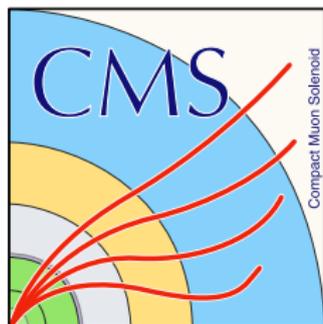


Anomalous Couplings in Diboson Final States

Multi-Boson Interactions, 28.08.2019, Thessaloniki



Hannes Mildner
on behalf of the ATLAS
and CMS collaborations



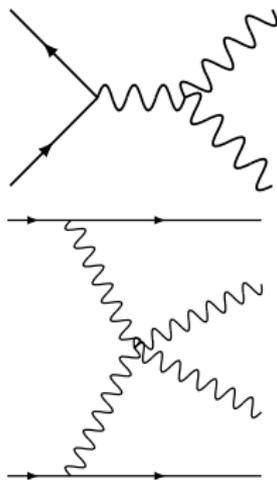
The
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Introduction

- ▶ Multiboson interactions due to SU(2) kinetic term in SM Lagrangian

$$\mathcal{L} = -\frac{1}{4}W^{a\mu\nu}W_{\mu\nu}^a = -\frac{1}{4}(\partial_\mu W_\nu^a - \partial_\nu W_\mu^a + g\epsilon^{abc}W_\mu^b W_\nu^c)^2$$

- ▶ Trilinear and quartic vertices (note: SM self-interactions always contain W^\pm 's)
 - ▶ New physics could manifest itself as varied or new multiboson couplings
- ▶ Anomalous gauge coupling measurements overview
 - ▶ *Anomalous triple gauge couplings*: WW and WZ (and VBF W/Z, W_γ – but not part of this talk)
 - ▶ *Neutral triple gauge couplings*: ZZ and Z_γ
 - ▶ *Anomalous quartic gauge couplings*: VBS production of boson pairs (and triboson, exclusive WW)
- ▶ Scope of this talk
 - ▶ Anomalous coupling results from Run 2 only
 - ▶ For more details of measurement, see talks by [Alicia](#), [Valerie](#), [Robin](#), [Andrew](#), [Narei](#)



Anomalous Triple Gauge Couplings (aTGCs)

Anomalous Triple Gauge Couplings

Effective Lagrangian Framework

C and P conserving effective Lagrangian for WWV interactions

$$i\mathcal{L}_{\text{eff}}^{WWW} = g_{WWW} \left[g_1^V V^\mu (W_{\mu\nu}^- W^{+\nu} - W_{\mu\nu}^+ W^{-\nu}) + \kappa_V W_\mu^+ W_\nu^- V^{\mu\nu} + \frac{\lambda_V}{m_W^2} V^{\mu\nu} W_\nu^{+\rho} W_{\rho\mu}^- \right]$$

- ▶ Anomalous triple gauge couplings described by $\Delta g_1^Z, \Delta\kappa_Z, \Delta\kappa_\gamma, \lambda_Z, \lambda_\gamma$
- ▶ If C/P-violating terms included: six additional parameters

- ▶ To respect gauge symmetry, LEP parameterization can be used, with only three degrees of freedom (e.g. $\Delta g_1^Z, \Delta\kappa_Z, \lambda_Z$)
- ▶ aTGCs yield amplitudes growing with \hat{s}/M_W^2 , causing unitarity violation
 - ▶ ad hoc cure: introduce form factor and replace aTGCs:
 $c \rightarrow \frac{c}{(1+\hat{s}/\Lambda_{\text{FF}}^2)^2}$ (= 0 for $\hat{s} \rightarrow \text{inf}$)
 - ▶ alternative: clipping (ignoring aTGC effects beyond $\sqrt{\hat{s}} > \Lambda_{\text{clip}}$)

EFT Approach for aTGCs

- ▶ In general, SM EFT expansion adds operator of energy dimension >4 to SM, suppressed by powers of new physics scale Λ

$$\mathcal{L}_{\text{SM EFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{\text{dim5}}}{\Lambda} O_i^{\text{dim5}} + \sum_i \frac{c_i^{\text{dim6}}}{\Lambda^2} O_i^{\text{dim6}} + \dots$$

- ▶ aTGC operators appear at dimension six
- ▶ Operator basis not unique, choice for aTGCs measurements:

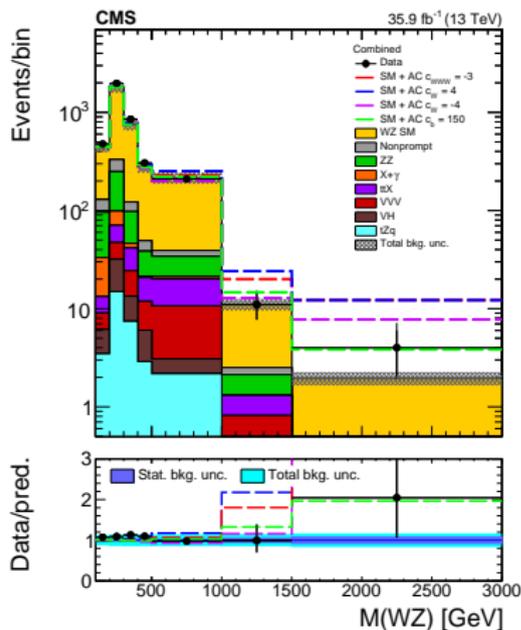
$$\begin{aligned} O_B &= (D_\mu H)^\dagger B^{\mu\nu} D_\nu H, & O_{\tilde{W}} &= (D_\mu H)^\dagger \tilde{W}^{\mu\nu} D_\nu H, \\ O_W &= (D_\mu H)^\dagger W^{\mu\nu} D_\nu H, & O_{\tilde{W}WW} &= \text{Tr}[W_{\mu\nu} W_\rho^\nu \tilde{W}^{\rho\mu}] \\ O_{WWW} &= \text{Tr}[W_{\mu\nu} W_\rho^\nu W^{\rho\mu}] \end{aligned}$$

- ▶ Coefficients can be mapped to aTGCs parameters
- ▶ Unitarity violation at high \sqrt{s} can be understood as breakdown of EFT expansion as \sqrt{s} approaches Λ
- ▶ Comparison of size of terms linear ($\propto c/\Lambda^n$) and quadratic ($\propto c^2/\Lambda^{2n}$) in EFT coefficients can be test of convergence of EFT expansion
- ▶ Energy scale probed by measurement relevant

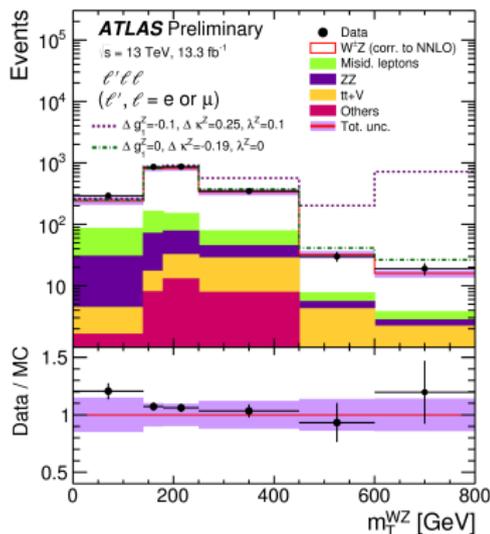
WZ (1/2)

