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**TESTING FOR A POSSIBLE STRONG-INTERACTING
ELECTROWEAK SYMMETRY BREAKING SECTOR
AT LHC AND SSC *)**

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ABSTRACT

We study gauge boson pair production at future hadron colliders in the presence of a strong interacting electroweak symmetry breaking sector. The calculations are carried out within the BESS model, with parameters limited from present experiments as well as in view of future attainable LEP precisions. The fusion production mechanism via longitudinal WW scattering is compared to the $q\bar{q}$ annihilation mechanism going through vector resonance that is typical of the BESS model. The $q\bar{q}$ mechanism is found to be in general largely dominant at LHC, making the calculated event rates observable at the projected LHC energy and luminosity, for reasonable ranges of the BESS parameters. Detailed studies of background and statistical significance of signals versus background are made both at LHC and SSC.

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The distributions we are interested in (invariant mass of the W/Z pair and transverse momentum of W or Z) can be derived from the knowledge of the differential cross-section $d\hat{\sigma}/d\hat{t}$ of the subprocess $q\bar{q}$ going into two longitudinally polarized gauge bosons. Since V does not couple to a pair of longitudinal Z 's, we restrict to the WW and WZ final states.

For WW production one has

$$\frac{d\hat{\sigma}}{d\hat{t}} = \frac{2}{3} \pi \alpha_{em}^2 \left(\frac{g_{V^0-W^+W^-}^2}{e^2} \right) (g_V^q{}^2 + g_A^q{}^2) \frac{1}{(\hat{s} - M_V^2)^2 + M_V^2 \Gamma_V^2} \times \left\{ \left(\frac{\hat{u}\hat{t}}{M_W^4} - 1 \right) \left[\frac{1}{4} - \frac{M_W^2}{\hat{s}} + 3 \frac{M_W^4}{\hat{s}^2} \right] + \frac{\hat{s}}{M_W^2} - 4 \right\} \quad (3.1)$$

whereas for WZ production one has

$$\frac{d\hat{\sigma}}{d\hat{t}} = \frac{2}{3} \pi \alpha_{em}^2 \left(\frac{g_{V^0-W^+W^-}^2}{e^2} \right) (g_V^q{}^2 + g_A^q{}^2) \frac{1}{(\hat{s} - M_V^2)^2 + M_V^2 \Gamma_V^2} \times \left\{ \left(\frac{\hat{u}\hat{t}}{M_W^2 M_Z^2} - 1 \right) \left[\frac{1}{4} - \frac{M_W^2 + M_Z^2}{2\hat{s}} + \frac{(M_W^2 + M_Z^2)^2 + 8M_W^2 M_Z^2}{4\hat{s}^2} \right] + \frac{M_W^2 + M_Z^2}{M_W^2 M_Z^2} \left[\frac{\hat{s}}{2} - M_W^2 - M_Z^2 + \frac{(M_W^2 - M_Z^2)^2}{2\hat{s}} \right] \right\} \quad (3.2)$$

The factor $1/3$ in eqs. (3.1) and (3.2) is due to the color average. The widths entering eqs. (3.1) and (3.2) are given by, respectively

$$\Gamma_{V^0-W^+W^-} = \frac{M_V g_{V^0-W^+W^-}^2}{12\pi} \frac{1}{16} \left(1 - 4 \frac{M_W^2}{M_V^2} \right)^{3/2} \left(\frac{M_V}{M_W} \right)^4 \times \left[1 + 20 \left(\frac{M_W}{M_V} \right)^2 + 12 \left(\frac{M_W}{M_V} \right)^4 \right] \quad (3.3)$$

and

$$\Gamma_{V^\pm-W^\pm Z} = \frac{M_V g_{V^\pm-W^\pm Z}^2}{12\pi} \frac{1}{16} \left[\left(1 + \frac{M_W^2 - M_Z^2}{M_V^2} \right)^2 - 4 \frac{M_W^2}{M_V^2} \right]^{3/2} \times \frac{M_V^4}{M_W^2 M_Z^2} \left[1 + 10 \left(\frac{M_W^2 + M_Z^2}{M_V^2} \right) + \frac{M_W^4 + M_Z^4 + 10M_W^2 M_Z^2}{M_V^4} \right] \quad (3.4)$$

The various couplings are defined as follows. In eq. (3.1) we have

$$g_{V^0-W^+W^-} = \frac{1}{2} \frac{g^2}{g''} \quad (3.5)$$

$$g_V^q = \frac{1}{2e} (CT_{3L}^q + 2DQ_{em}^q), \quad g_A^q = \frac{1}{2e} CT_{3L}^q \quad (3.6)$$

The quantities C and D are defined in eqs. (2.10) and (2.11) and $e^2 = 4\pi\alpha_{em}$ is the square of the electric charge.

