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

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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 forward proton detectors (PPS) located at $\sim$ 210 m with respect to the main interaction vertex.

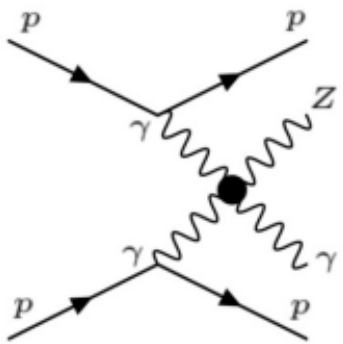
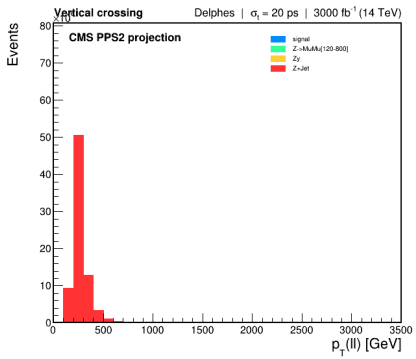
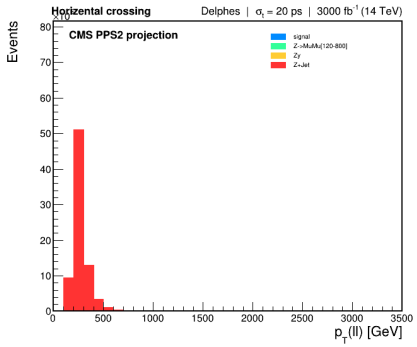


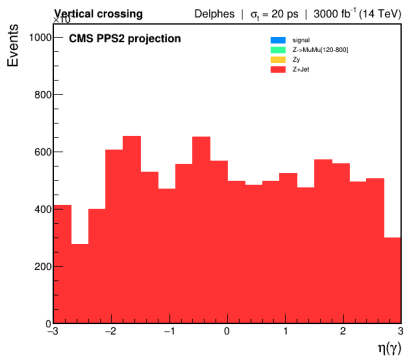
Table of Signal and Background Cross Sections

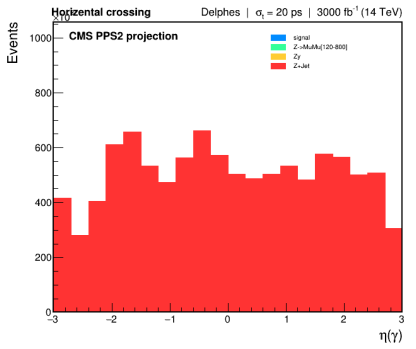
Signal/Background	Process	σ (pb)
Signal, Vertical ε	FPMC bSM 14TeV AAAAzeft A1A 0E0 A2A 1E-13 pt50-noHADR 3.556E-4 Zmumu.root	3.55e-4
Signal, Horizontal ε	FPMC bSM 14TeV AAAAzeft A1A 0E0 A2A 1E-13 pt50 horXing-noHADR 2.439E-3 Zmumu Delphes PU200.root	2.439e-3
DY background	ZToMuMu M-120to200 Tune CP5_14TeV-powheg-pythia8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

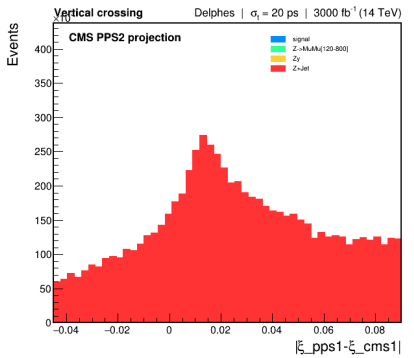
Central Object Selection (Muon Selection)

