Institute of Experimental Particle Physics

Karlsruher Institut für Technologie

$H \to \tau\tau$ MEASUREMENTS AT FCC-ee IN THE ZH CHANNEL AT 240 GeV

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$H \to \tau\tau$ CROSS-SECTION

Targets and news

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- Relative uncertainty of $H \to \tau\tau$ **cross-section** at $\sqrt{s} = 240$ GeV at FCC-ee
  ➜ already presented, updates in this presentation
  - **Explicit tau reconstruction** (from Maria Cepeda):
    - Found an issue with the cosine of the angle between the two taus
    - Updated the analysis consequently
  - **ML-based tau reconstruction** (FCC PNet jet tagger):
    - Parallel analysis to see which reconstruction would work better
    - Redefined some cuts and retrained BDTs

- CP violation in the same channel ➜ studies ongoing

Results

- **Combine shape-based fit** arXiv:2404.06614 with freely floating processes
  - Cut-based analysis: M_{recoil} for $Z \to \ell\ell$ and $Z \to qq$, M_{vis} for $Z \to \nu\nu$
  - BDT analysis: M_{recoil} for $Z \to \ell\ell$, BDT score above 0.5 for $Z \to qq$ and $Z \to \nu\nu$

- Relative uncertainty (68% CL) of $H \to \tau\tau$ cross section at $\sqrt{s}$=240 GeV, $\mathscr{L}$=10.8 ab^{-1}

	Explicit tau reconstruction	**PNet tau reconstruction**
Cut-based analysis	±1.17 %	±0.94 %
BDT analysis 200 trees	±1.06 %	±0.86 %
BDT analysis 1000 trees	±1.11 %	±0.85 %

Next steps

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- Reprocess analysis with the tagger as there were some bugs with jet clustering
- Study exclusive jet clustering based on the category selected, both with explicit and from PNet tau reconstruction (+ cut-based and BDT selection)
- Optimize the results:
  - Tau efficiencies of all these combinations
  - (Optional) optimize jet clustering parameters
  - (Optional) optimize BDT size
  - (Optional) apply NN for selection

$H \rightarrow \tau\tau$ CP

General info

- Working with gen level information at the moment to
  - Figure out if tau spin is properly propagated in the samples
  - Understand the EFT behaviour and what we expect to see

- Mapping of EFT Yukawa operator to kappa framework (commonly used in analyses)

$$\mathscr{L}_{\text{Yukawa},\kappa} = -\sum_f \frac{y_f^{\text{SM}}}{\sqrt{2}} \kappa_f \bar{f} \left(\cos\phi_f + i\gamma_5 \sin\phi_f\right) f \,,$$

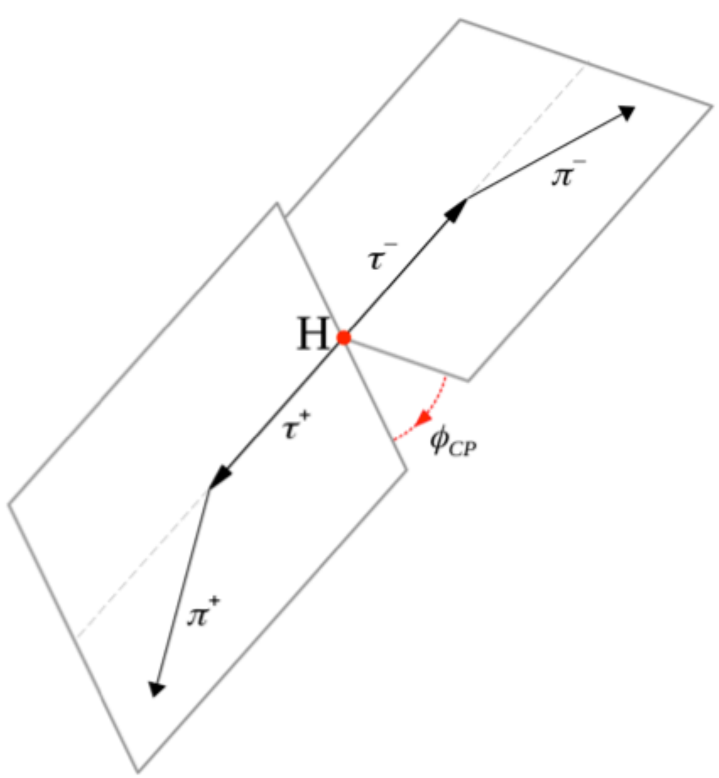
$$C_{fH,ij} = \text{Re}[C_{fH,ij}] + i\,\text{Im}[C_{fH,ij}] \equiv C_{fH+,ij} + iC_{fH-,ij} \,.$$

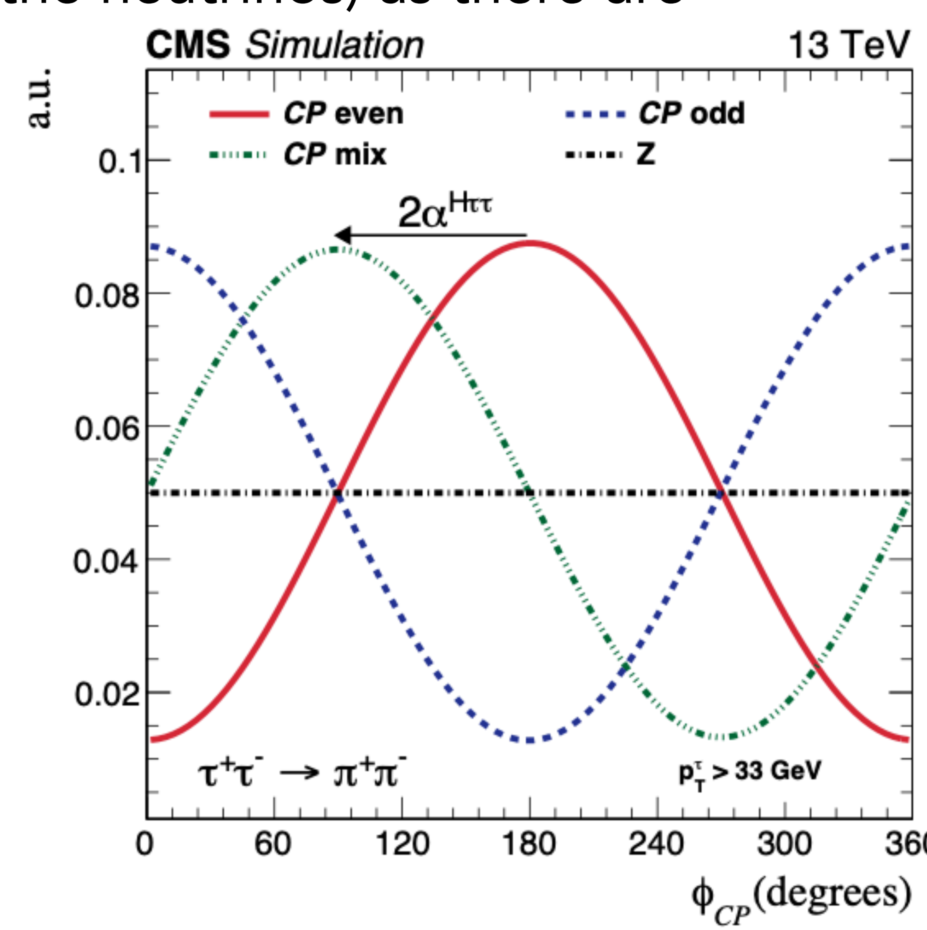
$$\kappa_f \cos\phi_f \doteq 1 - \frac{v}{\sqrt{2}m_f} \frac{v^2}{\Lambda^2} C_{fH+} \,, \qquad \kappa_f \sin\phi_f \doteq - \frac{v}{\sqrt{2}m_f} \frac{v^2}{\Lambda^2} C_{fH-} \,.$$

