WZ Cross-section Measurement and Anomalous Triple-Gauge-Boson-Coupling Limit at ATLAS using 1 fb^{-1} collision data

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Outline

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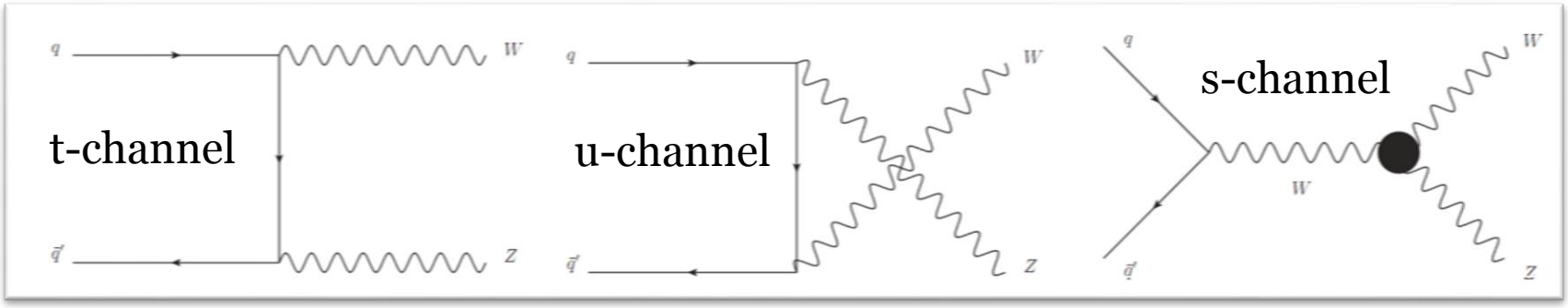
- **Limit on Anomalous Triple-Gauge-boson-Couplings (TGC)**
- **Summary**

Introduction

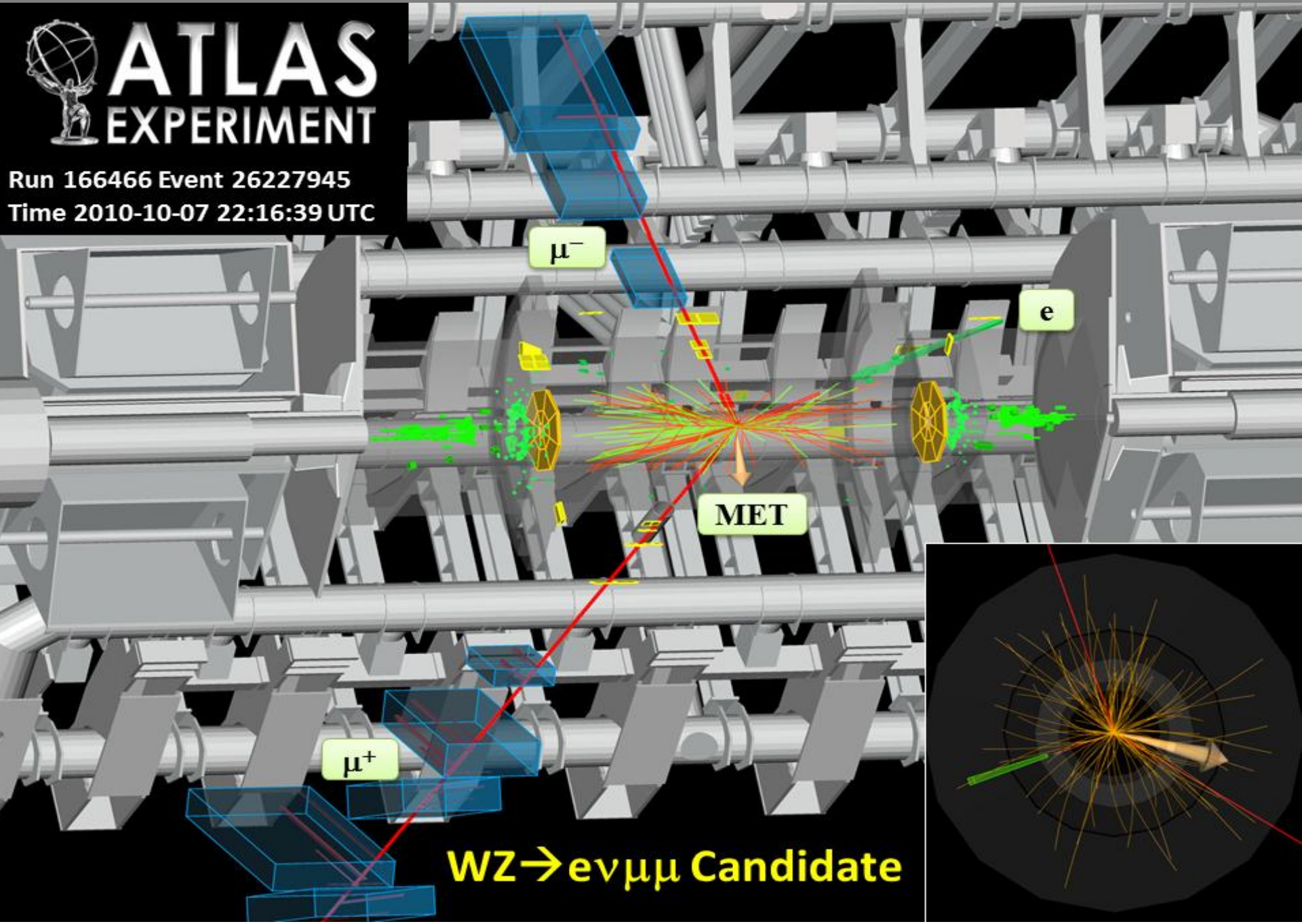
- Production of WZ pairs is the least studied di-boson process in SM and can only be produced at hadron collider.



