

Anomalous Triple Gauge Couplings in ATLAS

LPCC EWK WG
22 May 2012, CERN



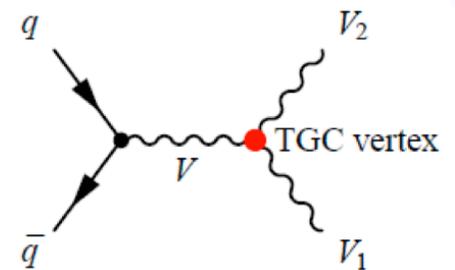
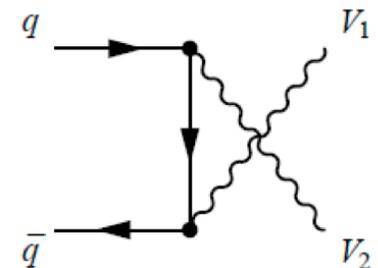
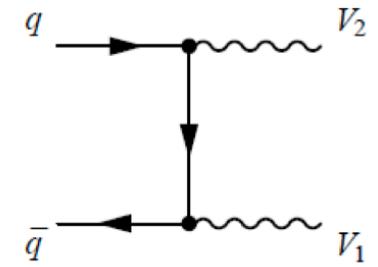
Laura Jeanty
Harvard University
On behalf of the ATLAS Collaboration



Motivation

Triple Gauge Coupling Studies

- Vector boson self-interactions fundamental prediction of standard model gauge symmetry
 - Couplings not yet well measured
 - Neutral couplings do not exist in SM
- Sensitive to new physics
 - New, heavy particles that couple to vector bosons, compositeness of the bosons



Outline

Overview of approach

Signal modeling

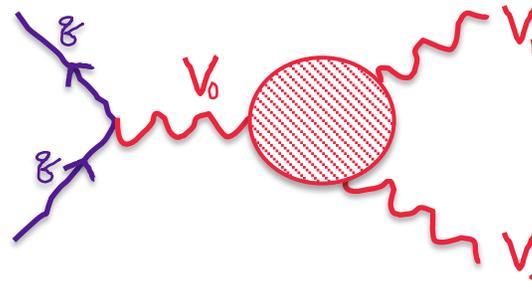
Fitting methods

Current Results

Wish List

Future plans

Effective Lagrangian Approach



Express model independent triple gauge couplings as parameters in effective Lagrangian:

$$\frac{\mathcal{L}_{WWV}}{g_{WWV}} = i \left[g_1^V (W_{\mu\nu}^\dagger W^{\mu\nu} V^\nu - W_{\mu\nu} W^{\dagger\mu\nu} V^\nu) + \kappa^V W_\mu^\dagger W_\nu V^{\mu\nu} + \frac{\lambda^V}{m_W^2} W_{\rho\mu}^\dagger W_\nu^\mu V^{\nu\rho} \right] \quad (\text{WW, WZ})$$

$$\mathcal{L}_{VZZ} = -\frac{e}{M_Z^2} \left[f_4^V (\partial_\mu V^{\mu\beta}) Z_\alpha (\partial^\alpha Z_\beta) + f_5^V (\partial^\sigma V_{\sigma\mu}) \tilde{Z}^{\mu\beta} Z_\beta \right] \quad (\text{ZZ})$$

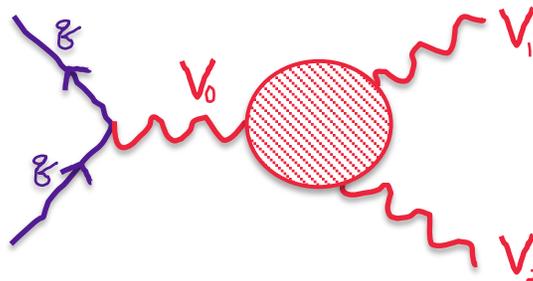
Notes on couplings:

- Couplings defined for on-shell bosons
- Charged couplings and f_5^V, h_3^V, h_4^V have CP invariance
- f_4^V, h_1^V, h_2^V do not conserve CP

In the Standard Model:

- $g_1^V = \kappa^V = 1$
 - set limits on $\Delta g = g - 1, \Delta \kappa = \kappa - 1$
 - g_1^V fixed to 1 due to U(1) EM invariance
- $\lambda^V = f_4^V = f_5^V = h_3^V = h_4^V = 0$

Unitarity Violation



To preserve unitarity at high \sqrt{s} , introduce form factor

$$\alpha \rightarrow a(s) \equiv \frac{\alpha}{(1 + \hat{s} / \Lambda_{FF}^2)^n}$$

Where Λ is the scale of new physics

- For WW, WZ: $n = 2$
- For ZZ: $n = 3$

Limits in ATLAS set in two scenarios:

- $\Lambda = 1.5, 2, 3$ TeV – preserves unitarity, but less general
- no form factor – violates unitarity at high energy, no model assumptions

TGC signal modeling

- Express expected signal yield in each bin i as a function of the aTGC parameters x

$$N_{sig} = [1 \quad x_1 \quad x_{\dots} \quad x_n] \begin{bmatrix} F_{00}^i & F_{01}^i & \dots & F_{0n}^i \\ 0 & F_{11}^i & \dots & F_{1n}^i \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & F_{nn}^i \end{bmatrix} \begin{bmatrix} 1 \\ x_1 \\ \dots \\ x_n \end{bmatrix}$$

- Matrix obtained from simulation with several different approaches
 - NLO event by event reweighting
 - WW – 3D reweighting (BHO)
 - WZ – full dimension (MC@NLO 4.07)
 - LO Event by Event reweighting
 - ZZ – full dimension, LO with one real emission jet (Bella/Hansen)
 - Grid parameterization (Tevatron method)
 - W γ /Z γ – 1D Histogram (MCFM)

Code and Combination

Moving toward common fitting code in ATLAS

- defined input data format (ASCII text file)
- Full treatment of systematic uncertainties and correlations

Common fitting code functionality

- Set delta-log-likelihood limits in 1D (trivial to extend to 2D)
- Set frequentist limits in 1D and 2D
- Set Bayesian limits in 1D (not easy to extend to 2D)

Combination between diboson channels

- Can be done with common fitting code
- Plan to publish combined limits with 5 fb⁻¹

Combination between experiments

- Common framework for combining TGC limits across experiments is a point of discussion
- Common statistical method under discussion

Fitting methods

- **Construct Poisson likelihood function** with aTGC parameters x and nuisance parameters β)

$$L(\vec{x}, \vec{\beta}) = \prod_{i=1}^m \text{Poisson}\left(N_{obs}^i N_{sig}^i(\vec{x}) \times (1 + \beta_i) + N_{bkg}^i \times (1 + \beta_{i+n})\right)$$

- **Several limit setting approaches**
 - Profile likelihood “delta-log likelihood” method: **ZZ**
 - Frequentist limits: **WZ**
 - Bayesian likelihood limits: **WW/W γ /Z γ**

Profile likelihood ratio

Profile likelihood ratio with Gaussian constraints on nuisance parameters:

$$L_{profile}(\bar{x}) = \max_{\beta} [L(\bar{x}, \vec{\beta}) \times \exp[-\frac{1}{2} \beta_i (C_{ij})^{-1} \beta_j]]$$

Define profile likelihood ratio $R(\bar{x}) = \frac{L_{prof}(\bar{x})}{\max[L_{prof}(\bar{x}')]}$

Two statistical approaches using ratio:

- $-\ln R(x) = 1.92$ gives approximate 95% limit
 - delta log-likelihood method
 - fast, but coverage not guaranteed
- Frequentist limits use R as ranking function

