Recoil Mass Reconstruction in W boson fusion at CEPC

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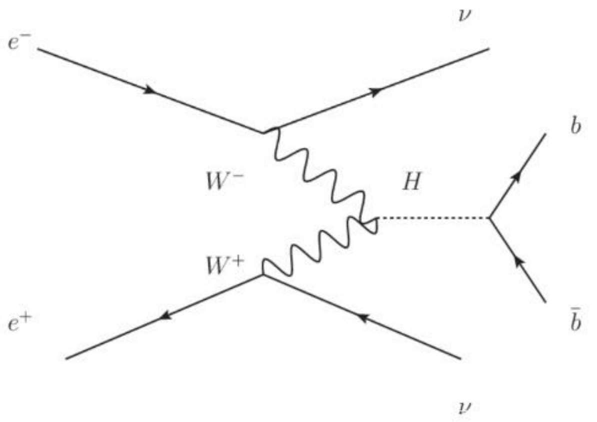
Outline

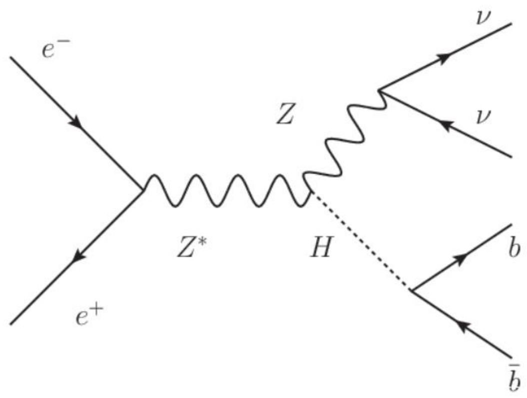
- Simulation of W boson fusion, $H \rightarrow bb$
  - ✓240GeV
- Comparison between methods of recoil mass calculation
  - ✓Understanding

Simulation - Samples

- Motivation:
  - ✓Most important process for measuring W boson fusion
- Samples
  - ✓Backgrounds:
    - □2fermions: bb
    - □4fermions: $\nu_e \nu_e bb(sznu\_sl)$, $\nu_{\mu\tau} \nu_{\mu\tau} qq(zz\_sl)$
    - □Higgs:$ZH, Z \to \nu\nu, H \to bb$
  - ✓Luminosity
    - □240GeV: $5600 fb^{-1}$
  - ✓CEPC detector (cepc_v4)



W fusion, $H \to bb$



$\nu\nu H(ZH), H \to bb$

Simulation – Cut chain

- Cut chain

240GeV

Signal and Higgs Backgrounds

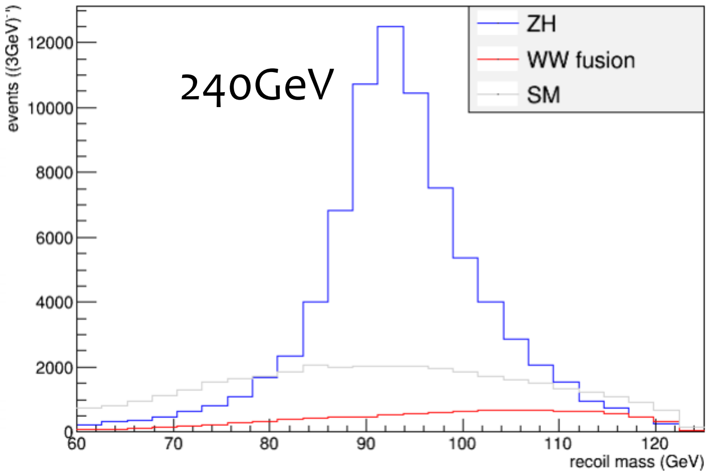
Cut	WW fusion	ZH
$N_{\mathrm{PFO}(E>0.4\mathrm{GeV})} > 20$	19912	122073
$105\mathrm{GeV} < E_{\mathrm{total}} < 155\mathrm{GeV}$	17939	114926
$P_T > 13\mathrm{GeV}/c$	16694	111663
Isolation lepton veto	15463	101951
$100 < M_{\mathrm{vis}} < 135$	13929	100289
$65 < M_{\mathrm{mis}} < 135$	13846	99750
y_{12}, y_{23}, y_{34}	12251	90976
$-0.98 < \cos(\theta_{2\mathrm{jets}}) < -0.4$	11416	88548
$bb - \mathrm{likeness} > 0.4$	10916	82597

