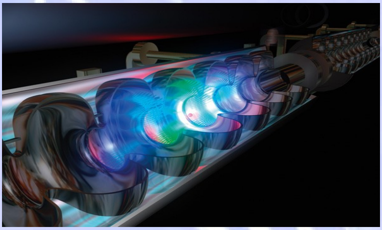
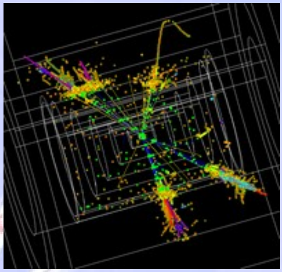
A new tool to understand the Universe:

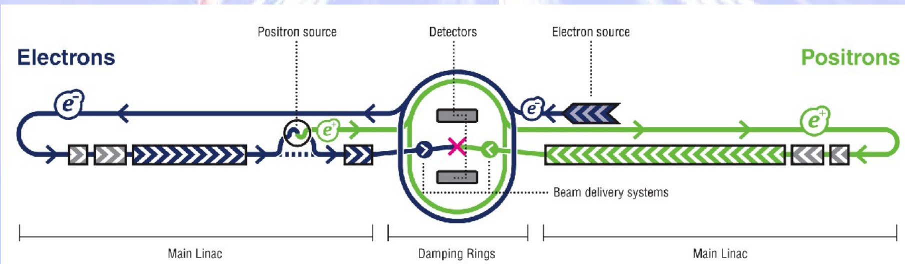
The International Linear Collider





In a few months the Large Hadron Collider (LHC) at CERN will start exploring new domains of particle physics...

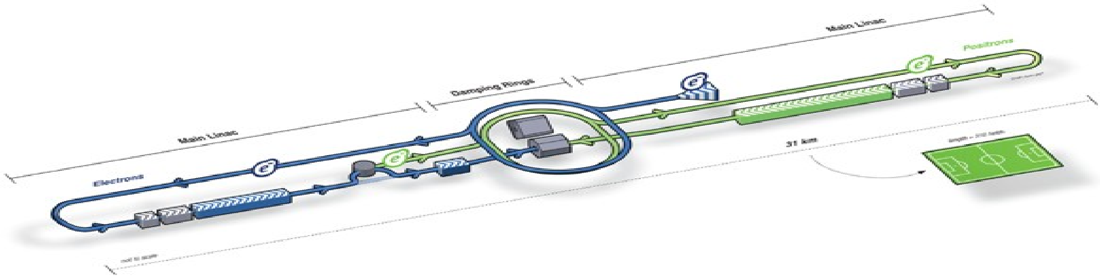
... In its footsteps the 31 km-long International Linear Collider (ILC) will allow precise measurements of these new domains and will have unique access to areas left unexplored by the LHC.

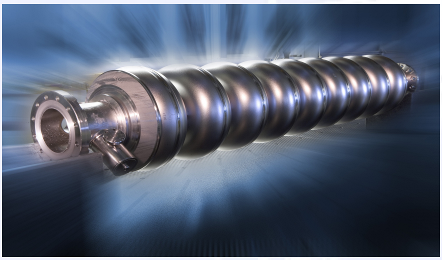


The following pages show how several research groups in the UK are solving the challenges raised by the complexity of such collider.

Overview of the ILC

At 31km in length, the **ILC** will be the largest and the most complex particle accelerator ever built. Two large 6-km rings called "damping rings" will be used to "cool" the particles and to give them the required quality. The particles will then be accelerated by two very long linear accelerators called "linacs". At the end of the linacs the particles will enter the "beam delivery section" where their final properties will be measured and adjusted just before they smash into each other. Physicists from all over the world participate in the design, and it is not yet decided where the machine will be built.

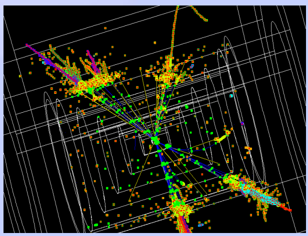




Each beam of the ILC will have an energy of 250 GeV (later 500 GeV), that is 5 to 10 times more than the very successful LEP that operated at CERN until 2000. The main linac will consists chiefly of superconducting acceleration structures.

