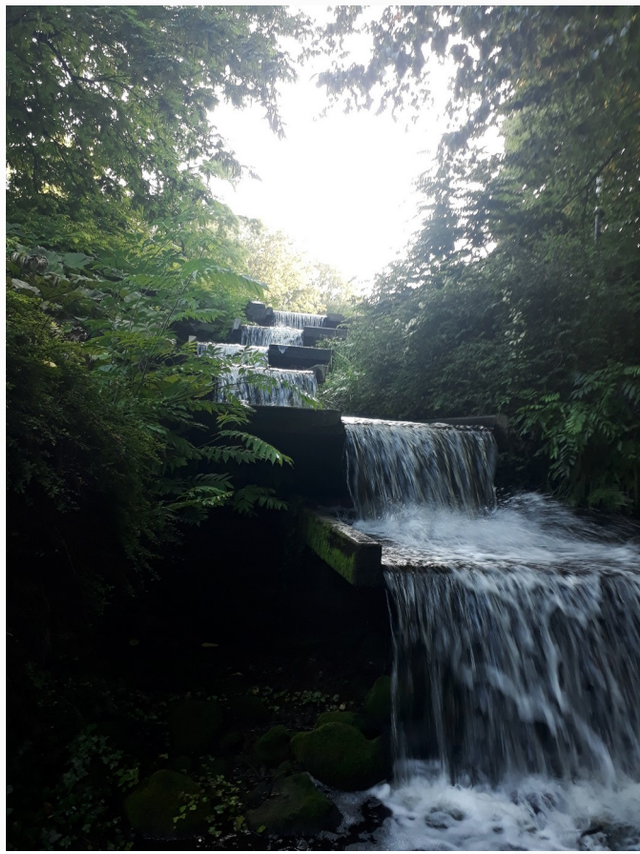
Triboson measurements with ATLAS and CMS



Raphaël Hulsken

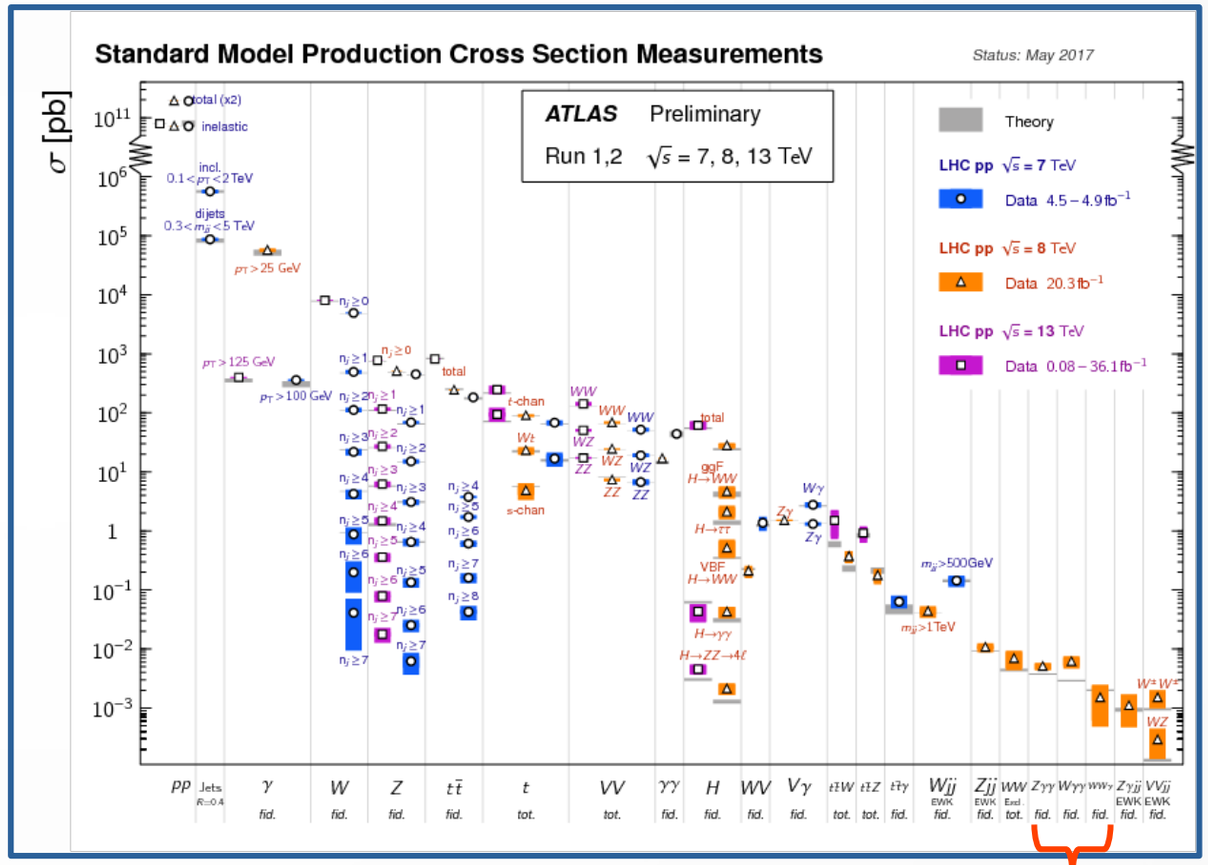
On behalf of the ATLAS and CMS collaborations

