Fake Background estimation in $W^{\pm}Z$ diboson production

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ΑΡΙΣΤΟΤΕΛΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΟΝΙΚΗΣ

Ευρωπαϊκή Ένωση
European Social Fund

Operational Programme
Human Resources Development, Education and Lifelong Learning
Co-financed by Greece and the European Union

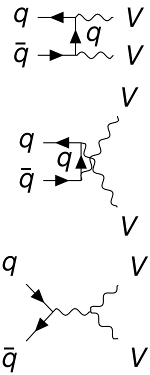
ΕΣΠΑ 2014-2020

June 18, 2021

Motivation

- Motivation for Diboson Processes:
  - EWSB probe at TeV scale
  - Sensitive to aTGCs / aQGCs
  - Polarization

Diboson Production (LO)



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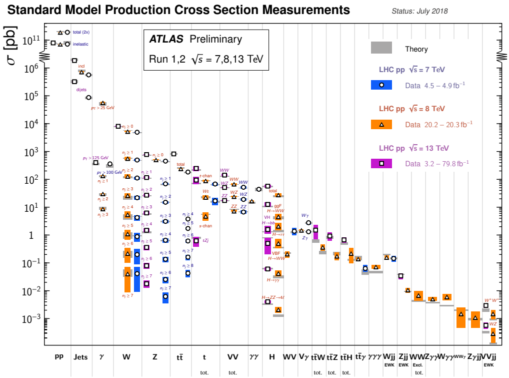
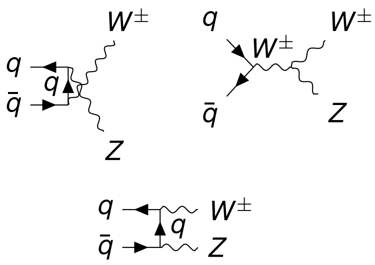


Motivation

- Motivation for Diboson Processes:
  - EWSB probe at TeV scale
  - Sensitive to aTGCs / aQGCs
  - Polarization
- and especially $W^{\pm}Z$:
  - $\frac{\sigma_{W^+Z}}{\sigma_{W^-Z}}$
  - NLO & NNLO corrections (1604.08576)

$W^{\pm}Z$ Production (LO)



$\sqrt{s}$	σ_{LO} [pb]	σ_{NLO} [pb]	σ_{NNLO} [pb]	$\sigma_{\text{NLO}}/\sigma_{\text{LO}}$	$\sigma_{\text{NNLO}}/\sigma_{\text{NLO}}$
7	$11.354(1)\,^{+0.5\%}_{-1.2\%}$	$18.500(1)\,^{+5.3\%}_{-4.1\%}$	$19.973(13)\,^{+1.7\%}_{-1.9\%}$	+62.9%	+ 8.0%
8	$13.654(1)\,^{+1.3\%}_{-2.1\%}$	$22.750(2)\,^{+5.1\%}_{-3.9\%}$	$24.690(16)\,^{+1.8\%}_{-1.9\%}$	+66.6%	+ 8.5%
13	$25.517(2)\,^{+4.3\%}_{-5.3\%}$	$46.068(3)\,^{+4.9\%}_{-3.9\%}$	$51.11(3)\,^{+2.2\%}_{-2.0\%}$	+80.5%	+10.9%
14	$27.933(2)\,^{+4.7\%}_{-5.7\%}$	$51.038(3)\,^{+5.0\%}_{-4.0\%}$	$56.85(3)\,^{+2.3\%}_{-2.0\%}$	+82.7%	+11.4%

Table 1: Total on-shell $W^{\pm}Z$ cross sections at LO, NLO and NNLO for relevant collider energ
the last two columns contain the relative corrections at NLO and NNLO, respectively.

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$W^{\pm}Z$ **Inclusive Event Selection**

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Event Cleaning	Reject LAr, Tile and SCT corrupted / incomplete events
Trigger and Vertex	Hard scattering vertex with $N_{\text{Tracks}} \geq 2$ Event must fire e/μ HLT

Event Selection

- $lll\nu$ signature

  3 sets of lepton selection cuts:

  - **Baseline:** $p_T > 5$ GeV, basic quality & isolation, overlap removal with other leptons etc.
  - **Z-type:** $p_T > 15$ GeV, better quality & isolation, OLR with selected jets etc.
  - **W-type:** $p_T > 20$ GeV, tighter quality criteria and stricter isolation

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Leading p_T	$p_T^{\text{lead}} > 27$ GeV (25 GeV for data / MC from 2015)

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Z Mass Window	$\lvert M_{ll} - M_Z \rvert < 10$ GeV
$W^{\pm}$ lepton	Remaining lepton passes $W^{\pm}$ selection
$W^{\pm}$ Transverse Mass	$m_T^W > 30$ GeV

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Reducible - $\geq$ 1 fake FS lepton

1. Heavy / Light flavour jets mis-identified as leptons
2. Leptons (electrons) from photon conversion

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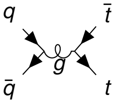
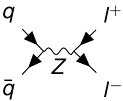
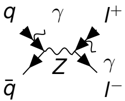
$t\bar{t}$



Z+jets



$Z\gamma$



Matrix Method for Background Estimation

→ The Matrix Method (MM) is a way to estimate the contribution of background processes to the SR without relying on Monte Carlo simulation.

