STATUS OF LINEAR COLLIDER PROJECTS*

Sabine Riemann

DESY, Platanenallee 6, D-15738 Zeuthen, Germany
sabine.riemann@desy.de

(Received October 29, 2009)

The status of the future linear collider projects, ILC and CLIC, is presented.

PACS numbers: 29.20.Ej, 29.27.–a, 29.27.Fh

1. Introduction

So far, the Standard Model agrees well with the measurements and no significant deviation has been observed. But the Higgs boson — important constituent of the Standard Model — has not yet been found. Electroweak precision measurements including top-quark and W boson masses measured at the Tevatron constrain the Higgs mass to values below 157 GeV [1]. Direct Higgs searches at the Tevatron exclude the mass range between 160 GeV and 170 GeV [2]. The LHC will detect the Higgs boson and new physics at the TeV scale if it exists. But to unravel the gauge structure of underlying symmetry, precision measurements at lepton colliders are required. In this contribution the status of the two linear collider projects, ILC and CLIC, is presented.

1.1. The key issues of high energy e^+e^- colliders

The advantages of lepton colliders are the clearly defined initial state, the known centre-of-mass energy for the hard scattering process, and the possibility to chose the helicity for the initial state leptons. The future e^+e^- collider should allow measurements beyond the highest energy reached at LEP (200 GeV) up to the TeV range. Focus is a center-of-mass energy of 500 GeV for studies of Standard Model processes as well as physics beyond. The necessity of threshold and resonance scans for SM and new particles

* Presented at the XXXIII International Conference of Theoretical Physics, "Matter to the Deepest", Ustroń, Poland, September 11–16, 2009.

requires a tunable energy. The highest energy that can be provided for collisions is finally determined by the accelerator technology. The high statistics required for precision measurements can only be achieved with high luminosity.

1.1.1. Luminosity

The luminosity of a collider is given by

$$L = \frac{n_b N^2 f_{\text{rep}}}{4\pi\sigma_x\sigma_y} \times H_D \,, \tag{1}$$

where N is the numbers of particles per bunch, n_b the number of bunches per train, and f_{rep} is the repetition rate of bunch trains. The parameter H_D describes the pinch effect which yields self-focussing of crossing beams resulting in increased luminosity. A high luminosity requires small beam sizes, σ_x and σ_y. But small beams create beamstrahlung: the radiation of hard photons is due to the strong electromagnetic fields between the particles in crossing bunches. The beamstrahlung is described by

$$\delta_{\text{BS}} = \frac{\Delta E}{E} \propto \frac{E_{\text{cm}}}{\sigma_z} \left(\frac{N}{\sigma_x + \sigma_y} \right)^2 , \tag{2}$$

it increases the energy uncertainty and induces background in the detectors. To minimize the beamstrahlung, flat beams are used: A small beam extension in y-direction minimizes the beamstrahlung but allows a reasonable luminosity with a relatively large value for $\sigma_y \times \sigma_x$. Another important issue for high luminosity and good performance of the accelerator is the power transfer. The radiofrequency power has to be brought with high transfer efficiency η_{RF} to the beam,

$$P_{\text{beam}} = E_{\text{cm}}\, f_{\text{rep}}\, n_b\, N = \eta P_{\text{RF}} \,. \tag{3}$$

The high transfer efficiency is one of the challenges for the high energy colliders.

2. The linear collider projects

There are currently two projects: The International Linear Collider (ILC) [3] and the Compact Linear Collider (CLIC) [4]. Superconducting acceleration is the basic technology for the ILC. CLIC is based on on a two-beam acceleration using normalconducting structures.

Both, the ILC and CLIC Collaborations, prepare the design for a linear collider including the detailed design concept, performance assessments, a reliable international costing, an industrialization plan, a siting analysis and detector concepts and scope. The final decision will be driven by the physics requirements after a few years running of LHC, the success of the technology, and the feasibility of the project also concerning the costs.

