On the effect of composite resonances in EWPT and Higgs decay to Two Photons.

Antonio Enrique Cárcamo Hernández.

Universidad Técnica Federico Santa María.

Les Rencontres de Physique de La Valle d'Aoste, 24th February-2rd March of 2013.

Based on: A. E. Cárcamo Hernández, Claudio O. Dib and Alfonso R. Zerwekh, to appear.

Introduction.

A $\sim$ 126 GeV Higgs boson has been found at the LHC. It remains to determine whether Electroweak Symmetry Breaking (EWSB) is weakly or strongly coupled.

- Weakly coupled, as the Standard Model (SM), 2HDM, Multi Higgs Models, Little Higgs, Gauge Higgs Unification models, $SU(3)_C \otimes SU(3)_L \otimes U(1)_X$ models (3-3-1 models), GUT and their supersymmetric extensions.
- Strongly coupled, as Technicolor, Composite Higgs, Strongly Interacting Light Higgs (SILH), Composite Higgs with composite Vectors, Randall-Sundrum (RS) models, RS models with condensing $4th$ generation, Holographic Composite Higgs Models, 10^{32} SM copies, Full Hierarchy Quiver Theories (FHQT).

The hierarchy problem provides a plausible motivation for considering strongly coupled theories of EWSB.

Effective Chiral Lagrangian with spin-0 and spin-1 fields.

$$U(x) = e^{i\hat{\pi}(x)/v}, \qquad \hat{\pi}(x) = \tau^a \pi^a, \qquad u \equiv \sqrt{U}, \qquad B_\mu = \frac{g'}{2}\tau^3 B_\mu^0,$$
$$D_\mu U = \partial_\mu U - iB_\mu U + iUW_\mu, \qquad W_\mu = \frac{g}{2}\tau^a W_\mu^a, \qquad R_\mu = \frac{1}{\sqrt{2}}\tau^a R_\mu^a,$$
$$R = V, A, \qquad \hat{X}_{\mu\nu} = \nabla_\mu X_\nu - \nabla_\nu X_\mu, \qquad X = R, u \qquad u_\mu = iu^\dagger D_\mu U u^\dagger,$$
$$\nabla_\mu R = \partial_\mu R + [\Gamma_\mu, R], \qquad \Gamma_\mu = \frac{1}{2}\left[u^\dagger\left(\partial_\mu - iB_\mu\right)u + u\left(\partial_\mu - iW_\mu\right)u^\dagger\right].$$

Here we make the following assumptions:

1. Before weak gauging, the Lagrangian responsible for EWSB has a $SU(2)_L \times SU(2)_R$ global symmetry.
2. The strong dynamics produces a composite triplet of parity even and parity odd vectors V and A as well as two composite scalar singlets h and H and one composite pseudoscalar singlet η under $SU(2)_{L+R}$. These resonances have masses below the cut-off $\Lambda \simeq 4\pi v \approx 3\,\text{TeV}$.
3. The spin-1 states couple to fermions only via SM gauge interactions.
4. The light scalar singlet of mass $m_h = 125$ GeV interacts with the Standard Model gauge bosons and fermions only via weak gauging and (proto)-Yukawa couplings, respectively. The heavy scalar H and pseudoscalar η are fermiofobic.

