WZ PRODUCTION FROM THE BESS MODEL AT THE LHC AND SSC COLLIDERS

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ABSTRACT

We study WZ 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. The fusion production mechanism via longitudinal WZ scattering is compared with the $q\bar{q}$ annihilation mechanism going through vector resonances. Detailed studies of background and statistical significance of signal versus background are made both at LHC and SSC. The new conclusion of our work is the generally dominant role, particularly at LHC, of production through $q\bar{q}$ annihilation. The increase of gauge boson pairs, 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.

1. INTRODUCTION

One of the most exciting opportunity which is offered by the next generation of hadronic colliders is to find the mechanism responsible for the symmetry breaking of the electroweak (EW) interaction. The last years have seen the accumulation of a large amount of data confirming more and more the standard model (SM). Despite of this enormous progress, some sectors of the SM still remain unproved and, in particular, no direct evidence of the Higgs sector has been seen. With the LHC [1] (or SSC [2]) machines hopefully it will be possible either to find the Higgs particle with a mass below 1 TeV or some manifestation of a strongly interacting system, to which the longitudinal W/Z's belong, in the TeV energy regime [3]. Here we will assume that the mechanism responsible for the EW symmetry breaking is based on a strongly interacting sector. We have tried to single out the major feature of such a scenario by formulating a scheme which, reproducing them, remains at low energy as close as possible to the SM picture. Such a scheme is the so called BESS model (BESS standing for Breaking Electroweak Symmetry Strongly) [4]. The model has no Higgs particle. In addition to W and Z it contains a triplet of new massive vector bosons V which are assumed to be the main consequence of having a strong interacting sector (one can naively think to the analogy with the pion system - possessing the same global symmetry of the scalar sector in the SM - and the corresponding ρ vector mesons). In the BESS model the EW 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 the standard gauge bosons and due to this mixing they are unavoidably coupled to the known fermions. In Sect. 2 we briefly recall the main properties of the V bosons in the BESS model. Among the various features of the model, the relevant one for the present computation is the following: the scattering of the longitudinal W/Z's is dominated by the exchange of the V's which are strongly coupled to the external states. At hadron colliders possible signals of the BESS model will be visible in the gauge boson pair production (see Sect. 3). The most promising channel is $pp \to W^{\pm}Z + X \to l^{\pm}l^{+}l^{-} + X$ and there are two mechanisms which compete: $q\bar{q}$ annihilation and WZ fusion. The results are discussed in Sect. 4.

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 [5]. 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 [6]. 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 diagonalizing the mass matrices in the charged and in the neutral sector one gets the expressions for the mixing angles and for the mass eigenstates [4,7]. For instance, in the charged sector, by calling g'' the V gauge coupling and g the standard $SU(2)_L$ one, we find that for $g'' \gg g$ (the limit $g'' \to \infty$ corresponds to decoupled V particles) the mixing angle φ between $W^\pm$ and $V^\pm$ is of the order of g/g'' and the W mass gets a correction of the order of $(g/g'')^2$. One also finds that, at the zeroth order in the weak couplings, the V mesons are degenerate in mass and $M_V^2 = v^2 \alpha g''^2/4$ where v and α are free parameters.

As far as the interactions with fermions are concerned, one must specify the current $\vec{J}$ to which the new triplet of states $\vec{V}$ couples. If we assume $\vec{J} = \vec{J}_L$ (see ref. [4] for a more general discussion), the $U(1)_{em}$ gauge invariance fixes the form of the interaction lagrangian. The complete list of couplings to fermions can be found in refs. [4,7]. Here we will only be concerned with the couplings to the charged currents. For example, the coupling of $V^\pm$ to $J_L^\mp$ is given by $h_V = (g \sin\varphi + (g''/2) b \cos\varphi)/(1+b)$. 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 parameter space of the model is given by (g, g', v, M_V, g'', b) with g' the $U(1)_Y$ gauge coupling. 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 rewritten 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. [7]. 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. For example the allowed region in the plane $(b, g/g'')$ for $M_V = 1500\ GeV$ is given in ref. [8].

