



# $H \rightarrow WW^*$ analysis with semi-leptonic final states

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# Contents

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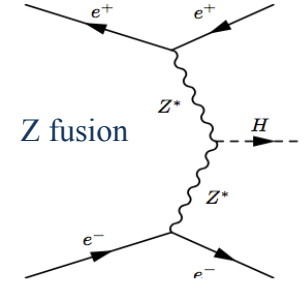
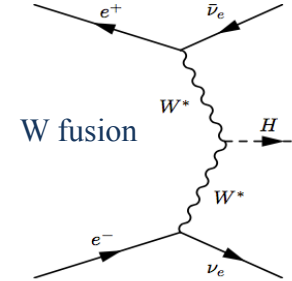
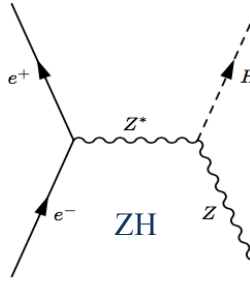
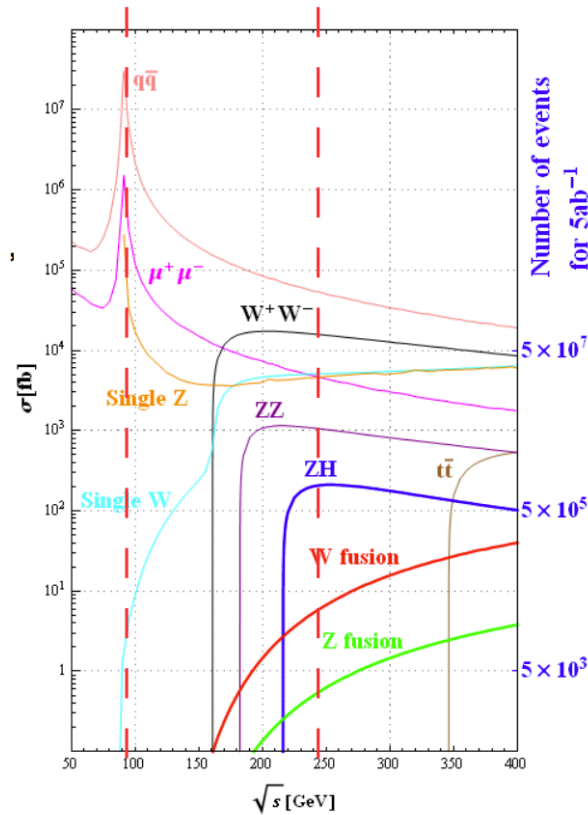
## ➤ Analysis with $Z \rightarrow \nu\nu$ , $H \rightarrow WW \rightarrow qqqq$

- CEPC\_v1      - CEPC\_4

## ➤ Plans

-  $Z \rightarrow ee$ ,  $H \rightarrow WW \rightarrow \mu\nu qq$

# Introduction



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

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

Higgs productions at CEPC.

# MC samples

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

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

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

Signal events of  $H \rightarrow WW$  processes.

