

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

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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 ~ 210 m with respect to the main interaction vertex.

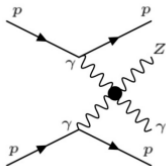
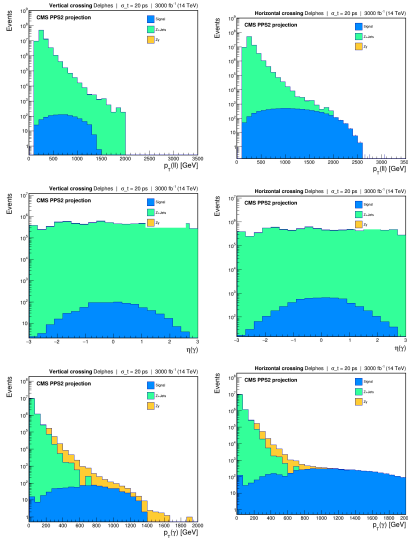


Table of Signal and Background Cross Sections

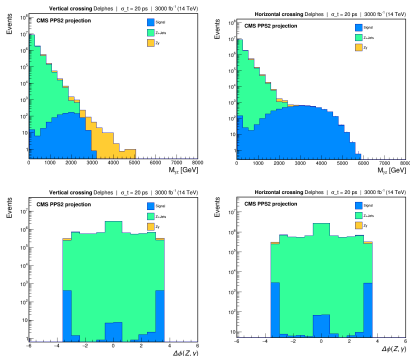
Signal/Background	Process	σ (pb)
Signal, Vertical ϵ	FPMC bSM 14TeV AAAAzeft A1A 0E0 A2A 1E-13 pt50-noHADR 3.556E-4 Zmumu.root	3.55e-4
Signal, Horizontal ϵ	FPMC bSM 14TeV AAAAzeft A1A 0E0 A2A 1E-13 pt50 horXing-noHADR 2.439E-3 Zmumu Delphes PU200.root	2.439e-3
SM Zy background	Zgamma_inc_SM_Madgraph5_PhotonPT200GeV_Delphes_PU200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

Central Object Selection (Muon Selection)



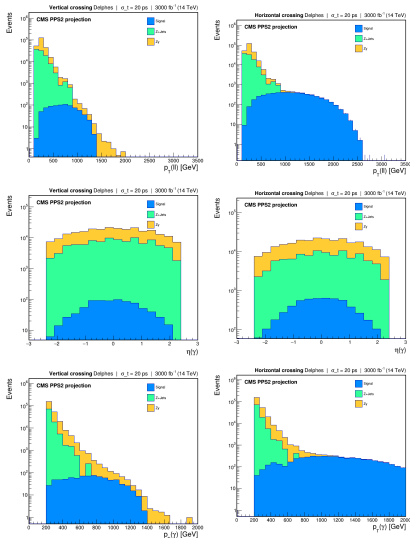
Two same flavor, oppositely signed charged leptons (Muons) with loose criteria, $\eta < 2.4$.
 $p_{T_Z} > 100$ GeV.

Central Object Selection (Muon Selection)



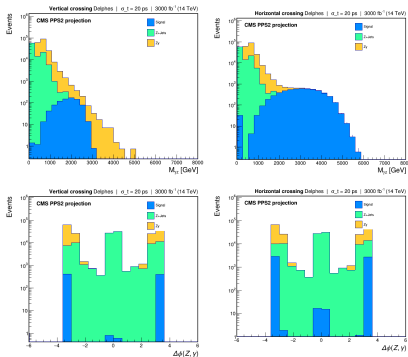
Two same flavor, oppositely signed charged leptons (Muons) with loose criteria, $\eta < 2.4$.
 $p_{TZ} > 100 \text{ GeV}$.

Central Object Selection (Photon Selection)



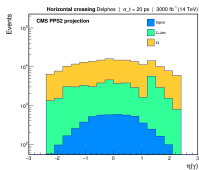
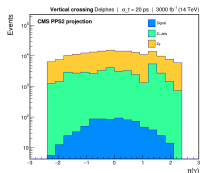
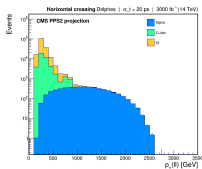
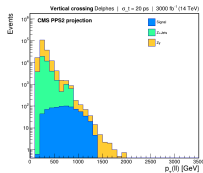
- $p_{T\gamma} > 200 \text{ GeV}$
- Loose criteria and $\eta < 2.4$
- Rejecting photons with:
 - $\text{SumPtCharged} > 5$
 - $\text{SumPtCharged} < 0$