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: the WW (WZ, ZZ) fusion and the $q\bar{q}$ annihilation [9]. The first one 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 [10]. The relevance of this mechanism is then related to the strength of the fusion process. In the standard model 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 SM [3,4] 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 $\alpha g''$) at each vertex. If some 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 the BESS model, 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/E) ($M = M_W$ or M_Z). The full expressions for the corresponding amplitudes can be found in ref. [9].

Another mechanism to produce W/Z pairs is the quark-antiquark annihilation into a V vector boson, which in turn decays into a pair of ordinary gauge vector bosons. In fact, 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). We have evaluated the $q\bar{q}$ contribution in the context of the parton model along the lines described in ref. [7], and the relevant expressions are given in ref. [9]. We stress 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, Z and γ always induces a coupling between the mass eigenstates V and the fermions, even if the original, unmixed, states were not coupled to matter. 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.

4. DISCUSSION OF THE RESULTS

In hadronic collisions the $pp \to W^\pm Z + X$ reaction appears to be the most promising one in the framework of the BESS model. In the ZZ does not proceed via an s-channel contribution in BESS and the W^+W^- mode is expected to suffer from a very severe $t\bar{t}$ background (if $m_{top} > M_W$). Final leptonic configurations from $t\bar{t}$ production might also simulate configurations from $W^\pm Z$, but the Z mass reconstruction should protect the signal from such a background [12]. The WZ pair is expected to be revealed more easily in the pure leptonic mode. Our results will be given in the Table 1 in terms of numbers of produced $W^\pm Z$ pairs. For both bosons decaying leptonically one has to multiply by the branching factor $B(Z \to \ell^+\ell^-) \cdot B(W^\pm \to \ell^\pm \bar{\nu}_\ell) \approx 1.5\%$, for ($\ell = e, \mu$). The assumed energy parameters for LHC and SSC are 16 TeV and 40 TeV respectively. The luminosities we have assumed are 10^{34} cm^{-2} sec^{-1} for LHC, and 10^{33} cm^{-2} sec^{-1} for SSC, and all the numbers refer to one effective year = 10^7 sec of running of the colliders. Use has been made of a Montecarlo simulation to study the details of the p_T (the transverse momentum of the Z) and of the M_{WZ} (the invariant mass of the WZ-pair) distributions. In our calculation we have used the DFLM structure functions [13], for $\Lambda_{QCD} = 260$ MeV. We have also run the computer programs by using the EHLQ1 structure functions [14] obtaining very similar results (actually the DFLM structure functions give a number of events which is about 6-8% lower than for EHLQ1). The value of Q^2 inside the structure functions for the fusion process is taken to be 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%. A cut on the rapidity of the final W and Z, $|y_{W,Z}| \leq 2.5$, was applied to all cases.

The relevant backgrounds included in this calculation are: the standard model production of $W^{\pm}Z$ through quark-antiquark annihilation [15], $\gamma W^{\pm}$ fusion [16], and $W_T^{\pm}Z_T$ fusion. Their relative contributions with respect to the total one, for $M_{WZ} > 0.5\ TeV$ and $p_T > 100\ GeV$, are the following: 66%, 17 %, 17 % at LHC and 45%, 24%, 31% at SSC.

In order to optimize the statistical significance of the signal we have applied a lower cut in M_{WZ}, approximately corresponding to the beginning of the resonance at the left of the peak. An upper cut has been fixed $M_{WZ} = 3\ TeV$, where in all the practical cases considered here, the resonance tail is already extinguished. Finally a cut in p_T has been obtained from the requirement of maximizing $S/(S+B)^{1/2}$, S being the signal and B the background. The results are summarized in Table 1 for the process $W^+Z + W^-Z$ (the W^-Z channel is roughly one half of the W^+Z one) at LHC and at SSC. We have considered an extensive choice of the BESS parameters which are well inside the region allowed from LEP1, and CDF/UA2 data [8]. The range of M_V values we have explored runs from 1 TeV up to 2.5 TeV. The expression for the width of the V particle (in the limit $M_V \gg M_W, M_Z$ and ignoring the fermionic decays which turn out to be completely negligible) is $\Gamma_V = (G_F^2/24\pi)(M_V^5/g''^2)$. Notice that the case $M_V = 2\ TeV$, $\Gamma_V = 353\ GeV$ corresponds almost exactly to a techni-ρ obtained by scaling from QCD [5]. For smaller g'' the resonance becomes broader. In the third and fourth columns of the Table 1 we have reported the optimal lower cuts performed in the various cases.

