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

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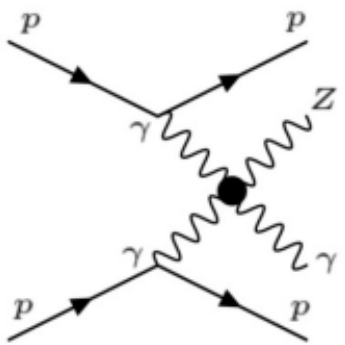
Institute For Research In Fundamental Science (IPM)

Proton POG Meeting

Exclusive Production of $\gamma\gamma \to \gamma Z$ 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 four Roman Pots (RP) in the forward proton detectors (PPS) located at different positions, approximately 210 m from the main interaction vertex.
- This interaction is driven by energetic photon-photon collisions, therefore result in a high p_T photon and Z boson.

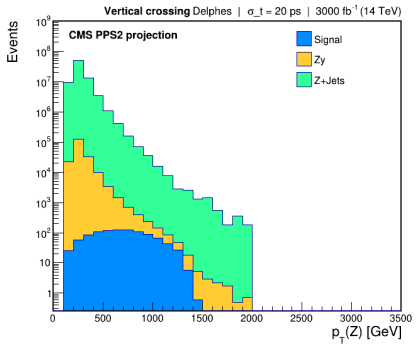


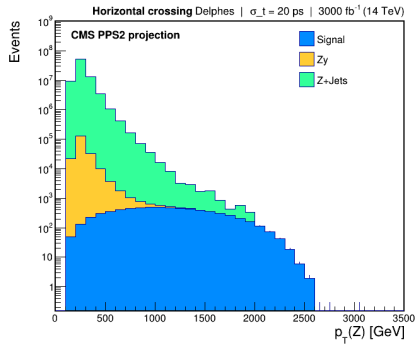
MC Samples

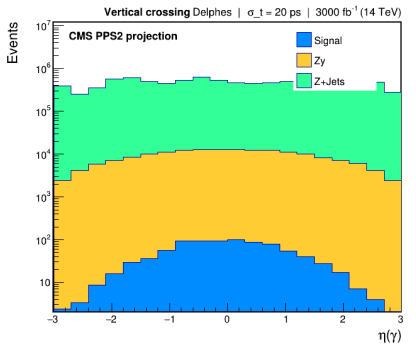
Signal/Background	Process	σ (pb)	Number of Events
Signal, Vertical	FPMC bSM 14TeV AAAAzeft A1A 0E0 A2A 1E-13 pt50-noHADR 3.556E-4 Zmumu.root	3.55e-4	5329
Signal, Horizontal	FPMC bSM 14TeV AAAAzeft A1A 0E0 A2A 1E-13 pt50 horXing-noHADR 2.439E-3 Zmumu Delphes PU200.root	2.439e-3	50000
SM Zy background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

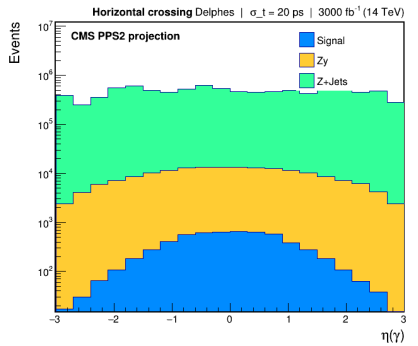
- The variables A1A and A2A represent coefficients of anomalous couplings in the EFT. In these samples, A1A is set to 0, and A2A is set to 1×10^{-13} for the exclusive production of $\gamma\gamma \rightarrow \gamma Z$.
- The samples were produced using FPMC and MadGraph, and were then passed through Delphes for detector simulation.

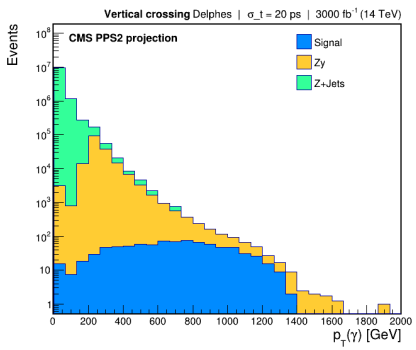
Central Object Selection (Muon Selection)

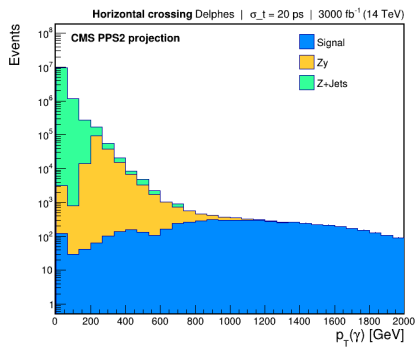












Two same flavor, oppositely signed charged leptons(Muons) with loose criteria, $\eta < 2.4$.
$p_{T_Z} > 100$ GeV.

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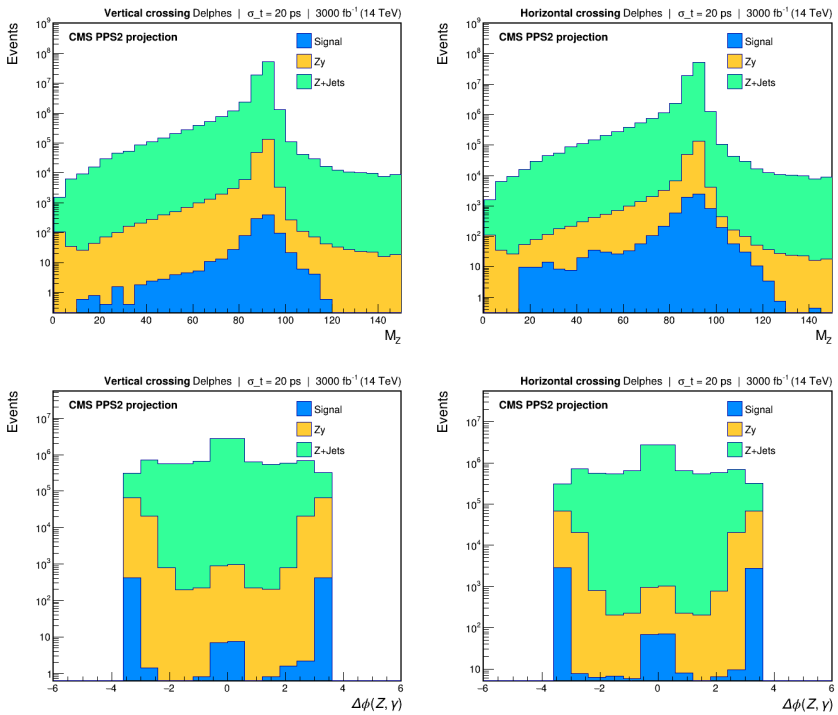

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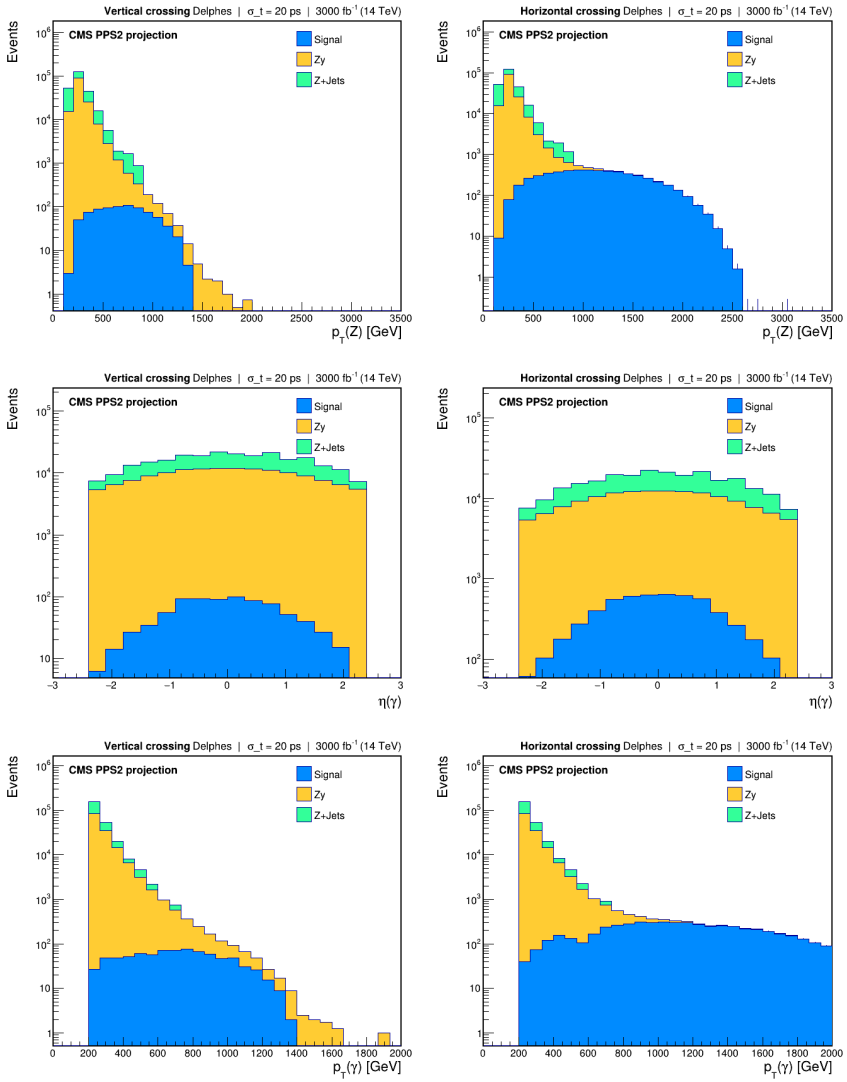
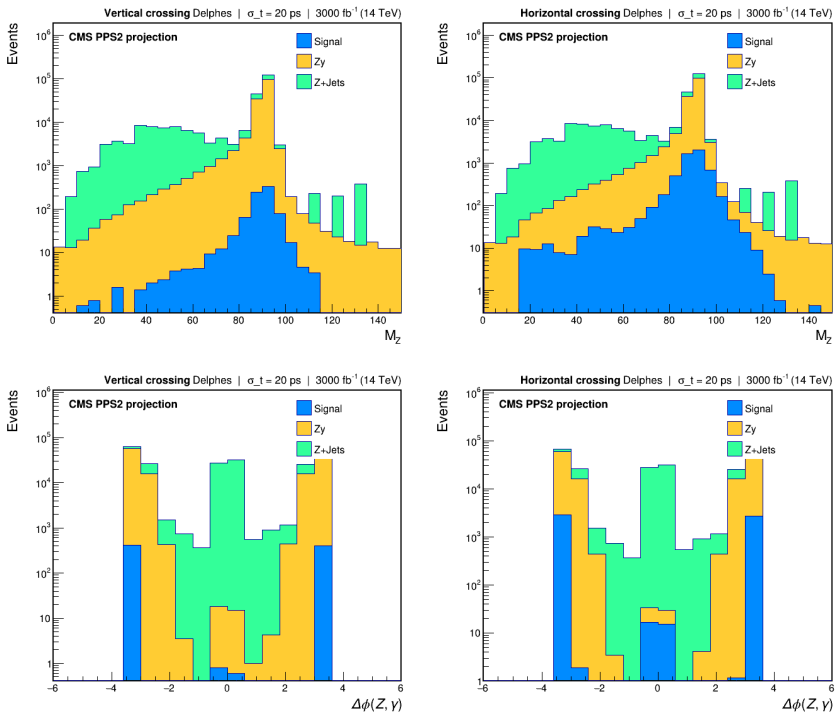
Central Object Selection (Photon Selection)



