Composite Higgs theories

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The Standard Model (SM) of particle physics, although its extraordinary success in explaining the big amount of data collected by high-energy colliders, cannot in any sense be considered the ultimate theory for the description of fundamental interactions, firstly because, as it is, it does not provide any description of gravity. Secondly, most of its parameters (at least 18) cannot be deduced from first principles, needing to be put by hand in the Lagrangian. Although the discovery of the Higgs has been such an historical breakthrough both from the theoretical and experimental standpoint, most of our current dissatisfaction about the SM comes from the Higgs boson itself. The principle of Naturalness, first introduced by t' Hooft in [6], states that some of the parameters of a physical theory are allowed to take very small values with respect to the other parameters only if, setting the former ones to zero, would increase the symmetry of the system. This argument, together with considering the SM as an effective field theory [5], leads to the hierarchy problem concerning the huge separation between the electroweak scale $v = 246\,\mathrm{GeV}$ and the Planck mass $m_{Pl} \sim 10^{19}\,\mathrm{GeV}$, or at least the grand–unification scale $\Lambda_{GU} \sim 10^{15}\,\mathrm{GeV}$.

A part from supersymmetry (see [8]), another vaible solution to assure a small mass for a scalar field is to assume that it is a composite bound state of some new gauge force and fermion sector [2, 4, 3]. In particular, in this picture the Higgs boson corresponds to a pseudo-Nambu-Goldstone boson (pNGB) generated by the spontaneous breaking, at a scale $f \gg v$, of the approximate global symmetry of the underlying new fermions, in perfect analogy with spontaneous chiral symmetry breaking occurring in QCD. Together with the Higgs boson, other pNGB may be delivered because of the spontaneous symmetry breaking, possibly leading to a rich and interesting phenomenology to be observed at colliders. Then, the Naturalness problem has turned now into the problem of finding a mechanism that accounts for a big scale separation between v and f. This is exactly the statement that the SM is an effective theory describing the behavior at the electroweak scale of a fundamental (high-energy, also called ultra-violet) theory without any fundamental scalar. It is worth mentioning that in the limit where $v/f \to 0$ all SM predictions are recovered [1]. However, the requirement of a big scale separation is highly non-trivial, since it may reintroduce some “eccessive” fine-tuning in the theory: this is what is called the “Vacuum misalignment problem”.

Currently, my work deals with the study and the building of so called Half-composite two-Higgs doublet models (see [7] for a review on 2HDM), where one of the two scalar particles is composite, while the other is fundamental, of course provided with a natural value for the mass. In these models, Electroweak-symmetry-breaking (EWSB) is achieved through an interplay between these two distinct particles, and one can consider different regions of parameter space, where the particle corresponding to the SM Higgs is mainly elementary [1], mainly composite, or lies in between these two pictures.

[1] Only for what concerns the observed particle sector, because of the possible existence of a plethora of other pNGB interacting with usual matter, which go on to exist even in this limit, being a byproduct of the spontaneous symmetry breaking.

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