- WZ production involves the WWZ vertex, which provides an unique chance for model-independent aTGC test. The test is a direct probe for new physics.

- Many extensions of SM predict additional heavy gauge bosons decaying into WZ pairs (e.g. W', ρ_T)

- The SM WZ production cross-section at ATLAS detector for $\sqrt{s} = 7$ TeV is 17.2pb (~4 times larger than Tevatron).

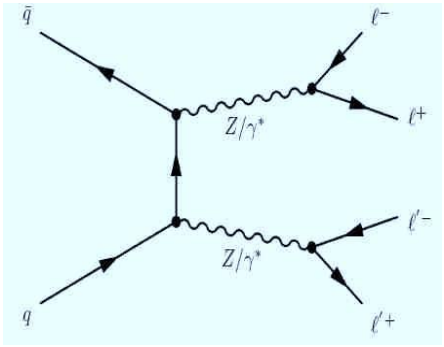

ATLAS
EXPERIMENT
Run 166466 Event 26227945
Time 2010-10-07 22:16:39 UTC
μ⁻
e
MET
μ⁺
WZ→eνμμ Candidate

WZ Signature and Background Sources

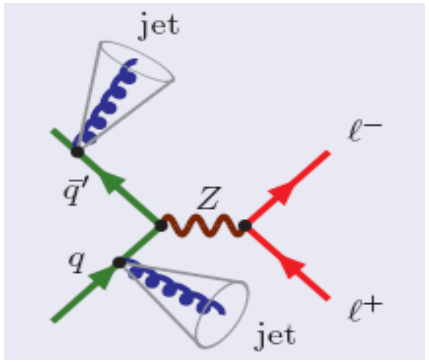
- We focus on the leptonic decay channels
  - Divided into **eee**, **eeμ**, **eμμ** and **μμμ** channels
  - Have three high-p_T isolated leptons plus large missing energy
  - Small (~1.5% branching fraction), but **Clean**!

- Background

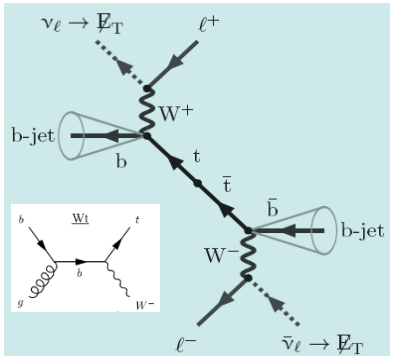
ZZ



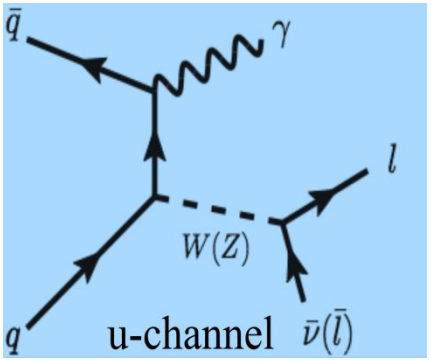
Z+jets



Top



Z+γ



ZZ : 3 leptons + MET caused by undetected lepton

Z+jets : 2 leptons + jet faked leptons + MET (from jet)

Top : 2 leptons (from W) + jet faked leptons + MET (from W)

Z+γ : 2 leptons (from Z) + electron (from γ conversion or mismatching) + MET (from jet)

Selection Cuts I : Object Definition

- The goal is to select **high p_T isolated good** leptons

- **Muon**
  - Combined (combination of ID and MS measurement) or Segment-tagged (ID track and MS segment, to recover efficiency loss in certain area)
  - p_T>15GeV, |η|<2.5, Generated from collision vertex, Isolation
  - Resolution corrected for MC

- **Electron**
  - Identified as "Medium" electron (cut on hadronic leakage, shower shape and tracking)
  - Cleaning cut
  - p_T>15GeV, |η|<1.36, 1.52<|η|<2.47, Generated from collision vertex, Isolation
  - Scale/Resolution corrected for MC

- **MET**
  - Built from other reconstruction objects to provide best calibrations

Selection Cuts II : WZ Selection

Event level common selection

1. Good Run List
2. Trigger: e/μ threshold is 20GeV / 18GeV
3. Collision Vertex: >=3 tracks associated
4. Remove event if bad jet exists or calorimeter problem presents

Lepton selection

1. Select good leptons

WZ selection

1. Has a Z: $|M_{ll}-M_Z|<10$GeV
2. At least 3 leptons
3. MET > 25GeV
4. W transverse mass > 20GeV, the W lepton is tightened (combined μ/tight e)
5. Trigger matching: one of the W/Z leptons must match the triggered μ(e) with p_T>20(25) GeV