→ Background processes may not be accurately modeled by existing software
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Toy single Bkg. Case

- Assuming SR selection C, expect: $\nu(C)$ events in total
- Substitute the selection efficiency

$$\nu(C) = \epsilon_C \nu_S + \epsilon_{C,B} \nu_B$$

- Create selection D targeting B:

$$\nu_{\text{sel}}(C) = \epsilon_C \nu_S + \epsilon_{C,B} \nu_B$$
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- In $W^{\pm}Z$ production, any of the leptons assigned to the W or the Z can be a fake. **Notation**: N_{RFR} denotes the number of events with a real lepton assigned to the W and the trailing Z-lepton, while the leading Z-lepton is fake

Matrix Method in $W^{\pm}Z$ production

1. Loose SR: Loosen the selection $\rightarrow$ enhance fakes

Electrons	Muons
$p_T > 15$ GeV	$p_T > 15$ GeV
$\|\eta\| < 2.47$	$\eta < 2.7$
$!(1.37 < \|\eta\| < 1.52)$	-
pass `Loose` LH ID	`Medium` LH ID
$\|d_0^{BL}/\sigma(d_0^{BL}) < 5$	$\|d_0^{BL}/\sigma(d_0^{BL}) < 3$ (if $\eta < 2.5$)
z0 <0.5	z0 <0.5 (if $\eta < 2.5$)

+ !isolation and/or !identification = Loose

- Loose lepton set disjoint from tight (SR) selection set

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2. Express selection combinations

$$
\begin{pmatrix} N_{TTT} \\ N_{TTL} \\ N_{TLT} \\ N_{LTT} \\ N_{TLL} \\ N_{LTL} \\ N_{LLT} \end{pmatrix}
=
\begin{pmatrix}
e_1 e_2 e_3 & e_1 e_2 f_3 & e_1 f_2 e_3 & f_1 e_2 e_3 & e_1 f_2 f_3 & f_1 e_2 f_3 & f_1 f_2 e_3 \\
e_1 e_2 \bar{e}_3 & e_1 e_2 \bar{f}_3 & e_1 f_2 \bar{e}_3 & f_1 e_2 \bar{e}_3 & e_1 f_2 \bar{f}_3 & f_1 e_2 \bar{f}_3 & f_1 f_2 \bar{e}_3 \\
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\end{pmatrix} \begin{pmatrix} N_{RRR} \\ N_{RRF} \\ N_{RFR} \\ N_{FRR} \\ N_{RFF} \\ N_{FRF} \\ N_{FFR} \end{pmatrix}$$

- Select real as tight $\rightarrow e$
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3. Matrix Method N_{fake} estimate equation

$$N_{fake} = N^{red}_{TTL} F_Z + N^{red}_{TLT} F_Z + N^{red}_{LTT} F_W - N^{red}_{TLL} F_Z F_Z - N^{red}_{LTL} F_W F_Z - N^{red}_{LTL} F_W F_Z - N^{red}_{LLT} F_W F_Z$$

$\uparrow$ Define Fake Factors $F_{Z/W} = \frac{f}{\bar{f}} = \frac{N_{\mathrm{T}}}{N_{!\mathrm{T}}}$

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Strategy

1. 3 sources of reducible background → 3 FFs
2. CR rich in non-prompt leptons → Fake Factor
3. A value combining 3 FFs is substituted in (3) to estimate N_{fake}

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↑ Define Fake Factors $F_{Z/W} = \frac{f}{\bar{f}} = \frac{N_{\mathrm{T}}}{N_{!\mathrm{T}}}$

Control Regions

- ***Z*+jets:** Create *Z*-pair by selecting 2 likely prompt leptons and a non-isolated lepton

≥ 2 *Z*-type leptons, same-flavour and opposite charge (e^+e^- or $\mu^+\mu^-$)	
$\lvert m_{ll} - m_Z^{PDG} < 15 \rvert$ GeV	
fake lepton is highest-p_{T} Matrix Method lepton	
fake electron	**fake muon**
$m_{\mathrm{T}}^W < 30$ GeV	$m_{\mathrm{T}}^W < 30$ GeV
$E_T^{miss} < 30$ GeV	-
$m_{ll} > 81$ GeV	-

- ***t$\bar{t}$* :** Select two likely prompt leptons from $t \to Wb$, while avoiding SFOC pairs.

≥ 1 *Z*-type electron e_Z
≥ 1 *Z*-type muon μ_Z
charge(μ_Z) $\cdot$ charge(e_Z) < 0
remaining highest-p_{T} Matrix Method lepton $\equiv$ fake lepton ℓ_m
lepton with different flavour than fake lepton passes *W*-lepton requirements: ℓ_W
charge(ℓ_m) $\cdot$ charge(ℓ_W) > 0

- ***Zγ* :** Similar to *Z*+jets CR, however use m_{ll} window below M_Z and an m_{3l} cut.

