DRAFT February 2007

THE INTERNATIONAL LINEAR COLLIDER

Gateway to the Quantum Universe

ilc international linear collider

01 INTRODUCTION

What is the International Linear Collider?

A scientific revolution is in the making. From revealing the origin of mass to uncurling hidden dimensions of space to explaining the mystery of matter, the *International Linear Collider* promises to radically change our understanding of the universe. Advanced superconducting technology will accelerate particles to incredibly high energies down tunnels that span a total of 31 kilometres in length. State-of-the-art detectors will record the collisions at the centre of the machine, opening a new gateway into the Quantum Universe. From the young graduate student to the university professor, more than a thousand international scientists are collaborating today to design, and build the particle accelerator of tomorrow.

About this Report:

The global ILC community has just published its Reference Design Report, a multiple-volume document that specifies in great detail the physics goals, technical challenges, R&D achievements, and general characteristics of the planned accelerator. This document, *The International Linear Collider: Gateway to the Quantum Universe,* translates the technical and detailed content of the *Reference Design Report.* The scientists who are designing and planning the ILC wrote this report. This is their story to explain why and how to build the next big machine for particle physics.

Note to reader: Following the guidelines of the United Nations Editorial Manual, this report has adopted British English language and style.

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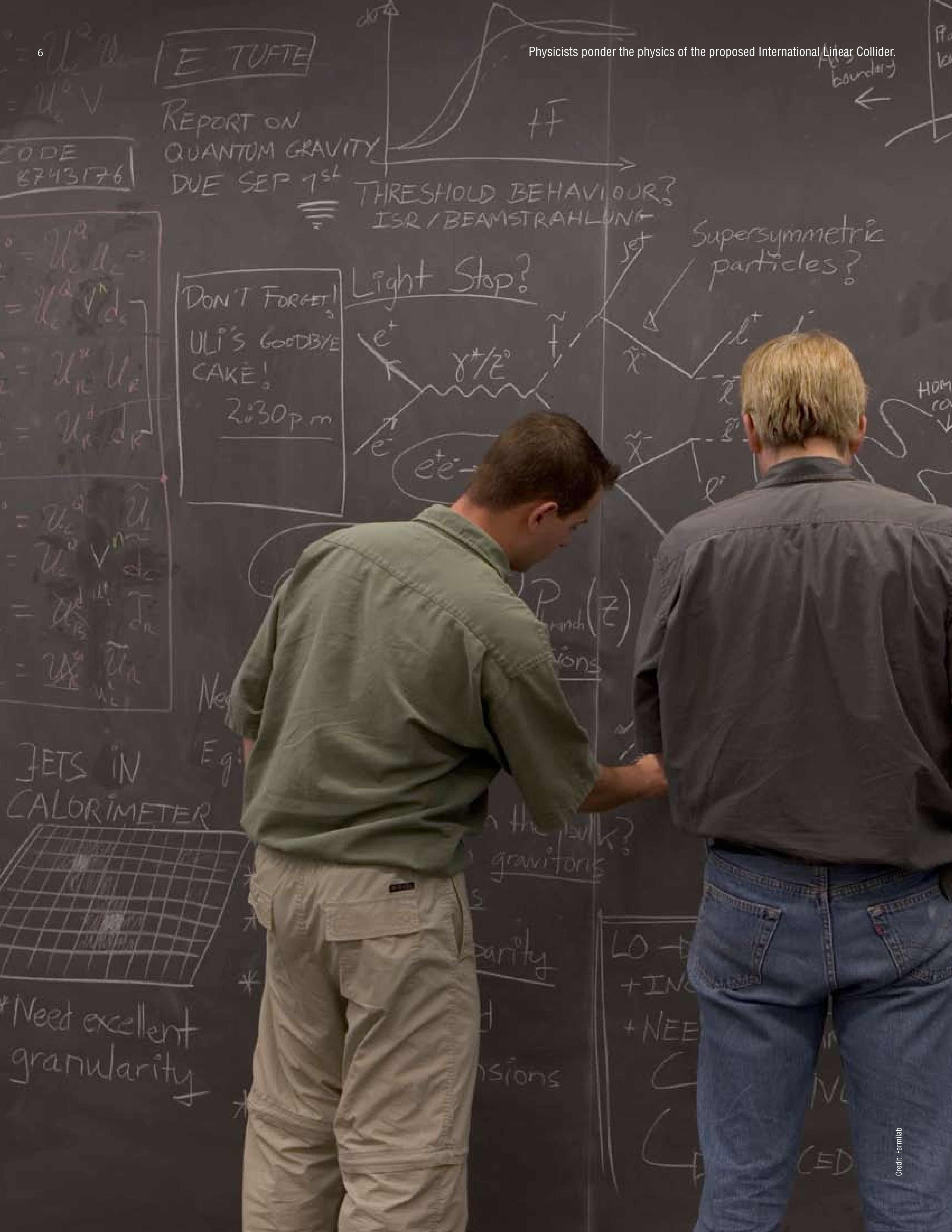


Physicists ponder the physics of the proposed International Linear Collider.

Credit: Fermilab

02 THE QUANTUM UNIVERSE

A revolution has begun in the way we see the universe.

In recent years, experiments and observations have revealed a universe far stranger and more wonderful than we had ever imagined – a universe filled with dark matter and dark energy, where ordinary matter is only a tiny minority.

The next generation of particle accelerators will stretch our imaginations even further and might reveal these new forms of matter, new forces of nature, and new dimensions of space and time. We will survey a new territory of discovery, the Terascale, named for the Tera-electronvolts (trillions of electronvolts) of energy needed to open it up for scientific discovery.

We know today that something new is out there – many superbly precise experiments from the past decades, performed by international teams, have told us so. We just do not know exactly what we might find. By exploring the Terascale, we expect to discover answers to our questions through a revolutionary new view of the universe and its physical laws – the Quantum Universe.

Universal questions

We are asking fundamental questions about the universe:

1. What is dark matter?
2. Can we solve the mystery of dark energy?
3. Are there extra dimensions of space?
4. Are there new laws of nature?
5. Is there one underlying force?
6. Why are there so many kinds of “elementary” particles?
7. What are neutrinos telling us?
8. What happened to all the antimatter?
9. How did the universe come to be?

The next-generation particle accelerators will help us to discover the answers.

