Standard Model electroweak highlights from CMS

with emphasis on

measurements of triple and quartic gauge couplings

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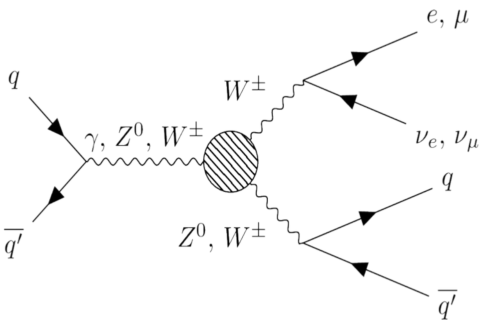
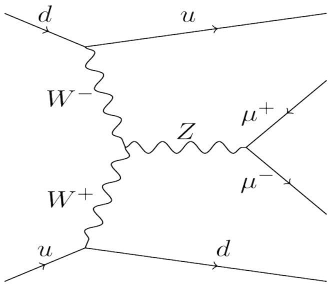
What breaks the electroweak symmetry?
Testing the EW sector of the Standard Model

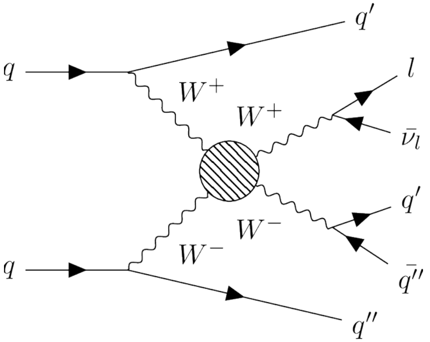
- Standard Model electroweak gauge sector:
  - **2 massive vector bosons**: W±, Z,
  - **1 massless vector boson**: γ,
  - **2 triple gauge couplings**: WWγ, WWZ, and
  - **4 quartic gauge couplings**: WWWW, WWZZ, WWZγ, WWγγ.

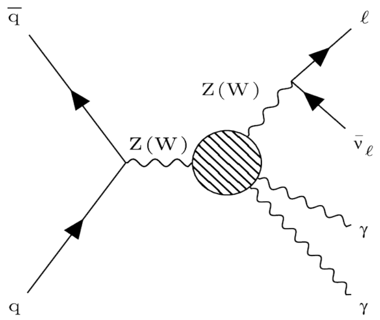
- All the above couplings are completely determined by theory. Any non-SM couplings will invoke divergences and require new particles to restore unitarity.

Anomalous couplings ⇔ New particles









- Diboson production processes → best to probe triple gauge couplings
  Single boson production in VBF mode → independent probe of triple couplings
  Vector Boson Scattering → best to probe quartic gauge couplings
  Triboson production processes → independent probe of quartic gauge couplings

Standard Model Effective Field Theory

- A theoretically consistent framework to describe the low energy behavior of BSM physics in a (quasi-) model independent way

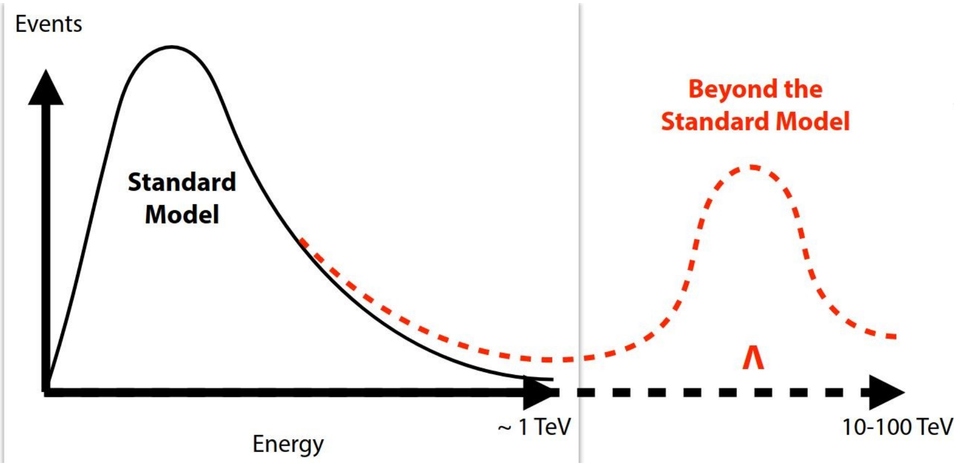
$$\mathcal{L}_{\rm Eff} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \frac{1}{\Lambda^3}\mathcal{L}_7 + \frac{1}{\Lambda^4}\mathcal{L}_8 + \cdots , \qquad \mathcal{L}_d = \sum_i c_i^{(d)} \mathcal{O}_i^{(d)}$$

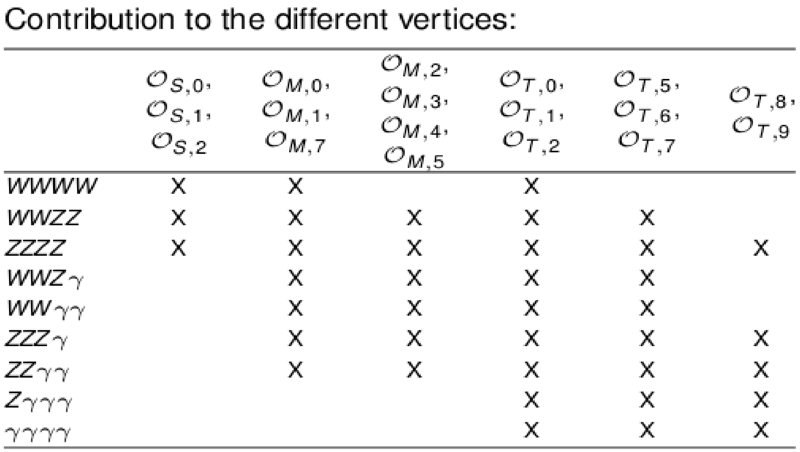
O_i – operators invariant under SM, of dimensionalities higher than 4, suppressed by appropriate powers of Λ – the energy scale of new physics,

c_i – dimensionless Wilson coefficients.

The approximation will break down at the cutoff scale Λ (unknown a priori)

- Of practical interest: dimension-6 operators c_{WWW}, c_W, c_B for aTGCs, and dimension-8 operators S0-2, M0-7, T0-9 (18 in total) for aQGCs



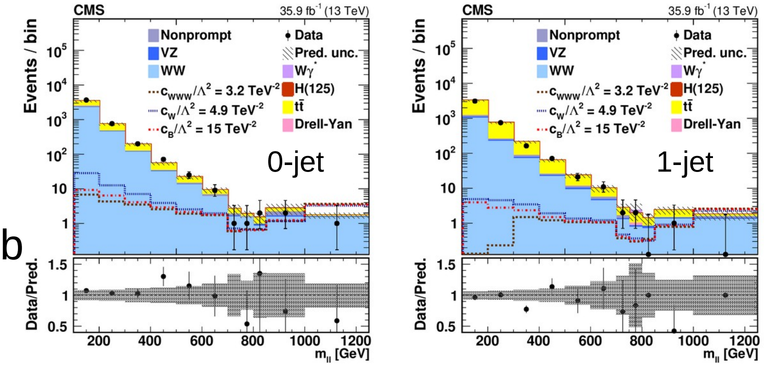


Contribution to the different vertices:

	$\mathcal{O}_{S,0}$, $\mathcal{O}_{S,1}$, $\mathcal{O}_{S,2}$	$\mathcal{O}_{M,0}$, $\mathcal{O}_{M,1}$, $\mathcal{O}_{M,7}$	$\mathcal{O}_{M,2}$, $\mathcal{O}_{M,3}$, $\mathcal{O}_{M,4}$, $\mathcal{O}_{M,5}$	$\mathcal{O}_{T,0}$, $\mathcal{O}_{T,1}$, $\mathcal{O}_{T,2}$	$\mathcal{O}_{T,5}$, $\mathcal{O}_{T,6}$, $\mathcal{O}_{T,7}$	$\mathcal{O}_{T,8}$, $\mathcal{O}_{T,9}$
$WWWW$	X	X		X		
$WWZZ$	X	X	X	X	X	
$ZZZZ$	X	X	X	X	X	X
$WWZ\gamma$		X	X	X	X	
$WW\gamma\gamma$		X	X	X	X	
$ZZZ\gamma$		X	X	X	X	X
$ZZ\gamma\gamma$		X	X	X	X	X
$Z\gamma\gamma\gamma$				X	X	X
$\gamma\gamma\gamma\gamma$				X	X	X

Overview of CMS Run 2 results

CMS results @ 13 TeV – diboson production

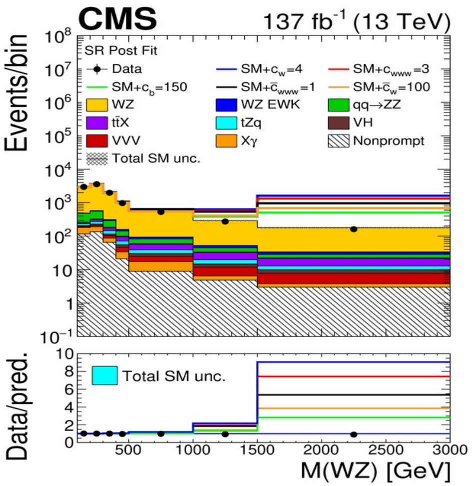


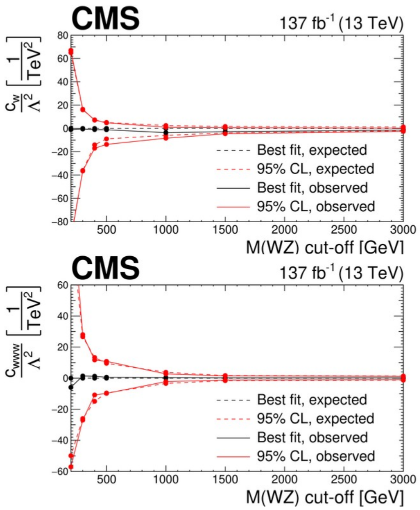
WW *PRD 102 (2020) 092001* 36/fb

Total & differential cross sections, limits on aTGCs

WZ *JHEP 04 (2019) 122* 36/fb, *JHEP 07 (2022) 032* 137/fb

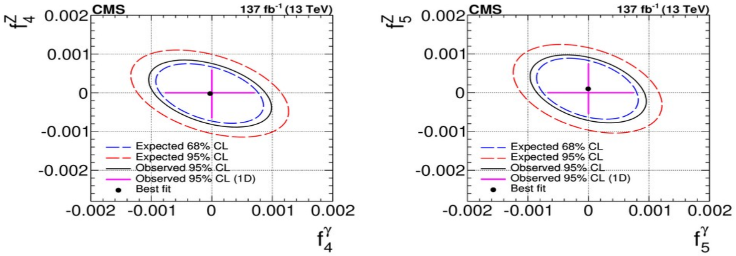
Total & differential cross sections,
limits on aTGCs incl. as a function of Λ,
comparison SM+Int.+BSM vs SM+Int.,
evidence of longitudinal polarizations