Frequentist and Bayesian limits

Frequentist Limits

- Compute frequentist limits by Neyman construction
 - For each hypothetical value of aTGC parameter, generate a large number of pseudo experiments
 - observed number of events drawn randomly from Poisson distribution
 - Central value of nuisance parameters from Gaussian distribution
 - If > 95% of pseudo experiments have larger ratio than actual experiment did, the aTGC value is rejected at 95% CL
- Guarantees statistical coverage
- CPU intensive

Bayesian Limits

- Marginalize the nuisance parameters by integrating over them with Gaussian PDF

$$L_{m \text{ arg}}(\bar{x}) = \int_{-\infty}^{\infty} L(\bar{x}, \vec{\beta}) \times \exp\left[-\frac{1}{2} \beta_i (C_{ij})^{-1} \beta_j\right] d^{2m} \vec{\beta}$$

- Interval l is computed to satisfy

$$\frac{\int_{\bar{x} \in l} L_{m \text{ arg}}(\bar{x})}{\int_{-\infty}^{\infty} L_{m \text{ arg}}(\bar{x})} = 0.95 \quad L_{m \text{ arg}}(\bar{x}) \geq L_{m \text{ arg}}(\bar{y}) \text{ for } \forall \bar{x} \in l \text{ and } \forall \bar{y} \notin l$$

Systematic Uncertainties

Treatment of systematic uncertainties

- Nuisance parameters with Gaussian constraints in likelihood function
- Full correlation between uncertainties across channels and bins computed as input to fitter

Sources of systematic uncertainty

- Luminosity
- Electron / muon / MET reconstruction
- Trigger efficiency
- PDFs
- Theoretical uncertainty on diboson production cross section
- Renormalization/factorization scale
- Data driven background estimates

