INFN Istituto Nazionale di Fisica Nucleare
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Particle accelerators DAΦNE

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.

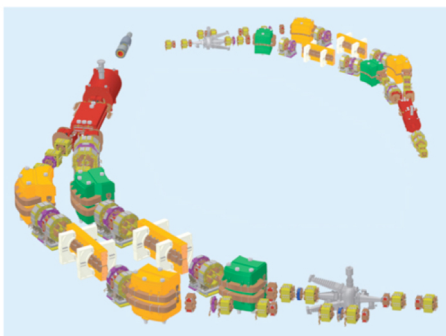
WHAT IS A COLLIDER?

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 (**D**ouble **A**nnular Φ Factory for **N**ice **E**xperiments) is the collision ring for electrons and positrons (particles identical to electrons but with opposite charge) currently in operation at Frascati.



WHAT IS DAΦNE FOR?

An approach complementary to increasing the energy of the beams is to increase the number of collisions that the beams can produce. In this approach, the key to understanding the fundamental properties of nature is the high-precision study of extremely rare phenomena produced in the collisions. The quantity related to the number of collisions produced is called **luminosity.**

Very high luminosity accelerators are called particle factories. **DAΦNE** is the first example of a new-generation accelerator dedicated to the production of Φ particles via electron-positron collisions at an energy corresponding to the exact value of the Φ mass. The Φ particle is unstable and immediately decays into lighter particles, including **K** particles, which contain the **s quark.** The goal of **DAΦNE** is the study of these particles, which will shed light on various questions concerning our current picture of the subnuclear world and the forces that dominate it.

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 insides 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 **ϕ'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 cm^2 per second. For **DAΦNE**:

$$L = \frac{N^{e+} N^{e-} f}{4 \pi \sigma_x \sigma_y} = 10^{32}\ cm^{-2} s^{-1}$$

N^{e+} = 2x10^{10} number of positrons per bunch
N^{e-} = 2x10^{10} number of electrons per bunch
σ_x = 1 mm horizontal bunch size
σ_y = 10 μm vertical bunch size
f = 3x10^8 s^{-1} collision frequency