# Vertexing At The International Linear Collider


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The International Linear Collider is an ambitious project to build an experiment that will measure the properties of the most fundamental particles. Whereas the Large Hadron Collider, due for completion next year, will have a higher energy, the International Linear Collider strives for far more precise measurements. One of the most crucial variables in such measurements will be determining where these particles originate, the so called vertex...

**Designs are still at an early stage, and a site is yet to be chosen, but the International Linear Collider is due to be completed around 2015. It will actually consist of two accelerators, one for electrons and one for positrons, facing each other to maximise the collision energy. The particles will collide with an energy of 500GeV (about $8\times10^{-8}$ Joules), with a later upgrade doubling this to 1TeV. At approximately 30km long it will be more than 10 times the size of the current largest linear collider, the Stanford Linear Accelerator in California.**

## The Accelerator

The electrons are produced by shining high intensity laser pulses on a target, which knocks out electrons. The pulses only last 2 nanoseconds, but each flash creates billions of electrons.
Positrons (or anti-electrons) are made by passing the electrons through a device called an undulator, which oscillates the electrons so that they emit lots of photons. The electrons then carry on to the main accelerator, while the photons pass on to hit a titanium alloy target, producing the positrons.
The bunches of particles are then accelerated directly at one another at close to the speed of light by 8000 superconducting cavities. To get the required acceleration the cavities are cooled to -271º C by pumping in liquid helium. If all goes well then the bunches of 20 billion electrons and positrons should collide at the interaction point with 500GeV of energy; and all this at 14000 times per second.

## The Detector

When the electrons and positrons collide at the interaction point, they annihilate each other in a shower of other fundamental particles, which is the interesting part we want to study. Because the International Linear Collider is at such an early stage in its development the detector design has not been finalised yet. There are currently four proposed designs, known as LDC, GLD, SiD and "the fourth concept". All of these are taking slightly different approaches, but to a large extent this does not extend to the vertex detector.
The vertex detector is the part of the detector closest to the interaction. This means it must be as thin as possible so that it does not impede particles from travelling to the other detector regions. It must also be robust against radiation damage, otherwise it will quickly go up in very expensive smoke, thanks to the levels of energy given off at the interaction point.

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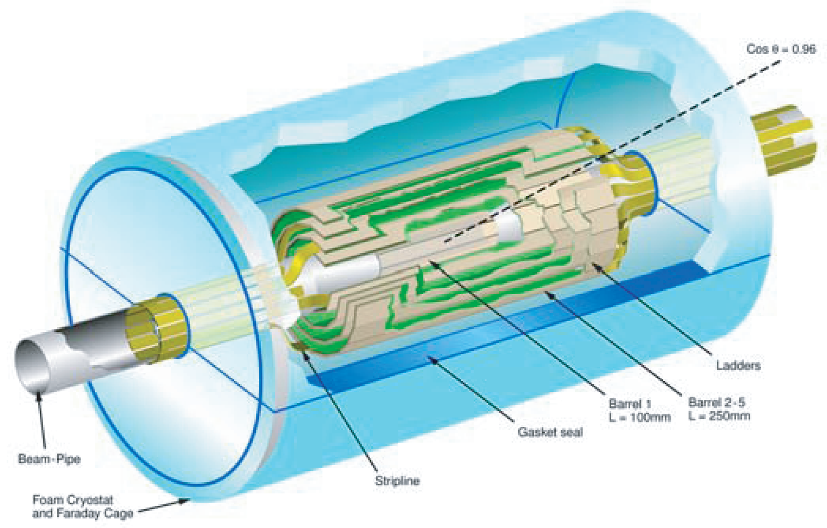
## Building A Vertex Detector

The LCFI collaboration, of which Bristol is part, has been working on a baseline vertex detector that can be used whichever of the four main detector designs are eventually chosen. The general idea behind the vertex detector is to have several rows of sensors arranged around the beam pipe in concentric layers. This will give several space points along a particle's trajectory so that a track can be constructed of the path taken by the particle in the early stages of the event.
Building the collider is going to be very costly, so it is essential to make sure the best possible physics can be extracted from it. To this end extensive studies have been (and still are) performed for the optimum detector design; for example, the number of sensor layers; their spacing; best time for result readout and so on.
One of Bristol's main contributions to the collaboration will be in mechanical support studies. Any support structures will have to be as thin as possible so as not to impeded particles, yet be strong enough to support the sensors. They will also need to have good thermal properties as well, as the whole detector will be cooled to around -100º C. Temperature fluctuations may also occur if the sensor drive electronics are only run during the electron-positron bunch trains (to conserve power). This means that the thermal expansion/contraction of the supports will have to be understood completely if the detector is not to lose precision.

