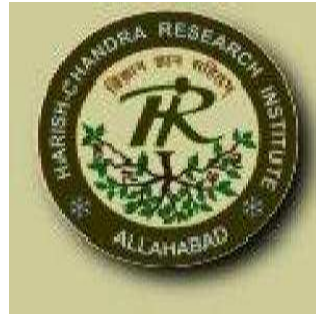
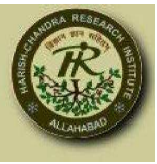

Let's talk about INO



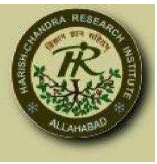
Amitava Raychaudhuri
Harish-Chandra Research Institute, Allahabad

Ref: INO Project Report (INO/2006/01)
<http://www.imsc.res.in/~ino>



Neutrino

- ν : An elusive chargeless elementary particle
- Partners of e^- , μ^- , $\tau^- \Rightarrow \nu_e, \nu_\mu, \nu_\tau$
- Result of the last decade: Neutrinos have mass
- Further, ν_e, ν_μ, ν_τ are superpositions of mass eigenstates (Quantum effect)
- Neutrinos oscillate: Wavelength $\propto (E/\Delta m^2)$
- Goes beyond the very successful Standard Model



Then and Now

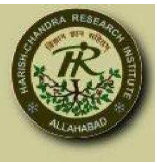
1930 \Leftrightarrow 2004

Then

I have hit upon a desperate remedy to save the exchange theorem and the conservation of energy. Namely, the possibility that there could exist electrically neutral spin $\frac{1}{2}$ particles of small mass ... Pauli (1930)

and Now

Much of what we know about neutrinos we have learned in the last six years. ... We have so many new questions, ... We are most certain of one thing: neutrinos will continue to surprise us. ... APS Neutrino Study Group (2004)



Neutrino interactions

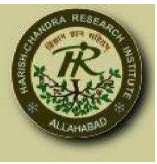
Neutrinos hardly interact

The Sun produces neutrinos in the fusion reactions.
Also produced in the earth's atmosphere by cosmic rays

50 trillion (solar) neutrinos pass through the human body every second. *No harm done!*

Human body has about 20mg of K^{40} . This emits 340 million neutrinos per day. *No damage!*

Corollary: Very hard to detect. *However, not impossible!!*



Then and Now

1930 \Leftrightarrow 2004

Then

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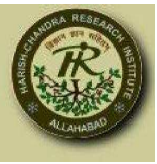
Plan

Neutrino Oscillations

India-based Neutrino Observatory (INO)

1. Genesis
2. The ICAL Detector design
3. Detector simulation
4. Physics issues
5. Site, Cost, . . .

Conclusions



Neutrino Oscillations

Neutrino oscillation ($\nu_e \leftrightarrow \nu_\mu$) is a consequence of quantum mechanical time evolution:

Quantum Mechanics: superposition of states is allowed

Two requirements for oscillation:

- Neutrinos have mass
- ν_e and ν_μ are superpositions of neutrinos of definite mass.

Neutrino oscillations established for solar and atmospheric neutrinos

Note: In the Standard Model neutrinos are massless!



