

Higgs CP via Higgs to ZZ final state in CEPC

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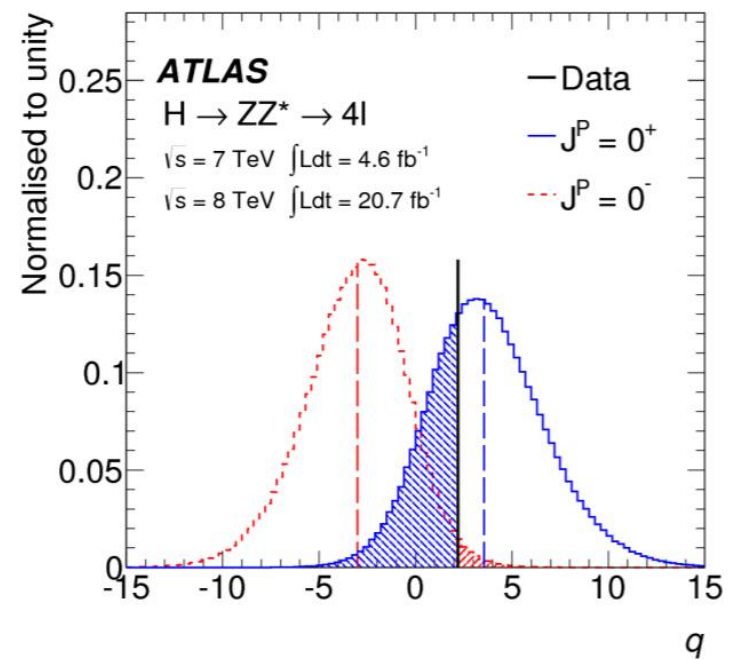
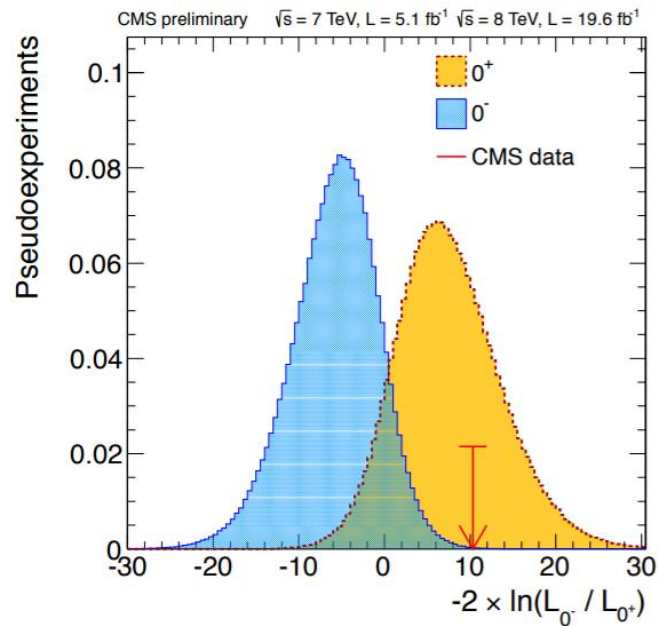
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Motivation