The next-generation accelerators

The *Large Hadron Collider* (LHC) at CERN, the *European Organization for Particle Physics,* Geneva, Switzerland, turns on in 2007. In a circular tunnel 27 kilometres in circumference, the LHC will smash together beams of protons. Flying around the LHC, each proton will have an energy of 7 Tera-electronvolts. Because protons are bags of quarks and gluons, only a fraction of the proton energy is used when the individual quarks and gluons collide to create new types of particles.

The *International Linear Collider* (ILC) will hurl together beams of electrons and positrons (the antimatter partners of electrons) at a combined energy of 500 billion electronvolts (GeV). Facing each other, two linear accelerators – one firing electrons and the other firing positrons – will stretch for approximately 31 kilometres. At the centre, electrons and positrons will travel at nearly the speed of light and smash together, creating spectacular collisions that release all their energy and produce new particles. The design allows for an upgrade to a machine with twice the energy, 1 Tera-electronvolt.

Why is the ILC linear rather than circular? When an electrically charged particle gets forced onto a curved track, it loses energy by emitting X-rays. The higher its energy, the more energy is lost. This energy loss is much more severe for electrons and positrons than for protons, which are 2,000 times heavier. The solution to reach high energies for electrons and positrons is to eliminate the bends, hence the “Linear” in ILC.

Gateways to the Quantum Universe

To take this leap into the unknown, physicists around the globe are working together to design and build the most advanced accelerators ever conceived. The *International Linear Collider* (ILC) will chart this new universe with unprecedented precision.
The first map of the Terascale will come from the *Large Hadron Collider* (LHC) currently under construction at CERN. No one knows exactly what the LHC will find, but the territory is vast and the potential for discovery is enormous.
The ILC will allow us to home in with exquisite precision on the new landscape. It will expand on the discoveries made by the LHC and reveal the new laws of nature at the Terascale.

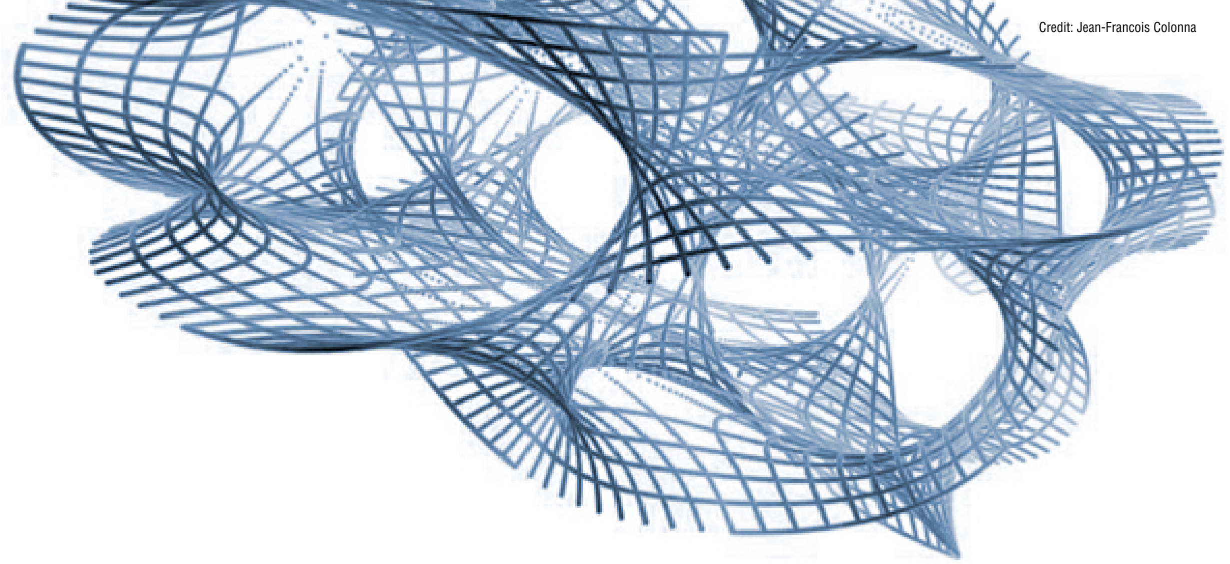
Together, these unprecedented discovery machines will bring the Quantum Universe into focus.

Secrets of the Terascale

Based on experiments and discoveries over the last decades, physicists believe that the Terascale will yield evidence for entirely new forms of matter, and possibly even extra dimensions of space. The new matter might include the Higgs boson, as well as an entire new family of elementary “superparticles”. These discoveries will tell us about the nature of the universe and how the laws of physics came to be.

Credit: Peter Ginter

Theory think tank.



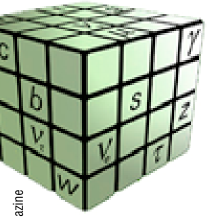
Credit: Jean-Francois Colonna

The Higgs boson

Today's Standard Model of particle physics, with its quarks and leptons and symmetry-linked forces, describes nearly all high-energy phenomena observed with existing particle accelerators. Its accuracy is remarkable, but it only works because of an unverified hypothesis: the Higgs mechanism. Like an invisible quantum liquid, the Higgs field fills the vacuum of space, slowing particle motion and giving mass to matter. Without this, all particles would be massless. Atoms would fly apart at the speed of light. When this quantum liquid gets shaken at sufficiently high energies we expect it to condense in the form of Higgs particles.

Precise measurements of the observed elementary particles allow us to estimate at what energy the Higgs boson will appear. This energy is at the limit of today's particle accelerators, but well within the range of the LHC and ILC.

At the ILC, we will create Higgs bosons in the electron-positron annihilations and then measure their properties very accurately: their mass, their characteristic spin, and the strength of their interaction with the other elementary particles. Will the Higgs properties be as first predicted as part of the Standard Model? Or will they indicate a more exotic Higgs superparticle? Will nature be even more complicated than that? The ILC will allow us to find out.



Credit: symmetry magazine

Revealing the ultimate: extra dimensions?

In our current understanding of the universe, the laws of the very large and the laws of the very small do not mesh. We have already discovered that three of the four known forces share the same mathematical structure described by quantum theory. Is it possible to reconcile gravity (the law of the very large) with quantum theory (the law of the very small)? Could there be a single underlying "theory of everything'? The ILC's unique properties could point the way towards the ultimate theory.

String theory is one promising candidate to unify the laws of the large and small. The theory holds that all particles and forces can be thought of as tiny vibrating strings. One vibration mode of the string makes it a quark, while another makes it a photon. String theory brings with it a number of dramatic concepts including supersymmetry and extra dimensions of space.

