CERN-TH.5813/90

$W^\pm Z^0$ SIGNALS FROM THE STRONGLY INTERACTING SYMMETRY BREAKING SECTOR

Antonio DOBADO¹

Maria J. HERRERO²

CERN, CH-1211 Geneva, Switzerland

and

Juan TERRON

Departamento de Fisica Teorica de la Universidad
Autonoma de Madrid, 28049 Madrid, Spain

ABSTRACT

We study the possibilities of unraveling the underlying dynamics of the symmetry breaking sector through the scattering of longitudinal weak bosons in pp collisions. $W^\pm Z^0$ channels are considered in the context of a general approach based on chiral perturbation theory, supplemented by a unitarization procedure. The channels considered here are the relevant ones for symmetry breaking sector dynamics such as technicolor, where a $I=J=1$ resonance appears in the spectrum. Direct WZ production from quark annihilation via ρ_{TC} -W mixing is also considered and compared with WZ production from the WZ fusion mechanism.

CERN-TH.5813/90
July 1990

¹On leave of absence from Departamento de Fisica Teorica de la Universidad Complutense de Madrid, 28040 Madrid, Spain

²On leave of absence from Departamento de Fisica Teorica de la Universidad Autonoma de Madrid, 28049 Madrid, Spain

1 Introduction

One of the main goals at the LHC and SSC is to bring some light into the nature of the symmetry breaking sector of the Standard Model (SBS). More than a decade ago it was established [1] that either the SBS is a weakly interacting system (with Higgs-like modes below 1 TeV) or it is a strongly interacting system (with just the longitudinal components of the weak bosons (LWB) being the light modes). Here we deal with the second possibility, the strongly interacting symmetry breaking sector (SISBS) that we will treat within the effective chiral Lagrangian approach. The relevance of using this approach as a tool to disentangle the dynamics governing the SBS was first pointed out in [2,3] and it was applied later in [4] to the study of the $Z^0 Z^0$ channel in the LHC and SSC. Here we apply it to the study of the $W^\pm Z^0$ channels.

The aim is to set up the typical signatures of the SISBS at the future supercolliders, LHC and SSC. One way of studying the dynamics that governs the SBS [5] is through the scattering of the LWB, that we compute by means of chiral perturbation theory ChPT [6]. This approach has the nice property of incorporating all what is known about the SBS.

In ChPT the LWB are considered to be the Goldstone bosons associated with the spontaneous symmetry breaking of an approximate global symmetry of the SBS, $G \rightarrow H$. Gauge invariance imposes the following conditions:

$$G \supset SU(2)_L \times U(1)_Y, \quad H \supset U(1)_{em} \quad (1)$$

We consider the experimental fact $\rho \cong 1$ [7] as the manifestation of an actual symmetry of the SBS, the $SU(2)$ custodial symmetry. Thus, we adopt the pattern $SU(2)_L \times SU(2)_R \rightarrow SU(2)_{L+R}$.

The degrees of freedom associated with the Goldstone bosons can be parametrized as $U(x) = \exp(i\omega^a(x)\sigma^a/v)$ with $v = 246\text{GeV}$ and σ^a being the Pauli matrices, so we can write down the most general Lagrangian compatible with the symmetries in terms of U . Using the first few terms of this Lagrangian (considered as an expansion in the number of derivatives) one can compute the amplitudes of LWB scattering at low energies (low compared to the energy scale that controls the chiral expansion, $4\pi v$). As we also work in the approximation that neglects the gauge couplings we have to restrict our predictions to large energies compared to the masses of the weak bosons. In particular we consider terms only up to order $O(p^4)$, that will enable us to distinguish between different underlying dynamics (the $O(p^2)$ results being the universal Low Energy Theorems).

It is well known that the amplitudes computed using ChPT verify unitarity only perturbatively. There is an energy scale beyond which unitarity is violated. This behaviour is improved when one includes $O(p^4)$ effects, however it is still $\sim 1.5\text{ TeV}$ [2] and one has to rely on some unitarization procedure. We have used here two unitarization methods: the Padé approximant method [8,9] and the K-matrix one [9,10].

