New Results on Multi-Boson Production with the ATLAS Detector

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on behalf of the ATLAS collaboration
BROOKHAVEN NATIONAL LABORATORY

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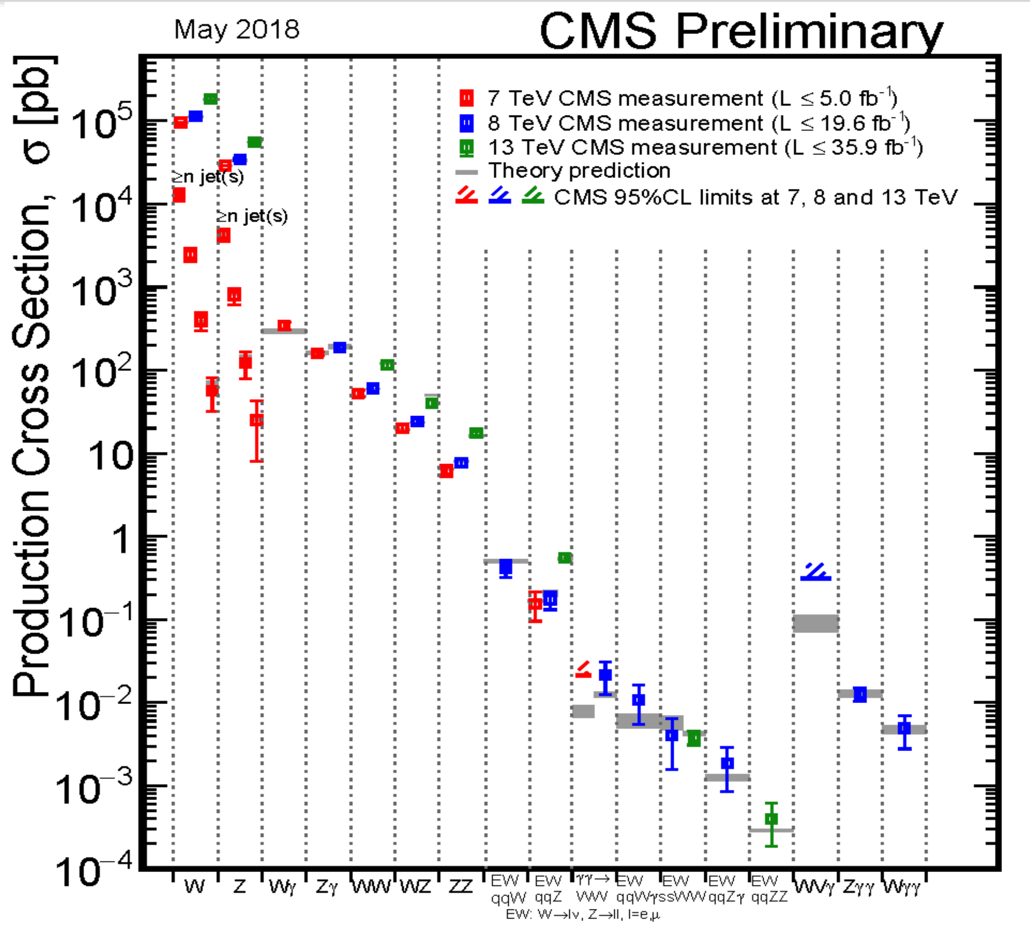
(Multi-) V Production



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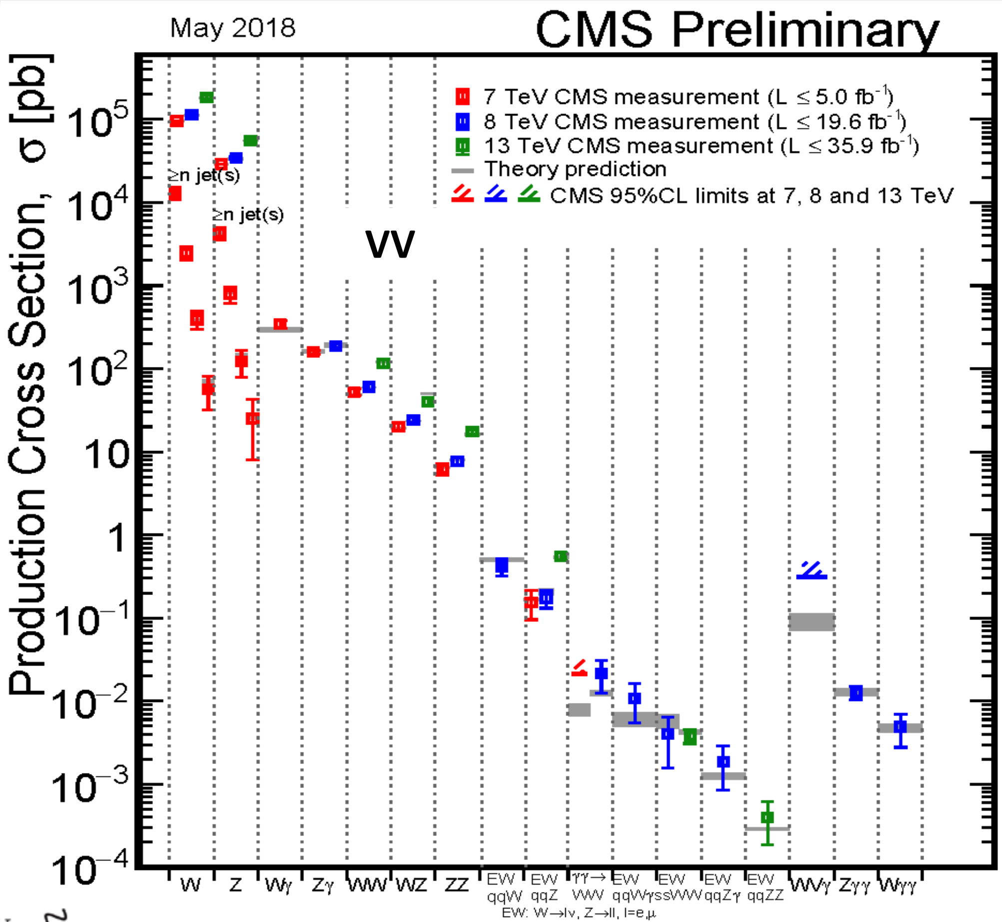

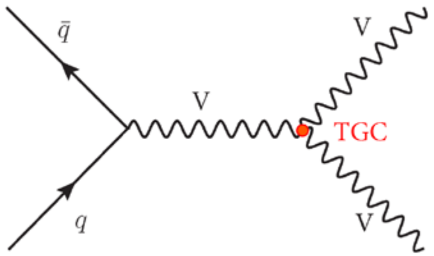

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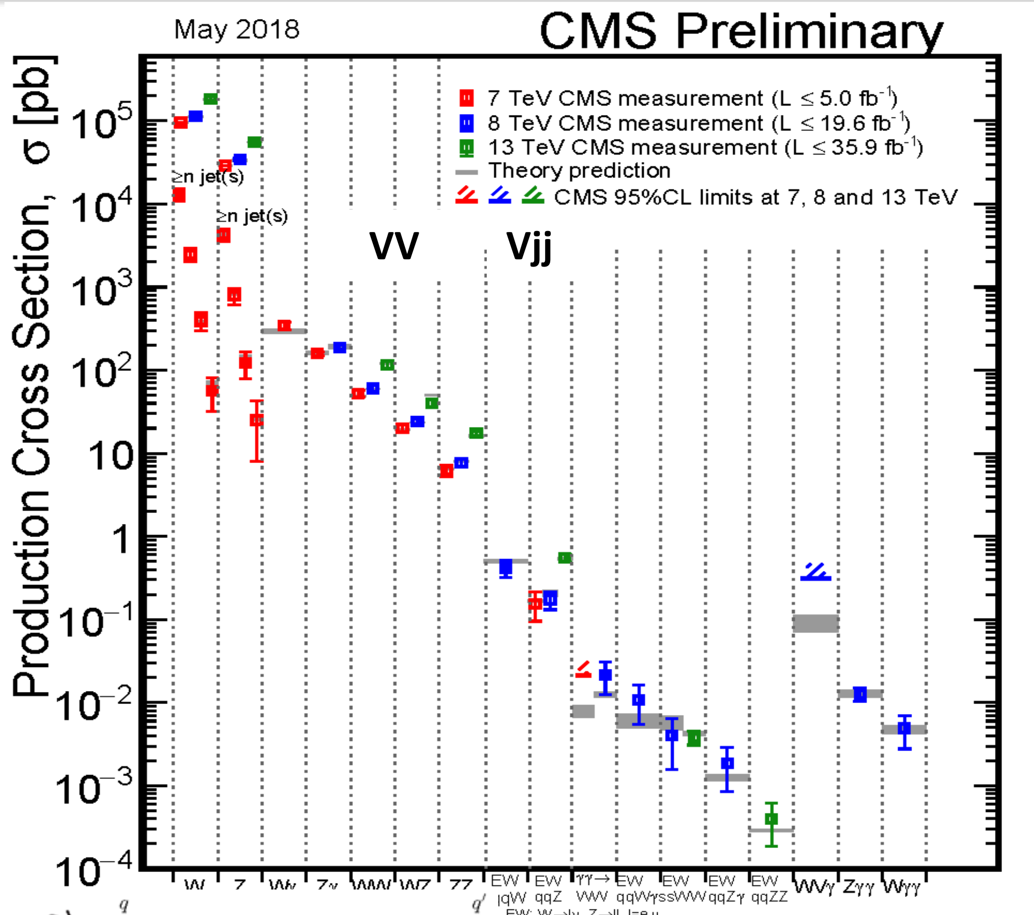