EPS-HEP 2023 in Hamburg

McGill

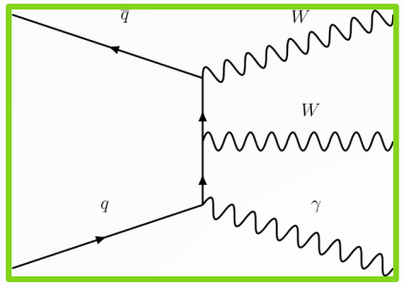
Physics motivations

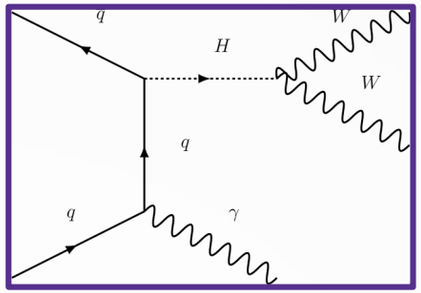
- Triboson final states have small cross section, only start being accessible with the full run 2 at LHC
- Test for beyond Standard Model theory
  - Sensitivity to Anomalous Quartic Gauge Coupling (AQGC)
  - Limit to Effective Field Theories can be set
- Understand those process as they are backgrounds for further analyses in run 3 (ZH(γγ) WH(γγ))



WWγ

CMS PAS SMP-22-006





- **First measurement** of WWγ fiducial cross section with 5.6 (4.7) standard deviation observed (expected)

  $\sigma_{measured}$ = 6.0 ± 1.0 (stat) ± 1.0 (syst) ± 0.9 (theo) fb (within 1.5 σ of theory prediction)

  σ_{Theory} =4.16 ± 0.34 (scale) ± 0.05 (PDF) fb

- Using opposite charge opposite flavor e/μ channel with 138fb^{-1} at 13TeV

  b-jet veto

  Likelihood 2D fit on M_T^{WW} and m_{lly}, using SR (splitting 0 jet and >=1 jet) and 2VR

- **Limit on Higgs Yukawa couplings** with light quarks (u,d,s,c)

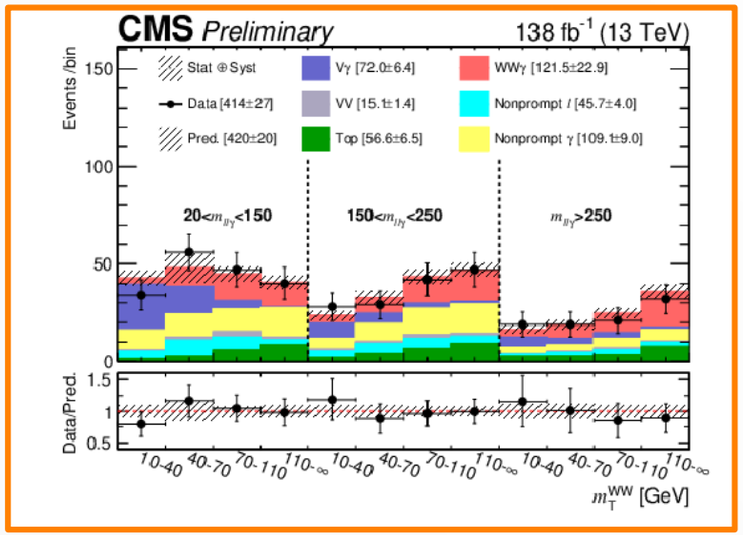
- **Background treatment:**
  - Non prompt photon/lepton
    - j→γ, main background

