Measurement of the $t\bar{t}Z$ and $t\bar{t}W$ production cross section in multilepton final states with the ATLAS detector

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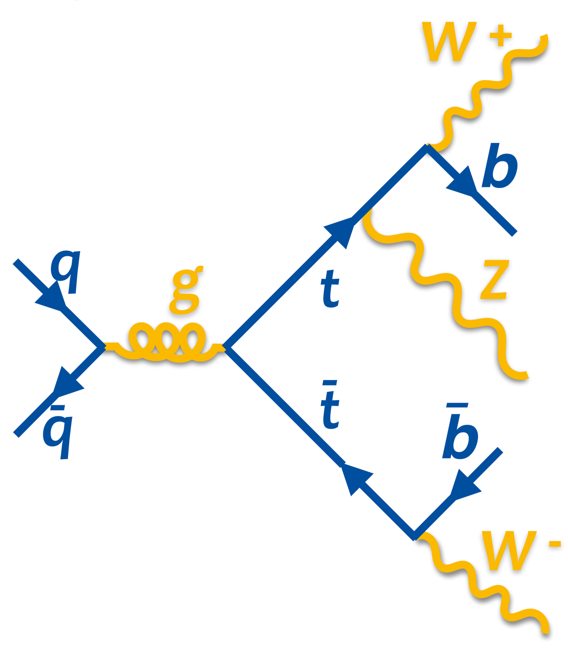
Introduction

Measuring $t\bar{t}Z$ and $t\bar{t}W$ provides direct access to the weak couplings of the top quark. Deviations from the SM predictions can be interpreted as BSM effects. The **dataset of 36.1 fb^{-1}** collected in 2015-2016 by the ATLAS detector is analysed.



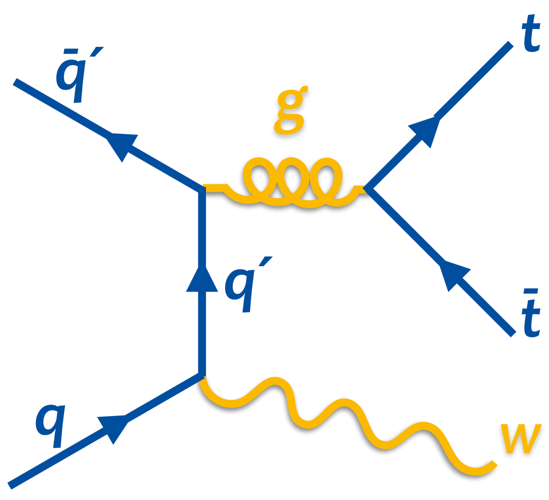
Multiple final states are considered. Multivariate techniques or dedicated estimations for the fake lepton background are used, depending on the channel. Control regions are defined to fit the normalisation of the irreducible backgrounds.

Previous measurements at 13 TeV

ATLAS (3.2 fb^{-1}) Eur. Phys. J. C77 (2017) 40

CMS (35.9 fb^{-1}) JHEP08 (2018) 011

Process	$t\bar{t}$ decay	Boson decay	Channel
$t\bar{t}W$	$(\ell^\pm\nu b)(q\bar{q}b)$	$\ell^\pm\nu$	SS dilepton
	$(\ell^\pm\nu b)(\ell^\mp\nu b)$	$\ell^\pm\nu$	Trilepton
$t\bar{t}Z$	$(q\bar{q}b)(q\bar{q}b)$	$\ell^+\ell^-$	OS dilepton
	$(\ell^\pm\nu b)(q\bar{q}b)$	$\ell^+\ell^-$	Trilepton
	$(\ell^\pm\nu b)(\ell^\mp\nu b)$	$\ell^+\ell^-$	Tetralepton