2.1. The ILC project

A Reference Design Report (RDR) [3] for the ILC project was presented in 2007 which describes the accelerator after the first round of design optimisation and cost evaluation. Together with the accelerator description the physics RDR [5] was published reporting the physics potential of the ILC. The ILC energy should be adjustable from 200–500 GeV and upgradeable to 1 TeV, the luminosity amounts $2 \times 10^{34}\,\mathrm{m}^{-2}\mathrm{s}^{-1}$ to collect $500\,\mathrm{fb}^{-1}$ within the first four years. The electron beam will be polarised with a degree $P_{e^-} \geq 80\%$, positron polarisation is foreseen as an upgrade option, $P_{e^-} \geq 60\%$. The energy stability and precision should be better than 0.1% to reach all physics goals. The layout of the machine is displayed in Fig. 1. The ILC includes the polarised electron source, the undulator-based positron source and the 5 GeV damping rings for electrons and positrons housed in a common tunnel at the center of the ILC. Each beam passes subsequently a bunch compressor system prior the injection into the 11 km long main linacs which are utilizing 1.3 GHz superconducting RF cavities operating at an average gradient of 31.5 MV/m. The RF pulse length is 1.6 ms, the pulse repetition rate is 5 Hz. The total power consumption is 230 MW.

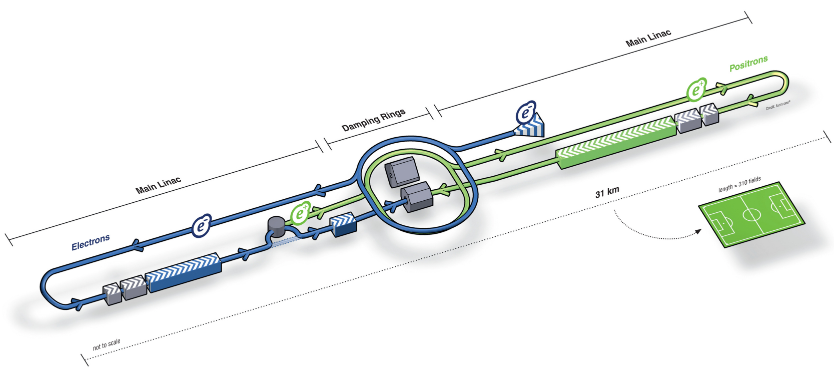

Fig. 1. Schematic layout of the ILC.

The ILC comprises one interaction region for measurements with two push–pull detectors.

The worldwide R&D efforts for the ILC is coordinated by the Global Design Effort (GDE).

2.2. The cost estimate in 2007

The costs for the ILC project were estimated in 2007 with 6.7 Billion ILC units (ILCU), where 1 ILCU corresponds to 1 US Dollar (2007), 0.83 Euro or 117 Yen, respectively. 4.87 BILCU are shared between all contributors, 1.78 BILCU are site-specific costs. The most important part of these costs, 37%, are required for conventional facilities and civil construction. A fraction of 35% is needed for the SCRF main linac, 37% are required for conventional facilities and civil construction, and 28% for the other accelerator systems. In addition, about 10,000 person-years implicit labour are estimated for engineering design, preparation activities, fabrication and tests of prototypes, as well as for surface acquisition, underground investigations, easement costs and last but not least for the detectors. With a new ILC baseline design also the cost assessment will be revised.

2.2.1. Technical design R&D plans

With the publication of the RDR also a schedule for the further strategy was published. In particular, it was planned to finalize an Engineering Design Report in 2010. Due to serious budget cuts the schedule has been delayed, the new strategy includes a revised schedule with a first phase for the technical design (TDP1) lasting until 2010, and a second phase (TDP2) till end 2012. At the end of TDP1 a new, optimized baseline design will be available. During TDP2 the feasibility of critical R&D issues will be demonstrated. End 2012/beginning 2013 the Technical Design Report will be published indicating that the ILC is ready for construction.

2.2.2. Superconducting RF

The production of superconducting accelerating structures (SCRF) is decisive, and it is a big cost driver. Hence it is important to demonstrate mass production and tests of cavities as well as their integration in cryomodules engineering the full accelerator of 2×11 km length. A successful industrialized production implies lower costs. Within TDP1 it has to be demonstrated that 50% of the produced cavities meet the requirements, in particular the gradient of 31.5 MV/m. After TDP2, this yield has to be increased to 90% due to a qualified production process. Currently, a yield of 45% is achieved be a qualified vendor producing cavities with a gradient 35 MV/m.

