Precision Higgs Physics at CEPC

Initial assessments of Higgs physics potential at the CEPC based on the white paper (to be submitted)

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CEPC Higgs Factory Operation

Designed to produce 1 million Higgs bosons \Rightarrow 7 years operation at $\sqrt{s} = 240$ GeV for an integrated luminosity of 5.6 ab⁻¹ (2 IPs)

At $\sqrt{s} = 240$ GeV, $ee \rightarrow ZH$ production is near the maximum and dominates with a smaller contribution from $ee \rightarrow vvH$.



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Event Rates in 5.6 ab⁻¹

Process	Cross section	Events in $5.6 \mathrm{ab}^{-1}$
Higgs boson pro	duction, cross sectio	n in fb
$e^+e^- \rightarrow ZH$	196.2	1.10×10^6
$e^+e^- \rightarrow \nu_e \bar{\nu}_e H$	6.19	3.47×10^4
$e^+e^-\!\to e^+e^-H$	0.28	$1.57 imes 10^3$
Total	203.7	1.14×10^{6}

Background processes, cross section in pb

$e^+e^- \rightarrow e^+e^-$ (Bhabha)	24.7	1.4×10^8
$e^+e^- \rightarrow q\bar{q}\left(\gamma\right)$	54.1	3.0×10^8
$e^+e^- \rightarrow \mu^+\mu^-(\gamma)$ [or $\tau^+\tau^-(\gamma)$]	5.3	$3.0 imes 10^7$
$e^+e^- \rightarrow WW$	16.7	$9.4 imes 10^7$
$e^+e^- \rightarrow ZZ$	1.1	$6.2 imes 10^6$
$e^+e^- \rightarrow e^+e^-Z$	4.54	$2.5 imes 10^7$
$e^+e^- \to e^+\nu W^-/e^-\bar\nu W^+$	5.09	$2.6 imes 10^7$

Main differences with LHC

• Production:

LHC: dominated by the QCD process \Rightarrow large theoretical uncertainties CEPC: pure electroweak process \Rightarrow precise theory calculations



• Trigger and identification:

LHC: based on specific Higgs boson decay signatures \Rightarrow *measure* $\sigma \times BR$ CEPC: Higgs boson decay blinded \Rightarrow *measure* σ *and BR*

• Environment:

LHC: suffer from underlying event and pileup effects CEPC: clean

• Statistics

HL-LHC: ~ 300 million Higgs bosons, recording about ~2% CEPC: ~ 1 million Higgs bosons, every event is gold

Cross Sections and Initial S/B's



Decay-Blinded Tagging of Higgs Boson

Unique to lepton colliders, the energy and momentum of the Higgs boson in $ee \rightarrow ZH$ can be measured by looking at the Z kinematics only: $E_{_H} = \sqrt{s} - E_{_Z}$, $\vec{p}_{_H} = -\vec{p}_{_Z}$





Recoil mass reconstruction:

$$m_{\rm recoil}^2 = \left(\sqrt{s} - E_Z\right)^2 - \left|\vec{p}_Z\right|^2$$

 \Rightarrow identify the Higgs boson without looking at the Higgs boson.

Measure $\sigma(ee \rightarrow ZH)$ independent of its decay ! (LHC always measures $\sigma \times BR$)

Simulation Studies

Most of the simulation studies were performed for CEPC-v1. The results were extrapolated to CEPC-v4, the setup for CDR.

CEPC-v1: B = 3.5 T, 250 GeV, 5×5 mm² ECAL

CEPC-v4: B = 3 T, 240 GeV, 10×10 mm² ECAL

The largest impact on the performance is the degraded track momentum resolution, Other changes are small. The extrapolation takes into account cross section changes as well.



Accessible Decay Modes

SI	M decay	Acce	essible?
mode	branching ratio	(HL-)LHC	Higgs factories
$H \rightarrow bb$	57.7%	\checkmark, \times *	\checkmark
H ightarrow gg	8.57%	×	\checkmark
$H \rightarrow cc$	2.91%	×	\checkmark
$H \rightarrow ss$	$2.46 imes 10^{-4}$	×	?
$H \to \tau \tau$	6.32%	\checkmark	\checkmark
$H ightarrow \mu \mu$	$2.19 imes 10^{-4}$	\checkmark	\checkmark
$H \to WW$	21.5%	\checkmark	\checkmark
$H \rightarrow ZZ$	2.64%	\checkmark	\checkmark
$H ightarrow \gamma \gamma$	0.23%	\checkmark	\checkmark
$H \to Z\gamma$	0.15%	\checkmark	\checkmark

* Not all production mode.

