STATUS OF INDIA-BASED NEUTRINO OBSERVATORY (INO)

NABA K MONDAL

For INO Collaboration, Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai-400 005 (India)

We report on the current status of an India-based Neutrino Observatory. We review the goals of INO, its physics potential and on-going efforts to prepare a detailed feasibility report.

1 Introduction

Recent data from several neutrino detectors around the world, in particular, that from the Super-Kamiokande detector[1] in Japan, and the Sudbury Neutrino Observatory (SNO)[2] in Canada, seem to indicate that neutrinos not only have mass, but also experience flavour mixing. This leads to the phenomenon of neutrino oscillations[3] that can then explain the discrepancy between theory and observation as seen in certain experiments. If correct, this will provide the first unambiguous evidence for physics beyond the so-called standard model of particle physics. The existence of non-zero neutrino masses has profound implications on fields as varied as nuclear physics, particle physics, astrophysics and cosmology. It is also important to note that with the observation of neutrinos from the core of the sun and also from the supernova[4] SN1987A, a new window to the universe has opened up. In future, neutrino astronomy is going to play a key role in our understanding of the universe. Most importantly, neutrino telescopes will allow us to look into the densest places of the universe which are completely opaque to optical astronomy. To exploit this emerging new area of observational neutrino physics, about two years ago, the idea to construct a neutrino detector at an India-based Neutrino Observatory (INO) was mooted. This proposal has now been formalised, with a Memorandum of Understanding (MoU) being signed by several research Institutes in India to form a National Neutrino Collaboration Group (NNCG), and the feasibility study is now in progress. In this article I plan to update you on the current status of INO. Since INO is still evolving, changes are likely to occur. We hope to provide regular updates on the INO website[5].

2 Genesis of INO

Historically, the Indian initiative in cosmic ray and neutrino physics experiments goes back several decades. In fact the first atmospheric neutrino event was recorded at the Kolar Gold Fields (KGF)[6] underground laboratory nearly thirty five years ago. The KGF experiments spanned several decades, involving a systematic study of cosmic ray muons and neutrinos, and other exotic processes at great depths underground. The experience gained here makes it possible for us to propose the current experiment. The decision by the Bharat Gold Mines Limited and the Ministry of Mines to close the deeper levels of the KGF mines progressively from 1990 onwards due to financial reasons, necessitated the termination of the underground experiments at KGF by about 1992. The experimental areas became unusable and the experiments closed formally a year later. The possibility of building a new neutrino detector in India was discussed as early as 1989 during several meetings held that year. Since then this question has come up in many discussions off and on. This issue was raised again in the first meeting of the Neutrino Physics and Cosmology working group during the Workshop on High Energy Physics Phenomenology (WHEPP) held at Chennai in January 2000 and it was decided then to collate concrete ideas for a neutrino detector[7].

Further discussions took place during August 2000 during a meeting on Neutrino Physics at the

Saha Institute of Nuclear Physics, Kolkata, when a small group of neutrino physics enthusiasts started discussing the possibilities. The Neutrino 2001 meeting was held at the Institute of Mathematical Sciences, Chennai, during February 2001, with the explicit objective of bringing experimentalists and theorists together. The INO collaboration was formed during this meeting. The first formal meeting of the collaboration was held in the Tata Institute of Fundamental Research, Mumbai, during September 6 and 7th, 2001. Various subgroups were formed for studying the detector options and electronics, simulation studies and site survey. A proposal to conduct a feasibility study towards building a neutrino observatory in India was submitted to the Government of India through the Department of Atomic Energy. It was proposed that at the end of this feasibility study a detailed project report will be prepared, spelling out all details about the site, tunnel and underground lab construction, the details of the proposed detector and its physics capabilities and the cost. It will also look into the availability of trained manpower for running this laboratory. The Department of Atomic Energy has now provided adequate financial asistance in its tenth plan outlay to conduct this feasibility study. A Memorandum of Understanding (MoU) has now been signed by Tata Institute of Fundamental Research (TIFR), Bhabha Atomic Research Centre (BARC), Institute of Mathematical Sciences (IMSc), Saha Institute of Nuclear Physics(SINP), Variable Energy Cyclotron Centre (VECC), Harish Chandra Research Institute (HRI) and Institute of Physics (IOP). This MoU spells out the operational aspect of this study and the mode of utilisation of the available funds by the neutrino collaboration. It is expected that this feasibility study will be completed in two years.

