

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

Sima Bashiri

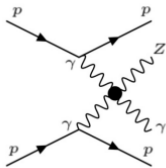
Institute For Research In Fundamental Science (IPM)

Proton POG Meeting



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

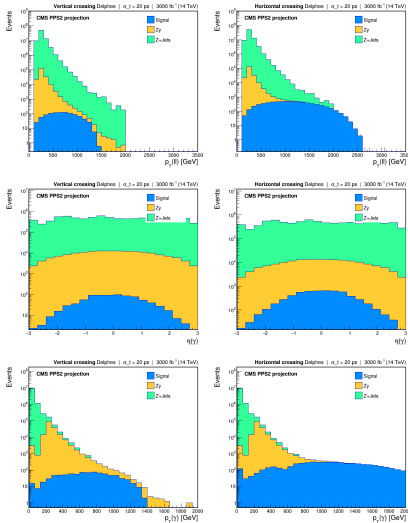
**Exclusive reactions  $pp \rightarrow p + X + p$**  can be studied by measuring  $X$  in a general purpose detector (CMS) and the scattered intact protons with forward proton detectors (PPS) located at  $\sim 210$  m with respect to the main interaction vertex.



# Table of Signal and Background Cross Sections

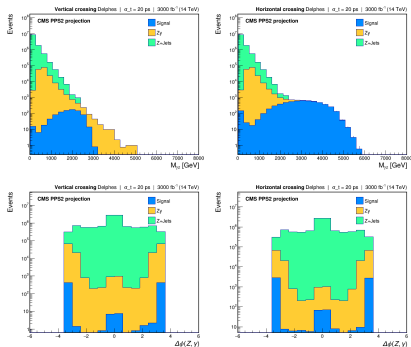
Signal/Background	Process	$\sigma$ (pb)	Number of Events
Signal, Vertical	FPMC bSM 14TeV AAAAzeft A1A 0E0 A2A 1E-13 pt50-noHADR 3.556E-4 Zmumu.root	3.55e-4	5329
Signal, Horizontal	FPMC bSM 14TeV AAAAzeft A1A 0E0 A2A 1E-13 pt50 horXing-noHADR 2.439E-3 Zmumu Delphes PU200.root	2.439e-3	50000
SM Zy background	Zgamma_inc_SM_Madgraph5_PhotonPT200GeV_Delphes_PU200	0.152	1838000
Z+jet (fake photon)	ZJets_inc_SM_Madgraph5_JetPT200GeV_Delphes_PU200	60.517	1000000

# Central Object Selection (Muon Selection)



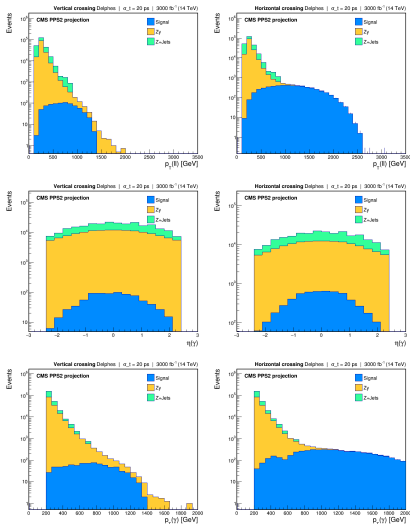
Two same flavor, oppositely signed charged leptons (Muons) with loose criteria,  $\eta < 2.4$ .  
 $p_{T_Z} > 100$  GeV.

# Central Object Selection (Muon Selection)



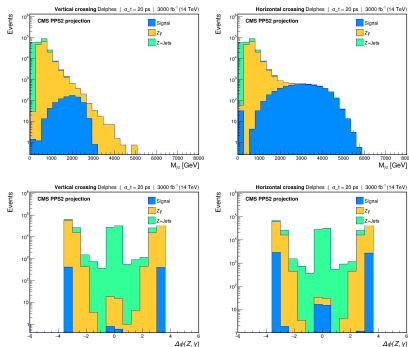
Two same flavor, oppositely signed charged leptons (Muons) with loose criteria,  $\eta < 2.4$ .  
 $p_{TZ} > 100$  GeV.

