The Strong Multi-Pole Interaction Scenario

Da Liu[a]

[a] *Center for Quantum Mathematics and Physics (QMAP), University of California, Davis, CA 95616, USA*

Email: daeliu@ucdavis.edu

This LoI is of interest to TF08/TF07/EF09/EF02.

Motivation: from Precision to Scale

The Large Hadron Collider (LHC) at CERN has entered into the high luminosity era with center-of-mass energy at 13 TeV or 14 TeV, where a great amount of data will be accumulated [1]. Although direct resonance searches will continue to be one of main efforts at the LHC, the possibility to perform precision measurement has drawn much attention recently [2–4]. The new physics effects on the SM processes below the masses of the resonances can be captured by the higher dimensional operators in the effective field theory approach [5–7]. In general, the LO observables in the low energy processes are the dimension-six operators [8]. So given a SM process, by dimensional analysis, the contribution from new physics effects compared with SM can be expressed as:

$$\frac{\delta\sigma}{\sigma_{\rm SM}} \sim \left(\frac{g_*}{g_{\rm SM}}\right)^n \frac{E^2}{m_*^2}. \tag{1}$$

Here g_*, m_* is the typical coupling, mass scale in the new physics sector. The expected size of g_* and the power n is strongly dependent on the assumption about the UV dynamics at the scale m_*. Given a precision δ_E in the energy bin E, we can reach scale as $m_* \sim \left(\frac{g_*}{g_{\rm SM}}\right)^{\frac{n}{2}} \frac{E}{\sqrt{\delta_E}}$. We can clearly see that to reach the same mass scale, one needs less precision if the cross section is measured in the larger energy bin, which is the advantage of the LHC compared with LEP. One can also infer that precision measurement will be more relevant for searching for new physics of strong dynamics with large coupling g_* and the large power n.

Strong Multi-Pole Interaction Scenario

Model	$\mathcal{O}_H$	$\mathcal{O}_{2W}$	$\mathcal{O}_{2B}$	$\mathcal{O}_{3W}$	$\mathcal{O}_{HW}$	$\mathcal{O}_{HB}$	$\mathcal{O}_{W,B}$	$\mathcal{O}_{BB}$	$\mathcal{O}_{y_\psi}$
SILH	g_*^2	$\frac{g^2}{g_*^2}$	$\frac{g'^2}{g_*^2}$	$\frac{g^3}{16\pi^2}$	$g\,\frac{g_*^2}{16\pi^2}$	$g'\,\frac{g_*^2}{16\pi^2}$	g, g'	$g'^2\,\frac{y_t^2}{16\pi^2}$	$y_\psi g_*^2$
SMPI		1	1	g_*					
SMPI+MCHM	g_*^2	1	1	g_*	g	g'	g, g'	g'^2	$y_\psi g_*^2$
SMPI+ ISO(4)	λ_h	1	1	g_*	g_*	g'	g, g'	g'^2	$y_\psi \lambda_h$

Table 1: The expected size of the Wilson coefficients in different scenarios.

