PROCEEDINGS OF SCIENCE

Measurement of the Higgs to $\gamma\gamma$ branching fraction at 3 TeV CLIC

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In this talk we address a full simulation of experimental measurement of the Standard Model Higgs boson decaying to di-photon at 3 TeV center-of-mass energy at the Compact Linear Collider (CLIC). Photons are massless and do not couple to Higgs boson at the tree level, but rather are created in a loop exchange of heavy particles either from the Standard Model or beyond. Any deviation of the Higgs to $\gamma\gamma$ branching fraction and consequently of the effective Higgs coupling may indicate a New Physics. It is shown that the product of the Higgs production cross section in WW-fusion and BR $(H \rightarrow \gamma\gamma)$, as the observable for determination of the Higgs to photon coupling, can be measured with a relative statistical precision of 5.5%, assuming the integrated luminosity of 5 ab^{-1} and unpolarized beams.

11th International Conference of the Balkan Physical Union (BPU11),
28 August - 1 September 2022
Belgrade, Serbia

*Speaker

PoS(BPU11)092

1. Introduction

The Compact Linear Collider (CLIC) is a mature option for a future linear electron positron collider at TeV scale center-of mass energies. One of the advantages of CLIC is that it offers high-precision measurement of the Higgs boson properties, in particular at the highest center-of-mass energy, exploiting statistically relevant producion of Higs boson via WW-fusion. Measurements of the Higgs branching ratios and consequently of the Higgs couplings provide a strong test of the Standard Model (SM). Since photons are massless, Higgs boson coupling to photons is realised through higher order processes involving heavy particles either from the Standard Model or beyond (Fig 1). Any deviation of the measured BR($H \rightarrow \gamma\gamma$), and consequently of the Higgs coupling $g_{H\gamma\gamma}$ from the predictions of the Standard Model, may indicate New Physics.

In the context of Higgs to di-photon decay analysis, all future electron-positron projects nicely complement HL-LHC results improving $g_{H\gamma\gamma}$ precision to a percent level [1]. Standalone CLIC operating at three energy stages delivers precision of Higgs coupling to photons of 4%.

The above precision is the combined result of global fit if all CLIC data, to be collected at 380 GeV, 1.4 TeV and 3 TeV operation. Individual measurements like the one presented here, serve as input to a global fit.

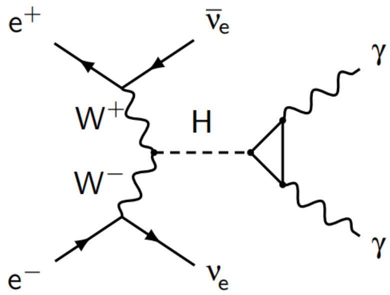

Figure 1: Lowest order Feynman diagram of the Higgs production in WW-fusion and subsequent Higgs decay to a pair of photons.

2. CLIC Detector

The CLIC_ILD detector model is based on the ILD detector proposed for ILC [2] and it has been modified to the CLIC experimental conditions. The CLIC_ILD detector concept is based on fine-grained electromagnetic and hadronic calorimeters optimized for particle-flow technique (PFA) [3]. High granularity in combination with the information from the central tracker leads to photon reconstruction efficiency of 99% and electron identification efficiency of 96% [6]. Photon identification efficiency is illustrated in Fig. 2 [4], while photon energy resolution as a function of number of electromagnetic calorimiter (ECAL) layers is shown in Fig. 3 [6].

More recently CLICdet detector model has been developed [7]. It is illustrated in Fig. 4. No significant impact on the $BR(H \rightarrow \gamma\gamma)$ is observed by the optimization of a particular detector model.

