EXPERIMENTS IN HIGH ENERGY PHYSICS: A BRIEF INTRODUCTION

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ABSTRACT

A brief description of a "standard" High Energy Physics experiment focussing on what are the main measurements and how they are obtained is herein reported. The historical example of the discovery of neutral currents by the Gargamelle experiment in 1973 is presented to show the long path between the data collection and the final results.

A "standard" experiment in High Energy Physics

The main idea in High Energy Physics is to collide two objects (particles), observe what comes out and try to guess what was in. To collide two particles we need accelerating and focusing devices, to observe we need detectors and to interpret the results we need models and theories [1].

According both to the beam and to the target, experiments can be classified as: fixed target experiments (an accelerated particle beam collides with a target at rest in the laboratory, fig.1a), collider experiments (two accelerated particle beams collide with each other, fig.1b) and cosmic rays experiments [2] (the target and the detector are waiting in the Laboratory for a cosmic ray to come, fig.1c).

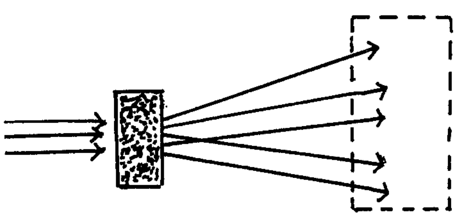

Fig. 1a) Fixed Target Experiment

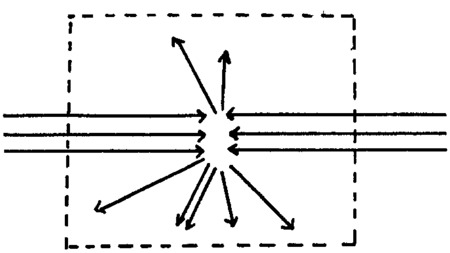

Fig. 1b) Collider Experiment

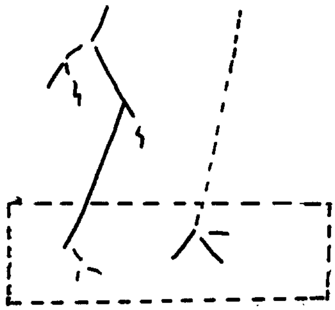

Fig. 1c) Cosmic Ray Experiment

The main building blocks of an accelerator are :the source, the electric field and the magnetic field. The source can either be primary if the particles are the constituints of the ordinary matter (protons, electrons, ions) or secondary if the particles are produced in a previous collision (anti-protons, positrons, pions, kaons,...). The electric field accelerates the beam and the magnetic field guides and focus it. The centre of mass energy provided by accelerators has been increasing in an exponential way since the thirties (1 Mev) till nowadays (1 TeV).

Detectors are mainly used to measure the momentum and the velocity of charged tracks and the energy of both charged and neutral tracks.

Charged tracks going through a thin layer of matter ionizes it. The ionization energy can be collected as visible energy (emission of γs by the excited nucleous in scintillators, fig. 2a) or directly as kinetic energy (in the wire or in the drift chambers the ions are accelerated by an electric field and collected in the cathod causing an electric current fig.2b). Either way the ionization is a mechanism that enables us to know where the particle has gone through and even if we have precise enough detectors, the energy that has been deposited. Using several layers of ionization detectors we are able to reconstruct the charged particles trajectories.

To measure the momentum of charged particles we can profite from the well known fact that, within constant magnetic fields, charged particles have circular trajectories and there is a trivial relationship between the radius of the trajectory and the momentum of the particle.

