Measurement of WW and WZ production with one vector boson decaying hadronically at ATLAS

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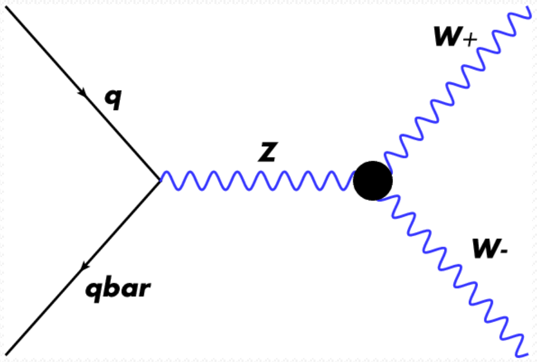
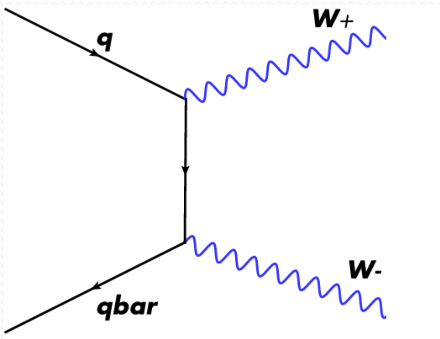
Why this measurement?

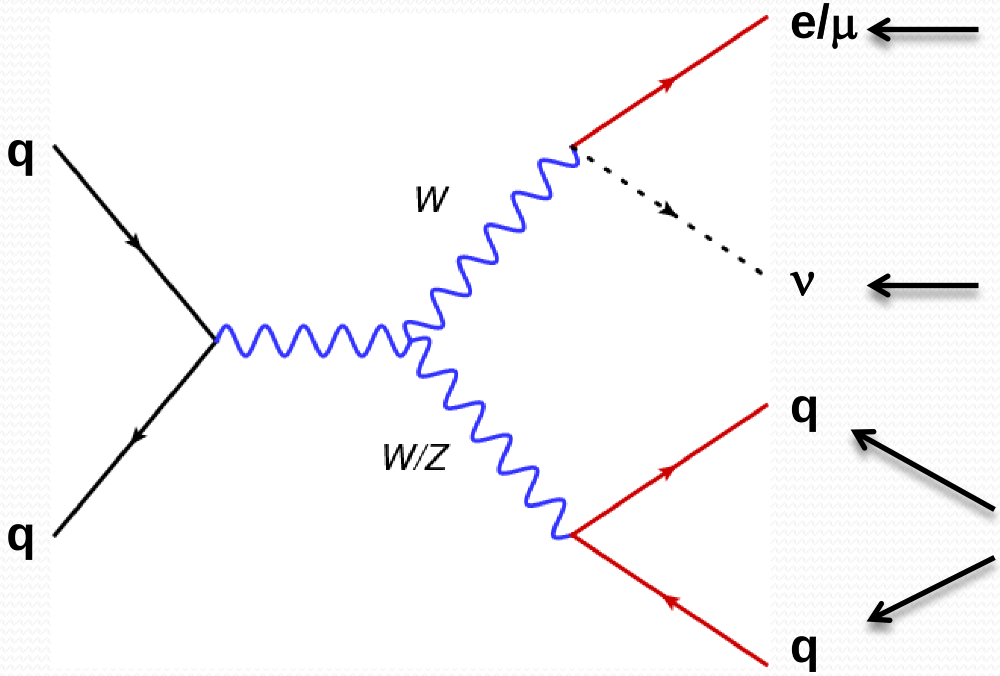
- Measure WW/WZ → lνjj
- Why interested in dibosons?
  - Verification of SM
  - New Physics in anomalous triple gauge couplings (TGC)
  - Step towards measurement of WW scattering (how is unitarity restored)





- Advantages compared to fully leptonic decays
  - Higher σxBF (lνjj ~6x larger than lνlν)
  - Better kinematic constraints (only 1 ν instead of 2)
- Disadvantage compared to fully leptonic:
  - Much higher backgrounds
  - W→jj from WW and Z→jj from WZ can't be distinguished due to the resolution of the dijet mass

Analysis strategy



- Trigger on charged lepton
- Require missing E_T
- 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<3%)
  - Understanding m_{jj} shape of backgrounds is critical

Background and Signal Model

- W/Z+jets
  - Alpgen+Herwig+Jimmy
  - W+Heavy Flavor modeled separately
- ttbar
  - MC@NLO+Herwig
- Single-top
  - MC@NLO
- Multi-jet
  - Data-driven – later in this talk

Normalizations from fit to data

- Signal (WW/WZ)
  - Herwig (LO)
  - Normalization from MCFM (NLO)

