Accelerator Terms

(to add to this list please submit your term and definition to uspas@fnal.gov)

- **Accelerator**
  Device used to produce high-energy beams of charged particles such as electrons, protons, or heavy ions for research in high -energy and nuclear physics, synchrotron radiation research, medical therapies, and some industrial applications.

- **Alternating gradient**
  Focusing with quadrupoles of alternating polarities, also called strong focusing.

- **BALS**
  Beijing Advanced Light Source.

- **Beam cooling**
  1) Making beams more focusable by reducing its phase space. Radiation, ionization, electron, stochastic, optical stochastic and laser Doppler are different ways to cool charged particle beams.
  2) Increasing the phase space density of the beam. More specifically, it is a non-Hamiltonian process in which Liouville's theorem is violated. Examples: stochastic cooling, electron cooling, laser Doppler cooling.

- **Beam coupling impedance**
  The beam coupling impedance is defined as a ratio of the generalized voltage (or kick, etc) created by a given perturbation of beam current interacting with a vacuum chamber element, to the amplitude of this current perturbation.

- **Beam position monitor (BMP)**
  This diagnostic is used to measure a beam's transverse position within the beam pipe, usually consisting of 4 plates (2 oriented vertically, 2 horizontally) that measure the strength of the electric field produced by the beam.

- **Beam power**
  The product of particle energy and beam current. A very important parameter to explore rare events which can open a window beyond the standard model.

- **BEPC II**
  The upgrading of the Beijing Electron-Epsitron Collider.

- **Beta function**
  A term that relates beam size to the emittance, $\beta = \sigma^2 / \varepsilon$

- **Betatron Oscillation**
  The wavelength of the transverse oscillation of a beam, measured in meters. The restoring force for the Betatron oscillations is provided by the quadrupole magnets which focus separately, in the vertical and horizontal planes. Therefore, there are both horizontal and vertical betatron oscillations. Beta is a Twiss parameter.

- **Beta Star**
  The value of the beta function at the IP. There is a horizontal and a vertical beta star.

- **Brightness**
  Particle density in phase space: it conveys both the "intensity" and quality of beams in accelerators.

- **Brilliance**
  1) A measure of the usefulness or quality of a charged particle beam;
  2) A characteristic of the people who built the machine.

- **C-ADS**
  Chinese ADS.

- **Cavity**
  The main part of any accelerator.

- **Chicane**
  A Beam line bump made with four bend magnets. Chicanes are used as energy filters to transmit only the part of the spectrum wanted or to eliminate particles of the wrong charge (as in the positron chicane in EP02). The strengths of the four bends are calculated to transmit beams of a specific energy. There are three chicanes in the SLC; the CID Compressor Chicane, the LI01 Chicane, and the EP02 Chicane.

- **Chromatic Aberration**
  The energy-dependent distortion caused by a quadrupole. Particles of different energy are focused to different points because high-energy particles are focused (or bent) less than lower-energy particles. This is analogous to light optics, where light of different colors has different wavelengths (energy) and therefore different indexes of refraction when passing through a thin lens.

- **Compton Back-Scattering**
  Light frequency shifting phenomenon based on the energy transfer in a collision between high energy electrons from a linac or storage ring and low energy photons from a laser.

- **Coupling**
  Energy exchange of beam motion between the different planes.

- **Compressor**
  A system, incorporating an RF source and a bending transport line section, used to reduce the length of a particle bunch. An energy spread is introduced into the bunch using a short accelerator section. The leading particles, with more energy, will traverse a longer path through the bend section because they bend less. The tail, or trailing particles of lower energy, will make a sharper bend and catch up with the head, thus reducing the bunch length.

- **Cryostat**
  An apparatus for maintaining a very low temperature. The final focus superconducting triplet quadrupoles and the spin rotator solenoids are enclosed in cryostats (a fancy name for a thermos bottle).

- **CSNS**
  China Spallation Neutron Source.

- **Damping Ring**
  A system to reduce the transverse emittance of a beam. In a ring, accelerated particles lose energy due to synchrotron radiation. In a damping ring, the lost energy is partially replaced by an RF source, which boosts the parallel (or longitudinal) energy, but does not correct the damping of the transverse emittance.

- **Dipole**
  A magnet with a North and South pole, typically used to bend or steer a beam.

- **Dogleg**
  A dispersionless translating section that consists of two bending dipoles whose bend angles are equal in magnitude but opposite in sign.

