Measurements of multi-boson production at ATLAS

Panel: Electroweak Physics and Beyond the Standard Model

XXVIII International Workshop on Deep-Inelastic Scattering and Related Subjects

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(University of Manchester)
On behalf of ATLAS collaboration
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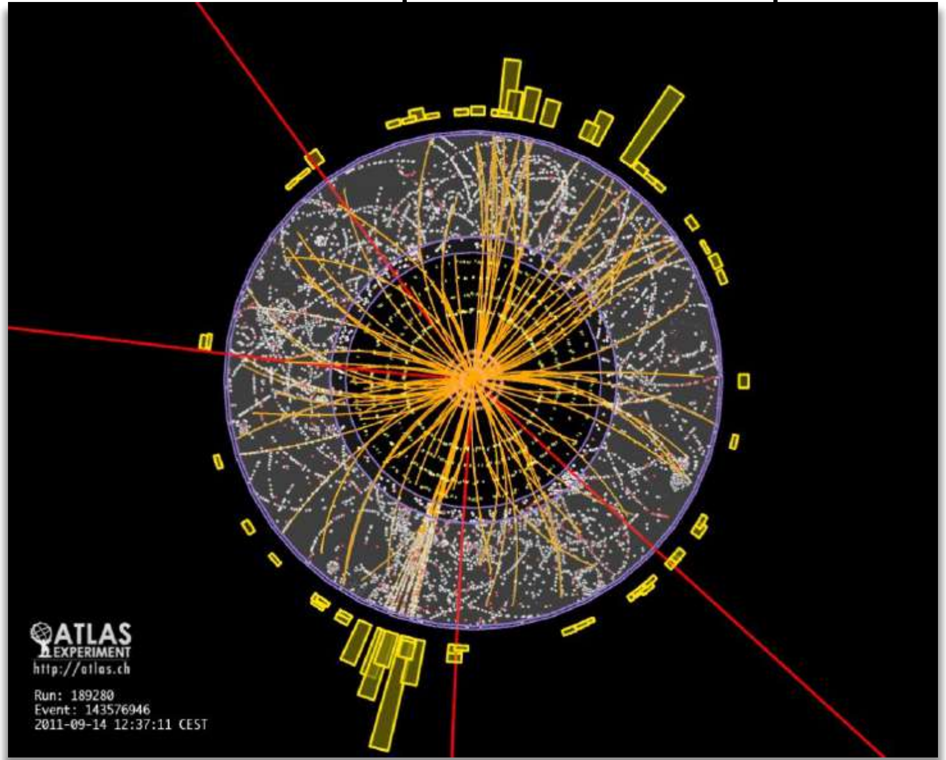
Multiboson Measurements in ATLAS

- Plethora of ATLAS measurements with the production of multi-bosons in an event
- Providing not only precision SM measurements but also input for BSM interpretation

1] Inclusive and differential cross-section measurements of **four-lepton** production in 13 TeV proton-proton collisions with the ATLAS detector arxiv:2103.01918 (Sub. to JHEP)

2] Measurement of the jet mass in high transverse momentum $\boldsymbol{Z(\rightarrow bb)\gamma}$ production at $\sqrt{s} = 13$ TeV using the ATLAS detector Phys. Lett. B 812 (2020) 135991

3] Measurements of $\boldsymbol{W^{+}W^{-} + \geq 1}$ **jet** production cross-sections in pp collisions at $\sqrt{s}$= 13 TeV with the ATLAS detector arxiv:2103.10319 (Sub. to JHEP)



Inclusive 4l: Motivation

Measuring events with at least 4 leptons (2x SFOS pairs: 4e,4mu, 2e2mu)

Inclusive

Including tau decays

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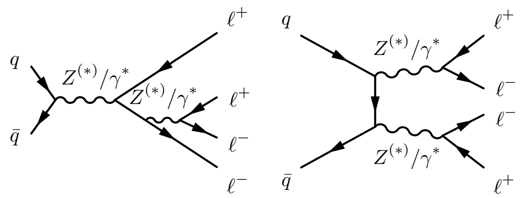
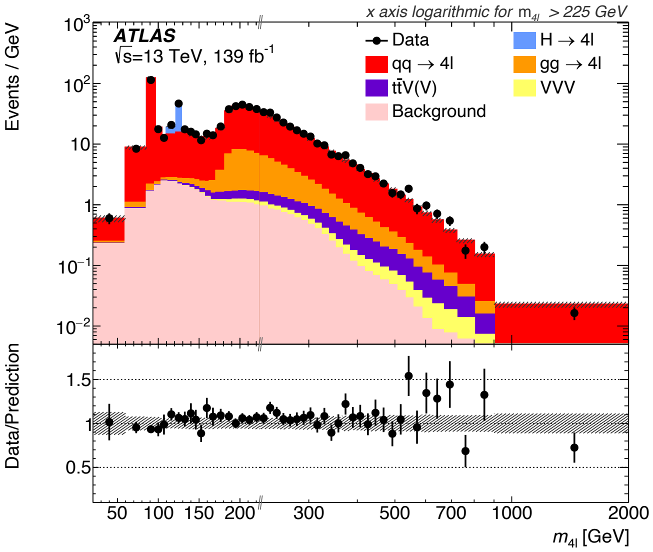
Rich SM 4l physics

Including tau decays

Quark initiated ZZ





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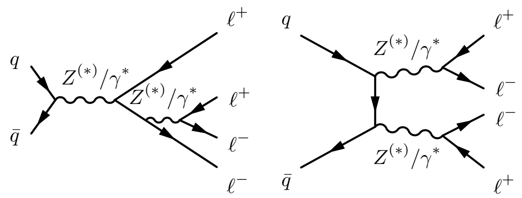

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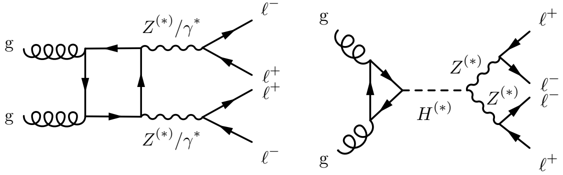
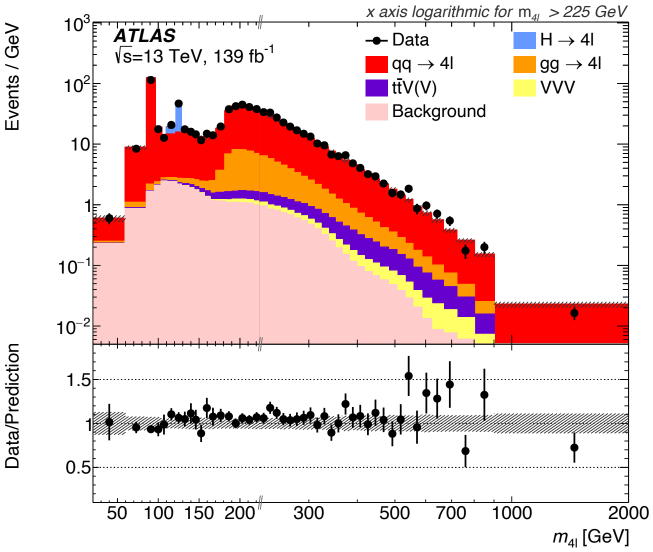
Higgs





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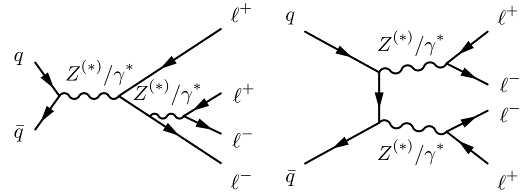

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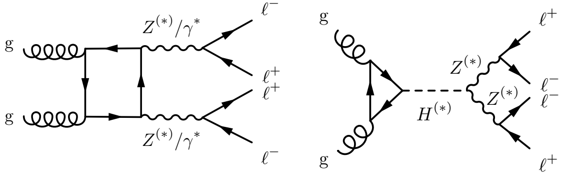
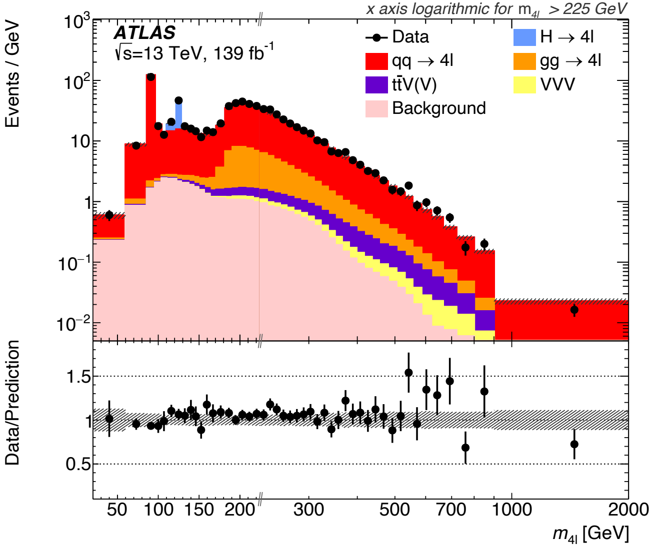
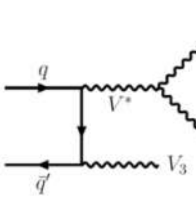
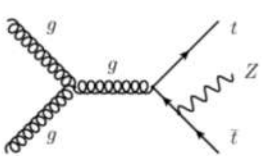




Triboson



ttbar + V(V)



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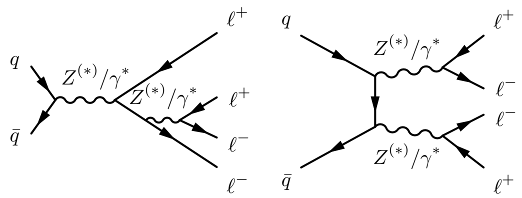

