tZq evidence @13TeV ATLAS/CMS comparison

Lidia Dell'Asta
with Mara Senghi Soares, Jeremy Andrea and Muhammad Alhroob

Outline

- Theory cross section
- Event selection
- Background estimation
- Analysis strategy
- Fitting strategy

LHC Top WG Meeting - 02/03.11.2017

Introduction

- TOPQ-2016-14 (submitted to PLB)
- 36.1 fb^{-1}
- Significance obs(exp): 4.2 (5.4)σ
- μ = 0.75
  $\pm$ 0.21 (stat.)
  $\pm$ 0.17 (syst.)
  $\pm$ 0.05 (th.)
- σ(tZq) = 600
  $\pm$ 170 (stat.)
  $\pm$ 140 (syst.) fb

- CMS-PAS-TOP-16-020
- 35.9 fb^{-1}
- Significance obs(exp): 3.7 (3.1)σ
- μ = 1.31
  +0.35-0.33 (stat.)
  +0.31-0.25 (syst.)
- σ(tllq) = 123
  +33-31 (stat.)
  +29-23 (syst.)

- Trying to make a comparison between the two analyses.
  - Where does the difference between the cross sections come from?
  - Is there any significant difference in the analysis strategy?

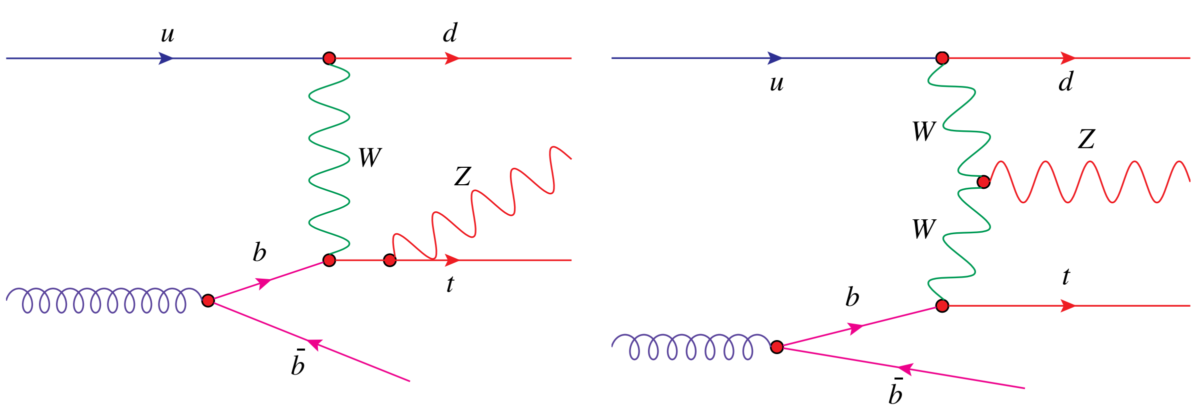
- Disclaimer: not a lot of public plots to compare the two.

Signal samples & theory cross section

- Signal MC: LO rescaled to NLO.

- Theory cross section:
  - Z boson is forced to be on shell,
  - no cuts are applied,
  - 4-flavour scheme.

  - $\sigma_{NLO}(tZq)$ = 800 fb
    - ±6/7% scale



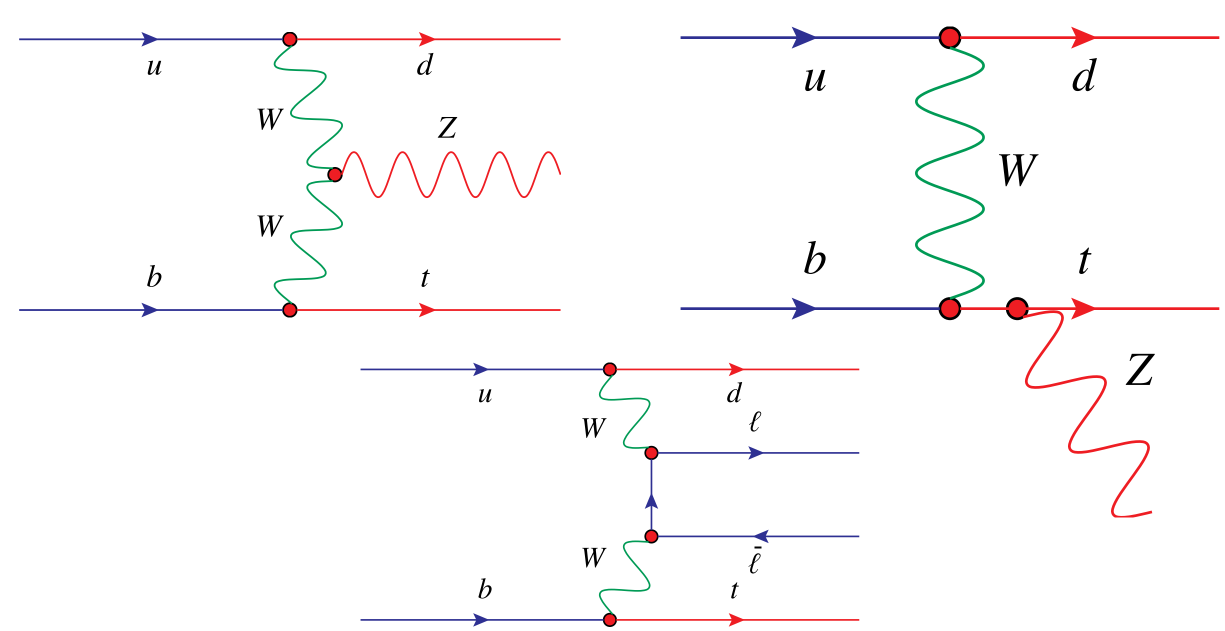
- Tau leptonic decays included.
- Different scale choice between ATLAS and CMS.

- Theory paper https://arxiv.org/abs/1302.3856
  - $\sigma_{NLO}(tZq)$ ~ 820 fb.

- Signal MC: NLO.

- Theory cross section:
  - Z boson can be off shell/γ* is also included,
  - m_{ll} > 30 GeV,
  - 5-flavour scheme (4FS for MC generation).

  - $\sigma_{NLO}(tllq)$ = 94 fb
    - ±2% scale
    - ±2.5% PDF



Signal samples & theory cross section

	FS	Scale	Cuts	x-sec (fb)	notes
tllq	5	$\mu = \frac{1}{2}\Sigma\sqrt{E^2 - p_z^2}$	-	94	CMS default
tllq	4	$\mu = \frac{1}{2}\Sigma\sqrt{E^2 - p_z^2}$	-	76	4 vs 5 FS 20% effect
tllq	5	$\mu = \frac{1}{2}\Sigma\sqrt{E^2 - p_z^2}$	m_{ll} > 80 GeV	89	
tZ(→ll)q	5	$\mu = \frac{1}{2}\Sigma\sqrt{E^2 - p_z^2}$	-	86	effect of missing contributions from off-shell/γ* and extra diagrams
tZq	4	$\mu = 4\sqrt{m_b^2 + p_{T,b}^2}$	-	800	ATLAS default
tZq	4	$\mu = \frac{1}{2}\Sigma\sqrt{E^2 - p_z^2}$	-	690	scale 15% effect
tZq	5	$\mu = \frac{1}{2}\Sigma\sqrt{E^2 - p_z^2}$	-	860	4 vs 5 FS 20% effect

- Need to converge on a common setup.
  - Include or not γ* contribution → current thinking is to include it
  - If including γ*, need to fix an m(ll) requirement → 30 GeV seems reasonable from the experimental side
  - Whether to use 4FS or 5FS → current thinking is 5FS (expected to be more precise for inclusive XS)
  - Which scale to use → theory guidance appreciated

Event selection

- Trigger
  - **single lepton triggers**
- Leptons
  - exactly three
  - **p_T(lep) > 28/25/15 GeV**
  - ≥ 1 OSSF pair
  - **$|m_{ll} - m_Z| < 10$ GeV**
- Jets
  - **exactly two**
  - p_T(jet) > 30 GeV
  - **1 b-tagged (77% WP, 1% mistag)**
- **$m_T(W) > 20$ GeV**

- Trigger
  - **OR of 1/2/3 lepton triggers**
- Leptons
  - exactly three
  - **p_T(lep) > 25 GeV**
  - ≥ 1 OSSF pair
  - **$|m_{ll} - m_Z| < 15$ GeV**
- Jets
  - **two or three**
  - p_T(jet) > 30 GeV
  - **1 b-tagged (83% WP, 10% mistag)**

Event selection

- Trigger
  - single lepton triggers
- Leptons
  - exactly three
  - p_T(lep) > 28/25/15 GeV
  - ≥ 1 OSSF pair
  - $|m_{ll} - m_Z| < 10$ GeV
- Jets
  - exactly two
  - p_T(jet) > 30 GeV
  - 1 b-tagged (77% WP, 1% mistag)
- $m_T(W) > 20$ GeV

- Trigger
  - OR of 1/2/3 lepton triggers
- Leptons
  - exactly three
  - p_T(lep) > 25 GeV
  - ≥ 1 OSSF pair
  - $|m_{ll} - m_Z| < 15$ GeV
- Jets
  - two or three
  - p_T(jet) > 30 GeV
  - 1 b-tagged (83% WP, 10% mistag)

- TRIGGER & LEPTON p_T
  - For ATLAS the 28 GeV cut on the 1st lepton p_T is driven by the trigger threshold. Not a killer though. The 1st lepton is quite hard.
  - Keeping the 3rd lepton p_T lower increases the Z+jet contamination, giving a better handle on this bkg when training the NN.