≥ 2 *Z*-type muons, opposite charge ($\mu^+\mu^-$)
$55 < m_{ll} < 85$ GeV
$m_{3l} < 105$ GeV
fake lepton is highest-p_{T} Matrix Method electron
$m_{\mathrm{T}}^W < 30$ GeV
$E_T^{miss} < 30$ GeV

Fake Factors for $t\bar{t}$ / Z+jets / $Z\gamma$

$$\mathrm{FF_{Data}} = \frac{N_{T,\text{ Data}} - N_{T,\text{RL\&ND } t\bar{t}/Z+\text{jets}/Z\gamma} - N_{T,\text{ Irr. MC}}}{N_{!T,\text{ Data}} - N_{!T,\text{RL\&ND } t\bar{t}/Z+\text{jets}/Z\gamma} - N_{!T,\text{ Irr. MC}}}$$

$$\mathrm{FF_{MC}} = \frac{N_{T,\ t\bar{t}/Z+\text{jets}/Z\gamma} - N_{T,\text{RL\&ND } t\bar{t}/Z+\text{jets}/Z\gamma}}{N_{!T,\ t\bar{t}/Z+\text{jets}/Z\gamma} - N_{!T,\text{RL\&ND } t\bar{t}/Z+\text{jets}/Z\gamma}}$$

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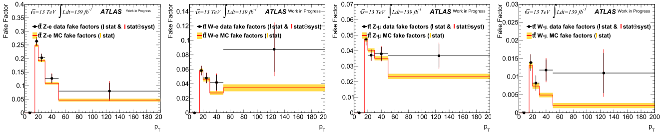
- **data fake factors (stat & stat⊕syst)**
- **MC fake factors (stat)**

$t\bar{t}$



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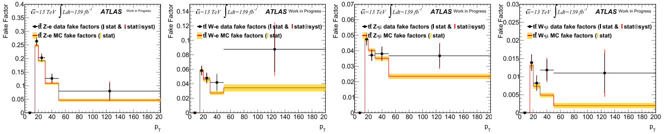
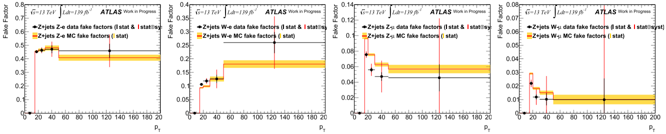
$$\mathrm{FF}_{\mathrm{Data}} = \frac{N_{T,\,\mathrm{Data}} - N_{T,\mathrm{RL\&ND}\ t\bar{t}/Z+\mathrm{jets}/Z\gamma} - N_{T,\,\mathrm{Irr.\ MC}}}{N_{!T,\,\mathrm{Data}} - N_{!T,\mathrm{RL\&ND}\ t\bar{t}/Z+\mathrm{jets}/Z\gamma} - N_{!T,\,\mathrm{Irr.\ MC}}}$$

- data fake factors (stat & stat⊕syst)
- MC fake factors (stat)

$t\bar{t}$



Z+jets



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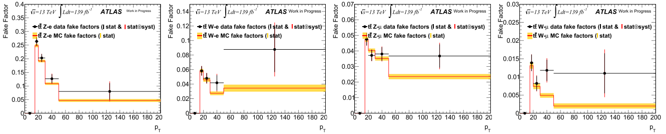
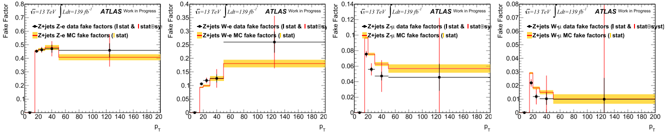
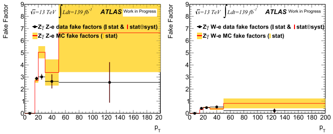


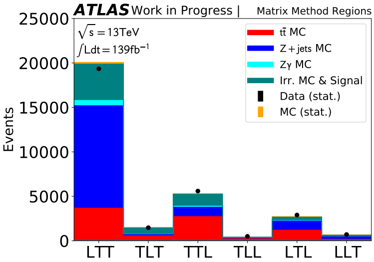
Z+jets



$Z\gamma$



Expected Composition of Loose SR



← Z+jets fake background contribution is dominant, followed by $t\bar{t}$

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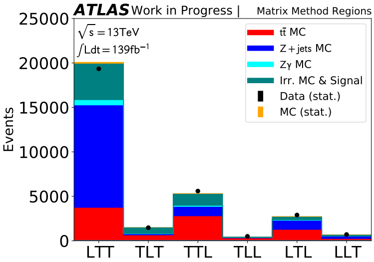

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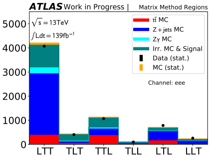
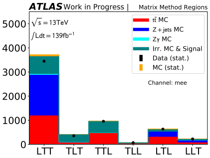
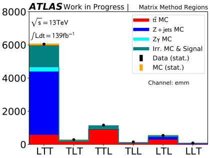
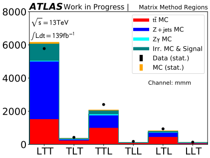
↓ Composition of Loose SR, per leptonic channel



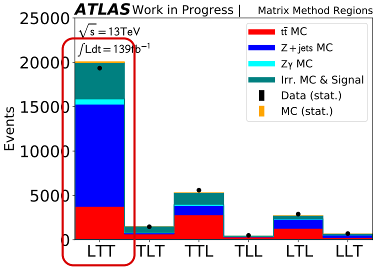






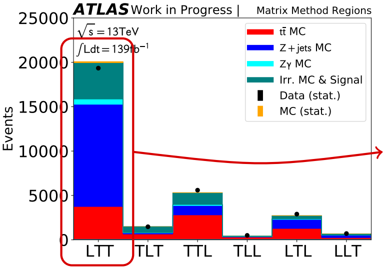
Composition-Weighted Average

- Utilize MC-based composition information



Composition-Weighted Average

- Utilize MC-based composition information
- in combining 3 Fake Factors



Average Fake Factors with Exp. Composition

Combined $FF =$

$FF_{Z+\text{jets}} \times (\%\, Z + \text{jets})$
$+FF_{Z\gamma} \times (\%\, Z\gamma)$
$+FF_{t\bar{t}} \times (\%\, t\bar{t})$

Composition-Weighted Average

- Utilize MC-based composition information
- in combining 3 Fake Factors

In the end:

→ 1 combined FF per Loose SR region

- FF_{LTT}, FF_{TLT} etc.

