Updates to FCC-ee ZH CP studies using kinematic observables

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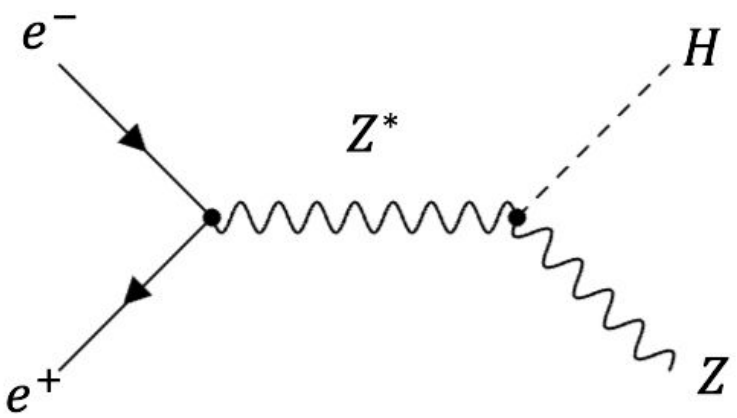
Massachusetts Institute of Technology

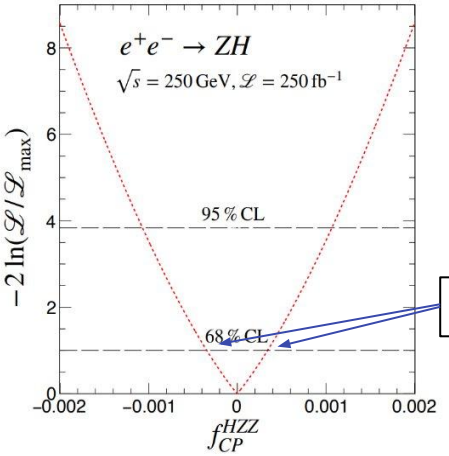
Outline

- Background/ review of past results
- Updates to current study
  - Z → e+e- final state
  - Discriminants
- Results and combined fits
- Next steps

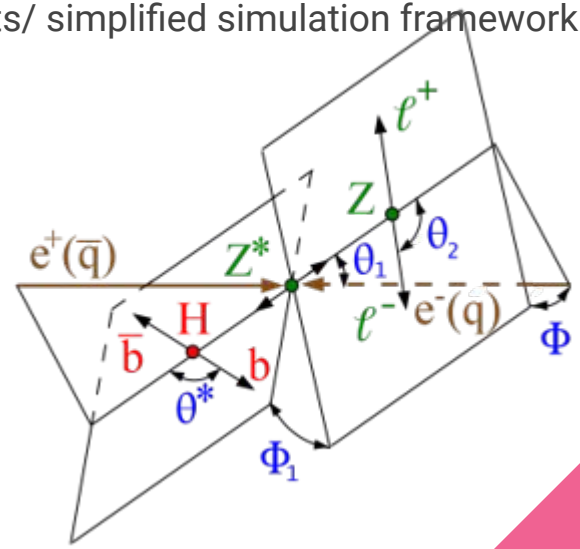


Background: Past studies

- Study based on Snowmass 2013 and 2022 papers
- Made predictions for *HVV* coupling measurements at *MC truth level* at various energy and luminosity scenarios using angular distributions
  - Only approximate detector effects/ simplified simulation framework



