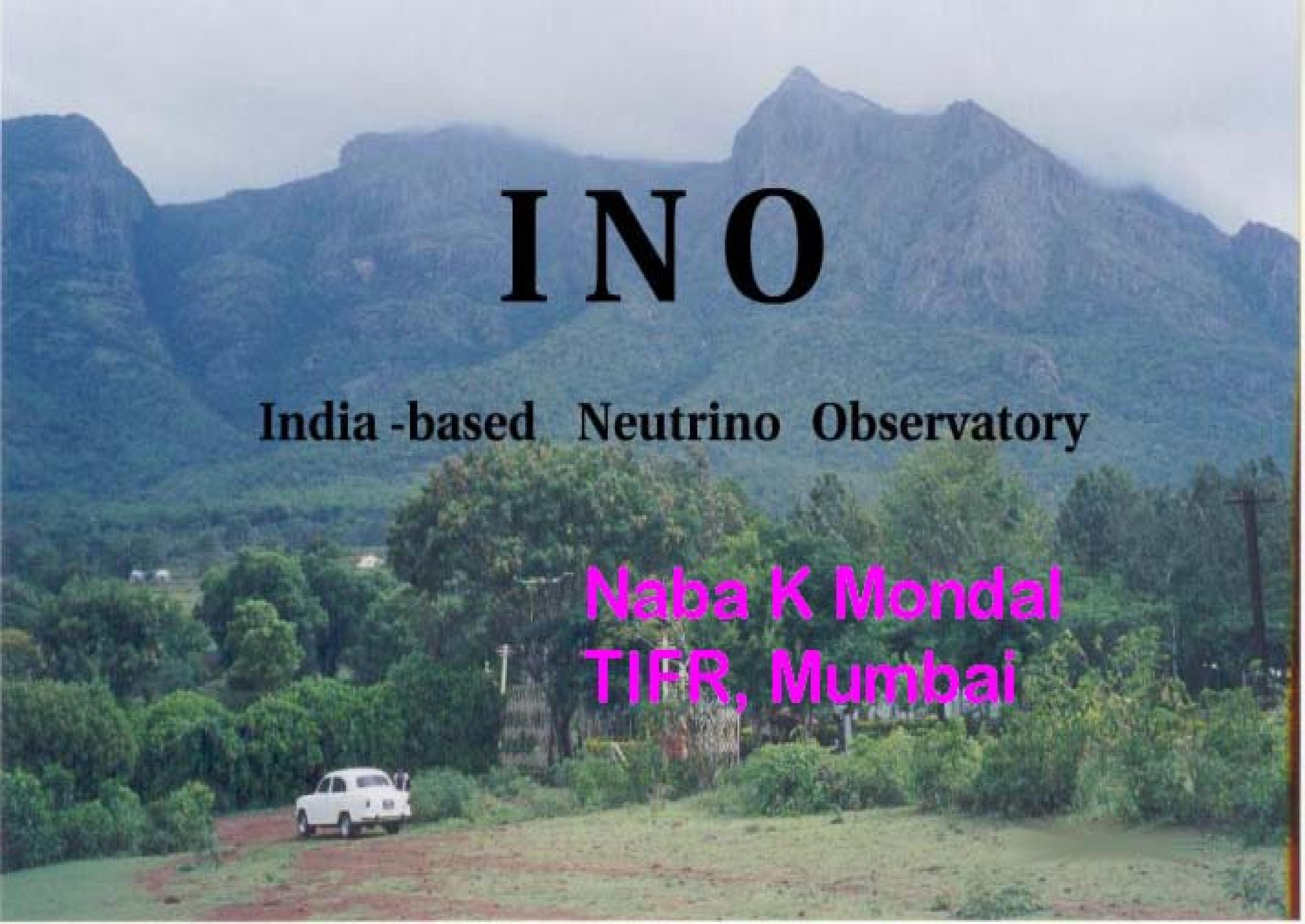
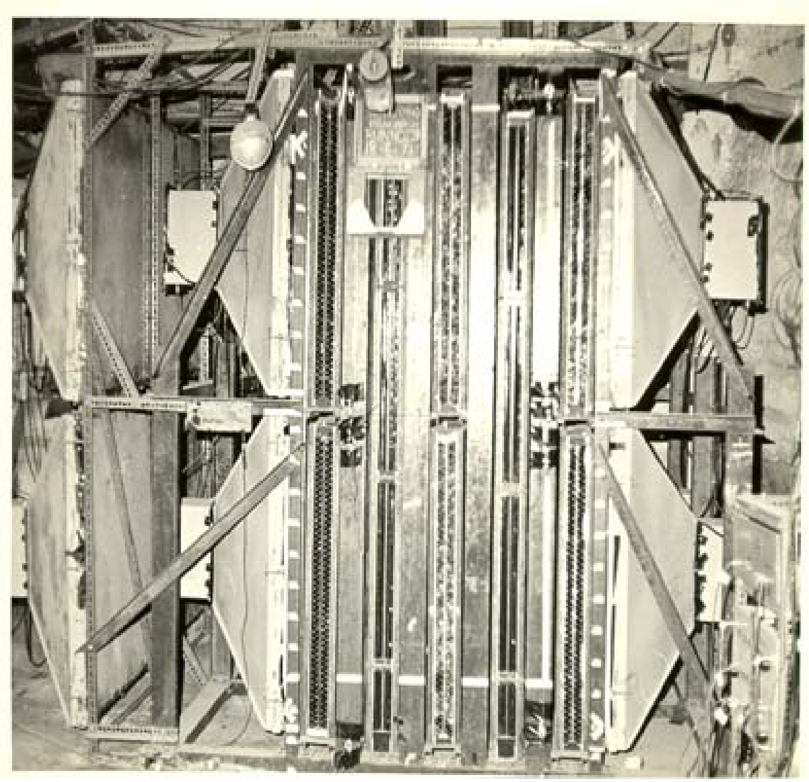

INO
India -based Neutrino Observatory
Naba K Mondal
TIFR, Mumbai

Atmospheric Neutrinos

Atmospheric neutrino detector at Kolar Gold Field –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 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
Case Institute of Technology, Cleveland, Ohio

and

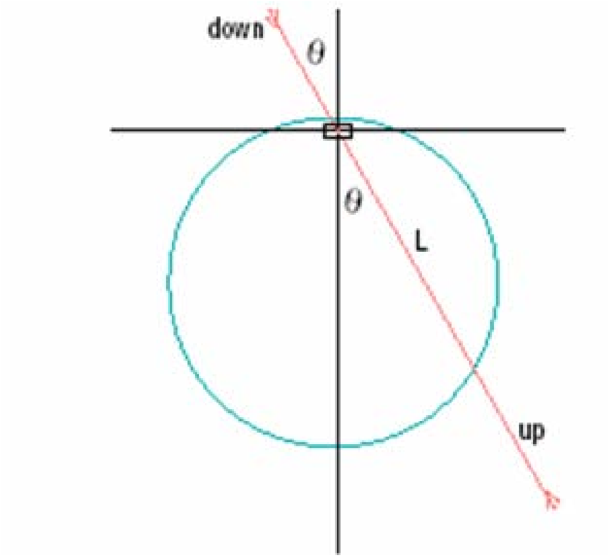
J. P. F. Sellschop and B. Meyer
University of the Witwatersrand, Johannesburg, Republic of South Africa
(Received 26 July 1965)

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 Δm_{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 ν_μ Vs. L/E

