Measuring CP nature of tau-lepton Yukawa coupling at the ep collider

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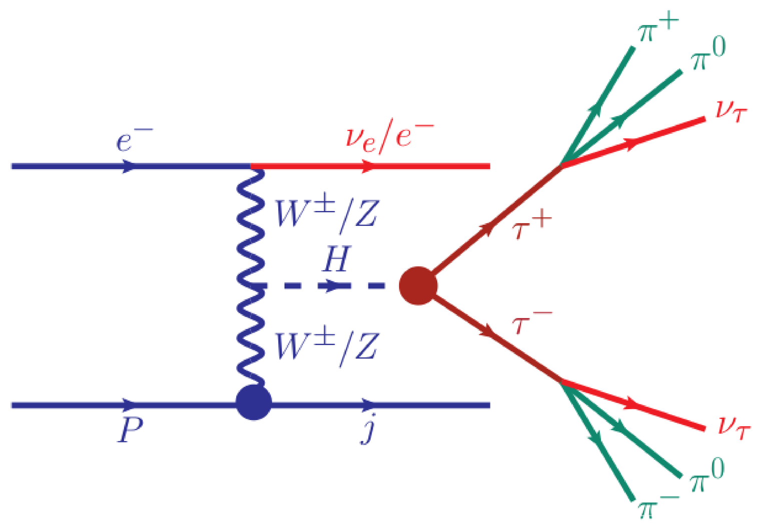
An Important Problem

- Searching for new physics beyond the Standard Model (SM) at the current and future collider experiments is of utmost importance after the phenomenal discovery of the Higgs boson by the CMS and the ATLAS collaborations.
- One of the interesting and efficient facility is the Large Hadron Electron Collider (LHeC) which is relatively clean compared to the Large Hadron Collider (LHC).
- Hence, it is natural to expect that LHeC might efficiently measure some new physics effects. Here we take this opportunity to estimate the prospect of measuring the CP phase of the Higgs boson.
- Measurement of the properties of the Higgs boson is an ideal place to expect new physics, if at all present. Many extensions of the SM modify the couplings of the SM Higgs to the gauge bosons and fermions.
- The CP conserving nature of the Higgs sector demands that the neutral mass eigenstates should have definite CP transformation property. Therefore, measurement of the couplings of the Higgs boson to the gauge bosons and the fermions plays a key role in constraining CP violation which essentially demands new physics.
- Owing to their large Yukawa couplings, the Higgs couplings with the third generation fermions become crucial, so here we focus on the tau lepton Yukawa coupling measurements at the LHeC.

Formalism and Process

- we focus on the process $e^- p \to \nu_e H j \to \nu_e \tau^+ \tau^- j \to \nu_e \pi^+ \pi^0 \bar{\nu}_\tau \pi^- \pi^0 \nu_\tau$ j and $e^- p \to e^- H j \to e^- \tau^+ \tau^- j \to e^- \pi^+ \pi^0 \bar{\nu}_\tau \pi^- \pi^0 \nu_\tau$ j.



- The Lagrangion in terms of CP-even and CP-odd mixing angle of tau lepton Yukawa coupling which serves our purpose is,

$$\mathcal{L}_0^f = -\frac{m_f}{v}[\tilde{a}\ \bar{\psi}_f \psi_f + \tilde{b}\ \bar{\psi}_f i\gamma_5 \psi_f] H \quad (1)$$

and the production of Higgs is via vector boson fusion at the LHeC as,

$$\mathcal{L}_0^V = \frac{2m_V^2}{v}[V_\mu V^\mu]\ H. \quad (2)$$

Observables

- The observable [1, 2] we utilize is known as neutral pion method and is defined as,

$$\phi^* = \ arccos(\hat{\lambda}_\perp^{*+}.\hat{\lambda}_\perp^{*-}) \quad (3)$$
$$O^* = \hat{q}^{*-}.(\hat{\lambda}_\perp^{*+} \times \hat{\lambda}_\perp^{*-}). \quad (4)$$

Where the $\lambda^\pm$ are the four momenta of the neutral pions from $\tau^\pm$ with the $*$ represents that all the quantities are calculated in $\pi^+\pi^-$ rest frame. Each quantity is normalised to get the unit vector which is denoted by the $\wedge$. And the $\lambda_\perp^{*\pm}$ are the transverse component of $\lambda^{*\pm}$ with respect to charged pions momentum, $q^{*\pm}$.

- The CP sensitive observable, Φ_{CP} is constructed from ϕ^* and O^* as,

$$\Phi_{CP} = \begin{cases} \phi^*, & \text{if } O^* \geq 0 \\ 360^\circ - \phi^*, & \text{if } O^* < 0 \end{cases} \quad (5)$$

- To avoid the destructive interference from differently polarised states of the mesons, the following quantities are defined,

$$y^{\tau^\pm} = \frac{E_{\pi^\pm} - E_{\pi^0}}{E_{\pi^\pm} + E_{\pi^0}}, \quad (6)$$

and $y^\tau = y^{\tau^+} * y^{\tau^-}$. When y^τ is negative Φ_{CP} is obtained with $360^\circ - \Phi_{CP}$.

