EFT Studies of high-p_T SM processes

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On behalf of the ATLAS and CMS collaborations

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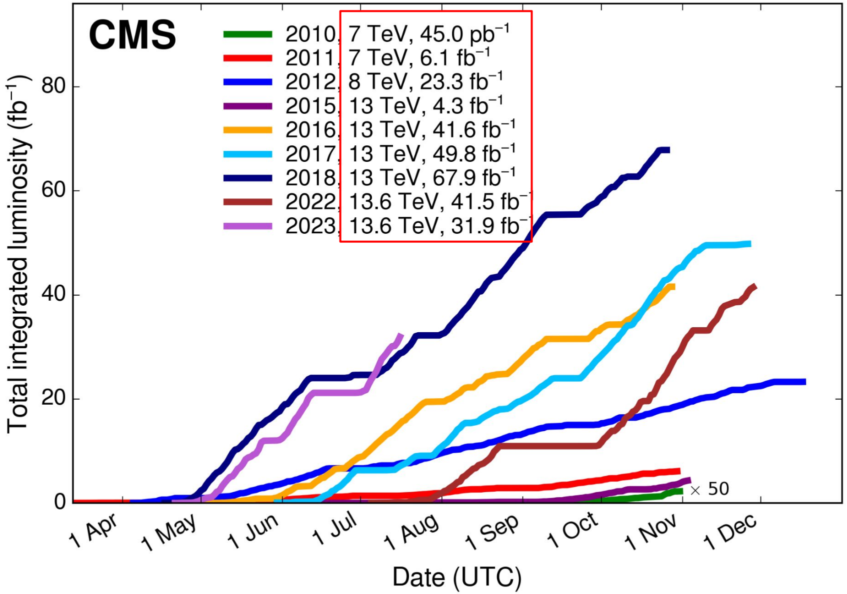
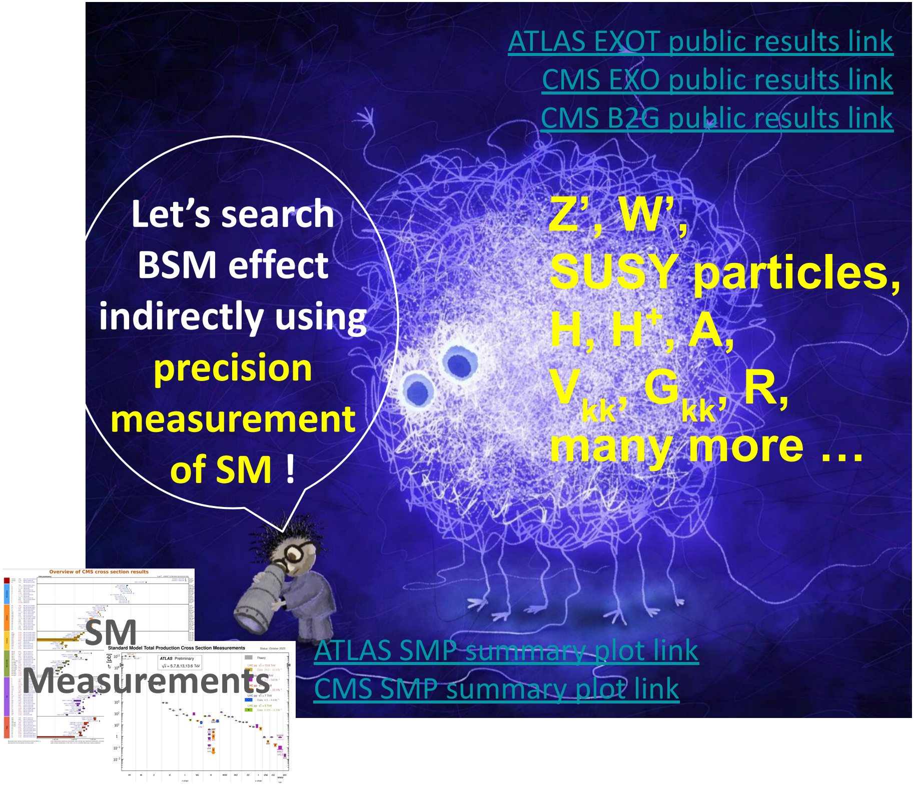
- No clear evidence of Beyond the Standard Model (BSM) particles at the LHC

  ⇒ A rise in the indirect search strategy

Large Hadron Collider
proton-proton collisions since 2010

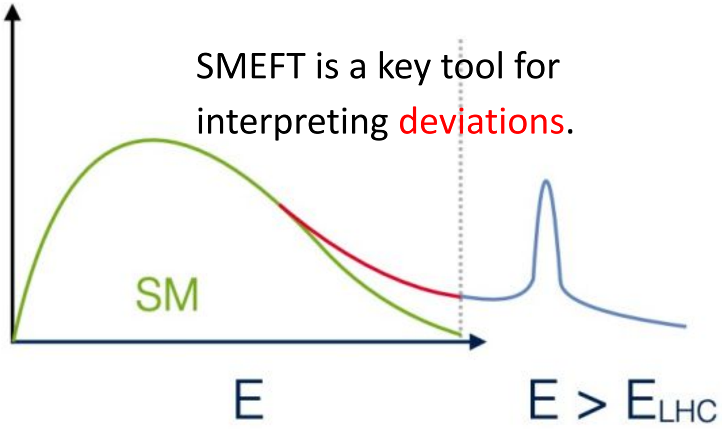




Why the Effective Field Theory?

- No clear evidence of BSM particles at the LHC
  ⇒ A rise in the indirect search strategy
- Standard Model Effective Field Theory (SMEFT) :
  - Low-energy limit of generic UV-complete models
  - Complete basis for interaction, and systematic parametrization of BSM effect
- New insights into the existing spectrum through reinterpretation, or directly measures coefficients using the primary likelihood method.
- EFT operators may induce growth with the center-of-mass-energy.
  ⇒ Better sensitivity in high energy at LHC.
  Exploit differential cross-sections in the TeV region

SMEFT is a key tool for interpreting deviations.

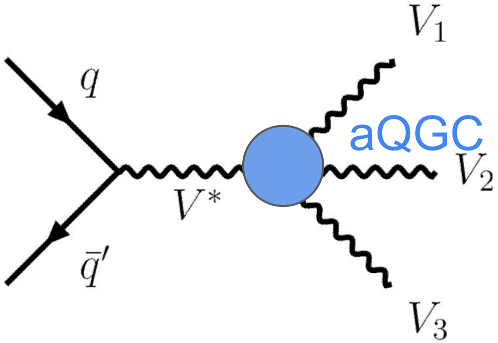


$$L_{\mathrm{EFT}} = L_{\mathrm{SM}} + \sum_i \frac{\bar{C}_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_i \frac{\bar{C}_i^{(8)}}{\Lambda^4}\mathcal{O}_i^{(8)} + \ldots$$

C_i free parameters (**Wilson coefficients**)
→ encode all UV information

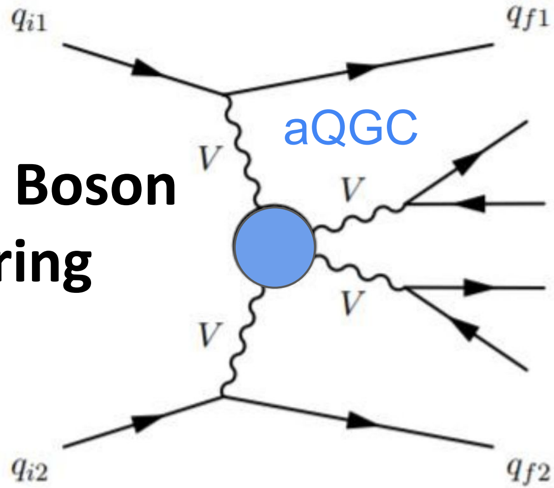
O_i invariant **operators** that form a complete, non-redundant basis
→ describe the IR information

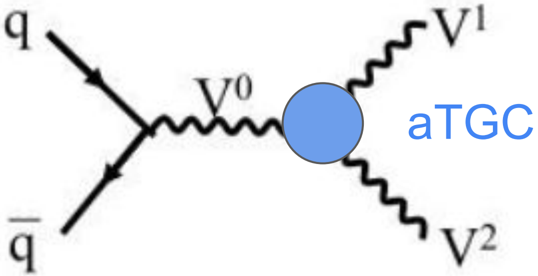
New physics in interactions



Tribosons

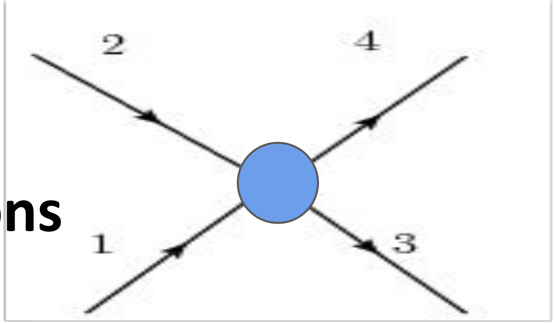
Vector Boson Scattering (VBS)





Dibosons

Contact Interactions



I will focus on EFT result in Electroweak Sector

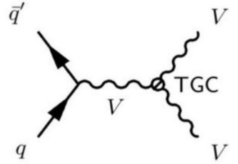
Recents EFT results in Electroweak sector

ATLAS

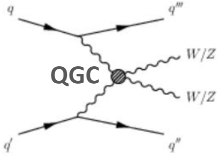
- **Global combined** EFT Interpretations
  ATL-PHYS-PUB-2022-037
- aTGC in **WW + ≥ 1 j**
  JHEP06(2021)003
- aQGC in **VBS ZZ+jj**
  JHEP01(2024)004
- aQGC in **VBS WW+jj**
  ATLAS-CONF-2023-023
- **ZZ** production at 13.6 TeV Run3
  ATLAS-CONF-2023-062

CMS

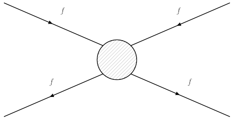
- aTGC in Electroweak **Wγ**
  Phys.Rev.D.105(2022)052003
- aTGC in Electroweak **WZ**
  JHEP07(2022)032
- aQGC in **VBS Wγ+jj**
  Phys.Rev.D.108(2023)032017
- EW Oblique parameter in **W**
  JHEP 07 (2022) 067



WWZ, WWγ (allowed SM at tree-level)
neutral TGC; ZZZ, ZZγ, Zγγ (forbidden)



WWWW, WWZZ, WWZγ, WWγγ (SM)
neutral QGCs;
ZZZZ, ZZZγ, ZZγγ, Zγγγ (forbidden)



4-fermion contact interaction

Recently ATLAS reported
aQGC in **VBS Wγ+jj** arxiv:2403.02809 (Given in Júlia's talk)

ATLAS Global EFT Interpretations

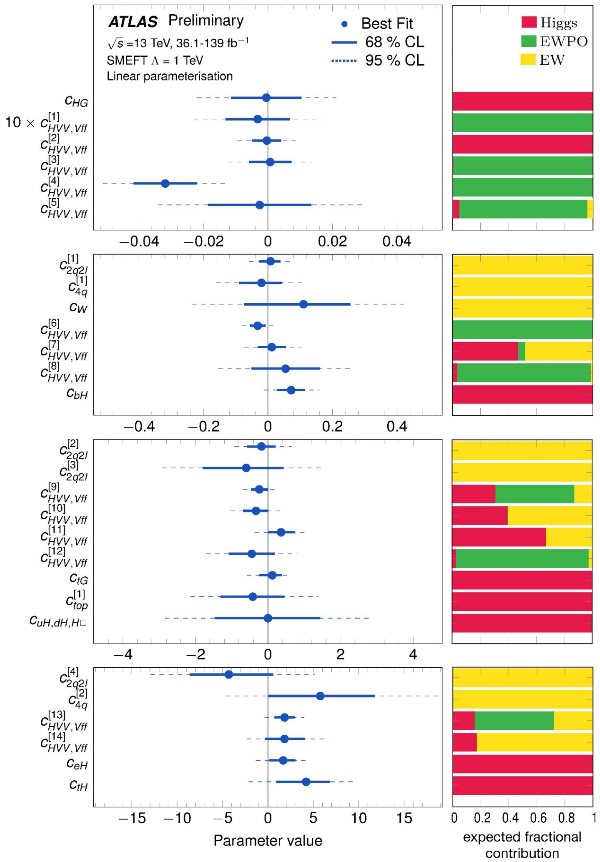
ATL-PHYS-PUB-2022-037

Higgs combination + EW (WW, WZ, 4l, Z+2jets) comb. + EWPO at LEP and SLC

Decay channel	Target Production Modes	$\mathcal{L}$ [fb^{-1}]	Ref.
$H \to \gamma\gamma$	ggF, VBF, WH, ZH, $t\bar{t}H$, tH	139	[10]
$H \to ZZ^*$	ggF, VBF, WH, ZH, $t\bar{t}H(4\ell)$	139	[11]
$H \to WW^*$	ggF, VBF	139	[12]
$H \to \tau\tau$	ggF, VBF, WH, ZH, $t\bar{t}H(\tau_{had}\tau_{had})$	139	[13]
	WH, ZH	139	[14,15,16]
$H \to b\bar{b}$	VBF	126	[17]
	$t\bar{t}H$	139	[18]