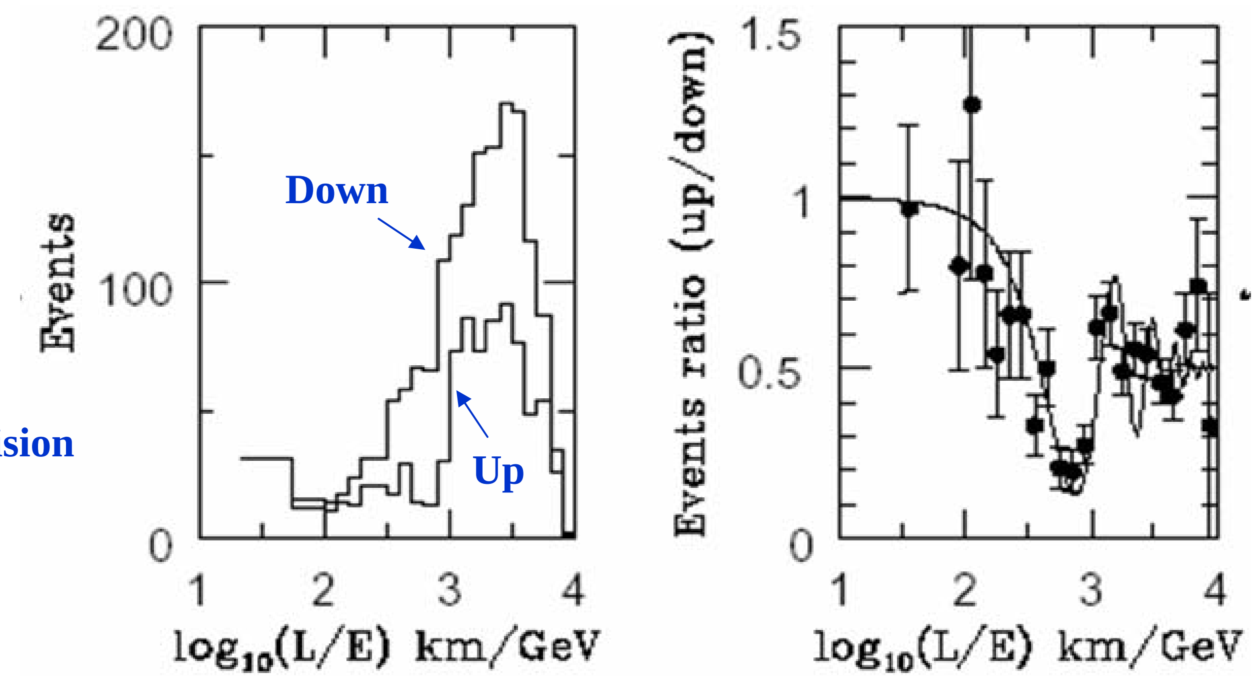
The disappearance probability can be measured with a single detector and two equal sources:



$$\frac{N_{up}(L/E)}{N_{down}(L'/E)} = P(\nu_\mu \rightarrow \nu_\mu; L/E)$$

$$= 1 - \sin^2(2\Theta)\sin^2(1.27\,\Delta m^2\, L/E)$$

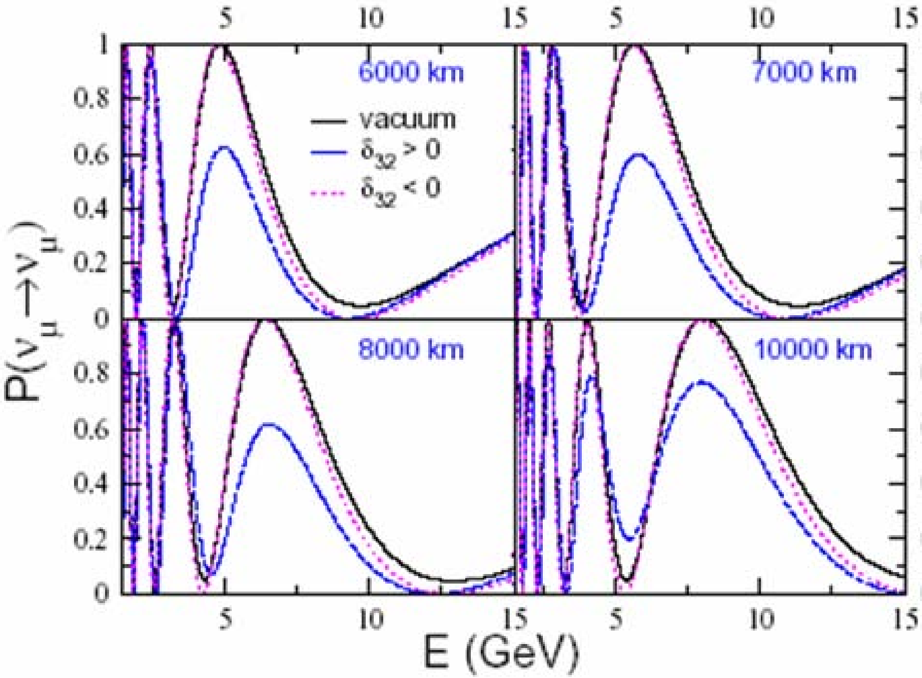
Expect to measure Δm^2 with 10% precision



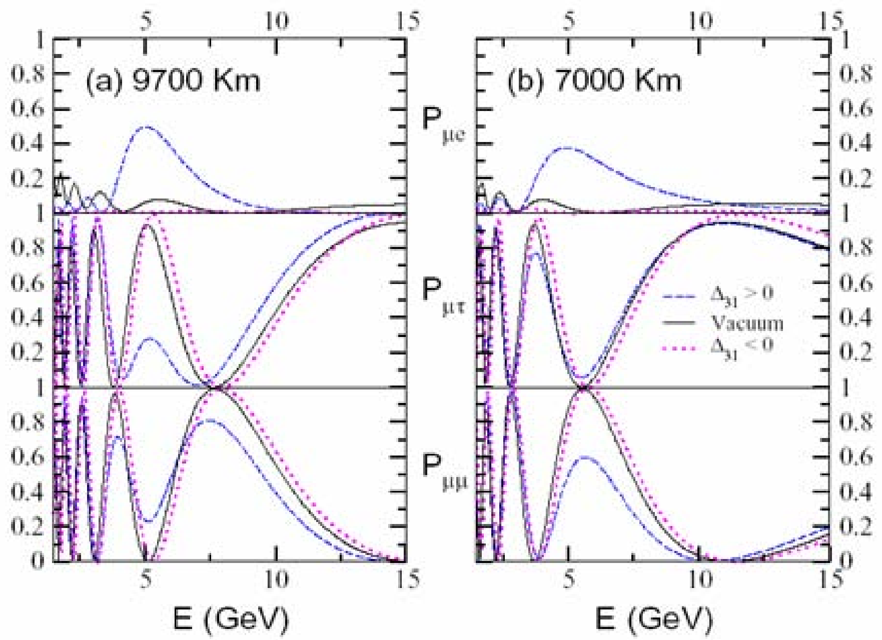
Matter Effect

Total no. of ν_μ charge current events:

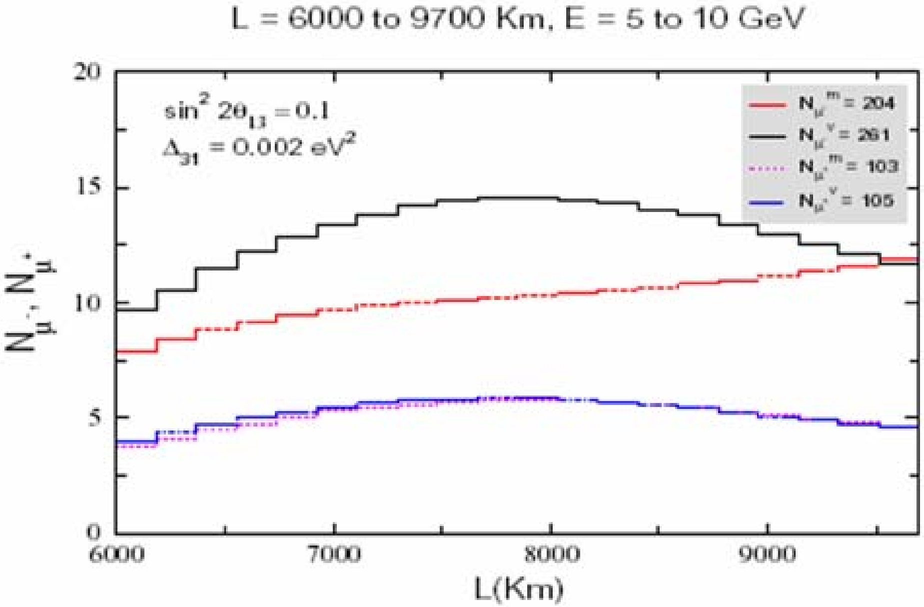
$$N_\mu = N_n \times M_Y \int dE \int d\cos\theta_z \left[\frac{d^2\phi_\mu}{dE\,d\cos\theta_z} P_{\mu\mu}(E,L) + \frac{d^2\phi_e}{dE\,d\cos\theta_z} P_{e\mu}(E,L) \right] \sigma_\mu(E)$$

