aQGC from WVgamma at CMS

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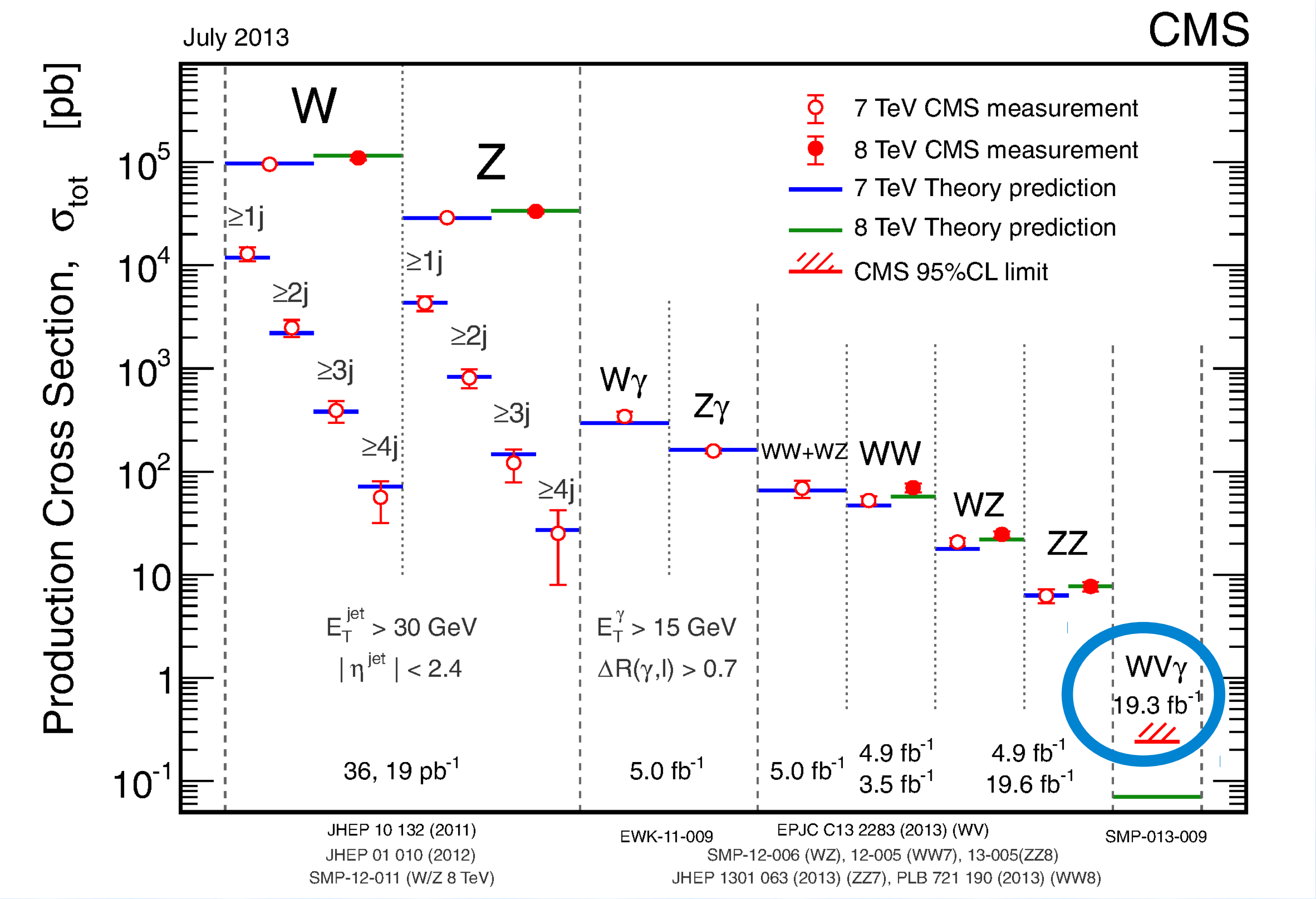
On behalf of CMS Collaboration

Anomalous Quartic Gauge Couplings
Helmholtz Alliance Workshop
From 30th September to 2nd October, 2013

