India-based Neutrino Observatory (INO)

Status Report

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For the INO Collaboration

(http://www.imsc.res.in/∼ino)

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  - The ICAL Detector: RPC's and magnet design
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- Other physics studies possible at INO

Neutrinos:

A (Very) Brief Overview

From: www.bnl.gov/

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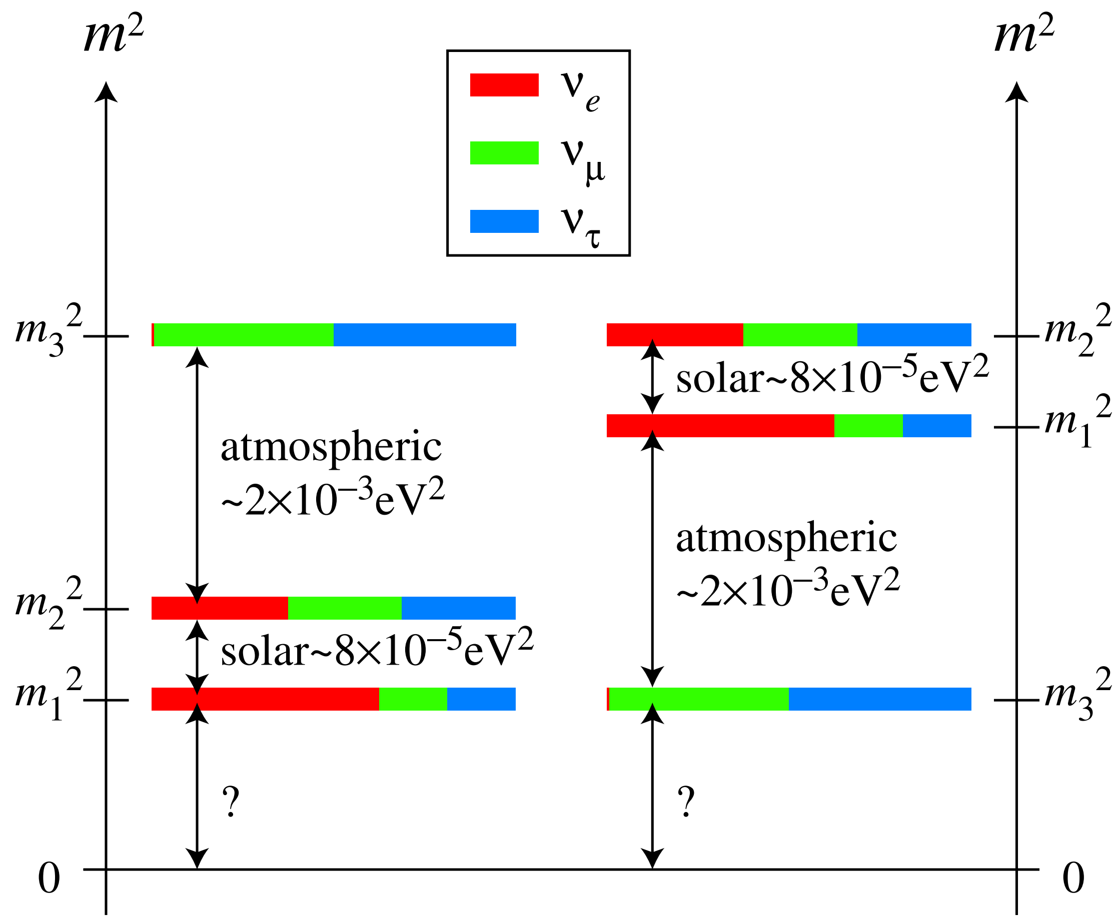

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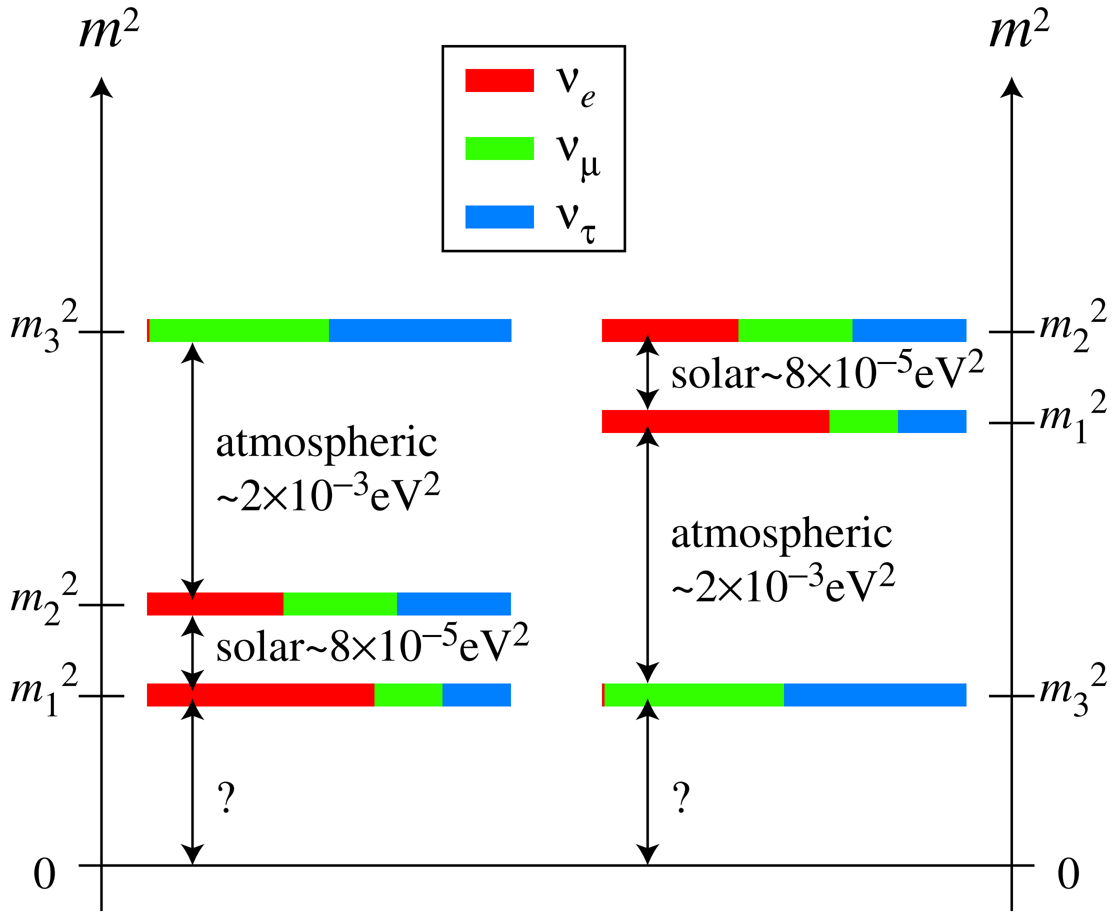
$|\Delta m_{32}^2| \sim 2.0 \times 10^{-3}$ eV^2 ;
$\sum_i m_i < 0.7$–2 eV.



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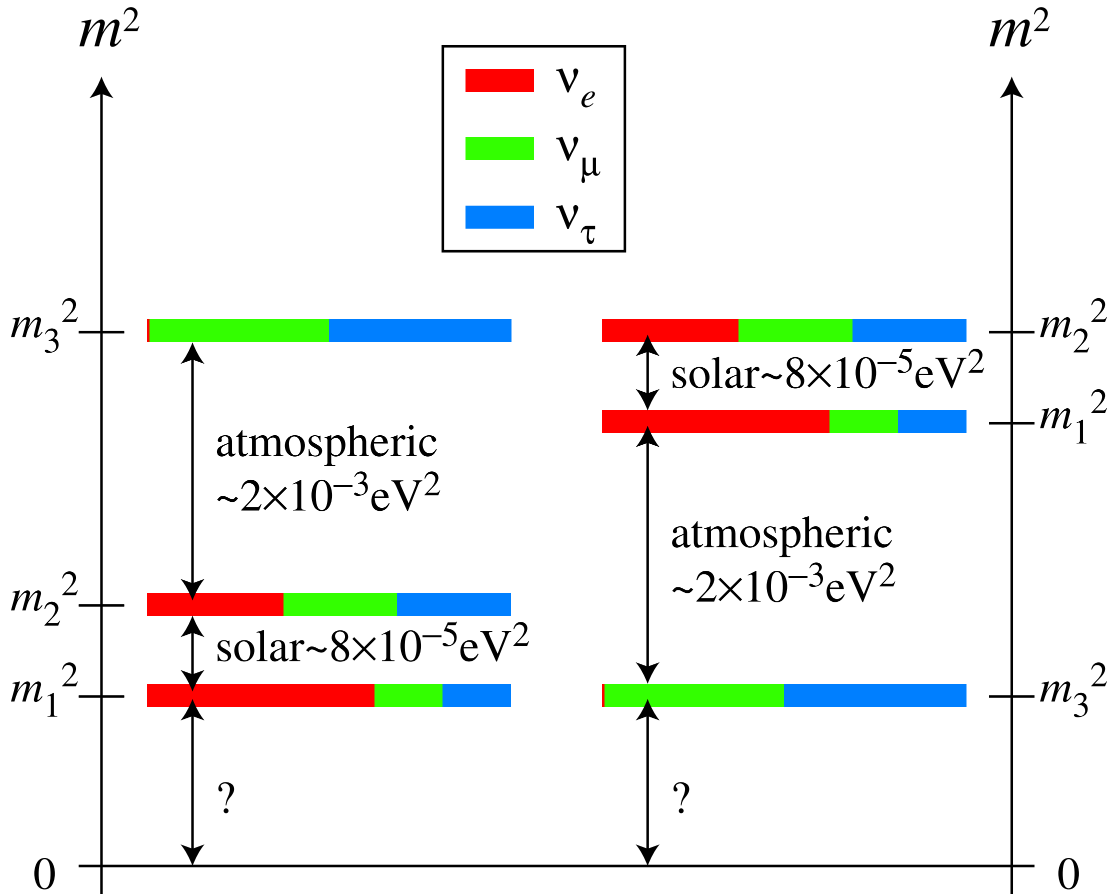
- $m_1 \sim m_2 \sim m_3 \sim 0.2$ eV (Degenerate hierarchy)
- $m_1 < m_2 \ll m_3$ (Normal hierarchy)
- $m_3 \ll m_1 < m_2$ Inverted hierarchy



