A Strong Electroweak Sector
with Decoupling at Low Energy

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Abstract

I discuss the possible symmetries of effective theories for spinless
and spin one bosons, to concentrate on a model with vector and ax-
ial vector strong interacting bosons possessing a discrete symmetry
demanding degeneracy (degenerate BESS model, BESS standing for
Breaking Electroweak Symmetry Strongly). The phenomenology at
future hadron colliders is also presented.

Introduction

The standard model (SM) of the electroweak interactions is confirmed with
excellent accuracy by the existing results at LEP, SLC and Tevatron. There-
fore only extensions which smoothly modify this theory are still conceivable.
The minimal supersymmetric standard model (MSSM) is the most favorite.
It solves the so-called hierarchy problem which is related to the presence
of quadratic mass divergences due to scalar fields and it has an interesting

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property of decoupling. In the limit in which all the supersymmetric particles become heavy one recovers the SM with a light Higgs.

This decoupling property however is not peculiar of the MSSM only. In fact in my talk I will present a model for a strong electroweak sector sharing this property.

Models of dynamical breaking of the electroweak symmetry are based just on the symmetry structure, not taking into account the underlying theory which is responsible of the breaking and the corresponding chiral lagrangians are built using, as degrees of freedom, the goldstone bosons, the longitudinal components of $W$ and $Z$. Experiments, like the measurement of the $\rho$ parameter, suggests the existence of a custodial symmetry $SU(2)$, which guarantees $\rho = 1$. Therefore chiral lagrangians can be built as a non linear $\sigma$-model assuming the spontaneous breaking $SU(2)_L \otimes SU(2)_R \rightarrow SU(2)_{L+R}$.

Effective lagrangians can be derived using the global symmetry $G = SU(2)_L \times SU(2)_R$ and an expansion in the energy. Goldstones are described by a unitary field $U(x) = \exp(i\pi^a(x)\tau^a/v)$, transforming under $G$ as $(2,2)$ or $U \rightarrow g_L U g_R^\dagger$. The most general chiral lagrangian is a sum of infinite number of terms with an increasing number of derivatives or equivalently in terms of increasing powers of energy or momentum. These lagrangians allow for a description of the physics below a cutoff scale $\Lambda$, related to the new physics. Vector resonances can be introduced in chiral lagrangians by following Weinberg or in equivalent way by means of the hidden local symmetry approach. The model so obtained when this technique is applied to the electroweak symmetry breaking sector is called BESS.

The model we will review here is a model with new vector and axial vector bosons degenerate in mass. These bosons correspond to the gauge bosons associated to a hidden symmetry, $H' = SU(2)_L \otimes SU(2)_R$. The symmetry group of the theory becomes $G' = G \otimes H'$. It breaks down spontaneously to $H_D = SU(2)$, the diagonal subgroup of $G'$, and gives rise to nine Goldstones. Six of these are absorbed by the vector and axial vector bosons. As soon as we perform the gauging of the subgroup $SU(2)_L \otimes U(1)_Y \subset G$, the three remaining Goldstones disappear giving masses to the SM gauge bosons. This general procedure for building models with vector and axial vector resonances is discussed in, while this special model has been proposed in. This model has the nice property that all the deviations in the low energy parameters from their SM values are strongly suppressed. This allows the existence of a strong electroweak sector at relatively low energies within the
precision of electroweak tests, such that it may be accessible with accelerators
designed for the near future. As such it offers possibilities of experimental
tests even with future or existing machines of relatively low energy. In the
following phenomenological implications at Tevatron upgrade and LHC will
be discussed [8].

Degenerate BESS Model

The model includes two new triplets of vector bosons \((L^\pm, L_3)\) and \((R^\pm, R_3)\).
The parameters of the model are a new gauge coupling constant \(g''\) and a
mass parameter \(M\), related to the scale of the underlying symmetry breaking
sector. In the following we give approximate formulas in the limit \(M \to \infty\)
and \(g'' \to \infty\). For the numerical analysis the exact formulas of [7] were used.

