# WWW Analysis with 8 TeV data on ATLAS

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# Introduction

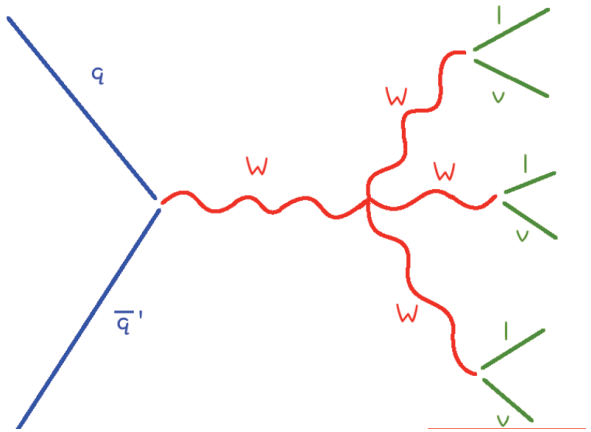
- Study WWWW vertex and HWW couplings, , first search for WWW production on ATLAS.
- Search in fully leptonic channel: cleanest signature.
- Any deviation from theoretical prediction will provide hints for new physics.
- Previous study on WWWW vertex by ssWW analysis.
- There is another WWW measurement for 2l2j final state.
- Now two analyses have been combined for one paper.

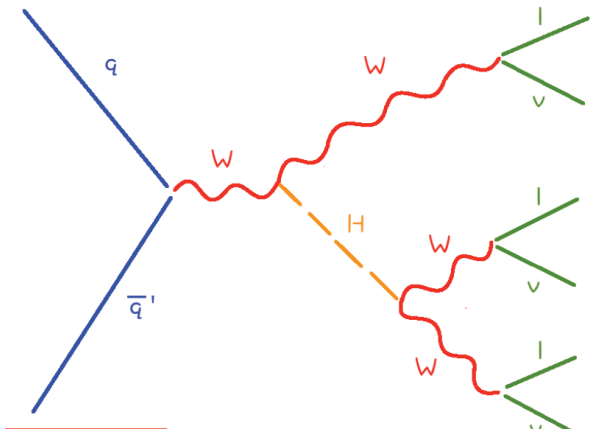
Higgs Field

$$\mathcal{L}_{S,0} = \frac{f_0}{\Lambda^4}\left[(D_\mu\Phi)^\dagger D_\nu\Phi\right] \times \left[(D^\mu\Phi)^\dagger D^\nu\Phi\right]$$

$$\mathcal{L}_{S,1} = \frac{f_1}{\Lambda^4}\left[(D_\mu\Phi)^\dagger D^\mu\Phi\right] \times \left[(D_\nu\Phi)^\dagger D^\nu\Phi\right]$$

anomalous quartic gauge coupling




| Sample | | Cross-section [fb] |
|---|---|---|
| MadGraph NLO | $W^+W^-W^+ \to$ Anything | $59.47 \pm 0.11$ |
| | $W^-W^+W^- \to$ Anything | $28.069 \pm 0.076$ |
| | $W^+H \to W^+W^+W^-(*) \to$ Anything | $99.106 \pm 0.019$ |
| | $W^-H \to W^-W^+W^-(*) \to$ Anything | $54.804 \pm 0.010$ |

