Experimental Particle Physics Group

(http://www.awa.tohoku.ac.jp)

Academic Staff

Professors	Atsuto Suzuki, Akira Yamaguchi and Hitoshi Yamamoto
Associate Professors	Jumpei Shirai, Fumihiko Suekane, Kunio Inoue and Tomoki Hayashino
Assistant Professors	Tadashi Nagamine, Takuya Hasegawa and Masayuki Koga

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Research Fellows	Tadao Mitsui, Kenji Ishihara, Masakazu Motoki, Jesse Goldman(to Feb.), Koichiro Furuno,Tetsuo Abe
Guest Research Fellows	Brian Fujikawa (to Sep.), Fabris Piquemal (from Oct.)
Teaching Staffs	Kyoko Tamae
Technical Staffs	Tomoaki Takayama, Hiromitsu Hanada, Takashi Nakajima, Minoru Nakajima and Kazuo Shimizu
Secretaries	Tomoko Sakai, Makie Sasaki (to Nov.), Yuri Endo (from Dec.), Akemi Ohtsuka
Graduate Students	Masayuki Etoh (D3), Toshiyuki Iwamoto (D3), Hiroshi Ogawa (D3), Sanshiro Enomoto (D3), Kazuhiro Oki (D3), Osamu Tajima (D3), Hideki Watanabe (D3), Haruo Ikeda (D2), Yoshihito Gando (D2), Fumiaki Handa (D2), Itaru Higuchi (D2), Kiyoshi Ikeda (M2), Kyo Nakajima (D1), Yuichi Matsuda (D1), Yoshinari Mikami (D1), Yousuke Yusa (D1), Koji Eguchi (M2), Tsunehiko Kawashima (M2), Manabu Saigo (M2), Itaru Shimizu (M2), Satoshi Tanaka (M2), Hajime Tamura (M2), Yoshikazu Fujisawa (M2) and Tatsuo Maeda (M2), Takahiro Kato (M1), Yotaro Koseki (M1), Ryosuke Yamauchi (M1), Kentaro Owada (M1), Ken'ichi Tada (M1)

I. The KamLAND group

(A.Suzuki, J.Shirai, F.Suekane, K.Inoue, M.Koga, T.Mitsui, K.Ishihara, J.Goldman, Y.Kishimoto, M.Motoki, K.Furuno, K.Tamae, T.Iwamoto, H.Ogawa, S.Enomoto, K.Oki, O.Tajima, H.Watanabe, H.Ikeda, K.Ikeda, K.Nakajima, K.Eguchi, T.Kawashima, I.Shimizu, T.Maeda, Y.Koseki, K.Owada and K.Tada)

The problem of solar neutrino deficit has been unresolved for more than 30 years. The discovery of atmospheric neutrino oscillation by the Super-Kamiokande (SK) group in 1998 established a finite mass of neutrino and the mixing of flavor and mass eigen-states of neutrinos. In natural extension, neutrino oscillation has been considered to be the most promising explanation of the solar neutrino problem. Recent results from SNO and SK data on solar neutrino flux showed that there are different neutrino flavor types than electron in the flux and that if all neutrino types are summed together, there is no more the 'deficit'. These results very strongly support the oscillation hypothesis. Combined analysis on the existing data on solar neutrino flux showed that the Large Mixing Angle (LMA) is the most promising solution in the mixing parameter space ($Dm^2 \sim 5 \cdot 10^{-3} eV^2$, $\sin^2 2q \sim 0.8$). The KamLAND experiment has a capability to examine the LMA solution by observing anti-neutrinos from power reactors widely spread in Japan. The well-known and controlled neutrino source makes the experiment quite reliable. Even if LMA turned out to be untrue, KamLAND will be able to test other solutions by detecting ^{7}Be solar neutrinos such as by day/night variation at the LOW solution, by seasonal variation at the just-so solution and by very low signal rate at the SMA solution. Thus, combined observation of reactor anti-neutrinos and ^{7}Be solar neutrinos will pinpoint the solutions, definitely.

