MEASUREMENT OF $Br(H \to WW^*)$ AT CEPC

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Outline:

1. Motivation
2. MC sample
3. Measurement of branch ratio
4. Summary

1. Motivation

1) This measurement is the most substantial channel to study Higgs to vector boson coupling behaviors at the CEPC.

2) The $Br(H \rightarrow WW^*)$ measurement is also a key ingredient for the determination of Higgs boson width.

3) It provides an excellent benchmark for the detector performance studies.

Excepted signal events of each type

W boson decay \ Z boson decay	ee	$\mu\mu$	$\tau\tau$	$\nu\nu$	qq
$WW^* \to e\nu e\nu$	88	88	88	525	1836
$WW^* \to \mu\nu\mu\nu$	87	87	87	517	1808
$WW^* \to e\nu\mu\nu$	175	175	175	1052	3644
$WW^* \to e\nu\tau\nu$	187	187	188	1116	3901
$WW^* \to \mu\nu\tau\nu$	186	186	186	1107	3872
$WW^* \to \tau\nu\tau\nu$	99	99	99	593	2072
$WW^* \to e\nu qq$	1111	1112	1114	6612	23112
$WW^* \to \mu\nu qq$	1103	1104	1105	6562	22939
$WW^* \to \tau\nu qq$	1181	1182	1183	7025	24558
$WW^* \to qqqq$	3498	3502	3506	20808	72735

Done

To do

Wei Yuqian's work

Mila

2. MC sample

Integrated luminosity: 5ab^{-1} , $m_H = 125\text{GeV}, \sqrt{s} = 250\text{GeV}$

Tool:

Generator: Whizard 1.95

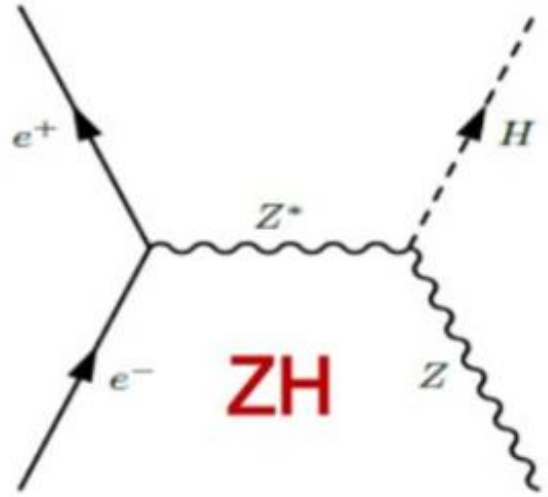
Simulation: Gent4

Particle reconstruction: Arbor_kd_3.3

Charged PID: LICH

Jet clustering: $ee - k_T$

Flavor tagging: LCFIPlus



Dominant diagram

Efficiency of lepton reconstruction

Z boson decay	W boson decay	Excepted	Yield	Observable	Efficiency
$\mu^+\mu^-$	$e\nu e\nu$	89	88	76	86%
	$\mu\nu\mu\nu$	87	89	80	90%
	$e\nu\mu\nu$	176	174	157	90%
	$e\nu q\bar{q}$	1117	1105	1042	94.3%
	$\mu\nu q\bar{q}$	1106	1110	1056	95.1%
e^+e^-	$e\nu e\nu$	95	91	62	68%
	$\mu\nu\mu\nu$	94	82	63	77%
	$e\nu\mu\nu$	188	178	132	74%
	$e\nu q\bar{q}$	1195	1182	1041	80.1%
	$\mu\nu q\bar{q}$	1184	1221	1194	80.0%

Table 5: Resonstruction efficiency of leptons in each decay channels. Excepted is the number of the theoretical events. Yield is the number of real generation events. Observable is the number of true events after leptons' and jets' number selection. The efficiency is observable over yield.

