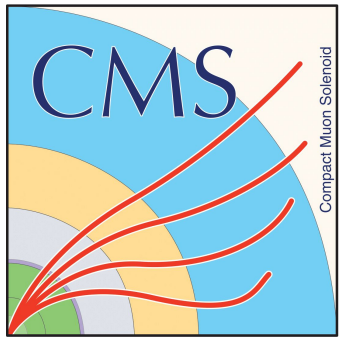
Triboson Measurements at ATLAS and CMS

Alessandro Ambler

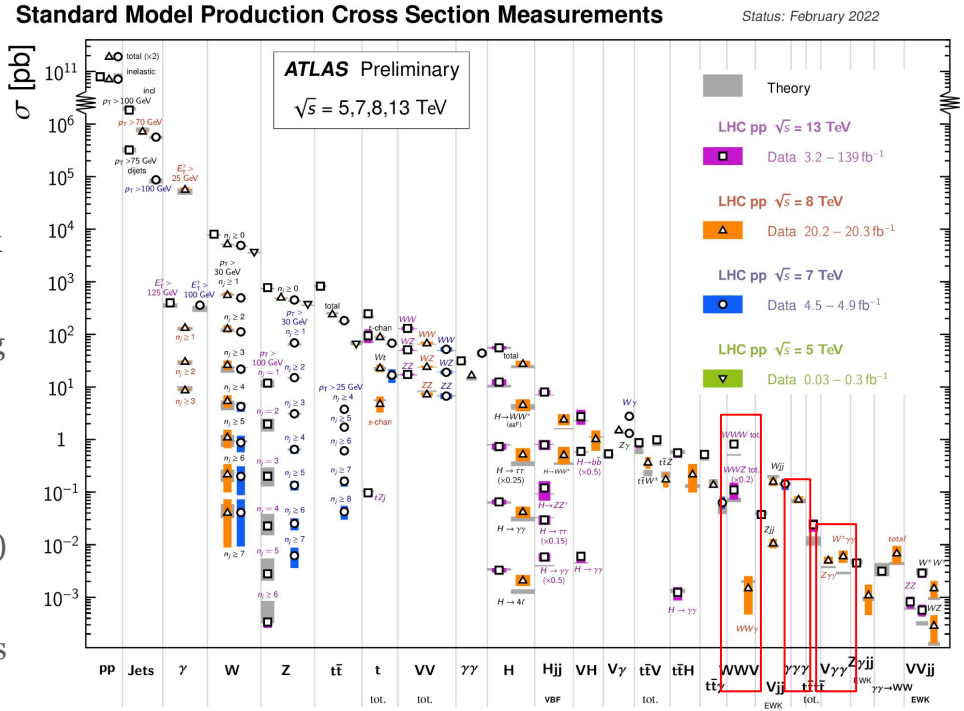
on behalf of the ATLAS and CMS collaborations