The KamLAND is a 1000-ton liquid scintillator detector aiming at observing low energy anti-neutrinos and neutrinos. The detector locates deep in the Kamioka mine with 1000-meter's rock overburden. There is an 18 m diameter stainless steel tank, which contains 3000 m^3 of liquid scintillator and buffer oil, in a cylindrical cavern of 20m diameter and 20m deep. A plastic balloon holding 1000 ton liquid scintillator is suspended in paraffin oil which constitutes a buffer region. The buffer oil is segmented into two layers, inner and outer buffers, with a thin acrylic plate so that most of radon sources (photo tubes, cables and also stainless tank) are isolated from the inner buffer. The scintillation light is viewed by 1325 of newly developed 17" tubes and 554 of old Kamiokande 20" tubes. A water Cherenkov anti detector is further constructed around the stainless tank and it uses 225 old Kamiokande photo tubes in ~3000 m^3 pure water. Our group hosts the experiment and is responsible for most of the experiment.

Following the 5-year construction data taking started in 22/Jan/2002. Trouble shootings and calibration work were done to understand the detector performances and to make the quality of the data better. Soon after the start of the data taking, it was found that the detector performances already exceeded the requirements to perform reactor neutrino physics. That is, the scintillation light yield is very high; >300pe/MeV with 17" PMT only (requirement was >100pe/MeV), the background level is extremely small; ^{238}U and ^{232}Th concentrations are estimated to be $(3.5 \pm 0.5)\times10^{-18}$g/g and $(5.2 \pm 0.8)\times10^{-17}$g/g, respectively by studies of Bi-Po decay chains and ^{40}K contamination is less than 2.7×10^{-16}g/g from the observed energy spectrum. These values are far better than the requirements for reactor neutrino detection and ^{238}U and ^{232}Th concentrations already satisfied the goal for the ^{7}Be solar neutrino detection. The energy and timing resolutions, uniformity and stability of the detector response are carefully studied by using several calibration sources and studies on radiation from ^{40}K, ^{232}Th and Bi-Po contaminants and ^{12}B- and ^{12}N- spallation products and γ rays from neutron capture, and other calibration devices such as laser and LED light sources; these studies have established the excellent detector performance. The primary trigger threshold is set at 0.7MeV with a reduced one of 0.4MeV during 1msec after the primary trigger. The trigger efficiency for reactor anti-neutrino events was determined to be 99.98%. All these achievement is made possible after the years of intensive R&D and construction effort of the collaboration. Also, a software has been developed to calculate the reactor neutrino flux from all the reactors in Japan based on the information provided by electric power companies.

Data taking was successfully continued and the accumulated data corresponding to a 162 ton •year were analyzed. We observed 54 events of reactor anti-neutrino in the visible energy region above 2.6MeV, while the expected number is 86.8 ± 5.6. The backgrounds are expected to be 1 ± 1events. The ratio of the background subtracted events to the expectation without oscillation is 0.611 ± 0.085(stat.)± 0.04(syst.), which is significantly less than one. The probability of the value being the fluctuation from the expectation is less than 0.05%. We observed for the first time the deficit of the reactor neutrinos. If we assume CPT invariance and the neutrino oscillation with a two-flavor context, all solutions except for the LMA to the solar neutrino problem were excluded. Furthermore, combined analysis on the neutrino flux and the spectrum shape of the primary signal strongly restricted the allowed region of the LMA. The best fit to the data yields the combination of the oscillation parameters; $\sin^2 2\theta=1.0$ and $\Delta m^2=6.9\times10^{-5}\mathrm{eV}^2$. The impact of our results are enormous not only because we may finally resolved the long-standing solar neutrino problem but the basic parameters of the neutrino (mixing angle and the mass-squared difference) are significantly narrowed. The result was announced and submitted for publication on Dec.6, 2002.