# Signal and backgrounds

**WZ->lllν**
Simulated using Powheg +Pythia 8 with three lepton filter. Charge mis-id contribution determined in data.

**Fake Lepton (W,Z,WW,ttbar)**
Uses data-driven estimate via Generalized Matrix Method.

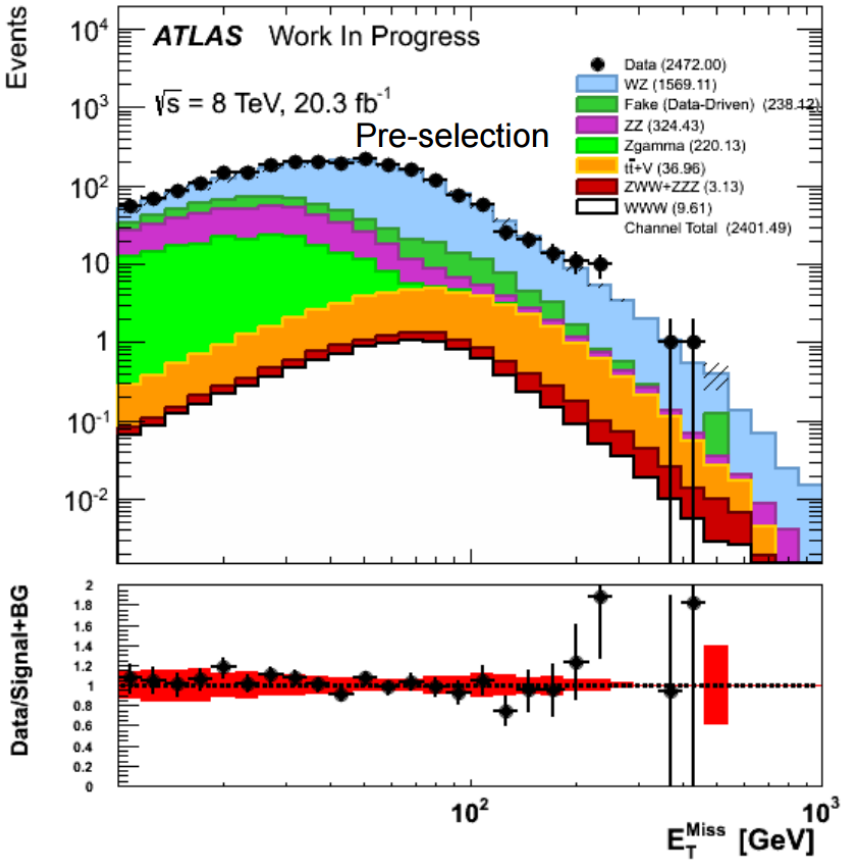
**ZZ->llll**
Estimated in same manner as WZ.

**Zgamma**
Estimated with MC using Sherpa.

**ttbarV**
Estimated from MC using Madgraph + Pythia samples.

**ZWW+ZZZ**
Estimated using Madgraph+ Pythia.

**WWW Signal**
Estimated using VBFNLO + Pythia 8.




Divide into 3 categories: 0 SFOS , 1 SFOS, 2 SFOS.
SFOS: same flavor opposite sign lepton pair.

# Electron Charge mis-Identification

- Electrons' charge can be mis-identified because of bremsstrahlung.