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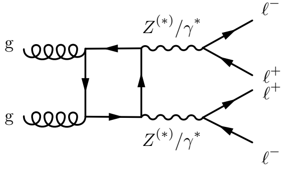

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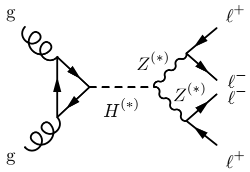

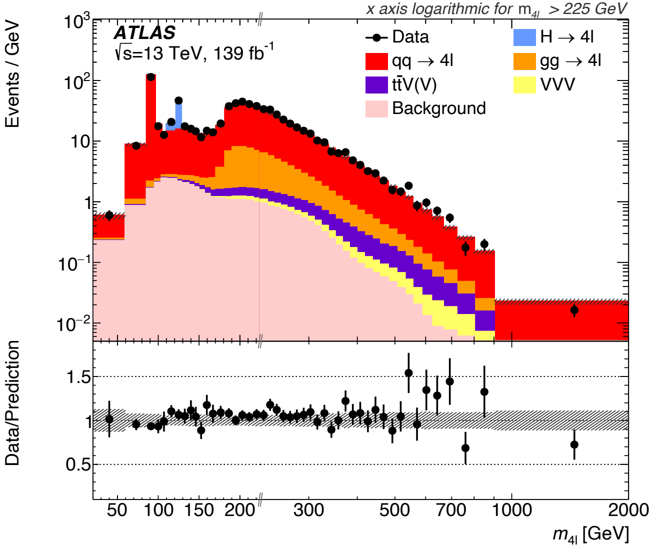

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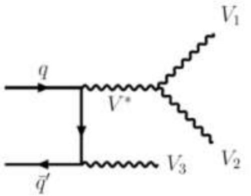

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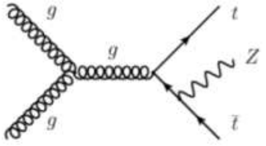
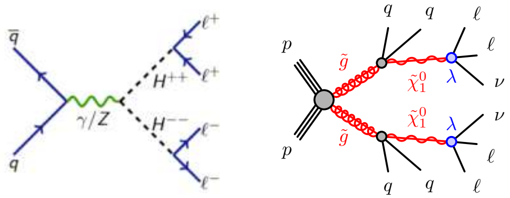
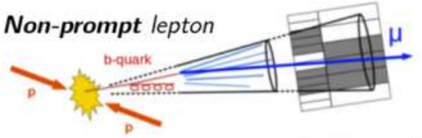


Beyond SM



- **Fake leptons** mainly from in flight decays (WZ, Z+jets,ttbar,…)
  - Estimated **from data** using fake factor (FF)



Example for 1 lepton FF estimates

F Measured in fake enriched region as a function of event kinematics

$$F = \frac{f}{1-f}$$

f: how likely it is for a fake lepton to be reconstructed as signal lepton

Number of fake leptons passing the signal selection

$$N^{Fake}_{Pass} = F \cdot N_{Fail}$$

Number of leptons failing the signal selection

Inclusive 4l: Background

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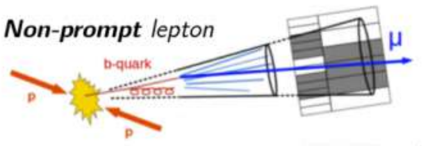

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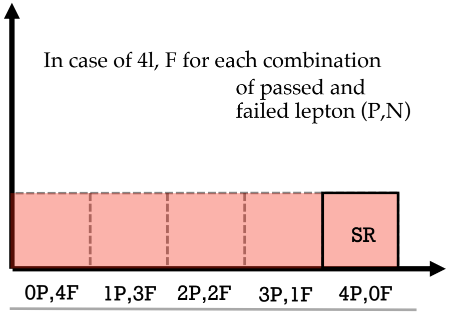

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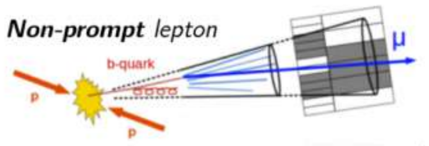

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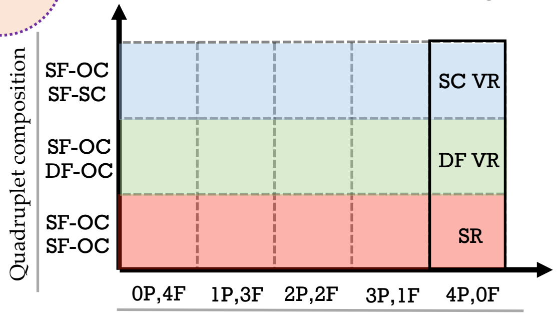
Validated in same charge (SC) and different flavour (DF) regions



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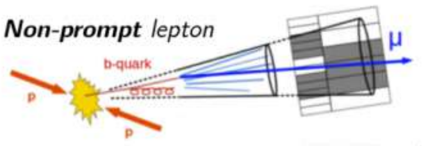

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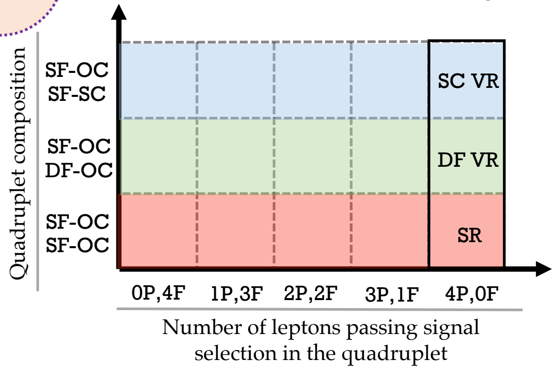
  - Overall 4% (falling off very quickly with m4l)

Validated in same charge (SC) and different flavour (DF) regions



- Z+ϒ taken from MC (Pythia8) represents only 0.2%

Inclusive 4l: Correction

- Correction for the remaining detector effects using **iterative bayesian unfolding** (2-3 iterations)

- Minimize dependence of SM lepton kinematics by using per lepton **pre-unfolding correction**

$$w = \frac{1}{\prod_{i=1}^{4} \epsilon_i [p_T^i, \eta^i]}$$

- Efficiencies measured in lepton kinematics, derived for tau and non-tau, final eff weighted per tau-fraction

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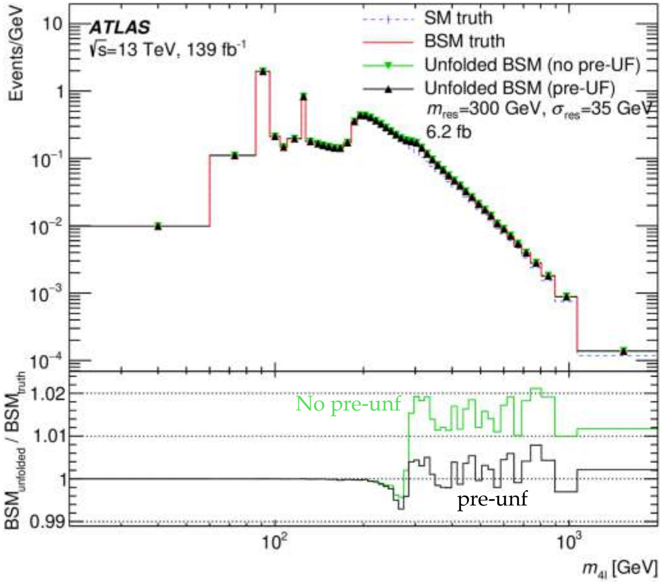
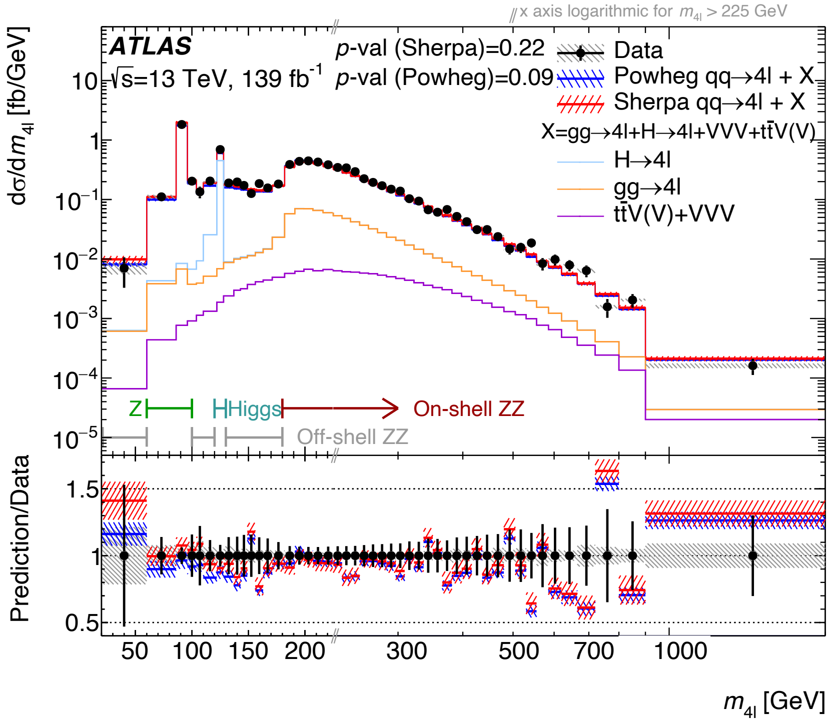
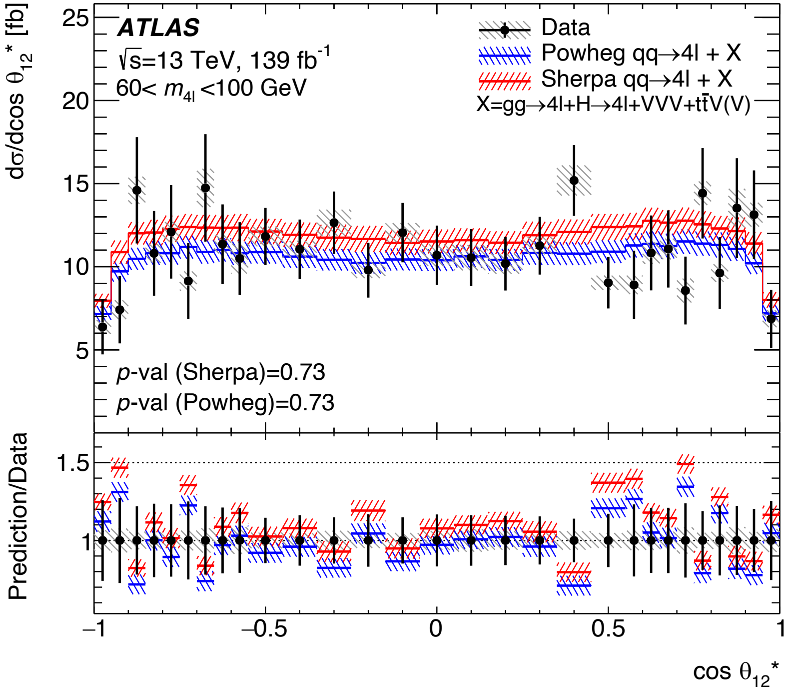


