Status report on INO

Outline of talk

1. Introduction
2. Physics goals and choice of detector
3. Status of project – magnet, RPC, electronics & DAq, environmental clearance, HRD, other experiments
4. Outlook & summary

V.M. Datar (BARC, Mumbai)

on behalf of the INO collaboration

27 May 2008, Neutrino 08

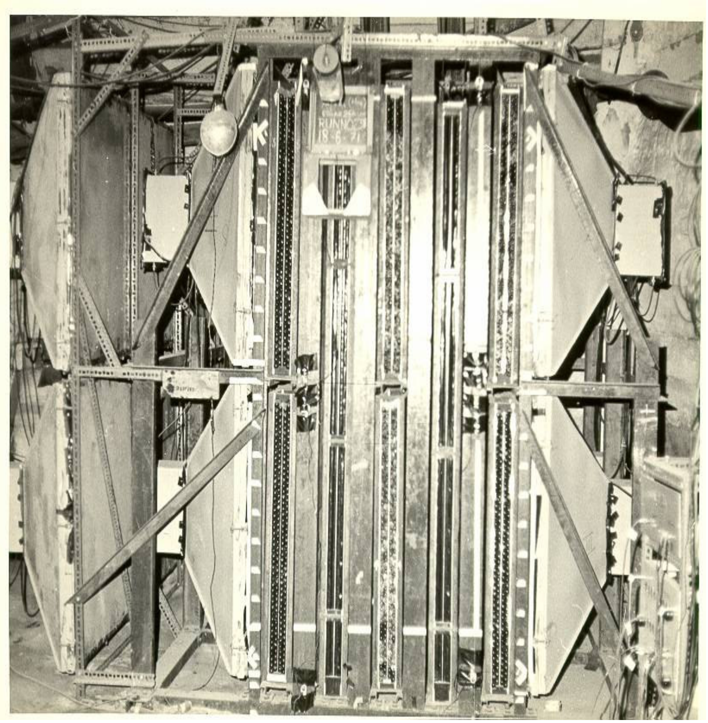
1. Introduction

Motivation for INO – some background

- Cosmic ray programme initiated by Bhabha in ’40s led to underground experiments at the deepest mine KGF (2.3 km)
- Atmospheric neutrinos first detected in 1965 at KGF (slide)
- First proton decay experiment to get off the ground (’80s)
- Closure of deepest parts of KGF ~ ’90 (economic unviability)
- HEP community shifted to accelerators thoughrime cosmic ray experiments continue at Ooty, Pachmarhi, Leh (HANLE)
- HEP community for domestic experiment to revive “exptl” culture and attract good students
- INO collaboration set up in 2002 through initiative of Dept. of Atomic Energy

Atmospheric neutrinos at KGF

- Atmospheric neutrino physics started when νs first detected at KGF (2.3 km deep gold mine in Southern India) in 1965
Phys. Lett. *18 (1965) 196* **(15th Aug 1965)**
and a little later by Reines in a South African gold mine
Phys. Rev. Lett 15 (1965) 429 **(30th Aug 1965)**



KGF detector

INO Collaboration

Spokesperson : N.K. Mondal

Collaborating institutions/universities

AMU, BHU, BARC, CU, DU, HRI, UoH, HPU, IITB,
IITKh, IGCAR, IMSc, IOP, LU, NBU, PU, PRL,
SINP, SMIT, TIFR, VECC

- Interim report* was submitted on May 1, 2005 to Chairman, DAE
- Updated report reviewed by 6 international experts in 2006

More information about INO at http://www.imsc.res.in/~ino

India based Neutrino Observatory (INO)

Aims to build an underground laboratory for science with neutrino physics as a major activity

1st phase

- Physics, Detector R & D, Site finalisation & clearances, HRD
- Construction of underground lab & ICAL detector

2nd phase

- Physics with atmospheric neutrinos, high energy muon spectra

3rd phase

- Physics with beams from neutrino factories

2. Physics goals & choice of detector

Phase 1

Measurements with *atmospheric neutrinos* and cosmic muons at INO

- direct observation of oscillation (fall & rise)
- precision measurement of oscillation parameters
- neutrino mass hierarchy (if $\theta_{13} > 5°$),
- CP and CPT violation in neutrino sector
- Kolar events (*tracks emerging from long lived particle produced in cosmic ray interaction with rock near proton decay detector*)
- 1-100 TeV cosmic muon flux measurement by pair counting technique

Phase 2

Using accelerator produced neutrinos (J-PARC, CERN, Fermilab)

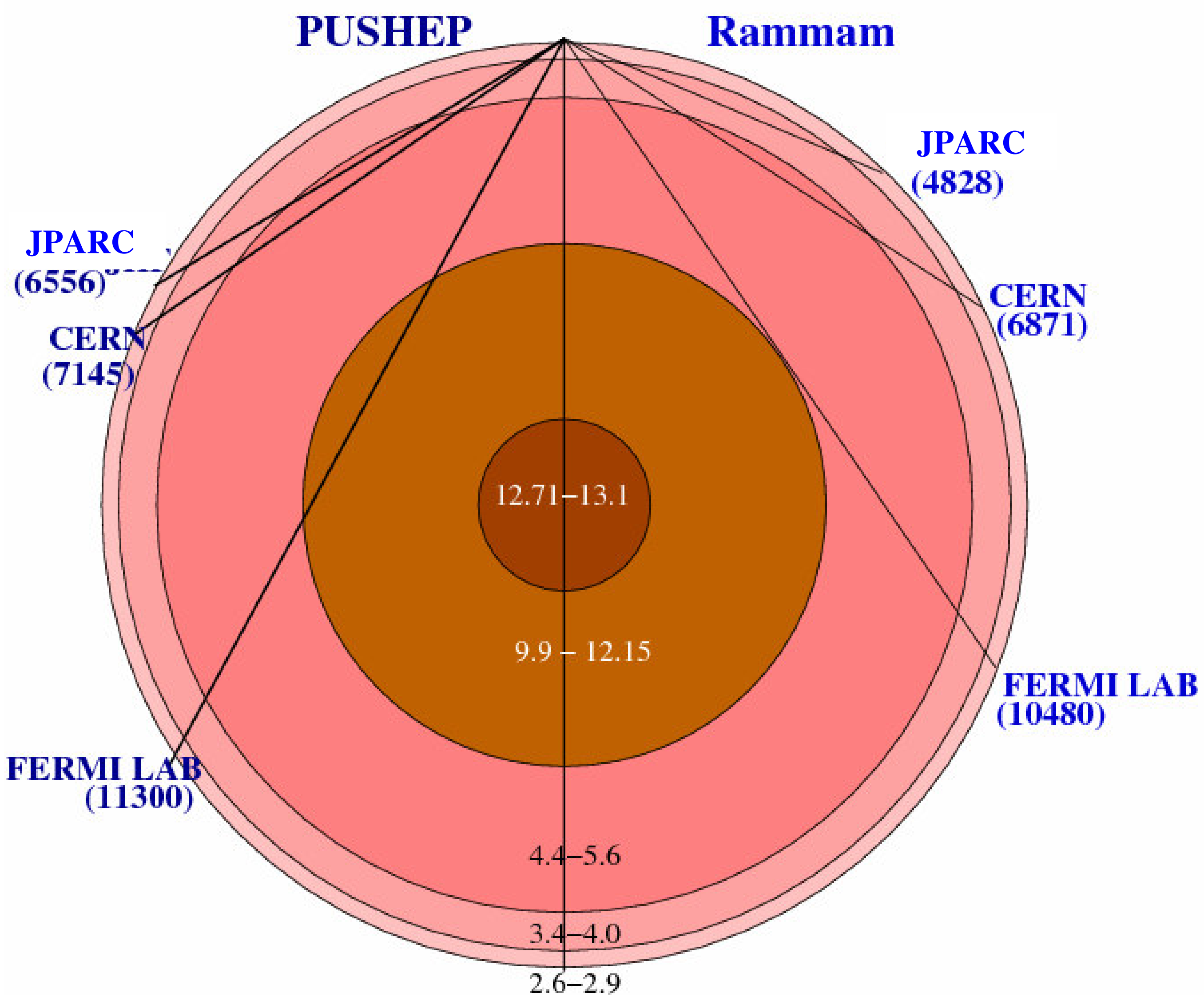
- Long baseline experiment – (6560, 7150, 11300 km)

  $\Rightarrow$ increased sensitivity & precision to smaller mixing angle

  θ_{13} and Δ_{23}, 2 distances (e.g. 3000 & 7000 km) for δ_{CP}

  Need neutrino factories producing ~ 10^{21} ν /yr /straight section

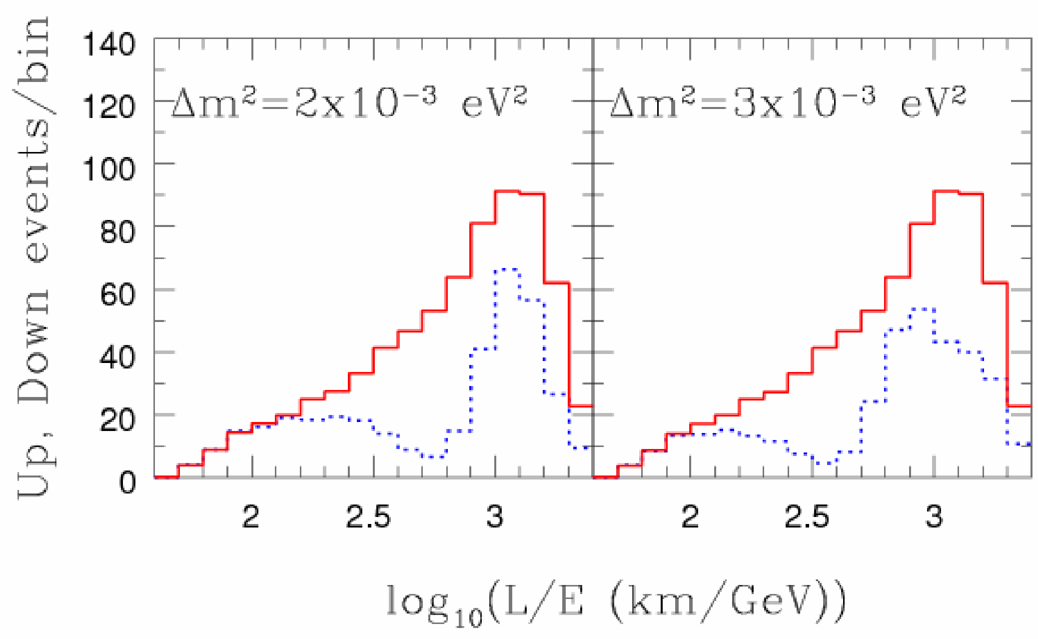
- Beta beams (ν_e from ultra-relativistic beta decaying RIBs such as ^8B, ^8Li) 6×10^{18} ν_e /yr for ν_μ appearance experiments


PUSHEP
Rammam
JPARC
(4828)
JPARC
(6556)
CERN
(7145)
CERN
(6871)
12.71−13.1
9.9 − 12.15
FERMI LAB
(10480)
FERMI LAB
(11300)
4.4−5.6
3.4−4.0
2.6−2.9

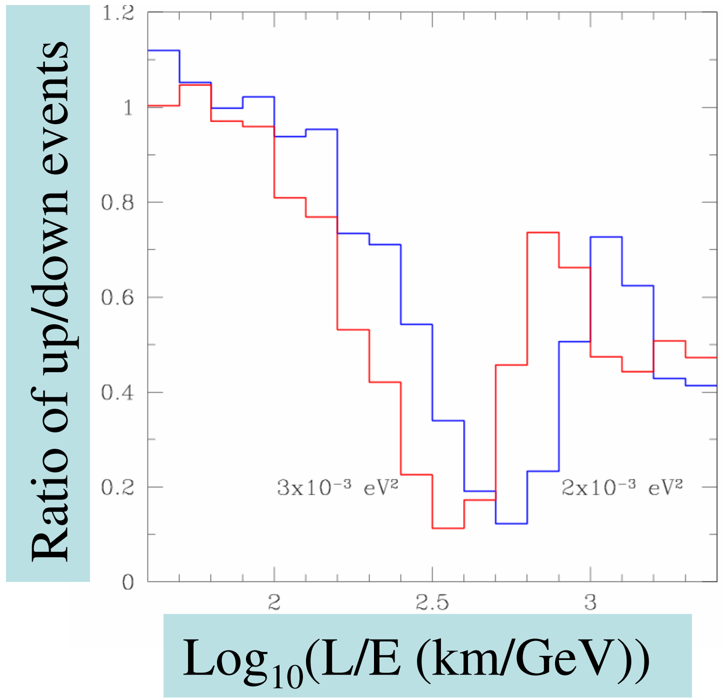
Other experiments at INO

- search for $0\nu 2\beta$ in ^{124}Sn via cryogenic bolometer (*feasibility ongoing*)