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

Simulation - Results

- Extract signal strength by fitting recoil mass and recoil angle



Approach 2

- Fit Model:
  - ✓240GeV $\log L = \log P(data; \mu_{WWF}, \mu_{ZH}) - 0.5\left(\frac{\mu_{ZH}-1}{0.39\%}\right)^2$ 3.0% with 240GeV for 5600fb^{-1}

Fore more details:
https://indico.ihep.ac.cn/event/7389/session/14/contribution/226/material/slides/0.pdf

Recoil mass calculation

- **3+** ways of reconstruction of recoil mass
  - ✓**1.**Raw methods:
    - ☐1.$M_{rec}(E,P) = (\sqrt{s} - E)^2 - P^2 = s - 2\sqrt{s}E + (E^2 - P^2)$
  - ✓**2+.**With use of the fact $E^2 - P^2 = M_H^2$
    - ☐$M_{rec}(E) = s - 2\sqrt{s}E + M_H^2$ (fit this, equivalently fit E)
    - ☐$M_{rec}(P) = s - 2\sqrt{s}\sqrt{M_H^2 + P^2} + M_H^2$ (fit this, equivalently fit P)
    - ☐Kinematic fit: $M_{rec}(P_{\text{fit}}) = s - 2\sqrt{s}\sqrt{M_H^2 + P_{\text{fit}}^2} + M_H^2$

      Not included in this report, but previous simulation (250GeV) shows the difference between $M_{rec}(P)$ and $M_{rec}(P_{\text{fit}})$ is small

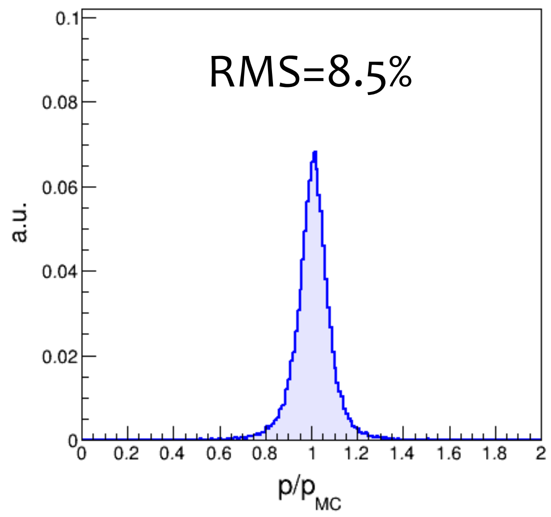
  For more discussion see Jiayin's work arXiv:1709.08645
  - ✓Before we compare the **recoil mass**

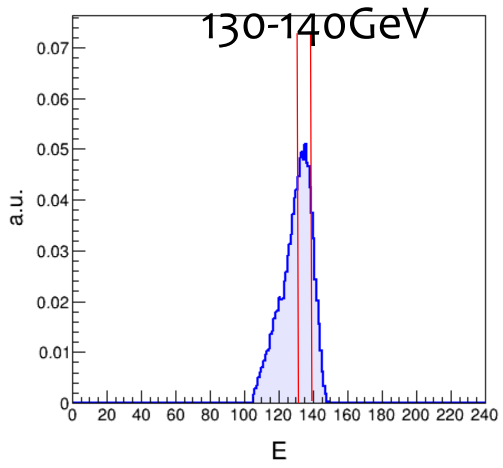
    let's compare the two methods of determining the **energy of Higgs**

Comparison in Energy Calculation

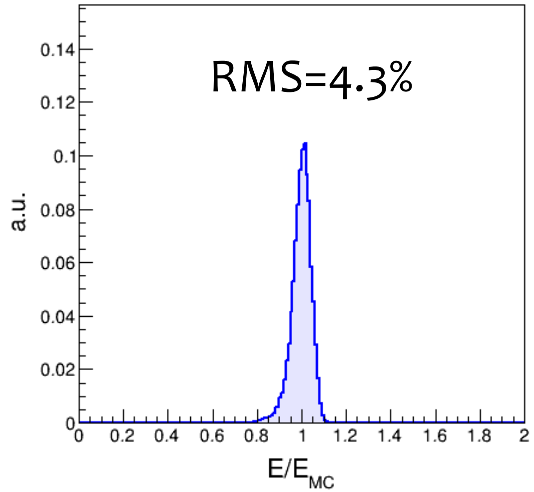
- Comparison conditions
  - ✓240GeV
    - ☐ $vvH(ZH), H \rightarrow bb$ as example
    - ☐ Cuts applied (including $E < 155\text{GeV}$, etc.)
    - ☐ E around 135 (+= 5GeV)
    - ☐ **p/E***8.5%= 3.2% larger than 2.1% (need more investigation)
    - ☐ ***Conclusion***: $\sqrt{M_H^2 + P^2}$ ***better*** than original E by 100%