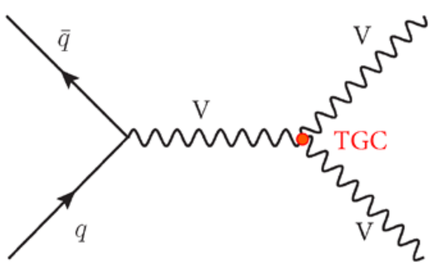

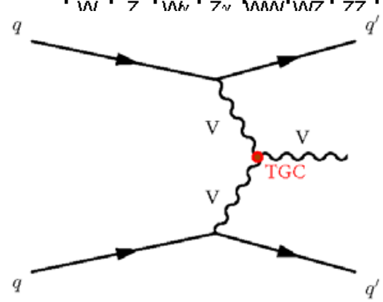

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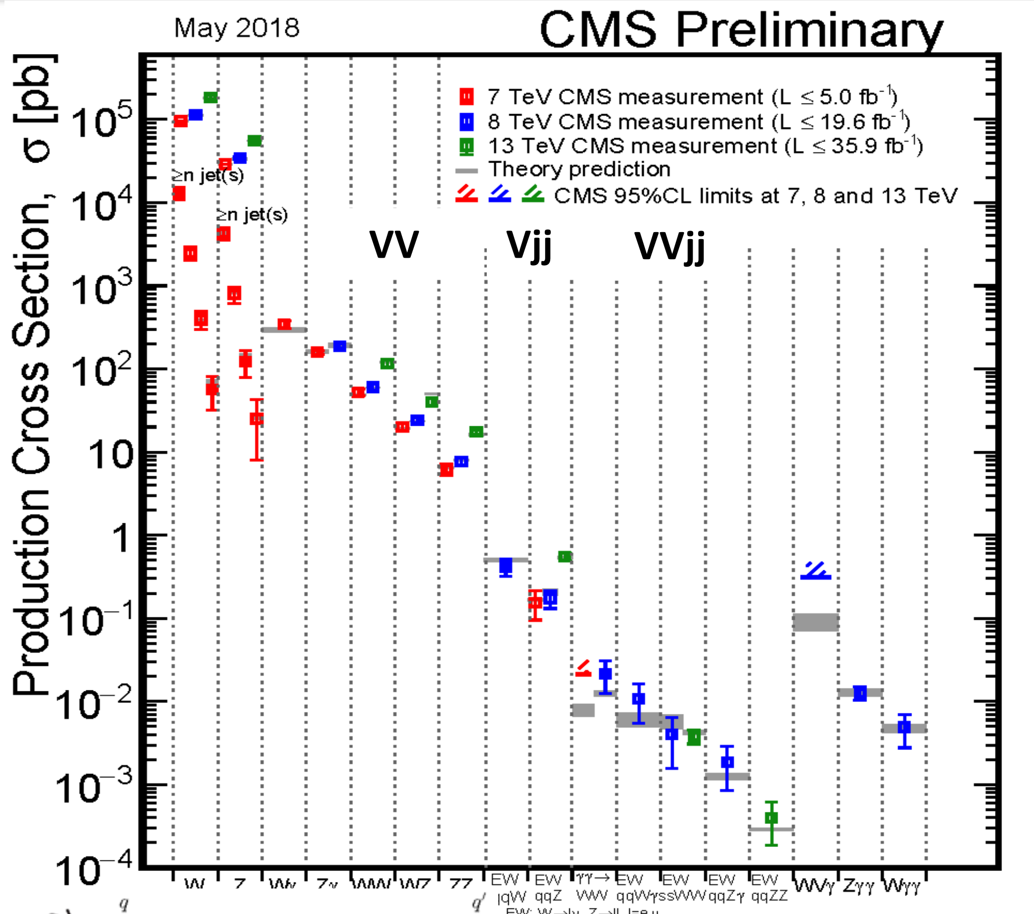

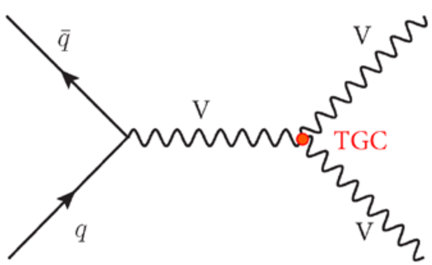

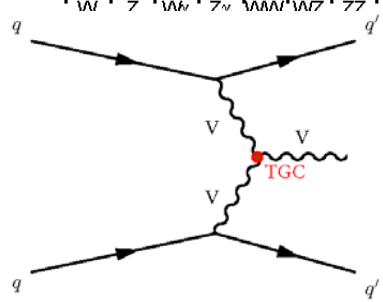

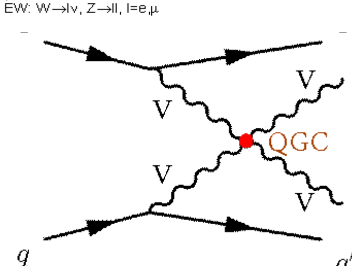

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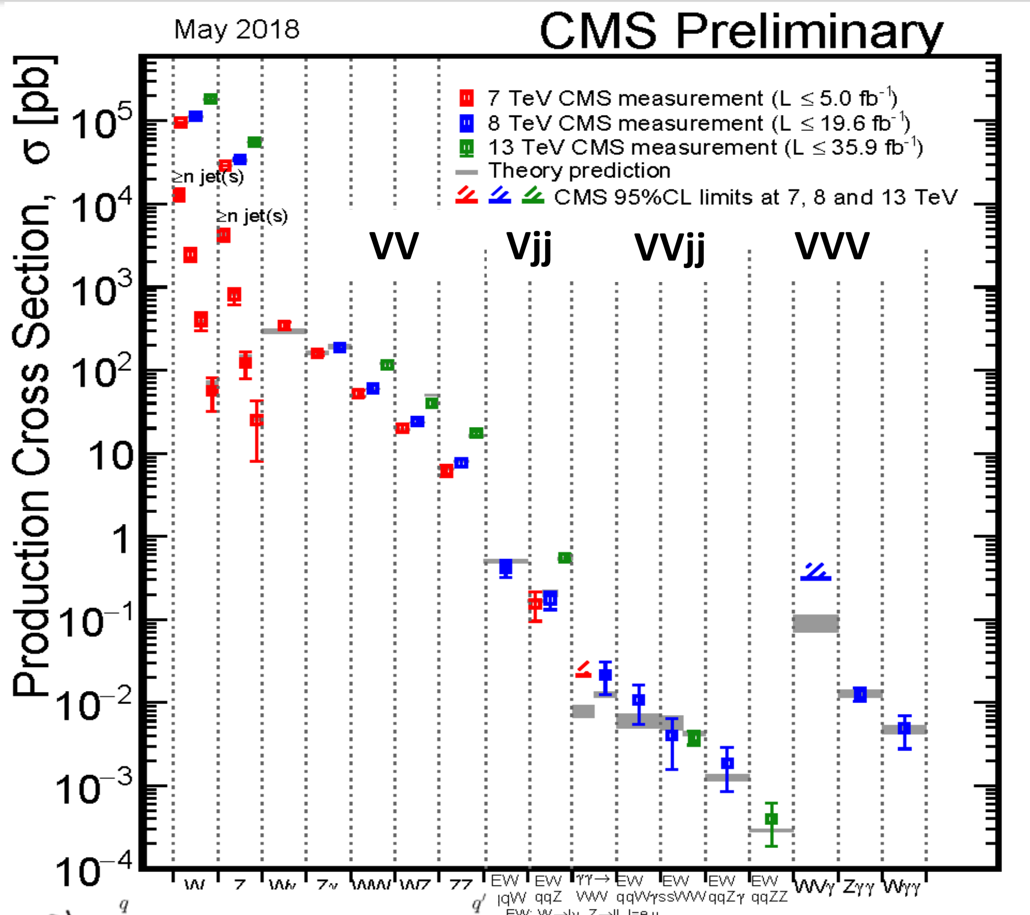

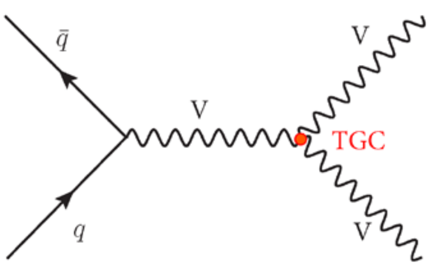

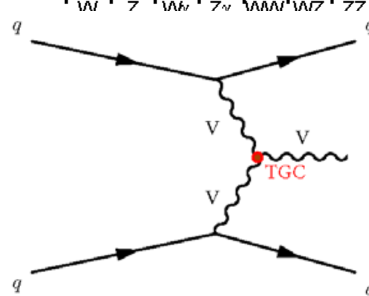

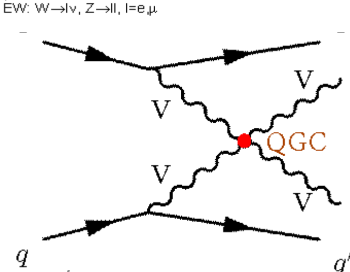

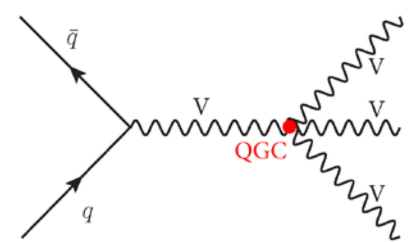

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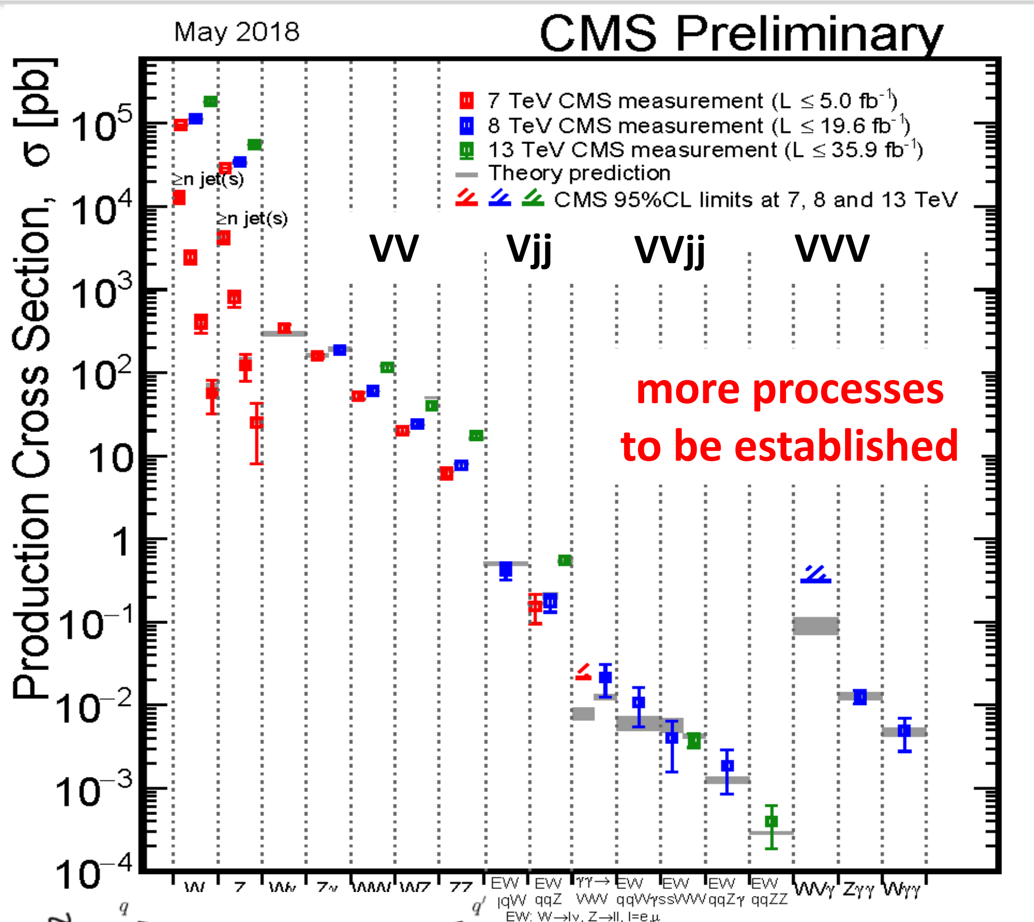
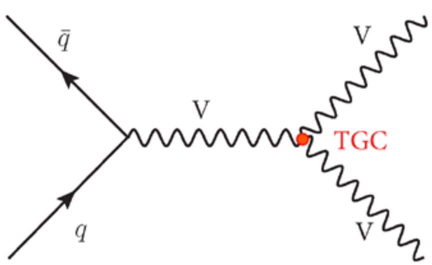
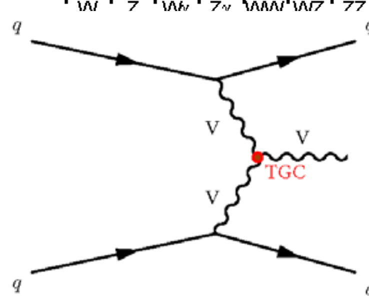
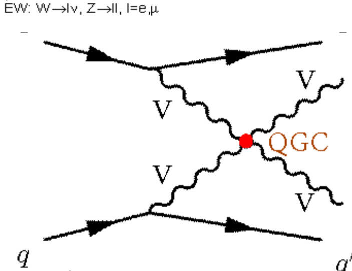
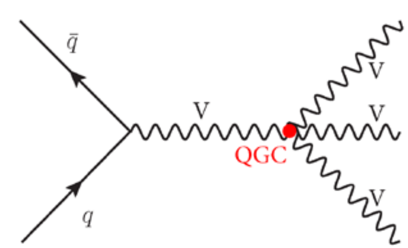










