Technicolour and Electroweak-Scale Strong Dynamics

James Barry

29 March 2010

1 Introduction

"If the force underlying the fermion condensate driving electroweak symmetry breaking is due to a strongly interacting gauge theory, these models are termed technicolour." [9]

1.1 Dynamical Electroweak symmetry breaking

There are two main avenues beyond the Standard Model [14]:

1. Extrapolating the Standard Model far beyond the EW scale: SUSY, grand unified symmetries, higher-dimensional space-time symmetries, string theory.

2. New strong interactions at TeV energies: composite W-bosons, a composite top-quark, **technicolour** or large extra dimensions.

1.2 Superconductivity vs. EWSB

- In superconductors, two electrons (or other fermions) bind together at low temperatures, to form Cooper's pairs. These "condense" to the ground state, leading to superconductivity.

- The Higgs mechanism is like superconductivity in the vacuum, EWSB leads to massive gauge bosons & massive fermions (via Yukawa couplings).

1.3 From colour to technicolour

- In QCD, when coupling becomes strong at $\Lambda_{\rm QCD}$, light quarks form condensates, breaking chiral symmetry, resulting in three "massless" spin-0 pions (the Goldstone bosons of QCD dynamical symmetry breaking).

- There is a natural generation of different scales in QCD: $\dfrac{\Lambda_{\rm QCD}}{M_{\rm Pl}} \sim 10^{-20}$.

- If QCD is the only source of EWSB (no Higgs mechanism), then pions are "eaten" to become longitudinal modes of $W^{\pm}$ and Z. This gives $M_W \approx 29$ MeV, which is too low. However, the correct ratio M_W/M_Z is reproduced.

- This motivates the addition of a new strong QCD-like interaction at the EW scale.

2 Technicolour basics

- TC: an additional non-abelian and strongly interacting gauge theory augmented with (techni) fermions.
- Intrinsic scale $\sim$ a few TeVs.
- Higgs mechanism without Higgs particle: W/Z are pions of new strong dynamics.
- First introduced in the late 1970s – b quark was the heaviest known quark, top quark expected at 15 GeV.

2.1 Pure technicolour: a simple model

- "Pure" technicolour is simply QCD at a higher scale.
- Introduce N_D doublets of massless technifermions, and an $SU(N_{TC})$ gauge group. The usual left-handed doublets and right-handed singlets of (techni) quarks.
- When TC force becomes confining, the technifermion condensate breaks the chiral symmetry, but now the energy scale is around the EW scale.
- These new (techni) objects are not observed in nature, thus we need to explain the decay of techniquarks into light leptons and quarks (see ETC).

2.2 Scaling rules: from QCD to QTD

QCD has a set of scaling rules which characterise its behaviour:

These rules can be extended to TC theories:

2.2.1 Some numbers

We can use a simple bottom-up approach to get a feel for the numbers involved:

2.3 TC model examples

3 Extended technicolour

- Pure TC models do not include masses for SM fermions.
- Extended technicolour (ETC) models have a new gauge interaction, $\mathcal{G}_{ETC}$, which contains techniflavour and SM flavour as subgroups.
- Can have mixing between technifermions and SM fermions, leading to mass terms for the SM fermions.

The scales of TC and ETC can be summarised as follows:

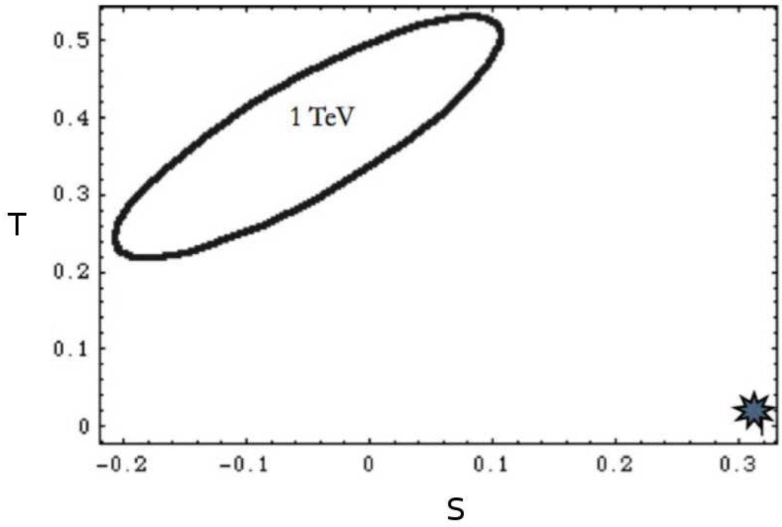

Figure 1: T against S for $SU(3)$ technicolour with one technifermion doublet (the full asterisk), and precision data for a 1 TeV composite Higgs mass.

