PROCEEDINGS OF SCIENCE

Study of Higgs couplings to leptons and Higgs CP properties at the ILC

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The International Linear Collider (ILC) is a proposed electron positron collider capable of providing collisions at centre-of-mass energies of 250 GeV at a luminosity of $\sim 10^{34} cm^{-2} s^{-1}$. Over a period of around 11 years, 0.5×10^6 Higgs bosons will be produced via the "Higgs-strahlung" process. In this contribution we describe how these events can be used to measure the Higgs boson coupling to leptons, and its CP properties via its decay to τ leptons. We find that the $\sigma \times BR$ can be measured to a precision of around 1.2% for $H \to \tau\tau$, 20% for $H \to \mu\mu$, and that the mixing angle between odd and even components of the Higgs boson determined to 75 mrad.

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1. Introduction

The International Linear Collider (ILC) [1] is a planned electron-positron collider, which will initially provide collisions at a centre-of-mass energy of 250 GeV. The electron (positron) beams will be 80% (30%) longitudinally polarised. Over the envisaged initial running period of 11 years, around half a million Higgs bosons will be produced via the “Higgs-strahlung” interaction. The linear arrangement of the ILC allows the possibility of future energy upgrades by lengthening the accelerators and by future improvements in accelerating technology.

The main physics aims of the first ILC stage at 250 GeV (ILC250) are centred on the investigation of the electro-weak sector via comprehensive and model independent measurements of the Higgs boson’s properties and high-precision studies of other electro-weak processes. In this contribution, we describe prospects for measurements using Higgs decays to leptonic final states.

2. International Large Detector

The International Large Detector (ILD) is one of two detector concepts being developed for ILC [2]. It is designed as a high-precision detector optimised for Particle Flow event reconstruction (PFA). It is built around a charged particle tracking system made up of a vertex detector, a large time projection chamber, and additional silicon tracking layers, all within a 3.5 T solenoidal magnetic field. Calorimeters with highly segmented readout provide the pattern recognition capabilities needed for optimal application of PFA techniques. The detector will provide impact parameter precision $\sigma_{d0} \sim 5\ \mu m$, transverse momentum resolution $\sigma_{pT}/p_T \sim 2 \times 10^{-5} p_T$, and jet energy resolution of $3 \rightarrow 4\%$ over a wide range of jet energies.

The detector geometry and readout are implemented in a Geant4-based simulation model, together with a set of detector signal digitisation processors. These simulated signals are treated by different reconstruction codes to identify charged particle tracks, cluster calorimeter deposits, and combined these into so-called Particle Flow Objects (PFOs), corresponding to individual reconstructed final state particles. The analyses presented in this contribution all use event samples subjected to such full simulation and reconstruction of ILD.

3. Higgs Yukawa – mass relation

In the Standard Model, the strength of the Yukawa coupling between the Higgs and fermions is predicted to be proportional to fermion masses. Different BSM models can predict variations in this relation, with deviations at the level of several % typical for models in which the scale of new physics is around a TeV. Measurements of couplings at the % level or better will allow these BSM models to be probed. In this contribution we present projections on the measurement of muon and tau leptons’ Yukawa coupling at ILC.

3.1 Higgs to τ

The cross–section measurement for the process $e^+e^- \rightarrow Zh(h \rightarrow \tau^+\tau^-)$ is simulated in ILD. In the analysis described in [3], decays of the Z boson into electrons, muons, and hadrons are considered. Tau lepton candidates are identified by searching for isolated narrow jets containing one or three charged particles, with a total charge of ± 1, and invariant mass below 2 GeV/c^2.

Various selection cuts are applied to reduce the majority of events from background processes. The collinear approximation is applied, assuming that the τ neutrino is collinear with the visible tau decay jet; the resulting $\tau\tau$ invariant mass distribution is shown in Fig.1 (left). As a final step, a boosted decision tree is trained to distinguish signal events from remaining backgrounds.

The estimated precision on the measurement on $\sigma(e^+e^- \to h+X; h \to \tau^+\tau^-)$ is 1.2% when using 2 ab^{-1} of data at 250 GeV centre-of-mass energy. Including an additional 4 ab^{-1} of data at 500 GeV improves the precision to 1.0%.

