CEPC HZZ Analysis Update

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Status

- **Statistic error added in table**
- **Unify some selection criteria**
- **Two μμHZZ's BDT study finished**

μμHqqνν before

Table 7: Cut flow table for $\mu\mu qq\nu\nu$ channel

Cut	Signal	ZH Background	2f Background	4f Background	$\frac{S}{\sqrt{S+B}}$
Expected	1000.88±3.17	1140511±6	801811977±420	107203890±11291	
$Pre-selection$	616.68±2.48	30494 ±89	480828±1893	515448±748	
$Signal\ or\ not$	211.44±1.45	30282 ±89	480828±1893	515448±748	
$M_{missing} < M_{dijet}$	103.46±1.02	28674 ±87	365766±1652	486638±728	0.1102
$N(pfo)$	100.24±1.0	21686 ±78	12184 ±301	332162±600	0.1657
M_{dimuon}	89.98 ±0.95	16833 ±54	9085 ±260	207927±474	0.186
M_{dijet}	82.95 ±0.91	2768 ±21	52 ±19	173775±433	0.1974
$M_{missing}$	71.56 ±0.85	1679 ±17	14 ±10	13434 ±120	0.5804
$*cos\ \theta$	71.56 ±0.85	1679 ±17	14 ±10	13434 ±120	0.5804
$cos\theta_{visible}$	67.99 ±0.82	1535 ±16	0 ±0	8545 ±96	0.6749
$Angle_{\mu j}$	57.71 ±0.76	1109 ±13	0 ±0	2197 ±48	0.995
M^{rec}_{dimuon}	56.5 ±0.75	1048 ±13	0 ±0	941 ±31	1.2488
$*M^{rec}_{dijet}$	56.5 ±0.75	1048 ±13	0 ±0	941 ±31	1.2488
$M_{visible}$	54.02 ±0.74	930 ±12	0 ±0	790 ±29	1.2823
$*P_{visible}$	54.02 ±0.74	930 ±12	0 ±0	790 ±29	1.2823
$*P_{T_{visible}}$	54.02 ±0.74	930 ±12	0 ±0	790 ±29	1.2823
$*E_{leading\ jet}$	54.02 ±0.74	930 ±12	0 ±0	790 ±29	1.2823
$*P_{T_{leading\ jet}}$	54.02 ±0.74	930 ±12	0 ±0	790 ±29	1.2823
$*E_{sub-leading\ jet}$	54.02 ±0.74	930 ±12	0 ±0	790 ±29	1.2823
$*P_{T_{sub-leading\ jet}}$	54.02 ±0.74	930 ±12	0 ±0	790 ±29	1.2823
$not\ qqHZZ$	46.67 ±0.68	738 ±11	0 ±0	644 ±26	1.2343
$not\ \nu\nu HZZ$	46.67 ±0.68	738 ±11	0 ±0	644 ±26	1.2343±0.2054

$$120 < Angle_{\mu j} < 170$$

μμHqqνν upgrade

Table 8: Cut flow table for $\mu\mu qq\nu\nu$ channel(upgrade)

Cut	Signal	ZH Background	2f Background	4f Background	$\frac{S}{\sqrt{S+B}}$
$Expected$	1000.88±3.17	1140511±6	801811977±420	107203890±11291	
$Pre-selection$	616.68±2.48	30494 ±89	480828±1893	515448±748	
$Signal\ or\ not$	211.44±1.45	30282 ±89	480828±1893	515448±748	
$M_{missing} < M_{dijet}$	103.46±1.02	28674 ±87	365766±1652	486638±728	0.1102
$N(pfo)$	100.24±1.0	21686 ±78	12184 ±301	332162±600	0.1657
M_{dimuon}	89.98 ±0.95	16833 ±54	9085 ±260	207927±474	0.186
M_{dijet}	82.95 ±0.91	2768 ±21	52 ±19	173775±433	0.1974
$M_{missing}$	71.56 ±0.85	1679 ±17	14 ±10	13434 ±120	0.5804
$*cos\ \theta$	71.56 ±0.85	1679 ±17	14 ±10	13434 ±120	0.5804
$cos\theta_{visible}$	67.99 ±0.82	1535 ±16	0 ±0	8545 ±96	0.6749
$Angle_{\mu j}(60, 170)$	60.89 ±0.78	1187 ±14	0 ±0	2233 ±49	1.0321
M^{rec}_{dimuon}	59.24 ±0.77	1111 ±13	0 ±0	965 ±32	1.2816
$*M^{rec}_{dijet}$	59.24 ±0.77	1111 ±13	0 ±0	965 ±32	1.2816
$M_{visible}$	55.35 ±0.74	966 ±12	0 ±0	805 ±29	1.295
$*P_{visible}$	55.35 ±0.74	966 ±12	0 ±0	805 ±29	1.295
$*P_{T_{visible}}$	55.35 ±0.74	966 ±12	0 ±0	805 ±29	1.295
$*E_{leading\ jet}$	55.35 ±0.74	966 ±12	0 ±0	805 ±29	1.295
$*P_{T_{leading\ jet}}$	55.35 ±0.74	966 ±12	0 ±0	805 ±29	1.295
$*E_{sub-leading\ jet}$	55.35 ±0.74	966 ±12	0 ±0	805 ±29	1.295
$*P_{T_{sub-leading\ jet}}$	55.35 ±0.74	966 ±12	0 ±0	805 ±29	1.295
$not\ qqHZZ$	48.0 ±0.69	774 ±11	0 ±0	659 ±26	1.247
$not\ \nu\nu HZZ$	48.0 ±0.69	774 ±11	0 ±0	659 ±26	1.247 ±0.2059

