HIGGS BOSON PRODUCTION IN ASSOCIATION WITH A SINGLE TOP QUARK AS A PROBE OF THE TOP YUKAWA COUPLING

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The associated production of a Higgs boson with a single top quark (th) constitutes a uniquely sensitive probe of the magnitude and sign of the top–Higgs Yukawa coupling. Owing to destructive interference between diagrams involving Higgs couplings to fermions and electroweak gauge bosons, the Standard Model predicts a strongly suppressed th production rate. Any deviation from this structure, including a sign inversion of the Yukawa coupling, leads to substantial enhancements in both inclusive cross sections and characteristic kinematic observables. In this contribution, we present a detailed phenomenological study of thq and twh production at the LHC, based on Monte Carlo simulations calibrated to ATLAS Run-2 analyses [1].

Higgs boson production in association with a single top quark proceeds primarily through two electroweak subprocesses: the tHq mode, dominated by t-channel single-top production, and the twh mode, involving the associated production of a Higgs boson with a top quark and a W boson. A third, s-channel contribution is numerically negligible at the LHC and is therefore omitted. Two examples of dominant leading-order (LO) Feynman diagrams for the thq and twh processes, both in the 4FS, are shown in Figure 1.

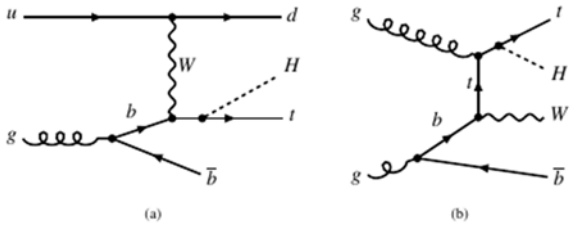

Fig. 1. Feynman diagrams for (a) thq and (b) twh production at LO, [1].

A key aspect of accurate modeling lies in the treatment of bottom quarks in the initial state. In this study, the thq process is simulated in the four-flavor scheme (4FS), where the bottom quark is treated as massive and absent from the proton PDFs, while tWH production is modeled in the five-flavor scheme (5FS), allowing for initial-state bottom quarks. This approach follows established ATLAS practice and minimizes double counting with related processes such as tth.

Event generation is performed using MadGraph5_aMC@NLO at leading order with MLM jet merging. Dynamic renormalization and factorization scales are employed, and ATLAS-like selection cuts are applied. The results of computer modeling with the inclusion of kinematical data and Flavor Schemes are presented in Table 1

Table 1. Production cross sections for thq and twh processes

Process	Cross-Section (pb)	Notes
pp → thq (LO)	0.0015	Basic LO calculation
pp → thq (NLO)	0.028	Basic NLO calculation
pp → thq (4FS, without b)	0.047	LO+MLM at 13 TeV
pp → thq (4FS, without b)	0.056	LO+MLM at 14 TeV
pp → twh (LO)	0.0076	Basic LO calculation
pp → twh (5FS, with b)	0.022	LO+MLM at 13 TeV
pp → twh (5FS, with b)	0.027	LO+MLM at 14 TeV

Under the Standard Model hypothesis ($\kappa_t = +1$), the combined tH production cross section at $\sqrt{s} = 13$ TeV is found to be of order 90 fb at NLO accuracy, with thq providing the dominant contribution. The ATLAS

NLO SM cross section for th (thq + twh) is 89.5 fb (0.0895 pb) [1, 2], while the calculated scaled σ(th) is 85.9 fb, i.e. ~4.0% lower than the SM NLO value, which lies within the quoted QCD scale uncertainties (+6.5% / −14.9%) and PDF+α_s uncertainties (±3.7%).

In the inverted Yukawa coupling scenario ($\kappa_t = -1$) [3], the destructive interference is converted into a constructive one, leading to a substantial enhancement of the production rate. At LO+MLM level, the total th cross section increases by a factor of approximately 4–5 relative to the SM prediction. When extrapolated to NLO accuracy, this enhancement approaches an order of magnitude, in qualitative agreement with ATLAS theoretical benchmarks.

Beyond inclusive rates, the kinematic structure of th events provides critical discriminatory power. We analyze a set of observables commonly used in experimental multivariate analyses, including the scalar sum of transverse momenta (H_T), transverse momentum spectra of the Higgs boson, top quark, and W boson, the pseudorapidity distribution of the forward jet, and angular separations between final-state objects.

For the thq process, the presence of a forward light-flavor jet at large pseudorapidity remains a defining feature, largely insensitive to the sign of the Yukawa coupling, (Figure 2).

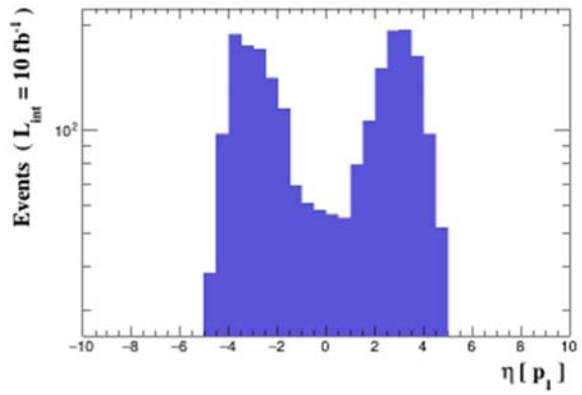

Fig. 2. The pseudorapidity distribution η of a jet, [4].

The Higgs transverse momentum spectrum is dominated by low and intermediate values, with a mild hardening observed in the inverted coupling scenario. Angular separations between the Higgs boson and the forward jet peak at large values, reflecting the characteristic t-channel topology.

The associated production of a Higgs boson with a single top quark represents one of the most sensitive probes of the top–Higgs Yukawa interaction currently accessible at the LHC. Through a detailed simulation study aligned with ATLAS analyses, we have demonstrated that simplified LO+MLM modeling, when properly normalized, provides a reliable qualitative description of both inclusive and differential th observables. The use of the four-flavor scheme for tHq and the five-flavor scheme for twh, together with dynamic scale choices and ATLAS-motivated selection criteria, allows for a controlled comparison with experimental measurements. After applying appropriate K-factors to approximate NLO QCD corrections, the resulting Standard Model prediction for the total th cross section at $\sqrt{s}$ = 13 TeV is found to be in good agreement with the NLO theoretical expectation, within the quoted scale and PDF uncertainties.

A central outcome of this study is the explicit demonstration of the dramatic enhancement of the th production rate under an inverted top Yukawa coupling scenario ($\kappa_t = -1$). In this case, the destructive interference present in the Standard Model is converted into a constructive one, leading to an increase of the total cross section by several factors already at LO+MLM level, and by nearly an order of magnitude when extrapolated to NLO accuracy. Our results qualitatively and quantitatively support the interpretation of the mild excess reported by ATLAS [1] in terms of scenarios with modified top–Higgs interactions.

1. ATLAS Collaboration. Search for the production of a Higgs boson in association with a single top quark in pp collisions at \sqrt{s} = 13 TeV with the ATLAS detector 2025. arXiv:2508.14695 [hep-ex].
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4. T. Obikhod, I. Petrenko. Higgs Boson Production in Association with a Single Top Quark as a Probe of the Top Yukawa Couplingar 2026. arXiv:2603.03404 [hep-ph].