Higgs CP via Higgs to ZZ final state in CEPC

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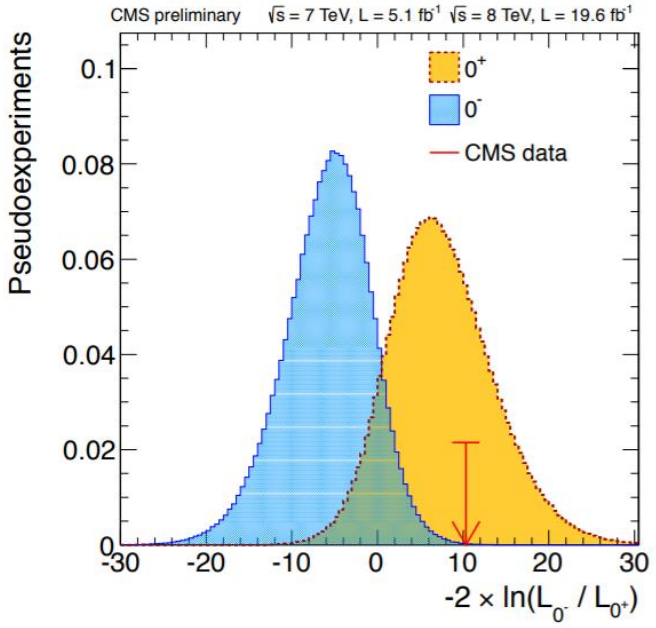
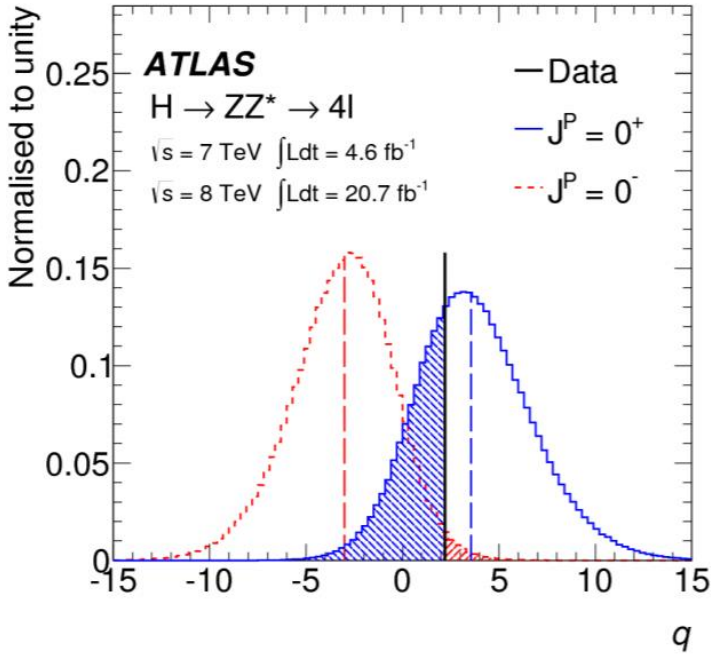
Motivation

- The observed 125 GeV Higgs is spin-0, CP-even
- New physics -> anomalous coupling



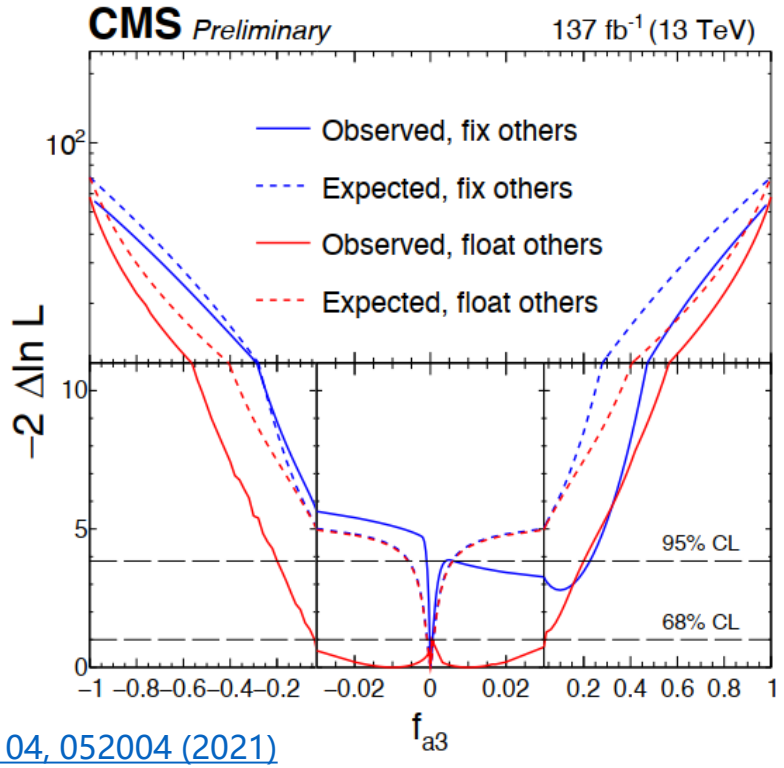


Experimental results on anomalous coupling

$$A(\mathrm{HVV}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_{\mathrm{V1}}^2 + \kappa_2^{\mathrm{VV}} q_{\mathrm{V2}}^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2}\right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu},$$

higher order CP even

CP odd



PRD 104, 052004 (2021)