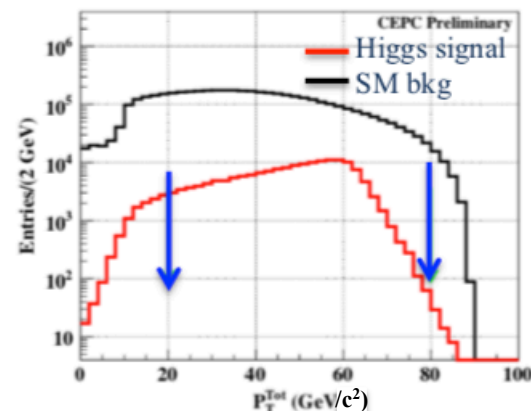
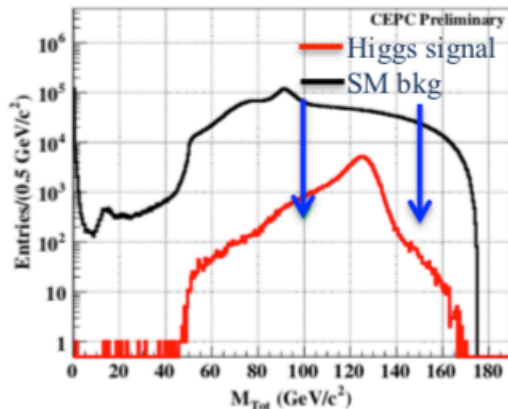
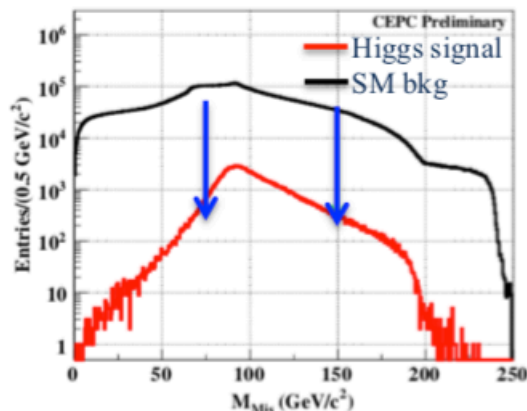
# MC samples

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- Two sets of  $Z \rightarrow \nu\nu$ ,  $H \rightarrow$ inclusive samples for signal process:
  - **CEPC\_v1** ( $\sqrt{s} = 250\text{GeV}$ , B field = 3.5Tesla...)
  - **CEPC\_v4** ( $\sqrt{s} = 240\text{GeV}$ , B field = 3.0Tesla...)
- Integrated luminosity is  $5 \text{ ab}^{-1}$ , 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.



$$\begin{aligned} 75 \text{ GeV}/c^2 &< M_{Mis} < 150 \text{ GeV}/c^2 \\ 100 \text{ GeV}/c^2 &< M_{Tot} < 150 \text{ GeV}/c^2 \\ 20 \text{ GeV}/c &< p_T < 80 \text{ GeV}/c \end{aligned}$$

Pre-selections criteria.

# Event selections

$$\begin{aligned} 75 \text{ GeV}/c^2 &< M_{Mis} < 150 \text{ GeV}/c^2 \\ 100 \text{ GeV}/c^2 &< M_{Tot} < 150 \text{ GeV}/c^2 \\ 20 \text{ GeV}/c &< p_T < 80 \text{ GeV}/c \end{aligned}$$

