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Measurement of ttZ and ttW production at ATLAS in 13 TeV data, using trilepton and same charge dimuon final states

Olga Bessidskaia Bylund*
On behalf of the ATLAS Collaboration
Stockholm University
E-mail: olga.bylund@cern.ch

The production of $t\bar{t}Z$ serves as an important probe of the coupling of top quarks to Z bosons. Modifications to the $t\bar{t}Z$ vertex by physics beyond the Standard Model would have an effect on the $t\bar{t}Z$ production rates. The first measurements of $t\bar{t}Z$ production were performed in 8 TeV data by the ATLAS and CMS experiments at the LHC. At 13 TeV collision energy, the production rate of $t\bar{t}Z$ increases by almost a factor of four and the effects of new physics, if present, should become more prominent. The first measurement by ATLAS of $t\bar{t}Z$ production at 13 TeV is presented here, with a focus placed on the selection region that requires three charged leptons. This signature constitutes a compromise between a higher branching ratio for hadronic top quark decay chains and the better separation from background of the leptonic top quark decays. Moreover, the $t\bar{t}W$ process is measured, using final states that contain either three charged leptons or two muons of the same charge. The first observation of $t\bar{t}W$ was performed by ATLAS using 8 TeV data. Measuring this process can probe several different models for physics beyond the Standard Model.

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*Speaker.

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1. Introduction

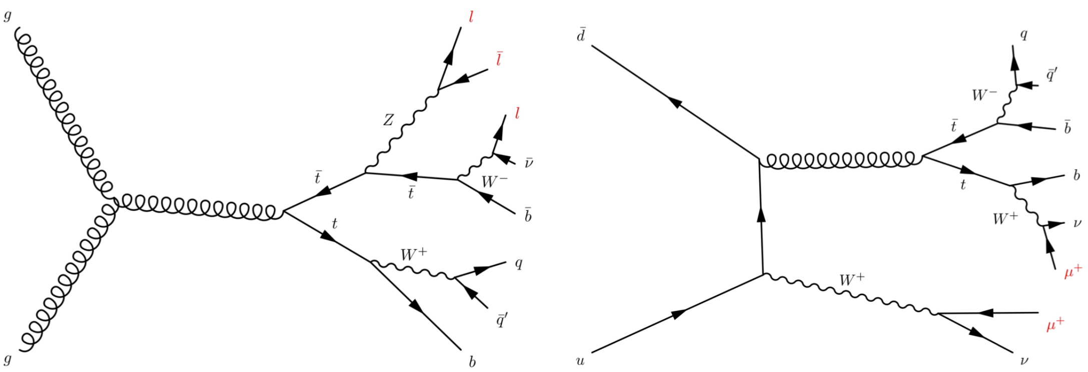

Figure 1: Example Feynman diagrams for $t\bar{t}Z$ production, giving a trilepton signature (left) and $t\bar{t}W$ production, giving a same-sign dimuon singature (right).

The production of a top quark pair in association with a Z or W boson was first observed in proton-proton collisions at $\sqrt{s} = 8$ TeV by CMS [1] and by ATLAS [2], [3] in 2014. Measuring the processes at higher energies and with greater precision would test the Standard Model and constrain any new physics that could contribute to these processes. From the fine-tuning problem, it is of interest to study the production of top quarks together with heavy bosons, aiming to gain a better understanding of electroweak symmetry breaking. Measuring $t\bar{t}Z$ production allows one to constrain new physics that would modify the $t\bar{t}Z$ vertex. Some models with a heavy top quark partner [4] have signatures similar to $t\bar{t}W$. Additionally, $t\bar{t}Z$ and $t\bar{t}W$ form major backgrounds for many searches for new physics.

The first measurement by ATLAS at $\sqrt{s} = 13$ TeV with an integrated luminosity of $3.2\,\text{fb}^{-1}$ is presented here, outlining the analysis in the trilepton and same sign-dimuon channels only. Example Feynman diagrams for the processes, giving a trilepton or same-sign dimuon signature, are shown in Fig. 1. Moreover, a tetralepton selection is used for the $t\bar{t}Z$ measurement and the results quoted here concern the combination with the tetralepton channel. The full analysis is described in greater detail in Ref. [5].