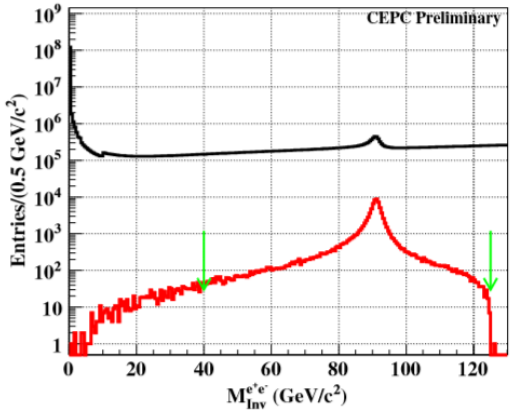
Efficiency of electron: >90%

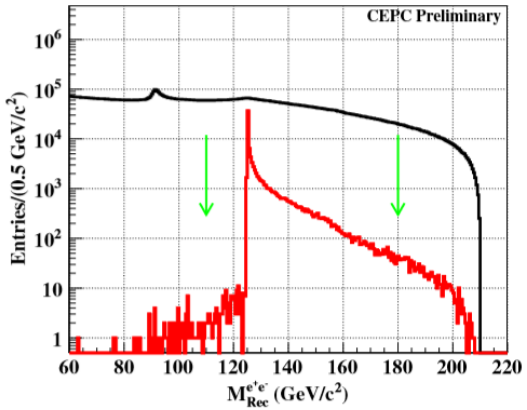
Efficiency of muon: >95%

2.1 Pre-selection

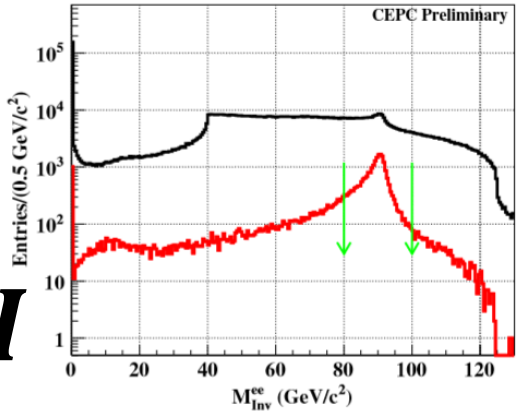
Key point:
Applied loose conditions in truth to make pre-selection reasonable.

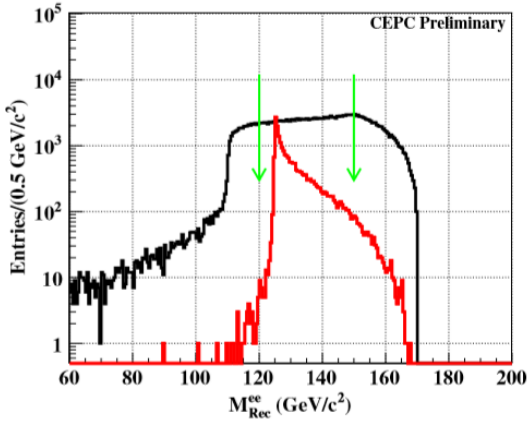
Four classes:
$\boldsymbol{llH(l = e, \mu)}$**,** $\boldsymbol{\tau\tau H}$**,** $\boldsymbol{\nu\nu H}$ **and** $\boldsymbol{qqH}$**.**
$\boldsymbol{llH(l = e, \mu)}$ ***and*** $\boldsymbol{\nu\nu H}$ **have been done.**

