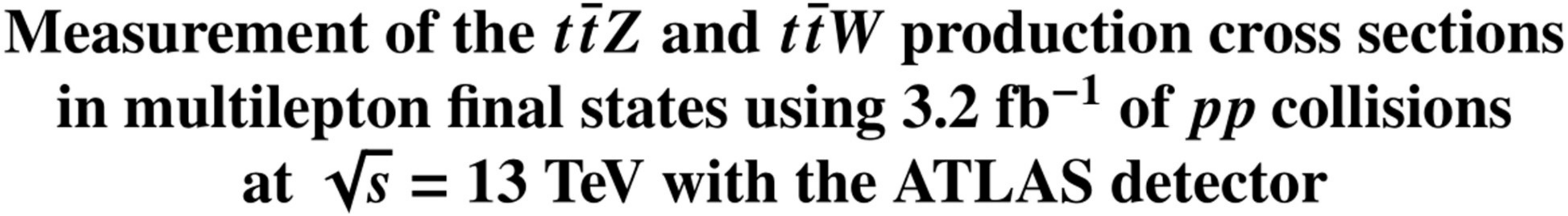
Recasting the events



Measurement of the $t\bar{t}Z$ and $t\bar{t}W$ production cross sections in multilepton final states using 3.2 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

with MAD tools

U-R. Kim,
In collaboration with
T. Flacke, Y. H. Jeong, Minho Kim,
Supervisors:
Eric Conte, Benjamin Fuks

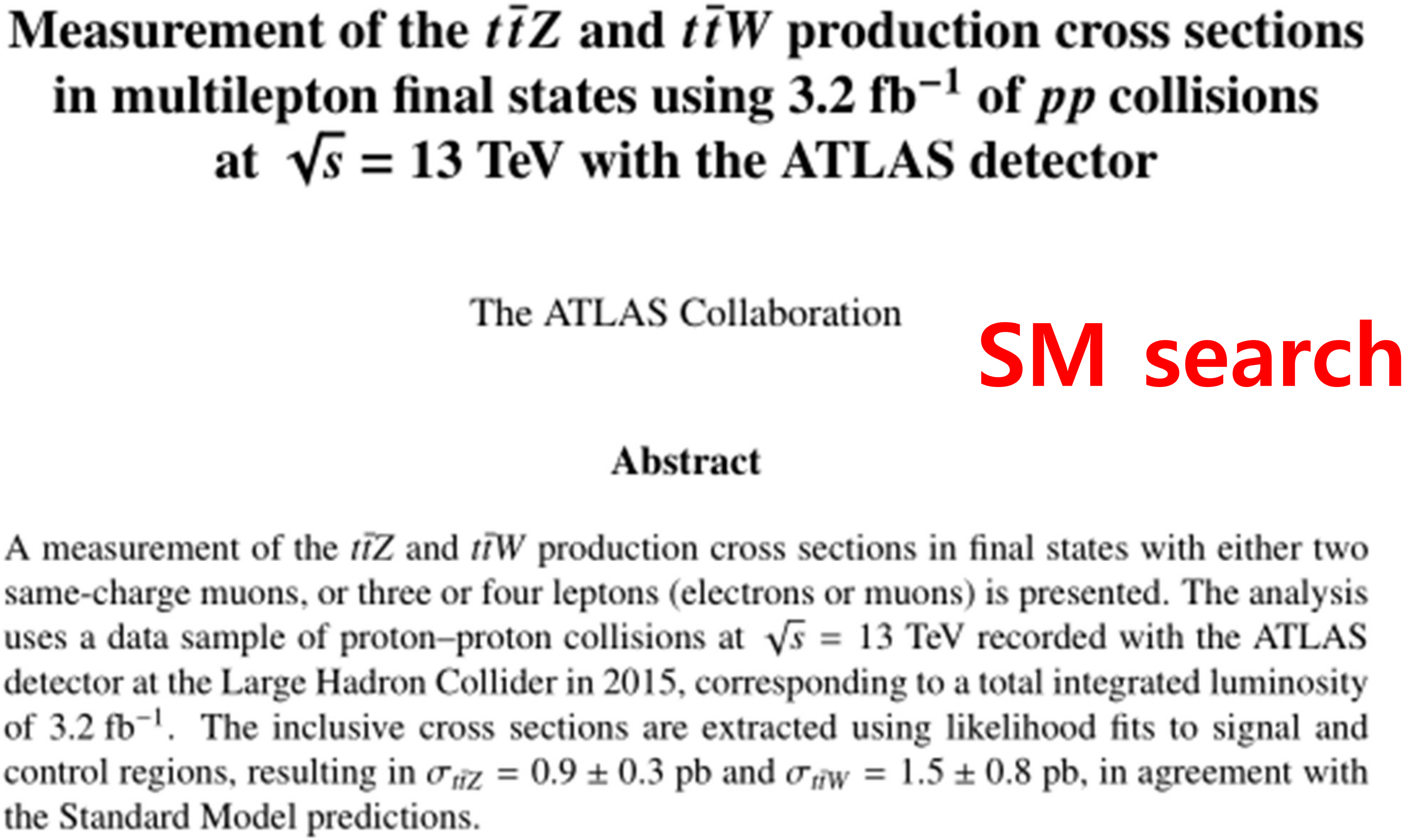
The first MadAnalysis 5 workshop
on LHC recasting @ Korea

Table of contents

- What we recast
- Generating the events
- MadAnalysis
- Current status
- Things to be done

What we recast

Abstract of exp.



Measurement of the $t\bar{t}Z$ and $t\bar{t}W$ production cross sections in multilepton final states using 3.2 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

The ATLAS Collaboration

SM search

Abstract

A measurement of the $t\bar{t}Z$ and $t\bar{t}W$ production cross sections in final states with either two same-charge muons, or three or four leptons (electrons or muons) is presented. The analysis uses a data sample of proton–proton collisions at $\sqrt{s} = 13$ TeV recorded with the ATLAS detector at the Large Hadron Collider in 2015, corresponding to a total integrated luminosity of 3.2 fb^{-1}. The inclusive cross sections are extracted using likelihood fits to signal and control regions, resulting in $\sigma_{t\bar{t}Z} = 0.9 \pm 0.3$ pb and $\sigma_{t\bar{t}W} = 1.5 \pm 0.8$ pb, in agreement with the Standard Model predictions.

What we recast

We consider multi-leptonic channels listed in below:

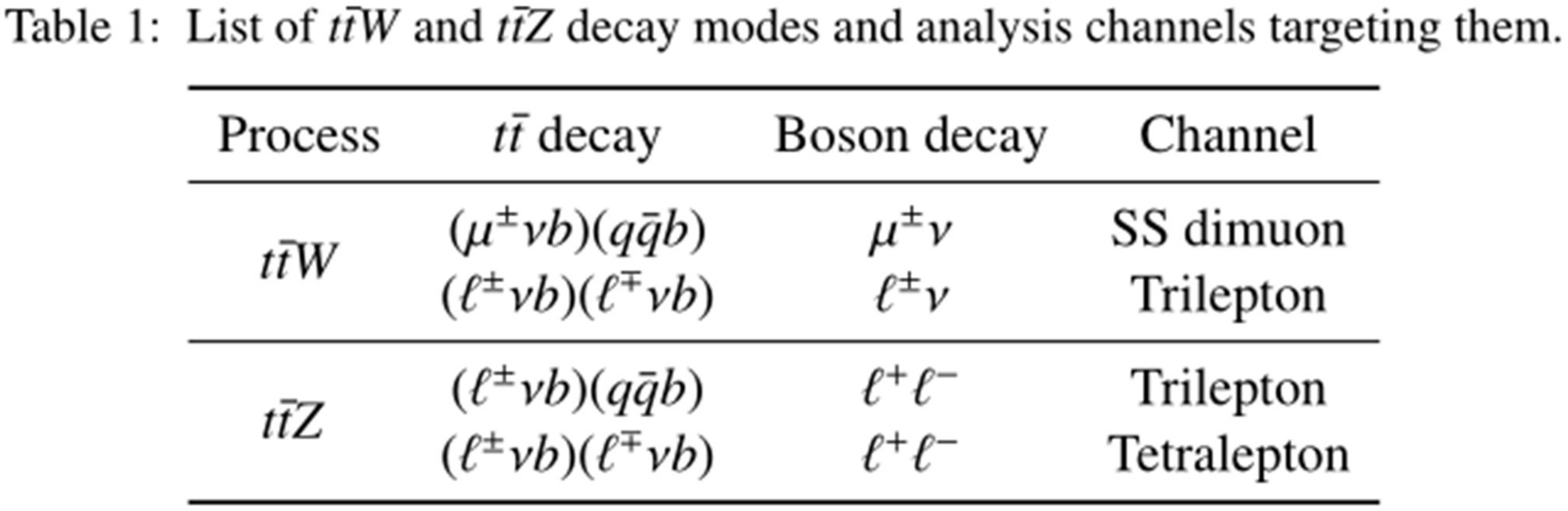


Table 1: List of $t\bar{t}W$ and $t\bar{t}Z$ decay modes and analysis channels targeting them.