Event selection

- Trigger
  - **single lepton triggers**
- Leptons
  - exactly three
  - **p_T(lep) > 28/25/15 GeV**
  - ≥ 1 OSSF pair
  - **$|m_{ll} - m_Z| < 10$ GeV**
- Jets
  - **exactly two**
  - p_T(jet) > 30 GeV
  - **1 b-tagged (77% WP, 1% mistag)**
- **$m_T(W) > 20$ GeV**

- Trigger
  - **OR of 1/2/3 lepton triggers**
- Leptons
  - exactly three
  - **p_T(lep) > 25 GeV**
  - ≥ 1 OSSF pair
  - **$|m_{ll} - m_Z| < 15$ GeV**
- Jets
  - **two or three**
  - p_T(jet) > 30 GeV
  - **1 b-tagged (83% WP, 10% mistag)**

- m_{ll}
  - Keeping the m_{ll} window cut wider increases the $t\bar{t}$ contribution.

Event selection

- Trigger
  - single lepton triggers
- Leptons
  - exactly three
  - p_T(lep) > 28/25/15 GeV
  - ≥ 1 OSSF pair
  - $|m_{ll} - m_Z| < 10$ GeV
- Jets
  - exactly two
  - p_T(jet) > 30 GeV
  - 1 b-tagged (77% WP, 1% mistag)
- $m_T(W) > 20$ GeV

- Trigger
  - OR of 1/2/3 lepton triggers
- Leptons
  - exactly three
  - p_T(lep) > 25 GeV
  - ≥ 1 OSSF pair
  - $|m_{ll} - m_Z| < 15$ GeV
- Jets
  - two or three
  - p_T(jet) > 30 GeV
  - 1 b-tagged (83% WP, 10% mistag)

- n_{jets}
  - Connected with LO vs NLO signal MC (LO does not take into account large fraction of signal in the 3 jets bin)
  - Having 3 jets might create ambiguity in defining the forward jet.
  - Likely increases $t\bar{t}$ fake contribution.

Background estimation

- $t\bar{t}$ and Z+jets non-prompt lepton backgrounds estimated separately.

- $t\bar{t}$: data/MC SF from OSOF region
  - shape from MC.

- Z+jets: Fake Factor method
  - e/μ treated separately
  - binned in p_T of W lepton
  - FF: TTT/LTT in region with $m_T(W) < 20$ GeV
  - applied to LTT data.
  - Uncertainty:
    - 30/40% normalisation.

- All “NPL” (non-prompt leptons) sources estimated together.

- “templates” from data with LTT leptons.
- e/μ treated separately.
- “2 step normalisation”
  - fit $m_T(W)$ in the 0bjet CR and get first normalisation factors for all channels.
  - NPL e and μ yields: two free parameters independent of each other in the fit.
  - Uncertainty:
    - shape uncertainty based on changing isolation requirements.

Background estimation

- Signal → tZq = tZq
- Fakes → tt̄+tW + Z+jets = NPL
- Diboson → Diboson = ZZ + WZ+c/b/light
- top → tt̄V+tt̄H+tWZ = tWZ + tt̄H + tt̄W + tt̄Z

ATLAS

Channel	Number of events Real data	CMS
tZq	26 ± 8	32.3 ± 5.0
$t\bar{t} + tW$	17 ± 7	} 91.3 ± 12.1
$Z+$jets	34 ± 11	
Diboson	48 ± 12	186.4 ± 11.5
$t\bar{t}V + t\bar{t}H + tWZ$	19 ± 3	34.8 ± 2.5
Total	143 ± 11	

	ATLAS		CMS	
Signal	26	18%	32	9%
Fakes	51	35%	91	26%
Diboson	48	33%	186	54%
top	19	13%	35	10%