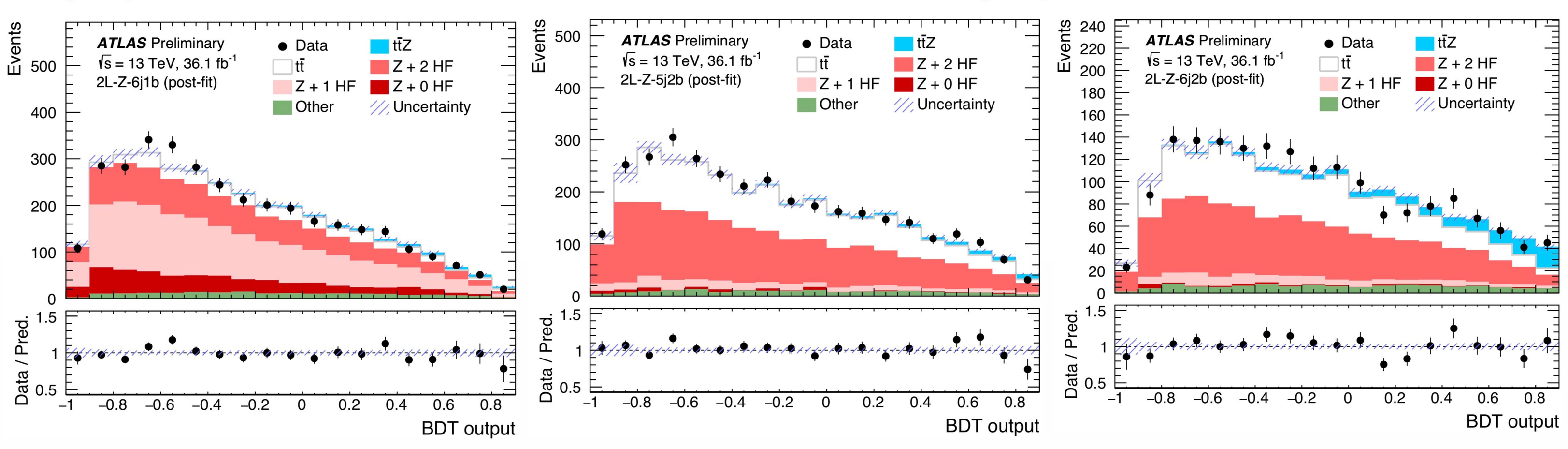
The $t\bar{t}Z$ analysis

The analysis includes the channels:

- 2ℓOS (exploiting multivariate techniques to suppress $t\bar{t}$)
- 3ℓ (most sensitive to $t\bar{t}Z$)
- 4ℓ (highest signal-to-background ratio)

Three boosted decision trees (BDTs) were trained in the **2ℓOS channel**, split according to the jet multiplicity. The normalisation of the Z+jets jet-flavour components are estimated by the fit.