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

India-based Neutrino Observatory

The INO Collaboration

- Stage I : Study of atmospheric neutrinos
  - Site Survey
  - Detector R & D, including construction of a prototype (latter in progress)
  - Physics Studies
  - Human resources development

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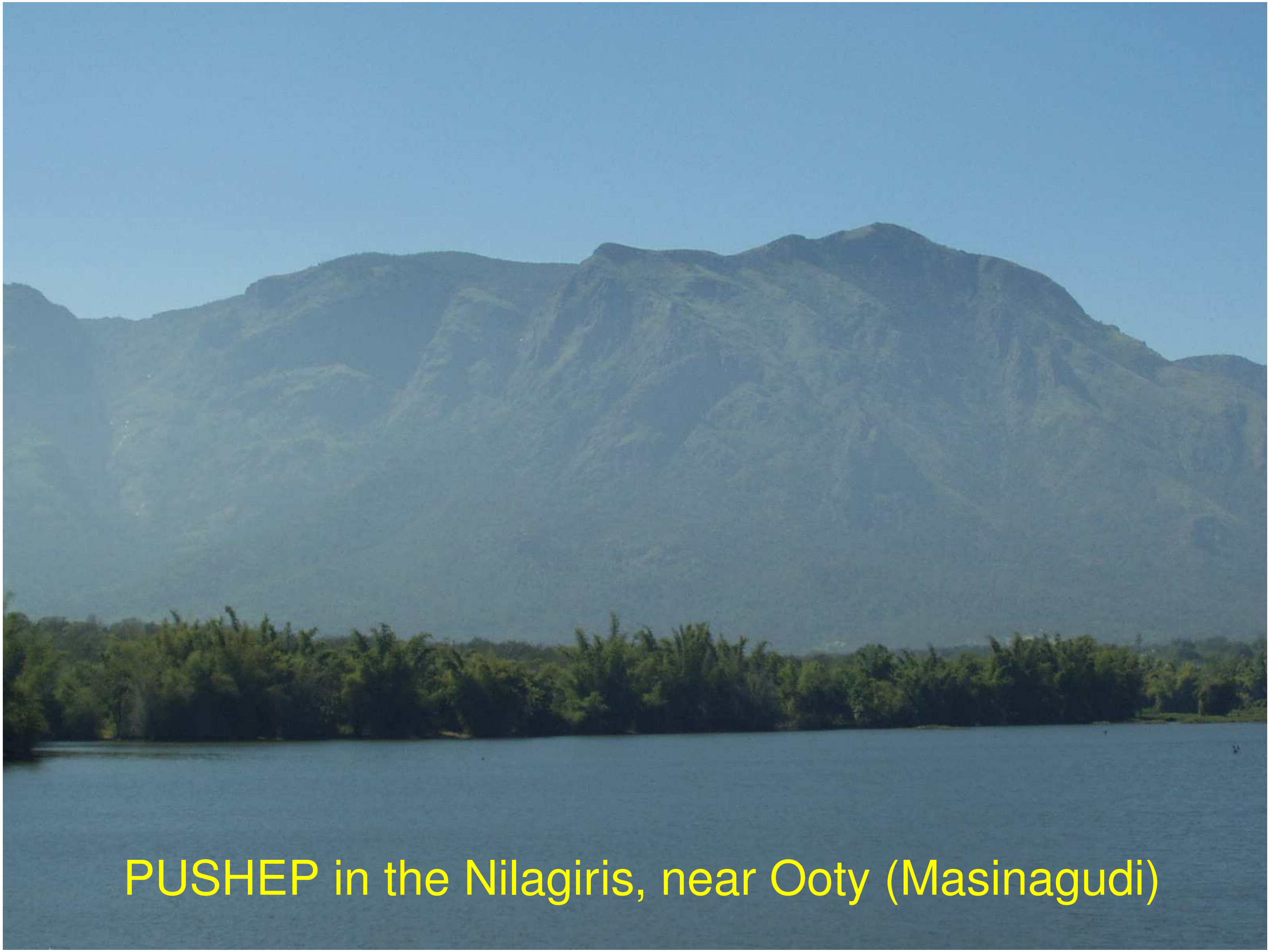
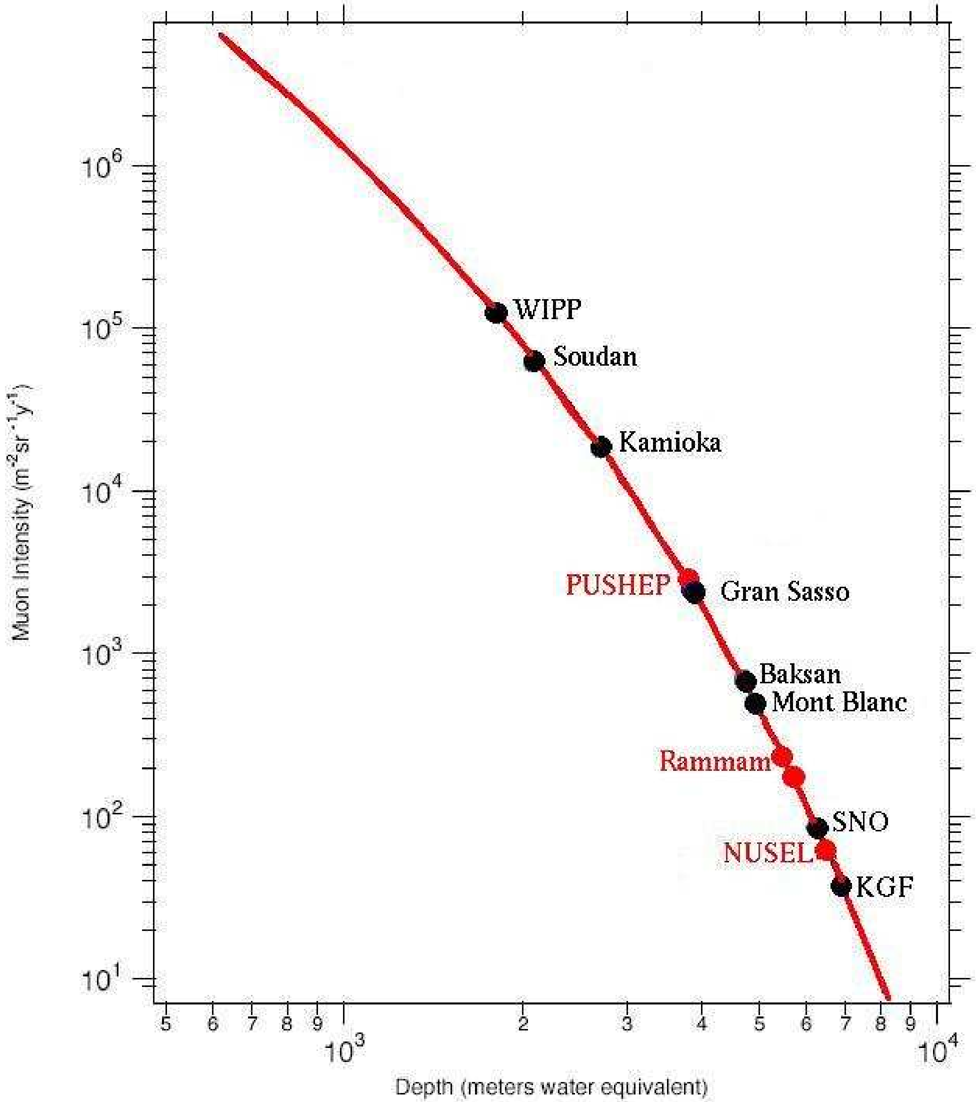
- Other detectors/physics like neutrinoless double beta decay?
- Should be an international facility
- The technical review of the INO proposal is complete and is favourable. It has now been submitted to the funding agencies for approval.

Site survey: PUSHEP



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).

