Status report on INO

Outline of talk

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

V.M. Datar (BARC, Mumbai)

on behalf of the INO collaboration

27 May 2008, Neutrino 08

INO Collaboration

Collaborating institutions/universities

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

14April 2008, BARC, Mumbai

1. Introduction

Motivation for INO – some background

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

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

- Interim report was submitted on May 1, 2005 to Chairman, DAE
- Updated report reviewed by 7 international experts in 2006

Report and more information about INO available at
http://www.imsc.res.in/~ino

2. Physics goals & choice of detector

Measurements with *atmospheric neutrinos* and cosmic muons at INO

- direct observation of oscillation (fall & rise)
- precision measurement of oscillation parameters
- neutrino mass hierarchy (if $\theta_{13} > 7°$)
- CPT violation in neutrino sector
- Kolar events (*tracks emerging from possible 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

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

- Long baseline experiment at Pushep (**6560, 7150, 11300 km**)

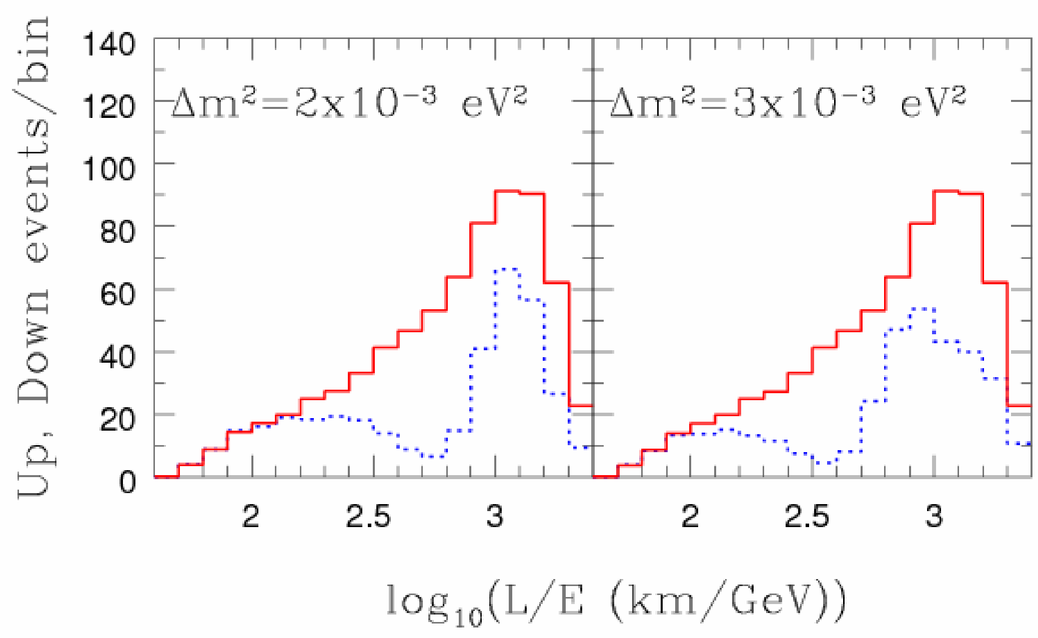
  mass hierarchy, magic baseline (~ 7200 km) allows clean measurement of small θ_{13} , with nearer detector (e.g. 3000 km) for δ_{CP}

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

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

Other experiments at INO

- search for $0\nu2\beta$ in ^{124}Sn via cryogenic bolometer (*feasibility ongoing*)
- nuclear cross sections for astrophysics using 500 kV accelerator



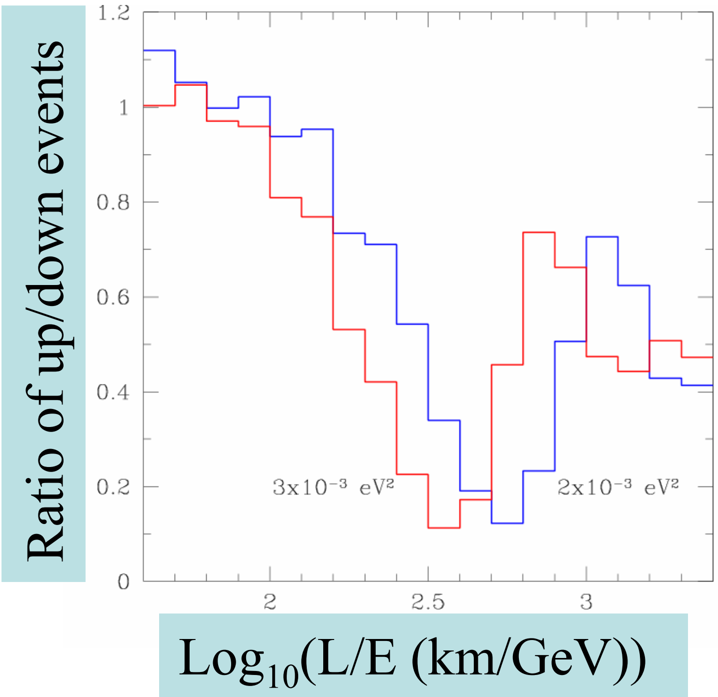
Simulated up & down going muons from CC μ interactions

