Higgs CP via Higgs to ZZ final state in CEPC

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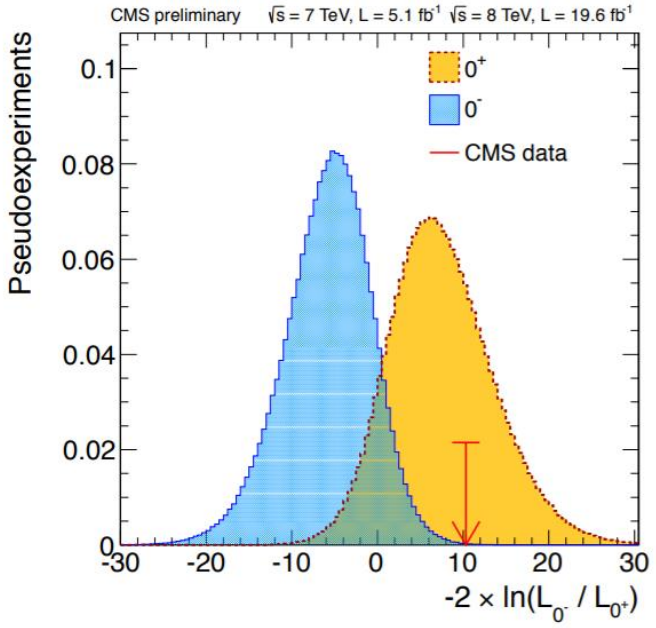
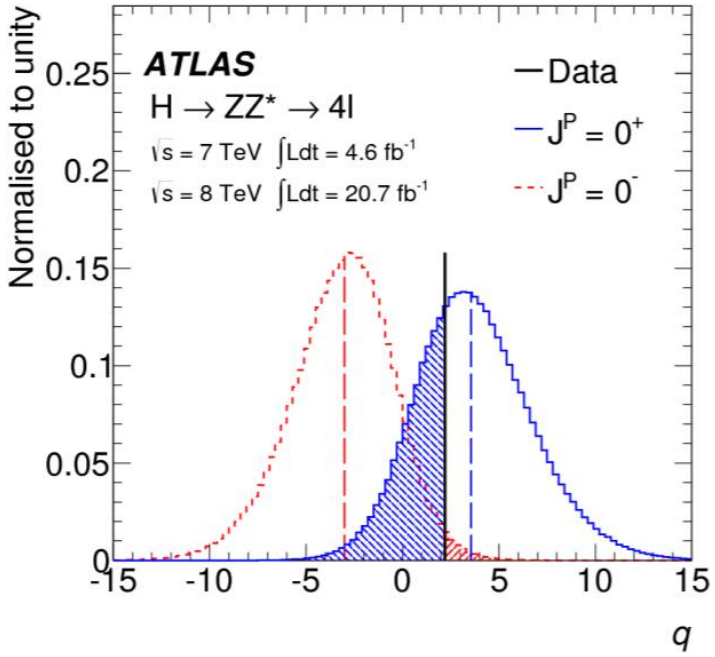
Motivation

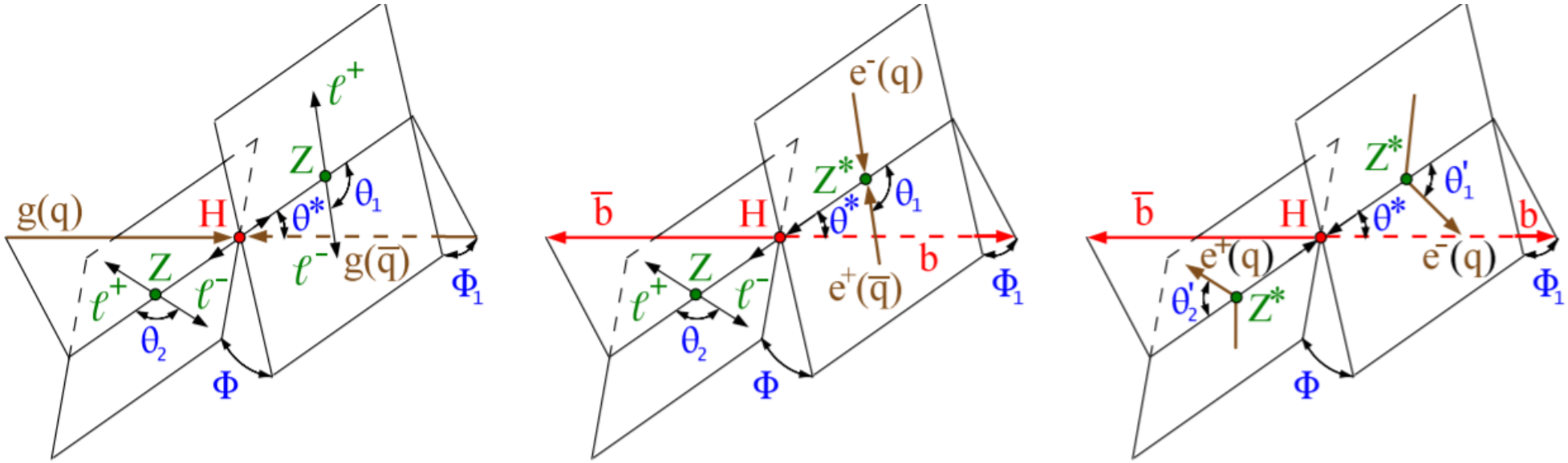
- The observed 125 GeV Higgs is spin-0, CP-even
- New physics -> anomalous coupling





The way to search for anomalous coupling

- Anomalous coupling is sensitive to angular distributions
- helicity angle and azimuthal angle