68% CL: ±3.4E-4

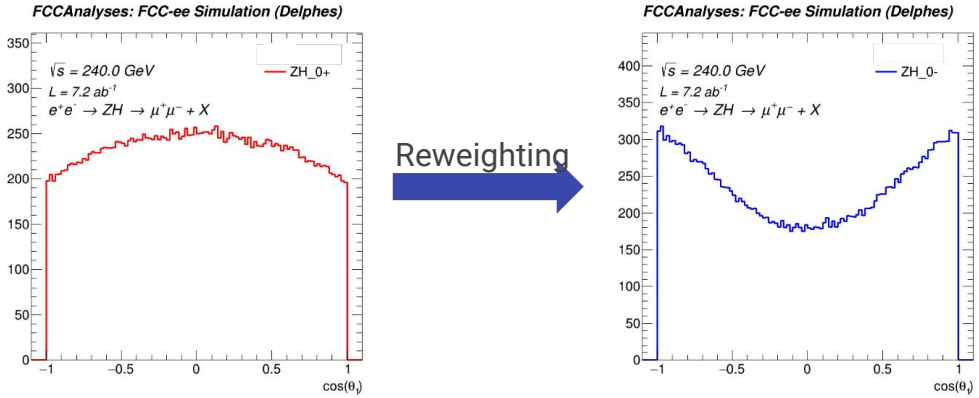


$$f_{\text{CP}}^{HX} \equiv \frac{\Gamma_{H\to X}^{\text{CP odd}}}{\Gamma_{H\to X}^{\text{CP odd}} + \Gamma_{H\to X}^{\text{CP even}}}$$

$$f_{CP}^{HVV} = \frac{|a_3^{HVV}|^2}{\sum |a_i^{HVV}|^2 (\sigma_i^{HVV}/\sigma_3^{HVV})},$$

Background: MELA

- Matrix Element Likelihood Approach
- Calculates transition probability between hypotheses using event kinematics
  - Gen-level: use these to reweight between hypotheses within one sample
  - Reco-level: use these to calculate optimal observables