Gen information

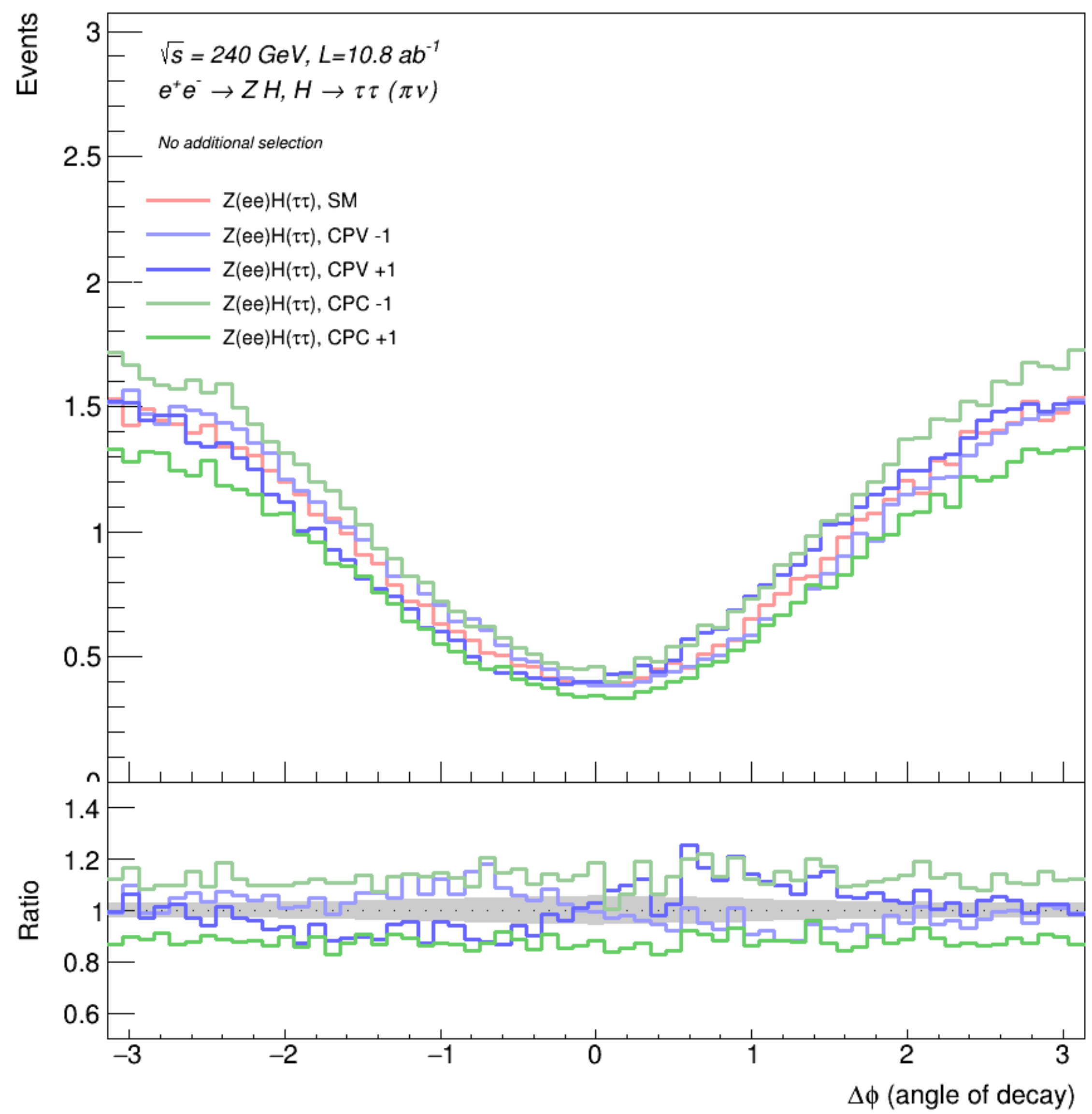
https://arxiv.org/pdf/2110.04836

- The general idea of all the reconstruction methods is to get the **angle between the decay planes** of the tau in the di-tau rest frame
- We can reconstruct the planes directly by knowing the tau and daughters' 4-momenta
- All vectors are boosted in the Higgs rest frame
- We take the direction of the τ^- as reference to get the value of ϕ_{CP}
- Can't use all decay modes (getting the plane with the neutrinos) as there are "destructive" effects overall