VBS/VVV Production and aQGCs

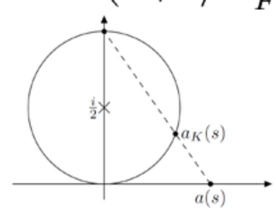
- Overview of studied aQGCs:

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

Vertex-specific conversions from WHIZARD α_4, α_5 exist, e.g. for WWWW:

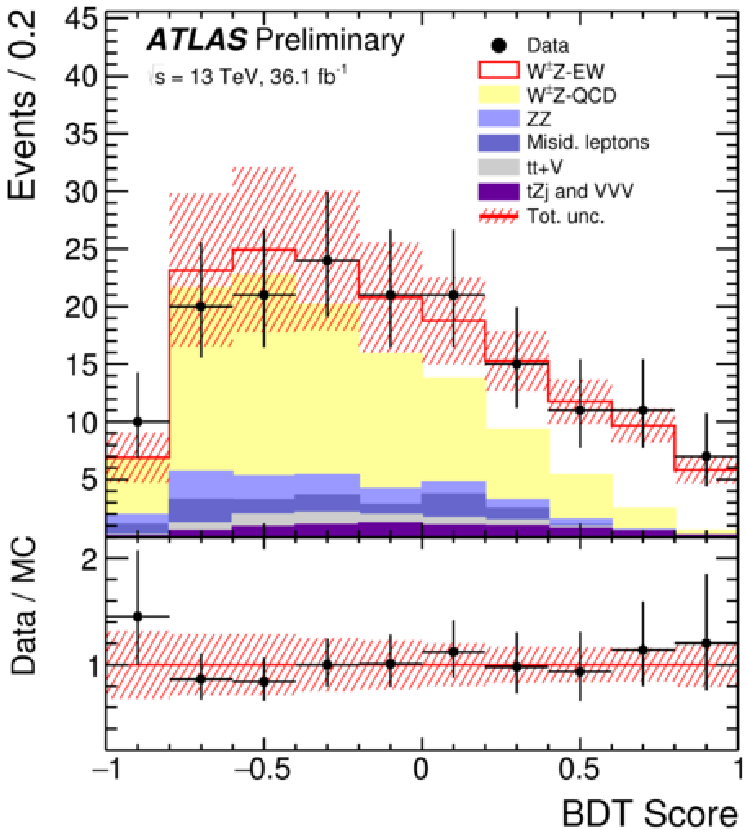
$$\alpha_4 = \frac{f_{S,0}}{\Lambda^4}\frac{v^4}{8}, \alpha_4 + 2\cdot\alpha_5 = \frac{f_{S,1}}{\Lambda^4}\frac{v^4}{8}$$

- Experimental access: aQGCs modify total production rate as well as event kinematics
  - Use cross-section measurement or kinematics to constrain aQGCs
- Unitarisation methods:
  - Form factor $\lambda(\hat{s}) = \frac{\lambda_0}{(1+\hat{s}/\Lambda_{FF}^2)^n}$
  - K-matrix unitarisation



$W^{\pm}Zjj \rightarrow \ell\nu\ell\ell jj$ ATLAS-CONF-2018-033

- 3 isolated leptons (e or μ), MET (via m_T) as WZ incl. (previous talk)
- VBS signal region (SR): $\geq$ 2 jets, $p_T > 40$ GeV , $m_{jj} > 500$ GeV, b-jet veto
- BDT discriminant based on 15 variables reflecting VBS kinematics



Post-fit background normalisations

$\mu_{WZ\text{-}QCD} = 0.60 \pm 0.25$

$\mu_{ttV} = 1.18 \pm 0.19$

$\mu_{ZZ} = 1.34 \pm 0.29$

WZjj-EW measured signal strength:

$$\mu_{EW} = 1.77 \pm 0.41(\text{stat.}) \pm 0.17(\text{syst.}) = 1.77 \pm 0.45$$

Observed sign.: 5.6σ (3.3σ expected)

Corresponding fid. cross section:

$$\sigma^{\text{fid., EW}}_{WZ^{\pm}jj \rightarrow \ell\nu\ell\ell jj} = 0.57 ^{+0.15}_{-0.14} \text{ fb}$$
$$= 0.57 ^{+0.14}_{-0.13} (\text{stat.}) ^{+0.05}_{-0.04} (\text{sys.}) ^{+0.04}_{-0.03} (\text{th.}) \text{ fb} .$$

- Background estimate constrained via 3 control regions fitted w/ SR

$W^{\pm}Zjj \rightarrow \ell\nu\ell\ell jj$

ATLAS-CONF-2018-033

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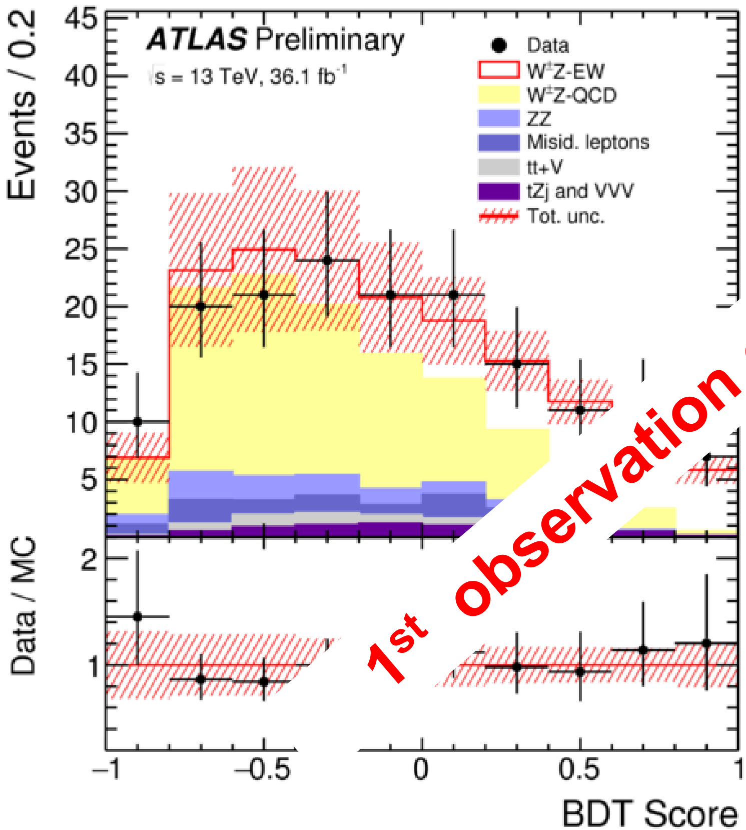
- BDT discriminant based on 15 variables refl… VBS kinematics

1st observation of EW W±Zjj production!



