Recommendations on Experiments for Particle and Nuclear Studies at KEK after 2008

IPNS Research Plan Committee

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Preface

IPNS-RPC, the Research Plan Committee (RPC) of the Institute for Particle and Nuclear Studies (IPNS) at the High Energy Accelerator Research Organization (KEK), was asked by the IPNS director to investigate experimental research plans in particle and nuclear studies after the completion of J-PARC phase I construction. At the first committee meeting that was held on Dec. 1, 2004, the committee was asked to include the following in the report:

1. The physics impact and expected achievements of J-PARC phase II, SuperKEKB and ILC, and

2. possible KEK scenarios for the three projects.

To fulfill these charges, we had twelve meetings, in which we heard presentations on the above three projects as well as related projects, and discussed possible roadmap options. During this procedure, we decided to include in our scope all the research activities of the IPNS at J-PARC after the commissioning in 2008. Because of this decision, the title of this report became "Recommendations on Experiments for Particle and Nuclear Studies at KEK after 2008".

This report consists of two parts. The first part gives an overview of the present status of particle and nuclear physics, and summarizes the recommendations of this committee. Therefore this is the main part of our report. The second part describes the physics impact and expected achievements for each project, where evaluations and suggestions for each project are provided independent of the relative priorities of the three projects. It thus serves as the basis of our main recommendations given in the first part.

The original report, which was submitted to the IPNS director in March 2006, is written in Japanese. This document is an English translation of the first part of the report.

1 Present status and future prospects for particle and nuclear physics

"What are the most fundamental building blocks of matter ?"
"What are the forces between them ?"
"How do these fundamental building blocks make up the complex structure of matter ?"

Human beings have been seeking answers to these questions for a very long time. In the last half of the 20th century, there has been great progress in the quest to answer these questions mainly from accelerator-based experiments. As a result of these experiments, we have obtained a unified picture of the fundamental building blocks of matter and the interactions among them, as well as a basic understanding of hadron and nuclear structure. Researchers in Japan have made large contributions to this development. In particular, we have made remarkable discoveries in neutrino experiments and in the Belle experiment at the KEK B factory, as well as in experiments on strangeness nuclear physics and on unstable nuclei. It should also be pointed out that researchers in our country have played important roles in many international collaborations for experiments that were carried out abroad.

In spite of the great success of particle and nuclear studies so far, there are several observations that indicate new phenomena beyond the present framework. Thus there are now growing expectations that discoveries will be made in the near future, which will be gateways to a new paradigm of particle and nuclear physics.

1.1 Present status

In particle physics, the validity of the standard model of elementary particles, which is based on gauge symmetries, the flavor structure with three generations of quarks and leptons, and the Higgs mechanism, has been established.

Precision measurements at LEP and other experiments scrutinized the interactions governed by gauge particles. K and B experiments have revealed that the overall framework of the flavor structure is well described by the Kobayashi-Maskawa theory of CP violation. However, the mechanism of spontaneous symmetry breaking, which is one of the pillars of the standard model, is not yet confirmed experimentally; this is now an urgent issue for elementary particle physics. The standard model also suffers from the hierarchy problem, the huge energy gap between the electroweak scale and the scale of gravity. To resolve the problem, it is thought that there is a more fundamental theory that may include supersymmetry or extra-dimensions at the electroweak scale. From recent experiments and astrophysical observations, it is also becoming clear that there should exist physics beyond the standard model. The standard model cannot explain dark matter, dark energy, the origin of the baryon asymmetry of the universe, and neutrino oscillations. It is clear that we need a new framework beyond the standard model.

Nuclear physics studies the diversity of many-body structures bound by strong interactions. We used to describe nuclei as objects that consist of protons and neutrons that are bound by exchanging mesons. Recently, significant progress has been made in our understanding of hadron structure in terms of quarks, and now nuclear physics can be reconstructed from the new viewpoint of quark nuclear physics. Of special note are studies of new types of nuclei that are absent in nature, namely, nuclei with new degrees of freedom such as strangeness, and unstable nuclei with excess neutrons. The field of nuclear physics pursues the varieties of matter under extreme conditions, in which new types of nuclei with extended flavor and isospin are created, and the wide region in the phase diagram of hadron and quark matter is investigated by changing temperature and density. It is expected that from these studies, the overall understanding of our matter world as quark many-body systems will be deepened. Furthermore, these studies will lead to an understanding of the evolution of matter in the universe through the big bang, nucleosynthesis, supernovae explosions, and the formation of neutron stars.