2 Symmetry Breaking Sector Models

In [4] we considered two possible scenarios for the SISBS: the Standard Model with a heavy Higgs boson to one loop level (Higgs-like scenario) and a scenario based in copying

the low energy phenomenology of QCD with the LWB of the SISBS playing the role of the pions of QCD (QCD-like scenario). We concluded that the $Z^0 Z^0$ channel is the most efficient way to probe the SISBS for Higgs-like dynamics. Now we deal with the $W^\pm Z^0$ channels that one expects to be the most sensitive ones to probe the SISBS in the case of dynamics of $SU(N)$ gauge type. The reason is that for $SU(N)$ theories such as Technicolor, one expects the appearance of a vector resonance with $I=J=1$ (the techniparticle in technicolor theories) that can be interchanged in $W^\pm Z^0$ channels and therefore can contribute relevantly to these channels. The presence of this resonance is assumed in analogy with the existence of the ρ resonance in QCD. The physical parameters that define this vector resonance, say the mass and the width, being dependent of the particular $SU(N)$ dynamics.

In this paper we consider three different scenarios, the two studied in [2,4] and a third one based in a $SU(N)$ gauge underlying theory within the spirit of Technicolor theories. We simulate the Higgs-like scenario by choosing the parameters of the effective Lagrangian to $O(p^4)$, M and N [2], so as to reproduce the amplitudes of scattering of LWB in the SM to one loop order and in the limit $m_H^2 \gg s$ [11]. In the QCD-like scenario we just transfer the $\pi - \pi$ scattering data from the scale of several hundreds MeV to the scale of several hundreds GeV by means of ChPT. This simply accounts for the rescaling $f_\pi \rightarrow v$, where $f_\pi = 94\text{MeV}$.

As mentioned before, we still have the possibility of changing the number of colors and, thus, considering $SU(N_{TC})$ scenarios in general. In this third scenario, $SU(N_{TC})$ Technicolor, we assume there is a vector resonance $I=J=1$ in the spectrum. Using large N_{TC} arguments one expects that the mass of the vector resonance goes like

$$M_{\rho_{TC}} \approx M_\rho \frac{v}{f_\pi} \left(\frac{3}{N_{TC}} \right)^{\frac{1}{2}} \quad (2)$$

where $M_\rho = 770\text{MeV}$. Increasing N_{TC} implies a lighter resonance as compared to the resonance in the QCD-like scenario with $M_{\rho_{QCD}} = 2\text{TeV}$ and $\Gamma_{\rho_{QCD}} = 487\text{GeV}$. By assuming the KSFR relation holds in $SU(N_{TC})$ theories as it (approximately) does in QCD, more specifically

$$\Gamma_{\rho_{TC}} = \frac{M_{\rho_{TC}}^3}{96\pi v^2} \quad (3)$$

then the larger N_{TC} is, the narrower turns out to be the resonance. In this way one can study the experimental possibilities of detectability of vector resonances over a wide range of mass values, based on some general assumptions. Lowering the resonance increases considerably the production rates of $W^\pm Z^0$ pairs and, thus, the observability of these resonances. The way one has to choose M and N in order to reproduce the low energy behaviour of these $SU(N_{TC})$ scenarios is the following one:

$$M_R^{TC} \left(\frac{v}{f_\pi} \left(\frac{3}{N_{TC}} \right)^{\frac{1}{2}} \right) \nu = \frac{N_{TC}}{3} M_R^{QCD}(\nu) \quad (4)$$

$$N_R^{TC} \left(\frac{v}{f_\pi} \left(\frac{3}{N_{TC}} \right)^{\frac{1}{2}} \right) \nu = \frac{N_{TC}}{3} N_R^{QCD}(\nu) \quad (5)$$

where M_R^{QCD} and N_R^{QCD} are the parameters of the $O(p^4)$ terms in the chiral Lagrangian of QCD.

In order to take into account properly in the computations the contribution of the $I=J=1$ resonance (the technirho) we have chosen the Padé unitarization method. The reason is that it provides a resonant behaviour in the $I=J=1$ channel with the particularity of fulfilling automatically the KSFR relation. In particular, it is known to reproduce very well the $\pi - \pi$ scattering data in the three channels, $I=J=0$, $I=J=1$ and $I=J=2$ (see first reference in [8]). As the main contribution to the process we are interested in comes from the $I=J=1$ channel, one can safely neglect other channels than $I=J=1$.