LHCP2023 in Belgrade



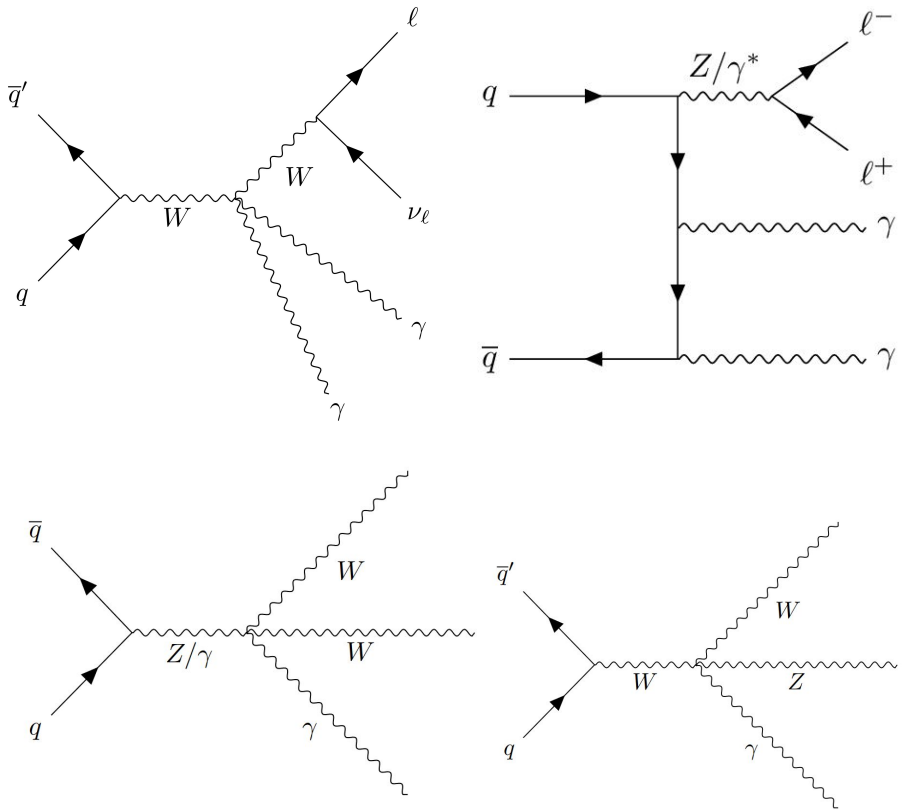
Motivation

- Triboson final states are rare and some are only now becoming accessible at the LHC
  - Many first observations in this presentation!
- Probe of non-Abelian self couplings of the electroweak gauge bosons in the Standard Model (SM)
  - Sensitive to anomalous Quartic Gauge Coupling (aQGC) operators
  - Can be used to set limits within Effective Field Theories (EFT)
- Backgrounds to SM processes like ZH(γγ) and WH(γγ) that will become accessible at run 3 and beyond
- Some final states can be used to probe Higgs couplings to light quarks



Overview

- Measurements covered in this talk
  - Wγγ, Zγγ and WZγ by ATLAS [1] [2] [3]
  - WWγ and Vγγ by CMS [4] [5]
- Measurements not covered in this talk
  - WVV, WWW by ATLAS [6] [7]
  - VVV by CMS [8]



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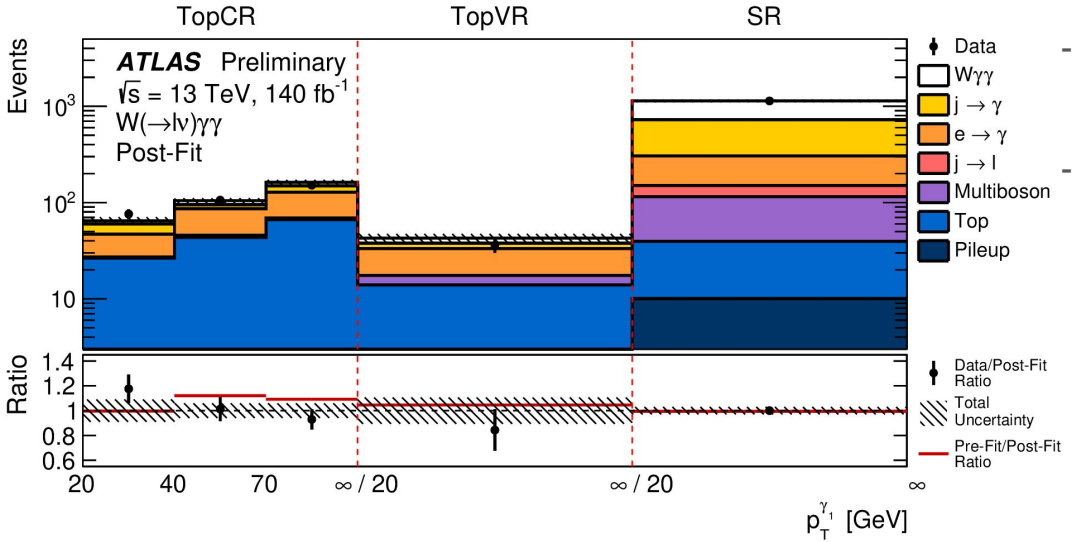
Wγγ



- **First observation at 5.6σ (5.6σ) obs.(exp.)!**
  - $\sigma^{meas} = 12.2^{+2.1}_{-2.0}$ fb, in agreement with SM
  - Dominant uncertainties : systematic on j→γ followed by stat. uncertainty
- e/μ channels, 13 TeV, 140 fb^{-1}
  - b-jet veto to reduce top backgrounds
- **Important backgrounds :**
  - **j→γ, largest background**
    - 2D template fits in data on leading and subleading photon isolation energy
  - **e→γ, second largest background in e channel**
    - Data-driven fake rate estimate Z→ee/eγ CR
  - **Top background constrained in ≥ 1 b-jet CR** simultaneously with SR
    - Validated in low E_T^{miss} region with ≥ 1 b-jet