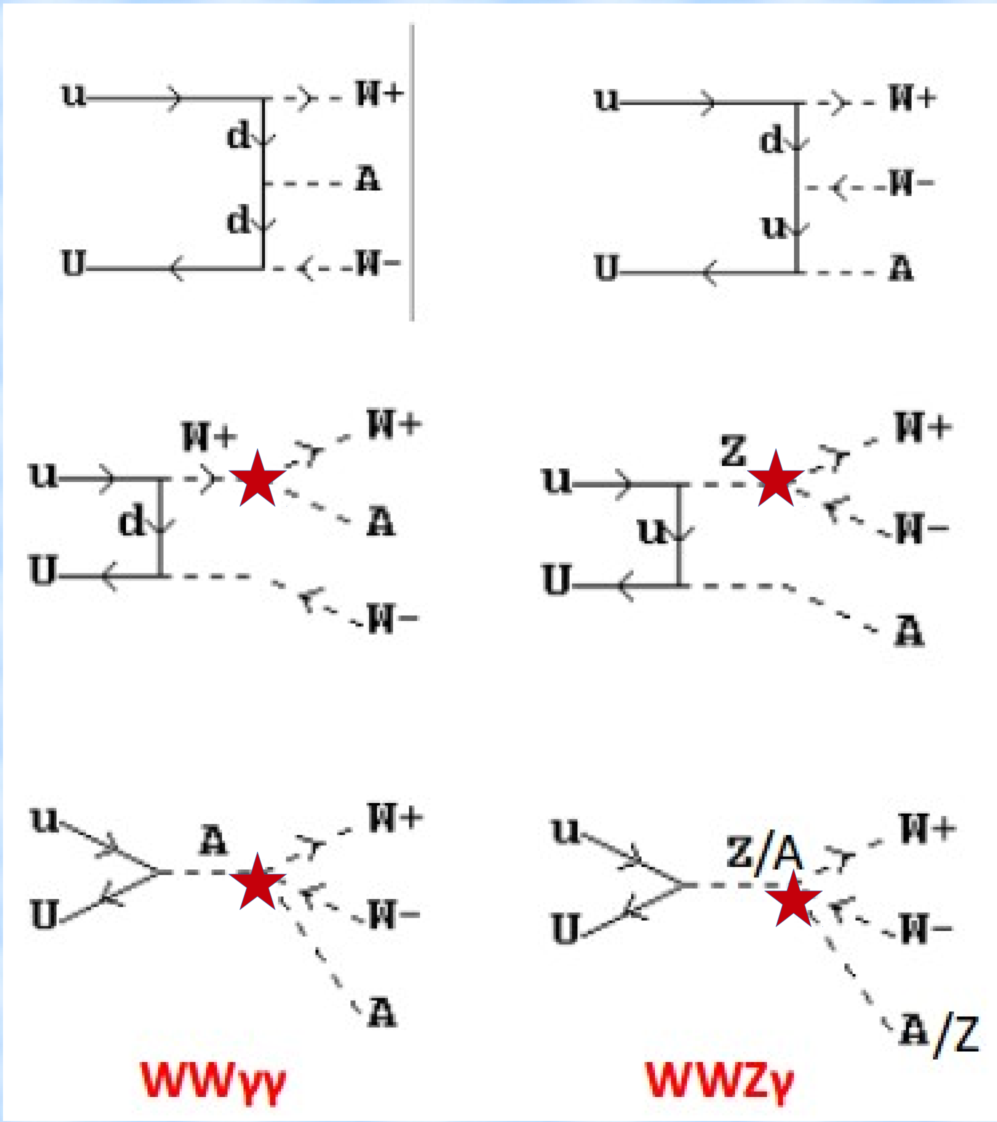
Motivation



https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP

- Three Gauge Boson Production is sensitive to the Quartic Gauge Vertex
- Semileptonic decay mode has higher Branching Ratio → WVγ → lepton+MET+2 jets+γ
- Precisely measured at the LHC and in agreement with the SM expectation
- Model-independent search for new physics

SM WVgamma Production



w/o multi-gauge boson interactions

Triple Gauge Coupling

Quartic Gauge Coupling

WVgamma Production Cross Section (expected @ NLO)

	Process	shape modeling	cross section [pb]
Signal	SM WW γ	MC	(NLO) 0.0582 ± 0.0138
Signal	SM WZ γ	MC	(NLO) 0.0121 ± 0.0029
Backgrounds	W γ +Jets	MC	(data) 10.872 ± 0.087
Backgrounds	jet -> γ	data	data
Backgrounds	Z γ +Jets	MC	(LO) 0.632 ± 0.126
Backgrounds	$t\bar{t}\gamma$	MC	(LO) 0.615 ± 0.123
Backgrounds	Single Top + γ (inclusive)	MC	(NLO) 0.310 ± 0.011

- p p collisions @ $\sqrt{s}$ = 8 TeV
- 2012 CMS Dataset with L = 19.3 fb^{-1}
- LO Samples: Madgraph 5.1.3 and POWHEG; Pythia 6.426 (showering)
- NLO Samples: aMC@NLO (K-factor)

Physics Objects Reconstruction Selection Criteria

	Variable	Muons	Electrons
Leptons	Single lepton trigger p_T threshold	>24 GeV	>27 GeV
	offline p_T threshold	>25 GeV	>30 GeV
	$\lvert\eta\rvert$	< 2.1	< 2.5, excluding 1.44 < $\lvert\eta\rvert$ < 1.57
	lepton must be compatible with the primary vertex		
	secondary loose lepton veto, muon (electron) p_T > 10(20) GeV		
MET	Missing transverse energy (MET)	> 35 GeV	> 35 GeV
	$\Delta\varphi$(MET,jet)	>0.4	>0.4
	W transverse mass (M_T)	> 30 GeV	> 30 GeV

Photons

Variable	Value
p_T threshold	>30 GeV
Photon $\lvert\eta\rvert$	< 1.44
Photon Isolation from jets Δ R	> 0.5
Photon Isolation from leptons Δ R	> 0.5

Physics Objects Reconstruction Selection Criteria (cont.)

PF Jets

Variable	Value
Anti-k_T clustering distance parameter R	0.5
at least 2 jets above p_T threshold	30 GeV
Jet $\|\eta\|$	< 2.4
Jet Isolation from leptons Δ R	> 0.3
Jet b-tag veto based on combined secondary vertex algorithm, medium operating point	

Additional Selection Requirements

Variable	Value
di-jet invariant mass (M_{jj})	$70 < M_{jj} < 100$ GeV
$\Delta\eta$ (jet 1,jet 2)	< 1.4
invariant mass of electron-photon pair $M_{e\gamma}$	$\|M_{e\gamma} - M_Z\| > 10$ GeV

Semileptonic decay mode cannot differentiate the two production processes WWγ and WZγ due to detector di-jet mass resolution (≈ 10 GeV) which is close to the mass difference between W and Z bosons. Therefore **both channels were treated as a combined signal** in this analysis.

