

QCD@LHC workshop
Oxford, UK – October 1, 2026

Multiboson Measurements at CMS

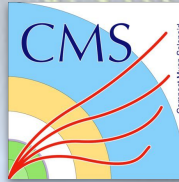


Cristiano Tarricone^(a,b)
on behalf of
the **CMS Collaboration**



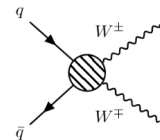
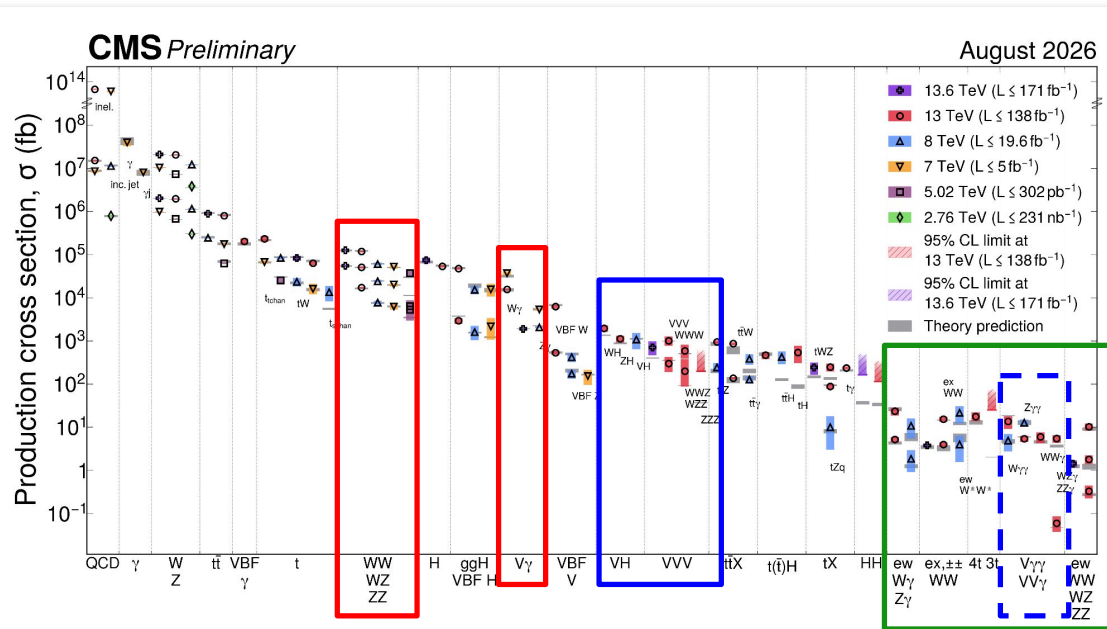
**UNIVERSITÀ
DI TORINO**

(a) Università degli Studi di Torino
(b) INFN Torino

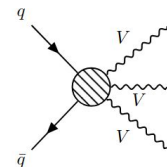


cristiano.tarricone@cern.ch

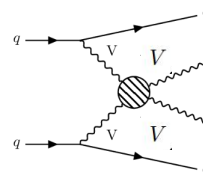
Gauge bosons **mutual/self-interaction** → due to the **non-Abelian structure** of the **electroweak (EW)** theory.



- **Diboson measurements:**
 - validation of the EW gauge sector
 - direct probe of **triple gauge couplings**



- **Triboson measurements**
 - explore **rare interactions**
 - direct probe of quartic gauge couplings
 - sensitivity to **new physics**
- 



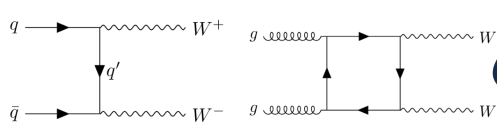
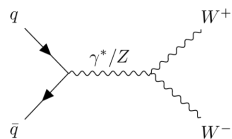
- **Vector boson scattering:**
→ direct probe of quartic gauge couplings and EWSB

see VBS [dedicated talk](#) by Ruobing Jiyang

Diboson measurements

WW ($W \rightarrow \tau_h \nu_\tau$)

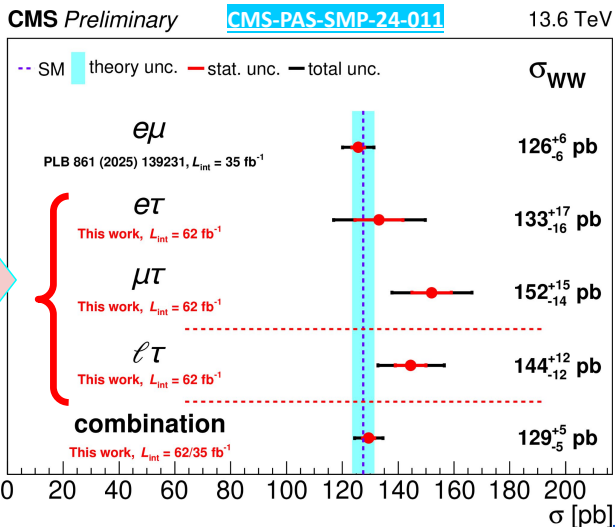
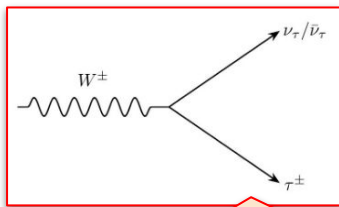
Run 3 (2022-2023 dataset) analysis



Simultaneous fit in 4 orthogonal regions:

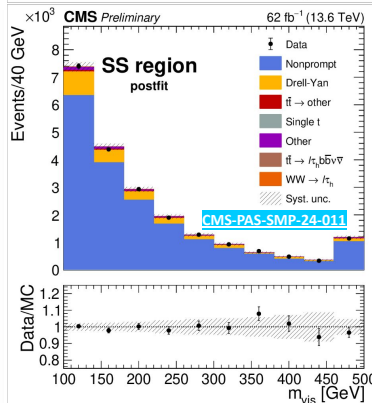
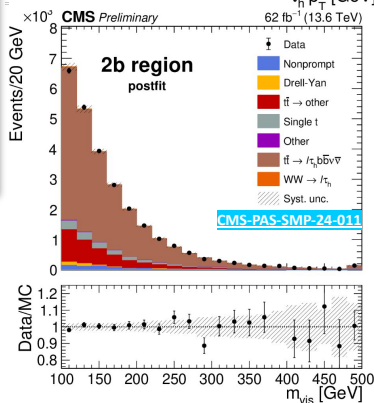
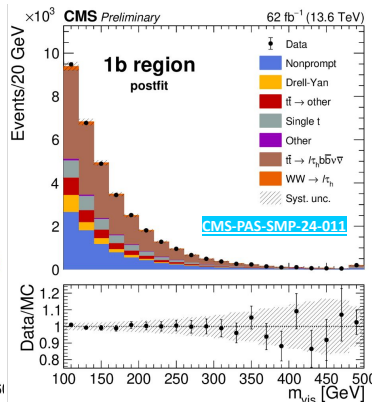
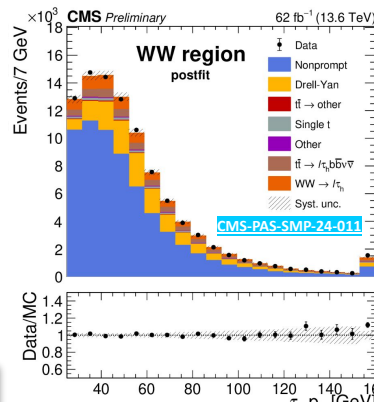
- **WW Region:** OS- $\ell\tau$, b-veto;
- **1b Region:** OS- $\ell\tau$, 1 b-tag jet;
- **2b Region:** OS- $\ell\tau$, ≥ 2 b-tag jet;
- **Same sign Region:** SS- $\ell\tau$, b-veto.

CMS-PAS-SMP-24-011



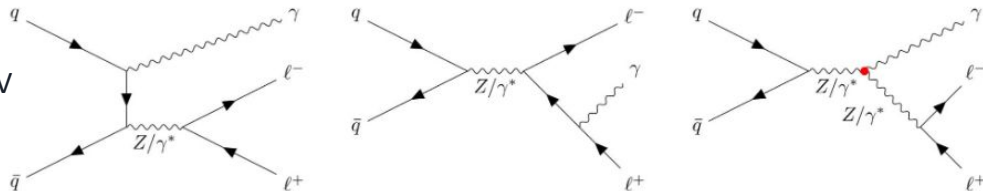
Probing WW production from a new angle:

- τ in the final state
- sensitivity to new couplings with τ



- Selections:

- $e^+e^-/\mu^+\mu^-$ pair: $71 < m_{\ell\ell} < 111$ GeV
- (Sub-)Leading lepton: $p_T > 25$ (20) GeV
- Photon: $p_T > 30$ GeV



- Non-prompt photon background** determined from sidebands of charged isolation and shower shape

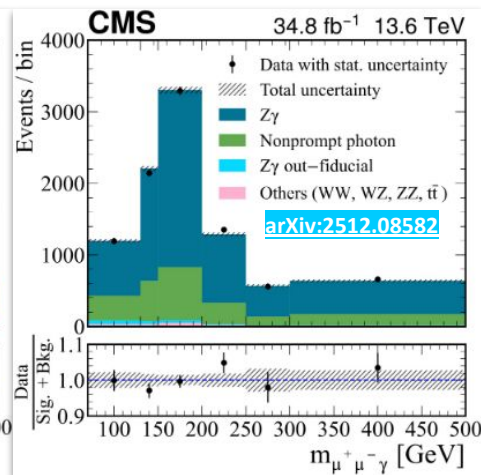
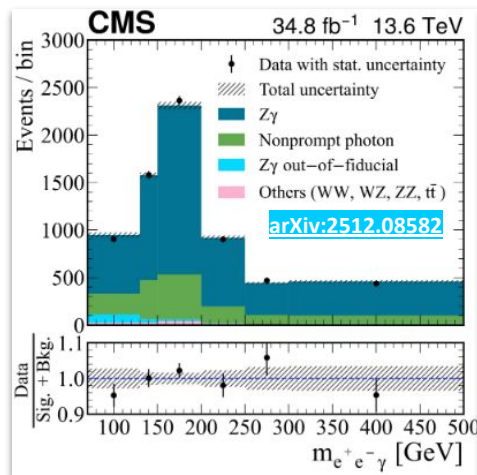
- Measured fiducial cross-sections:

Channel	$\sigma\mathcal{B} \pm \text{stat} \pm \text{syst} \pm \text{theo} \text{ (pb)}$
$Z\gamma (\mu\mu)$	$0.928 \pm 0.018 \pm 0.027 \pm 0.004$
$Z\gamma (ee)$	$0.975 \pm 0.021 \pm 0.038 \pm 0.003$
$Z\gamma$ (combined)	$1.896 \pm 0.033 \pm 0.054 \pm 0.006$

Cross-section predicted by the SM:

$$\sigma_{\text{SM}} = 1.922 \pm 0.094 \text{ pb}$$

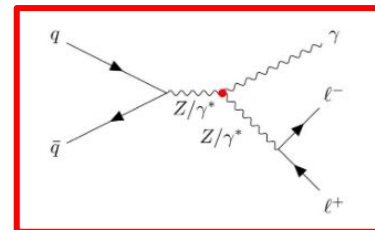
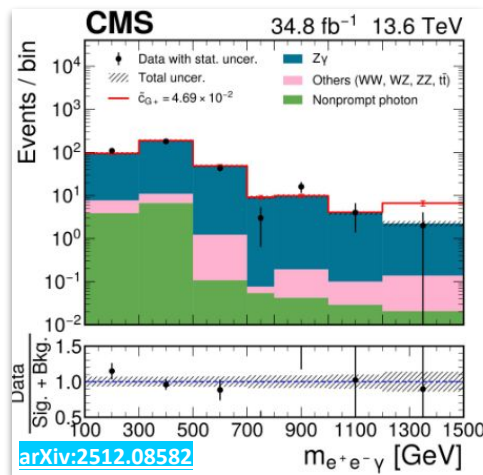
→ **good compatibility observed**



- Selections:
 - $e^+e^-/\mu^+\mu^-$ pair: $71 < m_{\ell\ell} < 111$ GeV
 - (Sub-)Leading lepton: $p_T > 25$ (20) GeV
 - Photon: $p_T > 30$ GeV
- **Non-prompt photon background** determined from sidebands of charged isolation and shower shape
- Constraints on dim.8 EFT operators $\rightarrow$ 2 models:
 - **Vertex Parametrization Model**
 - only $U(1)_{EM}$ symmetry preserved;
 - **Gauge Symmetry Preserving Model**
 - full $SU(2)_L \times U(1)_Y$ symmetry preserved

[Ellis et al. [PRD 107 \(2023\) 035005](#)]

[arXiv:2512.08582](#) Submitted to PLB

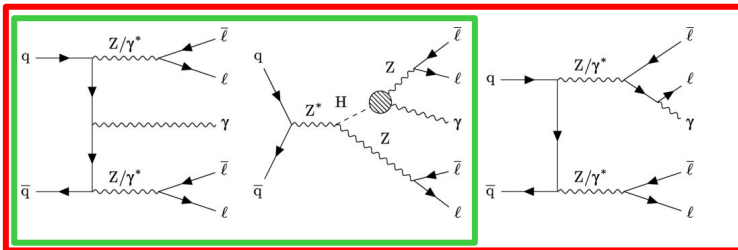


Constraints on
**anomalous neutral
triple gauge coupling
(aNTGC)**

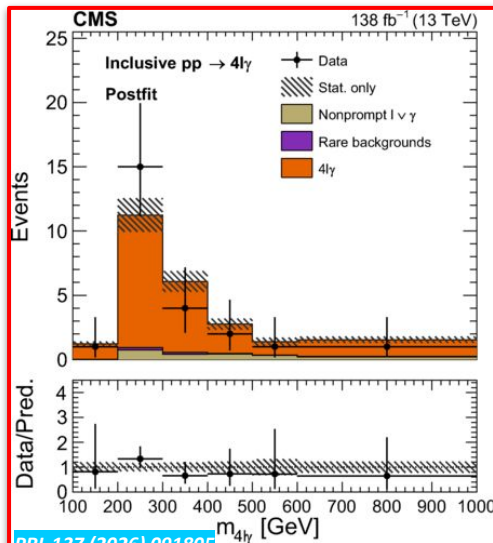
Limits	Expected		Observed	
	Lower	Upper	Lower	Upper
h_4^Z	-1.01×10^{-6}	1.01×10^{-6}	-8.17×10^{-7}	8.20×10^{-7}
h_3^γ	-8.34×10^{-4}	8.58×10^{-4}	-6.67×10^{-4}	6.88×10^{-4}
h_3^Z	-7.01×10^{-4}	6.96×10^{-4}	-5.69×10^{-4}	5.48×10^{-4}
$\tilde{c}_{G+}$	-3.83×10^{-2}	3.79×10^{-2}	-3.05×10^{-2}	3.06×10^{-2}
$\tilde{c}_{G-}$	-3.09	3.18	-2.44	2.54
$\tilde{c}_{\tilde{B}W}$	-1.24	1.26	-0.98	1.00