Limitations: statistics at Higgs factories, trigger and systematics at (HL-)LHC

Final States Studied

$H \rightarrow bb/cc/gg$

${\cal Z}$ decay mode	$H \to b \bar{b}$	$H\!\rightarrow\!c\bar{c}$	$H\!\rightarrow\!gg$
$Z \rightarrow e^+e^-$	1.3%	12.8%	6.8%
$Z \rightarrow \mu^+ \mu^-$	1.0%	9.4%	4.9%
$Z \rightarrow q\bar{q}$	0.5%	10.6%	3.5%
$Z \rightarrow \nu \bar{\nu}$	0.4%	3.7%	1.4%
Combined	0.3%	3.1%	1.2%

$H \rightarrow ZZ^*$

ZH final state		Precision
$Z \rightarrow \mu^+ \mu^-$	$H \rightarrow ZZ^* \rightarrow \nu \bar{\nu} q \bar{q}$	7.2%
$Z \rightarrow \nu \bar{\nu}$	$H\!\rightarrow\! ZZ^{\star}\!\rightarrow\!\ell^{+}\ell^{-}q\bar{q}$	7.9%
Combined		4.9%

$H \rightarrow \text{Invisible}$

ZH fi	inal	Relative precision	Upper limit on
state st	udied	on $\sigma \times BR$	$BR(H \rightarrow inv)$
$Z \rightarrow e^+e^-$	$H \rightarrow inv$	339%	0.82%
$Z \rightarrow \mu^+ \mu^-$	$H \rightarrow inv$	232%	0.60%
$Z \rightarrow q \bar{q}$	$H \rightarrow \text{inv}$	217%	0.57%
Comb	ined	143%	0.41%

 $H \rightarrow WW^*$

	ZH final state	
$Z\!\rightarrow\!e^+e^-$	$H \mathop{\rightarrow} WW^* \mathop{\rightarrow} \ell \nu \ell' \nu, \ell \nu q \bar{q}$	2.6%
$Z{\rightarrow}\mu^+\mu^-$	$H \mathop{\rightarrow} WW^{\star} \mathop{\rightarrow} \ell \nu \ell' \nu, \ell \nu q \bar{q}$	2.4%
$Z \rightarrow \nu \bar{\nu}$	$H \rightarrow WW^* \rightarrow \ell \nu q \bar{q}, q \bar{q} q \bar{q}$	1.5%
$Z \rightarrow q \bar{q}$	$H \mathop{\rightarrow} WW^* \mathop{\rightarrow} q\bar{q}q\bar{q}$	1.7%
	Combined	0.9%

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ZH final state		Precision
$Z \rightarrow \mu^+ \mu^-$	$H{\rightarrow}\tau^+\tau^-$	2.6%
$Z \rightarrow e^+e^-$	$H{\rightarrow}\tau^+\tau^-$	2.6%
$Z \rightarrow \nu \bar{\nu}$	$H{\rightarrow}\tau^+\tau^-$	2.5%
$Z \rightarrow q \bar{q}$	$H{\rightarrow}\tau^+\tau^-$	0.9%
Combined		0.79%

Other final states: $H \rightarrow \gamma\gamma: Z \rightarrow \mu\mu, \tau\tau, \nu\nu, qq$ $H \rightarrow Z\gamma: ZZ \rightarrow \nu\nu qq$ $H \rightarrow \mu\mu: Z \rightarrow \ell\ell, \nu\nu, qq$ $ee \rightarrow \nu\nu H \rightarrow \nu\nu bb$

A lot final states have been studied, many more remain unexplored...

Recoil mass analyses



Peak position $\Rightarrow m_{\mu}$; peak height $\Rightarrow \sigma(ZH)$

No Bremstrahlung radiation recovery yet, *ee* channel suffers from the large two-photon background.

