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KEK News

NEUTRINO OSCILLATION EXPERIMENT

First Asian Particle Accelerator Conference “APAC98”

The International Workshop on JHF Science (JHF98)

High Energy Accelerator Research Organization

NEUTRINO OSCILLATION EXPERIMENT

According to the present knowledge of particle physics, the universe consists of six quarks, six leptons, called fermions, and bosons which mediate interactions between them. Protons and neutrons which make all of the normal nucleus have mass about 1 GeV/c^2 (10^{-24} grams). The heaviest fermion observed so far is the “top quark”. This particle has mass of about 250 times that of protons (250 GeV/c^2). Other fermions have mass around 1/1000 to several times that of protons. On the other hand, the lightest fermion known is neutrinos that have mass less than 100-millionth of proton (less than about 10 eV/c^2).

Why there are so many fermions?

Ordinary matter (our body, stars, galaxies, etc.) are made of nucleus, which composed of protons and neutrons, and electrons. Nucleus sometime transforms into other nucleus, emitting electron-type neutrino. The essential ingredients of the present universe are four kinds of fermions, i.e., two types of quarks, which make proton and neutron, electron and electron-type neutrino. Other fermions can exist only in high energy environments, such as in accelerator experiments. It appears that other fermions are essentially copies of those four kinds of fermions. However, their masses are different! This is called “generation problem”. We simply have no idea why so many fermions exist in nature with different masses.

Why the fermions have those mass values?

This is one of the most fundamental subject in particle physics. We can expect quite reasonably that the studies of neutrino mass will lead us to physics beyond present understanding of particle physics. If the neutrino mass is exactly zero, it deserves a new presently-unknown principle which “demands” the neutrino mass to be zero. (The photon mass is zero because of electric charge conservation.) However, there is no compelling reason for neutrinos to be massless. On the contrary, most of the Grand Unified Theories (the class of theories that try to extend physics beyond present knowledge of particle physics) predict small but finite neutrino mass that would show up at much higher energy than presently reachable.

How we can search for such a small mass? - How neutrino oscillates with time?

In quantum mechanics, physical system (or particle) can be defined by various characteristics (called quantum numbers). If a particle is defined by one quantum number, it is a super-position of the states of other quantum numbers. Obviously mass is one of quantum numbers. Neutrinos have extra characteristics, called electron-type (ν_e), muon-type (ν_μ), and tau-type (ν_t). Each type determines what type of lepton is produced by neutrino interaction or what type of lepton is produced with a given neutrino. If neutrino produced with muon, for example, the neutrino is called muon-type neutrino and it produces muon when it interacts with matter. In general, ν_μ is the super-position of various states with given masses. Once ν_μ is produced, each component with given mass propagates in space-time differently, resulting different mixture from the original one. This is called neutrino oscillation. The smaller the mass difference is, the slower the oscillation is. If they travel a long distance, the effect of oscillation would be measurable. Neutrino oscillation studies are thought to be only possible mean to search for a neutrino mass difference well below $1eV/c^2$.

What kind of mass region we should be searching?

Although no definite theoretical guidance exists for the neutrino mass, there are a few indications that imply a finite neutrino mass. One is the existence of dark matter in the universe. This kind of matter must not interact strongly. Otherwise it can be seen by astronomical observation. Neutrino with finite mass can be a good candidate for such an object. If the dark matter is all due to massive neutrinos, the heaviest neutrino should have a mass greater than several eV/c^2. The experiment at 800 MeV proton linac (LSND : Liquid Scintillator Neutrino Detector, Los Alamos), using 30 MeV neutrinos with a distance of 30m, indicated a rather large (several $(eV/c^2)^2$) mass difference between ν_μ and ν_e.

