# *India-based Neutrino Observatory (INO)*

## Status Update

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For the INO Collaboration

(http://www.imsc.res.in/~ino)

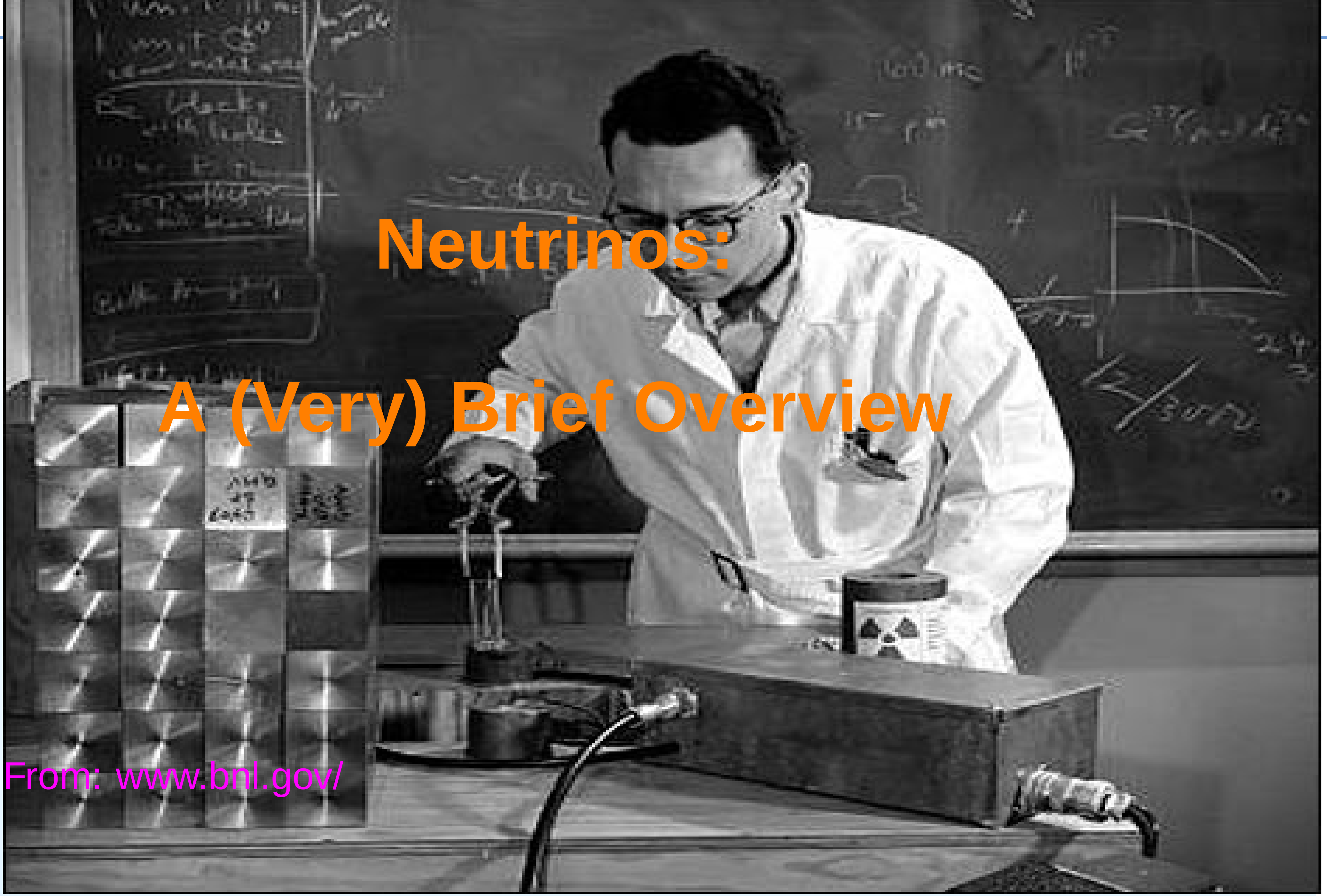
## Dedicated to

# C V K Baba
# 1937–2006

- In particular, for suggestions that led to an iron calorimeter detector as the choice for INO
- Also, for the first contact with GSI, Chennai, which led to finding the site at Masinagudi, and, later, at Rammam
- Above all, for his enthusiam, experience and guidance, that motivated us and was greatly responsible for the considerable progress made in INO

# Outline of talk

- Brief overview of neutrino properties
- Brief overview of the INO proposal and goals
- INO: Status Update



# Neutrinos:

# A (Very) Brief Overview

From: www.bnl.gov/

# A Schematic of Neutrino Properties

Neutrino masses are not well-known. Oscillation studies only determine the mass-squared differences: $\Delta m_{ij}^2 = m_i^2 - m_j^2$ and the mixing angles $\theta_{ij}$.

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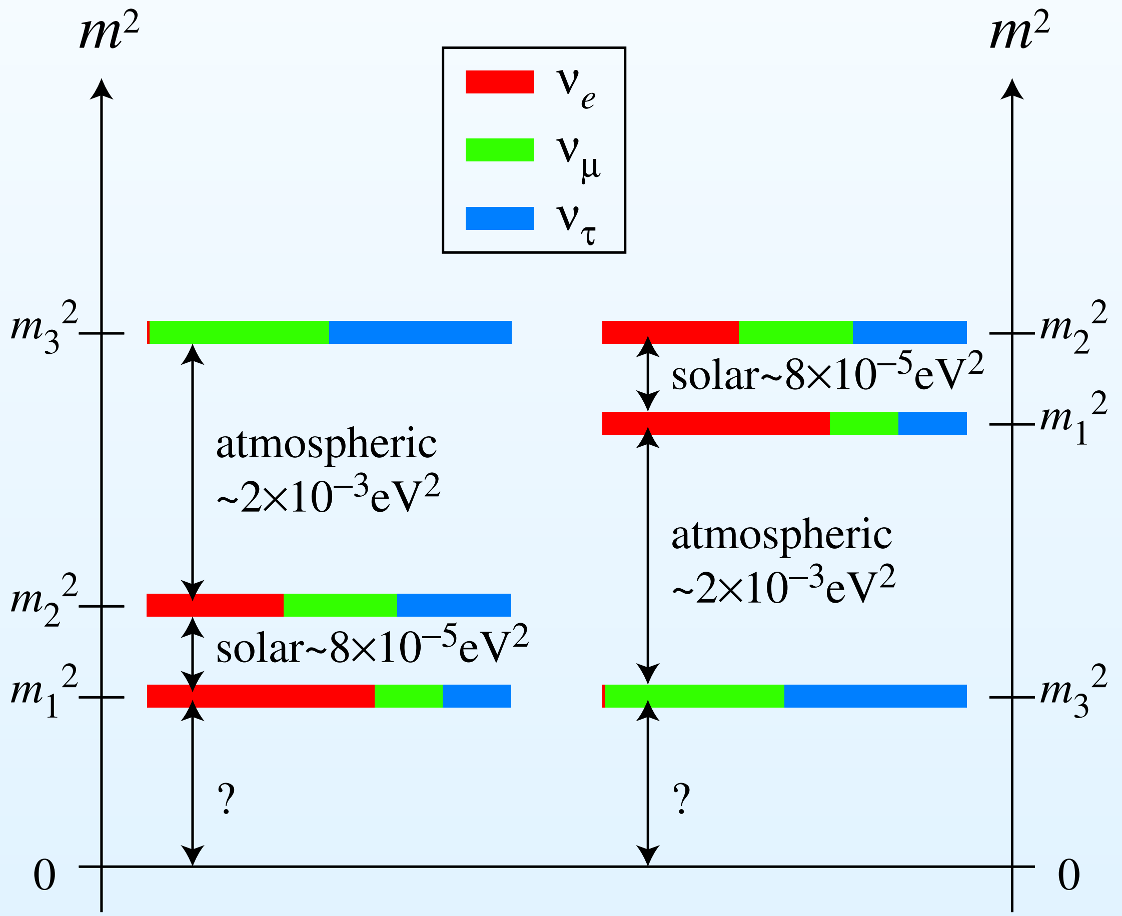

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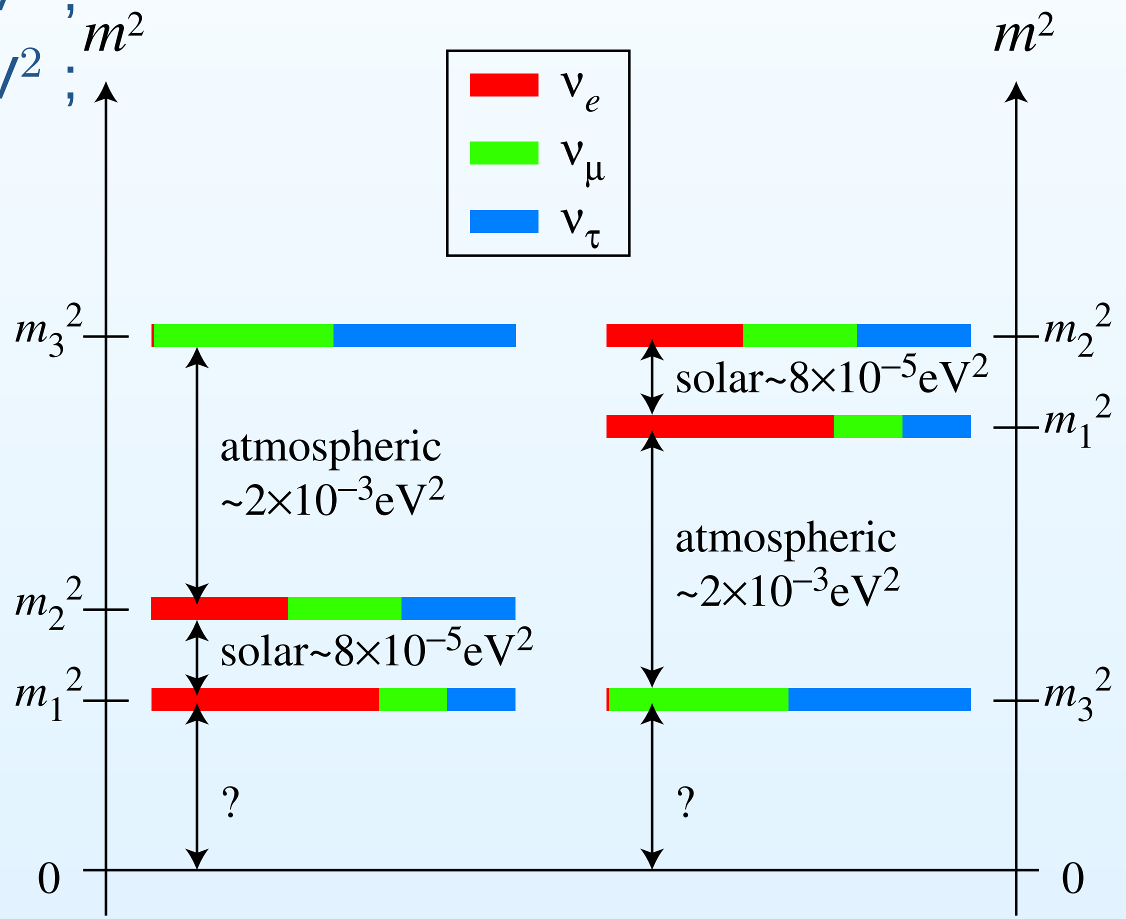
$\Delta m^2_{21} \sim 0.8 \times 10^{-4}$ eV$^2$ ;
$|\Delta m^2_{32}| \sim 2.0 \times 10^{-3}$ eV$^2$ ;
$\sum_i m_i < 0.7$–2 eV.



