PROCEEDINGS OF SCIENCE

Recent $t\bar{t}H$ measurements with ATLAS

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After the discovery of a Higgs boson, the measurement of its properties plays a very important role at the LHC. The determination of the associated production of the Higgs boson and a top-antitop quark pair ($t\bar{t}H$ production) is of particular importance as it offers a tree-level access to measuring the Higgs-top Yukawa coupling. With a predicted numerical value close to unity, this coupling plays a crucial role in the stability of the Higgs potential at high energy scales and can also be a probe for physics beyond the Standard Model (SM) through fine deviations from the SM predictions. The $t\bar{t}H$ production analysis at ATLAS exploits several Higgs decay modes, together with different top quark decay modes. In this proceeding, the latest results on the search for the $t\bar{t}H$ process in four final states with ATLAS is presented, with particular focus on the multilepton final state.

The Eighth Annual Conference on Large Hadron Collider Physics-LHCP2020
25-30 May, 2020
online

*Speaker

https://pos.sissa.it/

PoS(LHCP2020)179

1. Introduction

The $t\bar{t}H$ process has a complex and rich diversity of possible final states arising from combinations of $t\bar{t}$ and Higgs boson decays, which are classified in the particular physics analyses by the Higgs decay mode. It was observed based on the analysis of proton-proton collision data at $\sqrt{s}$ = 13 TeV recorded with the ATLAS detector [1] at the LHC using data corresponding to an integrated luminosity of up to 79.8 fb^{-1}, and considering the Higgs boson decays into $b\bar{b}$, WW^*, $\tau^-\tau^+$, $\gamma\gamma$, and ZZ^*. Since then, two of the four analyses ($H \to \gamma\gamma$ and $H \to ZZ^* \to 4\ell$) updated their measurement with a dataset corresponding to an integrated luminosity of 139 fb^{-1} (full Run 2 dataset), one analysis updated with a dataset corresponding to an integrated luminosity of 79.8 fb^{-1} (multilepton) and the studies are still ongoing to update the results in the $H \to b\bar{b}$ analysis.

2. Measurement in $t\bar{t}H(H \to b\bar{b})$ final state

The search for $t\bar{t}H$ production in the $H \to b\bar{b}$ final state [2] has the largest branching fraction, but suffers from a combinatoric and a large irreducible background (mainly from $t\bar{t}$ + heavy flavour jets) associated with big theoretical uncertainties. The normalisations of $t\bar{t}+ \geq 1b$ and $t\bar{t}+ \geq 1c$ backgrounds are derived from a simultaneous fit to data, and subcategories of them employed to assess uncertatinties. Event categories are divided depending on the number of leptons, the jet multiplicity and the b-tagging working point of each jet. In total nine signal regions (SRs) and ten control regions are defined. A boosted decision tree (BDT) is employed in most of the SRs to reconstruct the $t\bar{t}H$ system. Additionally in the single-lepton category, a Likelihood Discriminant is used in order to exploit all possible combinations, and a matrix element method in the single-lepton category to build a parton-level discriminating variable. Finally, the outputs of these methods are combined in a BDT together with the basic kinematic variables and b-tagging information. The signal extraction is performed through a combined profile likelihood fit. The significance of the observed (expected) signal is 1.4σ (1.6σ). The measured signal strength is in good agreement with the SM prediction within the relative measurement precision of 75%. This measurement is dominated by the systematic uncertainties (particularly $t\bar{t}+ \geq 1b$ modelling).

3. Measurement in multilepton final state

The search for $t\bar{t}H$ production in multilepton final states [3] targets WW^*, ZZ^* or $\tau^+\tau^-$ decays of the Higgs boson. The main background contributions arise from $t\bar{t}W$, $t\bar{t}Z/\gamma^*$, and diboson ($VV, V = W\ or\ Z$) production, as well as from $t\bar{t}$ production with additional light leptons (electron, muon) from heavy-flavour hadron decays, misidentified jets or photon conversions (together referred to as *non-prompt leptons*), and other processes where the electron charge is incorrectly assigned or where jets are misidentified as hadronically decaying tau (τ_{had}) candidates. Depending on the number and flavour of the leptons, the analysis is divided into six categories. The most sensitive categories ($2\ell SS$-two same-charge light leptons and 3ℓ-three light leptons) are further split into signal and control region categories to gain sensitivity. BDT discriminants are used to suppress electrons with a misidentifed charge as well as non-prompt leptons arising from heavy-flavour decays. Conversion electrons are defined by using the invariant mass of the associated track and the

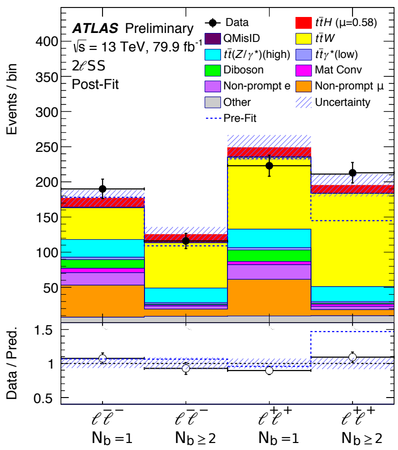

Figure 1: Distribution of the total charge and b-jet multiplicity split in four separate categories in $2\ell SS$.

