FUTURE CIRCULAR COLLIDER

Constraining Sensitivity to CP-Odd Contributions in the Higgstrahlung Process at FCC-ee

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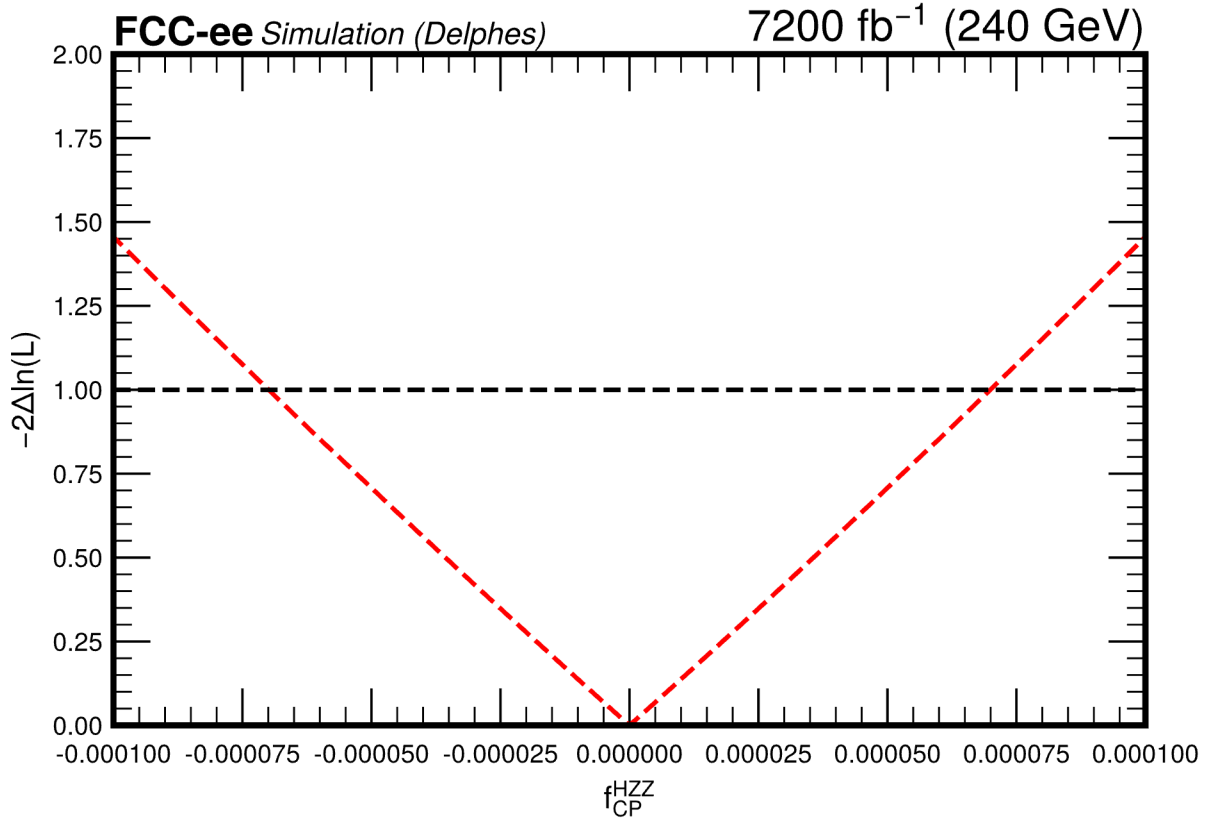
Outline:

- Overview
- Selection and efficiency
- MELA: What it is and how it's used
- Template details
- Results
- Summary and future avenues

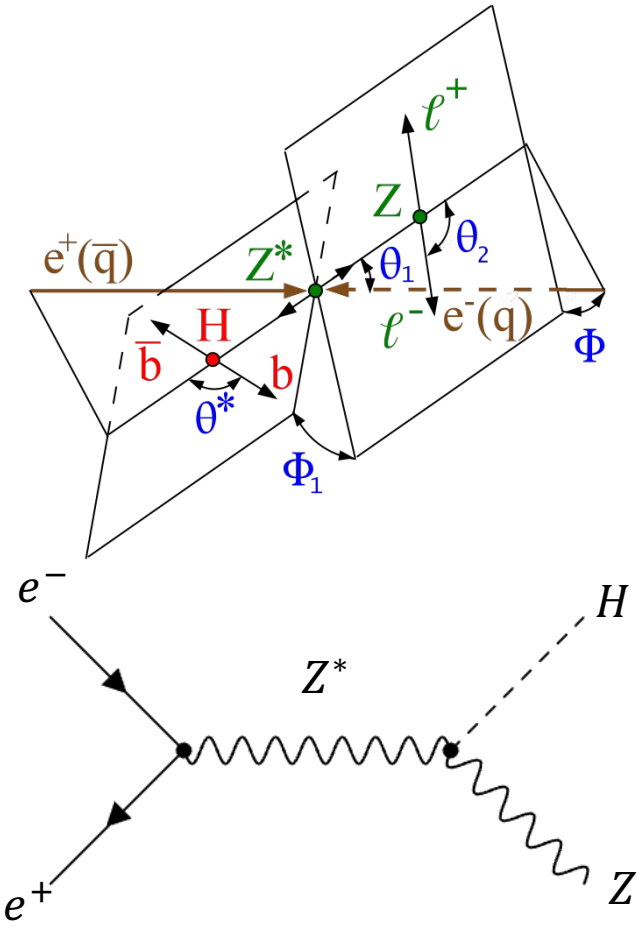


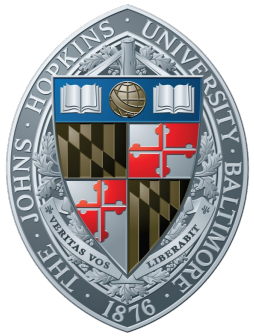
Overview of Current Study:

- Set constraints on f_{CP}^{HZZ} for simulated FCC Reco data.
  - $e^+e^- \longrightarrow$ ZH, H $\longrightarrow$ X (recoil), Z $\longrightarrow l^+l^-$
  - $\sqrt{s} = 240\ GeV$, Luminosity = 7200 fb^{-1}
  - Results also presented @ 250 fb^{-1} to compare to [Snowmass 2022]

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

$$A(H \to V_1V_2) = v^{-1}\left(a_1^{HVV} m_V^2 \epsilon_1^* \epsilon_2^* + a_2^{HVV} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{HVV} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}\right)$$





Overview of Current Study:

- Detector simulation uses DELPHES fast sim.
- Template fit made from 2 discriminants + recoil mass.
- Broader range of backgrounds used than Snowmass:
  - Primarily WW, ZZ, Z/γ^*
  - Rare backgrounds:
    - $e\,\gamma \longrightarrow e\,Z, Z \longrightarrow l^+l^-$
    - $\gamma\gamma \longrightarrow l^+l^-$