In eq (3.2) we have

$$g_{V^+-W^+Z} = \frac{1}{2} \frac{gG}{g''} \quad (3.7)$$

$$g_V^q = -g_A^q = \frac{1}{2\sqrt{2}e} h_V \quad (3.8)$$

where h_V is given in eq. (2.9).

Another mechanism to produce W/Z pairs is the rescattering of a pair of ordinary gauge vector bosons, each being initially emitted from a quark or antiquark leg. In the so-called effective- W approximation the initial W/Z 's are assumed to be real and the cross section for producing a W/Z pair is obtained by a double convolution of the cross section for the rescattering (or fusion) process with the luminosities of the initial W/Z 's inside the quarks and the structure functions of the quarks inside the proton [9]. The relevance of this mechanism is then related to the strength of the fusion process. In the standard model of electroweak interactions such a fusion process is expected to be weak. The potentially large amplitudes, those among the longitudinally polarized W/Z 's, are in fact asymptotically constant (for large energy), once the whole set of lowest order diagrams is taken into account. However such a constant depends on the Higgs mass m_H and for a sufficiently large value of m_H the asymptotic value of the amplitude violates the perturbative unitarity requirement. The speculations on a possible strongly interacting regime for the standard model [10,3] are based on this observation. In BESS the rescattering process is naturally strong. In fact the scattering of two longitudinally polarized W/Z 's proceeds via the exchange of a V vector boson with large couplings (of order ag'') at each vertex. If some of the W/Z 's is taken to be transverse, the corresponding amplitude is strongly depressed and will be neglected in our analysis. We have computed the scattering amplitudes among longitudinal W/Z 's in BESS, by making use of the equivalence theorem [11]. Such amplitudes approach the ones among the corresponding goldstone bosons as the

value of the energy increases, the difference being of order $(M/\sqrt{s})$ ($M = M_W$ or M_Z). For $\sqrt{s} \gg M$ we obtain

$$T(W_L^+ W_L^- \rightarrow W_L^+ W_L^-) = \left(1 - \frac{3}{4}\alpha\right) \left(\frac{-u}{v^2}\right) + \frac{\alpha}{4} \frac{M_V^2}{v^2} \left[\frac{u-t}{s-M_V^2+iM_V\Gamma_V} + \frac{u-s}{t-M_V^2+iM_V\Gamma_V} \right] \quad (3.9)$$

$$T(Z_L^0 Z_L^0 \rightarrow W_L^+ W_L^-) = T(W_L^+ W_L^- \rightarrow Z_L^0 Z_L^0) = \left(1 - \frac{3}{4}\alpha\right) \left(\frac{s}{v^2}\right) + \frac{\alpha}{4} \frac{M_V^2}{v^2} \left[\frac{-s+u}{t-M_V^2+iM_V\Gamma_V} + \frac{-s+t}{u-M_V^2+iM_V\Gamma_V} \right] \quad (3.10)$$

$$T(W_L^+ Z_L^0 \rightarrow W_L^+ Z_L^0) = T(W_L^- Z_L^0 \rightarrow W_L^- Z_L^0) = \left(1 - \frac{3}{4}\alpha\right) \left(\frac{t}{v^2}\right) + \frac{\alpha}{4} \frac{M_V^2}{v^2} \left[\frac{-t+u}{s-M_V^2+iM_V\Gamma_V} + \frac{-t+s}{u-M_V^2+iM_V\Gamma_V} \right] \quad (3.11)$$

$$T(W_L^+ W_L^+ \rightarrow W_L^+ W_L^+) = T(W_L^- W_L^- \rightarrow W_L^- W_L^-) = \left(1 - \frac{3}{4}\alpha\right) \left(\frac{-s}{v^2}\right) + \frac{\alpha}{4} \frac{M_V^2}{v^2} \left[\frac{s-u}{t-M_V^2+iM_V\Gamma_V} + \frac{s-t}{u-M_V^2+iM_V\Gamma_V} \right] \quad (3.12)$$