In order to study a wide range of signatures we have considered two technicolor scenarios:

$$M_{\rho_{TC}} = 1.07 \text{ TeV}, \quad \Gamma_{\rho_{TC}} = 55 \text{ GeV} \quad (6)$$

$$M_{\rho_{TC}} = 1.57 \text{ TeV}, \quad \Gamma_{\rho_{TC}} = 185 \text{ GeV} \quad (7)$$

The former, although being probably unrealistic from the theoretical point of view since it corresponds to a high number of technicolors ($N_{TC} \sim 12$), has some phenomenological interest.

3 pp Colliders and the WZ elastic scattering

It is important to determine the degree of precision which one would be able to reach in the study of the SISBS through the WZ channels at the planned pp colliders. Following our approach initiated in [4] we have made a systematic study of the three scenarios mentioned above, considering the WZ fusion mechanism as the dominant source of $W_L^\pm Z_L^0$ pairs. That is, in fact, what happens in general for any SISBS scenario whenever one imposes no additional assumptions on the particularities of the connection between the SBS and other sectors of the theory as for instance the fermionic one.

We have computed the cross section for the process

$$pp \rightarrow (W_L^\pm Z_L^0 \rightarrow W_L^\pm Z_L^0) + X \quad (8)$$

in the effective W approximation [12]. The technique we have used to compute the different quantities relevant for a phenomenological study of the SISBS is the same we used in [4]. For completeness we just make a few comments here. The total cross section is the result of the convolution of the WZ differential cross section with the luminosity of WZ partons in the pp beams. This luminosity is calculated from the convolution of the double bremsstrahlung of WZ from the quarks with the luminosity of the quark partons in the pp beams. The final formula is a 5-fold integral that we compute using the VEGAS Monte Carlo program [13]. The differential cross section for WZ scattering is written in terms of the partial wave amplitudes and then these are unitarized by either the Padé or the K-matrix method. These partial wave amplitudes are only dependent on the M and N parameters that determine the scenario we are dealing with.

We have also computed the signal that would be produced in the Standard Model at tree level with a heavy Higgs of $m_H = 17 \text{ TeV}$ (SMH), in order to compare the results with our Higgs-like scenario results that include the one loop corrections and a unitarization procedure. We have calculated the analytic expressions in the SMH case for all possible configurations of polarizations (TT, TL, LT, LL, T for transverse and L for longitudinal). As we have found some errors in the expressions for the $W_L^\pm Z_L^0 \rightarrow W_L^\pm Z_L^0$ amplitudes published in the literature [14], we have included in the appendix the corrected formulae. The formulae for the other configurations are too long to be included here and will be published elsewhere [15].

We present in table 1 the results for the three scenarios considered here where we have assumed that only the WZ fusion process contributes to the signal, together with the results for the SMH. The number of $W^+ Z^0 + W^- Z^0$ events are displayed for both cuts in the rapidities of the weak bosons and for the two planned colliders LHC and SSC. The main parameters assumed for these machines are:

$$\begin{aligned} \text{LHC, } \sqrt{s} &= 16 \text{ TeV}, L = 4 \cdot 10^{34} \text{ cm}^{-2} \text{ sec}^{-1} \\ \text{SSC, } \sqrt{s} &= 40 \text{ TeV}, L = 10^{33} \text{ cm}^{-2} \text{ sec}^{-1} \end{aligned}$$

and we give numbers of events for a running time of 10^7 sec . The number of events presented in table 1 correspond to impose the following ("minimal") cuts on the invariant mass of the weak boson pair, the transverse momentum of the bosons and on the rapidities of both bosons:

$$0.5 \text{ TeV} < M_{WZ} < 10 \text{ TeV} \quad |p_{TZ}| > 10 \text{ GeV} \quad |y| < 1.5 \quad \sigma \quad 2.5 \quad (9)$$

