Colliders

Ashwin Amalraj J

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Types of collision

In particle physics we distinguish two types of experimental set-ups:

- fixed target experiments
- collision experiments

The kinematics of a particle with mass m can be expressed by its momentum $\vec{p}$ and energy E which form a four-vector $P = (E, \vec{P})$ whose square p^2 is

$$\mathrm{p}^2 = E^2 - \vec{p}^2 = m^2 \tag{1}$$

In the collision of two particles of masses m_1 and m_2 the total centre of mass energy can be expressed in the form

$$(\mathrm{p}1 + \mathrm{p}2)^2 = E_{cm}^2 = (E_1 + E_2)^2 - (\vec{p}1 + \vec{p}2)^2 \tag{2}$$

Fixed target collision

In the case of a collider where the collision point is at rest in the laboratory frame (i.e. $\overrightarrow{p_1} = -\overrightarrow{p_2}$) the centre of mass energy becomes:

$$E_{cm}^2 = (E_1 + E_2)^2 \tag{3}$$

	E_{cm} as collider (GeV)	E_{cm} with fixed target (GeV)
p on p (7000 on 7000 GeV)	14000	114.6
e on e (100 on 100 GeV)	200	0.32
e on p (30 on 920 GeV)	235	7.5

Most particles of our present Standard model (all leptons, all quarks other than the t-quark, neutrinos) have been discovered in fixed target experiments.

Main characteristics of a collider

- the famous colliders that have been built is a synchrotrons, in which the colliding beams are accelerated and then kept at constant energy for several hours.
- In case of a particle/antiparticle collider it is sufficient to construct a synchrotron with a single beam tube, since the Lorentz-force keeping the particles on a bent orbit changes sign with the change of particle charge. Hence both counter-rotating beams can be kept in the same ring.
- If particles collisions of the same type (for example proton-proton) are wanted, the accelerator must have two beam pipes, which are made to intersect in the interaction regions.

Linear or circular colliders

- In the case of a linear collider one uses two independent linac structures in order to accelerate the two beams and makes them collide in a central region.
- Such colliders are only envisaged for the creation of highest particle masses

Maximum collision energy

- In the case of a circular collider the acceleration of the beams can be altered at any moment
- In a linear collider the beams have to pass in any case through the whole linac structure, which in general can only be operated for a fixed energy. Changes of the energy require significant changes to the settings of the accelerators if not changes to the hardware layout.

Interaction rate

- A very important quality indicator of a collider is the rate of particle interactions per unit time. This is characterized by a proportionality factor between the interaction rate $\dot{N}$ and its cross-section σ_{int}

$$\frac{dR}{dt} = \mathcal{L} \cdot \sigma_p \tag{4}$$

- The luminosity depends on the intensity of the accelerated beams, on the frequency by which they collide and on the density of the beams at the collision point. Standard units for the cross section are "barns"

Detector occupancy or Pile-up

- The number of interactions per beam crossings is called "detector-occupancy".
- If the collider produces a too high occupancy, the luminosity has to be lowered artificially.

Different particle combination for collision

- Lepton collisions:
- The lightest and stable members of the lepton family, electrons and positrons are considered elementary, point-like particles, which interact through the electromagnetic and the weak force.
- This makes them the ideal candidates as choice for collisions, most importantly because of the elementary nature of the particles

Proton Proton collision

- Almost free of synchrotron radiation protons can be accelerated in a circular accelerator to energies in the multi-TeV range.
- Also proton-antiproton colliders have been built, but due to the difficulties in getting large stacks of dense antiproton beams, modern designs for highest collison energies do not consider proton-antiproton colliders anymore due to low achievable luminosities
- But Protons are not elementary particles and they have its limitation. Most of these many pp interactions only create secondary fragments, which are of little interest to study

proton proton vs lepton collision

- A very significant difference between pp collisons and electron positron collisons is the high total cross- section of pp collisons.
- At 13 TeV cms energy the cross-section is about 100 mb, which is due to the strong interaction 100000 times higher than in the case of the electro-weak interactions in electron positron collisons.

other types

- Ion colliders: The main research objective is to study at very high particle densities. Ions being composed of many protons and neutrons have an even more complex internal structure, so in the event of an ion-ion interaction very high densities of secondary particles are created
- Hadron colliders: In these electron-proton collisions, the point-like electron acts like a tiny probe that scans the inside of the proton and reveals its inner structure. The higher the energy of the particle collision, the deeper physicists are able to gaze into the proton, and the more insights they obtain about the inner structure of the proton and the fundamental forces of nature.

A crazy one and The infant

- photon photon collider: The collisions of photons sounds crazy at the first sight, since photons as neutral particles can not be accelerated in an accelerator.
- But now the enemy synchrotron radiation helps
- The collision forms W boson
- Wakefield accelerator: All accelerators described so far use conventional Rf-Cavities for the particle acceleration but using wakefield gives us many more advantage. Since many years people try to use wakefields in plasma for the acceleration of electrons or positrons.

New developments in LHC

- TOTEM (TOTal Elastic and diffractive cross section Measurement) :
  This detector aims at measurement of total cross section, elastic scattering, and diffractive processes.
  The primary instrument of the detector is referred to as a Roman pot.
- MoEDAL (Monopole and Exotics Detector at the LHC):
  Its prime goal is to directly search for the magnetic monopole or dyon and other highly ionizing stable massive particles and pseudo-stable massive particles.
  To detect these particles, the project uses nuclear track detectors (NTDs), which suffer characteristic damage due to highly ionizing particles

FASER this year's blessing

- FASER (ForwArd Search ExpeRiment)
  It is designed to both search for new light and weakly coupled elementary particles, and to study the interactions of high-energy neutrinos.
- The experiment is located 480 m downstream from the interaction point used by the ATLAS
- In this location, the FASER experiment is placed into an intense and highly collimated beam of both neutrinos as well as possible new particles. Additionally, it is shielded from ATLAS by about 100 meters of rock and concrete, providing a low background environment.