BOOOSTED HIGGS CHANNELS

MATTHIAS SCHLÄFFER

DESY, Notkestrasse 85, D-22607 Hamburg, Germany

In gluon fusion both a modified top Yukawa and new colored particles can alter the cross section. However in a large set of composite Higgs models and in realistic areas of the MSSM parameter space, these two effects can conspire and hide new physics in a Standard Model-like inclusive cross section.

We first show that it is possible to break this degeneracy in the couplings by demanding a boosted Higgs recoiling against a high-\(p_T\) jet. Subsequently we propose an analysis based on this idea in the \(H \rightarrow 2\ell + E_T\) channels. This measurement allows an alternative determination of the important top Yukawa besides the \(t\bar{t}H\) channel.

1 Introduction

The top quark and its coupling to the Higgs play a central role in the hierarchy problem. Many models for physics beyond the Standard Model (BSM) addressing this issue predict a modified top Yukawa coupling and its precise measurement can thus give crucial input to the search for BSM dynamics.

Two important processes for this measurement are \(t\bar{t}h\) and gluon fusion. The former is difficult to measure due to the high multiplicity final state while the latter has a sizable cross section despite being loop suppressed. However gluon fusion is not only altered by a modified top Yukawa coupling but also by new colored particles, e.g. scalar tops or composite top partners, that can run in the loop besides the ordinary top quark.

If the new loop particles are heavier than the Higgs, \(m_h^2/4m_{\text{loop}}^2 \ll 1\), their contribution to the gluon fusion process can be described by an effective gluon-gluon-Higgs interaction

\[
\mathcal{L}_{\text{eff}} = \kappa_g \frac{\alpha_S}{12\pi \nu} G_{\mu\nu}^{a \mu\nu} h, \tag{1}
\]

where \(\kappa_g\) is a coefficient quantifying the size of the interaction with \(\kappa_g = 0\) corresponding to the Standard Model (SM), \(\alpha_S\) is the strong coupling constant, \(\nu \approx 246\) GeV the Higgs vacuum expectation value, and \(G_{\mu\nu}^{a \mu\nu}\) the gluon field strength tensor. The modified top Yukawa can be easily accounted for by multiplying the top Yukawa term by a new coefficient \(\kappa_t\), where \(\kappa_t = 1\) corresponds to the SM. Yet the mass relation \(m_h^2/4m_t^2 \ll 1\) is fulfilled for the top quark and thus the top induced gluon fusion process can be described alternatively by Eq. (1) with \(\kappa_g\) replaced by \(\kappa_t\). Consequently the inclusive gluon fusion cross section is given by \(\sigma_{\text{incl}}(\kappa_t, \kappa_g)/\sigma_{\text{incl}}^{\text{SM}} \approx (\kappa_t + \kappa_g)^2\) with corrections to this formula being beyond the reach of the LHC².

Therefore the inclusive gluon fusion process at the LHC cannot be used to disentangle the two coefficients. An independent measurement of \(\kappa_t\) and \(\kappa_g\) is however important as new physics could alter them such that their deviations from the SM value cancel mutually and yield a SM-like inclusive cross section.

This cancellation of BSM effects in gluon fusion is not merely of academic interest but actually happens in realistic scenarios. The prime example for this are composite Higgs models.
It was shown in Refs.\textsuperscript{4} that the effects of a modified Yukawa coupling cancel the contributions from the top partner loops in a large range of realistic models and make the inclusive cross section completely insensitive to the top partner mass spectrum. Only a small rescaling of the cross section is obtained.

In the MSSM the cancellation is not as generic as in the composite Higgs models but can happen as well for large values of the trilinear coupling $A_t$ when it is comparable to the mass of the second stop. Breaking the degeneracy could even be used to access stealth stops.

The main idea of the analysis proposed in the next two sections is to obtain a different relation between $\kappa_t$ and $\kappa_g$ by making the inclusion of top mass effects necessary. This is achieved by introducing a new scale to the process that lies above the top mass but below the potential mass of the top partners. To introduce this scale we demand that the Higgs is produced in association with a hard jet against which it recoils\textsuperscript{8}.

