PROCEEDINGS OF SCIENCE

Single top, W and Higgs associated production

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We study the associated production of a single top quark plus a W and a Higgs bosons (tWH) at the LHC, at NLO-QCD accuracy. We show results obtained with the technique known as Diagram Removal to treat the event generation in the NLO real-emission $tWbH$ channel, where tWH interferes with ttH. We provide NLO results for tWH total and differential cross sections at 13 TeV, also matching the matrix element for the hard scattering to a parton shower. Finally, we show the sensitivity of this process to a generic CP-mixed (i.e. BSM) Yukawa interaction between the Higgs and the top quark.

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1. Introduction

Despite its small cross section at the LHC, tWH production is an interesting case of study for two reasons: (1) rare processes where the Higgs is produced with a single top quark are more sensitive than ttH to study departures of the top Yukawa coupling from the SM prediction (see [1] and references therein), and (2) at NLO-QCD the tWH (singly resonant) and ttH (doubly resonant) processes interfere in the real-emission $tWbH$ channel (fig. 1), thus their separation is not trivial. The same situation is present also in the SM cases of tW/tt production [2, 3] and tWZ/ttZ, and in beyond-Standard-Model (BSM) processes [4–7]. This problem can be avoided with a full simulation of $WbWbH$ production at NLO [8]; however, this is highly non-trivial. Moreover, efficient generation of singly-resonant events (tWH) require to run separately the tWH and ttH processes. To this purpose, approximate techniques known as Diagram Removal and on-shell Diagram Subtraction are used to treat the $tWbH$ channel. Our results are obtained within the MADGRAPH5_AMC@NLO framework [9].

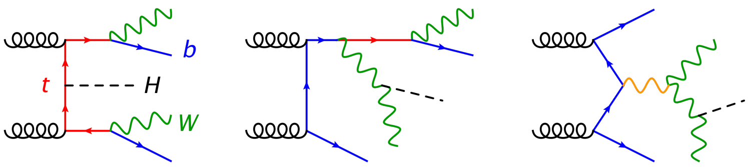

Figure 1: Examples of "ttH" doubly resonant amplitudes $\mathscr{A}_2$ (left), "tWH" singly resonant amplitudes $\mathscr{A}_1$ (center) and non resonant amplitudes $\mathscr{A}_0$ (right) contributing to the same $WbWbH$ final state.

In the $tWbH$ channel, the Diagram Removal (DR) matrix elements without (DR1) and with interference (DR2) are

$$\mathscr{M}_{\mathrm{DR1}} = |\mathscr{A}_1|^2 \qquad \text{and} \qquad \mathscr{M}_{\mathrm{DR2}} = |\mathscr{A}_2 + \mathscr{A}_1|^2 - |\mathscr{A}_2|^2 \ , \tag{1.1}$$

where the indices 1 and 2 indicate the number of on-shell top quarks in the diagrams. Both DR1 and DR2 are not guaranteed to preserve gauge invariance. We find a significant difference between DR1 and DR2, because the doubly-singly interference $\mathscr{A}_2\mathscr{A}_1^*$ contribution is large compared to the singly resonant contribution $|\mathscr{A}_1|^2$. Non-resonant contributions from $\mathscr{A}_0$ ("+0r") are numerically negligible.

We have also investigated results obtained using on-shell Diagram Subtraction (DS)

$$\mathscr{M}_{\mathrm{DS}} = |\mathscr{A}_2 + \mathscr{A}_1|^2 - \mathscr{C}_{\mathrm{DS}} \quad , \quad \mathscr{C}_{\mathrm{DS}}(\{p_i\}) = \frac{(m_t\Gamma_t)^2}{(p_{bW}^2 - m_t^2)^2 + (m_t\Gamma_t)^2} \left|\mathscr{A}_2(\{q_i^{\mathrm{OS}}\})\right|^2 \ , \tag{1.2}$$

where m_t and Γ_t are the mass and the width of top quark, while the external momenta reshuffling $\{p_i\} \to \{q_i^{\mathrm{OS}}\}$ puts on-shell the internal top propagator, to preserve gauge invariance (at least in the limit $\Gamma_t/m_t \to 0$). We have found a significant dependence on how the on-shell reshuffling $\{p_i\} \to \{q_i^{\mathrm{OS}}\}$ is performed; further investigations about the substantiality of this issue are ongoing.

