The Compact Linear e^+e^- Collider (CLIC)
Snowmass 2021 LoI: Physics Potential

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Abstract

By providing e^+e^- collisions over the broad energy range 380 GeV to 3 TeV, the Compact Linear Collider (CLIC) provides excellent sensitivity to Beyond Standard Model physics, through direct searches and via a broad set of precision measurements of Standard Model processes, particularly in the Higgs and top-quark sectors. We strongly encourage the full consideration of multi-TeV lepton collisions as part of the Snowmass 2021 process.

Energy Frontier Topical Groups:

- ■ (EF01) EW Physics: Higgs Boson properties and couplings
- ■ (EF02) EW Physics: Higgs Boson as a portal to new physics
- ■ (EF03) EW Physics: Heavy flavor and top quark physics
- ■ (EF04) EW Physics: EW Precision Physics and constraining new physics
- □ (EF05) QCD and strong interactions: Precision QCD
- □ (EF06) QCD and strong interactions: Hadronic structure and forward QCD
- □ (EF07) QCD and strong interactions: Heavy Ions
- ■ (EF08) BSM: Model-specific explorations
- ■ (EF09) BSM: More general explorations
- ■ (EF10) BSM: Dark Matter at colliders

See also LoIs relating to CLIC submitted to:

- ■ (AF) Accelerator Frontier
- ■ (IF) Instrumentation Frontier

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1 The Compact Linear Collider (CLIC)

The Compact Linear Collider (CLIC) [1] proposes e^+e^- collisions up to multi-TeV energies. The main accelerator technologies have been demonstrated, a detailed detector design prepared and dedicated detector R&D carried out, and extensive physics studies undertaken. Much of this work is documented in the Conceptual Design Report (2012) [2–4] and in recent comprehensive updates (2018/19) [5–9], and is summarized in submissions to the recent update of the European Strategy for Particle Physics [10, 11]. Many of these documents are gathered at http://clic.cern/european-strategy. Several scenarios were considered as part of the European Strategy, including the complete CLIC programme, and a hybrid scenario in which initial e^+e^- collisions are provided by CLIC in one or two stages, followed by a potential subsequent proton collider, should the necessary proton-collider accelerator technology be sufficiently developed [12].

Following the European Strategy update, CERN will continue to invest in the key CLIC accelerator technologies over the next period, such that CLIC could be realised should the parallel feasibility study into a 100 km-long circular tunnel fail to converge. Owing to the unique features and potential of multi-TeV lepton collisions, and the ongoing open question of which collider should be next constructed at CERN, we strongly encourage prospects for multi-TeV lepton collisions to be fully considered in the Snowmass process.

2 The CLIC Physics Potential

The CLIC baseline staging scenario includes operation at centre-of-mass energies of 380 GeV, 1.5 TeV, and 3 TeV in order optimally to explore the broad range of fundamental physics that is shown in Figure 1.

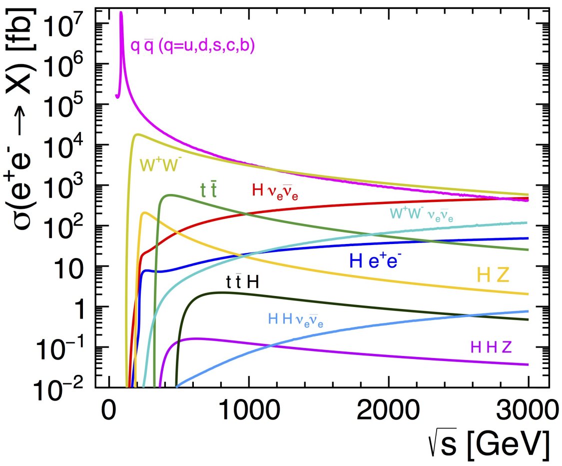

Figure 1: Production cross section as a function of centre-of-mass energy for various processes at an e^+e^- collider.

The current CLIC baseline staging scenario [13] assumes 1.0 ab^{-1}, 2.5 ab^{-1} and 5.0 ab^{-1} of luminosity collected at these three energy stages, respectively. The complete physics programme will span 25–30 years. The baseline CLIC accelerator provides ±80% longitudinal polarisation for the electron beam, and no positron polarisation. Equal amounts of −80% and +80% polarisation running are foreseen at the initial energy stage. At the two higher-energy stages, the running time is assumed to be shared between −80% and +80% electron polarisation in the ratio 80 : 20.

The CLIC physics programme will enable fundamental new insights beyond the capabilities of the HL-LHC.

Higgs Physics Highlights in Higgs physics include the high-precision extraction of the couplings to b- and c-quarks and W- and Z-bosons, enabled by the many complementary channels explored at CLIC; as well as the direct measurement of the Higgs self-coupling at the level of −8% to +11% [14]. Full-simulation Higgs studies are extensively documented in [15], updated for the baseline staging scenario in [13], and given for an example alternative running scenario with a longer initial stage in [16].

Top-quark Physics In top-quark physics an energy scan of $100\,\mathrm{fb}^{-1}$ during the initial stage around the $\mathrm{t\bar{t}}$ production threshold ensures a precise mass measurement; and measurement of production and asymmetries at all energy stages gives excellent sensitivity to new physics that couples to top quarks, as documented in [17].

Indirect Searches The flexibility and large accessible energy range provides a wide range of possibilities for discovery of new physics using very different approaches. Precision measurements of Higgs-boson, top-quark, and other Standard Model processes can be used to obtain indirect sensitivity to new physics scales via Effective Field Theories. This in turn allows decisive progress on a number of concrete BSM scenarios, including discovery of Higgs or top-quark compositeness that reaches far beyond the HL-LHC's potential exclusion, and sensitivity to potential contact operators that is comparable or extends beyond the reach of a 100 TeV proton collider, as detailed in the European Strategy Briefing Book [8, 18].

Direct Searches Furthermore, the high luminosity, absence of QCD backgrounds, precise knowledge of the initial state, and triggerless readout give access to very rare processes up to the kinematic limits at all energies. The CLIC experimental environment allows enhanced searches for non-standard signatures such as anomalous tracks, peculiar secondary vertices, or unexpected energy depositions in the calorimeters. The use of electron beam polarisation enhances this reach further and may help to characterise newly discovered phenomena; and threshold scans provide very precise measurements of particle masses. Many scenarios for new phenomena are assessed in [8, 18].

3 CLIC in the Snowmass Process

Studies of high-energy lepton collisions should be a feature of the Snowmass physics considerations. As particular areas of focus beyond Higgs physics we would like to emphasise:

- the importance of top-quark physics in $\mathrm{e^+e^-}$ collisions
- the importance of several energy stages in $\mathrm{e^+e^-}$ collisions
- direct searches, in particular for elusive signatures
- further and novel ways of constraining new physics from precision measurements
- the importance of beam polarisation
- BSM scenarios of particular interest in multi-TeV lepton collisions

Colleagues from the US and elsewhere are invited to participate in CLIC physics studies, for example using the CLIC Delphes card [19] and Whizard 2 settings [20], or alternatively the full DD4hep/GEANT simulation and iLCSoft/Key4hep reconstruction. In particular, if new Snowmass benchmarks are defined, we should be glad for CLIC sensitivities to them to be studied.

4 Conclusions

CLIC is a mature proposal for the next large facility in high energy physics, with a guaranteed programme of Higgs and top-quark physics coupled with unique reach for new phenomena enabled by the high-energy running. We strongly encourage further exploration of this physics potential during the Snowmass process.

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