Japan's Updated Strategy for Future Projects in Elementary Particle Physics

Japan Association of High Energy Physicists (JAHEP)[1]
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A submission to the 2020 update of the European Strategy for Particle Physics

Abstract

In September 2017, the Japanese high energy physics community, JAHEP (Japan Association of High Energy Physicists), updated the strategy for future particle physics by endorsing the Final Report of the Committee on Future Projects in High Energy Physics.

The Final Report summarizes Japan's future strategy as follows:

> In 2012, not only was a Higgs boson with a mass of 125 GeV discovered at the LHC, but three-generation neutrino mixing was also established. Taking full advantage of the opportunities provided by these discoveries the committee makes the following recommendations concerning large-scale projects, which comprise the core of future high energy physics research in Japan.
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> - With the discovery of the 125 GeV Higgs boson at the LHC, *construction of the International Linear Collider (ILC) with a collision energy of 250 GeV should start in Japan immediately* without delay so as to guide the pursuit of particle physics beyond the Standard Model through detailed research of the Higgs particle. In parallel, continuing studies of new physics should be pursued using the LHC and its upgrades.
> - Three-generation neutrino mixing has been established and has provided a path to study CP symmetry in the lepton sector. Therefore, *Japan should promote the early realization of Hyper-Kamiokande as an international project* due to its superior proton decay sensitivity, and should continue to search for CP violation with the T2K experiment and upgrades of the J-PARC neutrino beam.
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> The High Energy Physics Committee should pursue all available options to achieve the early realization of these key, large-scale projects.
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> It is important to complete construction of SuperKEKB and start physics studies as scheduled. Some of the medium- and small-scale projects currently under consideration have implicit potential to develop into important research fields in the future, as happened with neutrino physics. They should be promoted in parallel in order to pursue new physics from various directions. Flavor physics experiments, such as muon experiments at J-PARC, searches for dark matter and neutrinoless double beta decay, observations of CMB B-mode polarization and dark energy, are considered to be projects that have such potential.
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> Furthermore, accelerator R&D should be continued to dramatically increase particle collision energies in preparation for future experimental efforts that may indicate the existence of new particles and new phenomena at higher energy scale.

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[1] Represented by High Energy Physics Committee: H. Aihara (chair), A. Ichikawa, O. Jinnouchi, S. Kanemura T. Mori, T. Nakaya, K. Sakashita, M. Tomoto, Y. Ushiroda, T. Yamanaka, and S. Yamashita,

1 International Linear Collider as Higgs Factory

In October 2012, just after the discovery of Higgs boson at the LHC, JAHEP proposed to construct the International Linear Collider (ILC) in Japan under a global collaboration. It was welcomed by the international community and became essential part of the global future program in high energy physics.

In 2017, in view of the research developments after the Higgs discovery, JAHEP established the Committee on the Scientific Case of the ILC Operating at 250 GeV as a Higgs Factory, chaired by S. Asai, to discuss and develop a new strategy for the ILC aiming for as significant scientific outputs as possible under the current circumstances.

The Committee's final report is included in the Addendum and is also found at:
`http://www.jahep.org/files/ILC250GeVReport-EN-FINAL.pdf`

The Committee's conclusions are summarized as follows:

> The conclusions of this committee are the following four points:
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> 1. In order to maximally exploit the potential of the HL-LHC measurements, concurrent running of the ILC250 is crucial.
> 2. LHC has not yet discovered new phenomena beyond the Standard Model. The ILC250 operating as a Higgs Factory will play an indispensable role to fully cover new phenomena up to $\Lambda \sim 2-3$ TeV and uncover the origin of matter-antimatter asymmetry, combing all the results of ILC250, HL-LHC, the SuperKEKB, and other experiments. Synergy is a key.
> 3. Given that a new physics scale is yet to be found, ILC250 is expected to deliver physics outcomes, combined with those at HL-LHC, SuperKEKB and other experiments, that are nearly comparable to those previously estimated for ILC500 in precise examinations of the Higgs boson and the Standard Model.
> 4. The inherent advantage of a linear collider is its energy upgradability. The ILC250 has the potential, through an energy upgrade, to reach the energy scale of the new physics discovered by its own physics program.

