Di-boson and Tri-boson Measurements:

ZGamma, WZGamma, and Same-Sign WWGamma

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Based on:
SMP-24-002
SMP-22-018
SM-25-015

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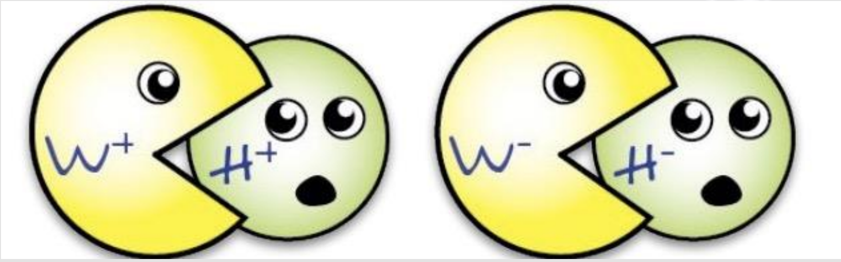
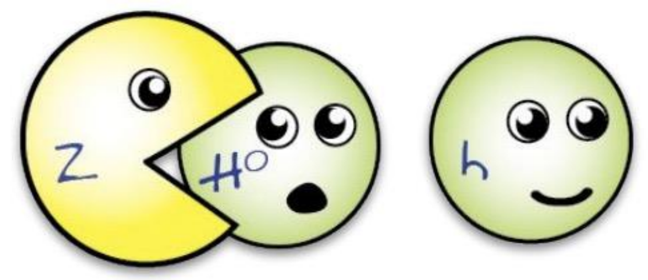
Why study multiboson?

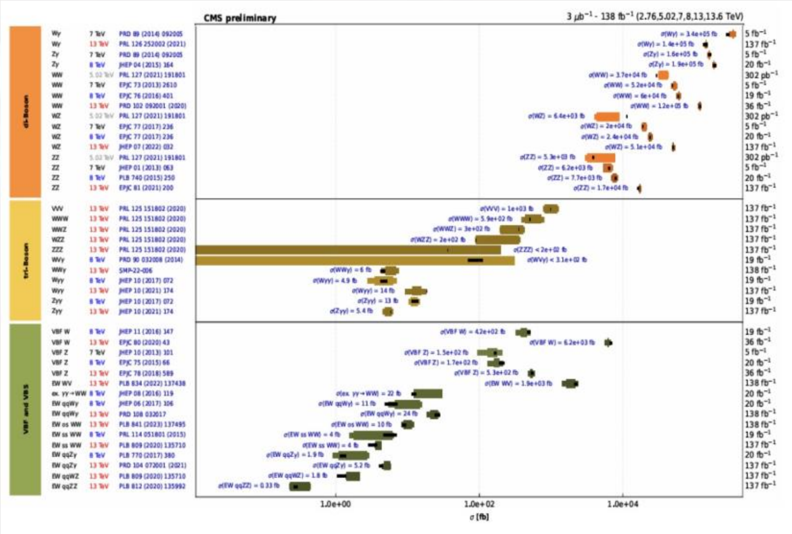
- Precise measurements of fundamental SM parameters and research on BSM.
  - Probe ingredients of the EWSB and realization of the Higgs mechanism independently from direct Higgs boson measurements.
  - Interesting corner to study new physics
    - Doubly charged Higgs, Heavy neutrinos, anomalous couplings in Effective Field Theory.
- A wide range of processes
  - Diboson, triboson, vector boson scattering





Multiboson Measurements in CMS

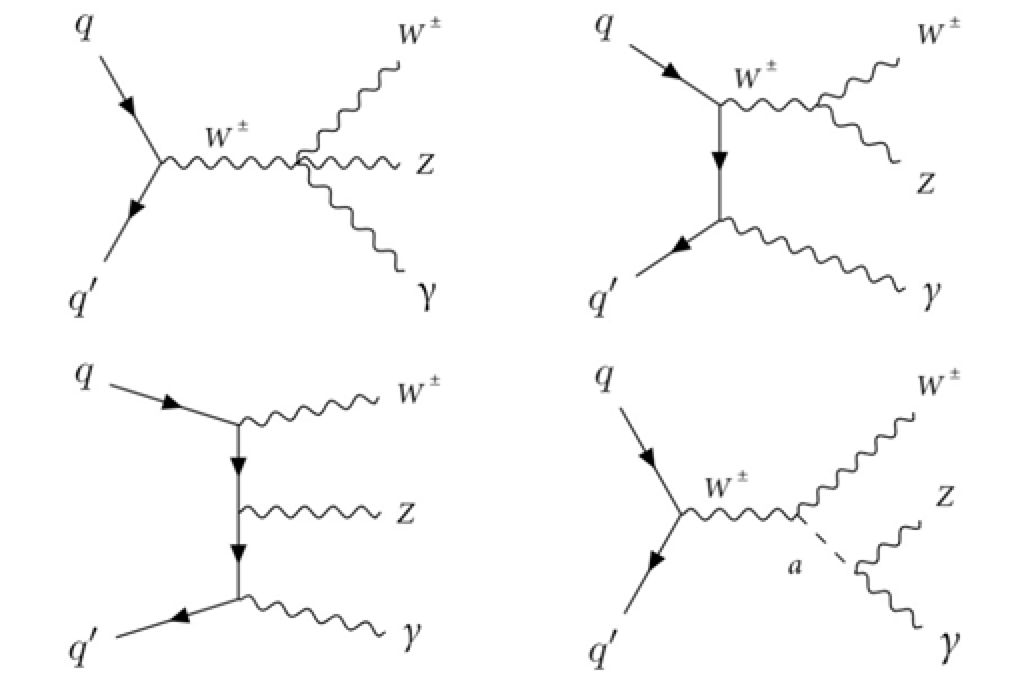
- Diboson production
  - – Z(→ ll)γ production @ 13.6 TeV CMS-PAS-SMP-24-002
  - – WW inclusive @ 13.6 TeV arXiv:2406.05101
  - – WZ cross section @ 13.6 TeV CMS-PAS-SMP-24-005
- Triboson production
  - – WZγ production @ 13 TeV Phys. Rev. D 112 (2025) 012009
  - – Observation of WWγ production @ 13 TeV Phys. Rev. Lett. 132 (2024) 121901
- Vector boson scattering
  - – Same-sign WWGamma @ 13 TeV CMS-SMP-25-015 (2->3 VBS)
  - – Same-sign WWH @13TeV CMS-PAS-HIG-24-001(2->3 VBS)
  - ......



WZγ @ 13 TeV [138fb^{-1}]

Motivation for WZγ

- Direct measurement of gauge boson self-couplings
- Anomalous Quartic Gauge Couplings (aQGC)
  - ◆Probing directly BSM physics as a modification of the WZγ production cross-section.
- Photonphobic Axion-Like Particle (ALP)
  - ◆ WZγ production offers a powerful probe to these vertices.
- Fully leptonic WZγ Results from ATLAS:
  https://doi.org/10.1103/PhysRevLett.132.021802
  - ◆Observed (Expected) Significance : 6.3 (5.0) σ
  - ◆Measured (Expected) fiducial cross section: 2.01 (1.50) fb



WZγ @ 13 TeV [$138 fb^{-1}$]

analysis strategy---Signal Region

Baseline selection

- At least 3 leptons with an opposite-sign sign same-flavor pair (OSSF).
- OSSF lepton pair with closest $M_{\ell\ell}$ to M_Z are "Z leptons", the remaining lepton is "W lepton".
- Minimum $M_{\ell\ell}$>4 GeV, $|M_{\ell Z1 \ell Z2} - M_Z| < 15$ GeV.

Signal Region

- At least one tight photon
- $M_{\ell W\gamma}$ <75 GeV or $M_{\ell W\gamma}$ > 105 GeV (when ℓ_W=e)
- $M_{\ell\ell\ell}$> 100 GeV

Against electron-photon conversion.

