Measurement of WW/WZ--> $l\nu jj$ at 7 TeV with ATLAS

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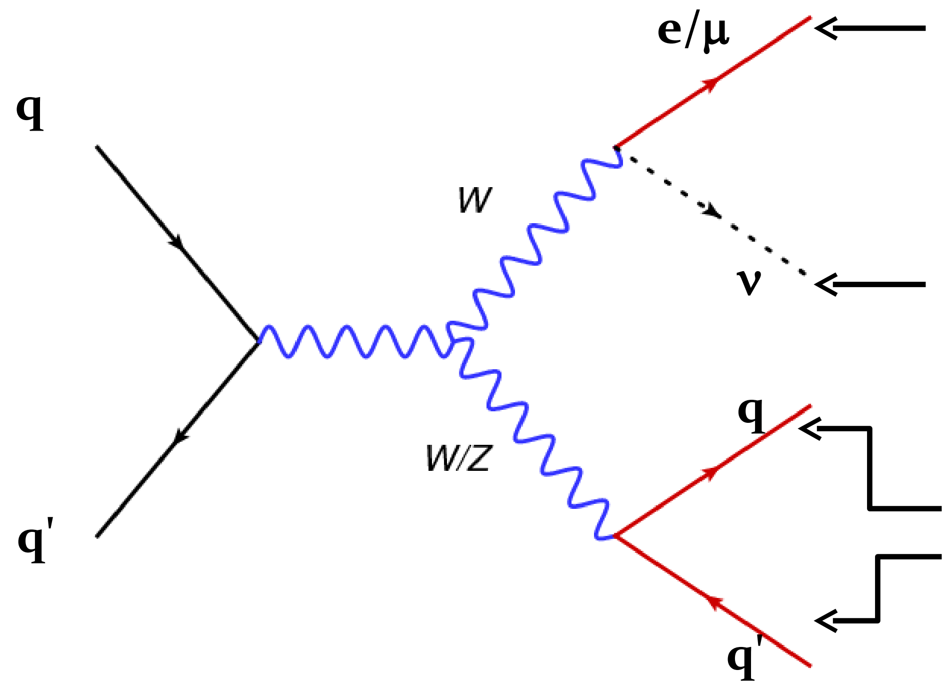
Introduction

- **Brand new result: submitted to JHEP on Oct 28!**
- Goal: measure **cross-section** of W(lnu)W(jj) + W(lnu)Z(jj) and use lvjj final state to place **limits on anomalous triple gauge couplings** (aTGCs)
- Advantages compared to fully leptonic decays:
  - Higher σxBF (lvjj ~6x larger than lvlv)
  - Better kinematic constraints (only 1 v instead of 2)
- Disadvantages:
  - MUCH higher backgrounds
  - Difficult to separate W->jj from Z->jj due to dijet mass resolution ==> We don't attempt to disentangle.

Cross Section Analysis Strategy



- Trigger on charged lepton
- Require missing ET
- Look for two jets and form invariant mass
- Fit signal+background dijet-mass shape to extract diboson cross-section

- Biggest problem: measuring signal on top of the enormous W+jets background (S/B<~4%)
- Understanding ***mjj shape of backgrounds*** is critical

CutFlow

leptonic W

muon channel:

- trigger: lowest unprescaled μ
- only 1 muon with $p_T > 25$ GeV
- veto on second lepton
- track and calo isolation
- vertex pointing: $d_0/\sigma(d_0) < 3$

electron channel:

- trigger: lowest unprescaled e
- only 1 electron with $p_T > 25$ GeV
- veto on second lepton
- track and calo isolation
- vertex pointing: $d_0/\sigma(d_0) < 10$

- $\not{E}_T > 30$ GeV
- $M_T(W) > 40$ GeV

hadronic W/Z

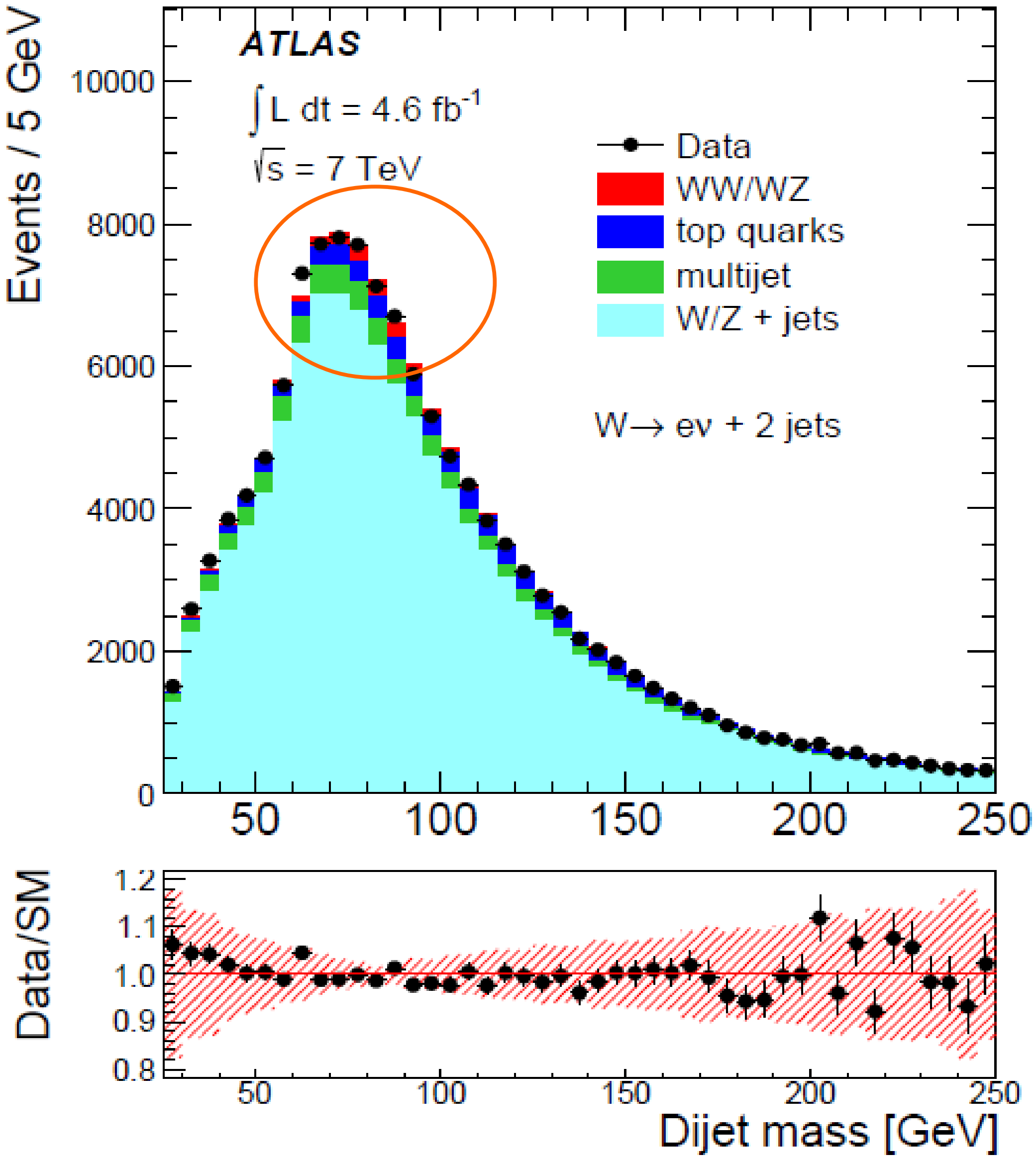
- jet cleaning and overlap removal
- at least 2 good jets with $p_T > 30, 25$ GeV
- $|\eta_{jet}| < 2.0$: increase S/B and select region with smaller JES uncertainty
- third jet veto for jets with $p_T > 25$ GeV and $|\eta| < 2.8$
- $|JVF| > 0.75$ if $|\eta| < 2.5$
- $\Delta\phi(\not{E}_T, j_{lead}) > 0.8$: further reduction of multijet background
- $\Delta R(j_1, j_2) > 0.7$ if $p_T(jj) < 250$ GeV: avoid mis-modeling due to a generator level cut
- $|\Delta\eta(j_1, j_2)| < 1.5$: improve S/B
- $25 \text{ GeV} < \mathrm{M_{jj}} < 250 \text{ GeV}$