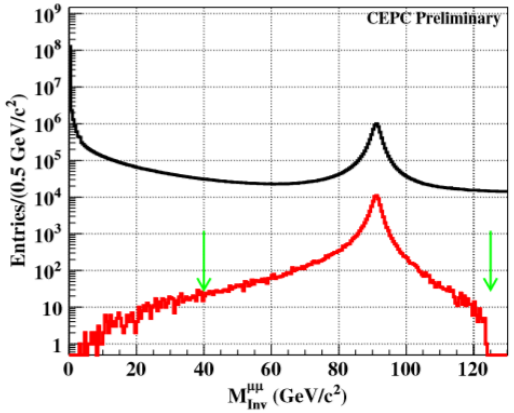


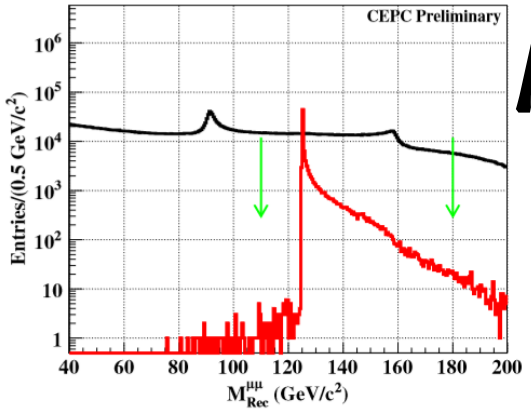


eeH

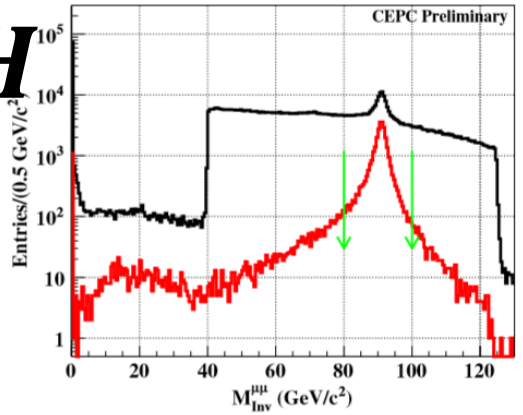


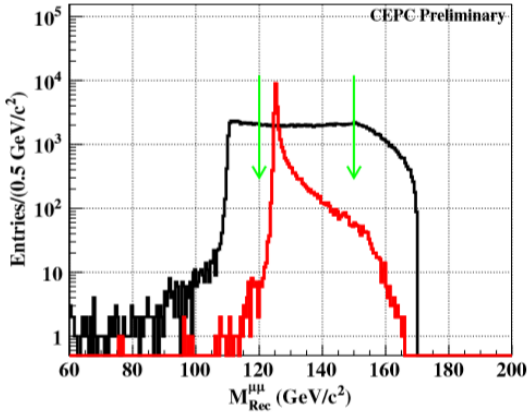




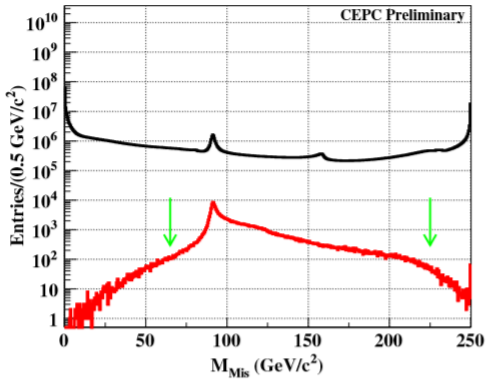


$\mu\mu H$





Process of signal	eeH process	$\mu\mu H$ process
conditions of pre-selection	$40\ \mathrm{GeV}/c^2 < M^{ee}_{Inv} < 130\ \mathrm{GeV}/c^2$ $110\ \mathrm{GeV}/c^2 < M^{ee}_{Rec} < 180\ \mathrm{GeV}/c^2$	$40\ \mathrm{GeV}/c^2 < M^{\mu\mu}_{Inv} < 130\ \mathrm{GeV}/c^2$ $110\ \mathrm{GeV}/c^2 < M^{\mu\mu}_{Rec} < 180\ \mathrm{GeV}/c^2$
conditions of validation	$80\ \mathrm{GeV}/c^2 < M^{ee}_{Inv} < 100\ \mathrm{GeV}/c^2$ $120\ \mathrm{GeV}/c^2 < M^{ee}_{Rec} < 150\ \mathrm{GeV}/c^2$	$80\ \mathrm{GeV}/c^2 < M^{\mu\mu}_{Inv} < 100\ \mathrm{GeV}/c^2$ $120\ \mathrm{GeV}/c^2 < M^{\mu\mu}_{Rec} < 150\ \mathrm{GeV}/c^2$



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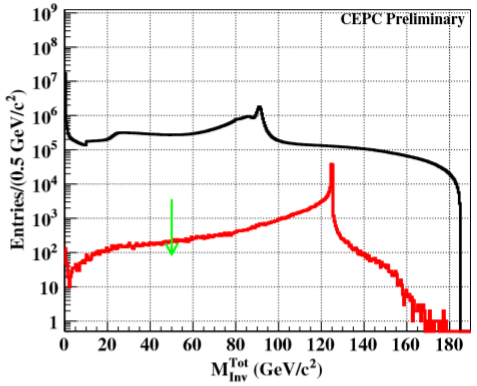
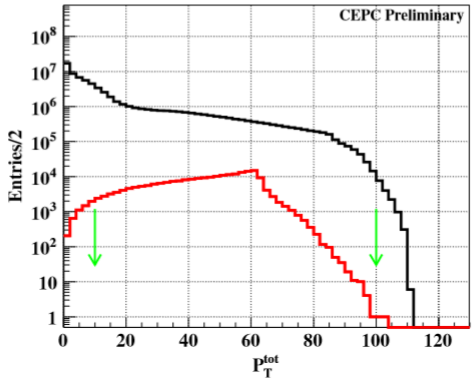
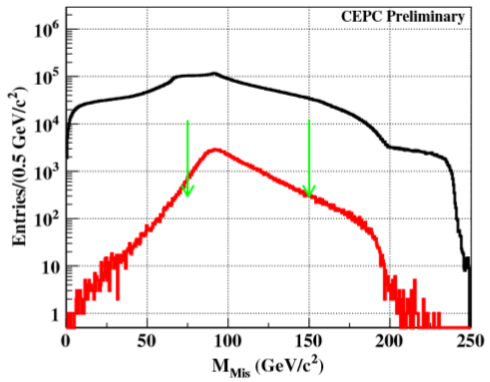


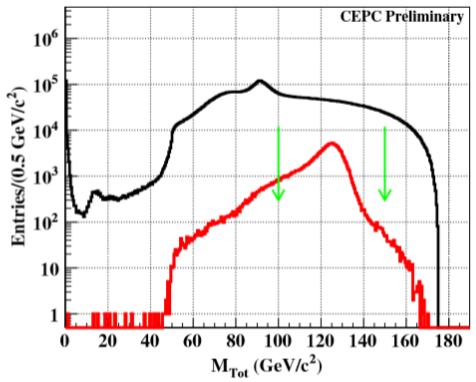
(b)