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

Validation of pre-selection

$$N_{Particle}^{Tot} > 20$$

$$B_{tag} < 0.9$$

$$\cos\theta_{2jets} > 0.87$$

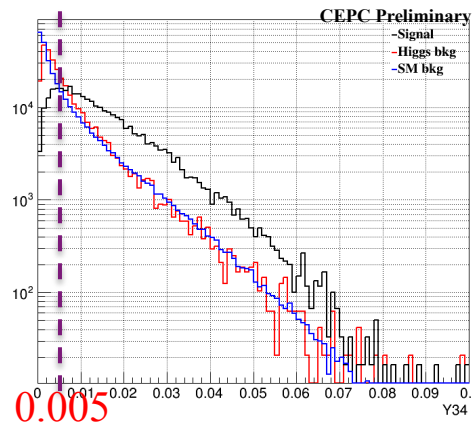
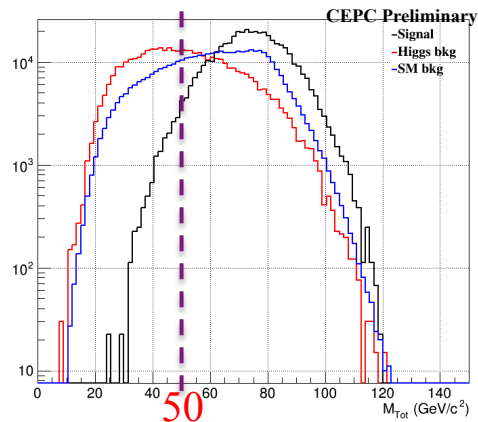
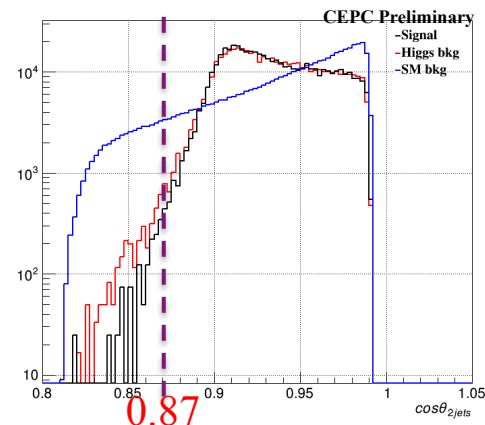
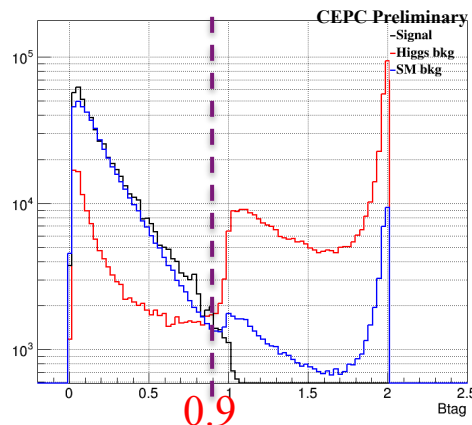
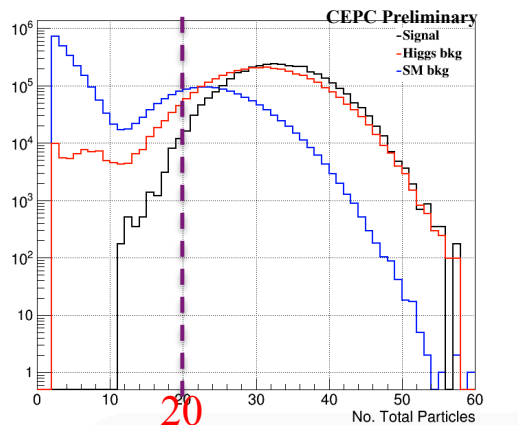
$$\Sigma|M_{Inv}^{2jet}| > 50 \text{ GeV}$$

$$Y_{34} > 0.005$$

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:

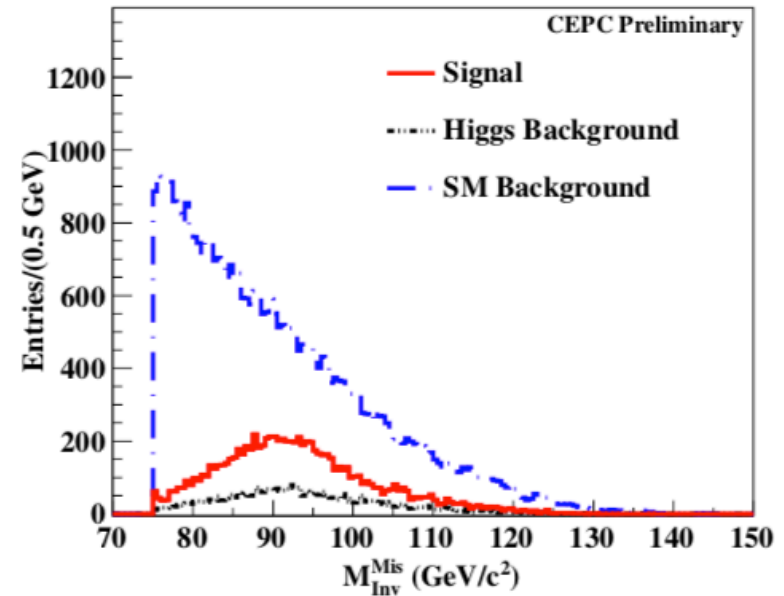
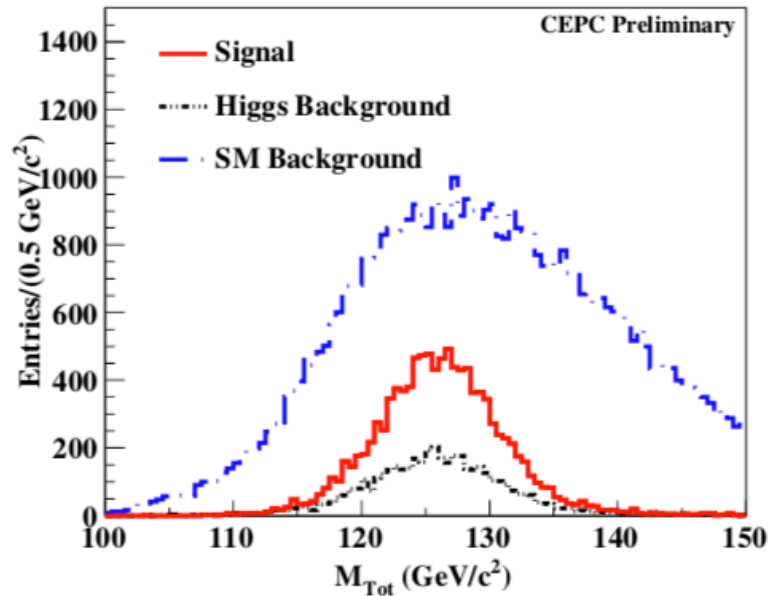
No. of signal	Relative efficiency	No. of Higgs bkg	Relative efficiency	No. of SM bkg	Relative efficiency
24889		222278		22687012	
20454	82.18%	144169	64.86%	3528746	15.55%
19729	96.46%	124341	86.25%	537839	15.24%
19390	98.28%	28954	23.29%	477099	88.71%
19336	99.72%	28761	99.33%	433563	90.87%
18657	96.49%	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 efficiency
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.

