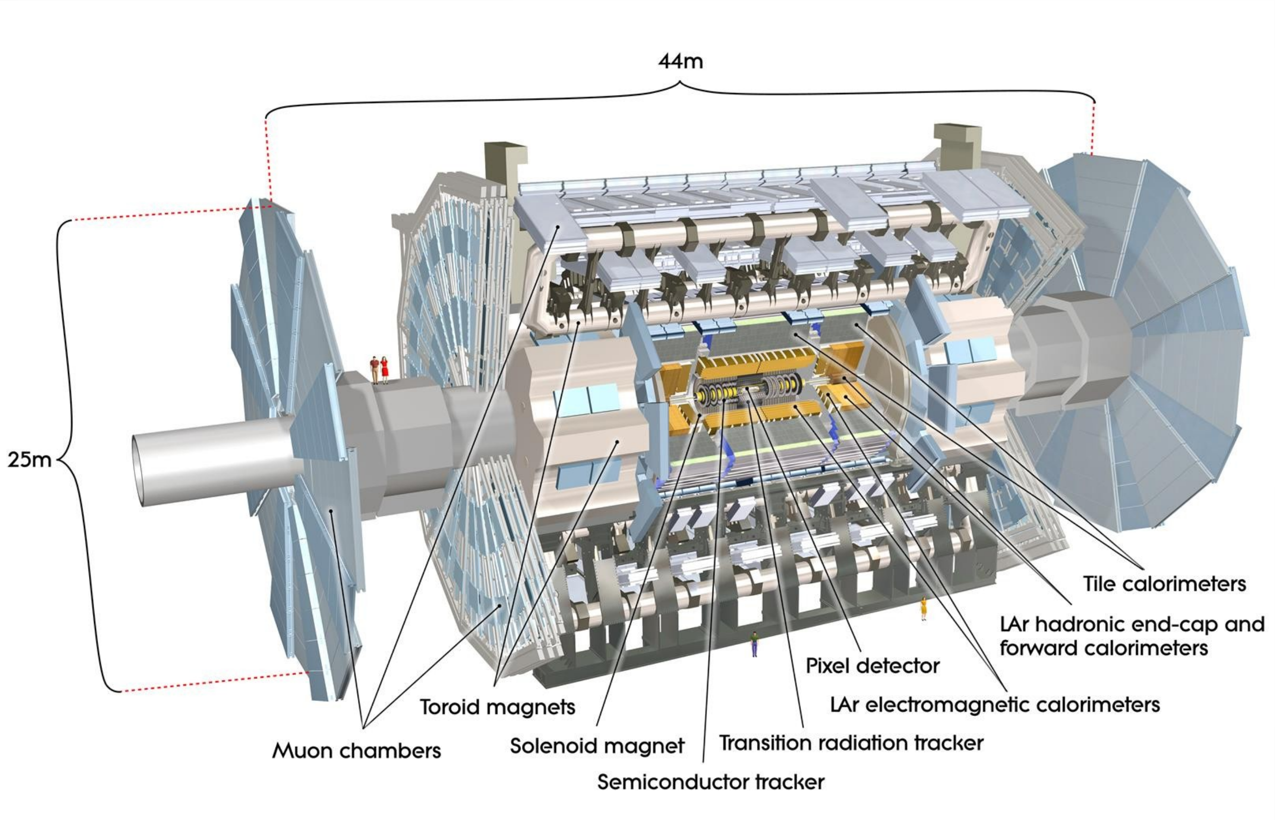
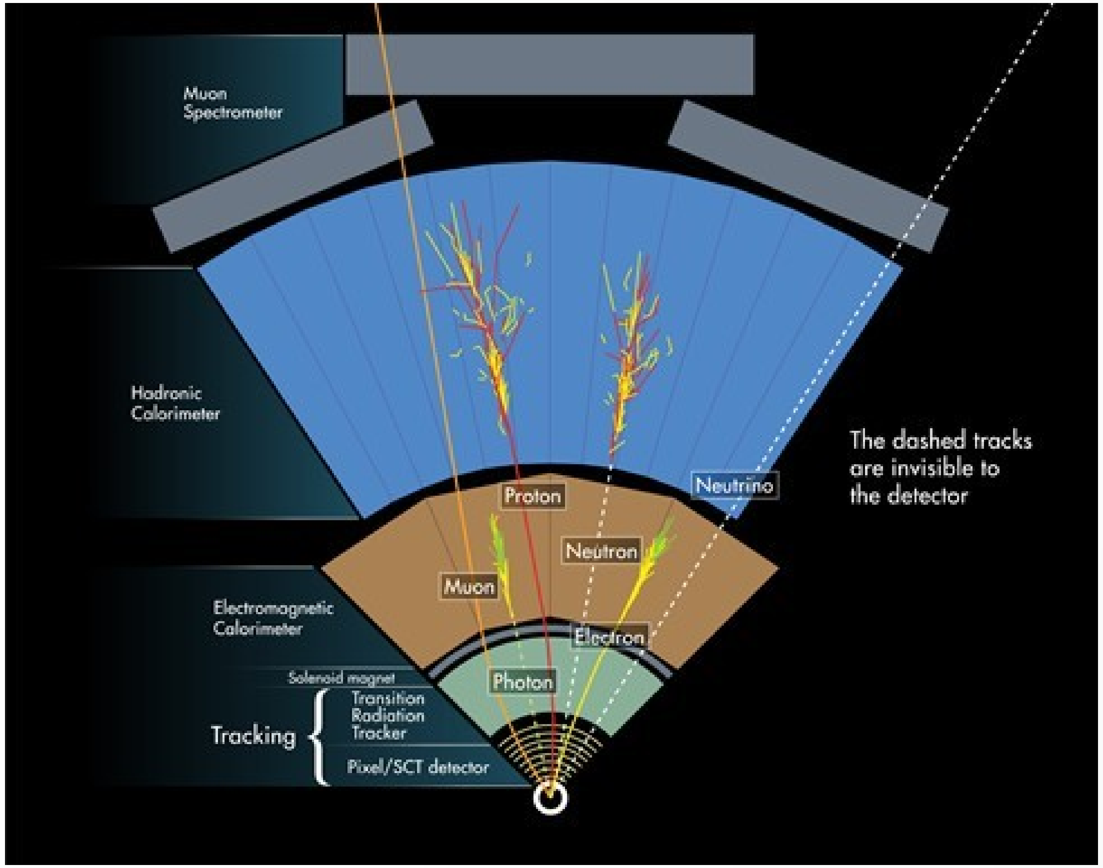
Multiboson production with the ATLAS detector

Raphaël Hulsken, McGill University
On behalf of the ATLAS collaboration

2024 CAP in London, Ontario

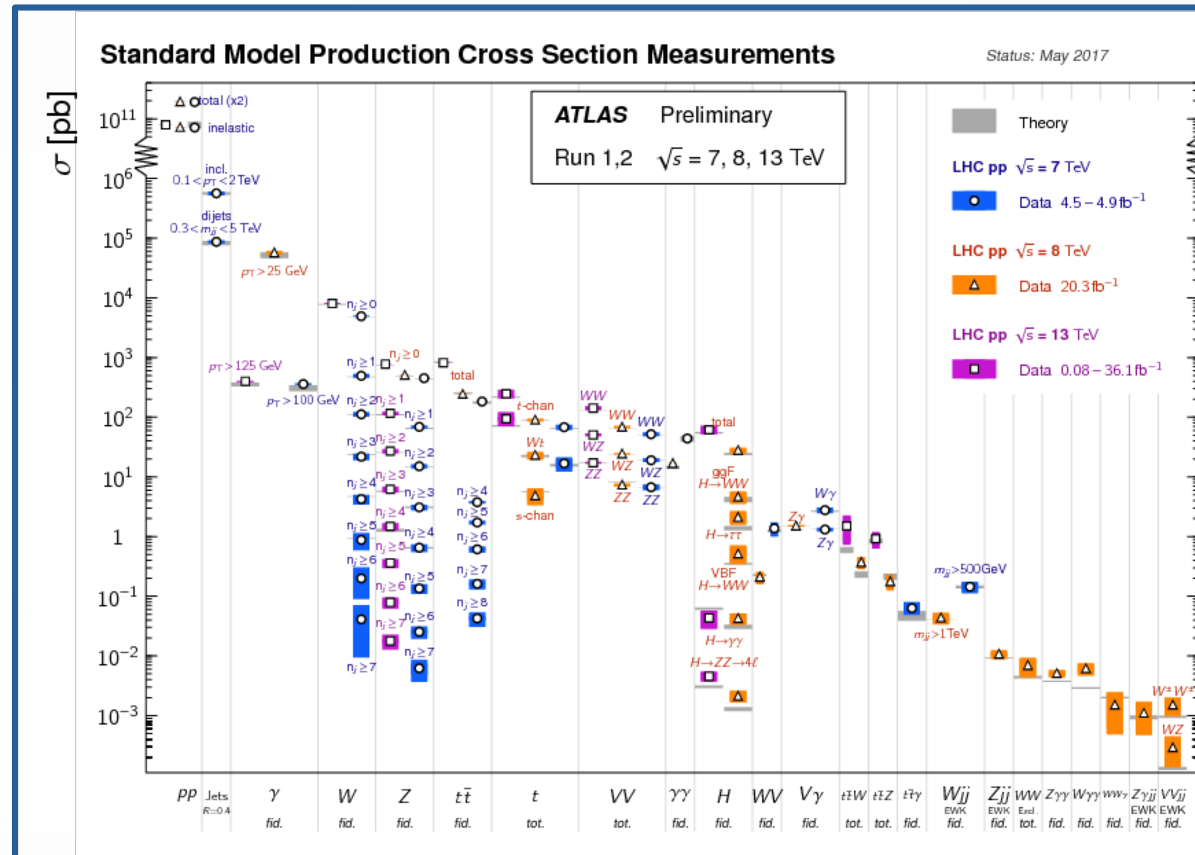
ATLAS detector





Physics motivations

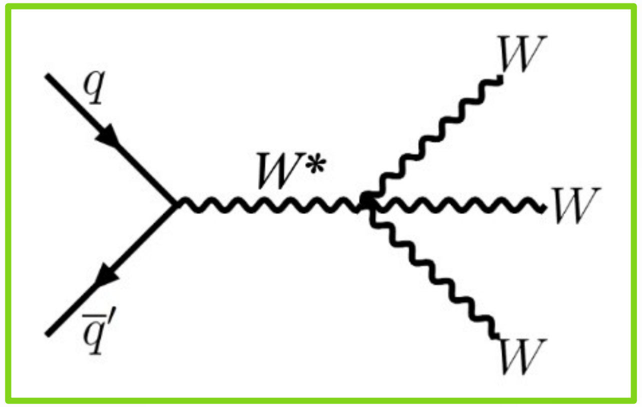
- Measure Triboson final states: small cross section, need full run 2 at LHC
- Test beyond Standard Model theories
  - Sensitivity to anomalous Quartic Gauge Coupling (aQGC)
  - Limit to Effective Field Theories can be set
- Backgrounds composition run 3 analysis (ZH(γγ) WH(γγ))



Triboson states presented here

WWW

STDM-2019-09



- **Background treatment :**
  - WZ+jets

    estimated in same flavour opposite sign lepton CR
  - WZ+jets in 2lep and ZZ+jets in 3l SR

    reduced with veto on additional loose lepton
  - Z(ll)

    Exlcude 80<m_{ll}<100 GeV

- **WWW Observation** at 8.0 (5.4) standard deviation (expected)
  Within 2.6 σ of theory prediction
- Using at least two lepton:

  2 lepton + 2 jets SR : using same-charge lepton

  3 leptons SR : no same flavour opposite sign lepton

- Fit method :

  Separate BDT for 2l and 3l, simultaneous fit for both **BDT distribution** and m_{ll} distribution for the WZ CR

WWW

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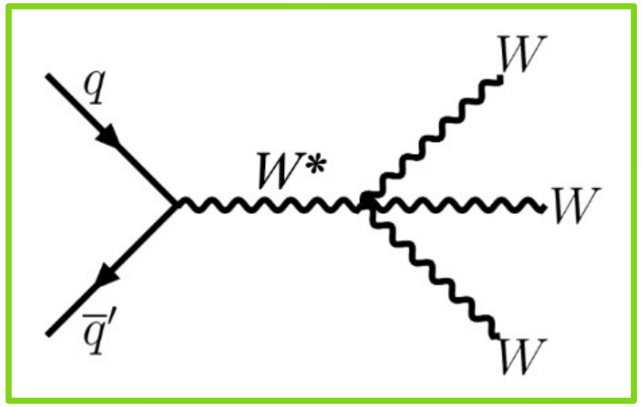