These extra dimensions are not visible in our everyday world. They are thought to be curled up so small that they will only become visible if probed with the most powerful accelerators imaginable. If new dimensions exist at the Terascale, the LHC could discover them, and the ILC could determine the number of new dimensions, their size and shape, and which particles live inside them. Together the LHC and ILC could thus open a window into a new world of quantum gravity.

Like the jelly beans in this jar, the universe is mostly dark: 96 percent consists of dark matter and dark energy. Only about four percent (the same proportion as the coloured jelly beans) of the universe – including the stars, planets, and us – is made of familiar atomic matter.


Credit: Fermilab

Shedding light on dark matter

The past decade has brought the startling discovery that 96 percent of the universe is not made of ordinary matter, but instead consists of “dark energy” (about 72%) and “dark matter” (about 24%) – a mysterious matter that does not emit light, making it difficult to detect with ordinary observation methods.

Clear evidence, however, for the dark universe comes from many sources, including astrophysical observations of clusters of galaxies that would have flown apart if ordinary matter were the only thing holding them together. Dark matter seems to hold the universe together.

But what is dark matter? Particle physics might provide the explanation because most models of the Terascale predict candidate dark matter particles. Produced copiously in the fiery cauldron of the big bang, enough particles might have survived until today to be the cosmological dark matter. To know for sure, we need to produce the particles and measure their properties precisely.

Theories of supersymmetry provide a case in point. The LHC and ILC should be able to produce and study supersymmetric particles if they exist in nature. By precisely measuring the masses of these particles at ILC, we can calculate the density of dark matter in the universe. In parallel, increasingly sophisticated cosmological observations will measure the density of dark matter to a corresponding accuracy. Comparing the ILC and cosmological measurements would provide us with overwhelming evidence that the dark matter is made of supersymmetric particles – or let us know exactly what, if anything, is missing.

Two forces become one

For centuries, scientists suspected a connection between electricity and magnetism: for example, when lightning struck a ship on the high seas, sailors noticed it had the ability to disturb a compass needle. In the 19th century James Clerk Maxwell successfully unified electricity and magnetism by creating a set of equations that firmly established electromagnetism as one of the four forces of nature that we know today. Our modern lifestyle from light bulbs to radio to computer chips rests on that achievement.

Today we are on a quest to discover whether the four forces originate from a single force that manifests itself at high energy scales. We might not be able to comprehend what the ultimate unified theory will yield, but the possibilities are endless.

A parallel superworld

In addition to dark matter, supersymmetry predicts a world of superparticles that partner the elementary particles we know today. The ILC will illuminate this parallel superworld, if it exists. The ILC's high-energy electron-positron collisions could produce these superparticles, allowing us to study the different types and measure how the members of the family interact with each other. These observations will determine the structure and definition of this superworld.

A telescope to the unknown

The great precision of its electron-positron collisions would allow the ILC to act as a telescope to see into energies far beyond those that any particle accelerator could ever directly achieve.

For now, though, our view is obscured by a lack of knowledge of Terascale physics. Data from the ILC would bring the Terascale into focus and give us a telescope to the beyond. The ILC would provide a view of energies a trillion times beyond its own – in the ultrahigh-energy realm where nature's forces might become unified.

Discovery scenarios

This table presents a summary of what the LHC and ILC would potentially discover. The exact scenario will depend upon what nature has chosen, but the abundance of exciting opportunities is clear.

THE HIGGS	**SUPERSYMMETRY**	**EXTRA DIMENSIONS**	**DARK MATTER**	**ULTIMATE UNIFICATION**
Determine why the Higgs exists Find other cousins of the Higgs Discover effects of extra dimensions Discover a new source of matter-antimatter asymmetry Determine the origin of mass	Detect the nature of supersymmetry Discover the supersymmetric nature of dark matter Reveal force unification and matter unification at ultra-high energies	Discover the number and shape of extra dimensions Determine which particles travel in extra dimensions Map out the locations of particles within extra dimensions	Discover the identity of heavy, weakly-interacting particles as dark matter Measure the abundance of weakly-interacting particles Connect dark matter candidates to deeper theories of extra dimensions, supersymmetry and the ultimate unified theory Use properties of dark matter to probe the early universe, giving us a window back to the big bang	Discover a previously unknown force of nature Connect new forces to the unification of quarks with neutrinos, or of quarks with the Higgs Connect unification to extra dimensions and string theory

Scientists and engineers from around the world are collaborating on R&D for the International Linear Collider.

Credit: Fermilab

03 ILC: THE MACHINE FOR THE FUTURE

Reaching our ambitious physics goals will be a major challenge. The ILC will not only enable us to expand the frontiers of our knowledge of the universe; it is already challenging us to push the boundaries in such diverse areas as advanced accelerator technology, materials engineering, and detector development. International teams of scientists and engineers are busy developing the design.