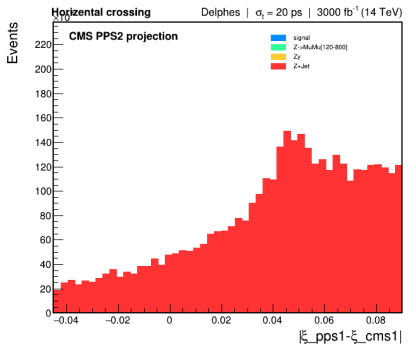






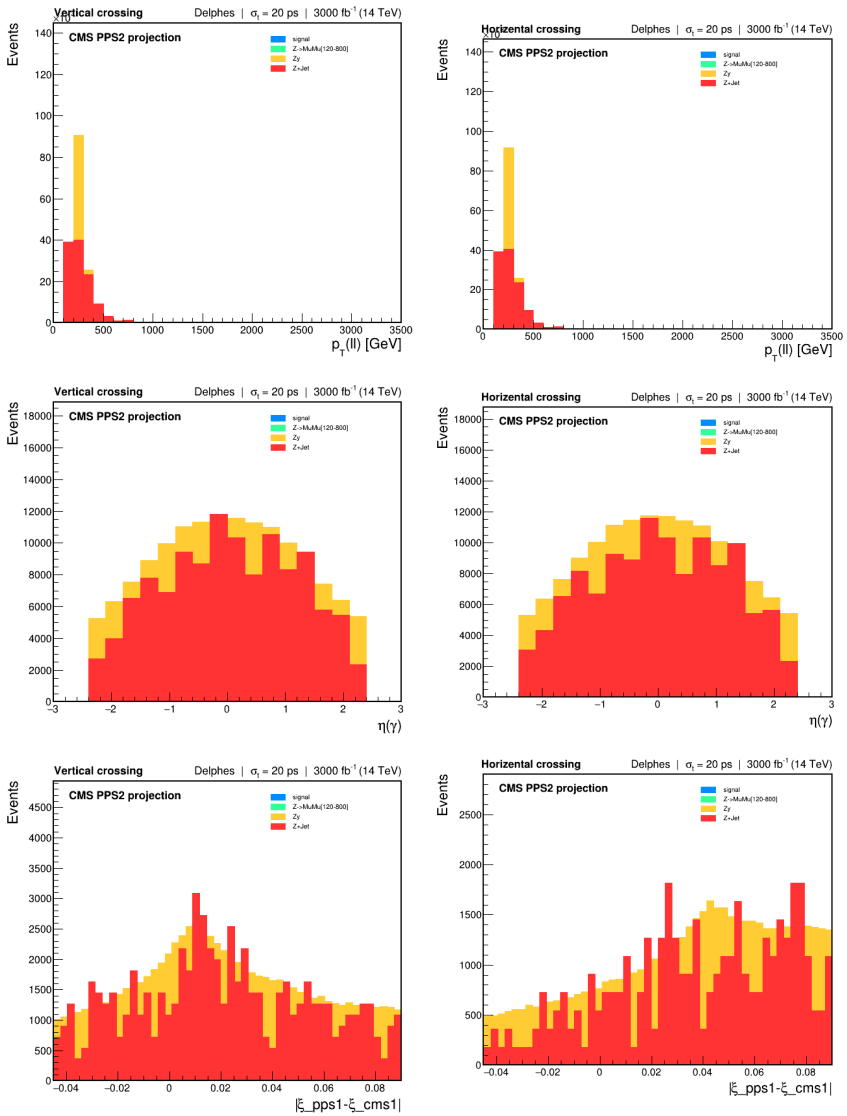






Two same flavor, oppositely signed charged leptons(Muons) with loose criteria, $\eta < 2.4$.
$p_{T_Z} > 100$ GeV.

Central Object Selection (Photon Selection)

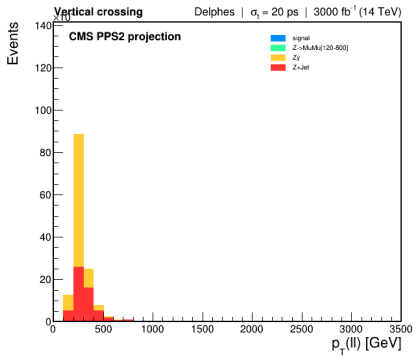


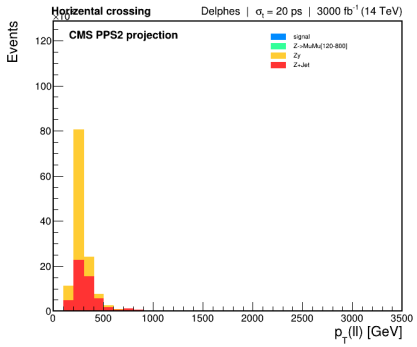
- $p_{T_\gamma} > 200\,\text{GeV}$
- Loose criteria and $\eta < 2.4$
- Rejecting photons with:
  - SumPtCharged > 10
  - SumPtCharged < 0

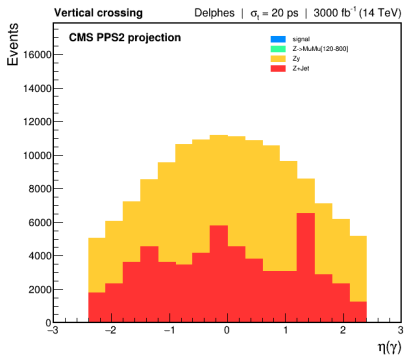
Proton Selection

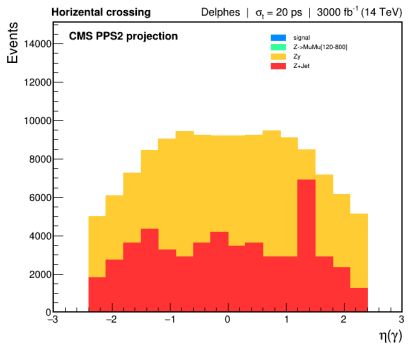
- Two protons are selected from both sides of the CMS detector.
- $\xi_{PPS} = 1 - |P_z(\text{GenProton})|/7000$.
- ξ and protons measured times are smeared by a Gaussian distribution with a mean of 0 and a standard deviation of 0.02 to account for the related PPS timing detector uncertainties.
- PPS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

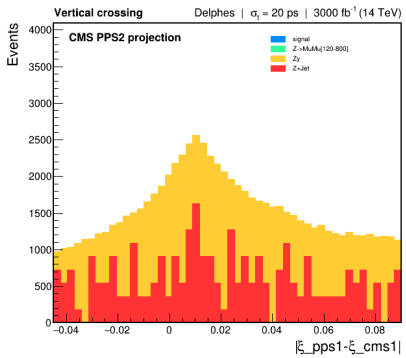
Central Object Selection (ξ Resolution Cut)

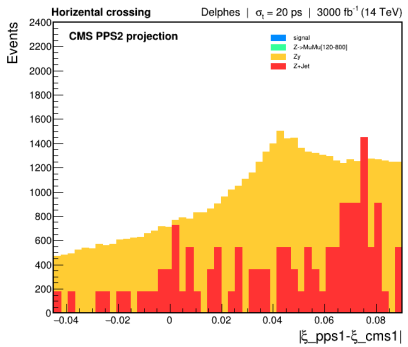










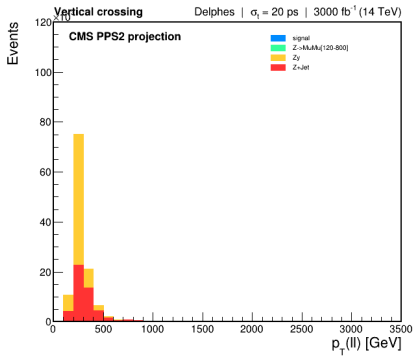


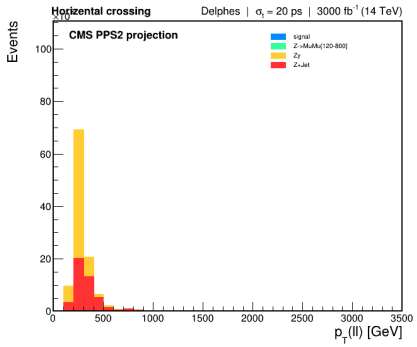
$$|\xi_{\text{cms}} - \xi_{\text{pps}}| < 0.2$$

