{1-x}{x}$$

$$F_{Z_L}(x) = \frac{\alpha [1 + (1 - 4s_W^2)^2] (1-x)}{16\pi s_W^2 c_W^2 x} \quad (2)$$

with, $s_W = \sin\theta_W$ and $c_W = \cos\theta_W$.

In addition, we have applied the Equivalence Theorem to our problem, which allows us to get the expression for the $V_{L1} V_{L2} \rightarrow V_{L3} V_{L4}$ amplitudes from the corresponding Goldstone boson amplitudes. This approximation should be valid up to corrections of order $M_W/\sqrt{s}$.

For completeness, we present here the results that were found in [3] for the one-loop scattering amplitudes $T_{\alpha\beta\gamma\delta}$ of the Goldstone bosons ($\alpha, \beta, \gamma, \delta = +, -, 0$). By the use of crossing symmetry any of these amplitudes can be related to the three independent ones T_{+-+-} , T_{0000} and T_{+-00} which have the general form:

$$T = T^{LE\bar{T}} + T^{(4)} \quad (3)$$

where $T^{LE\bar{T}}$ corresponds to the predictions of the LFT and $T^{(4)}$ are the corrections of order s^2 in the chiral Lagrangian approach. The precise form of these amplitudes is given by

$$\begin{aligned} T_{+-+-}^{LE\bar{T}} &= -\frac{\hat{u}}{v^2} \\ T_{0000}^{LE\bar{T}} &= 0 \\ T_{+-00}^{LE\bar{T}} &= \frac{\hat{s}}{v^2} \\ T_{+-+-}^{(4)} &= \frac{1}{v^4} (2M_R(\nu)(s^2 + \hat{l}^2) + N_R(\nu)(s^2 + \hat{l}^2 + 2\hat{u}^2)) \\ &\quad + \frac{1}{(4\pi)^2 v^4} \left(-\frac{1}{12} (9\hat{s}^2 + \hat{u}^2 - \hat{l}^2) \log \frac{-\hat{s}}{v^2} - \frac{1}{12} (9\hat{l}^2 + \hat{u}^2 - \hat{s}^2) \log \frac{-\hat{l}}{v^2} - \frac{1}{2} \hat{u}^2 \log \frac{-\hat{u}}{v^2} \right) \\ T_{0000}^{(4)} &= \frac{8}{v^4} (M_R(\nu) + N_R(\nu))(s^2 + \hat{l}^2 + \hat{u}^2) \\ &\quad + \frac{1}{(4\pi)^2 v^4} \left(-\hat{s}^2 \log \frac{-\hat{s}}{v^2} - \hat{l}^2 \log \frac{-\hat{l}}{v^2} - \hat{u}^2 \log \frac{-\hat{u}}{v^2} \right) \\ T_{+-00}^{(4)} &= \frac{1}{v^4} (2M_R(\nu)s^2 + N_R(\nu)(\hat{l}^2 + \hat{u}^2)) \\ &\quad + \frac{1}{(4\pi)^2 v^4} \left(-\frac{1}{12} (3\hat{l}^2 + \hat{u}^2 - \hat{s}^2) \log \frac{-\hat{l}}{v^2} - \frac{1}{12} (3\hat{u}^2 + \hat{l}^2 - \hat{s}^2) \log \frac{-\hat{u}}{v^2} - \frac{1}{2} \hat{s}^2 \log \frac{-\hat{s}}{v^2} \right) \end{aligned} \quad (4)$$

In these formulae $M_R(\nu)$ and $N_R(\nu)$ are the renormalized parameters evaluated at the scale ν and whose specific dependence on ν can be easily reobtained by demanding that the physical amplitudes be independent of ν . The result is:

$$\begin{aligned} M_R(\nu) &= M_R(\nu_0) - \frac{1}{12(4\pi)^2} \log \frac{\nu}{\nu_0} \\ N_R(\nu) &= N_R(\nu_0) - \frac{1}{6(4\pi)^2} \log \frac{\nu}{\nu_0} \end{aligned} \quad (5)$$

By the use of the equations (1) to (4) it is possible to obtain the cross-section for the process $e^+e^- \rightarrow V_{L3} V_{L4} X$ in terms of $M_R(\nu)$ and $N_R(\nu)$. The important point here is that for different choices of these unknown parameters different physical situations in the SBS can be described.

