INO
India-based Neutrino Observatory

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Atmospheric Neutrinos

Atmospheric neutrino detector at Kolar Gold Field –1965

DETECTION OF MUONS PRODUCED BY COSMIC RAY NEUTRINO DEEP UNDERGROUND

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Received 12 July 1965

EVIDENCE FOR HIGH-ENERGY COSMIC-RAY NEUTRINO INTERACTIONS*

F. Reines, M. F. Crouch, T. L. Jenkins, W. R. Kropp, H. S. Gurr, and G. R. Smith
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and

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(Received 26 July 1965)
Need For A Large Mass Magnetised Detector

• Atmospheric Neutrino Physics now entering a new era.
  – From observation of oscillation to precision measurement of parameters.

• A large mass detector with a magnetic field is essential to achieve many of the physics goals.
  – Reconfirmation of atmospheric neutrino oscillation through explicit observation of first oscillation swing as a fn. of L/E
  – Improved measurement of the oscillation parameters
  – Search for potential matter effect and sign of $\Delta m_{23}$
  – Discrimination between $\nu_\mu \rightarrow \nu_\tau$ vs $\nu_\mu \rightarrow \nu_s$
  – CP violation in neutrino sector
  – Probing CPT violation
  – Constraining long range leptonic forces

• Need a detector of size 50 to 100 Kton having charge measurement capability
Disappearance of $V_{\mu}$ Vs. L/E

The disappearance probability can be measured with a single detector and two equal sources:

$$\frac{N_{\text{up}}(L/E)}{N_{\text{down}}(L'/E)} = P(\nu_\mu \rightarrow \nu_\mu; L/E) = 1 - \sin^2(2\Theta) \sin^2(1.27 \Delta m^2 L/E)$$

Expect to measure $\Delta m^2$ with 10% precision
Total no. of $\nu_\mu$ charge current events:

$$N_\mu = N_n \times M_Y \int dE \int d \cos \theta_z \left[ \frac{d^2 \phi_\mu}{dEd \cos \theta_z} P_{\mu \mu}(E, L) + \frac{d^2 \phi_e}{dEd \cos \theta_z} P_{e \mu}(E, L) \right] \sigma_\mu(E)$$
Matter Effect

\[ \sin^2 2\theta_{13} = 0.1 \]
\[ \Delta_{31} = 0.002 \text{ eV}^2 \]
The neutrino and anti-neutrino up/down event ratios are different from each other as well as different with direct and inverted mass hierarchies.
$\nu_\mu \rightarrow \nu_\tau \ \text{VS} \ \nu_\mu \rightarrow \nu_s$

$\nu_\mu \rightarrow \nu_\tau$ events will give rise to excess of muonless events. There will be excess of upgoing muonless events.
CPT Violation

The expression for survival probability for the case of CPTV 2-flavour oscillations

\[ P_{\mu\mu} (L) = 1 - \sin^2 2\theta \sin^2 \left( \frac{\delta_{32}}{4E} + \frac{\delta b}{2} \right) L \]

and

\[ \Delta P^{CPT}_{\mu\mu} = P_{\mu\mu} - P_{\bar{\mu}\bar{\mu}} = -\sin^2 2\theta \sin \left( \frac{\delta_{32} L}{2E} \right) \sin (\delta b L) \]
Choice of Neutrino Source and Detector

**Neutrino Source**
- Need to cover a large L/E range
  - Large L range
  - Large $E_\nu$ range
- Use Atmospheric neutrinos as source : Phase I
- Beam from Neutrino factory : Phase II

**Detector Choice**
- Should have large target mass (50-100 KT)
- Good tracking and Energy resolution (Tracking calorimeter)
- Good directionality (<= 1 nsec time resolution)
- Ease of construction
- Modular with a possibility of phasing
- Use magnetised iron as target mass and RPC as active detector medium
Current INO related activities

- Detector Development.
- Detector Simulation.
- Physics Studies.
- Data Acquisition System.
- Site Survey.
- International Collaboration.
INO Detector Concept

INO IRON CALORIMETER

RPC Trays
Construction of RPC

Two 2 mm thick float Glass Separated by 2 mm spacer

2 mm thick spacer

Glass plates

Complete RPC

Pickup strips

Graphite coating on the outer surfaces of glass
Test of RPCs
RPC Efficiency & timing Studies

TIFR RPC Efficiency

- Freon-134a 62%
- Freon-134a 57%
- Freon-134a 52%
- Freon-134a 46%

Time Resolution

- RPC
- Trigger scintillator

Efficiency (%) vs High Voltage (KV)

Time Resolution (nsec) vs High Voltage (KV)
Detector and Physics Simulation

- **NUANCE Event Generator:**
  - Generate atmospheric neutrino events inside INO detector

- **GEANT Monte Carlo Package:**
  - Simulate the detector response for the neutrino event

- **Event Reconstruction:**
  - Fits the raw data to extract neutrino energy and direction

- **Physics Performance of the baseline INO detector.**
  - Analysis of reconstructed events to extract physics.

**These studies are going on at all the collaborating institutes**
Possible INO sites

- PUSHEP (Pykara Ultimate Stage Hydro Electric Project) in South India
  or
- RAMMAM Hydro Electric Project Site
Location of Rammam
Underground Cavern

- **Width**: 22 m
- **Height**: 25 m
- **Length**: > 120 m
Interim Report

Will submit the INO Interim Project Report To Indian funding agencies on 1 May, 2005
Summary

• A large magnetised detector of 50-100 Kton is needed to achieve some of the very exciting physics goals using neutrinos.
• A case for such a detector was highlighted earlier by the Monolith Collaboration.
• Physics case for such a detector is strong as evident from recent publications.
• It will complement the existing and planned water cherenkov detectors.
• Can be used as a far detector during neutrino factory era.
• We have started a very active R & D work towards building such a detector.
• Looking for participation from international neutrino community.
Ultimate Long Base Line Neutrino Experiment
Physics with Neutrinos from Beam

Physics with a Fe Calorimeter and a Neutrino Factory Beam

- Reach and measure of $\sin^2 2\theta_{13}$
- The sign of $\Delta m^2_{32}$

- Determining if CP violation is present in the leptonic sector
Measure of $\sin \theta_{13}$
Sign of $\Delta m_{23}^2$