## Vertexing Software

The LCFI collaboration is also working on a software package eagerly anticipated by the rest of the linear collider community. The main thrust of this is a conversion of the Fortran vertex finding algorithm known as ZVTop. The original code was used with great success at the Stanford Linear Accelerator. It is a fast and efficient algorithm designed to detangle all the seen tracks into groups coming from the same vertex, and the likely position of that vertex (see "What Is Vertexing?"). In fact, it is so fast that when first run the Stanford team thought there must be a problem, and had to check the code for errors.
The current C++ code being developed is far more than a straight port from the Fortran; it improves by removing approximations and creates a solid base for further International Linear Collider specific enhancements. It is currently in the early test stages, and already showing promising results, although the run time still needs to be reduced to match the original code.
Another part of the collaboration's package is a neural net based flavour tag. This will decide the likely quark content of particle jets in an interaction by matching their properties to those predicted by theory.



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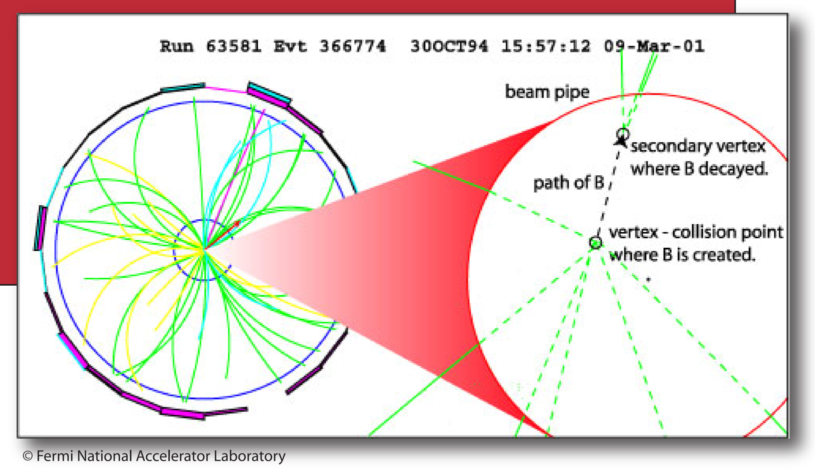
## What Is "Vertexing"?

Vertexing basically just means vertex finding. The trajectory of a particle's flight is known as a "track", and the beginning and end points, where it is generated and where it decays, are known as its vertices.

In modern particle experiments most of the interesting physics occurs very close (about 0.1mm in many cases) to where the accelerated particles collide (the interaction point). However, due to physical constraints a detector cannot be built closer than about 1.5cm. To work out where an interesting particle decayed inside this, the particles that it produces need to be traced back to their common production point. The picture below shows the observed tracks in solid green, and their projection to the inferred vertices in dashed green.
Doing this accurately can be difficult, particularly in a very cluttered event where it is not clear which tracks belong to a common vertex. The tracks also have to be measured to high precision; for the International Linear Collider, points on the seen particles trajectory need to be measured to better than 5μm.



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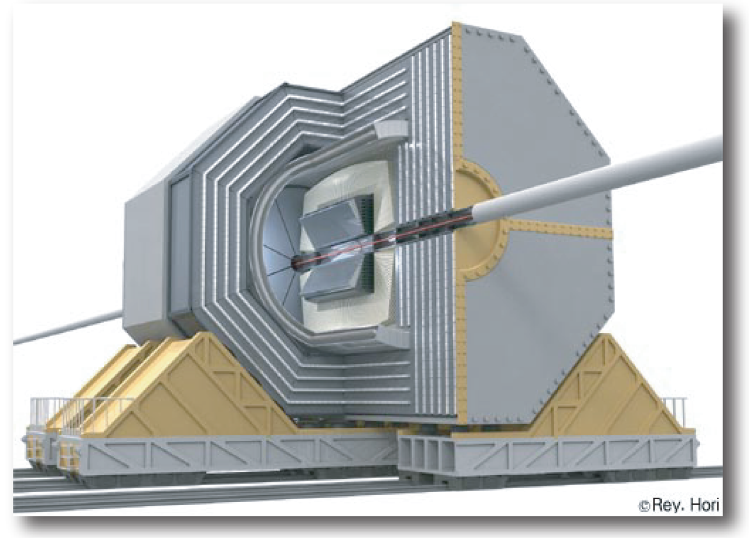
**RIGHT**
**An artist's impression of the GLD, one of the four detector concepts currently being researched.**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**RIGHT**
**Superconducting accelerator structures being moved into position at the TESLA test facility at DESY in Hamburg.**


