The ILC: The next step in Particle Physics

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Abstract. The international linear collider, ILC, is the next big project in particle physics, following the LHC. This machine will allow the precision study of the top quark and the electroweak gauge bosons. It will explore the Higgs sector, and study possible extensions of the Standard Model like supersymmetry with great precision. The ILC will be complementary to the LHC, which will start operation well before the ILC. Together both machine will offer the community the unique possibility to explore the physics at the TeV mass scale. In this paper the accelerator, the physics program and the experimental program at the ILC are reviewed.

1. Introduction
Over the past decades years the Standard Model of particle physics has been tested experimentally with an impressive accuracy. LEP/SLC, HERA and the Tevatron have measured many of the key parameters. No significant disagreement between the measurements and the theory has been found.

In 2007 the next big collider, the LHC, will start its operation. Running at a center of mass energy of 14 TeV, and colliding protons and protons, this collider will for the first time experimentally explore the energy regime of around 1 TeV. If it exists, the light Higgs boson will be found at the LHC. If light supersymmetry exists, the LHC will have a good chance to find it. If some totally new physics is realised, the LHC will have a good chance of seeing at least signs of this if the masses of these new states are below a few TeV.

In parallel to the startup of the LHC a new project is being defined, an electron positron linear collider running at energies between a few hundred to 1000 GeV, the international linear collider, ILC. This machine which is currently being designed, could start operation at the earliest in 2015.

The international linear collider will add to the capabilities of the LHC by providing high precision measurements at energies up to 1 TeV in the center of mass. The international community of particle physicists has put the ILC at the top of its list of priorities, after the LHC. At the moment the accelerator is designed in international collaboration, based on superconducting RF technology.

The international linear collider is a challenging project in many respects. It promises to add significantly to our knowledge of physics at the highest energies, and will ideally complement the results from the LHC. It is the first project of this magnitude in particle physics which from the beginning is executed as a truly international project. In fact, at the moment no site has been fixed yet, but the project is designed and proposed without a dedicated host laboratory.

The international linear collider offers many challenges to all people and groups involved. The machine is of a very advanced design, and pushes the limits of technologies in many areas. Most
obviously the use of superconducting cavities at very high gradients has never been attempted
before, but other areas of the machine are equally challenging. Building a detector which can
fully exploit the potential of the machine, and which can do the needed measurements with
the intended precision, is very difficult, and requires an extensive R&D program. Last but not
least the physics reach of the machine is very broad, and covers nearly all areas if interest at
the highest energies. Close interactions with theorists is therefore essential to understand the
physics potential and to optimally use the collider and the experiments.

In this paper the state of the design of the accelerator is briefly reviewed. This can by
nature only happen at an superficial level, and the reader is directed to much more material
now available in the form of the baseline configuration document [1], soon in the form of the
reference design report, of the ILC. This then sets the stage for a brief review of the physics
at the ILC, and a discussion on relevant detector developments and design issues. There are
many reports available in the literature which review the physics, the experimentation and the
machine design of the proposed linear collider. The first complete proposal for an accelerator
based on superconducting technology was published by the TESLA group in 2001 [2].

2. The ILC accelerator

In 2003 the international community of particle physicists formulated a requirement document
which sets down the main parameters of the linear electron positron collider at energies of
500 GeV and 1 TeV [3]. In this document, an accelerator was requested which could reach
energies between 90 GeV and 1 TeV (500 GeV in a first stage), deliver luminosities of a few
\(10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}\), or 500\(\text{fb}^{-1}\) over a few years integrated luminosity. The accelerator should deliver
polarised electrons, if possible, polarised positrons, and provide for ideally two independent
interaction regions. With these specifications, the community thinks that enough data can be
collected over a reasonable time that some of the most basic questions concerning the Higgs
Sector, supersymmetry or extensions beyond the Standard Model, and searches for new physics
can be done. In a first stage this machine should reach an energy of 500 GeV, but it should be
upgradable to a final center of mass energy of 1 TeV.

In 2005 the “International Technology Review Committee” started its deliberations, with the
goal of deciding by the end of the year the technology in which this collider should be built.
Two competing technologies were under review, the normal conducting one, developed at SLAC
and in Japan, and the superconducting RF technology, pushed by the TESLA collaboration and
the DESY laboratory. In the summer of 2005 the decision was made to recommend the cold
RF technology, which subsequently was adopted by the main bodies, the ICFA, ILCSC, and
welcomed around the world. The design work of the ILC was then re-organized in he Global
Design Effort, headed by B. Barish from Caltech. This decision ended many years of competition
between the major laboratories around the world interested in the ILC, and made them all unite
behind one common project. At the moment all laboratories have clearly identified the ILC as
their next major project in elementary particle physics, with the exception of CERN, which still
pushes its CLIC technology as an alternative.

2.1. Linear Colliders: an Introduction

The first large linear collider has been built in the United States at the SLAC laboratory.
It started out as an electron accelerator about 2 miles long with a fixed target experimental
program. In the 80ies it was converted into a colliding beam facility, to study the production
and decay of the intermediate weak gauge boson, the Z-boson.

The idea to use two linear accelerators facing each other was first raised in 1965 by Maury
Tigner. In the paper titled “A possible apparatus for electron positron collisions” he describes
already all elements needed to built a linear electron positron collider. One of the strong
arguments in favor of a high energy linear electron positron colliders is the cost. The size
of a circular electron accelerator is driven to a large extent by the synchroton radiation losses, which scale as the fourth power of the energy of the beam. Thus very large diameter rings are needed should the losses due to synchroton radiation be small enough. On the other hands the total cost of the machine scale more or less linearly with the length of the tunnel. At some point the additional complications of building a linear accelerator are more than compensated by the significantly shorter tunnel needed, since no Synchroton radiation losses have to be compensated. It is commonly believed that the LEP/ LHC tunnel at CERN, which has a length of around 27 km, is about the largest circular machine which can be built at acceptable cost. LEP2 reached an energy of slightly above 200 GeV. Higher energies require new technologies, and probably can only be realised in linear colliders.

The idea to build a linear collider to reach beyond LEP2 is not new. First discussions started already at the end of the 80ies, at a time when LEP and SLC were just starting. During the 90ies a number of projects were developed. SLAC and KEK pushed a design based on normal conducting cavities, operated in the 10 GHz regime. With this the hope was that gradients in excess of 100 MV/m could be reached, resulting in a fairly short machine with a consequently large energy reach. DESY assembled starting in 1992 the TESLA collaboration to explore ways to improve the superconducting technology for RF cavities to a point where a solid proposal for a superconducting linear collider could be made. The TESLA TDR was eventually published in 2001, based on superconducting cavities with gradients between 25 MV/m for the first, 500 GeV stage, and 35 MV/m for the upgrade to 800 GeV.