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

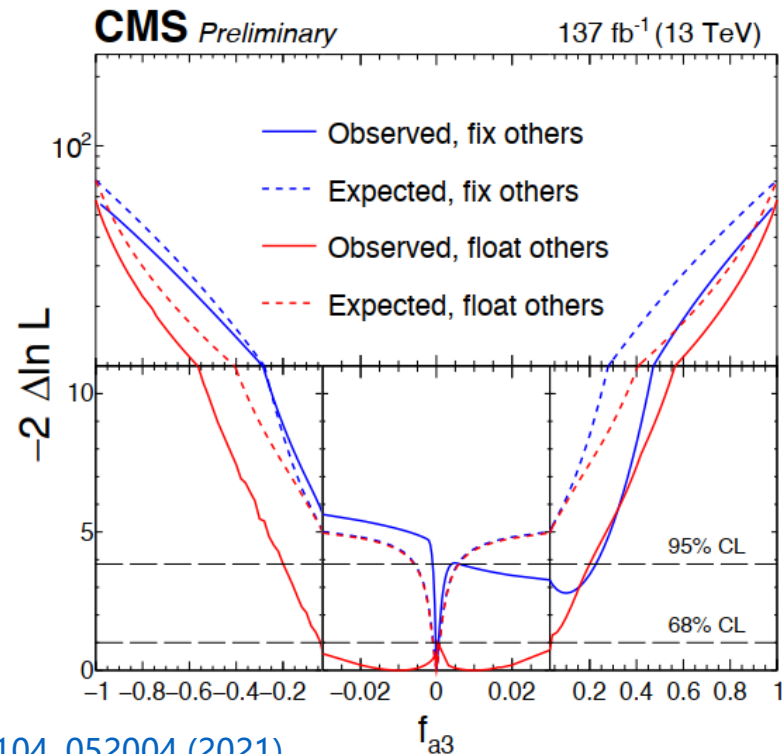


Experimental results on anomalous coupling

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

higher order
CP even

CP odd



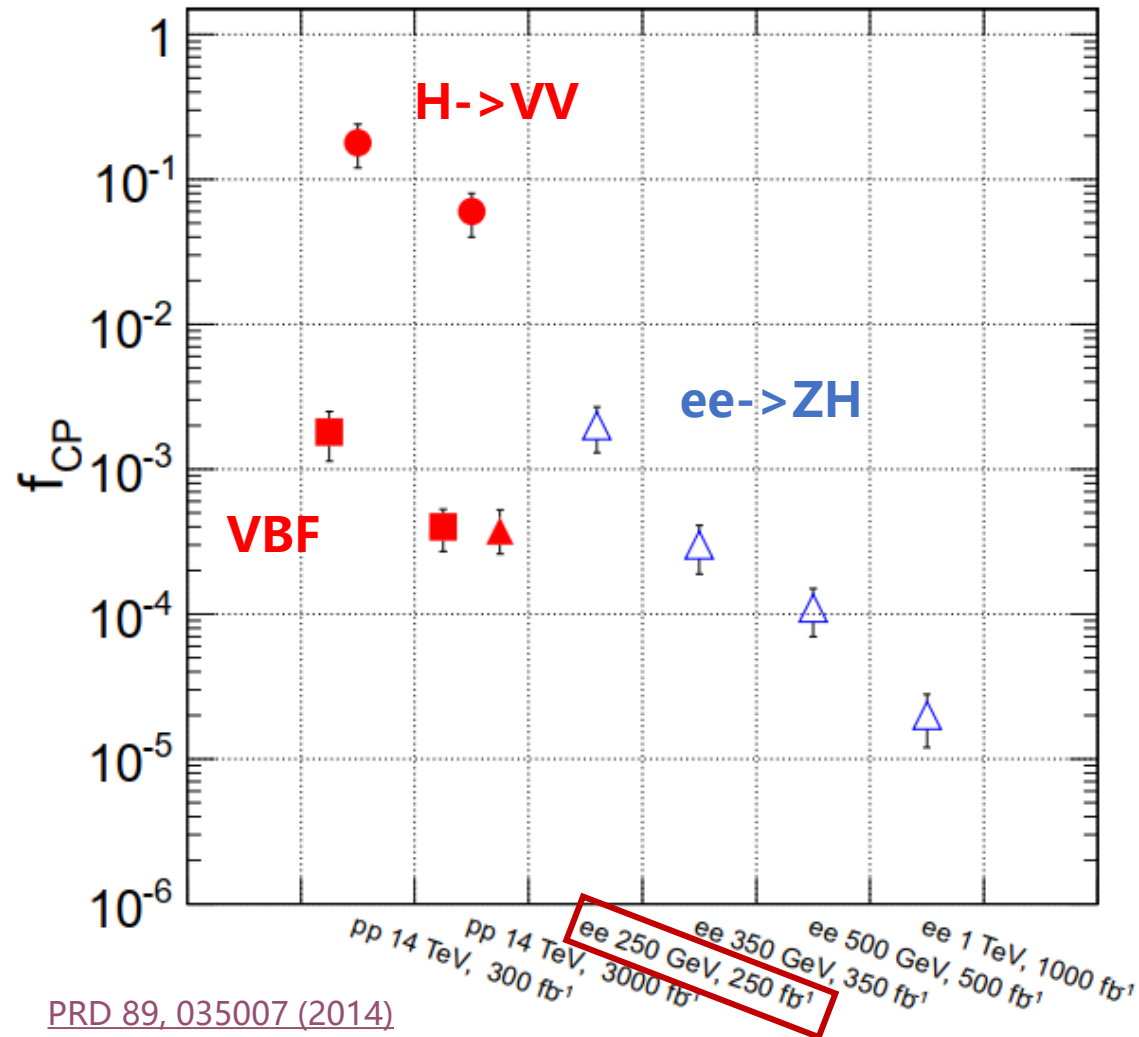
CP-odd contribution

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

For H → ZZ:

Observed (expected) limit at 95% C.L.: 1(4) × 10⁻³

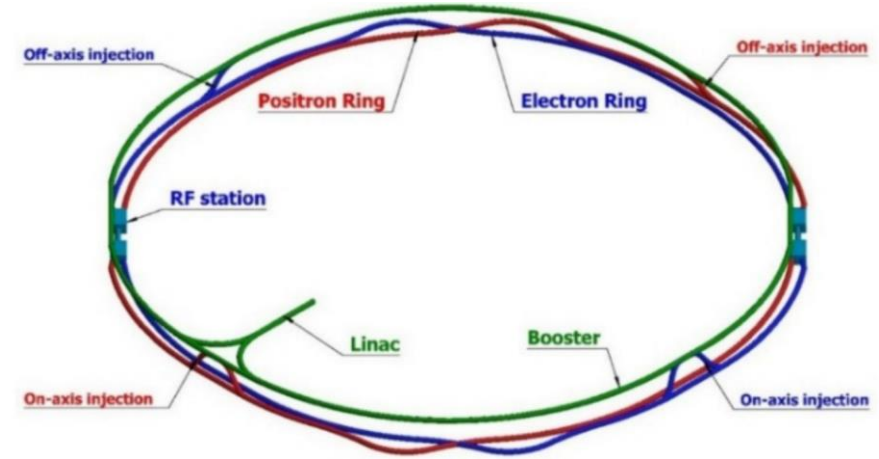
Expectation at hadron/lepton collider



- 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 $ee \rightarrow ZH$ and $H \rightarrow ZZ$

Circular Electron Positron Collider(CEPC)

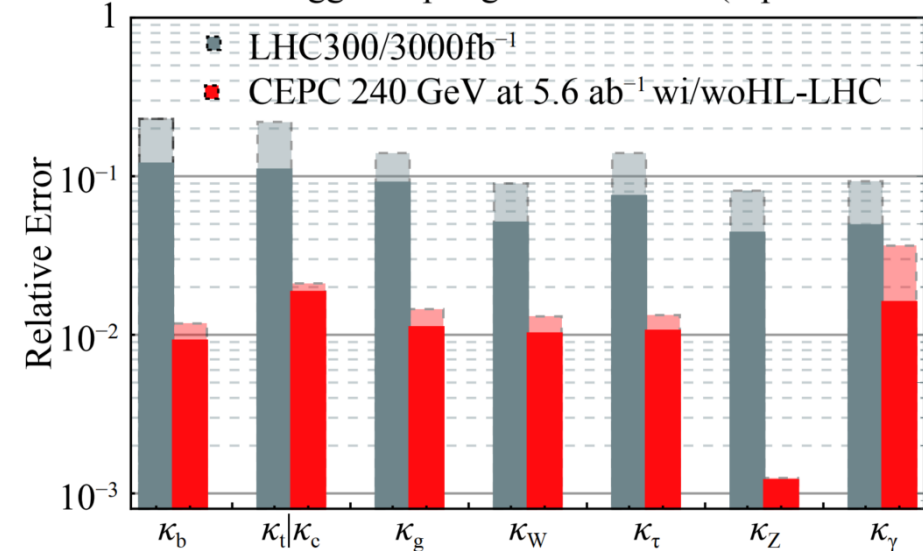
- Proposed project for precise measurement of Higgs properties
 - could also run as Z and W factories
- High luminosity, i.e. $3 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ at $\sqrt{s} = 240 \text{ GeV}$
 - Top-up operation is available
- Circumference: 100km
 - Reusable for SPPC