Data-Driven Background Estimation

- Fake factor method for Z+jets estimation
  - Control sample ($N_{control}^{event}$):
    - events with two good leptons + one loose lepton
    - loose lepton means electron failing "medium" and muon failing isolation
    - passing all other event selection cuts
  - Fake factor (f):
    - Looking at **Z events with an additional lepton** (loose + tight)
    - $f = \frac{N_{tight}^{lepton}}{N_{loose}^{lepton}}$
    - is calculated in different p_T bins and calculated in **low MET region** and then applied to high MET region
    - The differences of pt shape and low/high MET regions are included in systematics
  - Results : $N_{z+jets} = N_{control}^{event} \times f$

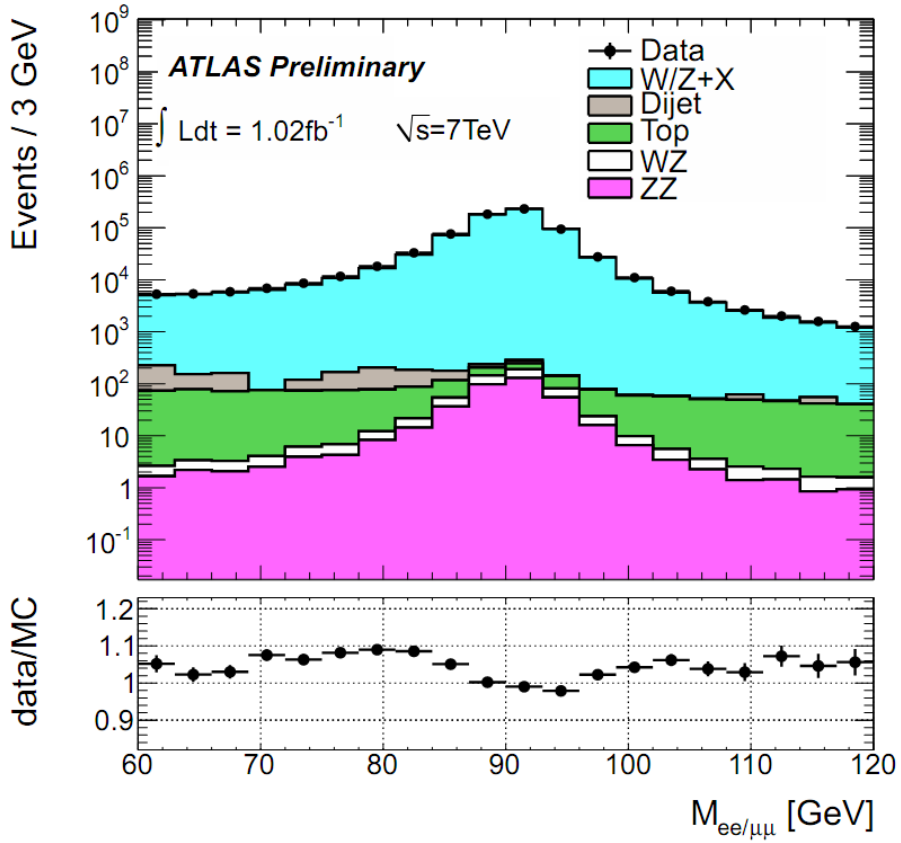
Channel	Expected events	Events in Control Sample
eee	$2.03 \pm 0.38^{+0.64}_{-0.64}$	24
$ee\mu$	$0.64 \pm 0.18^{+0.65}_{-0.47}$	10
$\mu\mu e$	$2.03 \pm 0.38^{+0.64}_{-0.64}$	24
$\mu\mu\mu$	$0.44 \pm 0.15^{+0.94}_{-0.33}$	15

