Japan's Updated Strategy for High Energy Physics for the ESPP Update 2026

Japan Association of High Energy Physics (JAHEP)
(Contact: Tsuyoshi Nakaya [t.nakaya@scphys.kyoto-u.ac.jp])

March, 2025 (Updated on October, 2025)

Abstract

The Japanese High Energy Physics community, JAHEP (Japan Association of High Energy Physicists), provides Japan's Updated Strategy for High Energy Physics for the ESPP Update 2026. High-energy physics research in Japan encompasses a variety of groundbreaking experiments conducted at major facilities. These include the SuperKEKB accelerator and the Belle II experiment, which focus on the search for new physics in heavy flavor decays; the high-power proton accelerator complex J-PARC, where experiments are conducted using the intense neutrino, kaon, muon, and neutron beams; and collaborative efforts in CERN's Large Hadron Collider (LHC and HL-LHC) experiments. For neutrino research, the construction of the Hyper-Kamiokande experiment is currently underway. We emphasize the importance of maintaining timely progress in these ongoing experiments and the construction of experimental facilities. We acknowledge significant contributions by European collaborators to the Japan-based experiments, and wish to see more participation. We also acknowledge the essential support of CERN to the experiments as a key hub for the European activities.

Looking into the future, the early realization of a Higgs factory through international collaboration is crucial for our field. We take into account the evolving situation of Higgs factory proposals: CEPC, FCC-ee, ILC, and LCF. To ensure the realization of a Higgs factory, we pursue the following key directions:

- We prioritize efforts to realize the ILC as a Global Project, taking a leading role in advancing ongoing initiatives. We will engage with international partners to discuss governance, responsibilities, and site selection. We intend to develop and expand our scientific and promotional activities to host the ILC as a Global Project in Japan.
- We also extend our activities in other Higgs factory proposals as a collective approach to maximize the chances of timely realizing a Higgs factory.

In line with this direction, as our response to the key questions posed by the Strategy Secretariat, we consider a Higgs factory collider project—specifically, the **FCC-ee** or the **LCF**—to represent a promising direction for CERN's next large-scale post-LHC accelerator. Should the FCC-ee be selected as the most favored option in Europe, the LCF would be regarded as the prioritized alternative if the preferred option is not feasible.

The ILC Technology Network (ITN), an international R&D framework for the ILC accelerator initiated by KEK and the ILC International Development Team (IDT), has started. The collaboration with CERN is essential for ITN. The detector R&D with test beams is essential for future experiments, and we would promote international collaborations in detector developments, such as ECFA-Detector R&D. Beyond a Higgs Factory, developing high-field magnets using state-of-the-art superconductors is critical to realize a future hadron collider.

By advancing current and future projects, we aim to continue contributing to fundamental discoveries and to foster international collaboration. We will actively participate in international discussions on shaping the global strategy for high-energy physics.

1 Current Status and Prospects of High-Energy Physics in Japan

1.1 Science Target

Particle physics explores the fundamental building blocks of the universe and seeks to understand their interactions. The Standard Model (SM) of particle physics, having withstood rigorous tests through highly precise experiments such as electroweak precision measurements and flavor experiments, was established with the discovery of the Higgs boson. However, the story does not end here. Indeed, the discovery of neutrino oscillations, which revealed that neutrinos have nonzero masses, provided the first hint of physics beyond the Standard Model. Moreover, several profound mysteries remain unresolved, such as

- Why does our universe consist only of matter, not antimatter?
- Why do quarks and leptons come in three generations? Understanding the mass hierarchy and flavor structure of quarks and leptons is essential.
- What is the dynamics behind the electroweak symmetry breaking?
- Why is the neutrino mass so small?
- Are the three fundamental forces unified at extremely high energies?
- We know that dark matter exists, but what is it?
- Why is our universe expanding at an accelerating rate, a phenomenon attributed to dark energy?
- Is there any hidden structure or symmetry in space-time, such as supersymmetry, extra dimensions, or any additional forces?
- Quantum Gravity: How can quantum mechanics and general relativity be merged?
- What is the origin of inflation?

A promising approach to addressing these questions is to examine the underlying symmetries or their violation through precision measurements. Driven by this motivation, we have undertaken groundbreaking experiments at major research facilities. In Japan, we lead pioneering efforts at: the SuperKEKB accelerator and the Belle II experiment, dedicated to searching for new physics in heavy flavor decays; the Japan Proton Accelerator Research Complex (J-PARC), where intense beams of neutrinos, kaons, muons, and neutrons enable a wide range of precision experiments. These experiments, in particular, provide crucial insights into CP violation, a key ingredient for understanding the dominance of matter over antimatter in the universe.

We also actively participate in off-shore experiments, with a major example being the ATLAS experiment at CERN's Large Hadron Collider (LHC and HL-LHC).

Exploring the Higgs sector and unravelling the underlying dynamics of electroweak symmetry breaking is one of the important topics. Looking ahead, a Higgs Factory is envisioned as a cornerstone of future global particle physics research. This next-generation facility would enable high-precision studies of the Higgs boson—the final piece of the SM—offering one of the most promising pathways to uncovering new physics beyond the Standard Model.

