ATLAS Measurements of Electroweak Boson Production Cross Sections

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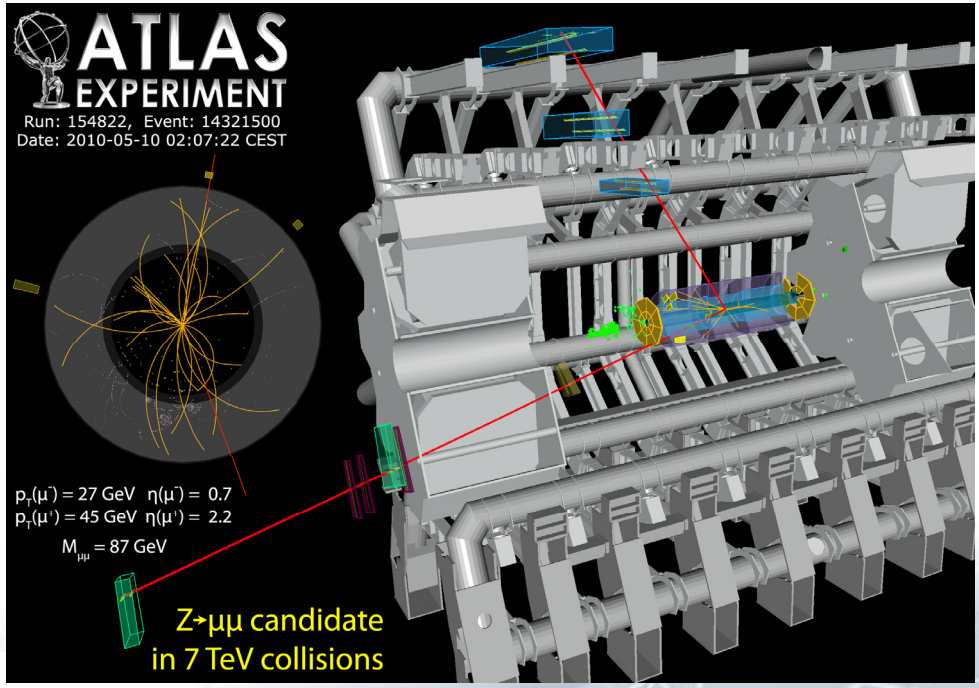
Cross section measurements:

- Inclusive W/Z
- W/Z+jets
- Diboson



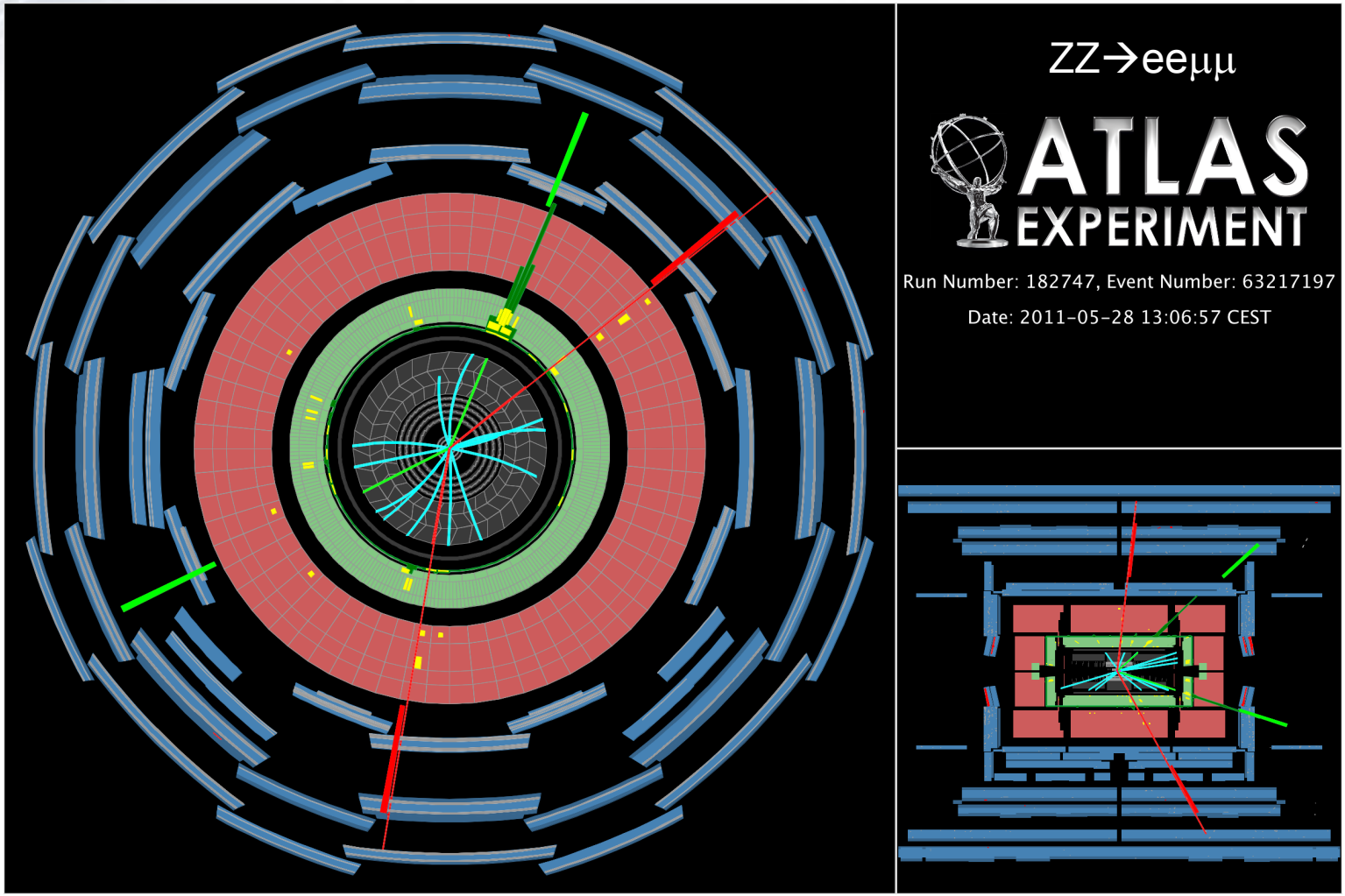
BMBF-Forschungsschwerpunkt
ATLAS Experiment
Physics on the TeV-scale at the Large Hadron Collider
FSP 101 ATLAS

Introduction

Cross section measurements:

- Inclusive W/Z
  - 2010 Dataset 33-36 pb^{-1}
  - Sensitive to Parton Density Functions (PDFs), W lepton universality
- W/Z+jets
  - 2010 Dataset 33-36 pb^{-1}
  - Test of QCD calculations and MC generators
- Diboson
  - 2011 Dataset (till June) 1 fb^{-1}
  - Sensitive to Triple Gauge Couplings (TGCs)
- Measurements done with high p_T electrons and muons
  - Precise understanding of lepton reconstruction, identification, calibration and resolution in W/Z events required

The ATLAS detector



- Tracking system ($|\eta| < 2.5$)
- Calorimeters (central $|\eta| < 2.5$, forward $|\eta| < 4.9$
- Muon systems ($|\eta| < 2.7$)

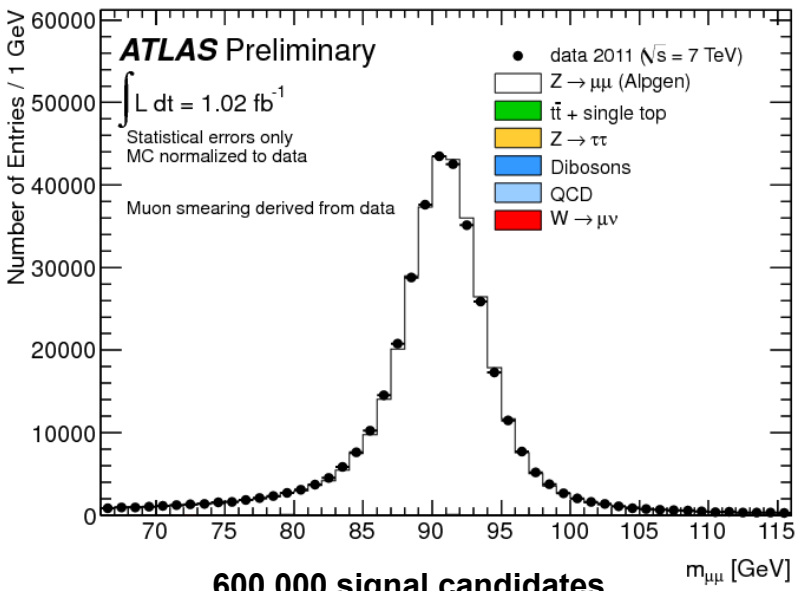
Inclusive W and Z

Selection

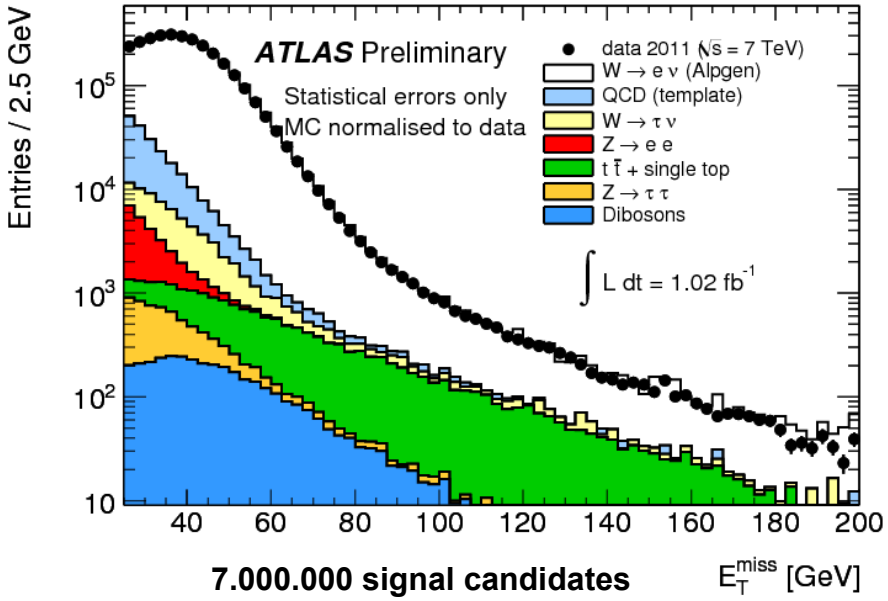
- High p_T lepton(s) l=e,μ
  - Electons: E_T>20GeV, Muons: p_T>20GeV, isolated
- Z candidate:
  - Mass in range [66,116] GeV, opposite charge
- W candidate:
  - High missing E_T and M_T
- Very clean signal