Central Object Selection (Photon Selection)

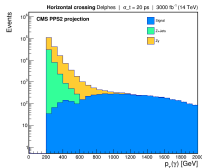
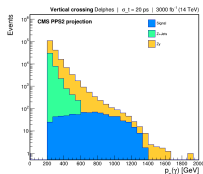


- $p_{T_\gamma} > 200$ GeV
- Loose criteria and $\eta < 2.4$
- Rejecting photons with:
 - SumPtCharged > 5
 - SumPtCharged < 0

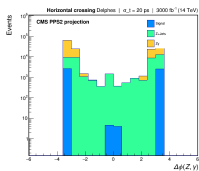
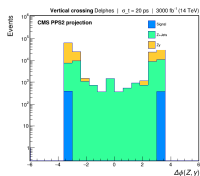
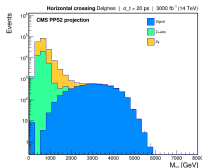
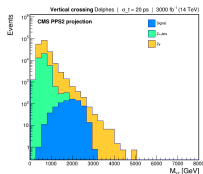
Central Object Selection (Z-boson mass)



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

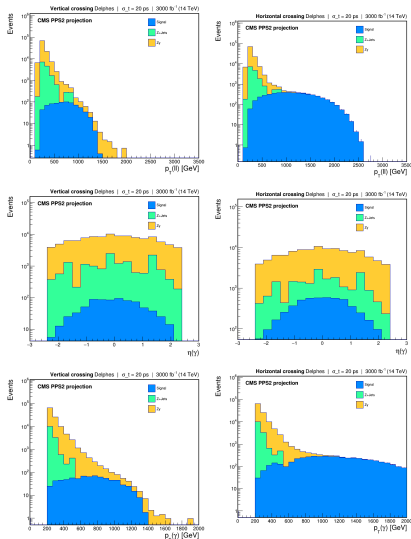


Central Object Selection (Z-boson mass)



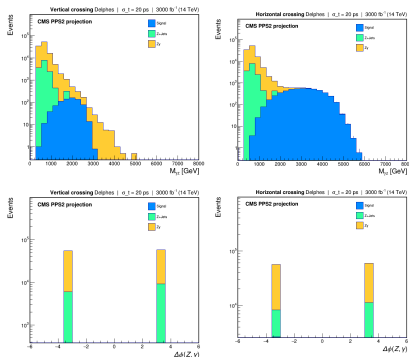
Reject events with
 $|M_Z - 90 \text{ GeV}| > 15 \text{ GeV}$.

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



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

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

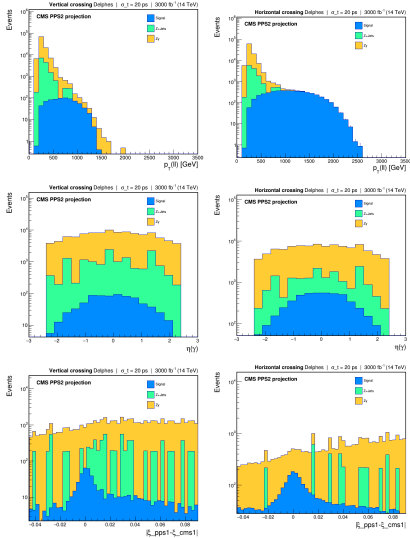


Expecting Z and γ to be back-to-back, reject events with $||\Delta\phi(Z, \gamma) - \pi| > 0.1$.

Proton Selection

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

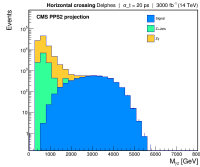
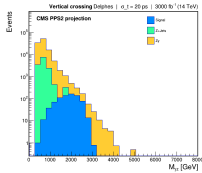
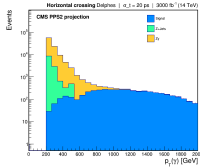
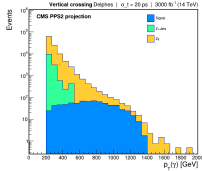


$$|\xi_{\text{cms}} - \xi_{\text{pps}}| < 0.2$$

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

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

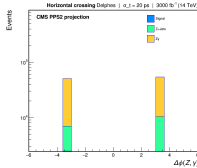
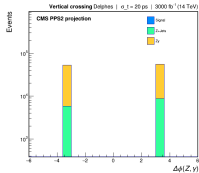
Central Object Selection (ξ Resolution Cut)