The other indications of neutrino oscillation exist in cosmic ray experiments. The results of Kamiokande and Super-Kamiokande on neutrinos produced in the atmosphere provided strong hints that neutrinos oscillate during the propagation between the production in the atmosphere and the detection on the ground level. The atmospheric-neutrino results clearly show that the ν_μ

flux is decreased relative to that of ν_e. The oscillation length in the atmosphere is from 10 km to 10,000 km with the neutrino energy of the order of 1 GeV. This parameter region can be explored with a high intensity neutrino beam from a proton accelerator and with massive detectors.
The other possible neutrino oscillation phenomenon is the solar neutrino deficit. The results indicate that a significant fraction of the ν_e from sun is lost or transformed into other type of neutrinos, which interact with less interaction cross section or do not interact at all in the detector.
These three experimental results give the following three distinct mass differences;
(1) LSND (ν_μ and ν_e) : several $(eV/c^2)^2$) ,
(2) Atmospheric neutrino (ν_μ and ν_x) : about 0.01 $(eV/c^2)^2$),
(3) solar neutrino (ν_μ and ν_x) : about 0.00001 $(eV/c^2)^2$).
Since we know there exists three types of neutrinos, there should be two mass differences. This implies that at least one of the experiments is giving incorrect answer or that a new kind of neutrino exists. We believe that it is now of utmost importance to further study the neutrino oscillation phenomena with well defined accelerator neutrino beams.

Advantages of the Experiment

The advantages in carrying out the long baseline neutrino oscillation experiment combining KEK-PS and Super-Kamiokande is summarized as below.

(i) The most massive neutrino detector in the world, Super-Kamiokande, is available. The cosmic-ray background that is especially severe in a low counting-rate experiment, is negligible thanks to the underground site of the detector, which in turn makes the synchronization easy.

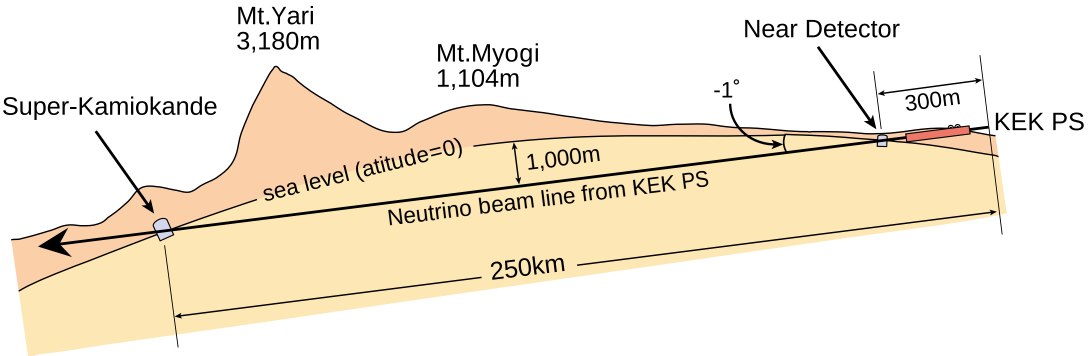
(ii) Neutrino beam energy expected from KEK-PS is well suited to water-Cherenkov detector technique. Since the neutrino beam energy is typically 1-2 GeV, most of the reactions are either quasi-elastic or single pion production, which are easily handled with a water-Cherenkov detector.

(iii) An electron, which is the signal for ν_μ-ν_e oscillations, can be identified easily in the low energy region due to small π^0 energy and low multiplicity of the events.

(iv) The neutrino beam is uniform over a broad angular region both in spectral shape and in flux. At low energies, those distributions are dominated by decay kinematics of pions. This makes the comparison of the near and far-detectors meaningful, even though they cover slightly different angular regions.

(v) The probability (P) that neutrinos of one type oscillate into the other is given by
$P=\sin^2 2\theta \times \sin^2[1.27 \times L\ (km) \times \Delta m^2\ (eV/c^2)^2\ /\ E\ (GeV)]$,
where L is the distance between the neutrino source and detector, E is the neutrino energy, Δm^2 is the mass square difference. For a given mixing angle θ, the oscillation becomes maximum at $1.27 \times L\ (km) \times \Delta m^2\ (eV/c^2)^2\ /\ E\ (GeV) = \pi/2$. Thus in order to investigate a small Δm^2 region, one must make L/E large i.e. a long baseline. For smaller distances, the same Δm^2 region can be explored with lower neutrino energies.