1.2 Experiments at the facilities in Japan

1.2.1 SuperKEKB/Belle II

Belle II is the largest international collaboration of high-energy physics hosted in Japan, involving 125 institutions from 28 countries and regions, among which 36 institutions are from Europe. The main physics goal of Belle II is to gain insights into new physics beyond the Standard Model from heavy flavor decays. Highly sensitive measurements of CP violation parameters, Lepton Flavor Violation searches, Lepton Flavor Universality tests, and Dark Sector searches will provide important input to the new physics models. SuperKEKB is the world's largest electron-positron collider exploring the luminosity frontier. Beam collisions with a vertical beam size of O(100) nanometers at the collision point provide billions of bottom, charm, and tau pairs in the center of the Belle II detector. Since the collisions take place in a clean environment with a known initial state 4-momentum, Belle II has a unique strength in studies with neutral particles in the final state and inclusive reconstruction of the final state. These features make Belle II complementary to LHCb at CERN, in addition to its competitiveness.

The operation of SuperKEKB has been challenging due to new findings in novel nano-beam collisions. However, continuous mitigation and improvement measures led to a new world record luminosity of $5.1 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ in late 2024 and confidence in even higher luminosities. Even with the world record luminosity, the experiment will take many years to reach the integrated luminosity that will give the final desired physics sensitivities. A further upgrade of the accelerator is planned for 2032 and is currently under development, which will make SuperKEKB with its nano-beam collision scheme a firm standard for future electron-positron colliders. Technical cooperation with international accelerator scientists, including those from FCC-ee and CEPC, is underway. To maximize the physics sensitivity in the long term, an upgrade of the detector is also in preparation on the same time scale as the upgrade of SuperKEKB. The upgrade of the vertex detector will be one of the key items, the design of which is complexly linked to the accelerator design and will require close collaboration. Furthermore, a design effort for the polarized electron beam in SuperKEKB, without affecting the accelerator complex and its performance, continues to enhance the future potential in physics outcomes.

1.2.2 J-PARC

J-PARC is a high-intensity proton accelerator complex located in Tokai Village, Japan. It has been in operation since 2009. J-PARC consists of three accelerator complexes: a 400 MeV LINAC, a 3 GeV Rapid Cycle Synchrotron (RCS), and a 30 GeV Main Ring (MR). A feature of J-PARC is its high beam power, which provides the world's highest intensity secondary beams. Currently, the RCS operates at 900 kW, the MR at 830 kW for neutrinos, and 92 kW for kaons. The RCS generates intense pulsed neutron and muon beams, as well as neutrinos from the decay of stopped pions and muons. MR generates intense neutrino beams and charged and neutral kaon beams. Various high-energy physics experiments are carried out at J-PARC to study flavor physics by searching for rare events and by precise measurements with neutrino, kaon, muon, and neutron beams.

The T2K neutrino experiment is a flagship experiment at J-PARC that uses the MR and the Super-Kamiokande (Super-K) detector to study neutrino oscillations. T2K has many European collaborators and greatly benefited from CERN's support, including the NA61/SHINE experiment and Neutrino Platform NP07. CERN has served as a key hub for European activities, and the contributions are essential for T2K. The NINJA experiment is conducting a physics run using the T2K beam to make precise measurements of neutrino-water interactions. It plans to conduct a study of neutrino-nucleus interactions using heavy water targets, and search for sterile neutrinos [1]. The JSNS^2 experiment (J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source) [2] uses the intense anti-muon neutrinos produced by RCS via muon decay at rest. The JSNS^2 and JSNS$^2-$II (the phase 2) [3] search for neutrino oscillations with short baselines, using two liquid scintillator detectors.

The KOTO kaon experiment searches for CP-violating rare kaon decay $K_L \to \pi^0\nu\overline{\nu}$ [4]. KOTO will reach a sensitivity better than 1×10^{-10} in 3-4 years, approaching the branching ratio of 3×10^{-11} predicted by the SM. A next-generation experiment, KOTO II, which aims to observe more than 30 $K_L \to \pi^0\nu\overline{\nu}$ events estimated by the SM and to study various K_L rare decays, is being discussed for realization in the 2030s in the extension project of the Hadron Experimental Facility [5]. KOTO II was scientifically approved by KEK and formed the collaboration with many European members.

The muon experiment, COMET, searches for the muon-to-electron conversion process with a sensitivity of $\sim 10^{-17}$ in a staged approach [6]. The MR is proven to provide a high-purity pulsed proton beam for COMET. It plans to start the first physics run in 2027. The J-PARC muon g-2/EDM experiment plans to measure the anomalous magnetic moment (g-2) and the electric dipole moment (EDM) of the muon with a novel muon accelerator and a compact magnetic storage ring. The construction of the experimental facility is in progress at MLF. The development of muon acceleration technology is a new and highly anticipated field, and it can also advance muon microscopy, which is valuable for industry and materials science. In energy frontier physics, this technology holds the potential to contribute to the development of a muon collider.

Some neutron experiments conducted by the NOP collaboration are developing advanced neutron optics that enable the best use of the wave properties of slow neutrons. They will test the standard model by neutron beta decay, and search for CP violation in EDM and nuclear reactions, baryon number non-conservation in neutron-antineutron oscillation, and new forces and dark energy appearing in neutron interference phenomena.

J-PARC is currently being upgraded, with the aim of 1.3 MW beam power for the next-generation neutrino experiment, Hyper-Kamiokande (Hyper-K). J-PARC will also provide $>$ 100 kW beam for the kaon experiment. The upgrade will be completed in 2027, and Hyper-K will start data taking with the upgraded neutrino beam in 2028.

1.2.3 Super-Kamiokande and Hyper-Kamiokande

Japan has a long-standing tradition of neutrino experiments, beginning with the Kamiokande experiment, which detected supernova neutrinos and pioneered neutrino astronomy. Kamiokande also found an indication of neutrino oscillations, which were subsequently discovered in its successor experiment, Super-K. Kamiokande also searched for proton decay and put a significant constraint on the Grand Unified Theory (GUT).

