India-based Neutrino Observatory (INO)

Status Report

D. Indumathi

The Institute of Mathematical Sciences, Chennai

(indu@imsc.res.in)

For the INO Collaboration

(http://www.imsc.res.in/∼ino)

Outline of talk

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- The India-based Neutrino Observatory
  - The ICAL Detector: RPC’s and magnet design
  - Physics possibilities at ICAL: atmospheric and long-baseline physics
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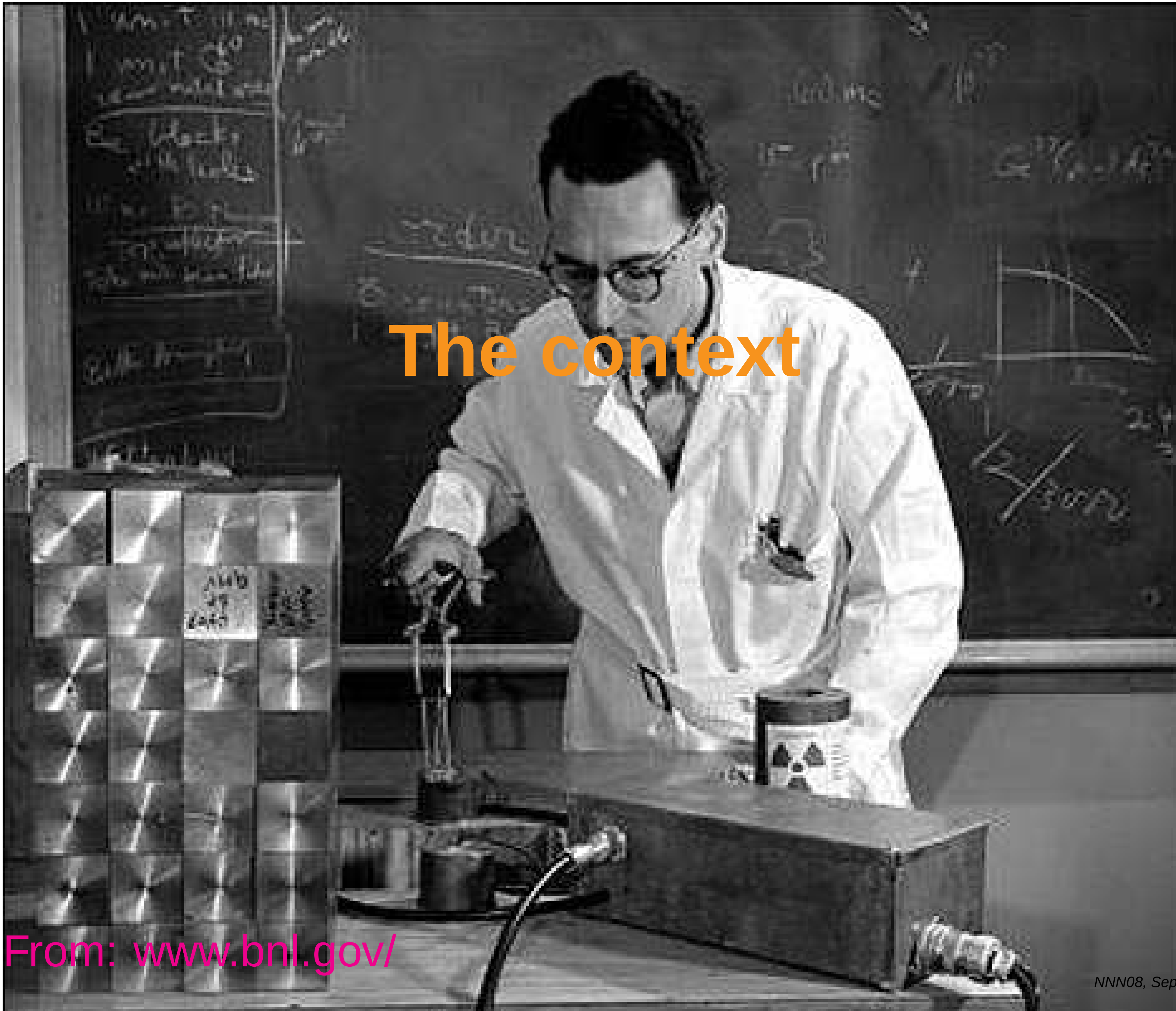
  - Location
- Current Status of INO

The context



From: www.bnl.gov/

A Schematic of Neutrino Properties

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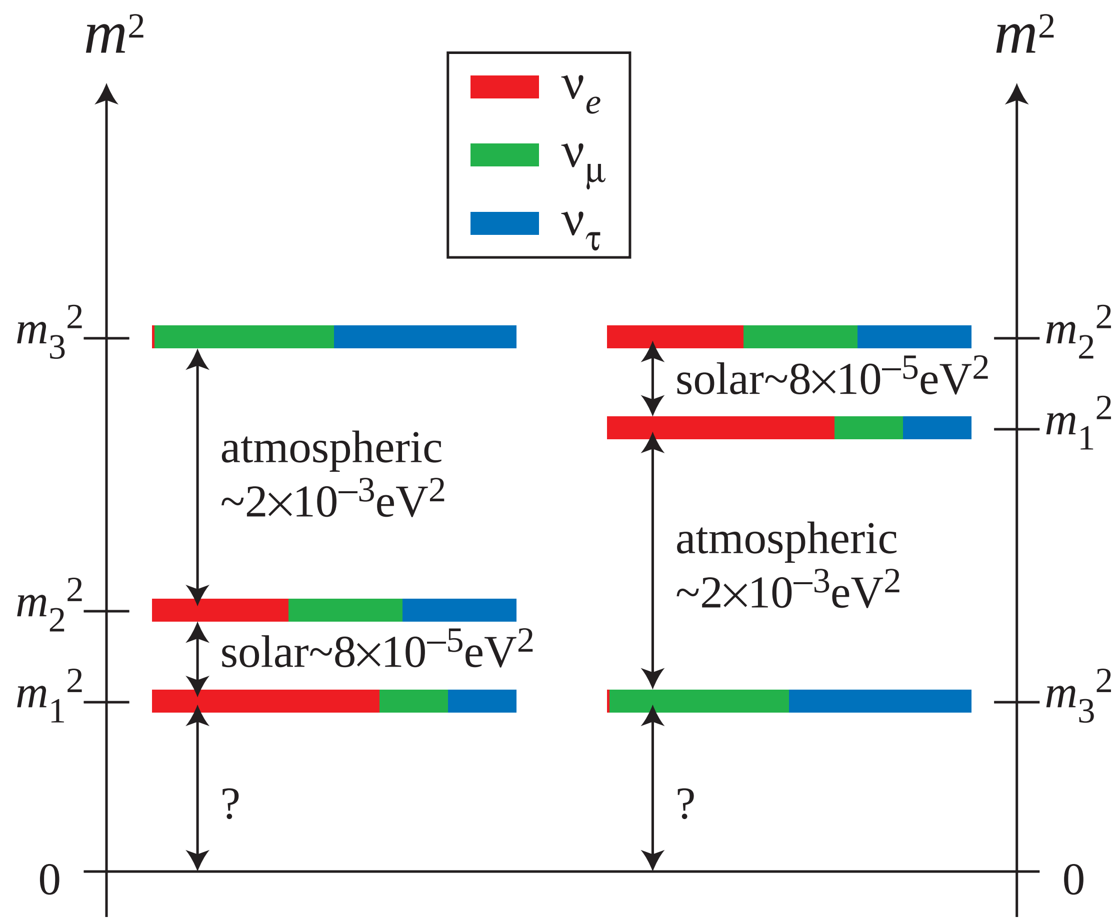