In the following and for the numerical estimates we will consider two of those different scenarios which are representative examples of scalar-dominated and vector-dominated theories respectively. The first model will be the minimal standard model (one scalar doublet) with a heavy Higgs ($M_H > 0(TeV)$). It will be referred to as MSM for short. This model has been defined so as to reproduce from our results of eqs.(3) and (4) the

recently computed [8] $V_L - V_L$ scattering amplitudes to one loop, within the SM and in the limit $s < m_H^2$. In particular we obtain the result of the first reference in [8] by setting the parameters to be:

$$\begin{aligned} M_R(\nu) &= \frac{1}{8} (c_1 - \frac{c_2}{2}) + \frac{1}{12(4\pi)^2} \log \frac{m_H}{\nu} \\ N_R(\nu) &= \frac{c_2}{8} + \frac{1}{6(4\pi)^2} \log \frac{m_H}{\nu} \end{aligned} \quad (6)$$

with

$$\begin{aligned} c_1 &= \frac{1}{(4\pi)^2} \left(\frac{9\pi}{2\sqrt{3}} - \frac{76}{9} \right) \\ c_2 &= -\frac{4}{9} \frac{1}{(4\pi)^2} \end{aligned} \quad (7)$$

Notice that within this scheme the scattering amplitudes will depend just on the value of m_H .

The second model is a QCD-rescaled model based on the simple hypothesis that a theory similar to QCD could be governing the dynamics in the SBS at the TeV energy scale. This is of course within the same spirit as technicolour models. We will define QCD-rescaled as a model with the same numerical values for the parameters M and N as those appearing in the chiral Lagrangian for low energy QCD but referred to the appropriate scale. In particular, the values for M and N of low energy QCD have been taken from ref.[9] where they were extracted from the fits to $\pi - \pi$ scattering data. More precisely,

$$\begin{aligned} M_R(\frac{\nu}{f_\pi} GeV) &= {}^{det} M_R^{QCD}(1 GeV) = {}^{exp} -0.011/4 \\ N_R(\frac{\nu}{f_\pi} GeV) &= {}^{det} N_R^{QCD}(1 GeV) = {}^{exp} 0.0046/4 \end{aligned} \quad (8)$$

where $f_\pi \simeq 94 MeV$ is the pion decay constant. This second model will be referred to as QCD for short.

We will study next the different patterns of both models in terms of the behaviour of the cross-section with energy for the various relevant subprocesses involving LWB. In particular, we will present here the results for the two processes $W_L^+ W_L^- \rightarrow Z_L Z_L$ and $W_L^+ Z_L \rightarrow W_L^+ Z_L$. As discussed below, these are the two relevant subprocesses as far as one deals with the problem of finding a significant signal-to-background ratio in pair production of LWB at e^+e^- colliders. The results of the cross-sections as a function of the energy are plotted in Fig.2 (a) and (b). For definiteness we have chosen $m_H = 2TeV$ in the Higgs-like model. The results of the cross-sections that are obtained from the LFT's are also included in the figure for comparison. It can be seen how the two curves corresponding to the two models clearly separate from each other as energy increases, and also how they separate from the LFT's predictions. This is in concordance with the results that were

found in ref.[3] in terms of the partial wave amplitudes. Whereas in the $W_L^\pm Z_L \rightarrow W_L^\pm Z_L$ case, the curve for the QCD-like model lies above the corresponding one to the Higgs-like model, the converse occurs in the $W_L^\pm W_L^\mp \rightarrow Z_L Z_L$ case. Numerically the ratio of the cross-section is quite significant. For instance, at $\sqrt{s} = 1250 \text{ GeV}$, we find

$$\frac{\sigma^{QCD}(W_L^\pm Z_L \rightarrow W_L^\pm Z_L)}{\sigma^{MSM}(W_L^\pm Z_L \rightarrow W_L^\pm Z_L)} \sim 1.4$$

and

$$\frac{\sigma^{MSM}(W_L^\pm W_L^\mp \rightarrow Z_L Z_L)}{\sigma^{QCD}(W_L^\pm W_L^\mp \rightarrow Z_L Z_L)} \sim 2.5 \quad (9)$$

where in this case the large ratio is an immediate consequence of the process $W^+ W^- \rightarrow Z_L Z_L$ being pure s wave in the lowest partial wave approximation.

