India-based Neutrino Observatory (INO)

Status Update

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For the INO Collaboration
(http://www.imsc.res.in/~ino)
In particular, for suggestions that led to an iron calorimeter detector as the choice for INO

Also, for the first contact with GSI, Chennai, which led to finding the site at Masinagudi, and, later, at Rammam

Above all, for his enthusiasm, experience and guidance, that motivated us and was greatly responsible for the considerable progress made in INO
Outline of talk

- Brief overview of neutrino properties
- Brief overview of the INO proposal and goals
- INO: Status Update
Neutrinos:

A (Very) Brief Overview

From: www.bnl.gov/
Neutrino masses are not well-known. Oscillation studies only determine the mass-squared differences: \[ \Delta m_{ij}^2 = m_i^2 - m_j^2 \] and the mixing angles \( \theta_{ij} \).
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\[
\begin{align*}
\Delta m_{12}^2 &\approx 7.5 \times 10^{-5} \text{eV}^2 \\
\Delta m_{23}^2 &\approx 2.5 \times 10^{-3} \text{eV}^2 \\
\Delta m_{13}^2 &\approx 2.5 \times 10^{-3} \text{eV}^2 \\
\end{align*}
\]
A Schematic of Neutrino Properties

Neutrino masses are not well-known. Oscillation studies only determine the mass-squared differences: $\Delta m_{ij}^2 = m_i^2 - m_j^2$ and the mixing angles $\theta_{ij}$.

$\Delta m_{21}^2 \sim 0.8 \times 10^{-4} \text{ eV}^2$;
$|\Delta m_{32}^2| \sim 2.0 \times 10^{-3} \text{ eV}^2$;
$\sum_i m_i < 0.7-2 \text{ eV}$. 

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A Schematic of Neutrino Properties

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\]

- \( m_1 \sim m_2 \sim m_3 \sim 0.2 \text{ eV} \) (Degenerate hierarchy)
- \( m_1 < m_2 \ll m_3 \) (Normal hierarchy)
- \( m_3 \ll m_1 < m_2 \) (Inverted hierarchy)

(APS multi-divisional neutrino study, physics/0411216)
India-based Neutrino Observatory: Quick Review
The INO Collaboration

Spokesperson: N K Mondal

Collaborating Institutions: AMU, BHU, BARC, CU, DU, HRI, UoH, HPU, IITB, IITKh, IGCAR, IMSc, IOP, LU, NBU, PU, PRL, SINP, SMIT, TIFR, VECC
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Stage I: Study of atmospheric neutrinos

- Physics Studies
- Detector R & D, including construction of a prototype (latter in progress)
- Site Survey, human resources development, interaction with industry
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Other detectors/physics like neutrinoless double beta decay?
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Other detectors/physics like neutrinoless double beta decay?

Should be an international facility
The choice of detector

Existing Detectors world-wide

- Cerenkov: Super-K (50 ktons water); SNO (1 kton heavy water)
- Iron Calorimeter: Fermi-Lab MINOS (5 kton magnetised iron)

ICAL

- Large target mass: 50 kton
- Good tracking and energy resolution
- Good directionality; hence nano-second time resolution for up/down discrimination
- Good charge resolution
- Ease of construction (modular)

Use (magnetised) iron as target mass and RPC as active detector element: ICAL. Similar to MONOLITH.

Note: Is sensitive mainly to muons (and hadrons), not electrons
The ICAL detector
The active detector elements: RPC

RPC Construction: Float glass, graphite, and spacers

- Two 2 mm thick float glass separated by 2 mm spacer
- 2 mm thick spacer
- Pickup strips
- Glass plates
- Graphite coating on the outer surfaces of glass
- Complete RPC
Fabricating RPCs

Small ↑

Large →
For the prototype . . .
Magnetic studies: field simulation

Orange : high B
Yellow : medium B
Green : lower B
Blue : least B
Field in 16 kton module

Field in $x$-direction uniform to within 0.25%.

Field in $z$-direction uniform except close to edges.

Cannot tolerate more than 4 mm gap in plate welding.