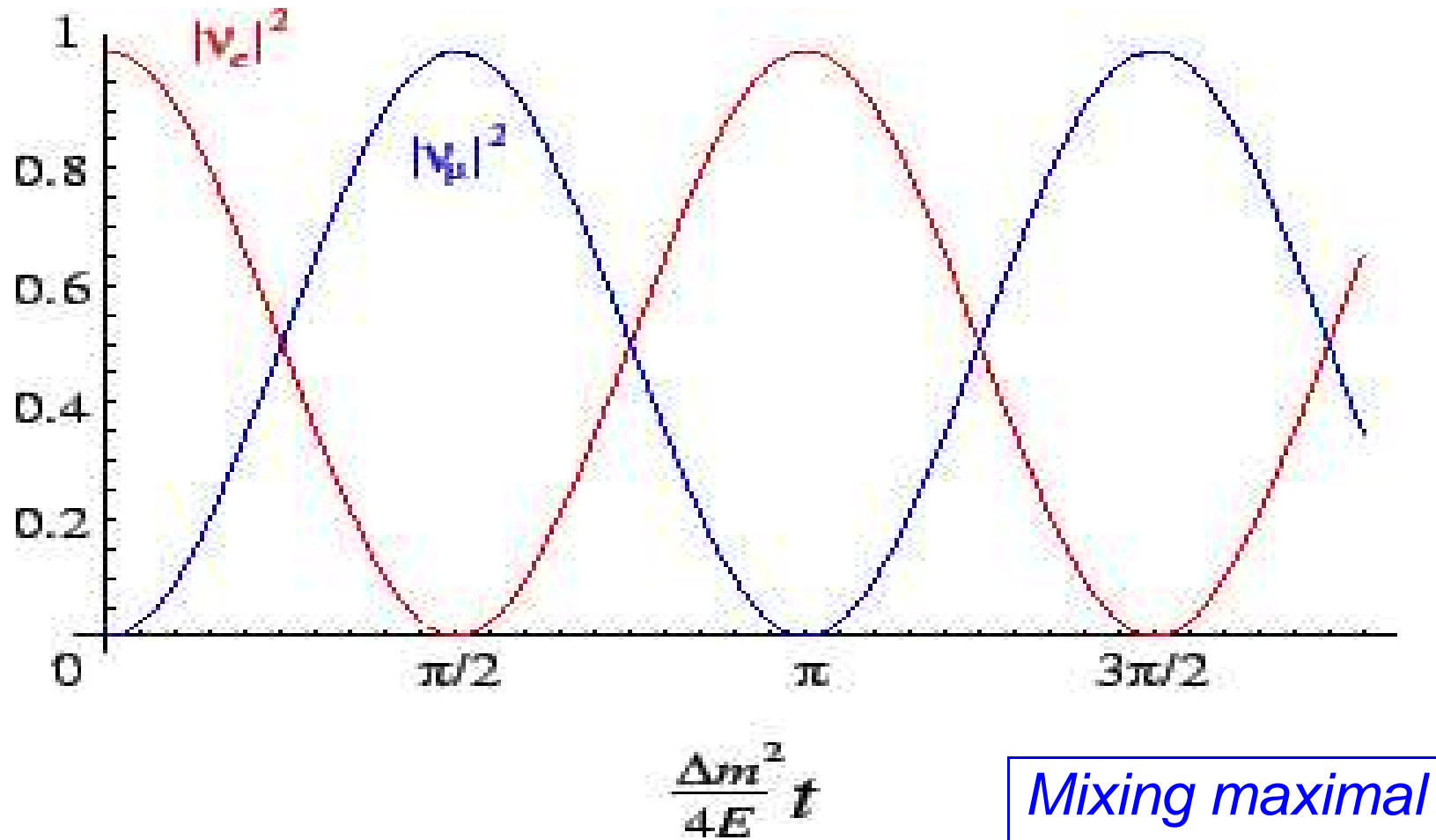
Neutrino Oscillations

Neutrino states change type (e.g., 2 flavours: $\nu_e \leftrightarrow \nu_\mu$) during propagation: $P_{\nu_e \rightarrow \nu_e} \equiv$ survival prob. is an oscillatory function

- At any stage, $P_{\nu_e \rightarrow \nu_e} \leq 1$
- Also $P_{\nu_e \rightarrow \nu_\mu} \leq 1$
- $P_{\nu_e \rightarrow \nu_e} + P_{\nu_e \rightarrow \nu_\mu} = 1$ at every stage
- $P_{\nu_e \rightarrow \nu_\mu}(t) = \sin^2 2\theta \sin^2 \left(\frac{\Delta m^2}{4p} t \right)$



Neutrino Oscillations



$\nu_e \leftrightarrow \nu_\mu$ oscillation probabilities



INO

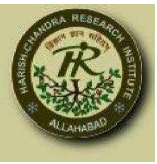
INO is the India-based Neutrino Observatory