At DESY the TESLA test facility was constructed, which demonstrated the use of superconducting cavities. Since 2005 this facility is in addition used to run a free electron laser, and to deliver routinely beam to a number of experiments. In 2003, the German government approved the construction of another, larger superconducting accelerator, which should reach 20 GeV, and drive a larger free electron laser, reaching X-ray wavelengths. This facility will start operation in 2012 at DESY in Hamburg. It will be of primary interest to life sciences, material sciences and solid state physicists. It will at the same time be a 10% test of the technologies needed to eventually construct the international linear collider in cold technology.

2.2. Luminosity of a Linear Collider

One of the key requirements the physics community has to the builders of a collider is to reach a certain luminosity. The goals for a ILC are particularly challenging, as a luminosity a few order of magnitude larger than ever reached in a high energy electron position collider are required.

The luminosity at a collider is approximately given by:

\[ \mathcal{L} = \frac{n_b N^2 f_{\text{rep}} H_D}{A} \]  

where \( n_b \) is the number of bunches in the machine, \( N \) is the number of particles per bunch, \( f_{\text{rep}} \) is the repetition frequency of the machine, \( A \) is the cross section of the beam at the interaction region, and \( H_D \) is the beam-beam enhancement factor (see later in this report). If we assume that the beams have a gaussian cross section, the equation reads:

\[ \mathcal{L} = \frac{n_b N^2 f_{\text{rep}} H_D}{4\pi\sigma_x\sigma_y} \]  

The main scaling laws relevant are that the luminosity is proportional to the number of particles colliding, to the repetition rate of the accelerator, and inverse proportional to the beam size in x and y. This shows one problem of a linear collider: due to problems with the cavities and with the total power to be provided, a linear collider runs most efficiently at a fairly low repetition rate. For the ILC a rate of below 100 Hz is foreseen. Circular machines easily operate a
repetition rates of 40-50 kHz (LEP operated at 44 kHz). This immediately results in a loss of luminosity of a factor of 400 for a linear collider. On the other hand by making the beams at the interaction region very small, the luminosity can be increased significantly. Sizes as small as $\sigma_x \times \sigma_y = 500 \times 5 \text{mm}^2$ are possible, compared to $\sigma_x \times \sigma_y = 130 \times 6 \mu\text{m}^2$ at LEP, resulting in an increase of the luminosity of six orders of magnitude. This is possible since the beams at the linear collider are thrown away after the collision, while at the circular accelerator they have to be reused. These extremely small beam sizes result in a significant disturbance of the beam behind the interaction, which make it essentially impossible to do anything other than put them on a dump.

2.3. Beam Beam Interactions at a Linear Collider

In the previous section the basic equations for the luminosity at the linear collider were presented. Large luminosity can be obtained by making the beam cross sections very small. If two very small beams collide, in addition to the hard scattering, interactions take place between the bunches as a whole. The electrons of the incoming bunch start to feel a force from the positrons in the outgoing bunch, which will tend to focus them towards the interaction region. This results in a focusing of the beam through the collision - and an effective increase in luminosity - but it also results in the emission of photons off the beam particles, the so-called beam Strahlung. This effect results in an energy loss of the beams in the collision, which can be as large as a few %, results in a large number of photons which might disturb the experimental program at the interaction region, and results in a blow-up of the beams behind the interaction region.

The energy lost due to beamstrahlung can be written in the following way:

$$\delta_{BS} = 0.86 e^3 \frac{e}{\sigma_z} \left( \frac{E_{cm}}{\sigma_z} \right) \frac{N^2}{(\sigma_x + \sigma_y)^2}$$

where $e$ is the electron charge, $r_e$ the classical electron radius, $E_{cm}$ the center of mass energy of the accelerator, $N$ the number of particles colliding, and $\sigma_{x,y,z}$ the beam size (measured as one standard deviation assuming a Gaussian beam profile) in the three spatial dimensions. $x, y$ are measured transverse to the beam, $z$ in the direction of the beam. The energy loss due to beamstrahlung is minimized for large beam cross sections. This however is contrary to 2, which says that the luminosity is maximized for small beam cross sections. To optimize both at the same time, a very flat beam profile is chosen, with $\sigma_x = 100 \times \sigma_y$. In this way both the beamstrahlung losses are confined to typically a few %, while the luminosity can be kept high.

In addition to the beam beam interactions within one bunch, long range effects can significantly disturb the operation of a linear collider. The outgoing bunch is extracted from the interaction region into a beam dump. However in particular for short inter-bunch spacings, it can see the next incoming bunch, and exert some force on that bunch. This can produce a kick for this next incoming bunch, which goes out of alignment and thus reduces the luminosity.

There are many more effects which can influence the luminosity at a linear collider, and which will not be discussed here in any detail. The interested reader is referred to the proceedings of the first ILC accelerator school, which took place in Japan in 2006.

2.4. Summary: ILC Luminosity

Taken together the subjects discussed in the previous two sections, the luminosity at a linear collider can be described by the following equation:

$$L = \frac{\eta_{RF} P_{RF}}{E_{cm}^{3/2} E_{cm}^{3/2}} \frac{\sqrt{\delta_{BS} \sigma_z}}{(\sigma_x + \sigma_y)^2}$$
where the variables have been defined before, except for $\eta_{RF}P_{RF}$ which is the total RF power and the efficiency with which the electrical power is converted into actual RF power. From eq. 4 one sees that to obtain a high luminosity at the linear collider, one needs:

- high conversion efficiency for the electrical power into RF power
- high RF power
- small vertical beam size, $\sigma_y$
- large bunch length, $\sigma_z$
- as large beamstrahlung as can be accepted by the physics program. Alternatively flatter beams will allow one to reduce the beamstrahlung.
- excellent control over the beam, to have efficient collisions of nm sized beams.

2.5. The Layout of the ILC

A linear collider has to have a number of elements to provide collisions to the user: In a source electrons of positrons are produced. They are collected and accelerated to a few GeV. They are then put into a so-called damping ring, with the purpose of reducing the phase space volume of the bunches, cleaning them, and preparing them to be used in the main acceleration. After the damping ring the bunches are compressed once more, and are then fed into the main linac. This linac accelerates them up to the final energy. Before the collision the beam delivery system conditions the bunches for the collision, collimates away tails, and eventually focuses the bunches into the interaction region. Behind the interaction region, the beam is extracted, and guided on a beam dump, where the energy of the beam is absorbed. A conceptual view of the ILC layout is shown in figure 1.