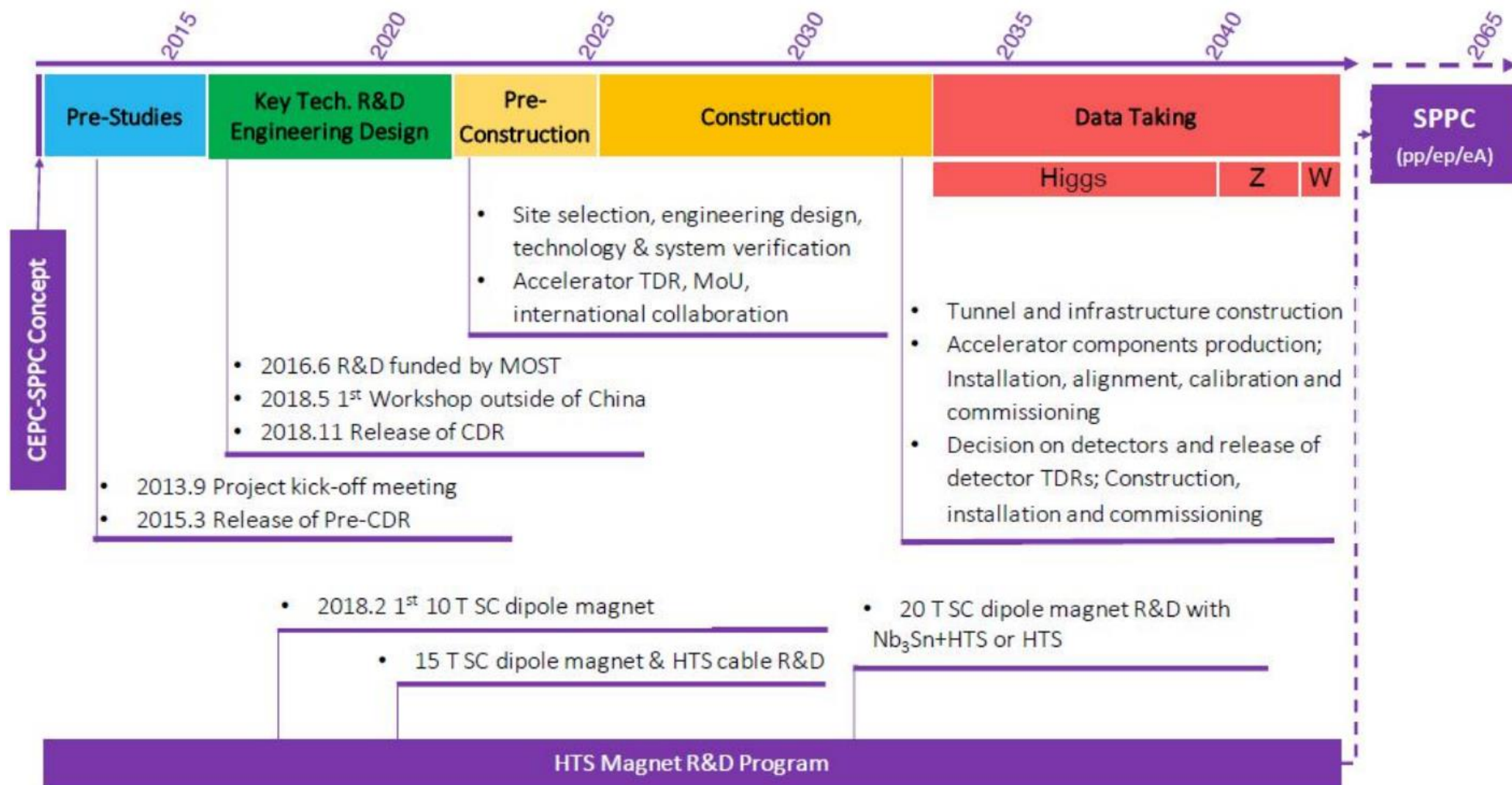
operation mode	Z factory	WW threshold	Higgs factory
\sqrt{s}/GeV	91.2	160	240
run time/y	2	1	7
instantaneous luminosity/ $(10^{34} \text{ cm}^{-2} \text{ s}^{-1})$	16–32	10	3
integrated luminosity/ (ab^{-1})	8–16	2.6	5.6
Higgs boson yield	–	–	10^6
W boson yield	–	10^7	10^8
Z boson yield	10^{11} – 10^{12}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

More details in [CDR](#)

Precision of Higgs coupling measurement (7-parameter Fit)

