ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ И АТОМНОГО ЯДРА
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STATUS OF THE T2K EXPERIMENT

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These lectures present the status of the Tokai-to-Kamioka Experiment (T2K) which just started taking data in early 2010. The goals and methodology for the experiment are presented as well as the challenges and prospects for determining the neutrino mixing parameters leading to neutrino oscillation with a particular attention to the determination of the mixing angle θ_{13}.

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GOALS

A large international collaboration, T2K [1], has been established to carry out a programme of precision determination of the parameters governing the oscillations of neutrinos with a specific goal of improving on the precision of the determination of θ_{23} and Δm_{23} (possibly establish whether or not maximal mixing is realized) and searching for the existence of a ν_μ-to-ν_e transition and its associated θ_{13} mixing angle.

The first objective is to achieve a sensitivity in ν_μ disappearance capable of testing whether or not θ_{23} is maximal ($\sin^2 2\theta_{23} = 1$) , the second objective is to reach a sensitivity on $\sin^2 2\theta_{13}$ of 0.01 which would either discover θ_{13} or push the present upper limit set by the Chooz experiment [2] by an order of magnitude.

NEUTRINO BEAM

The experiment exploits a unique neutrino beam from the high-intensity proton accelerator of J-PARC (30 GeV, 0.66 MW) and the SuperKamiokande detector (SK) located 295 km away from the neutrino source. Having set the baseline for the experiment, the neutrino beam energy is chosen to match the oscillation maximum for ν_μ disappearance based upon the current values of θ_{23} and Δm_{23} as measured by SK and Minos [3, 4].

To realize a narrow band neutrino beam peaked at 700 MeV, an off-axis beam geometry [5] is used which has the neutrino decay tunnel pointing 2.5° away from the SK line of sight. A schematic diagram of the neutrino beamline

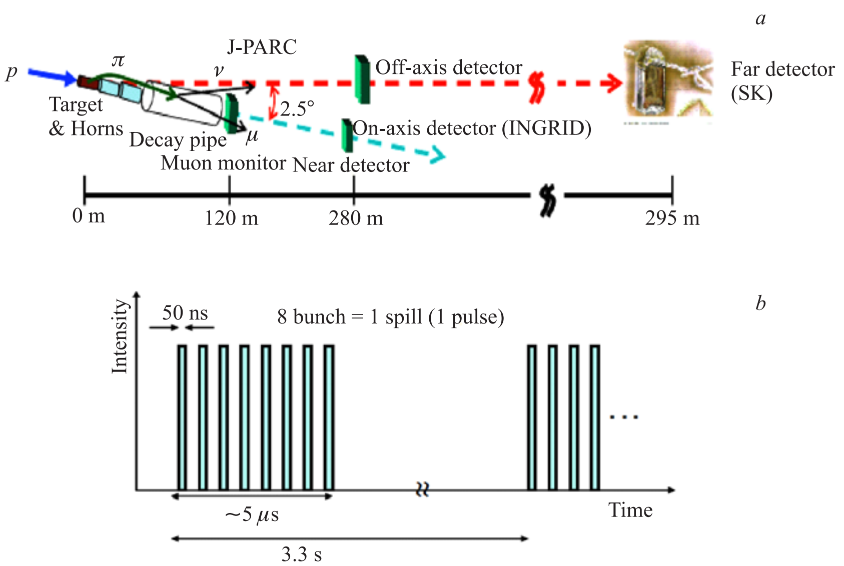

Fig. 1. *a*) Configuration of the T2K experiment; *b*) bunch structure of the J-PARC fast extracted proton beam

is shown on Fig. 1, a. This produces a ν_μ beam peaked at 750 MeV with a width of $\sim$ 400 MeV and a much reduced high energy tail compared to a conventional zero degree beam and a reduced contamination of ν_e, anti-ν_μ, and anti-ν_e in the beam.

DETECTOR SYSTEMS

The detector system includes a set of on-axis beam monitors at the end of the decay tunnel, an on-axis neutrino beam position and flux monitor called INGRID, and an off-axis complex of tracking detectors both at 280 m from the production target and the far detector SK at 295 km.

FAR DETECTOR

The far detector is the SuperKamiokande detector which has been operational for the last fifteen years and which was equipped with new dead-timeless electronics for improving its capability to record multiple events in a single bunch of the J-PARC neutrino beam. The water Cherenkov detector provides a fiducial mass of 22 kT of pure water, a timing resolution of a few ns and good muon to electron separation. All of its standards of performance can be monitored on line and off line using well-understood atmospheric neutrinos and calibration techniques. A complete simulation of the detector is available and has been validated in the energy range of the T2K experiment. A dual redundant GPS timing system allows for accurate time stamping (10 ns resolution) of the events to correlate their appearance with the arrival of the neutrino beam from J-PARC. The beam microstructure is providing a powerful discrimination against cosmic events. The J-PARC neutrino beam comes in 8 bunches (50 ns wide over a spill time of 5 μs repeating every $\sim$ 3 s, see Fig. $1, b$).

