FUTURE CIRCULAR COLLIDER

Update to the Hadronic Channel of the FCC-ee Higgs CP Study

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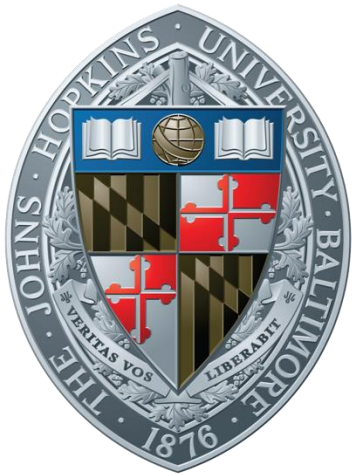
Virtual Session of 3rd ECFA Workshop

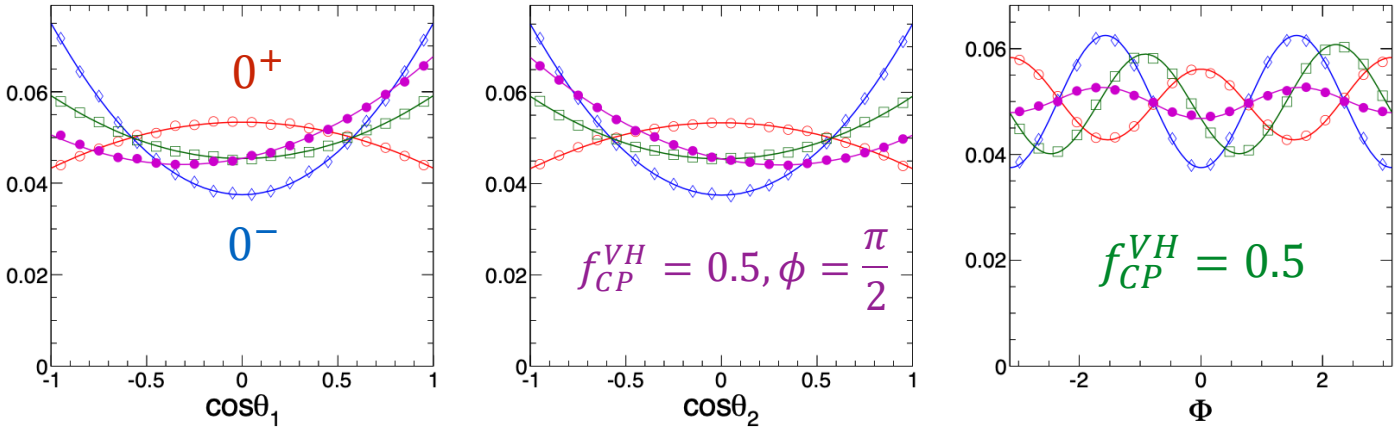
17 Oct 2024

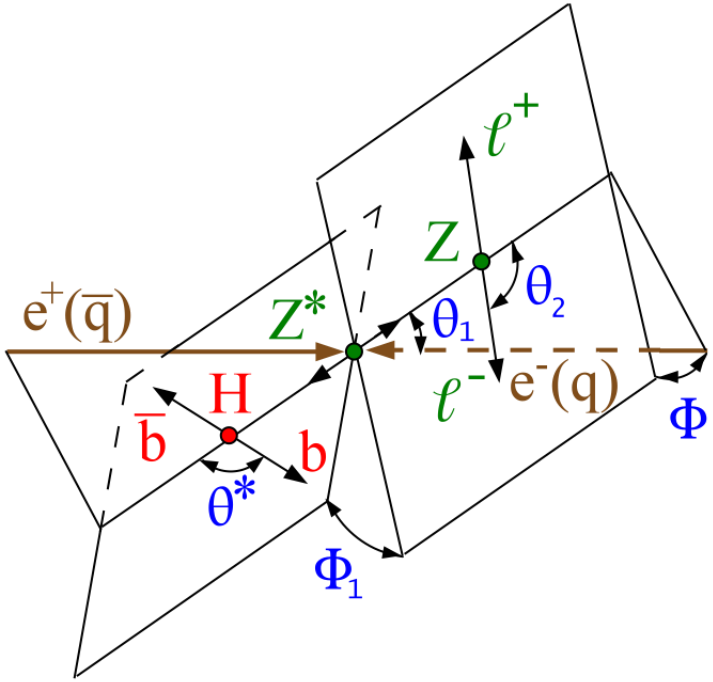


Massachusetts Institute of Technology

Parameters of Interest:

arXiv:1309.4819

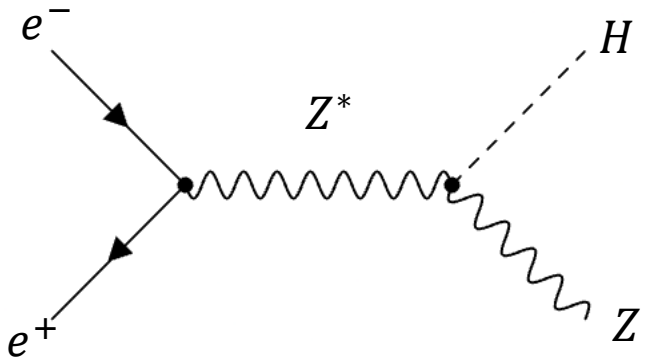




$$A(H \to V_1V_2) = v^{-1}\left(a_1^{HVV} m_V^2 \epsilon_1^* \epsilon_2^* + a_2^{HVV} f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + a_3^{HVV} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2),\mu\nu}\right)$$

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

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



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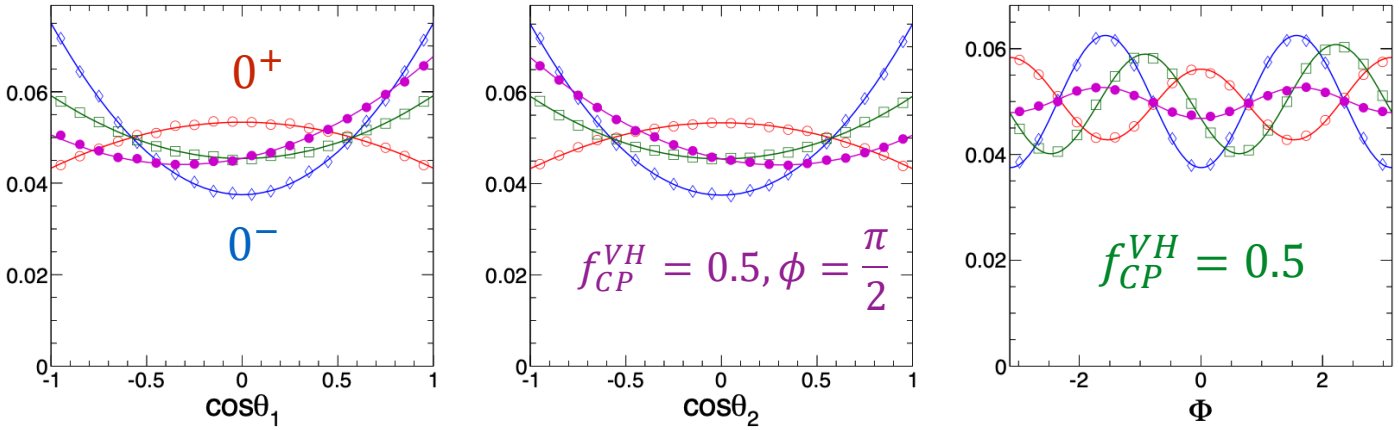

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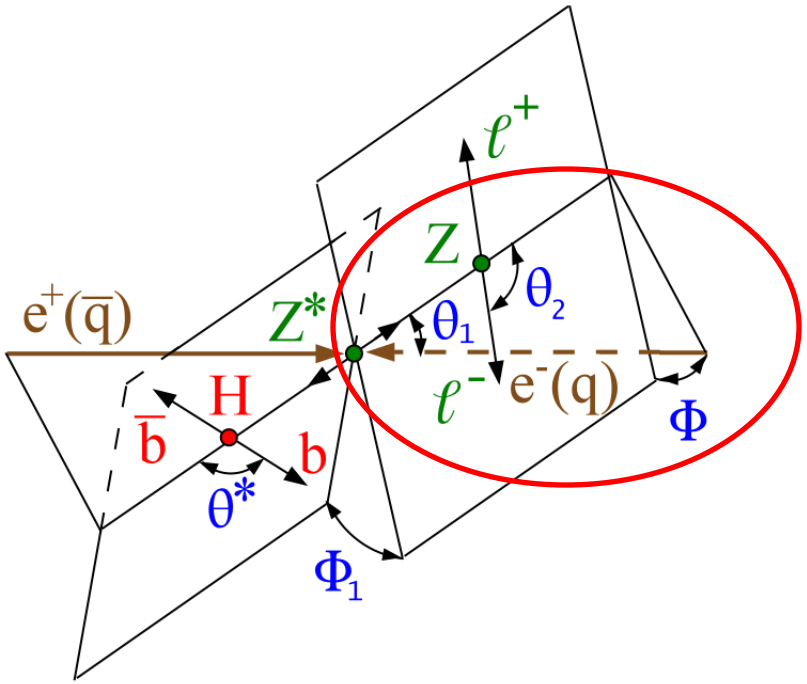
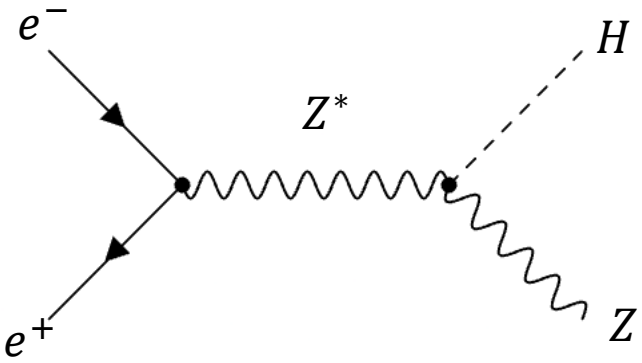
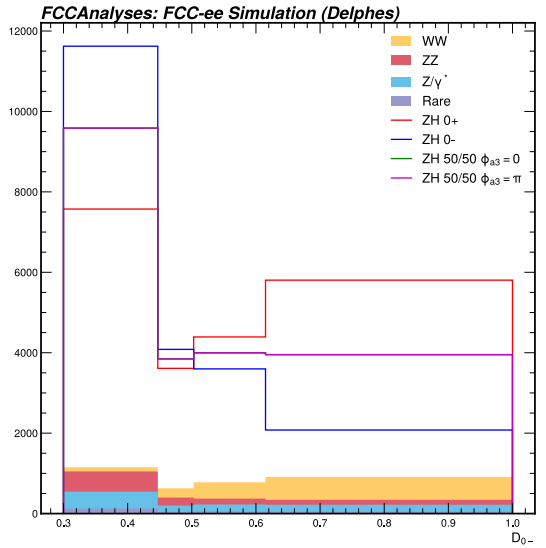