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

exposure = 250 kt.yr

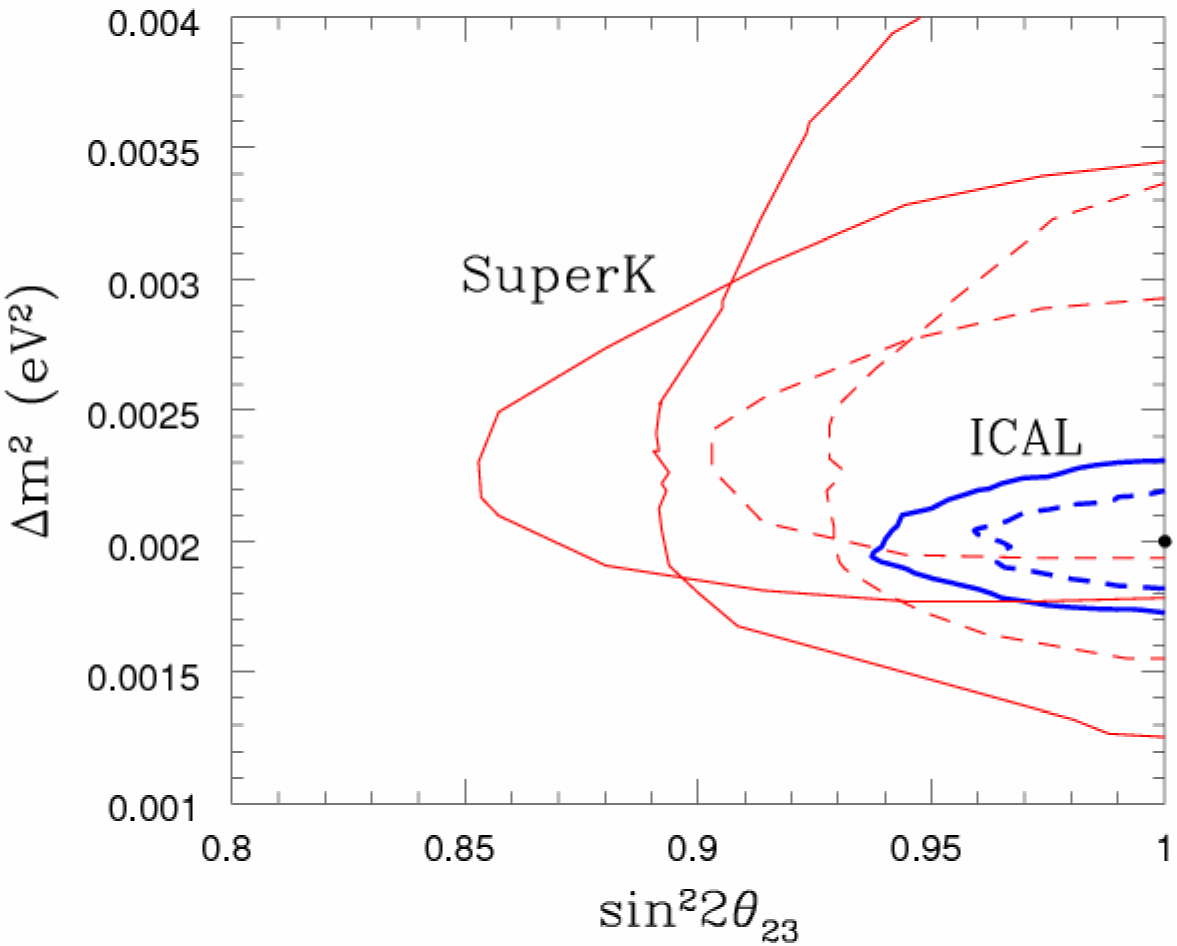
Red : downward μ

Blue : upward μ



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

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



--- SKamioka 90%CL

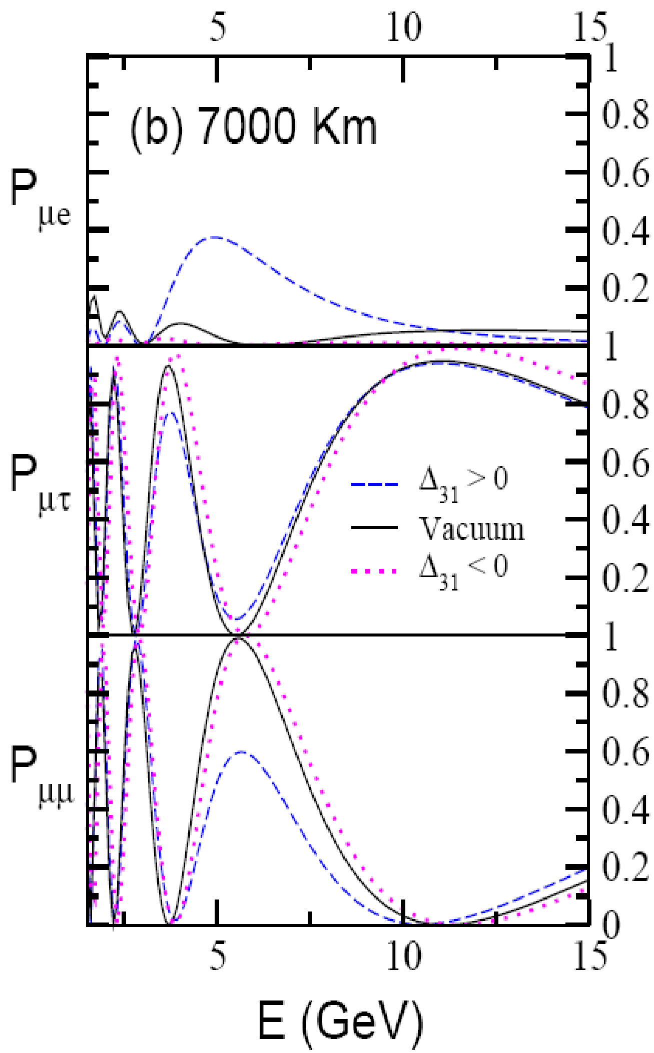
—SKamioka 99%CL

Zenith angle and L/E analyses

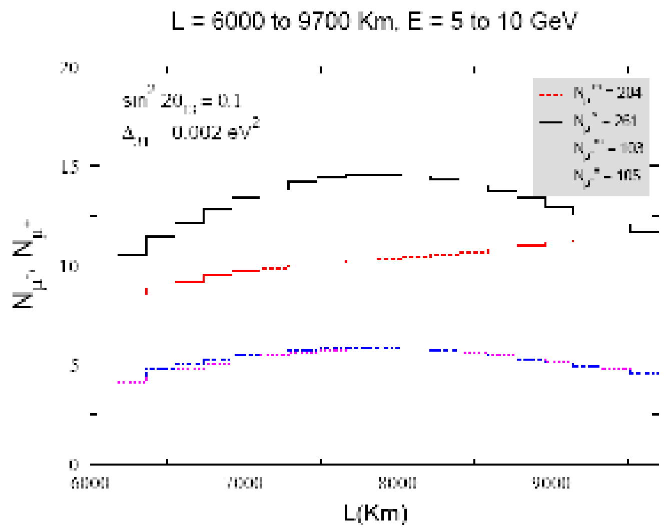
--- 300 kt.yr FC 90%CL

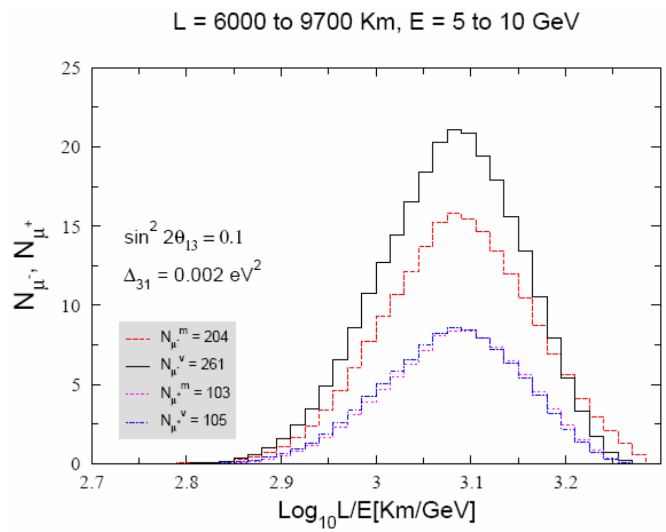
— ,, 99%CL

Appearance/survival probabilities for $\nu_\mu \rightarrow \nu_e, \nu_\tau, \nu_\mu$ in vacuum and matter for normal and inverted hierarchies & event rates for atmos. ν_μ



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





R. Gandhi et al., hep-ph/0411252

If θ_{13} vanishingly small….

Gandhi, Ghoshal, Goswami, Umasankar, hep-ph/0805.3474

What if $\sin^2 2\theta_{13} << 10^{-1}$? Assuming $\theta_{13} = 0$ it has been shown that

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

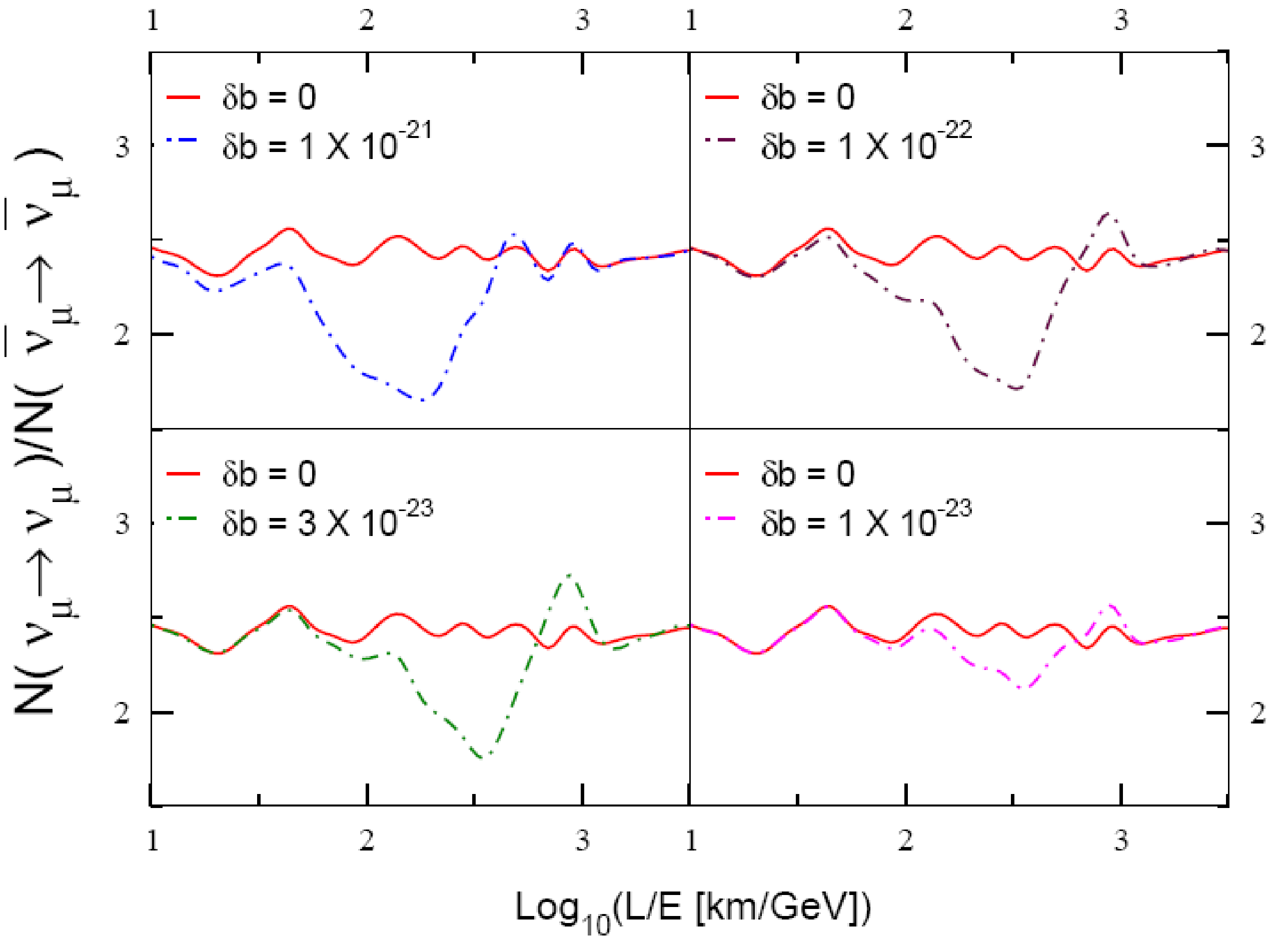
where $\Delta = |\Delta_{31}|L/4E$ and $\alpha = \Delta_{21}/|\Delta_{31}|$