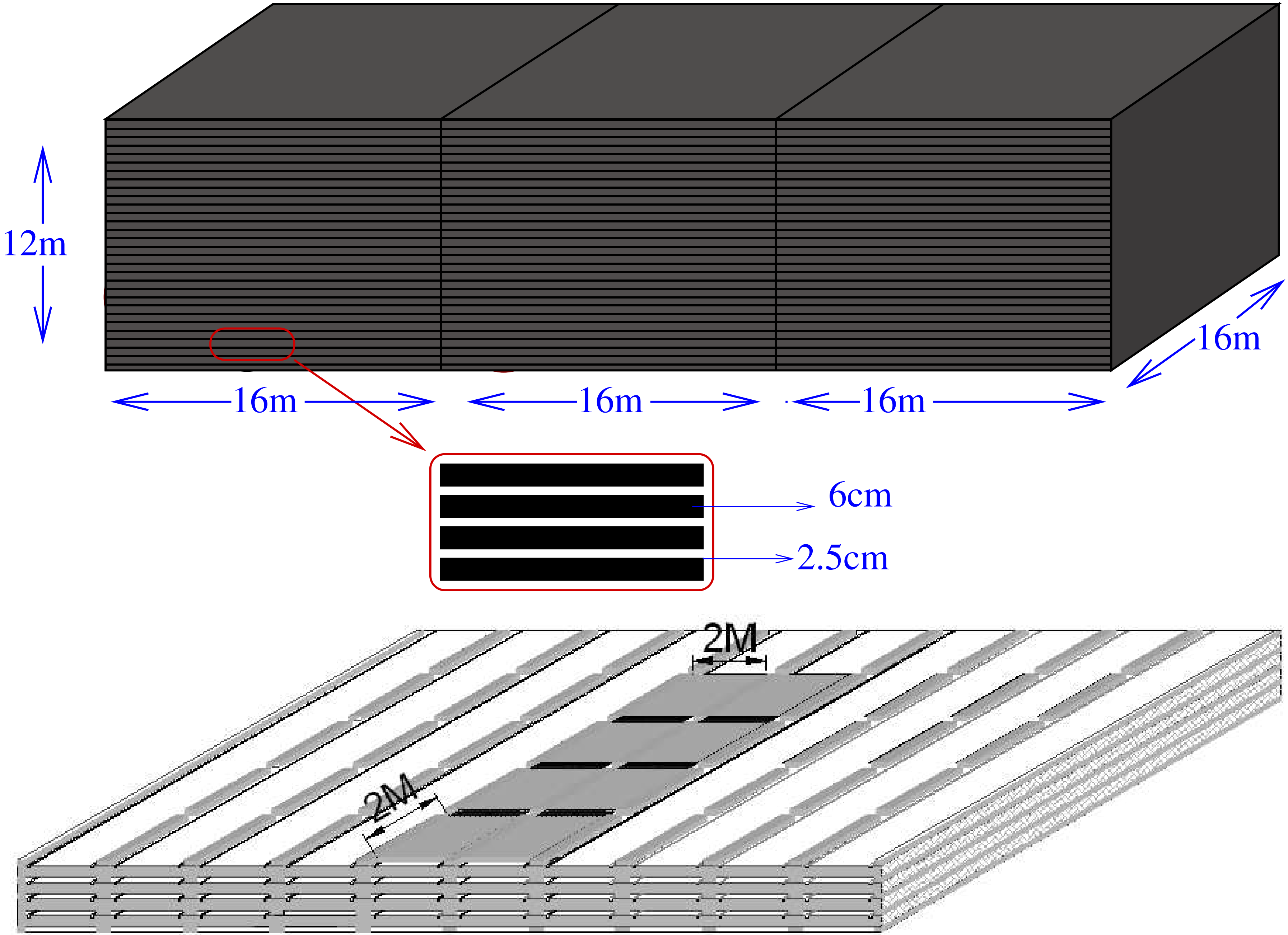
The choice of detector

- 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
- Ease of construction (modular)

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

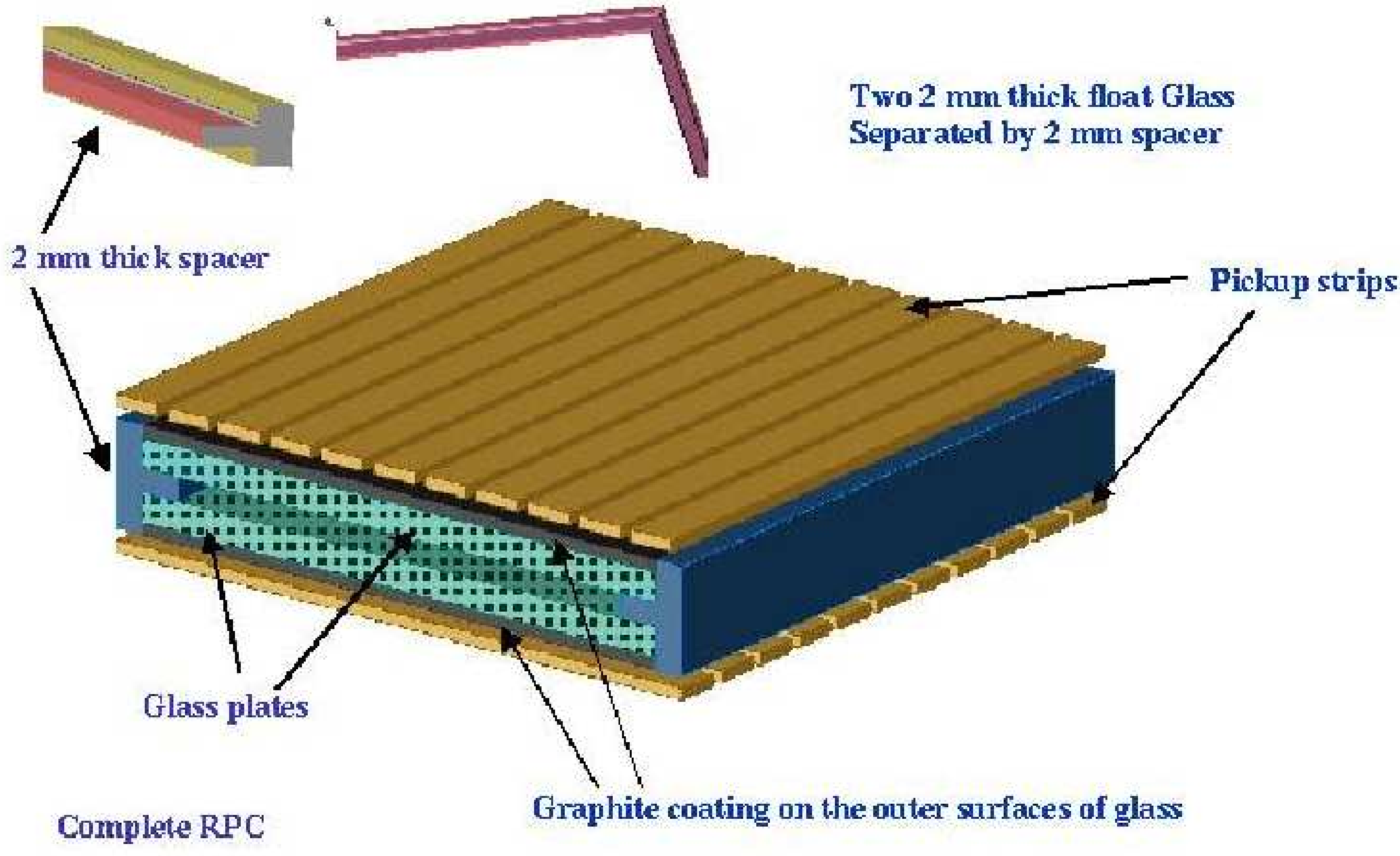
Note: Is sensitive to muons only, not electrons