Detailed background estimation

- Multi-jet ("QCD") by data driven methods
  - Template fit (cut inversion)
  - Matrix method
- Electroweak from MC



600.000 signal candidates



7.000.000 signal candidates

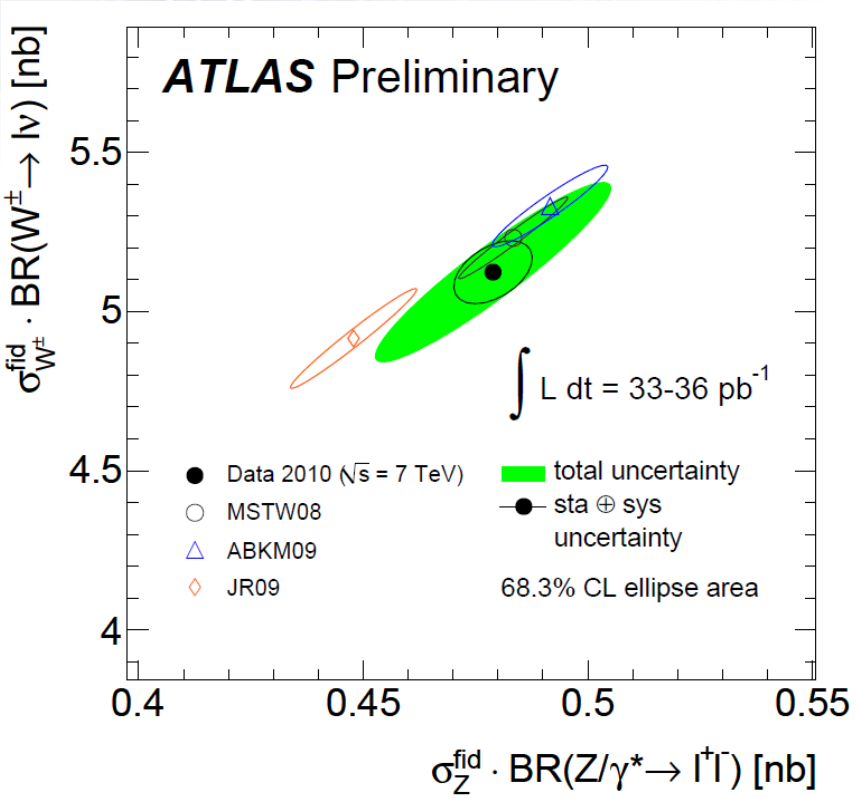
Inclusive W and Z

Fiducial cross section $\sigma_{Fid} = \frac{N_{Obs} - N_{Bkg}}{C \cdot L_{Int}}$

Total cross section $\sigma_{Tot} = \frac{N_{Obs} - N_{Bkg}}{A \cdot C \cdot L_{Int}}$

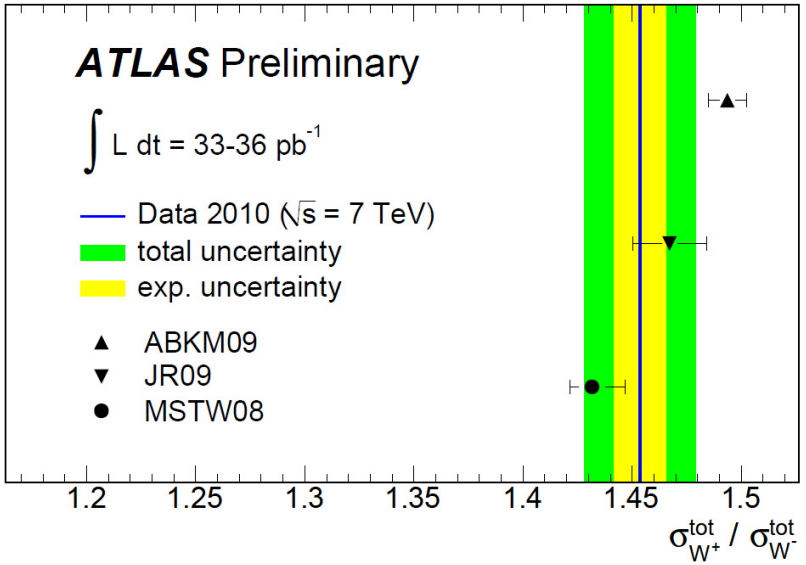
Uncertainties:

- Luminosity
- Acceptance
- Experimental ~1%
  - W: MET scale and resolution uncertainty
  - W,Z: electron/muon reconstruction and ID efficiency



Individual channel cross sections consistent

σ_{tot} [nb]	σ_{tot}	$\Delta\sigma_{stat}$	$\Delta\sigma_{syst}$	$\Delta\sigma_{lum}$	$\Delta\sigma_{acc}$
W^+ combined	6.041	0.016	0.077	0.205	0.096
W^- combined	4.156	0.014	0.058	0.141	0.083
W combined	10.197	0.021	0.127	0.347	0.165
Z/γ^* combined	0.937	0.006	0.009	0.032	0.016

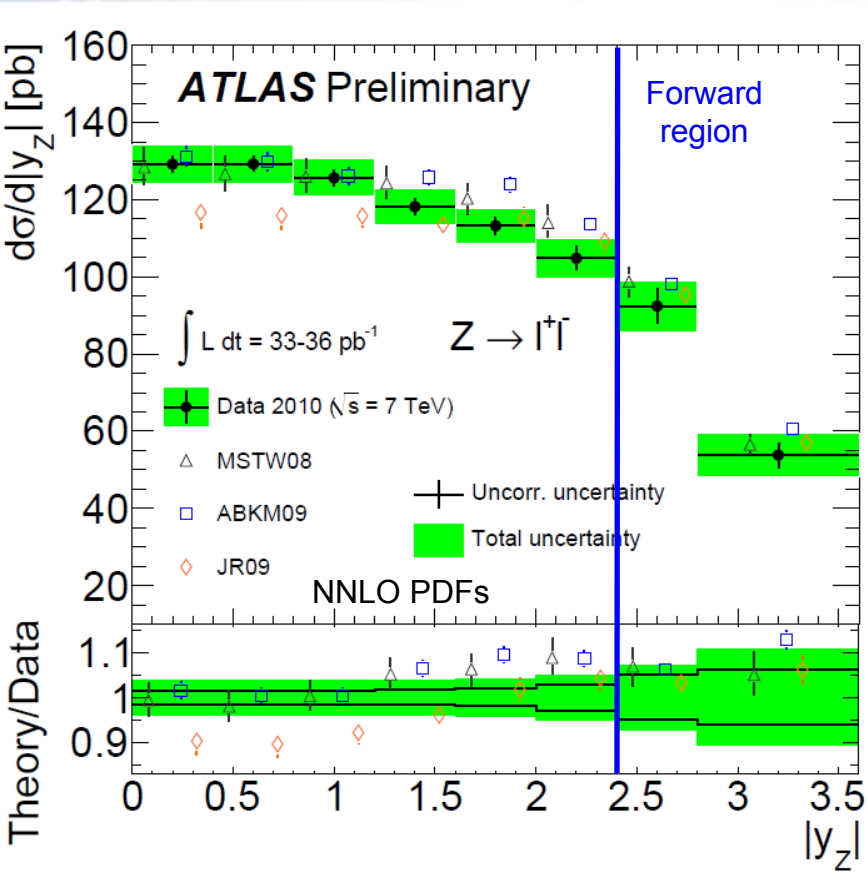


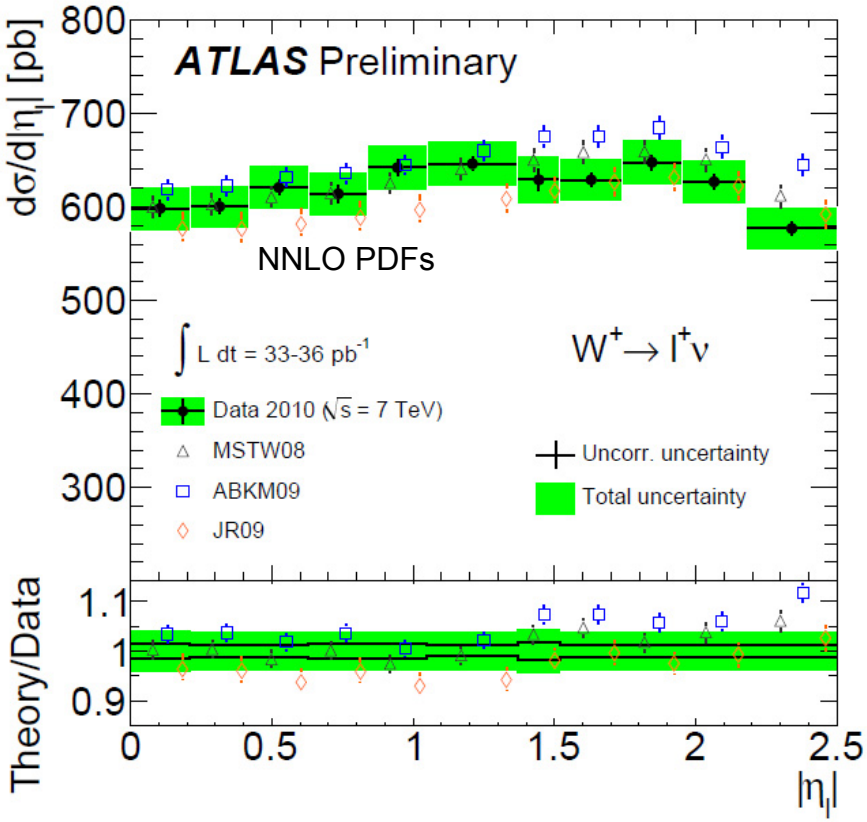
Experimental precision of ~1%!