Today, the Super-K, a Water Cherenkov detector with 22.5 kiloton fiducial mass, is in operation and studying neutrino astronomy, neutrino oscillations, and proton decay. Recently, Super-K has been upgraded with dissolved gadolinium, which enhances neutron tagging and improves anti-neutrino identification.

Hyper-K, the third family in the Kamiokande series, is a Water Cherenkov detector with a 190 kiloton fiducial mass. It was approved in 2020 and brings together more than 600 collaborators from all over the world, more than half of whom are from Europe. The assembly of the Hyper-K's electronics is being prepared at CERN in close cooperation with European collaborators. The T2K and Hyper-K collaborations wish to see more participation of CERN scientists in Japan-based neutrino experiments, in addition to the already existing contributions through the CERN neutrino platform. The J-PARC neutrino beam will be provided to Hyper-K for six months of each year and will continue for 10 years to study Neutrino CP violation and neutrino mass ordering together with atmospheric neutrinos. Hyper-K will also look for proton decay and supernova neutrinos. Alongside Hyper-K, discussions begin regarding the period and conditions for the continued operation of Super-K.

1.2.4 Detector R&D and test beam

KEK has played a central role in advancing detector development for high-energy physics experiments, utilizing its unique facilities and expertise in mechanical engineering, cryogenics, sensor development, and electronics for several high-energy experiments. The Instrumentation Technology Development Center (ITDC), established under KEK's Institute of Particle and Nuclear Studies (IPNS) in 2023, aims to further enhance these efforts. To promote detector development, especially among young researchers through inter-university collaboration, the ITDC operates the Test Beam Line using electron beams provided by the Photon Factory Advanced Ring at KEK Tsukuba Campus. To drive the development of next-generation detector technologies, the ITDC has integrated the mechanical engineering, cryogenics, and electronics groups and promotes the development of semiconductor detector sensors and superconducting detector magnets for future collider experiments such as the Higgs factory. For this purpose, the ITDC will strengthen the capability of the test beam and the facilities to host assembling sites for a large-scale detector system. In addition, the Cryo CMOS electronics that operate at extremely low temperatures in anticipation of future quantum technologies are being developed. Community-led research through three detector development platforms and a forum is being supported: (i) scintillators, including optical sensors and quantum dots, (ii) semiconductor sensors, (iii) gas and active media, and (iv) advanced electronics. The ITDC will continue to work alongside JAHEP and related fields to promote and advance these activities, also acting as a liaison for international collaborations in detector developments, such as with the ECFA-Detector R&D.

1.3 Experiments at Offshore Facilities

1.3.1 LHC/ATLAS

The Japanese high-energy physics community considers the energy frontier physics at the LHC [7], including currently ongoing LHC Run 3 and the future HL-LHC [8] runs, as one of the top priorities, and we mainly contribute to the ATLAS experiment [9] at the LHC. Direct observation of new physics is our major target through in-depth investigation of previously explored scenarios of new physics and expanding the frontier to new scenarios by utilizing extended statistics and advanced techniques. The scope also includes precision measurements in the Higgs, broader electroweak, and top-quark sectors. Studies of di-Higgs production are also a flagship physics target for the HL-LHC. They will provide us with fundamental insight, such as the origin of matter and anti-matter asymmetry, the stability of our universe, and possible new energy scales beyond the electroweak unification scale. It is also worth noting that novel approaches to extending the scope of the energy frontier are being explored, with recent examples including studies of unconventional observables such as quantum entanglement.

To maximize the physics potential of the LHC Run 3 and HL-LHC by employing advanced techniques in offline data analysis and online data-taking, we are engaged in physics data analyses, detector and TDAQ system operation, as well as computing within the WLCG framework. In the ATLAS Phase-II upgrade program, we play a central role, particularly in the silicon pixel and strip detectors, the muon detector, the trigger-DAQ system, and the computing, which is essential for the success of the physics program at the HL-LHC. In addition, a key factor in ensuring the success of these efforts is the active on-site participation at CERN. We will continue to send researchers – particularly early career scientists and PhD students – to CERN, where they will engage in a broad range of on-site research activities in international collaboration for construction, commissioning, operation, and physics analysis through the LHC and HL-LHC periods.

For the accelerator machine upgrade of the LHC to HL-LHC, Japan is contributing to upgrading the insertion regions around ATLAS and CMS detectors (IR1 and IR5) through a collaboration between KEK and CERN. For the upgrade of the IRs, we are responsible for the beam separation superconducting dipole magnets, the quench heater power supplies, and the crab cavity powering system. Looking ahead beyond the HL-LHC, the advancement of the hadron collider technologies should be pursued to the utmost in the long term. We consider that developing high-field magnets using state-of-the-art superconductors such as Nb_3Sn and HTS (High Temperature Superconductor) is crucial to further increase the achievable beam collision energy of the machine. Demonstration of well-industrialized high-field magnets to realize a future hadron collider is pivotal for determining future projects beyond a Higgs Factory, and we endeavor this direction of R&D's exemplified by ongoing collaborative works on Nb_3Sn wire developments between KEK and CERN.

1.3.2 Other Offshore Opportunities in Japan's Leadership

In the Japanese HEP community, there are also groups taking on leadership roles in small- to medium-sized experiments at offshore facilities.

The MEG / MEG II experiment, started and led by the Japanese initiative, has been running at the forefront of charged lepton flavour physics at Paul Scherrer Institute (PSI) searching for New Physics at the beginning of the Universe. Their 90% CL upper limit of 3.1×10^{-13} on the branching ratio of the $\mu \to e\gamma$ decay is one of the most stringent benchmarks for any new physics scenarios. They plan to achieve a sensitivity of 6×10^{-14} by 2026. A new High Intensity Muon Beamline (HIMB) that provides 100 times higher muon intensity is scheduled to be ready in 2028. An international study to realise a next-generation rare muon decay experiment at HIMB is intensively underway under the initiatives of European and Japanese groups.