- 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

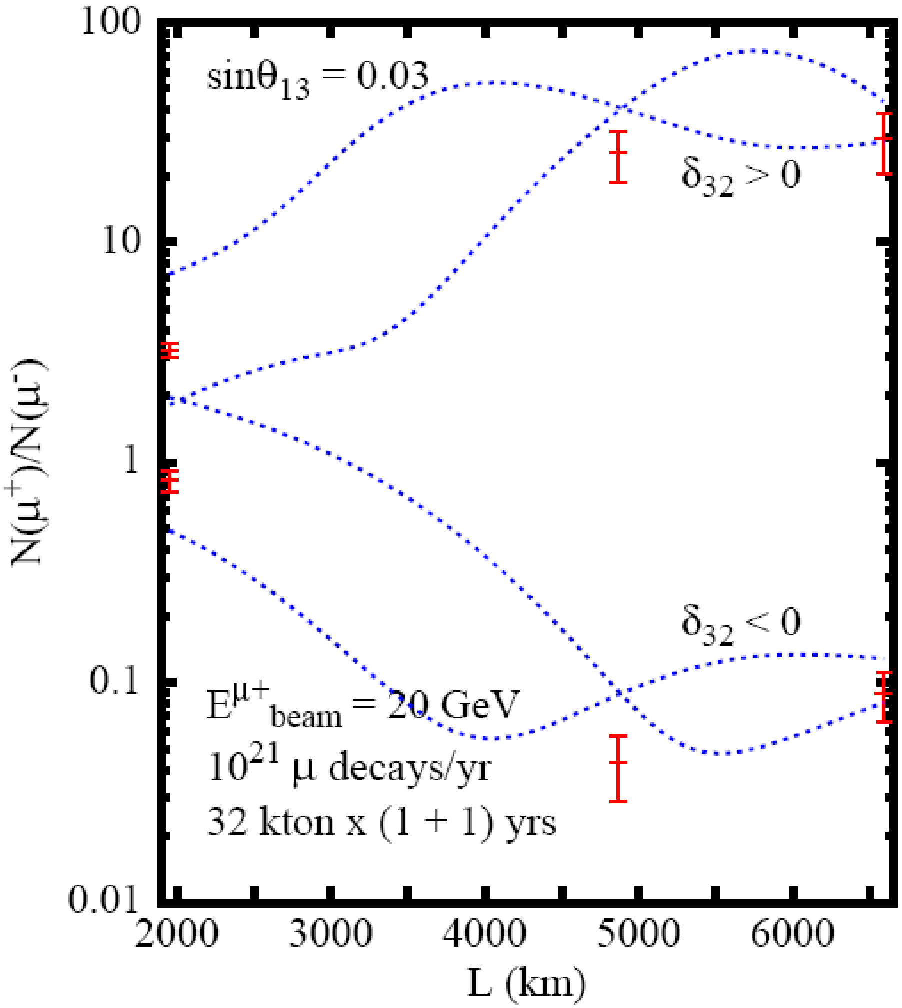
At ~ 2.3σ level and 1 Mton.yr NH or IH can be established

Search for CPT violation

Ratio of total up+down atmospheric ν_μ and anti-ν_μ



Search for CP violation



Wrong sign muons for equal # of decays of $\mu^{\pm}$

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

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

Distances from JPARC

2. (contd) Choice of detector and site

Existing detectors worldwide

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

Our choice

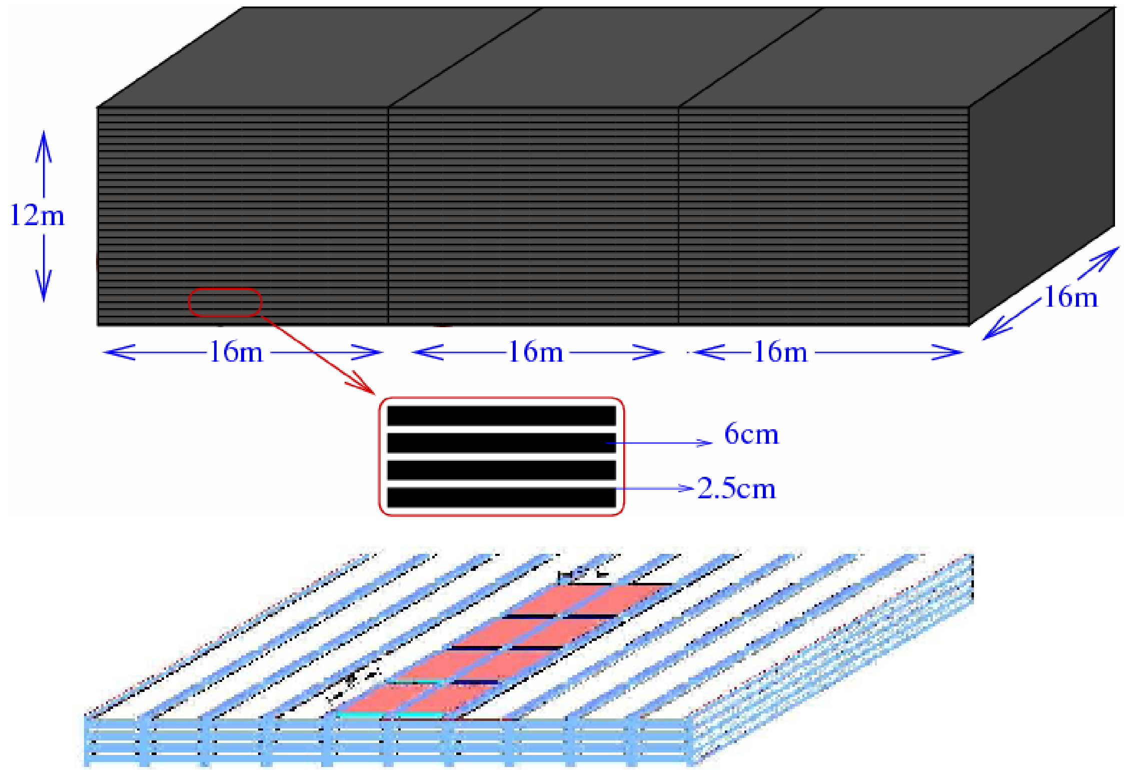
- Detector : physics reach, current technology $\Rightarrow$

  INO Collab. chose a 50-100 kT Iron Calorimeter (ICAL)