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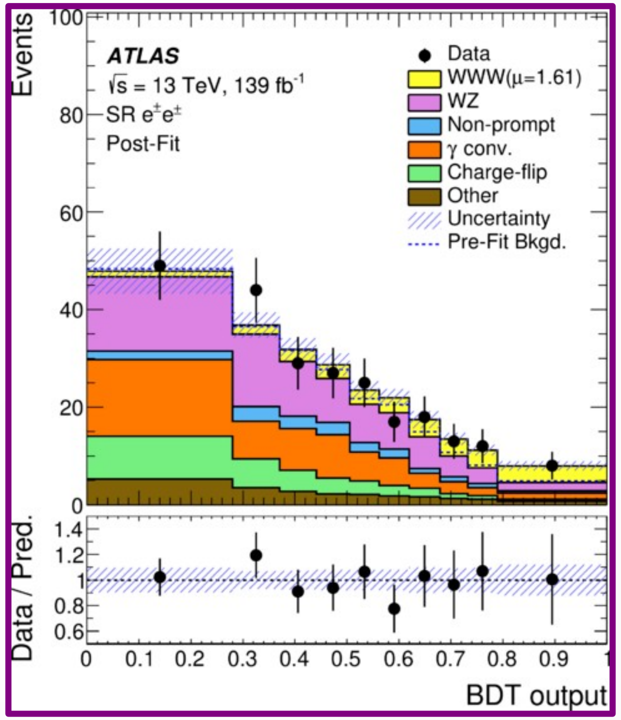
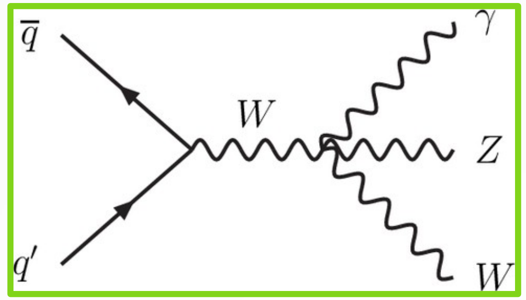


WZγ

STDM-2019-17



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  - j→γ background

    Estimation in looser selection CR using Z+jets sample
  - j→l background

    Estimated in looser selection CR using dijet sample
  - ZZγ and ZZ(e→γ)

    Reduced by $|m_{l(w)\gamma} - Z_{mass}| > 10$ GeV selection normalized with dedicated CR

- **First measurement** of WZγ cross section at 6.3 (5.0) standard deviation observed (expected)

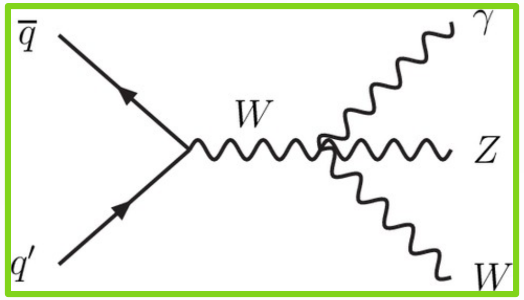
  within 1.5 σ of theory prediction
- Using l'llγ channel one same flavor opposite charge pair

  $m_{l(Z)l(Z)} > 81$ GeV for FSR reduction

Profile likelihood fit of the 4 e/μ final states (3 regions, 1SR and 2CR)

WZγ

STDM-2019-17



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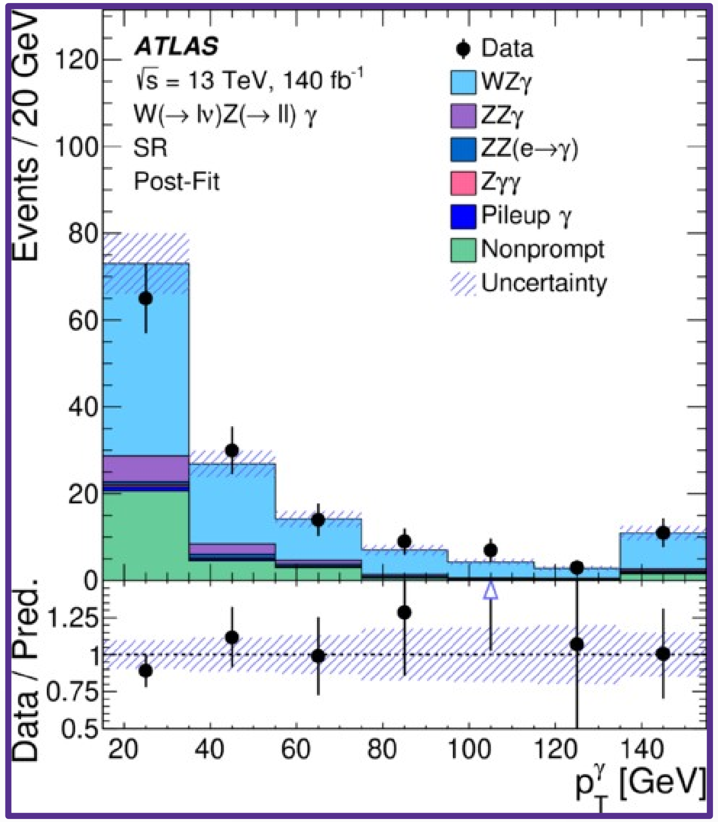
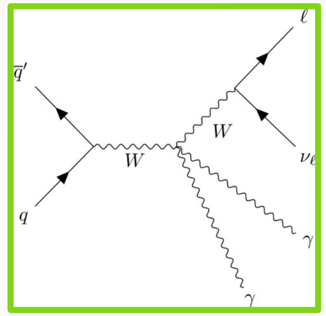


Wγγ

[STDM-2018-33](#)



- **First measurement** of Wγγ at 5.6 (5.6) standard deviation observed (expected) in agreement with the SM prediction
- Using e/μ channel

  E_T^{miss} presence

- **Background treatment:**
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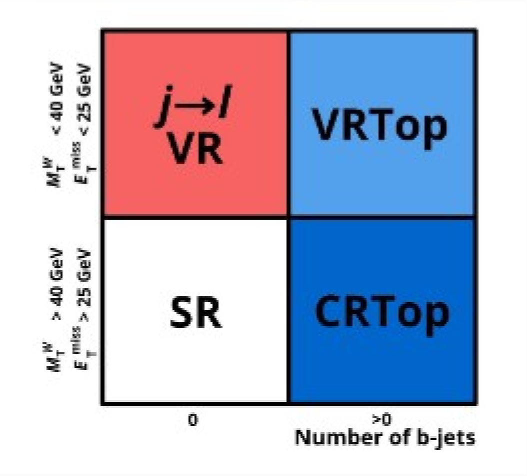
    2D (leading/sub-leading) template fit of photon isolation energy in data
  - e→γ

    Data driven fake rate estimate in Z→ee/eγ CR
  - Top background
    - Reduced via b veto
    - **Dedicated CR** (with >= 1 b-jet) for fit constrain
    - **Low E_T^{miss} region** (with >= 1 b-jet) for validation



Wγγ

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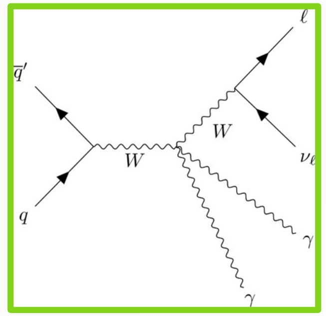

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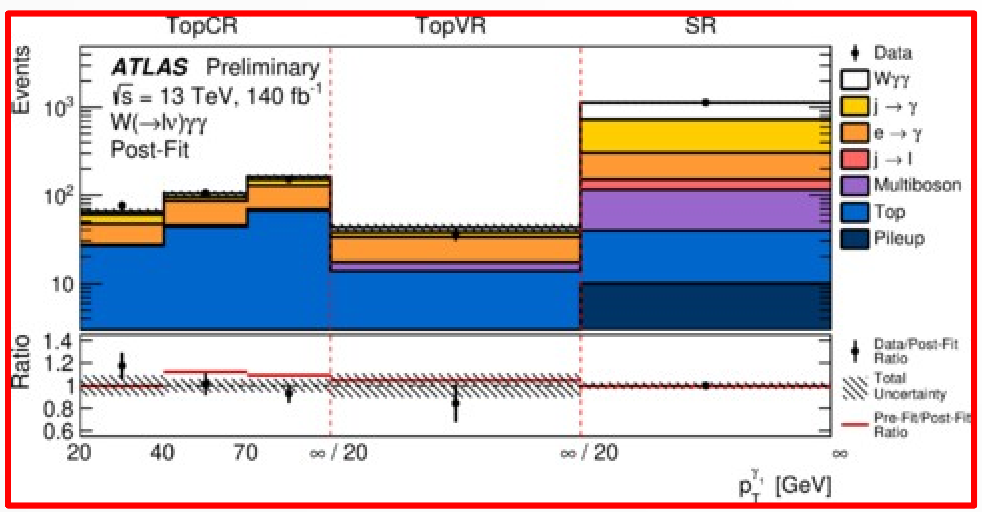
  4 bin likelihood fit (using **topCR**, **topVR** and SR)



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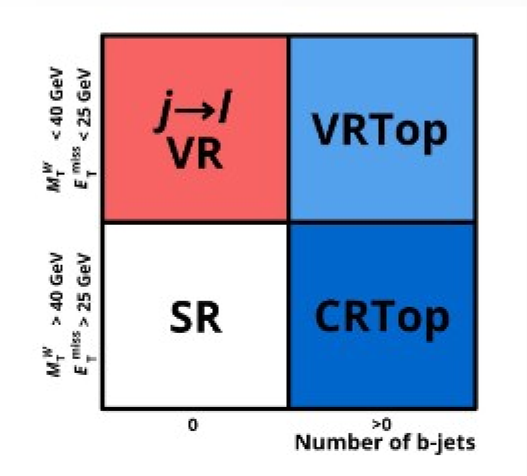

EFT interpretation aQGC

- Effective Field Theory (EFT) used to add higher dimension operator to the SM Lagrangian
- Dimension 6 and 8 contribute to anomalous Quartic Gauge Coupling (aQGC)

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \sum_{n=5}^{\infty} \frac{f_n}{\Lambda^{n-4}} \mathcal{O}_n,$$

$$\left| A_{\text{SM}} + \sum_i c_i A_i \right|^2 = |A_{\text{SM}}|^2 + \sum_i c_i \, 2\,\text{Re}(A^*_{\text{SM}} A_i) + \sum_i c_i^2 |A_i|^2 + \sum_{ij, i \neq j} c_i c_j \, 2\,\text{Re}(A_i A^*_j) \,,$$

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SM INT with SM aQGC

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Dimension 8 operators

- Three types of operator (using Eboli-Gonzalez–Garcia Model) can be defined respecting charge-conjugate and parity

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$$\mathcal{O}_{S,0} = \left[(D_\mu\Phi)^\dagger D_\nu\Phi\right] \times \left[(D^\mu\Phi)^\dagger D^\nu\Phi\right]$$
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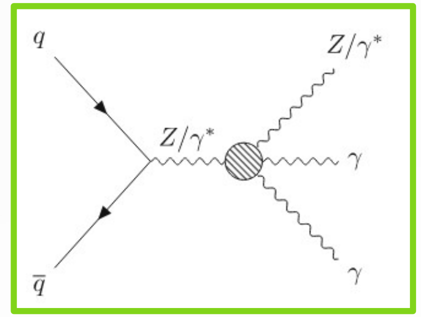
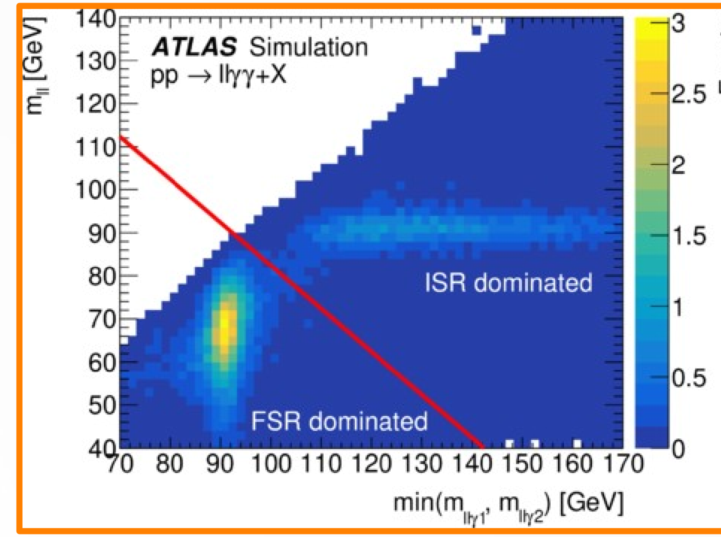
	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA	AAAA
$\mathcal{O}_{S,0}$, $\mathcal{O}_{S,1}$	X	X	X						
$\mathcal{O}_{M,0}$, $\mathcal{O}_{M,1}$,$\mathcal{O}_{M,6}$,$\mathcal{O}_{M,7}$	X	X	X	X	X	X	X		
$\mathcal{O}_{M,2}$,$\mathcal{O}_{M,3}$, $\mathcal{O}_{M,4}$,$\mathcal{O}_{M,5}$		X	X	X	X	X	X		
$\mathcal{O}_{T,0}$,$\mathcal{O}_{T,1}$,$\mathcal{O}_{T,2}$	X	X	X	X	X	X	X	X	X
$\mathcal{O}_{T,5}$,$\mathcal{O}_{T,6}$,$\mathcal{O}_{T,7}$		X	X	X	X	X	X	X	X
$\mathcal{O}_{T,8}$,$\mathcal{O}_{T,9}$			X			X	X	X	X

Zγγ

[Phys. J. C 83, 539](#)





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  measurement with 12 % precision