Process	Important phase space requirements	Observable	$\mathcal{L}$ [fb^{-1}]	Ref.
$pp \to e^\pm\nu\mu^\mp\nu$	$m_{\ell\ell} > 55\,GeV$, $p_T^{jet} < 35\,GeV$	$p_T^{lead.\ lep.}$	36	[19]
$pp \to \ell^\pm\nu\ell^+\ell^-$	$m_{\ell\ell} \in (81, 101)\,GeV$	m_T^{WZ}	36	[20]
$pp \to \ell^+\ell^-\ell^+\ell^-$	$m_{4\ell} > 180\,GeV$	m_{Z2}	139	[21]
$pp \to \ell^+\ell^- jj$	$m_{jj} > 1000\,GeV$, $m_{\ell\ell} \in (81, 101)\,GeV$	$\Delta\phi_{jj}$	139	[22]

Observable	Measurement	Prediction	Ratio
Γ_Z [MeV]	2495.2 ± 2.3	2495.7 ± 1	0.9998 ± 0.0010
R^0_ℓ	20.767 ± 0.025	20.758 ± 0.008	1.0004 ± 0.0013
R^0_c	0.1721 ± 0.0030	0.17223 ± 0.00003	0.999 ± 0.017
R^0_b	0.21629 ± 0.00066	0.21586 ± 0.00003	1.0020 ± 0.0031
$A^{0,\ell}_{FB}$	0.0171 ± 0.0010	0.01718 ± 0.00037	0.995 ± 0.062
$A^{0,c}_{FB}$	0.0707 ± 0.0035	0.0758 ± 0.0012	0.932 ± 0.048
$A^{0,b}_{FB}$	0.0992 ± 0.0016	0.1062 ± 0.0016	0.935 ± 0.021
σ^0_{had} [pb]	41488 ± 6	41489 ± 5	0.99998 ± 0.00019

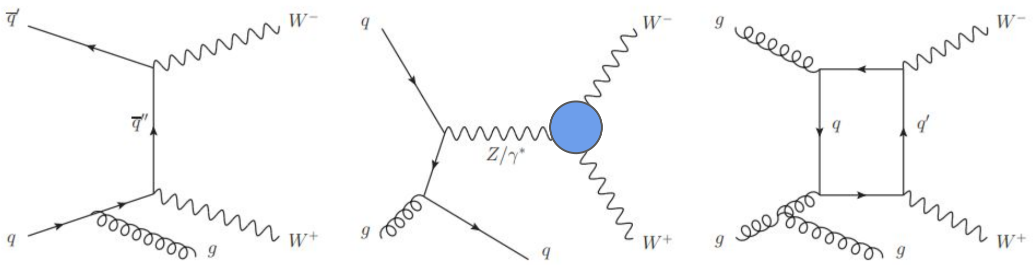


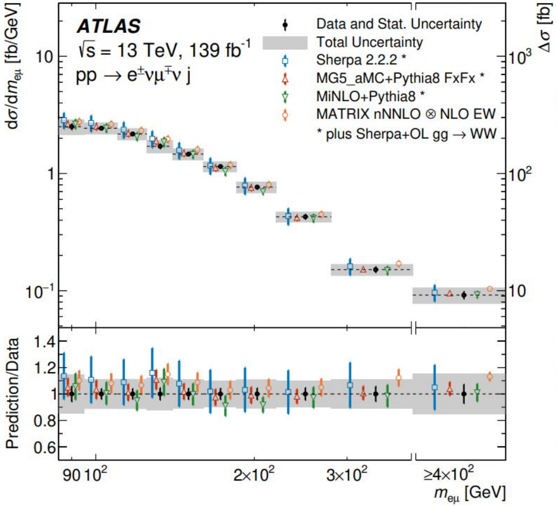
- Combining multiple operators across multiple channels can help to improve constraints and reduce blind directions
- Constraining 6 individual and 22 linear combinations of Wilson coefficients (linear).
- Several constraints driven by both ATLAS and LEP/SLD.
- Linear fits agree with the SM expectation for most fitted parameters, except for $c^{[4]}_{HVV,Vff}$ (excess driven by a well known discrepancy in $A^{0,b}_{FB}$ from the SM expectation.)

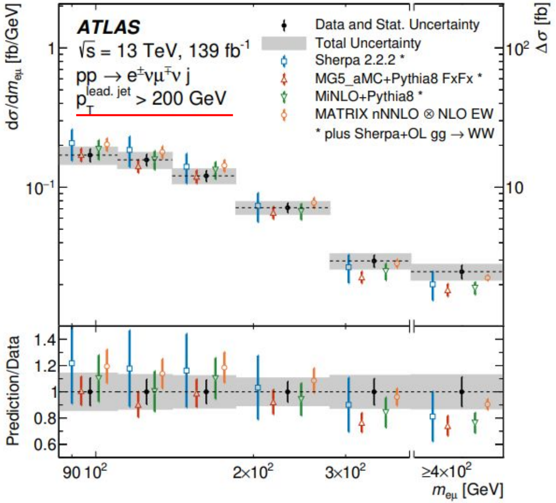
Electroweak WW + ≥ 1 jet

ATLAS JHEP06(2021)003

- Unexplored pp $\to e^{\pm}\nu\,\mu^{\mp}\nu$ + jets topology up to 5 jets.
- Fiducial integrated and differential cross sections in good agreement with SM with 10% uncertainty.
- Dim-6 C_W coefficient constrained also in high-p_T(leading jet) phase space using unfolded $\mathbf{m_{e\mu}}$ cross-section
- High-p_T(leading jet) SR enhances the sensitivity to SM and EFT interference effect (backup)







Fit performed both for jet p_T > 30 and jet p_T > 200 GeV

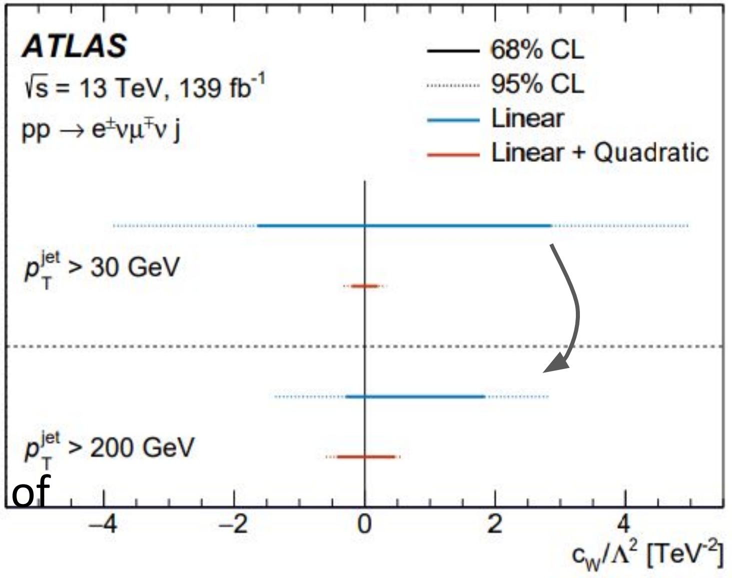
dim-6 aTGC in WW + ≥ 1 jet

The total EFT amplitude :

$$\left|A_{SM} + \sum_i c_i \cdot A_i\right|^2 = |A_{SM}|^2 + \sum_i c_i \cdot 2\,Re(A_{SM}^* \cdot A_i) + \sum_i c_i^2 \cdot |A_i|^2 + \sum_{i,j,i\neq j} c_i c_j \cdot Re(A_i^* \cdot A_j)$$

SM — Interference of SM-BSM (linear term) — Pure BSM (quadratic term) — interference between BSMs (cross term)

- Compare to see whether the pure BSM terms in EFT expansion are relevant in the different phase space.
- High-p_T jet SR enhances the sensitivity to effects proportional to c_W/Λ^2 due to the reduced suppression of the interference between the SM and the BSM.



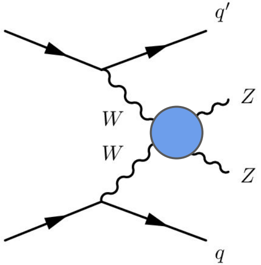
Limit for High-p_T jet improved relative to a p_T > 30 GeV

Jet p_T	Linear only	68% CI obs.	95% CI obs.	68% CI exp.	95% CI exp.
> 30 GeV	yes	[−1.64, 2.86]	[−3.85, 4.97]	[−2.30, 2.27]	[−4.53, 4.41]
> 30 GeV	no	[−0.20, 0.20]	[−0.33, 0.33]	[−0.28, 0.27]	[−0.39, 0.38]
> 200 GeV	yes	[−0.29, 1.84]	[−1.37, 2.81]	[−1.12, 1.09]	[−2.24, 2.10]
> 200 GeV	no	[−0.43, 0.46]	[−0.60, 0.58]	[−0.38, 0.33]	[−0.53, 0.48]

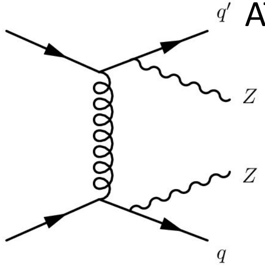
VBS ZZ + 2jets

ATLAS JHEP01(2024)004

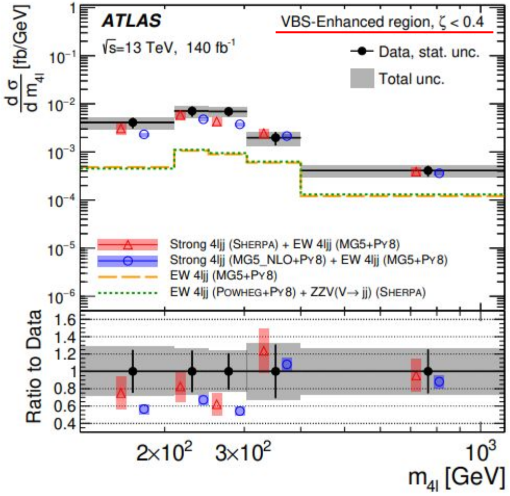
- Studying the rare VBS ZZ + 2 jets
- Differential cross-section measurement of 4 charged leptons + 2 jets production
- Key observables:
  - VBS sensitive
    ⇒ **m_{4l}**, $p_T(4l)$, **m_{jj}**, Δy_{jj}, $p_T(jj)$
  - Polarization and CP structure of WWZ and WWZZ self-interactions
    ⇒ $\cos\theta^*_{12}$, $\cos\theta^*_{34}$, m_{jj}, $\Delta\varphi_{jj}$, p_T (jj)
  - Sensitive to extra QCD radiation
    ⇒ $p_T(4ljj)$, $S_T(4ljj)$
- The measurements are used to test EFT dim-8 and dim-6 operators $O_{T,i}$ aQGC

