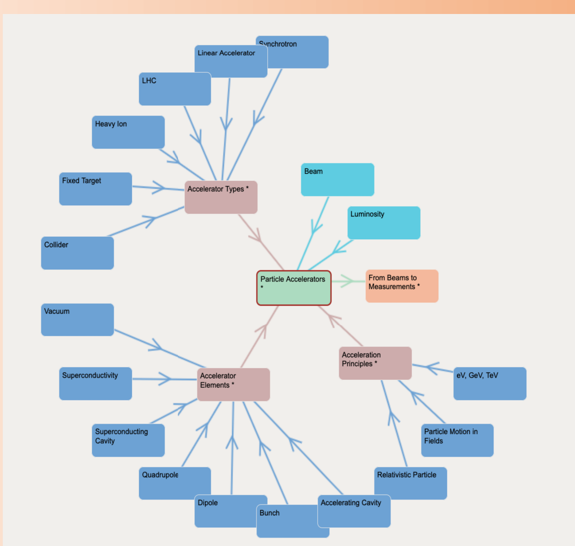
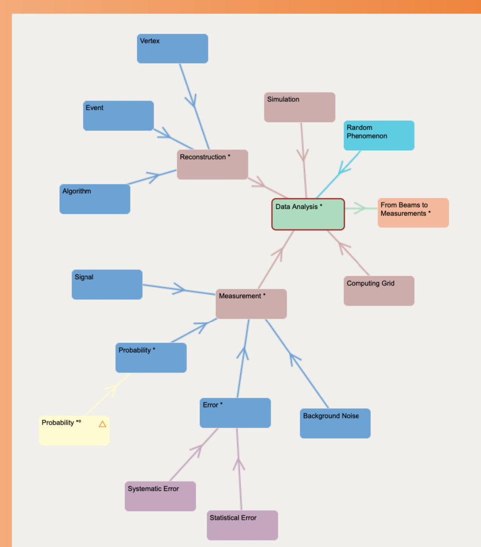
The Infinite Glossary: from Beams to Measurements

All the "Infinite Glossary" items are somehow linked. However, some links are stronger and more directs than others... Here are those related to experimental particle physics: laboratories, accelerators, detectors and data analysis.

Three laboratories and five collider experiments are currently members of IPPOG, and more are being planned.





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

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 kilometers, even tens of kilometers today.
Beam	In an accelerator, particles are gathered together in a beam. Beams can contain billions of particles and be divided into discrete portions called bunches. Each bunch is usually several centimetres long but just a few microns wide.
eV, GeV, TeV	One electron-Volt is the energy acquired by an electron accelerated by a 1 Volt electric tension.A Giga electron-Volt (GeV) equals a billion electron-Volts. A Tera electron-Volt (TeV) equals a thousand billion electron-Volts.Through Einstein's formula, GeV/c2 is a mass unit.
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.
	Accelerator Elements
Accelerating cavity	A device that produces the electric field accelerating the particles inside accelerators. As the electric field oscillates at radio frequency, accelerating cavities are also referred to as radio-frequency cavities.
Bunch	Particles in a collider do not circulate as a continuous flow, they are gathered in very dense bunches that are separated by vacuum. As an example, in fall 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.
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.
Quadrupole	A magnet with four poles, used to focus particle beams rather as glass lenses focus light. There are 392 main quadrupoles in the LHC.