[arXiv:2512.08582](#)

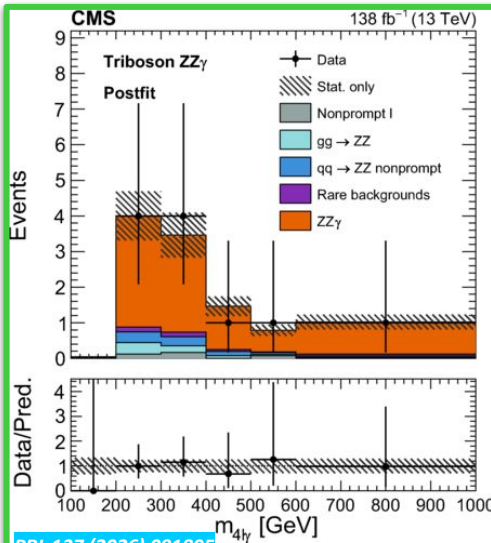
Triboson measurements



- **Inclusive 4 $\ell\gamma$** (no mitigation of FSR contribution)
 - Data-driven nonprompt γ and ℓ estimate
- **Triboson ZZ γ** (FSR suppressed) $\rightarrow$ requiring $\min\{m_{ll\gamma}\} > 100$ GeV
 - Fake γ from MC: $(qq/gg \rightarrow) ZZ \rightarrow 4\ell (+\gamma_{NP})$
 - Fake ℓ : data-driven technique



PRL 137 (2026) 091805



PRL 137 (2026) 091805

- Very stringent fiducial region (only 11 event candidates)
 - **Smallest (fiducial) cross-section at LHC:**
 $\rightarrow$ measured (predicted):
 60^{+27}_{-22} ab (47.56 ± 0.04 ab)
- **First evidence of the ZZ γ production** at 13 TeV with the CMS experiment:
 - Observed (expected) significance: **3.7 (3.1) S.D.**
- **First observation of the 4 $\ell\gamma$ production** at 13 TeV:
 - Observed (expected) significance: **5.0 (4.2) S.D.**

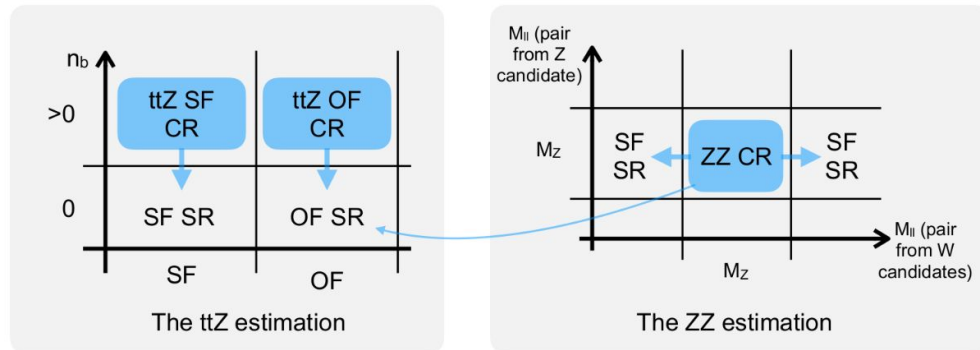
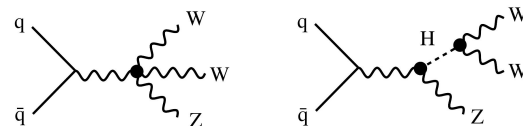
WWZ fully leptonic channel

CMS Run 2 (2016-2018) - 3 (2022-2023) analysis

PRL 135 (2025) 091802

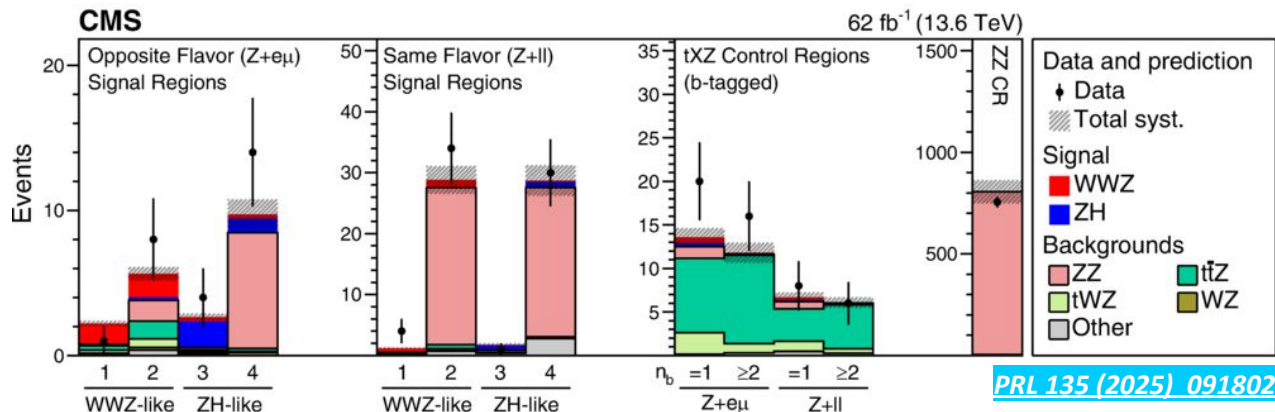
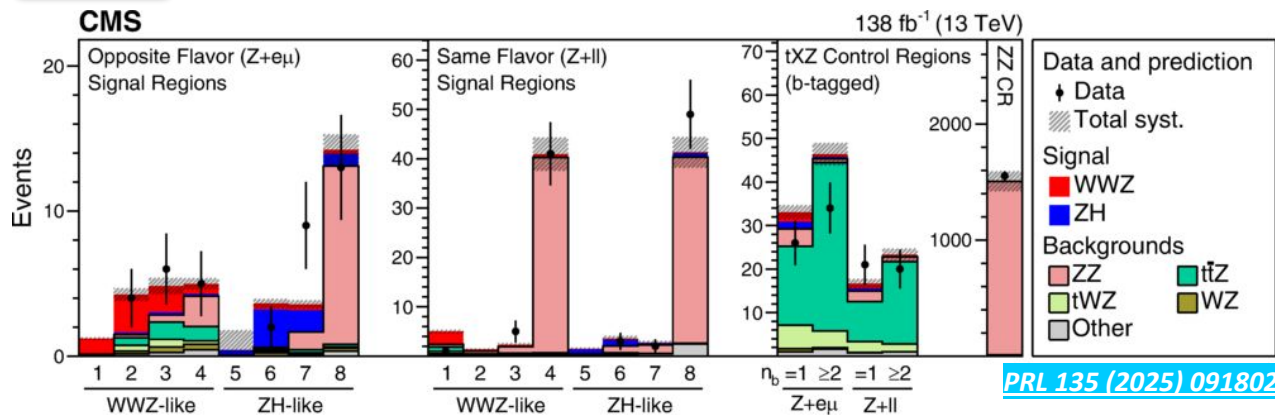
Measurement of W^+W^-Z and ZH signal strengths individually and together

- Final state selected with **4 charged leptons (e, μ)**
 - 2 charged leptons reconstructing the best **Z candidate**
 - The remaining 2 charged leptons must be **opposite-charge, same-flavor (SF)** or **opposite-flavor (OF)** defining 2 corresponding channels
- CRs to normalize the main backgrounds, i.e., ttZ and ZZ
- BDT multiclassifier** assigning three different scores (summed to 1)
 - non-resonant WWZ
 - $ZH, H \rightarrow WW^*$
 - background



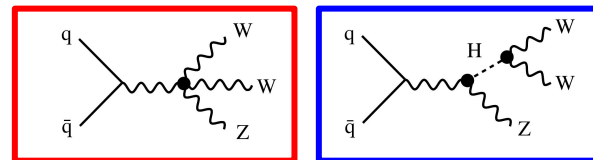
WWZ fully leptonic channel

CMS Run 2 (2016-2018) - 3 (2022-2023) analysis



Scores used to define a set of Signal Regions:

- 8(4) SRs per channel, *i.e.*, SF and OF channels
- Separately defined SRs per era, *i.e.*, Run 2 (13 TeV, 138/fb) and Run 3 (13.6 TeV, 62/fb)



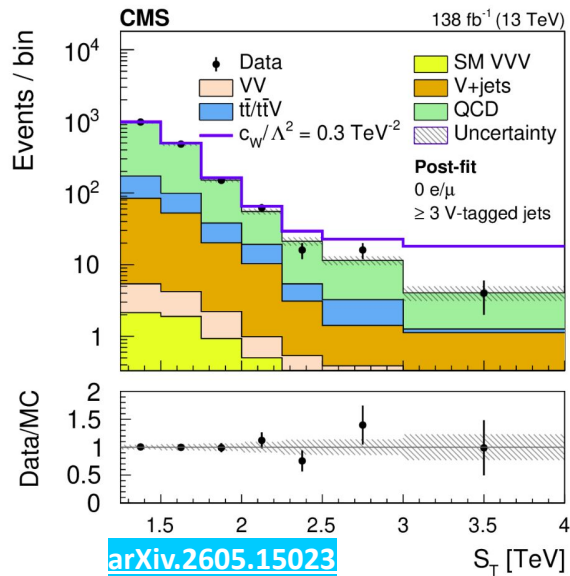
Era	Total	WWZ	ZH
Run 2	2.9 (4.4)	1.3 (3.1)	2.0 (2.6)
Run 3	3.8 (2.5)	2.5 (1.3)	2.5 (1.7)
Total	4.5 (5.0)	2.4 (3.3)	3.1 (3.1)

Observed (expected) significance per era

EFT Multiboson Combination

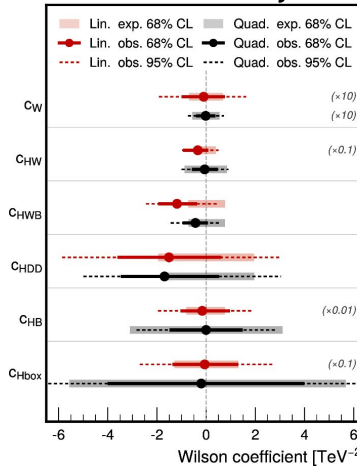
Multiboson EFT results → Combination (dim.6)

Run 2 (138 fb⁻¹) VBS (VVjj), VBF (Vjj), diboson (SS/OS-WW), and triboson (combined VVV = WWW, WWZ, WZZ, ZZZ) meas.

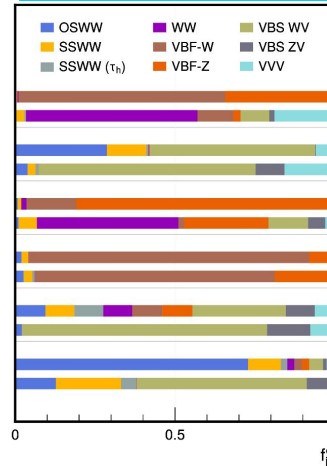


- High-yield inclusive dibosons drive bulk precision
- VBS and tribosons constrain high- p_T and high- m_{VV} tails.

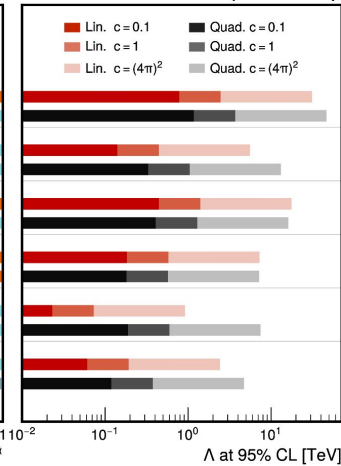
CMS Preliminary



CMS-PAS-SMP-25-002



138 fb⁻¹ (13 TeV)

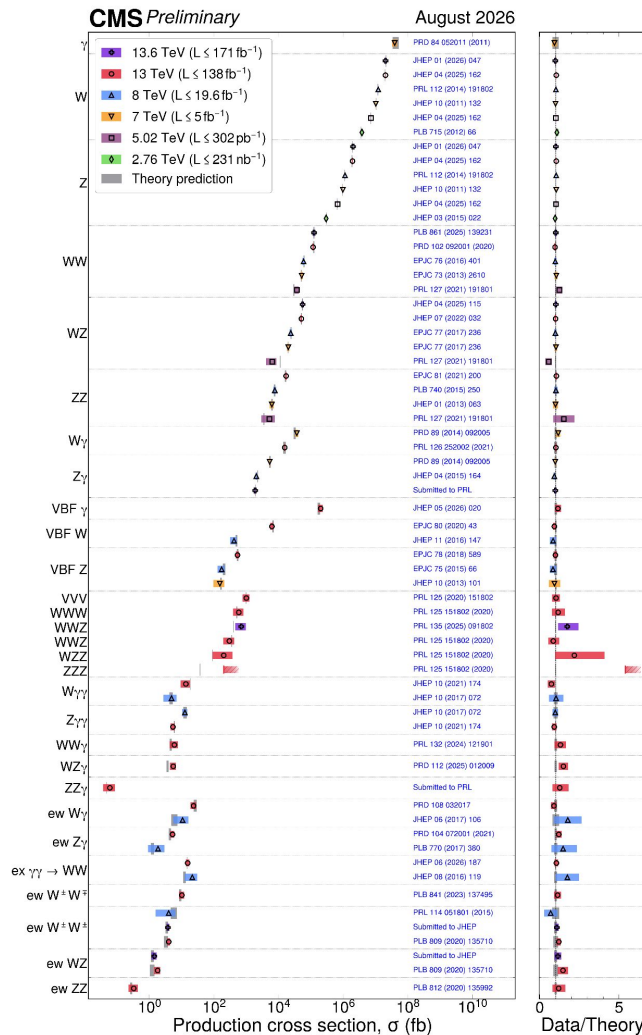


- Both linear and **linear + quadratic** terms are evaluated to quantify EFT truncation effects.
- Stringent limits set on triple-gauge (c_W), gauge-Higgs (c_{HW} , c_{HB}), and contact operators ($c_{H\ell}^{(3)}$, $c_{Hq}^{(3)}$)
- Combination tightens individual channel bounds by factors of ~2–5

Summary and Outlook

Stairway to discovery... ... and higher precision

- We have reached the era of precision for diboson measurements at the LHC
- Systematic uncertainties are starting to become more relevant than statistical ones
- Still a lot more to study with Run 3 data and beyond:
 - New final states
 - Differential cross sections
 - Polarization
 - EFT



Thank you!

