Report of The B-Factory Project Review Committee

June 9, 2003

Executive summary

B-Factory project at KEK was approved in 1994, and the data taking for particle physics started in July 1999. An International committee was established to evaluate its past research activities and their impact on the society at large. The committee met on March 13 and 14, 2003 and, after formal presentations by members of the institute, made the following report.

The committee recognizes the outstanding achievements of the experimental as well as the accelerator(KEKB) group of the B-Factory project. An international collaboration team using the BELLE detector along with the BABAR group firmly established the validity of Kobayashi-Maskawa theory of CP violation (matter-antimatter asymmetry), a 35-year-old mystery in particle physics.
Instrumental to this success, was the early successful achievement of high luminosity in the KEKB accelerator which is now holding the world record in accelerator luminosity competing with the B-Factory at SLAC (PEP II).

Successful implementation and management of a large international collaboration of unprecedented scale in Japanese scientific history is to be commended.

This report comments on the impact on society, public relations, university research and education, and relation with industry.

Contents

1 Introduction

Particle physics is an amazing field where experiments reveal deep inner structure of the matter, and thereby open new strange world full of mystery. According to the big-bang cosmology, matter and antimatter are created equally. We know, for example, that the matter we know is but a small part of the universe that is dominated by the presence of dark matter and dark energy [1, glossary]. We do not know anything about the nature of this dark matter and dark energy. We do not even understand why matter is there at all. Because we live in a matter world, we know the matter-antimatter symmetry must be broken(CP violation). But the violation we have observed on earth so far is not enough to explain why the remaining matter world did not annihilate entirely with its anti-matter counterpart and why only matter survived. To explain CP violation is to understand the origin of the matter.

All particles around us, as well as the nuclei and the atoms we are made of, have mass but we do not know what generates this mass. We do not even know if the space we live in is three dimensional or just a part of hyperspace with higher dimension. Supersymmetry [2, glossary], a hypothesis for explaining the unification of all forces and matter, postulates the existence of a new kind of particle partner for each known fundamental particle. The large hadron collider (LHC [3, glossary]), the largest man-made accelerator will explore those questions towards the end of the decade and perhaps reveal new structure that would have deep implications for the decay of B-mesons observed at KEKB. What we observe in one must correspond to what we observe in the other if we are to have the correct understanding of the laws of nature. Observations of these effects at KEKB either before or in conjunctions with LHC could lead to a marvellous culmination of the successful development of KEKB and BELLE.

KEKB and PEP II at SLAC (Stanford Linear Accelerator Center in USA) are the most powerful tools ever produced to try to understand why matter and anti-matter are not exact mirror images of each other. These accelerators have produced the highest luminosities of any collider in the world and have allowed the definitive observation of CP violation in B-meson decays, the first time that this phenomenon has been observed outside of K-meson decays.

The observation has confirmed the remarkable inference of Kobayashi and Maskawa that the phenomenon of CP violation could be explained by the existence of an additional family of particles at a time when such a family was totally unknown and unexpected.

Now that this inference is proved, the program of KEKB will turn towards determining the effects on these asymmetries due to the possible new particles not yet known. Such observation would be a major breakthrough. This is part of a quest to understand the Universe at its most fundamental level.

2 Scientific achievements of KEKB

2.1 Physics

In the world of high energy physics researches, two topics, CP violation and neutrino physics, have dominated the large scale international conferences in the past five years. The first observation of CP violation was made in the K-meson system back in 1967 and already in 1973, Kobayashi and Maskawa predicted the existence of 6 species of quarks when only three were known and that the CP violation will follow if three species of the quarks having the same charge mix to form an entirely different entity (flavor mixing). The discovery of the fourth and fifth quark and, in particular, the sixth quark, the top quark, in 1994 convinced people the correctness of the KM theory so that it was incorporated into the framework of the standard model of elementary particles. However, the definitive test could only be accomplished using rare decays of B-mesons that contain the fifth quark. An accelerator with two orders of magnitude higher luminosity than previously available was required.

KEKB and PEP II are the two cutting edge tools that were built for this purpose. The BELLE collaboration at KEK and BABAR at SLAC were in severe competition because the construction of PEP II started only 6 months prior to KEKB. By now, stimulated by competition, both groups accumulated data at a remarkable pace and both groups presented a definitive proof of the KM theory that agrees well with each other at the same time in a short period. The proof was given in a form of a measurement of the angle (ϕ_1) of the so-called unitarity triangle [4, glossary] identifying the effect of the CP violation (Figure 1).

