H→WW Branching Ratio Measurement

Tong LI

Shandong University

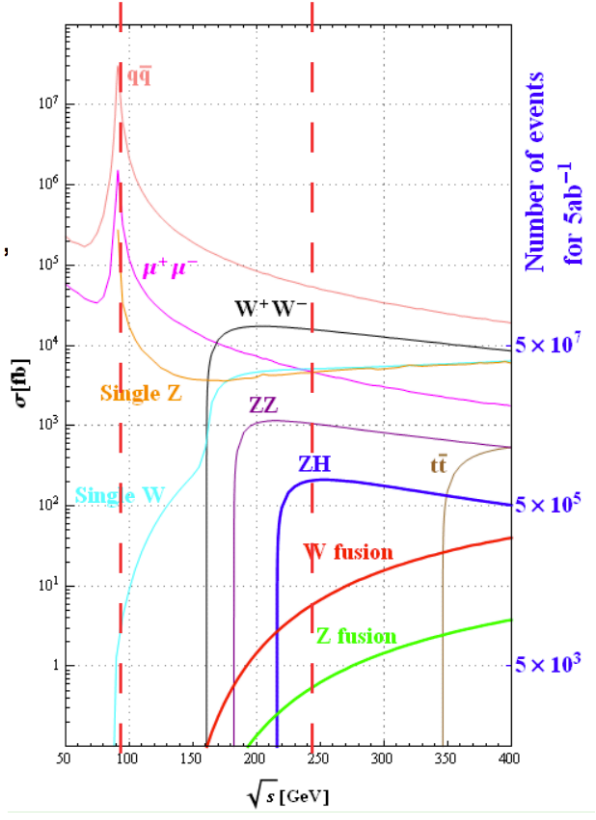
Workshop on the Circular Electron Positron Collider

24-26 May 2018, Rome

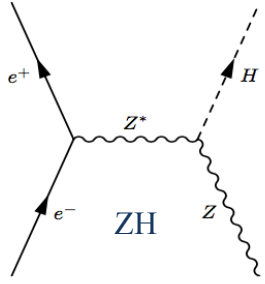
Contents

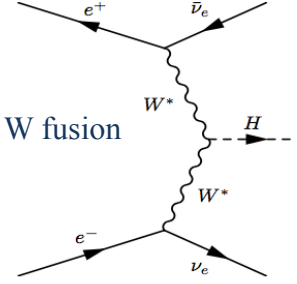
- Introduction
- MC samples
- Analysis with CEPC_v1 data
  - Pre-selections
  - Event selections
  - Results
- Analysis with CEPC_v4 data
  - Comparisons with CEPC_v1 results
- Summary

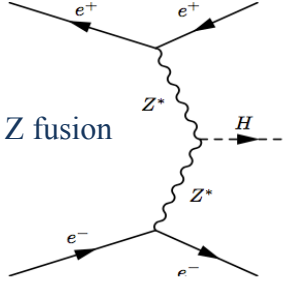
Introduction



Higgs productions at CEPC.







ZH process is the most dominant Higgs production channel at the CEPC.

As is predicted in the Standard Model theory, the branching ratio of H→WW is around 22%.

Motivation

- H->WW is an important channel to study Higgs couplings with vector bosons.
- Measurement of Br(H->WW) is crucial for the determination of Higgs width.
- Various final states of W boson decay (leptons, missing E_T, jets…) can provide a great benchmark to evaluate detector performance for CEPC.

MC samples

Process	Cross Section in fb	Number of Events in 5000fb^{-1}
Higgs production		
ZH	212	1.06×10^6
$\nu\bar{\nu}H$	6.27	3.36×10^4
e^+e^-H	0.63	3.15×10^3
total	219	1.10×10^6
Standard Model Background		
qq	50216	2.5×10^8
$\mu\mu$	4405	2.2×10^7
WW	15484	7.7×10^7
ZZ	1033	5.2×10^6
eeZ(single Z)	4734	2.4×10^7
$e\nu W$(single W)	5144	2.6×10^7
total	801016	3.54×10^8

Cross sections and number of events of signal and main SM background processes.

W boson decay \ Z boson decay	ee	$\mu\mu$	$\tau\tau$	$\nu\nu$	qq
$WW^* \to e\nu e\nu$	95	88	88	603	1836
$WW^* \to \mu\nu\mu\nu$	93	87	87	593	1808
$WW^* \to e\nu\mu\nu$	188	175	175	1206	3644
$WW^* \to e\nu\tau\nu$	201	187	188	1281	3901
$WW^* \to \mu\nu\tau\nu$	200	186	186	1271	3872
$WW^* \to \tau\nu\tau\nu$	107	99	99	681	2072
$WW^* \to e\nu qq$	1196	1112	1114	7589	23112
$WW^* \to \mu\nu qq$	1187	1104	1105	7530	22939
$WW^* \to \tau\nu qq$	1271	1182	1183	8066	24558
$WW^* \to qqqq$	3764	3502	3506	23884	72735

Signal events of H→WW processes.