Figure 1. Footprint of the ILC.

The design of the ILC is based on superconducting cavities (see figure 2). To reach the energy of the first stage of 500 GeV about 10km of accelerator are needed, based on a gradient of around 32 MV/m. The injection chain, the beam forming, and the beam delivery add another 5-8 km per side, so that in the end the total site length will be about 33 km. If an upgrade to
1TeV will be done later on, additional tunnel is needed which will provide additional RF power to the beam.

The electron source is planned to be a conventional laser based electron source, if it has been used at the SLC and also at the Tesla Test facility. This allows high intensity production of polarised electrons, and is a very well understood technology.

The situation is more complicated for the positron source. A conventional source would mean that a high intensity laser beam impact on a target, just as in the case of the electron source. However, at a much lower rate positrons are produced in this process as well through pair production. They are extracted through a magnetic lens, accelerated, cleaned, and eventually put into the damping ring. The main problem with the conventional source is to provide the needed intensity of positrons. This puts very stringent demands on the laser, and on the target, which has to stand huge heat loads.

An alternative to the conventional positron source is a undulator based source. A high energy electron beam - in principle the electron beam from the main linac can be used for this - is used to produce a very intense photon beam. These photons are then used to produce positrons. The advantage of this source is that it can deliver larger currents for the positron linac, and that it has the option of producing polarised positrons.

The damping rings are a major part of the overall ILC infrastructure. The current baseline foresees two rings, with 6km circumference each, at the start of the two linacs. The length of the damping ring is defined by the total bunch train length in the ILC, which is about 900 ns or 27km, compressed by stacking bunches at shorter inter-bunch distances with the fastest available kicker magnets. More aggressive schemes with a 3 km circumference ring are under study, but would require a different and untested technology for the kickers, not based on magnet technology but on RF cavities itself. When inside the damping ring, the bunches are subjected to wigglers which will help to reduce the vertical emittance of the bunches. For electrons a one stage damping is deemed sufficient, for positron, two rings on top of each other might be needed, to provide enough damping.

Figure 2. Photo of a superconducting 9-call cavity structure as foreseen for the ILC [4]
3. Physics at the ILC

The ILC will study physics at an energy scale up to one TeV. The current theory of particle physics, the Standard Model, has been developed over the last decades and describes very well physics up to the electroweak energy scale of about 200 GeV. It has been tested experimentally at a number of colliders with great success.

The Standard Model knows matter particles, gauge fields, and one scalar particle. Leptons and quarks are the matter particles, and all predicted particles have been experimentally found. The forces in the Standard Model are described by Gauge Fields, and all known forces except gravity are incorporated into the theory, and their gauge fields have been found. The masses of elementary particles are generated by the Higgs field, a scalar particle, and the only ingredient of the Standard Model which has not yet been found experimentally. This theory present an impressive theoretical work, and describes all observed phenomena with great accuracy.

Nevertheless there are a number of rather fundamental shortcomings in this theory. There is no explanation of the number of fundamental particles, nor of the fact that they are arranged in three families. There is no explanation for the underlying group structure $SU(3) \times SU(2) \times U(1)$. On an even more fundamental level gravity is not included at all in the Standard Model.

A number of problems within the Standard Model still remain open, and require the use of higher energy colliders to be solved:

- The top quark is special in the list of matter particles. It is much heavier than any other fundamental fermion known to date. Understanding the role of the top quark in nature, and in this way gaining insight into the question of the fermion mass hierarchy is an important goal of future experiments. Experimentally precise measurements of the quantum numbers of the top quark, and of the properties of the $t\bar{t}$ production and top decay are needed.

- The so far unobserved Higgs particle presents one of the great puzzles of particle physics at the moment. The LHC will most probably observe the Higgs, if it exists. A linear collider at energies around 500 GeV will be an ideal instrument to study the properties of this state in great detail. All indications - experimentally and theoretically - point towards a light Higgs, with a mass below 200 GeV.

- The structure of the electroweak interaction has been thoroughly studied at LEP, the LDC and at the Tevatron. Nevertheless a high luminosity linear collider will be able to significantly extend these studies, and look into the dynamics of the heavy gauge bosons. The measurement of the triple and quartic couplings of these gauge bosons, and their different moments, will provide sensitive tools to test the range of validity of the Standard Model. In fact, should no light Higgs be found in the energy range accessible at the LHC and the ILC, this type of measurements might be the last reminding resort to gain some insights and to understand where the current theory went wrong.

Many people believe - because of the shortcomings of the Standard Model - that the real underlying theory is something else. Supersymmetry, Superstring, extra dimensions etc are catch phrases which are being used to describe different models. The ILC will be a very powerful search and discovery machine, which, together with the LHC, will be able to look for such signs of new physics.

Supersymmetry is a theory favoured by many as a comparatively simple and elegant extension of the Standard Model. This novel symmetry concept unifies matter and forces by pairing associated fermions and bosons in common multiplets. Supersymmetry is theoretically attractive because it stabilizes the masses of a light Higgs particle at very high energies - something that is needed if the theory eventually should support unification at very high energies, in particular at the Planck scale. Supersymmetry can predict the value of the electroweak mixing angle, $\sin^2 \theta_W$ already in the minimal version of the theory with excellent precision (2 per-mille level). More recently interest in supersymmetric theories has received a boost from the mounting evidence
for dark matter and dark energy in the universe. The lightest supersymmetric particle, which is stable in many supersymmetric theories, can be a candidate for the cold dark matter component in the universe. Last but not least supersymmetry quite naturally includes gravity, much in the same way as local gauge invariance induces electromagnetism and other interactions.

It has also been shown that supersymmetric theories can be constructed in a way that they agree with current experimental limits, and at the same time allow a unification of the fundamental forces at the Planck scale. If masses of couplings of supersymmetric partners can be measured with sufficient accuracy, these predictions are actually testable by experiment, providing possibly the only means to experimentally access - though indirectly - physics at the Planck scale.

If no fundamental Higgs is found, neither at the LHC nor at the ILC, a new strong interaction will be observed at energy scales of order 1 TeV. The study of the elastic W bosons scattering at high energies around 1 TeV will then provide a handle on this new physics, and allow hopefully to deduce the microscopic structure of this.