# Central Object Selection (Photon Selection)



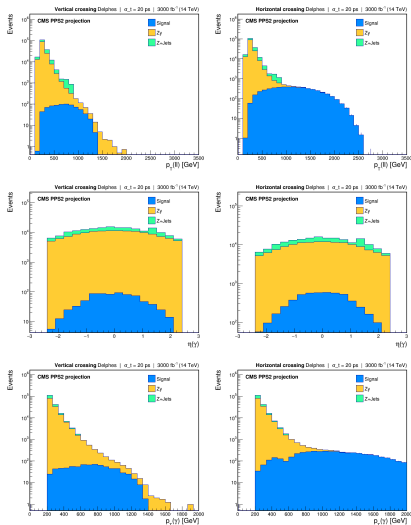
- $p_{T\gamma} > 200$  GeV
- Loose criteria and  $\eta < 2.4$
- Rejecting photons with:
  - $\text{SumPtCharged} > 5$
  - $\text{SumPtCharged} < 0$

# Central Object Selection (Photon Selection)



- $p_{T_\gamma} > 200 \text{ GeV}$
- Loose criteria and  $\eta < 2.4$
- Rejecting photons with:
  - $\text{SumPtCharged} > 5$
  - $\text{SumPtCharged} < 0$

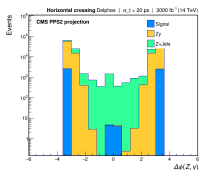
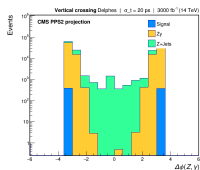
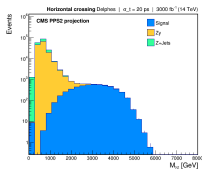
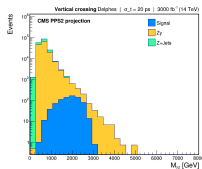
# Central Object Selection (Z-boson mass)



Reject events with  $|M_Z - 90 \text{ GeV}| > 15 \text{ GeV}$ .

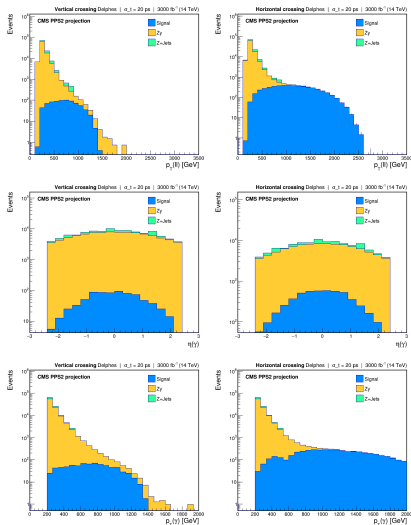


# Central Object Selection (Z-boson mass)



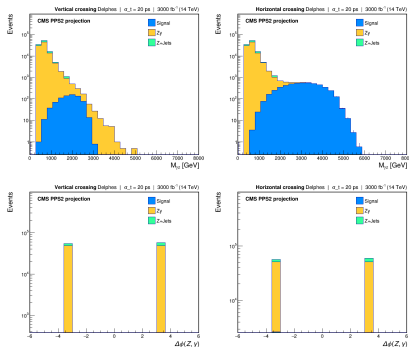
Reject events with  
 $|M_Z - 90 \text{ GeV}| > 15 \text{ GeV}.$

# Central Object Selection ( $\Delta\phi(Z, \gamma)$ )



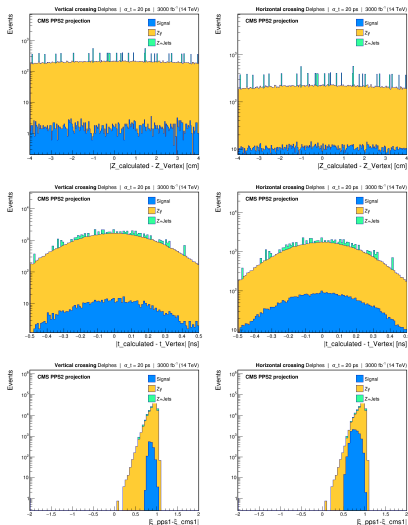
Expecting  $Z$  and  $\gamma$  to be back-to-back, reject events with  $||\Delta\phi(Z, \gamma) - \pi| > 0.1$ .