The ICAL detector

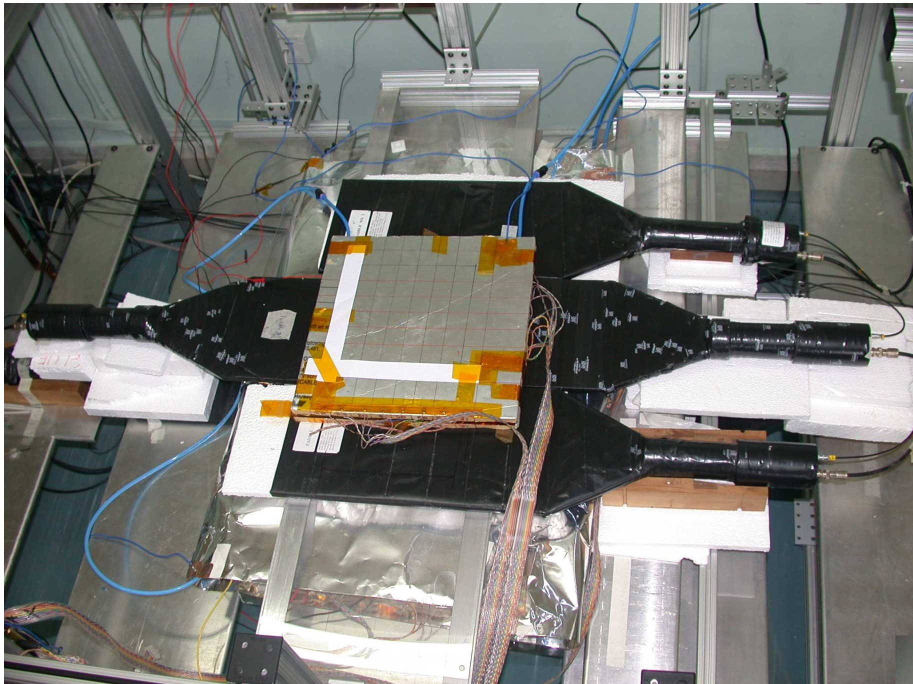


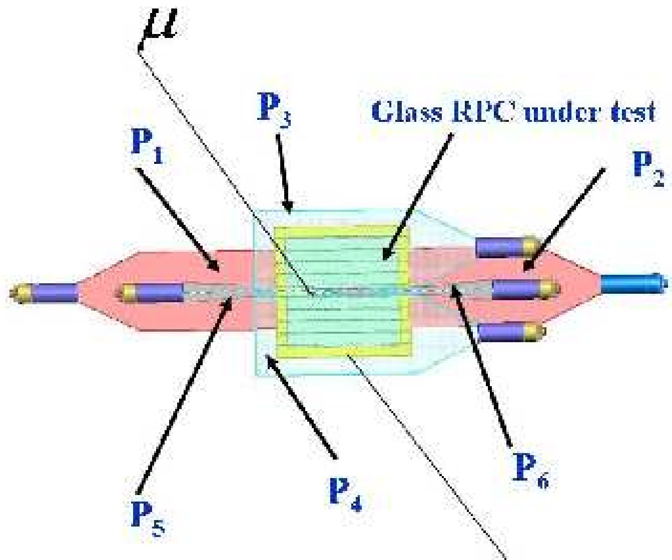
The active detector elements: RPC

RPC Construction: Float glass, graphite, and spacers



Fabricating RPC's





Initially: 30 cm $\times$ 30 cm

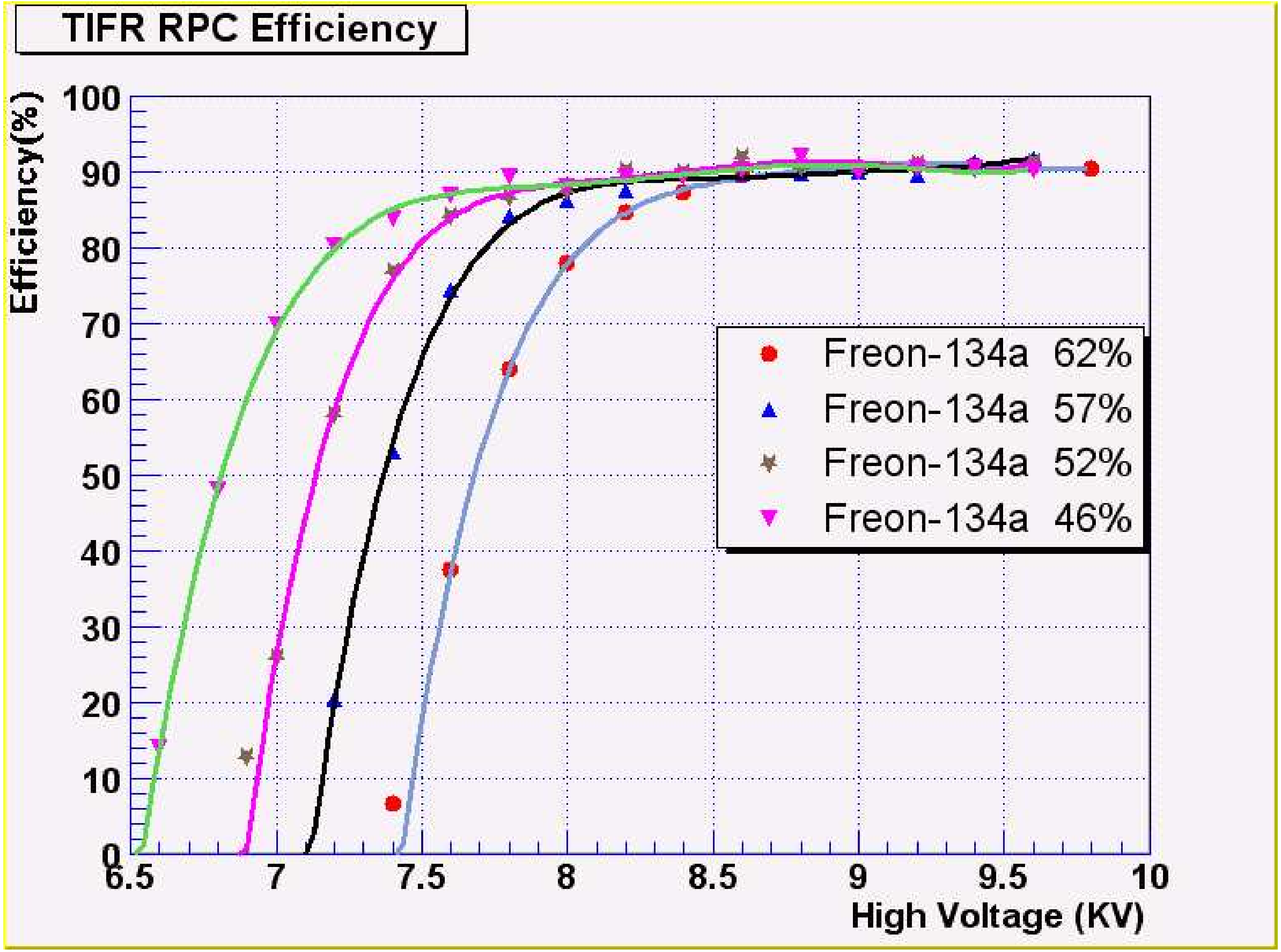
Currently: 1.0 m $\times$ 0.9 m

Specifications of the ICAL detector

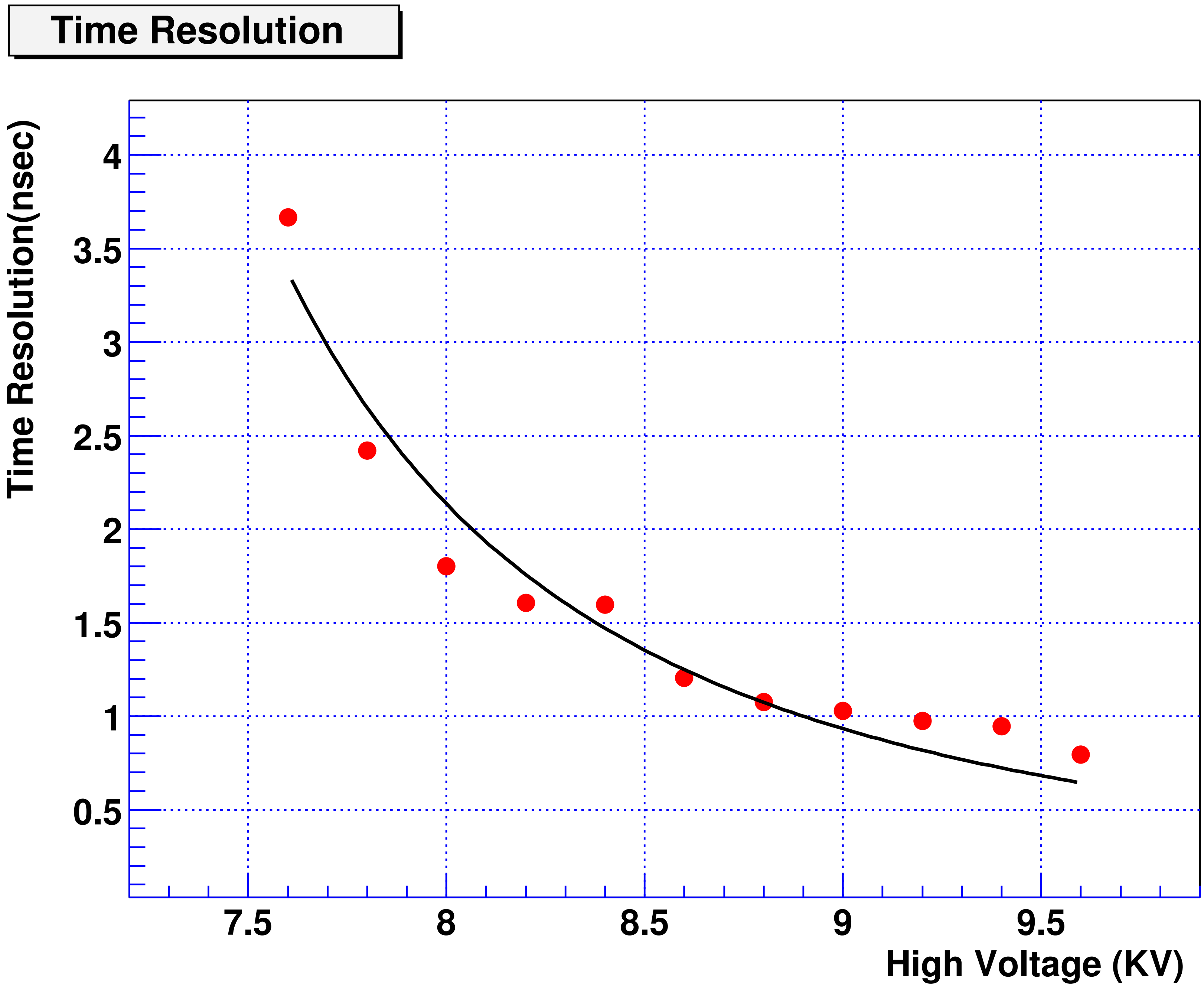
ICAL	
No. of modules	3
Module dimension	16 m $\times$ 16 m $\times$ 12 m
Detector dimension	48 m $\times$ 16 m $\times$ 12 m
No. of layers	140
Iron plate thickness	$\sim$ 6 cm
Gap for RPC trays	2.5 cm
Magnetic field	1.3 Tesla
RPC	
RPC unit dimension	2 m $\times$ 2 m
Readout strip width	3 cm
No. of RPC 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 $\times 10^6$