where $v^2 = (\sqrt{2}G_F)^{-1}$, and α is the parameter appearing in the lagrangian (2.2) and related to the V mass by (2.5) and (2.6). Their low energy limits can be checked to satisfy the well-known low energy theorems [12]. Consistently with the use of the equivalence theorem, in eqs. (3.9)-(3.12) the kinematical variables refer to the massless case and the width of V is given by

$$\Gamma_V = \frac{G_F^2}{24\pi} \frac{M_V^5}{g'^2} \quad (3.13)$$

which is the limit of eqs. (3.3) and (3.4) as $M_V \gg M_W, M_Z$. The above amplitudes do not include factors for identical particles. The differential cross section is given by

$$\frac{d\sigma}{d\cos\theta} = \frac{|T(s, t)|^2}{32\pi s} \quad (3.14)$$

s being the invariant mass of the produced W/Z pair. As anticipated such cross-section must be convoluted with the luminosities of the W/Z pair in the quarks and with the structure functions of the quarks inside the proton ^{*}.

^{*} Explicit expressions for the luminosities of the gauge vector bosons in the partons can be found in the first two papers of ref. [9]

4. DISCUSSION OF THE RESULTS

In hadronic collisions the $pp \rightarrow W^\pm Z + X$ reaction appears to be the most interesting one in the framework of the BESS model. The process $pp \rightarrow W^+ W^- + X$ is expected to suffer from a very severe background coming from $pp \rightarrow t\bar{t} + X$, with t and $\bar{t}$ both decaying into W , which should be the dominant mode for $m_{t\bar{t}} > M_W$. Final leptonic configurations from $t\bar{t}$ production might also simulate configurations from $W^\pm Z$, but the Z mass reconstruction should protect from such a background. The ZZ mode has not been considered because it does not proceed via an s -channel contribution in BESS.

Comparing the two channels $W^+ Z$ and $W^- Z$, we find that $W^- Z$ is roughly one half of the $W^+ Z$. Finally we remark that the final states observed at LHC and SSC will be demanded to contain leptons. Our results will be given in terms of numbers of produced $W^\pm Z$ pairs. For both bosons decaying leptonically one has to multiply by the branching factor $B(Z \rightarrow \ell^+ \ell^-) \cdot B(W^\pm \rightarrow \ell^\pm \nu_\ell) \approx 1.5\%$, for $(\ell = e, \mu)$.

The relevant backgrounds are the standard model production of $W^\pm Z$ through quark-antiquark annihilation [13] and $\gamma W^\pm$ fusion [14]. In our calculation we have made use of the DFLM structure functions [15], for $\Lambda_{QCD} = 260$ MeV. We have also run the computer programs by using the EHLQ1 structure functions [16] obtaining very similar results (actually the DFLM structure functions give a number of events which is about 6-8% lower than for EHLQ1). In the case of the fusion process, we have used a value of Q^2 inside the structure functions equal to the square of the invariant mass of the produced gauge boson pair. The K-factor coming from soft gluon resummation is not known for all the processes considered here, and we have decided not to introduce it. As a consequence the number of events we have evaluated is probably underestimated by about 20-30% (in fact, where the K-factor is known, as in the case of the V -production through $q\bar{q}$ [17], it has a value of about 1.3).

Our results were obtained through a Montecarlo simulation which allowed to study the details of the various final state distributions. They are summarized in Tables 1-4.

1. INTRODUCTION

In this note we shall examine the possibilities of colliders with the features of LHC [1] and SSC [2] to explore a possible strong sector responsible for electroweak symmetry breaking. Our analysis will be carried out within the BESS model (BESS standing for Breaking Electroweak Symmetry Strongly) [3]. The BESS model is at the same time very simple and it hopefully contains the most relevant elements of a possible strong electroweak breaking. The model has no Higgs particle. In addition to W and Z it contains a triplet of new massive vector bosons V . In BESS the electroweak symmetry breaking is described in a non-linear way. A local "hidden" $SU(2)$ symmetry is implicit in the description and the bosons V are indeed the associated gauge bosons. It is explicitly assumed that they constitute effective dynamical degrees of freedom. The bosons V mix with W and Z . The existing data of CDF/UA2 [4] and of LEP [5] already imply certain restrictions on BESS parameters. To remain on the safe side, we shall take into account not only these restrictions, but also possible stronger restrictions from future LEP data, assuming no deviations will be observed from the standard model within the foreseen experimental precision [6].