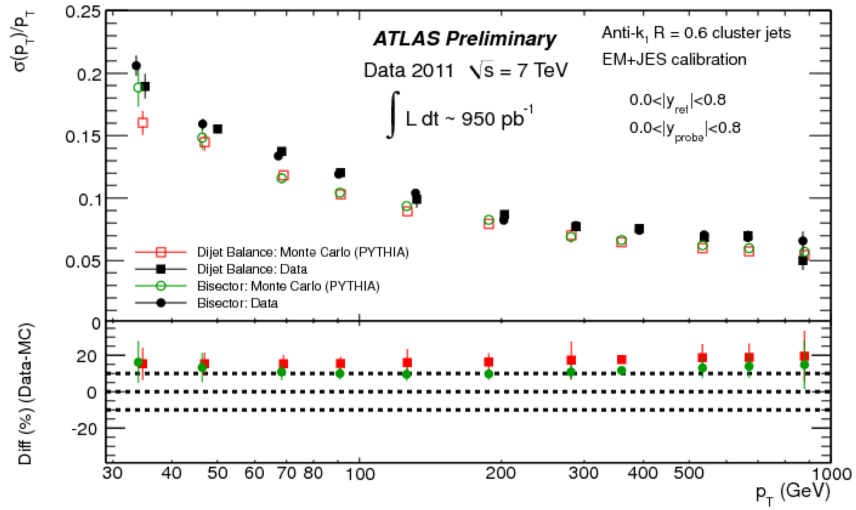
Event Selection

- 4.7 fb^{-1} at 7 TeV
- Use single-electron/muon triggers

- 1 isolated lepton with p_T>25 GeV
- Veto event if extra lepton with p_T>20 GeV
- $p_T(j_1)$> 30 GeV, $p_T(j_2)$> 25 GeV
- Veto event if >2 jets with p_T>20 GeV ← **Reduce ttbar**
- m_T > 40 GeV
- Missing E_T>30 GeV ← **Reduce multi-jet**
- Lepton matched to primary vertex ← **Reduce multi-jet**
- $\Delta\phi$(MET,j1)>0.8 ← **Reduce multi-jet**
- $\Delta R(j,\ell)$>0.5
- $\Delta\eta$(j1,j2)<1.5 and ΔR(j1,j2)>0.7

Jet Performance

- Jet p_T measured to ~15% in analysis phase-space
- Jet energy scale (JES) uncertainty 3-5%
  - Includes effect from pile-up



