with a mass of about 125 GeV. After spending eight or so months studying the particle, the LHC was shut down in February to undergo 18 months of upgrades and repairs that will allow it to reach 13 TeV collisions – near its full design energy of 14 TeV – when it switches back on in 2015.

The LHC will also undergo a high-luminosity upgrade that will boost its luminosity five-fold in the early 2020s. This increase will be achieved by installing "crab cavities" that cause the protons to collide head-on rather than cross at a small angle as they do now. There are also plans to give the LHC an energy upgrade later in that decade by installing 20 T magnets that would push the energy of the collider up by a factor of two.

But the ILC will be even more ambitious. Based on 20 years of R&D, the collider will be about 30 km in length and will smash electrons into positrons at energies of about 250 GeV – which is enough energy to study the Higgs. The main focus of the design is the machine's superconducting accelerator technology, which will feature around 8000 1 m-long "superconducting cavities" that will accelerate the electron and positron beams to 250 GeV. As the ILC uses fundamental particles, the collisions will be much cleaner than the LHC's and scientists will be able to precisely measure the Higgs boson's properties and how it interacts with other particles. There would also be scope to upgrade the ILC to 500 GeV and ultimately 1 TeV.

Evaluating times

Although the ILC is not the only game in town for the next big particle-physics experiment after the LHC (see box), Japan has, in fact, been searching for a site to host the collider since 1999. Back in 2003, 10 candidate sites were proposed, which were narrowed down to two in 2010 – the one in the Kitakami Mountains and the other in Sefuri on Kyushu, the southernmost of Japan's four main islands. In January the ILC Site Evaluation Committee of Japan began to examine the two options and plumped for the 50 km route under the Kitakami Mountains after some 300 hours of meetings. The committee noted that both sites had a "very good geology that satisfied the minimum conditions" for construction of the ILC but they varied in terms of risk and cost.

On closer comparison, the Kitakami site had the edge in terms of the risks of construction and operation, as well as cost. One main issue for the Sefuri site was that it would pass under a lake and a town. "The Sefuri site had several issues that the chosen site does not have," says Murayama. "There are active faults on parts of the proposed route, a reservoir and dam above the route that may make waterproofing an issue as well as a residential area that may make it harder or longer to obtain necessary permits."

Yet that does not mean there are no issues with the Kitakami site. The proposed route would also go under a river, with only 20 m rock below the riverbed, but the site does have the upper hand in terms of the geological conditions for tunnelling and stability. "Overall, the chosen site has a very good geological condition, and even after the earthquake on 11 March 2011 it did not 'bend' the rocks; they moved together," adds Murayama. "It looks very suitable for the ILC and we approved the chosen site unanimously." That view is backed up by Evans. "The chosen site is in very good geological condition, allowing an eventual upgrade of the energy with no active faults and a wealth of seismic data from the [March 2011] earthquake," he says.

The benefits of the Kitakami site were further boosted given that it would be near a Shinkansen railway line. However, the committee's report warns that more would need to be done in terms of integrating the foreign researchers who would work at the site, including boosting the number of international schools in the region. "Given Japan's ageing and declining population, opening up the country is a major push by politicians," says Murayama.

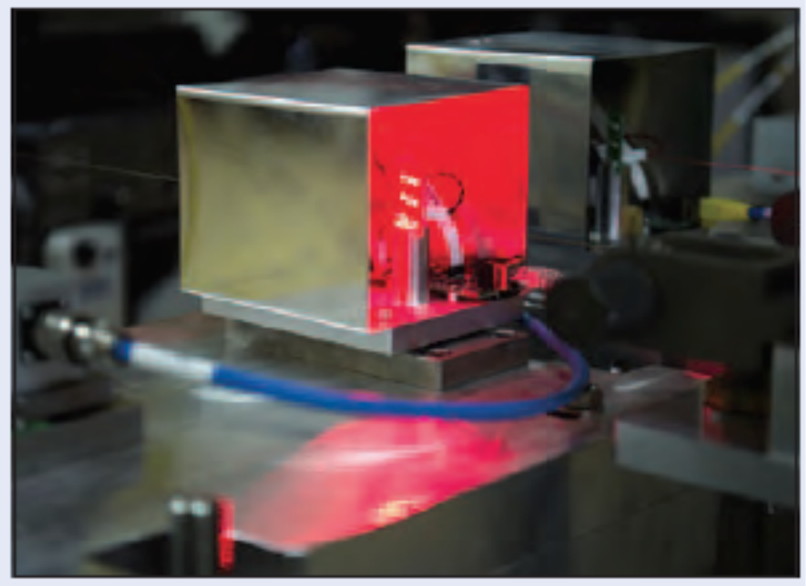
Move over ILC?

The International Linear Collider (ILC) has some competition to become the next big particle-physics experiment after CERN's Large Hadron Collider (LHC). The Compact Linear Collider (CLIC), being developed mainly at CERN, would use a novel "two-beam" acceleration concept that would involve running a high-current electron beam parallel to the main beam. Radio-frequency energy is extracted from this beam and sent to accelerating structures that drive the main electron and positron beams. According to CLIC supporters, the design could achieve collision energies as high as 3 TeV for a 48 km collider – although a shorter, less-energetic collider is also possible.

Yet there are also calls to perhaps ditch linear colliders and stick with circular ones. Some physicists have proposed a new 80–100 km ring that would not only study the Higgs, but also be used in the future for a 100 TeV proton collider. Dubbed "TLEP", the facility – which could be based near Geneva like the LHC – would operate at around 350 GeV, or even 500 GeV. Most of the cost of such a machine would be in excavating the tunnel, with the accelerator itself costing about one-third of the total. Researchers are planning to complete a conceptual design study by 2017 as an input to the next review of the European strategy for particle physics.

Some are thinking outside the box regarding the next particle collider. Physicists working in the International Coherent Amplification Network (ICAN) are looking into ways to combine the beams of tens of thousands of fibre lasers – a common component in the telecommunications industry – and coherently combine them into a "superbeam". The electron beams would be collided with photons from ICAN-style lasers to produce backscattered 63 GeV gamma-ray photons. These would then be collided to produce the Higgs.

Another option for a future particle smasher is a muon collider – one that would bang together positive and negative muons. As the muon is 200 times heavier than the electron, it presents an attractive alternative because it could reach the same energy at much lower speeds and not require at least 30 km of accelerator. It would also lose far less energy through synchrotron radiation if used for circular acceleration. However, while muons have some advantages over electrons, they are unstable and have a half-life of just over 2 μs, which means they have to be accelerated and collided very quickly. In August Nobel laureate Carlo Rubbia called for a muon collider demonstrator to be built to test the technology for a muon collider that could be used as a "Higgs factory" (arXiv:1308.6612).


CERN

Going through the options CERN has been developing technology for the CLIC – an alternative to the ILC.