- nuclear cross sections of astrophysical interest using 500 kV accelerator



Observing fall and rise of up/down $\nu_\mu \Rightarrow$ precise Δm^2_{23}



Simulated up & down going muons from CC μ interactions

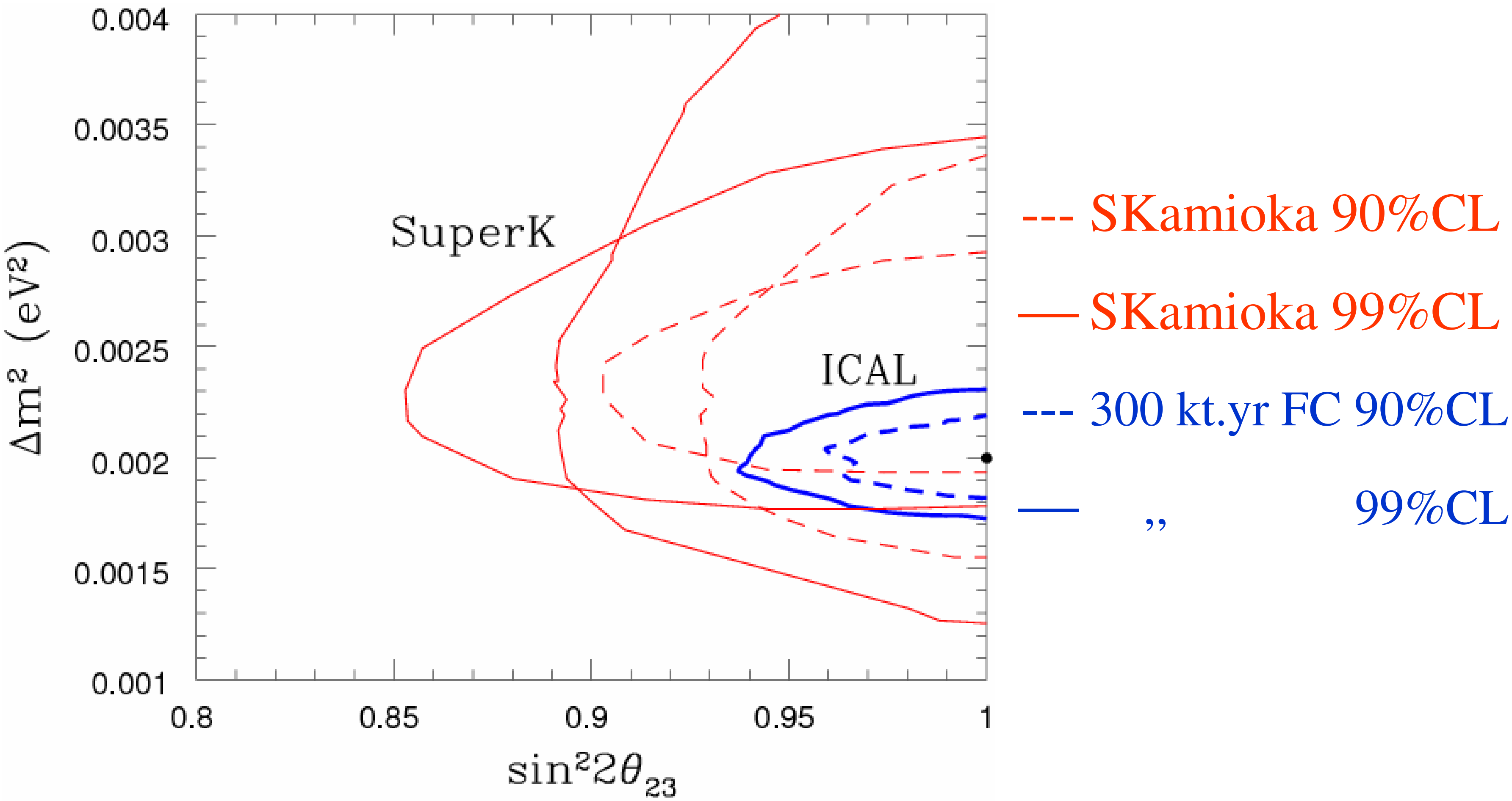
$\sin^2\theta_{23} = 0.5$,

exposure = 250 kt.yr

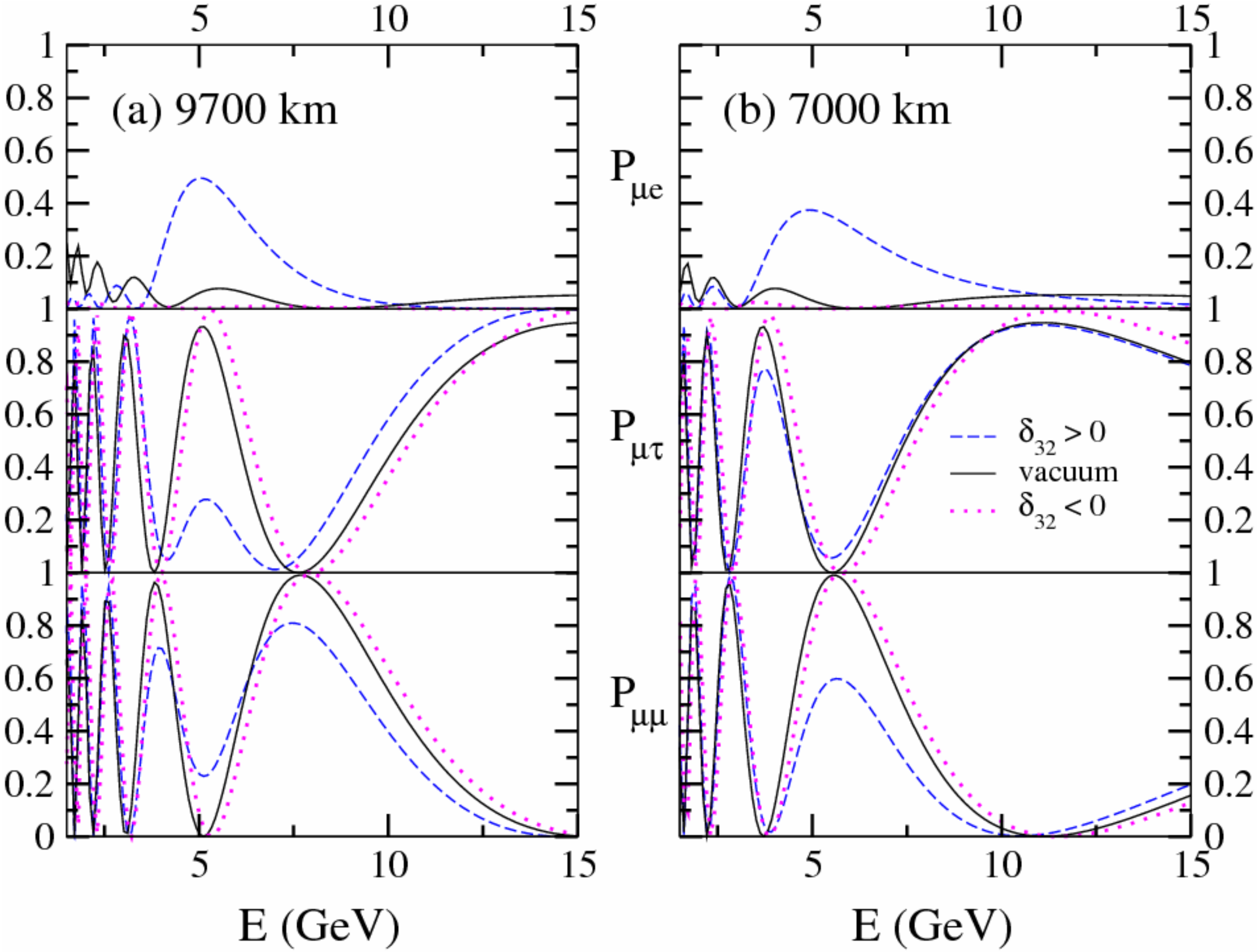
Red : downward μ

Blue : upward μ

Exclusion plot from simulated ICAL data for $\Delta m^2 - \sin^2 2\theta_{23}$

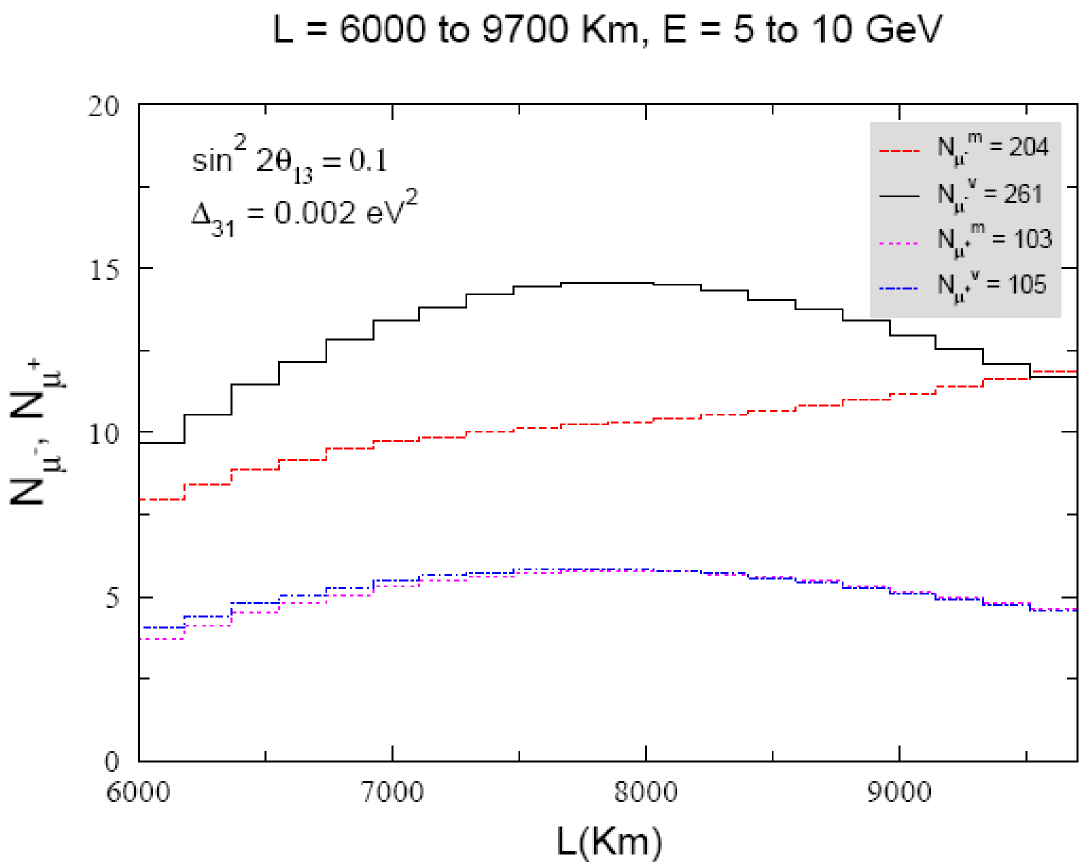


Appearance & survival probabilities for $\nu_\mu \rightarrow \nu_e$, ν_τ and ν_μ in vacuum and matter for normal and inverted hierarchies