- 4th loose lepton veto
- MET > 30 GeV

decrease the presence of dileptonic Z production with an associated non-prompt lepton.

- N_{bjet} = 0

WZγ @ 13 TeV [138fb^{-1}]

analysis strategy---Control Region

➢ Nonprompt lepton CR

- Revert the N requirement
- Revert $|M_{\ell_{z1}\ell_{z2}} - MZ|$ cut
- Remove the photon requirement

➢ Nonprompt photon CR

- Remove the 3rd lepton requirements
- Revert the N requirement

➢ ZZ CR

- Add a fourth tight lepton selection
- Remove the photon requirement
- Revert the MET cut

Region	N_ℓ	N_γ	N_{OSSF}	N_{btag}	MET [GeV]	$p_T\{\ell_{Z1}, \ell_{Z2}, \ell_W, \ell_4\}$ [GeV]	$\min(M(\ell\ell'))$ [GeV]	$\lvert M(\ell_{Z1}, \ell_{Z2}) - m_Z\rvert$ [GeV]	$M(\ell_{Z1}, \ell_{Z2}, \ell_W)$ [GeV]	$M(l_W, \gamma)$ [GeV]
SR	=3	≥ 1	≥ 1	=0	>30	>{25,15,25}	>4	<15	>100	<75 or >105
CR-ZZ	=4	-	≥ 1	=0	<30	>{25,15,25,15}	>4	<15	>100	-
CR-Fake ℓ	=3	-	≥ 1	>0	>30	>{25,15,25}	>4	>15	>100	-
CR-Fake γ	=2	≥ 1	=1	>0	<30	>{25,15}	>4	>15	-	-

Paper

WZγ @ 13 TeV [$138 fb^{-1}$]

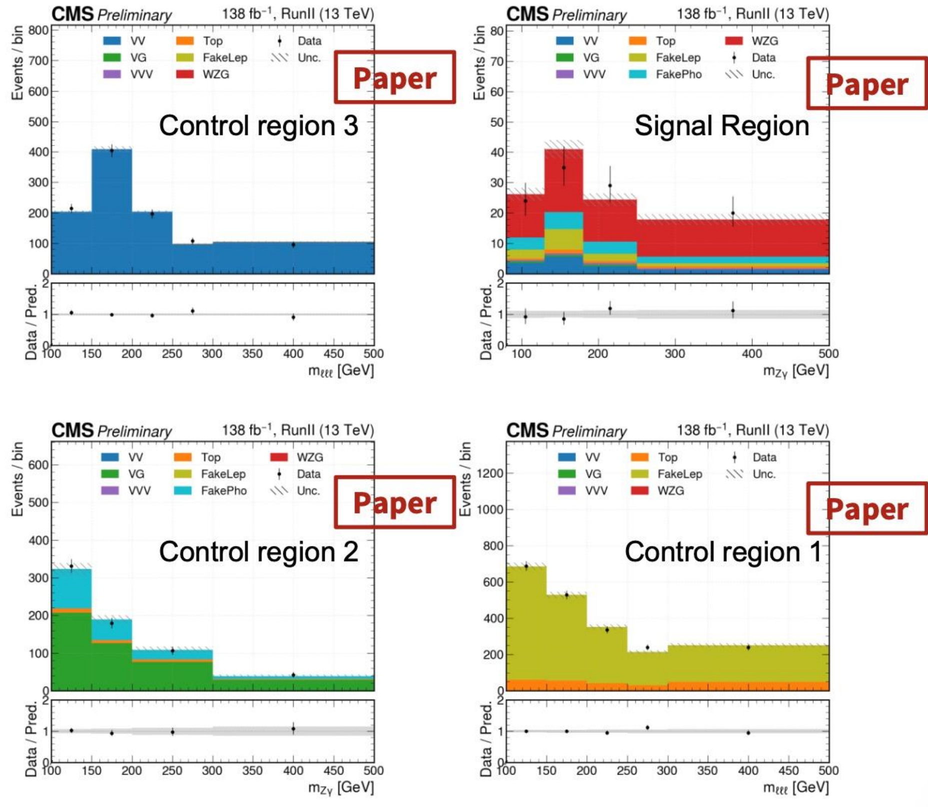
Fit Strategy

➢ 1 dimensional simultaneous fit (use Higgs Combine Tool for the implementation)

Region	Variable	binning
CR1 (Fake l)	M_{lll}	[100,150,200,250,300,500]
CR2 (Fake γ)	$M_{Z\gamma}$	[100,150,200,300,500]
CR3 (ZZ)	M_{lll}	[100,150,200,250,300,500]
SR	$M_{Z\gamma}$	[80,130,180,250,500]

- For SR and CR2, OSSF pair with closest M_{ll} to M_Z are "Z leptons"(l_{Z1}, l_{Z2})
- For CR3, we choose The OSSF pair with closest M_{ll} to M_Z plus the remaining p_T leading lepton as lll

- Freeze: FakeLep, FakePho (only affected by NP)
- Freely float: VV



Post-fit

WZγ @ 13 TeV [$138 fb^{-1}$]

aQGCs

- **Expand SM Lagrangian to higher order**

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i + \underbrace{\boxed{\sum_i \frac{f_j}{\Lambda^4}\mathcal{O}_j}}_{\text{Dim-8}} + \cdots$$

If $f_j \neq 0$, rate of WZγ production at high $\hat{s}$ enhanced

- **Complementary to current BSM searches**
- **Focus on dim-8 operators**

	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA	AAAA
$O_{S,0}, O_{S,1}$	√	√	√						
$O_{M,0}, O_{M,1}, O_{M,6}, O_{M,7}$	√	√	√	√	√	√	√		
$O_{M,2}, O_{M,3}, O_{M,4}, O_{M,5}$		√	√	√	√	√	√		
$O_{T,0}, O_{T,1}, O_{T,2}$	√	√	√	√	√	√	√	√	√
$O_{T,5}, O_{T,6}, O_{T,7}$		√	√	√	√	√	√	√	√
$O_{T,8}, O_{T,9}$			√			√	√	√	√

