CLICdp-Conf-2024-001
02 February 2024

The Compact Linear Collider: physics potential

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Abstract

The Compact Linear Collider (CLIC) is a proposed TeV-scale linear electron-positron collider based on a novel two-beam acceleration technology. With its high luminosity and a broad energy range, from 380 GeV to 3 TeV, CLIC presents a mature option for a future Higgs factory and discovery machine. Detailed studies of the CLIC physics potential have been performed, mostly based on full GEANT4 simulations using a dedicated detector concept, CLICdet. In this contribution, a general introduction to the CLIC programme and highlights of CLIC physics studies are reported.

Talk presented at The First Edition of the African Conference on High Energy Physics (ACHEP),
Rabat-Kénitra, Morocco,
23–27 October 2023

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Abstract. The Compact Linear Collider (CLIC) is a proposed TeV-scale linear electron-positron collider based on a novel two-beam acceleration technology. With its high luminosity and a broad energy range, from 380 GeV to 3 TeV, CLIC presents a mature option for a future Higgs factory and discovery machine. Detailed studies of the CLIC physics potential have been performed, mostly based on full GEANT4 simulations using a dedicated detector concept, CLICdet. In this contribution, a general introduction to the CLIC programme and highlights of CLIC physics studies are reported.

Keywords: future experiments · higgs factories · energy frontier.

1 Introduction

The CLIC implementation plan assumes three running stages: first with $\sqrt{s} = 380\,\mathrm{GeV}$, and two subsequent high-energy stages at $1.5\,\mathrm{TeV}$ and $3\,\mathrm{TeV}$ [5]. It is assumed that integrated luminosities of $1\,\mathrm{ab}^{-1}$, $2.5\,\mathrm{ab}^{-1}$ and $5\,\mathrm{ab}^{-1}$ will be collected, respectively, including $100\,\mathrm{fb}^{-1}$ for an energy scan around the top quark pair-production threshold at the first stage. The high luminosity and wide energy range enable a broad physics programme, while staged implementation allows this to be adjusted in case of potential discoveries.

The studies of the CLIC physics potential rely on state-of-the-art software. The main event generator is WHIZARD, and most of the results are based on detailed GEANT4 simulation, most recently implemented in DD4HEP. Reconstruction frameworks include Conformal Tracking and VLC jet clustering algorithm dedicated for CLIC, as well as PandoraPFA for particle flow, algorithms for flavour tagging, isolation, and more. These tools build on the ILCsoft framework and are now implemented in KEY4HEP [6]. Beam spectra and beam-induced backgrounds are also included in the full simulation, with dedicated timing cuts applied at the reconstruction level to reduce a large background of beam-induced $\gamma\gamma \to$ hadrons events. Implementation of CLICdet in DELPHES also enables fast simulation studies.

2 Higgs physics

At $\sqrt{s} = 380\,\mathrm{GeV}$ the Higgs-strahlung channel ($\mathrm{e}^+\mathrm{e}^- \to \mathrm{ZH}$) allows the identification of Higgs production regardless of the H^0 decay mode, by using the $\mathrm{Z} \to \mathrm{e}^+\mathrm{e}^-$,

$\mu^+\mu^-$ recoil mass. Therefore, it is possible to measure g_{HZZ} coupling and BR(H $\rightarrow$ invisible) in a model-independent way, the latter of which can be constrained to 1% at 95% C.L. [7]. Higgs-strahlung can also be used to measure the branching ratios for most of the Higgs decays. A global fit to $\sigma \times \mathrm{BR}$ measured in the HZ and VBF ($\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{H}\nu\nu$) channels provides an estimate of most of the Higgs couplings with a precision of less than 1%, without any assumptions on physics models [1,8].

The Higgs self-coupling is connected to multiple open problems in fundamental physics. Direct access to the g_{HHH} coupling is possible only above $\sqrt{s} \sim 500\,\mathrm{GeV}$. Therefore, the high-energy stages of CLIC are well suited for the extraction of g_{HHH} in the ZHH (at 1.5 TeV) and $\mathrm{HH}\nu\nu$ (at 3 TeV) production channels. Based on the measured HH distributions, it is expected that g_{HHH} will be measured with an uncertainty of $^{+11}_{-8}\%$ [10]. CLIC is the future Higgs factory that will give the earliest measurement of g_{HHH} with $\mathcal{O}(10\%)$ precision [4].

3 Top quark physics

CLIC is also well suited for top-quark studies in multiple production channels. The energy of the first CLIC stage is just above the maximum for the pair-production cross section while the second stage, with $\sqrt{s} = 1.5\,\mathrm{TeV}$, is close to the maximum rate for $\mathrm{t\bar{t}H}$ production (the luminosity of a linear collider increases with energy), with 3 TeV data allowing a direct measurement of the top Yukawa coupling. An interesting physics case is also provided by $\mathrm{t\bar{t}}$ production in VBF, which is very sensitive to BSM effects in many scenarios [2].

The top-quark mass can be measured at CLIC using three different methods [2]. The most precise involves a dedicated scan of the $\mathrm{t\bar{t}}$ production threshold, with 10 energy points and $10\,\mathrm{fb}^{-1}$ collected at each energy. The cross section shape in this region is sensitive to the top-quark mass and width, which can be extracted using a template fit. With the main systematic uncertainties coming from the strong coupling constant α_s and the top Yukawa coupling, 20 MeV statistical and 50 MeV total uncertainty on the top mass can be achieved. The second method is based on the measurement of the $\mathrm{t\bar{t}}\gamma$ events above the threshold, with a reconstructed hard ISR photon, in which the mass is extracted from the cross section dependence on the effective centre-of-mass energy spectrum, similar to the threshold scan. The precision of this method is around 140 MeV. The top mass can also be directly reconstructed from the invariant mass distribution; however, this method is limited by large theoretical and jet energy scale uncertainties.

Further top-sector measurements include electroweak coupllings, CP properties and searches for FCNC and compositeness, among others.

4 Beyond Standard Model searches

Direct and indirect searches for new physics are high priorities in the CLIC programme. The effective field theory framework provides tools that are sensitive to high new-physics scales in a model-independent way by using precision observables. Based on measurements of Higgs and top-quark couplings, WW production and 2-fermion processes at CLIC, it is possible to test scales in the 10–100 TeV range, depending on the operator [3]. This extends the reach of the HL-LHC by orders of magnitude. Similarly, in many direct searches, e.g. for SUSY particles, dark photon, or long-lived particles, CLIC can also surpass the HL-LHC sensitivity, probing many corners of the parameter space and mass ranges almost up to the kinematic limit [9].

5 Conclusion

The clean environment at CLIC, its high collision energies and electron beam polarisation enable unprecedented precision in Higgs, electroweak and top quark studies. Key highlights of the programme are a determination of all Higgs couplings, studies of CP violation effects and a top-threshold scan. At high energy stages, CLIC is well-suited for both direct and indirect BSM physics searches. Physics studies show that CLIC surpasses the HL-LHC in its potential for precision measurements and is competitive in the exploration of many new physics scenarios.

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