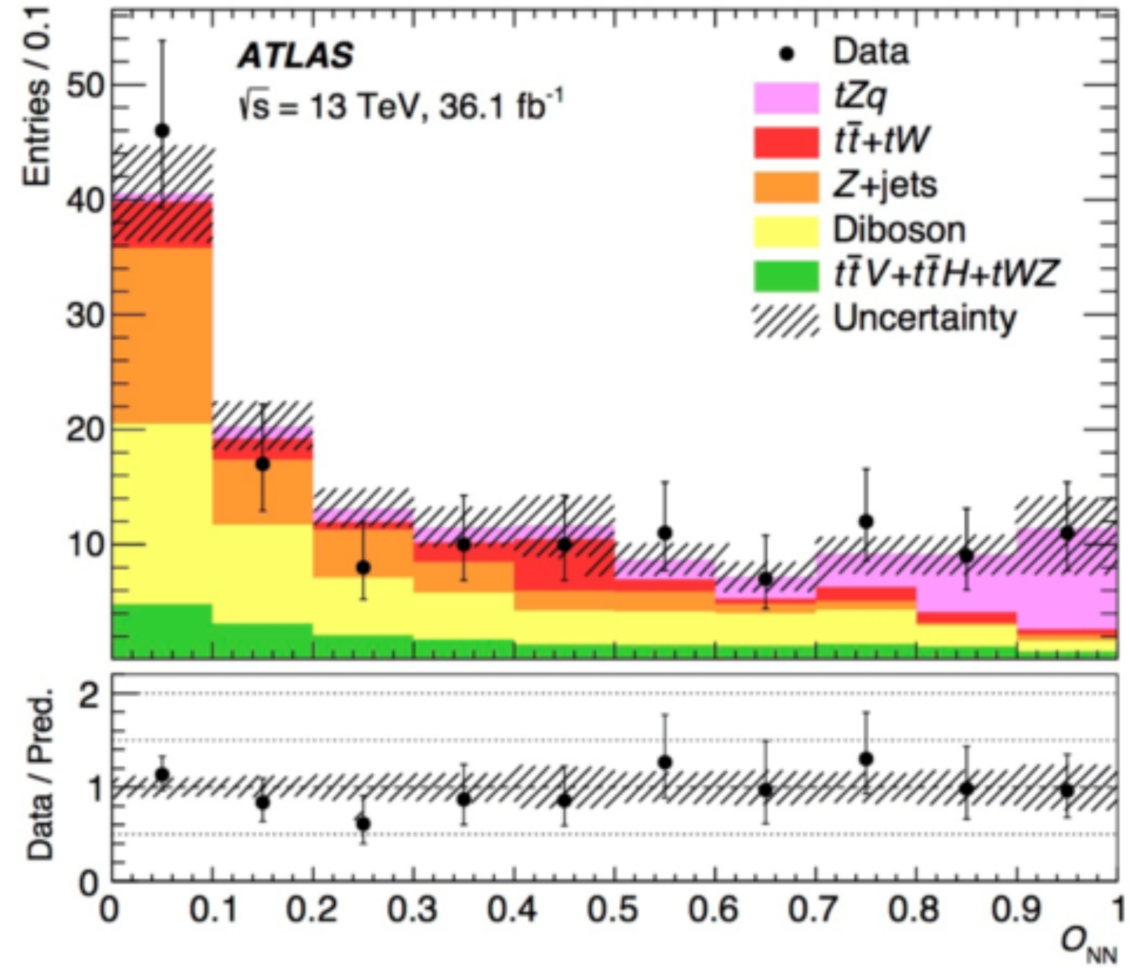
CMS

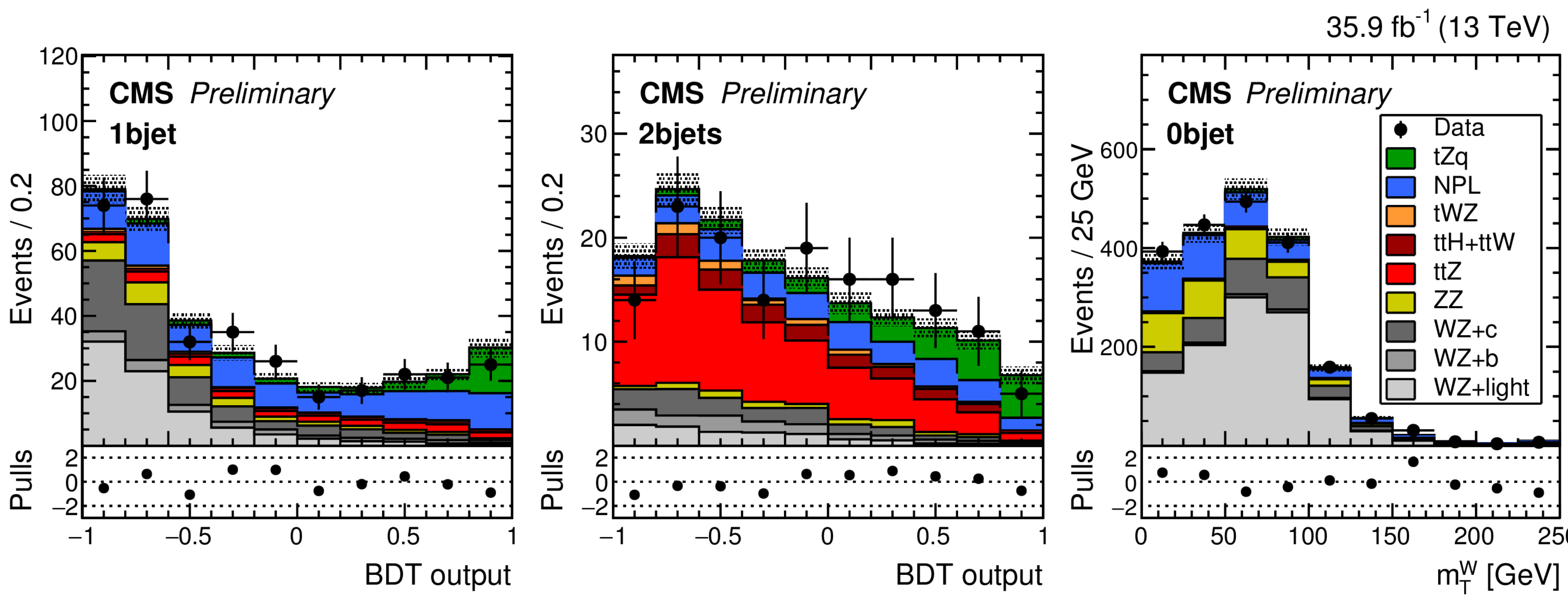
post-fit values

Process	eee	eeμ	$\mu\mu$e	$\mu\mu\mu$	All channels	$\frac{N^{obs}}{N^{pred}}$
tZq	5.0±1.5	6.6±1.9	8.5±2.5	12.3±3.6	32.3±5.0	–
tt̄Z	3.7±0.7	4.7±0.9	6.1±1.2	8.0±1.5	22.4±2.2	0.9±0.2
tt̄W	0.3±0.1	0.3±0.1	0.7±0.2	0.6±0.2	1.9±0.3	1.0±0.2
Z Z	4.8±1.3	3.2±0.9	9.0±2.5	7.8±2.2	24.7±3.6	1.3±0.3
WZ+b	3.0±0.9	3.4±1.1	4.6±1.4	5.5±1.7	16.6±2.6	1.0±0.2
WZ+c	9.0±2.4	13.7±3.7	18.0±4.9	24.2±6.5	64.8±9.3	1.0±0.2
WZ+light	12.2±1.6	16.6±2.0	22.4±2.8	29.1±3.4	80.3±5.1	0.7±0.1
tt̄H	0.6±0.2	0.9±0.3	1.0±0.3	1.5±0.4	4.0±0.6	1.0±0.2
tWZ	1.0±0.3	1.3±0.4	1.7±0.5	2.4±0.7	6.5±1.0	1.0±0.2
NPL: electrons	19.2±3.1	0.6±0.1	17.9±2.8	–	37.7±4.2	–
NPL: muons	–	7.2±2.3	31.1±9.9	15.3±4.9	53.6±11.3	–
Total	58.8±4.8	58.4±5.5	120.9±12.4	106.6±10.1	344.8±17.6	
Data	56	58	104	125	343	

Background estimation

- tZq = tZq
- $t\bar{t}$ + tW + Z+jets = NPL
- Diboson = ZZ + WZ+c/b/light
- $t\bar{t}$V + $t\bar{t}$H + tWZ = tWZ + $t\bar{t}$H + $t\bar{t}$W + $t\bar{t}$Z