In $SU(N_{TC})$ scenarios it is possible, under certain assumptions, to incorporate a new mechanism of probing the SISBS: $q\bar{q} \rightarrow W^\pm \rightarrow \rho_{TC} \rightarrow W_L^\pm Z_L^0$. This mechanism where $q\bar{q}$ annihilates into ρ_{TC} via $\rho_{TC} - W$ mixing is usually assumed to be well described in terms of Vector Meson Dominance (VMD) [16,17]. In the more general context of the effective chiral Lagrangian approach, the minimal way of coupling the fermionic sector to the SBS sector would be provided automatically when gauging the effective chiral Lagrangian and including the usual couplings of the fermions to the gauge fields [18] (that is without assuming new additional terms with new unknown parameters). This would apply irrespectively of the particular scenario for the SBS. However, for the purpose of this paper we will assume that VMD is a reasonable working hypothesis for the case of $SU(N_{TC})$ scenarios and we will use it in the numerical computations.

The comparison of the results for the two different mechanisms, the $q\bar{q}$ annihilation and the WZ fusion, will be discussed in the next section together with the various background contributions.

4 Background processes and Optimization procedures

In order to study the experimental prospects at the supercolliders we have taken into account the following background processes:

- 1) $q\bar{q}' \rightarrow W^\pm Z^0$. This is the main background. We have used the formulas of [16]. It amounts to 65% (45%) of the total background for the LHC(SSC) with the minimal cuts defined in section 3.
- 2) $\gamma W^\pm \rightarrow W^\pm Z^0$. We have calculated the amplitudes for this process in the Standard Model and checked the expressions of [19]. The ratio of the production rates is $\gamma W_L^\pm \rightarrow W^\pm Z^0 / \gamma W_T^\pm \rightarrow W^\pm Z^0 = 0.04$ for both the LHC and the SSC. They together contribute to $\sim 15\%$ (20%) of the total background for the LHC(SSC).
- 3) $W^\pm Z^0 \rightarrow W^\pm Z^0$. This background is defined as the contribution from all the polarization channels in WZ elastic scattering as predicted in the SM without the Higgs contribution [15](SMNH) and without the configuration $W_L^\pm Z_L^0 \rightarrow W_L^\pm Z_L^0$. The latter is considered by us as the signal and is described by means of the effective chiral Lagrangian. We have obtained the following relations for the production rates $W_T^\pm Z_L^0 \rightarrow W^\pm Z^0 : W_T^\pm Z_L^0 \rightarrow W^\pm Z^0 : W_L^\pm Z_L^0 \rightarrow W^\pm Z^0 = 1 : 0.1 : 0.003$ for both the LHC and the SSC for the 2.5 rapidity cut. They together amount to $\sim 20\%$ (35%) of the total background for the LHC(SSC).

In the computations we have made use of the EHLQ structure functions [16] (set II with $\Lambda = 290 \text{ MeV}$) and we have neglected the contribution of the top quark sea. The Q^2 scale used in each case is: $Q^2 = M_W^2$ for the WZ and γW fusion processes and $Q^2 = s$ for the $q\bar{q}'$ processes. For the choice of the rest of the parameters see [4].

In table 2 we present the number of events for the background processes having imposed the minimal cuts. We have also included the results of the SMH. In this case we present separately the results for the TT, TL+LT, LL initial state configurations (see also figure 1). In comparing the SMH and the Higgs-like scenario (named Higgs in the tables) results we find, as expected, comparable rates. On the other hand the rates for the TT, TL+LT configurations as predicted in the SMH versus the rates of the SMNH are also very similar. That clearly indicates that the Higgs particle contribution to the TT and TL+LT channels is very small.

In order to improve the observability of the signal over the background processes we follow two different strategies. These are based on making cuts simultaneously on M_{WZ} and p_{TZ} . Depending on the kind of the signal, we adopt one of the two strategies:

- A) Whenever there is a wide resonance or there is an excess of events over the continuum we follow the method explained in [4]. We look for the cuts (optimal cuts) that maximize the function

$$F((p_{TZ})_c, (M_{WZ})_c) = \frac{n_s(p_{TZ} > (p_{TZ})_c, M_{WZ} > (M_{WZ})_c)}{\sqrt{n_T(p_{TZ} > (p_{TZ})_c, M_{WZ} > (M_{WZ})_c)}} \quad (10)$$

where $n_s(\dots)$ ($n_T(\dots)$) is the number of events in the signal (total = signal + background) that satisfy the cuts indicated.

