CP violation at a linear collider with transverse polarization

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We show how transverse beam polarization at $e^+e^-$ colliders can provide a novel means to search for CP violation by observing the distribution of a single final-state particle without measuring its spin. We suggest an azimuthal asymmetry which single out interference terms between standard model contribution and new-physics scalar or tensor effective interactions in the limit in which the electron mass is neglected. Such terms are inaccessible with unpolarized or longitudinally polarized beams. The asymmetry is sensitive to CP violation when the transverse polarizations of the electron and positron are in opposite senses. The sensitivity of planned future linear colliders to new-physics CP violation in $e^+e^-\rightarrow t\bar{t}$ is estimated in a model-independent parametrization. It would be possible to put a bound of $\sim 7$ TeV on the new-physics scale $\Lambda$ at the 90% C.L. for $\sqrt{s}=500$ GeV and $\int dt L=500$ fb$^{-1}$, with transverse polarizations of 80% and 60% for the electron and positron beams, respectively.

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I. INTRODUCTION

An $e^+e^-$ linear collider operating at a center-of-mass (c.m.) energy of a few hundred GeV and with an integrated luminosity of several hundred inverse femtobarns is now a distinct possibility. It is likely that the beams can be longitudinally polarized, and there is also the possibility that spin rotators can be used to produce transversely polarized beams. Proposals include the GLC (Global Linear Collider) in Japan [1], the NLC (Next Linear Collider) in the USA [2], and TESLA (TeV-Energy Superconducting Linear Accelerator) in Germany [3]. The physics objectives of these facilities include the precision study of standard model (SM) particles, Higgs discovery and study, and the discovery of physics beyond the standard model.

One important manifestation of new physics would be the observation of CP violation outside the traditional setting of meson systems, since CP violation due to SM interactions is predicted to be unobservably small elsewhere. For instance, one may consider the presence of model independent “weak” and “electric” dipole form factors for heavy particles such as the $\tau$ lepton and the top quark. In case of the $\tau$ lepton, LEP experiments have constrained their magnitudes from certain CP-violating correlations proposed in [4]. Furthermore, it was pointed out that longitudinal polarization of the electron and/or positron beams dramatically improves the resolving power of other CP-violating correlations in $\tau$-lepton [5] and top-quark pair production [6], and of decay-lepton asymmetries in top-quark pair production [7].

Here we consider exploring new physics via the observation of CP violation in top-quark pair production, by exploiting the transverse polarization (TP) of the beams at these facilities. We rely on completely general and model-independent parametrization of beyond the standard model interactions [8–10] in terms of contact interactions, and on very general results on the role of TP effects due to Dass and Ross [11]. We demonstrate through explicit computations that only those interactions that transform as tensor or (pseudo-)scalar interactions under Lorentz transformations can contribute to CP-violating terms in the differential cross section at leading order when the beams have only TP. By considering realistic energies and integrated luminosities, and some angular-integrated asymmetries in $e^+e^-\rightarrow t\bar{t}$, we find that the scale $\Lambda$ at which new physics sets in can be probed at the 90% confidence level is $O(10)$ TeV. This effective scale can reach or go beyond what one might expect in popular extensions of the SM such as the minimal supersymmetric model, or extra-dimensional theories. Note that the tensor and (pseudo-)scalar interactions are accessible only at a higher order of perturbation theory without TP, even if longitudinal polarization is available. Also, in the foregoing, effects due to $m_\tau$ are neglected everywhere.

It may be mentioned that TP in the search of new physics has received sparse attention (for the limited old and recent references with or without CP violation, see [12]). In the CP violation context, the only work of relevance, to our knowledge, is that of Burgess and Robinson [13], who considered pair production of leptons and light quarks in the context of LEP and SLC. Our discussion of top pair production, which is in the context of much higher energies, does have some features in common with the work of Ref. [13], though the numerical analysis is necessarily different. Furthermore, we have included a discussion of CP violation for a general inclusive process.

In the process $e^+e^-\rightarrow f\bar{f}$, where $f$ is different from $f$, testing CP violation needs more than just the momenta of the particles to be measured. In the c.m. frame, there are only two vectors, $\vec{p}_e-\vec{p}_{e^+}$ and $\vec{p}_f-\vec{p}_\bar{f}$. The only scalar observable one can construct out of these is $(\vec{p}_e-\vec{p}_{e^+})\cdot(\vec{p}_f-\vec{p}_\bar{f})$. This is even under CP. Hence one needs either initial spin or final spin to be observed. Observing the final spin in the case of the top quark is feasible because of the...