Inclusive 4l: Results (differential fid. x-sec)

- single / double differential cross-sections (~ 1200 bins)
- m4l (inc., pT4l, y4l, flavour), Δy_{pairs}, $\Delta\phi_{pairs}$, $\Delta\phi_{ll}$, m_{Z1}, m_{Z2}, p_{TZ1}, p_{TZ2}, pol. variables



Z region



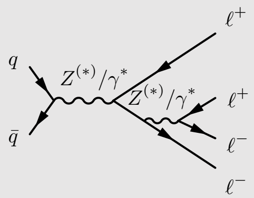
All results (including cov. matrices) in HepData

Inclusive 4l: Results (integrated fid. x-sec, BR)

1] Integrated fiducial cross-sections

	Full	$Z \to 4\ell$	$H \to 4\ell$	Off-shell ZZ	On-shell ZZ
			Region		
Measured fiducial cross-section [fb]	88.9 ±1.1 (stat.) ±2.3 (syst.) ±1.5 (lumi.) ±3.0 (total)	22.1 ±0.7 (stat.) ±1.1 (syst.) ±0.4 (lumi.) ±1.3 (total)	4.76 ±0.29 (stat.) ±0.18 (syst.) ±0.08 (lumi.) ±0.35 (total)	12.4 ±0.5 (stat.) ±0.6 (syst.) ±0.2 (lumi.) ±0.8 (total)	49.3 ±0.8 (stat.) ±0.8 (syst.) ±0.8 (lumi.) ±1.3 (total)
SHERPA	86±5	23.6±1.5	4.57±0.21	11.5±0.7	46.0±2.9
POWHEG + PYTHIA8	83±5	21.2±1.3	4.38±0.20	10.7±0.7	46.4±3.0

2] Branching fraction of Z->4l



Most precise results up to date!

$$B_{Z\to 4l} = (4.41 \pm 0.13(\text{stat}) \pm 0.23(\text{syst}) \pm 0.09(\text{theory}) \pm 0.12(\text{lumi})) \times 10^{-6} = (4.41 \pm 0.30) \times 10^{-6}$$

Powheg: $B_{Z\to 4l} = (4.50 \pm 0.01) \times 10^{-6}$ Phys. Rev. Lett. 112, 231806 (2014)

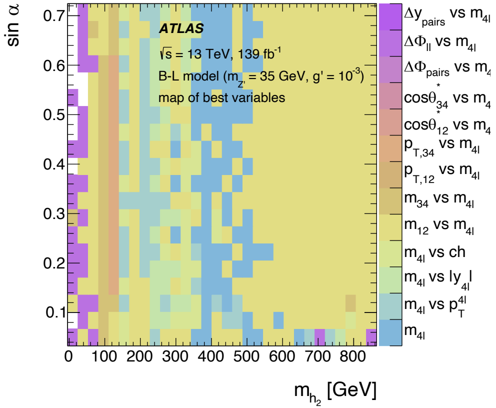
Inclusive 4l: Results (interpretation)

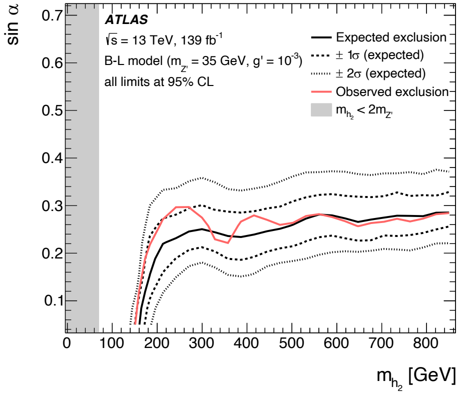
Used LH formula for the interpretation

$$\mathcal{L} = \frac{1}{\sqrt{(2\pi)^k |C|}} \exp\left\{ -\frac{1}{2}\left[\vec{\sigma}^{\text{meas}} - \vec{\sigma}^{\text{pred}}(\vec{\theta})\right]^T C^{-1} \left[\vec{\sigma}^{\text{meas}} - \vec{\sigma}^{\text{pred}}(\vec{\theta})\right]\right\} \times \prod_i \mathcal{G}(\theta_i, 0, 1)$$

Baryon – Lepton number gauge model

- Spontaneously broken local gauge B-L symmetry
- Predicts Z′ and exotic Higgs h2 mixing with SM Higgs via α, possible decays of both Higgs to ZZ and Z′Z′
- Model generated with Herwig 7.2

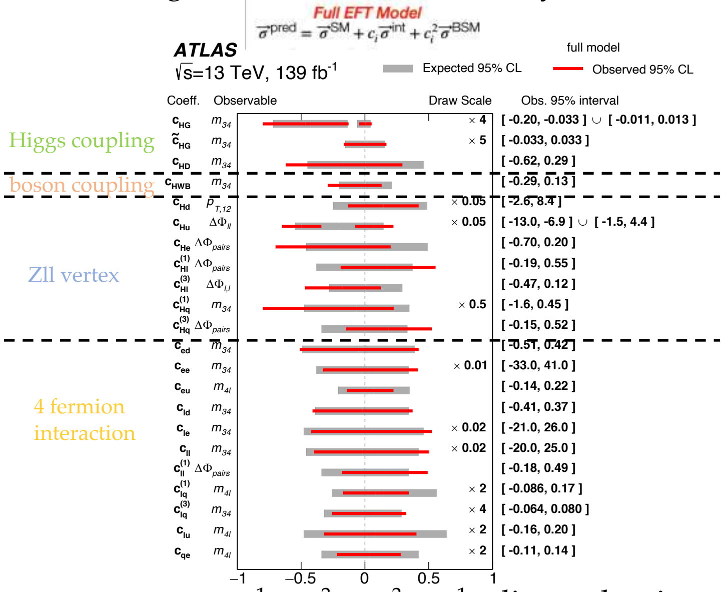




Effective Field Theory

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{\forall i} \frac{C_i \mathcal{O}^{(6)}}{\Lambda^2} + \sum_{\forall j} \frac{C_j \mathcal{O}^{(8)}}{\Lambda^4} + \sum_{\forall k, n=5,7,9\cdots} \frac{C_k \mathcal{O}^{(n)}}{\Lambda^{n-4}}$$

- Limits on 22 Wilson coefficient dim6
- EFT terms generated (Mg5@NLO + Py8) individually



- c_{HD}, c_{HWB}, c_{He}, c^1_{Hl}, c^3_{Hq}, c^3_{Hl}, c^1_{ll}, linear dominant

$Z(bb) + \gamma$: Motivation

- Probing jet grooming techniques to remove soft and wide angle radiation to mitigate pile up and underlying event

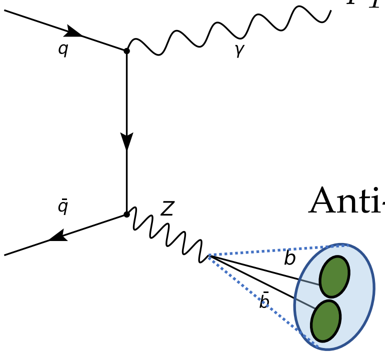
Trimming

- ATLAS default for boosted topologies
- Optimised on 8/13 TeV data
- [JHEP 1002:084,2010]

Soft drop

- Achieves higher theoretical precisions
- SD mass (NLO&NLL, LO&NNLL)
- [JHEP 1810 (2018) 137]

$p_T^{\gamma} > 175$ [GeV]



Anti-k_T (R=1), groomed

$p_T^{Rjet} > 200$ [GeV]

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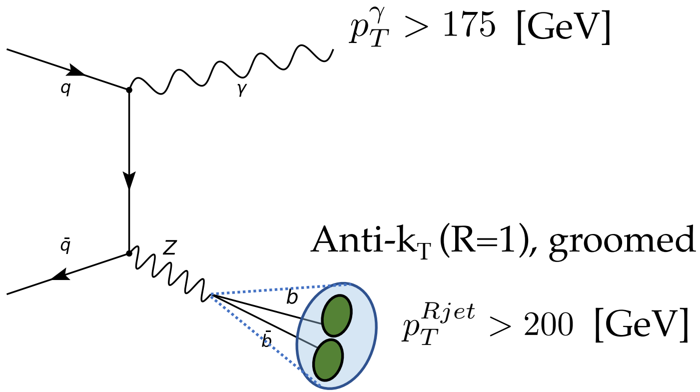
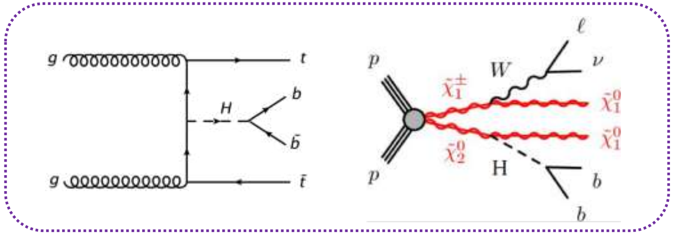


