The Higgs boson beyond Standard Model

Aleksandr Azatov[1]

[1]Dipartimento di Fisica, Università di Roma "La Sapienza"
and INFN Sezione di Roma; I-00185 Rome, Italy

DOI: http://dx.doi.org/10.3204/DESY-PROC-2012-02/176

We will review the status of the Higgs boson beyond Standard Model. This proceeding will be focused on the experimental and theoretical status of the Higgs boson in the Composite Higgs models. In particular we will discuss implications on the beyond Standard Model (BSM) Higgs coming from the observed excess at 125 GeV.

1 Introduction

Higgs fields is the only missing element of the Electroweak Symmetry breaking mechanism. With the recent hints from LHC about excess at 125 GeV [1, 2] it becomes crucial to understand the nature of this candidate for the Higgs boson and the mechanism that stabilizes its mass at the electroweak scale. One of the most attractive explanations of the Higgs mass stability is given in the models, where the Higgs appears as a composite field of some new strong dynamics [3]. However masses of the composite states in such framework are generically around TeV, so that we need additional mechanism to explain, why the Higgs is much lighter than the rest of the composite states. Such mass hierarchy can be naturally explained in the models, where Higgs is a pseudo Nambu-Goldstone boson of some larger global symmetry group[3, 4]. Recently this idea attracted more attention because this setup is dual to the extra dimensional models in warped geometry[5], where Higgs comes as a fifth component of the five dimensional gauge field [6]. Generically in such models the rest of the composite resonances are much heavier than the Higgs field, which makes them hard to produce directly at the LHC, however their indirect effects might be seen in the modifications of the Higgs couplings to the Standard Model(SM) fields. Within this framework first hints of new physics might be observed in the deviations of the Higgs couplings from their Standard Model expectations. In this note we will review generic predictions of the composite models as well as current constraints on the Higgs couplings.

2 Single Higgs effective theory

As we argued in the previous section, for the BSM Higgs we expect modifications of the Higgs couplings. To parametrize such interactions the Higgs field h, it is convenient to use Electroweak (EW) chiral lagrangian with all the possible additional interactions involving h[7, 8]. LEP constraints on $\Delta\rho$ parameter force our lagrangian to be symmetric under custodial $SU(2)_L \times SU(2)_R$ symmetry. Longitudinal polarizations of the W and Z correspond to the Nambu-Goldstone (NG) bosons of $SU(2)_L \times SU(2)_R / SU(2)_V$ symmetry breaking, and can be described by the 2×2 matrix

$$\Sigma(x) = \exp\left(i\sigma^a \chi^a(x)/v\right) , \tag{1}$$

where σ^a are the Pauli matrices and $v = 246\,\mathrm{GeV}$. The scalar h is assumed to be a singlet of the custodial $SU(2)_V$. The Lagrangian thus reads:

$$\mathcal{L} = -V(h) + \mathcal{L}^{(2)} + \mathcal{L}^{(4)} + \ldots \tag{2}$$

where $\mathcal{L}^{(n)}$ includes the terms with n derivatives and $V(h)$ is the potential for h. At the level of two derivatives one has [7]

$$\begin{aligned}
\mathcal{L}^{(2)} =& \frac{1}{2}(\partial_\mu h)^2 + \frac{v^2}{4} Tr\left(D_\mu \Sigma^\dagger D^\mu \Sigma\right)\left(1 + 2a\,\frac{h}{v} + b\,\frac{h^2}{v^2} + \cdots\right) \\
& - \frac{v}{\sqrt{2}} \lambda^u_{ij}\left(\bar{u}^{(i)}_L, \bar{d}^{(i)}_L\right)\Sigma\left(u^{(i)}_R, 0\right)^T\left(1 + c_u\,\frac{h}{v} + c_{2u}\,\frac{h^2}{v^2} + \cdots\right) + h.c. \\
& + (u_R \Leftrightarrow d_R, c_u \Leftrightarrow c_d) + ((u, d \Leftrightarrow \nu, e), c_u \Leftrightarrow c_l)
\end{aligned} \tag{3}$$