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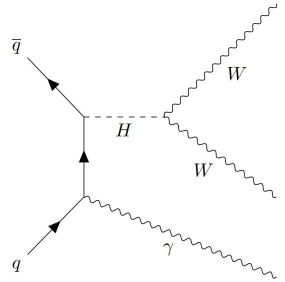
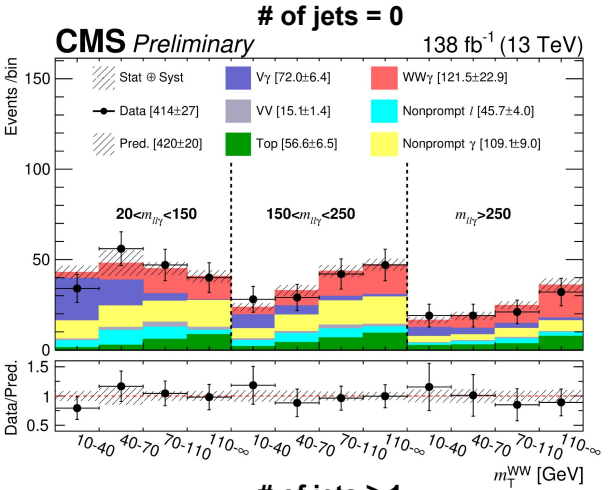
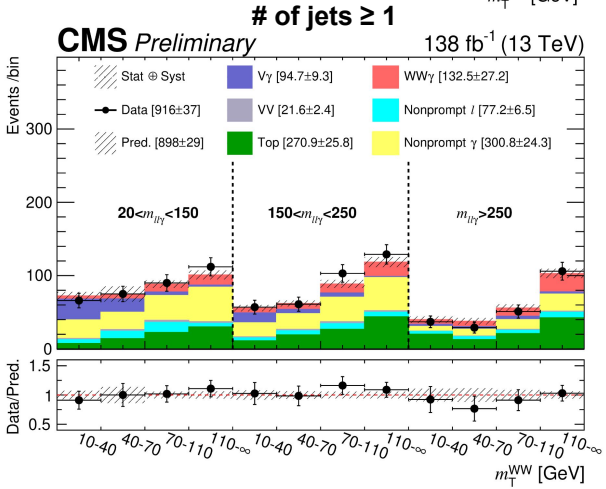
WWγ



- **First observation at 5.6σ (4.7σ) obs. (exp.)!**
  - σ^{meas} = 6.0 ± 1.0 (stat.) ± 1.0 (syst.) ± 0.9 (theo.) fb, in agreement with SM
  - Statistical, systematic and theory uncertainties comparable
  - **Limits set on Higgs Yukawa couplings** to u, d, s, c quarks
- e/μ channel, 13 TeV, 138 fb^{-1}
  - OFOS (W^+W^- → eνμν)
  - b-jet veto to reduce WZγ and top backgrounds

- **Important backgrounds** :
  - **j→γ, largest background**
    - Data-driven fake rate estimate in W+jets CR with a fit to the photon shower width to extract non-prompt component
  - **j→l, significant background**
    - Data driven fake rate estimate in dijet CR with lepton balanced by jet
  - **SSWW and Top CR** with ≥ 1 b-jet used to validate and constrain both j→l and j→γ backgrounds in simultaneous fit





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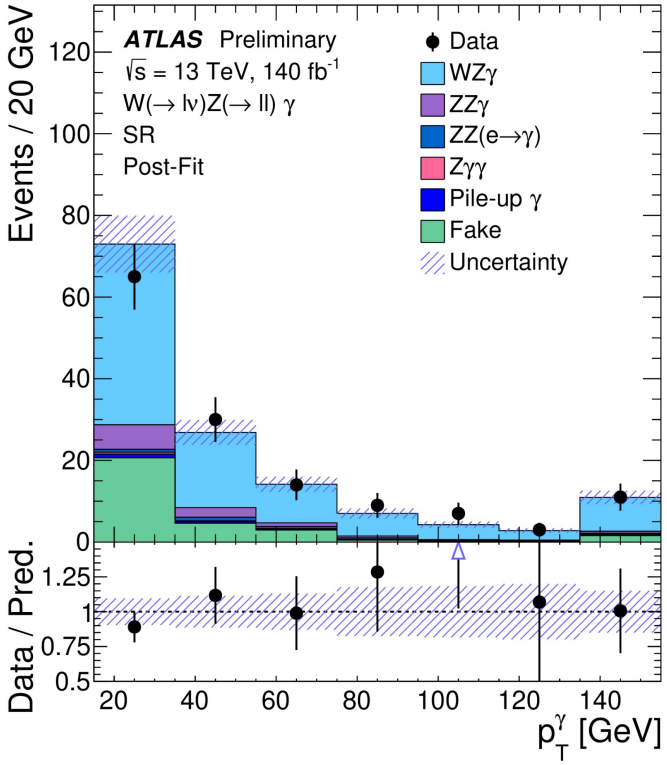
WZγ

