International Particle Physics Outreach Group

PASSPORT TO THE INFINITE

GLOSSARY

A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z

A | *accelerating gravity; algorithm; ALICE; alpha radioactive decay; (data) analysis; antihydrogen; antimatter; antiparticle; ATLAS; atom*

B | *background noise; baryon; baryon and lepton numbers conservation; beam; Belle II; beta radioactive decay; Big Bang; boson; bottom (or beauty); bunch*

C | *c (light speed); calorimeter; CERN (Europe); charge; charm; Cherenkov radiation; CMS; collider; colour; computing grid; confinement; conservation laws; cosmic messengers; cosmic rays; cosmology; CP symmetry; CP violation; current experiments*

D | *dark matter; decay and radioactivity; DESY (Germany); detection devices; detection principles; dipole; down*

E | *electric field; electromagnetic field; electromagnetism; electroweak theory; Einstein's formula $E=mc^2$; electron; electron cloud; elementary (particle); energy conservation; energy levels; error; eV, GeV, TeV; event, expansion, extra dimension*

F | *family, Fermilab (USA); Feynman diagram; field; fission; fixed target; flavour; from beams to measurements; fundamental interactions; fusion*

G | *gamma radioactive decay; general relativity; gluon; Grand Unified Theory (GUT); gravitation; GSI (Germany)*

H | *hadron; HAWC (Mexico); heavy ion; Higgs boson*

I | *inflation; ionization; international collaboration*

K | *Kamiokande; KEK (Japan)*

L | *leptons; LHC; LHCb; lifetime; light; linear accelerator; luminosity*

M | *magnetic field; mass; matter-antimatter asymmetry; matter constituents; measurement; meson; muon; muon chamber; muon tomography*

N | *neutrino; neutrino detector; neutrino oscillation; neutron; nucleon; nucleus*

O | *observatory; open data; open science; outreach*

P | *particle accelerator; particle detector; particle motion in fields; particle signature; periodic table; photoelectric effect; photomultiplier; photon Pierre Auger Observatory; pion; positron; primary cosmic rays; probability; proton*

Q | *quadrupole; quantum; Quantum chromodynamics (QCD); Quantum electrodynamics (QED); quantum field theory; quantum mechanics; quark; quark-gluon plasma*

R | *radioactivity; random phenomenon; range; reconstruction; relativistic particle; relativity principle*

S | *scientific model; scintillation; secondary cosmic ray showers; signal; simulation; spacetime; spectrometer; Standard Model of Cosmology; Standard Model of Particle Physics; statistical error; strange; strong interaction; superconducting cavity; supersymmetry; synchrotron; synchrotron radiation; systematic error*

T | *tau; theory; top; trajectograph; trigger*

U | *ultraviolet; unified theories; universal gravitation; unstable particle; up*

V | *vacuum; vertex; vertex detector*

W | *W boson; wave-particle duality; wavelength; weak interaction*

X | *X-ray*

Z | *Z boson*

– A –

Accelerating cavity

A device that produces the electric field accelerating the particles inside accelerators. Since the electric field oscillates at radio frequency, accelerating cavities are also referred to as radio-frequency cavities.

Algorithm

A systematic process aiming at problem resolution, involving a series of intelligible steps for a human or a computer to follow. At the end of the procedure, an unambiguous answer is given to the specific initial question. The quality of an algorithm is determined by the relevancy and accuracy of the answer. Another major parameter is the response time: the faster the algorithm, the broader its application field.

ALICE

One of the four major CERN experiments at the Large Hadron Collider (LHC). It is optimised to study the physics of strongly interacting matter at extreme energy densities, where a quark-gluon plasma forms.

Alpha radioactive decay

Alpha decay is a type of radioactive decay, denoted by α, in which an alpha particle – a helium nucleus – is emitted.

(Data) Analysis

In physics of the infinitely small, the study of a dataset recorded by a detector and the use of the provided information to search for a specific phenomenon, e.g. the decay of a particle into two others. If the phenomenon is observed, the analysis consists in measuring its properties with the highest precision. Most often, analysis results are published in an international scientific journal, along with a detailed report on the methods used to achieve them.

Antihydrogen

The simplest antiatom: the antihydrogen nucleus is an antiproton, around which one single antielectron orbits. Its properties are thoroughly examined at CERN, in the Antiproton Decelerator (AD) facility: very low energy antiprotons and antielectrons are combined and stored in magnetic traps in the centre of experiments that verify if the laws of physics are the same as for atoms.

Antimatter

The 'mirror image' of matter – which forms almost all the observable Universe. Just as matter is composed of particles, antimatter is composed of antiparticles.

Antiparticle

The theory describing the infinitely small states that each particle is associated with a 'mirror' particle, called antiparticle. This has been confirmed by experiments. A particle and its antiparticle share many properties. In particular, they have the same mass, but they have opposite charges. If enough energy is available, particle-antiparticle pairs can be produced. However, the antiparticle will annihilate if it crosses matter.

ATLAS

One of the four major CERN experiments using the collisions produced at the LHC. It was designed to discover and study the Higgs boson, but also to explore a wide range of physics topics, with the primary focus of improving our understanding of the fundamental constituents of matter. The CMS detector was built with the same objectives but different techniques, and data analysis is performed independently to allow cross-validation of the scientific results.

Atom

A fundamental component of matter. Electrically neutral, the atom is formed by a positively charged nucleus containing protons and neutrons, around which electrons orbit in a number equal to the number of protons. The atom's stability stems from the forces governing these particles and their interactions. Atoms combine into molecules and form the basis of chemistry.

– B –

Background noise

In any data analysis, the searched signal is received with parasite data, called background noise. While these two elements cannot completely be separated, the quality of an analysis relies on achieving the best ‘signal over background noise’ ratio.

Baryon

A particle made up of three quarks, each of a different colour. Nucleus components, protons and neutrons, are baryons.

Baryon and lepton numbers conservation

This law requires that the total baryon and lepton numbers are the same before and after an interaction occurs. To determine the total baryon number, every baryon is assigned +1 for matter, –1 for antimatter, and 0 for all other particles. The same applies for the electron-lepton, muon-lepton and tau-lepton numbers. These laws are used to easily identify which decay is forbidden for a given unstable particle, and their origin is an open question.

Beam

In an accelerator, particles are concentrated into a beam. Beams can contain billions of particles and be divided into discrete portions called bunches. Each bunch is usually several centimetres long but only a few microns wide.

Belle II

Belle II is an international experiment based at the KEK lab (Japan). It succeeded to the Belle experiment in 2019 to study beauty and charm hadrons as well as tau leptons, with the purpose of investigating the weak interaction and searching for new phenomena beyond the Standard Model of particle physics.

Beta radioactive decay

Beta decay is a type of radioactive decay, denoted by β, in which a beta particle (an electron or a positron) is emitted. If an electron (a negatively charged particle) is emitted, the emission is called beta minus (β^-) decay; if a positron (a positively charged particle) is emitted, the emission is called beta plus (β^+) decay. The weak interaction is at the origin of this type of radioactivity. For example, a neutron transforms into a proton by emitting an electron and an antineutrino.

