12-GeV PS 2008 Review Report
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0. Executive Summary

At the behest of the Director General of KEK and the Director of KEK-IPNS an international committee of high-energy and nuclear physicists met at the KEK from January 22 to 24, 2008, to review the scientific program of the 12-GeV Proton Synchrotron (PS) after it was shut down in December 2005. The purpose was (1) to evaluate the completion of the final suite of experiments, (2) to assess the impact of the previously completed group of experiments, all conducted at the PS, and (3) to review scientific impact, performance and value of the 12-GeV PS program over its lifetime.

The Committee found that the PS program completed its scientific program most successfully. The Program Advisory Committee had selected an excellent final suite of important experiments. The experimental groups and the PS accelerator staff performed outstandingly in producing significant new results for these and the earlier experiments. This success is underlined by that fact that publications by the KEK-PS experimental groups had peak years in 2006 and 2007. Of the 27 papers published in refereed journals over these two years, eight appeared in letter journals (PRL and PL) which have the highest standards of acceptance in high-energy and nuclear physics—an outstanding record.

First and foremost, the outstanding K2K long baseline neutrino experiment (E362) -- the first to demonstrate flavor changing oscillations with neutrinos produced by an accelerator -- has been the world leader in substantiating that the observed atmospheric disappearance signal is due to neutrino oscillations. This experiment has now moved to its second stage in the form of the T2K experiment at J-PARC which is being constructed by a very large international collaboration. The rare kaon decay experiments searched for some of the most rare decay processes that test the most fundamental symmetries of nature including CP violation in the $K_L^0 \to \pi^0 \nu\bar{\nu}$ decay (E391a) and exotic sources of T violation by searching for transverse muon polarization in $K^+ \to \pi^0 \mu^+ \nu_\mu$ $(K_{\mu 3})$ decay (E246).

In nuclear physics the KEK-PS program over the years has made KEK the world leader in hypernuclear physics, almost without competition. This has been achieved by using sophisticated experimental devices offsetting the lower beam intensities which the PS was able to offer. We mention the outstanding success of hypernuclear γ-ray spectroscopy (E-566) which determined the basic interactions between hyperons and nucleons in nuclei, the determination of the kaon-nucleus potential (E-548, E-549) as well as the experiments that rule out the existence of a bound double-strange di-baryon state (E-522) and of the penta-quark Θ particle ((E-559).

From a historical perspective the KEK-PS has been a resounding success for the KEK and for Japanese science. While budget constraints had restricted the PS to a relatively low energy of 12 GeV very well chosen experiments made the KEK-PS a highly respected international competitor in high energy and nuclear physics with a distinct scientific profile. It served as a very attractive research resource for Japanese universities. Its construction laid the foundation for accelerator science at KEK, brought Japanese industry into accelerator construction and now led to the world-class J-PARC facility. Many of the PS experiments will provide the strong starting program for J-PARC.

The Committee rates the completion of the 12-GeV -PS scientific program and its historical development an outstanding success.

1. Introduction

The 12-GeV Proton Synchrotron at the KEK started operation in December 1976 and effectively ceased operation in December 2005. It was the first internationally competitive high-energy physics accelerator in Japan and it played a seminal role in promoting modern high-energy and nuclear physics, as well as accelerator science and technology in Japan. During its lifetime it delivered beams for 122 PAC (Program Advisory Committee) -approved experiments and formed the backbone of the research programs of many major Japanese universities. Its program and performance were periodically reviewed by external committees in approximately five-year cycles, with the first review taking place in 1981 and the most recent one in 2004. At that time the end of accelerator operation was already in sight, but eight final approved experiments were still taking data until the accelerator shut down.

At end of 2007 the KEK Director General and the Director of KEK-IPNS called for a last external review of the 12-GeV-PS program. For this purpose a small committee of high-energy and nuclear scientists from the U.S. and Europe (Committee membership is listed in Appendix I) was charged with reviewing the results of the final suite of experiments and the completed result of the K2K neutrino experiment, with providing an assessment of eight previously completed and recently published experiments, and with giving an overall assessment of the quality and impact of the 12 GeV-PS program over its lifetime.

For the on-site review the Committee met at KEK from January 22 to 24, 2008 with the first two days given to presentations on the experiments under review, as well as a historical overview of the performance of the PS facility and its science program over its lifetime. The final day was left for discussions of the Committee internally and with senior KEK staff. The agenda for the review meeting is listed in Appendix II.

The program of the review was very well laid out. The informative talks by KEK research staff and faculty from collaborating universities provided a rather complete basis for the evaluation by the Committee. Additional facts and statistics were provided by laboratory staff. The Committee wishes to express its gratitude to Professor Kenzo Nakamura for arranging the review so smoothly and effectively, and for his untiring personal efforts to make the visit enjoyable for the Committee.

2. Historical setting and performance of the 12-GeV PS accelerator

While the accelerator, being already shut down, was not the subject of this review, we collect a few pertinent facts as background to our assessment of the success of the 12 GeV PS research program. With a construction start in 1971 as an 8 GeV accelerator (with the energy determined by available funds) the PS actually reached 12 GeV in December 1976 and in January 1977 began its research program with a fast-extracted beam. During its lifetime it was continuously upgraded in terms of capability (e.g. polarized beams and deuteron beams), slow extraction capability and beam intensity. The last impetus for an intensity and reliability upgrade was provided by the preparation for the K2K long base line neutrino experiment. By 1999 the ring peak intensity was boosted to 8×10^{12} particles per pulse which were delivered with 80% extraction efficiency for the K2K muon neutrino beam.

The limited proton energy relative to that of the BNL AGS and the CERN PS which had both been commissioned in the early 1960's meant that the PS had to serve a niche program. Thus it developed its own scientific character; with quite impressive success often based on cutting edge experimental equipment, as outlined later in this report. It provided beams for 122 scientific experiments over its lifetime. The experiments were all reviewed and approved by an external Program Advisory Committee (PAC). In addition 338 test beam experiments were performed using internal and external beams. Some of these were direct tests for the TRISTAN collider design, but most used secondary pion and kaon beams. It is noteworthy that 97 of these experiments were for international collaborations. These test runs were also subject to PAC approval if they required more than 20 shifts.

The 12-GeV PS served as the base of expertise for Japan to design and construct, in 1982, the TRISTAN electron-positron collider and then, starting in 1995, KEK-B. When TRISTAN became available in late 1986 it siphoned off most of the high energy physics research from the PS , while intermediate energy nuclear physics at the facility grew rapidly using the direct proton beam and secondary pion and kaon beams. Still a core of a few flagship high-energy physics experiments remained. This is indicated by the subject areas of the approved experiments: Overall of the 122 experiments 36 experiments were performed for high energy physics, 75 in nuclear physics, and 11 for chemistry, but in later beam periods 61 nuclear physics experiments compared with only 11 high-energy physics ones.