Average Fake Factors with Exp. Composition

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$|\eta|$-Dependence

- Ideally: Fake Factors calculated in 2-D bins of $p_{\mathrm{T}} - \eta$

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- Ideally: Fake Factors calculated in 2-D bins of $p_T - \eta$
- Alternatively: η-dependent correction on FF

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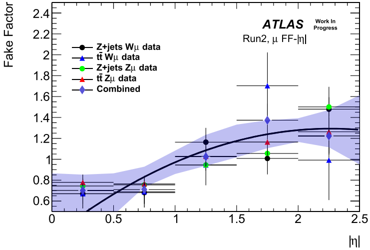

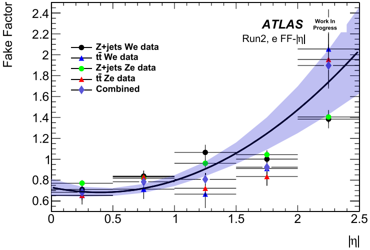

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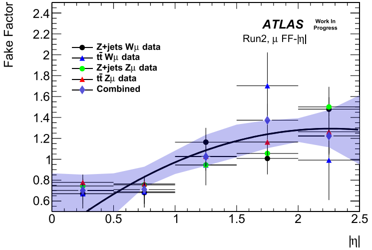

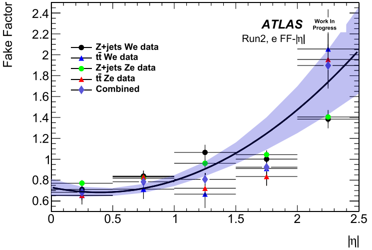

$\rightarrow$ Combined points from weighted average of data FFs of Z+jets and $t\bar{t}$, weights are the respective statistical errors

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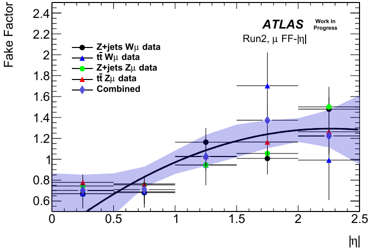

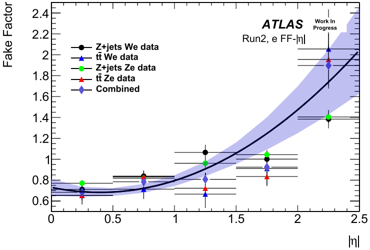

→ Combined points from weighted average of data FFs of Z+jets and $t\bar{t}$, weights are the respective statistical errors

→ Fit combined points with $y = ax^2 + bx + c$

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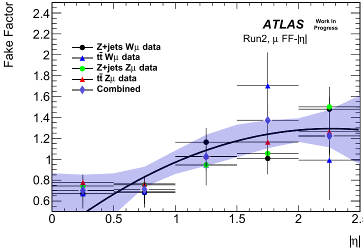

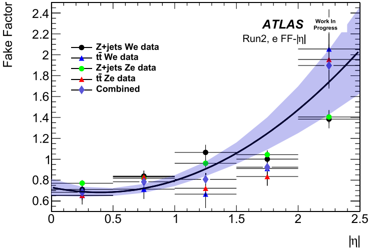

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1σ error band used to evaluate the systematic uncertainty of this correction

Systematics

Breakdown

Source	*eee*	μee	$e\mu\mu$	$\mu\mu\mu$	All
Relative uncertainties [%]					

Systematics

1. Statistical Uncertainties of the FFs
   0.5% to 4%

Breakdown

Source	eee	μee	$e\mu\mu$	$\mu\mu\mu$	All
Relative uncertainties [%]					
F_W muon	0.00	2.95	0.00	4.36	0.55
F_Z muon	0.00	0.00	0.32	2.31	0.31
F_W electron	3.18	0.00	5.29	0.00	3.56
F_Z electron	2.75	3.46	0.00	0.00	1.27

Systematics

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2. 15% cross-section uncertainty in Irreducible Subtraction in CR and SR
   17% (35% in $\mu\mu\mu$)

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   9% for electron fakes
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Correlated η correction (e)	9.70	8.14	9.89	0.00	8.87
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   17% (35% in $\mu\mu\mu$)
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   9% for electron fakes
   1% for muon fakes
4. Uncertainty assigned to Weighted Average
   $\rightarrow$ Expected Composition: 6.5%
   Vary expected reducible background yields by their statistical uncertainty

Breakdown

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Correlated η correction (μ)	0.00	1.90	0.58	10.24	1.21
W. Average Stat. Uncertainty	6.27	12.89	5.29	13.97	6.48
Total sys.	18.85	30.82	21.38	39.90	20.99
Stat.	2.88	5.48	1.78	1.66	1.52
Total	19.07	31.30	21.45	39.94	21.05
Absolute uncertainties					
Total	150.49	35.68	155.19	58.68	373.30

Multivariate per-event Weighted Average

- Idea: Utilize data-driven composition of Fake Background in W.A.