Limited by luminosity uncertainty!

Reference: **paper to be published (soon)**

Inclusive W and Z: y/η - differential



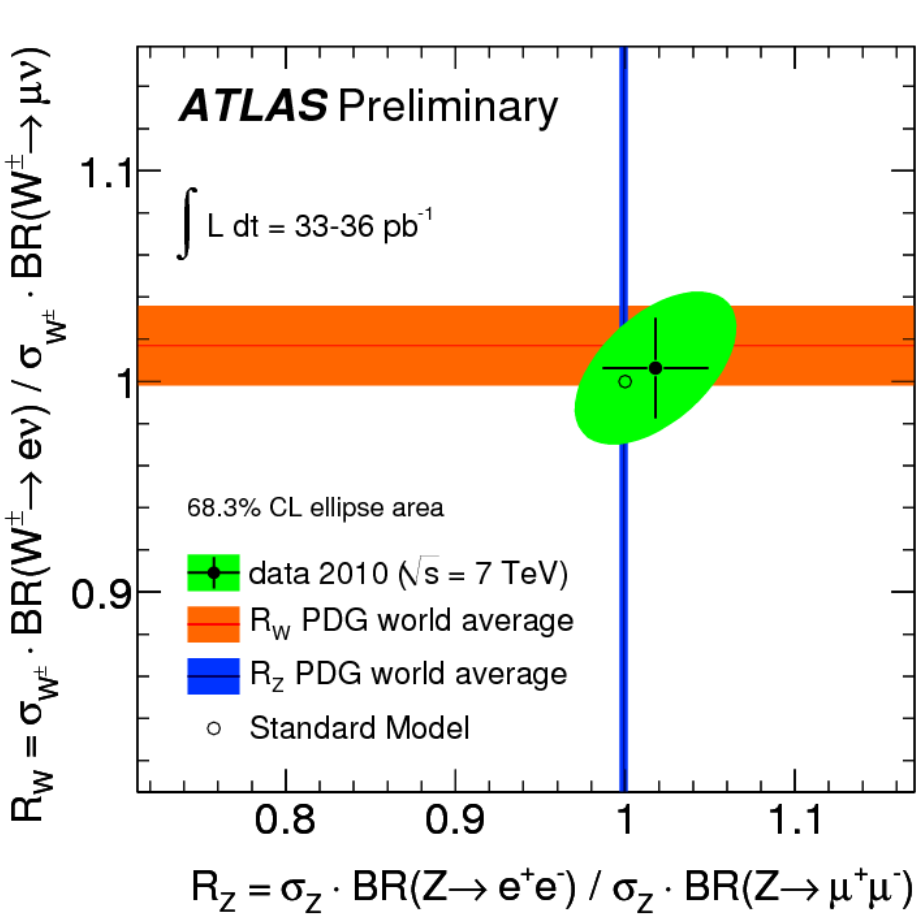


- Differential measurement includes forward electrons for the first time!

Can be used to improve PDFs

Reference: **paper to be published (soon)**

W lepton universality



- W lepton universality measurement competitive with PDG world average: 2.4% w.r.t. 1.9%

Precise test of SM

W/Z+jets

Motivation

- Test of QCD and MC generators
- Important background for SM processes and BSM searches

Reference: **ATLAS-CONF-2011-042**

Z+jets

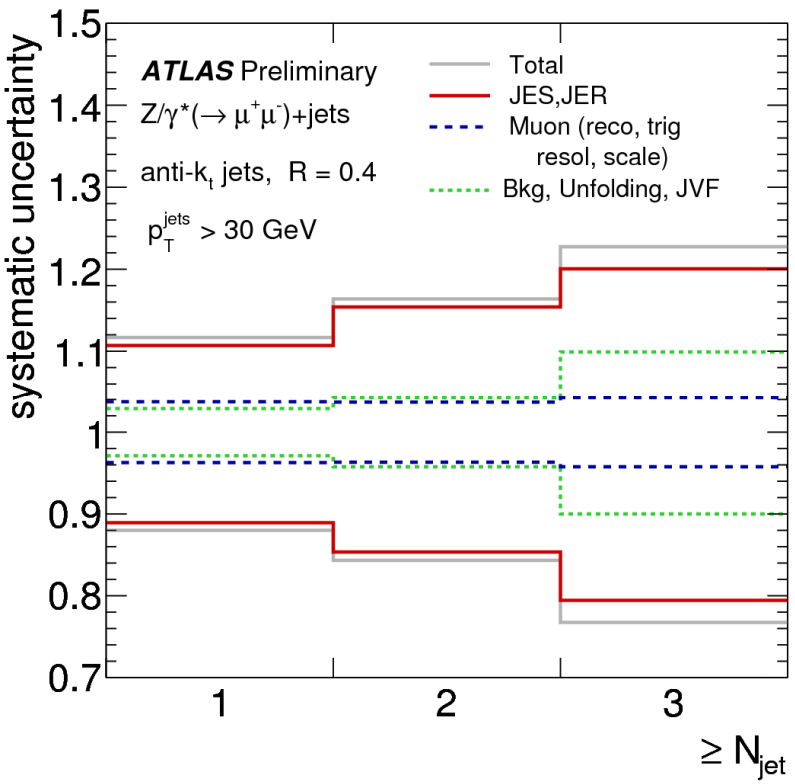
- Selection
  - 2 high p_T leptons
    - Z mass window, exactly 2 leptons of opposite charge
  - High p_T Jet
    - anti-k_T R=0.4, p_T>30 GeV, $|\eta| < 2.8$
- Differential cross sections
  - N_{jet}, $N_{jet/}$ N_{jet}-1,p_T,$p_{T,\text{leading jet}}$, $p_{T,2ng\ \text{leading jet}}$

Reference: **ATLAS-CONF-2011-060**

W+jets

- Selection
  - 1 high pT lepton
    - Isolated, second lepton veto
  - High p_T Jet
    - anti-k_T R=0.4, p_T>20 GeV, $|\eta| < 2.8$
  - High missing E_T
    - Missing E_T>25 GeV
- Differential cross sections
  - N_{jet}, $N_{jet/}$ N_{jet}-1,H_T,p_T (leading jet, 2nd, 3rd and 4th leading jet)

