Recommendations for Particle and Nuclear Physics Experiments at the JHF 50GeV Proton Synchrotron

The Author

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Introduction

According to the regulation [1], the charge of Research Plan Committee of the Institute of Particle and Nuclear Studies (IPNS) is defined as follows. "Upon request of the director of IPNS, the committee (1) investigates long range physics research programs and related projects, and (2) examines the progress and outcome of current research activities and makes recommendations for improvements ."

Among various future projects of IPNS, we decided to investigate the most urgent issue, – how should IPNS conduct experiments at the 50GeV proton synchrotron (hereafter abbreviated as the 50GeV PS) at JHF. We had meetings that totaled 10 days in the period of October, 2001 to September, 2002. We first invited 19 experts in various fields of particle and nuclear physics, to give reviews on the current status and future prospect of their field. We then discussed from various aspects on how to select and carry out experiments at the JHF 50 GeV PS, especially considering their physics importance. Here, we report our view and conclusions that we have reached unanimously in this committee.

1 Grand View of Particle and Nuclear Physics, and JHF

The goal of particle and nuclear physics is to understand the ultramicroscopic world, namely the most fundamental level of Nature. In the second half of the 20th century, this field made a rapid progress along with the advance of accelerators. Discoveries of new elementary particles have uncovered the fundamental interactions and their symmetries. In addition, together with studies on hadronic and nuclear structures, we have obtained a unified picture of the basic structure of matter and the history of the universe, founded on quantum theory and relativity.

[1] The IPNS research plan committee regulation (KEK regulation No.35 dated April 25, 1997 and its revision, regulation No.16, dated June 7, 2001)

In spite of such major efforts for understanding Nature, a multitude of challenging questions remains. A part of them are deeply connected to the basis of our very existence: the mass generation mechanism of fundamental particles, the origin of fundamental interactions, matter-antimatter asymmetry, the hierarchy problem between weak force and gravity, the source of spacetime structure, etc.. It has also became clear that multi-particle systems have a variety of quantum phenomena such as new forms of nuclear matters under extreme conditions, exotic nuclear structures of hypernuclei and nuclei far from stability, etc.. These questions or possibilities impress us of the depth and the extent of Nature and stimulate more than ever the intellectual curiosity of us human beings. Entering the 21st century, we are about to step into a new stage to challenge these unsolved problems.

The most direct means to look into the ultramicroscopic world is energy frontier experiments with high energy accelerators. While Tevatron currently being at the forefront, the LHC under construction and linear colliders being planned will push this energy frontier further forward, and lead us to deeper understanding of Nature, such as the origin of the elementary-particle masses. However, raising energy is not the only way. Even at a relatively low energy, one can still study physics at high energy scale by searching for rare phenomena with high intensity accelerators. Neutrino oscillation and B factory experiments are some of those good examples. In fact, such luminosity or intensity frontier experiments are the only means to access physics at the high energy scale that is beyond the reach of any high energy colliders.

For elucidation of the matter phases under extreme conditions, and new phenomena in quantum many-body systems, it is important to have systematic studies by varying parameters such as temperature, baryon density, strangeness, spin, isospin, etc.. For instance, the experiments for producing quark-gluon plasma with high energy heavy ion collisions at RHIC or LHC aim at investigating phase transitions of nuclear matter at high temperature. These are energy frontier experiments in the field of nuclear physics. On the contrary, nuclear physics experiments utilizing strangeness or hadrons as a probe, and experiments producing unstable nuclei by RI beams, can study various nuclei and nuclear matter phases that appear in neutron stars and supernovae. These are intensity frontier experiments in nuclear physics.

Therefore, high intensity accelerators cover wide range of particle and nuclear physics. The proton synchrotron at JHF will deliver the world's highest intensity (0.75 MW) beam, 3×10^{14} 50GeV protons every 3.4 s. This machine will make an important contribution to the world-wide physics community by offering a unique facility to open a new high intensity frontier of particle and nuclear physics in the 21st centry.

