INO

INDIA BASED NEUTRINO OBSERVATORY
A STATUS REPORT

Brajesh Choudhary
FERMILAB, and University of Delhi, India

PHENO 05, World Year of Phenomenology
University of Wisconsin, Madison, May 2-4, 2005.
PLAN OF THE TALK

1. Why INO?
2. History of Atmospheric \(\nu\) Physics in India
3. INO Detector
4. What Physics INO will do?
5. Site Selection
6. Cost Estimate
7. Time Frame
8. Summary and Conclusions
HISTORY OF ATMOSPHERIC NEUTRINO IN INDIA

- The KGF group from TIFR, Osaka, & Durham were the first to report observation of 3 atmospheric neutrino induced events in:
  - Events were recorded on 30th March, 27th April, and 25th May, 1965.
- Reines et al. reported observation of 7 events in:
  - The first ever neutrino event was recorded on 23rd Feb. 1965.
- KGF collaboration contributed immensely to the cosmic ray and related physics. Glorious period of “Cosmic Ray Physics in India”. The KGF mine was closed in early 90’s for financial reasons. What a shame!
- India-based Neutrino Observatory is an attempt not to just have an underground laboratory in India but to revive the culture of doing most fundamental physical sciences in India at a large scale with international collaboration.

*It has both excellent scientific and social value.*
HISTORY OF ATMOSPHERIC NEUTRINO IN INDIA

KGF reported – observation of 1\textsuperscript{st} Atmospheric $\nu$ event - published – 15 August 1965.

DETECTION OF MUONS PRODUCED BY COSMIC RAY NEUTRINO DEEP UNDERGROUND

C.V. ACHAR, M.G.K. MENON, V.S. NARASIMHAM, P.V. RAMANA MURTHY and B.V. SREEKANTAN,
Tata Institute of Fundamental Research, Colaba, Bombay

K. HINOTANI and S. MIYAKE,
Osaka City University, Osaka, Japan

D.R. CREED, J.L. OSBORNE, J.B.M. PATTISON and A.W. WOLFENDALE
University of Durham, Durham, U.K.

Received 13 July 1965

Table 1

<table>
<thead>
<tr>
<th>Event number</th>
<th>Type of coincidence</th>
<th>Projected zenith angle</th>
<th>Date</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TEL.2 N\textsubscript{4} $+$ S\textsubscript{4}</td>
<td>37\degree</td>
<td>30.3</td>
<td>20.04</td>
</tr>
<tr>
<td>2</td>
<td>TEL.1 N\textsubscript{1} $+$ S\textsubscript{1}</td>
<td>48 $\pm$ 1\degree</td>
<td>27.4</td>
<td>18.26</td>
</tr>
<tr>
<td>3</td>
<td>TEL.2 N\textsubscript{6} $+$ S\textsubscript{6}</td>
<td>75 $\pm$ 10\degree</td>
<td>25.5</td>
<td>20.03</td>
</tr>
</tbody>
</table>

50 days of operation $\sim$ 2140 m$^2$ days steradian
KOLAR GOLD FIELD – FEW INDIAN PHYSICISTS & TECHNICIANS
INO DETECTOR

Detector choice based on:

- Technological capabilities available within the country
- Existing/Planned other neutrino detectors around the world
- Modularity and the possibility of phasing
- Compactness and ease of construction

Detector should have:

- Large target mass (50-100 KTon)
- Good tracking and energy resolution (tracking calorimeter)
- Good directionality or time resolution ~ 1nsec

The proposed detector is:

- Phase I – A 50 KTon magnetized iron-RPC based modular detector
- Phase II – Expect to increase target mass to 100KTON

Magnetized Fe-RPC calorimeter, a la MONOLITH.
WHAT PHYSICS ONE CAN DO WITH SUCH A DETECTOR?

- **Phase I – Atmospheric neutrino**
  - Explicit observation of first oscillation swing as a function of L/E
  - Improved measurement of $\Delta m^2_{23}$ and $\sin^2 2\theta_{23}$
  - Search for potential matter effect and sign of $\Delta m^2_{23}$ from $\mu^+ & \mu^-$ events
  - Discrimination between $\nu_\mu \rightarrow \nu_\tau$ vs. $\nu_\mu \rightarrow \nu_s$
  - CPT violation
  - Constraining long range leptonic forces

- **Phase II – Beam neutrino (Neutrino Factory)**
  - Determination of $\theta_{13}$ from $\nu_e \rightarrow \nu_\mu$ oscillations
  - Sign of $\Delta m^2_{23}$ from $\nu_e \rightarrow \nu_\mu$ oscillations
  - CP violation
  - Search for potential matter effects in $\nu_\mu \rightarrow \nu_\tau$ and sign of $\Delta m^2_{23}$

- **Other Physics Possibilities**
  - Ultra high energy neutrinos and muons
Measure the disappearance probability with a single detector and two equal sources – down-going and up-going muons produced by neutrino interactions.