Systematic Uncertainties

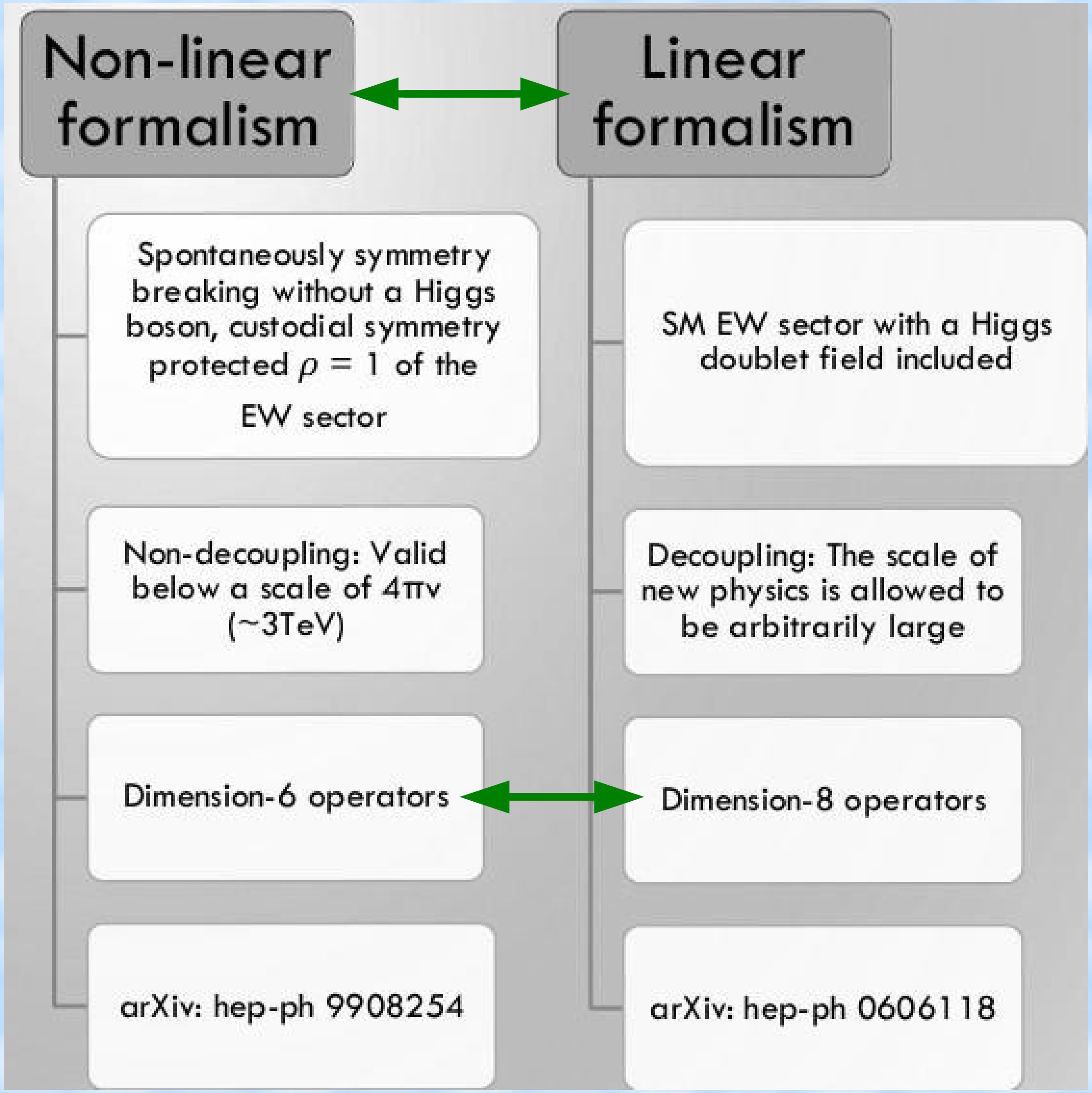
Source	Uncertainty
$W\gamma$ + Jets normalization	6.7%(mu), 7.9%(el)
jet -> γ	12% (30 GeV - 50 GeV)
	14% (50 GeV - 75 GeV)
	23% (75 GeV - 90 GeV)
	22% (90 GeV - 135 GeV)
	39% (> 135 GeV)
multijets	50%
Trigger Efficiency	1%
Lepton Selection Efficiency	2%
Jet Energy Resolution	1%
Jet Energy Scale	4.3%
Photon Energy Scale	1%
$\not{E}_T$	1%
Anti-b Tag ($t\bar{t}\gamma$)	11%
Anti-b Tag (single top + γ)	5%
Pileup modeling	1%
renormalization/factorization scale	23.4%
PDF	3.6%
Luminosity	4.4%

SM WVgamma Cross Section Results

Process	muon channel number of events	electron channel number of events
W γ+jets	136.9 ± 3.5 ± 9.2 ± 0.0	101.6 ± 2.9 ± 8.0 ± 0.0
WV+jet, jet -> γ	33.1 ± 1.3 ± 4.6 ± 0.0	21.3 ± 1.0 ± 3.1 ± 0.0
MC $t\bar{t}\gamma$	12.5 ± 0.8 ± 2.9 ± 0.5	9.1 ± 0.7 ± 2.1 ± 0.4
MC single top	2.8 ± 0.8 ± 0.2 ± 0.1	1.7 ± 0.6 ± 0.1 ± 0.1
MC Z γ+jets	1.7 ± 0.1 ± 0.1 ± 0.1	1.5 ± 0.1 ± 0.1 ± 0.1
multijets	< 0.2 ± 0.0 ± 0.1 ± 0.0	7.2 ± 3.6 ± 3.6 ± 0.0
SM WW γ	6.3 ± 0.1 ± 1.5 ± 0.3	4.7 ± 0.1 ± 1.1 ± 0.2
SM WZ γ	0.6 ± 0.0 ± 0.1 ± 0.0	0.5 ± 0.0 ± 0.1 ± 0.0
Total predicted	193.9 ± 3.9 ± 10.8 ± 1.0	147.6 ± 4.8 ± 9.6 ± 0.7
Data	183	139

- Cut & Count approach based on Selection Criteria
- 322 events observed in CMS 2012 data against 341.5 ± 15.8 events predicted
- Low statistics to measure the WVgamma cross section
- An upper limit of 0.24 pb at 95% C.L. for WVgamma at 8 TeV with 19.3 fb^{-1}
  - 3.4 x SM prediction

WVgamma aQGC



WVgamma aQGC (cont.)