Given the current status of the development of particle and nuclear physics described above, we believe that now is the time to explore new phenomena beyond the standard model and new forms of matter under extreme conditions.

1.2 Directions for future research

As mentioned in the previous section, we are at the dawn of a new era of particle and nuclear physics. A door to a new view of nature over a wide range of energy scales is open to us. New experiments at the Large Hadron Collider (LHC) at CERN will start in 2007. It is expected that the LHC will discover Higgs particles. Discoveries of physics beyond the standard model are expected as well. With heavy ion collisions, quark matter at high energy and high density will be explored. With these in mind, we should perform studies to deepen the understanding of nature at each energy scale, and should proceed to establish a unified view of our world that includes the understanding of the evolution of our universe from the very beginning.

To this end, the following items become particularly important in the area of elementary particle physics:

1. Further establishing the standard model

   It is urgent to establish experimentally the mechanism of electroweak symmetry breaking, which is one of the bases of the standard model. Discovering Higgs particles is not enough. By identifying the properties of Higgs particles from precision measurements of Higgs couplings to fermions as well as the self-coupling, we should establish the Higgs mechanism and its relation to the structure of the vacuum. In addition, from more precise measurements of the masses and couplings of the top quark and gauge particles, basic parameters of the standard model will be determined more precisely. On the other hand, we should determine the flavor structure of the quark sector from precision measurements of Cabibbo-Kobayashi-Maskawa (CKM) matrix elements and the unitarity triangle. Through all these measurements, we aim to more firmly establish the standard model, which then enables a search for new physics in phenomena that differ from the predictions of the standard model.

2. Unravelling new physics principles at the TeV scale

   Some new physics scenarios beyond the standard model, such as supersymmetry or extra dimensions, have been proposed as a solution to the problem of the hierarchy between the electroweak scale and the scale of gravity. We should try not only to find new elementary particles that are predicted in such theories, but also investigate their properties in order to explore the new physics principles behind them. To this end,

   (a) we should perform precision measurements of masses and properties of new particles at the LHC energy scale to study new physics principles,

   and at the same time,

   (b) we should uncover the flavor structure of new physics in the quark sector and the charged lepton sector from new high-luminosity (or high-intensity) measurements.

   Both of these two complementary approaches were essential to establish the standard model of elementary particles. It will remain important to pursue these two approaches to uncover the whole picture of the paradigm of new physics beyond the standard model. Through such a comprehensive approach, we will clarify not only the phenomena of new physics at the TeV scale, but acquire significant knowledge about new physics principles and physics far above the TeV energy scale.

3. Neutrino physics

   Neutrinos are massless within the standard model. Thus the observation of neutrino oscillation indicates the existence of physics beyond the standard model. It is important to determine θ_{13}, which is not yet measured, and further explore the possibility of measuring CP violation in the neutrino sector. Through these studies, we aim to clarify the origin of neutrino masses. It should also be stressed that knowledge of neutrino oscillations together with results from other flavor physics experiments are important to explore physics at very high-energy scales that are close to the scale of grand unification.

In nuclear physics, the following issues are important:

1. Hadron many-body systems

   Ordinary nuclei in nature consist of protons and neutrons. By producing hadron many-body systems that include strange particles and studying their structures, we can develop a new theory of hadron many-body systems with extended flavor. The existence of high-density kaonic nuclei induced by the strong attractive force between an anti-kaon and a nucleon was recently reported. Studies of this new structure will lead to a deeper understanding of low-temperature high-density hadron matter. In addition, from detailed studies of hypernuclei over the whole mass range, we expect to clarify properties of baryon-baryon interactions as an extension of the nuclear force as well as the resulting structures.