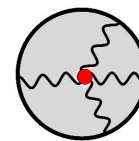
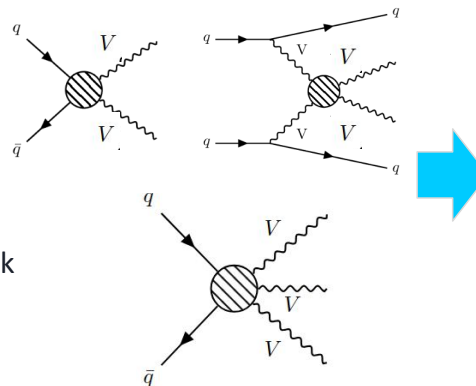
Other contents

Multiboson Physics

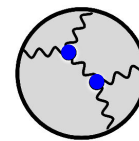
Diboson and Triboson production processes

- extremely **rare**
- valuable **precision tests** for the electroweak sector of the Standard Model
- **novel observation** of **very rare** processes
- **TGCs** and **QGCs** involved (and **couplings with the Higgs boson**)

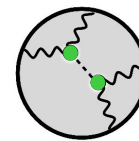
→ Powerful tool to probe the **EWSB**



Quartic gauge



Triple gauge

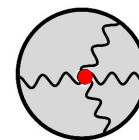
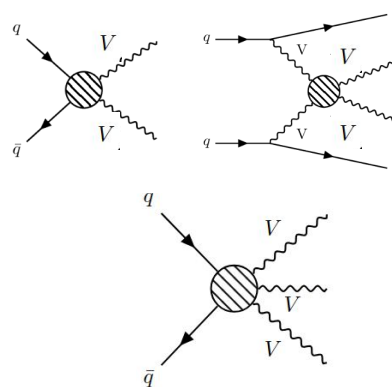


Higgs-gauge

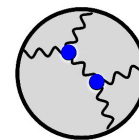
Multiboson Physics

Diboson and Triboson production processes

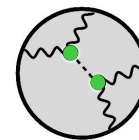
- Predicted by the SM (but extremely **rare**)
→ valuable **precision tests** for the EWSB
→ **very rare** processes' novel **observation**
- **TGCs** and **QGCs** involved (and **couplings with the Higgs boson**)
→ Potentially hiding **new physics**



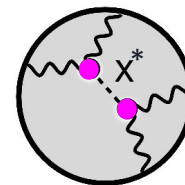
Quartic gauge



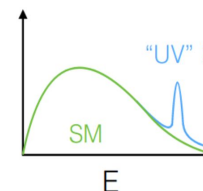
Triple gauge



Higgs-gauge



X particle



Multiboson new Physics → EFT Framework

Diboson and Triboson production processes

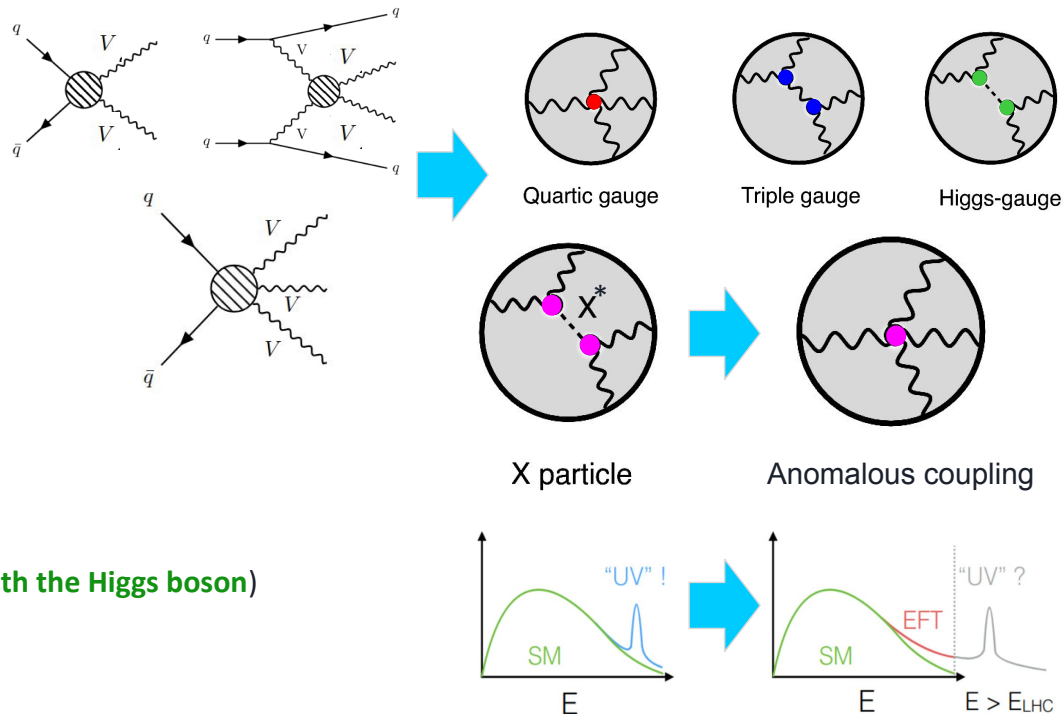
- Predicted by the SM (but extremely **rare**)
→ valuable **precision tests** for the EWSB
→ **very rare** processes' novel **observation**

- TGCs** and **QGCs** involved (and **couplings with the Higgs boson**)

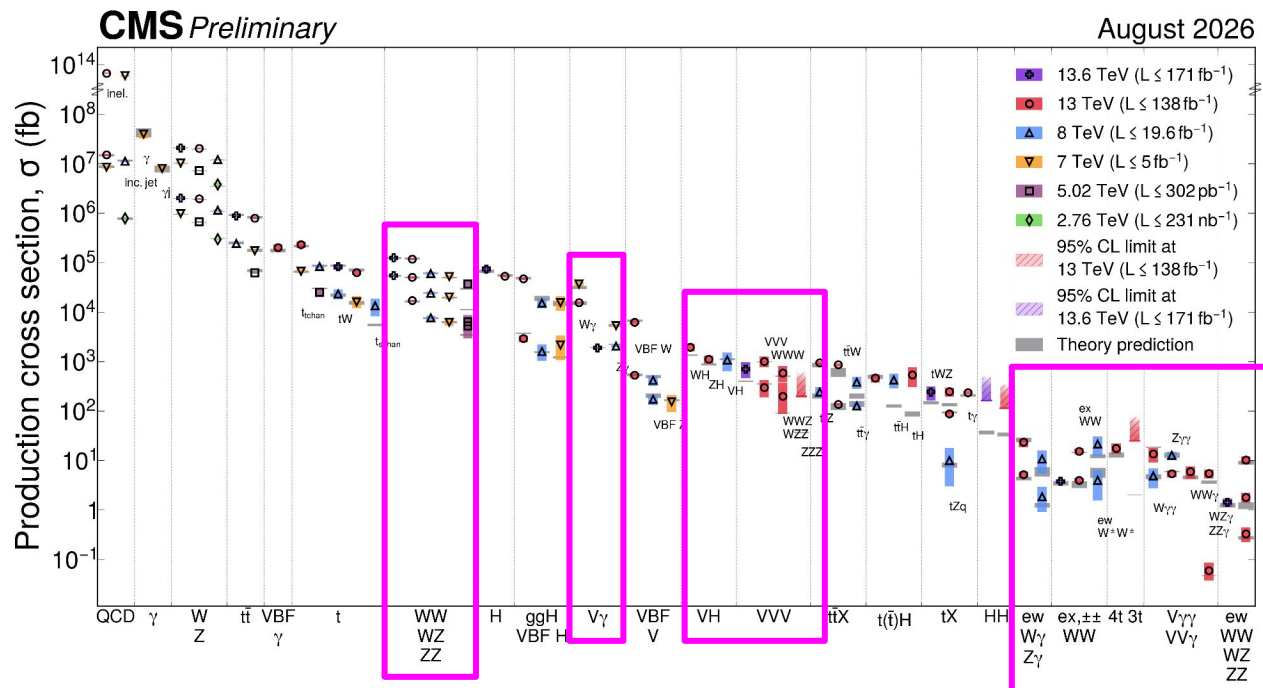
→ Potentially hiding **new physics**

→ Interpretable as a point-like interaction/anomalous couplings in an **effective field theory (EFT)**

→ **Systematic parametrization** to search for any subtle deviations → **constraints to guide future collider efforts**



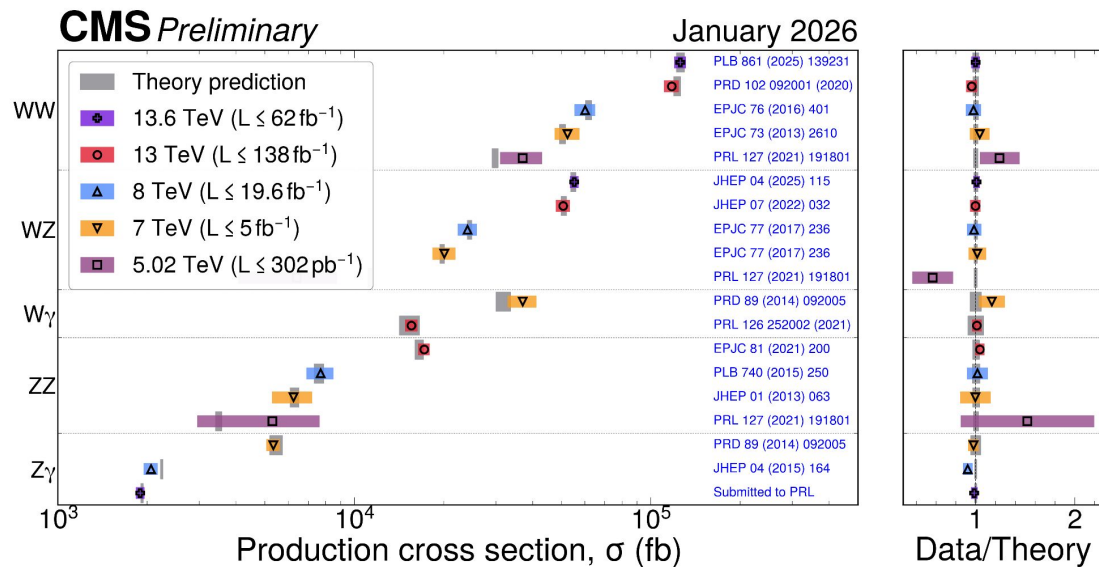
Multiboson measurements at CMS



- Run 1: first look at multiboson processes
- Run 2: several multiboson-final-state discoveries
- **Run 3 & HL-LHC:**
 - differential XS measurements
 - enhance new physics searches

Recent Diboson measurements

- Cross-section measurement of **WW production with hadronic tau decays** at 13.6 TeV [[CMS-PAS-24-011](#)]
- Cross-section measurement of **Z γ production** at 13.6 TeV [[arXiv:2512.08582](#) , Subm. to PRL]
- Constraints on **anomalous couplings** in **semi-leptonic channel** of **WV production** at 13 TeV [[arXiv.2608.18245](#) , Subm. to PLB]

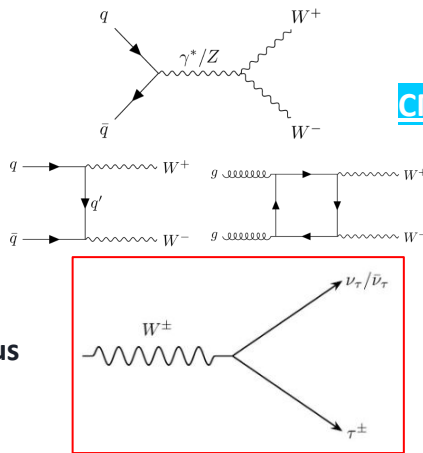


Note: many ongoing efforts within CMS dedicated to diboson production processes via **Vector Boson Scattering** → see [Ruobing Jiyang's dedicated talk](#) in this session

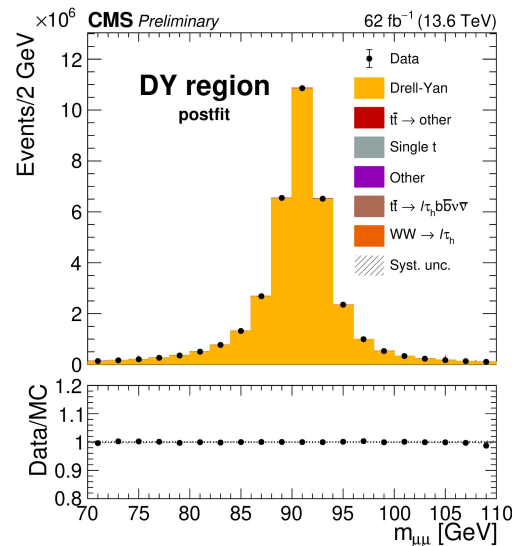
WW ($W \rightarrow \tau_h \nu_\tau$)

Run 3 (2022-2023 dataset) analysis

- Probing WW production from a new angle:
 - including taus in the final state
 - sensitive to new physics coupling with taus
- Selections:
 - 1 ℓ (e/ μ), with $p_T > 30$ GeV
 - 1 hadronic τ , with $p_T > 25$ GeV
 - $m_{\ell\tau} > 100$ GeV
- Backgrounds:
 - Non-prompt** → the dominant bkg.: estimation via Fake Factor method.
 - QCD-induced** and **W+jets** → considered separately and weighted to their expected contribution
 - ttbar: cross section measured through regions with b-tags
 - DY : controlled by $Z \rightarrow \mu\mu$ region
- WW signal is extracted via fit to BDT output distribution



