INTRODUCTION TO STRONG HIGGS SECTOR

Pierre CHIAPPETTA

Abstract

A brief introduction to strong Higgs sector i.e. the possibility of breaking electroweak symmetry without an elementary Higgs is given. Constraints from present LEP data are studied and the discovery potential of future colliders investigated.

Key-Words : strong Higgs, future colliders.

April 1994
CPT-94/P.3026

anonymous ftp or gopher : cpt.univ-mrs.fr
1 Introduction

The problem of symmetry breaking in electroweak interactions is achieved in the Standard Model (hereafter denoted as SM) by adding to the $SU(2)_L \otimes U(1)_Y$ gauge theory the Higgs lagrangian \[1\] :

$$D_\mu \Phi D^{\mu} \Phi^\dagger - V(\Phi)$$

where

$$V(\Phi) = -\mu^2 |\Phi|^2 + \lambda |\Phi|^4,$$

$\Phi$ being a $SU(2)$ doublet.

If $\mu^2$ is negative, $V(\Phi)$ has a minimum at :

$$\langle \Phi \rangle = \sqrt{\left(\frac{-\mu^2}{\lambda}\right)} = v = 246 \text{ GeV}.$$  

This mechanism gives masses to the weak bosons $W$ and $Z$ and also to quarks and leptons through Yukawa couplings. Since the Higgs doublet has four degrees of freedom and three are needed to give masses to weak bosons one is left with a scalar boson not yet discovered which is heavier than 63 GeV as indicated by LEP measurements \[2\].

Even if we can prove that the SM is not trivial i.e. that the Higgs self coupling constant $\lambda$ has not to be zero, which is still an open problem \[3\], this mechanism of symmetry breaking is nevertheless valid up to some scale $\Lambda$, we will specify. In fact the Higgs part of the lagrangian is not asymptotically free and the Landau pole, which corresponds to the scale where the coupling $\lambda$ is infinite, is very low (in the $TeV$ range). The situation is more complicated for the SM since it involves also fermions. It has been shown that if one assumes that the SM is valid up to a grand unification scale the Higgs has to be light \[4\]. Moreover in order to remain perturbative, the Higgs cannot be heavier than 630 GeV indicating that $\Lambda$ is around the $TeV$ scale. Moreover if a light Higgs is discovered, some new physics is mandatory to control radiative corrections.

In what follows we are interested in a scenario where no elementary Higgs boson exists. The Symmetry breaking mechanism is viewed as a manifestation of some underlying unknown strong interaction at the $TeV$ scale. In
what follows we will not consider a specific model like technicolor or extended technicolor [5] but describe a general framework involving symmetries [6]. More precisely the techniques we will use are based on the breaking of a global symmetry and similar to the description of low energy strong interactions involving pions in terms of effective theories ($\sigma$ models) valid up to the GeV scale.

In analogy with strong interactions the pions correspond to longitudinal gauge bosons and we will build vector resonances (like the $\rho$).

We will first show that the lagrangian of the SM can be viewed as the lagrangian of a linear $\sigma$ model when gauge interactions are put to zero. The Higgs doublet can be rewritten in a matricial notation :

$$M = \sqrt{2} (i \tau_2 \Phi^*, \Phi)$$

$$L = \frac{1}{4} Tr (\partial_\mu M \partial^\mu M^\dagger) - \frac{\lambda}{4} \left( \frac{1}{2} Tr (MM^\dagger) + \frac{\mu^2}{\lambda} \right)^2$$

To exhibit the correspondance with the linear $\sigma$ model we express the $SU(2)$ matrix as :

$$M = \sigma + i \pi.\tau$$

The lagrangian obtained has a global invariance under $SU(2)_L \otimes SU(2)_R$

$$M \rightarrow \exp \left( i \epsilon_L \frac{\tau}{2} \right) M \exp \left( -i \epsilon_R \frac{\tau}{2} \right)$$

which is spontaneously broken to $SU(2)_V$ if $\mu^2$ is negative. We get :

$$L = (\partial_\mu \sigma \partial^\mu \sigma) + (\partial_\mu \pi \partial^\mu \pi) + \frac{\lambda}{4} \left( \pi^2 + \sigma^2 - v^2 \right)^2$$

Let us now take the limit $\lambda \rightarrow \infty$. We must have : $(\pi^2 + \sigma^2 - v^2)^2 = 0$, which allows to eliminate the $\sigma$ i.e. the Higgs field.