2. tWH production at NLO+PS

The NLO cross section for tWH production at 13 TeV, computed with DR2, amounts to 15.6 fb and shows significantly reduced uncertainties compared to LO (table 1). The impact of tWH/ttH

interference can be estimated by taking the difference with the DR1 result (~ 5 fb), and amounts to about one third of the NLO cross section. Interference affects significantly also the shape of distributions of the top quark and the W boson, while the effect is milder for the Higgs (fig. 2).

tWH	σ [fb]	$\delta^{\%}_{\mu}$	$\delta^{\%}_{\rm PDF}$	K
LO	16.15(3)	$^{+12.9}_{-12.8}$	± 11.1	-
NLO DR1	20.65(3)	$^{+5.0}_{-3.2}$	± 3.0	1.28
NLO DR2	15.61(3)	$^{+4.6}_{-6.1}$	± 2.7	0.97

Table 1: Total cross sections at the 13-TeV LHC for $pp \to tW^-H + \bar{t}W^+H$, in the 5F scheme at LO and NLO accuracy (NLO results are obtained with Diagram Removal). We also report the scale and PDF uncertainties, as well as the NLO K factor. The dynamic scale $\mu = H_T/4$ has been used throughout the simulation.

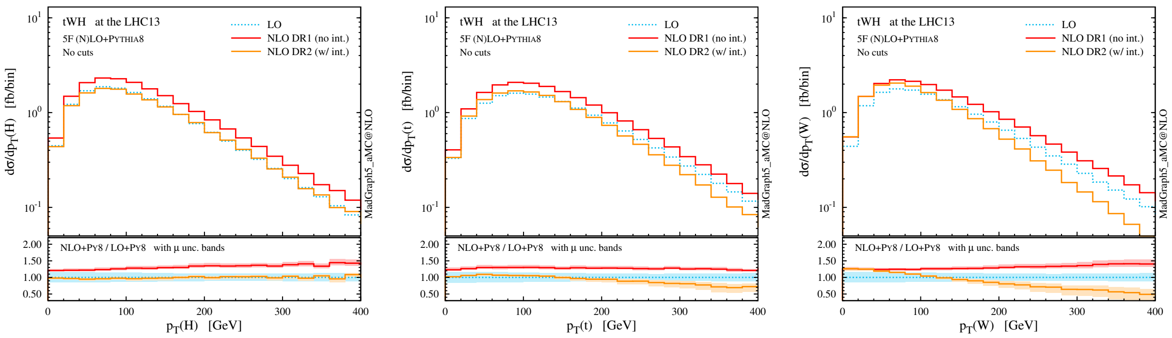

Figure 2: Transverse momentum distributions of the Higgs boson (left), the top quark (center) and the W boson (right) at NLO+PYTHIA8.

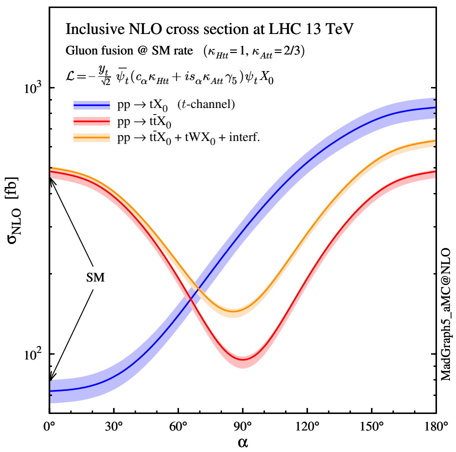

Figure 3: Total cross section with scale uncertainty for t-channel tX_0 (blue), ttX_0 (red) and $ttX_0 + tWX_0$ production computed with DR2 (orange), as a function of the CP-mixing angle α in the HC Lagrangian. The point $\alpha = 0°$ corresponds to the SM scenario, while $\alpha = 180°$ corresponds to $y_t = -y_t(\mathrm{SM})$.

Finally, we go beyond the Standard Model employing the Higgs Characterisation model ($H \to X_0$), where the Higgs-top Yukawa interaction is described by the Lagrangian

$$\mathscr{L}_0^t = -\overline{\psi}_t \left(c_\alpha \kappa_{Htt} g_{Htt} + i s_\alpha \kappa_{Att} g_{Att} \gamma_5 \right) \psi_t X_0 \,. \tag{2.1}$$

The SM case is reproduced when $c_\alpha \equiv \cos\alpha = 1$ and $\kappa_{Htt} = 1$. The sensitivity of the tWX_0 rate to the CP-mixing angle α is presented in fig. 3, together with ttX_0 and t-channel tX_0 for reference.

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