CMS-PAS-SMP-24-011



WV semi-leptonic channel

Run 2 analysis – constraints on anomalous couplings

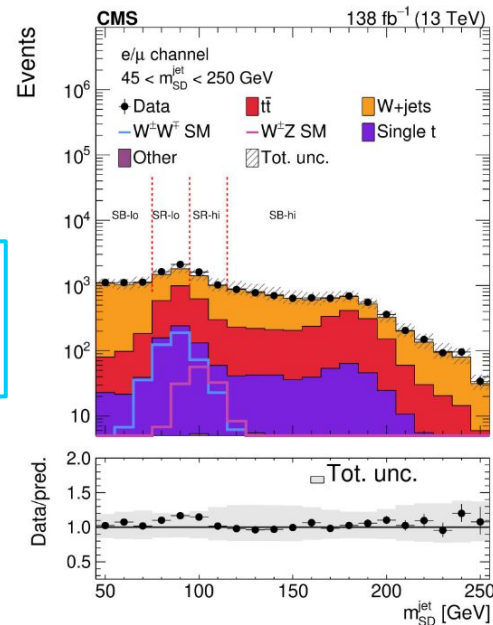
arXiv:2608.18245 Submitted to PLB

Selections:

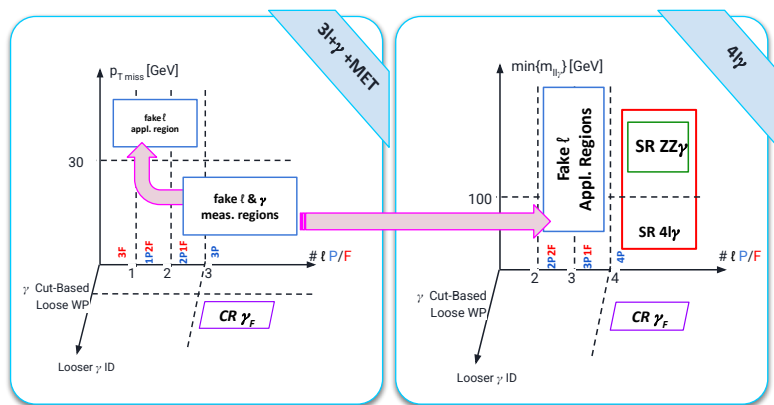
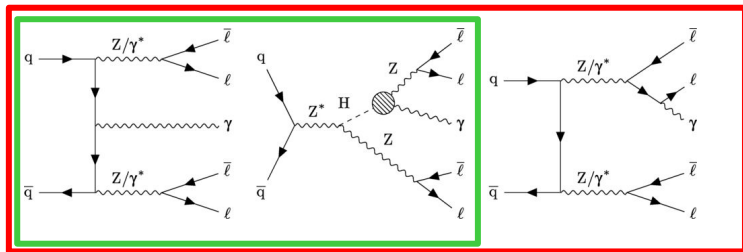
- 1 W/Z- tagged large-radius jet (ParticleNet)
→ $75 \text{ GeV} < m_{\text{VTJ}} < 115 \text{ GeV}$, $p_{\text{T}} > 200 \text{ GeV}$
- 1 $e/\mu \rightarrow p_{\text{T}} > 50 \text{ GeV}$
- $p_{\text{T,miss}} > 100 \text{ GeV}$
- 1 reconstructed leptonically decaying W boson
→ $p_{\text{T}} > 200 \text{ GeV}$

ML discriminator
used for signal
extraction

WC	Limits (TeV^{-2})			
	Expected 68%	Expected 95%	Observed 68%	Observed 95%
$c_B^{\text{HISZ}}/\Lambda^2$	[-3.09, 2.92]	[-4.69, 4.49]	[-2.81, 3.32]	[-5.18, 5.39]
$c_{\text{WWW}}^{\text{HISZ}}/\Lambda^2$	[-0.55, 0.55]	[-0.81, 0.82]	[-0.58, 0.55]	[-0.93, 0.93]
$c_W^{\text{HISZ}}/\Lambda^2$	[-1.15, 0.70]	[-1.66, 1.14]	[-0.56, 1.02]	[-1.44, 1.78]
$c_{\text{WWW}}^{\text{HISZ}}/\Lambda^2$	[-0.26, 0.27]	[-0.40, 0.40]	[-0.13, 0.33]	[-0.37, 0.49]
$c_W^{\text{HISZ}}/\Lambda^2$	[-1.66, 1.12]	[-2.37, 1.79]	[-1.31, 1.24]	[-2.24, 2.13]



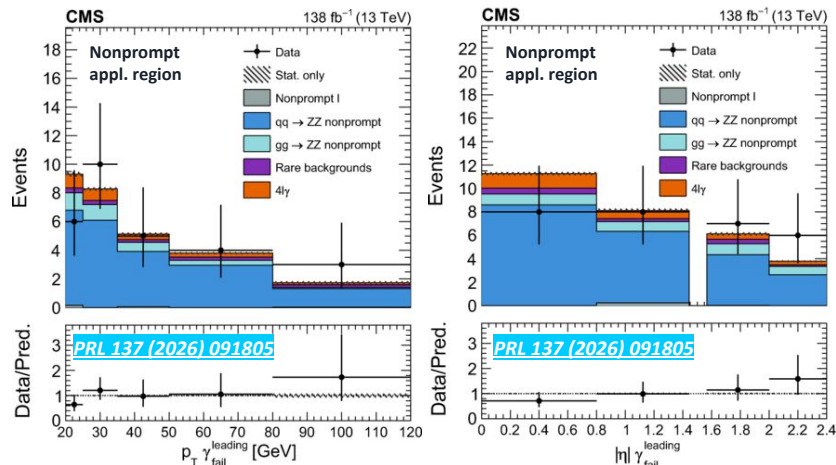
- Most stringent limits on operators involving TGCs
- Limits on quark-boson couplings competitive with inclusive jet measurements



Recently published!

PRL 137 (2026) 091805

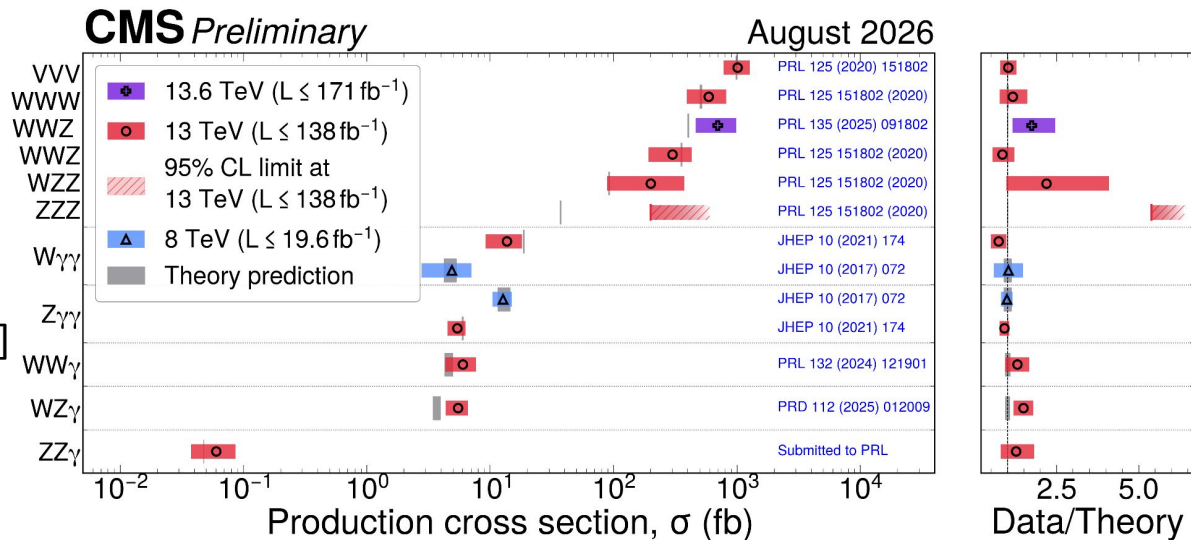
- **Inclusive 4 $\ell\gamma$** (no mitigation of FSR contribution)
 - Data-driven nonprompt γ and ℓ estimate
- **Triboson ZZ γ** (FSR suppressed) $\rightarrow$ requiring $\min\{m_{ll\gamma}\} > 100$ GeV
 - Fake γ from MC: $(qq/gg \rightarrow) ZZ \rightarrow 4\ell (+\gamma_{NP})$
 - Fake ℓ : data-driven technique



- The γ -FR is measured in a dedicated region, subtracting Z γ -prompt
- Events in **CR γ_F** ($4\ell_{PASS} + 1\gamma_{FAIL}$) are reweighted to estimate the background in the **SR**

Recent Triboson measurements

- Cross-section measurement of **ZZ γ production** at 13 TeV
[[PRL 137 \(2026\) 091805](#)]
- Cross-section measurement of **WWZ production** at 13 TeV and 13.6 TeV [[PRL 135 \(2025\) 091802](#)]
- Search for **new physics (EFT dim.-6 & 8)** in **VVV production** at 13 TeV
[[arXiv.2605.15023](#) Subm. to JHEP]



→ relevant in the global Multiboson CMS EFT Combination
[CMS-PAS-SMP-25-002]



WW γ

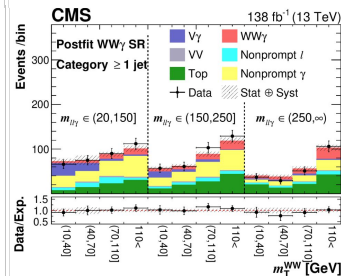
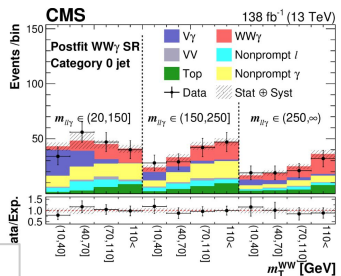
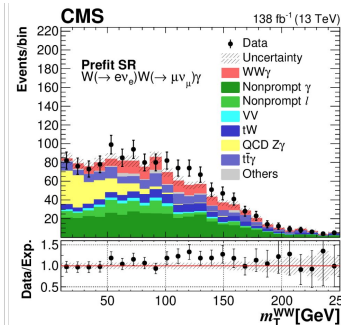
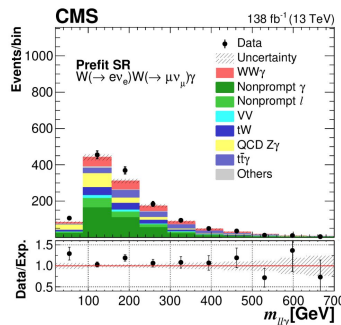
CMS Run 2 analysis

- Measurement of WW γ with fully leptonic final state
- Data-driven method for estimating bkg. processes containing a prompt lepton/photon
 - Z γ
 - ttbar+ γ
 - single-top
- Control Regions to validate the bkg. estimations:
 - SSWW γ
 - Top γ
 → $m_T^{WW} > 10$ GeV cut not applied in the CR

Measured fiducial cross section:

$$\sigma = 6.0 \pm 1.0(\text{stat}) \pm 1.0(\text{syst}) \pm 0.9(\text{theo}) \text{ fb}$$

$$\mu = 1.31 \pm 0.17(\text{stat}) \pm 0.21(\text{syst}) \quad 5.6(4.7) \text{ S.D.}$$

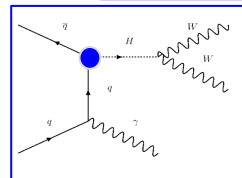
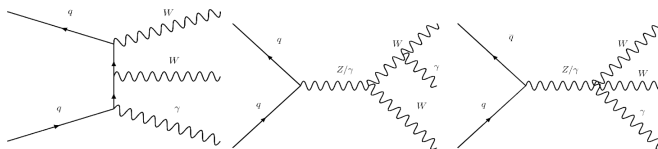


PRL 132 (2024) 121901



2D binned fit in m_T^{WW} vs $m_{l\bar{l}\gamma}$

Extraction of limits on Higgs couplings with light quarks from $H\gamma \rightarrow WW\gamma$



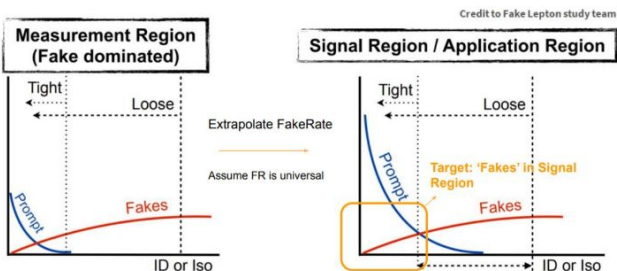
Process	σ upper limits obs. (exp.) [fb]	κ_q limits obs. (exp.) at 95% CL	$\bar{\kappa}_q$ limits obs. (exp.) at 95% CL
$u\bar{u} \rightarrow H + \gamma \rightarrow e\mu\nu_e\nu_\mu\gamma$	85 (67)	$ \kappa_u \leq 16000$ (13000)	$ \bar{\kappa}_u \leq 7.5$ (6.1)
$d\bar{d} \rightarrow H + \gamma \rightarrow e\mu\nu_e\nu_\mu\gamma$	72 (58)	$ \kappa_d \leq 17000$ (14000)	$ \bar{\kappa}_d \leq 16.6$ (14.7)
$s\bar{s} \rightarrow H + \gamma \rightarrow e\mu\nu_e\nu_\mu\gamma$	68 (49)	$ \kappa_s \leq 1700$ (1300)	$ \bar{\kappa}_s \leq 32.8$ (25.2)
$c\bar{c} \rightarrow H + \gamma \rightarrow e\mu\nu_e\nu_\mu\gamma$	87 (67)	$ \kappa_c \leq 200$ (110)	$ \bar{\kappa}_c \leq 45.4$ (25.0)