Signal/Background Samples

Signal processes		e	μ
WW	MC@NLO+Herwig	1435 ± 70	1603 ± 79
WZ	MC@NLO+Herwig	334 ± 23	370 ± 26
Background processes			
$W+$ jets	Alpgen+Herwig	$(107 \pm 21) \times 10^3$	$(116 \pm 23) \times 10^3$
$Z+$ jets	Alpgen+Herwig	$(55 \pm 11) \times 10^2$	$(46.3 \pm 9.3) \times 10^2$
$t\bar{t}$	MC@NLO	$(47.2 \pm 7.1) \times 10^2$	$(47.2 \pm 7.1) \times 10^2$
Single-top	MC@NLO, AcerMC	$(20.2 \pm 3.0) \times 10^2$	$(20.5 \pm 3.1) \times 10^2$
Multijet	data-driven	$(67 \pm 10) \times 10^2$	$(50.5 \pm 7.6) \times 10^2$
ZZ	Herwig	19.2 ± 3.8	21.1 ± 4.2
Total SM prediction		$(128 \pm 17) \times 10^3$	$(135 \pm 19) \times 10^3$
Total Data		127 650	134 846

- QCD data-driven estimate from control regions enhanced in multi-jet fakes:
- ***Electron: fail "tight", pass "medium" ID***
- ***Muon: invert d0sig requirement***
- Normalization estimated by fitting MET in range 0<MET<400 GeV.

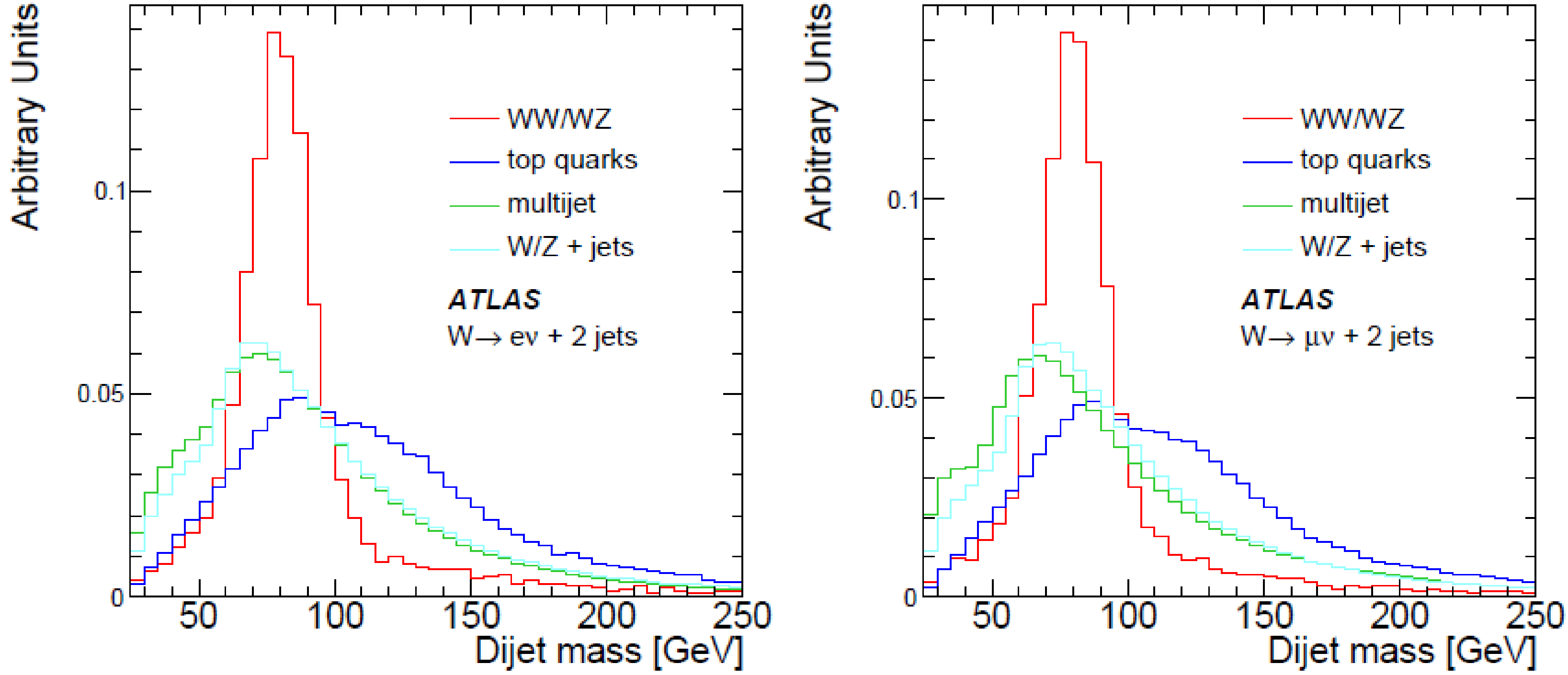
The Challenge



Fitting Procedure

- Fit mjj distribution, with separate templates for different background/signal components

Norm. to equal area



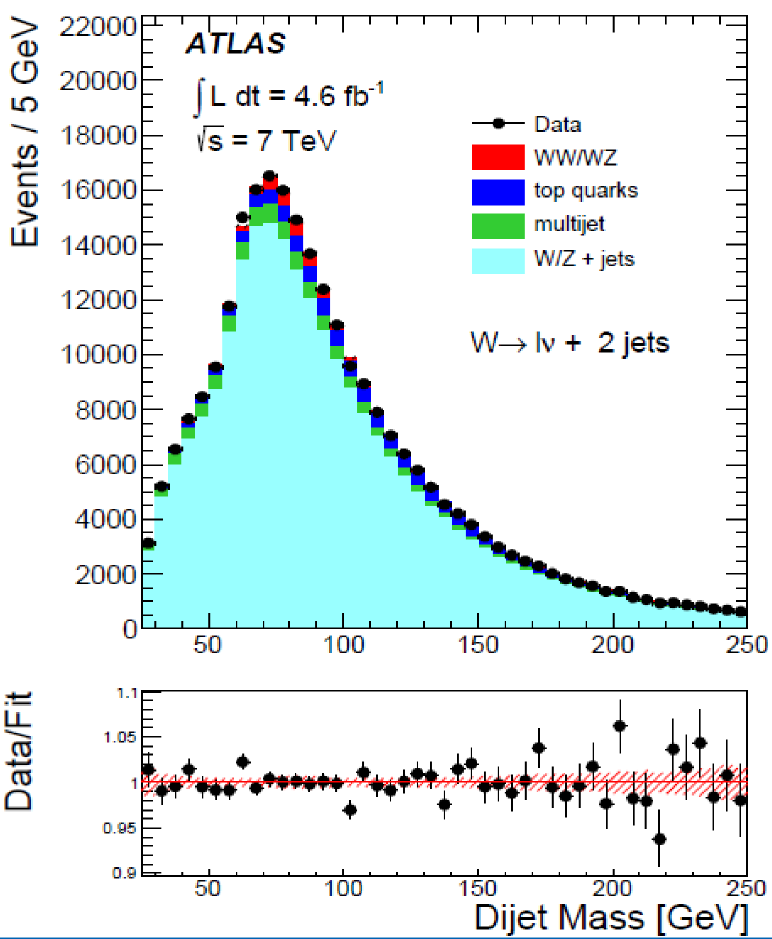
- Systematics incorporated into fit through nuis params
- Other systematics calculated separately.