Need to study assembly scheme, mechanical stability, transient and error analysis.
### Specifications of the ICAL detector

<table>
<thead>
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<th>ICAL</th>
<th></th>
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<tbody>
<tr>
<td>No. of modules</td>
<td>3</td>
</tr>
<tr>
<td>Module dimension</td>
<td>16 m × 16 m × 12 m</td>
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<tr>
<td>Detector dimension</td>
<td>48 m × 16 m × 12 m</td>
</tr>
<tr>
<td>No. of layers</td>
<td>140</td>
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<tr>
<td>Iron plate thickness</td>
<td>∼ 6 cm</td>
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<tr>
<td>Gap for RPC trays</td>
<td>2.5 cm</td>
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<tr>
<td>Magnetic field</td>
<td>1.3 Tesla</td>
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<table>
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<th>RPC</th>
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</thead>
<tbody>
<tr>
<td>RPC unit dimension</td>
<td>2 m × 2 m</td>
</tr>
<tr>
<td>Readout strip width</td>
<td>3 cm</td>
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<tr>
<td>No. of RPC units/Road/Layer</td>
<td>8</td>
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<tr>
<td>No. of Roads/Layer/Module</td>
<td>8</td>
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<tr>
<td>No. of RPC units/Layer</td>
<td>192</td>
</tr>
<tr>
<td>Total no. of RPC units</td>
<td>∼ 27000</td>
</tr>
<tr>
<td>No. of electronic readout channels</td>
<td>3.6 × 10^6</td>
</tr>
</tbody>
</table>
Event Simulations

Source: Atmospheric Neutrinos, 6 years’ exposure, from Nuance neutrino generator.

ICAL simulation with GEANT, $B_y = 1$ T.
Event Simulations II

- Source: Cosmic ray muons, both as background to neutrino events and high energy muons as events

- ICAL simulation with GEANT, using 1 Tesla uniform magnetic field in the $y$-direction.
Physics Studies with ICAL

$\Delta m^2_{31}$-precision

$\sin^2 \theta_{23}$-precision

5 years’ running; new NOVA 25kton, 6 yrs ($6 \times 10^{21}$ pot).

Matter effects involve the participation of all three (active) flavours; hence involves both $\sin \theta_{13}$ and the CP phase $\delta$.

Hence sensitive to the mass ordering of the 2–3 states, provided $\theta_{13} > 6^\circ$; however, needs large exposures.
The difference asymmetry

Sign of $\delta \equiv \Delta m_{32}^2$ for $\theta_{13} = 5, 7, 9, 11^\circ$

Hence sensitive to the mass ordering (red vs blue) of the 2–3 states

With exposures of 500 kton-years, can get a 90%CL result if

$\sin^2 2\theta_{13} > 0.09$ (10% R)

$\sin^2 2\theta_{13} > 0.07$ (5% R)

However, needs large exposures of about 800 kton-years for smaller

$\sin^2 2\theta_{13} > 0.07$ (10% R)

$\sin^2 2\theta_{13} > 0.05$ (5% R)

D: Direct/normal; I: Inverted hierarchy
Other physics possibilities

... with atmospheric neutrinos

- **Discrimination of octant of** $\theta_{23}$ **provided** $\theta_{13} > 7^\circ$
  $$(\sin^2 2\theta_{13} > 0.06); \text{ harder than mass ordering}$$

- **Probing CPT violation** from rates of neutrino- to rates of anti-neutrino events in the detector: sensitive to $\delta b$, which adds to $\Delta m^2_{32}/(2E)$ in oscillation probability expression.

- **Constraining long-range leptonic forces** by introducing a matter-dependent term in the oscillation probability even in the absence of $U_{e3}$, so that neutrinos and anti-neutrinos oscillate differently.

- **Discrimination between oscillation of** $\nu_\mu$ **to active** $\nu_\tau$ **and sterile** $\nu_s$ **from up/down ratio in “muon-less” events?**
Stage II: Neutrino factories and INO

$\sin^2 \theta_{13}$ vs $E_{\mu}^{\text{th}}$ (GeV)

- $E_{\mu}^{\text{beam}} = 20 \text{ GeV}$
- $10^{19} \mu$ decays/yr

- CHINA
- JHF–PUSHEP
- RAMMAM
- DAE-HEP
- Dec 13, 2006

$\theta_{13}$ reach and sign of $\Delta m_{32}^2$ vs wrong sign $\mu$

Can also study CP violation: note, JHF–PUSHEP (6556 km) and CERN–PUSHEP (7145 km) are close to magic.
India-based Neutrino Observatory: Status Update
RPC status

- A series of small (30 \times 30 \text{ cm}) and large (1 \text{ m} \times 1 \text{ m}) RPCs being fabricated and tested.

- Two RPCs using Japanese float glass operative for more than 14 months in avalanche mode without loss of efficiency.