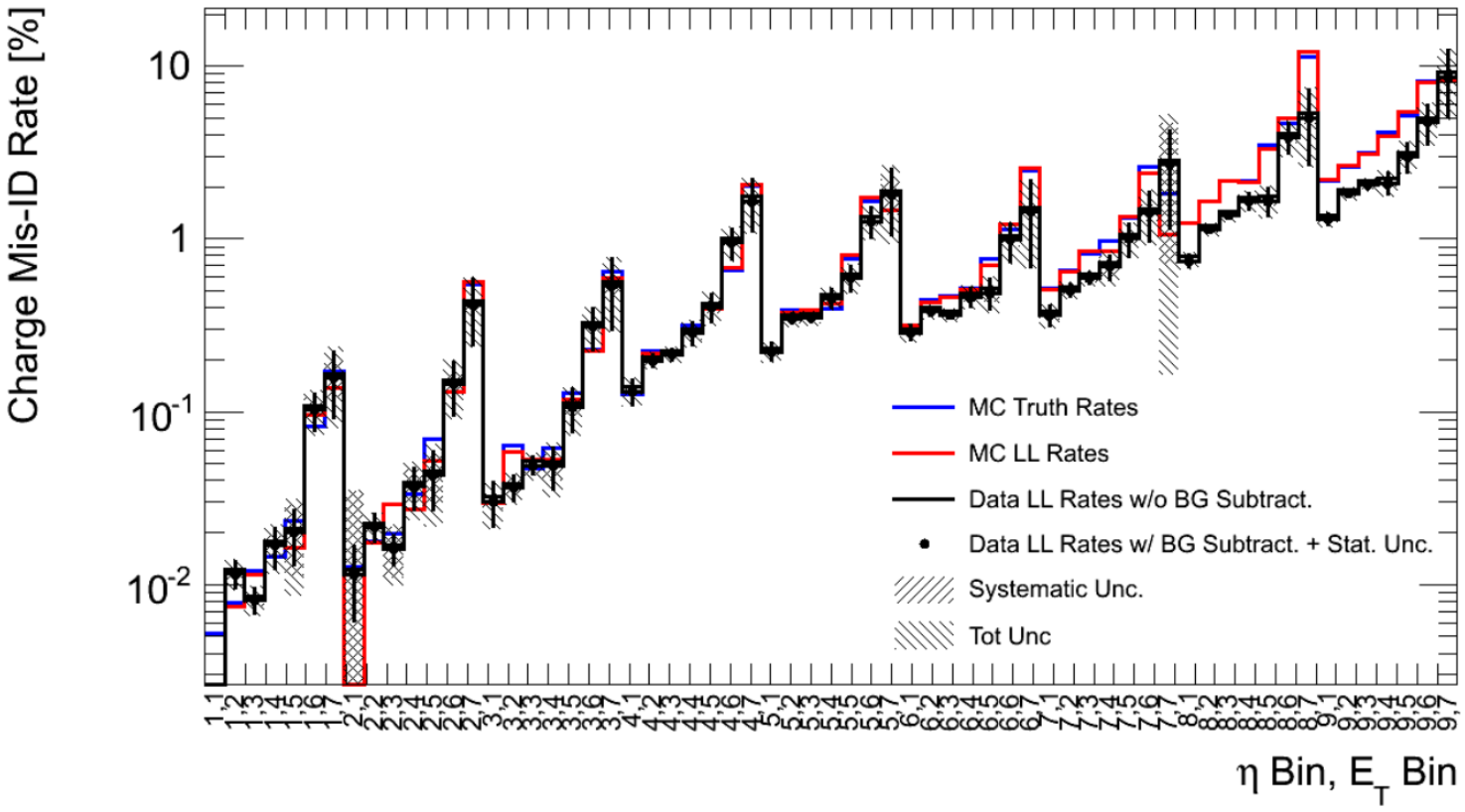
- Evaluate the mis-identified rate as a function of Pt and η.
  - Likelihood method:
    - Using Poisson probability to construct log-likelihood distribution.
    - $lnL = \sum_{i,j=1}\{N_{ss}^{i,j} \ln\left[N^{i,j}\left(\varepsilon_i + \varepsilon_j\right)\right] - N^{i,j}(\varepsilon_i + \varepsilon_j)\}$
    - Nss: number of events in data around Zee peak with same sign pairs.
    - N: number of total events.
    - $\varepsilon_i$ and $\varepsilon_j$ are the probabilities of charge misID for the two electrons in the i-th and j-th bin respectively.
    - Maximize log-likelihood to extract rates.
  - Compare reconstructed electron charge to its truth charge as cross check.

- Background subtraction performed using template fit.

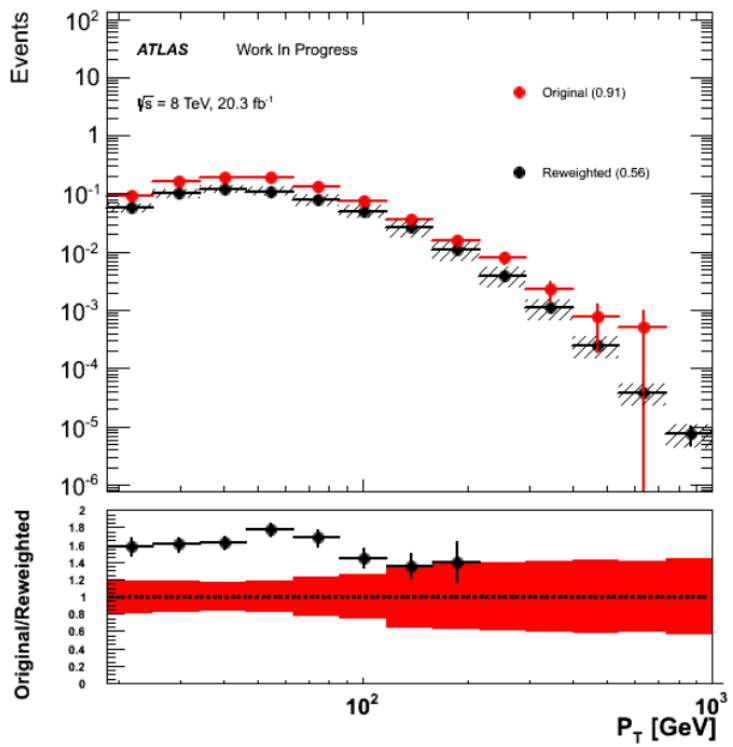
- Use the data-driven rates to reweight di-boson MC in 0SFOS region.

