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 ν 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:**
  - **Physics Letters 18, (1965) 196, dated 15th Aug 1965 .**
  - **Events were recorded on 30th March, 27th April, and 25th May, 1965.**
- Reines et al. reported observation of 7 events in:
  - PRL 15, (1965), 429, dated 30th Aug. 1965.
  - 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 1st Atmospheric ν 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

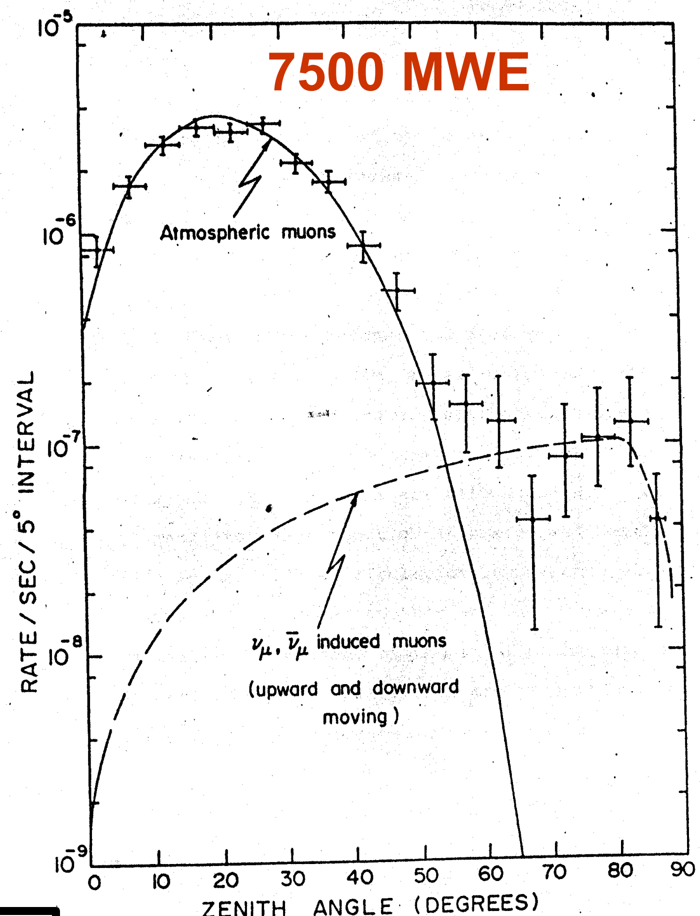
K. HINOTANI and S. MIYAKE,
Osaka City University, Osaka, Japan

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

Received 12 July 1965

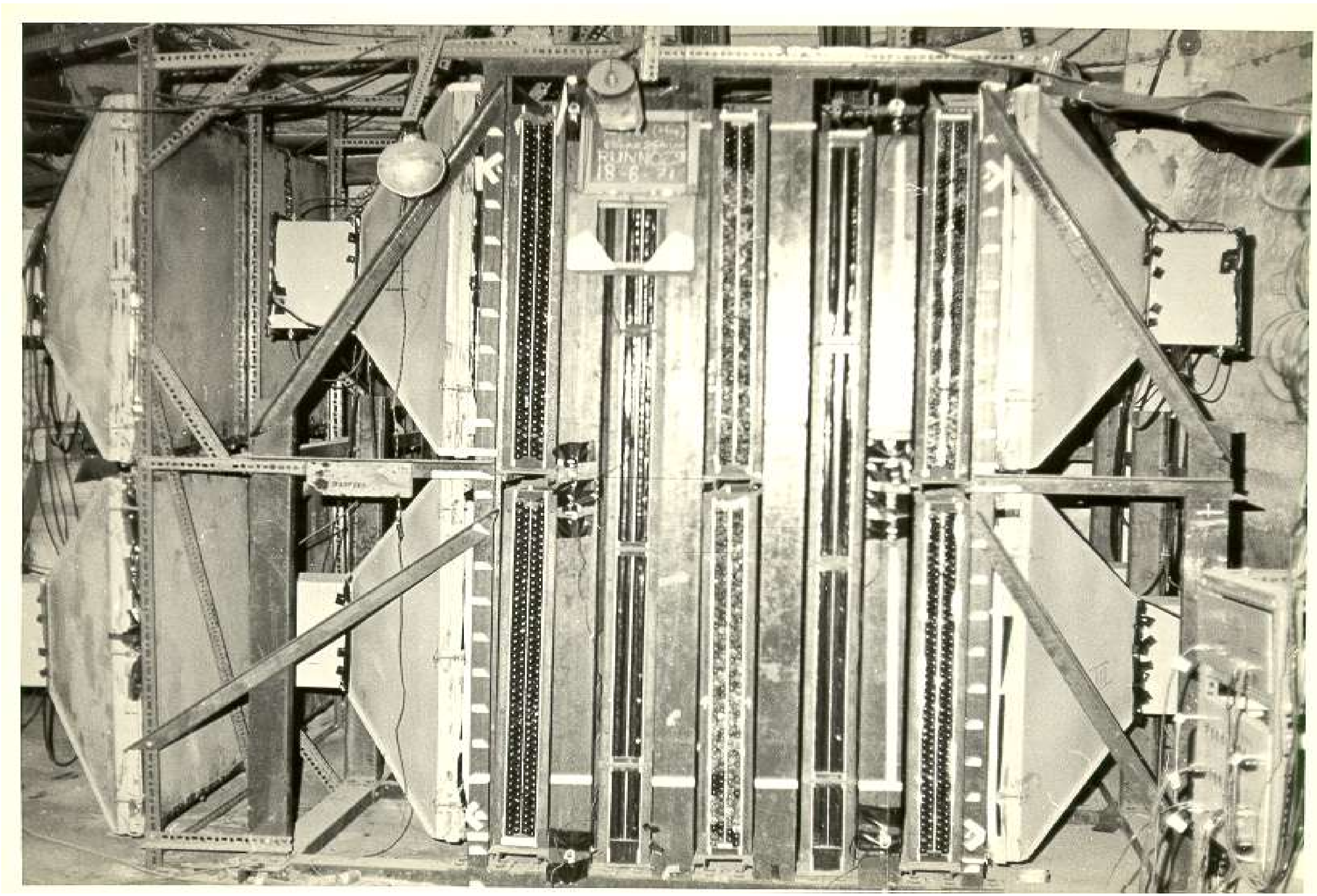
Table 1

Event number	Type of coincidence	Projected zenith angle	Date	Time
1	TEL. 2 $N_4 + S_4$	37°	30.3	20.04
2	TEL. 1 $N_1 + S_1$	48 ± 1°	27.4	18.26
3	TEL. 2 $N_6 + S_6$	75 ± 10°	25.5	20.03



50 days of operation ~ 2140 m² days steradian

KOLAR GOLD FIELD DETECTOR - 1965



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

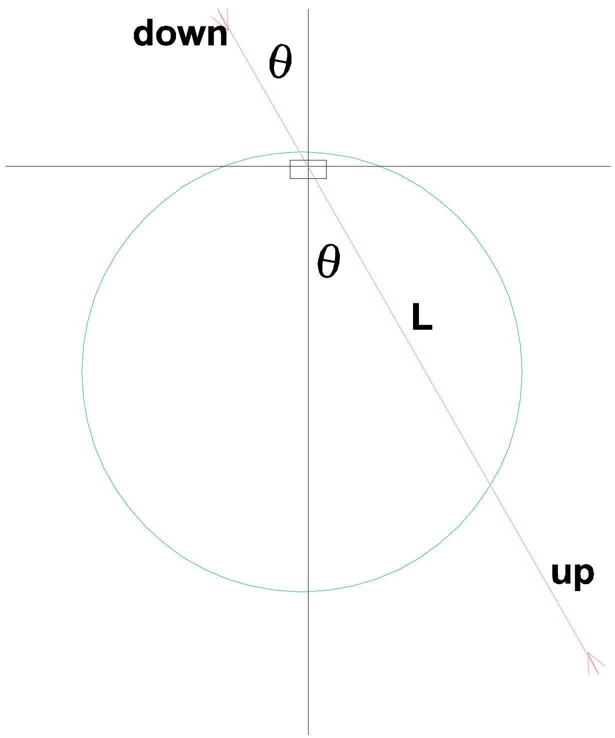
Magnetized Fe-RPC calorimeter, a la MONOLITH.