- Using e/μ channel

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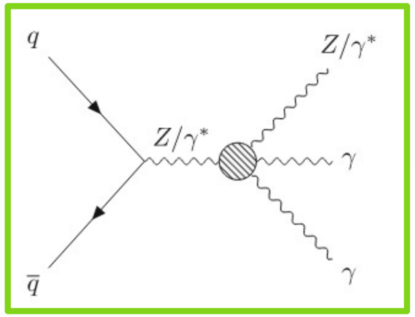
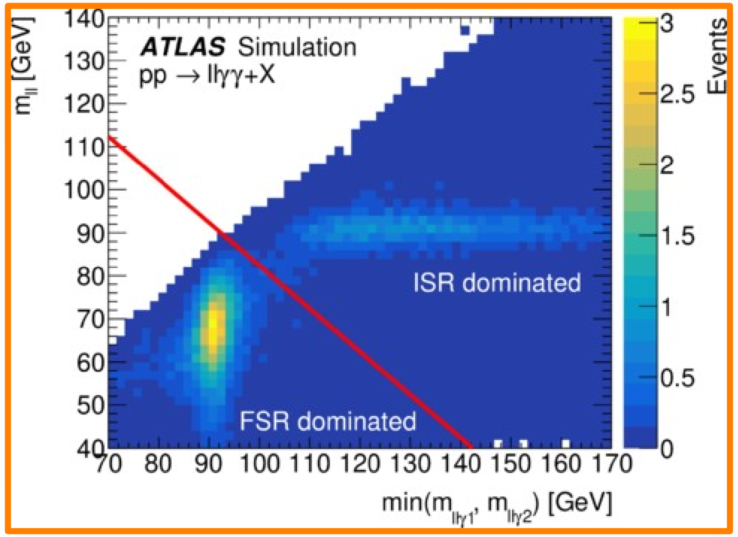
- Differential cross-sections (6 kinematic observables: $E_T^{\gamma 1}$, $E_T^{\gamma 2}$, p_T^{ll}, $p_T^{ll\gamma\gamma}$, $m_{\gamma\gamma}$, $m_{ll\gamma\gamma}$)

Zγγ

[Phys. J. C 83, 539]





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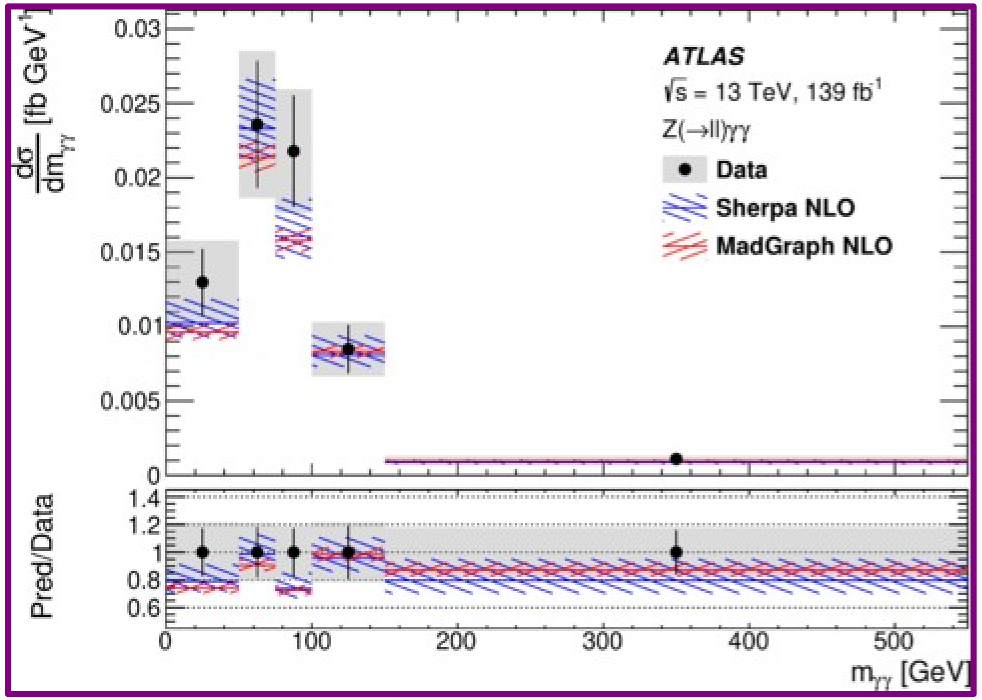
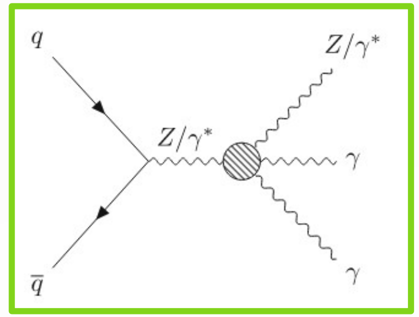
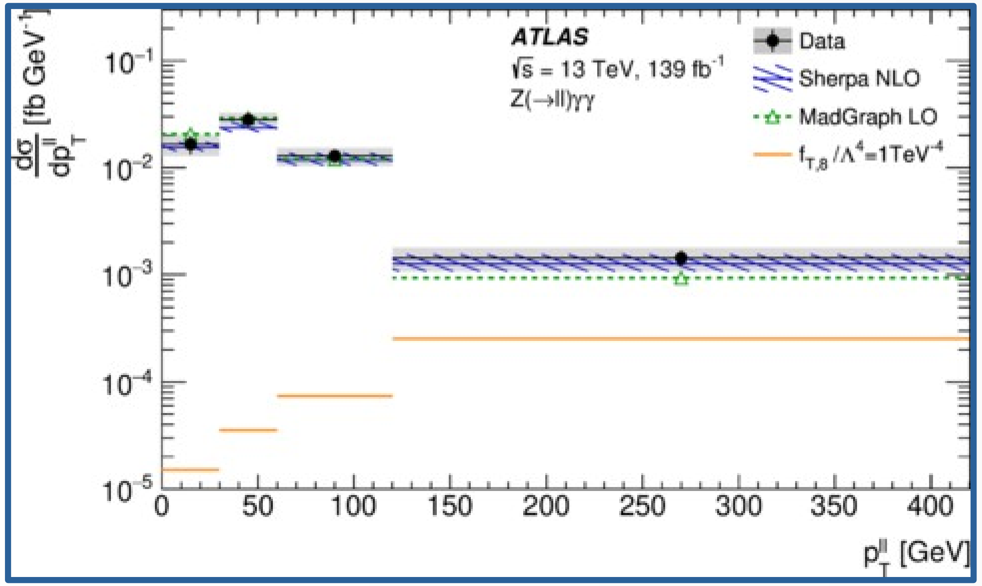


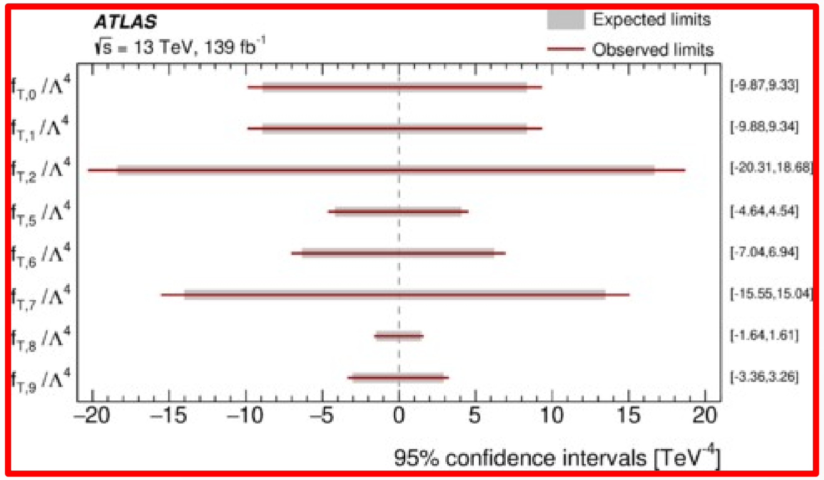
Zγγ (aQGC)



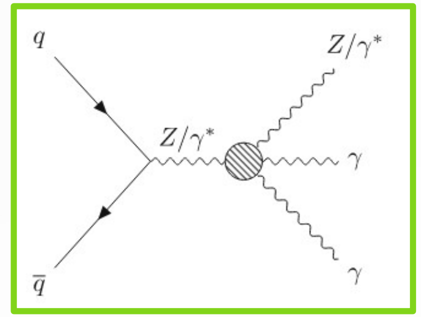
[Phys. J. C 83, 539]



- **Limit set on aQGC operators** using EFT approach
  - T_1, T_2, T_6, T_7 operator reduced up to two orders of magnitude compare to 8TeV (Phys. Rev. D 93, 112002)



Zγγ (aQGC)



Phys. J. C 83, 539

- **Limit set on aQGC operators** using EFT approach
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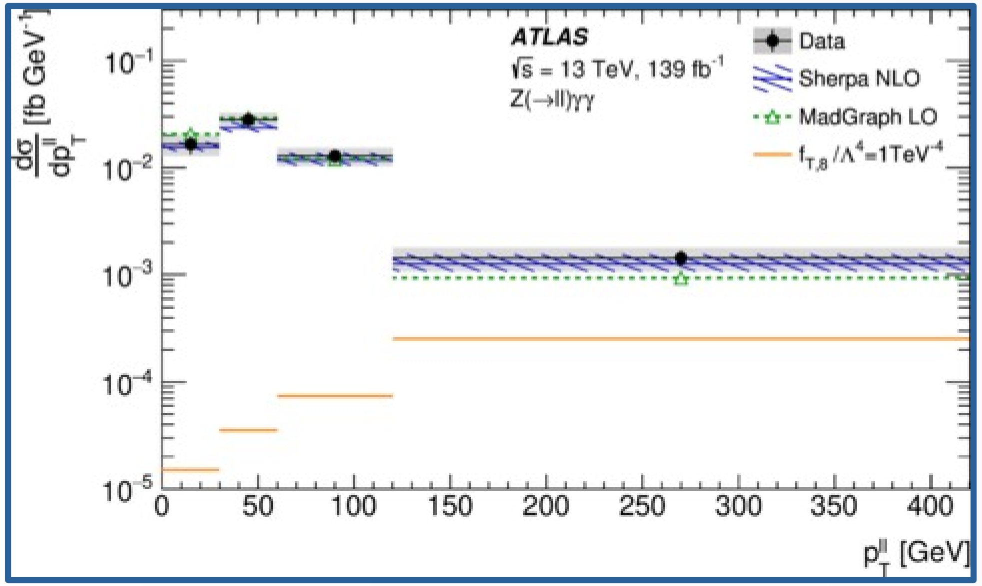
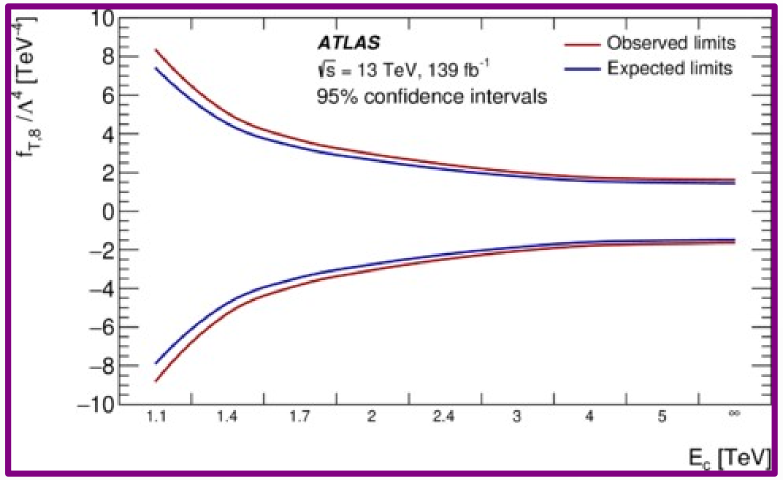
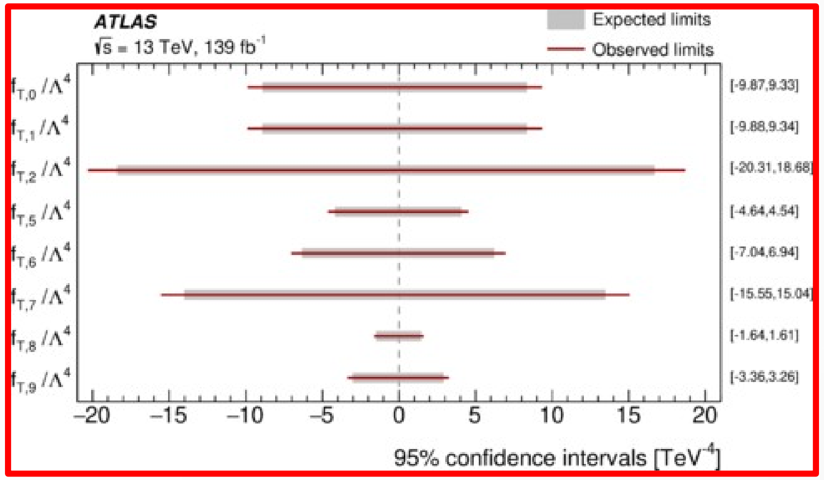
  - **Clipping method** used to restore unitary at large energy scale

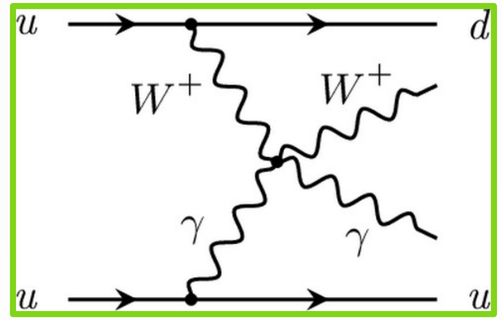






Wγjj

STDM-2018-31



$$\xi_{l\gamma} = \left|\left(y_{l\gamma} - \frac{(y_{j_1}+y_{j_2})}{2}\right)/(y_{j_1} - y_{j_2})\right|$$