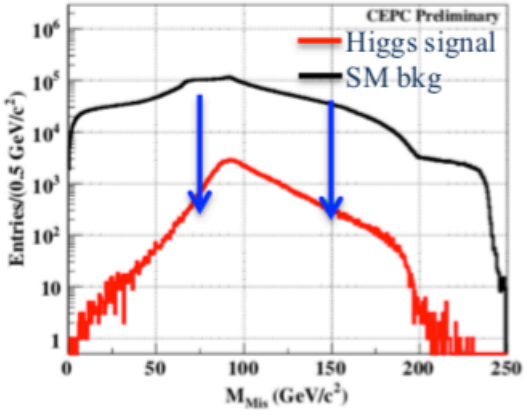
MC samples

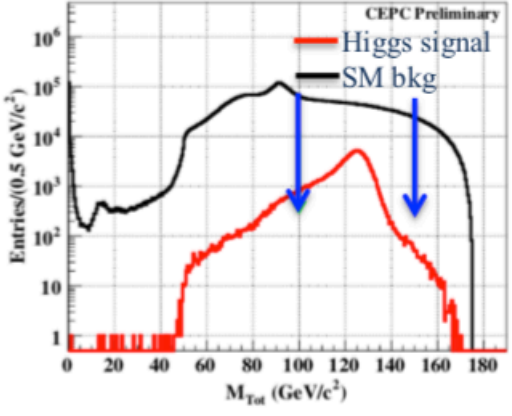
- Two sets of Z→νν, H→inclusive samples for signal process:
  - CEPC_v1 (√s = 250GeV, B field = 3.5Tesla…)
  - CEPC_v4 (√s = 240GeV, B field = 3.0Tesla…)

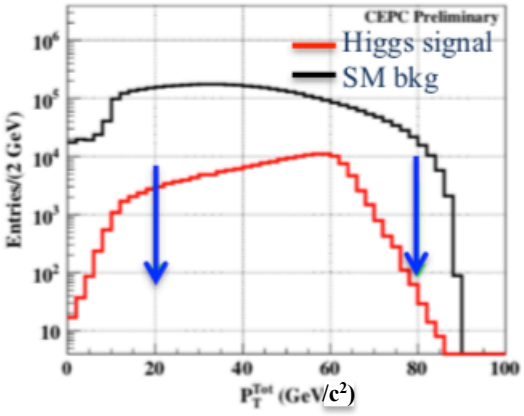
- Integrated luminosity is 5 ab^{-1}, background events are generated by Whizard1.95 including ISR, detector model is simulated by Geant4.
- Object reconstruction is done using the particle flow algorithm, Arbor. Charged particles identification is performed by LICH, ee-k_T algorithm is used for jet clustering, performance of b-tagging is given by LCFIPlus.

Analysis with CEPC_v1 data

- The missing mass, total mass and total p_T are used as the pre-selections.







$$75\ \mathrm{GeV}/c^2 < M_{Mis} < 150\ \mathrm{GeV}/c^2$$
$$100\ \mathrm{GeV}/c^2 < M_{Tot} < 150\ \mathrm{GeV}/c^2$$
$$20\ \mathrm{GeV}/c < p_T < 80\ \mathrm{GeV}/c$$

Pre-selections criteria.

Event selections

$$75\ \mathrm{GeV}/c^2 < M_{Mis} < 150\ \mathrm{GeV}/c^2$$
$$100\ \mathrm{GeV}/c^2 < M_{Tot} < 150\ \mathrm{GeV}/c^2$$
$$20\ \mathrm{GeV}/c < p_T < 80\ \mathrm{GeV}/c$$

- $65\ \mathrm{GeV}/c^2 < M_{Inv}^{Real4jet} < 85\ \mathrm{GeV}/c^2$,
- $15\ \mathrm{GeV}/c^2 < M_{Inv}^{Virt4jet} < 50\ \mathrm{GeV}/c^2$,
- $M_{Inv}^{Virt4jet} > -7/3 M_{Inv}^{Real4jet} + \frac{605}{3}\ \mathrm{GeV}/c^2$,

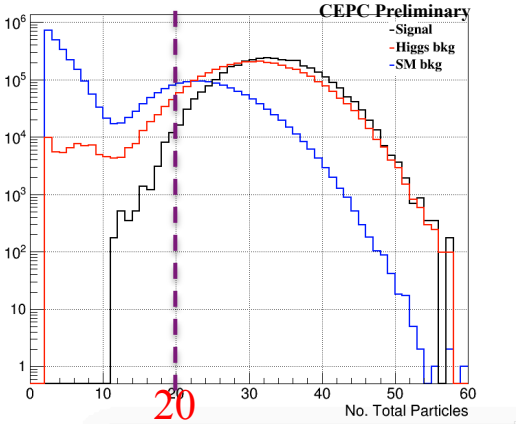
Validation of pre-selection

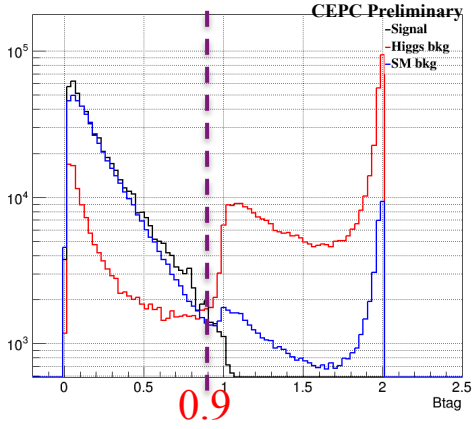
$$N_{Particle}^{Tot} > 20$$
$$Btag < 0.9$$
$$Cos\theta_{2jets} > 0.87$$
$$\Sigma|M_{Inv}^{2jet}| > 50\ \mathrm{GeV}$$
$$Y_{34} > 0.005$$