The machine reliability was very good. The annual operating time was nearly 6000 hrs/yr since 1999 when the neutrino beam came into operation. This corresponds to ~ 36 (24-7) weeks, which is comparable to the maximal historical operating time of the AGS at Brookhaven (running times of these machines are usually capped by available funds). Its beam delivery hours for physics experiments almost doubled from ~ 2,500 in the 1980s to over 4000 hrs beam on target during the K2K runs from 1999 to 2003. The suspension of this crucial neutrino experiment in2001 was caused by the unfortunate accident at the Super-Kamiokande neutrino detector and the termination of the experiment in 2004 was caused by failure of the neutrino horn, in neither case was it the fault of the accelerator. Operational efficiency of an accelerator has many definitions depending on whether accelerator test and tuning time or the down time of experiments for which beam was provided are included in the calculation. The PS definition of 67% efficiency for providing beam on target and producing physics is high considering that it does not include waiting time and a large number of test experiments. When these aspects are taken into account the actual machine failures amounted to only ~ 200 hrs/yr out of ~6000 hours operation, or 3.3%.

The experience gained with PS technology, both with injection linac and synchrotron design, has fed directly into the J-PARC project. Thus the 12-GeV PS, despite its limited energy range, has to be viewed as an excellent investment for Japan with a big pay-off indeed for Japanese science.

3. Highlights of the historical 12-GeV PS program in high-energy physics

The KEK-PS accelerator has supported a rich program of particle physics that developed over the years into a premier program of forefront experiments. In the early years of the accelerator operations, the experiments concentrated on measurements comparable to those being done at laboratories outside of Japan. Following the initiation of the TRISTAN collider, the KEK-PS fixed target program began to move towards establishing leadership in rare kaon decays and some meson spectroscopy. Notable forefront experiments done at the PS prior to 2000 include a clear refutation of reported baryonium observations at BNL and CERN, searches for the long-sought neutral current decay $K^+ \to \pi^+ \nu\bar{\nu}$ and for axions produced in the reaction $K^+ \to \pi^+ a$ and the lepton flavor-violating reaction $K_L^0 \to \mu e$. An order of magnitude advance was made in each case, compared to previous work. In addition, searches for heavy neutrinos and right-handed charged current in $K^+ \to \mu^+ \nu$ decays also produced prominent results. Some of these experiments introduced innovations in analysis of background processes and technologies such as very high speed (500 MHz) digitization of pulses which were incorporated in subsequent experiments.

Starting in 2000, the KEK-PS program moved into the forefront of particle physics with world- leading experiments including the K2K long-baseline neutrino oscillation experiment and several important rare kaon decay experiments. These experiments overcame the deficiency of the PS intensity by using clever and innovative experimental techniques. The K2K experiment provided a key confirmation of the Super-Kamiokande observation of atmospheric neutrino oscillation using an accelerator produced beam—the first long baseline neutrino oscillation experiment—and has been critical in substantiating that the observed atmospheric disappearance signal is due to neutrino oscillations. The rare kaon decay experiments searched for some of the most important rare processes including CP violation in the $K_L^0 \to \pi^0 \nu\bar{\nu}$ decay (E391a) and exotic sources of T violation by searching for transverse muon polarization in $K^+ \to \pi^0 \mu^+ \nu_\mu$ ($K_{\mu 3}$) decay (E246). The $K_L^0 \to \pi^0 \nu\bar{\nu}$ decay is one of the most important rare processes being sought because of its uniquely clean interpretation in the SM and its sensitivity to new physics at very high mass scales. The observation and quantitative measurement of this decay has been an intense goal also at overseas laboratories. The experiment at the PS coupled with its second step at J-PARC provides a promising path forward to a successful measurement. Although it is a very difficult process to isolate, the KEK E391a experiment, which was the first dedicated search for this process developed a new technique involving a pencil beam and has been able to make a search that is a factor of ten better than previous experiments. E391a may eventually do even better when the full data set has been analyzed. The results of E391a will be important in the development of future experiments on $K \to \pi\nu\bar{\nu}$ which are planned for J-PARC and possibly other facilities.

E246 provided the most stringent limits on parameters of several new physics models involving T violation such as SUSY models. It improved the sensitivity to transverse muon polarization in $K_{\mu 3}$ decay by a factor of 3 which remains the world standard for this process. E246 also made other measurements of significance involving low energy radiative processes.

In many measures, the KEK-PS program has risen to a strong position in particle physics over the last several decades. The moderate investment in the KEK-PS has clearly paid off in an internationally recognized high physics program that has made several leading measurements. It has moved the Japanese physicists working in high energy particle physics into a leadership position in significant areas of the field and laid the basis for a future exciting physics program at J-PARC.

4. Highlights of the historical 12-GeV PS program in nuclear physics

While the KEK-PS was originally conceived as a particle physics facility, it rapidly attracted the attention and interest of the intermediate energy nuclear physics community in Japan. Indeed, while the energy of the PS did not match that of the other high energy facilities worldwide, it was well suited for nuclear physics experiments. Throughout the operation of KEK a number of forefront results were obtained. The start of the TRISTAN and later Belle facilities increased the opportunities for the nuclear physics program at the KEK-PS.

The Leitmotif of the nuclear program at the KEK-PS may be described as the study of strangeness in nuclei and the search for medium modifications of hadrons in nuclei. While the limited intensity of the secondary kaon beams restricted the use of the well established recoilless (K^-, π^-) reactions, the intense pion beams proved to be ideal tools for hypernuclear spectroscopy through the use of (π, K) reactions. The beautiful experimental equipment that was assembled, examples of which are the SKS spectrometer and the Hyperball, eventually led to a complete characterization of the Λ-nucleon interaction in light nuclei and the discovery of a considerable number of Λ hypernuclei.

To the many notable achievements belong the first confirmed discovery of the ${}^{4}_{\Sigma}He$ hypernucleus and the result that heavier Σ-hypernuclei are unbound because of the repulsive nature of the effective isospin dependent Σ-nucleon interaction. A recent result is the determination of the Σ-nucleon spin-orbit interaction, which confirmed the long standing prediction that it would be far stronger than the Λ-nucleon spin-orbit interaction.

The achieved understanding of the form of the hyperon-nucleon interaction has significant implications on the structure and allowed mass range of neutron stars. As an example due to the repulsive interaction Σ-hyperons will not be formed in dense matter. Closely related to this behavior of strange nuclear matter was the prediction of a deeply bound double strange "H" dibaryon. The KEK-PS experiments have put restrictive limits on the possibility for H-dibaryons. Especially important in this regard was the discovery at the KEK-PS of the ${}_{\Lambda\Lambda}{}^{6}He$, ${}_{\Lambda\Lambda}{}^{10}Be$ and ${}_{\Lambda\Lambda}{}^{13}B$ hypernuclei. These double Λ hypernuclei gave the first empirical information on the $\Lambda\Lambda$ interaction. Further information was obtained from the observation of the strong $\Lambda\Lambda$ final state interaction in the missing mass spectrum of the ${}^{12}C$ (K^-,K^+) reaction.

Today Japan is the world center of hypernuclear physics. The stimulating interplay between the experimental program at KEK-PS and the nuclear theorists in Japan has been exemplary. The motivation for several experiments stemmed from the Japanese theory community. The definite interpretation of many of the experiments at KEK-PS has been supported by extensive theoretical analysis.