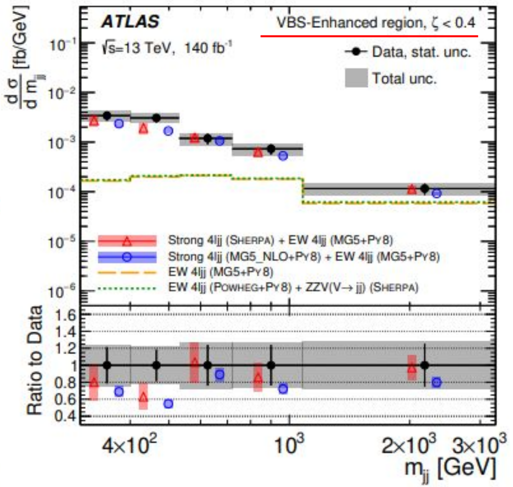


EW VBS ZZjj



Strong ZZjj



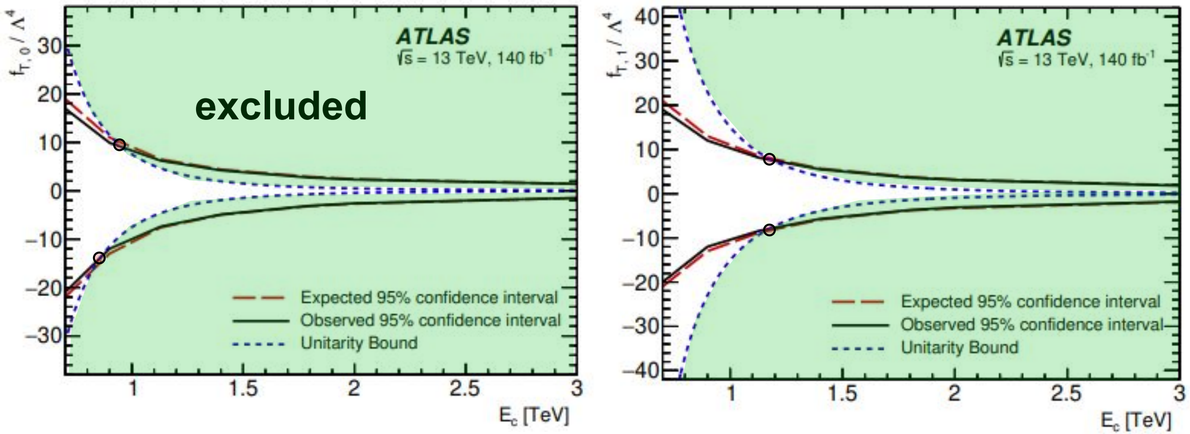


dim-8 aQGC in VBS ZZ+2jets

- Constraints on the dim-8 aQGC **including/excluding the pure dim-8 contributions** to the EFT prediction

$$|\mathcal{M}|^2 = |\mathcal{M}_{SM}|^2 + 2\,\mathrm{Re}(\mathcal{M}_{SM}{}^*\mathcal{M}_{d8}) + |\mathcal{M}_{d8}|^2;$$

- 95% CI for dim-8 operators as a function of cut-off scale ($m_{4l} < E_{cutoff}$) using 2D (m_{jj}, m_{4l}) fit.



most tightly constrained

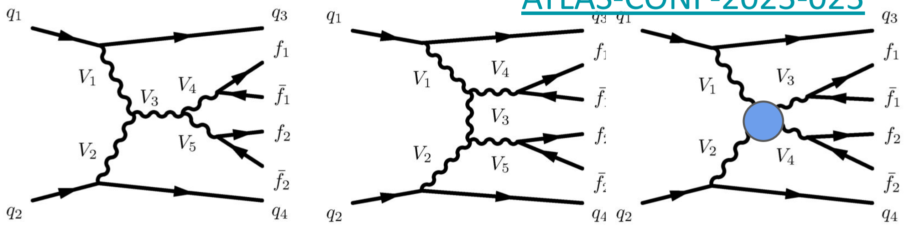
Wilson coefficient	$\lvert\mathcal{M}_{d8}\rvert^2$ Included	95% confidence interval [TeV^{-4}] Expected	Observed
$f_{T,0}/\Lambda^4$	yes	[-1.00, 0.97]	[-0.98, 0.93]
	no	[-19, 19]	[-23, 17]
$f_{T,1}/\Lambda^4$	yes	[-1.3, 1.3]	[-1.2, 1.2]
	no	[-140, 140]	[-160, 120]
$f_{T,2}/\Lambda^4$	yes	[-2.6, 2.5]	[-2.5, 2.4]
	no	[-63, 62]	[-74, 56]
$f_{T,5}/\Lambda^4$	yes	[-2.6, 2.5]	[-2.5, 2.4]
	no	[-68, 67]	[-79, 60]
$f_{T,6}/\Lambda^4$	yes	[-4.1, 4.1]	[-3.9, 3.9]
	no	[-550, 540]	[-640, 480]
$f_{T,7}/\Lambda^4$	yes	[-8.8, 8.4]	[-8.5, 8.1]
	no	[-220, 220]	[-260, 200]
$f_{T,8}/\Lambda^4$	yes	[-2.2, 2.2]	[-2.1, 2.1]
	no	[-3.9, 3.8]$\times 10^4$	[-4.6, 3.1]$\times 10^4$
$f_{T,9}/\Lambda^4$	yes	[-4.7, 4.7]	[-4.5, 4.5]
	no	[-6.4, 6.3]$\times 10^4$	[-7.5, 5.5]$\times 10^4$

$$c_i = c_i^{(8)} = f_i^{(8)}/\Lambda^4$$

(dim-6 limits are in backup)

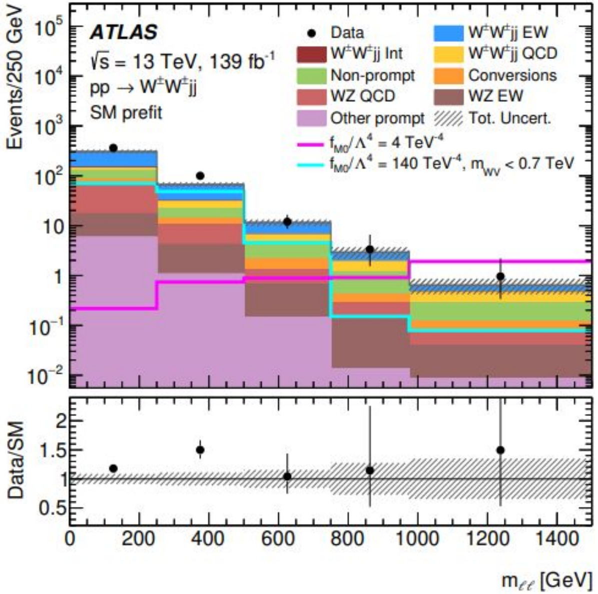
VBS WW +2jets

ATLAS-CONF-2023-023



- Studying the rare VBS same-sign WW + 2 forward jets
- Fiducial and differential cross-sections for inclusive and EW-enhanced phase space

- The m_{ll} is sensitive to constraint dim-8 wilson coefficients, and the binning is optimized.
  ⇒ The boundaries of the last m_{ll} bin are optimised to have best expected limits



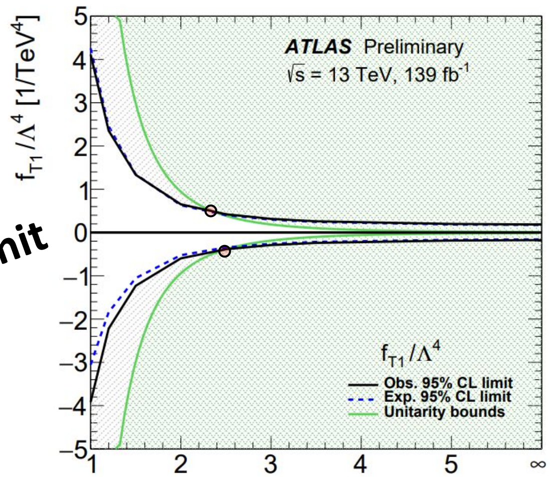
dim-8 aQGC in VBS WW+2jets

- 95% Confidence Intervals on 8 different coefficients of aQGC (Linear+Quadratic; SM + Interference + pure BSM)

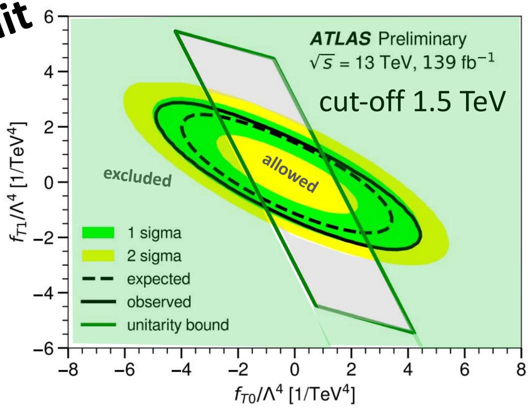
Coefficient	Type	No unitarisation cut-off [TeV^{-4}]	Lower, upper limit at the respective unitarity bound [TeV^{-4}]
f_{M0}/Λ^4	Exp.	[-3.9, 3.8]	-64 at 0.9 TeV, 40 at 1.0 TeV
	Obs.	[-4.1, 4.1]	-140 at 0.7 TeV, 117 at 0.8 TeV
f_{M1}/Λ^4	Exp.	[-6.3, 6.6]	-25.5 at 1.6 TeV, 31 at 1.5 TeV
	Obs.	[-6.8, 7.0]	-45 at 1.4 TeV, 54 at 1.3 TeV
f_{M7}/Λ^4	Exp.	[-9.3, 8.8]	-33 at 1.8 TeV, 29.1 at 1.8 TeV
	Obs.	[-9.8, 9.5]	-39 at 1.7 TeV, 42 at 1.7 TeV
f_{S02}/Λ^4	Exp.	[-5.5, 5.7]	-94 at 0.8 TeV, 122 at 0.7 TeV
	Obs.	[-5.9, 5.9]	–
f_{S1}/Λ^4	Exp.	[-22.0, 22.5]	–
	Obs.	[-23.5, 23.6]	–
f_{T0}/Λ^4	Exp.	[-0.34, 0.34]	-3.2 at 1.2 TeV, 4.9 at 1.1 TeV
	Obs.	[-0.36, 0.36]	-7.4 at 1.0 TeV, 12.4 at 0.9 TeV
f_{T1}/Λ^4	Exp.	[-0.158, 0.174] most tightly	-0.32 at 2.6 TeV, 0.44 at 2.4 TeV
	Obs.	[-0.174, 0.186] constrained	-0.38 at 2.5 TeV, 0.49 at 2.4 TeV
f_{T2}/Λ^4	Exp.	[-0.56, 0.70]	-2.60 at 1.7 TeV, 10.3 at 1.2 TeV
	Obs.	[-0.63, 0.74]	–

All other 1D, 2D limits are in backup

1D limit

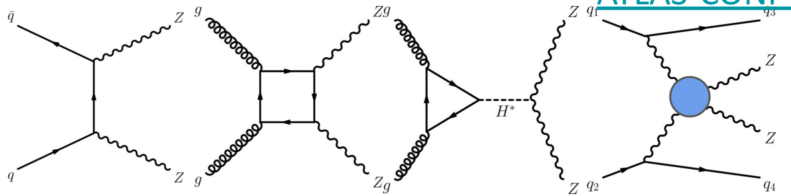


2D limit

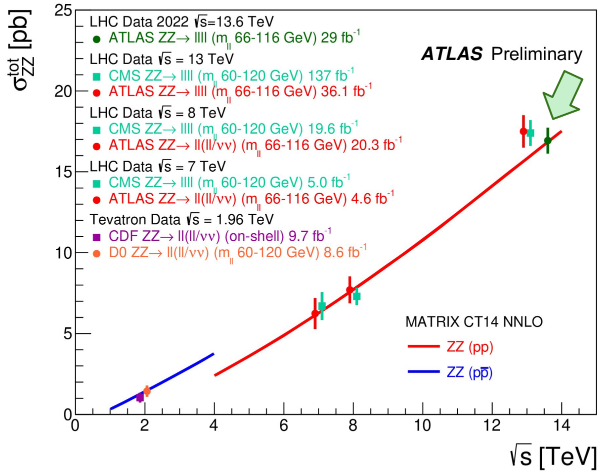


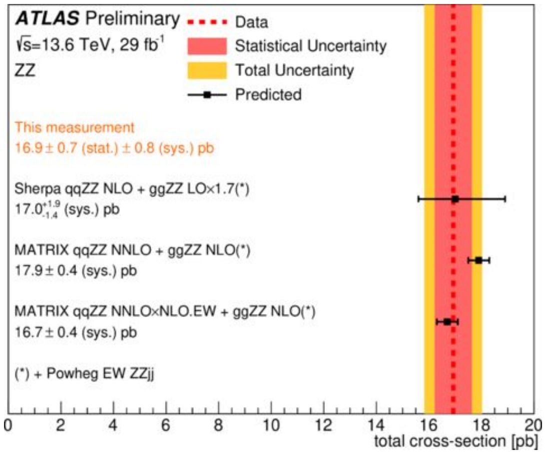
ZZ production at 13.6 TeV

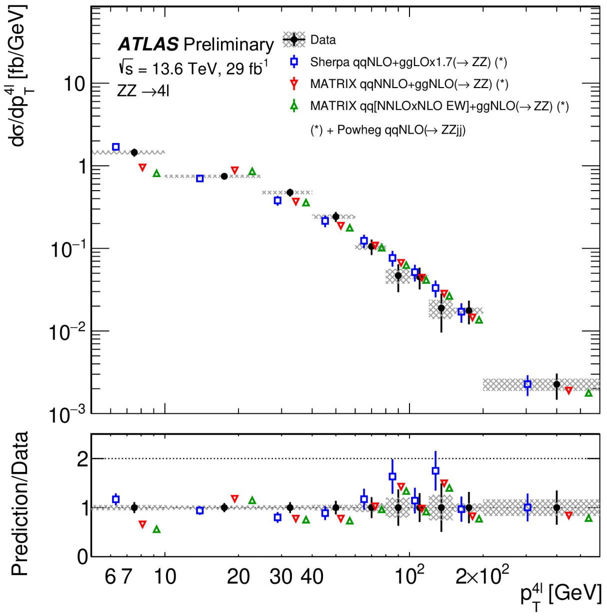
ATLAS-CONF-2023-062



- First measurements of integrated and differential fiducial cross-section using 13.6 TeV 2022 data (lumi = 29 fb^{-1})
- 2 input observables sensitive to aTGCs: ZZ → 4l, ZZ → 2l2ν, H → ZZ and EWK production
  - m_{4l}, $p_T(4l)$
- An excellent agreement of state-of-art-theory prediction with the data.