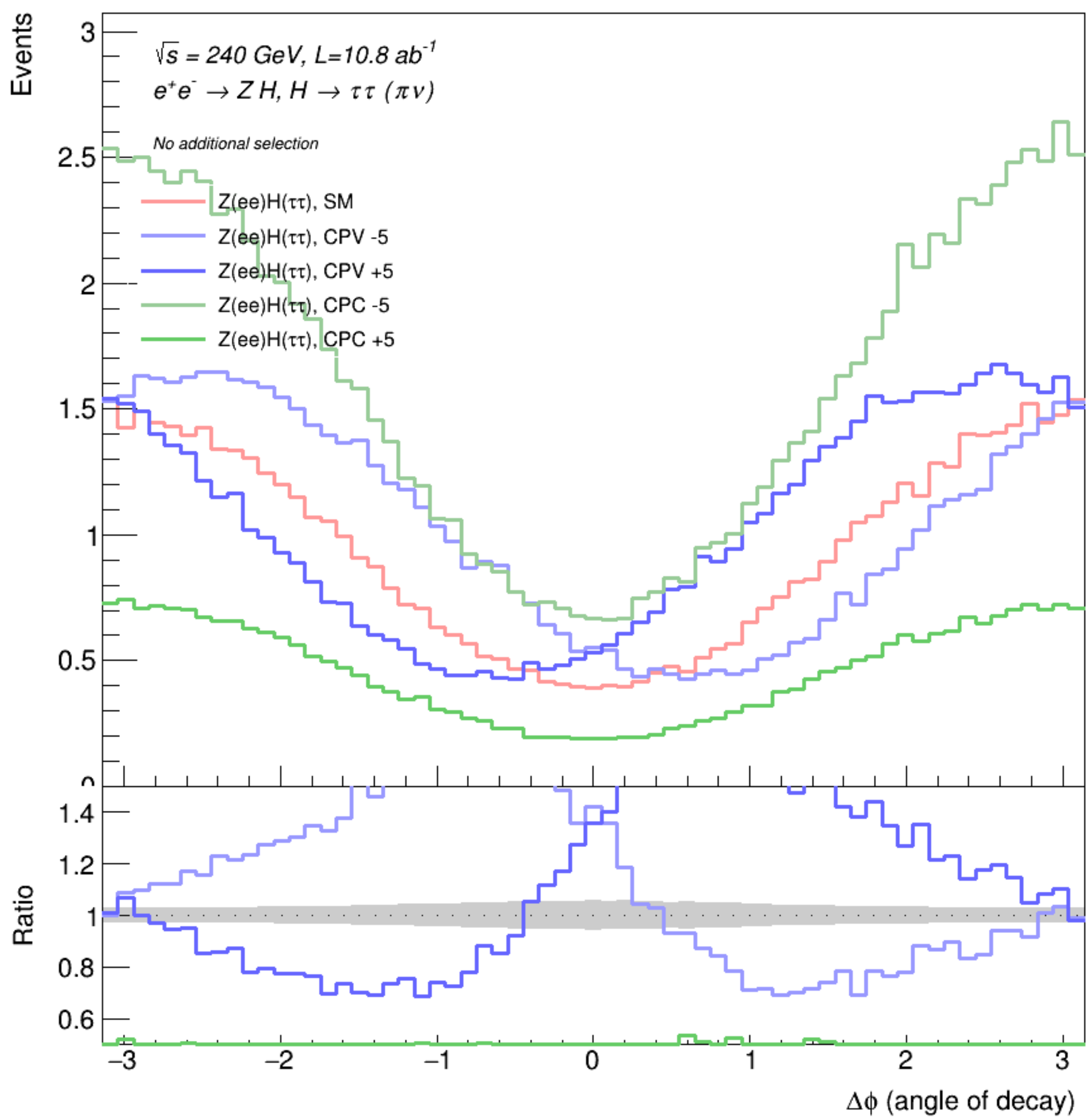


Gen information



- Tested Wilson Coefficients ± 1 for the operators $Re\{\mathcal{O}_{eh}\}, Im\{\mathcal{O}_{eh}\}$ in SMEFT@LO under the *topU3L* flavor assumption
- Only for $\tau \to \pi\nu$, everything is scaled to the appropriate cross-section
- There is a tiny phase shift with CP-violating samples while CP-conserving ones only have a cross-section difference with SM

Gen information



- Tested Wilson Coefficients ±5 for the operators $Re\{\mathcal{O}_{eh}\}, Im\{\mathcal{O}_{eh}\}$ in SMEFT@LO under the *topU3L* flavor assumption
- Only for $\tau \to \pi\nu$, everything is scaled to the appropriate cross-section

Gen information

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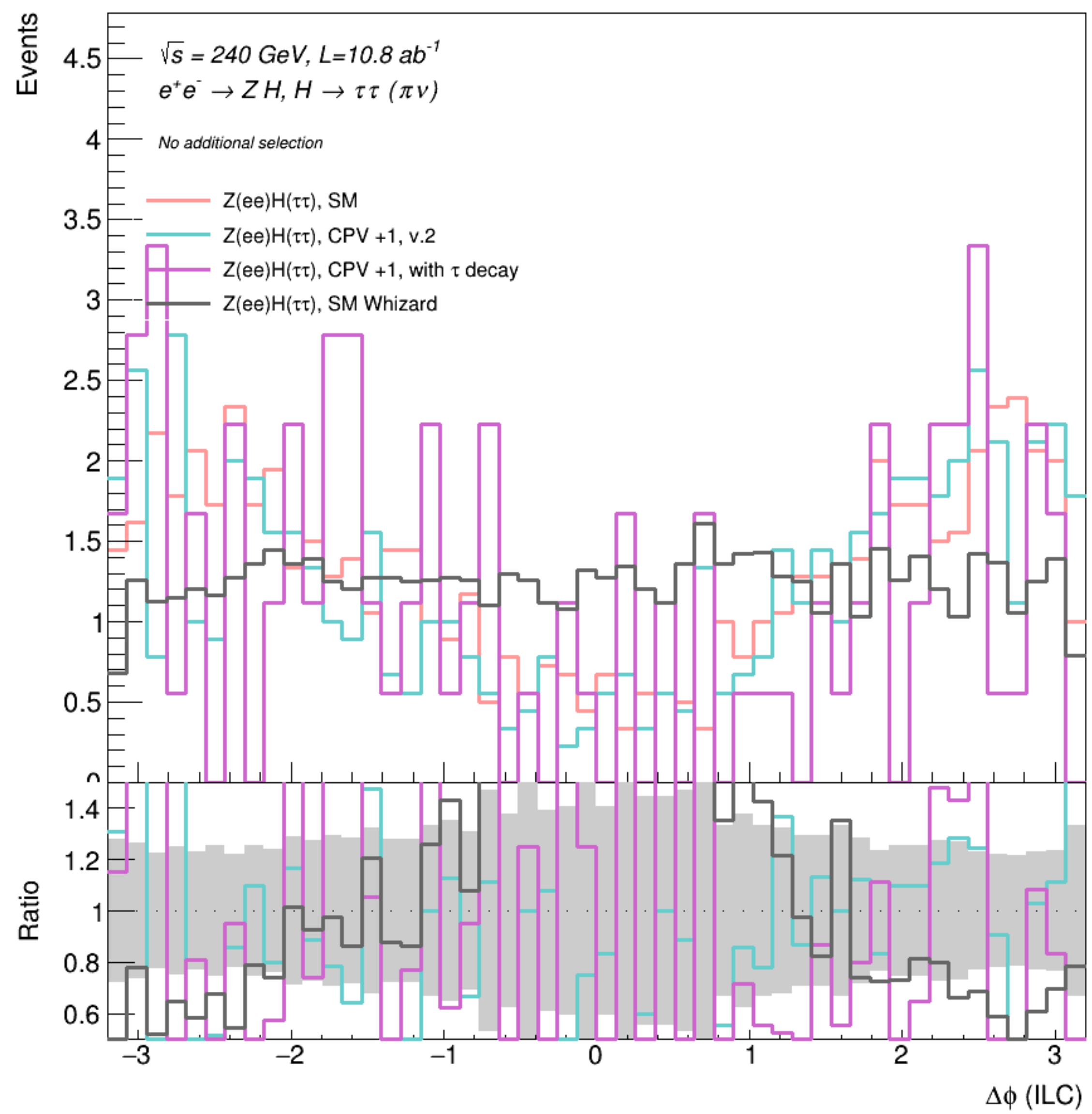