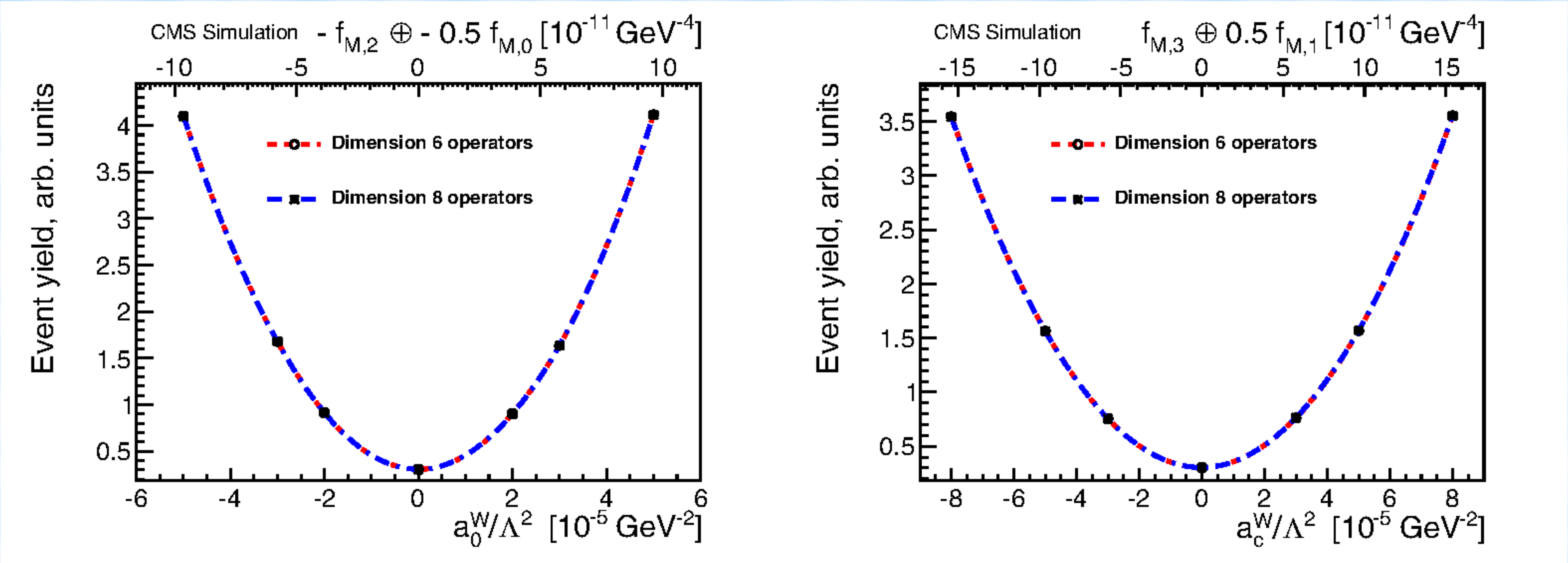
- Transformations between Dim. 6 and Dim. 8

$$\frac{q_i}{\Lambda^4} = \frac{8a_i}{\Lambda^2 M_W^2}$$

$$\mathcal{L}_{AQGC} = \frac{a_0^W}{4g^2}\mathcal{W}_0^\gamma + \frac{a_c^W}{4g^2}\mathcal{W}_c^\gamma + \sum_i k_i^W \mathcal{W}_i^Z + \mathcal{L}_{T,0} + \mathcal{L}_{T,1} + \mathcal{L}_{T,2}$$