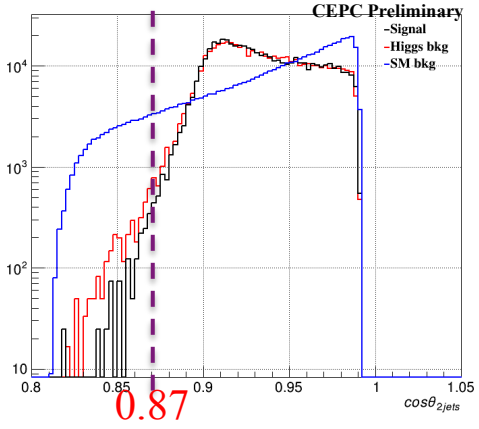
Combined Variable

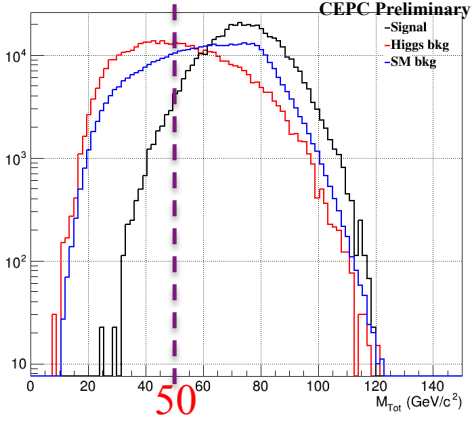
- Selections of jet is done by 2 steps:
  - Assuming that there are only 2 jets in each event, all particles are forced into 2 jets.
  - 4 jets hypothesis are made, to form all possible jet-pairs and the invariant mass are calculated. The jet-pair with invariant mass closest to W mass is taken as the on-shell W decay and the remaining 2 jets are assigned to the off-shell W decay.

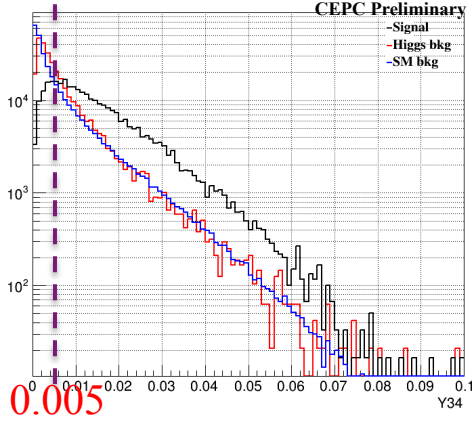
Distributions of discriminant variables











- No. of total particles.
- Sum of b-tagging of 2 jets.
- Cos angle of 2 jets.
- Total mass of 2 jets.
- Distance between jet3 and jet4.

Cut flow tables

My results:

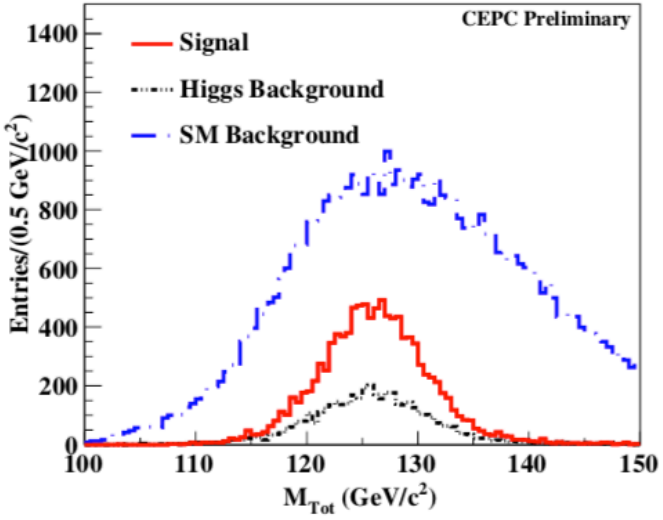
No. of signal	Relative efficiency	No. of Higgs bkg	Relative efficiency	No. of SM bkg	Relative effciency
24889		222278		22687012	
20454	82.18%	144169	64.86%	3528746	15.55%
19729	96.46%	124341	86.25%	537839	15.24%
19390	98.28%	28954	23.29%	477099	88.71%
19336	99.72%	28761	99.33%	433563	90.87%
18657	96.49%	14840	51.60%	309919	71.48%
15211	81.53%	6927	46.68%	122866	39.64%
9037	59.41%	3071	44.33%	38226	31.11%
Total efficiency	36.31%		1.38%		0.17%