A central question in nuclear physics is how the properties of hadrons may change in the nuclear medium. For example the restoration of chiral symmetry in dense nuclear matter is expected to lead to a lowering of hadron masses with increasing density and temperature. The recent KEK-PS measurement of the downward mass shifts of the ω (possibly also the ρ) and ϕ mesons in nuclei are therefore particularly interesting.

The strength of the medium energy program at the KEK-PS has obviously been a significant factor in the motivation for the J-PARC facility. Many components of medium energy program at KEK-PS will be continued at the J-PARC facility with vastly increased scientific reach.

5. Impact of PS program on universities & research in Japan

The KEK-PS was initially conceived as a way for the Japanese community to gain experience in experimental high-energy physics and to train young experimentalists, rather than as a forefront facility that could support world class science. The 1981 review succinctly put it, "*it was not possible at all to make the forefront research in particle physics with the KEK-PS*" and "*The primary purpose of the KEK-PS has been to obtain experiences for constructing and utilizing experimental apparatus, to educate and foster young researchers, and to give confidence to the Japanese high-energy physics community.*"

It is clear that that the KEK-PS achieved its mission, as evidenced by heavily subscribed beam time. Overall, it was used by 122 experiments spanning from particle and nuclear physics to chemistry producing 170 Ph.D. degrees, a large number given the size of the Japanese Physical Sciences community. Virtually every well-established high energy physics experimentalist in Japan has been either trained at the PS or performed experiments there. In addition, as noted above its test beam supported many experiments associated with Japanese Universities. Thus its impact reached well beyond the KEK laboratory, as its mission required.

It should not be forgotten that the KEK laboratory itself was founded because of the KEK-PS project, marking the birth of the modern domestic high-energy and intermediate energy nuclear physics programs in Japan. It paved the way to the later high-profile projects TRISTAN, KEK-B and J-PARC.

Despite the initial assessment of its purpose, the KEK-PS blossomed into a world class research facility thanks to its clever and effective use. Some of its initial successes, such as clear refutation of baryonium states reported by Brookhaven and CERN experiments, confirmed the Japanese community's ability to conduct world class research in high energy and medium energy nuclear physics. Gradually, a focused and wise choice of topics established KEK-PS as a world class and even world-leading facility in some areas. It successfully supported head-to-head competitions with other "superior" accelerators, such as the $K \rightarrow \mu e$ search. It allowed Japanese scientists to find a niche and eventually almost to dominate a field such as strong interaction physics with strangeness. It made major progress on experiments such as a dedicated search for an extremely rare $K_L \rightarrow \pi^0 \nu\nu$ or possible T-violation in the $K^+ \rightarrow \pi^0 \mu^+ \nu$ decay, which attracted a sizable international participation. In addition, compounded by the dearth of test beams worldwide, more than 10% of the projects at the KEK-PS test beam involved international partners or were conducted because of the request by international collaborators. Finally, K2K put KEK-PS into the history book of Japanese high-energy physics having gathered close to two thousand citations to date.

Over time, KEK-PS made a seminal impact on the Japanese community getting it started and enabling it to perform the world class science. It has lived up to the high expectations.

6. Scientific productivity of the KEK-PS

Over the history of the KEK-PS running with 122 completed experiments, there have been 320 physics papers published in refereed journals and 112 published technical papers. Of these 118 were in high energy physics, 179 in nuclear physics, and 23 in chemistry. It was gratifying to observe from the publication statistics that the publications by groups doing experiment at the KEK-PS had peak years in 2006 and 2007, attesting to the effort made by the experimental groups to harvest fully the results of the last suite of experiments. In fact of the 27 papers published in refereed journals over these last 2 years, 8 appeared in letter journals (PRL and PL) which have the highest standards for acceptance in high-energy and nuclear physics.

Over a third of the 122 papers have more than 10 citations showing that the published science has found broad interest in the community. It must be noted that the PS experiments in their experimental group structure predate the modern collider experiments, which have as a rule several hundred collaborators and a broad range of physics topics and measurements. In contrast the targeted PS experiments usually involved only a few senior collaborators and their graduate students and postdocs, who typically focused on one primary measurement.

Thus the publications record for the KEK Laboratory and its research program is judged to be excellent. It is noteworthy that each approved experiment resulted in refereed publications. The K2K (E362) neutrino oscillation experiments has one paper in the Spires data archive's "Renowned" category with 700 citations and two "Famous" papers with over 250 citations each. In addition, three published papers from the KEK-PS program reached the "Very well-known" category with over 100 citations. These include one associated with a rare kaon decay and axion search, and one associated with the direct observation of sequential weak decays of a double hypernucleus. The overall record of published papers indicates that the KEK-PS program has been recognized as a very important component of the fields of particle and nuclear physics.

Research facilities such as the KEK-PS derive their value for society not just through the discovery of new knowledge but also (and correlated) through the training of new scientists. The PS program produced 172 Ph.D. theses, of which 89 were in high-energy physics, 80 in nuclear physics and 3 in chemistry.

Although the Committee did not evaluate the test beam program in detail, it was struck by the high rate of publications and reports that derived from this program. For a recently tracked set of 191 test beam experiments, the record shows 162 publications in refereed journals, reports and conferences.

7. Assessment of eight experiments from the previous approval cycle

Most of these experiments show the broad collaborations among Japanese universities and national labs. Virtually all experiments were successful in providing science that was published in refereed journals.

E-521: Production of neutron-rich Λ hypernuclei by the (π^-, K^+) double-charge exchange reaction

Most of our information on hypernuclei come from reactions such as (K^-,π^-) and (π^+,K^+), that do not change the total charge of the nucleus and thereby follow the valley of beta stability. Much of the interest in hyperon-nucleon interactions relates to the potential impact on the occurrence of strange matter in the cores of neutron stars. The (π^-,K^+) double charge exchange reaction allows the population and spectroscopy of neutron-rich light hypernuclei such as ${}^{6}_{\Lambda}H$ and ${}^{10}_{\Lambda}Li$. There are also theoretical suggestions that coherent ΛN-ΣN coupling could have a dramatic impact on the Λ single particle potential in neutron matter, and also provide a one-step reaction mechanism for the (π^-,K^+) reaction. E521 measured the ${}^{10}B$(π^-, K^+) reaction at two energies. The experiment observed a rather flat distribution of events with Λ binding energies between 0 to 12 MeV without clearly seeing the expected s_Λ and p_Λ peaks and the extracted cross sections were a factor of 5-10 less than the original theoretical predictions. The preliminary interpretation suggests the possibility of order 0.5% Σ admixtures in ${}^{10}_{\Lambda}Li$. The concept of using the double charge exchange reaction to study neutron-rich hypernuclei is a valuable one. The current experiment was a significant first look but does not appear to have had the resolution or sensitivity to be definitive. The planned extension of the program at J-PARC should realize the needed higher resolution and sensitivity. The ${}^{6}_{\Lambda}H$ system, which is small enough that ab-initio structure calculations can be performed, is an important next step.

E-325: Study of chiral property of dense nuclear matter through measurement of meson mass modification in medium

The experiment studied the modification of the vector meson masses as observed in di-lepton decay modes of vector mesons produced in proton scattering on C and Cu. It has been a key task in hadron physics to establish the properties of vector mesons in nuclear matter at high densities and contrast these to the properties at high temperature, which are accessible through relativistic heavy ion scattering. One primary motivation is the possible restoration of chiral symmetry in dense nuclear matter, which might be revealed in reduced hadron masses**.** Measurements of the di-lepton decay of the vector mesons are considered to be the cleanest technique to study such medium effects.

