18th International Workshop on Top Quark Physics (TOP2025)

Sunday 21 September 2025 - Friday 26 September 2025

Book of Abstracts

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Quantum-Enhanced Inference for Four-Top-Quark Signal Classification at the LHC Using Graph Neural Networks

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Rare event classification in high-energy physics (HEP) plays a crucial role in probing physics beyond the Standard Model (BSM). Such processes serve as indirect searches for new physics by testing deviations from SM predictions in extreme kinematic regimes. The production of four top quarks in association with a (W^-) boson at ($\sqrt{s} = 13$) TeV is an exceptionally rare SM process with a next-to-leading-order (NLO) cross-section of $(6.6^{+2.4}_{-2.6} ab)$. In its fully hadronic decay mode, with intricate jet topology and overwhelming QCD background, demands advanced techniques for signal extraction, making it a prime candidate for new physics probes like anomalous top-quark interactions or EFT deviations . Identifying this process in the fully hadronic decay channel is particularly challenging due to overwhelming backgrounds from $t\bar{t}, t\bar{t}W, t\bar{t}Z$, and triple-top production processes. This study introduces **CrossQuantumPhysGNN (CQPGNN)**, a quantum-classical hybrid graph neural network (GNN) designed to tackle rare event classification. CQPGNN integrates GINEConv layers for particle-level features, a quantum circuit employing angle encoding and entanglement for global feature processing, and cross-attention fusion to combine local and quantum-enhanced global representations. Physics-informed losses enforce momentum conservation and jet multiplicity constraints derived from the event decay dynamics, making a faster physics informed convergence. Benchmarked against conventional methods, CQPGNN achieves a signal significance $(S/\sqrt{S+B})$ of $0.174 \pm 0.05\%$, recall of 0.957, and ROC-AUC of 0.961, surpassing BDTs ($0.148 \pm 0.04\%, 0.914, 0.908$) and Xgboost ($0.149 \pm 0.04\%, 0.924, 0.913$). The classification models are trained on parametrized Monte Carlo (MC) simulations of the CMS detector, with events normalized using cross-section-based reweighting to reflect their expected contributions in a dataset corresponding to $350 fb^{-1}$ of integrated luminosity. This ensures that significance calculations accurately reflect realistic collider conditions. The proposed method is benchmarked against conventional machine learning approaches, with results demonstrating improved classification significance. This quantum enhanced approach offers a novel framework for precision event selection at the LHC, leveraging high dimensional statistical learning and quantum-enhanced inference to tackle fundamental HEP challenges, aligning with cutting-edge ML developments.

Field:

Pheno

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Top decay width at NNNLO in QCD

Authors: Hai Tao Li[1]; Jian Wang[1]

[1] *Shandong University*

We present the first analytic results of next-to-next-to-next-to-leading-order (N3LO) QCD corrections to the top-quark decay width. We focus on the dominant leading color contribution, which

includes light-quark loops. At next-to-next-to-leading order (NNLO), this dominant contribution accounts for 95% of the total correction. By utilizing the optical theorem, the N3LO corrections are related to the imaginary parts of the four-loop self-energy Feynman diagrams, which are calculated with differential equations. The results are expressed in terms of harmonic polylogarithms, enabling fast and accurate evaluation. The third-order QCD corrections decrease the leading-order decay width by 0.667%, and the scale uncertainty is reduced by half compared to the NNLO result. The most precise prediction for the top-quark width is now 1.321 GeV for mt= 172.69 GeV.

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Run 2/3 detector performance and object reconstruction at ATLAS

Author: Monica Verducci[1]

[1] *Universita & INFN Pisa (IT)*

This talk is to present new techniques in ATLAS for object reconstruction and identification

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Advanced statistical methods (including unfolding) in ATLAS and CMS

Author: Monica Verducci[1]

[1] *Universita & INFN Pisa (IT)*

Complex statistical tools are required for the extraction and interpretation of measurements at the LHC experiments. Tools used by ATLAS and CMS are now public, e.g. Combine and TRExFitter. These can be used for more complex actions such as multi-analysis combinations, unfolding and EFT interpretations. This talk will discuss the underlying statistical methods, including recent developments and their implementation in these tools.

