

# Sensitivity Study of $\gamma\gamma \rightarrow \gamma Z$ Anomalous Coupling in HL-LHC

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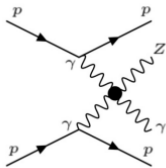
Institute For Research In Fundamental Science (IPM)

Proton POG Meeting



# Exclusive Production of $\gamma\gamma \rightarrow \gamma Z$ Anomalous Coupling

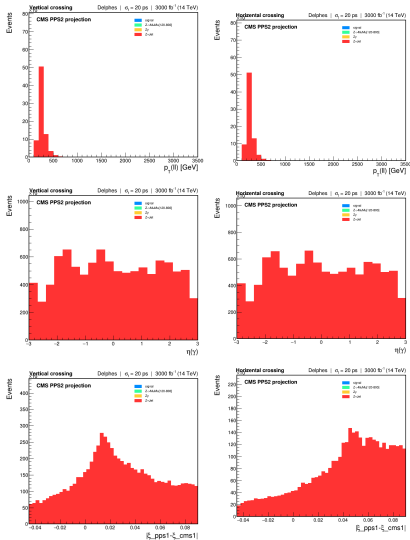
**Exclusive reactions**  $pp \rightarrow p + X + p$  can be studied by measuring  $X$  in a general purpose detector (CMS) and the scattered intact protons with forward proton detectors (PPS) located at  $\sim 210$  m with respect to the main interaction vertex.



# Table of Signal and Background Cross Sections

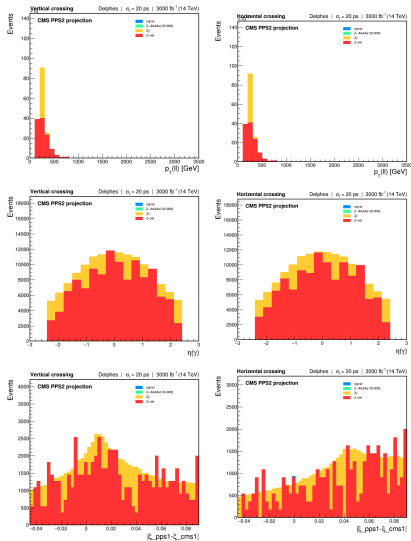
Signal/Background	Process	$\sigma$ (pb)
Signal, Vertical $\varepsilon$	FPMC bSM 14TeV AAAAzeft A1A 0E0 A2A 1E-13 pt50-noHADR 3.556E-4 Zmumu.root	3.55e-4
Signal, Horizontal $\varepsilon$	FPMC bSM 14TeV AAAAzeft A1A 0E0 A2A 1E-13 pt50 horXing-noHADR 2.439E-3 Zmumu Delphes PU200.root	2.439e-3
DY background	ZToMuMu M-120to200 Tune CP5_14TeV-powheg-pythia8	18.72
DY background	ZToMuMu M-200to400 Tune CP5_14TeV-powheg-pythia8	2.682
DY background	ZToMuMu M-400to800 Tune CP5_14TeV-powheg-pythia8	0.2396
SM Zy background	Zgamma_inc_SM_Madgraph5_Delphes.PU200	0.152
Z+jet (fake photon)	ZJets_inc_SM_Madgraph5_JetPT200GeV_Delphes.PU200	60.517

# Central Object Selection (Muon Selection)



Two same flavor, oppositely signed charged leptons (Muons) with loose criteria,  $\eta < 2.4$ .  
 $p_{T_Z} > 100$  GeV.

# Central Object Selection (Photon Selection)

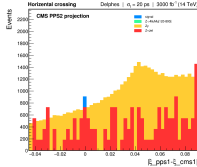
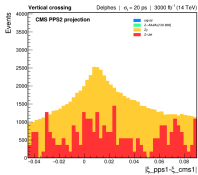
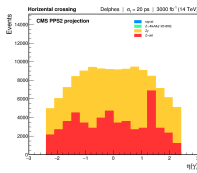
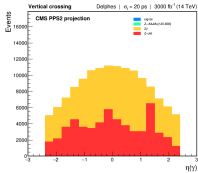
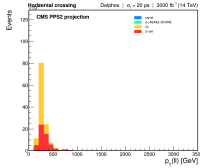
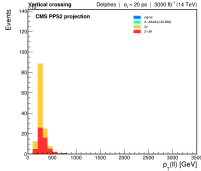


