Study of Quartic Boson Coupling in Triboson

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On behalf of the Snowmass EWK VBS/Triboso Group
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Snowmass Energy Frontier All hands-on Workshop
Seattle

Dim8 Operators

Dim8 operators unique to Triboson production

- No constraint from inclusive diboson process
- Complementary studies w.r.t. VBS scattering

Higgs Field

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

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

Higgs and Gauge boson

$$\mathcal{L}_{M,0} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right]$$

$$\mathcal{L}_{M,1} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right]$$

$$\mathcal{L}_{M,2} = \left[B_{\mu\nu}B^{\mu\nu}\right] \times \left[(D_\beta\Phi)^\dagger D^\beta\Phi\right]$$

$$\mathcal{L}_{M,3} = \left[B_{\mu\nu}B^{\nu\beta}\right] \times \left[(D_\beta\Phi)^\dagger D^\mu\Phi\right]$$

$$\mathcal{L}_{M,4} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu} D^\mu\Phi\right] \times B^{\beta\nu}$$

$$\mathcal{L}_{M,5} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu} D^\nu\Phi\right] \times B^{\beta\mu}$$

$$\mathcal{L}_{M,6} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu}\hat{W}^{\beta\nu} D^\mu\Phi\right]$$

$$\mathcal{L}_{M,7} = \left[(D_\mu\Phi)^\dagger \hat{W}_{\beta\nu}\hat{W}^{\beta\mu} D^\nu\Phi\right]$$

Gauge boson field only

$$\mathcal{L}_{T,0} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \mathrm{Tr}\left[\hat{W}_{\alpha\beta}\hat{W}^{\alpha\beta}\right]$$

$$\mathcal{L}_{T,1} = \mathrm{Tr}\left[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}\right] \times \mathrm{Tr}\left[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}\right]$$

$$\mathcal{L}_{T,2} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\right] \times \mathrm{Tr}\left[\hat{W}_{\beta\nu}\hat{W}^{\nu\alpha}\right]$$

$$\mathcal{L}_{T,5} = \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times B_{\alpha\beta}B^{\alpha\beta}$$

$$\mathcal{L}_{T,6} = \mathrm{Tr}\left[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}\right] \times B_{\mu\beta}B^{\alpha\nu}$$

$$\mathcal{L}_{T,7} = \mathrm{Tr}\left[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}\right] \times B_{\beta\nu}B^{\nu\alpha}$$

$$\mathcal{L}_{T,8} = B_{\mu\nu}B^{\mu\nu}B_{\alpha\beta}B^{\alpha\beta}$$

$$\mathcal{L}_{T,9} = B_{\alpha\mu}B^{\mu\beta}B_{\beta\nu}B^{\nu\alpha}$$

http://feynrules.irmp.ucl.ac.be/wiki/AnomalousGaugeCoupling

O.J.P. Eboli, et. al.
Phys.Rev.D74:073005,2006

QGC Vertex

	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

Table 1: Quartic vertices modified by each dimension-8 operator are marked with X.

14TeV 3000fb-1/33TeV 3000fb-1 Jenny Holzbauer and Mandy Rominsky

14TeV 300fb-1 /14TeV 3000fb-1 Lynn Marx and Shih-Chieh Hsu ATLAS-PHYS-PUB-2013-006