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

In case of *ttZ*, the mixing Z/A is included

Branching ratios of t, W, Z

Process	BR
$t \to \mu\nu b$	~0.13
$t \to q\bar{q}b$	~0.67
$t \to \ell\nu b$	~0.26
$W \to \mu\nu$	~0.10
$W \to \ell\nu$	~0.20
$Z \to \ell\ell$	~0.07

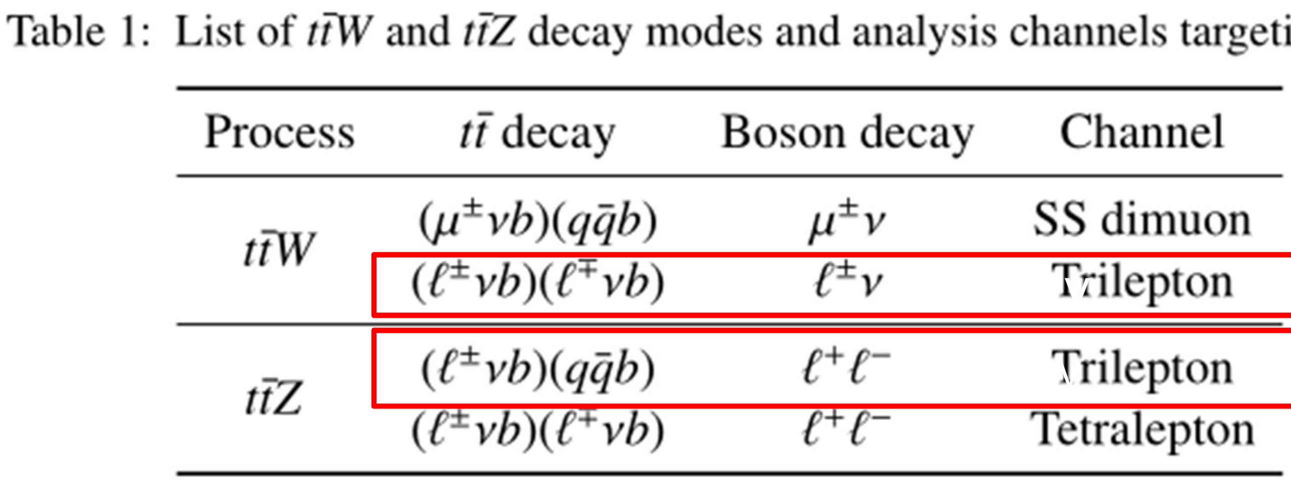


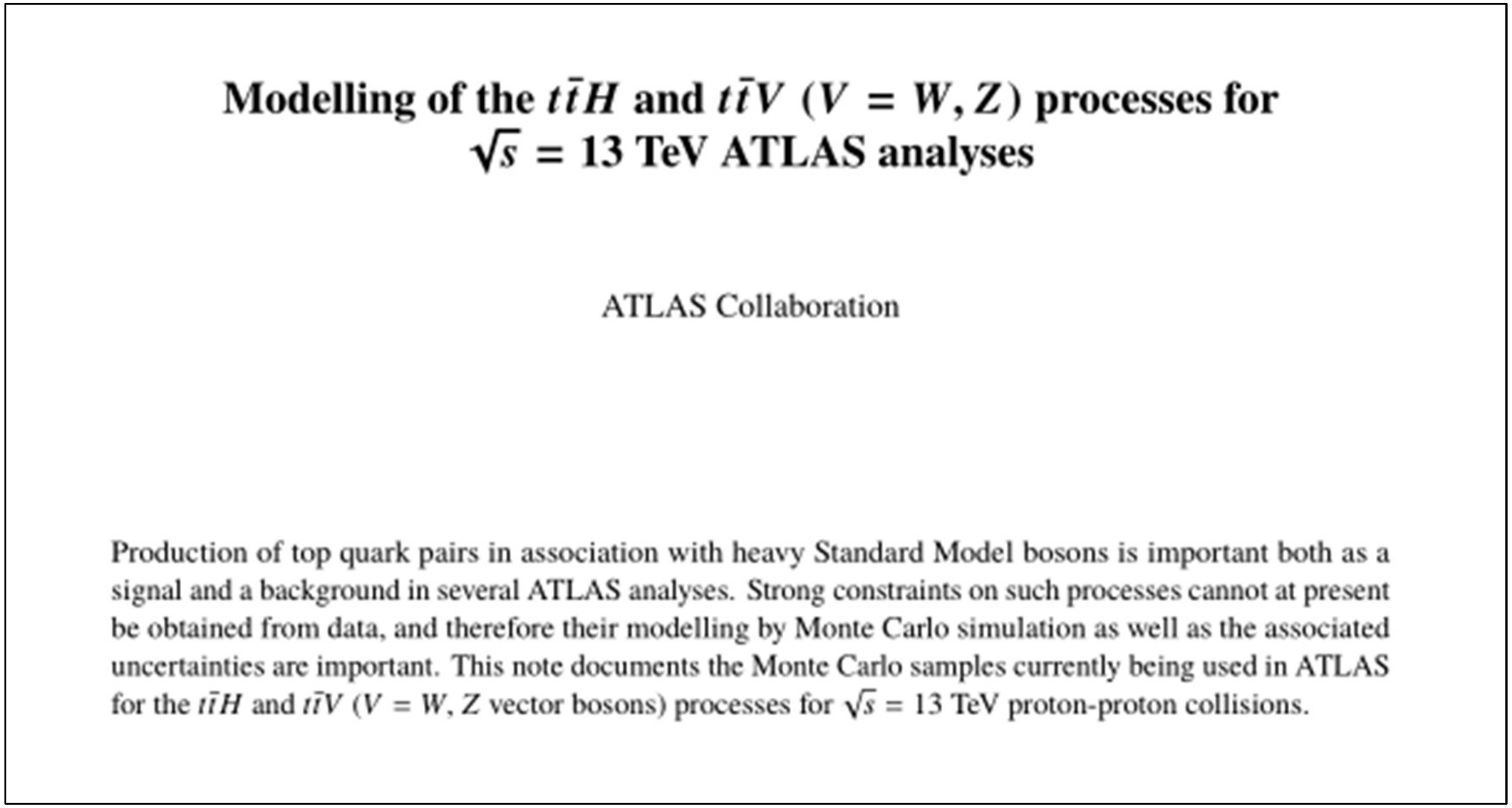
Table 1: List of $t\bar{t}W$ and $t\bar{t}Z$ decay modes and analysis channels targeting them.

Process	$t\bar{t}$ decay	Boson decay	Channel	Br	Expectation
$t\bar{t}W$	$(\mu^\pm\nu b)(q\bar{q}b)$	$\mu^\pm\nu$	SS dimuon	~0.00871	
	$(\ell^\pm\nu b)(\ell^\mp\nu b)$	$\ell^\pm\nu$	Trilepton	~0.01352	More #
$t\bar{t}Z$	$(\ell^\pm\nu b)(q\bar{q}b)$	$\ell^+\ell^-$	Trilepton	~0.012194	More #
	$(\ell^\pm\nu b)(\ell^\mp\nu b)$	$\ell^+\ell^-$	Tetralepton	~0.004732	

Generating the events

Reference

We followed the details of the way of the event generation in ATL-PHYS-PUB-2016-005



Modelling of the $t\bar{t}H$ and $t\bar{t}V$ $(V = W, Z)$ processes for $\sqrt{s} = 13$ TeV ATLAS analyses

ATLAS Collaboration

Production of top quark pairs in association with heavy Standard Model bosons is important both as a signal and a background in several ATLAS analyses. Strong constraints on such processes cannot at present be obtained from data, and therefore their modelling by Monte Carlo simulation as well as the associated uncertainties are important. This note documents the Monte Carlo samples currently being used in ATLAS for the $t\bar{t}H$ and $t\bar{t}V$ $(V = W, Z$ vector bosons) processes for $\sqrt{s} = 13$ TeV proton-proton collisions.

Step 1. Madgraph-*W*

Madgraph | Madspin | Pythia8 | Delphes

Generate events $pp \to t\bar{t}W$ $pp \to t\bar{t}Z$

$pp \to t\bar{t}W$

```
generate p p > t t~ W+
add process p p > t t~ W+ j
add process p p > t t~ W+ j j
output ttWp
```

In ref., 2j-level multileg is considered

we used 4-flavor scheme

Then, the result is saved in ./ttWp.
Before “launch”,
“run_card.dat” & “param_card.dat” should be edited

Step 1. Madgraph-*Z*

Madgraph | Madspin | Pythia8 | Delphes

Generate events $pp \to t\bar{t}W$ $pp \to t\bar{t}Z$

$pp \to t\bar{t}Z$

```
generate p p > t t~ l+ l-
add process p p > t t~ l+ l- j
output ttZ
```

In ref., 1j-level multileg is considered

we used 4-flavor scheme

To include the mixing between *Z* & *A*,
we generate t t~ l- l+ instead of t t~ Z

Step 1. run_card & param.dat

Madgraph Madspin Pythia8 Delphes

Change log

run_card.dat

1) make all cuts be off
2) give values to “mmll” and “ptj”

```
1.0    = mmll  ! min invariant mass of l+l- (same flavour) lepton pair
10.0   = ptj   ! minimum pt for the jets
3 = dynamical_scale_choice ! M_T/2
1.0   = scalefact         ! scale factor for event-by-event scales
```

param_card.dat

1) MT (top mass) is changed to 1.725*10^2

Now, we are ready to launch

Step 2. Madspin

Madgraph | **Madspin** | Pythia8 | Delphes

We let t, W, Z decay by making use of “Madspin”.
At the folder generated by “launch”,
one can run madspin, … in madevent (./bin/madevent)

Example of W decay for madspin_card.dat:

```
     set max_weight_ps_point 400      <<< default option
     decay t > w+ b, w+ > mu+ vm   <<< for top decay
     decay t~ > w- b~, w- > j j
     decay w+ > mu+ vm                    <<< for W decay
```