THE NEAR DETECTOR SYSTEMS

The direction, composition, energy profile, and intensity of the neutrino beam must be determined with good accuracy before any oscillation effect can take place. This is the role of the near detector systems.

The direction of the neutrino beam is determined by the position and direction of the proton beam hitting the 90 cm long graphite production target. A set of intensity, profile, and position monitors in the primary proton beamline can provide the targeting information needed to guarantee the safe operation of the target and the direction of the neutrino beam resulting from the decay of the produced hadrons in the 110 m long decay tunnel. In particular, an Optical Transition Radiation (OTR) detector located just a few cm upstream of the target provides profiles and position of the proton beam (with sub-mm precision) on a pulse-to-pulse basis which is interlocked to the proton beam delivery system. At the end of the decay tunnel, a set of muon monitors (arrays of Si diodes and ionisation chambers) are imbedded in the shielding immediately behind the primary beam dump. Their role is to determine the stability of the direction and of the flux of the secondary hadrons (which are the progenitors of the neutrinos) as they are focused by the three-horn lenses located around and behind the production target.

NEAR SITE NEUTRINO BEAM DETECTORS

The neutrino beam itself is monitored 280 m away from the production target, following 160 m of earth shield which removes all hadronic components of the beam (in particular penetrating neutrons). Two detectors are used: one in the tunnel axis direction named INGRID and the other on the axis of the SK detector named ND280 (Fig. 2).

The INGRID detector is composed of 14 assemblies of iron/scintillator sandwiches arranged on a cross-like configuration centered on the on-axis line of sight from the tunnel. With an active mass of 7.1 t per module, they provide enough

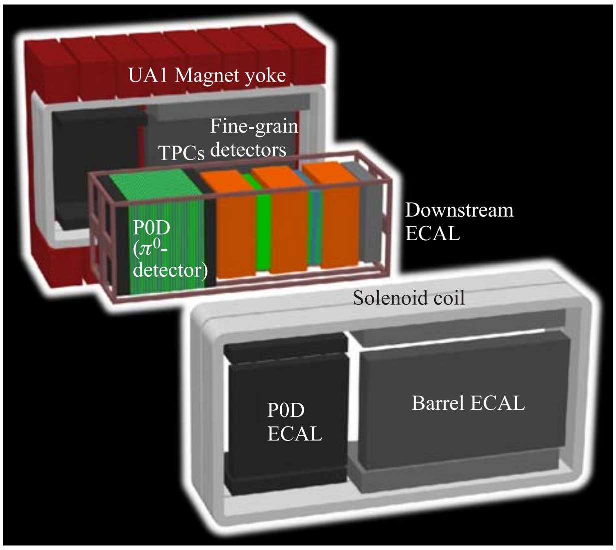

Fig. 2. Configuration of the ND280 off-axis detectors

events to monitor the neutrino beam direction to better than 1 mrad on a daily basis. (During the initial operation in the spring 2010 at the 50 kw power level, one event was recorded per 10 s on average.) Two extra modules are positioned off axis to monitor the rotational symmetry of the neutrino beam. Due to its rather coarse Fe/scint segmentation, the INGRID detectors provide a good measurement of the stability and magnitude of the high-energy part of the neutrino flux on axis.

Like for all the other scintillator detectors in the near detector complex, the scintillator light is read out with Multi Pixel Photon Counters (customized 667 pixel MPPC-Hamamatsu) which provide good gain (10^6), good linearity and dynamic range performances, and good timing resolution (2 ns) and are insensitive to magnetic fields.

The ND280 tracker detector is built around the former UA1 magnet (donated by CERN) which provides a 0.2 T field volume of $3.5 \times 3.6 \times 7.0$ m. The detector has been optimized to study the properties of the off-axis neutrino beam in terms of flux, energy distribution, and composition. By neutrino detector standards, it is a low-mass detector with low threshold and good particle identification. The central tracker is based upon two fully active scintillator arrays (Fine Grain Detector or FGD) and three low-mass gas tracking chambers (Time Projection Chambers or TPC). One of the FGD has alternating layers of water to allow measurements of neutrino interaction cross section in water since the far detector is made of water.