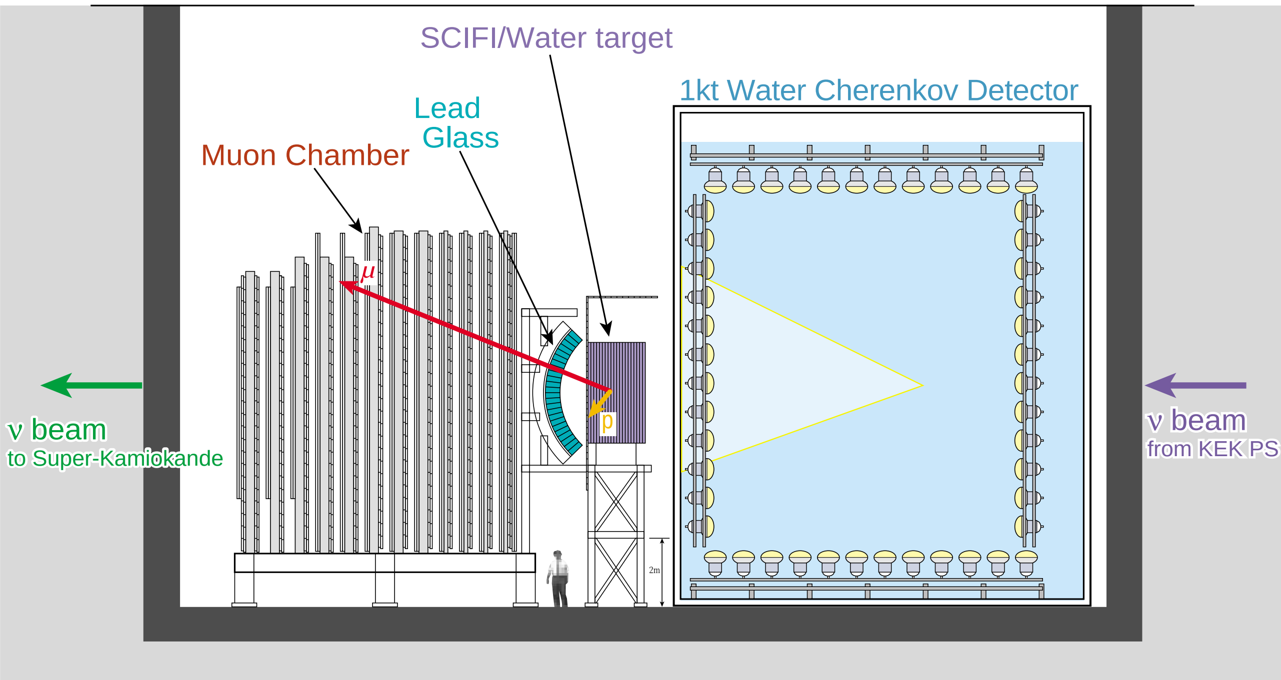
The experiment uses two water Cherenkov detectors and a fine-grained detector.



The distance between Dover and Paris which is approximately 250 km, between London and Paris is approximately 330 km, Calcutta and Daca is 250 km. Due to The spherical shape of the earth, the neutrino beam line has to aim downward (-1˚ degree) to reach Kamioka detector.

1k-ton water Cherenkov detector (Near Detector 1) :

Forty-ton fiducial volume in a 1,000 ton total detector mass can be used. The distance from the production target is 300m. The purpose of this detector is to measure neutrino interaction with the same methods as in the Super-Kamiokande detector, just after the neutrinos are produced.

