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SM-like Higgs decay into two muons at 1.4 TeV CLIC

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Abstract

The potential for measuring the Standard Model (SM) Higgs boson decay into two muons at a 1.4 TeV CLIC e^+e^-collider, presented at ICHEP2014, is addressed in this paper. The study is performed in the full Geant4 detector simulations of CLIC_ILD, taking into consideration all the relevant physics and the beam-induced background processes, as well as the instrumentation of the very forward region to tag forward electrons. In this analysis we show that the branching ratio BR($H\to\mu^+\mu^-$) times the Higgs production cross-section can be measured with 38% statistical accuracy at $\sqrt{s}$ =1.4 TeV using an integrated luminosity of 1.5 ab^{-1}. This study is part of an ongoing comprehensive Higgs physics benchmark study covering various Higgs production processes and decay modes, currently being carried out to estimate the full Higgs physics potential of CLIC.

Keywords: *Higgs, muons, branching fraction, Higgs couplings*

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1. Introduction

Measurements of the Higgs branching ratios and consequently Higgs couplings provide a strong test of the Standard Model (SM) and possible new physics beyond. Models that could possibly extend the SM Higgs sector (2HDM, Little Higgs models or Compositeness) will require Higgs couplings to electroweak bosons and Higgs-fermion Yukawa couplings (coupling-mass linearity) to deviate from the SM predictions.

CLIC represents an excellent environment to study properties of the Higgs boson, including Higgs couplings, with a very high precision. Measurement of the rare $H \to \mu^+\mu^-$decay is particularly challenging due to the very low branching ratio of order of 10^{-4} predicted by the SM. The measurement thus requires excellent muon identification efficiency and momentum resolution as well as comprehensive background suppression.

In e^+e^- collisions at $\sqrt{s}$ =1.4 TeV SM-like Higgs boson with a mass of 126 GeV is dominantly produced via W^+W^- fusion. In five years of operation with 200 running days per year and a 50% data-taking efficiency at an instantaneous luminosity of 3.2×10^{34} $cm^{-2}s^{-1}$, a total integrated luminosity of 1.5 ab^{-1} will be collected. Unpolarised beams are assumed. Higgs production through W^+W^- fusion can be statistically enhanced by a factor of 1.8 when using -80% electron beam polarisation and by a factor of 2.34 when using, in addition, +30% positron beam polarisation [1].

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2. Simulation and analysis tools

Higgs production through W^+W^- fusion was simulated in WHIZARD 1.95 [2] including CLIC beam spectrum and initial state radiation. The generator PYTHIA 6.4 [2] was used to simulate the Higgs decay into two muons. Background events were also generated with WHIZARD using PYTHIA to simulate hadronization and fragmentation processes. Tau decays were provided by TAUOLA [4]. The CLIC luminosity spectrum and the beam induced processes were obtained by GuineaPig 1.4.4[5].

The CLIC_ILD detector simulation was performed using Mokka[6] based on Geant4. The particle flow algorithm [7] was employed in the reconstruction of the final-state particles. The TMVA package [8] was used to separate signal from background by multivariate analysis (MVA) of signal and background kinematic properties.

3. Signal and background

The cross-section of W^+W^- fusion at $\sqrt{s}$ =1.4 TeV is 244 fb (Fig. 1).

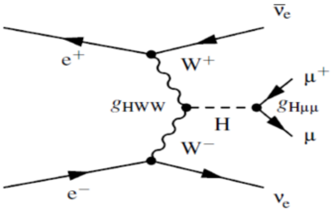

Fig. 1.Feynman diagram of the Higgs production in WW fusion and the subsequent decay to a pair of muons.

In Table 1, the full list of physics and beam-induced backgrounds is given. The process$e^+e^- \to \nu_e\bar{\nu}_e\mu^+\mu^-$ with the same final state as the signal represents an irreducible background. The four-fermion production process $e^+e^- \to e^+e^-\mu^+\mu^-$is realized dominantly through the two-photon exchange mechanism and it fakes the missing energy signature since electron spectators are emitted outside the acceptance of the main detector (smaller than 8deg). For that reason, the tagging of EM showers in the very forward calorimeters is applied.

4. Forward electron tagging

In this analysis, a parameterized simulation of electron tagging in the very forward region was applied. The candidate EM shower for tagging is constructed from particles (electrons, photons) in a 5 mrad cone around the selected particle, which corresponds to one Moliere radius. The tagging probability was simulated by parametrization of the background deposition in the forward detectors as a function of the polar angle. If the energy of the shower is higher than a 4σ fluctuation of the incoherent pair deposition in the layer with the maximal deposition, the shower is considered as tagged. In order to reduce the rate of coincident tagging of Bhabha events, additional cuts were applied requiring that the shower energy is higher than 200 GeV, and that the polar angle is above 30 mrad.

Tab.1:List of considered processes with their corresponding cross-sections. The cross-sections for all processes with photons in the initial state include cross sections from beam-induced background.