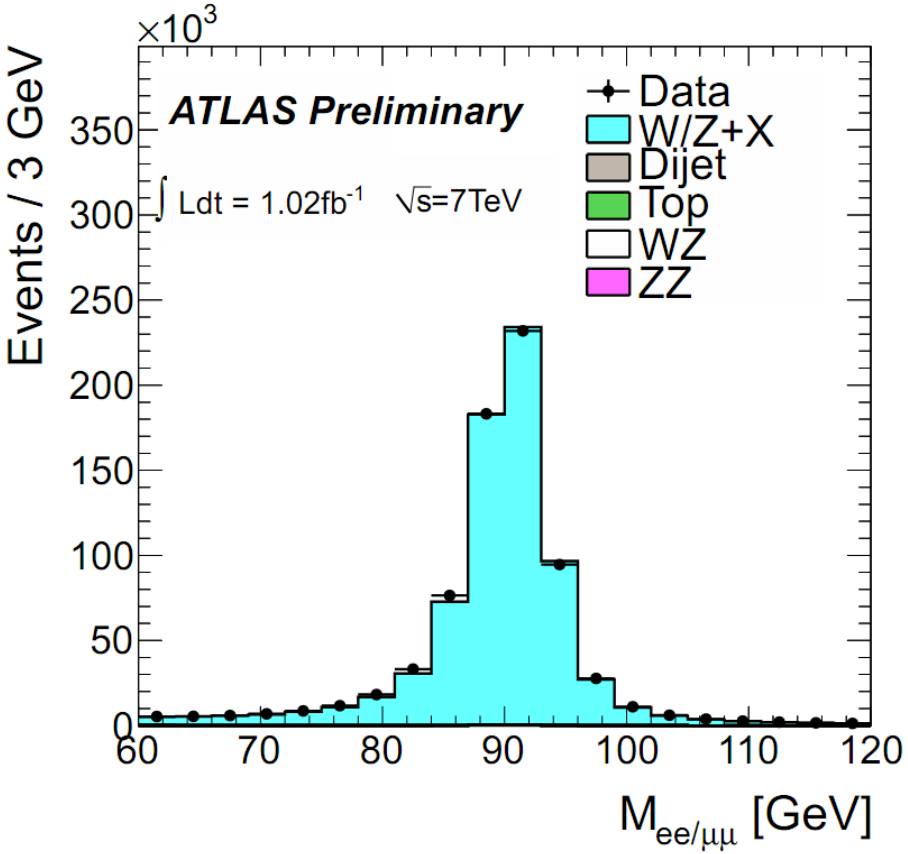
Observation and Prediction

Final State	$eee + E_T^{miss}$	$ee\mu + E_T^{miss}$	$e\mu\mu + E_T^{miss}$	$\mu\mu\mu + E_T^{miss}$	combined
Observed	11	9	22	29	71
ZZ	0.34±0.07	1.03±0.13	0.82±0.12	1.40±0.15	3.55±0.24±0.17
W/Z+jets	2.03±0.38	0.64±0.18	2.03±0.38	0.44±0.15	$5.14\pm0.59^{+2.97}_{-2.08}$
Top	0.26±0.10	0.31±0.09	0.41±0.12	0.60±0.15	1.58±0.23±0.10
$W/Z + \gamma$	0.49±0.28	–	0.56±0.39	–	1.05±0.48±0.08
Total Background	3.08±0.49	1.98±0.24	3.82±0.56	2.44±0.21	$10.5\pm0.8^{+2.9}_{-2.1}$
Expected Signal	7.55±0.17	11.27±0.20	12.12±0.22	18.16±0.27	49.1±0.4±3.02
Expected S/B	2.5	5.7	3.2	7.4	4.3

- **Data VS Prediction = 71 VS 60 (S: 49 + B: 11)**
- **Overall S/B ratio ~ 4.3**
- **Signal acceptances are about 27%, 18%, 17% and 11% for μμμ, eμμ, eeμ and eee**
- **τ contributes about 3.5% of the total signal**