Big Bang

In our present understanding of the Universe's history, the moment when it all started. Since then, the Universe has evolved from a hot, extremely dense state to its current cold, dilated state. The whole process has taken about 14 billion years. We are not able to describe the Big Bang event itself nor what existed before.

Boson

A particle carrying a fundamental interaction between particles of matter, often called a 'force mediator'. The electromagnetic force is transferred between two charged particles through the exchange of photons, resulting in the attraction or repulsion of the two entities, depending on their respective electric charges. The weak force mediators are the Z and W bosons, the strong force mediators are the gluons. The Higgs boson is a completely new type of boson (see Standard Model of Particle Physics).

Bottom (or beauty)

One of the six quarks in the Standard Model, and the second heaviest. Studying the 'b' quark helps us better understand the differences between matter and antimatter.

Bunch

Particles in a collider do not circulate as a continuous flow, they are gathered in very dense bunches that are separated by vacuum. For example, in autumn 2015, approx. 2,200 bunches of more than 100 billion protons each travelled in the LHC, with a speed of 11,245 rounds per second.

– C –

c (light speed)

The invariable and unsurpassable speed limit for all physical signals. In vacuum, electromagnetic waves (and, therefore, photons) travel at light speed. The value of this physical constant, denoted by *c* (for celerity), was set at 299,792,458 km/s in 1983.

Calorimeter

In physics, an instrument for measuring heat exchange. In particle physics, a calorimeter is used to measure the amount of energy carried by particles. The particles interact with the medium and release part or all of their energy, most often through a jet of secondary particles, whose total energy is measured. There are two types of calorimeters, electromagnetic and hadronic calorimeters, depending on the type of particle (photons and electrons; hadrons made up of quarks) measured.

CERN (Europe)

CERN, French abbreviation for European Council for Nuclear Research, is the largest laboratory in high-energy physics in the world. Founded in 1954 near the city of Geneva, Switzerland, it now includes 24 member states that contribute to its budget and decide on its scientific strategy and activities. Over 10,000 scientists, who are active in hundred collaborating states, design, build and run experiments, most notably the LHC programme.

Charge

The sensitivity of a particle to a fundamental interaction. Charges are respectively called electric charge for the electromagnetic interaction, weak isospin for the weak interaction, and colour for the strong interaction. If the charge of a particle is null, the particle is insensitive to the corresponding interaction. If not, the higher the charge, the stronger the effect. For example, electrons have an electric charge but no strong charge, which means that the strong interaction does not affect them.

Charm

The name given by physicists to the fourth of the six quarks known to date. The ‘c’ quark was discovered at the end of 1974 in the United States. It had been predicted a few years earlier in order to make sense of experimental observations for which no explanation could be found in a model that included only three light quarks: up, down, and strange quarks. This discovery, known as the ‘November revolution’, has shown that quarks are a central piece in our understanding of the infinitely small.

Cherenkov radiation

The light emitted by charged particles when they travel across a dense transparent medium faster than the speed of light in that medium. This effect is used in particle physics experiments and in telescopes.

CMS

One of the four major CERN experiments using the collisions produced at the LHC. It was designed to discover and study the Higgs boson, but also explore a wide range of physics topics, with the primary focus of improving our understanding of the fundamental constituents of matter. The ATLAS detector was built with the same objectives but different techniques, and data analysis is performed independently to allow cross-validation of the scientific results.

Collider

An accelerator in which two counter-rotating beams are accelerated and forced to collide at the centre of detectors that were specifically designed for observing these events. Only a few particles collide; the rest continues its way to later collisions. One benefit of colliders is that the energy available during collisions corresponds to the sum of the beams' energies. That information is used in data analysis to look for events where new particles would be created.

Colour

For the strong interaction, the charge (i.e. the fact of being affected by the force) is associated with a specific parameter that can take on 3 values. By analogy with the decomposition of white light, physicists refer to the charge as a 'colour' and its 3 states are called 'blue', 'green' and 'red'. This description is enriched by 'anticolours' to characterise the antimatter quarks, or antiquarks. A composite particle made up of quarks, a hadron, is 'white': the colours of its component add up.

Computing grid

The Worldwide LHC Computing Grid (WLCG) is a distributed computing infrastructure arranged in tiers. It gives near real-time access to LHC data to a community of over 12,200 scientists of 110 nationalities, from institutes located in more than 70 countries.

Confinement

Quarks are confined within hadrons through the strong interaction, which is also responsible for the cohesion of atomic nuclei. Confinement stems from a specificity of the strong interaction: the intensity of the interaction increases with the distance: the further two quarks are from each other, the stronger their bond! As a result, quarks cannot exist isolated. They are always associated with one or two other quarks within composite particles.

Conservation laws

Conservation laws are critical to an understanding of particle physics. Strong evidence exists that energy, momentum, and angular momentum are all conserved in all particle interactions. Just as electric charge is conserved in all electrostatic phenomena, the charges associated to other interactions are. These are by no means the only conservation laws in particle physics.

Cosmic messengers

Cosmological events involve complex interactions between a variety of astrophysical processes, each of which may independently emit signals of a characteristic ‘messenger’ type: electromagnetic radiation (including visible light), gravitational waves, neutrinos, and cosmic rays.

Cosmic rays

Cosmic rays are fast-moving particles from space that constantly bombard the earth from all directions. Most of the particles are single protons and electrons but few are much heavier nuclei, ranging up to lead. Cosmic ray particles travel at nearly the speed of light, and some are the most energetic particles ever observed in nature. The highest-energy cosmic rays have a hundred million times more energy than the particles produced in the world’s most powerful particle accelerator.

Cosmology

The science which studies the general characteristics of the Universe, such as its broad structures, its matter and its energy content, or its evolution from the Big Bang to the present time. Cosmology is a branch of astronomy that stands at the crossroads between the infinitely small and the infinitely large.

CP symmetry

CP symmetry states that the laws of physics should be the same if a particle is interchanged with its antiparticle (C-symmetry) while its spatial coordinates are inverted (‘mirror’ or P-symmetry). While the strong interaction and electromagnetic interaction seem to be invariant under the combined CP transformation operation, further experiments showed that this symmetry is slightly violated in certain types of decay.

CP violation

The Big Bang should have produced equal amounts of matter and antimatter, and there should have been total cancellation of both, resulting in a sea of radiation in the universe with no matter. Since this is not the case, after the Big Bang, physical laws must have acted differently for matter and antimatter. The violation of Charge conjugation and Parity symmetry (CP) is a subtle effect observed in the decays of certain particles revealing Nature’s preference for matter over antimatter.

Current experiments

It is impossible to list all the experiments and detectors currently active around the world. The few examples selected here contribute significantly to the IPPOG activities, in particular the Masterclass programme.

– D –

Dark matter

Dark matter is a currently unknown substance to which astrophysicists refer to explain the rotation speeds of stars and the formation of the Universe's structures. Its gravitational effects indicate that it accounts for 25% of the Universe's energy balance, five times more than ordinary matter. This new form of matter could consist of stable and electrically neutral particles predicted in many theories. Unravelling the nature of dark matter is one of the greatest interdisciplinary challenges.