$\nu\nu H$



(a)



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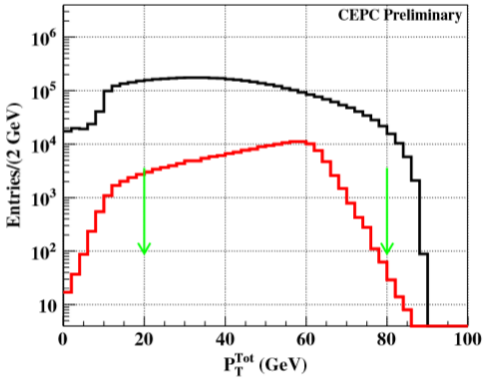


Process of signal	$\nu\nu H$
conditions of pre-selection	$65\ \mathrm{GeV}/c^2 < M_{Mis} < 225\ \mathrm{GeV}/c^2$ $M_{Tot} > 50\ \mathrm{GeV}/c^2$ $10\ \mathrm{GeV}/c < p_T < 100\ \mathrm{GeV}/c$
conditions of validation	$75\ \mathrm{GeV}/c^2 < M_{Mis} < 150\ \mathrm{GeV}/c^2$ $100\ \mathrm{GeV}/c^2 < M_{Tot} < 150\ \mathrm{GeV}/c^2$ $20\ \mathrm{GeV}/c < p_T < 80\ \mathrm{GeV}/c$

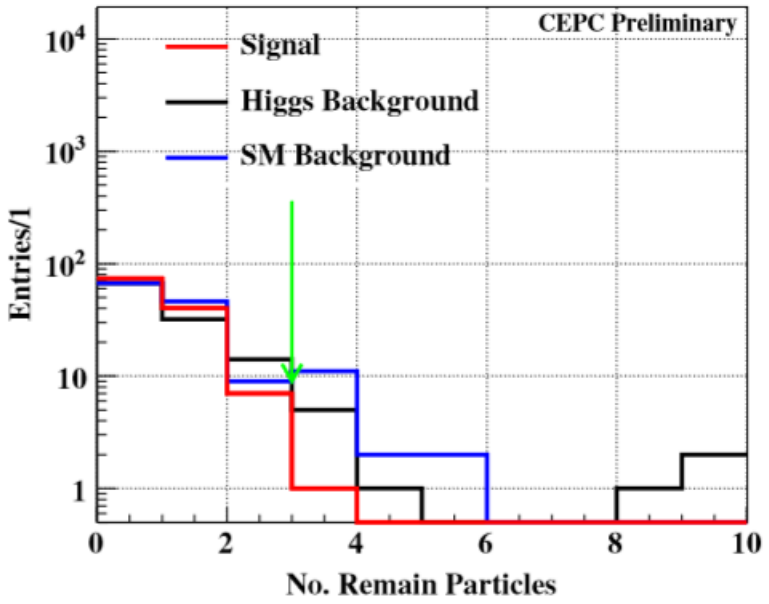
3. Measurement of branch ratio

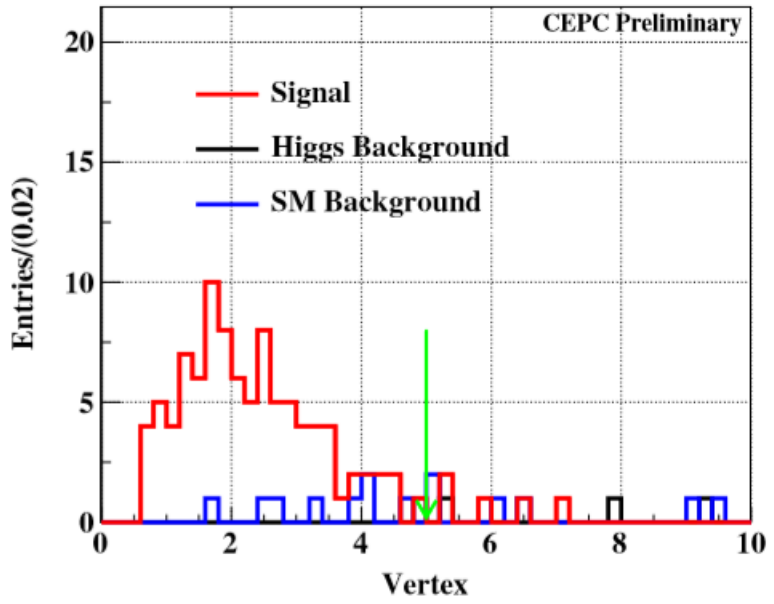
Three typical sub-channels would be described in details:

1. $e^+e^- \to ZH,\ \ Z \to \mu^+\mu^-,\ \ H \to WW^* \to e\nu\mu\nu$
2. $e^+e^- \to ZH,\ Z \to e^+e^-,\ H \to WW^* \to \mu\nu qq$
3. $e^+e^- \to ZH,\ Z \to \nu\bar{\nu},\ H \to WW^* \to qqqq$

Relative uncertainty results of the other sub-channels would be listed in the final page.