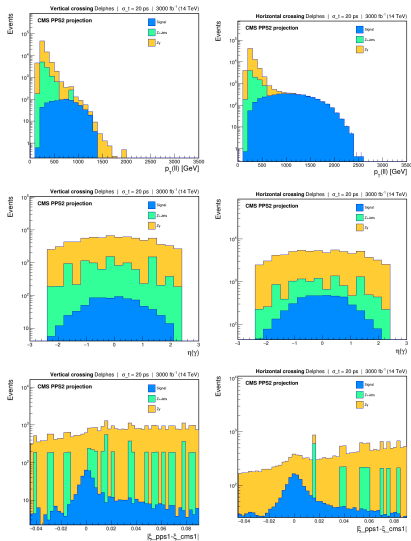
$$|\xi_{\text{cms}} - \xi_{\text{pps}}| < 0.2$$

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



Central Object Selection (Z Vertex Cut)



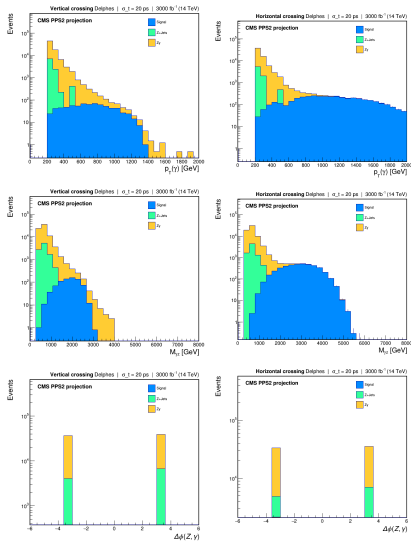
Selected Events within Z Vertex Cut for Vertical(Horizontal) crossing:

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

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

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

Central Object Selection (Z Vertex Cut)



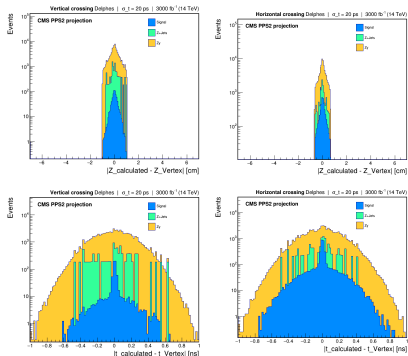
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Central Object Selection (Z Vertex Cut)



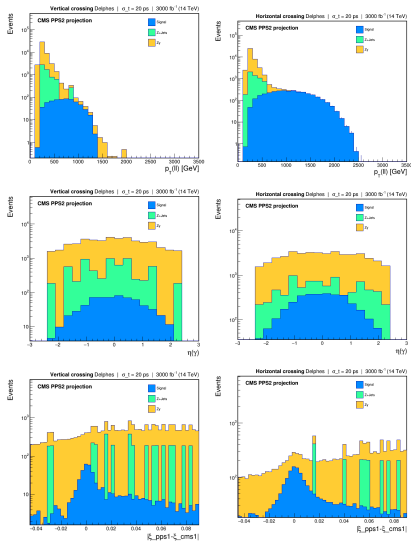
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where $C = 30 \text{ cm/ns}$.

Central Object Selection (Timing Cut)



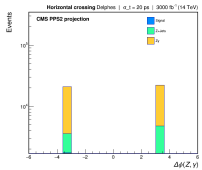
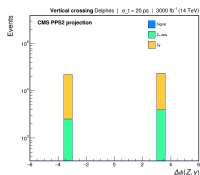
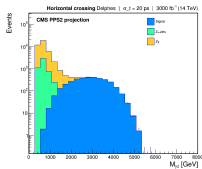
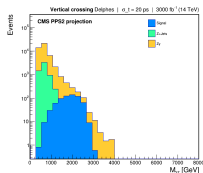
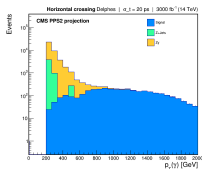
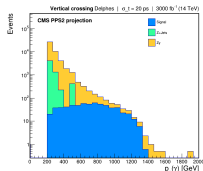
Timing Cut Condition:

$$|t_{\text{Vertex, cms}} - t_{\text{Vertex, PPS}}| < 0.2$$

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

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

Central Object Selection (Timing Cut)