Decay and radioactivity

In particle physics, an unstable particle decay is the spontaneous process of one unstable subatomic particle transforming into multiple lighter particles. A radioactive decay is the process by which an unstable atomic nucleus is transformed into a lighter nucleus along with the emission of particles, or radiation. Both have the same origin and are governed by the strong and weak interactions.

DESY (Germany)

DESY, short for *Deutsches Elektronen-Synchrotron* (English: German Electron Synchrotron), is located in Hamburg and Zeuthen near Berlin in Germany. It operates particle accelerators and conducts a broad spectrum of interdisciplinary scientific research in four main areas: particle and high energy physics; photon science; astroparticle physics; and the development, construction and operation of particle accelerators. It is one of the research centres members of the IPPOG collaboration.

Detection devices

Modern particle detectors consist of layers of subdetectors, each designed to look for particular properties or specific types of particles. Tracking devices reveal the path of a particle; calorimeters stop, absorb and measure a particle's energy; and particle-identification detectors use a range of techniques to pin down a particle's identity.

Detection principles

All particles of a beam or their secondary interaction or decay products will eventually interact with surrounding matter. Depending on the particle's type and energy, swift particles penetrating in a material will be subject to different atomic and nuclear processes whose effects are amplified and recorded. Collecting all these clues from different parts of the detector, physicists build up a snapshot of what was in the detector at the time of a collision.

Dipole

A magnet with two poles, like the north and south poles of a permanent horseshoe magnet. Dipoles are used in particle accelerators to bend charged particles' trajectories and keep them moving on a circular orbit.

Down

The down quark is one of the two quarks forming neutrons and protons, along with the up quark. All our surrounding matter consists of three elementary particles: 'u' quarks, 'd' quarks, and electrons.

– E –

Electric field

A field created in all points of space by the presence of electric charges. If an electric charge is placed in an electric field, it is subjected to a force proportional to the electric field and to the value of its charge, and is accelerated (energy gain) or repelled (energy loss).

Electromagnetic field

A variation of the electric and magnetic fields caused, for instance, by the alternating movement of electric charges. Characterised by its frequency (or its wavelength), the visible light is a fraction of electromagnetic waves. Classified by ascending frequency, electromagnetic waves are called radio waves, microwaves, infrared waves, red waves, yellow waves, green waves, blue waves, violet waves, ultraviolet waves, X-rays, and gamma rays. In vacuum, they travel at light speed *c*.

Electromagnetism

A theory introduced by Maxwell in 1864 unifying electricity and magnetism. Although the two phenomena manifest very differently in experiments, they have a common origin. In addition to unveiling the nature of light, this theory introduced a new constant – light speed in vacuum – whose universality was incompatible with classical mechanics. The problem was eventually resolved by Einstein's theory of special relativity in 1905.

Electroweak theory

A single theoretical and mathematical framework covering electromagnetism and the weak interaction, despite their apparent differences: the former has an infinite range, while the effect of the latter does not range beyond the atomic nucleus. The apparent difference is understood as the consequence of the mass difference between the mediators – the photon is massless, whereas the W^+, W^- and Z^0 bosons are heavy. The unification becomes visible only at high energies.

Einstein's formula $E=mc^2$

Einstein's famous formula associates the mass M and the invariant energy E of a particle: $E=Mc^2$, where *c* is the light speed in vacuum. As simple as the expression may be, the equation has profound consequences. First, mass is only a specific form of energy and can be expressed in energy units; then, the mass-energy equivalence means that, theoretically, one can be produced from the other. Given the high value of the c^2 factor, mass contains a tremendous amount of energy.

Electron

A massive, stable elementary particle whose electric charge is opposite to the proton's. It is one of the three constituents of ordinary matter, along with the up and down quarks grouped into protons and neutrons. Electrons play an essential role in numerous physical phenomena, such as electricity, magnetism, chemistry, and thermal conductivity. Electrons radiate or absorb energy in the form of photons when they are accelerated.

Electron cloud

All the electrons orbiting around an atomic nucleus to form an atom. The term 'electron cloud', which is purposedly rather vague, suggests that the electrons' positions cannot be determined with absolute precision due to the quantum nature of the objects involved.

Elementary (particle)

A particle with no internal structure, which makes up all the other, composite particles: it is indivisible, its properties do not reflect the existence of any simpler object that it might contain. The 'elementary' status of a particle can be questioned at any time, as it depends on the precision of the experiments. As science progressed, the atom, then the nucleus, and later the protons and neutrons were once thought to be elementary. Today, quarks seem to be. But for how long?

Energy conservation

Energy exists in many forms, such as kinetic energy, heat, potential energy, mass energy, etc. Though these forms may appear distinct at first, they are all in fact multiple manifestations of the same reality: energy, which is overall conserved in all physical phenomena. For example, when the fission of a heavy nucleus produces lighter nuclei, the missing mass isn't lost, it is converted into kinetic energy. Energy conservation is a cornerstone principle of physics.

Energy levels

Electrons orbit an atom nucleus in layers known as shells, each corresponding to a specific energy level. This structure, driven by quantum mechanics, helps explain why some chemical reactions are more favourable than others, the ionisation process, and the emission of light by atoms. Similarly, the shell model can be applied to the arrangement of protons and neutrons within a nucleus, providing insight into whether a nucleus is stable or prone to rapid decay.

Error

In science, the word 'error' does not carry the negative connotation it has in everyday language. Instead, it refers to the difference between a measured value and the true value or accepted standard. Since no instrument can achieve infinite precision, every measurement carries some degree of uncertainty. Accurately estimating this uncertainty is crucial for maximising the value of data collected by detectors, whether they are probing the infinitely large or the infinitely small.

eV, GeV, TeV

An electronvolt is the energy acquired by an electron accelerated by a one-Volt electric tension. A gigaelectronvolt (GeV) equals one billion electronvolts. A teraelectronvolt (TeV) equals one trillion electronvolts. Through Einstein’s formula, GeV/c^2 is a mass unit.

Event

In physics of the infinitely small, the decay of a particle or the collision of two or more particles, observed in a detector.

Expansion

In 1929, Edwin Hubble discovered that the Universe is continuously expanding. This implies that distances between galaxies and other cosmic structures are increasing over time. Further observations have suggested that the expansion is accelerating, a phenomenon attributed to a mysterious form of energy known as dark energy.

Extra dimension

Some theories draw on additional space dimensions, particularly those aiming to unify gravity with the other three forces affecting fundamental particles (electromagnetic, weak, and strong forces). These extra dimensions would explain why gravity appears so much weaker than the other forces, and would be sufficiently small to have eluded detection in our experiments thus far. Although evidence of these dimensions has yet to be found, no fundamental principle rules out their existence.

– F –

Family

The 12 fundamental particles currently known are organised into three groups of four, called families. The first family comprises the particles that constitute ordinary matter: the electron, up and down quarks (which make up protons and neutrons) and the electron neutrino. The other two families follow the same pattern, each containing a heavy ‘cousin’ of the electron (the muon or the tau), two quarks (one whose properties resemble the up quark’s, the other similar to the down quark), and a corresponding neutrino.