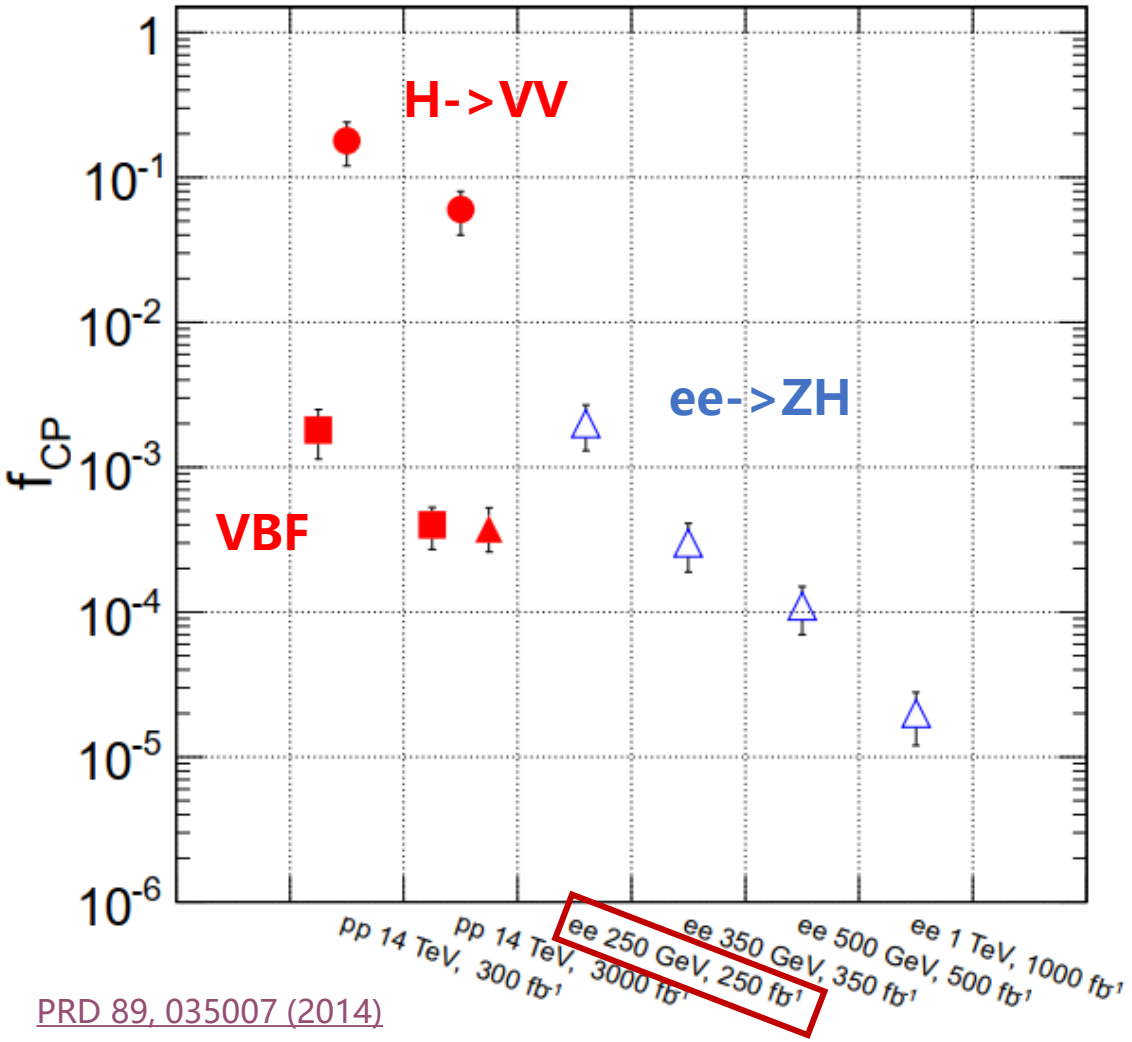
CP-odd contribution

$$f_{CP} = \frac{|a_3|^2 \sigma_3}{\sum |a_i|^2 \sigma_i}$$

For H->ZZ:

Observed (expected) limit at 95% C.L.: $1(4) \times 10^{-3}$

Expectation at hadron/lepton collider



PRD 89, 035007 (2014)

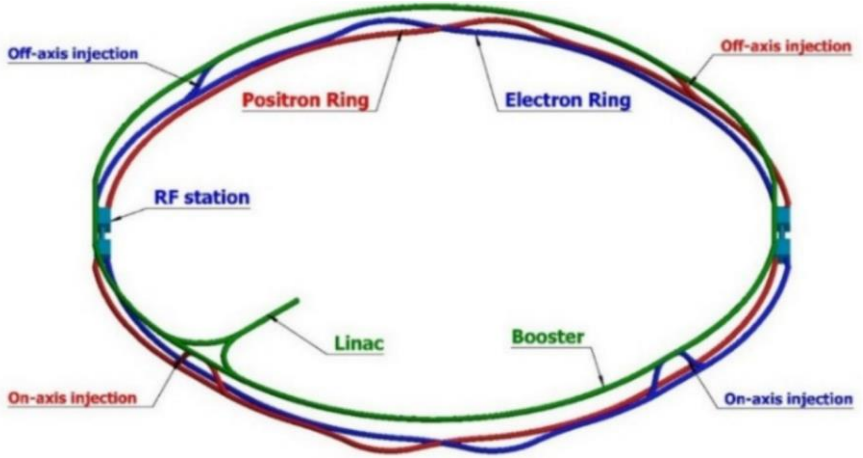
- At HL-LHC, sensitivity could reach 10^{-3}
- At lepton collider (250/fb at 250 GeV), sensitivity is comparable with HL-LHC
- Further improved from combination of $ee \to ZH$ and $H \to ZZ$

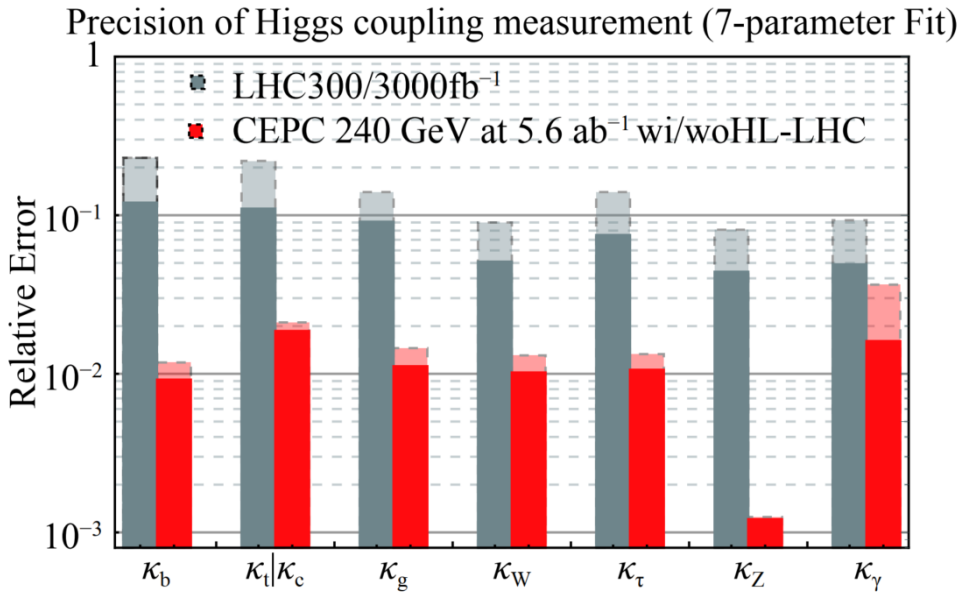
Circular Electron Positron Collider(CEPC)

- Proposed project for precise measurement of Higgs properties
  - could also run as Z and W factories
- High luminosity, i.e. 3×10^{34} cm^{-2}s^{-1} at $\sqrt{s} = 240$ GeV
  - Top-up operation is available
- Circumference: 100km
  - Reusable for SPPC