2. THE BESS MODEL

The vector resonances of the BESS model are bound states of a strongly interacting sector. In this sense they are similar to ordinary ρ vector mesons, or to the techni- ρ particle of technicolor theories [7]. Due to their composite nature, the V particles are then expected to mix to the photon and to the W and Z vector bosons. From this, a non trivial behaviour under the electromagnetic gauge group $U(1)_{em}$ is expected (see ref. [8]). Using this fact and the requirement that the electroweak ρ -parameter be equal to 1 at tree level, one can easily construct the most general mixing term of the V -particles with the ordinary vector bosons. By defining

$$\mathcal{V}_\mu = \sum_{i=1}^3 ig'' \frac{\tau_i}{2} \tilde{V}_\mu^i, \quad \mathcal{W}_\mu = \sum_{i=1}^3 ig' \frac{\tau_i}{2} \tilde{W}_\mu^i, \quad \tilde{B}_\mu = ig' \frac{\tau_3}{2} \tilde{B}_\mu \quad (2.1)$$

one has

$$\mathcal{L}_M = -\frac{v^2}{4} [\text{tr}(\mathcal{W} - \mathcal{B})^2 + \alpha \text{tr}(\mathcal{W} + \mathcal{B} - 2\mathcal{V})^2] \quad (2.2)$$

where v and α are free parameters. The first term is nothing but the usual mass term for the Weinberg-Salam fields, whereas the second one is the only mixing term compatible with the properties we have just discussed. As far as the interactions with fermions are concerned, one must specify the current $\tilde{J}$ to which the new triplet of states $\tilde{V}$ couples. If we assume $\tilde{J} = \tilde{J}_L$ (see ref. [3] for a more general discussion), the $U(1)_{em}$ gauge invariance requires the interaction lagrangian to be

$$\mathcal{L} = \frac{g}{1+b} \tilde{W} \cdot \tilde{J}_L + g' \tilde{B} J_Y + \frac{1}{2} \frac{b}{1+b} g'' \tilde{V} \cdot \tilde{J}_L \quad (2.3)$$

The parameter b specifies a possible direct coupling of the fermions to the new gauge vector bosons. However, it must be stressed that also when $b = 0$ a coupling of the physical V -particles to fermions is present due to their mixing with the physical Weinberg-Salam vector bosons.

The mass matrix in the neutral sector can be diagonalized by the following transformation

$$\begin{pmatrix} A \\ Z^0 \\ V^0 \end{pmatrix} = \begin{pmatrix} 0 & \cos \psi & \sin \psi \\ \cos \xi & \sin \xi \sin \psi & -\sin \xi \cos \psi \\ \sin \xi & -\cos \xi \sin \psi & \cos \xi \cos \psi \end{pmatrix} \begin{pmatrix} g/G & -g'/G & 0 \\ g'/G & g/G & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \tilde{W}_3 \\ \tilde{B} \\ \tilde{V}_3 \end{pmatrix} \quad (2.4)$$

where $G = (g^2 + g'^2)^{1/2}$. The mixing angles and masses will be evaluated for $g'' \gg g$ (the limit $g'' \rightarrow \infty$ corresponds to decoupled V particles). We have

$$\xi = -\frac{g^2 - g'^2}{g''G} \frac{1}{1 - (\frac{M_W}{M_V})^2 \frac{1}{\cos^2 \theta}}, \quad \psi = \frac{2gg'}{g''G}, \quad \sin \theta = \frac{g'}{G} \quad (2.5)$$

$$M_A^2 = 0, \quad M_Z^2 = \frac{1}{4} v^2 (g^2 + g'^2) \left[1 - \frac{(g^2 - g'^2)^2}{G^2 g''^2} \frac{1}{1 - (\frac{M_W}{M_V})^2 \frac{1}{\cos^2 \theta}} \right]$$

$$M_{V^0}^2 = \frac{1}{4} v^2 \alpha g''^2$$

In the same limit the mixing angle and the masses in the charged sector are given by

$$\varphi = -\frac{g}{g''} \frac{1}{1 - \left(\frac{M_W}{M_V}\right)^2}$$

$$M_W^2 = \frac{1}{4} v^2 g^2 \left(1 - \frac{g^2}{g'^2} \frac{1}{1 - \left(\frac{M_W}{M_V}\right)^2}\right), \quad M_{V\pm}^2 = \frac{1}{4} v^2 \alpha g'^2 \quad (2.6)$$