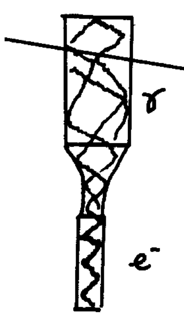

Fig. 2a) Scintillator

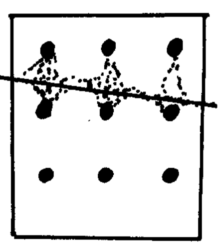

Fig. 2b) Wire Chamber

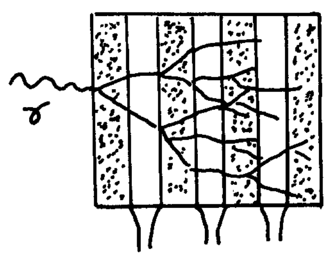

Fig. 3) Calorimeter

The energy of the particles, both charged and neutral, can be measured by stopping the particles inside a block of matter and collecting a fraction of the deposited energy. For instances in the detector shown in fig.3 (sampling calorimeter : sandwich of heavy material and scintillator) the particle goes through the first layer where it interacts with the atoms of the heavy material and it originates several secondary particles. These particles deposit some ionization energy in the first active layer and afterwards they go through the second layer where new interactions can take place. All the process is repeated in the next layers until all the energy is spent.

The measurement of the velocity of charged particles is usually made using the Cerenkov effect. A description of this measurement can be found elsewhere in these proceedings [2].

Some detectors give a "visual" image of the interaction (charged tracks only). A good example of these detectors is the bubble chamber (fig.4);the bubble chamber is a large vessel containing a liquid under pression and close to the boiling point. When the beam enters the chamber there is a sudden decompression and the boiling temperature is exceeded. A charged tracks leaves ions through its path that make little bubles. The charged tracks are, therefore, seen as a path of small bubbles.

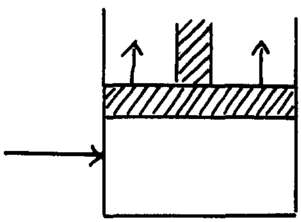

Fig. 4a) Beam entering a Bubble Chamber

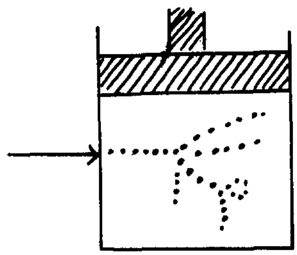

Fig. 4b) Interaction in a Bubble Chamber

Of course there are a lot of different detectors and they work in a much more subtle way than the oversimplified version that has been presented so far. In fig.5 a picture of DELPHI detector (one of the four LEP experiments) can be seen just to show how huge and complicated these detectors can be.

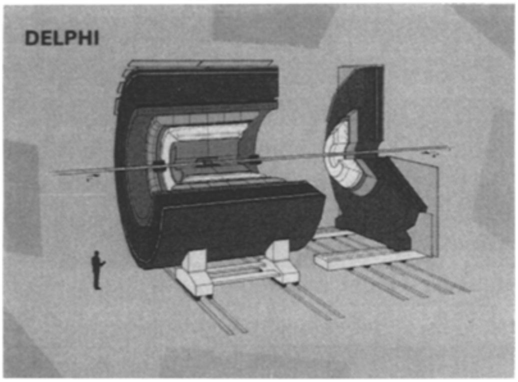

Fig. 5) Delphi Detector

An example : Experiments with neutrino beams in the Laboratory and the discovery of neutral currents

The story of neutrinos is a good example of the close interaction between experiment and theory. Several good reviews can be found elsewere [3],and here we will just focus briefly on some of the steps.

In the 1920's, while observing the continuos spectrum of the emited electron it was discovered, that the Beta decay apparently did not conserve either energy or angular and linear momentum. In 1930, Pauli suggested the existence of a low mass, low interaction particle which was called later on "neutrino" (by this time Niels Bohr was suggesting the possible violation of energy conservation), and soon afterwards Fermi proposed the so called Fermi Theory of the Weak Interaction which gave a good framework to compute the observed quantities in the following twenty years. But the first direct proof of neutrino existence was only obtained by Crown and Reines in 1956, using neutrinos from a nuclear reactor, and the first neutrino beam was produced in the beginning of the 60's from the decay of pions and kaons. A large number of experiments with neutrino beams have since then been performed and very important results have been obtained such as the existence of several neutrino families, the discovery of neutral currents, the test of quark and standard model and so forth.

