WZ Production and Triple Gauge Couplings in ATLAS

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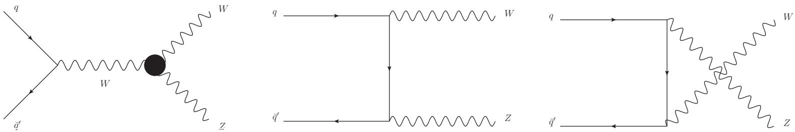
Introduction

- ATLAS has measured the $W^{\pm}Z$ production cross section at 7 and 8 TeV center-of-mass energies
- Set limits on anomalous triple gauge couplings at 7 TeV
- Documents presented herein:
  - Measurement of $W^{\pm}Z$ production in proton-proton collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector (Eur. Phys. J. C72 (2012) 2173)
  - A Measurement of $W^{\pm}Z$ Production in Proton-Proton Collisions at $\sqrt{s} = 8$ TeV with the ATLAS Detector (ATLAS-CONF-2013-021)

Overview

- Motivation
- Event Selection
- Background Estimation
- Candidate Events
- Cross Section Measurement
- Anomalous TGC Limits

Motivation



- Want to test precision of SM predictions at the energy frontier!
- $W^{\pm}Z$ associated production includes a triple gauge coupling term (s-channel diagram above)
- Anomalous contributions to TGC term not forbidden by symmetry $\Rightarrow$ want to set limits on anomalous TGCs (aTGCs)
- $W^{\pm}Z$ is a significant background to many searches, especially for signatures with a net charge/large $E_{\mathrm{T}}^{\mathrm{miss}}$ (e.g. $H^{\pm}$ and SUSY)

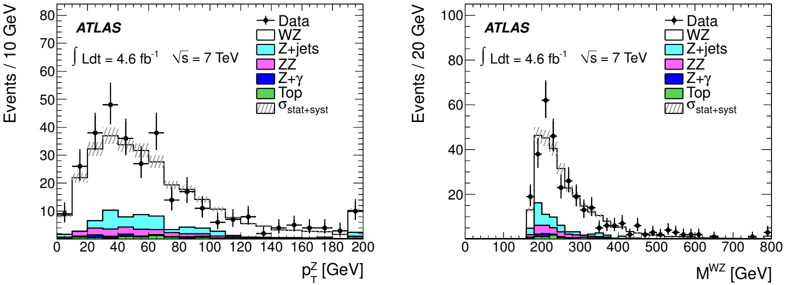
Event Selection

- Events only considered if the detection and reconstruction proceeded as expected
- Select events with at least 2 high-p_T ($>$ 15 GeV), isolated leptons
- Require a Z candidate whose mass is within 10 GeV of the PDG value
- Require an additional, higher-p_T ($>$ 20 GeV) lepton that meets tighter reconstruction criteria
- $E_T^{miss} >$ 25 GeV
- W candidate transverse mass $>$ 20 GeV
- Events only accepted if a lepton from $W^{\pm}Z \to \ell^{\pm}\nu_{\ell}\ell'^{+}\ell'^{-}$ decay satisfied the high-p_T single-lepton trigger

Backgrounds

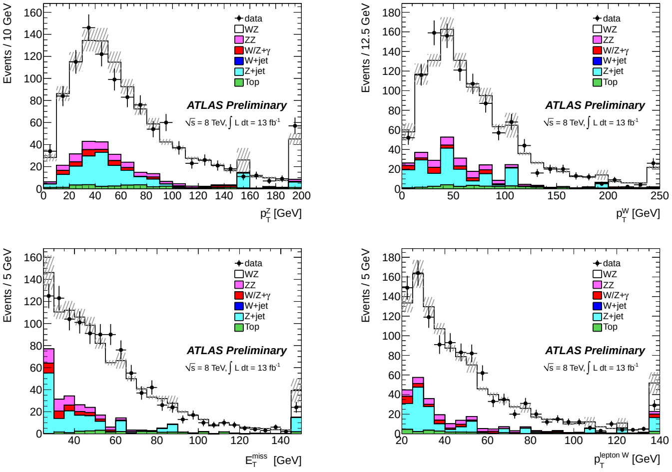
- Primary backgrounds in $\ell^{\pm}\nu_{\ell}\ell'^{+}\ell'^{-}$ channel: $Z+$jets, $Z\gamma$, ZZ and top (incl. $t\bar{t}$ and single-top)
- Estimate expected contribution from sources with three leptons from vector boson decays (viz. $Z\gamma$ and ZZ) using Monte Carlo simulation
- At 7 TeV:
  - Estimate contribution from $Z+$jets using fake factor method.
  - Estimate contribution from $t\bar{t}$ using scale factor method.
- At 8 TeV:
  - Estimate combined contribution from $Z+$jets and $t\bar{t}$ to $Z+\mu$ channels using transfer factor method (details in backup)
  - Estimate combined contribution from $Z+$jets and $t\bar{t}$ to $Z+e$ channels using matrix method