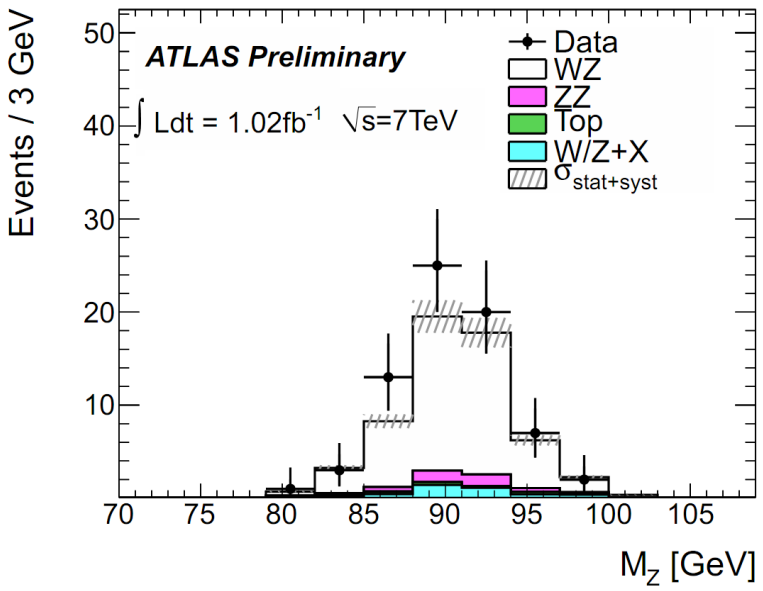
Plots for Z events

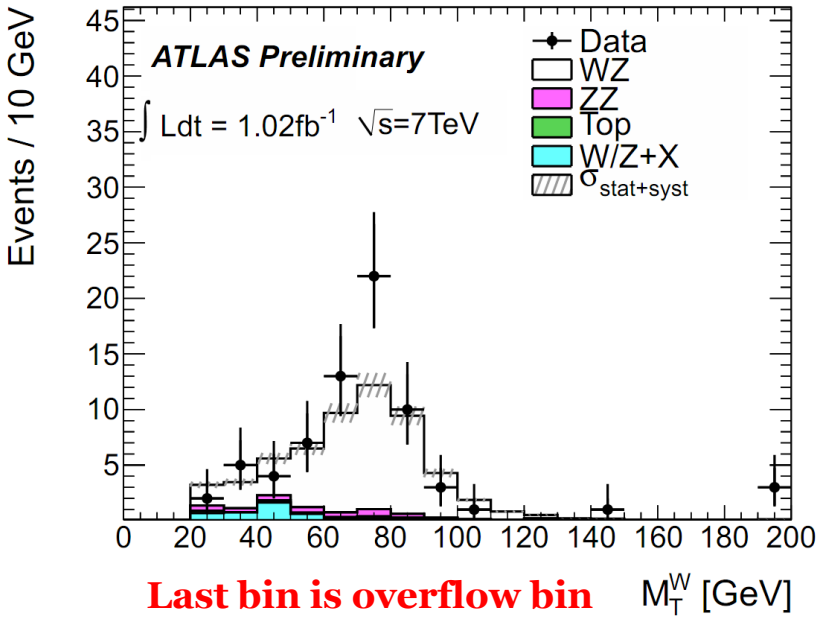




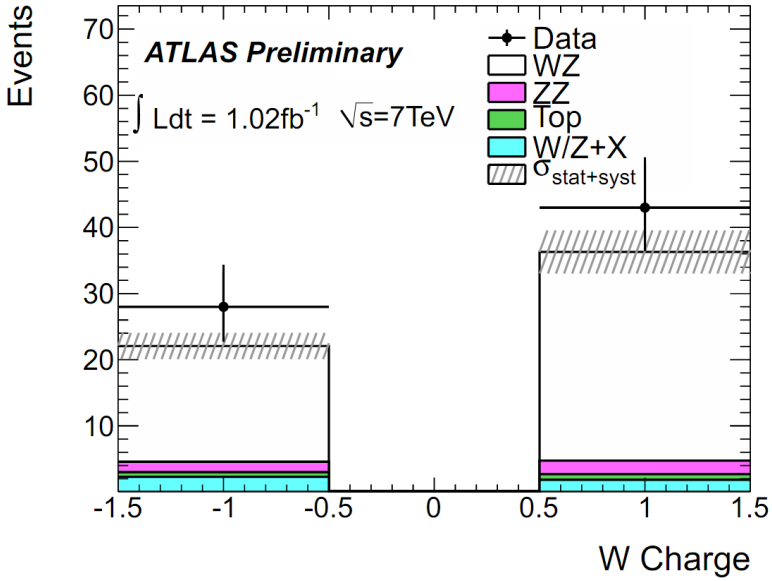
Nice data/MC agreement for Z events before making WZ selection

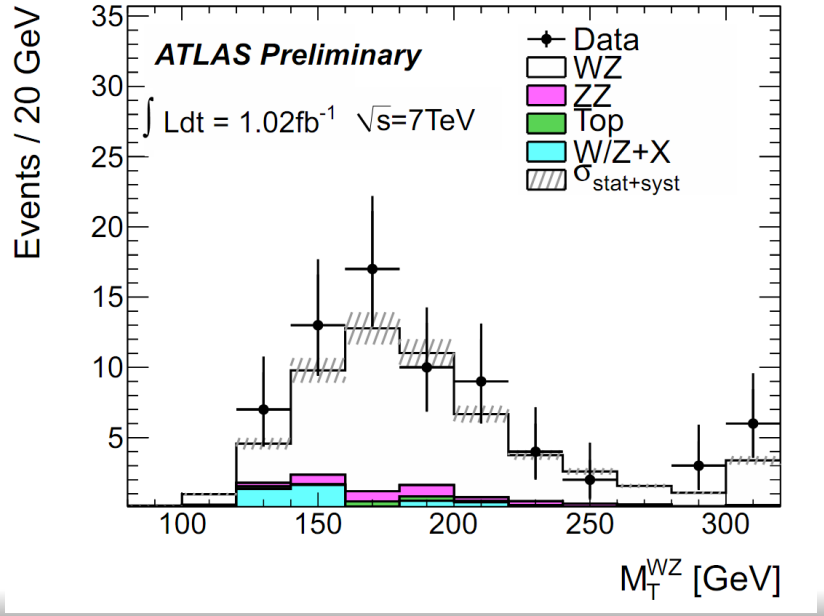
Plots for WZ Candidates (I)