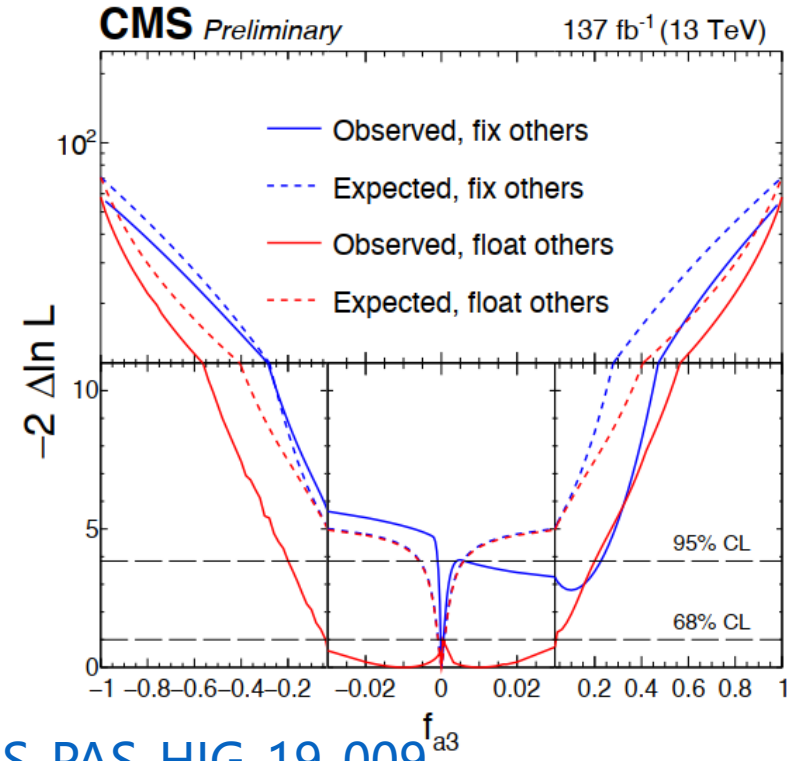


Experimental results on anomalous coupling

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

higher order CP even

CP odd



CP-odd contribution

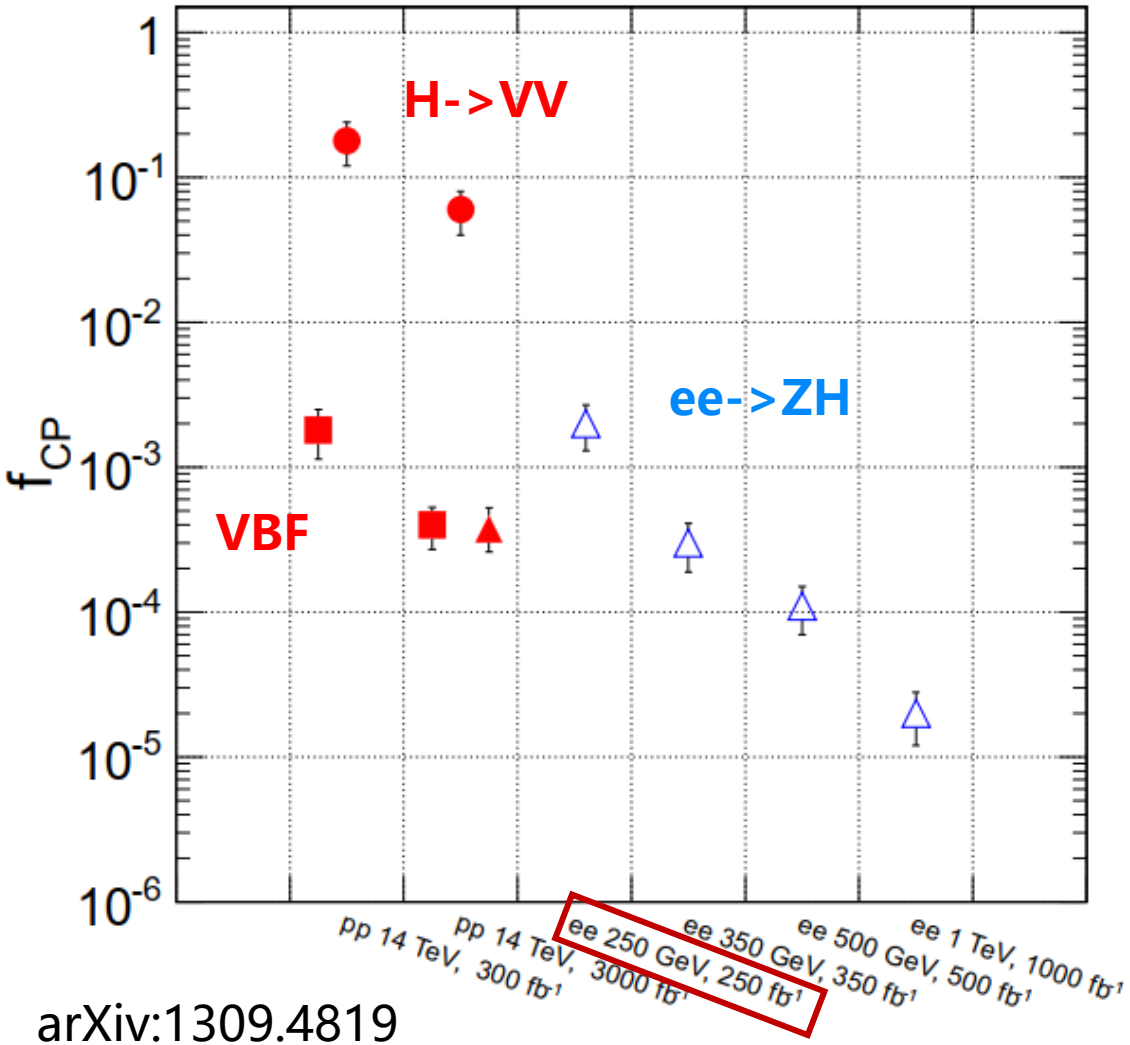
$$f_{CP} = \frac{|a_3|^2 \sigma_3}{\sum |a_i|^2 \sigma_i}$$