The TPCs provide a momentum measurement for the charged current produced leptons of better than 10% (σ) which in turn allows for a neutrino beam energy measurement when selecting quasi-elastic events (within the limitation of final-state interaction effects and Fermi-momentum distribution of the struck nucleons).

To determine the pi-zero production cross sections which are the main contributor to the background for the ν_e appearance search, a Pi-zero Detector (P0D) has been incorporated, which is made of alternating layers of lead/plastic scintillator and water target planes. The whole tracker is surrounded by lead scintillator catcher modules (ECAL) to improve the photon reconstruction capability and add to the electron identification.

The magnet is instrumented with scintillator plates inserted into the yoke (Side Muon Range Detector or SMRD), providing a selective cosmic rays trigger and identifying neutrino induced events in the walls of the cavity or in the yoke of the magnet.

OSCILLATION ANALYSIS REQUIREMENTS

The rate of neutrino-induced lepton events at the far detector is a function of the initial flux of neutrinos, the cross section for neutrino interaction leading to an observable lepton and efficiency of detecting that lepton to which must be added the background that can simulate the same leptons. The observed rate is then compared to the rate predicted with or without oscillations. Figure 3 shows the relationship between the measured events distribution at SK and the neutrino oscillation parameters in the ν_μ disappearance experiment. A Monte Carlo neutrino beam is used to predict the flux of the different neutrino species at the three detector locations (Muon monitors, ND280, SK) starting from the proton beam, production target information, and pions (and kaons) production

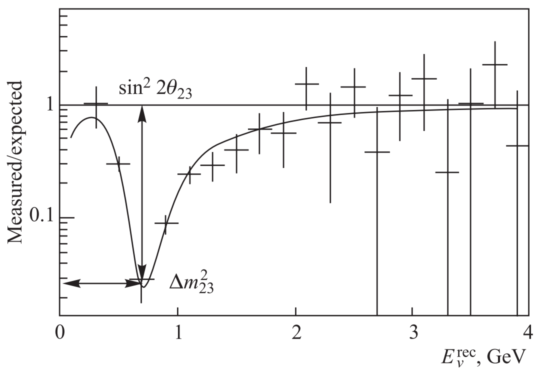

Fig. 3. Relation between the distribution of measured over expected events in SK and the oscillation parameters in the ν_μ disappearance experiment

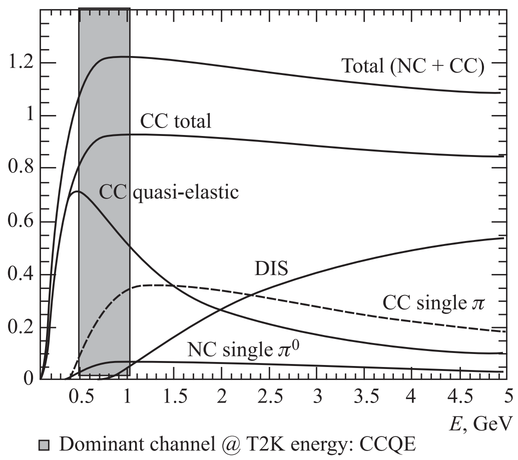

Fig. 4. Neutrino cross sections of relevance for T2K. The grey band indicates the energy (FWHM) of the J-PARC neutrino beam

cross sections. The Monte Carlo production cross sections are in part validated by exploiting the results from the NA61 experiment at CERN which is measuring pions and kaons production by a 30 GeV proton beam incident on both a thin and a replica T2K carbon targets. The off-axis ND280 detector is used to validate the neutrino flux predictions at the off-axis take-off angle of 2.5° before any oscillation effects can be significant. The high granularity of the off-axis detector provides a powerful way of measuring also the relevant neutrino cross sections in the energy range of the T2K experiment as shown in Fig. 4.

NEUTRINO CROSS SECTIONS MEASUREMENTS

The neutrino type and incident energy can be determined by observing the lepton associated with a charged current (CC) quasi-elastic process — a two-body reaction of a neutrino on a «quasi»-free nucleon. However, this is only strictly true for a reaction occurring on a free nucleon at rest. The contamination of other neutrino types will be linked to the detector ability to identify the lepton type while the energy resolution will be limited by the ability to recognize a quasi-free process and by the knowledge of the struck nucleon internal momentum distribution. In nonquasi-elastic processes, the final-state interaction of the associated hadrons in the target modifies the kinematics of the reaction and can also hide the associated hadrons. Hence the role of the off-axis detector is to experimentally determine the energy dependence of the quasi-elastic cross section and the relative importance of other CC reaction channels in the energy range of the experiment which are rather poorly known at present (20−30% uncertainty). Also since the far detector is using water as a target, these cross sections must be measured for water. This is the main objective for the FGD/TPC tracker supplemented by the ECAL.