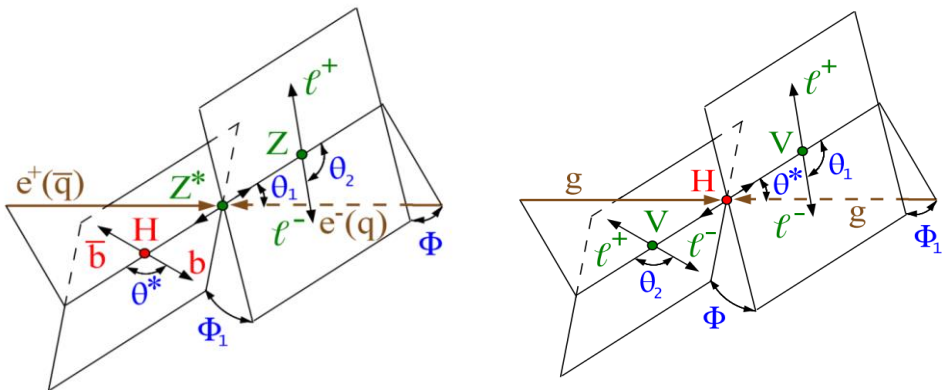


CEPC timeline

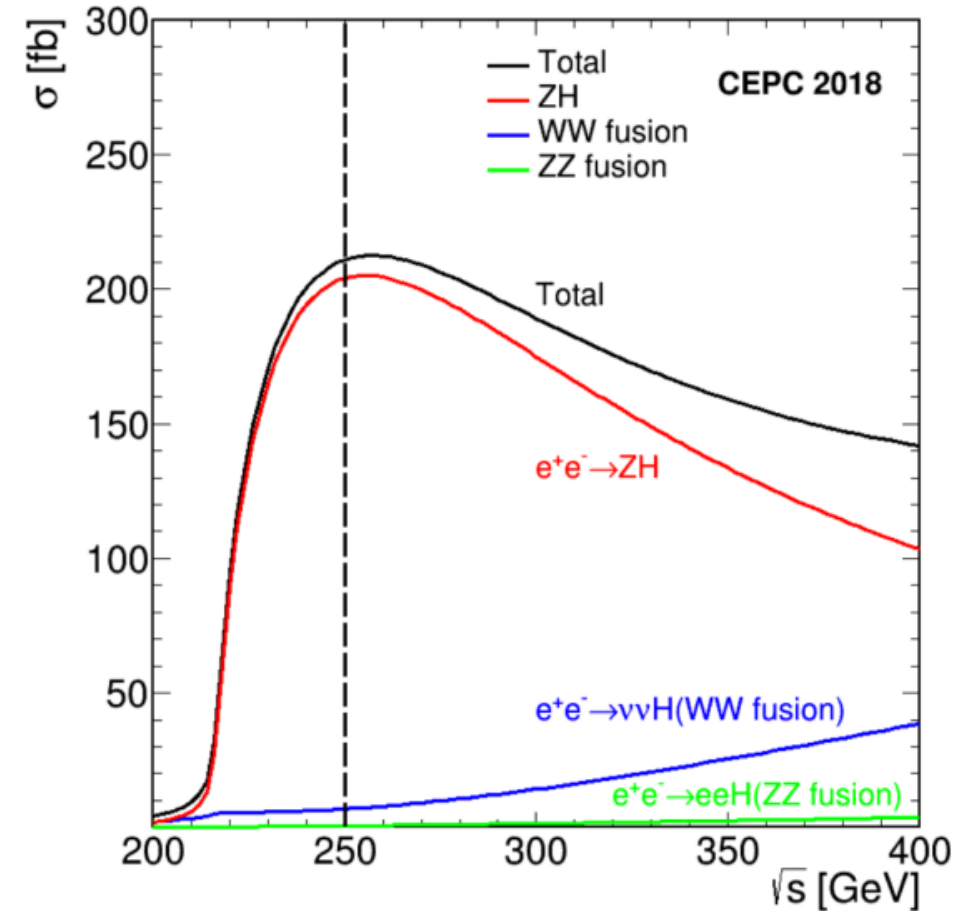


At CEPC

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



Production cross sections

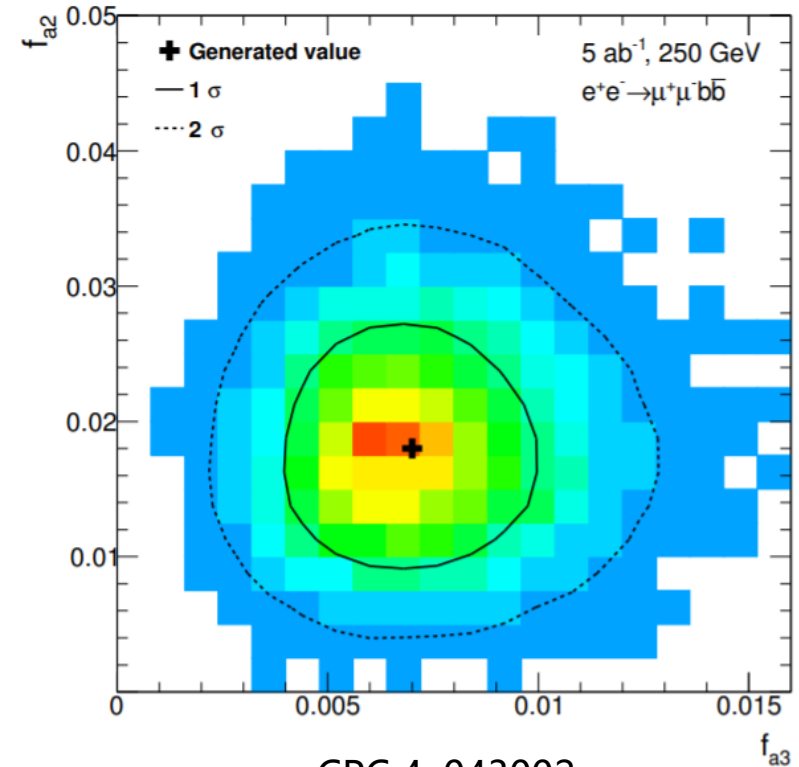
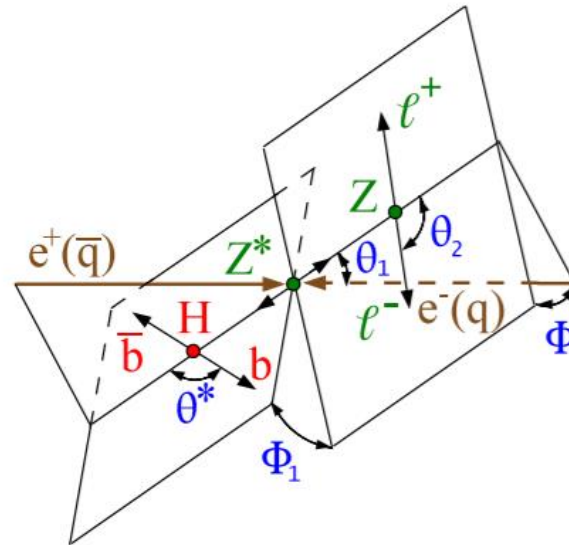


Previous study at CEPC