Post-fit backg… …rmalisations

$\mu_{WZ\text{-}QC}$… ± 0.25

μ_{tt}… 1.18 ± 0.19

… = 1.34 ± 0.29

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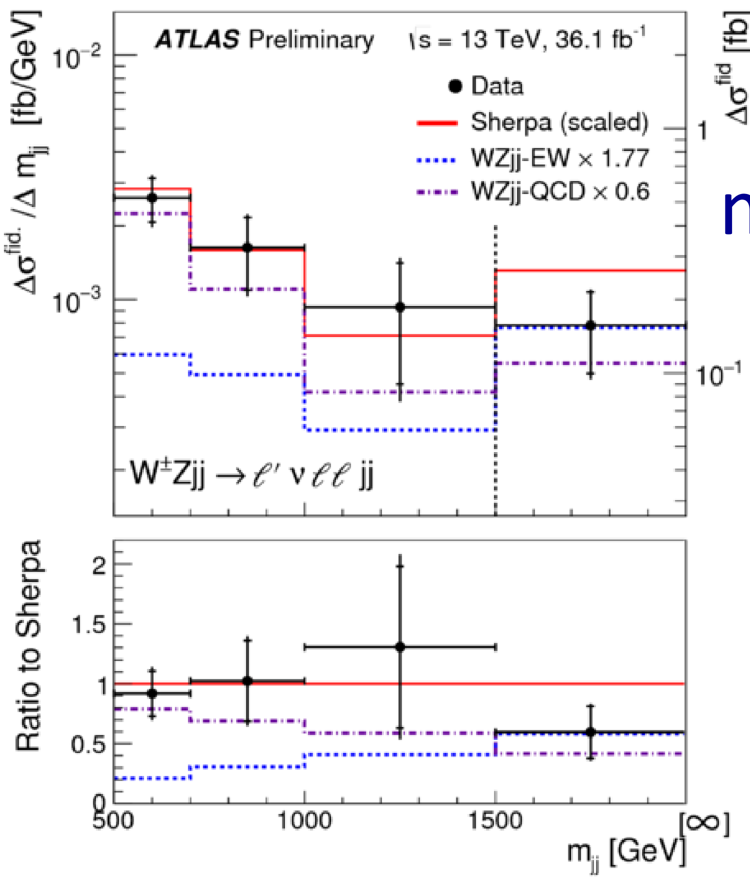
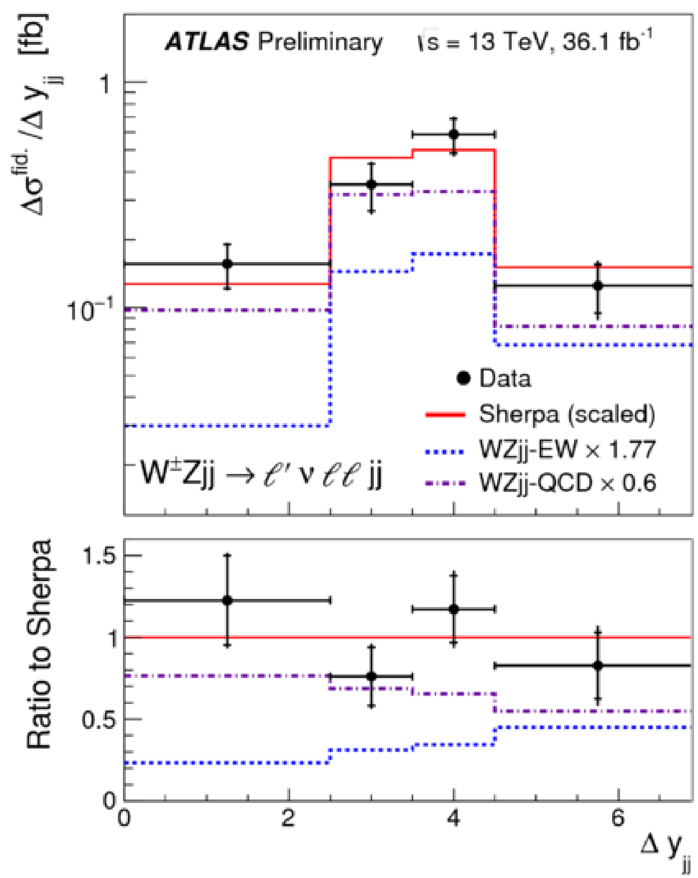
$W^{\pm}Zjj \rightarrow \ell\nu\ell\ell jj$

ATLAS-CONF-2018-033

- Differential cross-sections extracted in SR (mjj > 500 GeV)
- Compared to normalized Sherpa predictions for WZjj (QCD + EW)



m_{jj}



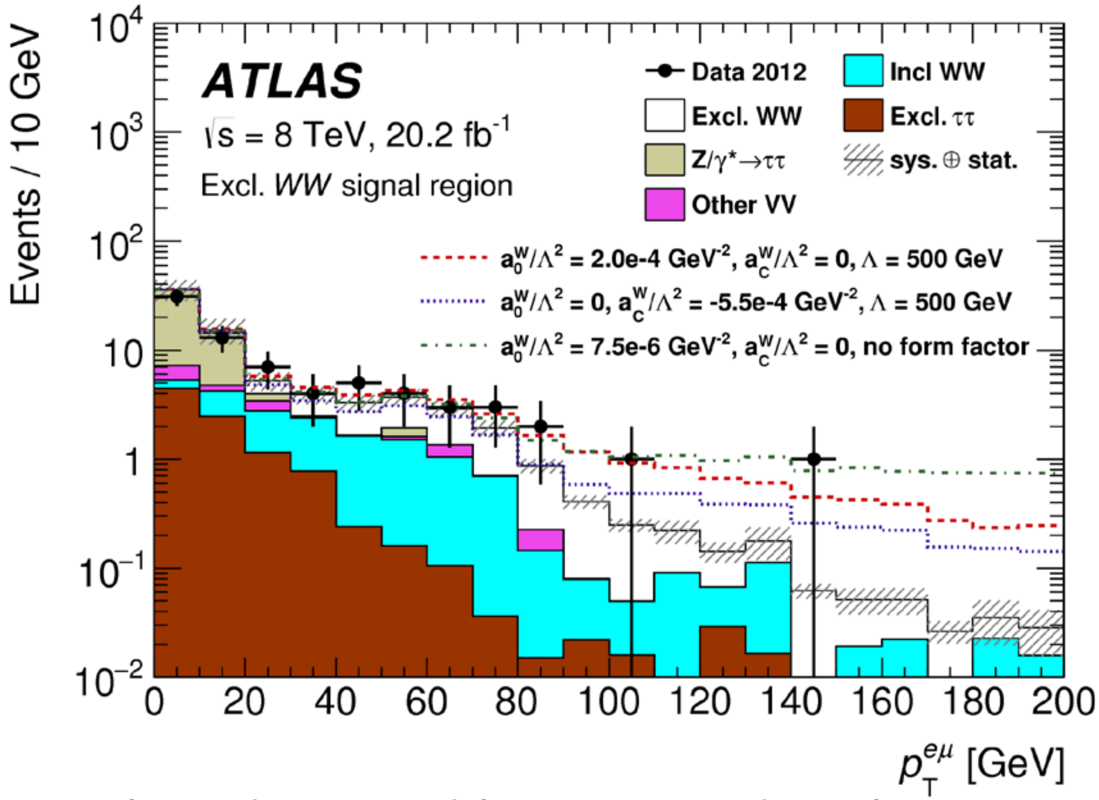
Δy_{jj}

- More distributions available: N_{jets}, Σp_T^{l}, m_T^{WZ}, $\Delta\phi_{jj}$, $\Delta\phi(W,Z)$, N_{jets}^{gap}

$\gamma\gamma \rightarrow$ WW @ 8 TeV

PRD 94, 032011 (2016)

- eμ pair with large pT, no other charged particles @ vertex
- 1st *SM signal* evidence: ATLAS: 3.0σ (8TeV)

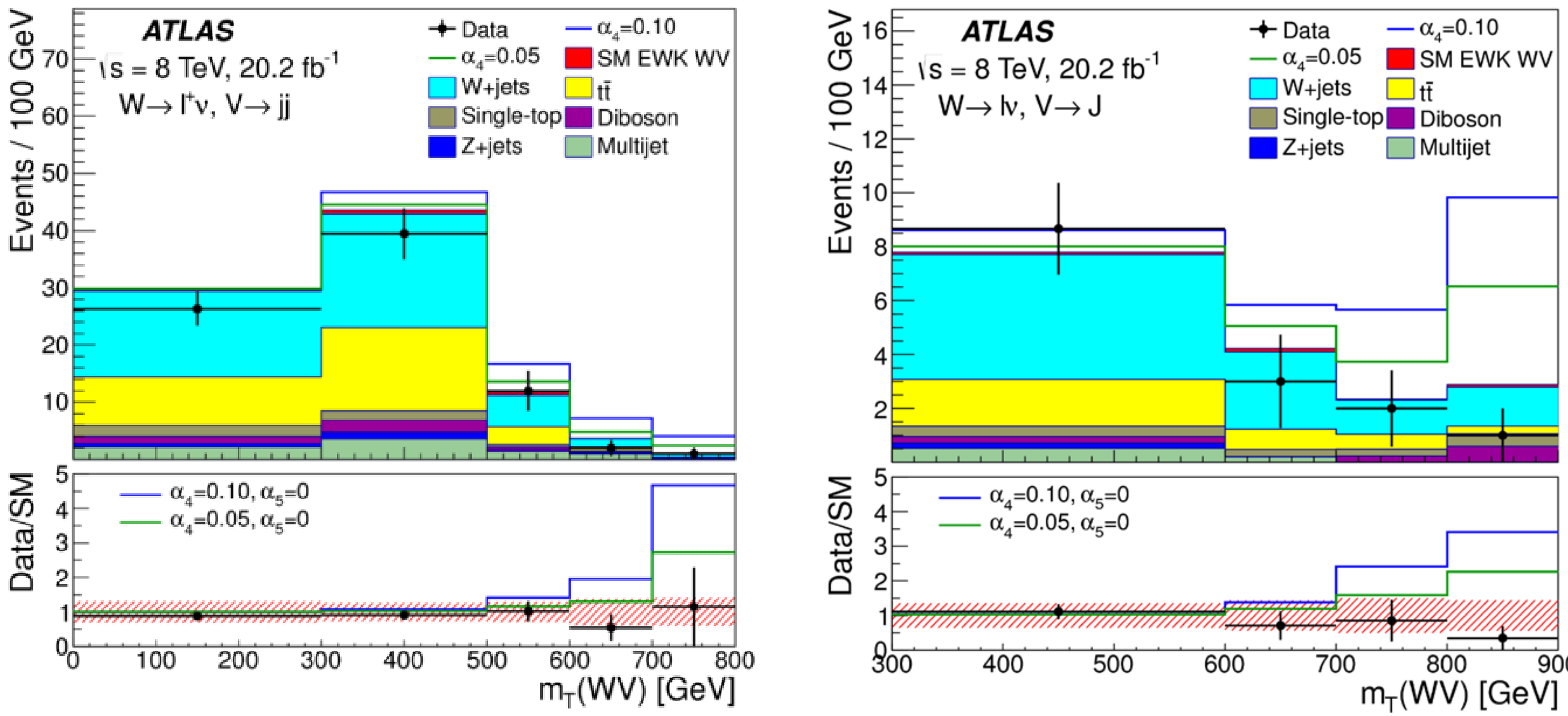


- aQGC limits placed using dilepton pT distribution
- No (tag) jets -> suppressed WWWW, WWZZ, WWZγ contributions

WVjj $\rightarrow \ell\nu$(jj/J) jj @ 8 TeV

PRD 95, 032001 (2017)

- 1 isolated lepton (e or μ), MET, jj/J **hadronic** V, two tagging jets
- Not sensitive to SM xsec yet, but optimized for aQGC $\alpha_{4,5}$