Every second 5 trains of 3000 bunches of electrons and positrons will be sent to interact in the middle of the detector. To get the most out of the ILC the particles bunches will have to be focussed to a beam size of just 5 nanometres.

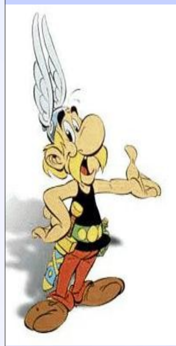
The ILC will allow studies of the Higgs mechanism, Supersymmetry (SUSY) or any other new phenomena. The precision achieved will allow a detailed study of the mass generation mechanism and if SUSY exists in Nature, the ILC can precisely measure the properties of accessible supersymmetric particles.

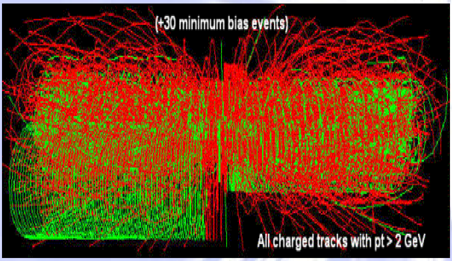


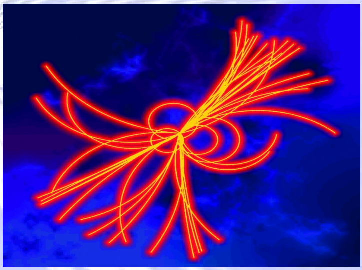
Synergy between the LHC and the ILC

At the Large Hadron Collider (LHC), protons will be fired around the CERN ring. Protons are composite particles – each proton is composed of three quarks. The LHC is a discovery machine, and will shed light on high energy physics.

At the International Linear Collider (ILC), electrons and their anti-particles, positrons, will annihilate into pure energy. Since electrons are fundamental particles, these collisions will produce clean, clear signals.





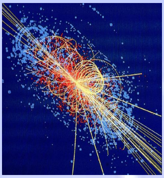


The synergy between the LHC and the ILC during simultaneous running of the two machines can maximise the physics gain from both facilities. The LHC has a large mass range for the discovery of new heavy particles, and the ILC's clean experimental environment and tunable collision energy allows it to perform detailed studies of directly accessible new particles. The ILC also has exquisite sensitivity to quantum effects of unknown physics - indeed, the fingerprints of very high scale new physics will often only show up in small effects whose measurement requires the greatest possible precision.

LHC / LC Study Group

World-wide working group:
http://www.ippp.dur.ac.uk/~georg/lhclc

THE HIGGS BOSON

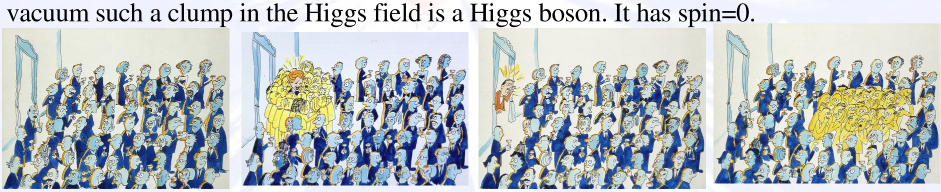


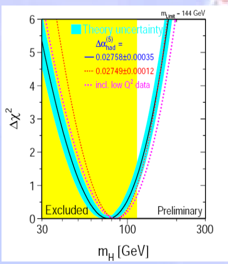
In 1964, Peter Higgs suggested the existence of a new field (now called the Higgs field) to explain why particles have mass. The Higgs mechanism explains mass by saying that the Universe is filled with the Higgs field. Interacting with the Higgs field gives the particles mass.