For H->ZZ:

Latest limit at 95% C.L.: ~0.006

CMS-PAS-HIG-19-009

Expectation at hadron/lepton collider

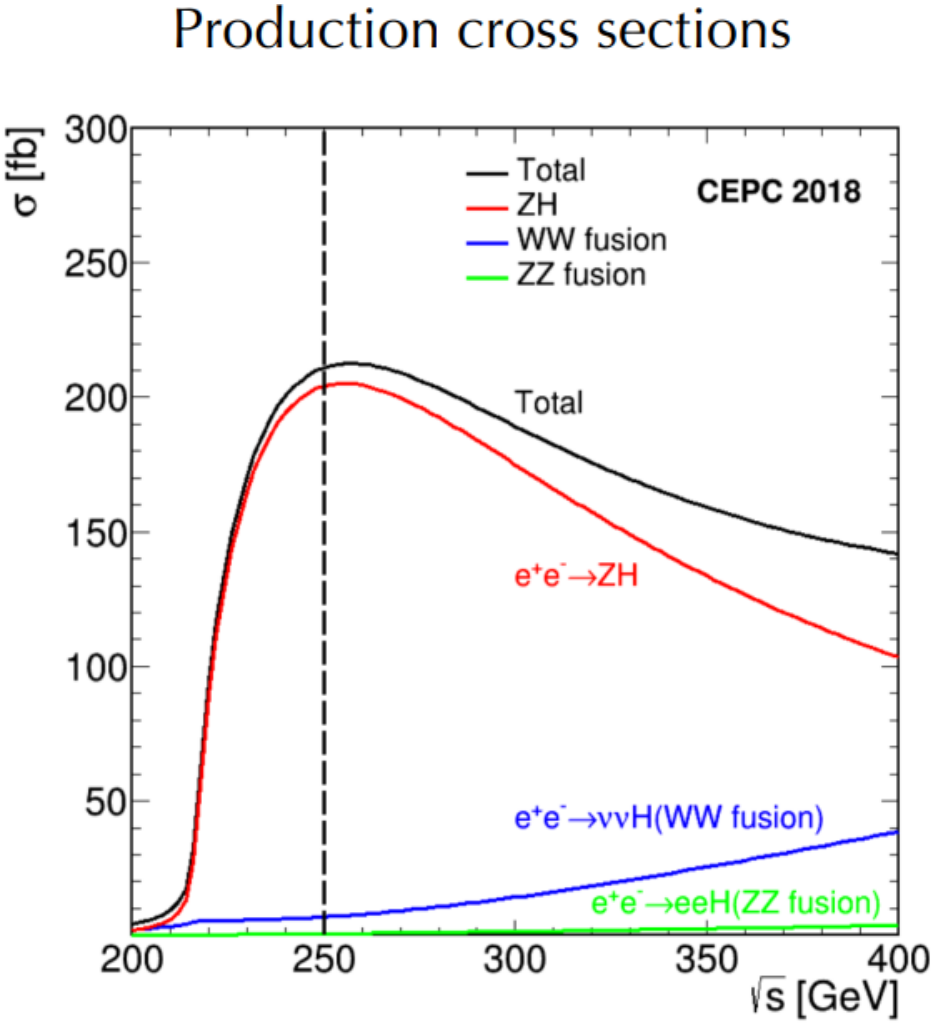


arXiv:1309.4819

- 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->ZH and H->VV

At CEPC

- ~ 5 ab^{-1} data at $\sqrt{s} = 240$ GeV
- ~1M ee->ZH events with much lower background than LHC
- Ideal place for search of anomalous coupling