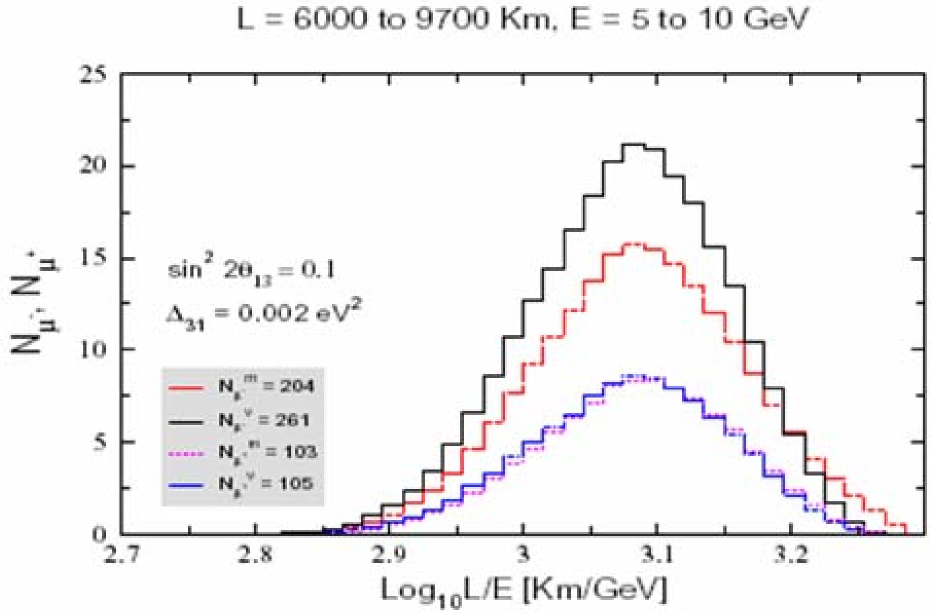


R. Gandhi *et al.*, Phys. Rev. Lett. **94**, 051801 (2005); hep-ph/0411252



Matter Effect



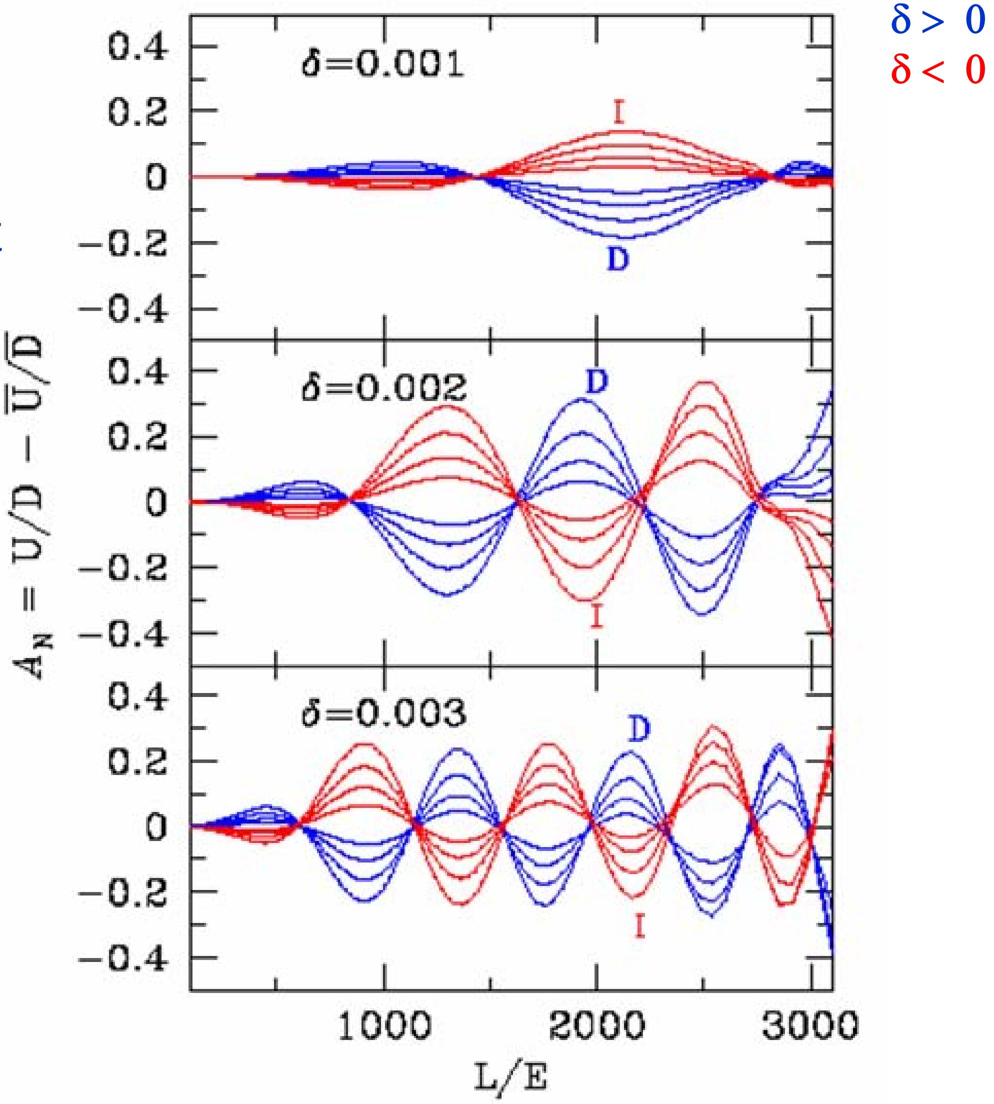


R. Gandhi *et al.*, hep-ph/0411252

Sign of Δm^2_{32}

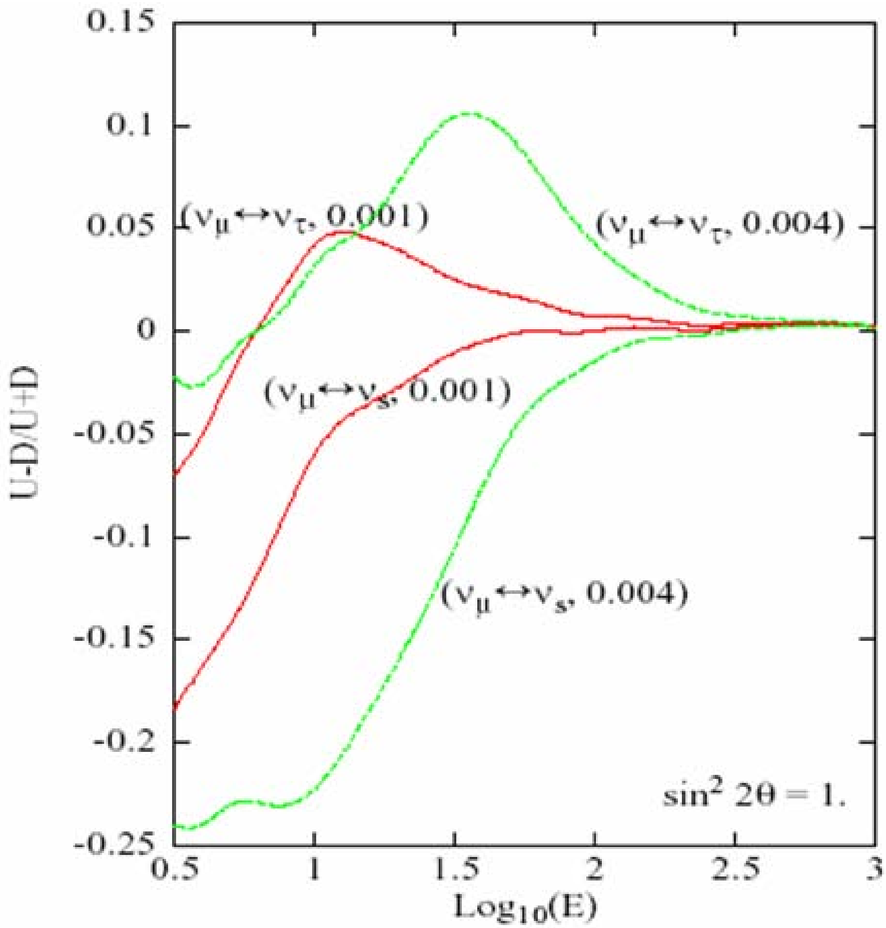
D. Indumathi *et al.*, Phys. Rev. D71, 013001 (2005)

The neutrino and anti-neutrino up/down event ratios are different from each other as well as different with direct and inverted mass hierarchies.