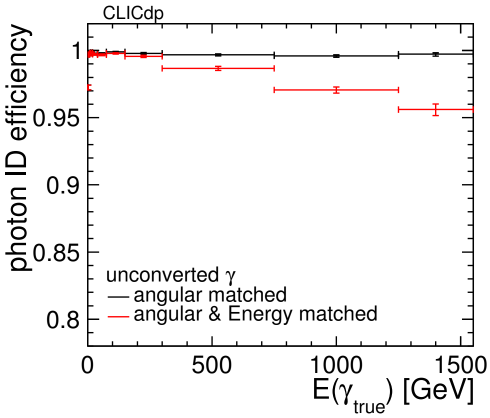

Figure 2: In a full detector simulation, photon is considered matched if its reconstructed position and energy are not different from the generated ones within certain margins that are discussed in detail in [4].

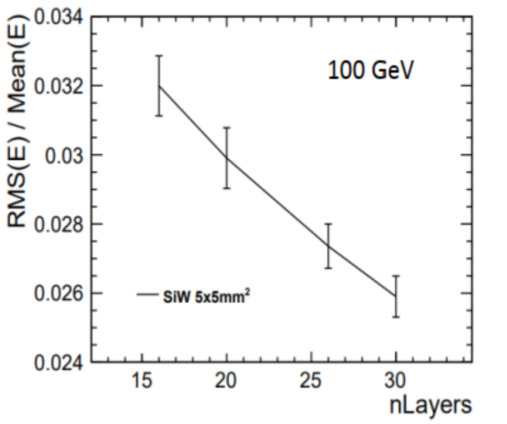

Figure 3: Photon energy resolution as a function of number of ECAL layers.

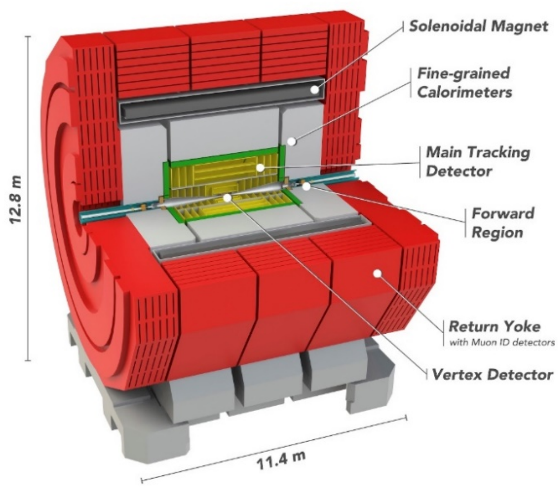

Figure 4: CLICdet model.

3. Signal separation

Cross-section for Higgs production at different center-of-mass energies is illustrated in Fig 5 [5]. In electron-positron collisions at 3 TeV center-of-mass energy, Higgs boson is dominantly produced via WW-fusion with an effective cross-section of 415 fb including realistic CLIC luminosity spectrum. Higgs production cross-section can be further increased by electron beam polarization due to a chiral nature of the charged current interaction. For a Higgs mass of 126 GeV, the SM prediction for the branching fraction BR($H \rightarrow \gamma\gamma$) is $2.23 \cdot 10^{-3}$. Assuming integrated luminosity of 5 ab^{-1}, it is expected that $2 \cdot 10^{6}$ Higgs bosons will be produced at 3 TeV center-of-mass energy. The expected signal yield is 5000 events. In Table 1, the full list of signal and background processes is

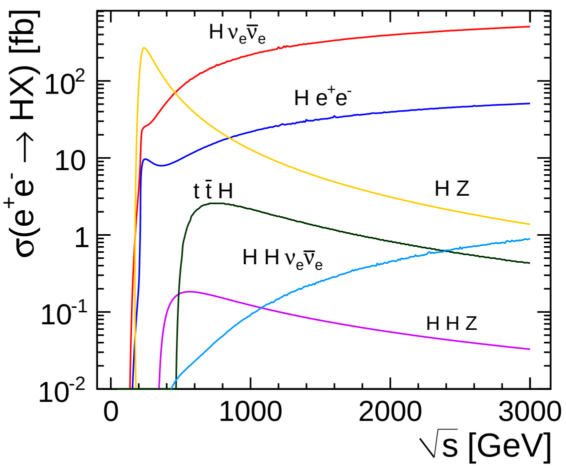

Figure 5: Higgs production cross-section for various processes as a function of center-of-mass-energy.