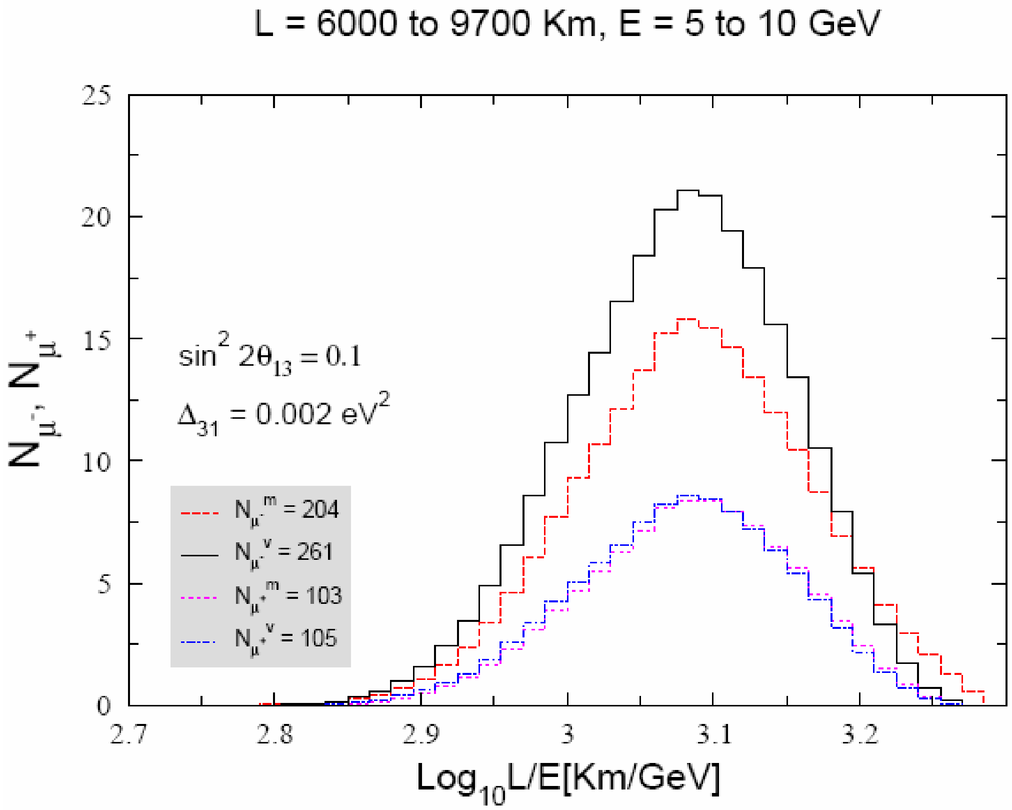
$\sin^2 2\theta_{13} = 0.1$ assumed

Atmospheric muon-neutrino induced $\mu^{\pm}$ events

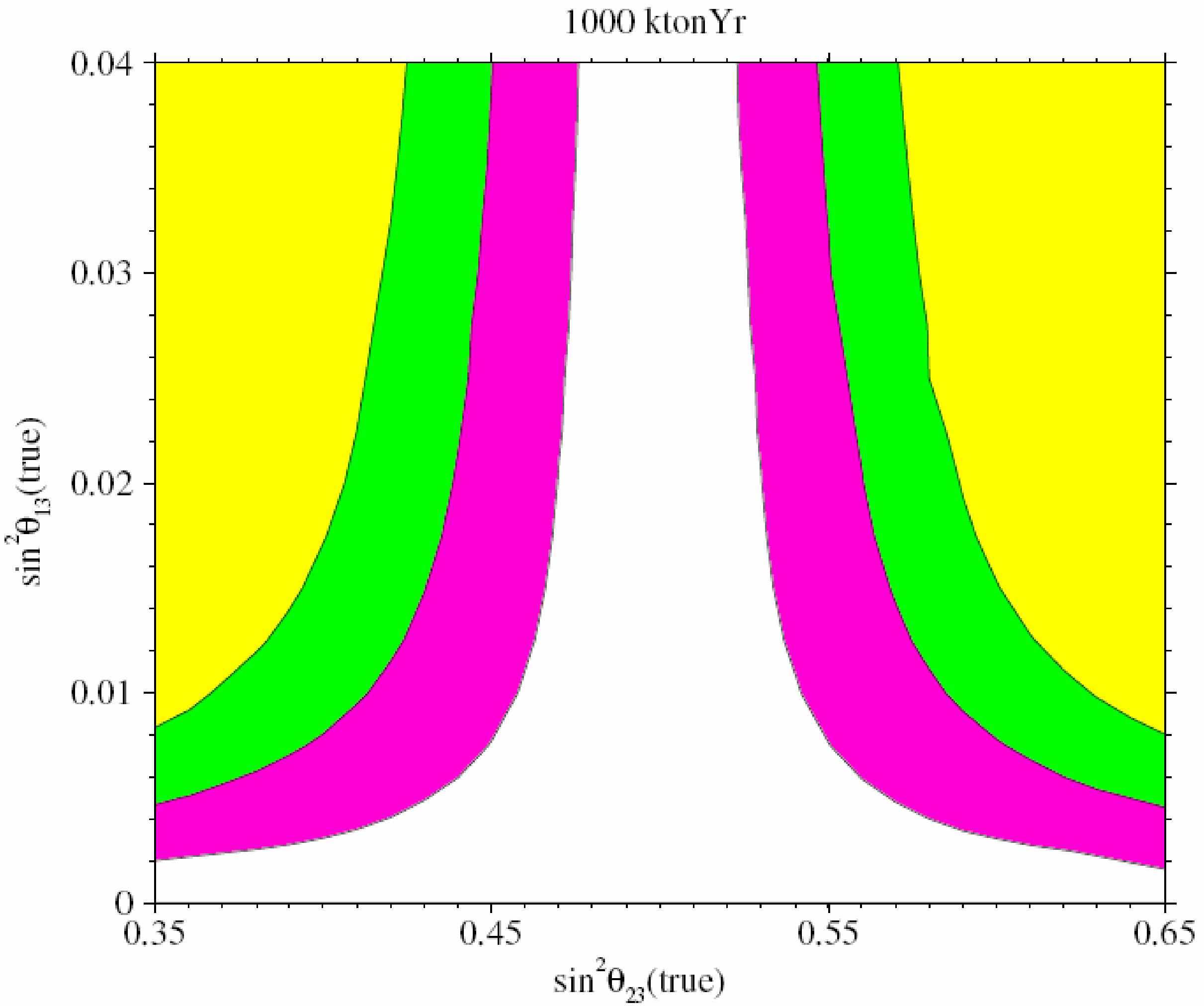


Gandhi et al., hep-ph 0411252

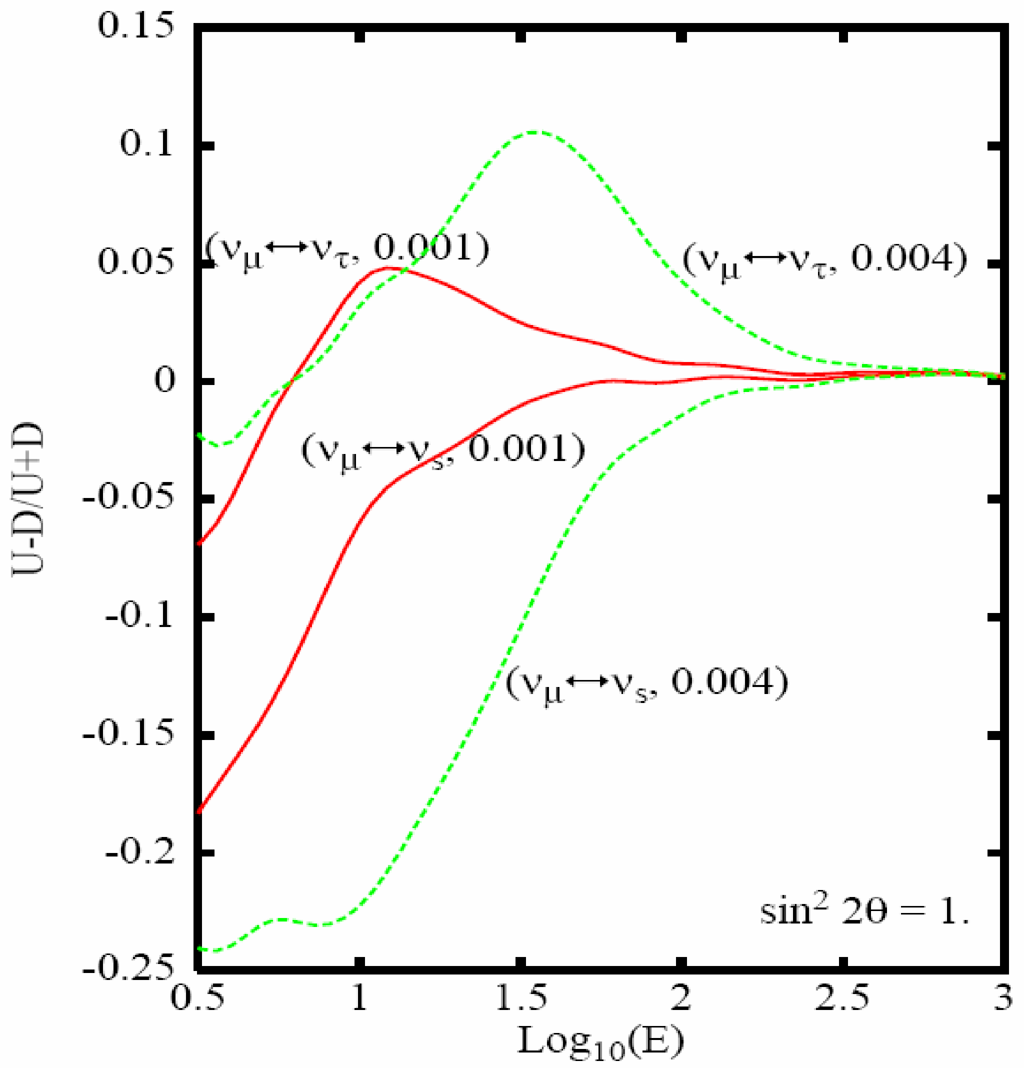
Event rate for $\mu^{\pm}$ showing matter effect



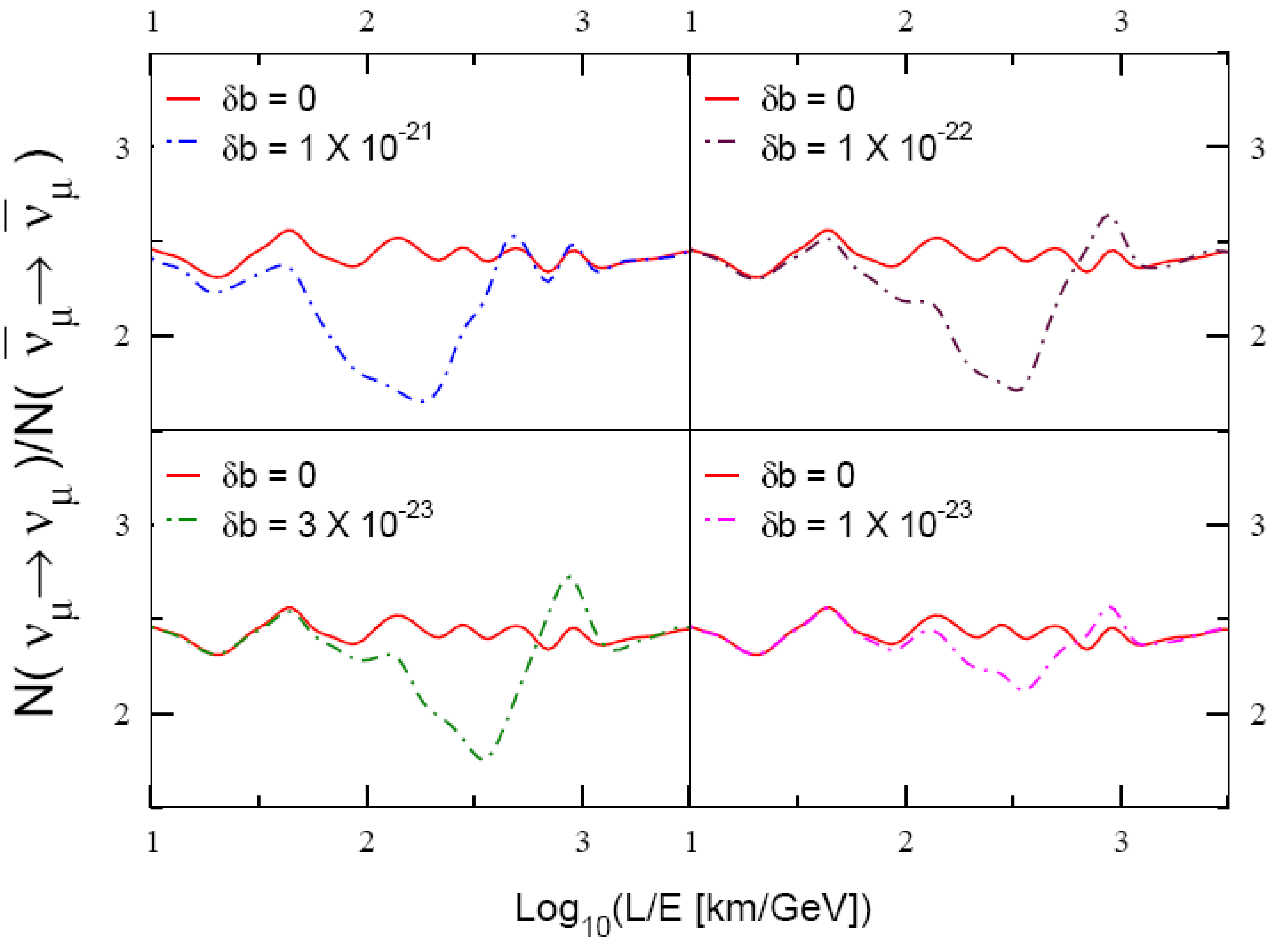
Octant ambiguity at ICAL



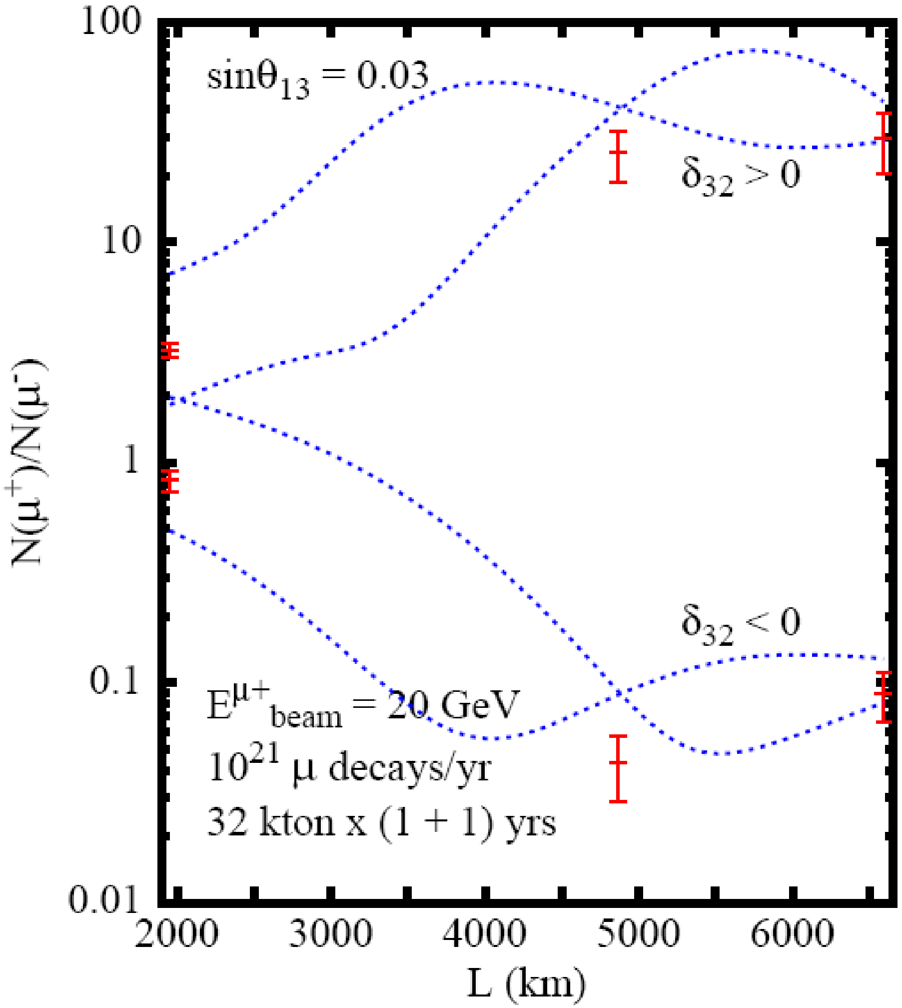
Discrimination between $\nu_\mu \rightarrow \nu_\tau$ and $\nu_\mu \rightarrow \nu_s$



Search for CPT violation



Search for CP violation



$\mathrm{Sin}^2\, 2\theta_{13} = 0.0036$

$\delta_{CP} = \pm\pi/2$

Distances from JPARC

If θ_{13} vanishingly small….

priv.comm. Gandhi, Ghoshal, Goswami, Umasankar (May 2008)

What if $\theta_{13} << 10^{-1}$?

Assuming $\theta_{13} = 0$

$$
\begin{aligned}
P_{\mu\mu} &= 1 - 4\cos^4\theta_{23}\sin^2\theta_{12}^m\cos^2\theta_{12}^m\sin^2\left(\Delta_{21}^m\frac{L}{4E}\right) \\
&-4\cos^2\theta_{23}\sin^2\theta_{23}\sin^2\theta_{12}^m\sin^2\left(\Delta_{31}^m\frac{L}{4E}\right) \\
&-4\cos^2\theta_{23}\sin^2\theta_{23}\cos^2\theta_{12}^m\sin^2\left(\Delta_{32}^m\frac{L}{4E}\right)
\end{aligned}
$$

Matter effect important only in θ_{12} and Δ_{21}

For $E_\nu > 1$ GeV, $A = 0.76 \times 10^{-4}\,\rho E_\nu >> \Delta_{21}$ and $\theta_{12}^m \simeq \pi/2$

Here $\Delta_{31}^m = \Delta_{31} - \Delta_{21}\cos^2\theta_{12}$ Sensitivity to sign of Δ_{31}

$$P^{m}_{\mu\mu}(\mathrm{NH}) - P^{\mathrm{m}}_{\mu\mu}(\mathrm{IH}) = 2\alpha\Delta c^2_{12}\sin 2\Delta$$

where $\Delta = |\Delta_{31}|L/4E$ and $\alpha = \Delta_{21}/|\Delta_{31}|$

- To observe this difference $L/E \sim 10^4$ km/GeV needed
- Suited for atmospheric neutrinos, large ν flux ~ 1- 2 GeV and $L \sim$ 9000 - 13000 km
- Effect does not have matter term so no charge ID needed
- Reduction in error in $|\Delta_{31}| < 0.5\ \Delta_{12}$ crucial

At ~ 3σ level and 1 Mton.yr NH or IH can be established

2. Physics goals and ICAL

Choice of detector and site

Existing detectors worldwide

- water Cerenkov (50 kT SuperKamioka)
- Fermilab-MINOS (5 kT Fe calorimetric detector)
- CERN- OPERA at Gran Sasso

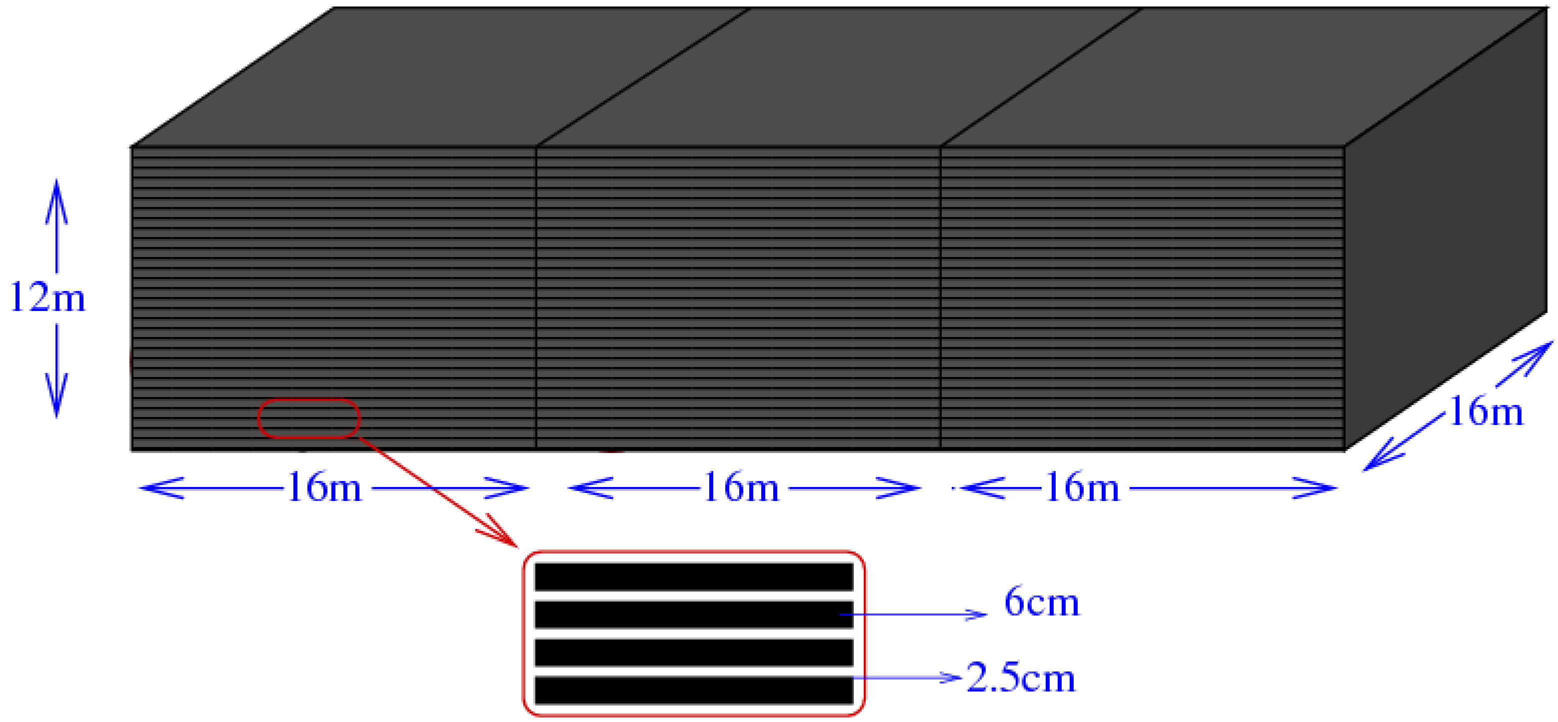
Our choice

- Detector – physics reach, our capabilities & limitations ⇒

  INO Collab. chose a 50-100 kT Iron Calorimeter (ICAL)
- Site requirement – 1 km rock cover all round detector