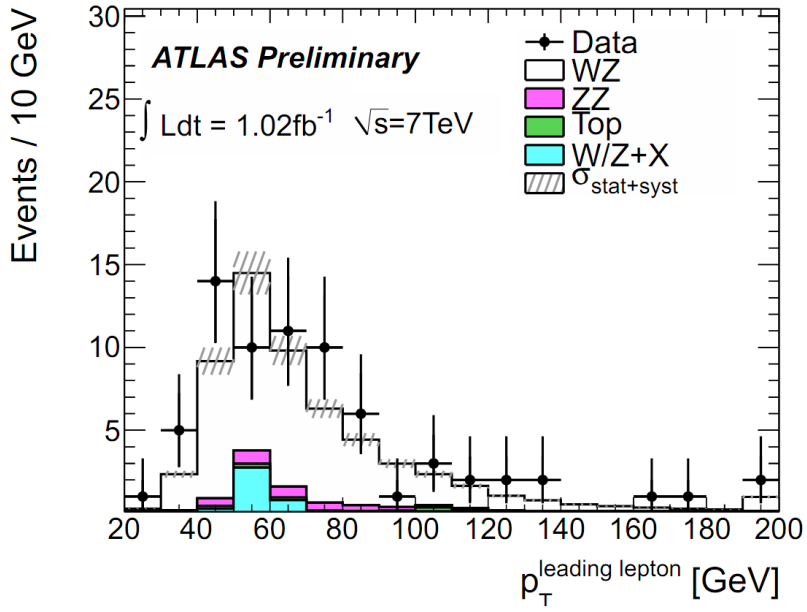


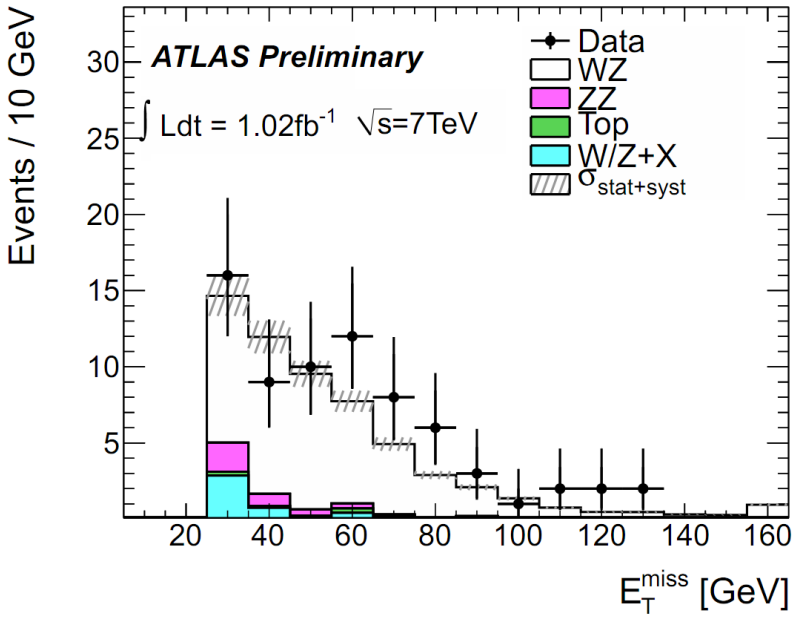
Last bin is overflow bin

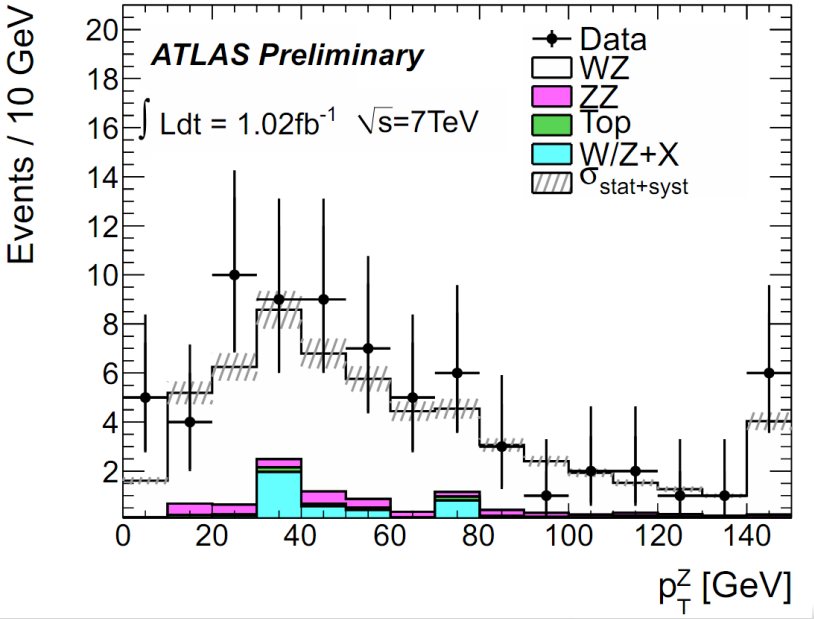


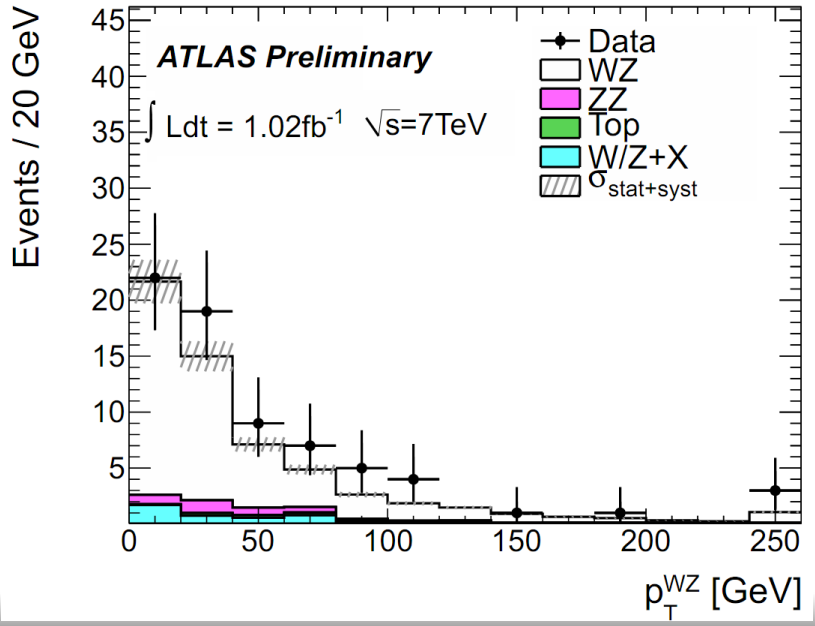


Plots for WZ Candidates (II)