Expect to measure $\Delta m^2_{23}$ to $\sim 10\%$ and $\sin^2 \theta_{23}$ to $\sim 30\%$ precision at $3\sigma$ (total spread around central value).
EXPLICIT MEASUREMENT OF L/E

\[ \frac{N_{\mu}^{\uparrow}(L/E)}{N_{\mu}^{\downarrow}(L/E)} = P(\nu_\mu \rightarrow \nu_\mu ; L/E) = 1 - \sin^2(2\theta_{23}) \sin^2(1.27\Delta m^2_{23}L/E) \]

\[ \Delta m^2 = 0.002 \text{ eV}^2 \]

\[ \sin^2 2\theta = 1 \]

200 Kton-yr

68%, 90% & 99% CL contours

Best fit point:
\[ \delta_{32} = 0.002 \text{ eV}^2 \]
\[ \sin^2 2\theta = 0.998 \]
$\nu_\mu \rightarrow \nu_\tau$ oscillation will give rise to an excess of NC or muonless event compared to $\nu_\mu \rightarrow \nu_s$ events.

- $\text{U-D} \quad \text{U+D}$
  - $\text{U-D} \quad \text{U+D}$

$\Delta m^2_{23} = 4 \times 10^{-3} \text{ eV}^2$

$\Delta m^2_{23} = 1 \times 10^{-3} \text{ eV}^2$
\[ P_{\mu \mu} (L) = 1 - \sin^2 2\theta \sin^2 \left[ \left( \frac{\delta_{32}}{4E} + \frac{\delta b}{2} \right) L \right] \]

\[ \Delta P_{\mu \mu}^{CPT} = P_{\mu \mu} - P_{\mu \mu} = -\sin^2 2\theta \sin \left( \frac{\delta_{32} L}{2E} \right) \sin(\delta b L) \]

R. Gandhi et al.,

Plots for values
\[ \Delta m_{23}^2 = 0.002 \text{ eV}^2 \]
\[ \sin^2 2\theta_{23} = 1.0 \]
MATTER EFFECT & SIGN OF $\Delta m^2_{23}$

NEXT TALK - TO BE GIVEN BY

Sankagiri Umasankar

Large matter effects in $\nu_\mu \rightarrow \nu_\tau$ oscillations
INO COLLABORATION

- At present INO collaboration consists of
  ~90 Physicists and Engineers from
  - 15 Indian institutions, and
  - 1 US Institution

- Spokesperson – Prof. Naba Mondal – TIFR, Mumbai

- Planned to be an international facility-
  - Begin with a Fe-RPC magnetized $\nu$ detector 50-100Kton
  - Later use the facility possibly for:
    - Low energy Neutrinos (solar $\nu$, reactor $\nu$, supernova $\nu$, $\beta$ decay, $0\nu\beta\beta$ decay, global radioactivity in earth, nucleon decay etc. etc.)
    - Neutrino Astronomy (cosmic ray composition, UHE $\nu$ astronomy)
    - Low Energy Accelerator for nuclear astrophysics

*International community is most welcome and we invite them to join the effort in this program – INO needs more experimentalists.*
CURRENT ACTIVITIES

- Detector Development
- Detector Simulation
- Physics Studies
- Data Acquisition System
- Site Survey
- International Collaboration
INO DETECTOR – INITIAL DESIGN CONCEPT

Magnetized Fe with RPCs (50 KTon with ~1.3T magnetic Field)

- 3 Modules of 16m X 16m X 12m each – 140 Layers/module
- Each layer - 6cm thick Fe + RPC in 2.5cm Gap
- Each RPC of size 2m X 2m – 27000 RPC’s needed
- Active Detector Area ~ 108,000 m²
- Magnetic Field ~ 1.3 Tesla
INO DETECTOR – INITIAL DESIGN CONCEPT

Magnetic field in a horizontal plane inside an Fe plate
CONSTRUCTION OF A COMPLETE RPC

- 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
RPC EFFICIENCY AND TIMING RESOLUTION

Efficiency $\geq 90\%$ for HV $\geq 8.5$ kV for all possible gas mixtures

Typical timing resolution ($\sigma$) as a function of applied voltage

Efficiency $\geq 90\%$ for HV $\geq 8.5$ kV for all possible gas mixtures
A model of the INO magnet - fabricated at VECC to understand

- If the measured field agrees with calculation
- Whether 2D calculation is OK
- To understand the magnet energizing time