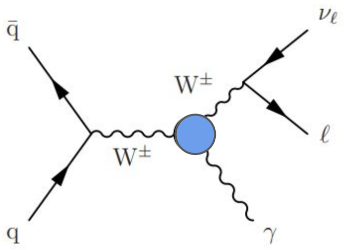


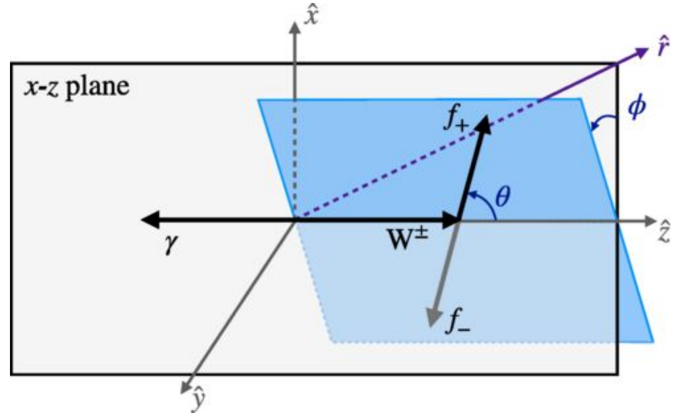


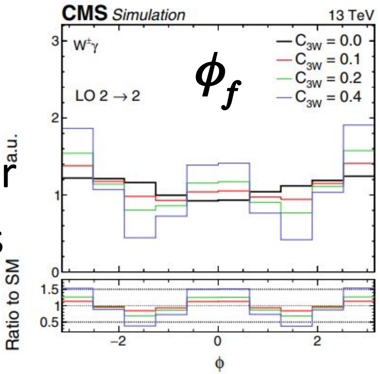
Electroweak Wγ

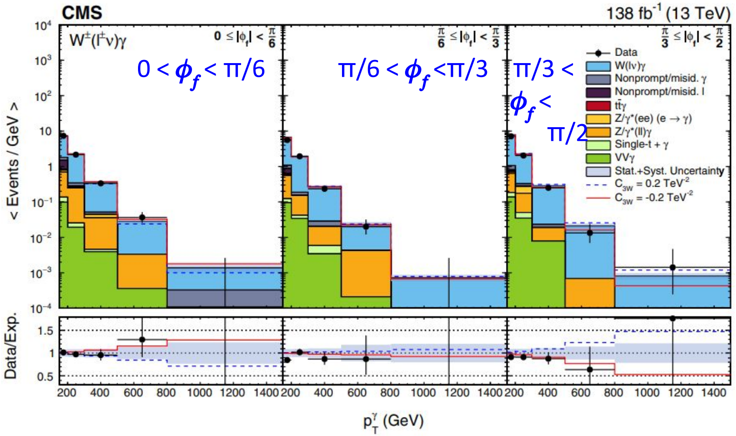
CMS Phys.Rev.D.105(2022)052003

- 1 photon and 1 e/μ coming from W
- **First differential cross section measurements at 13 TeV**
- Target dim-6 C_{3W} coefficient for aTGC
- EFT effects in decay angle ϕ_f in the Wγ center-of-mass frame to enhance sensitivity to SM-EFT interference **"Interference resurrection"**
- Important to capture the different final-state helicity configurations for the SM and BSM $W_T V_T$ components
- Fit with 2D ϕ_f - $p_T(\gamma)$



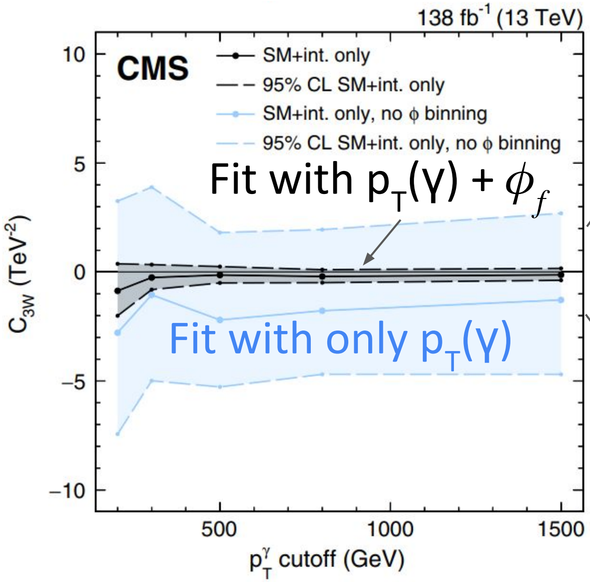


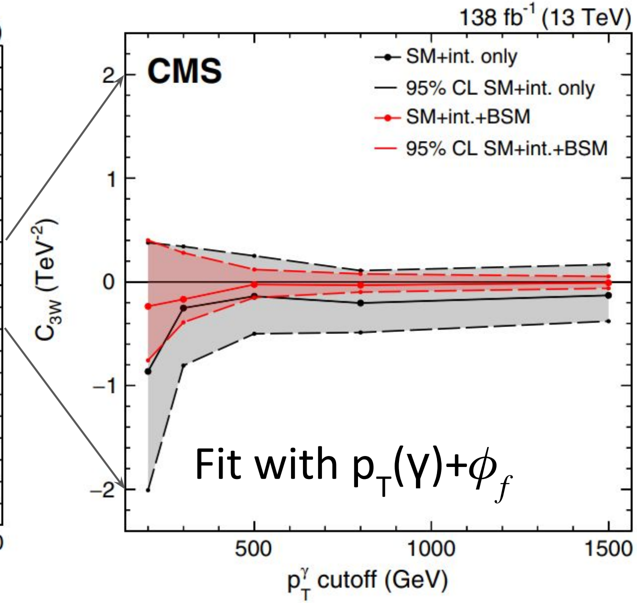




dim-6 aTGC in Electroweak Wγ

- Wγ is a new kind of diboson EFT analysis using angular info in addition to high energy enhancement.
- 2 sigma limits as a function of $p_T(\gamma)$ cutoff
- Information from ϕ_f dramatically improves sensitivity to interference
- Pure BSM term drives the overall results

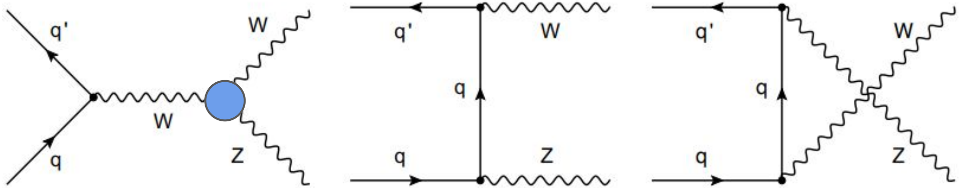




	Best fit C_{3W} (TeV^{-2})		Observed 95% CL (TeV^{-2})		Expected 95% CL (TeV^{-2})	
p_T^γ cutoff (GeV)	SM + int. only	SM + int. + BSM	SM + int. only	SM + int. + BSM	SM + int. only	SM + int. + BSM
200	−0.86	−0.24	[−2.01, 0.38]	[−0.76, 0.40]	[−1.16, 1.27]	[−0.81, 0.71]
300	−0.25	−0.17	[−0.81, 0.34]	[−0.39, 0.28]	[−0.56, 0.60]	[−0.33, 0.33]
500	−0.13	−0.025	[−0.50, 0.25]	[−0.15, 0.12]	[−0.35, 0.38]	[−0.17, 0.16]
800	−0.20	−0.033	[−0.49, 0.11]	[−0.10, 0.08]	[−0.29, 0.31]	[−0.097, 0.095]
1500	−0.13	−0.009	[−0.38, 0.17]	[−0.062, 0.052]	[−0.27, 0.29]	[−0.066, 0.065]

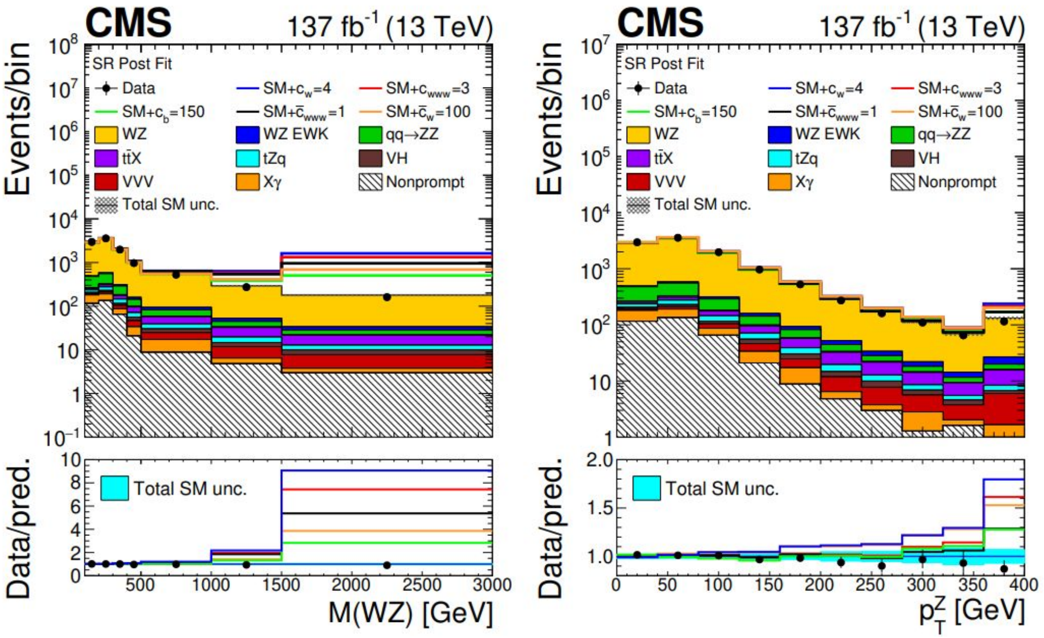
Electroweak WZ

CMS JHEP07(2022)032



- Three leptons (e or μ) with at least one OSSF pair coming from Z
  : Clean final state, high purity
- Measurement of the differential cross section for various observables

- Target dim-6 aTGC coefficients
- High tails of m_{WZ} and $p_T(Z)$ sensitive to presence of EFT effects
  : Compute the EFT effect in the m_{WZ}



dim-6 Charged aTGC in Electroweak WZ

CP-conserving terms

CP-violating terms

- The effect of **CP-violating** dim-6 operators is introduced for the **first time in WZ**, leading to CIs similar to those obtained in the CP-conserving case
- Provides stronger constraints than previous analyses by a factor of 2 (JHEP04(2019)122)
- Possible correlations across the CP-conserving EFT parameters are studied by producing 2D limit (backup)

$$\delta\mathcal{L}_{AC} = \frac{c_{\mathrm{www}}\mathrm{Tr}[W_{\mu\nu}W^{\nu\rho}W^{\mu}_{\rho}] + c_{\mathrm{w}}\left(D_{\mu}H\right)^{\dagger}W^{\mu\nu}\left(D_{\nu}H\right) + c_{\mathrm{b}}\left(D_{\mu}H\right)^{\dagger}B^{\mu\nu}\left(D_{\nu}H\right)}{\Lambda^2} + \frac{\tilde{c}_{\mathrm{www}}\mathrm{Tr}[\tilde{W}_{\mu\nu}W^{\nu\rho}W^{\mu}_{\rho}] + \tilde{c}_{\mathrm{w}}\left(D_{\mu}H\right)^{\dagger}\tilde{W}^{\mu\nu}\left(D_{\nu}H\right)}{\Lambda^2}$$