In particle physics, the JHF will contribute to neutrino oscillation physics, precision CP violation studies, searches for flavor violation, etc.. In nuclear physics, the JHF can study multi-body system of quarks and gluons by using strangeness and hadrons as probes. In addition, mass production of antiprotons will open up a new era of antiproton science.

As listed above, the JHF has many research programs that are expected to produce high quality results. These programs will complement other domestic and international energy frontier experiments, and together, they will accelerate the balanced progress of particle and nuclear physics fields in this country.

We should also stress that the JHF will also serve as a base to grow new generation of talented particle and nuclear physicists.

2 Basic Guidelines for the JHF 50GeV PS Programs

We recommend the following two basic guidelines for the JHF 50GeV PS to maximize the physics output from Phase 1 and Phase 2. [2].

1. **High priority should be given to scientifically important and urgent programs which Japan can take leadership.**
2. **Research programs should be established to pursue wide variety of physics utilizing the characteristics of JHF. The time line of these programs should be optimized to maximize the overall efficiency.**

3 Review and Recommendations for Each Program

Based on the basic guidelines described above, we have grouped experiments that had been considered into the following six programs for our reviews and discussions.

- Neutrino oscillation experiments (ν)
- Rare K decay experiments (K decay)
- High intensity muon physics (μ)
- Strangeness nuclear physics (Strangeness)
- Hadron physics (hadron)
- Antiproton science ($\bar{p}$)

Details of each program and its review are described in the full report (only available in Japanese). Here we list the executive summary of our review and recommendations on each program.

Neutrino oscillation experiments

Japan has been leading the field of neutrino oscillation, and recent observations have established the first signature of physics beyond the standard model. The mixing between generations in the neutrino sector was found to have a totally different structure from mixing

[2] Phase 1 is the period correponding to the approved 135 billion yen budget, and Phase 2 is the following period corresponding to 54 billion yen budget.

in the quark sector. This suggest that an unknown physics mechanism is behind neutrino oscillation. Neutrino physics should be pursued further, since the overall structure of neutrino mixing is still unclear; e.g. $\nu_\mu \to \nu_e$ oscillation has not been observed yet. The neutrino experiment at JHF can shoot neutrinos to Super Kamiokande with an intensity >100 times that of K2K. Not only will the experiment at JHF measure the oscillation parameters accurately, its future plan has the potential to discover CP violation in the lepton sector. Considering the importance of this physics, future potential, and competing experiments in the world, this program should be given high priority and the construction of the beam line should be started as soon as possible.

Rare K decay experiments

The CP violation due to Kobayashi-Maskawa mechanism has been established by the ϵ'/ϵ measurements at CERN and Fermilab, and by the high luminosity B factories at KEK and SLAC. The next step is to search for a CP violation caused by a physics beyond the standard model. These new CP violation sources can be searched for by precise measurements of the branching ratios of $K_L \to \pi^0\nu\bar{\nu}$, $K^+ \to \pi^+\nu\bar{\nu}$, and by a search for T-violation in $K^+ \to \pi^0\mu^+\nu$. Although it is ideal to do all these experiments, the kaon community should choose one of them for the start up phase of JHF, considering the efficiency and reality. The committee recommends the $K_L \to \pi^0\nu\bar{\nu}$ experiment. The experiment has a potential to achive the first observation of the decay by upgrading the current KEK PS E391a experiment for JHF Phase I, thereby to establish a base for a precise measurement of the branching ratio. However, before continuing on to the experiment in Phase II, it must be reviewed for its feasibility.

High intensity muon physics

Supersymmetric Model is one of the promising models to solve the hierarchy problem. The model predicts new phenomena beyond the standard model, such as the lepton number violating transition, $\mu \to e$. JHF can cover a wide range of predicted $\mu \to e$ transition rates, by using high quality and high rate muons produced by the high intensity 50GeV PS. The proposed plan uses ambitious technologies such as PRISM, to achieve 10^4 times larger intensity than existing facilities. The R&D of technologies necessary for the discovery of $\mu \to e$ should thus start immediately. These new technologies are not limited to the $\mu \to e$ experiment; they can be applied for high intensity muon facilities, and such facilities can evolve into a neutrino factories, and high energy frontier experiments. Considering these possibilities, the high intensity muon physics program has strategic importance, and can make international contributions to the future of the particle and nuclear physics.