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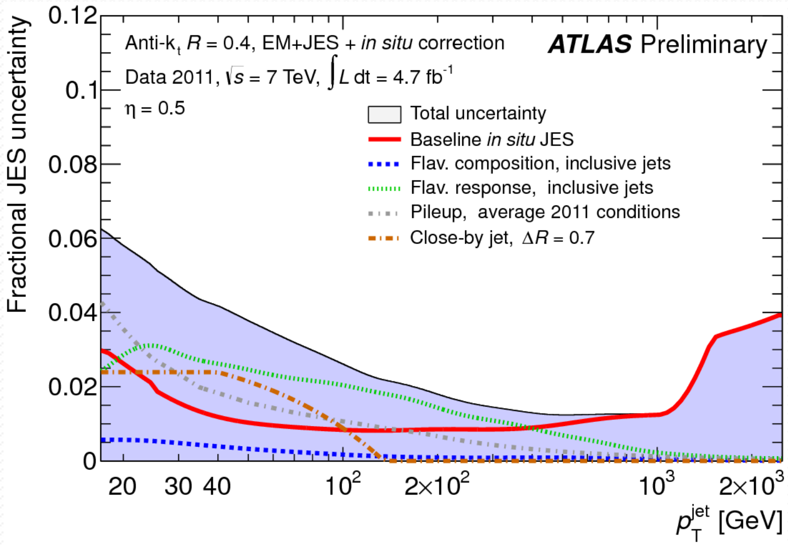
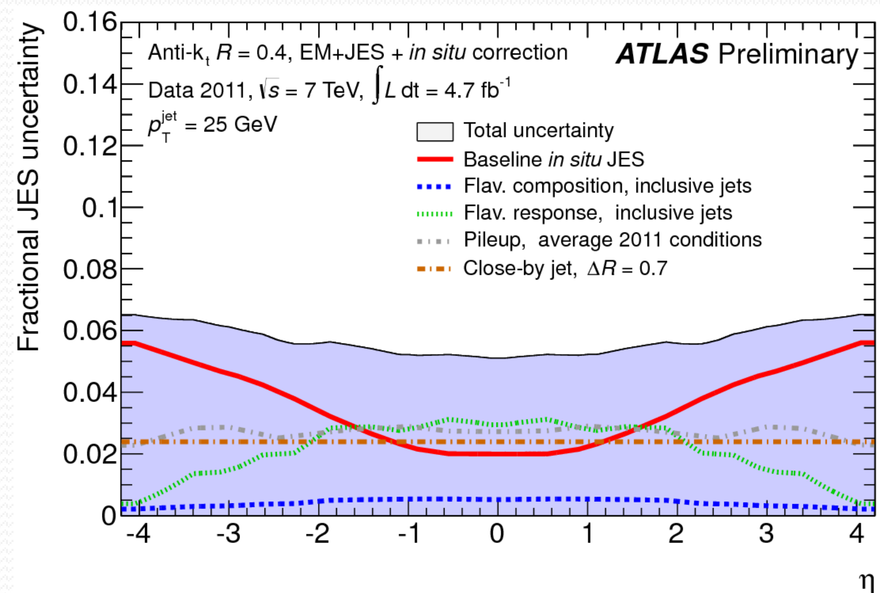
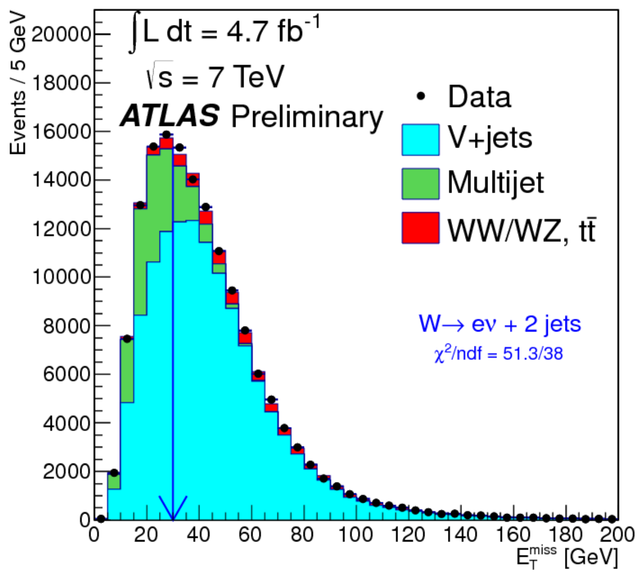
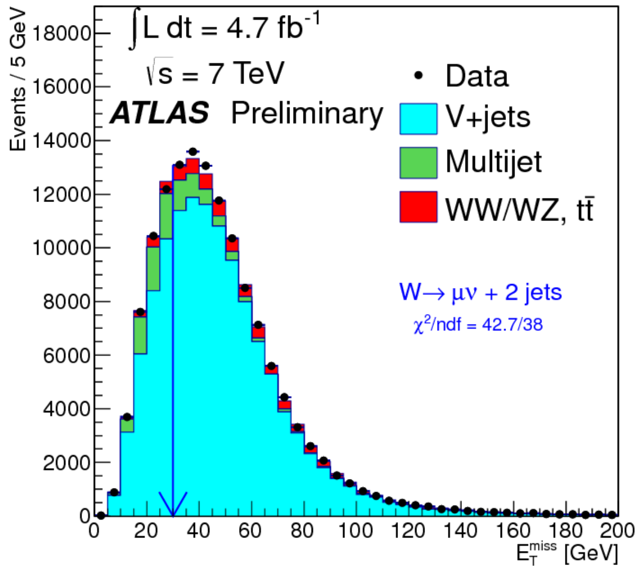




Data-driven multi-jet estimate

- Multi-jet background is due to fake leptons (jets faking electrons, or heavy-flavor jets decaying semi-leptonically)
- Control regions enhanced in multi-jet fakes:
  - Electron: fake electron without Transition Radiation signal
  - Muon: invert muon vertex-matching requirement
- Obtain MET templates from control regions
- Fit full MET distribution to extract multi-jet component
  - Simultaneously extract scale-factors for W/Z+jets used for data-MC comparison