- Various interesting SM & BSM processes with X-> bbbar

- Good understanding of Z boson can be used as CR to constrain syst. uncertainties

- Triggering on γ, extending to low pT of Z

Examples of processes with bb



Z(bb) + γ : Background

Dominant (~92%):

- γ + gluon splitting into bbar
- Derived **from data** using transfer factor

	$N_{b\text{-jet}} = 0$	$N_{b\text{-jet}} = 1$	$N_{b\text{-jet}} = 2$
Non-tight γ	CR-A	CR-C	CR-E
Tight γ	CR-B	CR-D	SR

γ + gluon estimate

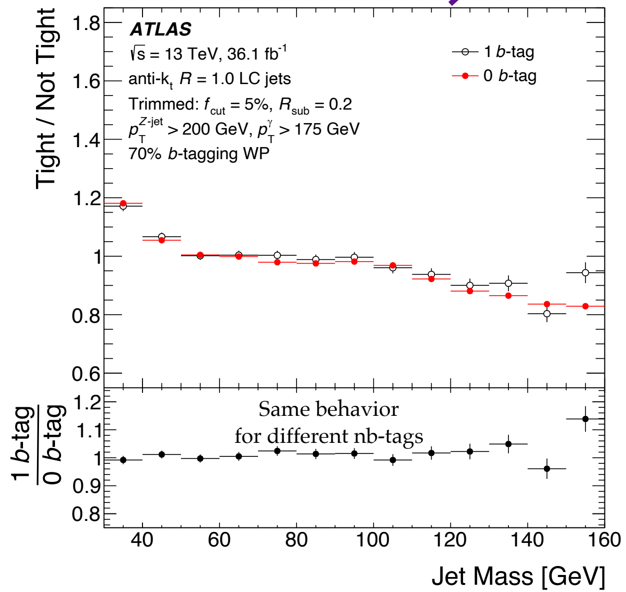
$$N^{\gamma+\text{jets}}_{\text{SR},i} = \left(\frac{N^{\gamma+\text{jets}}_{\text{CR-D},i}}{N^{\gamma+\text{jets}}_{\text{CR-C},i}}\right) N^{\gamma+\text{jets}}_{\text{CR-E},i}$$

Subdominant (< 1 %):

- γ + ttbar (MadGraph+Py8)
- γ + W (Sherpa 2.1.1)

Negligible:

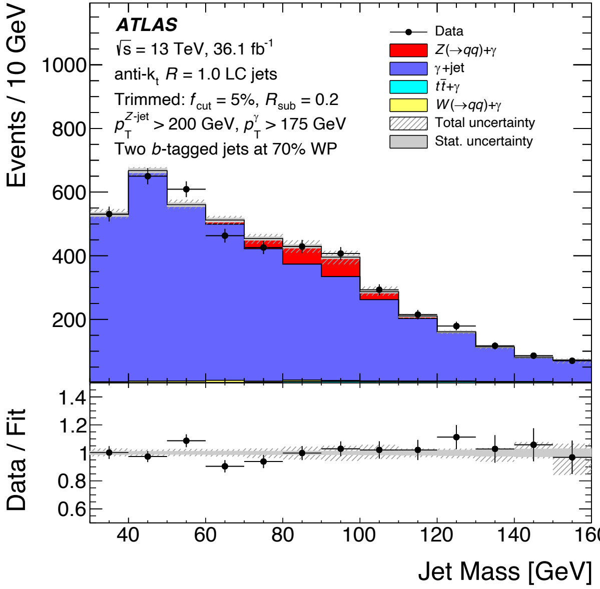
- multijets, misidentified jets + bosons



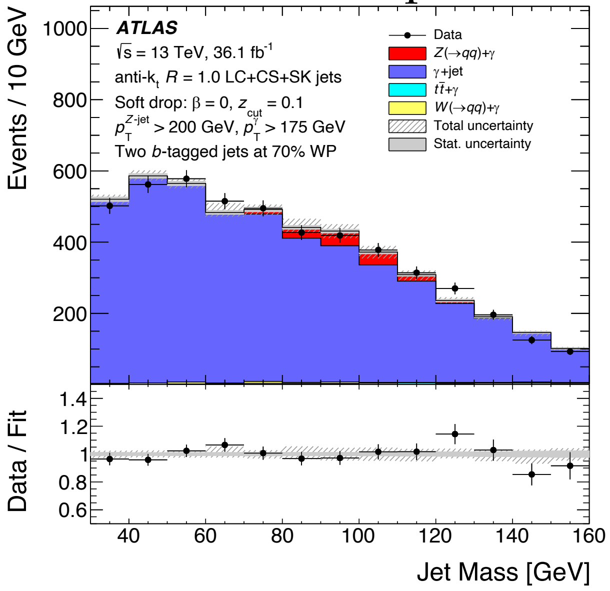
Z(bb) + γ : Signal fit & significance

- Signal and bkg templates fitted to data using binned maximum likelihood fit.

Trimmed



Soft Drop



Measured yields

Process	Trimmed jets	Soft-drop jets
$Z\gamma$	215 ± 61	167 ± 73
γ + jets	4180 ± 90	4630 ± 100
$W\gamma$	39 ± 8	37 ± 8
$t\bar{t}+\gamma$	39 ± 12	40 ± 12
Total	4480 ± 110	4870 ± 120
Data	4475	4874

Significance

	Trimmed jets	Soft-drop jets
Expected significance	3.8	2.7
Observed significance	3.9	2.7

Differences in the significance due to mass resolution and cross section

$Z(bb) + \gamma$: Integral and differential cross-sections

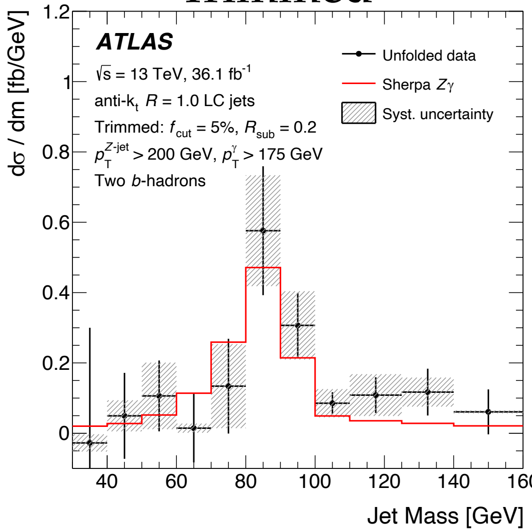
Integral fiducial cross-section

Jet definition	$\sigma\ (Z(\to b\bar{b})\gamma,\ p_T^{Z\text{-jet}} > 200$ GeV, $p_T^{\gamma} > 175$ GeV, $30 < m^{Z\text{-jet}} < 160$ GeV) [fb]	
Trimmed jets	Data	17.0 ± 5.0 (stat.) ± 3.6 (syst.)
	SHERPA $Z\gamma$ prediction	13.4 ± 0.2 (stat.)
	MADGRAPH+PYTHIA 8 $Z\gamma$ prediction	9.1 ± 0.1 (stat.)
Soft-drop jets	Data	12.5 ± 4.9 (stat.) ± 3.1 (syst.)
	SHERPA $Z\gamma$ prediction	15.4 ± 0.1 (stat.)
	MADGRAPH+PYTHIA 8 $Z\gamma$ prediction	10.2 ± 0.1 (stat.)

Dominant uncertainty from the fit normalisation

Differential cross-section in large R jet mass

Trimmed



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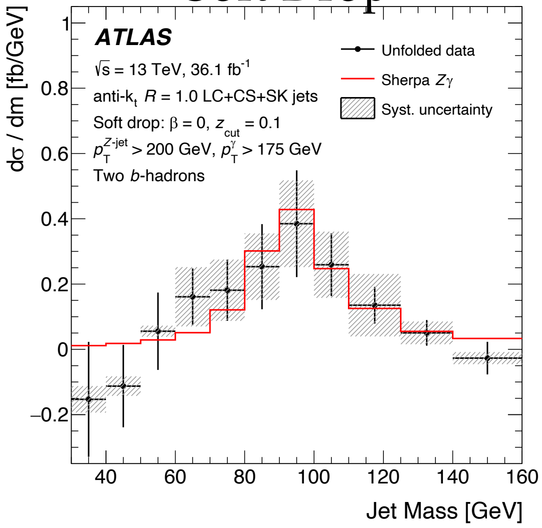
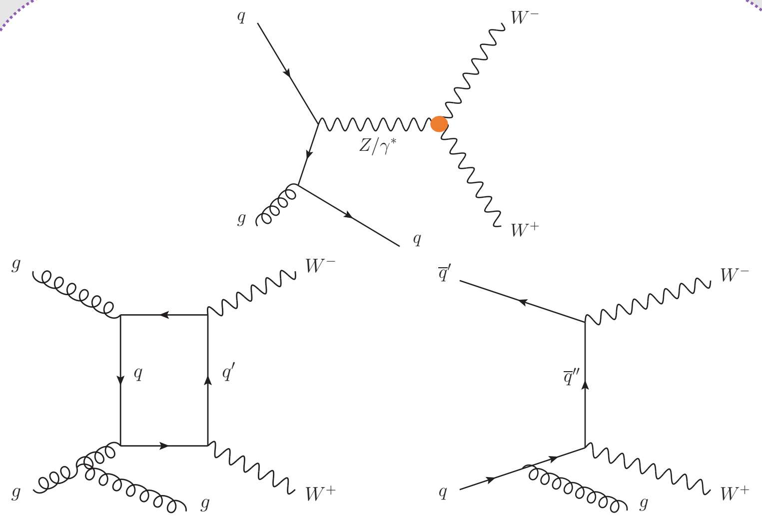