Step 3. Pythia8

Madgraph | Madspin | **Pythia8** | Delphes

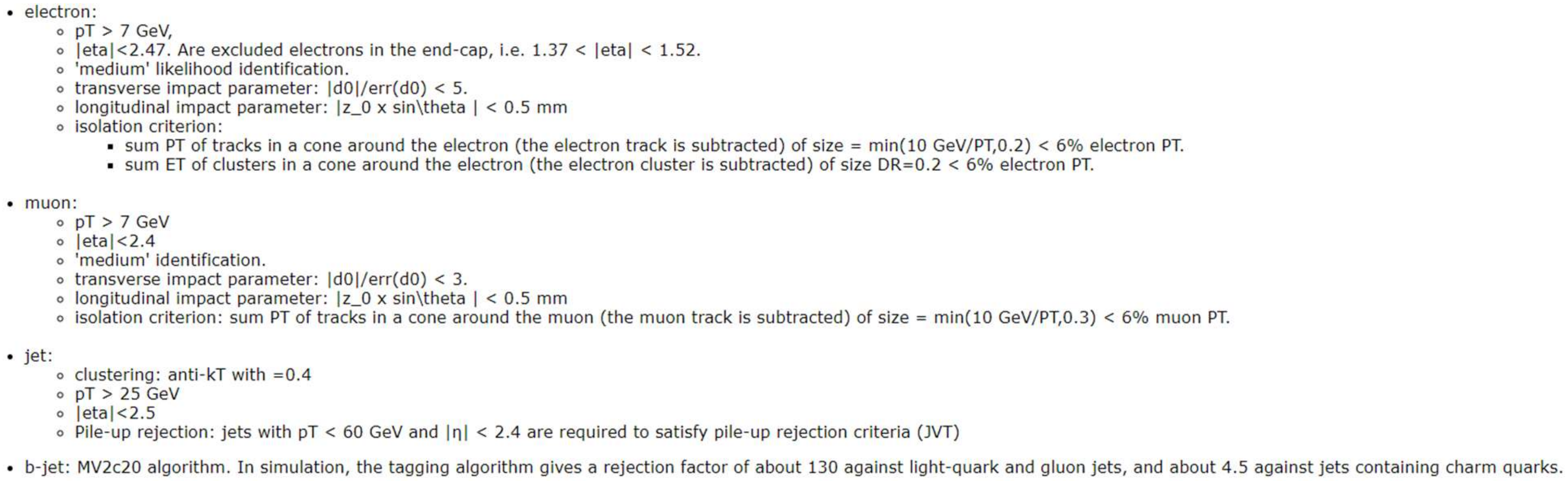
Using pythia8, we shower processes and merge
In “pythia8_card.dat”,
 * Merging:Process = guess
 * Merging:mayRemoveDecayProducts =on

And “A14 tune” is applied [ATL-PHYS-PUB-2014-021]
One import point in A14tune is that
'BeamRemnants:reconnectRange'
>>>'ColourReconnection:range‘ in pythia 8.2

Step 4. Delphes

Madgraph Madspin Pythia8 **Delphes**

At Delphes level, we impose the objections:



- electron:
    - pT > 7 GeV,
    - |eta|<2.47. Are excluded electrons in the end-cap, i.e. 1.37 < |eta| < 1.52.
    - 'medium' likelihood identification.
    - transverse impact parameter: |d0|/err(d0) < 5.
    - longitudinal impact parameter: |z_0 x sin\theta | < 0.5 mm
    - isolation criterion:
        - sum PT of tracks in a cone around the electron (the electron track is subtracted) of size = min(10 GeV/PT,0.2) < 6% electron PT.
        - sum ET of clusters in a cone around the electron (the electron cluster is subtracted) of size DR=0.2 < 6% electron PT.
- muon:
    - pT > 7 GeV
    - |eta|<2.4
    - 'medium' identification.
    - transverse impact parameter: |d0|/err(d0) < 3.
    - longitudinal impact parameter: |z_0 x sin\theta | < 0.5 mm
    - isolation criterion: sum PT of tracks in a cone around the muon (the muon track is subtracted) of size = min(10 GeV/PT,0.3) < 6% muon PT.
- jet:
    - clustering: anti-kT with =0.4
    - pT > 25 GeV
    - |eta|<2.5
    - Pile-up rejection: jets with pT < 60 GeV and |η| < 2.4 are required to satisfy pile-up rejection criteria (JVT)
- b-jet: MV2c20 algorithm. In simulation, the tagging algorithm gives a rejection factor of about 130 against light-quark and gluon jets, and about 4.5 against jets containing charm quarks.

“Isolation criterion” needs additional modules

impact parameter cut and pile-up rejection in jet are ignored

Madanalysis

Event Selection
SS dimuon

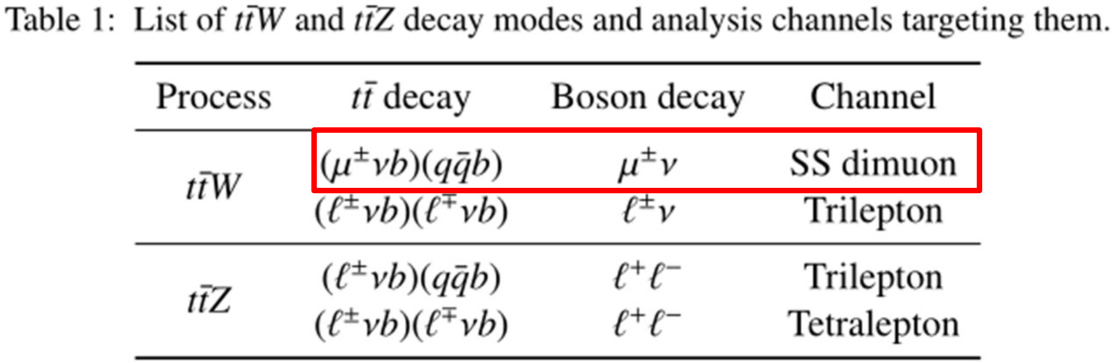


Table 1: List of $t\bar{t}W$ and $t\bar{t}Z$ decay modes and analysis channels targeting them.

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

1) Same-sign (SS) dimuon

- dimuons of same charge with PT > 25 GeV
- events with additional leptons are vetoed
- MET > 40 GeV
- HT > 240 GeV
- At least 2 b-jets

[HT: the scalar sum of the p T of selected leptons and jets]

Event Selection
Trilepton

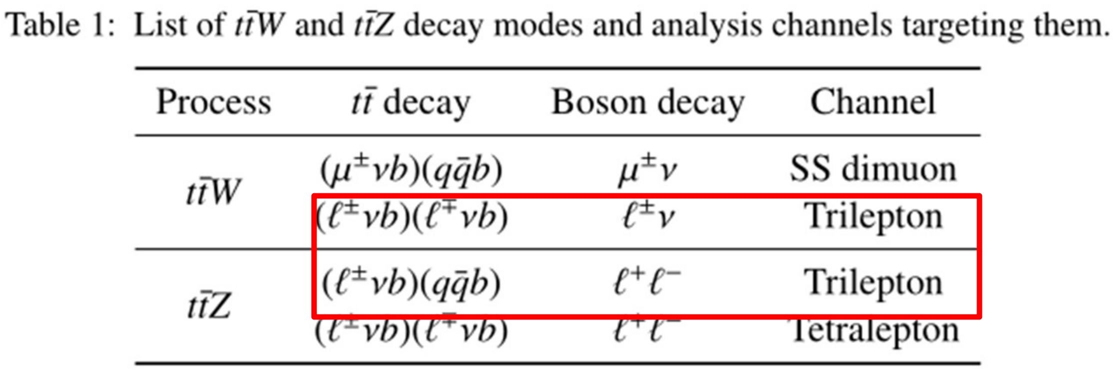
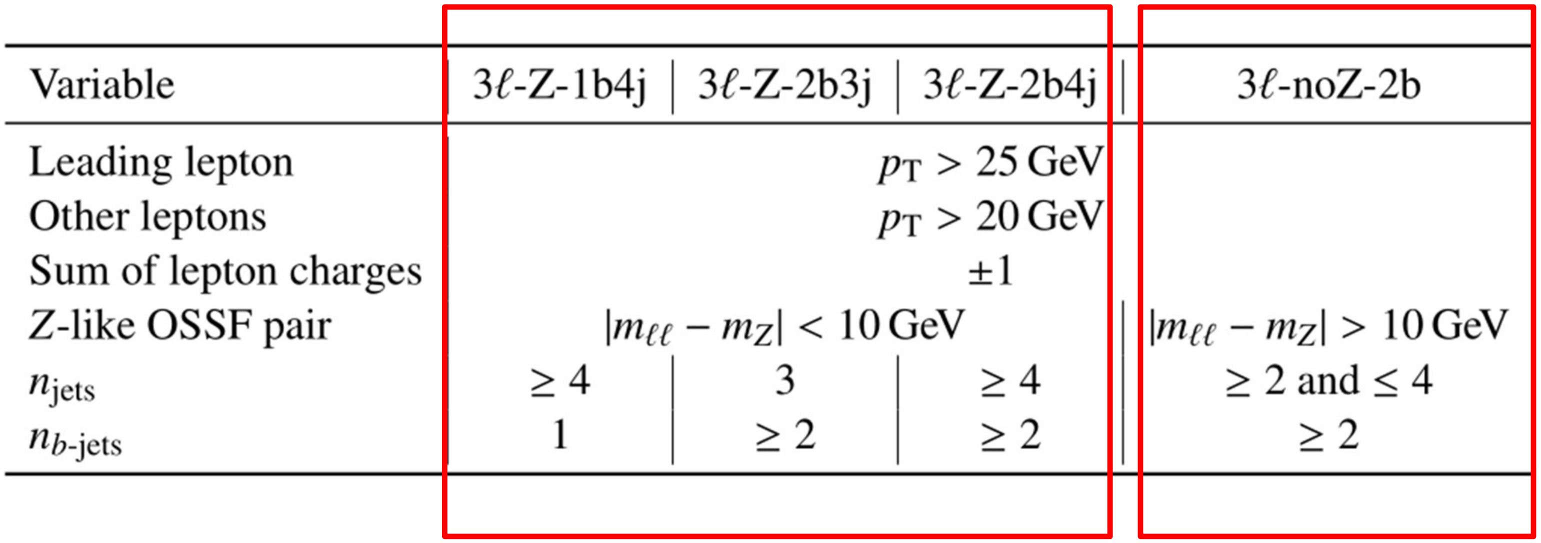


Table 1: List of $t\bar{t}W$ and $t\bar{t}Z$ decay modes and analysis channels targeting them.

