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Top-quark pair production in association with a Z boson in the 4ℓ channel with the ATLAS experiment

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The cross section of the $t\bar{t}Z$ and $t\bar{t}W$ processes are measured in a simultaneous fit using 36.1 fb^{-1} of of proton–proton collisions at a centre-of-mass energy of $\sqrt{s} = 13$ TeV recorded by the ATLAS experiment at the LHC. In addition, a fit is performed in the 4ℓ channel only, resulting in a cross section of $\sigma_{t\bar{t}Z} = 1.07 \pm 0.26$ pb. This result is consistent with the combined fit and agrees with the prediction by the Standard Model.

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1 Introduction

The $t\bar{t}Z$ processes provides direct access to the weak coupling of the top quark to the Z boson. It is an important background in searches involving final states with multiple leptons and b-quarks. Previous measurements by the ATLAS and CMS experiments [1, 2] indicate agreement with the Standard Model [3, 4].

Typically the $t\bar{t}Z$ process is measured in a two-dimensional fit together with the $t\bar{t}W$ process. One of the analysis channels targeting the $t\bar{t}Z$ process has four isolated prompt leptons. This final state provides the best signal-to-background ratio among all analysis channels. Due to the branching ratios of the top quark and the Z boson, the number of expected events is small in this analysis channel.

The dataset of 36.1 fb^{-1} collected in 2015 and 2016 by the ATLAS detector is considered for the presented analysis. More details about the analysis can be found in Reference [5].

2 Tetralepton analysis

Separate analysis channels are defined to target the $t\bar{t}Z$ and $t\bar{t}W$ processes. This document focuses on the 4ℓ channel, which is sensitive to the $t\bar{t}Z$ process. Both W bosons, resulting from the top-quark decays, and the Z boson are required to decay leptonically. The most dominant background processes arise from the diboson production, the production of a single top quark in association with a W and a Z boson as well as fake leptons. A fit is performed in the 4ℓ channel to extract the signal strength as well as the background normalization of the ZZ process.

Events with two pairs of opposite-sign leptons are selected, and at least one pair must have the same flavour. Among the lepton pairs with opposite charge and same flavour (OSSF), the pair with reconstructed invariant mass closest to m_Z is attributed to the Z boson decay and denoted in the following by Z_1. The two remaining leptons are used to define Z_2. Four 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 four signal regions are denoted as 4ℓ-SF-1b, 4ℓ-SF-2b, 4ℓ-DF-1b and 4ℓ-DF-2b.

In the same-flavour regions, requirements on $E_{\mathrm{T}}^{\mathrm{miss}}$ are applied in order to suppress the ZZ background. This requirement depends on whether the invariant mass of the Z_2 is close to the mass of the Z boson. 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 ($p_{\mathrm{T}34}$) are imposed. In other regions a requirement on the transverse momentum of all leptons needs to be satisfied, instead. The definitions of all signal regions are given in Table 1.

A control region used to determine the ZZ normalization, referred to as 4ℓ-ZZ-CR

Table 1: Definitions of the four signal regions in the 4ℓ channel targeting the $t\bar{t}Z$ process [5].

Region	Z_2 leptons	p_{T4}	p_{T34}	$|m_{Z_2} - m_Z|$	E_T^{miss}	$N_{b\text{-tagged jets}}$
4ℓ-DF-1b	$e^\pm\mu^\mp$	-	> 35 GeV	-	-	1
4ℓ-DF-2b	$e^\pm\mu^\mp$	> 10 GeV	-	-	-	≥ 2
4ℓ-SF-1b	$e^\pm e^\mp, \mu^\pm\mu^\mp$	-	> 25 GeV	> 10 GeV / < 10 GeV	> 40 GeV / > 80 GeV	1
4ℓ-SF-2b	$e^\pm e^\mp, \mu^\pm\mu^\mp$	> 10 GeV	-	> 10 GeV / < 10 GeV	- / > 40 GeV	≥ 2

is defined to have exactly four reconstructed leptons, a Z_2 pair with OSSF leptons, the value of both m_{Z_1} and m_{Z_2} within 10 GeV of the mass of the Z boson, and $20\,\text{GeV} < E_T^{miss} < 40\,\text{GeV}$. The normalization of the ZZ background is a free parameter in the fit.