RPC Efficiency studies

Using different combinations of gas



RPC Time resolution

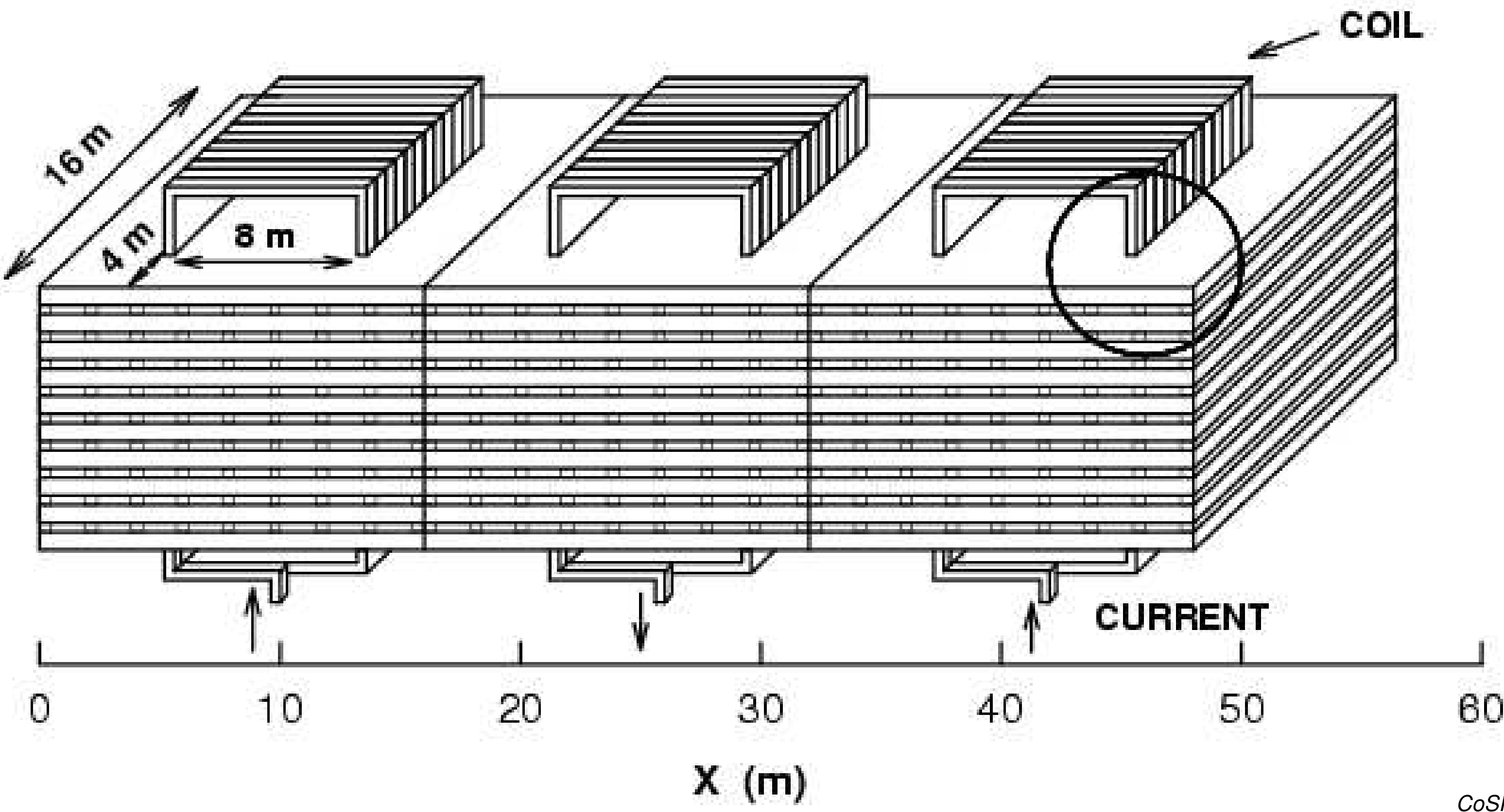


Magnet studies

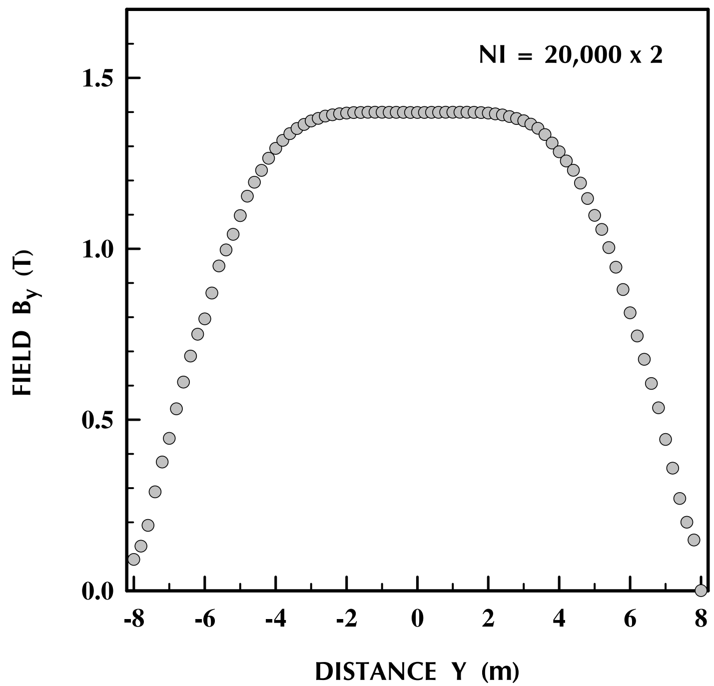
Design criteria:

- Field uniformity
- Modularity
- Optimum copper-to-steel ratio
- Access for maintenance