   Except for large nuclei, the numbers of protons and neutrons in ordinary stable nuclei are approximately equal. However, the ratio is quite different in unstable nuclei that have short lifetimes. Artificially creating unstable nuclei and examining their structure is important to study nuclear structure with extreme isospin numbers, and also to understand the nucleosynthesis of heavy elements in the universe. In recent studies of unstable nuclei, some new structures such as neutron halos and neutron skins have been discovered. Further developments in this area are expected.

2. Hadron structure

   An ordinary hadron is described either as a baryon that consists of three quarks or as a meson that consists of a quark and an anti-quark. However, studies of hadrons beyond this picture have become active recently. Exotic hadrons such as pentaquarks, glueballs, tetraquarks, dibaryons and meson molecules have been proposed, although they have yet to be experimentally confirmed. Clarifying whether these types of hadrons exist or not will be very important for further progress in hadron physics.

   Measurements of polarized structure functions have revealed that nuclear spin cannot be explained as a simple sum of contributions from constituent quarks. It is urgent to measure contributions from gluon spins and angular momenta. Studies of unpolarized parton distribution functions are in progress for regions of both small and large momentum fractions carried by a parton in a nucleon. These studies will be important in interpreting experimental results from the LHC and from high-energy cosmic ray experiments.

3. Phase structure of quark and hadron matter

   High-density states created in high-energy heavy ion collisions have been used to study the phase transition from hadron matter to quark-gluon plasma. Recent results on jet quenching in heavy ion collision experiments at RHIC indicate that the quark-gluon plasma is being produced. Interesting phenomena such as new states of matter that show fluid-like behavior have also been observed. Further evidence for the quark-gluon plasma is required to clarify the features of quark matter. Furthermore, studies of color superconductivity and chiral symmetry in regions of low-temperature and high pressure, which are different from those at RHIC and LHC, are in progress. Understanding of this region is also important to understand the properties of hadron-quark matter as an extreme state of matter over a wide range of the phase diagram.

These studies of elementary particles and nuclei are deeply related to astroparticle physics and cosmology. In order to uncover the ingredients of the universe and the evolutionary history of the early universe, it is crucial to understand physics beyond the standard model. Identification of dark matter is of particular importance. In addition to searches with dedicated experiments, energy frontier experiments also contribute to studies of dark matter properties if dark matter consists of weekly-interacting massive particles predicted in new physics scenarios at the TeV scale. In addition, detailed studies of the Higgs sector and the identification of physics beyond the standard model will provide clues to understand the creation of the universe, inflation, dark energy, and the origin of the baryon asymmetry of the universe.

Information from spectroscopy of hypernuclei and kaonic nuclei, and studies of color superconductivity are important to understand the interior structure of neutron stars. Creating unstable nuclei and clarifying their structure and interactions are needed to understand supernova explosions in which many heavy elements are created and unstable nuclei play important roles. Furthermore, in order to describe interactions of high energy cosmic rays with the atmosphere precisely, it is necessary to understand nuclear reactions in regions where the parton momentum fraction is small.

As described above, it is expected that the connections between particle and nuclear physics and astrophysics will become much closer in the future.

1.3 Future plans at KEK and the situation in the world

KEK has made great contributions to the development of fundamental physics through experiments that use accelerators; examples include experiments at the 12 GeV proton synchrotron (PS), at the TRISTAN e^+e^- collider that had the highest energy at the time it operated, and the Belle experiment at the KEKB collider. As an inter-university research institute corporation, KEK plays a core role for research at Japanese universities. KEK is also a research center in the world where many researchers visit from abroad, in particular at recent experiments such as Belle and those at the 12 GeV PS.