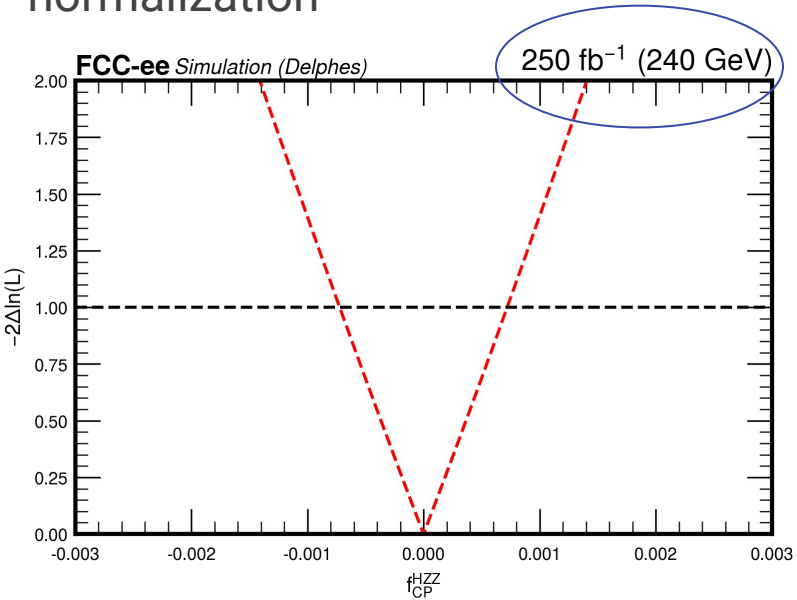


Review

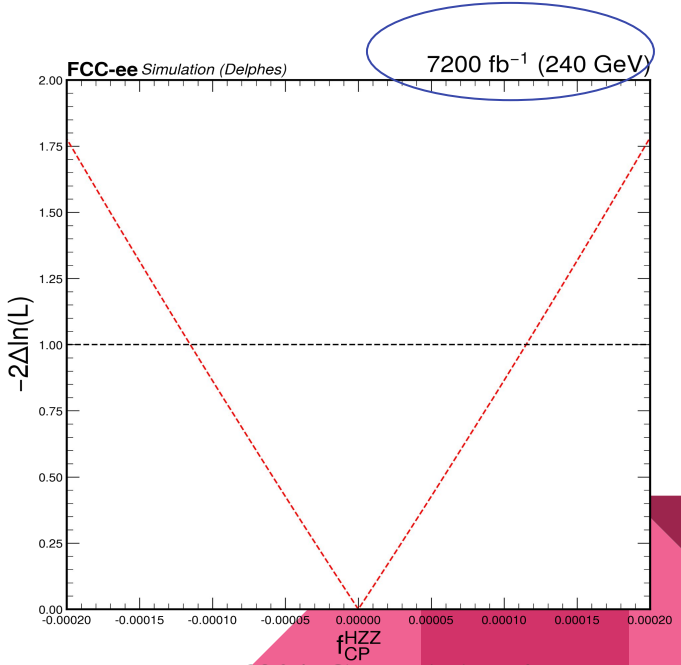
- Use kinematic observables to optimally constrain CP-odd contributions at FCC-ee
  - MELA probabilities for 0^- hypothesis and 50/50 mixture of $0^+/0^-$
  - Perform 3-D likelihood fit on reweighted angular distributions to extract f^{HZZ}_{CP} coupling
- Simulate using IDEA detector concept (DELPHES, Winter2023 campaign)
  - Realistic study (more complete than Snowmass)
  - $e^+e^- \rightarrow ZH$: $H \rightarrow X$ (recoil), $Z \rightarrow \mu\mu$ (3.4%)
  - More backgrounds (ZZ, WW, Z/gamma, etc.)
  - $\sqrt{s}$ = 240 GeV, lumi = 7200 fb^{-1}
- Compare to Snowmass 2022 study at $\sqrt{s}$ = 240 GeV, lumi = 250 fb^{-1}

Review: Z→μμ angular fits

- Note reduced resolution from past talk due to correction for interference normalization