Fermilab (USA)

Fermi National Accelerator Laboratory (Fermilab) is located in Batavia, Illinois, near Chicago. Until 2011, Fermilab housed the Tevatron accelerator, a 6.28 km (3.90 mi) circular collider where the top quark was discovered in 1995. Fermilab is now focused on becoming a world centre in neutrino physics, with the DUNE experiment (under construction). Among its ongoing experiments, NOvA is actively involved with IPPOG.

Feynman diagram

A visual representation of the mathematical expressions describing the behaviour and interactions of subatomic particles, named after physicist Richard Feynman, who introduced them. The calculation of probability amplitudes in theoretical particle physics involves complex integrals over numerous variables. By representing these integrals graphically, Feynman diagrams offer a powerful, increasingly used tool for theoretical physicists, facilitating critical calculations.

Field

A physical quantity that has a value at every point in space, e.g. temperature, pressure, or flow rate of a river. A field can vary across different locations – the flow of a rive changes when the riverbanks narrow or if there is a waterfall – and over time – in case of rising waters or drought conditions. The concept of a field is crucial in particle physics for describing wave-related phenomena. The concept is also instrumental in studying continuous media, such as the macroscopic properties of solids, fluids, etc.

Fission

The decay of a heavy nucleus into several smaller fragments as a result of a collision with a neutron. The mass of the reaction products is less than the mass of the initial nucleus. The missing mass M isn’t lost, it is converted into energy E (carried away by the reaction products) according to Einstein’s formula $E=Mc^2$. The factor c^2, a vastly large number, explains why fission nuclear reactions are significant sources of energy with various applications, be they civil or military.

Fixed target

In a fixed target experiment, a beam of accelerated particles is directed at a stationary piece of matter, usually a metal plate. This results in collisions between some beam particles and atoms in the target. Although the beam-fixed target collisions are simpler to produce than beam-beam collisions, fixed-target experiments have two main drawbacks: first, the particles in the target are used only once; second, only a small fraction of the beam's energy effectively contributes to the production of new particles.

Flavour

In particle physics, a property used to differentiate between various types of leptons and quarks. Leptons (electron, neutrino) have 3 flavours, each associated with the electron, the muon, and the tau. Quarks have 6 flavours (up, down, strange, charm, bottom, top). Flavours help distinguish particles that only differ in their masses, while have similar other properties, such as electric charge.

From beams to measurements

Scientists from institutes all over the world form experimental collaborations to build large and complex experimentsn and analyse the myriads of particles produced by collisions in accelerators.

Fundamental interactions

There are four fundamental interactions, or forces, in nature. Gravity, the most familiar to us, is also the weakest. Electromagnetism governs phenomena such as thunderstorms and the electricity flow. The other two forces, the weak and strong interactions, are confined in the atomic nucleus. The strong force binds the nucleus together, while the weak force causes certain nuclei to split.

Fusion

In a fusion reaction, two light nuclei merge to form a heavier nucleus, along with the release of a proton or neutron. During the process, a portion of the initial mass is converted into energy. For example, fusion reactions are the source of the energy that the sun produces and radiates towards the planets in the Solar System, including Earth.

– G –

Gamma radioactive decay

Gamma decay is the emission of electromagnetic radiation of extremely high frequency, i.e. of very high energy, from an unstable nucleus. The process releases excess energy to help the nucleus stabilise. Unlike alpha and beta decay, gamma decay does not alter the identity of the element.

General relativity

A relativistic theory of gravitation, here considered as the curvature of spacetime by the presence of a mass. It draws on a geometric perspective where the distribution of matter influences the structure of space and time, thereby affecting the motion of massive objects. General relativity encompasses and refines Isaac Newton's law of gravitation, which serves as an approximation of general relativity's predictions for low velocities (compared to light speed) and weak gravitational fields.

Gluon

The mediator particle of the strong interaction, responsible for binding quarks together within protons and neutrons. There are 8 types of gluons, each of which has zero mass and zero electric charge. Gluons themselves are subject to the strong interaction, as they carry both a colour charge and an anticolour charge.

Grand Unified Theory (GUT)

One of the primary goals of physics is to unify theories that explain the fundamental natural phenomena observed. After Isaac Newton's unification of gravity and celestial mechanics, and the success of the electroweak theory, the quest for unification continues. Grand Unified Theory (GUT) models, which aim to include the strong force as well, predict that protons are not stable, although they are yet to be confirmed. Incorporating gravity requires merging quantum mechanics with general relativity into a single framework known as quantum gravity.

Gravitation

The interaction responsible for the mutual attraction between massive bodies. Einstein's general relativity currently stands as the most accurate and comprehensive theory of gravitation. The universal law of gravitation, developed by Isaac Newton in the late 17th century, provides an excellent approximation for most everyday situations. However, at microscopic scales, gravitation is the weakest of the four fundamental interactions and has a negligible effect.

GSI (Germany)

The GSI Helmholtz Centre for Heavy Ion Research (German: GSI Helmholtzzentrum für Schwerionenforschung) is a heavy-ion research centre established in 1969 in Darmstadt, Germany. It conducts research on and with heavy-ion accelerators. An important technology developed at the GSI is the application of heavy-ion beams for cancer treatment (since 1997).

– H –

Hadron

A composite particle that contains quarks and/or antiquarks, bound together by gluons. Other hadrons of different compositions, called exotic hadrons, have been recently discovered: tetraquarks (made up of two quarks and two antiquarks) and pentaquarks (made up of four quarks and one antiquark).

HAWC (Mexico)

The High-Altitude Water Cherenkov Observatory is located in the Mexican state of Puebla at an altitude of 4,100 metres. HAWC detects showers produced by high-energy cosmic rays which hit the Earth's atmosphere. It monitors the northern sky and makes coincident observations with other observatories such as VERITAS, HESS, MAGIC, IceCube, CTA and the Fermi Gamma-ray Space Telescope, to obtain multi-wavelength and multi-messenger observations on cosmic phenomena.

Heavy ion

An electrically charged chemical element, generally produced by the addition or removal of electrons from an atom or a neutral molecule. In particle physics, the term 'heavy ions' is used to refer to atomic nuclei of heavy elements, such as lead, that are deprived of all their electrons and used as beams in colliders or for medical applications.

Higgs boson

The last elementary particle of the Standard Model to have been discovered (2012), the Higgs boson differs from the bosons carrying interactions, and from the fermions composing matter. It is a fundamental element of the Standard Model, as it is central to the BEH mechanism through which particles acquire their masses. This is the reason why the detailed analysis of its properties is one of the primary objectives of the LHC physics programme.

Inflation

A theory proposing a period of extremely rapid exponential expansion of the universe in its very early stages, right after the Big Bang. It is able to predict the universe uniformity in all directions and its tiny temperature fluctuations. Inflation has strong observational support, though there are still many details to uncover and understand.

Ionisation

To ionise means to remove or add electric charges (electrons) to an atom or a molecule. It is precisely what occurs when a charged particle travels in a detector and rips electrons from the components of the medium. The ejected electron is then detected.