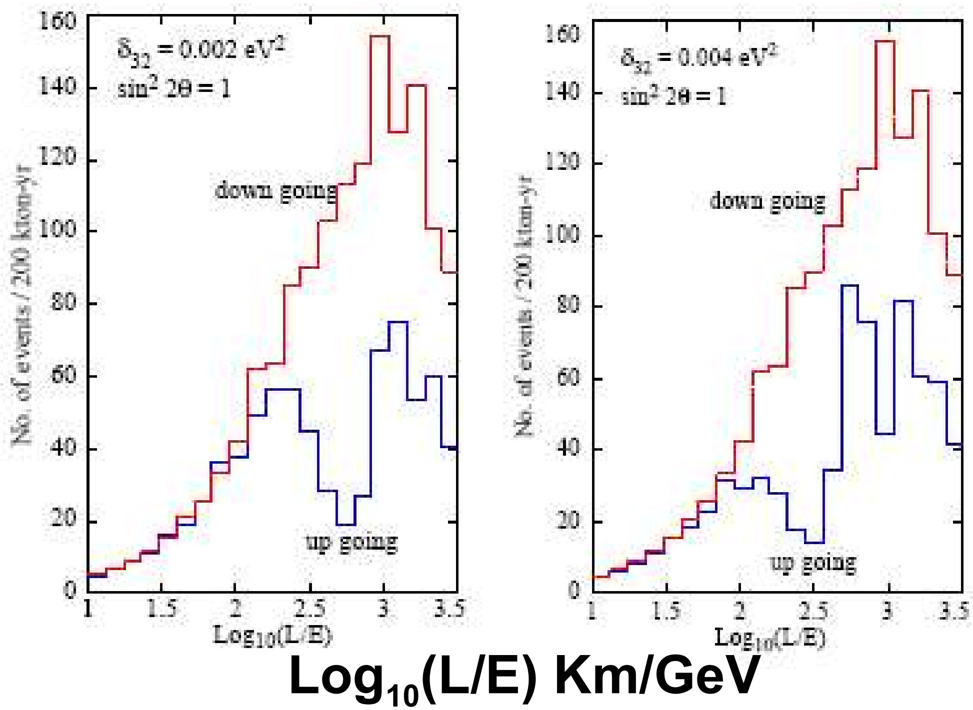
WHAT PHYSICE ONE CAN DO WIT SUCH A DETECTOR?

- **Phase I – Atmospheric neutrino**
  - ✓ Explicit observation of first oscillation swing as a function of L/E
  - ✓ Improved measurement of Δm^2_{23} and $Sin^2 2\theta_{23}$
  - ✓ Search for potential matter effect and sign of Δm^2_{23} from μ^+ & μ^- 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 θ_{13} from $\nu_e \rightarrow \nu_\mu$ oscillations
  - ✓ Sign of Δm^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 Δm^2_{23}
- **Other Physics Possibilities**
  - ✓ Ultra high energy neutrinos and muons

EXPLICIT MEASUREMENT OF L/E

Measure the disappearance probability with a single detector and two equal sources – down-going and up-going muons produced by neutrino interactions

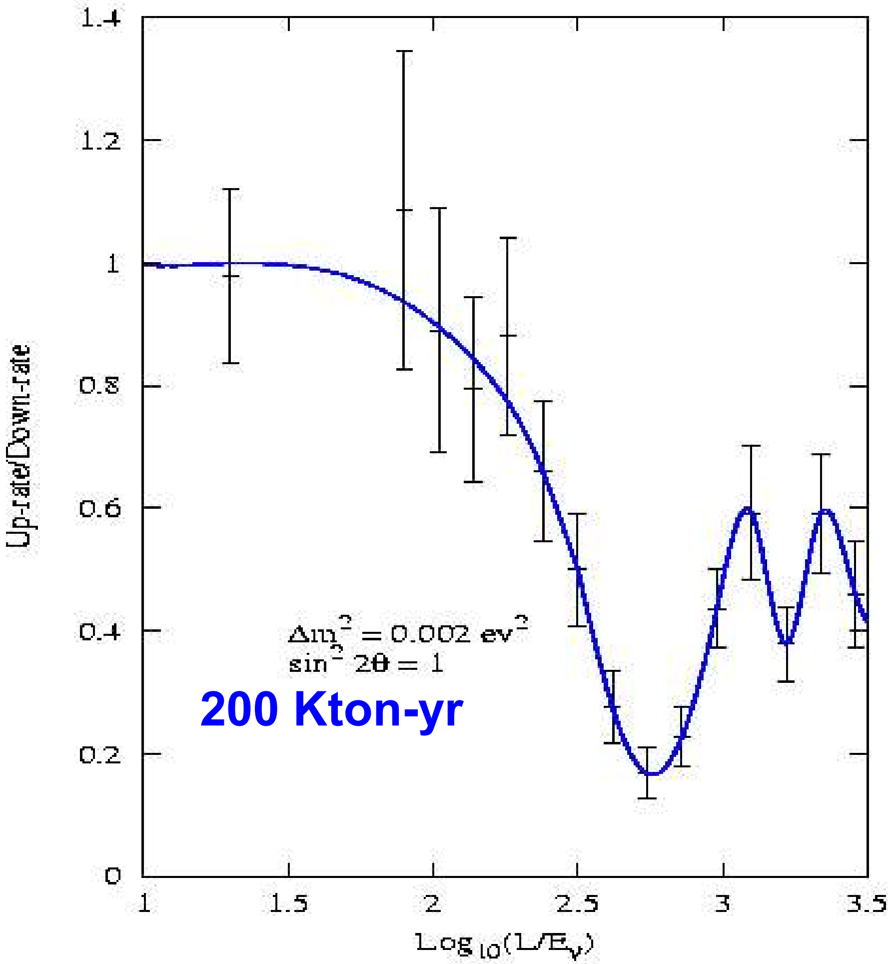


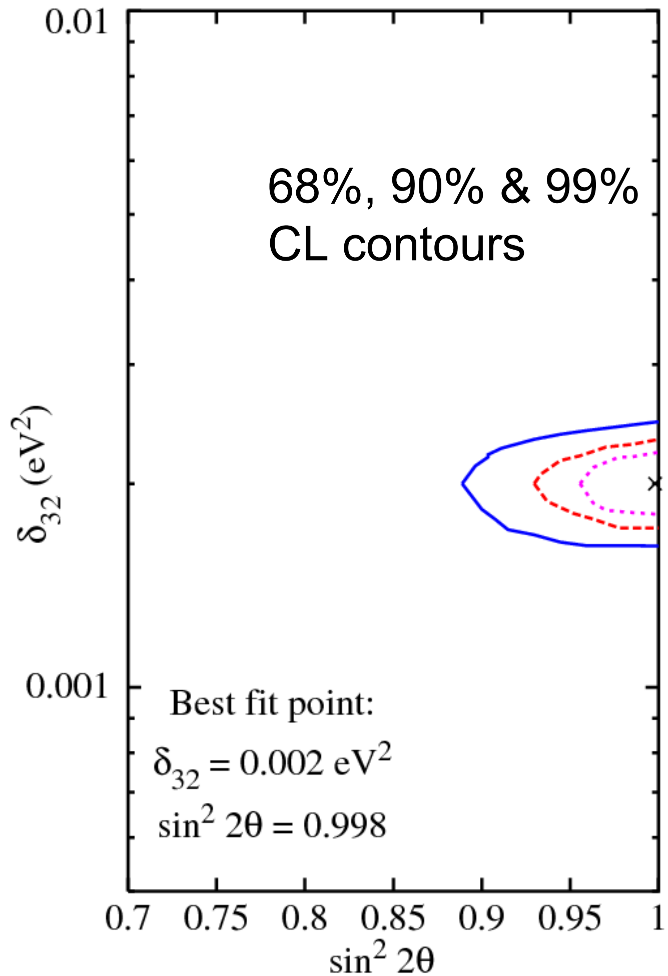


Expect to measure Δm^2_{23} to ~10% and $\text{Sin}^2\theta_{23}$ to ~30% precision at 3σ (total spread around central value)

EXPLICIT MEASUREMENT OF L/E

$$N^{\uparrow}_{\mu}(L/E)/N_{\downarrow}^{\mu}(L/E) = P(\nu_{\mu}\rightarrow\nu_{\mu}\ ;\ L/E) = 1 - \mathrm{Sin}^2(2\theta_{23})\ \mathrm{Sin}^2(1.27\Delta m^2_{23}L/E)$$



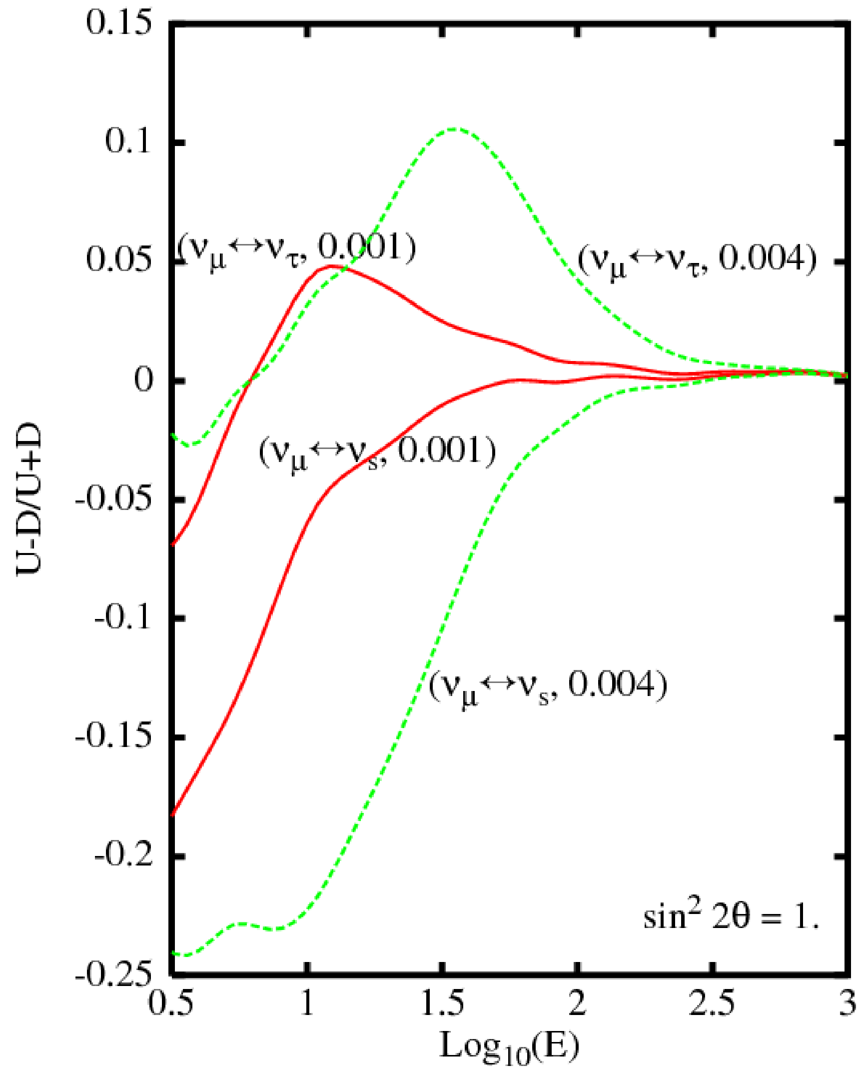


$\nu_\mu \rightarrow \nu_\tau$ vs. $\nu_\mu \rightarrow \nu_s$

$\nu_\mu \rightarrow \nu_\tau$ oscillation will give rise to an excess of NC or muonless event compared to $\nu_\mu \rightarrow \nu_s$ events.