Each Operator has different effects on different quartic boson vertex

Heavy Triboson

Cross-section and Ratio vs SM at 10 TeV-4 14TeV pp

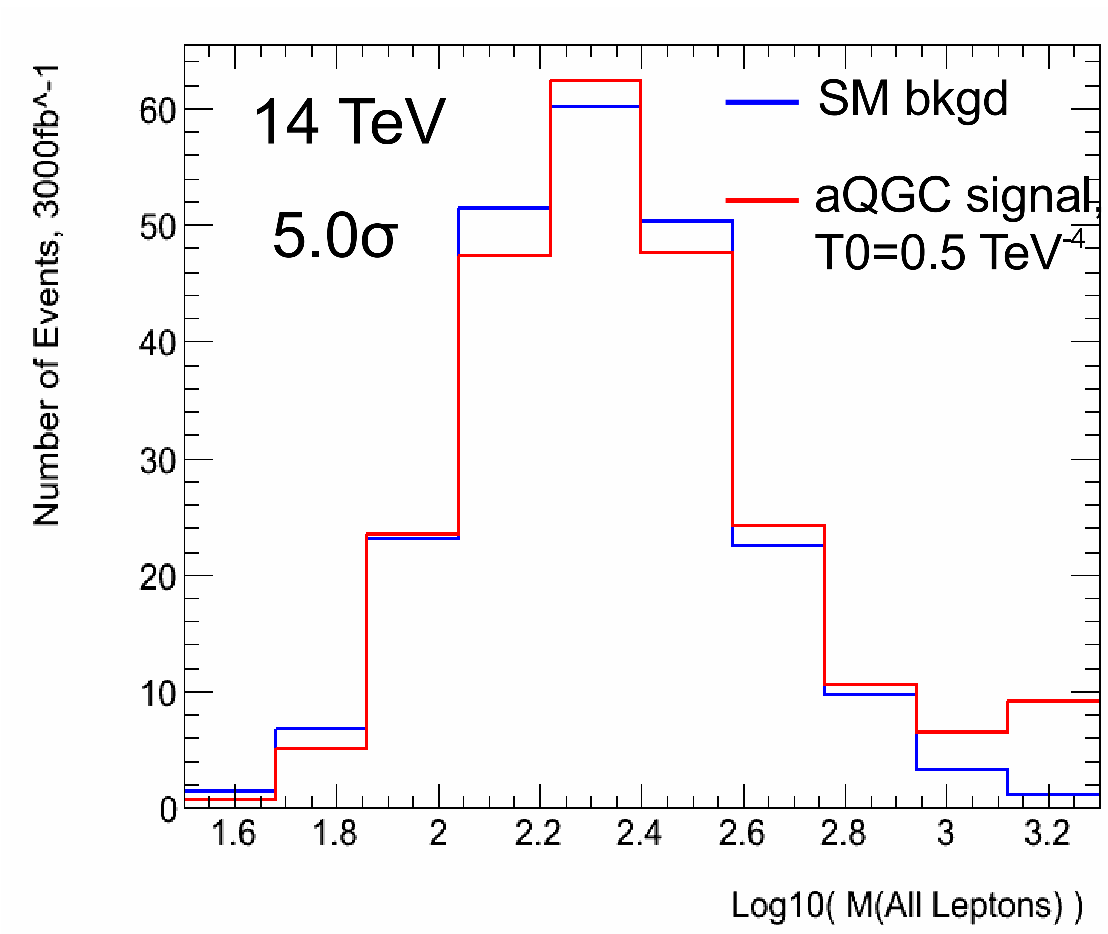
Coupling	WWW	WWZ	WZZ	ZZZ
Sm Cross-section(pb)	0.000568000	0.000111800	0.000009634	0.000000972
sm/sm	1.00	1.00	1.00	1.00
fs0/sm	1.00	1.00	1.00	1.00
fs1/sm	1.00	1.00	1.00	1.00
fm0/sm	1.49	1.09	1.05	1.02
fm1/sm	1.18	1.02	1.04	1.03
fm2/sm	1.00	1.05	1.00	1.02
fm3/sm	1.00	1.01	1.00	1.01
ft0/sm	19.10	4.23	3.38	2.90
ft1/sm	15.88	2.23	2.83	2.90
ft2/sm	4.61	1.33	1.35	1.54
ft8/sm	1.00	1.00	1.00	1.31
ft9/sm	1.00	1.00	1.00	1.08