In the charged sector the fields \(R^\pm\) are unmixed for any value of \(g''\). Their
mass is given by:

\[
M_{R^\pm}^2 \equiv M^2
\]

The charged fields \(W^\pm\) and \(L^\pm\) have the following masses:

\[
M_{W^\pm}^2 = \frac{v^2}{4} g'^2, \quad M_{L^\pm}^2 = M^2 (1 + 2x^2)
\]

where \(x = g/g''\), \(g\) is the usual \(SU(2)\) gauge coupling constant and \(v^2 = 1/(\sqrt{2}G_F)\).

In the neutral sector we have:

\[
M_Z^2 = \frac{M_{W^2}}{c_\theta^2}, \quad M_{L_3}^2 = M^2 \left(1 + 2x^2\right), \quad M_{R_3}^2 = M^2 \left(1 + 2x^2 \tan^2 \theta\right)
\]

where \(\tan \theta = s_\theta/c_\theta = g'/g\) and \(g'\) is the usual \(U(1)_Y\) gauge coupling constant.
Notice that for small \(x\) all the new vector resonances are degenerate in mass.

The charged part of the fermionic lagrangian is

\[
\mathcal{L}_{charged} = - \left( a_W W^-_\mu + a_L L^-_\mu \right) J_L^{(+)} + H.c.
\]

where

\[
a_W = \frac{g}{\sqrt{2}} \quad a_L = -gx
\]
Figure 1: 90% C.L. upper bounds on $g/g''$ vs. $M$ from LEP/Tevatron/SLC data.
apart from higher order terms and $J_{L}^{(+)}=\bar{\psi}_{L}\gamma^{\mu}\tau^{+}\psi_{L}$ with $\tau^{+}=(\tau_{1}+i\tau_{2})/2$.

Let us notice that the $R^{\pm}$ are not coupled to the fermions.

For the neutral part we get

$$L_{\text{neutral}} = -\left\{ eJ_{em}^{\mu}\gamma_{\mu} + \left[ AJ_{L}^{(3)\mu} + BJ_{em}^{\mu}\right]Z_{\mu} + \left[ CJ_{L}^{(3)\mu} + DJ_{em}^{\mu}\right]L_{3\mu} + \left[ EJ_{L}^{(3)\mu} + FJ_{em}^{\mu}\right]R_{3\mu}\right\} \tag{6}$$

where $\gamma_{\mu}$ in the preceding formula is the photon field and again in the limit $M \to \infty$, $x \to 0$,

$$A = \frac{g}{c_{\theta}} \quad B = -\frac{gs_{\theta}^{2}}{c_{\theta}} \quad C = -\sqrt{2}gx \quad D = 0 \quad E = \sqrt{2}g\frac{x}{c_{\theta}}\tan^{2}\theta \quad F = -E \tag{7}$$

and $J_{em}^{\mu} = Q\bar{\psi}\gamma^{\mu}\psi$, $J_{L}^{(3)\mu} = \bar{\psi}_{L}\gamma^{\mu}T_{L}^{3}\psi_{L}$ are the usual neutral currents.

In Fig. 1 90\% C.L. upper bounds on $g/g''$ versus $M$ from LEP, Tevatron and SLC data are shown. The limits (continuous line) are obtained calculating virtual effects up to order $M_{Z}^{2}/M^{2}$, and using the experimental data from ref. [9]. Note that in the low energy limit ($M \to \infty$) there are no deviations from the SM, thus allowing to consider light new resonances for the strong sector.

**Degenerate BESS at Tevatron and LHC**

We will now study the detection of charged and neutral vector resonances from a strong electroweak sector at the upgrading of the Fermilab Tevatron [10]. The option we have chosen is the so called TeV-33, with a c.m. energy of the collider of 2 TeV and an integrated luminosity of 10 $fb^{-1}$. We have considered the total cross-section $p\bar{p} \to L^{\pm}, W^{\pm} \to \mu \nu_{\mu}$ and compared it with the SM background.