# Central Object Selection ( $\Delta\phi(Z, \gamma)$ )



Expecting  $Z$  and  $\gamma$  to be back-to-back, reject events with  $||\Delta\phi(Z, \gamma) - \pi| > 0.1$ .

# Central Object Selection ( $\Delta\phi(Z, \gamma)$ )

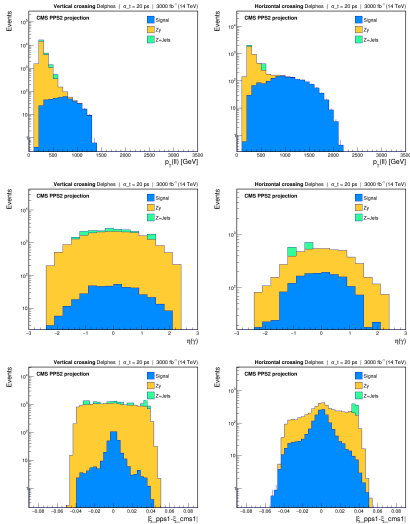


Expecting  $Z$  and  $\gamma$  to be back-to-back, reject events with  $||\Delta\phi(Z, \gamma) - \pi| > 0.1$ .

## Proton Selection

- Two protons are selected from both sides of the CMS detector.
- $\xi_{PPS} = 1 - |P_z(\text{GenProton})|/7000$ .
- $\xi$  and protons measured times are smeared by a Gaussian distribution with a mean of 0 and a standard deviation of 0.02 to account for the related PPS timing detector uncertainties.
- 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)



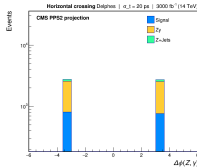
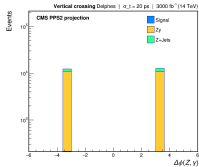
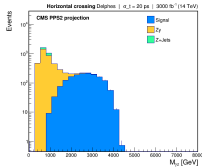
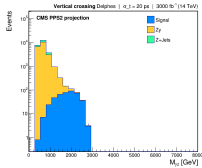
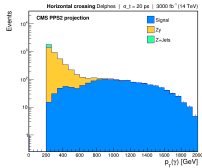
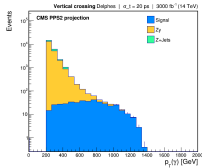
$$|\xi_{\text{cms}} - \xi_{\text{pps}}| < 0.2$$

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

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

where  $\sigma_t = 0.02 ns$ .

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



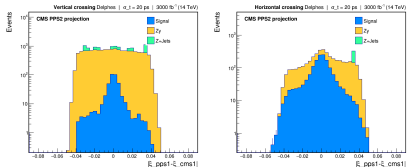
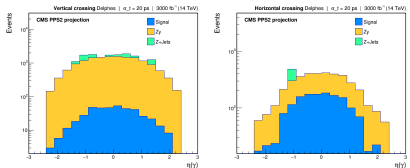
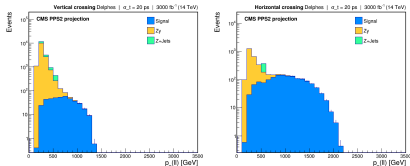
$$|\xi_{\text{cms}} - \xi_{\text{pps}}| < 2\sigma_t$$

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

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

where  $\sigma_t = 0.02 \text{ ns}$ .

# Central Object Selection (Z Vertex Cut)



**Selected Events within Z Vertex Cut for Vertical(Horizontal) crossing:**

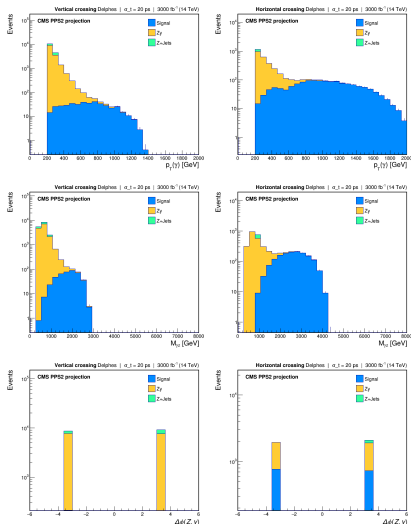
$$|Z_{\text{Vertex, cms}} - Z_{\text{Vertex, PPS}}| < 1(0.65)\text{cm}$$