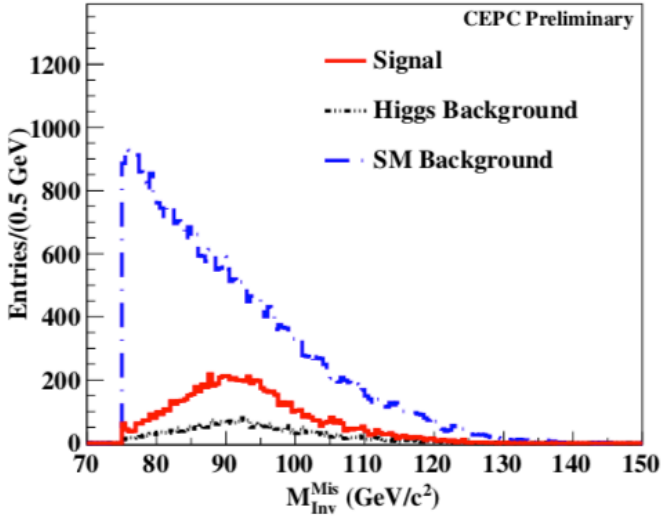
Results from Note:

No. of signal	Relative efficiency	No. of Higgs bkg	Relative efficiency	No. of SM bkg	Relative effciency
23938		208200		21314314	
20405	85.24%	143765	69.05%	3166923	14.86%
19681	96.45%	124112	86.33%	537839	16.98%
19349	98.31%	28857	23.25%	477099	88.71%
19289	99.69%	28673	99.36%	433563	90.87%
18621	96.54%	14793	51.59%	309919	71.48%
15183	81.54%	6919	46.77%	122866	39.64%
9022	59.42%	3075	44.44%	38226	31.11%
Total efficiency	37.68%		1.47%		0.17%

- Relative efficiency = Number of events after this cut / Number of events before this cut
- These results are consistent when considering the statistical uncertainty.

Results





Visible mass and missing mass after selections.

- N_{Signal} = 9037 ± 225
- Signal efficiency = 36.31%, ZH background efficiency = 1.38%
- Accuracy = √(S+B)/S = 2.49%

Branching ratio measurement

The formula for branching ratio measurement:

$$Br(H \to WW^*) = \frac{N_{sig}}{N_{total} \cdot \varepsilon \cdot Br_{rel.}}$$

$Br_{rel.}$ represents the branching fraction given by PDG:

	Total events N	$Br(W \to \ell\nu)$	$Br(W \to qq)$	$Br(Z \to \ell^+\ell^-)$	$Br(Z \to qq)$
Mean value	1060000	10.86%	67.41%	3.3658%	69.91%
Uncertainty	±4000	±0.09%	±0.27%	±0.0023%	±0.06%

According to the results of 13 sub-channels, the mean value of branching ratio is:

$$Br(H \to WW^*) = (\Sigma Br_i)/N$$

The Br_i is the result of each sub-channel. Br(H→WW) is 21.6%.

Precision for the measurement

The final result of precision is obtained by:

$$\Delta Br(H \to WW^*)/Br(H \to WW^*) = \sqrt{(\frac{\Delta N_{obs.}}{N_{obs.}})^2 + (\frac{\Delta N_{total}}{N_{total}})^2 + (\frac{\Delta Br_{rel.}}{Br_{rel.}})^2}$$

Precision of N_{total} and $Br_{rel.}$ are negligible. The equation would be:

$$\Delta Br(H \to WW^*)/Br(H \to WW^*) \sim \sqrt{(\frac{\Delta N_{obs.}}{N_{obs.}})^2}$$

Define a variable Υ_i as the precision of each sub-channel, Υ_{ij} as the combined precision of two sub-channels:

$$\Gamma_{ij}^2 = \frac{\Gamma_i^2 \Gamma_j^2}{\Gamma_i^2 + \Gamma_j^2}$$

The overall combination results of statistical uncertainty for Br(H→WW) is 1.29%.

