Light composite Higgs and precision electroweak measurements on the Z resonance: An update

Dennis D. Dietrich,[1] Francesco Sannino,[1] and Kimmo Tuominen[2,3]

[1]*The Niels Bohr Institute, Copenhagen, Denmark*

[2]*Department of Physics, University of Jyväskylä, Finland*

[3]*Helsinki Institute of Physics, University of Helsinki, Finland*

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We update our analysis of technicolor theories with techniquarks in higher dimensional representations of the technicolor gauge group in the light of the new electroweak precision data on the Z resonance.

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I. INTRODUCTION

In [1], we analyzed technicolor theories [2,3] for the breaking of the electroweak symmetry with the techniquarks in higher representations of the gauge group [4]. In this paper we concentrate on a particular model introduced in [1], and denoted by $S(2, 2)$ there. The $S(2, 2)$ model has the minimal techniquark content consisting only of two techniflavors in the two-index symmetric representation of the gauge group $\mathrm{SU_T}(2)$. In [1] this theory was identified as being consistent with the electroweak precision data available to that date [5].

At the same time, this theory is quasiconformal [6,7] (walking coupling). This feature is a necessity for being able to generate sufficiently high masses for the ordinary fermions. It also helps avoiding inconsistently large flavor-changing neutral currents and lepton number violation due to extended technicolor interactions [8,9]. Remarkably, also due to the walking, this special choice for the number of technicolors, techniflavors, and the representation leads to a predicted mass of the (nonelementary) Higgs of only 150 GeV.[1] [2] For this particular setup, in order to avoid the Witten anomaly [12], an additional family of leptons has to be included, which, amongst other things, provides possible nonhadronic components of dark matter. For the masses of these leptons we were able to make accurate predictions based on the electroweak precision data at hand. Since then new data has become available [13]. It, at the 68% level of confidence, leads to a considerably larger parameter space for the lepton masses than was expected previously at the 90% level of confidence.

Widely independently of this, in [1] we had given an overview of the expected spectrum of technicolor-neutral particles in the $S(2, 2)$-model. However, there, we did not mention that any number of techniquarks in the two-index symmetric representation of $\mathrm{SU_T}(2)$ can be made technicolor neutral by adding technigluons. This is so since for $\mathrm{SU_T}(2)$ the two-index symmetric representation coincides with the adjoint representation. The potentially lowest-lying technihadrons of this kind are bound states made out of one techniquark and technigluons. From the viewpoint of the standard model, such bound states possess only weak interactions and mimic an additional lepton family. However, they also interact directly via the technicolor sector.

II. ANALYSIS FOR THE NEW DATA

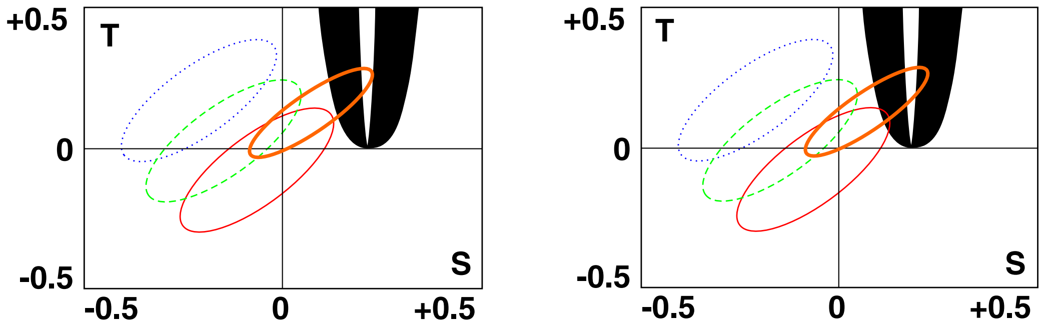
After having fixed the number of particles, the gauge group, and the representation, it still remains to define the hypercharge assignment, which is constrained but not fixed entirely by imposing the absence of gauge anomalies. We have studied the following cases [1,14]: (I) a standard - model-like case, in which the leptons are neutral and singly negatively charged, respectively; (II) a case, in which the leptons carry half elementary charges with opposite signs; (III) a singly and a doubly negatively charged lepton. Apart from various hadronic objects in all cases, in (I) the fourth neutrino is a natural dark matter candidate.

The black shaded areas in Figs. 1 and 2 show the accessible range of values of the oblique parameters S and T [15][3] for degenerate techniquarks and if the masses of the leptons are varied independently in the range from one to ten Z-boson masses. The value of the third oblique parameter U is close to zero for our model, consistent with presented data. The larger staggered ellipses in all of these plots are the 90% confidence level contours from the global fit to the data presented in [5]. The smaller single ellipse represents the 68% confidence level contour from the new global fit on the Z-pole in Appendix E of [13]. The new fit presents a clear shift of the confidence contours towards small but positive values of the S parameter. Unfortunately, it is not easy to pin down, from the presentation in the

[1]It is relevant to note that even for technicolor theories resembling QCD the scalar sector is not simply described by just a heavy composite Higgs. One might also observe for these type of technicolor theories at CERN-LHC a scalar substantially lighter than 1 TeV. This composite scalar is the direct analog of the QCD scalar $f_0(600)$ [10] and it is expected to be a four quark object.