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

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



# Central Object Selection (Z Vertex Cut)



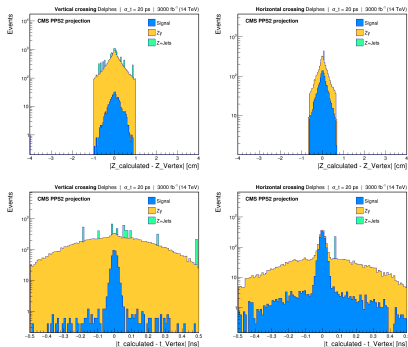
**Selected Events within Z Vertex Cut for Vertical(Horizontal) crossing:**

$$|Z_{\text{Vertex, cms}} - Z_{\text{Vertex, PPS}}| < 1(0.65)\text{cm}$$

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# Central Object Selection (Z Vertex Cut)



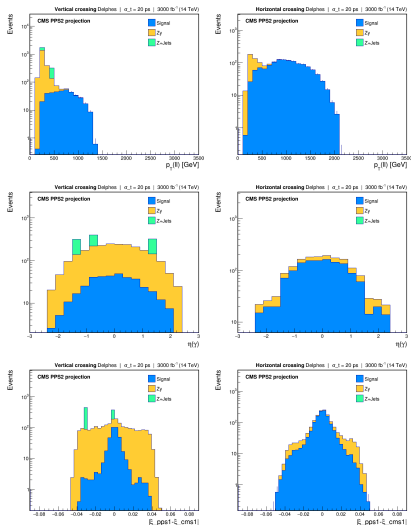
**Selected Events within Z Vertex Cut for Vertical(Horizontal) crossing:**

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# Central Object Selection (Timing Cut)



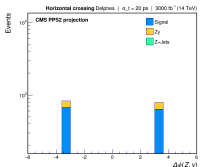
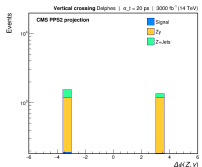
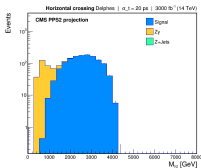
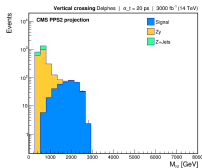
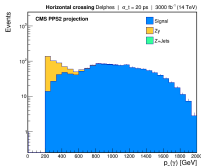
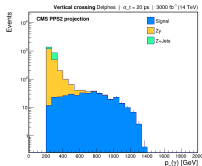
## Timing Cut Condition:

$$|t_{\text{Vertex, cms}} - t_{\text{Vertex, PPS}}| < 2\sigma_t$$

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

where  $C = 30 \text{ cm/ns}$ ,  $Z_{\text{PPS}} = 23400 \text{ cm}$ , and  $\sigma_t = 0.02 \text{ ns}$ .

# Central Object Selection (Timing Cut)



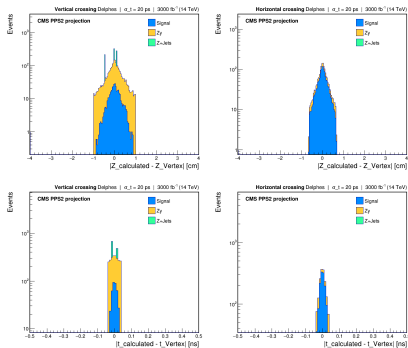
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# Central Object Selection (Timing Cut)



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where  $C = 30 \text{ cm/ns}$ ,  $Z_{\text{PPS}} = 23400 \text{ cm}$ , and  $\sigma_t = 0.02 \text{ ns}$ .