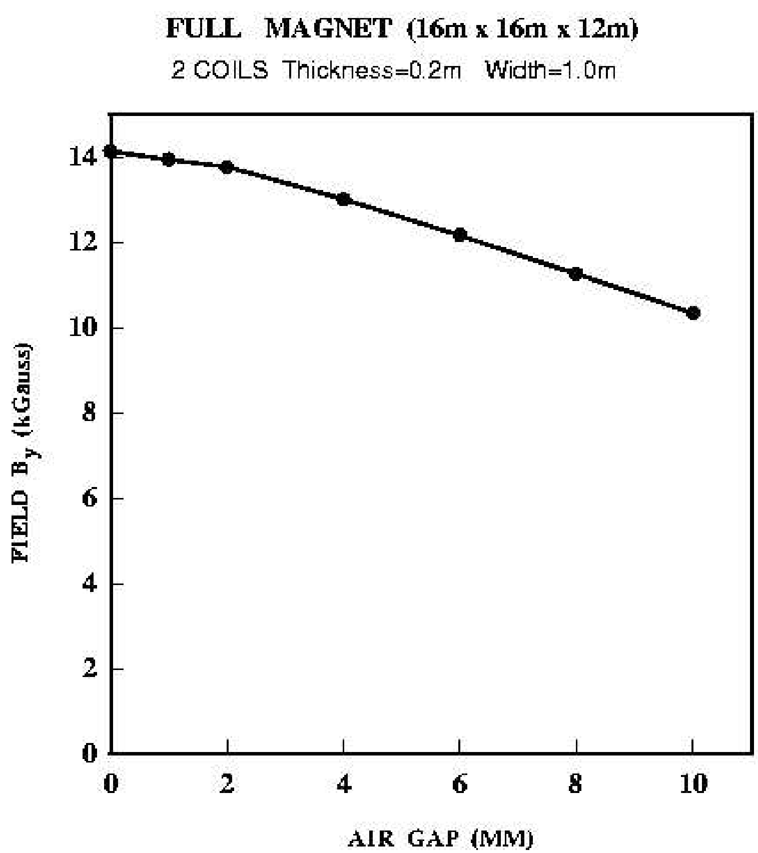
Toroidal Magnet design



Magnetic field simulation



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

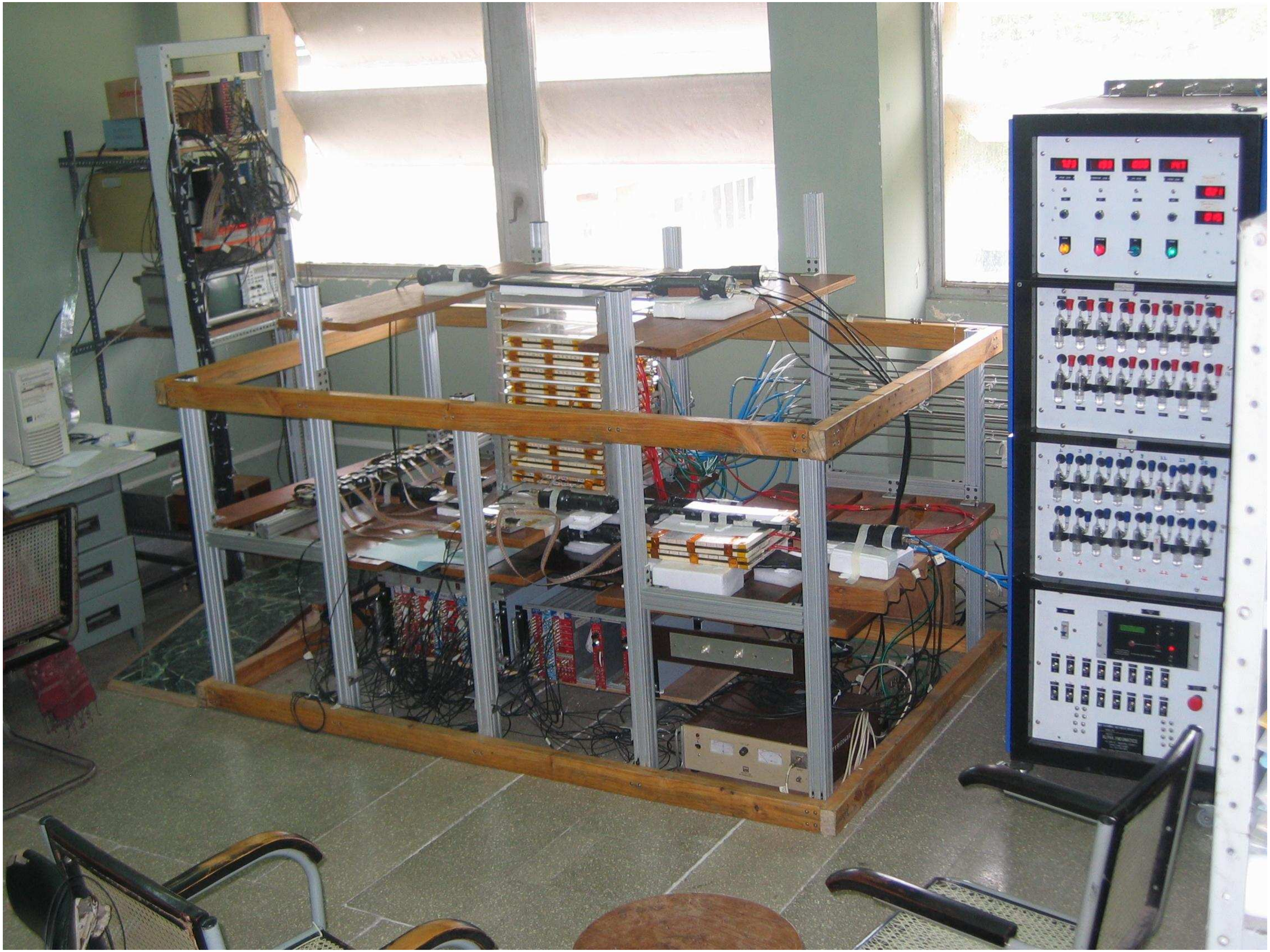


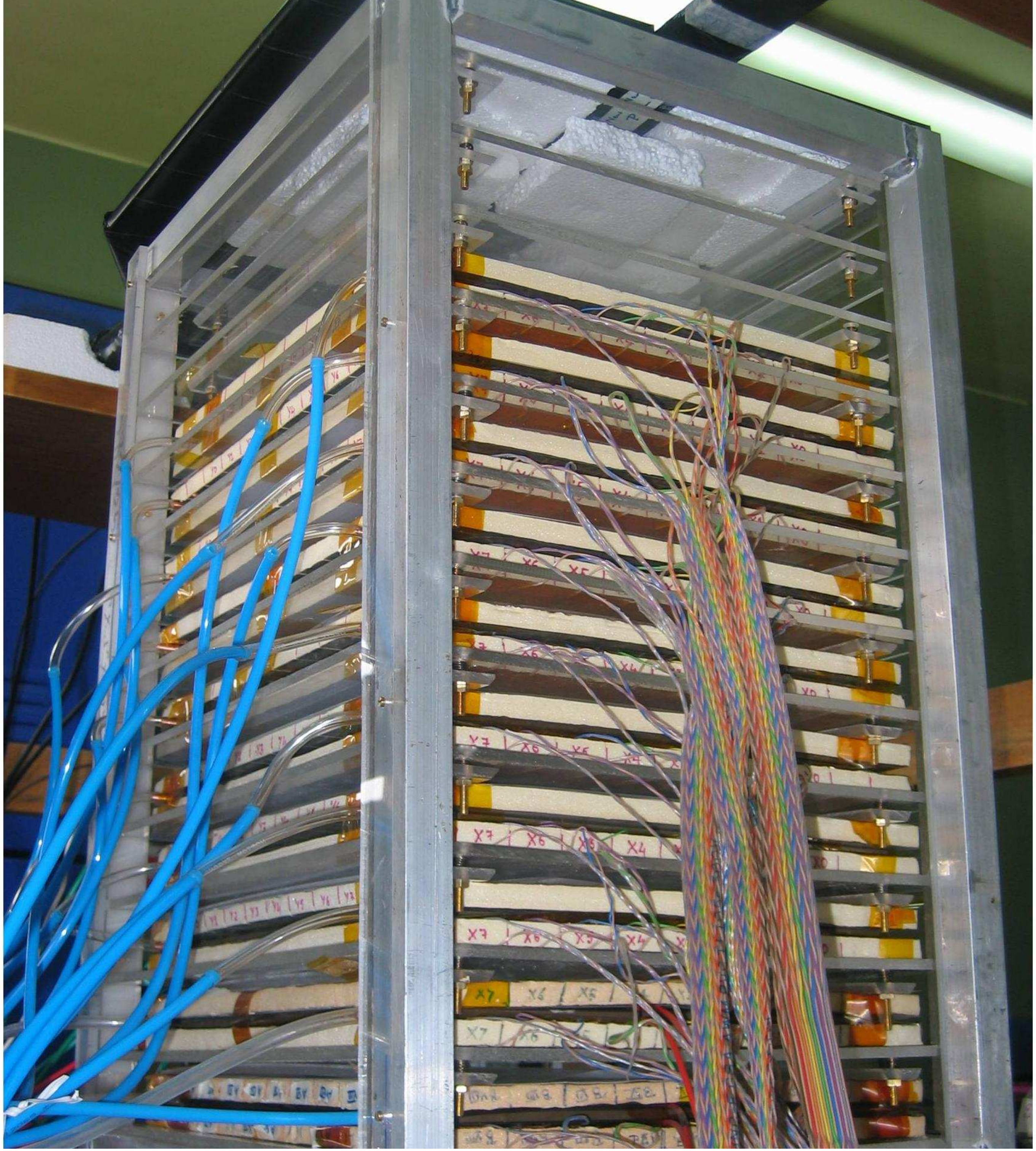
Field in x-direction uniform to within 0.25%.

Field in z-direction uniform except close to edges.

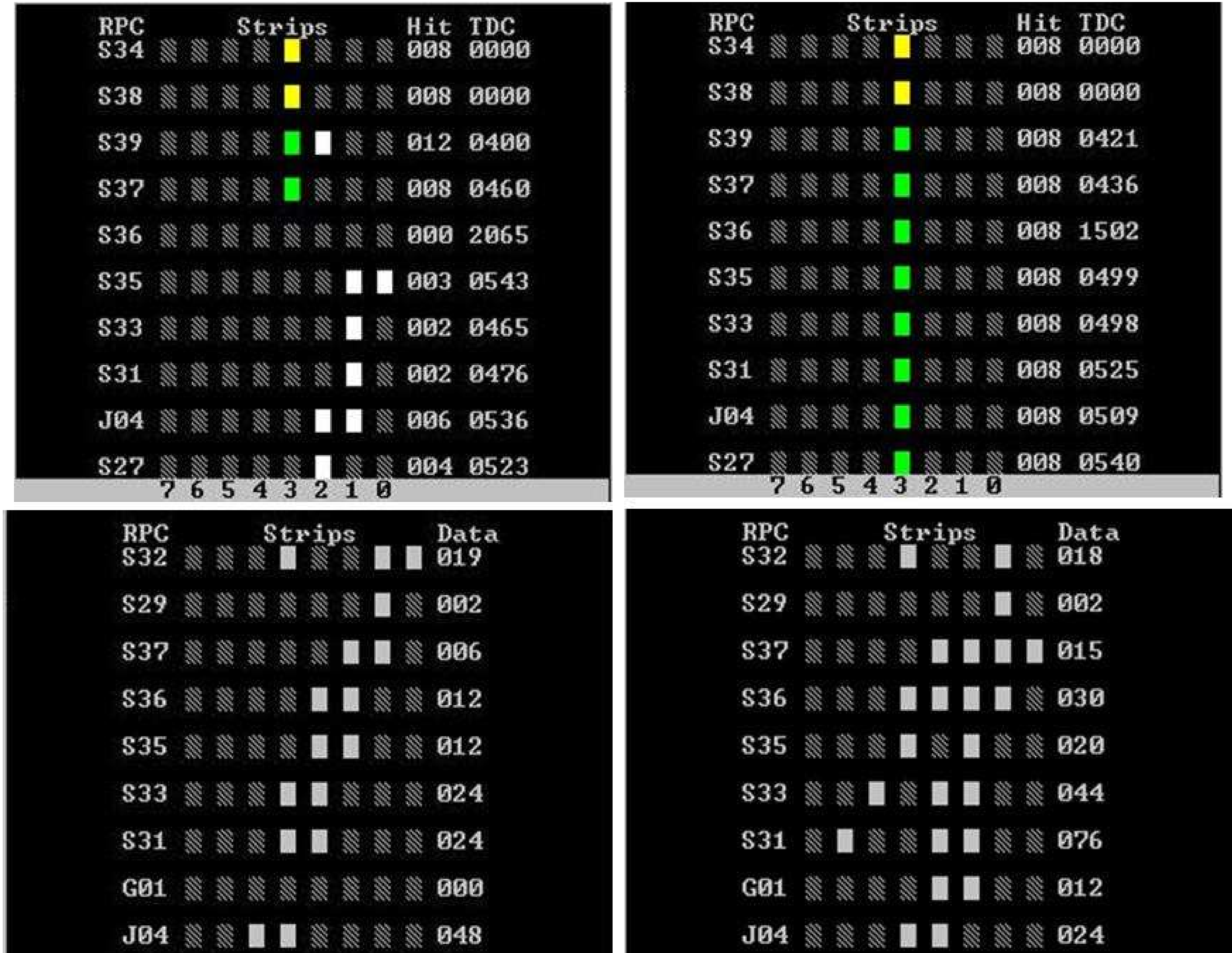
Cannot tolerate more than 4 mm gap in plate welding.

For the prototype, at TIFR . . .



