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

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Supervisors: Eric Conte, Benjamin Fuks

The first MadAnalysis 5 workshop on LHC recasting @ Korea
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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

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:

In case of $ttZ$, the mixing $Z/A$ is included.
### Branching ratios of t, W, Z

<table>
<thead>
<tr>
<th>Process</th>
<th>BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t \rightarrow \mu \nu b$</td>
<td>$\sim 0.13$</td>
</tr>
<tr>
<td>$t \rightarrow q\bar{q}b$</td>
<td>$\sim 0.67$</td>
</tr>
<tr>
<td>$t \rightarrow \ell \nu b$</td>
<td>$\sim 0.26$</td>
</tr>
<tr>
<td>$W \rightarrow \mu \nu$</td>
<td>$\sim 0.10$</td>
</tr>
<tr>
<td>$W \rightarrow \ell \nu$</td>
<td>$\sim 0.20$</td>
</tr>
<tr>
<td>$Z \rightarrow \ell \ell$</td>
<td>$\sim 0.07$</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Process</th>
<th>$t\bar{t}$ decay</th>
<th>Boson decay</th>
<th>Channel</th>
<th>Br</th>
<th>Expectation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}W$</td>
<td>$(\mu^{\pm}v b)(q\bar{q}b)$</td>
<td>$\mu^{\pm}v$</td>
<td>SS dimuon</td>
<td>$\sim 0.00871$</td>
<td>More #</td>
</tr>
<tr>
<td></td>
<td>$(\ell^{\pm}v b)(\ell^{\pm}v b)$</td>
<td>$\ell^{\pm}v$</td>
<td>Trilepton</td>
<td>$\sim 0.01352$</td>
<td>More #</td>
</tr>
<tr>
<td>$t\bar{t}Z$</td>
<td>$(\ell^{\pm}v b)(q\bar{q}b)$</td>
<td>$\ell^{+}\ell^{-}$</td>
<td>Trilepton</td>
<td>$\sim 0.012194$</td>
<td>More #</td>
</tr>
<tr>
<td></td>
<td>$(\ell^{\pm}v b)(\ell^{+}v b)$</td>
<td>$\ell^{+}\ell^{-}$</td>
<td>Tetralepton</td>
<td>$\sim 0.004732$</td>
<td></td>
</tr>
</tbody>
</table>
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 $pp \rightarrow ttW \quad pp \rightarrow ttZ$

$pp \rightarrow ttW$

- generate $p\ p \rightarrow t\ t^{\sim}\ W^{+}$
- add process $p\ p \rightarrow t\ t^{\sim}\ W^{+}\ j$
- add process $p\ p \rightarrow t\ t^{\sim}\ W^{+}\ j\ j$
- 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

**Generate events**  

\[ pp \rightarrow ttW \quad pp \rightarrow ttZ \]

\[ pp \rightarrow ttZ \]

generate \( p \ p \rightarrow t \ t \sim l^+ l^- \)  
add process \( p \ p \rightarrow t \ t \sim l^+ l^- j \)  
output \( ttZ \)

In ref., 1j-level multileg is considered  
we used 4-flavor scheme

To include the mixing between \( Z \ & A \),  
we generate \( t \ t \sim l^- l^+ \) instead of \( t \ t \sim Z \)
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

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

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

At Delphes level, we impose the objections:

- **electron:**
  - $p_T > 7$ GeV
  - $|\eta| < 2.47$. Are excluded electrons in the end-cap, i.e. $1.37 < |\eta| < 1.52$.
  - 'medium' likelihood identification.
  - transverse impact parameter: $(d_0)/\sqrt{(d_0^2/\text{err}(d_0))} < 5$.
  - longitudinal impact parameter: $|z_0 \sin \theta/\text{sin}(\theta) | < 0.5$ mm
  - isolation criterion:
    - sum PT of tracks in a cone around the electron (the electron track is subtracted) of size $= \min(10 \text{ GeV}/p_T, 0.2) < 6\%$ 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:**
  - $p_T > 7$ GeV
  - $|\eta| < 2.4$
  - 'medium' identification.
  - transverse impact parameter: $(d_0)/\sqrt{(d_0^2/\text{err}(d_0))} < 3$.
  - longitudinal impact parameter: $|z_0 \sin \theta/\text{sin}(\theta) | < 0.5$ mm
  - isolation criterion: sum PT of tracks in a cone around the muon (the muon track is subtracted) of size $= \min(10 \text{ GeV}/p_T, 0.3) < 6\%$ muon PT.

- **Jet:**
  - clustering: anti-$kT$ with $d_0<0.4$
  - $p_T > 25$ GeV
  - $|\eta| < 2.5$
  - Pile-up rejection: jets with $p_T < 60$ GeV and $|\eta| < 2.4$ 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

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.