**Expected Field Inside Fe ~14KG**

**Field measurement in the INO model (1/100 scale)**

- Calculated and measured field within the gap of the 1:100 prototype
DETECTOR AND PHYSICS SIMULATION

- Nuance Event Generator
  - Generate atmospheric neutrino events inside the INO detector

- GEANT Monte Carlo Package
  - Simulate the detector response for the neutrino events

- Event Reconstruction
  - Fit the raw data/hits to extract neutrino energy and direction

- Physics Performance of the Baseline INO detector
  - Analysis of reconstructed events to extract physics

Studies progressing at many collaborating institutions.
POSSIBLE SITES FOR INO

PUSHEP
Lat. N 11.5°
Long. E 76.6°

Rammam
Lat. N 27.4°
Long. E 88.1°
PUSHEP (Pykara Ultimate Stage Hydro Electric Project) in South India, near BANGALORE

Elevation in meter above MSL. (not to scale~1Km.)

4 possible alignment of INO tunnel at PUSHEP
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**Action Items:**

- Stress measurement at depths of 1000m
- Permission to conduct tests and approval for locating INO
- Possibility of building exploratory tunnel
### COST ESTIMATION FOR LAB. CONSTRUCTION

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Cost at PUSHEP in millions of USD</th>
<th>Cost at Rammam in millions of USD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel and cavern excavation</td>
<td>8</td>
<td>19.3</td>
</tr>
<tr>
<td>Civil work surface and underground(^1)</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Facilities in the cavern(^2)</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>~$21M</td>
<td>~$32M</td>
</tr>
</tbody>
</table>

1. Includes access tunnel, the cavern, surface laboratory, housing/accommodation
2. Includes overhead crane, air-circulation in tunnel, air-conditioning in laboratory, electrical work

*Estimate given by L & T Limited. – FY2004 PRICE.*
## DETECTOR COST (IN MILLIONS of USD)

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Cost for 50 KTon Detector</th>
<th>Cost for 100 KTon Detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRON (at $0.90/Kg)</td>
<td>45.5</td>
<td>91.0</td>
</tr>
<tr>
<td>Magnetization</td>
<td>4.6</td>
<td>9.2</td>
</tr>
<tr>
<td>Active Detector</td>
<td>27.3</td>
<td>54.6</td>
</tr>
<tr>
<td>Electronics and DAQ</td>
<td>5.7</td>
<td>11.4</td>
</tr>
<tr>
<td>Contingencies</td>
<td>9.1</td>
<td>18.2</td>
</tr>
<tr>
<td>TOTAL excluding IRON</td>
<td>46.7</td>
<td>93.4</td>
</tr>
<tr>
<td>TOTAL including IRON</td>
<td>~$92M</td>
<td>~$184M</td>
</tr>
</tbody>
</table>

**TOTAL COST FOR A 50 KTon DETECTOR + LAB = $115-125M**

**FY 2004 COST**
TIME SCALE

a. Phase I - 12 to 18 months
   1. Site investigation to draw up detailed design reports for tunnel and cavern complex. Could be faster if all permission from authorities are available?
   2. Detector R&D will be over. Detailed design report on detector structure, RPC’s, pick-up electrodes, FE electronics, power supply to be ready.

b. Phase II – 22 months for PUSHEP and 41 months for Rammam.
   1. Will include tunnel and cavern excavation and related support measure.
   2. Basic detector design frozen.
   3. Tenders for supply of Fe, magnet coils, cables etc. to be issued.
   4. Large scale RPC construction to begin.

c. Phase III – 12 to 18 months
   1. Laboratory outfitting, transport of detector components and assembly.
   2. The first module may be completed early and the data taking may begin

ONE CAN EXPECT TO COLLECT DATA WITH ATMOSPHERIC NEUTRINOS BY 2010-11
1. A large magnetized detector of 50-100 Kton can achieve some of the very interesting physics goals using neutrinos, especially:
   a. CPT violation, and
   b. Matter effect and sign of $\Delta m^2_{23}$

2. Magnetized Fe calorimeter will complement planned water cherenkov, scintillator, and LAr based detectors

3. Will compliment present long baseline and reactor experiments

4. Can be used as FAR detector during neutrino factory era

5. Proposal has been submitted to the funding agencies in India

6. R&D on all fronts progressing well

7. Looking for participation from larger international neutrino community.
✓ Reach and measure of $\sin^2 2\theta_{13}$
✓ Sign of $\Delta m^2_{32}$
✓ CP violation in lepton sector
$\sin \theta_{13}$ REACH vs. $E_\mu^\mu$ THRESHOLD
SIGN OF $\Delta m^2_{32}$

$E^{\mu_+}_{\text{beam}} = 20 \text{ GeV}$

$10^{19}$ $\mu$ decays/yr