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



Variable	3ℓ-Z-1b4j	3ℓ-Z-2b3j	3ℓ-Z-2b4j	3ℓ-noZ-2b
Leading lepton	$p_{\mathrm{T}} > 25$ GeV			
Other leptons	$p_{\mathrm{T}} > 20$ 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

Sensitive to *Z* **Main to *W***

Event Selection
Tetralepton

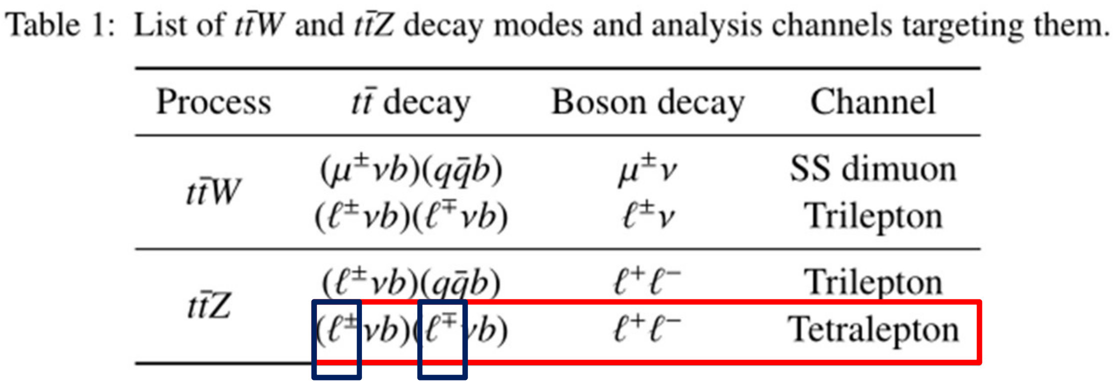
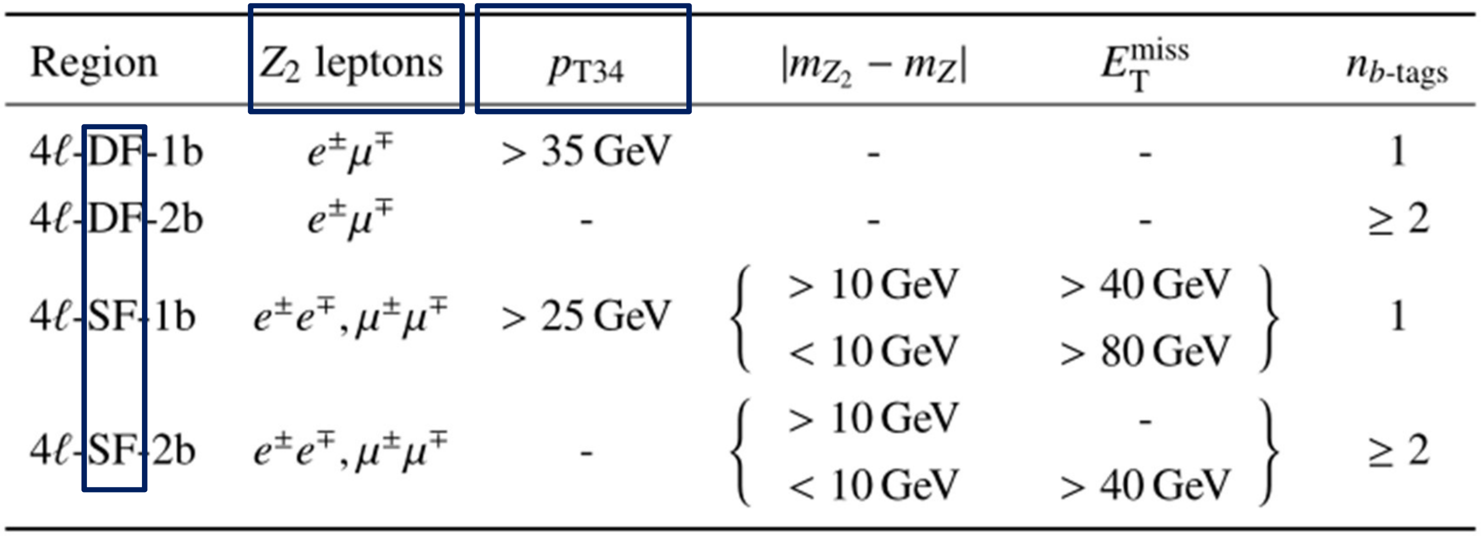


Table 1: List of $t\bar{t}W$ and $t\bar{t}Z$ decay modes and analysis channels targeting them.

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



Region	Z_2 leptons	p_{T34}	$\|m_{Z_2} - m_Z\|$	E_T^{miss}	$n_{b\text{-tags}}$
4ℓ-DF-1b	$e^{\pm}\mu^{\mp}$	> 35 GeV	-	-	1
4ℓ-DF-2b	$e^{\pm}\mu^{\mp}$	-	-	-	≥ 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	- > 40 GeV	≥ 2

Current of Status

What we did

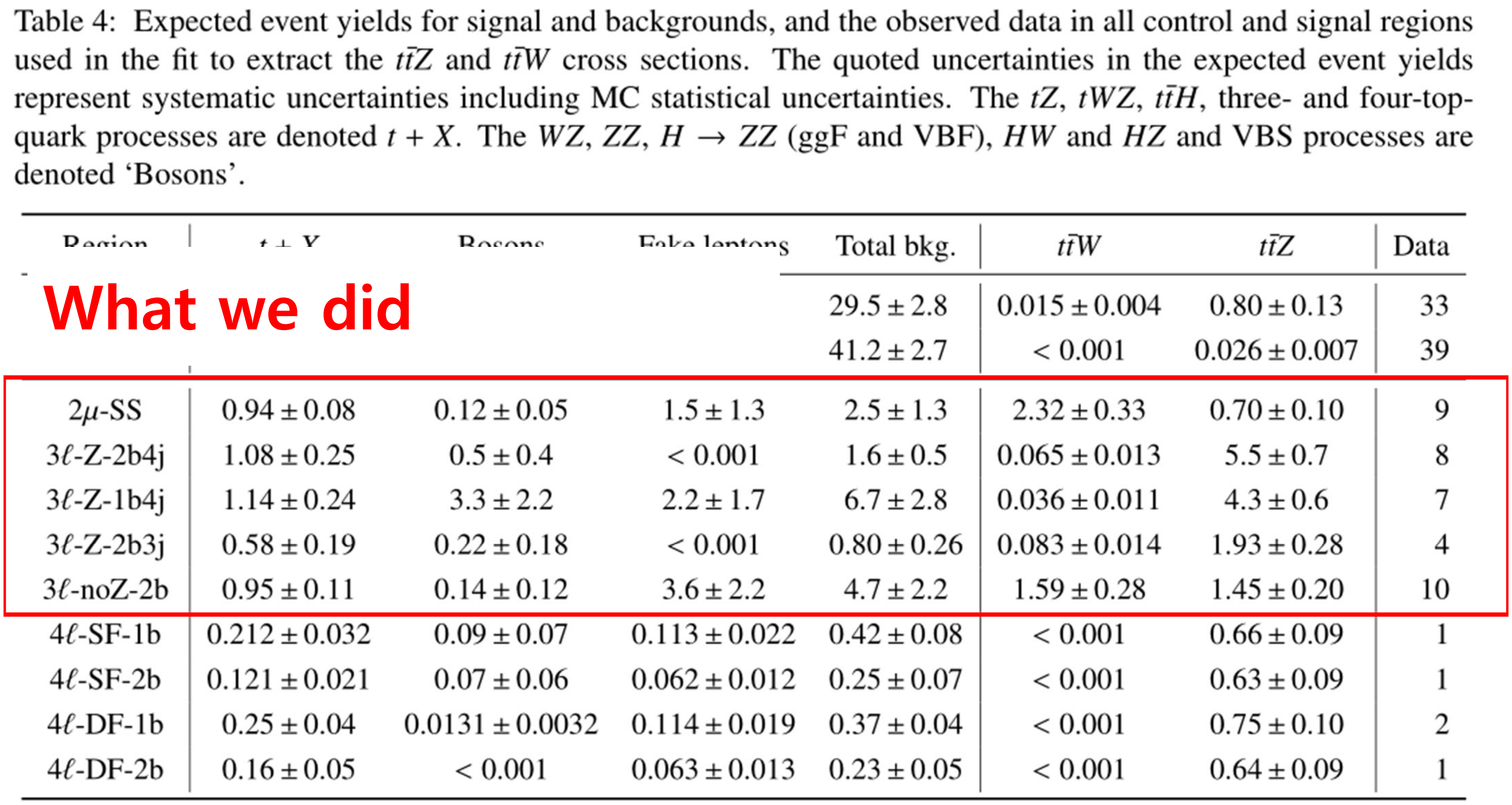


Table 4: Expected event yields for signal and backgrounds, and the observed data in all control and signal regions used in the fit to extract the $t\bar{t}Z$ and $t\bar{t}W$ cross sections. The quoted uncertainties in the expected event yields represent systematic uncertainties including MC statistical uncertainties. The tZ, tWZ, $t\bar{t}H$, three- and four-top-quark processes are denoted $t + X$. The WZ, ZZ, $H \rightarrow ZZ$ (ggF and VBF), HW and HZ and VBS processes are denoted 'Bosons'.