Goals \Rightarrow Precision measurement of neutrino properties using atmospheric neutrinos; end-detector for very long baseline neutrino experiments

Time frame: Funding in XIth Plan: Experiment to start in about five years (2012)

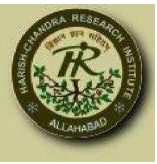
A challenging basic sciences project

Will be an unique international facility



Genesis of INO

- Early Indian track record of neutrino experiments at Kolar
First to detect ν_{μ}
- Preliminary explorations and discussions started more than five years ago
- Support for initiating R&D for INO (2002-07)
- MOU between a number of institutes
- INO detailed project report (2006) reviewed by international experts



International scene

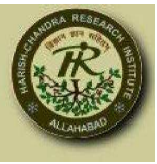
Solar and atmospheric neutrino experiments – neutrino mass and mixing – have attracted wide attention

Many open issues, some others still need independent confirmation

Much activity worldwide (Japan, USA, Europe, Canada, ...)

INO is a part of this bigger international enterprise

INO has unique advantages, e.g., size, magnetic field, location

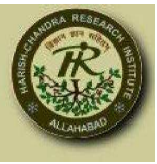


INO: The chosen site



PUSHEP Site (Lat: N11.5°, Long: E76.6°)

PUSHEP-Bangalore: 250km



The detector choice

Within available technological capabilities

Complements existing/planned detectors (like MONOLITH)

Good tracking and energy resolution

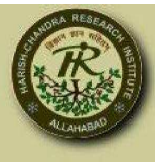
Good time resolution

First phase: Atmospheric neutrino measurements

50kt \Rightarrow 50kT + 50kT

Second phase: End detector for a long baseline experiment

Charge identification, Magic baseline to Europe (CERN)



The ICAL detector

Neutrinos detected via μ^\pm (muons) they produce

Neutrinos have a very tiny probability of interaction

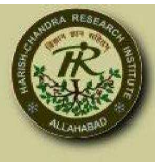
Dense material has a better prospect: Choose Iron,
Magnetic field feasible.

Iron CALorimeter (ICAL) selected for INO

For detection of muon use RPCs

Detector design: Stacks of alternate layers of iron and RPC detectors

From 'hits' in successive detectors get muon's path or 'track'