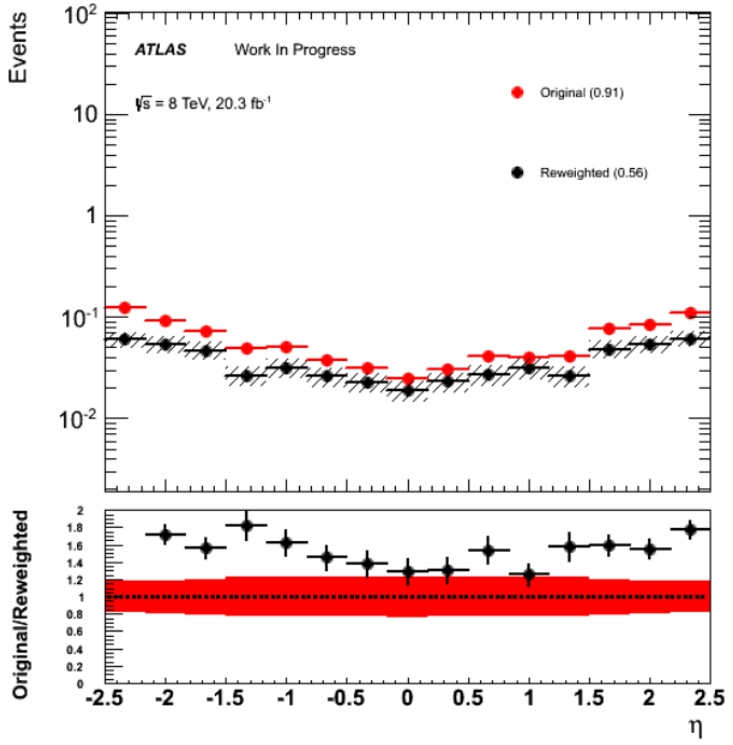
# Rate and systematic

- MC based cross check ok.
- Difference between truth and likelihood in MC used as systematic.
- Effect of background in data used as another systematic.



# Electron’s charge mis-id

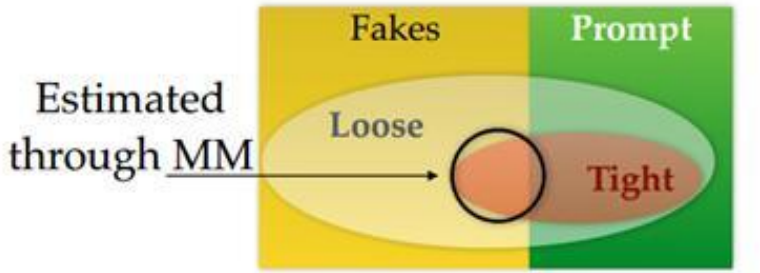



- Difference is covered partially by the systematic uncertainties of the method.
- Remaining difference could be expected from the difference in rates observed at high η and high ET and serves as justification for using the data-driven method.

# Fake lepton background

- Use data driven method(Matrix Method) to estimate fake lepton backgrounds.