- Low statistic for EFT samples with different ways of decaying taus but seems to be similar enough
- Whizard sample does not propagate spin correlations very clearly (mostly flat)

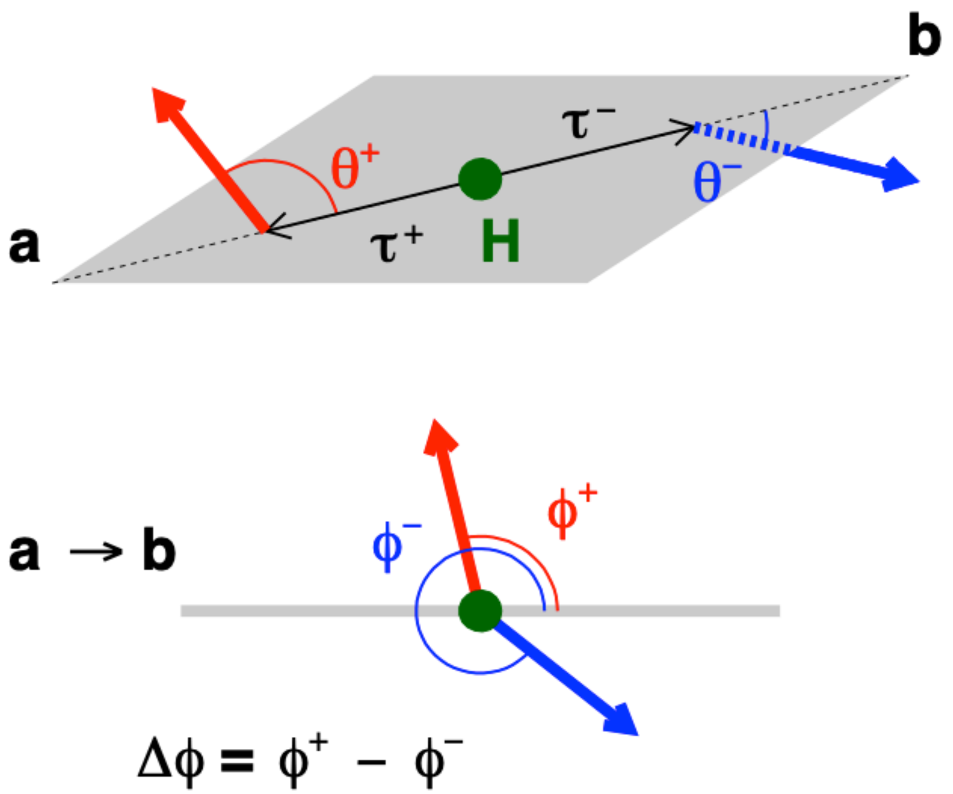
ILC method

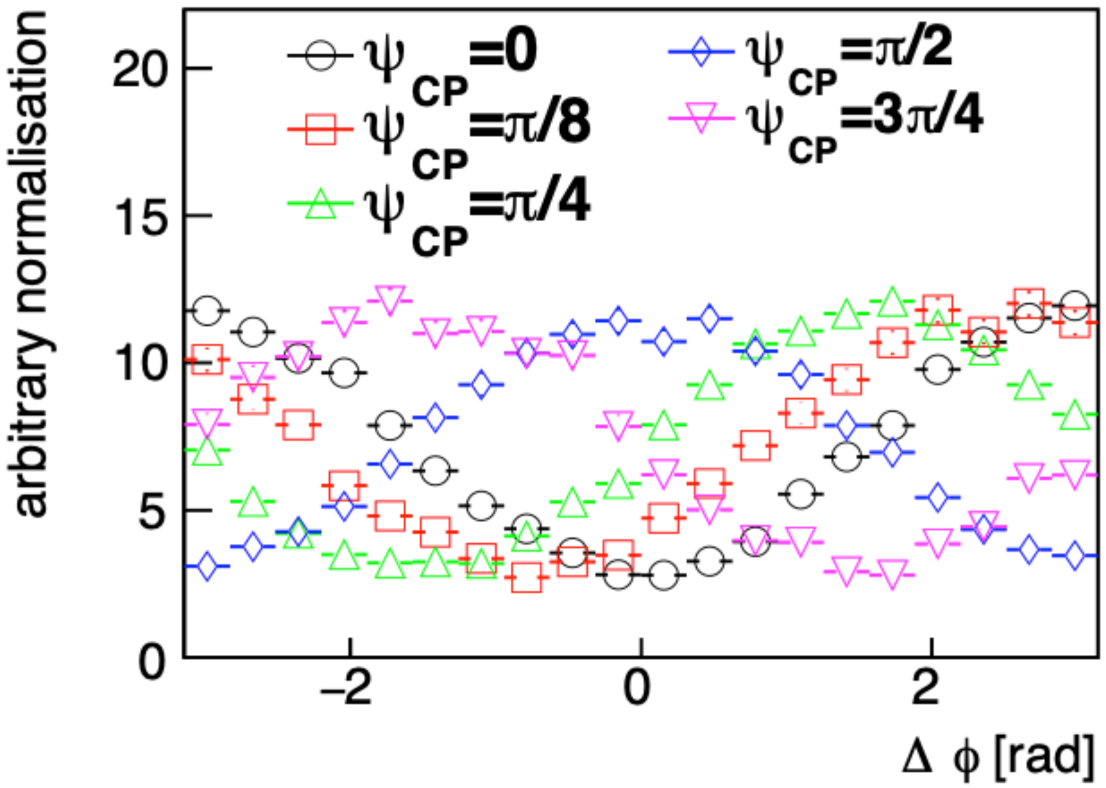
https://arxiv.org/pdf/1804.01241

- Same idea but using polarimeters (mostly for the reconstruction)