3.1 Event selection of $ZH \rightarrow \mu\mu e\nu\mu\nu$ process



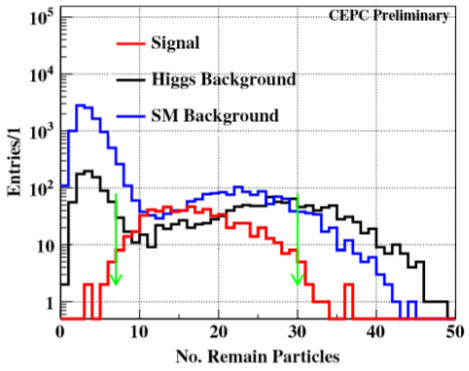


Category	Signal	ZH background	SM background
Total	172	34624	700311
Validation of pre-selection	136	29263	117395
$N_{ZPole} = 2; N_{Isolep} = 2; l_1 = e, l_2 = \mu$	122	145	150
$N_{Remain} < 3$	121	113	122
$10\ \text{GeV} < M_{Inv}^{e\mu} < 65\ \text{GeV}$	116	101	87
$M_{Missing} < 65\ \text{GeV}/c^2$	110	26	36
$\sqrt{(\frac{D0}{sigD0})^2 + (\frac{Z0}{sigZ0})^2} < 5$	93	3	10

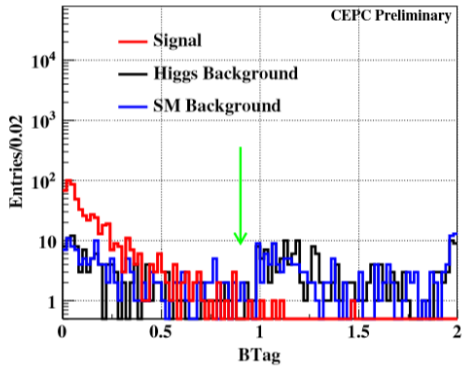
The main background of this channel is the events included τ or b-jet.

And after event selection, the main background is $e^+e^- \rightarrow ZZ \rightarrow \mu\mu\tau\tau$

3.2 Event selection of $ZH \rightarrow ee\mu\nu qq$ process



(a)



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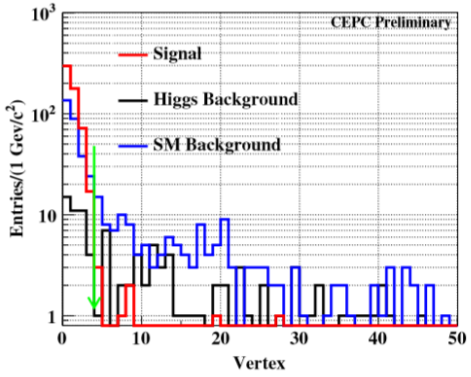
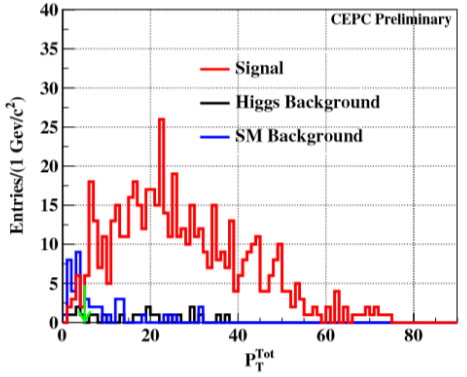
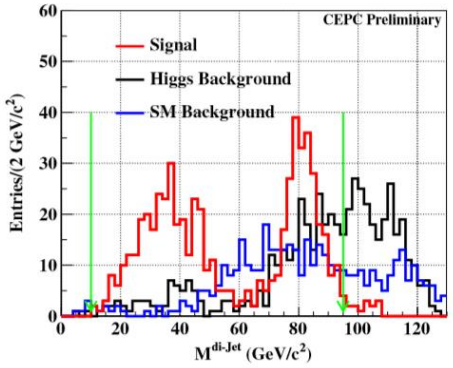






Category	Signal	ZH background	SM background
Total	1149	36319	1303847
$N_{ZPole} = 2; N_{Isolep} = 1; N_{Jets} = 2; l = \mu$	1022	1970	21857
Validation of pre-selection	631	1207	2987
$7 < N_{Remain} < 30$	603	540	436
$15\ \mathrm{GeV}/c^2 < M_{Rec}^{di-Jet} < 95\ \mathrm{GeV}/c^2$	589	284	278
$Btag < 0.9$	584	116	131
$M_{Missing} < 45\ \mathrm{GeV}/c^2$	571	72	102
$\sqrt{(\frac{D0}{sigD0})^2 + (\frac{Z0}{sigZ0})^2} < 4$	564	23	45
$p_T > 5$ GeV	551	18	21