- Identified companies for polycarbonate spacers, buttons, gas inlet/outlet nozzles. Designs prepared, dies and moulds developed, samples fabricated and quality checked. Now about to go for production.

- **Glass coating**: Collaboration with UDCT, Mumbai and Nerolac paints. Nerolac trying to develop the paint Coating being tried through a local small scale industry.

- **Glass edge and corner shaping**: Jigs developed. Local industry identified. Samples being tried.
RPC status . . .

- Foam-based signal pickup panels: Industry identified. Discussed specs. Samples made. Extensive tests such as characteristic impedance, delay, permittivity, capacitance etc measured and qualified. Ready to go for production.

- Mylar sheets for insulation: Local brand identified. Received samples. Electrical insulation tests carried out. Satisfied and is being used already.

- Gas mixing systems: Designed and developed with help of a local industry. Two made for TIFR, one for BARC, one for VECC, one for IITB in progress. 2-3 more in the pipeline.

- Optimising techniques for making large size chambers.
Electronics and Data Acquisition System

- Anode/cathode pick-up signals (induced on X- and Y-pickup strips) sent to timing discriminators.
- Also feeds latch and multiplexed TDC.
- For streamer/avalanche mode, signal $\sim 100–300 \text{ mV} / 1–5 \text{ mV}$ across 50 ohms.
- Impedance matched to input of timing discriminator or preamp.
- So for avalanche mode, fast current preamplifiers (risetime $\sim 1 \text{ nanosec}$) with gain 10–30 needed. 4 prototypes designed by ED/BARC and fabricated in BEL, Bangalore. Price/supply negotiations with BEL on-going.
- Design and fabrication of analog & timing discriminator board complete.
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Discrete comp. pre-amp

Hybrid versions (BEL-ED/BARC)
Status of DAQ, etc

- Physics-based choice of trigger initiates DAQ
- Event trigger generated by FPGA-based home-built module
- VME-based DAQ coupled to PCs with Linux OS
- In-house electronics development (TIFR): Full FPGA based data acquisition system for prototype fabricated and being tested
  16-ch analog front end DAQ control module
Prototype 2m × 2m × 13 plates of 5 cm iron is being constructed (40 tons).

Soft iron (magnetisable to 2 T) procured

Fabrication order placed with Pune vendor (Milman); includes assembly, testing with power supply and field measurement Hall probe

1m × 1 m RPCs for 12 layers of prototype being made/tested. Issues with RPC efficiency and stability being studied.

About 800 channels of preamp, timing discriminators being constructed

To be assembled at VECC, Kolkata
More on the site

- 2.1 km long access tunnel into mountain; cavern beneath the peak

- Experimental hall I: $25m \times 130m \times 30m$ (height) built to accommodate 50 kton + 50 kton modules (future expansion)

- Experimental Hall II: about half the size, to accommodate other, smaller experiment(s).
Site-specific geology

INDIA BASED NEUTRINO OBSERVATORY PROJECT
TENTATIVE GEOLOGICAL SECTION ALONG ALIGNMENT-2.

- Migmatite and Charnockite interbanded.
- Charnockite.
- Trace of foliation.
- Trace of shear zones.
- Trace of fracture zones.
- Trace of Sheared dyke.

C. Thonavelu.
R. Srinivasan.
Site-specific geology

Engineering Task Force has been formed and entrusted with the DPR preparation.

Members include engineers and scientists from BARC, IGCAR, VECC and GSI, TNEB.

ETF met at Masinagudi on Dec 7th to discuss DPR requirements. DPR draft/final to be ready by Feb 15/ March.

Environmental Impact Assessment and Environment Management Plan entrusted to Salim Ali Centre for Ornithology and Natural History (SACONH); will be ready by the end of January.

Permission for detailed site survey and geo-technical studies obtained

Detailed drawings of surface facilities and labs at Masinagudi have been prepared (includes hostel, guest house and conference facilities).