- The 4-momenta are boosted in the respective tau rest frame

$$\mathbf{h}(\tau^{\pm} \to \pi^{\pm}\nu) \propto \mathbf{p}_{\pi^{\pm}} \quad (6)$$

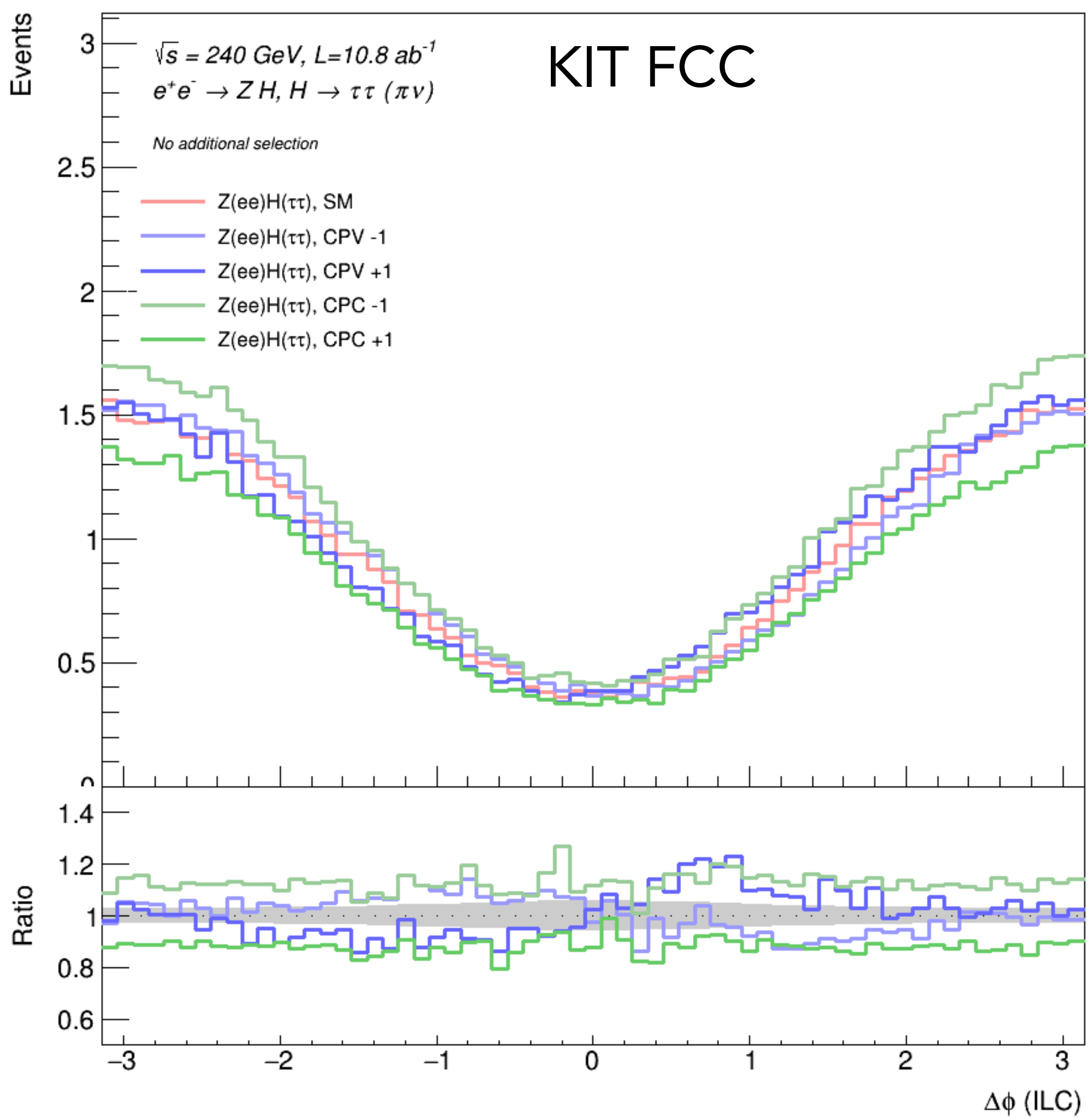
$$\mathbf{h}(\tau^{\pm} \to \pi^{\pm}\pi^{0}\nu) \propto m_{\tau}(E_{\pi^{\pm}} - E_{\pi^{0}})(\mathbf{p}_{\pi^{\pm}} - \mathbf{p}_{\pi^{0}}) + \frac{1}{2}(p_{\pi^{\pm}} + p_{\pi^{0}})^2 \mathbf{p}_{\nu}, \quad (7)$$