At another frontier of the charged lepton flavour physics is the PIONEER experiment that will investigate the lepton universality in the pion decays at the precision of 10^{-4} at PSI under the leadership of North America and Japan.

The TRIUMF UltraCold Advanced Neutron (TUCAN) project intends to measure the electric dipole moment (EDM) of neutrons at the precision of 10^{-27} e cm to uncover the origin of the universe's CP asymmetry beyond the CKM matrix. The project is based on the Ultra Cold Neutron (UCN) technology developed in Japan. The nEDM physics experiment is scheduled to begin in 2027 with an initial target sensitivity of 10^{-26} e cm, which would surpass the current measurement precision. Measurement at the sensitivity of 10^{-27} e cm is then scheduled to begin in the early 2030s.

The FASER experiment, operational since 2022, has opened up new associated and complementary physics programs in the forward region of the major collider experiments, represented by new particle searches in MeV–GeV mass range and exploring neutrinos at the TeV-scale. Several institutes from Japan have joined the collaboration, making significant contributions to its conceptual design, construction, and timely production of physics results such as Ref. [10, 11]. This sector of physics programs may further expand with the Forward Physics Facility (FPF) [12], a newly proposed larger-scale facility dedicated to forward physics in the HL-LHC era. Japanese researchers are making important contributions to the proposed FASER2 and FASERν2 experiments at the FPF, and their involvement is recognized as a key factor in enhancing the scientific potential.

Japanese physicists are also involved in other CERN experiments. The NA65/DsTau experiment investigates tau neutrino production in proton–nucleus interactions using emulsion technology developed by a Japanese group. It aims to reduce the flux uncertainty of the tau neutrino beam, which is crucial for future tau neutrino experiments such as SHiP, which will also use the emulsion technology. Another Japanese group is contributing to the development of cryogenic front-end electronics for the ProtoDUNE project and will take part in data analysis in the future.

1.4 ILC project

The International Linear Collider (ILC) is one of the candidate projects for a Higgs Factory and is being pursued under the framework of Global Project [1], where the Japanese HEP community has been playing a leading role since

[1] A project with a governance framework in which cost-sharing, human resource allocation, operation planning, and site selection are collectively decided between partner countries is called "Global Project". Such an approach has not yet been taken in the HEP

its inception. It utilizes the Superconducting RF (SRF) technology, and the primary objective of the ILC, with a collision energy of 250 GeV, is to precisely measure the Higgs couplings through decays to fermions and bosons, aiming to identify any deviations from Standard Model predictions. Through this approach, the project aims to uncover the nature of physics beyond the Standard Model and determine the relevant energy scale. One of the defining features of the ILC is its linear shape, which allows for energy extensions with upgrade possibilities offered by high gradient technologies, based on the results obtained from the Higgs sector.

Aiming at the realization of the ILC project an organization, ILC-Japan, was established under JAHEP as the representative of the Japanese HEP community [13]. In collaboration with KEK, ILC-Japan is taking responsibility for advancing research in physics, detectors, and accelerators while coordinating discussions with stakeholders of partner countries to advance the Global Project.

The accelerator technology of ILC is detailed in the Technical Design Report (2013) [14, 15]. The key technologies have been developed and successfully demonstrated at KEK. For instance, eight SRF cavities from three regions, Asia, North America, and Europe, were housed in cryomodules at the Superconducting RF Test Facility (STF) and successfully operated together in the S1-Global project [16]. Another example is the realization of a nano-beam with a size of 41 nm, mostly satisfying the requirement of 37 nm, which corresponds to 7.7 nm at the beam energy of 125 GeV. Beam stabilization is also crucial, and a fast feedback system with a latency of 133 nsec, incorporating a beam monitor, data processing unit, and beam kicker, was developed at the Accelerator Test Facility (ATF) [17].

Years of technological development have brought each technology to a basically mature stage. However, some of the developments mentioned above are still necessary, and engineering studies on the actual construction process still remain.To address these, an international R&D framework called the ILC Technology Network (ITN) is currently being pursued to facilitate further research and development [18]. ITN was initiated by KEK and the ILC International Development Team (IDT), and is based on bilateral arrangements between KEK and laboratories around the world. Alternatively, arrangements may be made via a hub-laboratory, where the hub-laboratory makes arrangements with KEK. (For instance, CERN is taking such a role in Europe.) The highest priority tasks have been defined as Work Packages, with key focus areas including SRF, Particle Sources, and Nano-beam. For SRF, efforts have been made in manufacturing and quality control at multiple sites worldwide. Those SRF cavities will be housed in the cryomodules, the design of which has been finalized. Regarding the positron source, development of a prototype including a rotating target is underway. Further studies on the design of the damping ring for the low emittance and large dynamic aperture are being conducted. Technological developments to achieve the target beam size are performed on a long time scale.

The Japanese community also plays a major role in the physics and detector studies for the ILC and future Higgs factories. Key physics cases in Higgs/Electroweak/Top measurements and BSM searches have been studied within the framework of the ILC detector concepts. Particular emphasis has been placed on Higgs coupling measurements, including self-coupling and CP properties, as well as electroweak precision studies and direct searches. These efforts were summarized in the ILC TDR [14] and in subsequent publications [19]. We have developed high-level reconstruction algorithms, such as jet clustering and flavor tagging, which are essential for achieving high performance in these physics measurements. More recently, we are incorporating modern deep learning techniques, such as transformer-based flavor tagging, which have led to significant improvements. The impact of these advancements on physics results has been summarized in the ECFA study on Higgs, Electroweak, and Top-quark factories [20].