  (*inspired by the MONOLITH proposal for Gran Sasso*)
- Site requirement : > 1 km rock cover all around 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 ⇒ $\boldsymbol{p}_\nu$, fast timing ⇒

  up-down, both of these ⇒ charge ID (μ^+ or μ^-) ⇒ ν_μ or anti-ν_μ

- Modular design

- Large size (total area for 50 kT detector ~ 10^5 m^2 ⇒ 4 M strips)

Options :

Plastic scintillator strips, large area gas detectors

RPC *appears* to be the better option due to simplicity (float glass, graphite paint, polycarbonate spacers) & cost/m^2 (RPC ~ $425 + 15/yr compared to plastic ~ $ 970). 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 (6 cm) ~ 3 × L_{rad}

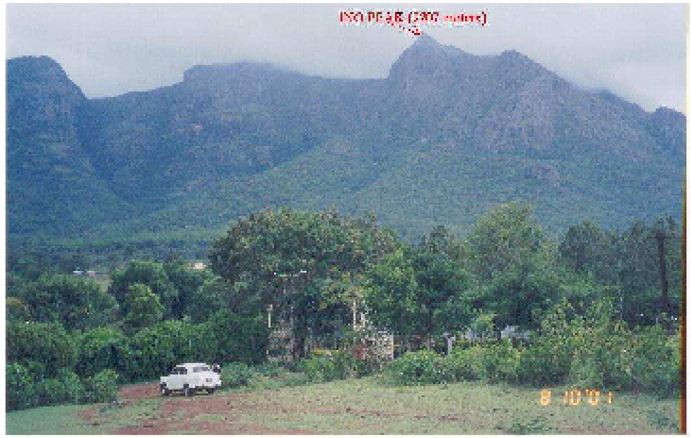
✓ Muon charge identification (~ 95% for E > 1 GeV if large part of track visible)

✓ Muon energy measurement – σ_E ~ 15% at 5 GeV

✓ Muon direction reconstruction – σ_θ ~ 10%

✓ Neutrino L, E reconstruction - σ_E ~ 25%, σ_L ~18% for atmos. ν_μ

Location of INO site



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

3. Status of project

ICAL Magnet

- Magnetic field B large enough (1- 1.5 Tesla) to enable ***p*** measurement for 1-10 GeV muons produced by ν_μ 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 ~ 10^4 m^3 toroidal Fe-free design possible,

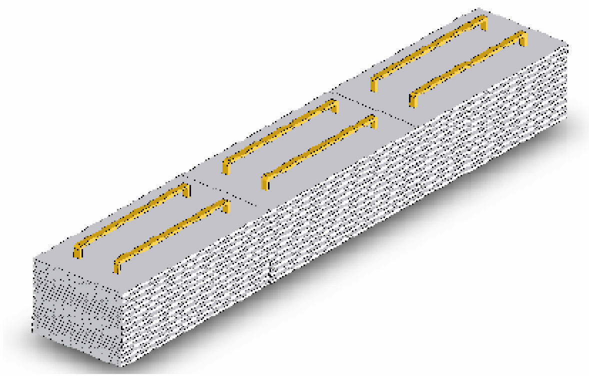
but designs with field returning within iron plates simpler:

MINOS (cylindrical symmetry)

MONOLITH proposal ("rectangular")

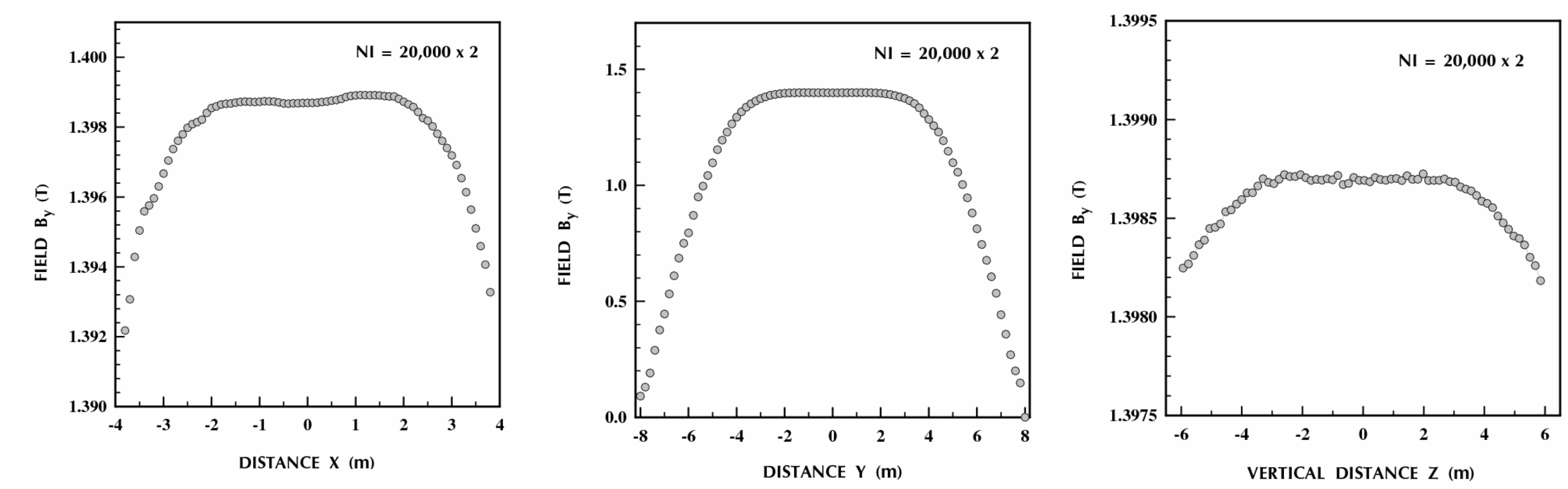
Other geometries

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



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

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

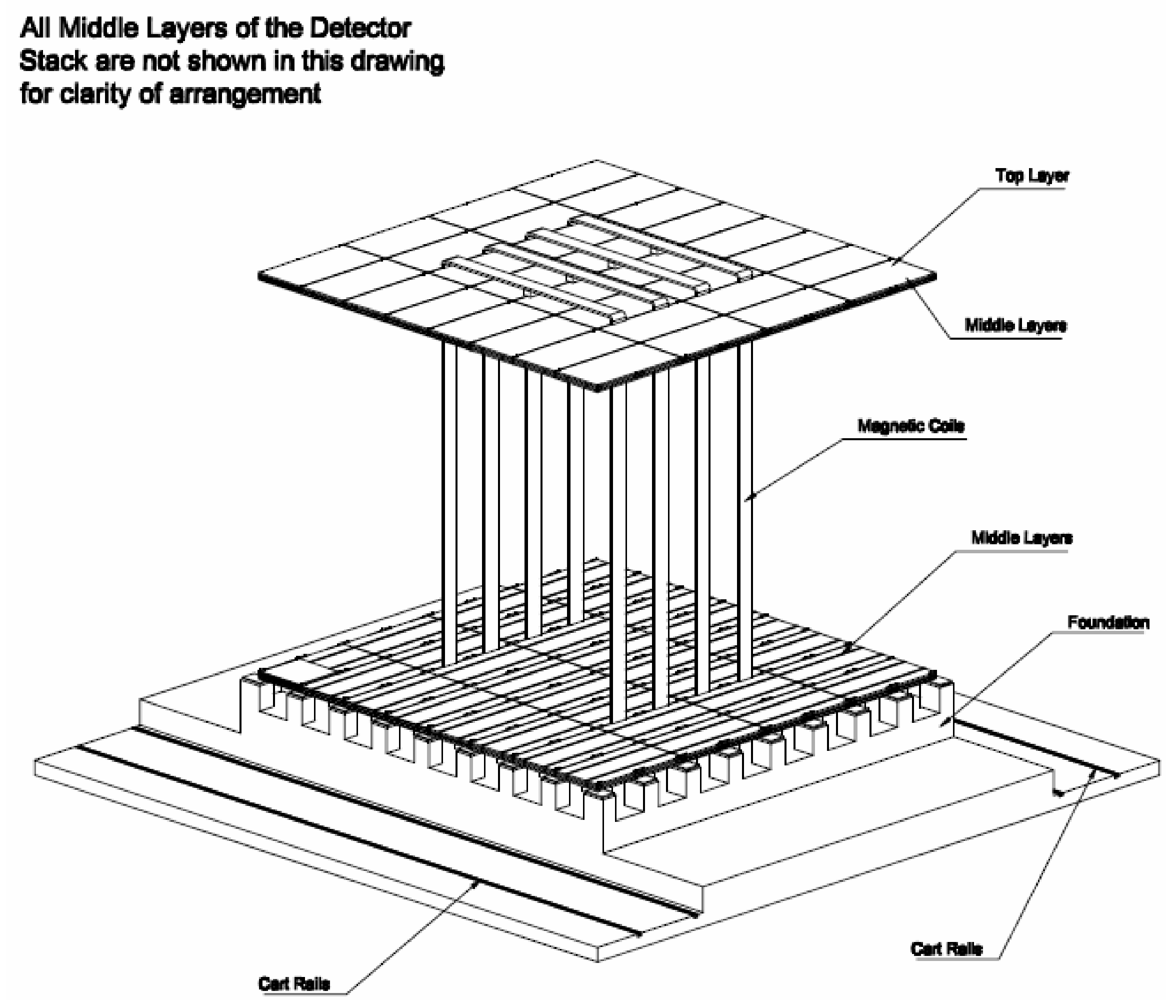
More studies necessary – assembly scheme, mechanical stability, transient and error analysis