- B) Whenever there is a narrow resonance we choose a window on the M_{WZ} variable and search for the cut on p_{TZ} that makes F maximal.

In table 3 the results (with optimal cuts) for the signal and background rates coming from the analysis of the WZ fusion are presented for the three scenarios and the SMH. These numbers represent the most general and conservative expectations for the SISBS signals.

When the contribution from the $q\bar{q}'$ annihilation mechanism is added to the signal in SU(N) scenarios the rates presented in table 4 are obtained. We present separately the contributions for the WZ fusion and $q\bar{q}'$ annihilation processes as well as the total signal rates. We have always used strategy B with 950-1050 GeV, 1400-1550 GeV, 1500-2500 GeV as the windows in M_{WZ} for $M_p = 1.0, 1.5, 2.0 \text{ TeV}$ respectively. The relative percentages of the WZ fusion contribution to the total signal are:

M_p	$rap.cut$		1.0 TeV	1.5 TeV	2.0 TeV
LHC	(2.5)		9%	24%	45%
SSC	(2.5)		22%	50%	72%

An increase in M_p results in a larger contribution from WZ fusion process, which reveals as the most efficient mechanism in probing the SISBS for large enough values of M_p . This fact is clearly reflected in figures 2 and 3. It is interesting to point out that the contribution of the fusion process is even more important at the SSC than at the LHC, due to the higher energy available at the sub-subprocess level. The comparison of these mechanisms in technicolor theories was first discussed by Chivukula in [17] in the context of the SSC.

Regarding the background processes, the different contributions after applying the optimal cuts are the following:

	LHC	SSC
$q\bar{q}'$		65%
$\gamma W^\pm$		15%
$W^\pm Z$		20%
		35%

Notice that the relative percentages of the different background contributions have not changed appreciably after applying the more stringent optimal cuts. In figures 4 (LHC) and 5 (SSC) the M_{WZ} invariant mass distributions of the different background processes are displayed and for reference we have also included the spectrum of the WZ fusion signal process (with the optimal cuts).

Until now we have given the number of events without taking into account the decay channels of the weak boson pair. To be on the safe side we will assume that only the leptonic decays of the weak boson will be amenable to experimental study at the future supercolliders. In that case one background process that we have not included here and could be expected to contribute significantly, is the $t\bar{t}$ production with subsequent top decays into real W's. This process fakes our signal when both W's decay leptonically and one of the bottom quarks decays semileptonically. Although the rate for this process at the starting point is huge as compared to the signal, a very preliminary study indicates that there exists a set of feasible cuts that diminishes this background to a level comparable (or lower) to the backgrounds considered here [29].

Temptative numbers of observable leptonic events are indicated (BR=1.5%) in tables 3 and 4.

5 Conclusions

With the results of WZ fusion at hand, the conclusions are the following: The signal/background ratio is too low to be observable in the Higgs-like scenario or in the SMH. On the contrary, in the QCD-like scenario there are actual possibilities of observing the signal over the background: with the signal/background ratio being ~ 1 . As it is clearly manifested in figures 2 and 3 the results are encouraging in the technicolor models, since there will be a large and clear signal in the M_{WZ} spectrum. This is for the minimal option of considering just the WZ fusion mechanism.

As an illustration of what would happen if there is also a coupling between the fermionic sector and the SBS sector we have studied the possibility of probing the SISBS with an additional mechanism: $q\bar{q}$ annihilation via $p_{TC} - W$ mixing. This corresponds to a specific choice of the coupling of the quarks to the SBS by means of the additional assumption of VMD and it is restricted to the context of $SU(N_{TC})$ dynamics. The results are spectacular and it turns out to be an important option for studying in detail this kind of dynamics at LHC and SSC.