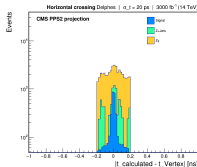
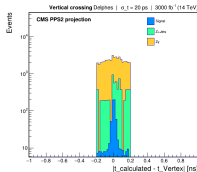
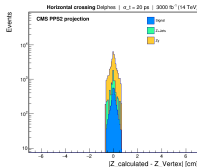
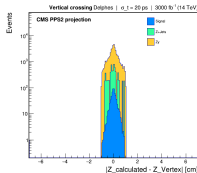
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where $C = 30 \text{ cm/ns}$ and $Z_{ppss} = 23400 \text{ cm}$.

Central Object Selection (Timing Cut)



Timing Cut Condition:

$$|t_{\text{Vertex, cms}} - t_{\text{Vertex, PPS}}| < 0.2$$

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

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

Cut-flow tables using Loose photon selection

Crossing: Vertical, Timing Resolution: 20 ps					
NEvents	signal(no 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, $0 < \text{textSumPtCharged} < 10$	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
$Resolution_{\xi_{cms1}} < 0.2$	701.273	760.828	94265.2	13798.0	2.314
$Resolution_{\xi_{cms2}} < 0.2$	701.273	760.828	94262.0	13798.0	2.314
$Resolution_{ZVertex} < 1.0(0.65)$	690.881	747.439	65454.4	9985.37	2.721
$Resolution_{time} < 0.2ns$	690.881	646.714	39149.8	5809.67	3.05

Crossing: Horizontal, Timing Resolution: 20 ps					
NEvents	signal(no 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, $0 < \text{extSumPtCharged} < 10$	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
$Resolution_{\xi_{cms1}} < 0.2$	2728.66	5129.07	87027.0	12527.1	16.256
$Resolution_{\xi_{cms2}} < 0.2$	2728.66	4900.34	86978.2	12527.1	15.535
$Resolution_{ZVertex} < 1.0(0.65)$	2381.1	4266.98	57603.1	7625.19	16.707
$Resolution_{time} < 0.2ns$	2381.1	3398.89	34695.7	4901.91	17.081

Cut-flow tables using Tight photon selection

Crossing: Vertical, Timing Resolution: 20 ps					
NEvents	signal(no 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, $0 < \text{textSumPtCharged} < 10$	654.908	654.908	110631.0	75162.6	1.519
$75 \text{ GeV} < M_Z < 110 \text{ GeV}$	612.94	612.94	106380.0	31771.6	1.649
$\Delta\phi(Z, \gamma)$	612.54	612.54	73422.9	11982.4	2.096
ProtonSelection	562.777	612.34	71692.2	11437.8	2.124
$Resolution_{\epsilon_{cms1}} < 0.2$	562.777	612.34	71691.5	11437.8	2.124
$Resolution_{\epsilon_{cms2}} < 0.2$	562.777	612.34	71688.5	11437.8	2.124
$Resolution_{ZVertex} < 1.0(0.65)$	553.784	601.148	49847.4	8169.85	2.496
$Resolution_{time} < 0.2ns$	553.784	518.81	29817.6	5083.46	2.777

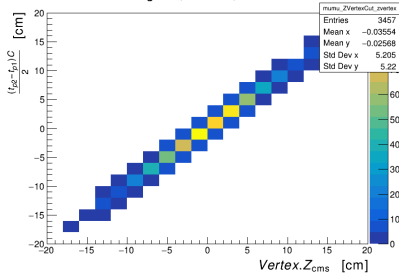
Crossing: Horizontal, Timing Resolution: 20 ps					
NEvents	signal(no PU)	signal(realistic)	$Z\gamma(SM)$	Z + Jet	S/\sqrt{B}
AllEvents	7317.0	7317.0	456000.0	181552000.0	0.542
$n_{Leptons} > 1$	6732.08	6732.08	357317.0	142313000.0	0.564
$p_{T,Z} > 100$ GeV	6710.27	6710.27	347348.0	138062000.0	0.57
$p_{T,\gamma} > 200$ GeV, $0 < \text{extSumPtCharged} < 10$	4549.71	4549.71	110631.0	75162.6	10.555
$75 \text{ GeV} < M_Z < 110 \text{ GeV}$	4204.06	4204.06	106380.0	31771.6	11.311
$\Delta\phi(Z, \gamma)$	4192.2	4192.2	73422.9	11982.4	14.345
ProtonSelection	2206.51	4174.64	72450.4	11619.3	14.398
$Resolution_{\epsilon_{cms1}} < 2\sqrt{2}$	2206.51	4146.4	66154.7	10530.0	14.973
$Resolution_{\epsilon_{cms2}} < 2\sqrt{2}$	2206.51	3964.06	66116.8	10530.0	14.318
$Resolution_{ZVertex} < 2\sqrt{2} \times 20ps \times C$	1925.83	3451.58	43841.0	6172.77	15.434
$Resolution_{time} < 2\sqrt{2} \times 20ps$	1925.83	2746.22	26388.7	4357.25	15.662