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

Central Object Selection (Photon Selection)



- $p_{T_\gamma} > 200\,\text{GeV}$
- Loose criteria and $\eta < 2.4$
- Rejecting photons with:
  - SumPtCharged > 5
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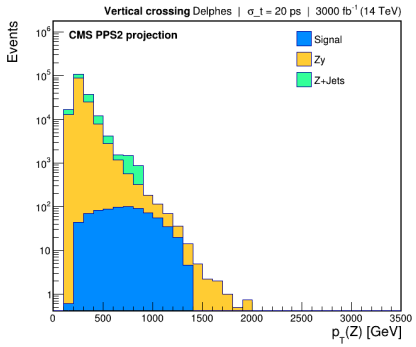
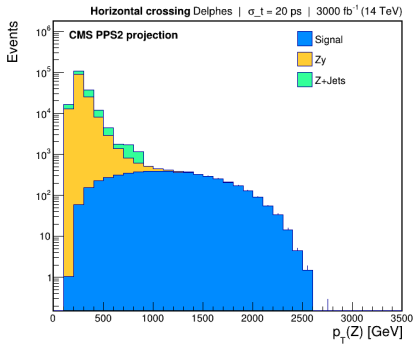
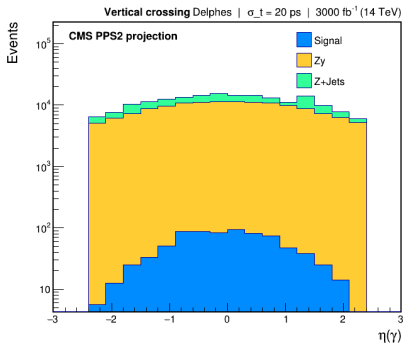
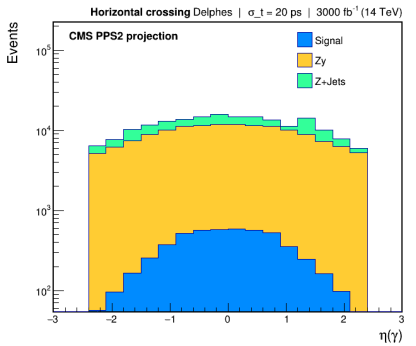
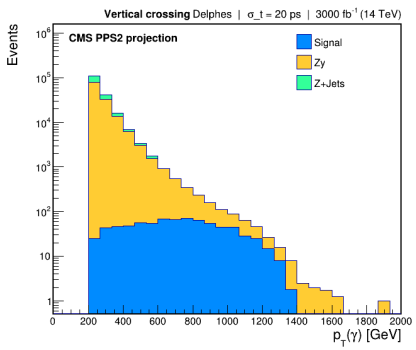
Central Object Selection (Z-boson mass)

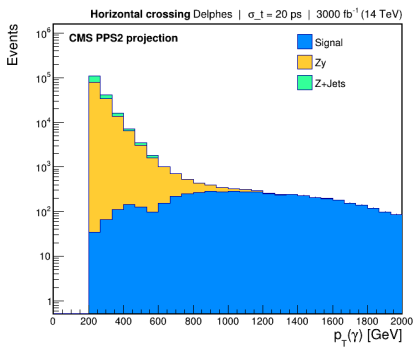












Reject events with $|M_Z - 90\,\text{GeV}| > 15\,\text{GeV}$.

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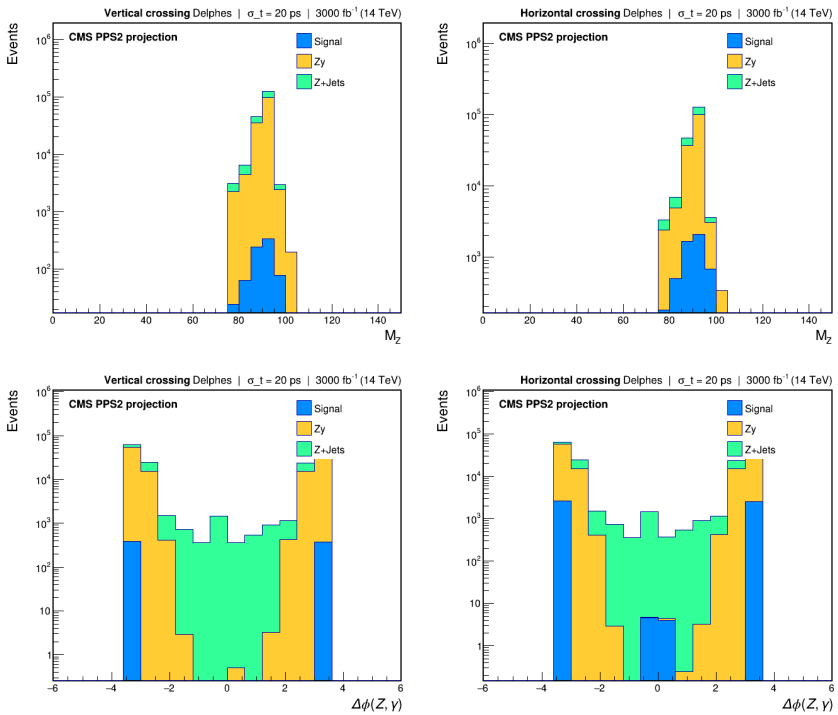
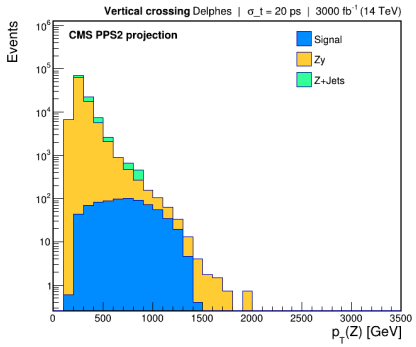
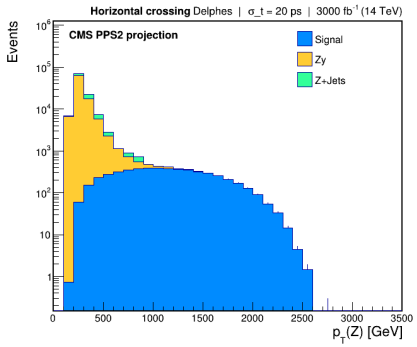
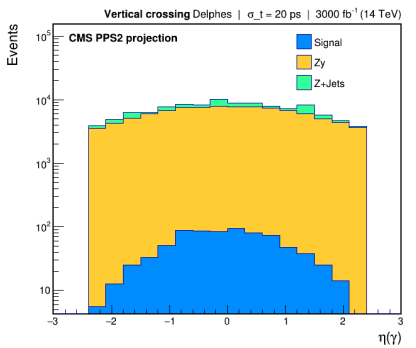


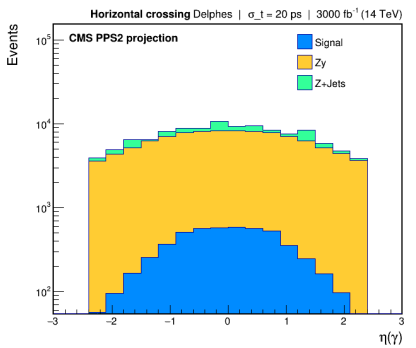
Reject events with $|M_Z - 90\,\text{GeV}| > 15\,\text{GeV}$.

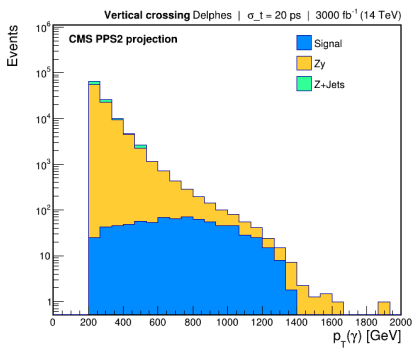
Central Object Selection ($\Delta\phi(Z,\gamma)$)

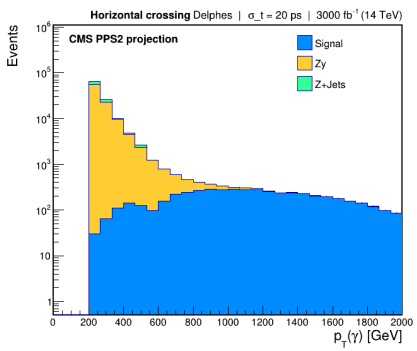






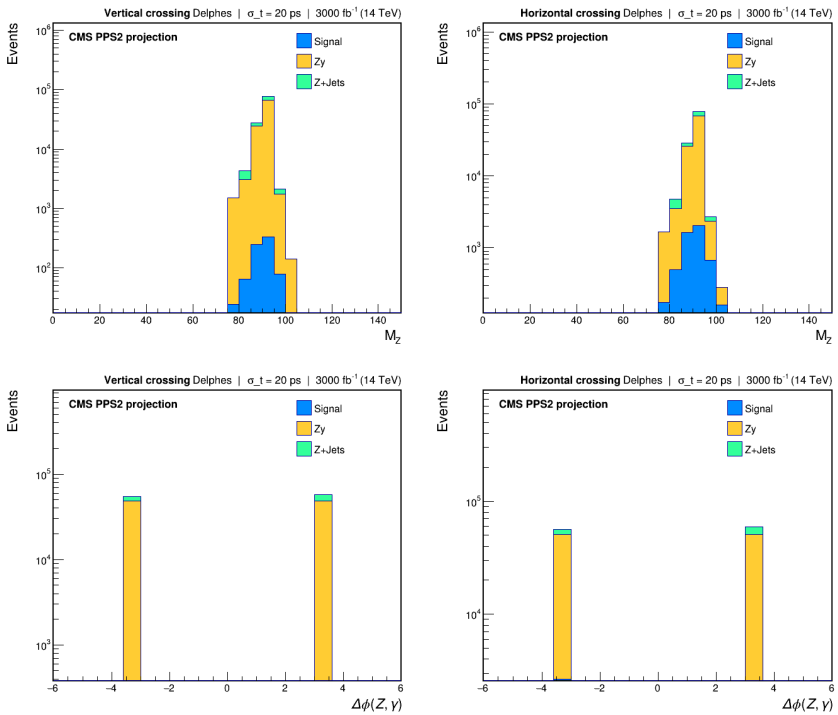






Expecting Z and γ to be back-to-back, reject events with $||\Delta\phi(Z,\gamma)| - \pi| > 0.1$.