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

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

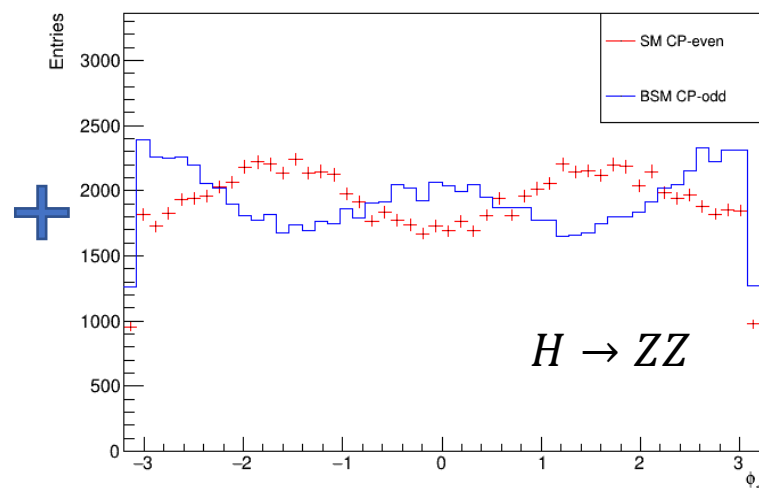
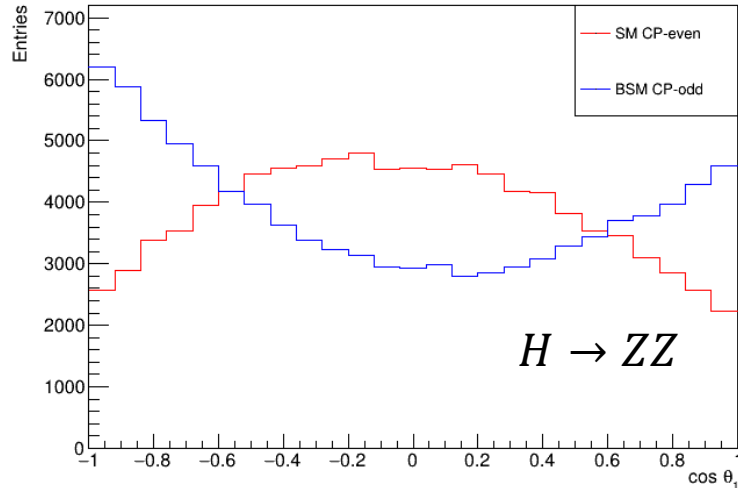
- Unique advantage at lepton collider:
 - Separately and jointly measure anomalous coupling at 240 and 125 GeV



