EFT (aGC) limits in ATLAS and CMS

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LHC EWWG Multiboson Meeting, April 4th, 2018

Introduction

- Both ATLAS and CMS have been actively searching for anomalous couplings using multiboson channels, but no obvious anomalies have been found so far
- We measure inclusively and differentially multiboson production cross-sections, and at the meanwhile, look for anomalies in high-s or high-pT regions
- Limits have been placed on aGCs parameters, with the parameterization evolving along the years, e.g. with parameters from effective Lagrangians / vertex functions to higher-dimension EFTs
  - ➢ Also more discussions on the physics validity of different, and more physical interpretations of the results
- Limits being improved significantly with increasing luminosities, surpassing results from past experiments (for constraints using tail distributions)

Outline

- Available results
- Summary plots
- Common topics in aGCs analyses
- Discussion points

Available aGCs results: 13 TeV

CMS	Electroweak production of two jets in association with a Z boson in proton-proton collisions at s=13 TeV	Submitted to EPJC
CMS	Measurements of the pp->ZZ production cross section and the Z → 4l branching fraction, and constraints on anomalous triple gauge couplings at s=13 TeV	Accepted by EPJC
CMS	Measurement of vector boson scattering and constraints on anomalous quartic couplings from events with four leptons and two jets in proton-proton collisions at s=13 TeV	PLB 774 (2017) 682
ATLAS	ZZ cross-section measurement and aTGC limits at 13 TeV	Phys. Rev. D 97 (2018) 032005
ATLAS	WZ boson pair-production at 13 TeV and limits on aTGCs	ATLAS-CONF-2016-043

Available aGCs results: 8 TeV

CMS	Measurements of pp->Wyy and pp->Zyy cross sections and limits on anomalous quartic gauge couplings at s=8 TeV	JHEP 10 (2017) 072
CMS	Search for anomalous couplings in boosted WW/WZ->lvqq¯production in proton-proton collisions at s=8 TeV	PLB 772 (2017) 21
CMS	Measurement of WZ production at s=7 and 8 TeV and search for anomalous triple gauge couplings at s=8 TeV	EPJC 77 (2017) 236
ATLAS	Wvγ cross sections and limits on aGCs at 8 TeV	Eur. Phys. J. C 77 (2017) 646
ATLAS	Semileptonic WW/WZ cross-section at 8 TeV	Eur. Phys. J. C 77 (2017) 563
ATLAS	Electroweak Zγ production 8 TeV	JHEP07(2017)107
ATLAS	Electroweak Wjj cross section and aGC Limits at 7 and 8 TeV	Eur. Phys. J. C 77 (2017) 474
ATLAS	Same-sign WW cross-section and aQGC Limits at 8 TeV	Phys. Rev. D 96 (2017) 012007
ATLAS	ZZ cross-section and aTGC limits at 8 TeV	JHEP 01 (2017) 099
ATLAS	Search for semileptonic WW/WZ VBS at 8 TeV	Phys. Rev. D 95 (2017) 032001
ATLAS	Exclusive WW cross-section at 8 TeV	Phys. Rev. D 94 (2016) 032011
ATLAS	Zy(y) cross section at 8 TeV	Submitted to PRD
ATLAS	WZ cross-sections and aTGC limits at 8 TeV	Phys. Rev. D 93, 092004 (2016)