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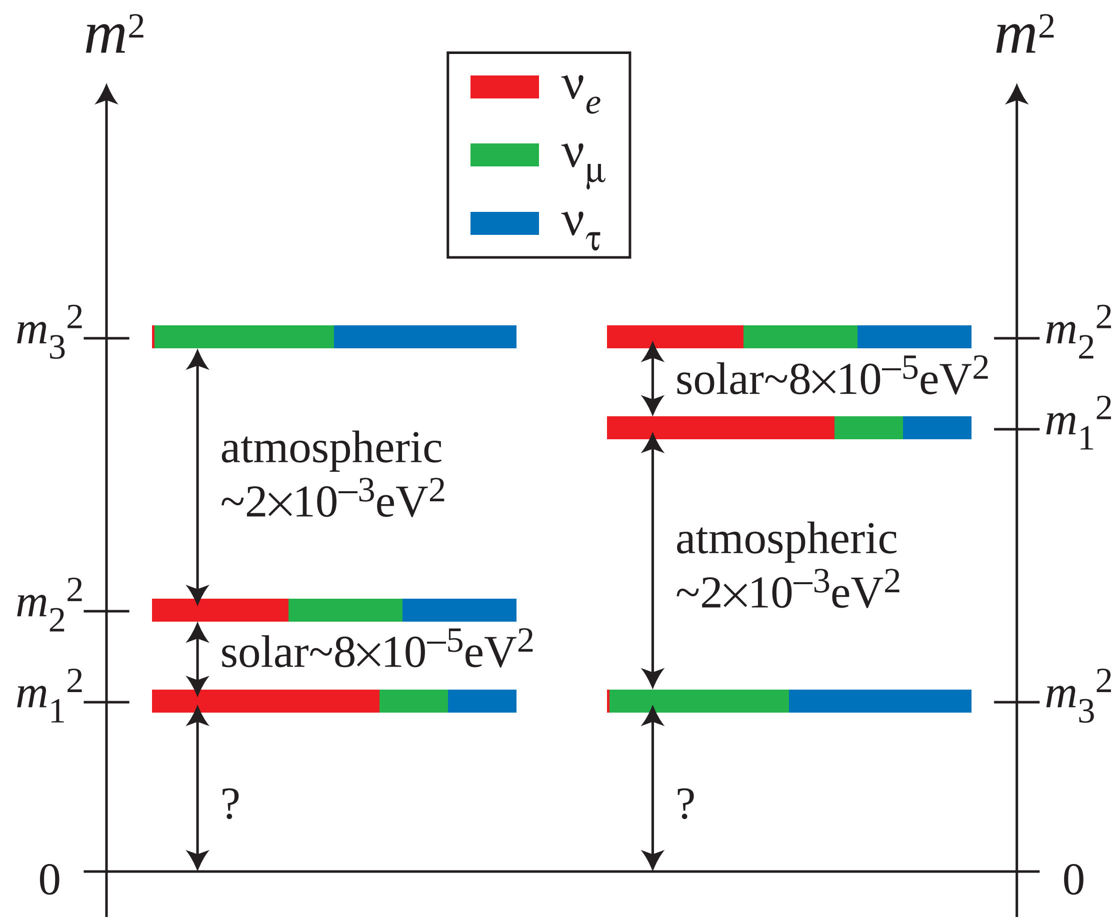
$\sum_i m_i < 0.7$–2 eV.



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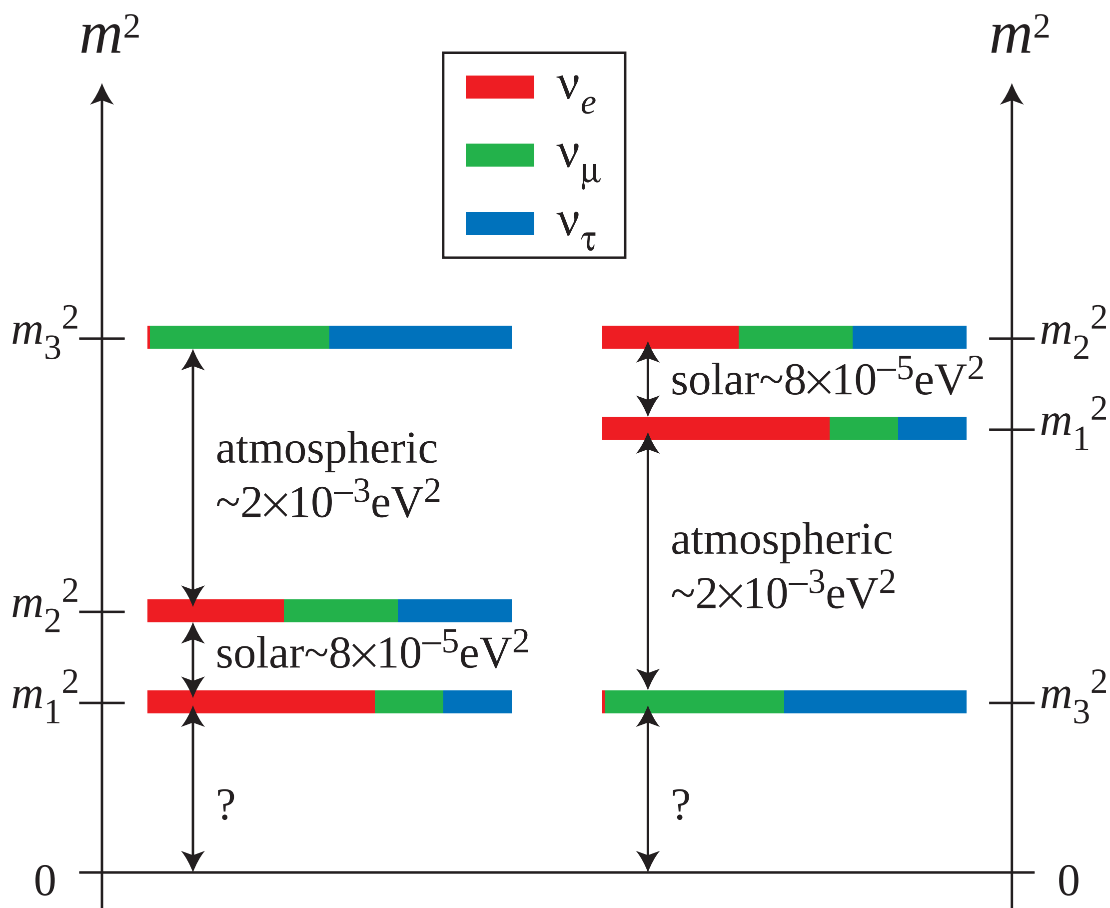
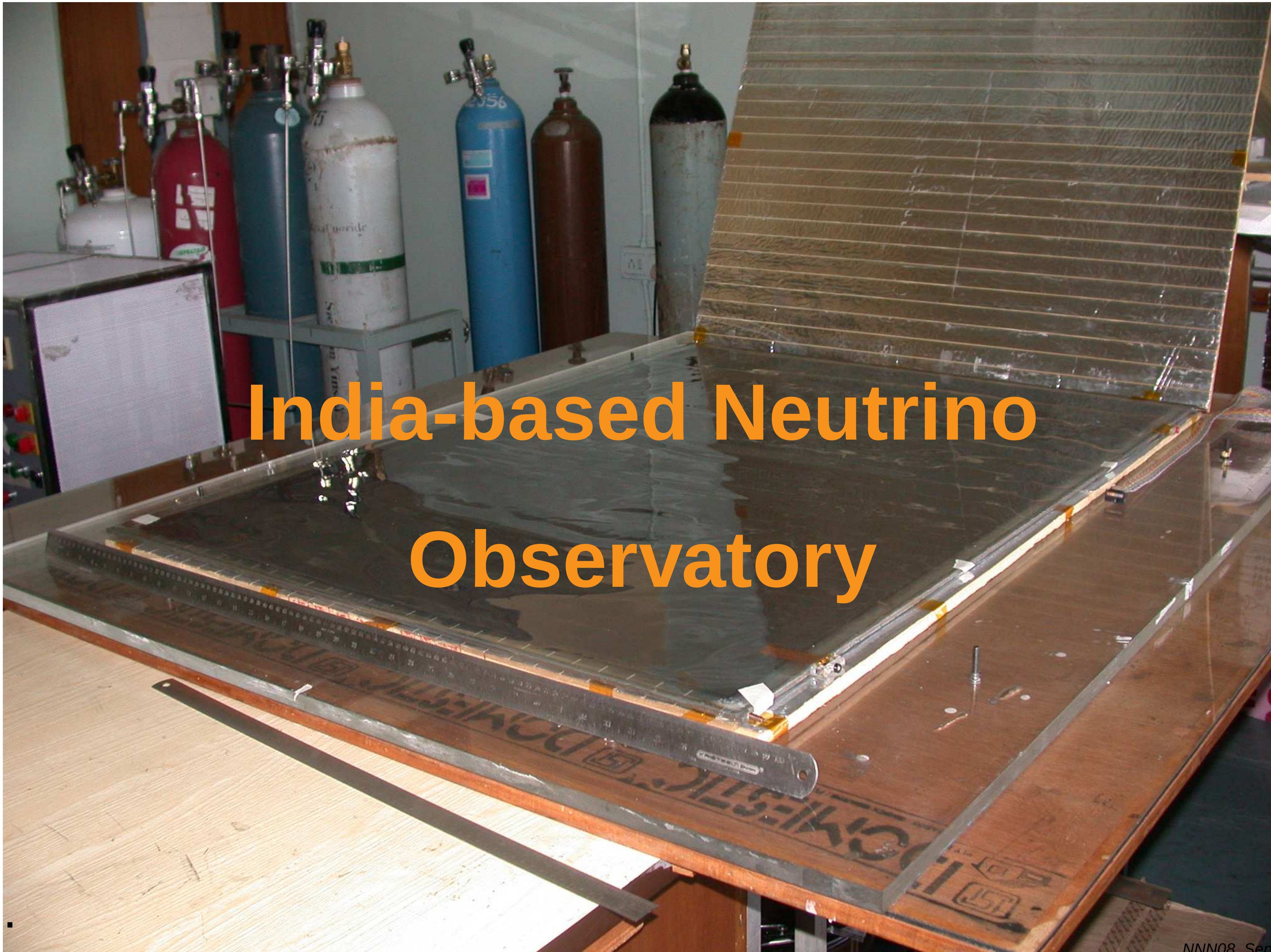
- $m_1 \sim m_2 \sim m_3 \sim 0.2$ eV (Degenerate hierarchy)
- $m_1 < m_2 \ll m_3$ (Normal hierarchy)
- $m_3 \ll m_1 < m_2$ Inverted hierarchy