The experiment revealed that there is a modest downward shift of about 3 % of the effective mass of the ϕ meson from its free space value and a corresponding increase of its width by a factor of 4 when extrapolated to normal nuclear matter density. The experiment achieved the first experimental limits on the medium dependence of the partial widths of the ϕ meson. In contrast to this modest medium dependence of the ϕ meson properties the effective mass of the ω meson was shifted down by 9 % (extrapolated to nuclear matter density). The observation of a smaller medium dependence of the ϕ meson than for the ω meson is consistent with the expectation that the ϕ -nucleon interaction should be weaker than the ω-nucleon interaction, as the former is mainly formed by strange quarks.

The results for the ω meson are consistent with those obtained at ELSA, but not with the recent unpublished results at CLAS (JLAB), which in a just-published report appear to see no observable medium dependence of the mass of the ρ mesons. This experiment drew wide attention in the nuclear physics community.

E-246: Search for T violation in the $K^+\to\pi^0\mu^+\nu$ decay

The KEK E246 Collaboration, a truly international group including Canadian, Japanese, Korean, Russian, Taiwanese, and US participants, has been performing a world-leading search for violation of *time reversal invariance* in kaon decays for several years. The transverse muon polarization, P_T, in $K^+\to\pi^0\mu^+\nu$ ($K_{\mu3}$) decay is one of the most sensitive observables of *time reversal invariance* (or *CP)* violation in models which go beyond the Standard Model (SM). *CP* violation, in general, is a subject of continuing interest in *K, B* and other meson decays, since a new source is needed to explain the puzzle of the dominance of matter over antimatter in the universe. A large value of P_T, which is defined as the muon polarization component perpendicular to the decay plane of the reaction, is a clear signature of a violation of time reversal (*T*) invariance, since the spurious effects from final state interactions are very small ($< 10^{-5}$). P_T nearly vanishes ($< 10^{-7}$) in the SM with the Cabibbo-Kobayashi-Maskawa scheme; it is therefore a very sensitive probe of *CP and T* violation mechanisms beyond the SM. Models such as those with multi-Higgs doublets or leptoquarks, and some supersymmetry (SUSY) approaches may give rise to P_T as large as 10^{-3}.

E246 used an innovative technique which built on and significantly expanded methods developed in earlier experiments for suppressing subtle systematic background effects. The final result of E246 was a new improved value $\mathrm{P_T} = 0.0017 \pm 0.0023(\mathrm{stat}) \pm 0.0011(\mathrm{syst})$ giving an upper limit $\mathrm{P_T} < 0.0050$ at the 90% CL. (The implied *T*-violation parameter was $\mathrm{Im}\xi = 0.0053 \pm 0.0071 \pm 0.0036$ giving an upper limit $|\mathrm{Im}\xi| < 0.016$ (90% CL).) These results represent the best yet achieved in this field and supersede those obtained earlier at Brookhaven National Laboratory by a factor of 3. This was one of the most outstanding experiments done at the KEK PS accelerator. Intensive studies of systematic effects in E246 have led to understanding that allows considerable improvements in sensitivity to be sought in future experiments. The approved J-PARC effort under development now aims to achieve more than an order of magnitude greater sensitivity which could lead to a dramatic discovery or further limit the theoretical possibilities for new sources of T violation.

E-470: Measurement of direct photon emission in $K^+\to\pi^+\pi^0\gamma$ decay and study of $K^+\to\pi^0\mu^+\nu_\mu\gamma$ decay.

This experiment consisted of two important studies of radiative kaon decays that resulted in enhanced knowledge of low energy strong interactions. The decay $K^+\to\pi^+\pi^0\gamma$ can be used to study the chiral anomaly, a fundamental property of chiral quantum field theories of which the Standard Model or quantum chromodynamics (QCD) are prominent examples. Measurement of the direct emission (DE) component of photons (as opposed to that due to bremsstrahlung) provides tests of the predictions of various models. The branching ratio for the DE component in the $\pi+$ kinetic energy region 55 to 90 MeV was been determined to be Br(DE) = $[3.8 \pm 0.8(\mathrm{stat}) \pm 0.7(\mathrm{syst})] \times 10^{-6}$, which is consistent with the results of the recent previous experiments. The good agreement of this result with the theoretical prediction for the branching ratio of the DE component, BR(DE) = 3.5 $\times 10^{-6}$, supports the hypothesis that the dominant contribution to direct photon emission is due to the pure magnetic transition given by the reducible anomalous amplitude.

Semi-leptonic radiative decays of K-mesons such as $K^+ \to \pi^0 \mu^+ \nu_\mu \gamma$ offer a good testing ground of hadron structure models making use of low-energy effective Lagrangians inspired by chiral perturbation theory (ChPT). The data sample of 125 $K^+ \to \pi^0 \mu^+ \nu_\mu \gamma$ events was obtained giving a final result for the branching ratio in a restricted phase space range [2.4 ±0.5(stat) ± 0.6(syst)] $\times 10^{-5}$, in good agreement with chiral perturbation theory. Although the current experimental result is not yet sensitive enough to study the contribution from hadron structure effects, which is predicted to be at the level of a few % of the rate or to search for T-violating triple correlations it is conceivable that such experiments may be now be attempted at J-PARC using the foundation laid by E470.

E-438: Study of Σ-Nucleus potential by the (π^-, K^+) reaction on heavy nuclei

This experiment is the latest in a long series that studies the production of hypernuclei in which a hyperon replaces a normal nucleon inside a nucleus. At the PS these studies can be done using reactions such as (π^-,K^+) and an experienced group has been doing a long series of fine experiments of that type. If a hyperon is placed into a specific orbit inside the nucleus the K+ spectrum displays peaks at specific energies. Thus the emerging kaons must be detected with excellent energy resolution. Here the experimental set up at the PS profits from the outstanding characteristics of the superconducting SKS spectrometer. Trapping the hyperon inside a nuclear orbit requires an attractive interaction. Earlier experiments at the PS and at the AGS at BNL had shown the existence of Λ hypernuclei throughout the nuclear mass table, and had shown a Σ hypernucleus in ^{4}He, later confirmed at BNL. However no heavier Σ hypernuclei were ever found. This experiment was set up to determine definitively whether the Σ-nucleus interaction is attractive or repulsive in heavy nuclei. The experiment was expertly set up and performed by an experienced group. The resulting kaon spectra indicated no peaks and a smooth spectrum of very similar shape for all target nuclei. The analysis showed a strongly repulsive interaction between the Σ particle and the target nucleus and indicated strong absorption. These findings were extended to the analysis of older data for nuclei as light as Carbon. The results show convincingly that bound Σ hyperon states cannot exist in nuclei such as Carbon and heavier. This has implications for the existence of Σ hyperons in neutron stars. The fact that the interaction is attractive for $^4_\Sigma$He but repulsive for heavier nuclei, as well as the difference to Λ hypernuclei, can be attributed to the isospin dependence of the interaction.

