Exploring the Energy Frontier in Particle Physics

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The desire to understand the elementary constituents of matter and their interactions has been one of the most important drivers of physics research. In the past 50 years, major progress in the field of particle physics has been made by accelerating particles to the highest energies available (the energy frontier) and by colliding them to produce and study new particles and interactions. Recent examples are the 1992 discovery of the top quark, by the Collider Detector at Fermilab (CDF) and D0 experiments, in the Tevatron collider at Fermilab; and the 2012 discovery of the Higgs boson, by the Compact Muon Solenoid (CMS) and A Toroidal LHC ApparatuS (ATLAS) experiments, in the Large Hadron Collider (LHC) at CERN. These important discoveries, as well as many others, are the experimental foundations of the Standard Model (SM) of particle physics.

The highest energy collider today is the LHC at CERN. LHC is a proton-proton circular collider with a center-of-mass energy of 13 TeV. The beams are brought to collision at four locations around the accelerator ring, where large particle detectors, ATLAS, CMS, ALICE, and LHCb, have been built to record the products of the collisions. In addition to the discovery of the Higgs boson, these experiments have performed detailed studies of the SM, and have searched for particles beyond the SM. So far, all the measurements agree with the SM and the experiments have set mass limits to many hypothetical particles to the TeV range.

The LHC program is ongoing and it will operate until 2035 or later. Two major upgrades are expected in 2019-20 and 2024-26 to increase the luminosity of the collider. The expected amount of data will allow physicists to test the Standard Model to an unprecedented degree of precision, study the Higgs interactions in all its decay channels, and extend the search for new phenomena by rare processes.

Due to the large investment needed to build high energy accelerators, international cooperation is a necessary practice in high energy physics (HEP). LHC experiments typically involve several thousand researchers from hundreds of institutes. Physicists from the Asia-Pacific region participate actively in the LHC program. For example, 33 out of 200 institutes of the CMS collaboration, and 37 out of 182 institutes of the ATLAS collaboration are from the Asia-Pacific region. They are important members of the experiments, contributing to the construction and operation of the experiments, as well as physics analysis.

While the LHC will remain the focus of particle physics for the coming years, the HEP society is preparing for the next generation of colliders in the energy frontier. Electron-positron colliders have been on the design board for many years. After the discovery of the Higgs boson at the LHC, precise measurements of its properties became a high priority issue. For this purpose, it is generally agreed that an electron-positron collider at about twice the Higgs mass is a good choice that balances the physics goals and the required resources. Currently, two projects are being seriously considered. In Japan, the International Linear Collider (ILC) applies an innovative superconducting technology to achieve a very high accelerating gradient in a linear design. The 250 GeV ILC has been endorsed by the International Committee for Future Accelerators (ICFA) during an ICFA meeting in November 2017. Intensive R&D is ongoing. Funding decisions by the Japanese government and foreign partners are now at a critical juncture.

In China, the Institute of High Energy Physics (IHEP) has taken a different approach and has proposed a circular collider called CEPC (the Circular Electron Positron Collider). This machine would be constructed in a tunnel with a circumference of ~100 km. The design concept follows closely the successful experience of CERN's LEP project in the 1990s. LEP was a circular electron-positron collider built for the precision measurement of the Z boson. After LEP successfully completed its goals, the LHC, a proton-proton "discovery machine", was constructed and installed in the same 27 km tunnel of LEP. This arrangement allows the LHC to share a lot of LEP's infrastructure and therefore reduces the cost significantly. The 250 GeV CEPC is designed to be a "Higgs factory" for precision measurements of the Higgs boson. Similar to the LEP-LHC arrangement, CEPC's design allows for flexibility in that the same tunnel can host a powerful ~100 TeV proton-proton collider in the future. Currently, CEPC is in the phase of extensive R&D for critical components.

It is encouraging that the HEP community continues to push forward into the energy frontier. We hope that, within 5 years, either ILC or CEPC, or both, will move to the construction phase. They will enable us to understand in detail the Higgs particle and the mechanism of electroweak symmetry breaking. Looking further ahead, conceptual designs of proton-proton colliders at the 100 TeV energy range are being made in several places. These machines, generally expected to be built 20-30 years from now, will be the next generation of LHC and will search for new particles in a wide range of possibilities.

The fact that both the ILC and CEPC are to be constructed in the Asia-Pacific region is an exciting development. This region's rate economic growth is quickly rising. We are happy to see that the investment in fundamental sciences increases correspondingly, and hopefully, scientific achievements will follow. This issue of the *AAPPS Bulletin* therefore features four articles to report on the latest status of this exciting field of research.

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