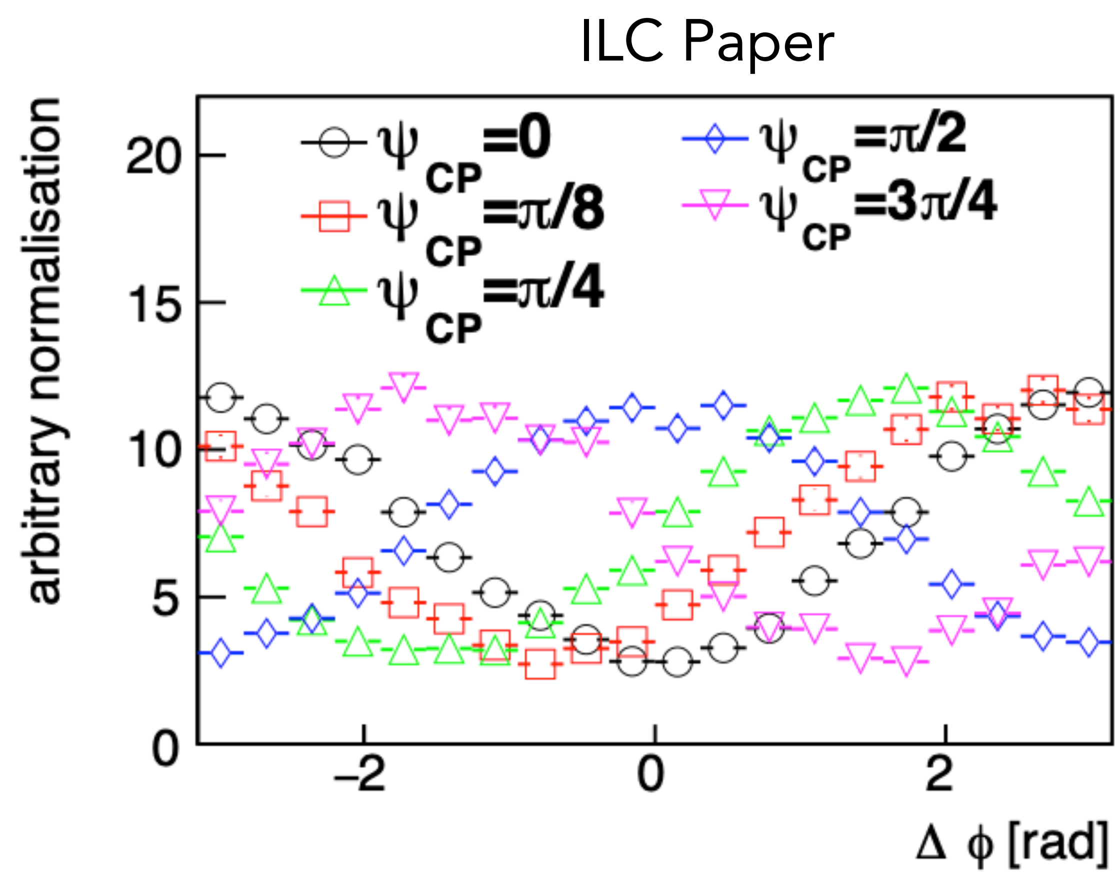




- In the ILC publication, samples with varying Higgs CP properties were simulated by changing the spin correlations applied in the decay of the τ pair by means of Pythia's `HiggsH1:phiParityparameter` to describe ψCP = 0 (i.e. the SM), π/8,π/4,π/2, and 3π/4 rad - we will also test this simulation setup despite should be equivalent to the EFT approach.

ILC method





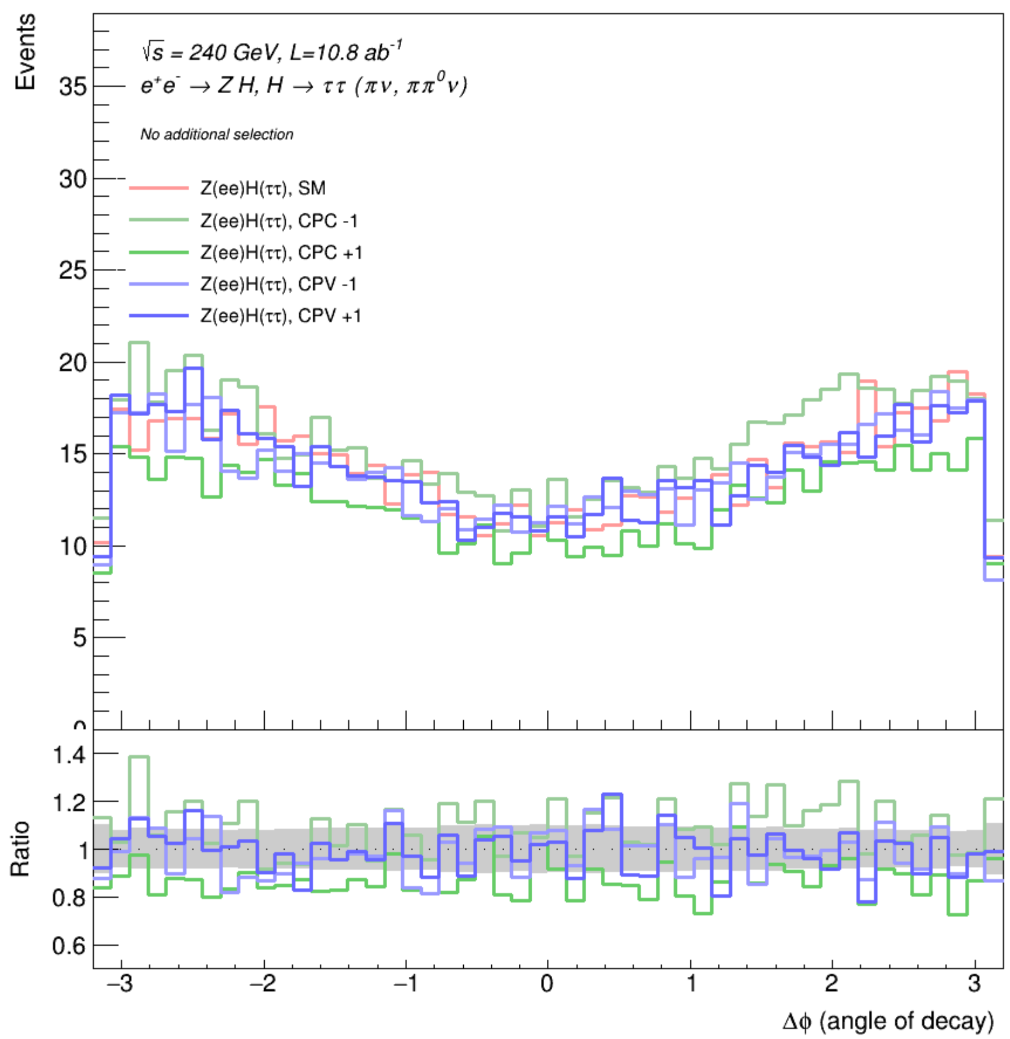
- Very similar to the true angle, the only difference is using the respective tau rest frames instead of the Higgs
- Same as before, whizard sample is flat (not plotted here)