Neutrino's interaction can be mediated by the charged W bosons (charged currents) or by the neutral Z^0 boson (neutral currents)- fig.6 . However a neutral current event is very difficult to observe for the incoming and the outcoming neutrinos can not be seen (they are neutral). The only sign in the detector is, in leptonic interactions, one electron, or, in semi-leptonic interactions, some hadrons that must be distinguished from the semi-leptonic neutrinos charged currents final states (some hadrons and a lepton). Detectors for neutrinos experiments must then be both massive (the interaction rate is very low) and very accurate (good final state identification).

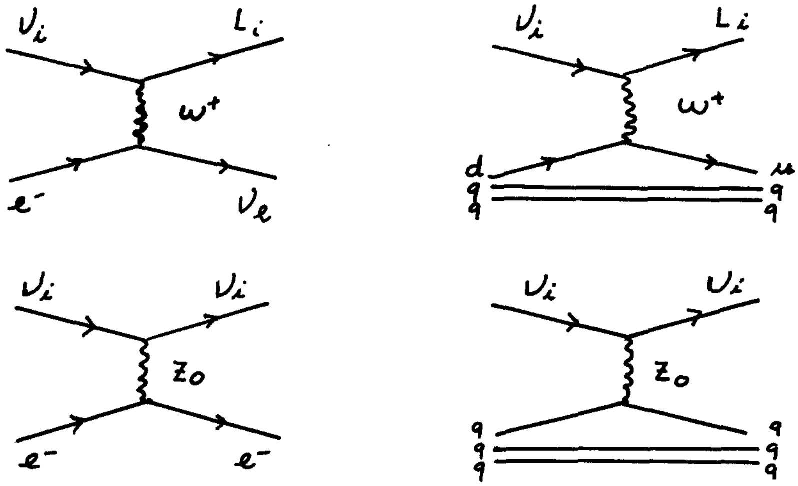

Fig. 6) Leptonic and semi-leptonic neutrino interactions

The neutral currents were first discovered [4] in Gargamelle experiment at CERN (1973). Gargamelle was an enormous bubble chamber ,5 meters long with 10 tons of liquid freon at 10 to 25 Atomspheres. More than 3 millions pictures were taken during its lifetime. In that famous experiment only one event over every 700.000 events had the characteristic signature of leptonic neutral current- an electron in the final state (fig.7).

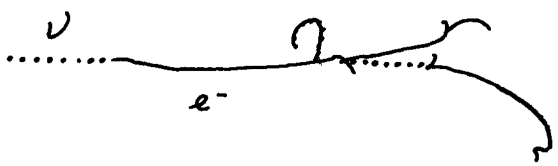

Fig. 7) The first neutral current event

Before computing a result we need to know more than just the number of the events that satisfy our experimental cuts. We have to study carefully the inefficiency of the method (the probability to loose a good event), the expected background (the number of events from all the other channels that can also satisfy the cuts), and of course to determine the number of particles in the beam and in the target (luminosity). Our result can then be expressed as a cross section (the number of observed events minus the expected background divided by the efficiency and by the luminosity) which is the usual form of presentation of results in a "standard" high energy physics experiment.

REFERENCES

1) There are many good books in elementary particle physics . The following references are therefore a small set of books I considered useful to a first introduction on the subject.

- Introduction to Elementary Particles, David Griffiths, John Wiley and Sons.
- The Experimental Foundations of Particle Physics, Robert N. Cahen and Gerson Goldhaben, Cambridge University Press
- Detectors for particle radiation, Konrad Kleinknecht, Cambridge University Press
- Statistics for nuclear and particle physicists, Louis Lyons, Cambridge University Press

2) - Experiments with neutrinos , Paula Bordalo , in these proceedings

3) - Weak Interactions of Leptons and Quarks , E.D. Commins and P.H. Bucksbaum, Cambridge University Press
- Weak interactions, D.Bailin, Adam Hilger Ltd

4) - Search for elastic Muon-Neutrino electron scatering, Hasert et al., PL 46B 121(73).
- Observation of neutrino like interactions without Muon or electron, PL 46B 148(73).