

## Progress for Higgs Bosons Physics at the LC <sup>\*</sup>

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### Abstract

A linear  $e^+e^-$  collider (LC) could go into operation in the next decade. The LHC is currently exploring the Higgs sector of the SM, various supersymmetric extensions and other models. The LC is necessary to complete the profile of a Higgs boson of any model. Experimental analyses and theory calculations for Higgs physics at the LC are currently performed. We review recent progress, as presented at the *LCWS 2011* in Granada, Spain.

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# Progress for Higgs Bosons Physics at the LC

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A linear  $e^+e^-$  collider (LC) could go into operation in the next decade. The LHC is currently exploring the Higgs sector of the SM, various supersymmetric extensions and other models. The LC is necessary to complete the profile of a Higgs boson of any model. Experimental analyses and theory calculations for Higgs physics at the LC are currently performed. We review recent progress, as presented at the *LCWS 2011* in Granada, Spain.

## 1 Introduction

There is a world-wide consensus that a linear  $e^+e^-$  Collider (LC) should be the next major project in the field of high-energy physics. Depending on decisions on design and site it could go into operation somewhen in the next decade. Currently the LHC is investigating the mechanism of electroweak symmetry breaking, where the Higgs sector of the Standard Model (SM) and of the Minimal Supersymmetric Standard Model (MSSM) are the leading candidates. Consequently, an LC will take data several years after the LHC Higgs sector exploration. However, the physics case for the LC, especially in Higgs physics, independent of what the LHC will find, has been made many times [1–3]. The complementarity and the synergy of the two colliders and combined physics analyses has been discussed extensively in Ref. [4].

A very important consideration in respect of the LC physics case is the question what the LC can add to the LHC (or what a combined LC/LHC analysis can add to the LHC). It has been shown [1–5] that in *all* conceivable scenarios of new physics the LC can add valuable and important information. In particular, it can add precision analyses, pinning down model parameters extremely precisely. Moreover, in contrast to the LHC, this can often be done in a model-independent way. Furthermore in many scenarios the LC can discover new states that cannot be detected at the LHC. The combination of these three capabilities (precision measurements, model independent analyses, discovery of new particles) enables the LC to determine the underlying physics model.

While the physics case for the LC has been made and the physics potential of the LC has been analyzed, there are still many tasks that have to be performed until the full potential of the LC can be exhausted. This concerns the experimental analyses as well as the (corresponding) theoretical calculations. In many scenarios the feasibility of the experimental analyses has to be worked out in detail. Theory calculations at the level of the anticipated LC precision still have to be performed. Progress in both directions has to be made over the next years in order to be ready once the LC operation starts. A status of the field and about recent progress was given at the *LCWS 2011* in Granada, Spain. Here we briefly review the presentations about new experimental analyses and new theory calculations given at the *LCWS 2011* in the field of Higgs physics.

## 2 Progress in Granada

If a (SM-like) Higgs mechanism is realized in nature, the LHC will find a Higgs boson and measure its characteristics [6–9]. To be certain the state observed is indeed the Higgs boson, it is necessary to measure the couplings of this state to the  $W$  and  $Z$  gauge bosons, and to fermions such as the top and bottom quarks and the tau leptons. Consequently, the measurements at the LHC include a mass determination at the per-cent level and coupling constant determination at the level of 10-20%. However, in order to do this several assumptions about the realization of the Higgs mechanism have to be made. Analyses could become much more involved if the Higgs boson decay rates are strongly different from the SM rates. Interesting physics could easily hide in the 10-20% precision achievable for the Higgs boson couplings. Higgs self-couplings are extremely complicated if not impossible to measure at the LHC. On the other hand, all these problems can be overcome with the LC measurements [1, 3, 5].

The main points on the progress that will be necessary to fully exploit the LC capabilities are:

- more analyses with full simulations of the relevant LC processes have to be performed,
- higher precision in the theory calculations for the relevant processes are needed to match the anticipated LC accuracy,
- the Higgs/EWSB sector of more models has to be worked out,
- tools (encoding new models and/or high-precision calculations) have to become available,
- the LHC/LC interplay has to be worked out in more detail.

These issues have (partially) been addressed at the *LCWS 2011*. Progress has been reported e.g. about the following subjects (more details can be found in the original publications).

### Theory:

- Progress in loop calculations for the LC was summarized in Ref. [10].
- Precision 2HDM studies for the LC [11].
- Theory calculations in the complex MSSM (cMSSM) for the Higgs production from SUSY decays [12] (to be implemented into the publicly available code `FeynHiggs` [13]).
- Higgs analyses for models with composite Higgs bosons [14].
- Higgs potential and Higgs decays in triplet Higgs models [15].
- ILC analyses for models with Higgs triplets [16].
- Extended SUSY Higgs sectors and their decoupling properties at colliders [17].
- Theory evaluations for the Higgs sector of the Non Minimal Flavor Violating MSSM [18].
- Theory evaluations for the Higgs sector of the MSSM with heavy Majorana neutrinos/sneutrinos [19].

- Higgs production in models with universal extra dimensions [20].
- Predictions for a fermiophobic Higgs at the LC [21].
- Multi tau lepton signatures in leptophilic two Higgs doublet model at the LC [22].
- Determining the CP parity of Higgs bosons at the ILC in the tau decay channels [23].
- Theory evaluations for the Higgs sector of a pure  $B - L$  model [24].
- Theory evaluations concerning dynamical symmetry breaking in SUSY extensions of the Nambu Jona-Lasinio model [25].

**Experiment:**

- Analysis for Higgs branching ratio measurements at the ILC [26].
- Measurement of the top Yukawa coupling at the ILC [27].
- Improved  $ZHH$  studies with ILD full simulation [28].
- Analysis of light Higgs decays at CLIC [29].
- Analysis of heavy Higgs bosons at CLIC [30].

### 3 Outlook

With the results on Higgs boson searches published recently by ATLAS [31] and CMS [32] the prospects for Higgs boson physics are brighter than ever before. It may well be that with the additional data to be collected in 2012 the hints reported in Refs. [31, 32] will turn into a discovery of a new state, compatible with a SM-like (or non-SM-like) Higgs particle, with a mass around  $\sim 125$  GeV. The particle physics community must be prepared for this possibility.

There is a large consensus that an LC running at relatively low energy (to maximize the production cross section) is the best machine to study such a new particle in detail. It would be the ideal motivation for the construction of the LC. Only an LC could measure the profile of such a Higgs-like state to a very high precision. This includes measurements of its mass, its couplings to SM fermions and gauge bosons, its width as well as its quantum numbers and spin. Possibly the high precision could even help to distinguish various models predicting such a state from each other. In the case of SUSY, an LC could strongly improve the reach for heavier Higgs bosons, either in  $e^+e^-$  pair production or in  $\gamma\gamma$  induced single production. However, we need more preparation from the theoretical and from the experimental side to be ready to produce and exploit the necessary high precision in LC Higgs physics. The contributions presented at the *LCWS 2011* presented a small, but relevant step into this direction.

In the case of a confirmation of the hints seen at 125 GeV a staged approach could turn out to be an ideal solution. In the first stage at low energy the LC can be used as a Higgs factory. In a second stage at energies above  $\sim 350$  GeV it would turn additionally into a top factory. Finally, in the highest energy stage the LC could continue the TeV scale exploration currently performed at the LHC. The various options provided by an LC (GigaZ [33], the  $\gamma\gamma$  mode, ...) have the potential to further improve our knowledge on the Higgs sector (and any other sector) of the underlying model.

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