Motivated by the argument above, in Ref. [9], we have constructed a structurally robust scenario that the SM transverse gauge bosons are part of the strong dynamics. In this scenario, the SM gauge couplings g, g' arise as small deformations of the symmetry of the new strong sector, where the multipolar interactions of the gauge bosons respect the symmetry and can be enhanced by the strong coupling g_*. In other words, the strong dynamic shows itself manifestly in the higher-derivative interactions of the gauge bosons. In the pure SMPI scenario, the $SU(2)_{\rm local}$ gauge group in the standard model can be considered as the smooth deformation of the semidirect product group $SU(2)_{\rm global} \ltimes U(1)^3_{\rm local}$, which is assumed to be the symmetry of the strong dynamics. Alternatively, one can view $SU(2)_{\rm global} \rtimes U(1)^3_{\rm local}$ as Inonu-Wigner contraction of the gauge group $SU(2)_{\rm local}$ with respect to its global subgroup $SU(2)_{\rm global}$ [10]. Simple power-counting rules select $\mathcal{O}_{3W}$ as enhanced by the strong coupling and the $\mathcal{O}_{2W,2B}$ have $\mathcal{O}(1)$ Wilson coefficient. One can enlarge the symmetry group of the strong sector to incorporate the Higgs boson as part of the strong dynamics, which is strongly motivated by the hierarchy problem. Broadly we can two options: $SO(5) \times \widetilde{SU(2)} \times U(1)_X \to SO(4) \times \widetilde{SU(2)} \times U(1)_X$ denoted as SMPI + MCHM and $ISO(4) \times U(1)_X \to SO(4) \times U(1)_X$ denoted as SMPI + ISO(4), where the $ISO(4)$ is isometric group of the 4D Euclidean space $SO(4) \rtimes T^4$. The resulting expected size of the Wilson coefficients are presented in Table 1. In particular, we see that the operator $\mathcal{O}_{HW}$ is enhanced by the strong coupling g_* in the second case, which provides an interesting correlation between the anomalous triple gauge boson couplings $\delta g_1^Z, \delta\kappa_\gamma$ and the $hZ\gamma$ vertex $\delta g_{hZ\gamma}$:

$$\delta g_1^Z = \frac{\delta\kappa_\gamma}{\cos^2\theta_W} = \frac{\delta g_{hZ\gamma}}{\sin\theta_W \cos\theta_W} \tag{2}$$

In Snowmass21, we plan to study the relevance of the dipole observables and the flavor processes in the SMPI scenario as we expect these operators involved the gauge boson field strengths and can be potentially enhanced by the strong coupling [11].

References

[1] **ATLAS, CMS** Collaboration, "Addendum to the report on the physics at the HL-LHC, and perspectives for the HE-LHC: Collection of notes from ATLAS and CMS," *CERN Yellow Rep. Monogr.* **7** (2019) Addendum, `arXiv:1902.10229 [hep-ex]`.

[2] A. Biekötter, A. Knochel, M. Krämer, D. Liu, and F. Riva, "Vices and virtues of Higgs effective field theories at large energy," *Phys. Rev. D* **91** (2015) 055029, `arXiv:1406.7320 [hep-ph]`.

[3] R. Franceschini, G. Panico, A. Pomarol, F. Riva, and A. Wulzer, "Electroweak Precision Tests in High-Energy Diboson Processes," *JHEP* **02** (2018) 111, `arXiv:1712.01310 [hep-ph]`.

[4] D. Liu and L.-T. Wang, "Prospects for precision measurement of diboson processes in the semileptonic decay channel in future LHC runs," *Phys. Rev. D* **99** no. 5, (2019) 055001, `arXiv:1804.08688 [hep-ph]`.

[5] G. F. Giudice, C. Grojean, A. Pomarol, and R. Rattazzi, "The Strongly-Interacting Light Higgs," *JHEP* **06** (2007) 045, `arXiv:hep-ph/0703164 [hep-ph]`.

[6] R. Contino, M. Ghezzi, C. Grojean, M. Muhlleitner, and M. Spira, "Effective Lagrangian for a light Higgs-like scalar," *JHEP* **07** (2013) 035, `arXiv:1303.3876 [hep-ph]`.

[7] J. Elias-Miro, J. R. Espinosa, E. Masso, and A. Pomarol, "Higgs windows to new physics through d=6 operators: constraints and one-loop anomalous dimensions," *JHEP* **11** (2013) 066, `arXiv:1308.1879 [hep-ph]`.

[8] B. Grzadkowski, M. Iskrzynski, M. Misiak, and J. Rosiek, "Dimension-Six Terms in the Standard Model Lagrangian," *JHEP* **10** (2010) 085, `arXiv:1008.4884 [hep-ph]`.

[9] D. Liu, A. Pomarol, R. Rattazzi, and F. Riva, "Patterns of Strong Coupling for LHC Searches," *JHEP* **11** (2016) 141, `arXiv:1603.03064 [hep-ph]`.

[10] E. Inonu and E. P. Wigner, "On the Contraction of groups and their represenations," *Proc. Nat. Acad. Sci.* **39** (1953) 510–524.

[11] D. Liu , work in progress.