What is a Particle Accelerator?

A particle accelerator is a powerful microscope that uses accelerated subatomic particles as probes to explore the tiniest structures in nature. To "accelerate" a particle means to increase its velocity. The higher the velocity of a particle, the higher is its energy and its penetrating power.

In addition to generating particles to be used as probes, accelerators can be used to generate new particles. By recreating conditions similar to those prevailing just after the Big Bang, accelerators allow the study of the first few instants in the life of our Universe, in which the Universe consisted of free particles - quarks and leptons.

How is a Particle Accelerator Made?
The simplest type of particle accelerator is a battery. If the terminals of a battery are connected to an electrical wire, the electrons in the wire are accelerated, generating an electrical current. By arranging many batteries in series, the energy of the electrons can be further increased.

In an accelerator, devices similar to batteries are used to increase the velocity of electrons to nearly the speed of light, at which point, as the electrons are accelerated further, their energy, rather than their velocity, is increased.

This method can be used to accelerate different types of particles besides just electrons, and to obtain different types of particles to be used as probes. Typically, beams consisting of billions of particles are accelerated.

When the beam reaches the desired energy, it is made to collide with a target. New particles are generated in the collision. The study of these new particles provides information not only about the structure of the target, but also about the type of interaction governing the process.

What is a Collider?

In the most common type of accelerator, powerful magnetic fields are used to maintain the beams in a circular trajectory. With a circular accelerator, particles that do not interact with the target can be reused.

Two beams of equal energy circulating in opposite directions themselves become targets. In collisions between particles from each beam, all of the particles' energy can be converted into new particles. This type of accelerator is known as a collider.

What is DAΦNE?

DAΦNE (Double Annular Φ Factory for Nice Experiments) is the collision ring for electrons and positrons (particles identical to electrons but with opposite charge) currently in operation at Frascati.

How is DAΦNE Made?

DAΦNE is a double-ring collider for electrons and positrons of 0.51 billion electron-volts per beam. The total energy, 1.02 billion electron-volts, corresponds to the mass of the Φ particle.

To decrease unwanted interactions between the beams, the electrons and positrons circulate in opposite directions in two distinct rings that intersect at only two points. To avoid collisions between the beams and residual gases, the inside of the rings are kept under extremely high vacuum (less than one thousand-billionth of an atmosphere).

DAΦNE's rings are 100 m in circumference. In each ring, more than 100 bunches each containing 100 billion particles execute more than three million orbits about the ring per second. The collisions between these bunches produce about 2000 0's per second. The dimensions of each bunch at the interaction point are 1 mm x 10 μm x 2 cm. Sophisticated magnets are used to shrink the bunches to these dimensions and control their orbits. Quadrupole magnets work like lenses to keep the bunches confined to the inside of the vacuum chamber, and dipole magnets arranged along the curved segments of the ring establish a vertical magnetic field, causing the beams to curve.

Accelerators - Toys for Physicists?

Particle accelerators are indispensable instruments not only for fundamental research, but also for industry and medicine. Particle beams are used for the diagnosis and treatment of cancers, for the production of pharmaceuticals, and can be used in surgery as precision scalpels. Accelerators can also be used to destroy radioactive wastes.

Quantities and Units

Two physical quantities characterize an accelerating machine:
- Energy
- Luminosity

The standard metric unit of energy is the Joule (J). In nuclear physics, the Joule is inconveniently large as a unit of energy. More convenient is the electron-volt (eV), defined as the energy acquired by an electron accelerated by a potential difference of 1 volt.

1 eV = 1.6 * 10^-19 J
1 keV = 10^3 eV (kiloelectron-volt)
1 MeV = 10^6 eV (megaelectron-volt)
1 GeV = 10^9 eV (gigaelectron-volt)
1 TeV = 10^12 eV (teraelectron-volt)

The luminosity is given by the number of interacting particles per cm² per second. For DAΦNE:

\[ L = \frac{N^e N^p}{4 \pi \sigma_i} = 10^{31} \text{ cm}^2 \text{ s}^{-1} \]

\[ N^e = 2 \times 10^{10} \text{ number of positrons per bunch} \]
\[ N^p = 2 \times 10^{10} \text{ number of electrons per bunch} \]
\[ \sigma_i = 1 \text{ mm horizontal bunch size} \]
\[ \sigma_v = 10 \mu\text{m vertical bunch size} \]
\[ I = 3 \times 10^9 \text{ s}^{-1} \text{ collision frequency} \]