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



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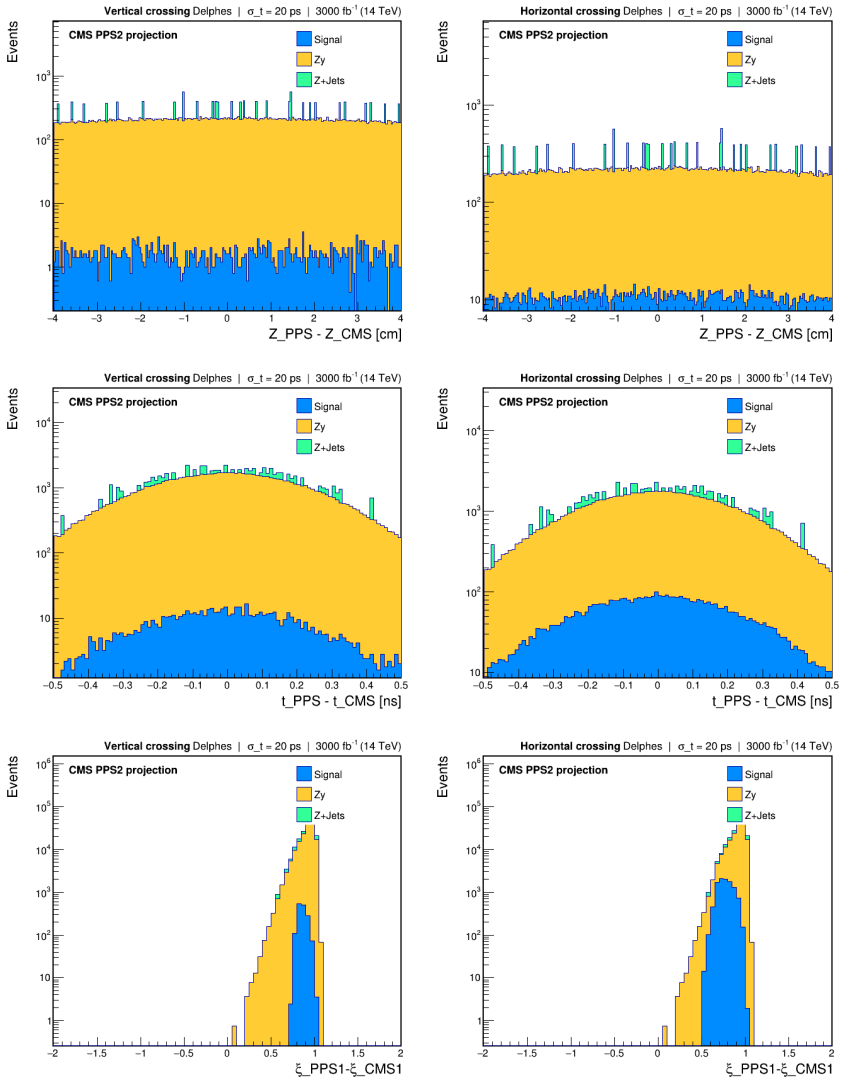

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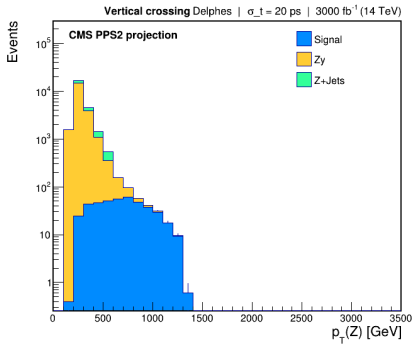
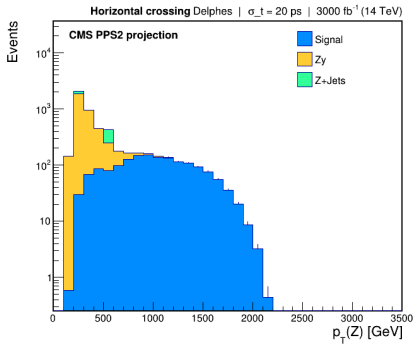
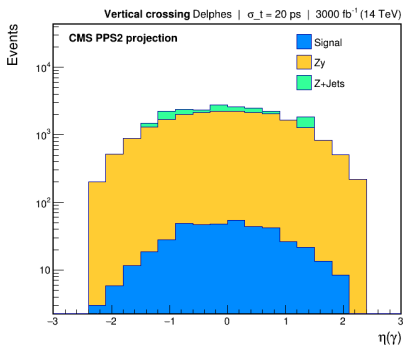
Proton Selection

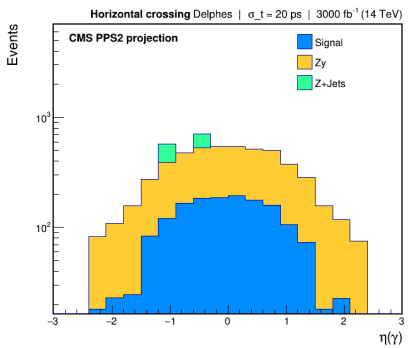
- Two protons are selected from opposite sides of the CMS detector.
- $\xi_{PPS} = 1 - |P_z(\text{GenProton})|/7000$.
- ξ and protons measured times are smeared by a Gaussian distribution with a mean of 0 and a standard deviation of 0.02 to account for the related PPS timing detector uncertainties.
- PPS acceptance:
  - $0.0147 < \xi_{\text{vertical}} < 0.196$
  - $0.0472 < \xi_{\text{horizontal}} < 0.287$
- To mitigate PU as much as possible, two protons with the smallest $|Z_{\text{Vertex, CMS}} - Z_{\text{Vertex, PPS}}|$ are selected.

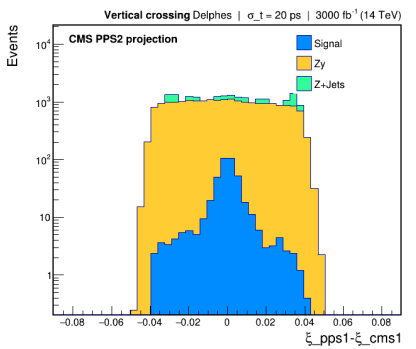
Central Object Selection (ξ Resolution Cut)

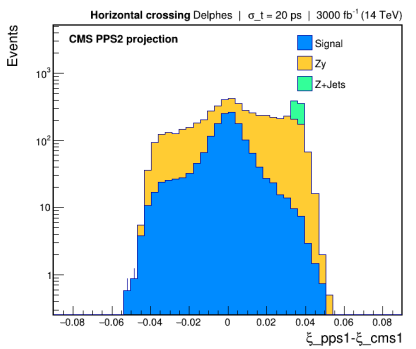












$$|\xi_{\mathrm{CMS}} - \xi_{\mathrm{PPS}}| < 2\sigma_t$$

$$\xi_{CMS1} = \frac{\sum_{i=l^+,l^-,\gamma}(E_i + |P_{z_i}|)}{\sqrt{s}},$$

$$\xi_{CMS2} = \frac{\sum_{i=l^+,l^-,\gamma}(E_i - |P_{z_i}|)}{\sqrt{s}},$$

where $\sigma_t = 0.02ns$.

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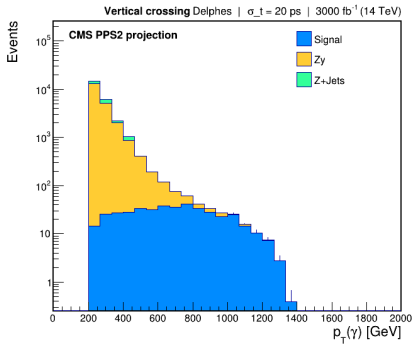