Unfolding used to correct results back to parton level

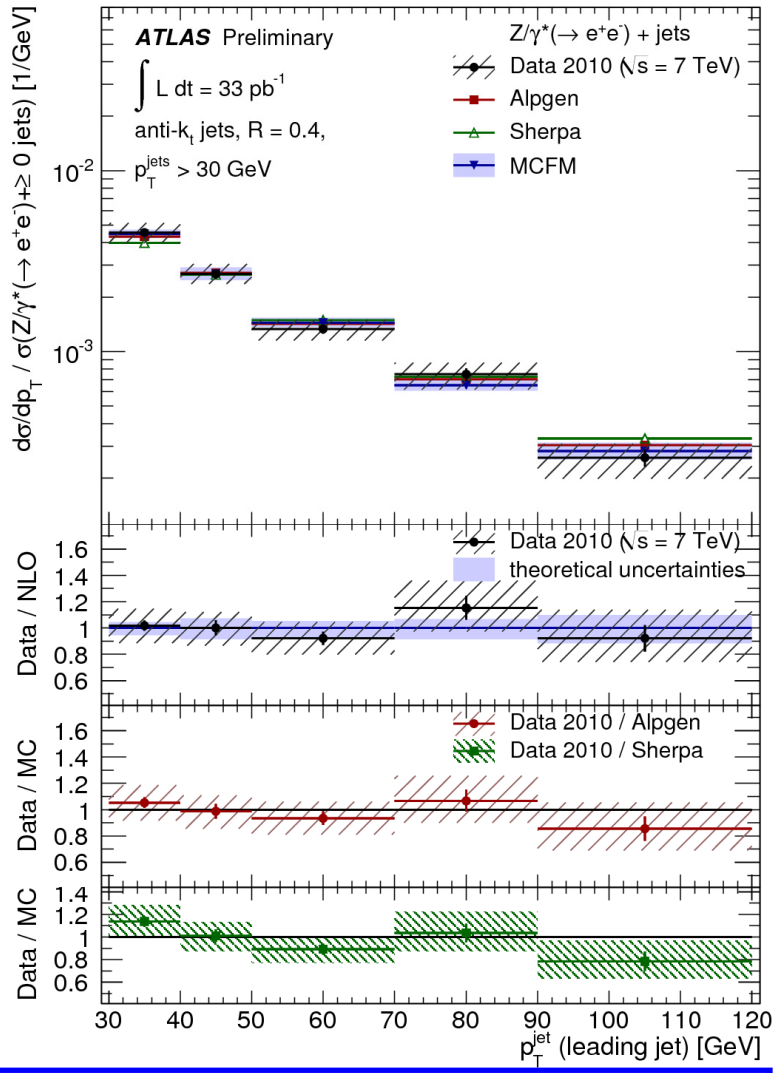


Precision limited by jet energy scale uncertainty

Cross section ratio of W+jets/Z+jets

Reference: **paper to be published**

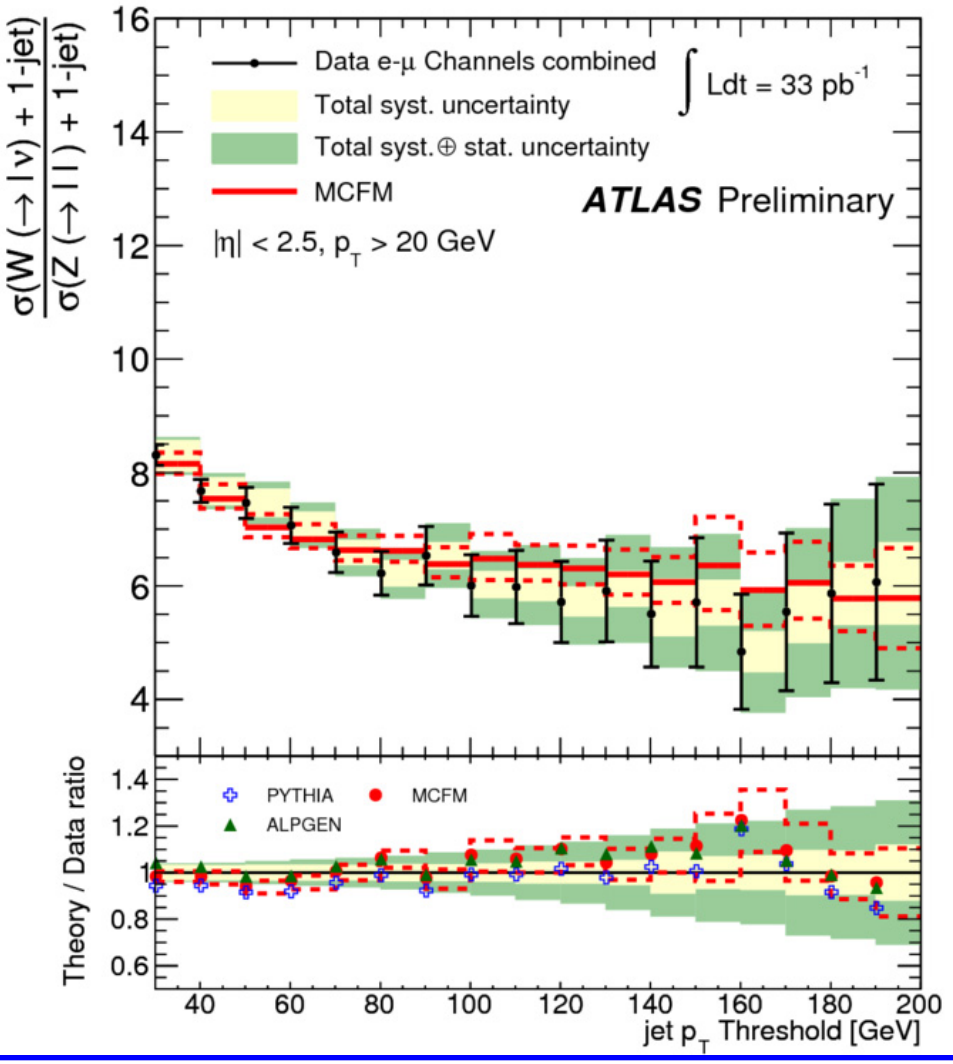
Z+jets



Good agreement with MC predictions

Limited by systematics

Ratio W+1jet/Z+1jet



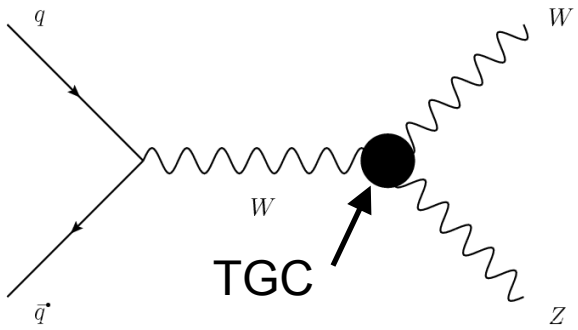
New analysis optimized for minimum uncertainty on ratio

Already reached systematic uncertainty below 5%

Diboson introduction

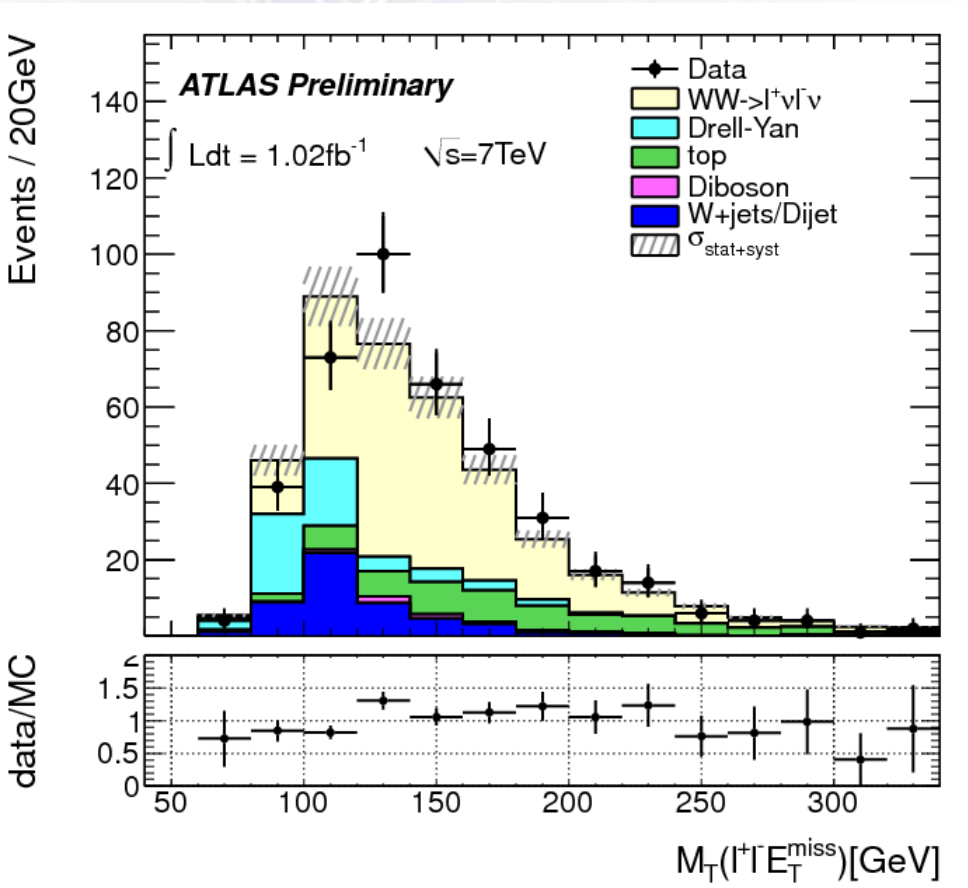
- Important background for both SM and BSM measurements
  - Higgs, SUSY etc.
- Non-abelian structure of the weak section of SM
  - ➢ Triple Gauge Couplings (TGC)
- Sensitive to new physics via anomalous TGCs

- Cross section measurements done:
  - WW
  - WZ (aTGC limits!)
  - ZZ (aTGC limits!)
  - W+gamma/Z+gamma



WW

- Channels:
  - ee, μμ or eμ + missing E_T
- Selection:
  - 2 high p_T leptons
    - Opposite charge, isolated
    - μ: p_T > 20 GeV
    - e: E_T > 25 (20) GeV leading(subleading
  - Outside of Z mass window
    - $|m_{ll}-m_Z|$ > 15 GeV
  - High missing E_T
    - $ME_{T,Rel}$[1]> (40, 45, 25) GeV (ee, μμ, eμ)
  - Jet veto
    - pT > 30 GeV, |η| < 4.5
- Background estimation
  - Top (data driven)
  - DY and Z+jets (MC+data driven)
  - W+jets (data driven)
  - Diboson (MC)
- Cross section extracted via log likelihood method



Cross section		σ	$\Delta\sigma_{stat}$	$\Delta\sigma_{syst}$	$\Delta\sigma_{lum}$
σ_{WW}^{tot}	pb	48.2	4.0	6.4	1.8
SM pred. (NLO)	pb	46		3	

[1] $M_{ET,Rel}$ is using topological information to improve rejection power

Reference: **ATLAS-CONF-2011-110**

Cross section consistent with theory prediction

Limited by systematic uncertainties

WZ

Channels measured:

- eee, eeμ, eμμ or μμμ + ME_T

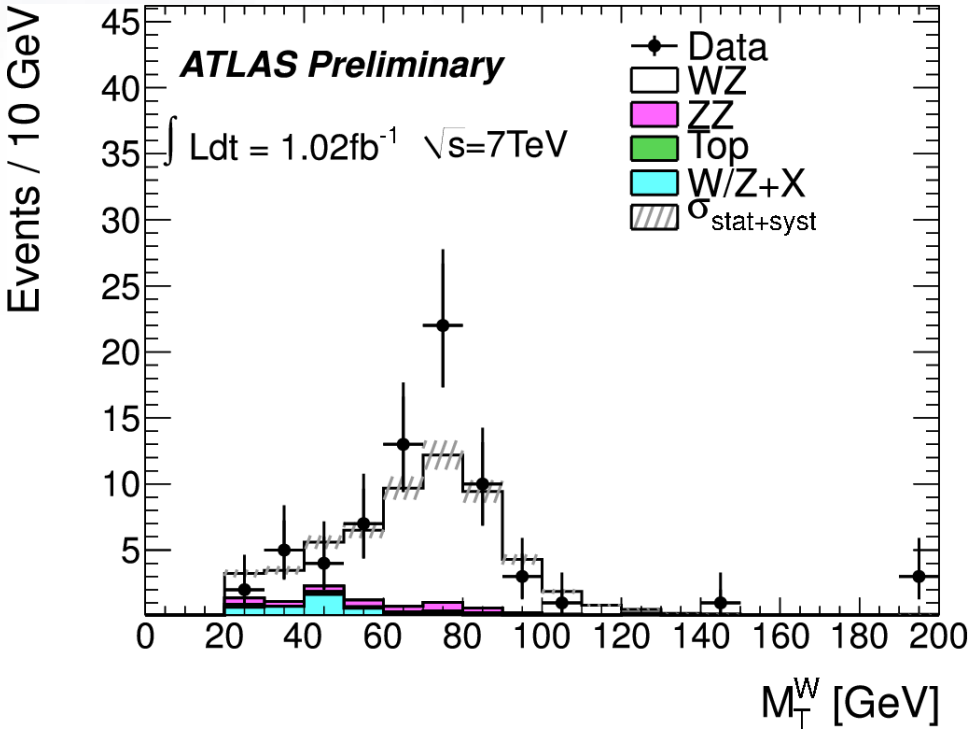
Event selection:

- 3 (or more) high pT leptons
  - isolated
  - W electron or trigger lepton: p_T>20 GeV
  - Other leptons: p_T > 15 GeV
- Z candidate
  - $|M_{ll}-M_Z|$<10GeV
- W candidate
  - Missing E_T>25GeV
  - M_T>20GeV

Background estimation

- W/Z+jets (data driven)
- ZZ (MC)
- Top (MC)
- W+γ (MC)

Cross section extracted via log likelihood method



Cross section		σ	$\Delta\sigma_{stat}$	$\Delta\sigma_{syst}$	$\Delta\sigma_{lum}$
σ_{WZ}^{tot}	pb	21.1	$^{+3.1}_{-2.8}$	$^{+1.2}_{-1.2}$	$^{+0.9}_{-0.8}$
SM prediction	pb	17.2		$^{+1.2}_{-0.8}$	

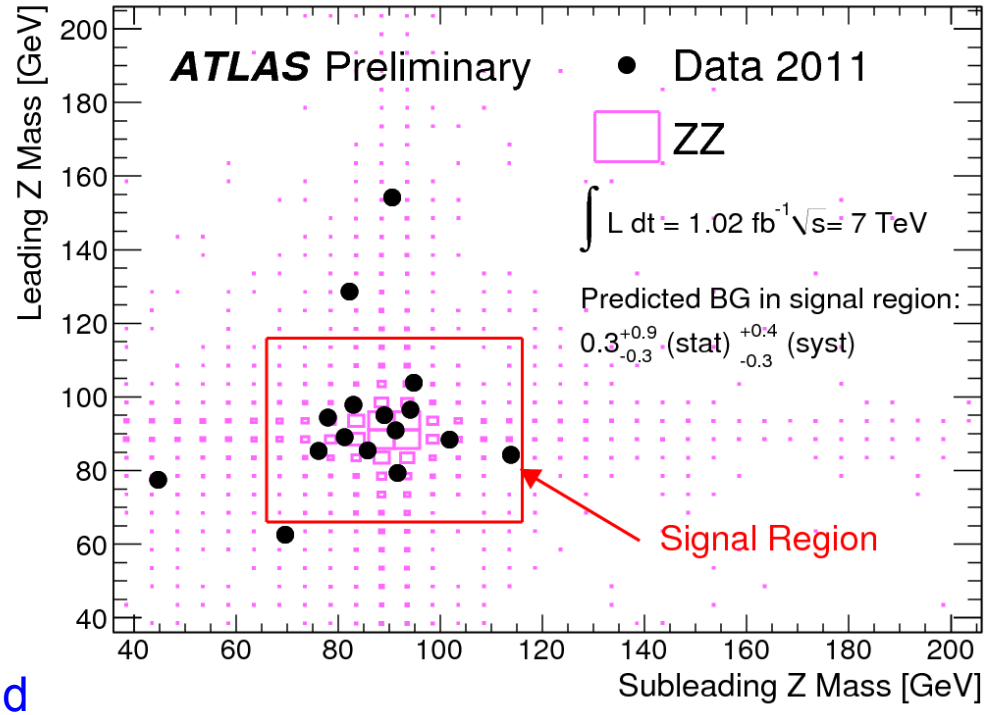
Cross section consistent with theory prediction

Limited by statistics uncertainty

Reference: **ATLAS-CONF-2011-099**

ZZ

- First ATLAS ZZ measurement!
- Channels:
  - eeee, eeμμ, μμμμ
- Selection:
  - 4 high p_T leptons
    - Exactly 4 isolated leptons, 2 pairs of same flavour and opposite charge
    - Leading e (μ): p_T> 25 (20) GeV
    - Subleading lepton: p_T> 15 GeV
  - Z mass window
    - 66 <M(l_1l_2 & l_3l_4)<116 GeV
- Very clean signal, low background
  - Z+X (misidentified jets)



Cross section		σ	$\Delta\sigma_{stat}$	$\Delta\sigma_{syst}$	$\Delta\sigma_{lum}$
σ_{ZZ}^{tot}	pb	8.4	$^{+2.7}_{-2.3}$	$^{+0.4}_{-0.7}$	0.3
SM pred. (NLO)	pb	6.5		$^{+0.3}_{-0.2}$	

Cross section consistent with theory prediction

Limited by statistics

Reference: **ATLAS-CONF-2011-107**

W/Z+gamma

Selection:

- High p_T lepton(s)
- Z candidate
  - Exactly two oppositely charged leptons
- W candidate
  - Exactly one lepton, $E_{T,Miss}$>25GeV, m_T>40 GeV
- High p_T photon
  - $E_{T,\gamma}$>15 GeV,γ isolation < 5 GeV
  - $\Delta R(l, \gamma) > 0.7$
  - Includes FSR and quark/gluon fragmentation contributions

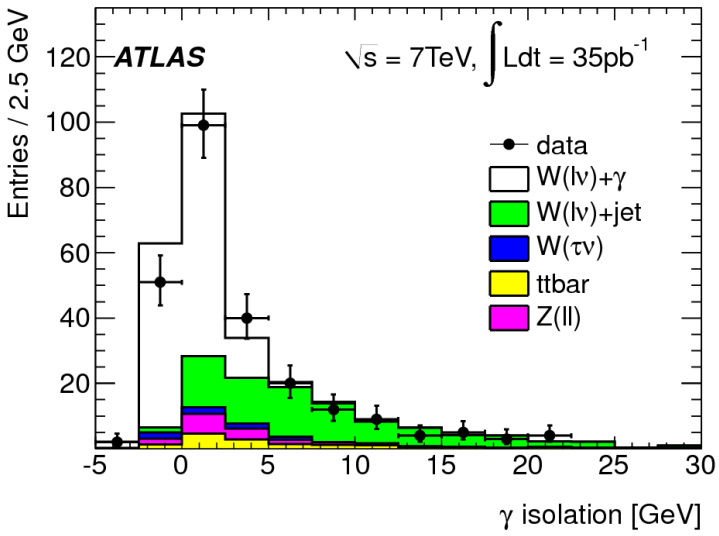
Cross section

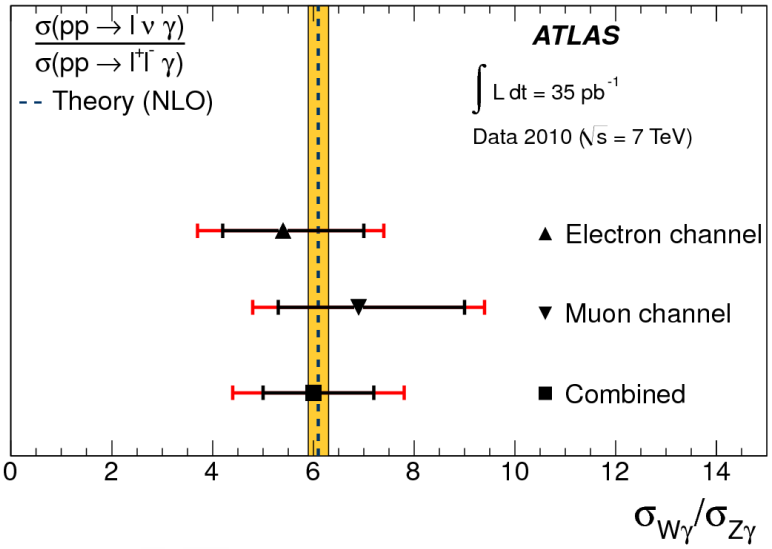
- Dominated by γ efficiency uncertainty
- Cancels in ratio $\sigma_{W\gamma}/\sigma_{Z\gamma}$

Backgrounds

- W(Z)+jets ($\pi^0 \rightarrow \gamma\gamma$)

Cross section		σ	$\Delta\sigma_{stat}$	$\Delta\sigma_{syst}$	$\Delta\sigma_{lum}$
$\sigma^{tot}_{W\gamma}$	pb	42.5	4.2	7.2	1.4
SM pred.	pb	42.1		2.7	
$\sigma^{tot}_{Z\gamma}$	pb	6.4	1.2	1.6	0.2
SM pred.	pb	6.9		0.5	