In these formulas we have included the order $(g/g'')^2$ with $(\bar{M}_W/M_V)^2$ fixed, where $\bar{M}_W$ can be taken as the limiting value of M_W for $g'' \rightarrow \infty$. The eqs. (2.5) and (2.6) express the degeneracy of the V particles at the lowest order in g/g'' . Also we can replace the parameter α with the physical mass of the V particle. One can derive the couplings of the mass eigenstates to the fermions. In the neutral sector one has

$$Z_\mu^0 (A T_L^3 + B Q_{em}) + V_\mu^0 (C T_L^3 + D Q_{em}) + e Q_{em} A_\mu \quad (2.7)$$

while in the charged sector

$$(h_W W_\mu^i + h_V V_\mu^i) T_L^i, \quad i = 1, 2 \quad (2.8)$$

A complete list of the couplings can be found in ref. [3]. Here we will give only the couplings of the V -particle

$$h_V = \frac{1}{1+b} \left(g \sin \varphi + \frac{1}{2} g'' b \cos \varphi \right) \quad (2.9)$$

$$C = \frac{G}{1+b} \sin \xi \left[1 + b \frac{g'^2}{G^2} \left(1 + \frac{g}{g'} \cot \xi \right) \right] \quad (2.10)$$

$$D = -\frac{g'^2}{G} \sin \xi \left(1 + \frac{g}{g'} \cot \xi \sin \psi \right) \quad (2.11)$$

The parameter space of the model is given by (g, g', v, M_V, g'', b) . We trade off (g, g', v) for (α_{em}, G_F, M_Z) and therefore we remain with (M_V, g'', b) . In turn, the parameter v can be reexpressed in terms of M_W , and the expressions of (g, g', M_W) in terms of (α_{em}, G_F, M_Z) can be found in ref. [6]. In order to get the physical region for the parameters (M_V, g'', b) we have considered the envelope of the 90% C.L. curves obtained from the

observables related to the Z -line shape measured at LEP1, and from the ratio M_W/M_Z measured at CDF and UA2. The most restrictive observables turn out to be Γ_{had} , Γ_Z and M_W/M_Z . The experimental values we have used come from the LEP1 combined data [5], $\Gamma_{had}(MeV) = 1755 \pm 21$, $\Gamma_Z(MeV) = 2498 \pm 20$, and from the CDF and UA2 combined data [4], $M_W/M_Z = 0.880 \pm 0.004$. As an example we give in Fig. 1 the allowed region in the plane $(b, g/g'')$ for $M_V = 1500$ GeV. We have taken $m_{top} = 150$ GeV and $\alpha_s = 0.12$. For increasing m_{top} and/or M_V the area of the allowed region has only a small increase. Notice that the origin of the plane (standard model limit) lies inside the allowed region.

3. GAUGE BOSON PAIR PRODUCTION IN THE BESS MODEL

At hadron colliders, as far as detection of a signal from a strongly interacting symmetry breaking sector is concerned, vector boson pair production is particularly relevant. In the BESS model there are two main mechanisms which compete for the production of a pair of ordinary gauge vector bosons at a pp collider: $q\bar{q}$ annihilation, and WW (WZ, ZZ) fusion.

In the first mechanism a quark-antiquark pair annihilates into a V vector boson, which in turn decays into a pair of ordinary gauge vector bosons. We stress the fact that this process is always operating in BESS independently of the existence of a direct coupling of V to fermions. In fact, the mixing of V with W and Z always induces a well determined coupling of order g/g'' between the mass eigenstates V and the fermions, even if the original, unmixed, states $\tilde{V}$ were not coupled to matter. We further observe that, at least in the range of masses for V we are interested in (few TeVs), the decay of V 's is dominated by the WW, WZ channels, due to the large coupling, (of order $\alpha g''$), for $V^0 W_L^+ W_L^-$ and $V^\pm W_L^\mp Z_L$ (L stands for the longitudinal components). On this basis we expect (and we shall verify quantitatively) that, even in the case $b = 0$, the $q\bar{q}$ mechanism remains efficient in producing a W/Z pair.