4 Problems with technicolour models

There are two main problems with TC models:

- **FCNCs**: the ETC interactions are not necessarily flavour diagonal. This leads to further constraints on the ETC parameters, and it turns out that the resulting masses for the SM quarks are too small.
- **EW precision constraints**: It's hard to calculate amplitudes for WZ or WW scattering in TC models. Using lowest order perturbation theory, the naive estimate for the S parameter turns out to be too large (Fig. 1). (A. Kartavstev's talk.)

Note that the main problems come from assuming that TC is "QCD-like", i.e., that the coupling constant runs in the same way.

4.1 A possible solution: "walking" TC

- In near conformal theories, the coupling remains large and nearly constant over a wide range of energies, these are termed "walking" theories.
- Leads to large anomalous dimensions, difficult to calculate.
- Walking coupling can enhance the mass scale to get realistic fermion masses.
- Precision EW tests? There is speculation that S is smaller in a walking theory, but no systematic derivation.
- Various other more exotic theories have been proposed: dynamical 'tumbling', special 3rd generation dynamics (Topcolour-Assisted Technicolour (TC2)), conformal technicolour ....

5 Alternative theories

An intermediate solution is that of a composite Higgs boson, i.e., the Higgs is a pseudo-Goldstone boson [11]. This is in a sense a combination of technicolour and the usual EWSB mechanism.

- The Higgs "pion" gets a VEV
- There is a new strong sector, with the Higgs lighter than all the other resonances
- In simple TC there are only 3 GBs, here there are 4
- These ideas can be extended to "holographic" extra-dimensional models

There is effectively a two-step process of symmetry breaking:

6 Summary and conclusions

- TC uses strong dynamics to break EWS, generating the mass scale difference $v_{EW} \ll \Lambda_{UV}$ naturally.
- To get SM fermion masses with gauge interactions alone (no scalars) we need ETC.
- ETC can lead to problematic FCNCs; in addition, the simplest TC theories are in conflict with EW precision observables.
- Walking technicolour is a possible solution to these problems, but it is difficult to calculate the anomalous dimension in these theories.
- An alternative is the composite Higgs model, which is naturally realised in holographic theories with extra dimensions.

References

[1] S. Weinberg, “Implications Of Dynamical Symmetry Breaking,” Phys. Rev. D **13**, 974 (1976); “Implications Of Dynamical Symmetry Breaking: An Addendum,” Phys. Rev. D **19**, 1277 (1979).

[2] L. Susskind, “Dynamics Of Spontaneous Symmetry Breaking In The Weinberg-Salam Theory,” Phys. Rev. D **20**, 2619 (1979).

[3] E. Farhi and L. Susskind, “Technicolor,” Phys. Rept. **74**, 277 (1981).

[4] R. S. Chivukula, “Technicolor and compositeness,” [arXiv:hep-ph/0011264].

[5] S. F. King, “Dynamical Electroweak Symmetry Breaking,” Rept. Prog. Phys. **58**, 263 (1995) [arXiv:hep-ph/9406401].

[6] C. T. Hill and E. H. Simmons, “Strong dynamics and electroweak symmetry breaking,” Phys. Rept. **381**, 235 (2003) [Erratum-ibid. **390**, 553 (2004)] [arXiv:hep-ph/0203079].

[7] K. Lane, “Two lectures on technicolor,” [arXiv:hep-ph/0202255].

[8] A. Martin, “Technicolor Signals at the LHC,” [arXiv:0812.1841 [hep-ph]].

[9] F. Sannino, “Conformal Dynamics for TeV Physics and Cosmology,” [arXiv:0911.0931 [hep-ph]].

[10] R. Contino, “New Physics at the LHC: Strong vs Weak symmetry breaking,” [arXiv:0908.3578 [hep-ph]].

[11] R. Contino, Y. Nomura and A. Pomarol, “Higgs as a holographic pseudo-Goldstone boson,” Nucl. Phys. B **671**, 148 (2003) [arXiv:hep-ph/0306259].

[12] R. Contino, “The Higgs as a Pseudo-Goldstone boson,” TASI Lectures, 2009, `http://physicslearning2.colorado.edu/tasi/tasi_2009/tasi_2009.htm`.

[13] A. Martin, “Electroweak-Scale Strong Dynamics,” Lectures at Parma International School of Theoretical Physics 2009, `http://www.pr.infn.it/snft/2009/LectureNotes/Martin/`.

[14] W. Buchmuller, “Summary & Outlook: Particles and Cosmology,” [arXiv:1003.1078 [hep-ph]].