

Dynamical electroweak symmetry breaking by quasiconformal technicolour theories

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In technicolour (TC) theories, the electroweak (EW) symmetry is broken by chiral symmetry breaking (χ SB) in an additional strongly interacting sector, added to the standard model (SM) without elementary Higgs sector. Quasiconformal, that is, walking technicolour (WTC) models with matter in higher representations of the technicolour gauge group are viable candidates for breaking the electroweak symmetry dynamically. They are not at odds with available electroweak precision data. Here, we start with a brief introduction into dynamical electroweak symmetry breaking by technicolour theories. Subsequently, we discuss the phase diagram of strongly interacting theories in the N_c - N_f -plane or, equivalently, the d_R - N_f -plane, where N_c stands for the number of colours, N_f for the number of flavours, and d_R for the dimension of the representation; and how to relate said phase diagram to the task of finding candidates for quasiconformal technicolour models. Continuing from there, we select the prime candidates [among them Minimal Walking Technicolour (MWT)] by using constraints from available electroweak precision data like, for example, bounds on flavour changing neutral currents (FCNCs), oblique parameters and the masses m_π of extra Nambu–Goldstone modes. The latter issue is also linked to the stability of the vacuum. We discuss the features of selected candidates in more detail. Their signals can be detected at the LHC, they feature dark matter (DM) candidates, and they are being studied actively with lattice computations, nonperturbative β -function techniques as well as AdS/CFT methods.

*The 2009 Europhysics Conference on High Energy Physics,
July 16 - 22 2009
Krakow, Poland*

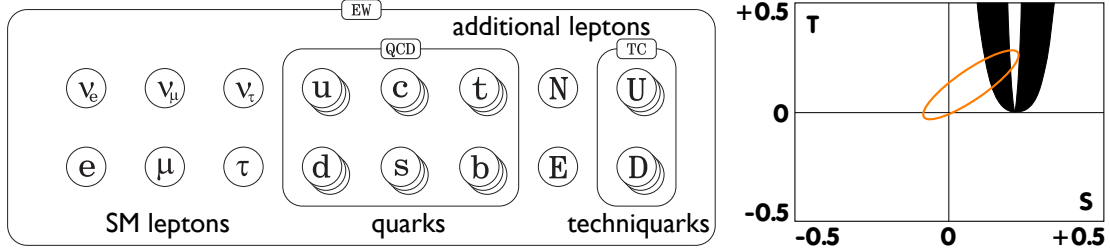


Figure 1: Lhs: TC using the example of MWT. Rhs: MWT vs. oblique parameters [1, 2].

In the SM the Higgs breaks the EW symmetry while preserving gauge invariance, perturbative renormalisability and unitarity. It is, however, as yet undiscovered and would be the first elementary scalar. On all other occasions in which we observe a Higgs phenomenon, like in superconductivity, the scalar dof is composite. There is no dynamical explanation for its negative mass term. As elementary scalar its mass is not symmetry protected and is thus quadratically divergent.

A way to break the EW symmetry (dynamically) without any elementary scalars is TC [3]. In TC, the EW symmetry is broken through χ SB in a strongly interacting, EWly charged sector with N_f technifermions added to the SM without its Higgs sector. The gauge group is $\mathcal{G}_{\text{SM}} \times \mathcal{G}_{\text{TC}}$. [See Fig. 1 (lhs).] For the corresponding pion decay constant we have $N_f f_\pi^2 = 2\Lambda_{\text{ew}}^2$, where Λ_{ew} is the EW scale. 3 of the possibly more pions are absorbed as longitudinal dofs of the weak gauge bosons. The mass of the composite scalar is protected by the chiral symmetry (χ S). At variance with the SM, the unitarity of the theory is not the sole responsibility of this composite scalar.

Available EW precision data requires that the TC sector have walking dynamics to reconcile the creation of the mass of the top quark through extended TC [3] interactions with the bounds on FCNCs. A small matter content is demanded by the bounds on the oblique parameters [4]. Potential additional pions must be sufficiently massive to escape the direct detection limits. The alignment of the EW gauge group in the flavour symmetry group must be stable [5].

A walking theory is one whose matter content is such that the χ S breaks just before an IR fixed point is reached. In that case, just before the χ S breaks, the β -function is almost zero. [See case E in Fig. 2 (lhs).] Consequently, the coupling constant stays constant for a big range of scales, which enhances the techniquark condensate through renormalisation effects. For constructing such a theory we can vary the gauge group (N_c), N_f , and the rep of the gauge group wrt which these flavours transform. For $SU(N_c)$ gauge groups and without partial gauging [6], we find [7] the lower bounds of the conformal windows in Fig. 2 (rhs). Walking theories lie slightly below these lines.