<table>
<thead>
<tr>
<th>Process</th>
<th>$t\bar{t}$ decay</th>
<th>Boson decay</th>
<th>Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}W$</td>
<td>$q\bar{q}b$</td>
<td>$\mu^\pm \nu$</td>
<td>SS dimuon</td>
</tr>
<tr>
<td></td>
<td>$b\ell^\pm \nu$</td>
<td>$\ell^\pm \nu$</td>
<td>Trilepton</td>
</tr>
<tr>
<td>$t\bar{t}Z$</td>
<td>$q\bar{q}b$</td>
<td>$\ell^+ \ell^-$</td>
<td>Trilepton</td>
</tr>
<tr>
<td></td>
<td>$b\ell^\pm \nu$</td>
<td>$\ell^+ \ell^-$</td>
<td>Tetralepton</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>$3\ell$-1b4j</th>
<th>$3\ell$-2b3j</th>
<th>$3\ell$-2b4j</th>
<th>$3\ell$-noZ-2b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leading lepton</td>
<td></td>
<td></td>
<td>$p_T &gt; 25$ GeV</td>
<td></td>
</tr>
<tr>
<td>Other leptons</td>
<td></td>
<td></td>
<td>$p_T &gt; 20$ GeV</td>
<td></td>
</tr>
<tr>
<td>Sum of lepton charges</td>
<td></td>
<td></td>
<td>±1</td>
<td></td>
</tr>
<tr>
<td>$Z$-like OSSF pair</td>
<td></td>
<td></td>
<td>$</td>
<td>m_{\ell\ell} - m_Z</td>
</tr>
<tr>
<td>$n_{jets}$</td>
<td>≥ 4</td>
<td>3</td>
<td>≥ 4</td>
<td>≥ 2 and ≤ 4</td>
</tr>
<tr>
<td>$n_{b-jets}$</td>
<td>1</td>
<td>≥ 2</td>
<td>≥ 2</td>
<td>≥ 2</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Process</th>
<th>$t\bar{t}$ decay</th>
<th>Boson decay</th>
<th>Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}W$</td>
<td>$(\mu^+\nu b)(q\bar{q}b)$</td>
<td>$\mu^+\nu$</td>
<td>SS dimuon</td>
</tr>
<tr>
<td></td>
<td>$(\ell^+\nu b)(\ell^-\nu b)$</td>
<td>$\ell^+\nu$</td>
<td>Trilepton</td>
</tr>
<tr>
<td>$t\bar{t}Z$</td>
<td>$(\ell^+\nu b)(q\bar{q}b)$</td>
<td>$\ell^+\ell^-$</td>
<td>Trilepton</td>
</tr>
<tr>
<td></td>
<td>$(\ell^-\nu b)(\ell^+\nu b)$</td>
<td>$\ell^+\ell^-$</td>
<td>Tetralepton</td>
</tr>
</tbody>
</table>

| Region | $Z_2$ leptons | $p_{T34}$ | $|m_{Z_2} - m_Z|$ | $E_T^{\text{miss}}$ | $n_b$-tags |
|--------|---------------|----------|-----------------|-----------------|-----------|
| 4$\ell$-DF-1b | $e^\pm \mu^\mp$ | > 35 GeV | - | - | 1 |
| 4$\ell$-DF-2b | $e^\pm \mu^\mp$ | - | - | - | $\geq 2$ |
| 4$\ell$-SF-1b | $e^\pm e^\pm, \mu^\pm \mu^\mp$ | > 25 GeV | $\begin{cases} > 10 \text{ GeV} \\
< 10 \text{ GeV}
\end{cases}$ | $\begin{cases} > 40 \text{ GeV} \\
> 80 \text{ GeV}
\end{cases}$ | 1 |
| 4$\ell$-SF-2b | $e^\pm e^\pm, \mu^\pm \mu^\mp$ | - | $\begin{cases} > 10 \text{ GeV} \\
< 10 \text{ GeV}
\end{cases}$ | $\begin{cases} - \\
> 40 \text{ GeV}
\end{cases}$ | $\geq 2$ |
Current of Status
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’.