- $\frac{U-D}{U+D}$ **+ ve for $\nu_\mu \rightarrow \nu_\tau$ and**
- $\frac{U-D}{U+D}$ **- ve for $\nu_\mu \rightarrow \nu_s$**

$\Delta m^2_{23} = 4\text{X}10^{-3}\ \text{eV}^2$ (green line)
$\Delta m^2_{23} = 1\text{X}10^{-3}\ \text{eV}^2$ (red line)



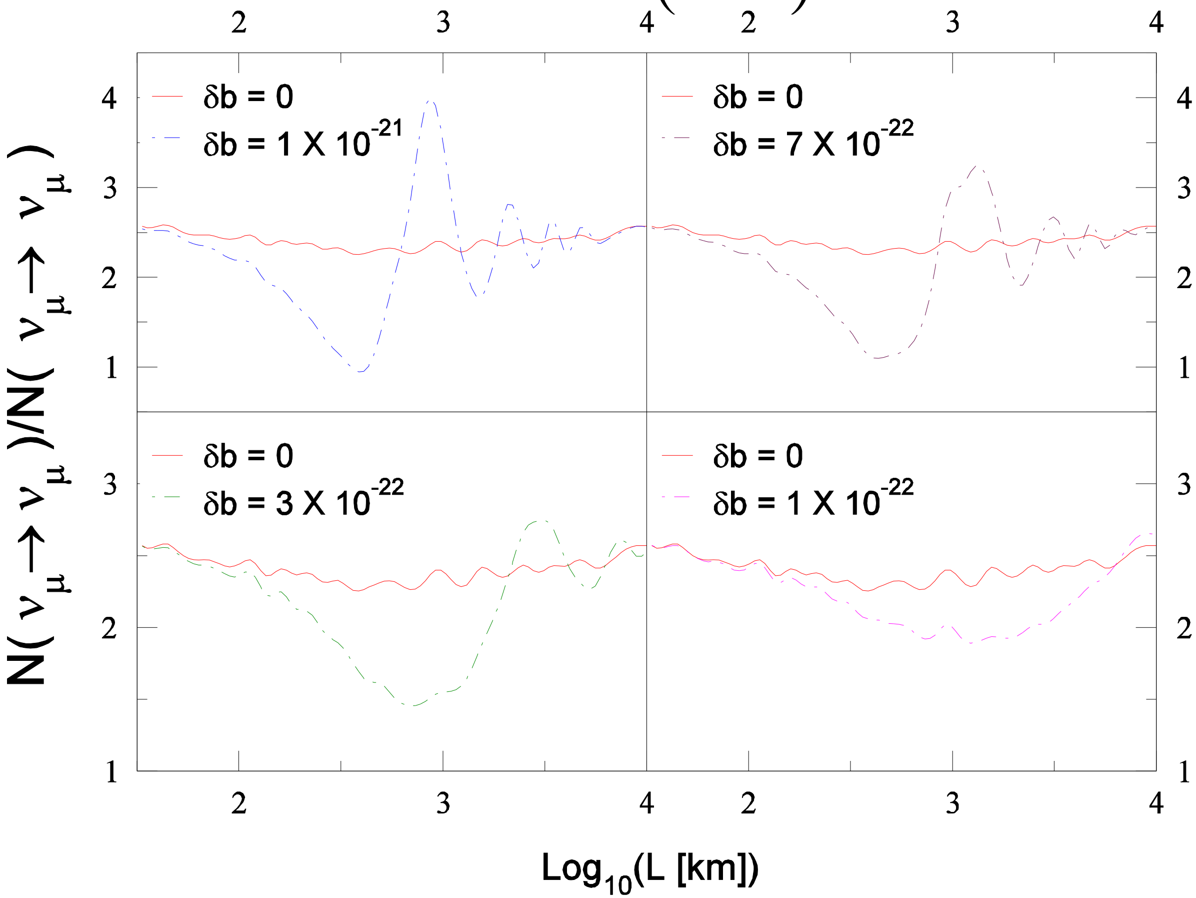
CPT VIOLATION

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

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

R. Gandhi et al.,

Phys. Lett. B597, 356 (2004)



Plots for values

$\Delta m^2_{23} = 0.002\ eV^2$

$\sin^2 2\theta_{23} = 1.0$

MATTER EFFECT & SIGN OF Δm^2_{23}

NEXT TALK - TO BE GIVEN BY

Sankagiri Umasankar

Large matter effects in $\nu_\mu \to \nu_\tau$ 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 ν detector 50-100Kton**
  - **Later use the facility possibly for:**
    - **Low energy Neutrinos (solar ν, reactor ν, supernova ν, β decay, 0νββ decay, global radioactivity in earth, nucleon decay etc. etc.)**
    - **Neutrino Astronomy (cosmic ray composition, UHE ν astronomy)**
    - **Low Energy Accelerator for nuclear astrophysics**

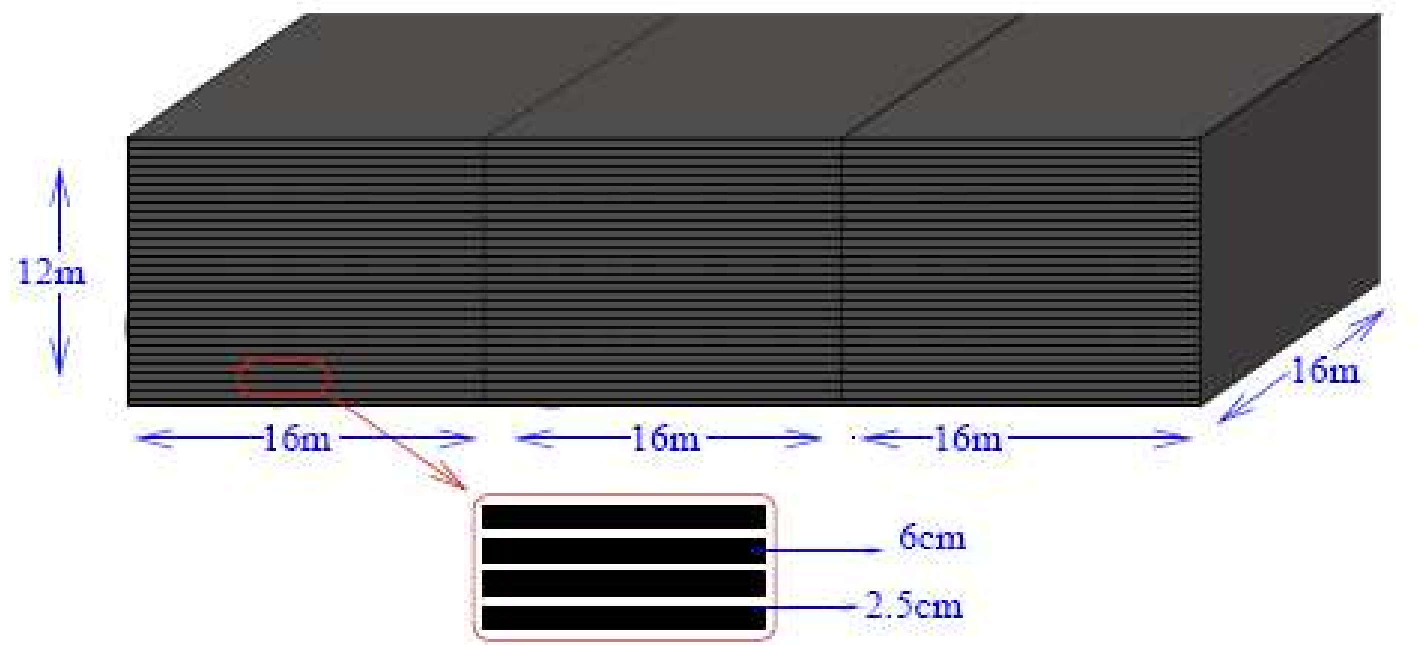
International community is most welcome and we invite them to join the effort in this program – INO needs more experimentalists.