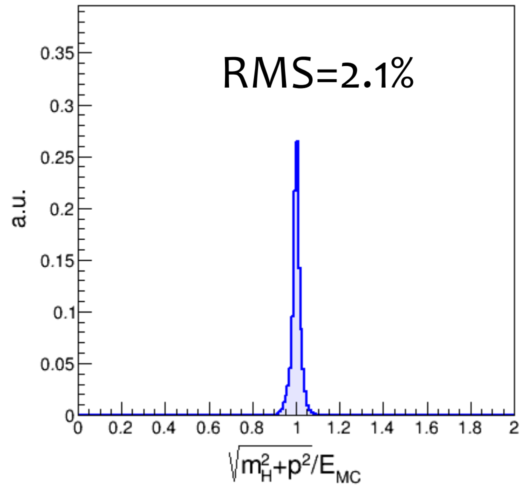
For more discussion see Jiayin's work arXiv:1709.08645





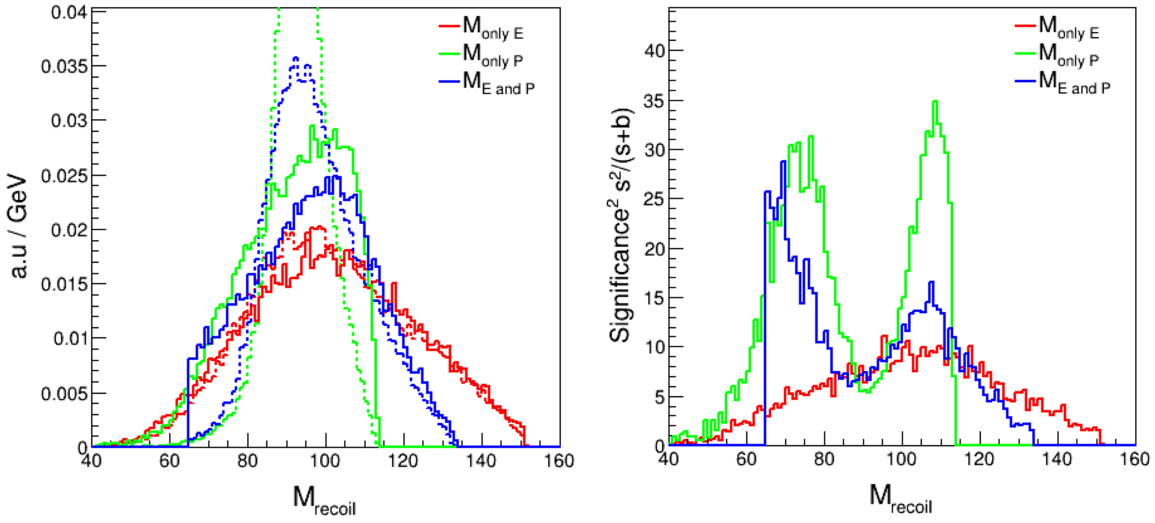
Energy of Higgs distribution @360GeV





Comparison between Methods of Recoil Mass Calculation

- Comparison condition
  - ✓ Cuts applied
  - ✓ **240GeV**
    - ☐ ***conclusion***: improvement very significant



Dashed: $\nu\nu bb(ZH)$, solid: $\nu\nu bb(W$ boson fusion)

$\nu\nu bb$ significance^2 of each bin (1GeV)

Accuracy ~ $\frac{1}{\sqrt{\text{Area}}}$

Comparison between Methods of Recoil Mass Calculation

- Conclusion:
  - ✓Formula $M_{rec}(P) = s - 2\sqrt{s}\sqrt{M_H^2 + P^2} + M_H^2$ would be best
  - ✓This trick is more useful in lower $\sqrt{s}$