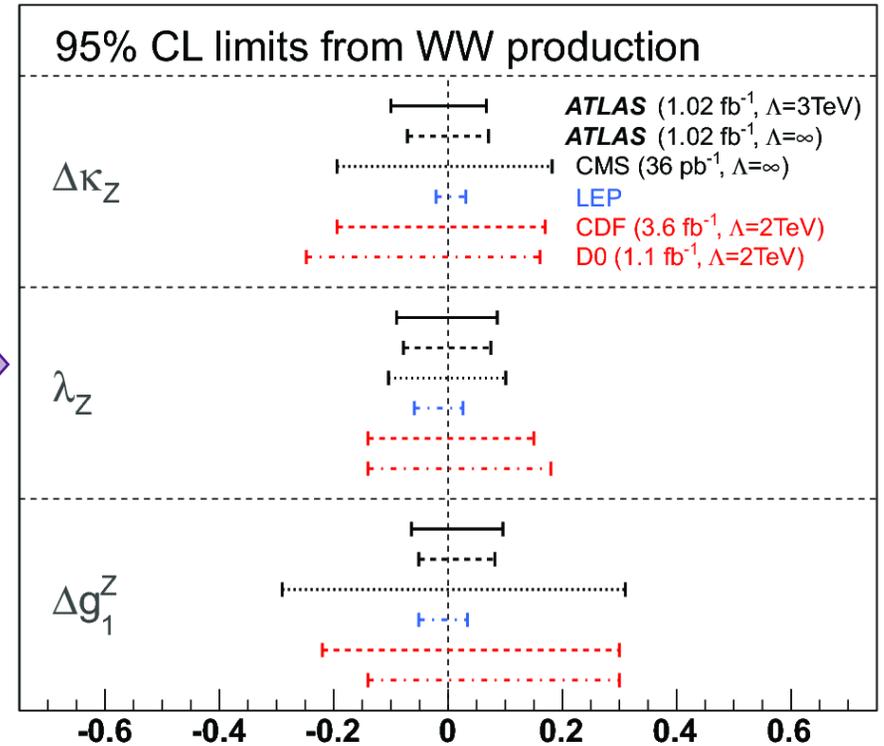
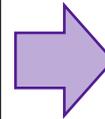
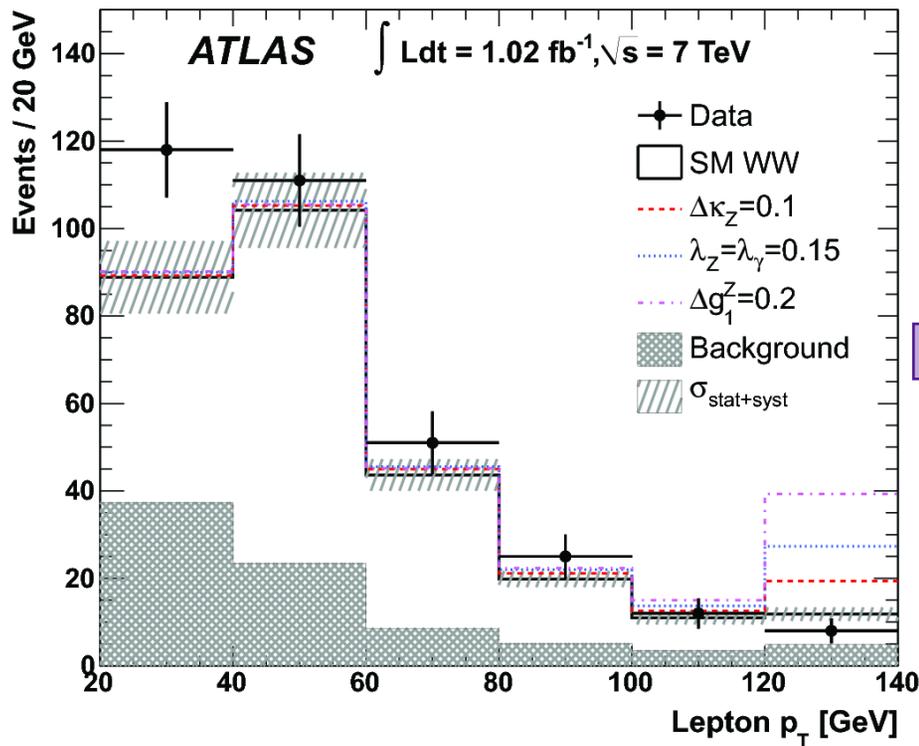
Overview of Public Results

ATLAS has measured and submitted all TGC results with 1 fb^{-1}

- **WW**
 - arXiv: 1203.6232 [hep-ex]
 - Submitted to PLB
- **WZ**
 - PLB 709 (2012) 314-357
- **ZZ**
 - PLR 108, 041804 (2012)
- **$W\gamma/Z\gamma$**
 - arXiv: 1205.2531 [hep-ex]
 - Submitted to PLB

5 fb^{-1} results coming soon!