As of 2006, KEK has turned off the 12 GeV PS, and is constructing a new proton synchrotron J-PARC, which will have the world-highest beam power. The e^+e^- collider KEKB has achieved the world's highest luminosity; KEK is now a center of B physics. SuperKEKB is a proposal to proceed much further with this study. The LHC experiment at CERN, which is under

Projects	J-PARC	SuperKEKB	ILC
Establish the standard model		CKM precision measurements	Higgs mechanism
New physics principles at the TeV scale	Flavor structure (K, μ)	Flavor structure (B, τ)	Properties of new particles
Neutrino physics	Neutrino oscillation		
Hadron many-body system	Hypernuclei Kaonic nuclei		
Hadron structure	Exotic hadrons Parton structure		
Quark-hadron matter and phase structure	Hadron mass Low-temperature high-density matter		

Table 1: Future projects at KEK and their relations to important topics in elementary particle physics and nuclear physics.

construction and will be operational in 2007, aims at searches for the Higgs particle and new physics at the TeV scale. Japanese researchers contribute to the LHC both in accelerator and detector construction. KEK is also one of centers for R&D on the linear collider, which will be an energy frontier machine with e^+e^- collisions. As such, KEK has a rich program of future projects in particle and nuclear physics, and preparatory work for these projects is active. At present the future prospects for KEK in the world are outstanding. Thus the research plans of KEK are important for the future of the entire field of particle and nuclear physics.

Of the three future projects at KEK, the linear collider will require the largest construction budget, and will proceed as an International Linear Collider (ILC). The site of the ILC is not yet decided. SuperKEKB is a project located at the KEK Tsukuba campus and J-PARC is a project at the Tokai campus.

To decide the future plan for KEK, it is necessary to find the best way to push forward the important studies mentioned in the previous section, which are summarized in Table 1. In the following, we explain them briefly. More details are found in the next section and in the second part of this report.

For elementary particle physics, results from LHC will be important to decide the direction for physics in the future. The research plan at KEK should be flexible enough that it can detail the properties of the Higgs particle and new particles in the TeV mass range, and that it allows us to tackle important issues in elementary particle physics even if LHC finds no new particle other than a standard-model-like Higgs. In this regard, the three projects, ILC, SuperKEKB and J-PARC, are all important as they play different roles. The ILC will aim at direct production of the Higgs particles and other new particles discovered at the LHC. SuperKEKB will perform precise measurements on the third-generation quarks and leptons, explore physics at a high-energy scale indirectly and in particular clarify its flavor structure. J-PARC will perform similar studies for the second-generation quarks and leptons.

The importance of neutrino experiments has been increasing. The neutrino program at J-PARC faces stiff competition from experiments in other countries. In addition to a long baseline neutrino experiment at CERN-Gran Sasso, preparation of an experiment at the Fermi National Accelerator Center (FNAL) with a higher intensity neutrino beam is in progress. Furthermore, there are many proposals for reactor-based neutrino oscillation experiments around the world.

In B physics, the B factory experiment at the Stanford Linear Accelerator Center (SLAC), which has been competing against the KEK B factory, will end within a few years. A new experiment at LHC, the LHCb experiment that is dedicated for B physics, will start in 2007. It will provide information complementary to the Belle experiment at KEKB, in particular studies of B_s mesons.

In nuclear physics, J-PARC will provide various opportunities. As for studies of hypernuclei and exotic hadrons, there are measurements that are unique to J-PARC, while some studies will face competition from experiments at JLab in the United States and Frascati in Italy. In the area of high-temperature high-density nuclear matter, studies of quark-gluon plasma are in progress at the Brookheaven National Laboratory (BNL) in the United States, and heavy ion collision experiments will also start at the LHC. J-PARC, on the contrary, will become an important place to study low-temperature high-density states. At GSI in Germany, although the heavy-ion experiments are being given priority, a comprehensive study at a new facility that is equipped with a proton beam is being planned. If it is approved, many experiments will compete against studies at J-PARC.

More detailed comparisons between overseas facilities and KEK projects will be given in the second part of the report. To conclude, the three proposed projects at KEK will enable us to perform cutting-edge studies in the face of world-wide competition.