Systematics

Source	$\mu\mu\mu$	$e\mu\mu$	$ee\mu$	eee
μ reconstruction efficiency	1.9%	1.3%	0.6%	-
μ p_T smearing	0.2%	0.2%	<0.1%	-
e reconstruction efficiency	-	1.8%	3.5%	5.2%
e energy scale	-	0.2%	0.3%	0.4%
e energy smearing	-	0.1%	0.15%	0.2%
calorimeter isolation	-	2.4%	2.9%	3.4%
E_T^{miss}: cluster energy scale	0.20%	0.51%	0.91%	0.76%
E_T^{miss}: electron energy scale	0.0%	0.37%	0.17%	0.23%
E_T^{miss}: electron energy resolution	0.0%	0.46%	0.17%	0.99%
E_T^{miss}: jet energy scale	0.38%	0.23%	0.18%	0.41%
E_T^{miss}: in-time pileup	0.25%	0.21%	0.37%	0.48%
E_T^{miss}: out-of-time pileup	0.23%	0.54%	0.21%	1.31%
trigger	1.0%	1.0%	1.0%	1.0%
PDF	1.6 %	1.7 %	1.7 %	1.6 %
Sum	3.05%	4.33%	5.08%	6.91%
luminosity	3.7%	3.7%	3.7%	3.7%

- Object uncertainties propagated to analysis (overall <8%)
- Derived from MC signal samples, and applied to Signal, ZZ, Z+γ and Top bkg
- PDF uncertainty only for signal
- Theoretical cross-section uncertainties are considered for MC based estimation

Cross-section Extraction I

Fiducial Volume and Acceptance

- $p_T^{\mu,e} > 15GeV, |\eta^{\mu,e}| < 2.5, p_T^{\nu} > 25GeV, |M_{ll} - M_Z| < 10GeV, M_T^W > 20GeV$
- Applied on generator kinematics
- The acceptance $A_{WZ\to\ell\nu\ell\ell}$ is about 39% for all channels
- The uncertainty on $A_{WZ\to\ell\nu\ell\ell}$: MC statistic ~2%, PDF ~1.6%

Fiducial Cross-section

- $\sigma_{WZ}^{fid} \times \mathcal{B}(WZ \to \ell\nu\ell\ell) = \sigma_{WZ\to\ell\nu\ell\ell}^{fid} = \frac{N_{\ell\nu\ell\ell}^{obs} - N_{\ell\nu\ell\ell}^{bkg}}{\mathcal{L} \times C_{WZ\to\ell\nu\ell\ell}} \times \left(1 - \frac{N_{\tau}^{MC}}{N_{sig}^{MC}}\right)$
- τ contribution removed (~3.5%)
- $C_{WZ\to\ell\nu\ell\ell}$: efficiency correction data/MC based on fiducial volume

Total Cross-section

- $\sigma_{WZ}^{tot} = \frac{N_{\ell\nu\ell\ell}^{obs} - N_{\ell\nu\ell\ell}^{bkg}}{\mathcal{L} \times \mathcal{B}(WZ\to\ell\nu\ell\ell) \times A_{WZ\to\ell\nu\ell\ell} \times C_{WZ\to\ell\nu\ell\ell}} \times \left(1 - \frac{N_{\tau}^{MC}}{N_{sig}^{MC}}\right)$

Cross-section Extraction II

- Result

$$\sigma^{fid}_{WZ\to\ell\nu\ell\ell} = 118^{+18}_{-16}(\text{stat})\ ^{+6}_{-6}(\text{syst})\ ^{+5}_{-5}(\text{lumi})\ \text{fb}$$

$$\sigma^{tot}_{WZ} = 21.1^{+3.1}_{-2.8}(\text{stat})\ ^{+1.2}_{-1.2}(\text{syst})\ ^{+0.9}_{-0.8}(\text{lumi})\ \text{pb}.$$

SM NLO Cross-section: $17.2^{+1.2}_{-0.8}\ pb$

In agreement with SM

  - Negative log-likelihood function used for fitting (minimization)
  - Systematics are included as additional Gaussian term

- Results (205 pb^{-1})

$$\sigma^{fid}_{WZ\to lvl'l'} = 96^{+37}_{-30}(\text{stat})\ ^{+15}_{-14}(\text{syst})\ ^{+5}_{-5}(\text{lumi})\ \text{fb, with } l = e, \mu$$

$$\sigma^{tot}_{WZ} = 18^{+7}_{-6}(\text{stat})\ ^{+3}_{-3}(\text{syst})\ ^{+1}_{-1}(\text{lumi})\ \text{pb}$$