Major contributions have been made to developments of trackers and high-granularity calorimeters through international collaboration framework. The performance of detector prototypes has been extensively evaluated using test-beam facilities as part of global efforts. Recently, our detector development activities have expanded into new technology areas, including advanced semiconductor detector sensors, dual-readout high-granularity calorimeters, and picosecond-timing calorimeters. To further accelerate these studies, we will advance the development and performance evaluation of detector prototypes by utilizing the local research infrastructure of the ITDC group at KEK, in close cooperation with international research networks such as ECFA-DRD and the CEPC collaboration.

2 Japan's Strategy for Future Higgs Factories

2.1 Background

An electron-positron Higgs factory is a well-established candidate for flagship next-generation high-energy physics projects, especially in the post-HL-LHC era. Here, a Higgs factory refers to an electron-positron collider facility that enables precise measurements of Higgs properties at the ZH production threshold as a primary scope and

community.

dedicated physics programs at other collision energies. These may include electroweak precision measurements around the Z-pole and the W pair production threshold, precision measurements of the top quarks around the $t\bar{t}$ pair production threshold, and Higgs pair production studies at $\sqrt{s} \sim 500$ GeV. With the HL-LHC expected to be completed in the early 2040s, ensuring a seamless continuation of high-energy collider physics is essential, and the realization of a Higgs factory that can be constructed around this timeframe is a key objective of the HEP field. This view is widely shared in the international high-energy physics community, including the Japanese community.

Japanese HEP community has been aiming to realize the ILC in Japan, as outlined in Japan's high-energy physics strategy reports in 2012 [21] and 2017 [22]. The proposal for the ILC realization in Japan has been thoroughly reviewed by expert panels organized by the relevant government ministry (MEXT [2]) and committees formed by the Science Council of Japan. While its scientific significance has been acknowledged, concerns have been raised regarding the implementation plans, including the necessary budget, human resources, and international cost-sharing. In February 2022, following the publication of the "Proposal for the ILC Preparatory Laboratory (ILC Pre-Lab)" by IDT [23], the MEXT expert panel concluded that the establishment of the ILC Pre-Lab was premature and issued recommendations on actions of the researcher community [24]. Following these recommendations, the Japanese HEP community's strategy for the ILC promotion has been restructured, and the current focus is on building consensus and strengthening international partnerships to initiate global discussions on the ILC as a "Global Project". The ILC-Japan has been formed as an expert team to advance integrated research in physics, accelerators, and detectors [13]. Also, a new international framework for collaborative research and development on ILC accelerator technologies, ITN, has been launched [25]. These recent developments and the current status of ILC promotion are detailed in Section 1.4.

Internationally, since the last update of the Japanese HEP community's strategy, there has been significant progress in the Higgs factory discussion in addition to the ILC proposal. Especially in Europe and China, discussions have advanced toward realizing a Higgs factory as circular colliders, namely the FCC-ee and CEPC, and concrete proposals are being extensively studied [26, 27]. Also, international situations toward the linear collider realization are evolving. Experts from a wide range of countries, including Japan, the United States, Europe, and other regions, have begun to develop a coherent vision for a future Linear Collider facility in connection with the 2026 update of the European Strategy for Particle Physics [28]. This includes a potential proposal for the Linear Collider Facility (LCF) at CERN based on ILC technology.

Given the development of the international situation around the Higgs factories and recent progress toward the realization of the ILC in Japan, we have conducted a comprehensive investigation and evaluation of the prospects of these Higgs factory proposals, including the physics cases, differences between circular and linear colliders, maturity of accelerator technologies, project feasibility, future prospects, and interests in the JAHEP community to update our strategy for the future Higgs factories.

2.2 Observations

We have made the following observations in our study.

- The physics significance of precise measurements of Higgs boson properties is substantial, providing key insights into electroweak symmetry breaking and the hierarchy problem. Besides the Higgs precision measurement program, linear colliders have energy upgrade capability enabling the observation of Higgs's self-interactions, which is essential for understanding the nature of electroweak symmetry breaking and testing electroweak baryogenesis scenarios. Furthermore, these upgrades play a significant role in advancing searches for WIMP dark matter. Circular colliders will give high-statistics Z boson data obtained at the Z-pole and allow precise measurements of the electroweak sector (Tera-Z program). Both approaches offer unique and essential insights for particle physics.

- The accelerator technologies for each proposal are mature enough to be feasible as a next-generation collider, concerning the post-HL-LHC timeframe at the latest [29].

- Each Higgs factory proposal is supported by well-established physics cases. The characteristics of linear and circular colliders differ (e.g., luminosity, energy efficiency dependencies on $\sqrt{s}$, polarization capabilities, and precision measurement potential at the Z resonance), and each approach will require different optimizations in terms of physics programs and operational scenarios to achieve the desired outcomes.

[2] The Ministry of Education, Culture, Sports, Science and Technology.

- All proposals are large-scale projects and have challenges for realization, such as high demands for human and financial resources.
- The ILC is being pursued under the framework of "Global Project", which the Japanese HEP community has led. The realization of the ILC as a Global Project follows a phased approach [30]. The process is currently in "Step 1", focusing on discussions with international partners to build consensus on the project's importance, participation, and guidelines for cost sharing, responsibilities, and site decisions. Based on these discussions, "Step 2" will aim to reach an agreement on the host country and site. "Step 3" will involve further planning for a Pre-Lab and the construction of the ILC. The efforts are focused on advancing Step 1 and building the necessary international consensus.
- In the longer term, the linear colliders have a unique potential for further energy upgrades, enabling a few TeV electron-positron collisions. In contrast, circular colliders provide pathways to future hadron colliders, enabling a ∼100 TeV hadron collider. Both approaches offer valuable opportunities for the future of high-energy physics.