\section{Analysis of Higgs + jet}

The amplitude for $pp \to h + \text{jet}$ is given by $M(\kappa_t, \kappa_g) = \kappa_t M_{IR} + \kappa_g M_{UV}$, where $M_{IR}$ is the amplitude for the top loop contribution given in Refs.\textsuperscript{5}, and $M_{UV}$ is the amplitude stemming from the effective gluon-Higgs interaction. In analogy to the expression for the inclusive cross section we write

$$\frac{\sigma_{p_T}^{\text{min}}(\kappa_t, \kappa_g)}{\sigma_{p_T}^{\text{SM}}} = (\kappa_t + \kappa_g)^2 + \delta \kappa_t \kappa_g + \epsilon \kappa_g^2,$$

(2)

where $\sigma_{p_T}^{\text{min}}$ stands for the cross section for $pp \to h + \text{jet}$ with a minimal transverse momentum of the Higgs of $p_T^{\text{min}}$. The newly introduced coefficients $\delta$ and $\epsilon$ quantify the deviation from the inclusive cross section and are calculated using the MSTW 2008 LO PDFs\textsuperscript{6} and the transverse mass $m_T = \sqrt{m_h^2 + p_T^2}$ as factorization and renormalization scale. For $p_T^{\text{min}} \to 0$ the process approaches the inclusive production and the coefficients vanish. However for $p_T^{\text{min}} = 800$ GeV they become $\delta(\epsilon) \approx 4(8)$. Of course these large coefficients come with the price of a small cross section due to the much smaller phase space. As a good compromise between large enough coefficients $\delta$ and $\epsilon$ and a not too small cross section we found $p_T^{\text{min}} = 650$ GeV by a rough optimization procedure. In order to cancel systematic uncertainties we divide the boosted cross section by the almost unboosted cross section with $p_T^{\text{min}} = 150$ GeV and take as observable

$$R^0 = \frac{\sigma_{650 \text{ GeV}}(\kappa_t, \kappa_g)}{\sigma_{150 \text{ GeV}}(\kappa_t, \kappa_g)} K_{650 \text{ GeV}} K_{150 \text{ GeV}},$$

(3)

where the cross sections are multiplied with the corresponding NLO K-factor obtained from MCFM-6.6\textsuperscript{7} to take higher order effects into account.

The allowed region in the $\kappa_t-\kappa_g$-parameter plane is constrained by performing a simple $\chi^2$-fit using the inclusive and the boosted cross section as input. For the 95\% CL contours in Fig. 1 we assumed the center of mass energy $\sqrt{s} = 14$ TeV, integrated luminosity $L = 3 \text{ ab}^{-1}$, and a systematic uncertainty of 20\% on both cross sections as well as a statistic error on the boosted cross section. As Higgs decay channel we chose the decay into $\tau^+ \tau^-$ with a SM branching ratio and the reconstruction efficiencies reported in Ref.\textsuperscript{8}. For more details and references see Ref\textsuperscript{9}.

\section{Collider study}

In order to confirm the promising results from the previous section we performed a realistic collider study. As final state for the signal process we consider $h \to 2\ell + \cancel{E_T}$ with its most dominant contribution coming from $h \to W_\ell W_\ell^*$ and $h \to \tau_\ell^+ \tau_\ell^-$. As background processes we

\textsuperscript{8}See Refs.\textsuperscript{3} for other studies considering the boosted Higgs production in association with a jet to access the Higgs couplings.
We used boosted Higgs production in gluon fusion to disentangle the contributions of a modified top Yukawa coupling and of new top partners quantified by $\kappa_t$ and $\kappa_g$, respectively. By combining the inclusive and the boosted cross section which have a different dependence on $\kappa_t$ and $\kappa_g$ the allowed region in the $\kappa_t$-$\kappa_g$-plane can be constrained. Assuming the worst case scenario with a SM inclusive cross section and a systematic uncertainty of 10%, $\kappa_g$ can be constrained at 95% CL to $-0.4 \leq \kappa_g \leq 0.3$ by considering only the decay $h \rightarrow \tau^+_\ell \tau^-_{\ell'}$ with an integrated luminosity

$$L = 300 \text{ fb}^{-1}$$

The corresponding values for $R^0$ are displayed and the star indicates the SM value.