Many extensions to the Standard Model predict some observable phenomena in the mass range between the electroweak scale and approx. 1 TeV. This makes a linear collider operating in this energy regime particularly interesting and powerful.

At the LHC new high mass vector bosons and particles carrying color quantum numbers can be searched for very efficiently. This will make the LHC a prime discovery machine for the next decade or so. At the ILC, this can be extended into non-colored states, which are much more difficult to find at the LHC. In addition the cleanliness of the collision at the ILC, and the high luminosity allows precision studies of states which can barely be discovered at the LHC. In this way the LHC and the ILC ideally add to each others physics reach.

In the following one of the main physics goals of the ILC, the Higgs physics, is discussed in a bit more detail. For other physics studies and scenarios, the reader is referred to other more in depth descriptions.

3.1. Higgs Physics at the ILC

Higgs physics is a cornerstone of the electroweak sector of the Standard Model. Through interaction with the Higgs field the fundamental Standard Model particle acquire a mass. The experimental establishment of the Higgs mechanisms is the top priority of elementary particle physics of the next decade.

To fully claim an understanding of the Higgs physics, three steps are necessary:

- The particle Higgs must be discovered.
- The couplings between the Higgs and the other Standard Model particle need to be measured, and the scaling of the coupling with the mass of the particles must be established.
- The Higgs potential must be reconstructed, as this is primarily responsible for the peculiar properties of the Higgs field and its role in the generation of masses in the Standard Model.

The only free parameter of the Higgs field in the Standard Model is its mass. At the moment only indirect limits exist, derived from precision measurements at the LEP experiments, at the SLD and at the Tevatron.

Once the mass of the Higgs is fixed through a direct measurement, most probably at the LHC, all other parameters of this particle are fixed in the Standard Model. A precise measurement of these parameters therefore can serve to show that a new state indeed serves as the Higgs particle, and, if done with sufficient precision, can also be used to look for subtle deviations from the expectations, which might indicate the presence of new and unexpected physics at higher energies.
At the ILC the Higgs will be produced, depending on its mass, predominantly in one of two reactions:

\[ e^+ e^- \rightarrow Z + H \]  \hspace{1cm} (5)

via the production of a virtual Z boson, or

\[ e^+ e^- \rightarrow \bar{\nu}_e \nu + H \]  \hspace{1cm} (6)

in the so-called WW fusion channel. The first process is particularly interesting since the Z-boson in the final state is mono-energetic. The Higgs mass can then be deduced by only reconstructing the Z decay products, through the recoil technique, and in this way a totally model independent analysis of the Higgs mass is possible [6].

In figure 4 the Recoil mass spectrum for a 120 GeV Higgs Boson is shown, reconstructed at the ILC at a center of mass energy of 500 GeV.

In case the Higgs is heavier than the WW threshold, the decay of the Higgs into two W bosons starts to become dominant. The measurement of the Higgs properties and the branching ratios into the heaviest bosons can still be done with great precision at the linear collider, though the analysis technique has to be more sophisticated [9]. In figure 6 the invariant mass spectrum for a reconstructed di-jet system is shown, for \( H \rightarrow WW \) and for \( H \rightarrow ZZ \) decays, and for background.

**Figure 3.** Experimental \( \chi^2 \) curve for the Higgs mass from direct searches (yellow plane) and from other electroweak parameters (curve with error bars) [5].
3.2. Non-Higgs Physics at the ILC

Supersymmetry is an extension of the Standard Model favoured by many, theoreticians and experimentalists alike. Nevertheless at the moment there is no clear experimental evidence that supersymmetry is indeed realised in nature. Its study though provides a good and powerful tool to explore the reach of a new machine like to ILC for new physics phenomena.

Supersymmetry is attractive for a number of reasons. Among them are that supersymmetry stabilized the Higgs sector of the Standard Model, by canceling divergences. It predicts the value of the weak mixing angle with per-mille level accuracy, from first principles. Supersymmetry does offer a first route towards a grand unification at the Planck scale.

The minimal extension of the Standard Model, the MSSM, is based on the Standard Model
Figure 6. Invariant di-jet mass spectrum for an assumed Higgs mass of 200 GeV, and backgrounds.

The group $SU(3) \times SU(2) \times U(1)$. It predicts a spectrum of five Higgs particles. The masses of at least some of these particles can be expected to lie between the electroweak scale and about 1 TeV, and thus should be accessible at the Linear Collider.

At the ILC many supersymmetric phenomena can be studied with great precision. The main production mechanism for neutral SUSY Higgs bosons are Higgs Strahlung and associated pair production. A few typical spectra are shown in figure 7.

Figure 7. (a) The di–jet invariant mass distribution for $e^+e^- \rightarrow H^+H^- \rightarrow t\bar{t} b\bar{b}$ candidates after applying the intermediate W and t mass and the equal mass final state constraints for 500 fb$^{-1}$ at $\sqrt{s} = 800$ GeV. (b) Mass peak for $e^+e^- \rightarrow H^0\tilde{A}^0 \rightarrow b\bar{b} b\bar{b}$ for 50 fb$^{-1}$ at $\sqrt{s} = 800$ GeV.

A typical method to search for new supersymmetric state is the search for threshold effects. Because the lightest supersymmetric partner in most theories is stable and only weakly interacting, it escapes detection in the detector. A typical energy spectrum for a supersymmetric partner therefore will be a so called box-spectrum, with a minimum and a maximum allowed energy. Because of the clear experimental environment at the ILC these characteristics can be
used to reconstruct and precisely measure many supersymmetric states. As an example the decay of the supersymmetric partner of the muon into a muon and a neutralino is shown in figure 8.

![Figure 8](image-url)

**Figure 8.** The energy distribution of the final state \( \mu \) in the decay \( \tilde{\mu}_R \rightarrow \mu + \tilde{\chi}_1^0 \) in flight [10].

The precision with which many of the parameters of possible new states can be measured at the ILC allows the indirect study of phenomena at very high energies. The evolution of many supersymmetric theories to very high energies is governed by only a small number of parameters. Many relations among these can be found which can be experimentally tested at lower energies. In many theories it will be possible to then evolve the quantities measured at low energies to very high energies, and, of the precision is adequate, make statements on a possible unification at these very high energies. This is illustrated in figure 9. Shown there are the evolutions of different quantities, based on their low energy value, to the Planck scale. Under the assumption that a unified theory at these energies exist, the degree to which the parameters meet can be used to study particular theories and their implications.

### 3.3. Physics at the ILC: Summary

In this section a brief outline of some of the physics issues which can be studied at the ILC has been given. It has only been a rather incomplete review of the very large and broad program.