The detector is in good condition and steadily taking data. If we continue to accumulate data detailed shape analysis becomes possible to see if there is a distortion which is characteristics of the neutrino oscillation. Also, the clean data show that the observation of the geo-neutrino is within our reach which will come out in the primary spectrum below 2.6MeV if we accumulate more data. It will open up the new study field of geophysics by neutrino. Finally, it should be stressed that we have already started R&D's aiming at ^{7}Be solar neutrino detection which will be realized in a coming years. They include significant reduction of environmental Rn and removing radio-impurities in the liquid scintillator such as ^{210}Pb, ^{85}Kr, $^{39,\ 42}$Ar and ^{222}Rn, which have been found to be main obstacles in improving the sensitivity of our experiment to lower energy neutrino.

II. BELLE group

(A. Yamaguchi, H. Yamamoto, T. Nagamine, T. Abe, F. Handa, I. Higuchi, Y. Mikami, Y. Yusa, Y. Fujisawa, M. Saigo, S. Tanaka, T. Kato)

KEK-B is a colliding beam experiment with a 8 GeV electron beam on a 3.5 GeV positron beam, one of the two such machines called B-factories in the world - the other one being PEP-II at Stanford, California. As of May 2003, KEK-B has achieved the design luminosity of $1.0 \cdot 10^{34}\,/cm\ \ s$ exceeding that of PEP-II by nearly factor of two, and accumulated 146 fb^{-1} of integrated luminosity which corresponds to more than 150 million B meson pairs produced.

The main subject of this experiment is to study the origin of CP-violation. Before B-factories, the only place where CP-violation has been observed was the neutral kaon system where CP asymmetries were of order 10^{-3}. The observed CP violation can be explained by a irreducible complex phase in the $3 \cdot 3$ matrix (Kobayashi-Maskawa matrix) that characterizes the quark-W couplings. It is a part of the standard model, and it predicted large CP asymmetries of order unity in the B meson system. In 2001, Belle has observed such asymmetry in the decay Bfi $J/y\ K_S/K_L$ and related modes. This measures the so-called angle $\pounds_1$ of the Kobayashi-Maskawa matrix. This indicated that the complex phase of the Kobayashi-Maskawa matrix is indeed the source of the CP violations observed so far.

As for our hardware efforts, we have successfully constructed and have been operating the glass resistive plate counter (RPC) for detection of muons in collaboration with Tohoku-Gakuin university, Osaka-City university, KEK, Aomori university, Princeton university and Virginia Technology. Construction of the endcap part of 120 modules, each consisting of 10 RPCs, was completed at Tohoku University. It has been operating successfully, providing Belle with the indispensable muon identification as well as that for neutrons and K_L.

For the last two years, we have been working with KEK to design and fabricate the region of machine detector interface which is critical in suppressing the beam-induced backgrounds so that the Belle detector can operate with the high beam currents. There are two main sources of beam backgrounds: the synchrotron radiations from the bending magnets and quadrupole magnets near the interaction point, and the stray beam particles showering near the detector. Tohoku have been organizing the related efforts and Abe has worked on the synchrotron radiation background which is now passed on to Tajima. We have also constructed a new beam pipe at the interaction point of Belle detector. In order to measure the decay vertex of B meson with higher accuracy, the beam pipe has been redesigned with the smaller radius of 15mm than the present radius of 20mm. It will increase the vertex accuracy from 100 *mm* to 70 *mm* and will be installed into the beam line in summer of 2003.

In parallel with the efforts for the current Belle experiment, we are also planning for the next major upgrade (Super-KEKB) which is to increase the luminosity by factor of ten or more. Here again, we would like to place the vertex detector as close to the beam as possible, r = 1 cm if that is allowed by the beam background. Our efforts are two prongs: one is to study the beam backgrounds in order to suppress them as much as possible, and the other is to develop a new vertex detector that can stand more beam background and hit rate. The desirable type for the vertex detector is a pixel-type where the true three-dimensional points can be obtained for hits on tracks. We have set up a silicon laboratory at Tohoku to perform R&D's for pixel detectors.