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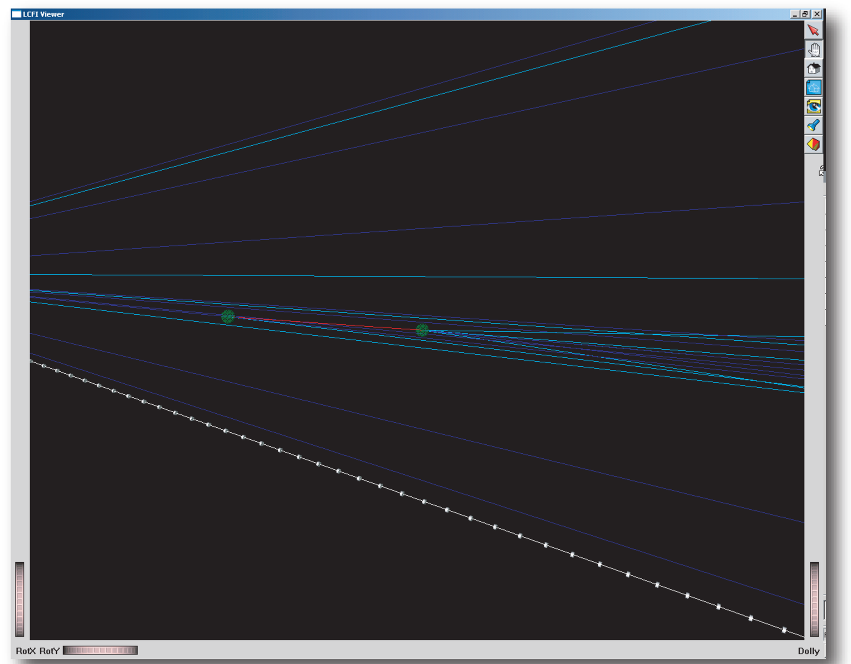
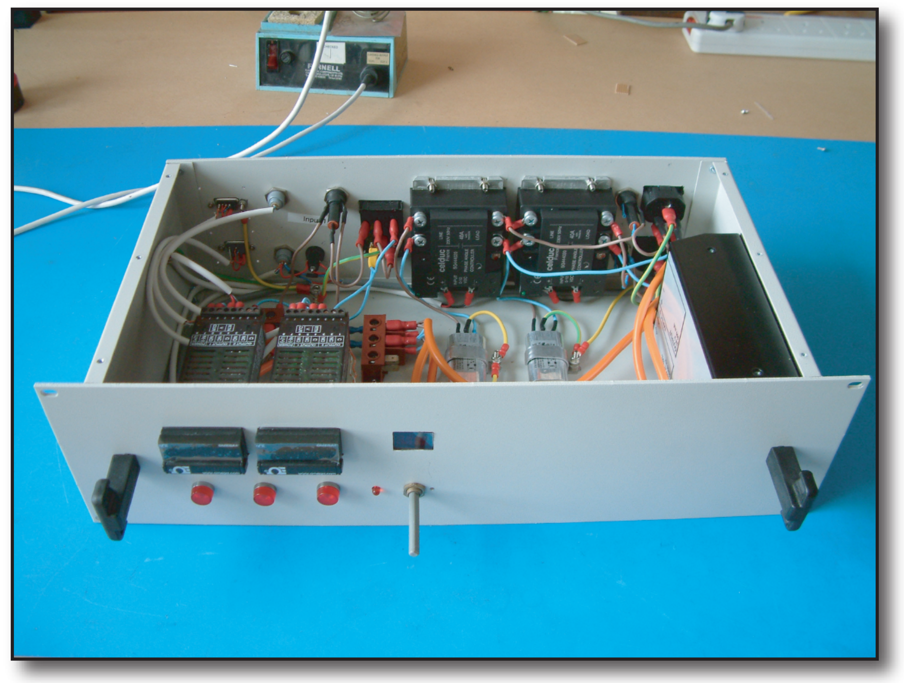
**BELOW**
**An image from the LCFI event display program that shows a D+ (in red) coming from a bottom decay before decaying into a jet of particles. The program is used to test and debug analysis code.**



**BELOW and RIGHT**
**Part of the cold test rig under development at Bristol. The system will be able to deliver gaseous nitrogen at various temperatures and flow rates to heat cycle vertex detector components. It will be used to test the sensor support structures and insulation materials for super capacitors.**



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