EFT ANALYSIS OF OFF-SHELL HIGGS PRODUCTION IN GLUON FUSION AT FCC

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Abstract

I will present the prospects to resolve the gluon-fusion loop, by studying off-shell Higgs producition at FCC.

1 Introduction

The discovery of the Higgs boson at LHC [1] moved us into the new era of the high energy physics: the precision Higgs boson measurements. This program has already started since the first measurements of the Higgs couplings at LHC [1] and will continue in the future. The next hadron collider FCC (Future Circular Collider), whose main aim will be to discover new resonances, will provide us with new opportunities to measure the Higgs boson couplings. One of the couplings, which are hard to measure directly at LHC, is the top quark Yukawa

Table 1: 95% *credibility intervals.*

full analysis	$c_t \in [0.96, 1.07]$
linear analysis	$c_t \in [0.93, 1.07]$
analysis with $\sqrt{s} < 1.5$ TeV	$c_t \in [0.92, 1.13]$

coupling. Even though the dominant production of the Higgs boson occurs in gluon fusion, which in the Standard Model (SM) is dominated by the top quark loop, we cannot differentiate between the SM and new physics contributions to gluon fusion. To make this discussion more clear, let us consider an effective Higgs interaction in the following form:

$$\mathcal{L}^h = -c_t \frac{h}{v} m_t \bar{t}t + \frac{c_g g_s^2}{48\pi^2} \frac{h}{v} G_{\mu\nu} G^{\mu\nu}. \tag{1}$$

We can see that the rate of inclusive Higgs production is proportional to $|c_t + c_g|$. This well-known fact can be explained by the Higgs low-energy theorems [2], which fix the strength of the Higgs-gluon interactions for particles in the loop much heavier than the Higgs field. This degeneracy of the Higgs couplings can be broken by studying Higgs production in association with a $t\bar{t}$ pair. Recently, it was shown [3] that off-shell Higgs production [4] can be an alternative way to break this degeneracy. Even though the prospects of the constraints coming from off-shell Higgs production are weaker than the ones from tth, both analyses probe the same ball-park of deviations of the Higgs couplings.

2 Breaking the (c_t, c_g) degeneracy

We will start by reviewing the results on the constraints on the c_t and c_g couplings at 100 TeV collider at 3 ab^{-1} luminosity. The details of the collider simulation are presented in [3].

The results are presented in Fig.1 and Table 1. We can see that the off-shell Higgs analysis will be sensitive to few percent deviations of the top Yukawa couplings. So far, we have not said anything about the origin of the couplings c_t and c_g; however, assuming that the Higgs boson appears as a doublet of $SU(2)_L$, these modifications can appear as effects of dimension-six operators :

$$\mathcal{L}^{dim=6} = c_u \frac{y_t |H|^2}{v^2} \bar{Q}_L \tilde{H} t_R + h.c. + \frac{c_g g_s^2}{48\pi^2 v^2} |H^2| G_{\mu\nu} G^{\mu\nu}. \tag{2}$$

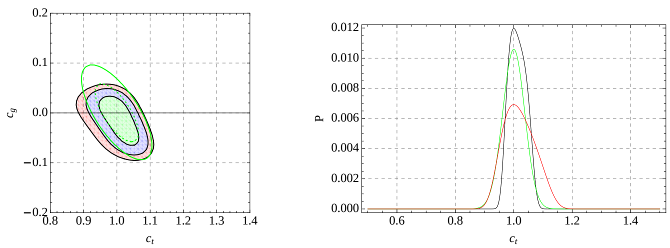

Figure 1: *Left - 68, 95, 99% credibility contours in the* (c_t, cg) *plane; the green contours correspond to the linear analysis. Right - posterior probability as a function of* c_t *once the condition* $c_t + c_g = 1$ *is imposed; the green curve corresponds to the linear analysis, the red one to the analysis with only the low-energy bins.*

The EFT (effective field theory) expansion is valid only if the effects of the operators with higher dimension are much smaller. Note that EFT provides us with the following self-consistency test: the contribution proportional to the squares of the dimension-six operators scales as a dimension-eight operator. So, the expansion is valid only if the effects proportional to $c_{u,g}^2$ are subleading with respect to the linear ones. We show in Fig.1 and Table 1 that indeed the FCC analysis will probe the deviation of the Higgs couplings, which are small enough to be described within the EFT expansion.