Available aGCs results: 8 TeV

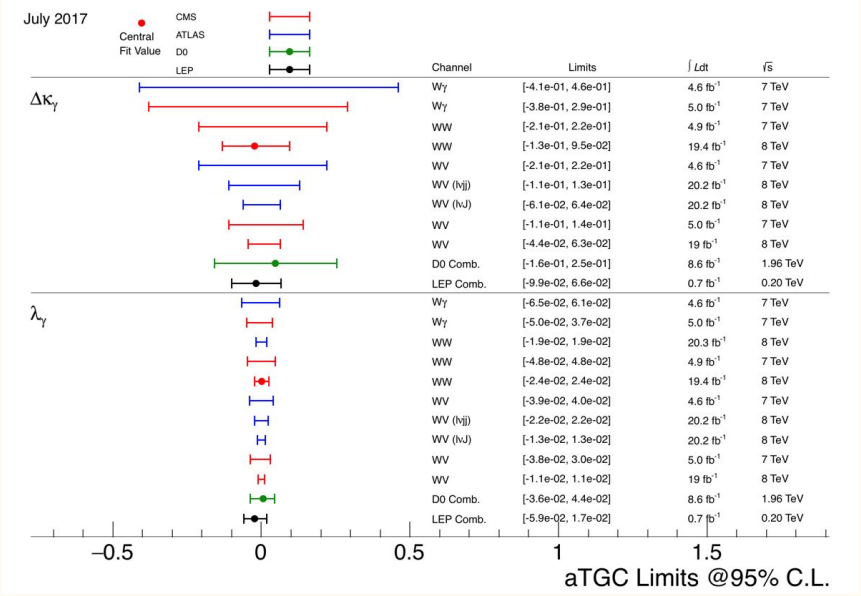
ATLAS	WW cross-section and aTGC limits at 8 TeV	JHEP 09 (2016) 029
CMS	Comparison of the Z/γ*+jets to γ+jets cross sections in pp collisions at s=8 TeV	JHEP 10 (2015) 128 [Err: JHEP 04 (2016)]
CMS	Measurements of ZZ production in the 2l2vchannel at s=7 and 8 TeV and constraints on triple gauge couplings	EPJC 75 (2015) 511
CMS	Measurement of the Zγproduction cross section at 8 TeV and search for anomalous triple gauge boson couplings	JHEP 04 (2015) 164
CMS	Study of vector boson scattering and search for new physics in events with two same-sign leptons and two jets	PRL 114 (2015) 051801
CMS	Measurement of pp->ZZ production and constraints on anomalous couplings in four-lepton final states at s=8 TeV	PLB 740 (2015) 250[Corr: PLB 757 (2016)]
ATLAS	Wγγ cross section at 8 TeV	Phys. Rev. Lett. 115, 031802 (2015)
ATLAS	Same-sign WW cross-section with evidence at 8 TeV	Figures | Phys. Rev. Lett. 113, 141803
ATLAS	Electroweak Zjj cross-section at 8 TeV	Figures | JHEP04(2014)031
CMS	A search for WWγ and WZγ production and constraints on anomalous quartic gauge couplings at s= 8 TeV	PRD 90 (2014) 032008
CMS	Measurement of WZ and ZZ production in pp collisions at s= 8 TeV in final states with b-tagged jets	EPJC 74 (2014) 2973

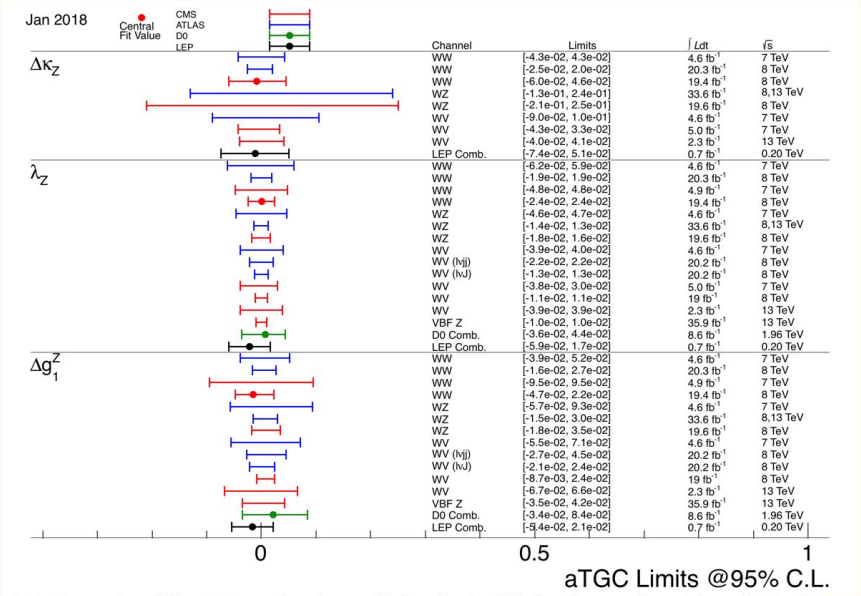
❖ Note: 7 TeV not listed since mostly obsolete by newer measurements

Limits on WWy and WWZ aTGC couplings

- Summary plots made within the LHC EW WG
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC

- Note: these all use aTGC formalism (as most of the input publications, LEP/Tevatron)





Note: trivial conversion of $\lambda_\gamma = \lambda_Z$ has been done in cases where measurements have direct sensitivity to λ_γ

Note: Conversion of $\Delta\kappa_\gamma$ to $\Delta\kappa_Z$ using $\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma tan^2\theta_W$ has been performed for analysis with direct and competitive sensitivity to $\Delta\kappa_Z$. For the CMS 7 TeV WV analysis Δg_1^Z is constrained to the SM values of zero while for the LEP Combined analysis the measured value and limits on Δg_1^Z are used.