- Mechanical design and assembly project report being prepared by Tata Consulting Engineers (TCE), Mumbai
- Draft Report expected by end June, 2008

Important features…

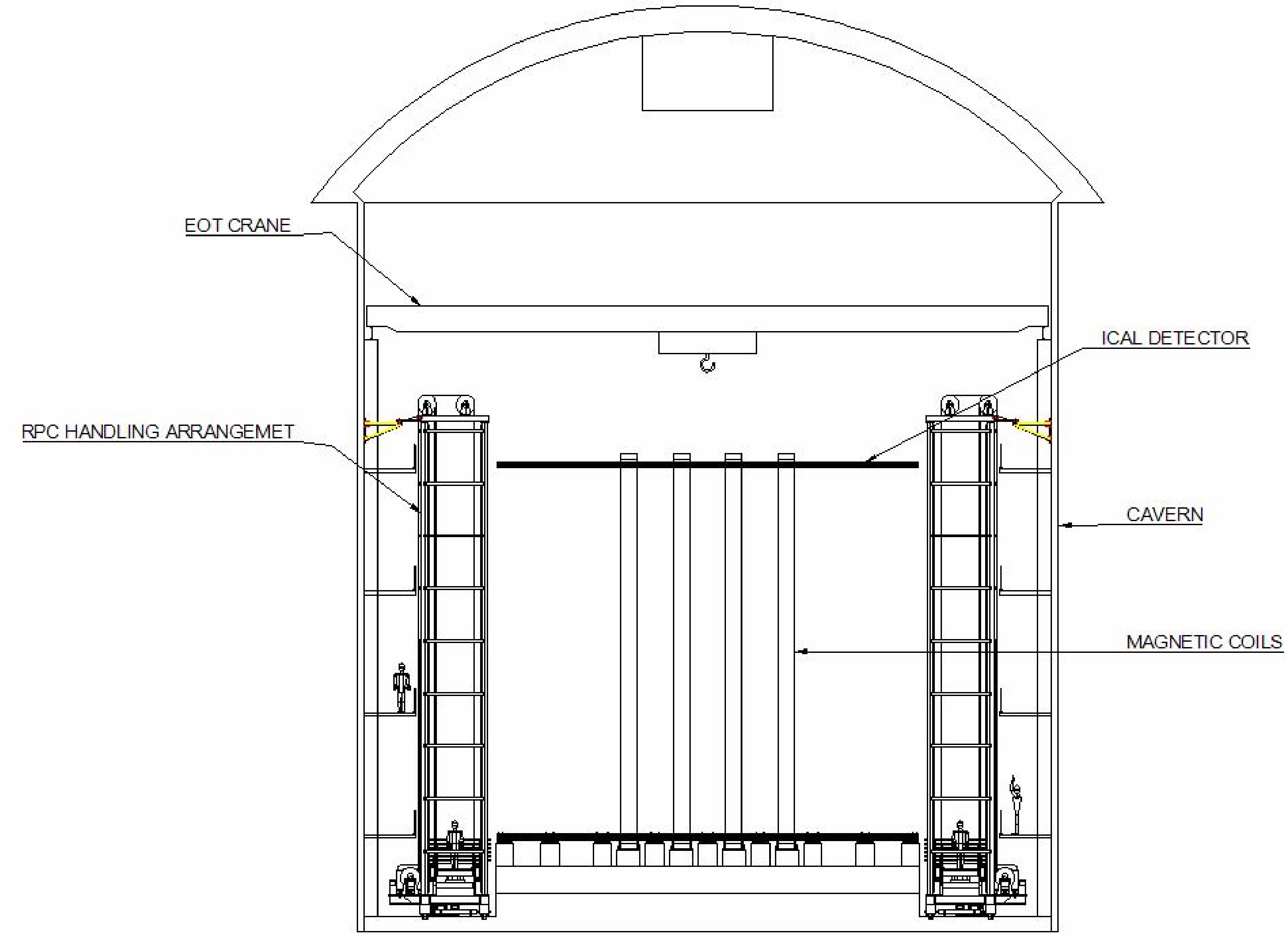
- 16 kton module will rest on 0.6 m × 0.6 m × 1 m (H) RCC posts
- Movable service lift on rails on either side of ICAL module along tunnel length
- Provision for removing upto 4 RPC modules from side
- Slot for Cu coils for DC current excitation & provision for support structure for coils

Proposed layout of Fe plates and Cu coils



4 m × 2 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)

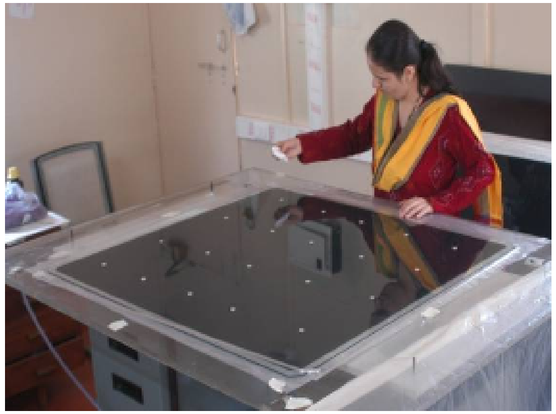
Resistive Plate Chamber (RPC) R & D

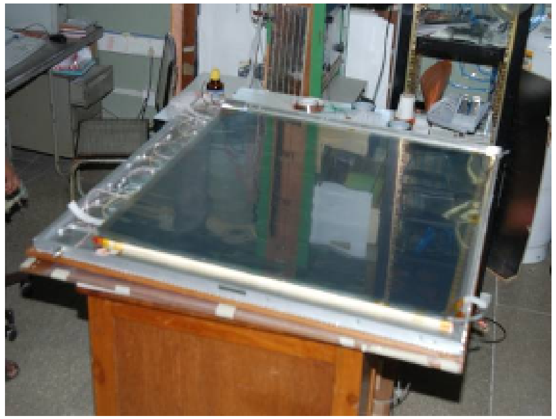
- Glass and bakelite RPC R&D being pursued at TIFR (Mumbai) & VECC+SINP (Kolkata)
- 1 m^2 glass RPCs work for long in *avalanche* mode
- 0.1 m^2 bakelite RPC in *streamer* mode

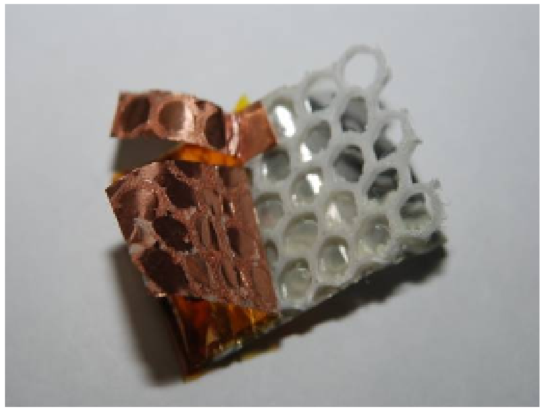
Both will be deployed in prototype detector at VECC, Kolkata