This study of hyperons in nuclei will be transferred to the J-PARC facility, where it will be extended to Cascade particle hypernuclei. These studies will profit from the availability of the intense J-PARC kaon beams.

E-462: Exclusive measurement of the non-mesonic weak decay of $^{5}{}_{\Lambda}He$, and
E-508: Coincidence measurement of the weak decay of $^{12}{}_{\Lambda}C$

N-N scattering, nuclei and hypernuclei offer the only possibilities to learn about baryon-baryon weak interactions. There have been a number of intriguing results in non-mesonic decays including some suggestions of violations of the ΔI=1/2 rule For many years the ratio of rates of the weak decays Λp→np to Λn→nn that are used to investigate the isospin structure of the non-mesonic weak decays have posed an interesting puzzle with one-pion-exchange mechanisms predicting a ratio of 0.1 while the experimental data hint at a much larger ratio 0.93+/-0.55. This experiment detected back-to-back np and nn pairs from $^{5}{}_{\Lambda}$He and $^{12}{}_{\Lambda}$C and determining the ratios to be 0.45+/-0.11+/-0.03 and 0.51+/-0.13+/-0.05 respectively. They also measured the asymmetry of the decay protons obtaining values consistent with zero. One-pion exchange, one-meson-exchange, and meson-exchange plus direct quark exchange do not appear to be able to simultaneously reproduce the np to nn ratio and the decay asymmetry unless σ meson exchange is included. This experiment achieved a very convincing measurement of these two baryon weak decay modes suggesting a significant contribution from the spin singlet ΛN initial state or, perhaps even a violation of the ΔI=1/2 rule. This program will continue at J-PARC focusing on four and five body systems to isolate other spin-isopin channels such as $^{1}S_{0}$ I=1.

E-452: Spin-dependent interactions in Σ^{+}-p scattering

The interaction of hyperons with nucleons provides deep insight into the origin of the force between nucleons. Early data on the Λ–nucleon interaction led to distinctive predictions on the interaction of a Σ-hyperon with a nucleon. The spin dependent observables for polarized Λ and Σ hyperon-nucleon elastic scattering have been measured to determine the strength of the hyperon-nucleon spin-orbit interaction. The polarized hyperons were produced through the p(π^{+}, K^{+}) reactions in the case of the Σ^{+} and n(π^{+}, K^{+}) reactions in the case of the Λ in a liquid-scintillator target. The scattering events were recorded with a scintillating track image camera detector that was crucial for the success of the experiment. The experiment achieved the first empirical determination of the strength of the Σ-nucleon spin-orbit interaction.

The experiment showed that the analyzing power is much larger in the case of the Σ^{+} than in the case of Λ production. Comparison to results obtained with realistic phenomenological interaction models then led to the conclusion that the spin-orbit component of the Λ-nucleon interaction is much weaker than that of the Σ-nucleon interaction.

The result is in good agreement with two of the realistic phenomenological hyperon-nucleon interaction models. On a more fundamental level it is also in agreement with the expectation based on quark models that the spin of the Λ hyperon, due to the strange quark, may be treated as a spectator.

8. Assessment of eight completed PS experiments from the final approval cycle

Many of these experiments completed important work, such as the long baseline neutrino oscillation experiment, or attempted to resolve outstanding issues, such as the existence of the H-dibaryon or the pentaquark. The Committee was pleased to hear that these last runs fulfilled their missions and completed the 12GeV-PS program in a meaningful and successful fashion.

E-362: Long baseline neutrino oscillation experiment (K2K)

In 1995, the K2K experiment was proposed to search for neutrino oscillations in the atmospheric neutrino oscillation region using a neutrino beam from the KEK-PS. Initial indications for the oscillation came from the original Kamiokande experiment as well as the IMB experiment, even though the situation remained controversial. In particular, many in the community remained skeptical about results obtained using cosmic-ray induced neutrinos, and there was a clear need to use man-made neutrinos to study the same phenomenon. Later, the Super-K collaboration saw a deficiency in the number of muon neutrinos produced in the atmosphere by incoming cosmic rays. This anomaly was fairly convincing as a signal for neutrino oscillations since the ratio of muon to electron neutrinos was different from the expected value and the zenith-angle dependence of the muon neutrino rate followed that expected from neutrino oscillations. Confirmation of the Super-K anomaly using an accelerator experiment was a key next step and the K2K collaboration along with strong support from KEK designed, constructed and commissioned the K2K experiment within four years and started data taking in 1999. With four years of running, the K2K experiment was able to make a definitive confirmation of a neutrino oscillation explanation for the Super-K atmospheric results and in addition further constrain the parameters associated with the neutrino mass and mixing. It is all the more remarkable that the K2K neutrino beam was the first neutrino beamline built in Japan and KEK became the world's first long-baseline neutrino oscillation experiment.

To accomplish the K2K experiment, KEK and the collaboration needed to solve many challenging technical issues and develop innovative techniques and apparatus. In order to reach a sensitivity to neutrino oscillations similar to the Super-K atmospheric measurements, K2K needed to use a two detector configuration with a multi-technology near-detector at 300 m from the π-meson production target to measure the neutrino flux and interaction cross section. These results were then combined with the Super-K detector measurements at 250 km from the KEK to search for neutrino oscillations. The K2K experiment presented many technical hurdles associated with coupling the data between the near and far detector in terms of time and spatial alignment.

A key requirement was to increase the extracted intensity of protons from PS accelerator using fast 1.2 μs extraction. The KEK PS division was able to satisfy this requirement and succeeded in providing an average of 5.5×10^{12} protons per pulse at a 2.2 s rep rate which is about a factor of two better than the previous delivery rate. To produce the high intensity neutrino beam, the K2K group needed to develop a new type of magnetic focusing horn for the pion beam that used a combined function aluminum target / inner conductor. The high radiation environment and high electrical current required for the focusing posed special challenges which were successfully met by replacing the focusing elements periodically throughout the data run.

The analysis of the K2K data was also a challenge and required bringing to bear the full suite of near detector results, external data from a CERN pion production experiment, HARP, using the K2K aluminum target, and a complete understanding of the Super-K detector response to neutrinos in the energy range of K2K near 1 GeV. The principle of the experiment was to use the above information to predict the observed neutrino event rate and energy distribution expected in the Super-K detector. This expectation was then compared to the observation to look for an indication of neutrinos disappearing as they traveled from KEK to the Super-K site. Over the four years of data, K2K observed 112 neutrino events where 158 ± 11 events were expected if no oscillations occurred. In addition, K2K observed a deficit of events in the 0.7 GeV energy region which is expected for neutrino oscillations with a Δm^2 value of approximately 2.5×10^{-3} eV^2. Taken together, these results rule out a non-oscillation hypothesis at the 99.985% confidence level and confirm the Super-K atmospheric oscillation result at high confidence level.

In addition, K2K provided a limit on electron appearance and useful measurements of neutrino cross sections relevant to other neutrino experiments. K2K also pioneered the use of new detector technologies such as the SciBar detector which was composed of extruded scintillator read out with wavelength shifting fibers into a new type of multi-anode photomultiplier tube developed by Hamamatsu. SciBar has now been moved to Fermilab where it is being used to make neutrino cross section measurements that are crucial to future oscillation experiments.