At the core of the program clearly is the Higgs, whether it exists or not. Searches and measurements of the Higgs, or searches for a replacement of the Higgs, should it not have been found at the LHC or at the ILC, will be a very important part of the program.

Many extensions of the Standard Model have been discussed in the literature. Here only the example of Supersymmetry has been briefly reviewed. The ILC however will be able to contribute to a very broad ranging sweep of the physics at the 1 TeV scale, which will be started by the LHC in a few years. Its precision and uniquely clean environment will allow the physicists to search for many new states, and to test precisely many different theories.

Some of the new states might also be excellent candidates for cold dark matter, thus linking the microcosm to the development of the largest scales in the universe. Again precision will be needed to study these states, and to understand their properties.

In summary the ILC will contribute greatly to our understanding of the physics of the TeV scale. In many ways it will complement the knowledge we will gain from the LHC. Together the
4. Experimentation at the ILC
Experimentation at a linear collider as described in the last section presents a significant challenge. The physics programme demands large amounts of data over a wide range of collision energies, between 90 and 800 GeV. The type of measurements which the detector has to be capable of performing range from identifying final states with isolated leptons and states with many jets to precisely measuring the decay vertices of of heavy flavour mesons.

A prime example illustrating the demands on the detector is the anticipated programme in the Higgs sector. If a light Higgs particle exists, a precise determination of the properties of the particle requires experiments with large data samples, approaching several ab$^{-1}$. If the Higgs mass is below about 140 GeV its dominant decay mode is to a pair of bottom quarks. In addition important information can be extracted from the study of the Higgs-top Yukawa coupling in $t\bar{t}H$ events and of the triple Higgs coupling in $ZH\bar{H}$ events. In each case excellent identification of the final state is needed, which stress the capabilities of the detector’s vertexing, tracking and particle flow measurement systems.

While precision measurements are the main focus of the detector, this would be particularly true if the ILC should be operated at the $Z$ pole. This so-called GigaZ programme is expected to collect about two orders of magnitude more data than LEPI, with subsequently much stricter requirements on the precision and calibration of the detector.

Enormous developments have been done in the past in preparation of the Tevatron and the LHC experimental program. Lots of new technologies have been developed for these programs. The focus for the ILC however is a different one: radiation hardness, the main driving force at the LHC, is not of much concern at the ILC. Instead precision, readout speed, and reasonable cost are major concerns for an ILC detector.

4.1. Experimental Environment
The conditions for experiments at the ILC are comparatively benign. The 337 ns between two bunches is relatively long, although the long bunch trains and large number of bunches in one train require special efforts for the data acquisition system. Compared to a typical event at
the LHC, the number of particles to be reconstructed is significantly lower. Backgrounds are relatively small. This results in low detector occupancies, allowing the construction of real high precision devices. It also allows the user of these experiments to focus very much on the reconstruction of individual particles, rather than event properties.

The beam-beam interaction at the linear collider will be very intense due to the strong focusing of the beams at the intersection point. The interactions have two consequences relevant for the experimental programme: For oppositely charged particle beams the luminosity is enhanced since the two beams attract and focus each other. At the ILC an enhancement of about a factor of 2 can be expected. At the same time the strong beam-beam interactions, bending the trajectories of the electrons and positrons, are a source of beamstrahlung photons, which are emitted from the interaction point into the forward region. Both effects together produce the luminosity spectrum shown in Fig. 10.

The beamstrahlung, in particular, strongly influences the design of the detector in the forward region. An intense flux of photons and electron-positron pairs is impacting on the detectors in the very forward region, and constitute a source of background for detectors close to the beampipe. To shield the rest of the detector from these backgrounds special protection measures have to be taken.

4.2. Detector Concepts
Over the last decade different concepts for a detector at a future linear collider have been studied. They have resulted in the formation of a number of detector concept groups, which aim at producing complete detector designs including a realistic cost estimate. At the moment four detector concepts are under development:

- The SiD detector relies on a SI-only tracking system, combined with a high precision calorimeter optimized for particle flow.
- The LDC detector uses a large volume gaseous tracker in the center, backed up by SI-based tracking. It uses as SiD a high granular calorimeter, optimized for particle flow.
The GLD detector is the largest of the concepts. It is very similar to the LDC in the inner part, with a combination of a TPC with SI tracking. For the calorimeter it tries to use simpler techniques, profiting from the larger radius of the calorimeter to obtain the same resolution in the end.

The 4th concept is the most recent one. It is based again on a central tracking system similar to the LDC one, but does not rely on particle flow as its main reconstruction technique. Instead it uses a compensating calorimeter, achieved through a dual readout of the electromagnetic and the hadronic shower component. This comes at the cost of a significantly reduced granularity of the calorimeter system.

All concepts have recently published the detector outline documents, summarizing the designs of the devices [12].

The requirements as given by the diverse physics programme can be summarized as follows:

- The detector has to have an excellent track momentum resolution. The benchmark reaction here is the analysis of the di-lepton mass in the process $HZ \rightarrow H\ell^+\ell^-$. This reaction allows the reconstruction of the Higgs mass independent of its decay mode via the reconstruction of the lepton recoil spectrum. In order that the momentum resolution of the detector does not limit the mass resolution achievable for the recoiling lepton system, stringent momentum resolution requirements have to be met.

- The reconstruction of the flavour of the final state can often be done best with the help of lifetime information of the decaying particles. For this, very powerful vertex detectors are needed. This is particularly important in the Higgs sector, where – at least for light Higgs bosons – a large fraction of the Higgs decays has bottom quarks in the final state. Many other physics signatures will produce complex final states with bottom or charm quarks as well. A supreme vertex detector therefore is needed to reconstruct these long lived particles with excellent resolution.

- The overall event is best reconstructed with the particle flow measurement. The particle flow technique combines the information from the tracking systems and from the calorimetric systems in an attempt to reconstruct the energy and the direction of both charged and neutral particles in the event. To minimize overlaps between neighboring particles, and to maximize the probability to correctly combine tracking and calorimeter information, excellent calorimeters are needed with very high granularity.

- Many physics signatures predict some undetectable particles, which escape from the detector. They can only be reconstructed by measuring the missing energy in the event. This requires that the detector is as hermetic as possible, to minimize the amount of energy that can escape detection. Particular care has to be given to the region surrounding the beampipe in the forward direction.