WW + >= 1 jet: Motivation

- First ATLAS measurement of jet inclusive cross sections with WW
- Test of perturbative QCD
- Represents large background in Higgs measurements and BSM searches
- Sensitive to EWK self interaction (aTGC)



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- Using **data-driven** approach due to bad modelling
- Constructing 1,2 b-tagged CR (ttbar dominated)

Correlation coeff $C_b \sim 1$
(b-tagging efficiency)

Yield in 1btag CR

Yield in 2btag CR

$$N_{0b}^{t\bar{t}} = \frac{C_b}{4} \frac{\left(N_{1b}^{t\bar{t}} + 2N_{2b}^{t\bar{t}}\right)^2}{N_{2b}^{t\bar{t}}} - N_{1b}^{t\bar{t}} - N_{2b}^{t\bar{t}}$$

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- Main contribution from ttbar (84%) and Wt
- Using **data-driven** approach due to bad modelling
- Constructing 1,2 b-tagged CR (ttbar dominated)

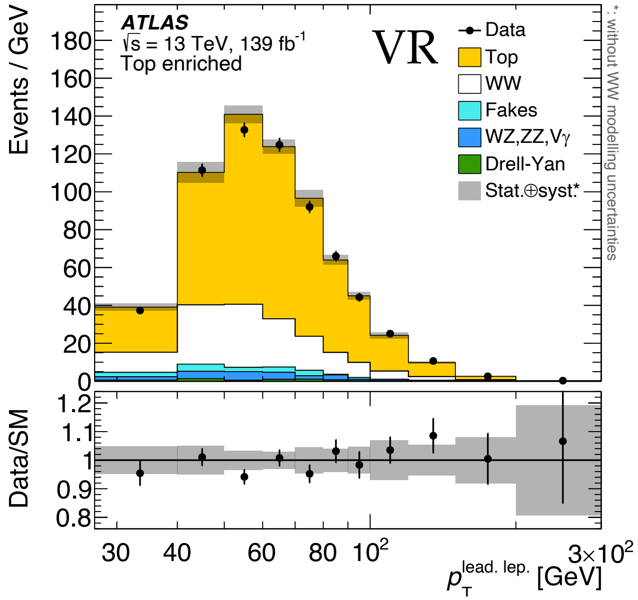
Correlation coeff C_b ~ 1
(b-tagging efficiency)

Yield in 1btag CR

Yield in 2btag CR

$$N_{0b}^{t\bar{t}} = \frac{C_b}{4} \frac{\left(N_{1b}^{t\bar{t}} + 2N_{2b}^{t\bar{t}}\right)^2}{N_{2b}^{t\bar{t}}} - N_{1b}^{t\bar{t}} - N_{2b}^{t\bar{t}}$$

Validation in top enhanced region



- Wt taken from MC (Sherpa 2.2.1)
- Other bkg: Fake leptons(3%), Drell-Yan (2%), Dibosons (3%)

WW + >= 1 jet: Correction & Results

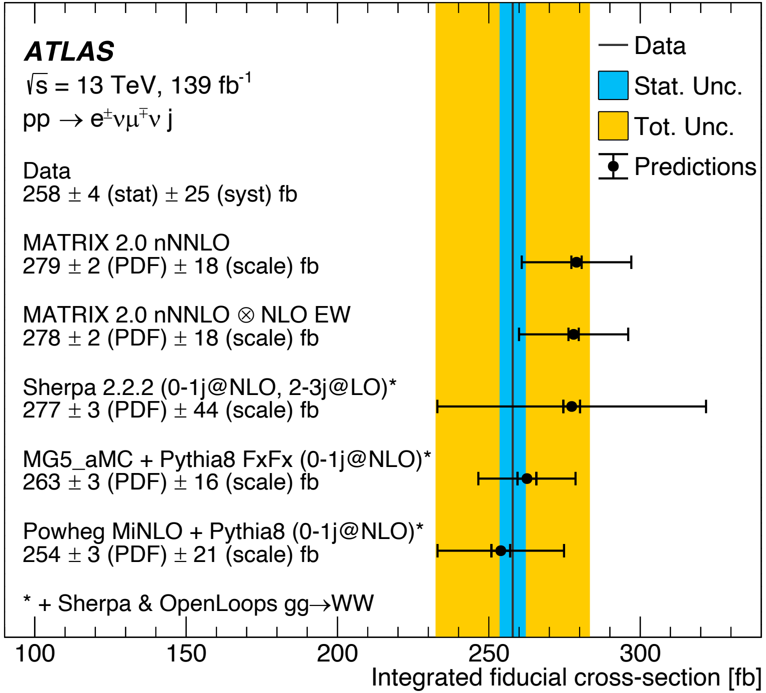
- Correction (C) for detector inefficiencies and resolution effects, luminosity (L)

$$\sigma_{\text{fid}} = \frac{N_{obs} - N_{bkg}}{C \times L}$$

$$\boxed{\sigma_{\text{fid}} = 258 \pm 4(\text{stat}) \pm 24(\text{syst})\text{fb}}$$

- Jet energy scale and calibration (~6%), top modelling (4.5%) are dominant systematics

- Measured cross-section consistent with various generator predictions at different precisions



WW + >= 1 jet: Differential cross-sections

- Correction to particle level using iterative bayesian unfolding (1-2 iterations)

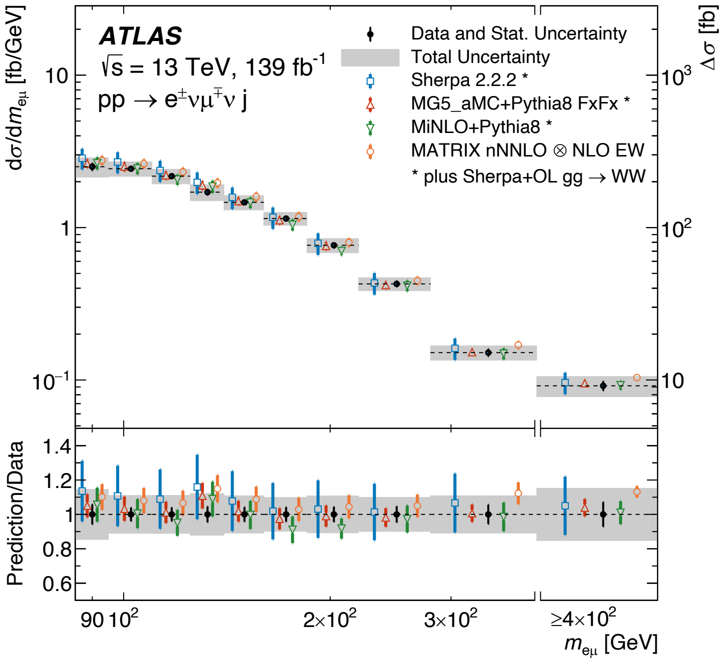
Measured distributions

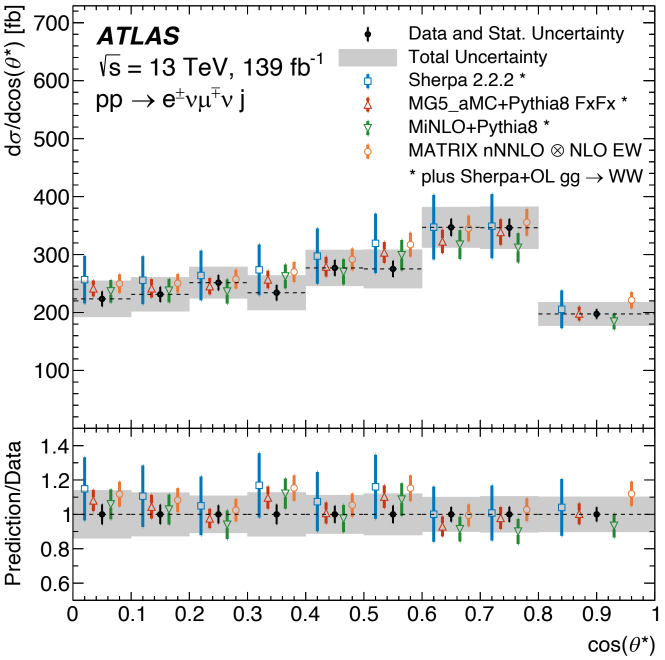
Lepton variables: $p_T^{leadlep}$, $p_T^{subleadlep}$, S_T

Dilepton variables: $m_{e\mu}$, $p_T^{e\mu}$, $\Delta\phi^{e\mu}$, $y^{e\mu}$, $m_{T,e\mu}$