Up to a region of 1 $TeV$ the limits from TeV-33 option are stronger with respect to LEPI (we recall that LEPII will only marginally improve LEPI results [7]).
The events where simulated using Pythia Monte Carlo [11]. The simulation was performed using the expected detector resolution, in particular a smearing of the energy of the leptons was done according to $\Delta E/\sqrt{E} = 10\%$ and the error on the 3-momentum determination was assumed to be between 3% for a mass of the order of 500 GeV and 5% for a mass of 1000 GeV.

We have examined various cases with different choices of $M$ and $g/g''$ (taken inside the physical region shown in Fig. 1) to give an estimate of the sensitivity of the model to this option for the upgrading of the Tevatron (see Table 1 for the charged case).

For each case we have selected cuts to maximize the statistical significance of the signal. We see that the number of signal events decreases for increasing mass of the resonance. The conclusion is that Tevatron with the high luminosity option will be able to discover a strong electroweak resonant sector as described by the degenerate BESS model for masses up to 1 TeV.

It can be seen from the calculation of the statistical significance (see [8]) that the charged process allows to push further the discovery limits of the new vector bosons with respect to the neutral process. However the experimental check of the model requires the proof of the existence of both neutral and charged vector bosons. Notice that the reconstruction of the resonance mass requires a careful study of the experimental setup, due to the smallness of the resonance width.

We have also considered the phenomenology at LHC with a center of mass energy $\sqrt{s} = 14 TeV$, a luminosity of $10^{34} cm^{-2} s^{-1}$ and one year run ($10^7 s$) [8].

In Fig. 2 we show the differential distribution of events at LHC of $pp \rightarrow L^\pm, W^\pm \rightarrow \mu \nu_\mu$ in the transverse mass of the new vector boson for $M = 1500 GeV$ and $g/g'' = 0.1$. The following cuts have been applied: $|p_{T\mu}| > 500 GeV$, $m_T > 1300 GeV$. The number of signal events per year is 469, the

| $g/g''$ | $M$  | $\Gamma_{L^\pm}$ | $S/\sqrt{S + B}$ |
|--------|------|----------------|-----------------|
| 0.12   | 400  | 0.4            | 24.9            |
| 0.20   | 600  | 1.7            | 15.4            |
| 0.40   | 1000 | 11.1           | 4.0             |

Table 1: Degenerate BESS at TEV-33 for the process $p\bar{p} \rightarrow L^\pm \rightarrow \mu \nu_\mu + X$. 

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Figure 2: Transverse mass differential distribution of $pp \rightarrow L^{\pm}, W^{\pm} \rightarrow \mu\nu_{\mu}$ events at LHC for $M = 1500 \text{ GeV}$, $g/g'' = 0.1$. 
corresponding background consists of 247 events. The energy of the muons was smeared by 10% and the error in the 3-momentum increases with the momentum of the muon from 3% to 9% as stated in [12].

The statistical significance for some choices of the parameters is given in Table 2, showing that the discovery of a charged resonance up to 2 TeV with $g/g'' \simeq 0.1$ is well within the reach of LHC. The limit of detection for a 2 TeV mass is reached for a value of $g/g'' = 0.03$.

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### Table 2: Degenerate BESS at LHC for the process $pp \rightarrow L^\pm \rightarrow \mu\nu_\mu + X$.

| $g/g''$ | $M$ (GeV) | $\Gamma_{L^\pm}$ (GeV) | $S/\sqrt{S+B}$ |
|---------|-----------|------------------------|----------------|
| 0.075   | 500       | 0.2                    | 95.8           |
| 0.1     | 1000      | 0.7                    | 43.5           |
| 0.1     | 1500      | 1.0                    | 17.5           |
| 0.1     | 2000      | 1.4                    | 9.4            |

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