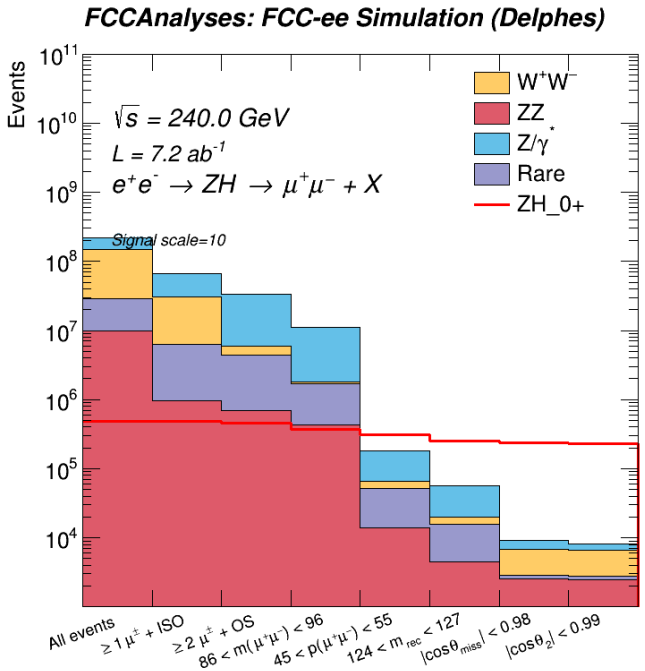
Cut Flow:

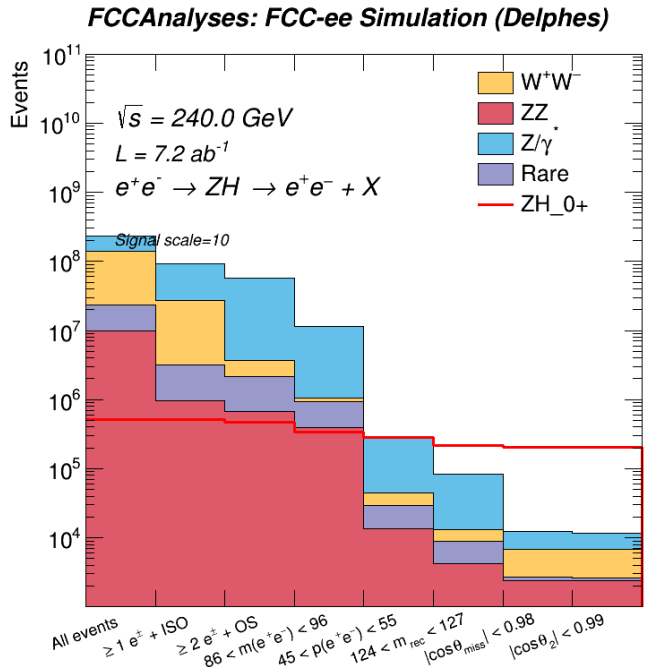
$\mu\mu$:

- Signal Selection Efficiency ~ 47.9%
- Signal : Background ~2.5

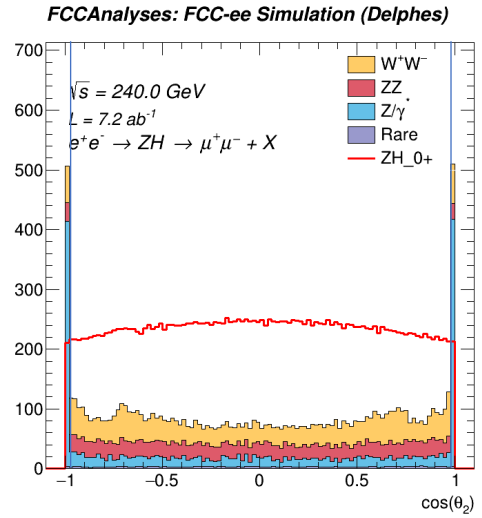
ee:

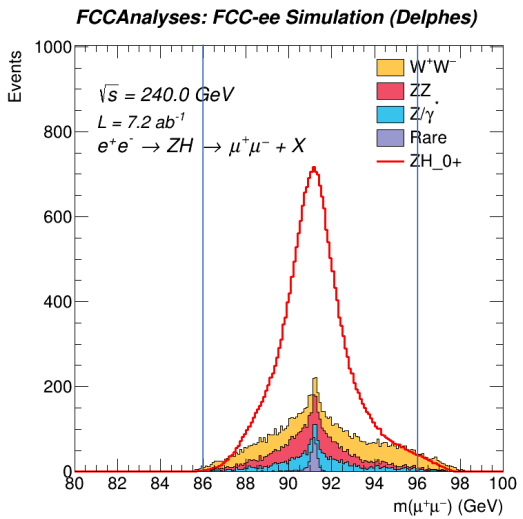
- Signal Selection Efficiency ~ 40.0%
- Signal : Background ~2.0

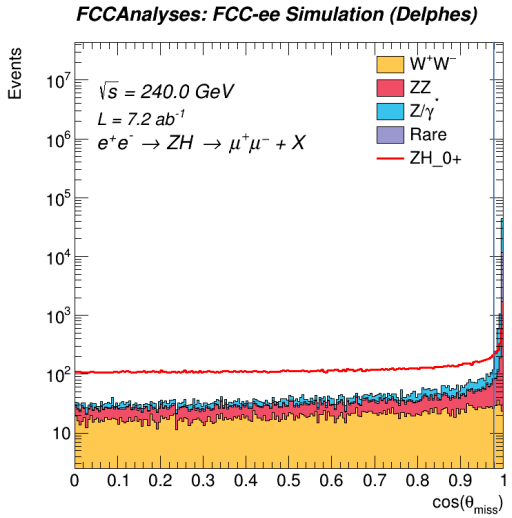


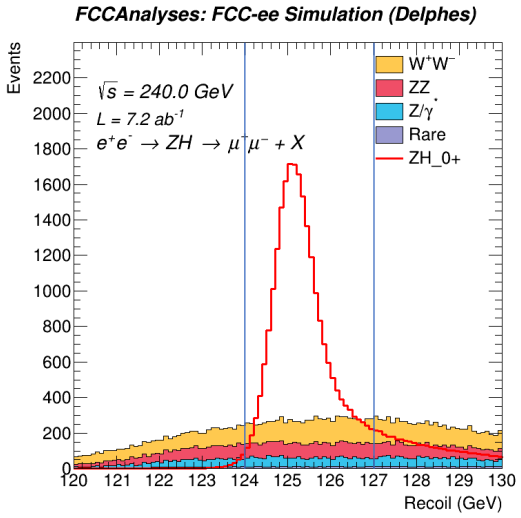


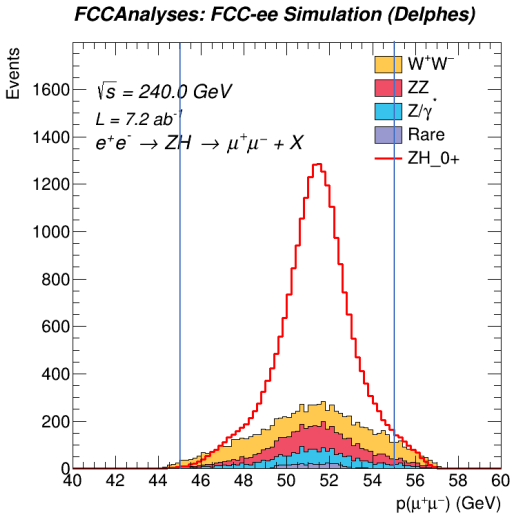
Current Selection ($\mu\mu$): N-1 Plots:



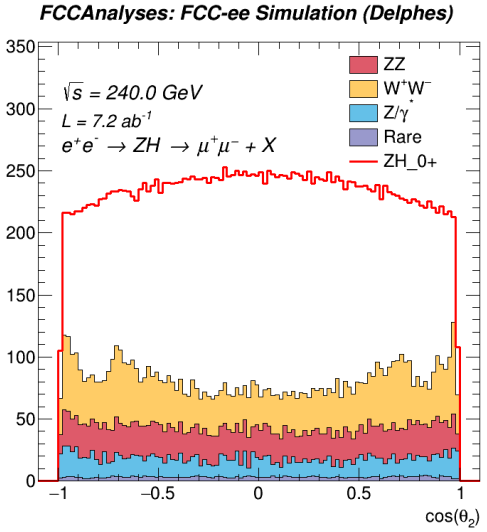


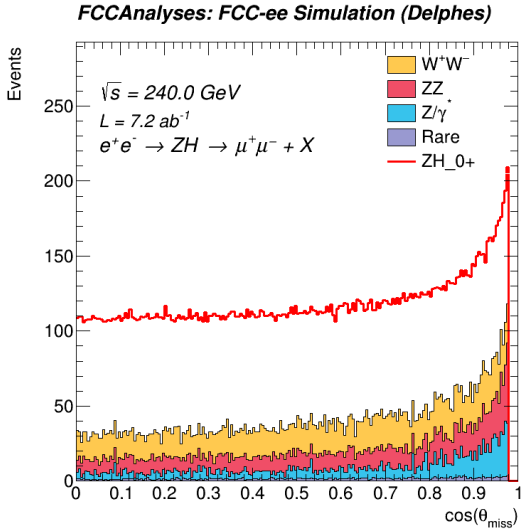


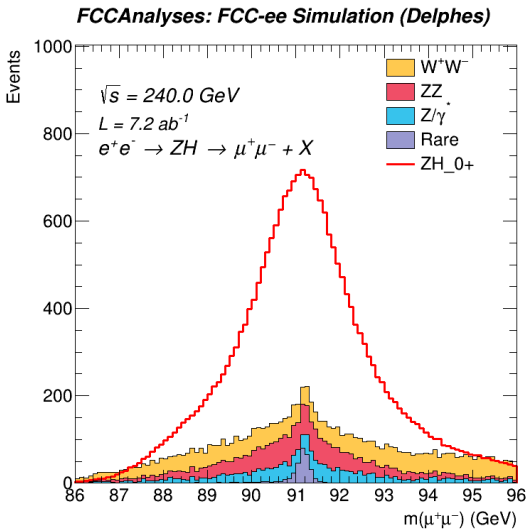


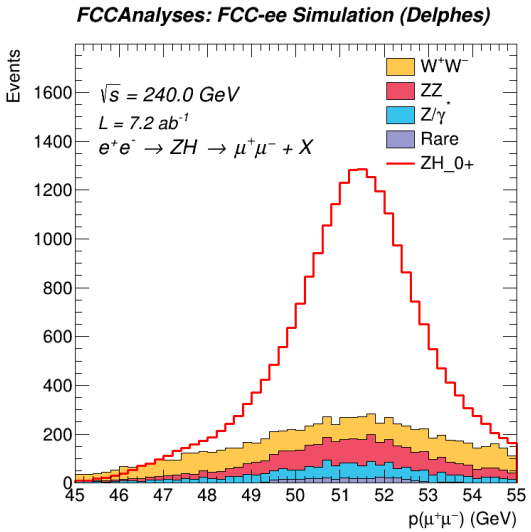


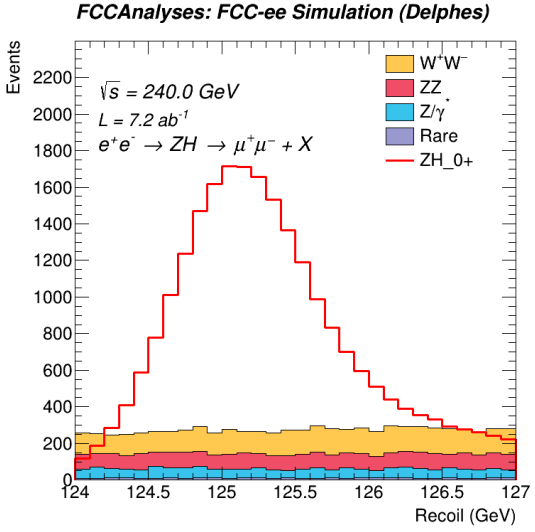
All Cuts Made ($\mu\mu$):

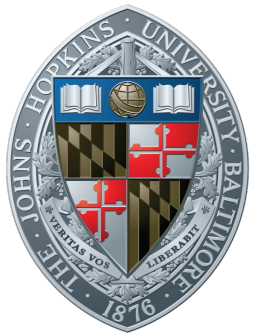










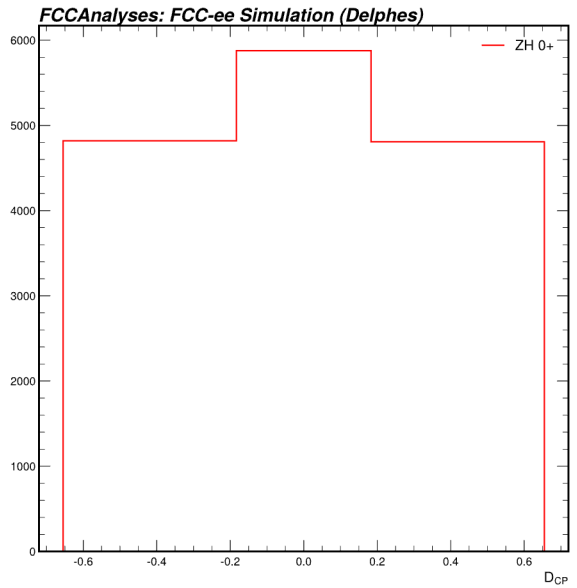


MELA:

- “Matrix Element Likelihood Approach”
- Calculates transition probability from one hypothesis to another using event kinematics.
- Reco-Level probabilities can be used to calculate optimal observables.
- Gen-Level probabilities can be used to perform reweighting.

Reweighting:

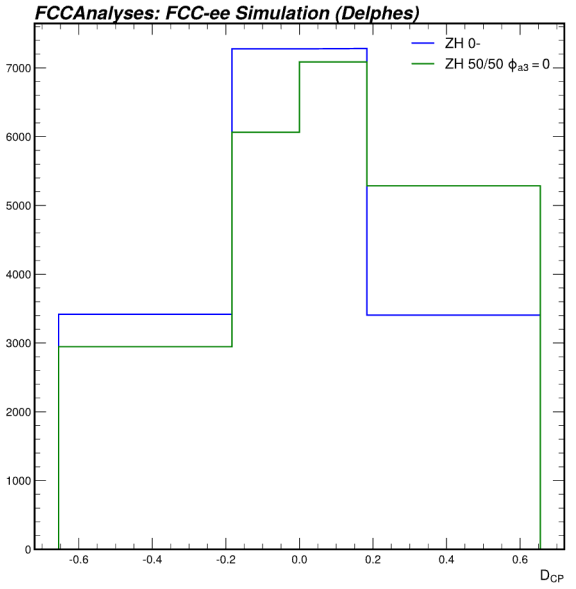
Simulated:



Reweighting:

$P(0^-)$

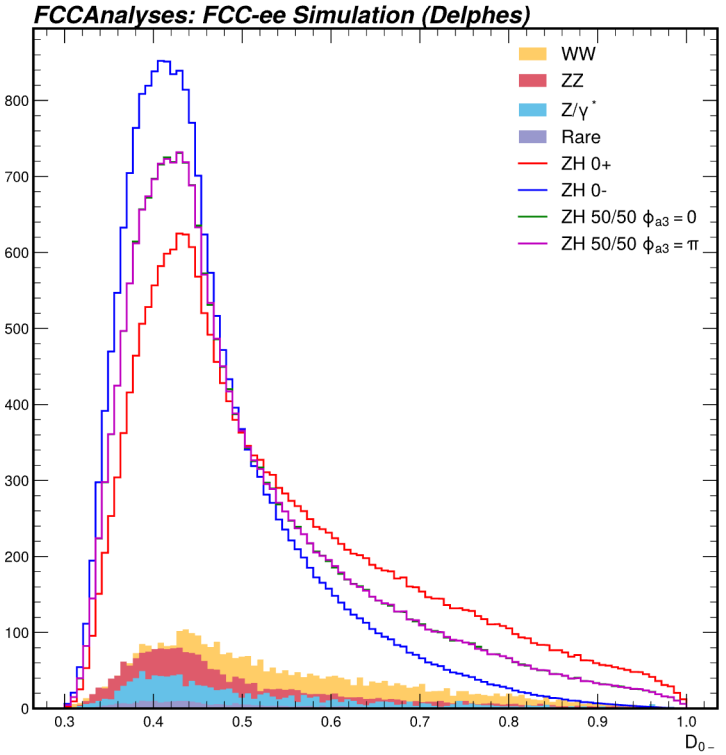
$P(50/50)$

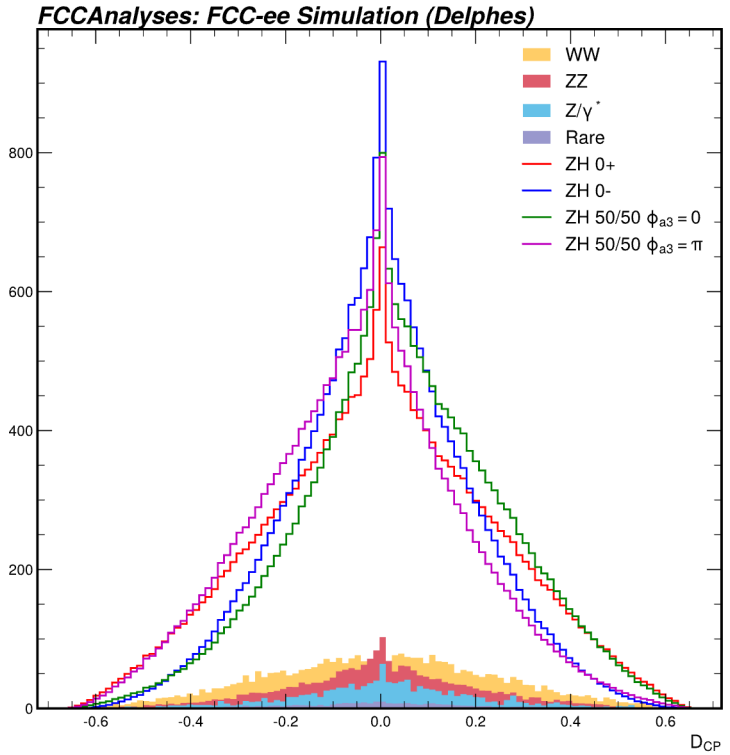


- Probabilities calculated by MELA.
- Reweights 0^+distribution to 0^- and 50/50 mixture distributions.

What is an optimal observable?

Neyman-Pearson Lemma: Likelihood ratio is optimal for separating two hypotheses.



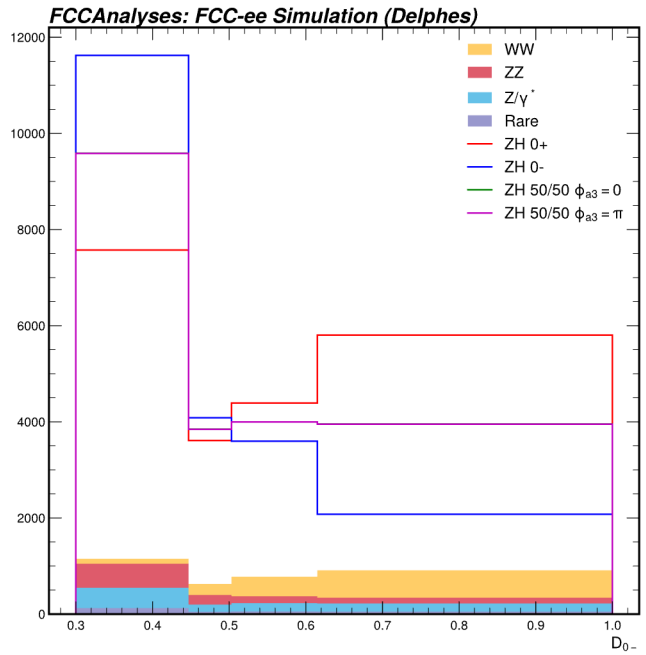


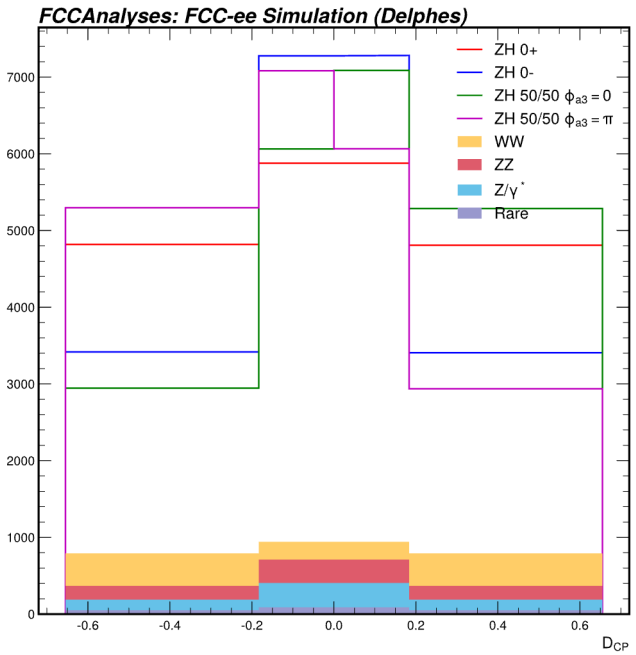
$$D_{0^-} = \frac{P(0^-)}{P(0^+)+P(0^-)}$$

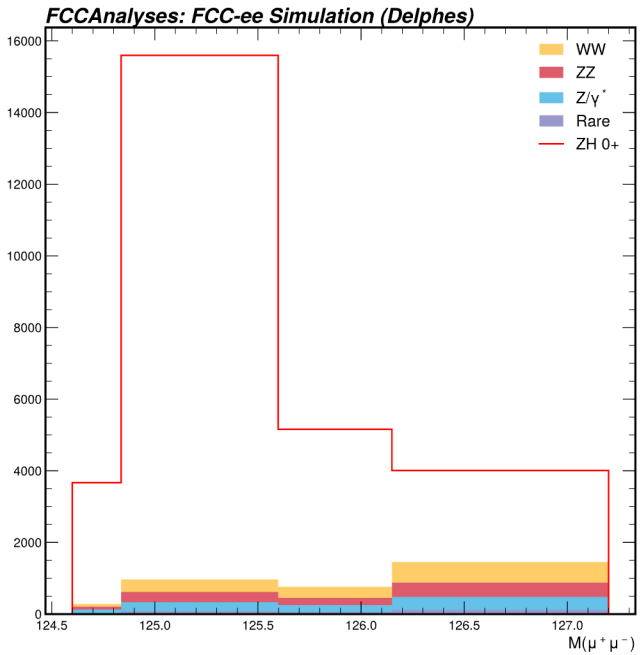
$$D_{CP} = \frac{P(int)}{2\sqrt{P(0^+)*P(0^-)}}$$