We have evaluated the $q\bar{q}$ contribution in the context of the parton model along the lines described in ref. [6]. Here for convenience we recall some useful expressions.

Tables 1 and 2 refer to the process W^+Z at LHC and at SSC respectively. The same is reported in Tables 3 and 4 for the process W^-Z . The assumed energy parameters for LHC and SSC are 16 TeV and 40 TeV respectively. The luminosities we have assumed are $10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$ for LHC, and $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$ for SSC, and all the numbers refer to 1 effective year = 10^7 sec of running of the colliders. In the Tables we have considered a very extensive choice of parameters. A first cut on the rapidity $y_{W,Z}$ of the final W and Z , $|y_{W,Z}| \leq 2.5$ was applied to all cases. Then we applied a lower cut in M_{WZ} (the invariant mass of the WZ -pair), approximately corresponding to the beginning of the resonance at the left of the peak. An upper cut has been fixed once for all at $M_{WZ} = 3 \text{ TeV}$, where in all the practical cases considered here the resonance tail is already extinguished. Finally a cut in p_T (the transverse momentum of the Z) has been obtained from the requirement of maximizing the statistical significance of the signal, $S/(S+B)^{1/2}$, S being the signal and B the background, which in our case includes the continuum standard WZ -pair production both from $q\bar{q}$ annihilation and γW fusion.

For a better understanding of the results we have exhibited in Tables 1 and 2 the different contributions, fusion and $q\bar{q}$ annihilation, to the signal. The ratio of the two contributions is similar in W^-Z . We have also given the number of events from the background and the total number of events. The range of M_V values we have explored runs from 1 TeV up to 2.5 TeV. The last value can be probably considered as a limiting value for discovery at both machines. About this point notice that in order to have a decent number of events at LHC (say about 10 leptonic events/year) for $M_V = 2500 \text{ GeV}$, one would need to run LHC at a luminosity of about $(1.5 - 2.3) \times 10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$ at least (which is below the projected peak-luminosity), for $b \approx 0$. Considering also the events coming from $pp \rightarrow W^-Z + X$, one would need only to increase the luminosity up to $1.5 \times 10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$.

The values chosen for g'' and b are well inside the region allowed from LEP1, and CDF/UA2 data (see Fig. 1). Furthermore (see ref. [6]) they will be inside the allowed region also after precision measurements of forward-backward asymmetry and of

tau-polarization will be made at LEP1, if we make the hypothesis that no deviation from the SM is observed within the expected experimental precision. For instance, from ref. [6] in the more restrictive case of $M_V = 250 \text{ GeV}$ one gets $g/g'' < 0.1$ at $b = 0$ both from A_{FB} and from A_+ . For the values of g'' that we have considered, one has a width for the V (see eq. (3.13)) which varies between 11 GeV and 44 GeV for $M_V = 1000 \text{ GeV}$, 84 GeV and 335 GeV for $M_V = 1500 \text{ GeV}$, whereas we have $\Gamma_V = 353 \text{ GeV}$ for $M_V = 2000 \text{ GeV}$ (notice that this case corresponds almost exactly to a techni- ρ obtained by scaling from QCD), and $\Gamma_V = 455 \text{ GeV}$ for $M_V = 2500 \text{ GeV}$. For smaller g'' the resonance becomes broader. In the computation of Γ_V we have ignored the contribution from the fermionic channels because it turns out to be completely negligible. In the Tables we have considered also values of b of the order $(g/g'')^2$ which should be considered as natural values if one thinks of b as generated by radiative corrections [3]. Notice that the $b = 0$ case corresponds, in practice, to the most pessimistic situation, since allowing for a direct coupling ($b < 0$) a much larger signal from production via $q\bar{q}$ annihilation is predicted. Direct couplings of techni- ρ to fermions emerge in extended technicolor theories (for calculations at SSC energies see ref. [18]).