(APS multi-divisional neutrino study, physics/0411216)

India-based Neutrino Observatory



The INO Collaboration

- Aims to build an underground laboratory for science with neutrino physics as a major activity
- Spokesperson: N. K. Mondal, TIFR
- Collaborating Institutions: AMU, BHU, BARC,CU, DU, HRI, UoH, HPU, IITB, IITKh, IGCAR, IMSc, IOP, LU, NBU, PU, PRL, SINP, SMIT, TIFR, VECC

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- Stage I : Study of atmospheric neutrinos
  - Physics Studies (atmospheric neutrinos); Detector R & D; construction of a prototype (in progress); HRD
  - Site choice and clearances; lab and detector construction

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  - Site choice and clearances; lab and detector construction
- Stage II : Study of long-baseline neutrinos, from a neutrino factory/beta beam
- Other detectors/physics like neutrinoless double beta decay?

The choice of detector

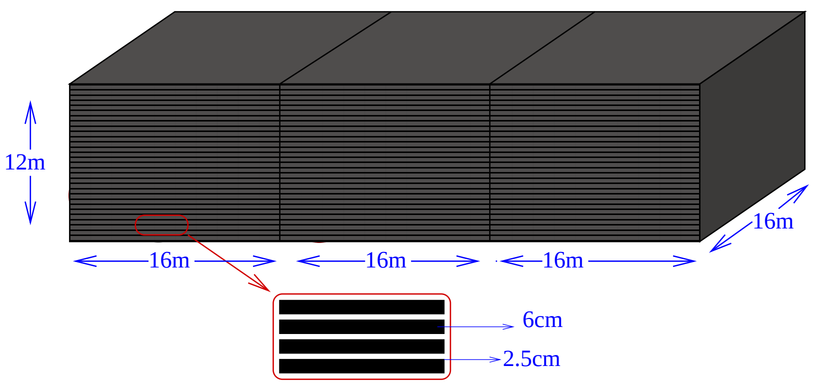
- Large target mass: began with 30 kton; current design 50 kton
- Good tracking and energy resolution
- Nano-second time resolution for up/down discrimination; hence good directionality
- Good charge resolution; magnetic field
- Ease of construction (modular)

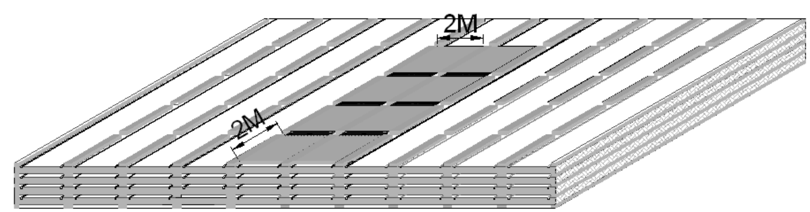
Use (magnetised) iron as target mass and RPC as active detector element. Similar to MONOLITH.

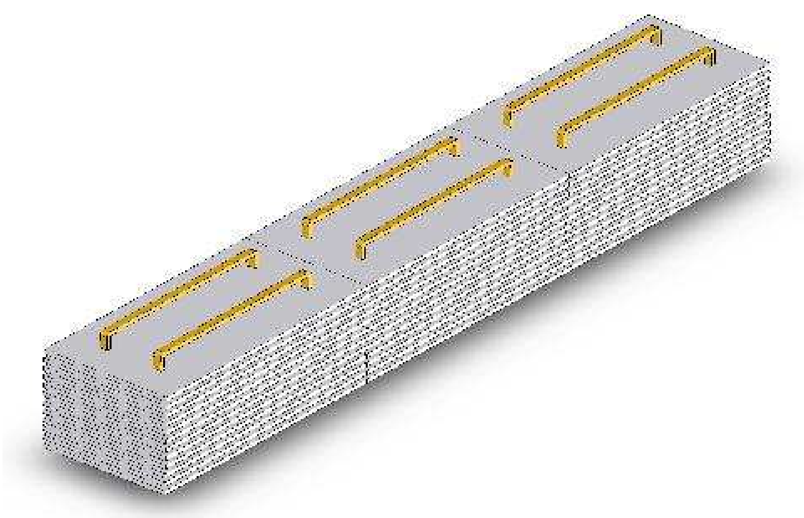
Note: Is sensitive to muons only, not electrons

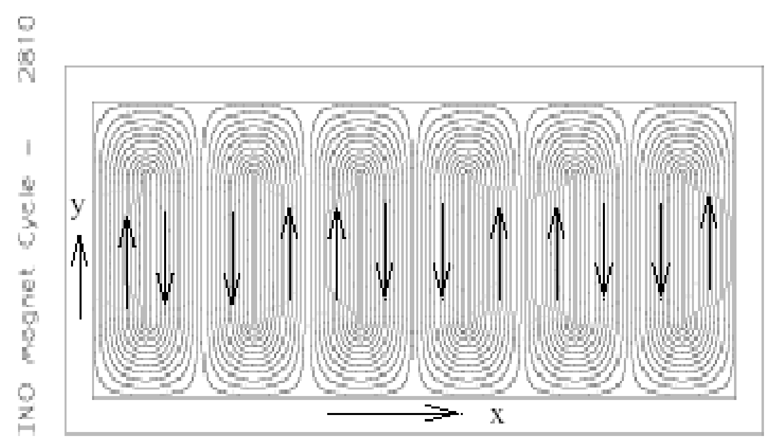
The ICAL detector

- 50 kton iron, magnetised to ~ 1.2 T with 140 layers of 6 cm plates in three modules
- Each module = $16 \times 16 \times 12 m^3$



