

complete the construction of the initial 600 GeV UNK machine and to limit work on the superconducting 3 TeV UNK accelerator to R&D. But even at 600 GeV the rate of neutrino interactions is interesting, and sighting the tau-neutrino and searching for oscillations into tau-neutrinos in new kinematic regions are still on the cards.

JAPAN

With the research structure for high energy physics attaining maturity, experimental neutrino physics flourished in Japan in the 1980s. Neutrino studies during this period used three approaches: accelerators, nuclear beta decays, and a deep underground experiment. The latter, using an imaging water Cherenkov detector, was so successful that it is being considerably expanded and will dominate Japanese research in this field in the 90s.

In the 80s, the E10 experiment (KEK/Tokyo/Osaka) was the first to search for a heavy neutrino in stopped-kaon decays at the Japanese KEK Laboratory's 12 GeV Proton Synchrotron, and was soon followed by dedicated experiments, E89 and E104 (Tokyo/KEK). Using a high resolution magnetic spectrometer with an extensive photon-veto system, a good 1982 limit linked mass and mixing probability in the 100 MeV mass range. After ten years, the synchrotron is again to go into action for neutrino-related research (experiment E261a - see below).

At KEK's TRISTAN electron-positron collider, the VENUS Collaboration studied radiative neutrino-

pair production, and combining their data with those from other electron-positron colliders, concluded that the number of light neutrino species had to be less than four, even before LEP experiments made their definitive 1989 measurement.

In late 1980, motivated by a claim by a Moscow experiment for the finite mass of the electron antineutrino, a group including physicists from INS (Institute for Nuclear Study, Tokyo) had proposed a precision measurement of the tritium beta-ray spectrum near its end point. Emphasis from the beginning was on reliable calibration.

About four years were spent developing an optimal beta-ray source and on calibration to give high quality measurements. Over the subsequent four years, a series of measurements gave a 13 eV upper mass limit.

Early in 1991, a KEK/INS collaboration, including also some American physicists, embarked on a decisive experiment on the controversial 17 keV neutrino. Knowing the danger of relying on subtle effects in beta spectrum slopes, they searched for a neutrino emission threshold effect in the spectrum with high resolution, low background and unprecedentedly high statistics. The result of a three month measurement clearly excluded such a neutrino.

Towards the end of the 1970s, the very attractive idea of the Grand Unification of forces had fostered a new generation of large underground experiments to search for the predicted decay of the proton. In Japan the large Kamiokande underground experiment (Tokyo/Institute for Cosmic Ray Research/KEK/Niigata collaboration) looked for proton decay in the 3000-ton imaging water Cherenkov detector 1000 m underground. Installation of 1000 specially

designed photomultiplier tubes was completed in July 1983 and the first result reported six months later.

Detector response was calibrated using electrons (below 5 MeV) from stopped cosmic-ray muons.

Successful measurement of such low energy electrons showed how the detector could also recognize recoil electrons from low energy neutrino interactions. To improve sensitivity to nucleon decay and to lower the energy threshold for solar neutrino detection, the collaboration was expanded to include a Pennsylvania group. A water Cherenkov veto counter was constructed around the main body, and the water purifier as well as the electronic system considerably improved. The upgraded detector, Kamiokande-II, went live at the end of 1985 and produced its first result the following year from 48.5 days of data.

To further reduce background radioactivity, work continued through 1986 to improve the water purification system.

These painful efforts were dramatically rewarded. On 25 February 1987, a telefax informed the group of an astronomically 'nearby' supernova. Perhaps the detector's routine running could have intercepted neutrinos from this explosion. Data tapes were immediately rushed to Tokyo for analysis.

On 27 February a whole night was spent scanning the few hundred pages of energy-versus-time plots collected over 2.5 days. An unmistakable burst of activity soon showed up. Recorded on 23 February at 07:35:35 UT (± 1 minute) and lasting 13 seconds, it contained 11 electron events with each energy ranging from 7.5 to 36 MeV. These neutrinos from the SN1987A supernova marked the beginning of neutrino astronomy.

With continuous operation of the detector under very low backgrounds and with the collaboration extended, a new range of physics opened up when solar neutrinos were detected for the first time in a real-time directional measurement. The recent result of the flux measurement, from a 1554-day data sample, is $0.50 \pm 0.04(\text{stat.}) \pm 0.06(\text{sys.})$ of the standard solar model prediction.