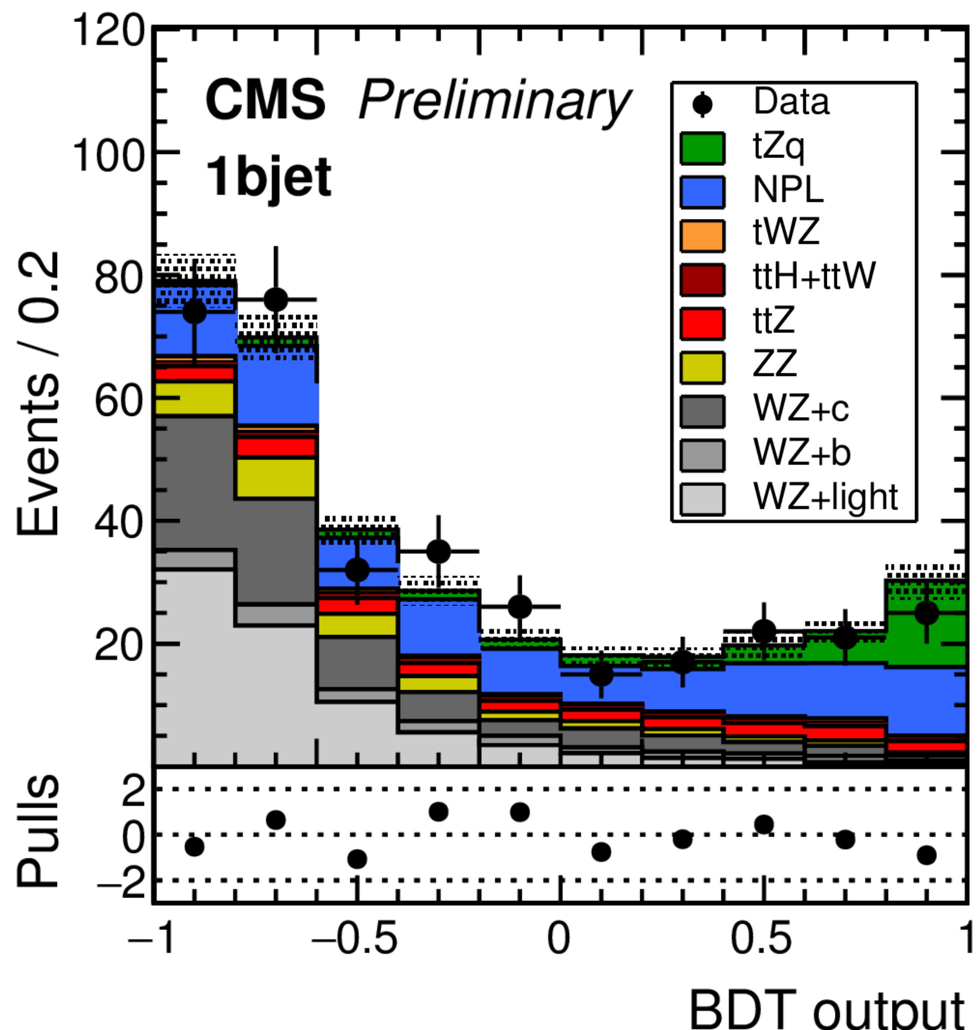


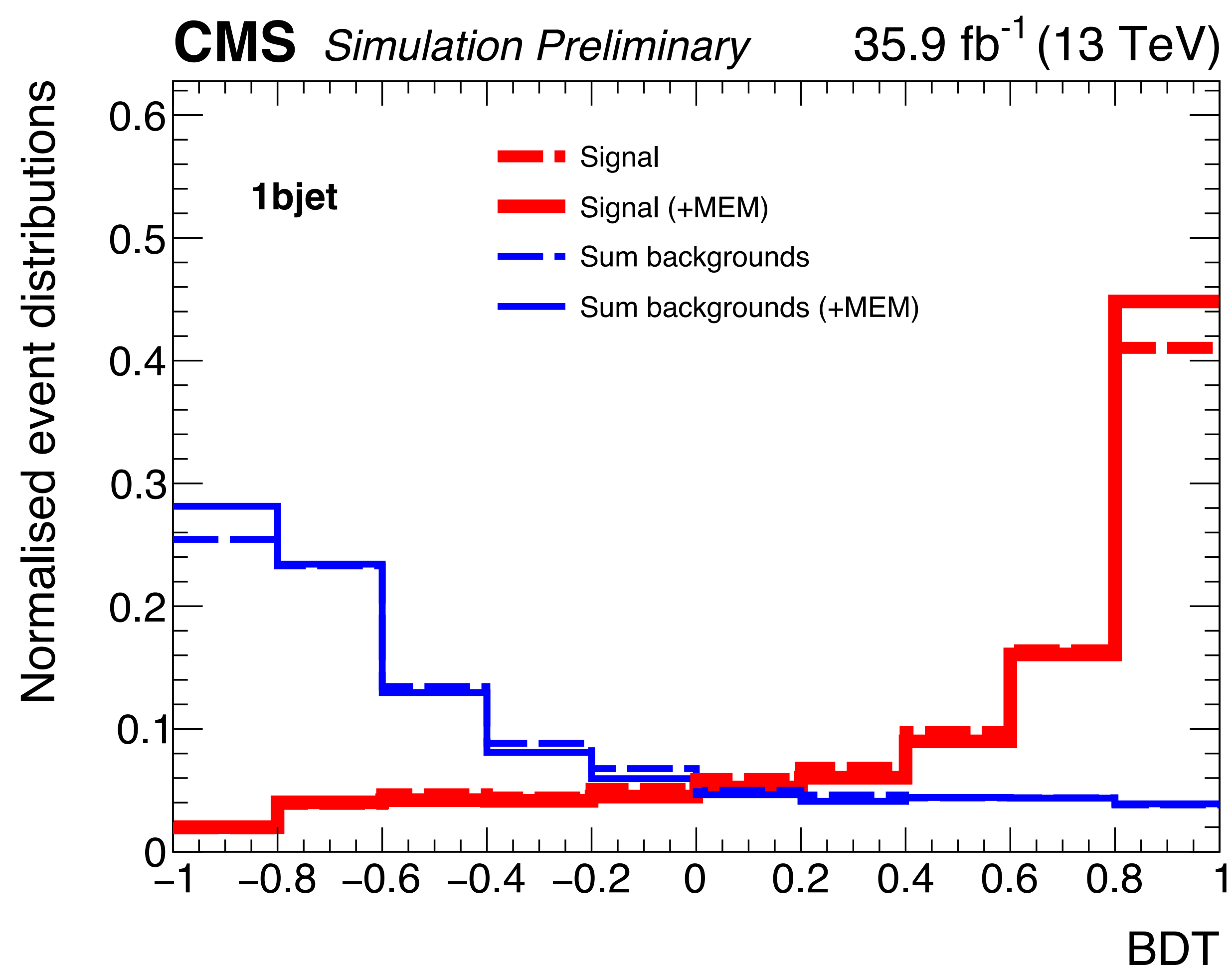


Multivariate analysis

- NN
- Training with signal and all backgrounds ($t\bar{t}$ excluded, fakes included)
- 10 variables
  - List in the paper
  - Most discriminating: $\eta(jet_{forward})$ and $p_T(jet_{forward})$.

- BDT
- Training with signal and all backgrounds (**excluding fakes** because of lack of stat.)
- Two BDTs for the 1bj and 2bj SRs.
- Various variables used for training.
  - Including **MEM** (Matrix Element Method) as input variables.
    - 10% significance improvement.





Signal Regions, Fitting and Systematics

- Fitting O_{NN} in SR (all channels summed together).

- Fitting 12 regions simultaneously.
  - eee, eeμ, eμμ, μμμ.
  - BDT in 1bjet (signal region).
  - BDT in 2bjet (to control $t\bar{t}Z$).
  - $m_T(W)$ in 0bjet (to control WZ+jets).

- Not enough information about systematic uncertainties.

Conclusions

- Comparison of tZq results from ATLAS and CMS.

- MC signal samples @LO for ATLAS and @NLO for CMS.

- Theory cross section calculations compatible but with several differences (tZq vs tllq, 4 vs 5 FS, scale choice).
  - Need to converge to a common approach.

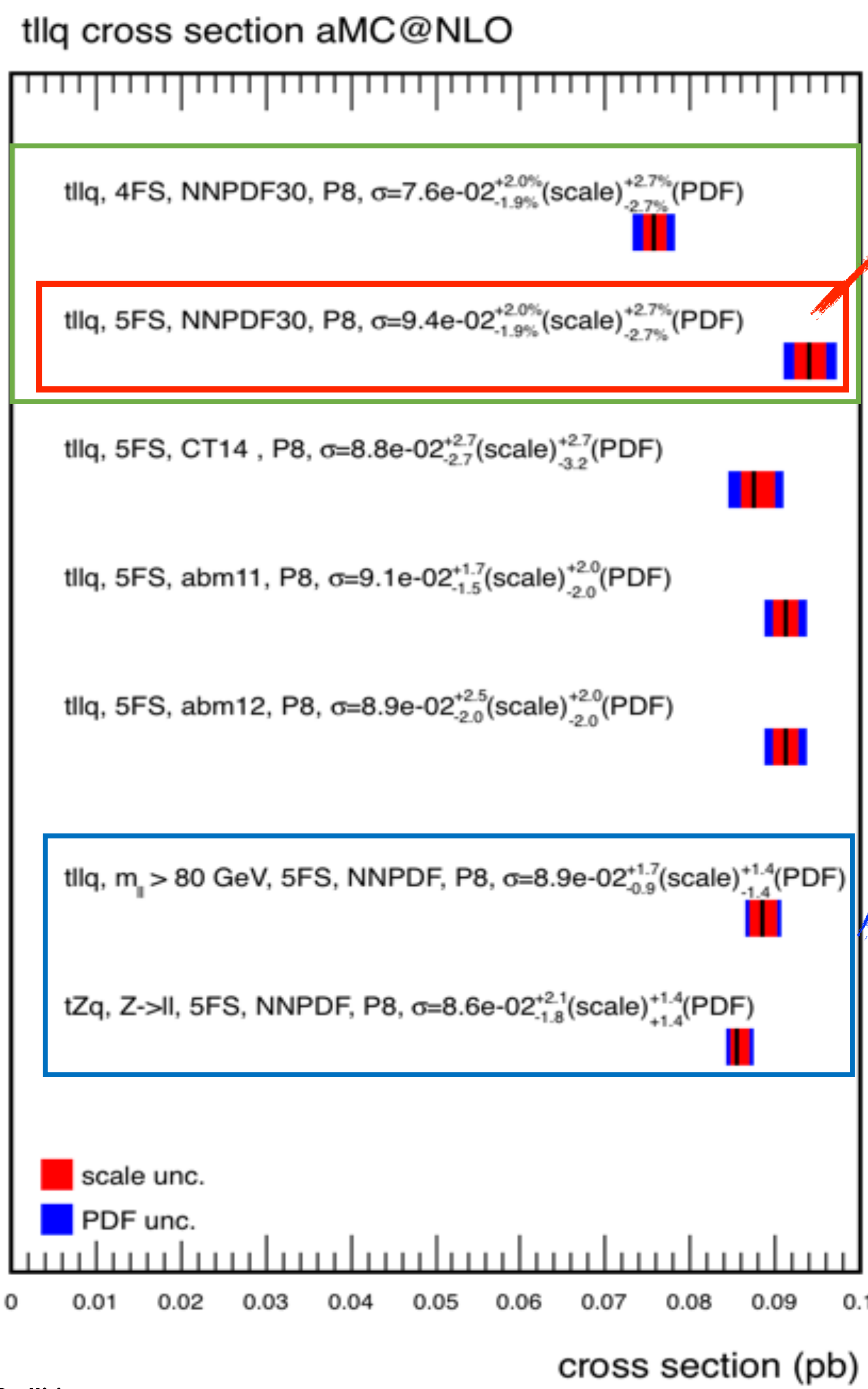
- Some different approaches for the event selection (e.g. lepton p_T cuts, number of jets, b-tagging WP) and background estimation.
  - Visible effect on the background composition in the SR.

- Multivariate analysis (NN for ATLAS and BDT for CMS).
  - Main difference coming from the use of fakes in training.

- Different way of fitting NN/BDT output distributions.