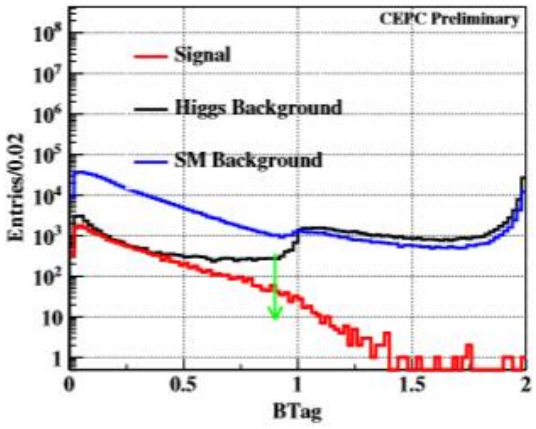
The main background of this channel is the events included τ or b-jet.

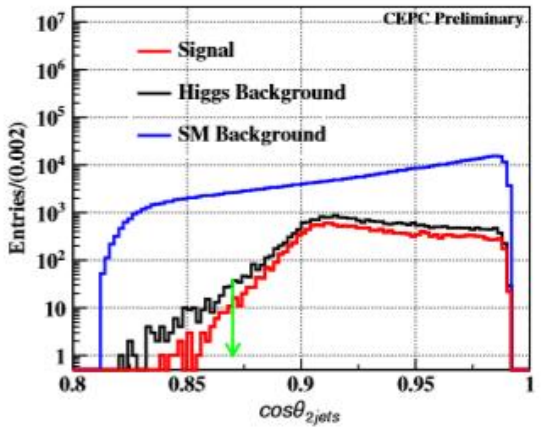
And after event selection, the main background is

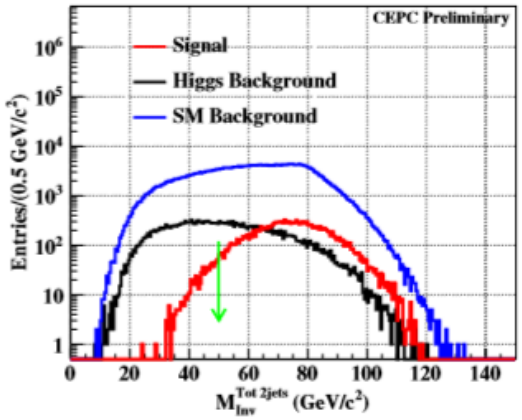
$$e^+e^- \rightarrow ZH \rightarrow ZWW^* \rightarrow \nu\nu\tau\nu qq$$

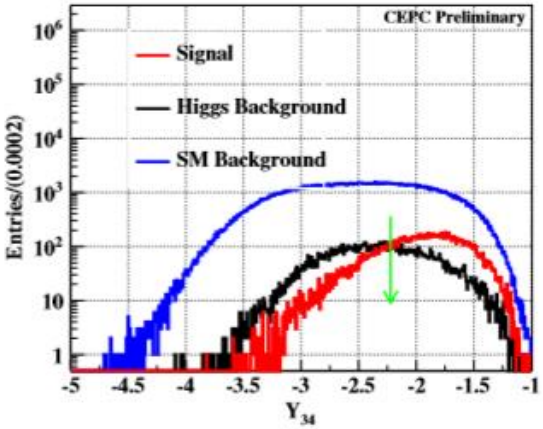
$$e^+e^- \rightarrow eeZ \rightarrow eeqq$$