Backup Slides

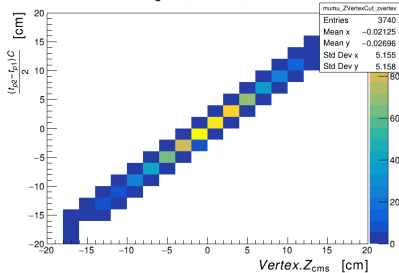
Some additional plots for validating the analysis strategy, provided using signal samples(both non-pileup and realistic) for vertical and horizontal crossings after mentioned cut on Vertex.Z.

Additional Plots(Vertex.Z)

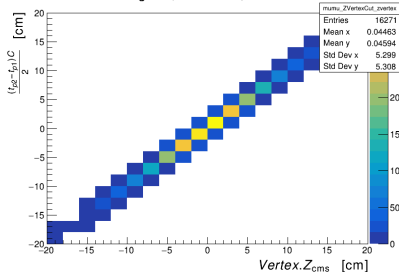
signal1, Vertical, noPU



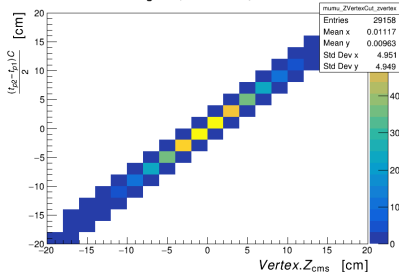
signal1, Vertical, PU



signal1, Horizontal, noPU

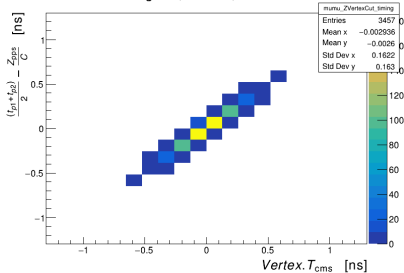


signal1, Horizontal, PU

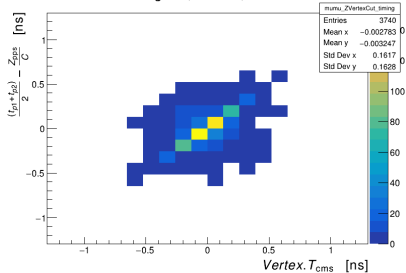


Additional Plots(Vertex.t)

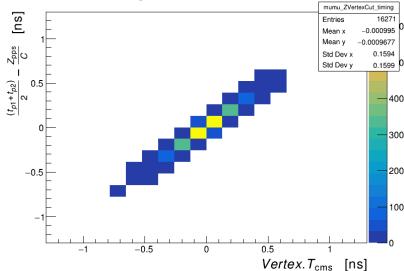
signal1, Vertical, noPU



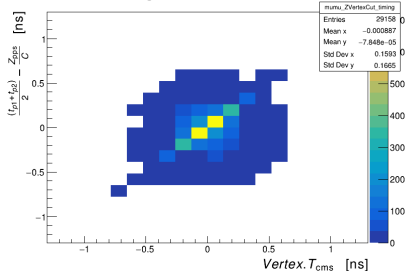
signal1, Vertical, PU



signal1, Horizontal, noPU

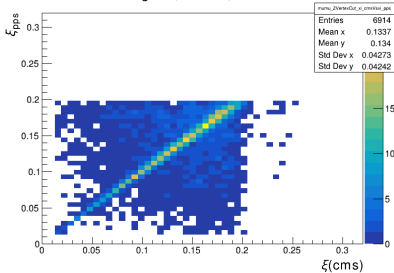


signal1, Horizontal, PU

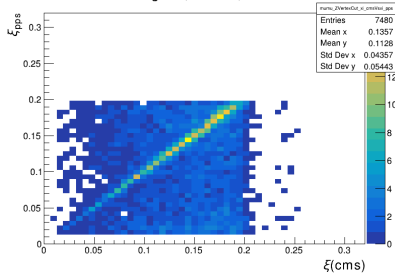


Additional Plots for cut Validation(xi)