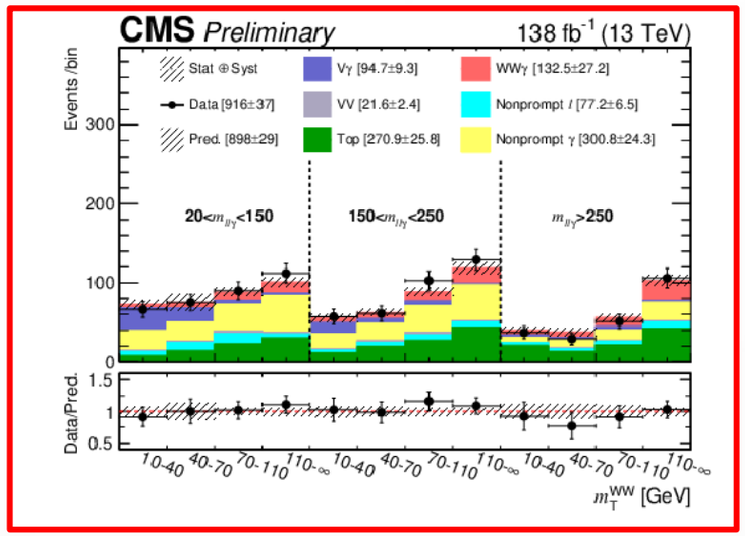
      Data driven estimation in W+jets Control Region (CR)
    - j→e, significant background

      Data driven fake rate estimate in dijet CR
    - Validation

      Top+γ VR with ≥ 1 b-jet for both background

      Same flavor lepton final state CR for j→ e background
  - WZγ and top, reduced by b-jet veto





Process	σ_{up} pb exp.(obs.)	Yukawa couplings limits exp.(obs.)
$u\bar{u} \to H + \gamma \to e\mu\gamma$	0.067 (0.085)	$\lvert\kappa_u\rvert$ ≤13000 (16000)
$d\bar{d} \to H + \gamma \to e\mu\gamma$	0.058 (0.072)	$\lvert\kappa_d\rvert$ ≤14000 (17000)
$s\bar{s} \to H + \gamma \to e\mu\gamma$	0.049 (0.068)	$\lvert\kappa_s\rvert$ ≤1300 (1700)
$c\bar{c} \to H + \gamma \to e\mu\gamma$	0.067 (0.087)	$\lvert\kappa_c\rvert$ ≤110(200)

WZγ

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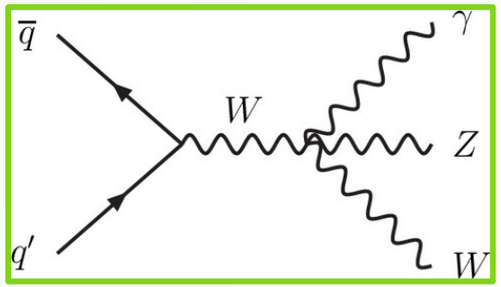


- **First measurement** of WZγ cross section at 6.3 (5.0) standard deviation observed (expected)

  $\sigma_{measured}$ = 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

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

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

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

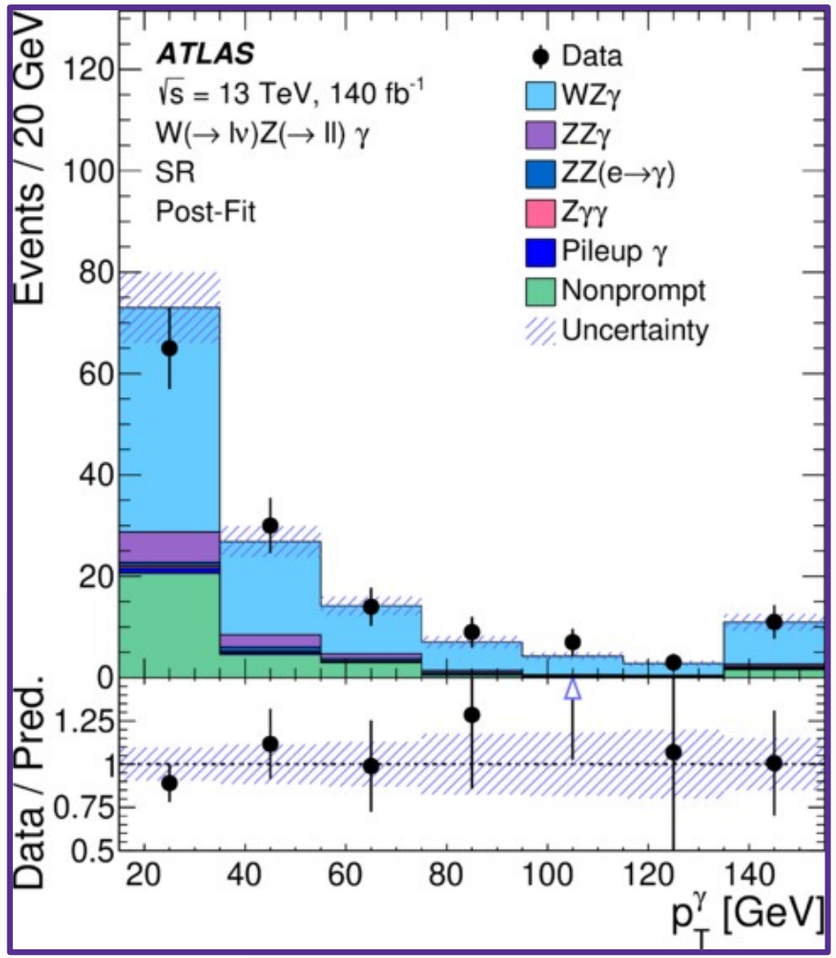
- **Background treatment:**
  - j→γ background