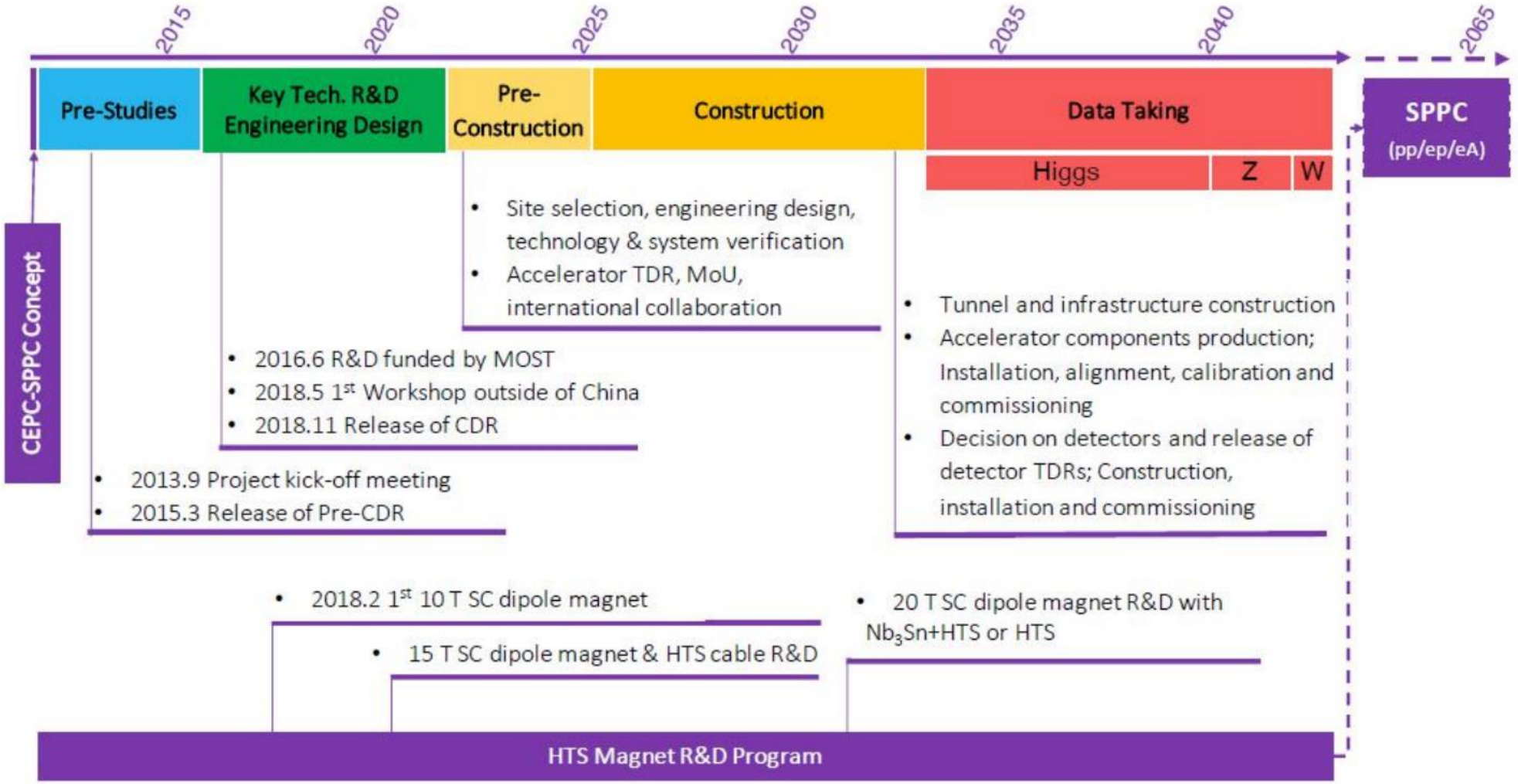
operation mode	Z factory	WW threshold	Higgs factory
$\sqrt{s}$/GeV	91.2	160	240
run time/y	2	1	7
instantaneous luminosity/(10^{34} cm^{-2} s^{-1})	16–32	10	3
integrated luminosity/(ab^{-1})	8–16	2.6	5.6
Higgs boson yield	–	–	10^6
W boson yield	–	10^7	10^8
Z boson yield	10^{11}–10^{12}	10^8	10^8