CMS SMP-18-002 and ATLAS-CONF-2016-043: $WZ \rightarrow \ell\nu\ell'\ell'$

- ▶ Measurements in relatively clean three-lepton channel
- ▶ Limits from tails of m^{WZ} (CMS) and m_{\top}^{WZ} (ATLAS) distribution, where impact of aTGC largest

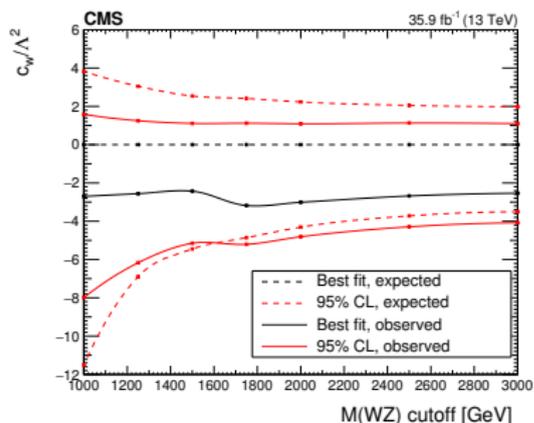


- ▶ aTGC analysis on smaller dataset for ATLAS (13.3 fb⁻¹)



WZ (2/2)

- ▶ Limits in aTGC and EFT approach from ATLAS, combination with Run 1
- ▶ CMS also provides limits with linear term only
- ▶ Different sign conventions used (?)
- ▶ Tighter limits from CMS (different binning, more data)



ATLAS limits (EFT approach)

Dataset	Coupling	Expected [TeV ⁻²]	Observed [TeV ⁻²]
13 TeV	$c_W / \Lambda_{\text{NP}}^2$	[-4.1; 7.6]	[-3.8; 8.6]
	$c_B / \Lambda_{\text{NP}}^2$	[-261; 193]	[-280; 163]
	$c_{WWW} / \Lambda_{\text{NP}}^2$	[-3.6; 3.4]	[-3.9; 3.7]
8 and 13 TeV	$c_W / \Lambda_{\text{NP}}^2$	[-3.4; 6.9]	[-3.6; 7.3]
	$c_B / \Lambda_{\text{NP}}^2$	[-221; 166]	[-253; 136]
	$c_{WWW} / \Lambda_{\text{NP}}^2$	[-3.2; 3.0]	[-3.3; 3.2]

CMS linear+quadratic terms

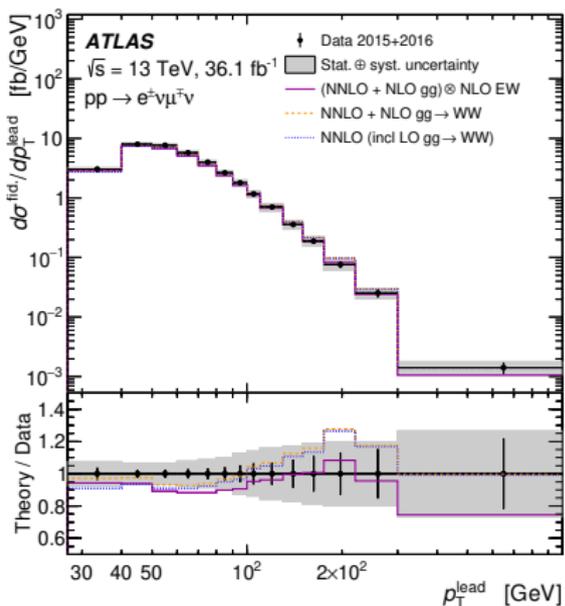
Parameter	95% CI (expected) [TeV ⁻²]	95% CI (observed) [TeV ⁻²]
c_W / Λ^2	[-3.3, 2.0]	[-4.1, 1.1]
c_{WWW} / Λ^2	[-1.8, 1.9]	[-2.0, 2.1]
c_b / Λ^2	[-130, 170]	[-100, 160]

CMS linear terms only

Parameter	95% CI (expected) [TeV ⁻²]	95% CI (observed) [TeV ⁻²]
c_W / Λ^2	[-2.3, 3.4]	[-2.2, 2.7]
c_{WWW} / Λ^2	[-33.2, 28.6]	[-13.8, 41.2]
c_b / Λ^2	[-360, 300]	[-230, 390]

- ▶ “Clipping” study performed by CMS: restrict effect of aTGC up to a cut-off value of $M(WZ)$

ATLAS STDM-2017-24: $WW \rightarrow e\nu\mu\nu$



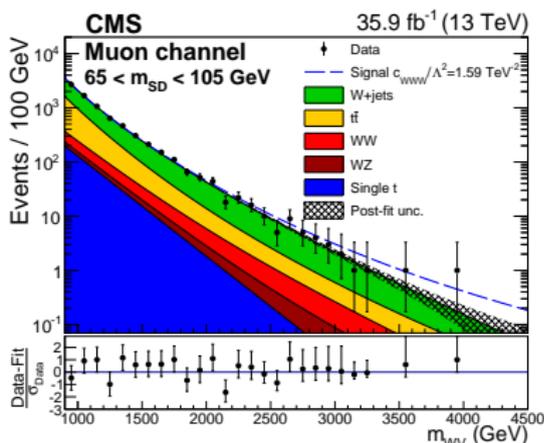
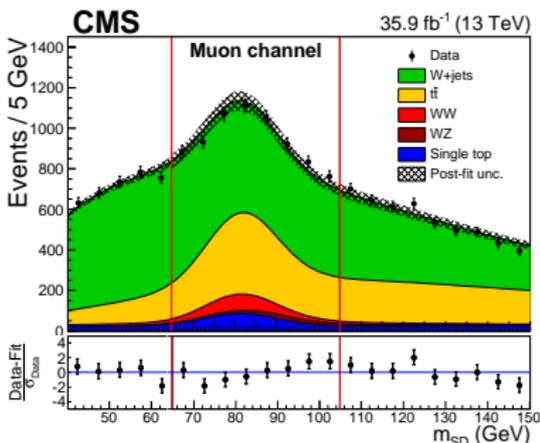
- ▶ More background than WZ, need to suppress $t\bar{t}$ with jet-veto
- ▶ Two neutrinos in final state
- ▶ Limits from unfolded leading p_T^ℓ fiducial cross section - validated BSM terms behave as SM in unfolding
- ▶ Large EWK correction to tail of p_T^ℓ
- ▶ Less sensitive to O_W, O_{WWW} than WZ
- ▶ Results given with and without quadratic term as well

Operator	95% CL (linear and quadratic terms)	95% CL (linear terms only)
c_{WWW}/Λ^2	$[-3.4 \text{ TeV}^{-2}, 3.3 \text{ TeV}^{-2}]$	$[-179 \text{ TeV}^{-2}, -17 \text{ TeV}^{-2}]$
c_W/Λ^2	$[-7.4 \text{ TeV}^{-2}, 4.1 \text{ TeV}^{-2}]$	$[-13.1 \text{ TeV}^{-2}, 7.1 \text{ TeV}^{-2}]$
c_B/Λ^2	$[-21 \text{ TeV}^{-2}, 18 \text{ TeV}^{-2}]$	$[-104 \text{ TeV}^{-2}, 101 \text{ TeV}^{-2}]$