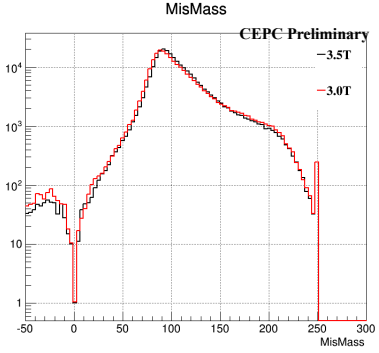
Summary of the results

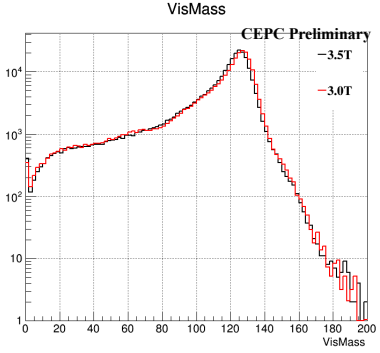
Category	Signal	Relative uncertainty	Efficiency of selection
$Z \to e^+e^-; H \to WW^* \to evev$	20±7	35.0%	21.1%
$Z \to e^+e^-; H \to WW^* \to \mu\nu\mu\nu$	44±8	18.2%	47.3%
$Z \to e^+e^-; H \to WW^* \to ev\mu\nu$	53±8	15.1%	28.2%
$Z \to e^+e^-; H \to WW^* \to evqq$	435±23	5.3%	36.4%
$Z \to e^+e^-; H \to WW^* \to \mu\nu qq$	551±24	4.5%	46.4%
$Z \to \mu^+\mu^-; H \to WW^* \to evev$	23±5	21.7%	26.1%
$Z \to \mu^+\mu^-; H \to WW^* \to \mu\nu\mu\nu$	39±7	17.9%	44.8%
$Z \to \mu^+\mu^-; H \to WW^* \to ev\mu\nu$	93±10	10.7%	53.1%
$Z \to \mu^+\mu^-; H \to WW^* \to evqq$	573±25	4.0%	51.5%
$Z \to \mu^+\mu^-; H \to WW^* \to \mu\nu qq$	756±30	4.4%	68.4%
$Z \to \mu^+\mu^-; H \to WW^* \to qqqq$	±	2.9%	
$Z \to \nu\bar{\nu}; H \to WW^* \to evqq$	680±32	4.7%	9.0%
$Z \to \nu\bar{\nu}; H \to WW^* \to \mu\nu qq$	790±43	4.2%	10.5%
$Z \to \nu\bar{\nu}; H \to WW^* \to qqqq$	9022±224	2.5%	37.8%

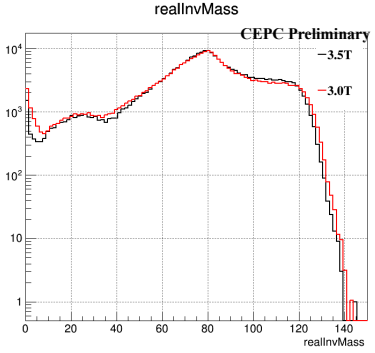
Summary of the H→WW branching ratio measurements with CEPC_v1.

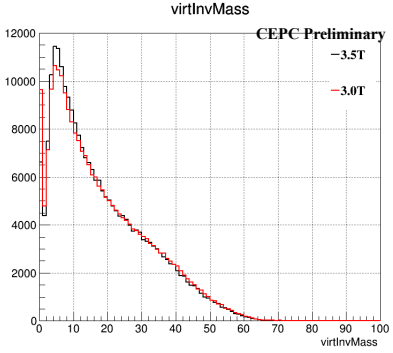
Analysis with CEPC_v4 data

Z→νν, H→inclusive:

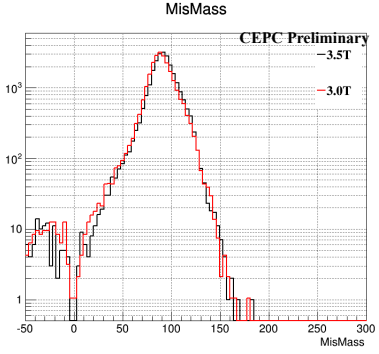


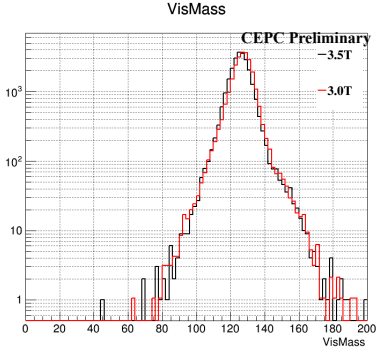


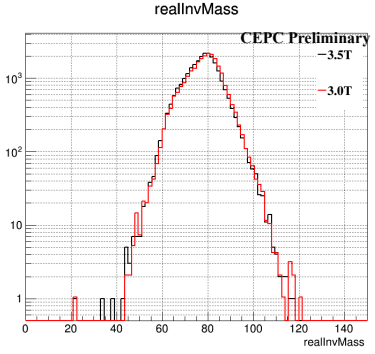


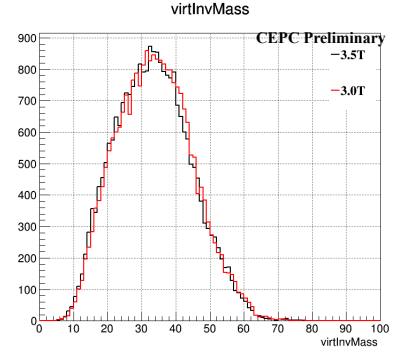


Z→νν, selected by H→WW→qqqq:



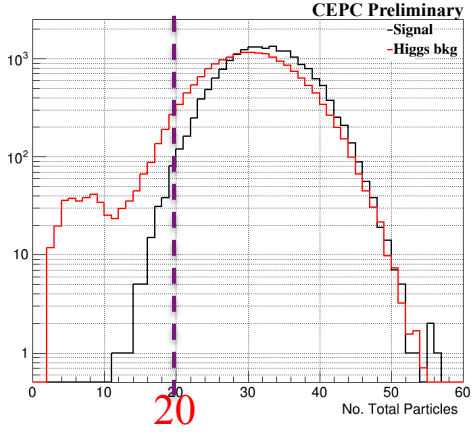


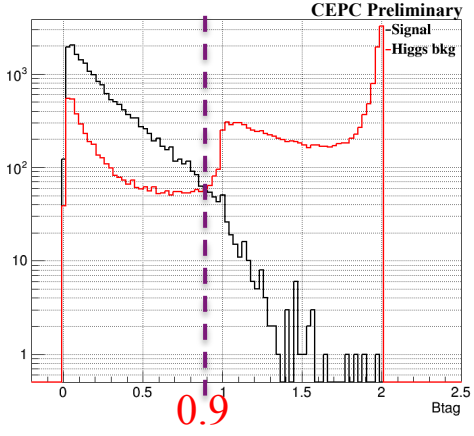


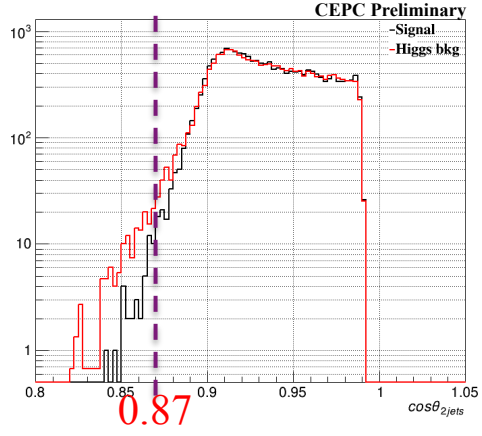


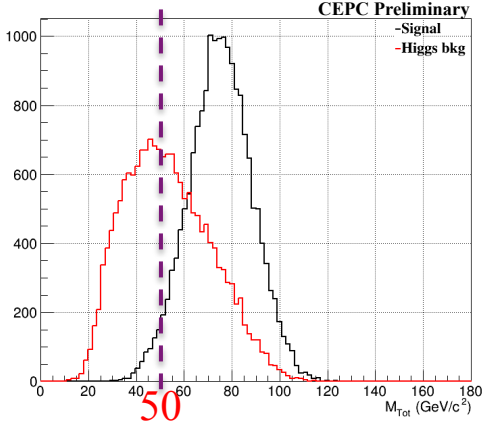
Missing-mass, visible-mass, invariant mass of 2 jets from real/virtual W decay.

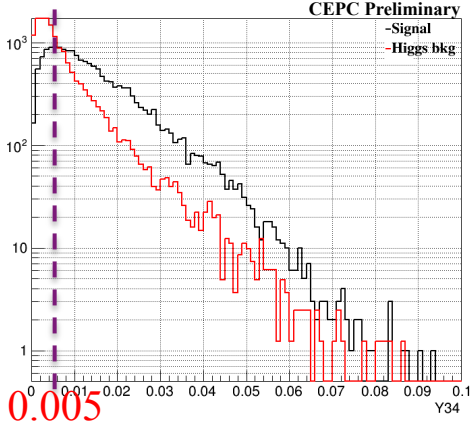
Distributions of discriminant variables in CEPC_v4











- No. of total particles.
- Sum of b-tagging of 2 jets.
- Cos angle of 2 jets.
- Total mass of 2 jets.
- Distance between jet3 and jet4.

Comparison of cut flow tables

CEPC_v1:

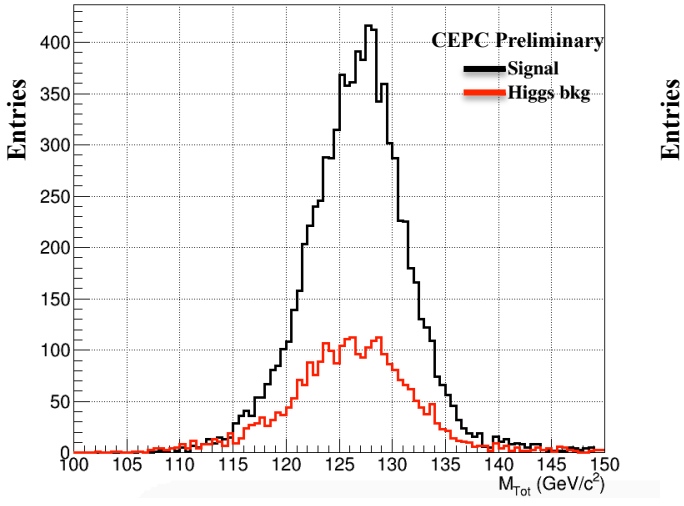
No. of signal	Relative efficiency	No. of Higgs bkg	Relative efficiency	No. of SM bkg	Relative effciency
24889		222278		22687012	
20454	82.18%	144169	64.86%	3528746	15.55%
19729	96.46%	124341	86.25%	537839	15.24%
19390	98.28%	28954	23.29%	477099	88.71%
19336	99.72%	28761	99.33%	433563	90.87%
18657	96.49%	14840	51.60%	309919	71.48%
15211	81.53%	6927	46.68%	122866	39.64%
9037	59.41%	3071	44.33%	38226	31.11%
Total efficiency	36.31%		1.38%		0.17%