$60 < Angle_{\mu j} < 170$

ννHqqμμ before

Table 12: Cut flow table for $\nu\nu qq\mu\mu$ channel

Cut	Signal	ZH Background	2f Background	4f Background	$\frac{S}{\sqrt{S+B}}$
$Expected$	6844.99±21.65	1140511±6	801811977±420	107203890±11210	
$Pre-selection$	238.62±4.04	30494 ±89	480828±1893	515424±748	
$Signal\ or\ not$	226.71±3.94	30268 ±89	480828±1893	515424±748	
$M_{dimuon} < M_{dijet}$	101.44±2.64	27436 ±88	58876 ±662	358431±625	0.1521
$N(pfo)$	97.54 ±2.58	20843 ±79	364 ±58	231698±501	0.1939
$M_{missing}$	79.06 ±2.33	769 ±23	37 ±31	2083 ±47	1.4508
M_{dimuon}	78.38 ±2.32	707 ±21	7 ±7	1732 ±43	1.5596
M_{dijet}	68.04 ±2.16	576 ±20	0 ±0	830 ±30	1.7719
$*cos\ \theta$	68.04 ±2.16	576 ±20	0 ±0	830 ±30	1.7719
$cos\theta_{visible}$	64.55 ±2.1	552 ±20	0 ±0	452 ±22	1.9743
$Angle_{\mu j}$	59.62 ±2.02	239 ±13	0 ±0	70 ±8	3.1041
M^{rec}_{dimuon}	58.59 ±2.0	214 ±13	0 ±0	65 ±8	3.184
$*M^{rec}_{dijet}$	58.59 ±2.0	214 ±13	0 ±0	65 ±8	3.184
$M_{visible}$	57.91 ±1.99	175 ±11	0 ±0	54 ±7	3.4122
$*P_{visible}$	57.91 ±1.99	175 ±11	0 ±0	54 ±7	3.4122
$*P_{T_{visible}}$	57.91 ±1.99	175 ±11	0 ±0	54 ±7	3.4122
$*E_{leading\ jet}$	57.91 ±1.99	175 ±11	0 ±0	54 ±7	3.4122
$*P_{T_{leading\ jet}}$	57.91 ±1.99	175 ±11	0 ±0	54 ±7	3.4122
$*E_{sub-leading\ jet}$	57.91 ±1.99	175 ±11	0 ±0	54 ±7	3.4122
$*P_{T_{sub-leading\ jet}}$	57.91 ±1.99	175 ±11	0 ±0	54 ±7	3.4122
$not\ \mu^+\mu^- HZZ$	57.91 ±1.99	175 ±11	0 ±0	54 ±7	3.4122
$not\ qqHZZ$	50.52 ±1.86	130 ±10	0 ±0	43 ±6	3.3773±0.2609