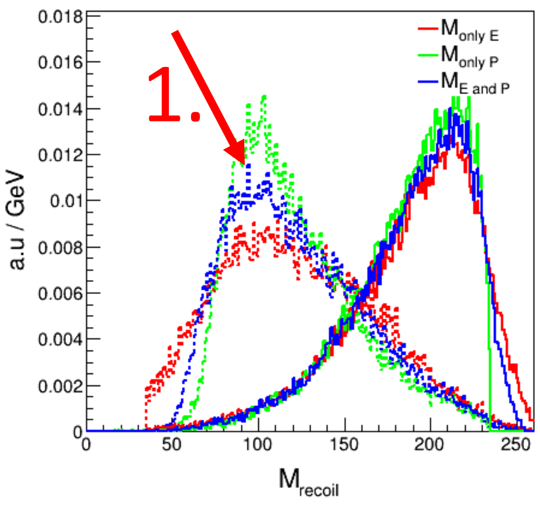
$\sqrt{s}$	240GeV	360GeV
Integral Luminosity	5600fb^{-1}	2000fb^{-1}
$M(E,P)$	3.8%	0.85%
$M(E)$	4.6%	0.87%
$M(P)$	**3.0%**	**0.84%**

Thanks!

Comparison between Methods of Recoil Mass Calculation

- Comparison condition
  - ✓ Cuts applied
  - ✓ <u>***360GeV***</u>
    - ☐ ***conclusion***: improvement not very significant

- Comparison condition
  - ✓ Cuts applied
  - ✓ <u>***240GeV***</u>
    - ☐ ***conclusion***: improvement very significant



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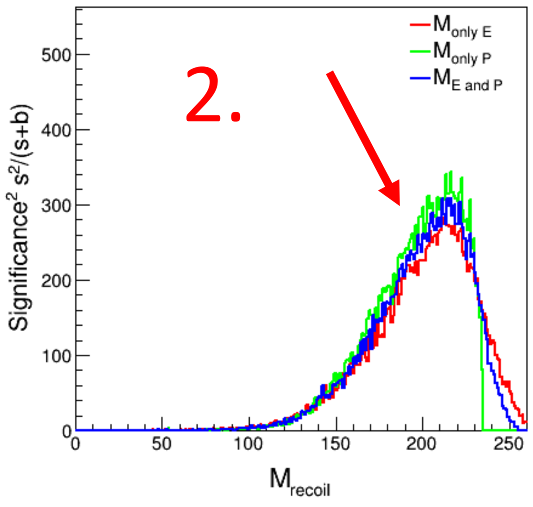

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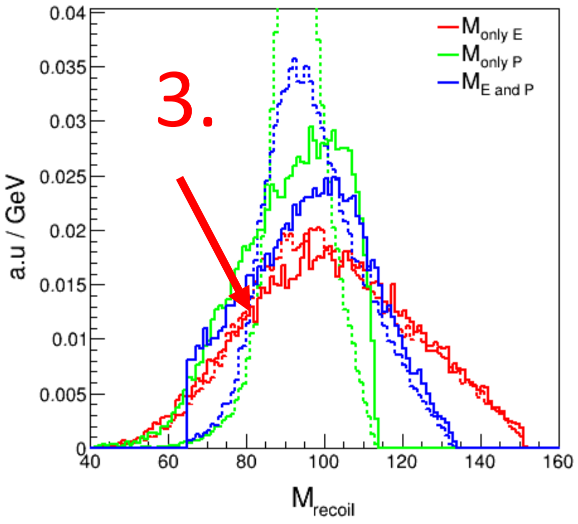

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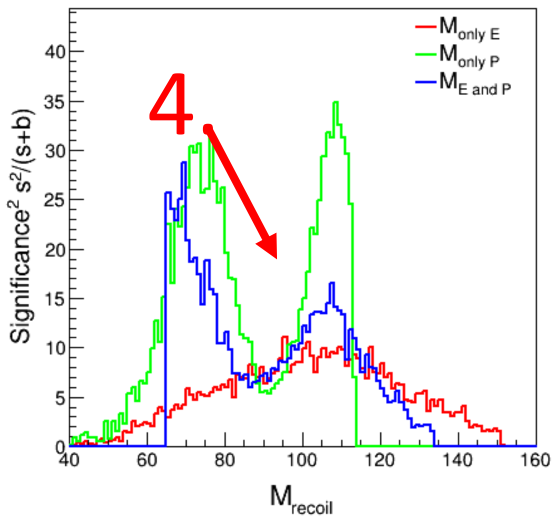