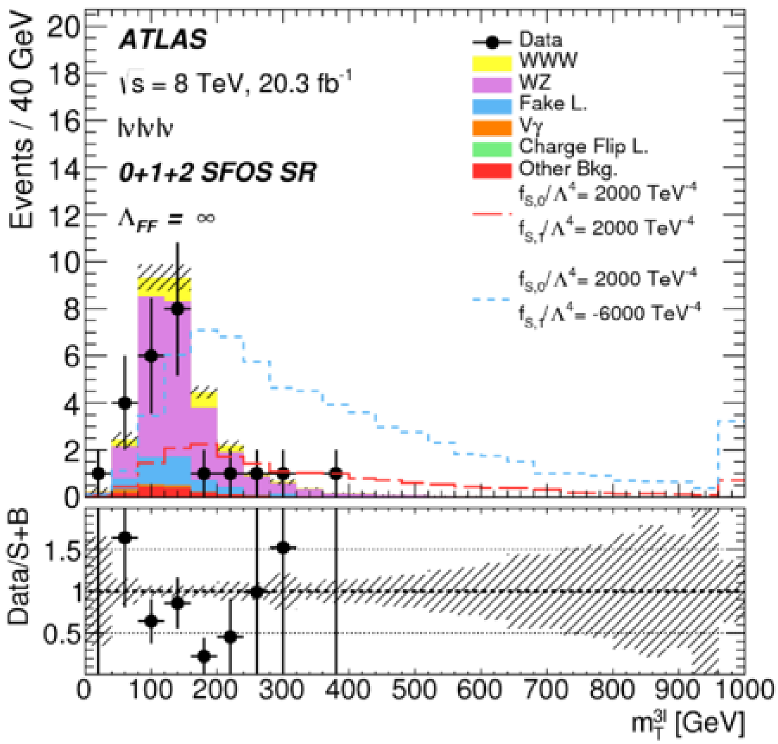


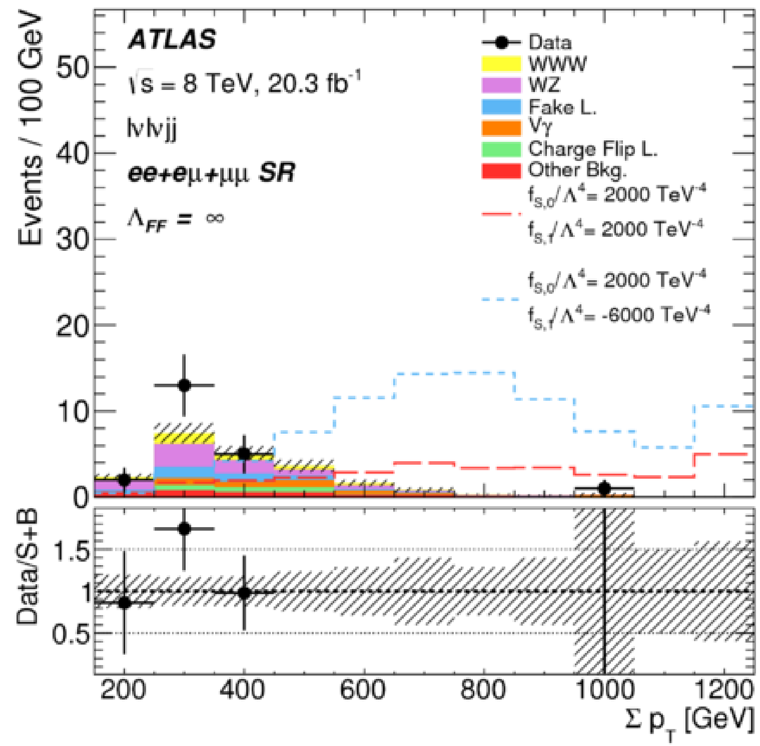
- Merged (J) category improves expected sensitivity by 40%
- No conversion $\alpha_{4,5}$ to $f_{s0,1}$ since WWjj *and* WZjj contribute

WWW → $3\ell3\nu/\ell^{\pm}\nu\ell^{\pm}\nu jj$ @ 8 TeV

EPJC 77 (2017) 141

- 3 isolated leptons (e or μ), MET – very clean, low statistics
- 2 isolated leptons (e or μ), MET, 2 jets ($W^{\pm} W^{\pm} jj$ VBS "spin-off")
- combined signal significance is ~1σ => place upper limits on xsec



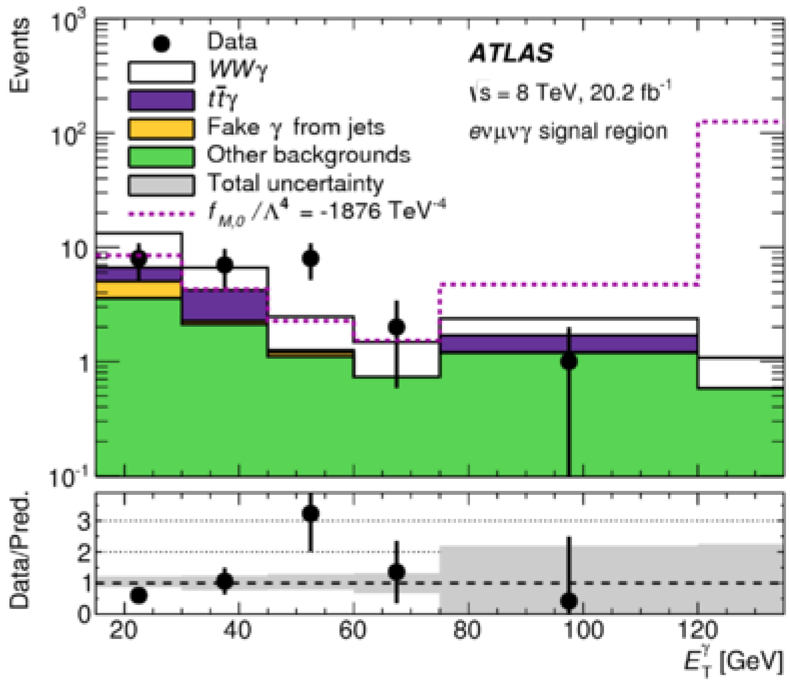


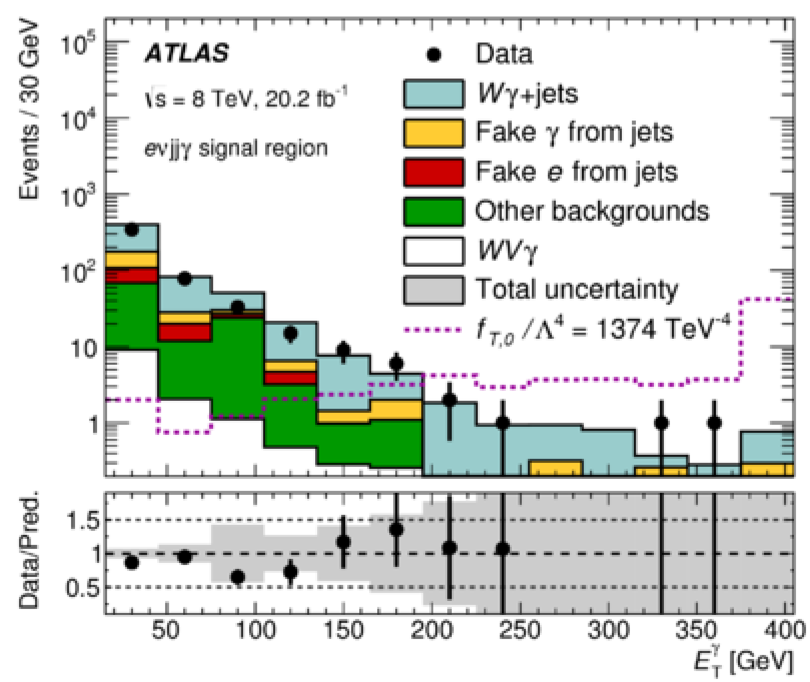
- Limits on dim-8 operators with couplings $f_{S0,1}$ set based on above distributions (combined final states)

WVγ @ 8 TeV

EPJC 77 (2017) 646

- 1 isolated lepton (e or μ), MET, ≥2 jets plus isolated photon(s): WVγ
- 1 isolated e, 1 isolated μ, MET plus isolated photon(s) : WWγ
- place upper limits on xsec in agreement with SM expectation



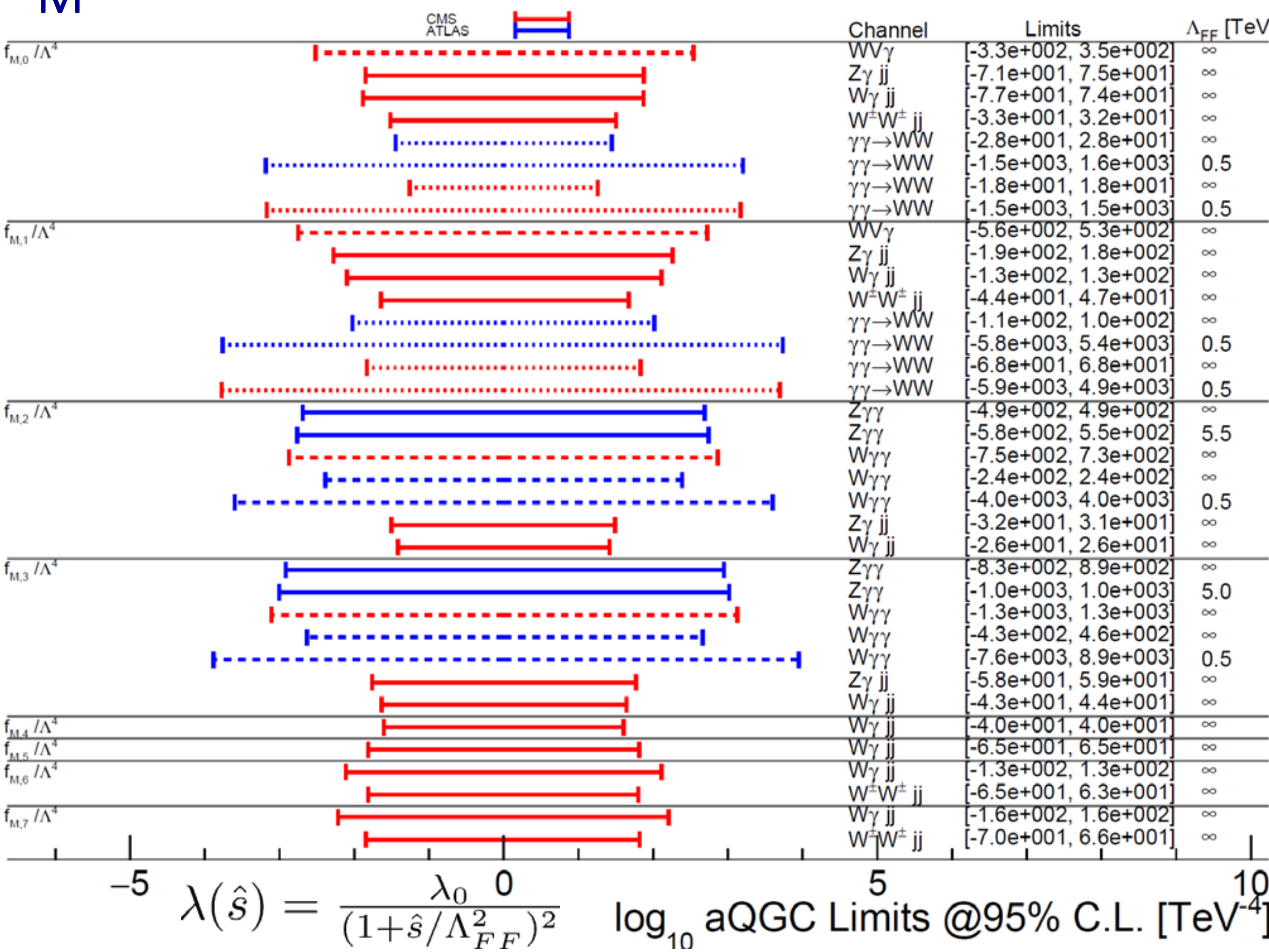


- Limits on 14 dim-8 operators with couplings $f_{Ti,}$ f_{Mi} set based on above distributions (combined final states).