Data vs expectation

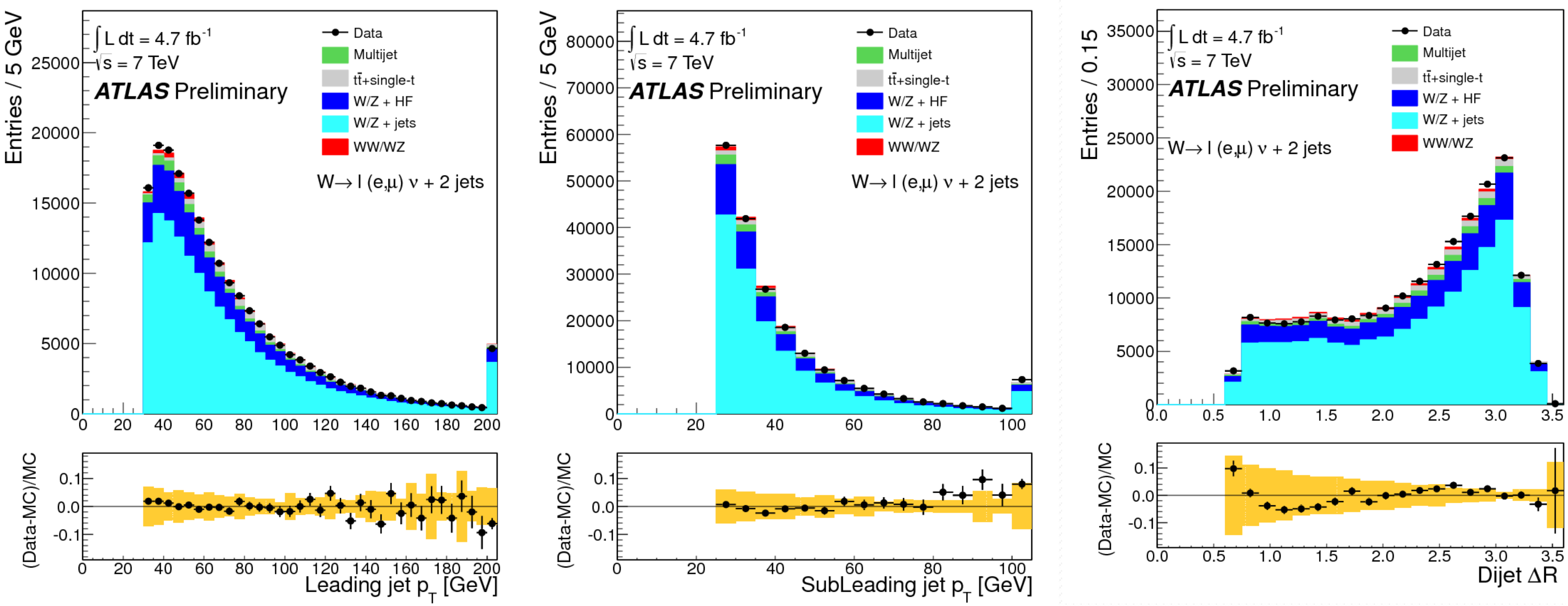
- Breakdown of expected backgrounds
- Expected signal+background agrees with data

Process	e	μ
WW	1250 ± 60	1360 ± 70
WZ	276 ± 19	306 ± 21
W + light jets	$(67 \pm 13) \times 10^3$	$(71 \pm 14) \times 10^3$
W/Z + heavy flavor jets	$(19 \pm 4) \times 10^3$	$(20 \pm 4) \times 10^3$
$t\bar{t}$	$(24.8 \pm 2.5)\times10^2$	$(24.6 \pm 2.5)\times10^2$
single top	$(13.5 \pm 1.3)\times10^2$	$(13.7 \pm 1.4)\times10^2$
multijet	$(50 \pm 15)\times10^2$	$(39 \pm 12)\times10^2$
Z + jets	$(35 \pm 7)\times10^2$	$(32 \pm 6)\times10^2$
$W\gamma + ZZ$	383 ± 19	464 ± 23
Total SM prediction	$(100 \pm 14)\times10^3$	$(103 \pm 15)\times10^3$
Total Data	100055	103627
Signal efficiency for $60 < m_{jj} < 120$ GeV	0.7%	0.9%
Signal to background ratio for $60 < m_{jj} < 120$ GeV	2.6%	2.8%

(errors in table are from cross-section uncertainties only)