Signal process	$\sigma(fb)$	$N@5ab^{-1}$
$e^+e^- \to H\nu\nu, H \to \gamma\gamma$	0.95	4750
Background processes		
$e^+e^- \to \gamma\gamma$	15	$7.6 \cdot 10^4$
$e^+e^- \to e^+e^-\gamma$	335	$1.7 \cdot 10^5$
$e^+e^- \to e^+e^-\gamma\gamma$	33	$1.5 \cdot 10^5$
$e^+e^- \to \nu\bar{\nu}\gamma$	13	$6.5 \cdot 10^4$
$e^+e^- \to \nu\bar{\nu}\gamma\gamma$	26	$1.3 \cdot 10^5$
$e^+e^- \to q\bar{q}\gamma$	210	$1.1 \cdot 10^6$
$e^+e^- \to q\bar{q}\gamma\gamma$	47	$2.3 \cdot 10^5$

Table 1: Signal and considered background processes with the corresponding cross-sections at 3 TeV centre-of-mass energy. All processes are produced with generator level cuts to reduce CPU time, requiring, in addition, 100 GeV < $M_{\gamma\gamma}$ < 150 GeV mass window for the two-photon system.

given with the corresponding effective[1] cross-sections.

Background dominates over the signal by a factor of ~ 700, so sophisticated event selection is employed to reduce the number of background events as much as possible while preserving the signal in a way that the statistical significance is maximized. Selection is done in several steps. First step is to find events with exactly two isolated photons with transverse momenta greater than 15 GeV. This requirement removes to a great extent reconstructed photons in a signal event that do not originate from the Higgs decay. A photon is considered isolated if the energy of the reconstructed particles in a 14 mrad cone around the photon is less than 20 GeV. There are several more conditions for event selection. Event will be preselected if:

1. The reconstructed di-photon invariant mass is in the range from 110 GeV to 140 GeV, corresponding to the Higgs mass window,

[1] To reduce simulation time, polar angle for di-photon production is restricted to the central tracker.

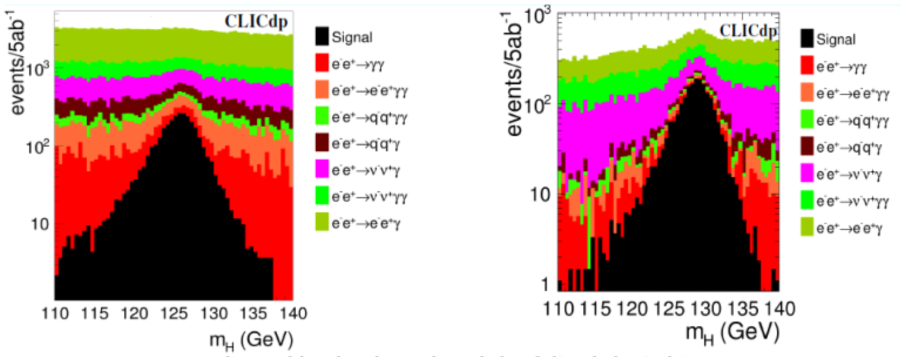

Figure 6: Reconstructed mass of the selected Higgs boson candidates before (left) and after (right) MVA .

2. The reconstructed di-photon energy is in the range between 100 GeV and 1000 GeV,
3. The reconstructed di-photon transverse momentum in the range between 20 GeV and 600 GeV.

The preselection is optimized to suppress high cross-section backgrounds like $e^+e^+ \to e^+e^-\gamma$ and $e^+e^- \to e^+e^-\gamma\gamma$, $e^+e^- \to q\bar{q}\gamma$. Most of the background events does not satisfy conditions of the preselection. Combined backgrounds are reduced by a factor of 10 with respect to the expected number of background events given in Table 1 after the generator level cuts, while preselection efficiency for the signal is 70%. To further separate signal and background events using their kinematic properties, multivariate analysis (MVA) employing Boosted Decision Tree Gradient (BDTG) is used. Twelve kinematic variables are used to train BDTG in signal and background separation. Some of the most sensitive variables are: energy and transverse momentum of di-photon system and of individual photons, polar angle distributions of candidate photons and energy depositions in electromagnetic and hadronic calorimeters. The MVA selection efficiency is found to be 60%, while the overall signal efficiency is 42%. Background to signal ratio is 10:1 after the MVA. Di-photon invariant mass distribution before and after the MVA selection is illustrated in Fig 6 .

