WW Fusion, $H \to bb$ and Higgs Width at CEPC

Hao Liang

CEPC Workshop

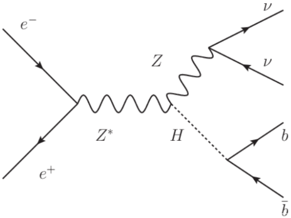
2018.11.9

Contents

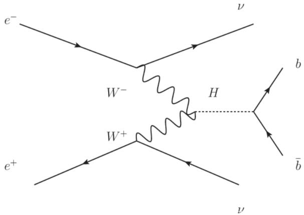
- Motivation
- Monte Carlo Samples
- Simulation
- Event Selection
- Recoil Mass Reconstruction
- Fit Model
- Result

Motivation

- Two main channels for final states $\nu\nu H, H \to b\bar{b}$:



ZH



WW fusion

Motivation Cont'd

- Higgs width is strongly of interest for physicists.
  - Extraction for absolute coupling of Higgs
  - New physics in Higgs invisible decay
- Best result from LHC
  - Only 4MeV predicted by SM
  - Best result: 20 MeV
  - $\sigma_{H \to ZZ} / \sigma_{H \to ZZ} \propto 1/\Gamma$

Motivation Cont'd

Two methods at CEPC

- Impossible to be extracted from the line shape directly
  - Mass resolution a few GeV $>>$ Higgs width (4 MeV)
- First method
  - $$\Gamma == \Gamma_{\mathrm{SM}} \cdot \frac{\mu_{ZH}}{\mathrm{Br}(H \to ZZ)}$$
  - Limited by the statistics of $H \to ZZ$, due to the small $\mathrm{Br}(H \to ZZ)$, which is only 2.3% by the SM.
- Second method
  - $$\Gamma = \Gamma_{\mathrm{SM}} \cdot \frac{\mu_{WW\mathrm{fusion}, H \to b\bar{b}}}{\mathrm{Br}(H \to b\bar{b})\mathrm{Br}(H \to W^{-}W^{+})}$$
  - The bottleneck: $WW\mathrm{fusion}, H \to b\bar{b}$
- Better one: the method related to $\mu_{WW\mathrm{fusion}, H \to b\bar{b}}$
- Focus: $WW\mathrm{fusion}, H \to b\bar{b}$

Monte Carlo Samples

- $\sqrt{s} = 240\mathrm{GeV}$
- Higgs samples
  - 100k WW fusion events
  - 100k ZH events
  - The interference can NOT be generated by current software
  - Assign weights corresponding to 5.6 ab^{-1}
- SM backgrounds samples
  - 2fermions + 4 fermions
- Simulated and reconstructed for CEPC-v4
- Result scaled to integral luminosity 5.6 ab^{-1}

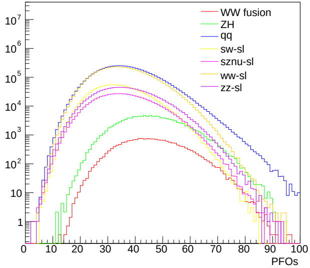
Event Selection

- Main backgrounds
  - $ZH, Z \to vv, H \to b\bar{b}$
  - $q\bar{q}$
  - Irreducible SM backgrounds: zz-sl, sznu-sl
  - Two b jets + single charged isolated lepton: ww-sl, sw-sl
- Pre-Cuts for SM backgrounds

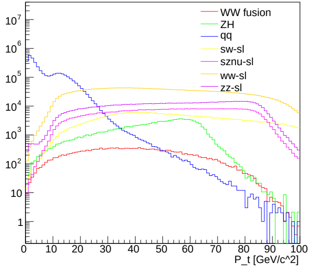
Pre-cut	Cut on reconstructed variables
$60\mathrm{GeV}/c^2 < M_{\mathrm{mis}} < 225\mathrm{GeV}/c^2$	$65\mathrm{GeV}/c^2 < M_{\mathrm{mis}} < 135\mathrm{GeV}/c^2$
$50\mathrm{GeV}/c^2 < M_{\mathrm{vis}}$	$100\mathrm{GeV}/c^2 < M_{\mathrm{vis}} < 135\mathrm{GeV}/c^2$
$10\mathrm{GeV}/c < P_T < 100\mathrm{GeV}/c$	$13\mathrm{GeV}/c < P_T < 90\mathrm{GeV}/c$

Event Selection Cont'd

- The distribution of cut variables: (Previous cuts applied)