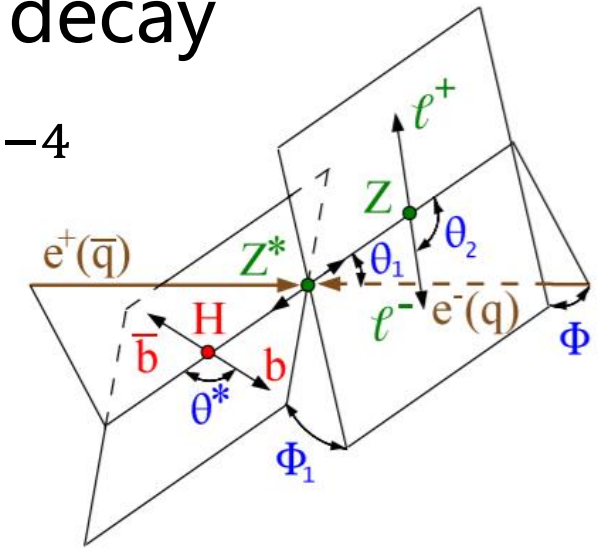


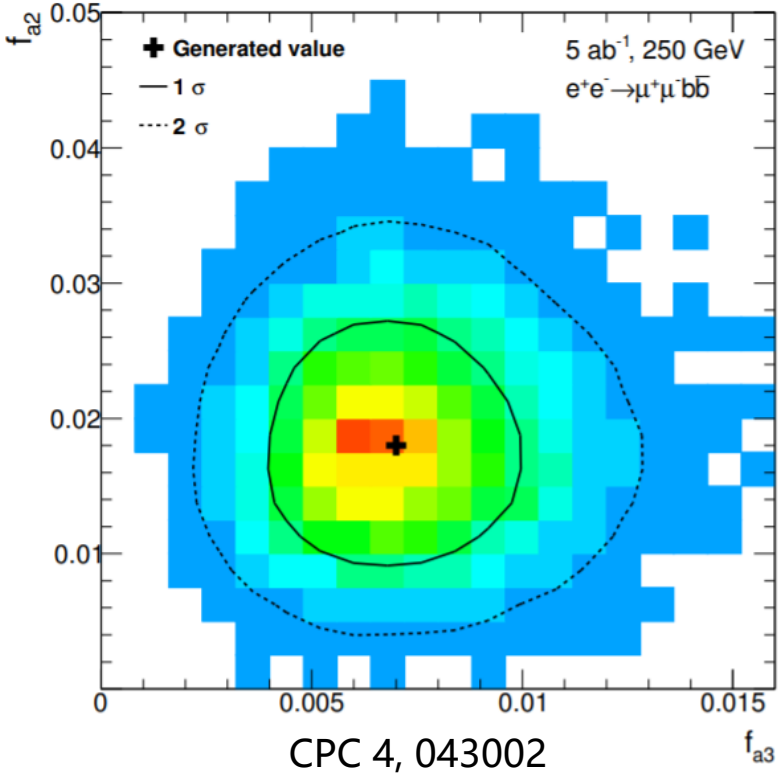
Previous study at CEPC

- Maximum likelihood fit on the angular distributions for $e^+e^- \to ZH \to \mu^{\pm}\mu^{\mp}b\bar{b}$
- Sensitivity for f_{a3} is 0.007
- convert to H->ZZ decay

$$f_{a3}^{dec} = 1.3 \times 10^{-4}$$

How about the study of H->ZZ ?



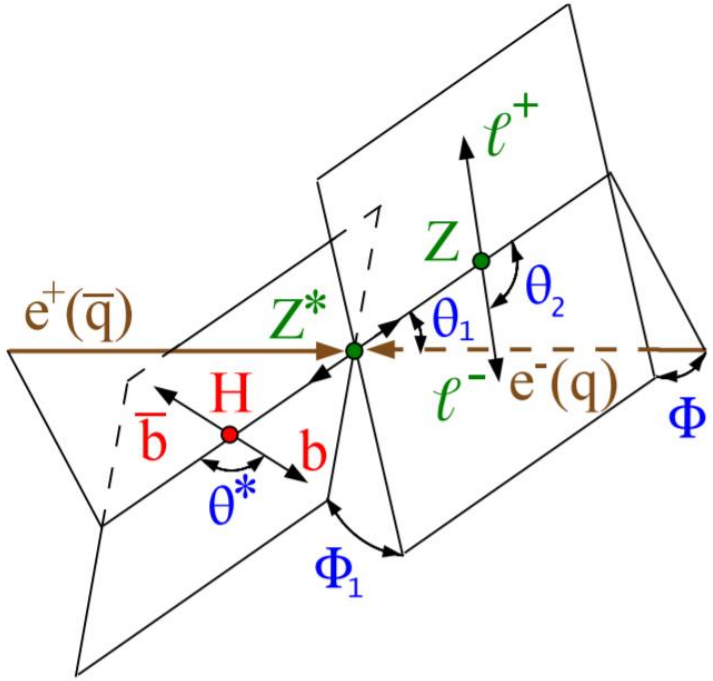


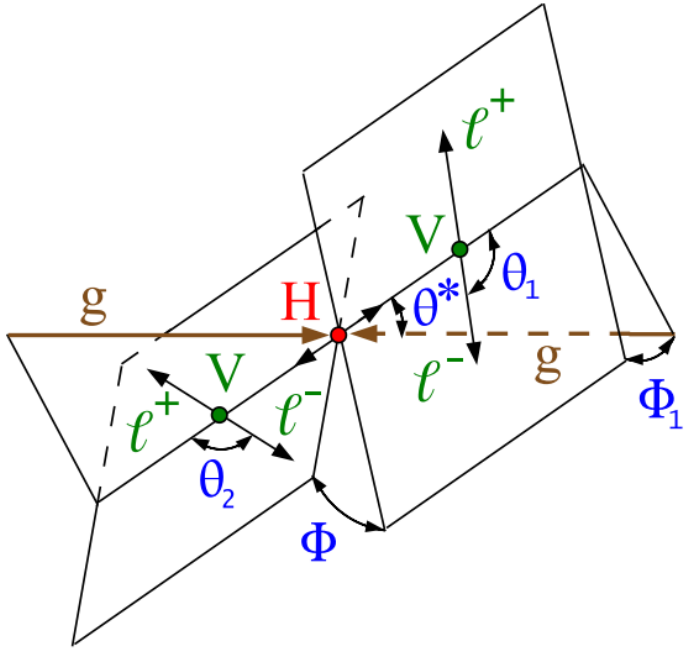
CPC 4, 043002

Analysis Strategy

- Start with generator-level analysis
  - Selections on truth kinematics (Pt > 3 GeV and $cos\theta < 0.85$)
- Analyze both production (ee->ZH) and decay (H->ZZ) vertex
  - H->bb or H->ZZ (start with ZZ-> 4μ)
  - Rich kinematics (helicity angles...) sensitive to anomalous couplings
    - Use BDT to combine all variables
- Anomalous couplings at two distinct Q^2(240 and 125 GeV)
- Unique advantage of CEPC
- Sensitive to difference phase space