In this limit the Higgs part of the SM corresponds to a non linear $\sigma$ model :

$$L = \frac{v^2}{4} Tr (\partial_\mu U \partial^\mu U^\dagger)$$

with the condition $UU^\dagger = 1$.

$U = \frac{M}{v}$ belongs to the coset space $SU(2)_L \otimes SU(2)_R / SU(2)_V$ and the degrees of freedom are the Goldstone bosons.
This lagrangian is the basic ingredient for the evaluation of scattering among longitudinal gauge bosons when the Higgs boson is very massive. These low energy theorems [7] are similar to those describing interactions among pions. They are valid in the energy range:

\[ M_W \ll \sqrt{S} \ll 4\sqrt{\pi v}, \]

the upper limit being given by unitarity.

The upper limit may be lower if for example a vector resonance exists: this is indeed the case in strong interactions due to the existence of the \( \rho \). The experimental signal will consist in an excess of production of pairs of longitudinal gauge bosons, difficult to be seen experimentally [8].

# 2 Vector resonances

The rest of the lecture is devoted to the description of vector resonances. The basic idea is to build the equivalent of the \( \rho \) resonance using the concept of hidden symmetry [9]. It is based on the fact that non linear \( \sigma \) models acting on a coset space \( \frac{G}{H} \) can be formulated as gauge theories of a group \( H \) which is the local version of the residual group \( H \) after symmetry breaking. We are therefore looking for a lagrangian invariant under:

\[ [SU(2)_L \otimes SU(2)_R]_{GLOBAL} \otimes SU(2)_{V LOCAL}. \]

If \( g \) is an element of the global group \( G \) and \( h \) an element of \( H \) we have the coset decomposition:

\[ g = \xi h. \]

We now introduce the Maurer Cartan differential form:

\[ \omega_\mu = \xi^\dagger \partial_\mu \xi \]

that we decompose in a component belonging to \( H \) called \( \omega_\parallel \) and an orthogonal one \( \omega_\perp \) belonging to the coset space.

The invariant quantities we can construct, which will lead to the most general lagrangian, are:

\[ L^{(1)} = Tr \left( \omega_\parallel \omega_\perp \right) \]
and

\[ L^{(2)} = \alpha Tr \left( \omega_\mu^{\parallel} \omega^\mu_{\parallel} \right), \]

\( \alpha \) being an arbitrary parameter.

We recover the SM by the gauge choice \( g(x) = \xi(x) \), which is equivalent to a gauge fixing term in Yang Mills theories.

Under local gauge transformations \( \omega_\mu^{\parallel} \) becomes:

\[ \omega_\mu^{\parallel} \rightarrow h^\dagger \omega_\mu^{\parallel} h + h^\dagger \partial_\mu h \]

i.e. acts as a triplet of gauge bosons \( V_\mu \):

\[ V_\mu \rightarrow \frac{2}{g''} h^\dagger \partial_\mu h + h^\dagger V_\mu h, \]

\( g'' \) being the \( SU(2)_V \) coupling constant.

If no kinetic term for \( V_\mu \) is present it is an auxiliary field and the Lagrangian contains only the \( L^{(1)} \) piece.

The main assumption is that \( V_\mu \) has to be a dynamical field. We will therefore add a kinetic term to the Lagrangian:

\[ L^{\text{kin}} = - \left( \frac{1}{g''} \right)^2 F_{\mu\nu}(V) F^{\mu\nu}(V). \]

Then we have to perform an \( SU(2)_L \otimes U(1)_Y \otimes SU(2)_V \) gauging and to eliminate goldstone bosons in order to give masses to \( W, Z \) and \( V \) bosons by going into the unitary gauge. One obtains finally a non renormalisable gauge theory with gauge group : \( SU(2)_L \otimes U(1)_Y \otimes SU(2)_V \) which breaks into \( U(1)_{EM} \). The Lagrangian we have built is called minimal BESS [6], [10] and predicts the existence of a triplet of gauge bosons. It contains three parameters:

- the mass \( M_V \) of the V triplet : \( M_V^2 = \alpha \frac{v^2}{4} g'' \).
- the \( SU(2)_V \) coupling constant \( g'' \) (we recover the SM in the limit \( g'' \rightarrow \infty \))
- a direct coupling of \( V \) bosons to fermions hereafter called \( b \). The coupling arises naturally from mixing.
Since $W^\pm$ mixes with $V^\pm$ and $Z^0$ with $V^0$, present colliders and especially LEP are sensitive to the strong Higgs sector. The existence of $V$ bosons affects not only the masses of $Z^0$ and $W$ bosons but also their couplings to fermions and the trilinear ones. The order of magnitude of the mixing angles and of the mixing parameter $b$ is:

$$\frac{g}{g''}.$$ 

LEP 200 will not improve significantly present LEP limits which are displayed in ref. [11]. We will wait for linear $e^+e^-$ colliders and to look for the process $e^+e^- \rightarrow W^+W^-$ well sensitive to $V^0$ [11], provided $W$ polarisation will be measurable.