Based on these observations, we have developed the following strategy.

2.3 Strategy

The early realization of a Higgs factory through international collaboration is crucial for the future of the field. According to the evolving situation around the Higgs factory proposals, our goal is to ensure the realization of a Higgs factory. In this context, we will pursue the following two key directions:

- We prioritize efforts to realize the ILC as a Global Project, taking a leading role in advancing ongoing initiatives. We will engage with international partners to discuss governance, responsibilities, and site selection. We intend to develop and expand our scientific and promotional activities to host the ILC as a Global Project in Japan.
- We also extend our activities in other Higgs factory proposals as a collective approach to maximize the chances of timely realizing a Higgs factory.

In alignment with the strategy outlined above, we intend to advance our research activities with the following key approaches.

1. Toward the realization of the ILC in Japan, we aim to further accelerate international collaborative research on accelerator technologies within the ITN framework and to enhance research on physics, detectors, and accelerators , respecting recommendations from the MEXT expert panel in 2022 [25].
2. To realize the ILC as a Global Project, we will take a leadership role in advancing international discussions, especially in the early stages, before a host country is decided. Many aspects of the decision-making process are expected to be complex and not straightforward. We aim to address these challenges through extensive discussions with international partners.
3. We will also extend our activities for the Higgs factory realization, including circular options. We will take advantage of Japan's unique expertise gained through the ILC development and broader particle physics experiments. Taking advantage of synergies between the ILC and other proposals will be key to formulating a collective approach for the Higgs factory proposals.
4. Regarding accelerator technologies, Japan is well-positioned to make unique contributions, especially through operational accelerator facilities. SuperKEKB is a unique facility that employs the nano-beam scheme and is currently in operation (see Section 1.2.1). Demonstration facilities for ILC development, the ATF and the STF, serve as unique testbeds for ILC technologies such as the nano-beam scheme and high-gradient superconducting RF acceleration (see Section 1.4). These facilities will contribute valuablely to global efforts to realize a Higgs factory. Sharing the experiences gained from addressing operation and development in these ongoing projects will benefit all Higgs factory proposals. SuperKEKB and ITN, which involve international cooperation, will continue to play a key role in advancing these efforts.

5. We will continue to review and refine our strategy in response to the evolving situation around Higgs factory proposals. We are paying close attention to the upcoming community reports in the coming ESPP update process, including the FCC-ee Feasibility Study (covering financial feasibility), the CEPC Engineering Design Report, updates on the cost assessment of the ILC, and the LC vision report, which includes considerations of the LCF at CERN. Given our strategy of promoting the ILC as a Global Project, we pay special attention to the development of discussions on the implementation of the LCF.

2.4 Considerations for Realization of Global Projects

The promotion of a collider as a Global Project is a new challenge beyond the traditional framework. As accelerator-based high-energy experiments grow in scale and cost, we consider that exploring such a new scheme is indispensable for realizing future colliders. Regarding the ongoing update of the European Strategy for Particle Physics, we consider that a new model of project implementation, which includes international sharing of governance and efforts in construction and operation, would be necessary for next-generation large-scale high-energy physics projects in general. The discussions on promoting the ILC as a Global Project provide a valuable opportunity as a working example in this context. Japan aims to take the lead in international discussions on this topic to build shared understanding and explore solutions to practical challenges in implementing a Global Project. To advance these discussions, active international participation, including from/to European countries, is essential. Broad cooperation from the global community will be key.

3 Response to key questions asked by the strategy secretariat

Below, we provide our responses to three key questions asked by the strategy secretariat.

(i) **What is the preferred large-scale post-LHC accelerator for CERN?**

A Higgs factory collider project, in particular the FCC-ee or the LCF.

We will desire to realize a Higgs Factory collider project, in terms of the overall precision of Higgs couplings, which is expected to improve by at least one order of magnitude or better than what the HL-LHC is expected to achieve. When we speak of a Higgs Factory, such a project should enable copious production of Higgs bosons to achieve the aforementioned precision. Also, such a project should offer subsidiary measurements in the electroweak sector, which are necessary and sufficient for constraining the Higgs coupling precision. Amongst proposed large-scale project options for CERN's future, the **FCC-ee** as the first step of the FCC integrated program and the **LCF** may be regarded as options that are well aligned with these directions. We regard both the FCC-ee and the LCF as significant options for realizing a Higgs Factory at CERN, with the following notes.

- Electroweak precision information obtained at the Z pole is — to some degree — a substantial ingredient for achieving the demanded precision of Higgs coupling measurements. Meanwhile, the implication of the proposed integrated luminosity of 200 ab^{-1}, the so-called "Tera Z" program, will need more critical assessment. It imposes additional requirements on accelerator performance that make detector and MDI (Machine-Detector Interface) designs drastically different and challenging, via the solenoid field constraint, data acquisition systems, as well as systematics control for achieving the precision. Thus, the efficacy of additional efforts and cost against achievable physics outcomes must be critically assessed.
- Regarding the LCF, we recognize that, compared with the FCC-ee as the first stage of the FCC integrated program, the feasibility study remains at a relatively premature stage. It will therefore be indispensable further to develop the LCF feasibility study through international collaboration to reach a comparable level of maturity.
- As described in Section 2.3, SuperKEKB and ITN will continue to play a key role in advancing accelerator technology in either case of the FCC-ee and the LCF.