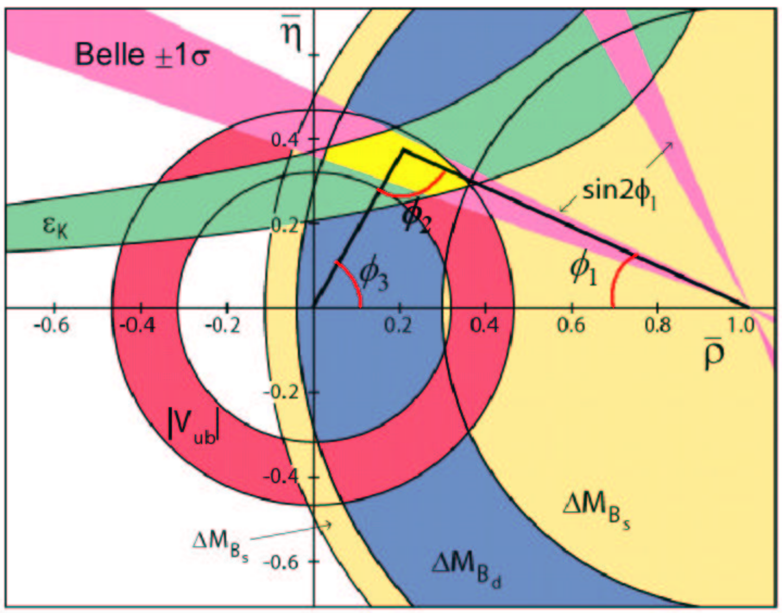

Figure 1: A picture showing the unitarity triangle and the measurement of the angle ϕ_1. The result of BELLE (and of BABAR) is right on the side of the triangle drawn using previous data; ε_K(green) derived from K-decays using proton machines, $|V_{ub}|$(red) obtained at CESR, ΔM_{B_d}(blue), ΔM_{B_s}(yellow) from LEP.

The confirmation of the KM theory can be considered as the major triumph for the standard model since the discovery of the top quark and sets a milestone for the advancement of our understanding of the fundamental nature of the matter. For details of the physics outputs from BELLE, we refer to the report of the Ninth Lepton Collider Program Advisory Committee on Physics (Appendix A.5). Some representative results of the BELLE group are:

- Precise measurement of $\sin 2\phi_1$ of the unitarity triangle in CP odd decay mode $B \to \psi K_s$.