Template Fit Details:

- 3D histogram filled with D_{0^-}, D_{CP}, M_{Rec} each on one axis.
- 4 bins/axis
- Example projections for $Z \to \mu\mu$ @ 7200 fb^{-1} :

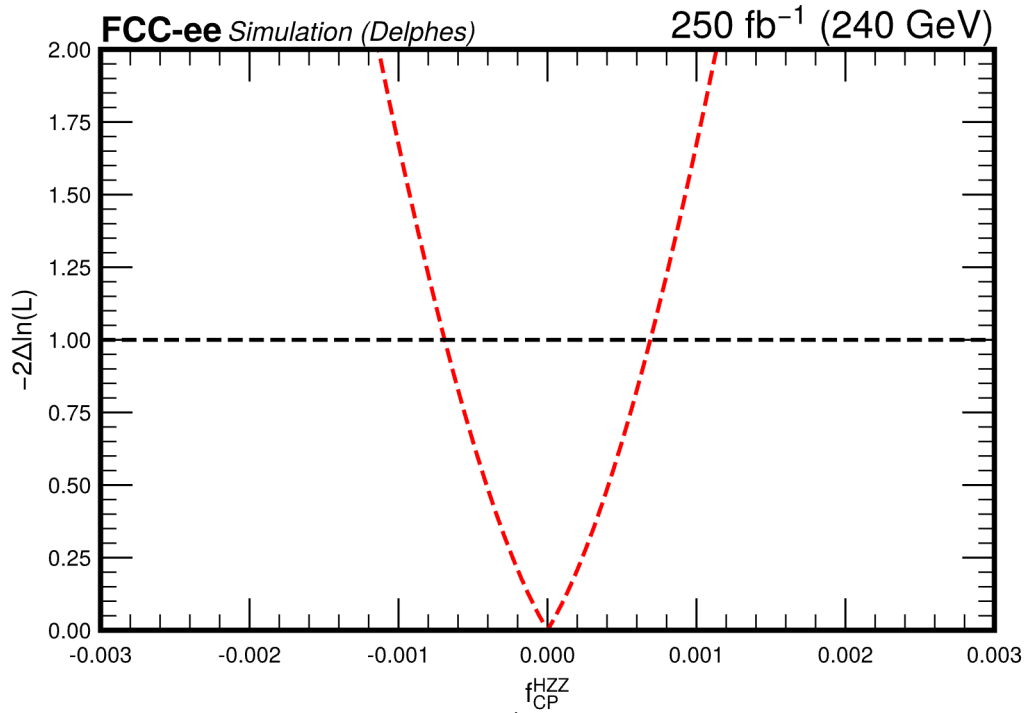






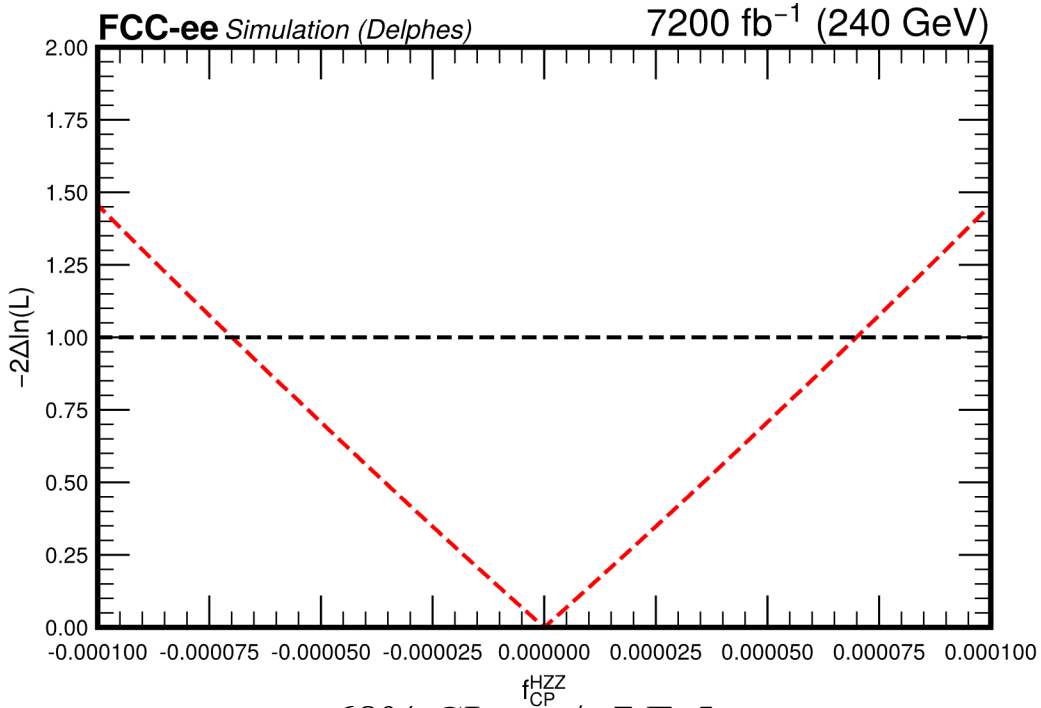
Fits with H $\longrightarrow$ X, Z $\longrightarrow \mu\mu$:

$@\ 250 fb^{-1}$



68% CL ≈ +/- 6.0 E-4

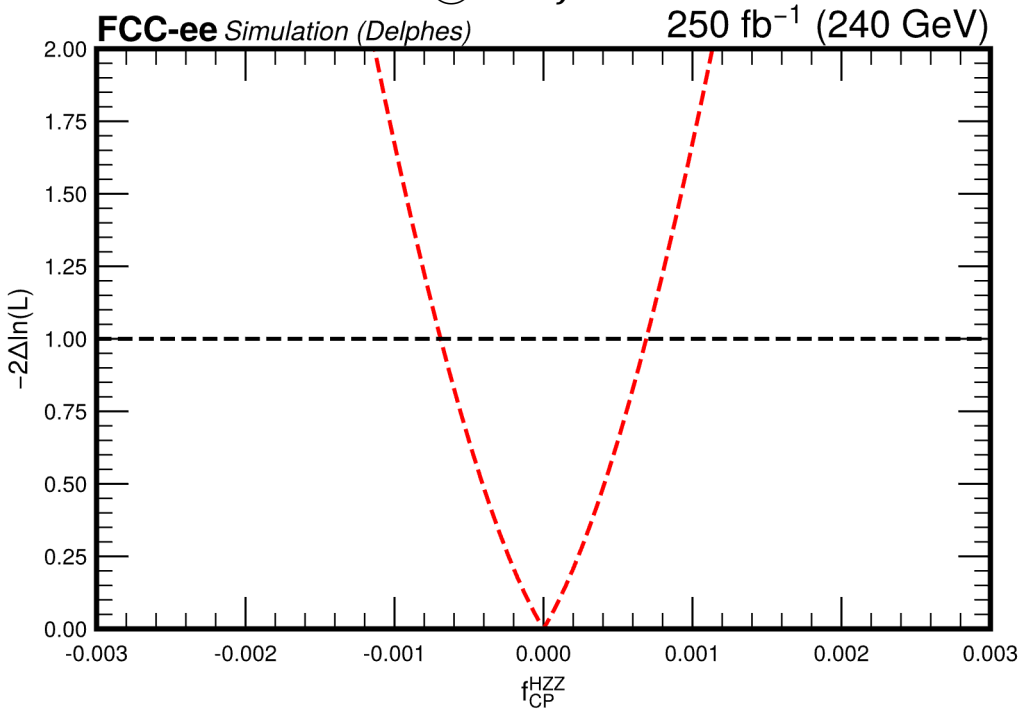
$@7200\ fb^{-1}$



68% CL ≈ +/- 7 E-5

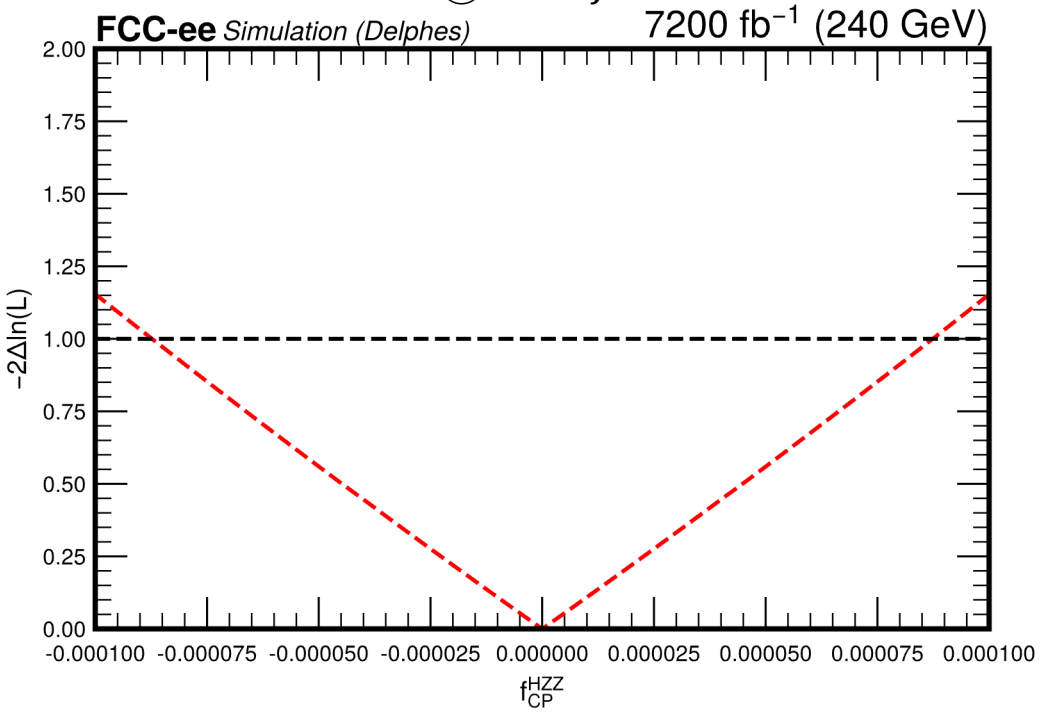
Fits with H $\longrightarrow$ X, Z $\longrightarrow$ ee:

$@\ 250 fb^{-1}$



68% CL ≈ +/- 6.5 E-4

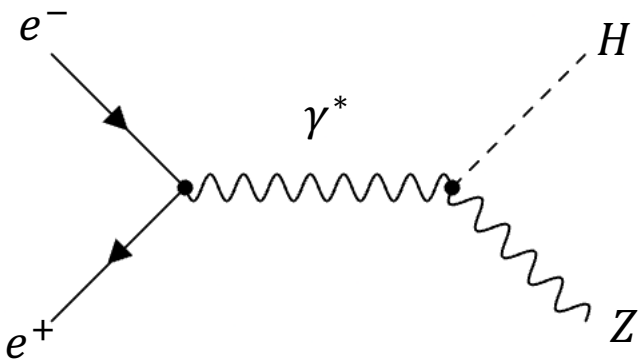
$@7200\ fb^{-1}$

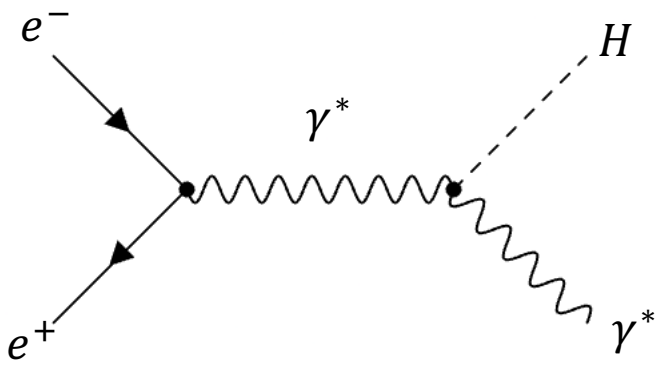


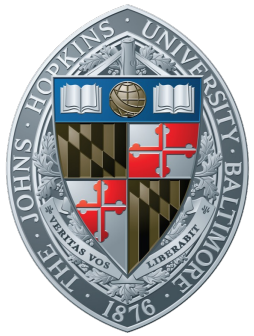
68% CL ≈ +/- 8E-5

Future studies:

- MELA can probe couplings besides f_{CP}^{HZZ}.
  - $f_{CP}^{HZ\gamma*}$, $f_{CP}^{H\gamma*\gamma*}$ studies also possible within FCC framework.
- Also plan to target Z ⟶ qq.