$\nu_\mu \rightarrow \nu_\tau$ vs $\nu_\mu \rightarrow \nu_s$

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



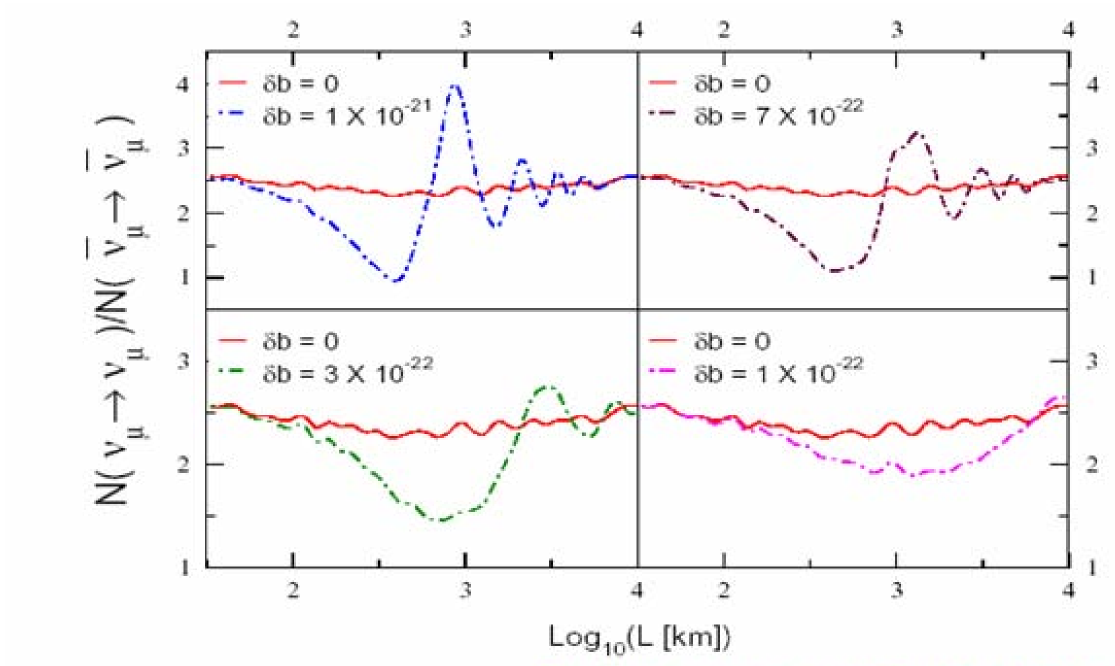
CPT Violation

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

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

and

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



R. Gandhi *et al.*, Phys. Lett. B597, 356 (2004)

Choice of Neutrino Source and Detector

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

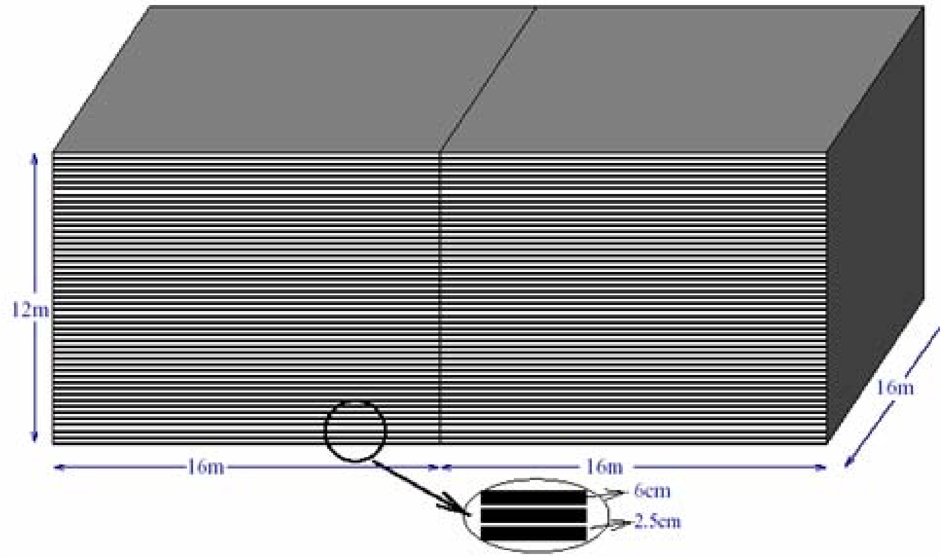
- **Detector Choice**
    - **Should have large target mass (50-100 KT)**
    - **Good tracking and Energy resolution (Tracking calorimeter)**
    - **Good directionality (<= 1 nsec time resolution)**
    - **Ease of construction**
    - **Modular with a possibility of phasing**
  - **Use magnetised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