(ii) **What is the preferred alternative, if the preferred option is not feasible?**

While both the FCC-ee and LCF are listed as preferred options in response to question (i), the LCF would be regarded as the prioritized alternative if the FCC-ee is chosen as the most preferred option in Europe.

Given that the FCC-ee will likely be the first choice of European countries concerning the open symposium discussion, the LCF of at least covering the 250 GeV collision is considered as a prioritized alternative option if the FCC-ee is not financially feasible. The LCF will provide a precision similar to that of FCC-ee for major Higgs couplings with polarization capability. Energy extendability is a unique advantage of the LCF, which will further expand physics potential from a long-term perspective. The technical maturity of the LCF is relatively clear, reflecting a similarity to that of the ILC project. However, the degree of feasibility study of alternative projects is not reaching the level accomplished for FCC-ee, including the LCF, especially for the studies related to civil engineering in the CERN area, and risks as mentioned in the answer to question (i). Therefore, conducting a comparable feasibility study for the LCF proposal is desired.

(iii) **What is the preferred alternative, if the preferred option would not be competitive?**

At this stage, no specific or concrete alternative has been formulated.

At this stage, we have not formulated specific and concrete alternative views in case the preferred option was not competitive, as the JAHEP.

4 Summary

For input to the ESPP Update 2026, we present a summary of the updated strategy of the Japanese High Energy physics programs. As our response to the key questions posed by the Strategy Secretariat, we consider a Higgs factory collider project—specifically, the **FCC-ee** or the **LCF**—to represent a promising direction for CERN's next large-scale post-LHC accelerator. Should the **FCC-ee** be selected as the most favored option in Europe, the **LCF** would be regarded as the prioritized alternative if the preferred option is not feasible.

High-energy physics is an essential scientific discipline for understanding the origin of the universe. Many profound questions in particle physics remain unresolved, and ongoing experiments will provide essential insights into these mysteries. We also recognize that a new facility enabling high-precision studies of the Higgs boson —the final piece of the Standard Model— offers one of the most promising pathways to uncovering new physics beyond the Standard Model.

High energy physics research in Japan encompasses a variety of groundbreaking experiments conducted at major facilities. These include the SuperKEKB accelerator and the Belle II experiment, which focus on search for new physics in heavy flavor decays; the high power proton accelerator complex J-PARC, where experiments are conducted using the high intensity neutrino, kaon, muon and neutrons beams; and collaborative efforts in CERN's Large Hadron Collider (LHC and HL-LHC) experiments. For neutrino research, the construction of the Hyper-Kamiokande experiment started and is currently underway. We emphasize the importance of maintaining timely progress in these ongoing experiments and construction of experimental facilities. We acknowledge significant contributions by European collaborators to the Japan-based experiments, and wish to see more participation. We also acknowledge essential support of CERN to the experiments as a key hub for the European activities. Through these experiments, we strengthen international collaborations and cooperation.

Looking into the future, the early realization of a Higgs factory through international collaboration is crucial for our field. We take into account the evolving situation of Higgs factory proposals: CEPC, FCC-ee, ILC, and LCF@CERN. To ensure the realization of a Higgs factory, we pursue the following key directions:

- We prioritize efforts to realize the ILC as Global Project, taking a leading role in advancing ongoing initiatives. We will engage with international partners to discuss governance, responsibilities, and site selection. We intend to develop and expand our scientific and promotional activities to host the ILC as Global Project in Japan .
- We also extend our activities in other Higgs factory proposals as a collective approach to maximize the chances of timely realizing a Higgs factory.

We also acknowledge that a Higgs Factory is a large-scale project with significant challenges, including high demands for human and financial resources, as well as long-term commitment. For the ILC realization in Japan, its implementation as a "Global Project" with international partners is considered a key approach to addressing these challenges. The ITN, international R&D framework for the ILC accelerator initiated by KEK and IDT, has started. The collaboration with CERN is essential for ITN. The detector R&D with test beams are essential for future experiments, and we would promote international collaborations in detector developments, such as ECFA-Detector R&D. For future projects beyond a Higgs Factory, developing high-field magnets using state-of-the-art superconductors is critical to realize a future hadron collider.

By advancing current and future projects, we aim to continue contributing to fundamental discoveries and to foster international collaboration. We will actively participate in international discussions on shaping the global strategy for high-energy physics.

References

[1] NINJA Collaboration. "Precise measurement of neutrino interactions and sterile neutrino search with nuclear emulsion detector at J-PARC, LOI submitted to 39th J-PARC PAC" (Jan. 2025). URL: https://kds.kek.jp/event/53355/.

[2] S. Ajimura et al. "The JSNS2 detector". *Nucl. Instrum. Meth. A* 1014 (2021), p. 165742. DOI: 10.1016/j.nima.2021.165742.

[3] S. Ajimura et al. "Proposal: JSNS^2-II" (Dec. 2020). arXiv: 2012.10807 [hep-ex].

[4] KOTO Collaboration. "Search for the $K_L \to \pi^0 \nu \bar{\nu}$ Decay at the J-PARC KOTO Experiment". *Phys. Rev. Lett.* 134 (2025), p. 081802. DOI: 10.1103/PhysRevLett.134.081802.

[5] KOTO II Collaboration. "Proposal of the KOTO II experiment" (Jan. 2025). arXiv: 2501.14827 [hep-ex].

[6] COMET Collaboration. "COMET Phase-I technical design report". *Progress of Theoretical and Experimental Physics* 2020.3 (Mar. 2020), p. 033C01. DOI: 10.1093/ptep/ptz125.