BackUp

Signal samples & Theory Cross Section

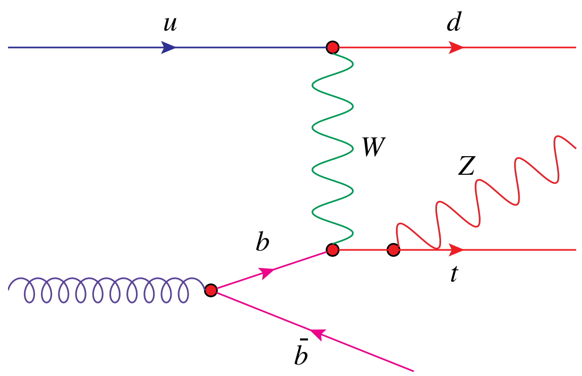


- CMS: σ_{NLO}(tllq) = 94 fb.
- Major difference with ATLAS :
  - Z decay BR → factor of 10,
  - 5FS vs 4FS →20% difference,
  - tZq vs tllq (contributions from off-shell/γ* and extra diagrams) → 10% difference,
  - scale dependence (next slide).
- tZq generation (not tllq) with the CMS param. card gives a cross section very similar to ATLAS.

Checks by CMS

Signal samples & Theory Cross Section

- Changing the scale choice.



$$\mu = 4.\sqrt{m_b^2 + P_{T,b}^2} \longrightarrow \mu = \frac{1}{2}.\Sigma\sqrt{E^2 - P_z^2}$$

800 fb → 690 fb

```
--------------------------------------------------------------
   Final results and run summary:
   Process p p > t b~ Z j $$ W+ W- [QCD] ; p p > t~ b Z j $$ W+ W- [QCD]
   Run at p-p collider (6500.0 + 6500.0 GeV)
   Total cross section: 6.878e-01 +- 4.0e-03 pb
--------------------------------------------------------------
   Scale variation (computed from histogram information):
       Dynamical_scale_choice -1 (envelope of 9 values):
           6.888e-01 pb  +7.5% -7.7%
   PDF variation (computed from histogram information):
       NNPDF30_nlo_as_0118_nf_4 (101 members; using replicas method):
           6.888e-01 pb  +0.9% -0.9%
--------------------------------------------------------------
```

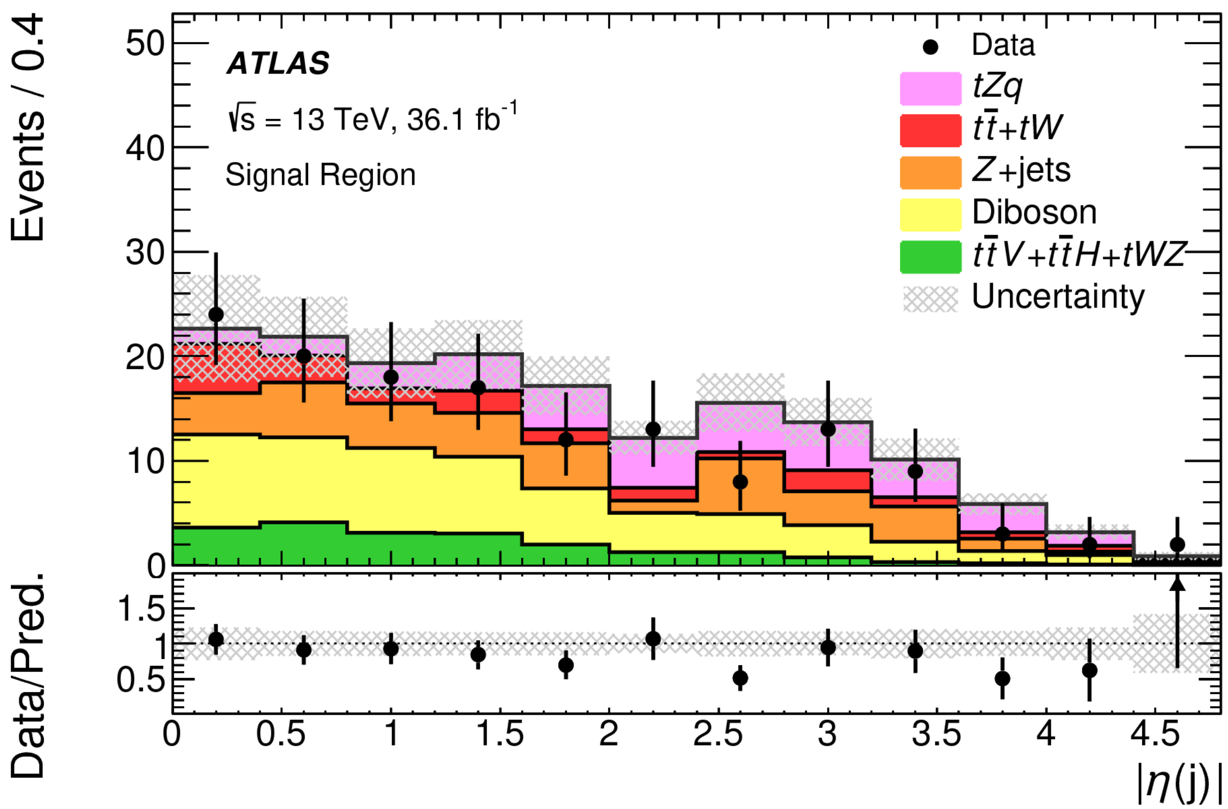
- Changing the scale choice + 5 FS.