aQGC status @ 8 TeV

RMP 89 (2017) no.3, 035008

f_M



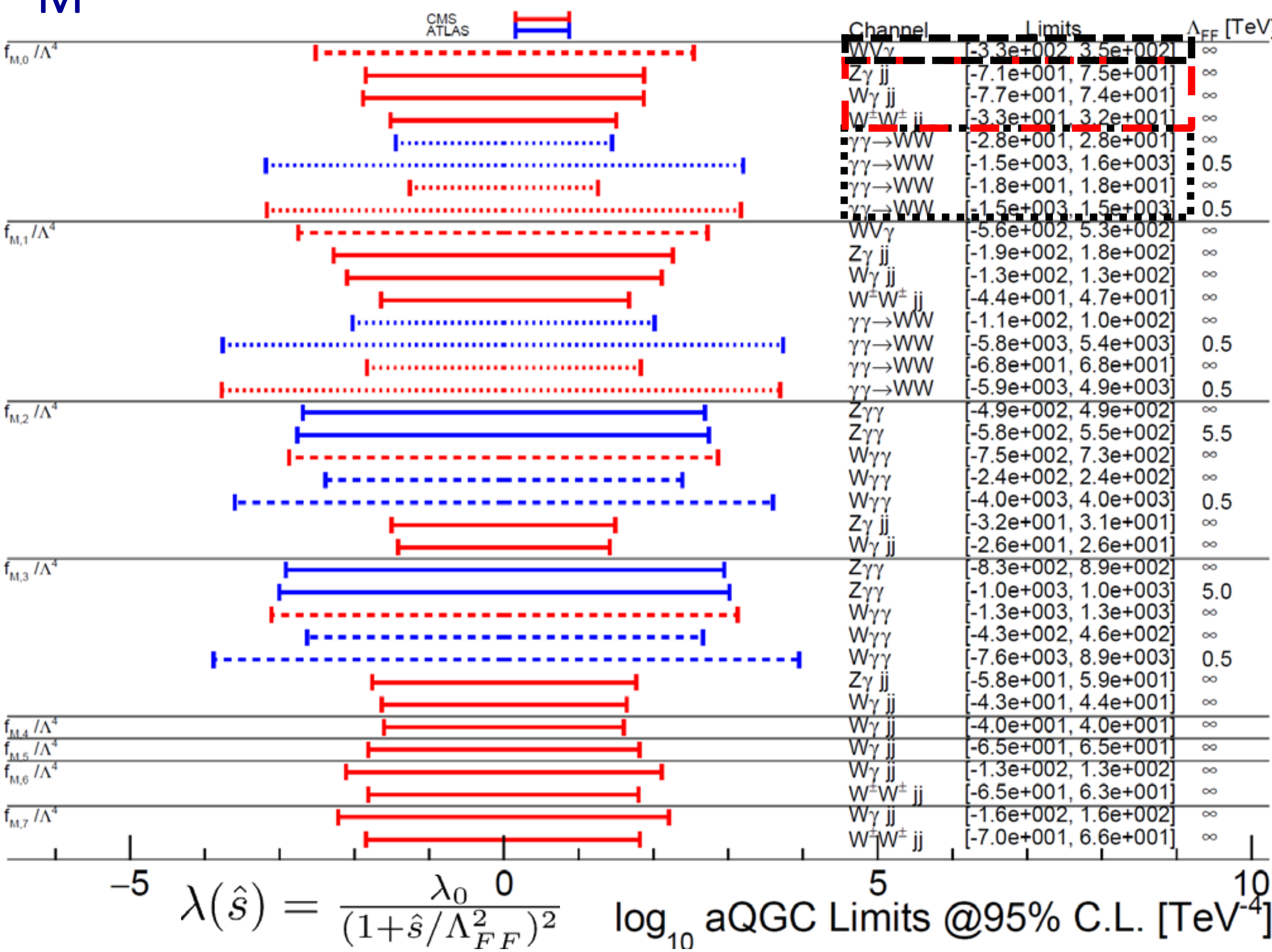
$$\lambda(\hat{s}) = \frac{\lambda_0}{(1+\hat{s}/\Lambda_{FF}^2)^2}$$

- All results use full 8 TeV datasets
- Trend that exclusive outperforms VBS, which is better than VVV
- Note **strong** impact of unitarisation
- Fair comparison requires some work

aQGC status @ 8 TeV

RMP 89 (2017) no.3, 035008

f_M



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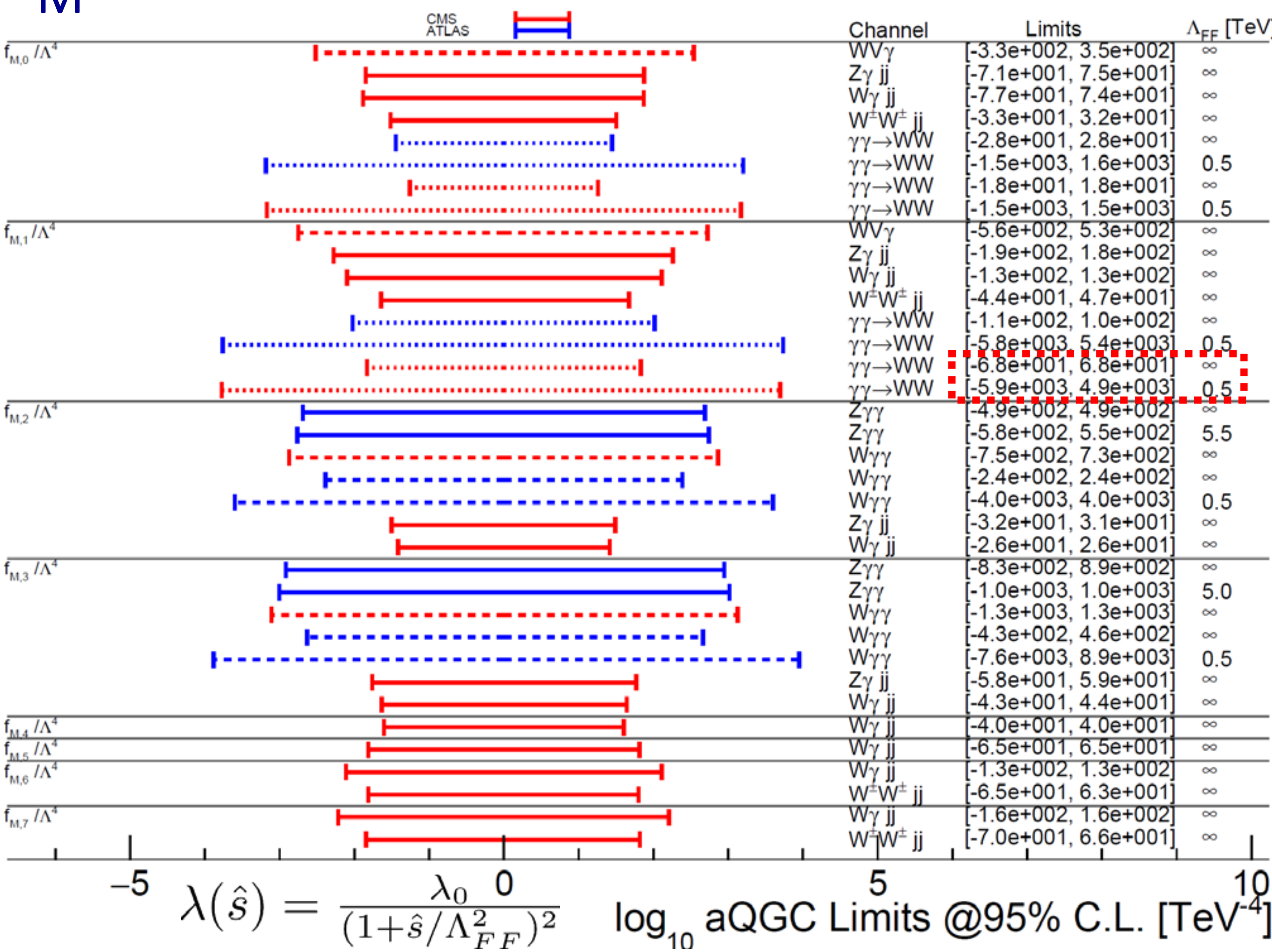
f_M