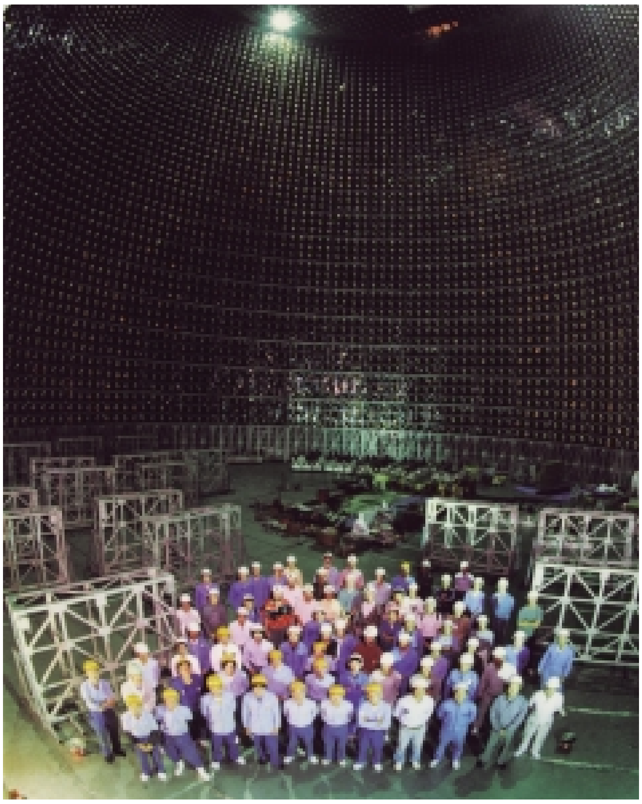


Near-detactor (see also photo on page 6).

Fine-grained detector (Near Detector 2) :

Four-ton fiducial mass immediately after the 1k-ton water Cherenkov detector can be used in analysis. The detector consists of water tubes with scintillation fiber sheets for tracking charged particles, scintillators for timing measurement, lead glass blocks for electron energy measurement, and iron with drift chambers for muon energy measurement. The main purpose of this detector is to measure flux, spectrum, and composition of ν_μ and ν_e in the neutrino beam. The detector can measure the muon momenta up to about 3 GeV/c and can define the fiducial volume with a resolution much higher than that of the 1k-ton detector.

Super-Kamiokande detector, The Far Detector :



The fiducial mass will be 22,000 ton and the distance is 250 km. This is the main detector to observe neutrino oscillations in the small Δm^2 region. The position of the detectors has been measured with the Global Positioning Satellite (GPS) system with an accuracy of less than 1m. Thus it is easy to align the whole detector system to much better than 1-mrad.

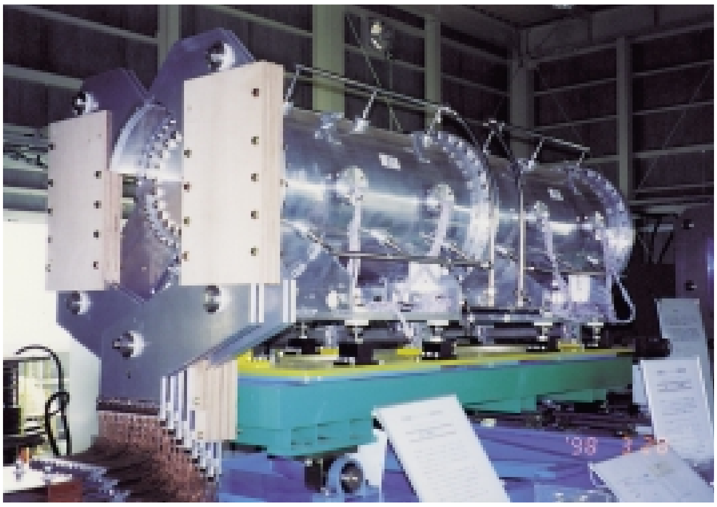
The KEK-PS produces an intense ν_μ beam with very small ν_e contamination (< 1%).
The energy of the ν_μ beam peaks at about 1 GeV and extends to 4 GeV, with an average energy of 1.4 GeV. In this energy region, the alignment of the beam line and detectors is not critical due to a rather large pion decay angles. For example, a 1 mrad mis-alignment of the central axis of each component induces less than 1% reduction in the neutrino flux. We expect more than 40,000 neutrino events in the 4-ton fiducial volume at the detector in twelve months, giving a good monitoring. We expect about 400 neutrino events in the 22,000-ton fiducial volume of the Super-Kamiokande detector, if there is no oscillation. If the results of an atmospheric neutrino observation are due to a neutrino oscillation, we expect large reduction of the number of events. These numbers are certainly large enough to definitely confirm the atmospheric neutrino results.

