CEPC Physics Workshop

# Differential measurement on Higgs

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# Introduction



- After the discovery of the SM Higgs particle a new era emerged in the so-called physics BSM;
- This comes from the fact that the neutrino oscillation experiments showed that the neutrinos possess a tiny masses, unlike the SM;
- In this context theorists and experimentalists are very keen to investigate this evidence;
- Many theories have been proposed in this regards. For instance, the 2HDM model, in which particles heavier than the SM Higgs are suggested but yet to be observed;
- Also, the crossing-symmetric of $e^+e^- \to HZ(\to \ell\ell)$ showed to be promising in probing BSM scenario; and
- This is by argue that the angular asymmetries have the potential to reveal the hidden BSM physics in its differential cross section.

# Introduction



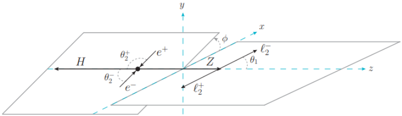
- A study showed the advantages of $e^+e^- \to HZ(\to \ell\ell)$ against $HZ(\to \ell\ell)$, see arXiv:1406.1361;
- It suggested that a high-energy $e^+e^-$ colliders would provide a clean way to estimate the Higgs couplings; (CEPC )

- In this study we are trying to develop a generator for $e^+e^- \to HZ(\to \ell\ell)$ within the CEPC framework;
- Hence, use sophisticated differential cross section analysis to do Higgs couplings measurements;

# The differential cross section

$e^+e^- \to HZ(\to \ell\ell)$






$$\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta_1 \mathrm{d}\cos\theta_2 \mathrm{d}\phi} = \frac{1}{m_H^2}\mathcal{N}_\sigma(q^2)\mathcal{J}(q^2, \theta_1, \theta_2, \phi)$$

- $\mathcal{N}_\sigma(q^2)$ is the normalisation factor and it can be written in terms of the dimensionless parameters $r$ and $s$ as:

$$\mathcal{N}_\sigma(q^2) = \frac{1}{2^{10}(2\pi)^3}\frac{1}{\sqrt{r}\gamma Z}\frac{\sqrt{\lambda(1, s, r)}}{s^2}$$

- The constant dimensionless parameters given by the following:

$$s = \frac{q_{\text{th}}^2}{m_H^2} \approx 2.98, \; r = \frac{m_Z^2}{m_H^2} \approx 0.53, \gamma Z = \frac{\Gamma_Z}{m_H} \approx 0.020$$

# The differential cross section

## $e^+e^- \to HZ(\to \ell\ell)$



- $\mathcal{J}(q^2, \theta_1, \theta_2, \phi)$ depends on nine $J_i$ functions expressed by:

$$
\begin{aligned}
\mathcal{J}(q^2, \theta_1, \theta_2, \phi) &= J_1(1 + \cos^2\theta_1 \cos^2\theta_2 + \cos^2\theta_1 + \cos^2\theta_2) \\
&+ J_2 \sin^2\theta_1 \sin^2\theta_2 + J_3 \cos\theta_1 \cos^2\theta_2 \\
&+ (J_4 \sin^2\theta_1 \sin^2\theta_2 + J_5 \sin 2\theta_1 \sin 2\theta_2) \sin\phi \\
&+ (J_6 \sin\theta_1 \sin\theta_2 + J_7 \sin 2\theta_1 \sin 2\theta_2) \cos\phi \\
&+ J_8 \sin^2\theta_1 \sin^2\theta_2 \sin 2\phi + J_9 \sin^2\theta_1 \sin^2\theta_2 \cos 2\phi
\end{aligned}
$$

# The differential cross section

$e^+e^- \to HZ(\to \ell\ell)$



- where the $J_i$ are given:

$$
\begin{aligned}
J_1 &= 2\, r\, s\, (g_A^2 + g_V^2)(|H_{1,V}|^2 + |H_{1,A}|^2), \\
J_2 &= \kappa(g_A^2 + g_V^2)\left[\kappa(|H_{1,V}|^2 + |H_{1,A}|^2) + \lambda\, \mathrm{Re}(H_{1,V}H_{2,V}^* + H_{1,A}H_{2,A}^*)\right], \\
J_3 &= 32\, r\, s\, g_A g_V\, \mathrm{Re}(H_{1,V}H_{1,A}^*), \\
J_4 &= 4\kappa\sqrt{r\, s\, \lambda}\, \mathrm{Re}(H_{1,V}H_{3,A}^* + H_{1,A}H_{3,V}^*), \\
J_5 &= \frac{1}{2}\kappa\sqrt{r\, s\, \lambda}\, (g_A^2 + g_V^2)\, \mathrm{Re}(H_{1,V}H_{3,A}^* + H_{1,A}H_{3,V}^*), \\
J_6 &= 4\sqrt{r\, s\, \lambda}\, g_A g_V \left[4\kappa\, \mathrm{Re}(H_{1,V}H_{2,V}^*) + \lambda\, \mathrm{Re}(H_{1,A}H_{2,V}^*)\right], \\
J_7 &= \frac{1}{2}\sqrt{r\, s}\, (g_A^2 + g_V^2)\left[2\kappa\, (|H_{1,V}|^2 + |H_{1,A}|^2) + \lambda\, \mathrm{Re}(H_{1,V}H_{2,V}^* + H_{1,A}H_{2,A}^*)\right], \\
J_8 &= 2\, r\, s\, \sqrt{\lambda}\, (g_A^2 + g_V^2)\, \mathrm{Re}(H_{1,V}H_{3,V}^* + H_{1,A}H_{3,A}^*), \\
J_9 &= 2\, r\, s\, \sqrt{\lambda}\, (g_A^2 + g_V^2)(|H_{1,V}|^2 + |H_{1,A}|^2).
\end{aligned}
$$

# The differential cross section

$e^+e^- \to HZ(\to \ell\ell)$



$$
\begin{aligned}
H_{1,V} &= -\frac{2m_H(\sqrt{2}G_F)^{1/2}r}{r-s}g_V\left(1+\hat{\alpha}_1^{\rm eff}-\frac{\kappa}{r}\hat{\alpha}_{ZZ}^{\rm eff}-\frac{\kappa}{2r}\frac{Q_l g_{em}(r-s)}{s g_V}\hat{\alpha}_{AZ}\right),\\
H_{1,A} &= \frac{2m_H(\sqrt{2}G_F)^{1/2}r}{r-s}g_A\left(1+\hat{\alpha}_2^{\rm eff}-\frac{\kappa}{r}\hat{\alpha}_{ZZ}\right),\\
H_{2,V} &= -\frac{2m_H(\sqrt{2}G_F)^{1/2}r}{r-s}g_V\left(2\hat{\alpha}_{ZZ}-\frac{Q_l g_{em}(r-s)}{s g_V}\hat{\alpha}_{AZ}\right),\\
H_{2,A} &= \frac{4m_H(\sqrt{2}G_F)^{1/2}r}{r-s}g_A\hat{\alpha}_{Z\hat{Z}},\\
H_{3,V} &= -\frac{2m_H(\sqrt{2}G_F)^{1/2}r}{r-s}g_V\left(2\hat{\alpha}_{Z\tilde{Z}}+\frac{Q_l g_{em}(r-s)}{s g_V}\hat{\alpha}_{A\tilde{Z}}\right),\\
H_{3,A} &= \frac{4m_H(\sqrt{2}G_F)^{1/2}r}{r-s}g_A\hat{\alpha}_{Z\tilde{Z}},
\end{aligned}
$$

Where $Q_l = -1$.

$$
\begin{aligned}
\hat{\alpha}_1^{\rm eff} &\equiv \hat{\alpha}_{ZZ}^{(1)} - \frac{m_H(\sqrt{2}G_F)^{1/2}(r-s)}{2\sqrt{r}}\frac{\hat{\alpha}_{\Phi l}^{V}}{g_V},\\
\hat{\alpha}_2^{\rm eff} &\equiv \hat{\alpha}_{ZZ}^{(1)} + \frac{m_H(\sqrt{2}G_F)^{1/2}(r-s)}{2\sqrt{r}}\frac{\hat{\alpha}_{\Phi l}^{A}}{g_A},
\end{aligned}
$$

- ☐ The $\hat{\alpha}_{\Phi l}^{V}$ and $\hat{\alpha}_{\Phi l}^{A}$ curry the $d = 6$ corrections into the Lagrangian.

# The differential cross section

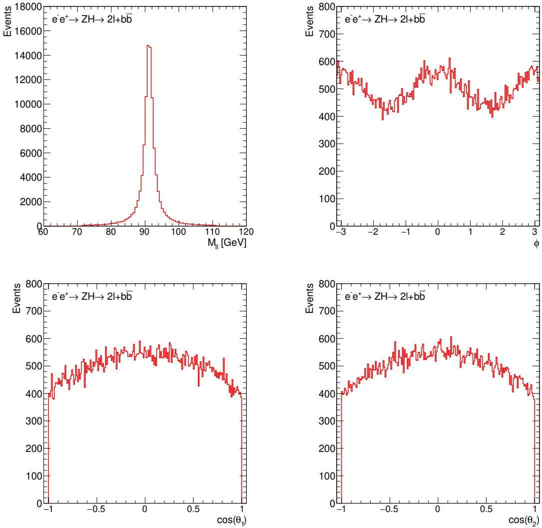
## $e^+e^- \to HZ(\to \ell\ell)$



- $J_i$, $H_{i,V}$ and $H_{i,A}$ are really hard to estimate;
- The challenge now is to figure out the $J_i$, $H_{i,V}$ and $H_{i,A}$;
- In our generator we try to kill the variables that curry $d = 6$;
- This brings us back to the SM expression;
- We show results for fixing $J_3$, $J_4$, $J_5$, $J_6$, $J_7$ and $J_8$ to zero;
- Always $J_1 = J_9$, and $J_3$ will be changed to see how the angles affected.