Results and Discussion

- The decay plane of the process we have considered [3] is displayed in the left panel of Fig. 1. The right panel represents the normalised distribution of the observable Φ_{CP} with red, blue and green histograms corresponds to the SM, maximal CP violation and pure pseudo-scalar respectively.
- Evidently the observable Φ_{CP} discriminates the maximal CP violating case with the SM quite efficiently.

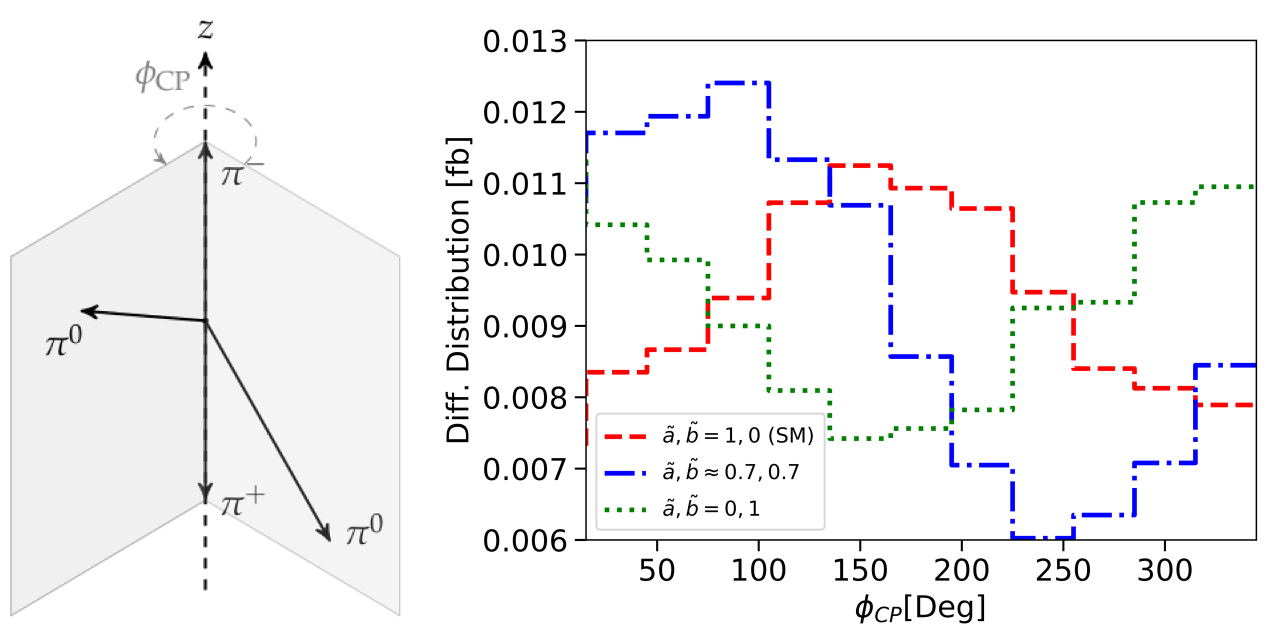


Fig. 1: figure

- We have estimated the sensitivity of the Φ_{CP} by measuring the χ^2 between the new physics and the Standard Model.

Summary and Remarks

- The Fig. 2 delineate the sensitivity achievable for the tau lepton Yukawa coupling at the LHeC.
- With the observable Φ_{CP} we can constrain the tau Yukawa coupling CP phase up to 23 degree which is really promising with 1 ab^{-1} luminosity.
- Although we have not taken the detector effects into account, but we believe the detector can be brought under control and Φ_{CP} will mildly affected by detector effects.
- We have performed this analysis with proton beam energy 7 TeV and electron beam energy 150 GeV. The SM Higgs production cross section with this set up, after a few base line cuts, turned out to be 15.20 fb.

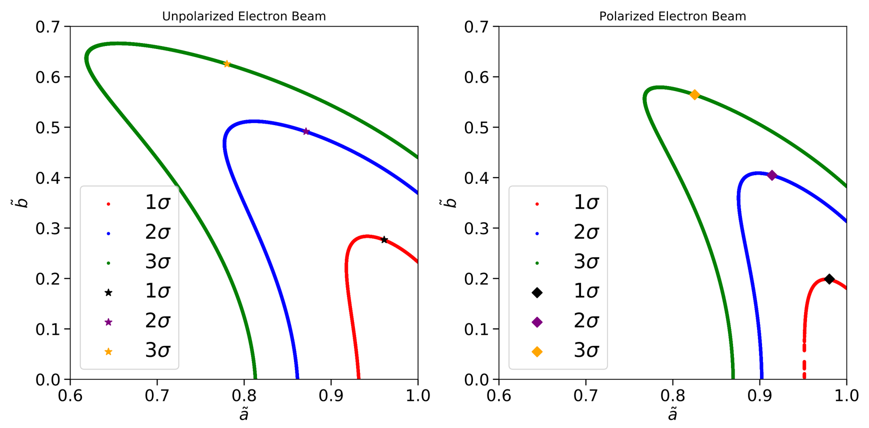


Fig. 2: Result

- Measuring the CP mixing angle of the tau lepton Yukawa coupling is extremely important.
- Future collider experiments like LHeC holds a great potential to measure the CP phase of the tau lepton Yukawa coupling.

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