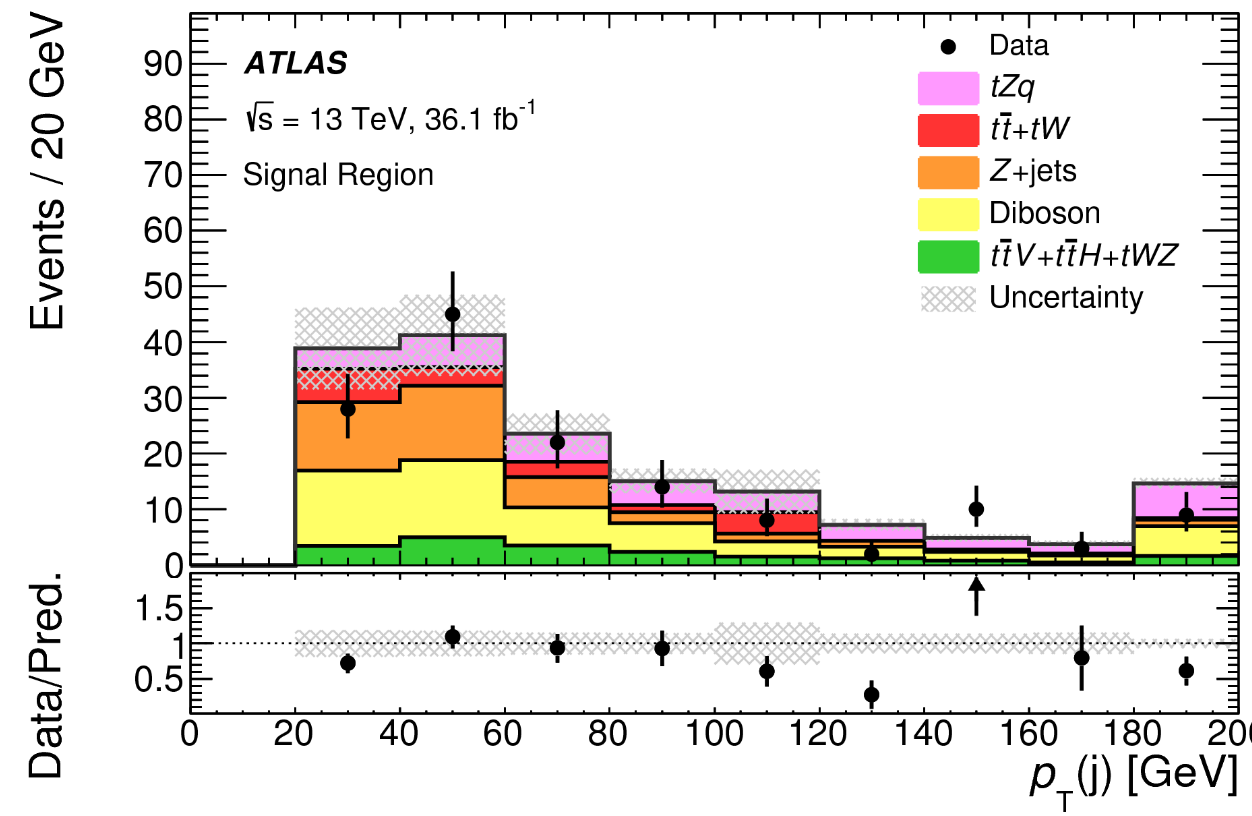
860 fb

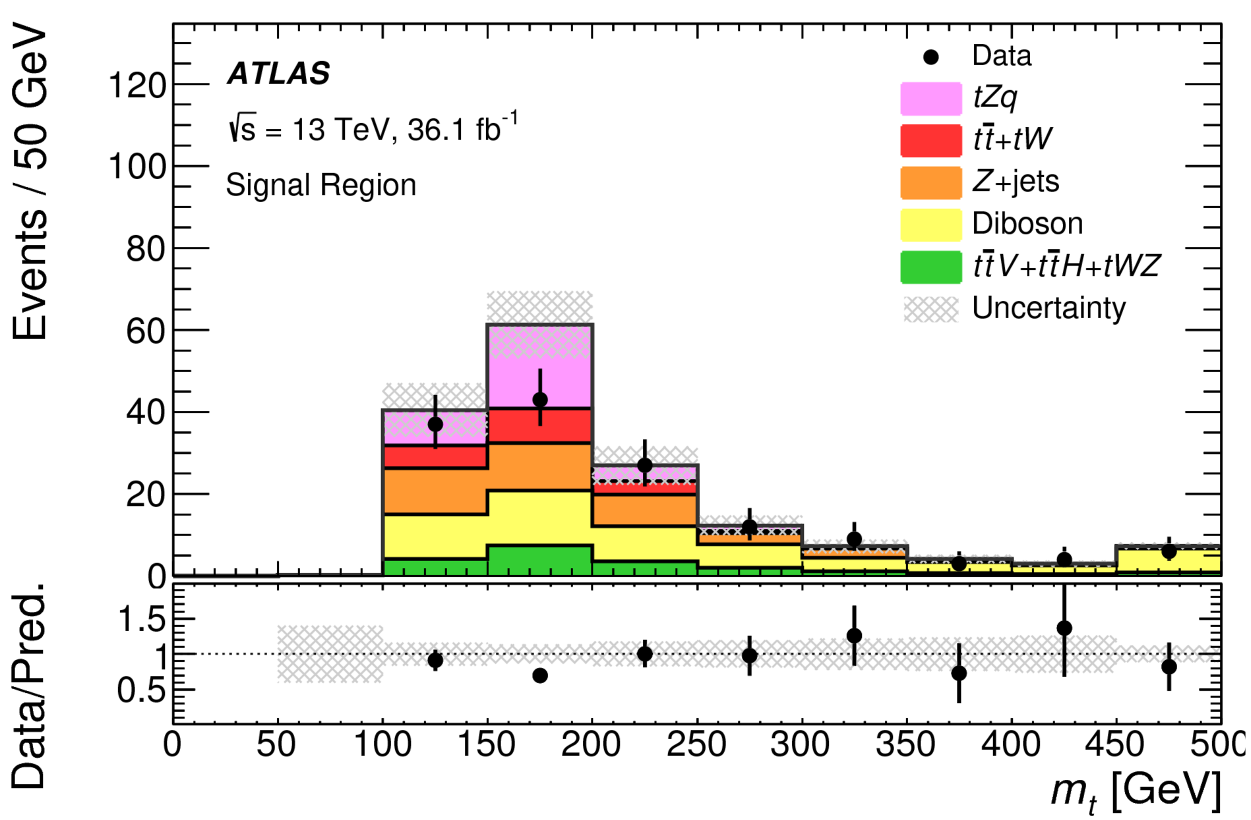
```
Summary:
Process p p > t Z j $$ W+ W- [QCD] ; p p > t~ Z j $$ W+ W- [QCD]
Run at p-p collider (6500.0 + 6500.0 GeV)
Total cross-section: 8.573e-01 +- 4.8e-03 pb
Ren. and fac. scale uncertainty: +2.1% -1.5%
PDF uncertainty: +1.3% -1.3%
Number of events generated: 10000
Parton shower to be used: PYTHIA8
Fraction of negative weights: 0.32
Total running time :  21m 24s
```