Parameter	Observed 95% CL [TeV^{-2}]	Expected 95% CL [TeV^{-2}]
c_{WWW}/Λ^2	$[-3.4, 3.3]$	$[-3.0, 3.0]$
c_W/Λ^2	$[-7.4, 4.1]$	$[-6.4, 5.1]$
c_B/Λ^2	$[-21, 18]$	$[-18, 17]$
c_{WWW}/Λ^2	$[-1.6, 1.6]$	$[-1.5, 1.5]$
$c_{\bar{W}}/\Lambda^2$	$[-76, 76]$	$[-91, 91]$

CMS SMP-18-008: $WV \rightarrow \ell\nu J$ ($J = \text{fat jet}$)

- ▶ Least clean channel – SM signal buried beneath $t\bar{t}$ and $W+\text{jets}$
- ▶ Higher statistics / energy reach for aTGCs
- ▶ Simultaneous unbinned fit of jet and diboson mass

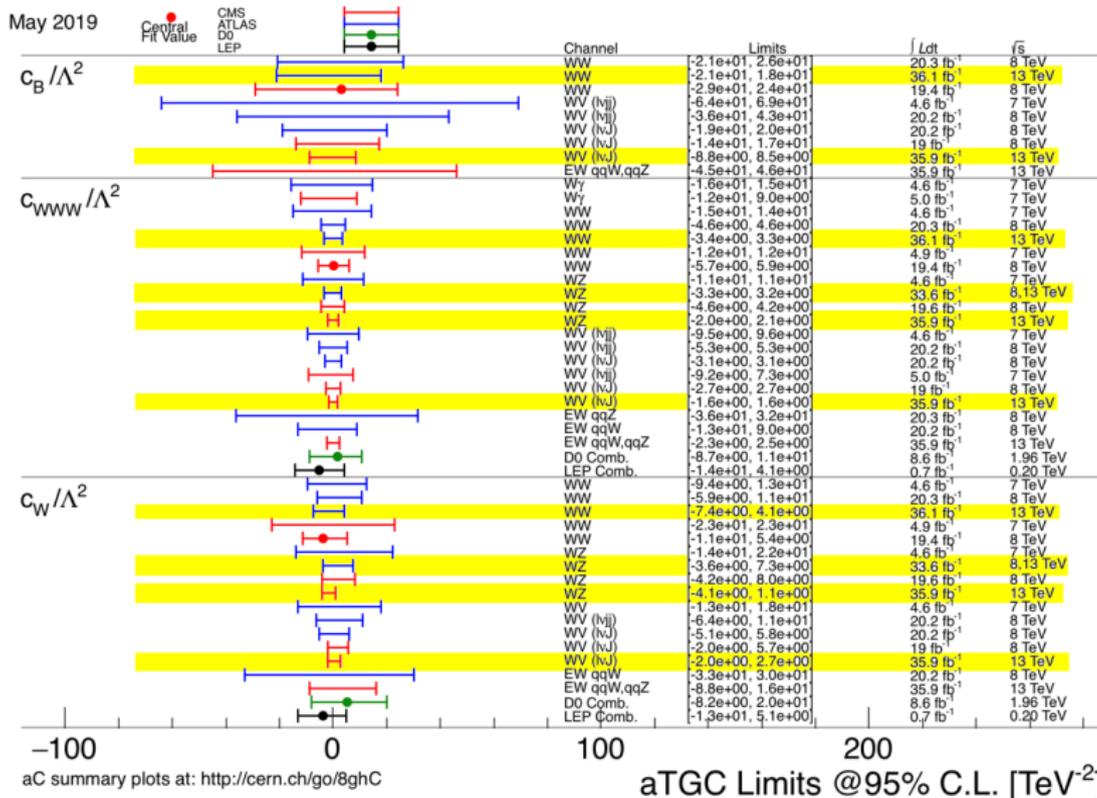


- ▶ Best sensitivity to all three tested operators

- ▶ No study on unitarity, energy scale probed, or quadratic terms

Parametrization	aTGC	Expected limit	Observed limit
EFT	c_{WWW}/Λ^2 (TeV ⁻²)	[-1.44, 1.47]	[-1.58, 1.59]
	c_W/Λ^2 (TeV ⁻²)	[-2.45, 2.08]	[-2.00, 2.65]
	c_B/Λ^2 (TeV ⁻²)	[-8.38, 8.06]	[-8.78, 8.54]

Summary of aTGC constraints (EFT approach)



Presented results (highlighted) most sensitive ones, far surpassing LEP

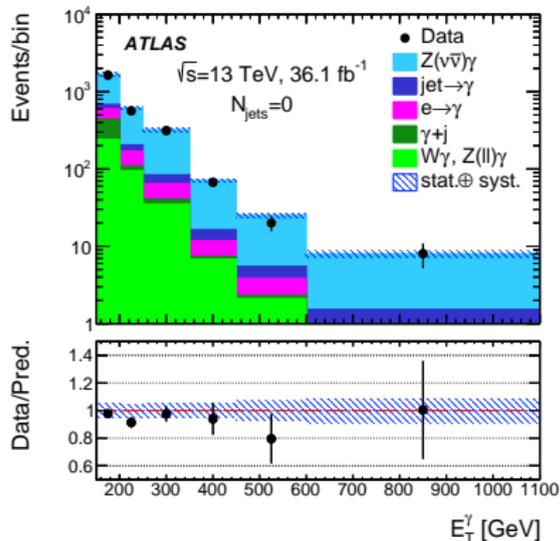
Neutral Triple Gauge Couplings (nTGCs)

- ▶ Reminder: no neutral triple gauge couplings in SM
- ▶ Can be constrained in $Z\gamma$ and ZZ production
- ▶ Usually effective vertex function approach chosen (essentially effective Lagrangian approach in momentum space)

Vertex function approach

- ▶ Eight parameters for $Z\gamma$ production: h_i^V ($i=1-4$, $V=Z,\gamma$),
(CP-violating h_1^V, h_2^V practically indistinguishable from h_3^V, h_4^V)
- ▶ Four parameters for two on-shell Z 's in ZZ production: f_4^V, f_5^V
- ▶ In EFT approach nTGC appear only at dim8, four degrees of freedom (can be parametrized as linear combinations of h_i^V 's and f_j^V 's)

$$\begin{aligned}
 O_{\widetilde{BW}} &= i H^\dagger \widetilde{B}_{\mu\nu} W^{\mu\rho} \{D_\rho, D^\nu\} H, & O_{WW} &= i H^\dagger W_{\mu\nu} W^{\mu\rho} \{D_\rho, D^\nu\} H, \\
 O_{BW} &= i H^\dagger B_{\mu\nu} W^{\mu\rho} \{D_\rho, D^\nu\} H, & O_{BB} &= i H^\dagger B_{\mu\nu} B^{\mu\rho} \{D_\rho, D^\nu\} H.
 \end{aligned}$$

ATLAS STDM-2017-18: Z($\nu\nu$) γ 

- $\nu\nu\gamma$ channel most sensitive channel for Z γ nTGCs (large branching ratio, no FSR)
- Limits extracted from $E_T^\gamma > 600$ GeV events, in zero-jet category