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Differential top-quark cross section measurements at ATLAS and CMS

Author: Monica Verducci[1]

[1] *Universita & INFN Pisa (IT)*

The LHC produces a vast sample of top quark pairs and single top quarks. Measurements of the inclusive top quark production rates at the LHC have reached a precision of several percent and test advanced Next-to-Next-to-Leading Order predictions in QCD. Differential measurements in several observables are important to test SM predictions and improve Monte Carlo generator predictions. In this contribution, comprehensive differential measurements of top-quark-antiquark pair and single-top-quark production are presented that use data recorded by the ATLAS and CMS experiments during Run 2/3.

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Top quark pair production + vector boson in ATLAS

Author: Monica Verducci[1]

[1] *Universita & INFN Pisa (IT)*

The high center-of-mass energy of proton-proton collisions and the large available datasets at the CERN Large Hadron Collider allow the study of rare processes of the Standard Model with unprecedented precision. Measurements of rare SM processes provide new tests of the SM predictions with the potential to unveil discrepancies with the SM predictions or provide important input for the improvement of theoretical calculations. In this contribution, total and differential measurements of associated top-quark production are shown using data taken with the ATLAS Experiment at a center-of-mass-energy of 13 TeV. These measurements provide important bounds on the electroweak couplings of the top quark, often with Effective Field Theory interpretations and constrain backgrounds that are important in searches for Higgs production and for new phenomena beyond the SM.

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Rare top processes in ATLAS and CMS

Author: Monica Verducci[1]

[1] *Universita & INFN Pisa (IT)*

The high center-of-mass energy of proton-proton collisions and the large available datasets at the CERN Large Hadron Collider allow the study of rare processes of the Standard Model with unprecedented precision. Measurements of rare SM processes provide new tests of the SM predictions with the potential to unveil discrepancies with the SM predictions or provide important input for the

improvement of theoretical calculations. In this contribution results on rare production processes including top-quarks are shown using data taken with the ATLAS Experiment at a center-of-mass-energy of 13 TeV.

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EFT results in the top quark sector in ATLAS

Author: Monica Verducci[1]

[1] *Universita & INFN Pisa (IT)*

Many-parameter fits to precise measurements in the framework of the Standard Model Effective Field Theory are becoming a standard interpretation of LHC and other collider data. In this contribution an overview is given of state-of-the-art EFT interpretations in ATLAS with particular emphasis on results in the top quark sector.

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Global EFT combinations in ATLAS and CMS

Author: Monica Verducci[1]

[1] *Universita & INFN Pisa (IT)*

Many-parameter fits to precise measurements in the framework of the Standard Model Effective Field Theory are becoming a standard interpretation of LHC and other collider data. In this contribution an overview is given of state-of-the-art EFT interpretations in ATLAS with particular emphasis on results in the top quark sector.

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Recent results on top mass from ATLAS and CMS

Author: Monica Verducci[1]

[1] *Universita & INFN Pisa (IT)*

The top-quark mass is one of the key fundamental parameters of the Standard Model that must be determined experimentally. Its value has an important effect on many precision measurements and tests of the Standard Model. The Tevatron and LHC experiments have developed an extensive program to determine the top quark mass using a variety of methods. In this contribution, the top quark mass measurements by the ATLAS and CMS experiments are reviewed. These include measurements in two broad categories, the direct measurements, where the mass is determined from a comparison with Monte Carlo templates, and determinations that compare differential cross-section measurements to first-principle calculations.