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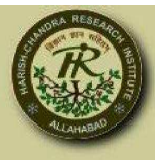
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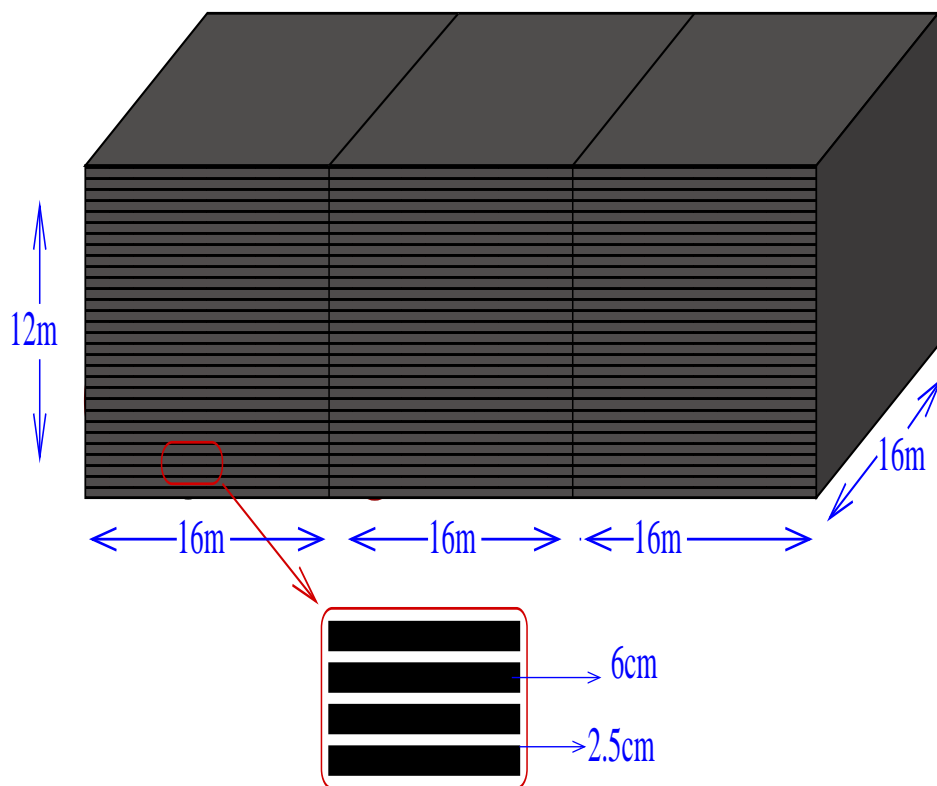
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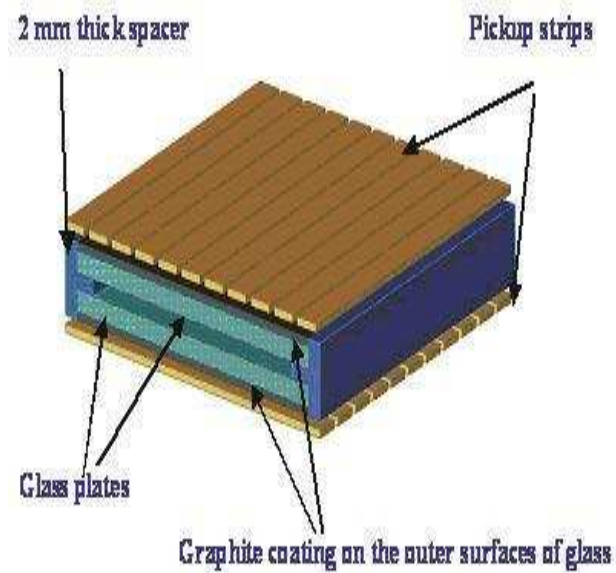
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ICAL Design