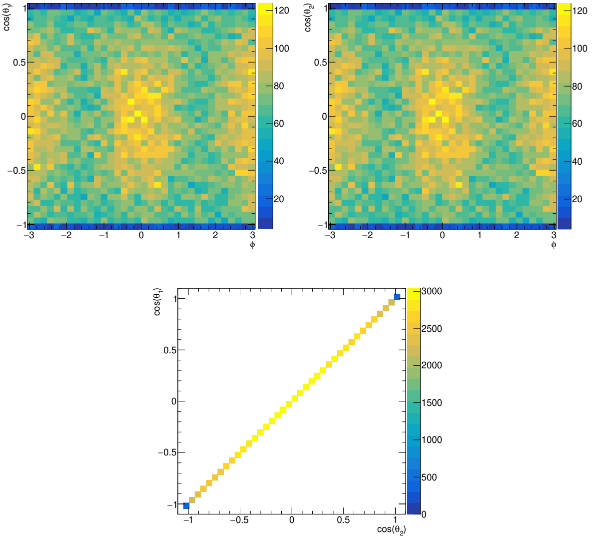
# Preliminary results
## SM





# Preliminary results

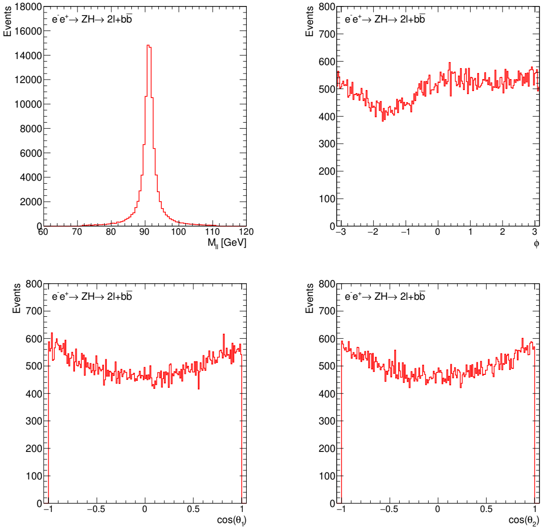
## SM



# Preliminary results

BSM ($J_1 = 3$, $J_2 = 3.5$, $J_1 = 1.0$, $J_8 = 1.0$, $J_9 = 1.0$)

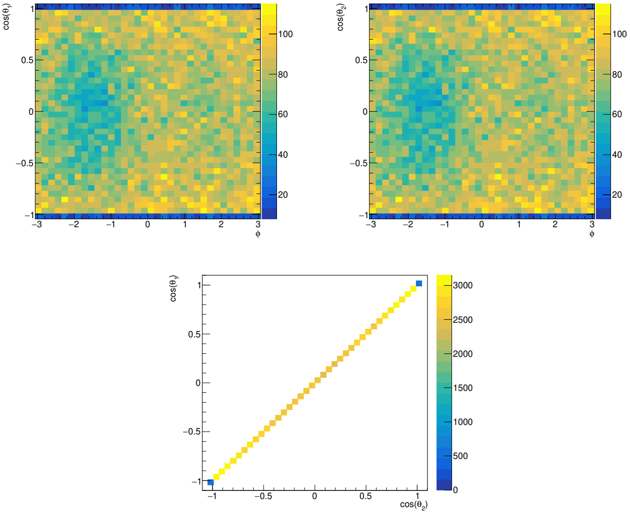




# Preliminary results

BSM ($J_1 = 3.0$, $J_2 = 3.5$, $J_1 = 1.0$, $J_8 = 1$, $J_9 = 1.0$)





# Summary



- ☐ We introduced the potential of the differential cross section of $e^+e^- \to HZ(\to \ell\ell)$ in probing the BSM scenario;
- ☐ The results provided here are from under developing generator for $e^+e^-$ collider; and
- ☐ However, still lots of work have to be done for the estimation of the $d = 6$ parameters.

## Plans

- Take background into account;
- Do a 3D fit over $\theta_1$, $\theta_2$ and $\phi$;
- See how the effect of the $J_i$'s, and probe the sensitivity of CEPC experiment.

# Thank you!