Angular distributions



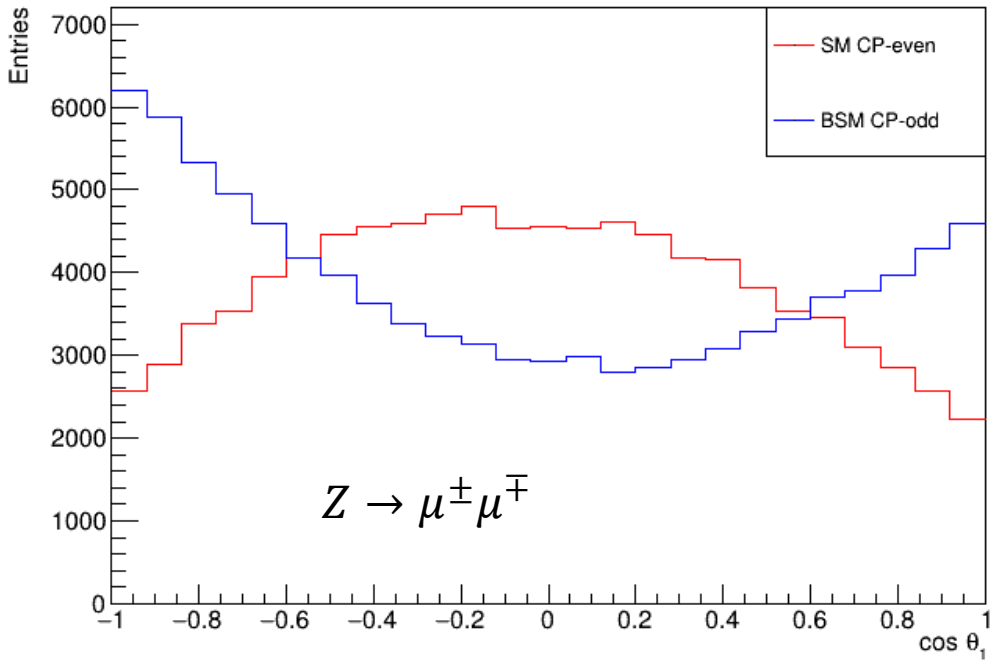


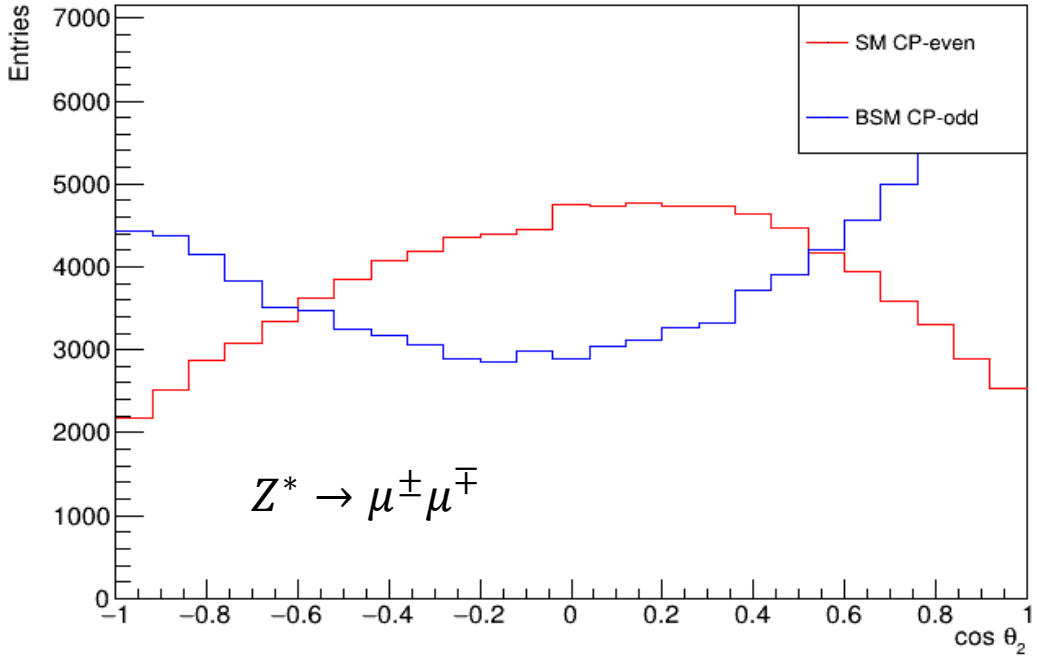
Useful observables: $\phi, \phi_1, cos\theta_1, cos\theta_2, cos\theta_*$

Other variables, e.g. Pt, will be tested

Angular distributions

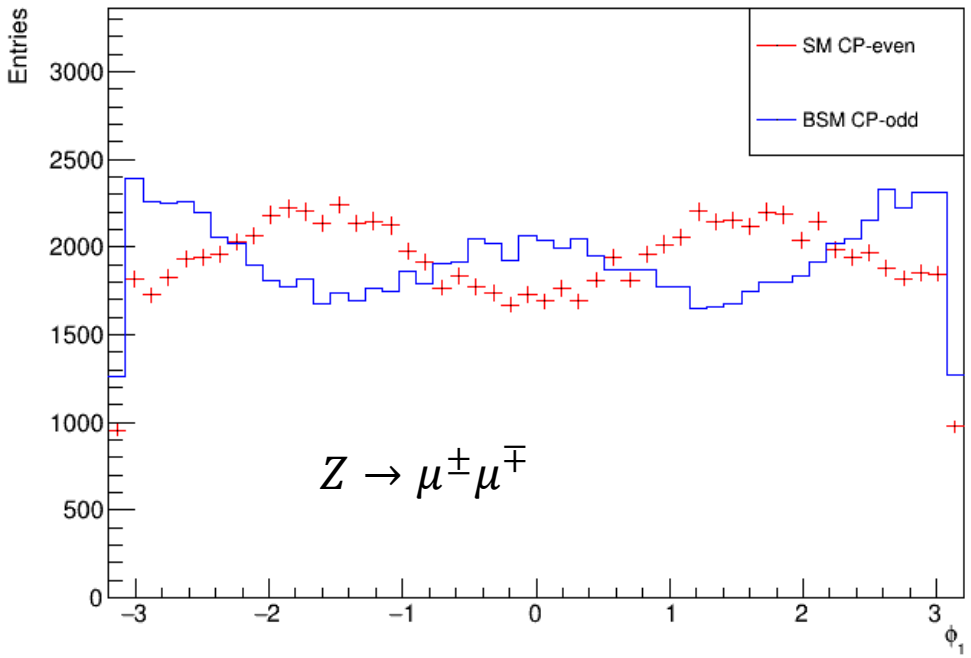
- For $H \to ZZ^*$ $(ZZ^* \to \mu^{\pm}\mu^{\mp}\mu^{\pm}\mu^{\mp})$
- Asymmetry caused by selections on kinematic variables