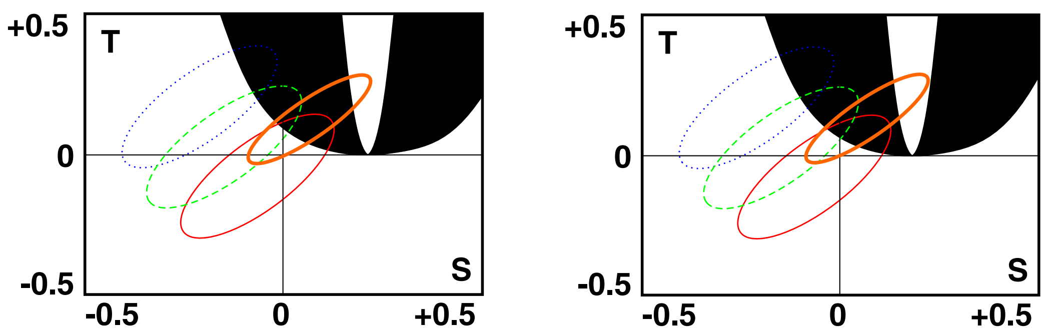
[2]Light Higgs bosons can also be found in other approaches, like, for example, in top-seesaw models [11].

[3]These parameters measure the contribution of the non–standard model particles to the vacuum polarization of the gauge bosons. Roughly speaking, S is connected to the mixing of the photon with the Z-boson and T to contributions to the violation of the isospin symmetry.



(a) Perturbative (b) Non-perturbative

FIG. 1 (color online). Standard model–like charge assignment. Left Panel: The area shaded in black corresponds to the accessible range for S and T with the masses of the extra neutrino and extra electron taken from m_Z to $10m_Z$. The perturbative estimate for the contribution to S from techniquarks equals $1/2\pi$. The three staggered ellipses are the 90% confidence level contours for the former global fit to the electroweak precision data [5] with U kept at 0. The values of U in our model lie typically between 0 and 0.05 whence they are consistent with these contours. These contours from bottom to top are for Higgs masses of $m_H = 117$, 340, 1000 GeV, respectively. The smaller ellipse to the upper right is the 68% confidence level contour for the new global fit to electroweak precision data [13] with $U = 0$ and for a Higgs $m_H = 150$ GeV as predicted for our model. Right Panel: With nonperturbative corrections to the S parameter taken into account in the technicolor sector of the theory.



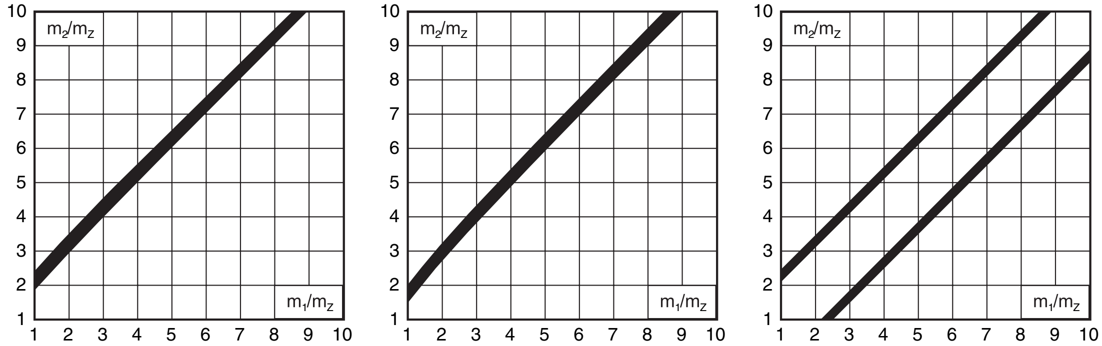
(a) Perturbative (b) Non-perturbative

FIG. 2 (color online). Leptons with integer charges. Left Panel: The parabolic area shaded in black corresponds to the accessible range for S and T with the masses of the extra neutrino and extra electron taken from m_Z to $10m_Z$. The perturbative estimate for the contribution to S from techniquarks equals $1/2\pi$. The three staggered ellipses are the 90% confidence level contours for the former global fit to the electroweak precision data [5] with U kept at 0. The values of U in our model lie typically between 0 and 0.05 whence they are consistent with these contours. These contours from bottom to top are for Higgs masses of $m_H = 117$, 340, 1000 GeV, respectively. The smaller ellipse to the upper right is the 68% confidence level contour for the new global fit to electroweak precision data [13] with $U = 0$ and for a Higgs $m_H = 150$ GeV as predicted for our model. Right Panel: With nonperturbative corrections to the S parameter taken into account in the technicolor sector of the theory.

