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

T.V. Obikhod, I.O. Petrenko
Institute for Nuclear Research, National Academy of Sciences of Ukraine, Kyiv, Ukraine
E-mail: obikhod@kinr.kiev.ua

The associated production of a Higgs boson with a single top quark (tH) serves as a uniquely sensitive probe of the magnitude and sign of the top-quark Yukawa coupling. In the Standard Model, destructive interference leads to a strongly suppressed production rate for this process. This study, based on Monte Carlo simulations in the 4FS (for tHq) and 5FS (for tWH) schemes, demonstrates that inverting the sign of the Yukawa coupling k_t = -1 converts the interference from destructive to constructive, increasing the cross-section by a factor of 4–5 at LO+MLM and by nearly an order of magnitude when extrapolated to NLO accuracy. The kinematic distributions remain signal-like, confirming the robustness of current experimental discrimination strategies. The results are consistent with a mild excess reported by ATLAS and highlight the potential of the HL-LHC, combined with improved theoretical precision and advanced analysis techniques, to place stringent constraints on the magnitude, sign, and CP structure of the top Yukawa coupling.

PACS: 14.80.Bn, 12.15.-y, 13.85.Hd

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 Fig. 1.

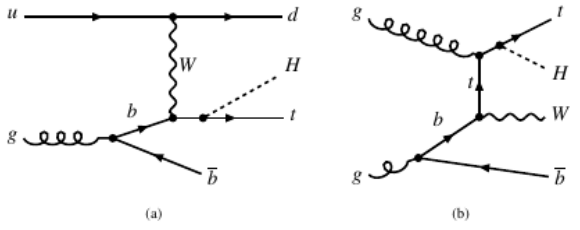

Fig. 1. Feynman diagrams for (a) tHq and (b) tWH production at LO, [1]

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.

Production cross sections for tHq and tW⁻h processes

Process	Cross-Section (pb)	Notes
pp → t h q (LO)	0.0015	Basic LO calculation
pp → t h q (NLO)	0.028	Basic NLO calculation
pp → t h q (LO+MLM, 13 TeV) j = g u c d s ū c̄ d̄ s̄ (4FS, without b)	0.047	LO+MLM at 13 TeV, including t h q j and t h q q j
pp → t h q (LO+MLM, 14 TeV) j = g u c d s ū c̄ d̄ s̄ (4FS, without b)	0.056	LO+MLM at 14 TeV, including t h q j and t h q q j
pp → t w⁻ h (LO)	0.0076	Basic LO calculation
pp → t w⁻ h (LO+MLM, 13 TeV) j = g u c d s b ū c̄ d̄ s̄ b̄ (5FS, with b)	0.022	LO+MLM at 13 TeV
pp → t w⁻ h (LO+MLM, 14 TeV) j = g u c d s b ū c̄ d̄ s̄ b̄ (5FS, with b)	0.027	LO+MLM at 14 TeV

Under the Standard Model hypothesis (κ_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 (κ_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, (Fig. 2).

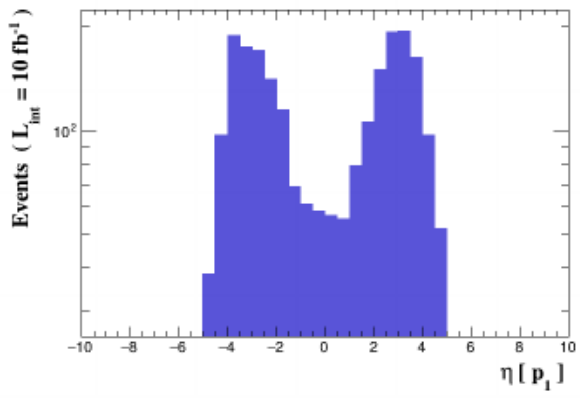

Fig. 2. The pseudorapidity distribution η of a jet

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.