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Higgs Boson Decay Analyses



(Other Higgs boson decays are included in the background for individual analyses, but are treated as signal in the combination.)

Expected Precision from Combination

Property	Estimated Precision
m_H	5.9 MeV
Γ_H	3.1%
$\sigma(ZH)$	0.5%
$\sigma(\nu\bar{\nu}H)$	3.0%

Decay mode	$\sigma(ZH) \times BR$	BR
$H \rightarrow b \bar{b}$	0.27%	0.56%
$H \to c \bar{c}$	3.3%	3.3%
$H \to gg$	1.3%	1.4%
$H \to WW^*$	1.0%	1.1%
$H \to Z Z^*$	5.1%	5.1%
$H\to\gamma\gamma$	6.8%	6.9%
$H\to Z\gamma$	15%	15%
$H \to \tau^+ \tau^-$	0.8%	1.0%
$H ightarrow \mu^+ \mu^-$	17%	17%
$H \to \mathrm{inv}$		< 0.30%

Statistical uncertainties only, but *taking into account correlations* among analyses.

Systematic uncertainties are expected to be small, but need studies

Width measurements:

$$\Gamma_{H} = \frac{\Gamma(H \to ZZ^{*})}{BR(H \to ZZ^{*})} \propto \frac{\sigma(ZH)}{BR(H \to ZZ^{*})}$$

$$\Gamma_{H} = \frac{\Gamma(H \to WW^{*})}{\mathsf{BR}(H \to WW^{*})} \propto \frac{\sigma(v\overline{v}H)}{\mathsf{BR}(H \to WW^{*})}$$

⇐ 95% CL upper limit on BSM contribution

Relative Precision on Coupling Modifiers



BR^{BSM}_{inv} shown are 95% CL upper limits



 e^+

e⁻

Η

Ζ

7-parameter fit assumes lepton universality and no BSM Higgs boson decays

Comparisons with HL-LHC



Higgs and Top Coupling

CEPC will be sensitive to the Higgs-Top coupling through the loop $H \rightarrow gg$ decay.



The expected high precision in the coupling measurement can be used to constrain the coupling as well as CP-violating phase



Precision of EFT Fits

A complete set of CP-even dimension-6 operators that contribute to the Higgs boson and diboson measurements, but not to the Z-pole observables, the W mass and fermion dipole interaction



precision reach of the 12-parameter EFT fit (Higgs basis)

Higgs Boson CP Studies



 f_{a2} : fraction of high-order CP-even contribution due to SM or BSM physics f_{a3} : fraction of CP-odd contribution due to BSM physics

 3σ discovery potential from ZH $\rightarrow \mu\mu bb$ $f_{a2} > 0.018$ or $f_{a3} > 0.007$

Summary

A preliminary assessment of CEPC's Higgs physics potential has been performed based on the simulation studies of the CEPC conceptual detector.

Percent-level precision or better can be achieved for many of the Higgs boson couplings, improving HL-LHC measurements by an order of magnitude in many cases.

More studies are needed to fully understand the potential of the CEPC as a Higgs factory.

CEPC will open a new frontier in precision physics and can "undress" the Higgs boson as what LEP has done to the Z boson. It has the potential to shed lights on new physics.

Comparison with FCC-ee

Relative precision of Higgs couplings

	CEPC		FCC-ee*
	5.6 ab^{-1} ,	$240 \mathrm{GeV}$	$5 \text{ ab}^{-1}, 240 \text{ GeV}$
Correlations	included	ignored	ignored
Γ_H	3.1%	2.9%	2.8%
κ_b	1.6%	1.4%	1.4%
κ_c	2.2%	2.1%	1.8%
κ_g	1.6%	1.5%	1.7%
κ_W	1.4%	1.3%	1.3%
κ_Z	0.25%	0.25%	0.25%
κ_{γ}	3.7%	3.7%	4.7%
$\kappa_{ au}$	1.5%	1.4%	1.4%
κ_{μ}	8.7%	8.7%	9.6%
BR_{inv}^{BSM}	< 0.3%	< 0.3%	—

 * presented at ICHEP 2018

Higgs Boson Decay Analyses