The cavities have to be integrated in a cryomodule, the cryomodules have to be combined to strings and tested with beam. Complementary tests will be performed in each region — in Europe at DESY, in Americas at FNAL and in Asia at KEK. The test facilities are under construction. At DESY, the FLASH facility (Free Electron Laser in Hamburg) is operated, a sketch of FLASH is shown in Fig. 2. An electron beam is accelerated using superconducting modules, and passes an undulator to produce a photon beam of high intensity and short wavelength. The parameters for the beam and the superconduction acceleration structures are similar to that foreseen for the ILC, but the beam energy is lower (1 GeV). Recently the successful and stable operation with 800 bunches of 3 nC over 15 hours has been demonstrated. Pulses with 1600 bunches were operated for several hours, and even 2200 bunches could be reached for short periods.

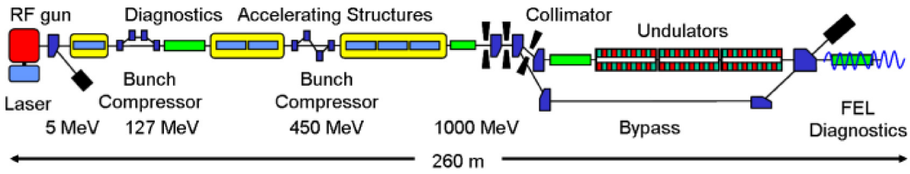

Fig. 2. Schematic layout of the FLASH facility at DESY. The accelerating structures upstream and downstream the bunch compressor are ILC-like superconducting modules.

2.2.3. The Minimal ILC Machine

The so-called Minimal Machine (MM) concept aims for cost saving without reducing the physics potential of the machine. Main elements of the minimal machine are related to the main cost drivers as tunnel and main linac. They are:

- Single-tunnel solution instead of the two-tunnel solution in the RDR.
- Integration of machine components in common housing, sharing the tunnel by the systems.
- Reduced power allows to reduce the number of RF klystrons, and could allow for smaller damping rings.
- Evaluation and engineering of civil facilities and siting.

The power reduction implies a lower luminosity. This loss can be compensated by utilizing the method of "traveling focus" [6]. The attracting beam-beam forces of crossing electron and positron bunches are used to decrease the beam sizes and to increase the luminosity.

The components for the MM are currently under consideration and will result in the new baseline design for the ILC in 2010.

2.2.4. Sample sites

Sites in each region are under study taking into account technical features and costs. Deep sites are considered in Americas (FNAL), Asia and Europe

(CERN), shallow sites are studied at DESY and also Dubna (Russia). But the choice of the real site will be a political decision which has to be prepared also by the ILC community.

2.3. The Compact Linear Collider (CLIC)

The LHC will allow to detect and study physics phenomena up to energies of about 5 TeV. To complement the LHC results with precision measurements it is desired to cover also the multi-TeV range with a e^+e^- linear collider. The corresponding physics goal is presented in reference [7]. The technology foreseen for CLIC affords operation at 500 GeV, up to the multi-TeV range. The luminosity will be in the range $10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Energy and luminosity will be reviewed again when LHC physics results will be available. The electron source will be polarised, polarised positrons are planned as an upgrade option.

The CLIC scheme uses high-frequency normal conducting accelerating structures. The parameters for the CLIC project were revised in 2007 [8]: the main linac RF frequency was reduced from 30 GHz to 12 GHz, and the accelerating field from 150 MV/m to 100 MV/m. So, a 3 TeV machine will have a length of 48 km instead of 34 km. The total power consumption should be below 500 MW.

The overall CLIC scheme is displayed in Fig. 3. The central injector complex includes sources, pre-damping and damping rings, bunch compressors and a 9 GeV booster. The injector complex prepares the ultra-low emittance beams which are needed for a high luminosity. The main technical feature is the acceleration scheme using two beams which is much more efficient than the operation of 12 GHz klystrons. The radiofrequency power for the main