- **Dragt – Finn factorization**
  Consider a map M that describes the transport of particle phase-space coordinates through some portion – either long or short – of a beamline or ring: $z^f = M = z^i$. The Dragt – Finn factorization theorem states that (assuming M is origin-preserving, or, equivalently, a map about a fixed-point) one may factor M in the form
  $M = e^{:f_2:} e^{:f_3:} e^{:f_4:} \ldots$.
  Here the f_m denotes homogeneous polynomials of degree m in the dynamical variables; and $:f:$ denotes the Lie operator that acts on any dynamical function g by computing a Poisson bracket:
  $$:f:g = [f,g] = \sum_{j=1}^{3} \left(\frac{\partial f}{\partial q_j}\frac{\partial g}{\partial p_j} - \frac{\partial f}{\partial p_j}\frac{\partial g}{\partial q_j} \right)$$

- **Emittance**

  1) The area of a particle beam in phase space, whether that's transverse phase space (spot size and divergence) or longitudinal (bunch length and energy spread).
  2) A measure of the quality of a beam with regard to the tightness and uniformity of the momentum of its individual particles. Consider a space where each particle is defined by its position x and its angle x'. Then the emittance is the area of the ellipse enclosing the particles within one sigma (s), defined as above. The emittance (e) is also related to the size of the beam by $\beta = \sigma^2 / \varepsilon$
  3) An inherent property of an accelerated charged particle beam in a particle accelerator. This is measured by an area intercepted by particles on six dimensional phase space. In any accelerator design, low emittance will allow most of the particles to be confined into small area that fits into beam pipe and magnets that make up the system. Collider beam accelerator also needs small emittance to obtain higher luminosity.
  4) Formally the volume of a particle bunch in phase-space. Important because it governs the desirable properties of colliders and light sources alike. I.e. luminosity and brilliance.

- **Energy Recovery Linac**
  Linear accelerating structure enabling to both accelerate and decelerate multiple beams.

- **FEL**
  Free-Electron Laser

- **Field emission**
  A process of electron extraction from a material due to an external electric field. Often associated with field enhancement whereby geometry is used to locally increase the gradient of the field at a point.

- **Final focusing system**
  1) In linear and circular colliders is the part of the lattice that focuses the beam to the smallest possible spot size in the collision point.
  2) In a linear collider, the section of beamline just before the interaction point that squeezes the beam to a small size in order to achieve a high luminosity.

- **Gradient**
  The derivative of the electric potential. The electric field (average), experienced by charged particles in an RF accelerating cavity, or – equivalently – the change in energy per charge (e.g. volts) of an accelerating particle divided by the distance traveled to gain that energy.

- **H-minus injection**
  Injection of negatively charged hydrogen ions instead of protons into a proton storage ring to reduce beam losses in the injection process, using a stripping foil at the injection point.

- **High voltage accelerator of ICT**
  The main parameter of accelerator is 60mA/400keV. It will be used for irradiation processing industry.

- **Injector**
  The source of beam particles into the accelerator structure..

- **Intra beam scattering (IBS)**
  1) A multiple Coulomb scattering effect leading to emittance blow up in all three planes. It is a limiting effect for ultra-low emittance, high density beams.
  2) Scattering among the particles that compose a bunch. Blows up emittance in high intensity, low emittance beams.

- **Ion source**
  A device used to produce ion beams (positive or negative) for various applications.

- **Klystron**
  An electron tube that amplifies microwaves by velocity modulation. A beam of electrons from a hot cathode is passed through a resonant cavity where it is modulated by high frequency radio waves. The electrons are bunched as they pass through a final cavity, where they induce RF with a higher gain. The RF from the klystrons is transmitted by rectangular waveguide to the DLWG of the LINAC.

- **Linac**
  A contraction of “Linear Accelerator”, a machine designed to accelerate charged particles in a single pass along a straight trajectory through a linear accelerating structure.

- **Luminosity**
  A measure of the number of events per second and per unit cross section at the IP.

- **Magnets**
  Devices that produce magnetic fields that are applied to charged particles to bend, focus or correct the trajectory.

- **Momentum compaction factor**
  A measure of path length change given a spread in momentum of particles bounded in cyclical motion ($\alpha_c = \frac{1}{c}\frac{d\Delta c}{d\delta}$, where c is circumference and δ is the fractional momentum deviation).

- **Multipactor**
  Resonant multiplication of electrons in evacuated RF & microwave structures.