More details in CDR





CEPC timeline



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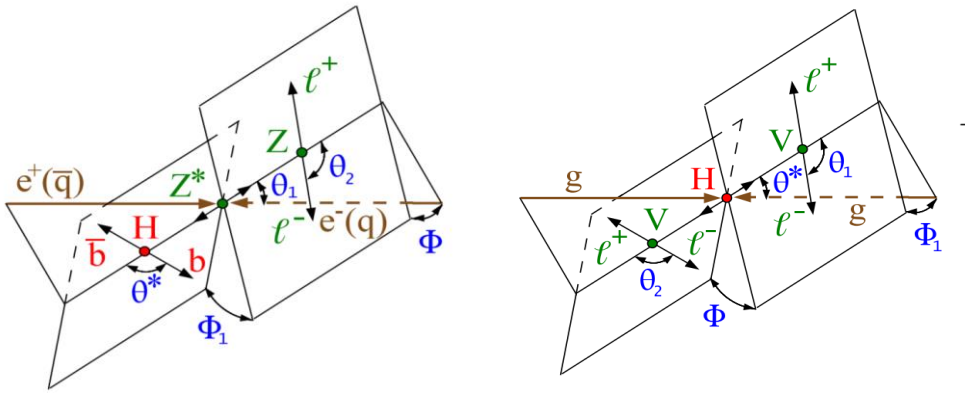
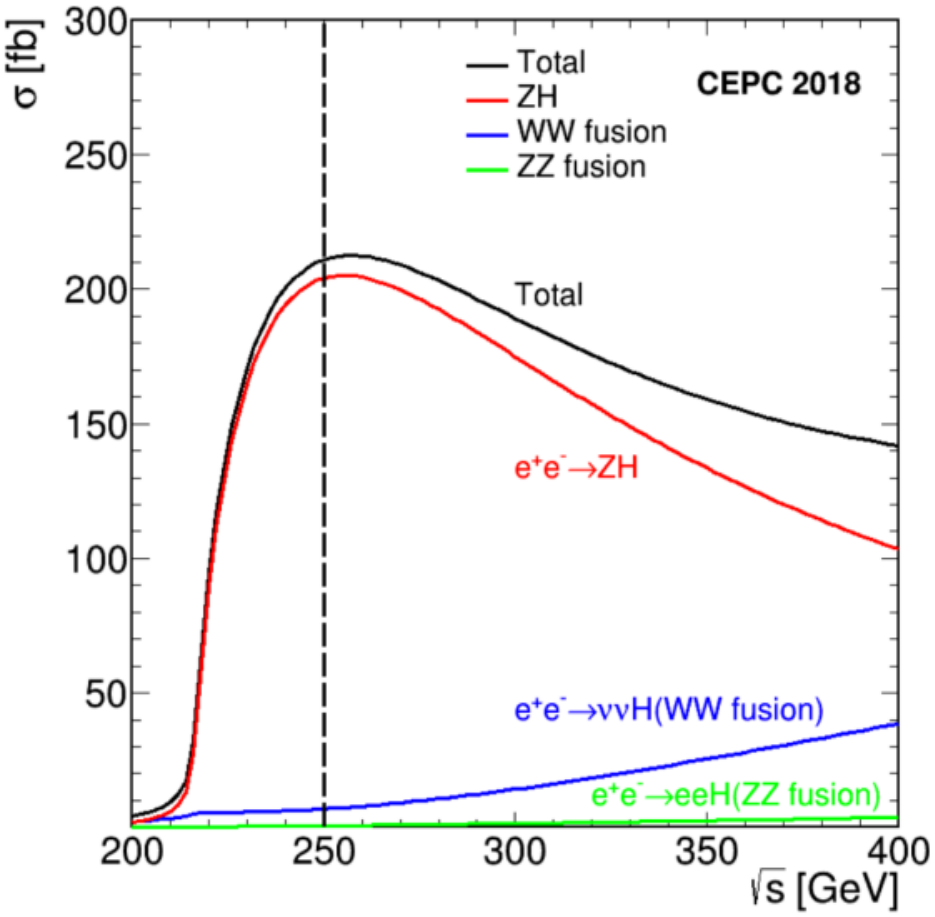
At CEPC

- ~1M $ee \to ZH$ events with much lower background than LHC
- Ideal place for search of anomalous coupling
  - Analyze both production ($ee \to ZH$) and decay ($H \to ZZ$) vertex
  - Investigate two distinct Q^2(240 and 125 GeV), different sensitivity to anomalous couplings
  - $H \to bb$ or $H \to ZZ$
- Anomalous coupling is sensitive to angular distributions
  - helicity angle and azimuthal angle
  - Use BDT to combine all variables