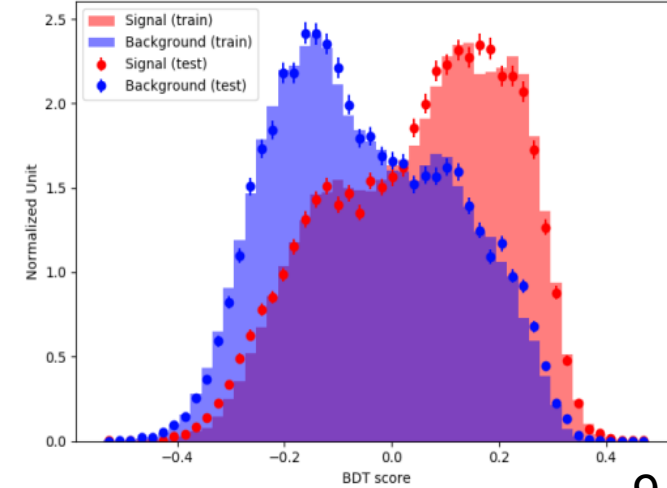
CPC 4, 043002

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 $ee \rightarrow ZH$ and $H \rightarrow ZZ$ separately
 - $ZH \rightarrow \mu\mu lljj/\mu\mu jjjj$
 - $ZH \rightarrow llll$ (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

- $ee \rightarrow ZH$ at 240 GeV

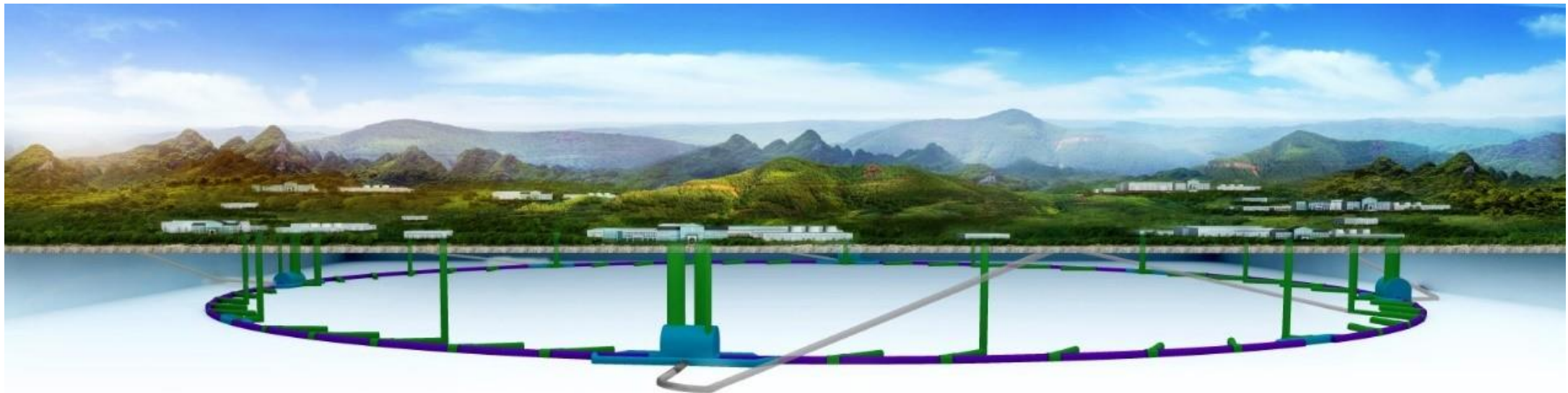
- Upperlimit at 95% C.L. of anomalous coupling ratio

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

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

Summary

- Naive generator-level analysis for anomalous coupling from both $ee \rightarrow ZH$ and $H \rightarrow ZZ$ 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