2 Recommendations on research plans for particles and nuclear physics

2.1 Recommendations

This committee recognizes the importance of the three projects, and recommends that the IPNS should maximize the physics outputs by realizing all of the three projects. The required budget and the time scale of each project are quite different. Therefore, the overall research plan should be such that the highest priority can be moved in a flexible manner from one project to another at the right time. In order to produce important results on particle and nuclear studies at the IPNS, the committee makes the following recommendations:

1. **At J-PARC, perform steadily the highest priority studies (the neutrino experiment, particle and nuclear experiments with kaons), which were assessed by the previous IPNS-RPC in 2002. To this end, it is important to recover the linac beam energy of 400 MeV by 2010 so that a high-intensity beam can be provided. Also, construction of multiple beamlines should be pushed forward so that a variety of experiments can be carried out at the same time.**
2. **Convert KEKB to SuperKEKB, and start the experiment in the beginning of the 2010's.**
3. **Proceed now with ILC R&D actively, and realize the experiment in the latter half of the 2010's in the framework of international collaboration.**

To carry out all of these projects, a large budget for construction and operation as well as significant human resources are required. Therefore,

4. **Form crossover R&D teams so that common issues of different projects are addressed in an efficient way. In addition, call actively for the participation from foreign institutions, and prepare a better system to handle contributions from foreign institutions.**

In the following, we overview each project and explain the reasons that we set the time ordering mentioned above.

2.2 J-PARC

The previous IPNS-RPC in 2001-2002 evaluated the physics cases and priority of proposed experiments at J-PARC. This committee believes that the conclusions of the previous committee [1] are still valid. After the report was submitted, however, there were some new experimental results and some important changes in the J-PARC machine parameters.

As for new experimental results, there has been great progress in neutrino experiments as well as experiments in strangeness and hadron nuclear physics.

1. New results from Super Kamiokande, K2K, KamLAND, SNO etc. have established neutrino oscillations. It has now been confirmed that the flavor structure of the Maki-Nakagawa-Sakata (MNS) matrix that describes neutrino oscillations is quite different from that of the CKM matrix for quark mixing. It is now urgent to determine the mixing angle θ_{13}, which is the only remaining unmeasured angle of the MNS matrix.

2. A KEK experiment reported an existence of deeply-bound states between a kaon and a light nucleus, which, in addition to hypernuclear physics, provides clues to explore high-density hadron many-body systems. In addition, the LEPS experiment at SPring-8 found evidence for pentaquarks, new baryons that include anti-strange quarks, which opened up a new hadron spectroscopy.

There is also steady progress in the R&D for kaon rare decay experiments and a high-intensity muon beam at J-PARC.

On the other hand, due to the tight funding situation, it has become evident that the initial performance of the J-PARC accelerator in 2008 will not reach the level that was assumed in the previous IPNS-RPC report.

Because of the reduced design of the linac, the neutrino beam intensity, which is approximately proportional to the beam power, will be half of the expected value originally assumed by the previous IPNS-RPC. The key to the success of the neutrino experiment is the beam intensity, and the most important feature of J-PARC is the expected high beam intensity. Since there are many competing neutrino programs in the world, with or without accelerators, the most important task at J-PARC is to restore the capability to achieve the high beam power that was originally planned.

At the hadron experiment facility that uses the slow extraction beam, at the beginning there will be only one secondary beamline. J-PARC will be the leading facility for particle and nuclear studies with kaons, such as hypernuclei spectroscopy, and researchers from all over the

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[1] The IPNS research plan committee, “Recommendations for Particle and Nuclear Physics Experiments at the JHF 50 GeV Proton Synchrotron”, KEK Report 2002-11, http://www-conf.kek.jp/ipns-rpc/2001-2002/drafts/Ereport_20030225.pdf.

world will join the experiments. It is inefficient to operate the J-PARC accelerator with only one secondary beamline for a long period, which will also compete with the neutrino experiment. Compared to the total budget of J-PARC, additional secondary beamlines can be constructed with modest cost. Restoration of the potential to achieve the high intensity of the primary beam at an early stage of J-PARC, which was mentioned above, will further strengthen the motivation for additional secondary beamlines.

This committee believes that the fully-equipped J-PARC phase I will start only if the aforementioned two issues, the restoration of the original linac performance and construction of additional beamlines, are realized.