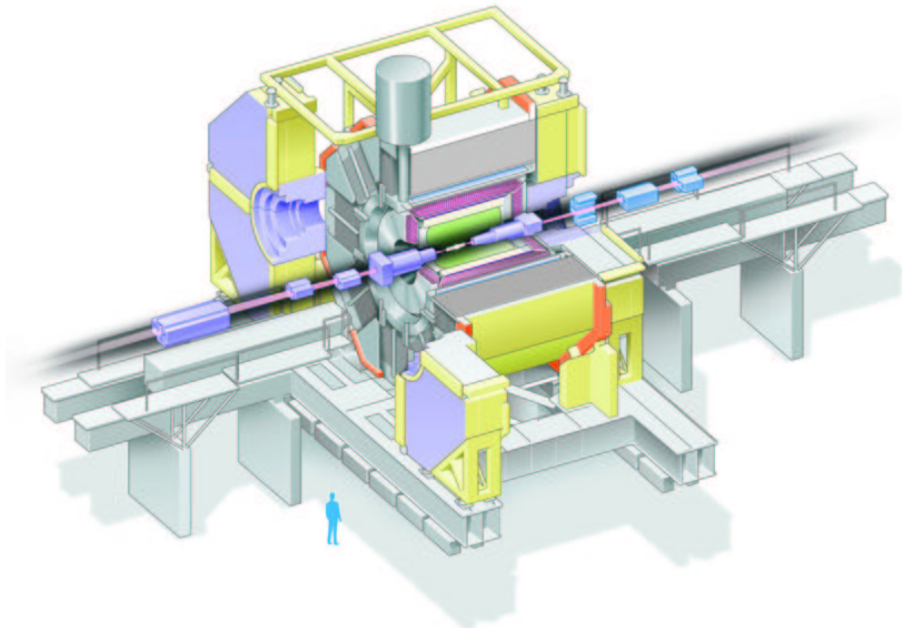

Figure 2: An isometric view of the BELLE detector

- Measurement of $\sin 2\phi_1$ in CP even decay mode $B \to \psi K_L(K^{*0})$.
- Measurement of CP asymmetry in $B \to \pi\pi$ which might shed some light on the angle ϕ_2
- Observation of a possible discrepancy between the decay rates of $B^0 \to \psi K_s$ and $B^0 \to \phi K_s$ which may hint a new physics.
- Measurement of $B \to l^+ l^- +$ hadrons with strangeness

In addition, both groups have long list of world's first observations of rare processes. The hint of new physics that the BELLE group has observed can only be proved by further investigation. The upgrading of KEKB accelerator to "Super KEKB" with one to two orders of magnitude higher luminosity is under study.

The physics achievement can be quantified as the number of publications. From 2001 to 2003, the BELLE collaboration has published 55 papers in refereed journals with high level of citations, gave 216 talks at international conferences, produced 38 Ph.D. theses (Appendix A.6).

2.2 Detector

The BELLE detector is capable of detecting, identifying and measuring nearly all the particles produced in the decay of B-mesons (Figure 2). Along with BABAR detector at SLAC, it is the most comprehensive detector ever to study these decays. The BELLE collaboration built many state-of-the-art components to measure the pions, kaons, electrons, muons and photons that come out of the decays.
Furthermore, they built a very precise silicon tracker to determine the position of the decays with great precision. Some of the detector components, like the aerogel cerenkov counter are

unique in the world. All of these components have performed well and are expected to be operational at higher luminosities than the original design.

2.3 Accelerator

KEKB is a very advanced charged particle accelerator and storage ring system providing collisions of positrons (3.5 GeV) and electrons (8 GeV) at an extremely high rate. The accelerator facility was constructed in five years which is a relatively short time in order to remain competitive with a similar project at SLAC in the US. In order to use all resources efficiently, to limit construction time and to keep cost at a minimum, facilities existing at KEK constructed for the previous electron-positron collider (TRISTAN) were re-used as much as possible.

The production of data started only a few months after the construction was completed in 1999. Already in 2001 a world record luminosity was achieved. Today it has reached the value of $8.4 \times 10^{33} cm^{-2} s^{-1}$, which is very close to the design value of $10 \times 10^{33} cm^{-2} s^{-1}$ (Figure 3). The integrated luminosity reaching $120 fb^{-1}$ is also renewing the world record every day. The evolution of the luminosity and the competence of the team make it very likely that the design value will be surpassed very soon[1].

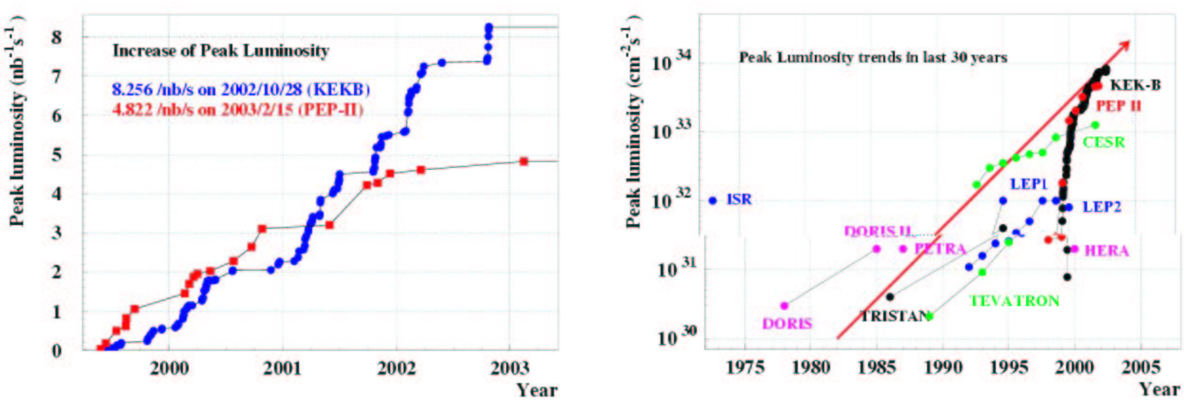

Figure 3: Peak luminosity of KEKB and PEP II since 1999(left), and of the world's colliders in the last 30 years(right)