Further Summary plots

- Limits on neutral ZZy and ZZZ aTGC couplings
- limits on dimension 8 mixed transverse and longitudinal parameters $f_{M,i}$
- limits on dimension 8 transverse parameters $f_{T,i}$
- Also to be found on:
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMPaTGC

- In general: still “old” parametrization, no “newer” EFT overview (that would also reflect the Higgs discovery)
- Mainly for historical reasons: comparison to LEP/Tevatron,
  BUT: all limits exceed those from LEP/Tevatron → are free to change parametrizations

Common Topics in aGCs Analyses: Variables & Binning

- Usual questions:
  - What variables to measure (in case of unfolded distributions)
  - Which are most sensitive to aGCs / EFT parameters?
  - What binning to choose
- Can be over- and under-optimised
  - E.g. WW 8 TeV: ATLAS optimized on MC and chose leading lepton pT -- yielding 20-30% better limits than CMS (using Mll distribution with less modelling uncertainties) *but* ATLAS had worse agreement between expected and observed limits due to pT mismodelling
    → How should one deal with these cases
  - Often only most obvious variables, correlated with centre-of-mass energy are used
  - Useful to receive feedback on other interesting distributions (e.g. angular variables, 2D distributions)

Common Topics in aGCs Analyses: Parameters?

- As reflected in summary plots: Currently old parameterizations used
  But: internal recommendation of experiments is to upgrade to more general EFTs
- Usually still most simple ones are used, often just using aTGC <-> EFT relations
  - Anomalous Gauge Boson Couplings -- Model including anomalous couplings among gauge bosons (O.J.P. Eboli, M.C. Gonzalez-Garcia)
  - Effective theory for weak gauge boson production -- Dimension-six operators invariant under the SM symmetries affecting triple gauge boson interactions (C.Degrande)
- Often not clear, which is best choice
- What about interplay with the Higgs? (or not so relevant because of dominance of linear vs. quadratic terms?)

Common Topics in aGCs Analyses: Unitarisation?

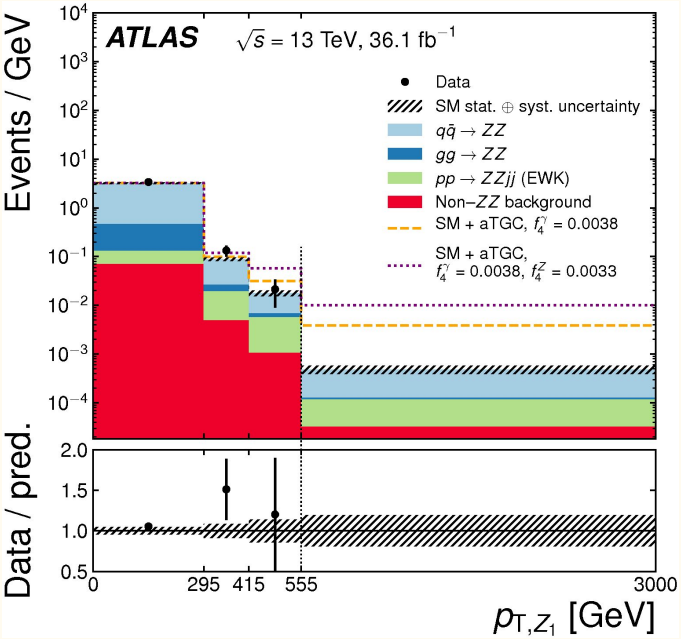
- Particularly for Dim-8 operators: Unitarisation is imperative!
  (for Dim-6 most likely no unitarization -- up to arbitrary energies, i.e. not-accessible at LHC -- is necessary, though not confirmed for all operators and processes).
- Many approaches on the market: k/T-Matrix, dipole form-factor, “clipping” (step function)
- “Clipping” (i.e. removing EFT signals above certain threshold on truth level)
  - easiest to implement and to compare
  - But specifics not yet well studied / defined
    - best variable for cut-off
    - how to decide threshold or what are scan ranges
    - Uncertainties?