CURRENT ACTIVITIES

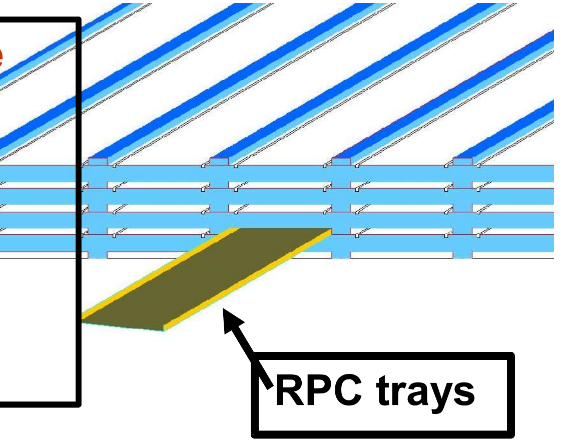
- **Detector Development**
- **Detector Simulation**
- **Physics Studies**
- **Data Acquisition System**
- **Site Survey**
- **International Collaboration**

INO DETECTOR – INITIAL DESIGN CONCEPT

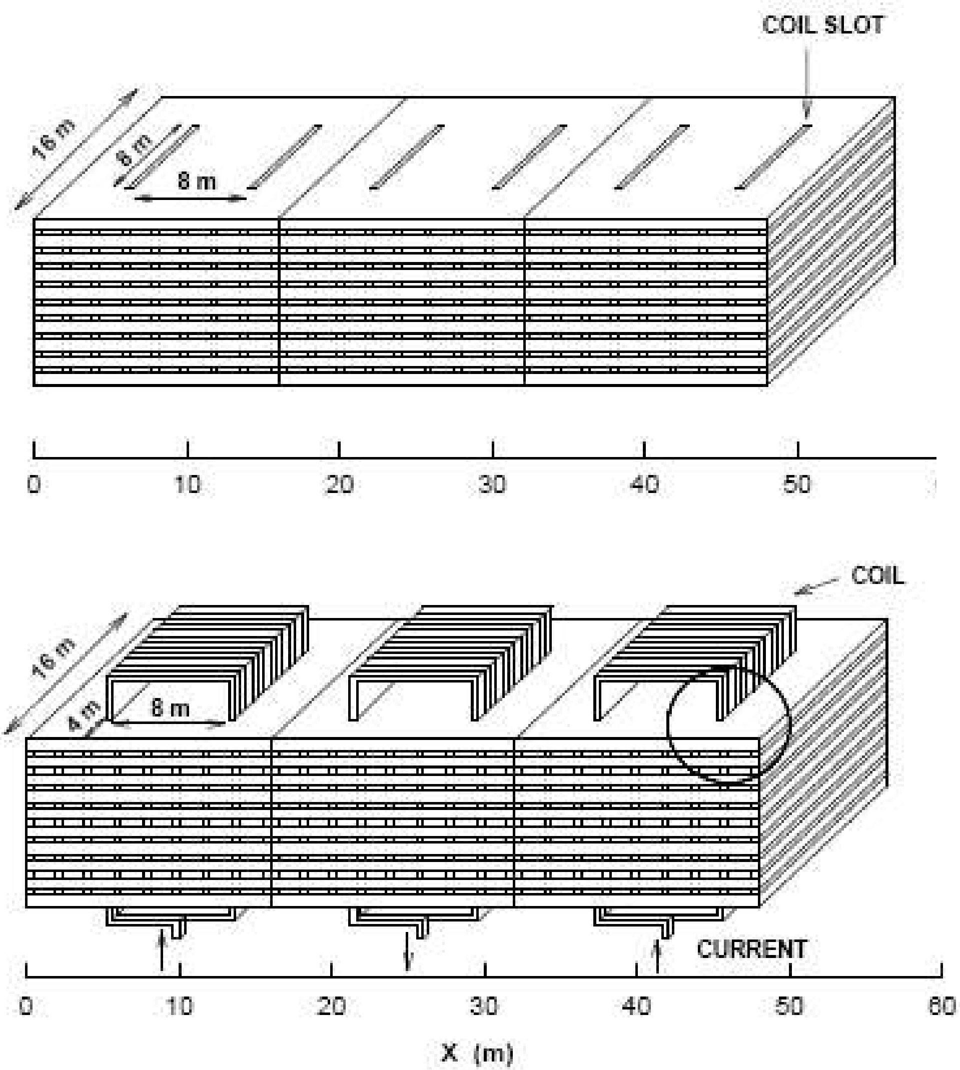
Magnetized Fe with RPCs (50 KTon with ~1.3T magnetic Field)

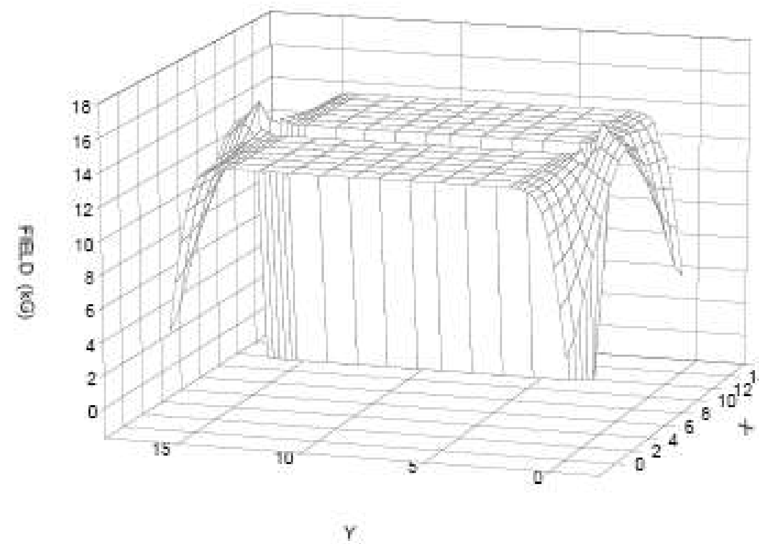


- ✓3 Modules of 16m X 16m X 12m each – 140 Layers/module
- ✓Each layer - 6cm thick Fe + RPC in 2.5cm Gap
- ✓Each RPC of size 2m X 2m – 27000 RPC's needed
- ✓Active Detector Area ~ 108,000 m^2
- ✓Magnetic Field ~ 1.3 Tesla