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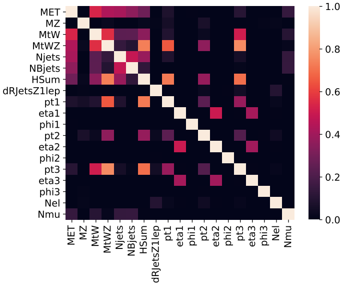

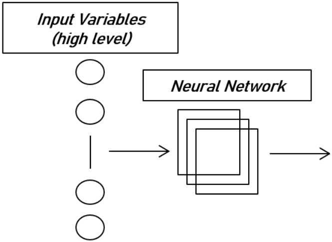

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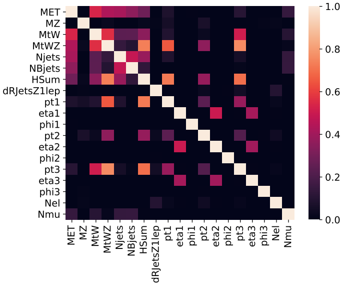

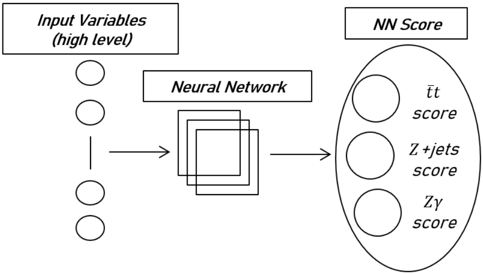

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Average Fake Factors with NN Score

$$\text{Combined } FF = FF_{Z+\text{jets}} \times (Z + \text{jets NN score}) + FF_{Z\gamma} \times (Z\gamma \text{ NN score}) + FF_{t\bar{t}} \times (t\bar{t} \text{ NN score})$$

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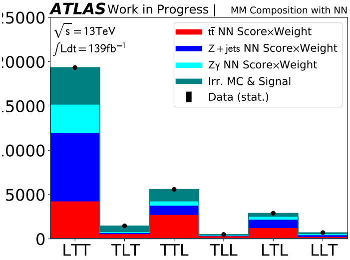

- The per-event NN score triplet can be used to provide a data-driven Reducible Background composition.

Performance of trained Classifiers

Train-Test N_{events} $(80 - 20)$

	Z+jets	$Z\gamma$	$t\bar{t}$
Train	41766	2988	47756
Test	10442	747	11939
Val.	13052	934	14924

NN Architecture

Num. Layers	Nodes	Drop-out	Batch Size
2	256	40%	1024

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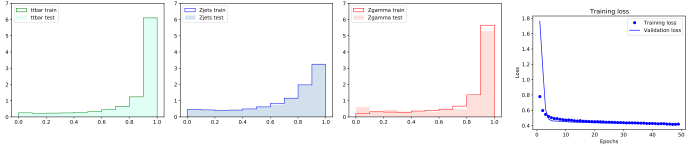
Train-Test set performance

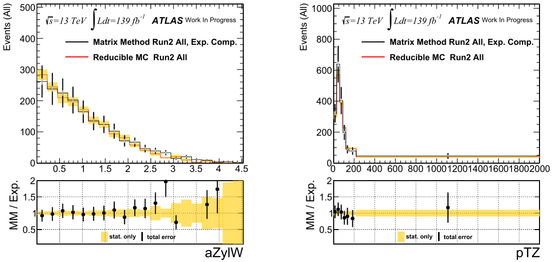


- Train-test distributions indicate smooth learning
- Z+jets train-test curves flatter than $t\bar{t}$ / $Z\gamma$

  Z+jets mis-classification as $Z\gamma$ leads to larger estimates, due to large $Z\gamma$ FF values contributing through the $Z\gamma$ score

Results - Using Expected Composition

Exp. Composition FF Weighted Average



← Comparison of distribution of $|y_Z - y_{lW}|$ and p_{TZ} with Expected Reducible MC, scaled with MC Scale Factors

Shown are MM stat. errors, MM total errors and MC stat. errors

Results - Using Expected Composition

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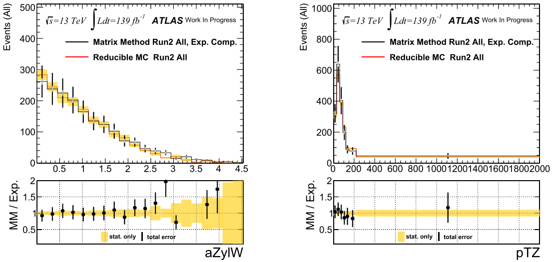


← Comparison of distribution of $|y_Z - y_{lW}|$ and p_{TZ} with Expected Reducible MC, scaled with MC Scale Factors

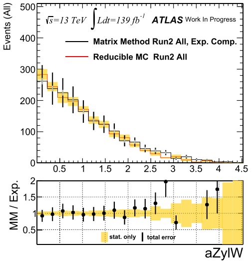
Shown are MM stat. errors, MM total errors and MC stat. errors

↓ Break-down of the result, localizing to each lepton channel.