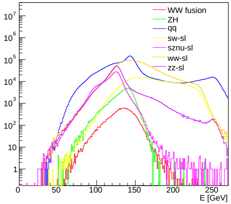
PFOs



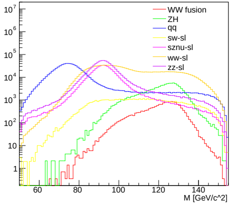
P_T

Event Selection Cont'd

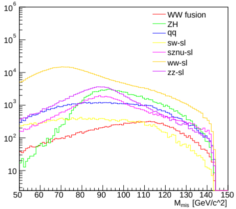
- The distribution of cut variables: (Previous cuts applied)



E_{vis}



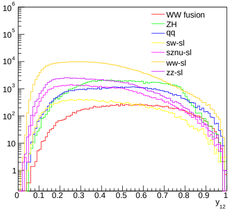
M_{vis}



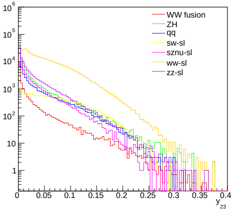
M_{recoil}

Event Selection Cont'd

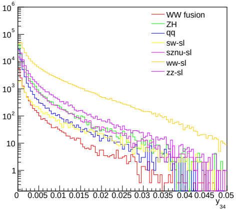
- The distribution of cut variables: (Previous cuts applied)



y_{12}



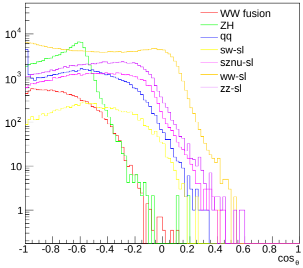
y_{23}



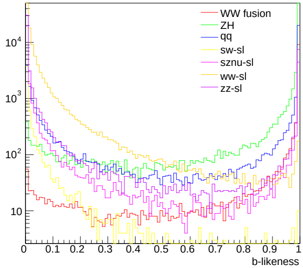
y_{34}

Event Selection Cont'd

- The distribution of cut variables: (Previous cuts applied)



$\cos(\theta_{\mathrm{2jets}})$



bb-likeness

Event Selection Cont'd

Main SM backgrounds

Cut	$q\bar{q}$	sw-sl	sz-nu	ww-sl	zz-sl
Generated	250283714	13025535	744000	23788000	2581000
Pre-cut & reconstructed	5924182	1193000	658000	5208810	1112000
$N_{\mathrm{PFO}(E>0.4\mathrm{GeV})} > 20$	5717282	1138089	629242	5077296	1066096
$105\mathrm{GeV} < E_{\mathrm{total}} < 155\mathrm{GeV}$	3821137	356219	529778	2883329	911700
$P_T > 13\mathrm{GeV}/c$	826961	351546	520798	2799966	891644
Isolation lepton veto	792950	59642	488958	1376469	818336
$100 < M_{\mathrm{vis}} < 135$	76396	33928	70942	652630	127555
$65 < M_{\mathrm{mis}} < 135$	62586	19427	62508	446045	110631
$0.15 < y_{12} < 1$	61719	18517	58941	409226	103750
$y_{23} < 0.06$	54797	9651	53150	277300	92458
$y_{34} < 0.01$	53711	8629	50802	245424	87819
$-0.98 < \cos(\theta_{2\mathrm{jets}}) < -0.4$	37224	5809	31017	133305	50646
$bb - \mathrm{likeness} > 0.4$	25630	124	5745	3230	9764

Signal and Higgs Backgrounds

Cut	WW fusion (v1)	WW fusion (v4)	ZH (v1)	ZH (v4)
$N_{\mathrm{PFO}(E>0.4\mathrm{GeV})} > 20$	20102	19912	122403	122073
$105\mathrm{GeV} < E_{\mathrm{total}} < 155\mathrm{GeV}$	18181	17939	115656	114926
$P_T > 13\mathrm{GeV}/c$	16935	16694	112297	111663
Isolation lepton veto	14969	15463	106993	101951
$100 < M_{\mathrm{vis}} < 135$	13513	13929	97766	100289
$65 < M_{\mathrm{mis}} < 135$	13441	13846	96172	99750
y_{12}, y_{23}, y_{34}	11959	12251	85453	90976
$-0.98 < \cos(\theta_{2\mathrm{jets}}) < -0.4$	11158	11416	83308	88548
$bb - \mathrm{likeness} > 0.4$	10639	10916	79623	82597