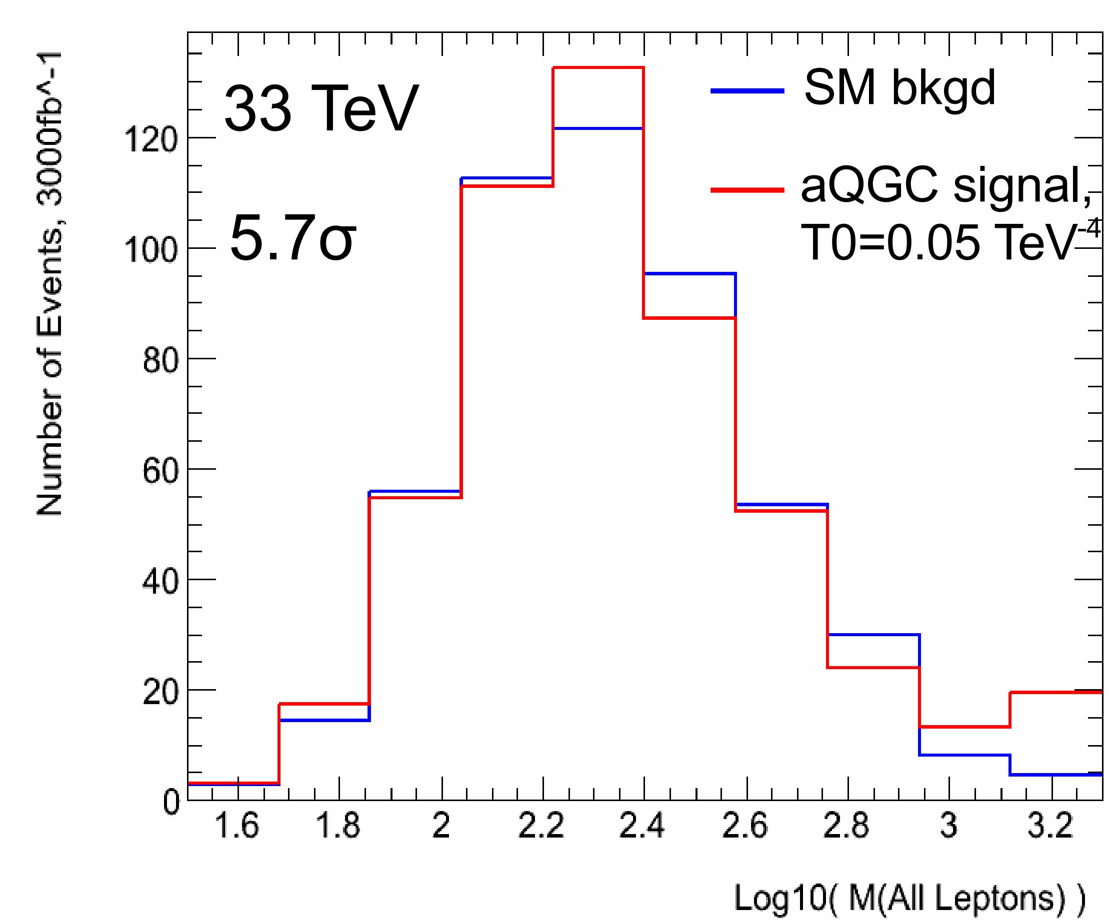
WWW

Event Selection:

- At least three leptons
- No events with two leptons with same flavor and opposite sign (suppress Diboson, W/Z+X)
- No missing ET cut (unnecessary + avoid pileup dependence)
- High M(lll) (to be considered in order to reduce tt~)

