The BESS model revisited as a Higgsless Linear Moose @ the LHC

Stefania De Curtis[*][†]

INFN, 50019 Sesto F., Firenze, Italy
E-mail: decurtis@fi.infn.it

We study the phenomenological consequences of a four site Higgsless model based on the $SU(2)_L \times SU(2)_1 \times SU(2)_2 \times U(1)_Y$ gauge symmetry, which predicts two neutral and four charged extra gauge bosons, $Z_{1,2}$ and $W_{1,2}^{\pm}$. The model represents an extension of the minimal three site version (or BESS model), largely investigated in the literature, which includes three heavy vector bosons. We compute the properties of the new particles, and derive indirect and direct limits on their masses and couplings from LEP and Tevatron data and from the perturbative unitarity requirements. In contrast to other Higgsless models characterized by fermiophobic extra gauge bosons, here sizeable fermion-boson couplings are allowed by the electroweak precision data. The prospects of detecting the new predicted particles in the favoured Drell-Yan channel at the LHC are thus investigated. The outcome is that all six extra gauge bosons could be discovered in the early stage of the LHC low-luminosity run.

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[*]Speaker.

[†]In collaboration with E. Accomando, D. Dominici, and L. Fedeli

1. Introduction

During the last years a remarkable activity has been devoted to investigate Higgsless models because they emerge in a natural way when considering local gauge theories in five dimensions. Their major outcome consists in delaying the unitarity violation of vector boson scattering amplitudes to higher energies compared to the answer of the Standard Model (SM) without a light Higgs, via the exchange of Kaluza-Klein (KK) excitations. The discretization of the compact fifth dimension to a lattice generates the so-called deconstructed theories which are chiral lagrangians with a number of replicas of the gauge group equal to the number of lattice sites [1]. The drawback of all these models, as with technicolor theories, is to reconcile the presence of a relatively low KK-spectrum, necessary to delay the unitarity violation to TeV-energies, with the electroweak precision tests (EWPT) whose measurements can be expressed in terms of the $\varepsilon_1, \varepsilon_2$ and ε_3 (or T, U, S) parameters. This problem can be solved by either delocalizing fermions along the fifth dimension [2] or, equivalently in the deconstructed picture, by allowing for direct couplings between new vector bosons and SM fermions [3]. In the simplest version of this latter class of models, corresponding to just three lattice sites and gauge symmetry $SU(2)_L \times SU(2) \times U(1)_Y$ (the so-called BESS model [4]), the requirement of vanishing of the ε_3 parameter implies that the new triplet of vector bosons is almost fermiophobic, then the only production channels for their search are those driven by boson-boson couplings. The Higgsless literature has been thus mostly focused on difficult multi-particle processes which require high luminosity to be detected, that is vector boson fusion and associated production of new gauge bosons with SM ones. We extend the minimal three site model by inserting an additional lattice site. This new four site Higgsless model, based on the $SU(2)_L \times SU(2)_1 \times SU(2)_2 \times U(1)_Y$ gauge symmetry, predicts two neutral and four charged extra gauge bosons, $Z_{1,2}$ and $W_{1,2}^{\pm}$, and satisfies the EWPT constraints without necessarily having fermiophobic resonances [5]. Within this framework, the more promising Drell-Yan processes become particularly relevant for the extra gauge boson search at the LHC.

2. The model: Unitarity and EWPT bounds

The class of models we are interested in, called linear *moose* models, follows the idea of dimensional deconstruction [1]. In their general formulation they are based on the $SU(2)_L \otimes SU(2)^K \otimes U(1)_Y$ gauge symmetry, and contain $K + 1$ non linear σ-model scalar fields Σ_i, interacting with the gauge fields. The new parameters are the K gauge coupling constants g_i and the $K + 1$ link couplings f_i. Different f_i, in the continuum limit, can describe a generic warped metric. For details see [6]. Direct couplings of new gauge bosons to SM fermions can be included in a way that preserve the symmetry of the model. According to [3], we consider only direct couplings of the new gauge bosons to the left-handed fermions with strength given by the parameters b_i. The case $K = 1$ corresponds to the BESS model [4]. Here we concentrate on the case $K = 2$. For simplicity we will assume $g_1 = g_2$ and $f_1 = f_3$. This choice corresponds to a L-R symmetry in the new gauge sector, leading to a definite parity for the corresponding gauge bosons once the standard gauge interactions are turned off. The charged and neutral gauge boson spectrum and their couplings to fermions are given in [5]. Summing up, the parameters of the four site model are g_1, f_1, f_2, b_1 and b_2. In order to reproduce the physical values of the SM gauge boson masses, we get a

relation among the parameters of the model and we end with four free parameters: b_1, b_2 and M_1, M_2 (related to f_1, f_2 and equal to, apart from weak corrections, the mass eigenvalues of the two new triplet of gauge bosons). We will call z the ratio M_1/M_2, with $z < 1$.
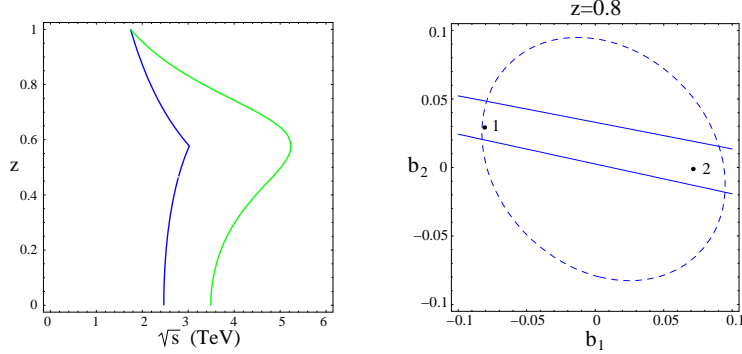