International collaboration

As science progresses, experiments focus on more elusive and complex effects. In the physics of the infinite, this trend leads to increasingly large projects (e.g. accelerators are designed bigger so as to reach higher collision energies) and generates more and more data. The teams who fund, build and use detectors adapt to this shift: they grow, extend beyond national boundaries, and involve a wide range of professions. Their organisation structures are called collaborations.

– J –

– K –

Kamiokande

A neutrino observatory located near Mozumi, Japan. Kamiokande and its successor, Super-Kamiokande and SuperKGd, were designed to detect high-energy, solar and atmospheric neutrinos and keep watch for supernovae in the Milky Way Galaxy by detecting the Cherenkov light emitted during reactions between neutrinos and the water contained in a large volume. Gadolinium was introduced into the water tank in 2020 in order to distinguish neutrinos from antineutrinos that arise from supernova explosions.

KEK (Japan)

The KEK is a Japanese organisation and laboratory whose purpose is to operate the largest particle physics laboratory in Japan. Situated in Tsukuba, its electron-positron collider (called SuperKEKB) is dedicated to the study of the quark b, with the Belle II experiment which is member of IPPOG.

– L –

Leptons

A class comprising six of the twelve elementary particles (electron, muon, tau, and their associated neutrinos) known to date, which are not affected by the strong interaction. Three of them (electron, muon, tau) have an electric charge, the other three (neutrinos) are neutral.

LHC

The Large Hadron Collider, the world's largest particle accelerator, started up at CERN in 2008 and will provide collisions until 2042. Proton beams are formed and accelerated in a linear accelerator (Linac 4) and two synchrotrons (PS and SPS) before being injected into the LHC, a 27-kilometre ring of superconducting magnets with a number of accelerating structures to boost the energy of the particles along the way.

LHCb

One of the four major CERN experiments. The LHCb investigates the differences between matter and antimatter by studying the b quarks. Instead of surrounding the entire collision point with an enclosed detector as ATLAS and CMS do, the LHCb experiment uses a series of subdetectors to detect mainly forward particles – those thrown forwards by the collision in one direction – where hadrons containing a b quark can be tagged and studied.

Lifetime

An unstable body decays to form more stable entities. The exact decay time is random but the law of probability governing this phenomenon is well known. Its mathematical expression depends on a single parameter known as lifetime. On average, the higher the lifetime, the longer the unstable body takes to decay. Lifetime can greatly vary from one body to another: a fraction of a second for the muon, some 15 minutes for an isolated neutron, over 4 billion years for the Uranium-238 nucleus.

Light

In classical physics, light is described as an electromagnetic radiation, i.e. a wave corresponding to the linear propagations of a magnetic field and of an electric field. In quantum physics, light can be described in two ways, either as the propagation of an electromagnetic radiation (variation of electric and magnetic fields), or as the emission of a zero-mass particle called a photon, whose energy is proportional to the wave frequency.

Linear accelerator

A linear particle accelerator (often shortened to linac) accelerates charged subatomic particles or ions to a high speed by subjecting them to a series of oscillating electric potentials along a linear beamline. Linacs have many applications: they generate X-rays and high-energy electrons for medicinal purposes in radiation therapy, serve as particle injectors for higher-energy accelerators, and are used directly for particle physics.

Luminosity

The collision rate in a particle accelerator is measured by a quantity called luminosity: the higher the luminosity, the higher the collision rate. Particles travel through the accelerator as bunches. The greater the number of bunches, the greater the number of particles per bunch and the smaller the size of the bunches at the collision point, the higher the luminosity.

– M –

Magnetic field

A field which is created in all points of space by moving electric charges and/or by the variation of an electric field over time. Since Maxwell's work, electric and magnetic fields can be described in a single formalism, the electromagnetic field. If an electric charge is placed in a magnetic field, the Lorentz force will bend its trajectory. The curvature of its path is proportional to the particle's energy and to the inverse of the field.

Mass

A general term which refers to two intrinsic properties of a body: one quantifies the body's inertia (inertial mass), and the other the body's contribution to the gravitational force (gravitational mass or gravity load). Although these masses might seem different in nature, experiments have in fact shown that they are equivalent. Mass appears in all classical physics calculations. In special relativity, (invariant) mass represents a body's intrinsic energy.

Matter-antimatter asymmetry

The Big Bang theory suggests that equal amounts of matter and antimatter should have been created in the early universe. Matter and antimatter particles are always produced in pairs, and when they meet, they annihilate each other, releasing pure energy. However, the observable universe today, from the smallest life forms on Earth to the largest stellar objects, is composed almost entirely of matter. One of the greatest challenges in physics is understanding why.

Matter constituents

The bulk matter of everyday life consists of large groups of atoms or molecules. Depending on temperature and other conditions, this matter can exist in various states: solids, liquids, gases, and plasmas. However, at the most fundamental level, matter is composed of elementary particles called quarks and leptons.

Measurement

Measurement is essential to physics, as this science constantly draws on comparisons between observations and theoretical models. However, absolute accuracy is unattainable: repeated measurements often fluctuate due to various environmental and intrinsic factors associated with the measuring method. Additionally, most phenomena studied in particle physics are inherently random: the same measurement has to be repeated numerous times to achieve an overall, statistical understanding of the underlying process.

Meson

A particle formed by a quark of a given colour and an antiquark of the associated anticolour. For example, pions are mesons.

Muon

A massive cousin of the electron. The muon shares the same properties, except for its mass, which is 207 times greater. It is not affected by the strong interaction, carries a negative electric charge equal to the elementary charge, and has a very short lifetime (2.2 μs at rest). Denoted by μ^-, the muon has an antiparticle, denoted by μ^+. On Earth, muons are produced by the decay of charged pions, which come from cosmic rays penetrating the upper atmosphere.

Muon chamber

A device that leverages the high penetrating power of muons to distinguish them from other charged particles. When combined with a magnetic system, a series of muon chambers forms a muon spectrometer, which is used to measure the momenta of these particles.

Muon tomography

An imaging technique that reconstructs the three-dimensional characteristics of an object by collecting one- or two-dimensional data on the penetration of radiation or particle beams. X-rays and positrons are commonly used in medical applications, while cosmic ray muons are employed to image larger structures, such as pyramids and volcanoes.

– N –

Neutrino

A fundamental particle produced by a decay caused by the weak interaction (e.g. beta radioactivity of unstable atomic nuclei). There are three different types of neutrinos, each associated with the electron, the muon, and the tau. Neutrinos were long thought to have zero mass. Recent experiments based on the study of neutrinos' oscillations have shown that their masses are very small compared to other particles, but not null.

Neutrino detector

Neutrinos only interact with other particles of matter through the weak force. A common technique to detect them is to place a huge tank of water, ice or of some other clear liquid underground to prevent cosmic ray signals from interfering with the measurements. Neutrinos coming from the sun, cosmic rays, supernova or accelerators are studied by an increasing number of detectors around the world.

Neutrino oscillation

A neutrino produced by the decay of another particle has a well-defined flavour (electron, muon, or tau). However, if the neutrino propagates and the flavour is measured after a certain time, a different result may be observed. Quantum mechanics explains this startling effect: a neutrino is considered as the superposition of three waves which correspond to particles of different masses. These waves do not propagate at the same frequency, which alters the blend composition over time.