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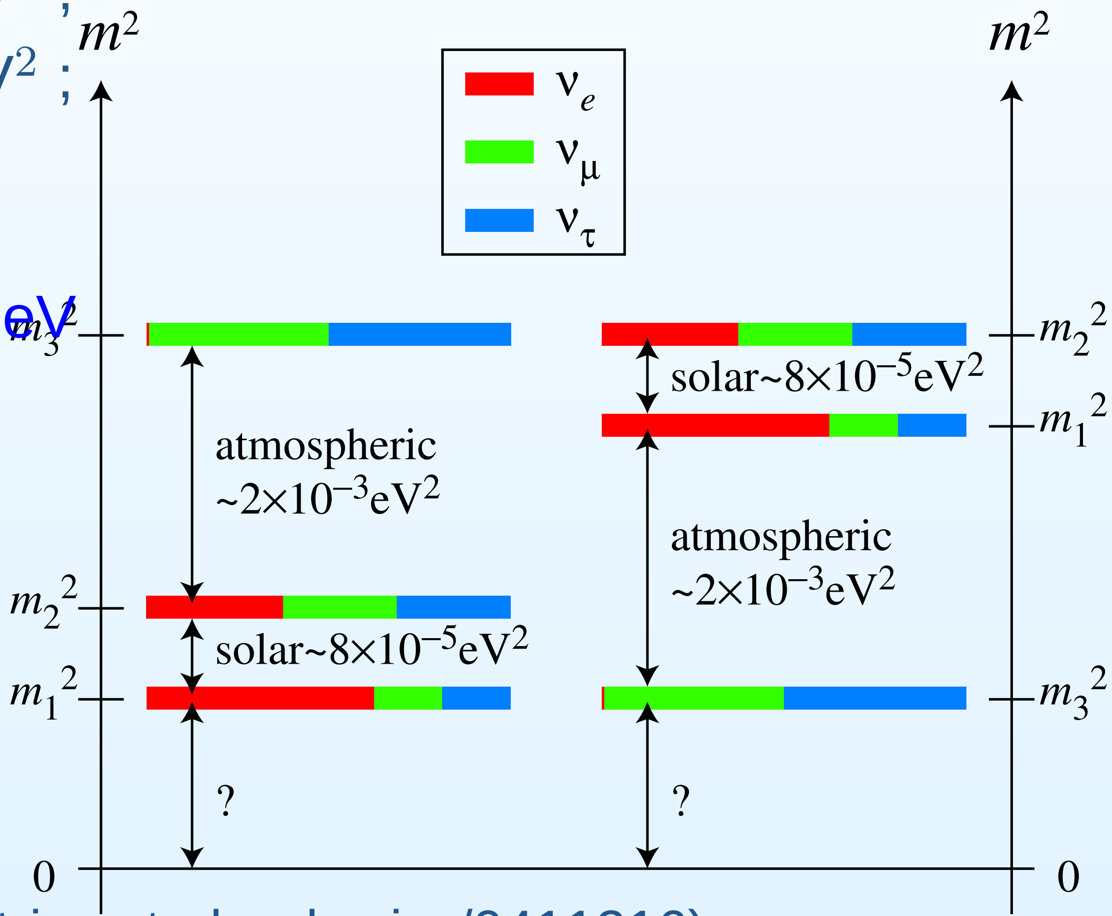
- $m_1 \sim m_2 \sim m_3 \sim 0.2$ eV
(Degenerate hierarchy)

- $m_1 < m_2 \ll m_3$
(Normal hierarchy)

- $m_3 \ll m_1 < m_2$
Inverted hierarchy




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

# India-based Neutrino Observatory: Quick Review

# The INO Collaboration

- Spokesperson: N K Mondal
- 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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  - Physics Studies
  - Detector R & D, including construction of a prototype (latter in progress)
  - Site Survey, human resources development, interaction with industry

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- Other detectors/physics like neutrinoless double beta decay?

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- Stage II : Study of long-baseline neutrinos, from a neutrino factory or beta-beam
- Other detectors/physics like neutrinoless double beta decay?
- Should be an international facility

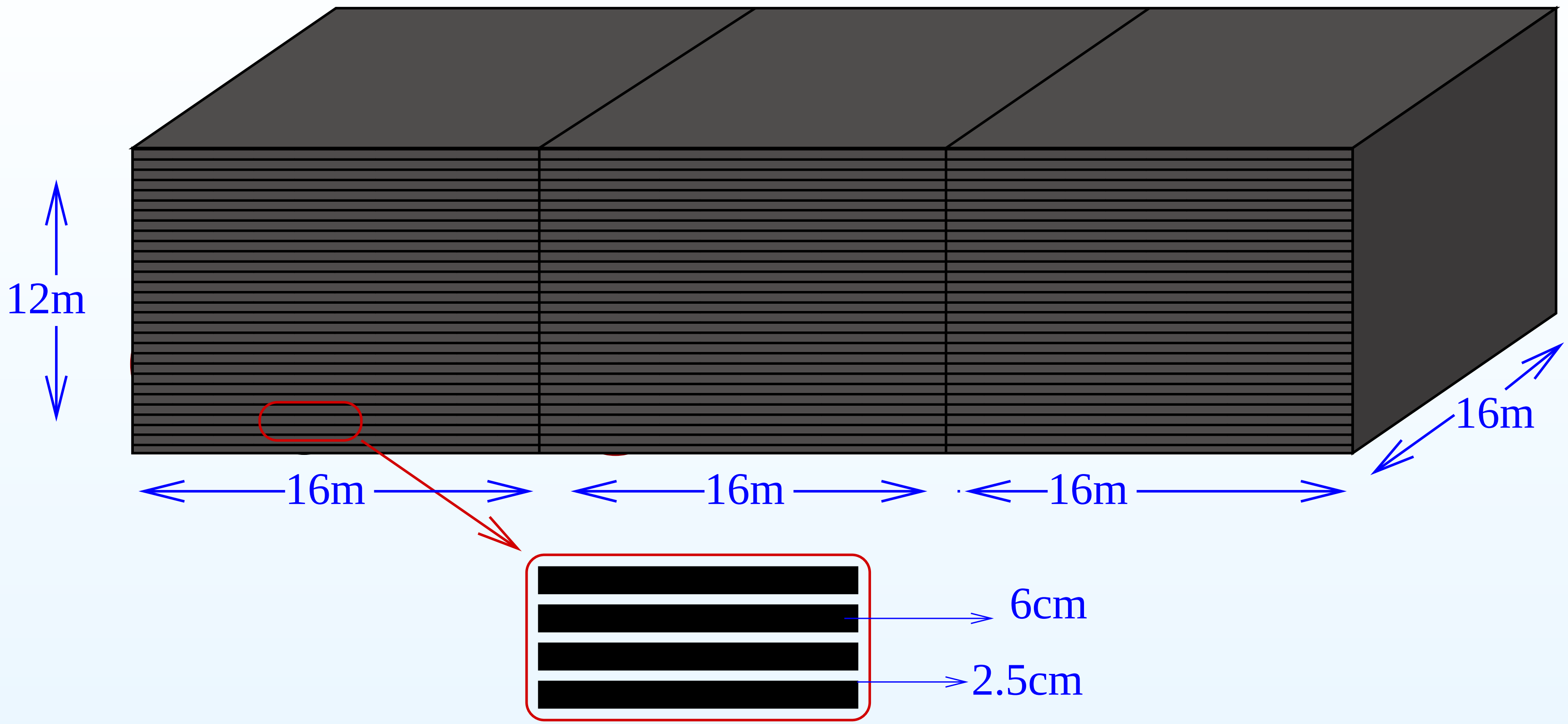
# The choice of detector

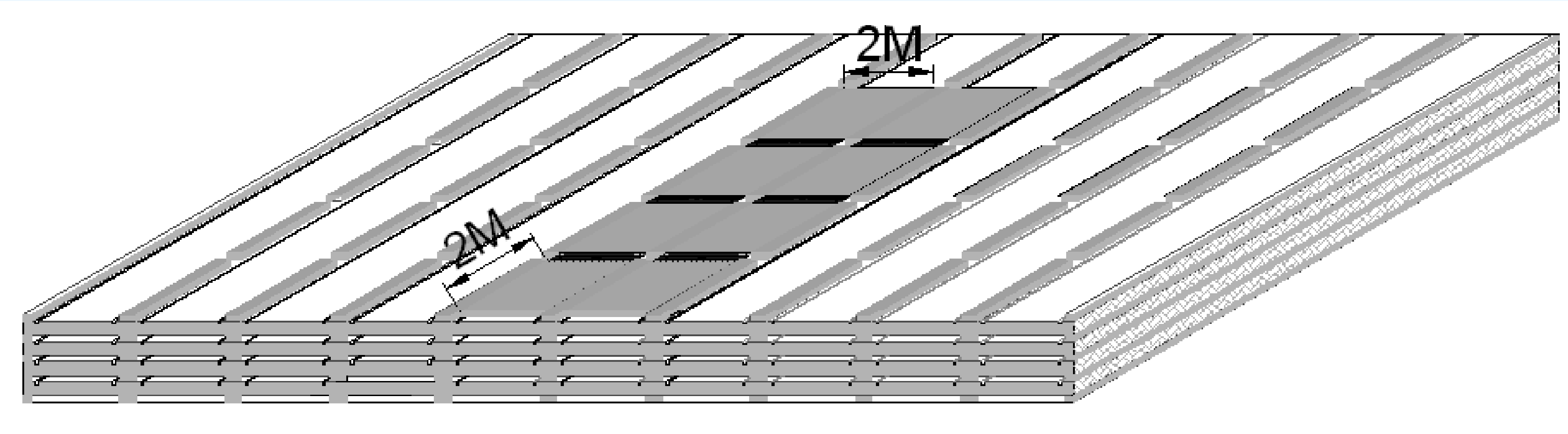
- Existing Detectors world-wide
  - Cerenkov: Super-K (50 ktons water); SNO (1 kton heavy water)
  - Iron Calorimeter: Fermi-Lab MINOS (5 kton magnetised iron)
- ICAL
  - Large target mass: 50 kton
  - Good tracking and energy resolution
  - Good directionality; hence nano-second time resolution for up/down discrimination
  - Good charge resolution
  - Ease of construction (modular)

