Measurement of the cross-section of the associated production of a top quark pair and a W or Z boson with the ATLAS detector

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In the Standard Model the coupling of the top quark to a vector boson is predicted via the weak interaction. New physics beyond the Standard Model can modify the $t\bar{t}V$ cross-section. As an example several of the operators introduced by effective field theory are sensitive to the $t\bar{t}Z$ and $t\bar{t}W$ production cross-sections. Multiple analysis channels with 2, 3 or 4 lepton final-states have been considered in the latest $t\bar{t}V$ cross section measurement by the ATLAS experiment located at the Large Hadron Collider (LHC). The dominant backgrounds in the analysis are mis-reconstructed leptons and the diboson process, depending on the analysis channel. A two-dimensional fit of the $t\bar{t}W$ and $t\bar{t}Z$ cross-section is performed to interpret possible deviations from the Standard Model.

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1. Introduction

The latest published $t\bar{t}V$ analysis by ATLAS [1] analyzed the 3.2 fb^1 dataset taken in 2015 [2]. The aim is a cross section measurement of both $t\bar{t}Z$ and $t\bar{t}W$ by simultaneously fitting both in a profile likelihood fit. Multiple analysis channels are considered, which are introduced in Section 2. Both processes are predicted by the Standard Model and a measurement of the cross section can indicate new physics, which could be interpreted with various models, such as effective field theories (EFT) which modify the SM Lagrangian, for example in Reference [6]. A previous measurement by ATLAS analyzed the $\sqrt{s} = 8$ TeV dataset and was in agreement with the Standard Model [3] and a more recent measurement by the CMS experiment can be seen in Reference [5].

2. Analysis overview and event selection

The $t\bar{t}V$ analysis is split into multiple analysis channels which are sensitive to either $t\bar{t}W$, $t\bar{t}Z$ or both. The main backgrounds include fake leptons, which is estimated by the data-driven matrix method for the di- and trilepton channels and by a MC based method for the tetralepton channels, and the diboson processes.

Only events with at least two leptons are considered, of which at least one lepton is required to satisfy $p_T > 25$ GeV. Detailed event selection for each region are described below.

2.1 $t\bar{t}W$ analysis

The $t\bar{t}W$ analysis is performed in the same-sign dimuoun channel (2μSS) and one of the trilepton $t\bar{t}Z$ regions, that also provides some sensitivity to $t\bar{t}W$. This channel provides the highest sensitivity among all channels, due to the high misidentifaction rate of electrons. Events are required to have two muon candidates, with the same charges and $p_T > 25$ GeV, $E_T^{\text{miss}} > 40$ GeV, the scalar sum of the p_T of the selected leptons and jets, H_T, above 240 GeV, and at least two b-tagged jets.

The dominant background in the 2μSS channel arises from events containing fake leptons, where the main source is $t\bar{t}$ events. A total of 9 events have been observed in the 2μSS channel.

2.2 $t\bar{t}Z$ analysis

Trilepton analysis

Four signal regions with exactly three leptons are considered. The first three are sensitive to $t\bar{t}Z$; each of these requires an opposite-sign same-flavour (OSSF) pair of leptons whose invariant mass is within 10 GeV of the Z boson mass. The signal regions are categorized by their jet and b-jet multiplicities and have different signal-to-background ratios. In the 3ℓ-Z-1b4j region, at least four jets are required, exactly one of which is b-tagged. In the 3ℓ-Z-2b3j region, exactly three jets with at least two b-tagged jets are required. In the 3ℓ-Z-2b4j region, at least four jets are required, of which at least two are b-tagged.

In the 3ℓ-noZ-2b region at least two and at most four jets are required, of which at least two are b-tagged, no OSSF lepton pair is allowed in the Z boson mass window, and the sum of the lepton charges must be ±1. This region primarily targets the $t\bar{t}W$ process but also has a sizable $t\bar{t}Z$ contribution.

The main backgrounds are the WZ process and fake leptons for the trilepton analysis. A total of 29 events have been observed among the four trilepton regions.

Tetralepton analysis

Four signal regions with exactly four leptons are considered. Events with two pairs of opposite-sign leptons are selected, and at least one pair must be of same flavour. The OSSF lepton pair with reconstructed invariant mass closest to m_Z is attributed to the Z boson decay and denoted Z_1. The two remaining leptons are used to define Z_2. The signal regions are defined according to the relative flavour of the two Z_2 leptons, different flavour (DF) or same flavour (SF), and the number of b-tagged jets: one, or at least two ($1b$, $2b$). The signal regions are thus 4ℓ-DF-1b, 4ℓ-DF-2b, 4ℓ-SF-1b and 4ℓ-SF-2b.