WWγγ

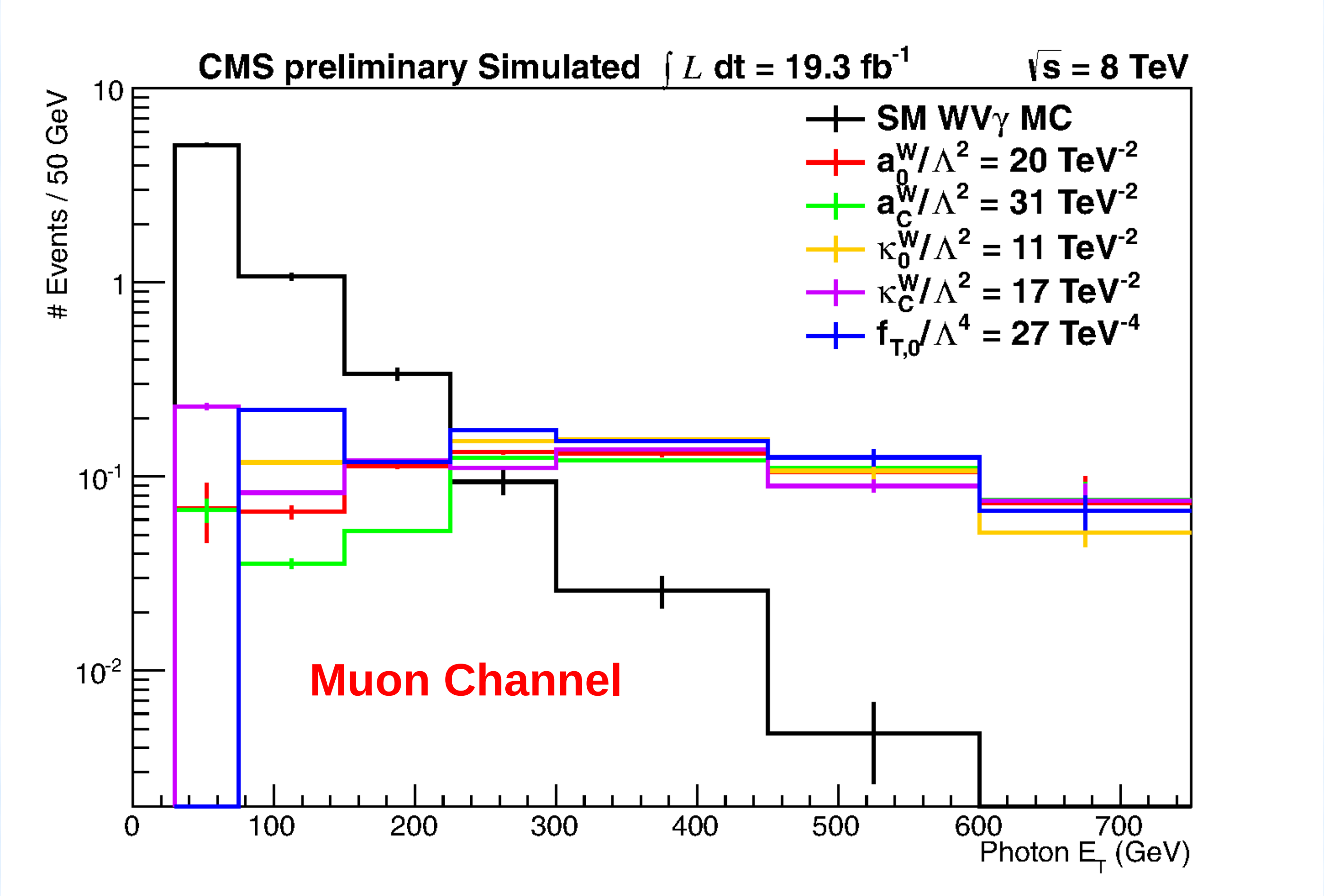
WWZγ contributions considered



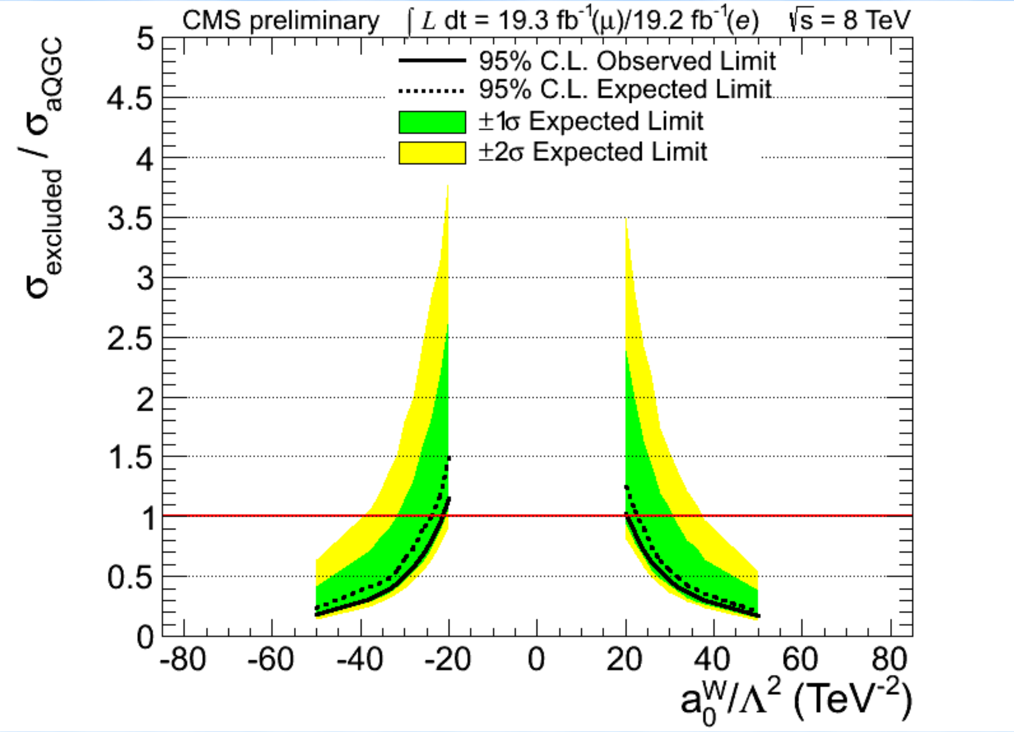
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSMP13009

Limits

- Photon p_T distribution used to set limits on aQGC parameters
- Input to limit setter algorithm segregated by lepton flavor



a_0^W/Λ^2 Limits



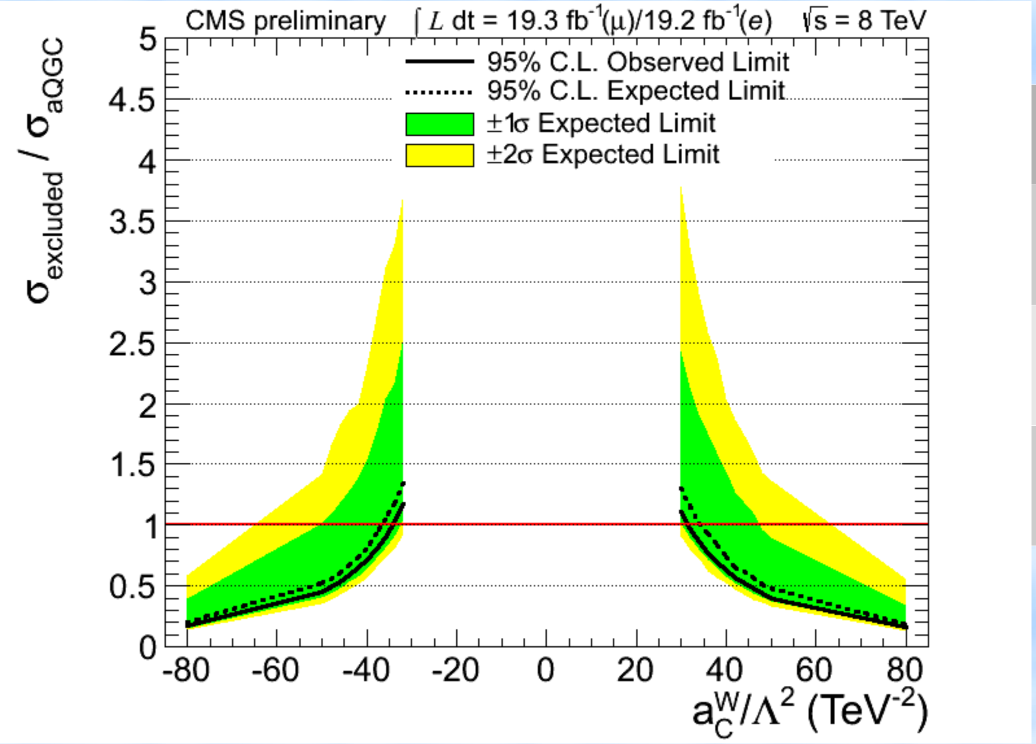
Observed Limits	Expected Limits
$-21 < a_0^W/\Lambda^2\ [\mathrm{TeV}^{-2}] < 20$	$-24 < a_0^W/\Lambda^2\ [\mathrm{TeV}^{-2}] < 23$
$-77 < f_{M,0}/\Lambda^4\ [\mathrm{TeV}^{-4}] < 81$	$-89 < f_{M,0}/\Lambda^4\ [\mathrm{TeV}^{-4}] < 93$
$-39 < f_{M,2}/\Lambda^4\ [\mathrm{TeV}^{-4}] < 40$	$-44 < f_{M,2}/\Lambda^4\ [\mathrm{TeV}^{-4}] < 46$

$$\mathcal{L}_{AQGC} = \frac{a_0^W}{4g^2}\mathcal{W}_0^\gamma + \frac{a_c^W}{4g^2}\mathcal{W}_c^\gamma + \sum_i k_i^W \mathcal{W}_i^Z + \mathcal{L}_{T,0} + \mathcal{L}_{T,1} + \mathcal{L}_{T,2}$$