ZZ *EPJC 78 (2018) 165* 36/fb,
EPJC 81 (2021) 200 137/fb

Total & differential cross sections,
limits on ZZZ and ZZγ



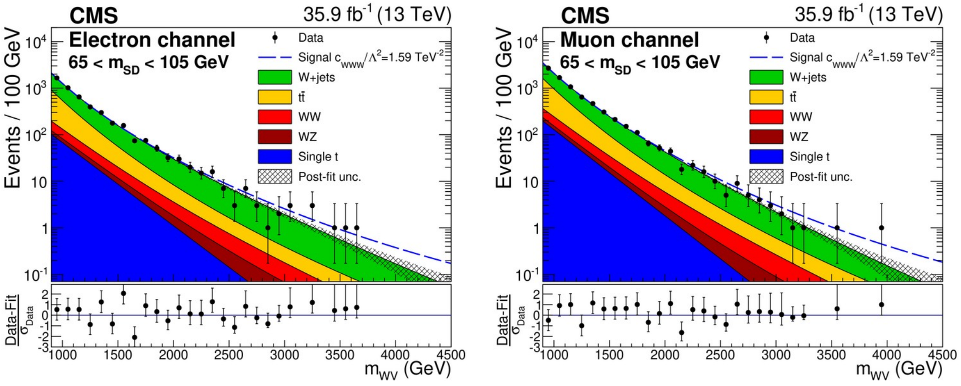
Wγ *PRL 126 (2021) 252002* 137/fb

Fiducial cross section, limits on aTGCs

Semileptonic WW+WZ

JHEP 12 (2019) 062 36/fb

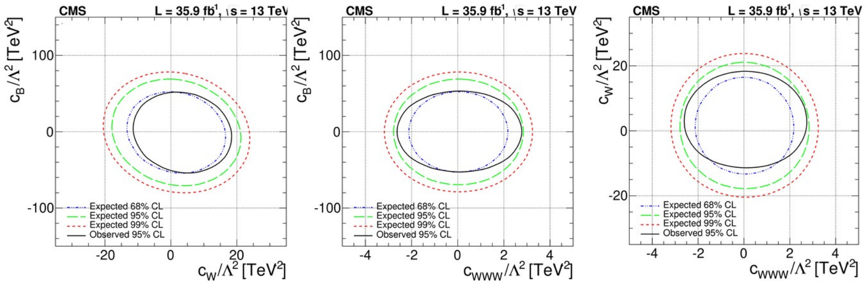
Limits (stringent!) on aTGCs

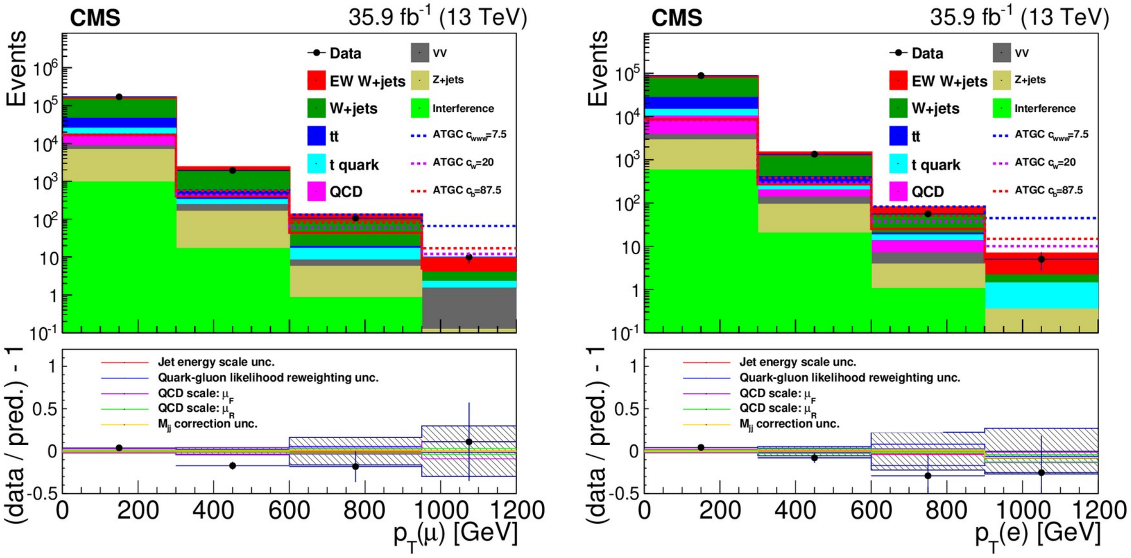


CMS results @ 13 TeV – single boson in VBF mode

W + 2 jets *EPJ C 80 (2020) 43* 36/fb

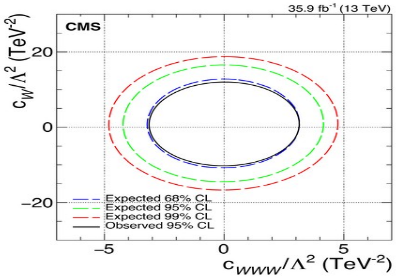
Fiducial EW cross section,
limits on aTGCs,
studies of hadronic and jet activity

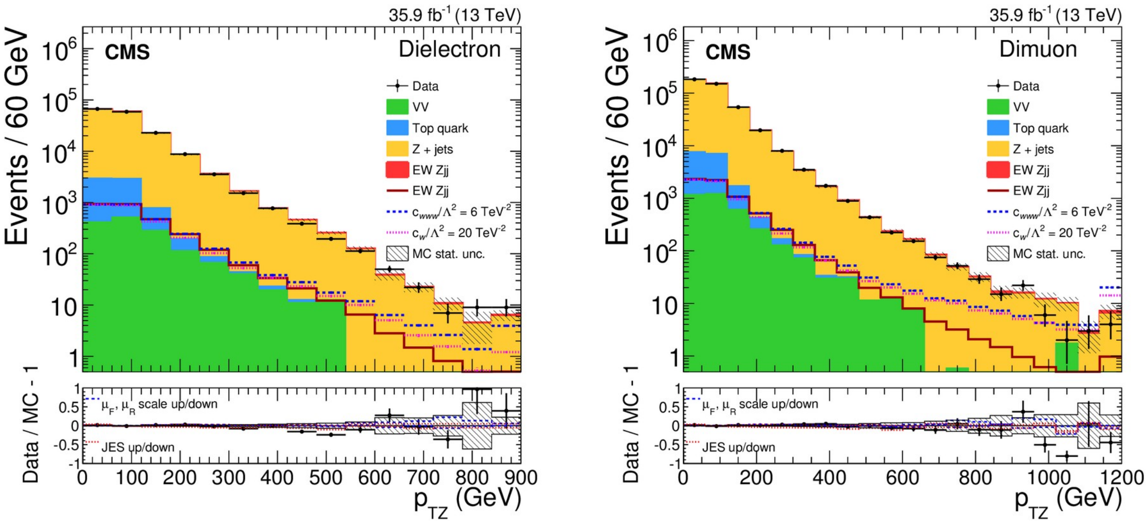




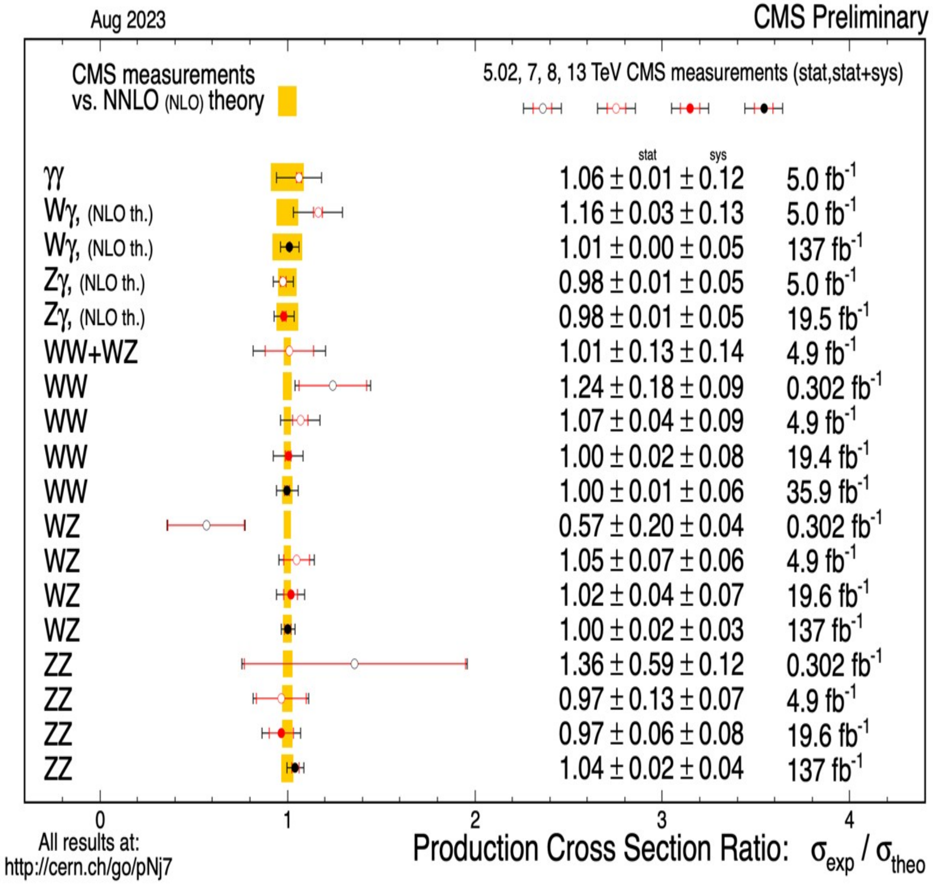
Z + 2 jets *EPJ C 78 (2018) 589* 36/fb

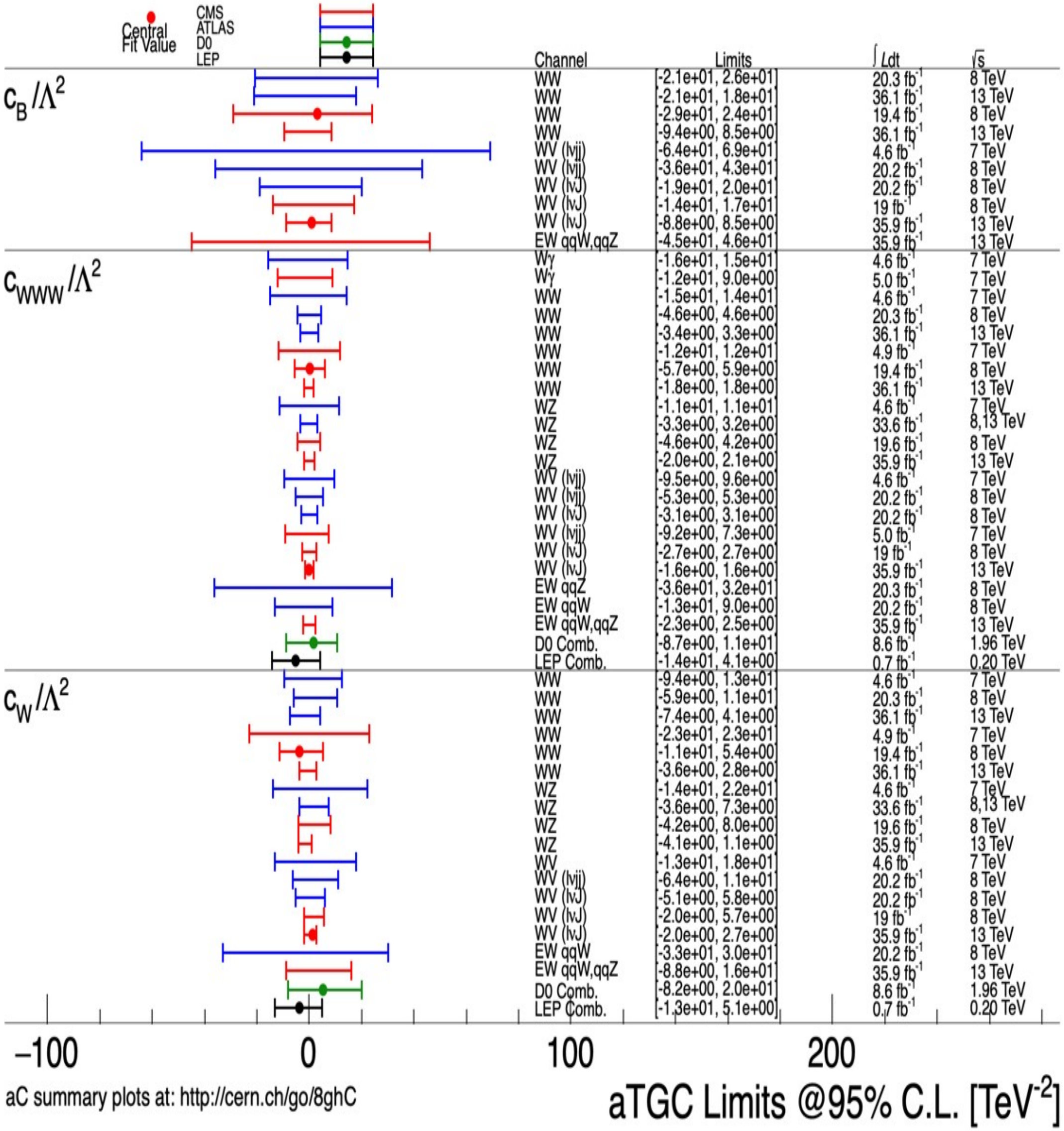
Fiducial EW cross sections,
limits on aTGCs,
studies of hadronic and jet activity





Diboson cross sections and aTGCs summary





CMS results @ 13 TeV – VBS processes

ssWW & WZ

ssWW *PRL 120 (2018) 081801* 36/fb,

WZ *PLB 795 (2019) 281* 36/fb,

ssWW, WZ *PLB 809 (2020) 135710* 137/fb

>5 sigma observation,
total and differential cross sections,
limits on aQGCs (S0, S1, T0-2, M0, M1, M7)
+ comparison clipping vs no clipping