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

Note: Is sensitive mainly to muons (and hadrons), not electrons

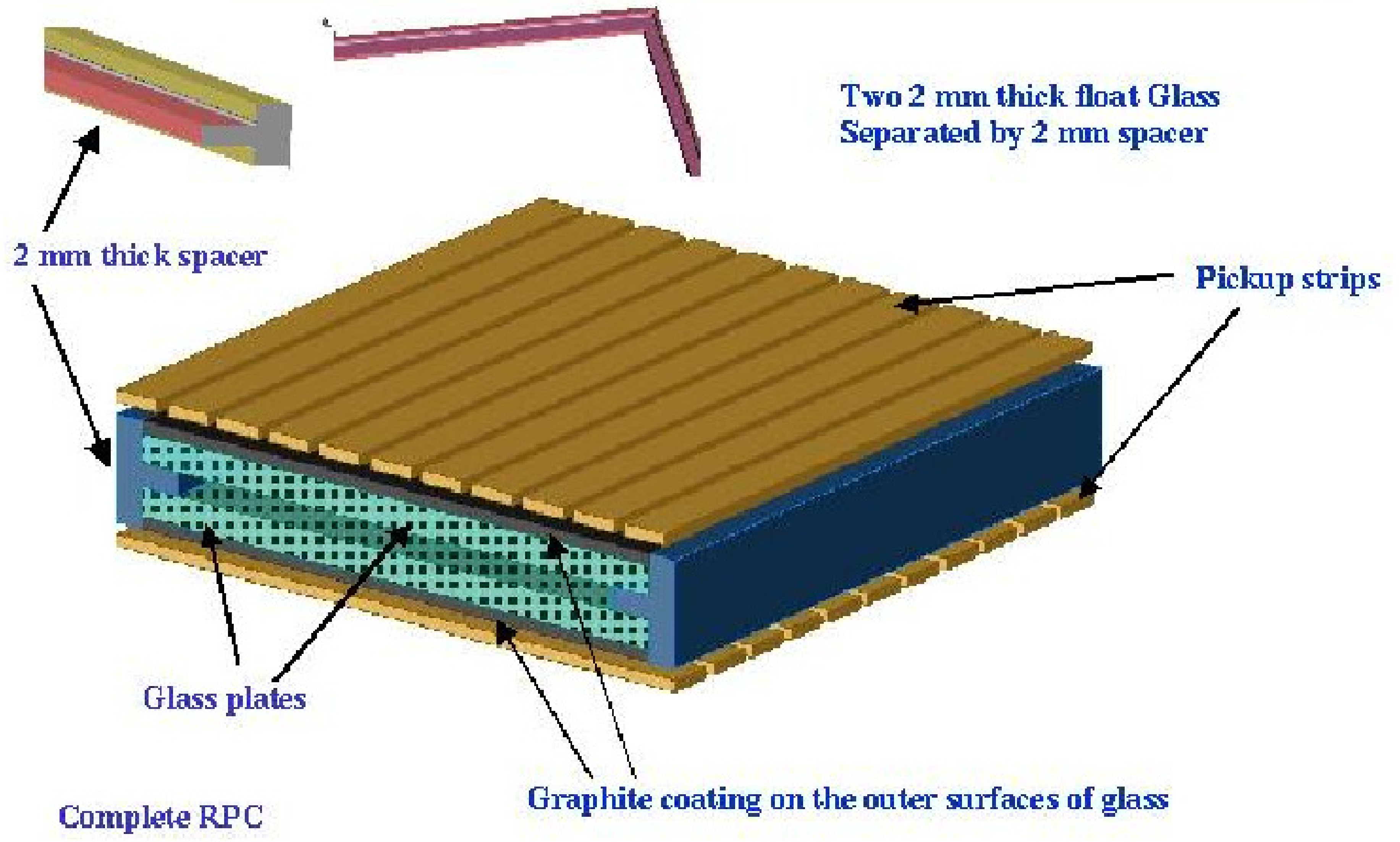
# The ICAL detector



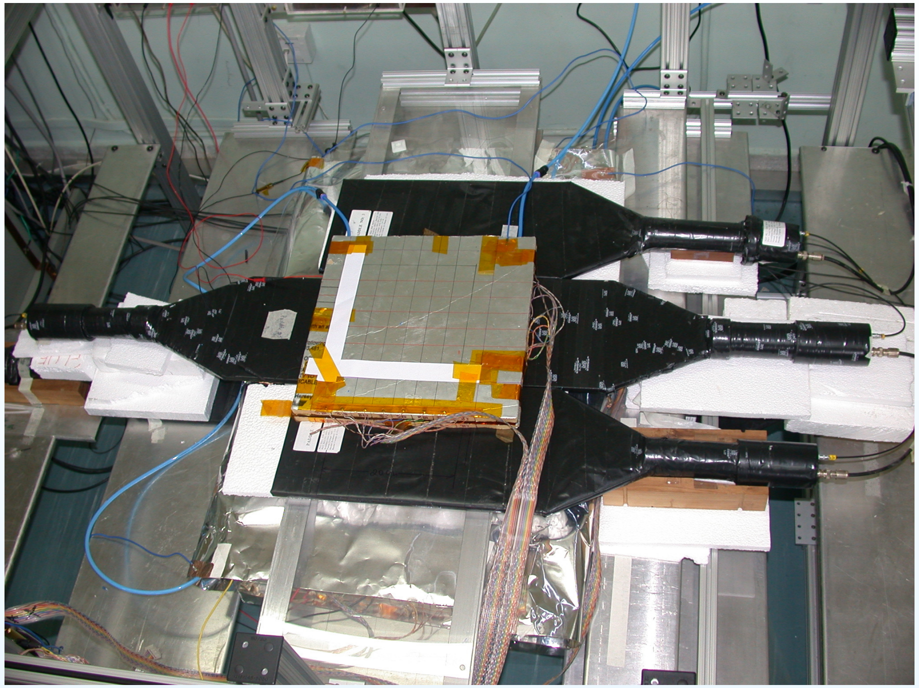



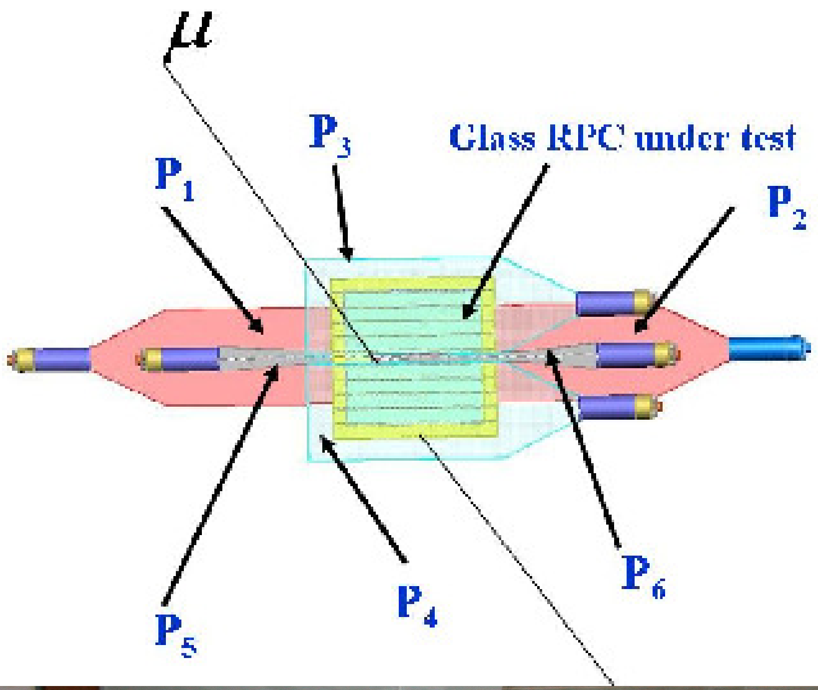