Process	σ(fb)
$e^+e^- \to H\nu_e\bar{\nu}_e, H \to \mu^+\mu^-$	0.0522
$e^+e^- \to \nu_e\bar{\nu}_e\mu^+\mu^-$	129
$e^\pm\gamma \to e^\pm\mu^+\mu^-$	1098*
$e^+e^- \to e^+e^-\mu^+\mu^-$	24.5
$e^\pm\gamma \to e^\pm\nu_\mu\bar{\nu}_\mu\mu^+\mu^-$	30
$\gamma\gamma \to \nu_\mu\bar{\nu}_\mu\mu^+\mu^-$	162
$e^+e^- \to e^+e^-\nu_\mu\bar{\nu}_\mu\mu^+\mu^-$	1.6

**Including a cut of 100GeV <$M(\mu^+\mu^-)$<150GeV and requiring a polar angle for both muons to be between 8° and 172°.*

By vetoing electron-tagged events at the preselection stage and with Bhabha coincidence included, rejection rates for four-fermion and $e^\pm\gamma \to e^\pm\mu^+\mu^-$processes can be obtained as 48% and 42%, respectively. The corresponding signal rejection of 7% is sufficiently low not to affect the signal statistics.

5. Preselection and MVA

Preselection in the analysis requires the reconstruction of two muons in an event, di-muon invariant mass in the range (105-145) GeV, absence of a high-energy electron (E>200 GeV) and polar angle above 30 mrad for all reconstructed electron candidates.

For the final selection, MVA techniques are used based on distributions of the following discriminating observables: visible energy of the event E_{vis}, transverse momentum of the di-muon system $p_T(\mu\mu)$, scalar sum of the transverse momenta of the two selected muons $p_T(\mu_1)+p_T(\mu_2)$, relativistic velocity of the di-muon system $\beta(\mu\mu)$, polar angle of the di-muon system $\theta(\mu\mu)$,cosine of the helicity angle$\cos\theta^*$, as used already in the CLIC study on $H\rightarrow\mu^+\mu^-$at $\sqrt{s}$ =3TeV [9].

A classifier output cut-off value of 0.098 is determined to minimize the relative statistical uncertainty of the measurement.

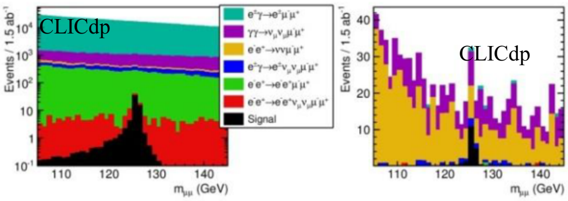

Fig.2. Stacked histograms of the Di-muon invariant mass distributions with preselection only (left) and after MVA selection (right).

The MVA selection efficiency for the signal is 32%. The overall signal efficiency including reconstruction, preselection, losses due to coincident tagging of Bhabha particles and MVA is 26%, resulting in an expected number of 20 signal events after all selection steps for a data set of 1.5ab-1.

6. Di muon invariant mass fit

In order to determine the BR($H\rightarrow\mu^+\mu^-$), the number of selected signal events N_s has to be known.

The number of signal events is determined by fitting the probability density functions (PDFs) describing signal and background of the di-muon invariant mass. Pseudo-data are obtained from randomly sampled fully-simulated signal events and by random generation of background from the corresponding PDF. In order to estimate the statistical uncertainty of the measurement and fit, 5000 toy Monte Carlo experiments are performed on pseudo-data. For each toy MC experiment, the di-muon invariant mass distribution is fitted by the function f,

$$f = k\cdot f_S + (1-k)\cdot f_{BCK}$$

where$f_S$and f_{BCK}stand for signal and background PDFs, k is a normalisation coefficient and the integration is performed in the mass region (105-145) GeV.

The number of signal events is determined as

$$N_S = k\cdot\int f_S dm$$

in the same mass integration range.

The RMS of the distribution of the number of signal events per experiment corresponds to a statistical uncertainty of the measurement of 38%(Fig. 3a). The pull distribution (Fig. 3b) confirms the proper signal and background description with PDFs.

This statistical uncertainty stems from the limited statistics of the signal and from the presence of irreducible backgrounds.

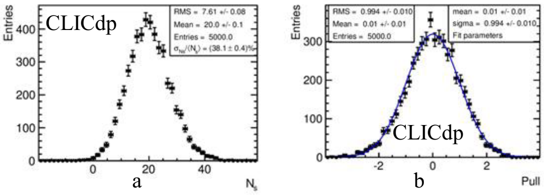

Fig.3. a) Distribution of the number of signal events in 5000 toy MC experiments; (b) The corresponding pull distribution.

7. Conclusion

The possibility to perform precision Higgs physics at CLIC allows for a search for signs of physics beyond the SM. Measurements of Higgs boson couplings are of particular interest. It has been shown that the measurement of the branching ratio for the SM Higgs decay into two muons can be performed with a statistical uncertainty of 38% at a 1.4 TeV CLIC with 1.5 ab^{-1} integrated luminosity. The result is dominated by the limited signal statistics and the irreducible background. This translates into an uncertainty on the coupling of Higgs to muons($g_{H\mu\mu}$)of 19%.

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