[7] "LHC Machine". *JINST* 3 (2008). Ed. by L. Evans and P. Bryant, S08001. DOI: 10.1088/1748-0221/3/08/S08001.

[8] I. Zurbano Fernandez et al. "High-Luminosity Large Hadron Collider (HL-LHC): Technical design report". 10/2020 (Dec. 2020). Ed. by I. Béjar Alonso, O. Brüning, P. Fessia, L. Rossi, L. Tavian, and M. Zerlauth. DOI: 10.23731/CYRM-2020-0010.

[9] G. Aad et al. "The ATLAS Experiment at the CERN Large Hadron Collider". *JINST* 3 (2008), S08003. DOI: 10.1088/1748-0221/3/08/S08003.

[10] FASER Collaboration. "First Direct Observation of Collider Neutrinos with FASER at the LHC". *Phys. Rev. Lett.* 131 (3 July 2023), p. 031801. DOI: 10.1103/PhysRevLett.131.031801. URL: https://link.aps.org/doi/10.1103/PhysRevLett.131.031801.

[11] FASER Collaboration. "First Measurement of ν_e and ν_μ Interaction Cross Sections at the LHC with FASER's Emulsion Detector". *Phys. Rev. Lett.* 133 (2 July 2024), p. 021802. DOI: 10.1103/PhysRevLett.133.021802. URL: https://link.aps.org/doi/10.1103/PhysRevLett.133.021802.

[12] A. Jyotismita *et al.* "Science and Project Planning for the Forward Physics Facility in Preparation for the 2024-2026 European Particle Physics Strategy Update". *Eur. Phys. J. C* 85 (2025), p. 430. DOI: 10.1140/epjc/s10052-025-14048-6. URL: https://link.springer.com/article/10.1140/epjc/s10052-025-14048-6.

[13] ILC-Japan. *ILC-Japan webapge.* URL: https://ilc-japan.org/en/.

[14] "The International Linear Collider Technical Design Report" (2013). DOI: 10.48550/arXiv.1306.6327. arXiv: 1306.6327 [physics]. URL: https://linearcollider.org/technical-design-report/.

[15] L. Evans and S. Michizono. "The International Linear Collider Machine Staging Report 2017" (2017). DOI: 10.48550/arXiv.1711.00568. arXiv: 1711.00568 [physics].

[16] N. Toge, J. Kerby, R. Paparella, W. D. Moeller, and H. Hayano. "S1 Global Report". (2012). URL: https://www2.kek.jp/stf/report/4_S1-G-Report-2013-3.pdf.

[17] ATF International Collaboration. "ATF Report 2020" (2020). URL: https://agenda.linearcollider.org/event/8626/attachments/35702/55436/ATF_Review_Report_2020_0831.pdf.

[18] "ILC Technology Network (ITN) and work packages" (2023). URL: https://linearcollider.org/wp-content/uploads/2023/09/IDT-EB-2023-002.pdf.

[19] H. Abramowicz et al. "International Large Detector: Interim Design Report" (Mar. 2020). arXiv: 2003.01116 [physics.ins-det].

[20] J. Altmann et al. *ECFA Higgs, electroweak, and top Factory Study.* Vol. 5/2025. CERN Yellow Reports: Monographs. June 2025. ISBN: 978-92-9083-700-8, 978-92-9083-701-5. DOI: 10.23731/CYRM-2025-005. arXiv: 2506.15390 [hep-ex].

[21] JAHEP CFP. "The Final Report of the Subcommittee on Future Projects of High Energy Physics". Feb. 2012. URL: https://www.jahep.org/office/doc/201202_hecsubc_report.pdf.

[22] JAHEP CFP. "Final report of the committee on Future Projects in High Energy Physics". Sept. 2017. URL: https://www.jahep.org/files/20170906-en.pdf.

[23] “Proposal for the ILC Preparatory Laboratory (Pre-lab)” (June 2021). DOI: 10.5281/zenodo.4742043. arXiv: 2106.00602 [physics.acc-ph].

[24] KEK. “Next step toward the ILC realization: MEXT expert panel publishes recommendation”. July 2022. URL: https://www.kek.jp/en/topics/202202251335.

[25] KEK. “KEK and CERN Conclude Agreement on R&D for International Linear Collider”. July 2023. URL: https://www.kek.jp/en/topics/202307081205.

[26] FCC Collaboration. “Future Circular Collider (FCC) Feasibility Study Midterm Report”.

[27] W. Abdallah *et al.* (CEPC Study Group). “CEPC Technical Design Report: Accelerator”. *Radiat. Detect. Technol. Methods* 8.1 (2024), pp. 1–1105. DOI: 10.1007/s41605-024-00463-y. arXiv: 2312.14363 [physics.acc-ph].

[28] Brian Foster, Daniel Schulte, Jenny List, Michael Peskin, Roman Poeschl, Shinichiro Michizono, Steinar Stapnes, Vladimir Litvinenko, Mihoko Nojiri. “Plenary: Open discussion sesson - Global Vision for a Linear Collider facility — Introduction and Kick-off Presentations”. *International Workshop on Future Linear Colliders, LCWS2024*. Tokyo, September 2024.

[29] T. Roser et al. “On the feasibility of future colliders: report of the Snowmass’21 Implementation Task Force”. *JINST* 18.05 (2023), P05018. DOI: 10.1088/1748-0221/18/05/P05018. arXiv: 2208.06030 [physics.acc-ph].

[30] M. Ishino. “Overview on ILC in Japan”. Linear Collider Vision Community Event 2025. Geneva, CERN, Jan. 2025. URL: https://indico.cern.ch/event/1471891/timetable/?view=standard#32-overview-on-ilc-in-japan.