With this fully-equipped J-PARC, the best measurement of the last mixing angle of neutrino oscillation θ_{13} will be provided. It is also possible, depending on the value of θ_{13}, that such a measurement will lead to a future discovery of the complex phase of the neutrino mixing matrix. In this case, the amount of CP violation will be determined both in the quark and lepton sectors. Additional secondary beamlines will allow us to perform spectroscopy of many hypernuclei, studies of bound states of kaonic nuclei and examinations of pentaquarks in parallel. These will lead to breakthroughs in nuclear physics. Furthermore, the first step toward the precision measurement of rare kaon decays can be carried out.

From the considerations above, this committee believes that the highest priority now is to restore the original specifications of J-PARC. To this end, it is important to recover the linac beam energy of 400 MeV by 2010, so that the potential for the original planned high beam intensity is available. The committee also recommends the construction of multiple beamlines in order to carry out a variety of studies.

Physics at J-PARC is not limited to the topics mentioned above. There are a wide range of proposals for hadron experiments with the primary beam, kaon rare decay experiments, experiments with a high-intensity muon beam, and experiments with antiprotons. Realizing such a diverse range of experiments is an important indicator of the success of the J-PARC project. Therefore, it is important to start preparation for experiments at J-PARC phase II at an early stage in the future. To carry out such studies, we need a comprehensive examination of the physics impact of the phase II proposals. The physics program at J-PARC phase II also depends on the achieved beam power and construction of additional beamlines.

2.3 SuperKEKB

The Belle experiment at KEKB discovered CP violation in the B meson system and confirmed that the dominant source of CP violation in the quark sector is the Kobayashi-Maskawa phase. Precision measurements for various B decays were also obtained, which lead to a much improved determination of the CKM parameters. Researchers in Japan played central roles in both theoretical and experimental aspects of these achievements in quark flavor physics.

The performance of the KEKB accelerator has improved year by year, offering an ideal experimental environment. Against a backdrop of heated competition against the BaBar experiment at SLAC, the performance of the KEKB accelerator now exceeds that of the SLAC accelerator (PEPII). With further improvements expected by introducing crab cavities in 2006, the KEKB accelerator will continue to lead the world in studies of B mesons for the near future.

The main issue for the present B factories so far is to clarify whether or not the Kobayashi-Maskawa phase is the dominant source of CP violation in quark transitions. However, now the central theme is moving towards searches for deviations from the standard model that arise from new kinds of mixing and new sources of CP violation. With a large improvement in the performance of the KEKB collider, the SuperKEKB collider will allow us to detect effects of new elementary particles at the TeV mass scale in transitions governed by loop diagrams. SuperKEKB is also expected to determine if there is a new CP violating phase beyond the Kobayashi-Maskawa phase. By combining results from SuperKEKB with those from LHCb and kaon experiments, we will obtain important information needed to explore the origin of CP violation and the mechanism of baryon number generation in the universe.

SuperKEKB and other flavor experiments will provide information complementary to those from energy-frontier experiments that can produce new particles directly. If new particles in the TeV region are found and their masses measured at the LHC, precise measurements of $b \to s$ transitions and searches for effects beyond the standard model in multiple channels including $\tau \to \mu$ transitions at SuperKEKB become important to understand the basic structure of interactions in the TeV energy region. Through loop diagrams, it is also possible at SuperKEKB to detect effects of new physics at energy scales even higher than what is directly accessible at the LHC.

An experiment dedicated to B meson studies (the LHCb experiment) will start in 2007 at the LHC. Although LHCb can measure properties of B_s mesons, which have not been studied well, an e^+e^- Super B factory is needed to carry out the important precision measurements to achieve the physics goals mentioned above.

A test of crab cavities at KEKB is planned in 2006. R&D for each detector component and readout electronics for the SuperKEKB detector is also being carried out actively. Therefore, we believe that an early realization of SuperKEKB is feasible from a technical point of view. This committee stresses that the KEK B factory has been leading the world so far, and believes it is important that KEK continues to be a world center for studies of B mesons and τ leptons.