Parameter	Limit 95% CL	
	Measured	Expected
h_3^γ	$(-3.7 \times 10^{-4}, 3.7 \times 10^{-4})$	$(-4.2 \times 10^{-4}, 4.3 \times 10^{-4})$
h_3^Z	$(-3.2 \times 10^{-4}, 3.3 \times 10^{-4})$	$(-3.8 \times 10^{-4}, 3.8 \times 10^{-4})$
h_4^γ	$(-4.4 \times 10^{-7}, 4.3 \times 10^{-7})$	$(-5.1 \times 10^{-7}, 5.0 \times 10^{-7})$
h_4^Z	$(-4.5 \times 10^{-7}, 4.4 \times 10^{-7})$	$(-5.3 \times 10^{-7}, 5.1 \times 10^{-7})$

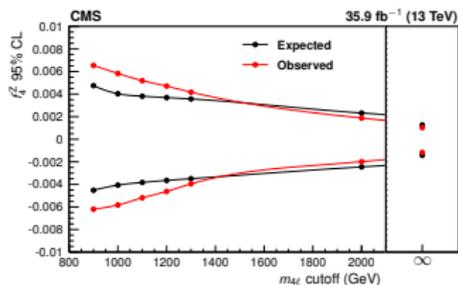
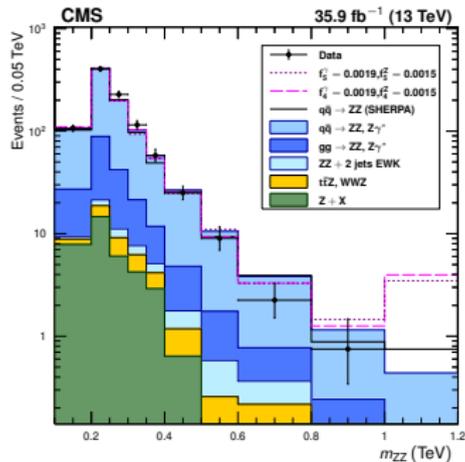
Parameter	Limit 95% CL	
	Measured [TeV $^{-4}$]	Expected [TeV $^{-4}$]
$C_{\bar{B}W}/\Lambda^4$	(-1.1, 1.1)	(-1.3, 1.3)
C_{BW}/Λ^4	(-0.65, 0.64)	(-0.74, 0.74)
C_{WW}/Λ^4	(-2.3, 2.3)	(-2.7, 2.7)
C_{BB}/Λ^4	(-0.24, 0.24)	(-0.28, 0.27)

- Events from nTGCs calculated with formula below, 7 % uncertainty on efficiency $C_{Z\gamma}$ (nTGCs change kinematics and thus $C_{Z\gamma}$)

$$N_{Z\gamma}^{\text{nTGC}}(h_3^V, h_4^V) = \sigma_{Z\gamma}^{\text{nTGC}}(h_3^V, h_4^V) \cdot C_{Z\gamma} \cdot A_{Z\gamma} \cdot C^{*(\text{parton} \rightarrow \text{particle})} \cdot \int L dt.$$

ZZ(4l)

ATLAS STDM-2016-15, CMS SMP-16-017: $ZZ \rightarrow 4l$



- Constraints from tail of m_{ZZ} by CMS, from p_T^Z by ATLAS (ATLAS applies p_T^Z -binned EW corrections)

CMS limits

$$-0.0012 < f_4^Z < 0.0010, \quad -0.0010 < f_5^Z < 0.0013,$$

$$-0.0012 < f_4^\gamma < 0.0013, \quad -0.0012 < f_5^\gamma < 0.0013.$$

ATLAS limits

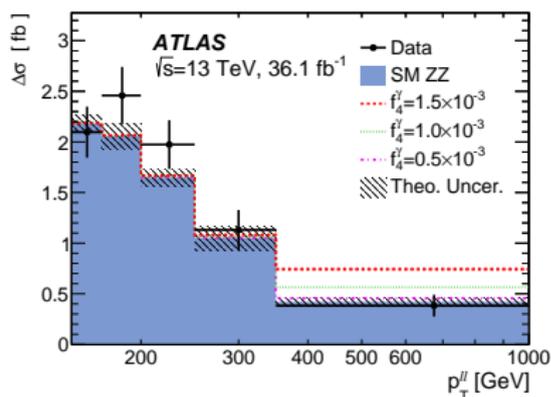
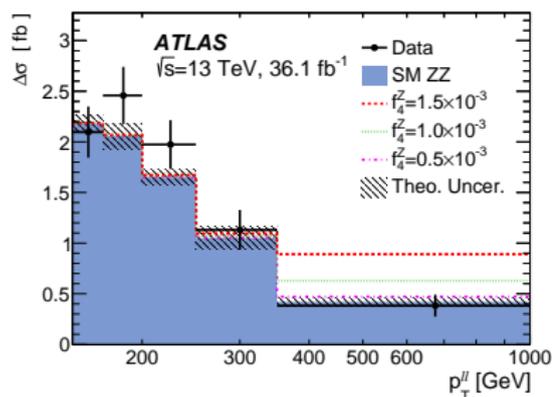
Coupling strength	Expected 95% CL [$\times 10^{-3}$]	Observed 95% CL [$\times 10^{-3}$]
f_4^Z	-2.4, 2.4	-1.8, 1.8
f_5^Z	-2.1, 2.1	-1.5, 1.5
f_4^γ	-2.4, 2.4	-1.8, 1.8
f_5^γ	-2.0, 2.0	-1.5, 1.5

EFT parameter	Expected 95% CL [TeV^{-4}]	Observed 95% CL [TeV^{-4}]
C_{BW}/Λ^4	-8.1, 8.1	-5.9, 5.9
C_{WW}/Λ^4	-4.0, 4.0	-3.0, 3.0
C_{BW}^2/Λ^4	-4.4, 4.4	-3.3, 3.3
C_{BB}/Λ^4	-3.7, 3.7	-2.7, 2.8

- EFT limits weak compared to $Z\gamma$
- CMS study (left): strong dependence on cut-off scale

ATLAS STDM-2017-03: $ZZ \rightarrow 2\ell 2\nu$

- ▶ ZZ measurement also performed in $2\ell 2\nu$ channel
- ▶ Unfolded $p_T^{\ell\ell}$ fiducial cross section used for limit extraction
→ 10 event minimum in last bin to work in Gaussian approximation