68% CL ≈ 7.2E-4

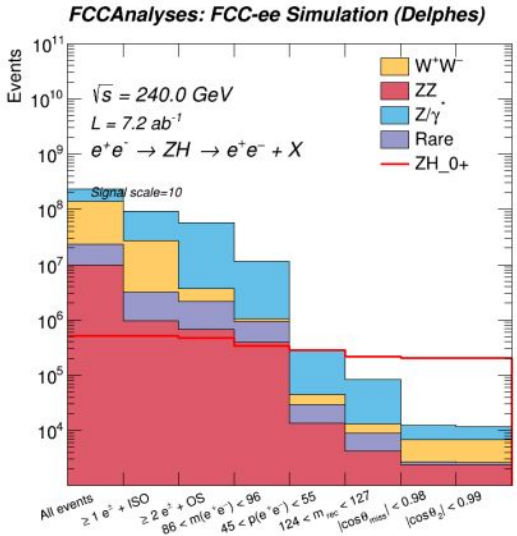


68% CL ≈ 1.1E-4

Selection

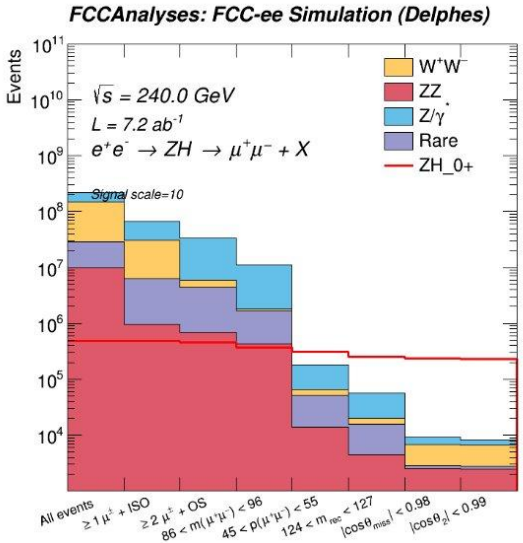
e+e-

- Signal selection efficiency ~ 40.0%
- Signal/background ratio ~ 2.0

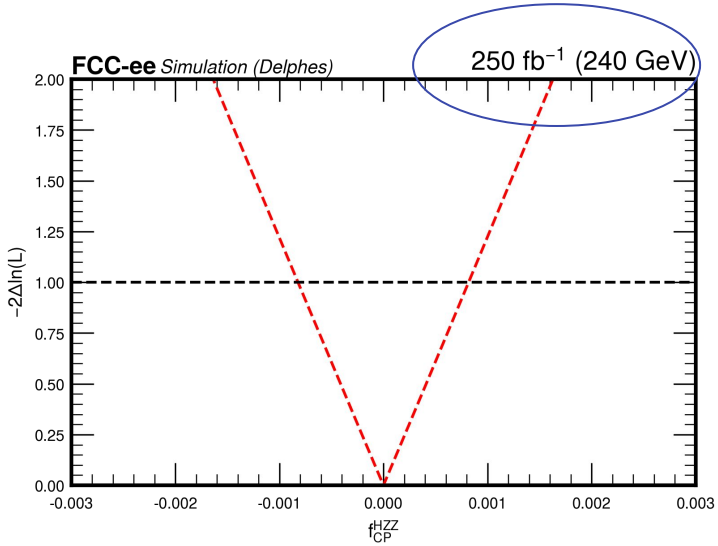


μμ

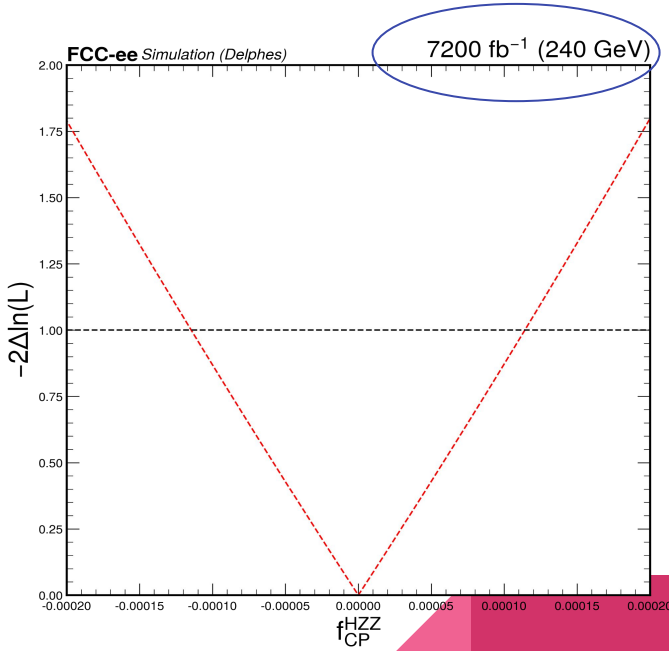
- Signal selection efficiency ~ 47.9%
- Signal/background ratio ~ 2.5