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

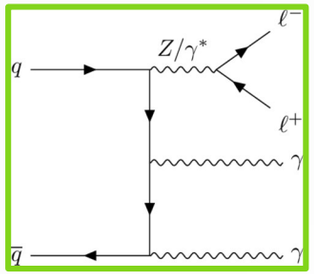
    Data driven fake rate estimate in looser identification/isolation selection CR using Z+jets sample
  - j→l background

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

    normalized with dedicated CR



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^{y1}_T, E^{y2}_T, p_T^{ll}, p_T^{llyy}, m_{yy}, m_{llyy})

- **Limit set on aQGC operators** using EFT approach
  - $O8_{T,1}$, $O8_{T,2}$, $O8_{T,6}$, $O8_{T,7}$ reduced up to two order of magnitude at 8TeV (Phys. Rev. D 93, 112002)
  - **Clipping method** used to restore unitary at large energy scale

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

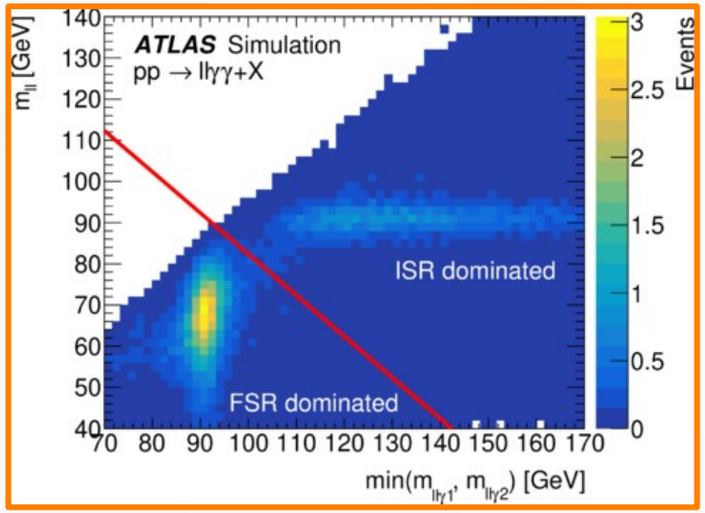
    data driven fake rate estimate using Zγ+jet and Z+jet
  - ttγγ with leptonic decay from top quark (second contribution)

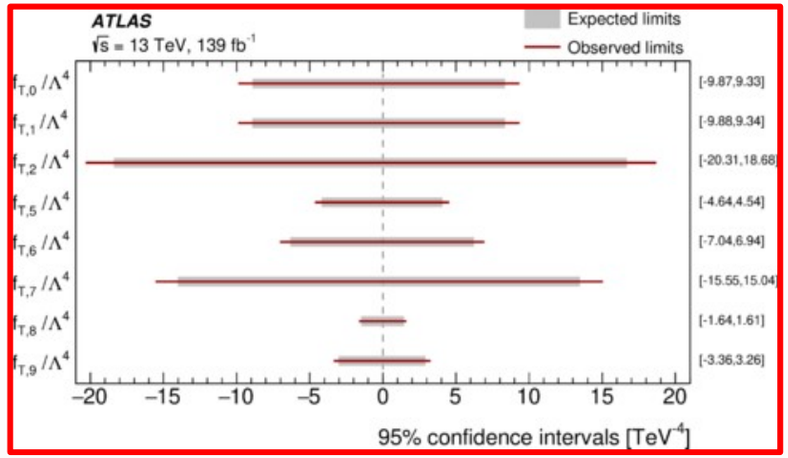
    Normalized using CR with opposite sign e/μ pair
  - Zγ+γ and Z+γγ from pile-up