If SuperKEKB starts at the beginning of 2010's, it is foreseen that during the first five years the statistics will double in a short period and the statistical precision of many measurements will be improved. Thus synergy between measurements at SuperKEKB and those at the LHC is expected. If the upgrade to SuperKEKB is not carried out and long-term operation of the present KEKB accelerator is assumed, the data-doubling time will be ten years by 2015 and the resulting cost performance ratio will be low. Furthermore, it is impossible without the upgrade to reach the statistics that are expected with a few years of SuperKEKB operation.

About 50 ab^{-1} of data are needed to reduce the experimental uncertainties of some key measurements on B mesons to the levels of hadronic uncertainties. To reach such precision, about ten years of data taking will be required even at SuperKEKB. Whether such long-term data taking is needed or not depends on the physics output of SuperKEKB in the first five years, and on results from the LHC and other experiments. Therefore, the latter half of the operation should be decided flexibly, depending on the results from SuperKEKB and also the status of ILC construction. Continuous improvement in performance has been realized in the operation of the present KEKB accelerator. It is also essential at SuperKEKB to aim for a higher luminosity than the present design value with such a program of continuous improvements.

As mentioned above, an early start of construction for SuperKEKB is technically feasible. SuperKEKB allows efficient data taking with a small data-doubling time. Synergy with the LHC is also expected by operating SuperKEKB at the same time that the LHC is running. This committee therefore believes that it is important to convert KEKB to SuperKEKB, and recommends starting the experiment in the beginning of the 2010's.

2.4 ILC

The ILC is an energy-frontier experiment within the clean environment of e^+e^- collisions. It offers opportunities to go beyond discoveries of new particles to detailed studies of their properties. The ILC, together with the LHC, plays an essential role in the experimental clarification of spontaneous electroweak symmetry breaking, which is one of the urgent issues in elementary particle physics today, as well as the identification of the origin of particle masses. Supersymmetry and other new ideas such as large extra dimensions have been proposed to resolve the hierarchy problem of the standard model; each new theory predicts some new particles. While LHC experiments are expected to discover these new particles, precision measurements of the new particles at the ILC are important to clarify the new principles of physics. This committee clearly recognizes the potential and the significance of the physics at the ILC.

An international framework called the global design effort (GDE) has been formed to realize the ILC, and world-wide efforts in R&D for both the accelerator and detectors are in progress. It is important for the IPNS to proceed with R&D on the ILC in close cooperation with the KEK accelerator division, so that the IPNS takes the lead toward the realization of the ILC experiment. However, the best design parameters for the ILC, such as the highest-possible collision energy, are subject to change depending on whether or not the LHC finds new particles, as well as the masses of the new particles found at the LHC. Therefore, this committee believes that the final design of the ILC should be optimized after obtaining initial results at the LHC.

There are large uncertainties on the location of ILC at this moment. After the ILC machine parameters are finalized, its site will be decided in a certain international framework based on an overall consideration of various factors such as accessibility, technical and financial advantages of the candidate sites and so on. To promote the ILC in such a situation, it is important to have original contributions from Japan on both the accelerator and the detector designs, with which it becomes possible to take the lead in the ILC activity.

From these viewpoints, this committee recommends proceeding actively now with accelerator and detector R&D to establish original technology in Japan, so that the ILC experiment can be started at the earliest possible time in the latter half of the 2010's.

2.5 Time ordering of the three projects

Of the three projects we have discussed so far, the ILC construction schedule has the largest impact on the roadmap of IPNS as it has the largest scale. To realize an early start of the ILC, a world-wide effort is being made following the initiative of the GDE. This committee clearly recognizes the significance of physics at the ILC. It is important to carry out R&D immediately for the accelerator and the detector, so that ILC construction can be started as soon as possible after the results from the LHC become available.

However, the start of the ILC experiment will be in 2015 at the earliest. The probability that the project will be delayed is high, depending on the need for R&D, negotiations among governments and those for site selection. Furthermore, this committee believes that it is most reasonable to optimize the ILC parameters, such as the highest-possible collision energy, after LHC results are available. With these considerations, it is inadvisable to concentrate on the ILC by sacrificing other projects.