- $p_{T\gamma} > 200$  GeV
- Loose criteria and  $\eta < 2.4$
- Rejecting photons with:
  - SumPtCharged  $> 10$
  - SumPtCharged  $< 0$

# Proton Selection

- Two protons are selected from both sides of the CMS detector.
- $\xi_{PPS} = 1 - |P_z(\text{GenProton})|/7000$ .
- $\xi$  is smeared by a Gaussian distribution with mean = 0 and std = 0.02.
- PPS acceptance:
  - $0.0147 < \xi_{\text{vertical}} < 0.196$
  - $0.0472 < \xi_{\text{horizontal}} < 0.287$
- To mitigate PU, two protons with the smallest  $|Z_{\text{Vertex, cms}} - Z_{\text{Vertex, PPS}}|$  are selected.

# Central Object Selection ( $\xi$ Resolution Cut)

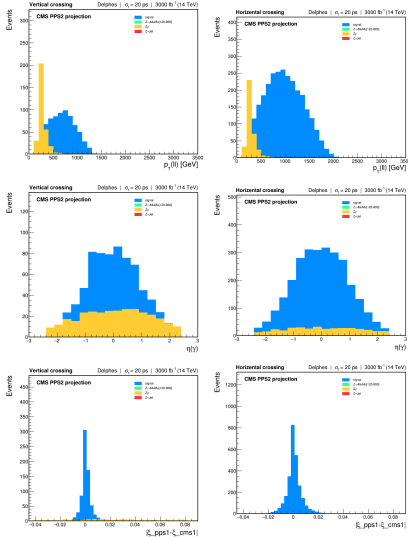


$$|\xi_{\text{cms}} - \xi_{\text{pps}}| < 0.2$$

$$\xi_1 = \frac{\sum_{i=I^+, I^-, \gamma} (E_i + P_{z_i})}{\sqrt{s}},$$

$$\xi_2 = \frac{\sum_{i=I^+, I^-, \gamma} (E_i - P_{z_i})}{\sqrt{s}}.$$

# Central Object Selection (Z Vertex Cut)



**Selected Events within Z Vertex Cut:**

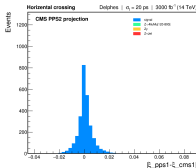
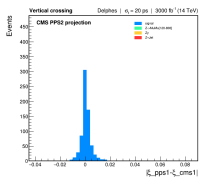
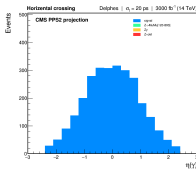
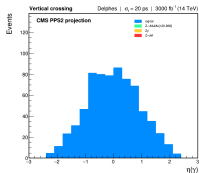
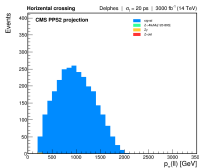
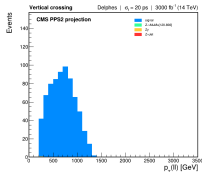
$$|Z_{\text{Vertex, cms}} - Z_{\text{Vertex, PPS}}| < 0.433$$

$$Z_{\text{Vertex, PPS}} = \frac{(t_{p1} - t_{p2})}{2} \times C$$

where  $C = 30 \text{ cm/ns}$ .



# Central Object Selection (Timing Cut)



## Timing Cut Condition:

$$|t_{\text{Vertex, cms}} - t_{\text{Vertex, PPS}}| < 0.0058$$

$$t_{\text{Vertex, PPS}} = \frac{(t_{p1} + t_{p2})}{2} - \frac{Z_{ppss}}{C}$$

where  $C = 30 \text{ cm/ns}$  and  $Z_{ppss} = 23400 \text{ cm}$ .