Jet variables: $p_T^{leadjet}$, nJets, H_T

Polarisation variable: $\cos(\theta^*) = \ |\tanh(\Delta\eta(e,\mu)/2)|$

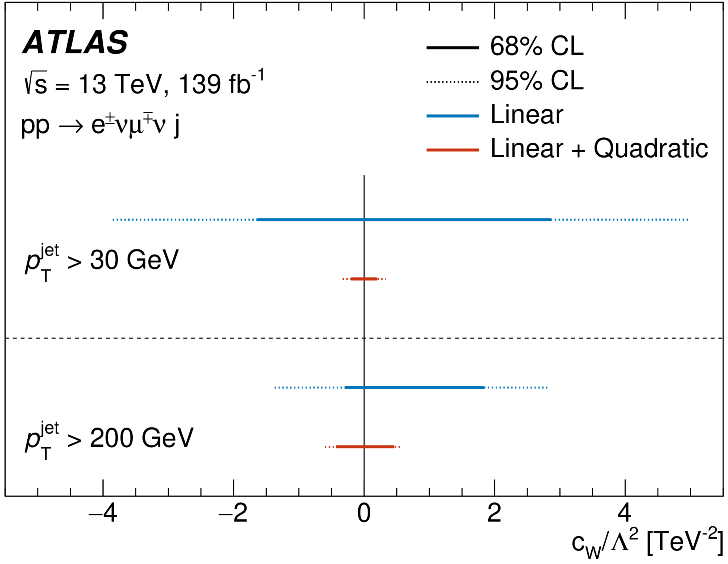




All results in HepData

WW + >= 1 jet: EFT interpretation

- Measurement used to study EFT (Mg5@NLO + Py8), in particular aTGC (using $m_{e\mu}$)
- Presence of **high pT jet** enhances aTGC sensitivity arXiv:1707.08060v1
- **Increased sensitivity** of PoI limits in high pT phase space using linear only terms

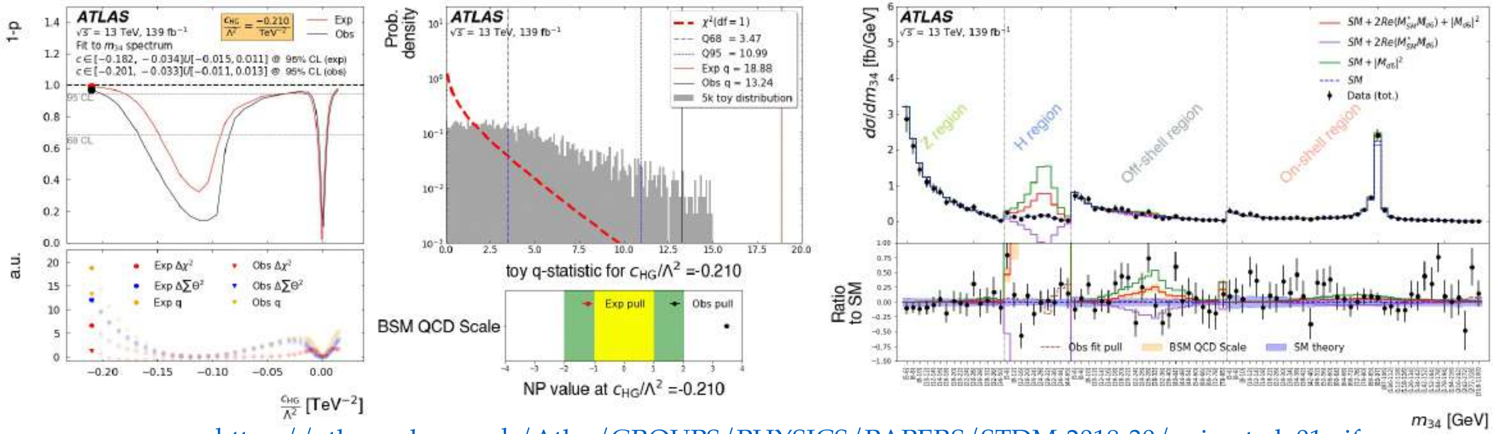


Multibosons: Summary

- 3 recent ATLAS multiboson measurements have been presented

- Providing precise SM measurements of integral and differential cross-sections
  - Using improved techniques with aim to reduce the model dependency
  - Probing jet substructures with higher QCD precisions
  - Possibilities to scan parameter phase spaces of BSM models (EFT, B-L, …)

Gif: scan of C_{HG} coefficient using one of measured distributions from inclusive 4l

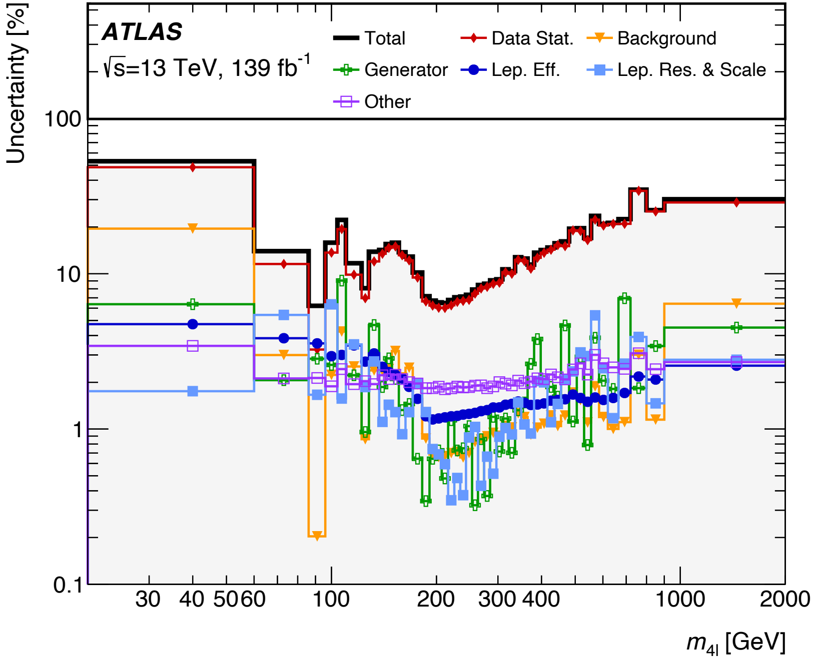


https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2018-30/animated_01.gif


I'm gonna need
backup

Inclusive 4l: Systematics

- Uncertainty dominated by data statistics (estimated with bootstrap method)
- Lepton efficiency, resolution, scale from data-driven measurements, propagated as scale factors
- Comparison of qq->ZZ generator prediction by Sherpa and Powheg+Py8
- Theoretical syst. of processes treated as uncorrelated, qqZZ uncorrelated across m4l slices



Inclusive 4l: Background

Example for 1 lepton FF estimates

In case of 4l 16x16 matrix

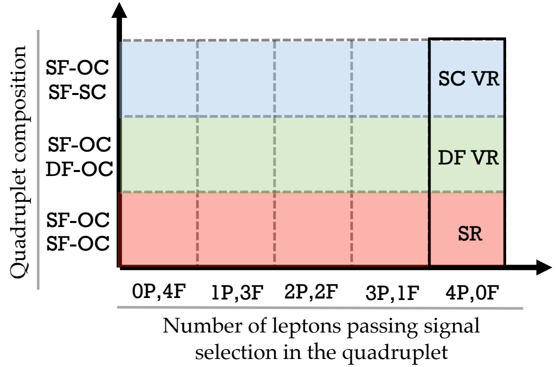
$$\begin{pmatrix} 1 & f \\ 0 & 1-f \end{pmatrix}\begin{pmatrix} N_{True} \\ N_{Fake} \end{pmatrix} = \begin{pmatrix} N_{Pass} \\ N_{Fail} \end{pmatrix} \rightarrow N^{Fake}_{Pass} = F \cdot N_{Fail}$$

f : how likely it is for a fake lepton to be reconstructed as signal lepton

$$F = \frac{f}{1-f}$$

F Measured in fake enriched region as a function of event kinematics

In case of 4l,
F for each combination

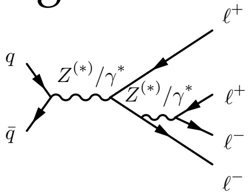


Inclusive 4l: Results (integrated fid. x-sec, BR)

1] Integrated fiducial cross-sections

	Full	$Z \to 4\ell$	Region $H \to 4\ell$	Off-shell ZZ	On-shell ZZ
Measured fiducial cross-section [fb]	88.9 ±1.1 (stat.) ±2.3 (syst.) ±1.5 (lumi.) ±3.0 (total)	22.1 ±0.7 (stat.) ±1.1 (syst.) ±0.4 (lumi.) ±1.3 (total)	4.76 ±0.29 (stat.) ±0.18 (syst.) ±0.08 (lumi.) ±0.35 (total)	12.4 ±0.5 (stat.) ±0.6 (syst.) ±0.2 (lumi.) ±0.8 (total)	49.3 ±0.8 (stat.) ±0.8 (syst.) ±0.8 (lumi.) ±1.3 (total)
Sherpa	86±5	23.6±1.5	4.57±0.21	11.5±0.7	46.0±2.9
Powheg + Pythia8	83±5	21.2±1.3	4.38±0.20	10.7±0.7	46.4±3.0

2] Branching fraction of Z->4l



Subtraction of predicted Non qqZZ processes

Fraction of single Z (rather than T channel)

$$B_{Z\to 4l} = \frac{\left(\sigma^{\text{meas}} - \sigma^{\text{pred}}_{\text{non}-q\bar{q}\to 4l}\right) \times f_Z \times f_{\text{non}-\tau}}{\sigma_Z \times A_{\text{fid}}}$$

Fraction of leptons Not originating from taus

Total cross-section for a single Z production
Phys. Lett. B 759 (2016) 601

Extrapolate to extend phase space
80 < m4l < 100, mll > 4, no kin. req on leptons

Most precise results up to date!

$$B_{Z\to 4l} = (4.41 \pm 0.13(\text{stat}) \pm 0.23(\text{syst}) \pm 0.09(\text{theory}) \pm 0.12(\text{lumi})) \times 10^{-6} = (4.41 \pm 0.30) \times 10^{-6}$$

Powheg: $B_{Z\to 4l} = (4.50 \pm 0.01) \times 10^{-6}$ Phys. Rev. Lett. 112, 231806 (2014)