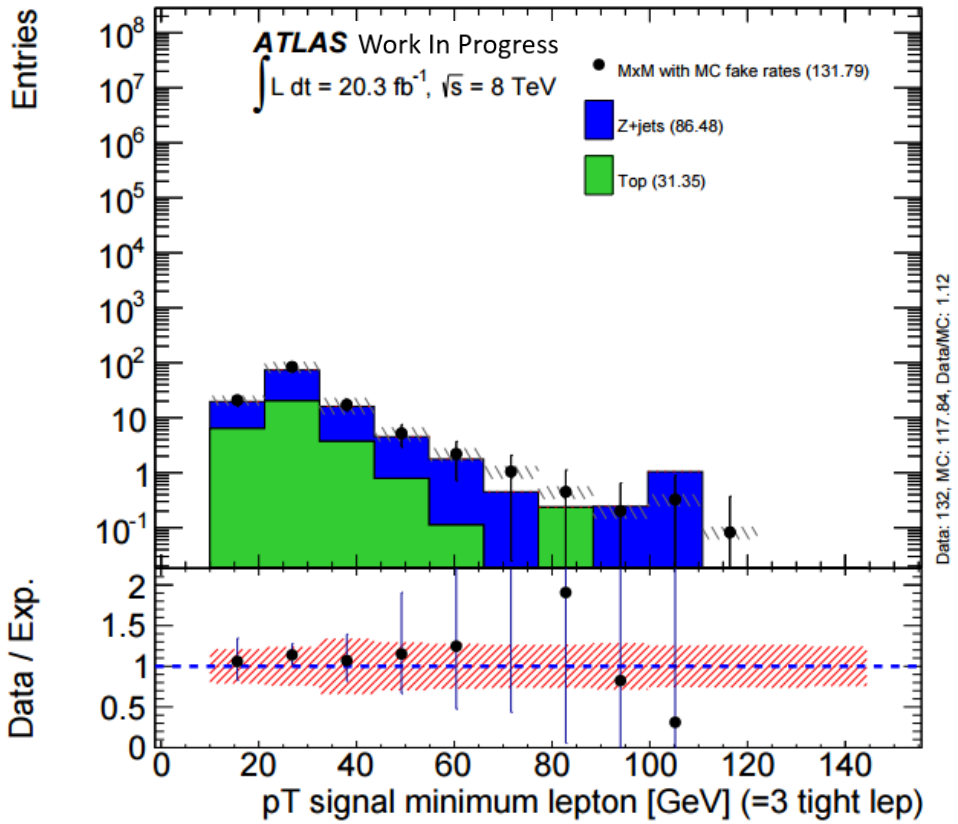


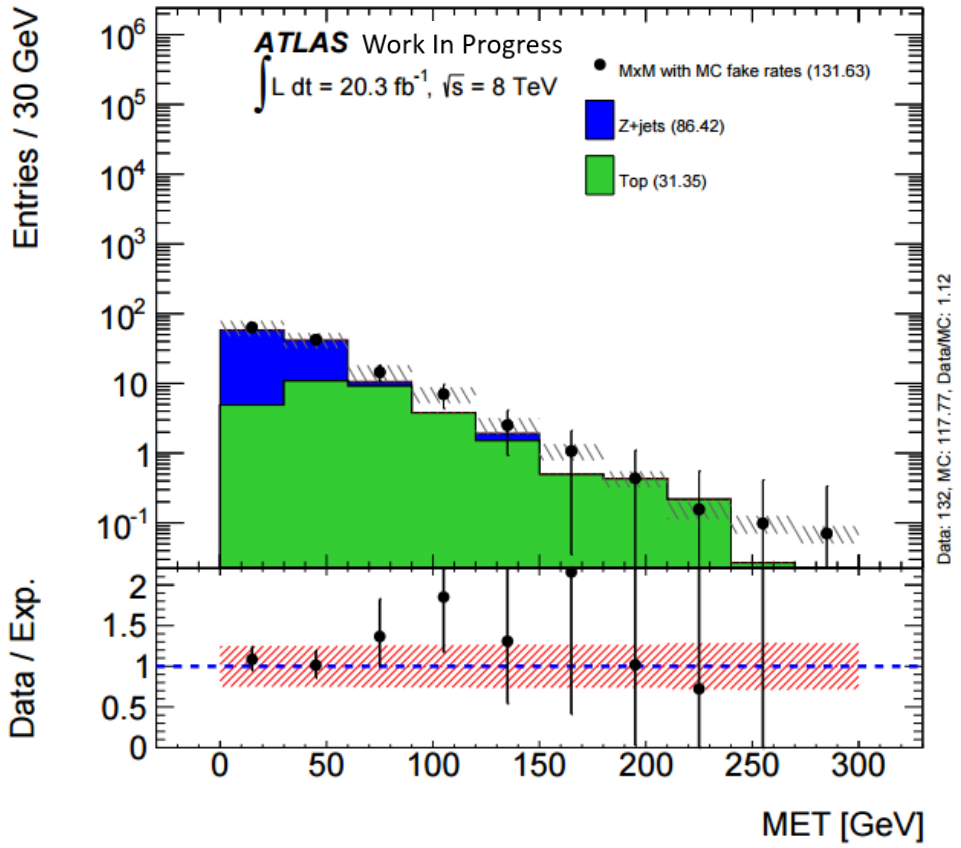

*4x4* Matrix in the 2 lepton case, *8x8* in the 3lep case

$$\begin{pmatrix} N_{tt} \\ N_{t\bar{t}} \\ N_{\bar{t}t} \\ N_{\bar{t}\bar{t}} \end{pmatrix} = M \begin{pmatrix} N^{ll}_{rr} \\ N^{ll}_{rf} \\ N^{ll}_{fr} \\ N^{ll}_{ff} \end{pmatrix}$$

- Matrix is made up of probabilities of fake lepton.
- The probabilities are calculated separately for electrons and muons.
- Probabilities along with numbers of events selected, are used to estimate the background in signal region.

