Higgs measurement in $H \rightarrow \gamma\gamma$ channel in CEPC

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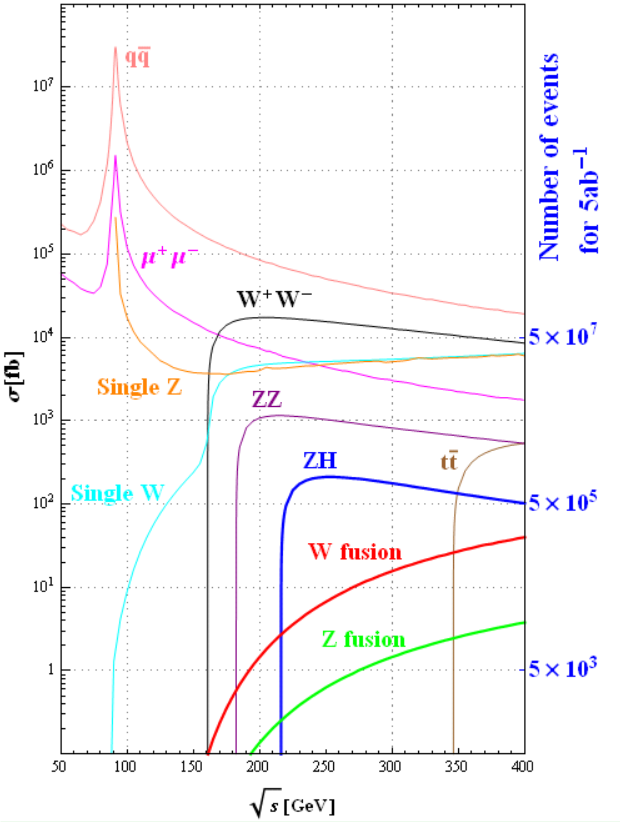
Content

Introduction

Higgs physics in CEPC

- Higgs production: $ee \rightarrow ZH$ process @ 240GeV $e^{+}e^{-}$ collider.
- $H \rightarrow \gamma\gamma$ could be studied in 3 sub-channels, depends on Z decay(leptonic, hadronic and invisible).
- A good channel for Higgs precise measurement in CEPC
- Also a benchmark for EM calorimeter design.



Previous review

$H \to \gamma\gamma$ physics analysis in CEPC CDR(2018):

- Design point at CEPC_v4, $\sqrt{s} = 240GeV, \mathcal{L} = 5.6ab^{-1}$
- Whizard 1.95 + MoccaC generator, dedicated fast simulation+smearing function based on parametrized detector response.
- Considered $H \to \gamma\gamma$ signal and 2 fermion dominant background
- Result: $\delta(Br(H \to \gamma\gamma) \times \sigma(ZH))$=6.84% in 3 combined channels.

CEPC Physics Workshop in PKU, July 2019

- Applied MVA method in $ZH \to qq\gamma\gamma$ channel, and gained ~30% improvement. Combined precision with MVA: 5.39%
- Expect to have similar improvement in all 3 sub-channels

MC samples and simulation

MC samples: Whizard 1.95 + MoccaC, 3 sub-channels

- Signal: $ee \rightarrow ZH \rightarrow qq\gamma\gamma/\mu\mu\gamma\gamma/\nu\nu\gamma\gamma$, 10k events for each channel.
- Background: 2 fermion process $ee \rightarrow ff$+radiation photons

Simulation:

- Background:

  Fast simulation: smear the objects with the resolution and efficiency with parametrized detector response to obtain a continuum spectrum.
- Signal:

  Full CEPC detector V4 simulation. Photon reconstruction & Isolation, jet clustering, etc.

define: γ_1/f_1 as photon/jet with lower energy, and γ_2/f_2 as higher energy one.

MC samples and simulation

$qq\gamma\gamma$ channel sample:

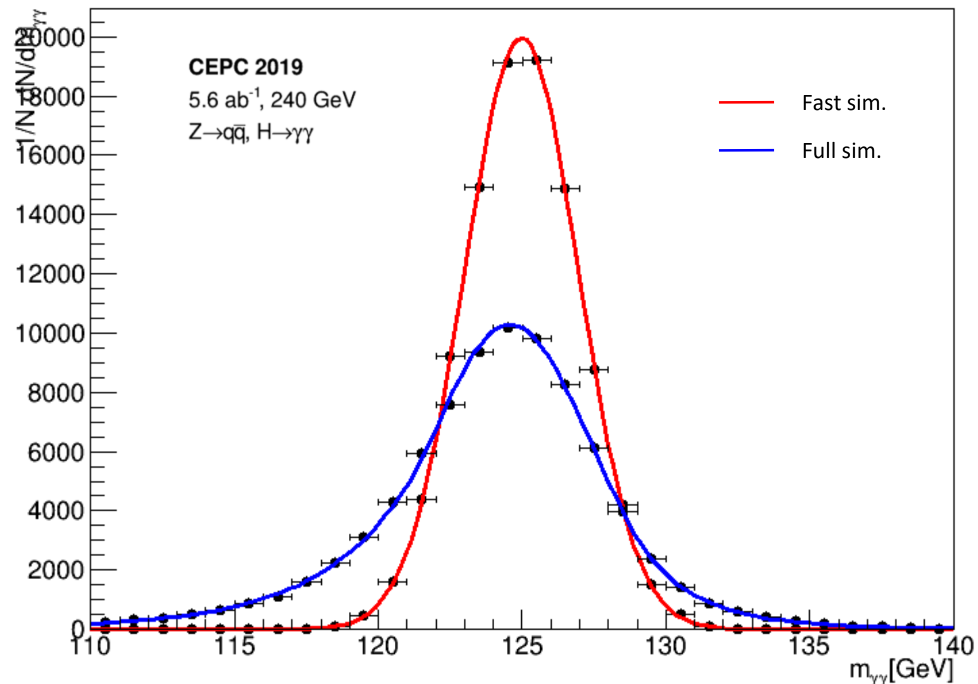
	$qq\gamma\gamma$ eff	Mass width
Fast sim	99.9%	1.98GeV
Full sim	85.6%	2.81GeV

$\mu\mu\gamma\gamma$ channel:

Lepton PID efficiency:87%

➡ $\mu\mu\gamma\gamma$ final state eff=70%

(also ~100% in fast sim.)



$m_{\gamma\gamma}$ shape for fast and full simulation in $ZH \rightarrow qq\gamma\gamma$ channel.

Fit shape: Gaussian for fast sim, Double-side Crystal Ball(DSCB) for full sim.

MVA based $\delta(\sigma \times Br)$ measurement

Pre-selection

$E_{\gamma 1} > 25GeV$
$35GeV < E_{\gamma 2} < 96GeV$
$cos\theta_{\gamma\gamma} >$ -0.95,
$cos\theta_{jj}$>-0.95
$pT_{\gamma 1} > 20GeV$,
$pT_{\gamma 1} > 30GeV$
$110GeV < m_{\gamma\gamma} < 140GeV$
$E_{\gamma\gamma} > 120GeV$
$\min|cos\theta_{\gamma j}|$<0.9

$qq\gamma\gamma$ channel.
Final eff: 61% for signal, 0.02% for background

$E_{\gamma} > 35GeV$
$|cos\theta_{\gamma}|$ <0.9
$10GeV < pT_{\gamma 1} < 70GeV$
$30GeV < pT_{\gamma 1} < 100GeV$
$110GeV < m_{\gamma\gamma} < 140GeV$
$\min|cos\theta_{\gamma j}|$<0.9
84GeV<$M_{\gamma\gamma}^{recoil}$<103GeV
125GeV<$E_{\gamma\gamma}$<143GeV

$\mu\mu\gamma\gamma$ channel.
Final eff: 46% for signal, 0.01% for background

$E_{\gamma} > 30GeV$
$|cos\theta_{\gamma}|$ <0.8
$pT_{\gamma} > 20GeV$
$110GeV < m_{\gamma\gamma} < 140GeV$
120GeV<$E_{\gamma\gamma}$<150GeV

$\nu\nu\gamma\gamma$ channel.
Final eff: 57% for signal, 0.002% for background

MVA based $\delta(\sigma \times Br)$ measurement

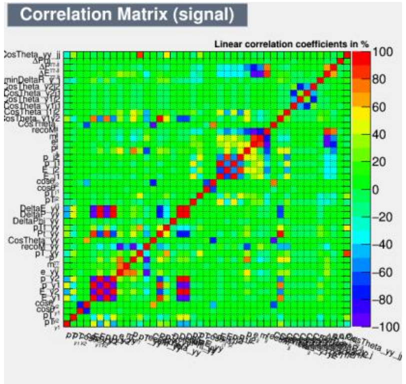
MVA analysis

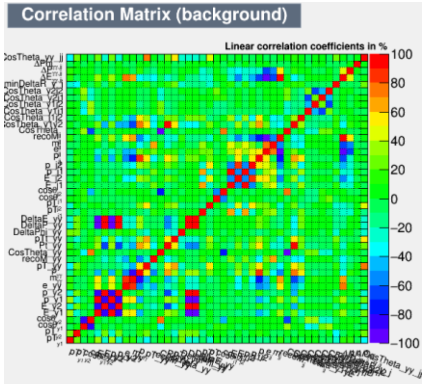
- Base variables: 4-vector of 4 particles in final state.
- Considered variables for MVA: constructed with 4-vector

  P, pT, E, $cos\theta$, recoil mass, missing mass(for ν channel) for photons, fermions, systems.