The Higgs boson would be an experimental evidence of the Higgs mechanism. The Higgs field doesn't just interact with particles – it also interacts with itself. This selfinteraction is the Higgs boson, see following story (by David J. Miller):

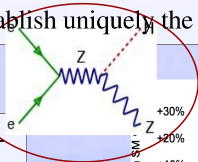
1. **The Higgs mechanism**: imagine the vacuum as a form of a cocktail party of political workers, uniformly spread across the room. A beloved ex primeminister enters and is immediately surrounded by wellwishers. The cluster of admirers gives her extra mass, i.e. more inertia; just as an electron acquires extra mass from the lattice in a semiconductor; or the W and Z from the Higgs field in vacuum.

2. **The Higgs Boson**: Now a scandalous rumour is launched into the party. The partygoers clump to transmit the rumour, just as they clumped around the ex-leaderine. Similar "dilaton" effects occur in solids. The clump can travel like a particle. In the vacuum such a clump in the Higgs field is a Higgs boson. It has spin=0.

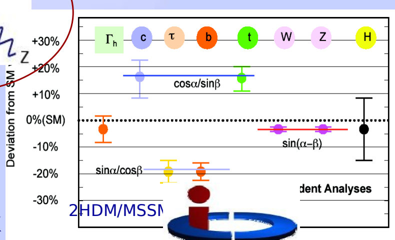




Despite no direct observation, there is a vast amount of indirect evidence that the Higgs boson mass is within the kinematic range to be seen at the LHC and ILC. The ILC will be able to make these precision measurements and to establish uniquely the Higgs mechanism.



At the ILC, we will be able to make a decay-mode-independent observation of the properties of the Higgs boson to incredible precision.



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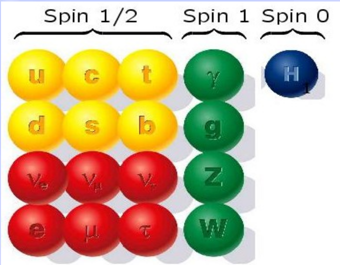
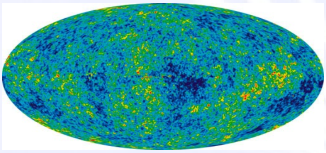
Durham University

SUPERSYMETRY

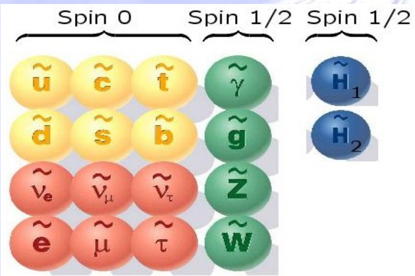


The Standard Model is an extremely precise model of the particles in our Universe and their interactions. There are two types of particle – fermions and bosons. All of the matter around us is made up of fermions, like electrons and quarks. The bosons are responsible for carrying the three forces of the Standard Model: electromagnetism, the strong force and the weak force.



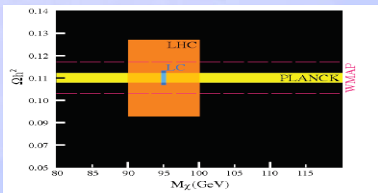
Despite its many triumphs, there are some problems with the Standard Model. For example, by studying the cosmic microwave background, and the rotation curves of galaxies, astronomers have determined that there is far more mass in the Universe than can be

accounted for by the normal 'shiny' matter that makes up stars and gas. Approximately a quarter of the Universe consists of dark matter, which isn't made up of any of the particles that are included in the Standard Model.



Supersymmetry is a way of directly relating fermions and bosons. The theory postulates that every particle in the standard model has a supersymmetric partner of the opposite type: for every Standard Model fermion, there is a corresponding supersymmetric boson, and for every boson there is a corresponding fermion.

The lightest supersymmetric particle provides an ideal candidate for dark matter. Precise measurements are needed to verify whether the properties of the lightest particle are consistent with cosmological data. The ILC will give us the chance to discover and study supersymmetry in depth, allowing the most precise measurements of supersymmetric particles.



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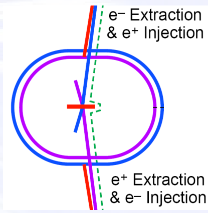
Accelerator and ...