WZ γ

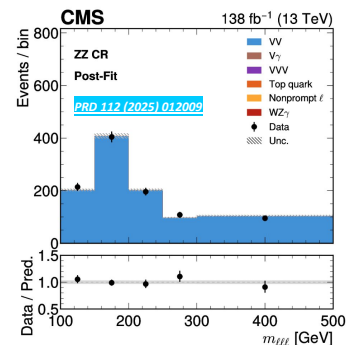
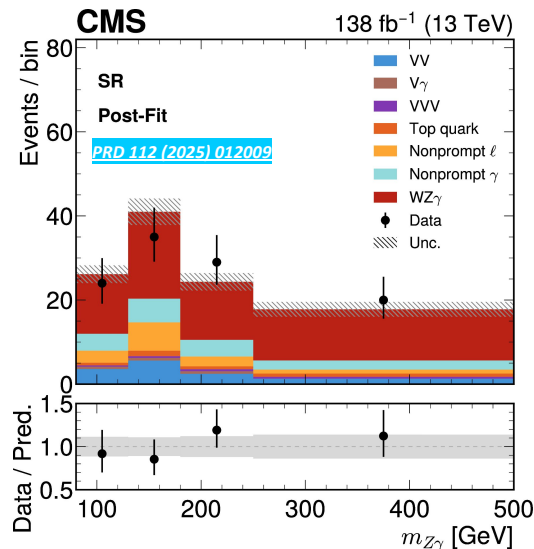
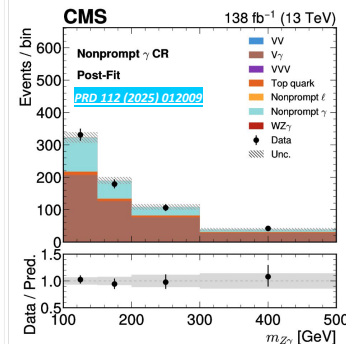
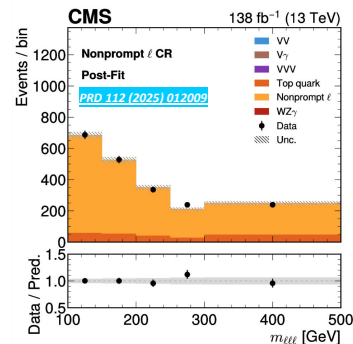
CMS Run 2 analysis

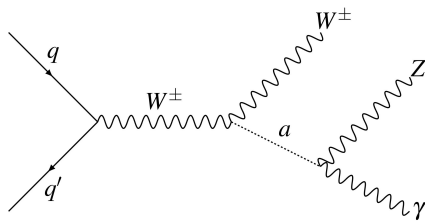
- Measurement of WZ γ with fully leptonic final state
- Tight-to-loose method to extract the fake rates to apply in the SR from nonprompt lepton/ γ -dominated CR (*measurement region*)



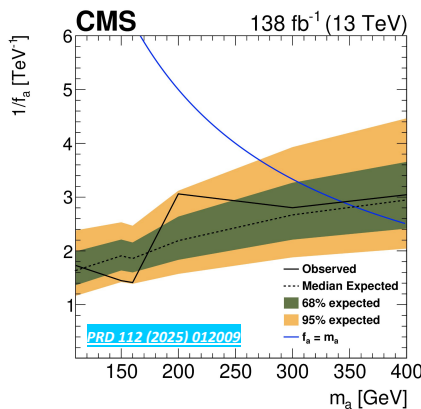
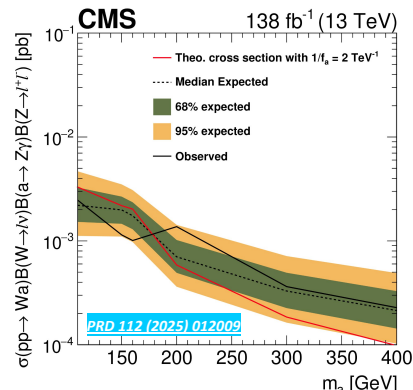
CMS observation of the WZ γ production process at 13 TeV

Observed (expected) significance: **5.4 (3.8) S.D.**





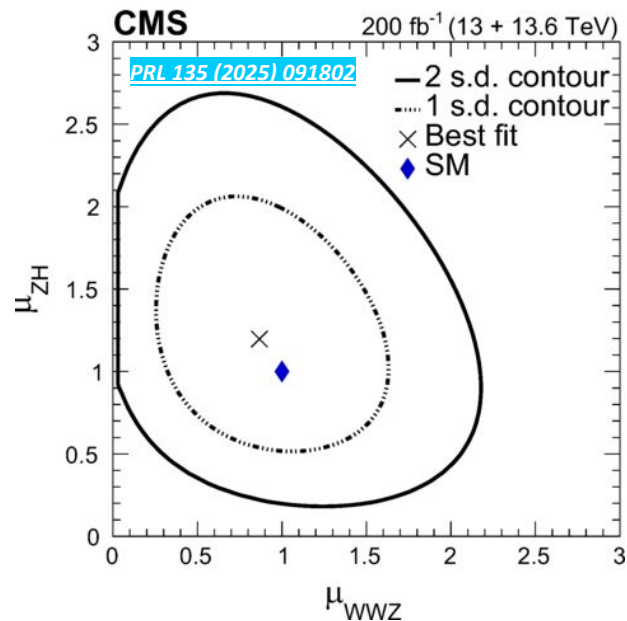
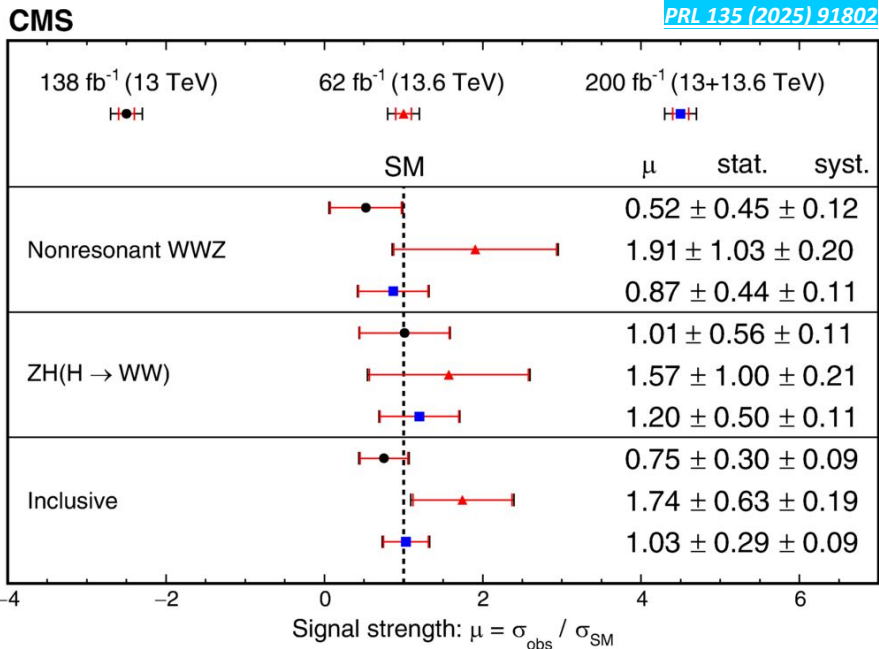
- BSM interpretation using a specific model
→ neutral gauge bosons production (Z γ) from the decay of a **photophobic Axion-like particle (ALP)**
 - BSM process searched is $pp \rightarrow Wa, a \rightarrow Z\gamma$
 - Invariant mass $m_{ALP\text{ Cand.}}$ as an observable for ALPs search
 - the SM WZ γ contribution as a background whose normalization is determined in the simultaneous fit
- No significant excess observed → limits extracted via CLs criterion
 - single free parameter $f_a \rightarrow$ ALPs–vector bosons couplings
 - This directly affects the cross section → $(\sigma \times \mathcal{B}) \propto 1/f_a^2$
- Results
 - some of the most stringent constraints for m_a in the range [200, 400] GeV
 - first interpretation for m_a in the range 110 – 200 GeV



Small fluctuation
near 160 GeV

→ due to the choice of
bin boundaries in
 $m_{ALP\text{ Cand.}}$ used in the
calculation

Results of WWZ CMS analysis



Era	Total	WWZ	ZH
Run 2	2.9 (4.4)	1.3 (3.1)	2.0 (2.6)
Run 3	3.8 (2.5)	2.5 (1.3)	2.5 (1.7)
Total	4.5 (5.0)	2.4 (3.3)	3.1 (3.1)

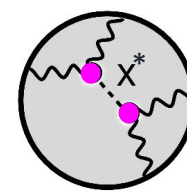
Observed (expected) significance per era

Multiboson new Physics → EFT Framework

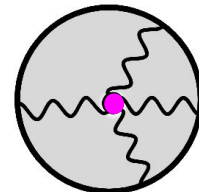
Operator $\mathcal{O}_i$	Wilson coefficient
Gauge boson self-interaction	
$\epsilon^{IJK} W_{\mu}^{I\nu} W_{\nu}^{J\rho} W_{\rho}^{K\mu}$	c_W
$\Phi^\dagger \Phi W_{I\mu\nu} W^{I\mu\nu}$	c_{HW}
$\Phi^\dagger \Phi B_{\mu\nu} B^{\mu\nu}$	c_{HB}
$\Phi^\dagger \tau^I \Phi W_{\mu\nu}^I B^{\mu\nu}$	c_{HWB}
$(\Phi^\dagger \Phi) \square (\Phi^\dagger \Phi)$	$c_{H\square}$
$(\Phi^\dagger D_\mu \Phi)^* (\Phi^\dagger D^\mu \Phi)$	c_{HDD}
Gauge boson and fermion interaction	
$(\Phi^\dagger i \overleftrightarrow{D}_\mu^I \Phi) (\bar{q}_p \tau^I \gamma^\mu q_r)$	c_{Hq3}
$(\Phi^\dagger i \overleftrightarrow{D}_\mu \Phi) (\bar{q}_p \gamma^\mu q_r)$	c_{Hq1}
$(\Phi^\dagger i \overleftrightarrow{D}_\mu \Phi) (\bar{u}_p \gamma^\mu u_r)$	c_{Hu}
$(\Phi^\dagger i \overleftrightarrow{D}_\mu \Phi) (\bar{d}_p \gamma^\mu d_r)$	c_{Hd}
$(\Phi^\dagger i \overleftrightarrow{D}_\mu^I \Phi) (\bar{\ell}_p \tau^I \gamma^\mu \ell_r)$	$c_{H\ell 3}$
Four-fermion interaction	
$(\bar{\ell}_p \gamma_\mu \ell_r) (\bar{\ell}_s \gamma^\mu \ell_t)$	$c_{\ell\ell 1}$

Operator $\mathcal{O}_j$	Wilson coefficient
Longitudinal operators	
$[(D_\mu \Phi)^\dagger D_\nu \Phi] [(D^\mu \Phi)^\dagger D^\nu \Phi]$	$f_{S,0}$
$[(D_\mu \Phi)^\dagger D^\mu \Phi] [(D_\nu \Phi)^\dagger D^\nu \Phi]$	$f_{S,1}$
$[(D_\mu \Phi)^\dagger D_\nu \Phi] [(D^\nu \Phi)^\dagger D^\mu \Phi]$	$f_{S,2}$
Transverse operators	
$\text{Tr}[\hat{W}_{\mu\nu} \hat{W}^{\mu\nu}] \text{Tr}[\hat{W}_{\alpha\beta} \hat{W}^{\alpha\beta}]$	$f_{T,0}$
$\text{Tr}[\hat{W}_{\alpha\nu} \hat{W}^{\mu\beta}] \text{Tr}[\hat{W}_{\mu\beta} \hat{W}^{\alpha\nu}]$	$f_{T,1}$
$\text{Tr}[\hat{W}_{\alpha\mu} \hat{W}^{\mu\beta}] \text{Tr}[\hat{W}_{\beta\nu} \hat{W}^{\nu\alpha}]$	$f_{T,2}$
$\text{Tr}[\hat{W}_{\mu\nu} \hat{W}_{\alpha\beta}] \text{Tr}[\hat{W}^{\alpha\nu} \hat{W}^{\mu\beta}]$	$f_{T,3}$
$\text{Tr}[\hat{W}_{\mu\nu} \hat{W}_{\alpha\beta}] B^{\alpha\nu} B^{\mu\beta}$	$f_{T,4}$
$\text{Tr}[\hat{W}_{\mu\nu} \hat{W}^{\mu\nu}] B_{\alpha\beta} B^{\alpha\beta}$	$f_{T,5}$
$\text{Tr}[\hat{W}_{\alpha\nu} \hat{W}^{\mu\beta}] B_{\mu\beta} B^{\alpha\nu}$	$f_{T,6}$
$\text{Tr}[\hat{W}_{\alpha\mu} \hat{W}^{\mu\beta}] B_{\beta\nu} B^{\nu\alpha}$	$f_{T,7}$
$B_{\mu\nu} B^{\mu\nu} B_{\alpha\beta} B^{\alpha\beta}$	$f_{T,8}$
$B_{\alpha\mu} B^{\mu\beta} B_{\beta\nu} B^{\nu\alpha}$	$f_{T,9}$
Mixed operators	
$\text{Tr}[\hat{W}_{\mu\nu} \hat{W}^{\mu\nu}] [(D_\beta \Phi)^\dagger D^\beta \Phi]$	$f_{M,0}$
$\text{Tr}[\hat{W}_{\mu\nu} \hat{W}^{\nu\beta}] [(D_\beta \Phi)^\dagger D^\mu \Phi]$	$f_{M,1}$
$[B_{\mu\nu} B^{\mu\nu}] [(D_\beta \Phi)^\dagger D^\beta \Phi]$	$f_{M,2}$
$[B_{\mu\nu} B^{\nu\beta}] [(D_\beta \Phi)^\dagger D^\mu \Phi]$	$f_{M,3}$
$[(D_\mu \Phi)^\dagger \hat{W}_{\beta\nu} D^\mu \Phi] B^{\beta\nu}$	$f_{M,4}$
$[(D_\mu \Phi)^\dagger \hat{W}_{\beta\nu} D^\nu \Phi] B^{\beta\mu} + \text{H.c.}$	$f_{M,5}$
$[(D_\mu \Phi)^\dagger \hat{W}_{\beta\nu} \hat{W}^{\beta\mu} D^\nu \Phi]$	$f_{M,7}$