# Cut-flow tables using Loose photon selection

Crossing: Vertical, Timing Resolution: 20 ps					
NEvents	signal(non-PU)	signal(realistic)	$Z\gamma(SM)$	Z + Jet	$S/\sqrt{B}$
AllEvents	1065.0	1065.0	456000.0	181552000.0	0.079
$n_{Leptons} > 1$	992.255	992.255	357317.0	142313000.0	0.083
$p_{T,Z} > 100$ GeV	984.66	984.66	347348.0	138062000.0	0.084
$p_{T,\gamma} > 200$ GeV, $0 < \text{SumPtCharged} < 10$	813.789	813.789	145456.0	101125.0	1.639
$75 \text{ GeV} < M_Z < 110 \text{ GeV}$	761.428	761.428	139870.0	41393.9	1.788
$\Delta\phi(Z, \gamma)$	761.428	761.428	96532.1	14342.6	2.287
ProtonSelection	701.273	760.828	94265.7	13798.0	2.314
$Resolution_{\xi_{cms1}} < 0.04$	698.076	561.778	31288.1	5446.57	2.931
$Resolution_{\xi_{cms2}} < 0.04$	698.076	423.082	21442.7	3267.94	2.691
$Resolution_{ZVertex} < 1.0(0.65)cm$	687.683	420.484	14905.6	2360.18	3.2
$Resolution_{time} < 0.04ns$	684.686	376.317	1972.86	544.657	7.5

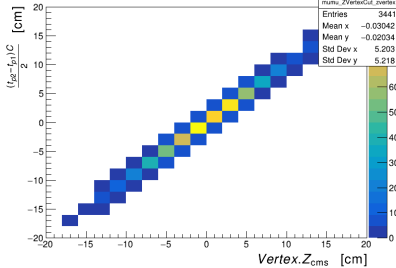
Crossing: Horizontal, Timing Resolution: 20 ps					
NEvents	signal(non-PU)	signal(realistic)	$Z\gamma(SM)$	Z + Jet	$S/\sqrt{B}$
AllEvents	7317.0	7317.0	456000.0	181552000.0	0.542
$n_{Leptons} > 1$	6732.08	6732.08	357317.0	142313000.0	0.564
$p_{T,Z} > 100$ GeV	6710.27	6710.27	347348.0	138062000.0	0.57
$p_{T,\gamma} > 200$ GeV, $0 < \text{SumPtCharged} < 10$	5601.02	5601.02	145456.0	101125.0	11.279
$75 \text{ GeV} < M_Z < 110 \text{ GeV}$	5195.36	5195.36	139870.0	41393.9	12.203
$\Delta\phi(Z, \gamma)$	5186.58	5186.58	96532.1	14342.6	15.576
ProtonSelection	2728.66	5163.75	95272.7	13979.5	15.622
$Resolution_{\xi_{cms1}} < 0.04$	2603.83	2227.29	18216.9	2904.84	15.325
$Resolution_{\xi_{cms2}} < 0.04$	2594.61	1575.94	3560.17	363.104	25.16
$Resolution_{ZVertex} < 1.0(0.65)cm$	2264.03	1497.79	2369.07	181.552	29.657
$Resolution_{time} < 0.04ns$	2251.15	1309.01	308.383	0.0	74.541

## Backup Slides

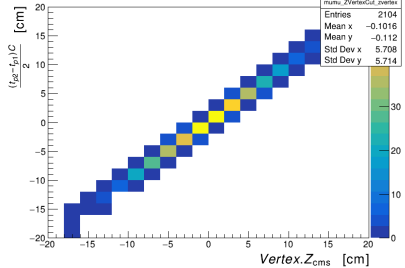
Some additional plots for validating the analysis strategy, provided using signal samples(both non-pileup and realistic) for vertical and horizontal crossings after mentioned cut on Vertex.Z.