- **Fiducial cross section** Observed (expected) >6 (6.3)
- Using 1 lepton and 1 photon
  - $|m_{l\gamma} - Z_{mass}|$ > 10 GeV to remove lepton consistent with Z
  - SR : no jet between leading jet; >0 jets for CR
  - **centrality of the lepton-photon** system relative to the VBS tagged jets to define SR and CR
- **Fit on the NN score** in SR and CR regions
- **Differential cross** section on 6 variables: m_{jj}, …, $\Delta\phi_{l\gamma}$, $m_{l\gamma}$

Wγjj

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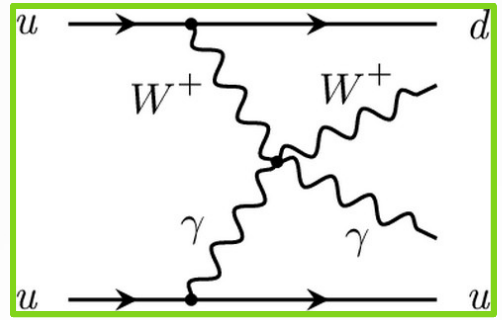

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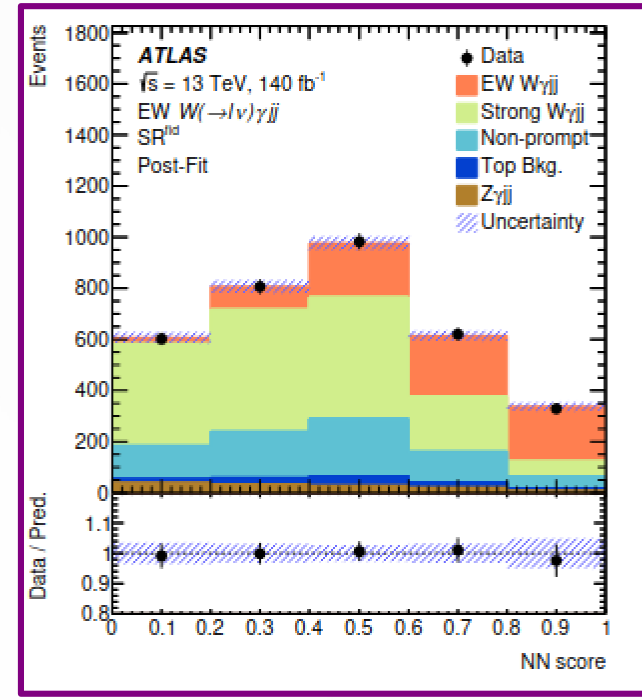

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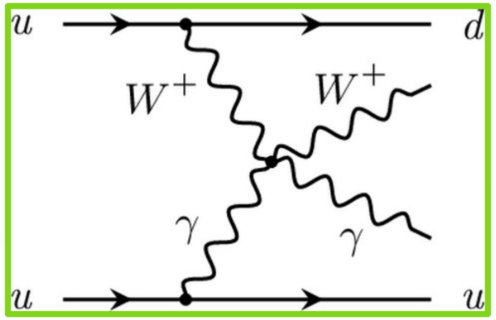
Wγjj

STDM-2018-31



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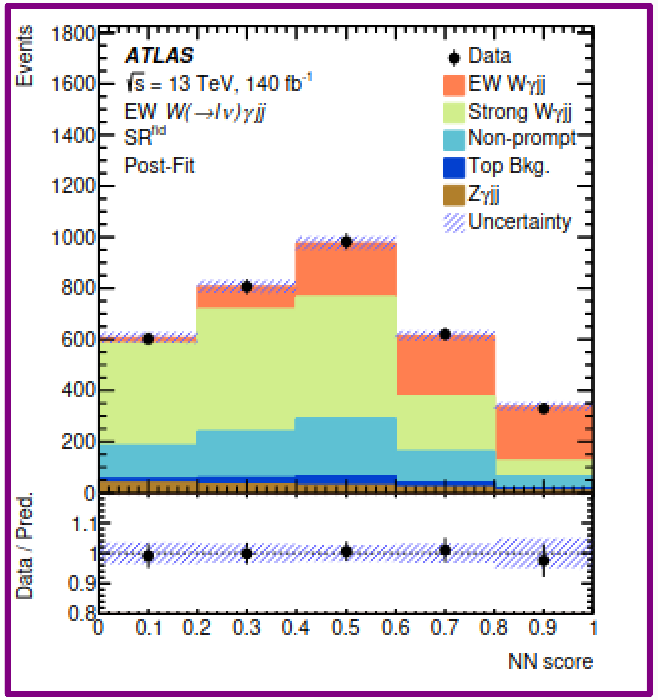

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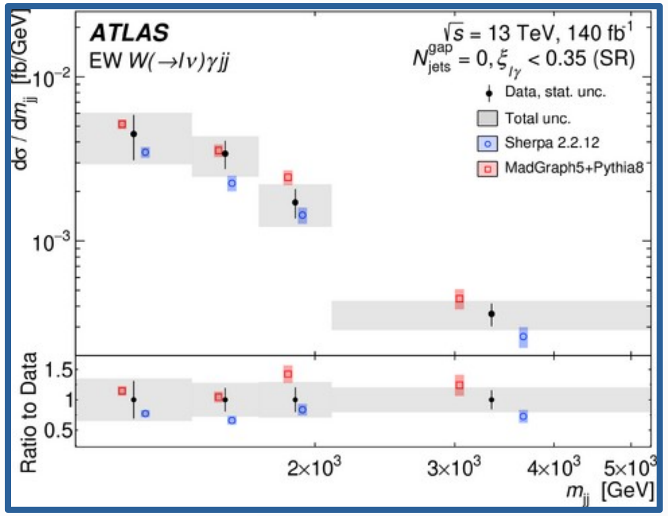
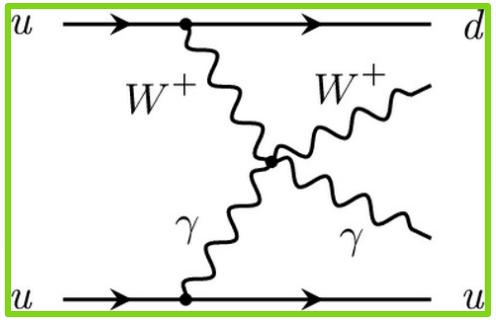


Wγjj (aQGC)



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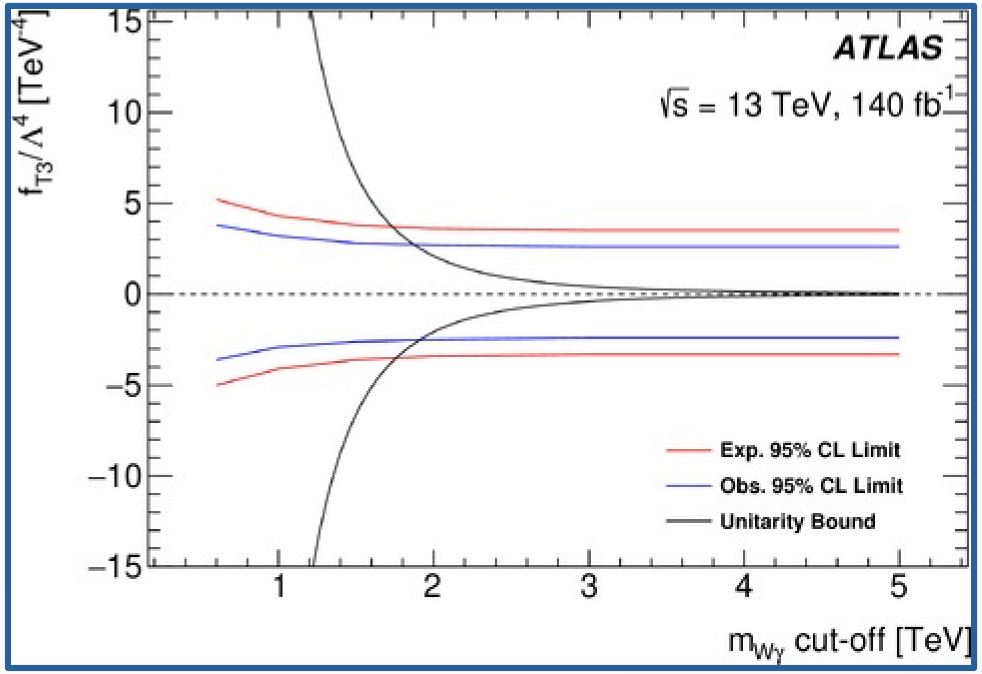
- **AQGC limit** computed with fit in P_T^{jj} for the T operator and P_T^{l} for M operator

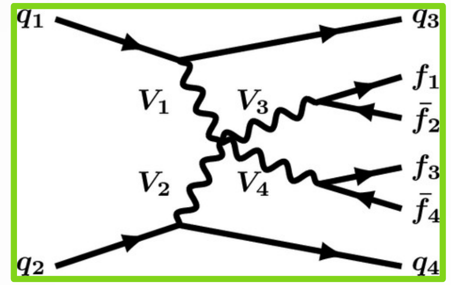
Unitarity restored using the clipping technique

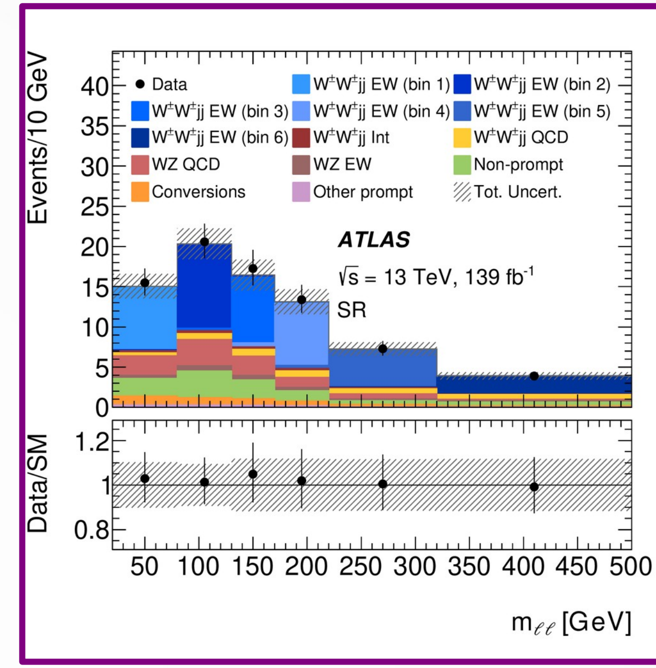
Cofficients [TeV^{-4}]	Observable	$M_{W\gamma}$ cut-off [TeV]	Expected [TeV^{-4}]	Observed [TeV^{-4}]
f_{T0}/Λ^4	p_T^{jj}	1.4	[-2.5, 2.6]	[-1.9, 1.9]
f_{T1}/Λ^4	p_T^{jj}	1.9	[-1.6, 1.6]	[-1.1, 1.2]
f_{T2}/Λ^4	p_T^{jj}	1.6	[-4.9, 5.3]	[-3.6, 4.0]
f_{T3}/Λ^4	p_T^{jj}	1.9	[-3.4, 3.6]	[-2.5, 2.7]
f_{T4}/Λ^4	p_T^{jj}	2.2	[-3.1, 3.1]	[-2.2, 2.3]
f_{T5}/Λ^4	p_T^{jj}	1.8	[-1.8, 1.8]	[-1.3, 1.3]
f_{T6}/Λ^4	p_T^{jj}	2.1	[-1.5, 1.5]	[-1.1, 1.1]
f_{T7}/Λ^4	p_T^{jj}	2.1	[-4.0, 4.1]	[-2.9, 3.0]
f_{M0}/Λ^4	p_T^{l}	1.1	[-45, 44]	[-32, 31]
f_{M1}/Λ^4	p_T^{l}	1.4	[-60, 62]	[-43, 44]
f_{M2}/Λ^4	p_T^{l}	1.4	[-15, 15]	[-11, 11]
f_{M3}/Λ^4	p_T^{l}	1.8	[-22, 22]	[-16, 16]
f_{M4}/Λ^4	p_T^{l}	1.5	[-28, 27]	[-20, 20]
f_{M5}/Λ^4	p_T^{l}	1.9	[-21, 23]	[-14, 17]
f_{M7}/Λ^4	p_T^{l}	1.5	[-100, 99]	[-73, 71]