Figure 1 shows the data compared to the expected distributions for all four signal regions combined, as well as for the control region, showing good agreement between data and expectation.
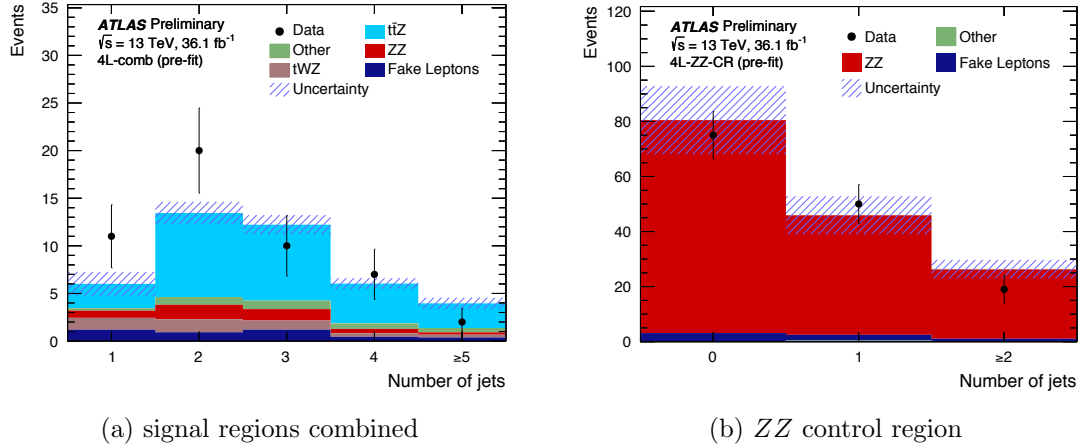

(a) signal regions combined

(b) ZZ control region

Figure 1: Distribution of the number of jets in the signal regions (left) and control region (right). The data distributions are compared to MC predictions before the fit [5].

The contribution from backgrounds containing fake leptons is estimated from simulation and corrected with scale factors determined in two control regions: one region enriched in $t\bar{t}$ events and one region enriched in Z+jets events. The scale factors are calibrated separately for electron and muon fake-lepton candidates, and separately

for leptons arising from heavy flavour hadrons and other sources. Therefore, four scale factors are determined in total. The scale factors are applied to all simulated events with fewer than four prompt leptons and depend on the number, flavour and origin of the fake leptons. It is verified that the scale factors for different generators used in the simulation are consistent with each other.

3   Results

A binned maximum-likelihood fit is performed, which includes the signal regions and the control region of the 4ℓ channel to extract the signal strength

$$\mu_{t\bar{t}Z} = \frac{\sigma_{t\bar{t}Z}}{\sigma_{t\bar{t}Z}^{\rm SM}}. \tag{1}$$

In all regions, good agreement between observed values and the expectation is observed. Figure 2 shows all regions included in the fit after the fit has been performed.
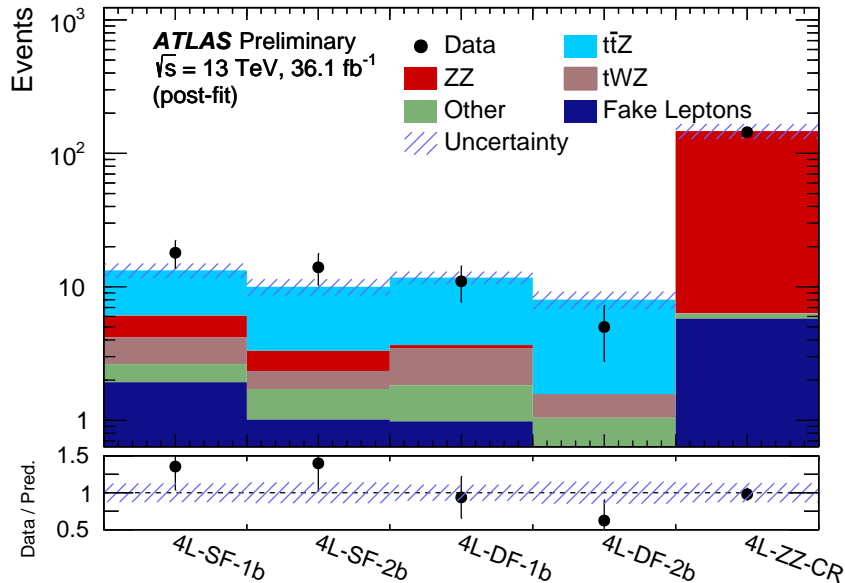

Figure 2: Data compared to the fit that extracts the $t\bar{t}Z$ cross section in the tetralepton regions after the fit has been performed. The background denoted as "Other" summarizes all minor Standard Model backgrounds with four reconstructed leptons [5].

The normalization correction for the ZZ background with respect to the prediction

is obtained from the fit and found to be compatible with unity: $\mu_{ZZ} = 0.94 \pm 0.18$. The obtained signal strength of the $t\bar{t}Z$ process is

$$\mu_{t\bar{t}Z} = 1.21 \pm 0.29 \qquad (2)$$

and both the observed and expected significances are found to be larger than 5 standard deviations. Using the theoretical prediction of $\sigma_{t\bar{t}Z} = 0.88^{+0.09}_{-0.11}$ pb [6], the extracted cross section from the fit in the 4ℓ channel is $\sigma^{4\ell}_{t\bar{t}Z} = 1.07 \pm 0.26$, pb demonstrating good agreement between the measured and predicted cross sections. The dominant systematic uncertainties are related to the modeling of the signal and flavour tagging.

ACKNOWLEDGEMENTS

References

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