Snowmass 2021 LoI, Composite Higgs

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Models of composite Higgs with partial compositeness in the top-quark sector give promising solutions to the hierarchy problem also providing candidates for dark matter, mechanisms for baryogenesis and a path for unification of forces.

In gauge theory realizations of compositeness, there are always additional pseudo Nambu-Goldstone bosons (pNGB): an interesting (and less studied) class of models is one where the neutral components of the multiplets (other than the Higgs boson) do not get a vacuum expectation value. In this case, the neutral scalars easily evade all LEP bounds and no corrections to the tree-level ρ-parameter arise. The main interactions with the vector bosons are given by calculable dimension five operators involving the field strength, as well as dimension four operators from the kinetic terms. Couplings to fermions are also quite relevant, although more model-dependent. (See, *e.g.*, refs. [1, 2] and references therein for details on these constructions.)

Those models may also feature singly-charged and doubly-charged scalars, as well as colored pNGBs (heavier due to the one-loop contribution of the SM vector bosons to their mass).

In this proposal, we plan to focus on the associated phenomenology at present and future hadron and lepton colliders.

• **Hadron colliders (HL-LHC, FCC-hh):** Neutral scalars for which gluon-fusion processes are available (in analogy to the Higgs boson) could still be copiously produced at LHC but are hard to discriminate from the background [3]. In contrast, neutral pNGBs interacting only with the electroweak sector are characterized by low cross-sections. In this case, the most promising channels are pair production in double pNGB-strahlung or via loops of colored particles, analogously to SM di-Higgs production. Single production via dimension five operators or loop-induced single production in association with the Higgs boson are also appealing possibilities.

Turning to the charged sector, among the interesting decays of singly- and doubly-charged scalars we note the $\phi^{++} \to W^+W^+$ channel leading to a same-sign W-boson system [4], and to signatures characterised by multi-leptons and multi-jets potentially with sizable missing transverse energy.

Searches for top partners or more general vector-like quarks (VLQs) required by partial compositeness must also be re-assessed in the light of additional pNGBs by studying decay modes in addition to the usual triad $T \to t\,Z, t\,h, b\,W$.

In principle, all charge-conserving decays of type $Q \to q\,\phi$ can occur, where Q is a VLQ and q a SM quark. These exotic decays $T/X \to t/b\,\phi$ might even be the most promising discovery channel in some regions of parameter space [5, 6, 7].

Work on simulation tools is on-going and needs to be completed and enlarged to investigate boosted object techniques. There is also the need to include full QCD NLO corrections in the simulation, extending the minimal simplified model parameterization of refs. [8, 9]

• **Lepton colliders:** If the measurements at the LHC (and HL-LHC) are consistent with the SM, a future precision machine will give further insight whether naturalness could be addressed via the vacuum misalignment mechanism.

For light neutral scalars, the presence of a coupling of type $\phi Z^{\mu\nu}\tilde{F}_{\mu\nu}$ induces modifications to the Z line shape that can be probed at a future e^+e^- collider, given that enough Z bosons are produced, and that they decay via $Z \to \gamma\,\phi$. Their light masses make them very hard to probe at the LHC. In contrast, future e^+e^- machines could open new avenues thanks to the high luminosity, in particular via the still overlooked $\gamma\,\phi$ final state [10].

In addition, the presence of the two effective couplings [11] $\partial_\mu\phi\,hZ^\mu$ and $h\phi\phi$, arising from higher dimensional operators before EWSB, can modify the h decay rates. The relevant processes are $h \to Z\,\phi$ and $h \to \phi\,\phi$ and can be probed in Higgs-factory mode. Such Higgs decay modes can also be of interest at the HL-LHC as possible ϕ production modes, see e.g. [12].

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