# Cut-Flow tables

Crossing: Vertical, Timing Resolution: 20 ps						
NEvents	Signal (no PU)	Signal (realistic)	DY+Jets, $M_Z = [120 - 800]$ GeV	$Z\gamma(SM)$	Z + Jet	$S/\sqrt{B}$
AllEvents	1065.0	1065.0	64924800.0	456000.0	181552000.0	0.068
$n_{Leptons} > 1$	926.104	1000.05	39363206.0	353890.0	140956000.0	0.074
$p_{T,Z} > 100$ GeV	919.909	993.853	2159559.0	347551.0	138170000.0	0.084
$p_{T,\gamma} > 200$ GeV, $0 < \text{SumPtCharged} < 10$	760.629	820.384	2009.63	144071.0	118190.0	1.596
$75 \text{ GeV} < M_Z < 110 \text{ GeV}$	711.066	767.823	115.008	138485.0	56825.8	1.737
ProtonSelection	711.066	767.823	115.008	138485.0	56825.8	1.737
$\text{Resolution}_{\xi_{cms1}} < 2\sqrt{2}$	711.066	767.823	115.008	138483.0	56825.8	1.737
$\text{Resolution}_{\xi_{cms2}} < 2\sqrt{2}$	711.066	767.823	115.008	138481.0	56825.8	1.737
$\text{Resolution}_{ZVertex} < 2\sqrt{2} \times 20ps \times C$	711.066	711.266	0.0	315.082	0.0	40.07
$\text{Resolution}_{time} < 2\sqrt{2} \times 20ps$	711.066	711.066	0.0	0.744	0.0	824.213

Crossing: Horizontal, Timing Resolution: 20 ps						
NEvents	Signal (no PU)	Signal (realistic)	DY+Jets, $M_Z = [120 - 800]$ GeV	$Z\gamma(SM)$	Z + Jet	$S/\sqrt{B}$
AllEvents	7317.0	7317.0	64924800.0	456000.0	181552000.0	0.466
$n_{Leptons} > 1$	3574.06	6782.86	39791238.0	357638.0	142511000.0	0.502
$p_{T,Z} > 100$ GeV	3563.67	6765.15	2180753.0	351232.0	139692000.0	0.567
$p_{T,\gamma} > 200$ GeV, $0 < \text{SumPtCharged} < 10$	2971.58	5647.55	2024.0	145615.0	119280.0	10.931
$75 \text{ GeV} < M_Z < 110 \text{ GeV}$	2763.48	5239.41	122.196	139969.0	57915.1	11.775
ProtonSelection	2763.48	5239.41	122.196	139969.0	57915.1	11.775
$\text{Resolution}_{\xi_{cms1}} < 2\sqrt{2}$	2763.48	5104.49	93.444	133101.0	55918.1	11.738
$\text{Resolution}_{\xi_{cms2}} < 2\sqrt{2}$	2763.48	4989.32	86.256	127664.0	54284.1	11.694
$\text{Resolution}_{ZVertex} < 2\sqrt{2} \times 20ps \times C$	2763.48	2772.26	0.0	371.647	0.0	143.803
$\text{Resolution}_{time} < 2\sqrt{2} \times 20ps$	2763.48	2764.07	0.0	4.466	0.0	1307.987

# $\gamma\gamma \rightarrow \gamma Z$ Anomalous Coupling in EFT Physics

The EFT Lagrangian for the process  $\gamma\gamma \rightarrow \gamma Z$  can be written as:

$$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \mathcal{L}_{\gamma Z}^0 + \mathcal{L}_{\gamma Z}^C \quad (1)$$

where:

$$\mathcal{L}_{\gamma Z}^0 = -\frac{e^2 a_0^Z}{16 \cos^2 \theta_W \Lambda^2} F_{\mu\nu} F^{\mu\nu} Z_\alpha A^\alpha \quad (2)$$

and

$$\mathcal{L}_{\gamma Z}^C = -\frac{e^2 a_C^Z}{16 \cos^2 \theta_W \Lambda^2} F_{\mu\alpha} F^{\mu\beta} Z_\beta A^\alpha \quad (3)$$

where:

- $e$  is the electromagnetic coupling,
- $F_{\mu\nu}$  is the photon field strength tensor,
- $Z_\alpha$  represents the  $Z$ -boson field, and  $A_\alpha$  represents the photon field,
- $\theta_W$  is the weak mixing angle,
- $\Lambda$  is the scale of new physics,
- $a_0^Z$  and  $a_C^Z$  are the coupling coefficients for this process.