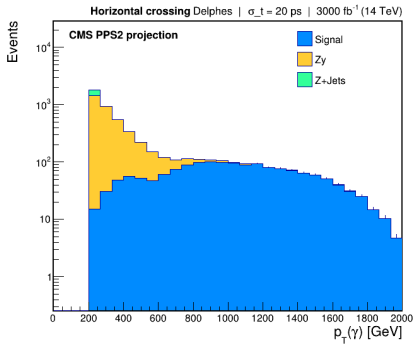

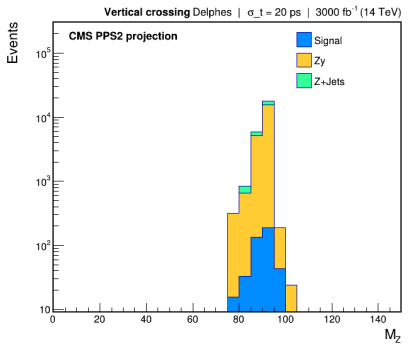

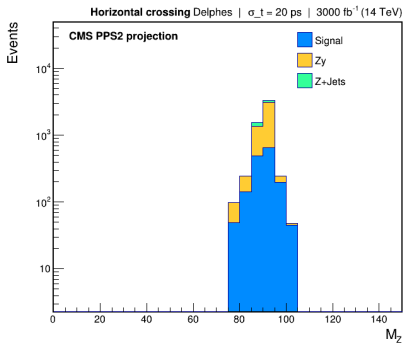

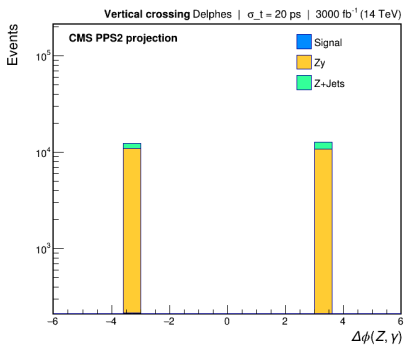

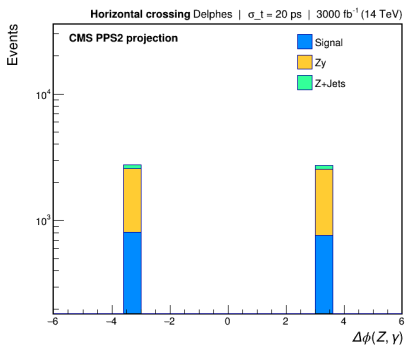

$$|\xi_{\mathrm{CMS}} - \xi_{\mathrm{pps}}| < 2\sigma_t$$

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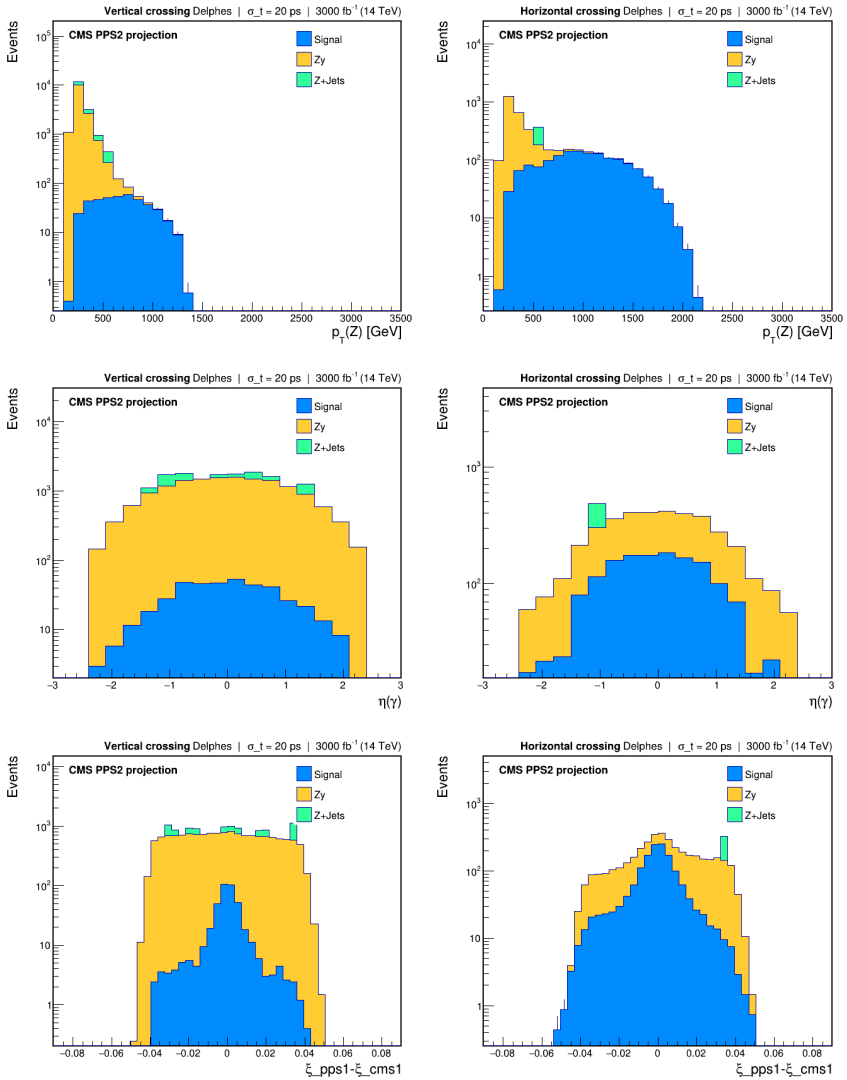
where $\sigma_t = 0.02ns$.

Central Object Selection (Vertex.Z Cut)



Selected Events within Vertex.Z 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 $C = 30\,\text{cm/ns}$.

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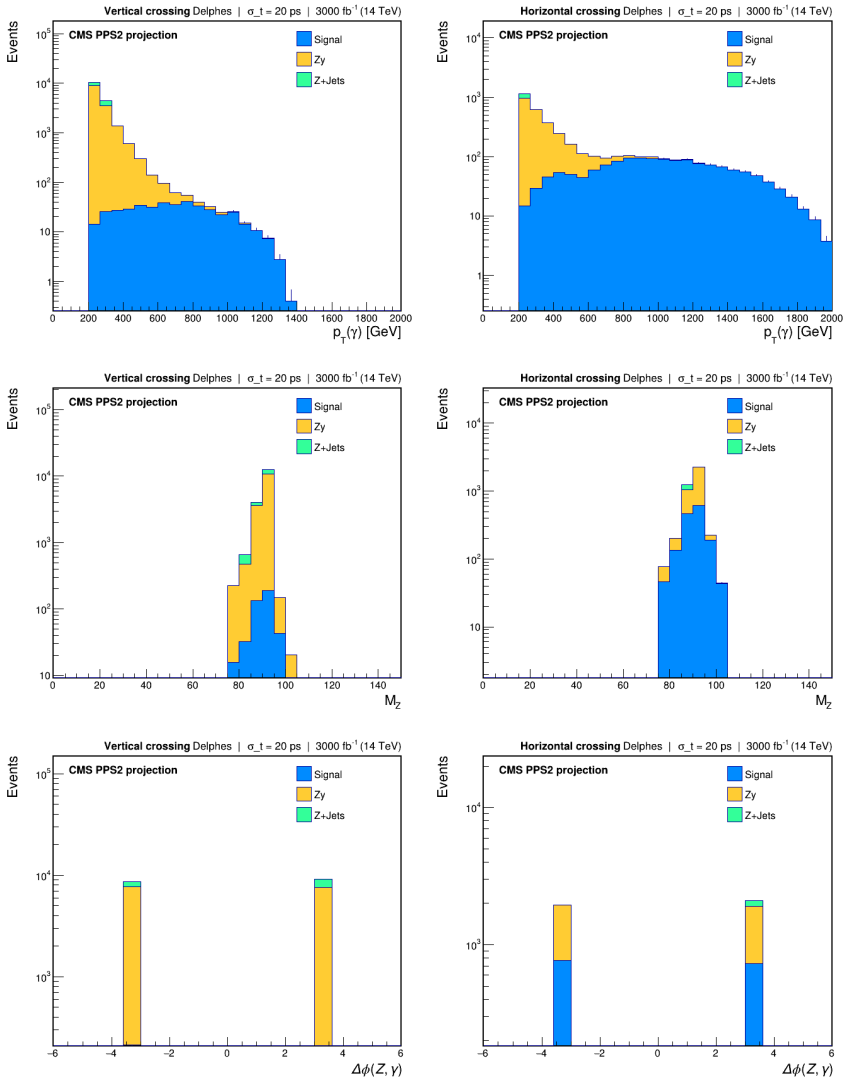

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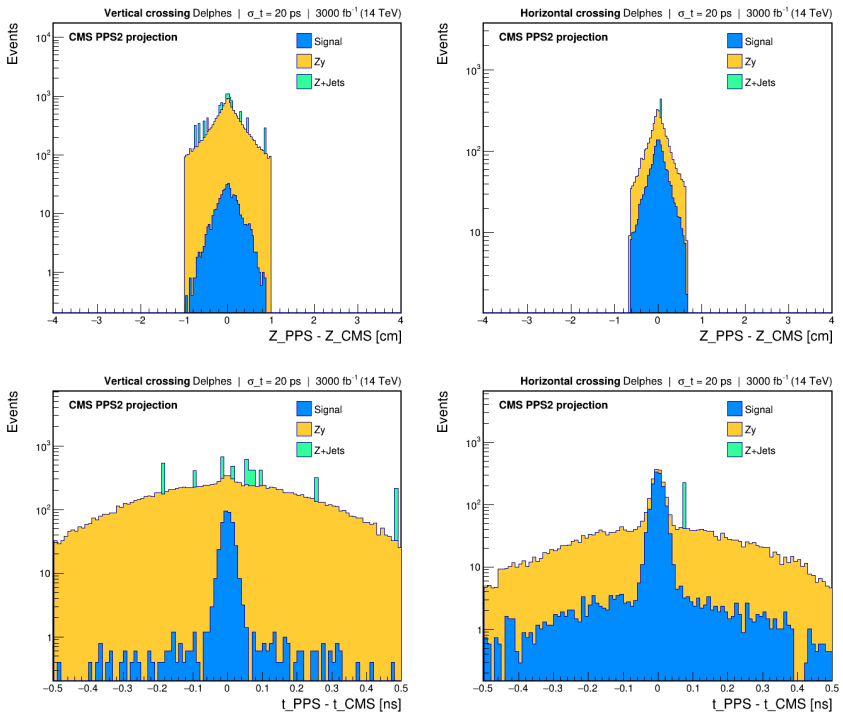

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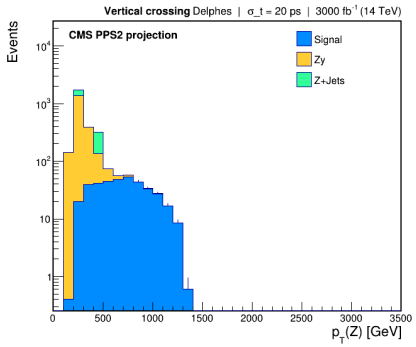
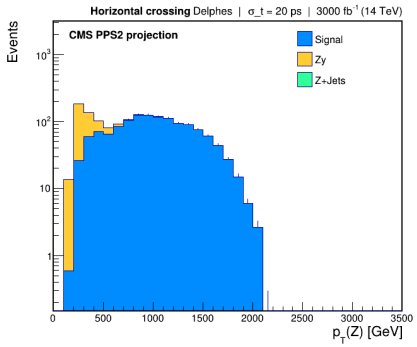
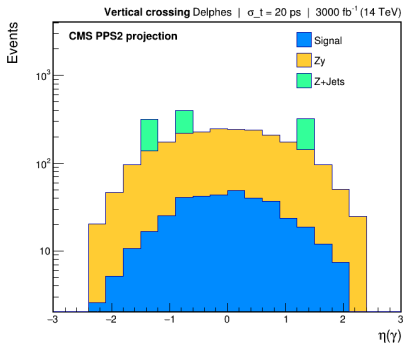
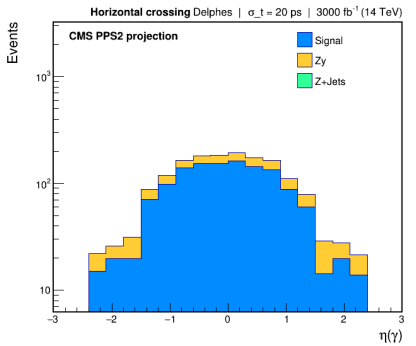
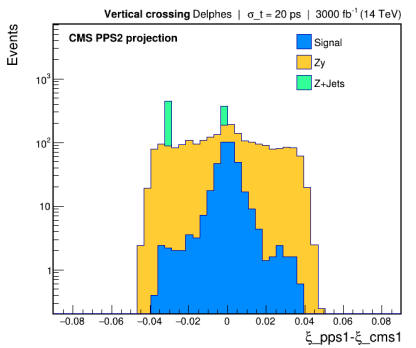
Central Object Selection (Timing Cut)

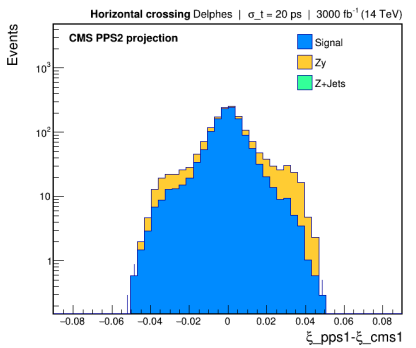












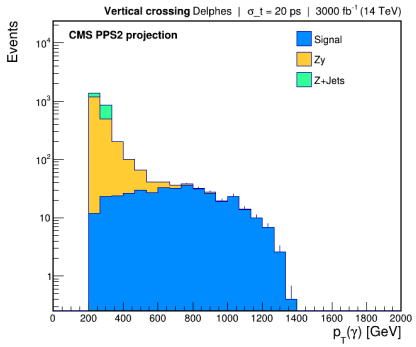
Timing Cut Condition:

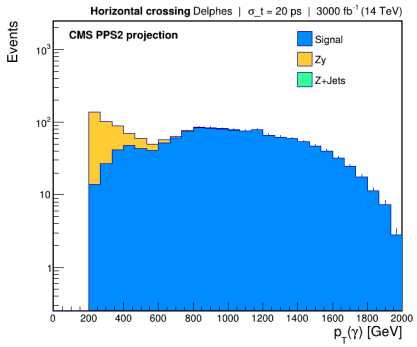
$$\left|t_{\text{Vertex, CMS}} - t_{\text{Vertex, PPS}}\right| < 2\sigma_t$$

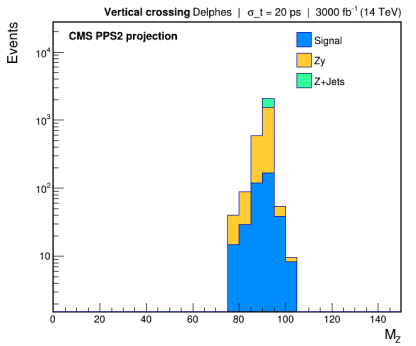
$$t_{\text{Vertex, PPS}} = \frac{(t_{p1} + t_{p2})}{2} - \frac{Z_{\text{PPS}}}{C}$$

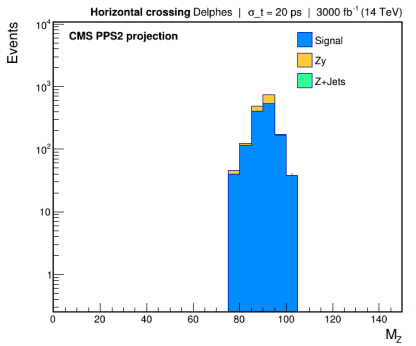
where $C = 30\,\text{cm/ns}$, $Z_{\text{PPS}} = 23400\,\text{cm}$, and $\sigma_t = 0.02\,\text{ns}$.

