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Measurement of the branching ratios for the Standard Model Higgs decays into muon pairs and into Z boson pairs at a 1.4 TeV CLIC

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On behalf of the CLICdp collaboration

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Abstract

The measurement of the Higgs production cross-section times the branching ratios for its decays into $\mu^+\mu^-$ and ZZ^* pairs at a 1.4 TeV CLIC collider is investigated in this paper. The Standard Model Higgs boson with a mass of 126 GeV is dominantly produced via WW fusion in e^+e^- collisions at 1.4 TeV centre-of-mass energy. Analyses for both decay channels are based on a full simulation of the CLIC_ILD detector. All relevant physics and beam-induced background processes are taken into account. An integrated luminosity of 1.5 ab^{-1} and unpolarised beams are assumed. For the $H \to ZZ^*$ decay, the purely hadronic final state ($ZZ^* \to q\bar{q}q\bar{q}$) is considered as well as ZZ^* decays into two jets and two leptons ($ZZ^* \to q\bar{q}l^+l^-$). It is shown that the branching ratio for the Higgs decay into a muon pair times the Higgs production cross-section can be measured with 38% statistical uncertainty. It is also shown that the statistical uncertainty of the Higgs branching fraction for decay into a Z boson pair times the Higgs production cross-section can be measured with a precision of 18.3% and 5.6% for the hadronic and semi-leptonic ZZ^* decays, respectively.

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Measurement Of The Branching Ratios For The Standard Model Higgs Decays Into Muon Pairs And Into Z Boson Pairs At A 1.4 TeV CLIC

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On behalf of the CLICdp collaboration

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Abstract. The measurement of the Higgs production cross-section times the branching ratios for its decays into $\mu^+\mu^-$ and ZZ^* pairs at a 1.4 TeV CLIC collider is investigated in this paper. The Standard Model Higgs boson with a mass of 126 GeV is dominantly produced via WW fusion in e^+e^- collisions at 1.4 TeV centre-of-mass energy. Analyses of both decay channels are based on a full simulation of the CLIC_ILD detector. All relevant physics and beam-induced background processes are taken into account. An integrated luminosity of 1.5 ab^{-1} and unpolarised beams are assumed. For the $H \rightarrow ZZ^*$ decay, the purely hadronic final state ($ZZ^* \rightarrow q\bar{q}q\bar{q}$) is considered as well as ZZ^* decays into two jets and two leptons ($ZZ^* \rightarrow qql^+l^-$). It is shown that the branching ratio for the Higgs decay into a muon pair times the Higgs production cross-section can be measured with 38% statistical uncertainty. It is also shown that the statistical uncertainty of the Higgs branching ratio for decay into a Z boson pair times the Higgs production cross-section can be measured with a precision of 18.3% and 5.6% for the hadronic and semi-leptonic ZZ^* decays, respectively.

INTRODUCTION

The Compact Linear Collider (CLIC) is an option for a future multi-TeV linear electron-positron collider. One of the main aims of CLIC would be the high-precision measurement of the Higgs boson properties [1,2]. In e^+e^- collisions at the centre-of-mass energy $\sqrt{s}$ =1.4 TeV the SM-like Higgs boson with a mass of 126 GeV is dominantly produced via WW fusion with ~370000 expected events in 1.5 ab^{-1} of data. This would lead to the measurements of the couplings of the Higgs boson to the electroweak gauge bosons at the percent level as well as give access to rare processes such as $H \rightarrow \mu^+\mu^-$.

In this paper, we discuss the measurement of $\sigma(H\nu_e\overline{\nu_e}) \times BR(H \rightarrow \mu^+\mu^-)$ which is particularly challenging due to the very low branching ratio of 2.14×10^{-4} predicted in the SM [3] and $\sigma(H\nu_e\overline{\nu_e}) \times BR(H \rightarrow ZZ^*)$ where fully hadronic ($ZZ^* \rightarrow q\bar{q}q\bar{q}$), and semi-leptonic ($ZZ^* \rightarrow qql^+l^-, l = e, \mu, \tau$) final states are considered. Both analyses are performed using the CLIC_ILD detector concept [4].

MEASUREMENT OF $\sigma(H\nu_e\overline{\nu_e}) \times BR(H \to \mu^+\mu^-)$

Event Samples

The cross-section for Higgs production in WW fusion at 1.4 TeV is 244 fb without beam polarization. The $H \to \mu^+\mu^-$ signal statistics are expected to be small (of the order of a few tens of events) because of the small branching ratio for this particular decay. In Table 1, the full list of physics backgrounds is given.