Strangeness nuclear physics

Japan has been leading the strangeness nuclear physics by developing innovative experimental methods. It has deepened our understanding of nuclear force involving strangeness, as acknowledged internationally. At JHF, the high intensity secondary beams will allow further systematic studies on the structure of hypernuclei, and hyperon–nucleon scattering. Through the properties of nuclear matter with strangeness, these studies will lead to the basic understanding of the nuclear forces. In addition, they will also offer important information required to build theoretical models for high density nuclear matter such as neutron stars. Since many of the proposed experiments are expected to produce new results from the early stage, they should be prioritized properly, and run in series from the JHF start up time. The entire program should be further developed by introducing new detectors and secondary beamline(s).

Hadron phyiscs

The hadron physics experiments can open a unique field utilizing the high intensity beams from JHF. The main focus will be on the study of structure functions of nucleons and nuclei, and the observation of non-perturbative QCD phenomena such as partial restoration of chiral symmetry in nuclei. These are studied by observing lepton pairs produced by high intensity primary or secondary beams. The program covers wide variety of studies, including some proposals from foreign countries. Therefore, multi-purpose beamline and detectors should be built, and the program should be continued in a long time span. Heavy ion acceleration for producing high density nuclear matter can lead to a new physics frontier, but the competitiveness against GSI should be taken into account.

Antiproton science

One of the antiproton programs at CERN-AD, lead by a core Japanese group, recently succeeded in mass-production of anti-hydrogens. This success has marked a new era in the antiproton science. The high-intensity antiproton beam at JHF can contribute to a wide field in science, ranging from basic science to various applications; the test of CPT, measurement of neutron-matter distributions in unstable nuclei, medical applications, etc.. The decision on the antiproton facility at JHF highly depends on the future plans of similar facilities in the world. JHF can produce low energy and high intensity beam in *DC mode*, and this feature should be a part of the plan for the JHF-$\bar{p}$ program to be competitive.

The star rating of each program is shown in Table 1.

4 Recommended Grand Plan for the JHF Programs

Based on our basic guidelines, and the review and recommendations on each physics program, we recommend the following grand plan for the 50GeV PS at JHF. Figure 1 shows the time line of the plan.

1. **Build the neutrino beam line as soon as possible, and push the neutrino oscillation program with the highest priority.** [3]
2. **In order to support wide variety of nuclear physics and high energy physics experiments, start strangeness nuclear physics and rare K decay (e.g. continuation of E391a experiment at JHF) experiments from Phase 1, as they are expected to produce steady results.** [4]
3. **The muon program must be developed to get physics output in Phase 2. It should start identifying and studying technological problems and test the feasibility (phase A study).**

[3] Note: The neutrino beam line is not included in the budget for the Phase 1. This recommendation is telling the laboratory to get extra funding for the neutrino beam line.

[4] Note: A part of A-line is included in the budget for the Phase 1, and these experiments uses the secondary beams from the A-line.

Program	Importance of physics for the first stage of JHF	Urgency	Feasibility	Cost		Man-power	Com-ments
				Facility	Detectors		
ν	$\star\star\star\star$	$\star\star\star$	$\star\star\star$	¥¥¥	¥¥	MMM	
K decay	$\star\star$	$\star\star\star$	$\star\star$	¥$\rightarrow$ ¥¥	¥$\rightarrow$ ¥¥	MM	1)
μ	$****$ see 2)		$\star$	¥¥¥	¥¥	MM	3)
Strangeness	$\star\star\star$	$\star\star$	$\star\star\star$	¥$\rightarrow$ ¥¥	¥$\rightarrow$ ¥¥	MMM	4)
Hadrons	$\star\star$	$\star$	$\star\star$	¥¥	¥	MM	
$\bar{p}$	$\star$	$\star$	$\star\star\star$	¥¥¥	¥	MM	5)