- **Nonlinear dynamics**
  Dynamics of particle far from design orbit. More generally the study of chaos, diffusivity, frequency shift, frequency mixing.

- **Normal form**
  A one turn map M - either linear or non-linear – for a circular machine can be factored in the form $M = A \cdot N \cdot A^{-1}$, where the normal form N has a particularly simple form. If the machine focuses in all degrees of freedom, the linear part of N will have three 2×2 rotation matrices on the diagonal. The rotation angles μ_j are related to the tunes υ_j according to $\mu_j = 2\pi\upsilon_j$. The normal form is an invariant of the ring. The nonlinear part of N describes how the tunes vary with amplitude.

- **Normalizing map**
  The normalized map A relates a one-turn map M to its normal form according to $M = A \cdot N \cdot A^{-1}$. The linear part of A encodes the linear lattice functions. The non-linear part of A describes non-linear extensions of the lattice functions.

- **Personal protection system (PPS)**
  A system of engineered and administrative controls designed to ensure that a hazardous beam cannot be delivered to an area occupied by people.

- **Photonic band gap structures**
  Periodic electromagnetic structures employed for filtering out HOM wakefields in accelerators.

- **Plasma wakefield accelerator**
  1) It is a novel acceleration technique to accelerate charged particles beam in a compact size system consisting of plasma generated either by beam or laser. Head of a launch generates wakefield and tail witness it and get acceleration.
  2) Plasmas can be used as compact, high gradient accelerator and focusing element.

- **Quadrupole**
  A four pole magnet used to focus beams. The strength of the field is proportional to the distance from the center. The focusing is in one plane only. In the other plane, the field is defocusing. Quadrupoles may be wired to be horizontally focusing (vertically defocusing) or horizontally defocusing (vertically focusing).

- **Quenching**
  1) Sudden transition from superconducting to normal conducting state, usually with large amount of energy dissipated.
  2) A change of phase in a superconducting magnet in which the superconducting properties are lost. The energy released can destroy the magnet, if proper precautions are not taken to safely dissipate the stored energy. Quenching may be caused by an imperfection in or movement of the supercooled conductor, resulting in a jump in resistance and rapid Joule heating.

- **Radio-frequency (RF)**
  Refers time varying electromagnetic fields typically in the range of MHz to GHz. RF-fields are essential to accelerate particles in a multi-pass accelerator.

- **RF acceleration**
  Acceleration of charged particles by means of varying EM field at synchronism condition.

- **RF cavity**
  A normal conducting or superconducting metal can with internal structure used for acceleration (or other manipulation) of the beam of charged particles.

- **RF technology**
  RF sources, RF amplifiers, cavities. And controls.

- **Septum**
  A magnet incorporating a partition with a strong field on one side and little or no field on the other. It is used in combination with a kicker to bend one beam while leaving another undisturbed, usually in order to inject and/or extract a beam from a storage ring. it can be either a vertical or horizontal bend.

- **Septum Bump**
  An orbit bump created around a septum magnet to move the beam path into the `no field' area of a septum. Septum bumps are usually four magnet bumps, which allow control of the beam's angle as well as its offset through the septum area.

- **Siberian Snake**
  A term coined by Y.S. Derbenev and A. Kondralenko at the Institute of Nuclear Physics in Novosibirsk, the Siberian Snake is a device to be inserted into the lattice of a circular accelerator to preserve the polarization of a proton beam during the acceleration process.

- **Space charge**
  1) The repulsive Coulomb forces in a bunch of particles of the same polarity.
  2) High density of particles within beam, such that there are significant intrabeam Coulombic intetactions that oppose containment of beam.

- **Streak camera**
  A device that measures temporal variation of intensity of a light pulse. Used for measuring bunch length of laser pulses or electron beams when combined with a deflecting mechanism and screen.

- **Stripping foil**
  Thin aluminum foil to strip a pair of electrons from negatively charged hydrogen ions to convert them to protons for injection into a proton storage ring.

- **Superconducting cavity**
  A cavity using superconducting technology for manipulating beam including accelerating / decelerating bunching of beam and beam position measurement!