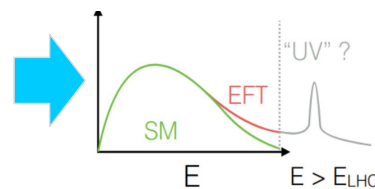
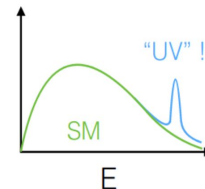
$$L = L_{\text{SM}} + \sum_{\text{dim-6}} \frac{c_i}{\Lambda^2} \mathcal{O}_i + \sum_{\text{dim-8}} \frac{f_j}{\Lambda^4} \mathcal{O}_j$$



X particle



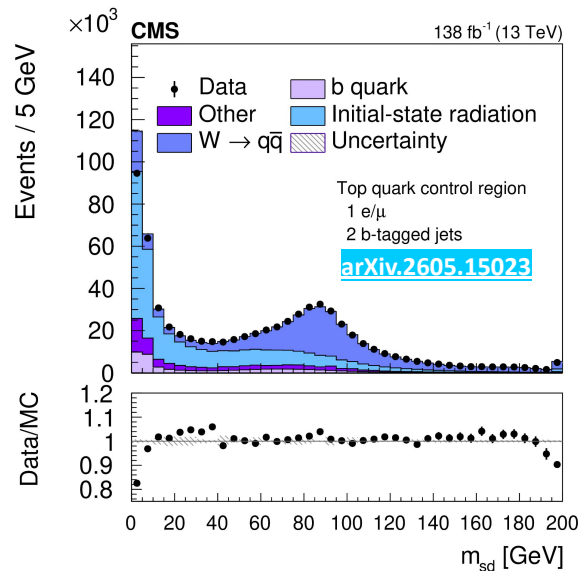
Anomalous coupling



Goal: Constraints on Wilson coefficients associated with 12 dimension-6 and 20 dimension-8 relevant EFT operators

- General strategy:

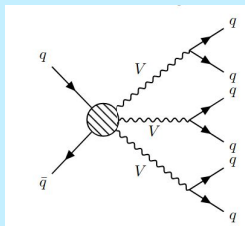
- MC EFT simulation at LO
 - additional parton to approximate NLO behavior, for capturing EFT interference
- ParticleNet algorithms
 - to tag large-radius jets originated from a boosted V boson decay (V-Tagged Jets)
- Background estimation:
 - MC simulation and data-driven techniques
 - Modeling validation in dedicated CRs
 - Soft-drop mass (m_{SD}) used in many cases in the side-bands to derive corrections to MC bkg.



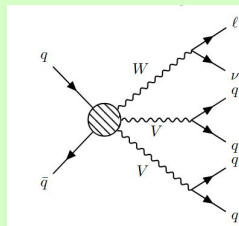
→ validation of MC modeling of m_{SD} shape for the main backgrounds: good agreement

VVV EFT Combination – Target Processes

Fully hadronic (0ℓ)
(≥ 2) V-Tagged Jets (VTJ)

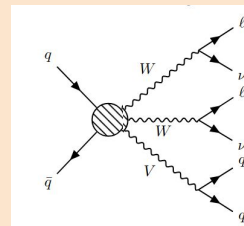


Single lepton
 $1\ell + (\geq 2)$ VTJ



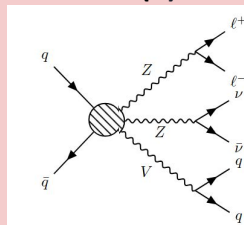
Target signal: WV

Same-Sign (SS) dilepton
 $\ell^\pm \ell^\pm + (\geq 1)$ VTJ



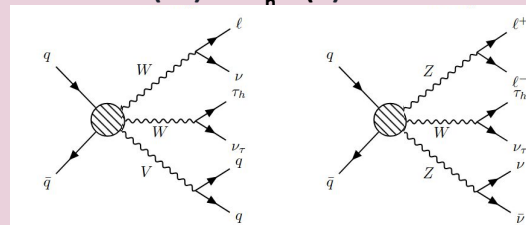
Target signal: WWV

Opposite-Sign (OS) dilepton
 $\ell^\pm \ell^\mp + (\geq 1)$ VTJ



Target signal: $ZZV \rightarrow 2\ell + 2\nu + VTJ$

Hadronically-decaying Tau
 $1\ell (2\ell) + 1\tau_h + (\geq 1)$ VTJ



Target signal: $W(\rightarrow \tau_h \nu_\tau)VV$

VVV EFT Combination – Signal Regions

Fully hadronic (0ℓ) ($\geq$)2 V-Tagged Jets (VTJ)

- ParticleNet medium w.p.
- VTJ $p_T > 200$ GeV
- electrons and muons vetoed
- $40 < m_{SD} < 150$ GeV

+ sel. depending on sub-SR

[SR-2VTJ](#)

[SR-\(\$\geq\$ \)3VTJ](#)

Single lepton $1\ell + (\geq)2$ VTJ

- ParticleNet loose w.p.
- VTJ $p_T > 200$ GeV
- $p_T^\ell > 150$ GeV → **suppr.**
- W+jets**
- b-veto → **suppr. Top bkg.**

Same-Sign (SS) dilepton $\ell^\pm \ell^\pm + (\geq)1$ VTJ

- ParticleNet medium w.p.
- $p_T^{\ell_1(\ell_2)} > 40$ (30) GeV
→ **suppr. misid. jet/ ℓ bkg.**
- b-veto → **suppr. $t\bar{t}$ bkg.**
- $|m_{ee} - m_Z| > 20$ GeV → **suppr.**
- Zjj**
- $\Delta R_{\ell\ell} > 1.2$ → **suppr. trident ev.s**

Opposite-Sign (OS) dilepton $\ell^\pm \ell^\mp + (\geq)1$ VTJ

- ParticleNet: ≥ 1 (2) tight (medium) VTJ, $p_T^j > 200$ GeV
- b-veto → **suppr. $t\bar{t}$ bkg.**

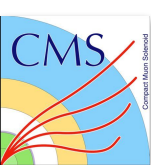
$e^\pm \mu^\mp$
[\(\$2\ell\$ -OS-DF \$\geq 1\$ VTJ\)](#)

$2e/2\mu$ ([2 \$\ell\$ -OS-SF \$\geq 1\$ VTJ](#))
[offZ](#) | [onZ](#)

→ $|m_{\ell\ell} - m_Z| \gtrsim 20$ GeV

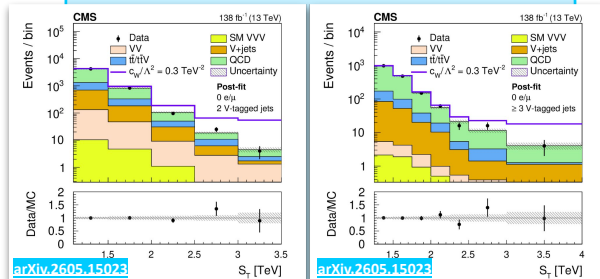
Hadronically-decaying Tau 1ℓ (2ℓ) + $1\tau_h$ + 1 (0) VTJ

- $N_\ell + N_{VTJ} + N_{\tau_h} = 3$ (triboson assumption)
- $\Delta R_{\ell\ell} > 0.4$
- $\sum_{\ell=e,\mu,\tau} \ell \text{ ch.} = \pm 1$
- $|m_{SF-OS-\ell\ell} - m_Z| > 20$ GeV → **suppr. Z+jets**



VVV EFT Combination

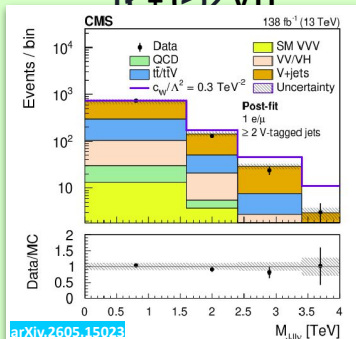
Fully hadronic (0ℓ)



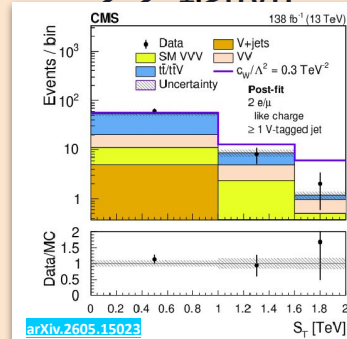
SR-2VTJ

SR-(≥)3VTJ

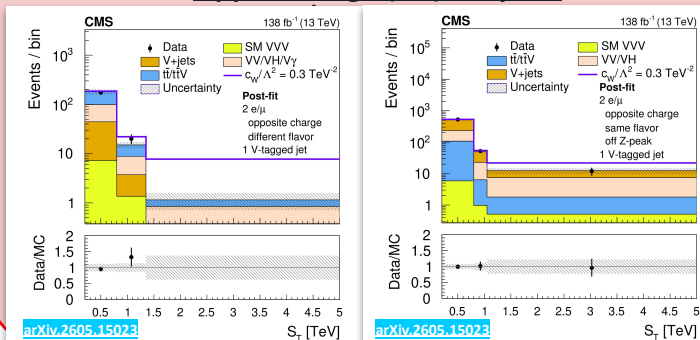
Single lepton 1ℓ + (>1) VTJ



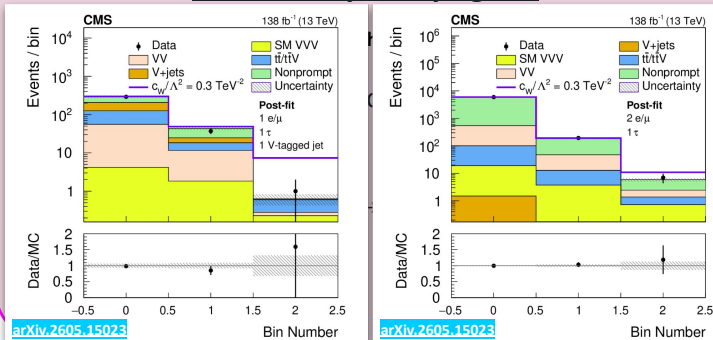
Same-Sign (SS) dilepton ±±ℓℓ + (>1) VTJ



Opposite-Sign (OS) dilepton



Hadronically-decaying Tau



Analysis channels
 SR-0ℓ-2VTJ and SR-0ℓ-3VTJ
 SR-1ℓ-2VTJ
 SR-2ℓ-OS-1VTJ
 SR-2ℓ-OS-2VTJ and SR-2ℓ-SS-1VTJ
 SR-1ℓ-1τ_h-1VTJ and SR-2ℓ-1τ_h-0VTJ

Discriminating variable
 $S_T = \sum p_{T,V \text{ jet}} + \sum p_{T,\text{jet}}$
 $m_{J1V} = \sqrt{(p_\ell + p_\nu + p_{V \text{ jet},1} + p_{V \text{ jet},2})^2}$
 $S_T = \sum p_{T,V \text{ jet}} + \sum p_{T,\text{jet}} + \sum p_{T,\ell}$
 $S_T = \sum p_{T,V \text{ jet}} + \sum p_{T,\text{jet}} + \sum p_{T,\ell} + p_T^{\text{miss}}$
 $S_T = \sum p_{T,\ell} + \sum p_{T,\text{jet}} + p_{T,t}$ and BDT scores



$\ell^\pm \ell^\mp (\text{OS pair}) + \geq 1 \text{ V-tagged jet}$

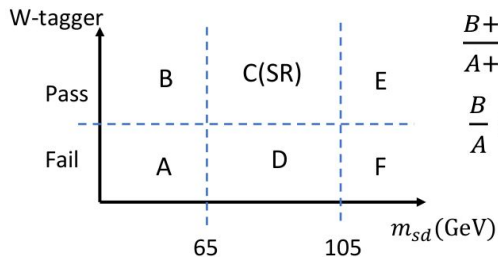
Channel	Leading Backgrounds
2 Same-Signed Leptons(SS) + 1 fatjet	$t\bar{t}$, WZ
2 Opposite-Signed Leptons(OS) + 1 fatjet	DY, Top
1 lepton + 2 fatjets	Top, W+jets
0 lepton + 2/3 fatjets	QCD

- SR defined as
 - Exactly 2 OS loose leptons passing tight ID
 - $p_{T,l1} > 25\text{GeV}$, $p_{T,l2} > 15\text{GeV}$
 - b-veto
 - ≥ 1 (2) tight (medium) VTJ,
 - $p_T^J > 200\text{GeV}$

- Categorization:
 - SFonZ+1VTJ
 - SFoffZ+1VTJ
 - DF+1VTJ

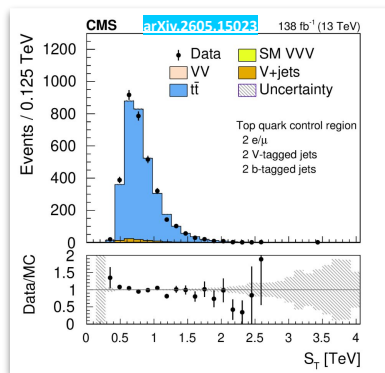
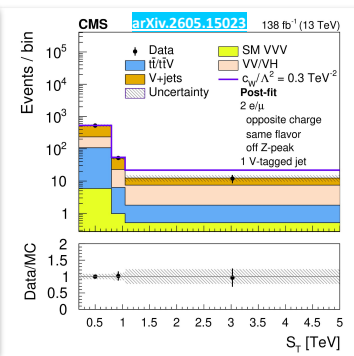
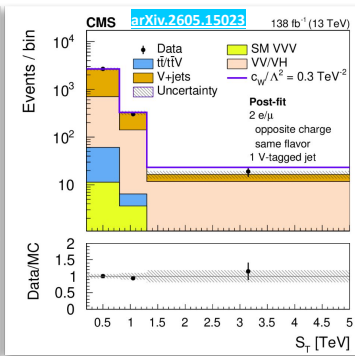
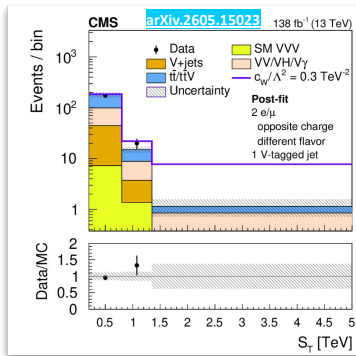
- Variable for the fit: $s_{T,MET} = \sum_{\text{lepton}} p_T + \sum_{AK8 \text{ jet}} p_T + \sum_{AK4 \text{ jet}, \Delta R_{JJ} > 0.8} p_T$