Cross section consistent with theory prediction

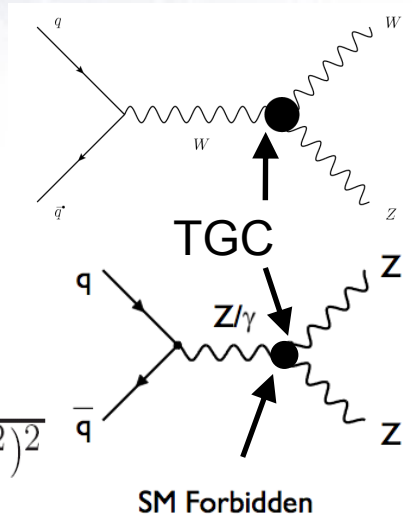
First analysis limited by syst, but can be improved

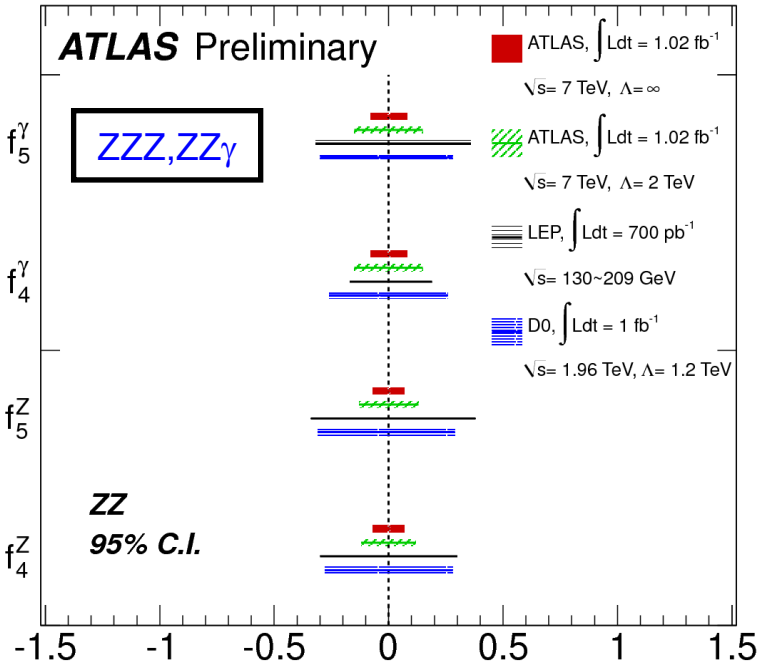
Reference: **arXiv:1104.5225**

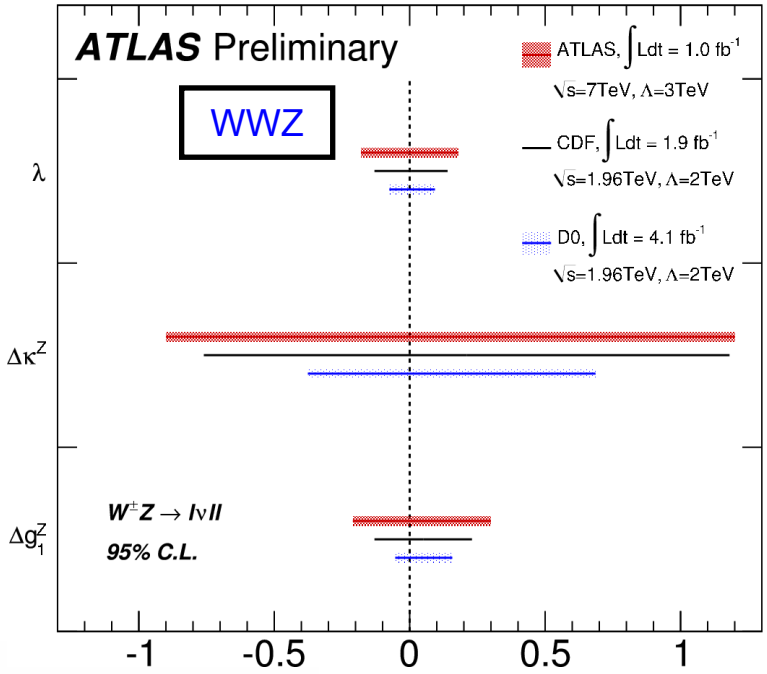
Triple Gauge Couplings

- Sensitivity to new physics!
- Possible vertices using a generalised Lagrangian
  - WWZ (couplings: $\alpha_0 = g_1^Z, \kappa^Z, \lambda$) SM = (1,1,0)
  - ZZZ, ZZγ (couplings: $\alpha_0 = f_4^Z, f_4^\gamma, f_5^Z, f_5^\gamma$) SM = (0,0,0,0)
- Scale dependent formfactor with cutoff scale Λ O(2TeV):
- ATLAS: cross sections as TGC limit input
- Tevatron: differential distributions as TGC limit input

$$\alpha(\hat{s}) = \frac{\alpha_0}{(1+\hat{s}/\Lambda^2)^2}$$



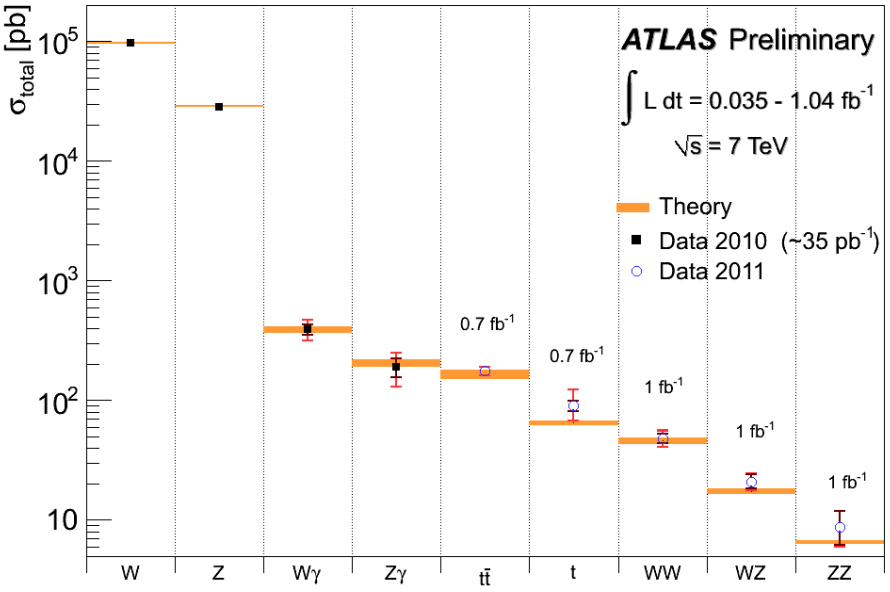




ATLAS limits consistent and competitive
Use of differential distributions: will increase sensitivity

Summary

- Precise measurements of production cross sections of electroweak gauge bosons with data up to 1 fb^{-1}@ 7 TeV
- Results consistent with SM expectations
- Event properties well described by MC
- Analysis presented:
  - W/Z inclusive
    - Sensitive to PDFs,
    - Sensitive to W lepton flavour universality
  - W/Z+jets
    - Test of QCD/MC
  - Diboson
    - Sensitive to TGCs



- Many more analysis available but not shown

More Details on W/Z inclusive measurements and PDF sensitivity: In session 5A talk by S. Chouridou:

W and Z Production Measured Using the ATLAS Detector, and Impact on Partons Densities of the Proton

List of available measurements

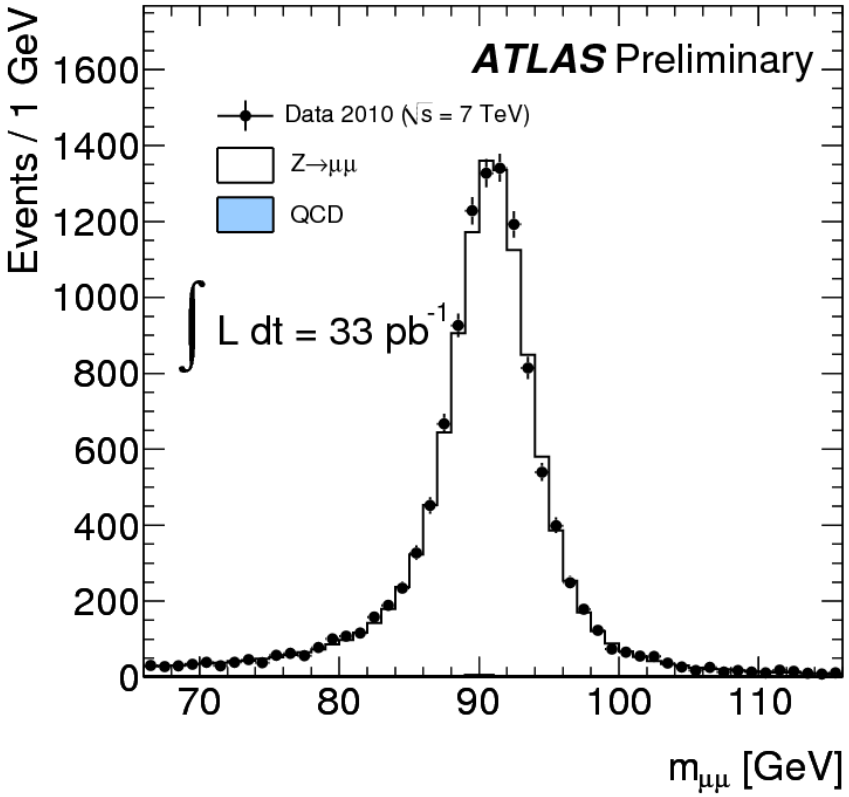
W/Z inclusive cross sections	**Paper to be published**
Differential Z distributions	**arXiv:1107.2381v1**
Differential W distributions	**Paper to be published**
Z->tautau cross section	**Paper to be published**
W->taunu cross section	**Paper to be published**
W+b cross section	**Paper to be published**
Z+b cross section	**Paper to be published**
W+jets	**ATLAS-CONF-2011-060**
Z+jets	**ATLAS-CONF-2011-042**
Ratio of the W+1jet to Z+1jet cross sections	**Paper to be published**
$W\gamma/Z\gamma$ cross section	**arXiv:1104.5225**
WW cross section	**ATLAS-CONF-2011-110**
WZ cross section	**ATLAS-CONF-2011-099**
ZZ cross section	**ATLAS-CONF-2011-107**