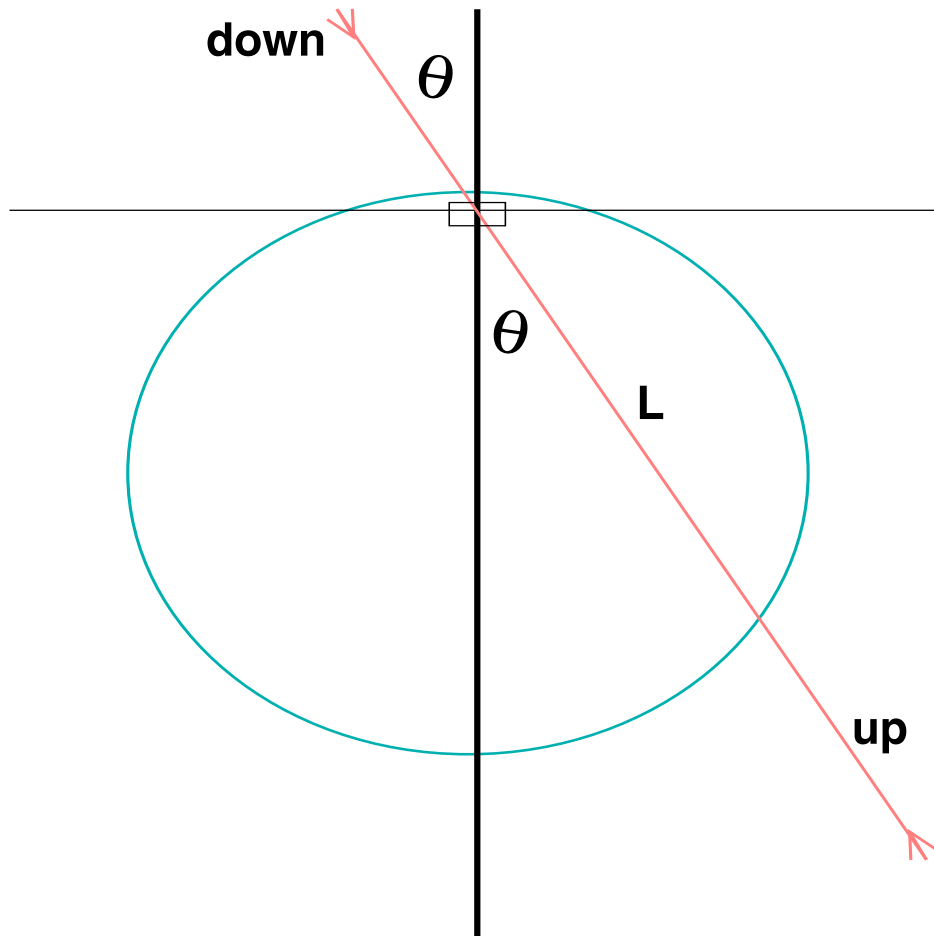
The ICAL Detector



A Glass RPC

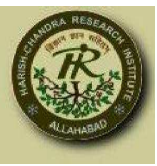


Atmospheric ν direction



For any zenith angle
down-going and up-going
neutrinos equal in number.

Up-going \Rightarrow far detector
Down-going \Rightarrow near de-
tector



Objectives

Neutrinos oscillate ($\nu_\mu \leftrightarrow \nu_\tau$). Wavelength \sim earth's radius

Down-going neutrinos travel short distance, little oscillation

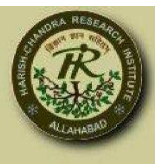
Up-going neutrinos travel through earth, oscillate \Rightarrow lost

No Up-down symmetry any more

Measure ratio (# of upgoing ν_μ)/(# of downgoing ν_μ):
mimics oscillations as zenith angle varies

Magnetic field distinguishes μ^- from μ^+ ,
i.e., parent ν_μ from $\bar{\nu}_\mu$

The latter gives an extra edge to ICAL



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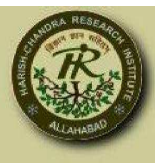
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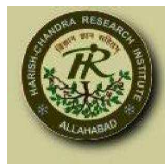
Up-going neutrinos travel through earth, oscillate

Up-down symmetry is lost

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RPC (Resistive Plate Chambers)

Neutrinos cannot be directly detected

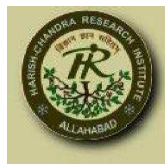
Atmospheric ν_μ produce μ^- when they interact

Like other charged particles, muons (μ^-) can be detected

A typical detector is an ionisation chamber which produces an electric pulse when a charged particle passes through it

An RPC is similar. Here an appropriate gas mixture is used so that the ionisation is localised.