Polarized ssWW

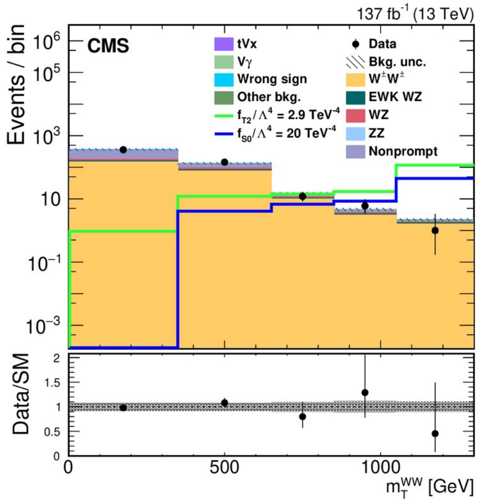
PLB 812 (2020) 136018 137/fb

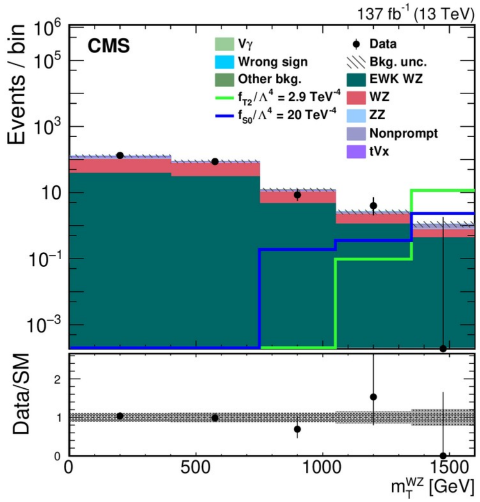
Hints of W_LW_L

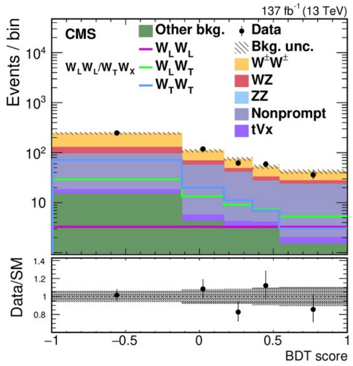
ZZ *PLB 774 (2017) 682* 36/fb

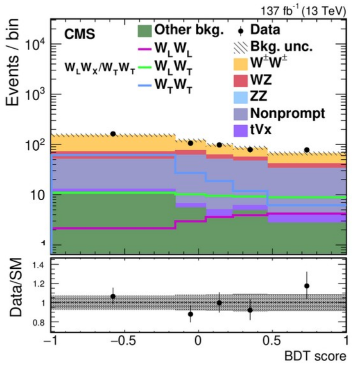
PLB 812 (2020) 135992 137/fb

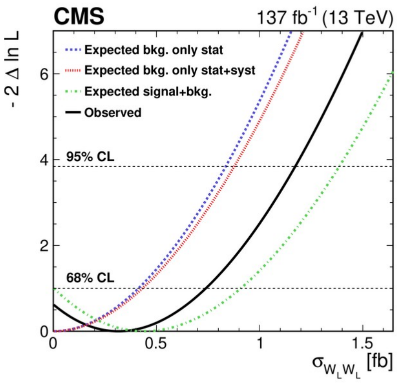
4 sigma evidence, total cross sections,
limits on aQGCs (T0-2, **T8, T9**)

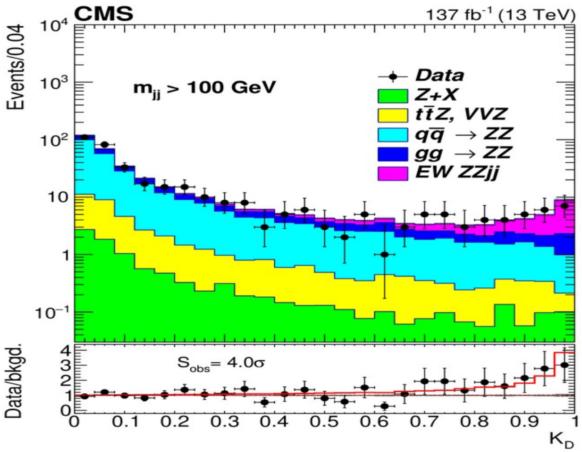


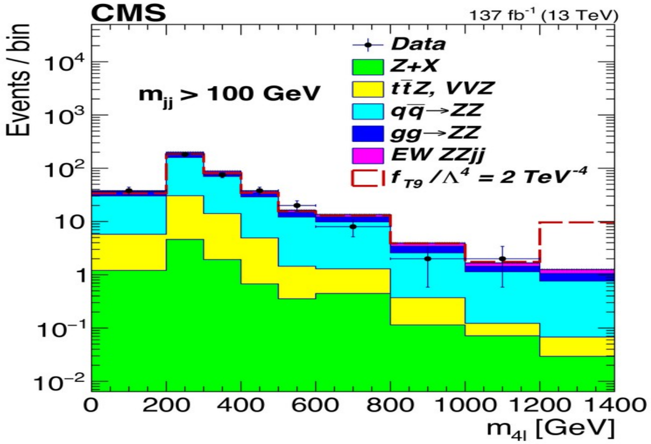






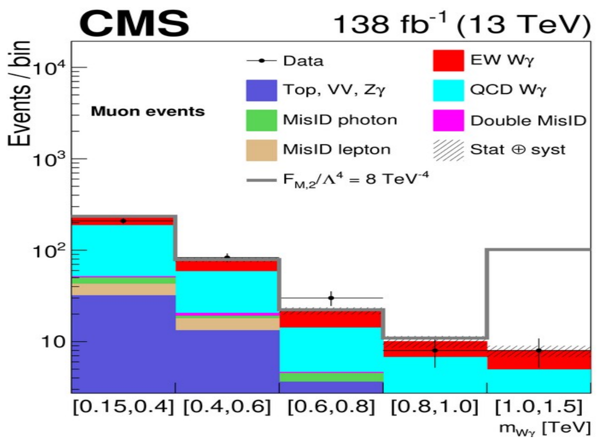




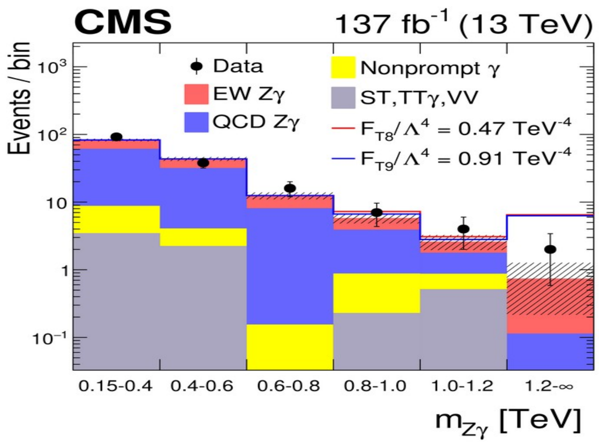


CMS results @ 13 TeV – VBS processes

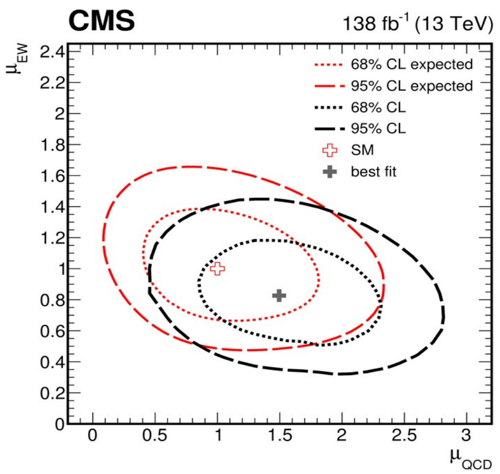
Wγ *PLB 811 (2020) 135988* 36/fb,
PRD 108 (2023) 032017 138/fb ← **NEW!**
>5 sigma observation, total and differential cross sections,
limits on aQGCs (M0, M1, M7, **M2-5**, T0-2, **T5-7**)

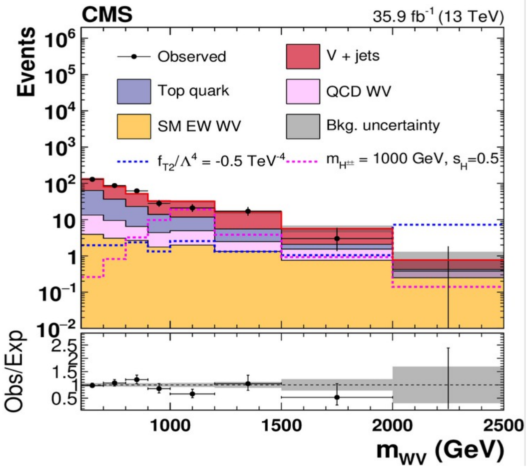


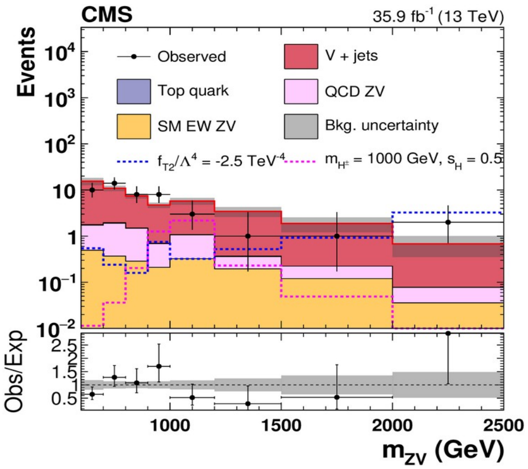
Zγ *JHEP 06 (2020) 076* 36/fb,
PRD 104 (2021) 072001 137/fb
>5 sigma observation, total and differential cross sections,
limits on aQGCs (M0-7, T0-2, T5-7, **T8, T9**)



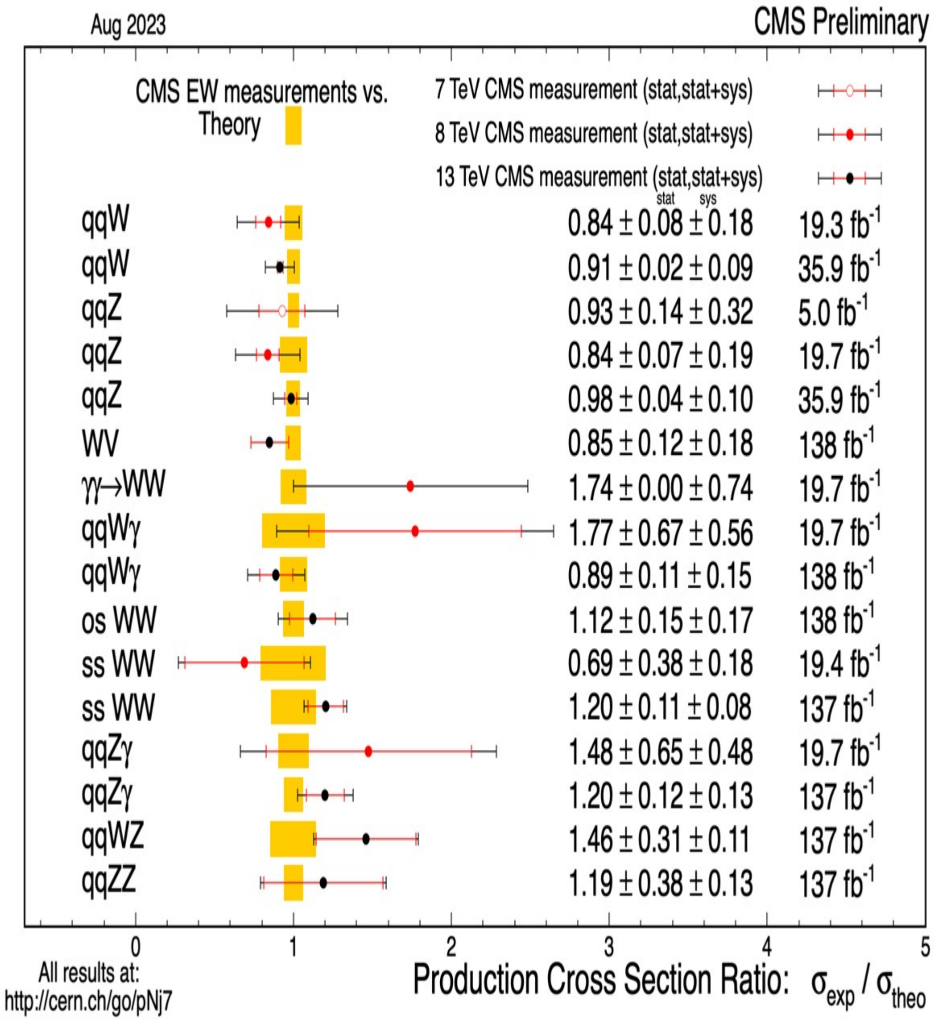
VV semileptonic
WW+WZ+ZZ *PLB 798 (2019) 134985* 36/fb,
WW+WZ *PLB 834 (2022) 137438* 137/fb
4.4 sigma evidence, total cross sections,
limits (stringent!) on aQGCs (S0, S1, T0-2, M0, M1, M7)