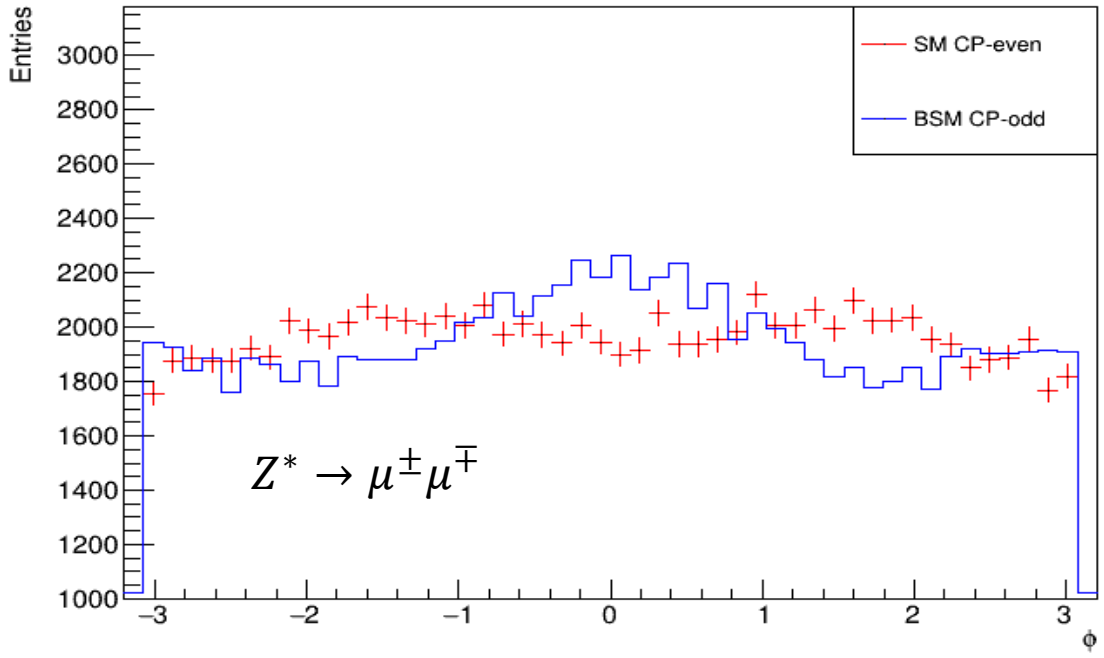




Azimuthal angle

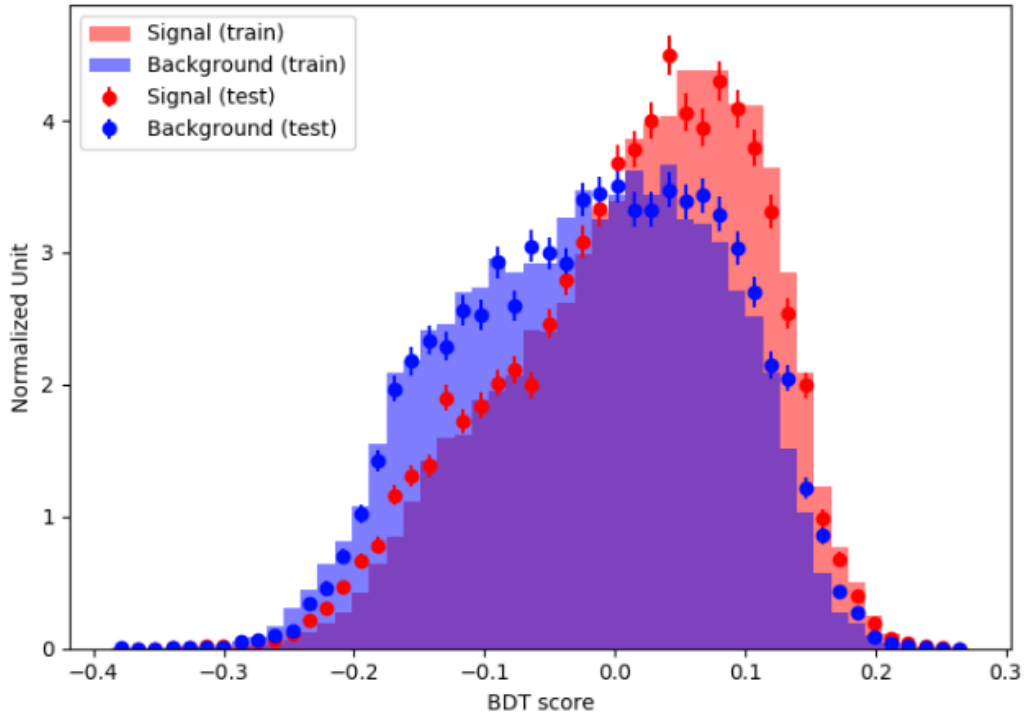
- azimuthal distribution is also helpful
- Final discriminer: BDT score