2. Signal regions

To increase the sensitivity to the $t\bar{t}Z$ and $t\bar{t}W$ cross sections, the trilepton channel is split by multiplicity of jets and b-tagged jets into four regions. Three of these regions are separately optimised for $t\bar{t}Z$ and the fourth for $t\bar{t}W$. In the three regions that target $t\bar{t}Z$, a requirement is imposed on the presence of a lepton pair of opposite-sign charge and same flavour (OSSF) with an invariant mass within 10 GeV of the Z-boson mass. The trilepton region targeting $t\bar{t}W$ instead has a veto against such an OSSF pair. The definition of the trilepton selections are shown in Table 1.

Moreover, a dilepton region with two muons of the same charge ($2\mu - SS$) is used and optimised for $t\bar{t}W$. Requirements of at least two b-tagged jets, muon p_{T} above 25 GeV, a missing transverse energy of at least 40 GeV and scalar transverse energy sum H_{T} above 240 GeV are applied to increase the sensitivity.

Variable	3ℓ-Z-1b4j	3ℓ-Z-2b3j	3ℓ-Z-2b4j	3ℓ-noZ-2b
Leading lepton p_{T}	> 25 GeV			
Other leptons' p_{T}	> 20 GeV			
Sum of lepton charges	± 1			
Z-like OSSF pair	$\lvert m_{\ell\ell} - m_Z \rvert < 10$ GeV			$\lvert m_{\ell\ell} - m_Z \rvert > 10$ GeV
n_{jets}	≥ 4	3	≥ 4	≥ 2 and ≤ 4
$n_{b-\mathrm{jets}}$	1	≥ 2	≥ 2	≥ 2

Table 1: The definition of signal regions in the trilepton channel.

3. Background estimation

The main backgrounds for $t\bar{t}Z$ are the production of single top in the Wt channel together with a Z boson (tWZ) and diboson WZ production. For $t\bar{t}W$, the main background originates from misidentified leptons. The contribution of the background processes in the signal regions can be seen in Fig. 3 in Section 4. These backgrounds are treated as follows.

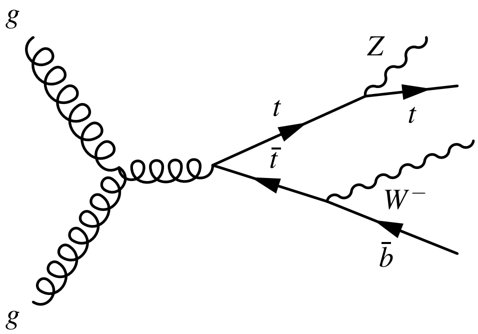

Figure 2: A Feynman diagram produced by generating tWZ at NLO in the five flavour scheme. The same diagram is produced in the generation of $t\bar{t}Z$.

The production of tWZ is assessed using aMC@NLO [6] and matching it with Pythia8 [7] for the parton shower. The five flavour scheme is employed in the event generation, with massless b quarks included in the matrix element. During generation of the process, diagrams that overlap with $t\bar{t}Z$ are produced, such as the one shown in Fig. 2. This overlap is removed using Diagram Removal 1 [8] in order to avoid double counting. The amplitudes of the overlapping diagrams are thus set to zero. An alternative method, Diagram Removal 2 [9], takes the interference of tWZ with $t\bar{t}Z$ and $t\bar{t}$ into account and is used to assess the systematic uncertainty on the prediction. The difference between the inclusive cross sections computed by the two Diagram Removal methods is -22%, corresponding to a sizeable destructive interference.

The WZ process is estimated using Sherpa [10] and matched to a dedicated parton shower. In the most sensitive region for $t\bar{t}Z$ (3ℓ-Z-2b4j), which requires three leptons and at least four jets, one or more jets originate from the shower, which introduces an uncertainty. Theoretical variations of scales, pdf sets and showering programs are used assess the modelling uncertainty. Moreover, a dedicated control region with three leptons is defined to constrain the WZ cross section.

The $t\bar{t}W$-targeting signal regions recieve large contributions from so-called fake leptons, which originate from jets misidentified or from leptons from photon conversions or hadronic decays. A data-driven method is employed to estimate the fake lepton yield. A likelihood fit is performed to the matrix method [11], with the real efficiencies r and fake rates f treated as free parameters.

The fit is performed in dilepton control regions, using the ee, $e\mu$ and $\mu\mu$ channels simultaneously. Once r and f are extracted from the fit in these control regions, they are applied using the matrix method in the trilepton and $2\mu - SS$ signal regions.