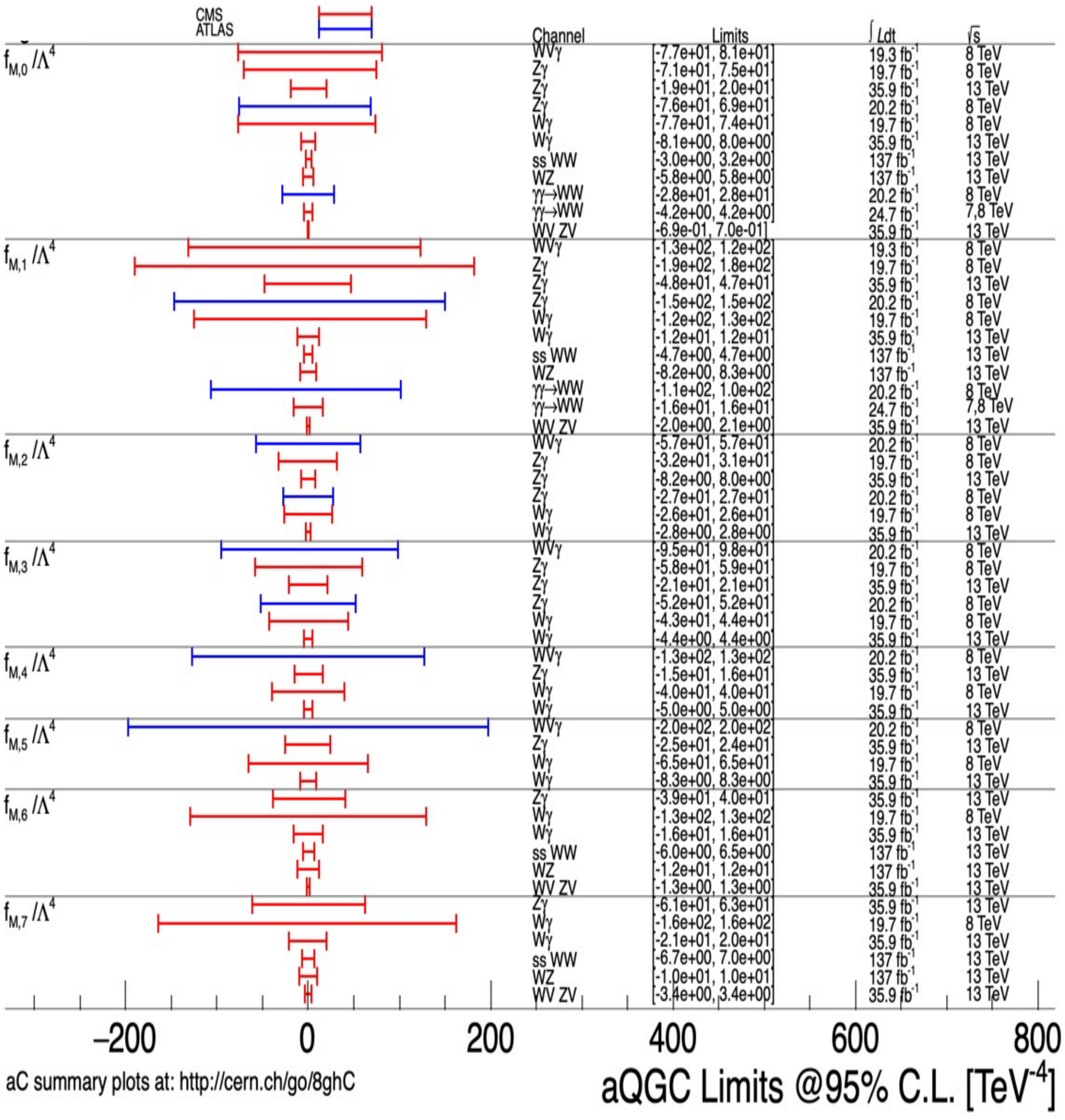




VBF/VBS EW cross sections and aQGCs summary

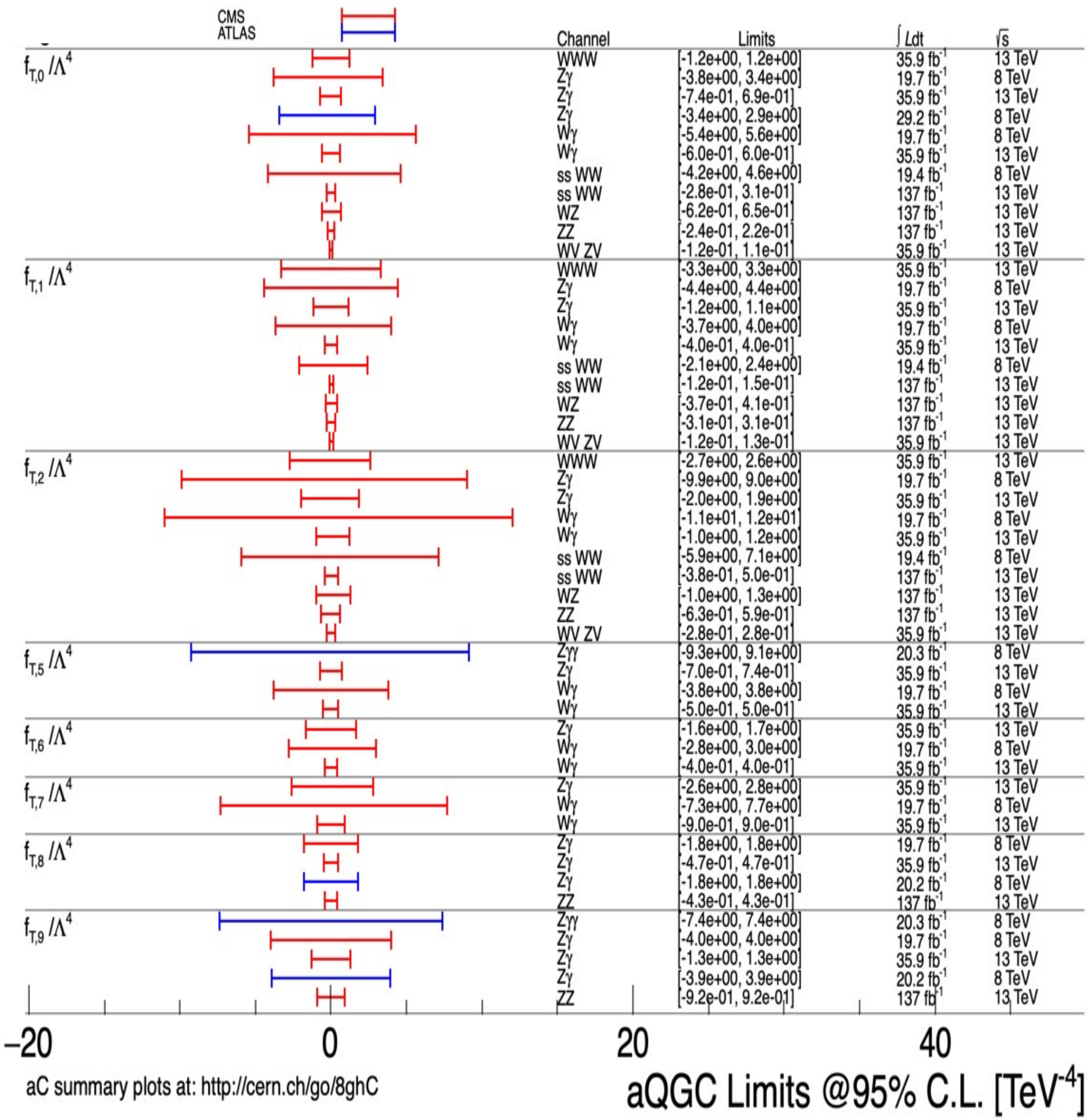


dim-8 M operators



aQGCs summary contd.: dim-8 T and S operators

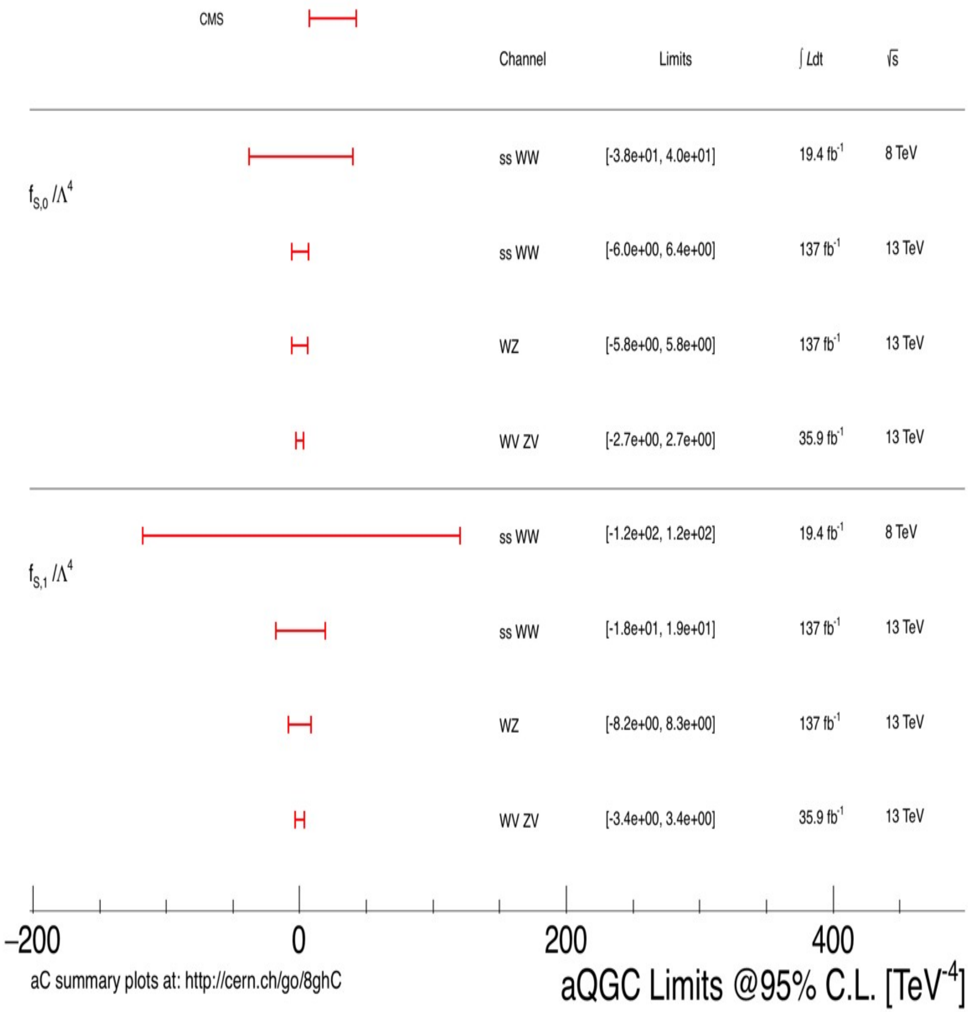
dim-8 T operators



	Channel	Limits	$\int Ldt$	$\sqrt{s}$
$f_{T,0}/\Lambda^4$	WWW	[-1.2e+00, 1.2e+00]	35.9 fb^{-1}	13 TeV
	Zγ	[-3.8e+00, 3.4e+00]	19.7 fb^{-1}	8 TeV
	Zγ	[-7.4e-01, 6.9e-01]	35.9 fb^{-1}	13 TeV
	Zγ	[-3.4e+00, 2.9e+00]	29.2 fb^{-1}	8 TeV
	Wγ	[-5.4e+00, 5.6e+00]	19.7 fb^{-1}	8 TeV
	Wγ	[-6.0e-01, 6.0e-01]	35.9 fb^{-1}	13 TeV
	ss WW	[-4.2e+00, 4.6e+00]	19.4 fb^{-1}	8 TeV
	ss WW	[-2.8e-01, 3.1e-01]	137 fb^{-1}	13 TeV
	WZ	[-6.2e-01, 6.5e-01]	137 fb^{-1}	13 TeV
	ZZ	[-2.4e-01, 2.2e-01]	137 fb^{-1}	13 TeV
	WV ZV	[-1.2e-01, 1.1e-01]	35.9 fb^{-1}	13 TeV
$f_{T,1}/\Lambda^4$	WWW	[-3.3e+00, 3.3e+00]	35.9 fb^{-1}	13 TeV
	Zγ	[-4.4e+00, 4.4e+00]	19.7 fb^{-1}	8 TeV
	Zγ	[-1.2e+00, 1.1e+00]	35.9 fb^{-1}	13 TeV
	Wγ	[-3.7e+00, 4.0e+00]	19.7 fb^{-1}	8 TeV
	Wγ	[-4.0e-01, 4.0e-01]	35.9 fb^{-1}	13 TeV
	ss WW	[-2.1e+00, 2.4e+00]	19.4 fb^{-1}	8 TeV
	ss WW	[-1.2e-01, 1.5e-01]	137 fb^{-1}	13 TeV
	WZ	[-3.7e-01, 4.1e-01]	137 fb^{-1}	13 TeV
	ZZ	[-3.1e-01, 3.1e-01]	137 fb^{-1}	13 TeV
	WV ZV	[-1.2e-01, 1.3e-01]	35.9 fb^{-1}	13 TeV
$f_{T,2}/\Lambda^4$	WWW	[-2.7e+00, 2.6e+00]	35.9 fb^{-1}	13 TeV
	Zγ	[-9.9e+00, 9.0e+00]	19.7 fb^{-1}	8 TeV
	Zγ	[-2.0e+00, 1.9e+00]	35.9 fb^{-1}	13 TeV
	Wγ	[-1.1e+01, 1.2e+01]	19.7 fb^{-1}	8 TeV
	Wγ	[-1.0e+00, 1.2e+00]	35.9 fb^{-1}	13 TeV
	ss WW	[-5.9e+00, 7.1e+00]	19.4 fb^{-1}	8 TeV
	ss WW	[-3.8e-01, 5.0e-01]	137 fb^{-1}	13 TeV
	WZ	[-1.0e+00, 1.3e+00]	137 fb^{-1}	13 TeV
	ZZ	[-6.3e-01, 5.9e-01]	137 fb^{-1}	13 TeV
	WV ZV	[-2.8e-01, 2.8e-01]	35.9 fb^{-1}	13 TeV
$f_{T,5}/\Lambda^4$	Zγγ	[-9.3e+00, 9.1e+00]	20.3 fb^{-1}	8 TeV
	Zγ	[-7.0e-01, 7.4e-01]	35.9 fb^{-1}	13 TeV
	Wγ	[-3.8e+00, 3.8e+00]	19.7 fb^{-1}	8 TeV
	Wγ	[-5.0e-01, 5.0e-01]	35.9 fb^{-1}	13 TeV