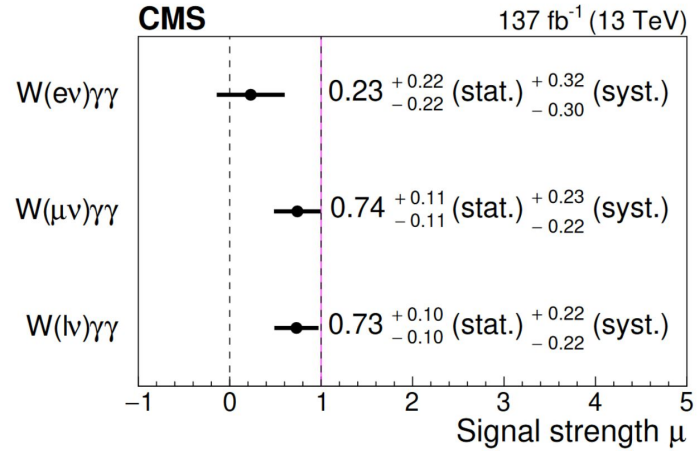
- **First observation with 6.3σ (5.0σ) obs. (exp.)!**
  - σ^{meas} = 2.01 ± 0.30 (stat.) ± 0.16 (syst.) fb, within 1.5σ of SM
  - Systematic uncertainty dominated by stat. uncertainty in non-prompt CRs
- e/μ channels, 13 TeV, 140 fb^{-1}
  - At least one SFOS pair,
  - $|m(e_W\gamma) - m(Z)| > 10$ GeV to reduce e→γ events
  - $m(l_Z l_Z) > 81$ GeV to reduce FSR
- **Important backgrounds :**
  - **j→γ background**
    - Data-driven fake rate estimated in Z+jet CR
  - **j→l background**
    - Data-driven fake rate estimated in dijet CR with one lepton balanced by a jet
  - ZZγ and e→γ background from ZZ
    - MC normalized in CRs

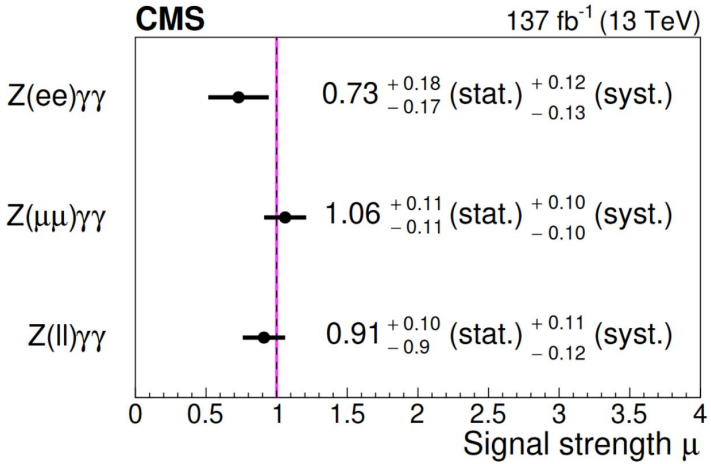


JHEP 2021

Vγγ

- **Zγγ : 4.8σ (5.8σ) obs. (exp.)**
  - Stat. and syst. are comparable
- **Wγγ : 3.1σ (4.5σ) obs. (exp.)**
  - Systematics dominated
- **Limits set on 10 aQGC operators using EFT approach**
- e/μ channels, 13 TeV, 137 fb^{-1}
  - γ removed if |m(eγ) - m(Z)| or |m(eγγ) - m(Z)| < 5 GeV to reduce FSR