μ (Z+1HF) = 1.19 ± 0.25 μ (Z+2HF) = 1.09 ± 0.13

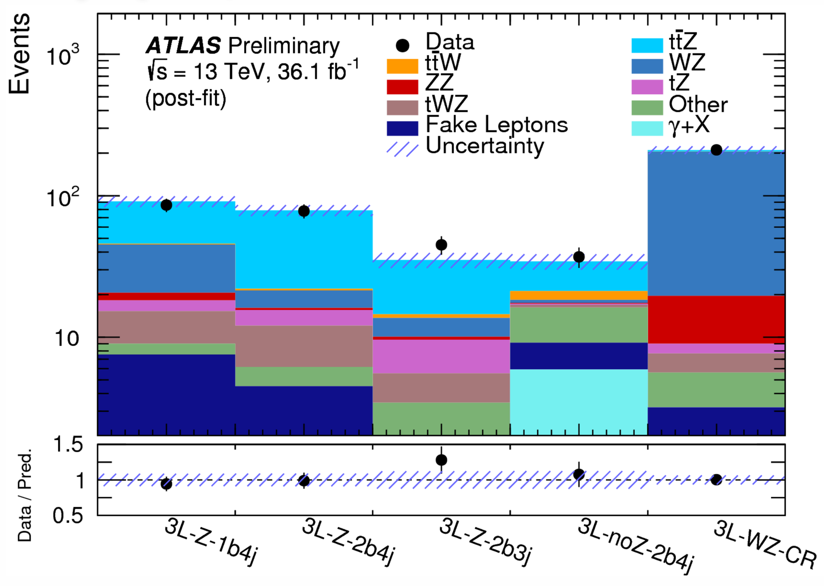


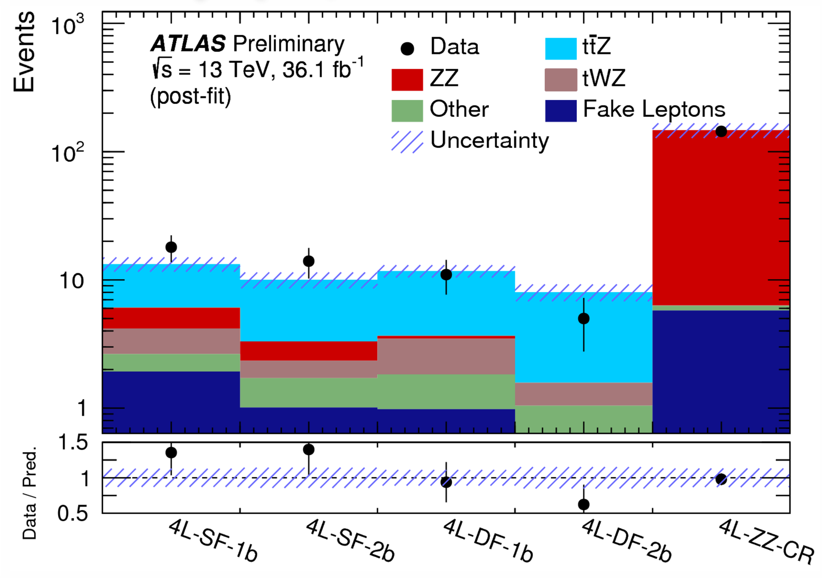
Variable	3ℓ-Z-1b4j	3ℓ-Z-2b3j	3ℓ-Z-2b4j	3ℓ-noZ-2b4j
Leading lepton		$p_T > 27$ GeV		
Other leptons		$p_T > 20$ GeV		
Sum of lepton charges		±1		
Z-like OSSF pair	$\lvert m_{\ell\ell} - m_Z\rvert < 10$ GeV			$\lvert m_{\ell\ell} - m_Z\rvert > 10$ GeV
n_{jets}	≥ 4	3	≥ 4	≥ 2 and ≤ 4
$n_{b\text{-jets}}$	1	≥ 2	≥ 2	≥ 2

Region	Z_2 leptons	p_{T4}	p_{T34}	$\lvert m_{Z_2} - m_Z\rvert$	E_T^{miss}	$n_{b\text{-tags}}$
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	> 40 GeV	1
				< 10 GeV	> 80 GeV	
4ℓ-SF-2b	$e^\pm e^\mp, \mu^\pm\mu^\mp$	> 10 GeV	-	> 10 GeV	-	≥ 2
				< 10 GeV	> 40 GeV	

The **tri- and tetralepton channels** use four signal regions each, depending on lepton flavour and jet multiplicities. Both channels include a control region dedicated to the diboson background processes (WZ and ZZ).