aTGC Limit I

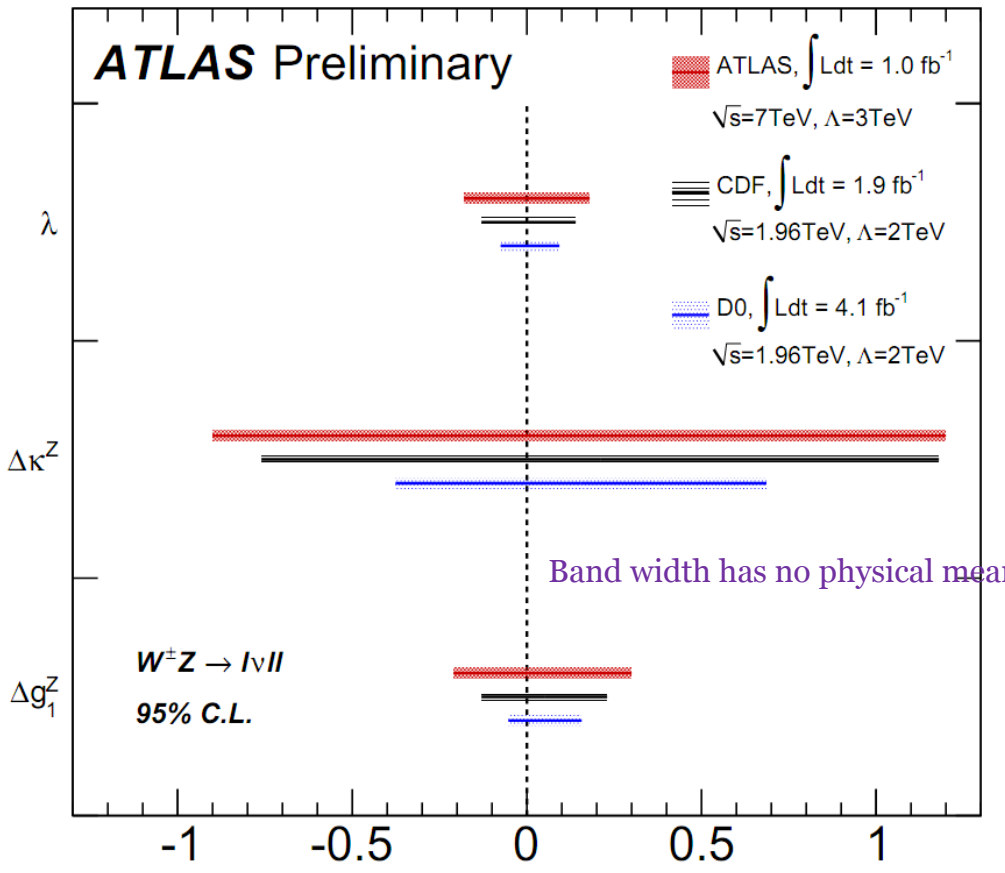
- TGC
  - WWZ vertex, model-independent, three free parameters

$$\frac{\mathcal{L}_{WWZ}}{g_{WWZ}} = i\left[g_1^Z(W^\dagger_{\mu\nu}W^\mu Z^\nu - W_{\mu\nu}W^{\dagger\mu}Z^\nu) + \kappa^Z W^\dagger_\mu W_\nu Z^{\mu\nu} + \frac{\lambda}{m_W^2}W^\dagger_{\rho\mu}W^\mu_\nu Z^{\nu\rho}\right]$$

  - For SM: $g_1^Z = 1, \kappa^Z = 1, \lambda = 0$
  - $g_1^Z, \lambda \propto \hat{S}, \kappa^Z \propto \sqrt{\hat{S}}$ (κ^Z is less sensitive)

- Limit extraction
  - Reweighing method is used
  - Use cross-section fitting to set limit
    - Calculate the cross-section point by point
    - 95% C.I. of cross-sections determines 95% C.I. of TGC

aTGC Limit II



Band width has no physical meaning

Anomalous Coupling	Limits of the 95% C.I.
Δg_1^Z	$[-0.21, 0.30]$
$\Delta\kappa^Z$	$[-0.9, 1.2]$
λ	$[-0.18, 0.18]$

- Comparable results to Tevatron
- No anomalous observed yet

Summary

- Summarized WZ→$\ell\nu\ell\ell$ analysis @ 1fb^{-1}
  - 71 candidates from data and 60 predicted events
  - The fiducial and total cross-sections are extracted, the values agree with SM prediction
  - TGC limit is also extracted, no anomalous yet observed

- Notes
  - For WZ cross-section measurement with 205pb^{-1} ATLAS-CONF-2011-084, http://cdsweb.cern.ch/record/1356191
  - For WZ cross-section measurement + TGC limit with 1fb^{-1} ATLAS-CONF-2011-099 http://cdsweb.cern.ch/record/1369214
  - Aim for a paper (ongoing…)

Backup

Datasets

- Collision Data
  - **1.02 fb^{-1}**, collected from April 2011 to July 2011
- MC

Process	Generator
WZ	MC@NLO
Top	MC@NLO
V+jets, V=W,Z	Alpgen, Pythia (for τ samples)
Z+γ	Pythia, MadGraph
ZZ	Herwig

  - Top, ZZ and Z+γ backgrounds are estimated from MC
  - Z+jets is estimated by data-driven methods

Selection Cuts I : Object Definition

- The goal is to select **high p_T isolated good** leptons

- **Muon**
  - Combined (combination of ID and MS measurement) or Segment-tagged (ID track and MS segment, to recover efficiency loss in certain area)
  - p_T>15GeV, |η|<2.5, from collision vertex
  - Isolation cut: $(\sum_{excluding\ muon\ track\ itself}^{tracks\ within\ \Delta R=0.2\ cone\ of\ muon} p_T^{trk})/p_T^{muon} < 0.1$
  - Resolution corrected for MC

- **Electron**
  - Identified as "Medium" electron (cut on hadronic leakage, shower shape and tracking)
  - Cleaning cut
  - p_T>15GeV, |η|<1.36, 1.52<|η|<2.47, from collision vertex
  - Isolation cut: sum of calorimeter energy in ΔR=0.3 (excluding itself) < 4GeV (corrected with p_T leakage and pileup)
  - Scale/Resolution corrected for MC

- **MET**
  - Built from other reconstruction objects to provide best calibrations

Plots for WZ Candidates (III)