Impact of interference effects on Higgs searches in the di-top final state at the LHC

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Executive summary

Extended Higgs sector scenarios feature additional scalar bosons. Scalar bosons with a mass scale of a few hundreds of GeV (heavy scalars) can be accessible to experiments at the LHC. For heavy scalars with a large top-Yukawa coupling the production via gluon fusion (proceeding through a virtual top-quark loop) and the subsequent decay to the top and anti-top quarks (top pairs) is an important experimental search channel. The resonant production of a heavy scalar and its subsequent decay to top pairs (the signal process) would be naively expected to manifest itself as a characteristic bump in the invariant mass distribution of the top-quark pair. However, the interference between the resonant heavy scalar production and the SM QCD background ($gg \to t\bar{t}$) results in a large destructive contribution[1]. This large interference with the SM QCD background leads to a characteristic peak–dip signature in the invariant mass distribution of the top pairs ($m_{t\bar{t}}$). The signal-background interference pattern depends on the CP-nature of the heavy scalars, their masses, and their decay widths. These interference effects can significantly alter the exclusion limits and leave a considerable parameter region unexcluded that would appear to be ruled out if the interference effects were neglected[2].

In addition to the large (usually destructive) signal-background interference effect, an additional signal-signal interference contribution can appear if two heavy scalars are considered that can mix with each other. The mixing between the tree-level interaction eigenstates arising from loop corrections to the scalar two-point function leads to the loop-level mass eigenstates. The calculations dealing with these mixing effects result in the determination of the two complex poles and UV-finite wave function normalization factors (called "Z-factors"; more details during the presentation) that in-general are complex numbers[3]. These Z-factors ensure the proper normalization of the S-matrix.

Signal-signal interferences in the di-top final state have not been investigated so far using Monte-Carlo event simulations which is a crucial ingredient for assessing the expected sensitivity of experimental searches. With this, we perform our analysis in a model-independent framework where the input parameters are the two tree-level masses (M_j; for $j \in \{1, 2\}$) (that have a minimum decay width to the top pairs) along with their respective CP-even ($c_{t,j}$) and CP-odd ($\tilde{c}_{t,j}$) Yukawa-couplings modifiers (these modify the couplings of the heavy scalar to the top pairs). The loop-corrected mass eigenstates are denoted as (M_a, M_b) with widths (Γ_a, Γ_b). With the Z-factors, we take into account large resonance-type effects arising from loop-level mixing between the scalars. The interference effects are studied both in an analytic way at the parton-level (see, Fig. 1) and with Monte-Carlo simulations (see, Fig. 2) for the di-top production process at the LHC. We demonstrate that signatures can emerge from these searches that may be unexpected or difficult to interpret.

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[3] E. Fuchs and G. Weiglein, Eur. Phys. J. C **78**, 87 (2018), E. Fuchs and G. Weiglein, JHEP **09**, 079 (2017).

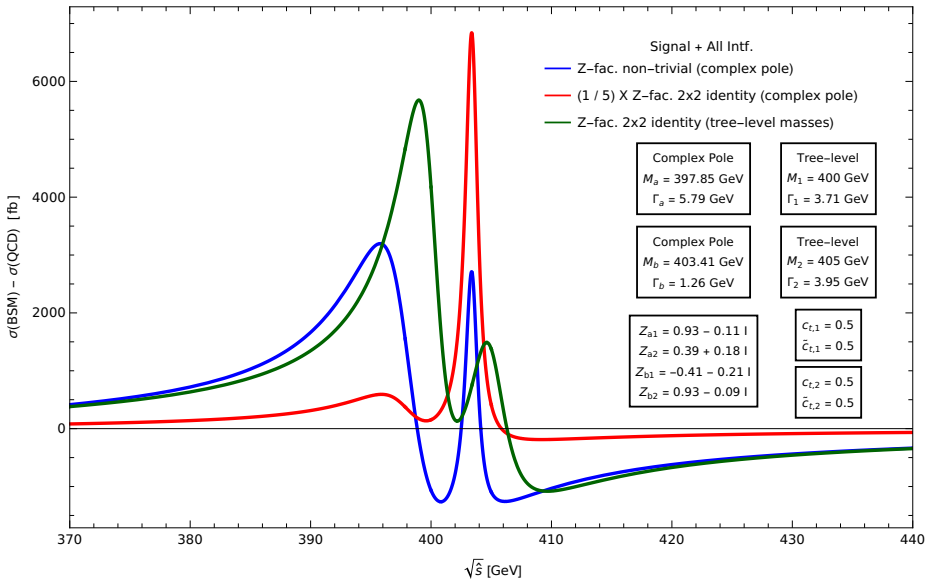

Figure 1: Demonstrating the impact of the Z-factors: comparing the expected BSM cross-section at the partonic-level with non-trivial Z-factors (blue), with trivial Z-factors (i.e., when the Z-factors are not utilized) (red), and when only the tree-level masses (dark-green) are assumed.

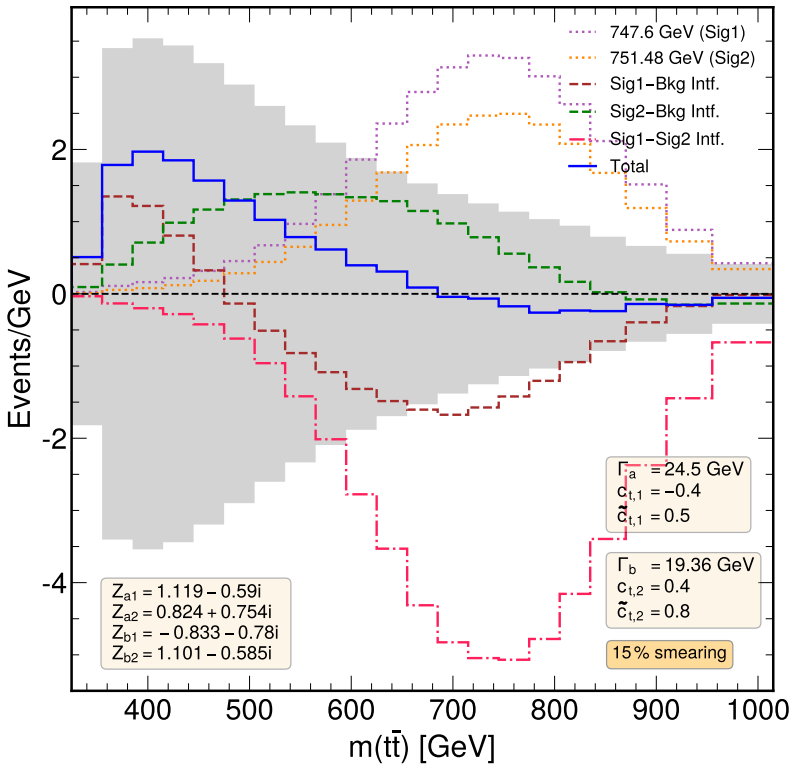

Figure 2: Monte-Carlo implementation with two CP-mixed scalars with the Z-factors (as indicated). We plot different cross-section distributions in the invariant mass of the top pairs. The purple (yellow) dotted curve is the signal resonance, and the brown (green) dashed curve is the signal-background interference for the first (second) scalar. The red dash-dotted curve is the signal-signal interference between the two scalars. The total sum of all the signal and interference contributions is shown by the solid blue curve. The region outside the gray band can be probed by the current experimental sensitivity. A Gaussian-smearing of 15% is applied to capture the experimental resolution in $m(t\bar{t})$.