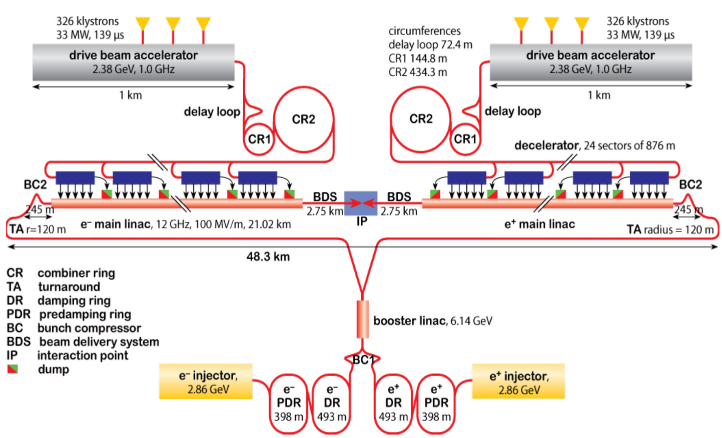

Fig. 3. Schematic layout of CLIC 3 TeV (not to scale).

linac is extracted from a high-intensity electron drive beam (100 A) which has a low energy of 2.4 GeV. This drive beam is decelerated to 240 MeV, and the power is transferred by Power Extraction and Transfer Structures (PETS) to the low current (1.2 A) main beam for acceleration. The scheme is depicted in Fig. 4.

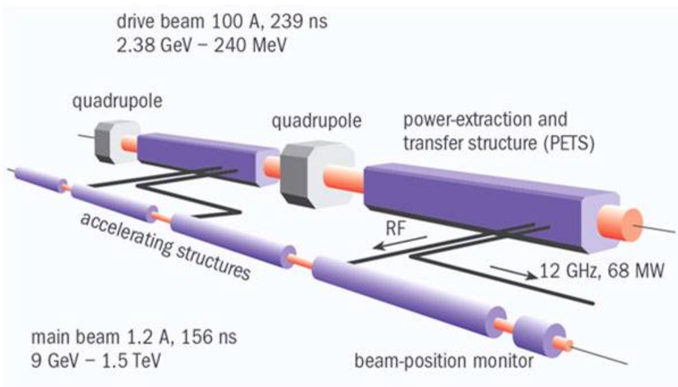

Fig. 4. Scheme of two-beam acceleration with drive and main beam.

2.3.1. CLIC parameters

Selected parameters for the CLIC facility are listed in Table I together with the corresponding ILC parameters. The extremely small beam sizes are necessary to achieve the high luminosities. It is a challenge to produce these low emittance beams and to transport them without degradation to the interaction point. Collisions of such small beams create substantially more beamstrahlung than beams at the ILC. In addition, the short bunch spacing will result in a pile-up of events which complicates the analysis.

TABLE I

Comparison of selected parameters of the linear collider projects.

	ILC 500 GeV	CLIC 500 GeV	CLIC 3 TeV
Luminosity [10^{34}cm^{-2}s^{-1}]	2	2.3	5.9
Repetition rate [Hz]	5	50	50
Bunch separation [ns]	370	0.5	0.5
Beam pulse duration	950 μs	177 ns	156 ns
Beam size hor./vert. [nm]	$\sim$ 600/6	200/2.3	40/1

2.3.2. CLIC accelerator program

CLIC is a growing international collaboration with an ambitious schedule towards a technical design. The CLIC scheme comprises novel concepts and challenging parameters which have to be tested experimentally. The main goals of the CLIC R&D programme are to demonstrate the drive beam generation with fully loaded beam, to test the CLIC accelerating structures, and to test the power production structures (PETS). These key issues are addressed at the CLIC test facility CTF3; a sketch of CTF3 is shown in Fig. 5. The delay loop and the combiner ring are used to realize the frequency multiplication of the intense drive beam. It is planned to demonstrate the feasibility of the CLIC technology and to prepare a linear collider conceptual design including a cost estimate in the CERN area until end 2010.

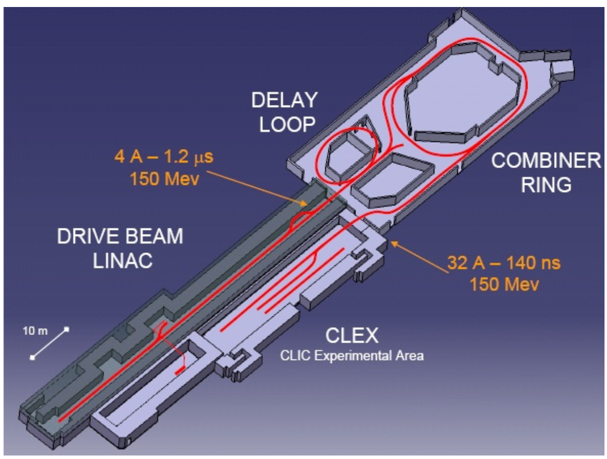

Fig. 5. Schematic layout of the CLIC test facility CTF3 at CERN.