# The active detector elements: RPC

RPC Construction: Float glass, graphite, and spacers



# Fabricating RPCs

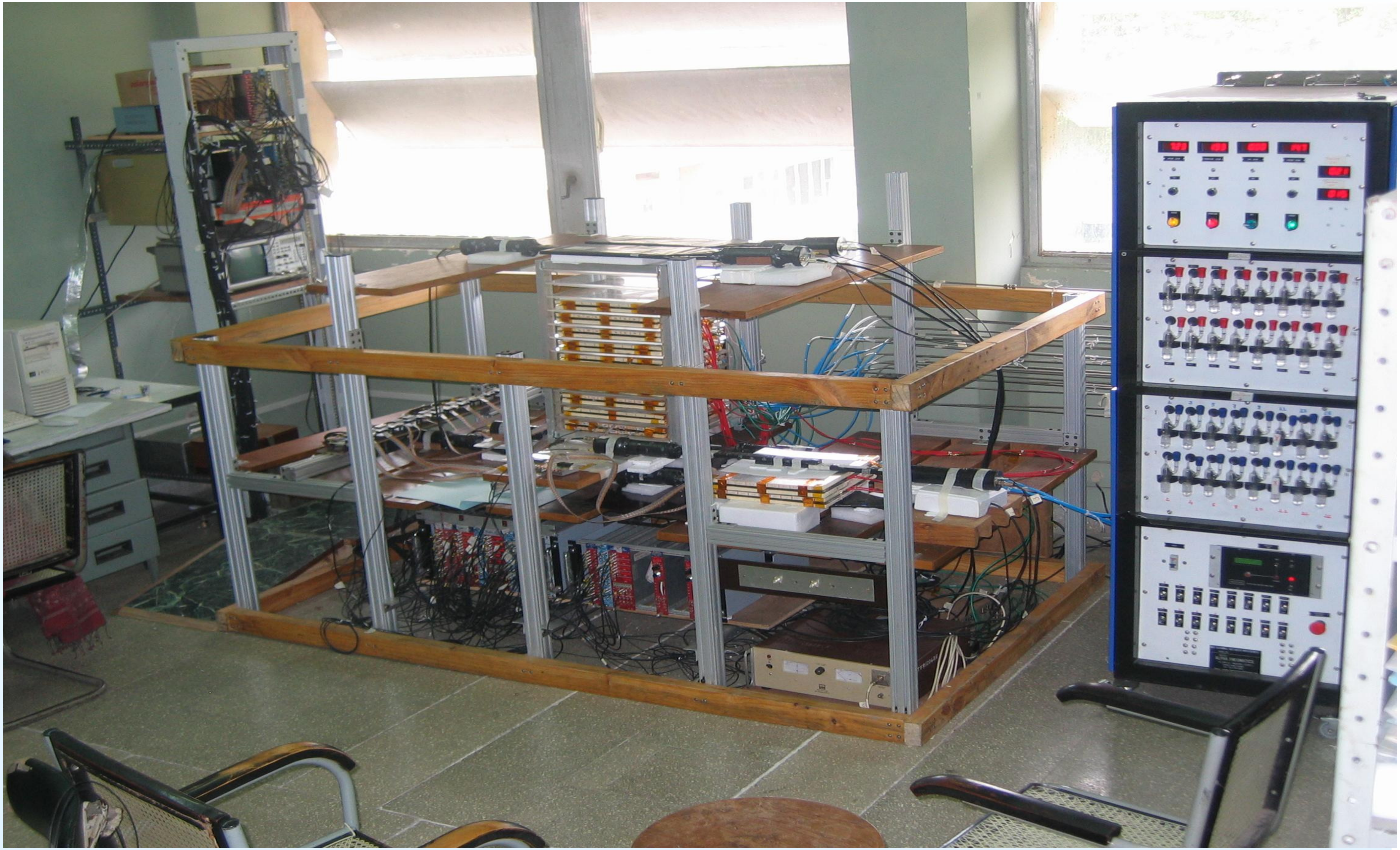




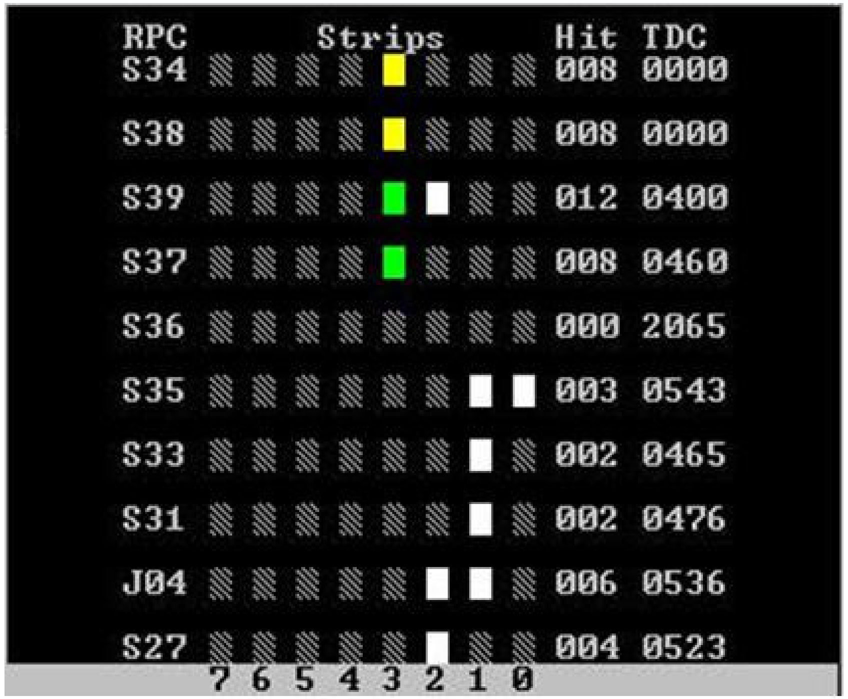

Small ↑

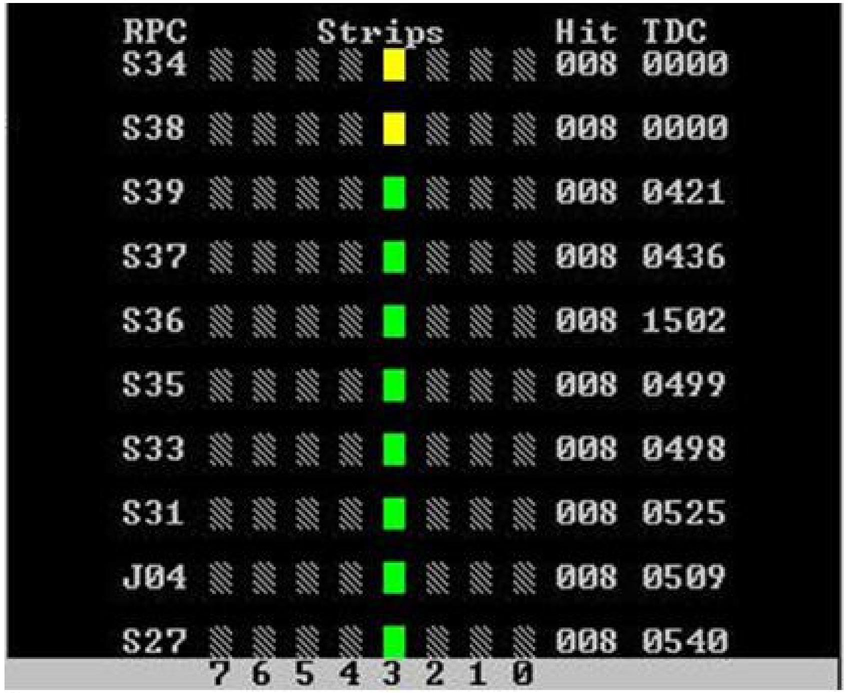
Large →

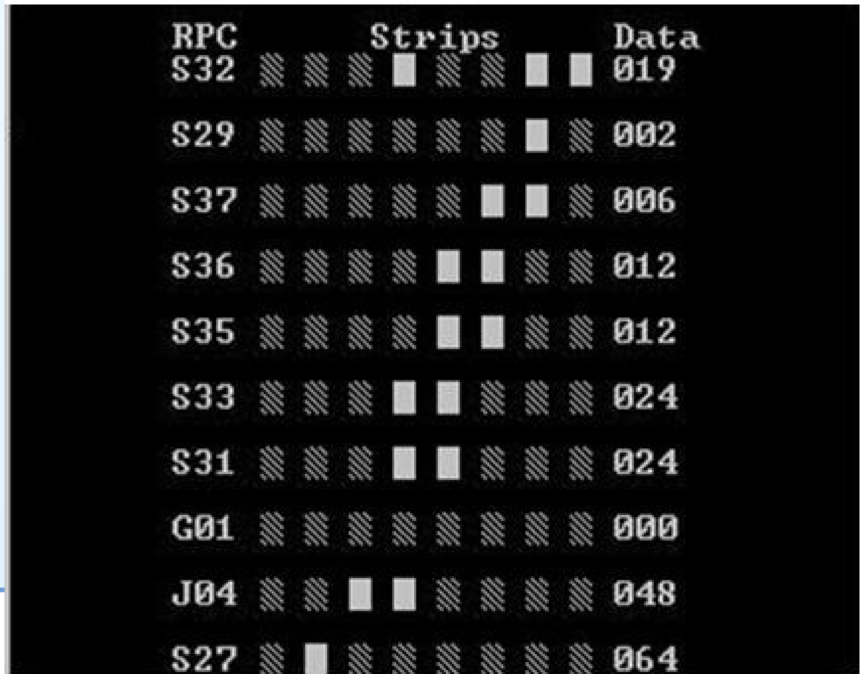
# For the prototype . . .