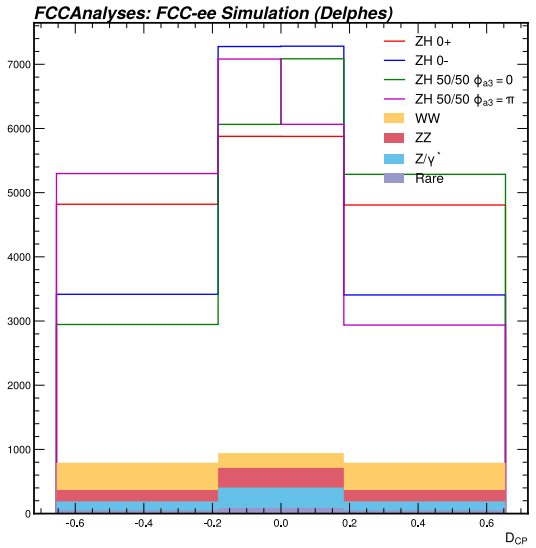


Previous Results:

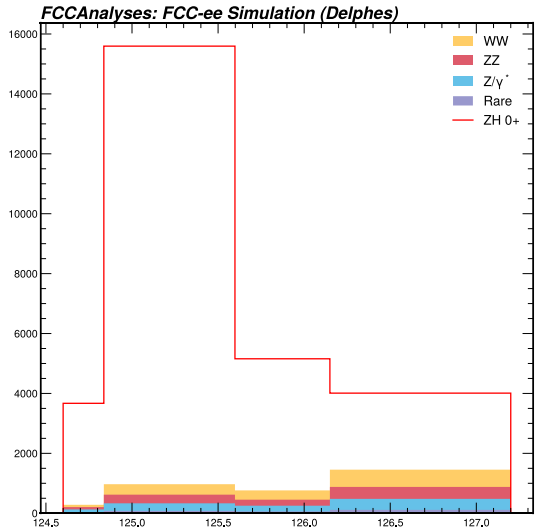
- Last presented on 18 June 2024.
- Target: ee ⟶ ZH, H ⟶ X (recoil),
  Z ⟶ $\mu\mu, ee$ (6.8%):
- Detector simulation uses DELPHES fast sim.
- Template fit made from optimal observables.
- Yields determined at integrated luminosity of $7200\ fb^{-1}$.
  - (Expected int. luminosity after ~3 years of operation.)



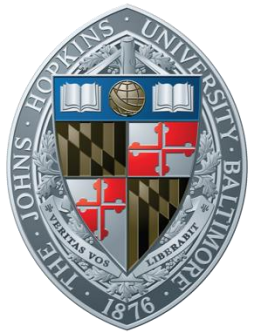
D_{0^-}



D_{CP}



M_{recoil}



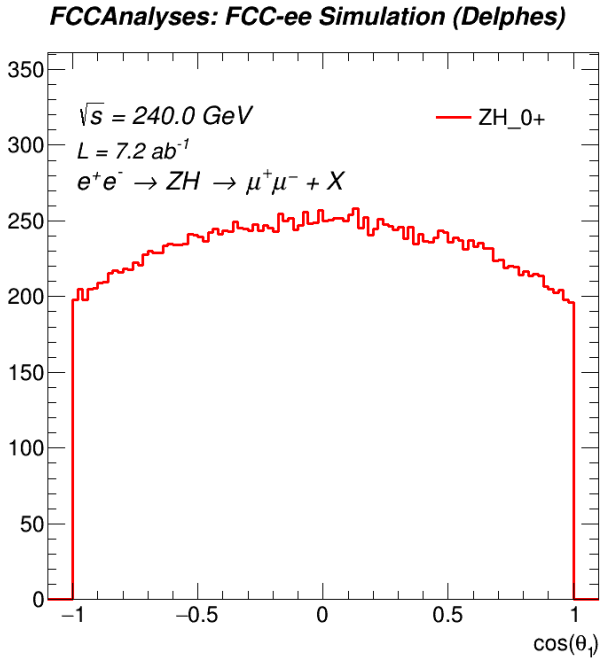
A Word on MELA:

- Matrix Element Likelihood Approach.

- From event kinematics, calculates transition probability from a given initial state to a desired final state.

Reweighting:

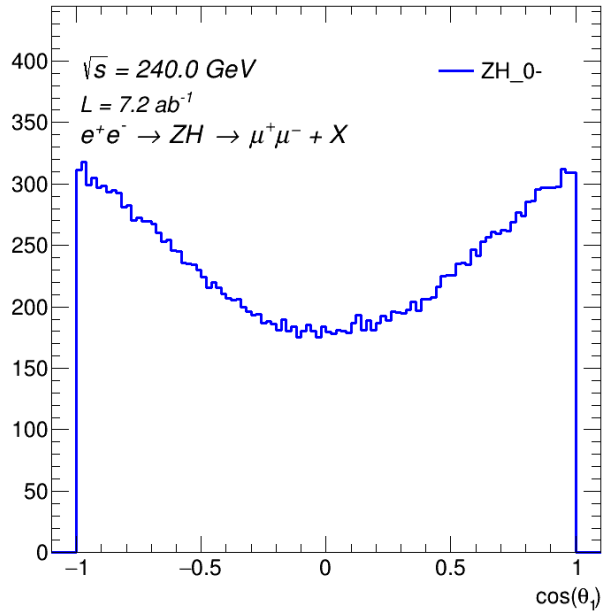
Simulated (Standard Model):

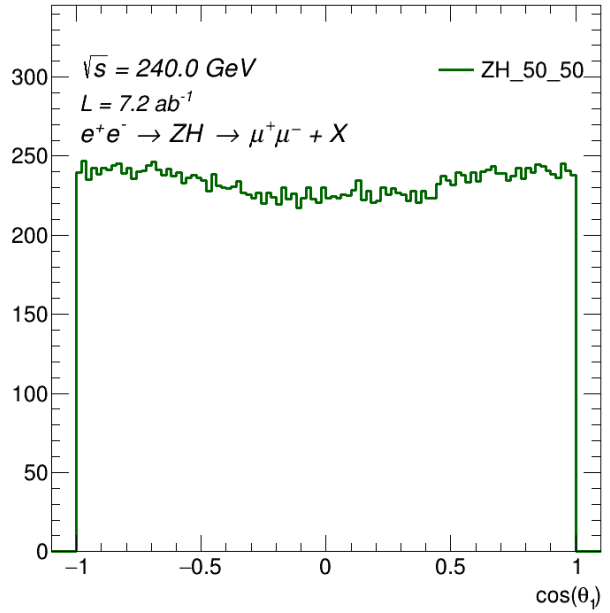


Reweighting:

$P(0^-)$

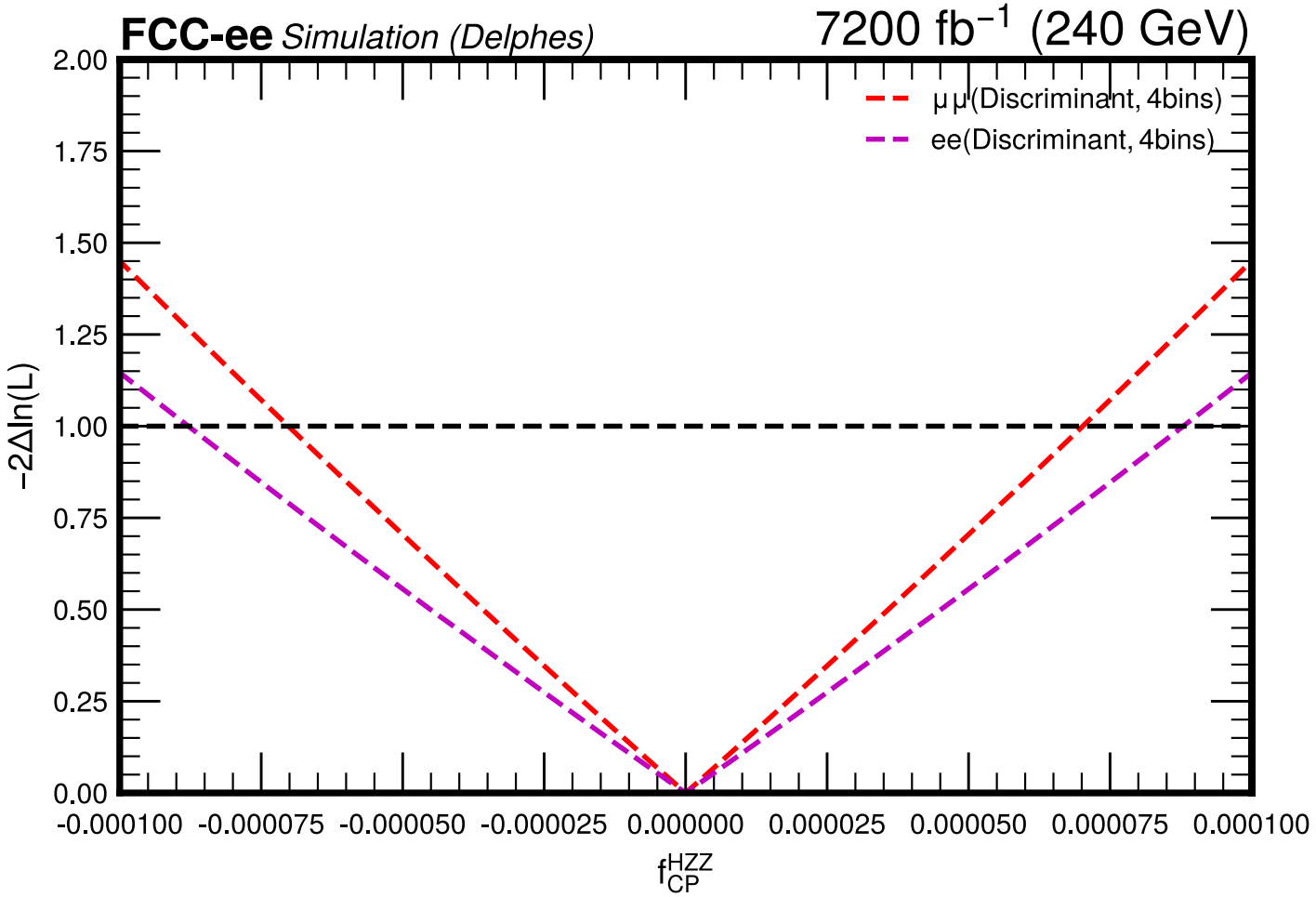
$P(50/50)$





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

Previous Results:



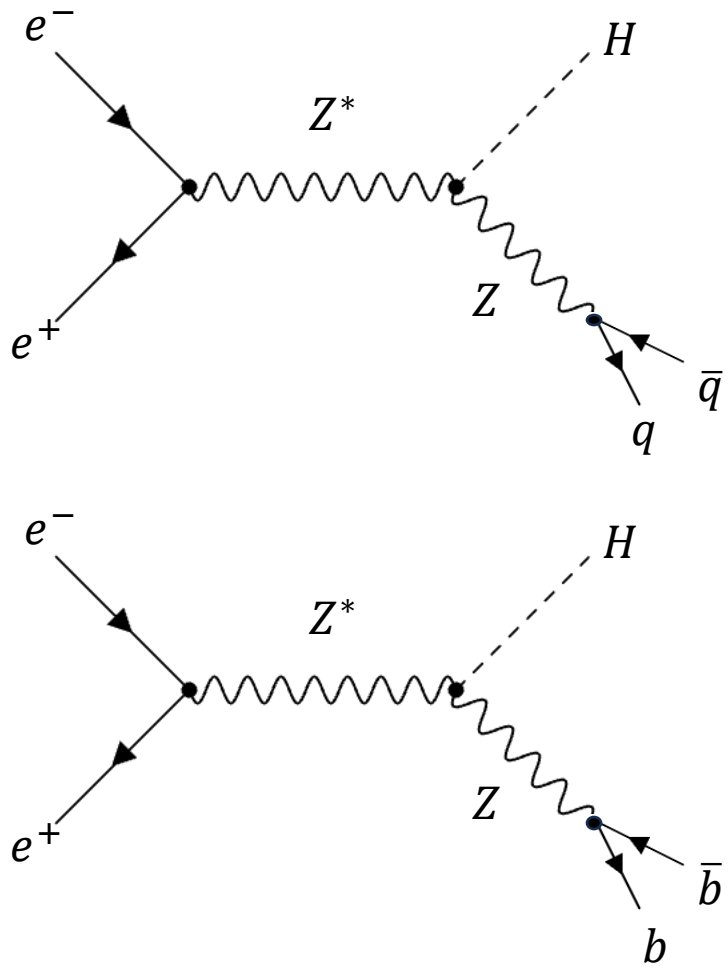
At 68% Confidence Level

- $\mu\mu \sim \pm 7 * 10^{-5}$
- $ee \sim \pm 8.5 * 10^{-5}$

Updates for Today:

- Include $H \to X$, $Z \to q\bar{q}$ $(u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c})$ and $Z \to b\bar{b}$.
  - Separation is done for background rejection
- Describe selection for hadronic final state.
- Present preliminary combined likelihood fit for

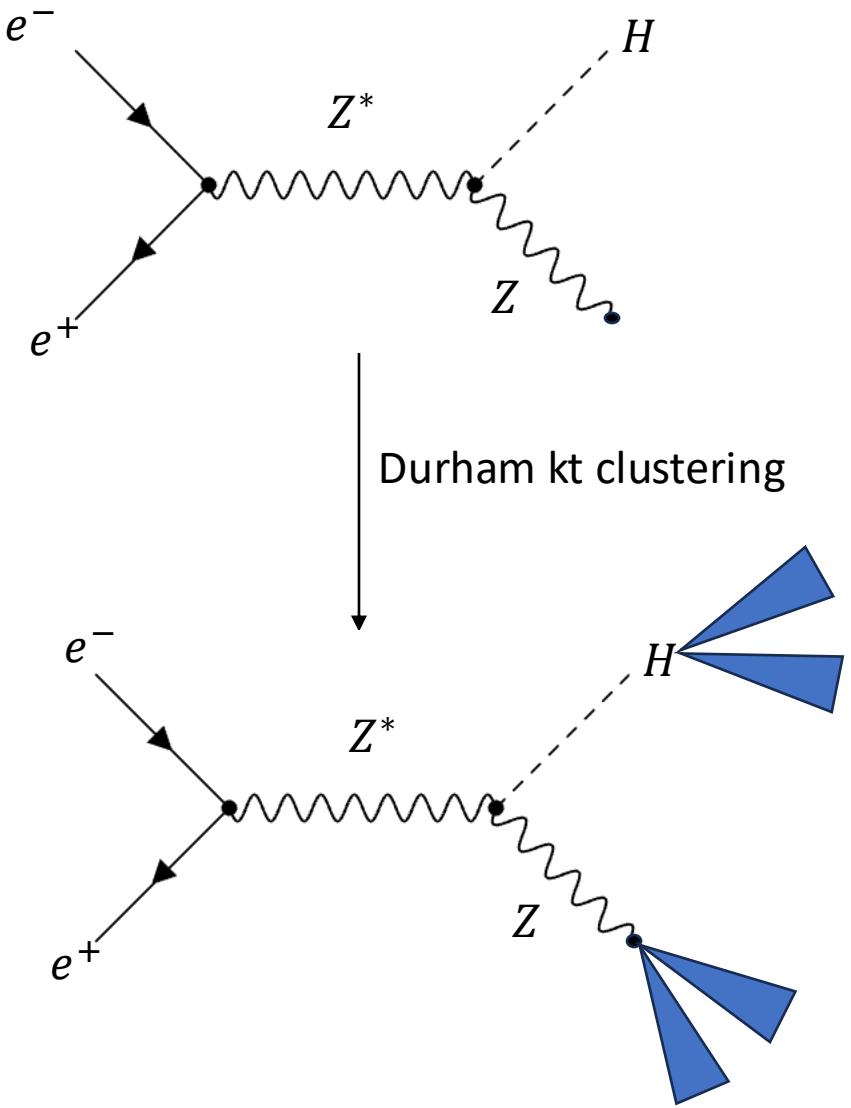
  $Z \to q\bar{q}, bb, ee, \mu\mu$ (~76%).



Event Selection:

- Cut 1 and Cut 2:
  - Reject events with > 2 $e^{\pm}$ and > 2 $\mu^{\pm}$.

- Reconstruct Z from dijet system
  - (jet clustering performed by FastJet):
  - Durham kt clustering to exclusive 4 jets.
  - From all combinations of jets, select dijet candidate that minimizes:
    - $\chi^2 = 0.8(M_{Dijet} - M_Z)^2 + 0.2(M_{Recoil} - M_H)^2$
  - Enforce flavor(q) = flavor($\bar{q}$)

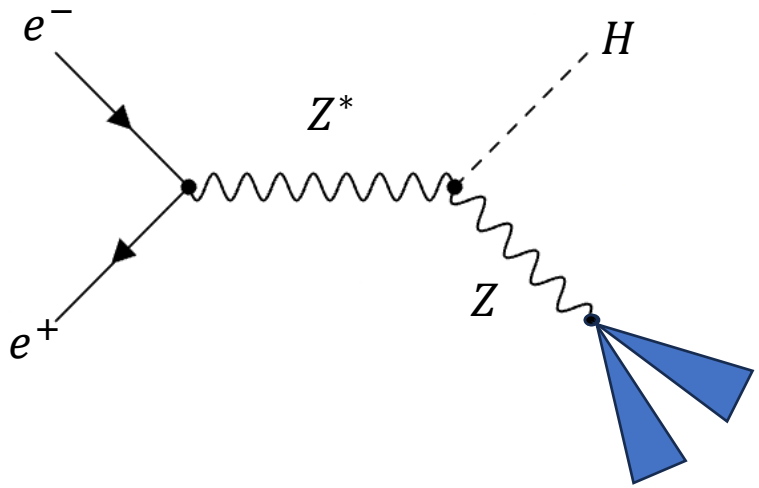


Reconstruct Z as dijet system that minimizes χ^2

Overview of $Z \rightarrow q\bar{q}$ Analysis:

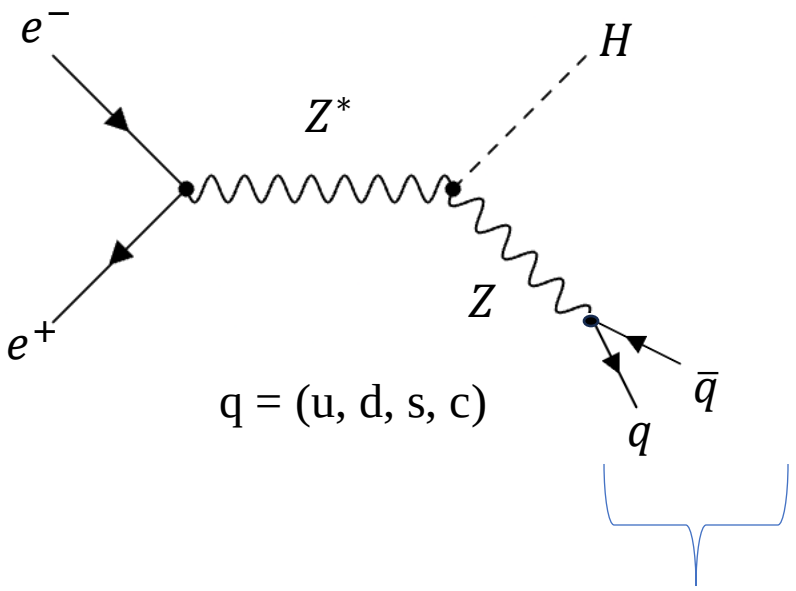
- Selection is determined by scores assigned by ParticleNet (arXiv:1902.08570)

- Each jet assigned a score for each flavor.
  - Flavors = Q (u or d), S, C, B, and G.
- Scores range from [0, 1].