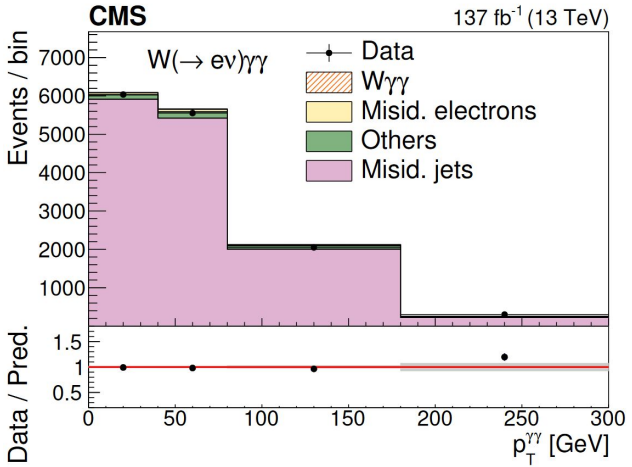


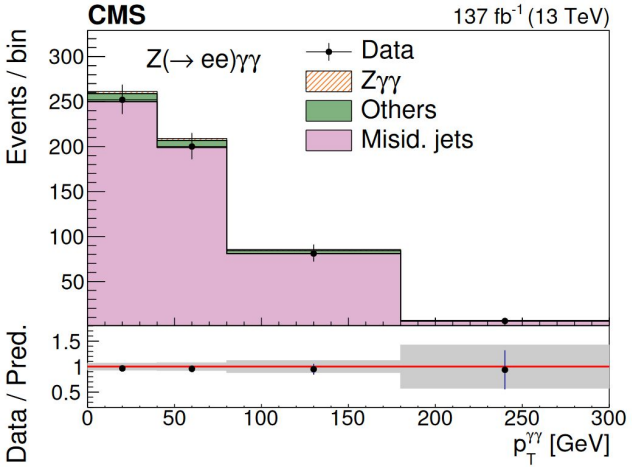


JHEP 2021

Vγγ

- **Important backgrounds :**
  - **j→γ background**, dominant in both W and Z channels
    - Probability for photons and jets to be isolated estimated in MC and data respectively
    - **Validation region** where both photons fail isolation
  - **e→γ background**, second largest in W electron channel
    - Scale factor computed in Zγ region
    - Signal and background extracted from fit on $m(e\gamma_{lead})$
    - Correction factor applied to MC
      - On average ≈ 20%





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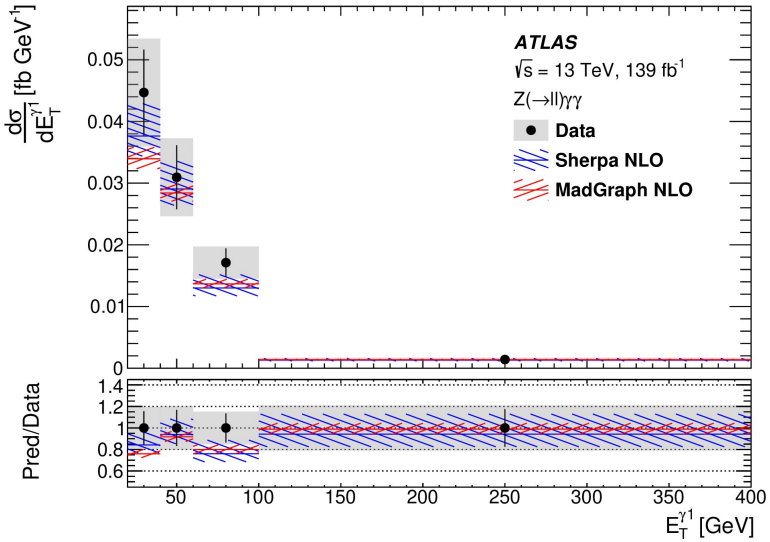
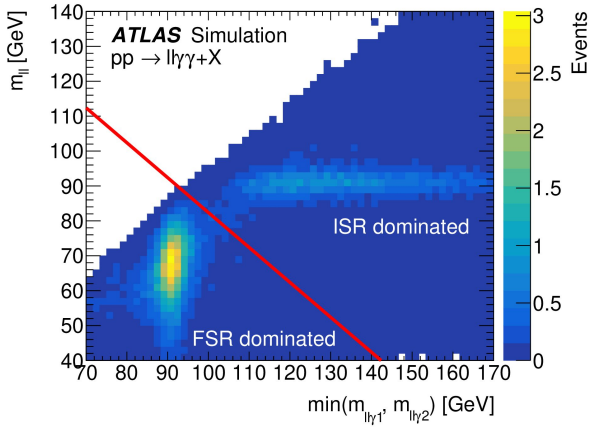
Zγγ