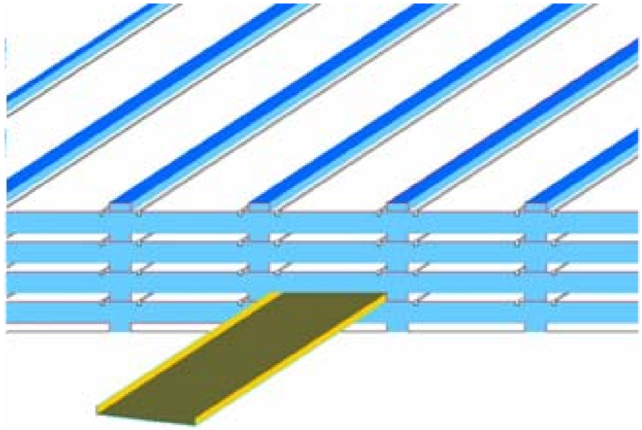
Current INO related activities

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

INO Detector Concept

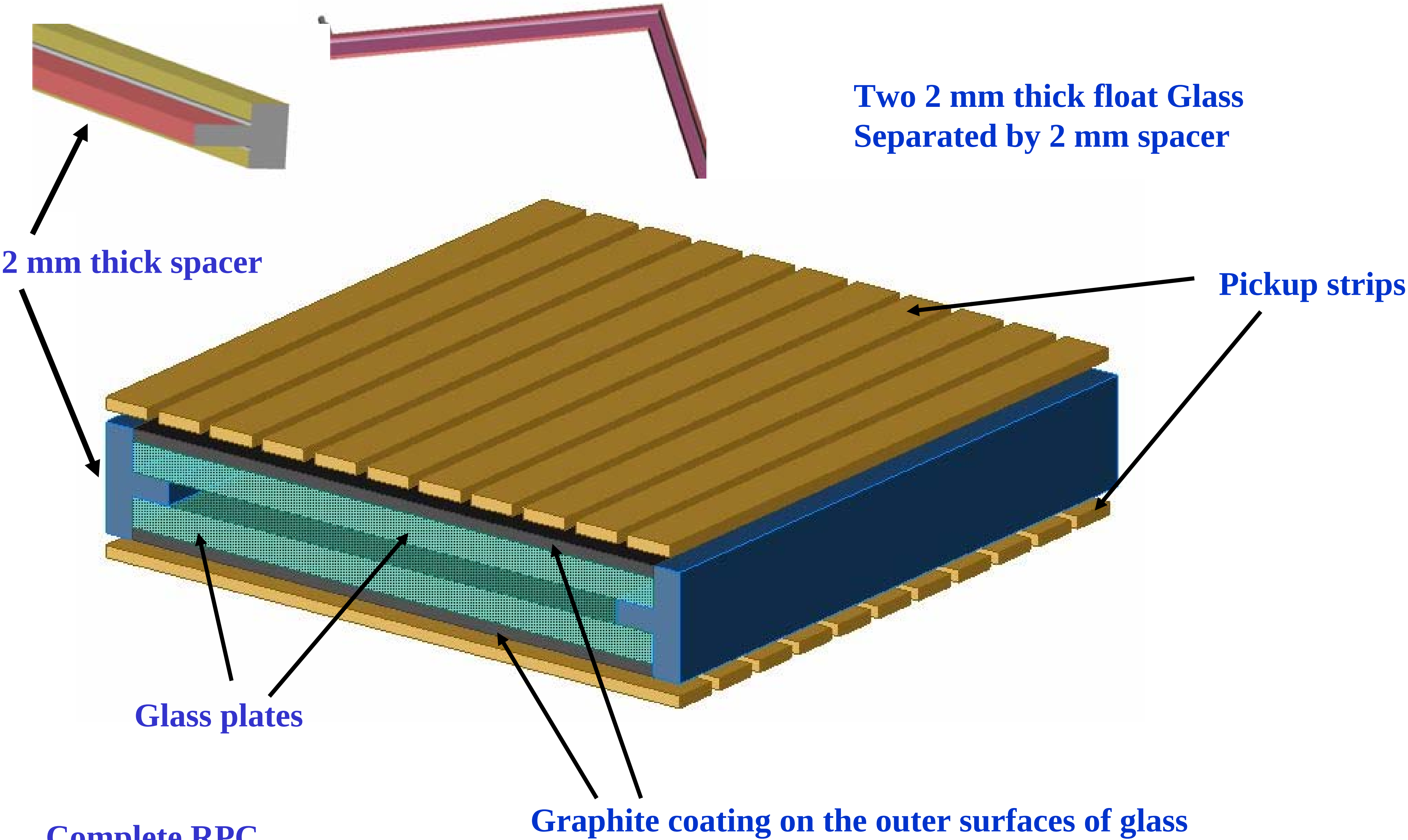
INO IRON CALORIMETER





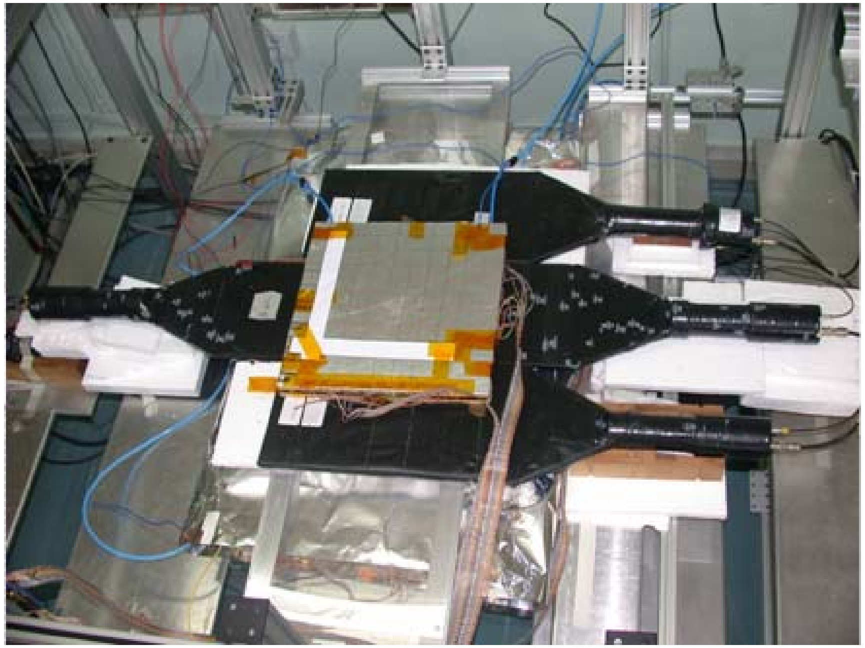
RPC Trays

Construction of RPC

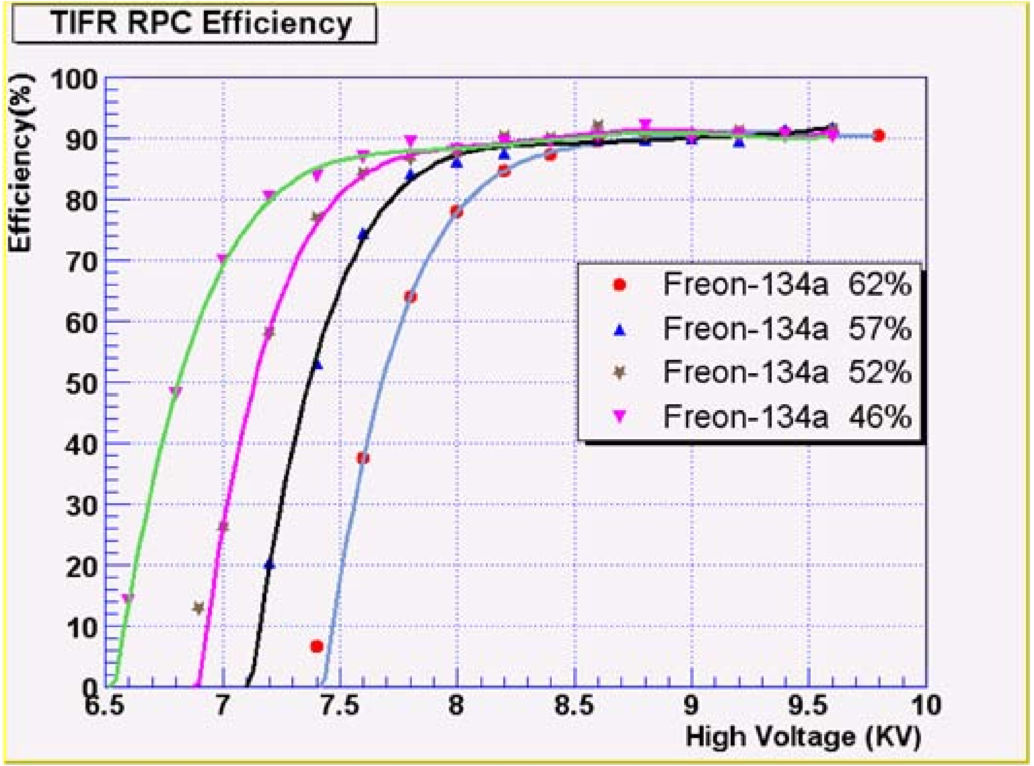


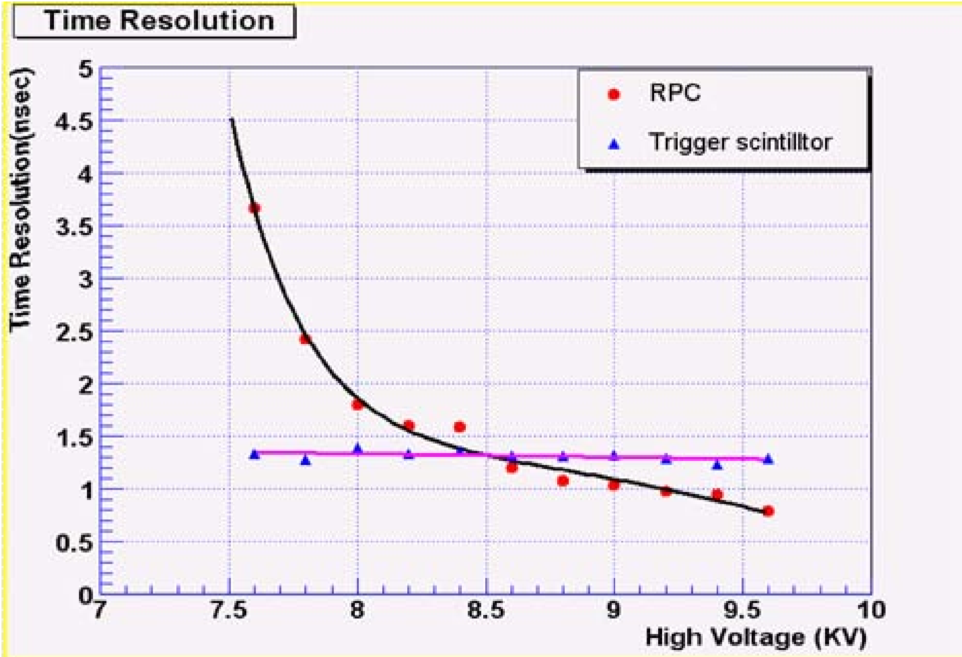
Complete RPC

Test of RPCs



RPC Efficiency & timing Studies





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.