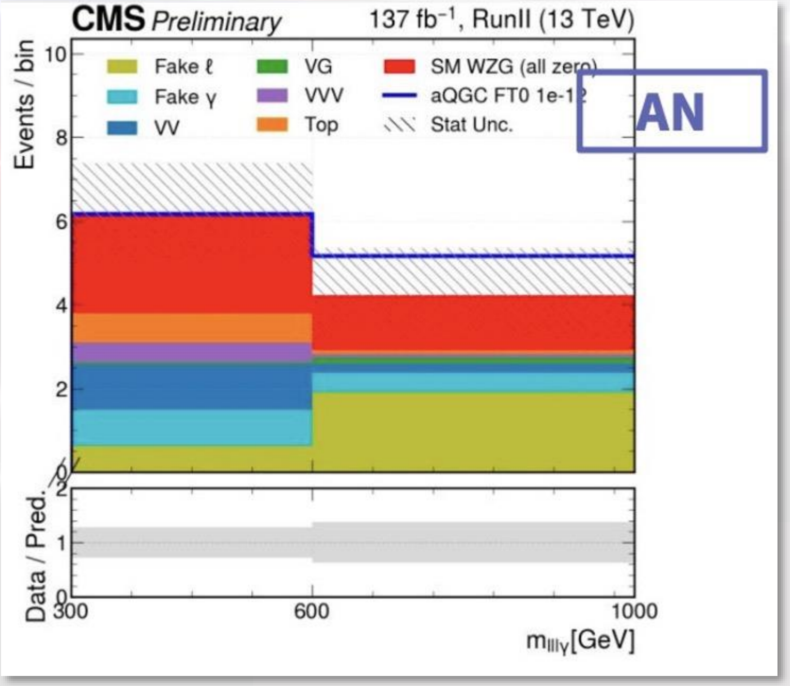
AN

$$\mathcal{L}_{T,0} = \frac{f_{T0}}{\Lambda^4} Tr[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}] \times Tr[\hat{W}_{\alpha\beta}\hat{W}^{\alpha\beta}],$$
$$\mathcal{L}_{T,1} = \frac{f_{T1}}{\Lambda^4} Tr[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}] \times Tr[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}],$$
$$\mathcal{L}_{T,2} = \frac{f_{T2}}{\Lambda^4} Tr[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}] \times Tr[\hat{W}_{\beta\nu}\hat{W}^{\nu\alpha}],$$
$$\mathcal{L}_{T,5} = \frac{f_{T5}}{\Lambda^4} Tr[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}] \times B_{\alpha\beta}B^{\alpha\beta},$$
$$\mathcal{L}_{T,6} = \frac{f_{T6}}{\Lambda^4} Tr[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}] \times B_{\mu\beta}B^{\alpha\nu},$$
$$\mathcal{L}_{T,7} = \frac{f_{T7}}{\Lambda^4} Tr[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}] \times B_{\beta\nu}B^{\nu\alpha},$$
$$\mathcal{L}_{T,8} = \frac{f_{T8}}{\Lambda^4} B_{\mu\nu}B^{\mu\nu}B_{\alpha\beta}B^{\alpha\beta},$$
$$\mathcal{L}_{T,9} = \frac{f_{T9}}{\Lambda^4} B_{\alpha\mu}B^{\mu\beta}B_{\beta\nu}B^{\nu\alpha}.$$

AN

aQGC signal region

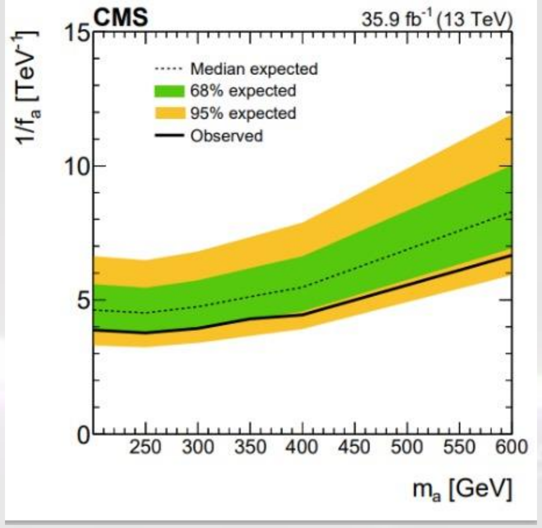
- **Additionally require pT,γ > 60 GeV**
- **Fitting variables: $m_{lll\gamma}$, Binning: [600, ∞] GeV**
- **Others are the same as the nominal SM analysis**

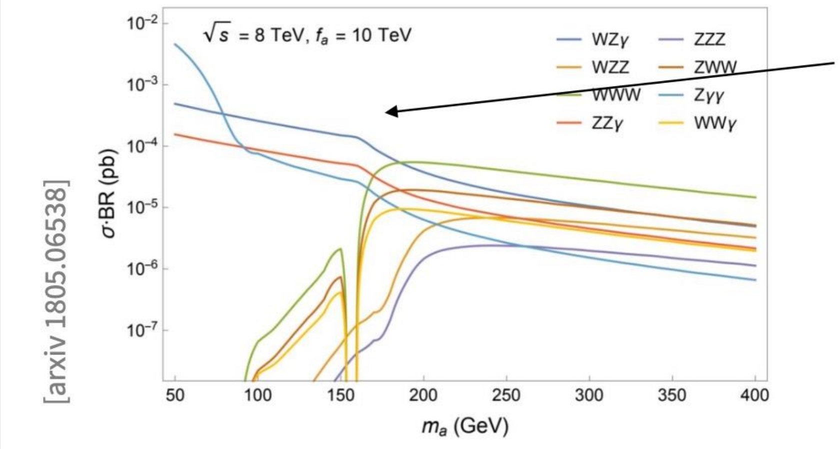


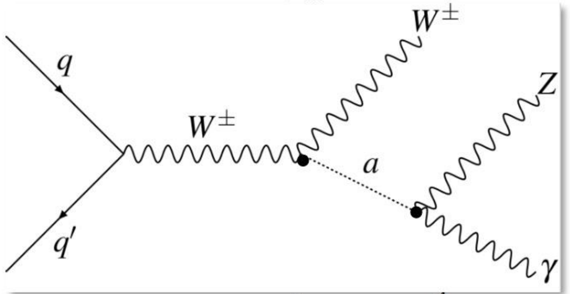
WZγ @ 13 TeV [$138 fb^{-1}$]

Photonphobic Axion-Like particle

- Model described[arxiv1805.06538]
- Photon-phobic ALPs, suppressed ALP to photon couplings at tree level
- A similar search was also performed in CMS before [SMP-17-013]
- WZγ has unique sensitivity in the 'low' ma region
- Other than the mass, only one free parameter $f_a (\sigma \times Br \cong \frac{1}{f_a^2})$

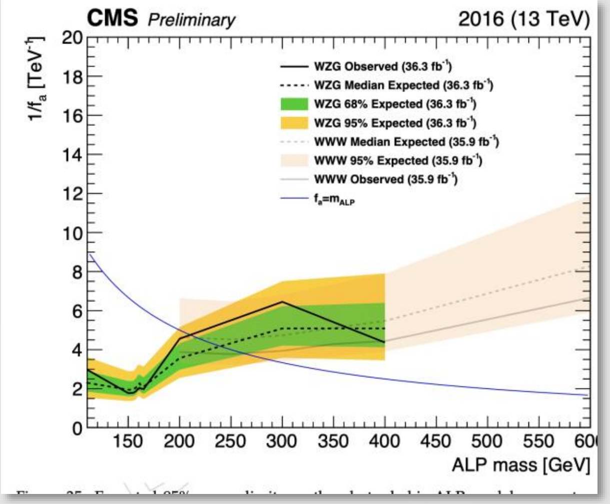






$$\Gamma(a \to Z\gamma) = \frac{1}{32\pi} \frac{e^4}{\sin^2\theta_W \cos^2\theta_W} \frac{m_a^3}{f_a^2} \left(1 - \frac{m_Z^2}{m_a^2}\right)^3$$

$$\Gamma(a \to WW) = \frac{1}{32\pi} \frac{e^4}{\sin^4\theta_W} \frac{m_a^3}{f_a^2} \left(1 - \frac{4m_W^2}{m_a^2}\right)^{3/2}$$



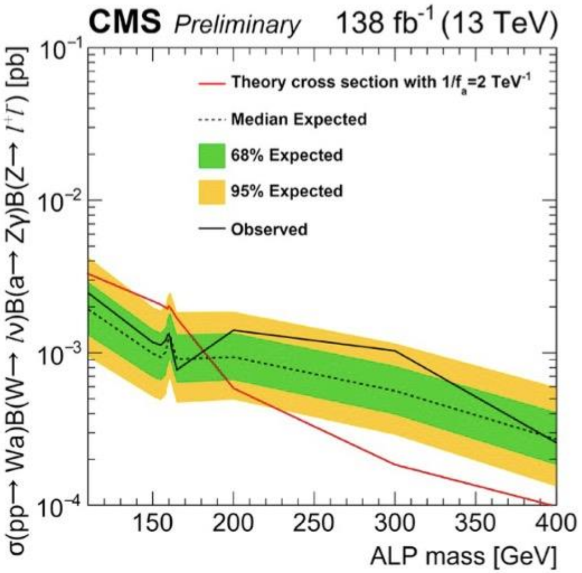
WZγ @ 13 TeV [$138 fb^{-1}$]