The approach in the United States appears to be the opposite; almost all high-energy colliders will be terminated by 2010 to concentrate on the ILC R&D, except for neutrino oscillation experiments. As a result, there will be few high-energy accelerators in operation in the world after 2010. As both J-PARC and SuperKEKB become the leading accelerators in the world in terms of the beam intensity or luminosity, they will allow us to lead particle and nuclear studies in the world and to carry out experiments that are complementary to the LHC.

If we are able to start J-PARC with a sufficient beam intensity as early as possible and take the lead in the keen world-wide competition for neutrino oscillation experiments, and can also proceed to particle and nuclear studies with multiple beamlines, the J-PARC facility will be fully efficient and a steady stream of discoveries can be expected.

As for SuperKEKB, a test of crab cavities at the present KEKB collider is planned in 2006, and an early start of SuperKEKB is feasible from a technical point of view. With the SuperKEKB upgrade, efficient data-taking with a small data-doubling time can be continued. Physics results on decays of B mesons and τ leptons from SuperKEKB then provide powerful synergy with the LHC experiments.

Constructing SuperKEKB immediately after the construction of J-PARC, followed by the ILC experiment that aims to start taking data in the latter half of 2010s, is the best scenario for KEK. In this way KEK can fully utilize existing facilities and the existing research environment. More importantly, in this way KEK can offer a research environment that leads the world for a long period in the decades following 2010 and 2020. Together with results from the LHC, the physics output from KEK will make a large contribution to the understanding of nature. This scenario also allows us to continuously produce physics output while constructing a next generation accelerator, which is very effective for education of graduate students and for training of the next generation of researchers.

2.6 Developing new approaches for the three projects at IPNS

To carry out these three projects, we may face shortages in both budgetary and human resources. The proposed priority and time ordering in this report are also subject to change, depending on the physics output in the near future. To carry out research efficiently and flexibly under such circumstances, we would like to give additional suggestions on possible new approaches for the three projects at IPNS.

Establishing cross-sectoral research activities As the complexity and the size of each project become large, a large amount of R&D is needed to build a new detector and its data taking system. We point out that a considerable part of such R&D efforts can be shared among different experiments. Other aspects of experiments, such as methods of data analyses, development of event simulators, efficient use of computing resources etc., also have many common issues. The physics goals are in part competing but are also complementary to each other at the same time; the best understanding of nature is obtained only by combining all results. Therefore, this committee recommends that the core people of each project, who tend to restrict themselves to their present activity, form study groups that span across these projects and proceed to R&D in close cooperation. In this regard, the newly established KEK Detector Technology Project is an important example of the approach that we suggest, and such activities should be encouraged.

IPNS activities will be extended to multiple experimental sites in the future. The new cross-sectoral approach is also useful to keep different divisions of IPNS united.

Promotion of international organizations The three projects will lead particle and nuclear studies in the world for more than a decade, and thus they are also attractive to researchers in foreign countries. Therefore, each project is asked to further promote international collaboration, to increase the number of collaborators from foreign countries, and to make an effort to obtain more financial contributions from foreign institutions. Although KEK already has a large amount of experience in international collaboration as a host institute, many problems remain in accepting and managing financial contributions from abroad. KEK was previously a national laboratory but is now an inter-university research institute corporation, which has much greater flexibility. We think it is important that KEK studies the systems at foreign laboratories and promotes internationalization beyond the present level.

Last of all, we would like to emphasize the importance of public relations. Particle and nuclear studies are activities to explore the fundamental building blocks of nature and the forces among them, and understand how the world is made of them. Such efforts are guided by the intellectual desire to resolve the fundamental enigmas of nature. The outputs of such research are not necessarily reflected immediately in our daily life. However, they contribute to our society in a way that they create valuable intellectual properties and offer new ways to view the world. This point should be actively promoted and explained to public. To construct and operate modern large-scale accelerators and detectors, a large amount of R&D is needed, which often leads to technological innovations. It should also be strongly emphasized that such innovations are the key to future developments in our society. Since research is supported by huge investments in construction and operation, it is important in return to explain the charm and achievements of our studies to the general public. Recent progress at KEK in this area is remarkable; a PR office has been set up and the communication plaza is open. Such efforts should be continued both at an individual level and at the level of the entire research community, so that further contributions to society are promoted.