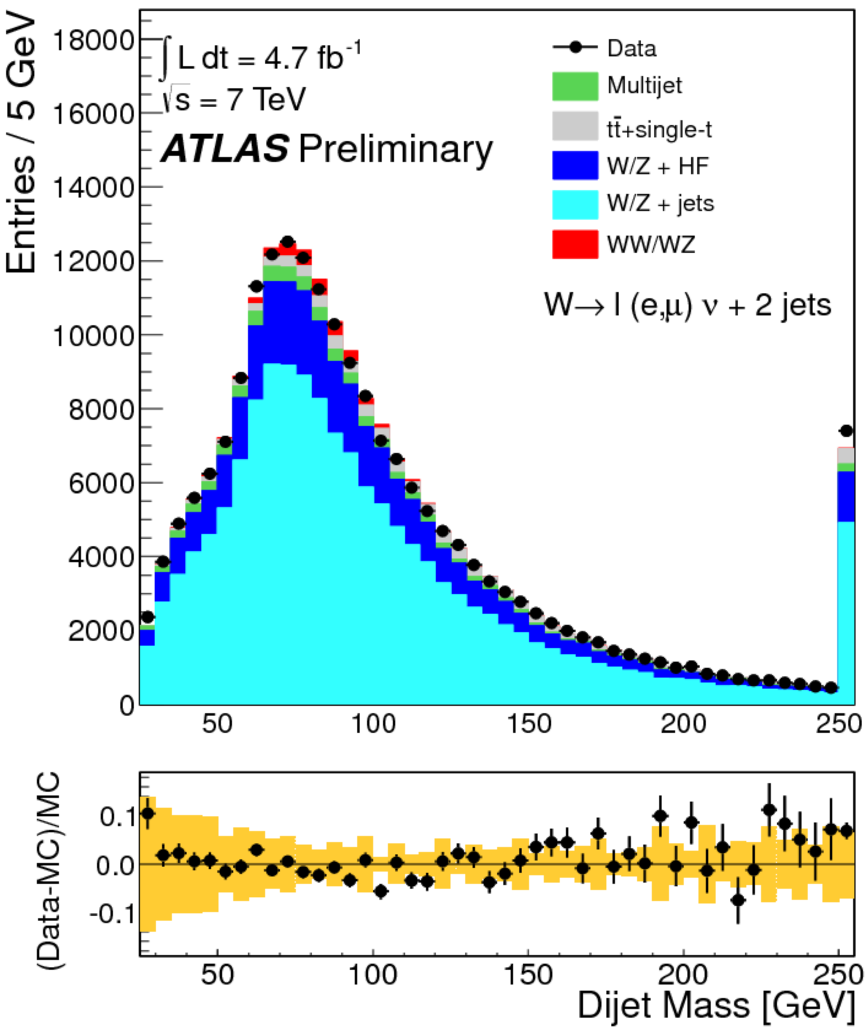
MC-data agreement

- Plots show kinematic distributions of jets forming the W/Z→jj candidate
- Data well described by MC, within systematic uncertainties
- Yellow error band gives effect of Jet Energy scale (JES) only



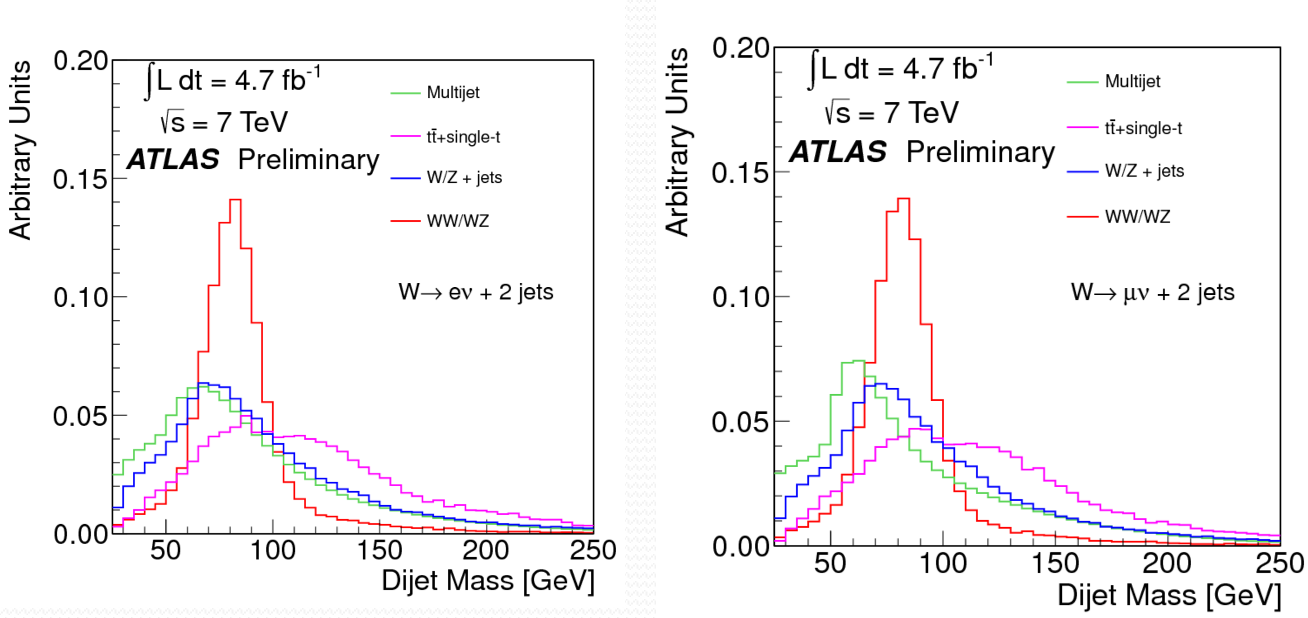
MC-data agreement (2)

- Dijet-mass spectrum well described by signal+background model
- W/Z+jets background (no true W/Z→jj) peaks close to the signal (true W/Z→jj)



Fitting procedure

- Perform binned maximum-likelihood fit to m_{jj} in interval [25-250] GeV.
- Fit separately and simultaneously the e and μ channels