Mass of three leptons is sensitive to aQGC



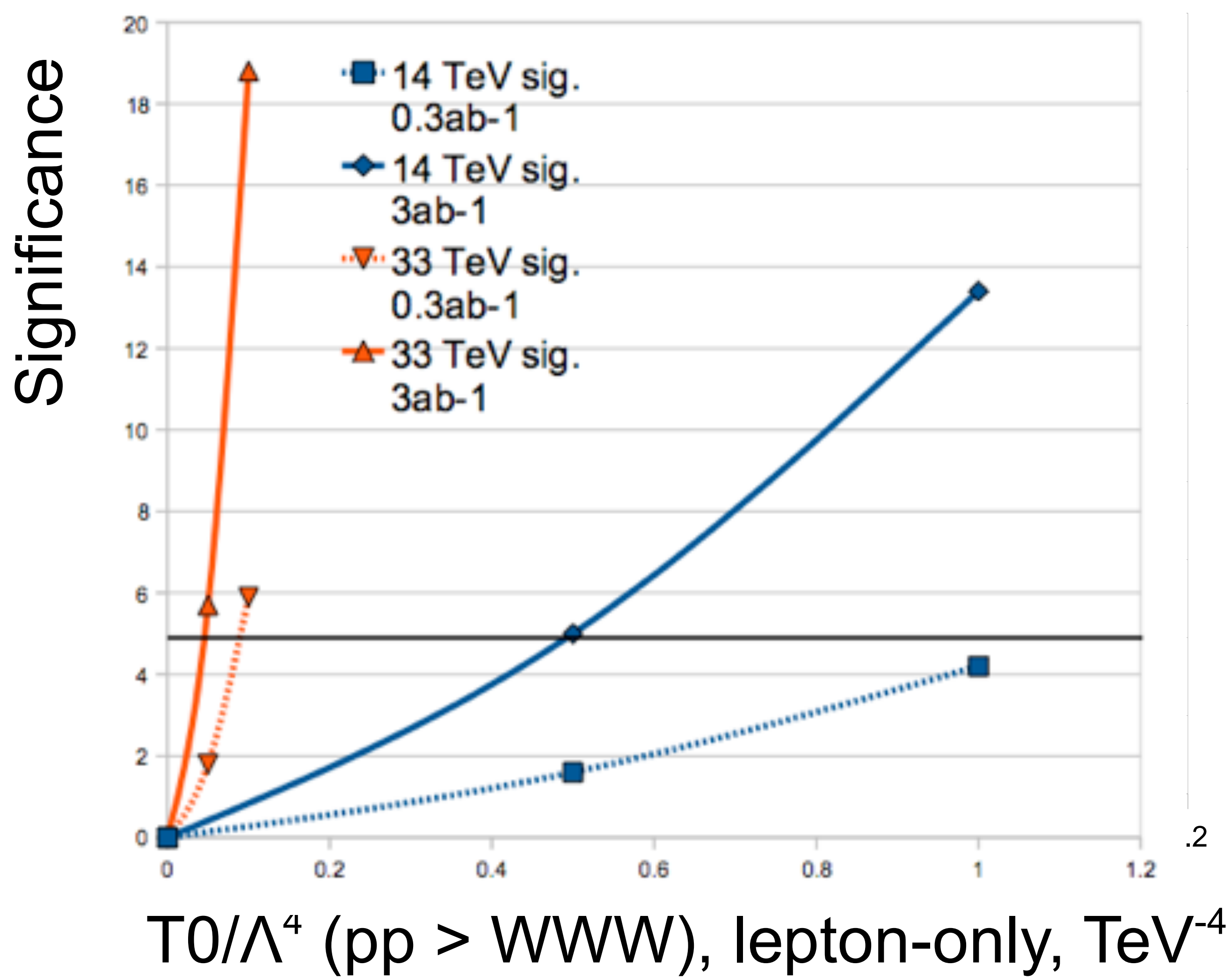


T0 Sensitivity

Sensitivity improvements:

- 300fb-1 vs 3ab-1: x2
- 14TeV vs 33 TeV: x10

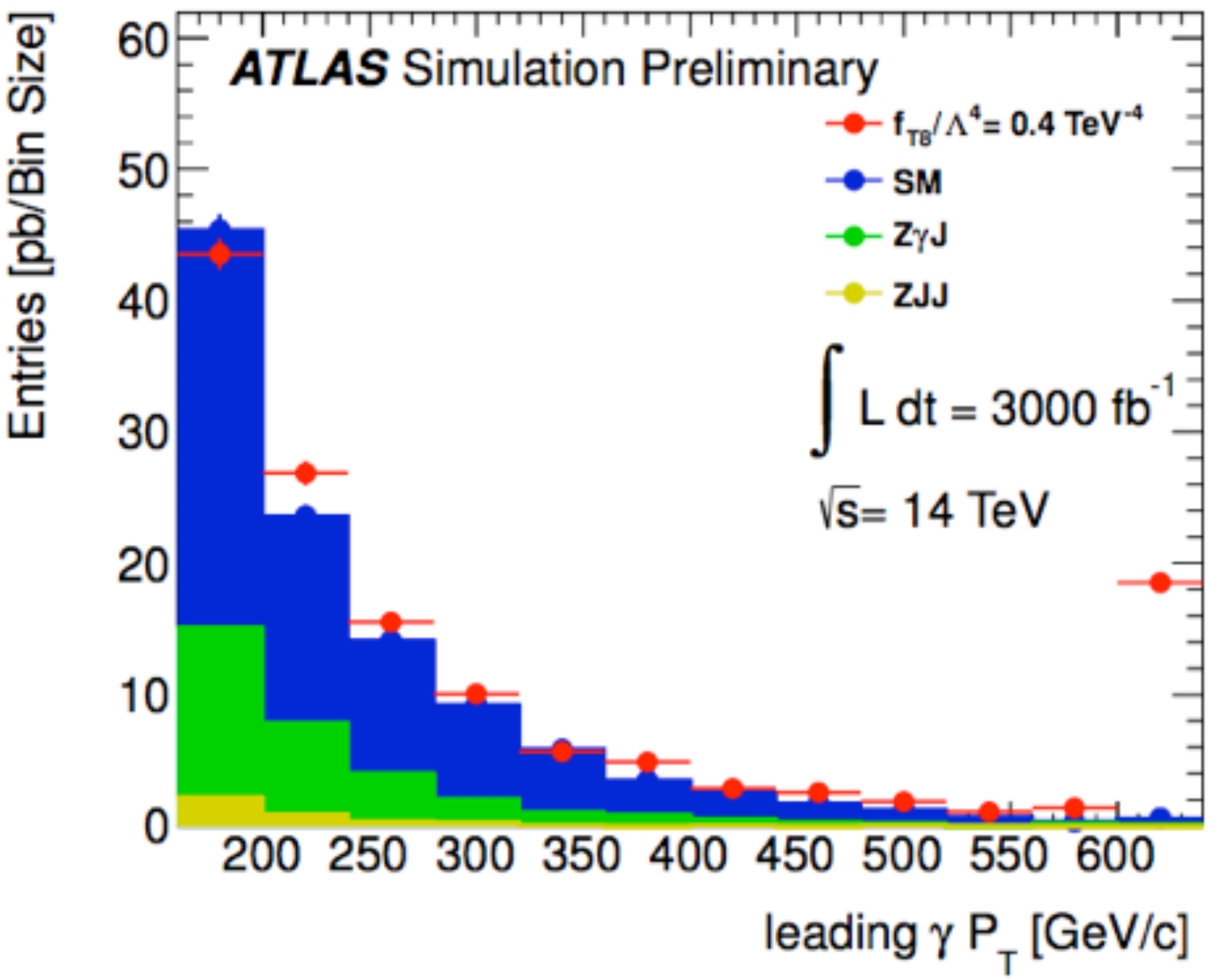
Unitarity violating phase space to be studied