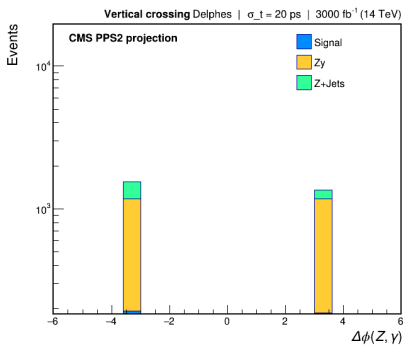
Central Object Selection (Timing Cut)

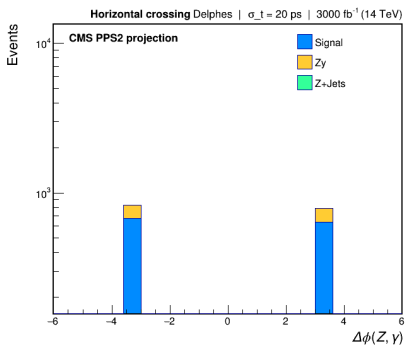












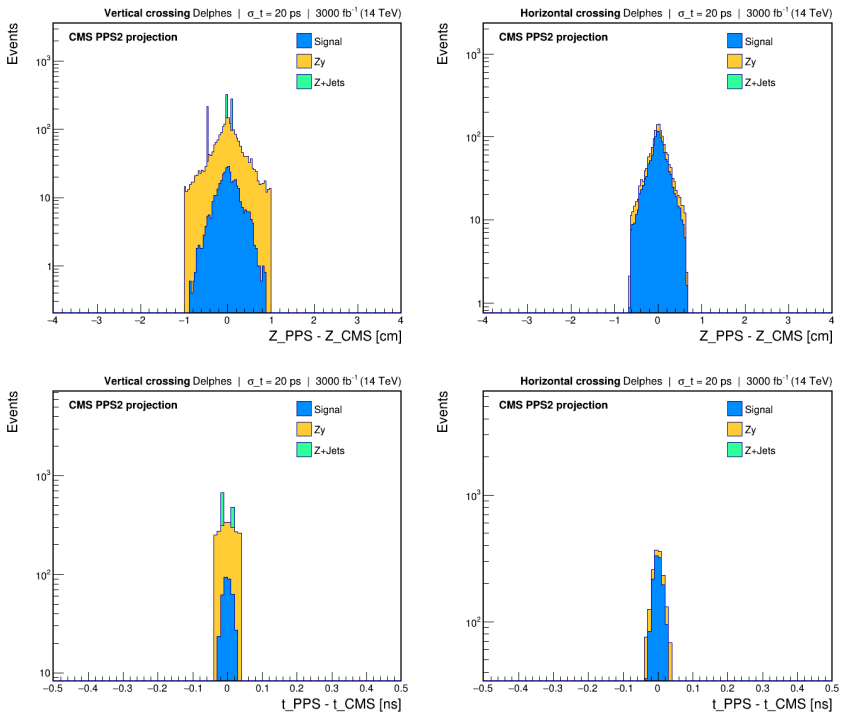
Timing Cut Condition:

$$\left|t_{\text{Vertex, CMS}} - t_{\text{Vertex, PPS}}\right| < 2\sigma_t$$

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

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

Central Object Selection (Timing Cut)



Timing Cut Condition:

$$\left|t_{\text{Vertex, CMS}} - t_{\text{Vertex, PPS}}\right| < 2\sigma_t$$

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

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

Cut-flow tables using Loose photon selection

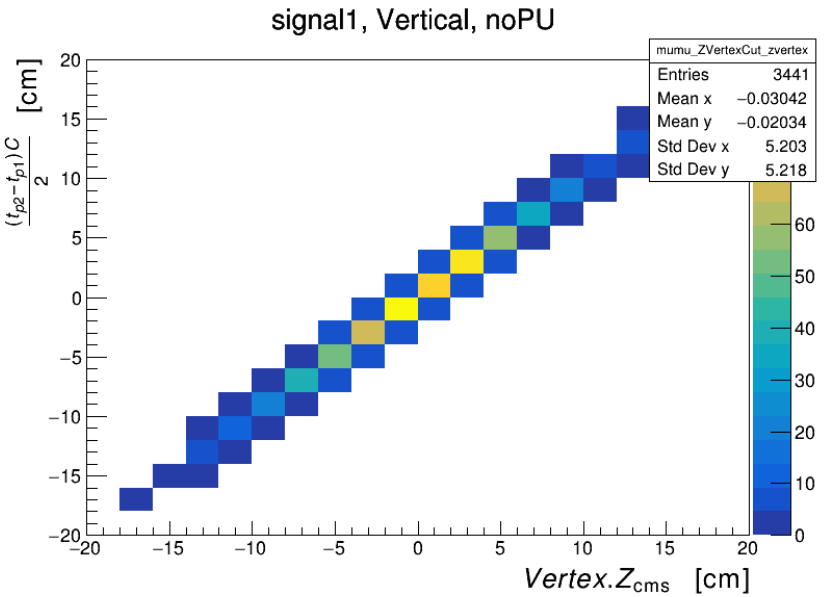
Crossing: Vertical, Timing Resolution: 20 ps					
NEvents	signal(non-PU)	signal(realistic)	$Z\gamma(SM)$	Z + Jet	$S/\sqrt{B}$
AllEvents	1065.0	1065.0	456000.0	181552000.0	0.079
$n_{Leptons} > 1$	992.255	992.255	357317.0	142313000.0	0.083
$p_{T,Z} > 100$ GeV	984.66	984.66	347348.0	138062000.0	0.084
$p_{T,\gamma} > 200GeV, 0 <$ SumPtCharged < 5	813.789	813.789	145456.0	101125.0	1.639
75 GeV $< M_Z <$ 110 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
$Resolution_{ZVertex} < 1.0cm$	687.683	420.484	14905.6	2360.18	3.2
$Resolution_{time} < 0.04ns$	684.686	376.317	1972.86	544.657	7.5

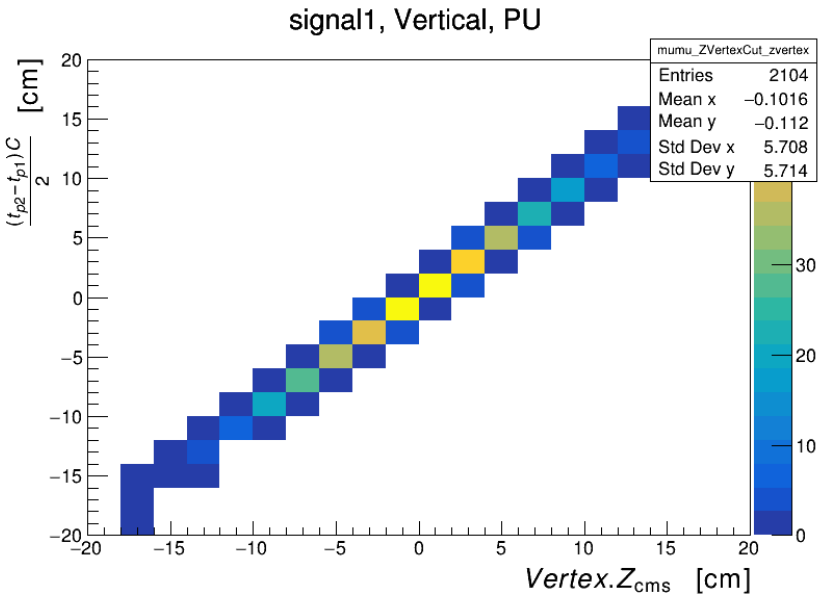
Crossing: Horizontal, Timing Resolution: 20 ps					
NEvents	signal(non-PU)	signal(realistic)	$Z\gamma(SM)$	Z + Jet	$S/\sqrt{B}$
AllEvents	7317.0	7317.0	456000.0	181552000.0	0.542
$n_{Leptons} > 1$	6732.08	6732.08	357317.0	142313000.0	0.564
$p_{T,Z} > 100$ GeV	6710.27	6710.27	347348.0	138062000.0	0.57
$p_{T,\gamma} > 200GeV, 0 <$ SumPtCharged < 5	5601.02	5601.02	145456.0	101125.0	11.279
75 GeV $< M_Z <$ 110 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
$Resolution_{ZVertex} < 0.65cm$	2264.03	1497.79	2369.07	181.552	29.657
$Resolution_{time} < 0.04ns$	2251.15	1309.01	308.383	0.0	74.541