*The **LC-ABD** (Linear Collider: Accelerator and Beam Delivery) consortium is a group of UK institutes aiming to develop new techniques for the control of intense relativistic particle beams at the nanometre level of precision for the International Linear Collider (ILC). This includes beam measurement, RF system development and work on positron sources.*

Polarised positrons: One of the major technological challenges of the ILC will be to produce positrons at the required rate of 100,000,000,000,000 per second.

An undulator-based design is been studied for the positron source. It has the extra characteristic of being able to produce polarised positrons which would significantly increase the scientific reach of the ILC.

Damping rings: The purpose of a damping ring is to reduce the width of a beam of electrons or positrons. Then they will be extracted and speeded up to very high energy by an accelerator. In a damping ring thousands of magnets are used to make the electrons go round in circle. As they do so they emit radiations. If you are very good and make sure that the thousands of magnets are all perfectly aligned, the oscillation will drop to a few micrometers. This is what **damping** means. Then everyone will be happy.

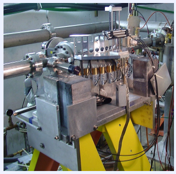


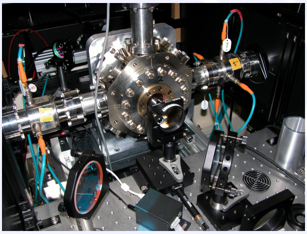
Crab cavities: As the linacs of the ILC are not aligned, bunches must be rotated into alignment to maximise the number of electron positron collisions at the IP. This can be done by driving accelerating cells at a higher frequency so they deflect or impart angular rotation to charged bunches.

Energy spectrometer: Physics requirement require the ILC beam energy to be known to **better than 1 part in 10000**. This can be achieved by measuring very precisely the **deflection of** the beams through a magnetic chicane.

... Beam Delivery

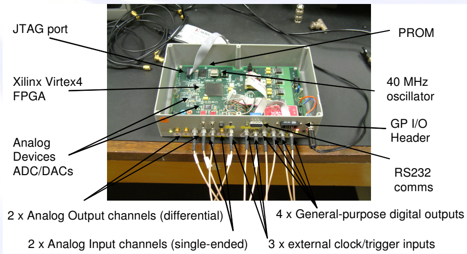
Longitudinal beam profile measurement: The Smith-Purcell group aims at measuring the longitudinal size of the electron bunches by observing the radiation emitted when a bunch passes near a grating.





Transverse beam profile measurement: The laser-wire collaboration uses high-power laser to measure the transverse size of the particle bunches with an unprecedented resolution. This is done by swiping a laser across the path of the particles and looking at the profile of the signal observed. The laser-wire R&D has led to the development of a new laser and a new focusing lens.

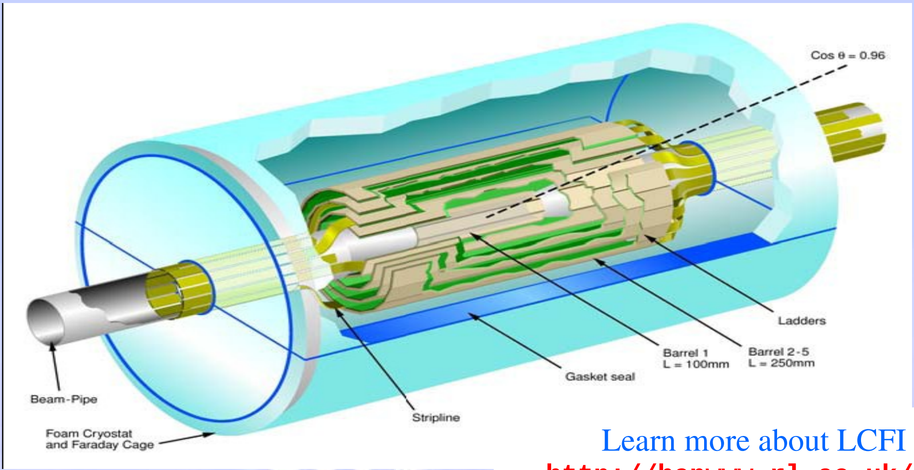
Feedback On Nano-second Timescales (FONT): The F.O.N.T. project was set up to research, design and test an intra-train beam-based feedback system to achieve and maintain beam collisions at a future electron-positron Linear Collider. The picture shows the FONT4 digital feedback prototype.