Higuchi is in charge of the mode $J/y\ K_L$ for the $£_1$ measurement. This analysis critically depends on the performance of RPC's. In order to prove that the matrix is unitary, as the theory predicts, one has to measure other angles ($£_2$ and $£_3$) and the absolute values of the matrix elements - in particular, the b-u-W coupling constant V_{ub}. Mikami is measuring V_{ub} using the inclusive D_S production in B decay. The angle $£_3$ can be measured by studying the decay time distributions of

B^0 or $\overline{B}^0$ decaying to $D^{+}p^{+}$, which is pursued by Handa, or by B^{-} decaying to D^0K^{-} and related modes, which is now started by Saigo. Since we have collected a large data sample for charm particles also, some rare decays that eluded detection so far are coming within reach. Fujisawa has observed a first radiative decay of charm, D^0fi fg, which Tajima is carrying on to complete the analysis.

III. Super-Kamiokande group

(A.Suzuki, J.Shirai, K.Inoue, T.Hasegawa, K.Ishihara and Y.Gando)

The Super-Kamiokande (SK) detector has been reconstructed from an unexpected destruction of almost half PMTs. Now, the experiment turns into the second stage as "SK-II" with PMTs being protected with Acrylic caps and FRP encapsulation. A possibility of chain reaction is eliminated with these protections. SK-II started taking data on 10th December 2002 with full of water. Modification of analysis tool and calibrations for new setup are being performed vigorously. For example, solar neutrino peak is already seen in the angular distribution of SK-II data.

During the reconstruction, all the SK-I data were analyzed and converged to the final SK-I results. Solar neutrino analysis accumulated 1,496 days of data from 31st May 1996 through 13th July 2001. We found 22,385 solar neutrino events in it and solar ^{8}B neutrino flux is precisely determined to be $(2.35 - 0.02\,(stat.) - 0.08\,(syst.)) \cdot 10^6 / cm^2 / \sec$ with this high statistics data sample. The ratio to the standard solar model is $0.465 - 0.005\,(stat.)^{+0.016}_{-0.015}\,(syst.)$.This high statistics data is also analyzed from the views of time variations (day/night, seasonal) and spectrum distortion. All of them are consistent with constant suppression and it brought strict limit on the neutrino oscillation hypothesis. SK-I alone excludes the possibility of small angle solution at about 3 sigma level. Combining with all other solar neutrino experiments, only the LMA solution ($\tan^2 q \sim 0.25 - 0.65$, $Dm^2 \sim 3 - 19 \cdot 10^{-5} eV^2$) is allowed at 98.9% C.L. in the two neutrino oscillation hypothesis. Currently allowed LMA solution predicts 0.1% to 5% day-night asymmetry and it may be checked by increased statistics with SK-II data.

The energy region above solar neutrino window is sensitive to the relic supernova neutrinos. Search for such neutrinos gave neutrino flux limits 20-130 $\bar{n}_e$ /cm^2/s depending on various time evolution models. This limit is 10 times better than the previous limits and some models are already excluded by this.

Neutrinos related to gamma ray bursts (GRBs) were also looked for in the energy region from 7 MeV to 100 TeV. There was no significant correlation and flux limits were obtained as 1.4/cm^2

(7-80MeV from low energy data analysis), 0.017/cm^2(200 MeV - 200 GeV from high energy data analysis) and 0.0011/cm^2 (2 GeV-100 TeV from up-going muon analysis) all at 90\% C.L.. They are million times, 10 thousand times and 30 times better limits than previous limits, respectively.