Figure 1: Left: Unitarity bounds on the plane $(\sqrt{s}, z)$, for $W_L W_L$ scattering amplitudes (green lighter curve), and for scattering amplitudes with external SM and extra gauge bosons (blue darker curve). The allowed regions are on the left of the curves. Right: 95% C.L. bounds on the plane (b_1, b_2) from ε_1 (dash line) and ε_3 (solid line) for $z = 0.8$ and $500 \leq M_1(\text{GeV}) \leq 1000$. The allowed regions are the internal ones. The points **1** and **2** correspond to the two scenarios considered in the following phenomenological analysis.

The four site Higgsless model is an effective description. The energy scale where the perturbative regime is still valid is plotted in Fig. 1. Owing to the exchange of the extra gauge bosons, the unitarity violation for the WW (all channels) longitudinal scattering amplitudes can be delayed up to $\sqrt{s} = 5(3)$ TeV [5]. Hence, the mass spectrum of the new particles is constrained to be within a few TeV. In general, the only way to combine the need of relatively low mass extra gauge bosons with EWPT is to impose the new particles to be fermiophobic. In our four site model this assumption is not necessary anymore. We get bounds on the parameter space of the model by deriving the new physics contribution to the electroweak parameters ε_1, ε_2 and ε_3 [7] and comparing with their experimental values. The result is shown in Fig. 1 for $z = 0.8$ and $500 \leq M_1(\text{GeV}) \leq 1000$. Here the bound from ε_3 goes from up to down by increasing M_1, that from ε_1 is quite insensitive to the value of the resonance masses (ε_2 doesn't give any relevant limit thanks to its negative experimental value). We see that, while the relation between the couplings b_1 and b_2 is strongly constrained by the ε_3-parameter, their magnitude is weakly limited by ε_1. As a result, the direct fermion-boson couplings can be of the same order of the SM ones. The phenomenological consequence is that the four site Higgsless model could be proved in the more promising Drell-Yan channel already at the LHC start-up.

3. Extra gauge boson production in Drell-Yan channels at the LHC

Let's now consider the production of the six new gauge bosons $Z_{1,2}$ and $W_{1,2}^{\pm}$ predicted by the four site Higgsless model at the LHC through Drell-Yan channels. We analyze two classes of processes: $pp \rightarrow l^+ l^-$ and $pp \rightarrow l\nu_l$, with $l = e, \mu$. The first class is characterized by two isolated charged leptons in the final state. The latter gives instead rise to one isolated charged lepton plus missing energy. The aforementioned neutral and charged Drell-Yan channels can involve the
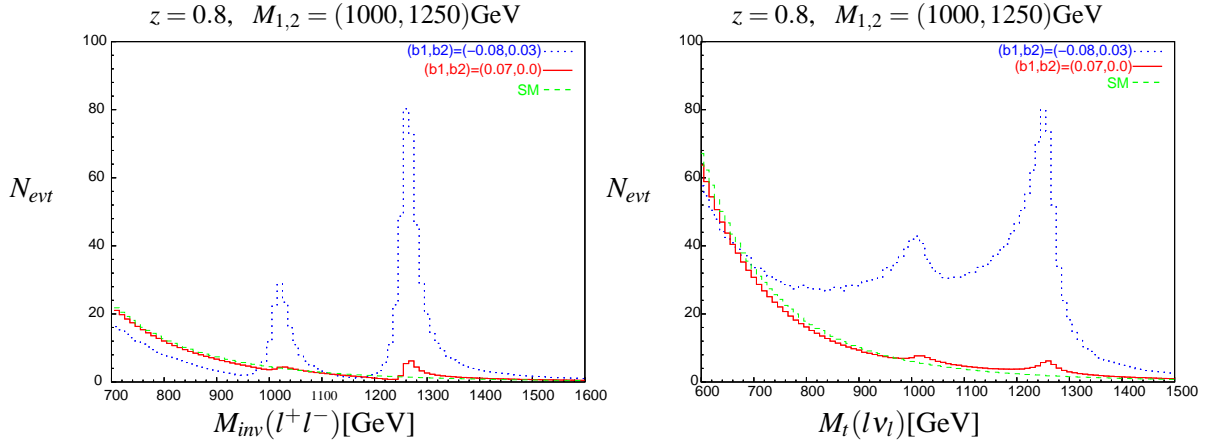
Figure 2: Total number of events in a 10 GeV-bin versus the dilepton invariant mass, $M_{inv}(l^+l^-)$ for the process $pp \to l^+l^-$ (left) and versus the lepton transverse mass, $M_t(l\nu_l)$ (right), for the process $pp \to l\nu_l$ at the integrated luminosity $L = 10$ fb^{-1} for $M_{1,2} = (1000, 1250)$GeV and the two scenarios **1**: $(b_1, b_2) = (-0.08, 0.03)$ and **2**: $(b_1, b_2) = (0.07, 0.0)$. We sum over e, μ and charge conjugate channels.