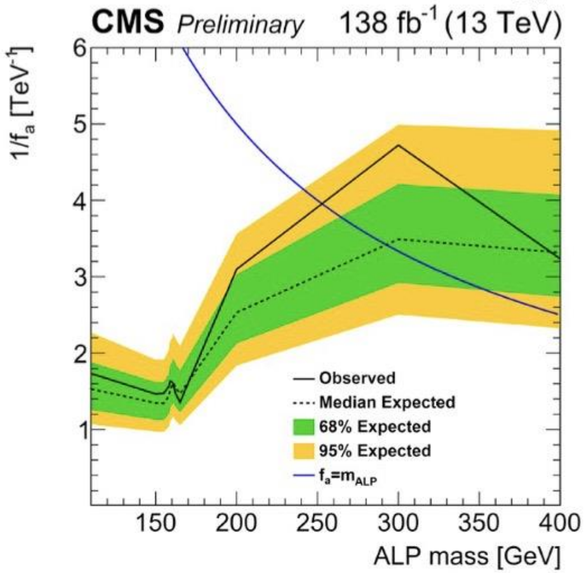
Results

- Measured fiducial cross section: **5.48 $\pm$ 0.95 (stat.) $\pm$ 0.57 (syst.) $\pm$ 0.10 (theo.) fb**
  - Theoretical predicted fiducial cross section (MadGraph5_aMC@NLO): **3.69 $\pm$ 0.19 (scale) $\pm$ 0.15 (PDF) fb**
  - Particle-level selection: $p_T^{e,\mu,\gamma} > 15$ GeV, $|\eta^{e,\mu,\gamma}| < 2.5$, m_Z between [60, 120] GeV
- Exclusion limits at the 95% CL for each aQGC coefficient

Operators	Observed limits [TeV $^{-4}$]	Expected limits [TeV $^{-4}$]	Unitarity bound [TeV]
$F_{T,0}/\Lambda^4$	[-2.60, 2.60]	[-2.52, 2.52]	1.32
$F_{T,1}/\Lambda^4$	[-3.28, 3.24]	[-3.18, 3.14]	1.48
$F_{T,2}/\Lambda^4$	[-7.15, 7.05]	[-6.95, 6.85]	1.35
$F_{T,5}/\Lambda^4$	[-2.54, 2.56]	[-2.46, 2.50]	1.55
$F_{T,6}/\Lambda^4$	[-3.18, 3.22]	[-3.08, 3.14]	1.61
$F_{T,7}/\Lambda^4$	[-6.85, 7.05]	[-6.65, 6.85]	1.71

- The observed (expected) significance of the WZγ signal is 5.4 (3.8) standard deviations
- Photophobic ALPs [JHEP09(2018)028], suppressed ALP to photon couplings at tree level
  - Only one free parameter f_a that directly determines the couplings between ALPs and vector bosons, ($\sigma \times Br \propto \frac{1}{f_a^2}$)





Same-sign WWγ @ 13 TeV [138fb^{-1}]

Motivation for SM SSWWG

- Search for process with:

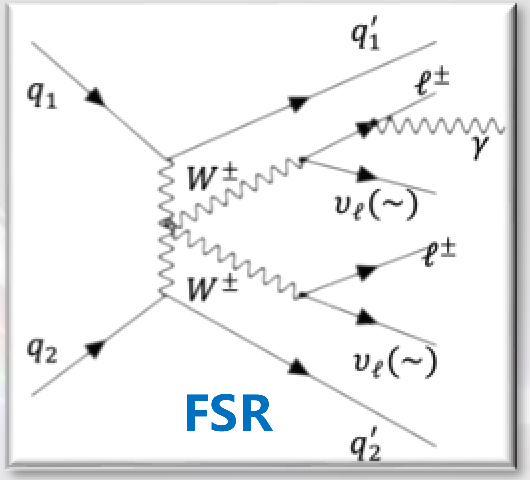
  The first 2->3 VBS tri-boson process！

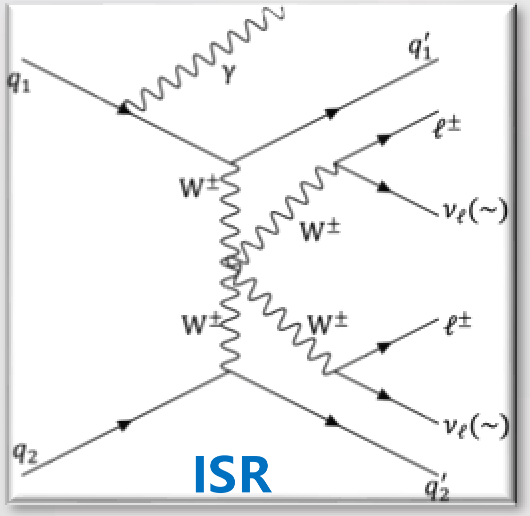
- Signal processes:
  - p p $\rightarrow \ell\ \ell\ \upsilon_\ell\ \upsilon_\ell$ j j γ (the QCD process)

    cross-section: 0.0009826+-1.559e-06pb
  - p p $\rightarrow \ell\ \ell\ \upsilon_\ell \upsilon_\ell$ j j γ QCD $=$ 0 (the EWK process)

    cross-section:0.001969+-3.871e-06pb

- Samples Information (Full RunII)
  - Signals: Private produced samples
  - Backgrounds: Official samples
  - Version: NanoAODv9 UL samples





Same-sign WWγ @ 13 TeV [138fb^{-1}]

Motivation for Doubly Charged Higgs Research

- **HIG-20-017:** "The H5 states are fermiophobic and are assumed to decay to vector boson pairs with a branching fraction of 100%"

Differ!

H5→H3 + W (high Branch ratio)

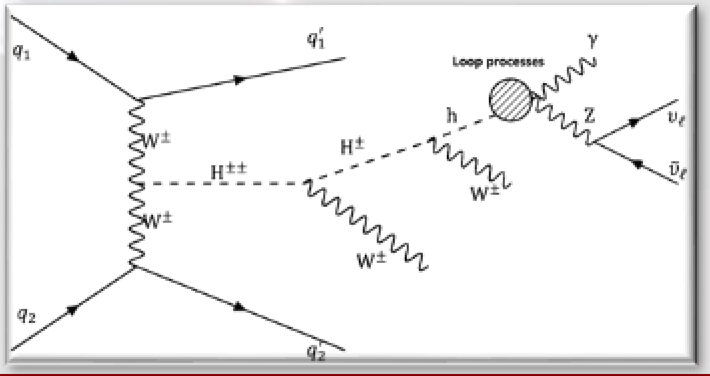
Model: The Georgi-Machacek (GM) model

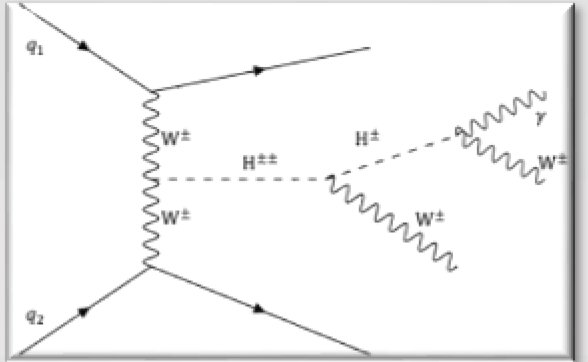
- The SM scalar sector is extended by adding one complex and one real SU(2) triplet.
- the hVV (and hhVV) coupling can be enhanced, and additional scalars exist.
  - The scalars: two custodial SU(2) singlets, a triplet and a fiveplet
  - Change the free dimensional parameters, specifically the M1 coefficient and M2 coefficient, to calculate the masses.

$$M_{H^\pm} = \sqrt{v^2\left(\frac{\lambda_5}{2} + \frac{M1coeff}{\times}4v_\chi\right)}$$

$$M_{H^{\pm\pm}} = \sqrt{12M2coeff \times v_\chi + 8\lambda_3 v_\chi^2 + \frac{3\lambda_5 v_\phi^2}{2} + \frac{M1coeff \times v_\phi^2}{4v_\chi}}$$