Recoil Mass Reconstruction

- The number of WW fusion, $H \to b\bar{b}$ events extracted from the fitting of recoil mass
- Approach 1: The recoil mass is calculated by

$$m_{\mathrm{recoil}} = \sqrt{(\sqrt{s} - E_H)^2 - p_H^2}$$

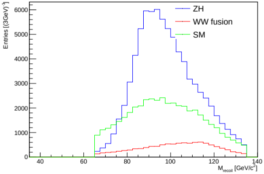
  where E_H and p_H is reconstructed energy and momentum of Higgs, respectively.
- Approach 2: The energy is replaced with the one calculated from the momentum

$$m_{\mathrm{recoil}} = \sqrt{(\sqrt{s} - \sqrt{m_H^2 + p_H^2})^2 - p_H^2}$$

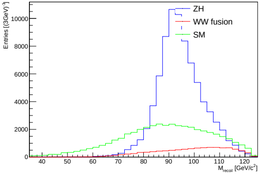
- The approach 2 is expected to be better, because:

  (sensitivity of m_{recoil} to p_H) $\times$ (p_H resolusion) $<$ (sensitivity of m_{recoil} to E_H) $\times$ (E_H resolusion)

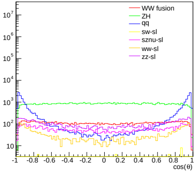
Signal Background Character



Raw: M_{recoil}



Refined: M_{recoil}



$\cos(\theta_z)$

Fit Model

- Methodology objective: as much realism as possible within acceptable analysis complexity
- SM backgrounds where assumed to be known very well, so the expected numbers of SM backgrounds events were fixed
- Additional information of $ZH, Z \to \nu\nu, H \to b\bar{b}$ obtained from eeH, $\mu\mu H$, and qqH where $H \to b\bar{b}$.
  - Assumption 1: The uncertainties due to electroweak physics are assumed to be negligible.
  - Assumption 2: ZZ fusion contribution to eeH is negligible
  - Consequent: Three signal strengthes are proportional to the $ZH, Z \to \nu\nu, H \to b\bar{b}$
  - Assumption 3: The measurement correlation of signal strengthes of three channels are negligible
  - Conclusion: The external constraint of $ZH, Z \to \nu\nu, H \to b\bar{b}$:
    - $1/\sqrt{\left(\frac{1}{\sigma_{eeH,H\to b\bar{b}}}\right)^2 + \left(\frac{1}{\sigma_{\mu\mu H,H\to b\bar{b}}}\right)^2 + \left(\frac{1}{\sigma_{qqH,H\to b\bar{b}}}\right)^2}$
    - $1/\sqrt{\left(\frac{1}{1.2\%}\right)^2 + \left(\frac{1}{1.1\%}\right)^2 + \left(\frac{1}{0.4\%}\right)^2} = 0.375\%$
    - See Yu Bai's report for newest values.

Fit Model Cont'd

- Binned log likelihood constructed as

$$\log L = \log P(data; \mu_{WWF}, \mu_{ZH}) - 0.5 \left(\frac{\mu_{ZH} - 1}{0.375\%} \right)^2 \qquad (1)$$

$$\log P = \sum_i \log \mathrm{Poisson} \left(n_{i,data}; n_{i,\mathrm{bkg}} + n_{i,ZH}\mu_{ZH} + n_{i,WWF}\mu_{WWF} \right) \qquad (2)$$

where $n_{i,data}$ is the events number in bin i; $n_{i,\mathrm{bkg}}$, $n_{i,ZH}$, $n_{i,WWF}$ the expected events number of backgrounds, $ZH, Z \to \nu\nu, H \to b\bar{b}$, and $WW\mathrm{fusion}, H \to b\bar{b}$ in bin i; Backgrounds means all backgrounds (SM backgrounds and Higgs backgrounds) except the $ZH, Z \to \nu\nu, H \to b\bar{b}$.

- The statistical uncertainty was determined via the hessian matrix at maximum point of the log likelihood

Result

- 2D-fit: recoil mass and θ

	1D	2D
Raw	3.9	3.8%
Refined	3.2	3.1%

In apporch 1, $m_{\mathrm{recoil}} = \sqrt{(\sqrt{s} - E_H)^2 - p_H^2}$. In approach 2, E_H is replaced with $\sqrt{p_H^2 + m_H^2}$

- 0.1% (absolute) improvement for 2D fit compared to 1D-fit