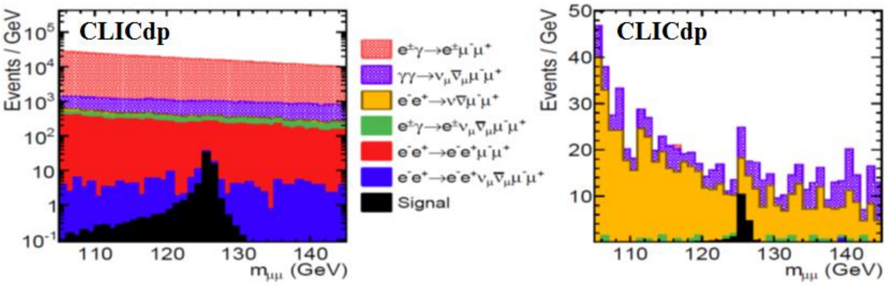
TABLE 1. List of considered processes with corresponding cross sections.

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

Preselection And Multivariate Analysis

The preselection in the analysis requires the reconstruction of a muon and an antimuon in an event, a di-muon invariant mass, $m_{\mu\mu}$, in the range (105-145) GeV, the absence of a high-energy electron (E>200 GeV) and a polar angle above 30 mrad.

For the final selection, multivariate analysis (MVA) techniques are used based on the boosted decision tree (BDT) classifier. The following 6 discriminating observables are used for the classification of events: visible energy of the event excluding the energy of the di-muon system (E_{vis}), transverse momentum of the di-muon system ($p_T(\mu\mu)$), scalar sum of the transverse momenta of the two selected muons ($p_T(\mu_1)$+ $p_T(\mu_2)$), boost of the di-muon system ($\beta(\mu\mu)$), polar angle of the di-muon system ($\theta(\mu\mu)$), cosine of the helicity angle ($\cos\theta^*$). The cut on the classifier output was optimised to minimise the statistical uncertainty of the measurement.



(a) (b)

FIGURE 1. Stacked histograms of the di-muon invariant mass distributions with preselecton only (a) and after MVA selection (b).

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 the MVA is 24%, resulting in an expected number of 19 signal events. Distributions of the di-muon invariant mass before and after the MVA selection are shown in Figure 1.

Di-Muon Invariant Mass Fit

In order to determine $\sigma(H\nu_e\overline{\nu}_e) \times BR(H \rightarrow \mu^+\mu^-)$, 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 the signal and the background distributions of the di-muon invariant mass. In order to estimate the statistical uncertainty of the measurement, 5000 toy Monte Carlo (MC) experiments are performed.

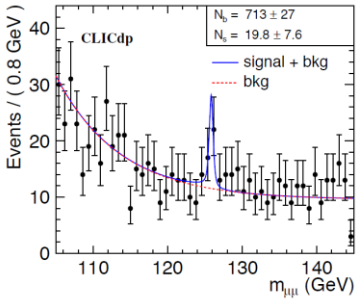


FIGURE 2. Fitted distribution of the di-muon invariant mass $m_{\mu\mu}$, for the sum of the signal and the total background in one toy MC experiment.

The RMS of the distribution of the number of signal events per experiment corresponds to the statistical uncertainty of the measurement of 38% [5].

MEASUREMENT OF $\boldsymbol{\sigma(H\nu_e\overline{\nu_e})} \times \boldsymbol{BR(H \rightarrow ZZ^*)}$

Event Samples

In this analysis, two final states are studied: the fully hadronic final state, $ZZ^* \rightarrow q\bar{q}q\bar{q}$, with a branching ratio of 49% resulting in an effective cross section of 3.45 fb and the semi-leptonic final state, $ZZ^* \rightarrow qql^+l^-$, with a branching ratio of 10% and an effective cross-section of 0.995 fb.

In Table 1, the list of the signal and main background processes is given with the corresponding cross sections.

Preselection And Multivariate Analysis

For the semi-leptonic final state, the first step of the physics object identification is searching for isolated leptons (electrons, muons or taus). Exactly two leptons are required, otherwise the event is rejected. Then, all particles in the event not identified as leptons are clustered by the k_t algorithm into two jets. For the hadronic final state, the event is directly clustered by the k_t algorithm into four jets.

For both final states, flavour-tagging is performed and a preselection based on kinematic variables is applied. The preselection cuts for the fully hadronic final state require one on-shell Z boson (45 GeV < m_Z < 110 GeV), one off-shell Z boson (m_{Z*}< 65 GeV), a Higgs invariant mass in the range (90 GeV < m_H < 165 GeV), the distance value between the two closest jets ($-\log y_{34} < 3.5$, $-\log y_{23} < 3.0$), a visible energy in the range (100 GeV < E_{vis} < 600 GeV), a missing transverse momentum above 80 GeV (p^T_{miss}>80 GeV) and b-tag probabilities of less than 0.95 for both jets ($P(b)^{(jet_1)}$, $P(b)^{(jet_2)}$<0.95).