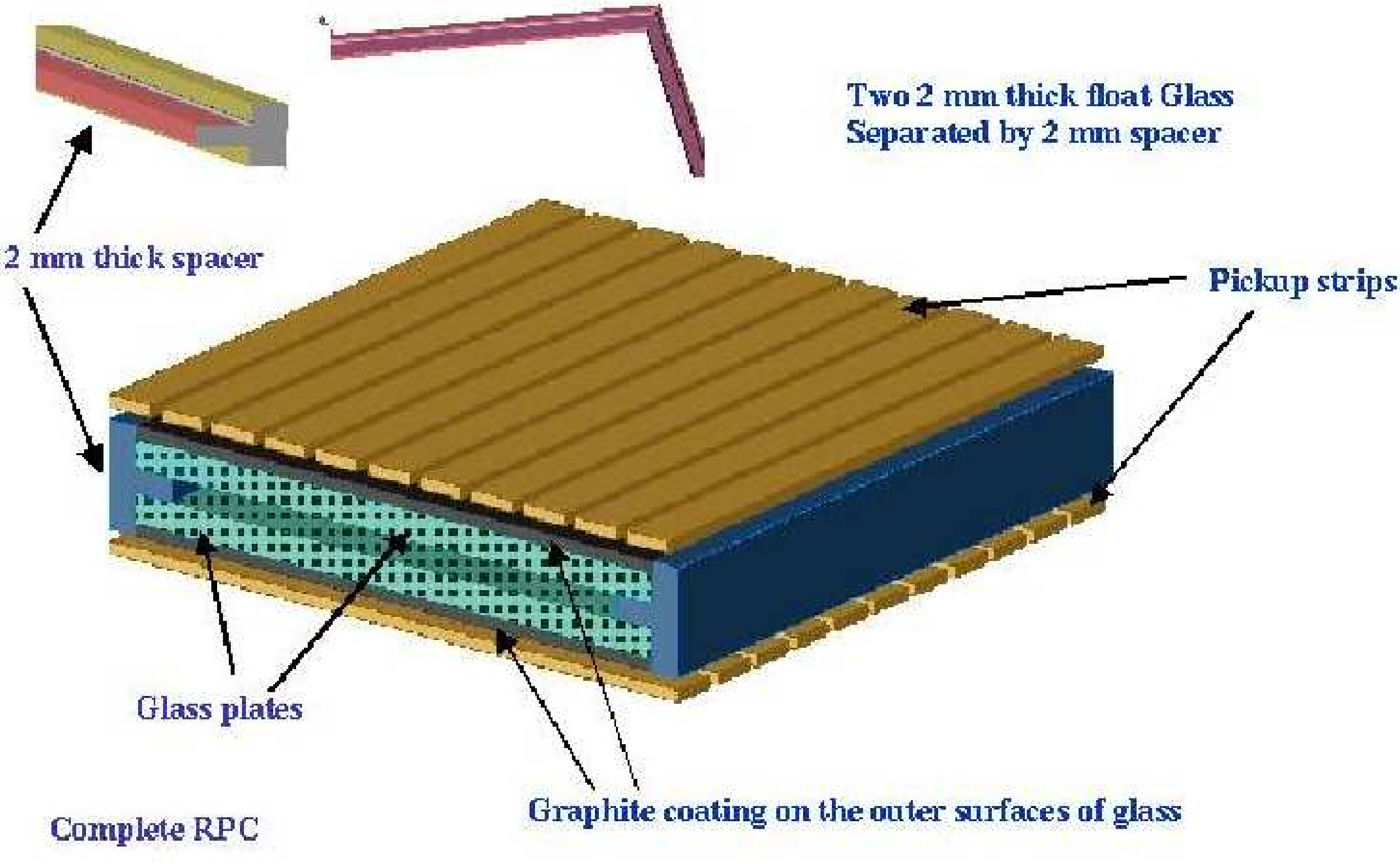






The active detector elements: RPC

RPC Construction: Float glass, graphite, and spacers



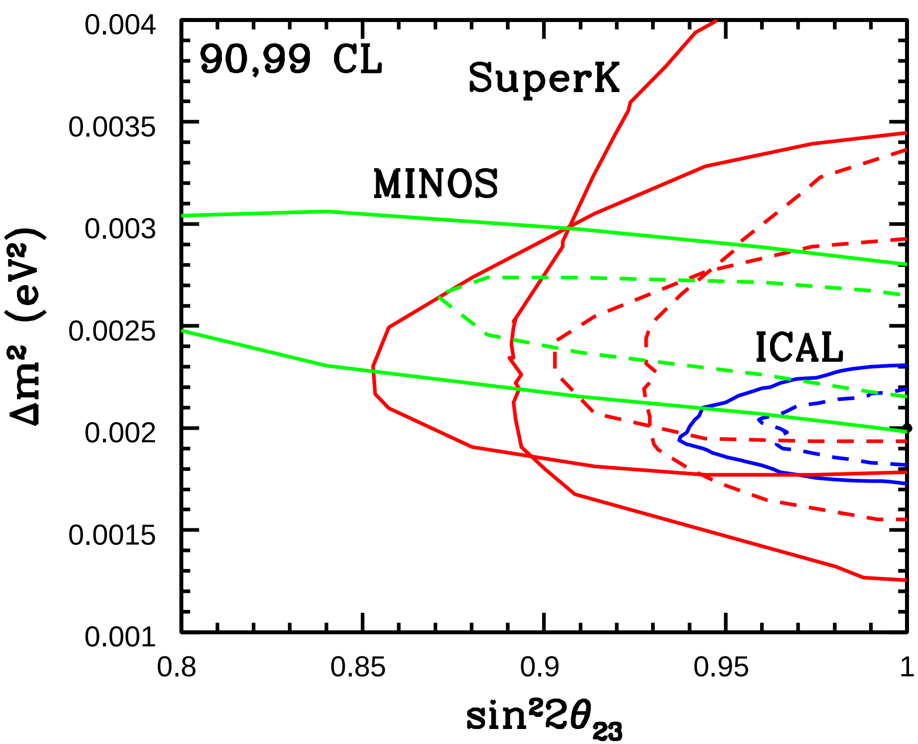
Fabricating RPC's

Specifications of the ICAL detector

ICAL	
No. of modules	3
Module dimension	16 m $\times$ 16 m $\times$ 12 m
Detector dimension	48 m $\times$ 16 m $\times$ 12 m
No. of layers	140
Iron plate thickness	$\sim$ 6 cm
Gap for RPC trays	2.5 cm
Magnetic field	1.3 Tesla
RPC	
RPC unit dimension	2 m $\times$ 2 m
Readout strip width	3 cm
No. of RPC units/Road/Layer	8
No. of Roads/Layer/Module	8
No. of RPC units/Layer	192
Total no. of RPC units	$\sim$ 27000
No. of electronic readout channels	3.6 $\times 10^6$

Physics Studies and Simulations

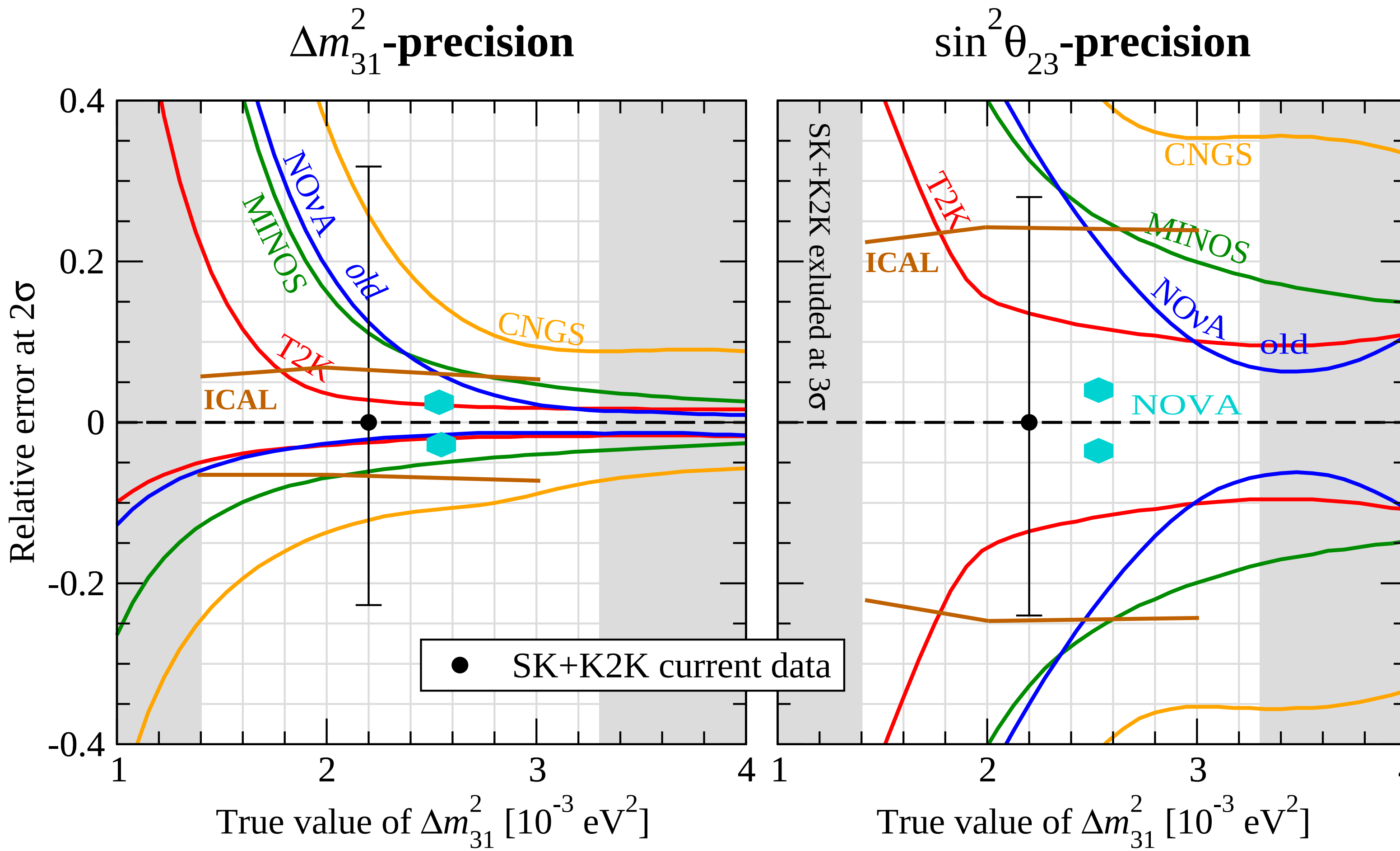
- Source: Atmospheric Neutrinos, 6 years' exposure, from Nuance neutrino generator.
- ICAL simulation with GEANT-3, $B_y = 1$ T.