# Additional Plots(Vertex.Z)

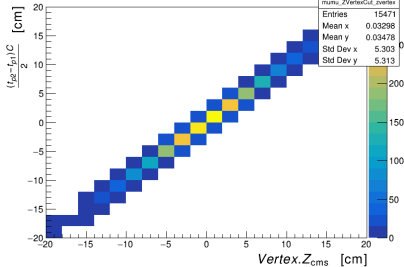
signal1, Vertical, noPU



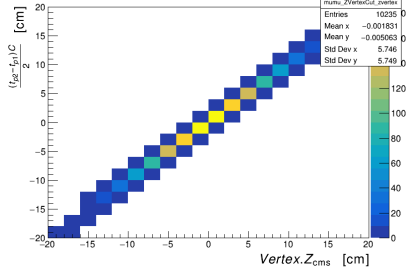
signal1, Vertical, PU



signal1, Horizontal, noPU



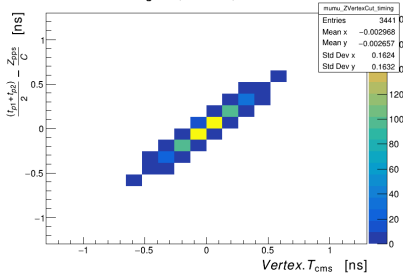
signal1, Horizontal, PU



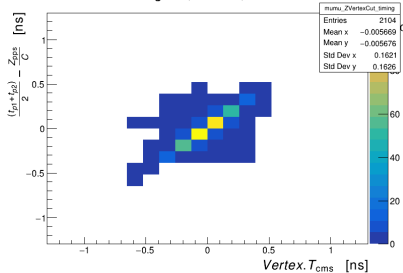


# Additional Plots(Vertex.t)

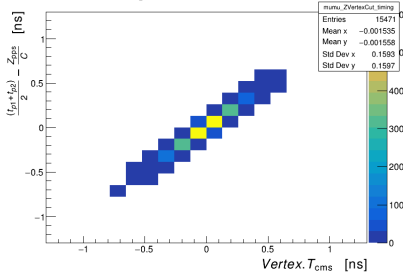
signal1, Vertical, noPU



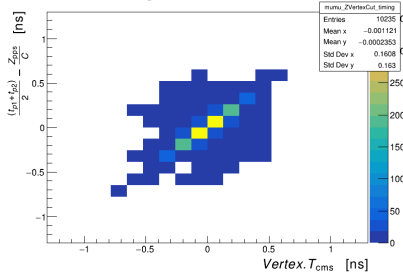
signal1, Vertical, PU



signal1, Horizontal, noPU

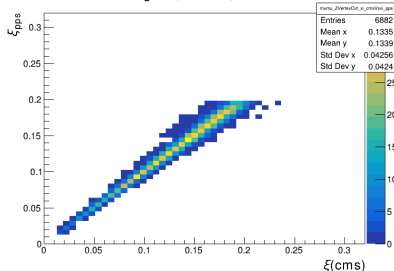


signal1, Horizontal, PU

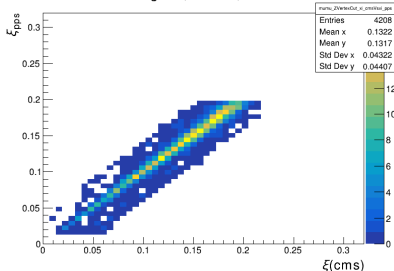


# Additional Plots for cut Validation( $\xi$ )

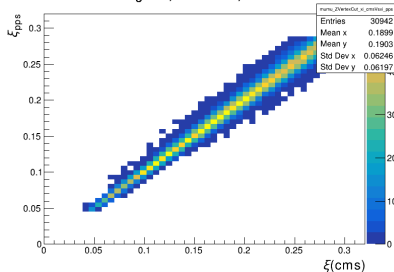
signal1, Vertical, noPU



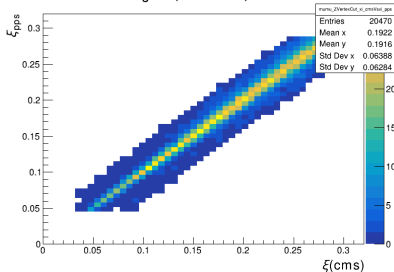
signal1, Vertical, PU



signal1, Horizontal, noPU

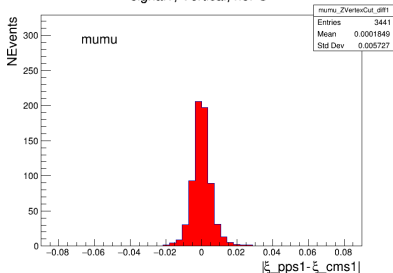


signal1, Horizontal, PU