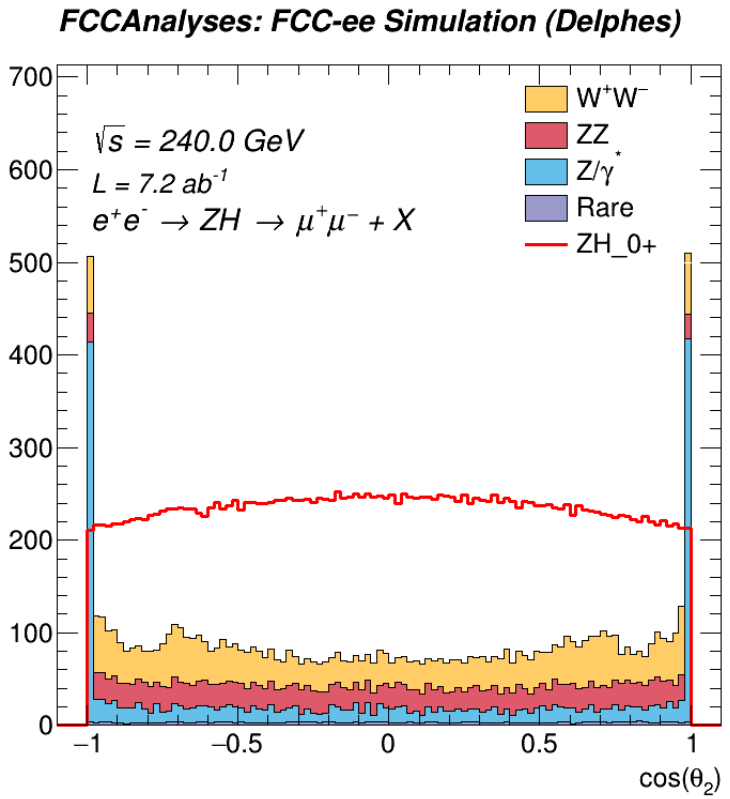


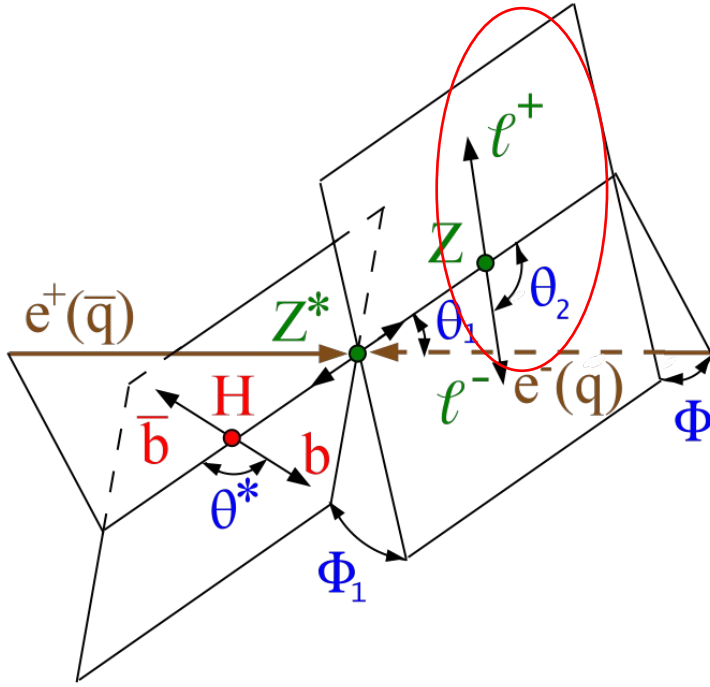
Summary:

- Likelihood fit from discriminants represents a realistic constraints on f_{CP}^{HZZ}.
  - 250 fb^{-1} scans in agreement with Snowmass 2022 study.
  - This study is updated with detector effects and a broader range of backgrounds.
- Plans to extend this study:
  - $Z \to qq$
  - Alternative couplings: $f_{CP}^{HZ\gamma*}$, $f_{CP}^{H\gamma*\gamma*}$

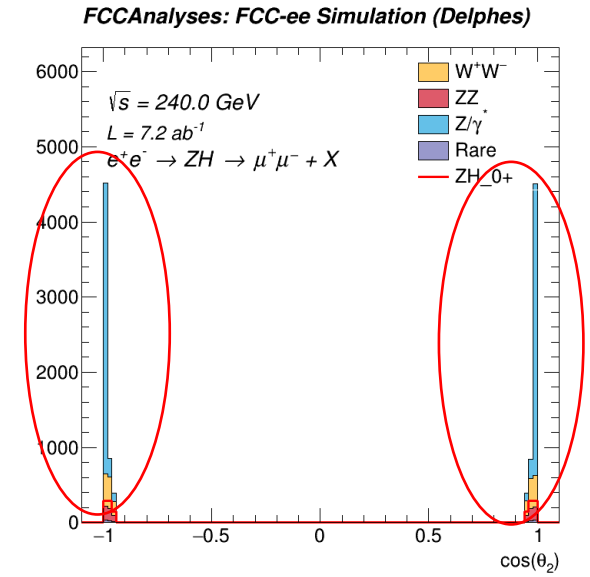
Backup: Behavior of $\mathrm{Cos}\,\theta_2$ Endpoints:

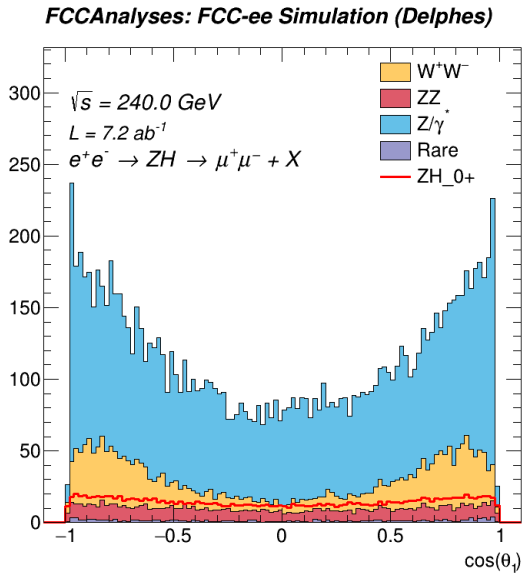
- $\mathrm{Cos}\,\theta_2$ is the angle between muon and recoil direction.
- ”Bullhorns” appear at the extrema of $\mathrm{Cos}\,\theta_2$ in $e^+e^- \rightarrow \tau^+\tau^-$

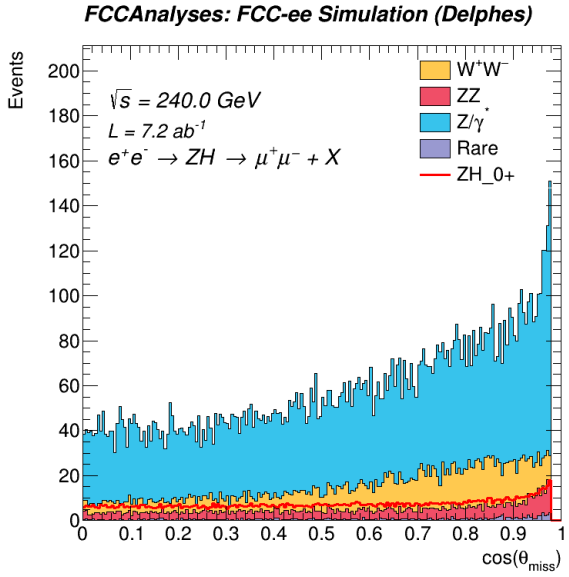


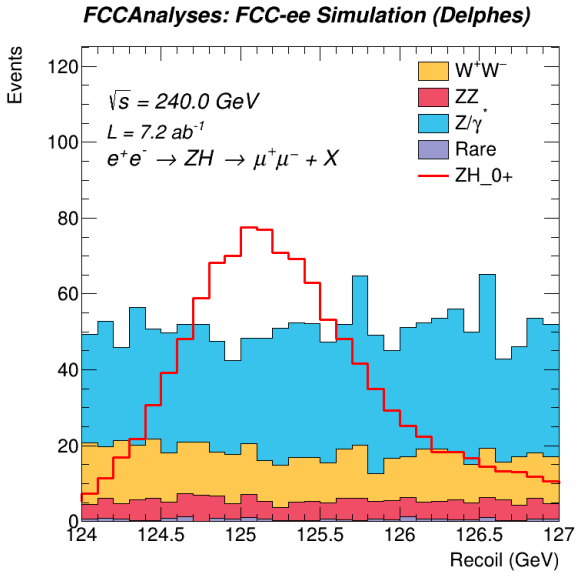


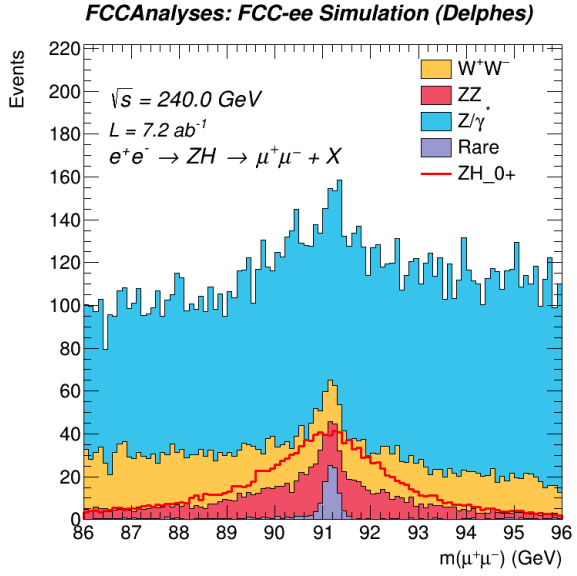
Backup: Events at Cos θ_2 Endpoints and Correlations to Other Observables:

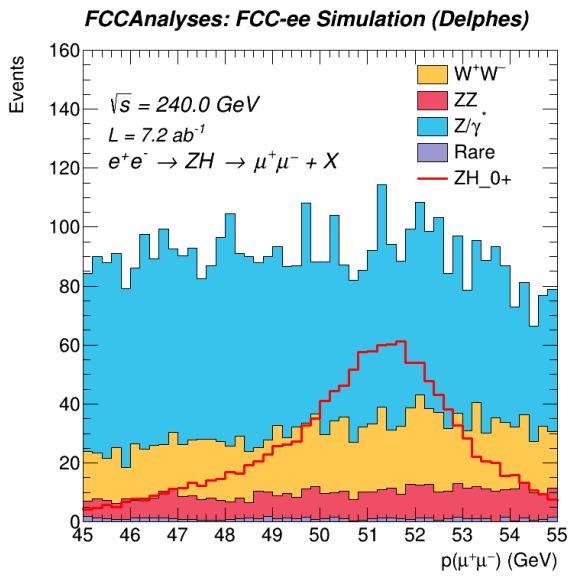




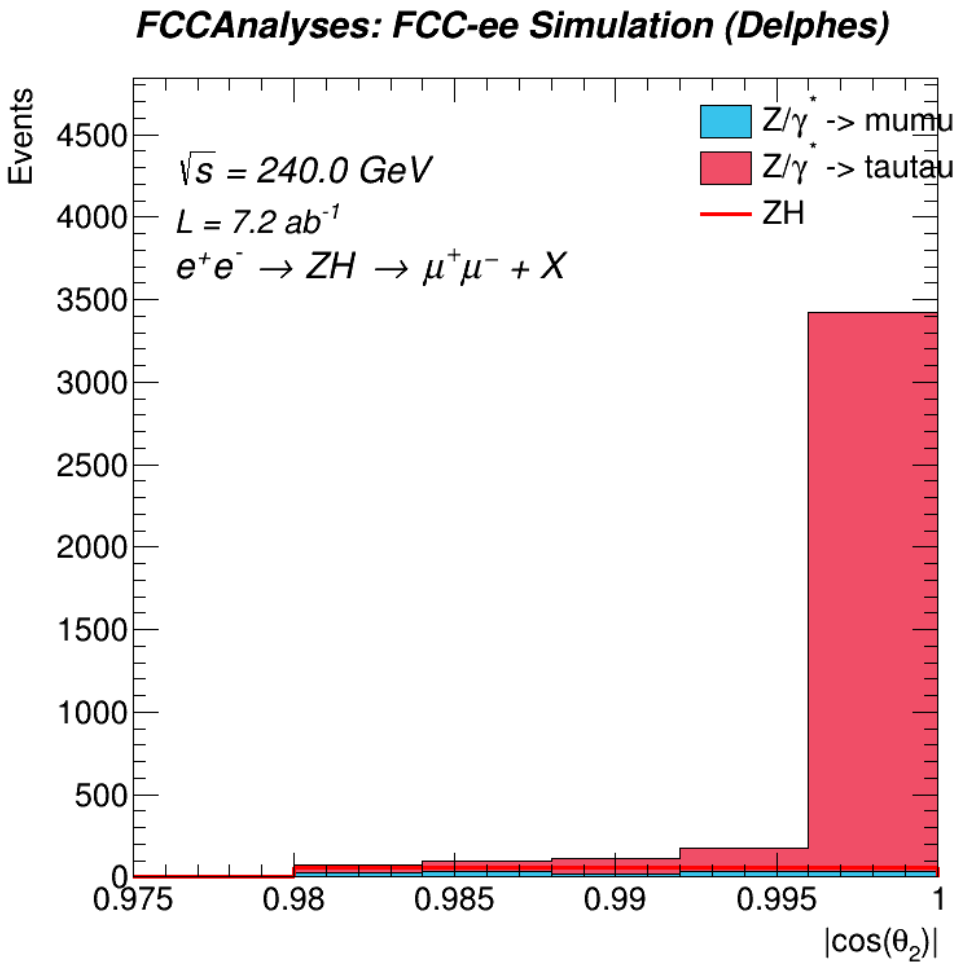


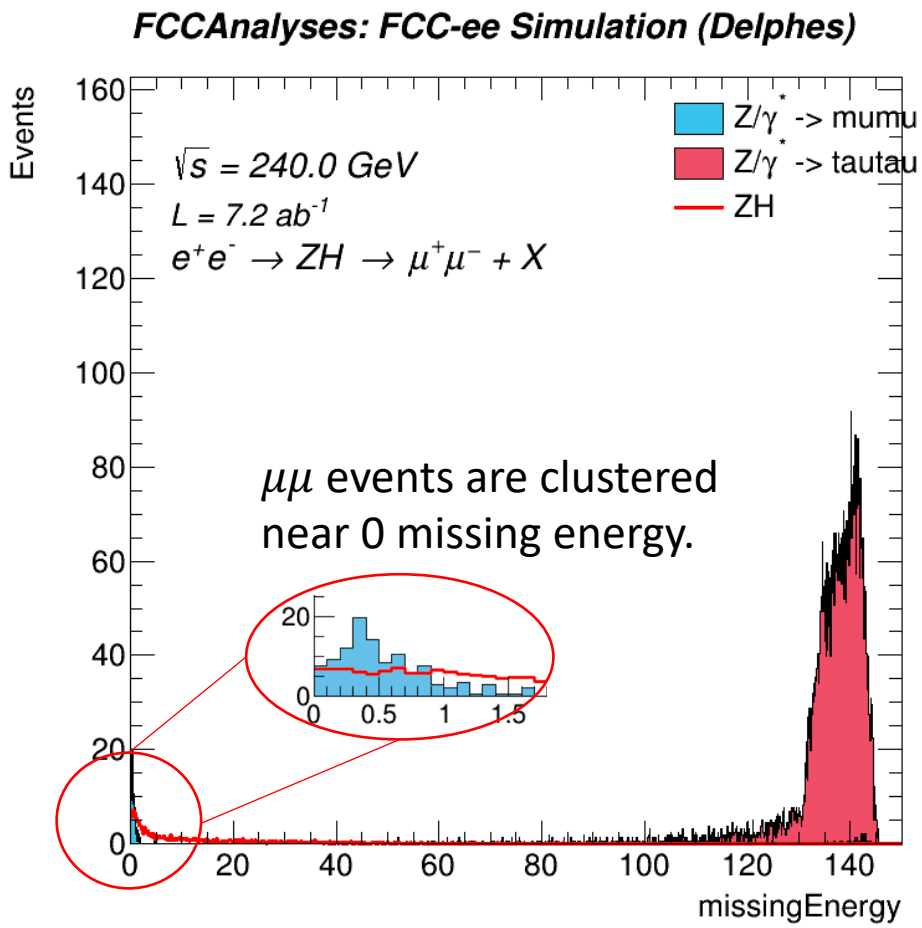






Backup: Cos θ_2 of $Z/\gamma^* \longrightarrow \mu\mu$ and $\tau\tau$:





Horns are nearly all from $\tau\tau$ events. No events in the bins below 0.98.

Missing energy from τ decays into neutrinos.