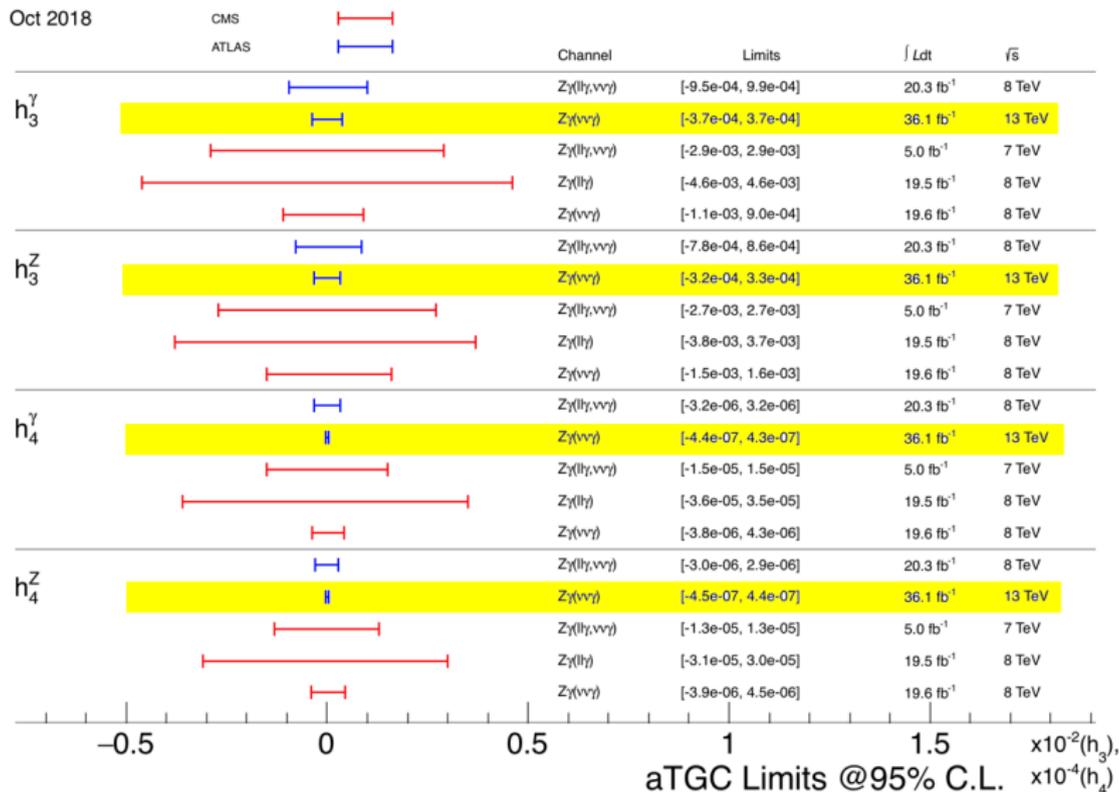
	f_4^{γ}	f_4^Z	f_5^{γ}	f_5^Z
Expected [$\times 10^{-3}$]	[-1.3, 1.3]	[-1.1, 1.1]	[-1.3, 1.3]	[-1.1, 1.1]
Observed [$\times 10^{-3}$]	[-1.2, 1.2]	[-1.0, 1.0]	[-1.2, 1.2]	[-1.0, 1.0]

EFT approach: $C_{\tilde{B}W}/\Lambda^4$ [TeV^{-4}]: [-4.0, 4.0]

- ▶ Very similar behaviour/limits for the four f_V^i
- ▶ Limits tighter than ATLAS 4ℓ measurement

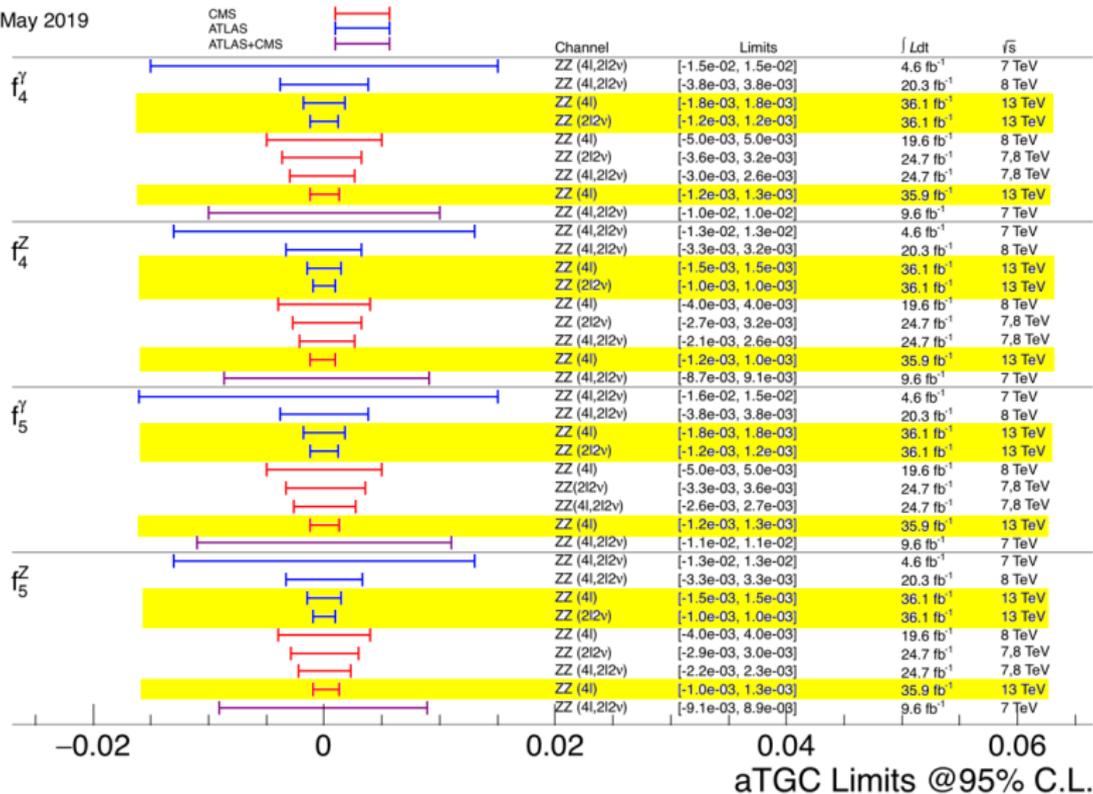
Summary of nTGC constraints (1/2)

Oct 2018



Summary of nTGC constraints (2/2)

May 2019



Anomalous Quartic Gauge Couplings (aQGCs)

- ▶ Run 1: different models and unitarization schemes used, difficult to compare analyses and measurements
- ▶ Run 2: most analyses now parametrize aQGCs in terms of twenty parity conserving dim-8 operators:
 $\mathcal{L}_{S,0-1} \propto (D_\mu \Phi)^4$, $\mathcal{L}_{M,0-7} \propto (F^{\mu\nu})^2 (D_\mu \Phi)^2$, $\mathcal{L}_{T,0-9} \propto (F^{\mu\nu})^4$
- ▶ Only at dim-8 (or higher) operators with quartic vertices but no two or three-boson couplings
- ▶ Assumption: aQGC due to dim-6 already constrained elsewhere
- ▶ Operators affect all quartic boson couplings

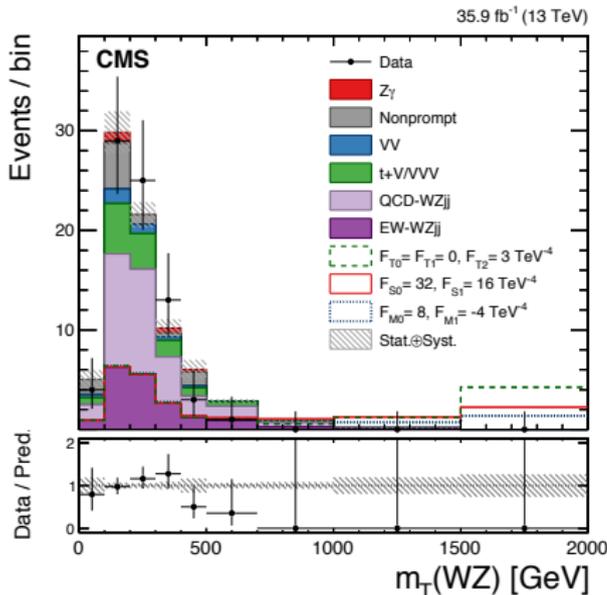
	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA	AAAA
$\mathcal{L}_{S,0}, \mathcal{L}_{S,1}$	X	X	X	O	O	O	O	O	O
$\mathcal{L}_{M,0}, \mathcal{L}_{M,1}, \mathcal{L}_{M,6}, \mathcal{L}_{M,7}$	X	X	X	X	X	X	X	O	O
$\mathcal{L}_{M,2}, \mathcal{L}_{M,3}, \mathcal{L}_{M,4}, \mathcal{L}_{M,5}$	O	X	X	X	X	X	X	O	O
$\mathcal{L}_{T,0}, \mathcal{L}_{T,1}, \mathcal{L}_{T,2}$	X	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,5}, \mathcal{L}_{T,6}, \mathcal{L}_{T,7}$	O	X	X	X	X	X	X	X	X
$\mathcal{L}_{T,9}, \mathcal{L}_{T,9}$	O	O	X	O	O	X	X	X	X