Production vertex (ee->ZH)

- BDT with $\phi, cos\theta_1, cos\theta_2$
- Very-preliminary results
- Maximum likelihood fit on the BDT distributions

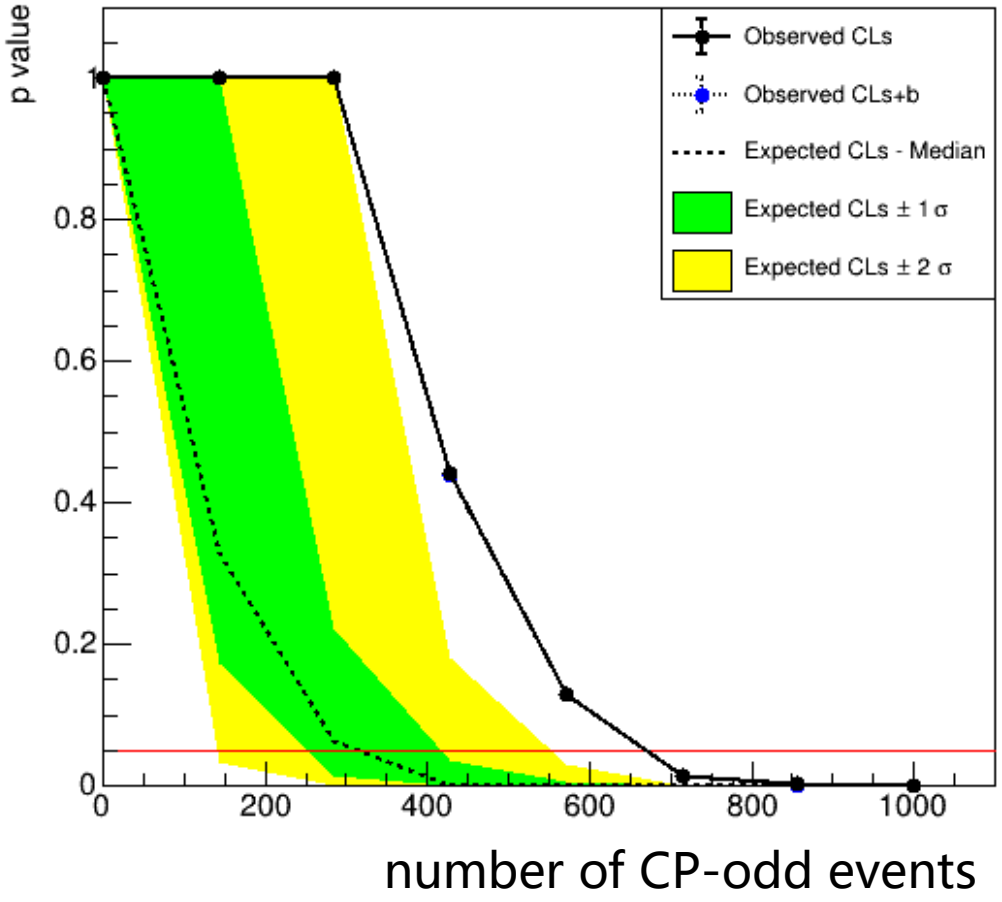


Expected results

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

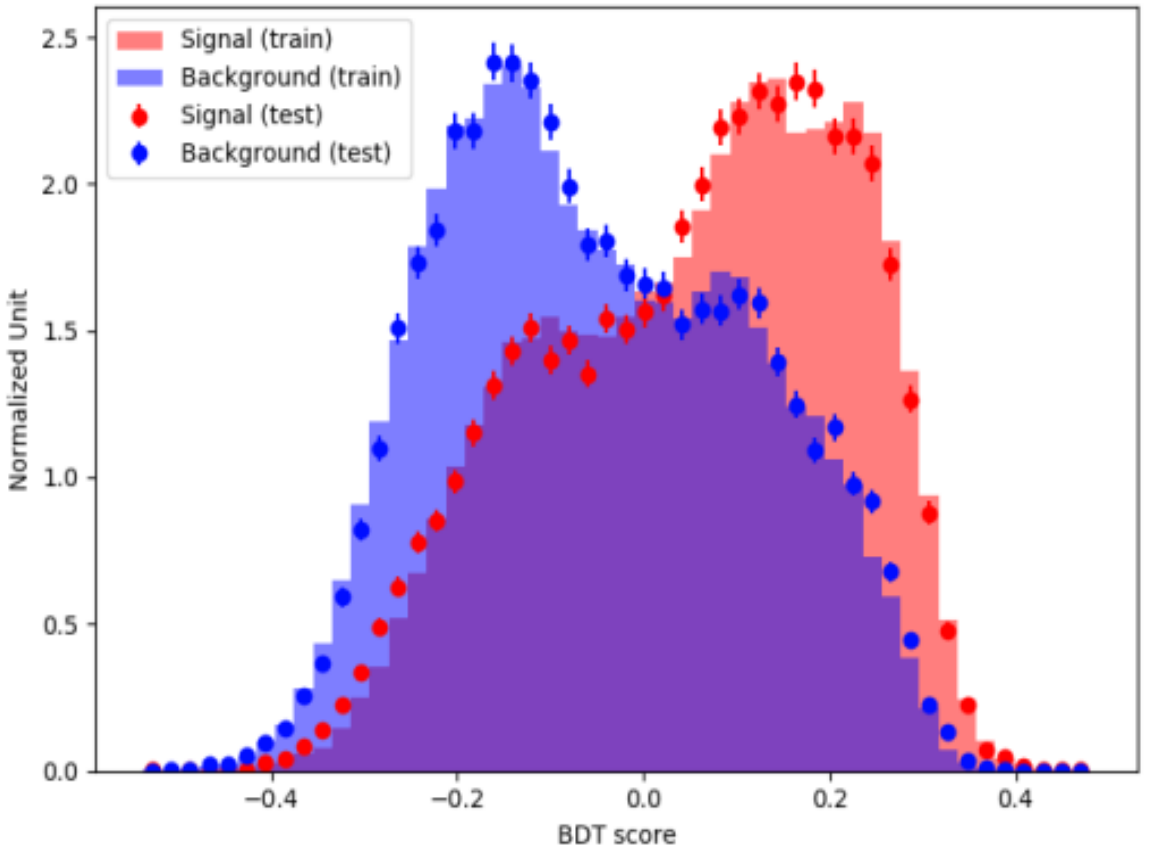
$$\frac{ghz_{odd}}{ghz_{SM}} < 3.9 \times 10^{-2}$$