4 Conclusion

We used boosted Higgs production in gluon fusion to disentangle the contributions of a modified top Yukawa coupling and of new top partners quantified by $\kappa_t$ and $\kappa_g$, respectively. By combining the inclusive and the boosted cross section which have a different dependence on $\kappa_t$ and $\kappa_g$ the allowed region in the $\kappa_t$-$\kappa_g$-plane can be constrained. Assuming the worst case scenario with a SM inclusive cross section and a systematic uncertainty of 10%, $\kappa_g$ can be constrained at 95% CL to $-0.4 \leq \kappa_g \leq 0.3$ by considering only the decay $h \rightarrow \tau^+_\ell \tau^-_{\ell'}$ with an integrated luminosity

$$L = 300 \text{ fb}^{-1}$$

The corresponding values for $R^0$ are displayed and the star indicates the SM value.
of 3 \text{ab}^{-1}. Therefore the boosted Higgs channel is an interesting alternative to determine the top Yukawa coupling independently of the $t\bar{t}h$ channel.

Acknowledgments

I would like to thank the organizers of the 27th Rencontres de Blois for the interesting workshop. I am grateful to Christophe Grojean, Ennio Salvioni, Michael Spannowsky, Michihisa Takeuchi, Andreas Weiler, and Chris Wymant for their contributions to the projects this talk is based on. Furthermore I acknowledge the funding by the Joachim-Herz-Stiftung.

References

1. J. R. Ellis, M. K. Gaillard and D. V. Nanopoulos, Nucl. Phys. B \textbf{106} (1976) 292; M. A. Shifman, A. I. Vainshtein, M. B. Voloshin and V. I. Zakharov, Sov. J. Nucl. Phys. \textbf{30} (1979) 711 [Yad. Fiz. \textbf{30} (1979) 1368].
2. M. Gillioz, R. Gröber, C. Grojean, M. Mühlleitner and E. Salvioni, JHEP \textbf{1210} (2012) 004, arXiv:1206.7120 [hep-ph].
3. R. V. Harlander and T. Neumann, Phys. Rev. D \textbf{88} (2013) 074015, arXiv:1308.2225 [hep-ph]. A. Banfi, A. Martin and V. Sanz, arXiv:1308.4771 [hep-ph]. A. Azatov and A. Paul, JHEP \textbf{1401} (2014) 014, arXiv:1309.5273 [hep-ph].
4. A. Falkowski, Phys. Rev. D \textbf{77} (2008) 055018, arXiv:0711.0828 [hep-ph]. I. Low and A. Vichi, Phys. Rev. D \textbf{84} (2011) 045019, arXiv:1010.2753 [hep-ph]. A. Azatov and J. Galloway, Phys. Rev. D \textbf{85} (2012) 055013, arXiv:1110.5646 [hep-ph]. C. DeLannay, C. Grojean and G. Perez, JHEP \textbf{1309} (2013) 090, arXiv:1303.5701 [hep-ph]. M. Montull, F. Riva, E. Salvioni and R. Torre, Phys. Rev. D \textbf{88} (2013) 095006, arXiv:1308.0559 [hep-ph].
5. R. K. Ellis, I. Hinchliffe, M. Soldate and J. J. van der Bij, Nucl. Phys. B \textbf{297} (1988) 221. U. Baur and E. W. N. Glover, Nucl. Phys. B \textbf{339} (1990) 38.
6. A. D. Martin, W. J. Stirling, R. S. Thorne and G. Watt, Eur. Phys. J. C \textbf{63} (2009) 189, arXiv:0901.0002 [hep-ph].
7. J. M. Campbell, R. K. Ellis and C. Williams, MCFM web page \url{http://mcfm.fnal.gov/}.
8. A. Katz, M. Son and B. Tweedie, Phys. Rev. D \textbf{83} (2011) 114033, arXiv:1011.4523 [hep-ph].
9. C. Grojean, E. Salvioni, M. Schlaffer and A. Weiler, JHEP \textbf{1405} (2014) 022 arXiv:1312.3317 [hep-ph].
10. T. Junk, Nucl. Instrum. Meth. A \textbf{434} (1999) 435 [hep-ex/9902006].
11. M. Schlaffer, M. Spannowsky, M. Takeuchi, A. Weiler and C. Wymant, Eur. Phys. J. C \textbf{74} (2014) 10, 3120 arXiv:1405.4295 [hep-ph].