For the neutrino electron appearance experiment, the main background is due to «faked» electrons associated with unrecognized pi-zero. Those are mainly (but not exclusively) produced in Neutral Current (NC) processes and their production rates are hence not affected by oscillation of neutrinos from one species to another. It is then critical to understand the production cross sections of pi-zero: This is the role of the P0D and associated ECAL detector. Again here the cross sections on water in a few GeV range are relevant for the far detector.

EARLY PERFORMANCE AND PROSPECTS

The experiment started to take data in February 2010 at reduced proton beam intensity. By the end of the run in June 2010, at a proton beam intensity of 50 kW in average, a total of $3.23\cdot10^{19}$ Protons on Target (POT) were accumulated leading to some 33 fully contained events in SK, 23 of which are seen in the fiducial volume of the far detector (see the Table). All events show timings within the expected arrival time related to the J-PARC beam bunches as shown in Fig. 5.

All installed detectors performed very well with more than 95% of the beam spills accepted and good data quality. This allowed for systematic calibrations and initial physics parameters reconstruction.

The main result from this period is the experimental confirmation of the expectation in terms of intensity, energy distribution, and contamination of the first off-axis neutrino beam ever used in an experiment. In particular, the sensitivity to neutrino oscillation parameters is already at the level of that achieved in the K2K experiment [6]. For fully contained one-ring muon-like events at SK, a

Number of fully contained and selected events in SK during the March–June 2010 runs

	Class/beam run				
	29–31	32	33	34	All
POT ($\times10^{19}$)	0.34	0.76	1.21	0.93	**3.23**
Fully Contained (FC)	2	15	9	7	**33**
+ Fiducial volume cut + visible energy > 30 MeV (FCFV)	2	11	8	2	**23**

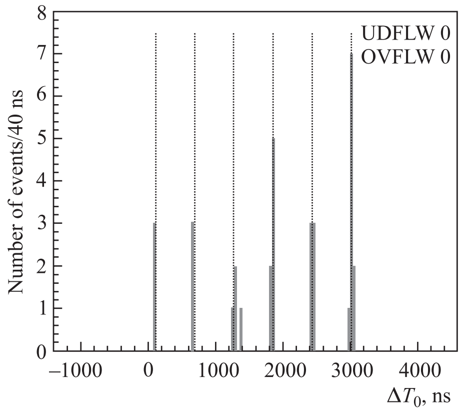

Fig. 5. Timing distribution of SK events in fiducial volume relative to J-PARC beam bursts

reduction by a factor of ~ 4 is predicted between the no oscillation case and the oscillated case at the currently known parameters while a signal/background level of 3/1 is expected in the electron neutrino appearance search compared to 3/5 in the K2K experiment. However the precision of the results from this run will still be dominated by statistics.

The experiment is scheduled to receive 10 times more protons on target in the next run to start in mid November 2010 and run until June 2011. At this time systematic errors will have to be understood at an improved level for which the full power of the near detector complex will be essential. In the future the J-PARC proton beam intensity will be gradually brought up to the 0.66 MW level with a main upgrade of the injector LINAC scheduled after the spring 2012 beam campaign.

This experiment was only made possible by the strong commitment of the Japanese funding agencies to build J-PARC, and its neutrino facility as well as maintaining and operating the SK detector. Strong financial and human support was provided by the other 11 nations involved. I used liberally information and presentations by some of my ~ 500 colleagues and I thank them for that. I thank also the organizers of this exciting neutrino school in memory of the great neutrino physicist Bruno Pontecorvo.

REFERENCES

1. http://j-parc.jp/NuclPart/pac_0606/pdf/p11-Nishikawa.pdf. 2006.
2. *Apollonio M. et al.* (*CH00Z Collab.*) // Search for Neutrino Oscillations on a Long Base-Line at the CHOOZ Nuclear Power Station // Eur. Phys. J. C. 2003. V. 27. P. 331–374.

3. *Ashie Y. et al.* (*Super-Kamiokande Collab.*) // Measurement of Atmospheric Neutrino Oscillation Parameters by SuperKamiokande // Phys. Rev. D. 2005. V. 71. P. 112005.

4. *Vahle P. et al.* // Presentation for the «Nu2010» Conf.: Measurement of Neutrino Oscillations with the MINOS Detectors in the NuMI Beam // Phys. Rev. Lett. 2008. V. 101. P. 131802.

5. *Beavis D. et al.* BNL–AGS Proposal E-889. 1995.

6. Measurement of Neutrino Oscillation by the K2K Experiment // Phys. Rev. D. 2006. V. 74. P. 072003.