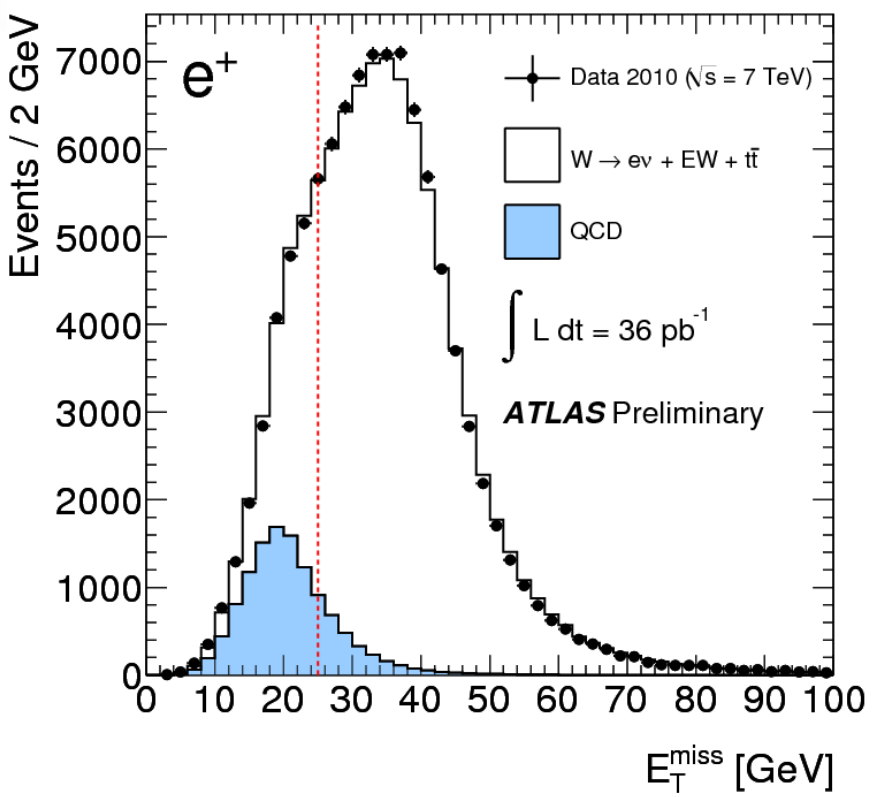
Backup

Event display

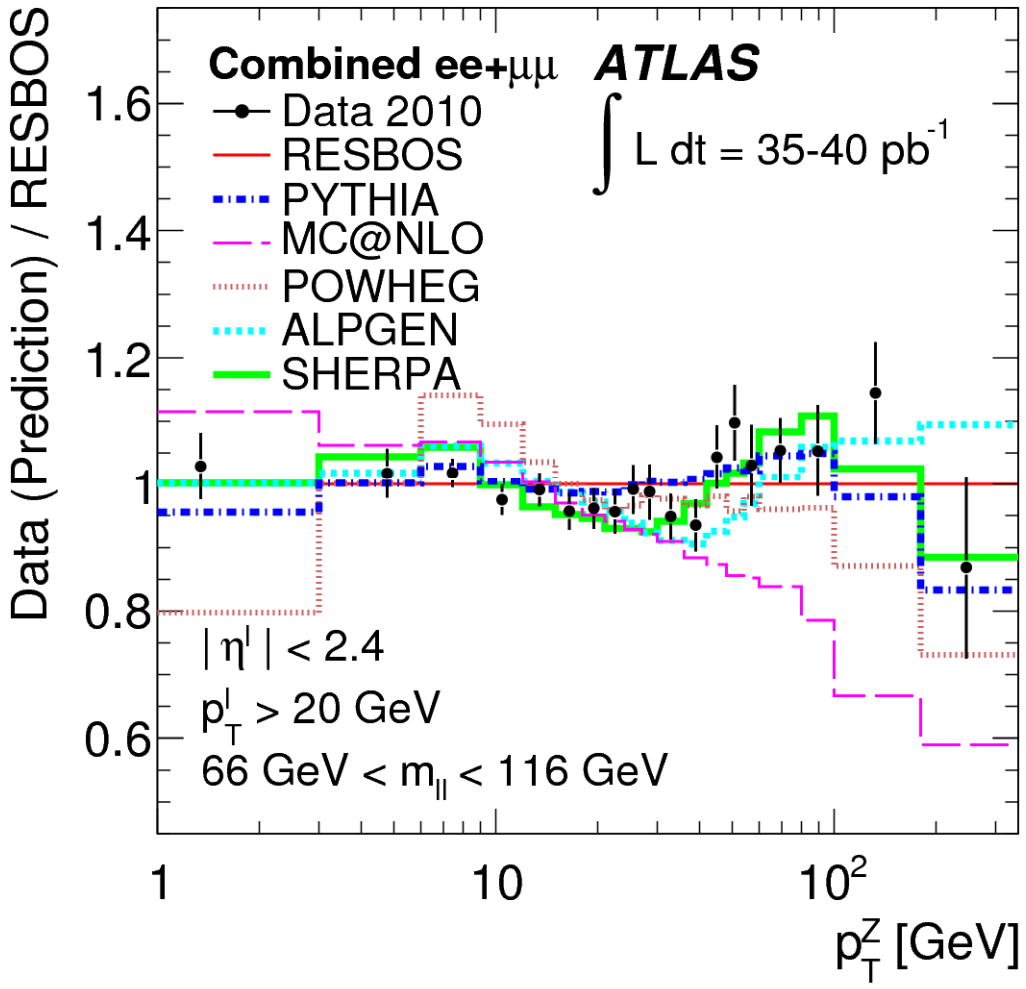
- Event display of a ZZ->eemumu candidate event (Run Number 182747, Event Number 63217197). One Z candidate has a mass of 85.9 GeV and a pt of 30.8 GeV and it is formed by two muons (in red) with {pt, eta, phi} of {44.9 GeV, 0.11, 0.69 rad} and {44.5 GeV, 0.53, -1.75 rad}, respectively. The other Z candidate has a mass of 85.5 GeV and a pt of 29.3 GeV, and it is formed by two electrons (in green) with {pt, eta, phi} of {39.6 GeV, 0.95, 1.19 rad} and {42.2 GeV, 1.85, -2.68 rad}, respectively. The four lepton system has a mass of 209.5 GeV and a pt of 4.6 GeV. Inner detector tracks with a transverse momentum pt larger than 1 GeV are displayed as blue helices.