Standard Model corresponds to the point where all $a = b = c_i = 1$ and $c_{2i} = 0$ At the level of four derivatives one can write the lagrangian as a sum of operators O_i

$$\mathcal{L}^{(4)} = \sum_i O_i \tag{4}$$

where O_i are defined in the following way

$$\begin{aligned}
& O_1 = \mathrm{Tr}\left[(D_\mu\Sigma)^\dagger(D^\mu\Sigma)\right](\partial_\nu F_1(h))^2, \quad O_2 = \mathrm{Tr}\left[(D_\mu\Sigma)^\dagger(D_\nu\Sigma)\right]\partial^\mu\partial^\nu F_2(h) \\
& O_{GG} = G_{\mu\nu}G^{\mu\nu}\,F_{GG}(h), \quad O_{BB} = B_{\mu\nu}B^{\mu\nu}\,F_{BB}(h) \\
& O_W = D_\mu W^a_{\mu\nu}\,\mathrm{Tr}\left[\Sigma^\dagger\sigma^a i \overleftrightarrow{D}_\nu\Sigma\right]F_W(h), \quad O_B = -\partial_\mu B_{\mu\nu}\,\mathrm{Tr}\left[\Sigma^\dagger i \overleftrightarrow{D}_\nu\Sigma\,\sigma^3\right]F_B(h) \\
& O_{WH} = i\,W^a_{\mu\nu}\,\mathrm{Tr}\left[(D^\mu\Sigma)^\dagger\sigma^a D^\nu\Sigma\right]F_{WH}(h), \quad O_{BH} = -i\,B_{\mu\nu}\,\mathrm{Tr}\left[(D^\mu\Sigma)^\dagger(D^\nu\Sigma)\sigma^3\right]F_{BH}(h) \\
& O_{W\partial H} = \frac{1}{2}\,W^a_{\mu\nu}\,\mathrm{Tr}\left[\Sigma^\dagger\sigma^a i\overleftrightarrow{D}^\mu\Sigma\right]\partial^\nu F_{W\partial H}(h), \quad O_{B\partial H} = -\frac{1}{2}\,B_{\mu\nu}\,\mathrm{Tr}\left[\Sigma^\dagger i\overleftrightarrow{D}^\mu\Sigma\sigma^3\right]\partial^\nu F_{W\partial B}(h) \\
& F_i(h) = \alpha_i^{(0)} + \alpha_i^{(1)}h + \alpha_i^{(2)}h^2 + \ldots
\end{aligned} \tag{5}$$

The operators O_W, O_B contribute to the S parameter and the operators O_{GG}, O_{BB} are important for the contribution of the Higgs couplings to gluons and photons. Generically all these operators have independent coefficients, which have to be determined during the experiment.

3 Current constraints on the Higgs couplings

In this section we will derive the current bounds on the Higgs couplings. Instead of considering the whole set of operators presented in the previous section we will focus on the following scenario

$$c_u = c_d = c_l \equiv c \tag{6}$$

and all the operators O_i vanish.[1] We will assume that couplings of the Higgs to gluons and photons are modified only due to the modification of the Higgs couplings to W and t no direct contribution to these vertices. Note that assumption Eq. 6 is realized in type I 2HDM and also in the composite Higgs scenarios, where both top and bottom mix with the same representations of composite group, for example in the models (MCHM4,5) based on the $SO(5)/SO(4)$ coset we have

$$\text{MCHM 4}: \quad a = c = \sqrt{1-\xi}$$
$$\text{MCHM 5}: \quad a = \sqrt{1-\xi},\ c = \frac{1-2\xi}{\sqrt{1-\xi}}, \tag{7}$$

where ($\xi = \frac{v^2}{f^2}$) and f is analogue of pion decay constant. To derive current constraints on the (a,c) parameters we assumed Bayesian approach and extracted likelihoods following the method suggested in [8]. The results are presented on the Figure 1.

We can see that for the Higgs mass above 130 GeV large part of the parameter space is excluded. Also note that for the light Higgs $m_h = 120, 130$ GeV iso-contours are not symmetric in ($c \Leftrightarrow -c$), this is because of the $\gamma\gamma$ channel where we can probe the relative sign between a and c due to the interference of the diagrams with loops of W and loops of t.

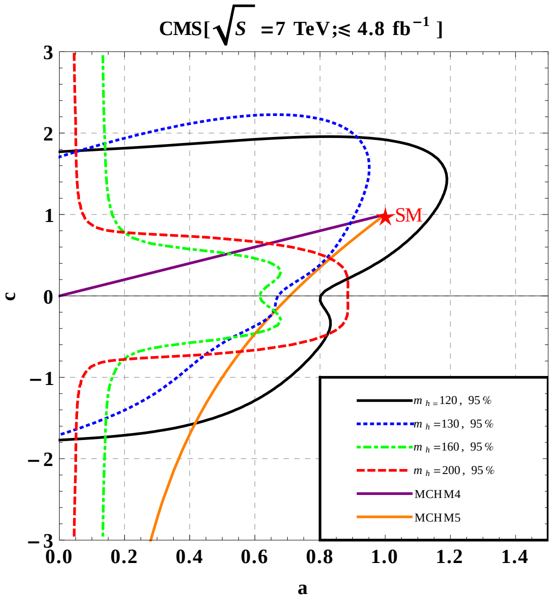

Figure 1: Current exclusions in the plane (a,c) for various Higgs masses as obtained with our method: the area to the right of each curve is excluded at 95% CL. These exclusions combine all search channels at CMS, with the full 2011 data set, purple and orange lines indicate MCHM4 and MCHM5 contours in the (a,c) plane