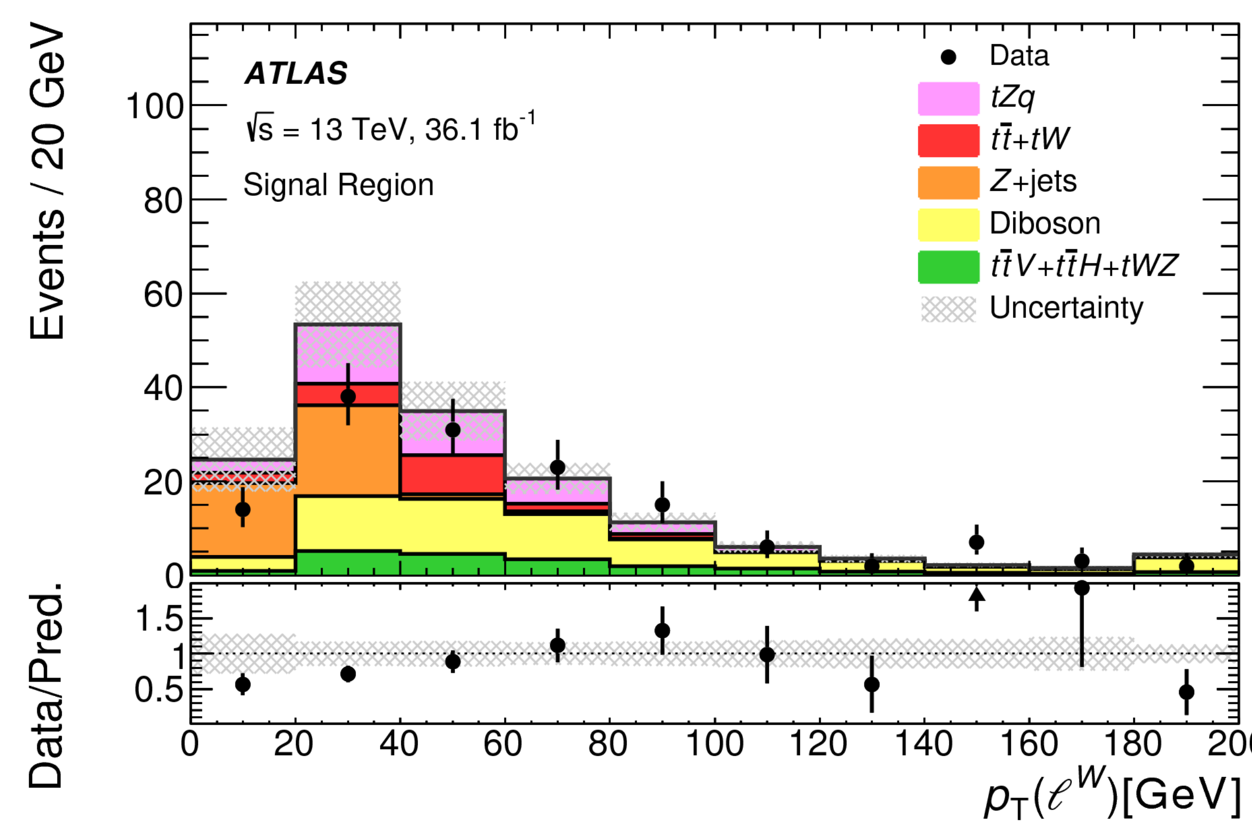
Checks by ATLAS

Multivariate analysis - ATLAS

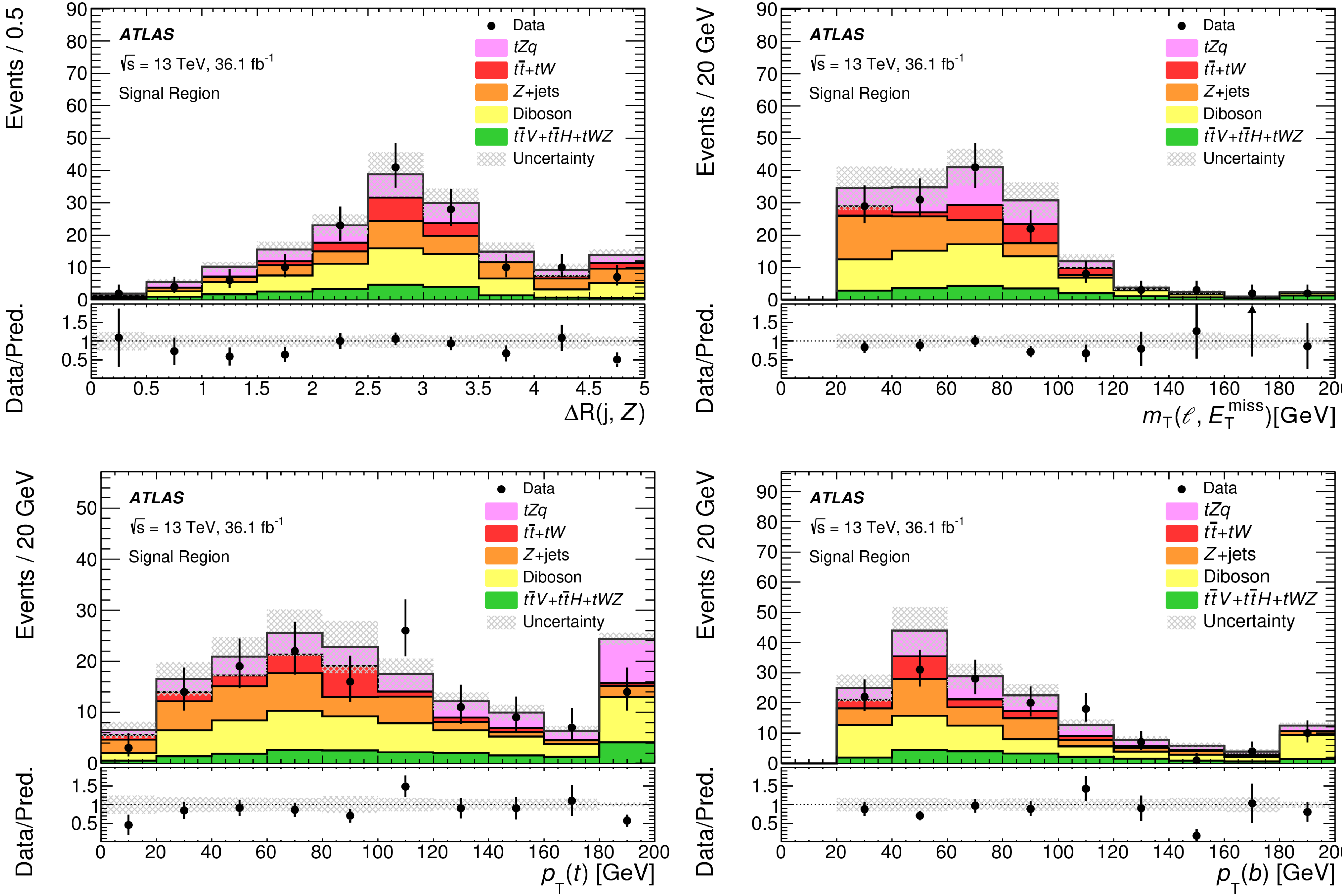




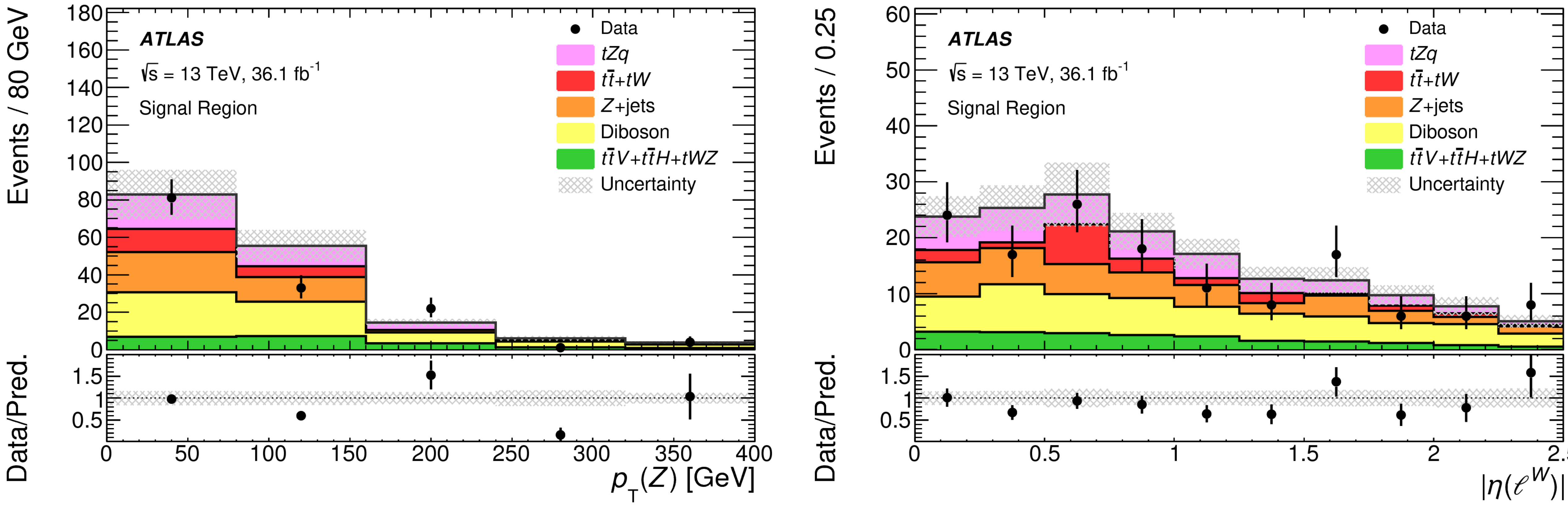




Multivariate analysis - ATLAS

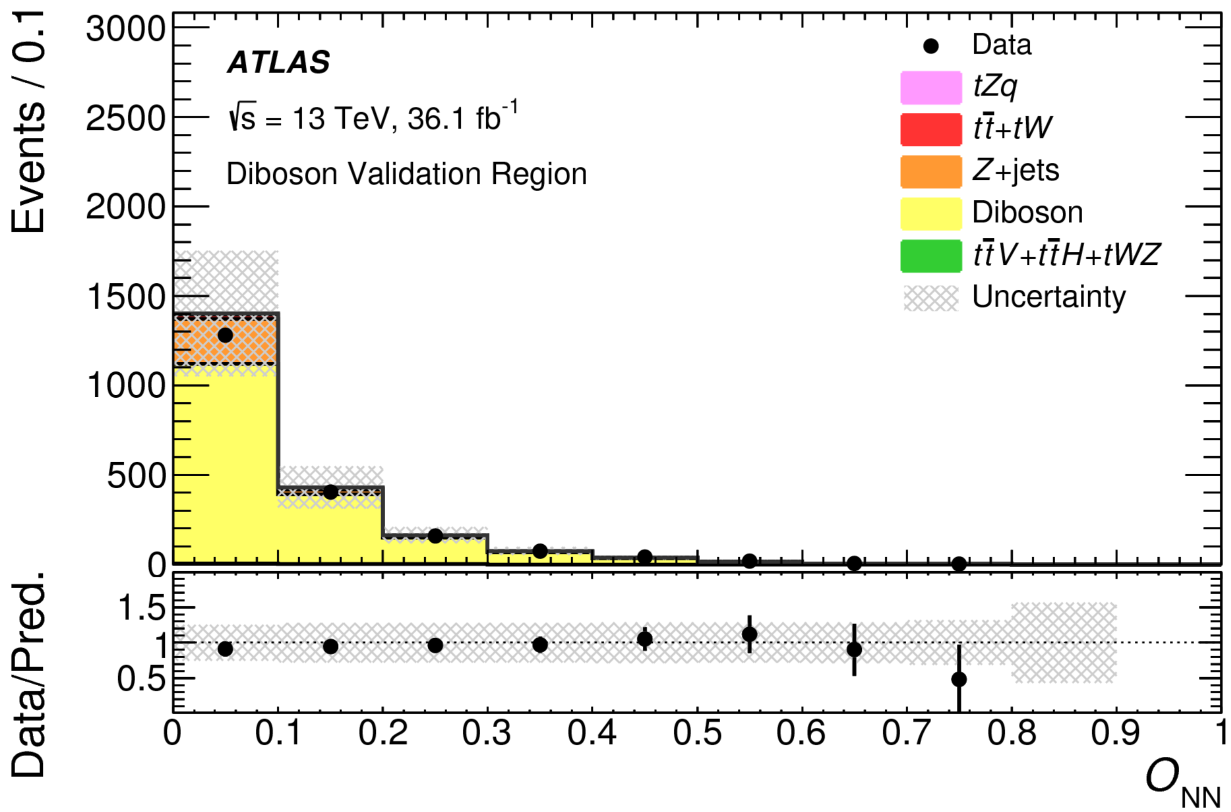


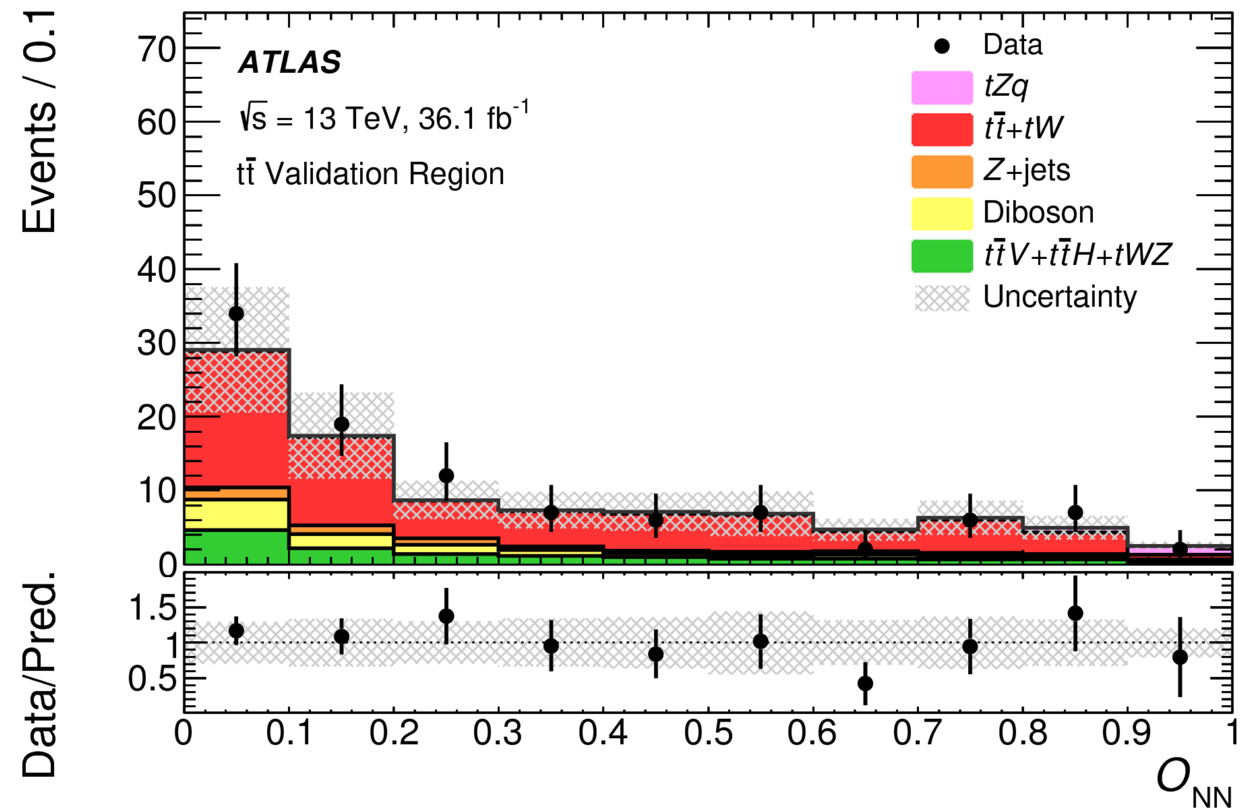
Multivariate analysis - ATLAS



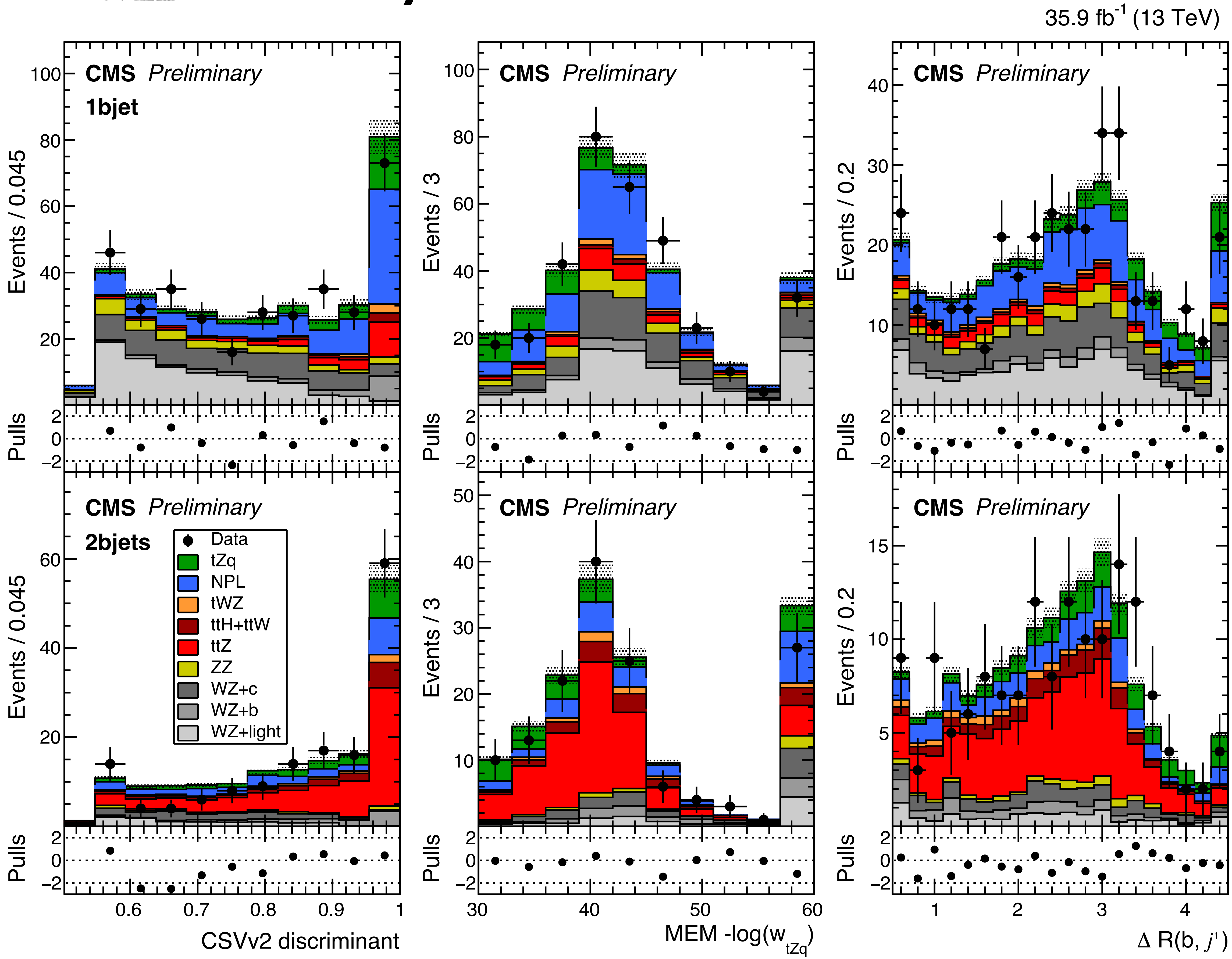
Variable	Definition
$\|\eta(\mathrm{j})\|$	Absolute value of untagged jet η
$p_{\mathrm{T}}(\mathrm{j})$	Untagged jet p_{T}
m_t	Reconstructed top-quark mass
$p_{\mathrm{T}}(\ell^W)$	p_{T} of the lepton from the W-boson decay
$\Delta R(\mathrm{j}, Z)$	ΔR between the untagged jet and the Z boson
$m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}})$	Transverse mass of W boson
$p_{\mathrm{T}}(t)$	Reconstructed top-quark p_{T}
$p_{\mathrm{T}}(b)$	Tagged jet p_{T}
$p_{\mathrm{T}}(Z)$	p_{T} of the reconstructed Z boson
$\|\eta(\ell^W)\|$	Absolute value of η of the lepton coming from the W-boson decay