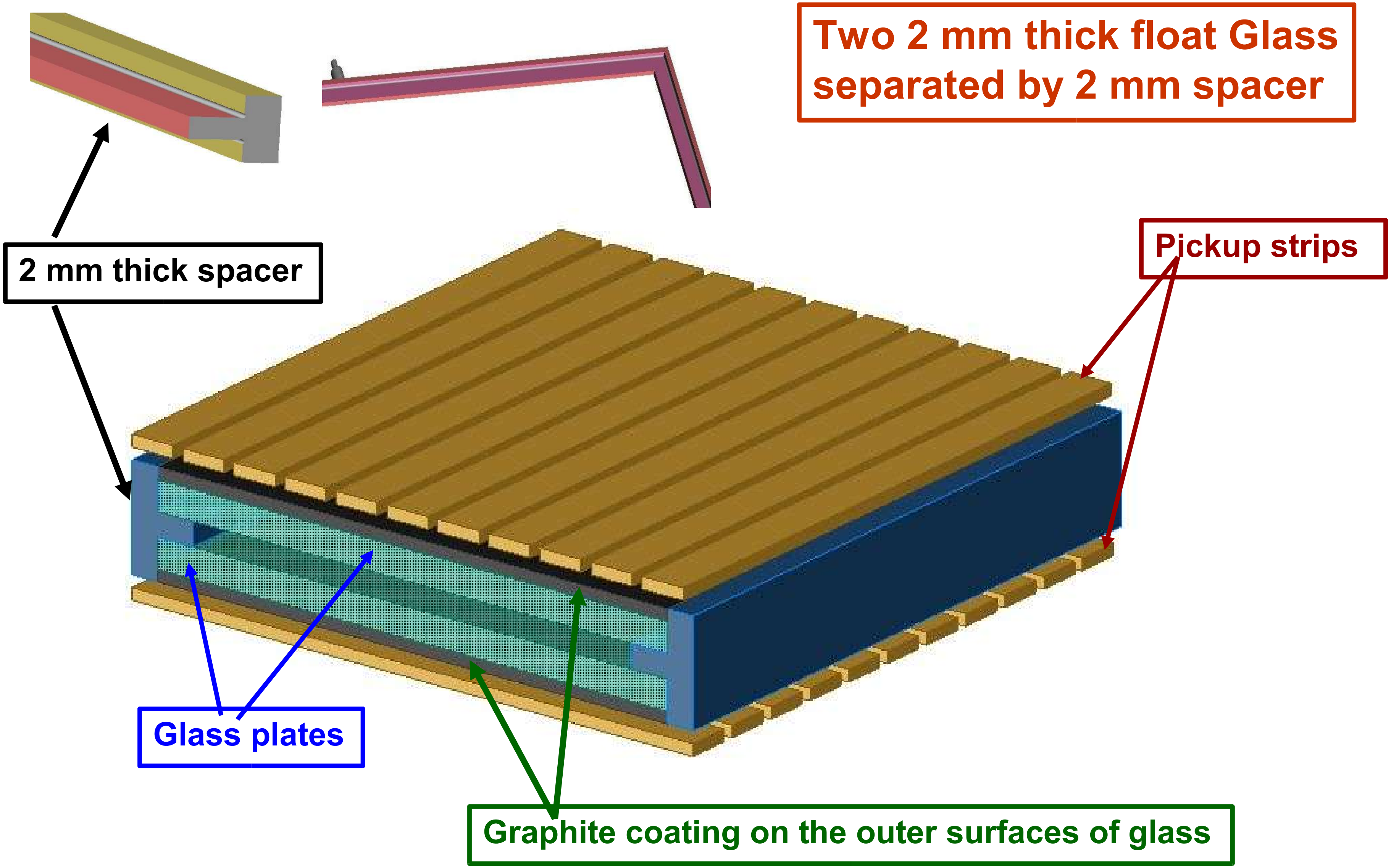
INO DETECTOR – INITIAL DESIGN CONCEPT



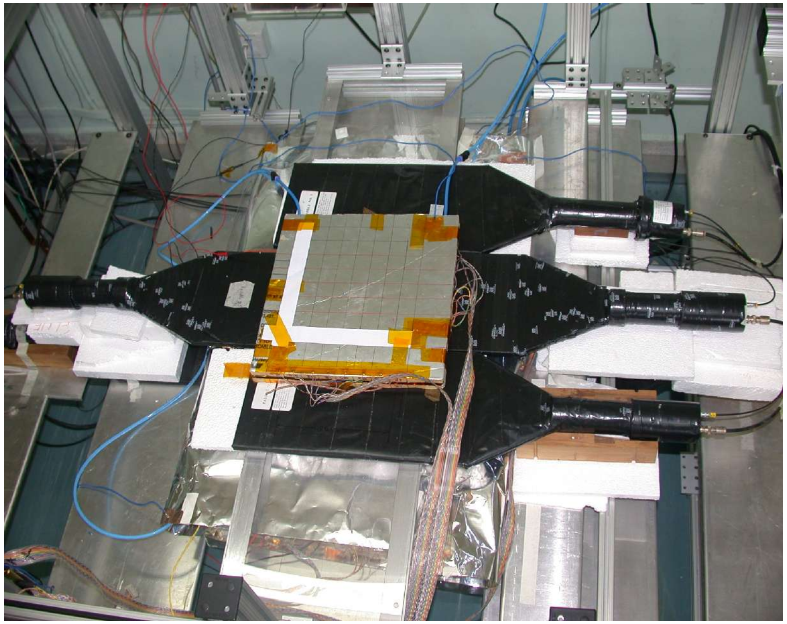


Magnetic field in a horizontal plane inside an Fe plate

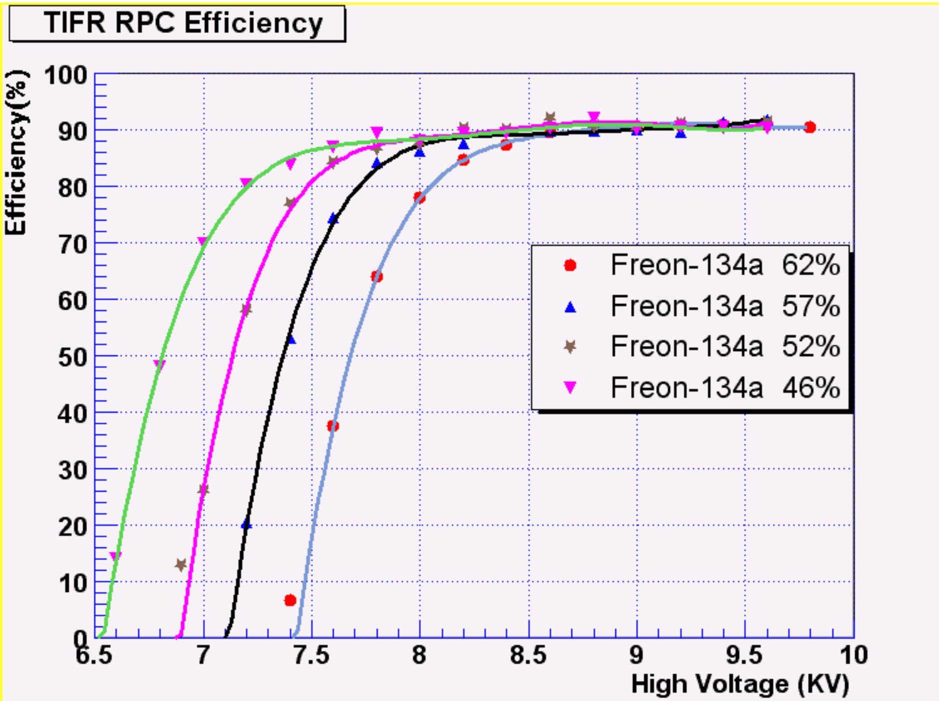
CONSTRUCTION OF A COMPLETE RPC



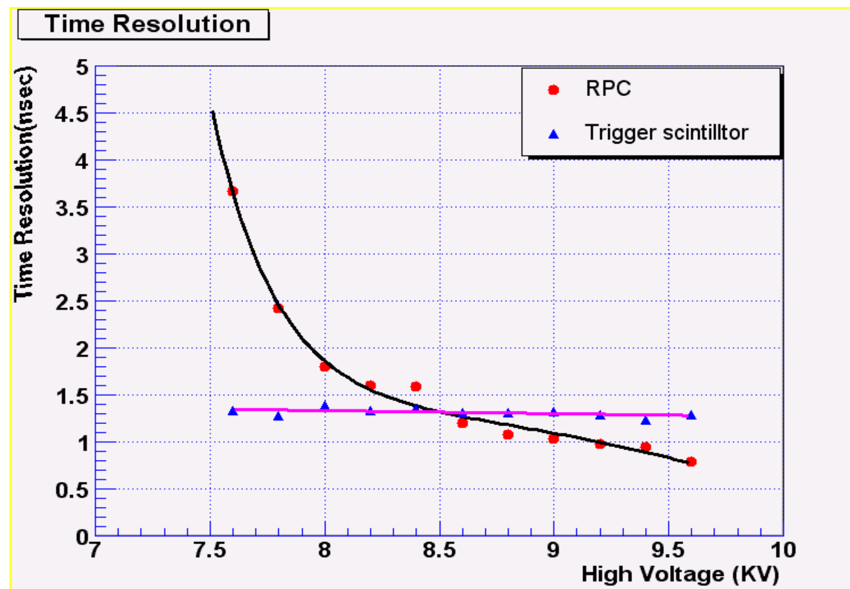
TEST OF RPC AT TIFR, MUMBAI & SINP, KOLKATTA



RPC EFFICIENCY AND TIMING RESOLUTION



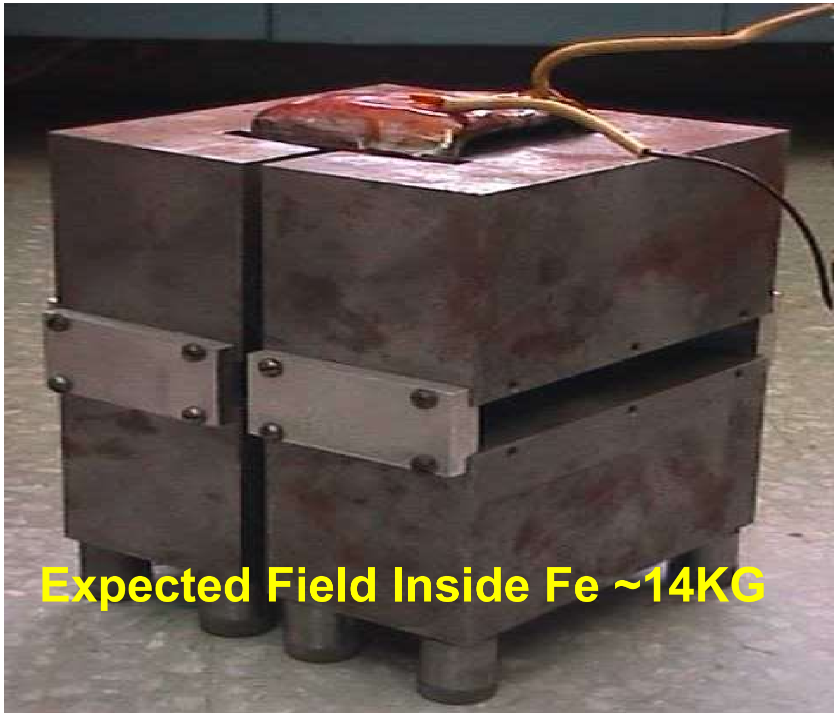
Typical timing resolution (σ) as a function of applied voltage