  Preferred site : Pushep (near Ooty, Tamilnadu)

Schematic of 50 kton Iron Calorimeter (ICAL)



- Magnetic field using low carbon steel (B ~ 1.3 Tesla)
- nsec timing (from RPC) ⇒ up/down discrimination of muons
- X-Y-Z tracking by RPC ⇒ ***p***/*q* ⇒ L/E for μ^+ and μ^- events

Requirements of active detector

- Position resolution ~ 2 cm, time resolution ~ 1 nsec

  track(s) of secondary charged particles $\Rightarrow$ $\boldsymbol{p}_\nu$, fast timing $\Rightarrow$

  up-down, both of these $\Rightarrow$ charge ID (μ^+ or μ^-) $\Rightarrow$ ν_μ or anti-ν_μ
- Modular design
- Large size (total area for 50 kT detector ~ 10^5 m^2)
- Large numbers so should be cheap, rugged, reliable

Options :

Plastic scintillator strips, large area gas detectors

RPC *appears* to be the better option from consideration of

- simplicity of construction & raw materials (float glass, polycarbonate spacers, conductive paint …)
- large pulses in streamer mode
- cost / m^2 coverage (~ \$425+15/yr)

Plastic scintillator option (incl. WLS fibres & photo-readout)

presently more expensive (~ \$970/m^2). With SiPMTs on horizon

+ dedicated extruding machine this option is worth evaluating ….

What ICAL can and cannot do

✓ Measure ν_μ ($\bar{\nu}_\mu$) induced μ^- (μ^+)

× ***Poor*** for ν_e ($\bar{\nu}_e$) since thickness of Fe ~ 3 × L_{rad}

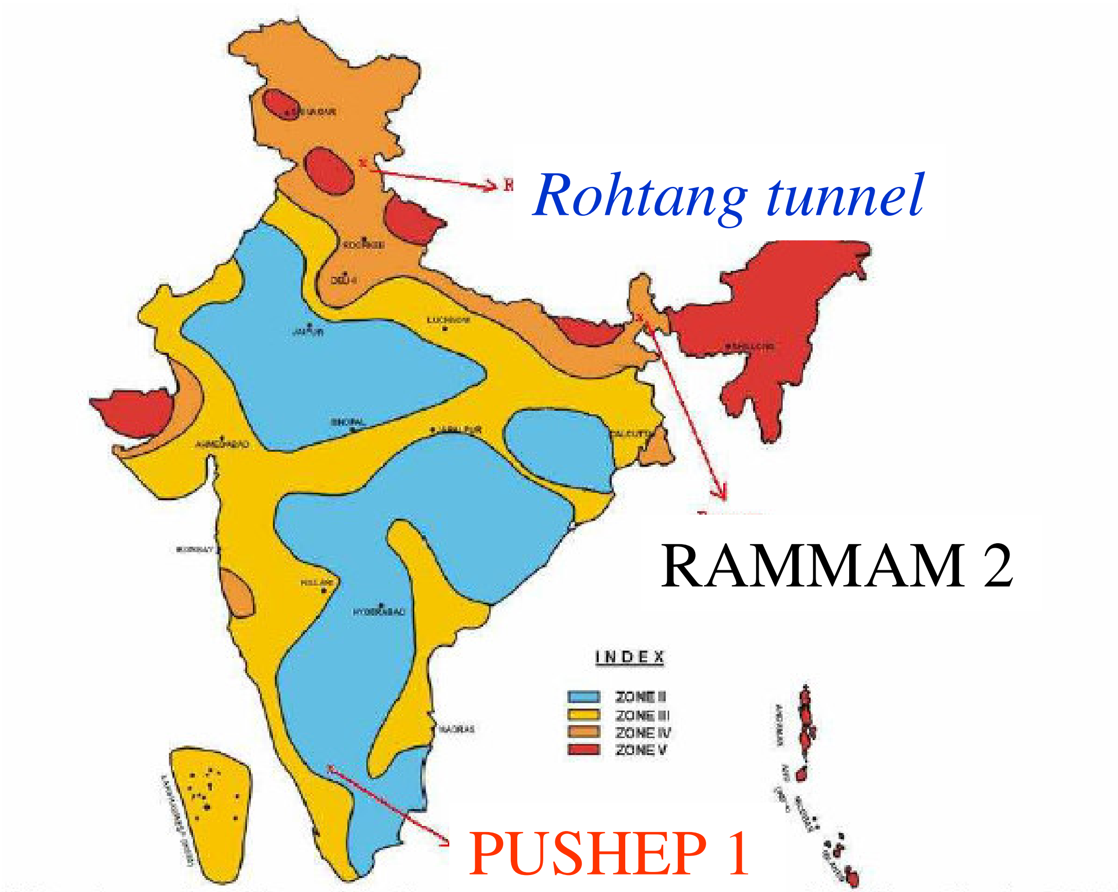
✓ Muon charge identification (~ 95% for E > 1 GeV if large part of track visible)

✓ Muon energy measurement – reconstructed & actual agree within ~ 5%

✓ Muon direction reconstruction – σ_θ ~ 10%

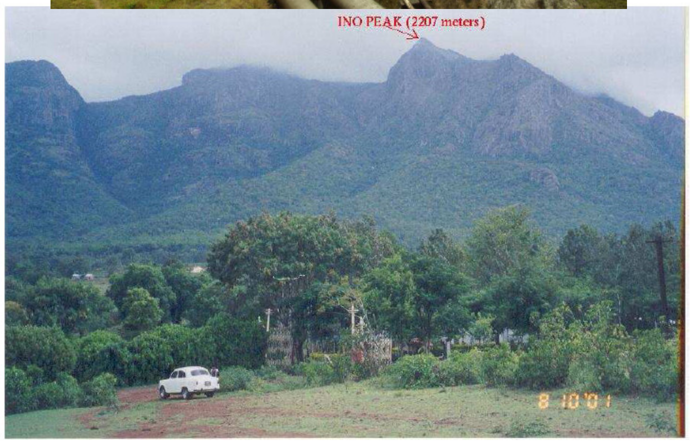
✓ Neutrino L, E reconstruction - σ_E ~ 30%, σ_L ~18%

Location of possible sites for INO



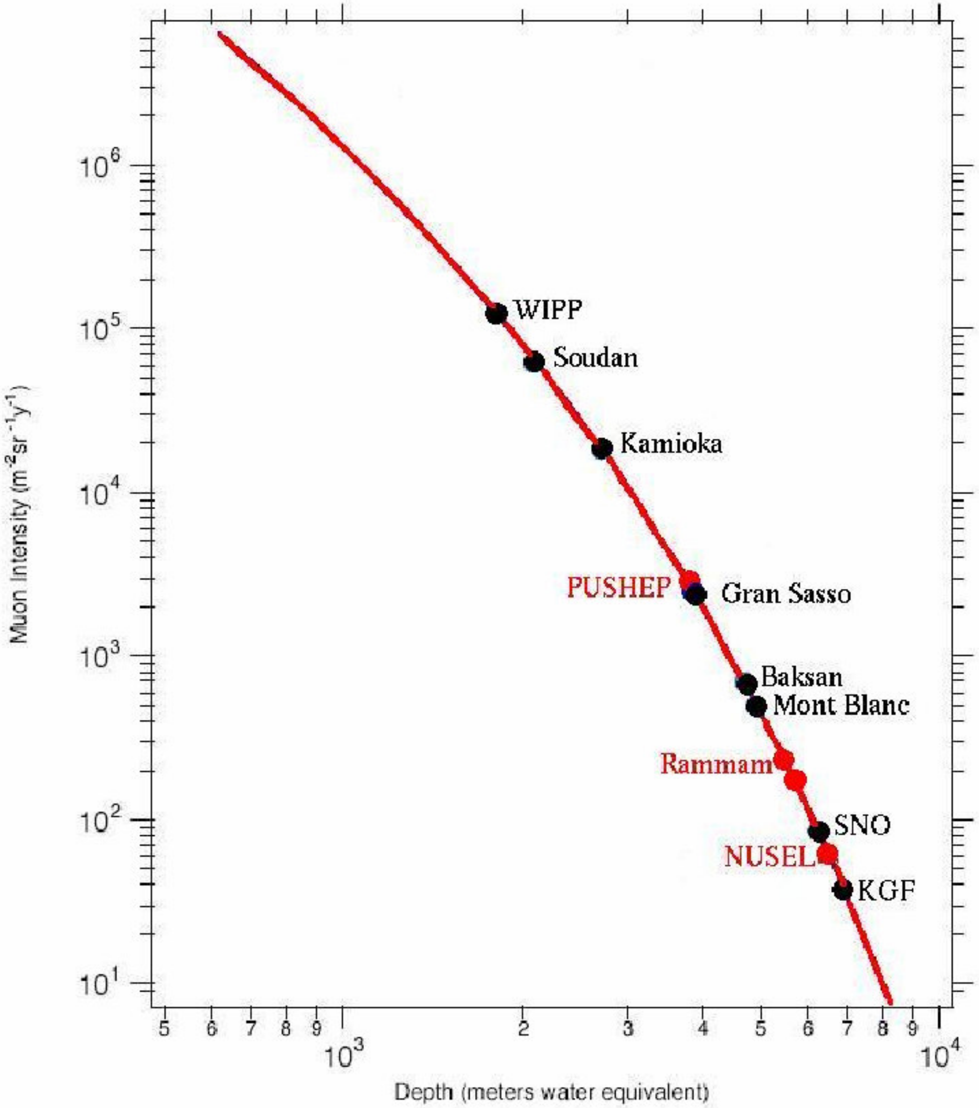
Seismic zoning Map of India- issued by Bereau of Indian Standards, 2000

PUSHEP : 11.5°N 76.6°E, 6.5 km from Masinagudi, 96.5 km from Mysore, 5 hrs from Bangalore, Coimbatore, Calicut



INDIA
States and Union Territories
N
PAKISTAN
CHINA (TIBET)
NEPAL
BHUTAN
BANGLADESH
MYANMAR
ARABIAN SEA
BAY OF BENGAL
JAMMU & KASHMIR
Srinagar
HIMACHAL PRADESH
Shimla
Chandigarh
PUNJAB
UTTARANCHAL
Dehradun
HARYANA
DELHI
RAJASTHAN
Jaipur
UTTAR PRADESH
Lucknow
SIKKIM
Gangtok
ARUNACHAL PRADESH
Itanagar
ASSAM
Dispur
NAGALAND
Kohima
Shillong
Imphal
MANIPUR
MEGHALAYA
Agartala
TRIPURA
Aizawl
MIZORAM
Patna
BIHAR
GUJARAT
Gandhinagar
Bhopal
MADHYA PRADESH
Ranchi
JHARKHAND
WEST BENGAL
Calcutta
CHHATTISGARH
Raipur
ORISSA
Bhubaneshwar
DIU
DAMAN
DADAR & NAGAR HAVELI
MAHARASHTRA
Mumbai (Bombay)
Hyderabad
ANDHRA PRADESH
YANAM (Pondicherry)
Panaji
GOA
KARNATAKA
Bangalore
Chennai (Madras)
PONDICHERRY (Puduchchery)
KARAIKAL (Pondicherry)
TAMILNADU
LAKSHADWEEP
MAHE (Pondicherry)
KERALA
Thiruvananthapuram
Port Blair
ANDAMAN & NICOBAR ISLANDS
Location of INO
Copyright © Compare Infobase Pvt. Ltd. 2003
Map not to Scale

Muon intensity vs. depth



3. Status of project

3.1 ICAL Magnet

- Magnetic field B large enough (1- 1.5 Tesla) to enable ***p*** measurement for 1-10 GeV muons produced by $\nu\mu$ interactions with detector
- Magnetic steel/soft iron should be reasonably cheap (50 ktons!)
- Piecewise uniformity
- Modularity, access for maintainance of RPC & electronics
- Optimum copper to steel ratio
- Mechanical stability

Possible configurations:

For a magnetic field over ~ 6000 m^3 toroidal Fe-free design possible,

but designs with field returning within iron plates simpler:

MINOS (cylindrical symmetry)

MONOLITH proposal ("rectangular")

