Probing p p→WWW production and anomalous quartic gauge couplings at CERN LHC and future collider

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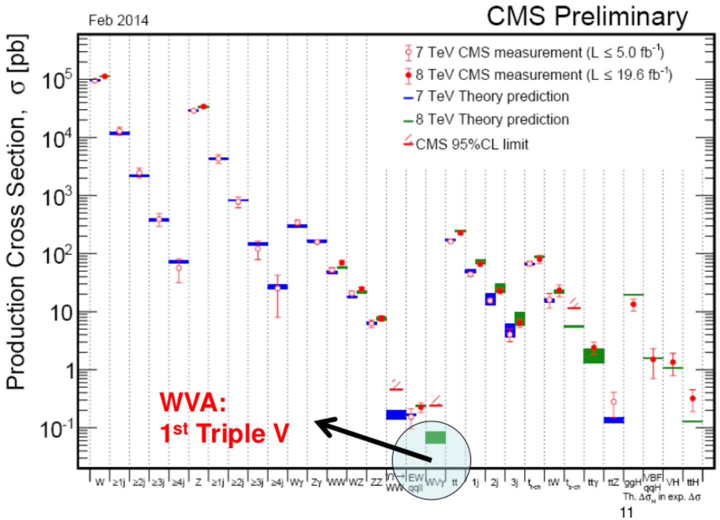
ElectroWeak Physics at the LHC

Physics goals

1. Precise measurement of electroweak(EW) parameters.
2. Gauge-boson self-interactions. (anomalous quartic couplings in this talk)
3. Spontaneouly symmetry breaking mechanism

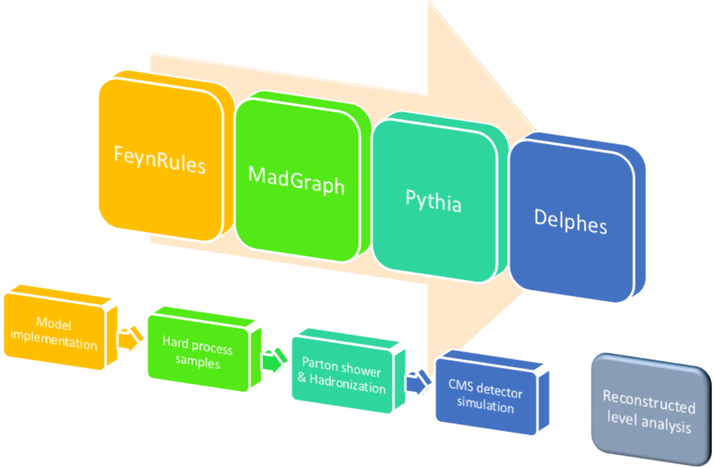
In this work, we present the Monte-Carlo feasibility study of measuring WWW production, with pure leptonic decays and semileptonic decays, and then related WWW anomalous couplings.

CMS results for gauge boson production cross sections

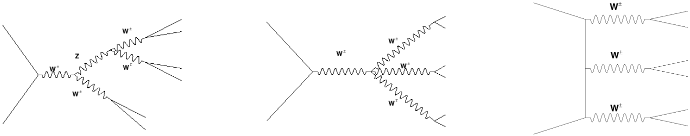


CMS-PAS-SMP-12-006; arXiv:1404.4619

Simulation framework



Signal and backgrounds



(a) With TGC (b) With (anomalous) QGC (c) QED Radiations from WW

- ⋆ 3 leptons and MET final state.
- ⋆ main backgrounds are: WZ, $t\bar{t}W$, ZZ, $t\bar{t}Z$, WWZ.

Event selection

Cut-based method:

1. Exactly 3 leptons, $P_T > 15\text{GeV}, \eta < 2.4$
2. MET>50GeV (25 in 14TeV LHC)
3. Veto b-jet $P_t > 50$ GeV
4. 2 schemes of leptons selection, more about this later
5. $M_{ll} > 12\text{GeV}$
6. Transverse Mass MT>200GeV
7. R_{lj}, $R_{ll} > 0.5$
8. leading lepton $P_T > 35\text{GeV}$

Note that:

$$MT = \sqrt{(\sqrt{{Pt_{lll}}^2 + {m_{lll}}^2} + \sqrt{MET^2 + {m_{lll}}^2})^2 - (\overrightarrow{Pt_{lll}} + \overrightarrow{MET})^2}$$

Scheme 1

Using 2 different analysis scripts, only cut 4 is different.