Same sign WW

STDM-2018-32

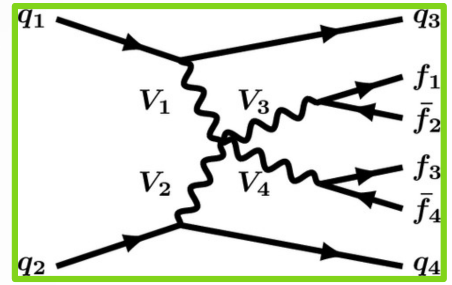


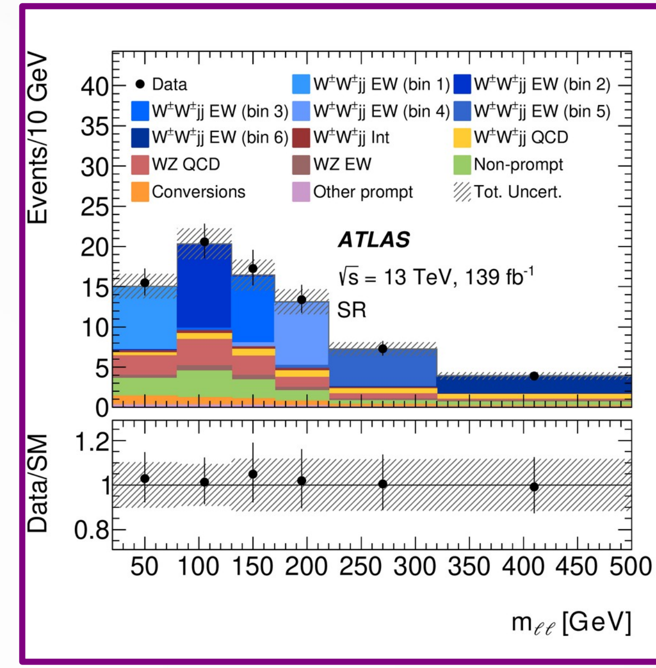


- WWjj **cross section measurement**
- Using same sign charged lepton pair
  - $|m_{ll}-Z_{mass}|>15$ to remove charged mis-identification
  - 0 bjet
  - Jet with large invariant mass >500 GeV
- EW and inclusive cross section measured with separate fits
  - on **m_{ll} SR** and low m_{jj} CR

Same sign WW

STDM-2018-32





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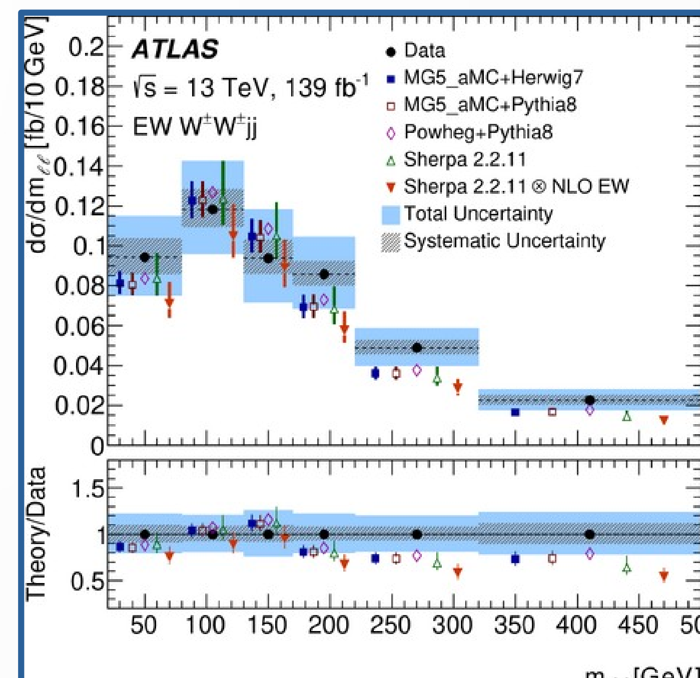
- Differential cross section on **m_{ll}**, m_T, m_{jj}, $N_{gap\ jet}$, ξ_{j3}



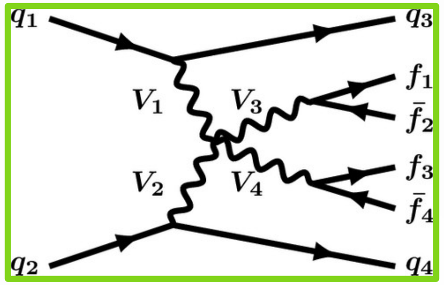
Same sign WW

[STDM-2018-32](#)

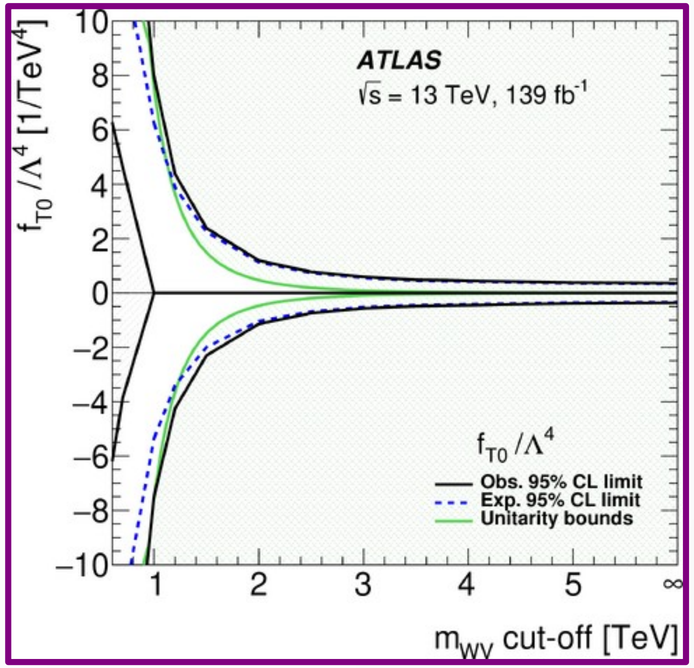
- **AQGC limit computed** with fit on mll re-optimized, **clipping method** on on limits

Limits set on 2D operators pairs

- M0-M1, M0-M7, M1-M7, S1-S02, T0-T1, T0-T2 and T1-T2

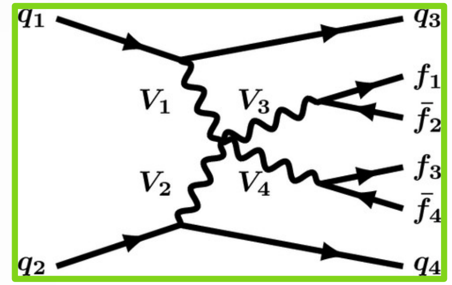


Coefficient	Type	No unitarisation cut-off [TeV^{-4}]	Lower, upper limit at the respective unitarity bound [TeV^{-4}]
f_{M0}/Λ^4	Exp.	[-3.9, 3.8]	-64 at 0.9 TeV, 40 at 1.0 TeV
	Obs.	[-4.1, 4.1]	-140 at 0.7 TeV, 117 at 0.8 TeV
f_{M1}/Λ^4	Exp.	[-6.3, 6.6]	-25.5 at 1.6 TeV, 31 at 1.5 TeV
	Obs.	[-6.8, 7.0]	-45 at 1.4 TeV, 54 at 1.3 TeV
f_{M7}/Λ^4	Exp.	[-9.3, 8.8]	-33 at 1.8 TeV, 29.1 at 1.8 TeV
	Obs.	[-9.8, 9.5]	-39 at 1.7 TeV, 42 at 1.7 TeV
f_{S02}/Λ^4	Exp.	[-5.5, 5.7]	-94 at 0.8 TeV, 122 at 0.7 TeV
	Obs.	[-5.9, 5.9]	–
f_{S1}/Λ^4	Exp.	[-22.0, 22.5]	–
	Obs.	[-23.5, 23.6]	–
f_{T0}/Λ^4	Exp.	[-0.34, 0.34]	-3.2 at 1.2 TeV, 4.9 at 1.1 TeV
	Obs.	[-0.36, 0.36]	-7.4 at 1.0 TeV, 12.4 at 0.9 TeV
f_{T1}/Λ^4	Exp.	[-0.158, 0.174]	-0.32 at 2.6 TeV, 0.44 at 2.4 TeV
	Obs.	[-0.174, 0.186]	-0.38 at 2.5 TeV, 0.49 at 2.4 TeV
f_{T2}/Λ^4	Exp.	[-0.56, 0.70]	-2.60 at 1.7 TeV, 10.3 at 1.2 TeV
	Obs.	[-0.63, 0.74]	–



Same sign WW

STDM-2018-32



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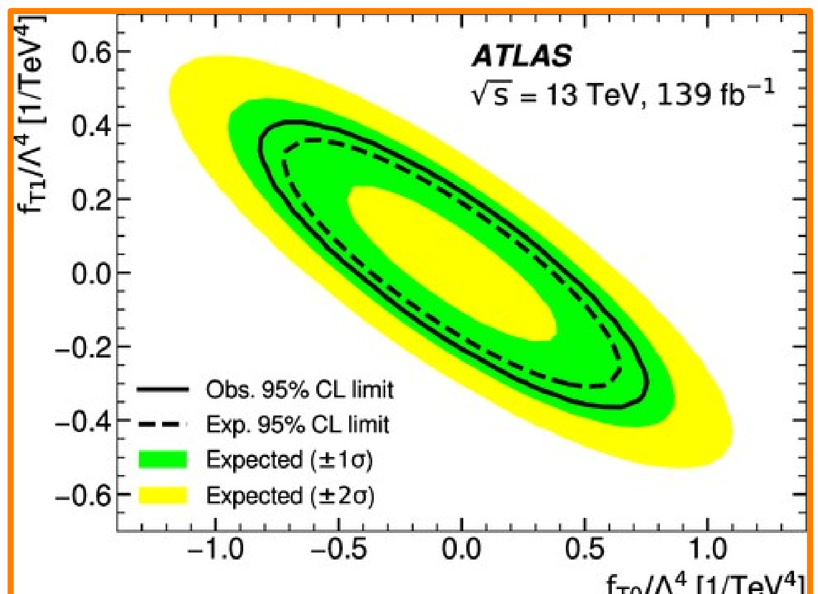
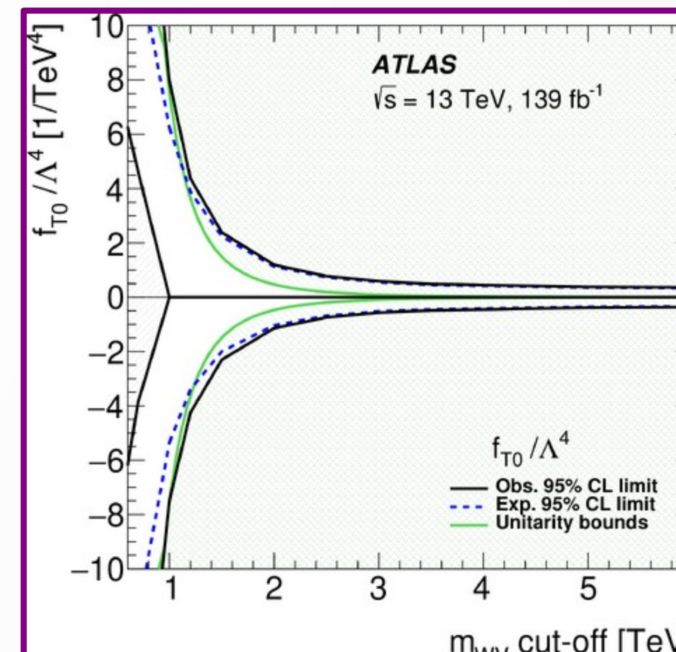
  - M0-M1, M0-M7, M1-M7, S1-S02, **T0-T1**, T0-T2 and T1-T2





Same sign WW

- Doubly charged Higgs boson (**H^{++}**) can decay to W+W+ final states
- **Georgi-Machacek** model theorize such Higgs

$$\chi = \begin{pmatrix} \chi^0 & \xi^+ & \chi^{++} \\ \chi^- & \xi^0 & \chi^+ \\ \chi^{--} & \xi^- & \chi^{0*} \end{pmatrix} \text{ and } \Phi = \begin{pmatrix} \Phi^+ \\ \Phi^0 \end{pmatrix} .$$

Same sign WW

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- Doubly charged Higgs boson (**H^{++}**) can decay to W+W+ final states
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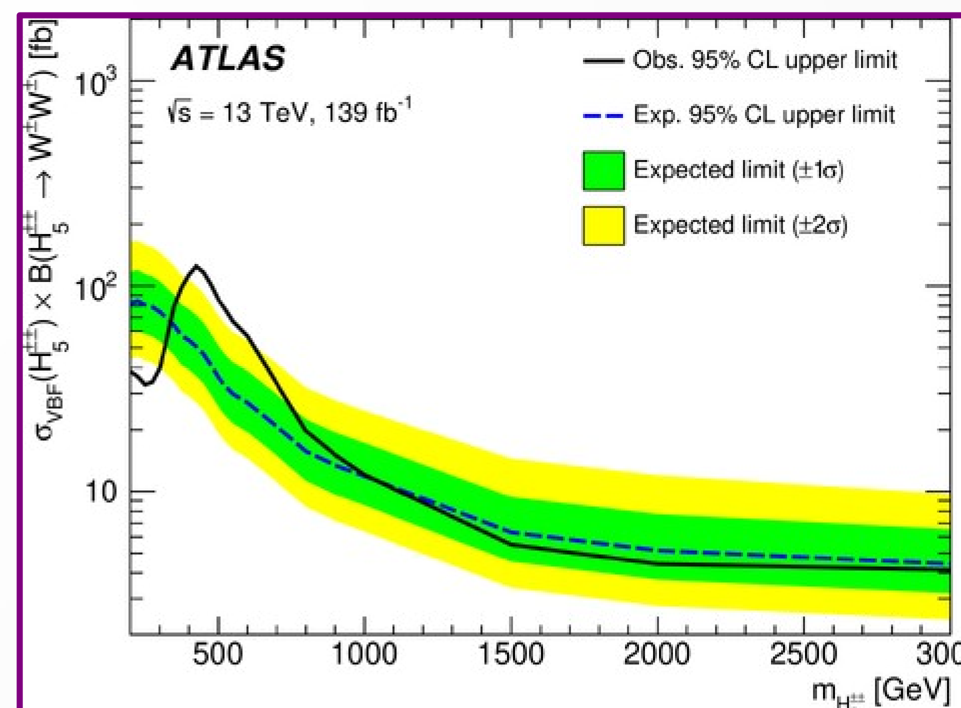
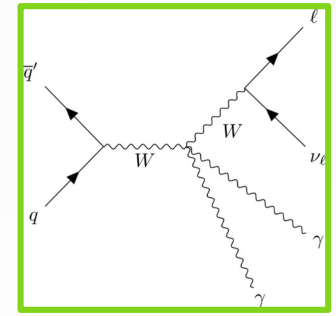
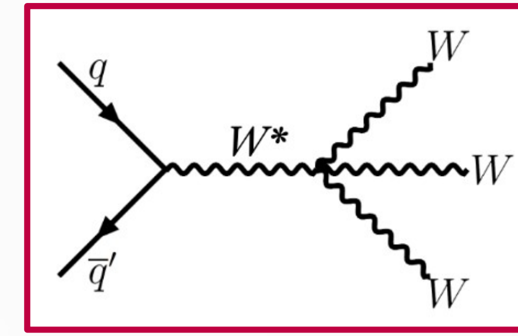
- Limit on **Branching ratio** and sin(θ)
- Excess largest at 450 GeV with local significance of 3.3 standard deviation