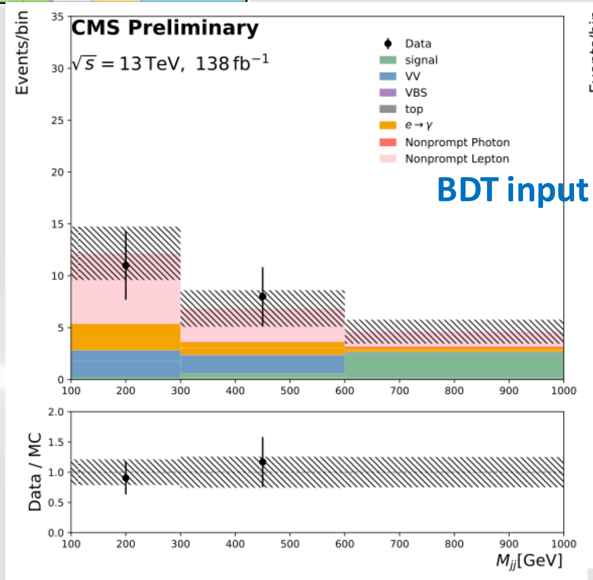
- fiveplet states: $H5^{\pm\pm}$, $H5^{\pm}$, $H5^{0}$
- Triplet states: $H3^{\pm}$, $H3^{0}$

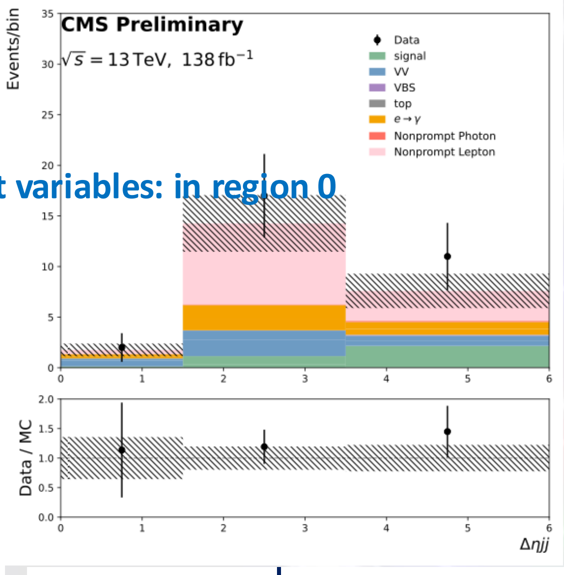




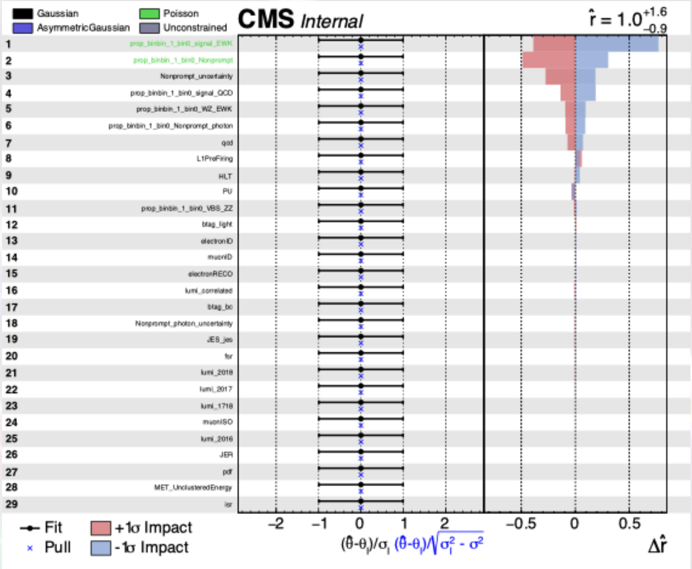
Same-sign WWγ @ 13 TeV [$138fb^{-1}$]

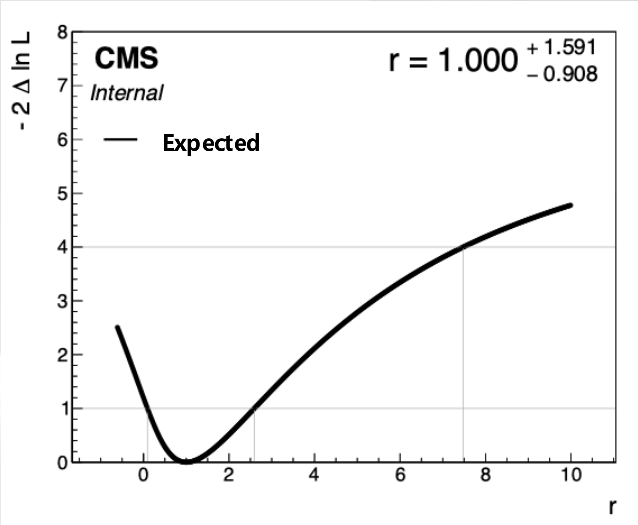
Results for SM

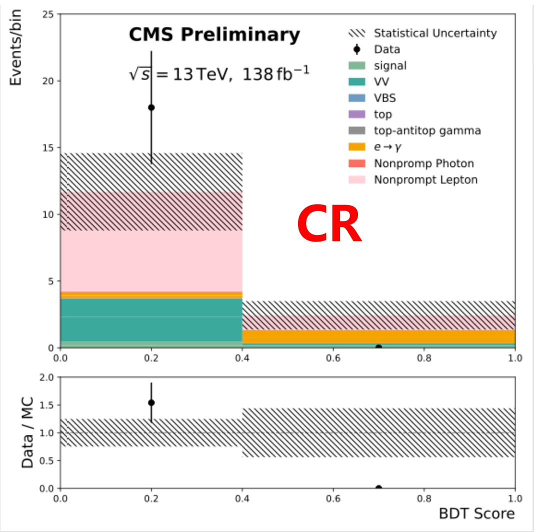


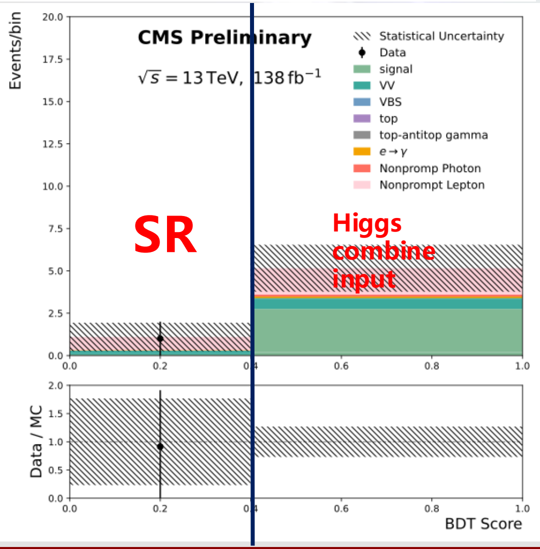


BDT input variables: in region 0









Significance: 1.1σ(Full RunII)

- Region 0
- $M_{jj} > 500$ GeV
- $\Delta\eta_{jj} > 0.5$

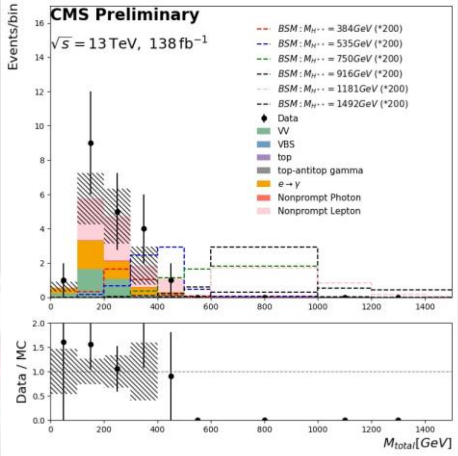
Higgs combine input: BDT score > 0.4

Same-sign WWγ @ 13 TeV [$138 fb^{-1}$]

