Visions is a series of papers which highlight exciting new areas of research in physics, and their theoretical and technological implications.

**AVAILABLE VISION PAPERS:**
- High intensity lasers
- Quantum information
- Exotic nuclear beams
- Physics and finance
- Spintronics
- The Large Hadron Collider

**FORTHCOMING VISION PAPERS:**
- Novel displays
- Superconductivity
- Gravity waves

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Further information about the proposed colliders can be obtained from the following websites:
http://webnt.physics.ox.ac.uk/lc/
http://cern.ch/muonstoragerings
http://hepunx.rl.ac.uk/neutrino-factory/

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**FUTURE EXPERIMENTS IN PARTICLE PHYSICS II**

**Particle accelerators – the next frontier**

The Large Hadron Collider will reveal a deeper level of reality. Ingenious machines of novel design will be needed to explore this uncharted territory.
The Large Hadron Collider (described in Visions 6) being built at CERN in Geneva will clearly offer a new level of understanding of matter and forces in the Universe. We hope to see and learn more about the celebrated Higgs particle, which gives other fundamental particles mass. "Supersymmetric" particles and other exotic phenomena may manifest themselves, providing key evidence for powerful new descriptions of how matter and energy unify at the most fundamental level.

company, Marconi Applied Technologies, is a world-leader in this technology). An international collaboration at DESY in Hamburg is developing a new concept for accelerating the particles based on superconducting RF cavities for its proposed linear accelerator TESLA. The main European particle physics laboratory, CERN, has gone for a very novel approach called the Compact Linear Collider (CCLC) using two sets of electron-positron beams, with the electric fields generated by the first beam being used to accelerate a second beam to very high energies.

Muon colliders
A more exotic concept is the possibility of producing and colliding particles called muons. These are the exotic brothers of electrons and are produced when protons make collisions with very heavy nuclei. Despite the considerable obstacle, enthusiasm around the world has been growing to investigate the feasibility of accelerating and storing muons for collider and other experiments.

Muons are produced by firing protons at a target such as carbon. Charged particles called pions are released which then decay into muons and neutrinos. The trick is to produce enough muons, compress them into a tight beam and accelerate them very quickly to take advantage of the resulting increased lifetime and then squish them into a storage ring before they decay. This requires some novel engineering. The proton beam would have to be very intense, requiring a robust target, and the pions produced collected as quickly as possible using a strong magnet. The muons resulting from pion decay would be very spread out in energy so they would have to be rapidly "cooled" to the same energy. One of the advantages of the muon flavour is that the energy losses from synchrotron radiation are much smaller, so they can be circulated in a fairly compact circular ring. The low radiative losses mean that it would be possible to tune the energy of the beams more exactly to make precise measurements. A medium-energy muon collider of half a gigaelectronvoults would be particularly effective at producing new particles such as Higgs particles which could then be studied in detail.

Neutrino factories
A particularly intriguing spin-off is that a muon storage ring could be used to make intense beams of neutrinos. These are the exotic brothers of positrons and would have little or no mass. They can be used to test the theory that the three kinds of neutrino, the electron, muon and tau neutrinos, can mix in a way that would imply they have mass, which is not predicted by standard theory. A "neutrino factory" could be employed to study these neutrino oscillations in detail. Negative muons, for example, would decay into electrons, and equal numbers of electron and muon neutrinos. A follow-on possibility would be to investigate subtle deviations of the symmetry between particles and antiparticles - "CP violation" - in neutrinos. In certain processes some particles behave differently from their mirrorlike anti-partners, which may explain the dominance of matter over antimatter in the Universe today. The transformation of electron neutrinos into muon neutrinos could be compared with the same processes for anti-neutrinos. A neutrino factory would be a more modest affair than a high-energy muon collider so could be a significant intermediary step in advancing muon accelerator technology. Linear colliders, neutrino factories and muon colliders offer exciting and challenging prospects for particle physics after the LHC. UK and European particle physicists are already participating in studies of these exciting projects.
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Neutrino factories
A particularly intriguing spin-off is that a muon storage ring could be used to make intense beams of neutrinos. These ghostly particles which have little or no mass play a key role in current particle theories. Physicists are currently very excited by the notion that the three kinds of neutrino, the electron, muon and tau neutrinos, may change from one kind to the other because that would imply they have mass, which is not predicted by standard theory. A "neutrino factory" could be employed to study these neutrino oscillations in detail. Negative muons, for example, would decay into electrons and equal numbers of electron and muon neutrinos.

Linear colliders
Whatever the LHC discovers at the new high energy frontier, a complementary approach using another kind of machine - a linear collider (LC) - will be essential to provide a cleaner, more fundamental test of the latest theories and extend our understanding of the underlying physics. The LC would reach the same effective collision energies as the LHC.

reason, LEP was ring-shaped, so allowing bunches of the colliding particles to keep circulating with the aid of magnetic fields. However, a more powerful electron-positron machine can't be circular because of a physical limit on "emittance" the particles radiate electromagnetic waves as their path is bent around the ring, so that they lose energy. At high energies, this "synchrotron radiation" is a serious obstacle for light particles like electrons but less so for protons which are much heavier.

The alternative, therefore, is to accelerate the electron and positron beams in opposite directions down a long, straight path before colliding them head-on. This is no easy task. To reach an energy of one teraelectronvolt - would require a string of devices called radio-frequency (RF) cavities capable of generating an extremely steep electric field gradient to accelerate the particles rapidly along a tunnel around 30 kilometres long. Just guiding the fine particle beams, a few nanometres across, so that they meet at a major technical challenge. Nevertheless, the pioneering Stanford Linear Collider in the US has already demonstrated that such schemes do work.

Various linear collider studies are under way around the world looking at different configurations and methods of acceleration. The Stanford Linear Accelerator Center (SLAC) and the KEK laboratory in Tsukuba, Japan are collaborating on R&D to develop powerful accelerating devices called X-band klystrons (one UK.

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http://wbnt.physics.ox.ac.uk/IC
http://cern.ch/muonstorage/Rings
http://hepunx.rl.ac.uk/neutrino-factory/