$f_{T,6}/\Lambda^4$	Zγ	[-1.6e+00, 1.7e+00]	35.9 fb^{-1}	13 TeV
	Wγ	[-2.8e+00, 3.0e+00]	19.7 fb^{-1}	8 TeV
	Wγ	[-4.0e-01, 4.0e-01]	35.9 fb^{-1}	13 TeV
$f_{T,7}/\Lambda^4$	Zγ	[-2.6e+00, 2.8e+00]	35.9 fb^{-1}	13 TeV
	Wγ	[-7.3e+00, 7.7e+00]	19.7 fb^{-1}	8 TeV
	Wγ	[-9.0e-01, 9.0e-01]	35.9 fb^{-1}	13 TeV
$f_{T,8}/\Lambda^4$	Zγ	[-1.8e+00, 1.8e+00]	19.7 fb^{-1}	8 TeV
	Zγ	[-4.7e-01, 4.7e-01]	35.9 fb^{-1}	13 TeV
	Zγ	[-1.8e+00, 1.8e+00]	20.2 fb^{-1}	8 TeV
	ZZ	[-4.3e-01, 4.3e-01]	137 fb^{-1}	13 TeV
$f_{T,9}/\Lambda^4$	Zγγ	[-7.4e+00, 7.4e+00]	20.3 fb^{-1}	8 TeV
	Zγ	[-4.0e+00, 4.0e+00]	19.7 fb^{-1}	8 TeV
	Zγ	[-1.3e+00, 1.3e+00]	35.9 fb^{-1}	13 TeV
	Zγ	[-3.9e+00, 3.9e+00]	20.2 fb^{-1}	8 TeV
	ZZ	[-9.2e-01, 9.2e-01]	137 fb^{-1}	13 TeV

aC summary plots at: http://cern.ch/go/8ghC

dim-8 S operators



	Channel	Limits	$\int Ldt$	$\sqrt{s}$
$f_{S,0}/\Lambda^4$	ss WW	[-3.8e+01, 4.0e+01]	19.4 fb^{-1}	8 TeV
	ss WW	[-6.0e+00, 6.4e+00]	137 fb^{-1}	13 TeV
	WZ	[-5.8e+00, 5.8e+00]	137 fb^{-1}	13 TeV
	WV ZV	[-2.7e+00, 2.7e+00]	35.9 fb^{-1}	13 TeV
$f_{S,1}/\Lambda^4$	ss WW	[-1.2e+02, 1.2e+02]	19.4 fb^{-1}	8 TeV
	ss WW	[-1.8e+01, 1.9e+01]	137 fb^{-1}	13 TeV
	WZ	[-8.2e+00, 8.3e+00]	137 fb^{-1}	13 TeV
	WV ZV	[-3.4e+00, 3.4e+00]	35.9 fb^{-1}	13 TeV

aC summary plots at: http://cern.ch/go/8ghC

CMS results @ 13 TeV – triboson production

WWW *PRD 100 (2019) 012004* 36/fb

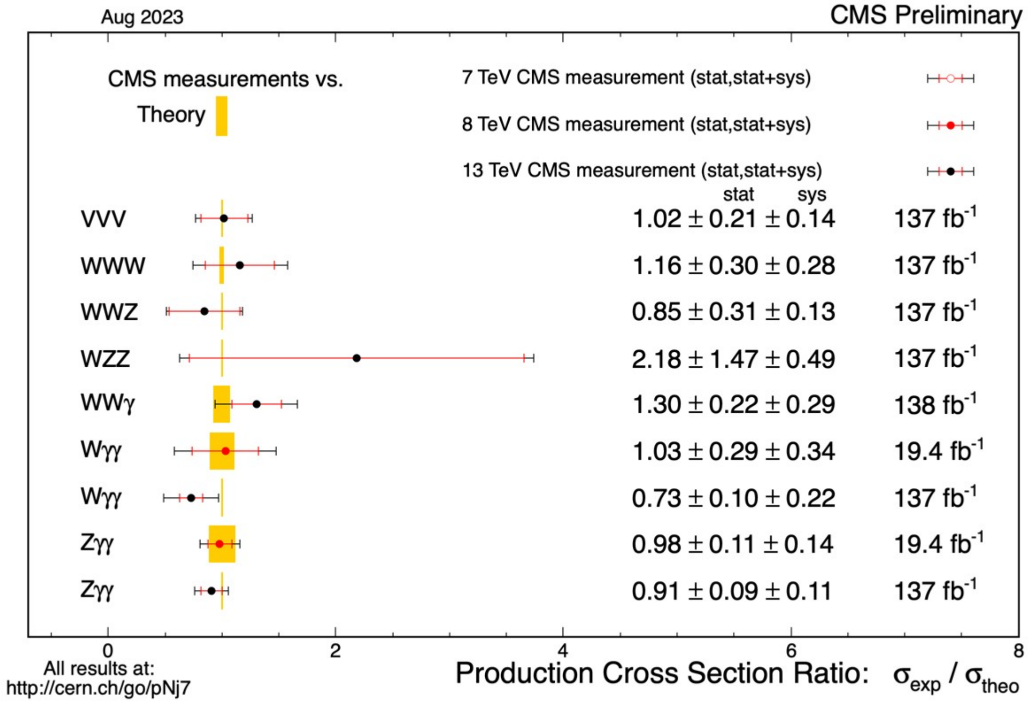
WWW, WWZ, WZZ, ZZZ

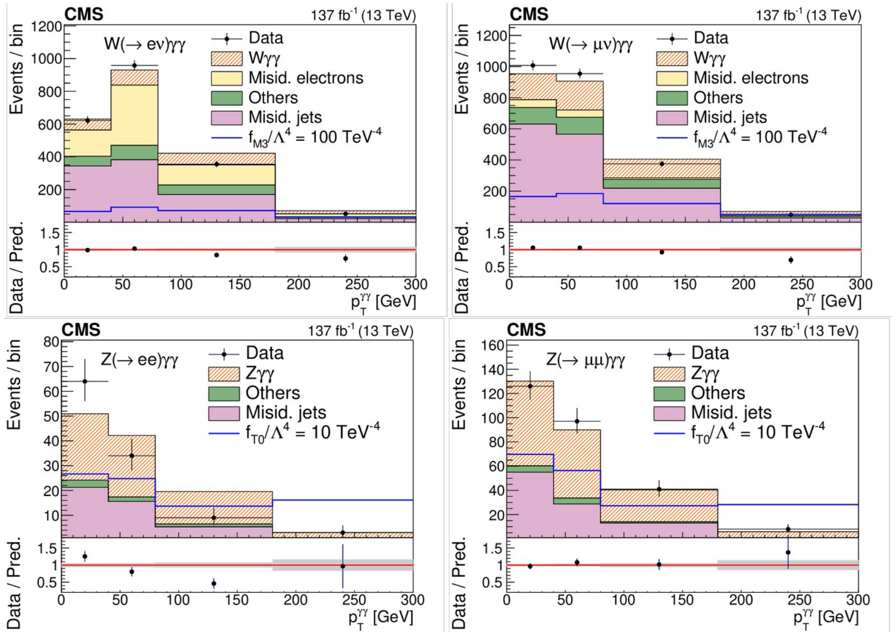
PRL 125 (2020) 151802 137/fb

5 sigma observation (total), total cross sections, limits on aQGCs (WWW)

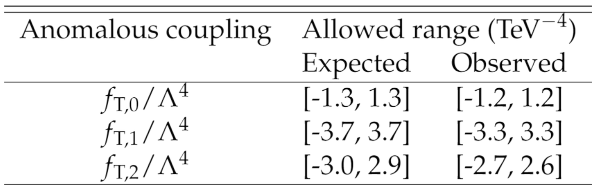
Wγγ, Zγγ *JHEP 10 (2021) 174* 137/fb

3.1 & 4.8 sigma evidence, total cross sections, limits on aQGCs

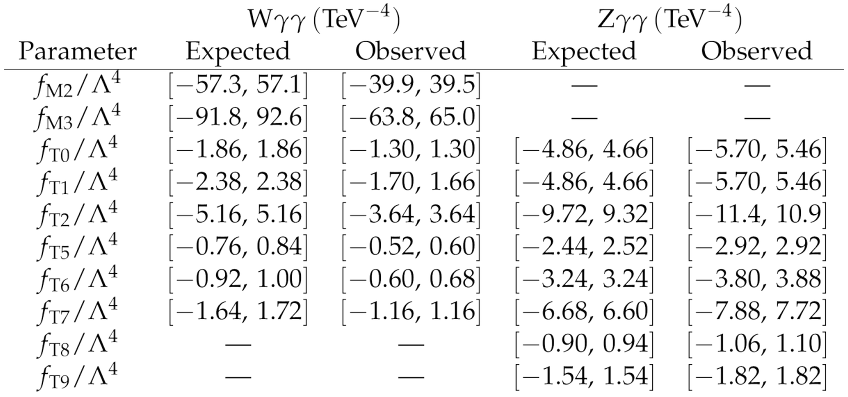




WWW



Anomalous coupling	Allowed range (TeV^{-4})	
	Expected	Observed
$f_{T,0}/\Lambda^4$	[-1.3, 1.3]	[-1.2, 1.2]
$f_{T,1}/\Lambda^4$	[-3.7, 3.7]	[-3.3, 3.3]
$f_{T,2}/\Lambda^4$	[-3.0, 2.9]	[-2.7, 2.6]