This rapid achievement of the top performance was made possible because the design incorporated from the beginning very advanced concepts facilitating high luminosity operation. The most notable of these concepts are

- a finite angle crossing providing easier beam separation and control of background in the BELLE detector
- superconducting radio-frequency (rf) accelerating cavities for operation with high beam currents
- a novel type of coupled rf cavities providing high beam stability due to their very high stored electro-magnetic energy

[1] It was achieved on May 09, 2003

- a design of the magnetic lattice focusing and guiding the particles providing high flexibility and having a minimum of non-linearity
- the upgrading of the linear accelerator for injection at operating energy and, eventually, for continuous injection to keep the circulating beam current virtually constant and to approach the average luminosity to the peak luminosity.
- the tight integration of extensive beam orbit instrumentation with a predictive model for the accelerator

For more technical details, we refer to the report of the Eighth KEKB Accelerator Review Committee (Appendix A.7). The successful design and rapid tuning of KEKB for high luminosity was also possible as KEK has built up over the years a very competent team of accelerator physicists and engineers. A further factor contributing to this success was the know-how and expertise of the Japanese industry which developed together with KEK reliable leading-edge technology and was able to provide it in mass production with high quality.

3 International Collaboration and Competition

The BELLE Collaboration was formed to build the detector and exploit the physics made possible by the KEKB Asymmetric Collider. It is a very large international collaboration with total of 411 scientists from 55 institutions worldwide. These institutions represent 13 countries (Figure 4, Appendix A.8).

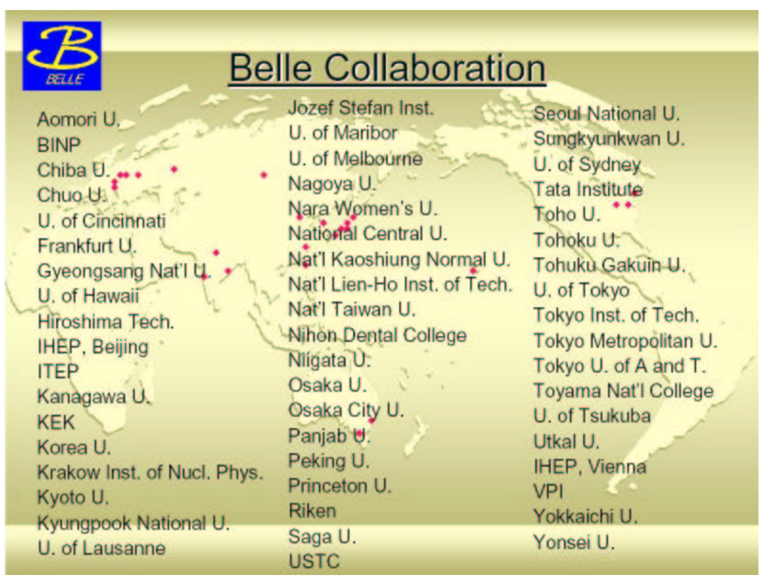

Figure 4: List of international collaborating institutions

The BELLE Collaboration together with the one operating the Super Kamiokande detector are the largest international collaborations in which institutions across the world have come together with Japanese institutions to exploit the opportunities of facilities built in Japan. The

BELLE collaboration has been extremely successful in completing the detector with many challenging technical components, in developing the software to analyze the data and in producing world class results.

The management of such diverse group of institutions, each bringing human, technical and financial resources, is, to say the least, very difficult. The BELLE collaboration has evolved a very successful model for managing such a large group of independent researchers and institutions of diverse cultural background. The management has provided strong guidance while respecting the independent nature of the collaborating institutions. It is a mixture of "top down" management combined with "bottom up" initiative that has worked very well. To make such an enterprise good communications are essential. The management structure itself reflects the bases of the collaboration having three scientific leaders representing KEK, the Japanese universities and the foreign institutions respectively. This approach can also be seen in the composition of the boards and working groups throughout the collaboration. International collaboration is very visible in accelerator sector also. Throughout the construction, commissioning and tuning, the collaboration with scientists and engineers from the Russian Federation, SLAC and IBM was essential.