Table 1: Star ratings of the JHF programs

"Importance of physics for the first stage of JHF" includes the international competitiveness.
"Urgency" takes international competition into account.
"Feasibility" takes into account the amount of required R& D work.
"Facility" and "Detector" show rough costs estimated by the committee; ¥:<\$10M, ¥¥:\$10∼50M, ¥¥¥\$>50M (assuming \$1M = 100M yen).
"Manpower" shows the estimated number of physicists who will work on the program; MM:O(10^1), MMM:O(10^2).
1) The program is assumed to take two steps, and shown in a format: step 1 $\rightarrow$ step 2.
2) Since this program has a potential to lead to a new generation of particle and nuclear physics experiments, we rated the importance of starting R&D early.
3) It is too early to judge its feasibility at this moment. It should be reviewed after proving the basic idea and studying technological problems. The "Facililty" includes the cost for the experimental hall.
4) The costs are shown in a format: Phase 1 $\rightarrow$ Phase 2. Phase 1 uses the existing detectors moved from KEK. Phase 2 assumes the upgrade/construction of beam line and detectors. The extension of K-Hall is also necessary for Phase 2.
5) The importance and the number of users will increase if GSI and CERN decide not to have $\bar{p}$ programs.

For Phase 2, the B-line/C-line and the extension of the counter hall should be constructed as originally planned, as these are required for running K decay, strangeness nuclear physics, and hadron physics experiments. While continuing the above programs:

4. **Run series of hadron physics experiments in the latter half of Phase 1 and Phase 2.**

5. **If necessary, start the $\bar{p}$ experiments from Phase 2. However, the decision highly depends on the plans of foreign $\bar{p}$ projects.**

All these programs should be reviewed at proper stages, and this overall plan should be revised if necessary. Especially, we recommend to give a higher priority to the muon program if its phase A studies give promising results.

These recommendations are made mainly based on the physics importance. Techinical reviews should be done in the future, in order to closely examine feasibility of each experiment once LOI or proposal are submitted, and to take into account the accelerator plan for reaching the designed intensity.