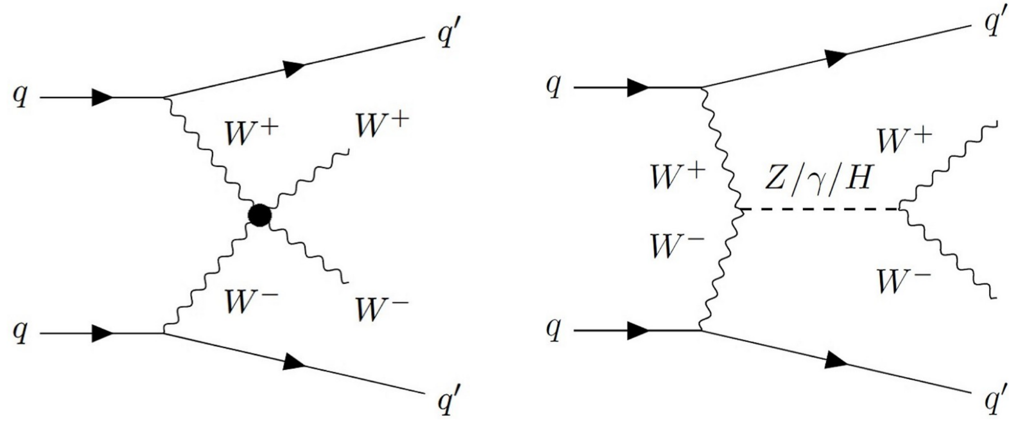


	$W\gamma\gamma$ (TeV^{-4})		$Z\gamma\gamma$ (TeV^{-4})	
Parameter	Expected	Observed	Expected	Observed
f_{M2}/Λ^4	$[-57.3, 57.1]$	$[-39.9, 39.5]$	—	—
f_{M3}/Λ^4	$[-91.8, 92.6]$	$[-63.8, 65.0]$	—	—
f_{T0}/Λ^4	$[-1.86, 1.86]$	$[-1.30, 1.30]$	$[-4.86, 4.66]$	$[-5.70, 5.46]$
f_{T1}/Λ^4	$[-2.38, 2.38]$	$[-1.70, 1.66]$	$[-4.86, 4.66]$	$[-5.70, 5.46]$
f_{T2}/Λ^4	$[-5.16, 5.16]$	$[-3.64, 3.64]$	$[-9.72, 9.32]$	$[-11.4, 10.9]$
f_{T5}/Λ^4	$[-0.76, 0.84]$	$[-0.52, 0.60]$	$[-2.44, 2.52]$	$[-2.92, 2.92]$
f_{T6}/Λ^4	$[-0.92, 1.00]$	$[-0.60, 0.68]$	$[-3.24, 3.24]$	$[-3.80, 3.88]$
f_{T7}/Λ^4	$[-1.64, 1.72]$	$[-1.16, 1.16]$	$[-6.68, 6.60]$	$[-7.88, 7.72]$
f_{T8}/Λ^4	—	—	$[-0.90, 0.94]$	$[-1.06, 1.10]$
f_{T9}/Λ^4	—	—	$[-1.54, 1.54]$	$[-1.82, 1.82]$

What’s new at this time:
latest results, updates and followups

VBS: osWW first observation

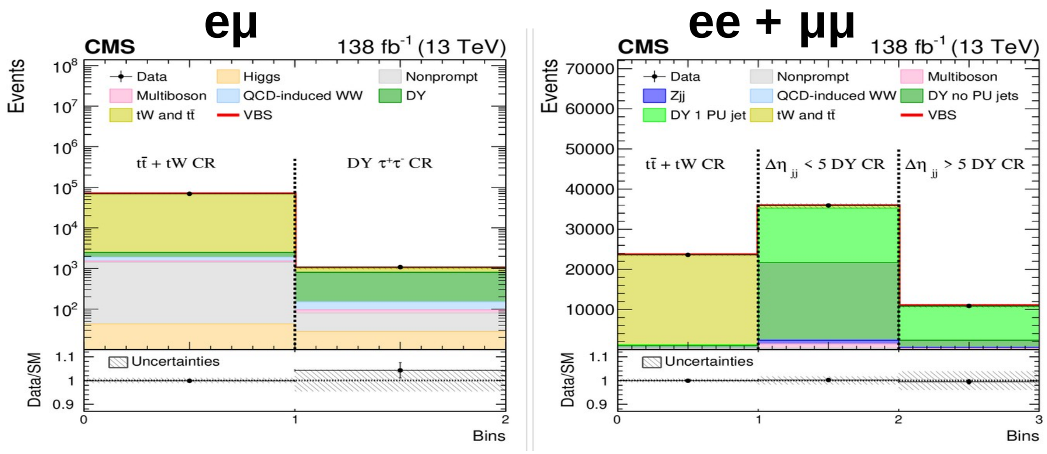
PLB 841 (2023) 137495
arXiv:2205.05711



Objects	Requirements
Leptons	eμ, ee, μμ (not from τ decay), opposite charge $p_T^{\text{dressed}\,\ell} = p_T^{\ell} + \sum_i p_T^{\gamma_i}$ if $\Delta R(\ell, \gamma_i) < 0.1$ $p_T^{\ell_1} > 25\,\text{GeV}$, $p_T^{\ell_2} > 13\,\text{GeV}$, $p_T^{\ell_3} < 10\,\text{GeV}$ $\lvert\eta\rvert < 2.5$ $p_T^{\ell\ell} > 30\,\text{GeV}$, $m_{\ell\ell} > 50\,\text{GeV}$
Jets	$p_T^{j} > 30\,\text{GeV}$ $\Delta R(j, \ell) > 0.4$ At least 2 jets, no b jets $\lvert\eta\rvert < 4.7$ $m_{jj} > 300\,\text{GeV}$, $\lvert\Delta\eta_{jj}\rvert > 2.5$
p_T^{miss}	$p_T^{\text{miss}} > 20\,\text{GeV}$

- DNN employed (eμ) to deal with dominant backgrounds: QCD induced WW, top production, DY. Kinematic inputs: m_{jj}, p_T^{j1}, $|\Delta\eta_{jj}|$, p_T^{j2}, Z_{l2}, p_T^{ll}, $\Delta\varphi_{ll}$, Z_{l1}, m_T^{l1}.

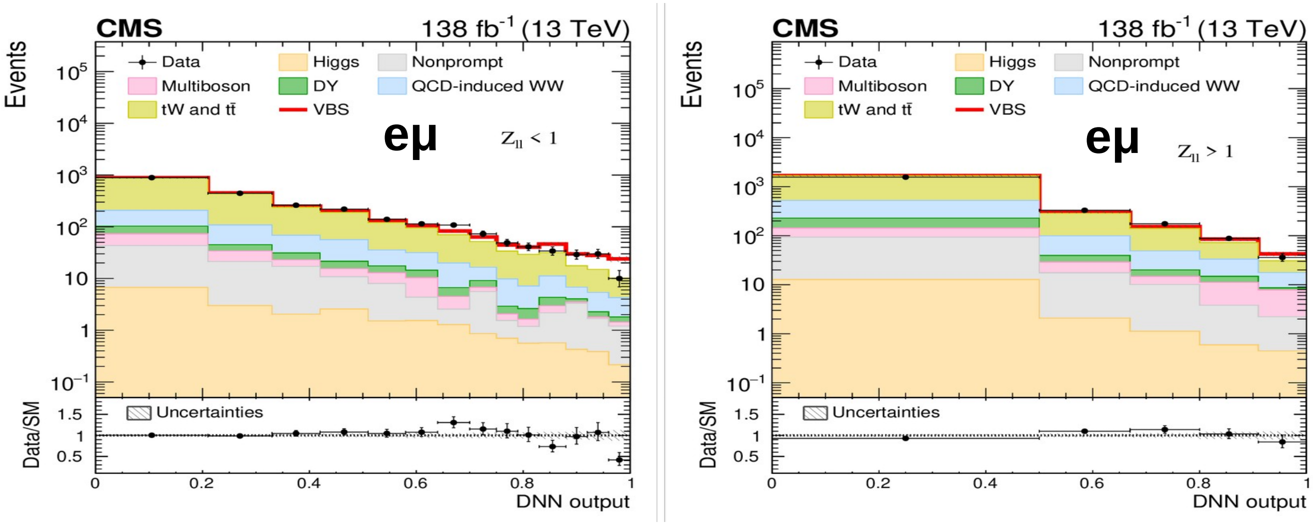
- Data driven background normalization techniques (top, DY), simultaneous fit to the data including background dominated control regions (CRs).



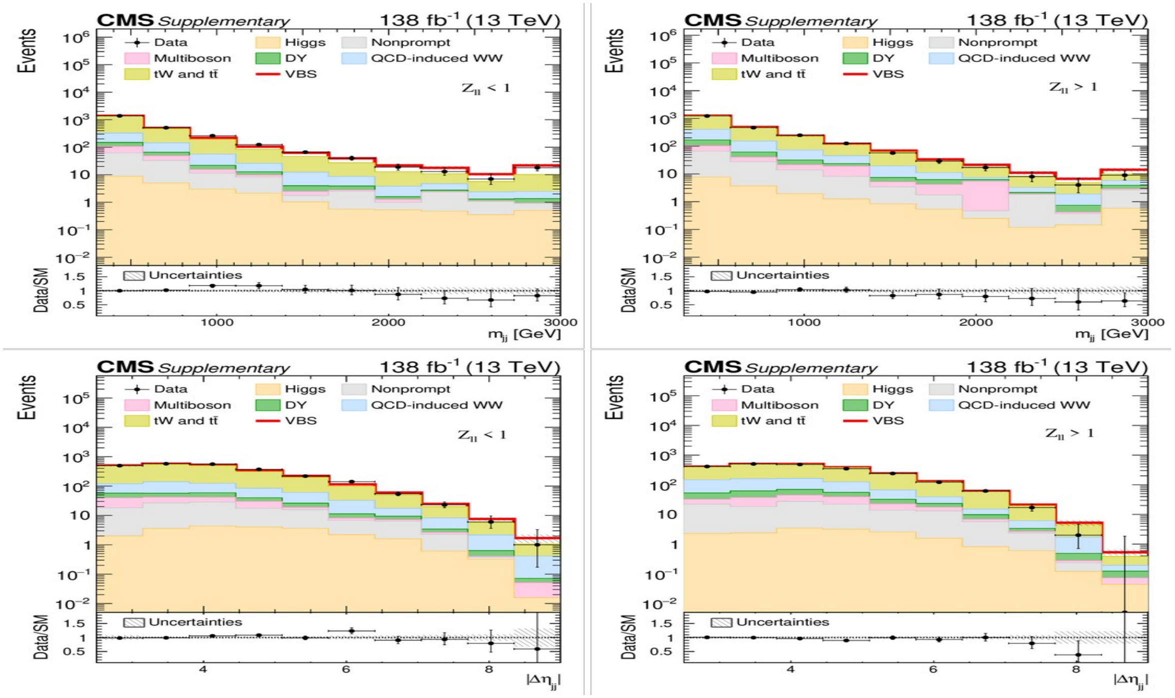
top CR: inverted b veto,
DY eμ CR: m_T inverted (< 60 GeV),
50 < m_{ll} < 80 GeV,
DY ee, μμ CR: $|m_{ll}-m_Z|$ < 15 GeV.

VBS: osWW first observation

- Observed (expected) signal significance of **5.6 sigma (5.2 sigma)**



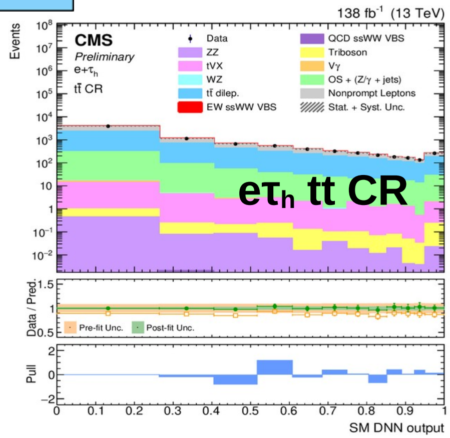
$Z_{ll} = |Z_{l1}+Z_{l2}|/2$

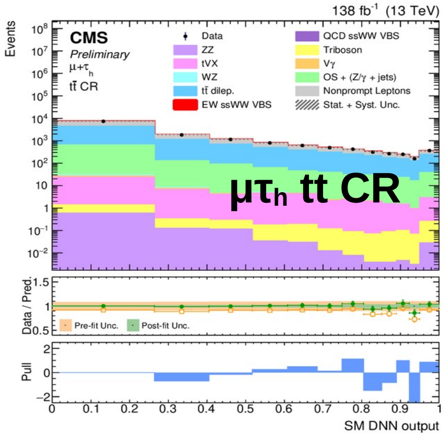


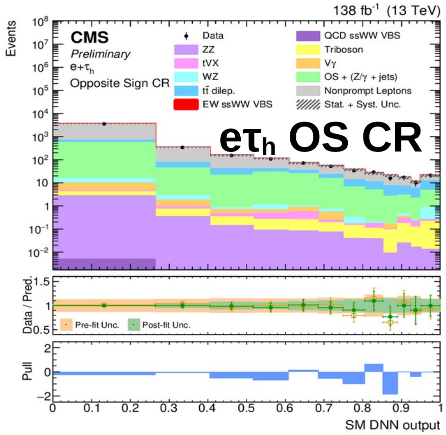
- Fiducial cross section:
  σ = 10.2 ± 2.0 fb,
  (SM: 9.1 ± 0.6 fb),

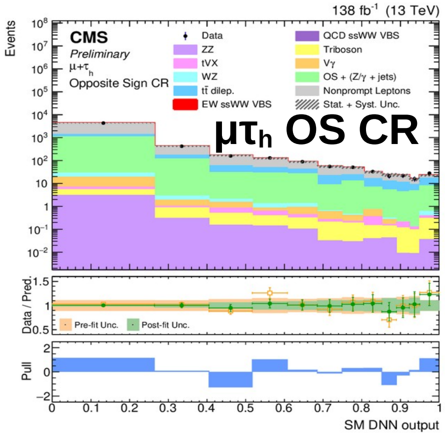
- Inclusive cross section
  ($p_T{}^q$ >10 GeV, m_{qq} > 100 GeV):
  σ = 99 ± 20 fb,
  (SM: 89 ± 5 fb).