Neutron

A subatomic particle composed of two down quarks and one up quark. It has a neutral electric charge and a mass of 939 MeV/c^2. When isolated, a neutron decays after fifteen minutes, on average. However, it is stable when found in atomic nuclei, bound with protons.

Nucleon

A generic term referring to the components of an atomic nucleus, i.e. protons and neutrons, each composed of three quarks. The total number of nucleons in an atom is generally denoted by 'A' and is known as the mass number.

Nucleus

The atomic nucleus is the central region an atom, consisting of protons and neutrons. The nucleus (10^{-14} m) is roughly 10,000 times smaller than the atom (10^{-10} m) but contains nearly all of the atom's mass.

– O –

Observatory

An observatory is a facility designed for monitoring terrestrial, marine, or celestial phenomena. Astronomical observatories are mainly categorized into four types: space-based, airborne, ground-based, and underground-based. Two of them are currently IPPOG members, the Pierre Auger Observatory and HAWC.

Open data

Experiments collect unique data at the frontiers of science using one-of-its-kind facilities and large-scale efforts with contributions from thousands of scientists. The data, which enables key insights into the nature of our world, represents a heritage of humanity, which experiments and research centres preserve, curate and share with the public. Given the complexity of particle physics, tutorials and educative material are also provided.

Open science

Open science is a movement aimed at making scientific research (including publications, data, physical samples, and software) and its dissemination accessible to all levels of society, from amateurs to professionals. It is one of the core values of particle physics in general, and CERN in particular.

Outreach

Science outreach refers to activities and initiatives designed to engage the general public with science, technology, engineering, and mathematics (STEM). The goal is to make scientific knowledge accessible, interesting, and relevant to a broader audience. A variety of formats and platforms are used to ‘reach out’ to diverse audiences, from online dissemination to participation to science festivals and fairs, and creation of educative programmes.

– P –

Particle accelerator

A machine used to provide energy to charged particles (electrons, protons, ions, etc.). Electric fields accelerate the particles while magnetic fields steer and focus them. The higher the targeted energies, the bigger the accelerator – its length can reach several kilometres, even tens of kilometres today.

Particle detector

A device used to take measurements during an experiment. It can be a telescope's camera sensitive to photons of a specific wavelength, or a device which absorbs a particle's energy and emits an electric signal proportional to its value. The word 'detector' is also used to describe the huge composite devices made of numerous smaller detectors. In the LHC's large detectors, each layer carries out a very specific task.

Particle motion in fields

In the presence of an electric field, a charged particle accelerates and has a linear motion, travelling in a straight line until it hits matter. In the presence of a magnetic field, the particle's energy remains constant, but its trajectory is curved into a circular path, and the radius of this circle is proportional to the particle's energy. This property is used to measure particle energies: the lower the particle's energy, the smaller the circle.

Particle signature

All the tracks that a particle leaves in a detector (path, energy deposition, etc.). After being converted into electric signals and recorded by software, the raw data are interpreted by physicists to estimate the properties of the particle that emitted them, such as its mass, speed, and energy.

Periodic table

The periodic table is an ordered arrangement of the chemical elements highlighting those with similar chemical properties. It is now understood to reflect the atomic structure: elements and isotopes differ based on the number of protons and neutrons in their nuclei. The resemblance with the 'families' of elementary particles is striking, though no equivalent sub-structure has yet been identified. Why are there three families? Why four types of particles? How to explain the vast mass differences between the lightest and the heaviest particles? Many questions remain open.

Photoelectric effect

The emission of electrons from a material exposed to light or crossed by high-energy charged particles. In 1905, Einstein explained this observation by the absorption of light quanta, called photons, that only eject electrons if they carry a sufficient amount of energy. In detectors, the emitted electron signals are amplified and recorded to reconstruct the incoming particle's trajectory and energy.

Photomultiplier

A type of photon detector. In a photomultiplier, the signal produced when a photon interacts with a cathode is greatly amplified – typically by a 10^6 factor – through a series of electrodes (dynodes) and converted into an electric pulse, which is read by an electronic chip. Photomultipliers allow for the detection of single photons with high time resolution.

Photon

The elementary grain of light, often denoted by γ. For particle physicists, electromagnetic waves are made up of photons, whose energy is proportional to the wave's frequency. Moreover, photons mediate electromagnetic interactions. Thus, two electrically charged particles attract or repel each other by exchanging protons.

Pierre Auger Observatory

The Pierre Auger Observatory is an international cosmic ray observatory located in Argentina and dedicated to detecting ultra-high-energy cosmic rays. When these particles enter Earth's atmosphere, they interact with air nuclei, creating cascades of various secondary particles known as 'air showers'. These secondary particles are detected and measured in a detection area of 3,000 km^2, allowing scientists to reconstruct the direction and energy of the primary cosmic rays.

Pion

The least massive type of subatomic particles composed of a quark and an antiquark (mesons). Pions exist in three forms, each with a very short lifetime. Two of them carry an electric charge equal to the elementary charge (π^+ and π^-); they have the same mass and lifetime, and differ only in the sign of their electric charge. The neutral pion (π^0), which is slightly less massive, has a much shorter lifetime than the charged pions.

Positron

The antiparticle of the electron was the first antimatter particle to have been predicted (by Dirac in 1927) and subsequently discovered (by Anderson in 1932). While the electron and the positron share many properties, such as mass, they have opposite electric charges. Positrons are used in medical application (PET) and can be accelerated into beams to produce electron-positron collisions.

Primary cosmic rays

Primary cosmic rays are charged particles that have been accelerated to enormous energies by astrophysical sources somewhere in our universe. They must be stable to survive their long journey through interstellar (or intergalactic) space. If they are charged, and therefore swerved by magnetic fields, it is extremely difficult to locate their source. Experiments on satellites can perform direct studies on their composition and look for the presence of antimatter.

Probability

A quantitative estimation of the frequency at which an event may occur. Quantum mechanics adopts a fundamentally probabilistic approach for all observations, enabling scientists to calculate the probability for a given phenomenon to be observed.

Proton

A subatomic particle with an elementary electric charge, composed of two up quarks and one down quark bound together by the strong interaction. The proton is a stable particle that forms the core of atomic nuclei.

– Q –

Quadrupole

A four-pole magnet used to focus particle beams in a manner similar to how glass lenses focus light. There are 392 main quadrupoles in the LHC.

Quantum (plur. quanta)

A quantum (a Latin word meaning 'how many') is the smallest indivisible unit of energy, motion or mass that can be gained, lost or exchanged. This concept is central to quantum theory, which emerged in the early 20th century and gave rise to quantum mechanics. Unlike classical mechanics, this theory posits that energy and other physical properties can be transferred in continuous, arbitrarily small amounts, quantum theory asserts that these quantities are exchanged in discrete, quantised units.

Quantum chromodynamics (QCD)

Quantum chromodynamics (QCD) is a fundamental theory in physics that describes the strong interaction. Developed in the early 1970s, QCD states that at extremely short distances or equivalently at very high energies, quarks interact weakly and behave almost like free particles – a phenomenon known as asymptotic freedom. As quarks move further apart, the force between them intensifies, effectively preventing the isolation of individual quarks – a phenomenon known as colour confinement.