To suppress events with fake leptons in the 1-b-tag multiplicity regions, additional requirements on the scalar sum of the transverse momenta of the third and fourth leptons (p_{T34}) are imposed. In the 4ℓ-SF-1b and 4ℓ-DF-1b regions, events are required to satisfy $p_{T34} > 25$ GeVand $p_{T34} > 35$ GeV, respectively. In all regions, the invariant mass of any two reconstructed OS leptons is required to be larger than 10 GeV.

The main backgrounds are the ZZ process, primarily in the SF regions, and fake leptons. A total of 5 events have been observed among the four tetralepton regions.

3. Results

A total of 43 events have been observed among all signal regions. Table 1 shows a list of uncertainties with their impact on the measurement for both $t\bar{t}Z$ and $t\bar{t}W$. As can be seen, both measurements are dominated by the statistical uncertainty. Figure 1 shows the extracted cross sections of the simultaneous fit of $t\bar{t}Z$ and $t\bar{t}W$, compared to the Standard Model prediction.

Uncertainty	$\sigma_{t\bar{t}Z}$	$\sigma_{t\bar{t}W}$
Luminosity	2.6%	3.1%
Reconstructed objects	8.3%	9.3%
Backgrounds from simulation	5.3%	3.1%
Fake leptons and charged misID	3.0%	19%
Signal modelling	2.3%	4.2%
Total systematic	11%	22%
Statistical	31%	48%
Total	32%	53%

Table 1: List of dominant and total uncertainties in the measured cross sections of the $t\bar{t}Z$ and $t\bar{t}W$ processes from the fit. All uncertainties are symmetrised [2].

The extracted cross sections are $\sigma_{t\bar{t}Z} = 0.92 \pm 0.29$ (stat.) ± 0.10 (syst.) pb and $\sigma_{t\bar{t}W} = 1.50 \pm 0.72$ (stat.) ± 0.33 (syst.) pb, which are both in agreement of the theory prediction of $\sigma_{t\bar{t}Z}^{SM} = 0.84 \pm 0.09$ pb and $\sigma_{t\bar{t}W}^{SM} = 0.60 \pm 0.08$ pb [4].
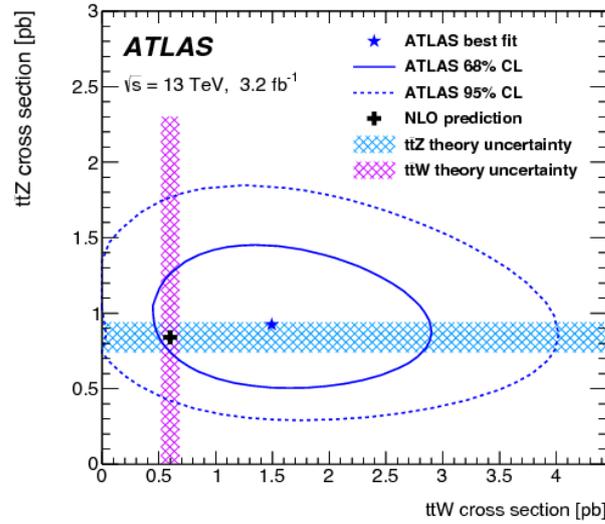
Figure 1: The result of the simultaneous fit to the $t\bar{t}Z$ and $t\bar{t}W$ cross sections along with the 68% and 95% confidence level (CL) contours. The shaded areas correspond to the theoretical uncertainties in the Standard Model predictions, and include renormalisation and factorisation scale uncertainties as well as PDF uncertainties including α_s variations [2].

4. Conclusions

The measured cross sections using the 2015 dataset of 3.2 fb^{-1} of $\sigma_{t\bar{t}Z} = 0.92 \pm 0.29$ (stat.) ± 0.10 (syst.) pb and $\sigma_{t\bar{t}W} = 1.50 \pm 0.72$ (stat.) ± 0.33 (syst.) pb measured with the ATLAS experiment at the LHC are in agreement with the Standard Model prediction [4]. The uncertainties are dominated by the statistical uncertainty and the systematic uncertainties on the fake estimation. A measurement with more data and an improved fake estimation can significantly improve these results. It is interesting to study the shape of certain distributions, like the p_T or the $\Delta\phi$ of the leptons from the Z boson. Those distributions should be sensitive to EFT operators [6] and can be studied with a larger dataset in the future.

References

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