Other geometries

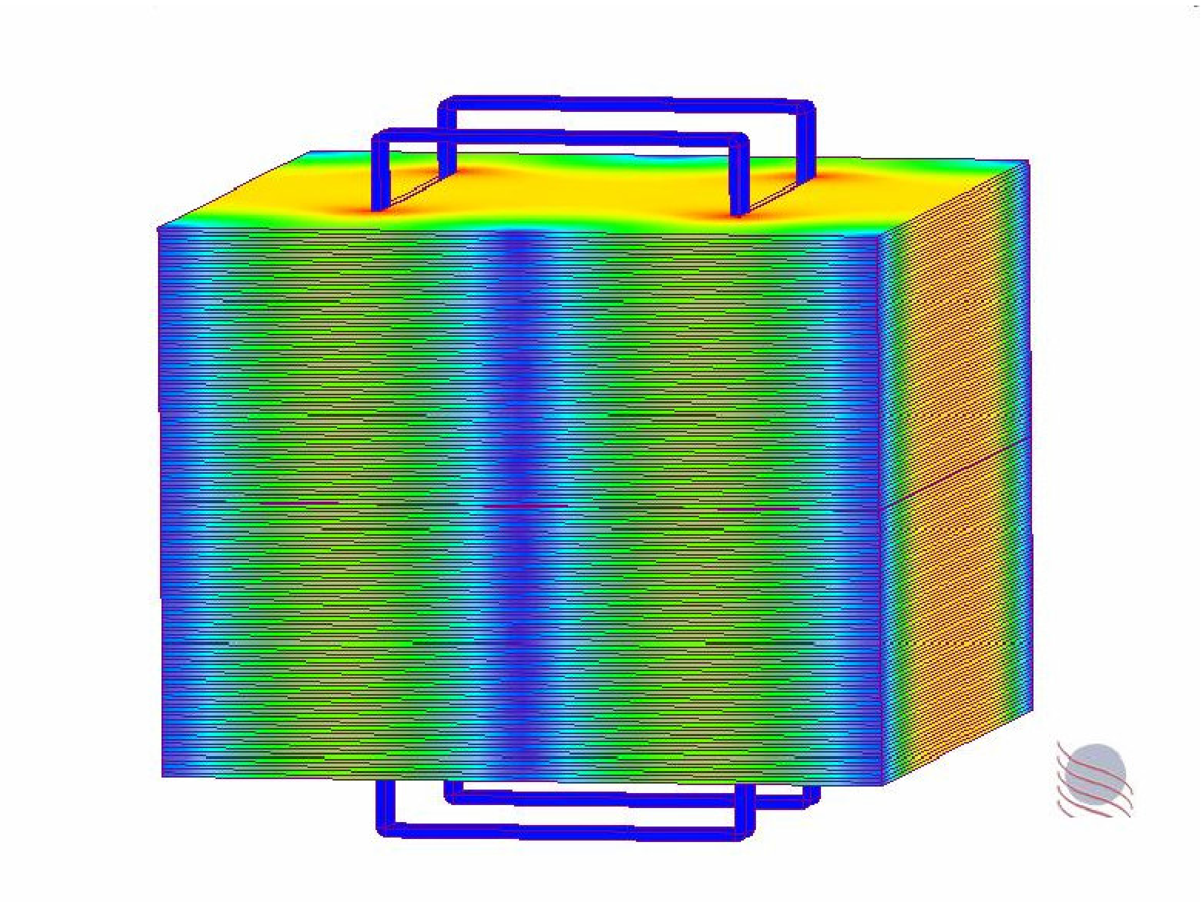
We decided to go for the "rectangular" design for simplicity

1^{st} step: Build a prototype ICAL detector to be tested with cosmic muons and, later, at a test beam facility

- Magnetic field calculation using Magnet 6.25 (Infolytica) FE software
- Implemented on quad-dual core Intel (3.2 MHz)
- Poor aspect ratio (large plate length/width : thickness)

  $\Rightarrow$ large time for meshing. For 16 kton magnet calc. time ~ 0.8 hr
- Calculations for ideal (no gap, single homogeneous plate/layer) and 2 m $\times$ 4 m plates with equal gaps 1-10 mm
- C-10 (low carbon) steel used in magnet simulation

Field map of ICAL magnet module



Orange – high B

Yellow – medium B

Green – lower B

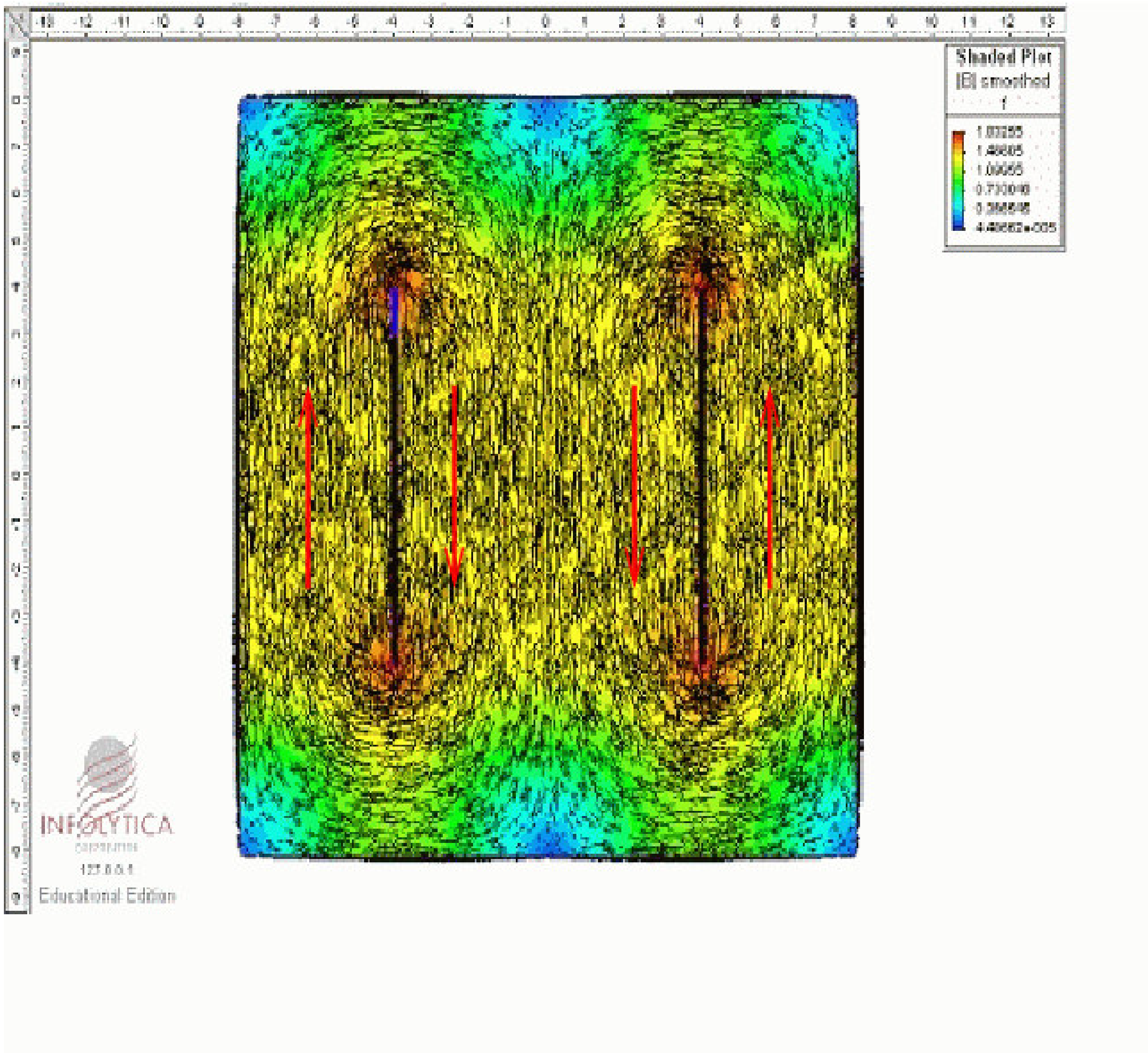
Blue – lowest B

Simulation with commercial finite element software

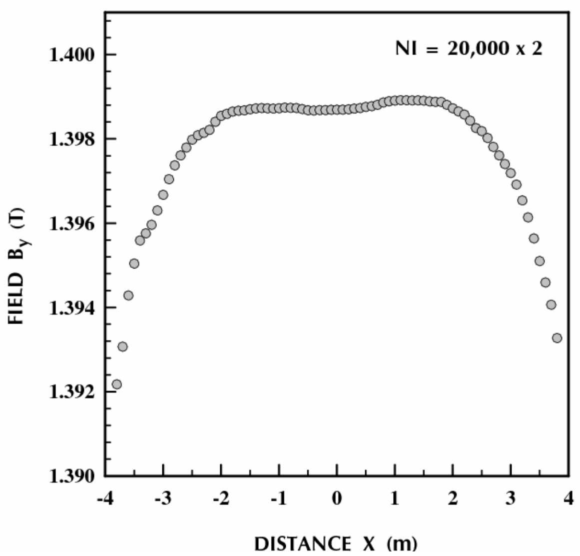
Magnet 6.0 used on Xeon Pentium with 4 GB RAM

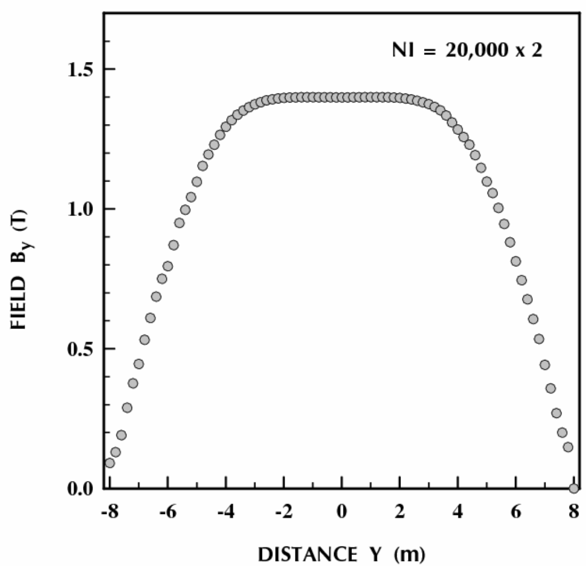
Simulation with commercial software Magnet 6.0 (Infolytica) on Xeon Pentium with 4 GB RAM

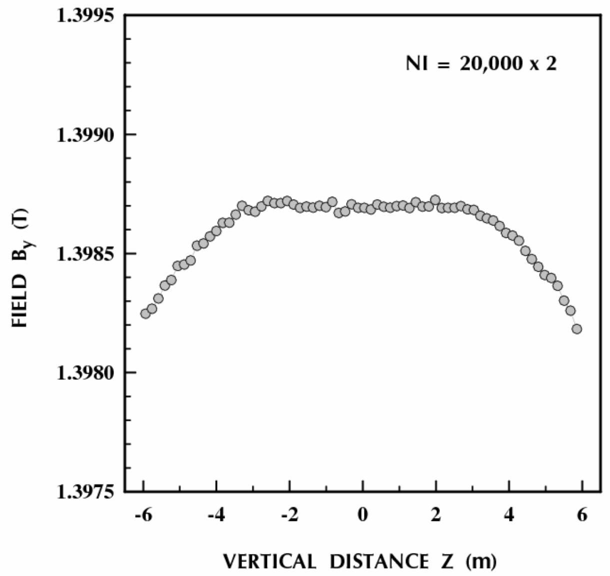
Magnetic field map in plate (for 2 coils)



Field along & normal the plane of the steel plates in 16 kton module







Effect of gap in steel plates 0 mm:2 mm:10 mm

1.0 : 0.97 : 0.70

More studies necessary – assembly scheme, mechanical stability, transient and error analysis

- Mechanical design and assembly project report being prepared by Tata Consulting Engineers (TCE), Mumbai

- Have played similar role in Giant Metre Radio telescope of NCRA, TIFR near Pune

- Draft Report expected by end June, 2008

Important features…

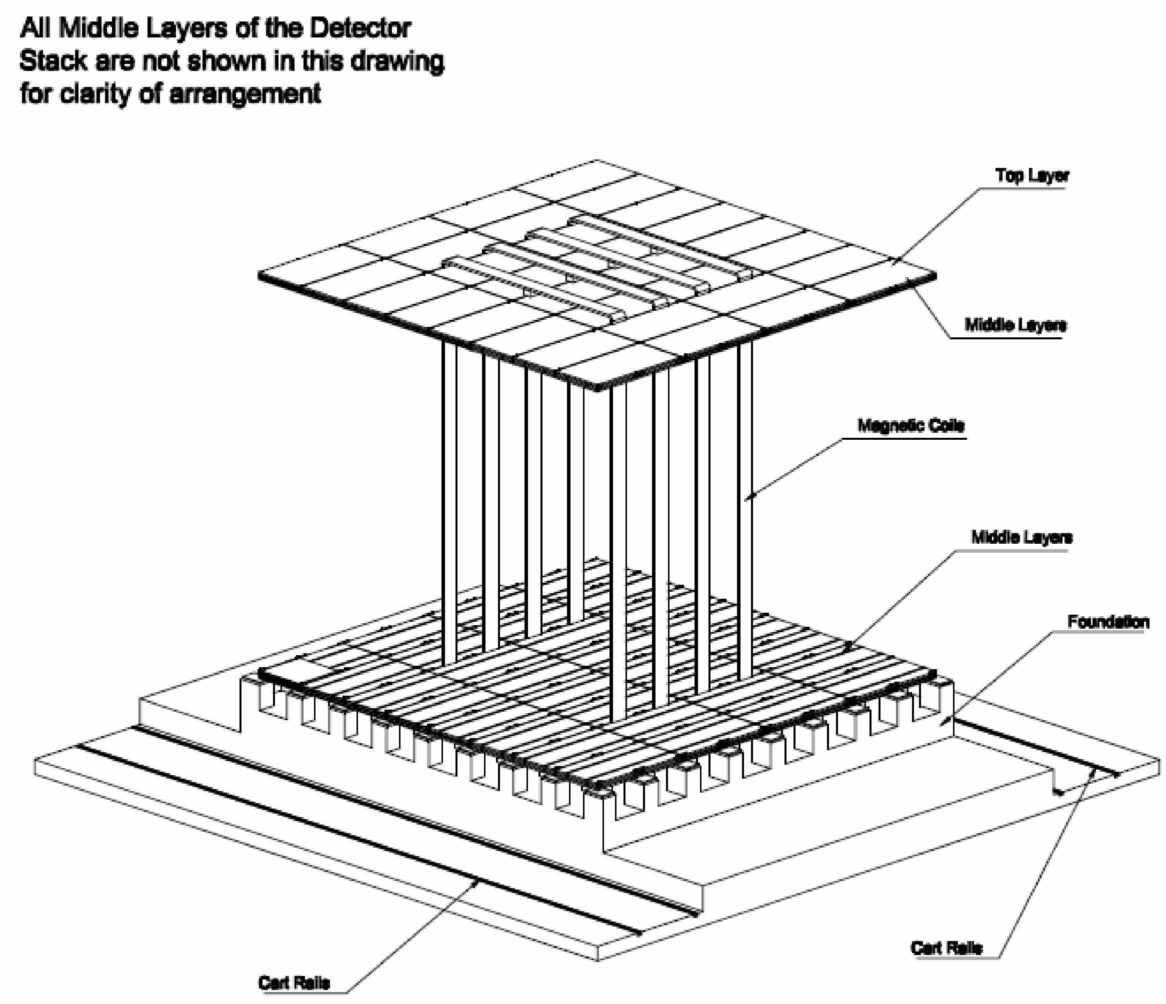
- 16 kton module will rest on 0.6 m × 0.6 m × 1 m (H) RCC posts

- Movable service lift on rails on either side of ICAL module along tunnel length