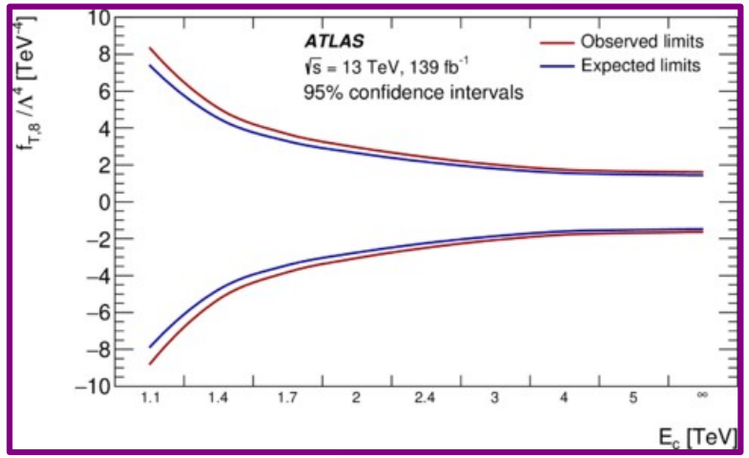
    Uncertainties computed via signal simulation reweighed to pile-up background p_T spectra
  - e → γ

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

    Estimated from simulation







Vγγ

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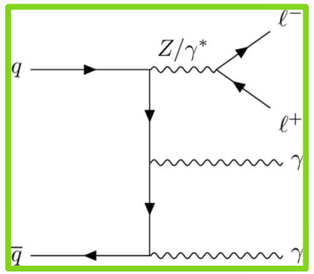
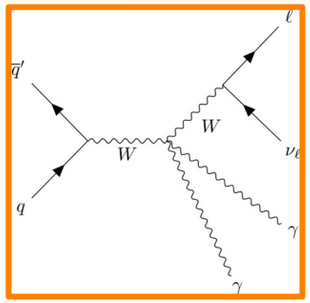




- Zγγ fiducial cross section

  $\sigma(Z\gamma\gamma) = 5.41^{+0.58}_{-0.55}\,(stat)^{+0.64}_{-0.70}$(syst) ± 0.06 (PDF + scale) fb

  4.8 (5.8) standard deviation observed (expected)

- Wγγ fiducial cross section

  $\sigma(W\gamma\gamma)^{meas}$ = 13.6 ±1.9 (stat) ±0.4 (syst) ± 0.08 (PDF + scale) fb

  3.1 (4.5) standard deviation observed (expected)

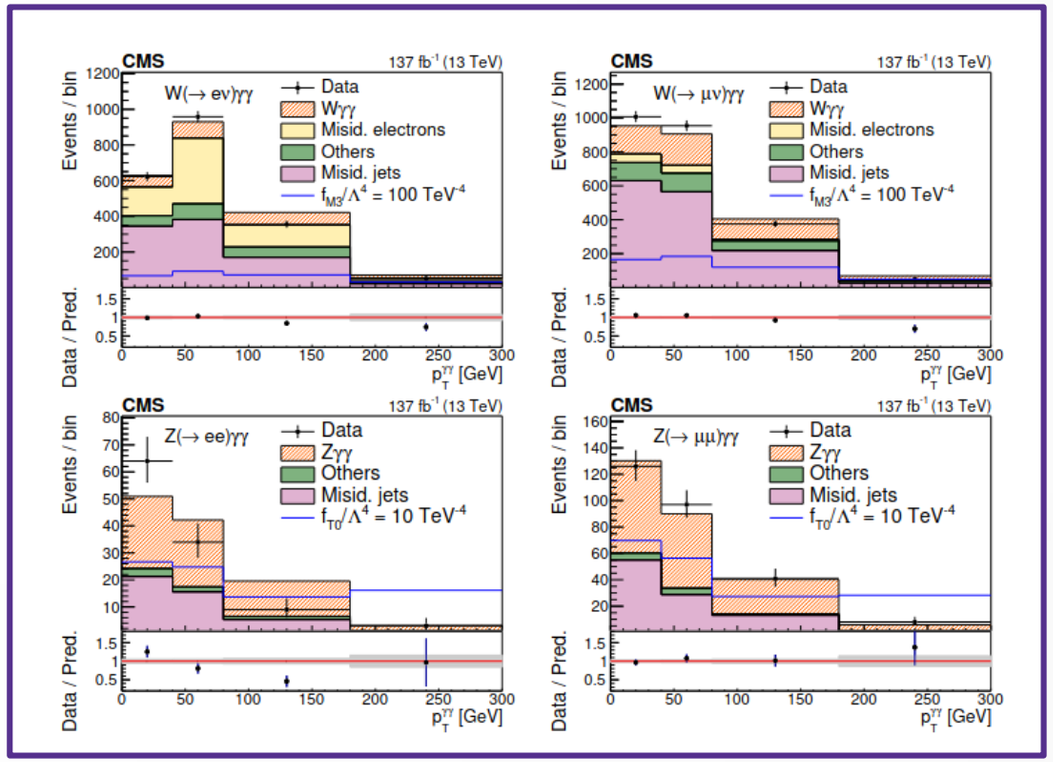
- Using e/μ channel with 137 fb^{-1} at 13TeV