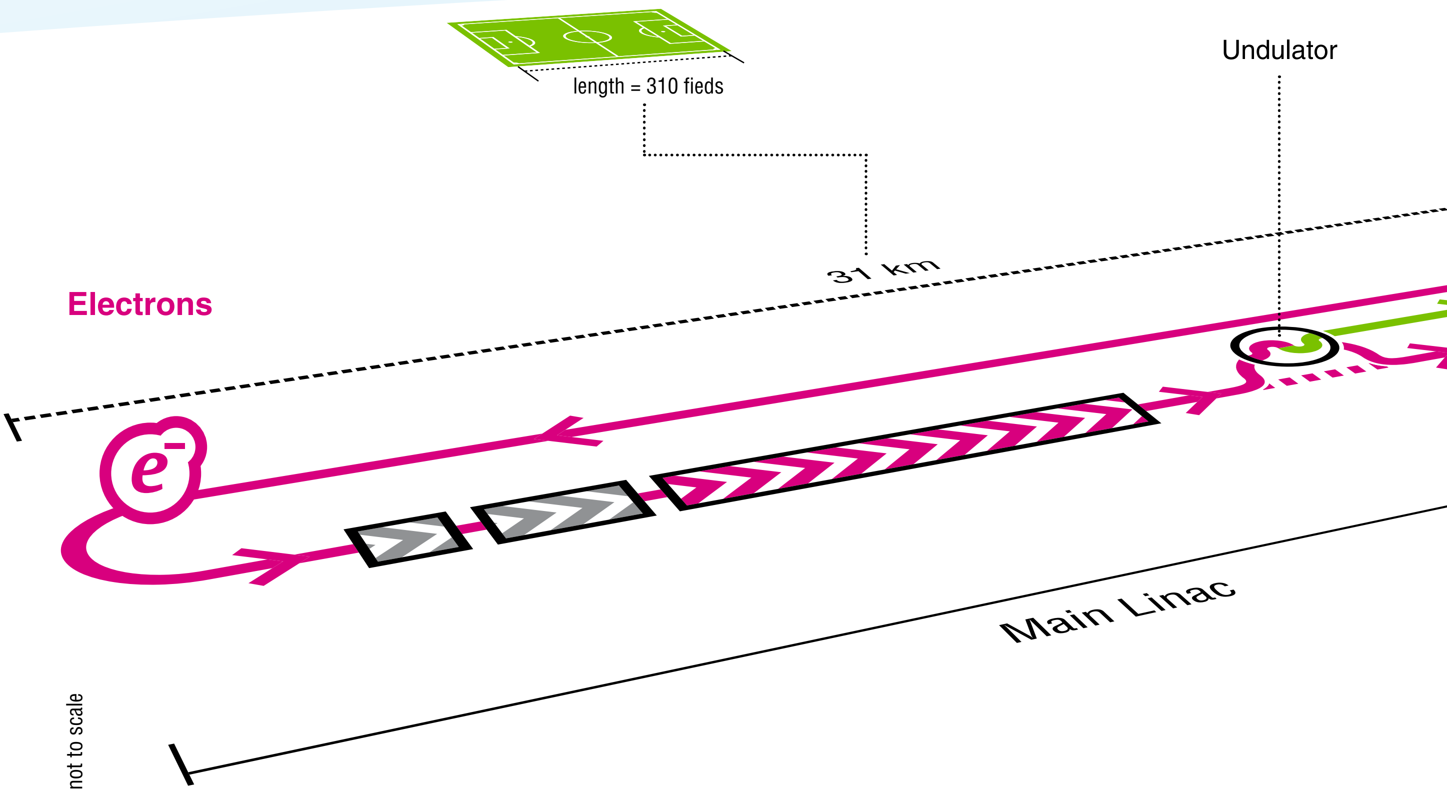
Creating the right tool

Exploring the Quantum Universe with accelerators is like methodically sweeping a flashlight to find something small in the dark.

We know that we want to collide electrons and their antiparticles, positrons, at total energies up to 500 billion electronvolts (500 GeV), as this is the energy range where we expect to gain access to many of the mysterious phenomena described in the previous chapter. When the electrons and positrons smash into each other, they will release their energies and create new particles that we can detect. This provides an environment that will allow us to make precise, incisive measurements. We know that we need a certain rate of electron-positron collisions, or “luminosity”, in order to produce enough interesting events to measure and study. These facts allow us to set the parameters for the design of the International Linear Collider.

We must direct our “flashlight” beam systematically to cover a broad search area. We know about some of the things we are looking for: dark matter, the Higgs boson, extra dimensions, and superparticles. And we know where to direct the flashlight to find them – and possibly discover things along the way that we didn’t expect. But, up until now, our flashlights do not reach far enough. By building the ILC we will have one that does.

Credit: form one®



The ILC – a step-by-step guide

Electrons

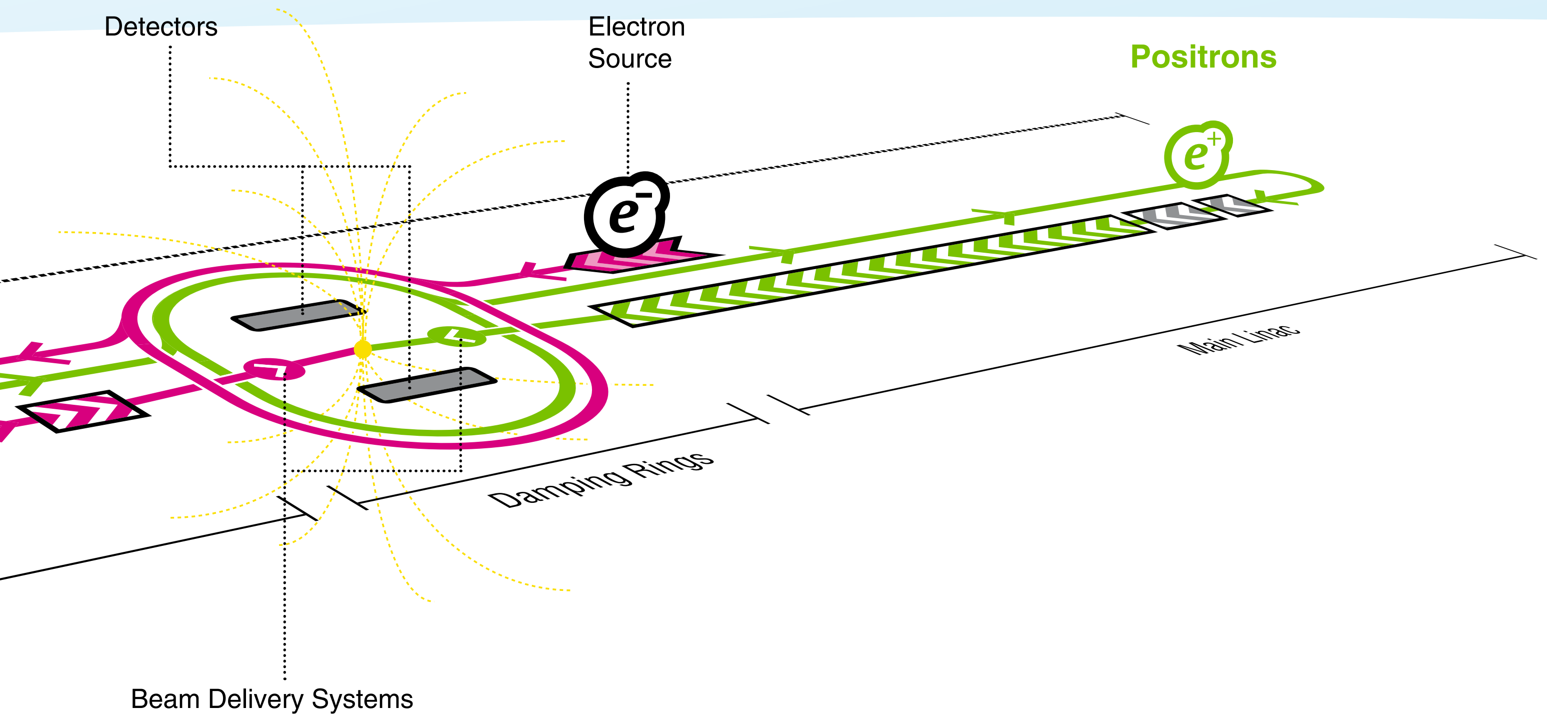
To produce electrons we will fire high-intensity, two-nanosecond light pulses from a laser at a target and knock out billions of electrons per pulse. We will gather the electrons using electric and magnetic fields to create bunches of particles and launch them into a 250-metre linear accelerator that boosts their energy to 5 GeV.