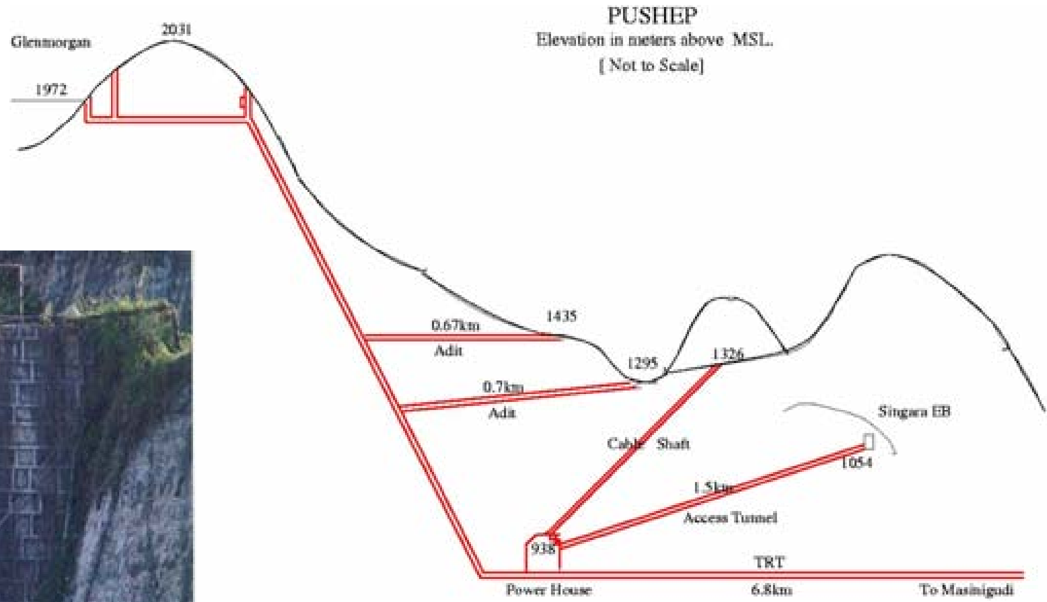
These studies are going on at all the collaborating institutes

Possible INO sites

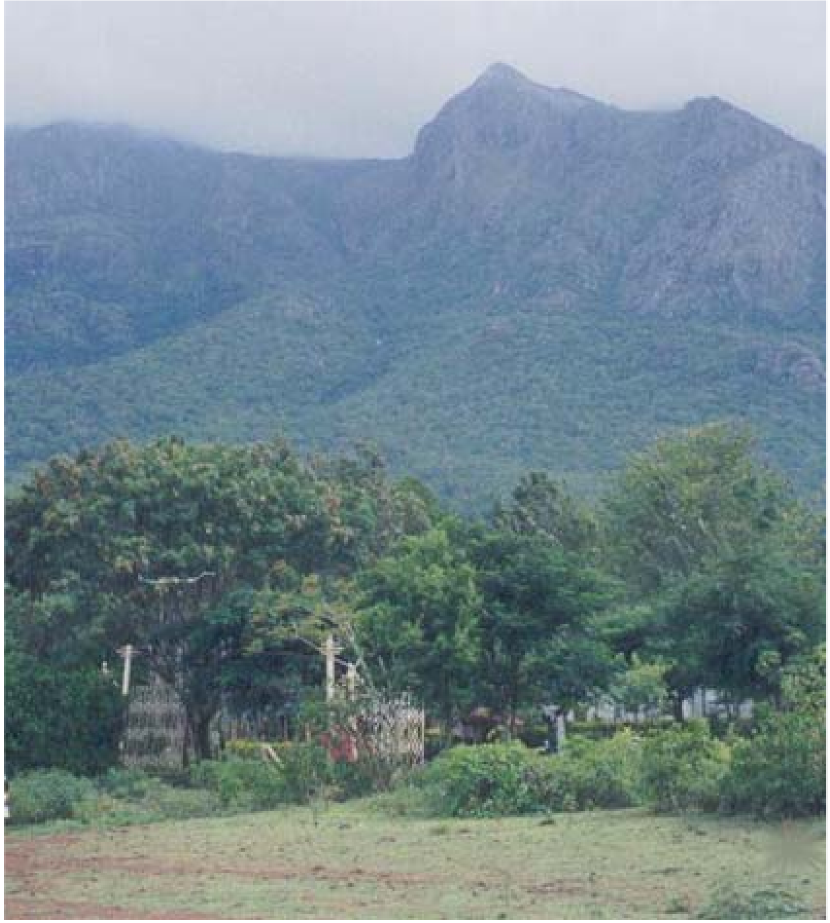
- **PUSHEP (Pykara Ultimate Stage Hydro Electric Project) in South India**