Superconducting Cavity	Schematically, metallic tubes connected to a very powerful electric energy generator which contain the intense electric fields that accelerate beams. While the cavities originally used ordinary conducting materials (e.g. copper), new cavities have been designed with supraconducting materials which offer no electric resistance but require very low temperature cooling systems for the supraconducting effects of the materials to manifest.
Superconductivity	A property of some materials, initially discovered at very low temperatures, that allows them to carry electricity without resistance. The absence of Joule effect loss is used to run powerful currents and, for instance, create very strong magnetic fields. Current research and development focus on high-temperature superconductors, discovered in 1986, that can be cooled with less expensive systems.
Vacuum	In physics, there is no such thing as absolute vacuum: a given volume, whatever its conditions, always contains molecules. The pressure of the residual gas is expressed in pascals (Pa) or in millibars (mbar). The atmosphere has a pressure of approx. 100,000 pascals (1 bar). In the LHC the "Ultra-vacuum", corresponds to a pressure of 10-8 Pa; there remain 2 million molecules par cubic centimetre. By comparison, interstellar gases contain a few atoms per cubic centimetre.
	Acceleration Principles
Particle motion in Fields	In the presence of an electric field a charged particle is accelerated and has a linear motion, it follows a straight line until it hits matter. In the presence of a magnetic field, its energy is not modified but its trajectory is curved into a circle, which radius is proportional to its energy. This property is used to measure the particle energies: the softer the particle is, the smaller the circle will be.
Relativistic Particle	A particle of matter that has been accelerated near the speed of light, at a relativistic speed. The kinetic energy of the particle is then comparable to its rest-mass energy (E = Mc2).
Synchrotron Radiation	The electromagnetic radiation emitted when relativistic charged particles are subject to an acceleration perpendicular to their velocity. Energy loss from synchrotron radiation in circular accelerators was originally considered a nuisance, as additional energy must be supplied to the beam in order to offset the losses. However, circular electron accelerators known as light sources have been constructed to deliberately produce intense beams of synchrotron radiation for research.

	Accelerator Types
Collider	Accelerator in which two counter-rotating beams are accelerated and forced to collide at the centre of detectors that was 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.
Fixed target	In a fixed target experiment, a beam of accelerated particles is projected on a fixed piece of matter, usually a metal plate. Collisions then occur between some particles and atoms of the target. While the beam-fixed target collisions are easier to produce than beam-beam collisions, there are two main drawbacks to the fixed target experiment: first, the particles can be used only once; second, only a small part of the energy provided by the beam is effectively used to create new particles.
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 a beams in colliders or for medical applications.
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 shaped 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.
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 beam line. 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.
Synchrotron	A particle accelerator in which a magnetic field bends the trajectories of the particles, and increases with their energy. This technique allows to keep beams on circular orbits through the whole acceleration process.

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 term "detector" is also used to describe the huge composite devices made of numerous smaller detectors. In the LHC large detectors each layer carries out a very specific task.
Particle Signature	All the tracks (path, energy deposition, etc.) which a particle leaves in a detector. After being converted into electric signals and recorded in a software programme, the raw data are interpreted by physicists to estimate the properties of the particle that emitted them: mass, speed, energy, etc.
Detection Devices	Modern particle detectors consist of layers of subdetectors, each designed to look for particular properties, or specific types of particle. 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.
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 Master-Class programme.
	Detection Devices Main Types
Calorimeter	In physics, an instrument for measuring heat exchange. In a 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.
Muon chamber	A device that makes use of the high penetrating power of muons to identify them among other charged particles. Associated with a magnetic system, a series of muon chambers creates a muon spectrometer to measure momenta.
Spectrometer	In particle physics, a detector system which contains a magnetic field to measure momenta of particles.

Trajectograph	A series of detectors used to follow the trajectories of the charged particles that cross it. A trajectograph records "hits", i.e. spots which a particle has passed at a given time. Highly complex software programs attempt to associate the hits that are very likely to stem from the same particle. The objective is to measure the position where the particles were produced as well as the particle direction and energy.
Trigger	Algorithms used to decide in real time if an event should be recorded. A trigger system combines several successive levels, which exploit data recorded by the detector in an increasingly extensive way. The first level uses a small number of essential, immediately available parameters; at the last level less events are analysed, which allows the algorithm to "take its time" and base its decision on a comprehensive reading of the detector. The whole process takes a fraction of a second.
Vertex detector	In particle physics a vertex refers to the spot where a given particle was created, either following a collision, or during the decay of another, unstable particle. Vertex detectors are located as close as possible to measure the particle directions and reconstruct the vertex position.
	Some of the Current Experiments
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.
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 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.
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 goal to study the weak interaction and search for new phenomena beyond the Standard Model of particle physics.

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

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, i.e. photons, that only eject electrons if they carry a sufficient amount of energy. In detectors, the electron signal is amplified and recorded to reconstruct the incoming particle trajectory and energy.
Photomultiplier	A photon detector. In the photomultiplier the signal emitted when a photon interacts with a cathode is strongly amplified (generally by a 10^6-order factor) through a series of electrodes (dynodes) and converted into an electric impulsion that is read by an electronic chip. With this device, single photons can be detected with a good time resolution.
Scintillation	The flash of light emitted by an electron when an excited atom returns to its ground state.