3   Detector Possibilities

Neutrinos are available over a wide range of energies and it is not possible to address all the physics issues with a single detector. It is however necessary to investigate the capabilities of a few detector types in order to zero in on the one that has maximum overlap with the interests of the majority of the neutrino community. Two basic detector types are being discussed by the INO collaboration. They are a magnetised iron calorimeter, which would be an extension of

and improvement over the old KGF detector and a water Cerenkov detector, similar to but much bigger than the existing Super-Kamiokande detector in Japan.

Magnetised Iron Calorimeter–ICAL

One avenue to explore some of the physics issues associated with neutrino oscillations involves the construction of a magnetised tracking calorimeter with good energy and time-of-flight measurement capabilities. Such a detector can be used to explicitly detect the as-yet elusive oscillation pattern in the L/E spectrum of the atmospheric muon neutrinos. This will clearly distinguish neutrino oscillation scenarios from neutrino decay ones. At a later stage such a detector can also be used as a far detector with a neutrino beam from one or several accelerator facilities around the world.

For a two-neutrino oscillation hypothesis, the probability for a neutrino produced in one flavor a to be observed in flavor b after traversing a distance L through vacuum is given by

$$P_{a \to b} = \sin^2 2\theta \ \sin^2 \left(\frac{1.27 \Delta m^2 L}{E_\nu} \right) , \quad \ldots (1)$$

where L is the distance traversed by the neutrino in km, E_ν is the energy of the neutrino in GeV, θ is the neutrino mixing angle between the flavor eigenstates and δm^2 is the mass-squared difference between the two mass eigenstates in eV^2.

Till today the best evidence for atmospheric muon neutrino oscillation is the deficit of atmospheric muon neutrino flux as a function of zenith angle as observed in the Super-Kamiokande detector[1]. Although this measurement is very suggestive of muon neutrino oscillation, the most important observation to establish the oscillation hypothesis would be the observation of the full oscillation pattern as a function of L/E as shown in eq.1. This oscillation pattern is not visible in the present Super-Kamiokande detector mainly due to its poor energy resolution as well as poor measurement of directionality. It will also not be possible to observe this oscillation pattern in the proposed long base-line experiments which will be using neutrinos from accelerators. The only way to observe this unique feature will be to measure simultaneously the energy as well as the direction of atmospheric neutrinos using a good tracking calorimeter.

In such a detector the energy of the neutrinos could be measured very accurately by detecting the

fully and partially confined events with vertex inside the detector. Energy of the fully confined events could be measured by track length method whereas for partially confined events, the energy of the escaping muon could be well estimated from the bending of such a track in the magnetic field within the detector. The path length L traversed by the neutrino in the Earth and its atmosphere could be estimated from the neutrino direction. The L/E ratio is expected to improve with energy due to improved measurement of the direction of the higher energy muon. Such a detector should have a large mass as well as high density to have sufficient number of contained events even at relatively higher energy.

The proposal for such a detector in the Gran Sasso Laboratory, called "Monolith"[8], has recently been submitted for funding. Our current proposal is similar in design and proposes to use the same Glass RPCs as the active element. Our proposal is currently based upon the detailed R & D carried out by the Monolith Colloboration. We have however started preliminary R & D work for the development of Glass Resistive plate chambers (RPC) in India. A major milestone has already been crossed with the development of RPCs with the efficiency crossing 90% beyond 8.6 KV.

We propose here an experiment having similar mass as the Super-Kamiokande detector but with significantly larger acceptance at higher neutrino energies (1–50 GeV) and superior L/E resolution to observe the full first oscillation swing i.e., the reappearance of the ν_μ.

Detector Structure: The proposed detector will have a modular structure of lateral size 32 m × 15 m and height 11.9 m with iron plates as the absorber and glass RPCs or scintillators as the active detector element. Fig. 1 shows the over-all layout of the detector. It comprises of 140 layers of horizontally arranged iron plates of 6 cm thickness interleaved with 2.5 cm gap between successive layers of iron plates to house the active detector elements. The iron plates will be magnetized at a magnetic field of 1.2–1.3 T. The total mass of detector will be around 35 kton.

Basic Detector Elements: The Glass Spark Chamber (GSC) is a gaseous detector composed of two parallel electrodes made of float glass with a volume resistivity of about 10^{12} Ω. The two electrodes, 2mm thick, are kept 2 mm apart by means of suitable spacers. Using a particular gas mixture and electric field configu-

ration, the detector will operate in the spark mode providing typical signal amplitudes of about 100-200 mV on 50 Ω cable. Use of high resistance glass as electrodes ensures that the spark discharges with a limited area around the spark. Efficiencies of more than 90% have already been obtained with a prototype detector.