$$Angle_{\mu j} < 130$$
$$165 < M^{rec}_{dimuon} < 215$$

μμHqqνν upgrade

Table 13: Cut flow table for $\nu\nu qq\mu\mu$ channel

Cut	Signal	ZH Background	2f Background	4f Background	$\frac{S}{\sqrt{S+B}}$
Expected	6844.99±21.65	1140511±6	801811977±420	107203890±11210	
Pre − selection	238.62±4.04	30494 ±89	480828±1893	515424±748	
Signal or not	226.71±3.94	30268 ±89	480828±1893	515424±748	
$M_{dimuon} < M_{dijet}$	101.44±2.64	27436 ±88	58876 ±662	358431±625	0.1521
$N(pfo)$	97.54 ±2.58	20843 ±79	364 ±58	231698±501	0.1939
$M_{missing}$	79.06 ±2.33	769 ±23	37 ±31	2083 ±47	1.4508
M_{dimuon}	78.38 ±2.32	707 ±21	7 ±7	1732 ±43	1.5596
M_{dijet}	68.04 ±2.16	576 ±20	0 ±0	830 ±30	1.7719
$*cos\,\theta$	68.04 ±2.16	576 ±20	0 ±0	830 ±30	1.7719
$cos\theta_{visible}$	64.55 ±2.1	552 ±20	0 ±0	452 ±22	1.9743
$Angle_{\mu j}(135)$	60.65 ±2.04	269 ±14	0 ±0	78 ±9	2.9985
$M^{rec}_{dimuon}(no)$	60.65 ±2.04	269 ±14	0 ±0	78 ±9	2.9985
$*M^{rec}_{dijet}$	60.65 ±2.04	269 ±14	0 ±0	78 ±9	2.9985
$M_{visible}$	59.89 ±2.02	211 ±12	0 ±0	65 ±8	3.2662
$*P_{visible}$	59.89 ±2.02	211 ±12	0 ±0	65 ±8	3.2662
$*P_{T_{visible}}$	59.89 ±2.02	211 ±12	0 ±0	65 ±8	3.2662
$*E_{leading\ jet}$	59.89 ±2.02	211 ±12	0 ±0	65 ±8	3.2662
$*P_{T_{leading\ jet}}$	59.89 ±2.02	211 ±12	0 ±0	65 ±8	3.2662
$*E_{sub-leading\ jet}$	59.89 ±2.02	211 ±12	0 ±0	65 ±8	3.2662
$*P_{T_{sub-leading\ jet}}$	59.89 ±2.02	211 ±12	0 ±0	65 ±8	3.2662
not $\mu^+\mu^- HZZ$	59.89 ±2.02	211 ±12	0 ±0	65 ±8	3.2662
not $qqHZZ$	52.3 ±1.89	159 ±11	0 ±0	52 ±7	3.2227±0.2547

$Angle_{\mu j} < 135$

qqHμμνν before

Table 17: Cut flow table for $qq\mu\mu\nu\nu$ channel

Cut	Signal	ZH Background	2f Background	4f Background	$\frac{S}{\sqrt{S+B}}$
$Expected$	20254.08±64.05	1140511±6	801811977±420	107203890±11210	
$Pre-selection$	826.57±12.94	30494 ±89	480828±1893	515424±748	
$Signal\ or\ not$	203.35±6.42	30291 ±89	480828±1893	515424±748	
$M_{missing} < M_{dimuon}$	108.36±4.68	27112 ±75	462222±1857	474655±718	0.1104
$N(pfo)$	103.09±4.57	19806 ±66	17185 ±358	313602±583	0.1741
M_{dijet}	97.83 ±4.45	4531 ±41	44 ±18	250527±521	0.1937
M_{dimuon}	83.85 ±4.12	3468 ±25	14 ±10	174150±434	0.1989
$M_{missing}$	64.81 ±3.62	1961 ±19	7 ±7	11132 ±109	0.5648
$*cos\ \theta$	64.81 ±3.62	1961 ±19	7 ±7	11132 ±109	0.5648
$cos\theta_{visible}$	60.76 ±3.51	1796 ±18	0 ±0	6827 ±86	0.652
$Angle_{\mu j}$	53.27 ±3.28	1197 ±14	0 ±0	1264 ±37	1.0622
M^{rec}_{dimuon}	51.24 ±3.22	1194 ±14	0 ±0	661 ±26	1.1737
M^{rec}_{dijet}	48.41 ±3.13	950 ±13	0 ±0	534 ±24	1.2364
$M_{visible}$	45.37 ±3.03	749 ±11	0 ±0	464 ±22	1.2781
$*P_{visible}$	45.37 ±3.03	749 ±11	0 ±0	464 ±22	1.2781
$*P_{T_{visible}}$	45.37 ±3.03	749 ±11	0 ±0	464 ±22	1.2781
$*E_{leading\ jet}$	45.37 ±3.03	749 ±11	0 ±0	464 ±22	1.2781
$*P_{T_{leading\ jet}}$	45.37 ±3.03	749 ±11	0 ±0	464 ±22	1.2781
$*E_{sub-leading\ jet}$	45.37 ±3.03	749 ±11	0 ±0	464 ±22	1.2781
$*P_{T_{sub-leading\ jet}}$	45.37 ±3.03	749 ±11	0 ±0	464 ±22	1.2781
$not\ \mu^+\mu^- HZZ$	39.5 ±2.83	275 ±7	0 ±0	345 ±19	1.5366
$not\ \nu\nu HZZ$	39.5 ±2.83	275 ±7	0 ±0	345 ±19	1.5366±0.2257