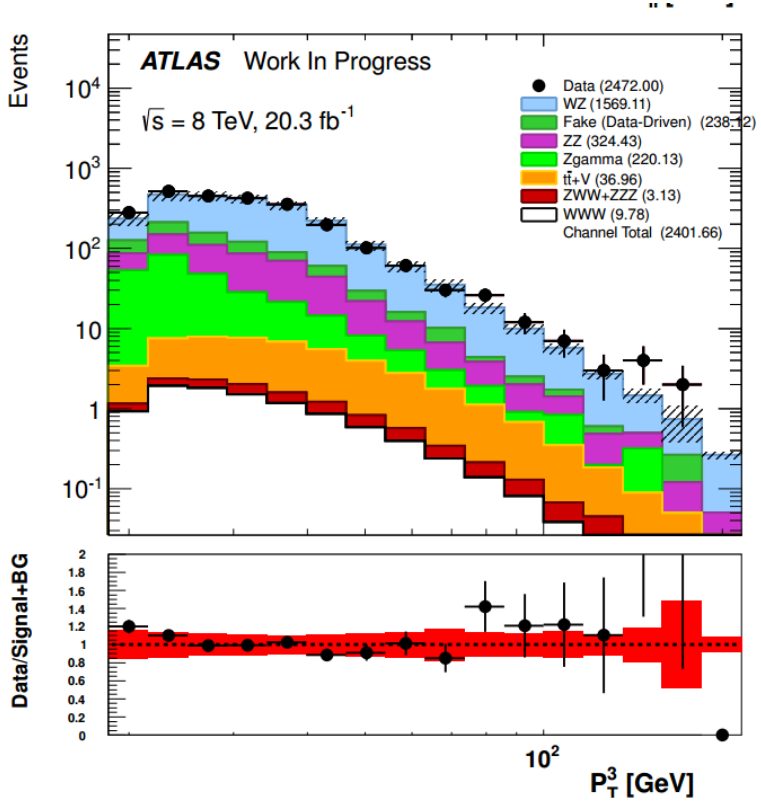
# Fake rates

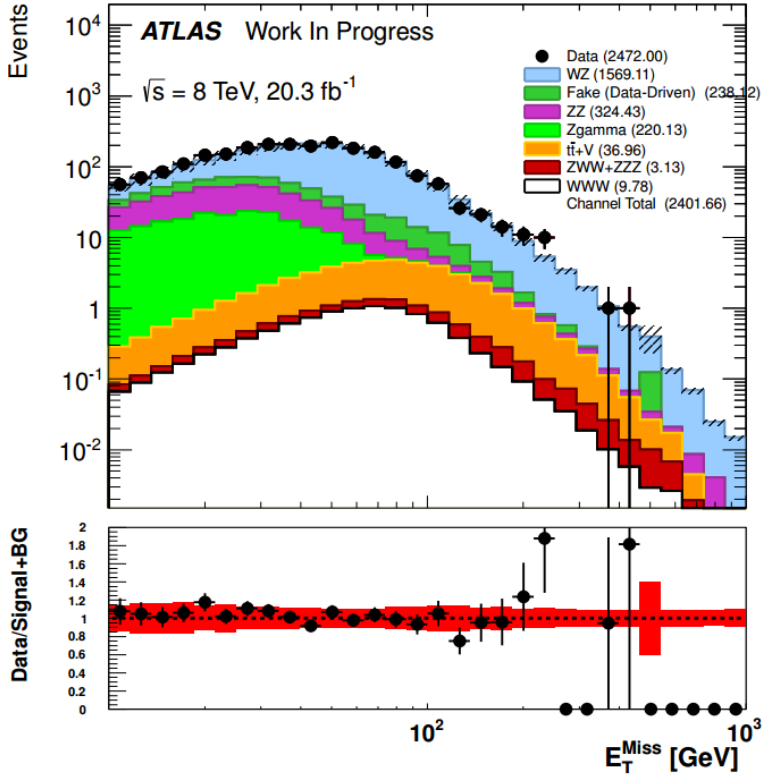


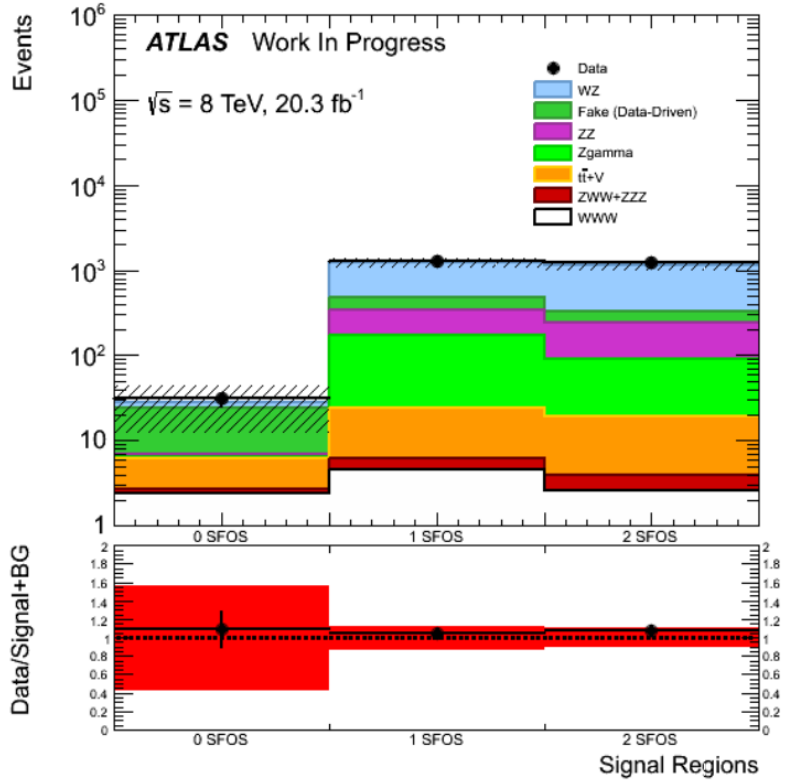




- Good agreement observed.

# Estimate at pre-selection



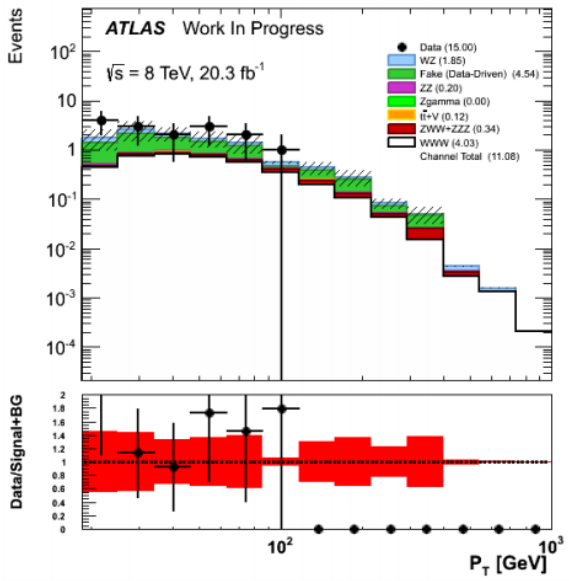

- Backgrounds are well estimated.