The international competition between KEKB and PEP II has had very positive effect on not only the advancement of science but also on mutual understanding of people from different cultures. It is to be mentioned that the competition across the ocean was done in a fair and friendly manner. Both institutes had annual meetings of their International Program Advisory Committee which included members from the other team. The advancement or challenges and problems in one institute have been quickly fed back to the other so that both sides have been kept well informed of the world's most advanced know-how and technology.

KEK has offered a good infrastructure to welcome people from abroad and make them feel comfortable. The structure here could serve as a model for possible future international laboratory. KEK is now one of the few world active centers providing large accelerator facilities for high energy physics. KEKB has attracted many scientists from all over the world notably from Asian countries. KEK is favorably located in Asia, a fact that has helped many Asian countries to develop their own high energy groups. If KEK keeps its progress to support people from abroad, KEK could develop into a major international center for accelerator researches in Asia and Pacific region.

4 Impact on the society

4.1 Intellectual curiosity and investment for the future

In modern societies, the progress of basic science and technology is closely related and is a vital element for long term economic prosperity.[2] It is wrong, though, to expect short term return

[2] A similar recognition came from the least expected sector, the US Department of Defense. To quote; "Americans are living off the economic and security benefits of the last three generations' investment in science and education, but we are now consuming capital."
The statement is cited from "Roadmap for the National Security" drawn by The United States Commission on National Security/21st Century (http://www.nssg.gov/PhaseIIIFR.pdf) which gave the second highest priority to "Recapitalizing America's Strengths in Science and Education".

from the basic science although it is not without side benefits some of which we refer later. Rather, the reward is the excitement itself people feel in satisfying their intellectual curiosity for the unknown, a uniquely human character. KEKB has provided us an opportunity to explore the deep inner structure of the matter, one of the world's forefront themes. The opportunity to do this in the limelight of a world arena, has attracted many young people. KEKB's participation and accomplishment of the intended aim in an international competition in the most advanced research field are something to be proud of and we hope those who invested, the tax payers, share the same excitement.

4.2 Public relations

Subjects and purposes of the KEKB are not easy to comprehend for general public. Those who are involved in this exciting but complex and difficult enterprise, are responsible to clearly transfer the information on the aim as well as resultant benefits to the public if they want to share their excitement with other people. Considering the recent trend of information driven society and for short return of financial investment, it is all the more important that scientists and people at KEK do their best for public relations and outreach to the society. We note that KEK has put an increased effort on the subject, but a little more effort like publishing more understandable contents on web pages, having closer relationship with the media, opening facilities for public, and opening schools for young people etc. deserves consideration.

4.3 University research and education

The high energy physics is a fundamental science and its long term success depends critically on healthy university research activities. KEK facilities offer university scientists an opportunity to do the forefront researches as well as educational fields not available elsewhere in Japan. It is noted that, in the past 20 years, practically all of the university researches in the field of high energy physics in Japan have been carried out at KEK and a few accelerator laboratories abroad. KEKB, in particular, has provided one of the world's most advanced research opportunities and it has attracted many scientists as well as students not only from domestic universities but also from abroad, notably from Asian pacific countries. The international contribution was vital to the success of KEKB and manifests itself in the list of contact persons of published papers and the number of Ph.D. theses (Appendix A.8).

Young students trained in forefront fields do not hesitate to move into or create a new field and will play a vital role in scientific and technological development of the next generation. A good example is seen in a design approach of accelerator physicists trained with TRISTAN in building the KEKB accelerator. The design incorporated many original and innovative concepts though a more conservative approach is the norm in building such a large scale and sophisticated apparatus.
As stated before, KEKB is one of the few active research centers in accelerator physics, and as such has attracted many young people. Knowledge production as well as training of young students associated with KEKB activities is an important Japanese contribution to the world.

Because of the vast size of the accelerator and detector cost, large laboratories like KEK play a dominant role in recent high energy activities. The trend is inevitable to meet the needs of the times and indeed KEK should play a leading role to remain in the forefront of research activities. However, KEK is also a joint laboratory that provides facilities to university researchers. A continuous flow of ideas and people between KEK and the universities is vital for both parties to remain active. A healthy relationship between them has to be established. Financial independence is an important ingredient. Unlike USA and other countries, where much funding is provided for universities which they can spend at large laboratories, all the KEKB funds (and practically all the high energy funds in Japan) are channeled through KEK. It explains a part of the reasons why the size of Japanese high energy community has remained relatively small in sharp contrast to the community's remarkable success. Obtaining independent funds is a must for the autonomy of any group. In a large enterprise like high energy physics, a way has to be found to redistribute the detector related funds among the university groups so that they can participate more independently in the joint construction of large detectors. Considering the vital role of universities to educate the next generation of people, more efforts to enhance the autonomy of the university groups should be made.