A sketch of a typical GSC is shown in Fig. 2. As mentioned earlier it consists of two float glass electrodes separated by 2mm using spacers clamping the edge of the glass electrodes. The high voltage will be applied to the electrodes either by means of a graphite coating or by means of resistive adhesive film. The detector unit will be inserted within an extended gas-tight PVC/NORYL envelope for gas containment. The HV connections as well as gas inlet and outlet will be located in the end cap of the envelope.

To summarise, the main characteristic of such a detector is a clean identification of muons with good energy and time resolution. Also, the presence of the magnetic field will distinguish positive and negative charged particles. These properties meet very well the conditions required to positively identify muon neutrino oscillation as the phenomenon responsible for the discrepancies between theory and observation, as observed by Super-Kamiokande and other detectors.

Physics Capabilities of a Magnetised Iron Calorimeter

The atmospheric neutrino physics programme possible with a magnetised iron calorimeter is substantial and germane. One of the strong reasons for building an Iron Calorimeter is its capability to provide conclusive proof of neutrino mass and oscillation via dips and peaks in the event-rate vs. L/E. This is possible due to the large range in sensitivity to L/E variations compared to water Cerenkov detectors, in particular, compared to Super-K. We present some calculations done recently for the INO feasibility study. We consider a prototype detector of 50 kton iron, with detection and charge discrimination capability for muons, provided by a B field of about 1.2 Tesla. Sensitive elements are assumed to be Glass Spark Counters (RPC). In Fig. 3 we plot the number of up-going (Solid line) and down-going muon events in each L/E bin, for the mass squared difference δ = 0.002 eV^2 and $\sin^2 2\theta = 1$, assuming a two generation $\nu_\mu \to \nu_x$ scenario with x being either ν_μ or ν_s. In Fig. 3 we also plot the ratio of these rates (upgo-
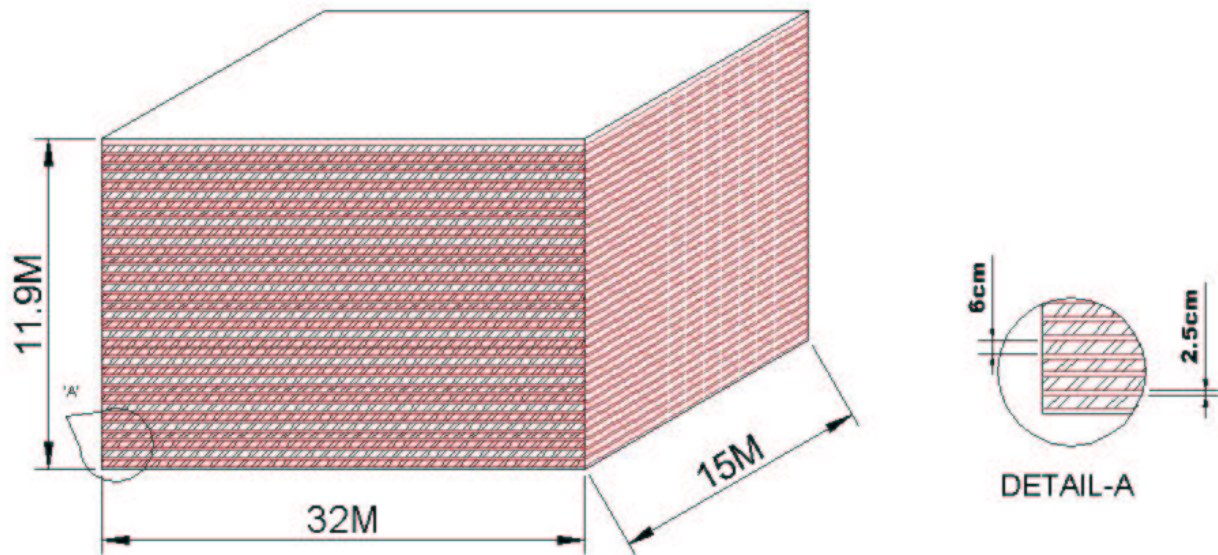
NABA K MONDAL