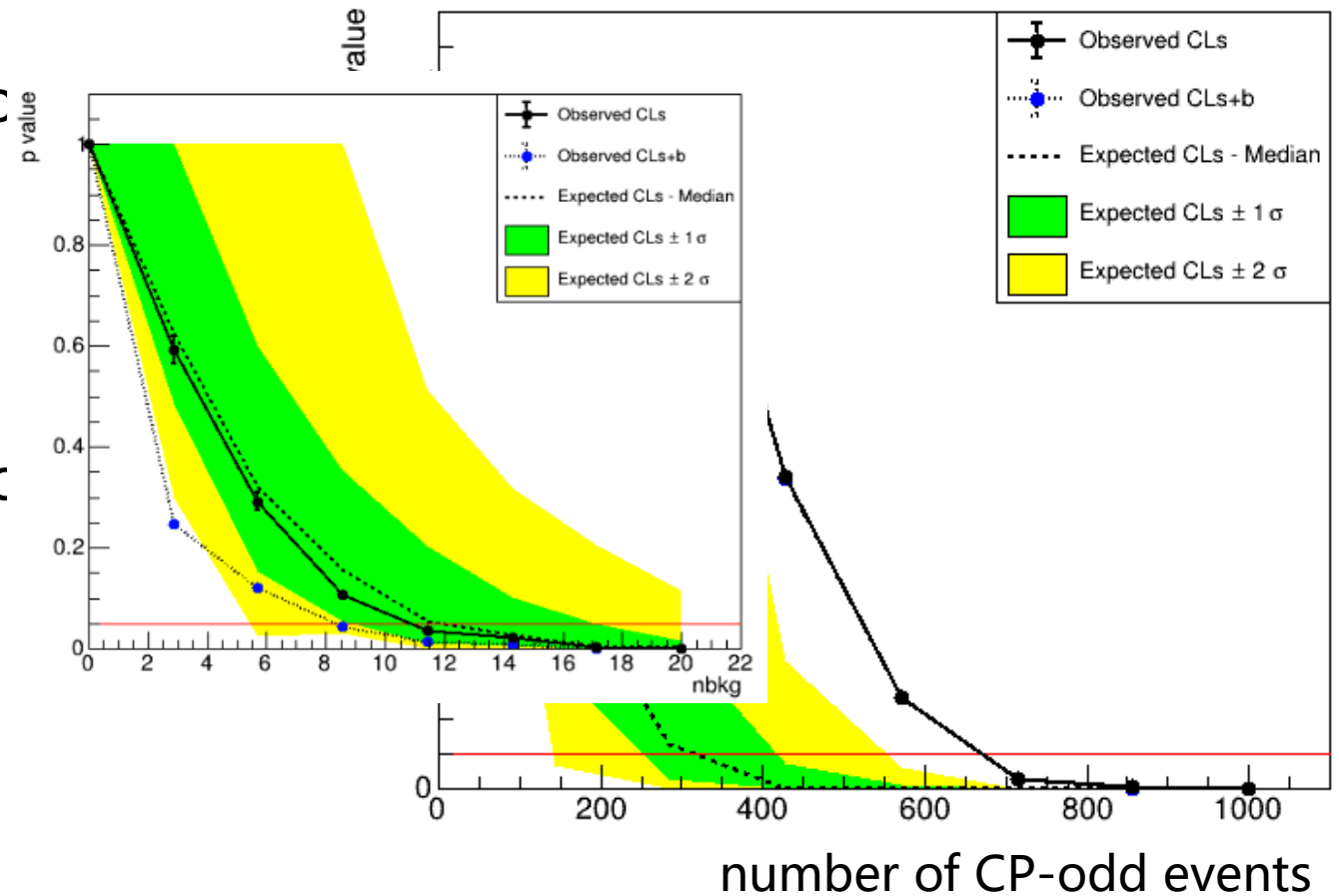
- Upperlimit at 95% C.L.
 - anomalous coupling ratio

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

- $f_{a3} < 1.2 \times 10^{-2}$
- Consist (slightly better) to CPEC results

- Convert to $H \rightarrow ZZ$

- $f_{a3}^{dec} < 2.3 \times 10^{-4}$



Decay vertex ($H \rightarrow ZZ^* \rightarrow \mu^\pm \mu^\mp \mu^\pm \mu^\mp$)

- Inclusive H- \rightarrow ZZ
 - $ZZ^* \rightarrow \mu^\pm \mu^\mp \mu^\pm \mu^\mp$ 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