Production cross sections

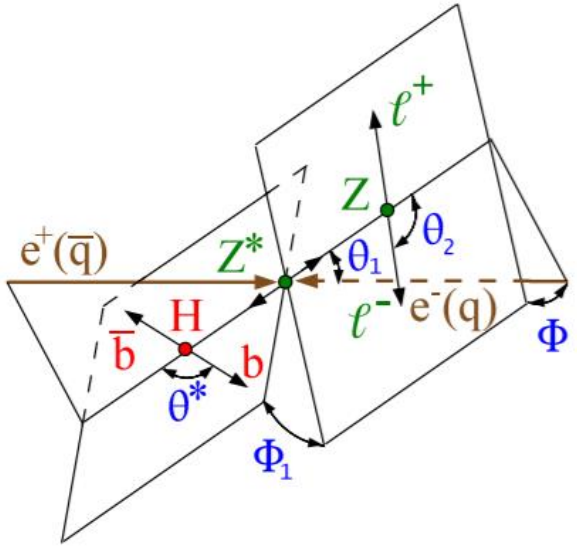


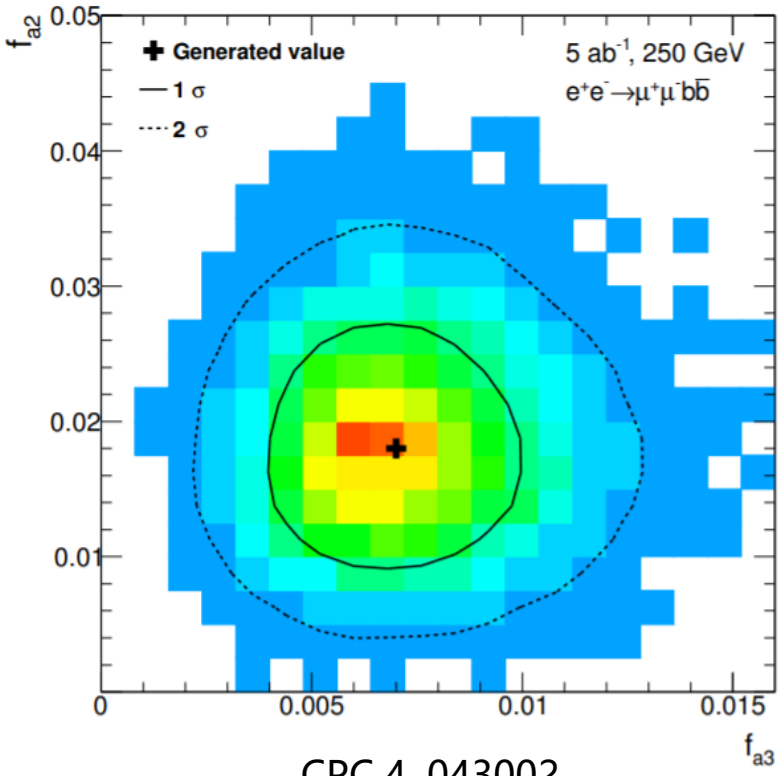
Previous study at CEPC

- Maximum likelihood fit on the angular distributions for $e^+e^- \to ZH \to \mu^\pm\mu^\mp b\bar{b}$
- Sensitivity for f_{CP} is 0.007
- convert to $H \to ZZ$ decay

$$f_{CP}^{dec} = 1.3 \times 10^{-4}$$

- Unique advantage at lepton collider:
  - Separately and jointly measure anomalous coupling at 240 and 125 GeV