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



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

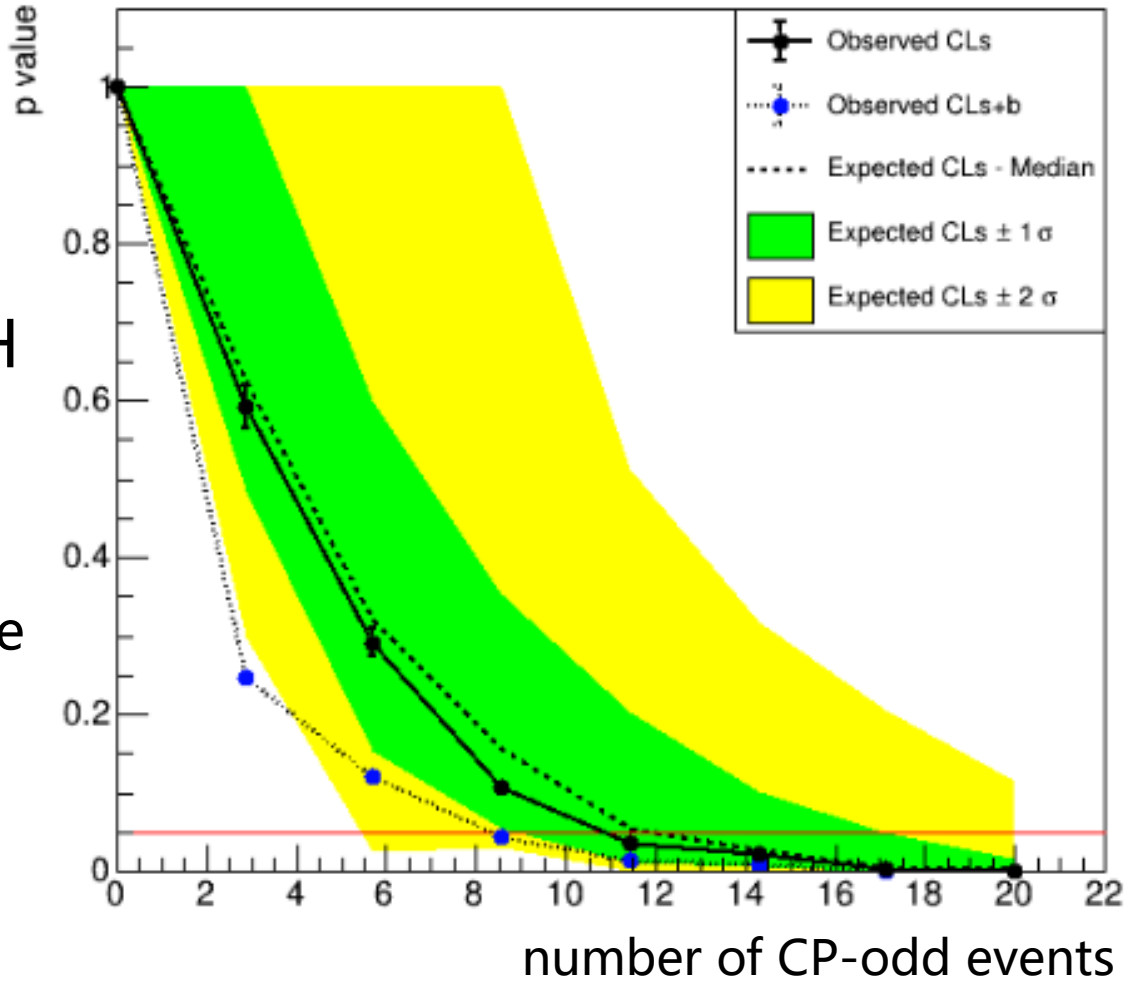
- Inclusive H->ZZ
  - $ZZ^* \to \mu^{\pm}\mu^{\mp}\mu^{\pm}\mu^{\mp}$ should be very clean
  - Background need to be studied carefully
- BDT with $\phi, \phi_1, cos\theta_1, cos\theta_2, cos\theta_*$
- Very-preliminary results
- Maximum likelihood fit on the BDT distributions



Expected results

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

    f_{a3}: $< 5.5 \times 10^{-3}$
- The converted limit from ee->ZH
  - $f_{a3}^{dec} < 2.3 \times 10^{-4}$
- Limited by statistics
  - More decay channels of Z should be helpful
  - Other channels, H->WW→$l^{\pm}\nu qq$, is possible at CEPC



Summary

- Naive generator-level analysis for anomalous coupling from both ee->ZH and H->ZZ channels are performed
- Sensitivity of H->ZZ is worse than ee->ZH but still comparable with the results from LHC, main limitation is statistics
- More channels will be added
- ee->ZH and H->ZZ will be analyzed simauteously
- More comprehensive analysis with CEPC simulation and reconstruction