The high gradient requires a very aggressive performance of the CLIC structures. Fig. 6 shows that the nominal CLIC accelerating gradient has been exceeded in an unloaded structure with a very low breakdown probability after 1200h RF conditioning. This is the result of a truly international effort — the structure was designed at CERN, built at KEK and tested at SLAC.

2.4. Collaboration between ILC and CLIC

Both groups, ILC and CLIC, will benefit from collaboration in design work. Although the basic concepts for ILC and CLIC are different, there is a great deal of mutual interest in areas which are not related to the accelerating structures. The collaboration of CLIC and ILC in selected fields will

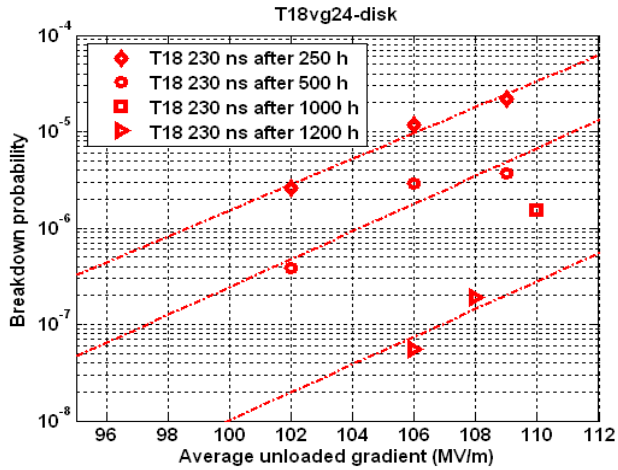

Fig. 6. Accelerating gradients in unloaded 12 GHz CLIC structure [9]. Goal is the nominal breakdown rate below 3×10^{-7}.

also strengthen the external coherence of the high-energy physics community. For a better communication between the projects common ILC/CLIC working groups were established on physics and detectors, beam delivery system and machine detector interface, civil engineering and conventional facilities, positron generation, damping rings, beam dynamics, and cost and schedule. The joint work will help to have the appropriate project in hand as soon as the LHC will establish the scientific case for a linear collider.

3. Summary

LHC results will strengthen the physics case for future linear e^+e^- colliders. Taking into account the complexity and the long time-scale to prepare these international collider projects, activities towards a linear collider have to be maintained and intensified. Both collaborations, ILC and CLIC, have a strong programme. Focus of the ILC community are the cost optimization, and the operation of high-gradient cryomodules and strings of cryomodules with nominal beam parameters in test facilities. CLIC has still to demonstrate that the scheme is feasible and the nominal parameters can be achieved. Although ILC and CLIC are based on different concepts, the collaboration on common problems has started.

I thank the organizers for this interesting conference hosted in a beautiful region of Silesia.

REFERENCES

[1] The LEP Electroweak Working Group, the Tevatron Electroweak Working Group and the SLD Electroweak and Heavy Flavour Groups, `http://lepewwg.web.cern.ch/LEPEWWG`

[2] The CDF and DØ Collaborations, Combined CDF and DØ Upper Limits on Standard Model Higgs-Boson Production with up to 4.2 fb^{-1} of Data (2009).

[3] J. Brau (Ed.) *et al.*, ILC Reference Design Report Volume 1 — Executive Summary (2007).

[4] R.W. Assmann *et al.*, A 3-TeV e^+e^- Linear Collider Based on CLIC Technology, CERN-2000-008.

[5] G. Aarons *et al.*, International Linear Collider Reference Design Report Volume 2: Physics at the ILC (2007).

[6] V.E. Balakin, Travelling Focus' Regime for Linear Collider VLEPP Proc. 77th ICFA Workshop on Beam Dynamics, May 13–16, Los Angeles 1991.

[7] E. Accomando *et al.*, `hep-ph/0412251`.

[8] H. Braun *et al.* [CLIC Study Team], CLIC 2008 Parameters, CERN-OPEN-2008-021.

[9] W. Wuensch, CERN-AB-2008-045, CLIC-Note 742 (2008).