The confirmation of the Super-Kamiokande result was a significant step in exploiting the neutrino oscillation phenomenology to expand our knowledge of neutrino masses and flavor mixings. The methods pioneered in K2K will be used by the new J-PARC T2K experiment and the NOVA experiment at Fermilab to make much improved measurements. T2K will use the much higher intensity beams available at J-PARC combined with an extensive set of near detectors on the J-PARC site to make precision measurements of the oscillation parameters including the third mixing angle, θ_{13}, and possibly CP violation in the neutrino sector. In addition to the technical developments pioneered by the program, the K2K experiment brought together a large number of foreign collaborators who participated fully in constructing the near detectors and in obtaining the physics results. This foreign participation has continued in the T2K collaboration where a majority of the collaborators are now from foreign institutions. A bright future of forefront neutrino experiments in Japan seems assured through the J-PARC program which is a direct outgrowth of the neutrino program and physics accomplished with the KEK-PS.

E-391a: Measurement of the decay $K_L^0 \to \pi^0 \nu\bar{\nu}$

KEK E391a was the first dedicated experiment in the world to search for the $K_L^0 \to \pi^0 \nu\bar{\nu}$ decay and as such represents one of the most outstanding achievements of the KEK PS. Among the many rare *K*- and *B*-decays, the $K \to \pi\nu\bar{\nu}$ modes are unique: are very sensitive to new physics, and their Standard Model (SM) rates can be computed to an exceptionally high degree of precision, more accurately than almost all other flavor-changing neutral current processes involving quarks. An important virtue of $K \to \pi\nu\bar{\nu}$ decays is that their clean theoretical character remains valid in essentially all extensions of the SM (contrary to the situation for most other rare processes and CP-violating observables).

The exceptionally clean theoretical predictions on the two decays, and their strong suppression within the SM imply a sensitivity to new particles well above the TeV scale in realistic scenarios, such as supersymmetry or little-Higgs models. As stressed in a series of recent works, sizable non-standard effects could show up in $K \to \pi\nu\bar{\nu}$ without significant signals in *B* decays and, in specific scenarios, even without new particles within the LHC reach. On the other hand, if LHC will find "new physics" in the TeV range, then the energy scale of the new degrees of freedom will be known and the measurements of the two $K \to \pi\nu\bar{\nu}$ rates will be essential in determining the flavor structure of the new theory. For instance, in models with Minimal Flavor Violation (MFV), tiny but possibly visible effects of $O(10\%)$ are expected in both channels, with a strict correlation characteristic of the MFV scenario, while larger and uncorrelated effects are possible beyond MFV. Hence a precise measurement of two channels could provide one of the best tools to experimentally confirm or disprove the validity of the MFV hypothesis.

The experiment included many important features which will influence the future efforts in this field including the concept of a pencil beam to provide kinematic constraints, enclosing the entire detector in vacuum which facilitates highly efficient charged and neutral particle detection, and careful study of background sources. Neutral kaons were produced by 12 GeV protons and precisely defined with a solid angle of 12.6 μstr using a series of six sets of collimators aligned at a production angle of 4 degrees. The neutral beam momentum peaked around 2 GeV/c at the entrance of the detector, 11 m downstream from the target. The components of the innovative detector were assembled cylindrically along the beam axis and installed inside the vacuum tank to minimize interactions of the particles before detection. The high-precision electromagnetic calorimeter measured the energy and position of the two photons from $\pi^0 \to \gamma\gamma$ decay. The experiment featured a highly efficient photon veto detector made of lead and scintillator sheets.

The E391a experiment started taking data in February 2004. In the first period, only a partial analysis was reported due to a membrane drooping into the neutral beam near the calorimeter and causing many neutron-induced backgrounds. After fixing this problem, they resumed the physics run in 2005. Analysis of data in the second period from February to April 2005 has been submitted for publication recently and an additional data set is under review. After performing a "blind analysis", as is now customary in such experiments, no events inside the signal box were observed compared to a background from all sources expected to be 0.4 events. The limit derived from this work is $B(K_L^0 \to \pi^0 \nu\bar{\nu}) < 6.7\ 10^{-8}$ at the 90% C.L. which is an order of magnitude lower than the pervious work done by the KTEV group at Fermilab reported in 2000. The results of E391a will be very important for guiding the direction of attack on the difficult problem of measuring $K_L^0 \to \pi^0 \nu\bar{\nu}$ to be pursued at J-PARC and possibly other facilities.

E-548: Study of kaonic nuclei by the (K^-, p) reaction

The intriguing theoretical prediction that the K^- nucleus interaction might be strongly attractive generated a great deal of experimental activity. This could have very important consequences on the structure of neutron stars and offer the potential to create high density few-body objects with additional binding provided by the kaons. This experiment measured the inclusive (K^-,p) and (K^-,n) reactions on ^{12}C and ^{16}O. In both reactions, substantial yield is observed at kaon binding energies up to 150 MeV. The yield is consistent with eikonal estimates of the cross sections suggesting that the reaction mechanism is single nucleon knockout. The data are fit with a kaon optical potential through a Green's function technique. The resulting optical potential are -190 –i 40 MeV from the (K^-, n) case and -160 –i 50 MeV in the (K^-,p) case. The difference is consistent with there being 20% more of attractive isospin 0 KN pairs in the (K^-,p) reaction. This experiment is a valuable complement to the studies that attempt to directly observe bound K^- nucleus states, which are most sensitive to narrow states. The large width observed in this experiment would seem to indicate it is not likely to directly observe bound K^- nucleus, unless the width decreases significantly in light systems. The deep attractive potentials do imply a significant impact on the role of strange matter in neutron stars.

E-566: Hypernuclear γ-ray spectroscopy on a ^{12}C target

The study of the spectroscopy of hypernuclei has been a main focus of the PS program with a long and systematic series of experiments using the (π, K) reaction in coincidence with nuclear gamma transitions. The aim of this research is the understanding of the hyperon-nucleon interaction with its connection to the nucleon-nucleon interaction and use of the hyperon as a taggable trace particle to study nuclear structure.

The program has traditionally included collaborative extensions to experiments using the high-intensity kaon beams of the AGS facility at Brookhaven National Laboratory. After the termination of the BNL fixed target program in the early 2000's the KEK PS has become the primary facility for hypernuclear structure experiments world-wide. This world-class program has produced results of exceptional quality through a long-term emphasis on cutting edge and innovative experimental equipment. In this respect the KEK program has now outstripped all international competition. The Hyperball with its capability of detecting the gamma rays from hypernuclear transitions with keV energy resolution and high efficiency coupled with the SKS superconducting particle spectrometer detecting the emerging kaon with high resolution is an outstanding experimental set-up for this research, producing the definitive data on hypernuclear gamma ray spectroscopy on ^{12}C targets. The goal of determining the components of the Λ-nucleon interaction has been largely achieved by systematic measurements in light nuclei. This last experiment at the PS represents the completion of the interaction studies with the determination of consistent interaction for all nuclei except ^{7}Li. The experiment attempted to go a step further in trying to determine the modification of the Λ by the nuclear medium. Detecting such modifications of strongly interacting particles predicted by many QCD inspired models is a grand challenge of nuclear physics. This experiment searches for such a modification through measurement of the hyperon magnetic moment that can be deduced from certain nuclear electromagnetic transitions. Unfortunately the lifetime of the relevant nuclear transition was too long for a successful measurement.