  $\Delta P, \Delta E, \Delta\Phi, \Delta cos\theta, \Delta R$ for 2 objects or systems.
- Correlation requirement for variables:

  $|Corr_{v-m_{\gamma\gamma}}|$<30%, $|Corr_{v_1-v_2}|$<40%





- ML training method: BDTG

  Separately in 3 channels.

MVA based $\delta(\sigma \times Br)$ measurement

Signal strength extraction $\mu = N^{obs}_{H\to\gamma\gamma}/N^{SM}_{H\to\gamma\gamma}$

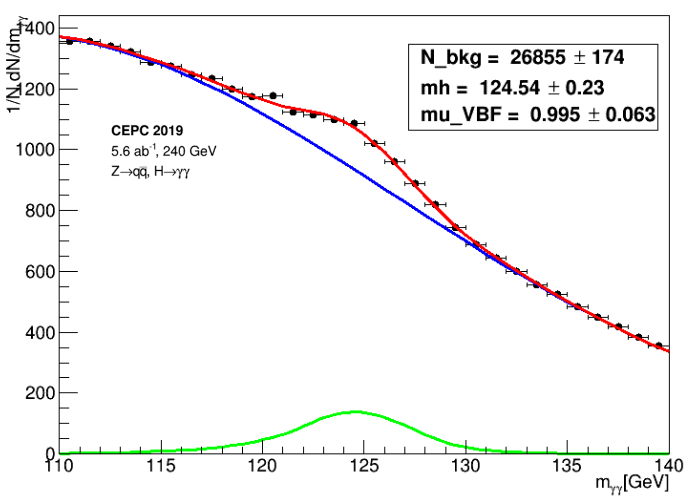
- Individual 2-D fit in $m_{\gamma\gamma}$ and BDT response.

  Fit function for $m_{\gamma\gamma}$: DSCB for signal, 2nd polynomial exponential for Bkg.

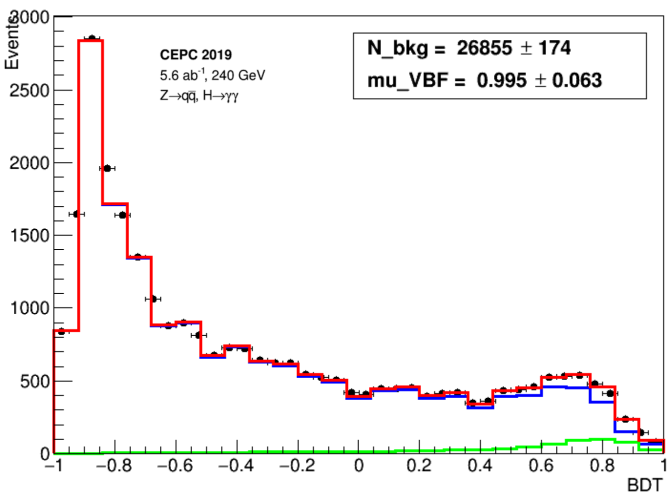
  Model for BDT: binned PDF for signal and Bkg.

  $PDF_{2D} = PDF_{m_{\gamma\gamma}} \times PDF_{BDT}$ ($|Corr_{m_{\gamma\gamma}-BDT}| = 3\%(15\%)$ for signal(Bkg))

Fit $m_{\gamma\gamma}$ in qqγγ channel



BDTout distribution in qqγγ channel



MVA based $\delta(\sigma \times Br)$ measurement

Results

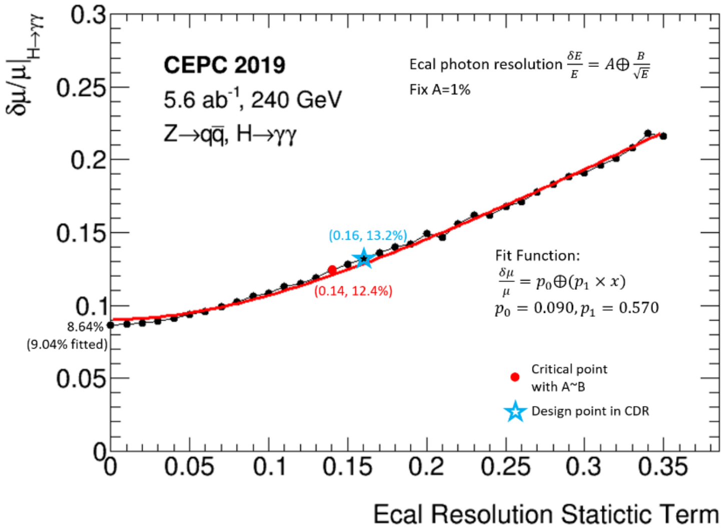
Channel	Full sim + MVA (New)	Fast sim + noMVA (CDR)	Change
$qq\gamma\gamma$	6.31%	9.84%	36% improved
$\mu\mu\gamma\gamma$	39%	23.7%	64% decreased
$\nu\nu\gamma\gamma$	18%	10.5%	71% decreased
combined	5.70%	6.84%	16% improved