CP-even terms, a “classic” in WZ production

CP-odd terms,are the first introduced in WZ production

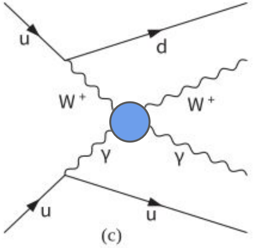
SM + Interference + pure BSM

Parameter	95% CI, exp. (TeV^{-2})	95% CI, obs. (TeV^{-2})	Best fit, obs. (TeV^{-2})
c_{w}/Λ^2	$[-2.0, 1.3]$	$[-2.5, 0.3]$	-1.3
$c_{\mathrm{www}}/\Lambda^2$	$[-1.3, 1.3]$	$[-1.0, 1.2]$	0.1
c_{b}/Λ^2	$[-86, 125]$	$[-43, 113]$	44
$\tilde{c}_{\mathrm{www}}/\Lambda^2$	$[-0.76, 0.65]$	$[-0.62, 0.53]$	-0.03
$\tilde{c}_{\mathrm{w}}/\Lambda^2$	$[-46, 46]$	$[-32, 32]$	0

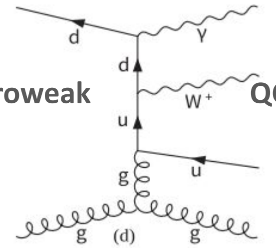
VBS Wγ+2jets

CMS Phys.Rev.D.108(2023)032017

- Well-displaced 2 jets, 1 photon, and 1 lepton coming from W boson
- Measure inclusive and differential cross-sections in a VBS phase space
- Target dim-8 aQGC coefficient in EW VBS process
- Separate SRs for barrel γ and endcap γ 2 approaches :
- SM fit performed using and m_{jj} and $m_{l\gamma}$
- EFT aQGCs would enhance yield at high-$m_{W\gamma}$ region

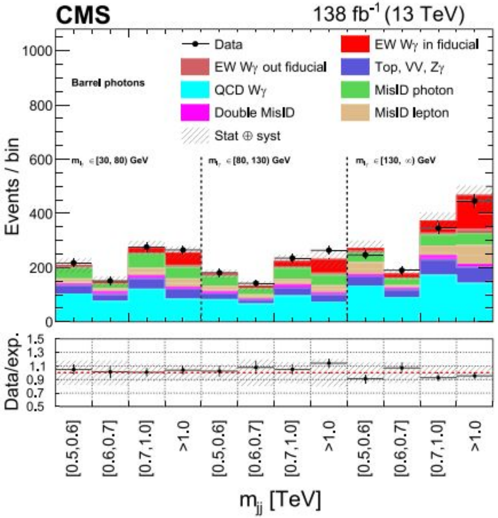


Purely electroweak



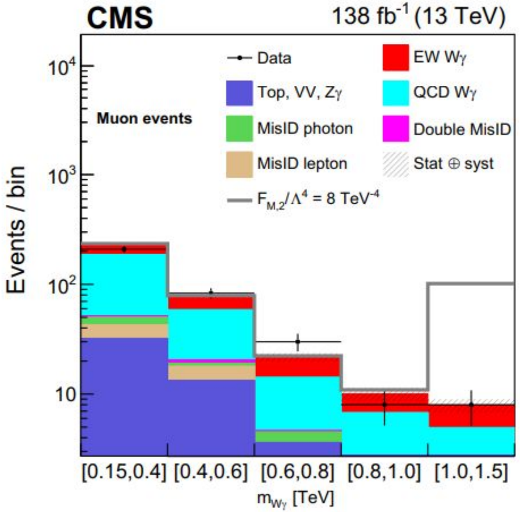
QCD-induced (BG)

SM Fit



aQGC Fit

VBS
$p_T(\gamma)$ > 100 GeV



dim-8 aQGC in VBS Wγ+2jets

- 95% Confidence Intervals on each aQGC coefficient (SM + Interference + pure BSM)
- **The most stringent limits to date** on :

  f_{M2-5} / Λ^4 and f_{T6-7} / Λ^4

- Provided U_{bound} [TeV] on scattering energy : Beyond this bound, a scattering amplitude violate unitarity. (EFT expansion is not valid)

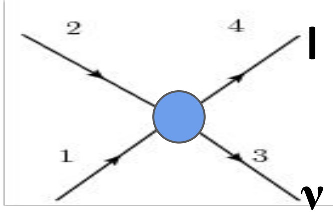
Expected limit	Observed limit	U_{bound}
$-5.1 < f_{M,0}/\Lambda^4 < 5.1$	$-5.6 < f_{M,0}/\Lambda^4 < 5.5$	1.7
$-7.1 < f_{M,1}/\Lambda^4 < 7.4$	$-7.8 < f_{M,1}/\Lambda^4 < 8.1$	2.1
$-1.8 < f_{M,2}/\Lambda^4 < 1.8$	$-1.9 < f_{M,2}/\Lambda^4 < 1.9$	2.0
$-2.5 < f_{M,3}/\Lambda^4 < 2.5$	$-2.7 < f_{M,3}/\Lambda^4 < 2.7$	2.7
$-3.3 < f_{M,4}/\Lambda^4 < 3.3$	$-3.7 < f_{M,4}/\Lambda^4 < 3.6$	2.3
$-3.4 < f_{M,5}/\Lambda^4 < 3.6$	$-3.9 < f_{M,5}/\Lambda^4 < 3.9$	2.7
$-13 < f_{M,7}/\Lambda^4 < 13$	$-14 < f_{M7}/\Lambda^4 < 14$	2.2
$-0.43 < f_{T,0}/\Lambda^4 < 0.51$	$-0.47 < f_{T,0}/\Lambda^4 < 0.51$	1.9
$-0.27 < f_{T,1}/\Lambda^4 < 0.31$	$-0.31 < f_{T,1}/\Lambda^4 < 0.34$	2.5
$-0.72 < f_{T,2}/\Lambda^4 < 0.92$	$-0.85 < f_{T,2}/\Lambda^4 < 1.0$	2.3
$-0.29 < f_{T,5}/\Lambda^4 < 0.31$	$-0.31 < f_{T,5}/\Lambda^4 < 0.33$	2.6
$-0.23 < f_{T,6}/\Lambda^4 < 0.25$	$-0.25 < f_{T,6}/\Lambda^4 < 0.27$	2.9
$-0.60 < f_{T,7}/\Lambda^4 < 0.68$	$-0.67 < f_{T,7}/\Lambda^4 < 0.73$	3.1

(TeV)

ATLAS also report **Wγ+2jets very recently!**
arxiv:2403.02809 (Given in Júlia's talk)

EW Oblique parameter in high lν

CMS JHEP 07 (2022) 067



PLB772(2017)210
JHEP02(2016)086

First result @ LHC in lν

- New resonances, when too heavy to be produced on-shell, contribute to 4-fermion contact interactions (or modify W/Z propagators when universal)
- Deviations entirely parametrized by 4 parameters : $\hat{S}, \hat{T}, W, Y$
- ***W, Y* grows with q² (√s) :** contribute to offshell DY

deviation weight (BSM/SM)

$$\left|\frac{P_W}{P_W^{(0)}}\right|^2 = \left(1 + \frac{(2t^2-1)W}{1-t^2} + \frac{t^2 Y}{1-t^2} - \frac{W(q^2-m_W^2)}{m_W^2}\right)^2$$

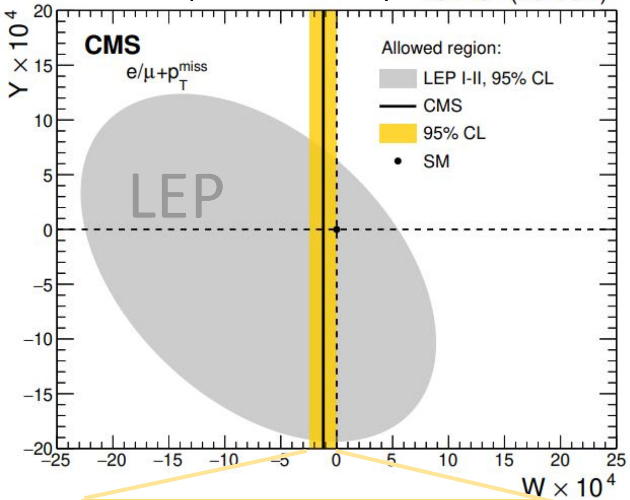
t = tangent of the SM weak mixing angle (≈ 0.3)

q = invariant mass of the l+ν system at the hard scattering level

m_W= W boson mass

W, Y = oblique parameters

(2017+2018)



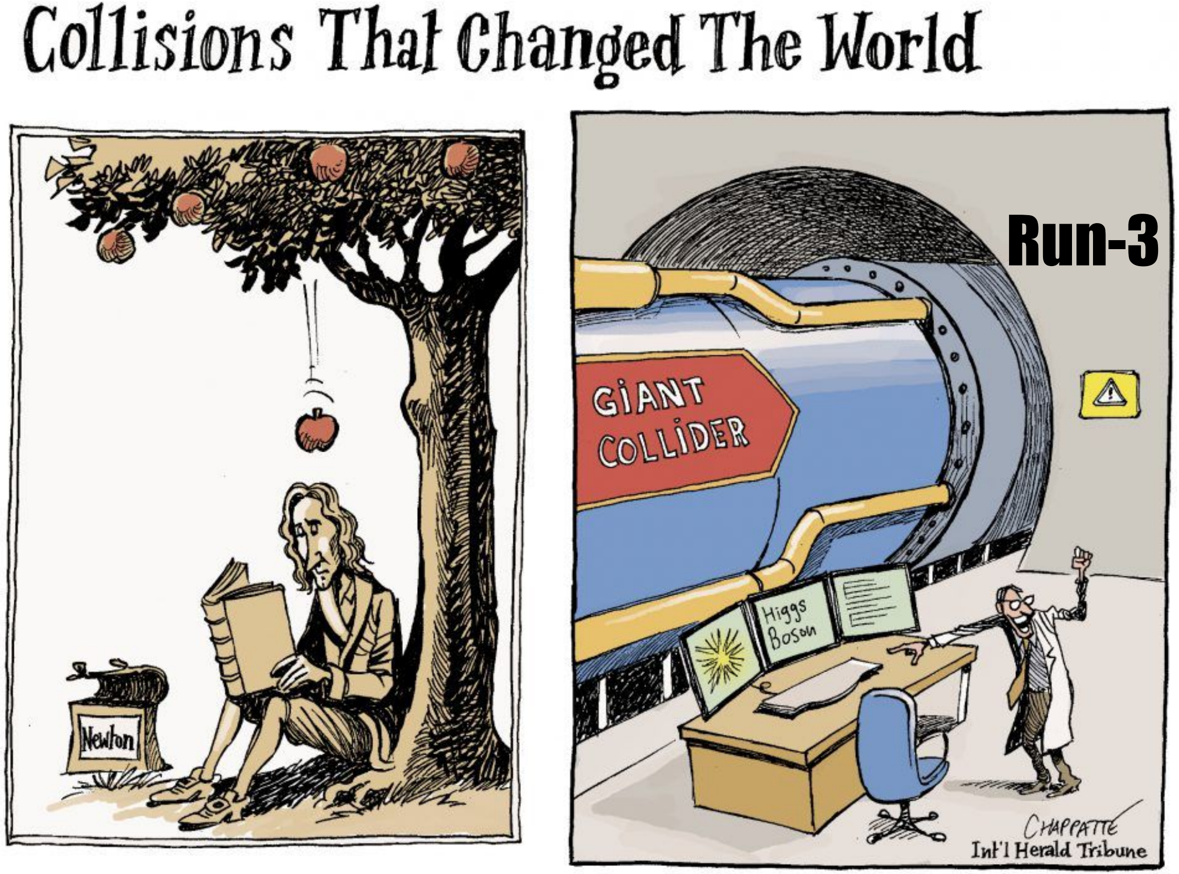
$$W = -1.2^{+0.5}_{-0.6} \times 10^{-4}$$

Conclusions

- Big efforts to scan all possible sources of indirect new physics effects with the EFT approach at the LHC
- Differential measurements of vector boson interactions provide unprecedented sensitivity to both anomalous Triple/Quartic Gauge Coupling (aTGC/aQGCs).
- Still No deviation from the SM was found.
- Global combination including Higgs, EWK and LEP/SLC EWPO are available.
- Further developments with more data, robust framework, advanced analysis techniques.
- **Stay tune for upcoming results.**