$$
\begin{aligned}
\mathcal{L} \;=\; & \frac{v^2}{4}\left\langle D_\mu U D^\mu U^\dagger \right\rangle - \frac{1}{2g^2}\left\langle W_{\mu\nu}W^{\mu\nu}\right\rangle - \frac{1}{2g'^2}\left\langle B_{\mu\nu}B^{\mu\nu}\right\rangle \\
& + \frac{c_{WB}}{4}\left\langle U^\dagger W_{\mu\nu} U B^{\mu\nu}\right\rangle + \sum_{R=V,A}\left[-\frac{1}{4}\left\langle R_{\mu\nu}R^{\mu\nu}\right\rangle + \frac{1}{2}M_R^2 R_\mu R^\mu\right] \\
& - \frac{f_V}{2\sqrt{2}}\left\langle V^{\mu\nu}\left(uW_{\mu\nu}u^\dagger + u^\dagger B_{\mu\nu}u\right)\right\rangle + \frac{f_A}{2\sqrt{2}}\left\langle u_{\mu\nu}A^{\mu\nu}\right\rangle + \mathcal{L}_{contact} \\
& - \frac{ig_V}{2\sqrt{2}}\left\langle V^{\mu\nu}\left[u_\mu, u_\nu\right]\right\rangle - \frac{if_A}{2\sqrt{2}}\left\langle\left(uW_{\mu\nu}u^\dagger + u^\dagger B_{\mu\nu}u\right)\left[A^\mu, u^\nu\right]\right\rangle \\
& - \frac{i\kappa f_A}{2\sqrt{2}}\left\langle u_{\mu\nu}\left[V^\mu, u^\nu\right]\right\rangle + \sum_{S=h,H,\eta}\left[\frac{1}{2}\partial_\mu S\partial^\mu S + \frac{m_S^2}{2}S^2\right] + \mathcal{L}_{3A,u} \\
& + \sum_{S=h,H}\left[\alpha_S S\left\langle u_\mu u^\mu\right\rangle + \beta_S S\left\langle V_\mu V^\mu\right\rangle + \gamma_S S\left\langle A_\mu A^\mu\right\rangle + \delta_S S\left\langle A_\mu u^\mu\right\rangle\right] \\
& + \beta_\eta\left\langle V_\mu u^\mu\right\rangle\eta - \frac{v}{\sqrt{2}}\sum_{i,j}\left(\bar{u}_L^{(i)} d_L^{(i)}\right) U\left(1 + a_{hff}\frac{h}{v}\right)\begin{pmatrix}\lambda_{ij}^u u_R^{(j)} \\ \lambda_{ij}^d d_R^{(j)}\end{pmatrix} \\
& + \alpha_\eta\left\langle V_\mu A^\mu\right\rangle\eta + \mathcal{L}_{2V} + \mathcal{L}_{2A} + \mathcal{L}_{1V,1A} + \mathcal{L}_{3V} + \mathcal{L}_{V,2A} + \mathcal{L}_{Au,2V} \\
& + \mathcal{L}_{4V} + \mathcal{L}_{4A} + \mathcal{L}_{2V2A} + \mathcal{L}_{2h} + \mathcal{L}_{2H} + \mathcal{L}_{2\eta} + \mathcal{L}_{hH} + \mathcal{L}_{h\eta} + \mathcal{L}_{H\eta}.
\end{aligned}
$$

We restrict to the case where this Lagrangian is based on the symmetry $G = SU(2)_L \times SU(2)_C \times SU(2)_D \times SU(2)_R$. Then, V_μ and A_μ are linear combinations of the gauge bosons of the hidden local symmetry $SU(2)_C \times SU(2)_D$ and of the SM gauge fields. In that case the different parameters (excepting c_{WB}) are functions of M_V and M_A, for example:

$$f_V \equiv \frac{1}{g_C} = \sqrt{\frac{1}{1-\kappa}}\frac{v}{M_V}, \quad f_A = -\kappa f_V, \quad g_V = \frac{1-\kappa^2}{2} f_V, \quad \kappa = \frac{M_V^2}{M_A^2}.$$

To cancel the growth of the $\pi\pi \to \bar{\psi}\psi$ scattering amplitude one has:

$$a_{hff} = \frac{1}{a_{hWW}}.$$

V_μ, h and H unitarize the elastic WW scattering, therefore a_{hWW} is different from 1. This situation is different than in the SM where $a_{hff} = a_{hWW} = 1$.

Decay rate for $h \to \gamma\gamma$

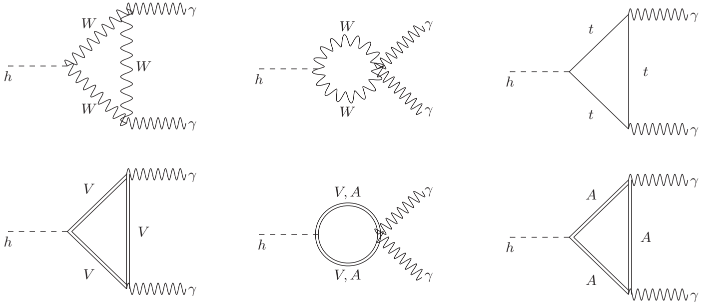


Figure: One loop Feynman diagrams in the Unitary Gauge contributing to the $h \to \gamma\gamma$ decay.