Quantum electrodynamics (QED)

Quantum electrodynamics (QED) is a fundamental theory in physics that describes the interaction between light and matter. It merges quantum mechanics with special relativity to describe particle interactions through complex probability amplitudes. QED is widely regarded as one of the most successful theories in physics due to its precise predictions and extensive experimental verification.

Quantum field theory

Quantum field theory arises from the alliance of quantum mechanics and special relativity. In this framework, particles are elementary excitations of a fundamental entity, the field, which varies in value across different points in spacetime. Imagine the water of an ocean as a 'field'. Elementary excitations are waves propagating on the surface. In quantum mechanics, the height of the waves can take on only specific values (they are 'quantised') and these 'elementary waves' are the particles.

Quantum mechanics

Quantum mechanics is the branch of physics that describes fundamental phenomena at atomic scales, complementing classical physics, which addresses with macroscopic scales. It explains phenomena such as superfluidity, superconductivity, and the photoelectric effect. Quantum mechanics breaks with classical physics by abolishing the wave-particle distinction and by abandoning the notion of perfectly determined and predictable physical quantities (e.g. position and speed) in favour of probabilities.

Quark

An elementary constituent of matter. Six types of quarks have been discovered, each of which has a corresponding antiparticle known as an antiquark. Since they are affected by the strong interaction, quarks are never found in isolation: they are always bound together in quark-antiquark pairs or groups of three through the strong interaction.

Quark-gluon plasma

When quarks are supplied with an extremely high amount of energy, they become so agitated that they can overcome the strong interaction and break free from hadrons. This deconfinement would produce a new state of matter known as plasma, in which quarks and gluons (mediators of the strong force) exist as free particles. QGP is believed to have existed shortly after the Big Bang and can be created in high-energy heavy-ion collisions, such as those conducted at CERN’s Large Hadron Collider (LHC).

– R –

Radioactivity

A natural phenomenon in which unstable atomic nuclei undergo transformation (‘decay’), emitting energy in the form of radiation as they decay into more stable nuclei with reduced mass. The type of radiation emitted depends on the decay process: α rays (helium nuclei), β rays (electrons or positrons), or γ rays (high-energy photons).

Random phenomenon

A phenomenon may appear random when we don’t fully understand. In the world of the infinitely small, randomness isn’t due to a lack of understanding; it is an intrinsic property of elementary particles. While the probability of an event can be calculated, the exact time of its occurrence cannot.

Range

The range of an interaction is the typical distance over which its effects are significant. Gravitation and the electromagnetic interaction have an infinite range, while the ranges of the strong and weak interactions are limited to subatomic distances.

Reconstruction

The effects generated by particles as they pass through materials are carefully recorded. This data is then analysed to reconstruct the sequence of events, starting from the initial collision and tracking the paths of all newly produced particles as they exit the detector. This stage, known as reconstruction, demands a deep understanding of the underlying physical phenomena and the detector’s response to each type of particle that interacts with it.

Relativistic particle

A particle of matter that has been accelerated to a speed near the speed of light, known as a relativistic speed. The particle’s kinetic energy is then comparable to its rest-mass energy ($E = Mc^2$).

Relativity principle

The relativity principle states that the laws of physics are identical in any inertial frame of reference – i.e. a frame in which an object not subjected to any force remains either at rest or in uniform, rectilinear translational motion. This implies that two identical experiments conducted in different inertial frames will yield the same results.

Scientific model

Physicists create and refine ‘models’ to represent scientific theories about specific phenomena. A model is generally built on a theoretical framework – a collection of hypotheses – and on a set of parameters derived from experimental data and/or observations. Computer simulations can sometimes be employed to assess a model’s accuracy. If the model proves sufficiently reliable, the simulation can even be used to predict outcomes under varying initial parameters.

Scintillation

The flash of light emitted by an electron when an excited atom returns to its ground state.

Secondary cosmic ray showers

When cosmic rays enter the Earth’s atmosphere, they collide with atoms and molecules, primarily oxygen and nitrogen. The interaction produces a cascade of lighter particles known as an air shower. This secondary radiation raining down includes X-rays, protons, alpha particles, pions, muons, electrons, neutrinos, and neutrons. These secondary particles travel along paths that deviate by no more than about one degree from the original trajectory of the primary cosmic ray. They are then detected by observatories.

Signal

In particle physics, a signal refers to the set of data or observations that indicate the presence or occurrence of the phenomenon being studied, in contrast to the background noise, which consists of data with similar characteristics but originating from other phenomena.

Simulation

To accurately understand how a detector identifies different particles produced during collisions and to ensure that the signal of interest is effectively isolated from background noise, scientists often use digital simulations that replicate the physical processes occurring within the detectors. With this ‘simulated’ data of perfectly controlled origin, they can determine whether or not the real-data analyses are sufficiently reliable and precise.

Spacetime

The space we inhabit consists of three dimensions: every movement can be broken down into three distinct directions – upward/downward, left/right and forward/backward. With Einstein’s theory of relativity, time was integrated into this framework, creating a four-dimensional spacetime. Time coordinates differ fundamentally from the other three dimensions: while backward movement is possible in space, time progresses only forward. However, time, like space, is relative: time elapses differently from one observer to the other.

Spectrometer

In particle physics, a detector system that includes a magnetic field to measure the momentum of particles.

Standard Model of Cosmology

The ΛCDM model is a mathematical framework to describe the large structures of the Universe. It is referred to as the standard model of Big Bang cosmology because it is the simplest model that provides a good account of current observations.

Standard Model of Particle Physics

The Standard Model is a theory that describes the strong, weak, and electromagnetic interactions, as well as all known fundamental particles. Developed in the 1970s, it has consistently matched experimental results for all tested predictions. The final missing component, the Higgs boson, was discovered at CERN in 2012.

Statistical error

The accuracy of a survey improves as the sample size increases. The same applies to physics measurements: part of the error on a quantity arises from the fact that the measurement is done a finite number of times. This is the statistical error. Mathematically, the statistical error decreases in proportion to the inverse of the square root of the number of measurements. In other words, achieving twice (or 10 times) greater precision requires for (or 100) times more experiments, repeated identically.

Strange

The third of the six quarks. Its name originates from particles discovered in cosmic ray experiments shortly after the end of WWII. These particles exhibited different signatures than those of the known particles at the time, hence their ‘strange’ nickname. Once quarks were discovered, these unusual behaviours were associated to the presence of a new quark within these particles, the ‘strange’ quark.

Strong interaction

One of the four fundamental forces existing in nature, alongside electromagnetism, the weak interaction, and gravitation. The strong interaction is responsible for confining quarks within hadrons and for ensuring the stability of atomic nuclei. As the name suggests, it is the most powerful force, even though its range is limited to the subatomic world.

Superconducting cavity

Schematically, metallic tubes connected to a very powerful electric energy generator, which create intense electric fields to accelerate particle beams. Initially, these cavities used ordinary conducting materials, such as copper. Newer designs employ superconducting materials, which eliminate electrical resistance but require extremely low temperature cooling systems for their superconducting effects to manifest.

