Available online at www.sciencedirect.com
SCIENCE DIRECT
PHYSICS LETTERS B
Physics Letters B 607 (2005) 139–143
www.elsevier.com/locate/physletb

A not so little Higgs?

D.G. Sutherland

Department of Physics and Astronomy University of Glasgow, Glasgow G12 8QQ, Scotland, UK

Received 17 November 2004; received in revised form 14 December 2004; accepted 16 December 2004

Available online 22 December 2004

Editor: P.V. Landshoff

Abstract

Most recent models assuming the Higgs boson is a pseudo-Nambu–Goldstone boson (pNGb) are motivated by the indication from Standard Model fits that its mass is $\leqslant 200$ GeV. Starting from a modified SM of Forshaw et al. with a triplet boson added and a heavier Higgs boson, we consider a pNGb model. This differs in several ways from most little Higgs models: apart from using only one loop, the cutoff scale is reduced to 5 TeV, and consequently a linear sigma model is used to alleviate FCNC effects; no new vector bosons are required, but vector-like isosinglet fermions are needed, but play no part in determining the mass of the Higgs boson. The phenomenology of the isosinglet pNGb that arises from the $SU(3) \times SU(3) \to SU(3)$ model we use is briefly discussed. Some potential theoretical and phenomenological problems are mentioned briefly.

PACS: 12.60.Cn; 12.60.Fr

Keywords: Higgs boson; Pseudo-Goldstone boson

1. Introduction

The indication from Standard Model (SM) fits to precision data that the mass of the Higgs boson is $\leqslant 200$ GeV has motivated many recent, and often ingenious, models, the little Higgs models (LHMs). For reviews see [1]. Typically these models assume a global symmetry group at $\simeq 10$ TeV which breaks spontaneously to give Nambu–Goldstone bosons amongst which are the Higgs bosons. These acquire mass from radiative corrections, but the models are constructed so that the one loop quadratic divergences cancel, thereby ensuring a light enough Higgs boson.

Experimentally, however, there is only a lower bound on the mass of the Higgs boson. Soon after the precision data appeared several authors [2] considered how the limit on the mass could be raised by modest alterations of the SM. Amongst these was a model due to Forshaw and collaborators [3]. They showed that by adding a real triplet scalar boson with a small vacuum expectation value adequate fits to precision data with a Higgs boson mass of 500 GeV (and similar mass for the triplet) could be obtained.

E-mail address: d.sutherland@physics.gla.ac.uk (D.G. Sutherland).

0370-2693/$ – see front matter
doi:10.1016/j.physletb.2004.12.044

This suggests the possibility of a model where the Higgs boson is a pseudo-Nambu–Goldstone boson (pNGb), but the global group is taken at 5 TeV, and, since 0.5 TeV $\simeq \sqrt{\alpha} \times 5$ TeV there may be no need for extra gauge bosons, or fermions to ensure the cancellation of divergences. It transpires that it is possible to eliminate the need for extra gauge bosons, but extra fermions seem necessary, but are not constrained by contributing to the mass of the Higgs boson as in many LHMs.

The model is presented in the next section with a particular emphasis on the need to use a linear, as opposed to the non-linear sigma model generally used in LHMs. The next section gives the Coleman–Weinberg [4] potential of the model. The Coleman–Weinberg potential for the isoscalar partner η of the Higgs is given in the next section, and the phenomenology of the η is discussed briefly. In the final section some open problems which remain to be resolved are discussed, and a conclusion given.

2. The model

Forshaw et al. add a real triplet scalar field to the SM. One must then look for a group whose breaking will produce a triplet ϕ^i, a complex doublet H^a and possibly some singlets as commonly arise in addition in LHMs. Without considering product groups no candidate has appeared, but the group $SU(3) \times SU(3)$ which breaks to $SU(3)$ seems well suited to this purpose, and gives just one singlet η.

Unlike most LHMs a linear rather than non-linear sigma model is used. There are three reasons for this. First a comparison with Forshaw et al.'s field theoretical analysis would be difficult for the non-linear case as higher powers of fields suppressed only by powers of the breaking scale $f \simeq 0.5$ TeV would appear. Secondly recall the old paper of Georgi and Kaplan [5] who used this same group with a non-linear sigma model, but felt dissatisfied as precision tests required f too large, a view strengthened now by f being $\geqslant 3$ TeV [6]. Georgi and Kaplan did not consider a small triplet vev so that one might think that allowing this could improve the situation, but by using their exponential parameterization one finds that the triplet vev and the 'effective triplet vev' $O(v^2/f^2)$ where v is vev of H^0 are out of phase by $\pi/2$, so that the problem is made worse.

A third reason comes from the constraints of FCNC. Chivukula et al. [7] have argued that these constraints require a cutoff scale well above the 10 TeV of LHMs. Clearly if one lowers the scale to 5 TeV this problem becomes more serious. One remedy suggested [8] is to have the LH as a linear sigma model which arises as a little Higgs model from a scale an order of magnitude higher. Such an idea has recently been implemented for the $SU(3) \times U(1)$ LHM [9]. This again suggests the use of a linear sigma model, though it has to be stressed that no UV completion has yet been obtained for the $SU(3) \times SU(3)$ model.

Extra fermions, singlets under $SU(2)$, will now appear to fill triplets along with t and b quarks, as well as along with lighter quark multiplets. The extra singlets can give rise to FCNC problems by mixing with quarks of the first two generations. This has recently been analysed by Deshpande et al. [10] who find the strong constraint $|U_{ds}| \leqslant 1.2 \times 10^{-5}$ from rare K decays in a model with an extra charge $-1/3$ quark, where U_{ds} denotes the mixing between d and s induced by the extra quarks. Provided the singlet quarks are heavy, and the decreasing mixing between light and heavy quarks seen in the SM can be extended to new quarks, this constraint may (just) be satisfied.

3. The Coleman–Weinberg potential for ϕ and H

The scalar potential used by Forshaw et al. is given, in our notation, by

$$\mu_1^2|H^2| + \mu_2^2/2|\phi^2| + \lambda_1|H^4| + \lambda_2/4|\phi^4| + \lambda_3/2|H^2||\phi^2| + L_3, \tag{1}$$

where

$$L_3 = \lambda_4 \phi^i H^\dagger \sigma^i H. \tag{2}$$

One can ask how much of this potential can be produced by a Coleman–Weinberg mechanism. The Coleman–Weinberg potential gives rise to quadratically divergent coefficients of ϕ^2 and H^2, as well as logarithmic divergences for ϕH^2 and terms quartic in ϕ and H. The ϕH^2 term is novel and such a term will not arise in the Coleman–Weinberg effective potential generated using only SM gauge bosons and fermion