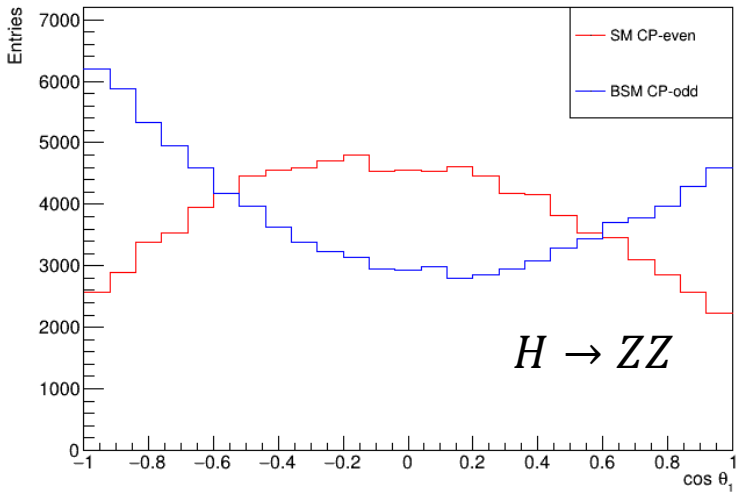


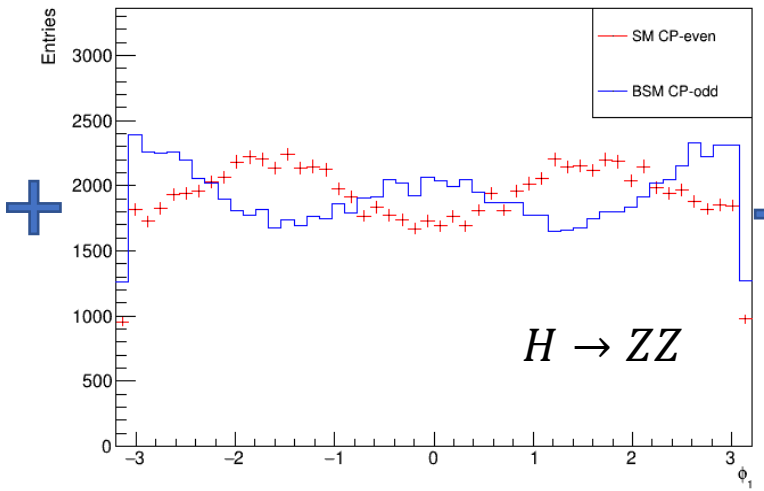
CPC 4, 043002

Truth-level study

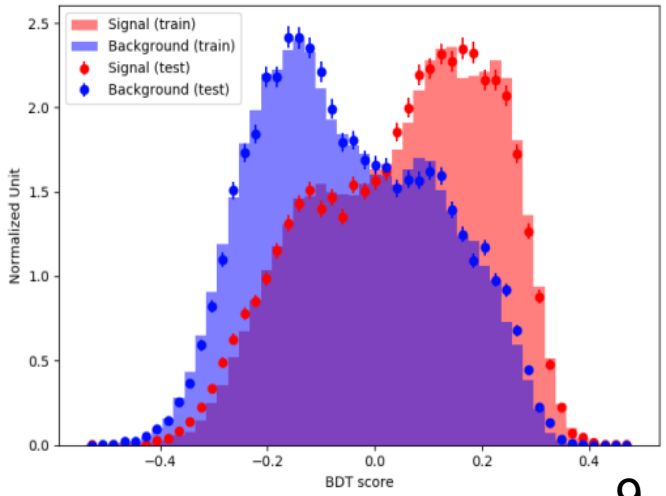
- First demonstrate the study with truth-level information
  - The study with detector response are in processing
- Limited by the statistics from previous study
- Analyze the $ee \to ZH$ and $H \to \mathrm{ZZ}$ separately
  - $ZH \to \mu\mu lljj/\mu\mu jjjj$
  - $ZH \to llllll$ (statistics is too low)

- Generator: JHUGen
- Signal: BSM CP-odd
- Bkg: SM CP-even
- No interference
- Detector acceptance and object selections are taken from CEPC CDR





BDT



Expected upperlimit

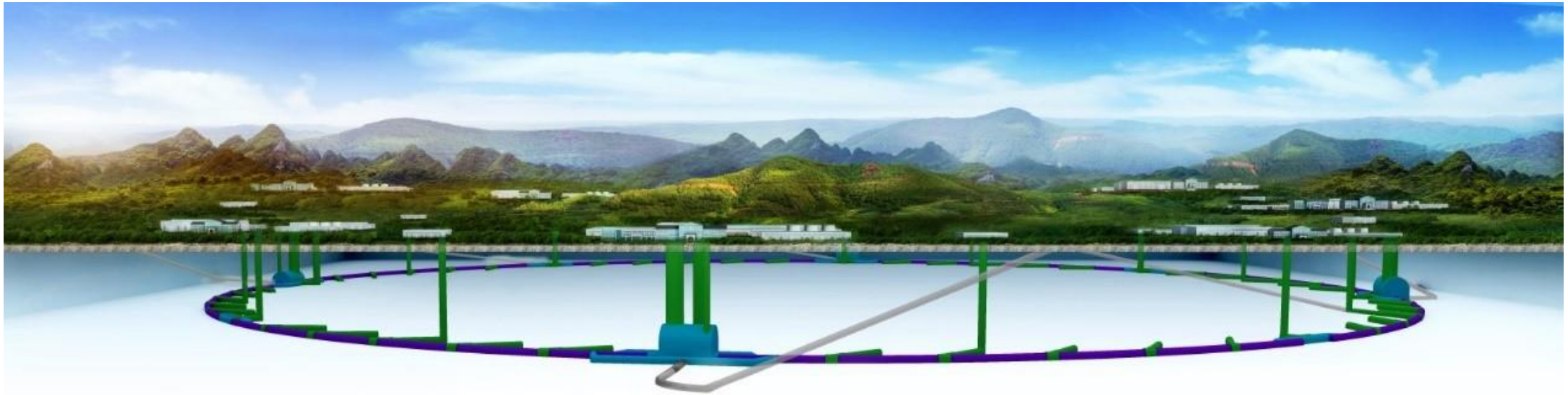
- $ee \to ZH$ at 240 GeV
  - Upperlimit at 95% C.L. of anomalous coupling ratio

$$\frac{ghz_{odd}}{ghz_{SM}} < 3.9 \times 10^{-2}$$

  - f_{CP}: $< 1.2 \times 10^{-2}$
  - Consist (slightly better) to previous CPEC results
  - Convert to $H \to ZZ$: $f_{CP}^{dec} < 2.3 \times 10^{-4}$
- $H \to ZZ$ $(ZZ \to llll/lljj/jjjj)$
  - f_{CP}^{dec}: $< 5.5 \times 10^{-4}$
- Limited by statistics, more channels ($Z \to bb/cc$) will improve the sensitivity