- ▶ Limits driven from high-energy regions, where unitarity can be violated \Rightarrow clipping scans or unitarisation important

Same Sign WW and VBS WZ

CMS SMP-17-004: $W^\pm(\ell^\pm\nu)W^\pm(\ell^\pm\nu)jj$, CMS SMP-18-001: $W(\ell\nu)Z(\ell\ell)jj$

- ▶ Limits derived from m_{ll} (WW) and m_T (WZ)
- ▶ Generally better limits from WW
- ▶ No studies of unitarity bounds



same sign WW

	Observed limits (TeV^{-4})	Expected limits (TeV^{-4})
f_{S0}/Λ^4	[-7.7, 7.7]	[-7.0, 7.2]
f_{S1}/Λ^4	[-21.6, 21.8]	[-19.9, 20.2]
f_{M0}/Λ^4	[-6.0, 5.9]	[-5.6, 5.5]
f_{M1}/Λ^4	[-8.7, 9.1]	[-7.9, 8.5]
f_{M6}/Λ^4	[-11.9, 11.8]	[-11.1, 11.0]
f_{M7}/Λ^4	[-13.3, 12.9]	[-12.4, 11.8]
f_{T0}/Λ^4	[-0.62, 0.65]	[-0.58, 0.61]
f_{T1}/Λ^4	[-0.28, 0.31]	[-0.26, 0.29]
f_{T2}/Λ^4	[-0.89, 1.02]	[-0.80, 0.95]

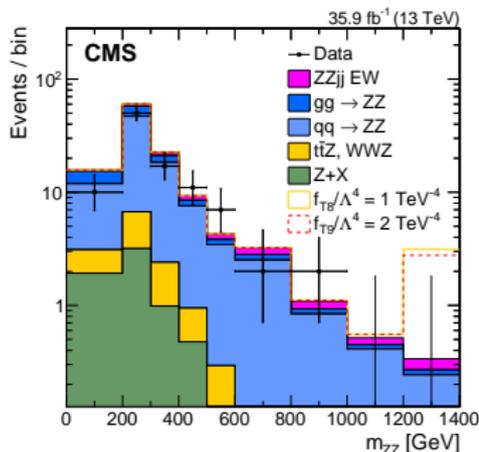
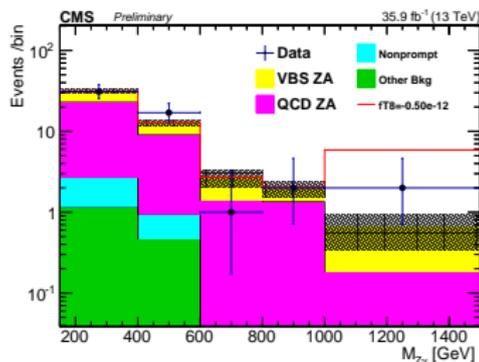
VBS WZ

Parameters	Exp. limit	Obs. limit
f_{M0}/Λ^4	[-11.2, 11.6]	[-9.15, 9.15]
f_{M1}/Λ^4	[-10.9, 11.6]	[-9.15, 9.45]
f_{S0}/Λ^4	[-32.5, 34.5]	[-26.5, 27.5]
f_{S1}/Λ^4	[-50.2, 53.2]	[-41.2, 42.8]
f_{T0}/Λ^4	[-0.87, 0.89]	[-0.75, 0.81]
f_{T1}/Λ^4	[-0.56, 0.60]	[-0.49, 0.55]
f_{T2}/Λ^4	[-1.78, 2.00]	[-1.49, 1.85]

VBS ZZ and Z γ

CMS SMP-17-006: ZZ, CMS SMP-18-007: Z γ

- ▶ aQGCs also constrained in ZZ, Z γ final states by CMS



Z γ limits

Coupling	Exp. lower	Exp. upper	Obs. lower	Obs. upper	Unitarity bound
f_{T0}/Λ^4	-0.53	0.51	-0.46	0.44	2.5
f_{T1}/Λ^4	-0.72	0.71	-0.61	0.61	2.3
f_{T2}/Λ^4	-1.4	1.4	-1.2	1.2	2.4
f_{T8}/Λ^4	-0.99	0.99	-0.84	0.84	2.8
f_{T9}/Λ^4	-2.1	2.1	-1.8	1.8	2.9