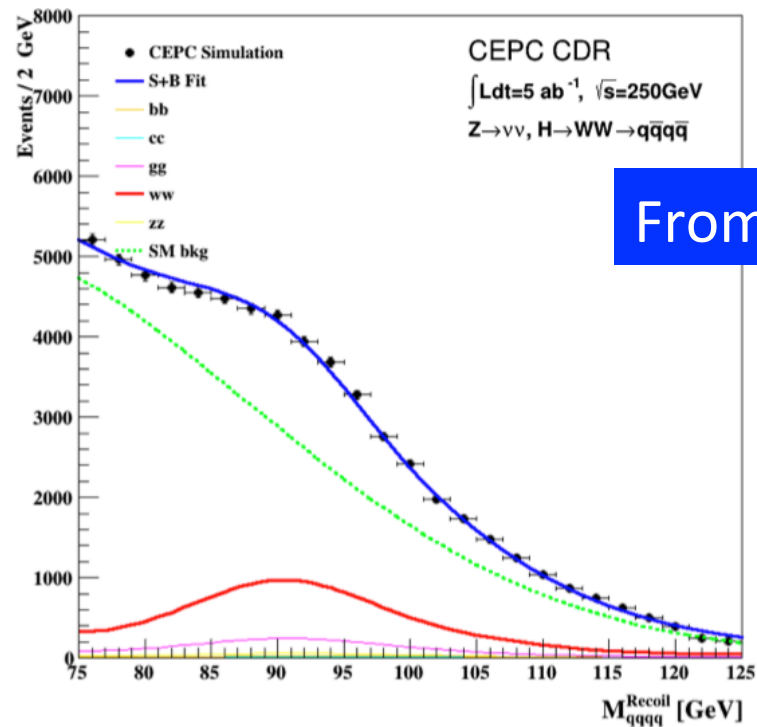
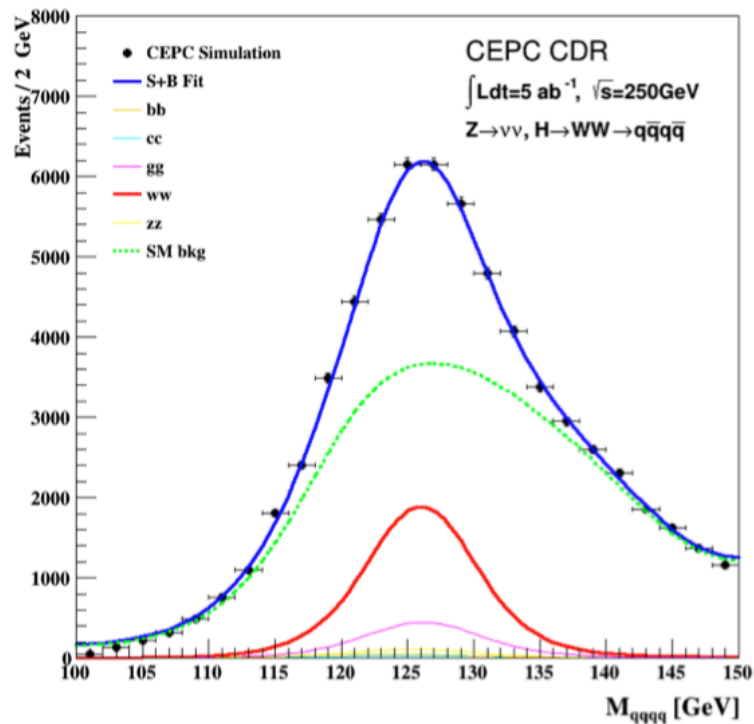
# Results



Visible mass and missing mass after selections.