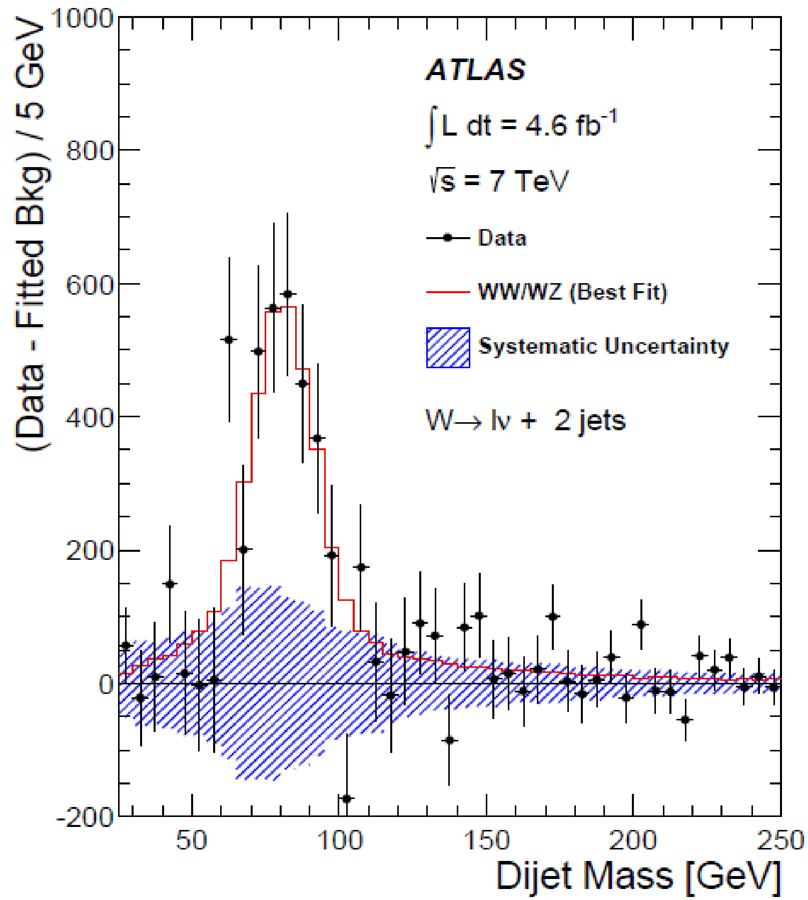
Fit Result

- Best fit β = 1.11 +/- 0.26 (β=sig/SM)

$$N_e^{WV} = 1970 \pm 200 \text{ (stat.)} \pm 500 \text{ (syst.)}$$

$$N_\mu^{WV} = 2190 \pm 220 \text{ (stat.)} \pm 560 \text{ (syst.)}$$





Fiducial and Total Cross sections

Fiducial $$\sigma_{fid} = \frac{N_{meas}}{\mathcal{L} \cdot D_{fid}}$$

$$D_{fid} = f_{fid}^{WW} \cdot C^{WW} + (1 - f_{fid}^{WW}) \cdot C^{WZ}$$

Total $$\sigma_{tot} = \frac{N_{meas}}{\mathcal{L} \cdot D_{tot}}$$

$$D_{tot} = f_{tot}^{WW} \cdot (C \cdot \mathcal{B} \cdot A)^{WW} + (1 - f_{tot}^{WW}) \cdot (C \cdot \mathcal{B} \cdot A)^{WZ}$$

- The main difference regarding systematics is the way that A enters into the total cross-section.
- σ_{fid} has very minor dependance on A, since (A^{WW}/A^{WZ}) enters into f^{WW}_{fid}

Cross-section Results

- From fit to mjj we get:
- β=1.11 +/- 0.26
- This is converted to:

$$\sigma_{\mathrm{fid}} = 1.37 \pm 0.14 \text{ (stat.)} \pm 0.37 \text{ (syst.) pb}$$

$$\sigma_{\mathrm{tot}} = 68 \pm 7 \text{ (stat.)} \pm 19 \text{ (syst.) pb}$$

- σ(tot,theor) = 61.1 +/- 2.2 pb
- Observed significance = 3.4 sigma (from pseudo-experiments)

Cross-section Systematics

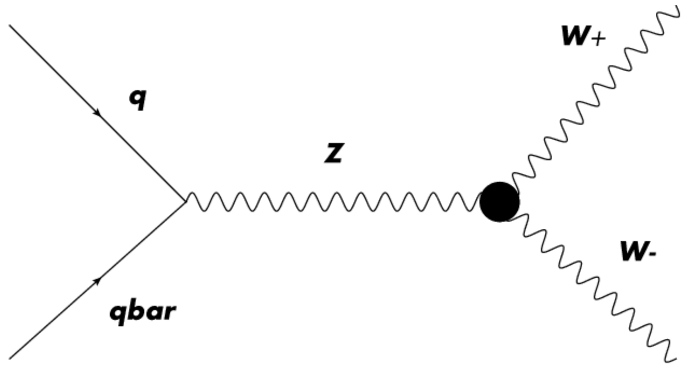
Source	σ_{fid}	σ_{tot}
	N_ℓ^{WV}	
Data statistics	±10	
MC statistics	±12	
W/Z + jets rate and shape modelling	±17	
Multijet shape and rate	±8	
Top rate and initial/final-state radiation shape modelling	±6	
Jet energy scale (background and signal shapes)	±9	
Jet energy resolution (background and signal shapes)	±11	
WV shape modelling	±5	
	D_{fid}	D_{tot}
JES/JER uncertainty	±6	±6
Signal modelling	±4	±5
Jet veto scale dependence	-	±5
Others (loss of spin-corr information, lepton uncertainties, PDF)	±1	±4
Luminosity	±1.8	
Total systematic uncertainty	±27	±28

N_{meas} systematics dominate

Systematics on acceptance small. σ_{fid} and σ_{tot} have virtually same uncertainty

aTGC Limits

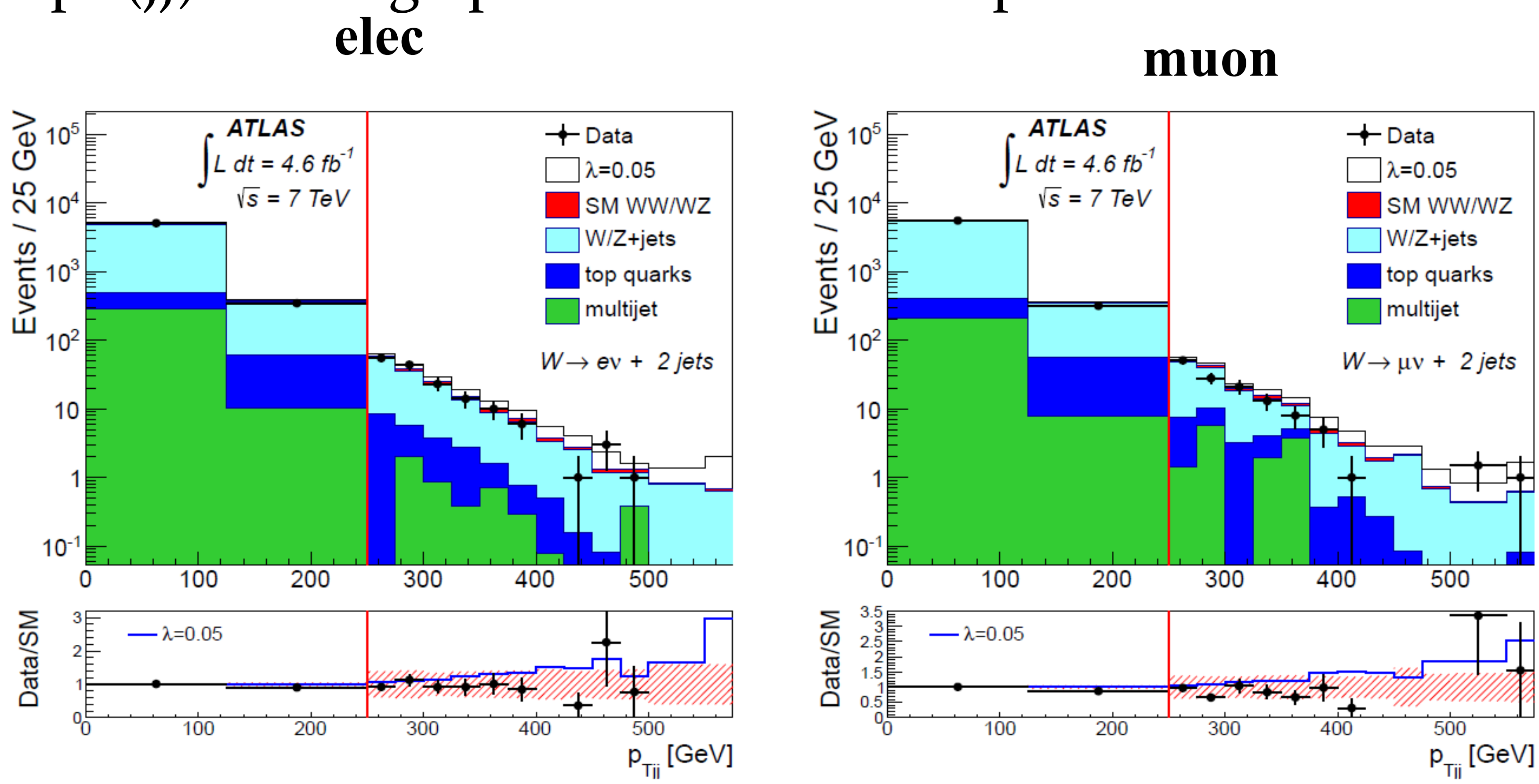
- Anomalous Triple Gauge Couplings (aTGC's) typically lead to enhanced cross-sections at high pT