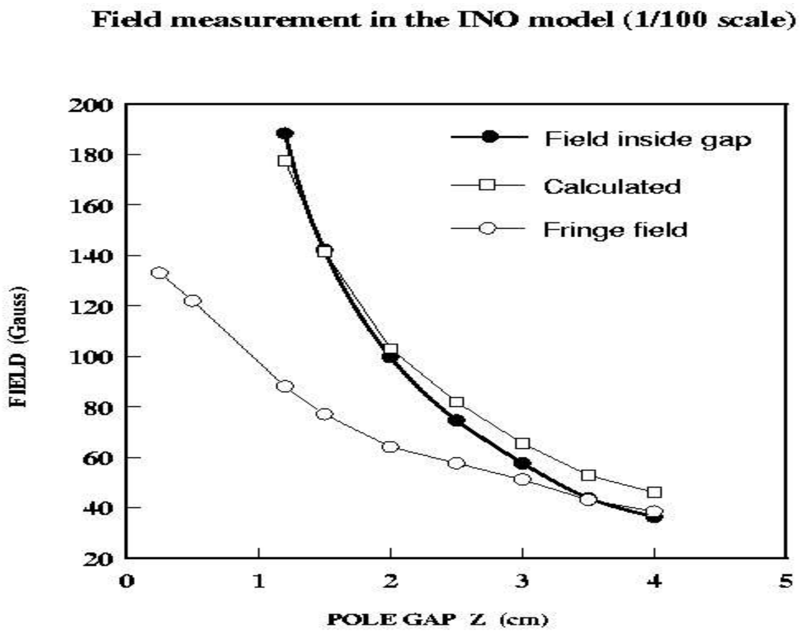


Efficiency ≥ 90% for HV ≥ 8.5 kV for all possible gas mixtures

MODEL MAGNET TEST DESIGN

- 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





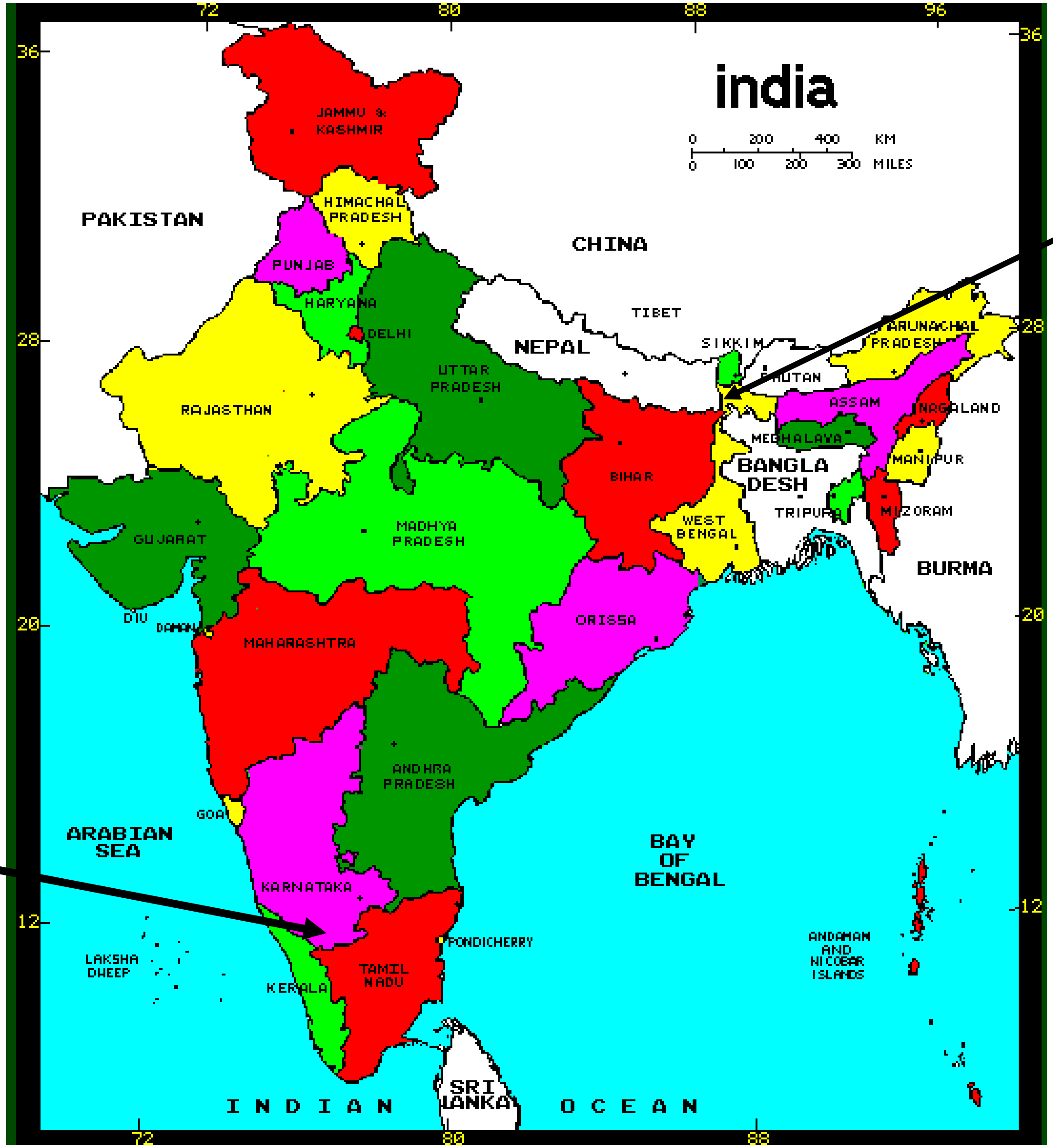
Calculated and measured field within the gap of the 1:100 prototype

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



Rammam

Lat. N 27.4^0

Long. E 88.1^0

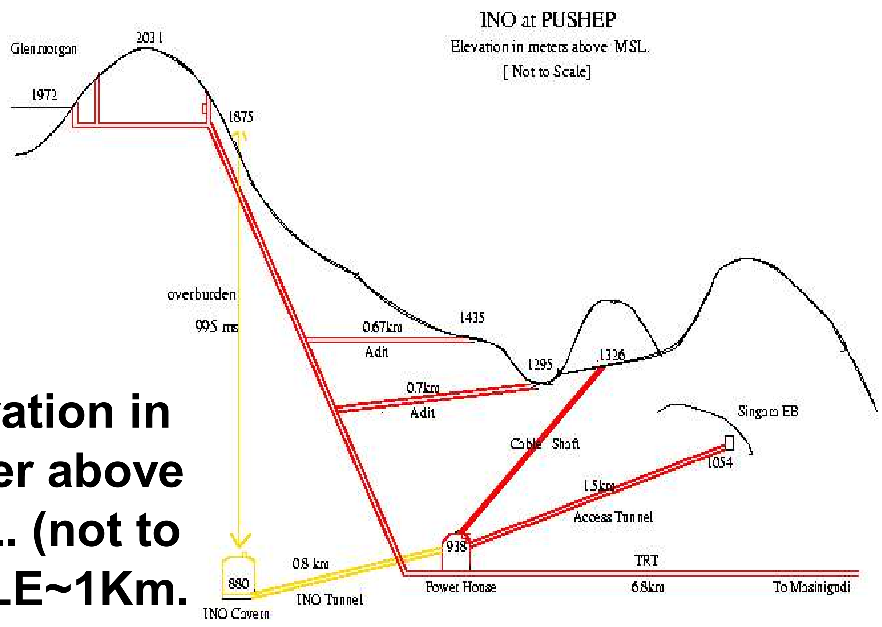
PUSHEP

Lat. N 11.5^0

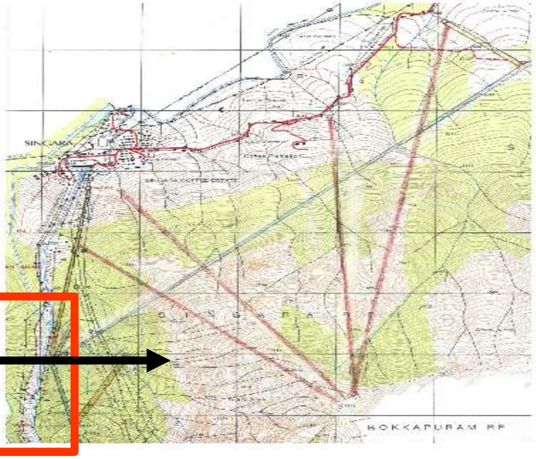
Long. E 76.6^0

PUSHEP

PUSHEP (Pykara Ultimate Stage Hydro Electric Project) in South India, near BANGALORE