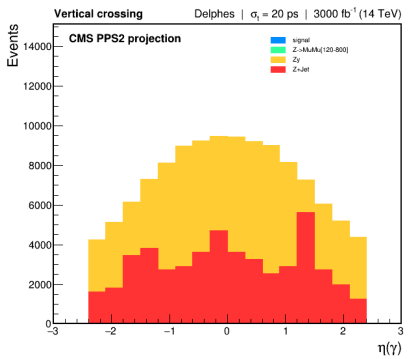
$$\xi_1 = \frac{\sum_{i=l+,l-,\gamma}(E_i + P_{z_i})}{\sqrt{s}},$$

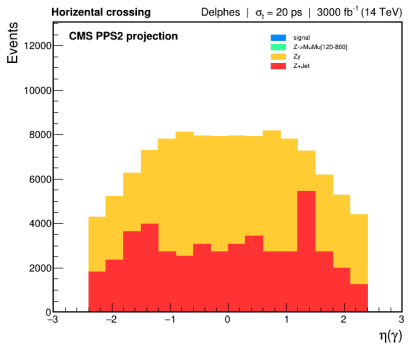
$$\xi_2 = \frac{\sum_{i=l+,l-,\gamma}(E_i - P_{z_i})}{\sqrt{s}}.$$

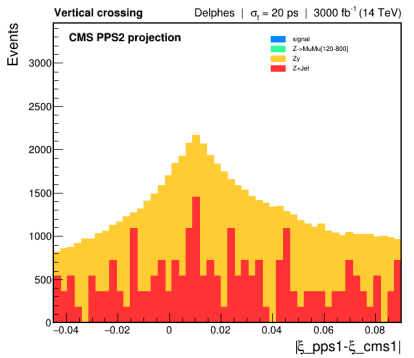
Central Object Selection (Z Vertex Cut)

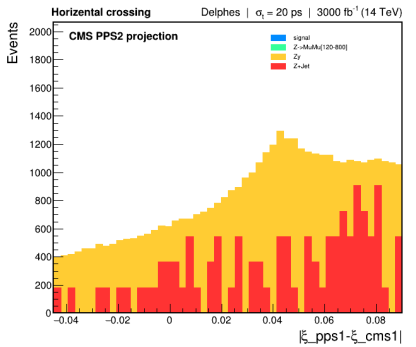












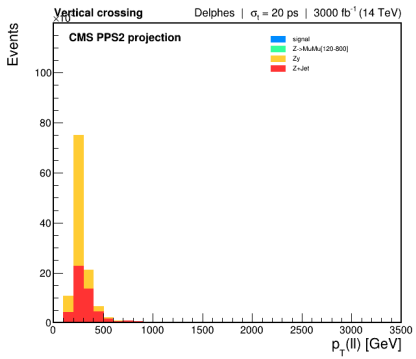
Selected Events within Z Vertex Cut:

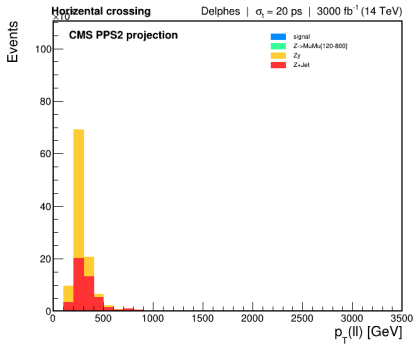
$$|Z_{\text{Vertex, cms}} - Z_{\text{Vertex, PPS}}| < 7$$

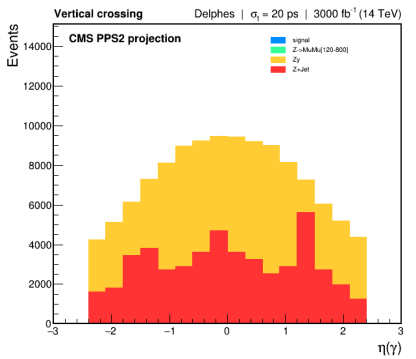
$$Z_{\text{Vertex, PPS}} = \frac{(t_{p1} - t_{p2})}{2} \times C$$

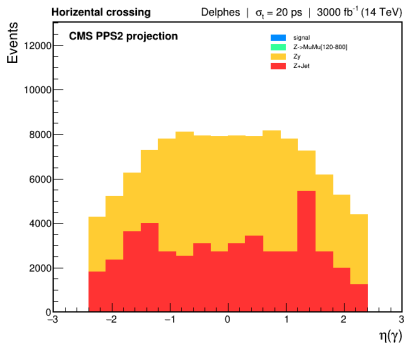
where $C = 30\,\text{cm/ns}$.

