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ScienceDirect

Nuclear Physics B 900 (2015) 295–330

NUCLEAR PHYSICS B

www.elsevier.com/locate/nuclphysb

Dynamical origin of the electroweak scale and the 125 GeV scalar

Stefano Di Chiara [a,b], Roshan Foadi [a,b], Kimmo Tuominen [c,b], Sara Tähtinen [a,b]

[a] *Department of Physics, University of Jyväskylä, P.O. Box 35, FI-40014, University of Jyväskylä, Finland*
[b] *Helsinki Institute of Physics, P.O. Box 64, FI-000140, University of Helsinki, Finland*
[c] *Department of Physics, University of Helsinki, P.O. Box 64, FI-000140, University of Helsinki, Finland*

Received 17 June 2015; received in revised form 14 September 2015; accepted 21 September 2015

Available online 28 September 2015

Editor: Hong-Jian He

Abstract

We consider a fully dynamical origin for the masses of weak gauge bosons and heavy quarks of the Standard Model. Electroweak symmetry breaking and the gauge boson masses arise from new strong dynamics, which leads to the appearance of a composite scalar in the spectrum of excitations. In order to generate mass for the Standard Model fermions, we consider extended gauge dynamics, effectively represented by four fermion interactions at presently accessible energies. By systematically treating these interactions, we show that they lead to a large reduction of the mass of the scalar resonance. Therefore, interpreting the scalar as the recently observed 125 GeV state implies that the mass originating solely from new strong dynamics can be much heavier, i.e. of the order of 1 TeV. In addition to reducing the mass of the scalar resonance, we show that the four-fermion interactions allow for contributions to the oblique corrections in agreement with the experimental constraints. The couplings of the scalar resonance with the Standard Model gauge bosons and fermions are evaluated, and found to be compatible with the current LHC results. Additional new resonances are expected to be heavy, with masses of the order of a few TeVs, and hence accessible in future experiments.

E-mail address: stefano.dichiara@helsinki.fi (S. Di Chiara).

http://dx.doi.org/10.1016/j.nuclphysb.2015.09.013

1. Introduction

The discovery of the Higgs boson at the Large Hadron Collider (LHC) [1,2] established the Standard Model (SM) as an accurate description of elementary particle interactions [3–5]. However, it is know that the SM is incomplete: for example, the SM itself does not provide any clue towards understanding the generational structure and mass patterns of the matter fields. Furthermore, understanding the origin of dark matter or the baryon–antibaryon asymmetry continue to provide motivation for searches of viable beyond-the-Standard-Model (BSM) scenarios.

So far the LHC has shown no sign of new particles typically predicted by various BSM setups, such as Technicolour (TC) and its variants (see [6,7] for review). Furthermore, the lightest resonance in a model of dynamical electroweak symmetry breaking is naturally expected to be much heavier than $M_H \simeq 125$ GeV [8]. These premature concerns rest on treating new strong dynamics in isolation, i.e. without taking the interaction with the SM fields into account. A light scalar can arise from approximate global symmetries, as in models where the Higgs is a pseudo Goldstone boson associated with chiral symmetry [9–11] or scale invariance [12–16]. Another possibility is that the light SM-like scalar arises from strong dynamics due to peculiar decoupling, see [17]. However, only recently it has been realised that also with QCD-like TC dynamics the scalar particle can become light because of loop corrections originating from extended sectors, which are always required in TC models to account for the generation of fermion masses. In [8] a preliminary analysis, using simply SM-like Yukawa couplings to parametrise the effects from the coupling with the top quark, was carried out to point out this effect. In [18] this effect was investigated in a fully dynamical model setup of simple extended Technicolour (ETC). Within this model, a computation in the large-N limit was carried out, where N is the dimension of the technifermion representation under the TC gauge group. It was then possible to rigorously demonstrate a large reduction of the scalar mass from the value arising solely from new strong dynamics. The amount of fine tuning involved is on the tolerable level of a few per cent [18]. However, the model considered in [18] was simple and devised only to illustrate this effect, and it could not be used for a realistic description of the origin of all mass scales of the SM.

In this paper we present a necessary further development of the model framework described above. We use a chiral fermion model, similar to the Nambu–Jona-Lasinio model (NLJ), to account for TC dynamics, and augment it with a whole set of four-fermion operators, low-energy remnants of ETC interactions. We show that the mechanism featured in [18] for the reduction of the scalar mass also works in this case, and that the effective couplings of the composite Higgs particle with the SM particles are very close to the SM-Higgs couplings, and hence compatible with the LHC data.[1] We also compute the oblique corrections and demonstrate the viability of the model with respect to the electroweak precision data. One of our robust and generic findings within this framework is that in order to reduce the Higgs mass from values near 1 TeV, natural for new strong dynamics, to 125 GeV, the ETC interactions must be strongly coupled. However, we only consider scenarios in which the ETC interactions, although strong, are not strong enough to generate fermion condensation. Therefore, we complement the analysis of [20], where a model with strong ETC dynamics and weak TC interactions was considered.

Model building of the full gauge dynamics required by ETC theories is challenging [21]. Our effective theory, formulated in terms of four fermion couplings, and taking into account only the third generation quarks, can hopefully be seen as a stepping stone towards more complete dy-

[1] See also [19] for a related study.