Positrons

Positrons, the antimatter partners of electrons, do not exist naturally on earth. To produce them we will send the high-energy electron beam through an undulator, a special arrangement of magnets in which electrons are sent on a “roller-coaster” course. This turbulent motion will cause the electrons to emit a stream of X-ray photons. Just beyond the undulator the electrons will return to the main accelerator, while the photons will hit a titanium-alloy target and produce pairs of electrons and positrons. The positrons will be collected and launched into their own 250-metre 5-GeV accelerator.

The damping rings

When created, neither the electron nor the positron bunches are compact enough to yield the high density needed to produce copious collisions inside the detectors. We will solve this problem by using seven-kilometre-circumference damping rings, one for electrons and one for positrons. In each ring, the bunches will repeatedly traverse a series of wigglers, devices that causes the beam trajectories to “wiggle” and emit photons. This process makes the bunches more compact. Each bunch will spend approximately two tenths of a second in its damping ring, circling roughly 10,000 times before being kicked out. Magnets will keep the particles on track and focussed in their circular orbits around the ring. Upon exiting the damping rings the bunches will be a few millimetres long and thinner than a human hair.



The linacs

We will use two main linear accelerators (“linacs”), one for electrons and one for positrons, each 12 kilometres long, to accelerate the bunches of particles toward the collision point. Each accelerator consists of superconducting cavities nestled within a series of cooled vessels to form cryomodules. The modules use liquid helium to cool the cavities to -271°C, only slightly above absolute zero, to make them superconducting. We will launch travelling electromagnetic waves into the cavities to “push” the particles through, and accelerate them to energies up to 250 GeV. Each electron and positron beam will then contain an energy of about a kilojoule, which corresponds to an average beam power of roughly 10 megawatts.

The whole process of production of electrons and positrons, damping, and acceleration will repeat five times every second.

The beam delivery systems

In order to maximise the luminosity we will then focus the bunches to extremely small sizes. We will use a series of magnets, arranged along two 2-kilometre beam delivery systems on each side of the collision point, to focus the beams to a few nanometres in height and a few hundred nanometres in width. The beam delivery systems will scrape off stray particles in the beams and protect the sensitive magnets and detectors. Magnets will steer the electrons and positrons into head-on collisions.

The detectors

Travelling towards each other at nearly the speed of light, the electron and positron bunches will collide with a total energy of up to 500 GeV. We will record the spectacular collisions in two giant particle detectors. These work like gigantic cameras, taking snapshots of the fleeting particles produced by the electron-positron annihilations. The two detectors will incorporate different but complementary state-of-the-art technologies to capture this precious information about every particle produced in each collision. Having these two detectors will allow vital cross-checking of the potentially-subtle physics discovery signatures.

The major challenges

Energy

The energy scales we will probe with the ILC are far beyond anything electron-positron colliders have ever achieved. To attain the beam energy of up to 250 GeV per particle, adding up to 500 GeV per collision, would require 167 billion standard AA batteries placed end to end.

Superconducting radio-frequency technology

A charged particle can only be accelerated by an electric field. To provide the necessary acceleration we will use superconducting niobium radio-frequency (RF) cavities. The accelerating electric field is established by supplying RF energy pulses to the cavities, which are immersed in liquid helium at a temperature of -271°C. The cavities sit inside vessels surrounded by thermal shields and an outer tank – a cryostat – to insulate them from the exterior, which will be 300 degrees hotter.

As many as 8,000 cavities per linac, each roughly a metre long, and placed end-to-end in cryomodules, will drive the electrons and positrons forward with an accelerating gradient of more than 30 million volts per metre. The higher this gradient, the shorter, and hence cheaper, the ILC can be made.

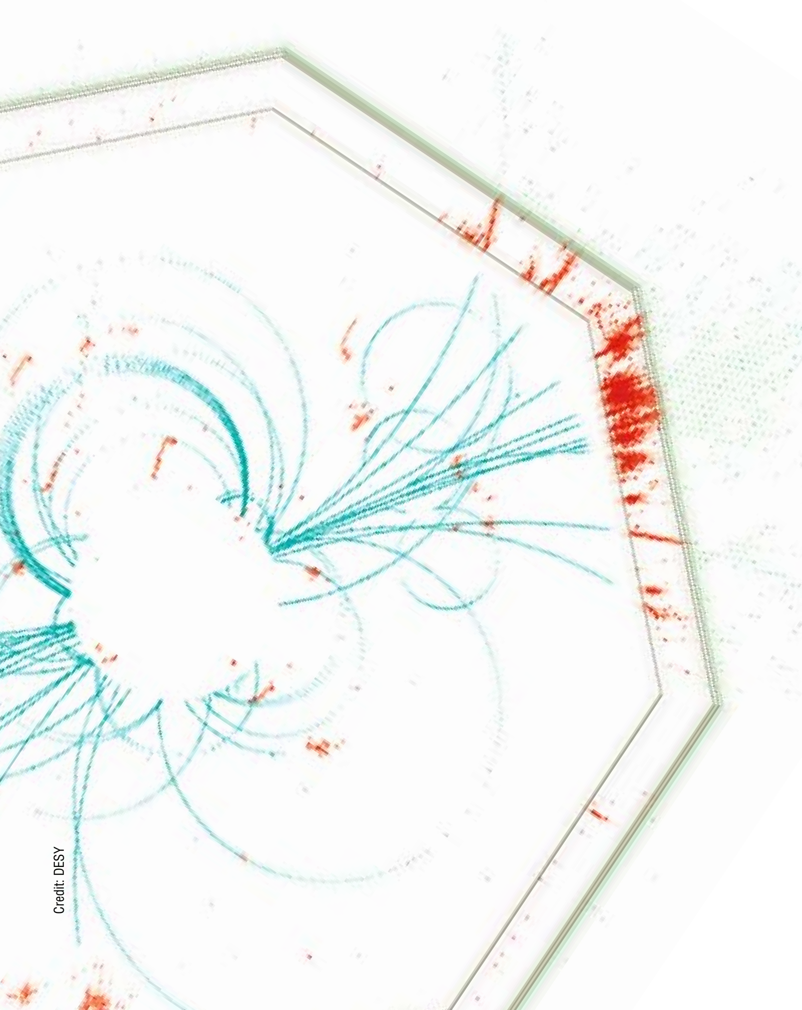
Luminosity

In order to make discoveries, we require large amounts of high-quality data. The more often electrons and positrons collide and annihilate, the larger the amount of interesting data that will be produced. This requires a high luminosity, or rate of collisions per cross-sectional area. The ILC requirement of luminosity in excess of 10^{34} electron-positron crossings per square centimetre per second represents a major design challenge.