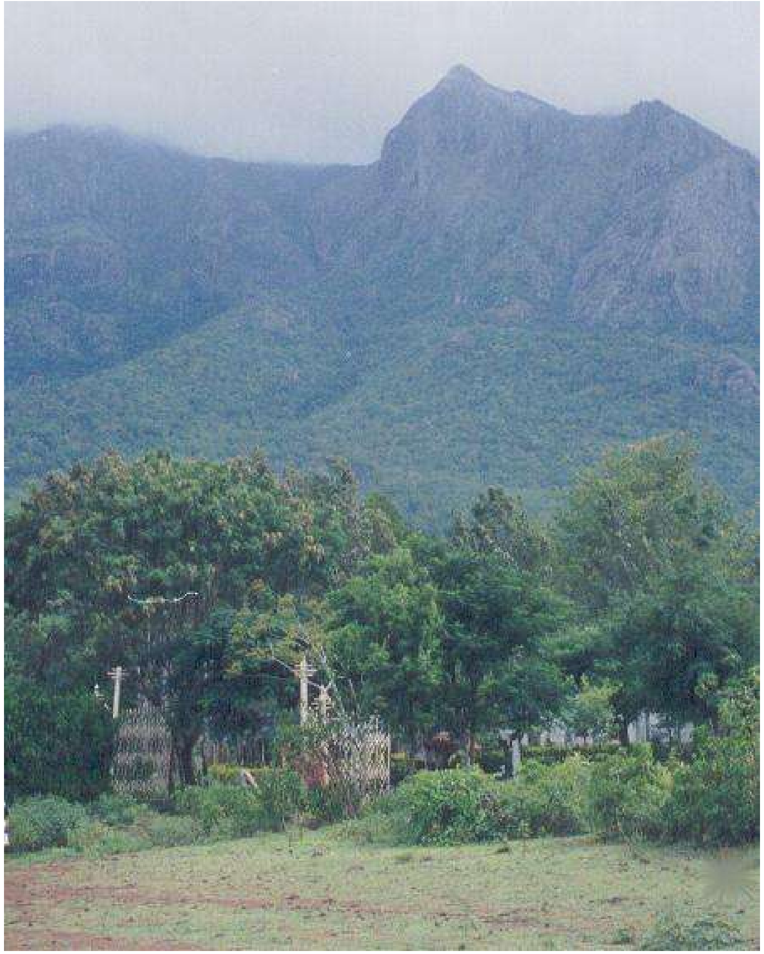


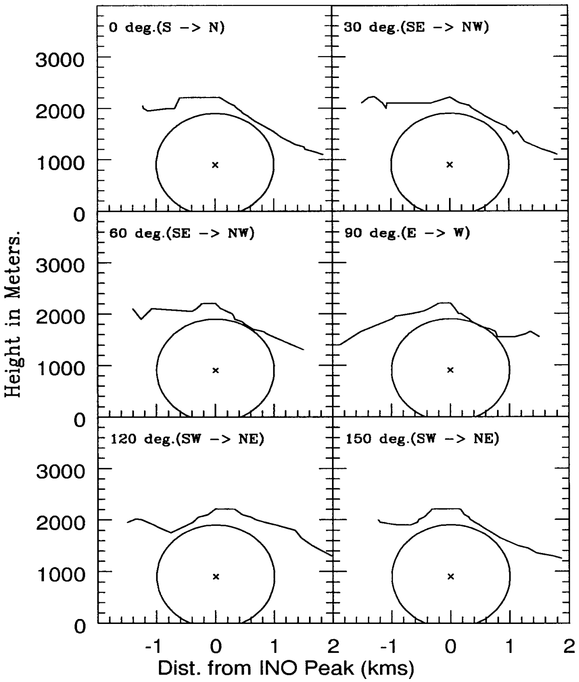
Elevation in meter above MSL. (not to scaLE~1Km.



4 possible alignment of INO tunnel at PUSHEP

PUSHEP





- **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

ITEM	Cost at PUSHEP in millions of USD	Cost at Rammam in millions of USD
Tunnel and cavern excavation	8	19.3
Civil work surface and underground[1]	8	8
Facilities in the cavern[2]	4.5	4.5
TOTAL	**~$21M**	**~$32M**

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)

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

TOTAL COST FOR A 50KTon 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.

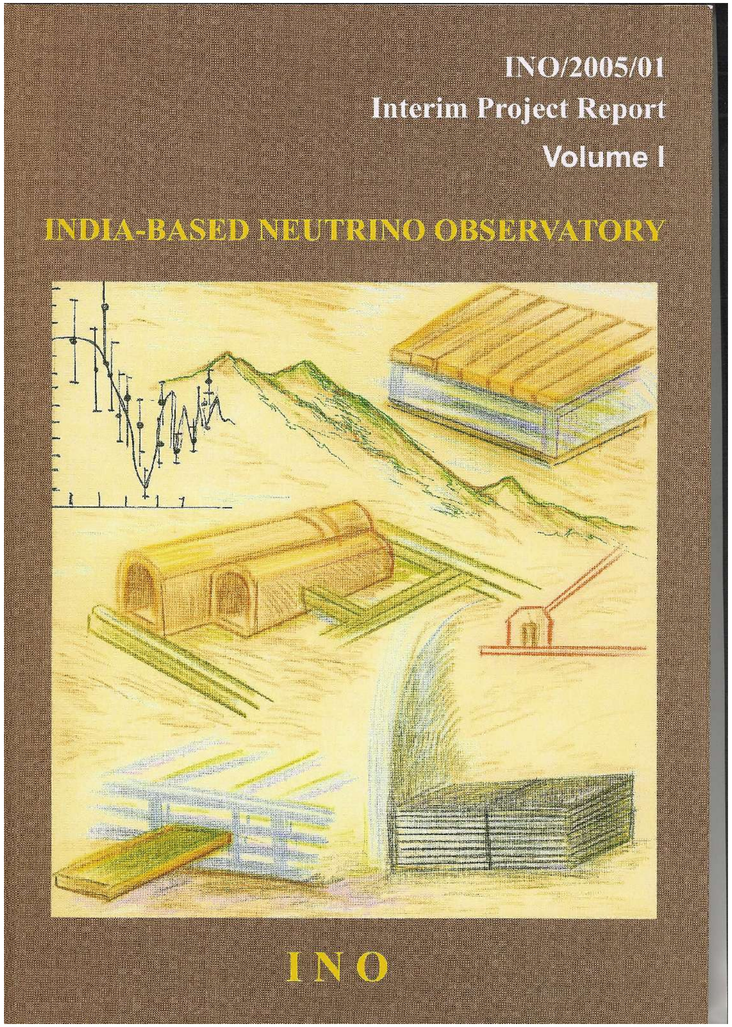
c. Phase III – 12 to 18 months

1. Laboratory outfitting, transport of detector components and assembly.
2. The first module may be completed early and the data taking may begin

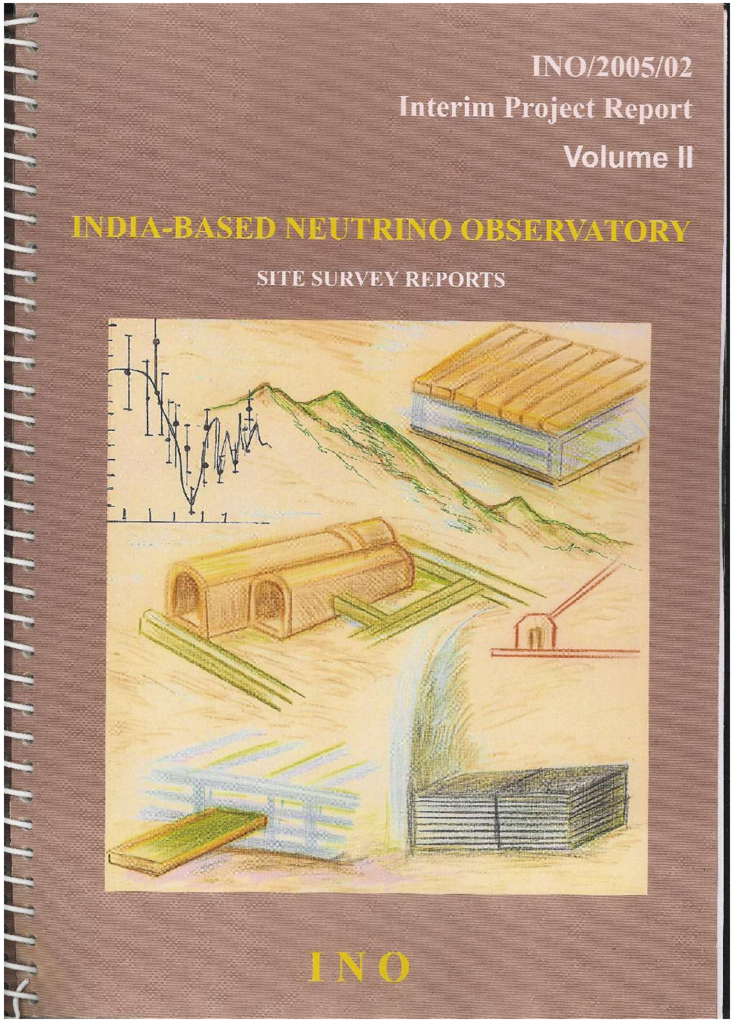
ONE CAN EXPECT TO COLLECT DATA WITH ATMOSPHERIC NEUTRINOS BY 2010-11

http://www.imsc.ernet.in/~ino/

E-mail: ino@imsc.res.in



Submitted to funding agency on 1st May 2005. To be released soon.