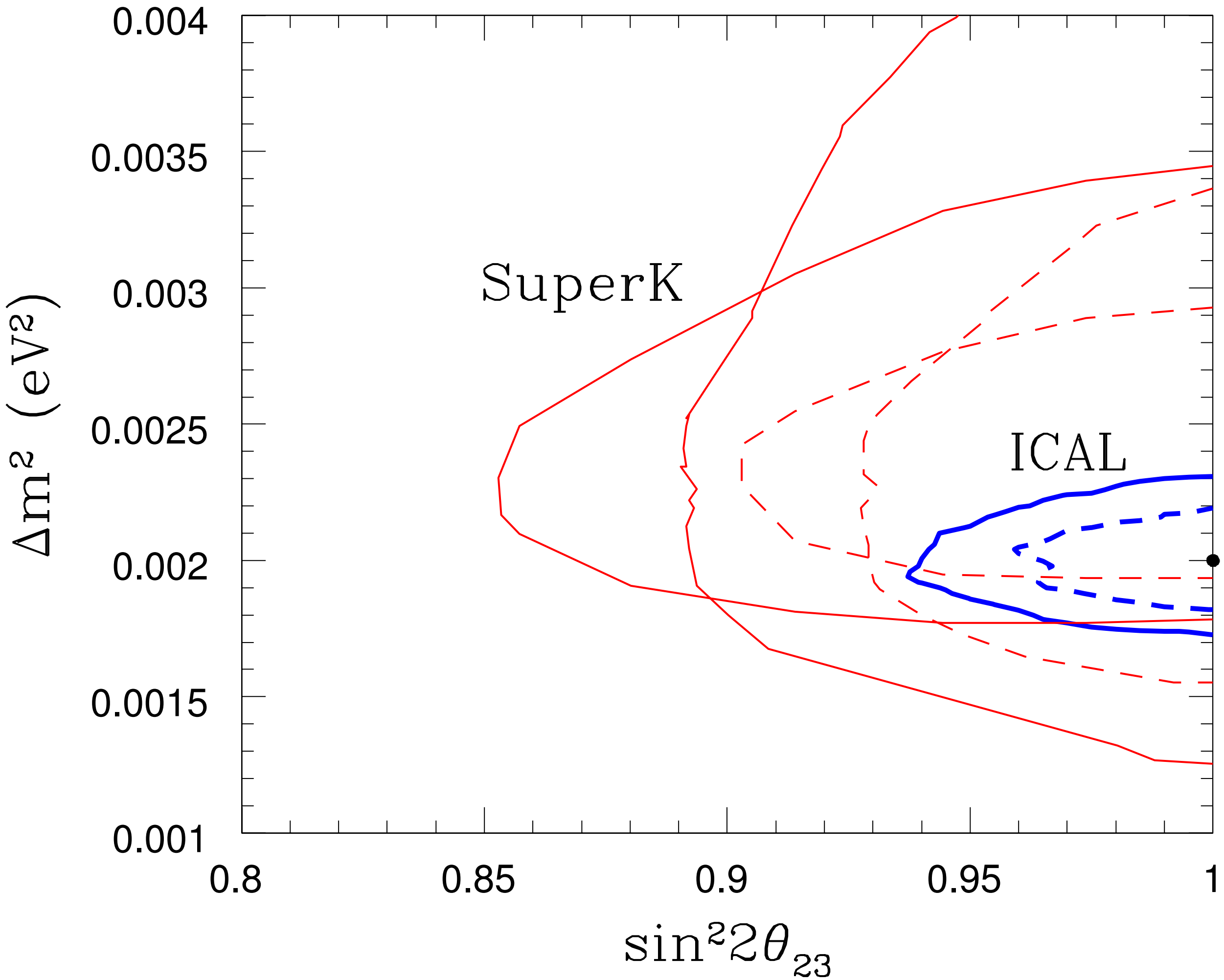


Tracks from atmospheric muons at TIFR



Event Simulations

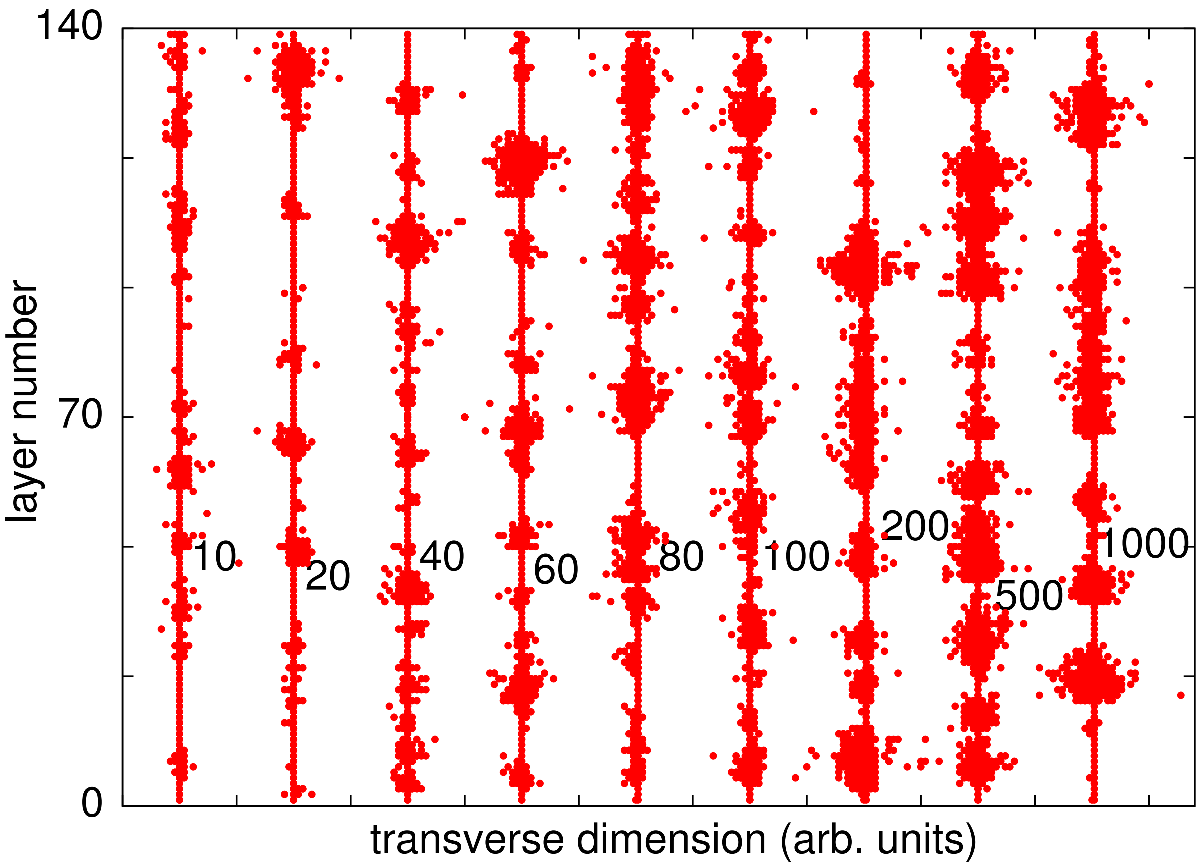
- Source: Atmospheric Neutrinos, 6 years' exposure, from Nuance neutrino generator.
- ICAL simulation with GEANT, $B_y = 1$ T.



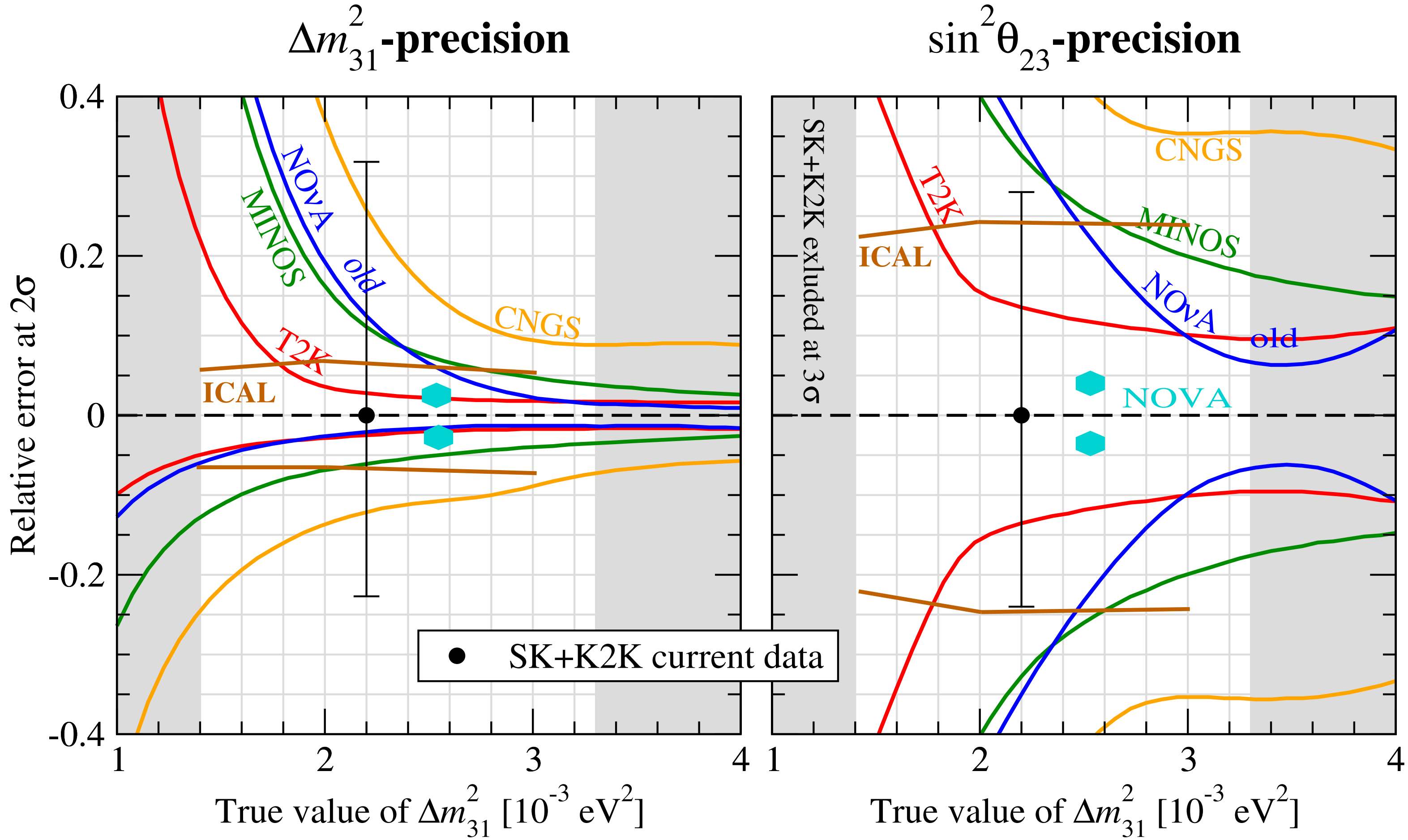
Shown are 90 and 99 CL contours in comparison with Super-K zenith angle as well as L/E results