We can achieve this high luminosity by cramming as many electrons and positrons as possible into the smallest beams we can make, and ensuring that the beams collide. In practice this means squeezing more than 10 billion electrons and positrons into beams roughly five nanometres tall by 500 nanometres wide, and then steering the bunches into collision using advanced feedback systems.

The particle detectors

The particle detectors will literally provide the centrepiece of the ILC. The detectors will enclose the collision point where electrons and positrons annihilate, and they will yield the clues that will allow us to unravel the Quantum Universe. Twelve metres long, high and wide to contain all components, cables and a powerful magnet, they will be as big as a three-storey building and weigh several thousand tons. Employing state-of-the-art components, the detectors will record every collision that takes place and each particle that gets produced. Millions of electronics channels will be needed to record the precious information and ensure that nothing is missed. Armed with this information, we will be able to reconstruct every collision and look at each such “event” to understand what happened. This analysis will allow us to find those events that contain dark matter particles, the Higgs boson, superparticles – or completely unanticipated things – and study them in great detail. We intend to use the ILC detectors to measure collisions more precisely than ever before.



Credit: DESY

The vertex detector

At the heart of the massive ILC detector system, the vertex detector, a compact tracking device about the size of a wine bottle surrounds the interaction region. Consisting of cylinders of silicon detectors, this high-tech device contains about a billion pixels in total – equivalent to hundreds of the finest digital cameras. It works just like a 3D camera or microscope because it measures the tracks of outgoing particles with micron precision. A few of the colliding particles might contain exotic heavy quarks, which live for a billionth of a second before they decay to familiar forms of matter. These quarks reveal themselves by decaying at “vertices” very near the collision point. The exotic quarks, made visible by the vertex detector, are pointers to new physics.

Credit: KEK

The 1-metre long superconducting cavities are made from pure niobium, treated and tested by scientists to ensure high-performance capabilities for accelerating particles.

Superconducting niobium cavities

How do superconducting cavities work? A voltage generator fills each hollow structure with an electric field. The voltage of the field changes with a certain frequency: a radio frequency, or RF. Charged particles feel the force of the electric field and accelerate. Build the cavity out of superconductor, such as niobium, and chill it to near absolute zero and you have a "superconducting RF cavity." They conduct electric current with no loss of energy, which means that almost all the electrical energy goes into accelerating the beam, rather than into heating up the accelerating structures themselves.

Designing and building the optimal cavity is not simple. The 1-metre long cavities are made from nine smooth cells, polished to provide micron-level surface quality, and free of impurities. Significant surface blemishes, or dust, could cause them to lose their superconductivity without sustaining the electric field needed to accelerate particles. A series of detailed chemical treatments and processes literally make the cavities sparkle.

Credit: Fermilab

04 A GLOBAL PROJECT

The International Linear Collider will be one of the world's largest and most sophisticated scientific endeavours. Planning, designing, funding, and building the ILC will require global participation and global organisation.

The Global Design Effort

The *International Committee on Future Accelerators* (ICFA) charged a subgroup, the *International Linear Collider Steering Committee* (ILCSC), with planning a global strategy for the ILC. To carry this strategy forward, the ILCSC established in early 2005 the *Global Design Effort,* an international team of more than 60 scientists and engineers from around the world. The GDE team, led by Barry Barish, sets the strategy and priorities for the thousand scientists and engineers at universities and laboratories around the world who are now collaborating on the project.

The GDE team supervised the production of a baseline design for the ILC, which was completed in late 2005. This baseline design has been used as the basis for the more detailed *Reference Design Report* (RDR), which provides a technical description of the project and includes an initial cost estimate. The RDR represents a major milestone on the path to reaching a final engineering design and a more detailed cost estimate.

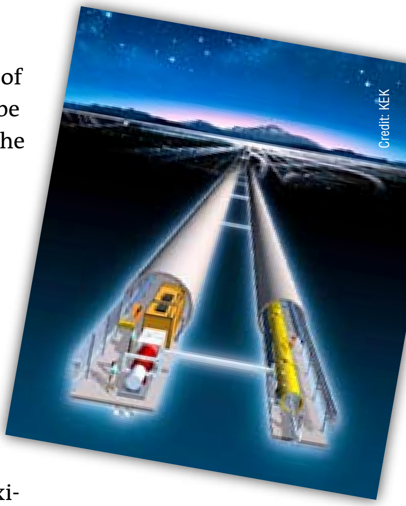
The RDR forms a basis for identifying priorities for the next engineering phase of the project, as well as for further developing the worldwide R&D programme that will lead to further cost reduction, decreased risks, and improved performance.

The GDE process has been monitored by a high-level international group comprised of representatives of funding agencies from around the world: *Funding Agencies for Large Colliders* (FALC). We expect that further international planning, including preparations for construction, will continue in a similar globally-collaborative fashion.

Site considerations

The design and R&D effort of the accelerator and detectors for the ILC is distributed among laboratories and universities around the world. Within the next few years, we hope to progress to a project with an internationally-agreed site. This immense step will depend on input from technical studies as well as considerations by the governments of the nations who might express interest in hosting the ILC.

In producing the RDR, the GDE evaluated sample sites in the Americas, Asia, and Europe. The site must accommodate the 72 kilometres of tunnel complex needed to build the 31-kilometre machine, with some sections as much as several hundred metres below ground. There will be 13 major access points with shafts and tunnels up to nine metres in diameter. In total, more than 450,000 cubic metres of underground construction will be required, consisting of the long main tunnels, alcoves, and halls for service equipment as well as the detectors themselves.


Credit: KEK

The primary concerns for any site include geological stability, the quality of the rock in which the tunnels would be bored, the mechanical vibrations in the floor of such tunnels due to seismic activity, industrial "noise" resulting from construction work and traffic, and issues of sealing the tunnels from ground water. Cost estimates were made for the civil engineering at each of the sample sites, involving local construction experts. While there are regional cost variations for particular services, the total cost turned out to be approximately the same for each sample site considered.