What we did

Region	$t + X$	Bosons	Fake leptons	Total bkg.	$t\bar{t}W$	$t\bar{t}Z$	Data
				29.5 ± 2.8	0.015 ± 0.004	0.80 ± 0.13	33
				41.2 ± 2.7	< 0.001	0.026 ± 0.007	39
2μ-SS	0.94 ± 0.08	0.12 ± 0.05	1.5 ± 1.3	2.5 ± 1.3	2.32 ± 0.33	0.70 ± 0.10	9
3ℓ-Z-2b4j	1.08 ± 0.25	0.5 ± 0.4	< 0.001	1.6 ± 0.5	0.065 ± 0.013	5.5 ± 0.7	8
3ℓ-Z-1b4j	1.14 ± 0.24	3.3 ± 2.2	2.2 ± 1.7	6.7 ± 2.8	0.036 ± 0.011	4.3 ± 0.6	7
3ℓ-Z-2b3j	0.58 ± 0.19	0.22 ± 0.18	< 0.001	0.80 ± 0.26	0.083 ± 0.014	1.93 ± 0.28	4
3ℓ-noZ-2b	0.95 ± 0.11	0.14 ± 0.12	3.6 ± 2.2	4.7 ± 2.2	1.59 ± 0.28	1.45 ± 0.20	10
4ℓ-SF-1b	0.212 ± 0.032	0.09 ± 0.07	0.113 ± 0.022	0.42 ± 0.08	< 0.001	0.66 ± 0.09	1
4ℓ-SF-2b	0.121 ± 0.021	0.07 ± 0.06	0.062 ± 0.012	0.25 ± 0.07	< 0.001	0.63 ± 0.09	1
4ℓ-DF-1b	0.25 ± 0.04	0.0131 ± 0.0032	0.114 ± 0.019	0.37 ± 0.04	< 0.001	0.75 ± 0.10	2
4ℓ-DF-2b	0.16 ± 0.05	< 0.001	0.063 ± 0.013	0.23 ± 0.05	< 0.001	0.64 ± 0.09	1

ttW event yield

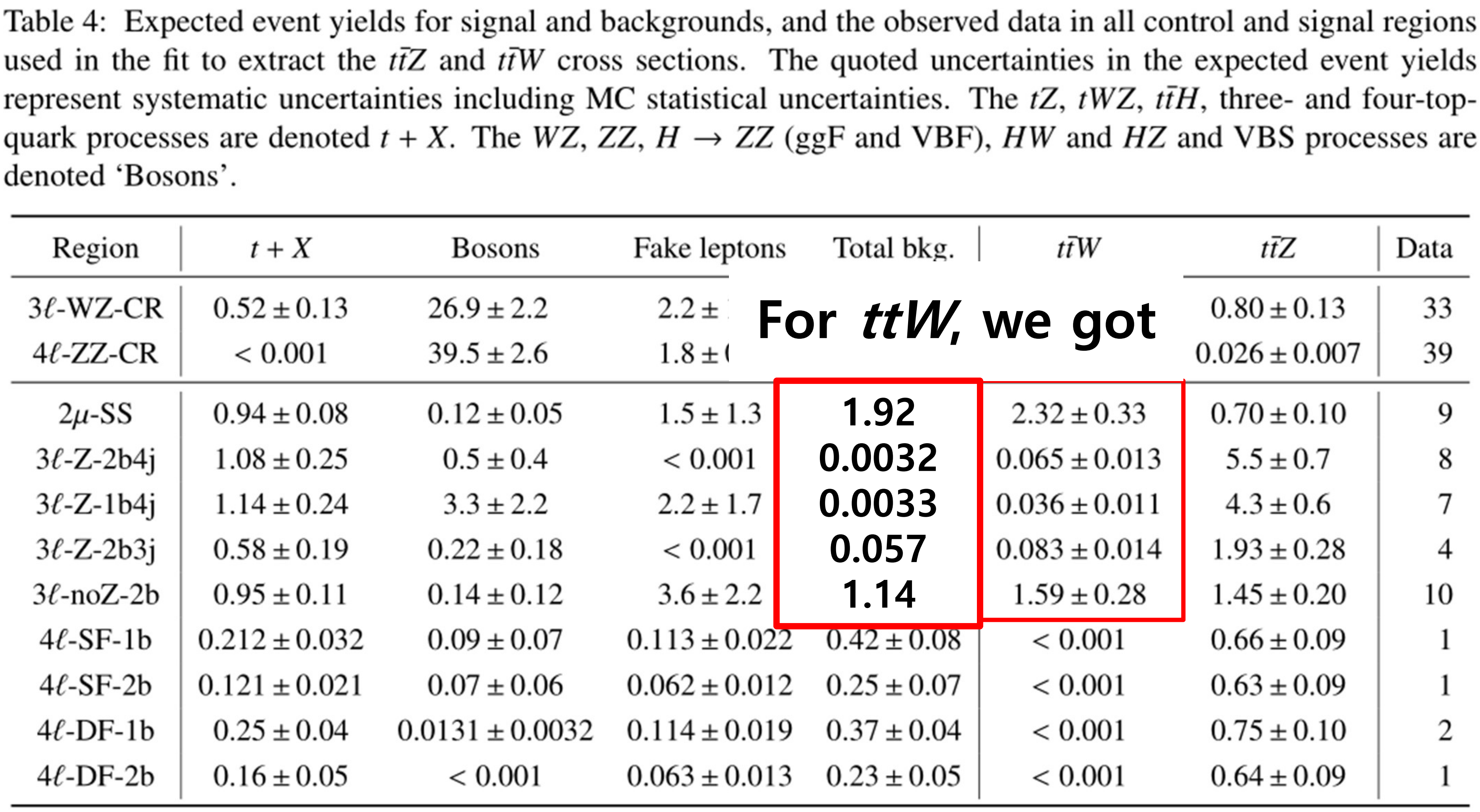


Table 4: Expected event yields for signal and backgrounds, and the observed data in all control and signal regions used in the fit to extract the $t\bar{t}Z$ and $t\bar{t}W$ cross sections. The quoted uncertainties in the expected event yields represent systematic uncertainties including MC statistical uncertainties. The tZ, tWZ, $t\bar{t}H$, three- and four-top-quark processes are denoted $t + X$. The WZ, ZZ, $H \rightarrow ZZ$ (ggF and VBF), HW and HZ and VBS processes are denoted ‘Bosons’.

For *ttW*, we got

Region	$t + X$	Bosons	Fake leptons	Total bkg.	$t\bar{t}W$	$t\bar{t}Z$	Data
3ℓ-WZ-CR	0.52 ± 0.13	26.9 ± 2.2	2.2 ±			0.80 ± 0.13	33
4ℓ-ZZ-CR	< 0.001	39.5 ± 2.6	1.8 ±			0.026 ± 0.007	39
2μ-SS	0.94 ± 0.08	0.12 ± 0.05	1.5 ± 1.3	**1.92**	2.32 ± 0.33	0.70 ± 0.10	9
3ℓ-Z-2b4j	1.08 ± 0.25	0.5 ± 0.4	< 0.001	**0.0032**	0.065 ± 0.013	5.5 ± 0.7	8
3ℓ-Z-1b4j	1.14 ± 0.24	3.3 ± 2.2	2.2 ± 1.7	**0.0033**	0.036 ± 0.011	4.3 ± 0.6	7
3ℓ-Z-2b3j	0.58 ± 0.19	0.22 ± 0.18	< 0.001	**0.057**	0.083 ± 0.014	1.93 ± 0.28	4
3ℓ-noZ-2b	0.95 ± 0.11	0.14 ± 0.12	3.6 ± 2.2	**1.14**	1.59 ± 0.28	1.45 ± 0.20	10
4ℓ-SF-1b	0.212 ± 0.032	0.09 ± 0.07	0.113 ± 0.022	0.42 ± 0.08	< 0.001	0.66 ± 0.09	1
4ℓ-SF-2b	0.121 ± 0.021	0.07 ± 0.06	0.062 ± 0.012	0.25 ± 0.07	< 0.001	0.63 ± 0.09	1
4ℓ-DF-1b	0.25 ± 0.04	0.0131 ± 0.0032	0.114 ± 0.019	0.37 ± 0.04	< 0.001	0.75 ± 0.10	2
4ℓ-DF-2b	0.16 ± 0.05	< 0.001	0.063 ± 0.013	0.23 ± 0.05	< 0.001	0.64 ± 0.09	1