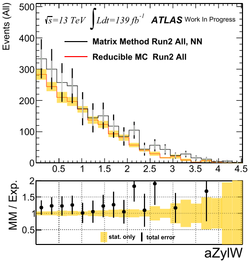
Source	eee	μee	$e\mu\mu$	$\mu\mu\mu$	All
$N_{LTT} \cdot F_W$	$478.3 \pm 11.0 \pm 108.9$	$23.8 \pm 0.6 \pm 26.7$	$683.5 \pm 12.8 \pm 153.2$	$44.3 \pm 0.8 \pm 43.8$	$1230.0 \pm 16.9 \pm 321.1$
$N_{TLT} \cdot F_Z$	$87.7 \pm 13.1 \pm 36.1$	$5.2 \pm 2.2 \pm 5.5$	$7.8 \pm 0.6 \pm 1.7$	$12.4 \pm 0.7 \pm 11.1$	$113.1 \pm 13.3 \pm 43.5$
$N_{TTL} \cdot F_Z$	$282.5 \pm 14.7 \pm 56.0$	$87.6 \pm 5.8 \pm 15.9$	$34.3 \pm 1.3 \pm 4.5$	$90.8 \pm 2.2 \pm 14.1$	$495.3 \pm 16.0 \pm 75.2$
-2L Terms	$-59.3 \pm 2.8 \pm 20.1$	$-2.7 \pm 0.2 \pm 1.7$	$-2.2 \pm 0.1 \pm 0.8$	$-0.6 \pm 0.0 \pm 0.4$	$-64.8 \pm 2.8 \pm 22.5$
Matrix Method result	$789.24 \pm 22.72 \pm 148.77$	$113.99 \pm 6.25 \pm 35.13$	$723.53 \pm 12.87 \pm 154.66$	$146.92 \pm 2.44 \pm 58.62$	$1773.68 \pm 26.96 \pm 372.33$
($t\bar{t}$ + Z+jets + $Z\gamma$) MC × SF	565.80 ± 25.70	198.00 ± 6.60	695.50 ± 31.60	270.60 ± 9.20	1730.00 ± 42.30

Comparison of results - Expected Comp. FF vs NN Score FF

Exp. Composition FF Weighted Average



NN Score FF Weighted Average



- NNscore combined FF is in general larger $\leftrightarrow$ contribution from large $Z\gamma$ FF values
- Larger total errors with NN, despite no systematic from Expected Composition

$$\text{Uncertainty due to limited Loose SR statistics} \leftarrow \sqrt{\sum_i (w_i \times \text{FF}_i)^2}$$

- All-channel estimate still within error, per-channel discrepancies remain

Summary

- Two methods for estimating the background of the $W^{\pm}Z \rightarrow l\bar{l}l'\nu_{l'}$ analysis using the Matrix Method
  - Fake Factors are defined for 3 CRs and their combination is substituted in the Matrix Method equation for Loose SR events
  - The Fake Factors are combined with a weighted average using: either the Expected Composition of the Reducible Background or a Multivariate Classifier's scores

- Future Investigation
  - Investigation of Loose SR & CR selection leading to small fake-μ rates for Z+jets and large Data and MC fake-e rates for $Z\gamma$
  - Damping of the $Z\gamma$ FF contribution in the NN score Matrix Method

$W^{\pm}Z$ Inclusive Object Selection

Electron object selection

Selection	Baseline selection	Z selection	W selection
$p_{\mathrm{T}} > 5$ GeV	✓	✓	✓
Electron object quality	✓	✓	✓
$\lvert\eta^{\mathrm{cluster}}\rvert < 2.47$, $\lvert\eta\rvert < 2.5$	✓	✓	✓
`LooseLH+BLayer` identification	✓	✓	✓
$\lvert d_0^{\mathrm{BL}}/\sigma(d_0^{\mathrm{BL}})\rvert < 5$	✓	✓	✓
$\lvert\Delta z_0^{\mathrm{BL}} \sin\theta\rvert < 0.5$ mm	✓	✓	✓
`FCLoose` isolation	✓	✓	✓
e-to-μ and e-to-e overlap removal	✓	✓	✓
e-to-jets overlap removal		✓	✓
$p_{\mathrm{T}} > 15$ GeV		✓	✓
Exclude $1.37 < \lvert\eta^{\mathrm{cluster}}\rvert < 1.52$		✓	✓
`MediumLH` identification		✓	✓
`HighPtCaloOnly` isolation		✓	✓
$p_{\mathrm{T}} > 20$ GeV			✓
`TightLH` identification			✓
`FCTight` isolation			✓
Unambiguous author			✓
`DFCommonAddAmbiguity` ≤ 0			✓

Muon object selection

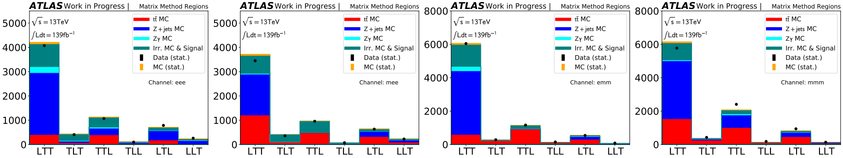
Selection	Baseline selection	Z selection	W selection
$p_{\mathrm{T}} > 5$ GeV	✓	✓	✓
$\lvert\eta\rvert < 2.7$	✓	✓	✓
`Loose` quality	✓	✓	✓
$\lvert d_0^{\mathrm{BL}}/\sigma(d_0^{\mathrm{BL}})\rvert < 3$ *(for $\lvert\eta\rvert < 2.5$ only)*	✓	✓	✓
$\lvert\Delta z_0^{\mathrm{BL}} \sin\theta\rvert < 0.5$ mm *(for $\lvert\eta\rvert < 2.5$ only)*	✓	✓	✓
`PflowLoose_FixedRad` isolation	✓	✓	✓
μ-jet Overlap Removal		✓	✓
$p_{\mathrm{T}} > 15$ GeV		✓	✓
$\lvert\eta\rvert < 2.5$		✓	✓
`Medium` quality		✓	✓
$p_{\mathrm{T}} > 20$ GeV			✓
`Tight` quality			✓
`PflowTight_FixedRad` isolation			✓