  Event removed if $|m_{e,\gamma} - m_Z| < 5$ GeV or $|m_{e,\gamma\gamma} - m_Z| < 5$GeV for FSR reduction

  Binned likelihood fit on **diphoton p_T distribution**

- **Limit set on 10 aQGC operators** using EFT approach

	$W\gamma\gamma$ (TeV^{-4})		$Z\gamma\gamma$ (TeV^{-4})	
Parameter	Expected	Observed	Expected	Observed
f_{M2}/Λ^4	[−57.3, 57.1]	[−39.9, 39.5]	—	—
f_{M3}/Λ^4	[−91.8, 92.6]	[−63.8, 65.0]	—	—
f_{T0}/Λ^4	[−1.86, 1.86]	[−1.30, 1.30]	[−4.86, 4.66]	[−5.70, 5.46]
f_{T1}/Λ^4	[−2.38, 2.38]	[−1.70, 1.66]	[−4.86, 4.66]	[−5.70, 5.46]
f_{T2}/Λ^4	[−5.16, 5.16]	[−3.64, 3.64]	[−9.72, 9.32]	[−11.4, 10.9]
f_{T5}/Λ^4	[−0.76, 0.84]	[−0.52, 0.60]	[−2.44, 2.52]	[−2.92, 2.92]
f_{T6}/Λ^4	[−0.92, 1.00]	[−0.60, 0.68]	[−3.24, 3.24]	[−3.80, 3.88]
f_{T7}/Λ^4	[−1.64, 1.72]	[−1.16, 1.16]	[−6.68, 6.60]	[−7.88, 7.72]
f_{T8}/Λ^4	—	—	[−0.90, 0.94]	[−1.06, 1.10]
f_{T9}/Λ^4	—	—	[−1.54, 1.54]	[−1.82, 1.82]



Vγγ

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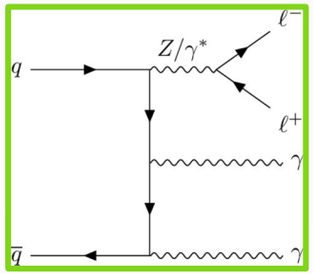
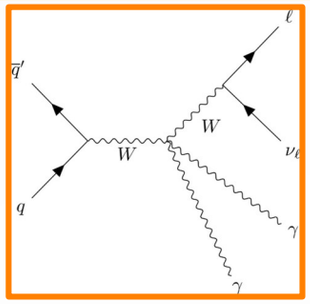
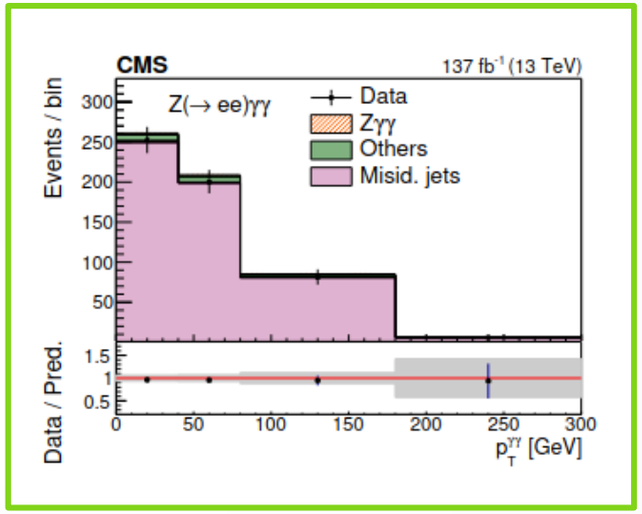
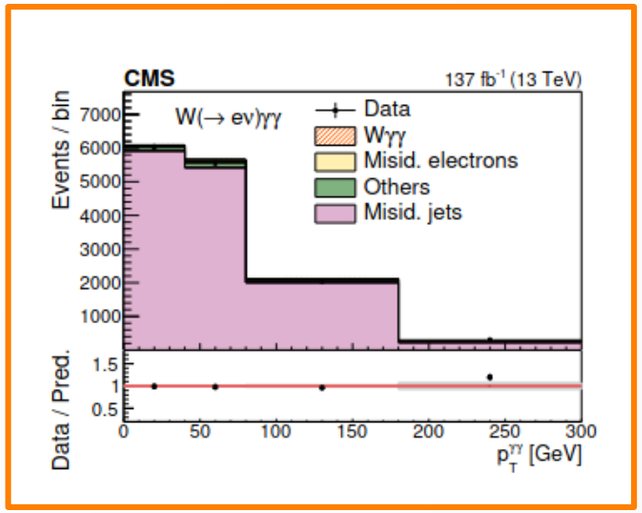