4. Pseudo-experiments

In order to measure the $BR(H \to \gamma\gamma)$, the number of selected signal events N_s has to be known. It is determined by fitting the di-photon invariant mass of pseudo-data distribution with the pre-determined probability density functions (PDFs) describing the signal and irreducible background left after MVA application:

$$f(m_{\gamma\gamma}) = N_s \cdot f_s(m_{\gamma\gamma}) + N_b \cdot f_b(m_{\gamma\gamma}), \qquad (1)$$

where f_s and f_b are signal and background PDFs, respectively, while N_S and N_b stand for number of selected signal and background events. Such a fit is considered as a pseudo-experiment because it is performed on a fully simulated experimental data in a same way it would be done in a real experiment. Example of a single pseudo-experiment is given in Fig. 7. PDF functions are determined from simulation, describing the shapes of di-photon invariant mass distribution for signal and background. In order to estimate the statistical dissipation of the mean of the measured number of signal events, 5000 pseudo-experiments with 5ab^{-1} of data are performed. RMS of the measurement is used as a statistical estimator of the uncertainty of the signal count. From Fig. 7 it can be read that the statistical uncertainty of the selected number of signal events is ~5.5%.

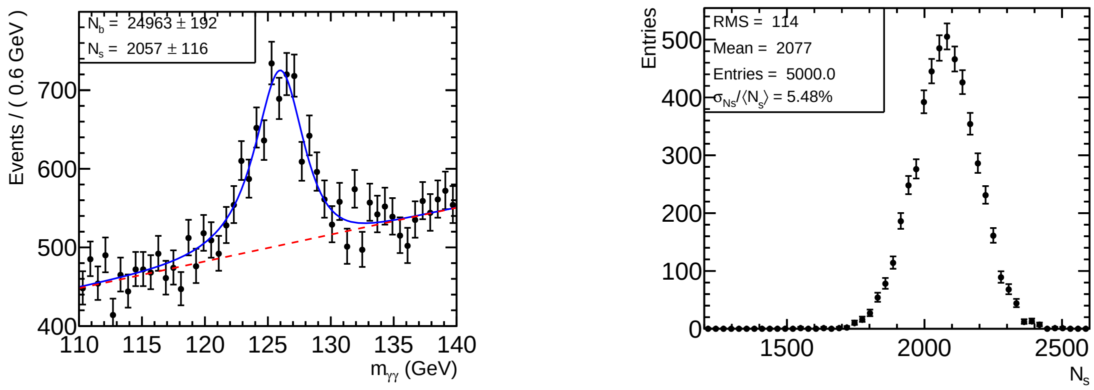

Figure 7: On the left hand side an example of a pseudoexperiment is shown, with di-photon invariant mass of pseudodata (points), fit function $f(m_{\gamma\gamma})$ from Eq. 1 (full line) and background fit function f_b (dashed line), while right hand side shows statistical dissipation of the mean of the signal count in 5000 pseudoexperiments.

Several sources of systematic uncertainty of the measurement are considered like uncertainties of photon identification efficiency, photon energy resolution, integrated luminosity, luminosity spectrum, effect of mathematical background modeling, etc. Relative systematic uncertainty of the measurement is found to be smaller than the statistical one. The result of the study presented here supersedes the estimates based on 1.4 TeV studies given in [8]. Detailed description of the analysis can be found in [9].

Acknowledgments

This research was funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia and by the Science Fund of the Republic of Serbia through the Grant No. 7699827, IDEJE HIGHTONE-P.

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