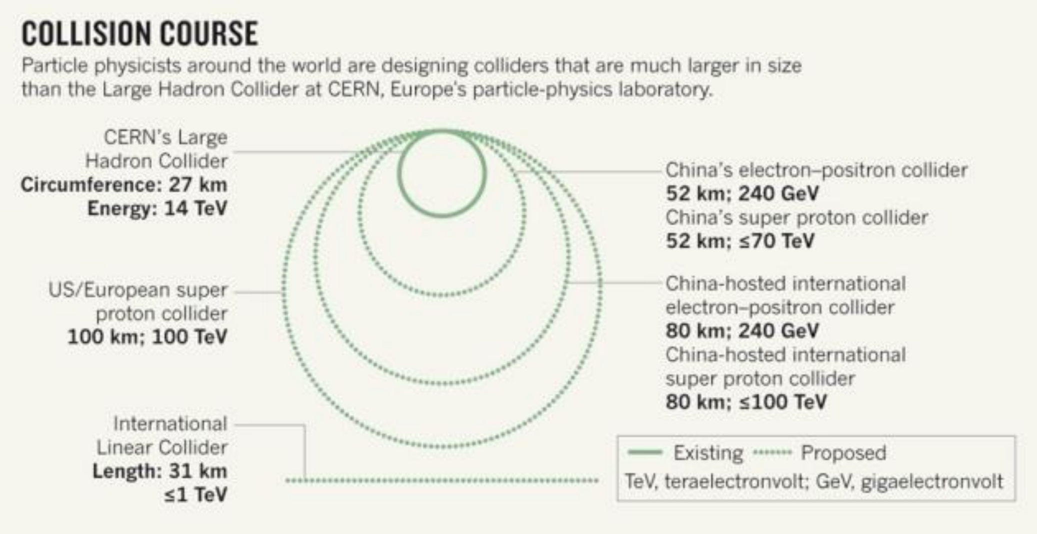
September, 2014

Is it the era of racing for colliders physics?

This question may be brought to mind after China's announcement this year that they plan to build a super collider. This announcement came after decades of the leading of Europe and the United States for the high-energy particle colliders community.

By Safinaz Salem



The particles collider planned by the scientists at the Institute of High Energy Physics in Beijing, working with international collaborators is a 'Higgs factory' - a 52-kilometer underground ring that would smash together electrons and positrons. It supposed to be built by 2028.

However, before today the particles accelerators have a long story which started since the beginnings of the twentieth century.

By around 1932, Synchrotrons were one of the initial models of accelerators that dealt with single beams of particles like Protons and Deuterons for research proposes was well established and known. A few years later in 1956, the Norwegian physicist Rolf Widerøe at Germany has published the first concept of particles collider. The idea grew up until 1960, when the CERN Council set up a study focused on a proton-proton collider, meanwhile, CERN's Proton Synchrotron (PS) was already under construction. Bring the first particles collider at the world into action, its design was based on the so called Intersecting Storage Rings (ISR) , which involving two interlaced proton-synchrotron rings that crossed at eight points, fig. (1,2).

The advantage of these rings is to obtain sufficient beams current (particles flux) . In Oct. 1970, after around ten years of planning, the first proton beam was injected and immediately circulated in Ring 1 . Once Ring 2 was available, the first collisions occurred on Jun. 1971 at a beam momentum of 15 GeV/c.

Comparing by nowadays facilities, that project can be considered a simpler one, but in the same time it was an important layout for a larger collider launched after that at CERN, the Electron-Positron (LEP) colider with 27-kilometer circumference.

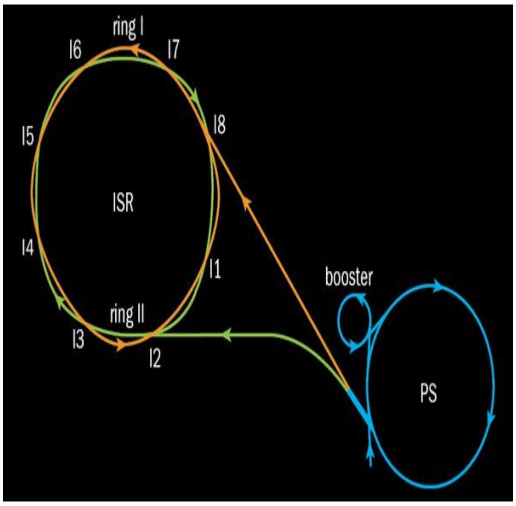


Figure 1: The ISR consisted of two interlaced proton synchrotron rings, both 300 m in diameter, which received protons from the PS.