Supersymmetry

One of the current theoretical extensions of the Standard Model of particle physics. It specifically predicts twice the number of fundamental particles through a new ‘supersymmetry’ – hence its name, often abbreviated as ‘SUSY’. This extension addresses several theoretical ‘gaps’ in the Standard Model, particularly those related to the Higgs boson and the nature of particle masses. Today, SUSY remains a mere hypothesis, which experiments at the LHC aim at confirming or refuting.

Synchrotron

A particle accelerator in which a magnetic field bends the trajectories of the particles and increases with their energy. This technique ensures that the beams remain confined to their circular orbits through the whole acceleration process.

Synchrotron radiation

Electromagnetic radiation emitted when relativistic charged particles are accelerated perpendicularly to their velocity. Initially, this energy loss from synchrotron radiation was seen as a drawback in circular accelerators, as additional energy was required to compensate for the losses. However, circular electron accelerators, known as synchrotron light sources, have since been developed to intentionally generate intense beams of synchrotron radiation for research purposes.

Systematic error

Systematic errors include instrumental issues such as faulty or improperly calibrated instruments that consistently produce inaccurate readings, external factors like temperature or magnetic fields that consistently influence measurements, observer biases, and incorrect or simplified models or assumptions used in calculations. Unlike statistical errors, systematic errors do not decrease when more data is collected. The scientists’ task is to minimise these errors through additional cross-checks and, if they cannot be eliminated, to accurately estimate the uncertainty of their results.

– T –

Tau

The lepton from the third family of fundamental particles. It is a cousin of the muon and the electron, but significantly more massive.

Theory

In physics, a theory generally is a mathematical framework based on a small set of fundamental principles and equations that is used to predict experimentally observable phenomena. A theory is distinguished by its broad scope and extensive experimental validation. In contrast, a model typically has a narrower application focus and is used to reproduce data more qualitatively than quantitatively.

Top

The most massive quark known to date. With a mass of 171 GeV/c^2, the ‘t’ quark is nearly as heavy as a gold atom.

Trajectograph

A series of detectors designed to track the trajectories of charged particles as they pass through it. A trajectograph records ‘hits’, which are points where a particle has interacted with the detector at specific times. Sophisticated software programmes then aim to identify and associate the hits that are likely to originate from the same particle. The goal is to determine the particles’ production points, directions, and energies with precision.

Trigger

Algorithms used to determine in real time whether an event should be recorded. A trigger system operates through multiple sequential levels, each analysing data from the detector with increasingly detail. The first level uses a limited set of critical, immediately available parameters. At the final level, fewer events are evaluated, which allows the algorithm to ‘take its time’ and base its decision on a comprehensive analysis of the detector. The whole process occurs within a fraction of a second.

– U –

Ultraviolet

A radiation of electromagnetic waves with wavelengths ranging from 10 nm (X-ray limit) to 400 nm (visible light limit). For the corresponding photons, these limits correspond to the energies of 120 eV and 3.1 eV, respectively.

Unified theories

In the 1860s, James Clerk Maxwell recognised the similarities between electricity and magnetism and developed his theory of a unified electromagnetic force. A similar discovery occurred a century later, when theorists began exploring the relations between electromagnetism, which has visible effects in everyday life, and the weak force, which primarily operates within the atomic nucleus. Building on these insights, theorists are now even investigating the possibility of unifying all fundamental forces into a single framework.

Universal gravitation

The law of universal gravitation, formulated by Isaac Newton in the late 17th century, describes gravity as the fundamental force responsible for the fall of bodies and the motions of celestial objects. It states that the attraction between two bodies is a force proportional to the product of their masses and inversely proportional to the square of the distance between them. This law provides an excellent approximation of Einstein's theory of general relativity in most everyday situations.

Unstable particle

The primary components of ordinary matter, e.g. protons and electrons, are stable. However, most particles produced in high-energy collisions are unstable and spontaneously decay into lighter particles. The resulting particles can also be unstable, leading to a cascade of decays until only stable particles remain. In collider experiments, the final set of particles is analysed to reconstruct the properties of the original particles involved in the collision.

Up

The least massive quark, with a mass ranging from 1.5 to 4 MeV/c^2. Up quarks combine with down quarks to form protons and neutrons.

– V –

Vacuum

In physics, there is no such thing as an absolute vacuum: any given volume, regardless of its conditions, always contains molecules. Residual gas pressure is measured in pascals (Pa) or millibars (mbar). Atmospheric pressure is approximately 100,000 pascals (1 bar). In the LHC, the ‘ultra-vacuum’ corresponds to a pressure of 10^{-8} Pa, with 2 million molecules par cubic centimetre remaining. In comparison, interstellar gases contain only a few atoms per cubic centimetre.

Vertex

In particle physics, a vertex refers to the point where a particle is produced, either from a collision or the decay of another, unstable particle. Knowing the vertex position is a critical input for accurate measurements and analysis.

Vertex detector

In particle physics, a vertex refers to the point where a particle is produced, either from a collision or the decay of another, unstable particle. Vertex detectors are positioned as close as possible to this point to accurately measure particle trajectories and reconstruct the vertex position.

– W –

W boson

The W boson, with a charge of +1 or -1, can alter the identity of particles involved in weak interactions, such as in radioactive decays. CERN announced its discovery in 1983. Since then, experimental physicists have progressively refined measurements of the W boson's properties, especially its mass, to compare with theoretical predictions, achieving ever greater precision.

Wave-particle duality

A wave is a disturbance that propagates through a medium, causing reversible changes in physical properties along its path. For example, sea waves alter water levels. In quantum mechanics, fundamental particles can sometimes be described as waves, and vice versa. This duality of quantum objects explains why photons, the elementary grains of light, exhibit both wave-like and particle-like behaviours. Depending on the context, either aspect may become prominent.

Wavelength

A physical quantity, homogeneous to length, that is used to characterise periodic phenomena. A wave is a physical phenomenon that propagates through space, with its pattern being identically reproduced at subsequent moments in time and locations. Wavelength represents the shortest distance between two strictly identical points of a wave at a specific time. When an electromagnetic wave propagates through a vacuum, the wavelength is inversely proportional to the frequency.

Weak interaction

The weak interaction is responsible for certain types of radioactive decay and operates exclusively within the atomic nuclei. It plays a crucial role in the energy production processes at the cores of stars, including the Sun. The weak force is mediated by massive bosons known as the Z^0 and W bosons. Due to their significant mass, the range of the interaction is limited, and the production and study of these bosons necessitates high-energy accelerators.

– X –

X-ray

An electromagnetic wave with a high frequency and a wavelength ranging from approximately 5 picometres to 10 nanometres. The energy of these photons spans from a few electronvolts (eV) to tens of megaelectronvolts (MeV). X-rays have a wide range of applications, including medical imaging and crystallography.

Z boson

The Z boson is a neutral elementary particle that, like its electrically charged cousin, the W boson, mediates the weak force. First proposed in 1958 as part of the theoretical unification of the electromagnetic and weak interactions, the Z boson became a cornerstone in the development of the Standard Model. Following extensive experimental efforts from 1973 to 1983, CERN was eventually able to confirm the existence of the Z^0 boson and study it in detail.