μ (WZ) = 0.91 ± 0.10 μ (ZZ) = 1.11 ± 0.17



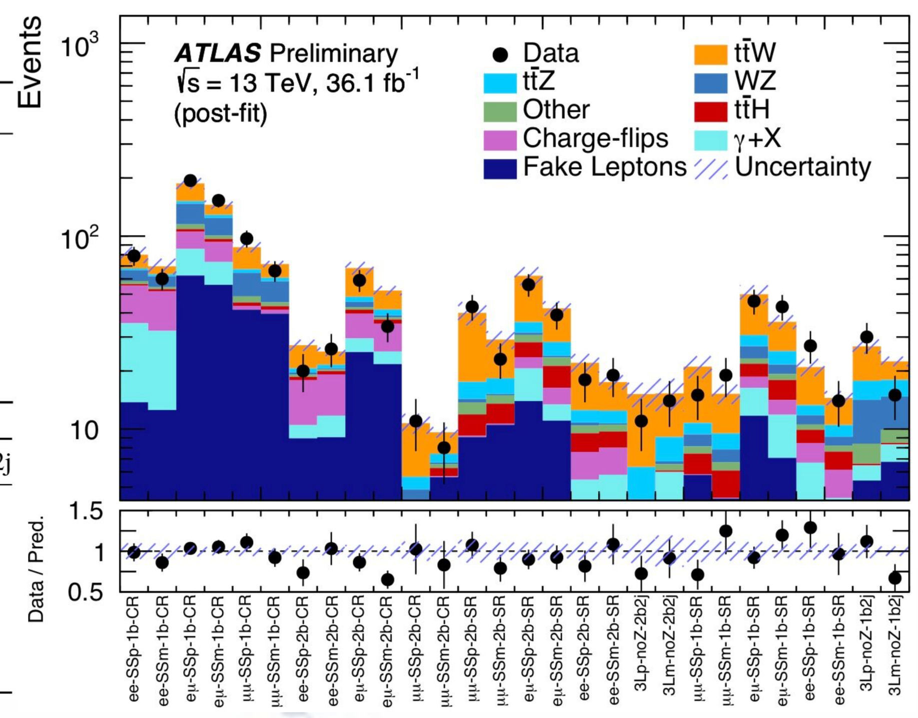


The $t\bar{t}W$ analysis

The dominant background source comes from **fake leptons**. The analysis includes 16 signal regions with same-sign dilepton and trilepton final states, as well as 12 same-sign dilepton control regions which are used for the fake lepton estimation. The control regions have non-negligible signal contamination and are thus included in the fit to measure the cross section.

Requirement	l_1l_2-SS(p,m)-1b	2μ-SS(p,m)-2b	l_1l_2-SS(p,m)-2b
$n_{b-\text{jets}}$	=1	≥ 2	
E_T^{miss}	> 40 GeV	> 20 GeV	> 40 GeV
H_T		> 240 GeV	
p_T (leading lepton)		> 27 GeV	
p_T (subleading lepton)		> 27 GeV	
n_{jets}	≥ 4	≥ 2	≥ 4
Z-like lepton pair	vetoed in the 2e and 2μ regions		

Variable	3ℓp-noZ-2b2j	3ℓm-noZ-2b2j	3ℓp-noZ-1b2j	3ℓm-noZ-1b2j
All leptons		$p_T > 27$ GeV		
Z-like OSSF pair		vetoed		
n_{jets}		2 or 3		
H_T	-		> 240 GeV	
Sum of lepton charges	+1	-1	+1	-1
$n_{b-\text{jets}}$	≥ 2	≥ 2	1	1

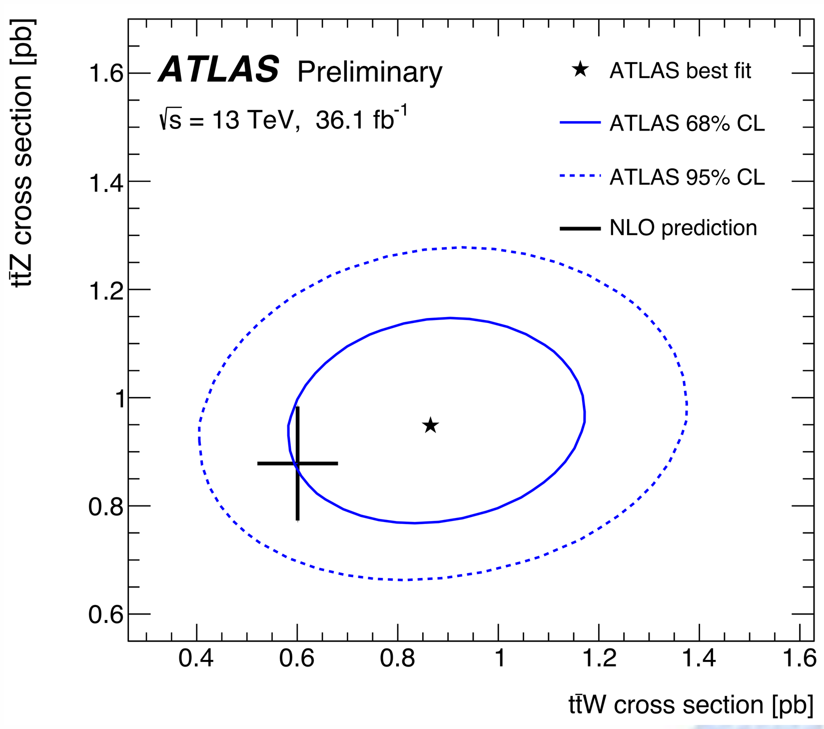


The fake lepton estimation is performed with the **data-driven matrix method** parameterised as a function of the lepton p_T.