Candidate Events (7 TeV)



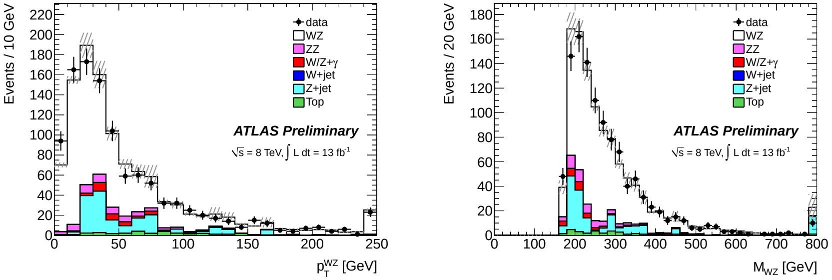
- Observed 317 candidate events in 4.6 fb^{-1} of data, with expected background of 68.1±5.5±8.2 events

Candidate Events (8 TeV)



- Observed 1094 candidate events in 13 fb^{-1} of data, with expected background of 277±9±24 events

Candidate Events (8 TeV, ctd.)



- Observed 1094 candidate events in 13 fb^{-1} of data, with expected background of 277±9±24 events

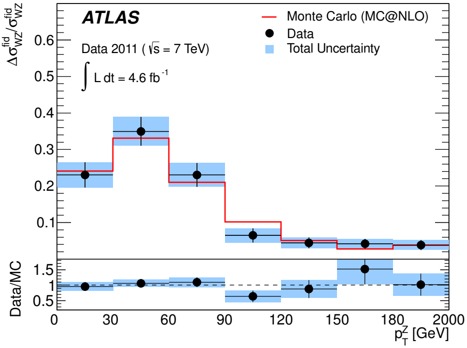
Cross Section Measurement (7 TeV)

- Construct standard Poisson likelihood function with Gaussian nuisance parameters for four flavor channels
- Measured cross section is value with highest likelihood of producing observed distribution
- Did measurement both in fiducial phase-space volume summing over the 4 $\ell^{\pm}\nu_{\ell}\ell'^{+}\ell'^{-}$ channels and then in total phase-space inclusive of channels via PDG branching fractions
- Z boson defined as Z/γ^{*} with mass within 10 GeV of PDG (i.e. 81.1876-101.1876 GeV)
- Results agree with the SM expectations of 85^{+7}_{-9} fb and $17.6^{+1.1}_{-1.0}$ pb.

$$\sigma^{\text{fid}}_{W^{\pm}Z} = 92^{+7}_{-6}(\text{stat.}) \pm 4(\text{syst.}) \pm 2(\text{lumi.})\ \text{fb}$$

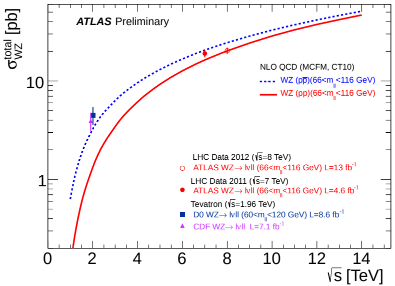
$$\sigma_{W^{\pm}Z} = 19.0^{+1.4}_{-1.3}(\text{stat.}) \pm 0.9(\text{syst.}) \pm 0.4(\text{lumi.})\ \text{pb}$$