Atmospheric (FC+PC) neutrino data sample has 1,489 days of data accumulation. It corresponds to 91.6 kton-year exposure. And up-going muon data sample was obtained from 1,657 days (up-stop) and 1,678 days (up-through) of data. The data has already established neutrino oscillation and excluded n_m to n_s nor n_m ton_e oscillation solutions in the two neutrino oscillation hypothesis. A precision measurement of n_m to n_t oscillation has been provided and also three neutrino oscillation has bees studied intensively. Now, the allowed region of n_m to n_t oscillation parameters narrowed to $\sin^2 2q$>0.92 and $1.6 \cdot 10^{-3} < Dm^2 < 3.9 \cdot 10^{-3}$ (eV^2) at 90% C.L.. Assuming Dm_{12}^2 is smaller than 10^{-4}eV^2 and thus much smaller than Dm_{13}^2, three flavor oscillation parameters can be deduced to only $\sin^2 2q_{13}$, $\sin^2 2q_{23}$ and Dm_{23}^2 for the atmospheric neutrino analysis. SK-I data is consistent with zero for $\sin^2 2q_{13}$ and provided a limit of $\sin^2 2q_{13} < 0.16$ at 90% C.L.. A neutrino decay hypothesis (n_3 to sterile state) turned out to be in good agreement with FC, PC, up-muon data sample. The hypothesis will decrease neutral current interaction rate of up-going neutrinos. In order to test the effect, enriched data sample for neutral current was prepared with criterion of FC multi-ring, brightest is e-like and visible energy greater than 400 MeV resulting 22% n_m neutral current. Possible up-down asymmetry was tested with this sample and the parameter region (mass over life time VS mixing angle) preferred by the usual data sample at 99% C.L. has been excluded at 99% C.L. with this sample.

Nucleon decay search has also been updated and there was no candidate event in 91.6 kton-year data sample. The obtained life time limits are; $2.2 \cdot 10^{33}$ years for p to $K^+ n$, $5.4 \cdot 10^{33}$ years for p to $e^+ p^0$.

IV. K2K group

(T.Hasegawa)

Based on all the data taken in the first experimental period from June 1999 to July 2001, corresponding to $4.8 \cdot 10^{19}$ protons on target (POT), the KEK to Kamioka long-baseline neutrino experiment (K2K) observes indications of neutrino oscillation: a reduction of n_m flux together with a distortion of the energy spectrum.

K2K uses an accelerator-produced neutrino beam with a neutrino flight distance of 250 km. The neutrino beam is produced by a 12 GeV proton beam from the KEK proton synchrotron. After the protons hitting an aluminum target, the produced positively charged particles, mainly pions, are focused by a pair of pulsed magnetic horns. The neutrinos produced from the decays of these particles are 98% pure muon neutrinos with a mean energy of 1.3 GeV. The pion momentum and angular distributions downstream of the second horn are measured with a gas-Cherenkov detector (PIMON) in order to verify the beam Monte Carlo(MC) simulation and to estimate the errors on the flux prediction at SK. The direction of the beam is monitored on a spill-by-spill basis by observing the profile of the muons from the pion decays with a set of ionization chambers and silicon pad detectors located just after the beam dump. The neutrino beam itself is measured in a set of near neutrino detectors(ND) located 300m from the proton target. The measurements made at the ND are used to verify the stability and the direction of the beam, and to determine the flux normalization and the energy spectrum before the neutrinos travel the 250 km to SK. The flux at SK is estimated from the flux of the ND by multiplying the Far/Near (F/N) ratio, the ratio of fluxes between the far detector (SK) and ND, to that of the ND. The F/N is inferred by PIMON measurement. The ND is comprised of two detector systems: a 1 kiloton water Cherenkov detector (1KT) and a fine-grained detector (FGD) system. The flux normalization is measured by the 1KT to estimate the expected number of events at SK. Since the 1KT has the same detector technology as SK, most of systematic uncertainties on the measurement are canceled. The energy spectrum is measured by analyzing the muon momentum and angular distributions in both detector systems. In addition, the spectrum measurement by PIMON is used as a constraint. The MC calculation of the neutrino energy spectrum agrees well with the data.