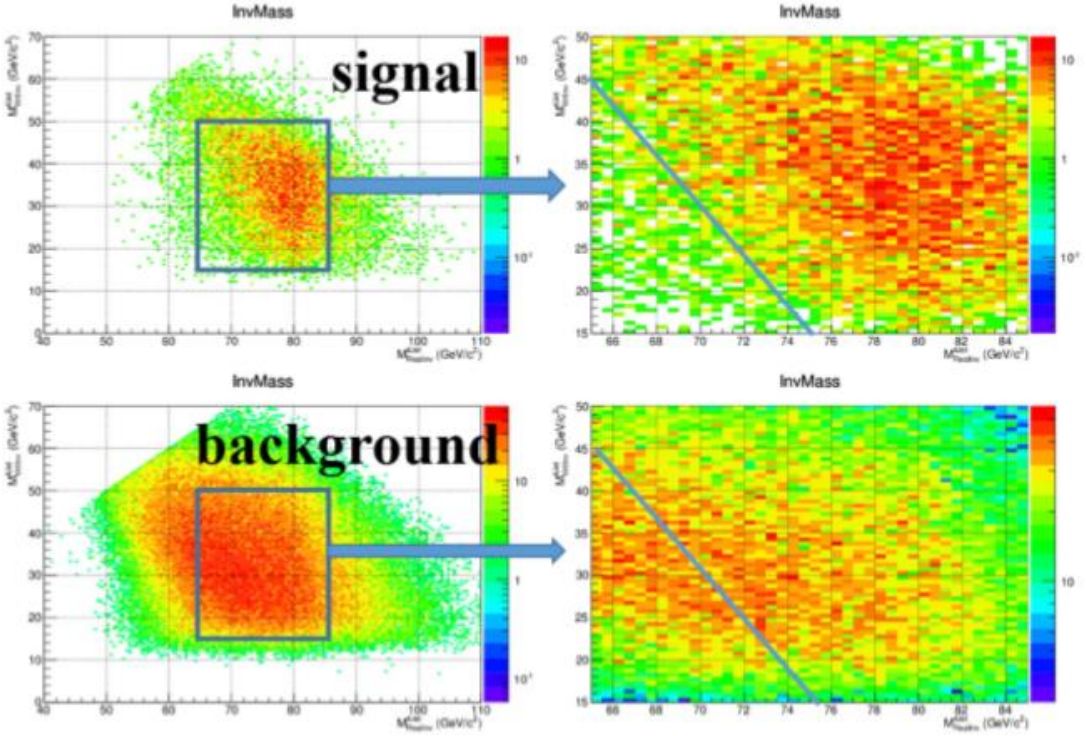
3.3 Event selection of $ZH \rightarrow vvqqqq$ process







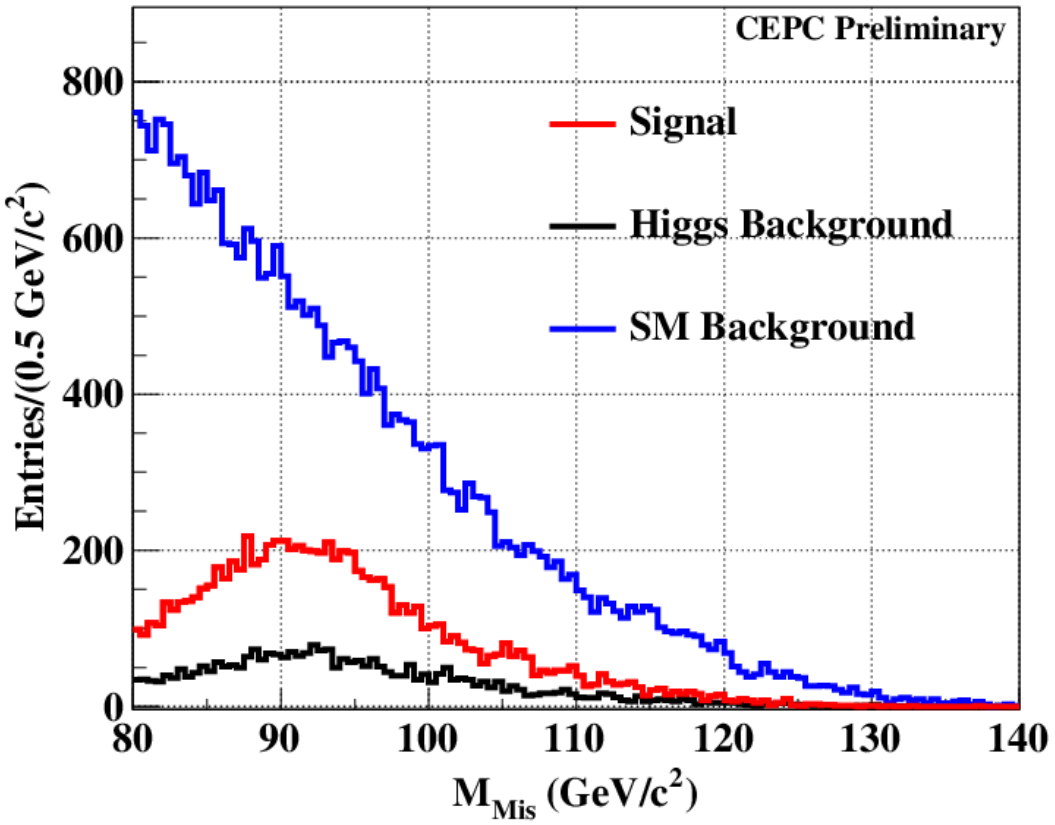




Category	Signal	ZH background	SM background
Total	23938	208200	21314314
Validation of pre-selection	20405	143765	3166923
$N^{Tot}_{Particle} > 20$	19681	124112	537839
$Btag < 0.9$	19349	28857	477099
$Cos\theta_{2jets} > 0.87$	19298	28673	433563
$\Sigma\lvert M^{2jet}_{Inv}\rvert > 50$ GeV	18621	14793	309919
$Y_{34} > 0.005$	15183	6919	122866
Combined Variable	9022	3075	38226