This low flux of solar boron-8 neutrinos, to which the Kamiokande detector is sensitive, confirmed the solar neutrino deficit first observed in the classic chlorine-based experiment. In addition, the measured Kamiokande flux has not shown any sign of seasonal variation or day-night variation.

Atmospheric neutrino interactions in the Kamiokande detector had to be carefully studied to establish the background for any proton decays. This background study led to a surprising conclusion - the so-called atmospheric neutrino anomaly - in which the measured ratio of muon-like to electron-like events is some

60% of the expected value. This smaller than expected muon-neutrino flux has been suggested to be the result of new neutrino behaviour.

Study of atmospheric neutrino events requires good knowledge of muon-electron discrimination, detection efficiency for low momentum muons and pions, and nuclear effects in neutrino interactions in water. In view of the potential importance of the measured anomaly, a thorough check of detector performance was called for and at the KEK Proton Synchrotron, experiment E261a (Kamiokande collaboration) was approved for the purpose. Construction of a 1000-ton water tank began in 1992 outside the North Experimental Hall, and the installation of 408 20-inch photomultipliers has just been completed. The experiment will start early next year with a beam of electrons, pions and muons of momenta from 0.2 to 1 GeV.

The tank is equipped with four beam entrances with beam pipes of different lengths. After this measurement, the collaboration working on

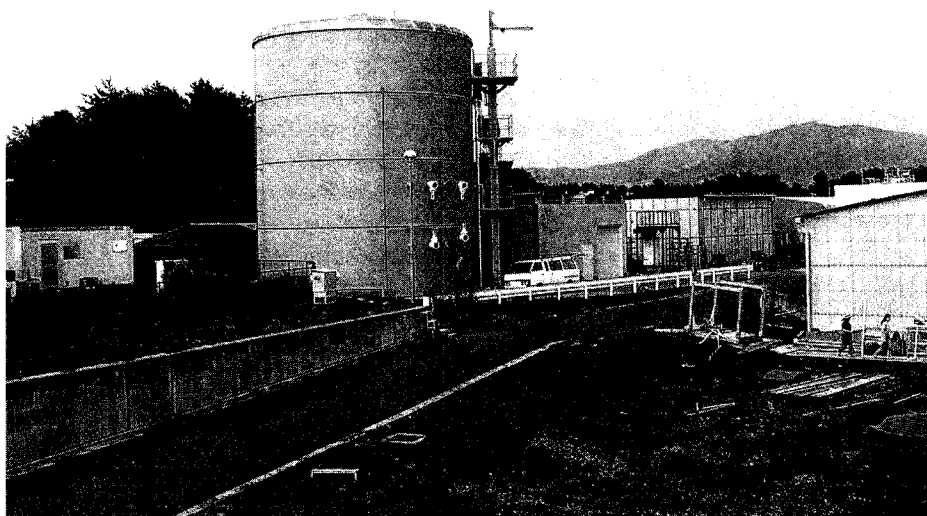
the IMB underground experiment in the US will bring in their photomultipliers for a similar experiment.

This water Cherenkov detector might also be used to study interactions of neutrinos from the synchrotron, where the beam energy spectrum happens to resemble that of atmospheric neutrinos.

As a next-generation underground experiment, the Super-Kamiokande project (an expanded Kamiokande collaboration, together with a similar number of American physicists) was approved in 1991 (May 1991, page 9).

Excavation for a 50,000-ton water tank (40m x 41 m) is well underway about 150 m from the present detector. New 20-inch photomultipliers and front-end electronics have already been developed and are in production. Prototype electronics has already been exploited in the last phase of the present experiment.

It will be operational from late 1996 and is expected to yield 26,000 solar neutrino events and 8,000 atmospheric neutrino events after three years. It should also serve as an astronomical neutrino observatory. There is also an idea to fire a KEK neutrino beam into this detector to search for neutrino oscillations.



An article on the KARMEN neutrino experiment by a Germany/UK collaboration at the Rutherford Appleton Laboratory will appear in a forthcoming issue.

1000-ton water Cherenkov detector constructed for tests near the experimental hall of the 12 GeV Proton Synchrotron at the Japanese KEK Laboratory. Construction is underway for a new low-momentum secondary beamline.

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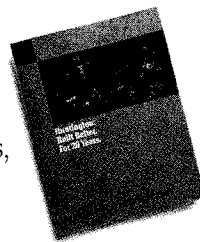
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