Result: Z⟶ e+e- angular fit at specific luminosity



68% CL ≈ 8.2E-4

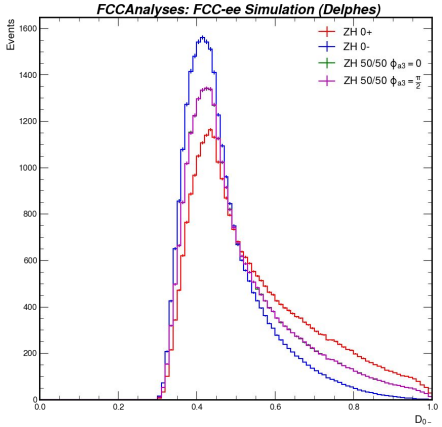


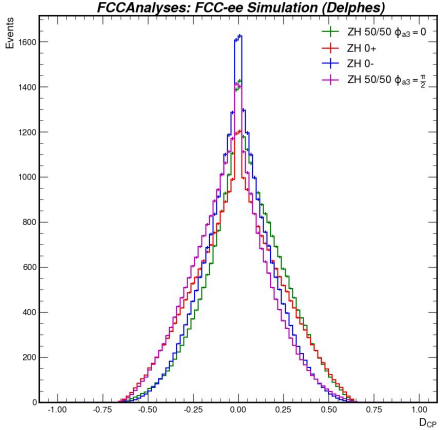
68% CL ≈ 1.2E-4

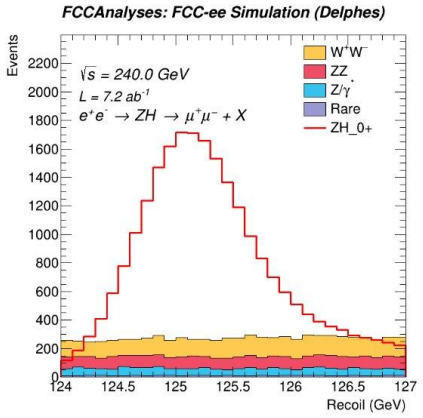
Discriminants

$$D_{0^-} = \frac{P(0^-)}{P(0^+)+P(0^-)}$$
$$D_{CP} = \frac{P(int)}{2\sqrt{P(0^+)*P(0^-)}}$$

- Optimal observables from MELA probabilities (Neyman-Pearson Lemma)
- Can more easily separate hypotheses from backgrounds and other hypotheses
- Create likelihood fit using D_{0-} , D_{CP} , m_{recoil}
  - Optimized on 4 bins/axis