Shown are 90 and 99 CL contours in comparison with Super-K and MINOS results.

Caution: MINOS $\equiv$ 3-flavour analysis, Schwetz et. al. hep-ph/0808.2016

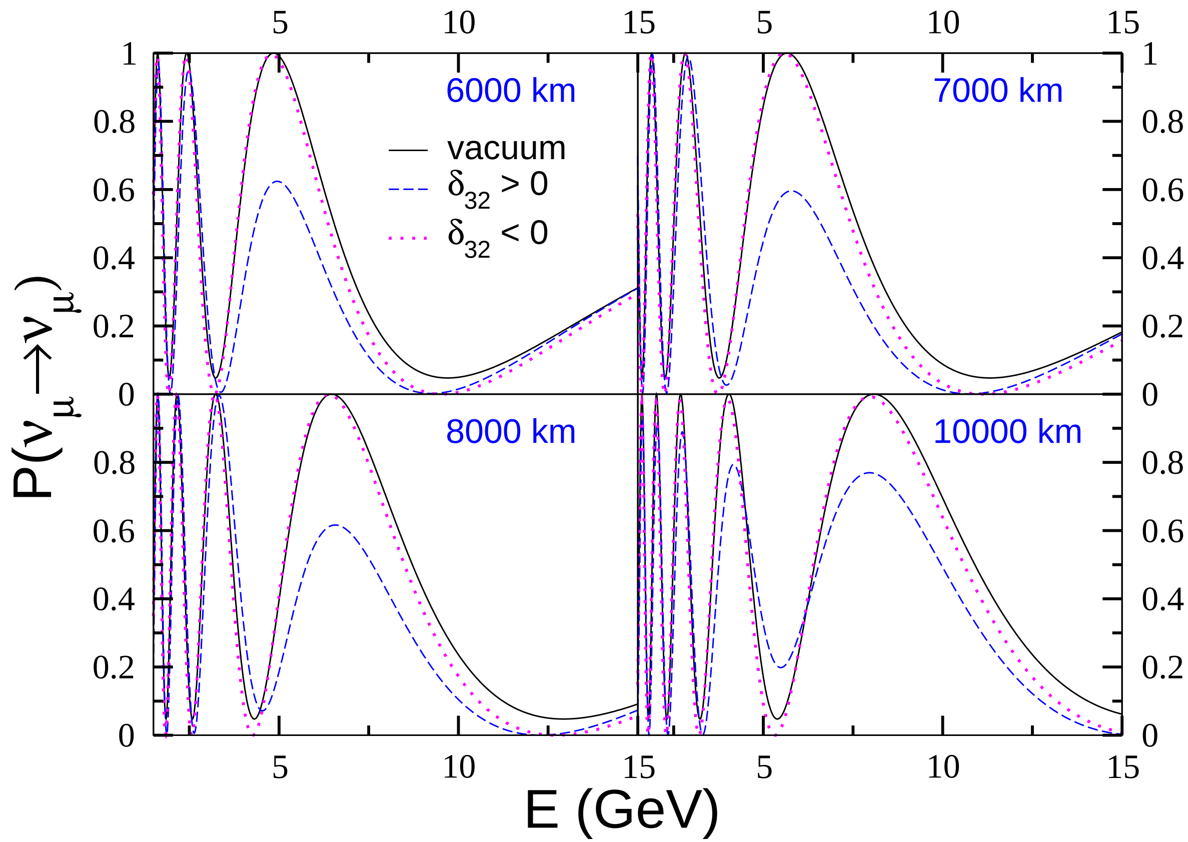
Physics Studies with ICAL



All experiments with 5 years' running; NOVA 25kton, 6 years (6×10^{21} pot).

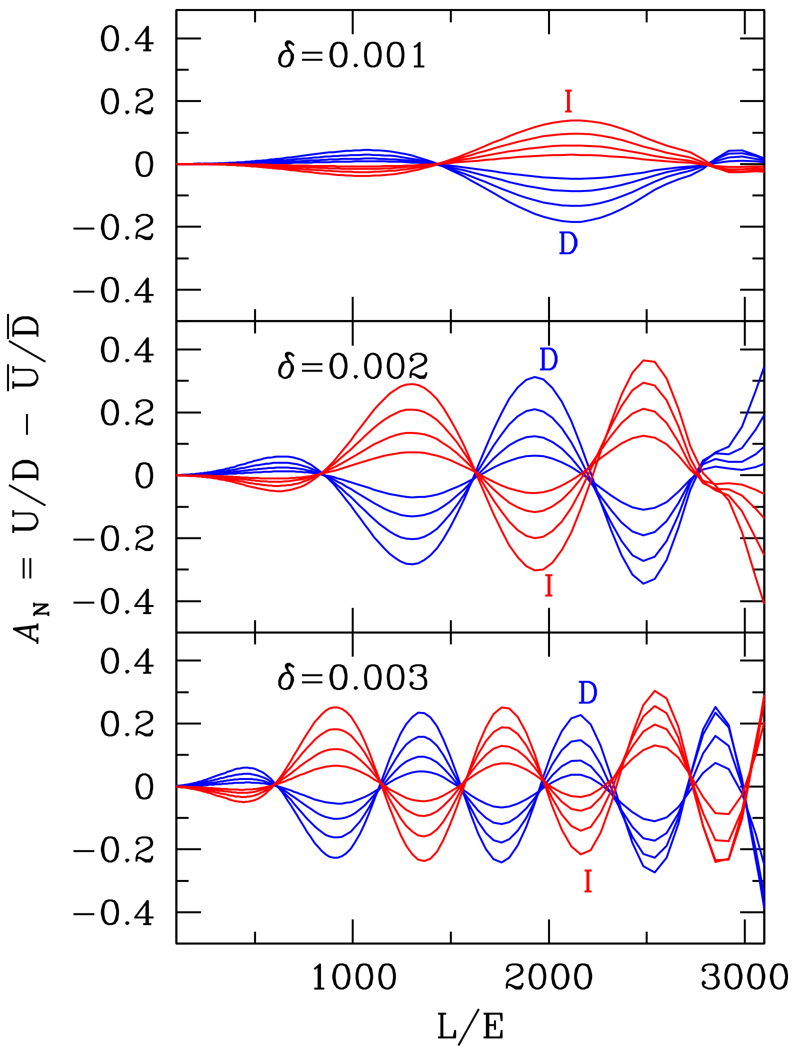
Adapted from: P. Huber, M. Lindner, M. Rolinec, T. Schwetz and W. Winter, hep-ph/0412133.

Matter effects with atmospheric neutrinos



- Matter effects involve the participation of all three (active) flavours; hence involves both $\sin\theta_{13}$ and the CP phase δ.
- Hence sensitive to the mass ordering of the 2–3 states, provided $\theta_{13} > 6^\circ$; however, needs large exposures

The difference asymmetry



Sign of $\delta \equiv \Delta m^2_{32}$ for $\theta_{13} = 5, 7, 9, 11°$

Hence sensitive to the mass ordering (red vs blue) of the 2–3 states

With exposures of 500 kton-years, can get a 90%CL result if

$\sin^2 2\theta_{13} > 0.09$ (10% R)

$\sin^2 2\theta_{13} > 0.07$ (5% R)

However, needs large exposures of about 800 kton-years for smaller

$\sin^2 2\theta_{13} > 0.07$ (10% R)

$\sin^2 2\theta_{13} > 0.05$ (5% R)