ATLAS EXPERIMENT

- **Differential cross section** along 6 kinematic variables
  - σ^{meas} = 2.45 ± 0.20 (stat.) ± 0.22 (syst.) ± 0.04 (lumi) fb
  - Uncertainty on j→γ dominates systematic uncertainty
- **Limits set on 8 aQGC parameters** using EFT approach
  - With and without clipping to constrain unitarity
- e/μ channels, 13 TeV, 139 fb-1
  - Cut on m(ll) and min(m(llγ$_1$), m(llγ$_2$)) to minimize FSR

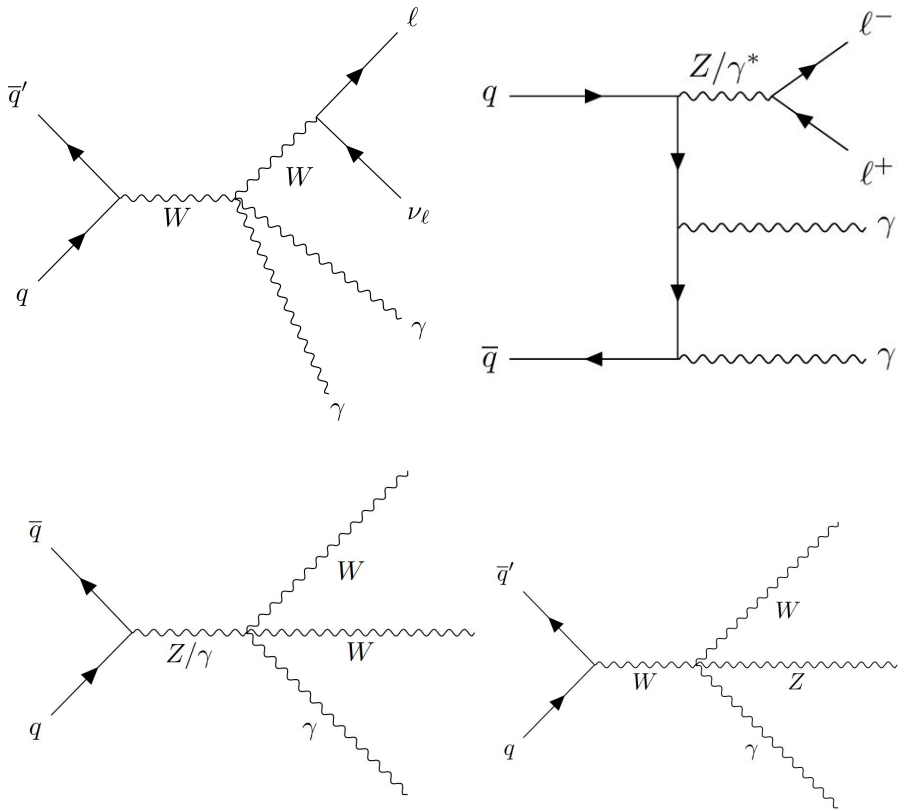




- **Important backgrounds :**
  - **j→γ, largest background**
    - Photon isolation efficiency and j→γ fake rate estimated in MC and data respectively
  - $t\bar{t}$ γγ background, MC
    - Normalized in OFOS CR
  - Zγ+γ and Z+γγ pileup background, MC
    - Estimated by overlaying Zγ and γ MC and Z and γγ MC events

Summary & Outlook

- **Exciting new first observations** of Wγγ and WZγ by ATLAS and WWγ by CMS
- New limits set on aQGC operators with the Zγγ and Vγγ analyses by ATLAS and CMS respectively
- New limits on Higgs coupling to light quarks with WWγ analysis by CMS
- No significant tension with SM as of yet
- With run 3 right around the corner, **many thing to look forward to**!



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[2] ATLAS Collaboration. (2022). Measurement of Zγγ production in pp collisions at √s = 13 TeV with the ATLAS detector. CERN.

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