Event Simulations II

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



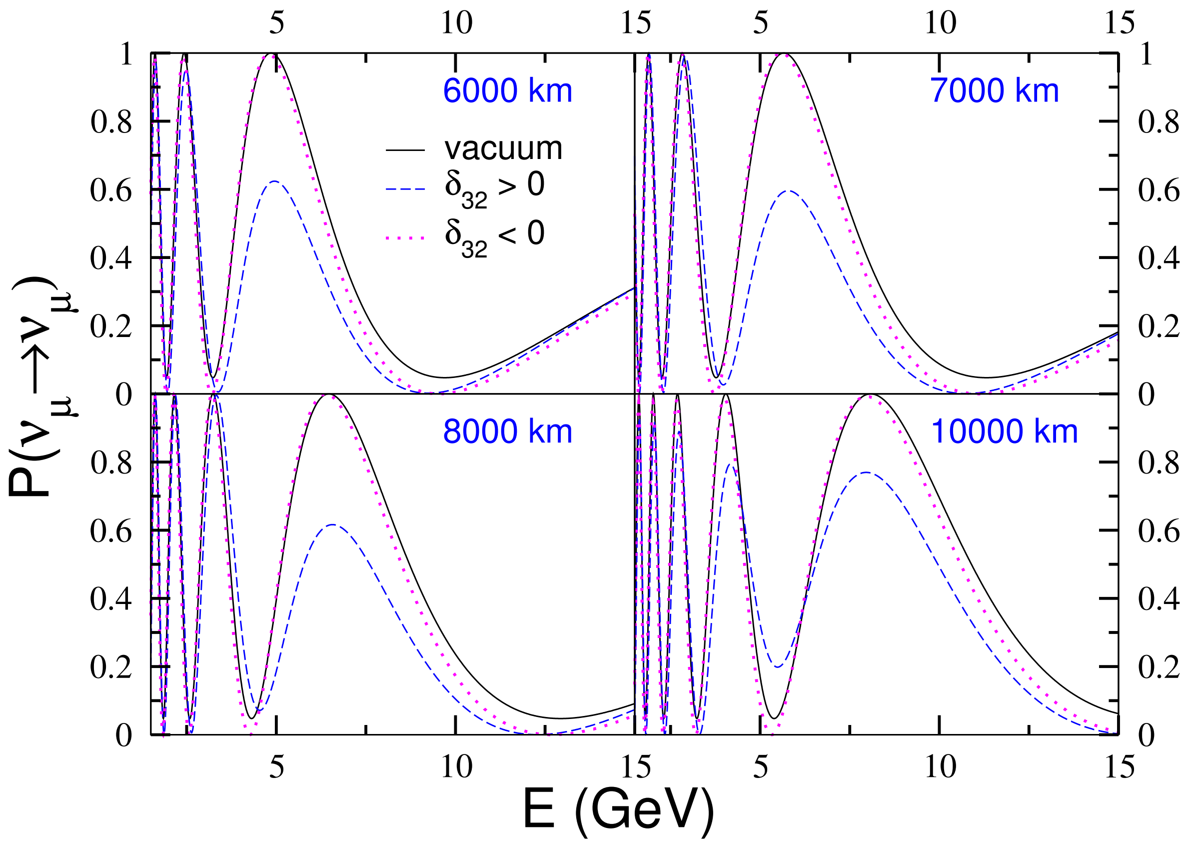
Physics Studies with ICAL



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

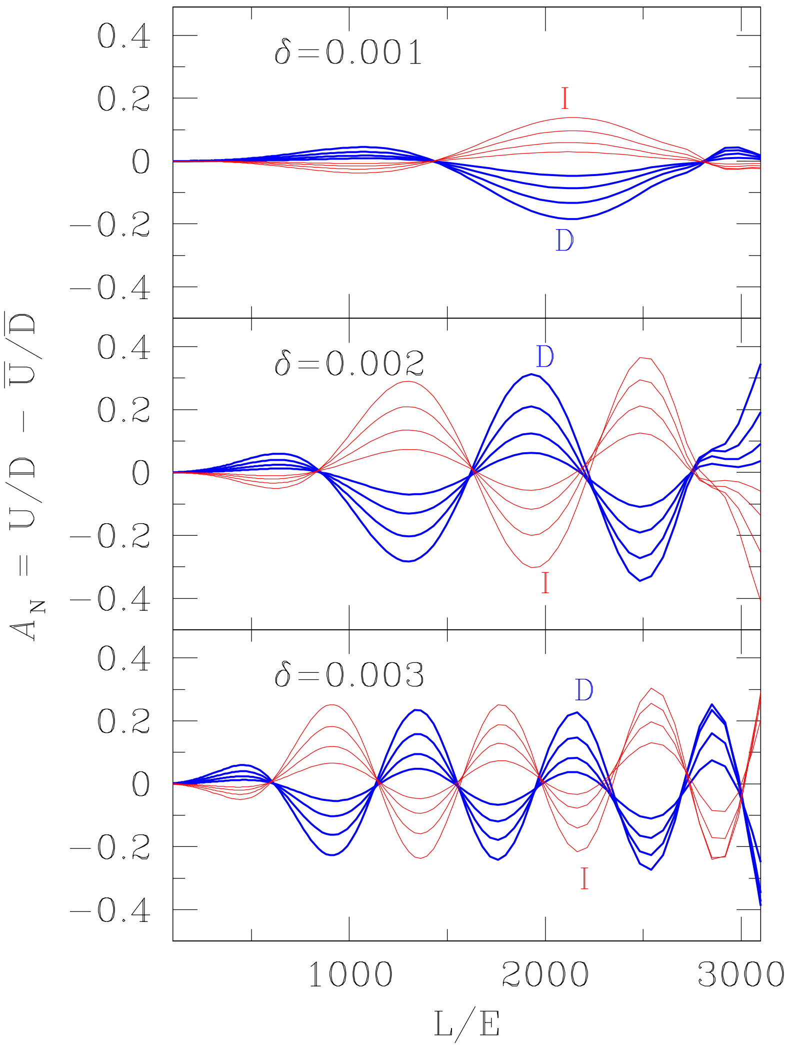
Adapted from: P. Huber, M. Lindner, M. Rolinec, T. Schwetz and W. Winter, hep-ph/0412133.

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 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 $\theta_{13} = 5, 7, 9, 11^\circ$

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)

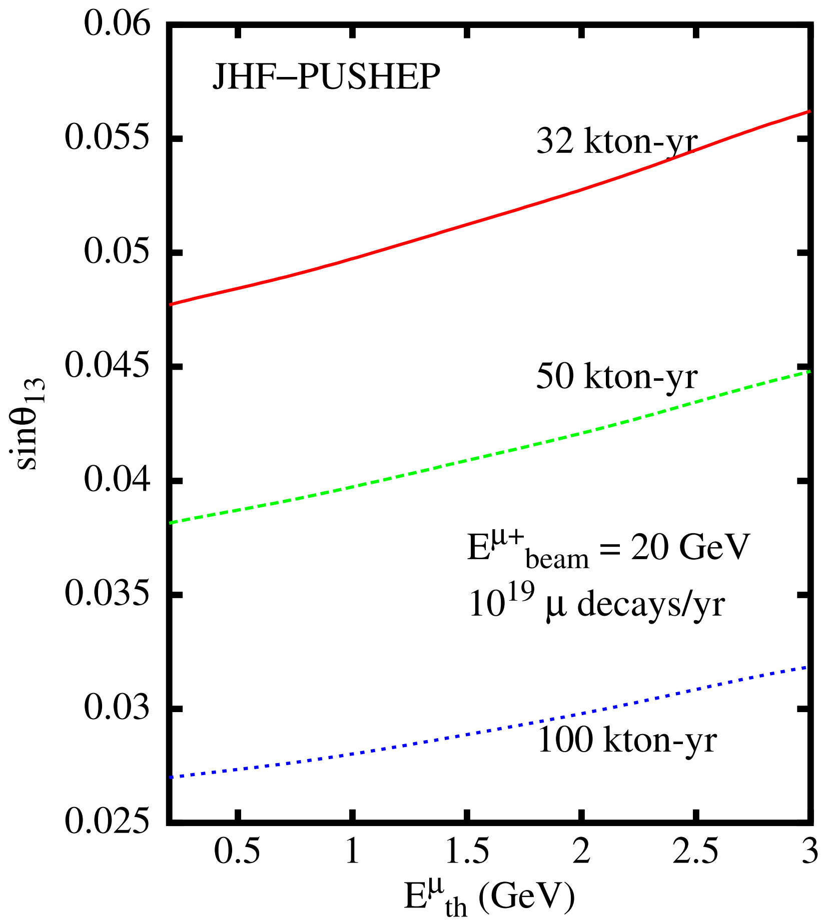
D: Direct/normal; I: Inverted hierarchy

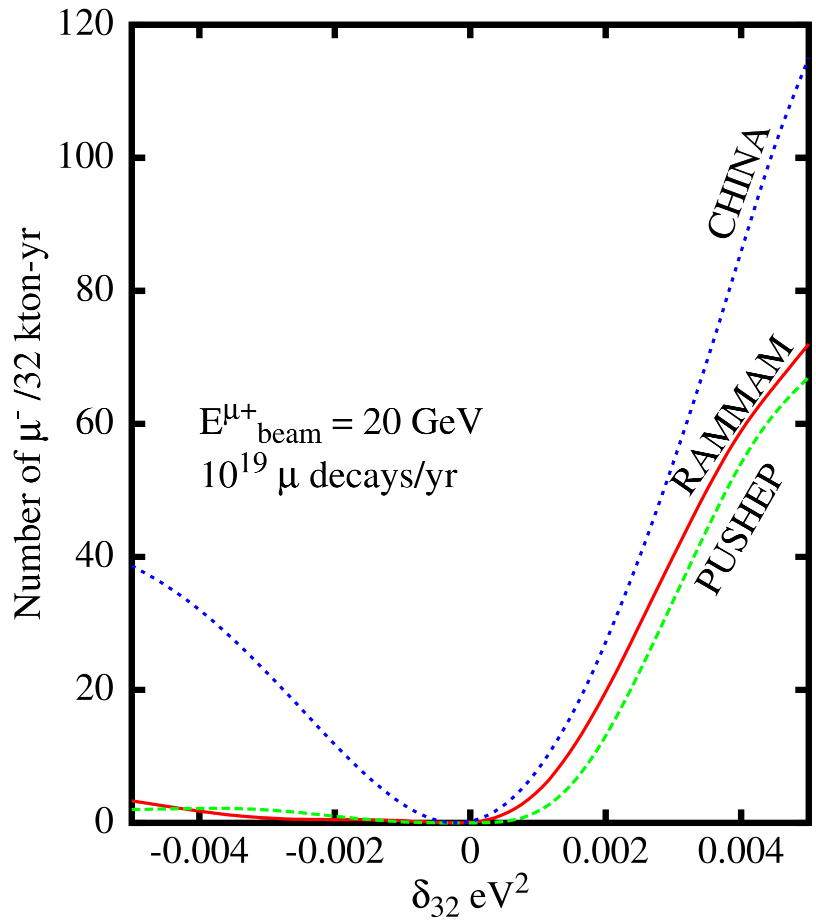
Other physics possibilities

... with atmospheric neutrinos

- Discrimination of octant of 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.

In short . . .

The outlook looks good! This is a massive project:

Looking for active collaboration both within India and abroad

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The INO Collaboration[1]

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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