WWAA

Set to Zero

a_C^W/Λ^2 Limits



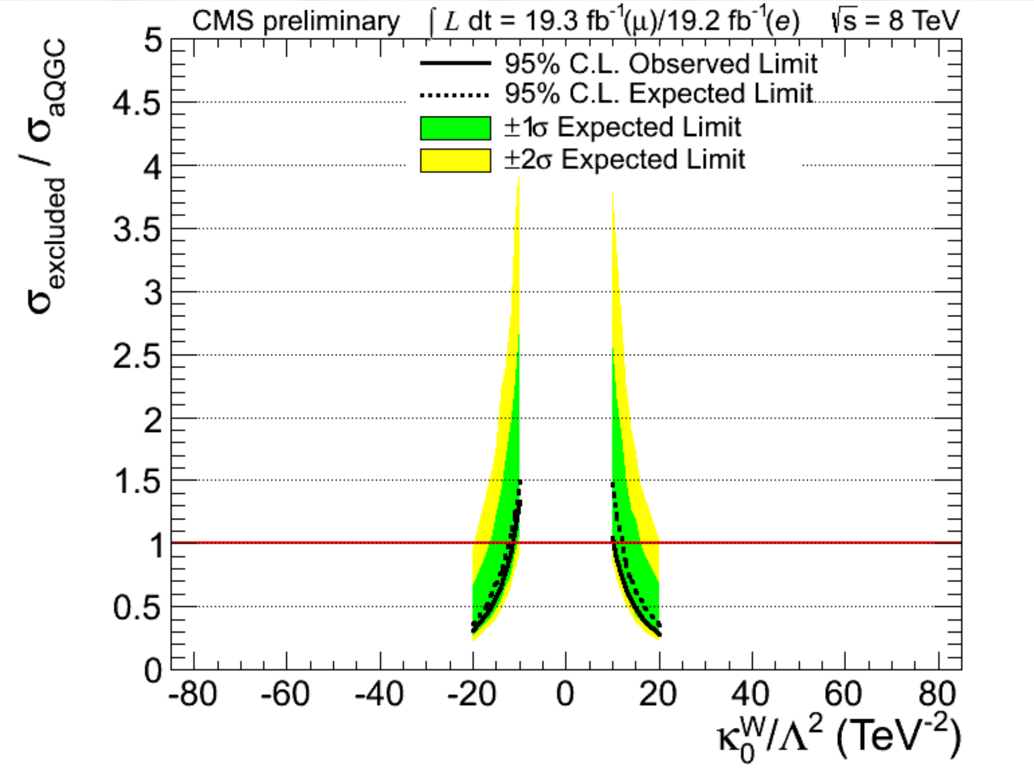
Observed Limits	Expected Limits
$-34 < a_C^W/\Lambda^2$ [TeV^{-2}] < 32	$-37 < a_C^W/\Lambda^2$ [TeV^{-2}] < 34
$-131 < f_{M,1}/\Lambda^4$ [TeV^{-4}] < 123	$-143 < f_{M,1}/\Lambda^4$ [TeV^{-4}] < 131
$-66 < f_{M,3}/\Lambda^4$ [TeV^{-4}] < 62	$-71 < f_{M,3}/\Lambda^4$ [TeV^{-4}] < 66

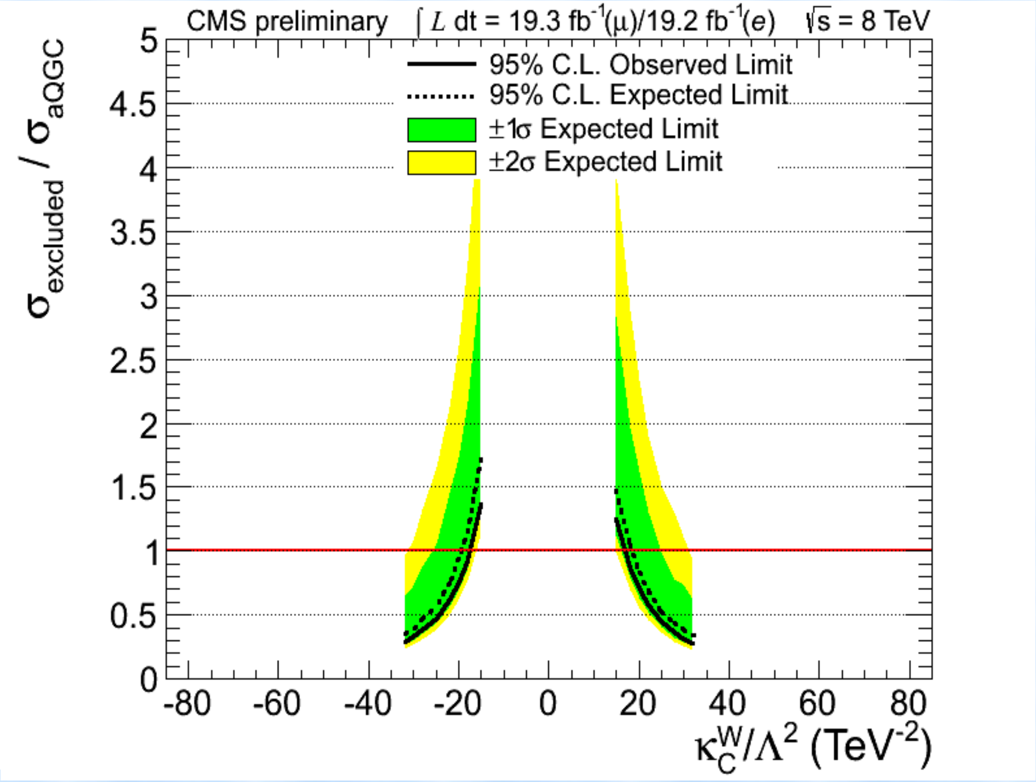
$$\mathcal{L}_{AQGC} = \frac{a_0^W}{4g^2}\mathcal{W}_0^\gamma + \frac{a_c^W}{4g^2}\mathcal{W}_c^\gamma + \sum_i k_i^W \mathcal{W}_i^Z + \mathcal{L}_{T,0} + \mathcal{L}_{T,1} + \mathcal{L}_{T,2}$$

WWAA

Set to Zero

$K_{0,C}^{W}/\Lambda^2$ Limits





Observed Limits [TeV^{-2}]	Expected Limits [TeV^{-2}]
$-12 < \kappa_0^W/\Lambda^2 < 10$	$-12 < \kappa_0^W/\Lambda^2 < 12$