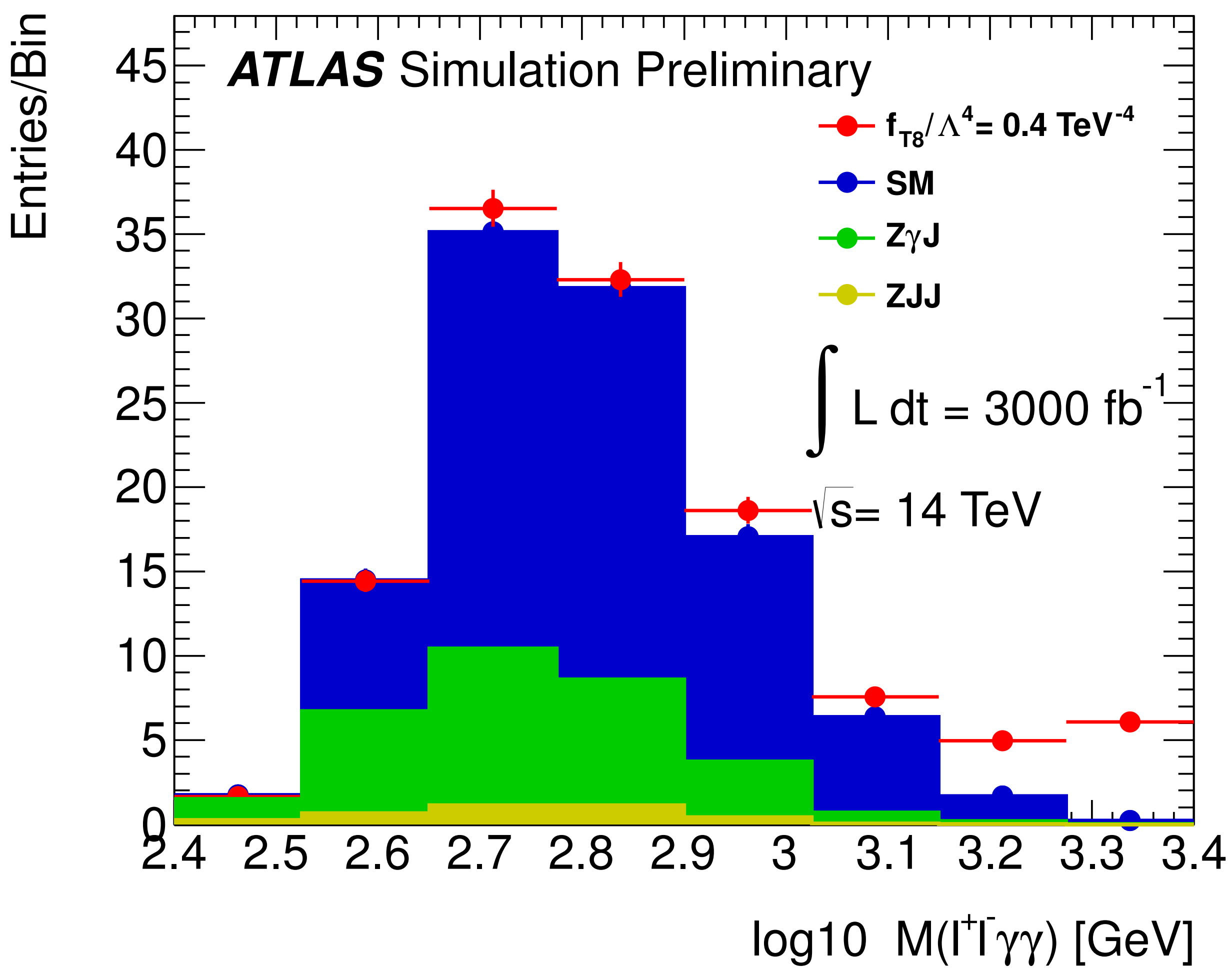


ZAA

Lead Photon pT > 160GeV
Photon/Muon/Ele pT>25 GeV
Photon/Muon/Ele |eta|<2

ATLAS ESG jet-to-pho fake rate (constant rate of 0.001)