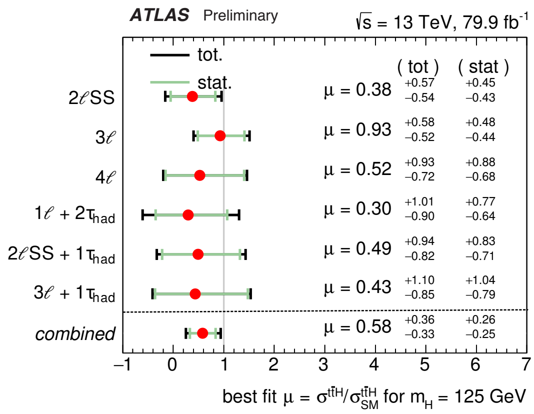

Figure 2: The observed best-fit values of the $t\bar{t}H$ signal strength and their uncertainties by analysis category.

closest opposite-charge track reconstructed and the displaced vertex radius. In $2\ell SS$, five different event categories are defined to control the different sources of backgrounds. The SR is optimised by using two different BDTs, trained against $t\bar{t}$ and $t\bar{t}V$. The 3ℓ category exploits a multinomial BDT targetting five different event classifications. The light lepton background estimation method relies on the normalisation of the different non-prompt contribution templates obtained from data, with their shapes given by simulation. Furthermore, categories sensitive to the $t\bar{t}W$ background have been introduced to the analysis to study and constrain this background. Disagreements between the data and the pre-fit prediction are observed. Three independent normalisation factors (NFs) for the $t\bar{t}W$ background are considered: two for the low jet and high jet categories of the $2\ell SS$, and one for the 3ℓ. Additional shape uncertainties associated with the modelling of the b-jet multiplicity and W-boson charge asymmetry in the $t\bar{t}W$ phase space are introduced (Figure 1). The measured $t\bar{t}W$ NFs are in the range 1.3–1.7 above the updated theoretical predictions. A maximum-likelihood fit is performed in the 25 event categories together with 218 nuisance parameters and 7 normalisation factors for non-prompt backgrounds and $t\bar{t}W$. The significance of the observed (expected) signal is 1.8σ (3.1σ) (Figure 2). The measured signal strength is in good agreement with the SM prediction within the relative measurement precision of 60%. The most impacting systematic uncertainties are jet energy scale and resolution, $t\bar{t}\ell\ell$ and $t\bar{t}W$ modelling.

4. Measurement in $t\bar{t}H(H \to \gamma\gamma)$ final state

The $\gamma\gamma$ final state [4] has very low systematics but also a very low branching ratio. In the $t\bar{t}H(H \to \gamma\gamma)$ analysis, events with well isolated photon candidates are selected. Photons are selected using a cut-based multivariate discriminant, and the diphoton invariant mass is required to fall within a window of $105 < m_{\gamma\gamma} < 160$ GeV. Two analysis regions are defined, the hadronic one with at least two jets and without leptons, and the leptonic region with at least one lepton. The analysis is based on data-driven background estimation, and simulated samples from the $t\bar{t}\gamma\gamma$ and continuum diphoton processes are exploited. A BDT is trained in each region to provide discrimination between signal and background. Events with high BDT scores are classified into multiple categories with different sensitivities. In total three (four) leptonic (hadronic) regions are defined, and a combined unbinned fit to the diphoton invariant mass distributions is performed, using a double-sided Crystal Ball function. The significance of the observed (expected) signal is 4.9σ (4.2σ). The measured signal strength is in good agreement with the SM prediction within the precision of 30%, dominated by statistical uncertainties.

5. Measurement in $t\bar{t}H(H \to ZZ^* \to 4\ell)$ final state

This analysis focuses on the Higgs boson decays into four light leptons (electron, muon) [5]. A Higgs candidate is considered for the range $115 < m_{4\ell} < 130$ GeV. The estimation of background contribution is done from a sample selected in a dedicated side-band region. The event categories are divided depending on the decay mode of the W bosons from top quark decays. The requirements on the jet multiplicity and b-tagging working point are used for both lepton enriched and hadron enriched regions, together with additional lepton requirements in the lepton enriched region. In the hadron enriched region, a neural network (NN) is used to identify $t\bar{t}H$-like and tXX-like events by assigning probabilities. Based on the outputs of the NN, two regions are defined, and one region is divided into two bins. Although the analysis is statistically limited, three candidates are observed in the full Run 2 dataset.

6. Conclusion

Since ATLAS has established observation of $t\bar{t}H$ production, some individual channels updated their results with more data and improved techniques. $H \to \gamma\gamma$ and $H \to ZZ^* \to 4\ell$ categories have updated their results with full Run 2 dataset, and show good improvement. The multilepton category updated the results with a dataset corresponding to an integrated luminosity of 79.8 fb^{-1}, and shows that a better understanding of $t\bar{t}W$ modelling is imperative.

References

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