We are now in a position to present our results for the production of gauge boson pairs through the process $e^+ e^- \rightarrow V_L V_{12} X \rightarrow V_{13} V_{12} X$. In Fig.3-(a) is shown the differential cross-section with respect to the invariant mass M_{1312} for the two subprocesses $W^+ W^- \rightarrow ZZ$ (solid lines) and $W^\pm Z \rightarrow W^\pm Z$ (dotted lines) for a centre-of-mass energy of $\sqrt{s} = 2 TeV$, and for the two discussed models. Again the separation with increasing invariant mass between the curves for the two models is clearly manifested in the figure. However, it should also be noticed that the absolute rates for the differential cross-section are quite low in the whole energy of interest due to the fact that the luminosity function for longitudinal gauge boson pairs takes small values at these energies and, consequently, it reduces significantly the signal (the longitudinal luminosities are typically a factor of a hundred smaller than the transverse ones).

A few comments are in order. Since there is no resonant behaviour in the $V_L V_{12} \rightarrow V_{13} V_{14}$ amplitudes over the whole energy range under study, the experimental signal for strong $V_L - V_L$ scattering in $e^+ e^-$ would be simply a broad enhancement in the high energy region of the differential cross-section with the invariant mass of the gauge boson pair. This means that in order to test the strongly interacting LWB hypothesis one should be able to recognize experimentally this enhancement over the continuum $V_L - V_L$ line shape coming from the several background processes.

In the following we will briefly summarize which are the relevant subprocesses contributing to the signal and which are the dominant background processes. In principle, if one does not distinguish between the decay products of the final $W's$ and $Z's$, the whole set of subprocesses contribute to the signal, namely, $W^+ W^- \rightarrow W^+ W^-$, $W^+ W^- \rightarrow ZZ$, $W^\pm Z \rightarrow W^\pm Z$, $ZZ \rightarrow W^\pm W^\mp$ and $ZZ \rightarrow ZZ$. However, in a first approximation, it is safe to ignore the two last channels with ZZ in the initial state due to the fact that the coupling of the Z to the $e^\pm$ is suppressed by about one third with respect to that of the W . On the other hand, the main background to $V_L V_L$ ($V_{3,4} = W^\pm$ or Z) production comes from the following processes:

$$1) \ e^+ e^- \rightarrow \gamma \gamma (e^+ e^-) \rightarrow W^+ W^- (e^+ e^-)$$

$$\begin{aligned} 2) \ e^+ e^- &\rightarrow \gamma W^\pm (e^\pm \nu) \rightarrow ZZ W^\pm (e^\pm \nu) \\ 3) \ e^+ e^- &\rightarrow e^+ e^- (\gamma \gamma) \rightarrow W^+ W^- (\gamma \gamma) \text{ or } ZZ (\gamma \gamma) \end{aligned}$$

Here we have neglected the background contribution from the process $e^+ e^- \rightarrow \gamma Z (e^+ e^-) \rightarrow W^+ W^- (e^+ e^-)$ that is suppressed with respect to process 2). In the three cases the particles in parentheses are assumed to be lost in the beam pipe, giving rise to a contribution to the missing energy of the event. Processes 1) and 2) have been considered previously in the literature as a background to heavy Higgs boson production in $e^+ e^-$ colliders [10]. Processes 1) and 3) were considered in [6] as a background to strong WW signals in $e^+ e^-$ machines.

As far as the rates are concerned, the most dangerous background is process 1) that, in fact, in the present form without any stringent cut or specific requirement for the final state, is overwhelming the signal by about a factor of a hundred. In order to avoid this background we must require (at least) one Z in the final state, in which case we are left with just two relevant processes contributing to the signal, namely, $W^+ W^- \rightarrow ZZ$ and $W^\pm Z \rightarrow W^\pm Z$. Furthermore, it implies that one Z must be reconstructed from its decay channels into charged leptons and, in consequence, the rates get a suppression factor of $BR(Z \rightarrow e^+ e^- \text{ and } \mu^+ \mu^-) \sim 10\%$, multiplied by two in the ZZ final state channel.

The next important background, process 2), can be very efficiently reduced by applying a cut of $|\cos \theta| < z_0$ on the angle of the final bosons in the $V_L V_L$ centre-of-mass system. Thus, we have checked that a cut of $|\cos \theta| < 0.7(0.5)$ reduces the $\gamma W^\pm$ background by a factor of about 20(40) whereas it does not greatly affect the signal (the reduction factor for $z_0 = 0.5$ is about 2 in the $W^+ W^- \rightarrow ZZ$ case and about 3 in the $W^\pm Z \rightarrow W^\pm Z$ case). On the other hand, we have estimated numerically the contribution of the background process number 3), and we have checked that a cut on the missing mass of $M_{miss} > 100 \text{ GeV}$ is sufficient to suppress it below the contribution coming from the signal.