- Data driven Drell-Yan estimation



$$\frac{B+E}{A+F} \times D \rightarrow \text{estim. in SR}$$

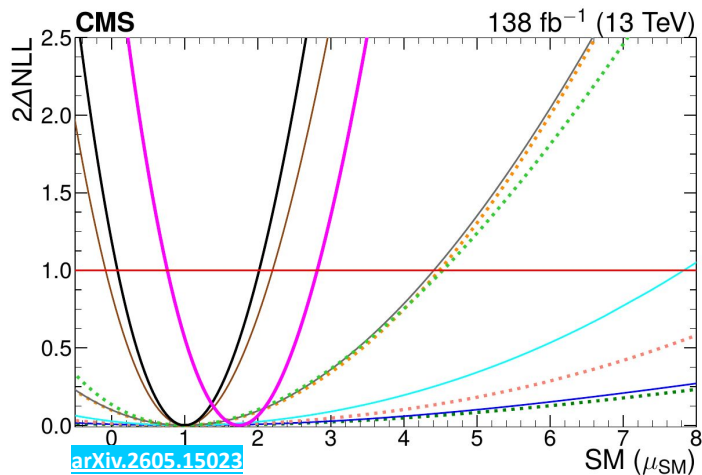
$$\frac{B}{A} \times F \rightarrow \text{validation}$$



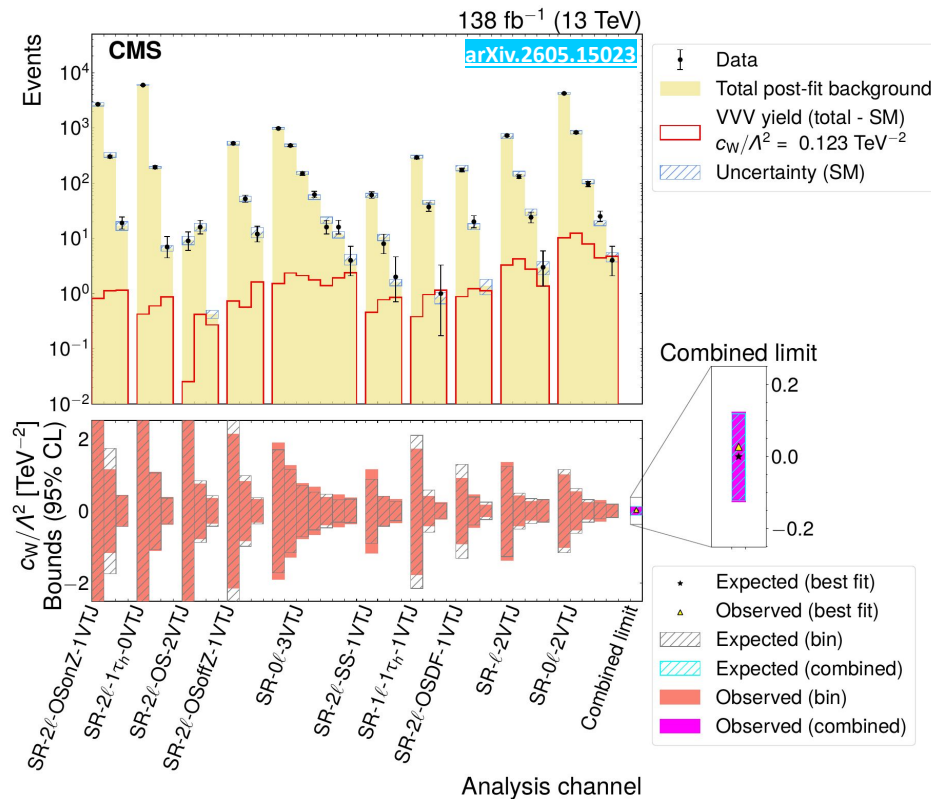
Top CR
→OF+1FJ w/reverted b-veto
for a data-driven dedicated
ttbar bkg. estimation

$$N_{t\bar{t},SR} = \frac{N_{t\bar{t},MC}^{SR}}{N_{t\bar{t},MC}^{CR}} \times (N_{data}^{CR} - N_{rest,MC}^{CR})$$

VVV EFT Combination

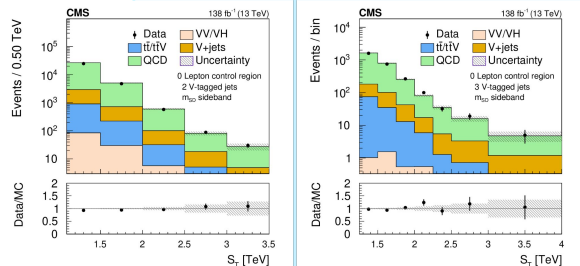


Full analysis Asimov $\hat{\mu}_{SM} = 1.00^{+1.02}_{-0.92}$	SR-2 ℓ -1 τ_h -0VTJ $\hat{\mu}_{SM} = 1.0^{+3.4}_{-3.1}$	SR-0 ℓ -3VTJ $\hat{\mu}_{SM} = 1^{+17}_{-15}$
Full analysis data $\hat{\mu}_{SM} = 1.74^{+1.07}_{-0.98}$	SR-2 ℓ -OS-1VTJ $\hat{\mu}_{SM} = 1.0^{+3.5}_{-3.1}$	SR-0 ℓ -2VTJ $\hat{\mu}_{SM} = 1^{+17}_{-16}$
SR-2 ℓ -SS-1VTJ $\hat{\mu}_{SM} = 1.00^{+1.20}_{-1.08}$	SR-2 ℓ -OS-2VTJ $\hat{\mu}_{SM} = 1.0^{+6.8}_{-5.6}$	2 Δ NLL threshold 68% CL
SR-1 ℓ -1 τ_h -1VTJ $\hat{\mu}_{SM} = 1.0^{+3.5}_{-2.4}$	SR- ℓ -2VTJ $\hat{\mu}_{SM} = 1.0^{+9.0}_{-8.7}$	

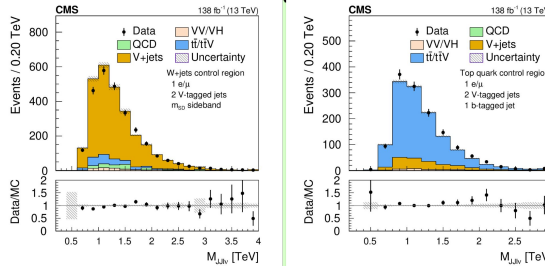


VVV EFT Combination – Control Regions

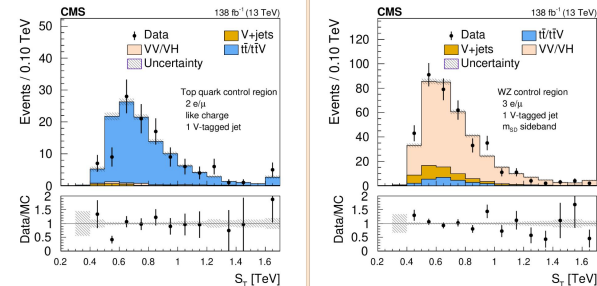
Fully hadronic (0ℓ)



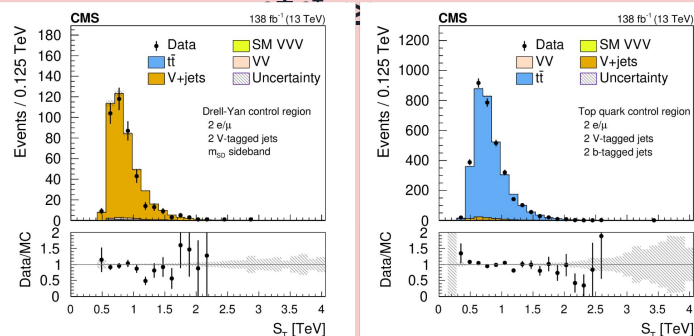
Single lepton $1\ell + (\geq)2 VTJ$



Same-Sign (SS) dilepton $\ell^\pm \ell^\pm + (\geq)1 VTJ$



Opposite-Sign (OS) dilepton



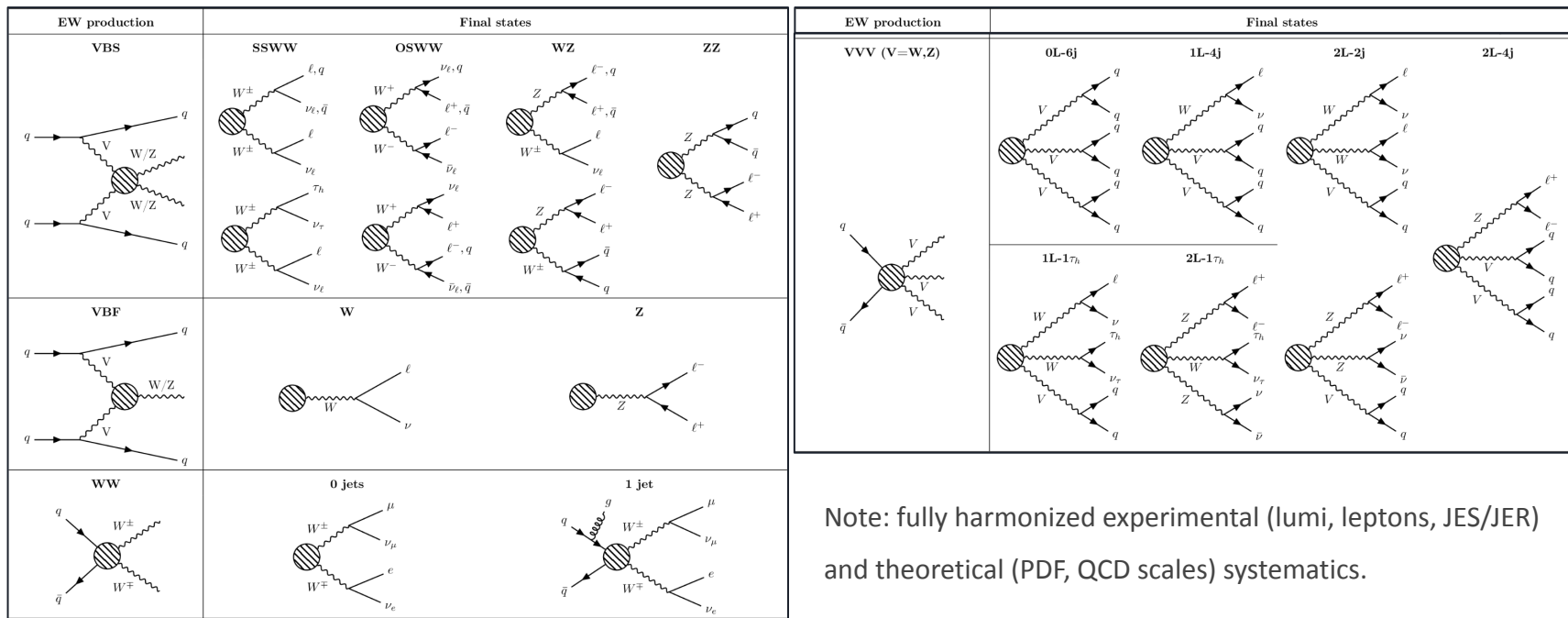
Hadronically-decaying Tau $1\ell (2\ell) + 1\tau_h + 1 (0) VTJ$

Tight-to-loose method to model nonprompt lepton background

Minor backgrounds (DY, Wjj, ttbar) estimated from MC

Multiboson EFT results → Combination (dim.6)

Run 2 (138 fb⁻¹) VBS (VVjj), VBF (Vjj), diboson (SS/OS-WW), and triboson (combined VVV = WWW, WWZ, WZZ, ZZZ) meas.



Note: fully harmonized experimental (lumi, leptons, JES/JER) and theoretical (PDF, QCD scales) systematics.

Multiboson EFT results → Combination (dim.6)

Run 2 (138 fb⁻¹) VBS (VVjj), VBF (Vjj), diboson (SS/OS-WW), and triboson (combined VVV = WWW, WWZ, WZZ, ZZZ) meas.

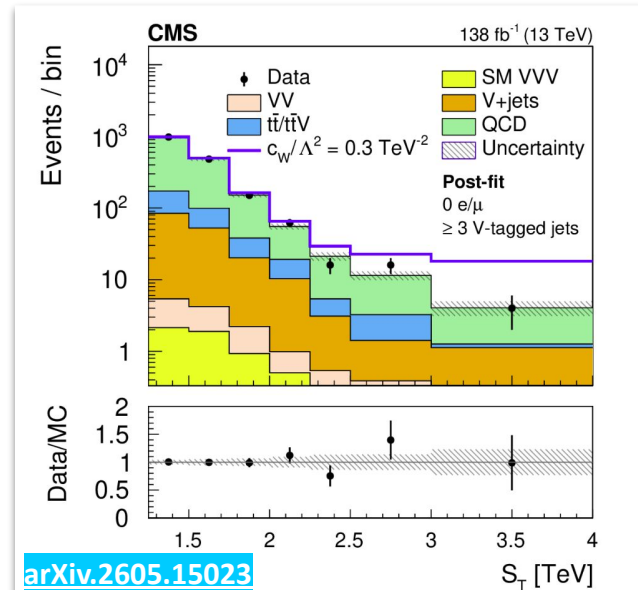
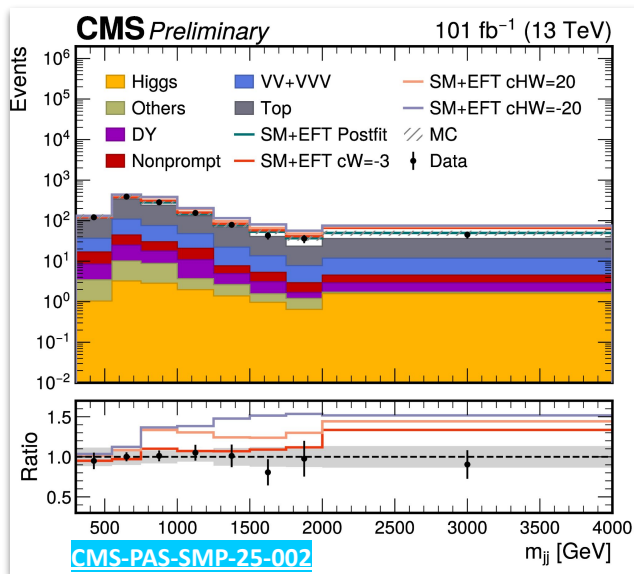
- High-yield inclusive dibosons drive bulk precision
- VBS and tribosons constrain high-p_T and high-m_{VV} tails.