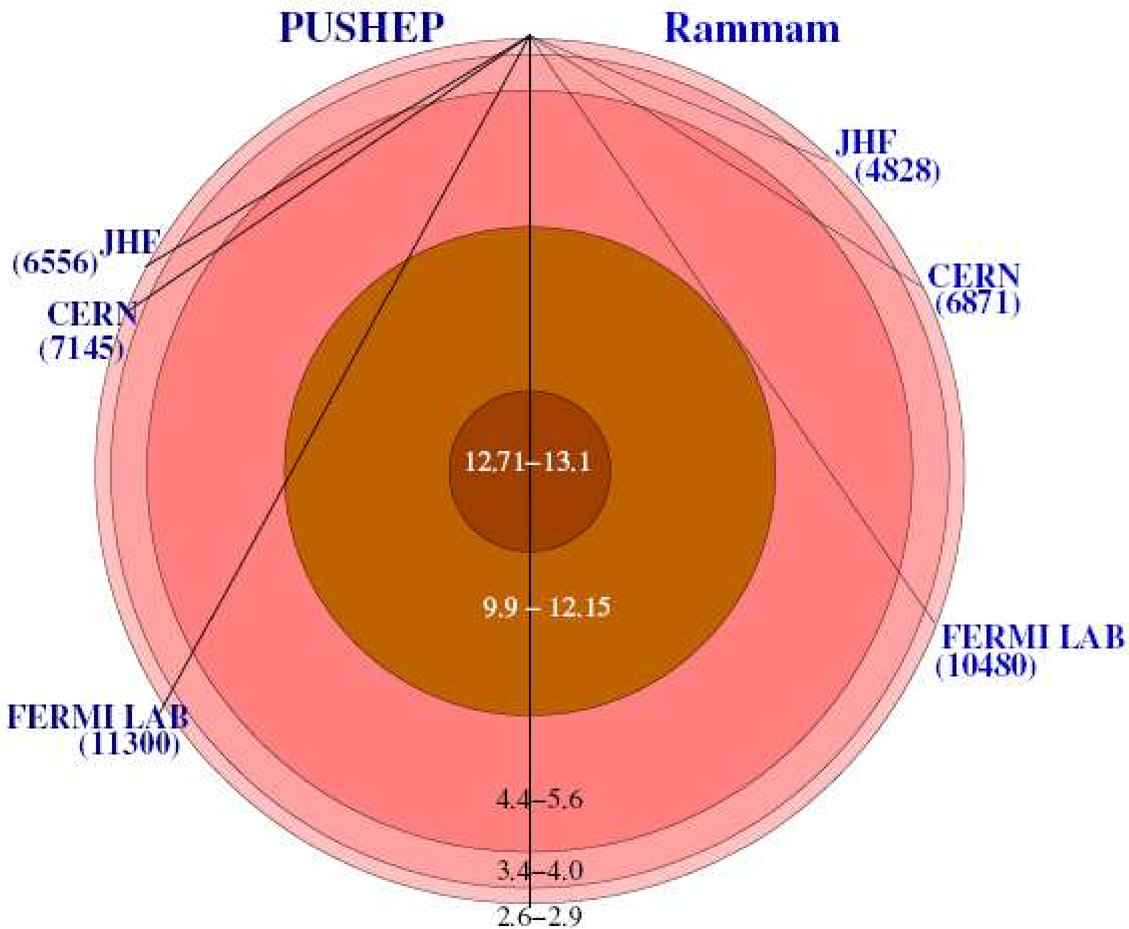


Internal to collaboration only.
Not for public release.

SUMMARY

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 Δm^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.

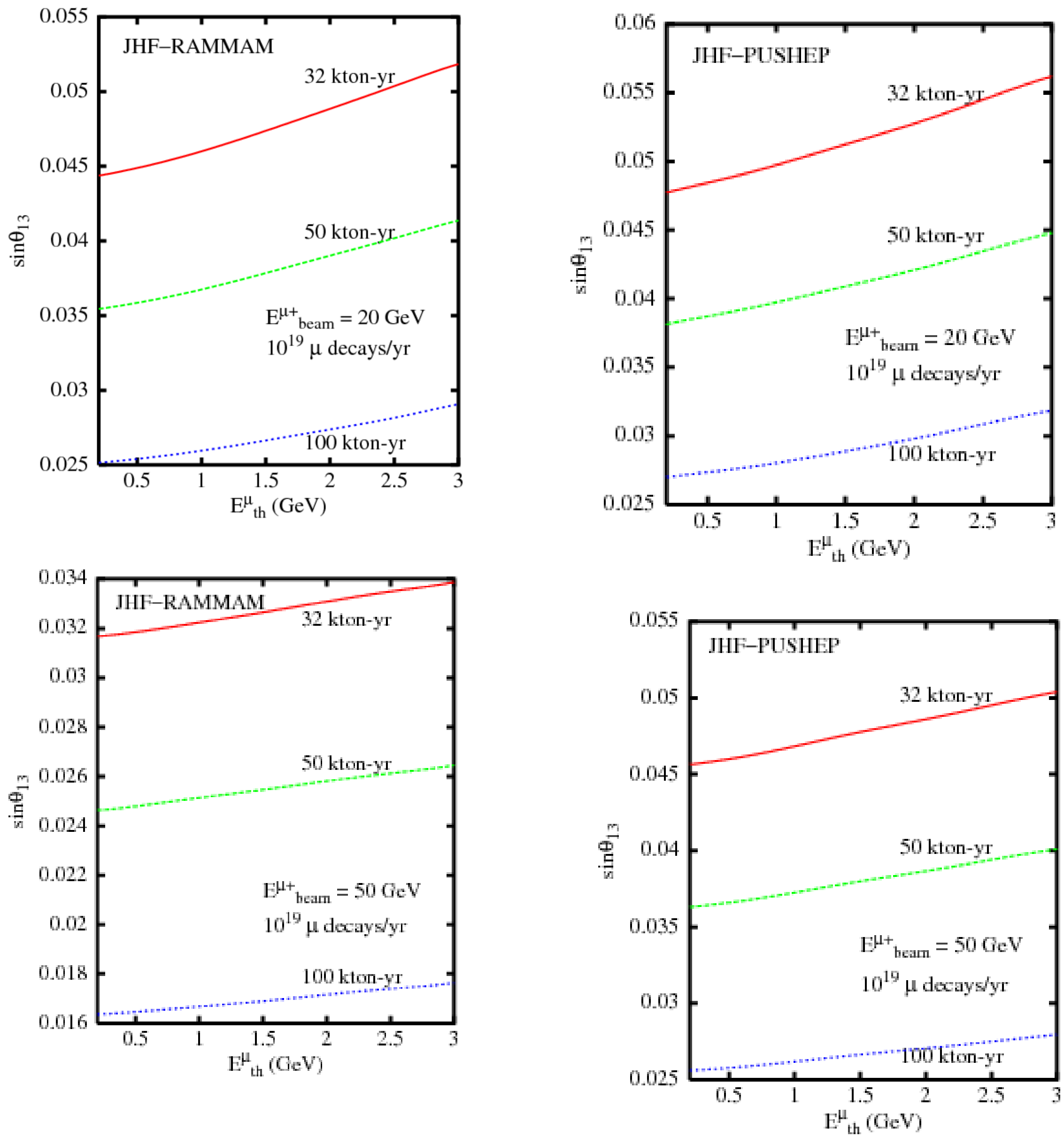
INO AS LONG BASELINE NEUTRINO DETECTOR



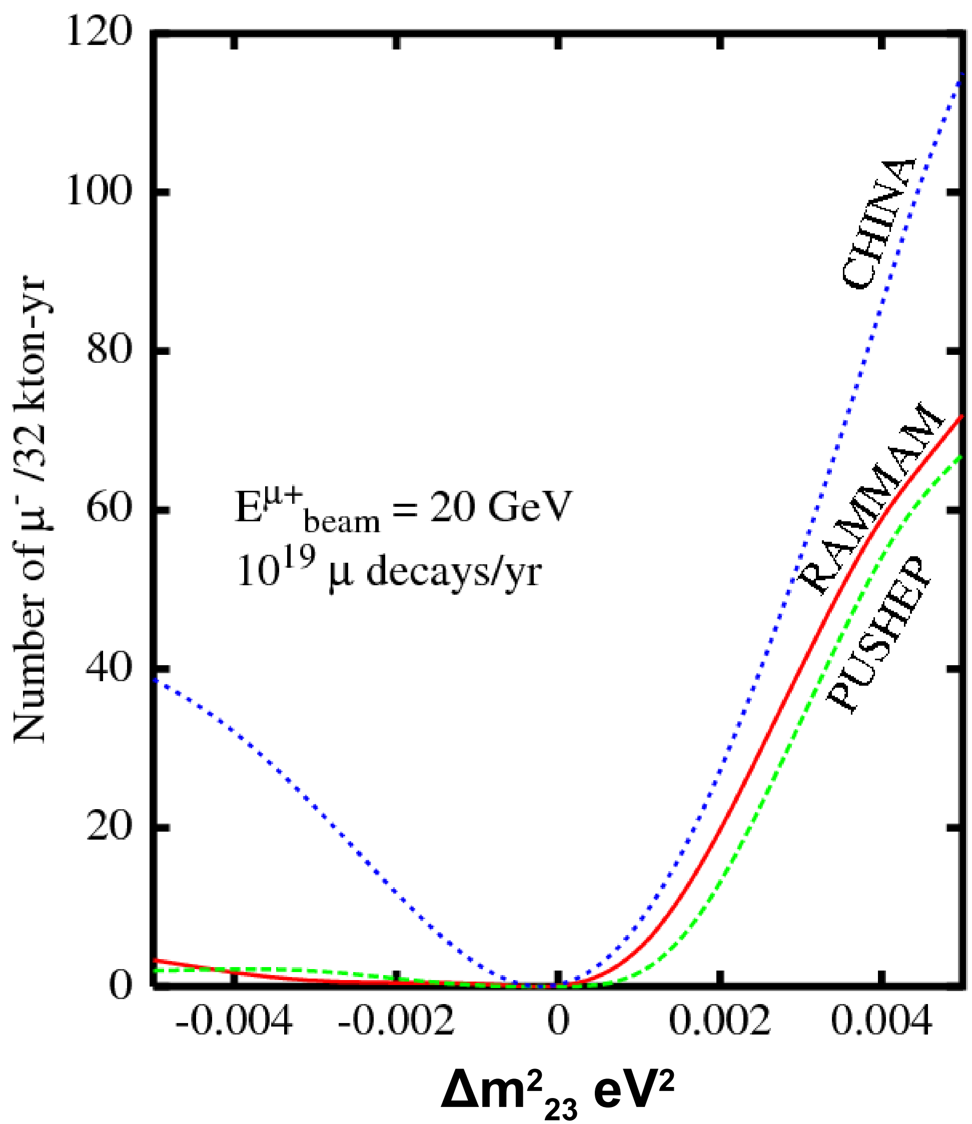
PHYSICS WITH NEUTRINO BEAM

- ✓**Reach and measure of $Sin^2 2\theta_{13}$**
- ✓**Sign of Δm^2_{32}**
- ✓**CP violation in lepton sector**

$\sin\theta_{13}$ REACH vs. E^{μ} THRESHOLD



SIGN OF Δm^2_{32}



CP VIOLATION IN THE LEPTON SECTOR