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Editorial

Review of fundamental composite dynamics

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Abstract This editorial provides a summary of the issues that our compendium, *Review of Fundamental Composite Dynamics* aims to address and an outline of the essays that appear in this collection.

With the discovery of the Higgs boson at the Large Hadron Collider (LHC), the Standard Model (SM) of High Energy Physics has been verified to a very good extent, the theory is consistent, renormalizable and unitarily complete and several electroweak observables predicted by the Standard Model have been verified to a high degree of precision in experiments. Of these, the observables in the gauge sector have provided the most precise comparison with experiment, while the fermion sector has met with more moderate success in this respect. The scalar sector, i.e the observables related to the Higgs sector, are the ones that have been studied the least. Taking a more positive view of the situation, one can say that it is the Higgs sector of the Standard Model that provides us a better chance to search for new physics—physics that purports to go Beyond the domain of the SM (BSM). It provides us the opportunity to understand theoretically, and probe experimentally, the possibility to have new physics related to the electroweak scale. In fact, the discovery of a new scalar resonance has not solved any of the shortcomings of the Standard Model, most notably the problem of the stability of the electroweak scale versus any higher scale (hierarchy problem with the Grand Unification and Planck scales), a dynamical explanation for electroweak symmetry breaking, and the presence of Dark Matter in the universe.

Many extensions of the Standard Model have been proposed in the past years with the aim of solving or easing the tension due to the hierarchy problem: supersymmetry, technicolor, Little Higgs and composite Higgs models being among the most popular. However, each model has been challenged by the absence of signals of new physics at the LHC so far. The reason behind this is the fact that most models predict the presence of new particles (often coloured) at a mass scale around a TeV. Especially in the most explored search channels—SUSY-like missing energy signatures and searches for new resonances—the results of LHC Run-II have now pushed such a scale close to or above a TeV, thus forcing many models to a corner of the parameter space. Indeed, to survive in the margins of the parameter spaces these models have to be invoked in rather fine-tuned incarnations.

In the current situation, models of strong dynamics play a special role. The possibility that the observed Higgs is a composite state of a strong dynamics is still viable. Higgs couplings to the SM fields, in the most accurately measured channels, agree with the SM predictions within an accuracy of about 10%, within which new physics can be present. These couplings will keep being tested in the next runs at the LHC and at future experiments. If the Higgs is realised as (part of) the pseudo-Nambu–Goldstone (pNGB) sector of strong dynamics with a TeV scale decay constant, deviations of its couplings at the order of a few percent are natural. Note that precisions below 1% are expected at future colliders, both at e^+e^- Higgs factories (ILC and/or FCC-ee) and at higher energy hadron colliders (FCC-hh) or electron–proton collisions (FCC-he). Other pNGBs, which are common in microscopic realisations of composite Higgs models, provide the most natural candidates for BSM resonances at or below the TeV scale. Remarkably, fundamental models of strong dynamics usually predict other non-pNGB resonances to be fairly heavy, naturally expected at masses in the multi-TeV range. This fact would explain why such states have escaped detection at the LHC so far, but may be a natural target for future high energy colliders. This simple discussion shows that future colliders, planned to achieve high precision (typically at leptonic colliders) as well as high energy (in hadronic ones),will

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be very effective in probing models of compositeness for the Higgs boson.

A review of models of composite dynamics and their implications is very much the need at the present juncture because, while a lot of new work has been recently published, the subject has a long history and some of the ideas in this area of research have been around for the last 40 years or so. While all the older models and ideas may not now be tenable, there are some of these which could still be relevant. It is, therefore, important to contextualize the subject in terms of this history. It is with this motivation that this review was embarked upon, hoping that current researchers will be able to find not just a discussion of the most recent papers but also their historical antecedents.

The review begins with an introduction to Composite Models [1] which helps bring to fore the most important issues that need to be discussed in the light of recent theoretical developments and in anticipation of new data from experiments, which may shed light on these theories. The introduction also helps set up the lexicon and grammar which is useful in contextualising the other contributions to this collection.

While the introduction provides an overview of the theory of composite models, the first essay [2] discusses attempts to go beyond the Standard Model which do not invoke low-energy supersymmetry. In particular, the warped extra dimensional models pioneered by Randall and Sundrum and the holographic interpretation of such models are discussed. These models do form an important part of composite model building and this essay, therefore, forms an important part of this review.

Another important class of composite models [3] do not venture into extra dimensions but use four-dimensional gauge theories with specific group-theoretic constructions of the fermionic sector. The construction and predictions of such models are described in detail in this essay.

The spike in the interest in composite models in the post-Higgs era has led to the rapid development of numerical tools to analyse such models. This essay [4] is a valuable account of the available tools and a comparison of their efficacy in analysing models of composite physics.

Lepton flavour physics provides an important sightpost into composite physics. The theory of flavour physics in the context of leptons, the phenomenological consequences and a discussion of experimental constraints and future prospects is reviewed in this essay [5].

Spin-1 resonances are ubiquitously present in composite models and may very likely provide the first signatures of such models. The theory and phenomenology of realistic models with spin-1 resonances are discussed [6] and the search prospects in experiments outlined.

In composite models that resemble QCD, massive vector mesons can be shown to be dark matter candidates. A detailed review of such dark meson theories is presented [7].

Pseudo-Goldstone bosons of non-minimal composite Higgs models are also viable dark matter candidates and such models and their implications for dark matter searches has been reviewed [8].

In some models of composite physics, bound states of fermions can work as inflaton fields that fuel the process of cosmic inflation. The viability of such models in countenancing cosmological constraints is discussed [9].

Finally, the experimental searches for vector-leptons and quarks or W' and Z' bosons, all of which are important predictions of composite theories, are discussed, the constraints on the parameters of the models derived from these searches are presented and the prospects for future colliders are also discussed briefly [10].

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