Analysis	Final state	Operators	Ref.
VBS-SSWW(e, μ)	$\ell^\pm \ell^\pm 2\nu jj$	$\mathcal{O}_{HD}, \mathcal{O}_{HW}, \mathcal{O}_{HWB}, \mathcal{O}_{H\Box}, \mathcal{O}_W$	[13]
VBS-SSWW(τ _h)	$\ell^\pm \tau_h^\pm 2\nu jj$	$\mathcal{O}_{HD}, \mathcal{O}_{HW}, \mathcal{O}_{HWB}, \mathcal{O}_{H\Box}, \mathcal{O}_W$	[14]
VBS-OSWW	$\ell^\pm \ell^\mp 2\nu jj$	$\mathcal{O}_{HD}, \mathcal{O}_{HW}, \mathcal{O}_{HWB}, \mathcal{O}_{H\Box}, \mathcal{O}_W$	[15]
VBS-WZ	$\ell^+ \ell^- \ell^\pm \nu jj$	$\mathcal{O}_{HD}, \mathcal{O}_{HW}, \mathcal{O}_{HWB}, \mathcal{O}_{H\Box}, \mathcal{O}_W$	[13]
VBS-WV	$\ell^\pm \nu jjjj$	$\mathcal{O}_{HB}, \mathcal{O}_{HW}, \mathcal{O}_{HWB}, \mathcal{O}_{H\Box}, \mathcal{O}_W$	[16]
VBS-ZV	$\ell^+ \ell^- jjjj$	$\mathcal{O}_{HD}, \mathcal{O}_{HW}, \mathcal{O}_{HWB}, \mathcal{O}_{H\Box}, \mathcal{O}_W$	[17]
VBF-W	$\ell^\pm \nu jj$	$\mathcal{O}_{HD}, \mathcal{O}_{HWB}, \mathcal{O}_W$	[18]
VBF-Z	$\ell^+ \ell^- jj$	$\mathcal{O}_{HD}, \mathcal{O}_{HWB}, \mathcal{O}_W$	[19]
WW	$\ell^+ \ell^- 2\nu$	$\mathcal{O}_{HWB}, \mathcal{O}_W$	[20]
VVV/γ	$6j, \ell^\pm \nu jjjj, \ell^+ \ell^- jjjj,$ $\ell^+ \ell^- 2\nu jj, \ell^\pm \ell^\pm 2\nu jj$ $\ell^\pm \tau_h^\pm 2\nu jj, \ell^+ \ell^- \tau_h^\pm 3\nu$	$\mathcal{O}_{HB}, \mathcal{O}_{HD}, \mathcal{O}_{HW}, \mathcal{O}_{HWB}, \mathcal{O}_{H\Box}, \mathcal{O}_W$	[21]

Multiboson EFT results → Combination (dim.6)

Run 2 (138 fb⁻¹) VBS (VVjj), VBF (Vjj), diboson (SS/OS-WW), and triboson (combined VVV = WWW, WWZ, WZZ, ZZZ) meas.

- High-yield inclusive dibosons drive bulk precision
- VBS and tribosons constrain high- p_T and high- m_{VV} tails.



All observations → fully consistent with the SM.

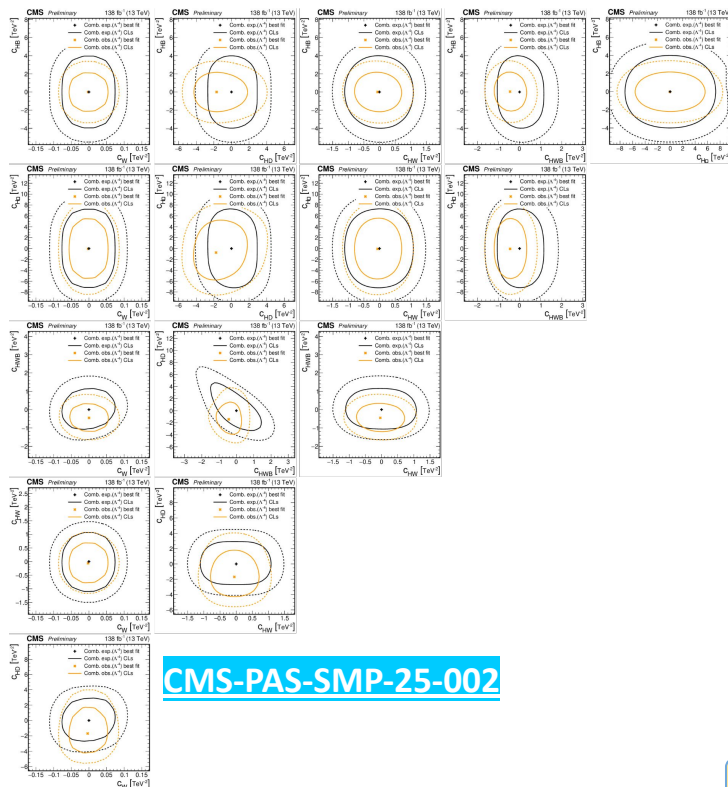
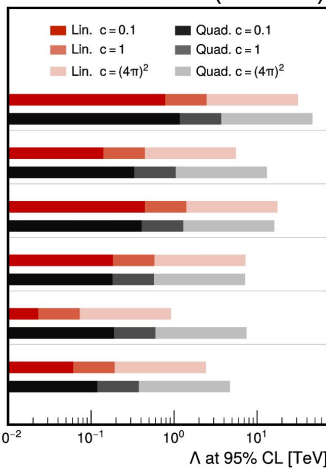
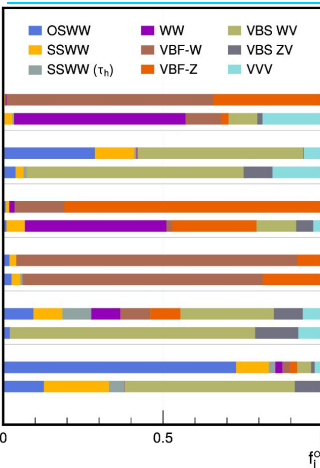
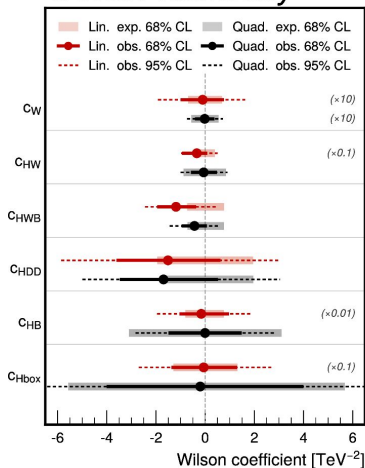
Multiboson EFT results → Combination (dim.6)

Run 2 (138 fb⁻¹) VBS (VVjj), VBF (Vjj), diboson (SS/OS-WW), and triboson (combined VVV = WWW, WWZ, WZZ, ZZZ) meas.

CMS Preliminary

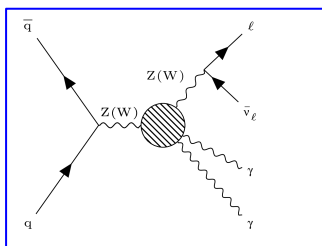
CMS-PAS-SMP-25-002

138 fb⁻¹ (13 TeV)



CMS-PAS-SMP-25-002

- Both linear and **linear + quadratic terms** are evaluated to quantify EFT truncation effects.
- Stringent limits set on triple-gauge (c_W), gauge-Higgs (c_{HW} , c_{HB}), and contact operators ($c_{H\ell}^{(3)}$, $c_{Hq}^{(3)}$)
- Combination tightens individual channel bounds by factors of ~2–5



Example of BSM diagram affected by aQGC

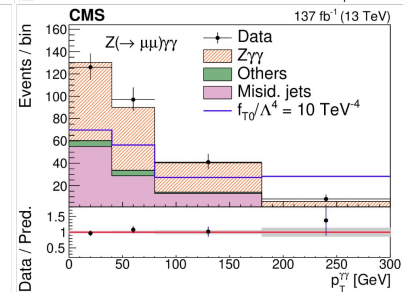
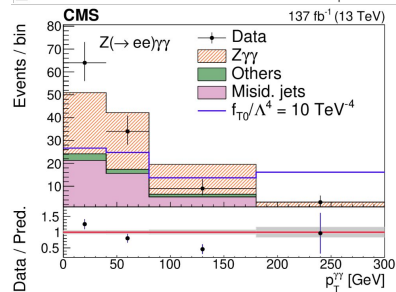
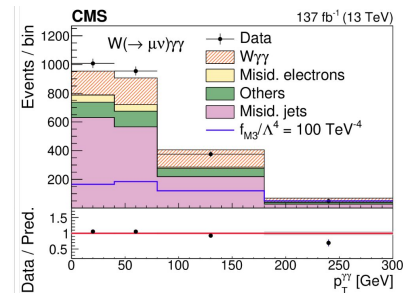
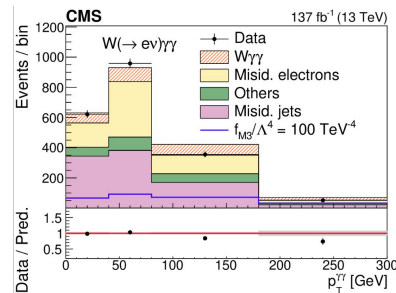
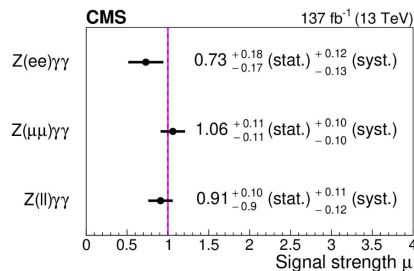
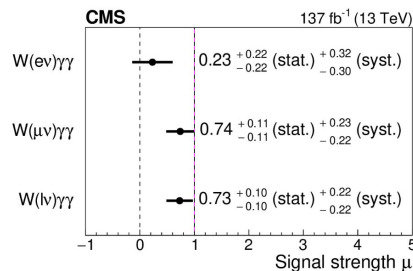
Measured cross section:

$$\sigma_{W\gamma\gamma} = 13.63^{+1.93}_{-1.89} (\text{stat.})^{+4.04}_{-4.02} (\text{syst.}) \pm 0.08 (\text{PDF+scale})$$

3.1 S.D

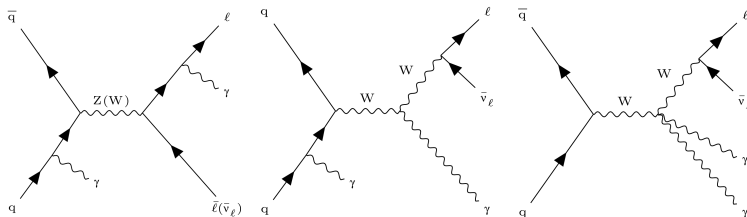
$$\sigma_{Z\gamma\gamma} = 5.41^{+0.58}_{-0.55} (\text{stat.})^{+0.64}_{-0.70} (\text{syst.}) \pm 0.06 (\text{PDF+scale})$$

4.8 S.D

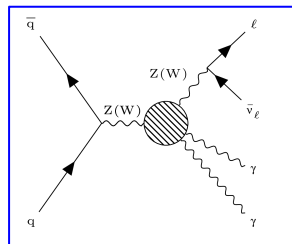


Parameter	$W\gamma\gamma$ (TeV^{-4})		$Z\gamma\gamma$ (TeV^{-4})	
	Expected	Observed	Expected	Observed
f_{M2}/Λ^4	[-57.3, 57.1]	[-39.9, 39.5]	—	—
f_{M3}/Λ^4	[-91.8, 92.6]	[-63.8, 65.0]	—	—
f_{T0}/Λ^4	[-1.86, 1.86]	[-1.30, 1.30]	[-4.86, 4.66]	[-5.70, 5.46]
f_{T1}/Λ^4	[-2.38, 2.38]	[-1.70, 1.66]	[-4.86, 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]

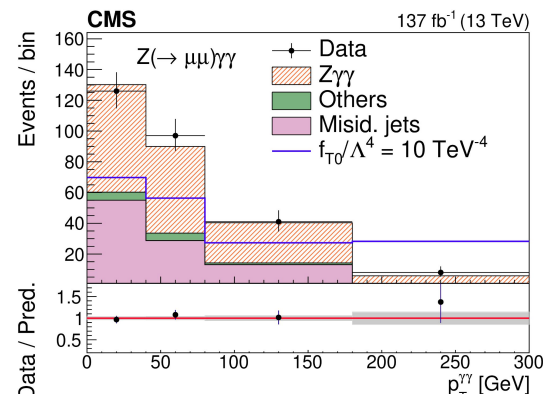
JHEP 10 (2021) 174



- Measurement of $V\gamma\gamma$ fully leptonic channels
 - $W\gamma\gamma$ can be produced via QGC
 - $Z\gamma\gamma$ does not involve QGCs (in the SM)
- γ can also be produced via ISR/FSR
- Data-driven method for major bkg.s estimation
- Systematics from data-driven background estimated by inverting lepton isolation and applying same strategy



Representative BSM diagram affected by aQGC



Parameter	$W\gamma\gamma$ (TeV^{-4})		$Z\gamma\gamma$ (TeV^{-4})	
	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]

Measured cross section:

$$\sigma_{W\gamma\gamma} = 13.63^{+1.93}_{-1.89} (\text{stat.}) \cdot 10^{4.04}_{-4.02} (\text{syst.}) \pm 0.08 (\text{PDF+scale}) \quad 3.1 \text{ S.D.}$$

$$\sigma_{Z\gamma\gamma} = 5.41^{+0.58}_{-0.55} (\text{stat.}) \cdot 10^{0.64}_{-0.70} (\text{syst.}) \pm 0.06 (\text{PDF+scale}) \quad 4.8 \text{ S.D.}$$