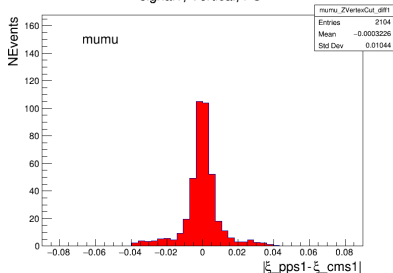


# Additional Plots( $\xi$ Resolution)

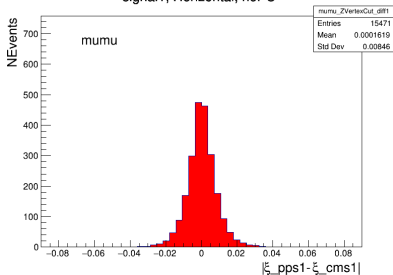
signal1, Vertical, noPU



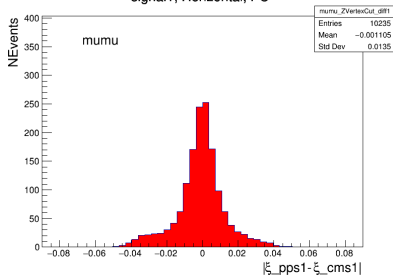
signal1, Vertical, PU



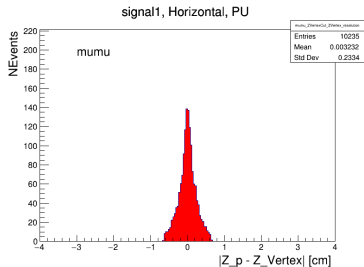
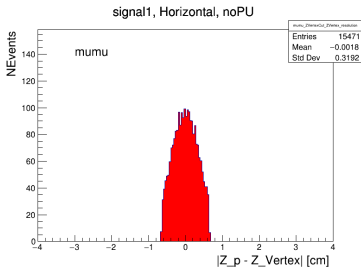
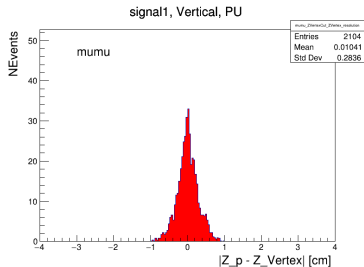
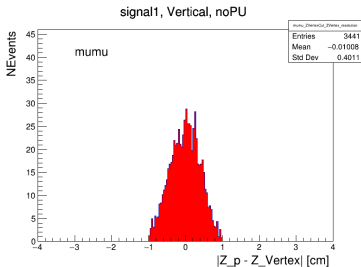
signal1, Horizontal, noPU



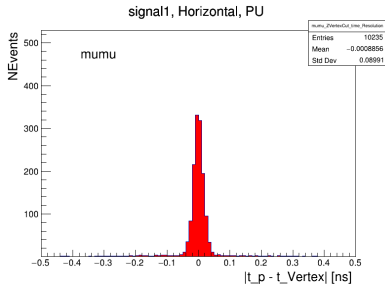
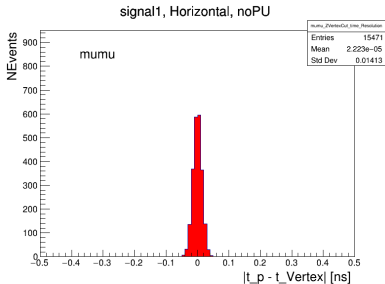
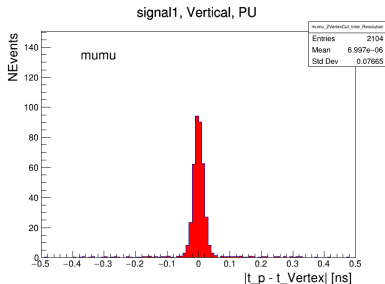
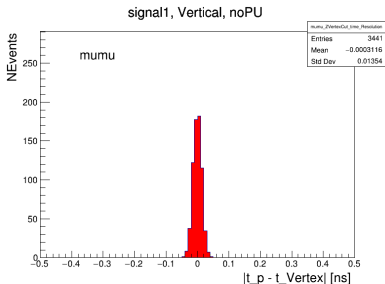
signal1, Horizontal, PU



# Additional Plots for cut Validation(Vertex.Z)



# Additional Plots for cut Validation(Vertex.T)



# Additional Plots (PhotonLoose.SumPtCharged)

We selected the cut of  $\text{PhotonLoose.SumPtCharged} > 5$ .

$\text{PhotonLoose.SumPtCharged}[0] \{ \text{PhotonLoose\_size} > 0 \}$