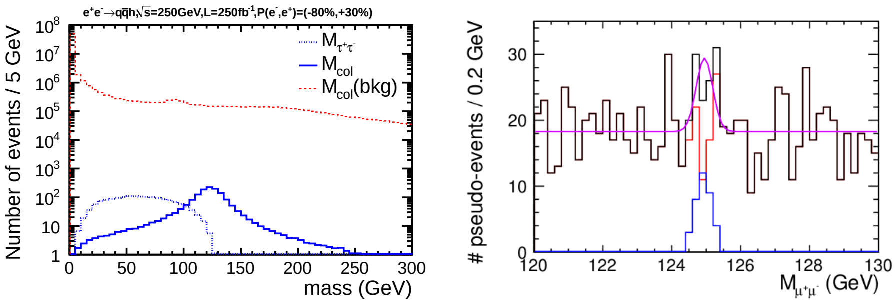

Figure 1: Left: Reconstructed $\tau\tau$ invariant mass in $h \to \tau^+\tau^-$ analysis (from [3]). Right: A single pseudo-experiment in the $h \to \mu^+\mu^-$ analysis, showing the $\mu^+\mu^-$ invariant mass. Signal shown in blue and background in red.

3.2 Higgs to μ

The main challenge of the measurement of the muon Yukawa coupling is its small expected branching ratio of around 2×10^{-4}. The full-simulation analysis presented in [4] considers $h \to \mu^+\mu^-$ production in association with a pair of either neutrinos or quarks. Events are selected by requiring a pair of prompt, isolated, oppositely-charged and well-measured muon candidate PFOs. After a preselection considering the angles of the muon candidates, and the activity in the remainder of the event, a multivariate discriminator is trained to distinguish signal from remaining backgrounds.

The resulting di-muon invariant mass distribution is used to estimate the number of signal events remaining after selection. Key to good experimental sensitivity is the muon momentum distribution: the better it is, the sharper is the signal peak which sits on the flat background distribution. The simulated distributions of selected signal and backgrounds are used to run a series of pseudo-experiments to estimate the experimental sensitivity. An example of one of these pseudo-experiments is shown in Fig.1 (right). Using 2 ab^{-1} of data at 250 GeV, $\sigma(e^+e^- \to h+X, h \to \mu^+\mu^-)$ can be measured with a precision of 20%, which improves to 15% when an additional 4 ab^{-1} of data at 500 GeV is included.

4. CP measurement in $h \to \tau^+\tau^-$

The decay into tau leptons of the Higgs boson provides an opportunity to access the CP nature of the Higgs and of its couplings. It is well known that the CP state of the tau pair affects transverse spin correlations between the two taus, as shown in Fig.2 (left). The distribution of tau lepton decay products are sensitive to the polarisation of the tau lepton, allowing these correlations to be measured. The high precision detectors envisaged for ILC, and the clean experimental environment of lepton colliders, enable such a measurement.

Higgs bosons produced in the Higgs-strahlung process, and in which the Z boson decays to electrons, muons, or hadrons, were considered as signal. The impact parameters of tau decay products are used to help reconstruct the tau momenta, following the approach presented in [5]. Powerful estimators of the tau spin direction, known as polarimeters, are simple to extract in the decays $\tau^\pm \to \pi^\pm \nu$ and $\tau^\pm \to \pi^\pm \pi^0 \nu$. In [6], these two decay modes, which together account for 37% of tau decays, were used to analyse Higgs-strahlung events in which the Higgs decays to tau leptons. After an event selection, events were classified according to their sensitivity to CP effects. Pseudo-experiments were run to estimate the experimental sensitivity. Using $2ab^{-1}$ of data at 250 GeV, the mixing angle between CP even and odd components of the tau-pair system can be measured to a precision of 75 mrad.

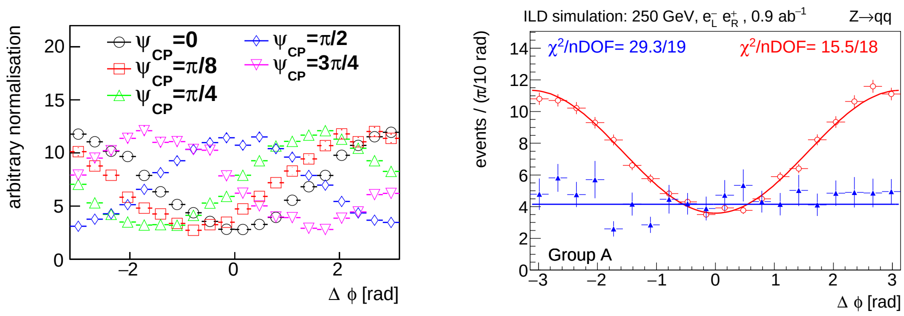

Figure 2: CP phase measurement in $H \to \tau\tau$. Left: distribution of the CP-sensitive correlation angle for different CP mixing cases, at MC level. Right: reconstructed angular distribution in the case of the SM, for a sub-sample of selected events; signal is shown in red, background in blue. Figures from [6].

References

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