This program is run by an outstanding group of scientists that publishes their results at a steady rate. First results of new experiments are routinely published in Physical Review Letters. The next stage of this experiment is set to shift to the J-PARC facility and will then profit enormously from the high-intensity kaon beams. It will have world-wide unique capabilities.

E549: Confirmation of nuclear kaonic state and search for excited states

The apparent observation of a narrow state in the $^{4}He(K^{-},p)$ reaction by PS-E471 seemed to provide dramatic support for the theoretical prediction of deeply bound and narrow K- states in nuclei. E549 improved on E471 with better statistics, better time of flight resolution, greater neutron detection efficiency and proton track measurements. The spectrum for both the (K^{-},p) and (K^{-},n) reactions in E549 reveal a smooth behavior in the vicinity of the proton momentum where E471 saw the peak and upper limits were set for a 20 MeV wide state of about 10^{-3} per stopped K^{-}. Re-examination of the E471 data revealed the peak appears to have been an artifact of the experimental analysis.

The experiment turned to exclusive rather than inclusive channels for the three body final state, examining Λ-nd final states. These could be cleanly identified but acceptance corrections are important. It appears likely a full Dalitz analysis must be undertaken. Plans for a J-PARC experiment involve the

$K^- + {}^3He$ system and an upgraded detector that can completely tag the formation and decay of the simpler K^-pp systems.

E-522: Search for H-dibaryon resonance via $^{12}C(K^-, K^+\Lambda\Lambda)$ and Study of $\Xi^- N$ interactions

The goal of Experiment E522 was to investigate the long-standing prediction of a deeply bound "H-dibaryon" state or a resonance in the ΛΛ system by measuring the invariant ΛΛ spectrum by the $^{12}C(K^-, K^+\Lambda\Lambda)$ reaction. If such a particle existed it would have far reaching consequences for the existence of "strange matter". Several earlier searches for an H-dibaryon had failed to find any evidence for its existence, but the experiment was motivated by the considerable theoretical interest in the issue. The experiment had much better statistics than a previous corresponding experiment at KEK, which had observed an enhancement near the ΛΛ threshold.

The present experiment confirmed the near threshold enhancement. The data were then compared to the calculated ΛΛ mass spectrum that was obtained with an internuclear cascade model. The calculated invariant mass spectra were found to be in good qualitative agreement with the empirical spectrum only when the final state interaction in the ΛΛ system was taken into account. This led to the conclusion that the observed threshold enhancement is a consequence of the final state interaction. No significant enhancement above the model predictions was observed. The experiment set a new upper limit for the cross section for production of an H-dibaryon between the ΛΛ and the NΞ thresholds. The results provide new information on the free Λ Λ interaction. The experiment has been published in 2007.

E-559: High-resolution spectroscopy of the Penta-quark Θ^+

The purpose of E559 was to confirm or disprove the existence of the pentaquark Θ^+ via the $K^+p \rightarrow \pi^+ X$ reaction with the SKS high resolution spectrometer. The early indications in many experiments, starting with an experiment at the Spin-8 facility, of the existence of this unusual five-quark state had generated wide interest in the international physics community. The virtue of this KEK experiment was the high resolution of the SKS spectrometer. Theoretical predictions had suggested that the above reaction would be favorable for the production of the Θ^+. The missing mass spectrum obtained in the experiment resolved the Σ^+ very well, but found no statistically significant peak in the region around 1530 MeV for the Θ^+. An upper limit for the production cross section in the mass region 1510 – 1550 MeV, which is well below the theoretical predictions, was established.

The negative result is consistent with the conclusions of other recent high-statistics experiments at the Jefferson Laboratory, Fermilab and FZ Jűlich. The result contributes to the growing consensus that there do not exist narrow strange pentaquarks in this energy range. The result was published in 2006.

E-567: Precise measurement of electronic X-rays from pionic atoms

It is the most recent step in a long series of studies that aims to detect and systematize the effects of replacing normal atoms in chemical molecules with pionic and muonic atoms. To this end negative pions and muons produced as secondary beams from the PS are stopped in selected molecules where a fraction of them are captured into atomic orbits. The presence of these heavy particles in the inner atomic orbits influences the electronic x-rays emitted by the atomic electrons. The experiment is able to detect the x-rays from electronic orbits in pionic atoms with good energy resolution and statistics. Small changes in the electronic x-rays were observed in atoms from Z=29 to 92 with the latest experiments concentrating on rare-earth compound. The occupancies of pionic levels can be inferred by comparing the data with calculations. The hope is that a detailed understanding of the dynamics of pionic and muonic atoms would lead to a new chemistry. A significant realization of this goal seems still to be well in the future.

These experiments are running parasitically and are thus inexpensive in terms of beam time and their effect on the main PS program. Their value lies with their radiochemical character and the (remote) potential for true surprises. We note that this work is outside of the general expertise of this committee. The results of the research are published in a timely manner in refereed journals and routinely presented at international conferences.

E-570: Precision spectroscopy of kaonic Helium 3d-2p X-rays

The experiment measured the energy of the 3d→2p X-ray in kaonic ^{4}He with a precision of a few eV in order to resolve a long standing disagreement between the results of three earlier experiments and many theoretical predictions of only a small shift. The earlier experiments had found an appreciable strong interaction shift (~43 eV) shift in contrast to the expectation based on systematics of only a small shift. The importance of resolving this puzzle was due to the fact that no similar discrepancy had been found for heavier atoms. A large strong-interaction shift would have implications for the possible existence of deeply bound kaonic states.

The key to this beautiful experiment was the use of high resolution silicon drift detectors and the in situ calibration technique. Particular care was taken to understand the detector resolution function. The experiment found that the strong interaction shift was only ~ (2 +-2 +-2) eV, thus entirely removing the discrepancy between theory and experiment.

The combination of the small (if any) shift and limits on the width of the 2p level place strong constraints on the possibility on deeply bound kaonic states. On the basis of this successful experiment a proposal has been approved at J-PARC to perform a precision measurement of the strong interaction shift of kaonic 3He.

9. Connection of the KEK-PS to the J-PARC facility

Eleven of the 16 experiments that the Committee reviewed have plans to continue their experimental program at the J-PARC facility when it comes online early next year and have submitted proposals that are extensions of the experiments that were reviewed here. Ten of these are listed as stage-2 approved, i.e. ready to go, experiments by the J-PARC PAC. In many cases they can move their existing equipment directly from the PS to J-PARC and five experiments are listed as “day-1” proposals in the J-PARC PAC list.

Most important among them is the flagship experiment T2K, which continues the long baseline neutrino studies of K2K with a new neutrino beam and near detector being put together by a very large and broad international collaboration. All of these experiments will profit from the vastly more intense proton and kaon beams available at the J-PARC facility. Five additional experiments that are topically connected to the PS program have been listed as “stage 1” approved indicating that they have physics approval and are working through the details of scheduling and resources. It is interesting that there are essentially no other approved experiments than those that are connected to a (former) KEK-PS program. This will likely change in the future and recently there has been a proposal to mount a muon to electron conversion experiment and proposals to accelerate and use polarized protons at the J-PARC facility.