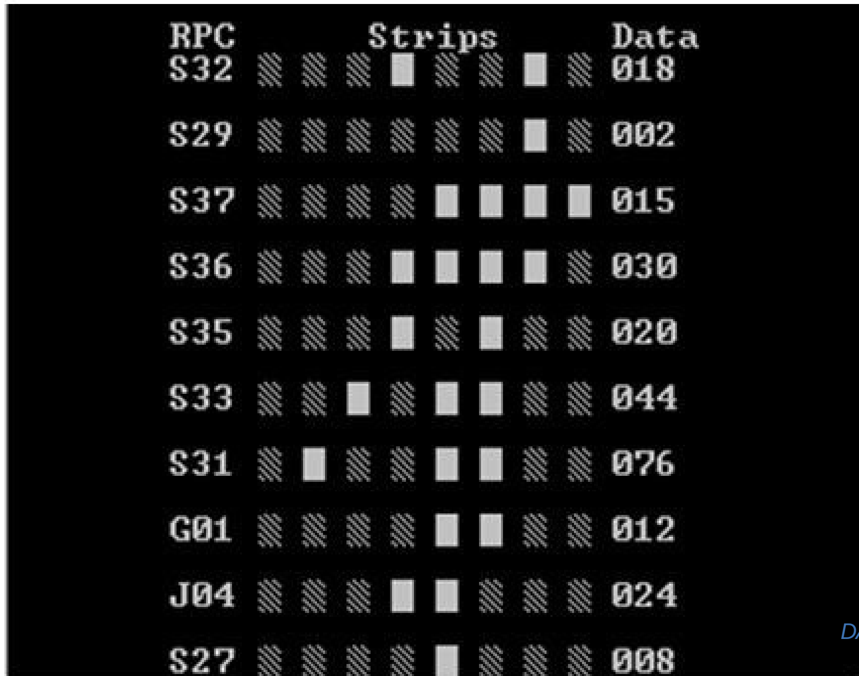


# Tracks from atmospheric muons

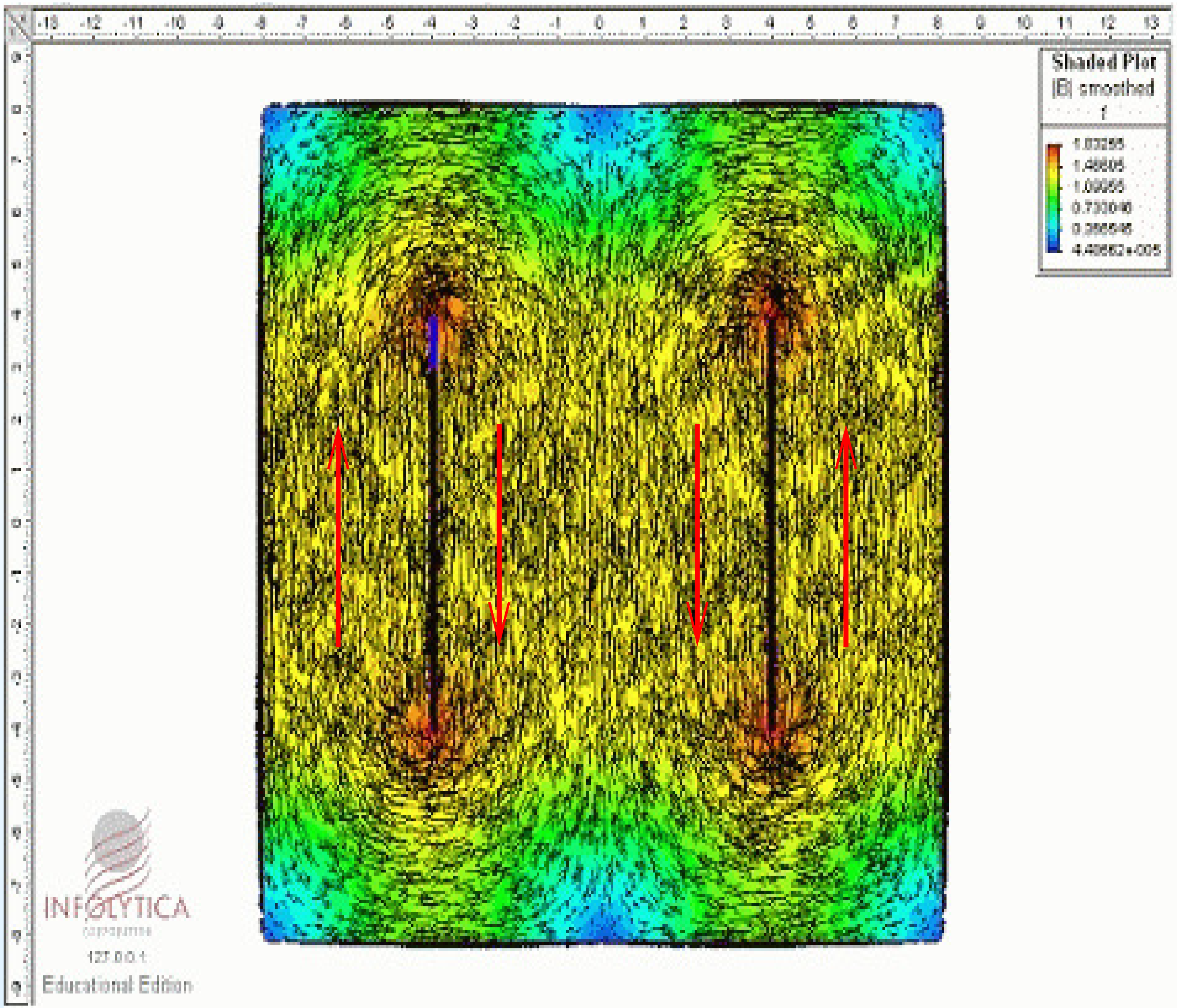


# Magnetic studies: field simulation



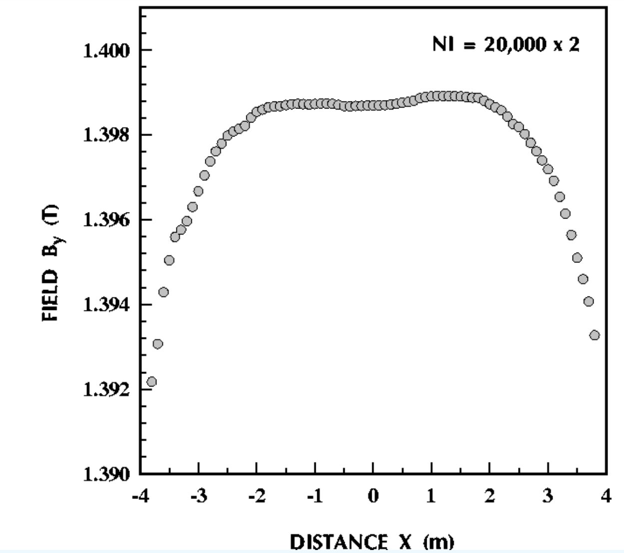

Orange : high B

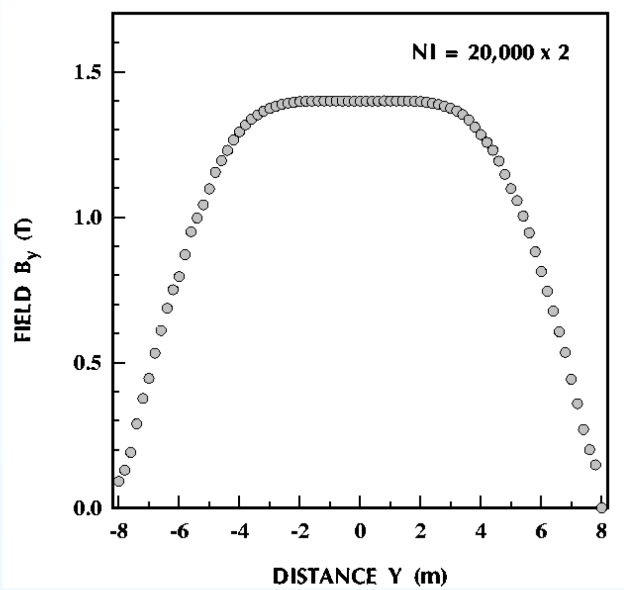
Yellow : medium B

Green : lower B

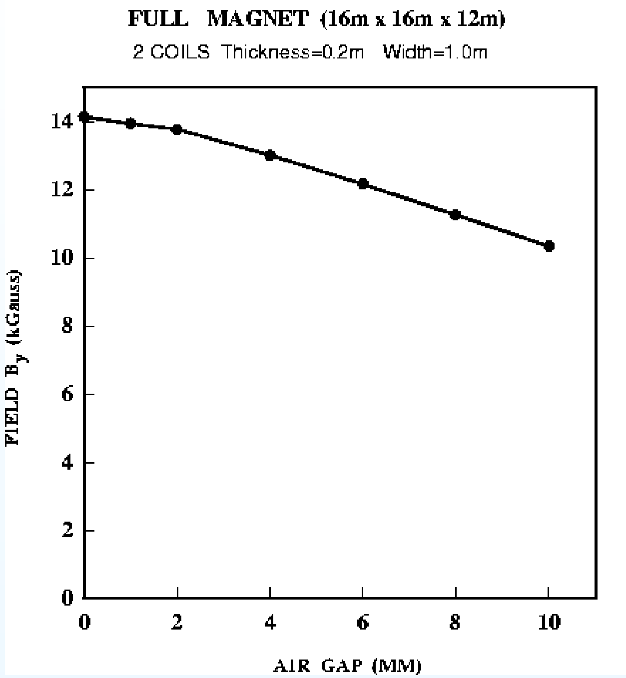
Blue : least B

# Magnetic field simulation




Field when there is a gap in a plate (dividing it along x-axis)



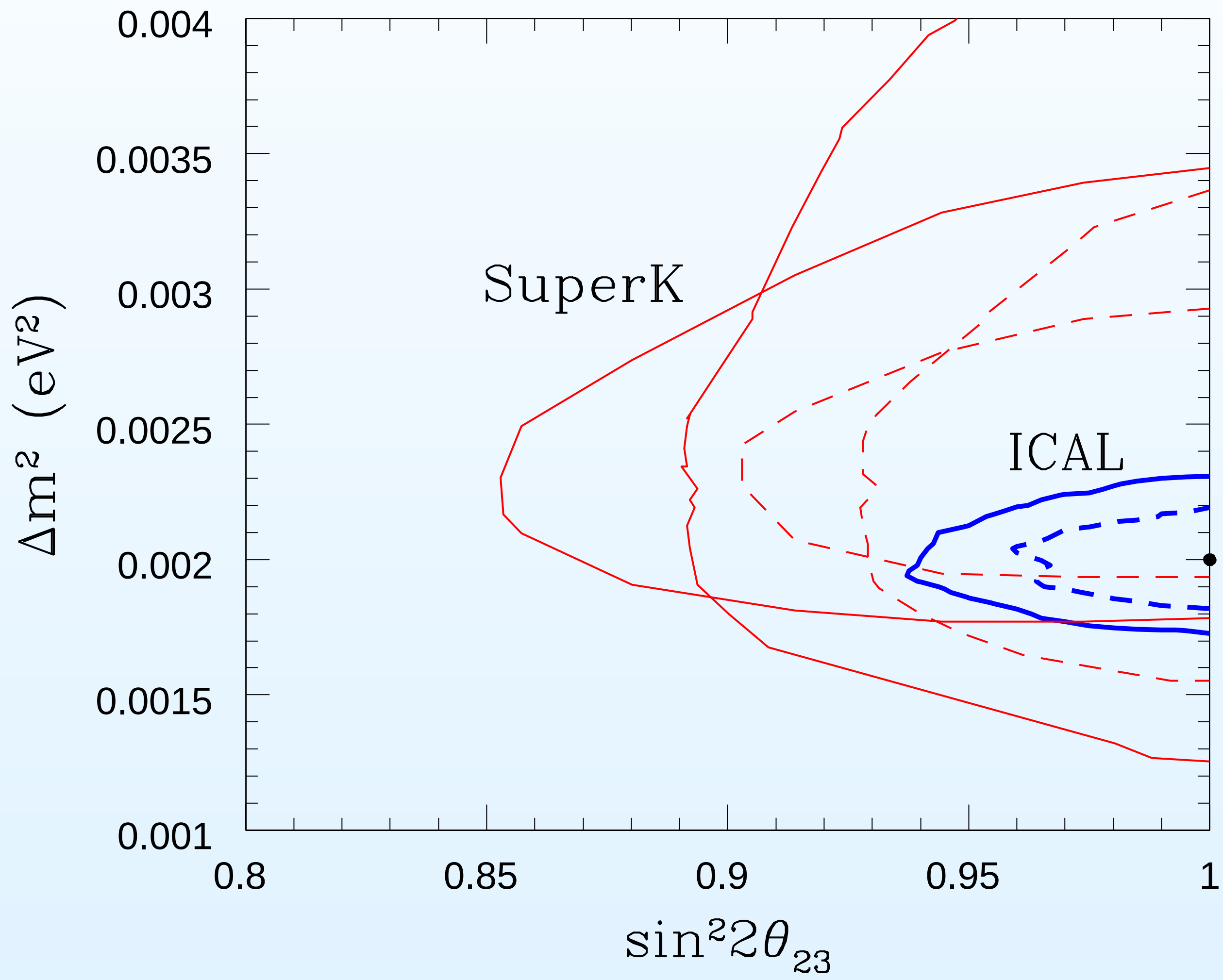

- Field in 16 kton module
- Field in $x$-direction uniform to within 0.25%.
- Field in $z$-direction uniform except close to edges.
- Cannot tolerate more than 4 mm gap in plate welding.
- Need to study assembly scheme, mechanical stability, transient and error analysis

