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Analysis of the di-tau final state

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A high energy electron positron collider will produce copious pairs of tau leptons. We are studying how these can be reconstructed experimentally, with what precision their properties can be measured, and the resulting sensitivity to Standard Model Effective Field Theory coefficients. Fast simulation of the ILD concept is used.

This work was carried out in the framework of the ILD Concept Group

1 Introduction

Fermion pair production at high energy electron positron colliders will provide high precision tests of the Standard Model thanks to their high cross-section and relatively simple event topologies.

The tau-pair final state provides unique possibilities for testing the Standard Model, thanks to access to the spin orientation of the final state fermions by consideration of the distribution of the tau lepton decay products. Both the longitudinal polarisation, which distinguishes between positive and negative helicity taus, and transverse spin components can be probed, as well as spin correlations between the two final state taus.

The basic detector-level observables which one would like to reconstruct are the tau-pair invariant mass and centre-of-mass scattering angle, along with estimators of the tau spin orientation (which we call "polarimeters").

2 Sensitivity to new physics

We have used the Madgraph event generator [1] interfaced with the TauDecay library [2] to investigate the sensitivity of tau polarisation observables to physics beyond the Standard Model in the context of Standard Model Effective Field Theory (SMEFT). A number of dimension-6 operators which affect the $\tau\tau W$ and $\tau\tau B$ vertex are being considered, as well as 4-fermion coupling between the electron and tau lepton. Figure 1 shows the definition of polarimeter components, and an example of variations in a polarimeter observable with some SMEFT coefficients.

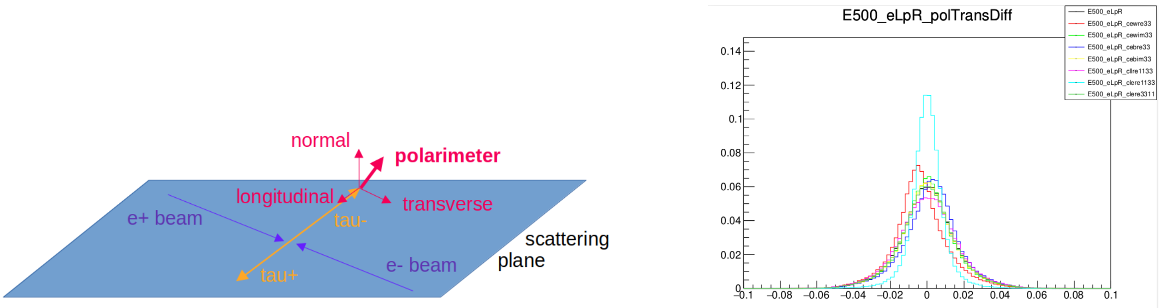

Figure 1: Left: definition of polarimeter components. Right: illustration of the variation of a particular combinations of polarimeter components (the difference of the two taus' transverse components), for di-tau production at 500 GeV centre-of-mass with 100% polarised left-handed electron and right-handed positron beams. Different colors represent different SMEFT operators.

3 Event reconstruction

The reconstruction of tau leptons is complicated by the neutrinos produced in their decay, which reduces the power of kinematic constraints. If the invariant mass and rest-frame of the tau-pair is known, as is the case at the Z pole where Initial State Radiation (ISR) is limited, then the "cone-method" can be used to reconstruct the tau momenta [3].

At higher energies ISR and beamstrahlung induce significant variations in the tau pair invariant mass and rest frame, so an alternative approach is required. We have developed a method which can reconstruct tau momenta in this case of reduced kinematic constraints, which uses in addition the detailed trajectories of charged tau daughters in the vicinity of the interaction point. We assume that a single ISR photon has escaped detection, and scan over possible momenta of this photon. At each candidate momentum, a solution is searched for which is consistent with 4-momentum conservation, the tau invariant mass, and with both taus being produced at the same point along the nominal beamline and decaying on the charged pion trajectories.

This method can identify zero, one, or multiple solutions per event. In the case of multiple solutions, there is no obvious way in which to decide which is correct, so all solutions are considered, producing a per-event distribution of estimated event quantities.

We consider the tau decay modes with one or two pions, representing over a third of tau decays, which are experimentally relatively easy to reconstruct and for which optimal polarimeter observables can be defined.

4 Polarization

Once the full kinematics of the tau decay is reconstructed, the well-known forms of optimal polarimeters in the one- and two-pion decay can be used to estimate the tau spin orientation [3]. An example of the reconstructed polarimeters' longitudinal component is shown in Fig. 2.

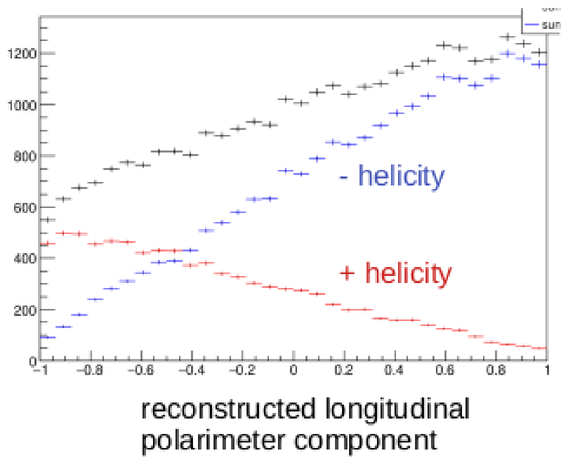

Figure 2: Example of the reconstructed longitudinal polarimeter distribution, using as input true values of pion momenta and trajectories. Extracting the tau polarisation involves fitting the total (black) distribution as the sum of positive/negative (red/blue) helicity contributions.

5 Detector optimisation

We have tested our method using as input the true momenta of pions taken from the MC, as well as estimates of these quantities after detector reconstruction by using the *Simulation a Grande Vitesse* (SGV) package [4], whose parameters are modeled on the expected performance of the ILD concept. We plan to vary sub-detector resolutions to study the effects on this analysis.

6 References

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[3] K. Yumino, D. Jeans, *Measuring the tau polarization at ILC*, Snowmass 2021, 2022, arXiv: 2203.07668 [hep-ex].

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