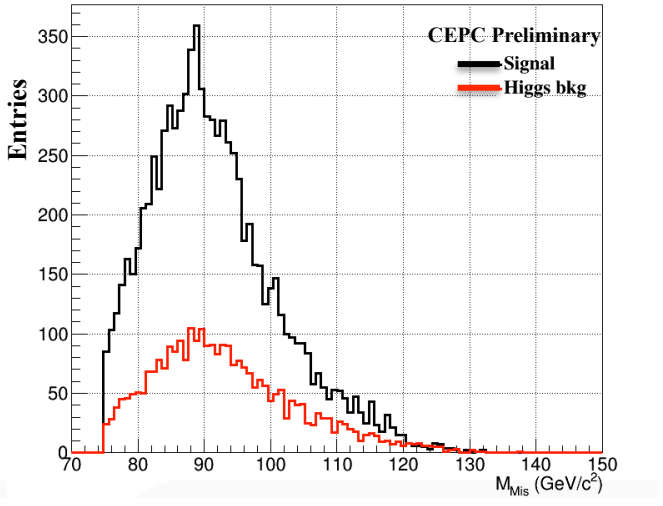
CEPC_v4:

No. of signal	Relative efficiency	No. of Higgs bkg	Relative efficiency
23675		211307	
18894	79.81%	134785	63.79%
18404	97.41%	118963	88.26%
18048	98.07%	26928	22.64%
18006	99.77%	26710	99.19%
17451	96.92%	14247	53.34%
14273	81.79%	6480	45.48%
8516	59.67%	2868	44.26%
Total efficiency	35.97%		1.35%

No obvious discrepancies showed in the cut flow tables.

Results

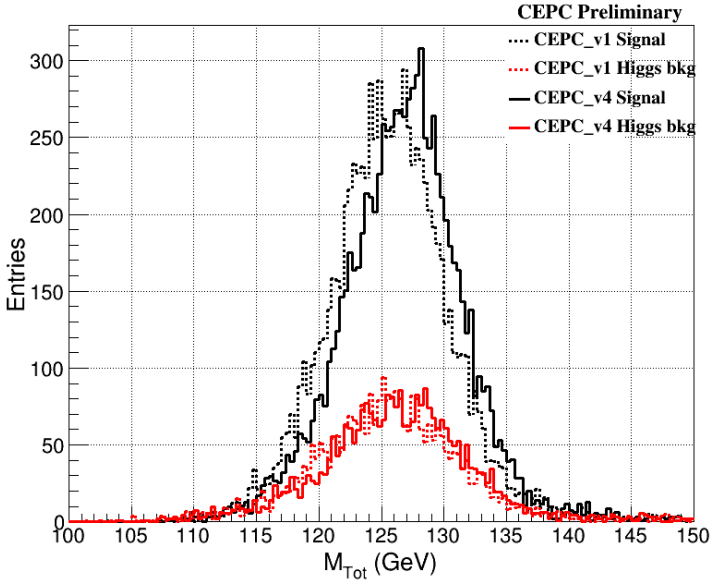


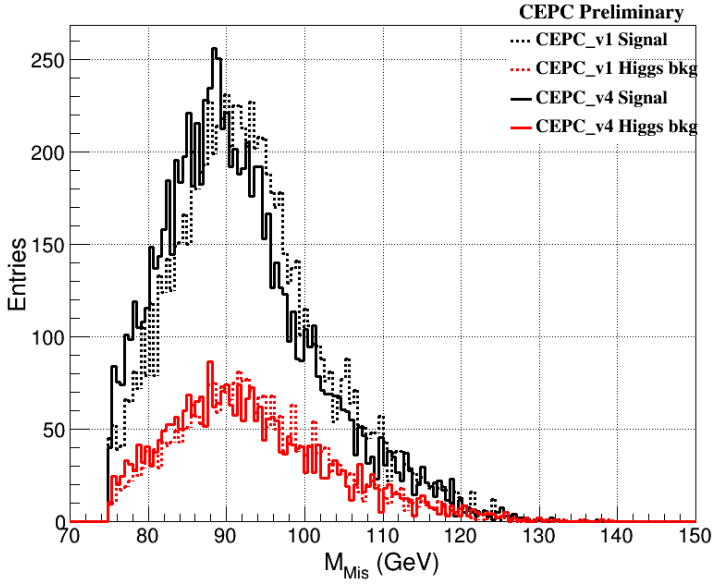


Visible mass and missing mass after selections.

- N_{Signal} = 8516 ± 92
- Signal efficiency = 35.97%, ZH background efficiency = 1.35%
- Accuracy = √(S+B)/S = 1.25%

Comparison of variables distributions





Distributions of visible mass and missing mass after selections.

Dash line: CEPC_v1, solid line: CEPC_v4.

