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

Sima Bashiri

Institute For Research In Fundamental Science (IPM)

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Exclusive Production of $\gamma\gamma \to \gamma Z$ Anomalous Coupling

Exclusive reactions pp $\to$ 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.

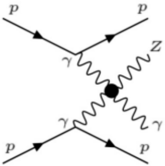
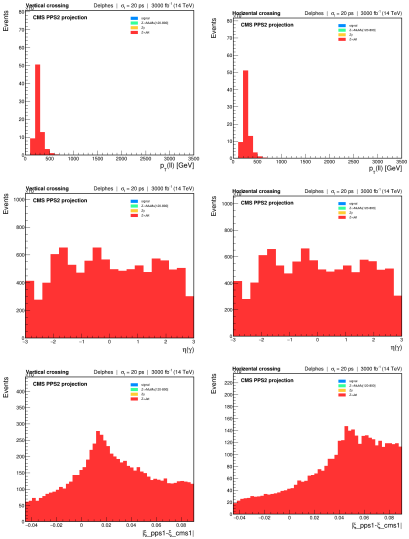


Table of Signal and Background Cross Sections

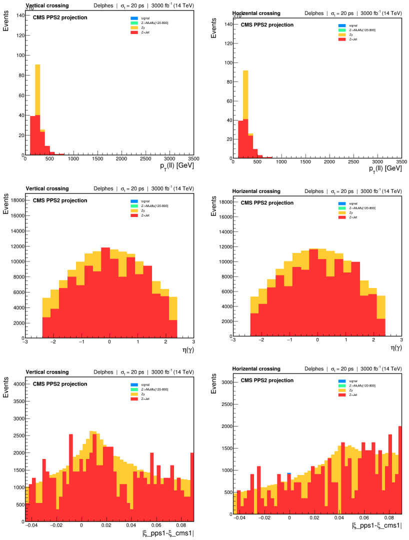
Signal/Background	Process	σ (pb)
Signal, Vertical ε	FPMC bSM 14TeV AAAAzeft A1A 0E0 A2A 1E-13 pt50-noHADR 3.556E-4 Zmumu.root	3.55e-4
Signal, Horizontal ε	FPMC bSM 14TeV AAAAzeft A1A 0E0 A2A 1E-13 pt50 horXing-noHADR 2.439E-3 Zmumu Delphes PU200.root	2.439e-3
DY background	ZToMuMu M-120to200 Tune CP5_14TeV-powheg-pythia8	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)

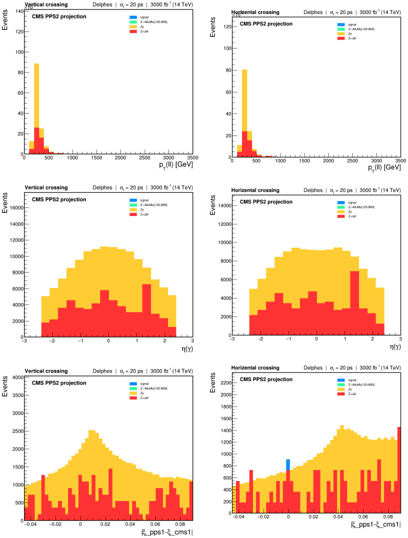


- $p_{T_\gamma} > 200$ GeV
- Loose criteria and $\eta < 2.4$
- Rejecting photons with:
    - SumPtCharged > 10
    - SumPtCharged < 0

Proton Selection

- Two protons are selected from both sides of the CMS detector.
- $\xi_{PPS} = 1 - |P_z(\text{GenProton})|/7000$.
- ξ 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 (ξ Resolution Cut)