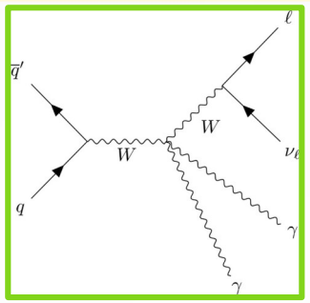


- **Background treatment:**
  - j → γ, dominant for both Wγγ and Zγγ
    data-driven fakes rate estimates
  - e → γ, important in W(e)γγ
    - Coming from Zγ events
    - Corrector factor computed in CR ($|m_{e,\gamma lead} - m_Z| < 5$ GeV removed) with fit on $m_{e,\gamma lead}$
  - VH(γγ) neglected





Wγγ



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- **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) ± 0.1 (lumi) fb in agreement with the SM prediction
- Using e/μ channel with 140fb^{-1} at 13 TeV

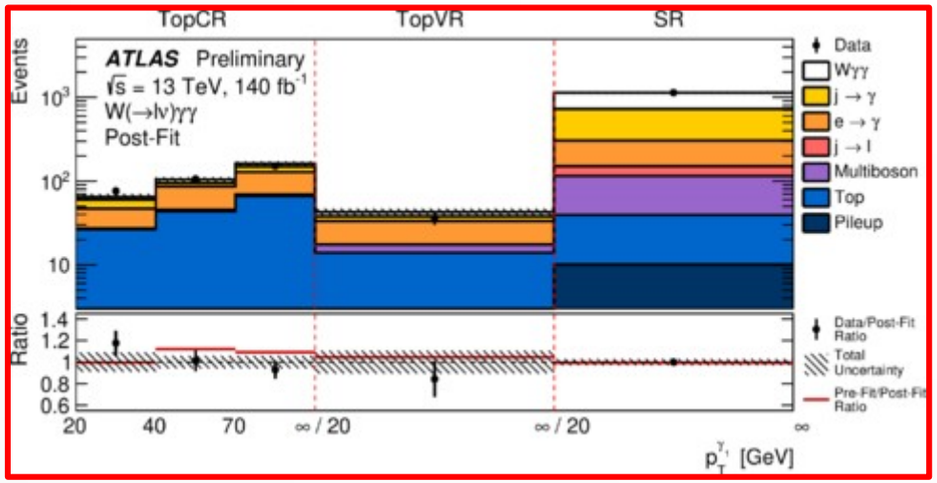
  B-jet veto and E_T^{miss} > 40 GeV selection

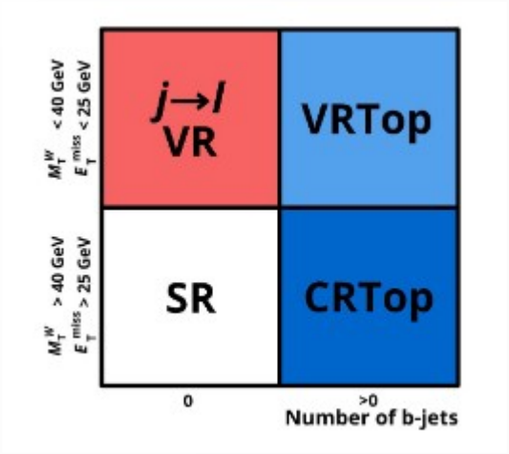
  4 bin likelihood fit (using **topCR**, **topVR** and SR)