3.3 Event selection of $ZH \rightarrow \nu\nu qqqq$ process

Final result:



After event selection, the main background is

$$e^+e^- \rightarrow ZH \rightarrow \nu\nu gg$$

$$e^+e^- \rightarrow WW \rightarrow \tau\nu qq$$

Decay Chain	Final States	Number of Events
$e^+e^- \rightarrow ZH, Z \rightarrow \nu\bar{\nu}, H \rightarrow c\bar{c}$	$\nu, \bar{\nu}, c, \bar{c}$	176
$e^+e^- \rightarrow ZH, Z \rightarrow \nu\bar{\nu}, H \rightarrow b\bar{b}$	$\nu, \bar{\nu}, b, \bar{b}$	337
$e^+e^- \rightarrow ZH, Z \rightarrow \nu\bar{\nu}, H \rightarrow gg$	$\nu, \bar{\nu}, 2g$	1881
$e^+e^- \rightarrow ZH, Z \rightarrow \nu\bar{\nu}, H \rightarrow ZZ^*, ZZ^* \rightarrow q\bar{q}q\bar{q}$	$\nu, \bar{\nu}, 2q, 2\bar{q}$	421
$e^+e^- \rightarrow ZZ, ZZ \rightarrow \nu\bar{\nu}q\bar{q}$	$\nu, \bar{\nu}, q, \bar{q}$	2826
$e^+e^- \rightarrow ZZ, ZZ \rightarrow \tau^+\tau^- q\bar{q}$	$\tau^+, \tau^-, q, \bar{q}$	733
$e^+e^- \rightarrow WW, WW \rightarrow \tau\nu q\bar{q}$	$\tau, \nu, q, \bar{q}$	22580
$e^+e^- \rightarrow WW, WW \rightarrow \mu\nu q\bar{q}$	$\mu, \nu, q, \bar{q}$	232
$e^+e^- \rightarrow \nu\bar{\nu}Z, Z \rightarrow q\bar{q}$	$\nu, \bar{\nu}, q, \bar{q}$	1721
$e^+e^- \rightarrow e\nu W, W \rightarrow e\nu q\bar{q}$	$e, \nu, q, \bar{q}$	1168
$e^+e^- \rightarrow qq$	$2q$	227

5. Summary

The relative uncertainties of $Br(Z \rightarrow X)$, $Br(W \rightarrow X)$ and N_{Total} are negligible

Category	Signal	Relative uncertainty	Efficiency of selection
$Z \rightarrow e^+e^-; H \rightarrow WW^* \rightarrow e\nu e\nu$	20±7	35%	25.0%
$Z \rightarrow e^+e^-; H \rightarrow WW^* \rightarrow \mu\nu\mu\nu$	44±8	18.2%	43.1%
$Z \rightarrow e^+e^-; H \rightarrow WW^* \rightarrow e\nu\mu\nu$	53±8	15.1%	27.6%
$Z \rightarrow e^+e^-; H \rightarrow WW^* \rightarrow e\nu qq$	435±23	5.3%	37.0%
$Z \rightarrow e^+e^-; H \rightarrow WW^* \rightarrow \mu\nu qq$	551±24	4.5%	48.0%
$Z \rightarrow \mu^+\mu^-; H \rightarrow WW^* \rightarrow e\nu e\nu$	23±5	21.7%	25.8%
$Z \rightarrow \mu^+\mu^-; H \rightarrow WW^* \rightarrow \mu\nu\mu\nu$	39±7	18%	44.8%
$Z \rightarrow \mu^+\mu^-; H \rightarrow WW^* \rightarrow e\nu\mu\nu$	93±10	11%	54.1%
$Z \rightarrow \mu^+\mu^-; H \rightarrow WW^* \rightarrow e\nu qq$	573±25	4.0%	51.7%
$Z \rightarrow \mu^+\mu^-; H \rightarrow WW^* \rightarrow \mu\nu qq$	756±30	4.4%	68.4%
$Z \rightarrow \nu\bar{\nu}; H \rightarrow WW^* \rightarrow qqqq$	8403±202	2.4%	34.7%
$Z \rightarrow \mu^+\mu^-; H \rightarrow WW^* \rightarrow qqqq$	±	2.93%	**Wei Yuqian's work**

$$\frac{\Delta Br(H \rightarrow WW^*)}{Br(H \rightarrow WW^*)} = 1.40\%$$

To do:

1, optimize the cut chain

2, do a reasonable fit

3, analysis the other sub-channel

Thank you!