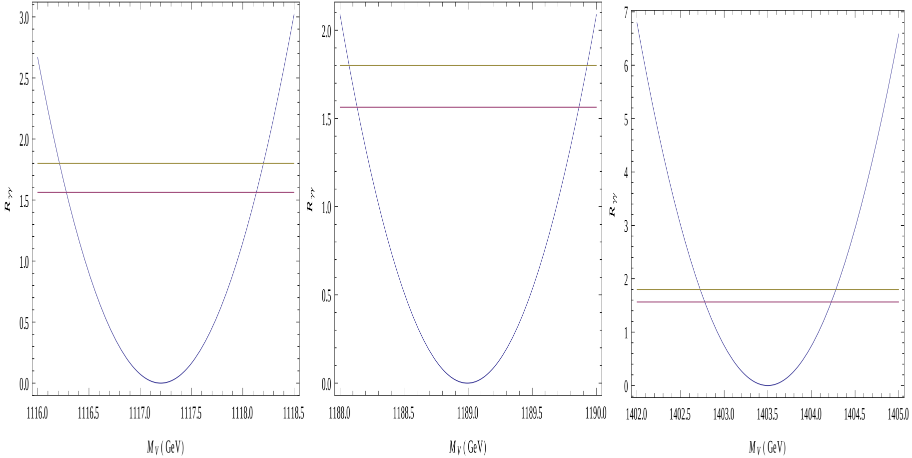


Figure: The ratio $R_{\gamma\gamma} = \frac{\sigma(pp\to h)\Gamma(h\to\gamma\gamma)}{\sigma(pp\to h)_{SM}\Gamma(h\to\gamma\gamma)_{SM}} \simeq a_{htt}^2 \frac{\Gamma(h\to\gamma\gamma)}{\Gamma(h\to\gamma\gamma)_{SM}}$ as a function of M_V for $M_A = 1.6$ TeV, 1.7 TeV and 2 TeV (from left to right). The horizontal lines are the $R_{\gamma\gamma}$ experimental bounds, whose values given by CMS and ATLAS are 1.6 and 1.8, respectively.

The T and S parameters.

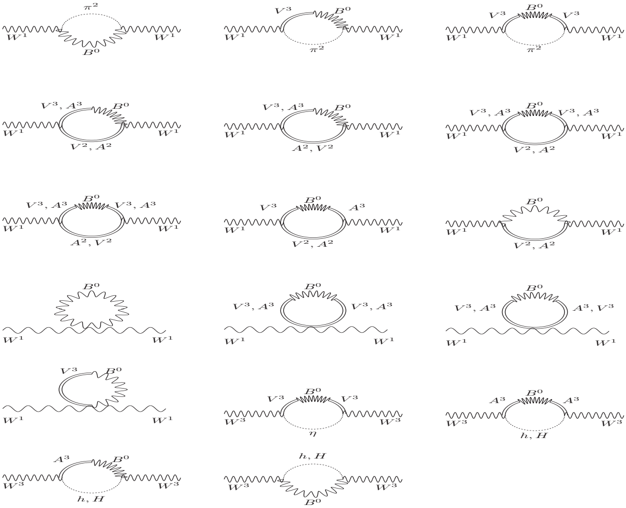


Figure: One loop Feynman diagrams contributing to the T parameter.