(M_V, g'', b)		$(p_T)_c$	$(M_{WZ})_c$	Fusion	$q\bar{q}$	Signal	Backgr.	Total
(1000,13,0)	LHC	360	850	858	10089	10947	4786	15733
Γ_V=11	SSC	300	800	1280	3969	5249	3963	9212
(1500,13,0)	LHC	480	1250	498	1929	2427	1121	3548
Γ_V=84	SSC	420	1250	895	1030	1925	1063	2988
(2000,13,.02)	LHC	540	1400	339	3863	4202	608	4810
Γ_V=353	SSC	480	1600	671	2814	3485	462	3947
(2000,13,0)	LHC	600	1600	241	443	684	310	994
Γ_V=353	SSC	480	1600	671	339	1010	462	1472
(2000,13,-.01)	LHC	540	1400	339	4186	4525	608	5133
Γ_V=353	SSC	480	1400	772	3119	3891	636	4527
(2500,20,0)	LHC	600	1400	212	57	269	430	699
Γ_V=455	SSC	540	1500	486	54	540	428	968
(2500,20,-.01)	LHC	600	1800	141	1807	1498	211	2159
Γ_V=455	SSC	600	1800	360	1721	2081	211	2292

Table 1 - *Events per year in* $pp \to (W^+Z + W^-Z) + X$ *at LHC and SSC from the BESS model. Masses, widths and cuts are expressed in GeV.*

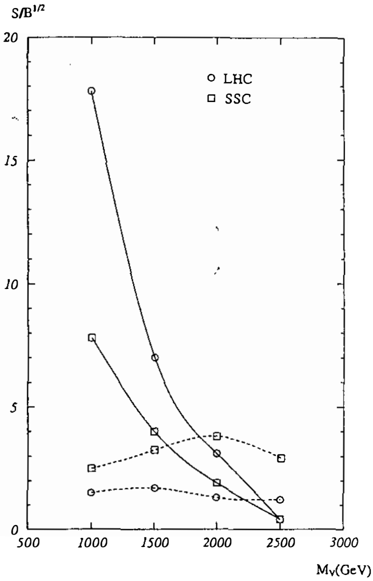

Fig. 1 - *Statistical significance of the signal in leptonic events as a function of M_V for $b = 0$. The two contributions are separated: fusion (dashed lines) and $q\bar{q}$ annihilation (solid lines).*

For a better understanding of the results, we have separately exhibited in Table 1 the fusion and $q\bar{q}$ annihilation contributions to the signal. We have also given the number of events from the background and the total number of events. Notice that the $b = 0$ case corresponds, in practice, to the most pessimistic situation, since in general allowing for a direct coupling ($b \neq 0$) 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. [17]). From the Table 1 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). In particular, for $b = 0$, at LHC the $q\bar{q}$ annihilation dominates for low M_V up to $M_V = 2\ TeV$, whereas at SSC the two mechanisms are already comparable at $M_V = 1.5\ TeV$ (see Fig. 1).
However for $b \neq 0$ the situation changes and, increasing $|b|$, the $q\bar{q}$ annihilation will overcome again the fusion contribution. We see that, if we require more than 10 leptonic events/year and a good statistical significance (for example $S/\sqrt{B} > 3$), the discovery limit for $b = 0$ at SSC is $M_V \leq 2.5\ TeV$, while at LHC $M_V = 2\ TeV$ is the limiting value for discovery in the luminosity configuration considered. In fact it can be shown that in order to have more than 10 leptonic events/year for $M_V = 2.5\ TeV$ and $b = 0$ one have to run LHC at a luminosity of about $3.5 \times 10^{34}\ cm^{-2}\ sec^{-1}$ at least. About this point notice that in the present computation of the background, we have not distinguished in the polarizations of the final W and Z. Since the signal is almost totally given by $W_L Z_L$-pairs, one would get a better statistical significance of the signal (and perhaps push forward the discovery limit) by considering the background contribution only in the longitudinal channel [18]. This work is now in progress.