Fig. 1 Sketch of the iron calorimeter detector. One hundred and forty layers of 6 cm thick iron plates are separated by 2.5 cm each to allow for the insertion of the active detector elements.
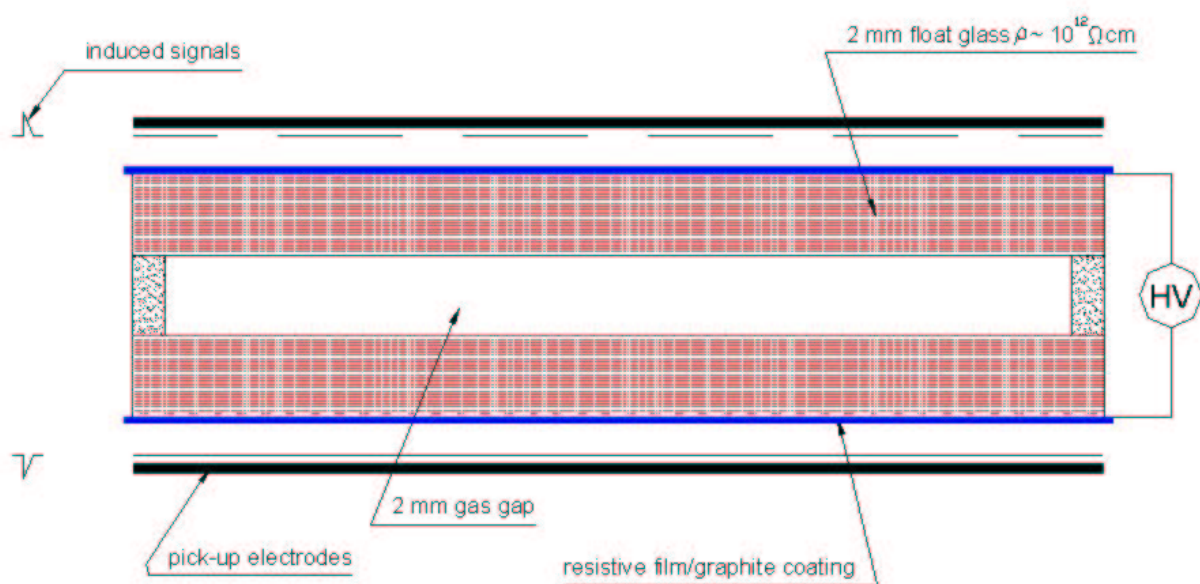

Fig. 2 Sketch of a typical glass spark chamber.

ing/downgoing) along with assumed $\sqrt{N}$ errors. The solid line is the best-fit curve. It is clear that the dip and the subsequent rise in this quantity should yield firm evidence of oscillations within a few years of data taking.

A Mega Water Cerenkov Detector

A mega water Cerenkov detector is yet another possibility. This technique has been used in the past by IMB and the Kamiokande groups and most recently by the Super-Kamiokande collaboration. Here one observes the Cerenkov radiation from interactions or decays in enormous volumes of water viewed by a surrounding surface array of photomultiplier tubes. The design philosophy for the current proposal is to make a relatively simple extension of the well-established water Cerenkov technology that will be more sensitive on the one hand to the high energy tail of the solar and supernove neutrinos and on the other hand will increase the sensitivity for nucleon decay searches by an order of magnitude.

We would like to consider several design options keeping in mind various practical limitations for water Cerenkov detectors techniques such as (1) pressure of water on the face of photomultipliers; (2) light attenuation length in pure water.

One possibility would be to build a single detector of outer dimensions 60m × 60m × 210m which can be segmented into three sub-detectors of size 60m × 60m × 70m. A second possibility will be to build several physically seperated detectors to achieve the same volume.

3   Site Survey

An important component of the INO feasibility study would be to find a suitable location underground with sufficient rock overburden to satisfy the physics objectives. Some of the parameters that one has to look for to identify possible sites are (i) rock quality, (ii) seismic activity in the area, (iii) existing infrastructural support, (iv) accessibility of the site, (v) local support and awareness. Using these criteria we have identified two potentially good sites for locating the underground laboratory. The first one is located on the northern slopes of the Nilgiris close to the TIFR cosmic ray laboratory and Radio telescope at Ooty in southern India. The second one is at a place called Rammam in the Darjeeling district in West Bengal. In both places adequate rock cover, comparable to other underground laboratories around the world, exists. The details of these two potential sites are listed below.