$$35 < N_{pfo} < 100$$
$$75 < M_{dijet} < 110$$

μμHqqνν upgrade

Table 18: Cut flow table for $qq\mu\mu\nu\nu$ channel

Cut	Signal	ZH Background	2f Background	4f Background	$\frac{S}{\sqrt{S+B}}$
Expected	20254.08±64.05	1140511±6	801811977±420	107203890±11210	
$Pre-selection$	826.57±12.94	30494 ±89	480828±1893	515424±748	
$Signal\ or\ not$	203.35±6.42	30291 ±89	480828±1893	515424±748	
$M_{missing} < M_{dimuon}$	108.36±4.68	27112 ±75	462222±1857	474655±718	0.1104
$N(pfo)(40,95)$	96.21 ±4.41	17726 ±63	10817 ±284	290704±561	0.1702
$M_{dijet}(75,105)$	87.7 ±4.21	3248 ±37	14 ±10	225594±494	0.1833
M_{dimuon}	74.94 ±3.9	2356 ±20	7 ±7	157235±412	0.1875
$M_{missing}$	57.52 ±3.41	1434 ±16	0 ±0	9677 ±102	0.5443
$*cos\ \theta$	57.52 ±3.41	1434 ±16	0 ±0	9677 ±102	0.5443
$cos\theta_{visible}$	54.48 ±3.32	1313 ±15	0 ±0	5748 ±78	0.6459
$Angle_{\mu j}$	48.2 ±3.12	952 ±12	0 ±0	1160 ±35	1.037
M^{rec}_{dimuon}	46.18 ±3.06	949 ±12	0 ±0	587 ±25	1.1606
M^{rec}_{dijet}	43.34 ±2.96	733 ±11	0 ±0	472 ±22	1.2264
$M_{visible}$	40.71 ±2.87	647 ±10	0 ±0	418 ±21	1.2237
$*P_{visible}$	40.71 ±2.87	647 ±10	0 ±0	418 ±21	1.2237
$*P_{T_{visible}}$	40.71 ±2.87	647 ±10	0 ±0	418 ±21	1.2237
$*E_{leading\ jet}$	40.71 ±2.87	647 ±10	0 ±0	418 ±21	1.2237
$*P_{T_{leading\ jet}}$	40.71 ±2.87	647 ±10	0 ±0	418 ±21	1.2237
$*E_{sub-leading\ jet}$	40.71 ±2.87	647 ±10	0 ±0	418 ±21	1.2237
$*P_{T_{sub-leading\ jet}}$	40.71 ±2.87	647 ±10	0 ±0	418 ±21	1.2237
$not\ \mu^+\mu^- HZZ$	35.44 ±2.68	206 ±6	0 ±0	305 ±18	1.5143
$not\ \nu\nu HZZ$	35.44 ±2.68	206 ±6	0 ±0	305 ±18	1.5143±0.2218

$$40 < N_{pfo} < 95$$
$$75 < M_{dijet} < 105$$

BDT on μμHZZ (vvjj)

➢ Pre-BDT cuts

Cut
$M_{missing} > M_{di-jet}$
$20 < N(pfo) < 90$
$80 < M_{di-muon} < 100$
$110 < M_{di-muon}^{recoil} < 140$
$\lvert\cos\theta_{visible}\rvert < 0.95$

➢ ROC Curve

BDT on μμHZZ (ννjj)

- **Output BDT score**

- **$\frac{S}{\sqrt{S+B}}$ vs BDT score cut**

BDT on μμHZZ (ννjj)

➢ **Cut Flow**

BDT this time

Cut	Signal	ZH Background	2f Background	4f Background	$\frac{S}{\sqrt{S+B}}$
$Expected$	1000	1140511	801811977	107203890	
$Pre-selection$	616	30494	480828	515424	
$Signal\ or\ not$	211	30282	480828	515424	
$M_{missing} > M_{dijet}$	107	1608	115062	28811	0.283
$N(pfo)$	104	908	33480	14161	0.4722
M_{dimuon}	92	296	24151	1629	0.5714
M^{rec}_{dimuon}	89	256	1642	406	1.8279
$cos\theta_{visible}$	85	240	388	127	2.9422
$BDT\ score$	45	6	0	2	6.1727