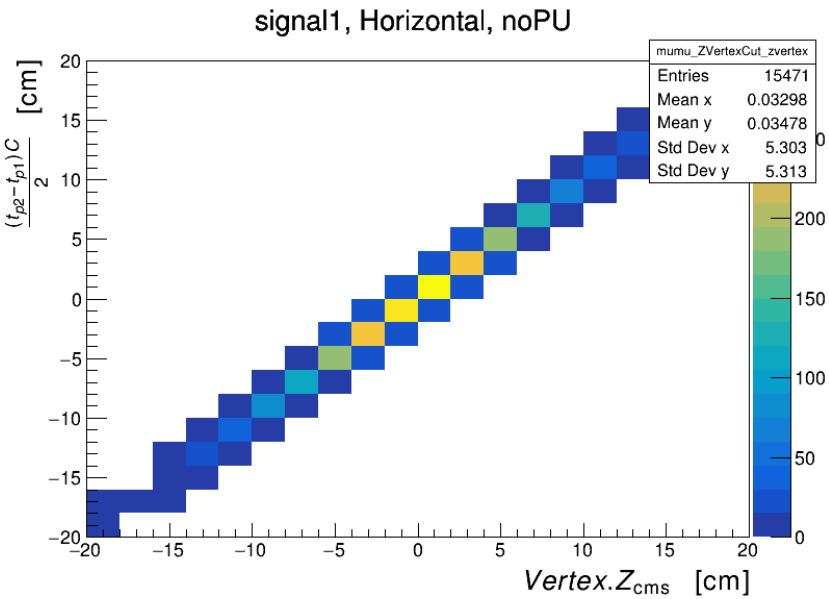
Backup Slides

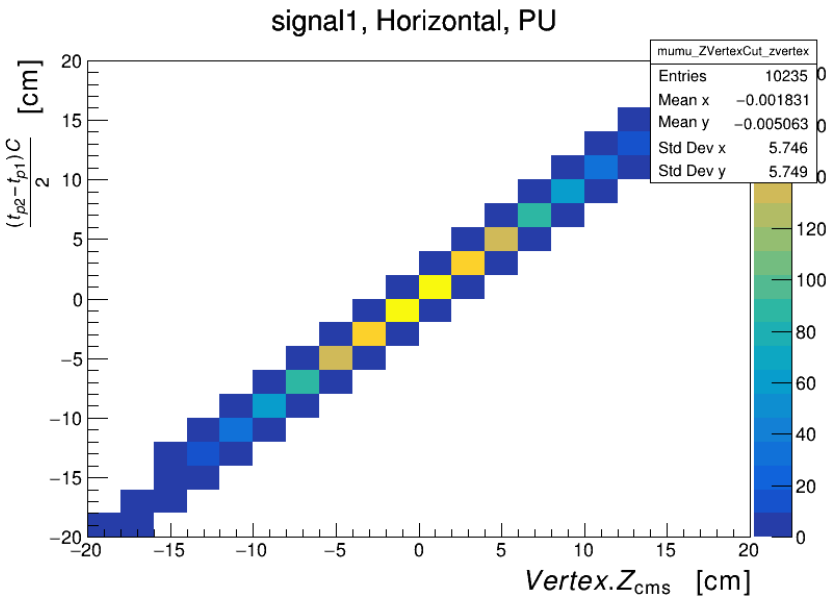
Some additional plots for validating the analysis strategy, provided using signal samples(both non-pileup and realistic) for vertical and horizontal crossings after mentioned cut on Vertex.Z.

Additional Plots(Vertex.Z)

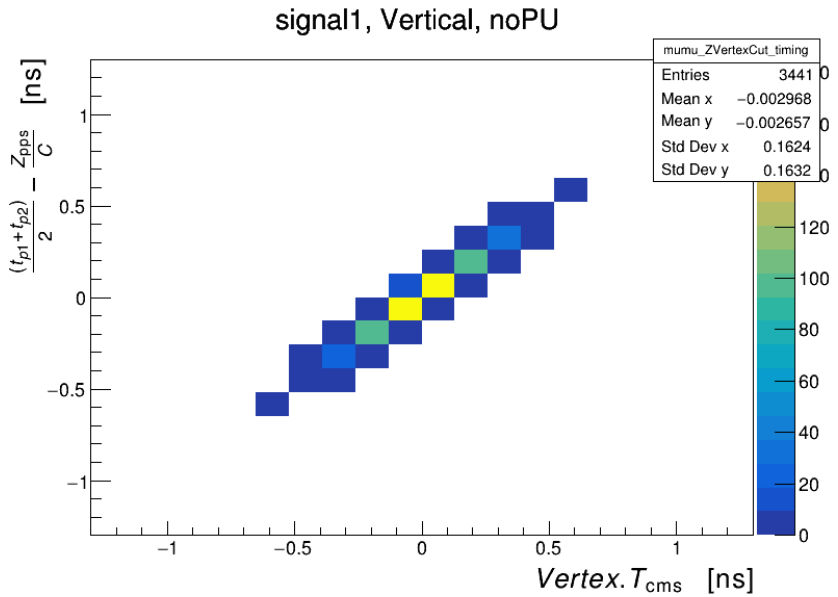


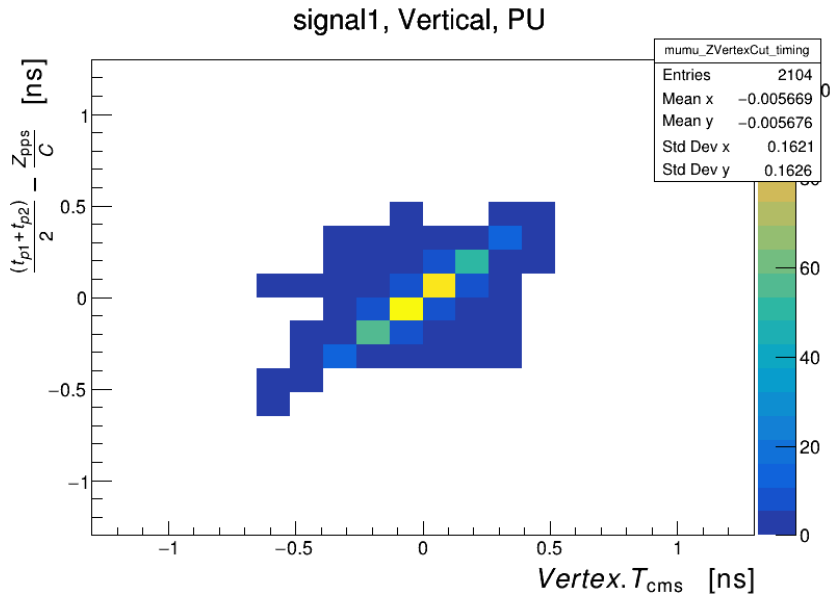


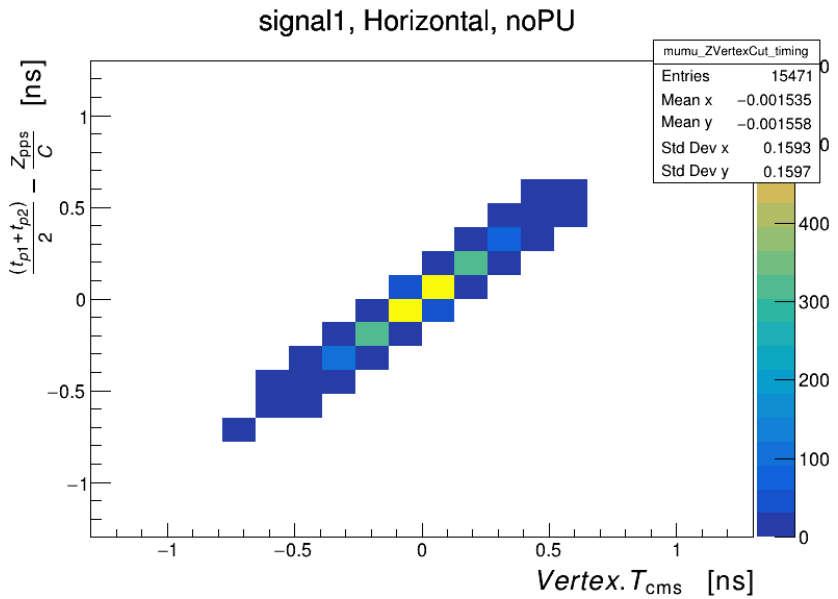


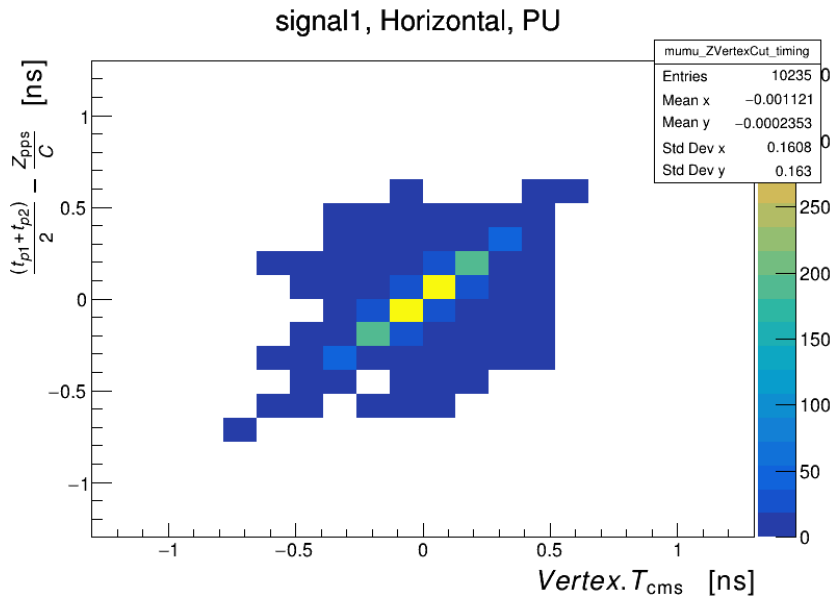


Additional Plots(Vertex.t)