- Signal efficiency = 36.31%, ZH background efficiency = 1.38%

# Results

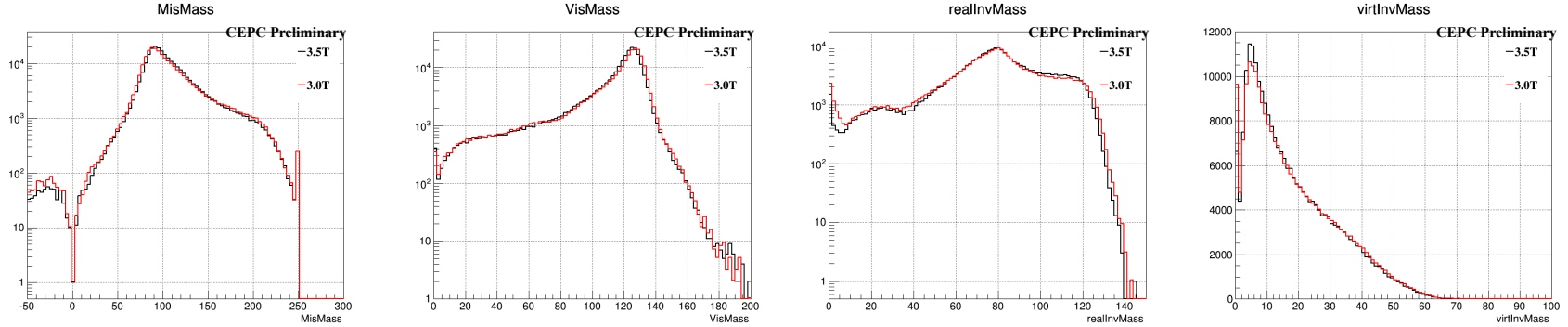


From Kaili

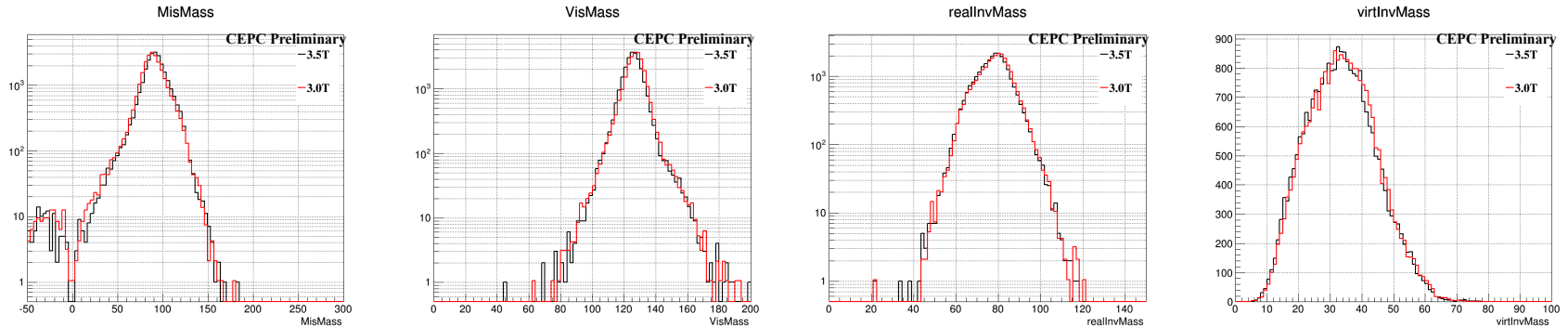
➤ Precision of this channel is 2.00%.

# Analysis with CEPC\_v4 data

$Z \rightarrow \nu\nu$ ,  $H \rightarrow$ inclusive:

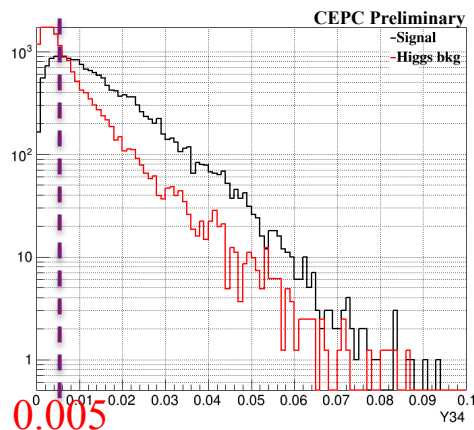
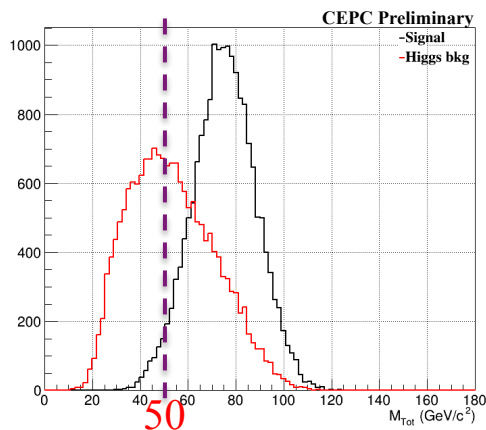
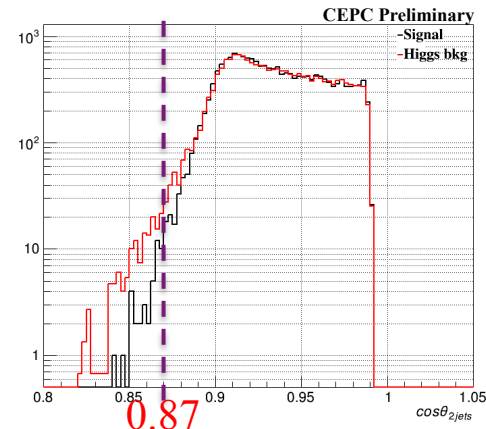
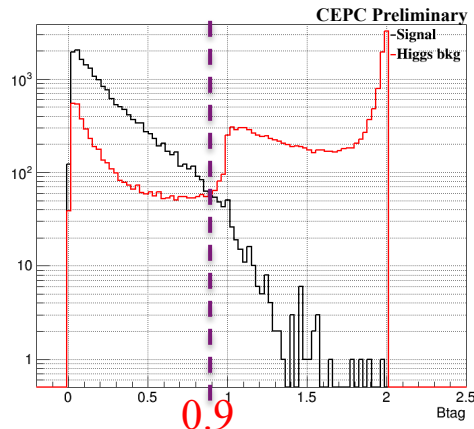
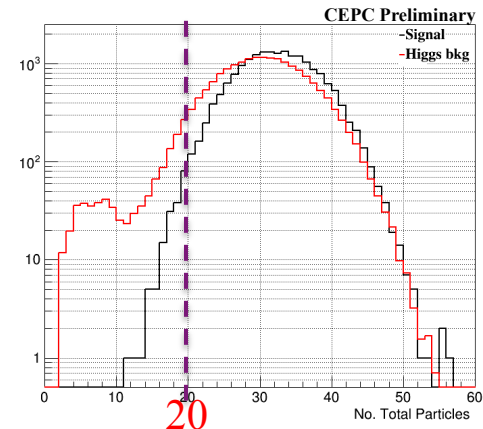