Cross Section Measurement: Differential (7 TeV)



- Used iterative Bayesian unfolding to correct measured Z boson p_T distribution for detector effects
- $\Rightarrow$ differential fiducial cross section measurement in Z boson p_T

Cross Section Measurement (8 TeV)



- Same procedure as at 7 TeV
- Except, Z boson defined as Z/γ^* in 66 to 116 GeV mass range
- Results agree with the SM expectations of 99.2 ± 3.6 fb and 20.3 ± 0.8 pb

$$\sigma^{fid}_{W^\pm Z} = 99.2^{+3.8}_{-3.0}(\text{stat.})^{+5.1}_{-5.4}(\text{syst.})^{+3.1}_{-3.0}(\text{lumi.})\text{ fb}$$

$$\sigma_{W^\pm Z} = 20.3^{+0.8}_{-0.7}(\text{stat.})^{+1.2}_{-1.1}(\text{syst.})^{+0.7}_{-0.6}(\text{lumi.})\text{ pb}$$

Anomalous Triple Gauge Coupling Limits

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

- 3 aTGC terms allowed by C and P conservation in Lagrangian produce 9 terms in cross section
- Each TGC event generated using MC@NLO contributes to both anomalous and SM terms
- Contribution to each term a function of couplings
- $\Rightarrow$ in each event, save weight of each contribution and use it to reweight to arbitrary couplings

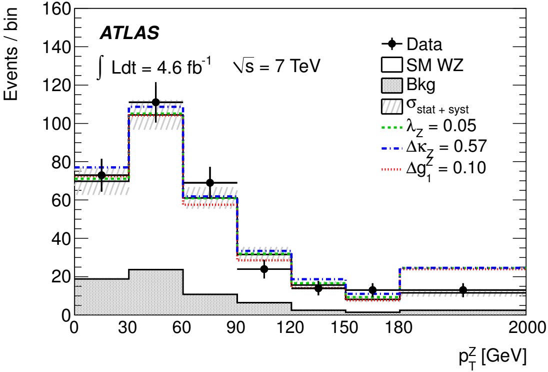
aTGC Limits: Cut-Off Scale

- Since aTGCs are effective theories, need to apply a form factor to ensure renormalizability:

$$\alpha \equiv \frac{\alpha_\infty}{\left(1 + \frac{\hat{s}}{\Lambda^2}\right)^2}$$

- Here, Λ is the scale and α_∞ is the bare coupling.
- $\Rightarrow$ can reweight from the 100 TeV default to arbitrary cut-off scale.
- Produce limits at both 2 TeV and ∞.

aTGC Limits: Z Boson p_T Distribution (7 TeV)



- Set limits using differential p_T distribution

aTGC Limits: Profile Likelihood Method

- For each aTGC, scan coupling space, using toy MC to generate pseudoexperiments at each point.
- In each pseudoexperiment, calculate the likelihood ratio, defined as:

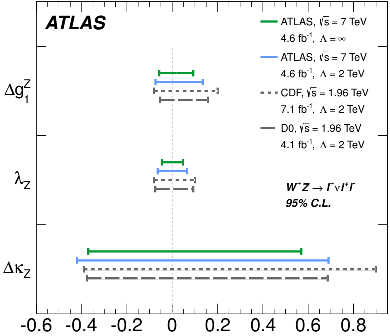
$$q(\alpha) \equiv \frac{\text{Maximum likelihood of pseudoexperiment with coupling fixed at } \alpha}{\text{Maximum likelihood of pseudoexperiment}}$$

- In both cases, using the standard Poisson likelihood function with Gaussian nuisance parameters for 7 p_{T} bins:

$$L(\alpha, \{x_k\}) = \prod_{i=1}^{7} \left(\frac{\left(N^i_{\mathrm{exp}}(\alpha, \{x_k\})\right)^{N^i_{\mathrm{obs}}} \cdot e^{-N^i_{\mathrm{exp}}(\alpha, \{x_k\})}}{N^i_{\mathrm{obs}}!} \right) \times \prod_{k=1}^{n} \left(e^{-\frac{x_k^2}{2}} \right)$$