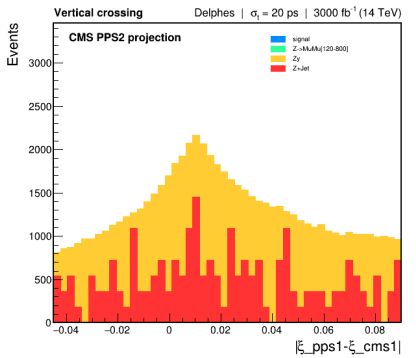
Central Object Selection (Timing Cut)

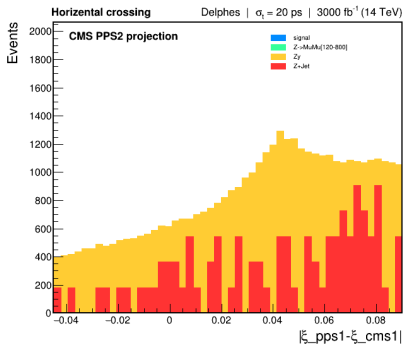












Timing Cut Condition:

$$|t_{\text{Vertex, cms}} - t_{\text{Vertex, PPS}}| < 0.8$$

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

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

Cut-Flow tables

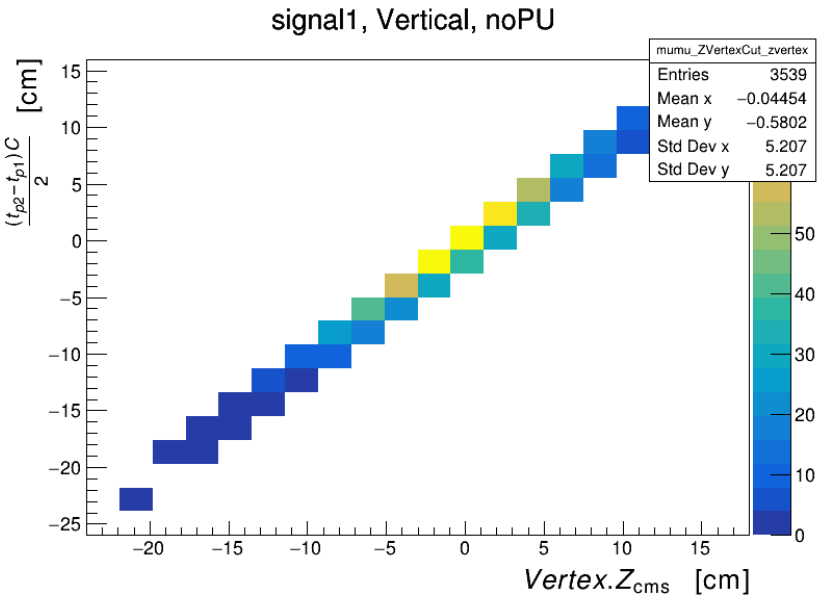
Crossing: Vertical, Timing Resolution: 20 ps						
NEvents	signal(no PU)	signal(realistic)	DY+Jets, $M_Z = [120 - 800]$GeV	$Z\gamma(SM)$	Z + Jet	$S/\sqrt{B}$
AllEvents	1065.0	1065.0	64924800.0	456000.0	181552000.0	0.068
$n_{Leptons} > 1$	921.708	999.649	39368048.0	353905.0	140968000.0	0.074
$p_{T,Z} > 100$ GeV	915.712	993.454	2158156.0	347567.0	138182000.0	0.084
$p_{T,\gamma} > 200GeV, 0 <$ SumPtCharged < 10	756.632	819.984	2009.63	144070.0	118190.0	1.595
75 GeV $< M_Z <$ 110 GeV	707.269	767.623	115.008	138486.0	57007.4	1.736
PPSXiCut	707.269	767.623	115.008	138486.0	57007.4	1.736
ProtonSelection	707.269	767.623	115.008	138484.0	57007.4	1.736
$Resolution_{\xi_{cms1}} < 2\sqrt{2}$	707.269	767.623	115.008	138483.0	57007.4	1.736
$Resolution_{\xi_{cms2}} < 2\sqrt{2}$	707.269	653.109	86.256	117454.0	48656.0	1.602
$Resolution_{ZVertex} < 2\sqrt{2} \times 20ps \times C$	707.269	653.109	86.256	117355.0	48656.0	1.603

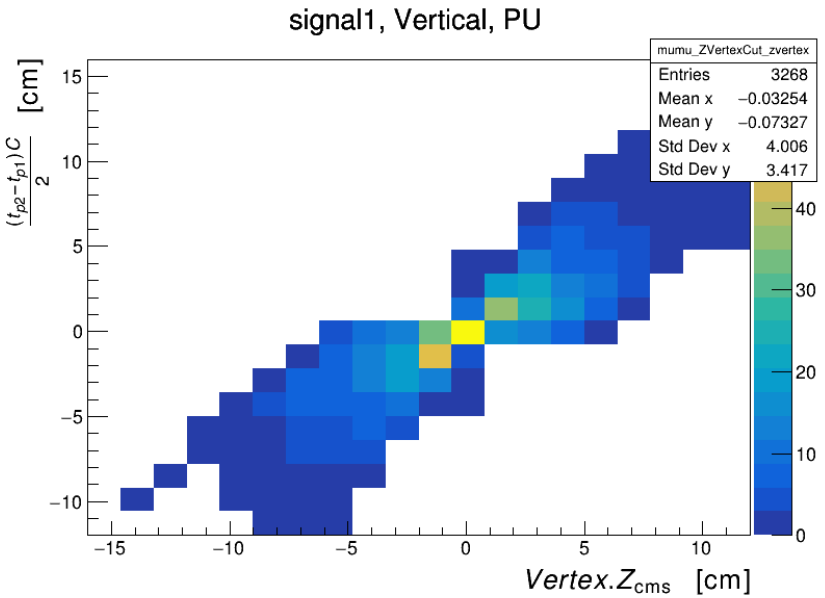
Crossing: Horizontal, Timing Resolution: 20 ps						
NEvents	signal(no PU)	signal(realistic)	DY+Jets, $M_Z = [120 - 800]$GeV	$Z\gamma(SM)$	Z + Jet	$S/\sqrt{B}$
AllEvents	7317.0	7317.0	64924800.0	456000.0	181552000.0	0.466
$n_{Leptons} > 1$	3577.72	6782.42	39800086.0	357663.0	142516000.0	0.502
$p_{T,Z} > 100$ GeV	3567.33	6764.71	2182727.0	351256.0	139697000.0	0.567
$p_{T,\gamma} > 200GeV, 0 <$ SumPtCharged < 10	2973.63	5647.26	2016.82	145622.0	119280.0	10.931
75 GeV $< M_Z <$ 110 GeV	2764.95	5239.12	122.196	139976.0	57915.1	11.774
PPSXiCut	2764.95	5239.12	122.196	139976.0	57915.1	11.774
ProtonSelection	2764.95	5084.14	111.414	133249.0	55736.5	11.692
$Resolution_{\xi_{cms1}} < 2\sqrt{2}$	2764.95	4956.54	104.226	127796.0	52831.7	11.659
$Resolution_{\xi_{cms2}} < 2\sqrt{2}$	2764.95	4156.2	82.662	109875.0	46295.8	10.514
$Resolution_{ZVertex} < 2\sqrt{2} \times 20ps \times C$	2764.95	4156.06	82.662	109773.0	46295.8	10.517