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Measurement of spin correlation and entanglement in ATLAS and CMS

Author: Monica Verducci[1]

[1] *Universita & INFN Pisa (IT)*

The exceptionally large dataset collected by the ATLAS and CMS detectors at the highest proton-proton collision energies provided by the LHC enables precision testing of theoretical predictions using an extensive sample of top quark events. One example of this is the spin correlation of top quarks, which can uniquely be probed due to the decay time being shorter than hadronisation time. This wealth of data has also opened the door to new measurements of top quark properties including those particularly sensitive to the ttbar threshold region, such as quantum entanglement, which were previously beyond reach. This contribution presents the latest highlights in this area from the ATLAS and CMS experiments.

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Latest results on ttbar production threshold in ATLAS

Author: Monica Verducci[1]

[1] *Universita & INFN Pisa (IT)*

The exceptionally large dataset collected by the ATLAS and CMS detectors at the highest proton-proton collision energies provided by the LHC enables precision testing of theoretical predictions using an extensive sample of top quark events. One example of this is the spin correlation of top quarks, which can uniquely be probed due to the decay time being shorter than hadronisation time. This wealth of data has also opened the door to new measurements of top quark properties including those particularly sensitive to the ttbar threshold region, such as quantum entanglement, which were previously beyond reach. This contribution presents the latest highlights in this area from the ATLAS and CMS experiments.

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Top quark physics at FCC-ee and FCC-hh

Author: Markus Klute[1]

[1] *Karlsruhe Inst. of Technology (GER)*

The Future Circular Collider (FCC) programme provides unique opportunities for comprehensive and precise studies of top quark physics. At the FCC-ee, operating at and slightly above the top pair threshold, a precise measurement of the top quark mass with a statistical and systematic accuracy down to the MeV level can be achieved through a threshold scan. Furthermore, the FCC-ee run at 365 GeV allows precise determinations of top quark electroweak couplings, particularly the ttZ vertex with sub-percent precision, and enables stringent constraints on flavor-changing neutral currents (FCNC), such as the Vts coupling. At the FCC-hh, the unprecedented center-of-mass energy of 84 TeV enables precise differential measurements of top quark production processes at very high momentum transfer, such as top quark pairs and rare four-top final states. These high Q^2 measurements provide critical sensitivity to new physics effects at multi-TeV scales and will complement precision measurements from FCC-ee, thus offering a comprehensive exploration of the top quark sector.

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Reconstructing Toponium using Recursive Jigsaw Reconstruction

Authors: Aman Desai[1]; Paul Jackson[2]

[1] *University of Adelaide (AU)*

[2] *University of Adelaide*

Recent results from the CMS experiment at the Large Hadron Collider indicate the presence of a top-quark pair bound state near the $t\bar{t}$ threshold region. We present a way to reconstruct a toponium state at the ttbar threshold region formed at the Large Hadron Collider using Recursive Jigsaw Reconstruction. We have considered the Non-Relativistic QCD based toponium model implemented in MadGraph5_aMC@NLO. The final states, consisting of two b-jets, two oppositely charged leptons and missing energy that arises from two neutrinos, are used. The goal of the Recursive Jigsaw Reconstruction is to make use of rules that can help resolve combinatorics ambiguity in preparing the decay tree for a given physics event. Additionally, missing energy coming from two neutrinos needs to be resolved so as to reconstruct the event. We apply four different strategies within the RestFrames package and compare the results of reconstruction resulting from each of the methods. Owing to the method, one can also access kinematic variables in rest frames belonging to the intermediate particle states thereby providing additional means to discriminate the SM ttbar background from the toponium. Our preliminary results indicate that this method may be useful to gain additional insights into physics phenomenology at the ttbar threshold region.