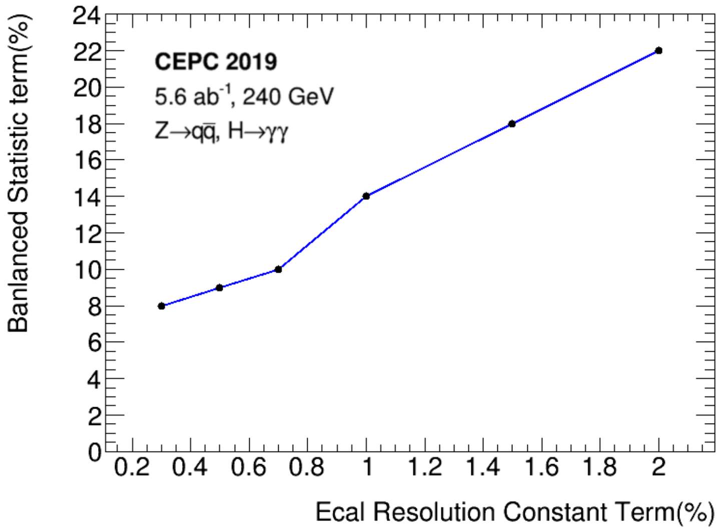
FCC-ee case:

- 3% @240GeV, $10ab^{-1}$, based on CMS ECal resolution, TLEP physics, 2013
- 9% @240GeV, $5ab^{-1}$, FCC-ee CDR, 2018

ECal resolution influence

Smear photon energy to different resolution $\frac{\delta E}{E} = A \oplus \frac{B}{\sqrt{E}}$, and fit $m_{\gamma\gamma}$ distribution to extract $\delta\mu(H \to \gamma\gamma)$





$\frac{\delta\mu}{\mu} = p_0 \oplus (p_1 \times B)$, p_0 represent constant term contribution in $\delta\mu$, p_1 represent statistics term.

Critical point(A-B balance) definition: $\delta\mu(B_c) = \sqrt{2}\delta\mu(B = 0)$, ⟸ $p_0 = p_1 B$

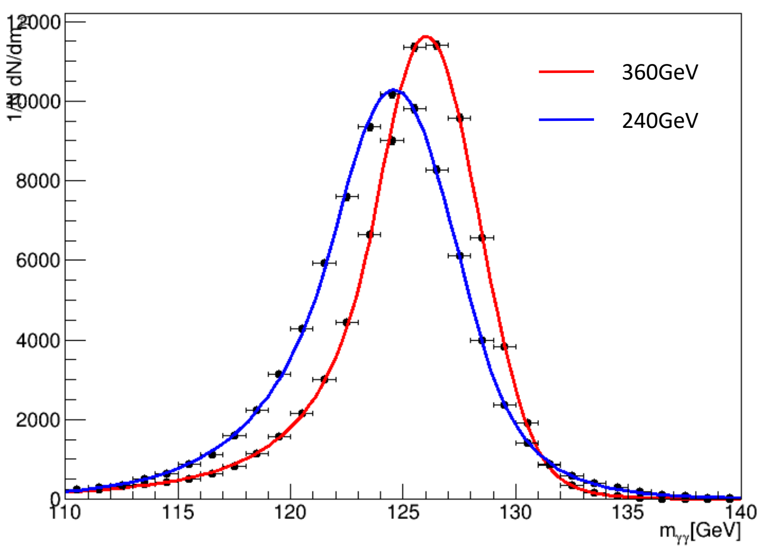
Extrapolation for 360GeV

If one day we want to see 360GeV @CEPC…

$\mu\mu\gamma\gamma$ Whizard MC @ $\sqrt{s} = 360GeV$ + 240GeV simulation

Difference:

- $m_{\gamma\gamma}$ width:
  2.84GeV@240GeV
  2.34GeV@360GeV
  ➡ Better photon resolution
- Efficiency:
  80%@360GeV, 85%@240GeV
- Mass peak:
  126.03GeV@360GeV.
  ➡ Re-calibration for detector



Conclusion

Full simulation + MVA analysis for $H \to \gamma\gamma$ channel

- Improvement from MVA + decrease from full simulation. combined precision 5.7% in 3 sub-channels.
- Photon correction like photon conversion was not included in full simulation, lepton PID efficiency need further study.

ECal resolution and precision

- 14% statistics term ~ 1% constant term.
- CEPC baseline detector still have improvement space.

Thank you