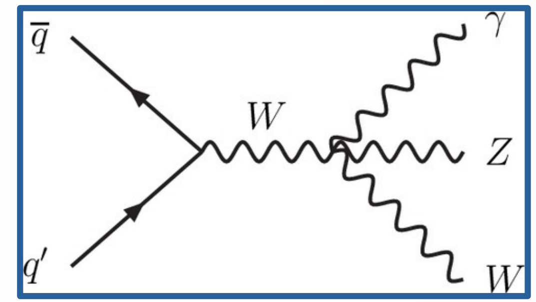


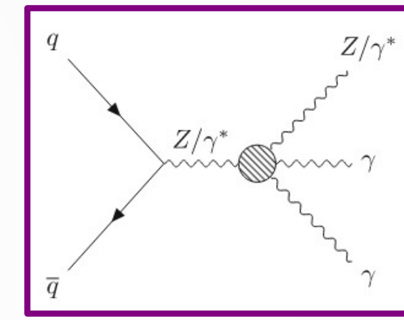
Key points

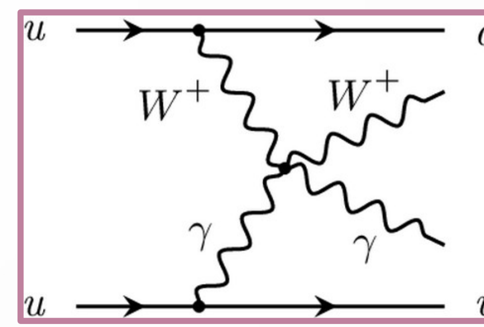
- **3 New first observations: Wγγ**[1], **WZγ**[2] and **WWW**[3] by ATLAS
- **Competitive limits set on EFT aQGC operators** with **Zγγ**[4]**,** **Wγ**[5] and **SSWW**[6] analysis by ATLAS
- Result in agreement with SM
- Limit on doubly charged Higgs production set and up to 3.3 local standard deviation with **SSWW**[6] analysis by ATLAS
- New result to come with the ongoing Run 3
- Not covered in this talk
  - **Z(νν)γ**[7], **WZ**[8], Z(ll)γ[9], WW[10][11][12], ZZ (4lepton)[13][14][15] production

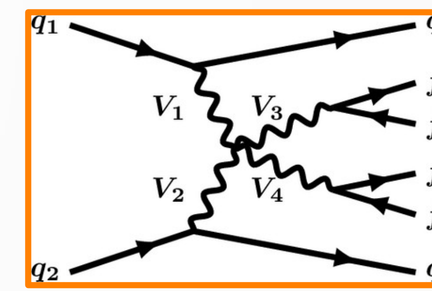


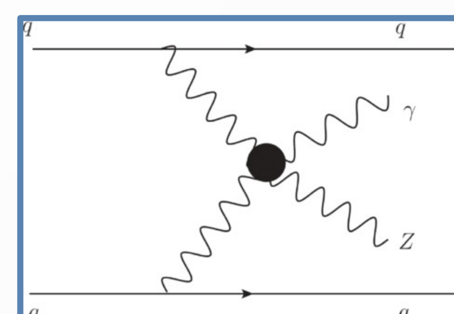


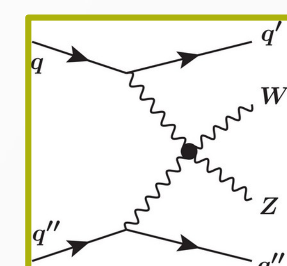












Thanks

Canadian Association of Physicists

Association canadienne des physiciens et physiciennes

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- [2] ATLAS Collaboration (2023). Observation of $WZ\gamma$ production in pp collisions $\sqrt{s}$ = 13 TeV with the ATLAS detector. CERN.
- [3] ATLAS Collaboration (2022). Observation of WWW Production in pp Collisions at $\sqrt{s}$ = 13 TeV with the ATLAS Detector. Phys. Rev. Lett., 129, 061803.
- [4] ATLAS Collaboration (2022). Measurement of $Z\gamma\gamma$ production in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector. CERN.
- [5] ATLAS Collaboration (2024). Fiducial and differential cross-section measurements of electroweak $W\gamma jj$ production in pp collisions at s√=13 TeV with the ATLAS detector. CERN
- [6] ATLAS Collaboration(2023). Measurement and interpretation of same-sign W boson pair production in association with two jets in pp collisions at s√=13 TeV with the ATLAS detector. CERN
- [7] ATLAS Collaboration (2022). Measurement of electroweak $Z(\nu\bar{\nu})\gamma jj$ production and limits on anomalous quartic gauge couplings in pp collisions at $\sqrt{s}$=13 TeV with the ATLAS detector. CERN
- [8] ATLAS Collaboration (2024). Measurements of electroweak $W^{\pm}Z$ boson pair production in association with two jets in pp collisions at s√=13 TeV with the ATLAS detector. CERN
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- [12] ATLAS Collaboration (2024). Observation of electroweak production of W^+W^- in association with jets in proton-proton collisions at $\sqrt{s}$=13 TeV with the ATLAS Detector . CERN
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- [15] ATLAS Collaboration (2023). Evidence of pair production of longitudinally polarised vector bosons and study of CP properties in $ZZ\rightarrow4\ell$ events with the ATLAS detector at s√=13 TeV. CERN

WWW

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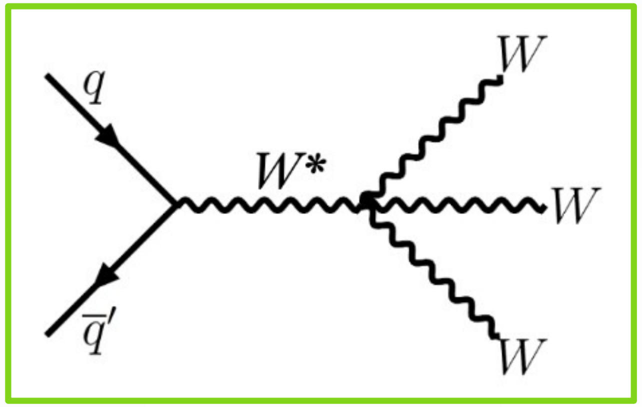


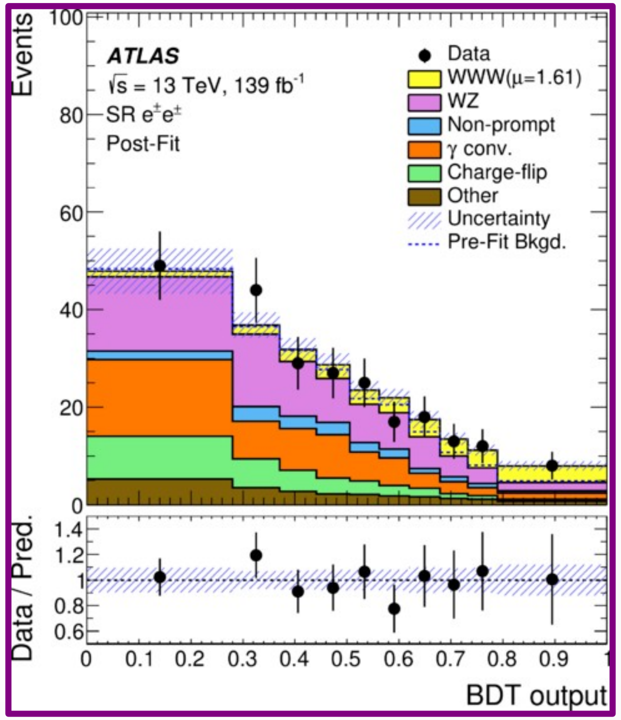
- **Background treatment :**
  - WZ+jets
    estimated with simulated events normalized with data using the same flavour opposite sign CR
  - WZ+jets in 2lep and ZZ+jets in 3l SR
    reduced with veto on additional loose lepton
  - Non-prompt lepton from hadron
    data driven method
  - Y→e background (Wy/Zy)
    evaluated via data driven method

- WWW Observation at 8.0 (5.4) standard deviation (expected)

  $\sigma_{measured}$ =820 ± 100 (stat) ± 80 (syst) fb (Within 2.6 σ of theory prediction)
- Using at least two lepton with 139 fb^{-1} at 13TeV:

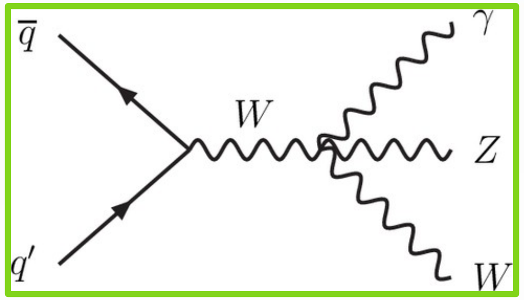
  2 lepton + 2 jets SR : using same-charge lepton
  - 40 GeV< m_{ll} <400 GeV
  - 80< m_{ll} < 100 to remove Z(ll)

  3 leptons SR : no same flavour opposite sign lepton
- Fit method :
  - Separate BDT for 2l and 3l, simultaneous fit for both **BDT distribution** and mll distribution for the three WZ CR
  - Normalization for WWW, WZ+0jet, WZ+1jet and WZ+2jets



WZγ

STDM-2019-17



- **First measurement** of WZγ cross section at 6.3 (5.0) standard deviation observed (expected)

  $\sigma_{measured}$ = 2.01 ± 0.3 (stat) ± 0.16 fb (within 1.5 σ of theory prediction)

  σ_{Theory} = 1.5 ± 0.06 fb

- Using l'llγ channel one same flavor opposite charge pair with 140fb^{-1} at 13TeV

  $|m_{e(w)\gamma} - m_Z|$ > 10GeV

  $m_{l(Z)l(Z)}$> 81 GeV for FSR reduction

  Profile likelihood fit of the 4 e/μ final states (3 bins, 1SR and 2CR)

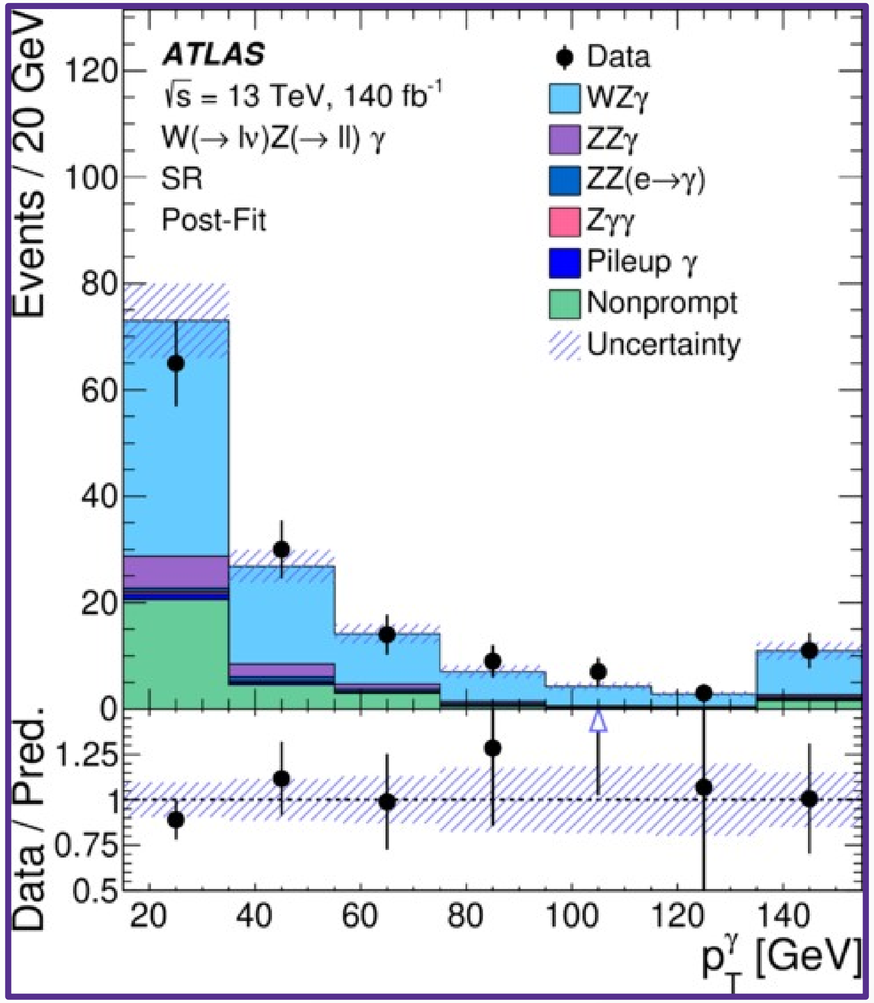
- **Background treatment:**
  - j→γ background