The main aim of LEP collider was studying carefully the Z boson and its charged partner the W boson , both discovered at CERN in 1983, are responsible for the weak force , which drives the radioactive decays, for example. In July, 1989, the first beam circulated in LEP, the collider's initial energy was around the Z boson mass ~ 91 GeV, so that Z bosons could be produced . There were four detectors at LEP, which built around four collision points within underground halls, ALEPH, DELPHI, OPAL, and L3, while , during its operation period near 100 GeV, LEP was capable to produce around 17 million Z . Observing the creation and decay of such short-lived particles was a real window to test the electroweak sector of the SM, in addition, one of the most interesting discoveries at LEP was to prove that there are three-and only three-generations of particles of matter (for example, leptons , there are only electrons, muons, and tau particles , which almost have identical properties except their masses) . LEP was closed down on 2 Nov. 2000 to make way for the construction of the Large Hadron Collider in the same tunnel, fig.3 .

US's Most Famous Particles Accelerators

Figure 2: This view of Intersection 5 (I5), (fig.1), in 1974 clearly shows the layout of the magnets and the crossing of the two beams pipes.

Meanwhile, on the other side of the globe, there were wide discussions to build proton- antiproton accelerator at Fermilab at the United States, between 1973 and 1981 . The Tevatron, fig.4, was designed to accelerate two beams of protons and antiprotons to 99.999954 percent of the speed of light around a four-mile circumference, after the collisions of the two beams, conditions similar to those in the early universe is reproduced, allowing to probe the structure of matter, space and time at a very small scale. Scientists at Fermilab also studied particle collisions by directing beams into stationary targets to produce neutrino beams (Fixed Target program). The main Tevatron experiments were CDF and DZero which are located on opposite sides of along the Tevatron's beam pipe. The TEV first run was in 1983, it accelerated protons up to energy of 512 GeV, the energy then increased gradually until it reached 1.9 TeV center of mass energy.

During its run, the most important discoveries of the Tevatron was the discovery of the top quark in 1977 and the discovery of the tau neutrino at DONUT (Direct Observation of the NU Tau) experiment in 2000. Although the Tevatron shut down Sept. 30, 2011, the scientists continue to make analysis on the previous collected data and in 2012 they presented constrains on the mass regions of the Higgs boson consistent with those from LHC.


Figure 3: The former LEP tunnel at CERN being filled with magnets for the LHC.

Also one of the famous experiments at the US, is the BaBar experiment at SLAC National Accelerator laboratory. The aim of the BaBar was to understand the inequality between the matter and antimatter content of the universe (so that, we still here and did not annihilated) by studying the interactions of the meson system and its antiparticle $\overline{B}$ (B bar), if the nature doesn't distinguish between both systems, the decay rate of B mesons and their antiparticles should be equal, but as found, that was not the case. The BaBar detector consisting of two rings, one for electron beam and other for positron beam, these beams accelerated to collide to each other to have B and $\overline{B}$ mesons among the collision products. The data record from BaBar extended from Oct. 1999 until April, 2008.

East Asian Contributions

On the other hand, Japan has paid a bigger attention for the neutrino researches due to its mysterious identity. The beginning was when the Super-Kamiokande observatory- an observatory located under Mount Kamioka at Jaban- indicated that atmospheric neutrinos, coming from the sun or from other cosmic sources undergo oscillations between different flavors (so identical types), following that observations, Japan tended to operate a new experiment at KEK laboratory to verify these results, the experiment was called the neutrino oscillation experiment K2K, it worked from 1999 until Nov. 2004, and that time a well-controlled beam of muon neutrinos was sent to long distances to detect the neutrinos behavior. K2K was able to introduce the first positive measurement of neutrino oscillations which consisted with the previous results.

However, according to the Standard Model the neutrino is a massless particle, which means that it can't has different flavors, so that the observation of the neutrino oscillations is considered so far one of the strongest contradictions to the SM.

Figure 4: The Tevatron at Fermilab.

The Bella- experiment was another experiment started in the same year with K2K experiment at KEK laboratory, Bella was as BaBar experiment, it was a B- factory which constructed to study rare decays, searches for exotic particles and precision measurements of the processes of B mesons and D mesons. Bella located at the collision point of $e^- - e^+$ asymmetric-energy collider (KEKB). The Belle II B-factory, an upgraded facility of Bella, has been approved in June 2010 and the design and construction work is ongoing.

More Future Studies

It's worth mentioning that, there is another plan set up for the future, an International Linear Collider (ILC), which is an electron-positron linear accelerator that could operate at much higher energies than China's proposed 52-kilometer electron-positron ring. Anyway still not clear which of the two projects will have an international support, yet what is the difference between the Hadron colliders such as the famous LHC and the $e^- - e^+$ colliders ? Hadrons collider collide proton-proton or proton-anitprotot beams together, while $e^- - e^+$colliders can have a lower energy and give more cleaner data that are easier to analyze, because they are already smashing together fundamental particles.

So, as we saw, for around 100 years scientists from all over the world worked out on enhancing and developing the particles colliders to introduce clues for the secrets of the universe around us and the searches are just going on.

Further readings

. cerncourier.com/cws/article/cern/44855

. www.fnal.gov/pub/tevatron/tevatron-accelerator.html