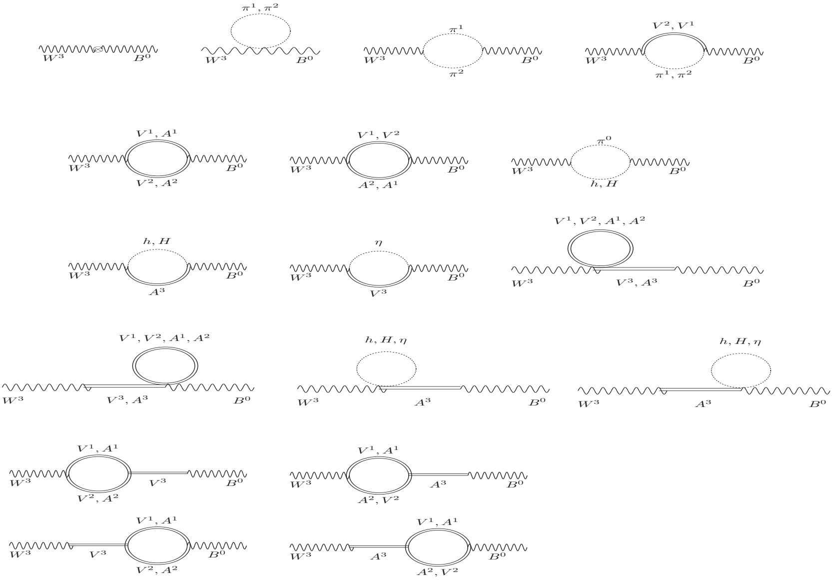
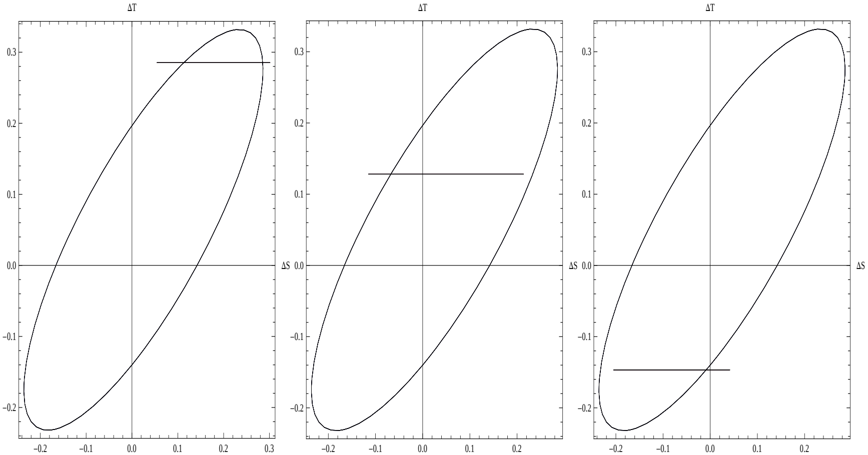


Figure: One loop Feynman diagrams contributing to the S parameter.



$M_A = 1600$ GeV, $M_V = 1116.23$ GeV (5.a) $M_A = 1700$ GeV, $M_V = 1189.90$ GeV (5.b) $M_A = 2000$ GeV, $M_V = 1402.75$ GeV (5.c)

Figure: The EFT model with parity even and parity odd spin 0 and 1 fields in the $\Delta S - \Delta T$ plane where $m_h = 125.7$ GeV and $m_H = m_\eta = 1$ TeV. Here $0.369 \leq c_{WB} \leq 0.372$, $0.306 \leq c_{WB} \leq 0.310$ and $0.190 \leq c_{WB} \leq 0.193$ for Figures 5.a, 5.b and 5.c, respectively.

Conclusions

- New particles need are are needed to stabilize the weak scale.
- Strongly coupled EWSB can be described by an Effective Lagrangian with composite spin-0 and spin-1 fields.
- Consistency with the T and S parameter and $h \to \gamma\gamma$ decay rate constraints requires 1.6 TeV $\lesssim M_A \lesssim 2$ TeV, $M_A - M_V \simeq 0.5$ TeV and a non standard kinetic mixing between the W^3 and B^0 fields. However the consistency with the $h \to \gamma\gamma$ decay rate constraint is highly sensitive under small variations of M_V and M_A.
- The LHC will shed light in the dynamics responsible for EWSB and the stabilization of EW scale.

Acknowledgements

Thank you very much to all of you for the attention. Special thanks for the organizers of Les Rencontres de Physique de La Valle d'Aoste 2013 for the opportunity.

References

- A. E. Cárcamo Hernández, Claudio O. Dib and Alfonso R. Zerwekh, to appear.
- A. E. Cárcamo Hernández, [arXiv:1008.1039[hep-ph]], Eur. Phys. J. C **72** (2012) 72:2154.
- A. E. Cárcamo Hernández and R. Torre, [arXiv:1005.3809[hep-ph]], Nucl. Phys. B 841 (2010) 188-204, [dx.doi.org/10.1016/j.nuclphysb.2010.08.004].
- R. Barbieri, A. E. Cárcamo Hernández, G. Corcella, R. Torre and E. Trincherini, JHEP **0310** (2010)068 [arXiv:0911.1942[hep-ph]].
- O. Cata, G. Isidori and J. F. Kamenik, Nucl. Phys. B **822** (2009) 230 [arXiv:0905.0490[hep-ph]].
- G. F. Giudice, C. Grojean, A. Pomarol and R. Rattazzi, JHEP 0706 (2007) 045 [arXiv:hep-ph/0703164].