Development of large area glass RPCs

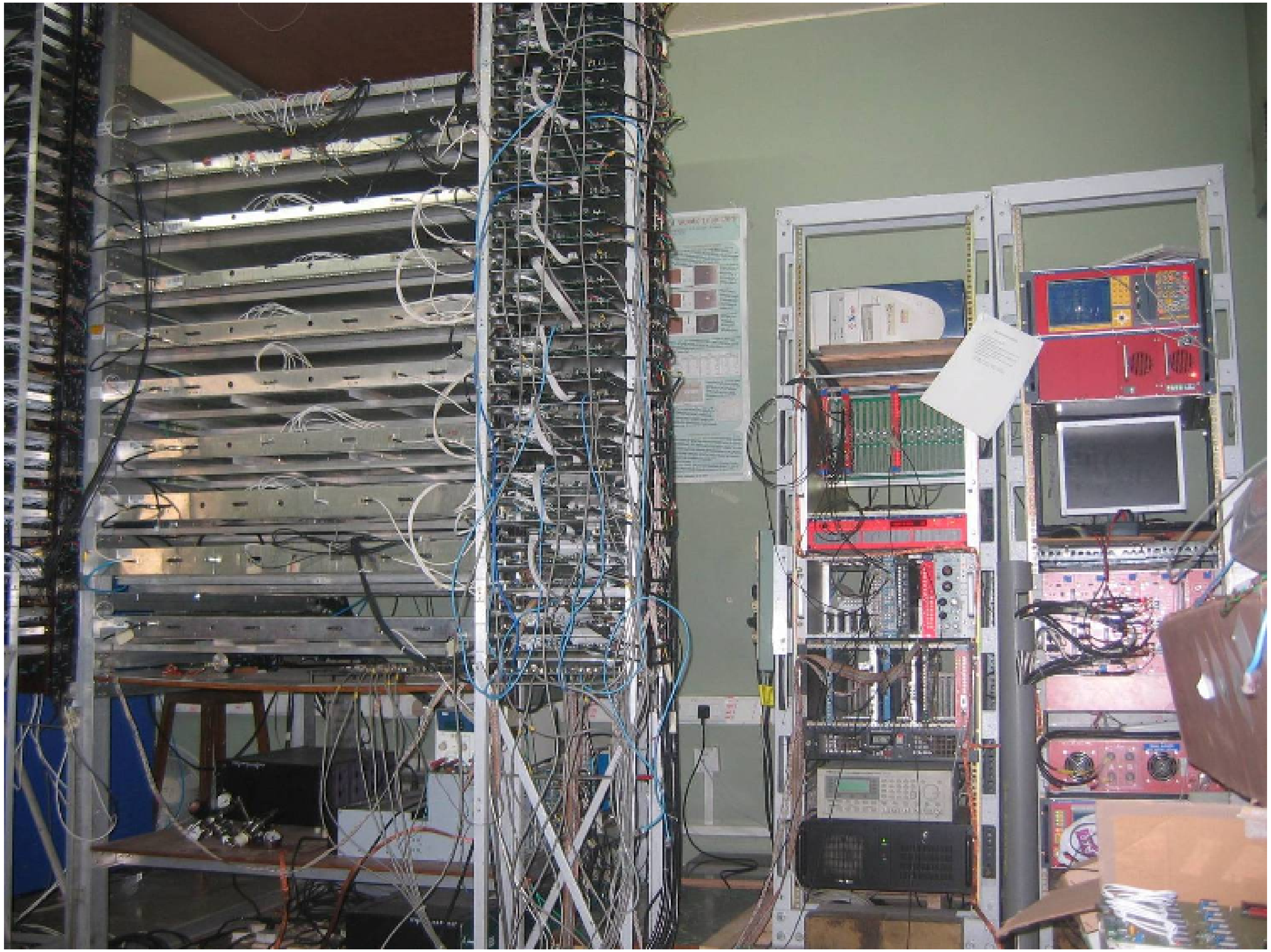


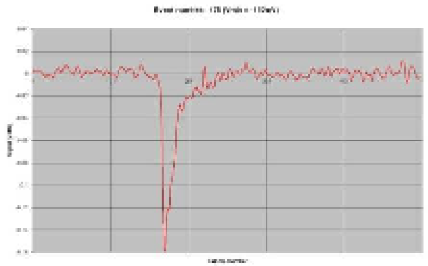


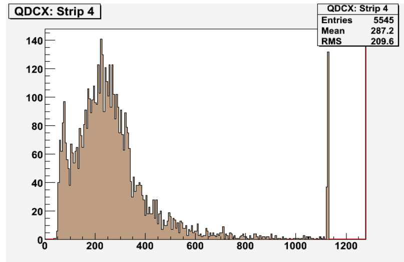



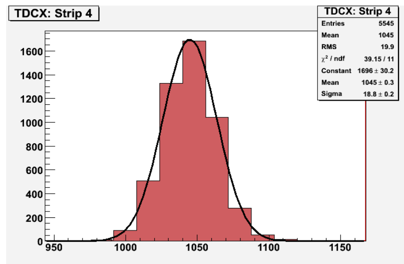
Cosmic ray test stand for 1 m^2 glass RPCs at TIFR