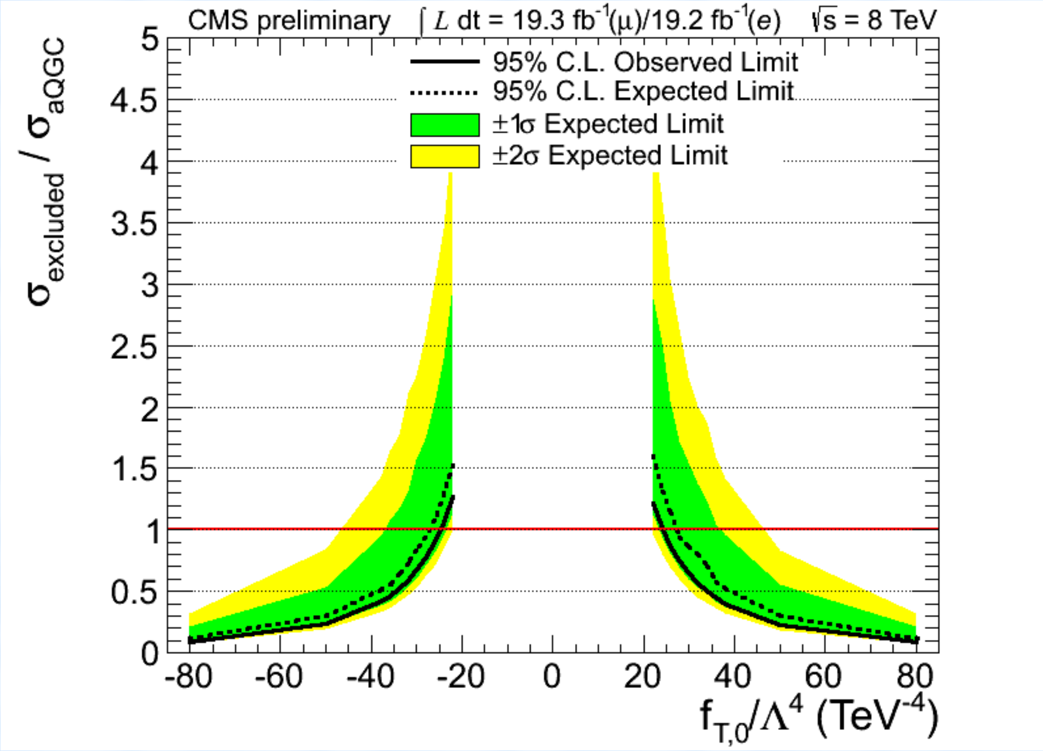
Observed Limits [TeV^{-2}]	Expected Limits [TeV^{-2}]
$-18 < \kappa_C^W/\Lambda^2 < 17$	$-19 < \kappa_C^W/\Lambda^2 < 18$

$$\mathcal{L}_{AQGC} = \frac{a_0^W}{4g^2}\mathcal{W}_0^\gamma + \frac{a_c^W}{4g^2}\mathcal{W}_c^\gamma + \sum_i k_i^W \mathcal{W}_i^Z + \mathcal{L}_{T,0} + \mathcal{L}_{T,1} + \mathcal{L}_{T,2}$$

WWZA

Set to Zero

$f_{T,0}/\Lambda^4$ Limits



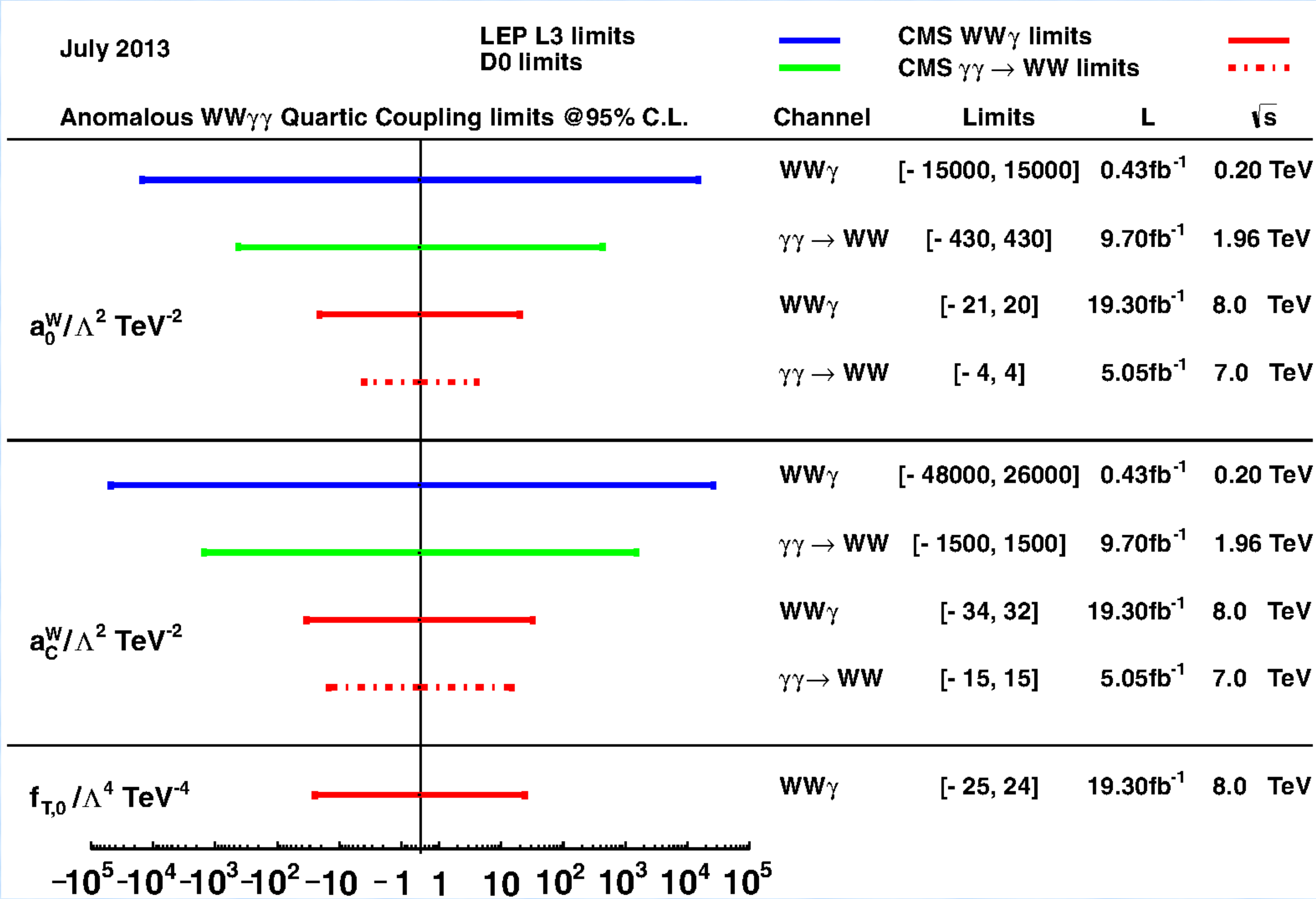
Observed Limits [TeV^{-4}]	Expected Limits [TeV^{-4}]
$-25 < f_{T,0}/\Lambda^4 < 24$	$-27 < f_{T,0}/\Lambda^4 < 27$

