# Measuring the CP properties of the Higgs sector at electron-positron colliders

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The violation of the CP symmetry is one of Sakharov's conditions for the matter–anti-matter asymmety of our universe. Currently known sources of CP violation in the quark and neutrino sectors are too small to account for this. Is CP also violated in the Higgs sector? Is the 125 GeV mass eigenstate a mixture of even and odd CP states of an extended Higgs sector, or is CP explicitly violated in Higgs interactions. With what precision could such effects be measured at future electron-positron colliders?

Several processes at $e^-e^+$ colliders are sensitive to the CP nature of the Higgs sector. Some are sensitive to fermionic, others to bosonic couplings; they also require different centre of mass energies, as summarised below.

| fermion couplings | |
|---|---|
| $H \to \tau^-\tau^+$ | 250+ GeV |
| $e^-e^+ \to Ht\bar{t}$ | 500+ GeV |
| boson couplings | |
| $e^-e^+ \to HZ$ | 250+ GeV |
| $H \to ZZ$ | 250+ GeV |
| $H \to WW$ | 250+ GeV |
| $e^-e^+ \to He^-e^+$ ($ZZ$-fusion) | 1000+ GeV |

The results of recent related measurements at LHC can be found at e.g. [1], [2], [3]. What can measurements at future $e^-e^+$ colliders add? Thanks to the clean experimental

environment and well-understood initial state at such facilities, significant sensitivity improvements are expected. Recent estimates for the sensitivity at ILC have been performed for $H \to \tau^- \tau^+$ (for a selection of $\tau$ decay modes) [4] and bosonic couplings [5].

We list a selection of questions about this subject which deserve closer investigation:

- How can CP measurements in the fermionic and bosonic sectors be considered in a unified way?
- What constraints do other measurements (e.g. the electron EDM) impose on CP properties of the Higgs sector? How model-dependent are these constraints?
- How well can tau leptons be reconstructed, and can they best be used to measure CP? Hadronic tau decays are most sensitive to the tau spin; how much additional sensitivity can leptonic decays provide?
- The $Ht\bar{t}$ process will produce complex final states. How well can these be reconstructed? How can they best be used to probe CP? What collider energy is optimal?
- Several of the above processes involve the $HZZ$ vertex: which is most powerful for probing CP? What role can measurements at different collider energies play?
- How does the experimental sensitivity at $e^- e^+$ colliders compare to that at HL-LHC?

We welcome collaborators to join us in the study of these and related questions.

## References


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[2] "Test of CP invariance in vector-boson fusion production of the Higgs boson in the $H \to \tau\tau$ channel in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector," Tech. Rep. ATLAS-CONF-2019-050, CERN, Geneva, Oct 2019.

[3] "Constraints on anomalous Higgs boson couplings to vector bosons and fermions in production and decay in the $H \to 4\ell$ channel," Tech. Rep. CMS-PAS-HIG-19-009, CERN, Geneva, 2020.

[4] D. Jeans and G. Wilson, "Measuring the CP state of tau lepton pairs from Higgs decay at the ILC," *Phys. Rev. D*, vol. 98, no. 1, p. 013007, 2018.

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