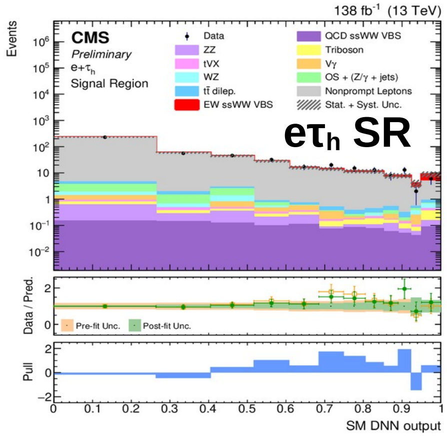
VBS: ssWW with 1τ in the final state

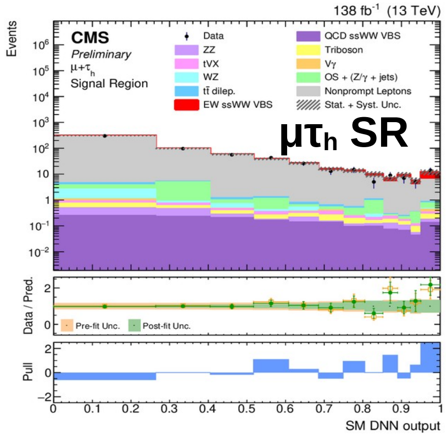












CMS-PAS-SMP-22-008
Preliminary

- VBS topology
- One hadronic τ + 1 light lepton
- DNN applied to identify hadronic taus, kinematic inputs: m_{jj}, $m_T(l, p_T^{miss})$, p_T^{j1}, p_T^{j2}, p_T^{τ}, p_T^{l},

$$M_{1T}^2 = \left(\sqrt{M_{\tau l}^2 + p_T^{\tau l\,2}} + p_T^{\mathrm{miss}}\right)^2 - \left|\vec{p_T}^{\,\tau l} + \vec{p}_T^{\mathrm{miss}}\right|^2,$$

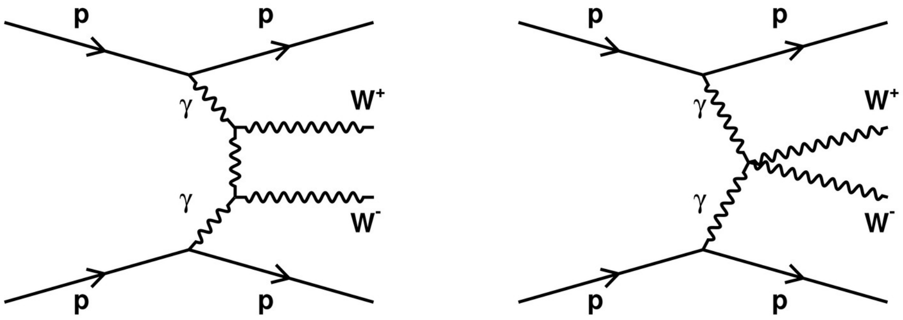
$$M_{o1}^2 = \left(p_T^{\tau} + p_T^{l} + p_T^{\mathrm{miss}}\right)^2 - \left|\vec{p_T}^{\,\tau} + \vec{p_T}^{\,l} + \vec{p}_T^{\mathrm{miss}}\right|^2.$$

- Data driven determination of non-prompt background
- Simultaneous fit to SR and CRs:
  OS CR: as SR but opposite sign,
  tt CR: OS and b veto reversed
- Observed (expected) signal significance: 2.7 (1.9) sigma.

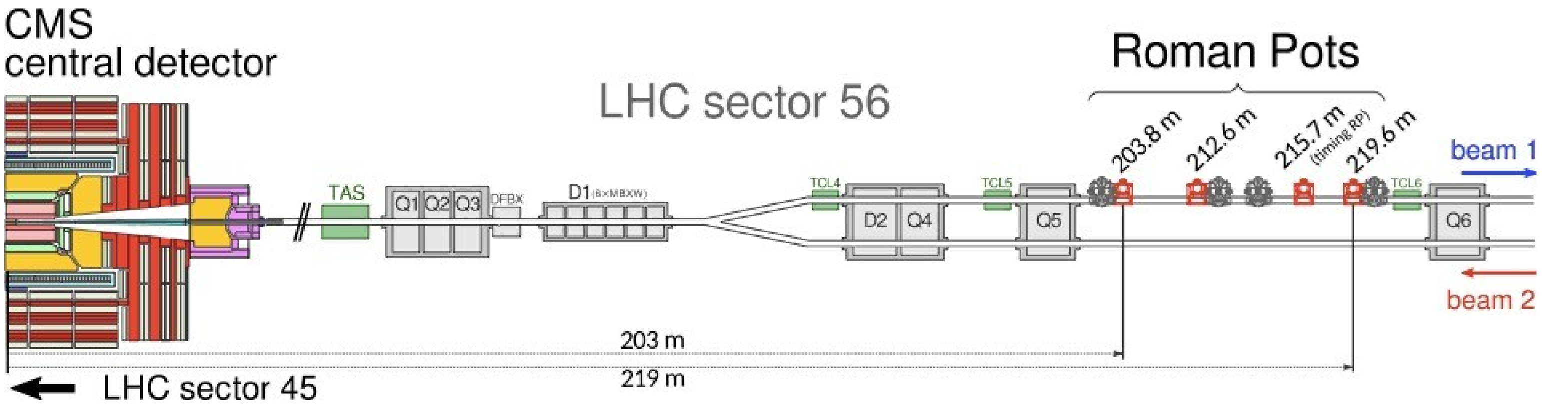
aQGC: exclusive $\gamma\gamma \rightarrow WW, ZZ$

JHEP 07 (2023) 229
arXiv:2211.16320

- Look for intact forward protons reconstructed in near-beam detector (Precision Proton Spectrometer) + 2 weak bosons decaying into boosted and merged jets.



Unique opportunity to independently study quartic vertices: WWγγ and ZZγγ (anomalous)

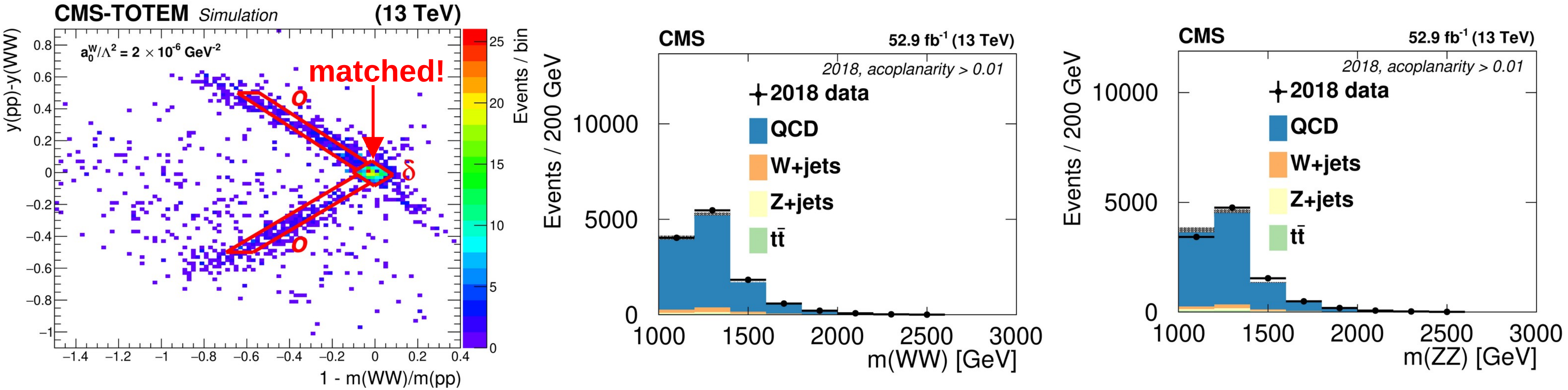


- The PPS allows to reconstruct the proton scattering angle and fractional momentum loss.

- N-subjettiness used to identify hadronic W and Z from QCD jets.
  Signal selection: $p_T^j > 200$ GeV, $m_{jj} > 1126$ GeV, $|\Delta\eta_{jj}| > 1.3$,
  acoplanarity requirement: $a = |1- |(\varphi_{j1} - \varphi_{j2})|/\pi| < 0.01$, $p_T^{j1}/p_T^{j2} < 1.3$

aQGC: exclusive γγ → WW, ZZ

- Matching protons to jets is based on respective rapidities and invariant masses



- Background: jets combined with unrelated protons from pileup, estimated from CRs defined by inverting acoplanarity and/or proton matching criteria.

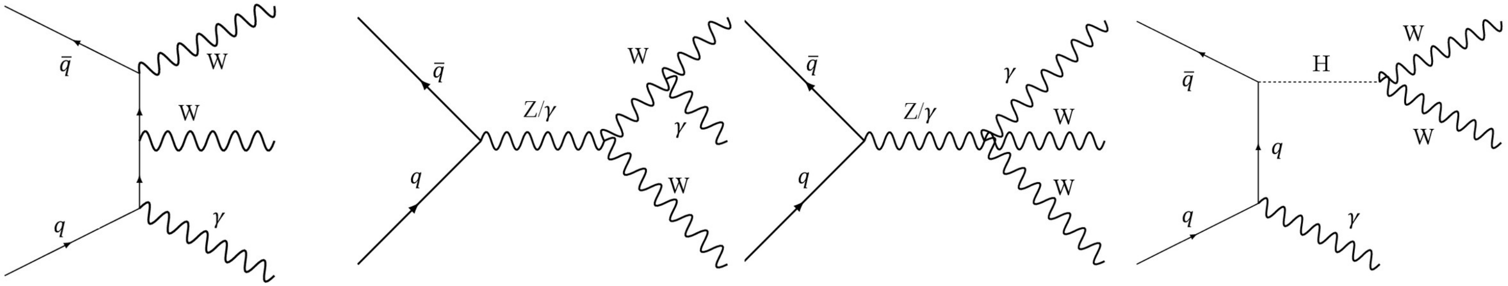
- Cross sections upper limits at 95% CL: **σ(pp → pWWp) < 67 fb, σ(pp → pZZp) < 43 fb**.

- Limits on SMEFT dim-8 operators

Coupling	Observed (expected) 95% CL upper limit No clipping	Observed (expected) 95% CL upper limit Clipping at 1.4 TeV
$\lvert f_{M,0}/\Lambda^4 \rvert$	66.0 (60.0) TeV^{-4}	79.8 (78.2) TeV^{-4}
$\lvert f_{M,1}/\Lambda^4 \rvert$	245.5 (214.8) TeV^{-4}	306.8 (306.8) TeV^{-4}
$\lvert f_{M,2}/\Lambda^4 \rvert$	9.8 (9.0) TeV^{-4}	11.9 (11.8) TeV^{-4}
$\lvert f_{M,3}/\Lambda^4 \rvert$	73.0 (64.6) TeV^{-4}	91.3 (92.3) TeV^{-4}
$\lvert f_{M,4}/\Lambda^4 \rvert$	36.0 (32.9) TeV^{-4}	43.5 (42.9) TeV^{-4}
$\lvert f_{M,5}/\Lambda^4 \rvert$	67.0 (58.9) TeV^{-4}	83.7 (84.1) TeV^{-4}
$\lvert f_{M,7}/\Lambda^4 \rvert$	490.9 (429.6) TeV^{-4}	613.7 (613.7) TeV^{-4}

Triboson: WWγ

arXiv:2310.05164
submitted to PRL



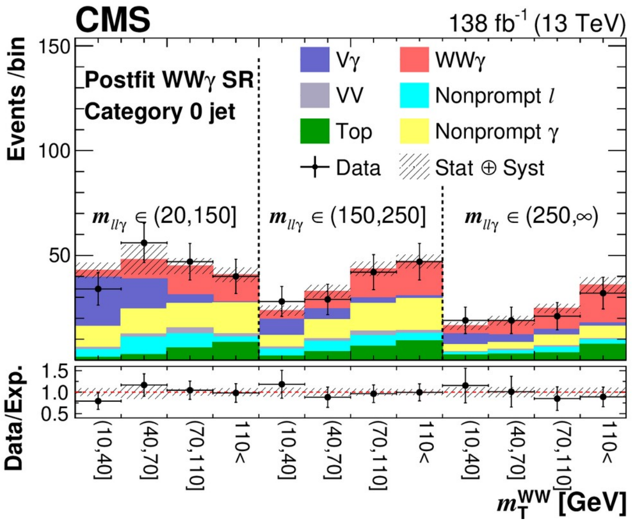
- Probes triple WWγ vertex, quartic vertices WWγγ & WWZγ

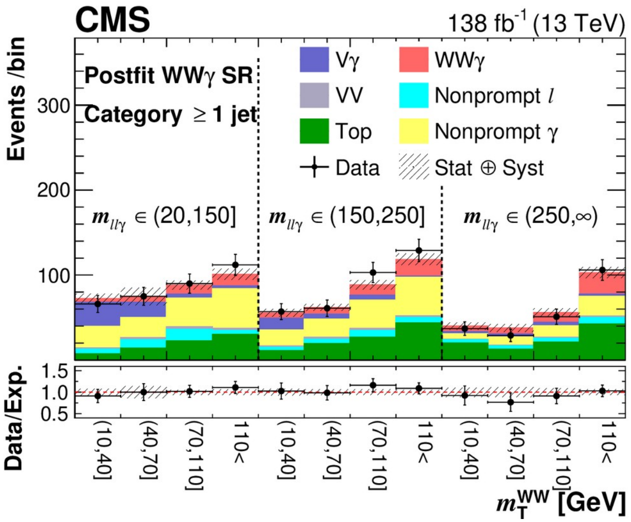
- Exactly two isolated opposite sign leptons ($e^+\mu^-$, $e^-\mu^+$) + photon
  $p_T^{miss} > 20$ GeV, $m_{ll} > 10$ GeV, $p_T^{ll} > 15$ GeV, $m_T^W > 10$ GeV

- Simultaneous fit with CRs: ss WWγ CR (non-prompt background): same sign & no m_T^W cut,
  Top-γ CR (top production): b veto inverted & no m_T^W cut.

