

 $H\to\gamma\gamma$

CEPC Physics Performance for RefTDR Monday meeting

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Introduction

Motivation:

 ${}^{-\!H} \to \gamma\gamma$ is a key probe, crucial to Higgs boson discovery + loop-mediated process sensitive to BSM physics.

-Importance for precision measurements of Higgs properties.



CEPC:

-Future e^+e^- collider: high-precision Higgs factory (around 4M H @ 20 ab^{-1} over 10 years).

-Expected luminosity, clean environment (low background compared to hadron colliders).

 $\mbox{-}H \rightarrow \gamma\gamma$ main benchmark for Physics at CEPC (Photon ID & ECAL Resolution)

Theoretical Background

-Sensitivity to new physics (charged particles entering loops).



-Branching ratio & SM predictions (≈0.23% in SM).



Electromagnetic calorimeter (ECAL) performance:

-PFA-oriented calorimetry: high-granularity homogeneous crystal ECAL -Crystal-bar ECAL resolution \approx 1.3%/ $\sqrt{E}~\oplus$ 0.7%

-Photon Identification (still under work not implemented in study yet)

Trigger & event selection for $H \rightarrow \gamma \gamma$.: (almost triggerless)

- -Pile-up free(@240 GeV)
- –Low background
- -High hermeticity : a complete event without fake particles
- $\cdot |\cos \theta|$ up to 0.98
- -Different selections applied according to each sub-channel

-Main focus on ZH (ZH associate production/Higgsstrahlung), for diphoton decay, we consider three main sub-channels: $q\bar{q}\gamma\gamma$, $\mu^+\mu^-\gamma\gamma$, $\nu\bar{\nu}\gamma\gamma$

-Diphoton invariant mass $(m_{\gamma\gamma})$: key observable.

-Backgrounds: mainly $e^+e^- \rightarrow q\bar{q}(\gamma\gamma)/\mu^+\mu^-(\gamma\gamma)/\nu\bar{\nu}(\gamma\gamma)$ (each corresponding to one of the sub-channels)

-Analysis chainflow and statistical methods:

Specific cutflows, multivariate techniques (BDT), systematic uncertainties, likelihood fit.

-Result: Expected significance/precision on $\sigma \times Br$ with CEPC data.

*3 sub-channels with differents final state physics objects identification and selection within the signal samples

- $\cdot e^+e^- \rightarrow ZH \rightarrow q\bar{q}H(H \rightarrow \gamma\gamma)$
 - 2 photons
 - 2 jets

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$$e^+e^- \rightarrow ZH \rightarrow \mu^+\mu^-H(H \rightarrow \gamma\gamma)$$

- 2 muons
- 2 photons
- Nothing else
- · $e^+e^- \rightarrow ZH \rightarrow \nu \bar{\nu} H(H \rightarrow \gamma \gamma)$
 - 2 photons
 - Missing energy

Signal events		Background events	
Selection Step	Events (Efficiency)	Selection Step	Events (Efficiency)
Total events generated Inclusive 2 photons $E_{\gamma} > 30 \text{ GeV}$ $ \cos(\theta_{\gamma}) < 0.8$ $p_{T,\gamma} > 20 \text{ GeV}$ $M_{\text{missing}} > 60 \text{ GeV}$ 110 GeV $< m_{\gamma\gamma} < 140 \text{ GeV}$ 120 GeV $< E_{\gamma\gamma} < 150 \text{ GeV}$	8913 8825 (99.0127%) 7936 (89.9263%) 5688 (71.6734%) 5688 (100%) 5443 (95.6927%) 5346 (98.2179%) 5318 (99.4762%)	Total events generated Gen Filter ($M_{\gamma\gamma} \ge 90$) Delphes fast sim ($M_{\gamma\gamma} \ge 90$) $E_{\gamma} > 30 \text{ GeV}$ $ \cos \theta_{\gamma} < 0.8$ $p_{T,\gamma} > 20 \text{ GeV}$ $M_{\text{missing}} > 60 \text{ GeV}$ 110 GeV $< m_{\gamma\gamma} < 140 \text{ GeV}$ 120 GeV $< E_{\gamma\gamma} < 150 \text{ GeV}$	82,804,236 (100%) 1,491,000 (1.80%) 50,138 (3.36271%) 41,930 (83.6292%) 3,114 (7.42666%) 3,099 (99.5183%) 3,086 (99.5805%) 1,505 (48.7686%) 1,499 (99.6013%)
Final selected events Expected yield at 20 ab ⁻¹	5318 (59.6657%) 1253.91 events	Final selected events Expected yield at 20 ab ⁻¹	1,499 (0.00181%) 19655.5 events

Diphoton $\nu \bar{\nu}$ sub-channel: $m_{\gamma \gamma}$ signal distribution



Tail weird aspect (right more important) due to reconstruction issues in CyberPFA - calibration also needed

Diphoton $uar{ u}$ sub-channel: $m_{\gamma\gamma}$ signal distribution (comparison with CDR)



in CDR, different detector baseline, specifically ECAL (Silicion-Tungsten previously vs. Crystal Glass-ECAL): stochastic term around 16% -> wider distribution