Since both a suppression in the number of events and a distortion of the spectrum are expected for neutrinos which travel a fixed path length in the presence of oscillations, both the number of observed events and the spectral shape information at SK are compared with expectation. All of the beam-induced neutrino events observed within the fiducial volume of SK are used to measure the overall suppression of flux. In order to study the spectral distortion, 1 ring m-like events (1 Rm) are selected to enhance the fraction of charged-current (CC) quasi-elastic (QE) interactions ($n_m + n$fi $m + p$). Only the muon is visible in these reactions since the proton momentum is typically below Cherenkov threshold. The energy of the parent neutrino can be calculated by using the observed momentum of the muon, assuming QE interactions, and neglecting Fermi momentum.

The events in SK are selected using the timing information provided by the global positioning system. Events detected in SK must occur within an expected beam arrival time window of 1.5 $m$sec. In addition, the detected events must have no activity in outer detector, and have an energy deposit greater than 30 MeV with a vertex reconstructed within the 22.5 kiloton fiducial volume. This sample of events is referred to as the fully contained (FC) sample. The efficiency of this selection is 93% for CC interactions. Fifty-six events satisfy the criteria, while the expected number of FC events at SK without oscillation is estimated to be $80.1^{+6.2}_{-5.4}$. With the timing cut, the expected number of atmospheric neutrino background is approximately 10^{-3} events. The correlations between energy bins from the spectrum measurement at the ND and the F/N ratio are taken into account in the estimation of the systematic errors. The major contributions to the errors come from the uncertainties in the F/N ratio ($^{+4.9\%}_{-5.0\%}$) and the normalization (5.0%), dominated by uncertainties of the fiducial volumes due to vertex reconstruction both at the 1KT and SK.

A two flavor neutrino oscillation analysis, with n_m disappearance, is performed by the maximum-likelihood method. In the analysis, both the number of FC events and the energy spectrum shape for 1 *Rm* events are used. The likelihood is calculated at each point in the Dm^2 and $\sin^2 2q$ space to search for the point where the likelihood is maximized. The best fit point in the physical region of oscillation parameter space is found to be at ($\sin^2 2q, Dm^2$)=(1.0, $2.8 \cdot 10^{-3}eV^2$). If the whole space including the unphysical region is considered the values are (1.03, $2.8 \cdot 10^{-3}eV^2$). At the best fit point in the physical region the total number of predicted events is 54.2, which agrees with the observation of 56 within statistical error. The best fit spectrum shape agrees with the observations.

The probability that the observations are due to a statistical fluctuation instead of neutrino oscillation is estimated by computing the likelihood ratio of the no-oscillation case to the best fit point. The no-oscillation probabilities are calculated to be 0.7%. When only normalization (shape) information is used, the probabilities are 1.3% (16%). Allowed regions of oscillation parameters are evaluated by calculating the likelihood ratio of each point to the best fit point. The 90% C.L. contour crosses the $\sin^2 2q$=1 axis at 1.5 and $3.9 \cdot 10^{-3}eV^2$ for Dm^2. The oscillation parameters preferred by the total flux suppression and the energy distortions alone also agree well.

After rebuilding the far detector, Super-Kamiokande, K2K resumed December 2002. Up to 17 March 2003, K2K has accumulated additional 10^{19} POT.

V. Linear Collider

(H. Yamamoto, T. Hasegawa, S. Tanaka, M. Saigo)

Linear Collider has been designated as the highest priority project by the U.S, and Japanese high energy physics communities. It collides e^+ and e^- beams at the center of mass energy of 500 GeV or more. Each beam is accelerated by a straight linac, and the total length will be about 30 km. Among its physics goals is the most important issue of the current elementary particle physics - the origin of the electroweak symmetry breaking, or the study of Higgs particle. LHC will probably obtain the first signal of Higgs or related effects, but the clean environment of linear collider allows far better resolutions, with which many new discoveries can be expected.

We have been involved with the preparation efforts of linear collider (site studies, Japanese steering committee works, international study group organization works, etc.). Hasegawa has been active on site studies, and this year Yamamoto succeeded S. Komamiya of Tokyo University as the co-chair of the committee for the worldwide study on physics and detector.