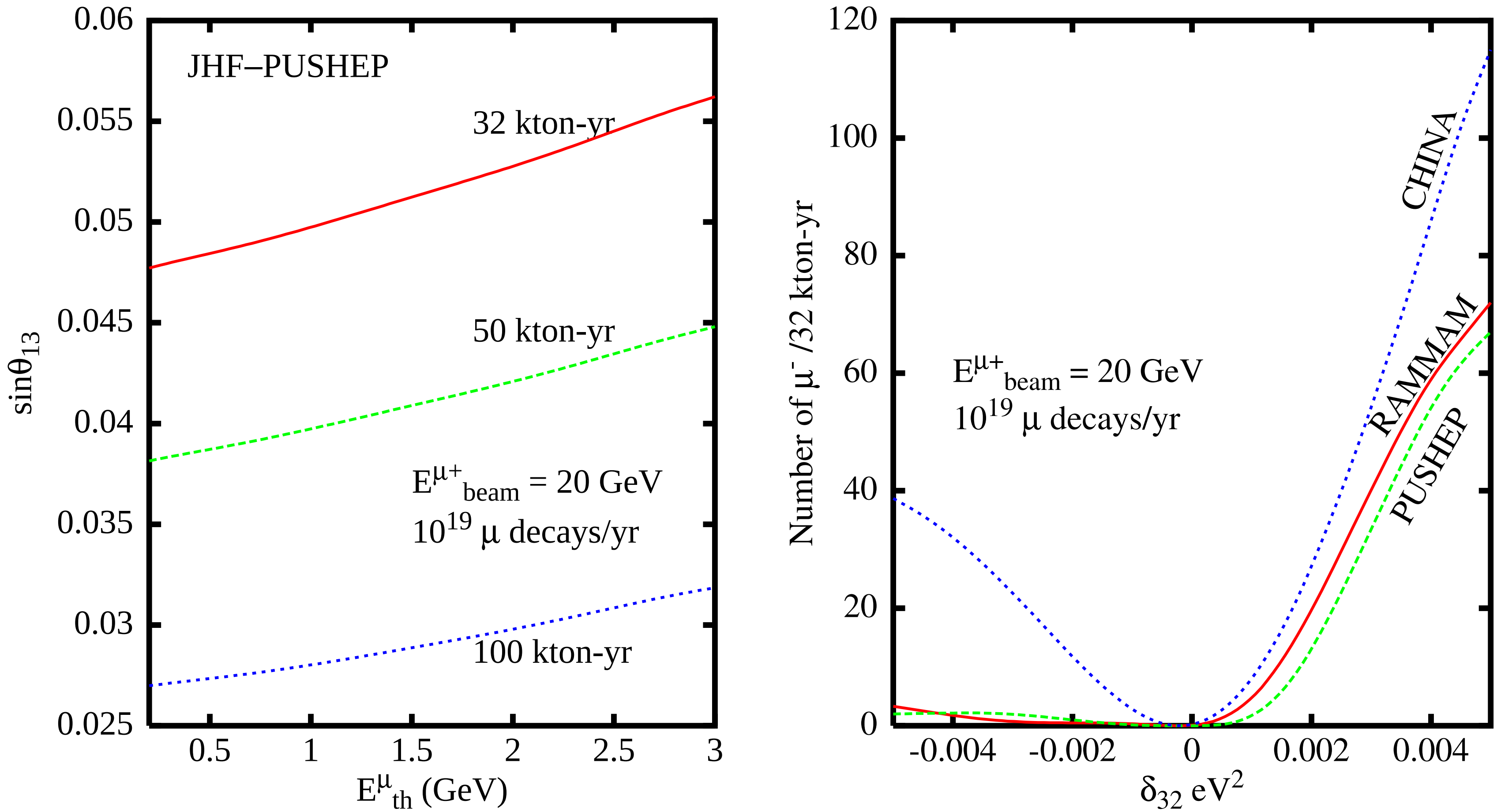
D: Direct/normal; I: Inverted hierarchy

Other physics possibilities

$\ldots$ with atmospheric neutrinos

- Discrimination of octant of θ_{23} provided $\theta_{13} > 7^\circ$ ($\sin^2 2\theta_{13} > 0.06$); harder than mass ordering
- Probing CPT violation from rates of neutrino- to rates of anti-neutrino events in the detector: sensitive to δb, which adds to $\Delta m^2_{32}/(2E)$ in oscillation probability expression.
- Constraining long-range leptonic forces by introducing a matter-dependent term in the oscillation probability even in the absence of U_{e3}, so that neutrinos and anti-neutrinos oscillate differently.
- Discrimination between oscillation of ν_μ to active ν_τ and sterile ν_s from up/down ratio in "muon-less" events?

Stage II: Neutrino factories and INO

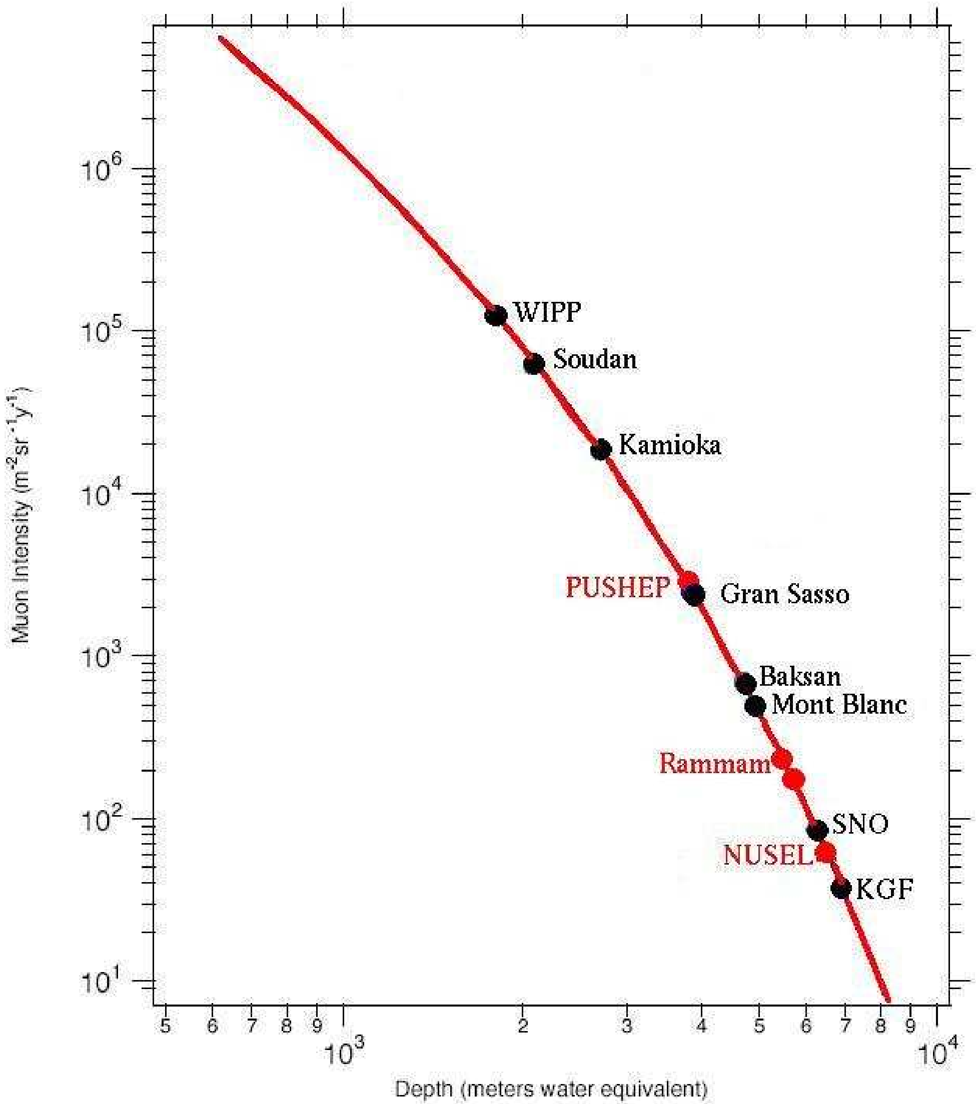


θ_{13} reach and sign of Δm^2_{32} vs wrong sign μ

Can also study CP violation: note, JHF–PUSHEP (6556 km) and CERN–PUSHEP (7145 km) are close to magic.

Location of INO

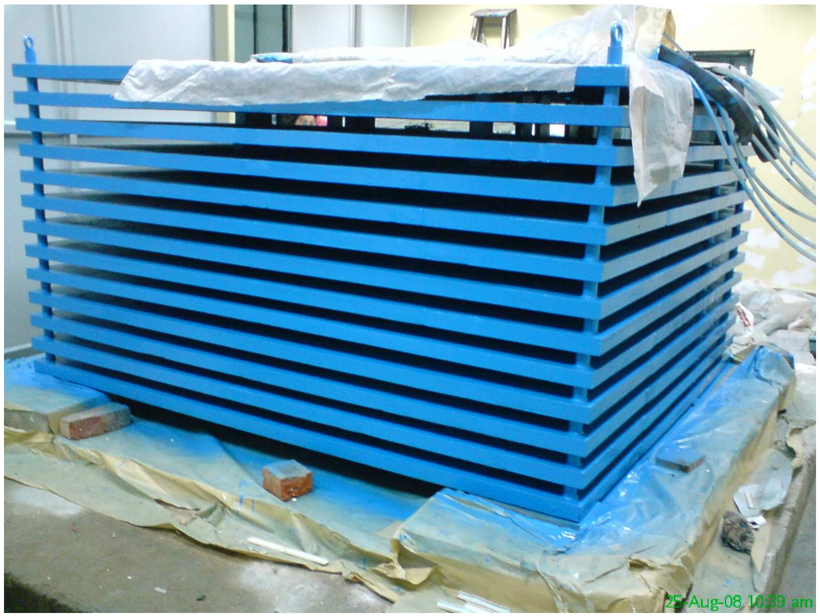
More on the site

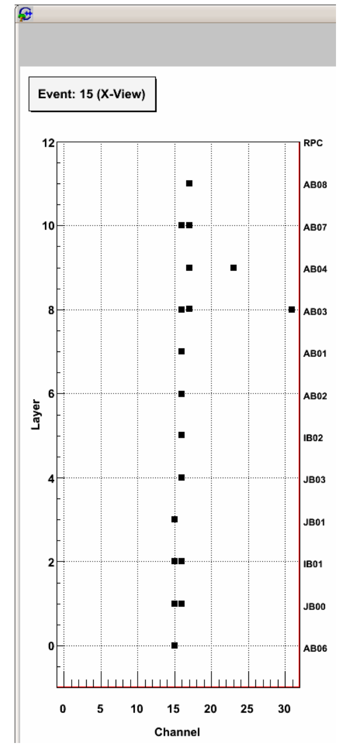


- 2.1 km long access tunnel into mountain; cavern beneath the peak
- Experimental hall I: $25m \times 130m \times 30m$ (height) built to accommodate 50 kton + 50 kton modules (future expansion)
- Experimental Hall II: about half the size, to accommodate other, smaller experiment(s).