Present status

KEK PS Beam Line: For the fast extraction of 12 GeV proton beam from KEK-PS, the fast kicker magnets are being constructed. The system will be installed in summer of 1998. The installation of magnets for 12 GeV proton beam will be completed by the end of 1998. Other critical items of neutrino beam is the target and horn system. The horn system consists of two horns. The horn system has been constructed and tested extensively. The photograph on opposite page shows the newly constructed horn to be used in the experiment.

Near-Detector: We have modified and moved the existing 1,000 ton detector previously used for other experiment.

The entire near-detector will be installed by the end of 1998 and we are planning to start data taking in January 1999. This schedule makes KEK-Super-Kamiokande long baseline neutrino oscillation experiment to be the first accelerator experiment in the world, exploring the Δm^2 around 10^{-2} eV^2 region. And we can attain enough sensitivity by the year 2001, if the accelerator can deliver $6x10^{12}$ protons on target per each spill for total of 12 months of beam time.



newly constructed horn.

installation of near-detector in progress

The author of this article, ***Koichiro NISHIKAWA***, is the spokesperson of the neutrino oscillation experiment.

Editional coments

There was an announcement of an evidence on a neutrino oscillation at “Neutrino ’98” conference, held between June 4-9. Now this project looks more promising and exciting. (TKO)

First Asian Particle Accelerator Conference "APAC98"

Four hundred people got together at KEK on March 23 - 27, 1998, to participate in the First Asian Particle Accelerator Conference, "APAC98". It was a big success, and without doubt, will be remembered among the Asian accelerator science community as a memorable event in its history.

The accelerator science and technology in the Asian region is not new. Low energy accelerators like high-voltage generators, electron linear accelerators and cyclotrons have been quite common in many Asian countries. This situation changed very much in 1980's, when synchrotron radiation become a worldwide hit. Asian region was not an exception to this and has taken a lot of interests in the development of synchrotron radiation sources. Synchrotron radiation, being a very bright source of light from ultra-violet to x-rays, has attracted scientists in the fields of physics, chemistry, biology, and medicine. Many light sources were constructed and some are being planned in the Asian region. Asian Committee for Future Accelerator (ACFA) was formed in April, 1996 to promote mutual understanding of activities and to strengthen the international collaboration among the Asian regions. The first ACFA meeting was held in Pohang, Korea where the Pohang Light Source is located. At the meeting, ACFA decided to regularly hold Asian Particle Accelerator Conference (APAC) and to have the first conference in Tsukuba, Japan in March, 1998.

The first day was for the reports from each country and region on their activities. The speakers were Shuxian Fang (China), S. S. Kapoor (India), A. Djaloeis (Indonesia), M. Inoue (Japan), Won Namkung (Korea), Swee-Ping Chia (Malaysia), Richard Sah (Taiwan), Weerapong Pairuswan (Thailand) and Van-Do Nguyen (Vietnam). Invited talk from Novosibirsk was presented by I. Chatounov in place of A. N. Skrinsky.

Electron-Positron Collider

From the area of high energy physics, the activities of the Beijing Electron-Positron Collider and the KEK B-factory were reported. The B factory is a new electron-positron collider being constructed at KEK which is now in the final stage of construction. Among the next generation high energy accelerator concepts, linear colliders have been the most seriously considered. Linear colliders (which produce head-on collisions of electrons and positrons accelerated by linear accelerators of about 20 kilometers in length) are technically very challenging and status reports were presented by KEK, SLAC, DESY, and BINP.

High-intensity proton accelerators

Interests in high-intensity proton accelerators have grown in Asia. Major reasons are for; the production of high-intensity neutrons for basic materials research and the development of advanced nuclear power technologies for accelerator-driven nuclear waste transmutation and power production. Reported were; the Neutron Science Project by JAERI, the Japan Hadron Facility project proposed by KEK and

KOMAC Project (Korean Multipurpose Accelerator Complex) by KAERI. Both the JAERI and the KOMAC designs incorporates a super-conducting linear accelerator at around 1 GeV with very novel technology. The KEK proposal applies a cascade of two synchrotrons with the energy of 3 GeV and 50 GeV.