Histograms normalized

- 3 backgrounds: W/Z+jets, top, and multi-jet, allowed to float, subject to log-normal constraints → large sidebands allows backgrounds to be constrained
- Fit for $\mu=\sigma(\text{fitted})/\sigma(\text{SM})$, σ(SM) at NLO using MCFM

Incorporation of Systematics

- Systematics can affect both the shapes and normalization of histograms in the m_{jj} fit
- Shape systematics: float nuisance parameters α_j that interpolate between nominal and modified histogram shapes

Shape

- MC statistics (mainly W/Z+jets) -- 18%
- Jet energy scale – 12%
- Jet energy resolution – 6%
- Multi-jet shape/normalization – 5%

Normalization

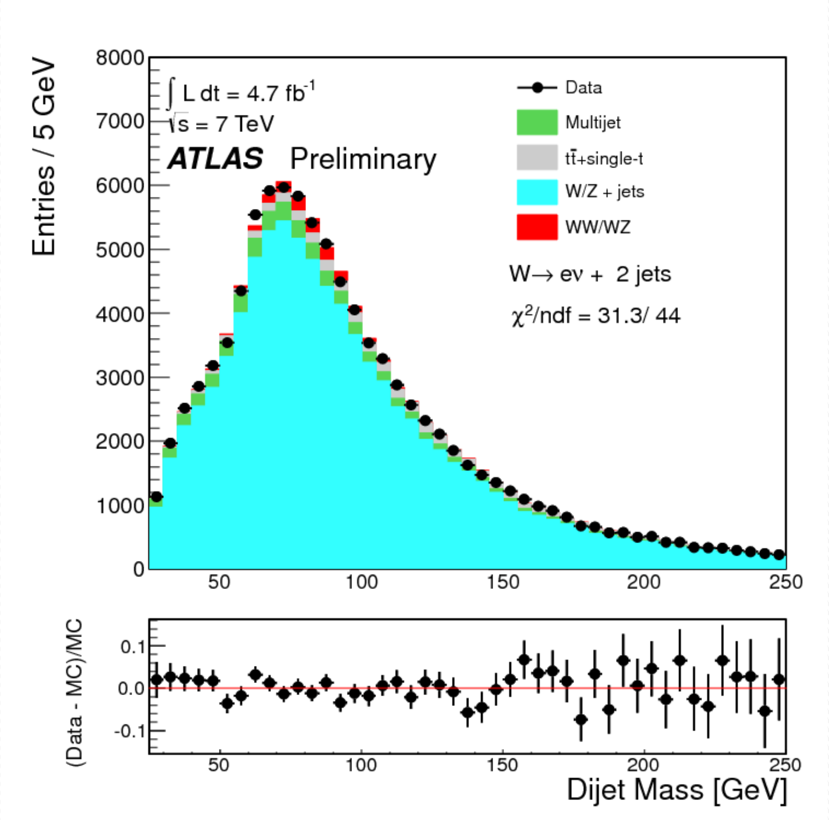
- W/Z+jets normalization – 11%
- Top normalization – 6%
- Luminosity -- 3.9%

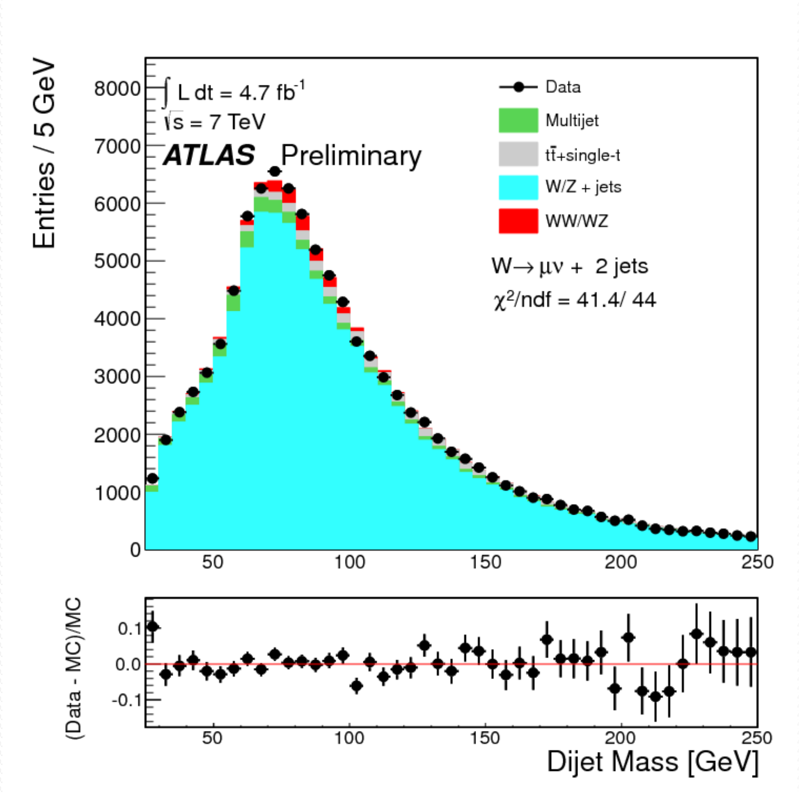
Total systematics: 28%

- MC statistics and JES systematic not profiled in fit; instead, varied up and down in a toy MC method