The data runs at the KEK-PS as precursors to the J-PARC experiments have given these programs a clear advantage with respect to timescale, design, and robustness. In particular for the field of strangeness in nuclei, J-PARC will be without peer world-wide for the currently foreseeable future. The T2K, time reversal-violation search and the $K^0 \to \pi^0 \nu \bar{\nu}$ experiments have the opportunity to be well ahead of their world-wide competition. This demonstrates the important role that the 12-GeV PS played in enabling a world-class science capability for high-energy and nuclear physics in Japan.

10. Technological and industrial impact of the KEK-PS program

The value of high energy and nuclear physics accelerator facilities and their concomitant experiments in driving technological and then industrial development is well known. SLAC and CERN are outstanding examples for producing technological advances of world-wide impact. The KEK-PS has produced technological advances and industrial spin-offs that had an impact for Japan well beyond the KEK Laboratory. The Committee understands that the PS was *the* facility that motivated Japanese industry to get involved in a major way in the construction of scientific projects and this may have been the most important impact of the PS. Later the development of superconducting magnet technology in Japan emerged from the construction of the high-momentum pion beam line at the PS and then led to the large-scale superconducting solenoids at the TOPAZ detector at TRISTAN. The Japanese development emphasized high magnetic field quality. This technology recently found applications at the LHC and its ATLAS experiment at CERN.

The PS scientific program was also innovative in its target and detector developments. It was a major international competitor in the technology of frozen-spin deuterium targets. KEK developed the technology for a windowless solid hydrogen target for nuclear experiments at RIKEN. It built a 1.3 Kelvin superfluid ^4He target for several PS experiments. The SciFi detector for the K2K neutrino experiment used *all* scintillating fibers with large image intensifier read-out for track detection. Later the SciBar detector developed for the K2K experiment used a similar read out and has recently been transferred to Fermilab for a new experiment. PS experiments were part of the international effort to use novel crystal detectors such as pure CsI and PWO ($PbWO_4$) crystals for the detection of electromagnetic radiation. The most direct interaction with industry occurred with Hamamatsu Photonics on the development of multi-cathode photomultipliers and photomultipliers that can be operated in the presence of significant magnetic fields.

In summary the KEK-PS facility and its programs were very much part of the international frontline effort in detector technology including data read-out and analysis software. It is this high-tech environment that probably made the largest (if often intangible) contribution to the technological advance of a country’s economy.

Appendix I: Membership of the Review Committee

	Douglas Bryman	Professor of Physics	Univ. of British Columbia
	Donald Geesaman	Senior Scientist	Argonne National Laboratory
	Hitoshi Murayama	Professor of Physics Director	UC Berkeley IPMU Univ. of Tokyo
Committee Chair	Peter Paul	Professor emeritus & Research Professor	Stony Brook University
	Dan-Olof Riska	Director	Helsinki Institute of Physics
	Michael Shaevitz	Professor of Physics	Columbia University
	William J. Willis	Professor of Physics	Columbia University

Appendix II: Review Schedule

KEK-PS External Review 2008

January 22-24, 2008
Seminar Hall, Bldg. 4

• Program

Time schedule				Speaker	Exp. No.	Titles etc.	@J-PARC
January 22 (Tue)							
9:00	-	9:30				Closed Session	
9:30	-	9:35	[5]	F. Takasaki		Opening Address	
9:35	-	10:10	[25+10]	K.Nakamura		Overview of KEK-PS Experiments	
10:10	-	10:45	[25+10]	H. Sato		Overview of KEK12-GeV PS Accelerator	
10:45	-	11:05	[20]			Coffee break	
11:05	-	11:50	[30+15]	Y. Nagashma		Overview of Particle Physics Experiments	
11:50	-	12:35	[30+15]	K. Nakai		Overview of Nuclear Physics Experiments	
						Lunch	
13:50	-	14:10	[14+6]	T. Fukuda	E521	Production of neutron-rich Λ hypernuclei by the (π^-, K^+) double-charge exchange reaction	E10
14:10	-	14:50	[27+13]	H. Enyo	E325	Study of Chiral Property of Dense Nuclear Matter through Measurement of Meson Mass Modification in Medium	E16
14:50	-	15:30	[27+13]	J. Imazato	E246 E470	Search for T violation in the $K^+ \rightarrow \pi^0\mu^+\nu$ decay Measurement of direct photon emission in $K^+ \rightarrow \pi^+ \pi^0\gamma$	E06 -
15:30	-	15:50	[20]			Coffee break	
15:50	-	16:10	[14+6]	H. Noumi	E438	Study of Σ-Nucleus Potential by the (π^-, K^+) Reaction on Heavy Nuclei	-
16:10	-	16:30	[14+6]	H. Outa	E462 E508	Exclusive Measurement of the Non-Mesonic Weak Decay of ${}^{5}_{\Lambda}$He Coincidence Measurement of the Weak Decay of ${}^{12}_{\Lambda}$C	E18
16:30	-	16:50	[14+6]	K. Nakai	E452	Spin-dependent Interactions in Σ^+-p Scattering	-
16:50	-	17:10	[14+6]	M. Ieiri		Experiments for Test	

17:10	-	17:55	[30+15]	N. Saito		Overview of J-PARC and Nuclear and Particle Physics Experiments	
17:55	-	19:00	[65]			Closed Session	
19:30	-	21:00	[90]			Reception	
January 23 (Wed)							
9:00	-	9:45	[30+15]	K. Nishikawa	E362	Long Baseline Neutrino Oscillation Experiment	E11
9:45	-	10:30	[30+15]	T. Inagaki	E391a	Measurement of the $K^0_L \to \pi^0 \nu \bar{\nu}$ Decay	E14
10:30	-	10:50	[20]			Coffee break	
10:50	-	11:25	[25+10]	T. Kishimoto	E548	Study of Kaonic Nuclei by the (K^-, p) Reactions	-
11:25	-	12:10	[30+15]	H. Tamura	E566	Hypernuclear γ spectroscopy on ^{12}C target	E13
						Lunch	
13:40	-	14:25	[30+15]	M. Iwasaki	E549	Confirmation of Nuclear Kaonic State and Search for its Excited States	E15
14:25	-	15:10	[30+15]	K. Imai	E522 E559	Search for H-dibaryon resonance via $^{12}C(K^-, K^+\Lambda\Lambda)$ and Study of $\Xi^- N$ interactions High Resolution Spectroscopy of Penta-quark Θ^+	E07 E19
15:10	-	15:30	[20]			Coffee break	
15:30	-	16:05	[25+10]	A. Shinohara	E567	Precise Measurement of Electronic X rays from pionic atoms	-
16:05	-	16:50	[30+15]	R.S. Hayano	E570	Precision Spectroscopy of Kaonic Helium 3d-2p X-rays	E17
16:50	-	18:30	[100]			Closed Session	
January 24 (Thu)							
9:00	-	12:00	[180]			Closed Session	