$$\mathcal{L}_{AQGC} = \frac{a_0^W}{4g^2}\mathcal{W}_0^\gamma + \frac{a_c^W}{4g^2}\mathcal{W}_c^\gamma + \sum_i k_i^W \mathcal{W}_i^Z + \mathcal{L}_{T,0} + \mathcal{L}_{T,1} + \mathcal{L}_{T,2}$$

WWZA

Set to Zero

Overview of aQGC Limits



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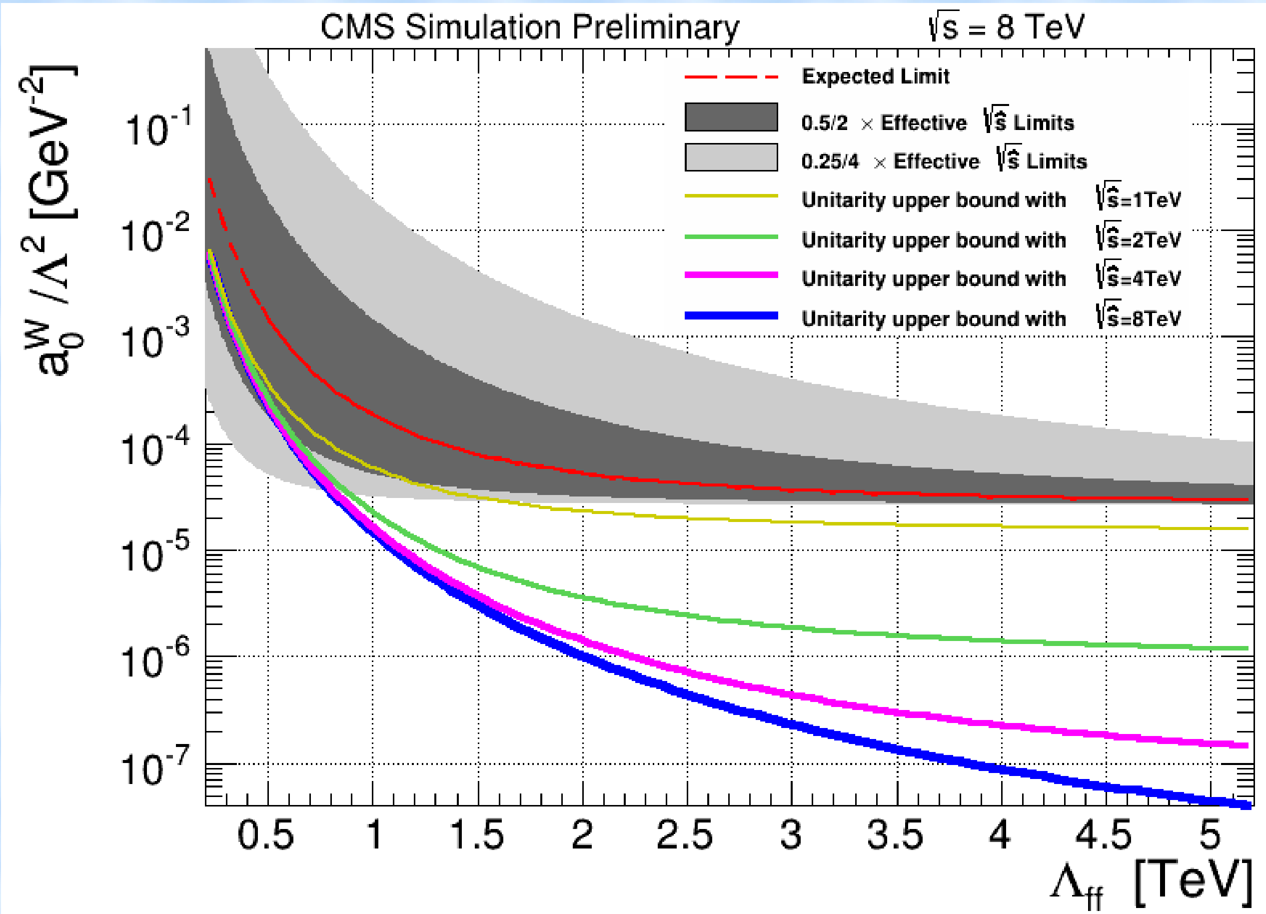
Unitary Violation



$$a_{0,c}^{W} \rightarrow \frac{a_{0,c}^{W}}{(1+\hat{s}/\Lambda_{ff}^{2})^{2}}$$

- Form Factor dampens aQGCs
  - Used to conserve unitarity
    - Little effect on low-energy events
    - Dampens high-energy events towards zero
- In non-unitary regime
  - No matter the Form Factor choice

$$\frac{1}{N}\left(\frac{\alpha a s}{16}\right)^{2}\left(1-\frac{4M_{W}^{2}}{s}\right)^{1/2}\left(3-\frac{s}{M_{W}^{2}}+\frac{s^{2}}{4M_{W}^{4}}\right)\leq 1$$

2 → 2 Process Approximate Unitary Bound Equation from: arXiv: hep-ph 0912.5161

Summary

- WVgamma cross section in pp collisions at $\sqrt{s}$ = 8 TeV is not accessible with the data collected in 2012 by the CMS detector
  - Set upper limit of 0.24 pb at 95% C.L. (3.4 times SM prediction)
- No evidence of anomalous WWγγ and WWZγ quartic gauge couplings was found
- 95% C.L. limits were obtained for several anomalous couplings
  - First ever limits on Dim. 8 f_{T0} and Dim. 6 CP conserving couplings k_0^W and k_C^W

Unitary Violation Cont.