The approaches to meet these demands differ in the size of the proposed detector. In the SiD detector the tracking is done entirely by a compact Silicon based tracking detector, surrounded by a calorimeter system. This has the advantage of a compact – and therefore relatively cheap – calorimeter, combined with a very high-precision tracker. The disadvantage is that only a few points can be reconstructed on each track, since otherwise too much material is introduced in front of the calorimeter, and that solid state tracking detectors have only a very limited capability to identify particles. The LDC detector features a combined Silicon and gaseous tracking system, followed by a larger calorimeter. A small, high precision SI vertex detector is followed by a gaseous drift chamber, e.g. a time projection chamber. To reach a good tracking resolution the tracker has to extend to a significantly larger radius than in the case of the small detector. The advantage of this type of detector is that a large number of space points per track is available, which also allows a measurement of the specific energy loss of the particle to
identify its type. This adds redundancy to the system, and helps performance in particular in dense jet environments. The calorimeter on the other hand is larger, and thus more expensive. However since it is located at larger radii it is easier to separate close-by charged and neutral particles, thus helping in the particle flow performance.

In the following we will discuss the large detector concept designed for an experiment at the ILC. A conceptual layout of the detector is shown in Fig. 11.

4.3. Tracking System
The tracking system has to do three jobs: it has to find and reconstruct the tracks of charged particles, it has to measure its momenta, and it has to identify and measure decay vertices of particles decaying away from the primary interaction point.

This requires a separation into at least two main components. Very close to the beampipe a Silicon vertex detector is located. Its main purpose is the identification and reconstruction of secondary vertices. To this end it can measure points on tracks with excellent accuracy, and resolve two hits down to distances of a few 10μm. The measurements of the track parameters are mostly done by a large volume time projection chamber, which provides up to 200 points on
Figure 12. Track impact parameter resolution in $r\Phi$ vs. momentum for tracks under 90 deg polar angle in the CCD vertex detector.

4.3.1. Silicon Tracking Detectors  The innermost part of the detector is constructed from three different types of silicon detectors: a high precision vertex detector immediately surrounding the beampipe, a silicon strip detector outside the vertex detector, and a system of silicon disks to instrument the forward region.

To meet the demands on resolution and robustness against background, a pixel vertex detector is chosen in all designs. Different technologies are being investigated at the moment. The best resolution and thinnest detector can at the moment be realized with a CCD type detector. Starting from just 1.5 cm away from the interaction point five cylinders are arranged around the beampipe. Pixels are of a size of typically $20 \times 20\mu m$, which allows the reconstruction of a coordinate on the detector with a precision of $1.5 - 3\mu m$. Special techniques allow the thinning of the individual detector layers to a thickness of approximately $0.05% \ X_0$. The detector is mounted inside a foam cryostat, so that it can be operated at slightly reduced temperatures compared to the ambient environment.

A particular problem is the readout of such devices in the short time available. For the CCD option a so-called column parallel readout is under development, which should allow the total readout of all approx. 800 Million pixels in $250\mu s$. This still extends over several bunch crossings at the ILC, but will keep the occupancy in the detector low enough to still be able to disentangle the different events.

The performance of this detector is characterized best by the measurement of the impact parameter, $d$. The precision with which this quantity can be determined with the CCD detector is illustrated in Fig. 12.

The vertex detector is complemented by a system of more conventional silicon detectors outside the vertex detector and in the forward region. The forward detectors are important to maintain good coverage at low angles, where the vertex detector is no longer efficient. This detector allows good track reconstruction and impact parameter measurements down to
cos \theta \approx 0.99. Outside of the vertex detector two layers of silicon strip detectors will be installed to increase the linking efficiency to the outer tracker elements, and to improve the reconstruction of vertices of long lived particles like $K^0$s.

One of the most important contributions to the physics programme is the reconstruction of life-times. Due to the excellent resolution an identification and separation of different long lived mesons, in particular a separation of bottom and charm mesons, is possible. As will be discussed later in this report this will contribute greatly to the understanding of the Higgs and therefore of electroweak symmetry.

4.3.2. Central Tracking Detectors  The central tracking system consists of gas-filled chambers, a large time projection chamber (TPC), and a forward tracking chamber (FCH), located behind the endplate of the TPC. A large volume gas filled tracking system has a number of advantages over a solution based entirely on silicon. A large number of points can be measured along a track, with good resolution and good particle identification capability through the measurement of the specific energy loss. This gives a large degree of redundancy in the reconstruction of tracks, which is particularly important in the dense, multi-jet environment expected at the ILC. Since a TPC reconstructs a true three-dimensional space point along the track, confusion from overlapping tracks or from backgrounds is minimized. In addition the large active volume covered by a TPC allows for the efficient detection and reconstruction of long lived particles. A TPC was chosen because it presents a minimum of material to the particles, thus least compromising the performance of the calorimeters, and, because a TPC is a very robust device, easy to maintain over long periods.

The general layout of one quarter of the central tracking system is shown in Fig. 13. The conceptual design draws on the large body of experience gained in constructing TPC’s at LEP, at RHIC and at other colliders. The TPC has a total length of about 5 m, separated into two halves by the central membrane. The total time it takes to completely read out one event from the TPC is around 50 $\mu$s, and thus much larger than the time between two ILC bunches. However the timing information from the TPC is sufficiently precise to disentangle the contributions...
from different bunch crossings at a later time. A particular challenge and a large difference to existing systems is the requirement that the TPC be active throughout the complete ILC bunch train. Conventionally a TPC is switched into the active state only after a trigger, and then read out with newly incoming events being ignored. This approach would result in a large reduced efficiency at the ILC. Thus a design is under development whereby the TPC can be operated continuously throughout one full bunch train, or approximately 1 ms. This requires the development of novel readout systems at the anode of the TPC, to suppress the back-flow of ions into the drift volume which are produced during the amplification step.

Apart from the question of the continuous operation, the biggest challenge is to meet the performance requirements of the TPC. In order that the momentum resolution does not limit the measurement of the recoil mass in events of the type $ZH \rightarrow H\ell^+\ell^-$ a momentum resolution of $\delta p_t/p^2 = 2 \times 10^{-4}$ (GeV/c) is needed. This is around one order of magnitude better than what has been achieved before. This implies significant development work to address the main sources of systematic errors, to control the operational parameters, and to calibrate the device well enough.

The readout of the TPC is concentrated on the endplate. Although every effort will be made to reduce the amount of material present in the endplate, nevertheless the endplate will significantly impact on the precision with which tracks and clusters can be reconstructed in this area. To alleviate this problem at least partially a system of forward drift chambers is planned to be installed behind the endplate, in front of the calorimeter. This should provide another precise three dimensional space point on tracks, and can be used to improve the quality of the track reconstruction, and can serve as a pre-shower detector for the calorimeter.

