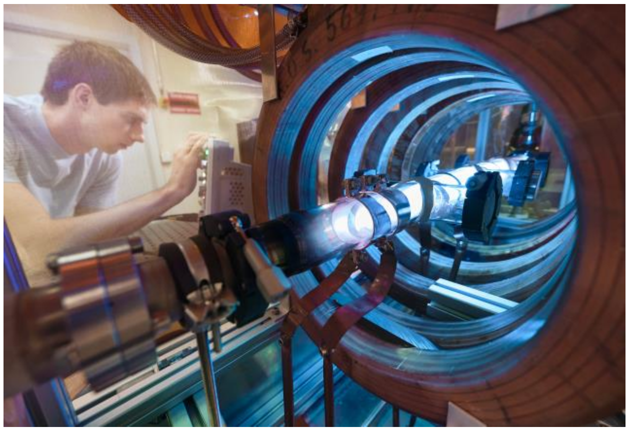
Future Colliders

Although the LHC's scientific programme is in full swing, design and construction timescales are such that the global scientific community is already considering the priorities for the second half of the 21st century and the next generation of instruments, accelerators, and detectors to be built.



Credit: CERN

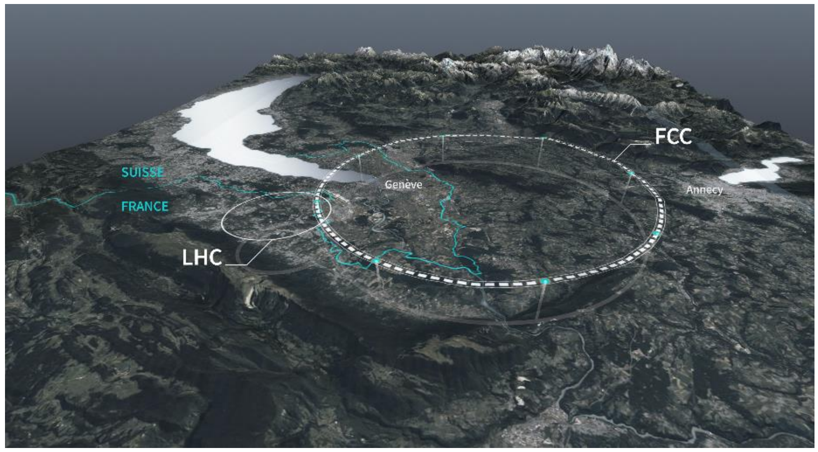
AWAKE helicon plasma cell prototype

The Advanced Proton Driven Plasma Wakefield Acceleration Experiment (AWAKE) is an accelerator R&D project that investigates the use of plasma wakefields driven by a proton bunch to accelerate charged particles. Such process would allow the construction of a new generation of shorter and less expensive high-energy accelerators, representing a big step in the particle accelerators technology.

The size of a collider depends on several parameters: the type of particles accelerated, the energy of the beams and the luminosity (i.e. collision rate). In the end, the size is determined by three main constraints: scientific objectives, research and development needs, and the international consensus which enables its funding and construction.

The radius of a circular collider, such as the LHC, is a compromise between the need to control synchrotron radiation loss – which increases with the energy and lightness of the accelerated particles –, the strength of the magnetic field provided by the dipole magnets bending the particles' trajectories, and the volume of the collider. The beam can consist of protons, as in the LHC, or electrons and positrons, as in its predecessor, the LEP. Protons are composite particles and their collisions are complex, but they allow for the consideration of higher energy beams and the exploration of a wide range of processes. As elementary particles, electrons can, in a very complementary way, facilitate the production of specific particles, such as Higgs or Z bosons, by operating at precise energy levels. To compensate for synchrotron radiation loss, some teams are exploring the use of muons, massive cousins of the electron, which generate less synchrotron radiation but are unstable. Many years of research and development will be required to validate this approach.

A linear collider avoids the synchrotron radiation issue. However, it cannot accelerate particles continuously in a circular storing ring. Instead, accelerating cavities must be placed end to end. Despite significant improvements in their performance, the accelerator could end up being several tens of kilometres long. Additionally, the bunches of particles produced and accelerated are lost after a single crossing, whereas in a circular collider, they can circulate for hours. Therefore, to be competitive in the amount of data accumulated, a linear collider must compress the beams to a record level so that sufficient simultaneous collisions occur when two bunches cross.



Credit: CERN

How can the discussion move forward? In Europe, the European Committee for Future Accelerators (ECFA) organises consultations and debates, before issuing recommendations every 5 years, which are submitted to the CERN Council. In 2020, CERN was mandated to launch a feasibility study for a new collider, the FCC, with a circumference of approximately 90 km. This collider would follow a two-stage scientific programme, beginning with electron-positron beams, then proton beams. Upon the study's completion, in 2025, if the outcome is positive – in other words, if the project is deemed technically viable and its cost manageable – the CERN Council will make a decision.

Possible location of the Future Circular Collider project

The FCC Feasibility Study was launched in 2021 in response to a recommendation from the 2020 update of the European Strategy for Particle Physics. After three years of work, mobilising the expertise of scientists and engineers around the world, the mid-term report proposed the following placement for the ring. The final report is expected for 2025.

Other continents have their own projects as well: a neutrino platform and long-term investigations into a potential muon collider in the United States, a collider project similar to and competing with CERN's in China, a linear accelerator in Japan. In the laboratories of the main countries, research and development also focus on new technologies such as high-temperature cryogenics and the use of plasma.

Researchers are also considering complementary approaches to highlight new phenomena: specialising in a decay that seems extremely rare, but which could be more frequent in the presence of new physics; or examining in more detail the properties of known particles, such as the top quark or neutrinos. Which of these approaches will provide the first information on physics beyond the Standard Model? Bets are on!

The directors of the main laboratories currently believe that a 'Higgs factory' is needed and will be built around the world, but also, and perhaps above all, that collaboration is essential to develop more compact, more energy-efficient equipment, with beneficial technological spin-offs.

Translated from 'Les prochains collisionneurs',* Passeport pour les deux infinis, *IN2P3/Dunod, https://pass2i.ijclab.in2p3.fr/ (French); updated with ICHEP2024 conference (https://ichep2024.org) for IPPOG