The final site selection will involve many nations and a proposal to host the facility according to procedures that will be agreed on by the international funding partners.

Estimate for the ILC machine

The Reference Design Report provides the first detailed technical snapshot of the ILC. One of the most important components in developing this reference design is to understand enough about the costs to provide a reliable indication of the project's scale. Equally important, this preliminary estimate will help guide the final engineering phase of the project. The estimate will be used to study options for further reducing costs, improving performance, and developing a prioritised global R&D programme. The costing will also provide important information on the relative value of the different components and thereby enable partners to assess their contributions.

This estimate gives a first evaluation of the ILC cost at this time. It serves as a preliminary basis for continuing ILC engineering, and these estimates will continue to evolve.

What did we estimate?

We estimated two quantities: the VALUE for items provided (in 2007 US dollars), and the LABOUR (in person-years). These quantities are independent of individual national costing methods but can be translated into any local currency or costing system. The total VALUE has two components: the value of shared components and the site-dependent value for hosting the machine.

What are shared components?

These are the high-technology components and other technical parts where there is global capability and we can make a single world estimate. For example, all regions can supply such technical components as water cooling and electrical distribution systems.

What does "site-dependent" mean?

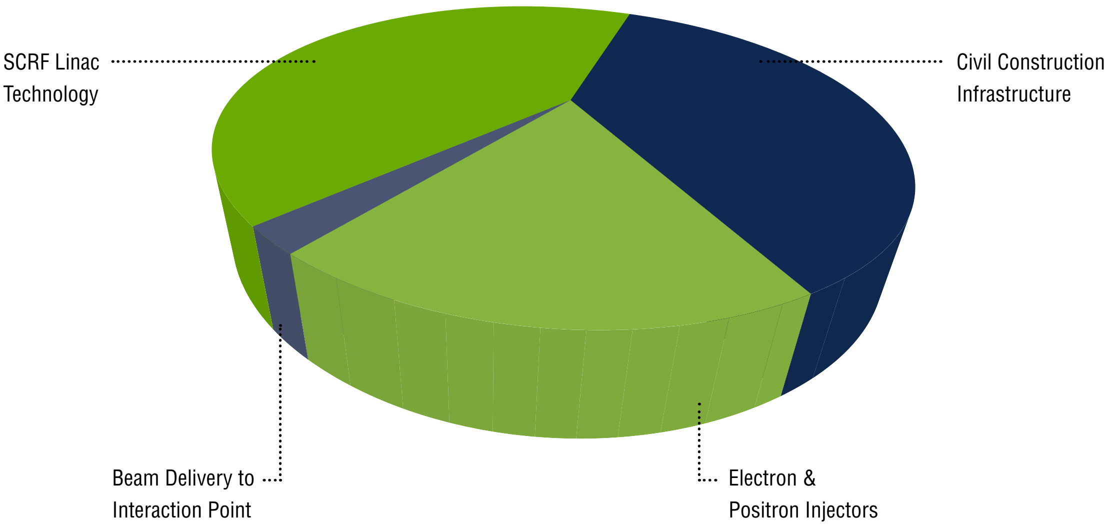
These are such things as tunnelling, where we make separate estimates for each region. The site-dependent elements include all the civil engineering, high-voltage electrical power needs, and water cooling needs. These are generally expected to be the items where the costs will be borne by the host country.

How did we arrive at the estimate?

We obtained our cost estimate by involving technical and costing experts in Europe, Asia, and the Americas. We used a value accounting process that is becoming standard for international scientific projects such as the ILC. Based on the detailed technical requirements of the ILC, we determined the values of components based on a worldwide call for tender to obtain the required quality at the lowest reasonable cost.

Both LABOUR and VALUE are universally-accepted estimates of the value for each technical component. These figures will be used by partner nations to apportion their contributions fairly. The VALUE and LABOUR estimates can be converted by individual funding agencies to determine costs in their own costing systems and in local currency units.

An approximate breakdown of the ILC estimate by main categories.



What are the numbers?

The following figures are the base VALUE and LABOUR quantities that can be translated into costs, by using a given national costing method:

SHARED VALUE =	4.87 Billion ILC VALUE UNITS
SITE-DEPENDENT VALUE =	1.78 Billion ILC VALUE UNITS
TOTAL VALUE = *(shared + site-dependent)*	**6.65 Billion ILC VALUE UNITS**
LABOUR =	22 million person-hours = 13,000 person-years (assuming 1700 person-hours per person-year)
1 ILC VALUE UNIT =	1 US Dollar (2007) = 0.83 Euros = 117 Yen

What does the estimate include and exclude?

The VALUE and LABOUR amounts include:

- construction of a 500 GeV machine and the essential elements to enable an optional future upgrade to 1 TeV;
- tooling-up industry, final engineering designs, and construction management;
- construction of all conventional facilities including tunnels, surface buildings, detector assembly buildings, underground experimental halls, and access shafts; and
- explicit labour including that for management and administrative personnel.

The VALUE and LABOUR amounts exclude:

- engineering, design or preparation activities that must be accomplished before project funding (such as R&D), proof-of-principle, and prototype tests;
- surface land acquisition or underground easement costs;
- detectors, which are assumed to be funded by a separate agreement;
- contingencies for risks; and
- escalation (inflation).