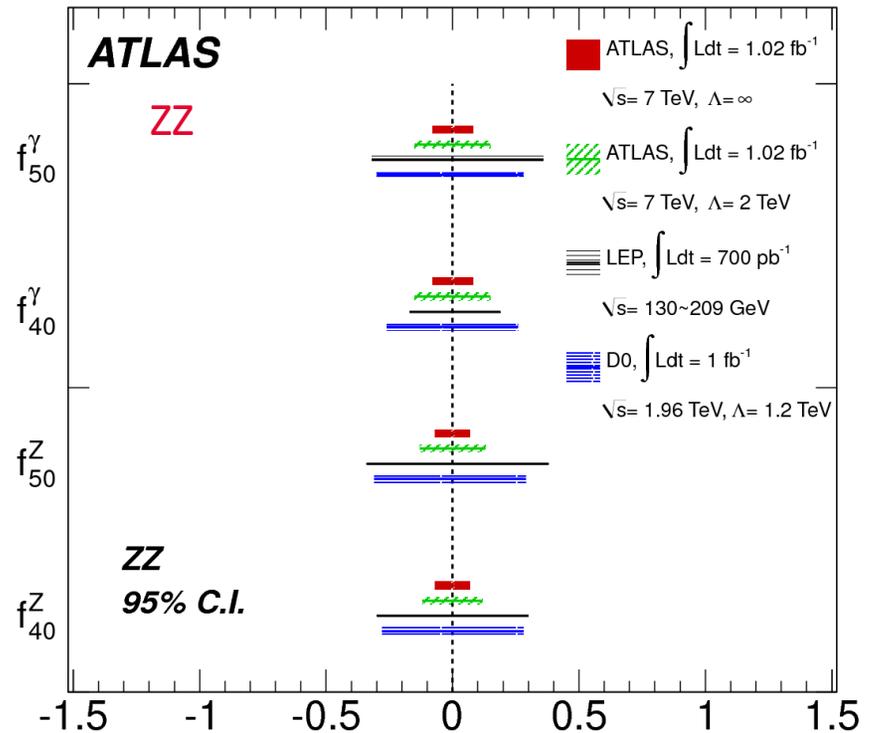
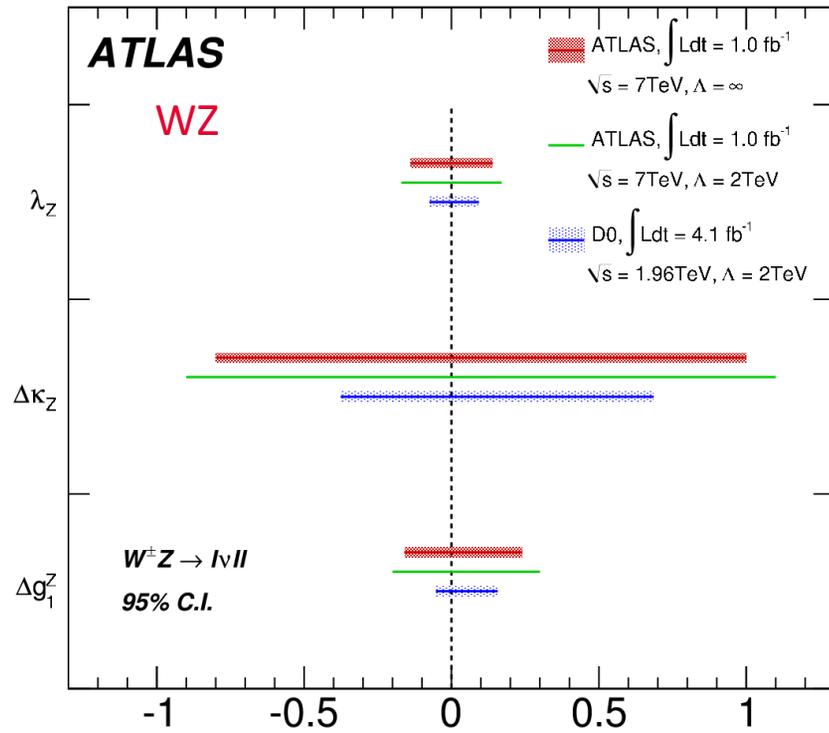
WW \rightarrow $l\nu l\nu$ aTGC results



WW limits

- Sensitive to WWZ and WW γ aTGC vertex
- Limits set using leading lepton p_T spectrum
- Bayesian likelihood limits set using LEP aTGC scenario with 3 parameters