    Reduced by $m_{e(w)\gamma}$ selection

    Data driven fake rate estimate in looser identification/isolation selection CR using Z+jets sample
  - j→l background

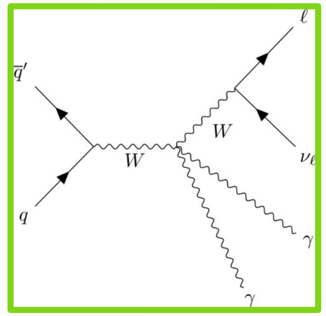
    Data driven fake rate estimate in looser identification/isolation selection CR using dijet sample
  - ZZγ and ZZ(e→γ)

    normalized with dedicated CR



Wγγ

STDM-2018-33



- **First measurement** of Wγγ at 5.6 (5.6) standard deviation observed (expected)

  $\sigma_{measured} = 12.2 \pm 1.0\,(stat)^{+1.9}_{-1.8}\,(syst) \pm 0.1\,(lumi)$ fb in agreement with the SM prediction
- Using e/μ channel with 140fb^{-1} at 13 TeV

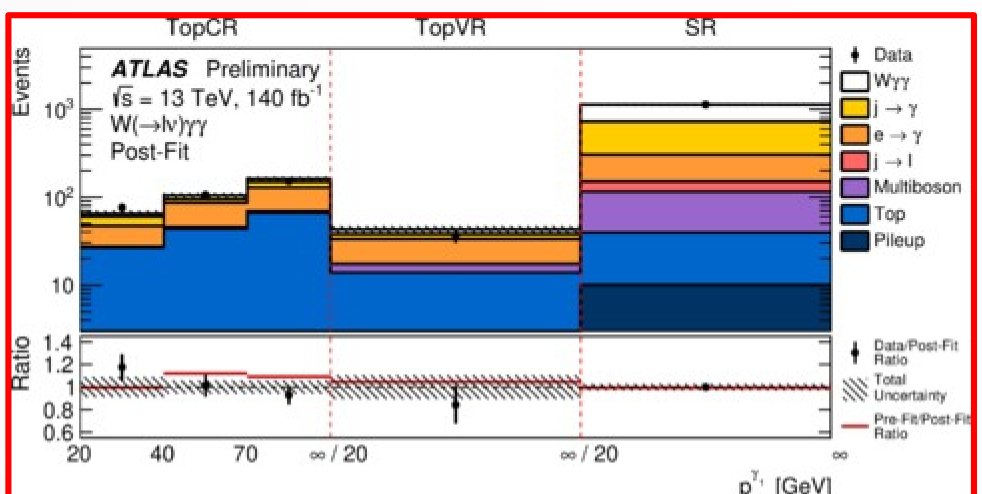
  B-jet veto and $E_T^{miss} > 40$ GeV selection

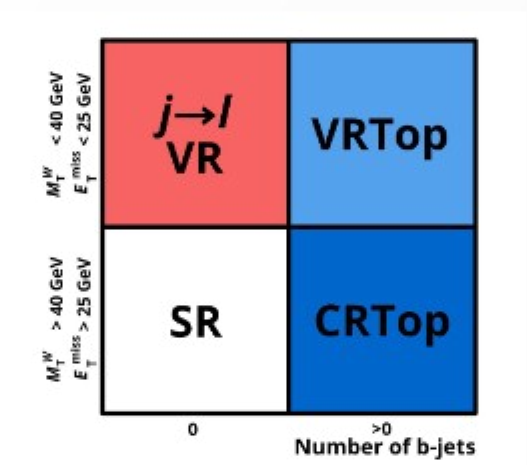
  4 bin likelihood fit (using topCR, topVR and SR)

- **Background treatment:**
  - j→γ main background

    2D (leading/sub-leading) template fit of photon isolation energy in data
  - e→γ

    Data driven fake rate estimate in Z→ee/eγ CR
  - Top background
    - Reduced via b veto
    - **Dedicated CR** (with >= 1 b-jet) for fit constrain
    - **Low E_T^{miss} region** (with >= 1 b-jet) for validation





Zγγ

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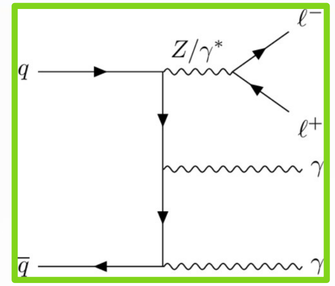


- **Fiducial cross section**

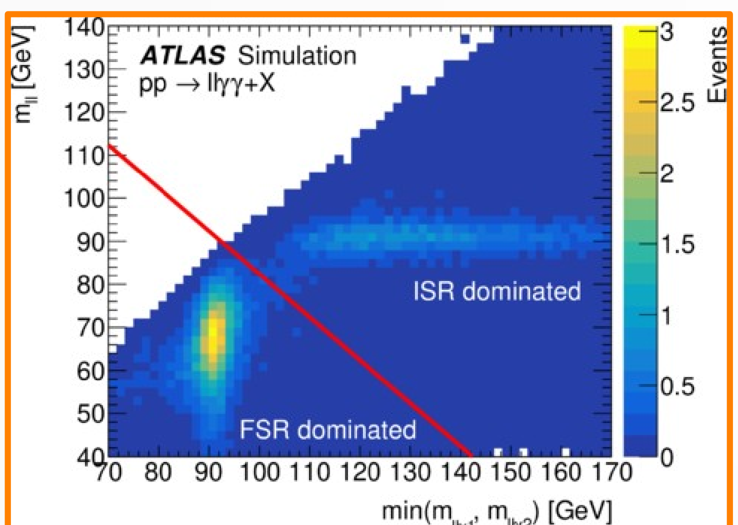
  $\sigma_{measured}$ = 2.45 ± 0.20 (stat) ± 0.22(syst) ± 0.04(lumi) fb

  measurement with 12 % precision

- Using e/μ channel with 139fb^{-1} at 13TeV

  (m_{ll}+min($m_{ll\gamma,1}$,$m_{ll\gamma,2}$))>2M_Z for FSR contribution removal

  Differential cross-sections (6 kinematic observables:
  $E^{\gamma 1}_T$, $E^{\gamma 2}_T$, **p_T^{ll}**, $p_T^{ll\gamma\gamma}$, $m_{\gamma\gamma}$, $m_{ll\gamma\gamma}$)



- **Background treatment:**
  - j→γ background (main background)

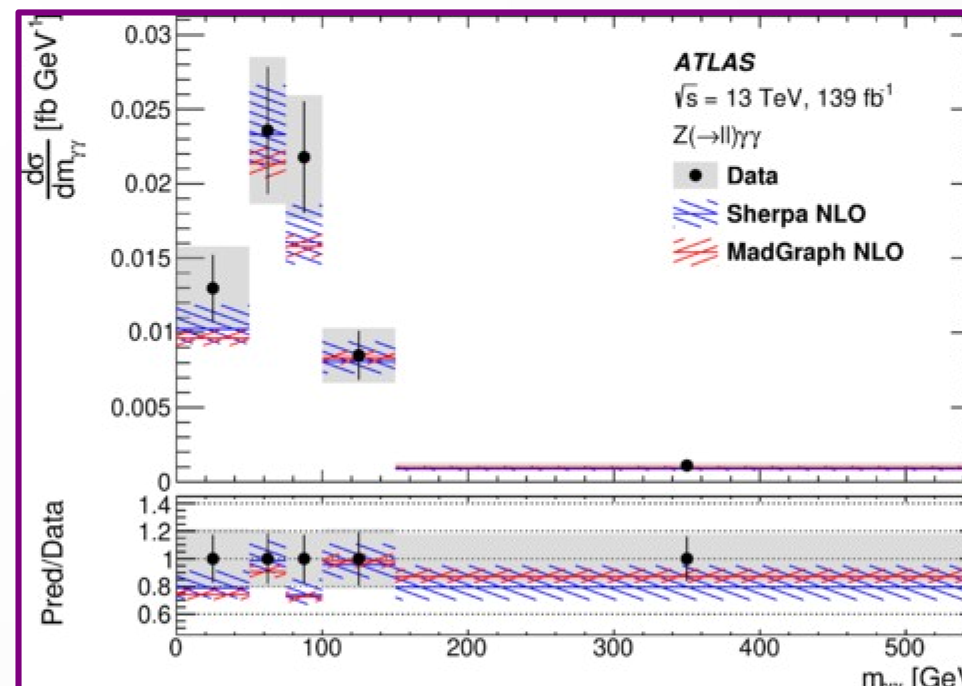
    data driven fake rate estimate using Zγ+jet and Z+jet
  - ttγγ with leptonic decay from top quark (second contribution)

    Normalized using CR with opposite sign e/μ pair
  - Zγ+γ and Z+γγ from pile-up

    Uncertainties computed via signal simulation reweighed to pile-up background p_T spectra
  - e → y

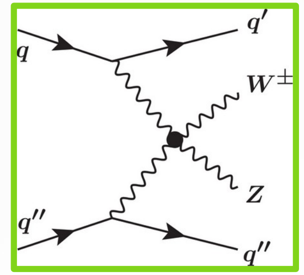
    Modelled by ZZ and WZγ simulation
  - Z(ll)H(γγ)

    Estimated from simulation



WZ

[STDM-2018-35]

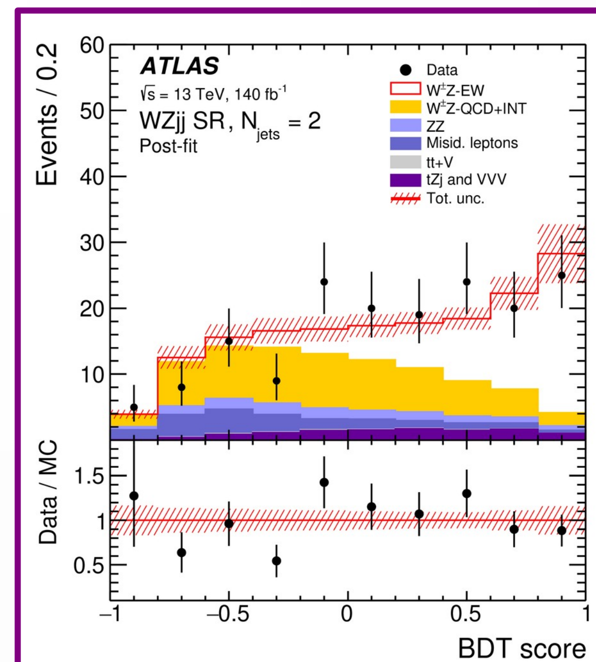


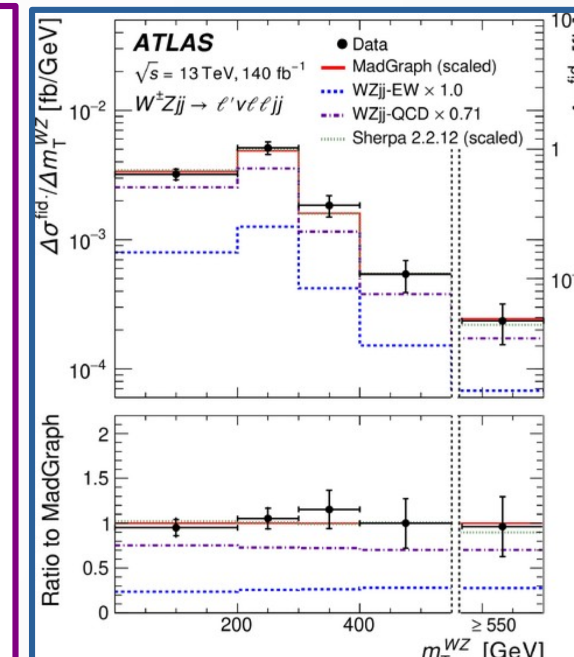
- **Background treatment:**
  - ZZ and tt+V :

    Constrained with 2CR ZZ-CR (at least 4 lep) and b-CR (at least 1 b-jet), modeled with MC
  - Reducible Z+j, Zy, tt, Wt and WW

    data driven method inversion of efficiency and mis-identification of promt and fake lepton