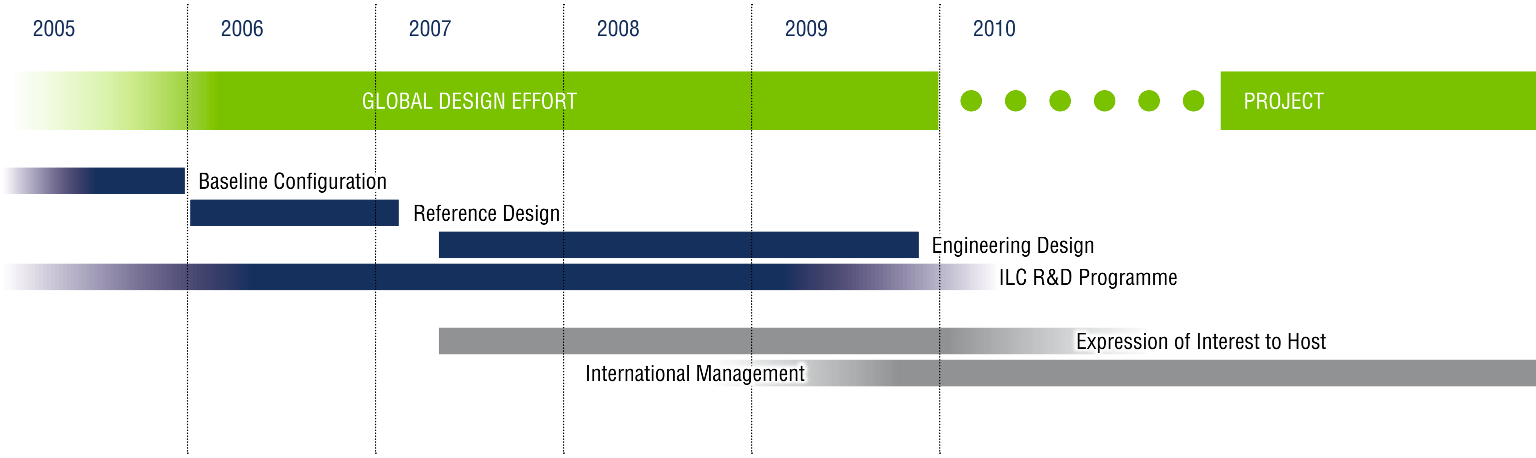
Credit: DESY

The next steps

Since the decision to use superconducting technology in mid-2004 and the subsequent foundation of the GDE in early 2005, the ILC has made remarkable progress. The publication of the RDR completes this initial phase and marks the beginning of a new era.


Credit: KEK

In the next steps we will evolve and improve the design through continuing R&D and value engineering. We aim to make engineering choices for further optimising the performance relative to cost. This process will take two to three years using the solid basis provided by the RDR, and will lead to a detailed Engineering Design Report (EDR). The EDR will form a "blueprint", with a refined cost estimate, so that ILC construction can start at the selected site. Starting from the formal project approval, we estimate the time for construction of the accelerator complex and detectors to be approximately seven years.



A possible projected timeline for the ILC

To arrive at an estimate, the GDE used a value accounting process that is becoming standard for international scientific projects.


Credit: KEK

05 THE ROAD AHEAD

It has become clear over the past few years that to successfully realise a scientific project on the scale of the ILC requires a global pooling of resources. This is natural in high-energy physics – the phrase "global high-energy physics community" is a real and meaningful one. The worldwide community is used to speaking the same language of key physics questions, reading the same papers, and attending the same conferences. Indeed, the tools we have developed to share information among ourselves, such as the World Wide Web, have had a huge impact.

The "I" in "ILC"

We have long and very successful experience with the construction of accelerators and detectors as international projects. Recently, for example, the construction of the major detectors for the LHC has required global collaborations of physicists with significant hardware coming from Europe, Asia, and the Americas. As well as technical success in carrying out big projects, this mode of working has enriched the culture of all the participants and promoted international understanding. For young people especially, the opportunity to work closely with peers from other cultures is a valuable and often eye-opening experience that breaks down cultural barriers and stereotypes.

In the case of the ILC, we need to take this successful record of collaboration to the next level: we aim to build and operate a global facility for high-energy physics. We can build on the considerable body of experience amassed so far, and also learn from other twenty-first-century global projects like the astronomy project ALMA and fusion project ITER. This gives us confidence that we can be successful, but there is no fully-worked out model we can follow – we are entering new territory, and that is exciting.

The GDE, and the process that led to it, has shown that it is possible for scientists from around the world to come together in pursuit of a common goal. We can take tough decisions such as the choice of RF technology and can focus and align our R&D efforts. We can exercise effective project management, despite our geographic spread and separate national funding sources.

Of course, as the project moves towards approval and construction it will be necessary to add some greater formality to the management structure. But it is important not to move away from the idea of the ILC as a truly global project, because wherever the ILC is sited, the very significant investments needed from the other regions will only come if all partners feel a true sense of co-ownership. This means having a proper say in operations and management, and deriving the appropriate economic impact and training opportunities for their own scientists and engineers.

The ILC will take international collaboration in science and technology to a new level. It can be a model for the emerging science projects of our new century.

Industrialisation

By the scale of the numbers alone, the ILC shows the critical need for a global partnership between industry, technology, and science: 16,000 cavities, 2,000 cryomodules, 700 klystrons, as well as many kilometres of tunnel complex, are examples of the components that we need in large numbers. Laboratories and research institutes alone cannot manufacture them; we need the skills and capabilities of industry across the globe. It will be a monumental and exciting challenge.

Scientists, engineers, and industry representatives have already established ILC industrial forums in the three participating regions. These forums foster communication and coordination between the scientific and industrial partners. We are working together to develop capabilities, create prototypes, and lower costs. We aim to enable large-volume production of high-quality technical components that meet specifications at a realistic and affordable cost.

Industries around the world will play a major role in building the ILC.

Credit: KEK

Because the industrialisation of the ILC will be as international as the project itself, industries around the world are beginning now to establish standards and procedures for producing the myriad components needed. Parts originating from across the world must be manufactured to work in synergy: the beams should never know where, for example, a niobium cavity was made.

The technologies that we must develop have other potentially significant applications. Accelerators based on superconducting RF technology are being planned for use in many areas of science and medicine, such as next-generation X-ray imaging facilities. Our development of advanced diagnostic tools and techniques, control systems, and methods for handling vibration isolation, for example, are all likely to find wider use.

The ILC will need 16,000 of these superconducting cavities, produced by the project's industrial partners.

Credit: DESY

Credit: DESY

Today's children are the future scientists who might unlock the deepest mysteries of the universe.

Training the Next Generation

Somewhere in the world, a twelve-year-old child sits in a classroom and asks the teacher why things work the way they do. Fast forward a decade or so and that young researcher might be mining the ILC data, searching for evidence of dark matter and extra dimensions, leading us into the Quantum Universe.

The ILC will capture the imaginations of future generations of young scientists and engineers and stimulate them to see further into the unknown. We ask some of the deepest, most thought-provoking questions about the universe; they will challenge the next generations, and the answers provided by ILC will inspire wonder and awe.

Today at laboratories and universities around the world, several hundred students, under the guidance of senior scientists and engineers, are already contributing to the ILC. The experience and knowledge that they gain from working on an international advanced-technology project provide them with key skills that benefit all of us. We are working together across time zones, borders, and languages: the ILC provides a beacon for future worldwide collaborations in science, technology, and beyond.

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