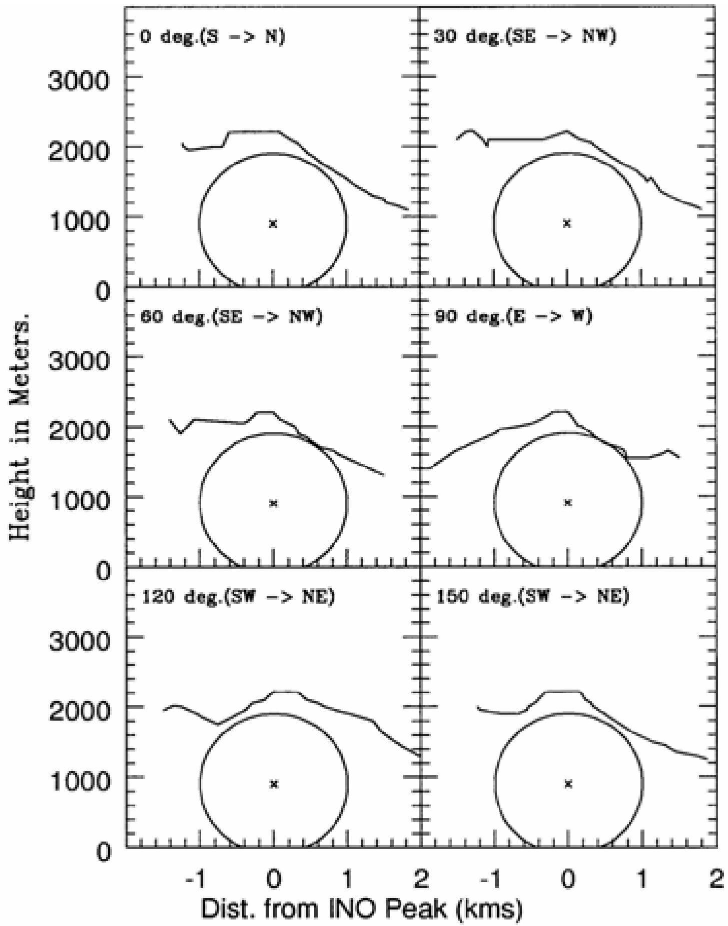
  or

- **RAMMAM Hydro Electric Project Site**

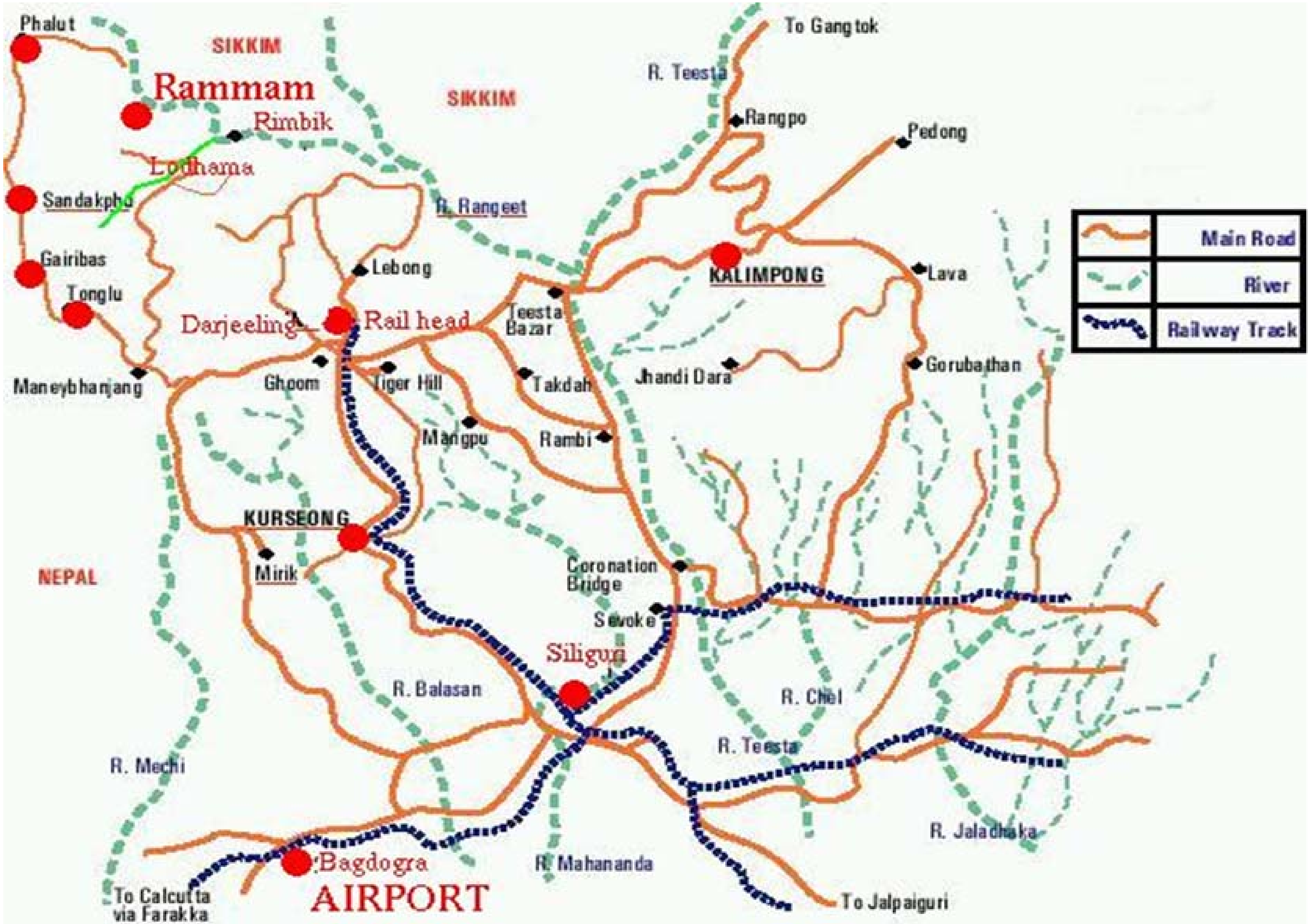


PUSHEP

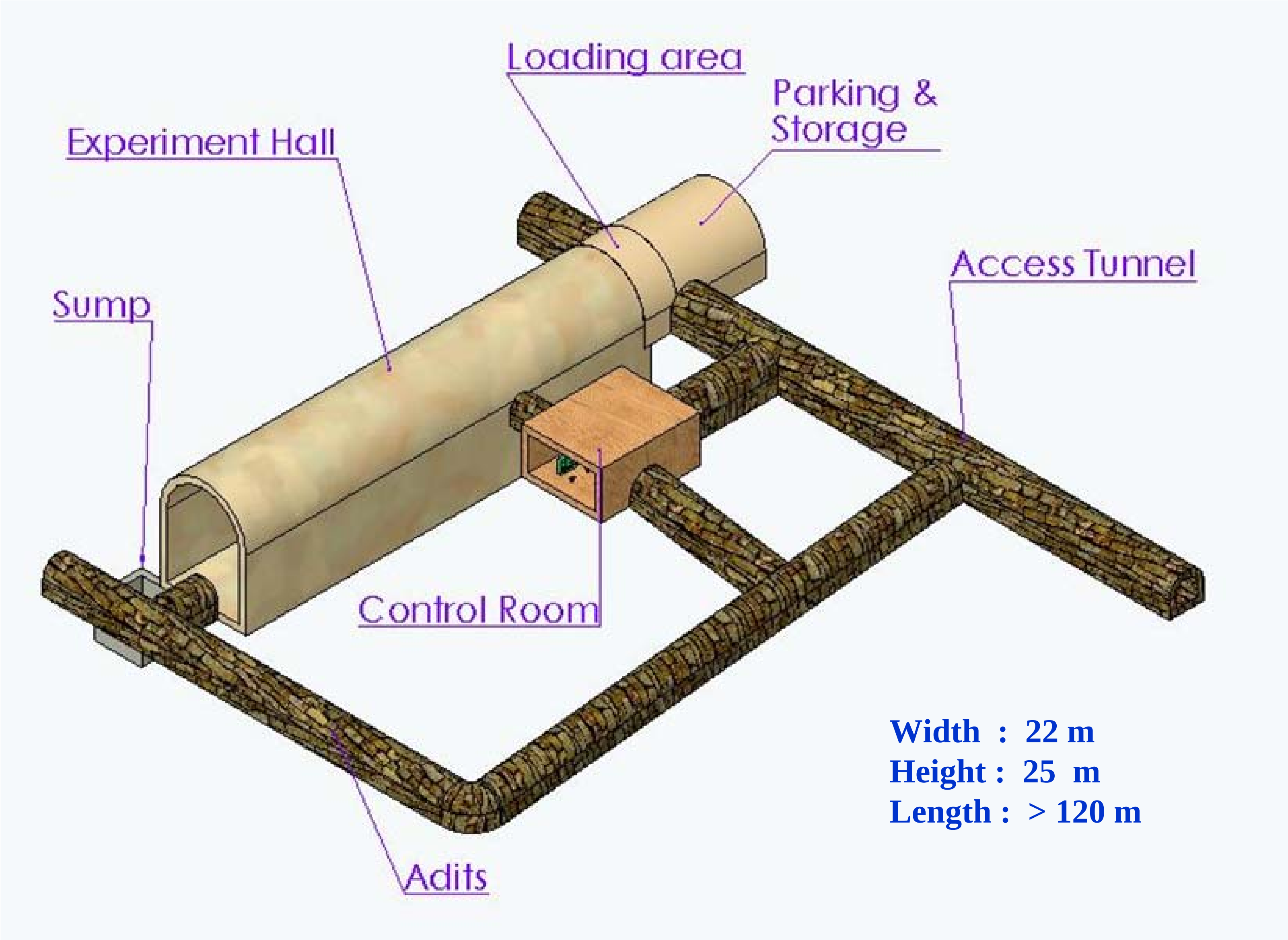



0 deg.(S -> N)
30 deg.(SE -> NW)
60 deg.(SE -> NW)
90 deg.(E -> W)
120 deg.(SW -> NE)
150 deg.(SW -> NE)
Height in Meters.
0
1000
2000
3000
-1
0
1
2
Dist. from INO Peak (kms)