In summary, a conservative analysis based just in the WZ fusion process indicates that the $W^\pm Z^0$ channels are the most appropriate to reveal the SISBS underlying dynamics that contain a vector resonance $I=J=1$ (QCD-like or Technicolor scenarios) and that it will be possible to detect them at the future supercolliders, LHC and SSC. If one also includes other mechanisms (as the one we study here) the expectations will be enhanced. At the LHC the statistics is greater than at the SSC due to the factor 40 of increase in the luminosity of the LHC, while at the SSC the signal/background ratio is better than at LHC.

As a combined conclusion of the results presented in [4] and the ones reached here, it is the combined analysis of the $Z^0 Z^0$ and $W^\pm Z^0$ channels that would help to unravel the nature of the SBS at the planned colliders LHC and SSC.

Appendix

Using the same notation as the authors of [14], the corrected formulae for the amplitudes of the $W_L^\pm Z_L^0 \rightarrow W_L^\pm Z_L^0$ scattering process are:

$$a_4 = \frac{-ig^2(1-x)}{M_W^2 M_Z^2} [E^2 E'^2 (\cos^2 \theta - 1) - 2k^2 \cos \theta (E^2 + E'^2 + EE') - 2k^2 EE'] \quad (11)$$

$$a_{4H} = \frac{-ig^2(k^2 - E^2 \cos \theta)(k^2 - E'^2 \cos \theta)}{M_W^2(t - M_H^2)} \quad (12)$$

$$a_{4W} = \frac{+ig^2(1-x)}{M_W^2 M_Z^2(s - M_W^2)} \{-4k^2 \cos \theta (E + E')^4 + (k^2 + EE')^2 [(E - E')^2 - 4k^2 \cos \theta] + 8k^2(k^2 + EE')(E + E')^2 \cos \theta - \frac{1}{M_W^2} (E^2 - E'^2)^2 (k^2 + EE')^2\} \quad (13)$$

$$a_{4W} = \frac{-ig^2(1-x)}{M_W^2 M_Z^2(u - M_W^2)} \{-4k^2(E' + E \cos \theta)(E + E' \cos \theta)(k^2 + EE') + 4k^2(E' + E \cos \theta)(k^2 + EE' \cos \theta)(2E' - E' \cos \theta + E) - 4k^2(E' + E \cos \theta)^2(k^2 - E'^2 \cos \theta) - \frac{1}{2}(k^2 + EE' \cos \theta)^2[(E + E')^2 + 2k^2(1 - \cos \theta)] + \frac{1}{2M_W^2}(k^2 + EE' \cos \theta)^2(E^2 - E'^2)^2 + [E \leftrightarrow E']\} \quad (14)$$

Table Captions

Table 1: Number of $W^+Z^0 + W^-Z^0$ events for the WZ fusion signal process with the minimal cuts.

Table 2: Number of $W^+Z^0 + W^-Z^0$ events for the background processes with the minimal cuts.

Table 3: Number of $W^+Z^0 + W^-Z^0$ events for the WZ fusion signal process and the background processes (signal/background) with the optimal cuts (in parentheses and in GeV). In the cases we have applied strategy A we indicate both optimal cuts (p_{Tz}, M_{WZ}) while whenever we have applied strategy B we just indicate the (p_{Tz}) optimal cut. At the bottom of each entry the observable signal/background leptonic events are also included.

Table 4: Number of $W^+Z^0 + W^-Z^0$ events for the signal (fusion+qq' annihilation) and the background processes (signal / background) with the p_{Tz} optimal cuts (in parentheses and in GeV). The separated contributions from the WZ fusion and the qq' annihilation processes are also displayed. At the bottom of each entry the observable signal/background leptonic events are also included.

Figure Captions

Fig. 1: WZ invariant mass distribution for the various WZ fusion signal processes: $W_LZ_L \rightarrow WZ$ in the SMH (dotted histogram), $W_LZ_L \rightarrow W_LZ_L$ in the Higgs-like scenario (lower solid histogram), and for the processes $W_TZ_T \rightarrow WZ$ (upper solid histogram) and $W_TZ_L + W_LZ_T \rightarrow WZ$ (dashed histogram) computed in the SMH, for the LHC (with the 2.5 rapidity cut and a P_{Tz} cut of 240 GeV).