TNEB land for the purpose earmarked. Acquisition needs approval from Chairman, TNEB.
Time lines for INO

- **May, 2005**: INO interim report was presented to the funding authorities as well as to the general scientific community at a meeting in TIFR, Mumbai
- **August 2005**: It was presented to the SAC-PM committee
- **April 2006**: It was endorsed by the community at a meeting in Mumbai to define the joint road-map for HEP and NP research in the country
- **August 2006**: Recommended by the committee set up by the Planning Commission to the Mega Science projects for funding
- **October 2006**: Reports from the international panel of referees received by Chairman, INO-PMC (Director, TIFR)

The technical review of the INO proposal is complete and is favourable. It is now with the funding agencies for approval.
The outlook looks good! This is a massive project: Looking for active collaboration both within India and abroad

The INO Collaboration

- Aligarh Muslim University, Aligarh: M. SajjadAthar, Rashid Hasan, S. K. Singh
- Banaras Hindu University, Varanasi: B. K. Singh, C. P. Singh, V. Singh
- Calcutta University (CU), Kolkata: Amitava Raychaudhuri
- Delhi University (DU), Delhi: Brajesh Choudhary, Delyssty Choudhury, Sukanta Dutta, Ashok Goyal, Kirti Ranjan
- University of Hawaii (UHW), Hawaii: Sandip Pakvasa
- Himachal Pradesh University (HPU), Shimla: S. D. Sharma
- Indian Institute of Technology (IIT), Bombay (IFTB), Mumbai: Basant Nandi, S. Uma Sankar, N. Gangopadhyay
- Indira Gandhi Center for Atomic Research, Kalpakkam: J. Jayapandian, G. S. Ramakrishna
- The Institute of Mathematical Sciences (IMSc), Chennai: D. Indumathi, H. S. Mani, M. V. N. Murthy, G. Rajasekaran, Nita Sinha, D. V. Ramakrishna
- Institute of Physics (IOP), Bhubaneswar: Pankaj Agrawal, D. P. Mahapatra, S. C. Phatak
- North Bengal University (NBU), Siliguri: A. Bhadra, B. Ghosh, A. Mukherjee, K. S. Sarkar
- Panjab University (PU), Chandigarh: Vinod Bhatnagar, M. M. Gupta, J. B. Singh
- Physical Research Laboratory (PRL), Ahmedabad: A. S. Joshi, Surendra Mohanty, S. D. Randhan
- Saha Institute of Nuclear Physics (SINP), Kolkata: Sudeb Bhattacharya, Suvendu Bose, Sukalyan Chattopadhyay, Ambar Ghosal, Asimandu Goswami, Kamaleswar Debnath, Prasad Goel, Palash B. Pal, Satyajit Saha, Abhijit Samanta, Abhijit Samyad, Sandip Sarkar, Swapan Sen, Manoj Sharan
- Sikkim Manipal Institute of Technology, Sikkim: G. C. Mishra

Scientific Steering Committee

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Ramanath Cowsik, Indian Institute of Astrophysics, Bangalore
H. S. Mani, Tata Institute of Fundamental Research, Mumbai
V. S. Narasimham, Tata Institute of Fundamental Research, Mumbai
G. Rajasekharan, The Institute of Mathematical Sciences, Chennai
Amit Ray, Nuclear Science Centre, New Delhi
Prabir Roy, Tata Institute of Fundamental Research, Mumbai
Bikash Sinha, Tata Institute of Nuclear Physics, Variable Energy Cyclotron Centre, Kolkata

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URL: http://www.imsc.res.in/~ino

1This is an open collaboration and experimentalists are especially encouraged to join.
2Since retired
3Replacing Abdul Salam who was a member until March 5, 2005
$3\sigma$ Precision of parameters

at $\Delta m_{32}^2 = 2.0 \times 10^{-3}$ eV$^2$ and $\sin^2 \theta_{23} = 0.5$

| Experiment         | $P(|\Delta m_{32}^2|)$ | $P(\sin^2 \theta_{23})$ | hierarchy          |
|---------------------|--------------------------|---------------------------|--------------------|
| Current             | 88%                      | 79%                       | –                  |
| MINOS               | 17%                      | 65%                       | –                  |
| CNGS                | 37%                      | –                         | –                  |
| NO$\nu$A ($6 \times 10^{21}$ pot) | $\sim 5\%$       | $\sim 9\%$               | in comb            |
| T2K (Super-K, 0.75 MW) | 12%                      | 46%                       |                    |
| ICAL (50 kton)      | 20%                      | 60%                       | $\sin^2 2\theta_{13} > 0.06$ |
Other issues w.r.t RPC R & D

- RPC timing
- RPC charge distribution
- Mean charge vs voltage (seen to be linear)
- RPC noise
- Gas composition ($C_2H_2F_4$ (R-134a), Argon, Isobutane ($\leq 8\%$))
- RPC Cross talk (as a function of gas mixture)
- Gas mixing