- **Strategy**
- cut tightly on 75<mjj<95 to enhance S/B
- Fit the pT(jj) spectrum to extract limits on aTGC's
- pT(jj) is better proxy than pT(l) for pT(W).

pT(jj) distribution

- pT(jj) binning optimized for best expected limits:



Large systematics at high pT dominated by W+jets modeling (Alpgen)

Final aTGC Limits

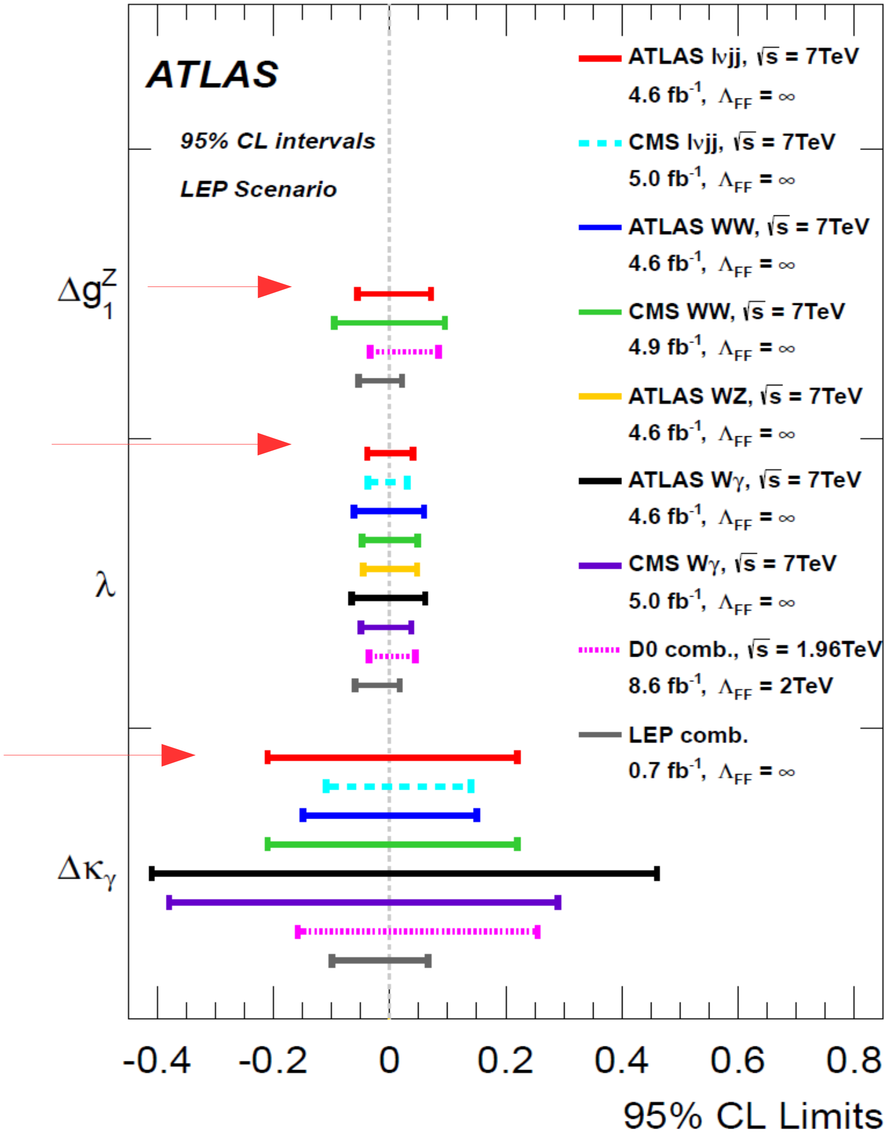
- All limits without form-factor.

LEP scenario

Parameter	Observed Limit	Expected Limit
$\lambda_Z = \lambda_\gamma$	[-0.039, 0.040]	[-0.048, 0.047]
$\Delta\kappa_\gamma$	[-0.21, 0.22]	[-0.23, 0.25]
Δg_1^Z	[-0.055, 0.071]	[-0.072, 0.085]

No constraint scenario

Parameter	Observed Limit	Expected Limit
λ_Z	[-0.043 , 0.044]	[-0.056, 0.056]
$\Delta\kappa_Z$	[-0.090 , 0.105]	[-0.11, 0.12]
Δg_1^Z	[-0.073, 0.095]	[-0.11, 0.12]
λ_γ	[-0.15, 0.15]	[-0.17, 0.16]
$\Delta\kappa_\gamma$	[-0.19, 0.23]	[-0.22, 0.25]



Interpretation in Effective Field Theory

- Follow approach in Degrande et al (arXiv:1205.4231)
- Put limits on cW, cB, cWWW, which have simple translation to aTGC's:

$$\begin{aligned}\frac{c_W}{\Lambda^2} &= \frac{2}{m_Z^2}\Delta g_1^Z\\ \frac{c_B}{\Lambda^2} &= \frac{2}{m_W^2}\Delta\kappa_\gamma - \frac{2}{m_Z^2}\Delta g_1^Z\\ \frac{c_{WWW}}{\Lambda^2} &= \frac{2}{3g^2 m_W^2}\lambda\,,\end{aligned}$$

Λ: scale above which EFT is not valid (i.e. scale of New Physics)

Final EFT Results

Parameter	Observed Limit	Expected Limit
c_{WWW}/Λ^2	[-9.5, 9.6] TeV^{-2}	[-11.6, 11.5] TeV^{-2}
c_B/Λ^2	[-64, 69] TeV^{-2}	[-73, 79] TeV^{-2}
c_W/Λ^2	[-13, 18] TeV^{-2}	[-17, 21] TeV^{-2}

arXiv:1410.7238

Summary

- **3.4 sigma evidence** for WV-->lnujj production at 7 TeV
- Cross section in agreement with SM expectation:

$$\sigma_{\text{fid}} = 1.37 \pm 0.14 \text{ (stat.)} \pm 0.37 \text{ (syst.) pb}$$

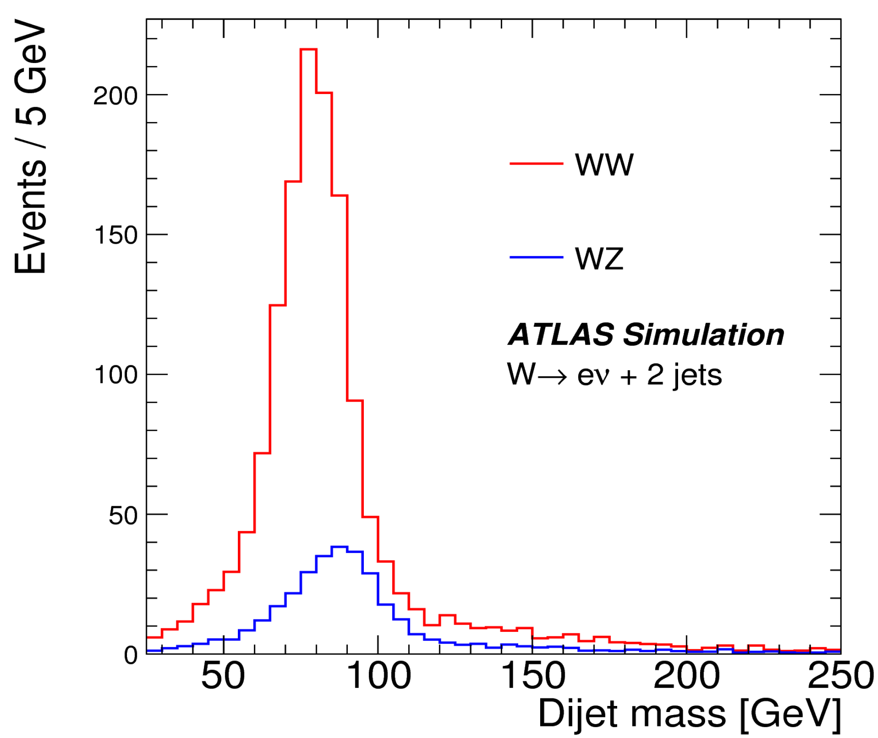
$$\sigma_{\text{tot}} = 68 \pm 7 \text{ (stat.)} \pm 19 \text{ (syst.) pb}$$