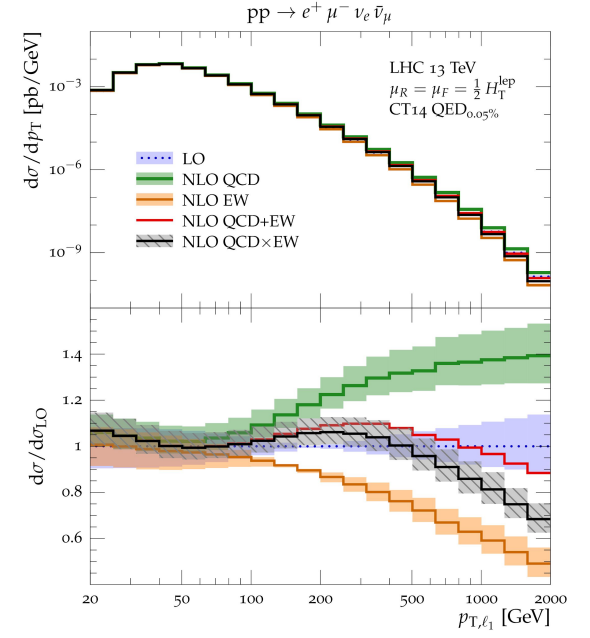
Common Topics in aGCs Analyses: Tools

- Approaches for simulation, interpolation and extrapolation of EFT parameters divers
- MC generators: VBFNLO, MCatNLO, aMCatNLO, ...
- Can lead to inconsistencies if not fully clear to users, e.g. sign-difference in EFT (MadGraph-Model) vs. conversion from MCatNLO aTGC parameterisation
- What is the best approach to interpolate between EFT≠0 points?
  - VBFNLO → external interpolation (e.g. morphing, own-build quadratic fit, …)
  - MCatNLO → helicity decomposition
  - aMCatNLO → reweighting, possibility to generate single terms
- Could be good to have an overview over possible approaches (in Yellow Report)

Common Topics: Theory uncertainty at tails

- Might suffer significantly from theory uncertainties





Significant QCD or EWK corrections at certain tail regions, also interplay between the two.

How about these unc. on aGCs?

Example from ZZ 13 TeV ATLAS

arXiv:1705.00598v1

Common Topics: Statistical Methods

- delta-log-likelihood method
- Toy MC methods such as the Feldman-Cousins method
- CLs method

All three methods have been used in experimental results, and in most cases, they yielded similar results

- In general, if last bin has an expected number of events more than 3 events, a delta-log-likelihood approximation is OK
- If aGCs are being extracted with bins having <=O(1) events, better to go with Toy MC methods
- CLs method gives more conservative results

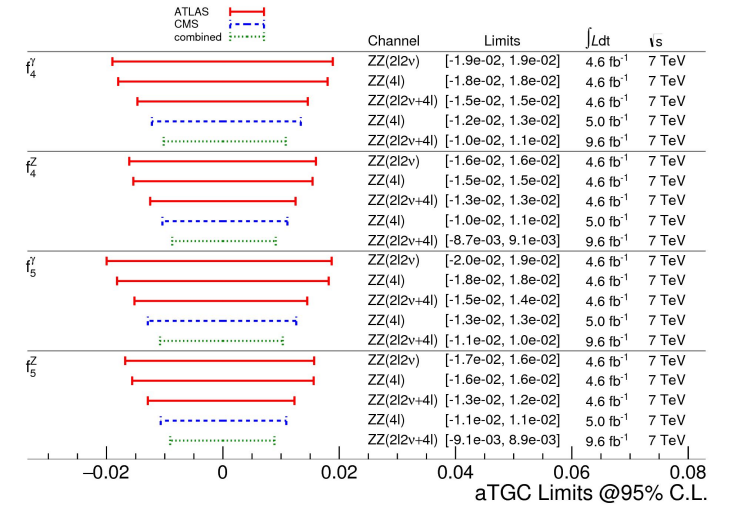
Observed limit	f_4^γ	f_4^Z	f_5^γ	f_5^Z
deltaNLL ATLAS	[-0.015, 0.015]	[-0.013, 0.013]	[-0.015, 0.015]	[-0.013, 0.012]
deltaNLL CMS	[-0.012, 0.013]	[-0.010, 0.011]	[-0.013, 0.013]	[-0.011, 0.011]
deltaNLL combined	[-0.010, 0.011]	[-0.0087, 0.0091]	[-0.011, 0.010]	[-0.0091, 0.0089]
F-C combined	[-0.010, 0.011]	[-0.0089, 0.0092]	[-0.011, 0.010]	[-0.0092, 0.0089]

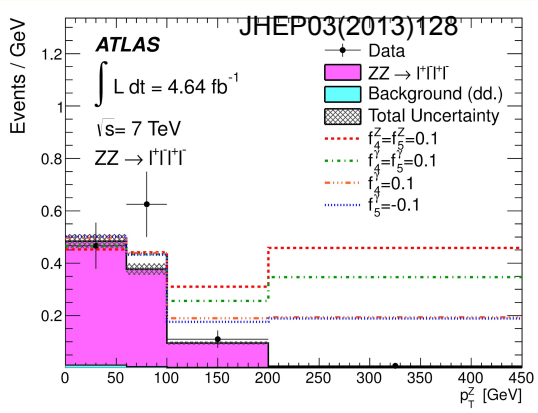
Example from *ATLAS+CMS 7 TeV ZZ combination*