W,Z inclusive



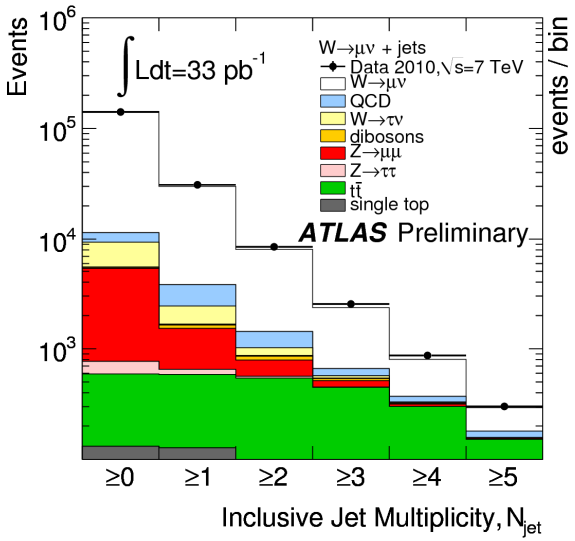


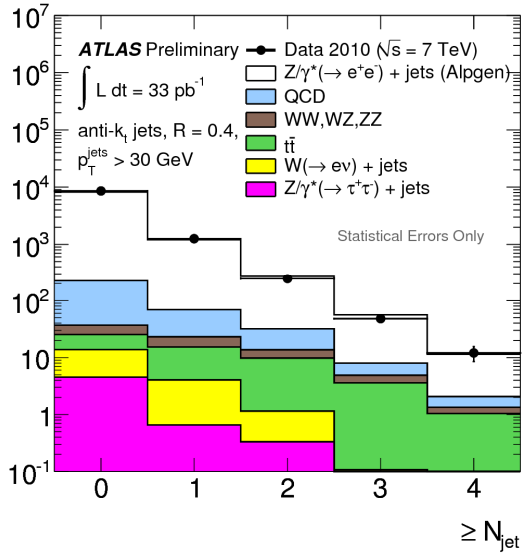
Z p_T-differential

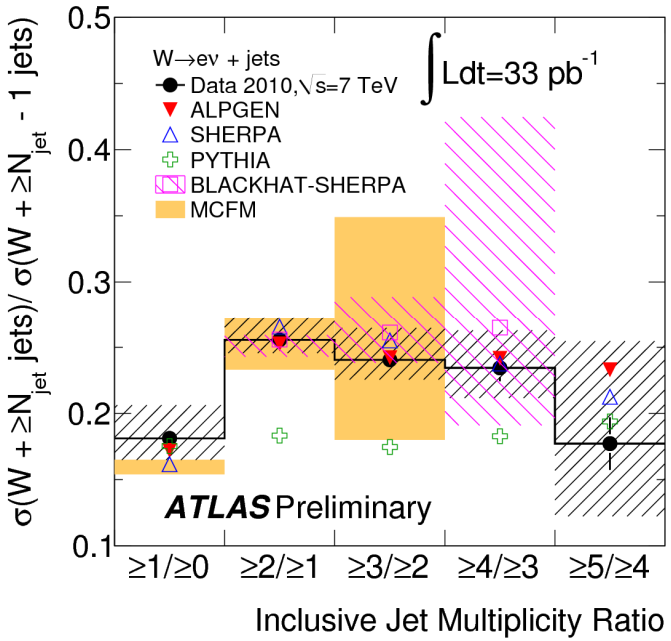


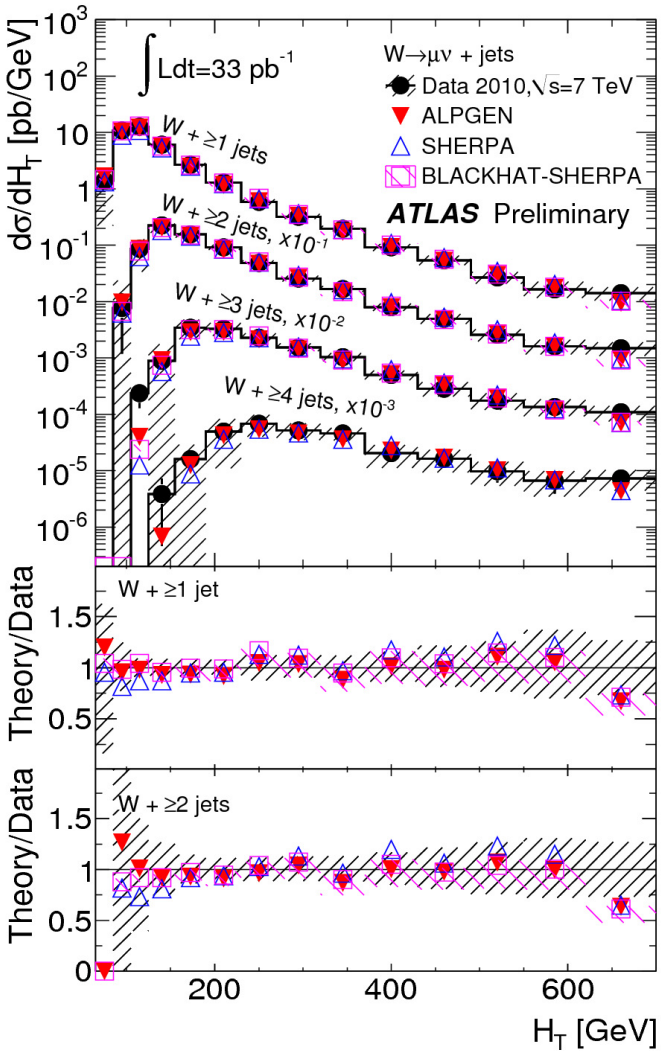
Reference: **arXiv:1107.2381v1**

W/Z+iets









H_T: Skalar sum of p_T of jets passing the selection

W/Z+jets

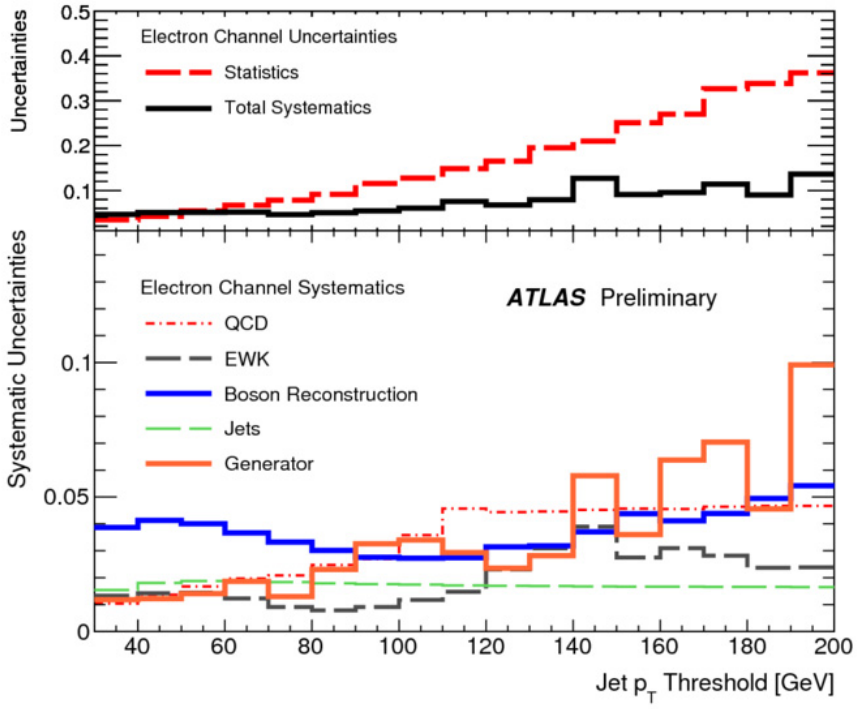
Z+jets

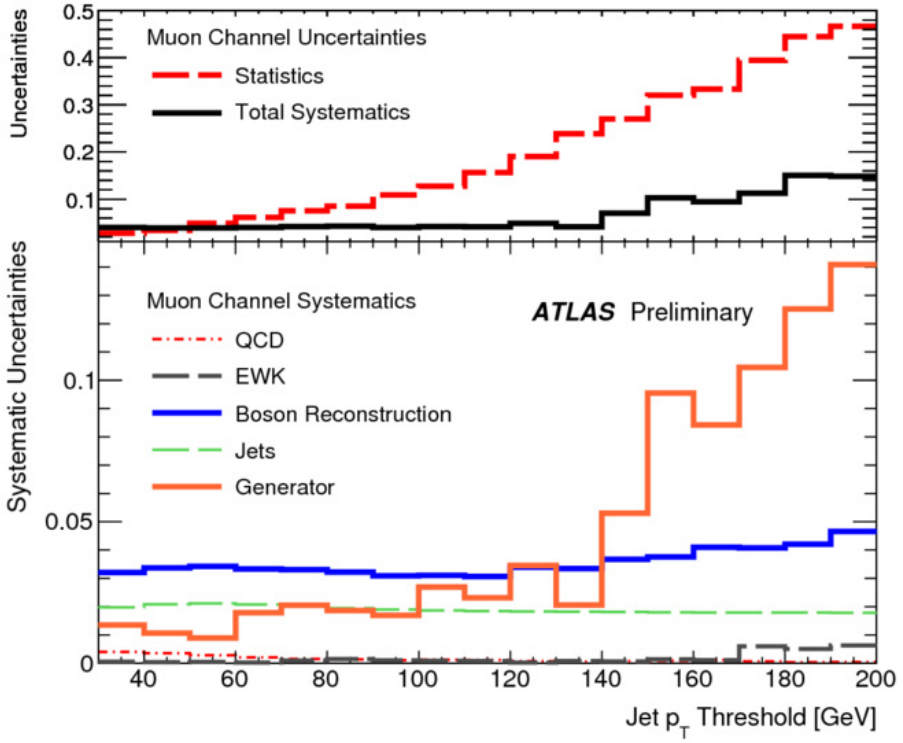
- Background estimation
  - QCD in ee+jet final state data driven (template fit)
  - Other backgrounds estimated via MC
- Unfolding
  - Bin-by-bin using ALPGEN
  - Systematics: use SHERPA instead of ALPGEN, use differences as error

W+jets

- Background estimation
  - QCD data driven (template fit for e and μ)
  - Other backgrounds estimated via MC
- Unfolding
  - Separate unfolding in N_{jet},p_T,H_T
  - Systematics: use SHERPA instead of ALPGEN, use differences as error

Ratio of W+1jet/Z+1jet





WW

- Definition of relative missing energy:

$$E_{\mathrm{T,\,Rel}}^{\mathrm{miss}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} \times \sin\left(\Delta\phi_{\ell,j}\right) & \text{if } \Delta\phi < \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi \geq \pi/2 \end{cases}$$

WZ background estimation

- Most important contribution: Z+jets (+ minor W+jets)
- Estimated from data besides C_{MET}
- Sample of Z+jet:
  - 2 leptons + 1 lepton-like jet passing all selection criteria "llj"
    - Exception: lepton-like jet fails electron ID / muon isolation:

$$N_{bkg} = N(llj) \bullet f(p_T) \bullet C_{MET}$$

  - Fake factor: probability to fail ID/isolation cut
    - Derived from Z + lepton-like jet sample (no MET, M_T requirements)

$$f(p_T) = \frac{N(l, MET < 25GeV)}{N(j, MET < 25GeV)}$$

  - C_{MET}: Interpolation from low to high missing ET region, done via MC
    - Validated with dijet-events in data and MC

ZZ background estimation

- Estimate background from data
  - Dominant: one jet fakes a lepton

$$N(bkg) = N(lllj) \bullet f - N(lljj) \bullet f^2 - N(ZZcandidates)$$

- Fake factor f(p_T,η)
  - Ratio of probability for a jet to pass full lepton criteria over probability to pass lepton-like criteria
  - Derived from data sample in which true leptons are suppressed
  - Derived as single lepton quantity
  - Cross checked with MC
- N(lllj) (N(lljj)): number of events with 1 (2) lepton-like jets
  - Lepton-like jet: satisfies all criteria besides electron ID/ muon isolation
- To avoid double counting: substract N(lljj)