The overall performance of the central tracking system is summarized in Fig. 14. In the left plot the efficiency with which charged particles are reconstructed correctly in the central tracking system is shown. An efficiency above 90% for the full solid angle is found. In the right plot the momentum resolution as a function of the polar angle is found, for different detector configurations. In particular in the forward region the role of the forward chambers is clearly visible.

Figure 14. Left: Efficiency to reconstruct charged particles in the central tracking system. Right: Momentum resolution for 250 GeV/c muons as a function of the polar angle, for different detector configurations.
4.4. **Calorimeter System**

Many of the physics signatures at the ILC will show up in complex hadronic final states. An excellent recognition of neutral hadrons and a very good measurement of the electromagnetic and hadronic energy in an event are essential tools to meet these requirements. Experience at LEP and elsewhere shows that the concept of the particle flow reconstruction provides a very powerful tool to reconstruct these final states. In this the information from the tracking detectors and from the calorimeter is combined to obtain the best possible measurement of the total energy and the direction of the primary partons in the event.

The main idea of particle flow is to reconstruct charged particles in the tracker, photons in the electromagnetic calorimeter, and neutral hadrons in the ECAL and in the HCAL. About 60% of the energy in typical ILC events is carried by charged particles, and can thus be measured by the tracker. For typical ILC momenta, which are per particle at the level of at most 100 GeV, the tracker is by far the most precise device. The calorimeter information is not used to add to the determination of the particle parameters, but is only utilized to identify hits belonging to the charged particle, and removing them from the event.

Photons are identified in the remaining event based on the extremely precise and detailed information from the electromagnetic calorimeter. With typical cell sizes of $1 \times 1 \text{cm}^2$ or less, and with a large number of longitudinal samples, photon identification works well even inside dense jets.

Only in the rest of the event, information from the HCAL is utilized. Showers from neutral hadrons are identified, and reconstructed. With a granularity of around $3 \times 3 \text{cm}^2$ in the HCAL something close to tracking of the hadronic shower can be done, and detailed information on the shower can be used to identify and reconstruct the properties of the neutral hadrons. Nevertheless even though neutral hadrons contribute only around 10% to the total energy for typical ILC events, nevertheless the obtainably resolution for these 10% in the HCAL in the end will determine the final resolution of the overall reconstruction. Therefore particular emphasis is put on the developments of excellent hadronic calorimeters, and on a detailed understanding of the hadronic shower physics. The CALICE group makes at the moment a major effort to validate the GEANT4 hadronic shower models with test beam data, obtained with a very granular electromagnetic and hadronic calorimeter.

The situation is made more difficult by the presence of beamstrahlung and initial state radiation. Both change the energy effectively available for the reactions, thus making it very difficult to use beam-energy constraint methods as were used very successfully at colliders of less energy.

These considerations call for a calorimeter system with unprecedented performance and can be translated into the following requirements:

- excellent energy resolution for jets
- excellent reconstruction of the direction of jets
- excellent reconstruction of neutral particles, in particular photons, even in the core of jets
- hermeticity down to smallest polar angles.

These requirements are best realized in a dense sampling calorimeter, with a small transverse cell size, and many longitudinal samples. The best particle flow resolution relies not so much on the best possible energy resolution, but rather on the best possible separation and individual identification of particles contributing to a particular jet of particles.

In particular the requirement on the positional resolution forces the requirement that the coil has to be outside of the calorimeter. To maintain a hermetic detector both electromagnetic and hadronic calorimeters should be inside the coil. While this results in a large (and expensive) coil the gain in calorimeter performance is spectacular. The overall layout of the proposed calorimeter system is shown in Fig. 15.
Figure 15. View of the barrel of the calorimeter, showing both the electromagnetic and the hadronic calorimeter. On the right the arrangement of the modules of the electromagnetic calorimeter are shown.

The CALICE collaboration [13] has formed in recent years with the goal of understanding and developing a working model for such a calorimeter.

4.4.1. The Electromagnetic Calorimeter
The ideal calorimeter would provide a three dimensional picture of the shower developing inside the detector. This ideal detector can be approximated by a sampling calorimeter with the typical size of a cell given approximately by the Molière radius in the material. If this is backed up by many samples longitudinally along the shower, a detailed reconstruction of individual showers becomes possible. The reconstruction of particles in dense jets is helped by the fact that the calorimeter is immersed in the strong central magnetic field of 4T. This field helps to separate charged and neutral particles before they enter the calorimeter. An attractive solution to these requirements is a sampling calorimeter with the absorbers made from Tungsten, the active sensors from thin silicon diodes.

A detector of the size and complexity as the LDC electromagnetic calorimeter presents a sizeable challenge if it should be instrumented with Si diodes over its whole area. Many technological questions concerning reliability, production and cost of the sensors need to be answered before a final design can be attempted. However, preliminary investigations and simulations indicate that such a device would offer unchallenged performance and would significantly contribute to the physics potential of a linear collider.

4.4.2. The Hadronic Calorimeter
The hadronic calorimeter is lined up behind the electromagnetic modules, inside the coil. Together both measure the energy of neutral and charged particles. Two different solutions are currently under investigation.

The first approach is based on a conventional sampling calorimeter. The active medium is small scintillator tiles, read out via a system of wave-length shifting fibers and Silicon photo multipliers mounted directly on the tiles. The anticipated cell size is $3 \times 3 \text{ cm}^2$ throughout the calorimeter, possibly slightly increasing towards the back end of the device. The reconstruction of particles in the calorimeter uses both the topological information from the position of hits and the energy information from the size of the deposit in the cell.

The second approach relies on a layout with very small cells also in the hadronic part. The only information extracted is whether a cell has been hit or not. No energy measurement
Figure 16. Detection capability of the low angle calorimeter: shown is the 90% CL energy vs the polar angle. If an electron hits the calorimeter face with an energy larger than the one indicated it can be separated from the background with better than 90% probability.

per se is performed. Using topological information cells are combined into clusters, and the energy is reconstructed purely by counting the number of cells contributing to a cluster. The advantage of this approach is that it might allow an unprecedented tracking of particles inside a hadronic shower in the calorimeter, and thus help in separating overlapping charged and neutral particles. The drawback is the very large number of cells needed, which make new efficient and cheap detection and readout techniques necessary. In addition such a digital calorimeter is fairly sensitive to backgrounds, since the only information that can be used to separate background from real hits is the energy threshold for a hit to be counted, and the topology of the hit.