ttZ event yield

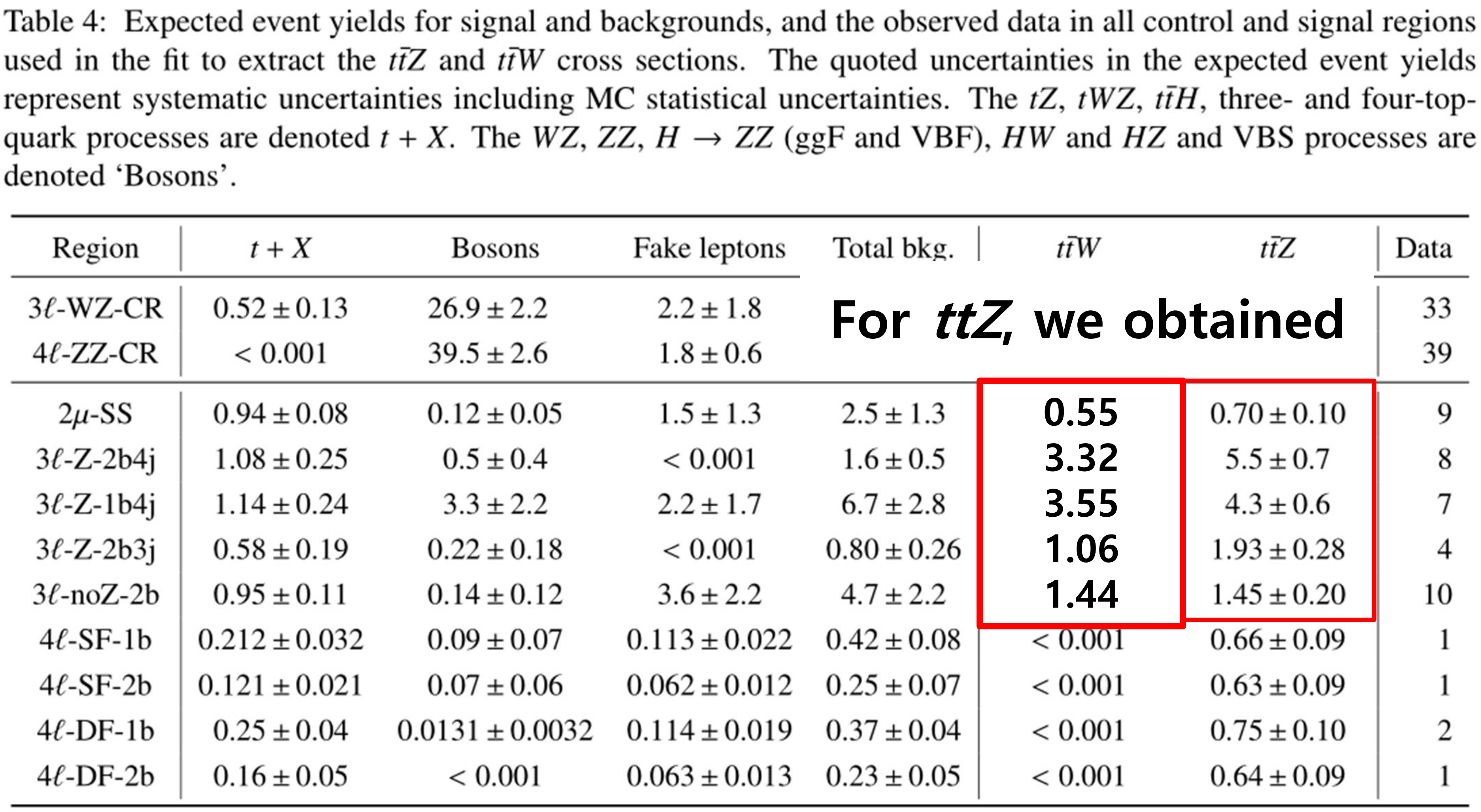


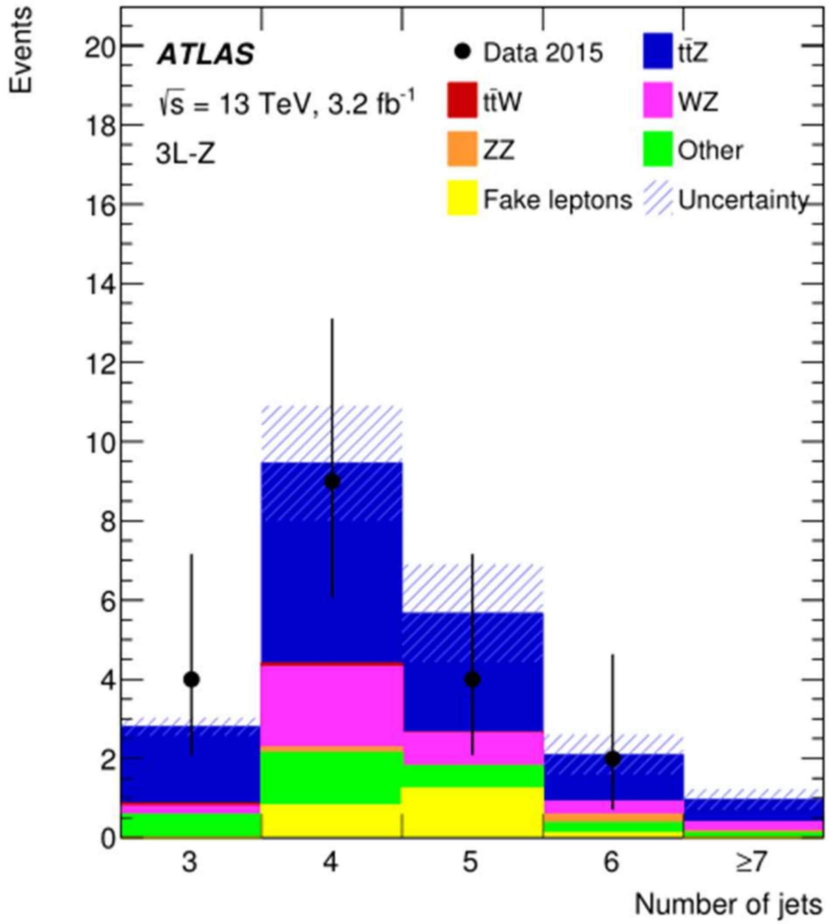
Table 4: Expected event yields for signal and backgrounds, and the observed data in all control and signal regions used in the fit to extract the $t\bar{t}Z$ and $t\bar{t}W$ cross sections. The quoted uncertainties in the expected event yields represent systematic uncertainties including MC statistical uncertainties. The tZ, tWZ, $t\bar{t}H$, three- and four-top-quark processes are denoted $t + X$. The WZ, ZZ, $H \rightarrow ZZ$ (ggF and VBF), HW and HZ and VBS processes are denoted 'Bosons'.

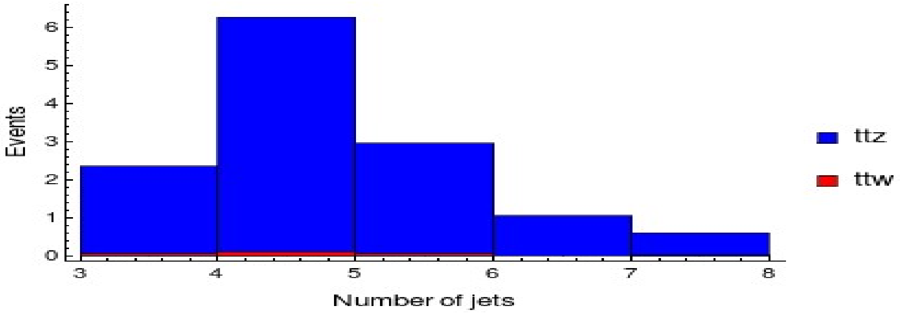
Region	$t + X$	Bosons	Fake leptons	Total bkg.	$t\bar{t}W$	$t\bar{t}Z$	Data
3ℓ-WZ-CR	0.52 ± 0.13	26.9 ± 2.2	2.2 ± 1.8				33
4ℓ-ZZ-CR	< 0.001	39.5 ± 2.6	1.8 ± 0.6				39
2μ-SS	0.94 ± 0.08	0.12 ± 0.05	1.5 ± 1.3	2.5 ± 1.3	**0.55**	0.70 ± 0.10	9
3ℓ-Z-2b4j	1.08 ± 0.25	0.5 ± 0.4	< 0.001	1.6 ± 0.5	**3.32**	5.5 ± 0.7	8
3ℓ-Z-1b4j	1.14 ± 0.24	3.3 ± 2.2	2.2 ± 1.7	6.7 ± 2.8	**3.55**	4.3 ± 0.6	7
3ℓ-Z-2b3j	0.58 ± 0.19	0.22 ± 0.18	< 0.001	0.80 ± 0.26	**1.06**	1.93 ± 0.28	4
3ℓ-noZ-2b	0.95 ± 0.11	0.14 ± 0.12	3.6 ± 2.2	4.7 ± 2.2	**1.44**	1.45 ± 0.20	10
4ℓ-SF-1b	0.212 ± 0.032	0.09 ± 0.07	0.113 ± 0.022	0.42 ± 0.08	< 0.001	0.66 ± 0.09	1
4ℓ-SF-2b	0.121 ± 0.021	0.07 ± 0.06	0.062 ± 0.012	0.25 ± 0.07	< 0.001	0.63 ± 0.09	1
4ℓ-DF-1b	0.25 ± 0.04	0.0131 ± 0.0032	0.114 ± 0.019	0.37 ± 0.04	< 0.001	0.75 ± 0.10	2
4ℓ-DF-2b	0.16 ± 0.05	< 0.001	0.063 ± 0.013	0.23 ± 0.05	< 0.001	0.64 ± 0.09	1