$Z \rightarrow \nu\nu$ , selected by  $H \rightarrow WW \rightarrow qqqq$ :



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:

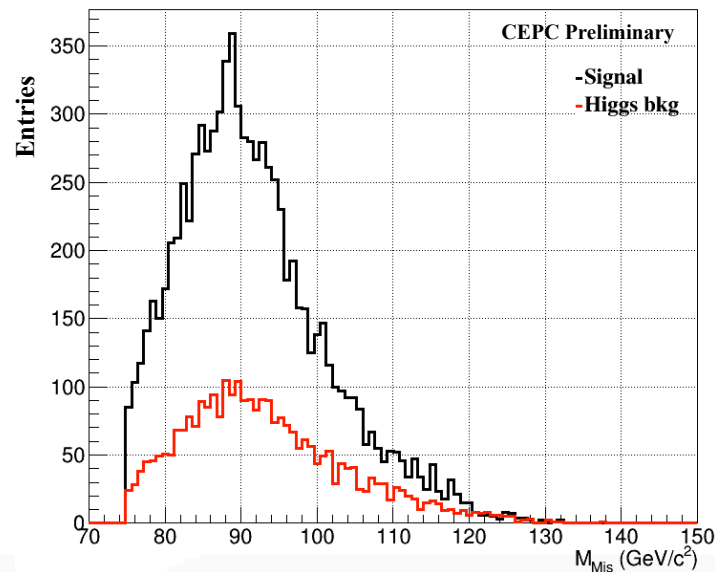
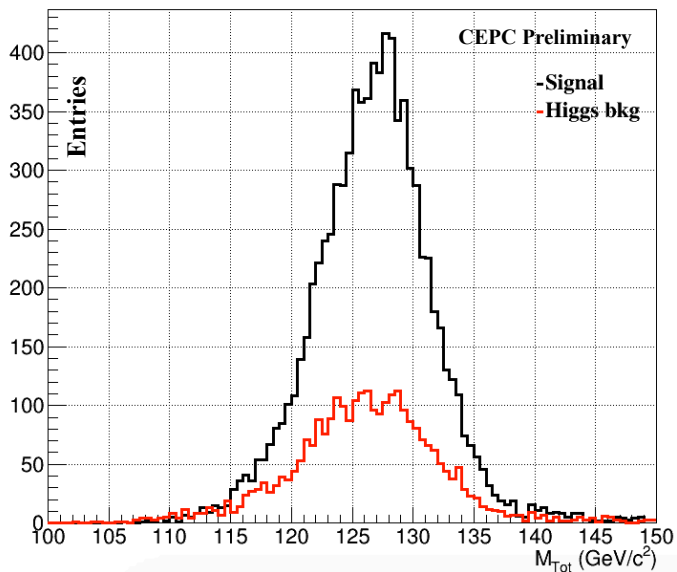
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15211	81.53%	6927	46.68%	122866	39.64%
9037	59.41%	3071	44.33%	38226	31.11%
Total efficiency	36.31%		1.38%		0.17%