experimental review papers, a specific reason for this change.[4]

Even though it can be considered as a conservative estimate, already the perturbative assessment of the oblique parameters in our theories shows a considerable overlap with the data [see Figs. 1(a) and 2(a)]. In nearly conformal theories like ours the contribution of the techniquarks is further reduced by nonperturbative effects [17,18]. This reduction is of the order of 20% [18]. In the case of the integerly charged leptons (III), the nonperturbative contributions do not change the characteristics of the results (see Fig. 2). The same holds for the fractionally charged leptons (II). No dedicated plot has been devoted to that case because it corresponds to a vertical line exactly in the opening of the area shaded in black in the other plots. Put differently, the black area is contracted to zero width in the direction of S. The situation is slightly different for the standard-model-like charges, where an additional overlap with the right branch of the black area is achieved. This

[4]It is, however, clear that the NuTeV data are not included in the analysis of [13]. The implications of the NuTeV data are still under active discussion, see e.g. [16] and it would certainly be very interesting to investigate their effects in the future.



(a) Standard-model-like (I) (b) Integer charges (III) (c) Fractional charges (II)

FIG. 3. The shaded areas depict the range for the masses of the new leptons which are accessible due to the oblique corrections in accordance with the electroweak precision data without taking into account nonperturbative corrections. m_1 (m_2) is the mass, in units of m_Z, for the lepton with the higher (lower) charge. The black stripes do not correspond exactly to the overlap of the parabolic area with the 68% ellipse in the (S, T)-plane from [13] but with a polygonal area defined by $-0.1 < S + T < +0.5$, $-0.15 < S - T < +0.025$, and $S < 0.22$. After taking into account nonperturbative corrections subfigures (b) and (c) stay qualitatively the same, while for not too small masses (a) has a second branch with $m_1 < m_2$ like in (c). This corresponds to the overlap of the ellipse with the right branch of the parabolic area in Fig. 1(b) as opposed to Fig. 1(a).

corresponds to a second branch in the relative plot shown in Fig. 3. For our model, the expected mass of the composite Higgs is 150 GeV [1]. Let it be noted that, even if it was as heavy as 1 TeV there would still be an overlap between the measurements and the values attainable in our model. This can also be achieved in top-seesaw models [19]. Regarding Fig. 1, we can also remark how the models with different numbers of technicolors considered in [1] would appear with respect to the precision data. The models with techniflavors in the two-index antisymmetric representation are excluded by the precision data [1,7]. In the model with two technifermion flavors in the two-index symmetric representation of the gauge group $SU_T(3)$ (denoted by $S(3, 2)$ in [1]) there is no Witten anomaly and hence no need to introduce the new fermion generation. The contribution of the techniquarks yields $S = 0.32$ and $T = 0$. Taking into account the possible reduction of 20% leads to $S = 0.25$, a value close to the tip of the shaded parabola in Fig. 1.

Let us then set aside the other variants and continue to analyze in detail the $S(2, 2)$-model. Translating the overlap depicted in the perturbative versions of Figs. 1 and 2 to values of the lepton masses favored at the 68% level of confidence leads to the plots in Fig. 3. For technical reasons, the exact intersection of the parabolic shape with the interior of the ellipse is not presented but instead with the interior of a polygon characterized by: $-0.1 < S + T < +0.5$, $-0.15 < S - T < +0.025$, and $S < 0.22$. In all investigated cases there exists a branch for which the more negatively charged lepton (m_2) is about one Z-boson mass (m_Z) heavier than the more positively charged lepton (m_1). The mass gap of approximately one m_Z is mostly dictated by the limits in the $(S - T)$-direction. The second branch with $m_1 > m_2$ is usually forbidden by the limits imposed on S. This does not affect the situation for the fractionally charged leptons (II), which yield no variation in S as a function of their masses. Incorporating nonperturbative corrections leads to a second branch for not too small masses in the standard model–like situation (I). This corresponds to the overlap of the ellipse with the right half of the black area in Fig. 1(b).

III. SUMMARY

In light of the fact that new relevant electroweak precision data have appeared very recently we have investigated the consequences for the technicolor theory with two techniflavors in the two-index symmetric representation of $SU_T(2)$ and one additional lepton generation presented in [1]. We found that the range of masses of the leptons, consistent with the new data at the 68% level of confidence [13], is much larger than with the previous data at the 90% level of confidence [5]. The comparison of our theory with the new precision measurements further strengthens our claim that certain technicolor theories are directly compatible with precision measurements.

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