4.4.3. Forward Calorimeter  The physics at a linear collider calls for a hermetic calorimeter. The presence of intense beamstrahlung makes a dedicated approach to the very forward region necessary. The instrumentation in this region has to be able to survive the large background of mostly electromagnetic radiation emitted from the beam-beam interaction. At the same time it should be capable to at least veto large energy deposits by single particles.

In the current design two devices are foreseen, a Luminosity calorimeter (LumiCal), and a very forward calorimeter, used mostly to monitor the beam (BeamCal). Both are sampling calorimeters, built with large segmentation and fast readout systems to survive in the harsh environment. Particular emphasis needs to be placed on the radiation hardness of these devices, as they will need to operate in the presence of large electromagnetic backgrounds, and will need to stand very large neutron fluxes.

In Fig. 16 the energy is shown, as a function of the polar angle, above which an electron hitting the calorimeter is still distinguishable from the background with 90% confidence. The plot shows that down to very small angles a reasonable vetoing capability is preserved.

4.5. Muon System
The iron return of the coil surrounds the detector nearly completely. It is instrumented to serve as a muon detection system. In addition it can be used to detect energy leakage behind the coil, and thus contribute to the overall measurement of the event energy. The system should be capable of identifying the penetrating particles, and of measuring their momenta.

The performance of the system is illustrated in Fig. 17. The efficiency with which a muon in a $b\bar{b}$ final state is identified is shown as a function of the momentum of the muon. Good identification efficiency is found for muons with momentum above approximately 5 GeV.
Figure 17. Efficiency vs. momentum for muons in $b\bar{b}$ final states in the barrel region of the muon identification system.

Figure 18. Generated and reconstructed $Z$-mass (a) and recoil mass for $e^+e^- \rightarrow ZH \rightarrow \ell^+\ell^- H$ events (b).

4.6. Detector Performance

In this section only a few illustrative examples are given to demonstrate the performance of the proposed detector. A model independent analysis of the Higgs mass relies on the reconstruction of the recoil mass distribution in events $ZH \rightarrow \ell^+\ell^- H$. The quality of the reconstruction largely depends on the performance of the tracking system. In Fig. 18 the reconstructed and the generated $Z$ and recoil mass spectrums are compared. Excellent agreement is found illustrating that the resolution of the tracking system does not significantly contribute to the width of the reconstructed mass distribution.
Figure 19. Purity vs. efficiency of the $b$ and $c$ tag for $Z$ decays. The triangles show the performance in a sample of natural flavour composition at the $Z$-pole. The filled circles indicate the performance if the $u-d-s$ quark background has already been suppressed, and thus illustrate the separation between the charm and the bottom events. Also shown are the relevant points for the SLD experiment [14].

For many analyzes flavour tagging is of utmost importance. In Fig. 19 the purity to identify a bottom or charm final state is shown, as the function of the efficiency of the reconstruction. To compare to existing detectors the plot has been made for an energy of the collider of 91 GeV.

The third important task of the detector is the measurement of the particle flow in the event. Its performance relies on the design of the detector, but also critically on the state of the reconstruction software. With the currently available reconstruction tools, which are still very much under development, the reconstructed mass of hadronic $Z$-decays at rest is shown in Fig. 20. The width of the distribution corresponds to an jet mass resolution around $30\%/\sqrt{E}$, where $E$ is expressed in GeV, over most of the angular acceptance. Only in the very forward region a deterioration is visible.

While these results look very promising for events at the $Z$-pole, things are more difficult at higher energies. Here the currently achievable resolution of the invariant jet mass resolution is still worse than the goal of $30\%/\sqrt{E}$. This is due to a much more difficult environment at these higher energies, with very close-by particles in a jet, and in consequence many problems separating neutral and charged particles. Nevertheless it is widely believed that it should be possible to reach the goal of $30\%/\sqrt{E}$ with sufficiently advanced reconstruction software.

The influence of the particle flow resolution is shown in Fig. 21. These plots were done for the analysis of the $e^+e^- \rightarrow ZHH$ process, used to study the trilinear couplings of the Higgs boson. There a huge standard model background has to be separated from a tiny signal. This requires an excellent jet mass resolution, since the final state is characterized by six jets. In the figure a variable describing the agreement between the $ZHH$ hypothesis ($\text{dist} = 0$) and the background hypothesis ($\text{dist} > 0$) is plotted. It is clearly visible that the separation between signal and background is only possible if the particle flow resolution is close to the goal of $30\%/\sqrt{E}$, where
4.7. Summary: A Detector for the ILC

In summary, the LDC detector for the linear collider has been optimized to fulfill the requirements defined by the ambitious physics programme of this machine. The detector can be used over the full centre of mass energy range proposed from 90 GeV to 1000 GeV. It is well suited to analyze complex final states, and at the same time do precision measurements of the
properties of many of the particles in the final state. The design has been optimized in such a way that the detector resolutions do not limit the capabilities of the detector.

The other detector concepts, which have not been discussed here in any detail, promise to show similar performance, at least with the current level of understanding of reconstruction techniques, ILC events and ILC backgrounds. Over the next years, both the technologies and the reconstruction algorithms for the ILC physics will mature. It is hoped than towards the end of the decade, when a decision on the ILC becomes imminent, the tools and the understanding has developed sufficiently to make more reliable statement and to compare performance of different detector concepts.

5. Conclusion and Outlook
The physics community has adopted an electron positron linear collider reaching energies between 500 GeV and 1 TeV as its next major project after the LHC. The feasibility and the design of such a collider is currently worked out in international collaboration.

The physics program at such a machine is extremely rich, and promises to contribute deep insights into the physics at the energy frontier. The properties of a lepton collider - well defined center of mass energy, clear experimental collisions, no underlying event, no multi-collision environment - is well suited for a precision exploration of a new energy regime.

Experimentation at this collider is a very challenging task, though at a very different level than it is at the LHC. The main goal of detector developments is to provide devices with the needed precision, and to develop algorithms which can extract the physics from the events with adequate precision. Radiation hardness, a major topic at the LHC, is of no real concern at the ILC.

It is hoped that the ILC construction can start at the end of the decade, and that first collisions can be observed towards the middle of the next decade. This would place the ILC ideally to have a significant overlap with the operation of the LHC, thus maximizing the scientific cross-fertilization. A major effort by the community however is needed to meet this challenging time scale, and to finish both machine and detectors on time.

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