Field:

Pheno

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Search for H->cc and measurement of H->bb via ttH production

Author: Jose Enrique Palencia Cortezon[1]

[1] *Universidad de Oviedo (ES)*

A search for the standard model Higgs boson decaying to a cc pair, produced in association with a tt pair (ttH) is presented. The search is performed with the full Run 2 dataset, corresponding to an integrated luminosity of 138/fb. Advanced machine learning techniques are employed for jet flavor identification and event classification. The H->bb decay is measured simultaneously. The measurement provides the best individual limits on H->cc to date, and achieves a 4.4 std. dev. significance for the existence of ttH(H->bb). The measurement relies heavily on the background estimation of tt+heavy flavor jets, and should be an interesting highlight for the TOP2025 conference.

Field:

CMS

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BSM interpretation of four top quark production in CMS

Author: Jose Enrique Palencia Cortezon[1]

[1] *Universidad de Oviedo (ES)*

A reinterpretation of four top quark (tttt) production is presented using the full Run 2 dataset recorded by the CMS experiment, corresponding to an integrated luminosity of 138/fb. The analysis targets BSM scenarios using the existing tttt production measurement, including constraints on effective field theory (EFT) operators, top-philic heavy resonances, and the top-Yukawa coupling. The results provide competitive limits on several new physics models and demonstrate the sensitivity of multi-top final states to a wide range of BSM effects.

Field:

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EFT measurement in ttbar process

Author: Jose Enrique Palencia Cortezon[1]

[1] *Universidad de Oviedo (ES)*

Effective Field Theory (EFT) provides a universal framework for probing beyond the Standard Model physics at LHC scales. Recent advances in analysis techniques and increased dataset complexity have significantly enhanced the sensitivity of EFT studies. We present the latest results on EFT obtained using ttbar production by the CMS collaboration, probing interactions between the top quark and the SM Higgs and vector bosons.

Field:

CMS

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Top-quark pair production and decay: toward NNLO+PS accuracy

Author: Chiara Signorile [None]

Co-authors: Christian Biello ; Giulia Zanderighi ; Marius Wiesemann

In this presentation, we will discuss recent advancements in NNLO+PS predictions for top-quark pair production and decay within the MiNNLO framework. MiNNLO provides a robust method for incorporating next-to-next-to-leading order (NNLO) QCD corrections directly into fully differential predictions, offering unprecedented accuracy. This approach enables a consistent treatment of both production and decay processes, ensuring realistic event simulation compatible with experimental analyses. I will highlight the theoretical developments, key challenges, and the impact of these improvements on phenomenological studies, with a focus on their relevance to the increasing precision demands of LHC experiments.

Field:

Pheno

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Towards a NNLO+PS generator for ttH production in POWHEG

Author: Christian Biello[1]

[1] *Max-Planck Institute for Physics*

The current MiNNLOPS technology enables next-to-next-to-leading order (NNLO) QCD predictions matched to parton showers (NNLO+PS) for heavy-quark pair production in arbitrary kinematics (QQF), within the POWHEG framework. Among QQF processes, Higgs production in association with a heavy-quark pair is particularly relevant for LHC phenomenology. In the case of ttH production, the main bottleneck is the absence of the exact two-loop (double-virtual) contribution. Compared to bbH production, the presence of the large top-quark mass requires a combination of different approximations across distinct kinematic regimes. We present a validation of soft and high-energy approximations at the NLO+PS level and provide first differential results at NNLO+PS, with the estimated double-virtual corrections. Once the exact two-loop amplitude becomes available, the reweighting capabilities of the POWHEG framework will offer a valid path to achieving full NNLO+PS accuracy, without the need for new grid evaluations or event generation.

Field:

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Search for Non-Resonant $t\bar{t}HH$ Production with Full Run 2 and Partial Run 3 Dataset

Author: Doğa Elitez[1]

[1] *CERN*

We present the first search for Higgs boson pair production in association with top quarks ($t\bar{t}HH$), using proton–proton collision data recorded by the ATLAS detector, corresponding to the full Run 2 and partial Run 3 datasets. The $t\bar{t}HH$ process is the third most significant production mode for Higgs boson pairs at the LHC and offers direct sensitivity to the anomalous $t\bar{t}HH$ quartic interaction. This analysis aims to contribute to the constraint of the $c(t\bar{t}HH)$ parameter.

