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Effective fermion–Higgs interactions at an e^+e^- collider with polarized beams

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Abstract

We consider the possibility of new physics giving rise to effective interactions of the form $e^+e^-Hf\bar{f}$, where f represents a charged lepton ℓ or a (light) quark q, and H the recently discovered Higgs boson. Such vertices would give contributions beyond the standard model to the Higgs production processes $e^+e^- \to H\ell^+\ell^-$ and $e^+e^- \to Hq\bar{q}$ at a future e^+e^- collider. We write the most general form for these vertices allowed by Lorentz symmetry. Assuming that such interactions contribute in addition to the standard model production processes, where the final-state fermion pair comes from the decay of the Z boson, we obtain the differential cross section for the processes $e^+e^- \to H\ell^+\ell^-$ and $e^+e^- \to Hq\bar{q}$ to linear order in the effective interactions. We propose several observables with differing CP and T properties which, if measured, can be used to constrain the couplings occurring in interaction vertices. We derive possible limits on these couplings that may be obtained at a collider with centre-of-mass energy of 500 GeV and an integrated luminosity of 500 fb^{-1}. We also carry out the analysis assuming that both the electron and positron beams can be longitudinally polarized, and find that the sensitivity to the couplings can be improved by a factor of 2–4 by a specific choice of the signs of the polarizations of both the electron and positron beams for the same integrated luminosity.

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1. Introduction

While the present data from the LHC indicate that the particle of mass around 125 GeV discovered recently may be the standard model (SM) Higgs boson, the accuracy of the present experiments is not sufficient to nail the issue. Many of its couplings to fermions and gauge bosons have been measured and found to be consistent with those expected from the SM [1]. Nevertheless, the data as yet allows for wide deviations from the SM. It is thus an open question whether the SM is the ultimate theory. We need to investigate alternative scenarios for electroweak symmetry breaking, which would be tested at future runs of the LHC, or possibly, at an e^+e^- collider which has now a reasonable hope of being constructed [2].

There are a number of scenarios beyond the standard model for spontaneous symmetry breaking, and ascertaining the mass and other properties of the scalar boson or bosons is an important task. This task would prove extremely difficult for the LHC. However, scenarios beyond SM, with more than just one Higgs doublet, as in the case of the minimal supersymmetric standard model (MSSM), would be more amenable to discovery at a linear e^+e^- collider operating at centre-of-mass (cm) energies of 500–1000 GeV. Even if direct discovery of new particles may still not be possible, indirect signals through higher precision of measurements of Higgs couplings would be accessible.

Scenarios going beyond the SM mechanism of symmetry breaking, and incorporating new mechanisms of CP violation, have also become a necessity in order to understand baryogenesis which has resulted in the present-day baryon–antibaryon asymmetry in the universe. In a theory with an extended Higgs sector and new mechanisms of CP violation, the physical Higgs bosons are not necessarily eigenstates of CP. In such a case, the production of a physical Higgs can proceed through more than one channel, and the interference between two channels can give rise to a CP-violating signal in the production.

There have been a number of studies examining possibilities of measuring couplings of a Higgs boson which may belong to an extension of the standard model [3–15]. Here we consider in a general model-independent way the production of a Higgs mass eigenstate H in a possible extension of the SM at an e^+e^- collider. We restrict ourselves to the case when the Higgs boson is accompanied by a fermion pair. Such a final state can arise in the SM or its extensions through the HiggsStrahlung (HS) process $e^+e^- \to HZ$, an important mechanism for the production of the Higgs boson, with the final Z decaying into a fermion pair. In case the final-state leptons are e^+e^-, the final state can also arise in the process of vector boson fusion (VBF), when virtual Z bosons emitted by the e^+ and e^- beams fuse to produce a Higgs boson. However, this does not exhaust all possibilities. We consider here an effective anomalous $e^+e^-Hf\bar{f}$ vertex, where f represents a charged lepton ($\ell \equiv e, \mu, \tau$) or a light quark. This vertex is supposed to represent a contribution to the process $e^+e^- \to Hf\bar{f}$ of interactions beyond the SM (BSM), the SM contributions being HS and VBF described above. However, it includes contributions of HS and VBF processes going beyond SM. Not only that, it can include contributions which do not fall under these two categories, as for example, contributions coming from box diagrams for ZH production, or pentagon diagrams for a $Hf\bar{f}$ final state.

We will parametrize the five-particle vertex by means of various Lorentz structures, whose coefficients will be momentum-dependent form factors. We will then propose kinematic observables, whose measurements at an e^+e^- collider could enable a determination of these form factors, or at least contrain them. We will also estimate 95% confidence-level (C.L.) limits that can be put on these form factors at a collider operating at a centre-of-mass energy of 500 GeV with an integrated luminosity of 500 fb^{-1}.