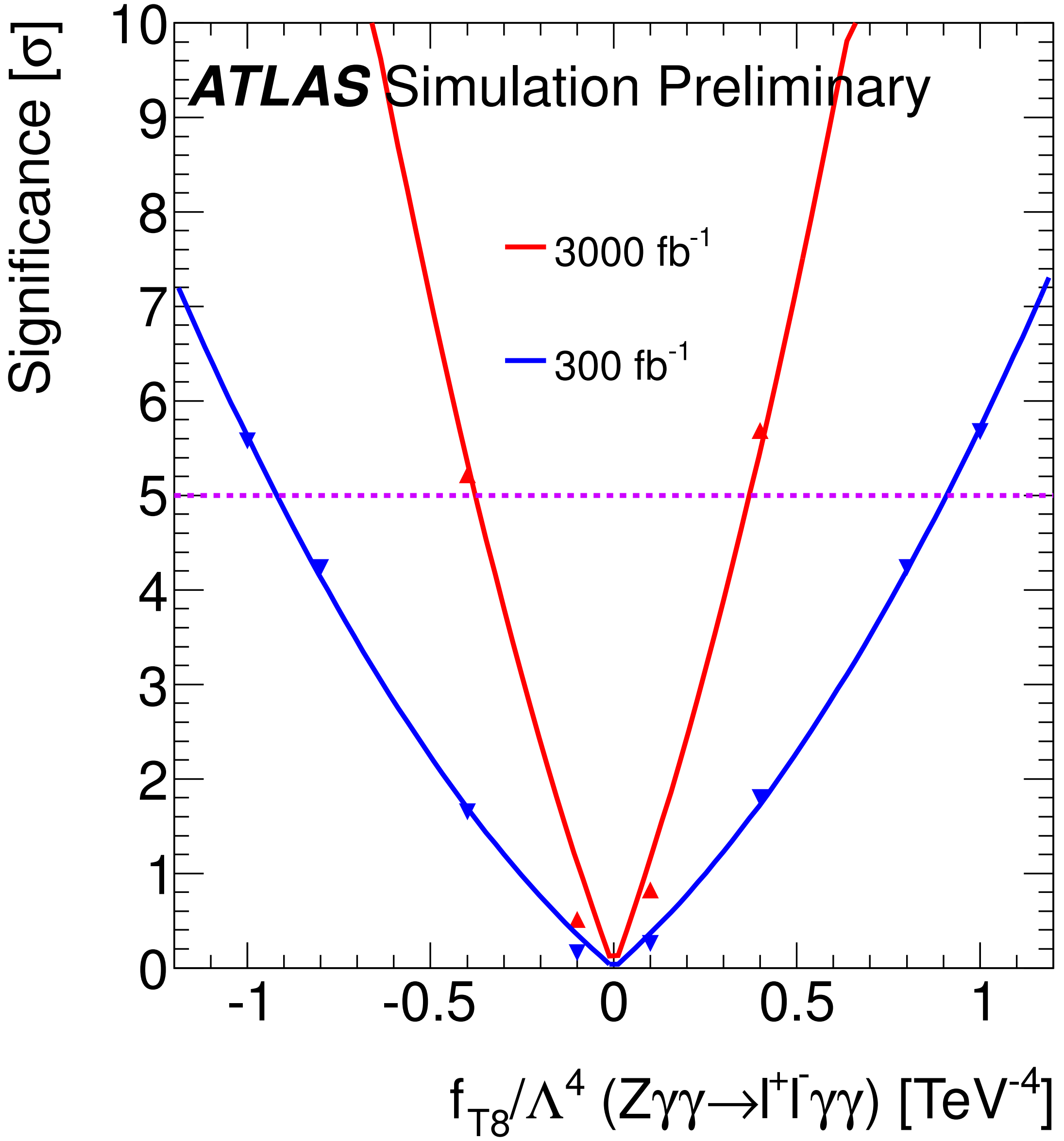


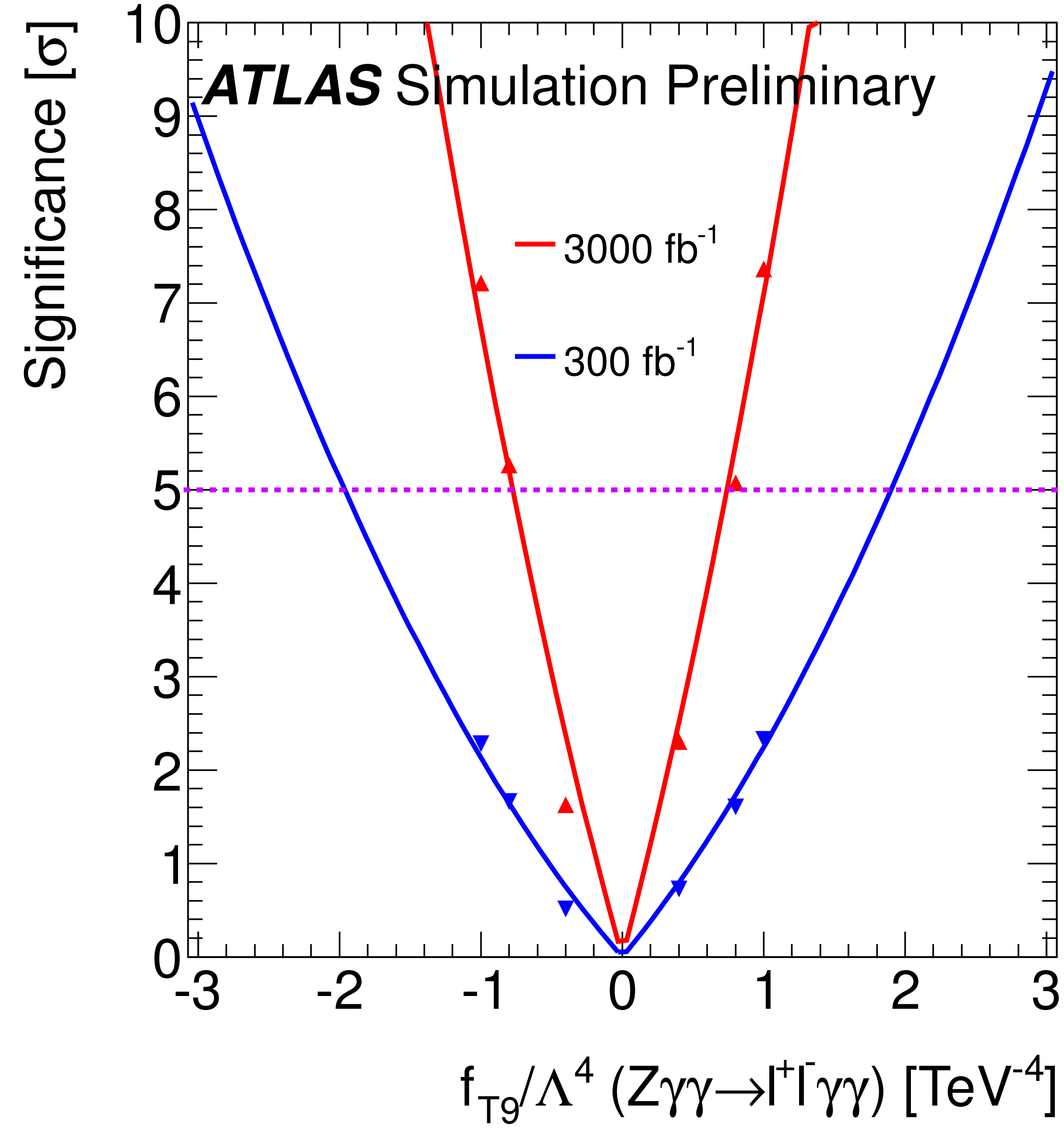
T8/T9 Limit

sensitivity doubled from 300fb-1 to 3000fb-1

$$\mathcal{L}_{T,8} = \frac{f_{T8}}{\Lambda^4} B_{\mu\nu} B^{\mu\nu} B_{\alpha\beta} B^{\alpha\beta}$$

$$\mathcal{L}_{T,9} = \frac{f_{T9}}{\Lambda^4} B_{\alpha\mu} B^{\mu\beta} B_{\beta\nu} B^{\nu\alpha}$$





Summary

- A systematic survey of aQGC in multi-boson final states benchmarked with Dim8 operators (ATLAS-PHYS-PUB-2013-006)

Parameter	dimension	channel	Λ_{UV} [TeV]	300 fb^{-1}		3000 fb^{-1}	
				5σ	95% CL	5σ	95% CL
$c_{\phi W}/\Lambda^2$	6	ZZ	1.9	34 TeV^{-2}	20 TeV^{-2}	16 TeV^{-2}	9.3 TeV^{-2}
f_{S0}/Λ^4	8	$W^{\pm}W^{\pm}$	2.0	10 TeV^{-4}	6.8 TeV^{-4}	4.5 TeV^{-4}	0.8 TeV^{-4}
f_{T1}/Λ^4	8	WZ	3.7	1.3 TeV^{-4}	0.7 TeV^{-4}	0.6 TeV^{-4}	0.3 TeV^{-4}
f_{T8}/Λ^4	8	$Z\gamma\gamma$	12	0.9 TeV^{-4}	0.5 TeV^{-4}	0.4 TeV^{-4}	0.2 TeV^{-4}
f_{T9}/Λ^4	8	$Z\gamma\gamma$	13	2.0 TeV^{-4}	0.9 TeV^{-4}	0.7 TeV^{-4}	0.3 TeV^{-4}