We have also made an extensive study of the $(p_T)_Z$ and M_{WZ} distributions. Here we give examples in Figs. 2, 3 of the two distributions both at LHC and SSC. 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 Table 1). Also the lower, intermediate and higher histograms

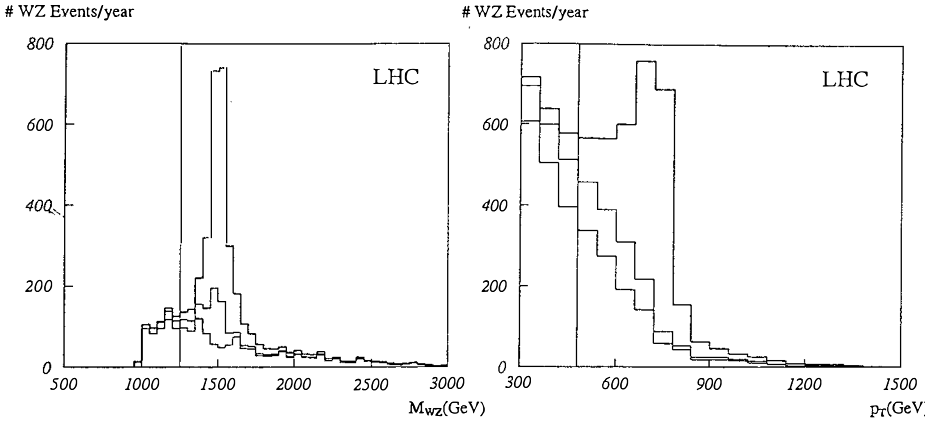

Fig. 2 - *Invariant mass and* $(p_T)_Z$ *distribution of the* $W^+Z + W^-Z$ *pairs produced per year at LHC for* $M_V = 1500$ GeV, $g'' = 13$ *and* $b = 0$.

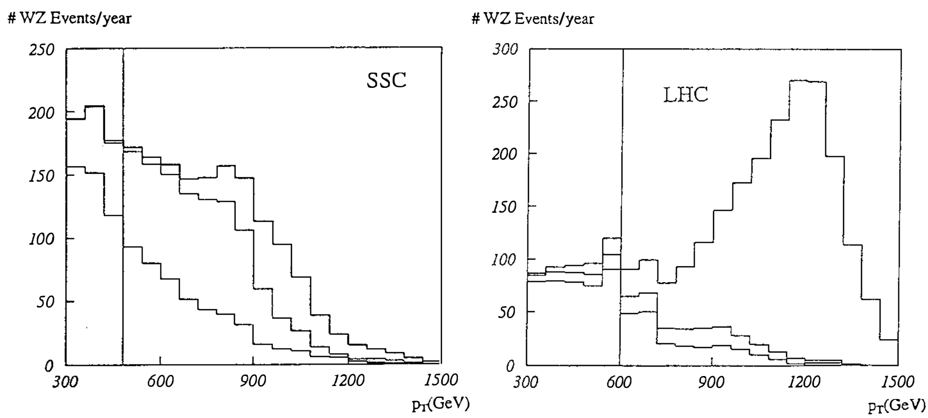

Fig. 3 - $(p_T)_Z$ *distributions of the* W^+Z+W^-Z *pairs produced per year for* $M_V = 2500$ GeV, $g'' = 20$ *at SSC for* $b = 0$ *(left-hand side) and at LHC for* $b = -0.01$ *(right-hand side).*

in the figures refer to the background, background plus fusion signal and background plus fusion signal plus $q\bar{q}$ annihilation signal, respectively. In Fig. 2 we have both the M_{WZ} and the p_T distributions for a V resonance with $M_V = 1.5$ TeV and $\Gamma_V = 84$ GeV at LHC. In Fig. 3 (left-hand side) is well visible how the fusion contribution to the signal makes a resonance of 2.5 TeV detectable at SSC. The large increase of the $q\bar{q}$-annihilation contribution to the signal obtainable even with a small value of b is clear in Fig. 3 (right-hand side). The figures shown are only some examples and we emphasize that the statistical significance of the signal versus the background is very good practically in all the cases we have considered in this note. 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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