Scheme 1

In order to suppress backgrounds which contains Z boson. Requiring mass difference between the invariant mass of the same flavor opposite sign lepton pairs and mass of Z is larger than 15 GeV.

Namely, $|Mll_{SFOS} - M_z| > 15 GeV$

Scheme 2

Scheme 2

Class 2 types of lepton combination

Type 1: 3 electrons, 3 muons, mu+ mu- e, e+ e- mu

Type 2: mu+(-) mu+(-) e, e+(-) e+(-) mu

veto the Type 1 event since only the *WWW* process contains Type 2 event topology.

14 TeV LHC(simulated with CMS)

	XS[fb]	Events						
		cut-based						BDT
		Pileup 0		Pileup 50		Pileup 140		Pileup 0
		s1	s2	s1	s2	s1	s2	s1
WWW	2.1	20.9	6.2	19	5.8	17	5.1	20
WZ	411	421	6.8	428	6.7	397	6.5	337
$t\bar{t}W$	9.8	33	10.3	38	11	38	11	56
ZZ	272	40	1.0	98	1.6	106	2.7	32
$t\bar{t}Z$	6.3	10	2.7	12	3.4	13	3.6	18
WWZ	0.8	3.7	1.0	3.0	1.0	3.5	0.94	3.2
significance		0.92	1.2	0.82	1.1	0.75	0.98	0.94

Table: Cut flow at the LHC with $\sqrt{s} = 14$ TeV and integrated luminosity of 100 fb^{-1}.

100 TeV future collider (simulated with "Snowmass" detector)results

	XS[fb]	Events			
		cut-based			
		Pileup 50		Pileup 140	
		s1	s2	s1	s2
WWW	15.61	4758	1416	3855	1156
WZ	2570	92185	1670	82060	1696
$t\bar{t}W$	89.66	8607	2539	9930	3211
ZZ	2674	26633	481	24226	1283
$t\bar{t}Z$	453.6	15240	4408	18180	5034
WWZ	14.13	1164	317	993	255
significance		12.54	14.59	10.47	10.79

Table: Cut flow at future p p collider with $\sqrt{s} = 100$ TeV and integrated luminosity of 3000 fb^{-1}.

Effective field theory(EFT)

- ⋆ Construct the effective Lagrangian of aQGC in a model independent way
- ⋆ Still assuming the new physics keeps $SU(2)_L \otimes U(1)_Y$
- ⋆ The Lagrangian can be expressed in non-linear or linear representation
- ⋆ Since a Higgs was discovered, the linear one is more preferable.
- ⋆ The lowest order of genuine linear representation EFT operator is dimension 8.
- ⋆ The Lagrangian we are interested

$$\mathcal{L} = \mathcal{L}_{SM} + \frac{f_j}{\Lambda^4}\mathcal{O}_j$$

$\mathcal{L}_{S,0}$, $\mathcal{L}_{S,1}$ and $\mathcal{L}_{T,0}$

Operators affect the *WWWW* vertice:

$$\mathcal{L}_{S,0} = \frac{f_{S0}}{\Lambda^4}[(D_\mu\Phi)^\dagger D_\nu\Phi] \times [(D^\mu\Phi)^\dagger D^\nu\Phi]$$

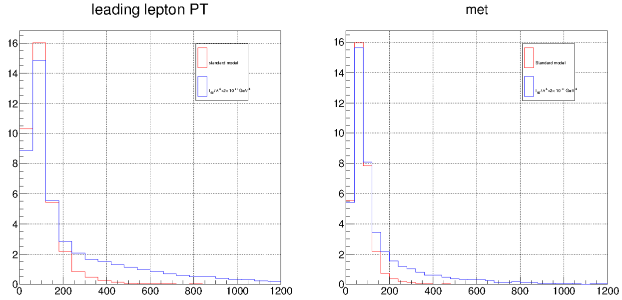
$$\mathcal{L}_{S,1} = \frac{f_{S1}}{\Lambda^4}[(D_\mu\Phi)^\dagger D^\mu\Phi] \times [(D_\nu\Phi)^\dagger D^\nu\Phi]$$

$$\mathcal{L}_{T,0} = \frac{f_{T0}}{\Lambda^4}\mathrm{Tr}[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}] \times \mathrm{Tr}[\hat{W}_{\alpha\beta}\hat{W}^{\alpha\beta}]$$