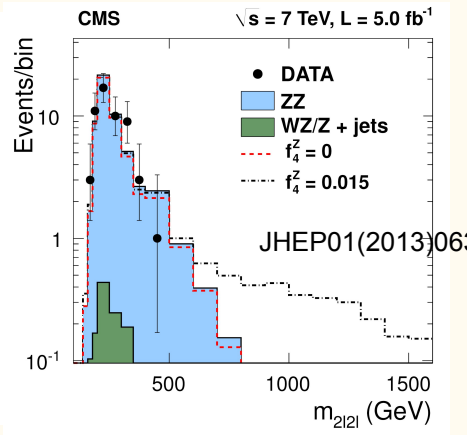
Common Topics: Combination

- Often statistically limited when probing high-s region using individual channels, combination of results from different channels / experiments will help

Example: *ATLAS+CMS 7 TeV ZZ combination*







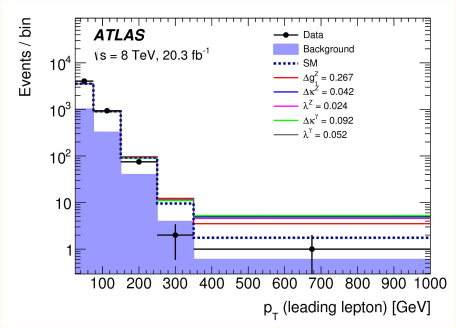
- That effort would serve as a proof of principle, ~50% improvement from combination
- Combination could be important at the end of each data taken period, to best approach a desired precision of aGCs, e.g. eventually 10^-4 level for ZZ case?

Common Topics: Combination

- Effects of different aGCs often not distinguishable from a single channel, combination will hopefully give a more realistic and global constraints to aGCs

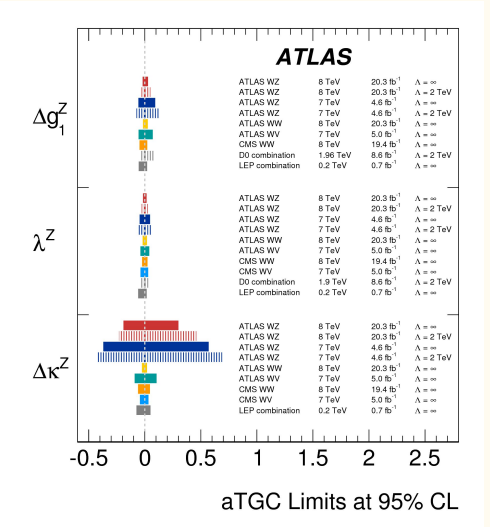
Example of dim-6 operators v.s. vertices
arXiv:1309.7890

	$\mathcal{O}_{WWW}$	$\mathcal{O}_{W}$	$\mathcal{O}_{B}$	$\mathcal{O}_{WW}$	$\mathcal{O}_{BB}$	$\mathcal{O}_{\phi,2}$	$\mathcal{O}_{\widetilde{W}WW}$	$\mathcal{O}_{\widetilde{W}}$	$\mathcal{O}_{\widetilde{B}}$	$\mathcal{O}_{\widetilde{W}W}$	$\mathcal{O}_{\widetilde{B}B}$
WWZ	X	X	X				X	X	X		
$WW\gamma$	X	X	X				X	X	X		
HWW		X		X		X		X		X	
HZZ		X	X	X	X	X		X	X	X	X
$HZ\gamma$		X	X	X	X	(X)		X	X	X	X
$H\gamma\gamma$				X	X	(X)				X	X
$WWWW$	X	X					X				
$WWZZ$	X	X					X				
$WWZ\gamma$	X	X					X				
$WW\gamma\gamma$	X						X				



aGCs on a single channel, example with ATLAS WW 8TeV

WZ v.s. WW



Factors for future combinations:

- Channels; Common Inputs, Uncertainty correlation, etc.

Further Discussion Points

- Some unified recommendations useful for
  - Unitarisation
  - EFT models to use
  - Additional distributions / parameters
- Usual conflicts: Quotation/Usage of results
  - Detector level vs. Unfolded distributions
  - Long standing request from theory side → publication of full likelihood ***-- How?***
  - Would theorists publish likelihoods for e.g. low-energy / precision data?
- Are there any other recommendations / discussion points?
- What would be the ideal package to have for the full Run-2 ?