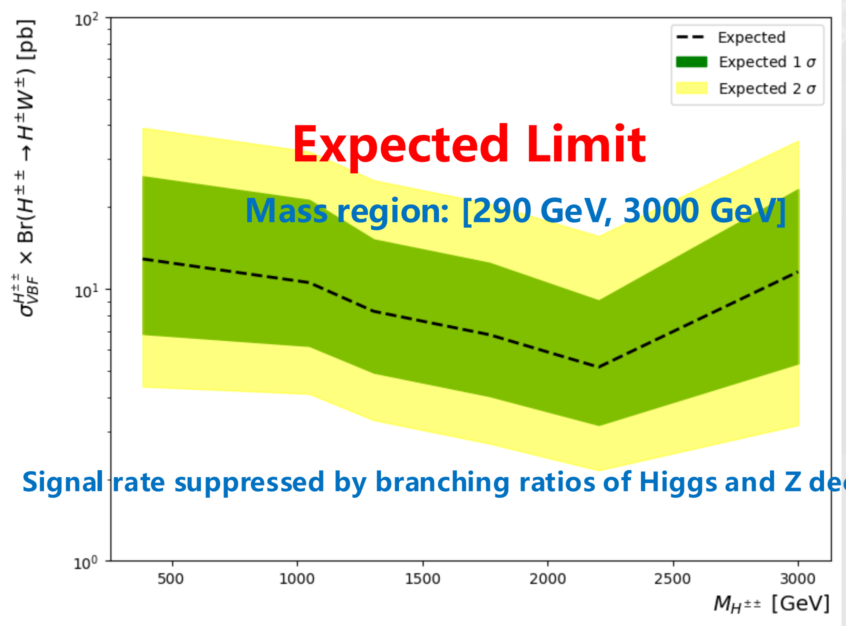
Result for scenario a

M1coeff	22	50	100	200	300	500	900	1500	2000
M2coeff	400	500	1000	4000	5500	8000	15,000	30000	60000
M_{H5pp}	290 GeV	384GeV	535GeV	878 GeV	1.0TeV	1.3TeV	1.7TeV	2TeV	3.1TeV
M_{H3pp}	205GeV	300GeV	422GeV	594 GeV	726GeV	936GeV	1.2TeV	1.4TeV	1.8TeV
Br($H5pp \to H3p + W^+$)	7.3%	26.3%	81.2 %	98.5%	93.4%	94.0%	87.1%	70%	50%
Br ($H5pp \to W^+W^+$)	20.5%	73.6%	18.6 %	1.45%	3.5%	4.3%	3.7%	4.0%	4.0%

optimize	384GeV	535GeV	878GeV	1049GeV	1306GeV	1768GeV	3000GeV
Mtotal	-	-	>400GeV	>400GeV	>400GeV	>400GeV	> 400GeV
Mjj	>500GeV	>500GeV	>500GeV	>500GeV	>500GeV	>500GeV	>500GeV
$\Delta\eta_{jj}$	>0.5	>0.5	>0.5	>0.5	>0.5	>0.5	>0.5
BDT score	[0.55,1]	[0.55,1]	[0.2,1]	[0.2,1]	[0.2,1]	[0.2,1]	[0.2,1]



Mtotal:
- Invariant mass of two leptons,
- MET,
- photon pt



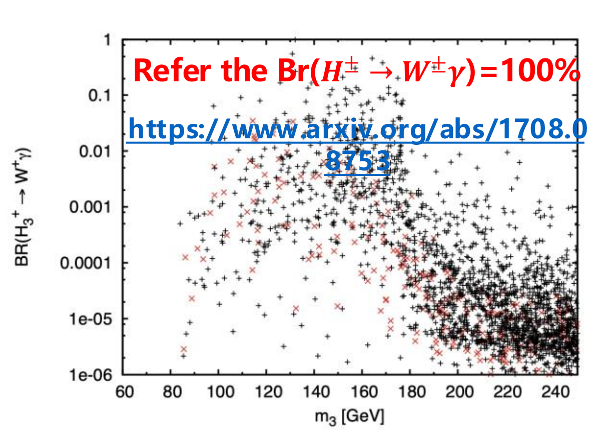
Signal rate suppressed by branching ratios of Higgs and Z decays

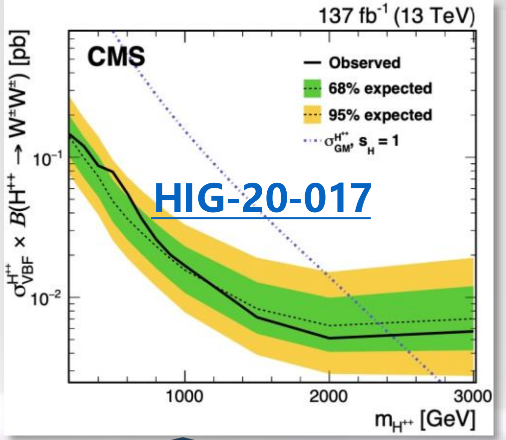
Same-sign WWγ @ 13 TeV [$138 fb^{-1}$]

Result for scenario b

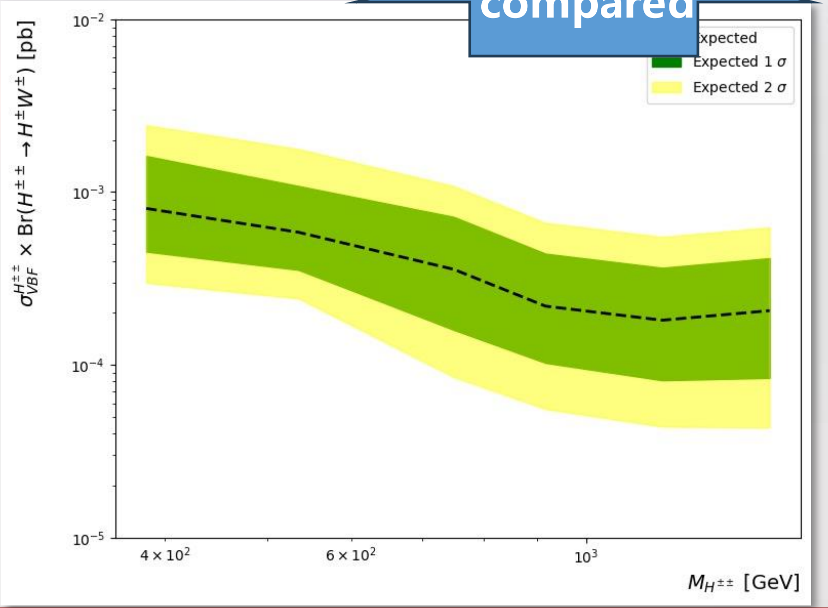
M1coeff	50	100	200	300	500	800
M2coeff	500	1000	2000	3000	5000	8000
M_{H5PP}(GeV)	384	535	750	916	1181	1492
M_{H3P}(GeV)	300	422	594	726	936	1184
BR($H5^{\pm\pm} \to H3^{\pm} + W^{\pm}$)	26.3%	81.2%	87.4%	88.6%	89.4%	89.4%
BR($H5^{\pm\pm} \to W^{\pm} + W^{\pm}$)	73.6%	18.6%	12.3%	11%	10%	9.6%

M2coeff = M1coeff *10





compared



optimize	384GeV	535GeV	750GeV	916GeV	1181GeV	1492GeV
Mtotal	-	-	>500GeV	>500GeV	>500GeV	>500GeV
Mjj	>500GeV	>500GeV	>100GeV	>100GeV	>100GeV	>100GeV
$\Delta\eta_{jj}$	>0.5	>0.5	-	-	-	-
BDT score	[0.55,1]	[0.55,1]	[0.2,1]	[0.2,1]	[0.2,1]	[0.2,1]