# 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 $\times 10^6$ |

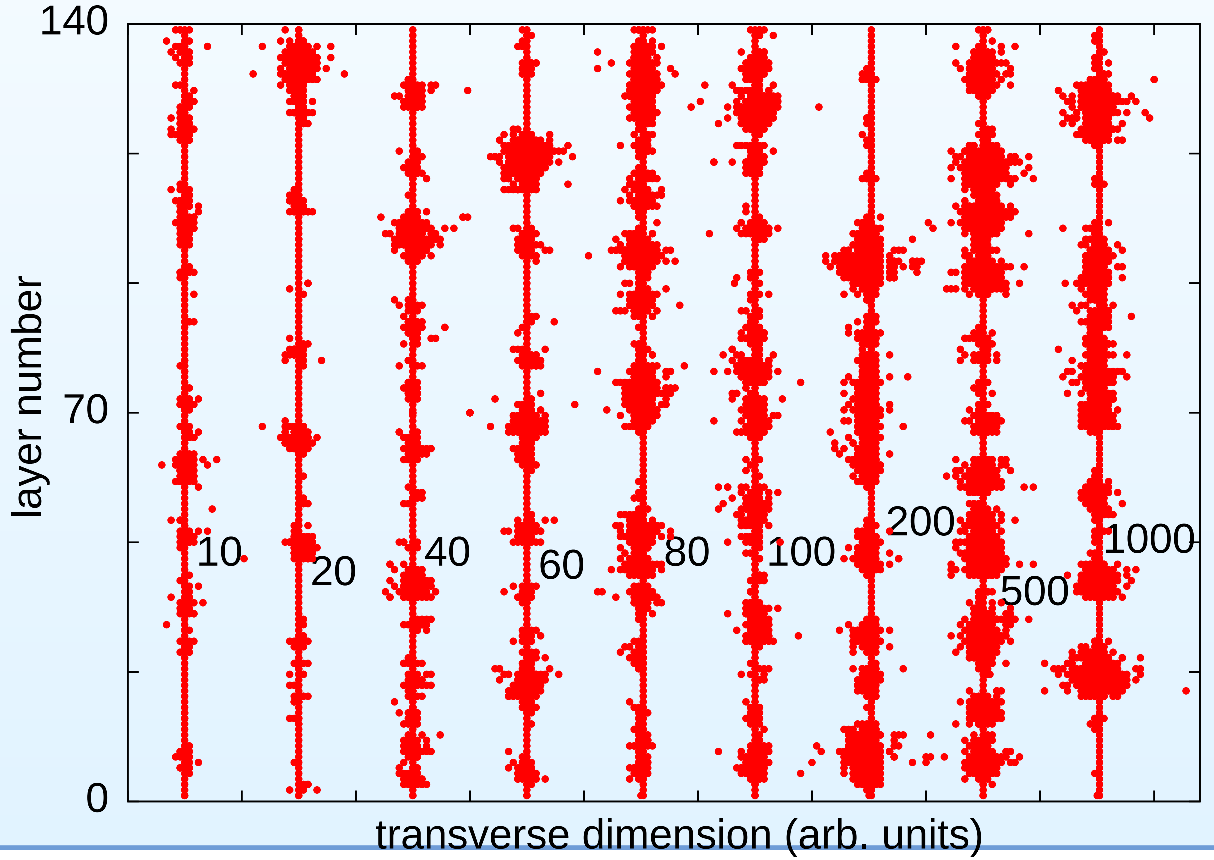
# Event Simulations

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

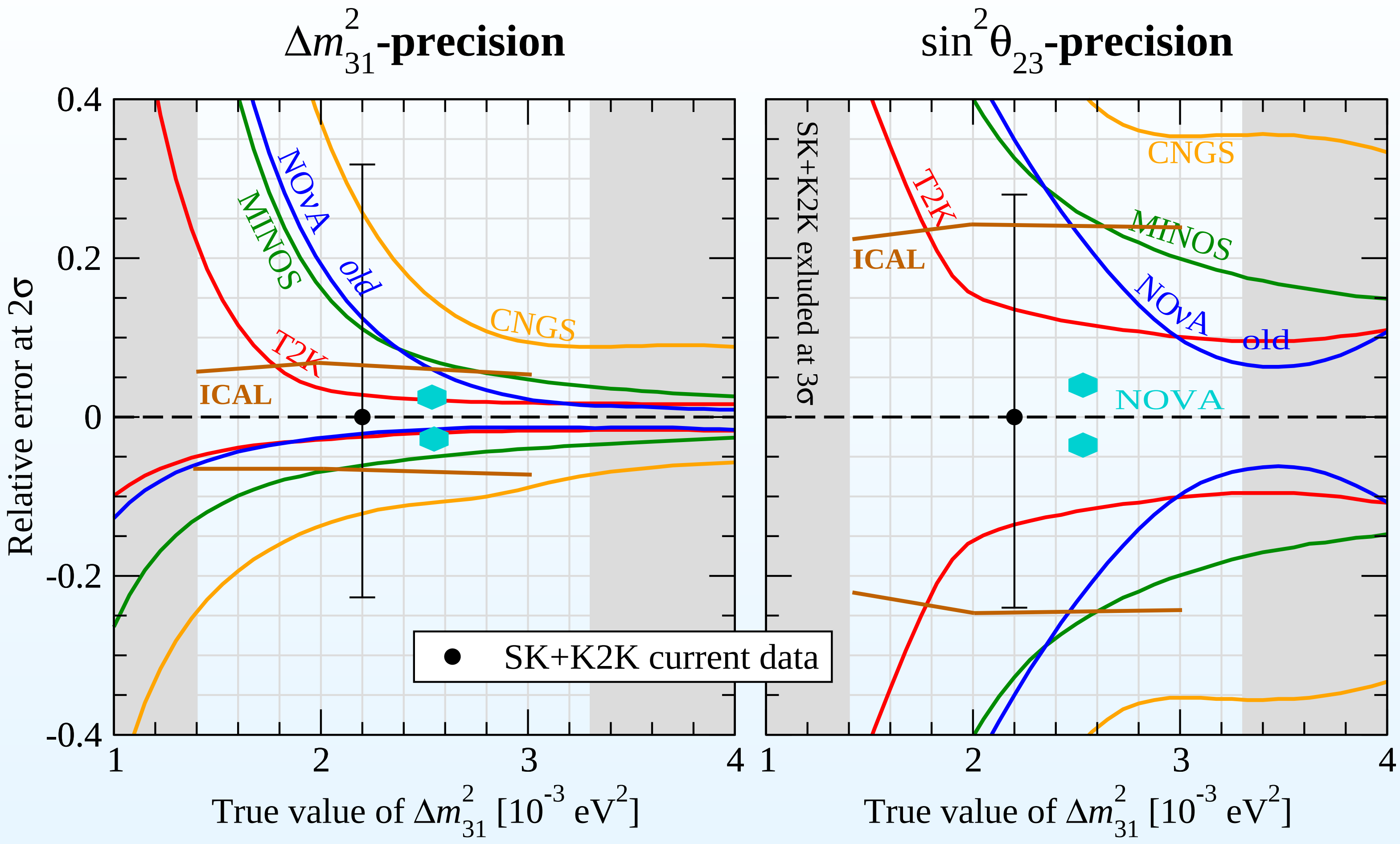


# Event Simulations II

- Source: Cosmic ray muons, both as background to neutrino events and high energy muons as events
- ICAL simulation with GEANT, using 1 Tesla uniform magnetic field in the $y$-direction.



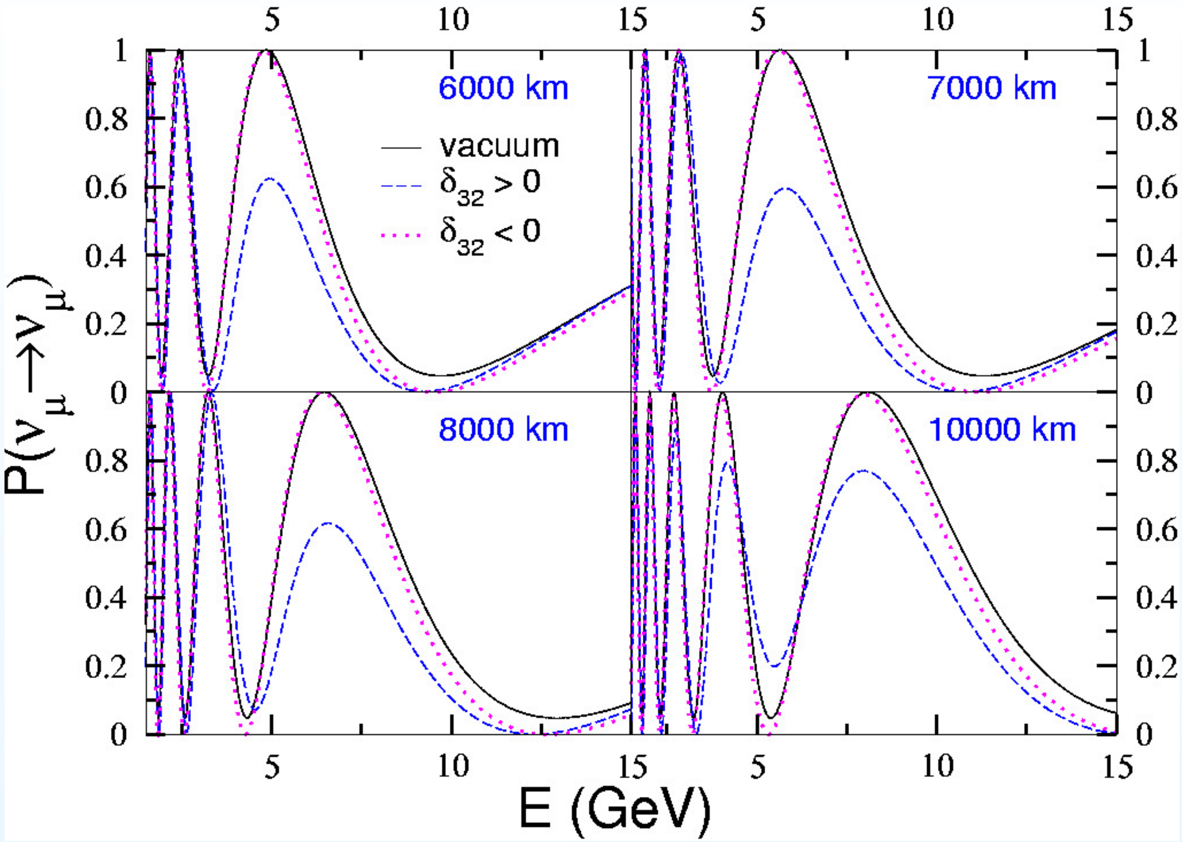
# Physics Studies with ICAL




5 years' running; new NOVA 25kton, 6 yrs ($6 \times 10^{21}$ pot).