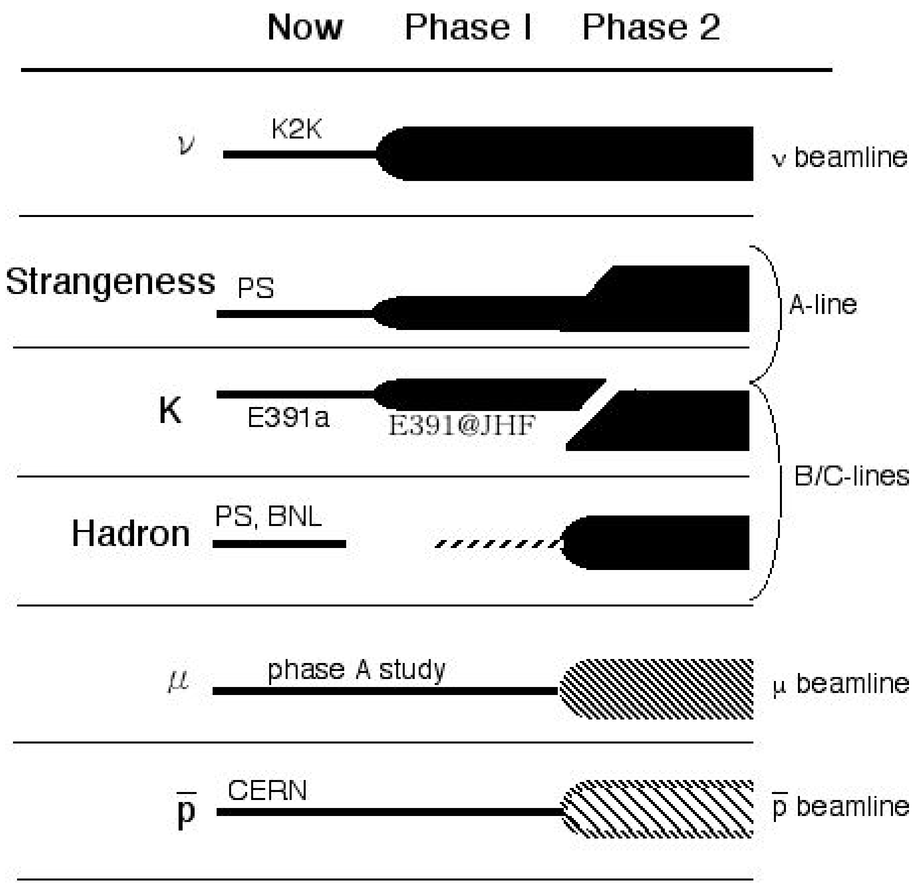

Figure 1: The time line of the overall plan of JHF programs. The muon program in Phase 2 depends on the result of phase A study. The $\bar{p}$ science program depends on the plan of foreign competing projects.

Appendix B. Members

Term June 1, 2001 to March 31, 2003

Name	Position	Note
Enyo, Hideto	Chief Researcher, RIKEN	Nuclear Physics
Okada, Yasuhiro	Prof., Physics Research Division 2*	Theoretical Physics
Kamiya, Yukihide	Director, Accelerator Laboratory*	Ex Officio
Kim, ShingHong	Prof., Physics Division, Univ. of Tsukuba	High Energy Physics
Kurokawa, Shin-ichi	Deputy Director, Accelerator Laboratory*	Ex Officio
Kondo, Kenjiro	Director, Applied Research Laboratory*	Ex Officio
Sakurai, Hiroyoshi	Assoc. Prof., Grad. School of Science, Univ. of Tokyo	Nuclear Physics
Takahashi, Tadayuki	Prof., CAST, Inst. of Space & Astronautical Science (ISAS)	Cosmic Ray/Astrophysics
Tamura, Hirokazu	Assoc. Prof., Grad. School of Science, Tohoku Univ.	Nuclear Physics
Nakahata, Masayuki	Prof., Kamioka Observatory, ICRR, Univ. of Tokyo	Cosmic Ray/Astrophysics
Nakaya, Tsuyoshi	Assoc. Prof., Grad. School of Science, Kyoto Univ.	High Energy Physics
Nojiri, Mihoko	Assoc. Prof., Grad. School of Science, Kyoto Univ.	Theoretical Physics
Hazumi, Masashi	Assoc. Prof., Physics Research Division 1*	High Energy Physics
Hatsuda, Tetsuo	Prof., Grad. School of Science, Univ. of Tokyo	Theoretical Physics
Hikasa, Ken-ichi	Prof., Grad. School of Science, Tohoku Univ.	Theoretical Physics
Fujii, Keisuke	Assoc. Prof., Physics Research Division 2*	High Energy Physics‡
Miyatake, Hiroari	Assoc. Prof., Physics Research Division 4*	Nuclear Physics
Yamanaka, Taku	Prof., Grad. School of Science, Osaka Univ.	High Energy Physics†
Yoshimura, Koji	Assoc. Prof., Physics Research Division 3*	High Energy Physics
	* : committee member from the inside of KEK	† : Chair, ‡ : Secretary

Appendix C. Record of Meetings and Events

- 1st Meeting
  Date: Fri., Oct. 12, 2001
  Place: Seminar Hall, Building 4, KEK
  Major Subjects: Nomination of the chair and the secretary. Director's explanation on the charge of the committee. Review talks by Nakao, Ohda, Lim, Kobayashi, Sawada, Ishiyama on Belle, hyper nuclei, K, K2K, the joint project, Unstable nuclei, respectively. The committee chose as its first matter for discussion how to carry forward experiments at JHF.

- 2nd Meeting
  Date: Fri., Feb. 22, 2002
  Place: Seminar Hall, Building 4, KEK
  Major Subjects: Review talks by working group conveners of NP01: Ieiri, Sawada, Komatsubara, Kuno, Nishikawa, on strangeness, hadron, K, μ, ν, respectively. Discussion on the scope of the report, how to proceed, and how to come to a consensus.