Location of Rammam



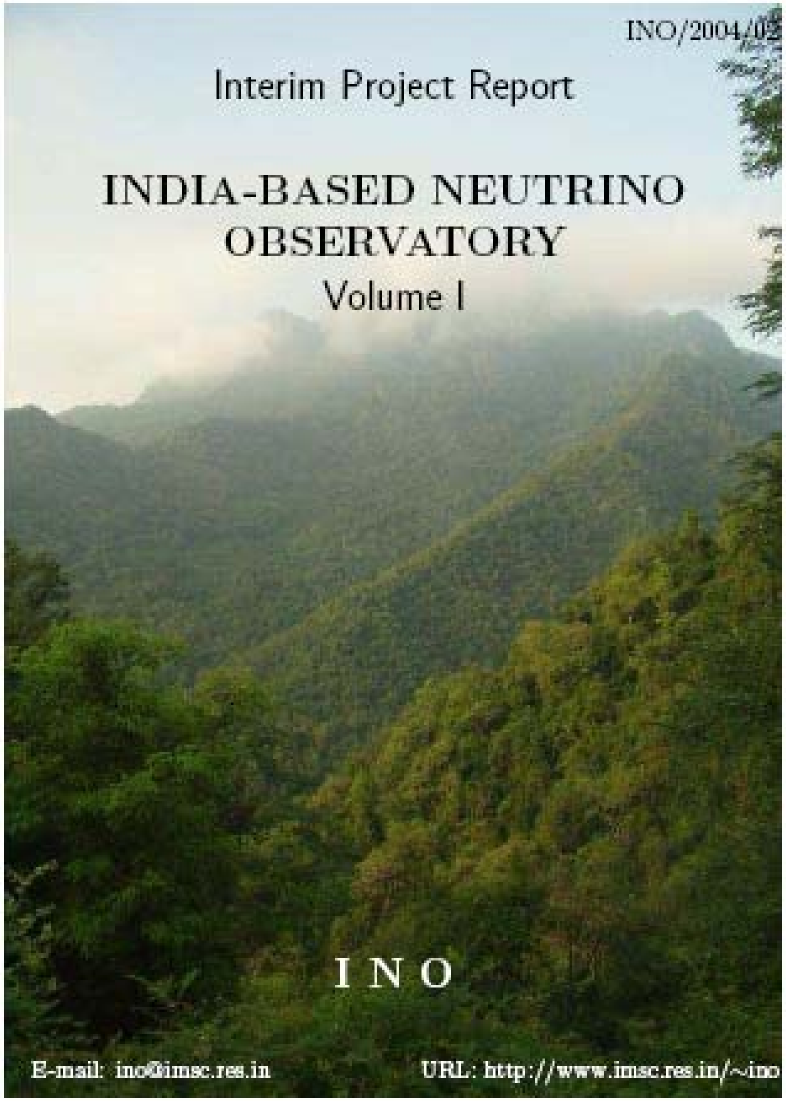
Underground Cavern



Width : 22 m
Height : 25 m
Length : > 120 m

Interim Report

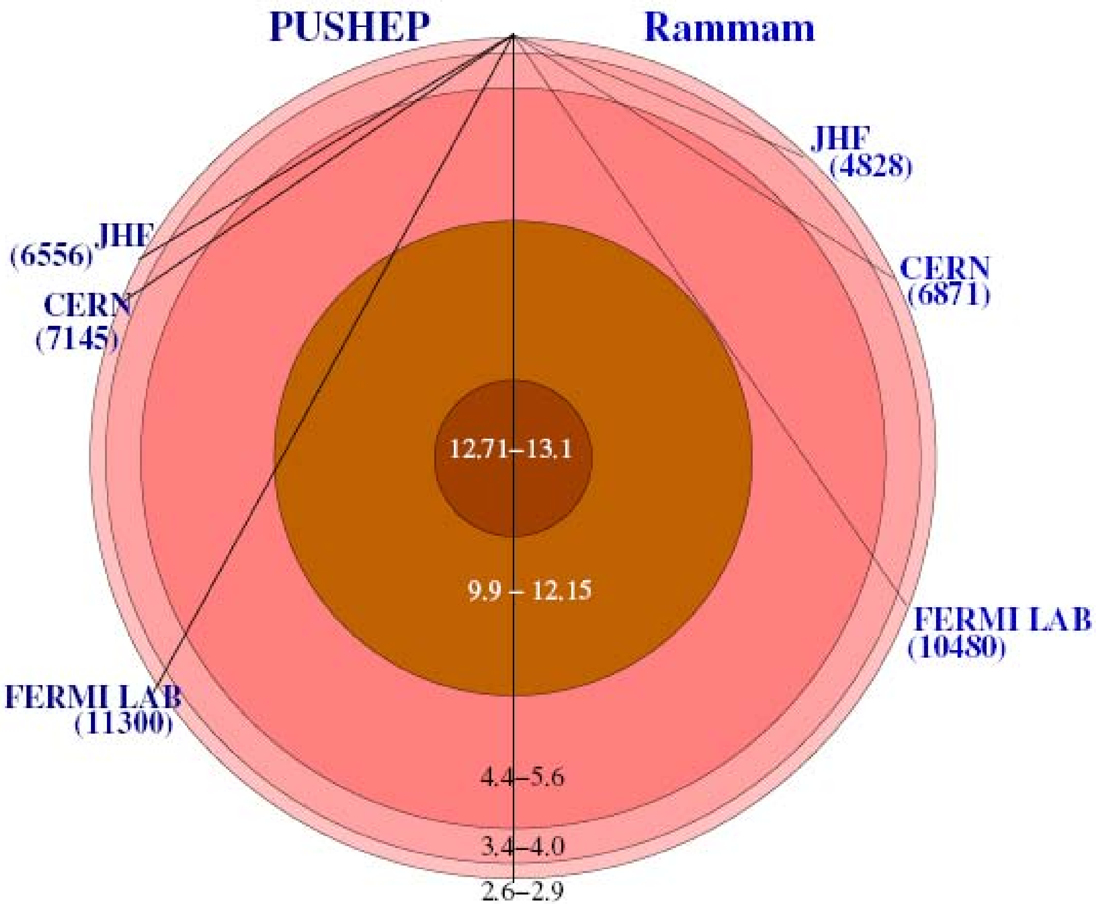
Will submit the INO Interim Project Report
To Indian funding agencies on 1 May, 2005



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

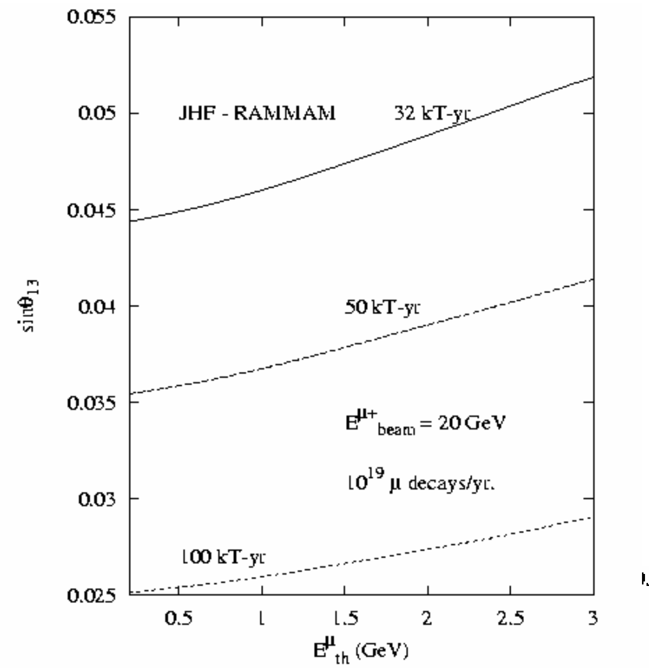


Physics withNeutrinos from Beam

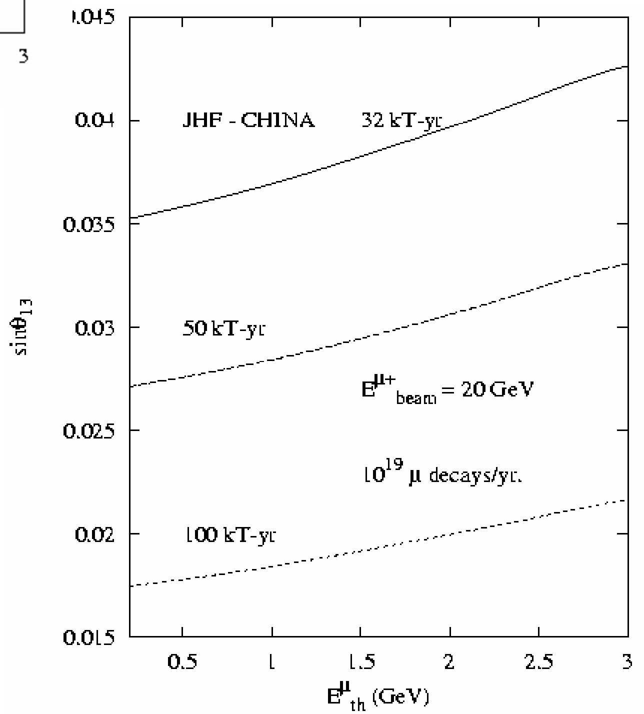
Physics with A Fe Calorimeter and a Neutrino Factory Beam

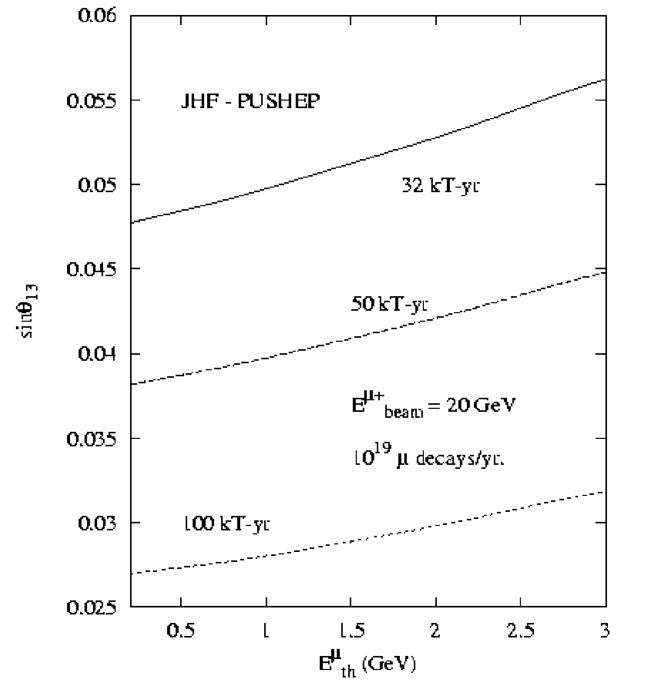
- Reach and measure of $sin^2 2\theta_{13}$
- The sign of Δm^2_{32}
- Determining if CP violation is present in the leptonic sector

Measure of $\sin\theta_{13}$



Δm^2_{23}





Sign of $\Delta m^2{}_{23}$