Jet object selection

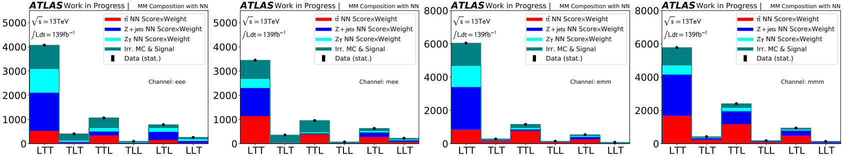
	Selection
anti-k_t $\Delta R = 0.4$	✓
$p_{\mathrm{T}} > 25$ GeV	✓
JVT > 0.59 (for $p_{\mathrm{T}} < 60$ GeV & $\lvert\eta\rvert < 2.4$)	✓
ΔR (jet - baseline electron) ≥ 0.2	✓
ΔR (jet with ≤ 3 tracks - baseline muon) ≥ 0.4	✓

Comparison of Expected - Neural Net compositions per channel

- Expected MC Compositions



- Neural Network score-based Composition



Comparison of Expected - Neural Net compositions per channel

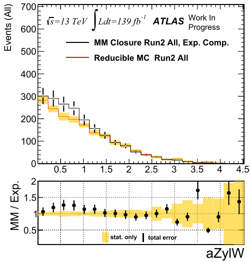
- Results of MC closure with Exp. Comp. Weighted Average of FFs

Source	eee	μee	$e\mu\mu$	$\mu\mu\mu$	All
$N_{LTT} \cdot F_W$	$478.3 \pm 11.0 \pm 108.9$	$23.8 \pm 0.6 \pm 26.7$	$683.5 \pm 12.8 \pm 153.2$	$44.3 \pm 0.8 \pm 43.8$	$1230.0 \pm 16.9 \pm 321.1$
$N_{TLT} \cdot F_Z$	$87.7 \pm 13.1 \pm 36.1$	$5.2 \pm 2.2 \pm 5.5$	$7.8 \pm 0.6 \pm 1.7$	$12.4 \pm 0.7 \pm 11.1$	$113.1 \pm 13.3 \pm 43.5$
$N_{TTL} \cdot F_Z$	$282.5 \pm 14.7 \pm 56.0$	$87.6 \pm 5.8 \pm 15.9$	$34.3 \pm 1.3 \pm 4.5$	$90.8 \pm 2.2 \pm 14.1$	$495.3 \pm 16.0 \pm 75.2$
$-$2L Terms	$-59.3 \pm 2.8 \pm 20.1$	$-2.7 \pm 0.2 \pm 1.7$	$-2.2 \pm 0.1 \pm 0.8$	$-0.6 \pm 0.0 \pm 0.4$	$-64.8 \pm 2.8 \pm 22.5$
Matrix Method result	$789.24 \pm 22.72 \pm 148.77$	$113.99 \pm 6.25 \pm 35.13$	$723.53 \pm 12.87 \pm 154.66$	$146.92 \pm 2.44 \pm 58.62$	$1773.68 \pm 26.96 \pm 372.33$
($t\bar{t}$ + Z+jets + $Z\gamma$) MC $\times$ SF	565.80 ± 25.70	198.00 ± 6.60	695.50 ± 31.60	270.60 ± 9.20	1730.00 ± 42.30

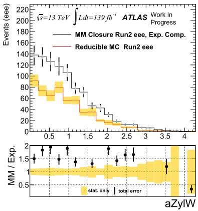
- Results of MC closure with NN-score Weighted Average of FFs

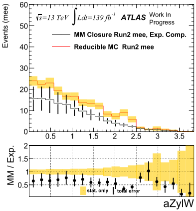
Source	eee	μee	$e\mu\mu$	$\mu\mu\mu$	All
$N_{LTT} \cdot F_W$	$582.3 \pm 14.9 \pm 123.7$	$20.9 \pm 0.5 \pm 13.8$	$818.7 \pm 17.4 \pm 171.7$	$39.7 \pm 0.7 \pm 27.2$	$1461.6 \pm 22.9 \pm 312.0$
$N_{TLT} \cdot F_Z$	$160.9 \pm 31.2 \pm 87.9$	$-1.7 \pm 24.7 \pm 56.6$	$7.4 \pm 0.5 \pm 1.8$	$12.0 \pm 0.7 \pm 3.6$	$178.7 \pm 39.8 \pm 130.9$
$N_{TTL} \cdot F_Z$	$498.4 \pm 42.3 \pm 108.0$	$215.6 \pm 35.6 \pm 91.8$	$32.5 \pm 1.2 \pm 4.4$	$85.8 \pm 2.1 \pm 12.1$	$832.2 \pm 55.3 \pm 201.3$
$-$2L Terms	$-284.6 \pm 32.4 \pm 112.8$	$-34.1 \pm 22.7 \pm 28.4$	$-2.0 \pm 0.1 \pm 0.6$	$-0.6 \pm 0.0 \pm 0.4$	$-321.3 \pm 39.6 \pm 137.7$
Matrix Method result	$957.05 \pm 63.49 \pm 187.37$	$200.67 \pm 48.89 \pm 138.76$	$856.58 \pm 17.47 \pm 172.93$	$137.00 \pm 2.35 \pm 39.78$	$2151.30 \pm 82.05 \pm 454.55$
($t\bar{t}$ + Z+jets + $Z\gamma$) MC $\times$ SF	565.80 ± 25.70	198.00 ± 6.60	695.50 ± 31.60	270.60 ± 9.20	1730.00 ± 42.30

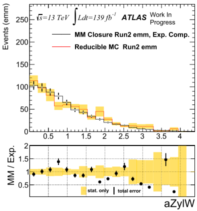
MC Closure Distributions - $|y_Z - y_{lW}|$

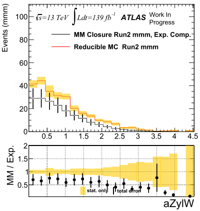


- Comparison of distribution of $|y_Z - y_{lW}|$ and Expected Reducible MC, scaled with MC Scale Factors.
- Per MC event, the weighted average of the 3 MC-derived FFs (weights being the Exp. MC composition) are used.
- Shown are MM stat. errors, MM total errors and MC stat. errors.