4.4 Relation with industries

Traditionally, scientific research at any scale in Japan has been carried out in close collaboration with companies. This is partially because lack of supporting engineers in the academic sector has forced scientists to rely on them for manufacturing research tools, and the companies, in return, have cooperated, often at no profit, expecting technology transfer and future spin-off. The tradition continues today. The industries have provided many components in the construction of KEKB as shown in Appendix A.9. There are a number of special technologies to realize the KEKB accelerator, many with potential spin-off to them.

Another example is the information technology. It is an integral part of high energy physics, perhaps more pervasive than any other scientific discipline. The progress has been driven by the rapid increase of data volume, complexity of data processing to filter a signal out of vast backgrounds (a needle in a haystack), and the necessity of data access from university scientists scattered all over the world. The invention of www (world wide web) at CERN was no coincidence.
We point to just an example outcome of the information technology in KEKB that may have benefited the industries. The data acquisition rate at the BELLE detector is up to 15M bytes per seconds and the required capability of the BELLE computer firms reaches a few teraflops. The associated bulk data storage system have to handle some 100 terabytes a year and demands the most advanced technology. The company which made this storage system has made a commercial product out of it.

Collaboration with the industries is even more imperative as the accelerator becomes larger and more sophisticated. However, we have observed that the long recession has forced some companies to restructure their accelerator related division because of its specialization and close relationship with the nuclear power suffering from a lack of public support. Furthermore, companies may no longer be interested in technology which is not leading-edge, like manufacturing conventional magnets, a vital component for any accelerator. We may be seeing a cloud on the horizon. International collaboration in the construction of the accelerator may be a possible alternative for this trend.

5 Summary

- The first phase of KEKB and BELLE operation has been extremely successful. Constructing KEKB accelerator in five years to overcome the half year delay, the accelerator group succeeded in supplying the BELLE detector with an integrated luminosity comparable to PEP II in the first two critical years.

- The BELLE group produced a precise measurement on the CKM angle ϕ_1 simultaneously with the BABAR group. Both data agreed well and the correctness of KM theory was definitively established. This is a major achievement of the decade in high energy physics and set another milestone in our understanding of the deep structure of the matter.

- The next phase of the experiment will be precise measurements of various reactions. Establishment of the deviation from the KM theory will be a sure sign of new physics. Now that KEKB is delivering the world's highest luminosity, the BELLE group is in advantage.

- Upgrade to Super KEKB with higher luminosity may play a crucial role for the new exploration.

- Successful operation of large scale BELLE collaboration and concurrent development of KEK infrastructure could serve as a model for the future international laboratory.

- A proper balance between universities and national laboratory is key to long term success of high energy physics. Constant efforts to maintain the correct balance are required.

6 Appendices

A.1 Committee Membership

Kurt Hubner	Director of Accelerators Emeritus	CERN
Taizo Muta	President	Hiroshima University
Yorikiyo Nagashima (Chairman)	Professor Emeritus	Osaka University
Pier Oddone	Deputy Director	Lawrence Berkeley Laboratory
Ichiro Sanda	Professor	Nagoya University
Takashi Tachibana	Science Writer and Commentator	

A.2 Charge to the Committee

The Requirements for the B-Factory Project Review Committee

December 20, 2002

By the order of the Director General:

Article 1 (Purpose) The requirements for reviewing the B-Factory Project at the High Energy Accelerator Research Organization are as specified in the requirements for reviewing on researches in the High Energy Accelerator Research Organization, hereinafter called "the Review Requirements", and in addition as specified here.

Article 2 (Establishing the committee) The B-Factory Project Review Committee, hereinafter called "the Committee", will be established according to the Article 4 of the Review Requirements.

Article 3 (Responsibility) The Committee will review the research activities of the B-Factory Project.

Article 4 (Members) The members of the Committee will be formed by the specialists on high energy physics, the specialists on electron- positron collider and other specialists less than 10 persons.