For walking theories, the oblique S -parameter is reduced wrt its perturbative value $12\pi S_{\text{pert}} = d_R N_f^g$. Experimental data requires it to be small, hence, using S_{pert} is conservative. Accordingly, the most favourable model is MWT [6, 8] with 2 adjoint flavours of $SU(2)$ plus 2 leptons to avoid a Witten anomaly. For Fig. 1 (rhs), we vary their masses between 1 and $10 m_Z$, compute the oblique S and T parameters, and find considerable overlap with the experimental 68%-confidence ellipse.

The adjoint is a real rep and the flavour symmetry of MWT is enhanced to $SU(4) \rightarrow SO(4)$ leading to 9 pions. The 3 technimesons are absorbed as longitudinal dofs of the weak gauge bosons and the remaining 6 are technibaryons. Depending on the hypercharge assignment (constrained but not fully fixed by requiring the absence of gauge anomalies), some of the latter can be electrically

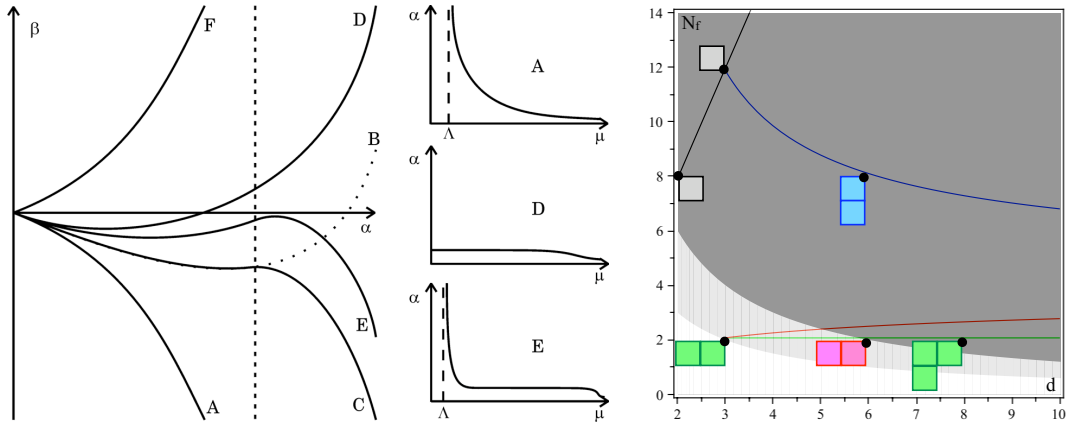


Figure 2: Lhs: Behaviour of the β -function as a function of the coupling α and of the coupling as a function of the energy scale μ , depending on the matter content of the theory, from [9]. A) Little matter; B) perturbative Caswell–Banks–Zaks fixed point; C) actual shape due to χ SB; D) realised fixed point; E) walking case; F) loss of asymptotic freedom. Short-dashed line: critical value of the coupling for χ SB. Rhs: Lower bounds of the conformal window in the d_R - N_f -plane for the (from top to bottom) fundamental (black), 2-index-antisymmetric (blue), 2-index-symmetric (red) or adjoint (green) rep of $SU(N_c)$. White area: $\pi S_{\text{pert}} < 1/2$, light-gray: $\pi S_{\text{pert}} < 1$. The Young tableaux indicate some walking theories [7].

neutral and thus, candidates for DM [10]. The EW contribution to m_π is typically $> m_Z$ [11], which takes them outside the direct exclusion limit for technimesons. They are, however, technibaryons, which can only be produced in pairs. The positive contribution to m_π^2 stabilises the embedding of the EW gauge group in the flavour symmetry group, which ensures the correct breaking of the former. The 2 flavours of next-to-MWT transform under the [non(pseudo)real] 2-index symmetric rep of $SU(3)$. The corresponding basic $SU(2)_L \times SU(2)_R \rightarrow SU(2)_V$ breaking yields only the 3 longitudinal modes of the weak gauge bosons and the correct vacuum alignment is no issue.

Dynamical electroweak symmetry breaking by WTC is feasible. Bounds on FCNCs, oblique parameters, and m_π can be reconciled with the generation of SM fermion masses by walking together with techniquarks in higher reps of the TC gauge group. WTC models can be detected at the LHC [12] and feature DM candidates [10]. WTC theories are actively investigated with nonperturbative β -function techniques [9, 14], AdS/CFT methods [13] and lattice computations [15]. There are many more candidates beyond MWT & NMWT [7] (with full or partial gauging [6]).

The work of DDD was supported by the Danish Natural Science Research Council.

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