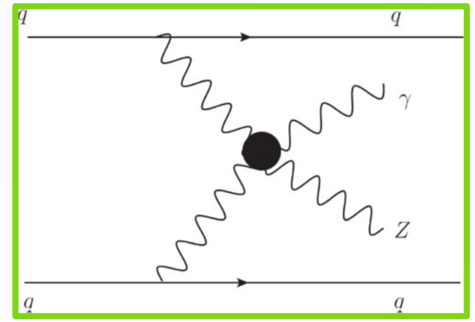
- EW and inclusive cross section measurement
  - XS EW = 0.368 ± 0.037 (stat) ± 0.059 (syst) ± 0.003 (lumi)
  - XS incl = 1.462 ± 0.063 (stat) ± 0.118 (syst) ± 0.012 (lumi)
- Differential measurement on m_T^{WZ}, $\Delta\phi_{WZ}$ and Sum P_T^l
- Using 3 lepton with 1 same flavor opposite charge pair with 140 fb^{-1} at 13 TeV
  - veto on 4 lepton with loose criteria
  - SR m_{jj}>500 GeV and b-jet veto
- ANN to separate EW and QCD without biais in m_{jj} and other BDT variable
- Fit on **BDT score** 2 category 2 jet more than 2, on the BDT b-CR and the m_{jj} in ZZ-CR

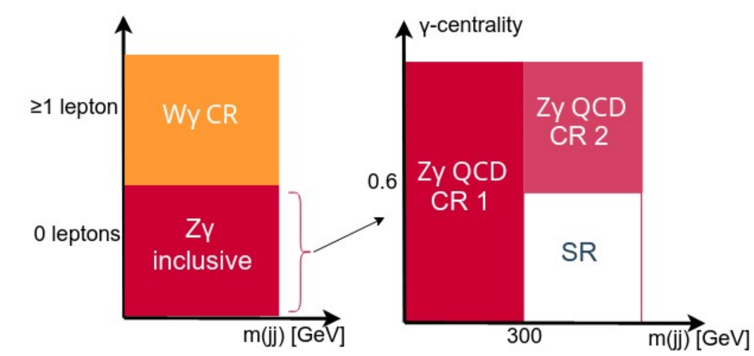




Z(νν)γjj

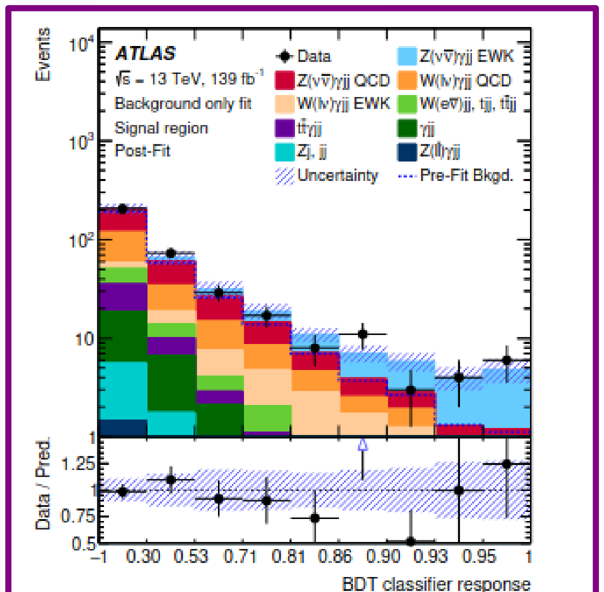
STDM-2018-59





- **First measurement Z(νν)γ** observed (expected) 3.2 (3.7) σ
  - Observed (expected) 6.3 (6.6) σ when combined with previous analysis
  - Agreement with the standard model
- Using Higt Met and High photon pT

  Lepton veto to remove Z(ll)γjj and W(lν)γjj
- BDT to separate signal to bkg
- **Max likelihood on BDT** distribution in SR and mjj fit in 3 **CR QCD CR1/2** and **Wγ CR**



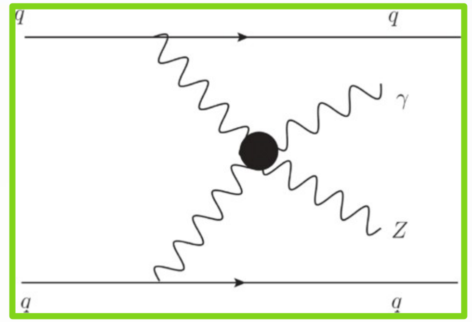
- **Background treatment:**
  - Main bkg QCD Z(νν)γjj process (~36 % of SR)

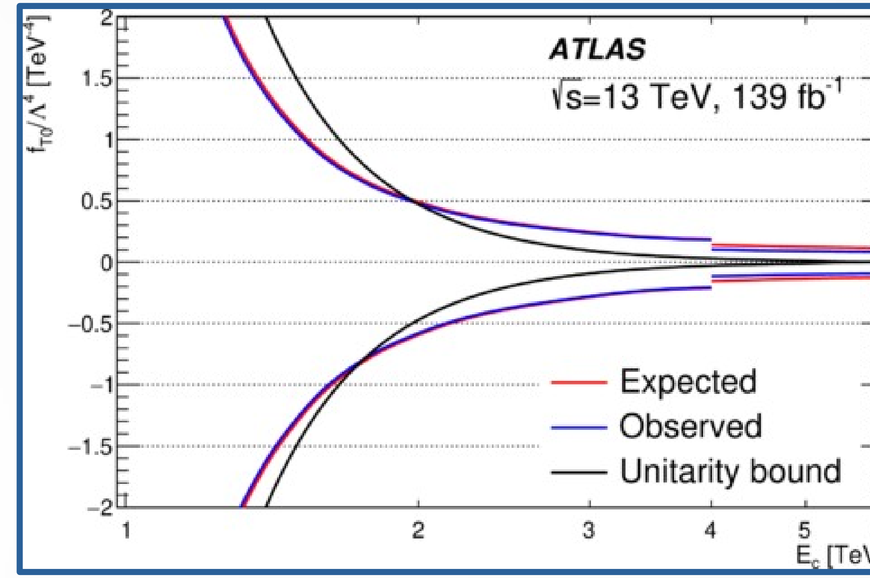
    Estimated via fit in MC to data in **CR**
  - W(lν) QCD (25%) and EW (7%), ttγjj (6%)

    Fixed with simultaneous fit
  - Mis-identification estimated from data
    - e→γ, MET mis-measurement, j→γ

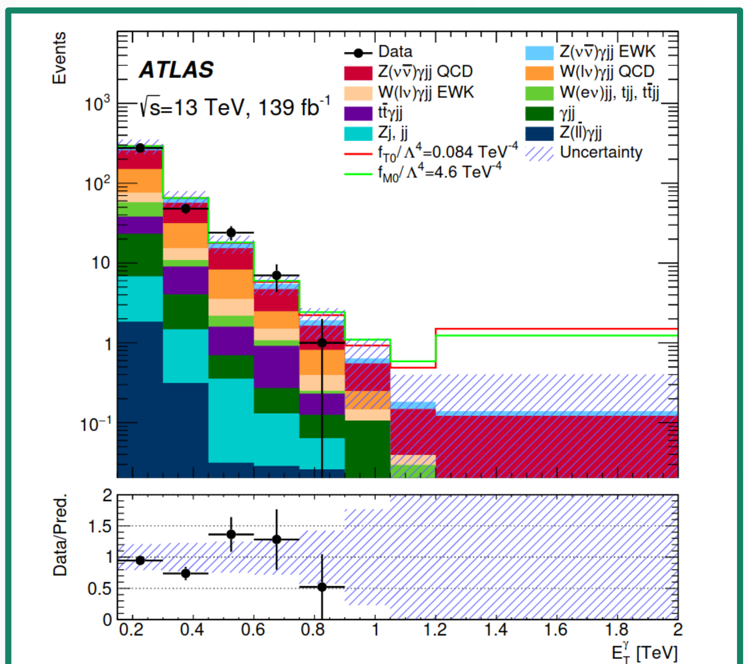
Z(νν)γjj (aQGC)

STDM-2018-59





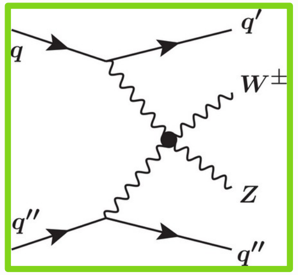
- **aQGC computed** in bin of SR with additional E_T^γ selection, **clipping technique** used to restore unitarity

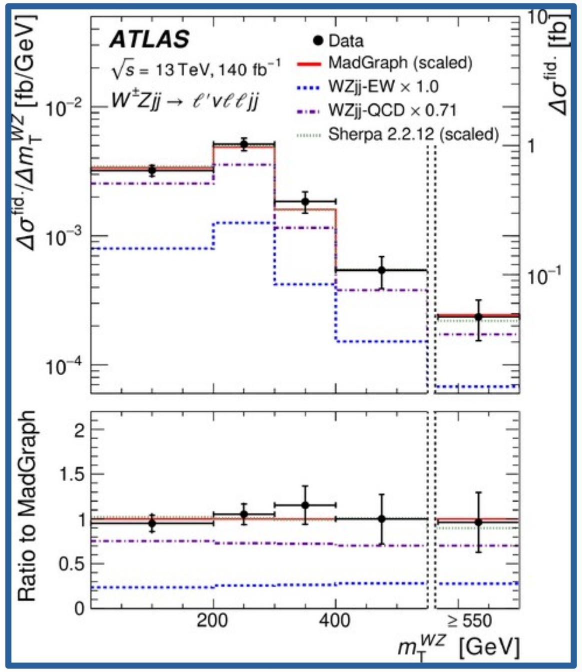


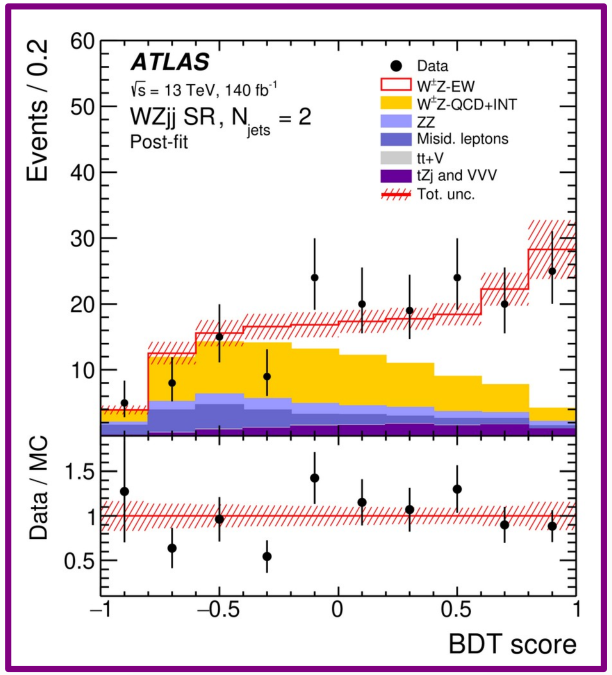
Coefficient	E_c [TeV]	Observed limit [TeV $^{-4}$]	Expected limit [TeV^{-4}]
f_{T0}/Λ^4	1.7	$[-8.7, 7.1] \times 10^{-1}$	$[-8.9, 7.3] \times 10^{-1}$
f_{T5}/Λ^4	2.4	$[-3.4, 4.2] \times 10^{-1}$	$[-3.5, 4.3] \times 10^{-1}$
f_{T8}/Λ^4	1.7	$[-5.2, 5.2] \times 10^{-1}$	$[-5.3, 5.3] \times 10^{-1}$
f_{T9}/Λ^4	1.9	$[-7.9, 7.9] \times 10^{-1}$	$[-8.1, 8.1] \times 10^{-1}$
f_{M0}/Λ^4	0.7	$[-1.6, 1.6] \times 10^{2}$	$[-1.5, 1.5] \times 10^{2}$
f_{M1}/Λ^4	1.0	$[-1.6, 1.5] \times 10^{2}$	$[-1.4, 1.4] \times 10^{2}$
f_{M2}/Λ^4	1.0	$[-3.3, 3.2] \times 10^{1}$	$[-3.0, 3.0] \times 10^{1}$

WZ

[STDM-2018-35]



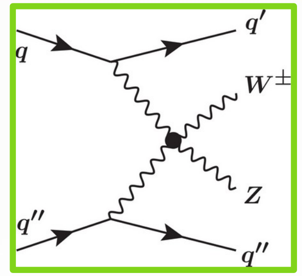




- EW and inclusive **cross section measurement**
- Differential measurement on $\mathbf{m_T^{WZ}}$, $\Delta\phi_{WZ}$ and Sum P_T^l
- Using 3 lepton with 1 same flavor opposite charge pair
  - veto on 4 lepton with loose criteria
  - SR m_{jj}>500 GeV and b-jet veto
- Fit on **BDT score** 2 category 2 jet and more than 2 jet, on the BDT b-CR and the m_{jj} in ZZ-CR

WZ (aQGC)

STDM-2018-35



	Expected $[\mathrm{TeV}^{-4}]$	Observed $[\mathrm{TeV}^{-4}]$
f_{T0}/Λ^4	[-7.0, 7.0]	[-1.5, 1.6]
f_{T1}/Λ^4	[-1.1, 1.0]	[-0.7, 0.6]
f_{T2}/Λ^4	[-12, 6]	[-2.4, 1.8]
f_{M0}/Λ^4	[-60, 60]	[-12, 12]
f_{M1}/Λ^4	[-32, 32]	[-15, 15]
f_{M7}/Λ^4	[-30, 30]	[-15, 15]
f_{S02}/Λ^4	[-41, 41]	[-18, 18]
f_{S1}/Λ^4	—	—

- **Limit set on AQGC** with 4 bin inBDT and 5 mTWZ → **20 bins**, limit at **unitary cut-off**
- **2D limits on interval** coefficient for T0 and T1