  - σ(tot,theor) = 61.1 +/- 2.2 pb

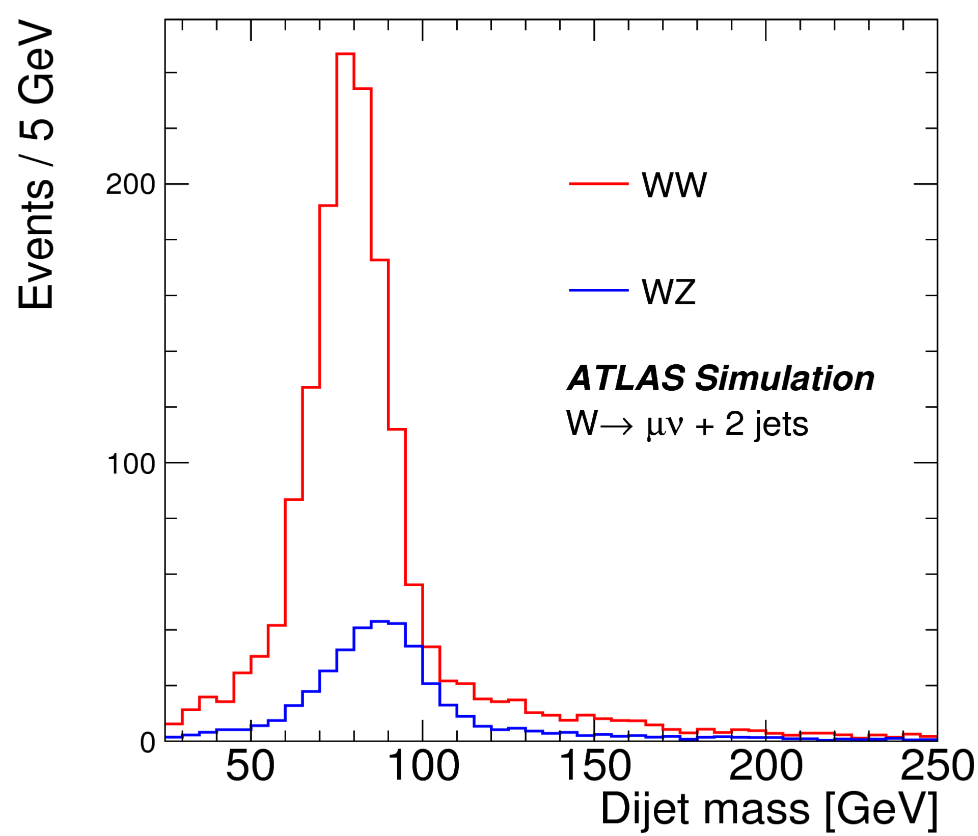
- Limits placed on aTGCs. Limits **competitive with other diboson analyses** and other experiments.
- **First ATLAS aTGC analysis to recast results in an EFT**

Backup

WW vs WZ

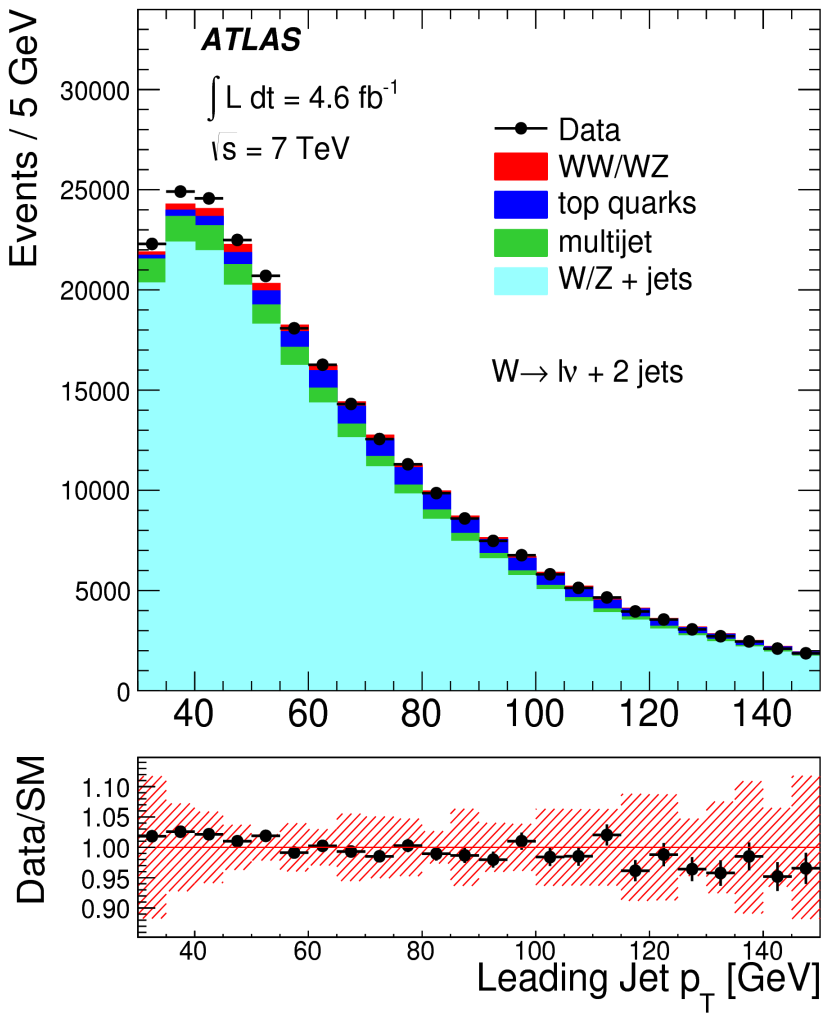


Events / 5 GeV
200
150
100
50
0
50
100
150
200
250
Dijet mass [GeV]
WW
WZ
ATLAS Simulation
W→ eν + 2 jets

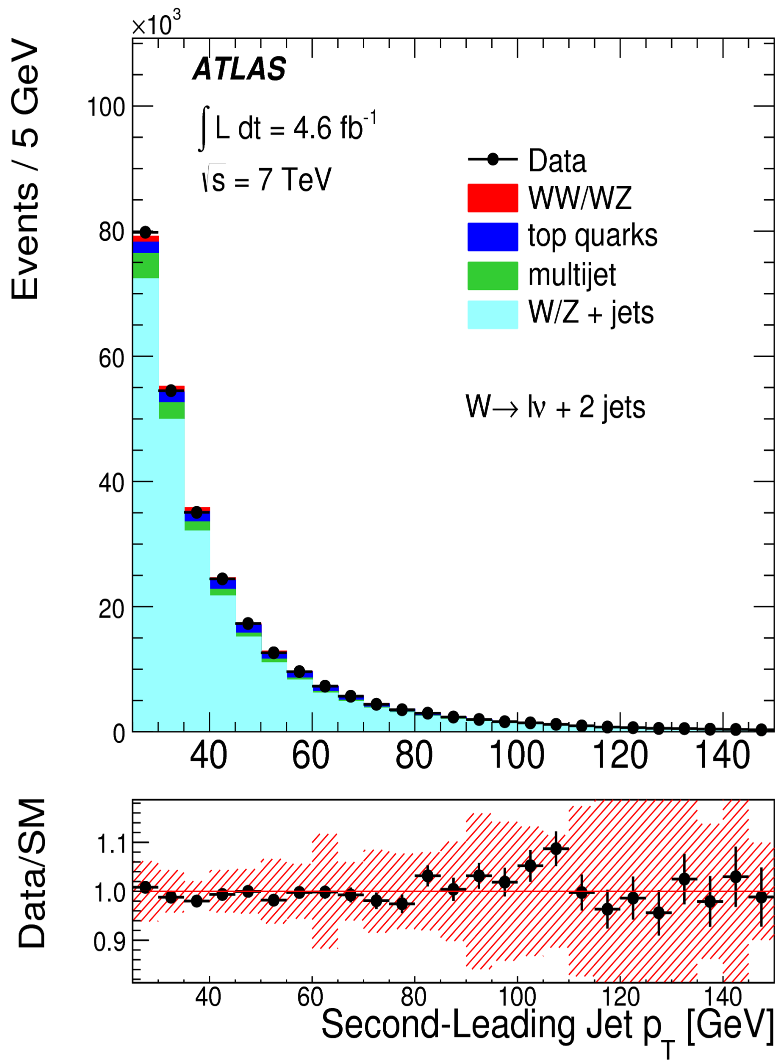


Events / 5 GeV
200
100
0
50
100
150
200
250
Dijet mass [GeV]
WW
WZ
ATLAS Simulation
W→ μν + 2 jets