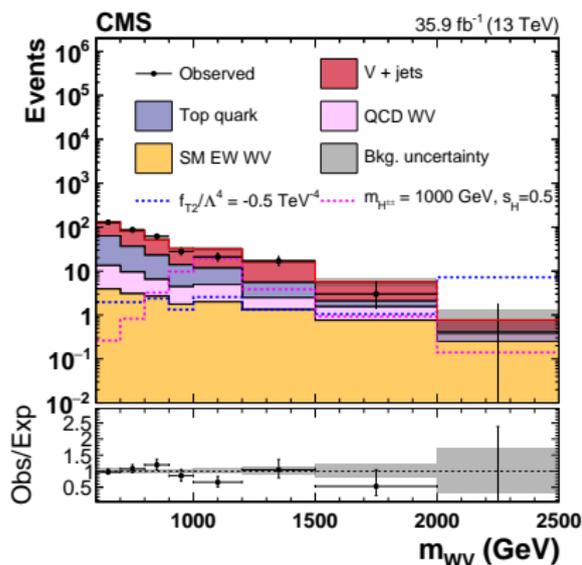
ZZ limits

Observed Limits (TeV $^{-4}$)	Expected Limits (TeV $^{-4}$)	Unitarity Bound
$-19.3 < F_{M,0}/\Lambda^4 < 20.2$	$-15.0 < F_{M,0}/\Lambda^4 < 15.1$	1.0
$-47.8 < F_{M,1}/\Lambda^4 < 46.9$	$-30.1 < F_{M,1}/\Lambda^4 < 30.0$	1.2
$-8.16 < F_{M,2}/\Lambda^4 < 8.04$	$-6.09 < F_{M,2}/\Lambda^4 < 6.06$	1.3
$-20.9 < F_{M,3}/\Lambda^4 < 21.1$	$-13.2 < F_{M,3}/\Lambda^4 < 13.3$	1.5
$-15.2 < F_{M,4}/\Lambda^4 < 15.8$	$-11.7 < F_{M,4}/\Lambda^4 < 11.7$	1.5
$-24.9 < F_{M,5}/\Lambda^4 < 24.4$	$-19.1 < F_{M,5}/\Lambda^4 < 18.2$	1.8
$-38.6 < F_{M,6}/\Lambda^4 < 40.5$	$-30.0 < F_{M,6}/\Lambda^4 < 30.1$	1.0
$-60.8 < F_{M,7}/\Lambda^4 < 62.6$	$-46.1 < F_{M,7}/\Lambda^4 < 46.3$	1.3
$-0.74 < F_{T,0}/\Lambda^4 < 0.69$	$-0.56 < F_{T,0}/\Lambda^4 < 0.51$	1.4
$-1.16 < F_{T,1}/\Lambda^4 < 1.15$	$-0.73 < F_{T,1}/\Lambda^4 < 0.72$	1.5
$-1.96 < F_{T,2}/\Lambda^4 < 1.85$	$-1.48 < F_{T,2}/\Lambda^4 < 1.37$	1.5
$-0.70 < F_{T,5}/\Lambda^4 < 0.74$	$-0.51 < F_{T,5}/\Lambda^4 < 0.57$	1.8
$-1.64 < F_{T,6}/\Lambda^4 < 1.67$	$-1.23 < F_{T,6}/\Lambda^4 < 1.26$	1.7
$-2.59 < F_{T,7}/\Lambda^4 < 2.80$	$-1.91 < F_{T,7}/\Lambda^4 < 2.12$	1.8
$-0.47 < F_{T,8}/\Lambda^4 < 0.47$	$-0.36 < F_{T,8}/\Lambda^4 < 0.36$	1.6
$-1.26 < F_{T,9}/\Lambda^4 < 1.27$	$-0.95 < F_{T,9}/\Lambda^4 < 0.95$	1.5

- ▶ Comparable limits from four aQGC measurement shown so far
- ▶ Unitarity bound: energy at which coupling value equal to limit violates unitarity

CMS SMP-18-006: $WW \rightarrow \ell\nu$ and $ZV \rightarrow \ell\ell$

- ▶ Lepton(s) + fat jet + VBS jets final state
- ▶ As in semi-leptonic aTGC analysis: no attempt to discover SM process, only constraints of new physics
- ▶ Fit of m_{WW} distribution, binning as aggressive as MC statistics permits
- ▶ World-best limits for all operators tested
- ▶ No study of unitarity bounds

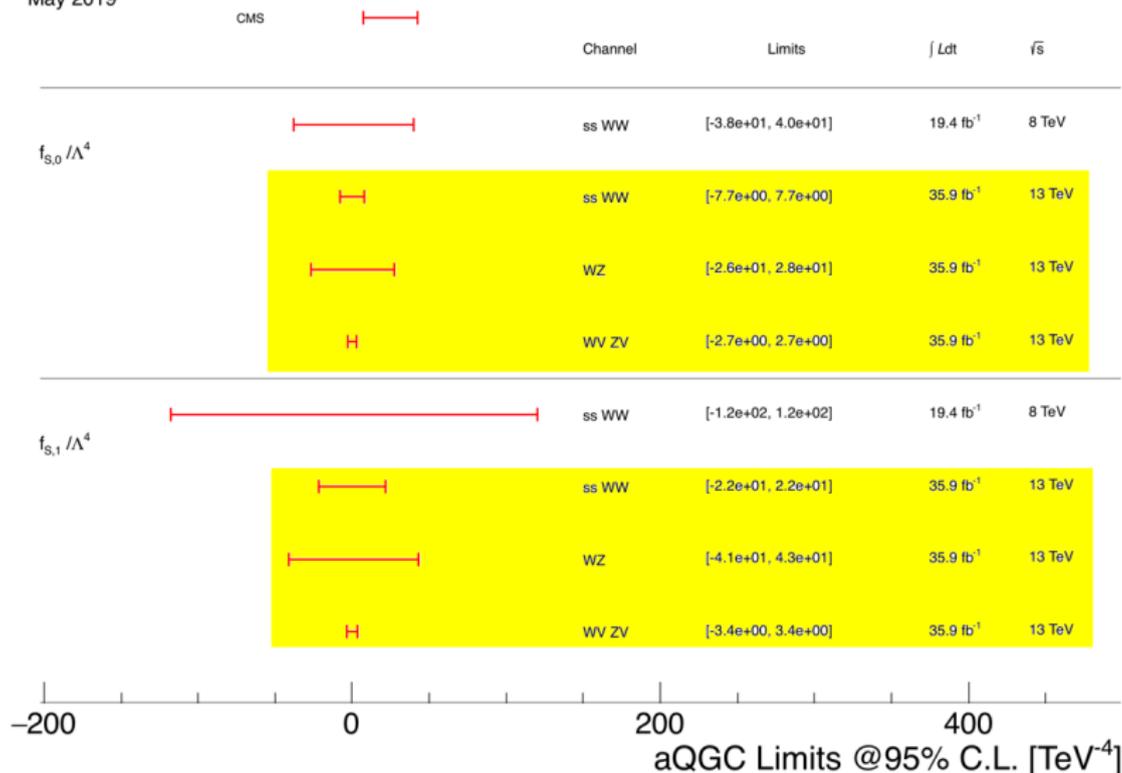


	Observed (WW) (TeV ⁻⁴)	Expected (WW) (TeV ⁻⁴)	Observed (ZV) (TeV ⁻⁴)	Expected (ZV) (TeV ⁻⁴)	Observed (TeV ⁻⁴)	Expected (TeV ⁻⁴)
f_{S0}/Λ^4	[-2.7, 2.7]	[-4.2, 4.2]	[-40, 40]	[-31, 31]	[-2.7, 2.7]	[-4.2, 4.2]
f_{S1}/Λ^4	[-3.3, 3.4]	[-5.2, 5.2]	[-32, 32]	[-24, 24]	[-3.4, 3.4]	[-5.2, 5.2]
f_{M0}/Λ^4	[-0.69, 0.69]	[-1.0, 1.0]	[-7.5, 7.5]	[-5.3, 5.3]	[-0.69, 0.70]	[-1.0, 1.0]
f_{M1}/Λ^4	[-2.0, 2.0]	[-3.0, 3.0]	[-22, 23]	[-16, 16]	[-2.0, 2.1]	[-3.0, 3.0]
f_{M6}/Λ^4	[-1.4, 1.4]	[-2.0, 2.0]	[-15, 15]	[-11, 11]	[-1.3, 1.3]	[-1.4, 1.4]
f_{M7}/Λ^4	[-3.4, 3.4]	[-5.1, 5.1]	[-35, 36]	[-25, 26]	[-3.4, 3.4]	[-5.1, 5.1]
f_{T0}/Λ^4	[-0.12, 0.11]	[-0.17, 0.16]	[-1.4, 1.4]	[-1.0, 1.0]	[-0.12, 0.11]	[-0.17, 0.16]
f_{T1}/Λ^4	[-0.12, 0.13]	[-0.18, 0.18]	[-1.5, 1.5]	[-1.0, 1.0]	[-0.12, 0.13]	[-0.18, 0.18]
f_{T2}/Λ^4	[-0.28, 0.28]	[-0.41, 0.41]	[-3.4, 3.4]	[-2.4, 2.4]	[-0.28, 0.28]	[-0.41, 0.41]

