International Particle
Physics Outreach Group

PASSPORT TO THE INFINITE

Particle Accelerators

Large quantities of particles are produced in accelerators and collide at the centre of detectors which study their interactions. The energy reached and the collision repetition rate are the two main parameters of accelerators, whose operation requires great technical achievements.

Credit: Bernaudin/GANIL

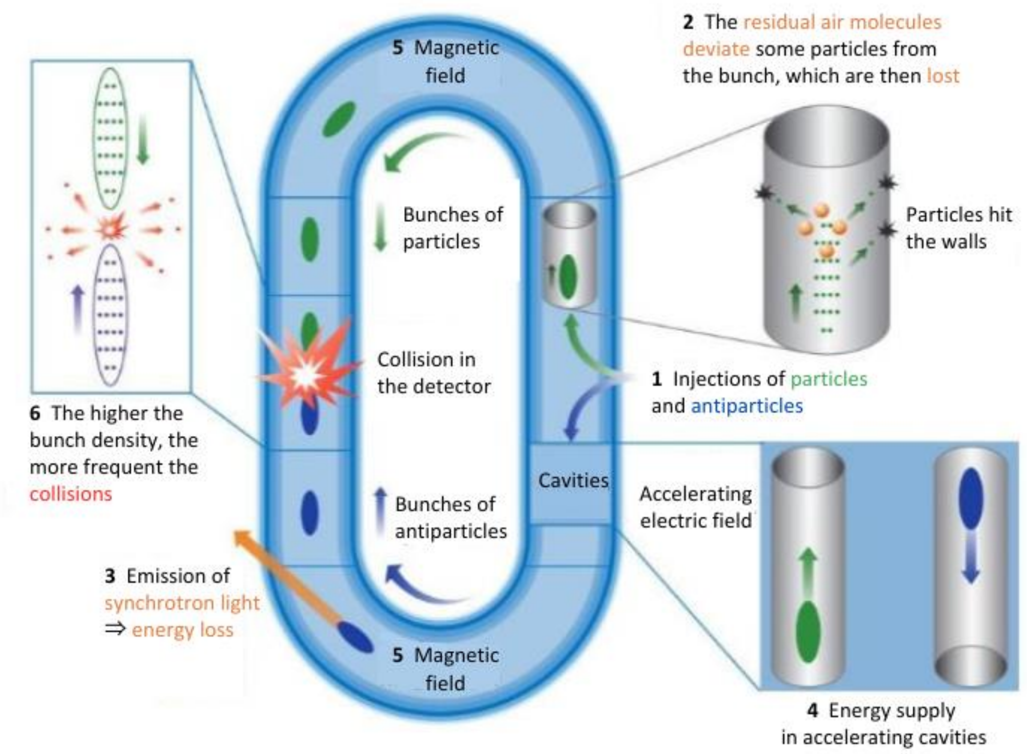
Cryomodules of the SPIRAL2 linear accelerator at GANIL

SPIRAL2 (2d-Generation On-Line Radioactive Ion Production System) is a supraconducting linear accelerator that started operation in 2016 at the Large Heavy Ion National Accelerator (GANIL, Caen, France). It provides unique beams for nuclear physics purposes.

To study particle interactions, one needs to have the largest possible sample. This hasn't been lost on physicists, who started building accelerators as early as in the 1920s. This 'artificial' mode of particle production rapidly supplanted cosmic ray observation and developed alongside detectors.

We mostly use electrons, protons or ions (lead, gold, etc.) travelling in very dense bunches that are separated by vacuum. They are produced from low-volume sources of ordinary matter (gas, pieces of metal) containing huge amounts of molecules or atoms – million billion billions of them, at the very least. While technology and performance have made considerable advances, the basic principles of accelerators remain the same. Beams of charged particles, which are sensitive to electric fields (on which they 'surf' to gain energy) and magnetic fields (used to steer their trajectories), travel unhindered in insulated tubes at ultra-high vacuum. At the start of the process, speed and energy increase at the same rate, but this changes as particles approach the speed of light, which cannot be exceeded, according to the theory of relativity. 'Acceleration' then loses its usual meaning, as it boils down to an increase in energy at near-constant speed.

In most cases, a part of the accelerator is quasi circular and particles travel through it a great number of times. This strategy limits the size of the machine, which can nonetheless reach the order of a kilometre. The particles are accelerated in dedicated



Credit: N. Arnaud

rectilinear sections: the aim is either to bring them to the target energy, or to compensate for the losses occurring all along their course, particularly in curved areas. In colliders, two beams travelling in opposite directions meet at the centre of detectors. Every time they cross, only a few particles collide; the others are not deflected and go for another round. Thus, the same bunches are 'recycled' and produce many collisions. Other experiments, known as fixed-target experiments, use a single beam projected onto a dense volume of matter.

But why accelerate particles at all? The main reason is Einstein's formula demonstrating the mass-energy equivalence. When particles collide, the energy they carry is used to create new particles. The higher the energy available, the heavier and more numerous the new particles. The record energies achieved at the LHC have allowed us produce sufficient quantities of Higgs bosons. The quality of an accelerator also depends on its luminosity, i.e. the number of collisions per second. The higher the luminosity, the greater the chance for physicists to observe a rare phenomenon.

A simplified diagram of a collider

Two beams of charged particles (in green and blue) are injected (1) in independent vacuum tubes after having been accelerated. During their course, they suffer several kinds of damage: loss of particles after collisions with residual air molecules (2); loss of energy through synchrotron radiation (3). The former effect is compensated by injecting new particles into the ring while the particles receive additional energy at each round thanks to accelerating electric fields (4). Magnetic fields (5) bend the particle bunches and steer them on a near-circular and immutable orbit. Every round of collisions occurs at the centre of the detector (6).

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