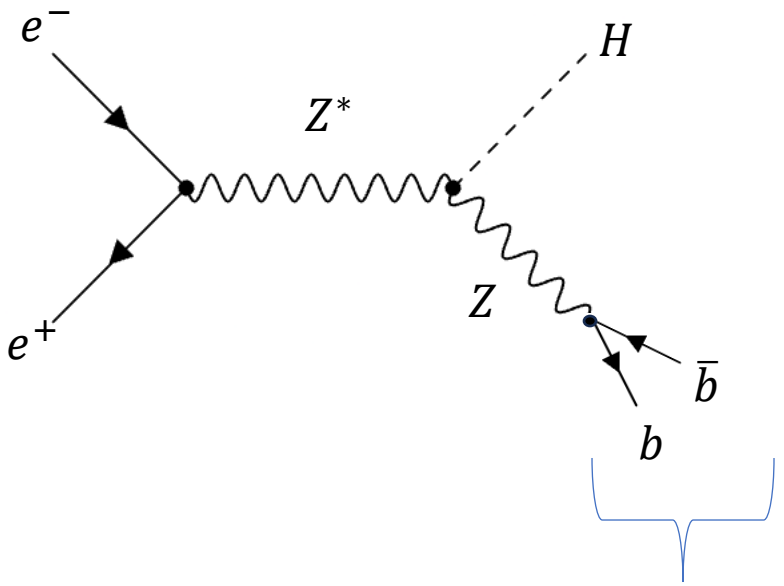
Overview of $Z \rightarrow q\bar{q}$ Analysis:

Split analysis into two channels based on the sum of the B-scores:



q = (u, d, s, c)

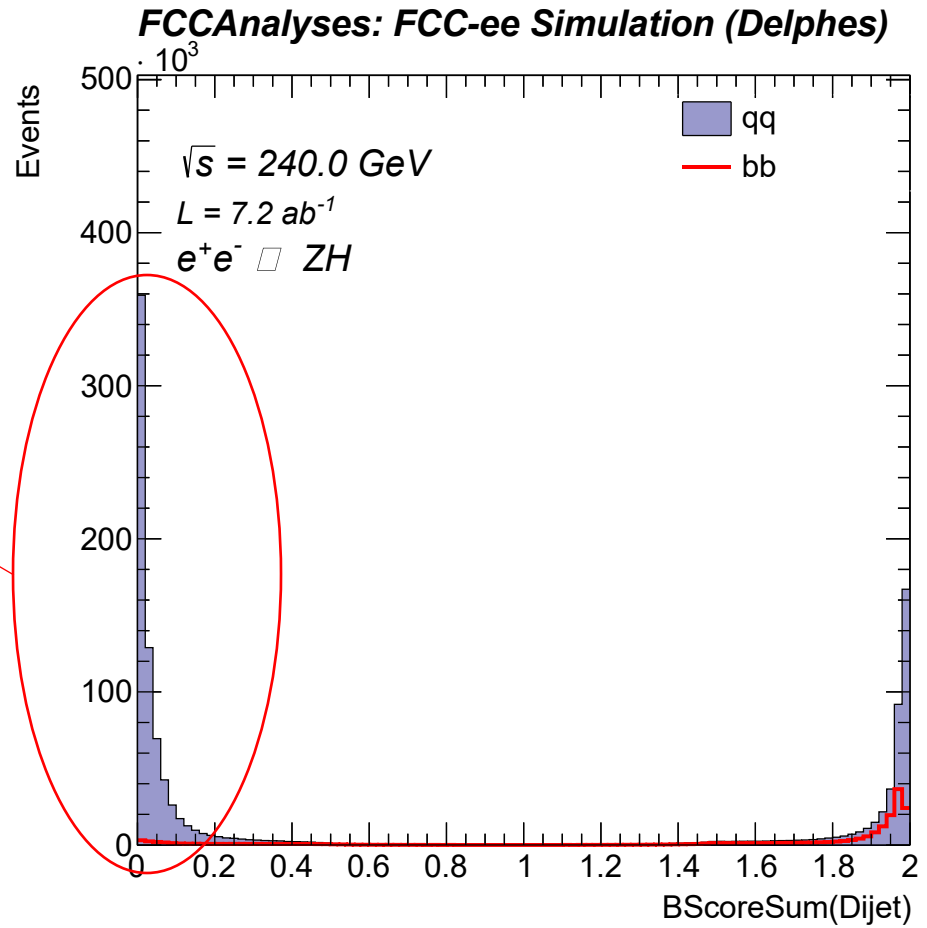
Sum of B-Scores < 1.7



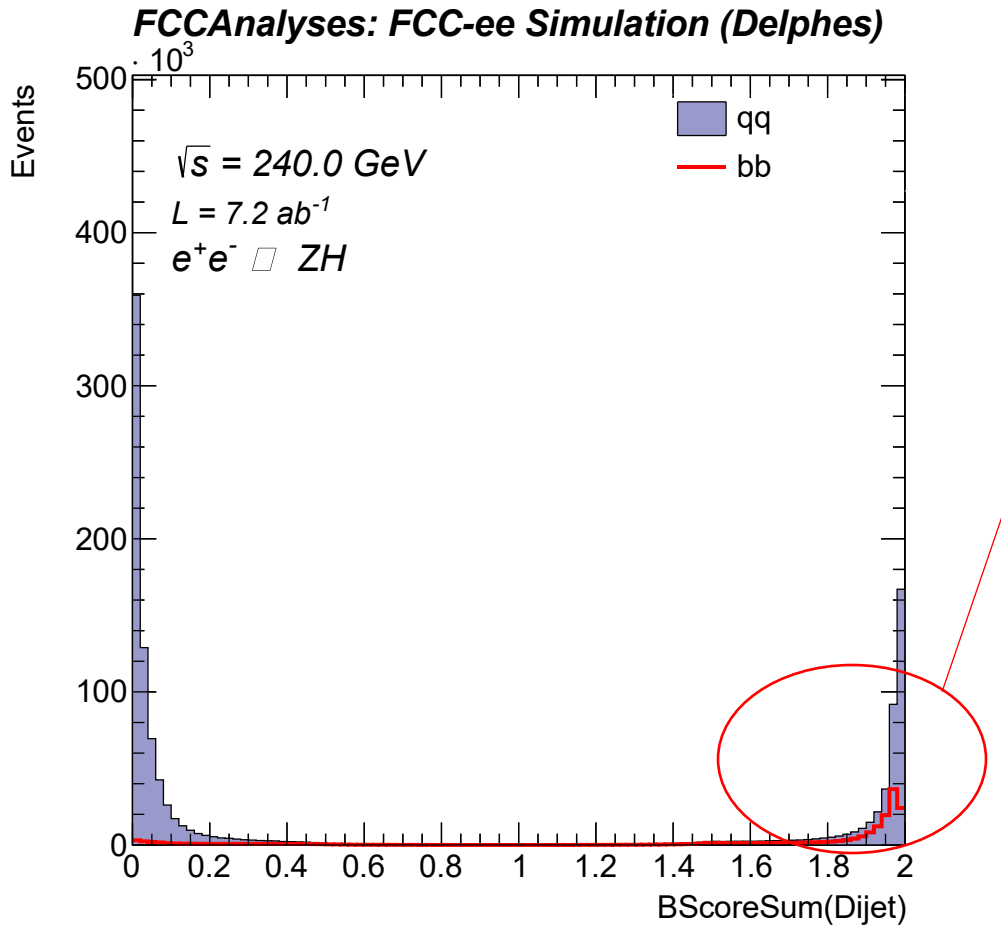
Sum of B-Scores ≥ 1.7

Overview of $Z \rightarrow q\bar{q}$ Analysis:

qq Analysis



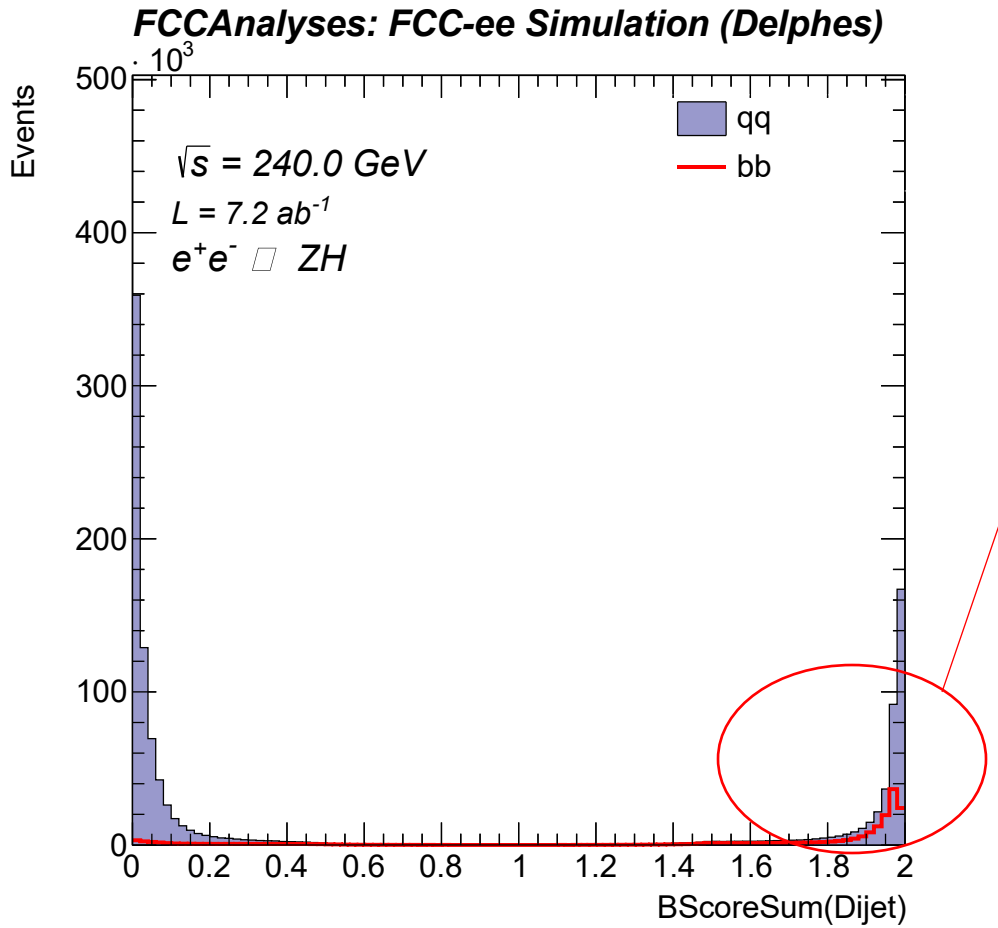
Overview of $Z \rightarrow q\bar{q}$ Analysis:



bb Analysis

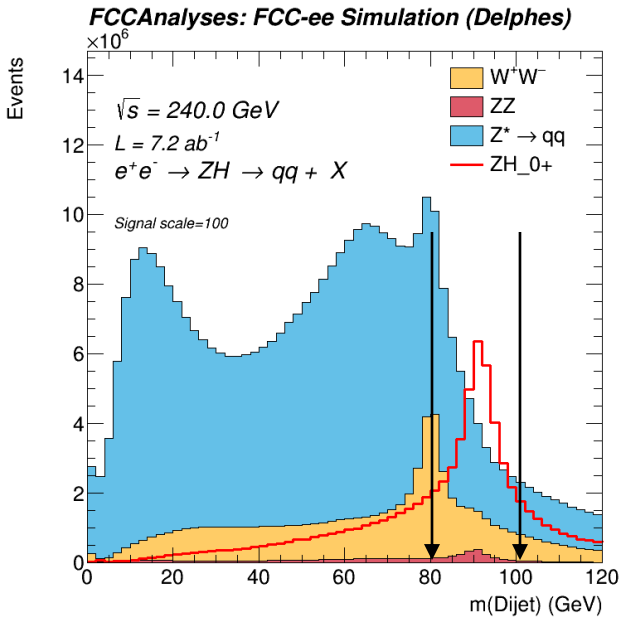
Note: No cuts have been applied yet besides lepton filter and dijet flavor enforcement.

Overview of $Z \rightarrow q\bar{q}$ Analysis:

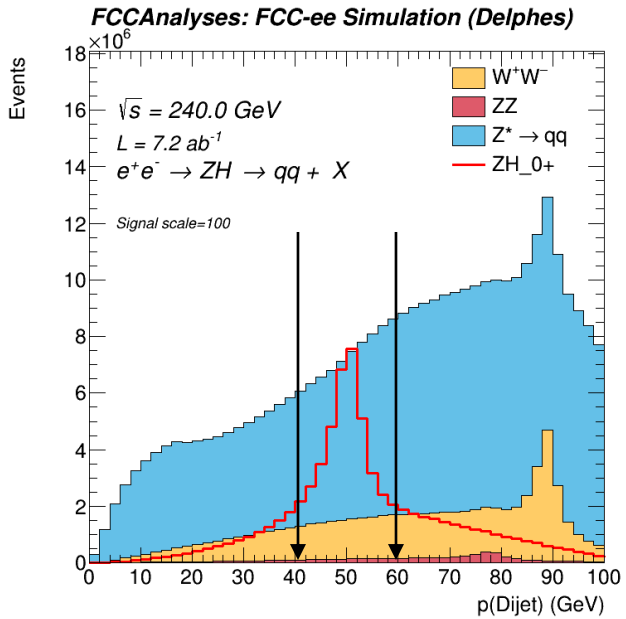


qq on the right mostly come from Higgs->bb.

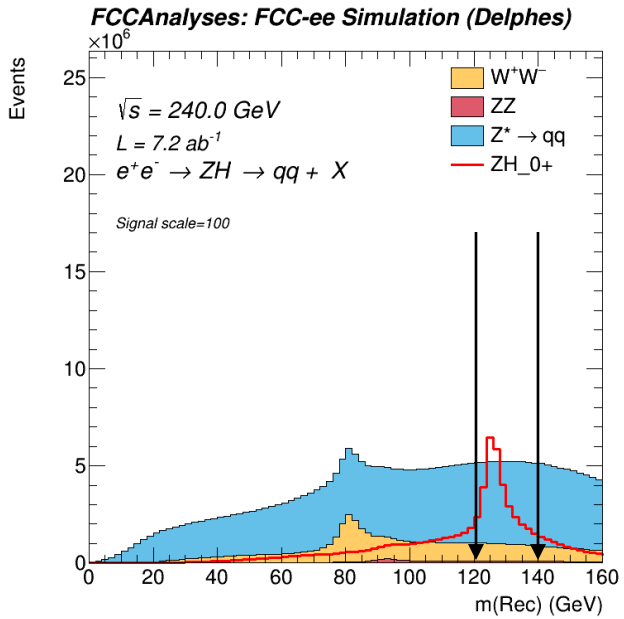
qq Event Selection (N-1 Plots):



$80 < M_{dijet} < 100$

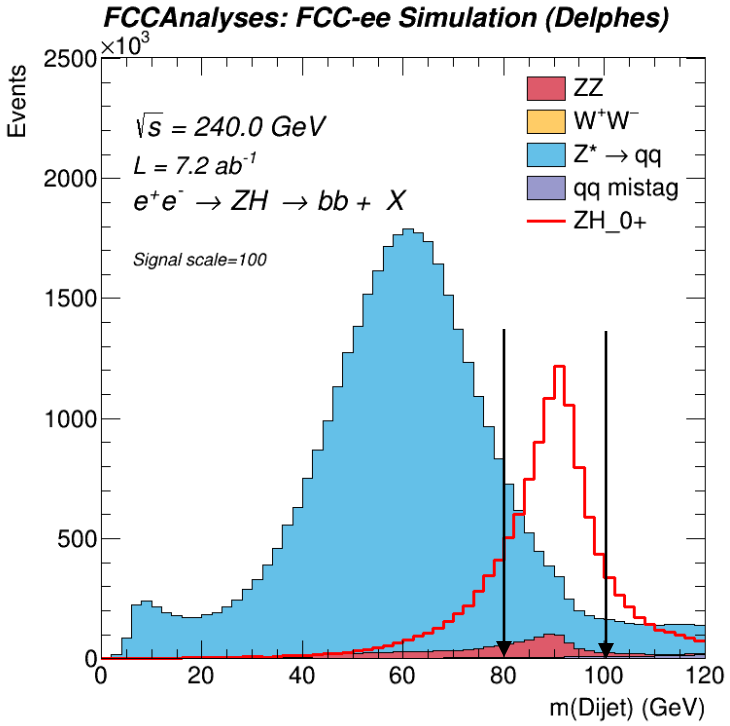


$40 < P_{dijet} < 60$

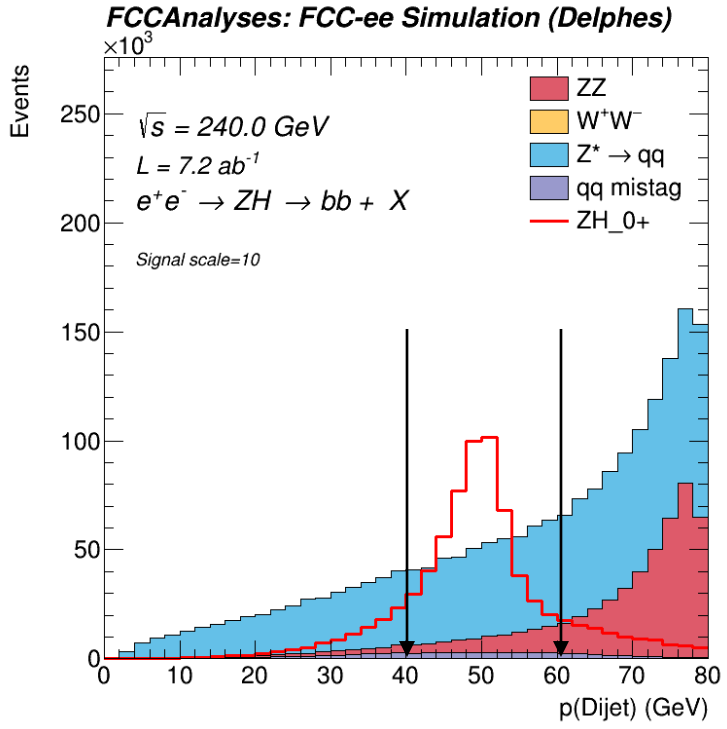


$120 < M_{recoil} < 140$

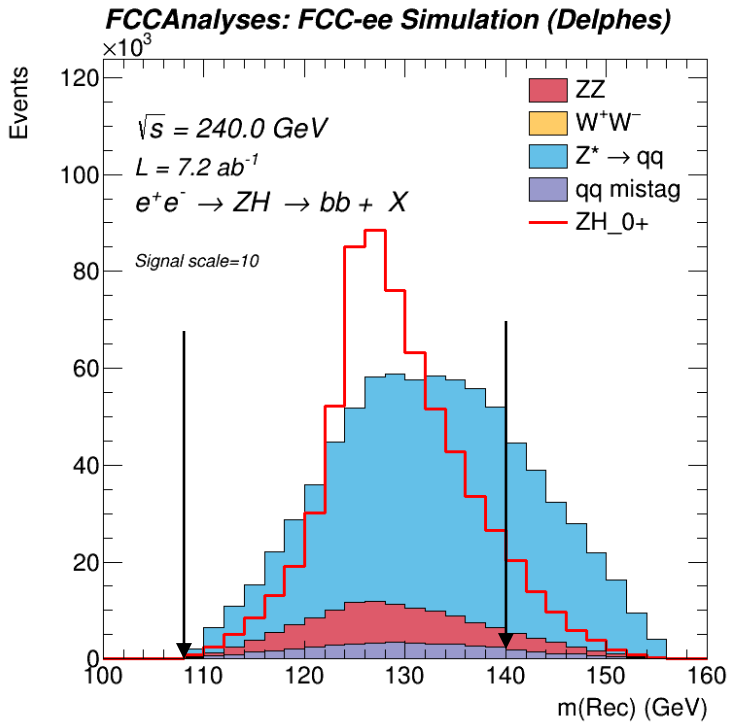
bb Event Selection (N-1 Plots):