Some indicative results of strong $V_L V_L$ scattering in the high energy region are summarized in the following in terms of the total cross-section. The branching ratio of Z decays to charged leptons is not included in the quoted rates.

1.- For $\sqrt{s} = 2 TeV$, $z_0 = 0.5$, and $500 \text{ GeV} < M_{VV} < 1500 \text{ GeV}$

i) with intermediate subprocess $W^+ W^- \rightarrow ZZ$:

$$\sigma_{tot}^{MSM} = 2.2 \times 10^{-3} \text{ pb}, \text{ and } \sigma_{tot}^{QCD} = 1.45 \times 10^{-3} \text{ pb}$$

ii) with intermediate subprocess $W^+ Z \rightarrow W^+ Z$ or $W^- Z \rightarrow W^- Z$:

$$\sigma_{tot}^{MSM} = 2.93 \times 10^{-4} \text{ pb}, \text{ and } \sigma_{tot}^{QCD} = 2.72 \times 10^{-4} \text{ pb}$$

These rates should be compared with the background contribution:

iii) with intermediate subprocess $\gamma W^+ \rightarrow Z W^+$ or $\gamma W^- \rightarrow Z W^-$:

$$\sigma_{tot}^{BACK} = 5.6 \times 10^{-3} pb$$

II.- For $\sqrt{s} = 3TeV$, $z_0 = 0.5$, and $500GeV < M_{VV} < 1500GeV$

the corresponding numbers are:

$$i) \sigma_{tot}^{MSM} = 5.66 \times 10^{-3} pb, \text{ and } \sigma_{tot}^{QCD} = 3.35 \times 10^{-3} pb$$

$$ii) \sigma_{tot}^{MSM} = 7.55 \times 10^{-4} pb, \text{ and } \sigma_{tot}^{QCD} = 6.90 \times 10^{-4} pb$$

$$iii) \sigma_{tot}^{BACK} = 1.09 \times 10^{-2} pb$$

As can be inferred from these numerical results, to integrate in the energy range $500GeV < M_{VV} < 1500GeV$ is not enough to discriminate between strong scattering signals and the continuum background.

In order to enlarge the above interval up to higher energies we have extrapolated our model above the energy threshold imposed by unitarity $s_{VV}^U \simeq 1500GeV^2$ (see ref.[3]) as follows. We define the amplitudes for the subprocesses in terms of the lowest partial wave amplitudes ($J=0, 1; l=0, 2$) in the standard way. For energies below and up to the threshold value, $s_{VV} \leq s_{VV}^U$, it is verified that $|a_{IJ}(s_{VV})| < 1$. For energies at and above this threshold we keep the partial wave amplitudes equal to its value at threshold, and consequently $|a_{IJ}(s_{VV})| < 1$ is fulfilled in the whole energy range.

In Figs.3-(b) and 3-(c) the corresponding result for the differential cross-section with respect to the invariant mass at centre-of-mass energies of $\sqrt{s} = 2TeV$ and $\sqrt{s} = 3TeV$ respectively is plotted. For simplicity in the comparison with the background we have only included in the figures the predictions for the MSM model. The dotted lines are the contribution to the signal from subprocess $W^+ W^- \rightarrow ZZ$. The dashed lines are the corresponding one from process $W^\pm Z \rightarrow W^\pm Z$. The solid lines are the results for the background coming from the subprocess $\gamma W^\pm \rightarrow Z W^\pm$. In the computation of these results a stringent cut of $z_0 = 0.5$ was applied.

It is obvious from Fig.3-(b) that the case $\sqrt{s} = 2TeV$ is hopeless. There is no significant enhancement in the high energy region of the plot. It is also clear that in the case with $\sqrt{s} = 3TeV$ the situation is much more promising. The annunciated broad enhancement for large values of the invariant mass ($M_{VV} > 1000GeV$) is shown in Fig.3-(c).

Finally, in order to compare in a more quantitative way the signal and background contributions, we present in the following the results in terms of the total cross-section and the expected total number of events.