<table>
<thead>
<tr>
<th>Region</th>
<th>$t + X$</th>
<th>Bosons</th>
<th>Fake leptons</th>
<th>Total bkg.</th>
<th>$t\bar{t}W$</th>
<th>$t\bar{t}Z$</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>2+$\mu$-SS</td>
<td>0.94 ± 0.08</td>
<td>0.12 ± 0.05</td>
<td>1.5 ± 1.3</td>
<td>2.5 ± 1.3</td>
<td>2.32 ± 0.33</td>
<td>0.70 ± 0.10</td>
<td>33</td>
</tr>
<tr>
<td>3+$ell$-Z-2b4j</td>
<td>1.08 ± 0.25</td>
<td>0.5 ± 0.4</td>
<td>&lt; 0.001</td>
<td>1.6 ± 0.5</td>
<td>0.065 ± 0.013</td>
<td>5.5 ± 0.7</td>
<td>8</td>
</tr>
<tr>
<td>3+$ell$-1b4j</td>
<td>1.14 ± 0.24</td>
<td>3.3 ± 2.2</td>
<td>2.2 ± 1.7</td>
<td>6.7 ± 2.8</td>
<td>0.036 ± 0.011</td>
<td>4.3 ± 0.6</td>
<td>7</td>
</tr>
<tr>
<td>3+$ell$-Z-2b3j</td>
<td>0.58 ± 0.19</td>
<td>0.22 ± 0.18</td>
<td>&lt; 0.001</td>
<td>0.80 ± 0.26</td>
<td>0.083 ± 0.014</td>
<td>1.93 ± 0.28</td>
<td>4</td>
</tr>
<tr>
<td>3+$ell$-noZ-2b</td>
<td>0.95 ± 0.11</td>
<td>0.14 ± 0.12</td>
<td>3.6 ± 2.2</td>
<td>4.7 ± 2.2</td>
<td>1.59 ± 0.28</td>
<td>1.45 ± 0.20</td>
<td>10</td>
</tr>
<tr>
<td>4+$vell$-SF-1b</td>
<td>0.212 ± 0.032</td>
<td>0.09 ± 0.07</td>
<td>0.113 ± 0.022</td>
<td>0.42 ± 0.08</td>
<td>&lt; 0.001</td>
<td>0.66 ± 0.09</td>
<td>1</td>
</tr>
<tr>
<td>4+$vell$-SF-2b</td>
<td>0.121 ± 0.021</td>
<td>0.07 ± 0.06</td>
<td>0.062 ± 0.012</td>
<td>0.25 ± 0.07</td>
<td>&lt; 0.001</td>
<td>0.63 ± 0.09</td>
<td>1</td>
</tr>
<tr>
<td>4+$vell$-DF-1b</td>
<td>0.25 ± 0.04</td>
<td>0.0131 ± 0.0032</td>
<td>0.114 ± 0.019</td>
<td>0.37 ± 0.04</td>
<td>&lt; 0.001</td>
<td>0.75 ± 0.10</td>
<td>2</td>
</tr>
<tr>
<td>4+$vell$-DF-2b</td>
<td>0.16 ± 0.05</td>
<td>&lt; 0.001</td>
<td>0.063 ± 0.013</td>
<td>0.23 ± 0.05</td>
<td>&lt; 0.001</td>
<td>0.64 ± 0.09</td>
<td>1</td>
</tr>
</tbody>
</table>
## $ttW$ 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 $ttW$ 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’.

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

For $ttW$, we got 1.92, 0.0032, 0.0033, 0.057, 1.14.

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For $ttZ$, we obtained

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

**Number of jets**

![Graph showing the number of jets for different processes: $t\bar{t}$Z, tW, WZ, ZZ, Other, Fake leptons, and Uncertainty. The graph includes data from ATLAS with $\sqrt{s} = 13$ TeV and 3.2 fb$^{-1}$, with a focus on the number of jets ranging from 3 to 7.](image-url)
3ℓ-Z-1b4j, 3ℓ-Z-2b3j or 3ℓ-Z-2b4j

Number of b-tagged jets

ATLAS
\( \sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1} \)

3L-Z

- Data 2015
- t\bar{t}Z
- t\bar{t}W
- WZ
- ZZ
- Other
- Fake leptons
- Uncertainty

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

Missing ET

**ATLAS**

\( \sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1} \)

3L-Z

- Data 2015
- t\bar{t}Z
- t\bar{t}W
- WZ
- ZZ
- Other
- Fake leptons
- Uncertainty

Events / 20 GeV

\( E_T^{\text{miss}} \) [GeV]
$3\ell-Z-1b4j, \ 3\ell-Z-2b3j \ or \ 3\ell-Z-2b4j$

**PT of the third lepton**

![Graph showing the distribution of the third lepton's $p_T$](image)

*ATLAS*

$\sqrt{s} = 13$ TeV, 3.2 fb$^{-1}$

- Data 2015
- $t\bar{t}Z$
- $t\bar{t}W$
- WZ
- ZZ
- Other
- Fake leptons
- Uncertainty
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
In ATL-PHYS-PUB-2015-022,

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

Deeper Understanding b-tagging algorithm in Delphes is needed.
Thank you