- Observed (expected) signal significance: **5.6 (4.7) sigma**.

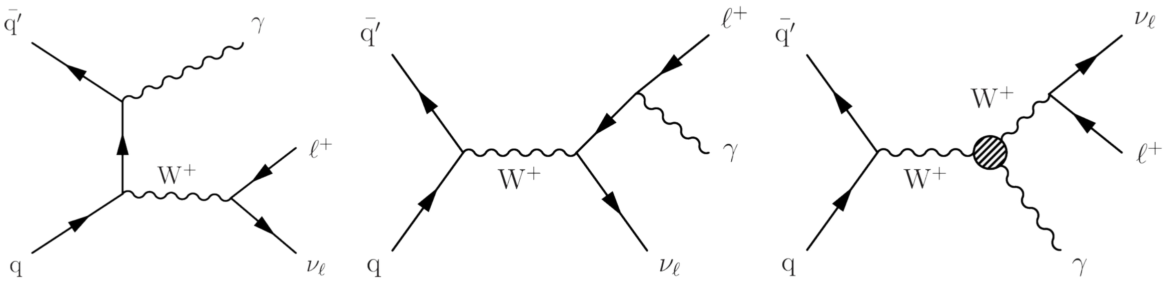
- Fiducial cross section: **$\sigma = 6.0 \pm 1.7$ fb**, in agreement with SM (NLO QCD).





Diboson: Wγ

PRD 105 (2022) 052003
arXiv:2111.13948



Probes WWγ vertex, potential aTGC contributions from dim-6 operator c_{3W}

- The interference issue of EFT

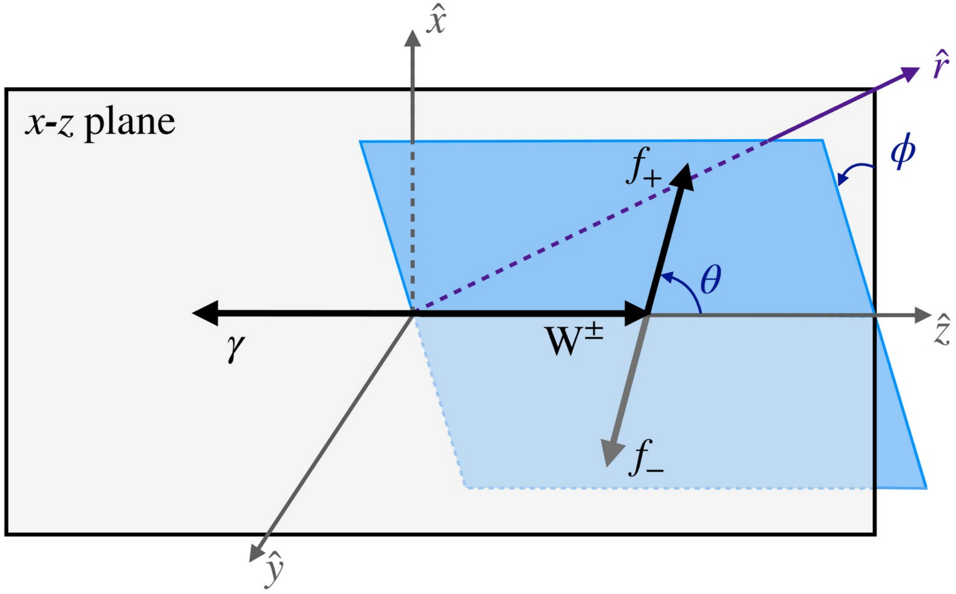
$$\sigma \propto |A_{full}|^2 = |A_{SM}|^2 + \underbrace{(A_{SM}A^*_{dim-6} + hc)}_{\sim \frac{c}{\Lambda^2}} + \underbrace{|A_{dim-6}|^2}_{\sim \frac{c^2}{\Lambda^4}}$$

same order in Λ as dim-8!

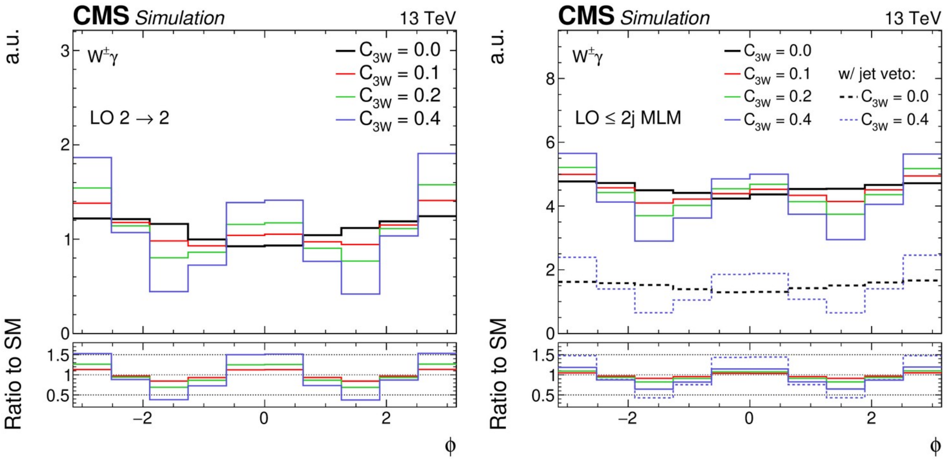
- EFT fact: we naturally expect results being driven by the interference term, otherwise it is not justified to truncate the expansion at dim-6.

- "Interference resurrection" achieved by looking at azimuthal angle φ between the +ve helicity lepton (l^+ or anti-ν) in the Wγ c.o.m. frame (*arXiv:1901.04821*).

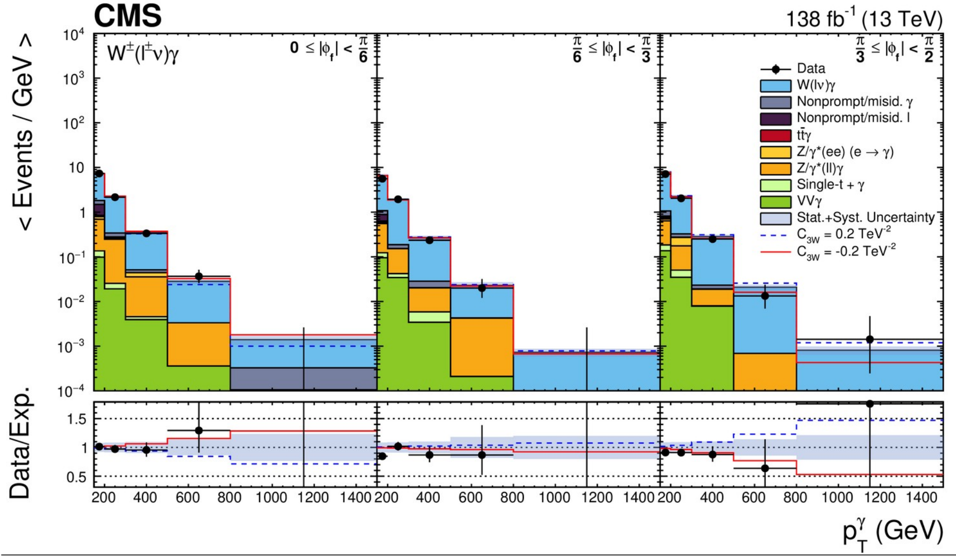
Here $\hat{y} = \hat{z}$ x $\hat{r}$,
$\hat{r}$ – direction of Lorentz boost to the c.o.m. frame



Diboson: Wγ

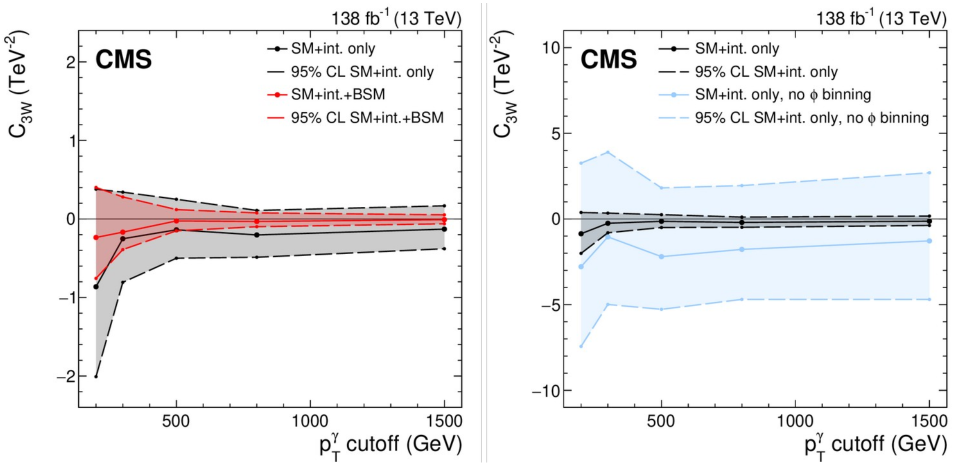


- The effects of SM-BSM interference show up in the distribution of φ.
- Limits on c_{3W} calculated using SM+int. only become an order of magnitude more stringent by measuring φ and much closer to limits calculated using SM+int.+BSM



				$\sigma(\mathrm{fb})$				
Number of jets	Best fit	Stat	Syst	MG5_aMC+PY8	MATRIX	MCFM	MCFM (EW)	GENEVA
$=0$	1400^{+71}_{-67}	$^{+11}_{-11}$	$^{+70}_{-67}$	1650 ± 110	1473 ± 19	1544 ± 18	1471 ± 18	1584 ± 26
$=1$	1246^{+61}_{-58}	$^{+11}_{-11}$	$^{+60}_{-57}$	1590 ± 120	1304 ± 64	1397 ± 62	1376 ± 62	1490 ± 110
≥ 2	1037^{+78}_{-79}	$^{+10}_{-10}$	$^{+77}_{-78}$	820 ± 120	950 ± 260	990 ± 270	950 ± 270	790 ± 140

p_T^γ cutoff (GeV)	Best fit C_{3W} (TeV^{-2})		Observed 95% CL (TeV^{-2})		Expected 95% CL (TeV^{-2})	
	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]



Outlook

- Run 2 has produced a lot of results from the EW gauge sector, including:
  - diboson production cross sections WW, WZ, ZZ, Wγ, WV,
  - limits on anomalous triple couplings, including ZZZ (non-SM),
  - electroweak diboson (VBS) cross sections ssWW, WZ, ZZ, Wγ, Zγ, WV+ZV, osWW
  - study of quartic gauge couplings – limits have been put on all 18 relevant SMEFT dim-8 operators,
  - triboson production cross sections VVV, Wγγ, Zγγ, WWγ, and complementary check of quartic gauge couplings.

- The Standard Model is well.

- But we are only warming up for more data: Run 3 analyses are on the way and we look forward to Phase 2.

- We will benefit from additional statistics and we expect a lot of improvement in the EFT interpretation of the data.

- The most interesting results are yet to come!