Following community discussion on the Committee's report, JAHEP made a statement that proposes early realization of the ILC as a Higgs factory with the collision energy of 250 GeV. This proposal was strongly endorsed by Linear Collider Board (LCB) and International Committee for Future Accelerators (ICFA). It is currently under serious consideration by the Japanese government.

The JAHEP statement, "Scientific Significance of ILC and Proposal of its Early Realization in light of the Outcomes of LHC Run 2," is attached in the Addendum and is also found at:
`http://www.jahep.org/files/JAHEP-ILCstatement-170816-EN.pdf`

The following are the whole JAHEP statement:

> Scientific Significance of ILC and Proposal of its Early Realization
> in light of the Outcomes of LHC Run 2
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> The International Linear Collider (ILC) is a linear electron-positron collider, a key experimental facility that enables forefront research at the energy frontier in high energy physics. The ILC has been developed through an international collaboration overseen by the International Committee for Future Accelerators (ICFA). The international team

of physicists, Global Design Effort, published in 2013 the Technical Design Report of a 200-500 GeV (extendable to 1TeV) center-of-mass collider. In October 2012, the Japan Association of High Energy Physicists (JAHEP) proposed to construct ILC in Japan under a global collaboration with consensus of the international community and active participation from each country. This proposal received many positive responses from the international community. In particular, it garnered support from European countries and the United States, who were also developing their future particle physics projects, as well as from the ICFA. Upon the launch of JAHEP's proposal, the Science Council of Japan and a panel of experts under the Ministry of Education, Culture, Sports, Science and Technology discussed the proposal. They noted that the large expense and cost sharing are issues that must be solved. Subsequently, a research and development project was initiated to reduce the costs associated with ILC based on the discussions between the governments of Japan and United States. Meanwhile, the Large Hadron Collider (LHC) Run 2 experiments at CERN have continued to progress, and new results have been published. In this context, JAHEP has deliberated the scientific significance of ILC and has come to a conclusion; JAHEP proposes to construct a 250 GeV center-of-mass ILC promptly as a Higgs factory.

The driving force for JAHEP's proposal released in October 2012 is that particle physics entered a new phase following the discovery of a Higgs boson. Research in the 20th century particle physics focused on elucidating fundamental forces, save gravity, of nature: strong, weak and electromagnetic forces. The existence of a Higgs boson was predicted by the Standard Model, which successfully describes these three forces in a unified way. A Higgs boson was discovered as predicted, indicating that our understanding of these three forces has greatly advanced. On the other hand, the real nature of the Higgs boson remains unknown. Candidate theories to explain the origin of Higgs bosons include new forces, new hierarchies of matter, and extension of the space-time structure. In this light, studying the Higgs boson is definitively important to determine the future of elementary particle physics. The ILC, with additional advantage of energy-extendable and beam-polarization capabilities due to being a linear accelerator, would be the best suited facility for this purpose.

The LHC experiments have an excellent ability to explore new physics by observing new strongly-interacting particles and their decays. The LHC Run 2 experiment, where the center-of-mass energy was increased from 8 TeV to 13 TeV, began in 2015 and the accelerator operated smoothly throughout 2016. The exploratory area (or mass scale) of the Run 2 has, indeed, significantly expanded compared to that under 8-TeV-energy operations. The results reported in 2016 showed that new particles anticipated by physics beyond the Standard Model are unlikely to exist below the mass scale of 1 TeV. This important finding at LHC underscores that the most imminent and important goal of ILC is to explore new physics by precision measurements of the Higgs boson and search for a class of new particles that ILC could directly produce but LHC has difficulty to observe.