WZ, ZZ aTGC results



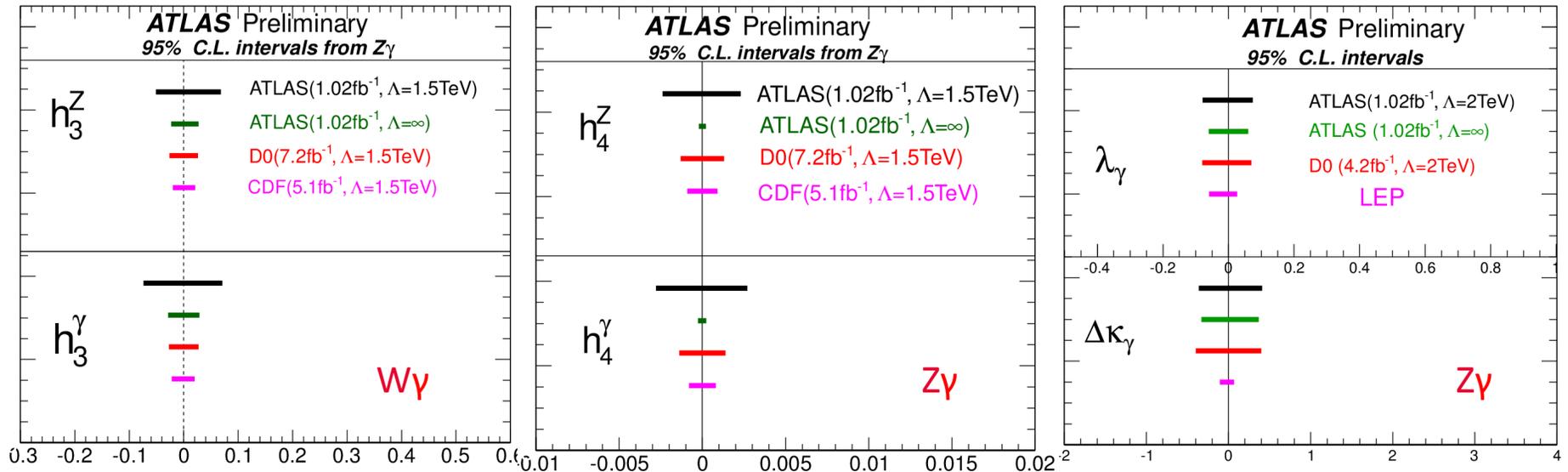
WZ limits

- Analysis sensitive to WWZ vertex
- Limits extracted using observed event yield
- Frequentist limits set

ZZ limits

- Analysis sensitive to ZZ γ and ZZZ aTGC vertices
- Limits extracted using observed event yield
- Profile likelihood limits set

$W\gamma, Z\gamma$ aTGC Results



$W\gamma, Z\gamma$ limits

- $W\gamma$ analysis sensitive to $WW\gamma$ aTGC vertex
- $Z\gamma$ analysis sensitive to $Z\gamma\gamma$ and $ZZ\gamma$ aTGC vertices
- Limits extracted using exclusive fiducial cross-section (no jets) in high E_t^γ regime
 - $E_t^\gamma > 100$ GeV for $W\gamma$
 - $E_t^\gamma > 60$ GeV for $Z\gamma$
- Bayesian likelihood limits set

Analysis Issue

- Boosted Zs in $Z\gamma$ events with large E_t^γ have small delta R between leptons
 → loss of efficiency due to isolation cut

Generator Plans and Wish List

Proposed future approaches

- MC@NLO 4.0: WW/WZ (leptonic decay mode)
 - further generalization to other channels ?
- Bella/Hansen: WW/WZ/ZZ/W γ /Z γ (leptonic decay channel)

Wish List

- NLO calculation (and simulation?) of neutral aTGC
- NLO event weight implementation of W γ , Z γ , and ZZ
- Event by event reweighting for the POWHEG method
- Quartic coupling implementation

Future plans

Near future, 7 TeV

- 5 fb⁻¹ results from all fully leptonic channels
- WZ, ZZ limits from differential distributions
- combined limits between diboson channels

Longer term, 8 TeV

- LHC will press most stringent limits for all TGC parameters
 - WZ example: with 15 fb⁻¹, expected limit for $\lambda_z \sim -0.03 < \lambda_z < 0.03$
- limits as function of Λ ?
- TGC limits are limited by statistics
 - Motivation for combination with CMS
 - Two experiments should develop combination framework
 - Preference for coherent approach