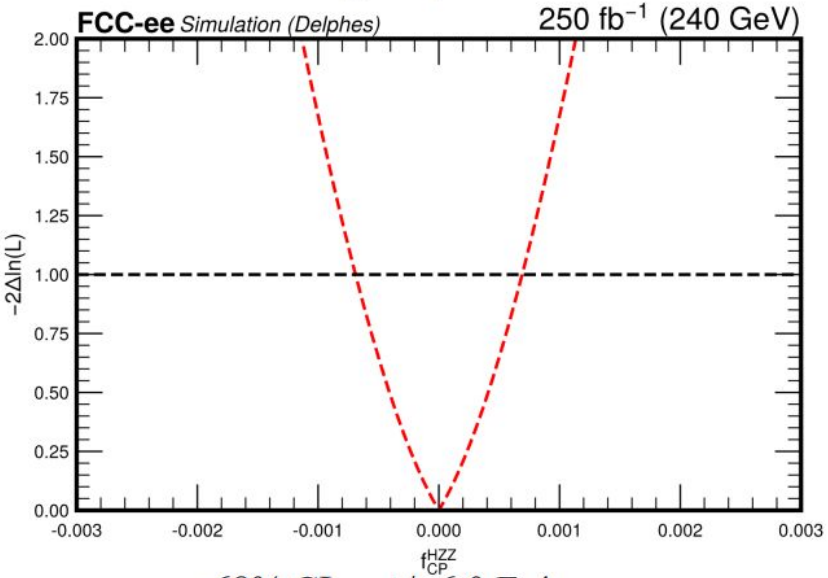






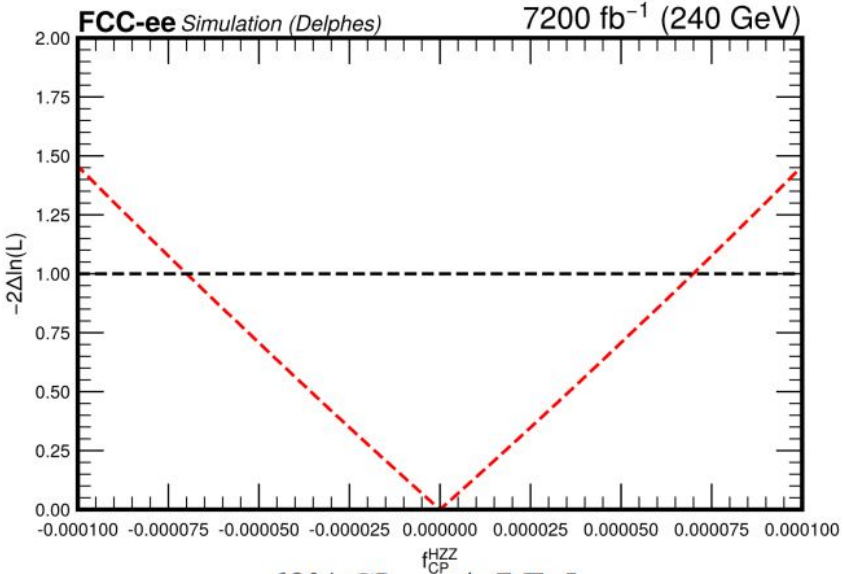
Result: Discriminant fits at Z→μμ

$@\ 250 fb^{-1}$



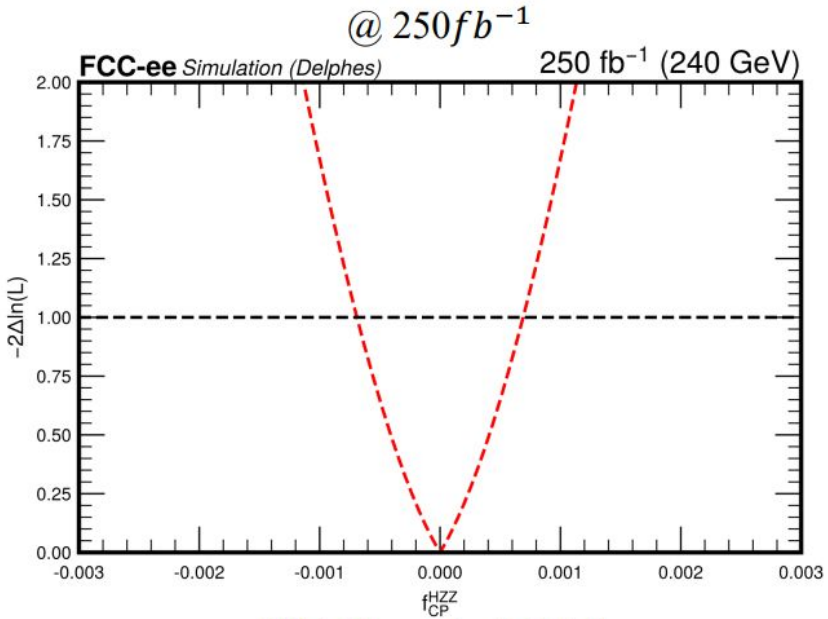
68% CL ≈ +/- 6.0 E-4

$@7200\ fb^{-1}$

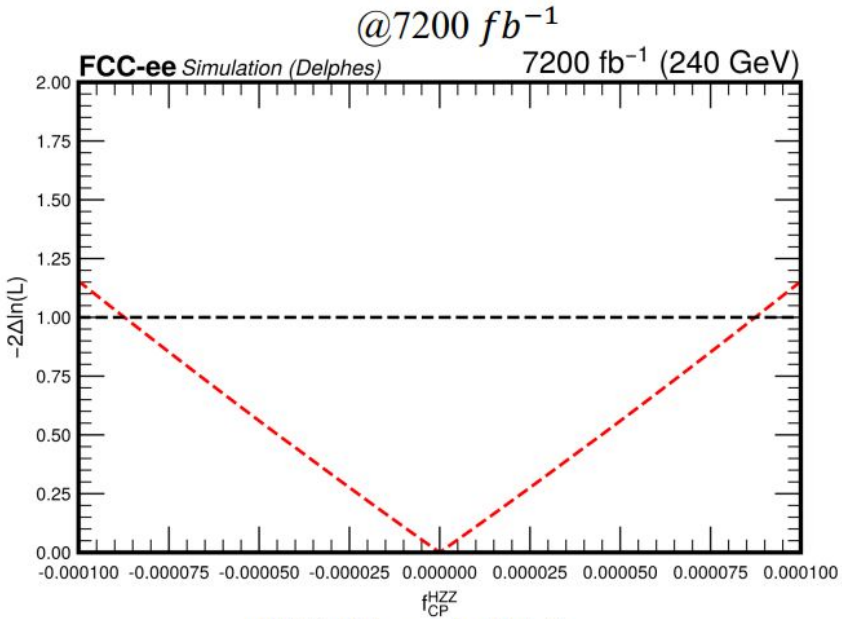


68% CL ≈ +/- 7 E-5

Result: Discriminant fits at Z→e+e-



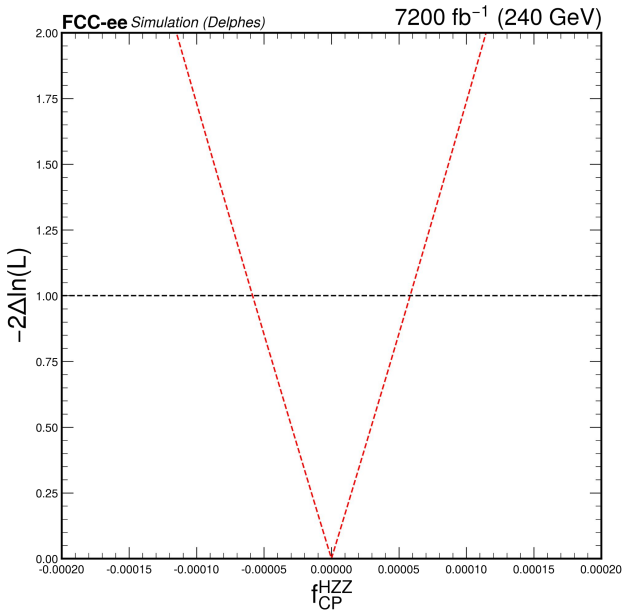
68% CL ≈ +/- 6.5 E-4



68% CL ≈ +/- 8E-5

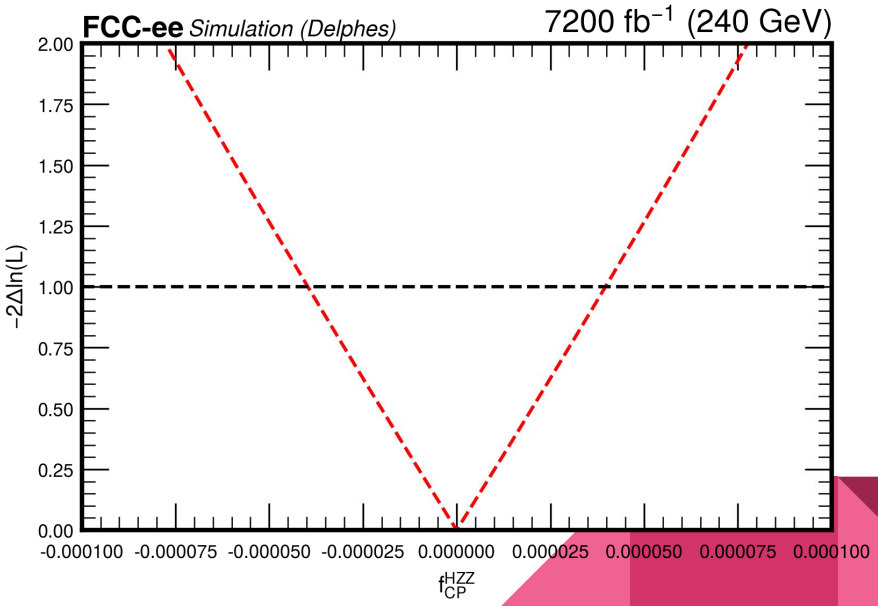
Result: Combined fits at 7200 fb^{-1}

Angular



68% CL ≈ 5.8E-5

Discriminant



68% CL ≈ 4.0E-5

Final notes + next steps

- Likelihood fit on angular distributions is realistic constraint on f^{HZZ}_{CP}!!!
  - Slightly lower resolution at Z →ee
  - Discriminant direction seems promising
- What's next?
  - Z → qq final state
  - Can explore alternative couplings $f^{HZ\gamma^*}_{CP}$, $f^{H\gamma^*\gamma^*}_{CP}$ with same MELA tools