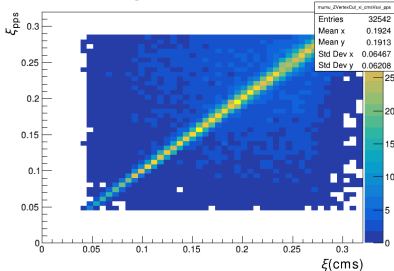
signal1, Vertical, noPU



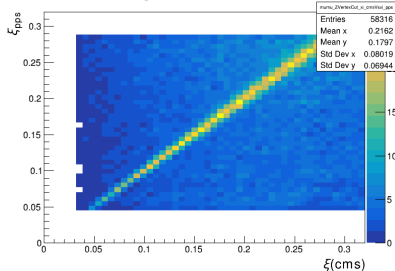
signal1, Vertical, PU



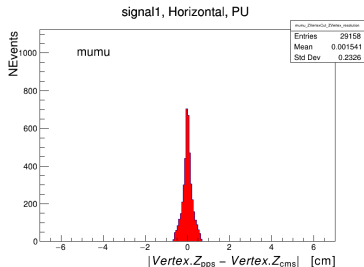
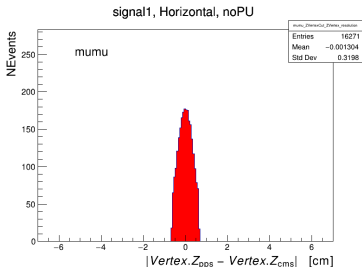
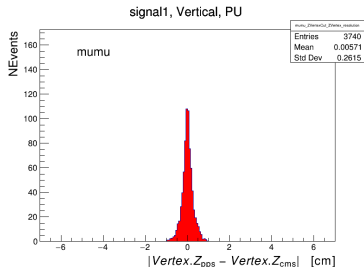
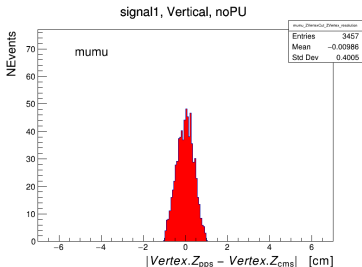
signal1, Horizontal, noPU



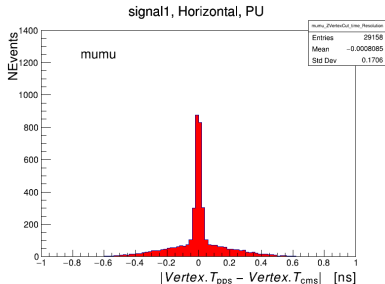
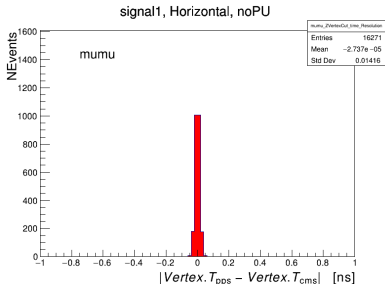
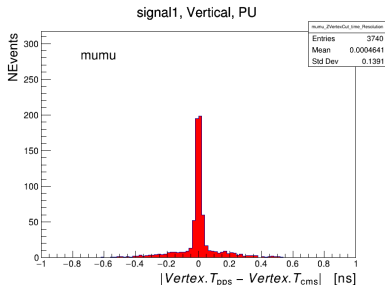
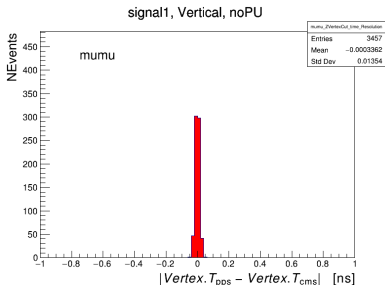
signal1, Horizontal, PU



Additional Plots for cut Validation(Vertex.Z)



Additional Plots for cut Validation(Vertex.T)



Additional Plots (PhotonLoose.SumPtCharged)

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

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