PUSHEP Site

This site located in South India is an extension of an upcoming underground Hydel project located about 6.5 kms from a town called Masinagudi (90 km south of Mysore) at the edge of the Mudumalai sanctuary near the border between Tamil Nadu, Karnataka and Kerala. It is called the Pykara Ultimate Stage Hydro Electric Project (PUSHEP) and is being executed by the Tamil Nadu Electricity Board (TNEB). In this project, water from the Pykara forebay will be brought down by pipes running underground, at an angle of 60° to the horizontal. The powerhouse is also located in a cavern underground accessed by a 1.5 km long tunnel. The underground cavern is 20 meters wide, 39 meters high and 70 meters long. The access tunnel to the power house is 6.5 meters wide and 6.5 meters high with 3 meters high vertical sections and a Dee shaped top. The existence of a number of tunnels is important for future forecasting. The site is also conveniently located in seismic zone-2.

The location of the INO Cavern has now been frozen and is located below the "INO peak" whose coordinates are North $11°31'$ and East $76°36.5'$. The INO peak is the highest peak on the northern slopes of the Nilgiris. South of INO peak is the plateau with an average elevation of 2000 ms above sea level. It is a part of the southern peninsular shield,

A vertical overburden 1300-1400 ms, and an all around cover in excess of 1000 ms is possible. The tunnelling medium and overburden consists of uniform rock medium with a mean density of 2.72 gm/cc. Lab cavern may be reached by a proposed access tunnel, approximately 2km in length. Detailed geotechnical survey of this site is now complete and a report by the geologists of the Geological Survey of India, Chennai is available on the INO website[5].

The site is also conveniently located close to Cosmic Ray Laboratory and Radio Astronomy Centre at Ooty which may act as surface laboratories along with facilities already available at the housing colony near PUSHEP in Masinagudi. The site is also close to big cities, like Bangalore, Mysore, Calicut and Coimbatore, with excellent industrial and academic infra-
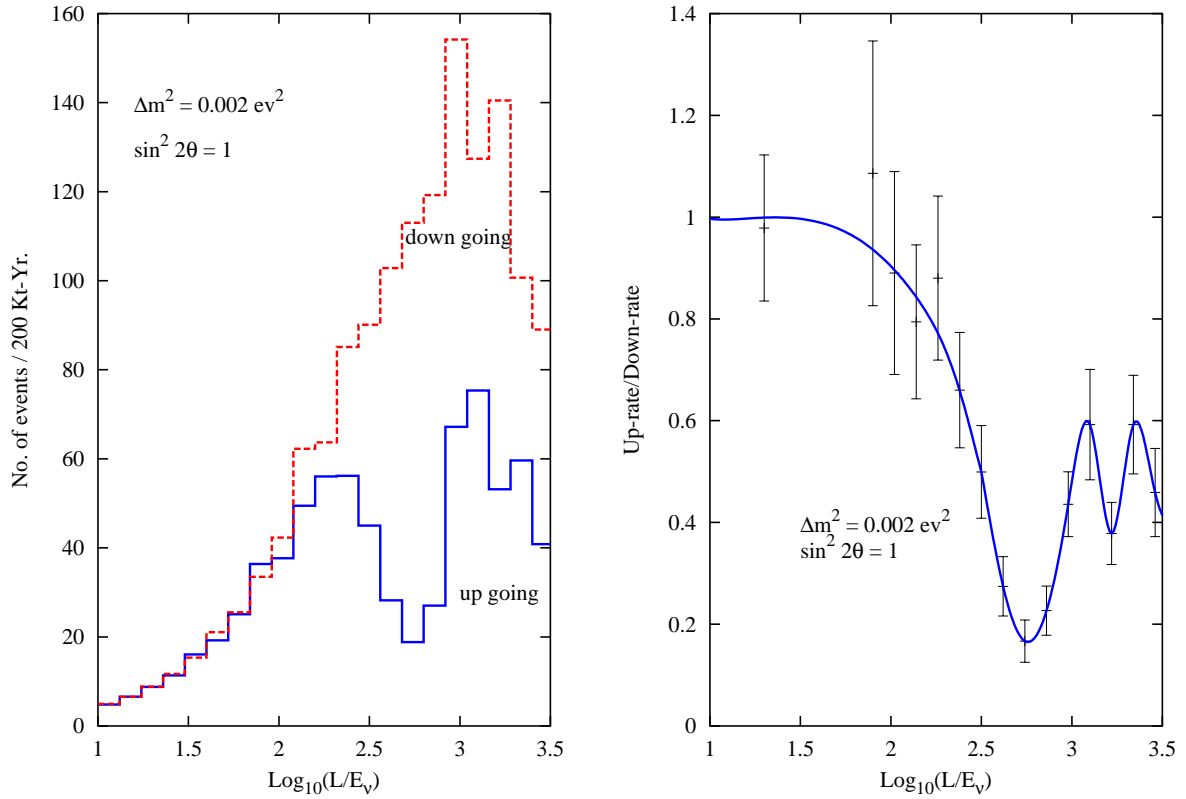
Fig. 3 The number of events of up going and down-going muons shown as a function of l/E for $\delta = 0.002 \text{ e}V^2$ and $\sin^2 2\theta = 1$.

structure. The weather is moderate throughout the year.