- Provision for removing upto 4 RPC modules from side

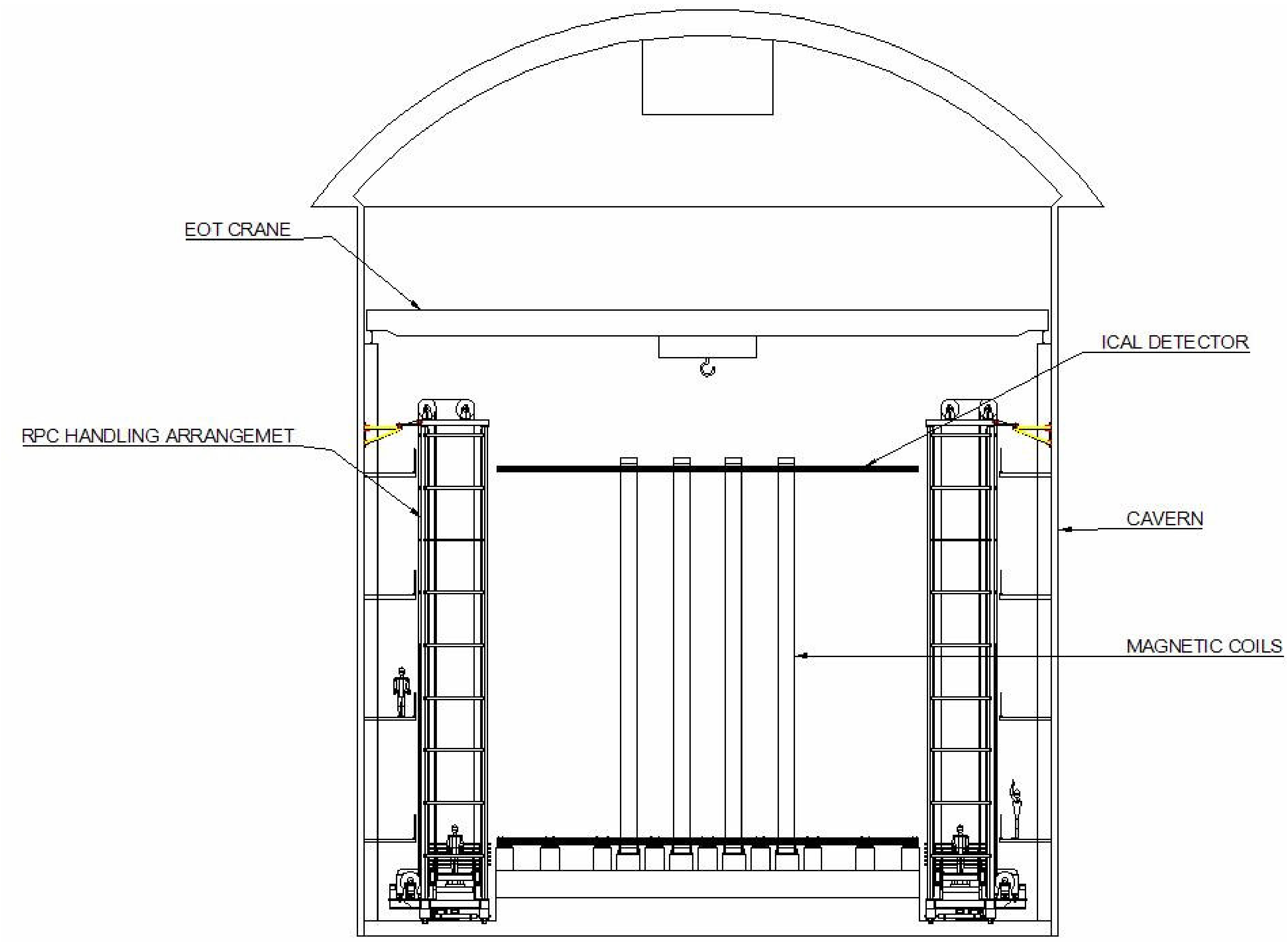
- Slot for Cu coils for DC current excitation & provision for support structure for coils

Proposed layout of Fe plates and Cu coils



4 m × 4 m Fe plates stacked on 99 nos of equally spaced (1.5 m apart) 0.6 m × 0.6 m RCC posts of height ~ 0.5 m

View of proposed layout of ICAL in main INO cavern



Coil winding issues

- Nominal ampere turns for 16 kton module (CR 1010 low carbon steel) – 50,000
- Dimensions of coil – 12 m (ht) × 8 m (wide)

  Total external dimensions in cross section not to exceed 60 cm × 80 cm
- Coil in 2/many parts OR many smaller coils (e.g. 4 m ht)
- Vendor(s) for such large sized coils have to be developed

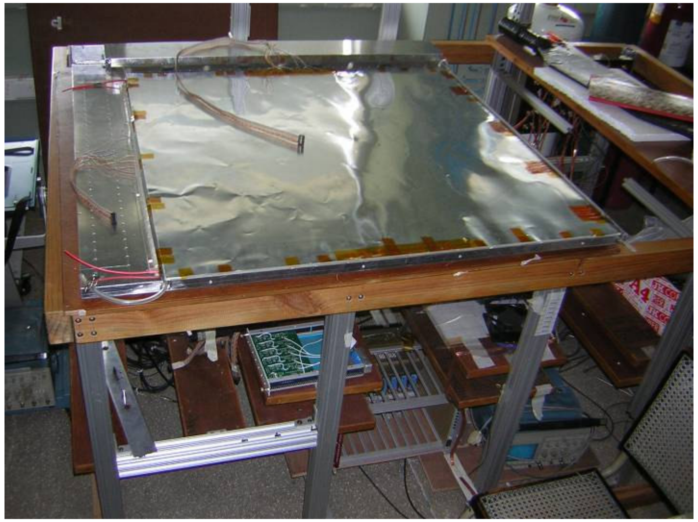
  (2 companies have shown interest)

Resistive Plate Chamber (RPC) R & D

- Glass and bakelite RPC R&D being pursued at TIFR (Mumbai) & VECC+SINP (Kolkata)
- 1 m^2 glass RPCs work for long in *avalanche* mode
- 0.1 m^2 bakelite RPC in *streamer* mode

Both will be deployed in prototype detector at VECC, Kolkata

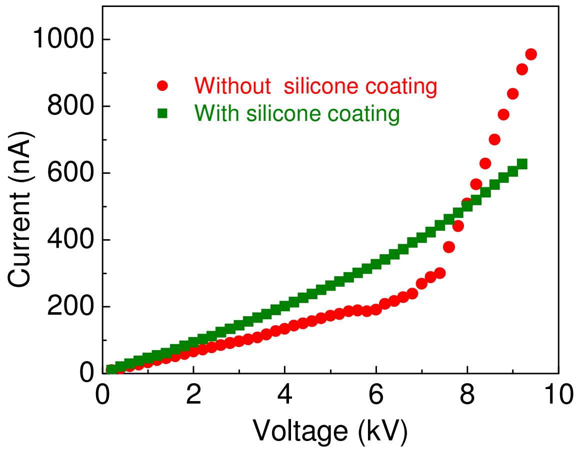
RPC lab at TIFR….

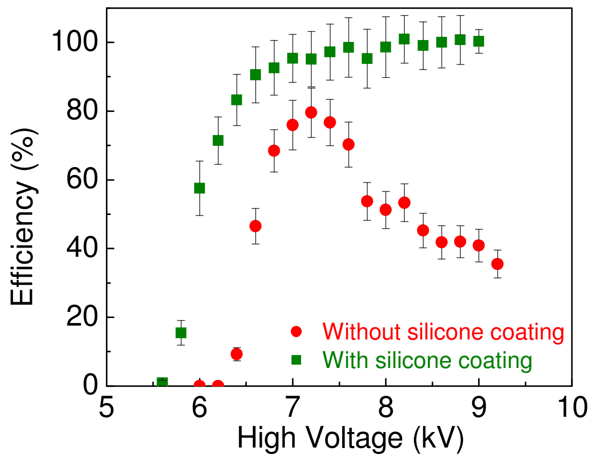


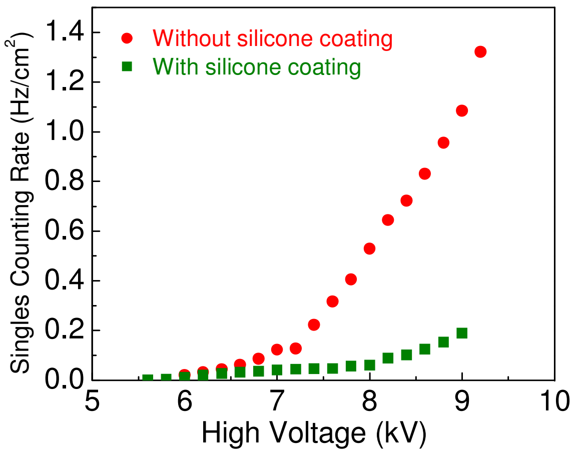
Top : 1 m^2 glass RPC assembly

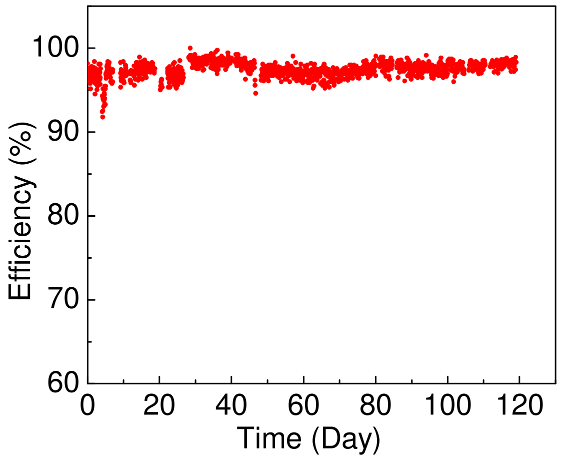
Left : Gas mixing & distribution system

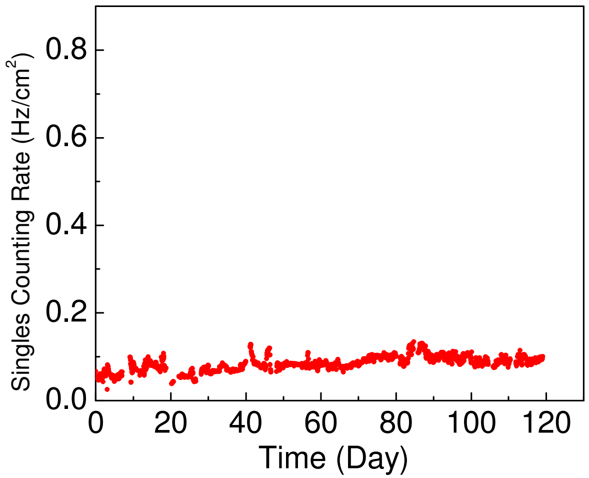
Bakelite RPC at VECC/SINP, Kolkata with silicone coating





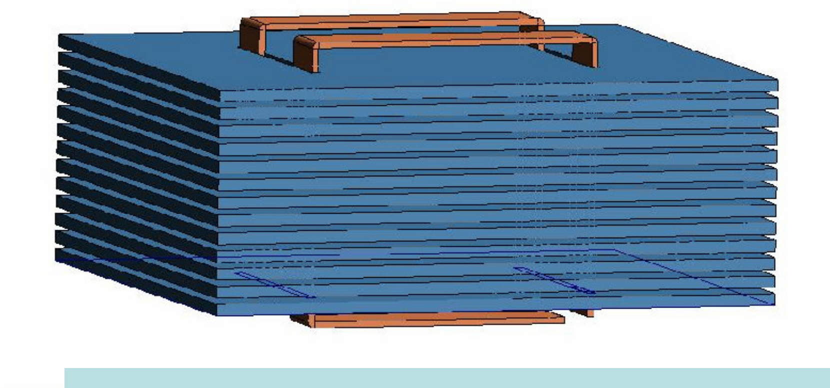






Bakelite P-120 + silicone oil coating improves longitivity & performance

Prototype ICAL magnet & electronics



Total weight ~ 40 tons

Dimensions 2.5 m × 2.3 m

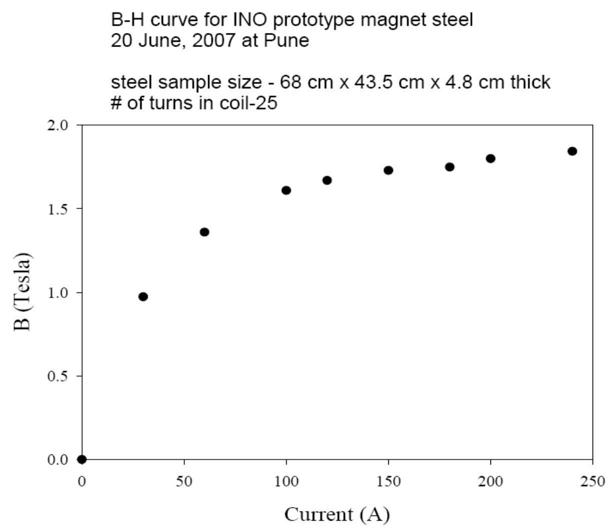
NI_{max} = 10000 A. turns

B_{max} ~ 1.5 T (expected)

- 13 layers of 5 cm thick soft iron, 12 layers of 1 m × 1 m RPCs
- ~ 800 channels of preamp, timing discriminators
- being set up at VECC, Kolkata

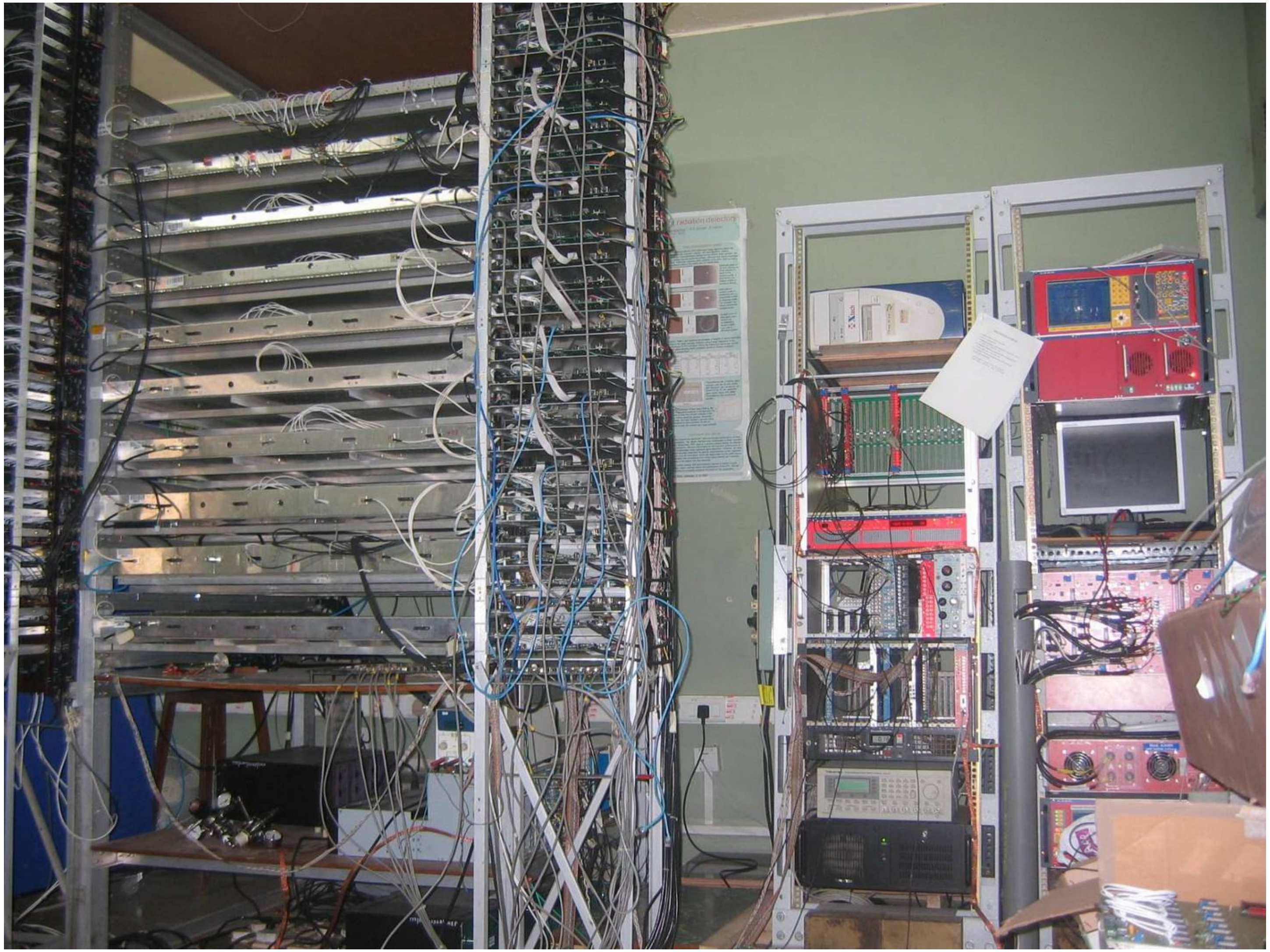
Some details of prototype magnet

- Low carbon steel scavenged from dismantled 330 ton MHD magnet (BARC-BHEL) at Trichy
- Fabrication order was placed with Pune vendor (Milman) included assembly, testing with power supply and field measurement
- Asssembly at VECC complete including Cu coils (4×5 turns, hollow conductor), 500 A DC power supply awaited