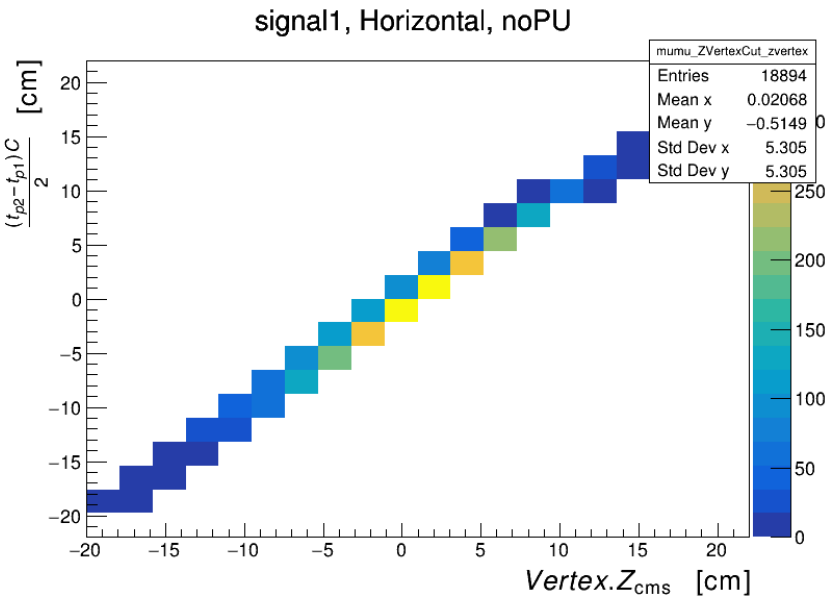
Backup Slides

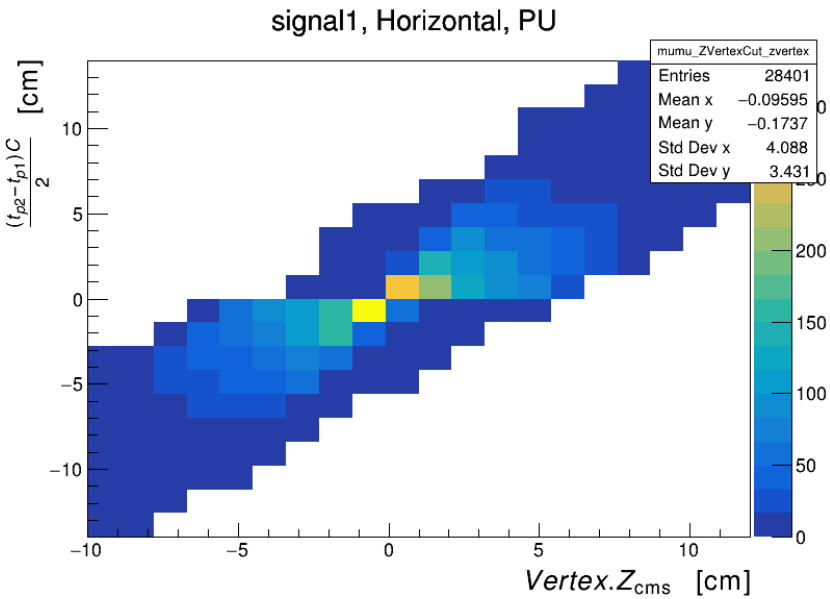
Some additional plots for validating the analysis strategy, provided using signal samples(both non-pileup and realistic) for vertical and horizontal crossings after mentioned cut on Vertex.Z.

Additional Plots(Vertex.Z)