4 Excess at 125 GeV

Recently both collaborations ATLAS and CMS reported excess of events at $m_h \approx 125$ GeV, so it is interesting to know what we can learn about the couplings of this resonance with the current LHC data. On the Fig. 2 we plotted posterior probability fixed contours in the (a,c) plane. We can see that so far SM Higgs is well in agreement with the current data. Also note that due to the $\gamma\gamma$ channel probability contours are asymmetric in ($c \Leftrightarrow -c$), and there is always a solution with negative c. Another interesting feature is a big difference between CMS and ATLAS plots near the fermiophobic line $c = 0$. This is due to the fact that CMS collaboration presents results for the exclusive searches in $\gamma\gamma$ and WW channels. For example, cuts requiring

[1] Note that this assumption is not as bad as it might seem, because only $O_{GG}, O_{BB}, O_{W,B}, O_{W(B)\partial H}$ are important for the single Higgs production, however constraints from S parameter require $O_{W,B}$ to be small. Also in the case when Higgs is a pNGB field, operators $O_{GG,(BB)}$ explicitly break shift symmetry and should be suppressed.

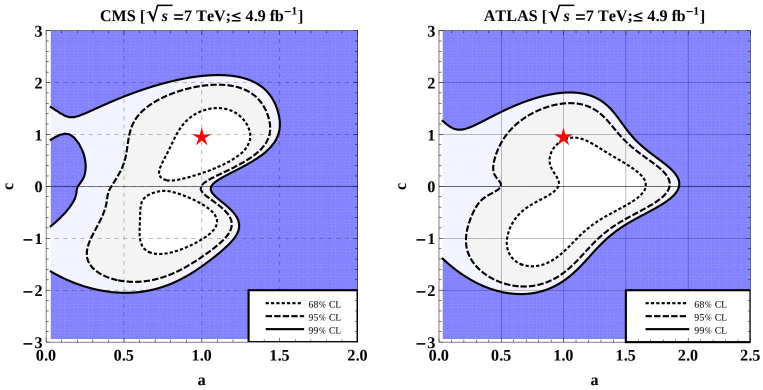

Figure 2: Isocontours of 68%, 95%, 99% probability in the (a, c) plane for 125 GeV Higgs coming from CMS (left) and ATLAS (right), Standard Model is indicated by star

two extra high p_T jets in the forward region in the final state help to select events produced mainly through the vector boson fusion mechanism, this allows us to probe a region of parameter space in the $c = 0$ region. This illustrates explicitly, how important exclusive analysis is for determining Higgs couplings in the future.

5 Summary

We reviewed current status of the BSM Higgs at LHC and analysed current constraints on the Higgs couplings from ATLAS and CMS at 5 fb^{-1}. Even now at low luminosity we can extract some information about the Higgs couplings, and constrain the parameter space of the composite models. This exercise demonstrates that exclusive analysis is essential in understanding the nature of the Higgs boson.

References

[1] ATLAS Collaboration, "Combined search for the Standard Model Higgs boson using up to 4.9 fb-1 of pp collision data at sqrt(s) = 7 TeV with the ATLAS detector at the LHC," arXiv:1202.1408 [hep-ex].

[2] CMS Collaboration, "Combination of CMS searches for a Standard Model Higgs boson" CMS-PAS HIG-11-032

[3] D. B. Kaplan, H. Georgi and S. Dimopoulos, Phys. Lett. B **136**, 187 (1984).

[4] G. F. Giudice, C. Grojean, A. Pomarol and R. Rattazzi, JHEP **0706**, 045 (2007) [hep-ph/0703164].

[5] L. Randall and R. Sundrum, Phys. Rev. Lett. **83**, 3370 (1999) [hep-ph/9905221].

[6] K. Agashe, R. Contino and A. Pomarol, Nucl. Phys. B **719**, 165 (2005) [hep-ph/0412089].

[7] R. Contino, C. Grojean, M. Moretti, F. Piccinini and R. Rattazzi, JHEP **1005**, 089 (2010) [arXiv:1002.1011 [hep-ph]].

[8] A. Azatov, R. Contino and J. Galloway, JHEP **1204**, 127 (2012) [arXiv:1202.3415 [hep-ph]].