$80 < M_{dijet} < 100$

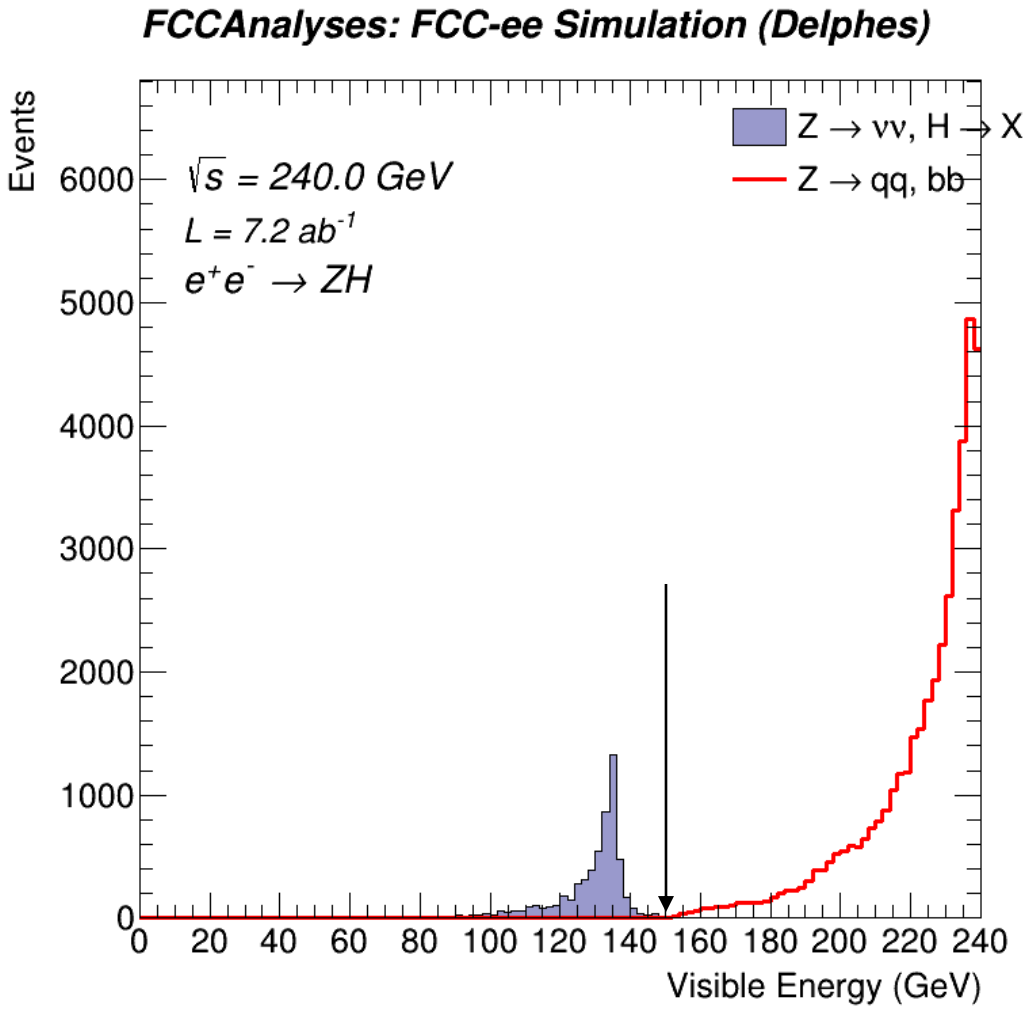


$40 < P_{dijet} < 60$



$110 < M_{recoil} < 140$

Event Selection:



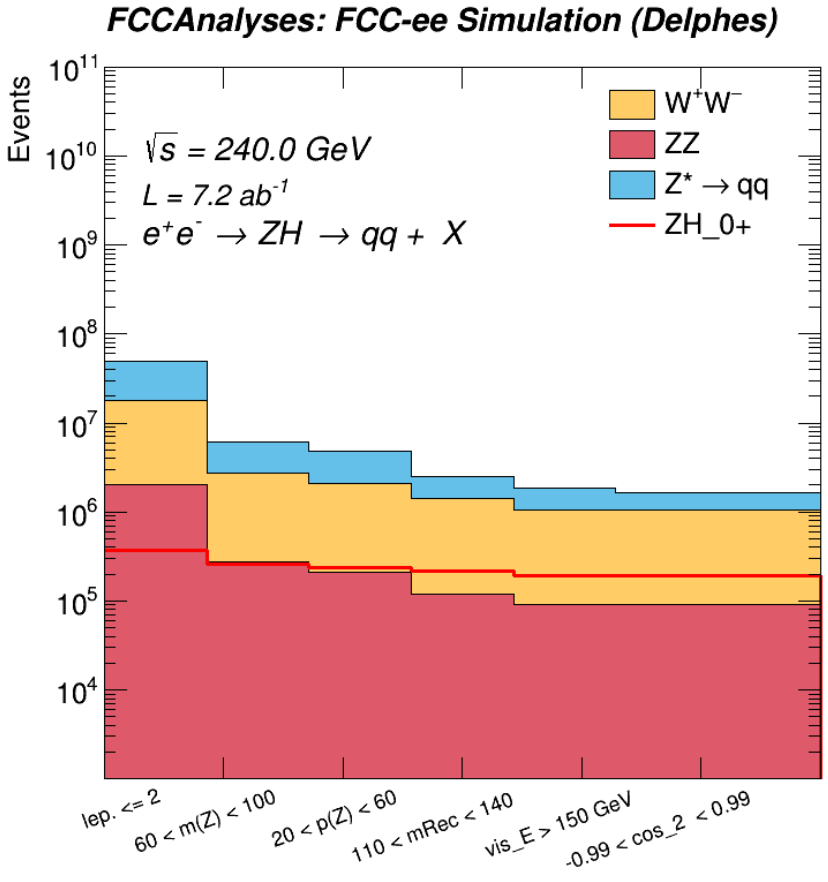
Analysis Cutflow:

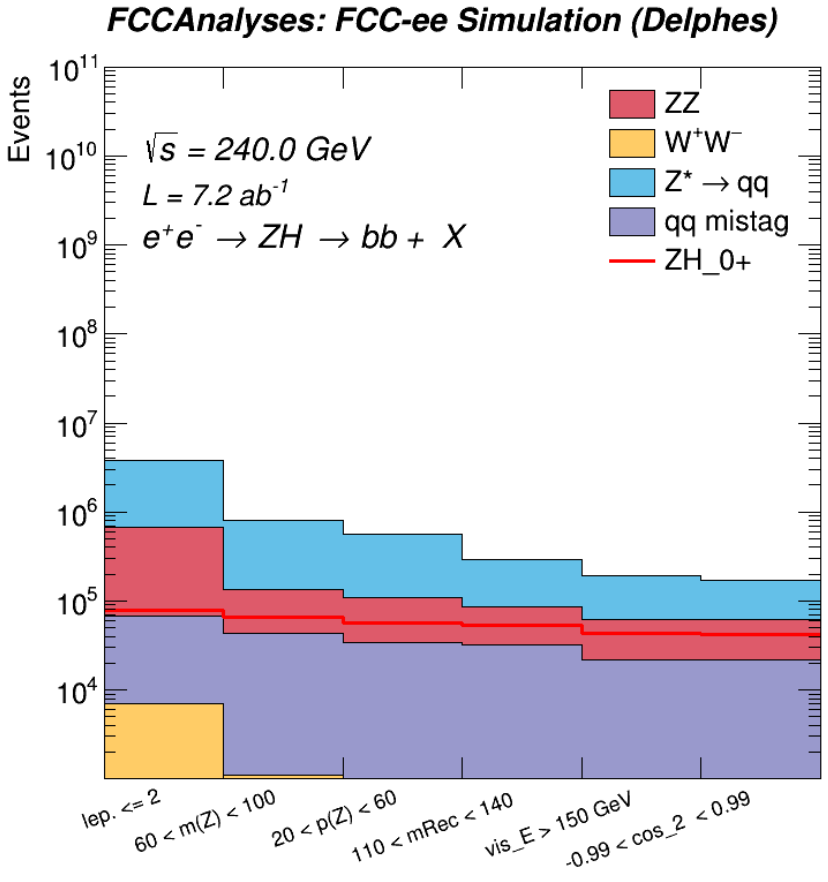
qq:

- Sig:Bkg ~ 0.12
- Selection Efficiency: ~15%

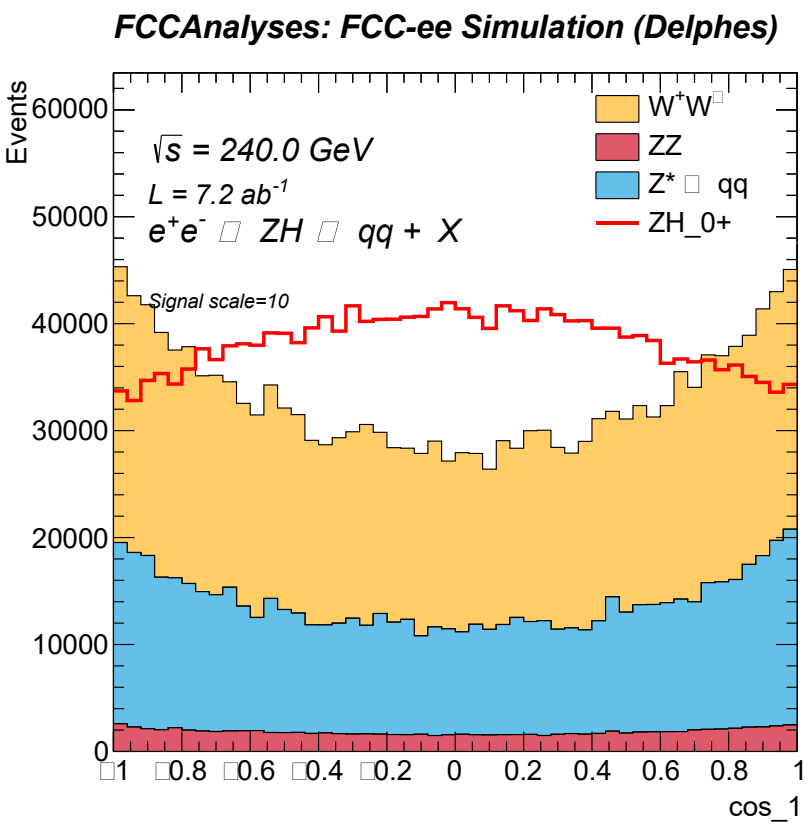
bb:

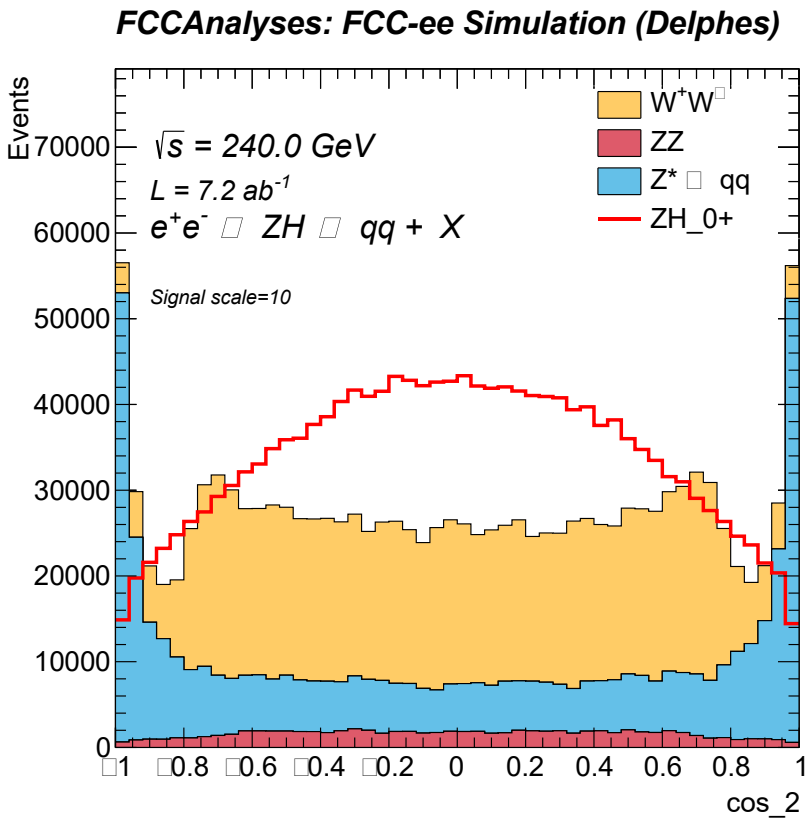
- Sig:Bkg ~ 0.24
- Selection Efficiency: ~19%

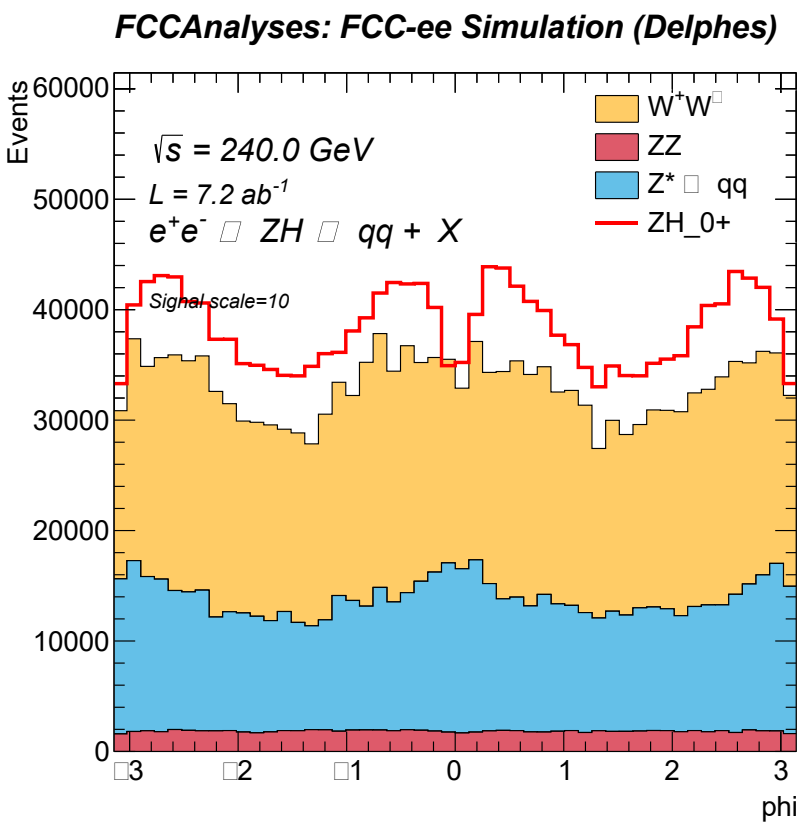




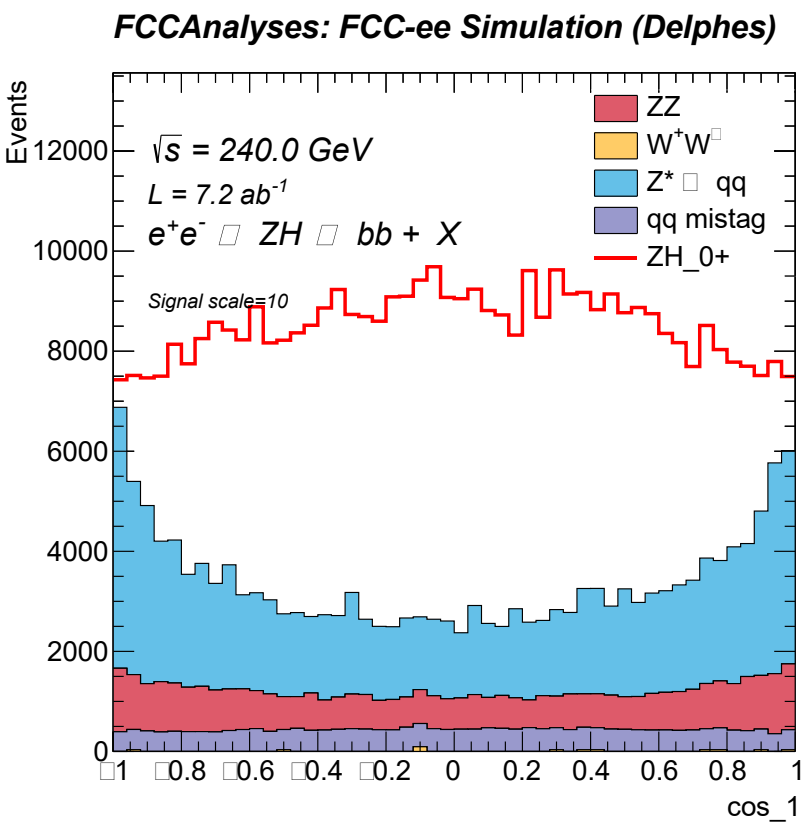
qq-Template Observables:

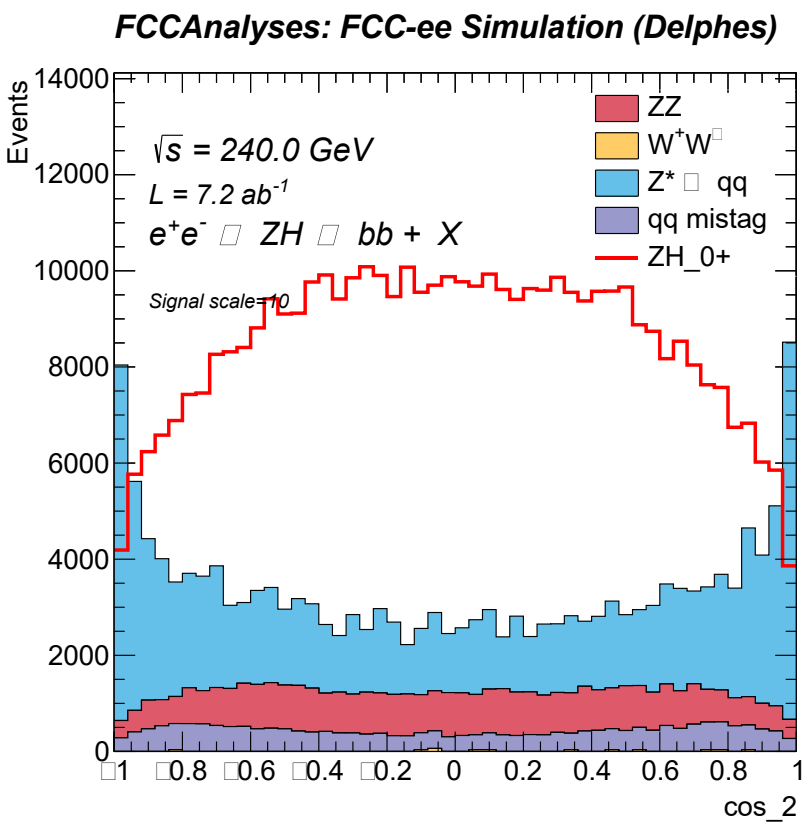


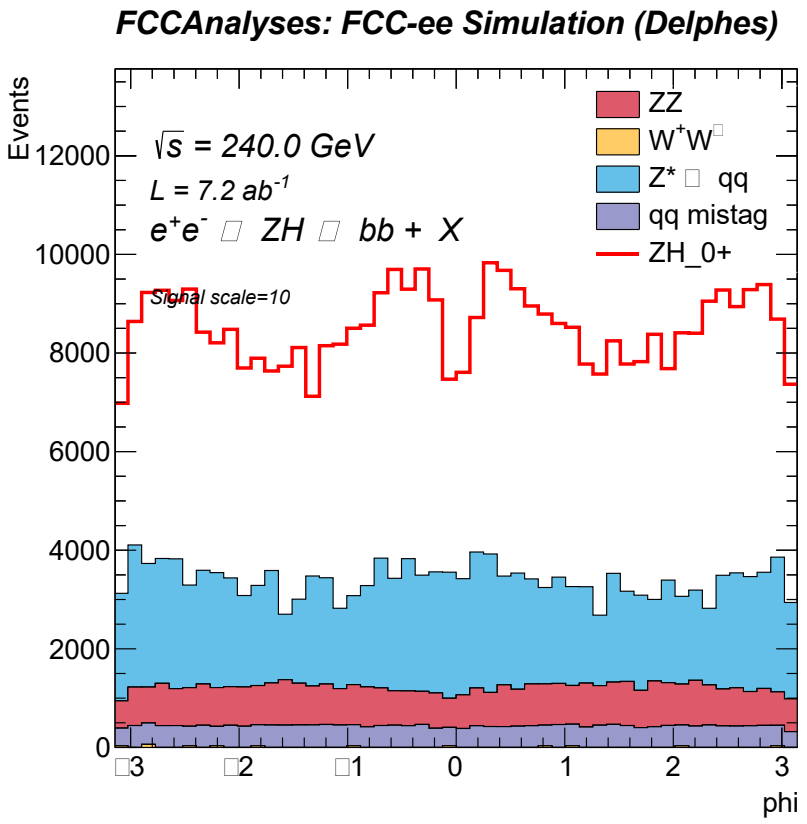




bb-Template Observables:



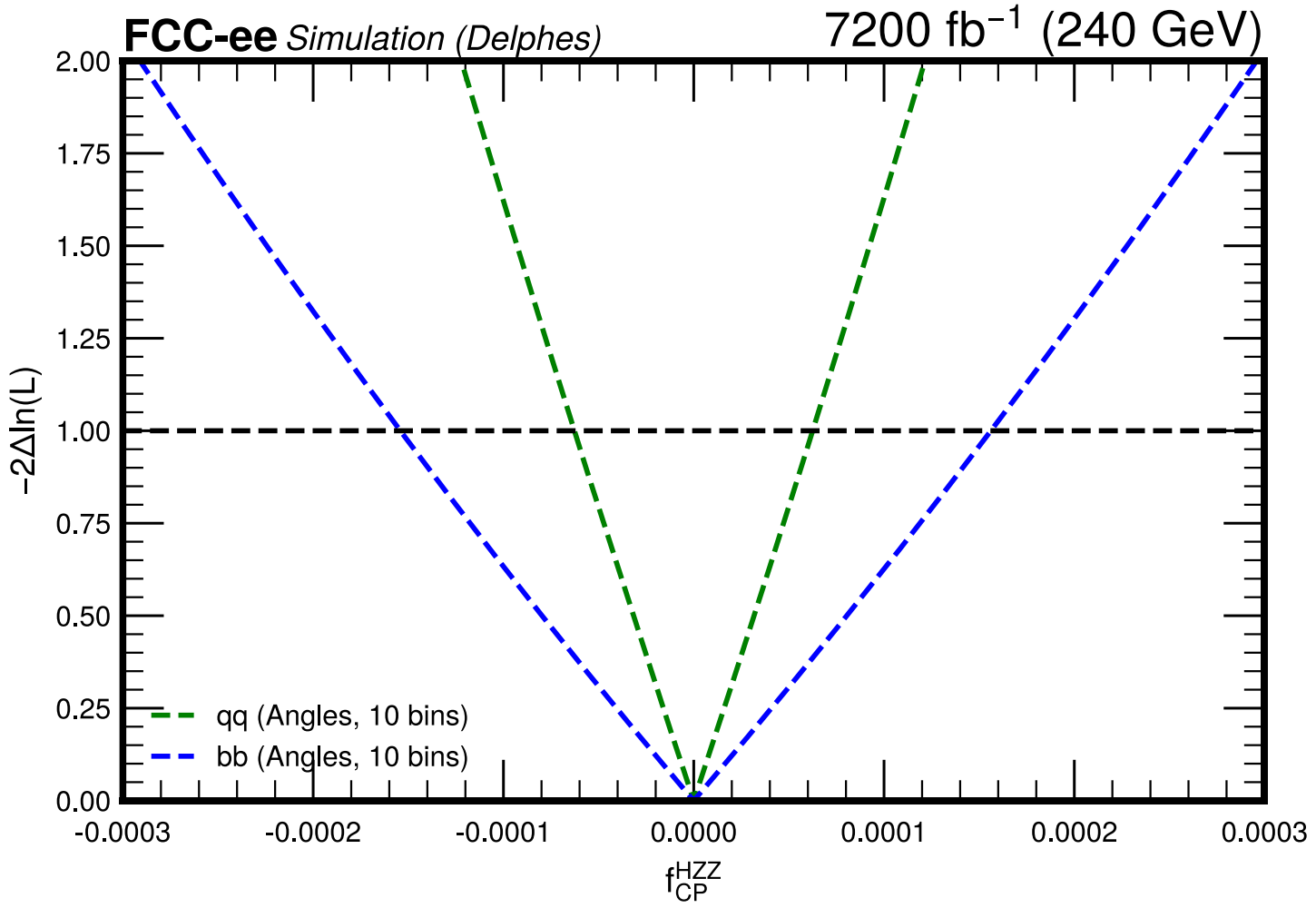




Hadronic Template Fits:

- 3D Histogram filled with $\cos\theta_1, \cos\theta_2, \Phi$ on each axis.
- 10 bins/ axis, 1000 bins total.
- $0^+, 0^-$, and interference templates created with signal.

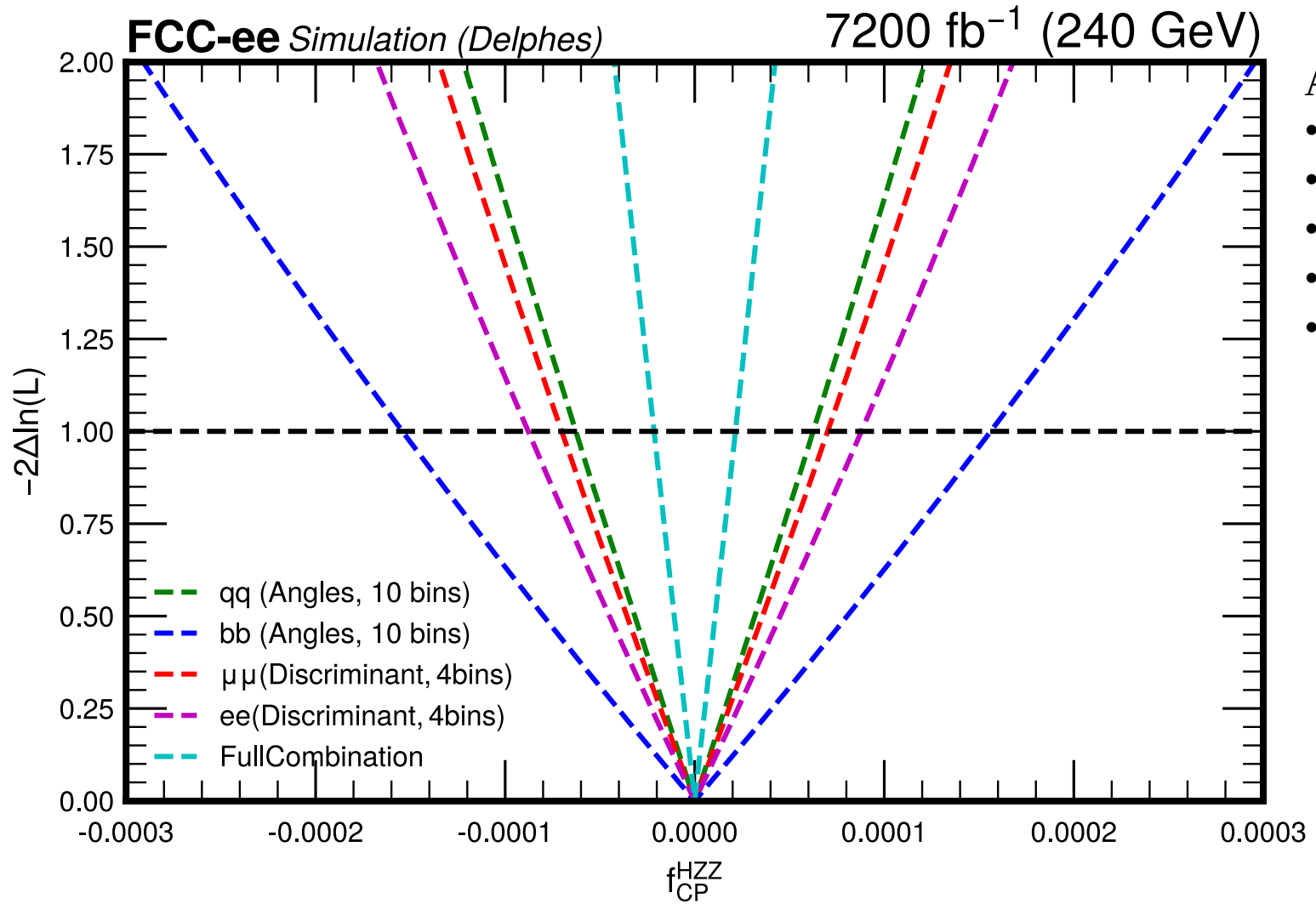
Likelihood Fit with Hadronic Templates:



At 68% Confidence Level

- $qq\sim \pm 6 * 10^{-5}$
- $bb\sim \pm 1.5 * 10^{-4}$

Progression of fits with Reconstructed Signal, $Z \longrightarrow q\bar{q}, b\bar{b}, ee, \mu\mu$:



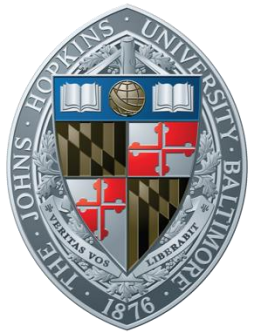
At 68% Confidence Level

- $qq \sim \pm 6 * 10^{-5}$
- $bb \sim \pm 1.5 * 10^{-4}$
- $\mu\mu \sim \pm 7 * 10^{-5}$
- $ee \sim \pm 8.5 * 10^{-5}$
- Combined~ $\pm 2 * 10^{-5}$

Conclusions

- Combined result represents ~79% of Z decays.

- Need to incorporate more statistics on WW and $Z^* \rightarrow q\bar{q}$ backgrounds.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1876

Backup