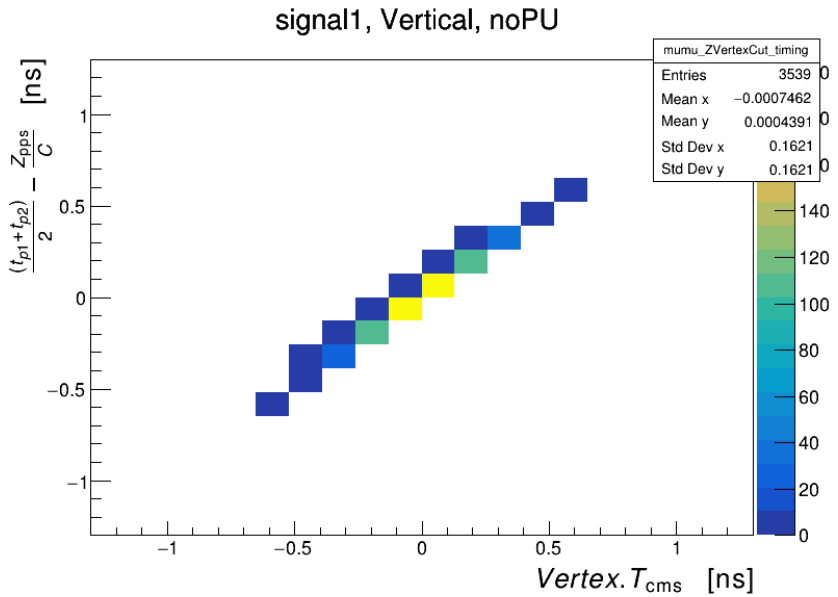


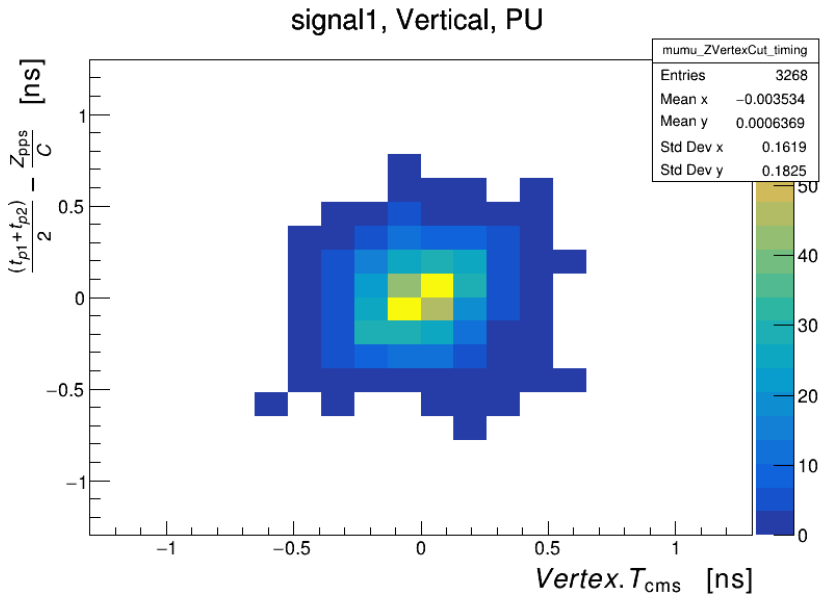


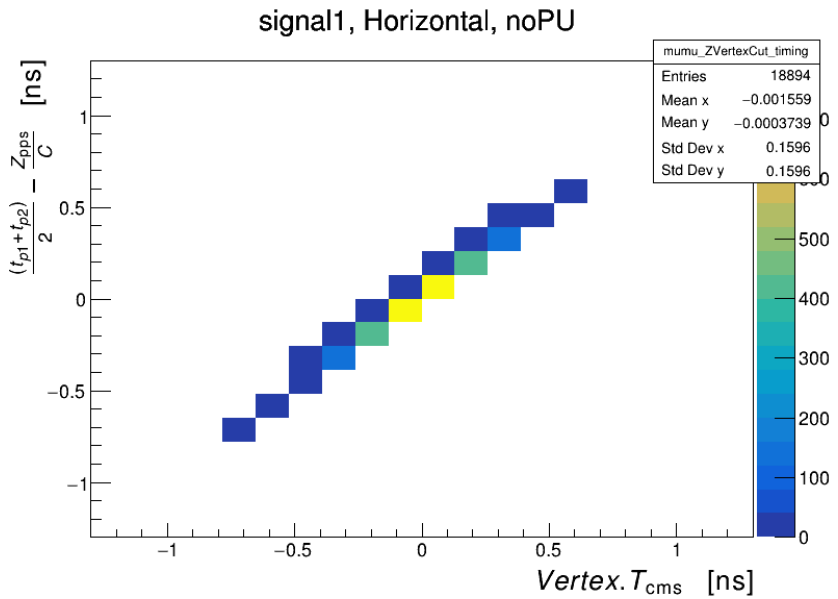


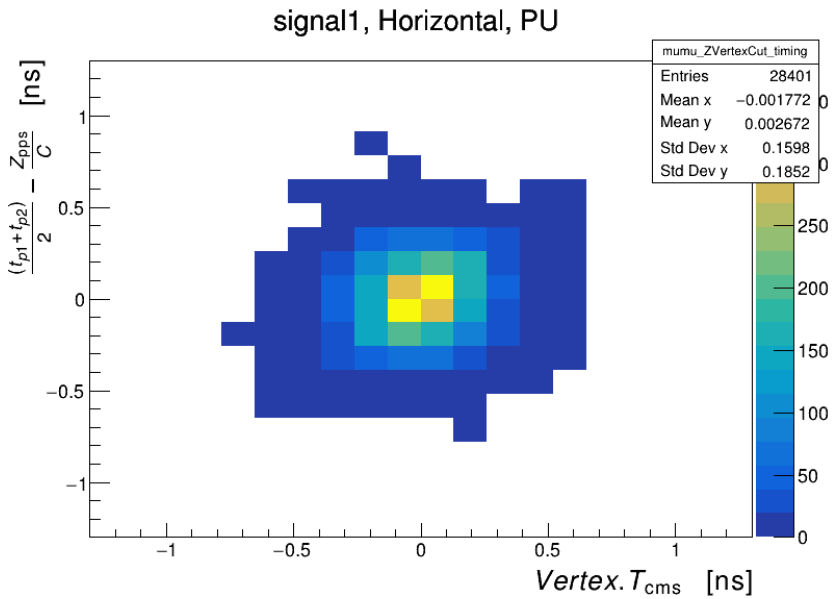


Additional Plots(Vertex.t)