Fig. 2: WZ invariant mass distribution of the signal and background processes with the optimal cuts for the LHC (the 2.5 rapidity cut has been chosen). The results from the SU(N)-like scenarios are displayed: lower solid histogram represents WZ fusion and dotted histogram represents qq' annihilation signal process. The total background is the dashed histogram and the total background + signal is the upper solid histogram.

Fig. 3: Same as figure 2 for the SSC.

Fig. 4: WZ invariant mass distribution for the WZ fusion signal process (solid histogram) and for the background processes (dashed histogram for qq', dotted histogram for γ W fusion and dash-dotted histogram for WZ fusion background process) of the QCD-scaled scenario for the LHC (the 2.5 rapidity cut has been chosen).

Fig. 5: Same as figure 4 for the SSC.

References

- [1] D.A. Dicus, V. Mathur, *Phys.Rev. D7* (1973) 3111
B.W. Lee, C.Quigg, H. Thacker, *Phys.Rev. D16* (1977) 1519
M. Veltman *Act. Phys. Pol. B8* (1977) 475
- [2] A. Dobado, M.J. Herrero, *Phys. Lett. B228* (1989) 495; *B233* (1989) 505
- [3] J.F. Donoghue, C. Ramirez, *Phys.Lett B234* (1990) 361
- [4] A. Dobado, M.J. Herrero, J. Terron, CERN preprint CERN-TH.5670/90
- [5] M.S. Chanowitz, M.K. Gaillard, *Nucl.Phys. B261* (1985) 379
- [6] J. Gasser, H. Leutwyler, *Ann. of Phys.* 158 (1984) 142
H. Georgi, *Weak interactions and Modern Particle Theory*, Benjamin-Cummings, 1981
- [7] U. Amaldi et al., *Phys.Rev. D36* (1987) 1385
G. Costa et al., *Nucl.Phys. B297* (1988) 244
- [8] A. Dobado, M.J. Herrero, T.N. Truong, *Phys.Lett. B235* (1990) 129 and 134
A. Dobado, *Phys.Lett. B237* (1990) 457
D.A. Dicus, W.W. Repko, Michigan State University preprint, MSUTH 89/06, December 1989
- [9] O. Cheyette and M.K. Gaillard, *Phys. Lett. B197* (1987) 205
- [10] S.N. Gupta, *Quantum Electrodynamics*, Ed. by Gordon and Breach, New York (1981), 191
D.A. Dicus, W. Repko, *Phys. Lett. B228* (1989) 503
- [11] S. Dawson, S. Willenbrock, *Phys. Rev. Lett. 62* (1989) 1232 ; *Phys. Rev. D40* (1989) 2880
M. Veltman, F.J. Yndurain, *Nucl. Phys. B325* (1989) 1
- [12] S. Dawson, *Nucl.Phys. B249* (1985) 42
- [13] G.P. Lepage, *J. Comput.Phys. 27* (1978) 192
- [14] M.C. Bento, C.H. Llewellyn Smith, *Nucl. Phys. B289* (1987) 36
- [15] A. Dobado, M.J. Herrero and J. Terron, in preparation.
- [16] E. Eichten et al., *Rev. Mod. Phys. 56* (1984) 579
- [17] R.S. Chivukula, Boston University preprint, BUHEP-88-16.
R. Rosenfeld, J.L. Rosner *Phys. Rev. D38* (1988) 1530
J.J. Sakurai, *Currents and Mesons*, University of Chicago Press, 1969
- [18] A. Dobado, M.J. Herrero and J. Terron, in preparation.
- [19] B. Mele, *Proceedings of the Workshop on Physics at Future Accelerators*, Vol. II, p13; Ed. J. Mulvey (1987)
- [20] M.I. Josa and T. Rodrigo, private communication. Work in preparation for the LHC workshop to be held at Aachen (october 1990)

Table 1:

Method	Scenario	LHC (1.5)	LHC (2.5)	SSC (1.5)	SSC (2.5)
Padé	TECHN 1.0	18581	35538	2514	6348
Padé	TECHN 1.5	5679	11968	1217	2949
Padé	QCD 2.0	4560	8290	1012	2157
Padé	HIGGS	2301	4011	394	777
None	SMH	2695	5190	397	817
K-Matrix	HIGGS	2099	3630	469	863
K-Matrix	QCD 2.0	2915	5318	613	1282