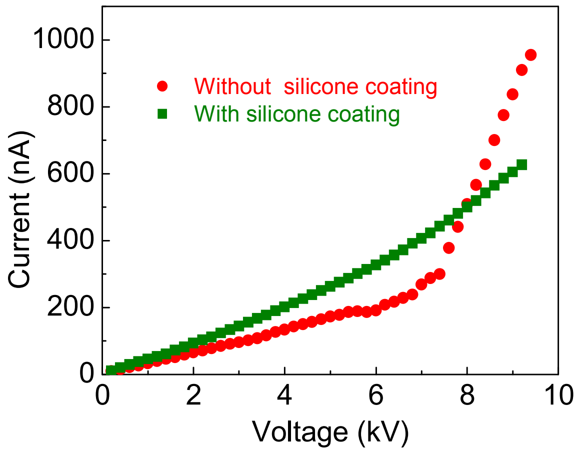


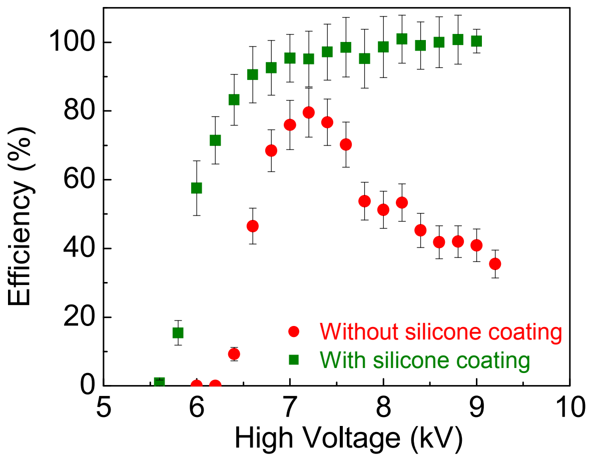
Charge distribution

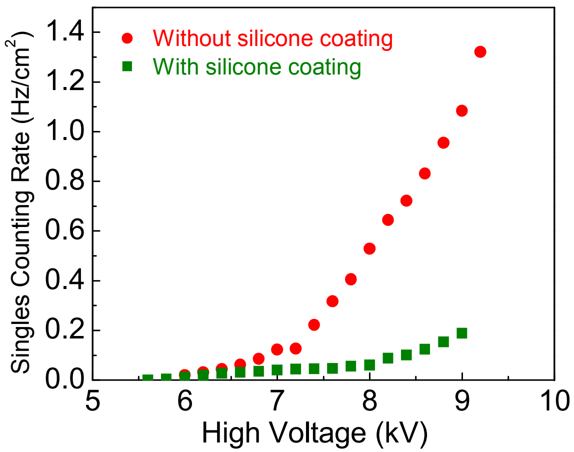


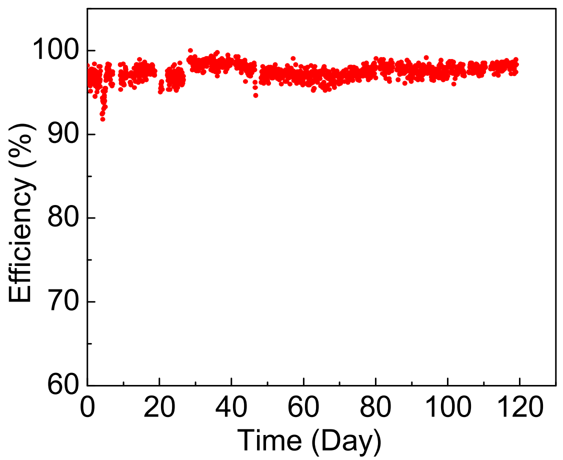
Timing spectrum

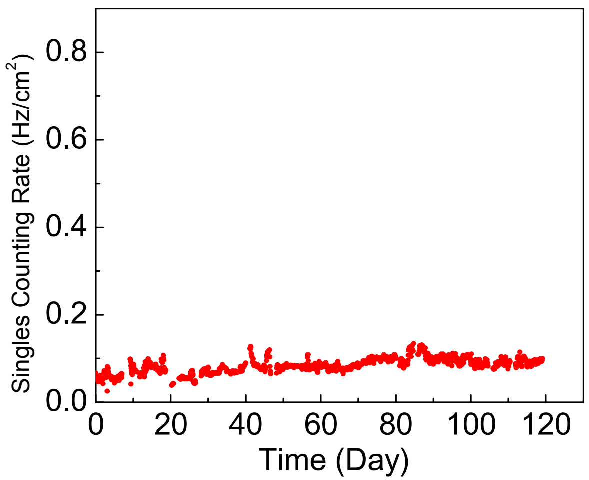
Development of bakelite RPC with silicone coating