Linear Collider Alignment and Survey (LiCAS): The collaboration has developed a prototype to survey the ILC tunnel. This prototype utilises Frequency Scanning Interferometers, Laser Straightness monitors and gravity referenced tilt sensors to reach a predicted accuracy of 120 (50) microns vertically (horizonally) over 600m at a speed of 3km per day.

Stabilisation: The MonAliSA group develops accurate, nanometre resolution, interferometric systems to stabilise the final focus magnets.

Flavour Identification

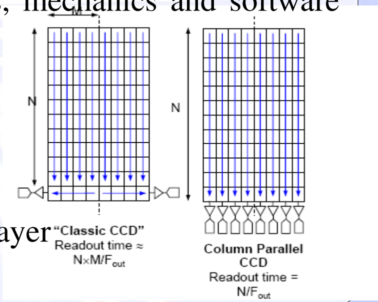


Learn more about LCFI at
http://hepwww.rl.ac.uk/lcfi/

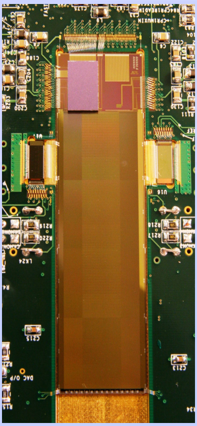
Long-lived particles like b- and c-quarks can be identified because after being created they travel a few micrometres and thus create a displaced vertex. The LCFI (Linear Collider Flavour Identification) collaboration develops sensor technologies, readout electronics, mechanics and software algorithms for the Vertex Detector at the ILC.

Requirements:

- Resolution: 3 micrometres
- 1 billion channels in five layers
- Low material budget: 0.1% radiation length per layer
- Fast readout



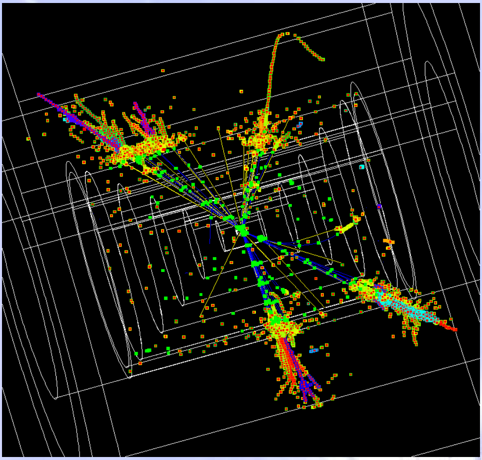
The predicted performance of the algorithms developed by LCFI considerably exceeds the previously achieved parameters.

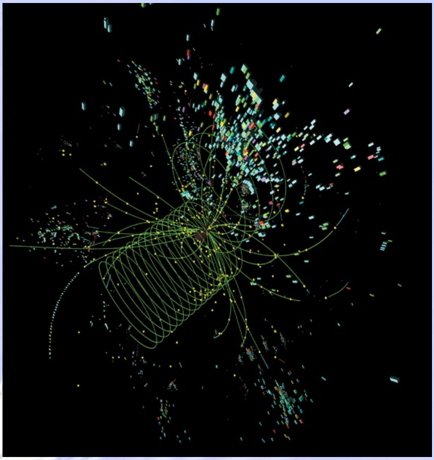


CPC2 sensor

LCFI is developing CCD (Charged Coupled Device) based sensors with column readout which allows to shorten the readout time by orders of magnitude. Despite this ‘parallel processing’ the readout rate is still challenging.

Calorimeter R&D at the ILC (CALICE)





In a particle physics detector, the calorimeter is used to measure the energy of the particles.
Particle physics calorimeters are usually divided into 2 parts:
- an electromagnetic calorimeter dedicated to the measurement of the energy of the electrons and photons and,
- a hadronic calorimeter to measure the energy of protons, neutrons and other hadronic particles.