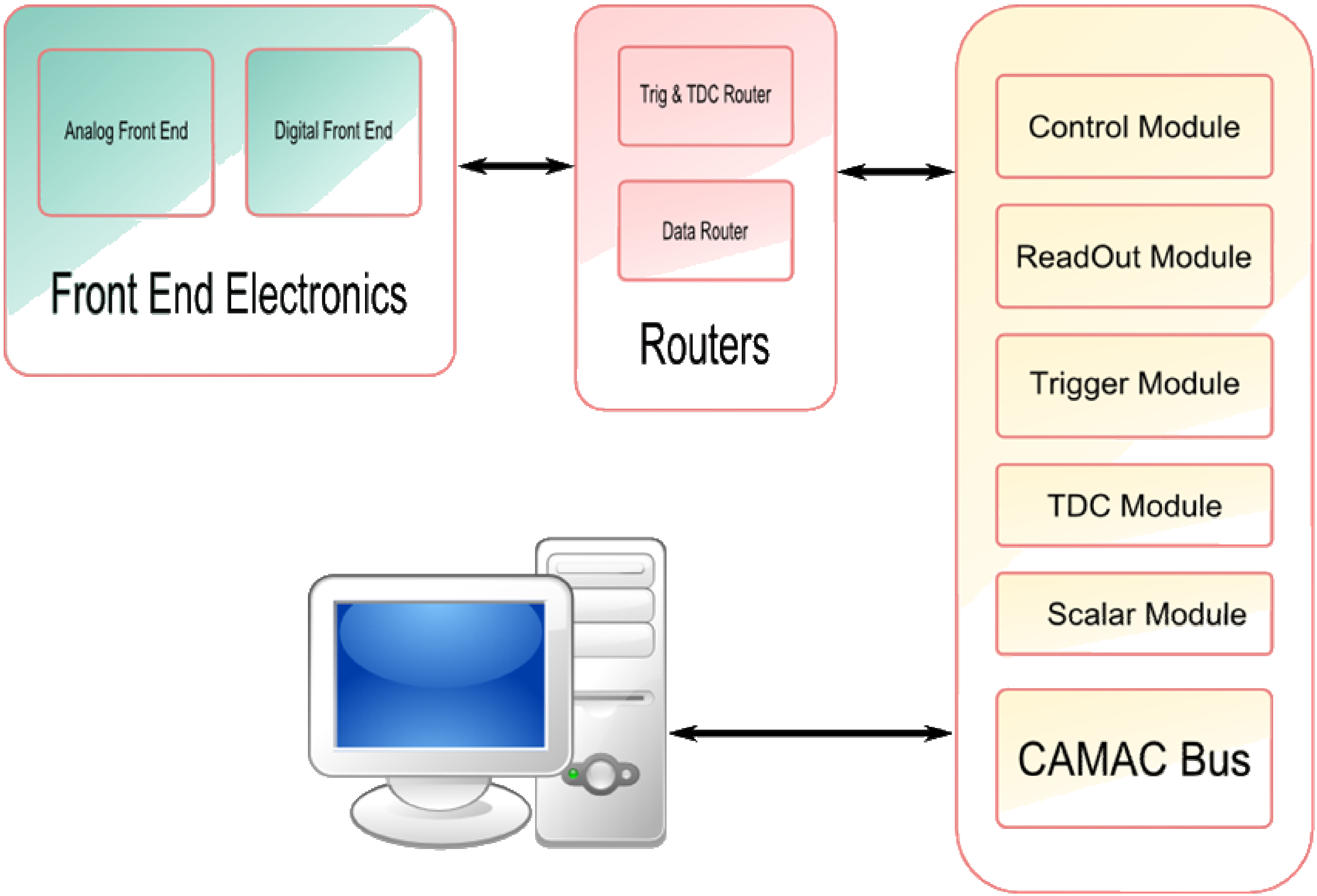
Some photos of prototype ICAL magnet at VECC, Kolkata (Oct'07)

RPCs and electronics for prototype ICAL



Cosmic ray test stand for 1 m^2 glass RPCs at TIFR

Electronics scheme for prototype



Preamplifiers for prototype

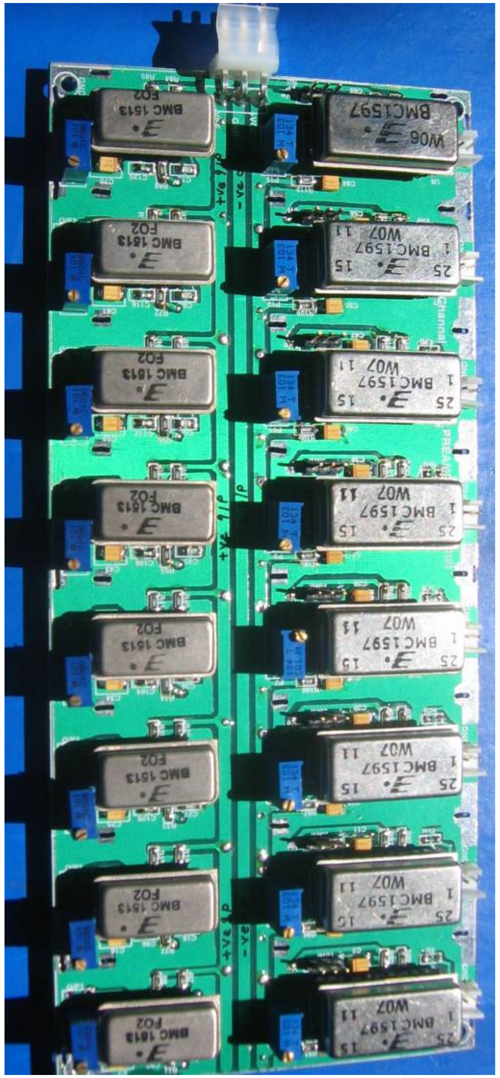
- Hybrid preamp chips of BARC design, made at BEL, Bangalore

  First stage negative input – BMC 1595 (anode)

  First stage positive input – BMC 1597 (cathode)

  Second stage – BMC 1513

  2 types of preamps for X and Y planes
- Cascaded HMCs, Gain: 80, 8-in-1 board
- 2 types of preamps for X and Y planes
- Rise time: 3 ns, Noise band: ±7mV
- About 100 boards needed
- About 15 ready, 6 installed on X-plane



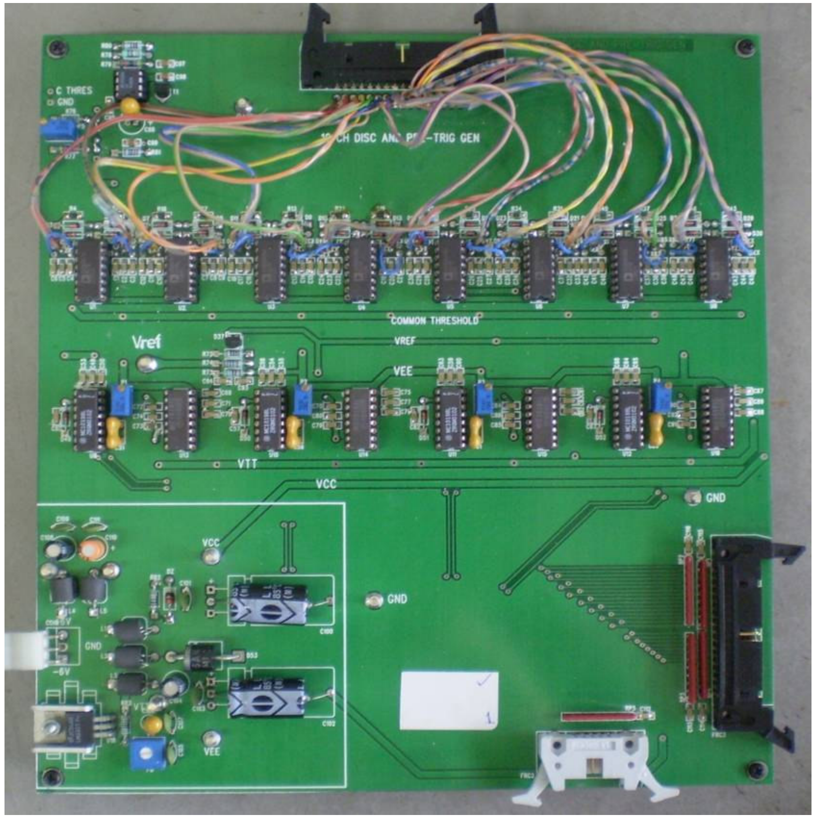
16-channel analog front-end

Functions

- digitize the preamp signals
- form the pre-trigger logic
- signal shaping

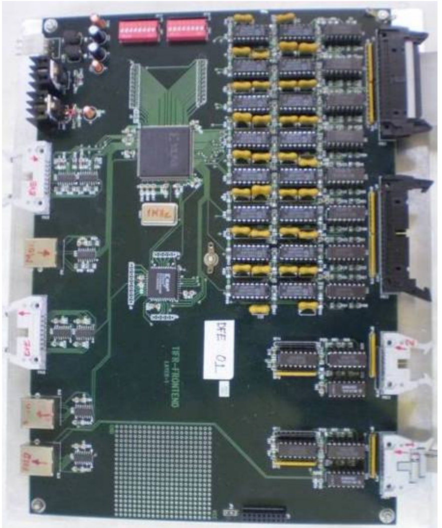
Features

- Uses AD96687 ultra-fast comparator
- Common adjustable threshold
  V_{thresh} now at -20 mV
- ECL output for low I/O delay and fast rise times