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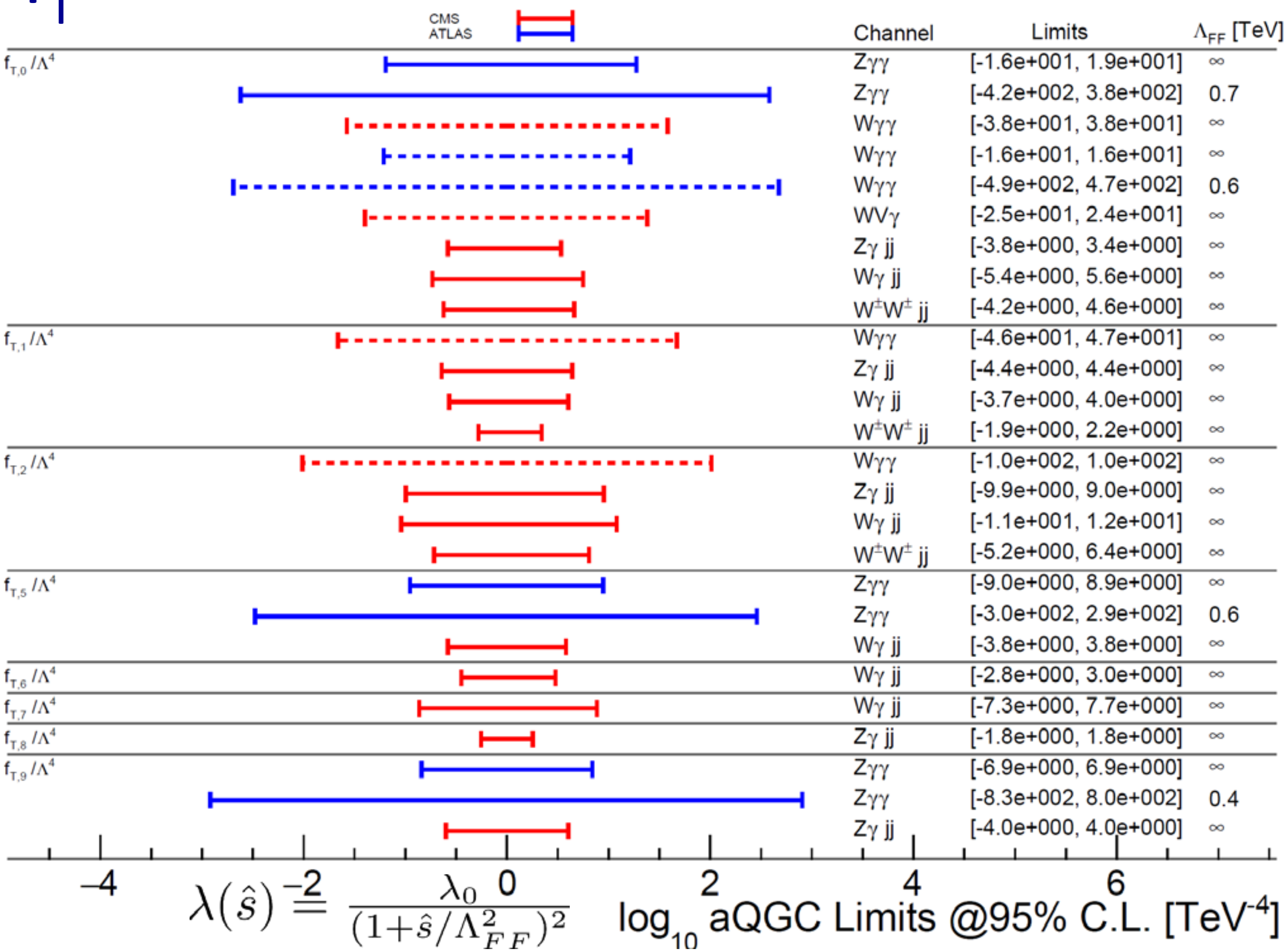
aQGC status @ 8 TeV

RMP 89 (2017) no.3, 035008

f_T



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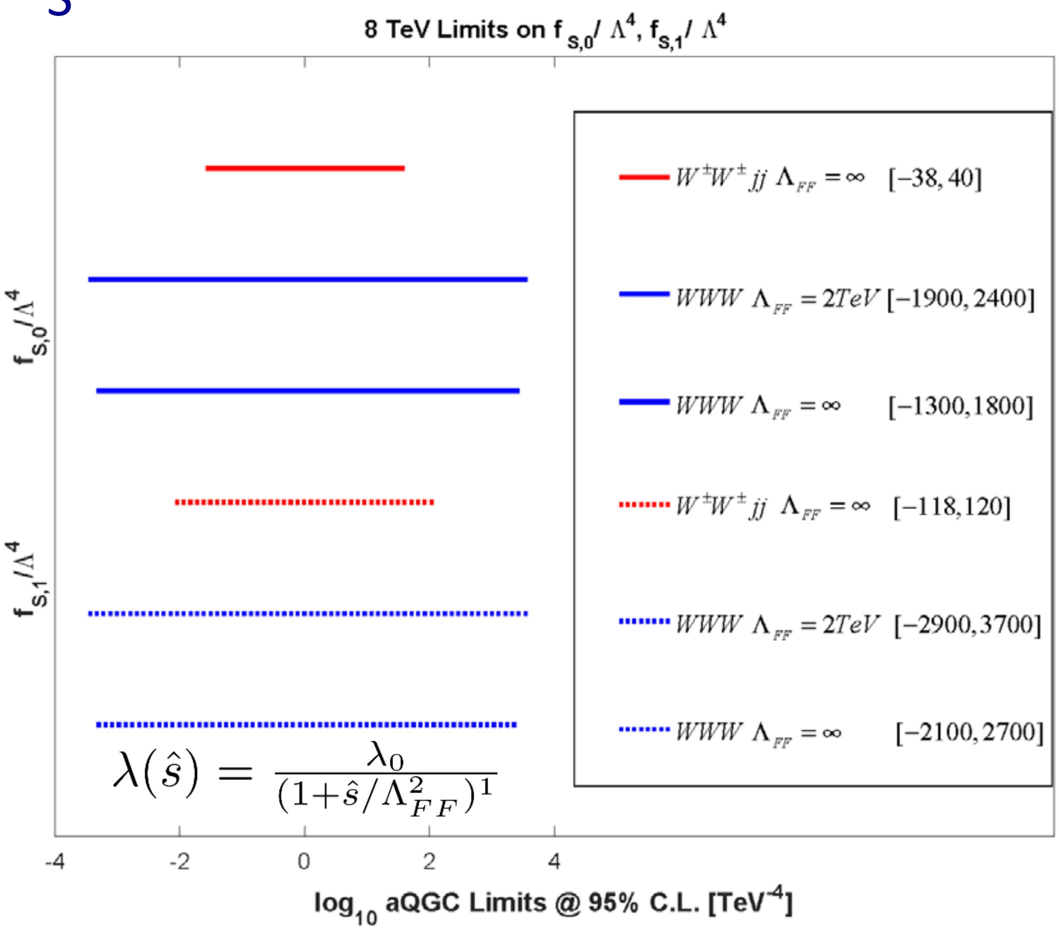
aQGC status @ 8 TeV

RMP 89 (2017) no.3, 035008

f_S



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aQGC status @ 8 TeV

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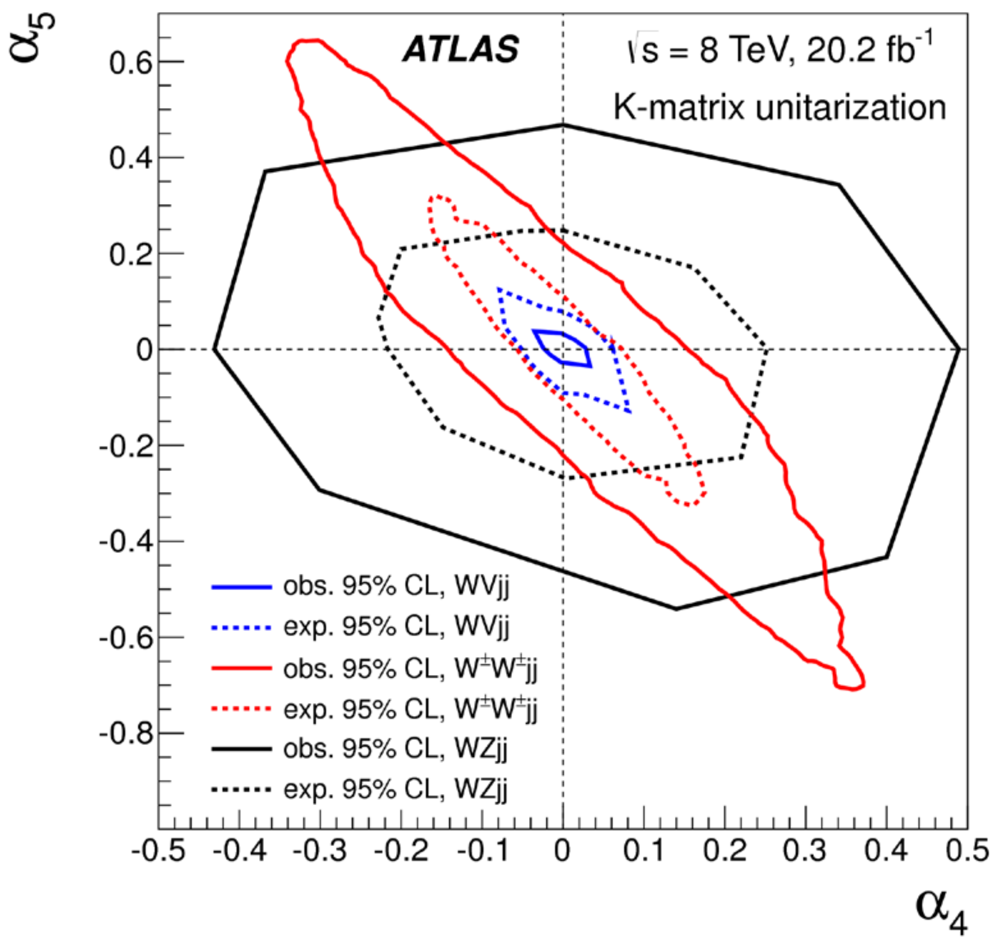