- Produce likelihood profile versus coupling ($p(\alpha)$), defined at each value of couplings as the fraction of pseudoexperiments with smaller $q(\alpha)$ than the value calculated with observed distribution
- Define 95% confidence interval as region where $p \geq 5\%$.

aTGC Limits: Results (7 TeV)



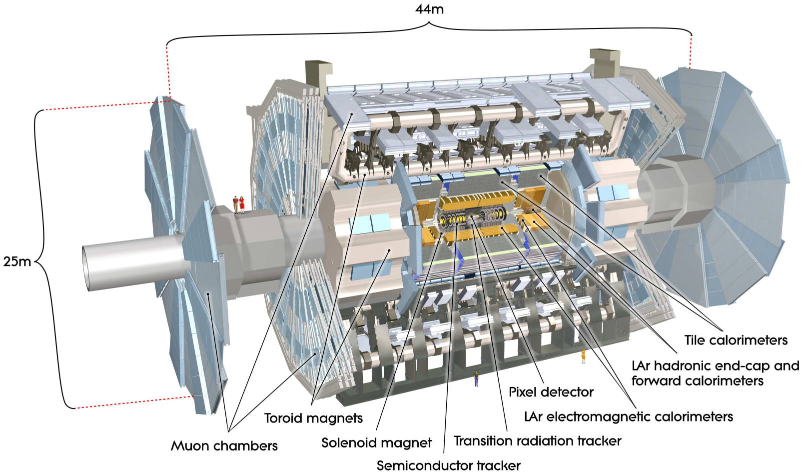
Coupling	Observed ($\Lambda = 2$ TeV)	Observed ($\Lambda = \infty$)
Δg_1^Z	$[-0.074, 0.133]$	$[-0.057, 0.093]$
$\Delta\kappa_Z$	$[-0.42, 0.69]$	$[-0.37, 0.57]$
λ_Z	$[-0.064, 0.066]$	$[-0.046, 0.047]$

Conclusions

- Measured fiducial and total cross sections at 7 and 8 TeV
- All agree with Standard Model predictions
- Set limits on three aTGCs (viz. $\Delta g_1^Z,\ \Delta\kappa_Z,\ \lambda_Z$) at 7 TeV
- aTGC limits at 8 TeV forthcoming

Questions?

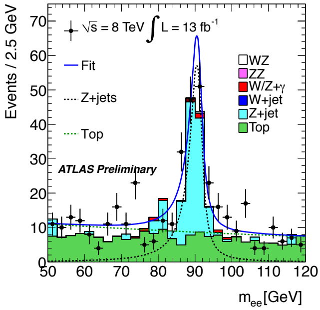
ATLAS

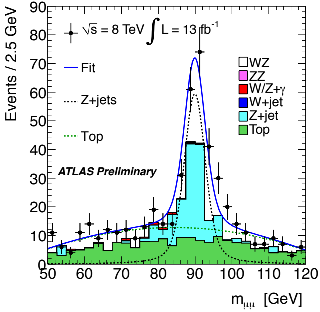

44m
25m
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker

Monte Carlo Simulation

Process	ME	UE	PS
$W^{\pm}Z$ (7 TeV)	MC@NLO	JIMMY	HERWIG
$W^{\pm}Z$ (8 TeV)	POWHEGBOX	PYTHIA8	
ZZ (7 TeV)	PYTHIA		
ZZ (8 TeV)	POWHEGBOX	PYTHIA8	
$Z\gamma$	SHERPA		
$Z+$jets	ALPGEN	JIMMY	HERWIG
$t\bar{t}$	MC@NLO	JIMMY	HERWIG

Backgrounds: Transfer Factor Method (8 TeV)





- Use simulated transfer factor, verified in data, to extrapolate from background enhanced control region to signal region
- Use Breit-Wigner+Crystal Ball to model Z+jets and 2nd order Chebyshev to model $t\bar{t}$ in control region, to extract relative contributions of each process