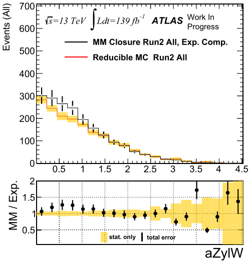








MC Closure Distributions - $|y_Z - y_{lW}|$



- Comparison of distribution of $|y_Z - y_{lW}|$ and Expected Reducible MC, scaled with MC Scale Factors.
- Per MC event, the weighted average of the 3 MC-derived FFs (weights being the Exp. MC composition) are used.
- Shown are MM stat. errors, MM total errors and MC stat. errors.

- Results of MC closure with Exp. Comp. Weighted Average of FFs

Source	eee	μee	$e\mu\mu$	$\mu\mu\mu$	All
$N_{LTT} \cdot F_W$	$461.4 \pm 6.5 \pm 49.7$	$34.9 \pm 0.5 \pm 43.5$	$627.0 \pm 7.0 \pm 55.6$	$67.0 \pm 0.7 \pm 49.9$	$1190.2 \pm 9.6 \pm 191.6$
$N_{TLT} \cdot F_Z$	$177.1 \pm 12.0 \pm 54.0$	$9.2 \pm 0.4 \pm 0.4$	$6.6 \pm 0.2 \pm 0.9$	$11.0 \pm 0.3 \pm 18.3$	$203.9 \pm 12.0 \pm 57.3$
$N_{TTL} \cdot F_Z$	$384.3 \pm 9.4 \pm 87.3$	$86.2 \pm 1.6 \pm 2.4$	$37.5 \pm 0.5 \pm 0.9$	$100.0 \pm 1.2 \pm 1.5$	$607.9 \pm 9.6 \pm 89.6$
$-$2L Terms	$-65.4 \pm 1.9 \pm 9.4$	$-2.8 \pm 0.1 \pm 0.2$	$-2.4 \pm 0.1 \pm 0.7$	$-0.5 \pm 0.0 \pm 0.4$	$-71.2 \pm 1.9 \pm 9.8$
Matrix Method result	$957.32 \pm 16.67 \pm 112.72$	$127.53 \pm 1.70 \pm 43.57$	$668.56 \pm 7.04 \pm 55.58$	$177.45 \pm 1.45 \pm 53.19$	$1930.86 \pm 18.23 \pm 225.69$
($t\bar{t}$ + Z+jets + $Z\gamma$) MC $\times$ SF	565.80 ± 25.70	198.00 ± 6.60	695.50 ± 31.60	270.60 ± 9.20	1730.00 ± 42.30

Systematics of MM with NN

Breakdown (NN)

Source	eee	μee	$e\mu\mu$	$\mu\mu\mu$	All
Relative uncertainties [%]					
F_W muon	0.00	1.12	0.00	3.54	0.33
F_Z muon	0.00	0.00	0.23	2.32	0.24
F_W electron	5.30	0.00	14.63	0.00	8.18
F_Z electron	1.03	9.96	0.00	0.00	1.19
Correlated Irr. subtraction (CR)	3.26	6.92	7.36	26.71	6.73
Irr. subtraction (SR)	17.05	67.45	5.59	2.46	16.26
Correlated η correction (e)	7.28	9.10	10.39	0.00	8.22
Correlated η correction (μ)	0.00	0.89	0.46	10.28	0.92
W. Average Stat. Uncertainty	0.00	0.00	0.00	0.00	0.00
Total sys.	19.58	69.15	20.19	29.04	21.13
Stat.	6.63	24.36	2.04	1.72	3.81
Total	20.67	73.31	20.29	29.09	21.47
Absolute uncertainties					
Total	197.84	147.12	173.81	39.85	461.90

Breakdown (Exp. Comp.)

Source	eee	μee	$e\mu\mu$	$\mu\mu\mu$	All
Relative uncertainties [%]					
F_W muon	0.00	2.95	0.00	4.36	0.55
F_Z muon	0.00	0.00	0.32	2.31	0.31
F_W electron	3.18	0.00	5.29	0.00	3.56
F_Z electron	2.75	3.46	0.00	0.00	1.27
Correlated Irr. subtraction	14.28	26.32	17.40	35.61	17.43
Correlated η correction (e)	9.70	8.14	9.89	0.00	8.87
Correlated η correction (μ)	0.00	1.90	0.58	10.24	1.21
W. Average Stat. Uncertainty	6.27	12.89	5.29	13.97	6.48
Total sys.	18.85	30.82	21.38	39.90	20.99
Stat.	2.88	5.48	1.78	1.66	1.52
Total	19.07	31.30	21.45	39.94	21.05
Absolute uncertainties					
Total	150.49	35.68	155.19	58.68	373.30