4. Results

The results of the measurement are presented here, with the tetralepton channel included for the $t\bar{t}Z$ measurement. The cross sections are extracted using a binned likelihood fit. The event yield in the signal regions, as well as control regions for WZ and ZZ, is shown in the post-fit plots in Fig. 3. The signal processes $t\bar{t}Z$ and $t\bar{t}W$ are shown in red and blue respectively. The results from the fits are $\sigma_{t\bar{t}Z} = 0.9 \pm 0.3$ pb, $\sigma_{t\bar{t}W} = 1.4 \pm 0.8$ pb, which is consistent with the Standard Model predcitions from aMC@NLO of $\sigma_{t\bar{t}Z} = 0.76 \pm 0.08$ pb, $\sigma_{t\bar{t}W} = 0.57 \pm 0.06$ pb. A combined measurement of $t\bar{t}Z$ and $t\bar{t}W$, using all signal regions simultaneously, is planned for the near future.

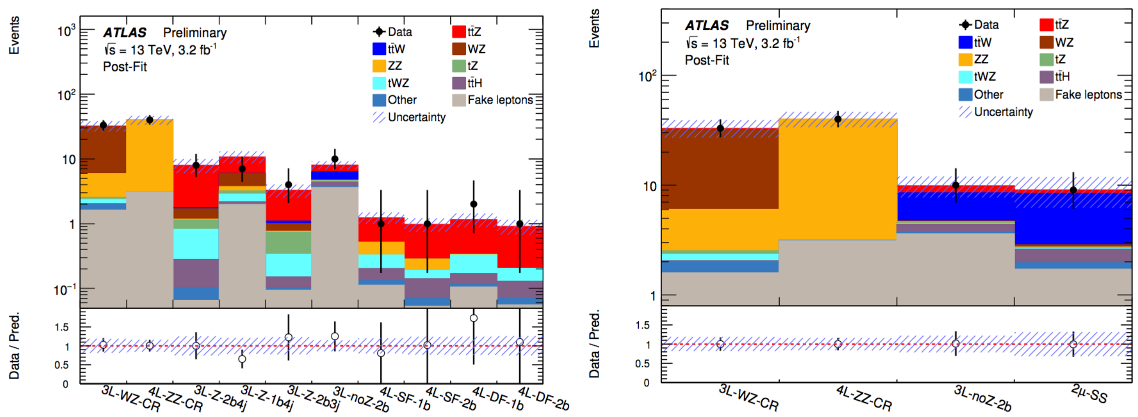

Figure 3: The observed number of events in the signal regions, including the tetralepton channel for $t\bar{t}Z$ [5]. The signal processes are shown in red ($t\bar{t}Z$) and in blue ($t\bar{t}W$). The main backgrounds for the $t\bar{t}Z$ fit are shown in light blue (tWZ) and brown (WZ) and the main background for $t\bar{t}W$ (fake leptons) is shown in grey. The control regions 3L-WZ-CR and 4L-ZZ-CR are included in both the $t\bar{t}Z$ and $t\bar{t}W$ fits.

The statistical uncertainties dominate the measurements, as shown in Table 2. Reconstructed objects, in particular electrons, have the greatest contribution to the systematic uncertainty for $t\bar{t}Z$, while fake leptons and leptons with misidentified charge drive the systematic uncertainty for the $t\bar{t}W$ measurement.

5. Conclusions

The first measurement of $t\bar{t}Z$ and $t\bar{t}W$ at a 13 TeV center of mass energy has been performed by the ATLAS collaboration. The event selection and treatment of uncertainties is briefly described here for the trilepton and same-sign dimuon channels. A combination is performed with the tetralepton channel for the $t\bar{t}Z$ measurement. The results show agreement with the predictions of the Standard Model. The statistical uncertainty dominates the measurement at present. With a higher integrated luminosity in the next run, the precision can be greatly improved, putting new physics scenarios with similar signatures to a test.

Uncertainty	$\sigma_{t\bar{t}Z}$	$\sigma_{t\bar{t}W}$
Luminosity	6.4%	7.0%
Reconstructed objects	7.0%	7.3%
Backgrounds from simulation	5.5%	3.7%
Fake leptons and charge misID	3.9%	21%
Total systematic	12%	24%
Statistical	32%	51%
Total	34%	56%

Table 2: The impact of the uncertainties on the measurements.

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