In tWH production, kinematic distributions are moderately broader (Fig. 3) due to the additional W boson in the final state, yet remain softer than those of dominant backgrounds such as ttW.

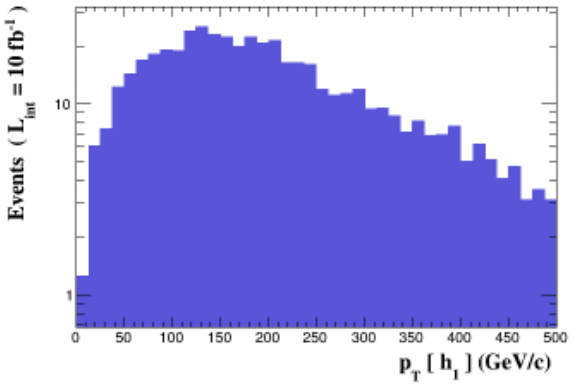

Fig. 3. The transverse momentum distribution of the Higgs boson, $p_T(h)$, for simulated tWh kinematics

The shape in Fig. 3 is typical for tWh kinematics, where the Higgs p_T is moderate from recoil against the top and W, with tails suppressed by phase space – similar to tHq but with additional contributions from W decays (lepton/neutrino), leading to slightly broader low-p_T shoulders.

Importantly, while the inverted Yukawa coupling significantly enhances normalization, the shapes of the principal observables remain signal-like, supporting the robustness of existing experimental discrimination strategies.

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 in terms of scenarios with modified top–Higgs interactions.

Obtained results reinforce the interpretation that scenarios with an inverted top Yukawa coupling can naturally account for enhanced tH production rates and remain consistent with observed kinematic patterns. Looking forward, the increased luminosity of the HL-LHC, combined with improved theoretical precision and advanced multivariate techniques, will enable significantly tighter constraints on the magnitude, sign, and CP structure of the top Yukawa coupling, thereby deepening our understanding of the Higgs sector and its possible extensions beyond the Standard Model.

REFERENCES

1. ATLAS Collaboration, Search for Higgs boson production in association with a single top quark in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector, arXiv:2508.14695 [hep-ex], 2025.

2. F. Demartin, F. Maltoni, K. Mawatari, B. Page, M. Zaro. Higgs production in association with a single top quark at the LHC // *Eur. Phys. J. C*. 2015, v. 75, p. 267; doi: 10.1140/epjc/s10052-015-3475-9, arXiv:1504.00611 [hep-ph].

3. T.M.P. Tait, C.-P. Yuan. Single top quark production as a window to physics beyond the Standard Model // *Phys. Rev. D*. 2000, v. 63, p. 014018;
doi: 10.1103/PhysRevD.63.014018, arXiv:hep-ph/0007298

НАРОДЖЕННЯ БОЗОНА ХІГГСА В АСОЦІАЦІЇ З ТОП-КВАРКОМ ЯК ІНСТРУМЕНТ ДОСЛІДЖЕННЯ ВЗАЄМОДІЇ ЮКАВИ ТОП-КВАРКА

Т.В. Обіход, Є.О. Петренко

Асоційоване народження бозона Хіггса з одним топ-кварком (tH) є унікально чутливим інструментом для дослідження величини та знаку константи Юкави топ-кварка. У Стандартній моделі через деструктивну інтерференцію цей процес сильно пригнічений. Дослідження, засноване на моделюванні методом Монте-Карло у схемах 4FS (для tHq) та 5FS (для tWH), демонструє, що зміна знаку зв'язку Юкави kt = -1 перетворює інтерференцію на конструктивну, збільшуючи переріз у 4–5 разів на LO+MLM рівні та майже на порядок при екстраполяції до NLO. Кінематичні розподіли залишаються схожими на сигнал, підтверджуючи ефективність поточних стратегій виділення. Результати узгоджуються з можливим надлишком, спостережуваним ATLAS, та вказують на перспективи суворої перевірки природи взаємодії топ-кварка з полем Хіггса на HL-LHC.