More results in
ATLAS publications, CMS publications

Backup


Collisions That Changed The World
Newton
GIANT COLLIDER
Higgs Boson
Run-3
CHAPPATTE
Int'l Herald Tribune

dim6 EFT operators

Warsaw basis

Gauge boson self-interactions highlighted

$\mathcal{L}_6^{(1)} - X^3$	
Q_G	$f^{abc} G_\mu^{a\nu} G_\nu^{b\rho} G_\rho^{c\mu}$
$Q_{\widetilde{G}}$	$f^{abc} \widetilde{G}_\mu^{a\nu} G_\nu^{b\rho} G_\rho^{c\mu}$
Q_W	$\varepsilon^{ijk} W_\mu^{i\nu} W_\nu^{j\rho} W_\rho^{k\mu}$
$Q_{\widetilde{W}}$	$\varepsilon^{ijk} \widetilde{W}_\mu^{i\nu} W_\nu^{j\rho} W_\rho^{k\mu}$
$\mathcal{L}_6^{(2)} - H^6$	
Q_H	$(H^\dagger H)^3$
$\mathcal{L}_6^{(3)} - H^4 D^2$	
$Q_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$
Q_{HD}	$(D^\mu H^\dagger H)\,(H^\dagger D_\mu H)$
$\mathcal{L}_6^{(4)} - X^2 H^2$	
Q_{HG}	$H^\dagger H\, G^a_{\mu\nu} G^{a\mu\nu}$
$Q_{H\widetilde{G}}$	$H^\dagger H\, \widetilde{G}^a_{\mu\nu} G^{a\mu\nu}$
Q_{HW}	$H^\dagger H\, W^i_{\mu\nu} W^{I\mu\nu}$
$Q_{H\widetilde{W}}$	$H^\dagger H\, \widetilde{W}^i_{\mu\nu} W^{i\mu\nu}$
Q_{HB}	$H^\dagger H\, B_{\mu\nu} B^{\mu\nu}$
$Q_{H\widetilde{B}}$	$H^\dagger H\, \widetilde{B}_{\mu\nu} B^{\mu\nu}$
Q_{HWB}	$H^\dagger \sigma^i H\, W^i_{\mu\nu} B^{\mu\nu}$
$Q_{H\widetilde{W}B}$	$H^\dagger \sigma^i H\, \widetilde{W}^i_{\mu\nu} B^{\mu\nu}$
$\mathcal{L}_6^{(5)} - \psi^2 H^3$	
Q_{eH}	$(H^\dagger H)(\bar{l}_p e_r H)$
Q_{uH}	$(H^\dagger H)(\bar{q}_p u_r \widetilde{H})$
Q_{dH}	$(H^\dagger H)(\bar{q}_p d_r H)$

$\mathcal{L}_6^{(6)} - \psi^2 X H$	
Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\sigma^i H W^i_{\mu\nu}$
Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) H B_{\mu\nu}$
Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^a u_r)\widetilde{H}\, G^a_{\mu\nu}$
Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\sigma^i \widetilde{H}\, W^i_{\mu\nu}$
Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\widetilde{H}\, B_{\mu\nu}$
Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^a d_r) H\, G^a_{\mu\nu}$
Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\sigma^i H\, W^i_{\mu\nu}$
Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) H\, B_{\mu\nu}$
$\mathcal{L}_6^{(7)} - \psi^2 H^2 D$	
$Q_{Hl}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}_p \gamma^\mu l_r)$
$Q_{Hl}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}^i_\mu H)(\bar{l}_p \sigma^i \gamma^\mu l_r)$
Q_{He}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_p \gamma^\mu e_r)$
$Q_{Hq}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}_p \gamma^\mu q_r)$
$Q_{Hq}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}^i_\mu H)(\bar{q}_p \sigma^i \gamma^\mu q_r)$
Q_{Hu}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}_p \gamma^\mu u_r)$
Q_{Hd}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}_p \gamma^\mu d_r)$
Q_{Hud} + h.c.	$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}_p \gamma^\mu d_r)$
$\mathcal{L}_6^{(8a)} - (\bar{L}L)(\bar{L}L)$	
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \sigma^i q_r)(\bar{q}_s \gamma^\mu \sigma^i q_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \sigma^i l_r)(\bar{q}_s \gamma^\mu \sigma^i q_t)$

$\mathcal{L}_6^{(8b)} - (\bar{R}R)(\bar{R}R)$	
Q_{ee}	$(\bar{e}_p \gamma_\mu e_r)(\bar{e}_s \gamma^\mu e_t)$
Q_{uu}	$(\bar{u}_p \gamma_\mu u_r)(\bar{u}_s \gamma^\mu u_t)$
Q_{dd}	$(\bar{d}_p \gamma_\mu d_r)(\bar{d}_s \gamma^\mu d_t)$
Q_{eu}	$(\bar{e}_p \gamma_\mu e_r)(\bar{u}_s \gamma^\mu u_t)$
Q_{ed}	$(\bar{e}_p \gamma_\mu e_r)(\bar{d}_s \gamma^\mu d_t)$
$Q_{ud}^{(1)}$	$(\bar{u}_p \gamma_\mu u_r)(\bar{d}_s \gamma^\mu d_t)$
$Q_{ud}^{(8)}$	$(\bar{u}_p \gamma_\mu T^a u_r)(\bar{d}_s \gamma^\mu T^a d_t)$
$\mathcal{L}_6^{(8c)} - (\bar{L}L)(\bar{R}R)$	
Q_{le}	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$
Q_{lu}	$(\bar{l}_p \gamma_\mu l_r)(\bar{u}_s \gamma^\mu u_t)$
Q_{ld}	$(\bar{l}_p \gamma_\mu l_r)(\bar{d}_s \gamma^\mu d_t)$
Q_{qe}	$(\bar{q}_p \gamma_\mu q_r)(\bar{e}_s \gamma^\mu e_t)$
$Q_{qu}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{u}_s \gamma^\mu u_t)$
$Q_{qu}^{(8)}$	$(\bar{q}_p \gamma_\mu T^a q_r)(\bar{u}_s \gamma^\mu T^a u_t)$
$Q_{qd}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{d}_s \gamma^\mu d_t)$
$Q_{qd}^{(8)}$	$(\bar{q}_p \gamma_\mu T^a q_r)(\bar{d}_s \gamma^\mu T^a d_t)$
$\mathcal{L}_6^{(8d)} - (\bar{L}R)(\bar{R}L), (\bar{L}R)(\bar{L}R)$	
Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_{tj})$
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\varepsilon_{jk}(\bar{q}_s^k d_t)$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^a u_r)\varepsilon_{jk}(\bar{q}_s^k T^a d_t)$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\varepsilon_{jk}(\bar{q}_s^k u_t)$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar{q}_s^k \sigma^{\mu\nu} u_t)$

dim8 EFT operators for QGCs

O. J. P. Éboli et al. PhysRevD.74.073005

Higgs field ($\mathcal{L}_S$ scalar type)

$$\mathcal{L}_{S,0} = \left[(D_\mu\Phi)^\dagger D_\nu\Phi\right] \times \left[(D^\mu\Phi)^\dagger D^\nu\Phi\right]$$
$$\mathcal{L}_{S,1} = \left[(D_\mu\Phi)^\dagger D^\mu\Phi\right] \times \left[(D_\nu\Phi)^\dagger D^\nu\Phi\right]$$

Higgs - Gauge boson field ($\mathcal{L}_M$ mixed -scalar tensor type)

$$\mathcal{L}_{M,0} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right]$$
$$\mathcal{L}_{M,1} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right]$$
$$\mathcal{L}_{M,2} = \left[B_{\mu\nu}B^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right]$$
$$\mathcal{L}_{M,3} = \left[B_{\mu\nu}B^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right]$$
$$\mathcal{L}_{M,4} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu} D^\mu\Phi\right] \times B^{\beta\nu}$$
$$\mathcal{L}_{M,5} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu} D^\nu\Phi\right] \times B^{\beta\mu}$$
$$\mathcal{L}_{M,6} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu}\hat{W}^{\beta\nu} D^\mu\Phi\right]$$
$$\mathcal{L}_{M,7} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu}\hat{W}^{\beta\mu} D^\nu\Phi\right]$$

Gauge boson field ($\mathcal{L}_T$ tensor type)

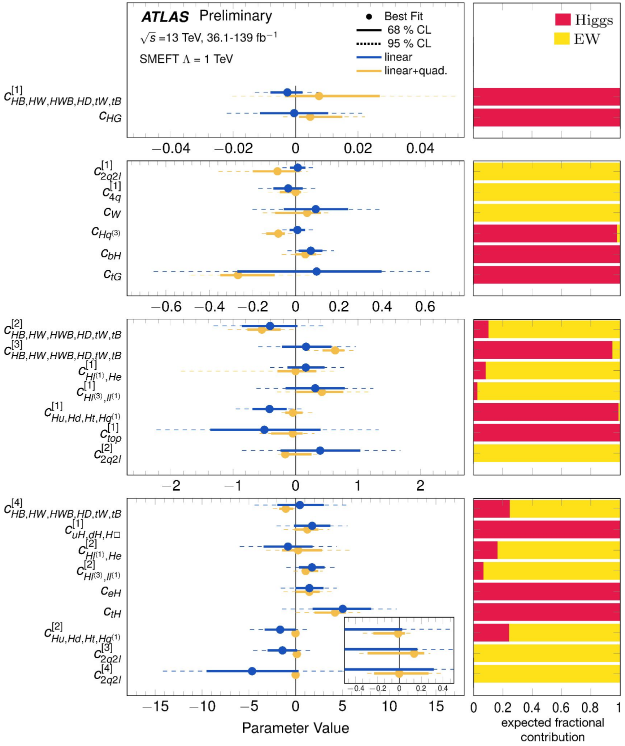
$$\mathcal{L}_{T,0} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \mathrm{Tr}\left[\hat{W}_{\alpha\beta}\hat{W}^{\alpha\beta}\right]$$
$$\mathcal{L}_{T,1} = \mathrm{Tr}\left[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}\right] \times \mathrm{Tr}\left[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}\right]$$
$$\mathcal{L}_{T,2} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\right] \times \mathrm{Tr}\left[\hat{W}_{\beta\nu}\hat{W}^{\nu\alpha}\right]$$
$$\mathcal{L}_{T,3} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\hat{W}^{\nu\alpha}\right] \times B_{\beta\nu}$$
$$\mathcal{L}_{T,4} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\alpha\mu}\hat{W}^{\beta\nu}\right] \times B_{\beta\nu}$$
$$\mathcal{L}_{T,5} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times B_{\alpha\beta}B^{\alpha\beta}$$
$$\mathcal{L}_{T,6} = \mathrm{Tr}\left[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}\right] \times B_{\mu\beta}B^{\alpha\nu}$$
$$\mathcal{L}_{T,7} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\right] \times B_{\beta\nu}B^{\nu\alpha}$$
$$\mathcal{L}_{T,8} = B_{\mu\nu}B^{\mu\nu}B_{\alpha\beta}B^{\alpha\beta}$$
$$\mathcal{L}_{T,9} = B_{\alpha\mu}B^{\mu\beta}B_{\beta\nu}B^{\nu\alpha}$$

Set of dim-8 operators affecting quartic boson vertices:

	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA	AAAA
$\mathcal{O}_{S,0}$, $\mathcal{O}_{S,1}$	●	●	●						
$\mathcal{O}_{M,0}$, $\mathcal{O}_{M,1}$, $\mathcal{O}_{M,6}$, $\mathcal{O}_{M,7}$	●	●	●	●	●	●	●		
$\mathcal{O}_{M,2}$, $\mathcal{O}_{M,3}$, $\mathcal{O}_{M,4}$, $\mathcal{O}_{M,5}$		●	●	●	●	●	●		
$\mathcal{O}_{T,0}$, $\mathcal{O}_{T,1}$, $\mathcal{O}_{T,2}$	●	●	●	●	●	●	●	●	●
$\mathcal{O}_{T,5}$, $\mathcal{O}_{T,6}$, $\mathcal{O}_{T,7}$		●	●	●	●	●	●	●	●
$\mathcal{O}_{T,8}$, $\mathcal{O}_{T,9}$			●			●	●	●	●