Table 2:

Process	LHC(1.5)	LHC(2.5)	SSC(1.5)	SSC(2.5)
$q\bar{q}' \rightarrow W^\pm Z^0$	98938	580827	6240	37507
$\gamma W_T^\pm \rightarrow W^\pm Z^0$	24180	157711	2801	19174
$\gamma W_L^\pm \rightarrow W^\pm Z^0$	909	6048	98	688
SMNH $W_T^\pm Z_L^0 \rightarrow W^\pm Z^0$	27027	188086	3768	27003
SMNH $W_T^\pm Z_L^0 \rightarrow W^\pm Z^0$	1999	10810	271	1501
SMNH $W_L^\pm Z_L^0 \rightarrow W^\pm Z^0$	2167	11123	295	1551
SMNH $W_L^\pm Z_L^0 \rightarrow W^\pm Z^0$	332	462	48	74
SMH $W_T^\pm Z_L^0 \rightarrow W^\pm Z^0$	27004	187967	3754	26989
SMH $W_T^\pm Z_L^0 \rightarrow W^\pm Z^0$	1853	10602	243	1460
SMH $W_T^\pm Z_L^0 \rightarrow W^\pm Z^0$	1958	10834	256	1491
SMH $W_L^\pm Z_L^0 \rightarrow W^\pm Z^0$	2695	5190	397	817

Table 3:

Method	Scenario	LHC (1.5)	LHC (2.5)	SSC (1.5)	SSC (2.5)
PADE	TECHN 1.0	10713/4724 (10)	21206/14181 (180)	1728/491 (10)	3922/1586 (180)
		161/71	318/213	26/7	59/24
PADE	TECHN 1.5	2255/1128 (10)	3968/2852 (300)	521/143 (300)	1184/546 (240)
		34/17	60/43	8/2	18/8
PADE	QCD 2.0	1616/1791 (420,1550)	2373/3494 (420,1600)	593/390 (420,1450)	1121/1095 (420,1450)
		24/27	36/52	9/6	17/16
PADE	HIGGS	1310/29061 (300,500)	1817/52370 (300,500)	185/1105 (420,500)	302/2272 (420,500)
		20/434	27/786	3/17	5/34
None	SMH	1956/60485 (240,500)	2625/116250 (240,500)	313/5788 (240,500)	489/13041 (240,500)
		29/907	39/1744	5/87	7/196
K-MATRIX	HIGGS	393/540 (780,1700)	489/844 (720,1650)	223/163 (720,1650)	316/321 (660,1700)
		6/8	7/13	3/2	5/5
K-MATRIX	QCD 2.0	484/1124 (480,1700)	739/2293 (540,1550)	240/198 (540,1750)	434/513 (540,1700)
		7/17	11/34	4/3	7/8

Table 4:

Scenario	rap. cut	LHC (total)	SSC (total)
TECHN 1.0	1.5	114186/4724	9501/491
		10713 (fusion)	1728 (fusion)
		103473 (qq') (10)	7772 (qq') (10)
TECHN 1.0	2.5	1713/71	142/7
		175187/14181	17515/1586
		21206 (fusion) 153980 (qq') (180)	3922 (fusion) 13593 (qq') (180)
TECHN 1.5	1.5	2628/213	263/24
		9046/1042	1183/143
		2202 (fusion) 6844 (qq') (360)	521 (fusion) 662 (qq') (300)
TECHN 1.5	2.5	136/16	18/2
		13139/2852	2194/408
		3968 (fusion) 9171 (qq') (300)	1098 (fusion) 1096 (qq') (300)
QCD 2.0	1.5	197/43	33/6
		3531/1679	754/270
		1563 (fusion) 1969 (qq') (480)	509 (fusion) 245 (qq') (480)
QCD 2.0	2.5	53/25	11/4
		4311/2059	1387/772
		1934 (fusion) 2376 (qq') (540)	1002 (fusion) 386 (qq') (420)
		65/31	21/12

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5