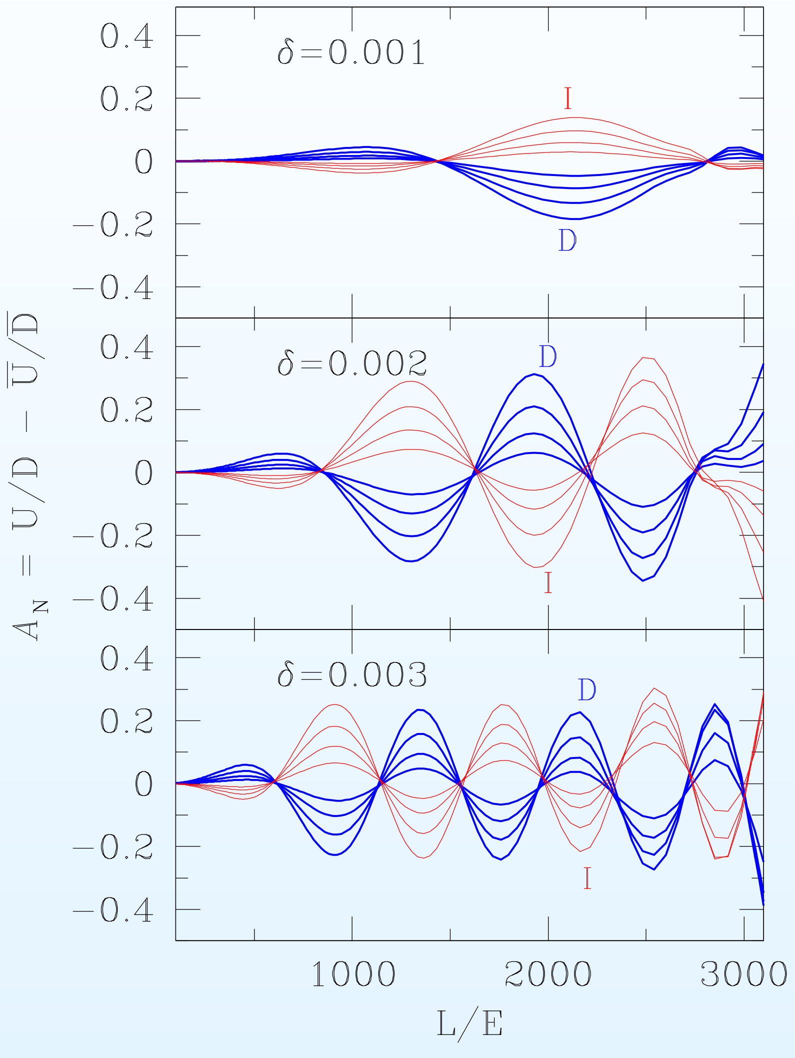
*Adapted from:* P. Huber, M. Lindner, M. Rolinec, T. Schwetz and W. Winter, hep-ph/0412133.

# 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 $\delta$.
- 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 $\theta_{13} = 5, 7, 9, 11^\circ$

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)

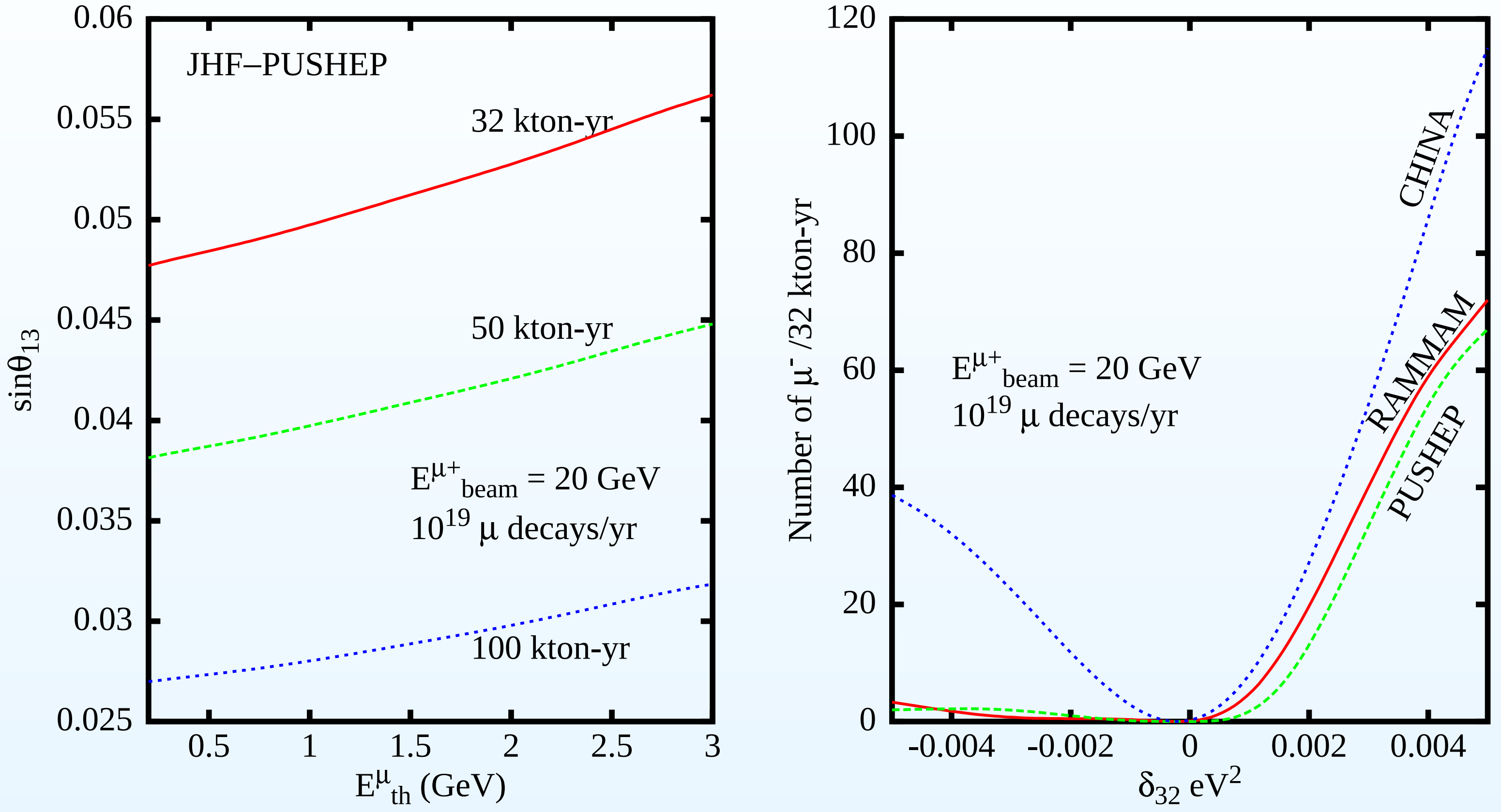
D: Direct/normal; I: Inverted hierarchy

# Other physics possibilities

. . . with atmospheric neutrinos

- Discrimination of octant of $\theta_{23}$ 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 $\delta b$, 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 $\nu_\mu$ to active $\nu_\tau$ and sterile $\nu_s$ from up/down ratio in “muon-less” events?

# Stage II: Neutrino factories and INO




$\theta_{13}$ reach and sign of $\Delta m^2_{32}$ vs wrong sign $\mu$

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


India-based Neutrino
Observatory: Status Update

# RPC status

- A series of small (30 $\times$ 30 cm) and large (1 m $\times$ 1m) RPCs being fabricated and tested
- Two RPCs using Japanese float glass operative for more than 14 months in avalanche mode without loss of efficiency
- Identified companies for polycarbonate spacers, buttons, gas inlet/outlet nozzles. Designs prepared, dies and moulds developed, samples fabricated and quality checked. Now about to go for production
- Glass coating: Collaboration with UDCT, Mumbai and Nerolac paints. Nerolac trying to develop the paint Coating being tried through a local small scale industry
- Glass edge and corner shaping: Jigs developed. Local industry identified. Samples being tried

# RPC status . . .

- Foam-based signal pickup panels: Industry identified. Discussed specs. Samples made. Extensive tests such as characteristic impedance, delay, permittivity, capacitance etc measured and qualified. Ready to go for production.
- Mylar sheets for insulation: Local brand identified. Received samples. Electrical insulation tests carried out. Satisfied and is being used already.
- Gas mixing systems: Designed and developed with help of a local industry. Two made for TIFR, one for BARC, one for VECC, one for IITB in progress. 2-3 more in the pipe line.
- Optimising techniques for making large size chambers.

# Electronics and Data Acquisition System

- Anode/cathode pick-up signals (induced on X- and Y-pickup strips) sent to timing discriminators
- Also feeds latch and multiplexed TDC
- For streamer/avalanche mode, signal $\sim$ 100–300 mV/1–5 mV across 50 ohms
- Impedance matched to input of timing discriminator or preamp
- So for avalanche mode, fast current preamplifiers (risetime $\sim 1$ nanosec) with gain 10–30 needed. 4 prototypes designed by ED/BARC and fabricated in BEL, Bangalore. Price/supply negotiations with BEL on-going.
- Design and fabrication of analog & timing discriminator board complete

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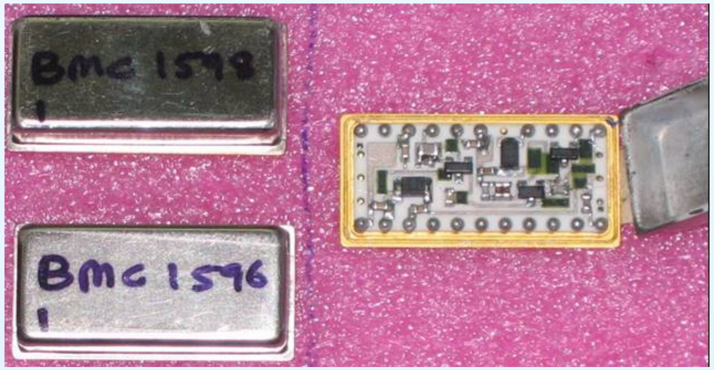
Discrete comp. pre-amp

Hybrid versions (BEL-ED/BARC)

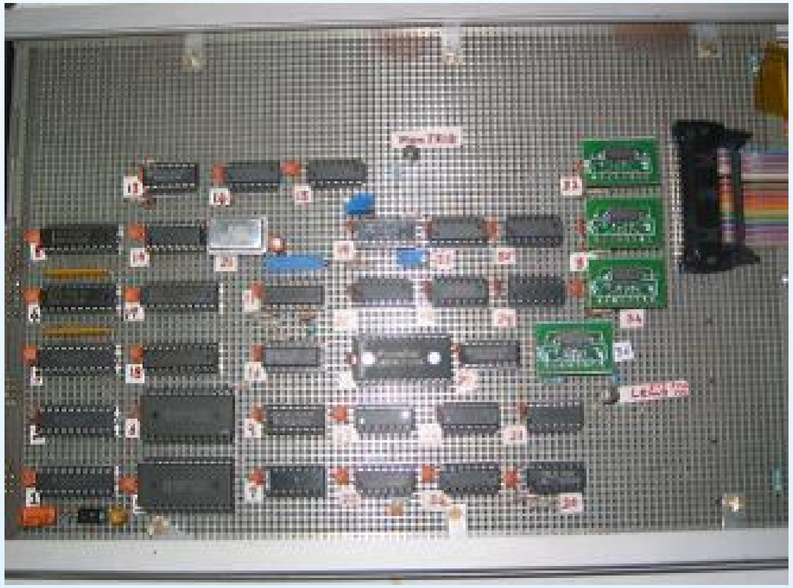


## Status of DAQ, etc

- Physics-based choice of trigger initiates DAQ
- Event trigger generated by FPGA-based home-built module
- VME-based DAQ coupled to PCs with Linux OS
- In-house electronics development (TIFR): Full FPGA based data acquisition system for prototype fabricated and being tested