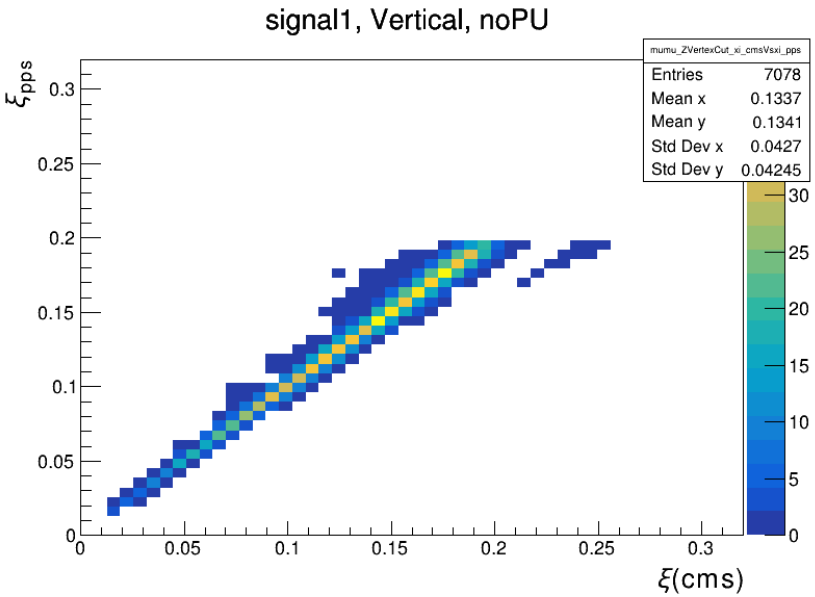


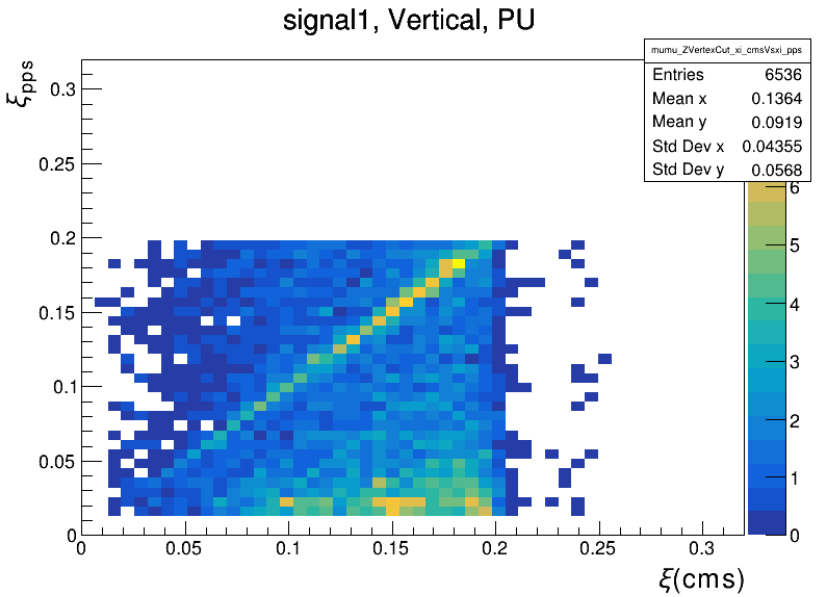


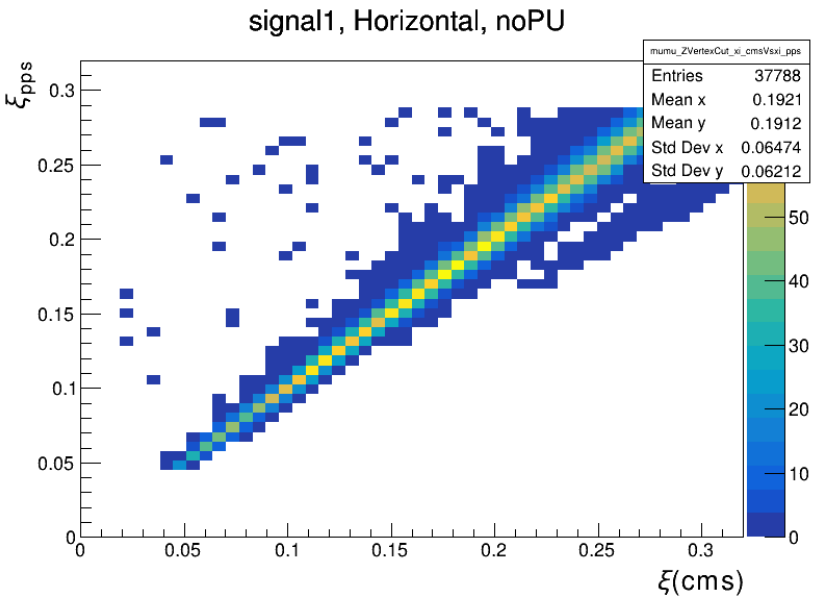


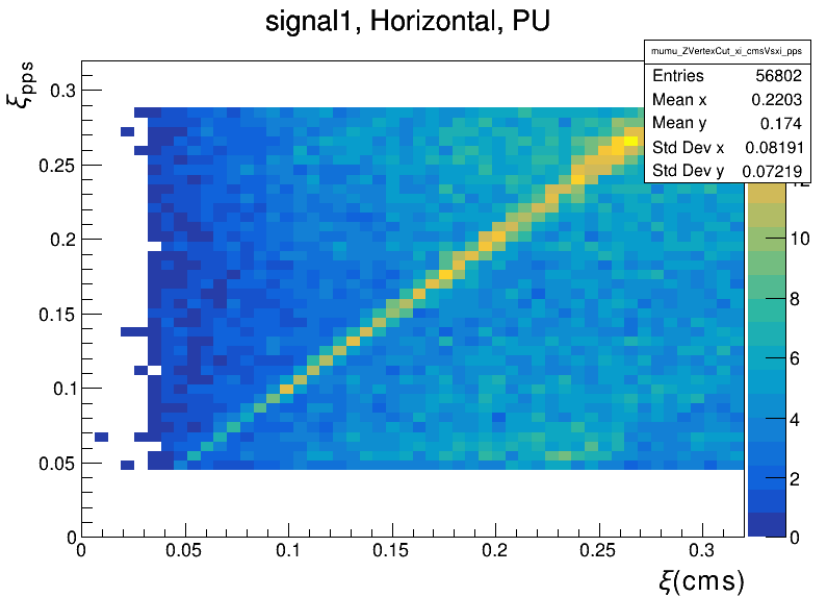


Additional Plots(xi)