Summary

- Naive generator-level analysis for anomalous coupling from both $ee \to ZH$ and $H \to ZZ$ channels are performed
- Good sensitivity is observed compared to LHC.
  - Mainly limited by statistics
- More comprehensive analysis with CEPC simulation and reconstruction is in processing



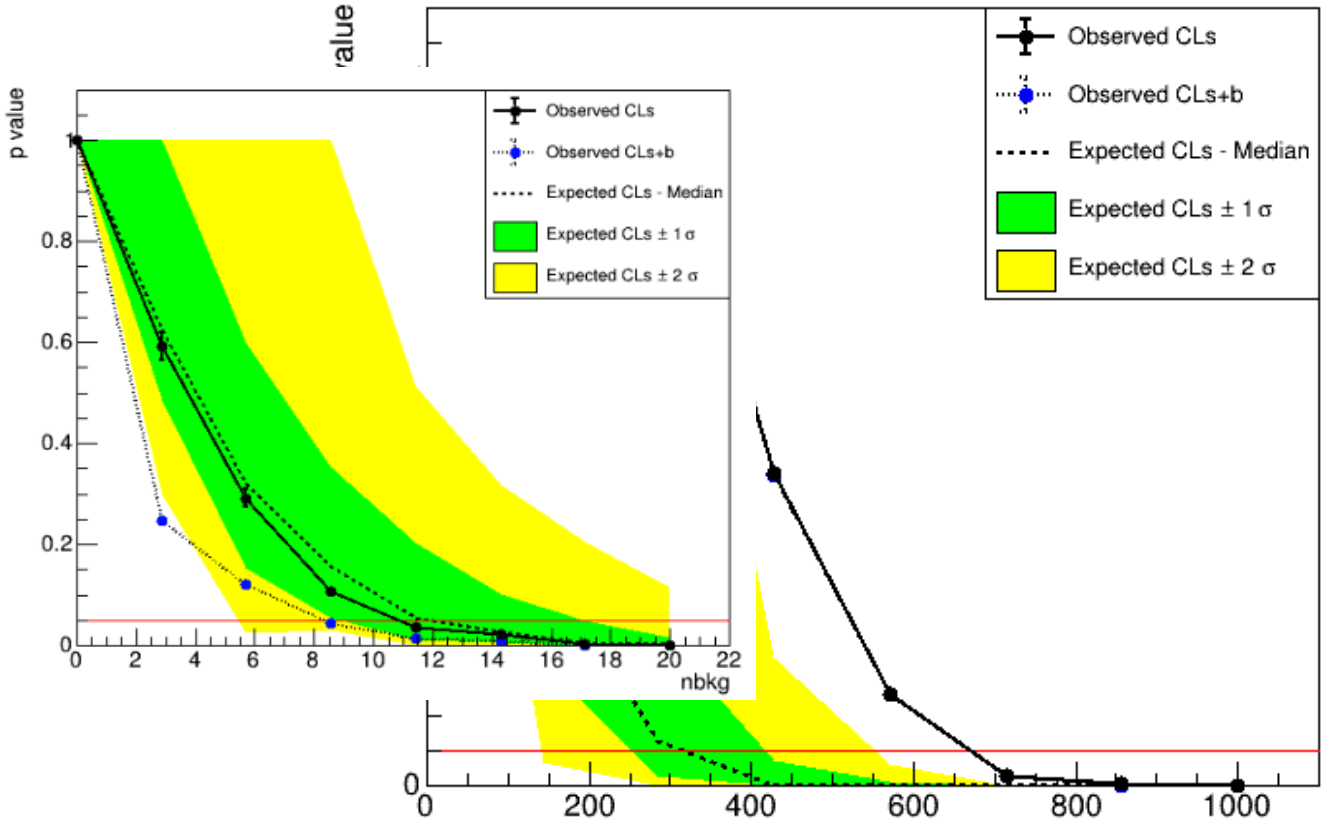
Back-up

Expected results

- Upperlimit at 95% C.L.
  - anomalous coupling ratio

$$\frac{ghz_{odd}}{ghz_{SM}} < 3.9 \times 10^{-2}$$

  - f_{a3}: $< 1.2 \times 10^{-2}$
  - Consist (slightly better) to CPEC results
- Convert to H->ZZ
  - $f_{a3}^{dec} < 2.3 \times 10^{-4}$



Decay vertex ($H \to ZZ^* \to \mu^{\pm}\mu^{\mp}\mu^{\pm}\mu^{\mp}$)

- Inclusive H->ZZ
  - $ZZ^* \to \mu^{\pm}\mu^{\mp}\mu^{\pm}\mu^{\mp}$ should be very clean
  - Background need to be studied carefully
- BDT with $\phi, \phi_1, cos\theta_1, cos\theta_2, cos\theta_*$
- Very-preliminary results
- Maximum likelihood fit on the BDT distributions