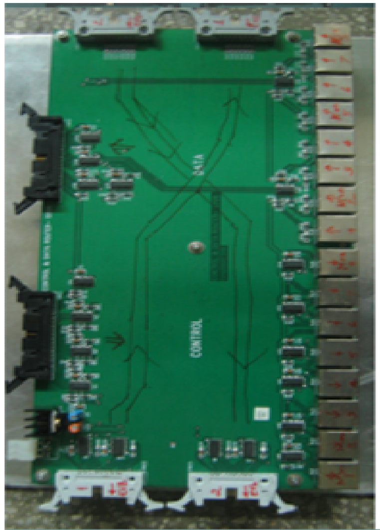


In house electronics for prototype

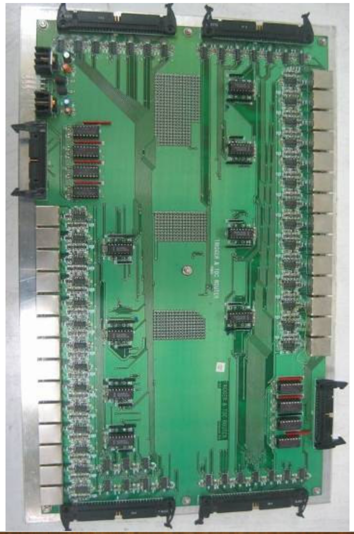
32 ch digital front end

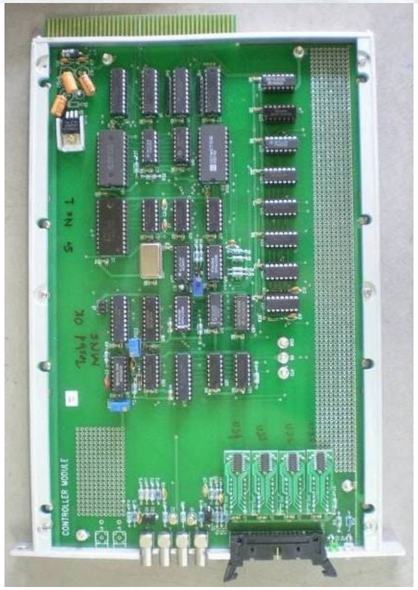


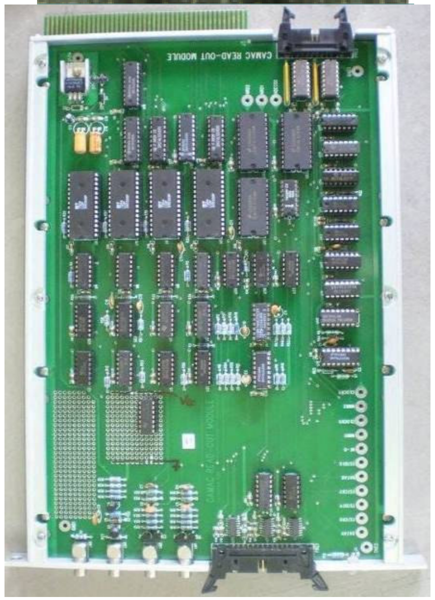
Control & data router



Trigger & TDC router



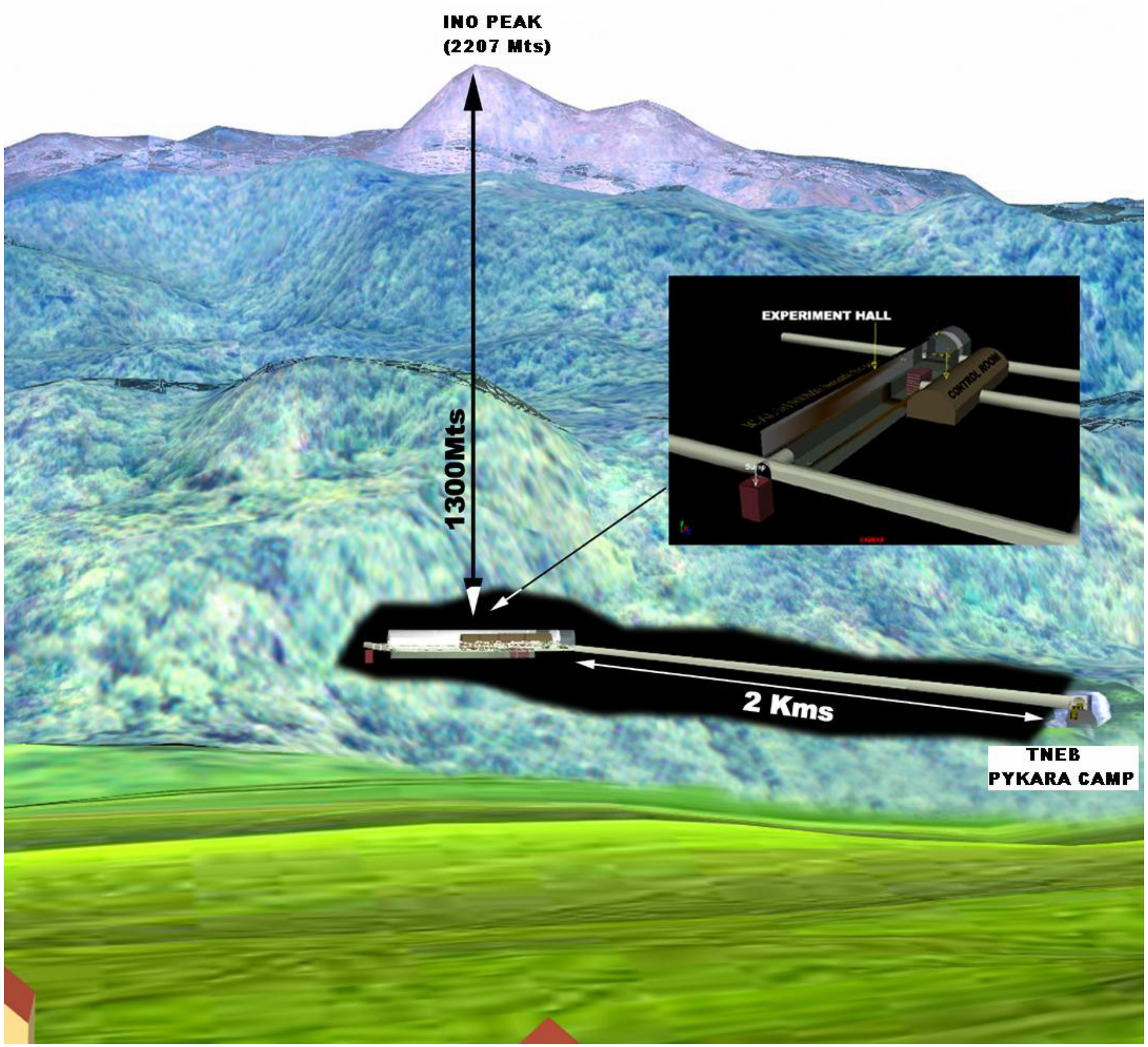




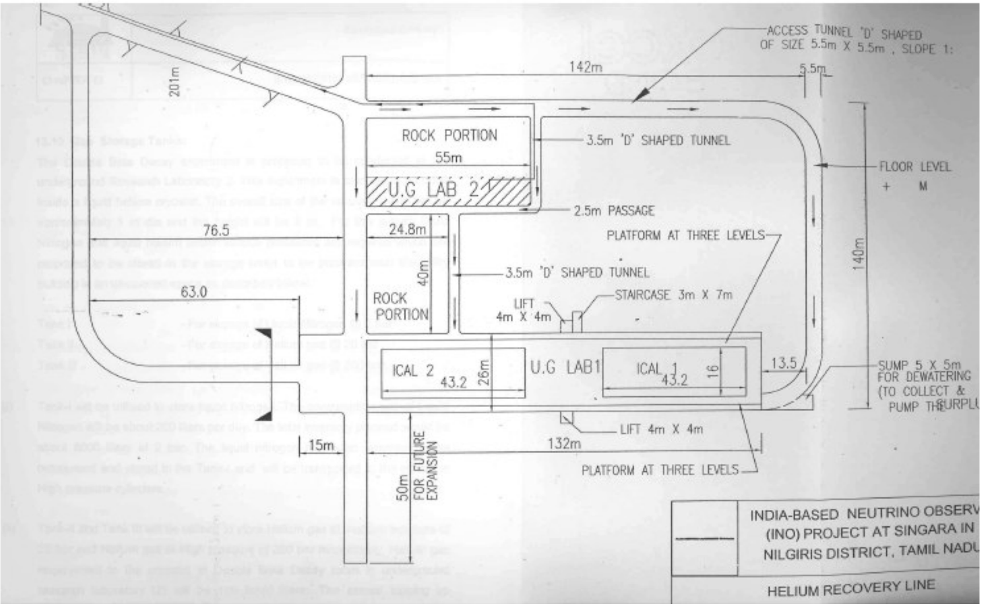
Data & monitor control & readout

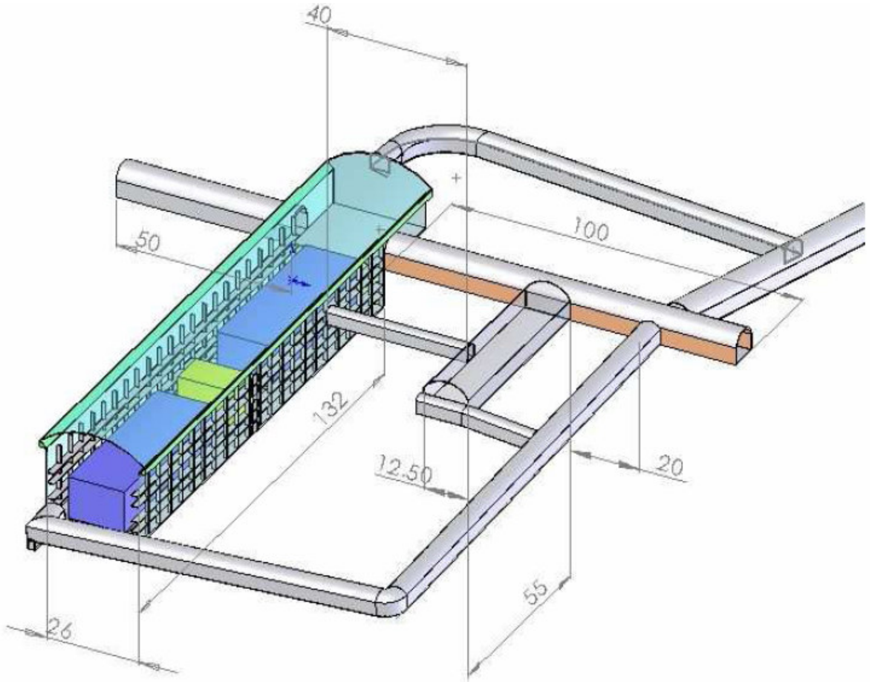
Final trigger

Conceptual layout of INO tunnel



Cavern layout and perspective





➢ Cavern size 26 m (W) × 25 m (H) × 132 m (L) with RCC columns every 6 m for 25 ton crane

➢ 4 floors, lift, staircase between ICAL modules, 2 m wide platform on sides for PS, control panels

3.4 Environment and forest clearances

- Rapid EIA Study : SACON, Coimbatore- June 2007

- Infrastructure Detailed Project Report : DAE Engg. task force & Tamilnadu Electicity Board – June 2007

- Environmental Impact and Management Report : CARE-EARTH, Chennai - April 2008

Environment/forest dept. clearances (contd.)

- MoEF clearance pending Forest Dept. clearance
- Issue: INO in manipulation zone of Nilgiri Biosphere Reserve. Close to Mudumulai Wildlife Sanctuary which is part of the Project Tiger initiative of Govt. of India
- First meeting with Collector, Ooty. Local body (panchayat) members, wildlife activists. Presentation of INO project with Environment Management Plan (EMP) prepared by Care Earth. One/two more interaction meetings planned
- Main issues : disruption in elephant corridor, disposal of stone during tunnel excavation, employment opportunities for locals. EMP has recommendations on each of these issues.

INO Graduate School

- Advertisement in leading newspapers, posters to Universities & Institutes
- 2 years course work for B.Sc. , 1 year for M.Sc.
- Initially at HRI (Allahabad) and TIFR (Mumbai)
- Faculty from all over India + few from overseas

Work plan for DBD experiment

Make a prototype bolometric detector of ^{124}Sn

I a) Make a natural Sn bolometric detector ~ 0.5–1 kg (TIFR, BARC)

Refurbish an old refrigerator (Cooling power ~20μW at 30 mK)

Will serve as a test bench for optimizing the various aspects of milli-Kelvin bolometry. Expected energy resolution ~ 0.5%

b) Radiation background studies: measurements & simulations

(IIT-KGP, SINP, VECC)

c) Reliable NTME calculations (Univ. of Lucknow, IIT-KGP , PRL, IOP)

II a) Enrichment of ^{124}Sn (> 50%) (BARC & IIT- KGP)

b) Sensor development

c) Build ~ 1 kg enriched ^{124}Sn detector (TIFR, BARC)

III Preparation of DPR

Nuclear cross sections of astrophysical interest

- 11^{th} plan proposal from SINP, Kolkata for one *overground* and one underground (at INO lab) accelerator
- Gran Sasso pioneered such measurements using the low background environment at large depth
- 500 kV DC accelerator for stable light ions (upto ~ A=12)

A few potentially interesting measurements at **Gamow peak** energies

$^{12}C(\alpha,\gamma)^{16}O$, $^{13}C(p,\gamma)^{14}N$, $^{14}N((p,\gamma)^{15}O$, $^{15}N(p,\gamma)^{16}O$, $^{15}N(p,\alpha)^{12}C$

environmental effects on nuclear processes

Estimated cost and schedule

	Rs (crores)	
	11th plan	12th plan
Infrastructure (*underground lab, services..*)	100	
Soft iron 50 kton @Rs 60/kg	100	200
Detector (RPC, electronics, DAQ)	75	130
Salaries	15	
Contingencies	30	20
Mysore Centre	50	
DST	100	100
TOTAL	470 +	450 = 920 (230 M$)

- Financial sanction expected ~ 3rd quarter 2008
- Phase 1 – 12-18 months: Details planning of infrastructure, permissions, detector design (engg)
- Phase 2 – 22 months: Tunnel excavation, procurement of detector components and start of fabrication
- Phase 3 – 12-18 months: Assembly of detector modules ½

Summary of present status of INO

- Interim Project Report sent for review to 7 experts

  - generally very positive and encouraging

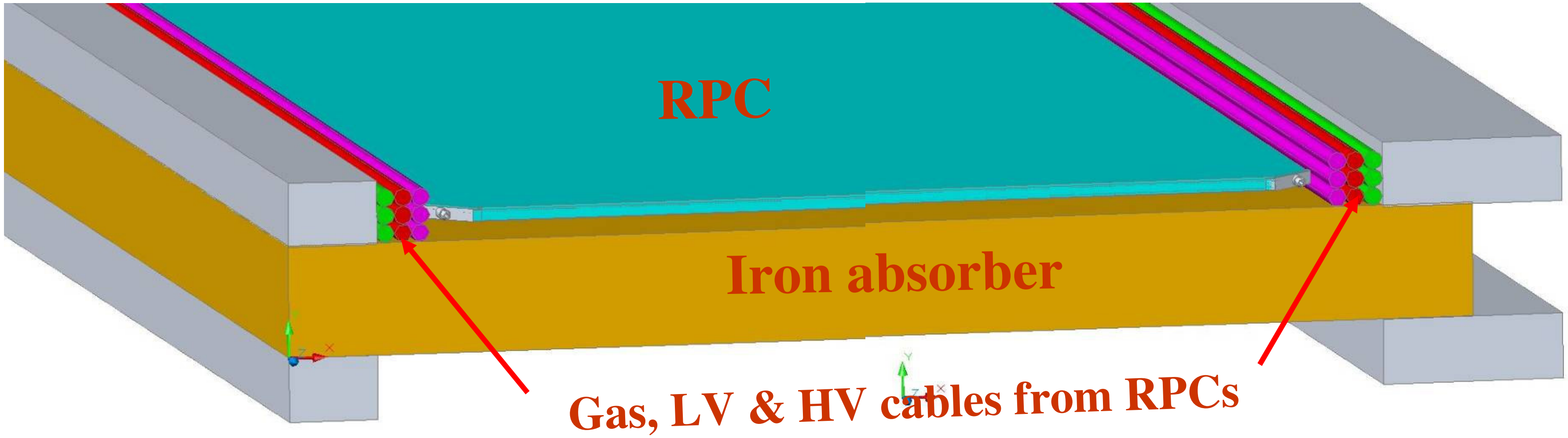
- Site and infrastructure related Detailed Project Report (DPR) prepared by ETF & TNEB (June2007)
- ICAL prototype being assembled at VECC, Kolkata
- Design of 16 kT ICAL magnet module in progress
- R&D on glass RPC for longer lifespan in progress
- Vendor development (RPC related, gas recirculation & purification, electronics, magnet…) ongoing
- INO proposal with DAE for AEC, Cabinet approvals
- MoEF clearance given subject to Min. of Forests OK

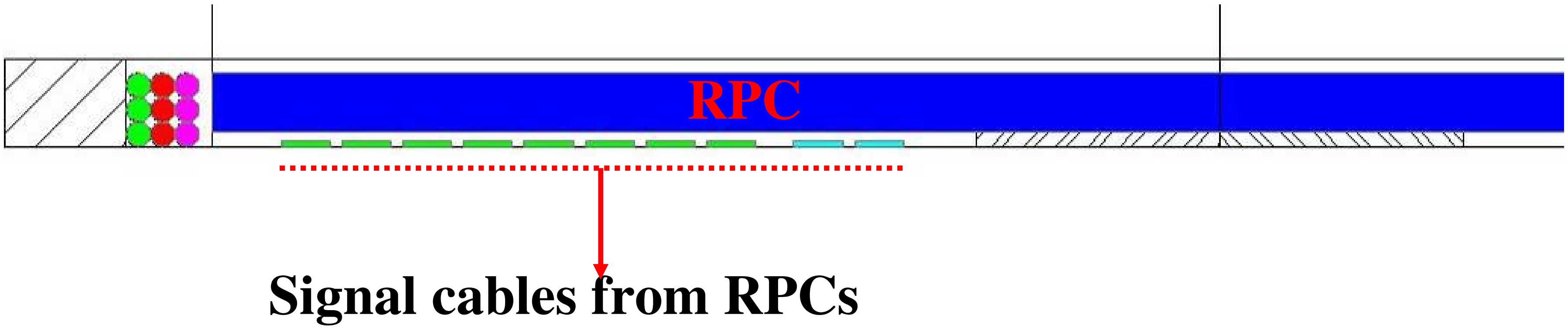
INO Collaboration members

14April 2008, BARC, Mumbai

Additional slides

Cables & services routing for ICAL module





DAQ & services' sub-stations