Events are selected and categorized into three final states, each targeting different $t\bar{t}HH$ decay channels. Events with at least one charged lepton and multiple jets are divided into single-lepton and multi-lepton final states, based on the number and charge of leptons. Events containing photons are categorized into the $b\bar{b}\gamma\gamma$ final state.

Dedicated control regions are used to constrain the dominant backgrounds. A transformer-based machine learning model is employed to enhance discrimination between signal and background events.

Field:

ATLAS

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Rare and exclusive few-body decays of the top quark

Authors: David d'Enterria[1]; Van Dung Le[2]

[1] *CERN*

[2] *Vietnam National University (VN)*

We will report on an extensive survey of rare and exclusive few-body decays of the top quark, defined as those with branching fractions BR$\boxtimes 10^{-5}$ and two or three final-state particles [1]. Such rare decays probe physics beyond the Standard Model (BSM), constitute a background for exotic decays into new BSM particles, and provide precise information on quantum chromodynamics factorization with small nonperturbative corrections. We tabulate the theoretical BR values for almost 40 rare decay channels of the heaviest elementary particle, indicating the current experimental limits in their observation. Among those, we have computed for the first time semiexclusive top-quark decays into a quark plus a meson, while updating predictions for a few other rare partial widths. The feasibility of measuring each of these unobserved decays is estimated for p-p collisions at the high-luminosity Large Hadron Collider (HL-LHC), and for e+e- and p-p collisions at the future circular collider (FCC).

[1] David d'Enterria, Van Dung Le, "Rare and exclusive few-body decays of the Higgs, Z, W bosons, and the top quark", J.Phys.G 52 (2025) 5, 053001; arXiv:2312.11211 [hep-ph]

Field:

Pheno

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The interference effect of ⊠ and new physics near ⊠ threashold at LHC

Author: JINHEUNG KIM[None]

Many Beyond the Standard Model (BSM) theories predict new scalar bosons ⊠ that couple to top quarks. Such scalars contribute to $gg \to t\bar{t}$ production via $gg \to \phi^* \to t\bar{t}$, leading to significant interference with the Standard Model $gg \to t\bar{t}$ amplitude. Near the $t\bar{t}$ threshold, top quark pairs form bound states, requiring careful theoretical treatment of the production dynamics. In this work, we study the interference between BSM scalar and SM $t\bar{t}$ production while explicitly incorporating bound state effects through matrix element reweighting techniques. This approach allows us to properly account for the modified kinematics and enhanced sensitivity to new physics signatures in the near-threshold region.

Field:

Pheno

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One-loop Amplitudes for $t\bar{t}j$ and $t\bar{t}\gamma$ Productions at the LHC

Authors: Colomba Brancaccio[None]; Dhimiter Canko[1]; Heribertus Bayu Hartanto[2]; Souvik Bera[3]

[1] *NSCR "Demokritos"*

[2] *Asia Pacific Center for Theoretical Physics (APCTP), Pohang, South Korea*

[3] *Asia Pacific Center for Theoretical Physics*

We present analytic expressions for the one-loop QCD helicity amplitudes contributing to top-quark pair production in association with a photon or a jet at the Large Hadron Collider (LHC), evaluated through $O(\epsilon^2)$ in the dimensional regularisation parameter, ϵ. These amplitudes are required to construct the two-loop hard functions that enter the NNLO QCD computation. The helicity amplitudes are expressed as linear combinations of algebraically independent components of the ϵ-expanded master integrals, with the corresponding rational coefficients written in terms of momentum-twistor variables. We derive differential equations for the pentagon functions, which enable efficient numerical evaluation via generalised power series expansion method.