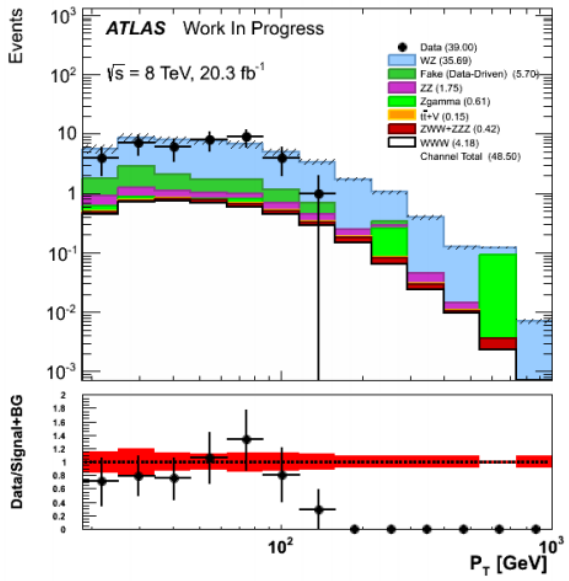
# Selection for signal region

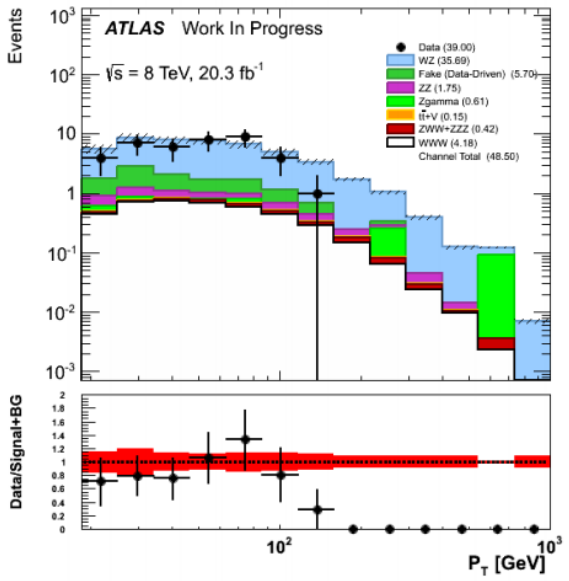
| | 0 SFOS | 1 SFOS | 2 SFOS |
|---|---|---|---|
| Pre-selection | Exactly 3 leptons with $P_T > 20$ GeV where at least one is trigger matched. (See Section 6.1) | | |
| b-tagged Jet Veto | $N_{b-jet} = 0$ (85 % b-tagging efficiency) | | |
| Same-Flavor Mass | $m_{SF} > 20$ GeV | | |
| Z-Veto ($m_Z = 91.1876$ GeV) | $\lvert m_{ee} - m_Z \rvert > 15$ GeV | No $m_{SFOS}$ with $m_Z - 35\text{GeV} < m_{SFOS} < m_Z + 20$ GeV | $\lvert m_{SFOS} - m_Z \rvert > 20$ GeV |
| Missing $E_T$ | | $E_T^{Miss} > 45$ GeV | $E_T^{Miss} > 55$ GeV |
| Lepton-Missing $E_T$ Angle | $\lvert \phi(3l) - \phi(E_T^{Miss}) \rvert > 2.5$ | | |
| Inclusive Jet veto | $N_{jet} \leq 1$ | | |

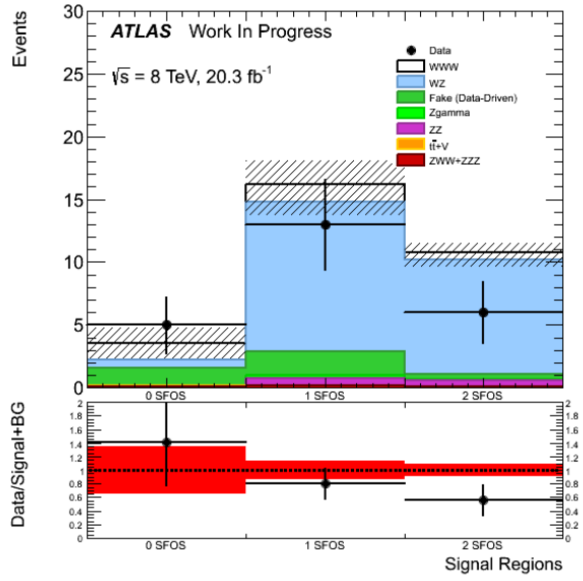
Table 15: Optimized signal selection split by number of Same-Flavor Opposite-Sign (SFOS) lepton pairs.

# Signal Region




- Agreement between data and signal plus background estimation is good.

# Cross section and aQGC limits

- The discovery significance is tested using frequentist statistics with the background only hypothesis.
- The measurement is evaluated by using the shape of the profile likelihood ratio.
- The likelihood used is constructed as follow:

$$L(\mu, \boldsymbol{\theta}) = \mathrm{Gaus}(\mathcal{L}; \mathcal{L}_0, \Delta_{\mathcal{L}}) \prod_{i \in \mathrm{Chan}} \mathrm{Pois}(N_i^{obs} | N_i^{exp}(\mu, \boldsymbol{\theta})) \prod_{j \in \mathrm{Sys}} \mathrm{Gaus}(\theta_j; \theta_j^0, 1)$$

- Combine the channels of both analyses to get the best possible measurement.
  - Full leptonic and semi-leptonic analysis.
- Cross section measured and now is under ATLAS internal review.

- No significant excess is observed, set limits on the anomalous quartic gauge coupling parameter.
- Limit on aQGC obtained and now is under ATLAS internal review.

# Summary

- The WWW production is measured for the first time.
- Results being reviewed for publication.