Physics at ILC

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Abstract. The physics case for the International Linear Collider (ILC) project is discussed. The project is proposed to be built in Japan and a final decision has to be taken in 2016 on a government level. The initial data taking with $e^+e^-$ beams is planned at the center-of-mass energy of 500 GeV with following runs at 250 GeV and 350 GeV. Potential physics studies at ILC are discussed with a special attention to the measurements, which are expected to have a better sensitivity at ILC in respect to the LHC experiments.

1. Introduction
The linear $e^+e^-$ collider at a few hundred GeV center-of-mass (CM) energy is a next mega-size project, which has to be built in high energy physics after the LHC [1]. Realization of such project, so-called International Linear Collider (ILC), was recently proposed in Japan. The basic physics goal, which has to be reached at ILC, is a detailed study of Higgs boson behaviours. The Higgs boson was discovered at Large Hadron Collider (LHC) a few years ago and by now several decay channels of this particle have been observed. However, the number of the studied channels and their statistical significance is limited at LHC and will be limited even after modernization. In contrast, the linear collider will allow to reconstruct several tens of thousands of the Higgs bosons. It will provide an opportunity to study already observed channels with a high statistical sensitivity and to discover new rare decays of the Higgs boson. The linear collider will allow to measure precisely different parameters of the Higgs boson, such as its mass, width and $CP$ quantum number admixture [2].

Besides the detailed studies of the Higgs boson, the linear collider is well suited for precise studies of the top quark, $Z$ and $W$ bosons and searches for physics Beyond the Standard Model (BSM) [3]. In particular, a high rate is expected for the $e^+e^- \rightarrow t\bar{t}$ process, providing a huge sample of top quarks, taking into account the process production cross section of about 1 pb at the 350 GeV CM energy. ILC has several advantages over LHC, such as cleanliness (low backgrounds), a high production rate for heavy particles, simplicity of experimental event topology and a high accuracy of underlying processes theoretical calculations.

2. Proposed linear collider in Japan
In 2013 the candidate site for the linear collider construction was proposed in Kitakami, Japan. The general layout for ILC is shown in figure 1. The basic scenario supposes the data taking start at the 500 GeV CM energy with 31 km long collider. The later upgrade assumes increasing the size to 50 km and the energy to 1 TeV. The expected beam size at the interaction point is 6 nm x 500 nm x 300 mm.
The ILC luminosity should reach \( \sim 2 \times 10^{34} \text{ cm}^{-2} \text{s}^{-1} \) with a possible increase by a factor two; the beam polarization is expected to be > 80\% for \( e^- \) and 30-40\% for \( e^+ \) beams.

![Figure 1. Basic layout of the International Linear Collider.](image)

The current scenario assumes to take about 500 fb\(^{-1}\) integrated luminosity at the beginning of the data taking, with following collection of 200 fb\(^{-1}\) at 350 GeV and of 500 fb\(^{-1}\) at 250 GeV. The physics at 500 GeV CM energy is more comprehensive, comparing with 250 GeV and 350 GeV, due to three-body channels opening, such as \( e^+ e^- \rightarrow t \bar{t} H \). To increase the cross section for the later channel the CM energy can be initially raised to 550 GeV.

3. ILC detectors: ILD and SiD
The two detectors (figure 2) are proposed for the ILC project: International Large Detector (ILD) and Silicon Detector (SiD).

![Figure 2. General 3D view of the detectors: a) ILD; b) SiD.](image)
ILD detector combines excellent tracking and finely-grained calorimetry systems. This gives ILD the ability to reconstruct the energy of individual particles, known as the Particle Flow approach. The precision that can be achieved by ILD is ideal for studies in particle physics which call for accurate measurements of particles and their properties.

SiD is a multi-purpose detector, optimized for the broad range of physics opportunities at ILC. It is a compact, cost-constrained detector made possible with a 5 Tesla magnetic field and silicon tracking. The SiD concept incorporates Si/W electromagnetic calorimetry and all-Si tracking in a detector design which attempts to optimize physics performance, constrain costs, and be robust against physics and machine backgrounds. The highly granular calorimeter is optimized for particle flow analysis.

4. Physics case for the ILC experiments
4.1 Higgs boson measurements
The main goal of the ILC experiments is measurements of the Higgs couplings. It can be done using three major Higgs boson production processes: $e^+ e^- \rightarrow Z H$ ("higgsstrahlung"), $e^+ e^- \rightarrow \nu \bar{\nu} H$ ("W fusion"), and $e^+ e^- \rightarrow e^+ e^- H$ ("Z fusion"). These processes have large production cross sections at the region of the 230-500 GeV CM energy (figure 3). For each of these processes we can identify all of the major Higgs decays modes, such as $H \rightarrow b \bar{b}$, WW*, c\bar{c}, \tau\tau and $\gamma \gamma$, with high efficiency.

![Figure 3. Cross sections for the three major Higgs production processes as a function of CM energy.](image)

The higgsstrahlung process $e^+ e^- \rightarrow Z H$ has a special advantage. By reconstructing the $Z$ boson at two lepton mode its recoil mass can be calculated. The recoil mass to $Z$ can be used to observe a clear Higgs signal without looking at the Higgs decay at all. This has three important consequences. First, it gives an opportunity to determine the total width of the Higgs boson and to obtain the absolute normalization of the Higgs couplings. Second, it allows to obtain the rate of the Higgs decays to invisible or exotic states. Third, it provides the way for a very precise determination of the mass of the Higgs boson.

Using the absolute normalization of the Higgs couplings the partial couplings to different final states can be measured in a model-independent way with a high accuracy. The accuracy of the most couplings measurements can reach the precision of 1% or better in the course of the ILC program. Running ILC at 550 GeV rather that 500 GeV would improve the precision from 9% to
3% using the channel $e^+e^- \rightarrow t\bar{t}H$. Such measurements are very important and can be used for indirect searches for a New Physics. Different BSM models will result in different biases from the couplings, expected in the Standard Model (figure 4).

Figure 4. Two examples of BSM models and their predicted effects on the pattern of Higgs boson couplings. a) a supersymmetric model; b) a model with Higgs boson compositeness. The error bars indicate the 1σ uncertainties expected from the model-independent fit to the full ILC data set.

4.2 Top quark measurements.

Comprehensive studies of the top quark can be performed with the linear collider. This includes precise measurements of the top quark mass, width, CP-violating effects [4] and couplings. Top production cross section close to threshold of two top masses has to be measured to obtain a precise value of mass. Also the $e^+e^- \rightarrow t\bar{t}$ process is sensitive to the intermediate $Z'$ boson contribution, additionally to the regular $Z$ boson. It is also important to measure the forward-backward asymmetry in top production processes to resolve the tension between experiment and theory, observed for that parameter at Tevatron.

4.3 Other measurements

An important part of the ILC program is a search for new particles, which are not presented in the Standard Model. The QCD processes can be studied and compared with theoretical predictions with a high accuracy. Potentially CP-violation effects can emerge in various processes, indirectly indicating to BSM contributions. The linear collider has a strong physics program, which is complementary to the LHC physics program in many aspects.

References

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