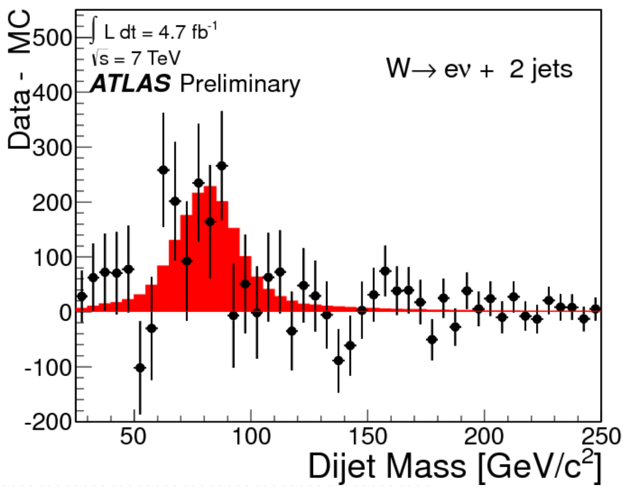
Fit result

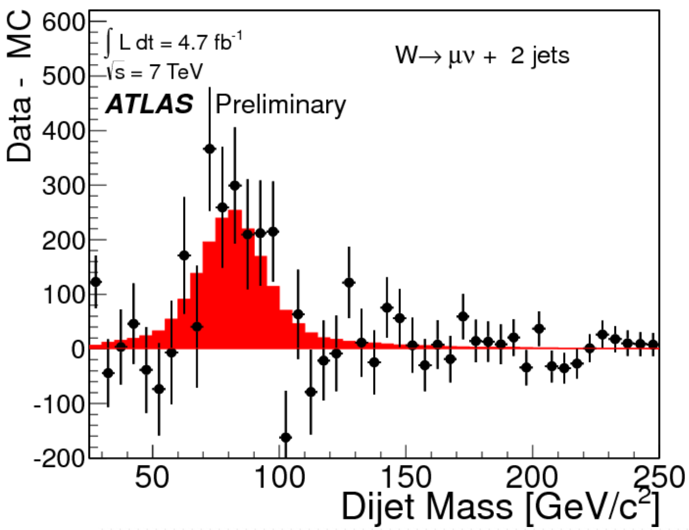
- σ(fitted)/σ(SM) = 1.13 ± 0.34
- σ(WW+WZ) = 72 ± 9 (stat) ± 15 (syst) ± 13 (MC stat) pb
- SM prediction: σ = 63.4 ± 2.6 pb