Diphoton $\nu\bar{\nu}$ sub-channel: $m_{\gamma\gamma}$ background distribution



Fitted with 1st Chebyshev

Diphoton $\nu\bar{\nu}$ sub-channel: Signal over background plot



Diphoton $q\bar{q}$ sub-channel: Efficiencies

		background events	
Signal events		Selection Step	Events (Efficiency)
Selection Step	Events (Efficiency)	Total events generated	24,739,403 (100%)
Total events generated	99800	Gen Filter ($M_{\gamma\gamma} \ge 90$)	3,375,000 (13.64%)
Exclusive 2 jets and 2 photons	90823 (91.005%)	Delphes fast sim ($M_{\gamma\gamma} \ge 90$)	440,203 (13.04%)
$E_{\gamma 1} > 20 \text{ GeV}$	82841 (91.2115%)	$E_{\gamma 1} > 20 \text{ GeV}$	433,340 (98.4409%)
30 GeV $< E_{\gamma 2} <$ 100 GeV	81358 (98.2098%)	$30~{ m GeV} < E_{\gamma^2} < 100~{ m GeV}$	109,508 (25.2707%)
$\cos \theta_{\gamma\gamma} > -0.95$	79662 (97.9154%)	$\cos heta_{\gamma\gamma} > -0.95$	98,097 (89.5798%)
$\cos heta_{jj} > -0.95$	77967 (97.8723%)	$\cos heta_{jj} > -0.95$	87,978 (89.6847%)
$p_{T,\gamma 1} > 20 \text{ GeV}$	71433 (91.6195%)	$p_{T,\gamma 1} > 20 \text{ GeV}$	45,863 (52.1301%)
$p_{T,\gamma^2} > 30 \text{ GeV}$	67626 (94.6705%)	$p_{T,\gamma^2} > 30 \text{ GeV}$	34,073 (74.293%)
110 $< m_{\gamma\gamma} <$ 140 GeV	64266 (95.0315%)	110 $< m_{\gamma\gamma} <$ 140 GeV	15,069 (44.2256%)
$E_{\gamma\gamma} > 110 GeV$	64266 (100%)	$E_{\gamma\gamma}$ > 110 GeV	15,069 (100%)
$\min \cos_{\gamma j} > 0.9 \text{ GeV}$	64266 (100%)	$\min \cos_{\gamma j} > 0.9 \text{ GeV}$	15,034 (99.7677%)
Final selected events	64266 (64.3948%)	Final selected events	15,034 (0.0607%)
Expected yield at 20 ab ⁻¹	3999.67 events	Expected yield at 20 ab	657525.5 events ₁

Dackground avanta

Diphoton $q\bar{q}$ sub-channel: $m_{\gamma\gamma}$ signal distribution



Diphoton $q\bar{q}$ sub-channel: $m_{\gamma\gamma}$ signal distribution (comparison with CDR)



Diphoton $q\bar{q}$ sub-channel: $m_{\gamma\gamma}$ background distribution



Diphoton⁻sub-channel: Signal over background plot



Signal efficiency ===== Event Selection Summary ===== Total events processed: 10000 Exclusive 2 muons and 2 photons: 7227 (72.27%) E_y > 35 GeV: 6778 (93.7872%) |cos(theta_y)| < 0.9: 5772 (85.1579%) 10 GeV < pT_y1 < 70 GeV: 5770 (99.9653%) 30 GeV < pT_y2 < 100 GeV: 5759 (99.8094%) 110 GeV <m_yy < 140 GeV: 5673 (98.5067%) 85 GeV < m^recoil_yy < 105 GeV: 5045 (88.93%) 125 GeV < E_yy < 145 GeV: 5037 (99.8414%) Final selected events: 5037 (50.37%) Expected yield at 20ab^-1: 154.816 events

Background efficiency 2 $e^+e^- \rightarrow \mu^+\mu^-$ process efficiency

Selections	Efficiency	Event Number
Generator	100%	10778370
Gen Filter $(M_{\gamma\gamma} >= 90 GeV)$	8.19%	882451
Delphes fast sim $(M_{\gamma\gamma} >= 90 GeV)$	7.25581%	64029
$E_{\gamma} > 35 GeV$	61.861%	39609
$ \cos \theta_{\gamma} < 0.9$	35.8706%	14208
$pT_{\gamma 1} \in [10, 70]GeV$	92.8491%	13192
$pT_{\gamma 2} \in [30, 100] GeV$	87.1892%	11502
$m_{\gamma\gamma} \in [110, 140] GeV$	48.4611%	5574
$M_{\gamma\gamma}^{recoil} \in [85, 105] GeV$	21.4926%	1198
$E_{\gamma\gamma} \in [125, 145] GeV$	98.1636%	1176
Total eff	0.01%	1176

Yield at 20 ab^{-1} : 12050.9 events

Diphoton $\mu^+\mu^-$ sub-channel: $m_{\gamma\gamma}$ signal distribution



Diphoton $\mu^+\mu^-$ sub-channel: $m_{\gamma\gamma}$ background distribution



Diphoton⁻sub-channel: Signal over background plot



*Few modifications suggested by analysis review committee (Dr. Shuo Han & Dr. Junquan Tao): -Implementing photon ID (considering photon isolation?) -Considering other backgrounds ($Z\gamma + jets$) and fake photons (should be have extremely small contribution) -Following up calibration corrections (implementing vertex selections?) and checks on signal modeling ($m_{\gamma\gamma}$ a bit shifted to 126 GeV) -Checking a wider fit range -Test with official fitting tool (ATLAS or CMS Higgs combination tool) *Implement BDTs for better signal-background separation

*Studying systematic uncertainties

*Final results with maximum likelihood applied to get an idea on signal strength and get results for $\sigma \times BR$

Thank you!

Back-up