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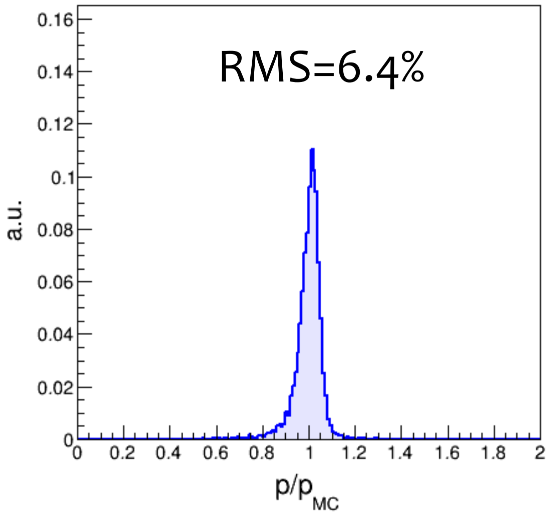
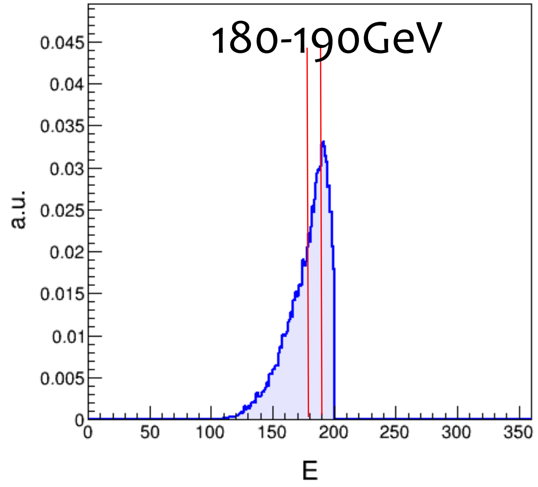
Comparison in Energy calculation

- Comparison conditions
  - ✓360GeV
    - ☐ $\nu\nu H(ZH), H \rightarrow bb$ as example
    - ☐ Cuts applied (including $E < 200\text{GeV}$, etc.)
    - ☐ E around 185 ($+= 5\text{GeV}$)
    - ☐ **p/E***6.4%=4.7% larger than 4.2%
    - ☐ ***Conclusion***: $\sqrt{M_H^2 + P^2}$ ***better*** than original E by 25%





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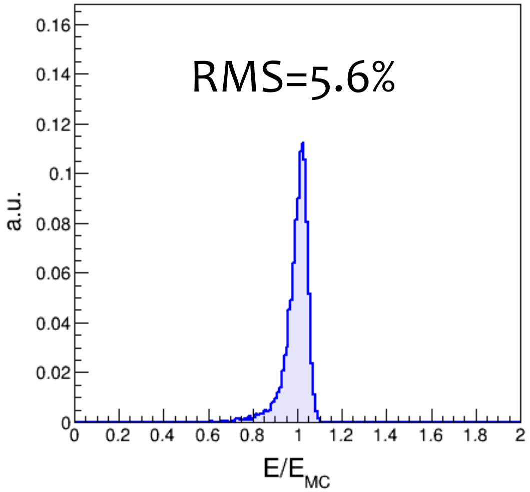
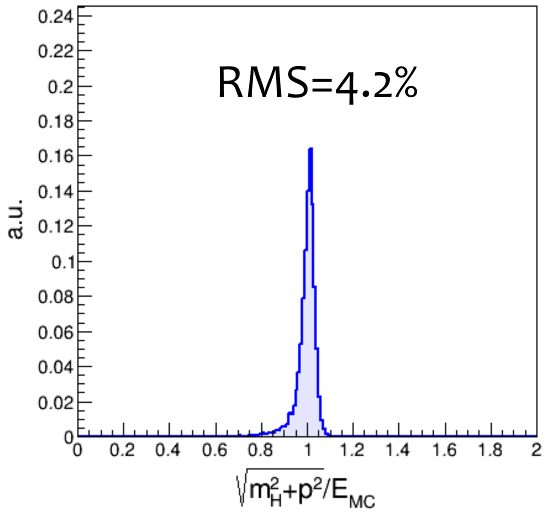