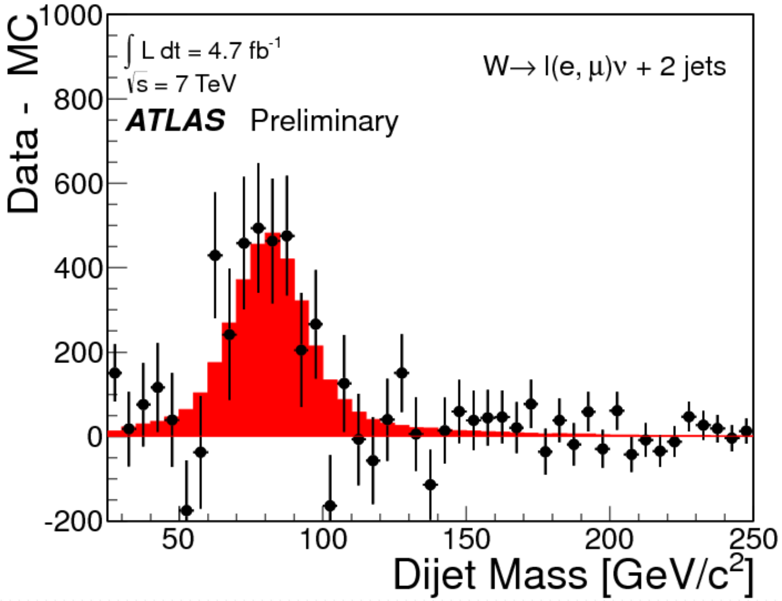




Background subtracted

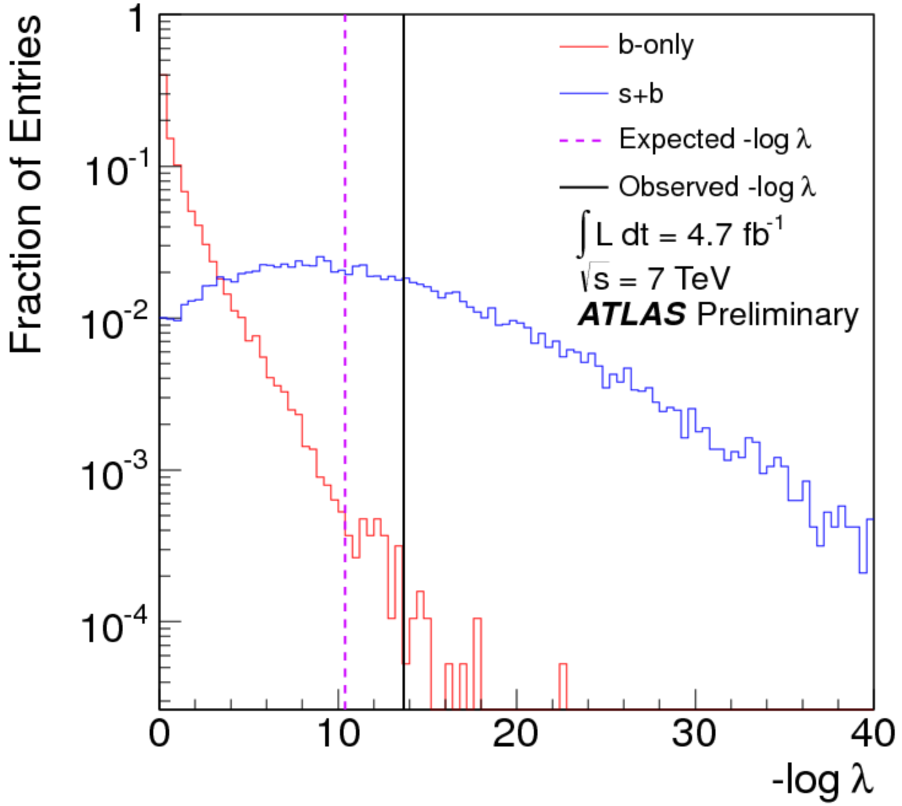






Significance

- Calculate significance using toy MC method
- Use profile-likelihood ratio λ as test-statistic
- Compute λ for both bkg-only and sig+bkg toys to estimate expected significance
- Includes systematics



- Expected: 3.0 sigma
- Observed: 3.3 sigma

Summary

- Evidence (3.3 sigma) for WW/WZ process in the challenging semileptonic channel at ATLAS

- Signal/SignalSM = 1.13 ± 0.34
- σ(WW+WZ) = 72 ± 9 (stat) ± 15 (syst) ± 13 (MC stat) pb
- Consistent with SM: 63.4 ± 2.6 pb

Backup

Incorporation of Systematics

- Systematics can affect both the shapes and normalization of histograms in the m_{jj} fit
- Shape systematics: float nuisance parameters α_j that interpolate between nominal and modified histogram shapes

$$h_{jk}(x) = h^0_{jk}(x) + \alpha_j \left(h^+_{jk}(x) - h^0_{jk}(x)\right), \; \alpha_j \geq 0,$$
$$h^0_{jk}(x) - \alpha_j \left(h^-_{jk}(x) - h^0_{jk}(x)\right), \; \alpha_j < 0.$$

- JES systematic not fitted; instead, varied up and down in toys

Source of Systematic	Type	Profiled
W/Z+jets rate	Norm.	yes
W/Z+jet modeling	Shape	yes
$t\bar{t}$+single t rate	Norm.	yes
ISR/FSR for $t\bar{t}$	Norm. and Shape	yes
multijet rate	Norm.	no
multijet shape	Shape	no
PDF all processes but multijet	Norm.	no
JES uncertainty all processes but multijet	Shape	no
JES uncertainty signal	Norm.	no
JER uncertainty background except multijet	Shape	yes
JER uncertainty WW/WZ	Norm. and Shape	yes
lepton reconstruction all processes except multijet	Norm.	no
ISR/FSR for WW/WZ	Norm. and Shape	yes
MC statistics all processes	N.A.	no

Systematics table

Mainly W+jets MC statistics

Source	$\Delta\sigma/\sigma[\%]$
Data Statistics	± 12
MC Statistics	± 18
W/Z+jets normalization	± 11
W/Z jets shape variation	± 5
Multijet shape and normalization	± 5
Top normalization	± 6
Top ISR/FSR	± 1
Jet energy scale (all samples)	± 12
Jet energy resolution (all samples)	± 6
Lepton reconstruction (all samples)	± 1
WW/WZ ISR/FSR	± 2
JES uncertainty on WW/WZ normalization	± 6
PDF (all samples)	± 2
Luminosity	± 3.9
Total systematics	± 28