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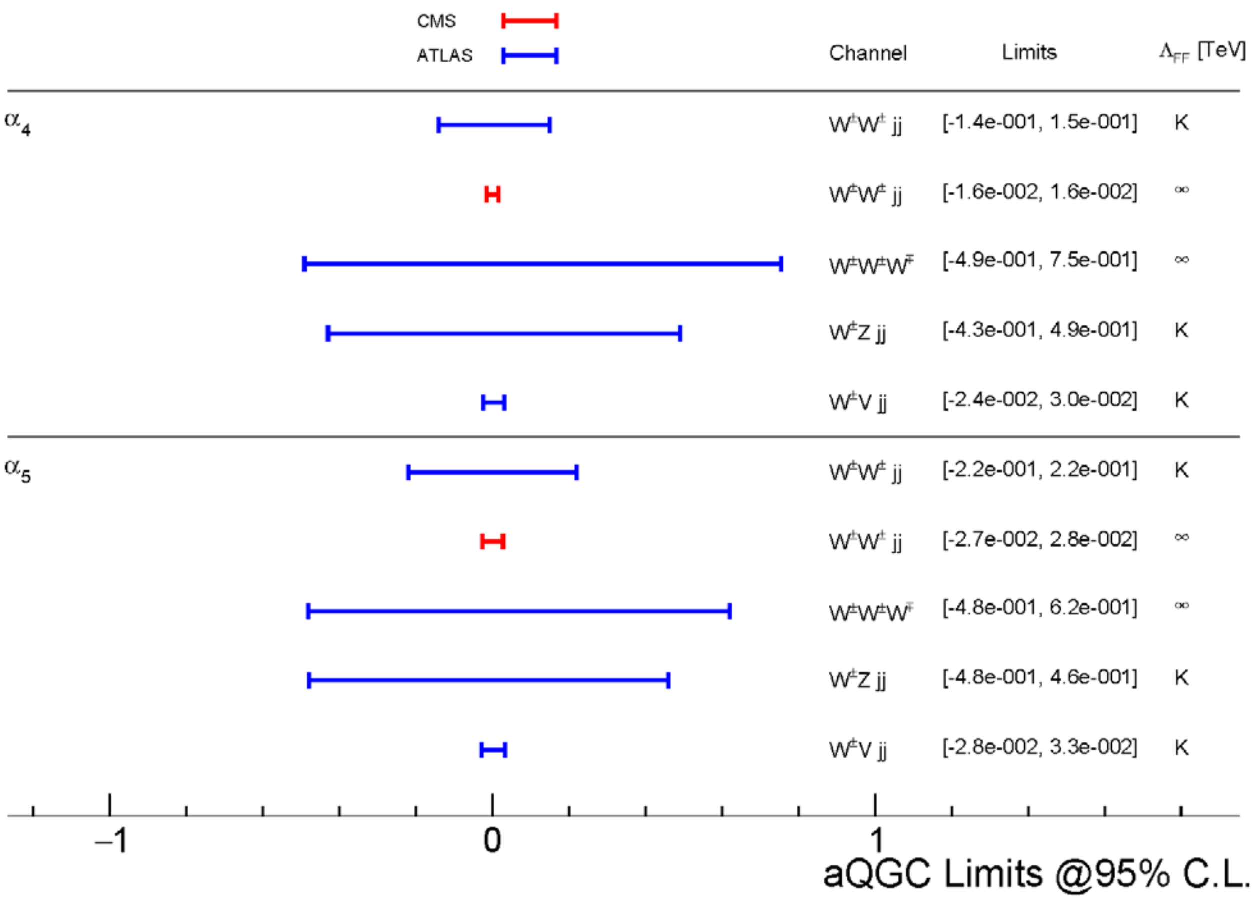
- Semileptonic VBS analysis **very** sensitive!

aQGC status @ 8 TeV

RMP 89 (2017) no.3, 035008



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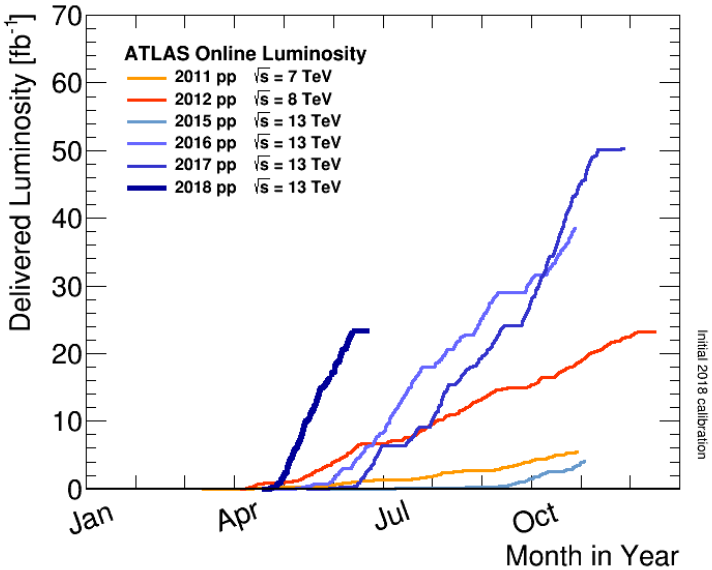
Summary

- Harvest of Run I multi-boson analyses is concluding – established many new multi-boson processes, probed new couplings.
- Run II providing access to more processes (VBS, VVV), and better BSM sensitivity!
  - First observation of EW $W^{\pm}Zjj$ production!
- The Standard model is a tough nut to crack!

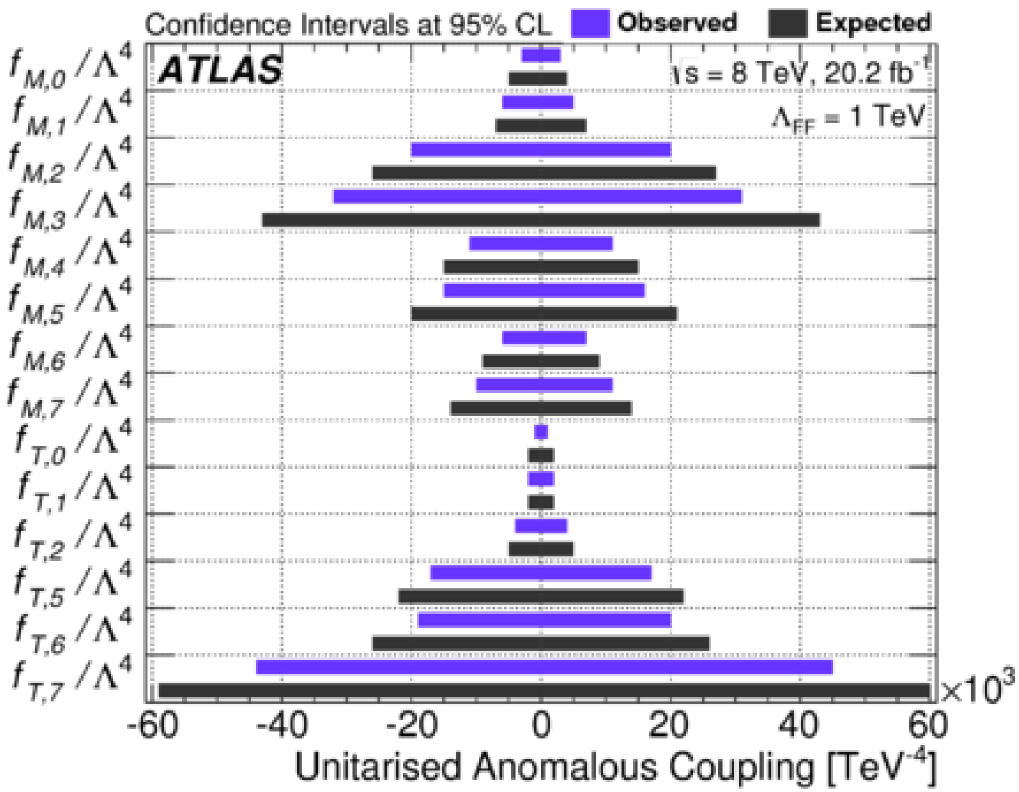


Dessert

WVγ aQGC limits @ 8 TeV

EPJC 77 (2017) 646

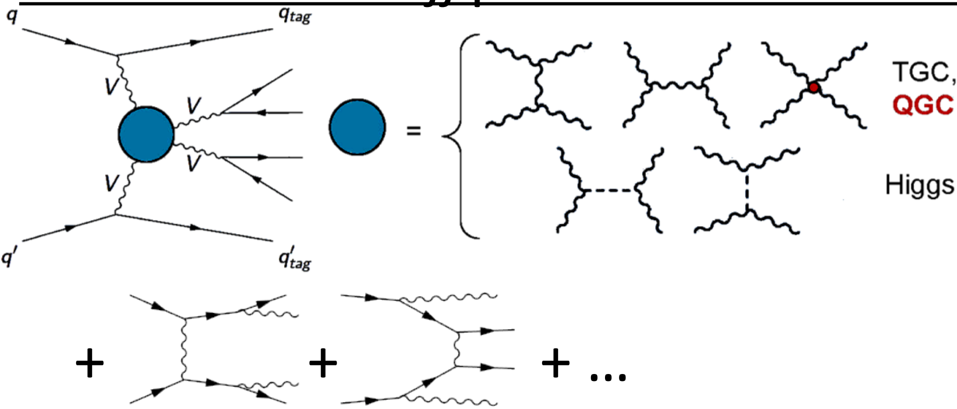
- Observed and expected 95% CL intervals on anomalous quartic gauge couplings for the combined WVγ analysis.
- Couplings are unitarised using a dipole form factor with a form factor energy scale of Λ_{FF} = 1 TeV.

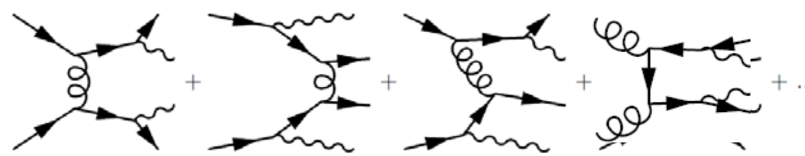


Vector Boson Scattering

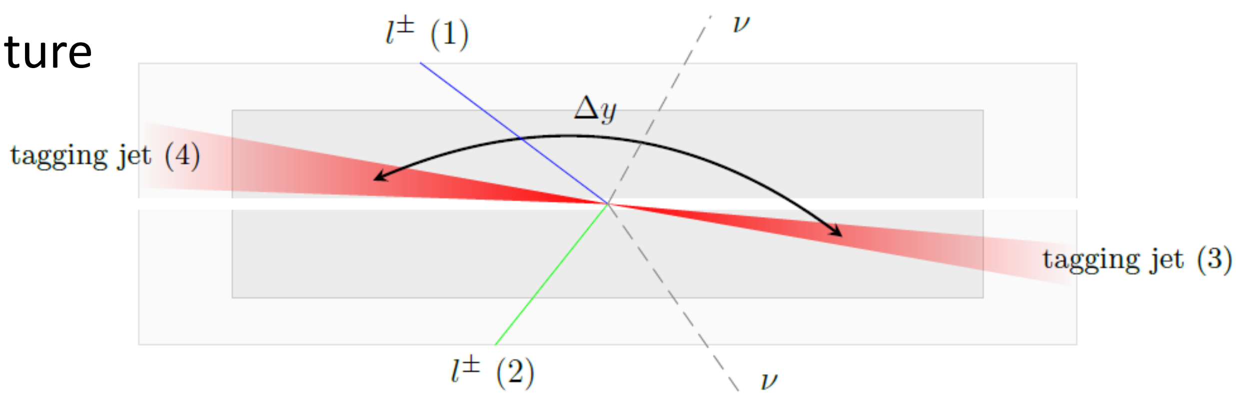
- VV $\rightarrow$ VV provides insight into EWSB mechanism, access to quartic couplings:

electroweak VVjj production includes: strong VVjj production includes:





- Experimental signature ($W^{\pm}W^{\pm}$ example):



- 1,2 = Central, high-p_T charged leptons from V decays
- 3,4 = Forward/backward tagging jets (large m_{jj} and well separated in y)