Field:

Pheno

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Two-loop QCD corrections for radiative top decay process

Authors: Colomba Brancaccio[None]; Heribertus Bayu Hartanto[1]; Manfred Kraus[2]

[1] *Asia Pacific Center for Theoretical Physics (APCTP), Pohang, South Korea*

[2] *UNAM*

I will present the calculation of two-loop QCD amplitudes for the radiative top decay process t->Wbg, with the W-boson decay to a lepton-neutrino pair included. This amplitude is required in the computation of top quark pair production in association with a jet at NNLO QCD accuracy where the top decays are included in the narrow width approximation. Analytic form of the two-loop helicity

amplitudes are derived in terms of master integrals. These master integrals are evaluated numerically using generalised series expansion method to solve the associated differential equations.

Field:

Pheno

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Two-loop Integrals for leading colour ttW production

Author: Dhimiter Canko[1]

[1] *Università di Bologna*

We present the calculation of two-loop Feynman integrals contributing to NNLO QCD corrections to the production of a top-quark pair in association with a W boson at hadron colliders, in the leading colour approximation. This process constitutes a key signature at the Large Hadron Collider, and the precise prediction of its cross-section is imperative for comparisons with experimental data. In our study, we employ the method of differential equations, facilitated by using finite field methods to reconstruct the differential equation matrices. The presence of the top quark in the virtual propagators, in addition to the mass of the external W boson, gives rise to complex algebraic and analytic structures, such as nested square roots and three elliptic curves.

Field:

Pheno

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Single top plus Higgs production at the LHC

Author: Ya-Juan Zheng[None]

We study the single top plus Higgs production process at the LHC with a CP violating Yukawa coupling from a dimension-6 operator. The amplitude of the subprocess ub>dtH is obtained both in the Unitary (U) and Feynman-Diagram (FD) gauges. Energy and angular distributions of the cross section and CP violating asymmetries are understood from the interference among the FD gauge amplitudes.

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Simulation of on and off-shell top quark productions with bb4l generator

Author: Jose Enrique Palencia Cortezon[1]

[1] *Universidad de Oviedo (ES)*

We present studies of the b_bbar_4l (bb4l) package from the POWHEG BOX RES Monte Carlo generator, used to model top quark productions for the CMS experiment at the LHC. The bb4l package includes next-to-leading order matrix element calculations interfaced to parton shower for top quark pair production, the associated production of a single top quark with a W boson, their interferences, and the non-resonant production of two charged leptons, two neutrinos, and two b quarks. Events generated with the bb4l package are compared to predictions from the POWHEG BOX V2 generators across several observables sensitive to off-shell and interference effects.

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Charged Lepton Flavour Violation in the top quark sector at CMS

Author: Jose Enrique Palencia Cortezon[1]

[1] *Universidad de Oviedo (ES)*

A search for charged lepton flavor violation (CLFV) in top quark interactions is presented. The search uses proton-proton collision data collected with the CMS experiment at the LHC during Run2, corresponding to an integrated luminosity of 138 fbˆ{-1} at a center-of-mass energy of 13 TeV. The study targets both single top production via CLFV interaction and top quark pair production followed by a CLFV decay, focusing on final states containing an oppositely charged muon and a hadronically decaying tau and at least three jets, where one has been identified to originate from the fragmentation of a bottom quark. A model-independent approach based on Effective Field Theory is employed, and signal extraction is enhanced through deep neural networks. The upper limits at 95% confidence level are set and consistent with the standard model expectations.

Field:

CMS

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Measurement of CP violation in single top t-channel production at 13 TeV

Author: Jose Enrique Palencia Cortezon[1]

[1] *Universidad de Oviedo (ES)*

A violation of the charge-parity (CP) symmetry can explain the paradox of the baryon asymmetry of the universe. We have studied a forward-backward asymmetry of an angular distribution defined in the top quark sector, which is strongly related to the CP-violation. The measurement is performed in the t-channel production of single top quark in proton-proton collisions, at center-of-mass energy of 13 TeV, using data collected by the CMS detector at the LHC from 2016 to 2018, corresponding to an integrated luminosity of 138/fb.

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