JAHEP has established the "Committee on the Physics Significance of ILC 250 GeV Higgs Factory." The charge to this committee is to verify the significance of a 250 GeV center-of-mass energy ILC ("ILC250"), in particular, by comparing with the case for a 500 GeV center-of-mass ILC ("ILC500") and the case for no ILC at all. The roles that ILC250 should play were examined from the following perspectives: determination of the energy scale of new physics by precision measurement of the Higgs boson and thorough examination of the Standard Model, elucidation of electroweak symmetry breaking and the origin of matter and antimatter asymmetry, and searching for particles that are candidates of the dark matter. In the Committee's deliberation, possible synergies with the High-Luminosity LHC (HL-LHC) and SuperKEKB /Belle II were taken into account.

The Committee's conclusions are summarized as follows:

- ILC250 should run concurrently with HL-LHC to enhance physics outcomes from LHC.
- Given that a new physics scale is yet to be found, ILC250 is expected to deliver physics outcomes that are nearly comparable to those previously estimated for ILC500 in precise examinations of the Higgs boson and the Standard Model.
- The ILC250 Higgs factory, together with HL-LHC and SuperKEKB, will play an indispensable role in the discovery of new phenomena originating from new physics with the energy scale up to 2-3 TeV and the elucidation of the origin of matter-antimatter asymmetry.
- A linear collider has a definite advantage for energy-upgrade capability. ILC250 possesses a good potential for its upgrades to reach the higher energy of new physics that the findings of ILC250 might indicate.

As discussed above, the scientific significance and importance of ILC has been further clarified considering the current LHC outcomes. ILC250 should play an essential role in precision measurement of the Higgs boson and, with HL-LHC and SuperKEKB, in determining the future path of new physics. Based on ILC250's outcomes, a future plan of energy upgrade will be determined so that the facility can provide the optimum experimental environment by considering requirements in particle physics and by taking advantage of the advancement of accelerator technologies. It is expected that ILC will lead particle physics well into the 21st century.

To conclude, in light of the recent outcomes of LHC Run 2, JAHEP proposes to promptly construct ILC as a Higgs factory with the center-of-mass energy of 250 GeV in Japan.

2 Japanese Strategy Update in 2017

In parallel with the discussions on the ILC, a standing committee of JAHEP, the Committee on Future Projects in High Energy Physics, updated the Japanese strategy that had been previously established in March 2012, after year-long community discussions. The Final Report of the Committee was endorsed by JAHEP in September 2017.

The Final Report is included in the Addendum. It is also found at:
`http://www.jahep.org/files/20170906-en.pdf`

In the Final Report the Committee made the following recommendations that have updated the strategy for future high energy physics in Japan:

In 2012, not only was a Higgs boson with a mass of 125 GeV discovered at the LHC, but three-generation neutrino mixing was also established. Taking full advantage of the opportunities provided by these discoveries the committee makes the following recommendations concerning large-scale projects, which comprise the core of future high energy physics research in Japan.

- With the discovery of the 125 GeV Higgs boson at the LHC, *construction of the International Linear Collider (ILC) with a collision energy of 250 GeV should start in Japan immediately* without delay so as to guide the pursuit of particle physics beyond the Standard Model through detailed research of the Higgs particle. In parallel, continuing studies of new physics should be pursued using the LHC and its upgrades.

- Three-generation neutrino mixing has been established and has provided a path to study CP symmetry in the lepton sector. Therefore, *Japan should promote the early realization of Hyper-Kamiokande as an international project* due to its superior proton decay sensitivity, and should continue to search for CP violation with the T2K experiment and upgrades of the J-PARC neutrino beam.

The High Energy Physics Committee should pursue all available options to achieve the early realization of these key, large-scale projects.

It is important to complete construction of SuperKEKB and start physics studies as scheduled. Some of the medium- and small-scale projects currently under consideration have implicit potential to develop into important research fields in the future, as happened with neutrino physics. They should be promoted in parallel in order to pursue new physics from various directions. Flavor physics experiments, such as muon experiments at J-PARC, searches for dark matter and neutrinoless double beta decay, observations of CMB B-mode polarization and dark energy, are considered to be projects that have such potential.

Furthermore, accelerator R&D should be continued to dramatically increase particle collision energies in preparation for future experimental efforts that may indicate the existence of new particles and new phenomena at higher energy scale.