Current Status of INO

Prototype Studies at VECC/TIFR





Magnet Weight$\sim$ 40 tons; 2.5 m $\times$ 2.3 m

13 layers of 5 cm soft iron; 12 layers of $1 \times 1 m^2$ RPCs

$NI_{\mathrm{max}} = 10,000$ A.turns

$B_{max} = 1.5$ T (expected)

800 channels of preamp, timing discriminators for avalanche RPCs

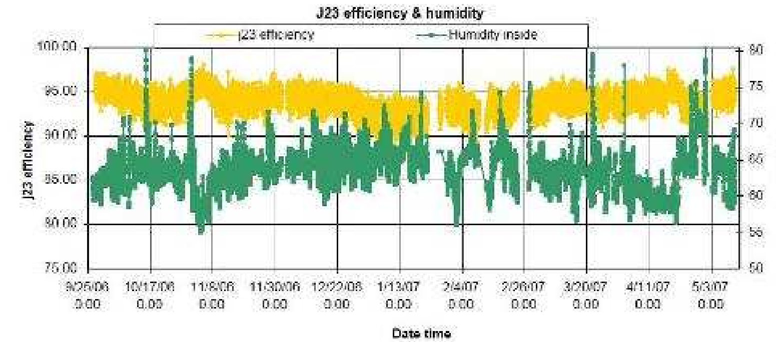
RPC Efficiency Studies

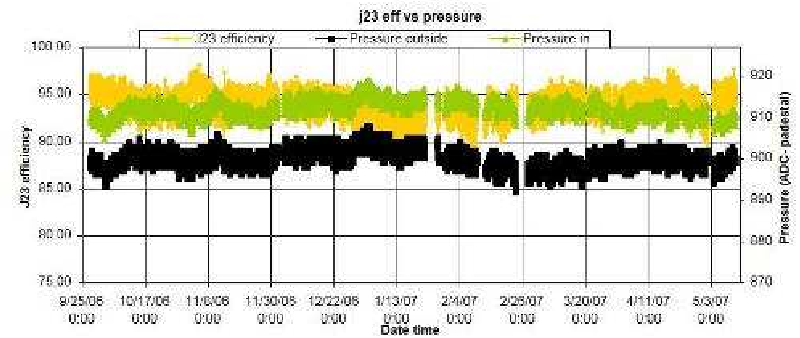
RPCs now operated in avalanche mode R134a:95.5%; rest isobutane, at 9.3 KV

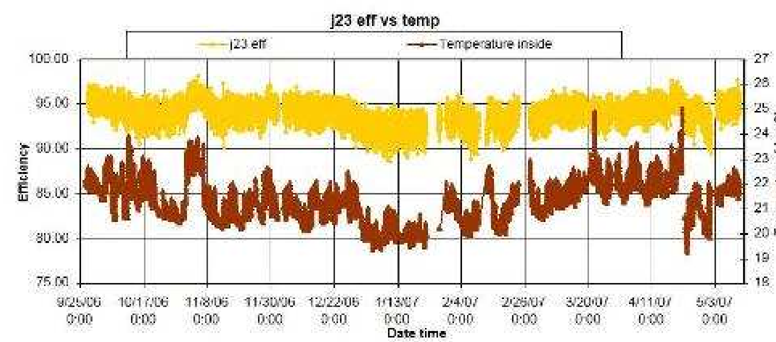
Round-the-clock monitoring of 2 RPCs for two years now—temperature, relative humidity, pressure.

Efficiency stable; chamber currents, noise rates, stable.

Testing bakelite RPCs at VECC and BARC



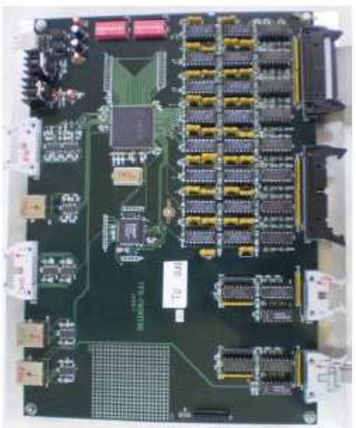




Hardware issues

- Mechanical design and assembly project report being pepared by Tata Consulting Engineers (TCE), Mumbai
- In-house electronics development for prototype for both front and back-ends.

32 ch digital front end



Control & data router

Trigger & TDC router

Data & monitor control & readout

Final trigger

Environment and Forest Clearances

- Main issue: INO is located in Manipulation Zone of Nilgiri biosphere reserve.
- No clearance or occupation of forest. (Access and buildings completely within TNEB power house campus). However,
  - disruption in nearby elephant corridor;
  - disposal of stone excavated;
  - employment opportunities for locals.
- Rapid-EIA by SACON; detailed EMP by Care-Earth: recommendations on each of these issues
- Meetings with local bodies (panchayats), wildlife scientists, activists. One/two more interaction meetings planned.

Other Updates

- Simulations for ICAL detector: comparison of GEANT3 and GEANT4; differences in hadrons, yet to be fully understood
- A DPR for a planned DBD experiment; bolometric ^{124}Sn prototype of 0.5 to 1 kg
- INO Graduate School, began in August this year
- Lectures at HRI/TIFR; Faculty from all over India
- A new centre at Mysore will take charge of the INO related activities

Costs/Schedules

	Rs (crores) 11th plan	12th plan
Infrastructure (labs, services, ...)	100	
Soft iron 50 kton	100	200
Detector (RPC, electronics, DAQ)	75	130
Misc. inclusive. salaries	45	20
Mysore Centre	50	
DST 100	100	
TOTAL	470+	450
	920 =	230 M$

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$t = 0 \leq$ 6 months?

- 12–18 months: planning, permissions, engg design
- 22 months: excavation, detector fabrication
- 12–18 months assembly of 1–2 modules

Approval Status

- DAE has given an "in-principle" approval for the project.
- The request for funding project is jointly submitted to DAE-DST.
- The requested funding for the current plan period ending March 2012 has been allocated by the Indian Planning Commission.
- Detailed Project Report with year-wise funding request is required for sanction of money, including for construction.
- DPR is in the approval chain. Expected to take a few more months.
- Thank You