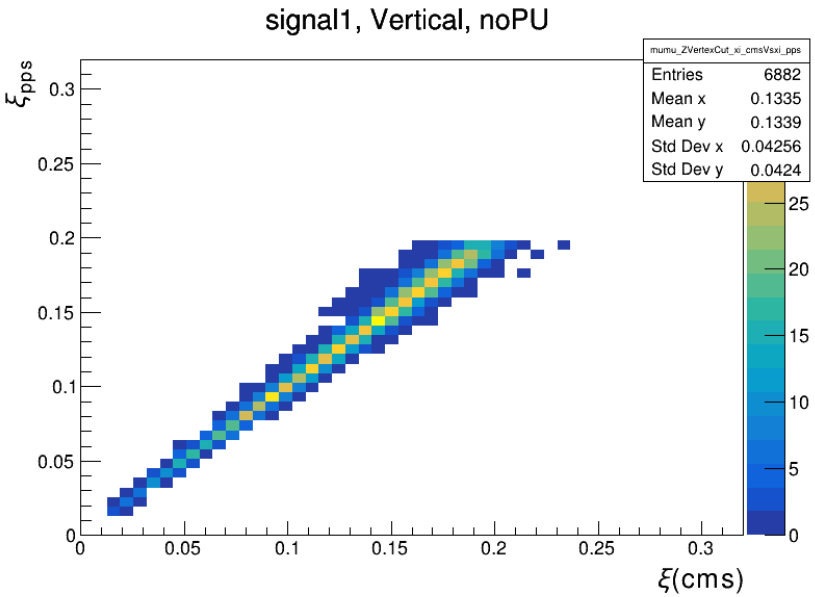


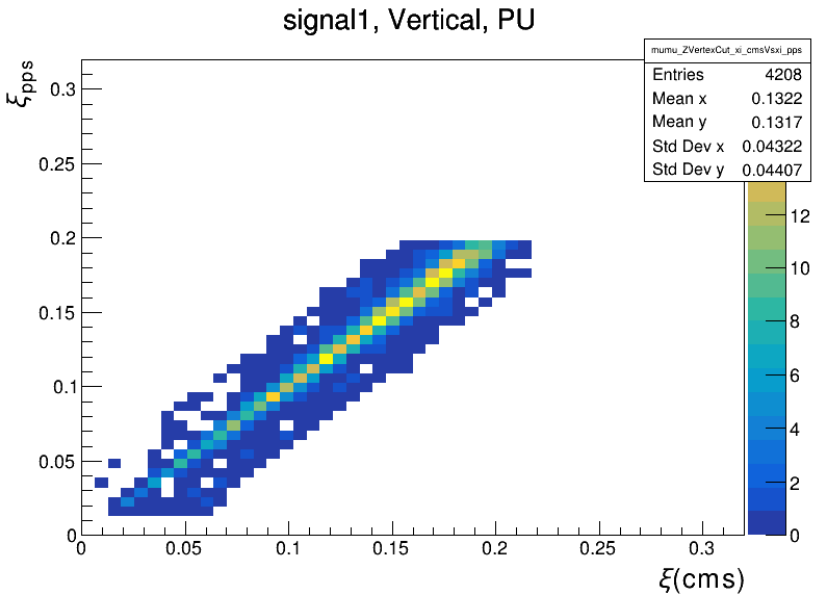


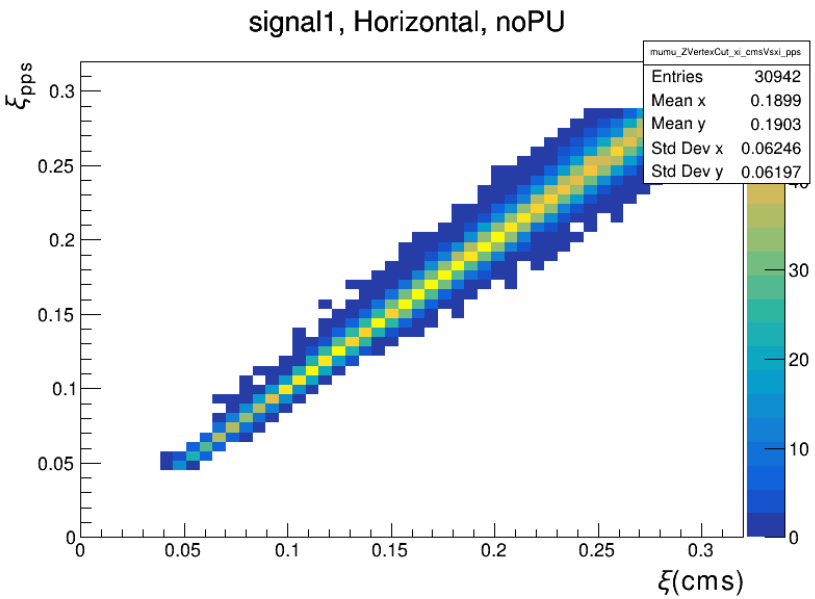


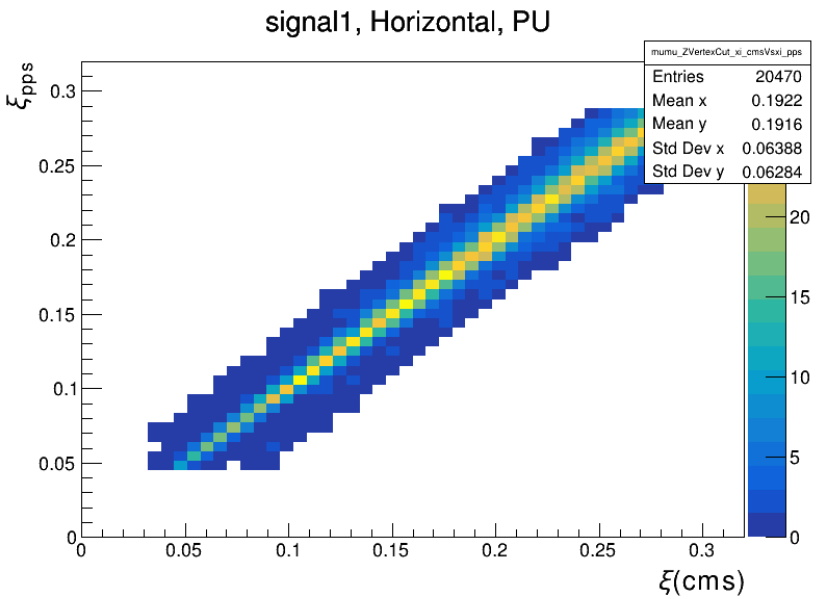


Additional Plots for cut Validation(ξ)

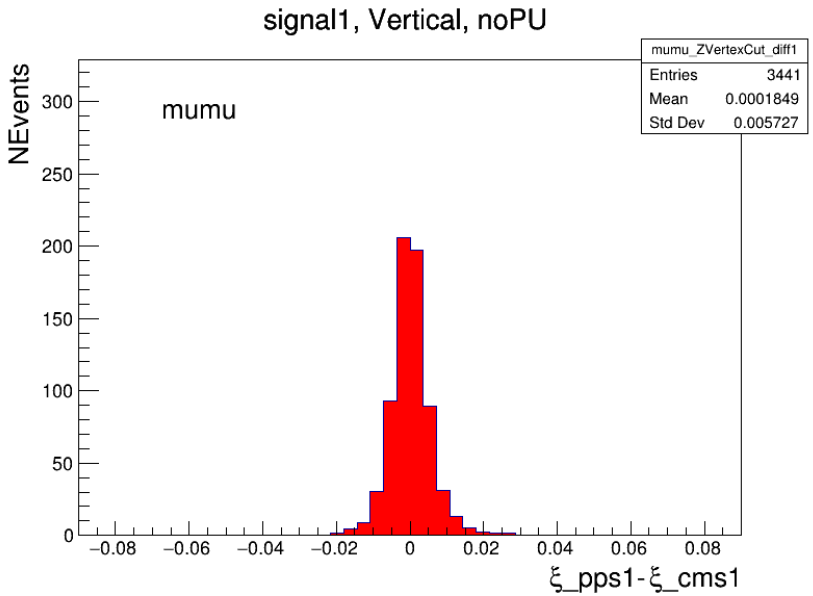


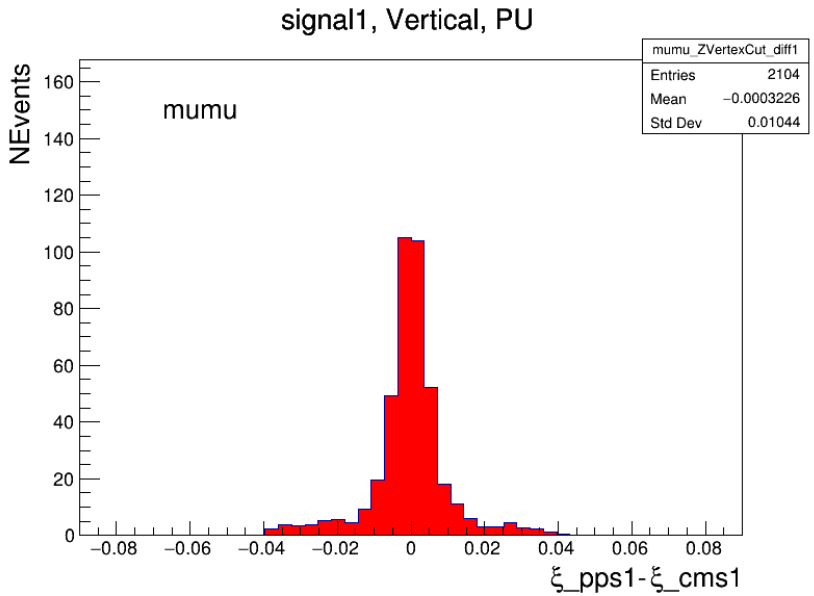


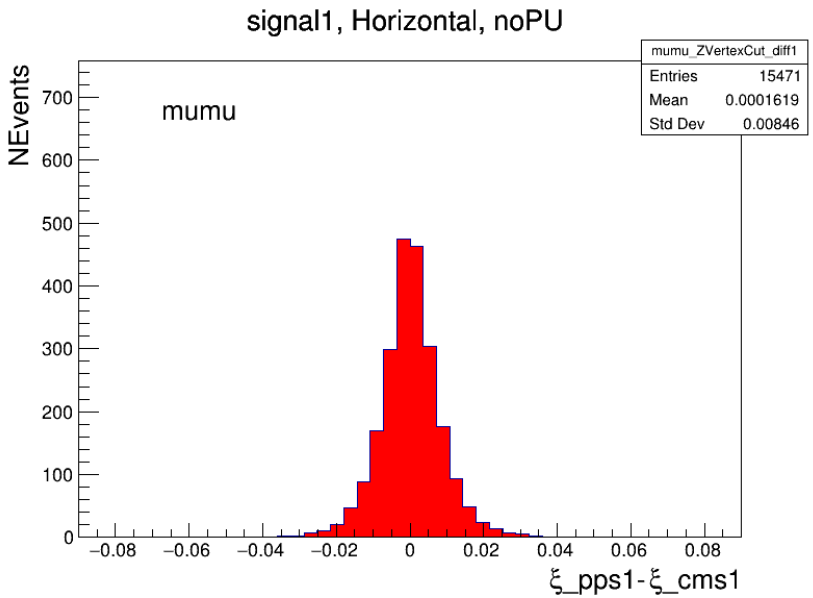


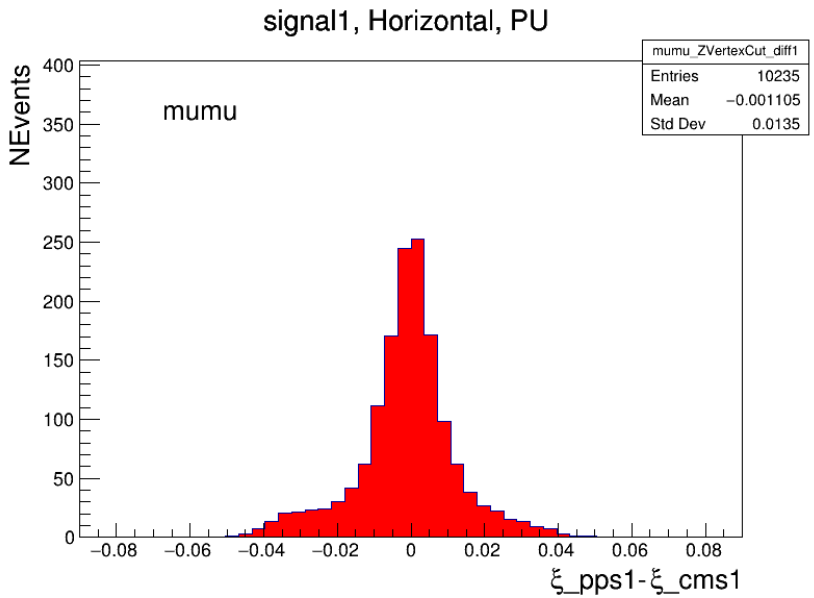


Additional Plots(ξ Resolution)