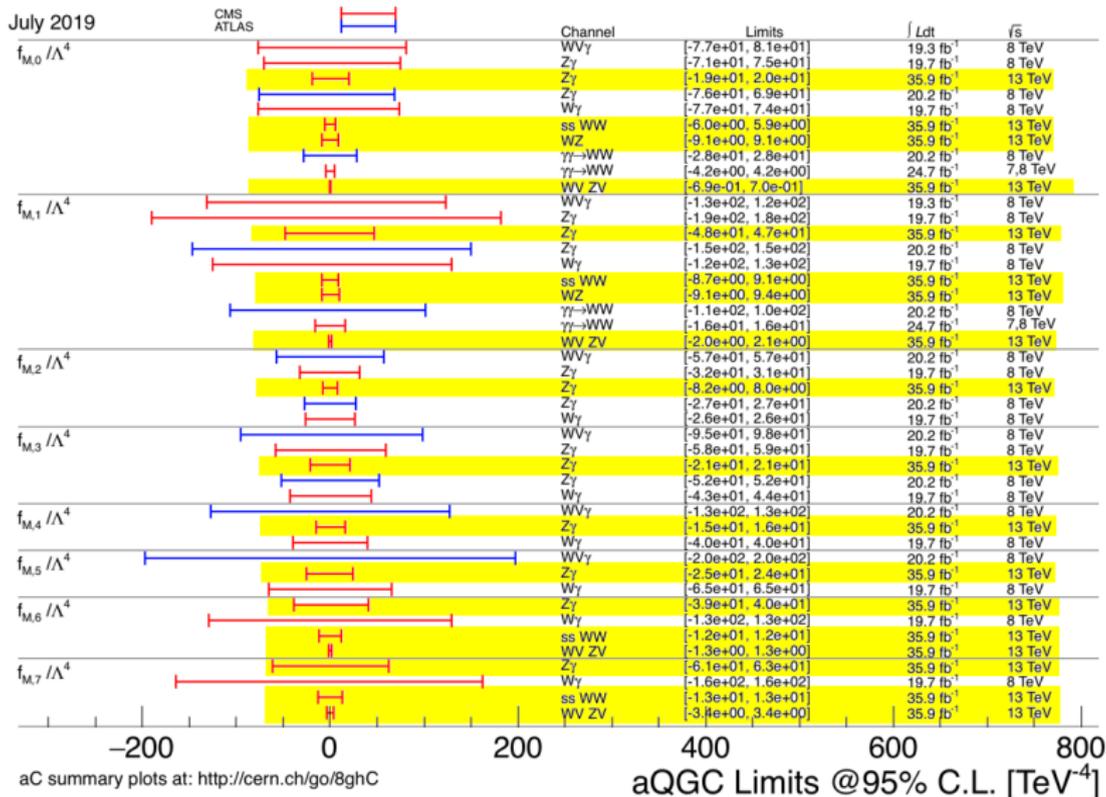
- ▶ Constraints from WW channel tighter than from ZV (higher event yield)

Summary of aQGC constraints (1/3)

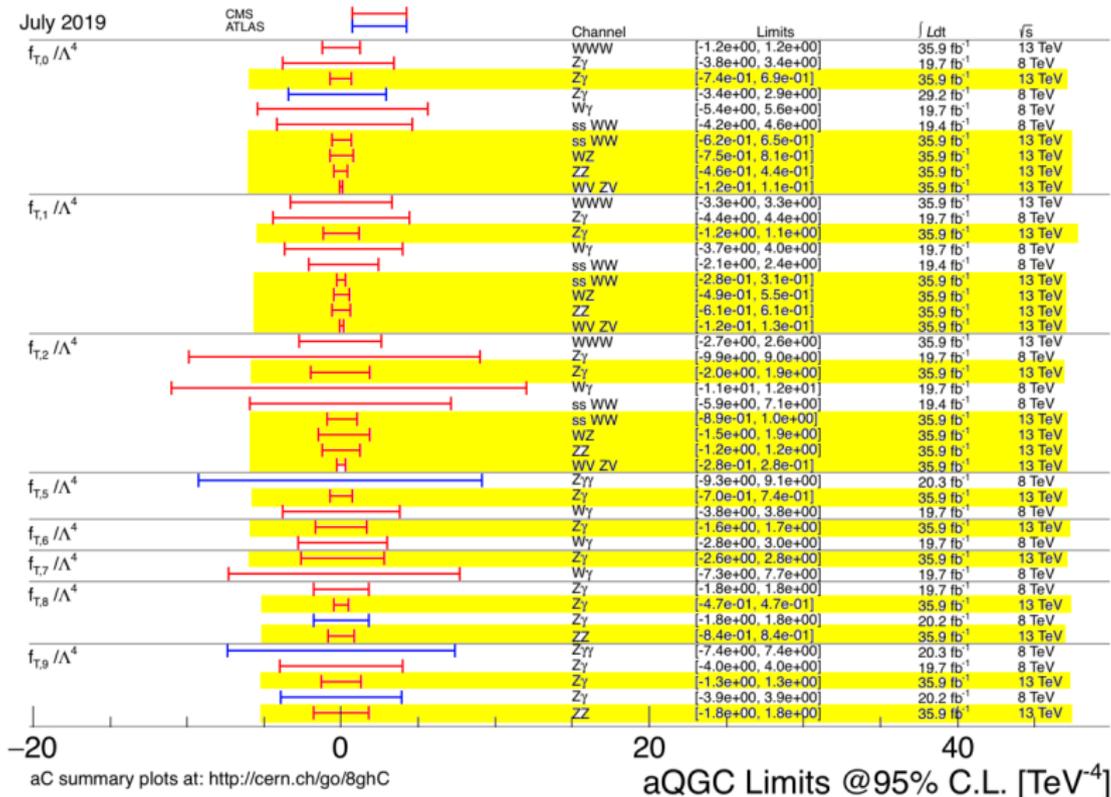
May 2019



Summary of aQGC constraints (2/3)



Summary of aQGC constraints (3/3)



Conclusion

General comments, observations

- ▶ Most analyses provide 2D limits as well (but generally no marginalisation of parameters)
- ▶ Unitarity bounds, probed \sqrt{s} , linearised EFT studied only sporadically
- ▶ Few combinations (full Run 2 dataset better opportunity for that)
- ▶ Some limits from unfolded measurements
 - ▶ No detector simulation necessary, can help re-interpretation
 - ▶ Needs more conservative binning, need to check for SM bias
- ▶ Impact of QCD and EWK corrections not to be underestimated
 - ▶ SM QCD corrections sometimes applied to BSM terms
 - ▶ EWK correction typically growing with \sqrt{s} – like EFT operators
- ▶ Possible to perform more global EFT fits?
 - ▶ Combinations beyond multibosons (e.g. with Higgs measurements) interesting?
 - ▶ Complete dimension-six basis exists (Warsaw basis, implemented in [SMEFTsim](#)) allows for consideration of all dim-6 operator effects

Summary

- ▶ Large number of diboson measurements performed by ATLAS and CMS collaborations
- ▶ Many include anomalous coupling or EFT interpretations
- ▶ All constrain new physics in tails of kinematic distributions (m_{VV} or proxies)
- ▶ No excesses observed
- ▶ Across the board: limits greatly improved compared to Run 1
- ▶ Tightest limits from semi-leptonic measurements
- ▶ Some analyses of 2015/16 data still unpublished, anomalous coupling interpretations missing from some measurements
- ▶ Usually limited by statistics – sensitivity will improve with full Run 2 dataset