Article 5 (Chairperson) The Chairperson will chair the Committee. When the Chairperson could not chair the Committee for some reason, a member of the Committee named by the Chairperson shall chair the Committee.

Article 6 (Call) The Committee meeting will be called by the Chairperson as required.

Article 7 (Quorum) If the number of attendants fall short of the quorum, which is two thirds of the members, the Committee shall not make a decision.

Article 8 (Secretarial work) The Secretarial work for the Committee will be done by the Research Cooperation Division of the International Research Cooperation Department.

Article 9 (Others) In addition to the requirements specified here, the Committee will decide the way to proceed the review as necessary.

Effective date
These requirements will be effective starting December 20, 2002.

The Requirements for the Interim Reviewing of the B-Factory Project

March 13, 2003

Decision of the Committee

Article 1 (Purpose) This Requirements will specify the necessary terms for the Committee to review the B-Factory Project of the High Energy Accelerator Research Organization

Article 2 (Review Objectives) Objectives of the review are: overall performance of the accelerator, performance of the Belle detector and the progress of the experiment. The review committee will make use of the report of the Review Committee for the B-Factory Accelerator.

Article 3 (Review Process) Reviewing will be done by interviews and investigation at the site. The subjects to be reviewed shall follow the Review Requirements on researches of the High Energy Accelerator Organization, to which some additions and omissions may be applied depending on the subject.

Article 4 (Publicizing the review result) The result of the review will be publicized in English. Summaries of the review result in both English and in Japanese shall be made open to public on KEK web site. However, sections considered to be of appropriate nature such as personal information, intellectual property and that considered to be inappropriate by the Committee may be omitted.

Effective date
These requirements will be effective starting March 13, 2003.

A.3 Agenda of The B-Factory Project Review Committee Meeting

Date: March 13 and 14, 2003
Place: Meeting Room, 4F, 4-go-kan, KEK

March 13

09:00 - 09:15	Opening address	H.Sugawara
09:15 - 09:20	Selection of chairperson	
09:20 - 09:50	Purpose and schedule of the meeting	S.Yamada
09:50 - 10:40	KEKB project overview	F.Takasaki
	Coffee break	
11:10 - 12:00	KEKB accelerator	K.Oide
	Lunch	
13:30 - 14:20	BELLE detector	J.Haba
14:20 - 15:10	Physics results	M.Yamauchi
	Coffee break	
15:40 - 16:30	Discussion with speakers	
16:30 - 17:30	Executive session	

March 14

09:00 - 10:00	Executive session
10:00 - 11:00	Discussion with speakers
11:00 - 13:00	Executive session
	Lunch
14:00 - 15:00	KEKB/BELLE tour
15:00	Adjourn

A.4 Glossary

[1] **Dark matter and dark energy**: Recent space probes have revealed an amazing fact that most of the matter in the universe is dark, detectable only by its gravitational pull and that empty space is filled with unknown form of dark energy pushing the universe to expand at an ever-increasing rate. The conventional matter occupies only 5% of the cosmic energy, the dark matter 30%, and the rest is the dark energy.

[2] **Supersymmetry**: A symmetry between particles with different spin. Spin is a magnitude of rotating power of particles and takes values either integer or half integer in units of Planck's constant. Supersymmetry is considered an essential symmetry for the unification of all the forces (electromagnetic, weak, strong and gravitational). Physics which has built-in supersymmetry is the most promising new field that we may encounter. The sign of the supersymmetry is the existence of a new set of partner particles with spin differing by half an integer for every known fundamaental paricle.

[3] **Large Hadron Collider**: A proton-proton colliding accelerator under construction at CERN. It has a circumference of 23 km, a total energy of 28 TeV and is expected to start operation in 2007. Its major aims are, to discover the Higgs particle which is a fundamental ingredient of the standard model of elementary particles and possibly supersymmetry particles, too.

[4] **Unitarity Triangle**: Kobayashi-Maskawa theory requires that three quarks (d,s,b) mix. Elements of mixing matrix, often called CKM matrix (C for Cabibbo who proposed mixing), satisfy certain relations which makes a triangle in the complex number plane. The CP violation effects follows from the finite size of the area.

A.5 Report of Ninth LCPAC on Physics

A.6 Scientific achievements

A.7 Report of Eighth Review Committee on Accelerator

A.8 International activities

A.9 Industrial contributions

These appendices can be found in the full document.