ATLAS Global combination of EFT result

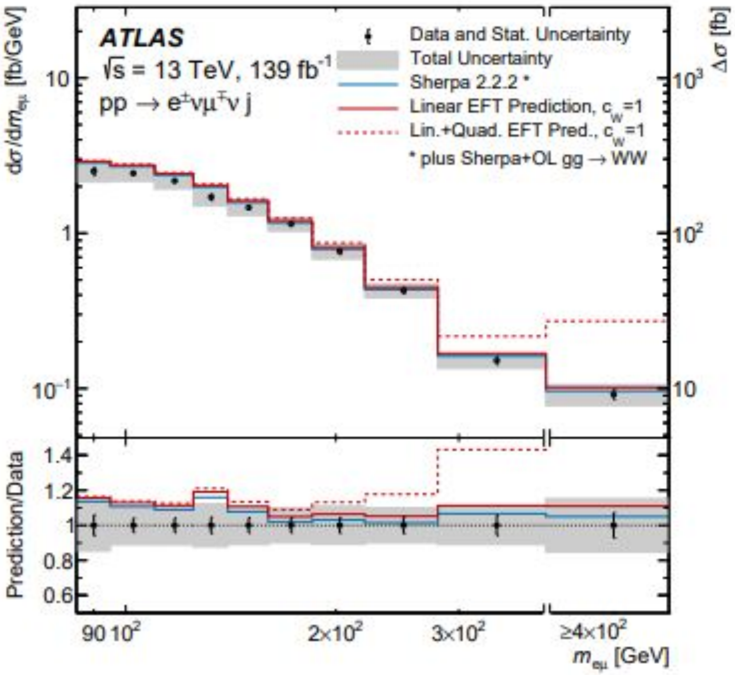
ATL-PHYS-PUB-2022-037

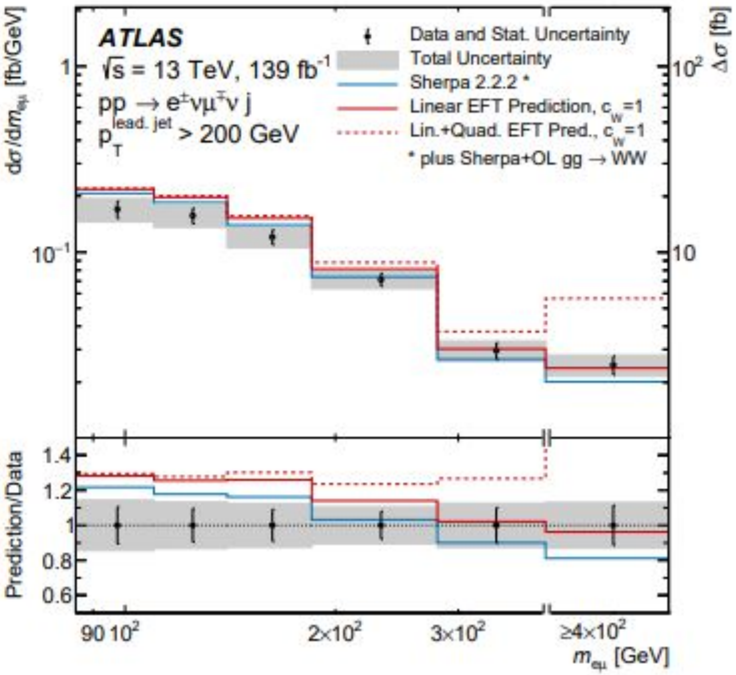


Wilson coefficient	Operator	LEP/SLD EWPO	ATLAS Higgs	ATLAS electroweak
$c_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$		✓	
c_G	$f^{abc}G^{a\nu}_{\mu}G^{b\rho}_{\nu}G^{c\mu}_{\rho}$		✓	✓
c_W	$\epsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$		✓	✓
c_{HD}	$\left(H^\dagger D_\mu H\right)^*\left(H^\dagger D_\mu H\right)$		✓	✓
c_{HG}	$H^\dagger H\, G^A_{\mu\nu}G^{A\mu\nu}$		✓	
c_{HB}	$H^\dagger H\, B_{\mu\nu}B^{\mu\nu}$		✓	
c_{HW}	$H^\dagger H\, W^I_{\mu\nu}W^{I\mu\nu}$		✓	
c_{HWB}	$H^\dagger\tau^I H\, W^I_{\mu\nu}B^{\mu\nu}$	✓	✓	✓
c_{eH}	$(H^\dagger H)(\bar{l}_p e_r H)$		✓	
c_{uH}	$(H^\dagger H)(\bar{q}Y_u^\dagger u\tilde{H})$		✓	
c_{tH}	$(H^\dagger H)(\bar{Q}\tilde{H}t)$		✓	
c_{bH}	$(H^\dagger H)(\bar{Q}Hb)$		✓	
$c^{(1)}_{Hl}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}\gamma^\mu l)$	✓	✓	✓
$c^{(3)}_{Hl}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{l}\tau^I\gamma^\mu l)$	✓	✓	✓
c_{He}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}\gamma^\mu e)$	✓	✓	✓
$c^{(1)}_{Hq}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}\gamma^\mu q)$	✓	✓	✓
$c^{(3)}_{Hq}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{q}\tau^I\gamma^\mu q)$	✓	✓	✓
c_{Hu}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}\gamma^\mu u)$	✓	✓	✓
c_{Hd}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}\gamma^\mu d)$	✓	✓	✓
$c^{(1)}_{HQ}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{Q}\gamma^\mu Q)$	✓	✓	
$c^{(3)}_{HQ}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{Q}\tau^I\gamma^\mu Q)$	✓	✓	
c_{Hb}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{b}\gamma^\mu b)$	✓		
c_{Ht}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{t}\gamma^\mu t)$	✓	✓	
c_{tG}	$(\bar{Q}\sigma^{\mu\nu}T^A t)\tilde{H}\,G^A_{\mu\nu}$		✓	
c_{tW}	$(\bar{Q}\sigma^{\mu\nu}t)\tau^I\tilde{H}\,W^I_{\mu\nu}$		✓	
c_{tB}	$(\bar{Q}\sigma^{\mu\nu}t)\tilde{H}\,B_{\mu\nu}$		✓	
c_{ll}	$(\bar{l}\gamma_\mu l)(\bar{l}\gamma^\mu l)$	✓		✓

Wilson coefficient	Operator	LEP/SLD EWPO	ATLAS Higgs	ATLAS electroweak
$c^{(1)}_{lq}$	$(\bar{l}\gamma_\mu l)(\bar{q}\gamma^\mu q)$			✓
$c^{(3)}_{lq}$	$(\bar{l}\gamma_\mu\tau^I l)(\bar{q}\gamma^\mu\tau^I q)$			✓
c_{eu}	$(\bar{e}\gamma_\mu e)(\bar{u}\gamma^\mu u)$			✓
c_{ed}	$(\bar{e}\gamma_\mu e)(\bar{d}\gamma^\mu d)$			✓
c_{lu}	$(\bar{l}\gamma_\mu l)(\bar{u}\gamma^\mu u)$			✓
c_{ld}	$(\bar{l}\gamma_\mu l)(\bar{d}\gamma^\mu d)$			✓
c_{qe}	$(\bar{q}\gamma_\mu q)(\bar{e}\gamma^\mu e)$			✓
$c^{(1,1)}_{qq}$	$(\bar{q}\gamma_\mu q)(\bar{q}\gamma^\mu q)$			✓
$c^{(1,8)}_{qq}$	$(\bar{q}T^a\gamma_\mu q)(\bar{q}T^a\gamma^\mu q)$			✓
$c^{(3,1)}_{qq}$	$(\bar{q}\sigma^i\gamma_\mu q)(\bar{q}\sigma^i\gamma^\mu q)$			✓
$c^{(3,8)}_{qq}$	$(\bar{q}\sigma^i T^a\gamma_\mu q)(\bar{q}\sigma^i T^a\gamma^\mu q)$			✓
$c^{(1)}_{uu}$	$(\bar{u}\gamma_\mu u)(\bar{u}\gamma^\mu u)$			✓
$c^{(8)}_{uu}$	$(\bar{u}T^a\gamma_\mu u)(\bar{u}T^a\gamma^\mu u)$			✓
$c^{(1)}_{dd}$	$(\bar{d}\gamma_\mu d)(\bar{d}\gamma^\mu d)$			✓
$c^{(8)}_{dd}$	$(\bar{d}T^a\gamma_\mu d)(\bar{d}T^a\gamma^\mu d)$			✓
$c^{(1)}_{ud}$	$(\bar{u}\gamma_\mu u)(\bar{d}\gamma^\mu d)$			✓
$c^{(8)}_{ud}$	$(\bar{u}T^a\gamma_\mu u)(\bar{d}T^a\gamma^\mu d)$			✓
$c^{(1)}_{qu}$	$(\bar{q}\gamma_\mu q)(\bar{u}\gamma^\mu u)$			✓
$c^{(8)}_{qu}$	$(\bar{q}T^a\gamma_\mu q)(\bar{u}T^a\gamma^\mu u)$			✓
$c^{(1)}_{qd}$	$(\bar{q}\gamma_\mu q)(\bar{d}\gamma^\mu d)$			✓
$c^{(8)}_{qd}$	$(\bar{q}T^a\gamma_\mu q)(\bar{d}T^a\gamma^\mu d)$			✓
$c^{(1,1)}_{Qq}$	$(\bar{Q}\gamma_\mu Q)(\bar{q}\gamma^\mu q)$		✓	
$c^{(1,8)}_{Qq}$	$(\bar{Q}T^a\gamma_\mu Q)(\bar{q}T^a\gamma^\mu q)$		✓	
$c^{(3,1)}_{Qq}$	$(\bar{Q}\sigma^i\gamma_\mu Q)(\bar{q}\sigma^i\gamma^\mu q)$		✓	
$c^{(3,8)}_{Qq}$	$(\bar{Q}\sigma^i T^a\gamma_\mu Q)(\bar{q}\sigma^i T^a\gamma^\mu q)$		✓	
$c^{(1)}_{tu}$	$(\bar{t}\gamma_\mu t)(\bar{u}\gamma^\mu u)$		✓	
$c^{(1)}_{Qu}$	$(\bar{Q}\gamma_\mu Q)(\bar{u}\gamma^\mu u)$		✓	
$c^{(8)}_{Qu}$	$(\bar{Q}T^a\gamma_\mu Q)(\bar{u}T^a\gamma^\mu u)$		✓	
$c^{(1)}_{Qd}$	$(\bar{Q}\gamma_\mu Q)(\bar{d}\gamma^\mu d)$		✓	
$c^{(8)}_{Qd}$	$(\bar{Q}T^a\gamma_\mu Q)(\bar{d}T^a\gamma^\mu d)$		✓	
$c^{(1)}_{tq}$	$(\bar{q}\gamma_\mu q)(\bar{t}\gamma^\mu t)$		✓	
$c^{(8)}_{tq}$	$(\bar{q}T^a\gamma_\mu q)(\bar{t}T^a\gamma^\mu t)$		✓	

Electroweak WW + ≥ 1 jet

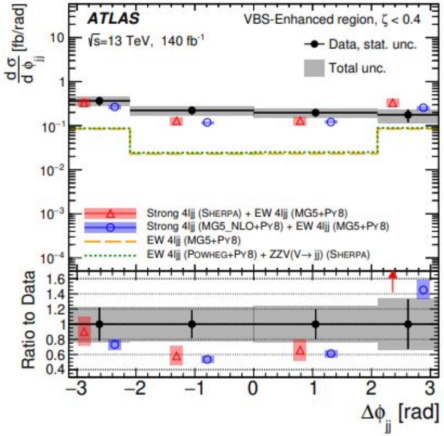




Interference Resurrection (VBS ZZ+2jets)

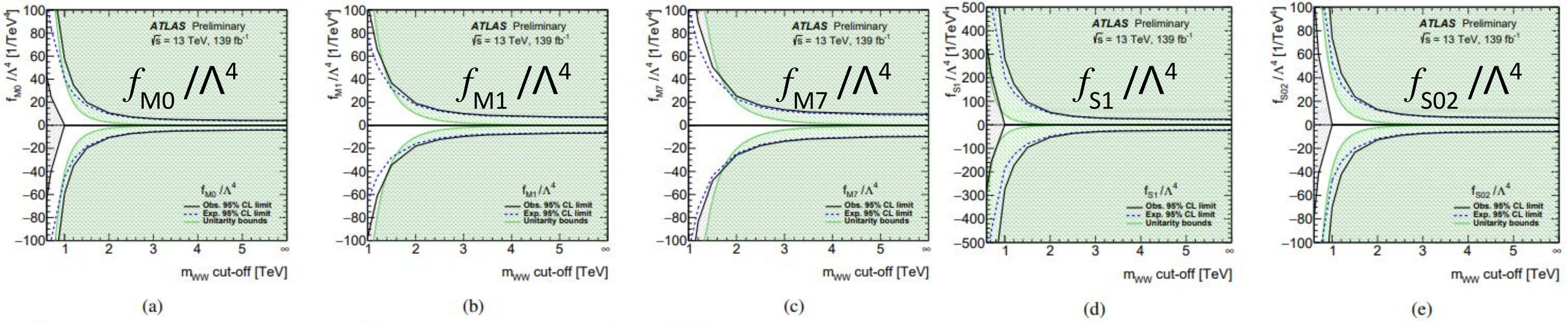
arxiv:1708.07823 Diboson interference resurrection