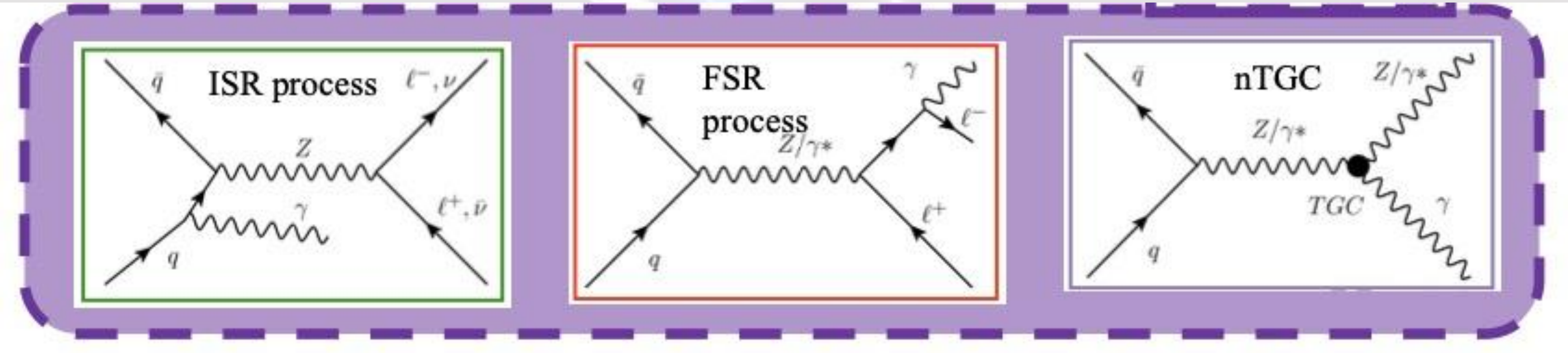
Zγ @ 13.6 TeV[Full 2022, 34.75fb^{-1}]

Motivation for Zγ

- Zγ production occurs at a large rate at CMS.
- It can be compared with the precision generator prediction.
- Data: Full 2022, ~ 34.75 fb-1
- Samples Information: NanoAOD v12.
- Goals:

- Fiducial cross section of Zγ→llγ at center-of-mass energy of 13.6 TeV.
- Calculate and compare the limits for the new nTGC model and the old nTGC model.

Collab	Process	$\sqrt{s}$ /TeV	Reference
ATLAS	Zγ > llγ	13	JHEP07(2023)072
CMS	Zγ > ννγ	13	SMP-22-009
CMS	Zγ > ννγ	8	SMP-14-019
CMS	Zγ > llγ	8	SMP-13-014



$Z\gamma$ @ 13.6 TeV[Full 2022, 34.75fb^{-1}]

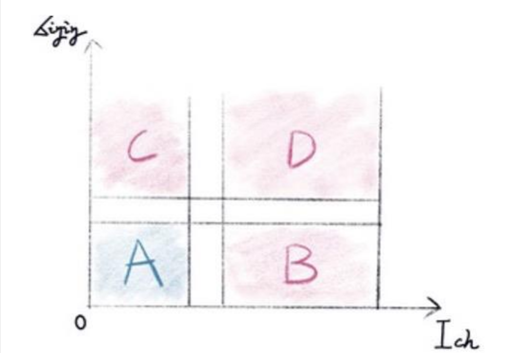
Nonprompt photon estimation

ABCD method (2-dimensional sideband method)

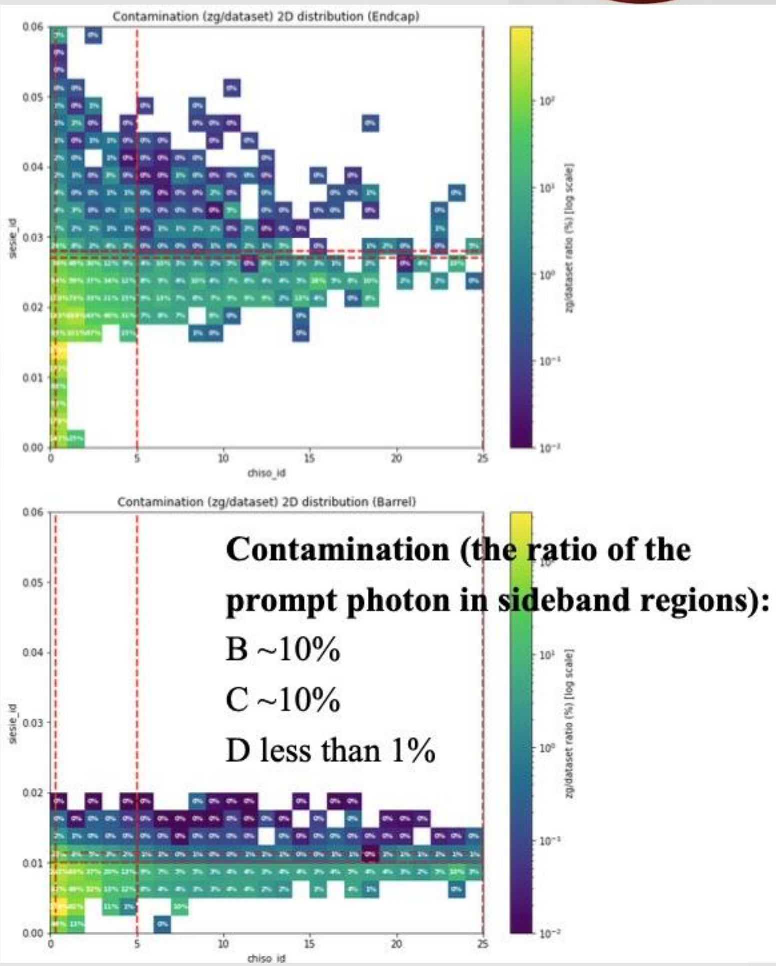
- First dimension: Ich
- Second dimension: $\sigma_{i\eta i\eta}$

ABCD definition

- A: Pass tight cut for $\sigma_{i\eta i\eta}$ dimension and pass tight cut for I23 dimension.
- B: Pass tight cut for $\sigma_{i\eta i\eta}$ dimension, $5 < Ich < 25$
- C: $\sigma i\eta i\eta >$ 0. 0115(0.0276), pass tight cut for I23 dimension.
- D: $\sigma i\eta i\eta >$ 0. 0115(0.0276), $5 < Ich < 25$



arXiv: 1605.03495
arXiv: 1012.4389



Contamination (the ratio of the prompt photon in sideband regions):
B ~10%
C ~10%
D less than 1%

$Z\gamma$ @ 13.6 TeV[Full 2022, 34.75fb^{-1}]

SMEFT interpretation

Laboratoire Leprince-Ringuet

➢ SMEFT

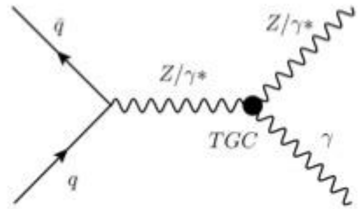
- Well-defined theoretical approach, write an effective Lagrangian with only light (SM) particles.
- nTGCs are forbidden at tree level in the SM, but could arise from SMEFT dim-8 operators; they provide a unique probe of dim-8 operators.

dimension-6 dimension-8

Dimensionless coefficients ci

$$\mathcal{L} = \mathcal{L}_{SM} + \sum \frac{c_i}{\Lambda^2} \mathcal{O}_i^{d=6} + \sum \frac{c_i}{\Lambda^4} \mathcal{O}_i^{d=8} + \ldots$$

BSM effects SM particles



nTGC model

- ✓ A new nTGC model is proposed: Paper link

  Selected as Editors' Suggestion by PRD!
- ✓ What is this new model?

  It derives the neutral triple gauge vertices generated by the dimension-8 operators in the broken phase.
- ✓ Why is this a new model?
  - The conventional form factor formulation of nTGC only considers the unbroken $U(1)_{em}$ gauge symmetry.
  - This new model preserves the full electroweak gauge group $SU(2)_L \otimes U(1)_Y$ of the SM.