III.- For $\sqrt{s} = 2TeV$, $z_0 = 0.5$, and $M_{VV} > 700GeV$:

$$i) \sigma_{tot}^{MSM} = 1.42 \times 10^{-3} pb, \text{ and } \sigma_{tot}^{QCD} = 8.27 \times 10^{-4} pb$$

$$ii) \sigma_{tot}^{MSM} = 1.85 \times 10^{-4} pb, \text{ and } \sigma_{tot}^{QCD} = 1.77 \times 10^{-4} pb$$

to be compared with:

$$iii) \sigma_{tot}^{BACK} = 1.70 \times 10^{-3} pb$$

IV.- For $\sqrt{s} = 3TeV$, $z_0 = 0.5$, and $M_{VV} > 700GeV$:

$$i) \sigma_{tot}^{MSM} = 4.95 \times 10^{-3} pb, \text{ and } \sigma_{tot}^{QCD} = 2.46 \times 10^{-3} pb$$

$$ii) \sigma_{tot}^{MSM} = 6.66 \times 10^{-4} pb, \text{ and } \sigma_{tot}^{QCD} = 6.34 \times 10^{-4} pb$$

to be compared with:

$$iii) \sigma_{tot}^{BACK} = 3.91 \times 10^{-3} pb$$

The total number of events with one Z in the final state that are expected in a run of one year if a luminosity of $L = 10^{33} cm^{-2} sec^{-1}$ ($10^{34} cm^{-2} sec^{-1}$) can be reached are: For $\sqrt{s} = 2TeV$: $N^{MSM} = 3(32)$ in the Higgs-like model, and $N^{QCD} = 2(20)$ in the QCD-like model. The background contribution is $N^{BACK} = 3(34)$.

For $\sqrt{s} = 3TeV$: $N^{MSM} = 11(112)$ in the Higgs-like model, and $N^{QCD} = 6(62)$ in the QCD-like model. The background is $N^{BACK} = 8(78)$.

The conclusion of this work can be directly inferred from the above numbers. If there is no resonant behaviour in the strong scattering amplitudes $V_{L1} V_{L2} \rightarrow V_{L3} V_{L4}$, there is no

hope for the observation of experimental signatures that point to strongly interacting $W's$ and $Z's$ at an e^+e^- collider with $\sqrt{s} = 2TeV$, such as the planned CLIC accelerator. The signal-to-background ratio is about one but the statistics are insufficient. The situation is much more promising for an e^+e^- collider with $\sqrt{s} = 3TeV$, mainly if the symmetry breaking sector of the Standard Model behaves as in the Higgs-like model discussed in this note. In this case the signal-to-background ratio is already larger than one, but in order to have significative statistics a luminosity of $L = 10^{31} cm^{-2} sec^{-1}$ must be required. The computed rates for the QCD-like model are in both cases, $\sqrt{s} = 2TeV$ and $\sqrt{s} = 3TeV$, below the background values. From this we can conclude that in order to be able to discriminate among the different possible underlying dynamics, an e^+e^- collider with higher energy than $\sqrt{s} = 3TeV$ is needed. Of course, this conclusion does not apply in the alternative case, not considered in this paper, where the amplitudes present a resonant behaviour in the studied energy range.

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Figure Captions

Fig. 1: Schematic representation of the so-called $V_L - V_L$ fusion process in e^+e^- collisions.

Fig. 2: Cross-section for the subprocesses a) $W_L^+W_L^- \rightarrow Z_L Z_L$ and b) $W_L^\pm Z_L \rightarrow W_L^\pm Z_L$ as a function of the energy. Solid lines correspond to the QCD-like model. Dotted lines correspond to the Higgs-like model with $m_H = 2TeV$. Dashed lines are the LEP predictions. The background $\gamma W_L^\pm \rightarrow Z_L W_L^\pm$ is also included (dot-dashed line in b)) for comparison.

Fig. 3: (a) Differential cross-section with respect to the invariant mass M_{VV} for the fusion process shown in Fig.1 at $\sqrt{s} = 2TeV$. Solid lines are the predictions for the $W_L^+W_L^- \rightarrow Z_L Z_L$ process and dotted lines the corresponding ones for the $W_L^\pm Z_L \rightarrow W_L^\pm Z_L$ process. The upper solid curve and the lower dotted curve correspond to the Higgs-like model with $m_H = 2TeV$. The lower solid curve and the upper dotted curve correspond to the QCD-like model. (b) Differential cross-section with respect to the invariant mass M_{VV} for production of gauge boson pairs in e^+e^- at $\sqrt{s} = 2TeV$. A cut of $z_0 = 0.5$ has been applied. Solid line is the background contribution from subprocess $\gamma W^\pm \rightarrow ZW^\pm$. Dotted line is the contribution to the signal from subprocess $W^+W^- \rightarrow ZZ$. Dashed line is the contribution to the signal from subprocess $W^\pm Z \rightarrow W^\pm Z$. The signal refers to the Higgs-like model with $m_H = 2TeV$. (c) Same as (b) but for $\sqrt{s} = 3TeV$.

Fig. 1

Fig. 2

Fig. 3