RI beam (RIB) factories

Since the invention of a cyclotron in 1932, many were constructed for nuclear physics at first and then for medical applications in recent years. A noticeable advancement in this area is the construction of RI beam (RIB) factories. RIB (accelerated unstable nuclei produced by cyclotrons) have very attractive properties not only for nuclear physics but also for materials science and for medical applications. In Asia, two facilities have been operating: Institute of Modern Physics in China and RIKEN (The Institute of Physical and Chemical Research) in Japan. An approval of a new RIB Factory project at RIKEN was reported by Y.Yano. When completed, it will be the most powerful RIB factory in the world.

Synchrotron radiation

Synchrotron radiation and free-electron lasers also attracted scientists. Many light sources as user facilities exist in Asia; two in China, one in India, three in Japan, one in Korea and one in Taiwan. The Siam Photon project in Thailand has already been approved and as Hongjie Xu from Shanghai Synchrotron Radiation Facility (SSRF) Project reported, the SSRF project has finished the R&D stage and is waiting for the final approval for construction.

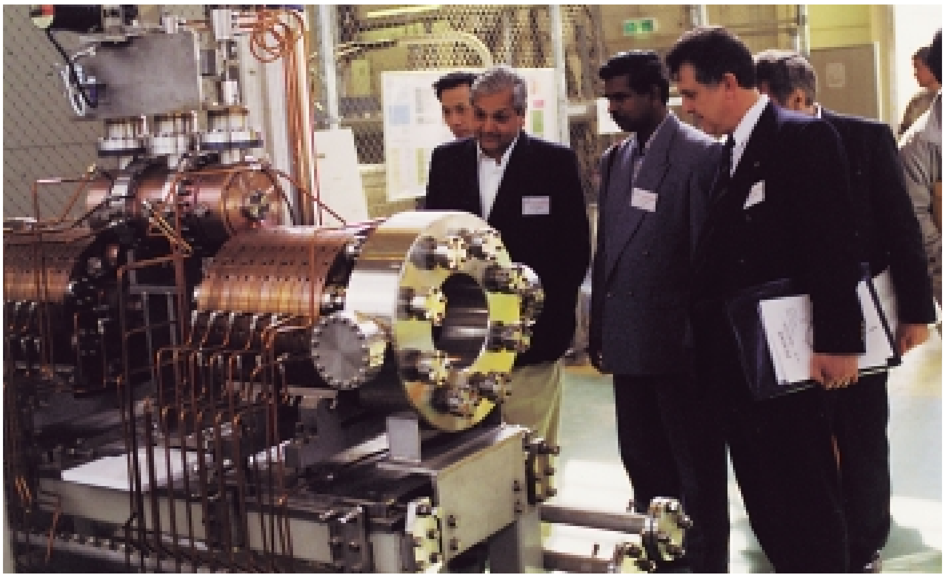
Low-or medium-energy accelerators

Low-or medium-energy accelerators and their uses were also important subjects at the APAC. Examples of their applications are the medical applications such as cancer therapy and isotope production. Recently, proton or heavy-ion therapy has been developed and several such facilities have been constructed at hospitals in Japan. Plans for such facilities exist in China, Korea and Taiwan as well.

Materials microanalyses are also classical techniques using low-energy accelerators. An interesting application is related to environmental problems. Accelerator mass spectrometry technique has been widely applied to detect an extremely small amount of elements contained in our environment.

Compact electron linear accelerator

Another interesting development reported at the conference was a very compact electron linear accelerator which uses very high

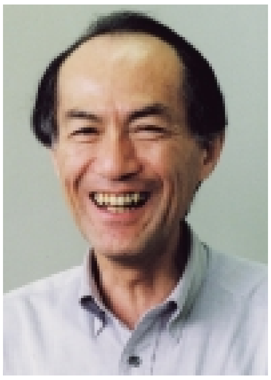


microwave frequency for baggage inspection at airports. The conference program included 24 oral and 200 poster presentations besides the invited talks.