This allows a better determination of the location of the muon



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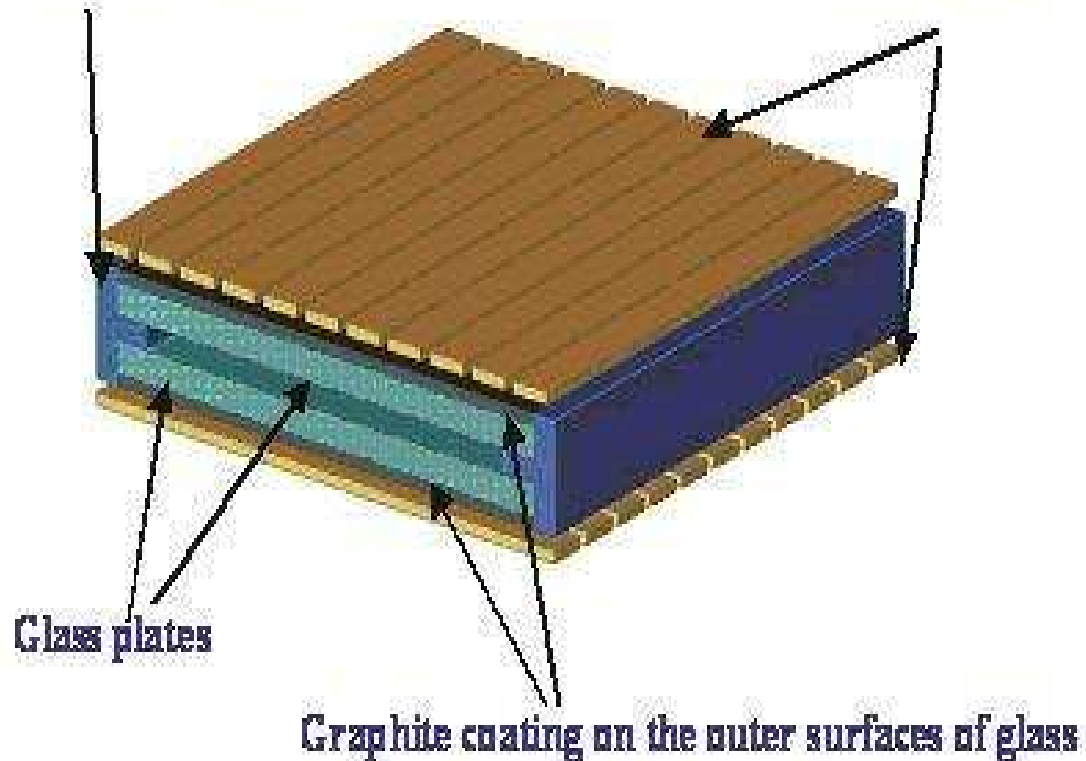
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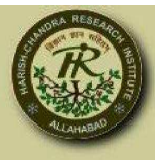