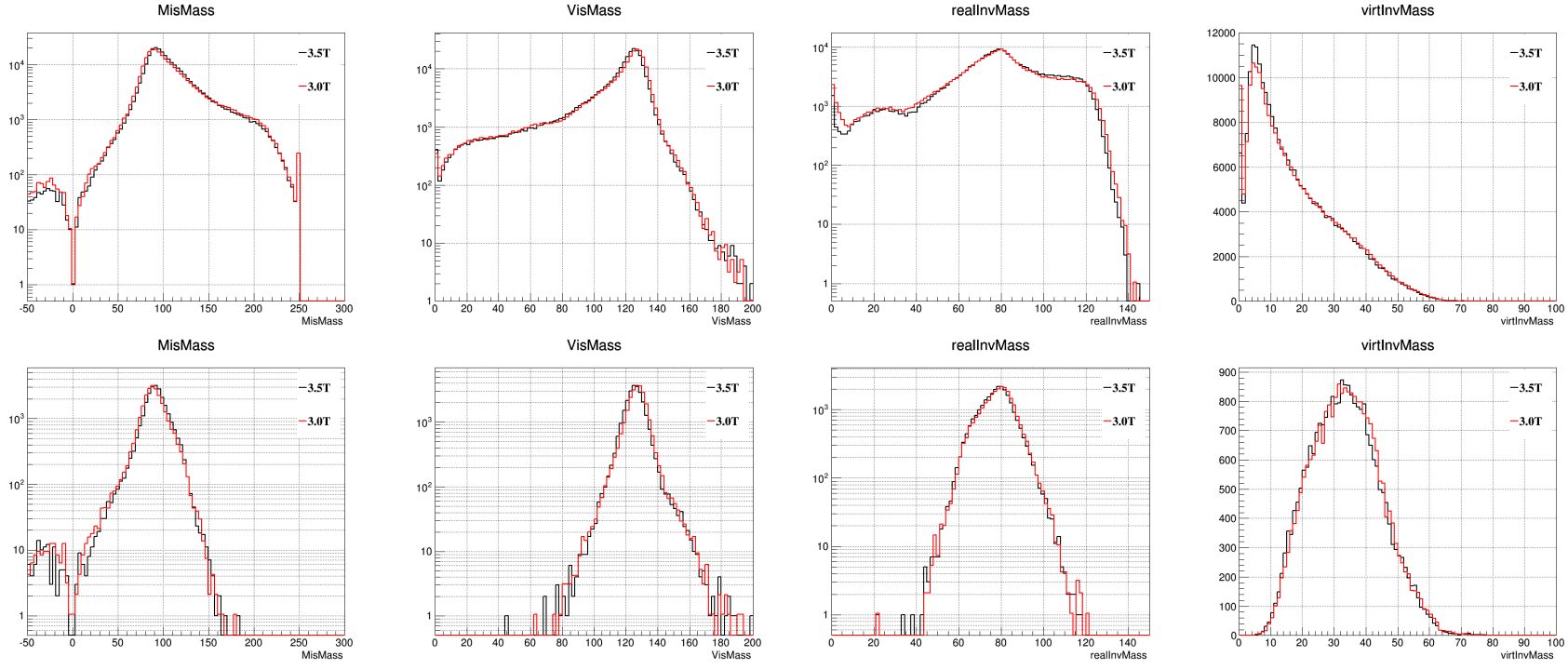
Black line: signal, red line: Higgs background.

Summary

- No obvious discrepancies showed with two sets of samples according to the variables distributions.
- No distinct change of performance for ZH->vvqqqq channel when we turn to CEPC_v4 detector model from CEPC_v1.
- For the H→WW branching ratio measurement, the other channels need to be done based on CEPC_v4 samples.

backup

Comparisons between 2 samples



Missing-mass, visible-mass, invariant mass of 2 jets from real/virtual W decay.

Top: Z->vv, H->inclusive. Bottom: Z->vv, selected by H->WW->qqqq.

Black line: CEPC_v1, 3.5T. Red line: CEPC_v4, 3.0T.

Cut flow table

My results:

No. of signal	Relative efficiency	No. of Higgs bkg	Relative efficiency	No. of SM bkg	Relative effciency
24889		222278		22687012	
20454	82.18%	144169	64.86%	3528746	15.55%
19729	96.46%	124341	86.25%	537839	15.24%
19390	98.28%	28954	23.29%	477099	88.71%
19336	99.72%	28761	99.33%	433563	90.87%
18657	96.49%	14840	51.60%	309919	71.48%
15211	81.53%	6927	46.68%	122866	39.64%
9037	59.41%	3071	44.33%	38226	31.11%
Total efficiency	36.31%		1.38%		0.17%

Results from Note:

No. of signal	Relative efficiency	No. of Higgs bkg	Relative efficiency	No. of SM bkg	Relative effciency
23938		208200		21314314	
20405	85.24%	143765	69.05%	3166923	14.86%
19681	96.45%	124112	86.33%	537839	16.98%
19349	98.31%	28857	23.25%	477099	88.71%
19289	99.69%	28673	99.36%	433563	90.87%
18621	96.54%	14793	51.59%	309919	71.48%
15183	81.54%	6919	46.77%	122866	39.64%
9022	59.42%	3075	44.44%	38226	31.11%
Total efficiency	37.68%		1.47%		0.17%

Relative efficiency = Number of events after this cut/Number of events before this cut
These results are consistent.