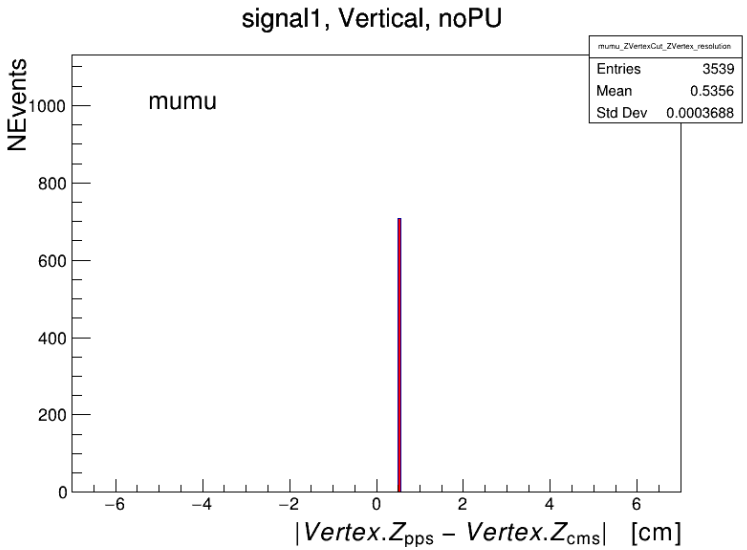


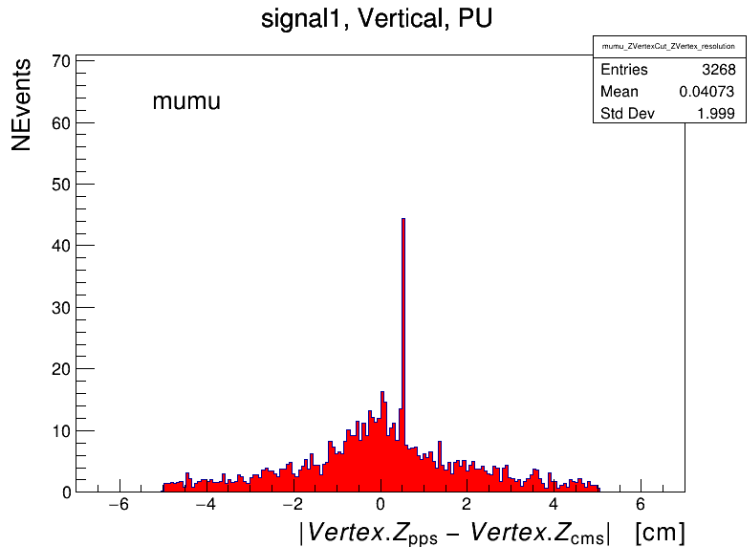


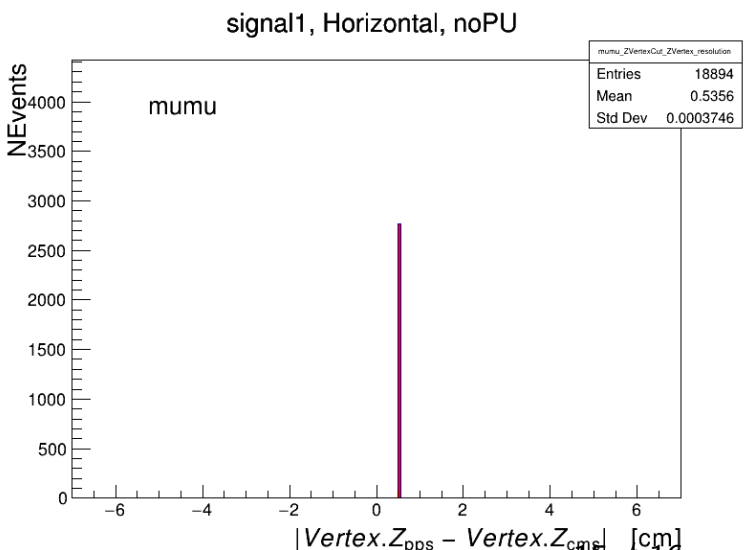


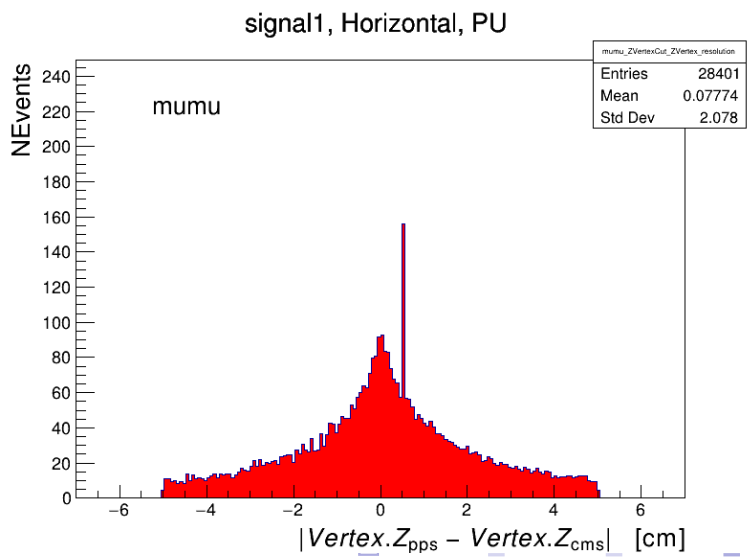
Additional Plots (Vertex.Z)

- The vertex Z difference, using the non-pileup signal sample after the applied Z_vertex cut, is distributed around 0.5. When the smearing of protons' measured times is removed, the distribution centers exactly around 0.









Additional Plots for Validation(Vertex.T)