An RPC

2 mm thick spacer

Pickup strips





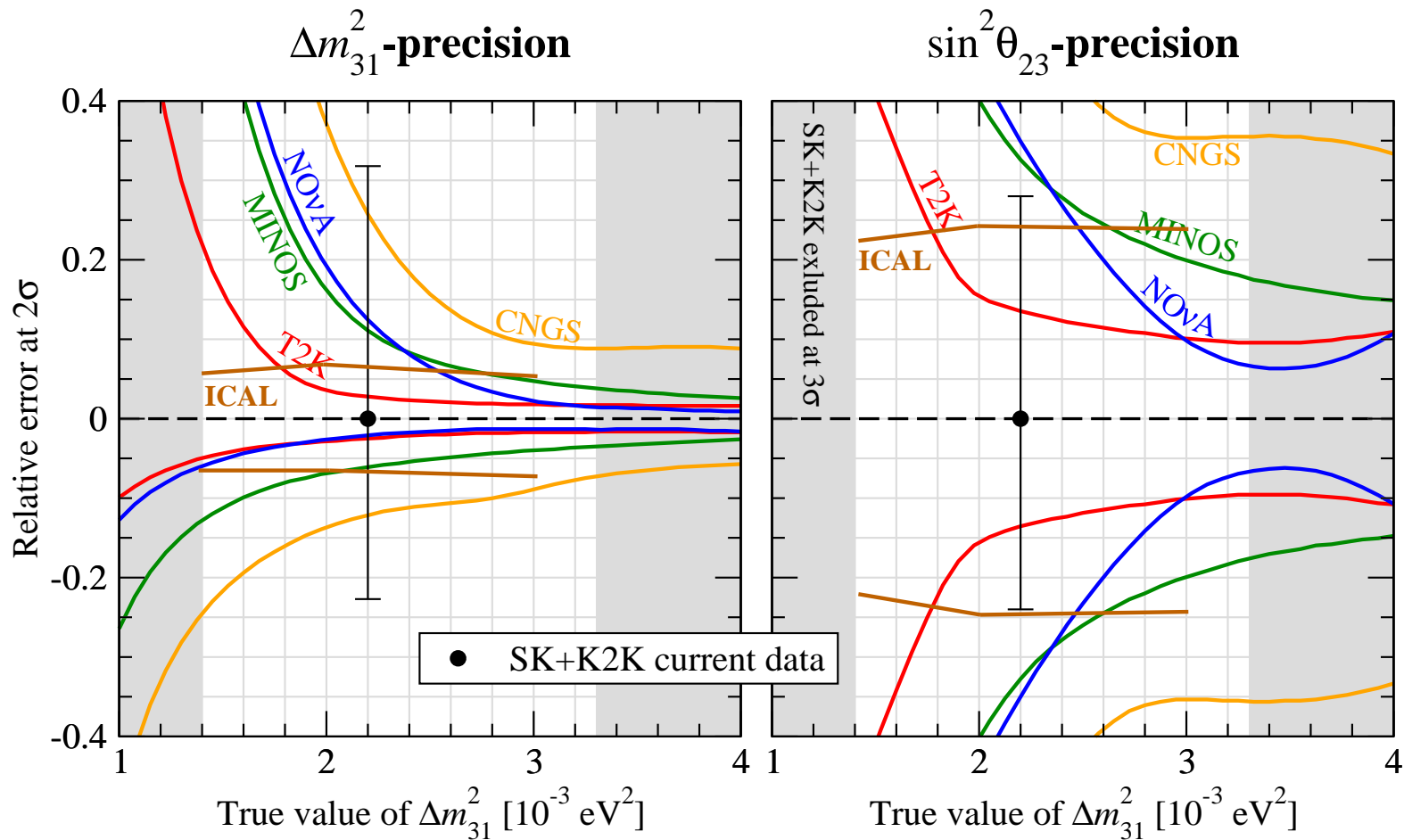
ICAL configuration

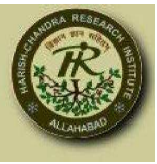
- Mass: 50 kTon
- Size: 48m (x) \times 16m (y) \times 12m (z)
Split into three modules: 16m \times 16m \times 12m each
- 140 layers of 6cm iron, 2.5cm gap for active elements
- 1.3T Magnetic field
- RPC: 2m (x) \times 2m (y) \rightarrow *64 per layer/module*
- Total No. of RPCs: \sim 27,000

1 m³ prototype being designed



Precision comparison





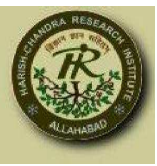
INO Status

Prototype Glass RPCs fabricated and tested at TIFR & SINP
Gas mixing units for these designed and built at SINP & TIFR
Magnet design in progress at BARC and VECC
DAQ: Work in progress at TIFR, ...

Simulation: Atmospheric ν detailed study, Long baseline
prospects examined at HRI, SINP, IMSc

Site: PUSHEP (near Mysore)
INO Centre at Mysore University

INO report (May 2006) <http://www.imsc.res.in/~ino/>
Spokesperson: Prof. N.K. Mondal, TIFR



Second phase

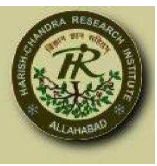
Increase the detector size to 100 kT. Increases sensitivity

End detector for a long baseline experiment

Long baseline \Rightarrow Source in Europe/US and detector at INO

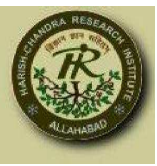
CERN-INO distance \sim *Magic Baseline* which holds advantages for physics

Neutrino Source: Neutrino factory or Beta-Beams
(Both in R&D stage)



ICAL/INO other possibilities

- Precision measurement of neutrino mass splitting and mixing
- End detector for very long baseline experiment with ν -factory/Beta-Beam source
- Low background experiments
 1. Neutrinoless double beta decay
 2. Dark matter search
- Geophysical studies, Pollution free life sciences laboratory



Summary/Conclusions

90 physicists and engineers from 15 Indian (and 1 US) institutions

International Review completed

Important results in neutrino physics expected soon.
Physics potential is good

INO funding clearance in final stage of consideration

Time over-runs can be critical. Competing experiments

Manpower: Nuclear and High Energy physicists needed

THANK YOU!