Rammam Site

The Rammam hydel project area in the district of Darjeeling, West Bengal, seems to be another excellent site for the INO laboratory. Ramman is located at North 27^0 and East 88^0 and at a height of about 1500 m. It is at a distance of about 140 kms from the nearest airport at Bagdogra. At this location, a dedicated tunnel of length 3-5 km with a downward slope of 1:20 along with an adit of about 2 km for alternate access route can reach an overburden of 1400-1850 ms. The area is however in seismic zone-4. So extra precuations need to be taken for the construction. But there are a number of long tunnels and large caverns already built in and around this area. So it does not seem to be an insurmountable problem. A detailed survey of this area is in progress.

4   Simulation Studies

A simulation program based on the GEANT package has been developed for the proposed iron calorimeter as well as for the water Cerenkov option. For the iron calorimeter option a detailed description of the detector geometry as described earlier with iron absorber, active RPC detector elements and the magnetic field configuration has been implemented. In the Geant simulation package, the iron calorimeter is composed of 140 horizontal layers of 6 cm thick iron plates interleaved by an equal number of sensitive detector elements i.e., RPCs. The RPCs are housed in the 2.5 cm gap between two successive iron layers. This detector simulation package is interfaced to a neutrino event generator called NUANCE originally developed by the Kamiokande group. It has been provided to us by Dave Casper[9]. This generator program originally written for water target has now been modified to generate neutrino events in the iron target. An interface to use the output of the NUANCE as input to INO detector simulation program has also been developed. The simulation group is now concentrating on event reconstruction specially on track reconstruction and to estimate the expected momentum and energy resolution of the proposed detector. A ROOT-based C++ reconstruction program is being tested at present.

5 Detector and Magnet R & D

The INO detector group is currently engaged in developing RPCs. Several prototypes have been developed and signals produced by cosmic rays muons have been recorded. Various designs of the pickup strips are also being studied. Currently the group is involved in studying the efficiency of the detectors being developed and also exploring the effect of gas composition on efficiency and noise. A prototype of the iron calorimeter will be built and cosmic ray muons will be studied to understand and estimate the time resolution of the detector. The magnetisation of the iron plates is another issue which needs to be looked at in detail. A promising begining has been made in terms of design of the coil. The main issue here is the uniformity of the field and the power requirements. These studies are currently going on.

Summary

To summarise, INO collaboration is progressing well. It has presently about 55 members from about fifteen Institutions and Universities from all around the country and is now engaged in Site survey, detector R & D and Physics simulation. There are some areas which are yet to be addressed like availability of iron at a resonable cost, the structural stability of the proposed lab as well as the detector and some other engineering questions.

References

1   Y Fukuda *et al* The Super-Kamiokande collaboration *Phys Lett* B **433** (1998) 9; B **436** (1998) 33

2   Q R Ahmad *et al* The SNO-Collaboration *Phys Rev Lett* **87** (2001) 071301; Q R Ahmad *et al* (The SNO collaboration) *Phys Rev Lett* **89** (2002) 011301

3   B Pontecorvo *JETP* **6** (1958) 429; Z Maki, M Nakazawa and S Sakata *Prog Theor Phys* **28** (1962) 870; M Mikheyev and A Smirnov *Sov J Nucl Phys* **42** (1986) 913; L Wolfenstein *Phys Rev* D **17** 2369 (1978) 23; *ibid* D **20** (1979) 2634

4   IAU Circular No 4316, 1987; Kamiokande II Collaboration K Hirata *et al Phys Rev Lett* **58** (1987) 1490; IMB Collaboration R M Bionta *et al Phys Rev Lett* **58** (1987) 1494

5   The website is presently located at this address: http://www.imsc.res.in/~ino

6   For a detailed history of KGF experiments, see the article by V S Narasimham in this volume.

7   M V N Murthy *et al Pramana* **55** (2000) 347 (A very preliminary report of the discussions on INO)

8   MONOLITH Proposal NY Aafonova *et al* CERN/SPSC 2000-031 LNGS P26/2000

9   The Nuance home page is located at: http://nuint.ps.uci.edu/nuance