Merely cut-based

Cut	Signal	ZH Background	2f Background	4f Background	$\frac{S}{\sqrt{S+B}}$
$Expected$	1000	1140511	801811977	107203890	
$Pre-selection$	616	30494	480828	515448	
$Signal\ or\ not$	211	30282	480828	515448	
$M_{missing} > M_{dijet}$	107	1608	115062	28809	0.283
$N(pfo)$	104	908	33480	14159	0.4722
M_{dimuon}	92	296	24151	1625	0.5714
M_{dijet}	87	280	851	819	1.9395
$M_{missing}$	71	124	97	101	3.6196
$*cos\ \theta$	71	124	97	101	3.6196
$cos\theta_{visible}$	68	118	22	39	4.349
$Angle_{\mu j}$	62	95	14	20	4.4919
M^{rec}_{dimuon}	61	79	14	8	4.7795
M^{rec}_{dijet}	59	69	0	4	5.1374
$*M_{visible}$	59	69	0	4	5.1374
$*P_{visible}$	59	69	0	4	5.1374
$*P_{T_{visible}}$	59	69	0	4	5.1374
$*E_{leading\ jet}$	59	69	0	4	5.1374
$*P_{T_{leading\ jet}}$	59	69	0	4	5.1374
$*E_{sub-leading\ jet}$	59	69	0	4	5.1374
$*P_{T_{sub-leading\ jet}}$	59	69	0	4	5.1374
$not\ qqHZZ$	59	69	0	4	5.1374
$not\ \nu\nu HZZ$	50	36	0	4	5.2503

BDT on μμHZZ (jjνν)

➢ Pre-BDT cuts

Cut
$M_{missing} < M_{di-jet}$
$20 < N(pfo) < 90$
$80 < M_{di-muon} < 100$
$110 < M_{di-muon}^{recoil} < 140$
$\lvert\cos\theta_{visible}\rvert < 0.95$

➢ ROC Curve

BDT on μμHZZ (jjνν)

- **Output BDT score**

- **$\frac{S}{\sqrt{S+B}}$ vs BDT score cut**

BDT on μμHZZ (jjνν)

- **Cut Flow**

BDT this time

Cut	Signal	ZH Background	2f Background	4f Background	$\frac{S}{\sqrt{S+B}}$
$Expected$	1000	1140511	801811977	107203890	
$Pre-selection$	616	30494	480828	515424	
$Signal\ or\ not$	211	30282	480828	515424	
$M_{missing} < M_{dijet}$	103	28674	365766	486613	0.1102
$N(pfo)$	100	21686	12184	332136	0.1657
M_{dimuon}	89	16833	9085	207927	0.186
M^{rec}_{dimuon}	87	16144	321	25675	0.4236
$cos\theta_{visible}$	82	14667	0	12539	0.4992
$BDT\ score$	54	806	0	605	1.4262

Merely cut-base

Cut	Signal	ZH Background	2f Background	4f Background	$\frac{S}{\sqrt{S+B}}$
$Expected$	1000	1140511	801811977	107203890	
$Pre-selection$	616	30494	480828	515448	
$Signal\ or\ not$	211	30282	480828	515448	
$M_{missing} < M_{dijet}$	103	28674	365766	486638	0.1102
$N(pfo)$	100	21686	12184	332162	0.1657
M_{dimuon}	89	16833	9085	207927	0.186
M_{dijet}	82	2768	52	173775	0.1974
$M_{missing}$	71	1679	14	13434	0.5804
$*cos\ \theta$	71	1679	14	13434	0.5804
$cos\theta_{visible}$	67	1535	0	8545	0.6749
$Angle_{\mu j}$	57	1109	0	2197	0.995
M^{rec}_{dimuon}	56	1048	0	941	1.2488
$*M^{rec}_{dijet}$	56	1048	0	941	1.2488
$M_{visible}$	54	930	0	790	1.2823
$*P_{visible}$	54	930	0	790	1.2823
$*P_{T_{visible}}$	54	930	0	790	1.2823
$*E_{leading\ jet}$	54	930	0	790	1.2823
$*P_{T_{leading\ jet}}$	54	930	0	790	1.2823
$*E_{sub-leading\ jet}$	54	930	0	790	1.2823
$*P_{T_{sub-leading\ jet}}$	54	930	0	790	1.2823
$not\ qqHZZ$	46	738	0	644	1.2343
$not\ \nu\nu HZZ$	46	738	0	644	1.2343

Next to do

- **Complete the other 4 channels' BDT study**