- **Symplectic condition**
  An important relation obeyed by all Hamiltonian systems. Consider an arbitrary initial point z^i in a phase-space of a Hamiltonian dynamical system, and follow the trajectory of that point toward to some future phase-space point z^f. The symplectic condition states that the Jacobian matrix with elements $M_{ab} = \frac{\partial z_a^f}{\partial z_b^i}$ is a symplectic matrix for all possible initial points z^i. This means that $M^T \cdot J \cdot M = J$, where J denotes the fundamental symplectic unit. If the phase-space variables are arranged in the order $z = (q_1, \ldots q_n, p_1, \ldots p_n)$, then

$$J = \begin{pmatrix} 0_{n\times n} & 1_{n\times n} \\ -1_{n\times n} & 0_{n\times n} \end{pmatrix}$$

  If $z = (q_1, p_1, \ldots, q_n, p_n)$, then

$$J = \begin{pmatrix} J_2 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & J_2 \end{pmatrix}, \text{ where } J_2 = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}.$$

  Symplectic integrator
  An integration method that will, when applied to a Hamiltonian dynamical system, preserve the symplectic condition. When performing long-time integration of a Hamiltonian system, we should use symplectic integrators.

- **Synchrotron Oscillation**
  A longitudinal oscillation induced in an accelerated bunch by the RF driving forces imparted to the bunch by the cavities.

- **Synchrotron Radiation**
  When a charged particle such as an electron or positron is bent in a magnetic field, it loses energy in the form of photons (light) which are given off in a direction tangential to the curved path of the charged particle. These photons are called Synchrotron Radiation after the high energy physics machine where they were first observed. The photon energy increases with the 4th power of the beam energy and

decreases with the square of the radius of curvature. Synchrotron light, or X-rays, are used for beam observation purposes, for the study of the structure of matter, and for medical research.

- **Thyratron**
  A gas filled tube used as a switching device for modulators and for kickers. The tube holds off high voltage until its grid is pulsed, ionizing the gas, and allowing immediate high current flow. Its solid state equivalent is the SCR, or silicon controlled rectifier.

- **Transfer matrix**
  Matrix that describes the evolution of a particle beam (taiss parameters / phase space and single particle trajectories) through a lattice of linear magnetic elements.

- **Transformer ratio**
  The ratio of the maximum energy gain of the witness bunch to the maximum energy loss of the drive bunch in a process of wakefield acceleration.

- **Tune**
  The number of betatron oscillations a beam makes in the circulation time of a circular accelerator. This is typically a fixed value for the machine, and its value is very important for beam dynamics.

- **Tune depression**
  Ratio between tunes υ and υ_0, where υ is the observed tune and υ_0 is the tune in the absence of space charge effects (ideal single particle tune).

- **Tune footprint**
  Area in the space of horizontal and vertical betatron tunes occupied by particles of the bunch. Plotting footprint together with resonance lines helps understand beam dynamics issues related to betatron and synchrobetatron resonancy.

- **Undulator**
  1) Magnetic system generating periodic magnetic field for synchrotron radiation or FEL.
  2) Magnet composed by a sequence of alternating field dipoles. Used to make oscillating beam. Used in accelerators to do damping and in the FEL to produce radiation.
  3) Array of alternating magnets that cause a charged particle beam to oscillate when it passes through, producing radiation.

- **Wakefield**
  1) A field generated by a beam passing through plasma or structure.
  2) The field created by a bunch of charged particles as it passes through a beam pipe. The charges induced in the wall of a beam pipe by the leading edge of the bunch have an effect (usually bad) on the tail of the bunch. If the beam is centered, wakefields will cancel each other by symmetry, but if the beam is closer to one wall, the tail will be attracted to this wall resulting in a `banana' shaped bunch (Transverse Wakefield). A wakefield also can be created in RF cavities by the loading effect: the tail gets less energy than the head of the bunch (Longitudinal Wakefield).

- **Wall current monitor (WCM)**
  This diagnostic is used to measure the AC beam current within the beam pipe. As the beam passes, it produces an image current in the wall of the pipe that is measured as it passes through a resistor.

- **Wiggler**
  See “undulator”.

- Wire Scanner
  Wire scanners are beam profile monitors used to provide accurate measurements of beam size and position in all three planes (vertical, horizontal and longitudinal) for beam feedback systems and beam optimization procedures. Components include wires capable of being moved precisely through the path of a beam, and a detector which can accurately measure the amount of charge striking a wire. When in use, a wire is scanned across the path of a beam, and a plot of wire position versus beam intensity is generated that represents the beam profile. Wire scanners are used to measure the emittance of the beam.

- **XFEL**
  X-ray FEL at the German laboratory DESY

- **Yoshida Trick**
  A technique for using a symplectic integrator at one order to construct a higher-order symplectic integrator