One of the challenges of the ILC will be to measure the energy of the particles with a very high accuracy and with the ability to separate jets of particles from each other.

- This requires excellent Energy Resolution
- Particle Flow Algorithms can achieve this resolution
    - By combining Tracking and Calorimetry
    - High spatial resolution required

The CALICE collaboration proposes a highly granular Electromagnetic Calorimeter made of Silicon Tungsten for Particle Flow reconstruction

An international project

A big and international collaboration: Nearly 300 laboratories and Universities around the world are involved in the ILC. More than 700 people are working on the accelerator design and another 900 are working on detector development. In the UK more than 125 scientists are involved on the design of the ILC.

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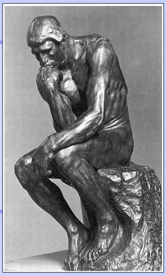
Timescale: The project is currently in its Technical Design Phase until approximately 2012. This will be followed by international negotiations on the funding and location of the ILC and then its construction will start.

Location: The ILC is a truly international project and no decision has been made yet on where it will be located, this will depend on the financial commitments each country and each region will be ready to take.

Cost: The cost of an international project such as the ILC depends on many different factors. In 2007 an extensive costing exercise was done, leading to an estimated cost of 6.6 billion US Dollars (2007), that is approximately 3.4 billion pounds. A significant fraction of this amount will be spent on cutting edge high-tech industries.

Spin offs from HEP

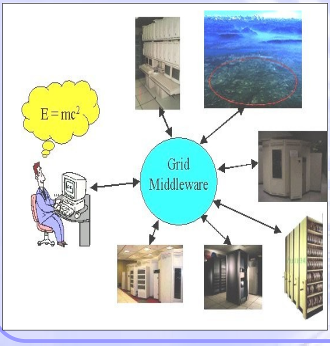


There is an intrinsic value inherent in basic science; most people are happy to know that the Earth orbits the sun rather than vice versa, but the practical and economic benefits are compelling as well.

A previous spin-off:

The World Wide Web itself was invented for particle physics by Tim Berners-Lee working at CERN.

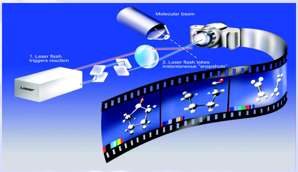
Spin-off from the LHC:



Particle Physicists and CERN are now working on a new development called the GRID. The WEB allowed people to share information over the internet, the GRID allows sharing of computer resources and will cause a revolution in many fields as far apart as game consoles and artificial intelligence as well as cutting-edge science.

Spin-off from the ILC:

Linacs similar to those designed for the ILC can be used to produce ultra-short pulses of X-rays with applications in several fields such as biology, chemistry and engineering...



Imaging spin-offs:

The work done by LCFI on CCDs can be applied to areas where ultra fast imaging is essential: adaptive optics, electron microscopy, various types of molecular and crystal spectroscopy and also medicine.

Aside from fundamental knowledge and spin-offs, investment in basic science provides technologically and mathematically literate people able to drive innovation in diverse fields such as IT, finance and industrial research and development. It also allows the industry to work on cutting-edge technologies.

Links and more...

You can find more information about the ILC at
`http://www.linearcollider.org/`

To find more information about particle physics in general you can visit
`http://www.interactions.org/` or `http://www.particlephysics.ac.uk/`

The posters of this exhibition are available at
`http://www.ippp.dur.ac.uk/~gudrid/exhibition/iop/`

The LC-UK collaboration (including LC-ABD, LCFI and CALICE) involves the following institutes and Universities:

This work is funded by STFC (PPARC) and the European Union (EuroTeV). Important contributions and support have been received from CERN, SLAC, KEK and DESY.

This booklet has been realised by Sophy Palmer, Jamie Tattersall, Karina Williams, Gudrid Moortgat-Pick (IPPP Durham) and Nicolas Delerue (JAI, Oxford) with contributions from several members of the LC-UK collaboration. Some images in this booklet are courtesy of interactions.org or the ILC GDE.