From the Tables we see that the fusion signal increases going from LHC to SSC, whereas the signal from $q\bar{q}$ decreases (of course the decreasing in the luminosity by a factor 10 has to be considered). This is expected on the basis of the different ratio of LHC and SSC values for $q\bar{q}$ and $W_L W_L$ luminosities [19]. In particular, for $b = 0$, at LHC the $q\bar{q}$ annihilation dominates for low V masses up to $M_V = 2 \text{ TeV}$, whereas at SSC the two mechanisms are already comparable at $M_V = 1500 \text{ GeV}$. However for $b < 0$ the situation changes and, increasing $|b|$, the $q\bar{q}$ annihilation will again overcome the fusion contribution.

We have also made an extensive study of the p_T and M_{WZ} distributions. Here we give only an example in Figs. 2-5 of the two distributions both at LHC (Figs. 2 and 3) and SSC (Figs. 4 and 5) in the case of $M_V = 1500 \text{ GeV}$, $g'' = 13$ and $b = 0$. The figures show that, even after multiplying by the branching factor corresponding to selecting only leptonic decays of W and Z , one is left with a statistically significant signal having quite

well distinguished features both in M_{WZ} and $(p_T)_Z$ distributions. The vertical lines in the graphs indicate where the lower cuts in M_{WZ} and p_T have been put for the illustrated cases (see corresponding entries in Tables 1-4). We emphasize that the statistical significance of the signal versus the background is very good in practically all the cases we have considered in this note.

5. CONCLUSIONS

We studied WZ pair production at LHC and SSC within the BESS model, which is simple and probably contains the dominant features of a strong electroweak breaking. To extrapolate to possible future scenarios, we have restricted the BESS parameters below the expected limitations from future LEP data, assuming these come out not to deviate, within the expected precision, from the standard model prediction. The new conclusion of our work is the generally dominant role, particularly at LHC, of production through $q\bar{q}$ annihilation, as compared to the extensively studied boson pair fusion mechanism. The increase of gauge boson pairs, resulting from the $q\bar{q}$ mechanism, as expected in the BESS model, together with its distinguished features in the p_T and invariant mass distributions, suggests an important role of LHC and SSC in the exploration of a possible strong electroweak symmetry breaking sector.

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FIGURE CAPTIONS

Fig. 1 Allowed region (90% C.L.) in the $(b, g/g'')$ plane for $M_V = 1500 \text{ GeV}$, $m_{top} = 150 \text{ GeV}$ and $\alpha_s = 0.12$, from M_W/M_Z (continuous line), Γ_Z (dashed line) and Γ_{had} (dashed-dotted line). The origin (corresponding to the standard model limit) is inside the allowed region.

Fig. 2 Invariant mass distribution of the W^+Z pairs produced per year at LHC for $M_V = 1500 \text{ GeV}$, $g/g'' = 13$ and $b = 0$, with a luminosity of $10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$. The applied cuts are: $|y_{W,Z}| < 2.5$, $(p_T)_Z > 480 \text{ GeV}$ and $M_{WZ} > 1250 \text{ GeV}$. The lower, intermediate and higher histograms refer to the background, background plus fusion signal and background plus fusion signal plus $q\bar{q}$ annihilation signal, respectively.

Fig. 3 $(p_T)_Z$ distribution from the W^+Z pairs produced per year at LHC for $M_V = 1500 \text{ GeV}$, $g/g'' = 13$ and $b = 0$, for a luminosity of $10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$. The applied cuts are: $|y_{W,Z}| < 2.5$, $(p_T)_Z > 480 \text{ GeV}$ and $M_{WZ} > 1250 \text{ GeV}$. The lower, intermediate and higher histograms refer to the background, background plus fusion signal and background plus fusion signal plus $q\bar{q}$ annihilation signal, respectively.

Fig. 4 Invariant mass distribution of the W^+Z pairs produced per year at SSC for $M_V = 1500 \text{ GeV}$, $g/g'' = 13$ and $b = 0$, for a luminosity of $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$. The applied cuts are: $|y_{W,Z}| < 2.5$, $(p_T)_Z > 360 \text{ GeV}$ and $M_{WZ} > 1250 \text{ GeV}$. The lower, intermediate and higher histograms refer to the background, background plus fusion signal and background plus fusion signal plus $q\bar{q}$ annihilation signal, respectively.