Data-mc (1)

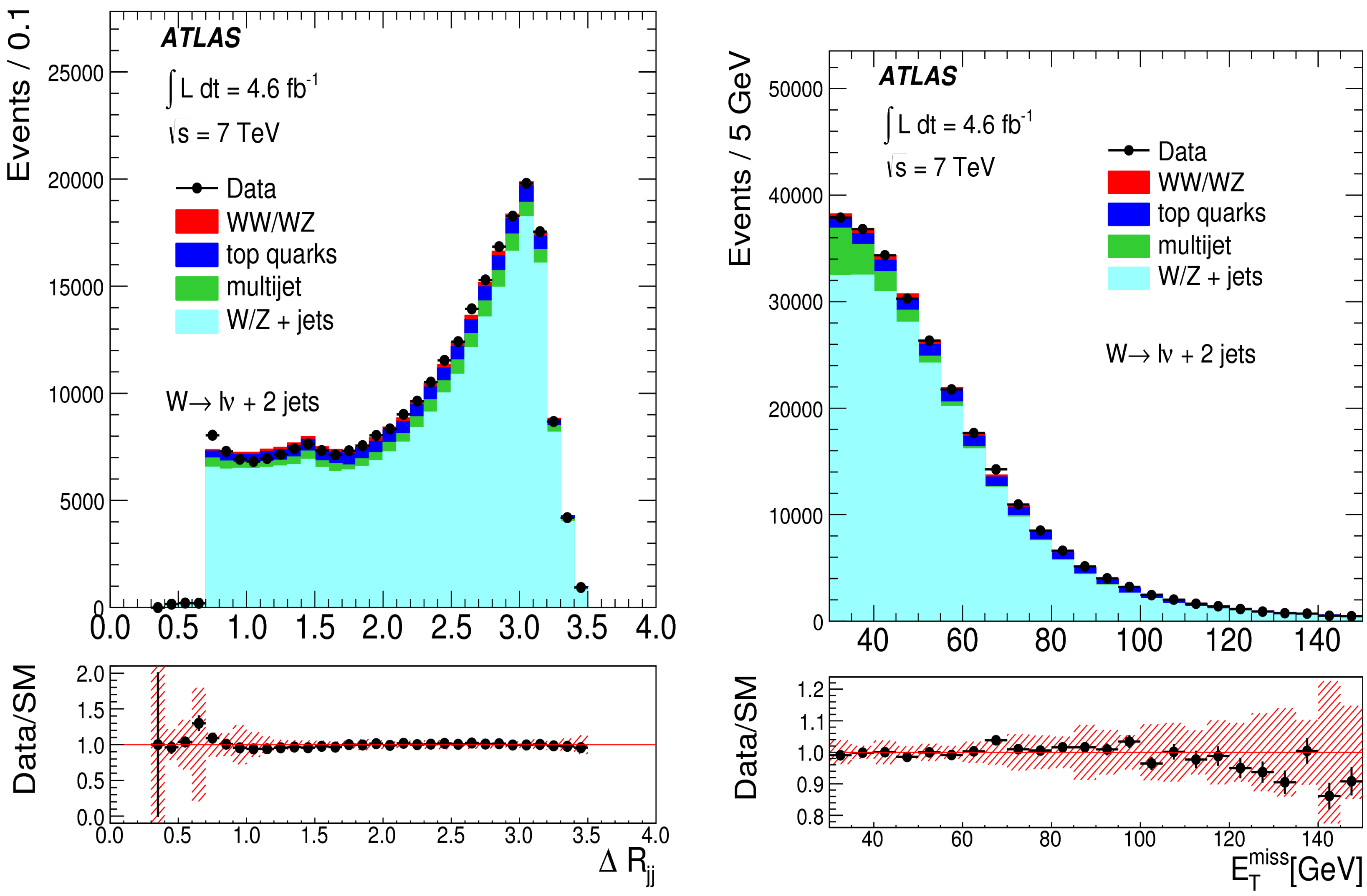


ATLAS
$\int L\,dt = 4.6\ fb^{-1}$
$\sqrt{s}$ = 7 TeV
Data
WW/WZ
top quarks
multijet
W/Z + jets
W→ lν + 2 jets
Events / 5 GeV
Data/SM
Leading Jet p_T [GeV]

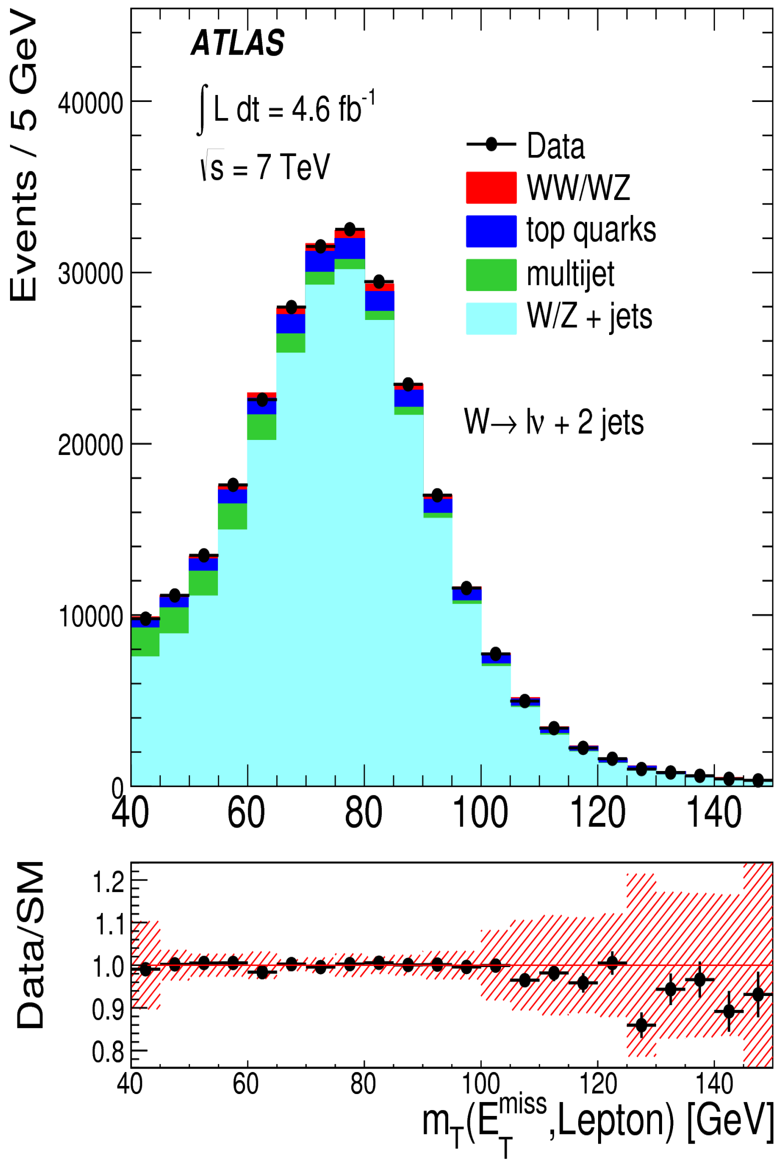


ATLAS
$\int L\,dt = 4.6\ fb^{-1}$
$\sqrt{s}$ = 7 TeV
Data
WW/WZ
top quarks
multijet
W/Z + jets
W→ lν + 2 jets
Events / 5 GeV
$\times 10^3$
Data/SM
Second-Leading Jet p_T [GeV]