- 3rd Meeting
  Date: Fri., Apr. 12, 2002
  Place: Meeting Room 1F, Building 3, KEK
  Major Subjects: Review talks by Yamauchi, Tanaka, Matsui, Imai, Tanihata, respectively on present status and future perspectives of B, hadron colliders, linear collider projects, nuclear physics outside JHF, from the project promoters' point of view. Discussion on the scope of the report and the way to proceed.

- 4th Meeting
  Date: Fri., May 17, 2002
  Place: Meeting Room 1F, Building 3, KEK
  Major Subjects: Review talks by Hiyama and Yamaguchi on the present and future of theoretical nuclear and particle physics. A report by Nagamiya on the current status of the JHF project. Discussion on the matters to work out, how to process and share them, and the schedule. Formation of working groups corresponding to individual research programs and designation of their working group conveners. The conveners were asked to prepare tentative proposals for discussion by the next meeting.

  From the view point of the balance among different disciplines, the working groups were setup as follows:
  ν: Nakaya, Kurokawa, Sakurai, Tamura, Nakahata, Nojiri, Fujii
  K: Yamanaka, Okada, Kamiya, Takhashi, Hazumi, Miyatake
  μ: Yoshimura, Kurokawa, Nakahata, Hikasa, Yamanaka
  Y: Tamura, Takahashi, Nojiri, Fujii, Miyatake
  Hadron: Enyo, Kondo, Kim, Hazumi, Hatsuda, Hikasa, Yoshimura
  $\bar{p}$: Sakurai, Okada, Kamiya, Kim, Nakaya

- 5th Meeting
  Date: Wed., Jul. 19, 2002
  Place: Seminar Hall, Building 4, KEK
  Major Subjects: Parallel sessions of the individual working groups followed by a plenary session in which conveners reported the matters discussed in the parallel sessions. Exchange of opinions about the way to proceed, etc. The conveners were asked to prepare a draft based on discussions made in each parallel session and distribute it via mailing list.

- 6th Meeting
  Date: Tue., Jul. 23, 2002
  Place: Seminar Hall, Building 4, KEK
  Major Subjects: Parallel discussions within the individual working groups and a subsequent plenary session consisting of parallel session reports and discussions on them. The individual working groups were asked to revise their drafts into their almost final forms.

- 7th Meeting
  Date: Sat.&Sun., Aug. 17-18, 2002
  Place: Seminar Hall, Building 4, KEK
  Major Subjects: The working groups' reports and subsequent discussions on ν, K, μ, hyper nuclei, hadron over the period of two full days. Intensive discussions and resultant decisions on the structure and the scope of the final report including how to carry forward various research programs (Fig.1), star-rating (Table 1), etc.

- 8th Meeting
  Date: Sat., Sep. 7, 2002
  Place: School of Science, Univ. of Tokyo
  Major Subjects: The remaining working group reports and corresponding discussions on anti-proton and hadron physics. Intensive discussions on the contents of the report concerning star-rating, how to sort out and carry forward various research programs. The committee

decided to reflect what had been discussed to the drafts and to aim at finishing up the executive summary part of the final report in the next meeting.

- 9th Meeting
  Date: Tue., Sep. 17, 2002
  Place: Gakushi Kaikan Bunkan (Hongo)
  Major Subjects: Intensive discussions on the executive summary. The committee decided to collect all the possible feedback from the committee members by the next Thursday and, after some rearrangement, submit the summary to Director on Sep. 24.

- Tue., Sep. 24, 2002
  The committee submitted the executive summary (Part 1) to Director Yamada.

- 10th Meeting
  Date: Fri., Oct. 25, 2002
  Place: Meeting Room 4F, Building 4, KEK
  Major Subjects: Discussions on Part 2 that follows the executive summary, concerning grand view and individual experimental programs. Decision on the schedule for completion of the final report. The committee decided this meeting to be the last one dealing with this subject.

- Fri., Nov. 22, 2002
  The committee submitted the final report to Director Yamada.