Additional Slides

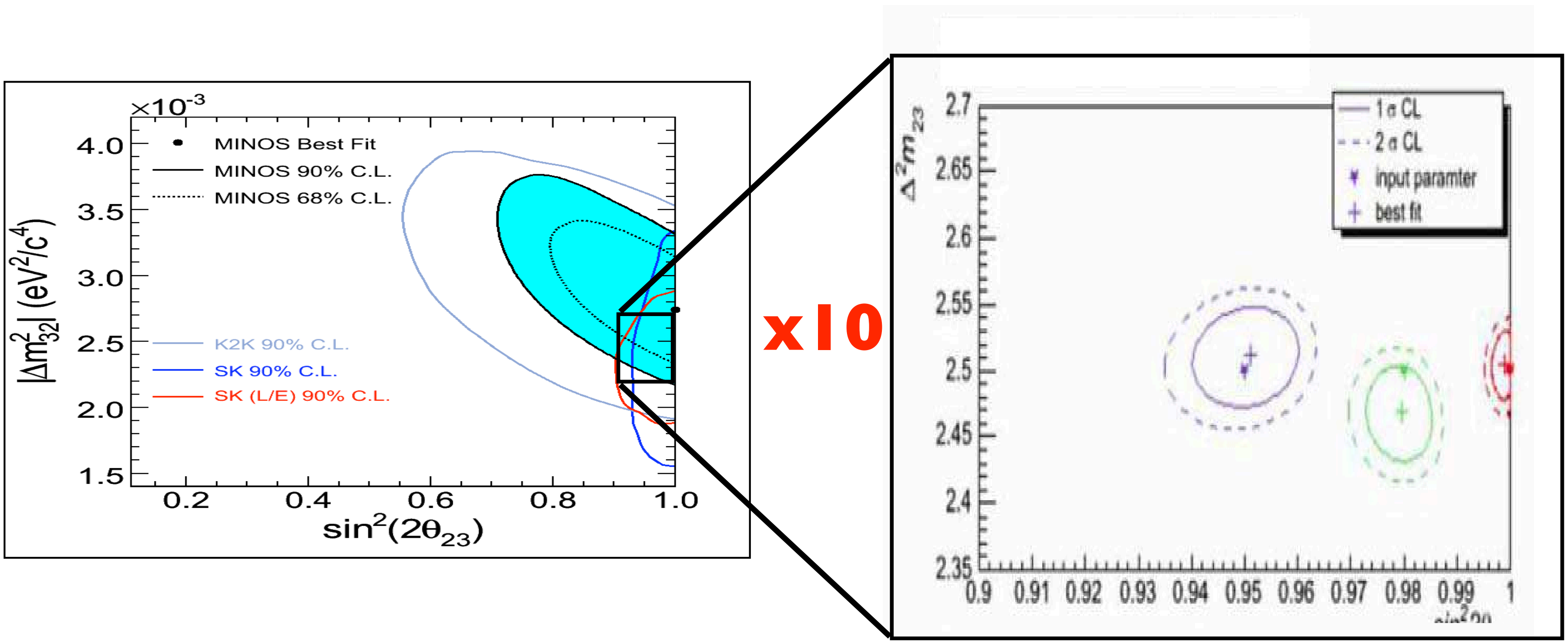
3σ Precision of parameters

at $\Delta m^2_{32} = 2.0 \times 10^{-3}$ eV^2 and $\sin^2\theta_{23} = 0.5$

Experiment	P($\lvert\Delta m^2_{32}$)	P($\sin^2\theta_{23}$)	hierarchy
Current	88%	79%	–
MINOS	17%	65%	–
CNGS	37%	–	–
NOνA (6×10^{21} pot)	$\sim$ 5%	$\sim$ 9%	in comb
T2K (Super-K, 0.75 MW)	12%	46%	
ICAL (50 kton)	20%	60%	$\sin^2 2\theta_{13} > 0.06$

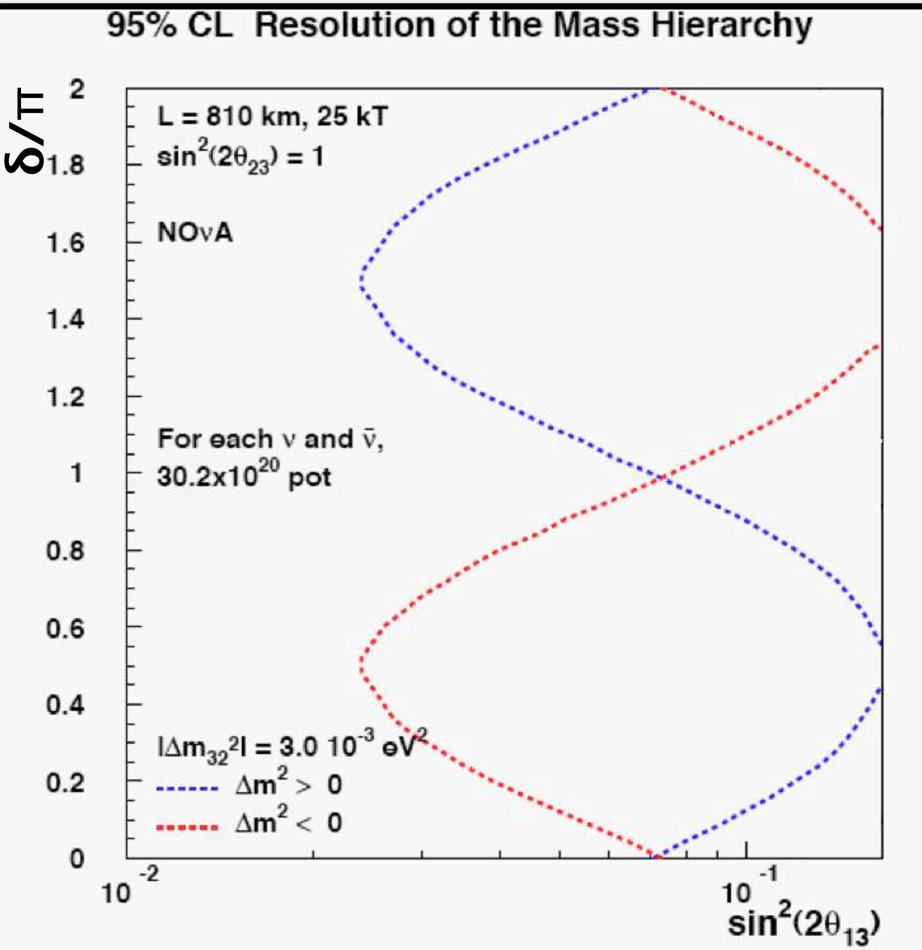
δδ Disappearance Measurement

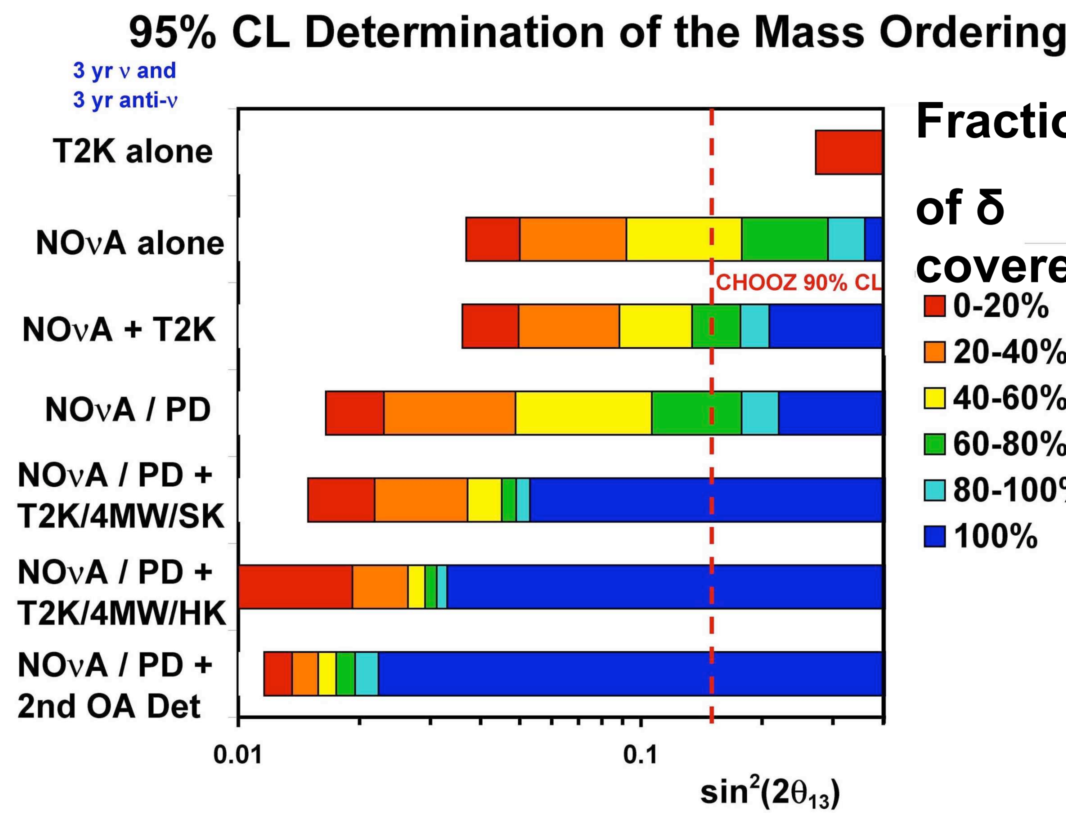
- **NOδA can still do** **δδ disappearance measurement**, **measure the mixing angle δ23 and δm²23.**



Measure sin²2δ23 to 0.5-1%

Hierarchy Sensitivity





Measurement unique to NOδA

Other issues w.r.t RPC R & D

- RPC timing
- RPC charge distribution
- Mean charge vs voltage (seen to be linear)
- RPC noise
- Gas composition ($C_2H_2F_4$ (R-134a), Argon, Isobutane ($\leq$ 8%))
- RPC Cross talk (as a function of gas mixture)
- Gas mixing