production of two neutral extra gauge bosons, Z_1 and Z_2, and four charged extra gauge bosons $W_1^{\pm}$ and $W_2^{\pm}$ as intermediate states, respectively.

Our numerical setup is here summarized: $M_Z = 91.187$GeV, $\alpha(M_Z) = 1/128.8$, $G_\mu = 1.1664 \cdot 10^{-5}$GeV^{-2}. We adopt the fixed-width scheme and apply standard acceptance cuts: $P_t(l) > 20$GeV, $P_t^{miss} > 20$GeV, $\eta(l) < 2.5$. The distribution functions CTEQ6L are used. As an example of the four site Higgsless model prediction, we choose two sets of free parameters: setup **1**: $(b_1, b_2) = (-0.08, 0.03)$ and setup **2**: $(b_1, b_2) = (0.07, 0)$ at fixed values $M_{1,2} = (1000, 1250)$GeV, corresponding to $z = 0.8$. We compute the full Drell-Yan process, considering signal and SM-background, at EW and QCD leading order. A luminosity L=10 fb^{-1} is assumed. In Fig. 2, we plot the distributions both in the charged and neutral Drell-Yan channels. For example, the number of signal (total) events in the range $|M_{inv}(l^+l^-) - M_{1,2}| < \Gamma_{1,2}$ for the neutral channel is $N_{evt}(Z_1) = 108(119)$ and $N_{evt}(Z_2) = 291(302)$ for the setup **1** and $N_{evt}(Z_1) = 3(28)$ and $N_{evt}(Z_2) = 15(22)$ for the setup **2**. The results show that, while the setup **2** would need high luminosity, in the first one the new gauge bosons could be discovered already at the LHC start-up, with a minimum luminosity L=1 fb^{-1}. A detailed analysis is given in [5].

In Fig. 3 we plot the 5σ-discovery contours at L=100 fb^{-1} in the plane $(\hat{a}_{2L}^e, M_2)$, where $\hat{a}_{2L}^e$ is the left-handed coupling between the Z_2-boson and the SM electron (in -e units) and M_2 is the Z_2-mass apart from weak corrections (see [5]). We consider $M_2 \le 2$ TeV in order to agree with the strongest partial wave unitarity bound shown in Fig. 1. In the dashed region, where only the Z_2-resonance is visible, the four site Higgsless model could be misidentified. A useful observable to distinguish it from other theories can be the forward-backward charge asymmetry A_{FB} [5].

The main information one gets from Fig. 3 is that the four site Higgsless model can be explored at the LHC in the favoured Drell-Yan channel, over a large portion of the parameter space. The same analysis has been performed in the charged channel [5] where the statistical significance can be about a factor two bigger than in the neutral one, however the charged Drell-Yan observables
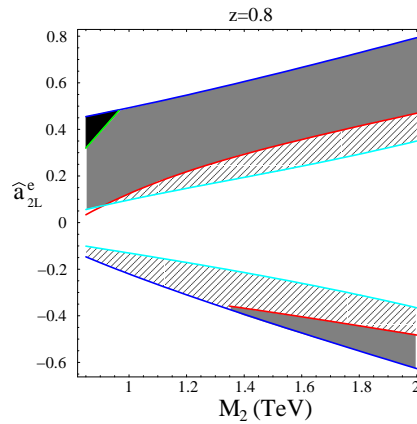
Figure 3: 5σ-discovery plot at L=100 fb^{-1} in the plane $(\hat{a}_{2L}^e, M_2)$ for $z = 0.8$. The upper and lower parts are excluded by EWPT, the black triangle is the region excluded by the direct search at the Tevatron for a luminosity of 4 fb^{-1}. Inside the dark-grey regions both $Z_{1,2}$ are visible; inside the grey (dashed) ones only Z_1 (Z_2) can be detected. Inside the central uncolored region no resonance is visible in the Drell-Yan channel.

are not that clean. In order to have a well defined information on the four site Higgsless model predictions, neutral and charged Drell-Yan channels are thus complementary. And, more important, there are regions in the parameter space where they could be both investigated for the search of all six extra gauge bosons, $W_{1,2}^{\pm}$ and $Z_{1,2}$, at the LHC start-up with a luminosity of the order of 1-2 fb^{-1} for $M_{1,2} \leq 1$ TeV. These results do not include the detector simulation. At present, this work is in progress, but we do not expect a drastic change in our conclusions owing to the very clean signals.

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