17

Future Colliders

Beyond the Standard Model

By the early 1980s there were persuasive arguments that the full exploration of the Standard Model was likely to require a very high energy hadron collider. Of course, the lesson of high energy physics has been that higher energies have generally revealed new facets of fundamental interactions. However, a more specific argument was available. A literal interpretation of the Standard Model required a Higgs boson, whose mass was not known a priori. Since the Higgs boson is closely connected to $v = 246$ GeV, it is reasonable to anticipate a mass of this scale. More important, it is not possible to postpone indefinitely new physics associated with the Higgs boson. To see this, one calculates in lowest order the scattering of longitudinally polarized W^+ and W^-. If the Higgs boson is very heavy, then the WW scattering will exceed the unitarity limit when the c.m. energy reaches about 1 -2 TeV . This means that the lowest order calculation is inadequate: the interaction is strong and no longer perturbative. Quite generally, then, either the Higgs boson has a mass less than about 1 TeV or the weak gauge bosons are strongly interacting at this energy scale.

This is not just a formal argument. At very high energies, quarks will emit virtual Ws and Zs just as an electron e photons when it scatters from a nucleon. The virtual Ws and Zs collide in a process that could produce a very heavy Higgs boson or show evidence of the strong scattering of the Ws and Zs.

The most feasible way to explore the 1 TeV scale was in a proton-proton collider of enormous scale. Detailed studies identified a 20 TeV on 20 TeV machine with a luminosity of $10^{33}\text{cm}^{-2}\text{s}^{-1}$ as optimal. In 1986 Central Design Group was formed and located at Berkeley. A Conceptual Design Report established the general outlines of the project. A site centered on Waxahachie, Texas was selected and the Superconducting Super Collider project was established in 1989? When 14 of the 53 miles of tunnel were dug, the project was terminated.

In the meantime, CERN had started its own project, which would use the existing LEP tunnel, whose radius is about 4 km. Using $p(\text{TeV}) = 0.3B(\text{T})r(\text{km})$, filling 70% of the ring with 8 T magnets would reach a beam energy of about 7 TeV, one-third of that planned for the SSC. Originally, CERN hoped to complete its Large Hadron Collider a couple of years prior to the operation of the SSC. To compensate for the lower energy, it would aim for a luminosity of $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. With the cancellation of the SSC by the U.S. Congress, LHC became the default future of international high energy physics.

The LHC project calls for two multipurpose detectors, ATLAS and CMS. The scale of these detectors is unprecedented. Each involves about 1500 physicists, while the dimensions of the detector are roughly 20 m x 20 m x 60 m. They are the canonical form pioneered by CDF at Fermilab. Proceeding from inside to outside, there is tracking, calorimetry, and muon detectors. The tracking is immersed in an axial magnetic field. The muon measurements are made in a separate magnetic region. Despite the tremendous interaction rate - 20 hadronic collisions every 25 nanoseconds - there will detailed tracking. This requires systems will enormous numbers of channels.

The effectiveness of silicon strip trackers at hadron colliders was established by CDF. However, such a system would, by itself, not be adequate at the LHC. For the innermost detectors, the strips would have to be subdivided, into pixels with dimensions roughly 50×300 microns. This provides better spatial resolution, enough channels (of order 10^8) so that only a small fraction are hit in a single beam crossing, and reduces the problem of radiation damage to the detectors. Behind the layers of pixel detectors are silicon strip detectors, adapted to survive in the intense environment of the LHC.

Crystals like those used at e^+e^-colliders would not survive at a hadron collider. Instead, electromagnetic calorimetry uses a sampling technique similar to that used for hadronic calorimetry.

The Standard Model represents a minimal solution to challenge of explaining fundamental interactions. While it has passed every experimental challenge to date, it is not altogether satisfying. It has elements of arbitrariness that are hard to accept in a fundamental theory. On its face, it has at least eighteen parameters that are a priori arbitrary. These are the masses of the quarks and charged leptons, the couplings of the strong interactions and of the SU(2) and U(1) interactions of the electroweak force, the four parameters of the CKM matrix, the Higgs mass and the vacuum expectation value, v.