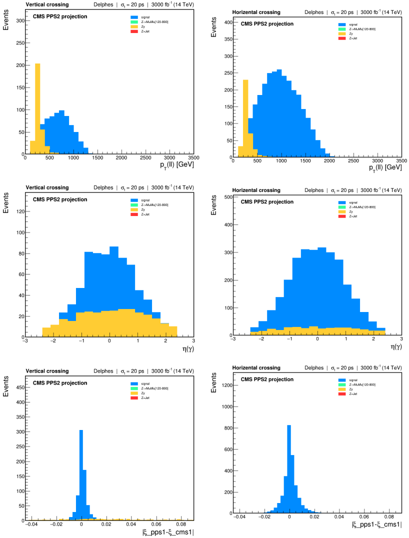


$$|\xi_{\text{cms}} - \xi_{\text{pps}}| < 0.2$$

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

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

Central Object Selection (Z Vertex Cut)



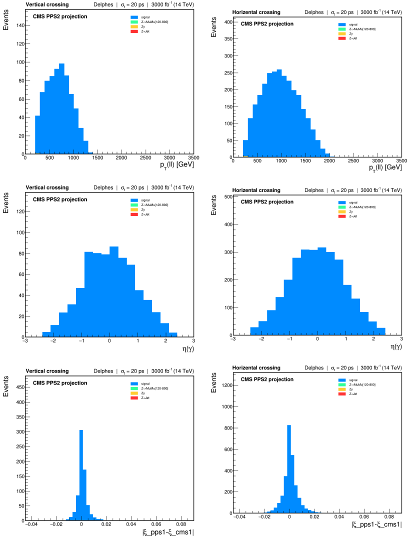
Selected Events within Z Vertex Cut:

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

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

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

Central Object Selection (Timing Cut)



Timing Cut Condition:

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

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

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
$p_{T,\gamma} > 200 GeV, 0 <$ SumPtCharged < 10	760.629	820.384	2009.63	144071.0	118190.0	1.596
75 GeV $< M_Z <$ 110 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
$Resolution_{\xi_{cms1}} < 2\sqrt{2}$	711.066	767.823	115.008	138483.0	56825.8	1.737
$Resolution_{\xi_{cms2}} < 2\sqrt{2}$	711.066	767.823	115.008	138481.0	56825.8	1.737
$Resolution_{ZVertex} < 2\sqrt{2} \times 20ps \times C$	711.066	711.266	0.0	315.082	0.0	40.07
$Resolution_{time} < 2\sqrt{2} \times 20ps$	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
$p_{T,\gamma} > 200 GeV, 0 <$ SumPtCharged < 10	2971.58	5647.55	2024.0	145615.0	119280.0	10.931
75 GeV $< M_Z <$ 110 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
$Resolution_{\xi_{cms1}} < 2\sqrt{2}$	2763.48	5104.49	93.444	133101.0	55918.1	11.738
$Resolution_{\xi_{cms2}} < 2\sqrt{2}$	2763.48	4989.32	86.256	127664.0	54284.1	11.694
$Resolution_{ZVertex} < 2\sqrt{2} \times 20ps \times C$	2763.48	2772.26	0.0	371.647	0.0	143.803
$Resolution_{time} < 2\sqrt{2} \times 20ps$	2763.48	2764.07	0.0	4.466	0.0	1307.987

$\gamma\gamma \to \gamma Z$ Anomalous Coupling in EFT Physics

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

$$\mathcal{L}_{\gamma\gamma\gamma Z} = \zeta \mathcal{O}_{\gamma Z} + \tilde{\zeta}\tilde{\mathcal{O}}_{\gamma Z} = \frac{\zeta}{\Lambda^4} F_{\mu\nu} F^{\mu\nu} F_{\rho\sigma} Z^{\rho\sigma} + \frac{\tilde{\zeta}}{\Lambda^4} F_{\mu\nu} \tilde{F}^{\mu\nu} F_{\rho\sigma} \tilde{Z}^{\rho\sigma} \tag{1}$$

$\tilde{F}_{\mu\nu}$ and $\tilde{Z}_{\mu\nu}$ are the dual field strength tensors, defined as:

$$\tilde{F}_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\rho\sigma} F^{\rho\sigma}, \quad \tilde{Z}_{\mu\nu} = \frac{1}{2}\epsilon_{\mu\nu\rho\sigma} Z^{\rho\sigma} \tag{2}$$