Fit Results

The cross sections of $t\bar{t}Z$ and $t\bar{t}W$ are extracted simultaneously in a two dimensional fit. The **dominant systematic uncertainties** are related to signal modeling, flavour tagging and the fake lepton estimation. Fits are also performed in the individual the individual analysis channels.

Fit configuration	$\mu_{t\bar{t}Z}$	$\mu_{t\bar{t}W}$
Combined	1.08 ± 0.14	1.44 ± 0.32
2ℓ-OS	0.73 ± 0.28	-
3ℓ $t\bar{t}Z$	1.08 ± 0.18	-
2ℓ-SS and 3ℓ $t\bar{t}W$	-	1.41 ± 0.33
4ℓ	1.21 ± 0.29	-



Uncertainty	$\sigma_{t\bar{t}Z}$	$\sigma_{t\bar{t}W}$
Luminosity	2.9%	4.5%
CR and simulated sample statistics	1.8%	7.6%
JES/JER	1.9%	4.1%
Flavour tagging	4.2%	3.7%
Other object-related	3.7%	2.5%
Data-driven background normalization	2.4%	3.9%
Modeling of backgrounds from simulation	5.3%	2.6%
Background cross sections	2.3%	4.9%
Fake leptons and charge misID	1.8%	5.7%
$t\bar{t}Z$ modeling	4.9%	0.7%
$t\bar{t}W$ modeling	0.3%	8.5%
Total systematic	10%	16%
Statistical	8.4%	15%
Total	13%	22%

SM prediction

$\sigma_{t\bar{t}Z} = 0.88 \pm 0.08$ pb

$\sigma_{t\bar{t}W} = 0.60 \pm 0.10$ pp

The extracted cross sections **agree within the SM prediction** with observed (expected) significances of >>5σ for $t\bar{t}Z$ and 4.3σ (3.4σ) for $t\bar{t}W$.

$\sigma_{t\bar{t}Z} = 0.95 \pm 0.08$ (stat.) ± 0.10 (syst.) pb

$\sigma_{t\bar{t}W} = 0.87 \pm 0.13$ (stat.) ± 0.14 (syst.) pb

Interpretation

Possible deviations from the SM are considered in a **model-independent approach.** Effective field theory (EFT) operators of dimension six are added to the SM Lagrangian. One EFT operator is considered at a time.

$$\sigma_{tot,i} = \sigma_{SM} + \frac{C_i}{(\Lambda/1\text{TeV})^2}\sigma_i^{(1)} + \frac{C_i^2}{(\Lambda/1\text{TeV})^4}\sigma_{ii}^{(2)}$$

A fit is performed in $t\bar{t}Z$ signal regions with three or four lepton final states to extract C_i/Λ^2.

Coefficient	Expected limits at 68% and 95 % CL	Observed limits at 68% and 95 % CL	Previous constraints at 95 % CL
$(C_{\phi Q}^{(3)} - C_{\phi Q}^{(1)})/\Lambda^2$	[-2.1, 1.9], [-4.6, 3.7]	[-1.0, 2.7], [-3.4, 4.3]	[-3.4, 7.5]
$C_{\phi t}/\Lambda^2$	[-3.8, 2.8], [-23, 5.0]	[-2.0, 3.6], [-27, 5.7]	[-2.0, 5.7]
C_{tB}/Λ^2	[-8.3, 8.6], [-12, 13]	[-11, 10], [-15, 15]	[-16, 43]
C_{tW}/Λ^2	[-2.8, 2.8], [-4.0, 4.1]	[-2.2, 2.5], [-3.6, 3.8]	[-0.15, 1.9]