16-ch analog front end module

DAQ control



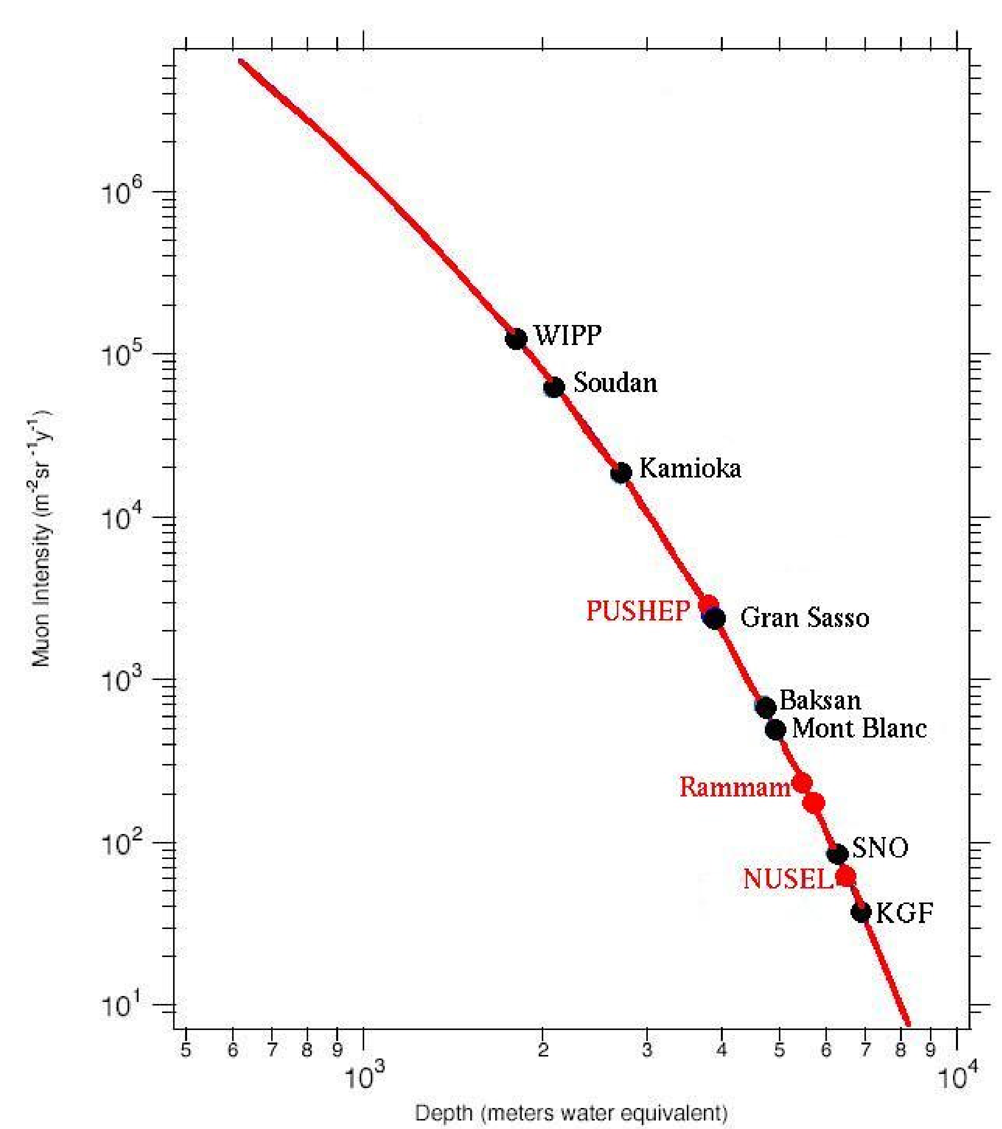
# ICAL Prototype Assembly

- Prototype 2m $\times$ 2m $\times$ 13 plates of 5 cm iron is being constructed (40 tons).
- Soft iron (magnetisable to 2 T) procured
- Fabrication order placed with Pune vendor (Milman); includes assembly, testing with power supply and field measurement Hall probe
- 1m $\times$ 1 m RPCs for 12 layers of prototype being made/tested. Issues with RPC efficiency and stability being studied.
- About 800 channels of preamp, timing discriminators being constructed
- To be assembled at VECC, Kolkata

# Site survey: PUSHEP

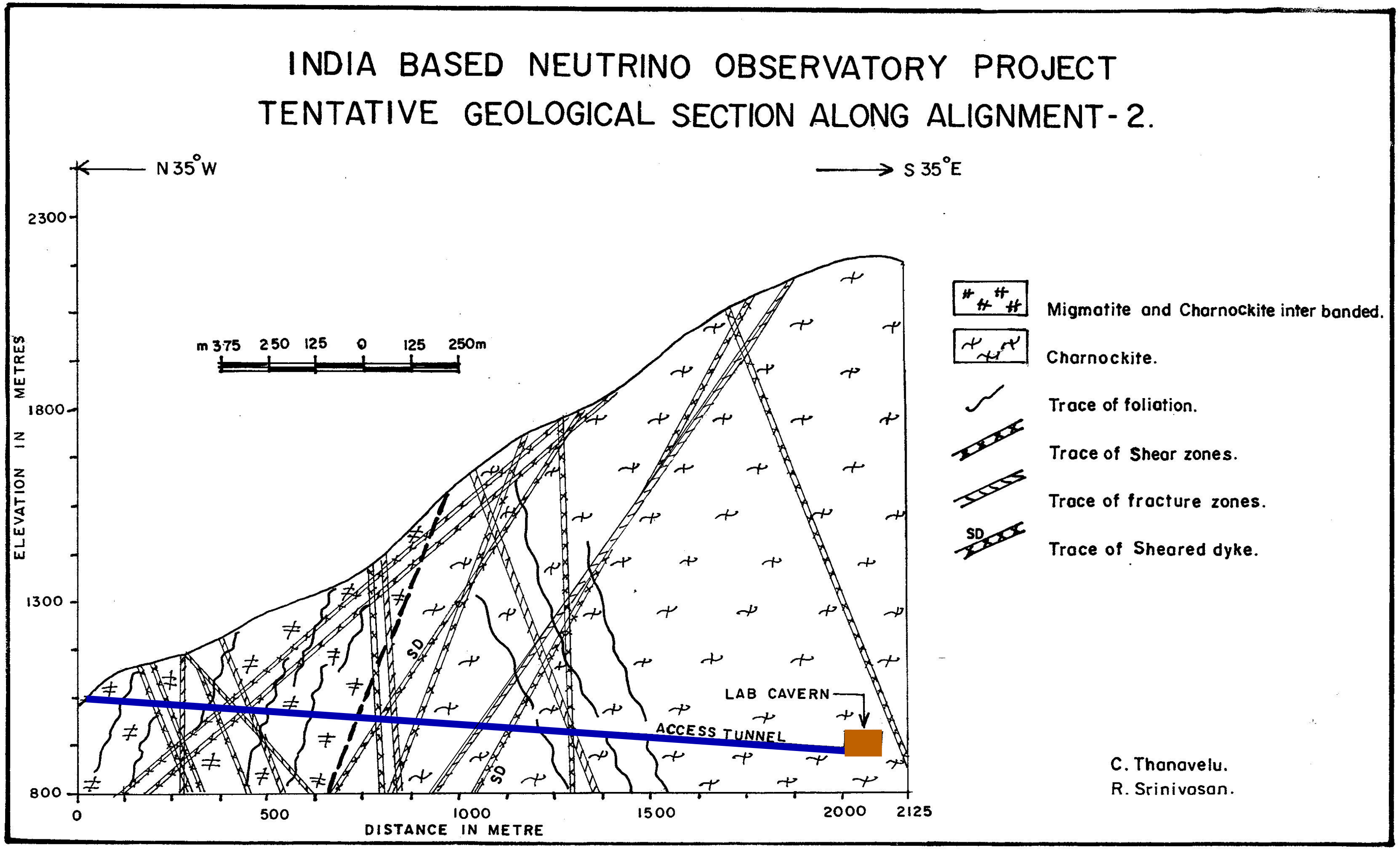
PUSHEP in the Nilagiris, near Ooty (Masinagudi)

# 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).

# Site-specific geology



# Site-specific geology

- Engineering Task Force has been formed and entrusted with the DPR preparation.
- Members include engineers and scientists from BARC, IGCAR, VECC and GSI, TNEB.
- ETF met at Masinagudi on Dec 7th to discuss DPR requirements. DPR draft/final to be ready by Feb 15/ March.
- Environmental Impact Assessment and Environment Management Plan entrusted to Salim Ali Centre for Ornithology and Natural History (SACONH); will be ready by the end of January.
- Permission for detailed site survey and geo-technical studies obtained
- Detailed drawings of surface facilities and labs at Masinagudi have been prepared (includes hostel, guest house and conference facilities).
- TNEB land for the purpose earmarked. Acquisition needs approval from Chairman, TNEB.

## Time lines for INO

- May, 2005: INO interim report was presented to the funding authorities as well as to the general scientific community at a meeting in TIFR, Mumbai
- August 2005: It was presented to the SAC-PM committee
- April 2006: It was endorsed by the community at a meeting in Mumbai to define the joint road-map for HEP and NP research in the country
- August 2006: Recommended by the committee set up by the Planning Commission to the Mega Science projects for funding
- October 2006: Reports from the international panel of referees received by Chairman, INO-PMC (Director, TIFR)
- The technical review of the INO proposal is complete and is favourable. It is now with the funding agencies for approval.

# In short . . .

The outlook looks good! This is a massive project:

Looking for active collaboration both within India and abroad

### The INO Collaboration[1]

- **Aligarh Muslim University, Aligarh:**
  M. Sajjad Athar, Rashid Hasan, S. K. Singh
- **Banaras Hindu University, Varanasi:**
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- **Calcutta University (CU), Kolkata:**
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  Sandip Pakvasa
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- **Panjab University (PU), Chandigarh:**
  Vipin Bhatnagar, M. M. Gupta, J. B. Singh
- **Physical Research Laboratory (PRL), Ahmedabad:**
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- **Saha Institute of Nuclear Physics (SINP), Kolkata:**
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- **Variable Energy Cyclotron Centre (VECC), Kolkata:**
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### Scientific Steering Committee

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[1] This is an open collaboration and experimentalists are especially encouraged to join.
[2] since retired
[3] Replacing Abdul Salam who was a member until March 5, 2005

# Additional Slides

# $3\sigma$ Precision of parameters

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

| Experiment | P($\lvert\Delta m^2_{32}\rvert$) | P($\sin^2\theta_{23}$) | hierarchy |
|---|---|---|---|
| Current | 88% | 79% | – |
| MINOS | 17% | 65% | – |
| CNGS | 37% | – | – |
| NO$\nu$A ($6 \times 10^{21}$ pot) | $\sim$ 5% | $\sim$ 9% | in comb |
| T2K (Super-K, 0.75 MW) | 12% | 46% | |
| ICAL (50 kton) | 20% | 60% | $\sin^2 2\theta_{13} > 0.06$ |

# 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