After the preselection, an MVA event selection based on the BDT classifier is performed to obtain the final results. In both final states, the BDT cut maximising the significance is chosen, giving an overall efficiency of 18% and 30.4%, for the fully-hadronic and semi-leptonic final states, respectively. Figure 3 (a) includes all events that pass the preselection, while Figure 3 (b) shows all events passing the BDT selection for semi-leptonic final state. The statistical uncertainty for $\sigma(H\nu_e\overline{\nu}_e) \times BR(H \rightarrow ZZ^*)$ is calculated as:

$$\sigma(H\nu_e\overline{\nu}_e) \times BR(H \rightarrow ZZ^*) = \frac{\sqrt{S+B}}{S} \cdot 100\%, \quad (1)$$

where S denotes the number of selected signal events, and B the number of selected background events. The final result is found to be 18.3% and 5.6% for the fully-hadronic and semi-leptonic final state, respectively.

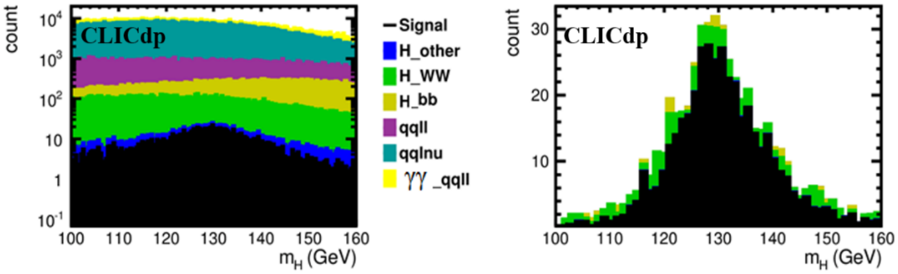


FIGURE 3. The Higgs invariant mass distributions after preselection (a) and after MVA selection (b) for the semi-leptonic final state.

TABLE 2. List of considered processes with corresponding cross sections for the $\sigma(H\nu_e\overline{\nu_e}) \times BR(H \to ZZ^*)$ measurement.

Process	**σ(fb)**
$e^+e^- \to H\nu\bar{\nu}, H \to ZZ^* \to q\bar{q}q\bar{q}$	3.45
$e^+e^- \to H\nu\bar{\nu}, H \to ZZ^* \to q\bar{q}l^+l^-$	0.995
$e^+e^- \to H\nu\bar{\nu}, H \to WW \to q\bar{q}q\bar{q}$	27.6
$e^+e^- \to H\nu\bar{\nu}, H \to b\bar{b}$	136.9
$e^+e^- \to q\bar{q}q\bar{q}\nu\bar{\nu}$	24.7
$\gamma\gamma \to qqll$	13829.7
$e^+e^- \to qqll$	2725.8
$e^+e^- \to qql\nu$	4309.7
eγ → $qqqq\nu$	338.5

RESULTS AND CONCLUSIONS

The expected precisions for the measurements of $\sigma(H\nu_e\overline{\nu_e}) \times BR(H \to \mu^+\mu^-)$, $\sigma(H\nu_e\overline{\nu_e}) \times BR(H \to ZZ^* \to q\bar{q}q\bar{q})$ and $\sigma(H\nu_e\overline{\nu_e}) \times BR(H \to ZZ^* \to q\bar{q}l^+l^-)$ are found to be 38%, 18.3% and 5.6%, respectively. They are dominated by the limited signal statistics and the presence of large backgrounds. The obtained results are included in the fit to all possible measurements at CLIC to contribute to the Higgs to Z coupling, Higgs to μ coupling and to the total Higgs width Γ_H.

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REFERENCES

1. L. Linssen et al., eds., Physics and Detectors at CLIC: CLIC Conceptual Design Report, ANL-HEP-TR-12-01, CERN-2012-003, DESY 12-008, KEK Report 2011-7, 1202.5940, CERN, 2012.
2. H. Abramowicz et al., Physics at the CLIC e+e− Linear Collider – Input to the Snowmass process 2013, 1307.5288, 2013.
3. S. Dittmaier, et al., Handbook of LHC higgs cross sections: 2. differential distributions. (2012). arXiv:1201.3084
4. A. Münnich, A. Sailer, The CLIC_ILD_CDR Geometry for the CDR Monte Carlo Mass Production, LCD-Note-2011-002, 2011.
5. G. Milutinovic-Dumbelovic, et al., Physics potential for the measurement of $\sigma(H\nu_e\overline{\nu_e}) \times BR(H \to \mu^+\mu^-)$ at the 1.4 TeV CLIC collider, Eur. Phys. J. **C 75**, 515, 2015.