On the hardware side, we have been developing the beam profile monitor which measures the nano-meter-scale beam size at the interaction point. It utilizes the large amount of e^+e^- pairs created at the collision point which retains the information on the transverse beam sizes as the azimuthal distribution of the particles created. They hit the disc-shaped beam profile monitor about 1.5 m from the interaction point on each side. The monitor should stand a large amount of hits and radiation dose, and a pixel detector is a natural choice. A simulation study was performed by Saigo, and a prototype readout electronics was developed, fabricated, and tested by S. Tanaka in collaboration with KEK. The pixel sensor has been designed and fabricated in collaboration with Sherwood Parker of University of Hawaii. Its design is called `3D' where electores are poles of diameter ~ 20 mm running transverse to the plane of the sensor. The depletion voltage is about 20 times less, and the charge collection time is about 10 times less than the conventional pixel sensors. The prototype sensors have been delivered to Tohoku university for testing.

VI. Astrophysics Group

(T.HAYASHINO, Y.MATSUDA, H.TAMURA, R.YAMAUCHI)

We are carrying out narrowband imaging survey to find Lya emission objects at high red shifts with the prime focus camera(Suprime-Cam) having a wide field of view of 34 $\cdot$27 arcmin^2 installed on the Subaru telescope. In the analysis of the observational data taken in September 2002(Subaru proposal S02A-122) applying a narrowband filter with the center wavelength of 4970 Å and the bandwidth of 80 Å, we have discovered 60 Mpc scale large structure of Lya emitters at z=3.09 in the Suprime-Cam field of view(FoV) centered on SSA22a field. (here, we adopt $W_0 = 0.3$, $l_0 = 0.7$, h=0.7 cosmology(LCDM))

The large scale structure(LSS) discovered seems to have two belt-like structures with lengths of 60

Mpc and 30 Mpc respectively. They contain a lot of candidate *Lya* emitters, strong *Lya* absorbers and extended *Lya* sources, strongly indicating that the LSS found at z=3.09 should be a ``Giant Galaxy-Forming Region", where many kinds of primeval objects are forming. It is very important to point out that this large scale structure would be only a part of huge structure, because the belt-like structures reach the edge of the present FoV. They will probably extend to the next FoV. Moreover, these belts can be slice of huge sheets and similar belts may appear in foreground or background NB slice. Therefore, it is necessary to carry out a successive survey around this field to examine three dimensional extension of the belt-like structures and determine a characteristic scale of the structure.

Three dimensional map of high red shift objects in large scales as discussed here should offer valuable information on structure formation in the universe, though WMAP has presented all sky temperature map with high statistics.

VII. SLD Group

(F.Suekane, T.Nagamine)

The SLD (Stanford Large Detector) experiment of 50GeV polarized electron collision with 50GeV positron was terminated in June 1998 after collecting 550,000 polarized Z^0's. Tohoku group made major contributions for the development of CRID(Cherenkov Ring Imaging Detector) and VXD3(the 3rd-generation CCD Vertex Detector) and analyses of heavy quark physics and the strong interaction. The data analysis has been continuing. This year, results of B meson studies were published.

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Doctor Theses

D1) Measurement of Reactor Anti-Neutrino Disappearance in KamLAND.
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D2) Measurement of Electron Anti-Neutrino Oscillation Parameters with a Large Volume Liquid Scintillator Detector, KamLAND.

Osamu Tajima

Master Theses

M1) Development of a Gd loaded organic liquid scintillator for solar neutrino detection.
Itaru Shimizu

M2) Background study for KamLAND experiment.
Tsunehiko Kawashima

M3) Study of high red shift large structure using Subaru telescope
Hajime Tamura

M4) Study of rare D meson decays.
Yoshikazu Fujisawa

M5) Study of method to measure nanometer beam at Linear Collider.
Manabu Saigo

M6) Development of readout electronics for beam profile monitor at Linear Collider.
Satoshi Tanaka