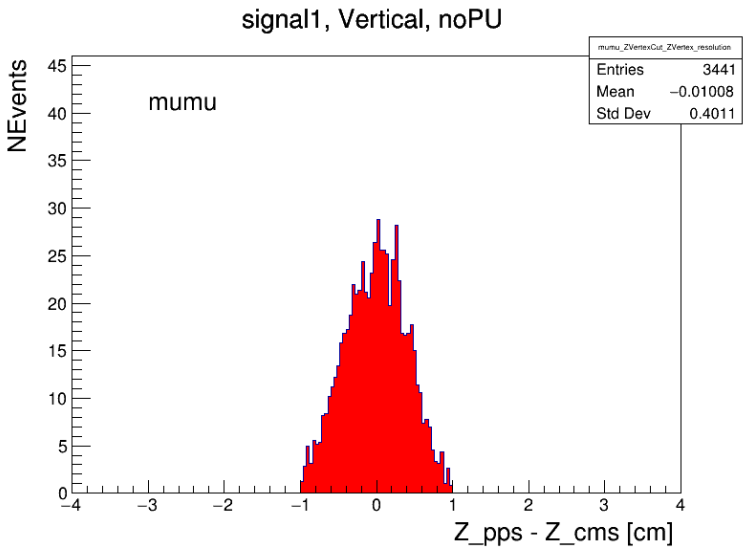


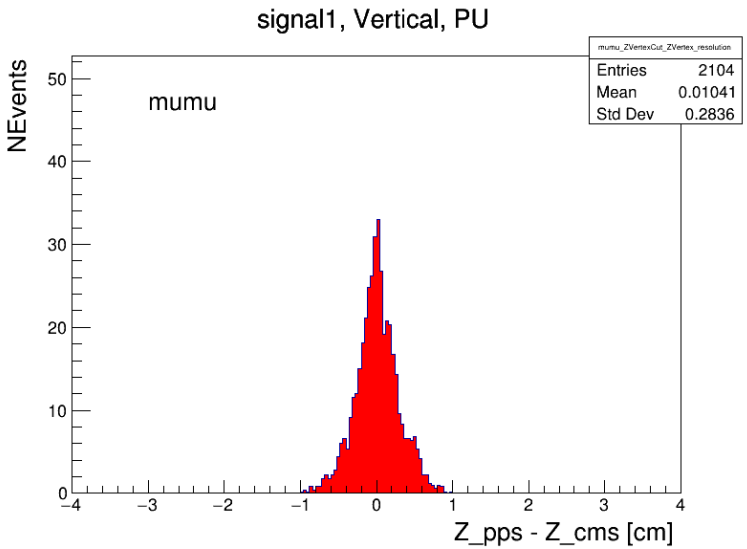


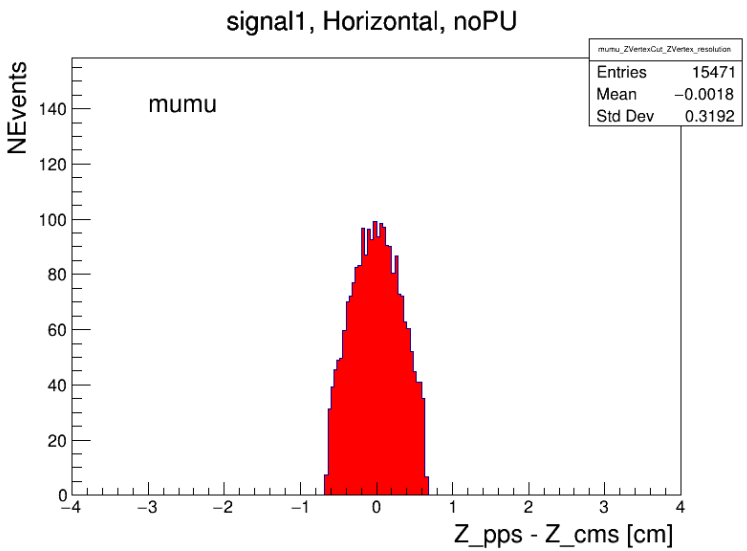


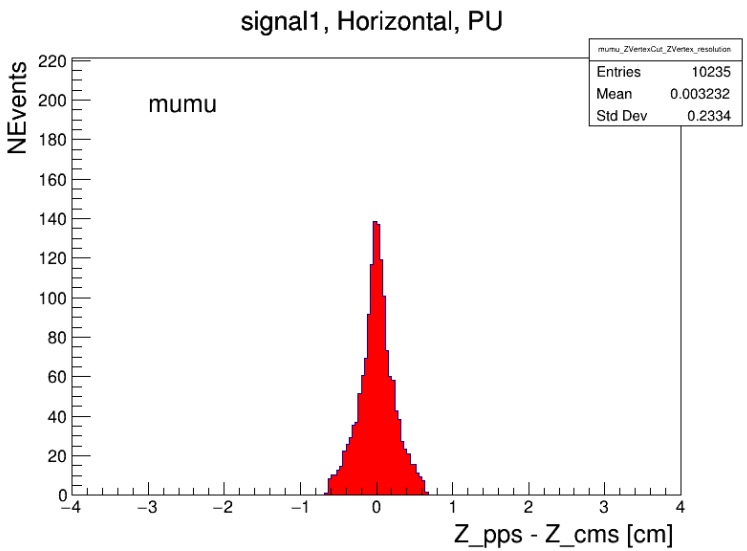


Additional Plots for cut Validation(Vertex.Z)

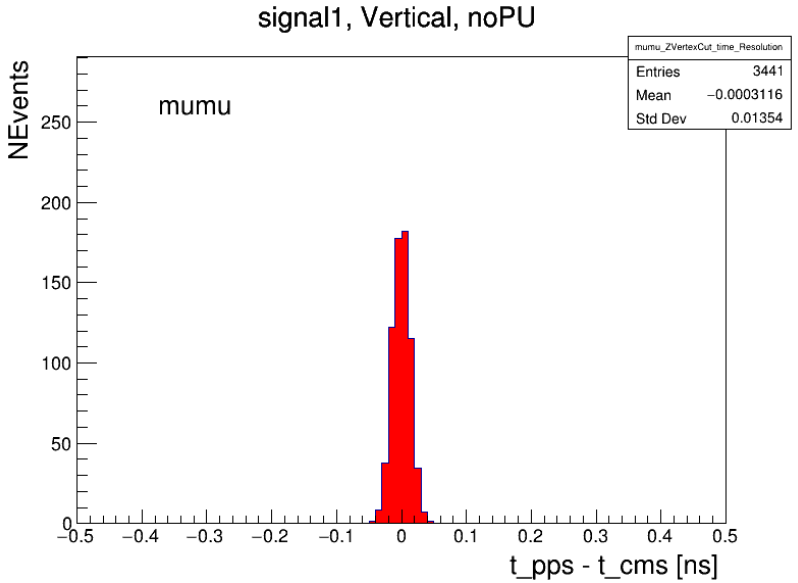


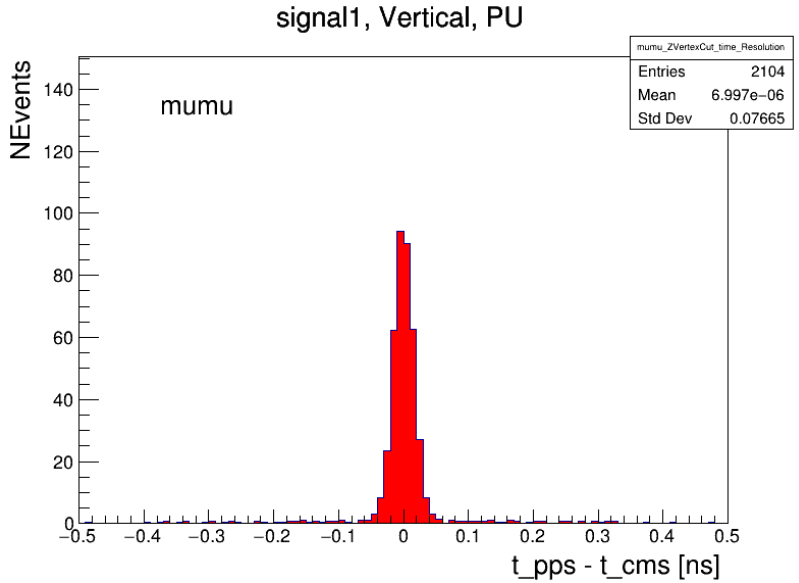


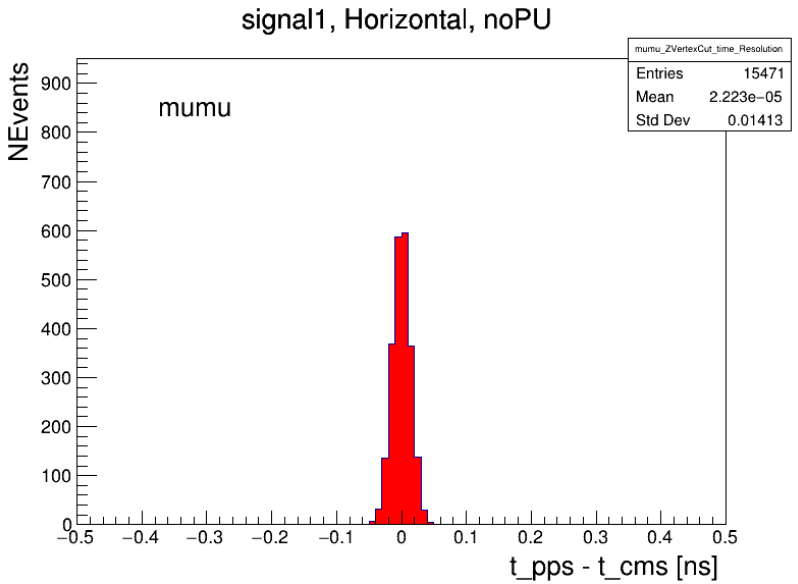


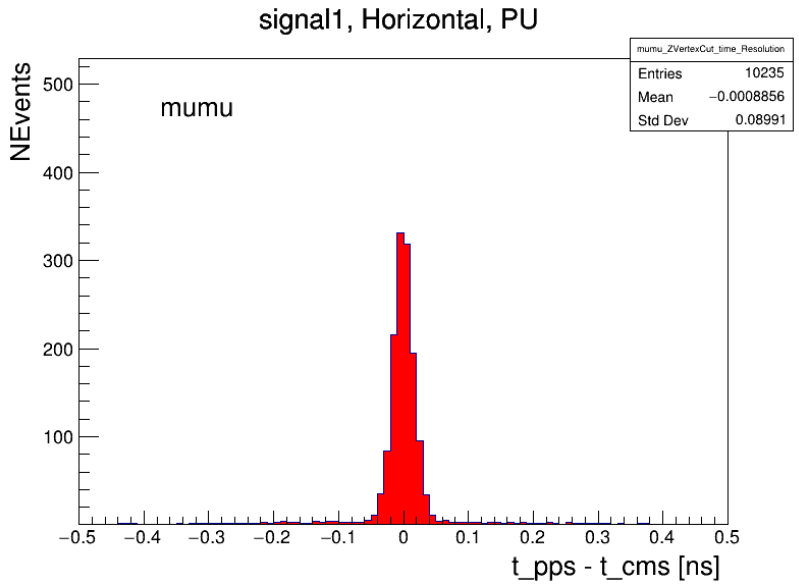


Additional Plots for cut Validation(Vertex.T)









Additional Plots (PhotonLoose.SumPtCharged)

We selected the cut of PhotonLoose.SumPtCharged > 5.