Where Φ is the Higgs doublet, $D_\mu\Phi = (\partial_\mu - igW^j_\mu\frac{\sigma^j}{2} - ig'B_\mu\frac{1}{2})\Phi$ and $\hat{W}_{\mu\nu} \equiv \sum_j W^j_{\mu\nu}\frac{\sigma^j}{2}$. And $W^i_{\mu\nu}$ is the $SU(2)_L$ field strength and $B_{\mu\nu}$ is the $U(1)_Y$ one.

arXiv:hep-ph/0606118

aQGC event selection



The aQGCs lead to excesses on hard tails. Modify selection cuts to separate the aQGC

1. (1) $met > 350\text{GeV}$.
2. (2) $M_T > 1000$ GeV.
3. (3) leading lepton $P_T > 200$ GeV.

Results

⋆ The constraints on aQGC couplings are at 95%CL in 14 TeV LHC with 100 fb^{-1}

Scheme 1:

$$-1.78\times 10^{-10}\text{GeV}^{-4} < f_{S0}/\Lambda^4 < 1.79\times 10^{-10}\text{GeV}^{-4}, \quad (1)$$
$$-2.66\times 10^{-10}\text{GeV}^{-4} < f_{S1}/\Lambda^4 < 2.78\times 10^{-10}\text{GeV}^{-4}, \quad (2)$$
$$-5.80\times 10^{-13}\text{GeV}^{-4} < f_{T0}/\Lambda^4 < 5.87\times 10^{-13}\text{GeV}^{-4}, \quad (3)$$

Scheme 2:

$$-1.9\times 10^{-10}\text{GeV}^{-4} < f_{S0}/\Lambda^4 < 1.75\times 10^{-10}\text{GeV}^{-4}, \quad (4)$$
$$-2.64\times 10^{-10}\text{GeV}^{-4} < f_{S1}/\Lambda^4 < 2.90\times 10^{-10}\text{GeV}^{-4}, \quad (5)$$
$$-6.02\times 10^{-13}\text{GeV}^{-4} < f_{T0}/\Lambda^4 < 6.06\times 10^{-13}\text{GeV}^{-4}, \quad (6)$$

Comparison

	WWW 95% CL 100 fb^{-1}	†VBF WW 99%CL 100fb^{-1}	‡ Snowmass 5σ 300fb^{-1}
$\frac{f_{S0}}{\Lambda^4}$ [GeV^{-4}]	1.8×10^{-10}	2.4×10^{-11}	-
$\frac{f_{S1}}{\Lambda^4}$ [GeV^{-4}]	2.7×10^{-10}	2.5×10^{-11}	-
$\frac{f_{T0}}{\Lambda^4}$ [GeV^{-4}]	§ 5.8×10^{-13}	-	1.2×10^{-12}

Table: Constraints on aQGC parameter upper limit comparison to previous MC study.

§ 8×10^{-13} in 5 σ with 100 fb^{-1}

† arXiv:hep-ph/0606118 by Eboli et al.

‡ arXiv:1309.1475 by Snowmass

same sign dilepton + 2 jets

	$14\text{TeV}, 100\text{fb}^{-1}$			$100\text{TeV}, 100\text{fb}^{-1}$		
Pileup	0	50	140	0	50	140
cut-based	1.7	1.2	0.9	3.8	2.0	1.2
BDT	1.8	1.4	1.3	4.4	3.0	2.6

Table 3. Significance

	14TeV				100TeV	
	100fb-1		3000fb-1		3000fb-1	
	Lower	Upper	Lower	Upper	Lower	Upper
FS0	-430.7	445.6	-201.2	211.3	-110.8	73.4
FS1	-951.5	971.2	-415.5	460.4	-168.0	239.3
FT0	-2.80	2.71	-1.30	1.19	-0.20	0.22

Unit: TeV^{-4}

Summary

- ⋆ Our study show that it reaches 1.2 σ to observe *WWW* production with pure leptonic decay channel at 14 TeV LHC with 100 fb^{-1} and 10 σ at 100TeV next generation proton-proton collider with 3000fb^{-1}.
- ⋆ A significance of 1.4 σ to observe *WWW* production with semi-leptonic decay channel at 14 TeV LHC with 100 fb^{-1} and 4 σ at 100TeV next generation proton-proton collider with 100fb^{-1}.
- ⋆ We gave a better results on *WWWW* aQGC than Snowmass but less stringent than VBF