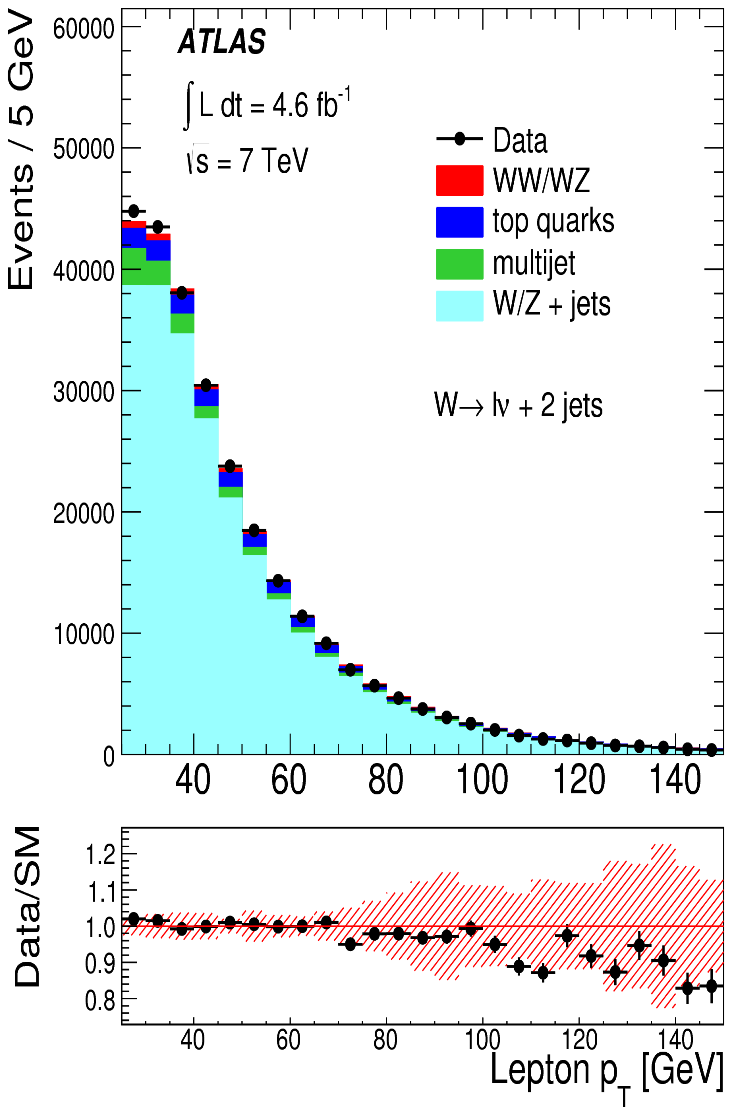
Data-mc (2)


ATLAS
∫ L dt = 4.6 fb-1
√s = 7 TeV
Data
WW/WZ
top quarks
multijet
W/Z + jets
W→ lν + 2 jets
Events / 0.1
Data/SM
Δ Rjj
Events / 5 GeV
E_T^miss [GeV]

Data-mc (3)

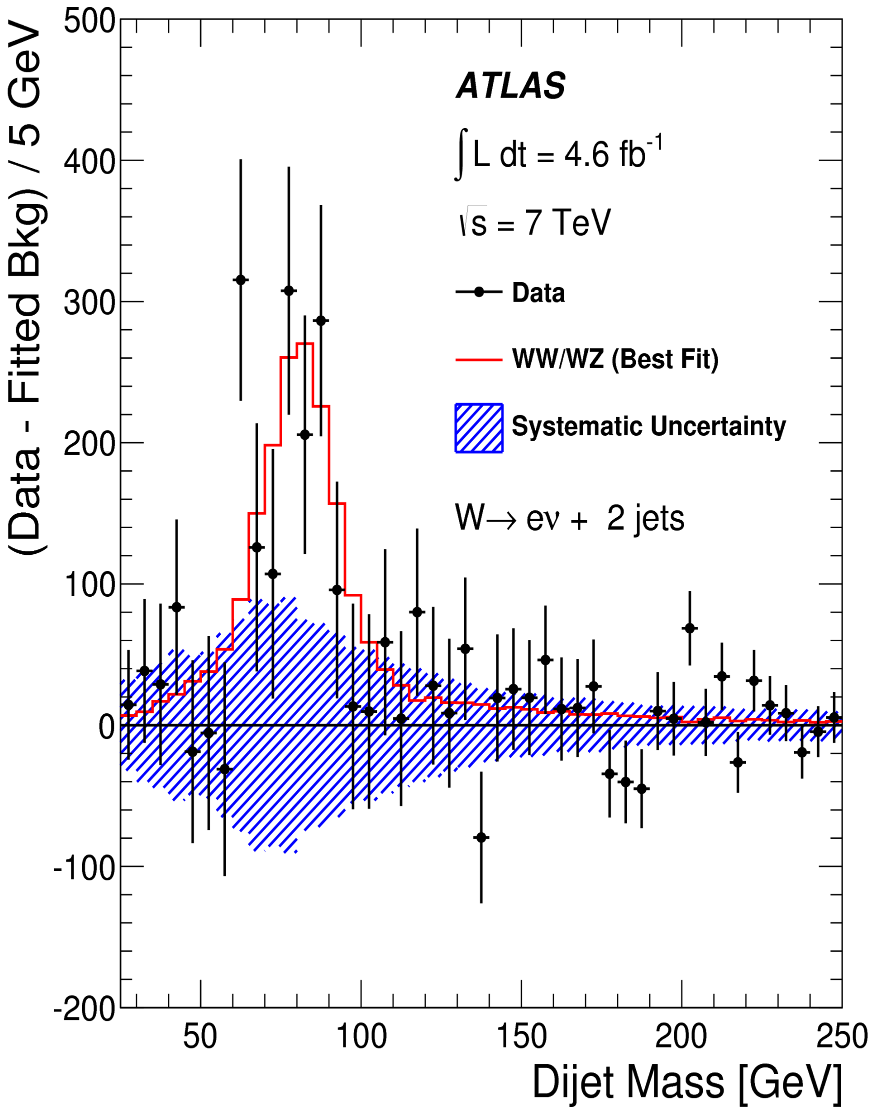


ATLAS
∫L dt = 4.6 fb-1
√s = 7 TeV
Data
WW/WZ
top quarks
multijet
W/Z + jets
W→ lν + 2 jets
Events / 5 GeV
Data/SM
m_T(E_T^miss,Lepton) [GeV]

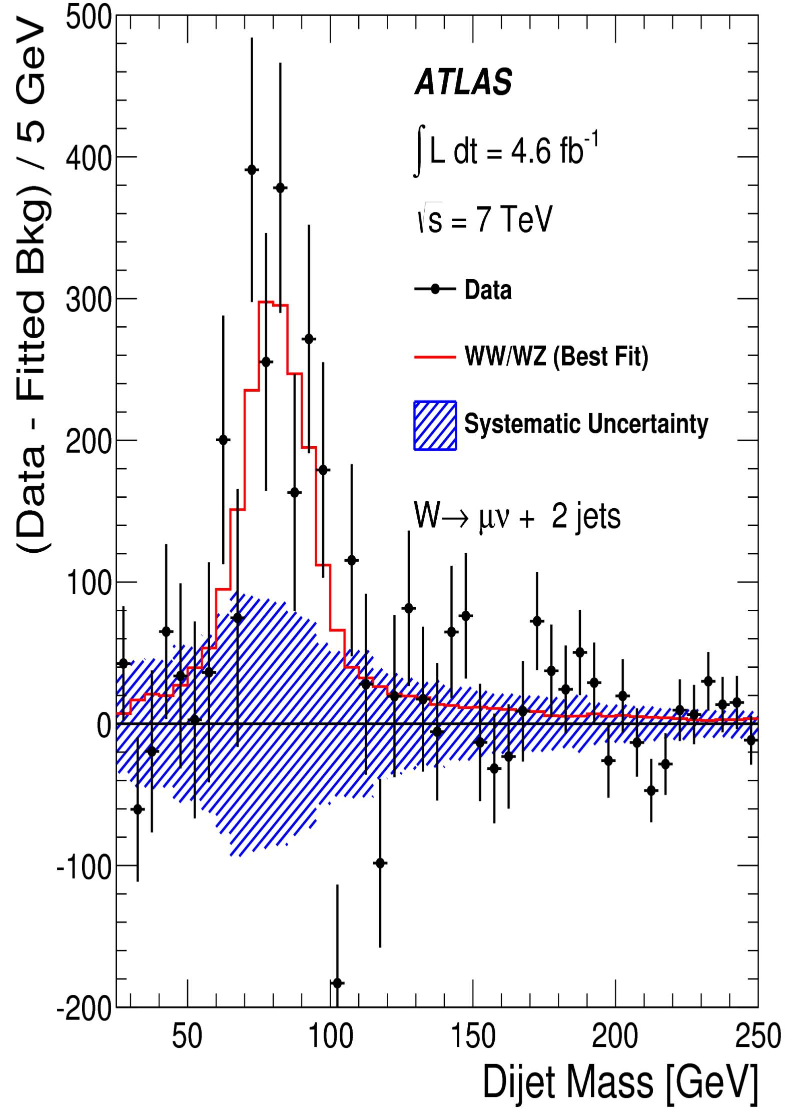


ATLAS
∫L dt = 4.6 fb-1
√s = 7 TeV
Data
WW/WZ
top quarks
multijet
W/Z + jets
W→ lν + 2 jets
Events / 5 GeV
Data/SM
Lepton p_T [GeV]