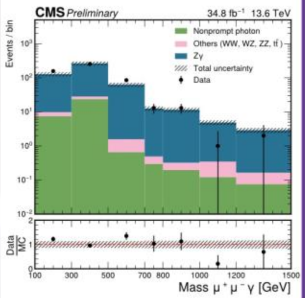
$Z\gamma$ @ 13.6 TeV[Full 2022, 34.75fb^{-1}]

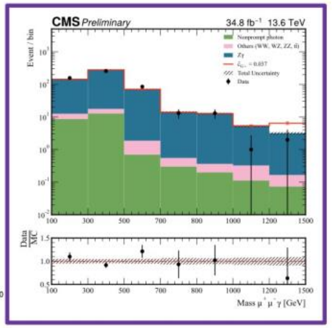
Results---fiducial cross-section

$$\sigma_{fiducial\_region} = \sigma_{generator} * \mu_{signal\_strength} * \epsilon_{generated\_to\_fiducial}$$

Muon channel

Pre-fit | Post-fit

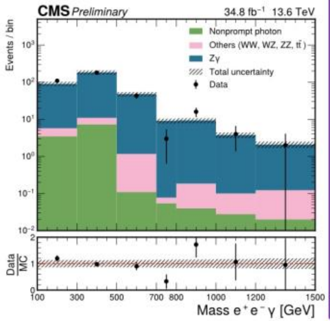


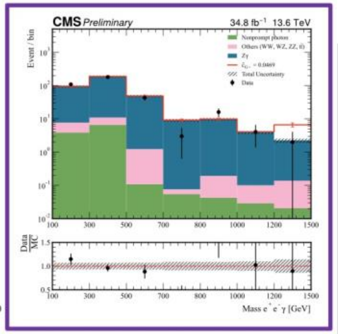


PAPER

Electron channel

Pre-fit | Post-fit





PAPER

- $\sigma_{generator}$ is the cross section of the Monte Carlo signal sample.

ZG_10-50	124 pb	GenXSecAnalyzer(NLO)
ZG_50-100	2.088 pb	GenXSecAnalyzer(NLO)
ZG_100-200	0.3493 pb	GenXSecAnalyzer(NLO)
ZG_200	0.04723 pb	GenXSecAnalyzer(NLO)
total	126.48 pb	

- $\mu_{signal\_strength}$ is the signal strength from fitting.

(Expected) Combined channel : $1.000^{+0.003}_{-0.003}(theory)^{+0.029}_{-0.027}(sys)^{+0.017}_{-0.017}(stat)$

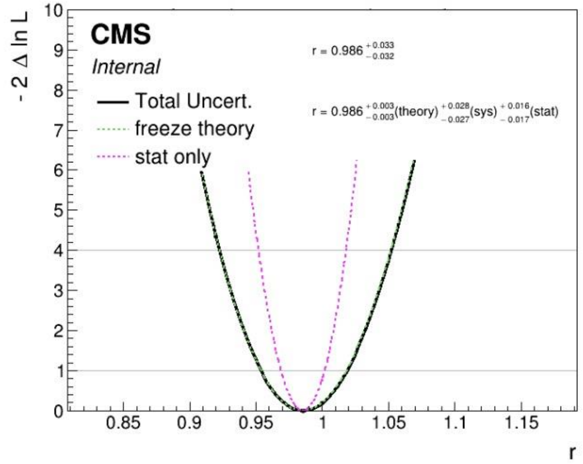
(Observed) Combined channel : $0.986^{+0.003}_{-0.003}(theory)^{+0.028}_{-0.027}(sys)^{+0.016}_{-0.017}(stat)$

- $\epsilon_{generated\_to\_fiducial}$ is the fraction of the generated signal events passing the fiducial region selection.

$$\epsilon_{generated\_to\_fiducial} = \frac{N_{in fiducial\,region}}{N_{total}}$$

Combined channel: 1.52%

Combined channel, Observed result



$\sigma B^{\pm}$ theory.+sys. $\pm$ stat.	fiducial cross section (pb)
expected ZG($\mu\mu$)	$0.961 \pm 0.004 \pm 0.028 \pm 0.019$
expected ZG(ee)	$0.961 \pm 0.004 \pm 0.037 \pm 0.021$
expected ZG(combined)	$1.922 \pm 0.006 \pm 0.056 \pm 0.033$
observed ZG($\mu\mu$)	$0.928 \pm 0.004 \pm 0.027 \pm 0.018$
observed ZG(ee)	$0.975 \pm 0.003 \pm 0.038 \pm 0.021$
observed ZG(combined)	$1.896 \pm 0.006 \pm 0.054 \pm 0.033$

$Z\gamma$ @ 13.6 TeV[Full 2022, 34.75fb^{-1}]

Results---nTGCs limits

- Calculate the test statistics using the Higgs Combination tool

The test statistic follows a $\chi2$ distribution.

Extract the limit directly: 95%CL – 3.84

- Limits for the old model and the new model

Method		Higgscombine tools
$\sqrt{s}$		13.6 TeV (ll)
L (fb^{-1})		34.75
h_4^Z	Old model	[-8.17E-07,8.20E-07]
h_3^Z	Old model	[-5.69E-04, 5.48E-04]
h_3^a	Old model	[-6.67E-04, 6.88E-04]
$\tilde{c}_{G+}$	New model	[-3.05E-02,3.06E-02]
$\tilde{c}_{\tilde{B}W}$	New model	[-0.98,1.00]
$\tilde{c}_{G-}$	New model	[-2.44,2.54]

- Comparison of the old model

JHEP 04 (2015) 164 SMP-22-009

Source	This work	CMS	CMS
$\sqrt{s}$ (TeV)	13.6 (z-ll)	8 (z-ll)	13 (z-νν)
L (fb^{-1})	34.8	19.5	139
h_3^a	[-6.67E-04, 6.88E-04]	[-4.6E-03, 4.6E-03]	-
h_3^z	[-5.69E-04, 5.48E-04]	[-3.8E-03, 3.7E-03]	[-1.820E-04, 1.842E-04]
h_4^z	[-8.17E-07,8.20E-07]	[-3.1E-05, 3.0E-05]	[-3.671E-07, 3.635E-07]

- Comparison between old and new model

PhysRevD.107.035005

Source	This work	New model prediction
$\sqrt{s}$	13.6 TeV (ll)	13 TeV (ll)
L (fb^{-1})	34.8	139
$h_4(new)$	[-3.65E-05,3.63E-05]	1.4 E-05
$h_4^z(old)$	[-8.17E-07,8.20E-07]	7.5 E-07

Consistent with the new model' s studies:
"We see that the sensitivities to the conventional Form Factor hV are generally stronger than those of the SMEFT Form Factor h4 by large factors, ranging from O(20) at the LHC to $O(10^2)$ at a 100 TeV pp collider."

Summary

- CMS has a strong and comprehensive program of multiboson measurements & Searches/Probes
  - Precision multiboson measurements
  - Beyond Standard Model extensions: Anomalous couplings, EFT, Higgs properties, ALP, etc.
    - Run2 WZγ:
      - The observed (expected) significance for WZγ production is 5.4 σ (3.8 σ)
      - We report limits on anomalous gauge couplings to dimension-8 operators
      - We also report limits on the photon-phobic ALP model
    - Run2 Same-sign WWγ:
      - A first 2->3 SM VBS measurement is presented here: 1.1 σ
      - A first $\mathrm{H5}^{\pm\pm} \rightarrow \mathrm{H3}^{\pm}\mathrm{W}^{\pm}$ measurement is presented here
        - Consider two scenarios for $H3^{\pm}$ decay.
    - Run3 Zγ:
      - The $m_{\ell\ell\gamma}$ distribution was fitted to extract the fiducial cross-section for the Zγ process.
      - Limits on Neutral Triple Gauge Couplings (nTGC) were calculated based on the $m_{\ell\ell\gamma}$ distribution.
- Lots of opportunities with the Run-3 data coming in!
  - VBS Tri-boson production……

Thank you !!