Multivariate analysis - ATLAS





Multivariate analysis - CMS



Signal and control regions - ATLAS

Common selections			
Exactly 3 leptons with $\|\eta\| < 2.5$ and $p_{\mathrm{T}} > 15$ GeV $p_{\mathrm{T}}(\ell_1) > 28$ GeV, $p_{\mathrm{T}}(\ell_2) > 25$ GeV, $p_{\mathrm{T}}(\ell_3) > 15$ GeV $p_{\mathrm{T}}(\mathrm{jet}) > 30$ GeV $m_{\mathrm{T}}(\ell_W, \nu) > 20$ GeV			
SR	Diboson VR / CR	$t\bar{t}$ VR	$t\bar{t}$ CR
≥ 1 OSSF pair	≥ 1 OSSF pair	≥ 1 OSSF pair	≥ 1 OSDF pair
$\|m_{\ell\ell} - m_Z\| < 10$ GeV	$\|m_{\ell\ell} - m_Z\| < 10$ GeV	$\|m_{\ell\ell} - m_Z\| > 10$ GeV	No OSSF pair
2 jets, $\|\eta\| < 4.5$	1 jet, $\|\eta\| < 4.5$	2 jets, $\|\eta\| < 4.5$	2 jets, $\|\eta\| < 4.5$
1 b-jet, $\|\eta\| < 2.5$	—	1 b-jet, $\|\eta\| < 2.5$	1 b-jet, $\|\eta\| < 2.5$
—	VR/CR: $m_{\mathrm{T}}(\ell_W, \nu) > 20/60$ GeV	—	—

Uncertainties - ATLAS

Source	Uncertainty [%]
tZq radiation	±10.8
Jets	±4.6
b-tagging	±2.9
MC statistics	±2.8
Luminosity	±2.1
Leptons	±2.1
tZq PDF	±1.2
E_T^{miss}	±0.3