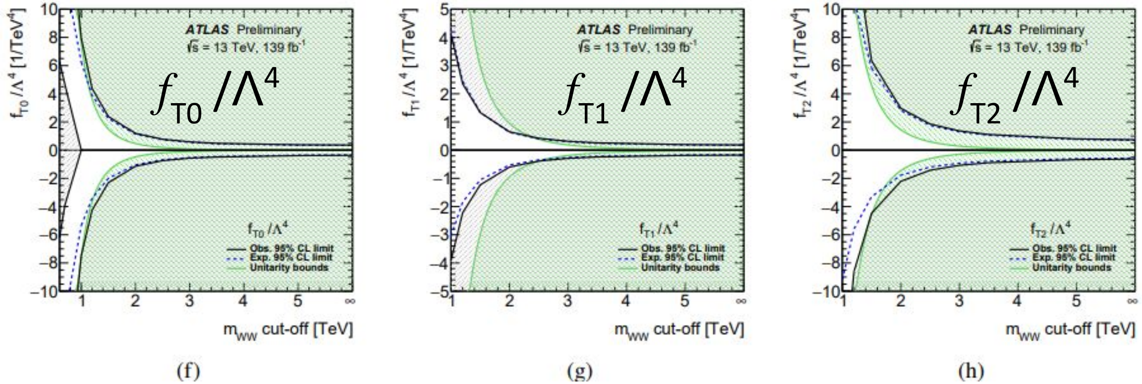
- The interference cannot be experimentally detected with "inclusive" observables
- Different helicity configurations for SM and BSM components
  ⇒ Leads to suppression of interference
- Try exclusive measurement!
  (ex) Differential angle acquires sensitivity to interference
- CP-odd dim-6 operators (blue box*), constraints are obtained using $\Delta\varphi_{jj}$ distribution
  ⇒ large asymmetric effects for SM-EFT interference.



Wilson coefficient	$\|\mathcal{M}_{d6}\|^2$ Included	95% confidence interval [TeV^{-2}] Expected	Observed
c_W/Λ^2	yes	[-1.3, 1.3]	[-1.2, 1.2]
	no	[-32, 32]	[-37, 28]
$c_{\tilde{W}}/\Lambda^2$	yes	[-1.3, 1.3]	[-1.2, 1.2]
	no	[-17, 17]*	[0, 30]*
c_{HWB}/Λ^2	yes	[-16, 7]	[-16, 6]
	no	[-12, 12]	[-15, 10]
$c_{H\tilde{W}B}/\Lambda^2$	yes	[-1.3, 1.3]	[-1.2, 1.2]
	no	[-67, 67]*	[-25, 130]*
c_{HB}/Λ^2	yes	[-13, 13]	[-12, 12]
	no	[-38, 38]	[-38, 38]
$c_{H\tilde{B}}/\Lambda^2$	yes	[-13, 13]	[-12, 12]
	no	[-420, 420]*	[-200, 790]*

dim8 aTGC in VBS WWjj



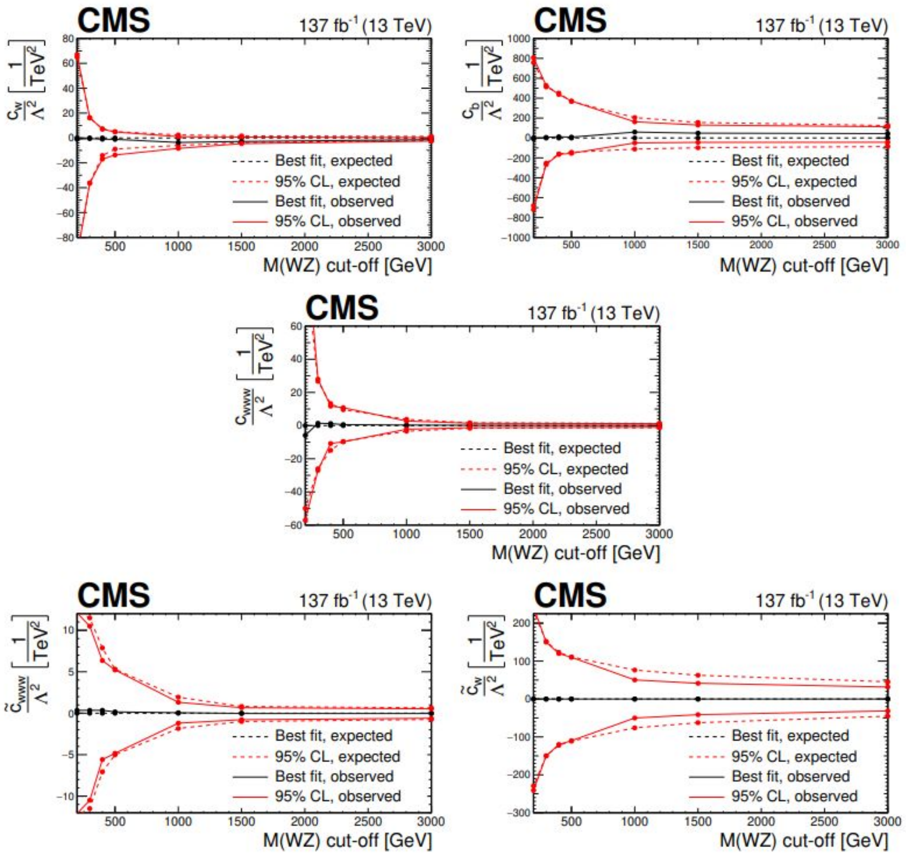


95% CIs of the EFT dim8 operator coefficients (quartic operators) as a function of the m_{WW} cut-off scale.

M7 without considering SM-EFT interference for EW WZjj final state

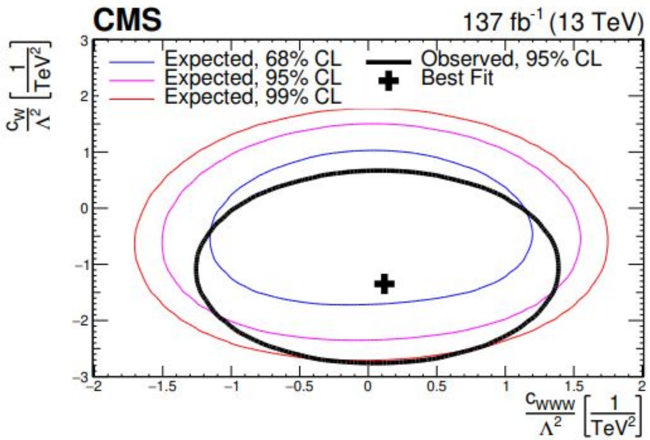
Charged aTGC in Electroweak WZ

- compute the EFT effect in the high tails of M(WZ)



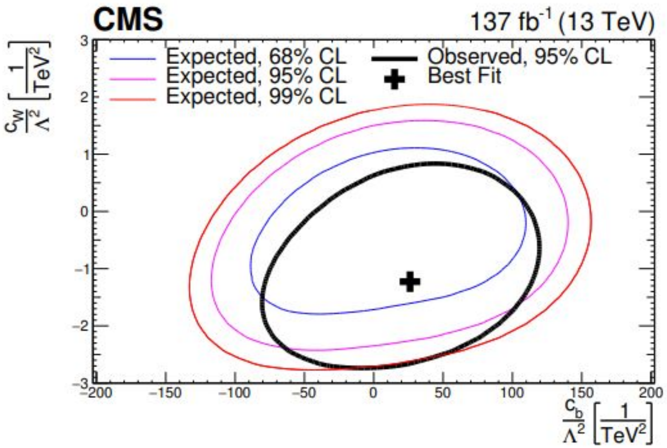
2D Limit on CP conserving aTGC in WZ

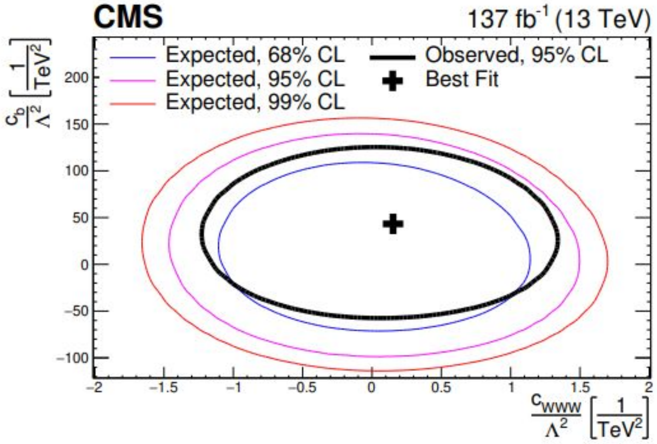
- Possible correlations across the CP-conserving EFT terms are studied by producing 2D CIs



CP-conserving terms

Parameter
c_w/Λ^2
c_{www}/Λ^2
c_b/Λ^2





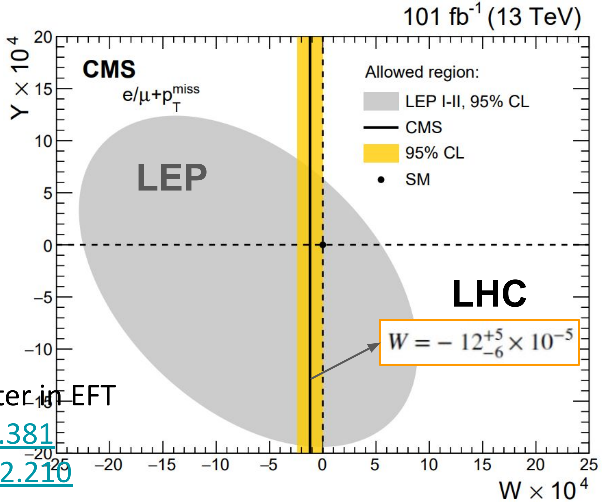
EFT - Composite Higgs Interpretation

Effective Field Theory Approach

EFT approach quantifies potential deviations from the SM expectations through the *W* parameter

$$\left|\frac{P_W}{P_W^{(0)}}\right|^2 = \left(1 + \frac{(2t^2-1)W}{1-t^2} + \frac{t^2 Y}{1-t^2} - \frac{W\,(q^2 - m_W^2)}{m_W^2}\right)^2$$

Modified SM predictions by **reweighting method.**
Compared with data and set the W-parameter



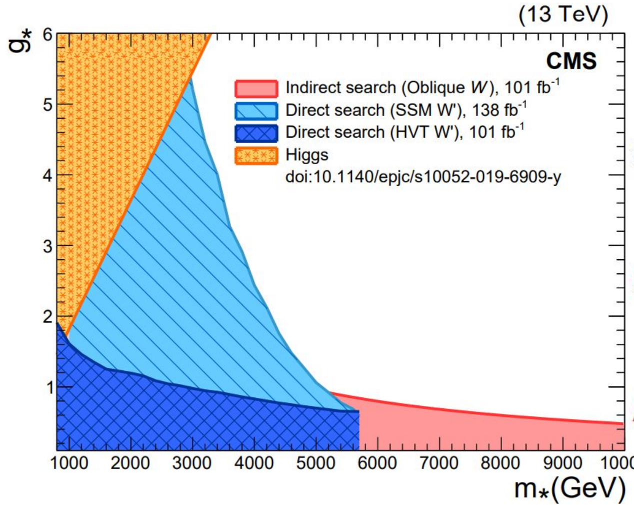
W, Y parameter in EFT
PhysRevD.46.381
PhysLettB.772.210

Composite Higgs boson models

H compositeness
JHEP06(2007)

Input for this reinterpretation comes in 3 complementary ways

1. **direct W' search** : W' boson to be a composite resonance. The gauge coupling to the new constituents is g*
2. **indirect EFT approach** : *W* parameter is used to quantify deviations from the SM.
3. **Higgs** : NP modify SM prediction of H prod/decay modification can be scaled.



$$g_{W'} = \frac{g^2}{g_*}$$

$$g_*^{\,2} = \frac{g^2 M_W^2}{W m_*^2}$$

$$\Delta\mu_H = \frac{g_*^{\,2} v^2}{m_*^2}$$