For *ttZ*, we obtained

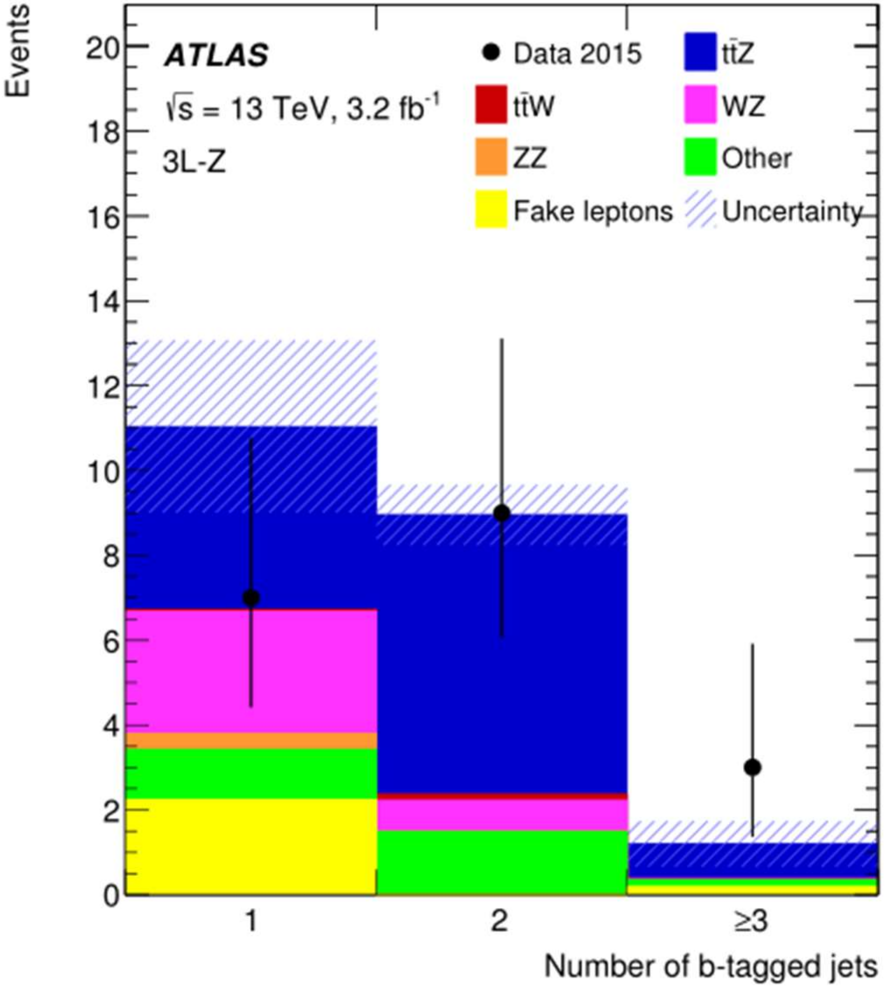
3ℓ-Z-1b4j, 3ℓ-Z-2b3j or 3ℓ-Z-2b4j

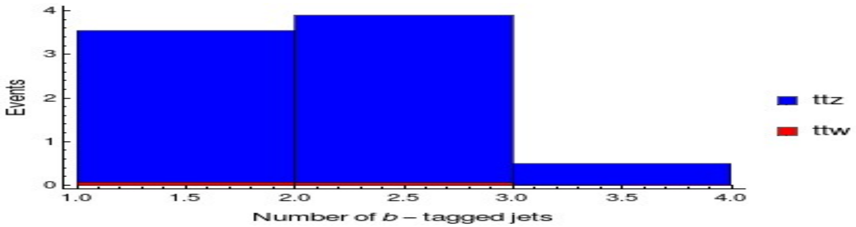
Number of jets





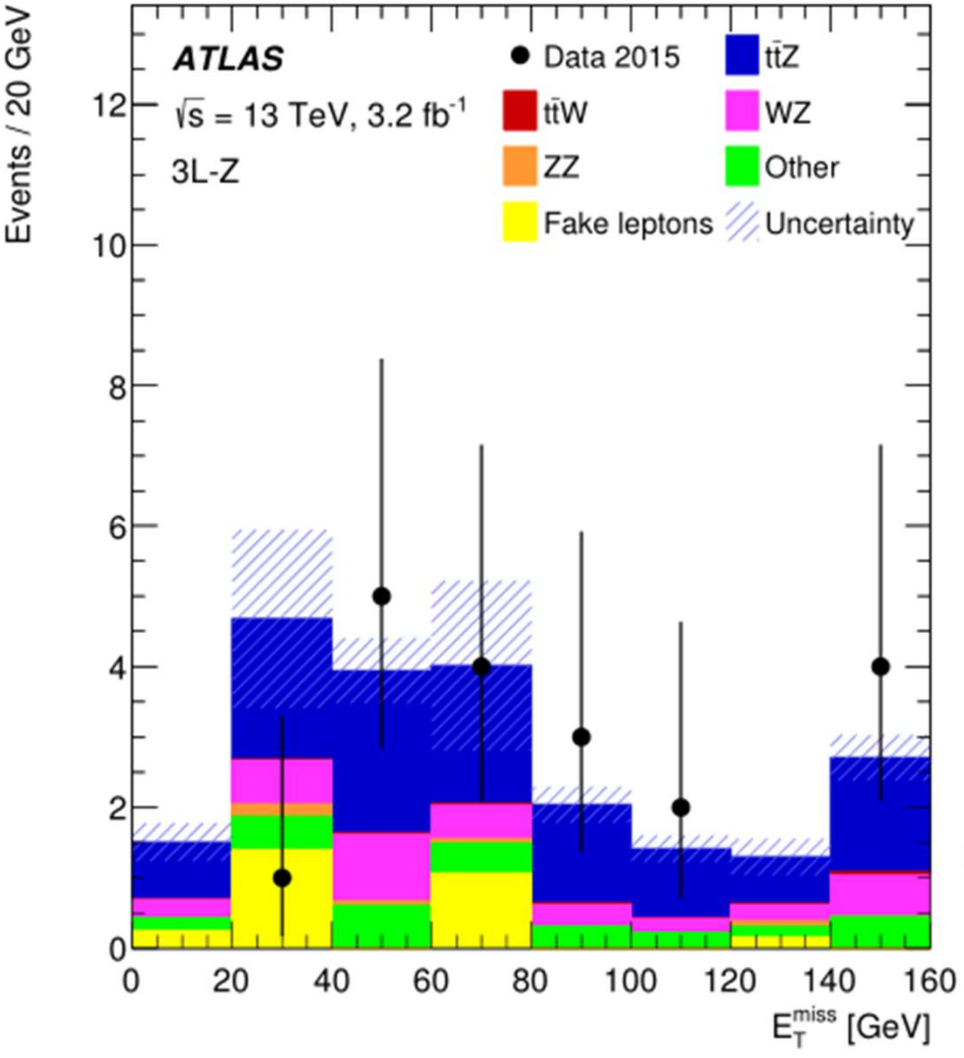
3ℓ-Z-1b4j, 3ℓ-Z-2b3j or 3ℓ-Z-2b4j
Number of b-tagged jets

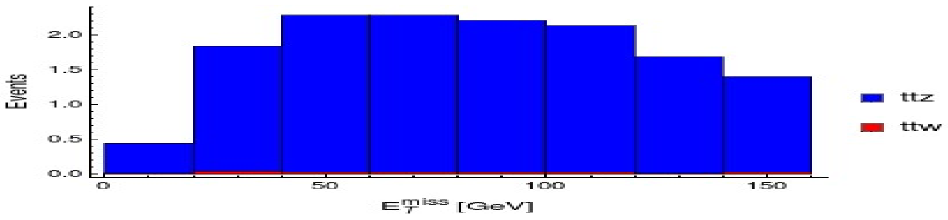




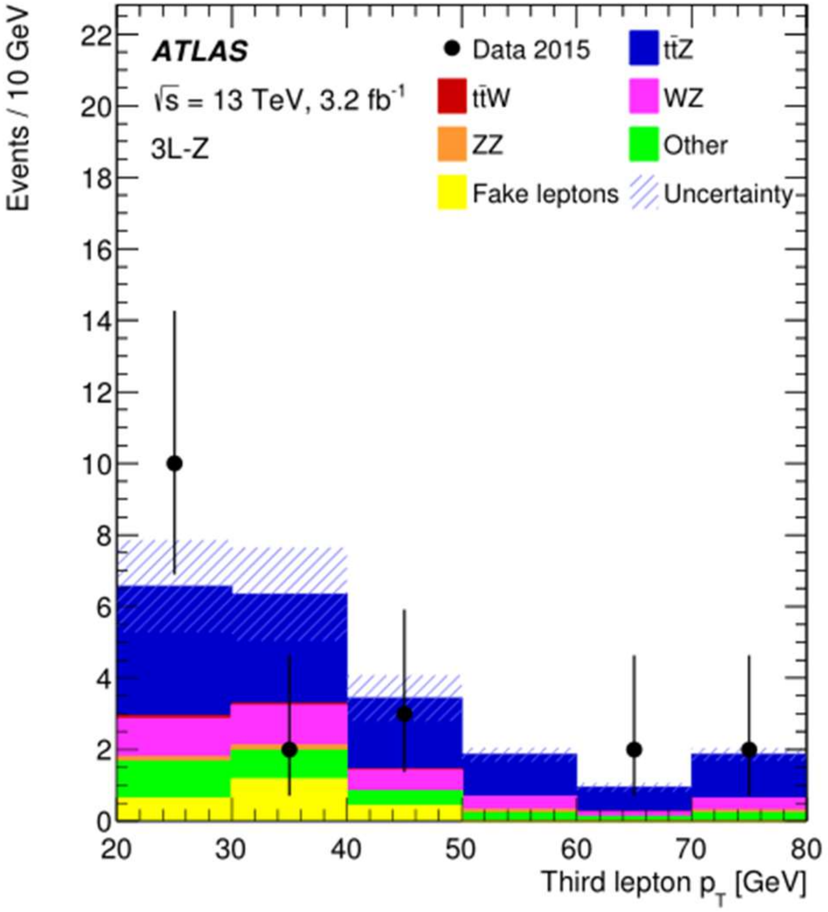
3ℓ-Z-1b4j, 3ℓ-Z-2b3j or 3ℓ-Z-2b4j

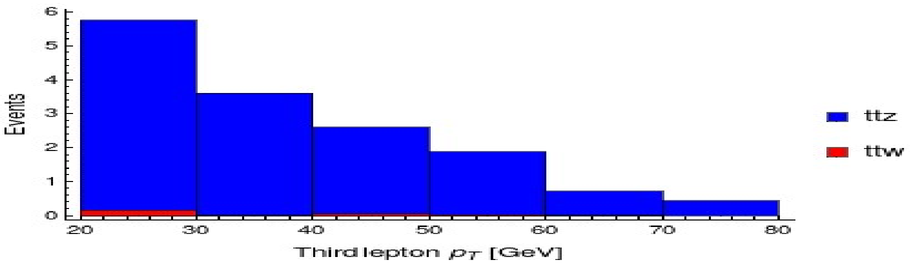
Missing ET





3ℓ-Z-1b4j, 3ℓ-Z-2b3j or 3ℓ-Z-2b4j
PT of the third lepton





Things to be done

- **Extracting # of data of each bin**

To compare the data with our result more precisely, we need to digitize the figures in the ref.

