The four-site Higgsless model at the LHC

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Summary. — We consider the four-site Higgsless model, which predicts the existence of four charged and two neutral extra gauge bosons, $W_{1,2}^\pm$ and $Z_{1,2}$. In contrast to other Higgsless models, characterized by fermiophobic extra gauge bosons, here sizeable fermion-boson couplings are allowed by the electroweak precision data. We thus analyse the prospects of detecting the new predicted particles in the mostly favored Drell-Yan channel at the LHC.

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1. – Introduction

In recent years, a renewed attention has been focused on Higgsless models [1]. They emerge naturally from local gauge theories in five dimensions, and their major outcome is delaying the unitarity violation of vector-boson scattering (VBS) amplitudes to high energies by the exchange of Kaluza-Klein excitations [2]. Their common drawback is to reconcile unitarity with the ElectroWeak Precision Test (EWPT) bounds.

Within this framework, and in the attempt to solve this dichotomy, many models have been proposed. We concentrate on the so called deconstructed theories [3] which come out from the discretization of the fifth dimension to a lattice, and are described by chiral lagrangians with a number of gauge-group replicas equal to the number of lattice sites. The simplest version of this class of models is related to the old BESS model [4], a lattice with only three sites and $SU(2)_L \times SU(2) \times U(1)_Y$ gauge symmetry (for it, sometimes called three-site Higgsless model). In view of the LHC experiments, its phenomenological consequences have recently received a renewed attention. The investigated extra-gauge-boson production channels require however high luminosity to be detected. In order to reconcile unitarity and EWPT-bounds, this minimal version predicts indeed the new triplet of vector bosons to be almost fermiophobic. Hence, only di-boson channels, vector boson fusion and triple gauge boson production processes have been analysed [5].

We extend the minimal model by inserting an additional lattice site. This new four-site Higgsless model [6, 7], based on the $SU(2)_L \times SU(2)_1 \times SU(2)_2 \times U(1)_Y$ gauge symmetry, predicts four charged and two neutral extra gauge bosons, $W_{1,2}^\pm$ and $Z_{1,2}$, and...
satisfies the EWPT bounds without forcing the new resonances to be fermiophobic. As a consequence, they could be detected at the LHC in the promising Drell-Yan channel.

2. – Unitarity and EWPT bounds

The four-site Higgsless model is described by four parameters: $b_1, b_2, M_1, M_2$. These are related to the two direct couplings between $V_{1,2}$-bosons ($V=W,Z$) and SM fermions and the two $V_{1,2}$ masses (charged and neutral gauge bosons are degenerate), respectively. The introduction of $b_{1,2}$ represents the novelty of the proposed model. It allows to reconcile unitarity and EWPT bounds, leaving a calculable and not fine-tuned parameter space.

The energy range, where the perturbative regime is still valid is plotted in Fig.1L for different values of $z = M_1/M_2$. Owing to the exchange of the extra gauge bosons, the unitarity violation can be delayed up to an energy scale of about $\sqrt{s} \simeq 3$ TeV. Hence, the mass spectrum of the new particles is constrained to be within a few TeV.

In the literature, the only way to combine the need of relatively low mass extra gauge bosons with EWPT was to impose the new particles to be fermiophobic. In the four-site Higgsless model, this strong assumption is not necessary anymore. In Fig.1R, we plot the bounds on the charged fermion-boson couplings from the EWPT expressed in terms of the $\epsilon_{1,3}$ parameters. The outcome is that $\epsilon_3$ constraints the relation between the two couplings, while $\epsilon_1$ limits their magnitude. Neutral couplings share a similar behaviour. The allowed fermion-boson couplings are thus bounded, but still sizeable. We can then explore their phenomenological consequences in Drell-Yan production at the LHC.

3. – $W_{1,2}^{\pm}$ and $Z_{1,2}$ Drell-Yan production at the LHC

In this section, we discuss the prospects of detecting the six extra gauge bosons at the LHC. Our numerical setup is here summarized: $M_Z = 91.187$ GeV, $\alpha(M_Z) = 1/128.8$, $G_\mu = 1.1664 \times 10^{-5}$ GeV$^{-2}$. We adopt the fixed-width scheme and apply standard acceptance cuts: $P_t(l) > 20$ GeV, $P_t^{\text{miss}}(l) > 20$ GeV, $\eta(l) < 2.5$. The CTEQ6L is used. As an example of the four-site Higgsless model prediction, we choose two sets of free parameters: $(b_1, b_2) = (-0.075, 0.035)$ and $(b_1, b_2) = (0.085, -0.01)$ at fixed values $M_1 = 1$ TeV, $M_2 = 1.3$ TeV. 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 analyse both charged and neutral Drell-Yan channels. From top to bottom, the three curves represent the first setup, the latter and the SM prediction. In Fig. 2L, we plot the number of events in a 10-GeV bin as a function of the leptonic transvers mass, $M_T(l\nu_l)$, for the process $pp \rightarrow l\nu_l$. Fig. 2R shows instead the number of events in a 10-GeV bin as a function of the leptonic invariant mass, $M_{inv}(l^+l^-)$, for the process $pp \rightarrow l^+l^-$. The number of signal (total) events in the range $|M_{inv}(l^+l^-) - M_{1,2}| < \Gamma_{1,2}$ for the neutral channel is given by $N_{evt}(Z_1) = 83(96)$ and $N_{evt}(Z_2) = 242(254)$ for the first setup. The results show that, while the second setup 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 $L = 1\text{fb}^{-1}$.

4. – Conclusions

The four-site Higgsless model is calculable and not fined-tuned. It predicts the existence of six extra gauge bosons, $W_{1,2}^\pm$ and $Z_{1,2}$, which can have sizeable couplings to fermions. They could thus be seen in the favoured Drell-Yan channel at the LHC, even during its early-stage run at low luminosity. A detailed analysis will be given in Ref.[7].

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