Monte Caro Sample

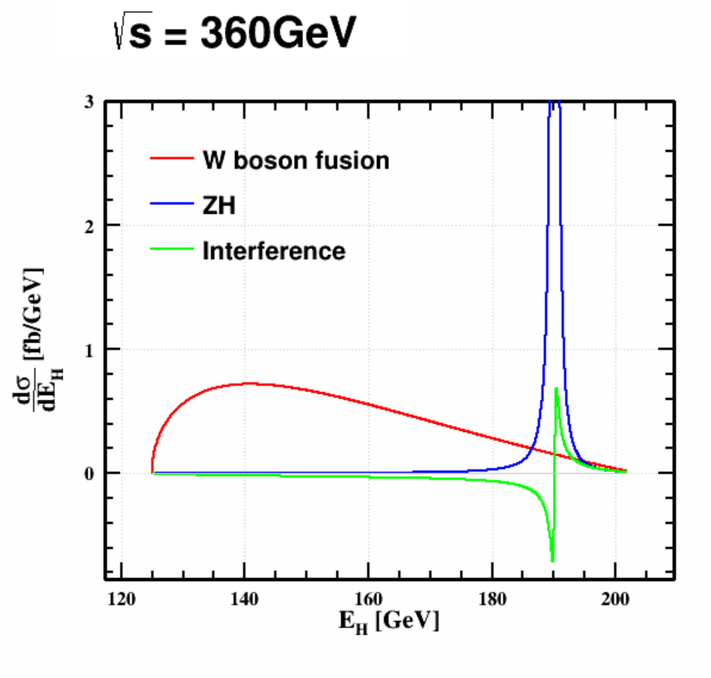
Generation

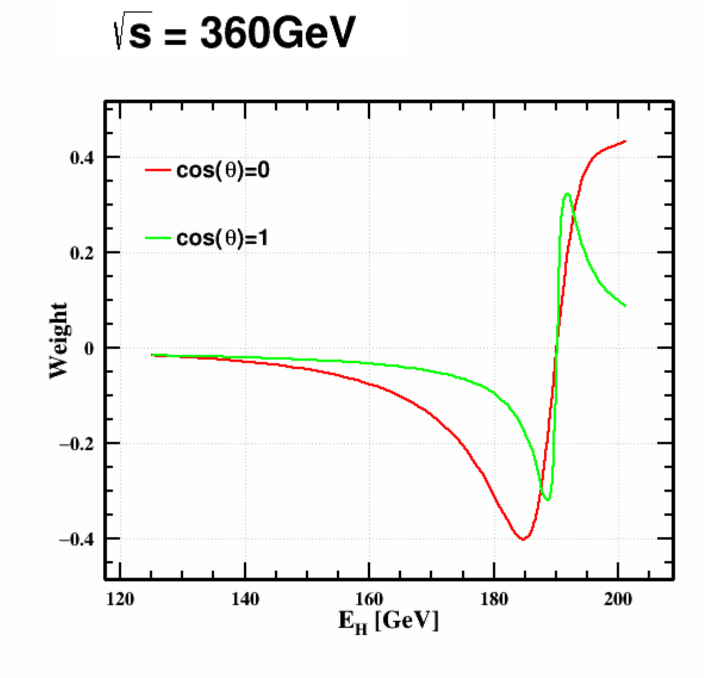
- ✓ *Whizard* 1.95 (tree level, w/ ISR photons)

Simulated with baseline detector of CEPC

Interference

- ✓ Re-weighting the sample of ZH and W boson fusion
- ✓ $\mathrm{Weight}_{ZH} = \mathrm{Weight}_{\mathrm{W\ fusion}} \approx \frac{\mathrm{d}^2\sigma_{\mathrm{Inter}}/\mathrm{d}E_H^*\mathrm{d}\theta_H^*(\sqrt{s^*})}{\mathrm{d}^2\sigma_{ZH+W\mathrm{fusion}}/\mathrm{d}E_H^*\mathrm{d}\theta_H^*(\sqrt{s^*})}$ star → center of mass frame of $\nu\nu H$ system





Result and Discussion

- Interference

Fake data w/ inter. ?	✔	✘	✔
p.d.f w/ inter. ?	✔	✘	✘
Statistical Accuracy	1 ± 0.085	1 ± 0.085	0.949 ± 0.084

✓No degradation on statistical error w/ interference

✓Need to consider in real data analysis, to avoid big bias