Inclusive 4l: Correction

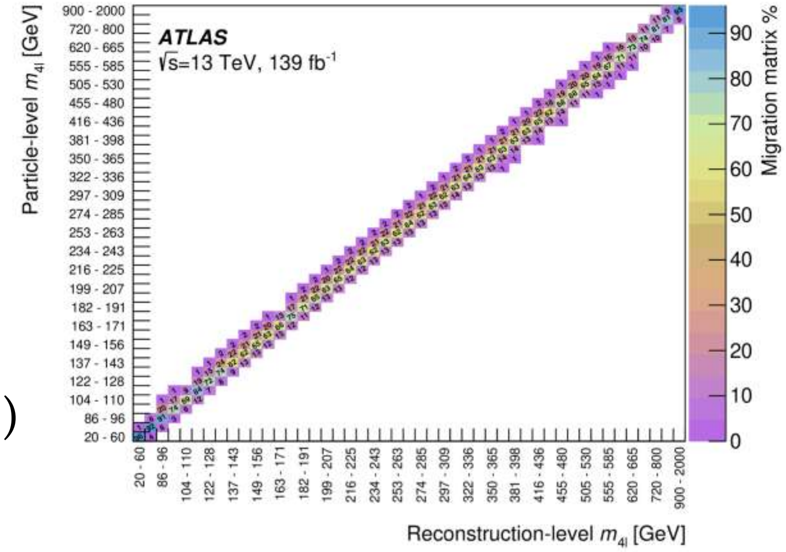
- Minimize dependence of SM lepton kinematics by using per lepton **pre-unfolding correction**

- Efficiencies measured in lepton kinematics, derived for tau and non-tau, final eff weighted per tau-fraction

- Correction for the remaining detector effects using **iterative bayesian unfolding** (2-3 iterations)

- Statistical uncertainty on data is the dominant systematic of the measurement (bootstrapped)

m4l Response Matrix

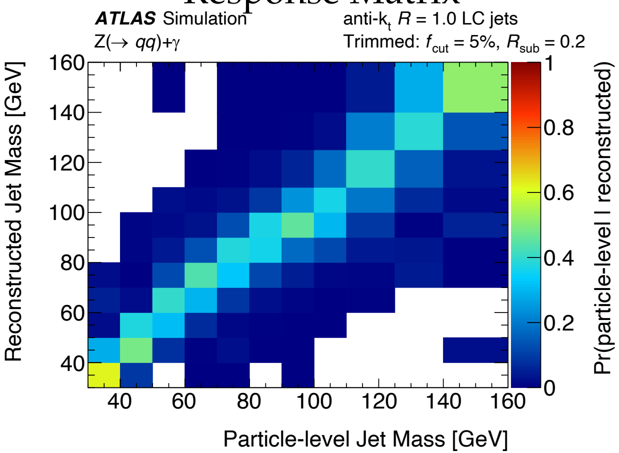


$Z(bb) + \gamma$: Corrections & Systematics

- Corrected to particle level using iterative bayesian unfolding (1 iteration)

- Response matrix from Sherpa 2.2.1
Generator systematic from Mg5@NLO+Py8

Response Matrix



Reweighting of MC based on data distribution

Unc. on normalization of signal and bkg. template from the fit

Source	Uncertainty [%] Trimmed jets	Uncertainty [%] Soft-drop jets
Luminosity	2.1	2.1
Jet energy resolution	0.4	< 0.1
Jet mass resolution	5.1	6.0
Jet energy and mass scale	7.2	7.4
b-tagging	5.3	5.8
Photon related	1.3	1.2
Muon related	0.1	< 0.1
Photon trigger	0.4	0.4
Transfer factor: 0-tag vs 1-tag	7.5	4.0
Transfer factor: statistical	2.9	1.5
$t\bar{t} + \gamma$ related	1.7	2.8
$W\gamma$ related	< 0.1	< 0.1
$Z\gamma$ modelling	12	15
Unfolding non-closure	9.4	5.8
Signal MC response: statistical	3.9	6.0
Background template: statistical	5.9	13
Fit statistical uncertainty	30	39
Total uncertainty	37	46

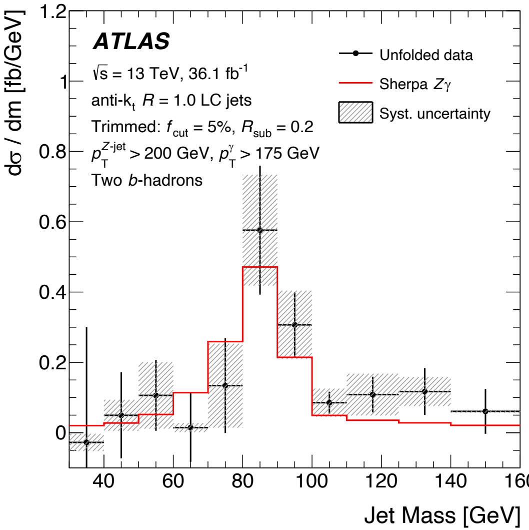
Z(bb) + γ: Integral and differential cross-sections

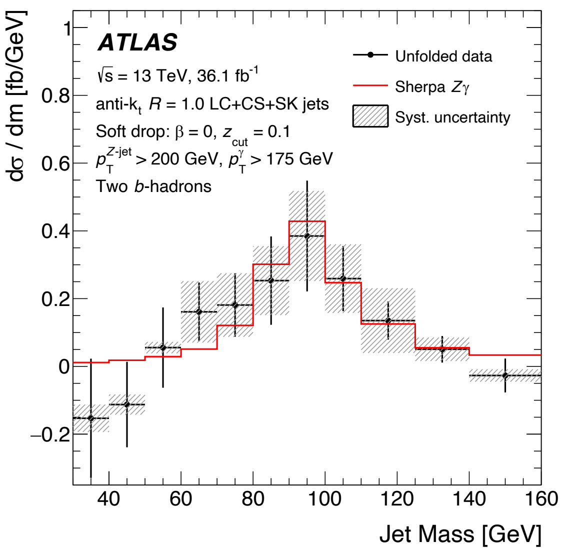
- Corrected to particle level using iterative bayesian unfolding (1 iteration)
- Response matrix from Sherpa 2.2.1, compared to Mg5@NLO+Py8
- Dominant systematic from fit normalisation of signal and background template (30%)

Integral fiducial cross-section

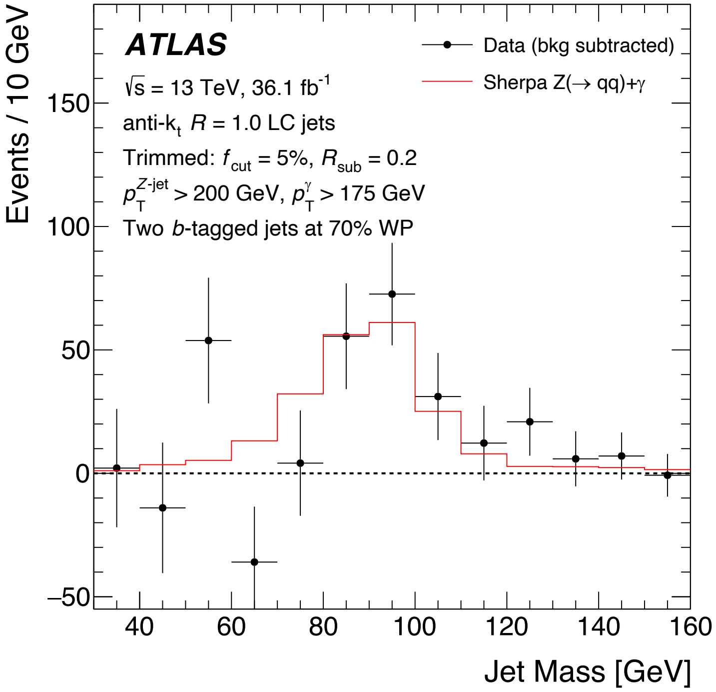
Jet definition	σ $(Z(\to b\bar{b})\gamma,\ p_{\mathrm{T}}^{Z\text{-jet}} > 200$ GeV, $p_{\mathrm{T}}^{\gamma} > 175$ GeV, $30 < m^{Z\text{-jet}} < 160$ GeV) [fb]	
Trimmed jets	Data	17.0 ± 5.0 (stat.) ± 3.6 (syst.)
	Sherpa $Z\gamma$ prediction	13.4 ± 0.2 (stat.)
	MadGraph+Pythia 8 $Z\gamma$ prediction	9.1 ± 0.1 (stat.)
Soft-drop jets	Data	12.5 ± 4.9 (stat.) ± 3.1 (syst.)
	Sherpa $Z\gamma$ prediction	15.4 ± 0.1 (stat.)
	MadGraph+Pythia 8 $Z\gamma$ prediction	10.2 ± 0.1 (stat.)

