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

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Abstract

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

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I. INTRODUCTION

In [1], we analysed technicolour theories [2, 3] for the breaking of the electroweak symmetry with the techniquarks in higher representations of the gauge group [4]. We identified theories with two techniflavours in the two-index symmetric representation of $SU_T(2)$ as being consistent with the electroweak precision data available to that date [5]. At the same time, this theory is quasi-conformal [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 flavour-changing neutral currents and lepton number violation due to extended technicolour interactions [8, 9]. Remarkably, also due to the walking, this special choice for the number of technicolours, techniflavours, and the representation leads to a predicted mass of the (non-elementary) Higgs of only 150 GeV $^1$. For this particular set-up, in order to avoid the Witten anomaly [11], an additional family of leptons has to be included, which, amongst other things, provides possible non-hadronic 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 [12]. 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 technicolour-neutral particles. However, there, we did not mention that any number of techniquarks in the two-index symmetric representation of $SU_T(2)$ can be made technicolour neutral by adding technigluons. This is so since for $SU_T(2)$ 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 technicolour sector.

$^1$ It is relevant to note that even for technicolour theories resembling QCD the scalar sector is not simply described by just a heavy composite Higgs. One might also observe for these type of technicolour theories at CERN-LHC a scalar substantially lighter than one 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.
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 \[1,13\]: (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 $T$\footnote{These parameters measure the contribution of the non-standard-model particles to the vacuum polarisation 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.} 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 \cite{13}. The smaller single ellipse represents the 68\% confidence level contour from the new global fit in \cite{12}.

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. 1a and 2a). In nearly conformal theories like ours the contribution of the techniquarks is further reduced by non-perturbative effects \cite{16,17}. This reduction is of the order of 20\% \cite{17}. 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 corresponds to a second branch in the relative plot shown in Fig. 3. For our model, the expected mass of the composite Higgs is 150GeV \cite{1}. Let it be noted that, even if it was as heavy as 1TeV there...
would still be an overlap between the measurements and the values attainable in our model.

Translating the overlap depicted in the perturbative versions of Figs. 1 and 2 to values of the lepton masses favoured at the 68% level of confidence leads to the plots in Fig. 3. For technical reasons not the exact intersection of the parabolic shape with the interior of the ellipse is presented but with the interior of a polygon characterised 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 non-perturbative 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. 1b.

III. SUMMARY

In light of the fact that new relevant electroweak precision data have appeared very recently we have investigated the consequences for the technicolour theory with two techniflavours in the two-index symmetric representation of $\text{SU}_{T}(2)$ 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 [12], 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 technicolour theories are directly compatible with precision measurements.

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FIG. 1: 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 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 with $U = 0$ and for a Higgs $m_H = 150$ GeV as predicted for our model. Right Panel: With non-perturbative corrections to the $S$ parameter taken into account in the technicolour sector of the theory.
FIG. 2: 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 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 with $U = 0$ and for a Higgs $m_H = 150$GeV as predicted for our model. **Right Panel:** With non-perturbative corrections to the $S$ parameter taken into account in the technicolour sector of the theory.
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 non-perturbative 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 [12] 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 non-perturbative 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. 1b as opposed to Fig. 1a.