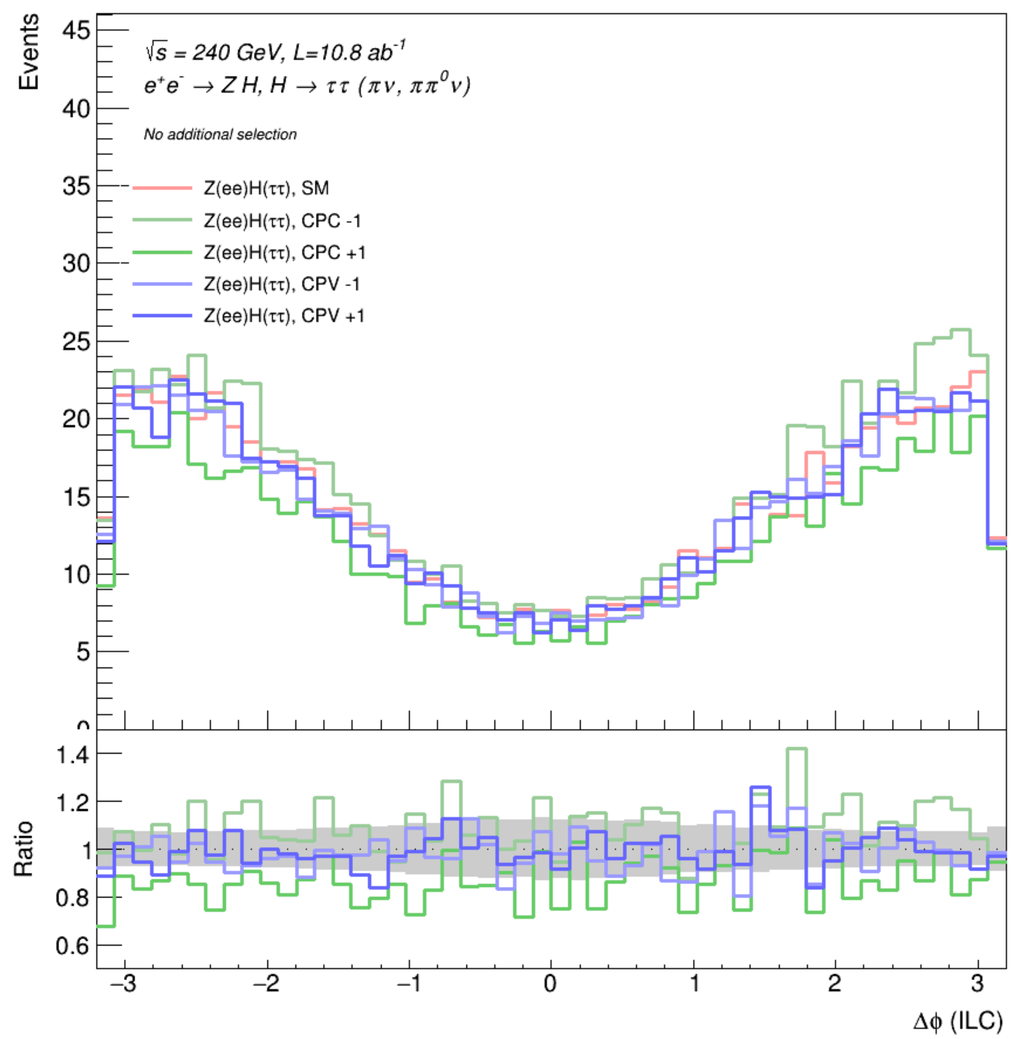
Comparison

- Combining $\tau \to \pi\nu$ and $\tau \to \rho\nu$, taking the π or the ρ $(\pi + \gamma + \gamma)$ respectively
- Samples inclusive in tau decay modes (lower statistic for specific decay modes)

angle between planes

polarimeters





- Using the polarimeter gives higher amplitude, probably optimized method

CMS reconstruction

https://arxiv.org/pdf/2110.04836

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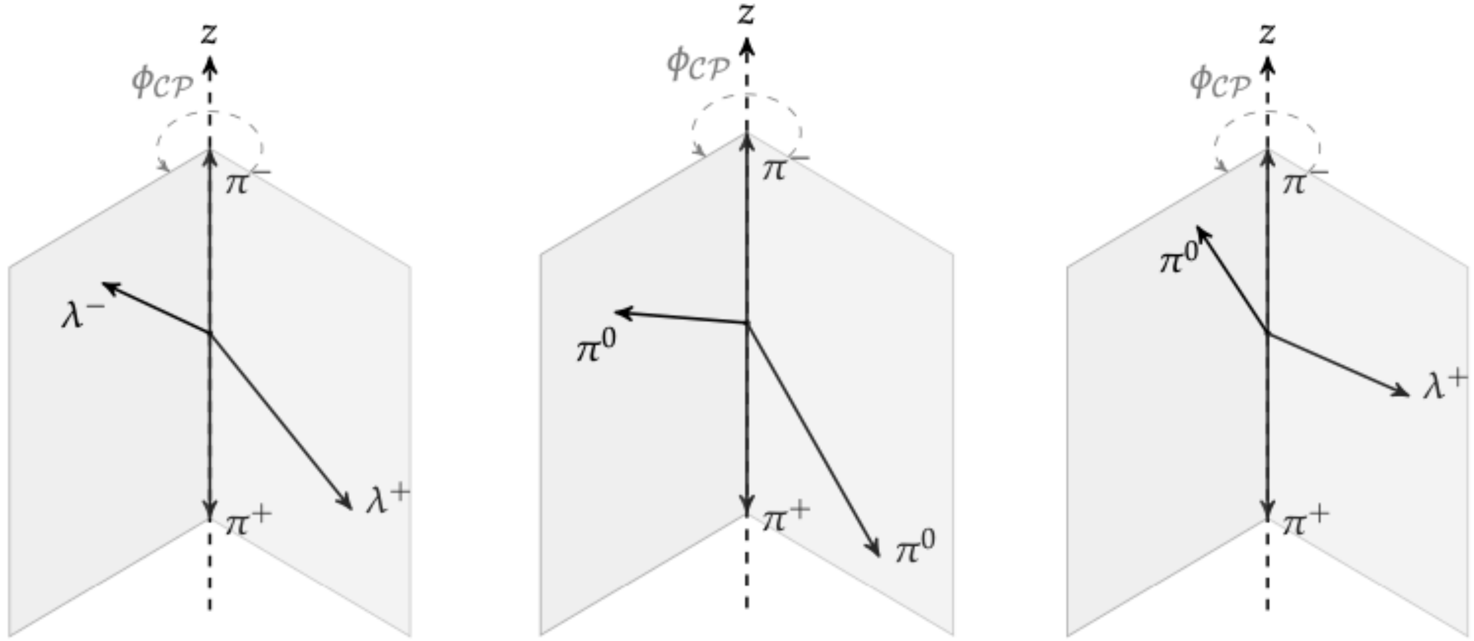
- Reconstruct the angle between the decay planes without accessing the tau 4-momentum
- Uses instead the impact parameter vector for one-prong decay or π^0 and π for rho decays (also possible to mix them) with boost in the charged particles zero momentum frame