Data-bkg



ATLAS
$\int L\,dt = 4.6\ fb^{-1}$
$\sqrt{s} = 7$ TeV
Data
WW/WZ (Best Fit)
Systematic Uncertainty
W→ eν + 2 jets
(Data - Fitted Bkg) / 5 GeV
Dijet Mass [GeV]



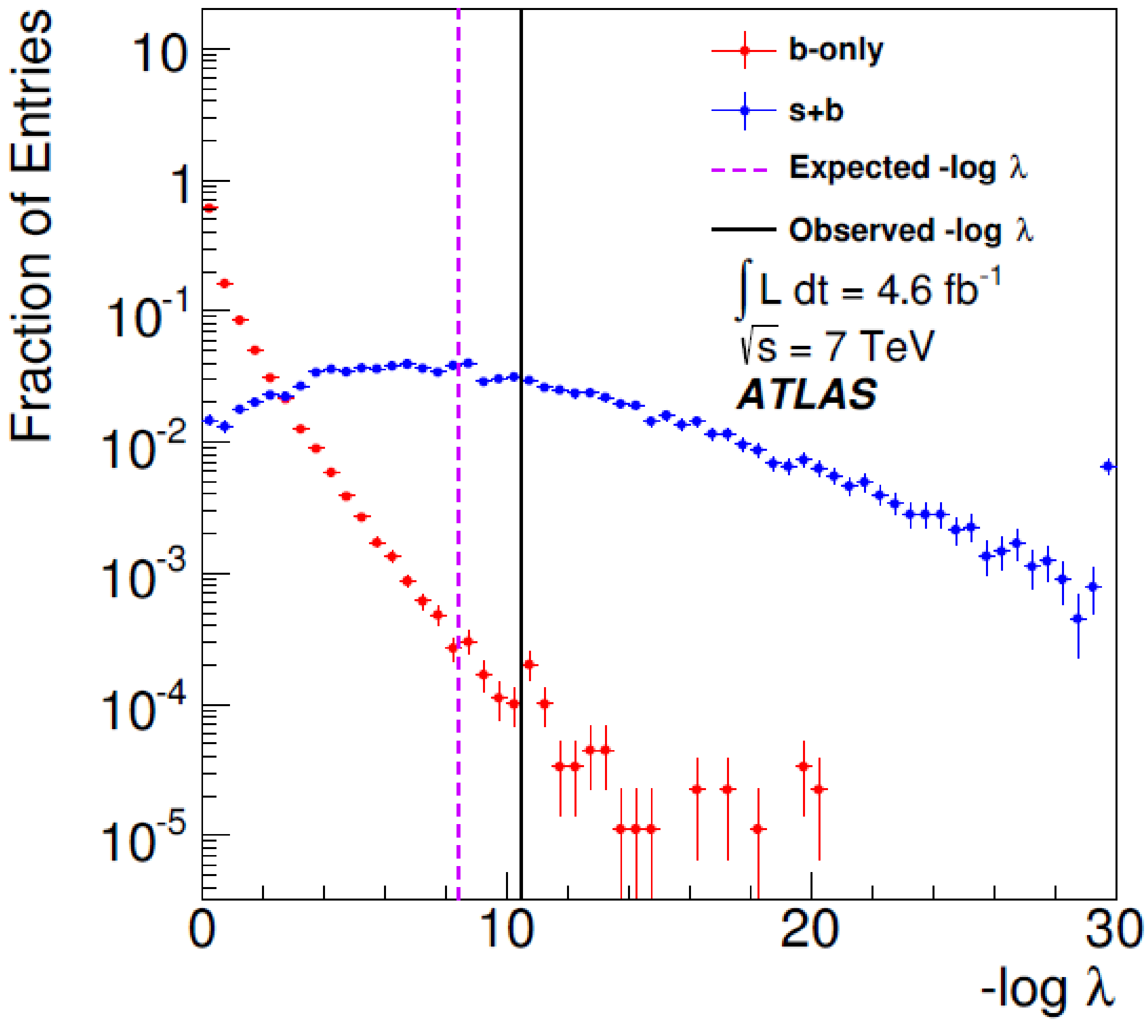
ATLAS
$\int L\,dt = 4.6\ fb^{-1}$
$\sqrt{s} = 7$ TeV
Data
WW/WZ (Best Fit)
Systematic Uncertainty
W→ μν + 2 jets
(Data - Fitted Bkg) / 5 GeV
Dijet Mass [GeV]

W+jets modeling systematics

- We have large systematics on shape of W+jets pT distribution. These come from varying two parameters in Alpgen:
  - ΔR jet-parton matching scheme
  - Renorm/fact. Scale ("qfac")

- For ΔR, samples generated for ΔR=0.4, 1.0 (nominal=0.7)
- For qfac, samples generated with double and half the nominal scale.

Auxiliary Plots (5)



Fiducial Phase-space (same for e/μ)

- $W \rightarrow l\nu$ with lepton pT>25 GeV, $|\eta|<2.47$ ($l=e,\mu$)
- 2 jets with $|\eta|<2.0$. pT1>30 GeV, pT2> 25 GeV.
- MET>30 GeV
- mT>40 GeV
- $\Delta\phi$(MET,j1)>0.8
- $|\Delta\eta(j1,j2)|<1.5$
- $\Delta R(j1,j2)>0.7$ for pTjj<250 GeV
- 25<m(j1,j2)<250 GeV

aTGC formalism

- 5 C- and P-conserving aTGC parameters total: Δg_1^Z, $\Delta\kappa_Z$, λ_Z, $\Delta\kappa_\gamma$, λ_γ

$$\mathcal{L}_{WWV} = -i\, g_{WWV}\Big[g_1^V(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + \kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\lambda_V}{M_W^2} W^\dagger_{\lambda\mu} W^\mu_\nu V^{\nu\lambda}\Big]$$

- To simplify limits, work within the “LEP” scenario:

$$\lambda_z = \lambda_\gamma$$

$$\Delta\kappa_z = \Delta g_1^z - \Delta\kappa_\gamma \tan^2\theta_w$$

- Fit three parameters: λ and $\Delta\kappa_\gamma$ and Δg_1^Z

Fiducial Cross-section

- New addition to analysis: fiducial cross-section measurement
- Standard fiducial cross-section definition:

$$\sigma_{fid} = \frac{N_{meas}}{\mathcal{L} \cdot C}$$

- For us, measuring WW+WZ simultaneously, so fiducial cross-section more complicated:

$$\sigma_{fid} = \frac{N_{meas}}{\mathcal{L} \cdot D_{fid}}$$

$$D_{fid} = f_{fid}^{WW} \cdot C^{WW} + (1 - f_{fid}^{WW}) \cdot C^{WZ}$$

$$f_{fid}^{WW} = \frac{1}{1 + \frac{\sigma_{\mathrm{WZ,MC@NLO}} \cdot A^{WZ} \cdot \mathcal{B}^{WZ}}{\sigma_{\mathrm{WW,MC@NLO}} \cdot A^{WW} \cdot \mathcal{B}^{WW}}}$$

Nmeas = β*Nexp, where β is extracted from mjj fit

Denominator has weighted average of CWW and CWZ

Data-Driven Multi-jet Estimate

- Control regions enhanced in multi-jet fakes:
- ***Electron: medium++, not tight++***
- ***Muon: invert d0sig requirement***
- Obtain MET templates from control regions
- Fit full MET distribution to extract multi-jet normalization
- Simultaneously extract scale-factors for W/Z+jets used for data-MC comparison

- QCD mjj shape obtained from control region, after subtracting other bkgs

aTGC limit calculation

- aTGC's modeled with MC@NLO+Herwig – same generator as for SM signal.

- Systematics handled by introducing nuisance parameters into fit.
- Normalization systematics: 20% W+jets, 15% top, 15% QCD multi-jet (same as xsec-fit), **15% signal (larger than for x-sec, because of extra mjj cut)**
- Shape systematic: same as xsec-fit, except for negligible components.