LHC is well suited for $V^\pm$ identification through the reaction $pp \rightarrow WZ$ by looking at the invariant $WZ$ mass distribution or for a Jacobian peak in the transverse momentum of the $Z$ [12]. It allows to discover charged vector resonances up to 2 $\text{TeV}$.

Extended technicolor is a particular case of the BESS model. It is assumed that the underlying strong interaction responsible for symmetry breaking is a scaled QCD scenario of group $SU(N)_{TC}$ involving doublets of technifermions whose condensates break the symmetry like ordinary quarks condensates break the chiral symmetry in strong interactions. In extended technicolor the parameter $\alpha$ is fixed to 2 and $N_{TC}$ is related to $g''$.

The direct coupling to fermions is also fixed:

$$b = -2 \left(\frac{v}{\Lambda_{ETC}}\right)^2$$

where $\Lambda_{ETC}$ is the unknown scale for extended technicolor.

LEP has already excluded:

$$N_{TC}N_{DOUBLETS} \leq 12$$

The BESS model can be extended [13] if we start from a larger global symmetry like $SU(8)_L \otimes SU(8)_R$ broken into $SU(8)_{L+R}$. This leads to a very rich spectrum of vector resonances, axial vector ones and also pseudogoldstone bosons which are either singlets or triplets of $SU(2)_L$ and either singlets, triplets or octets of $SU(3)_C$.

Since they give a negative contribution to one of the self energies of the SM, i.e. $\epsilon_3$, the extended BESS model is still alive for a larger parameter
space domain. Moreover the bounds on the top mass, which can be derived from $\epsilon_1$, are weakened. This self energy is also sensitive to the splitting in pseudogoldstone multiplets. Compared to minimal BESS the width of vector resonances increases and the identification of $V^\pm$ through $WZ$ channel is less promising. The production of pseudogoldstone bosons at hadronic colliders suffers from a huge hadronic background. Linear $e^+e^-$ colliders are more promising if resonant production from $V^0$ is possible.

### 3 Conclusion

To conclude present LEP data constrain but do not exclude a strong breaking of the electroweak symmetry. The BESS model, on which we have focused our discussion, has the advantage to provide a very general frame leading in its minimal version to the existence of a triplet of vector resonances to be discovered at LHC collider for charged ones and at future linear $e^+e^-$ linear colliders for the neutral one.

### References

[1] P.W. Higgs, Phys. Rev. Lett. 12, 132 (1964) ; Phys. Rev. 145, 1156 (1966).

[2] S. Komamiya, these proceedings.

[3] For a review see M. Sher, Phys. Rep. 179, 273 (1989).

[4] M. Lindner, Z. Phys. C31, 1295 (1986).

[5] M.E. Peskin, Nucl. Phys. B175, 197 (1980).

[6] R. Casalbuoni, S. de Curtis, D. Dominici, R. Gatto, Nucl. Phys. B282, 235 (1987).

[7] M.S. Chanowitz and M.K. Gaillard, Nucl. Phys. B261, 379 (1985).

[8] F. Pauss, these proceedings.
[9] A.P. Balachandran, A. Stern and G. Trahern, Phys. Rev. B19, 2416 (1979). M. Bando, T. Kugo and K. Yamawaki, Prog. Theor. Phys. 73, 1541 (1985).

[10] R. Casalbuoni, P. Chiappetta, D. Dominici, F. Feruglio and R. Gatto, Nucl. Phys. B310, 181 (1988).

[11] R. Casalbuoni, P. Chiappetta, A. Deandrea, S. de Curtis, D. Dominici and R. Gatto, Z. Phys. C60, 315 (1993).

[12] R. Casalbuoni, P. Chiappetta, S. de Curtis, F. Feruglio, R. Gatto and J. Terron, Phys. Lett. B249, 130 (1990).

[13] R. Casalbuoni, S. de Curtis, A. Deandrea, N. di Bartolomeo, R. Gatto, D. Dominici and F. Feruglio, Nucl. Phys. B409, 257 (1993).