And...

A KEK tour provided opportunities for on-location discussions between the participants and KEK staffs which was very fruitful for younger participants in particular. Evenings were also quite lively at parties and a banquet which further helped the participants to get to know each other well.

The third ACFA meeting was held on March 25, where Zhipeng Zheng of IHEP (China) and Won Namkung of POSTECH (Korea) were elected as the next chairperson and the vice-chairperson. Next ACFA secretaries will be Shu-hong Wang of IHEP and In-Soo Ko of POSTECH. We look forward to the next APAC in China.



Motohiro Kihara, the author of this article, is the Director of Accelerator Laboratory, KEK.

The International Workshop on JHF Science (JHF98)

Japan Hadron Facility (JHF) is the near future plan which KEK has been pushing for approval by the Japanese government. An International Workshop on JHF Science ("JHF98") was held at KEK between March 4th and March 7th as a part of the preparation for the JHF project, especially because it will be a facility for international collaborations. Number of registered participants were 441. (Japan 322, U.S. 37, Canada 18, China 4, Taiwan 4, India 5, Korea 4, U.K. 8, France 3, Germany 10, Swiss 10, Austria 2, Italy 7 and Russia 7). This was beyond what was expected and the JHF project received great encouragement from the international science community of broad discipline.

The main goal

The main goal of the workshop was to draw a clearer picture on real experiments at JHF. Intensive discussions were done on goals of experiment(s), their importance in physics and requirements for beam characteristics, beam lines, detectors, experimental floors and others. Since the JHF is a multi-purpose accelerator facility, the topics covered were diverse as expected.

The workshop started with plenary sessions.

Plenary sessions

Speakers and topics were:

S. Nagamiya (JHF Project), S. Wojcicki (Neutrino Oscillation), W. Marciano (Rare Processes and Related Physics), V. Metag (Future Prospects in Nuclear Physics and the JHF), M. Oka (QCD Nuclear Physics), Y. Mori (JHF Accelerator), W.I.F. David (Material Sciences with Neutron Beams), J. Trewhella (Biological Sciences with Neutron Beams), S. Cox (Muon Science), G. Mathews (Nuclear Astrophysics with RI Beams) and R. Kiefl (From Nuclear Sciences to Material Sciences).

The four experimental facilities

JHF facility is designed to have four experimental facilities, called K-, N-,M- and E-Arena, to accommodate various experimental needs. Hence the parallel sessions were divided into sessions related to particulars of each arena for most of them. (Although each arena is not totally independent from each other and overlapped regions were covered by other sessions including plenary sessions.)

Topics for each arena were,.

(1) K-Arena : kaon and muon rare decays, neutrino physics, strangeness nuclear physics, physics with primary beams, and hadron spectroscopy and physics with anti-proton and anti-nuclei.

(2) N-Arena : solid target technology, new science with neutrons, and fundamental physics with neutrons.

(3) M-Arena : next generation μSR experiments.

(4) E-Arena : facilities, nuclear astrophysics, fundamental and nuclear physics with ISOL-based RNB, material science, post accelerators, and production targets and ion sources.

Part of the working sessions of the E-arena was held as the KEK and TRIUMF Joint Workshop on Physics and Techniques of Radioactive Nuclear Beams. In conjunction with JHF98, "Multi-Purpose Hadron Working Group Meeting for the OECD Mega Science Forum (Nuclear Physics)" was also held at KEK on March 3rd and in the afternoon on March 7th.

And the evenings were...

Not only the daytime sessions were lively, but banquet and parties were filled with good discussions that went quite well with good food and drinks.

Shoji Nagamiya
is the project leader of the JHF project.

Tomokazu Fukuda
is the author of this article and one of the important proponents of the JHF project.

EVENTS

KEK Council Meeting (2/16)

KEK council meeting was held on Feb.16. Major discussion was on the terms of office of KEK Director-General and Directors.