- If the tau momenta is instead well known (three-prong), they use the polarimetric method and the secondary vertex to determine the a direction

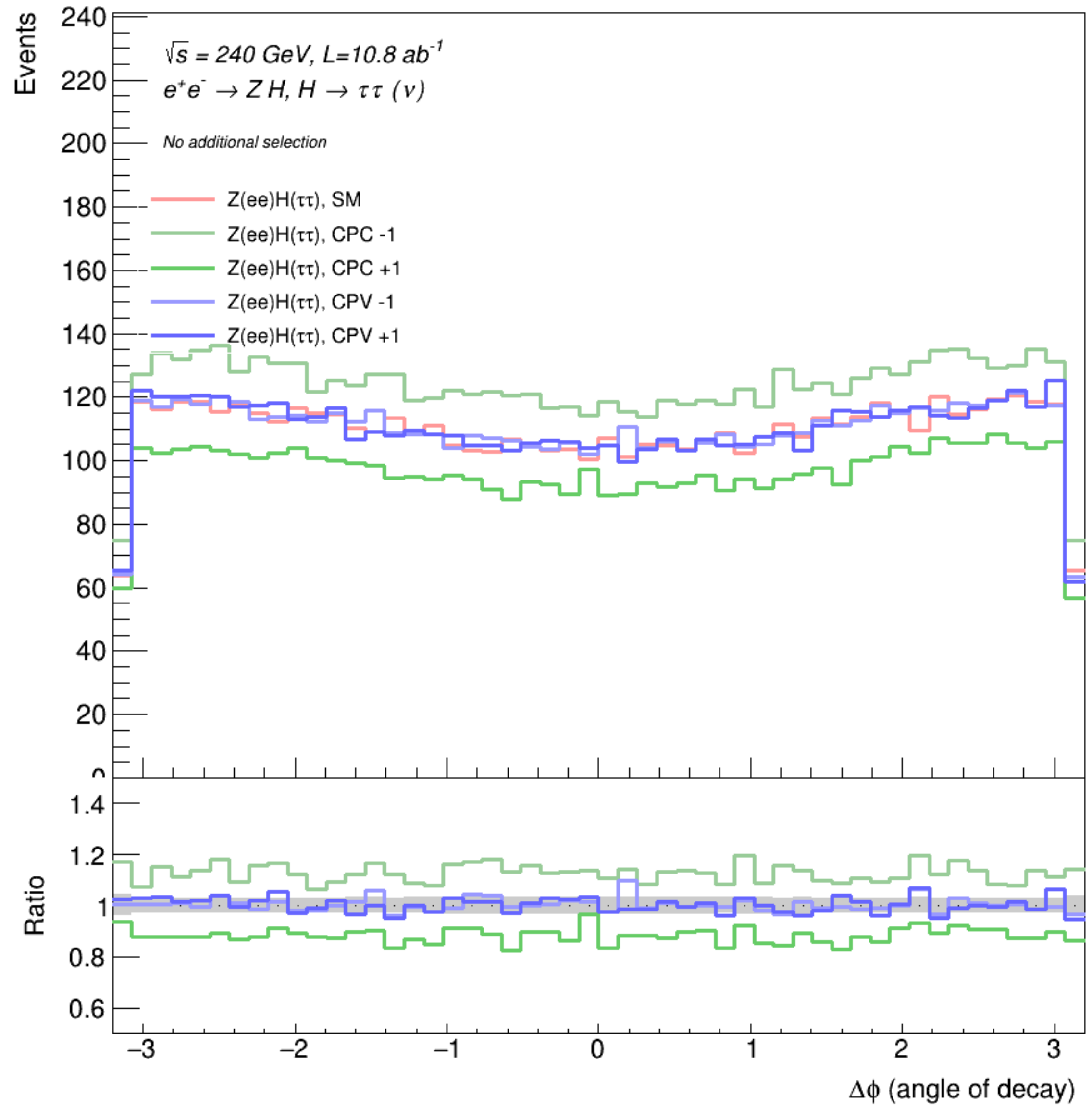
$$|\vec{p}_\tau| = \frac{(m_{\mathrm{a}_1}^2 + m_\tau^2)|\vec{p}_{\mathrm{a}_1}|\cos\theta_{\mathrm{GJ}} \pm \sqrt{(m_{\mathrm{a}_1}^2 + |\vec{p}_{\mathrm{a}_1}|^2)((m_{\mathrm{a}_1}^2 - m_\tau^2)^2 - 4m_\tau^2|\vec{p}_{\mathrm{a}_1}|^2\sin^2\theta_{\mathrm{GJ}})}}{2(m_{\mathrm{a}_1}^2 + |\vec{p}_{\mathrm{a}_1}|^2\sin^2\theta_{\mathrm{GJ}})}. \quad (9)$$

The maximal allowed value $\theta_{\mathrm{GJ}}^{\max}$ of the Gottfried–Jackson angle is defined as

$$\theta_{\mathrm{GJ}}^{\max} = \arcsin\left(\frac{m_\tau^2 - m_{\mathrm{a}_1}^2}{2m_\tau|\vec{p}_{\mathrm{a}_1}|}\right). \quad (10)$$

BACKUP

Combination



- Amplitude is much lower than expected if combining all channels for the angle between the decay planes