3 Constraining the ttZ interactions

Another application of off-shell Higgs production could be the constraints on the ttZ interactions. We remind the reader that the current collider constraints on this interaction are still weak. Generically, we can parameterise the ttZ interactions in the following form:

$$\mathcal{L} = e\bar{t}\left[c_v + \gamma_5 c_A\right] tZ^\mu;$$
$$c_V^{SM} = \frac{3-8\sin^2\theta_W}{12\sin\theta_W\cos\theta_W}\ ,\ c_A^{SM} = -\frac{1}{4\sin\theta_W\cos\theta_W}, \tag{3}$$

where we have indicated the SM values of the couplings. By performing a similar analysis, we can show that at 3 ab^{-1} we can constrain the deviations of c_A to be of the order of 5% and, at the same time, the constraints on c_V are very weak (see Fig. 2). This deviation of the Z boson couplings can appear as

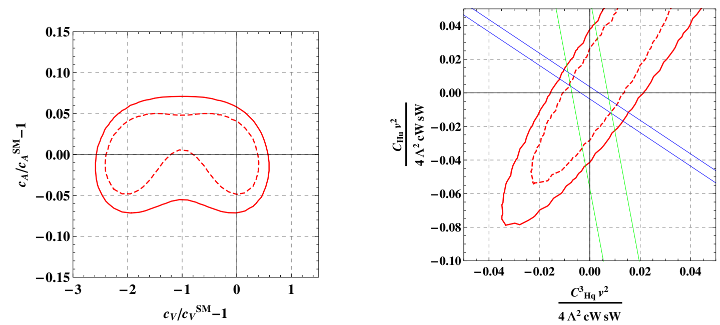

Figure 2: *Left -68, 95% credibility contours for the deviations of the* (c_V, c_A) *couplings. Right - credibility contours for the Wilson coefficients* (C_{Hu}, C^3_{Hq})*; on the top, the current constraints the electroweak precision tests (blue:* ΔT*, green:* $\Delta\epsilon_B$*) are presented.*

a result of the dimension six operators:

$$O^3_{Hq} = i(H^\dagger \tau^I \overleftrightarrow{D}_\mu H)(\bar{q}_L \gamma_\mu \tau^I q_L),\ O^1_{Hq} = i(H^\dagger \overleftrightarrow{D}_\mu H)(\bar{q}_L \gamma_\mu q_L),$$
$$O_{Hu} = i(H^\dagger \tau^I \overleftrightarrow{D}_\mu H)(\bar{u}_R \gamma_\mu u_R). \tag{4}$$

The Zbb constraints from LEP [5] rule out any possibility of large modifications of the Zbb coupling, thus fixing $C^1_{Hq} = -C^3_{Hq}$. Then, we can easily relate the Wilson coefficients to the c_V, c_A couplings:

$$c_{V,A} = c^{SM}_{V,A} + \frac{v^2}{4\Lambda^2 \sin\theta_W \cos\theta_W}\left(\pm 2C^3_{Hq} - C_{Hu}\right). \tag{5}$$

The results of the fit are shown in Fig.2. Note that the same operators at one-loop order will contribute to the electroweak precision observables, namely ΔT and $\Delta\epsilon_B$ [6], which right now lead to constraints as strong as our predictions for the off-shell production sensitivity. However, since the precision constraints result as an effect of one-loop insertions of the dimension-six operators, they are more model-dependent than our analysis.

4 Conclusion

We have studied the FCC prospects on constraining the effective field theories in the off-shell Higgs boson production via gluon fusion. We have shown that this channel can be used to put new constraints on the tth, ttZ and ggH interactions. The results, even though weaker than the other channels, still lead to interesting constraints on these interactions.

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