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

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

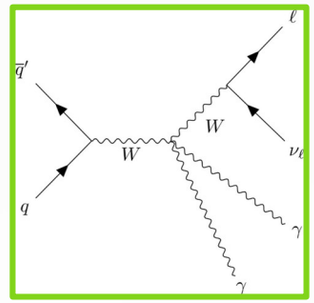
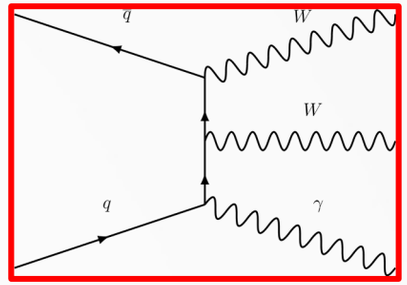
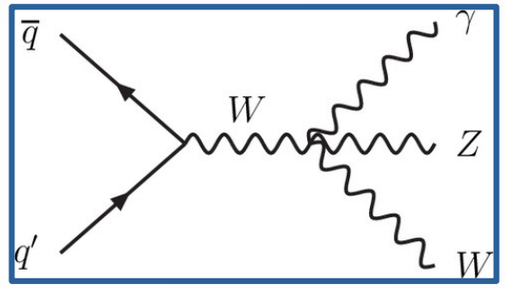
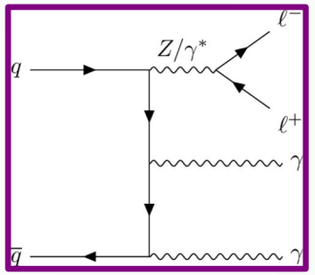
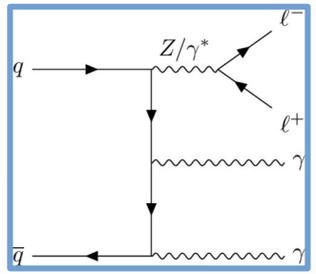
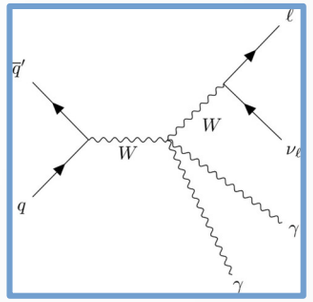
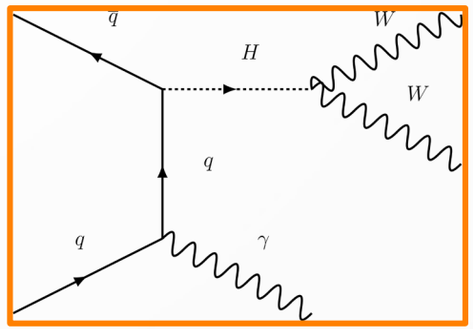
    Data driven fake rate estimate in Z→ee/eγ CR
  - Top background
    - Reduced via b veto
    - **Dedicated CR** (with >= 1 b-jet) for fit constrain
    - **Low E_T^{miss} region** (with >= 1 b-jet) for validation





Key points

- **3 New first observations: Wγγ[1]** and **WZγ[2]** by ATLAS and **WWγ[3]** by CMS
- **Limit set on EFT aQGC operators** with **Zγγ[4]** analysis by ATLAS and **Vγγ[5]** analysis by CMS
- Result in agreement with SM
- Limit on Higgs coupling with light quarks (u,d,s,c) set with **WWγ[3]** analysis by CMS
- New result to come with the ongoing Run 3
- Not covered in this talk
  - WVV[6], WWW[7] analysis by ATLAS
  - VVV[8] analysis by CMS

References

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- [2] ATLAS Collaboration (2023). Observation of WZγ production in pp collisions √s = 13 TeV with the ATLAS detector. CERN.
- [3] CMS Collaboration (2023). Observation of WWγ production and constraints on Higgs couplings to light quarks in proton-proton collisions at √s = 13TeV. CERN.
- [4] ATLAS Collaboration. (2022). Measurement of Zγγ production in pp collisions at √s = 13 TeV with the ATLAS detector. CERN.
- [5] CMS Collaboration (2021). Measurements of the pp → Wγγ and pp → Zγγ cross sections at √s = 13 TeV and limits on anomalous quartic gauge couplings.Journal of High Energy Physics.
- [6] ATLAS Collaboration (2019). Evidence for the production of three massive vector bosons with the ATLAS detector. Physics Letters B, 798, 134913.
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