- HL or HE hadron colliders?

Parameter	channel	14TeV 0.3ab-1	14TeV 3ab-1	33TeV 3ab-1
CΦW/Λ2	ZZjj	34 TeV-2	16.0 TeV-2	12.5 TeV-4
fT0 /Λ4	WWW	1.2 TeV-4	0.5 TeV-4	0.05 TeV-4
fT1 /Λ4	WZjj	1.3 TeV-4	0.6 TeV-4	0.3 TeV-4

- Toward Snowmass white paper:
  - Restrict studies to non-Unitarity violation phase space for all channels
  - Include more channels: Wγγ, WWγ, WWZ, ...
  - Comparison: facilities (100TeV pp/ILC) operators: chiral Lagrangian

Tools for this Study

- Monte Carlo
  - MadGraph : 5.1.5.10
  - Pythia : 6.426
  - Delphes-ATLAS-ESG-2-0-0 by Peter Onyisi
  - FeynRule UFO Files by Oscar Eboli et. al.

  http://feynrules.irmp.ucl.ac.be/wiki/AnomalousGaugeCoupling
  - PotonParam by Fernando G. Monticelli et. al.

  svn+ssh://svn.cern.ch/reps/atlasgroups/PhysicsAnalysis/EuropeanStrategy/

- Limit Calculators
  - Today - just simple single bin counting experiments
  - For approval - use Chris Pollard's limit calculator

  https://svnweb.cern.ch/trac/atlasusr/browser/cpollard/UpgradePythia/trunk