

PhD PROJECT DISCUSSION

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TOPICS



- ALPs
- Higgs CP from $H \rightarrow \tau\tau$
- (Tau reconstruction)

ALPs

- Feebly-interacting particles
- DM candidate
- Solution to the strong CP and/or hierarchy problems
- FCC-ee clean environment and large integrated luminosities will render it very sensitive to EW-coupled ALPs
- Decay into $\ell^+ \ell^-$, $\bar{q}q$, $\gamma\gamma$, gg , $\pi\pi\pi$, with at least dim-5 effective Lagrangian, from dim-6 to include H coupling

ALPs at FCC-ee



- $a \rightarrow \ell^+ \ell^-$, $a \rightarrow \gamma\gamma$ from $H \rightarrow aa, Ha, Za$ [projected sensitivity](#)
- $Z \rightarrow \gamma(a \rightarrow \gamma\gamma)$ [snowmass 2022](#), gen level
- $\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$ [photon fusion](#), IDEA reco, different ecm, prompt and DV, only photon coupling
- $\bar{f}f(a \rightarrow \gamma\gamma)$, $f = e, \mu, \nu$, $\sqrt{s} = 240 \text{ GeV}$ bounds on [photon and Z couplings](#)

ALPs at LHC

- $\bar{t}t(a \rightarrow \mu\mu)$ [LLP](#), only top coupling, no detector sim
- $\bar{t}t(a \rightarrow ee/\mu\mu)$ prompt from [CMS](#) and ATLAS too
- $t \rightarrow q(a \rightarrow \bar{q}q)$ [decay in HCAL](#), flavor changing decay (based on ATLAS?)
- $a \rightarrow \gamma\gamma$ from $Pb - Pb, pp, VBF, H \rightarrow aa, H \rightarrow Za$ ([review of ATLAS/CMS](#))
- $pp \rightarrow a \rightarrow ZH/ZZ$ [CMS](#), non-resonant coupling to bosons in EFT approach
- [VBS](#) with ALPs produced in non-resonant coupling to ZZ, WW and $Z\gamma$, re-interpretation of LHC data in SMEFT of dim-5

ALPs POSSIBILITIES

- Consider all SMEFT relevant operators (and total BR) instead of single ones for a more complete approach
- Lepton (tied to τ reconstruction) and quark channels haven't been explored at FCC-ee
- Lepton channel is less excluded (see [projected sensitivity](#))
- $H \rightarrow Za, H \rightarrow aa, Z \rightarrow a\gamma$ and different mass-coupling hypotheses to probe a large portion of space

HIGGS CP

- Higgs is CP-even in SM, CP-odd Higgs is excluded at $\sim 3\sigma$ (CMS+ATLAS)
- Direct approach: CP-odd observables using angular distributions
- Indirect approach: effect of CP-odd interactions on CP-even observables
- CPV with massive vector boson can only be induced at loop level in a generic BSM theory and is expected to be small
- CPV with fermions can occur unsuppressed making it especially interesting from a phenomenological point of view
- CPV in the Higgs sector might have implications for weak scale baryogenesis in several BSM scenarios

HIGGS CP at FCC-ee



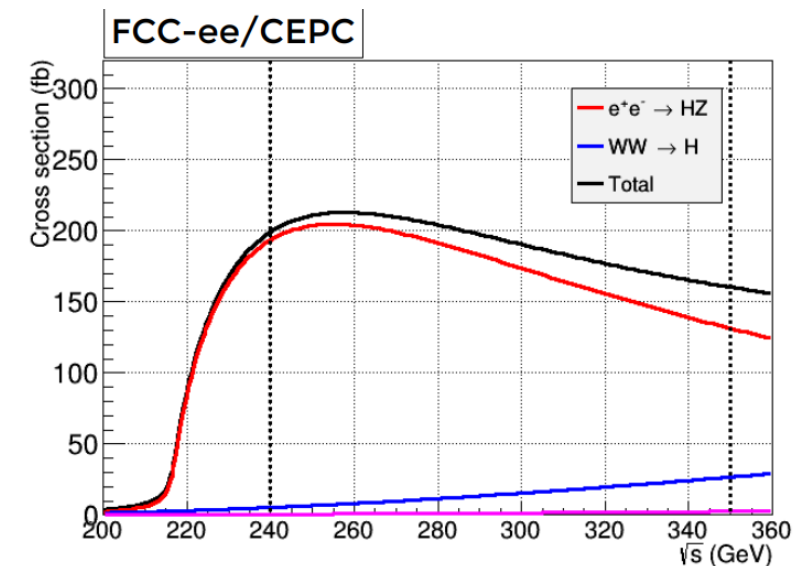
- [CP HZZ](#), $Z(\rightarrow \ell^+ \ell^-)H(\rightarrow b^- b)$ studying angular observables from parameterised amplitudes, CP-even, CP-odd, CP-mixed (50%)
- [ILC](#) $Z(\rightarrow e^+ e^-, \mu^+ \mu^-, \bar{u}u, \bar{d}d, \bar{s}s)H(\rightarrow \tau^+ \tau^-)$ with most decay modes of τ , CP-odd, CP-even, CP-mixed (50%)
- [CEPC](#) $Z(\rightarrow e^+ e^-, \mu^+ \mu^-)H(\rightarrow gg / b^- b / c^- c)$ with SMEFT, only CP-odd parameters

HIGGS CP at LHC

- CMS and ATLAS $\bar{t}tH, H \rightarrow \gamma\gamma$, also with machine learning
- CMS $H \rightarrow \tau\tau$ with κ, τ decays hadronically, semileptonic or leptonic, from VBF, ggH, VH and ttH, tH
- CMS $H \rightarrow \tau\tau$ with κ and anomalous couplings related to two SMEFT operators from VBF, ggH, VH
- ATLAS $H \rightarrow \tau\tau$ with SMEFT, τ decays leptonically or semi, from VBF
- ATLAS $H \rightarrow \tau\tau$ with κ , most τ decay modes

HIGGS CP POSSIBILITIES

- For FCC-ee it seems like there is a lot of room for exploration
- $H \rightarrow \tau\tau$ is seen as a very promising channel, there are a few options in terms of ecm and production channel (excl. tH, ttH) , τ reconstruction
- If studying it from an EFT (SMEFT, HEFT?) perspective with multiple operators then it would also be interesting in CMS
- Different assumptions by selecting relevant operators: CP-even, CP-odd, CP-mix



TAU RECONSTRUCTION



- At FCC-ee DV from tau decays can be specifically searched for and used for tau reconstruction
- Cleaner environment than LHC, especially for leptonic decays
- Hadronic tau reconstruction from jet tagging algorithms (tested on CLIC)
- Study on tau polarisation in $e^+e^- \rightarrow \tau^+\tau^-$ (gen level)