Fig. 5 $(p_T)_Z$ distribution from the W^+Z pairs produced per year at SSC for $M_V = 1500 \text{ GeV}$, $g/g'' = 13$ and $b = 0$, for a luminosity of $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$. The applied cuts are: $|y_{W,Z}| < 2.5$, $(p_T)_Z > 360 \text{ GeV}$ and $M_{WZ} > 1250 \text{ GeV}$. The lower, intermediate and higher histograms refer to the background, background plus fusion signal and background plus fusion signal plus $q\bar{q}$ annihilation signal, respectively.

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Table 1. Events per year in $pp \rightarrow W^+ Z + X$ at LHC from BESS model

(M_V, g'', b)	$(p_T)_{cut}^{min}(GeV)$	$(M_{WZ})_{cut}^{min}(GeV)$	Fusion	$q\bar{q}$	Signal	Backg.	Total
(1000,6.5,0)	240	800	2579	29600	32179	6695	38874
(1000,13,0)	300	850	788	7158	7946	4107	12053
(1500,6.5,0)	420	1000	1179	5126	6305	1393	7698
(1500,13,0)	420	1250	419	1357	1776	896	2672
(2000,13,0)	600	1600	168	310	478	184	662
(2000,13,-0.002)	600	1400	198	621	819	258	1077
(2000,13,-0.01)	540	1400	236	2930	3166	365	3531
(2500,20,0)	600	1400	151	40	191	258	449
(2500,20,-0.001)	720	1500	99	84	183	103	286
(2500,20,-0.01)	600	1800	102	1287	1389	135	1524

Table 2. Events per year in $pp \rightarrow W^+ Z + X$ at SSC from BESS model

(M_V, g'', b)	$(p_T)_{cut}^{min}(GeV)$	$(M_{WZ})_{cut}^{min}(GeV)$	Fusion	$q\bar{q}$	Signal	Backg.	Total
(1000,6.5,0)	240	800	2159	10003	12162	2665	14827
(1000,13,0)	300	850	792	2367	3159	1714	4874
(1500,6.5,0)	300	1000	2070	2705	4775	1286	6061
(1500,13,0)	360	1250	641	650	1291	623	1914
(2000,13,0)	420	1600	466	219	685	272	957
(2000,13,-0.002)	420	1400	542	436	978	373	1351
(2000,13,-0.01)	420	1400	542	2011	2553	373	2926
(2500,20,0)	480	1500	335	35	370	257	627
(2500,20,-0.001)	480	1500	335	76	411	257	668
(2500,20,-0.01)	540	1800	250	1132	1382	127	1509

Table 3. Events per year in $pp \rightarrow W^- Z + X$ at LHC from BESS model

(M_V, g'', b)	$(p_T)_{\text{cut}}^{\text{min}} (\text{GeV})$	$(M_{WZ})_{\text{cut}}^{\text{min}} (\text{GeV})$	Signal	Backg.	Total
(1000,6.5,0)	240	800	16973	3604	20577
(1000,13,0)	300	850	4195	2147	6342
(1500,6.5,0)	420	1000	2920	709	3629
(1500,13,0)	480	1250	776	312	1088
(2000,13,0)	480	1600	234	154	388
(2000,13,-0.002)	600	1400	351	127	478
(2000,13,-0.01)	480	1400	1395	218	1613
(2500,20,0)	660	1400	68	83	151
(2500,20,-0.001)	660	1500	83	74	157
(2500,20,-0.01)	660	1800	548	36	584

Table 4. Events per year in $pp \rightarrow W^- Z + X$ at SSC from BESS model

(M_V, g'', b)	$(p_T)_{\text{cut}}^{\text{min}} (\text{GeV})$	$(M_{WZ})_{\text{cut}}^{\text{min}} (\text{GeV})$	Signal	Backg.	Total
(1000,6.5,0)	240	800	8111	1795	9906
(1000,13,0)	300	850	2090	1129	3219
(1500,6.5,0)	300	1000	2853	825	3678
(1500,13,0)	300	1250	815	484	1299
(2000,13,0)	360	1600	405	201	606
(2000,13,-0.002)	420	1400	550	231	781
(2000,13,-0.01)	420	1400	1432	231	1663
(2500,20,0)	480	1500	208	155	363
(2500,20,-0.001)	480	1500	230	155	385
(2500,20,-0.01)	600	1800	724	64	788

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5