- **Fig. 1 (SS-dimuon)**

Figures are not ready yet

- **Tetralepton analysis**

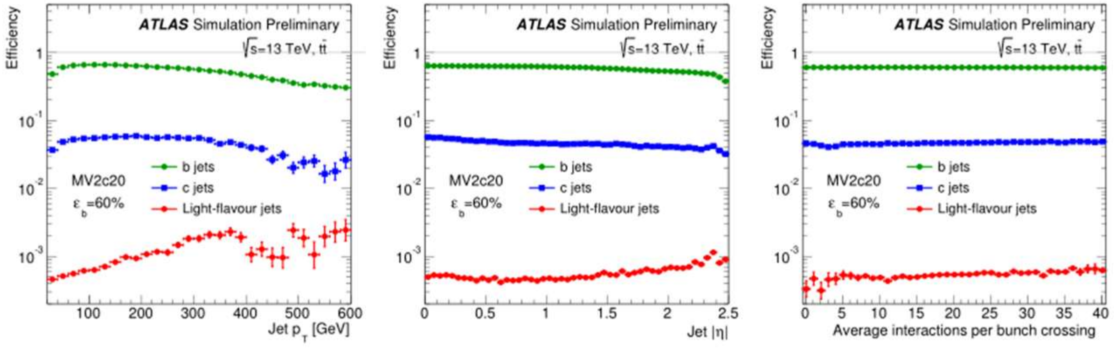
We have not completed the tetralepton analysis yet

- **Find the reasons of discrepancies**

One possibility is *b* tagging

b-tagging efficiency

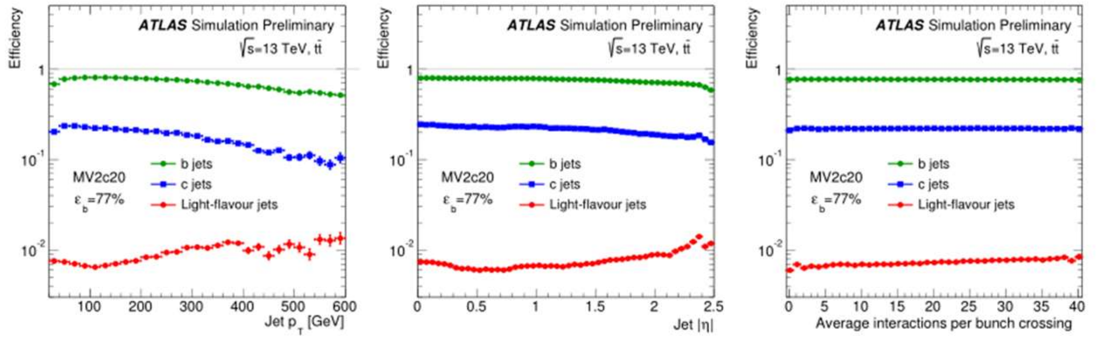
In ATL-PHYS-PUB-2015-022,



(a) (b) (c)

Figure 14: The efficiency to tag b (green), c (blue) and light-flavour (red) jets for the MV2c20 tagger with the 60% operating point. Efficiencies are shown as a function of the jet p_T (a), $|\eta|$ (b) and the average number of interaction per bunch crossing (c).

We use MV2c20 tagger with 60% operating point. This is the default tagger in Delphes



(a) (b) (c)

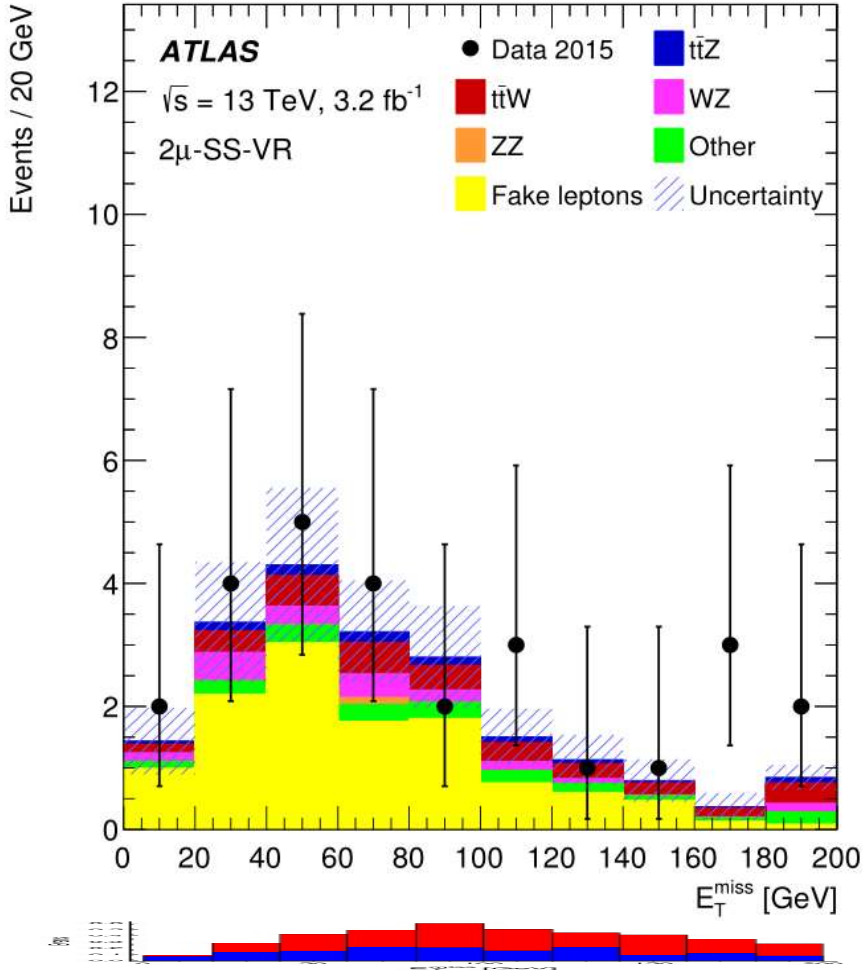
Figure 15: The efficiency to tag b (green), c (blue) and light-flavour (red) jets for the MV2c20 tagger with the 77% operating point. Efficiencies are shown as a function of the jet p_T (a), $|\eta|$ (b) and the average number of interaction per bunch crossing (c).

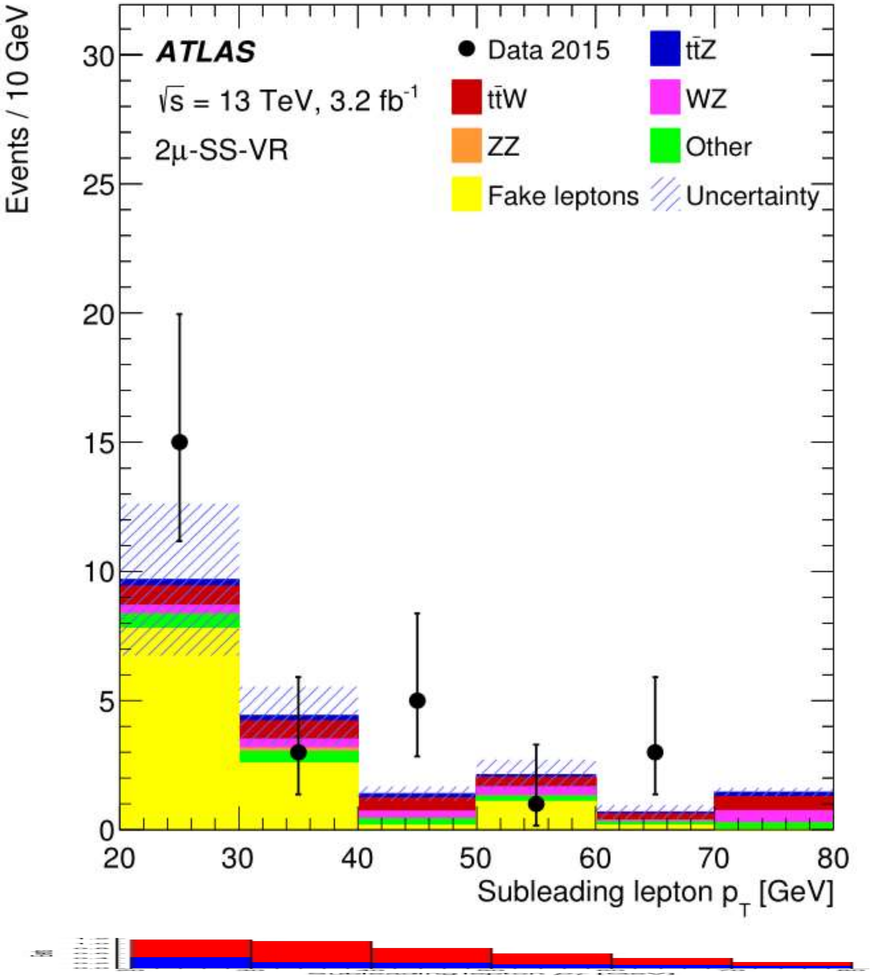
The Analysis use MV2c20 tagger with 77% operating point.

Deeper Understanding b-tagging algorithm in Delphes is needed

Thank you

Backup


ATLAS
$\sqrt{s}$ = 13 TeV, 3.2 fb^{-1}
2μ-SS-VR
Data 2015
$t\bar{t}Z$
$t\bar{t}W$
WZ
ZZ
Other
Fake leptons
Uncertainty
Events / 20 GeV
0
2
4
6
8
10
12
0
20
40
60
80
100
120
140
160
180
200
E_T^{miss} [GeV]


ATLAS
$\sqrt{s}$ = 13 TeV, 3.2 fb^{-1}
2μ-SS-VR
Data 2015
$t\bar{t}Z$
$t\bar{t}W$
WZ
ZZ
Other
Fake leptons
Uncertainty
Events / 10 GeV
0
5
10
15
20
25
30
20
30
40
50
60
70
80
Subleading lepton p_T [GeV]