CERN Colloquium

SPEAKER: Prof. Francois Englert (Universite Libre de Bruxelles)

TITLE: **Broken Symmetry**

DATE: Thu 24/02/2011 16:30

PLACE: Council Chamber

ABSTRACT

- Physics, as we know it, attempts to interpret the diverse natural phenomena as particular manifestations of general laws. This vision of a world ruled by general testable laws is relatively recent in the history of mankind. Basically it was initiated by the Galilean inertial principle. The subsequent rapid development of large-scale physics is certainly tributary to the fact that gravitational and electromagnetic forces are long-range and hence can be perceived directly without the mediation of highly sophisticated technical devices.
- The discovery of subatomic structures and of the concomitant weak and strong short-range forces raised the question of how to cope with short-range forces in relativistic quantum field theory. The Fermi theory of weak interactions, formulated in terms of point-like current-current interaction, was well-defined in lowest order perturbation theory and accounted for existing experimental data.However, it was inconsistent in higher orders because of uncontrollable divergent quantum fluctuations. In technical terms, in contradistinction to quantum electrodynamics, the Fermi theorywas not “renormalizable”. This difficulty could not be solved by smoothing the point-like interaction by a massive, and therefore short-range, charged “vector” particle exchange: theories with massive charged vector bosons were not renormalizable either. In the early nineteen sixties, there seemed to be insuperable obstacles to formulating a consistent theory with short-range forces mediated by massive vectors.
- The breakthrough came from the notion of spontaneous symmetry breaking which arose in the study of phase transitions and was introduced in field theory by Nambu in 1960.
- Ferromagnets illustrate the notion in phase transitions. Although no direction is dynamically preferred, the magnetization selects a global orientation. This is a spontaneous broken symmetry(SBS)of rotational invariance. Such continuous SBS imply the existence of “massless” modes (here spin-waves), which are the ancestors of the NG bosons discussed below. Fluctuations of the order parameter (the magnetization) are described by a “massive” SBS mode.
- In field theory, Nambu showed that broken chiral symmetry from a spontaneous generation of hadron masses induces massless pseudoscalar modes (identified with a massless limit of pion fields). This illustrates a general phenomenon made explicit by Goldstone: massless Nambu-Goldstone (NG) bosons are a necessary concomitant of spontaneously broken continuous symmetries. Massive SBS scalars bosons describe, as in phase transitions, the fluctuations of the SBS order parameters.
- In 1964, with Robert Brout, we discovered a mechanism based on SBS by which short range interactions are generated from long range ones. A similar proposal was then made independently by Higgs in a different approach. Qualitatively, our mechanism works as follows. The long range
fundamental electromagnetic and gravitational interactions are governed by extended symmetries,called gauge symmetries, which were supposed to guarantee that the elementary field constituents which transmit the forces, photons or gravitons, be massless. We considered a generalization of the electromagnetic “vector” field, known as Yang-Mills fields, and coupled them to fields which acquire from SBS constant values in the vacuum. These fields pervade space, as did magnetization, but they have no spatial orientation: they are “scalar’’ fields. The vector Yang-Mills fields which interact with the scalar fields become massive and hence the forces they mediate become short
ranged. We also showed that the mechanism can survive in absence of elementary scalar fields.
- Because of the extended symmetries, the nature of SBS is profoundly altered: the NG fields are absorbed into the massive vector Yang-Mills fields and restore the gauge symmetry. This has a dramatic consequence. To confront precision experiments, the mechanism should be consistent at
the quantum mechanical level, or in technical terms, should yield a “renormalizable” theory. From our analysis of the preserved gauge symmetry, we suggested in 1966 that this is indeed the case, in
contradistinction to the aforementioned earlier theories of charged massive vector fields. The full proof of “renormalizability” is subtle and was achieved in the impressive work of ‘t Hooft and Veltman. One gains some insight into the subtleties by making explicit the equivalence of Higgs’ approach with ours.
- To a large extend, the LHC was build to detect the massive SBS scalar boson, i.e. the fluctuations of the scalar field. More elaborate realizations of the mechanism without elementary scalars are
possible, but their experimental confirmation may (or may not) be outside the scope of present available technology.
- The mechanism of Brout, Englert and Higgs unified in the same theoretical framework short- and long-range forces. It became the cornerstone of the electroweak theory and opened the way to a modern view on unified laws of nature.

Organised by: Ignatios Antoniadis & Luis Alvarez-Gaume/PH-TH......**Tea and Coffee will be serve at 16h00**