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

Error	In science the term "error" does not have the negative connotation it has in ordinary speech. Error refers to the difference between a measured value and the true value or accepted standard. Since no instrument can have infinite precision, any measurement is riddled with uncertainty. Estimating the uncertainty is a must to make the most of the data collected by detectors, be it turned toward the infinitely large or toward the infinitely small.
Event	In the physics of the infinitely small, the decay of a particle or the collision of two or more particles, observed in a detector.
Measurement	Measurement is essential in physics, as this science constantly draws on comparisons between observations and models. However, absolute accuracy cannot be achieved: repeated measurements will fluctuate due to various environmental and instrinsic factors, linked to the measuring method. In addition, most phenomena studied in particle physics are random in nature: the same measurement has to be repeated many times to obtain an overall, statistical understanding of the phenomenon.
Probability	A quantitative estimation of the frequency at which an event may occur. Quantum mechanics takes on a fully probabilistic perspective for all observations, and allows us to calculate the probability for a given phenomenon to be observed.
Random Phenomenon	A phenomenon sometimes seems random because we do not understand it well enough. In the world of the infinitely small, randomness does not stem from a lack of understanding: it is an intrinsic property of elementary particles. The probability can be calculated, not the exact occurrence time.
Reconstruction	The effects created by the particles in the materials they pass through are recorded. The data are then analysed to reconstruct the chain of events, from the initial collision to the exiting of all the newly produced particles from the detector. This stage, called reconstruction, requires comprehensive knowledge of the physical phenomena involved, as well as of the behavior of the detector when each type of particle passes through it.
Signal	In particle physics, a signal refers to the set of data or observations that indicate the presence or occurrence of the phenomenon under study, in contrast to the background noise, which encompasses similar characteristics but stemming from other phenomena.

Simulation	In order to thoroughly understand how a detector identifies the different particles produced during collisions and to ensure that the searched signal is properly isolated from other background noise sources, scientists often need digital simulations which reproduce the physical processes occurring within the detectors. Thus, they can determine whether or not the real-data analyses are sufficiently reliable and precise by using "simulated" data whose origin is perfectly controlled.
Statistical error	A survey is all the more accurate as the number of people surveyed is great. The same applies to physics: part of the error on a quantity stems from the fact that the measurement was done a finite number of times. This is the statistical error. Mathematically, it can be shown that the statistical error decreases as the inverse of the square root of the number of measurements. In other words, a 2(10)-time better precision requires 4(100) times more experiments repeated identically.
Systematic error	Instrumental errors, such as faulty or improperly calibrated instruments that consistently give inaccurate readings, external factors such as temperature or magnetic fields that consistently affect measurements, biases introduced by the observer or incorrect or simplified models or assumptions used in calculations or analysis are all " systematic errors" that – unlike the statistical errors – do not decrease when more data is collected. The scientists task is to reduce such errors by additional cross-checks and, if they cannot be eliminated, estimate accurately the level of uncertainty.
Vertex	In particle physics a vertex refers to the spot where a given particle was created, either following a collision, or during the decay of another, unstable particle. The knowledge of the vertex position is an essential input to the measurement.

Laboratories	
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 close to the city of Geneva, Switzerland, it now includes 23 member states that contribute to its budget and decide on its scientific strategy and activities. Over ten thousand scientists, active in hundred collaborating states, design, build and run experiments, most notably the LHC programme.
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. Is is one of the research centers member of the IPPOG collaboration
Fermilab – USA	Fermi National Accelerator Laboratory (Fermilab) is located in Batavia, Illinois, near Chicago. Until 2011, Fermilab was the home of the 6.28 km (3.90 mi) circumference Tevatron accelerator, where the top quark was discovered in 1995. Fermilab aims to become a world center in neutrino physics, with the DUNE experiment (in construction). Among the ongoing experiments, NOvA is active in IPPOG.
GSI – Germany	The GSI Helmholtz Centre for Heavy Ion Research (German: GSI Helmholtzzentrum für Schwerionenforschung) is a heavy ion research center founded in 1969 in Darmstadt, Germany, to conduct research on and with heavy-ion accelerators. An important technology developed at the GSI is the use of heavy ion beams for cancer treatment (from 1997).
KEK – Japan	The KEK is a Japanese organization 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.