OECD Mega-Science Forum (3/3,7) / JHF workshop (March 4-7)

Japan Hadron Facility (JHF) related workshop was held with over 400 attendants. See page 11-12.

B-Accelerator review (3/ 5-7)

The third KEKB accelerator review committee was held on March 5-7 to review the present status of KEKB accelerator system. This committee is a subcommittee under LCPAC and 10 committee members took part in it.

LCPAC (3/ 9-10)

The annual LCPAC (Lepton Collider Program Advisory Committee) was held on March 9-10. Discussed were the issues of KEKB accelerator, BELLE experiment and R&D on JLC.

APAC (3/23-27)

The first Asian Particle Accelerator Conference (APAC) was held in great success. See page 7-10.

ATLAS review (3/24)

A one-day review of ATLAS-Japan group was held on March 23rd as the ATLAS-Japan group is nearing the mass production stage.

Steven Chu's colloquium (3/24)

Steven Chu, a Nobel laureate of 1997, who did an experiment at KEK gave a KEK general colloquium on Precision Atom Interferometry.

Symposium on Laser Application to Muon Science (3/25-27)

Symposium "Laser Application to Muon Science" was held at Tsukuba Kyoiku-Kaikan during the period of March 24-27, 1998 with 78 participants including 7 from overseas. 44 presentations and intense discussion covered wide range of topics.

Neutrino beam line (3/25)

On completion of the neutrino beam line civil engineering, the groupe held a party. Installation of Near-Detector and magnets cintinues.

KEK International "Hanami" party (4/3)

KEK International Affairs Division hosted a party under on-site cherry blossoms in full broom. The party went along with an informal tea ceremony.

Colloquium on ITER project (5/27)

President of Japan Atomic Energy Research Institute, Dr. Masaji Yoshikawa, gave a talk on International Thermonuclear Experimental Reactor (ITER) project.

ANNOUNCEMENTS

International Science School (ISS'98) (7/22-31)

International Science School will be held between July 22 and July 31 this year. It has been an annual event where high school students from many countries are given a chance to learn from lectures and tours at KEK. This year, Photon Factory is the division in charge at KEK. The title of the school is "Light for the future"

VISITORS TO KEK

We are honored to have many VIPs visited KEK for a tour and discussions. Other important visitors are also listed below.

VIPs from Saudi Arabia (3/6) :

Deputy Minister of Ministry of Education, Mr. Al-Sayagh and 4 others.

VIPs from Saudi Arabia (3/18) :

Minister of Higher Education, Dr. Al-Angari and 11 others.

VIPs from Morocco (3/26) :

Mr. Said Belcadi, Director General of Scientific Research and Inter-university Cooperation Division, Ministry of Education and Mr. Abdeslam Zefri, the First Secretary of Embassy.

USA high school students (3/24):

Forty high school students from US DOD Dependents Schools of Pacific Region.

UK-Japan Symposium Members (4/20)..

Members of Japan-UK Symposium on "New Partnership between the University and Industry in the 21st Century"

VIPs from Israel Embassy (4/23):

The Israel Ambassador to Japan, Mr. Moshe Ben-Yaacov and 4 others.

"International Symposium on Indium-phosphates and Relatde Materials" (5/14)

Fifty attendants of the symposium held in Tsukuba.

The picture on the back cover is the Main Building of the Todaiji Temple.

It is the largest wooden building existing in the world where it houses a 18 meters tall bronze statue of Buddha Vairocana (also shown). After burned down several times in its history, present building (rebuilt in 1709) is smaller than the previous buildings built as early as in 752. Yet its dimensions, 49 m high, 57 m wide and 50 m deep is very impressive even by today's architectural standard.

Front cover shows a "Ja-ki", an evil spirit, trampled by a guardian of buddhism. This sculpture is also installed at the middle gate of the Main Building. The Todaiji, the very highly regarded temple, is in Nara city, one of the old capitals of Japan. (The editor would like to thank the Todaiji for their understanding and kind support in taking these pictures.)

"Central Japan Relief Map" on the first page : Courtesy of Japan Map Center
The editor would like to thank Geographical Survey Institute for their help.

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