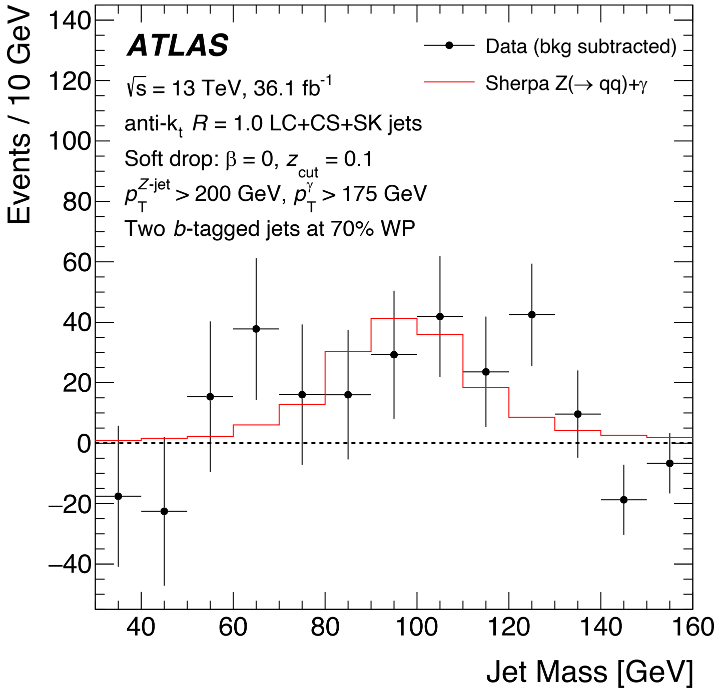
Differential cross-section in large R jet mass





Z(bb) + γ: Signal yields





WW + >= 1 jet: Subdominant backgrounds

Fake leptons (3%)

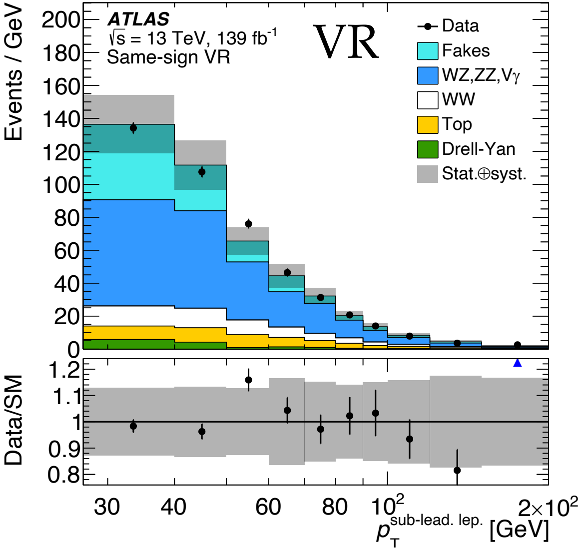
- Leptons from quark in flight decays (W+jets)
- Data driven
- Fake Factor in dijet
- Validated in the same sign region

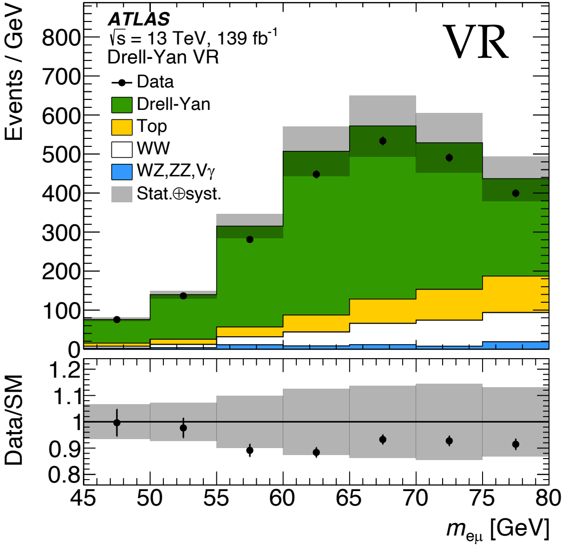
Drell-Yan (2%)

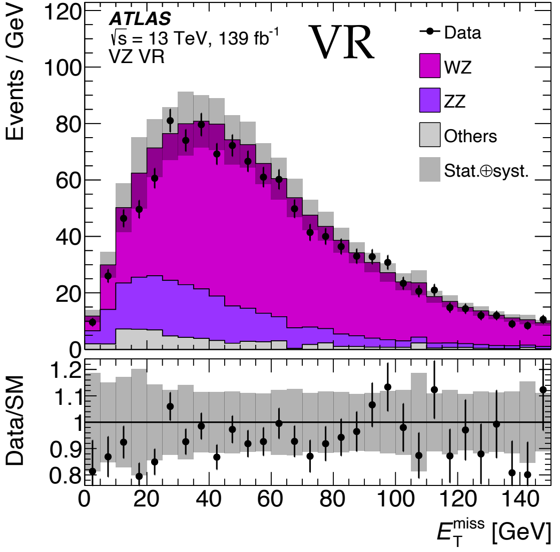
- Estimated from MC (Sherpa 2.2.1)
- Mostly Z->tautau
- Comparison to Mg5_aMC@NLO

Dibosons (3%)

- Main ZZ, WZ, $W\gamma$, $Z\gamma$
- Sherpa 2.2.1/2.2.8
- Comp to Pow+Py8
- VV VR 3rd lep
- $V\gamma$ loosend ID







WW + >= 1 jet: Correction and Systematics

- Iterative Bayesian unfolding (1-2 iterations)
- Sherpa MC used for response matrix
- Dominant: Jet energy scale and calibration
- Modelling uncertainties assest through alternative simulations

signal: Powheg-Box v2 @NLO in QCD +Py8
top bkg: MadGraph5_aMC@ 2.6.2 + Py8

Uncertainty source	Relative effect
Total uncertainty	10%
Signal region statistical uncertainty	1.1%
Data-driven background and MC statistics	1.2%
Jet calibration	6.3%
Top modelling	4.5%
Fake-lepton background	4.3%
Signal modelling	2.7%
Other background	2.3%
Flavour tagging	2.3%
Luminosity	1.9%
Other systematic uncertainties	0.6%

WW + >= 1 jet: Dominant background

- Dominant background comes from top processes (61%)
- Main contribution from ttbar (84%) and Wt
- Using **data-driven** approach due to bad modelling

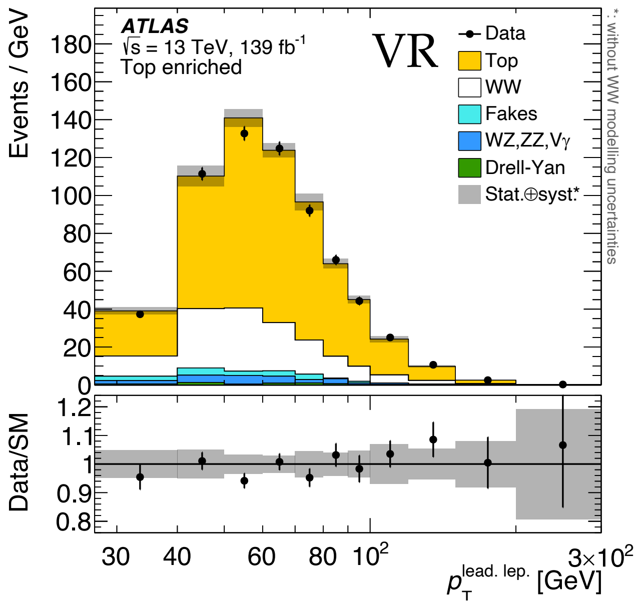
$$N_{1b}^{t\bar{t}} = N_{1b} - N_{1b}^{others} = L\sigma_{t\bar{t}}\epsilon_{e\mu} \cdot 2\epsilon_b(1 - C_b\epsilon_b)$$ Wt impurity in 2 bjet 13%

$$N_{2b}^{t\bar{t}} = N_{2b} - N_{2b}^{others} = L\sigma_{t\bar{t}}\epsilon_{e\mu} \cdot C_b\epsilon_b^2$$ Wt impurity in 2 bjet 4%

SR $\rightarrow$ $$N_{0b}^{t\bar{t}} = L\sigma_{t\bar{t}}\epsilon_{e\mu}(1 - 2\epsilon_b + C_b\epsilon_b^2)$$ Correlation coeff $C_b \sim 1$

$$N_{0b}^{t\bar{t}} = \frac{C_b}{4}\frac{\left(N_{1b}^{t\bar{t}} + 2N_{2b}^{t\bar{t}}\right)^2}{N_{2b}^{t\bar{t}}} - N_{1b}^{t\bar{t}} - N_{2b}^{t\bar{t}}$$

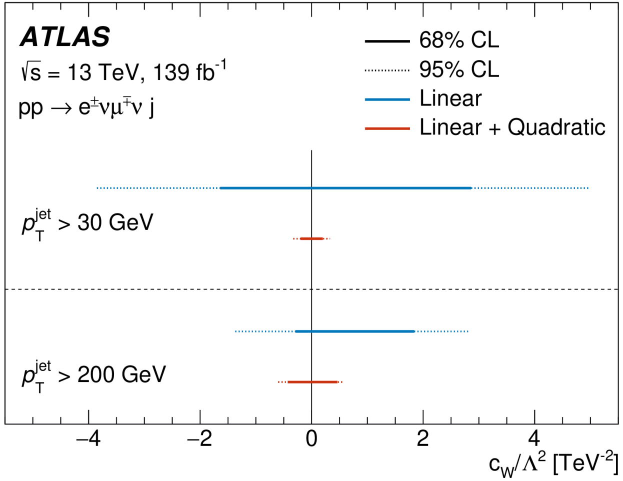
Validation in top enhanced region



- Wt taken from MC (Sherpa 2.2.1)
- Other bkg: Fake leptons(3%), Drell-Yan (2%), Dibosons (3%)

WW + >= 1 jet: EFT interpretation

- Measurement used to study EFT (Mg5@NLO + Py8), in particular aTGC (using $m_{e\mu}$)
- Presence of **high pT jet** enhances aTGC sensitivity arXiv:1707.08060v1
- **Increased sensitivity** of PoI limits in high pT phase space using linear only terms



- Lin + quad. result missing effect of dim8 EFT operators

Jet p_T	Linear only	68% CI obs.	95% CI obs.	68% CI exp.	95% CI exp.
> 30 GeV	yes	[–1.64, 2.86]	[–3.85, 4.97]	[–2.30, 2.27]	[–4.53, 4.41]
> 30 GeV	no	[–0.20, 0.20]	[–0.33, 0.33]	[–0.28, 0.27]	[–0.39, 0.38]
> 200 GeV	yes	[–0.29, 1.84]	[–1.37, 2.81]	[–1.12, 1.09]	[–2.24, 2.10]
> 200 GeV	no	[–0.43, 0.46]	[–0.60, 0.58]	[–0.38, 0.33]	[–0.53, 0.48]

- Lin+quad results weaker than WW Eur. Phys. J. C 79 (2019) 884
- Best lin results: EWK Zjj Eur. Phys. J. C 81 (2021) 163