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Effects of fermion localization in Higgsless theories and electroweak constraints

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Abstract

Extra-dimensional Higgsless models with electroweak symmetry breaking through boundary conditions generically have difficulties with electroweak precision constraints, when the fermions are localized to the “branes” in the fifth dimension. In this Letter we show that these constraints can be relaxed by allowing the light fermions to have a finite extent into the bulk of the fifth dimension. The T and U electroweak parameters can be naturally suppressed by a custodial symmetry, while the S parameter can be made to vanish through a cancellation, if the leakage into the bulk of the light gauge fields and the light left-handed fermion fields are of the same size. This cancellation is possible while allowing realistic values for the first two generations of fermion masses, although special treatment is probably required for the top quark. We present this idea here in the context of a specific continuum theory-space model; however, it can be applied to any five-dimensional Higgsless model, either with a flat or a warped background.

Keywords: Beyond Standard Model; Spontaneous symmetry breaking

1. Introduction

In the Standard Model (SM), the Higgs sector is responsible for electroweak symmetry breaking. The exchange of a virtual Higgs boson perturbatively unitarizes the longitudinal gauge boson scattering amplitude. Without a physical Higgs boson, the theory would break down around the TeV scale. Higgsless theories have been proposed [1], as alternatives to the SM, in which electroweak symmetry breaking is due to boundary conditions on gauge fields that propagate in five dimensions—the usual Minkowskian four dimensions plus an additional fifth spatial dimension. As is the usual practice, we refer to the extra-dimensional interval as the “bulk”, and its four-dimensional endpoints as “branes”. In Higgsless theories, even though

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a physical scalar Higgs boson is not present in the theory, it has been shown [2] that the onset of unitarily violation can be delayed due to new contributions from the Kaluza–Klein (KK) excitations of the gauge bosons. In our previous work [3] we used deconstruction [4] to obtain a Higgsless theory-space model with a $U(1) \times [SU(2)]^N \times SU(2)_{N+1}$ gauge structure. We found that perturbative unitarity violation could be delayed satisfactorily if the heavy vector boson states come in below about the TeV scale. The continuum limit of this theory-space model was a five-dimensional $SU(2)$ gauge theory with boundary conditions that break the theory to $U(1)$ on one of the branes and with gauge kinetic terms localized on both branes.

The issue of whether Higgsless theories are compatible with precision electroweak constraints is being actively investigated. In Ref. [5] it was shown that Higgsless theories have trouble satisfying precision electroweak constraints, even if brane-localized gauge kinetic terms are included. In our previous work [3], we showed that in our model, with standard model fermions confined to the branes, the contributions to electroweak observables could be described in terms of the oblique S, T and U parameters [6]. We found that owing to an approximate custodial symmetry, T (and U) was compatible with data, but S was in violation if the KK states had masses low enough to satisfy perturbative unitarity. Possibilities for reducing S in Higgsless theories have been found [7], but only at the expense of producing a negative value of T. In Ref. [8] it is claimed that it is not possible to set both the S and T parameters simultaneously to zero, even if the bulk gauge coupling is made position-dependent.

It is important to note that all of these conclusions about electroweak constraints apply specifically to Higgsless theories with light fermions bound to the branes. In this Letter we shall explore how these conclusions change when the light fermions are allowed to have some extension into the bulk.[1] We shall use the continuum theory from Ref. [3] as our model, although the basic results should be applicable to any Higgsless theory. In Section 2 we begin by describing the gauge sector, along with a recapitulation of the results from Ref. [3] with brane-localized fermions. We then extend this theory to incorporate fermions with some finite extension into the bulk. In Section 3 we show that in this Higgsless model, which contains bulk fermions as well as fermion brane kinetic terms, it will be possible to make all of the S, T and U parameters small enough to agree with the data. This will be the main result of this Letter. Finally, in Section 4, we will offer our conclusions and comment on some remaining issues to be tackled.

2. Higgsless theory with fermions

2.1. Gauge sector

As our toy model, we will consider the continuum limit of the theory of Ref. [3], which is arguably one of the simplest models of Higgsless electroweak symmetry breaking. This model is an $SU(2)$ gauge theory, defined on a fifth-dimensional line segment, $0 \leqslant y \leqslant \pi R$, where the boundary conditions break the gauge symmetry down to $U(1)$ at one end of the interval. The five-dimensional action is[2]

$$\mathcal{S} = \int_0^{\pi R} dy \int d^4x \biggl[-\frac{1}{4(\pi R)\hat{g}_5^2} W^{aMN} W^a_{MN} - \delta(y)\frac{1}{4g^2} W^{a\mu\nu} W^a_{\mu\nu} - \delta(\pi R - y)\frac{1}{4g'^2} W^{3\mu\nu} W^3_{\mu\nu} \biggr], \tag{2.1}$$

where, in this equation, the indices M, N run over the 5 dimensions, and we impose the Dirichlet boundary condition, $W^a_\mu = 0$, at $y = \pi R$ for $a \neq 3$. The boundary kinetic energy term at $y = 0$ is defined by interpreting the δ-function as $\delta(y - \epsilon)$ with $\epsilon \to 0^+$ and the fields having Neumann boundary conditions, $dW^a_\mu/dy = 0$, at $y = 0$. The δ-function and the field W^3_μ at $y = \pi R$ should be interpreted similarly. Note that in the limit of small g and g' the theory looks like an $SU(2)$ gauge theory and a $U(1)$ gauge theory, living

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[1] The idea of fermion de-localization as a potential mechanism to ease constraints from electroweak precision measurements was mentioned, but not pursued, in Ref. [5].

[2] Note that we have taken $y \leftrightarrow \pi R - y$ with respect to the action in Ref. [3]. We have also scaled out a factor πR in the first term in order to make $\hat{g}_5$ dimensionless.