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.

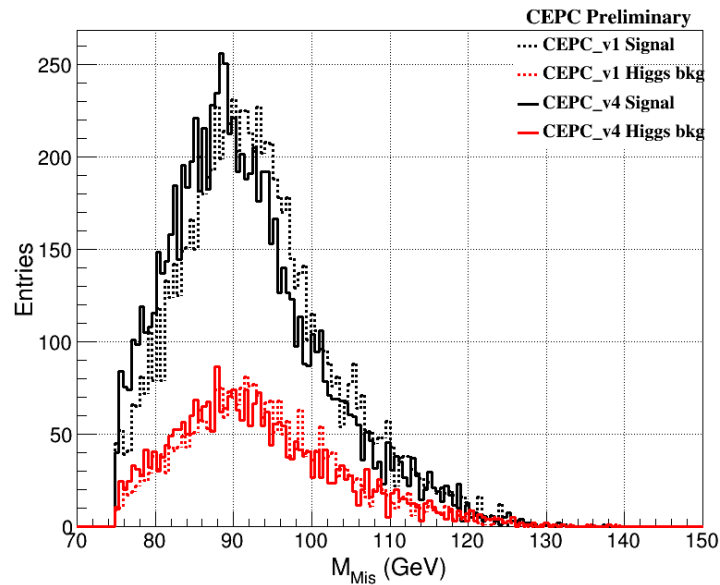
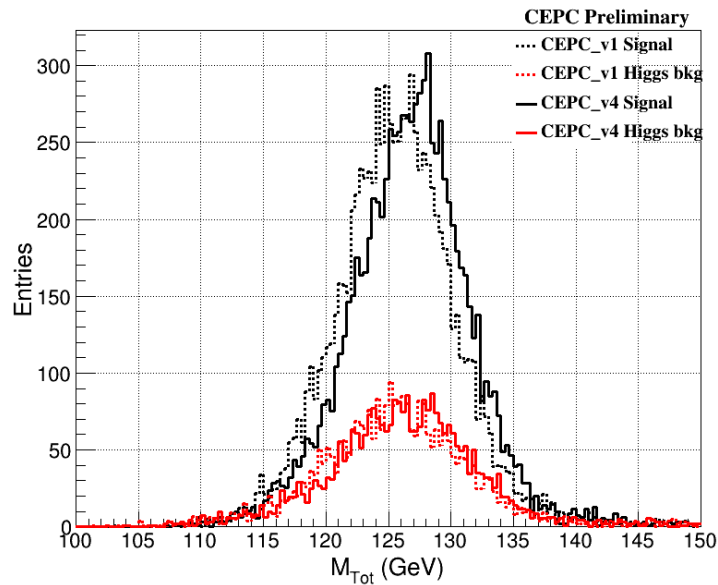
# Results



Visible mass and missing mass after selections.

➤ Signal efficiency = 35.97%, ZH background efficiency = 1.35%

# Variables distributions of CEPC\_v1 and v4



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 and plans

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- No distinct change of performance showed for  $ZH \rightarrow \nu\nu qqqq$  channel when we turn to CEPC\_v4 detector model from CEPC\_v1.
- The other channels:
  - $Z \rightarrow ee, H \rightarrow WW \rightarrow \mu\nu qq$



# backup