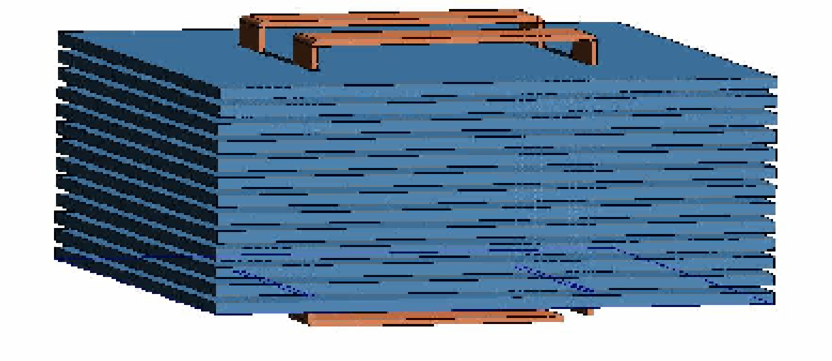






Bakelite P-120 + silicone oil coating improves longitivity & performance

Prototype ICAL magnet & electronics



Total weight ~ 40 tons

Dimensions 2.5 m × 2.3 m

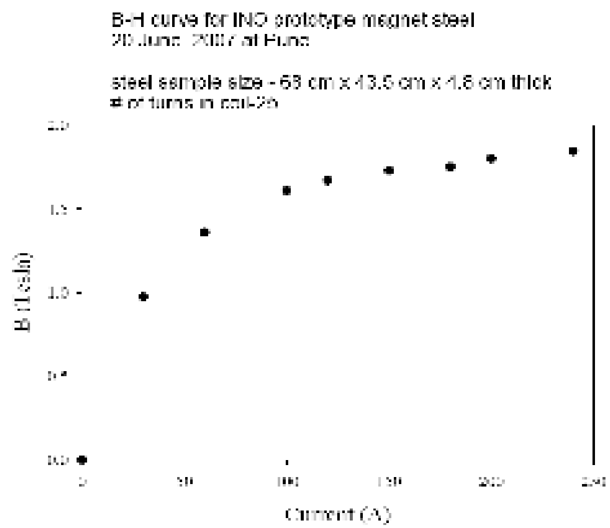
NI_{max} = 10000 A. turns

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

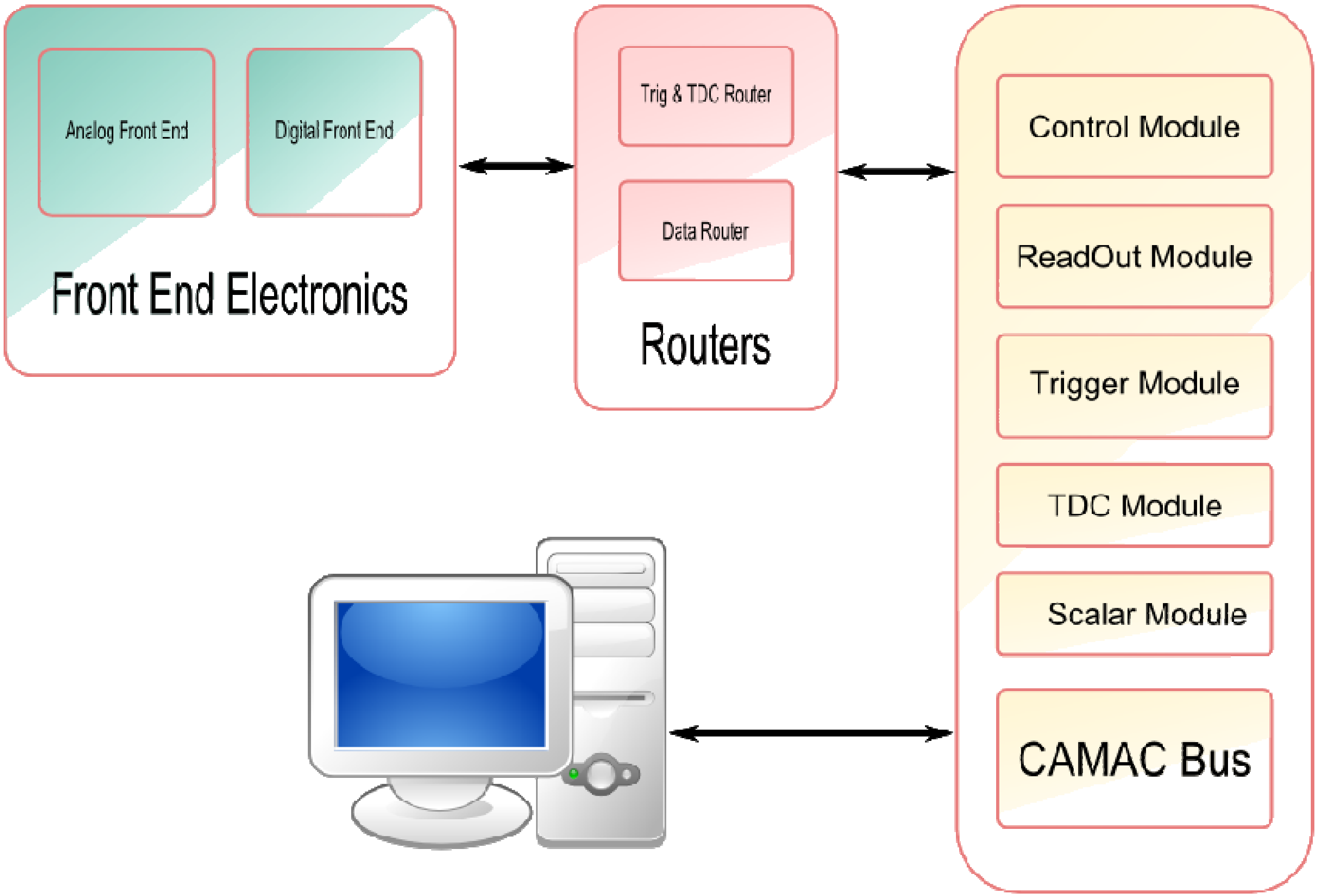
Some details of prototype magnet

- 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



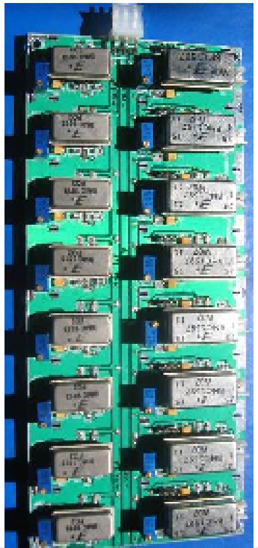
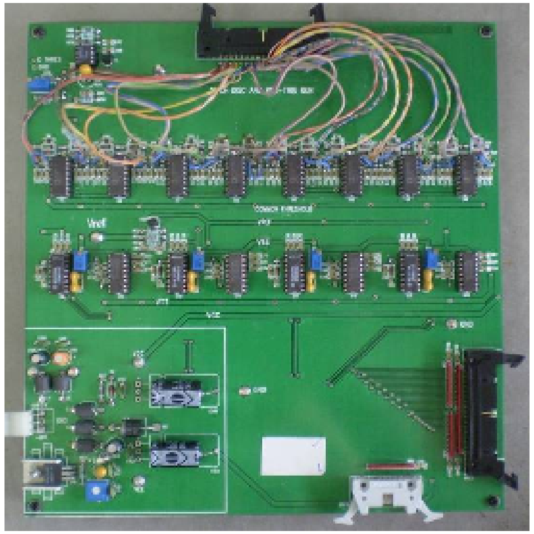
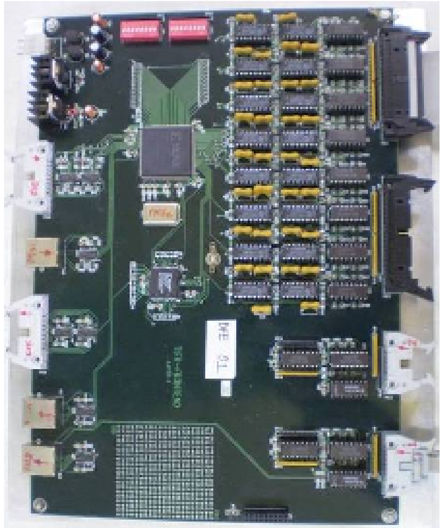
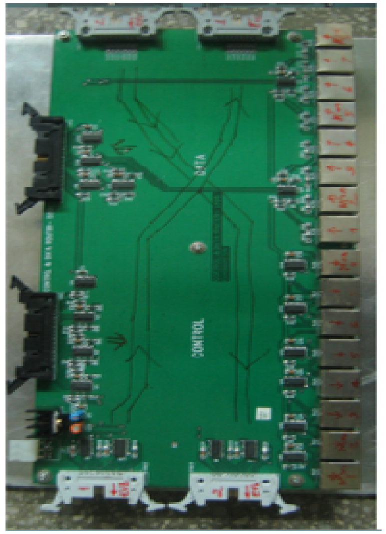
Some photos of prototype ICAL magnet at VECC, Kolkata (Oct'07)

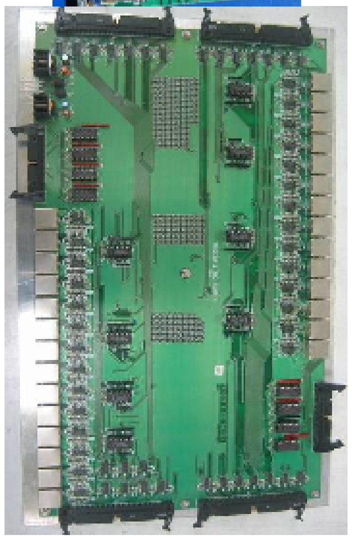
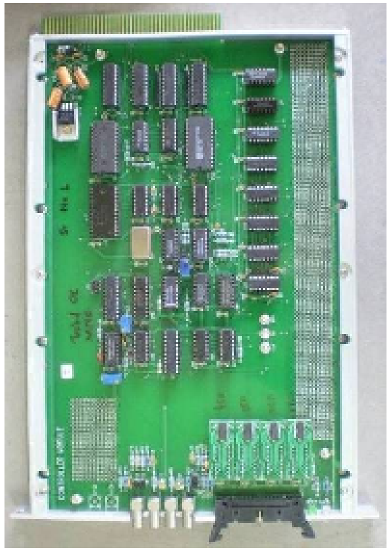
Electronics scheme for prototype



In house electronics for prototype

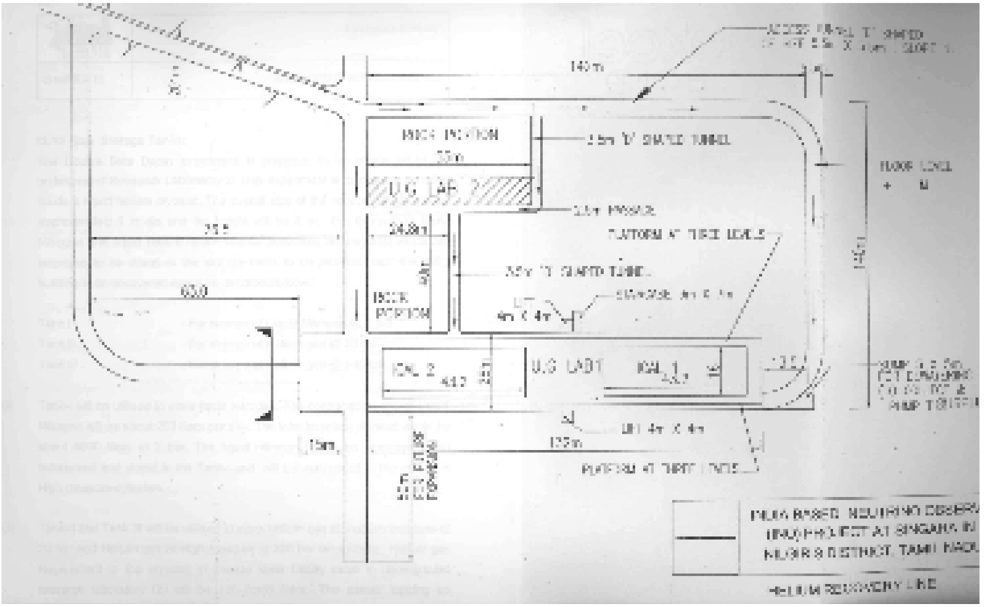
8-ch preamps | 16-ch digital FE | 32 ch digital front end | Control & data router

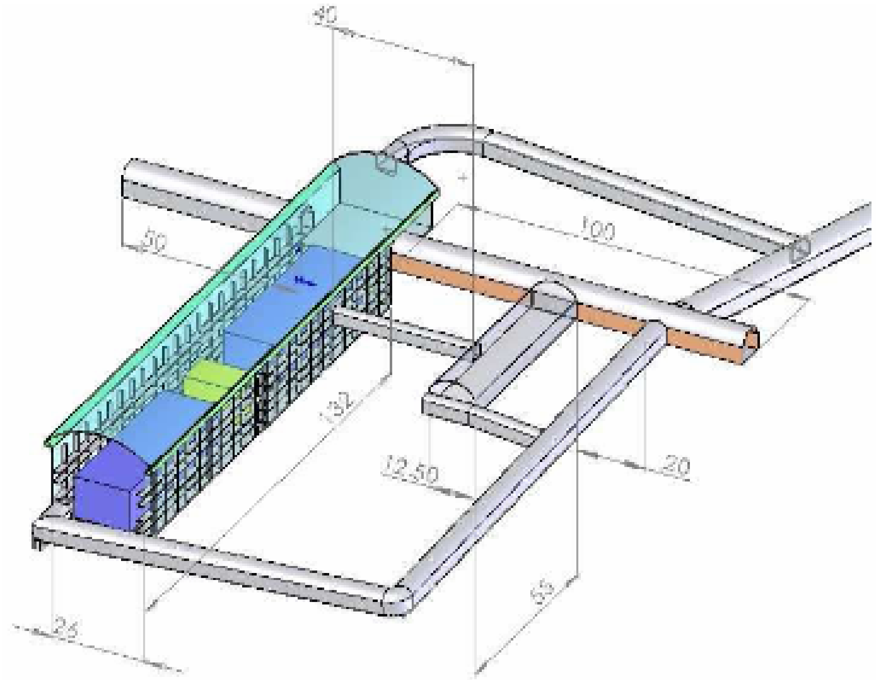





Trigger & TDC router | Data & monitor control & readout | Final trigger

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

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

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
- Data taking with 1st module 5 years after t = 0
- 2 more modules in 8 years after t = 0

Summary of present status of INO

- Interim Project Report sent for review to 7 experts

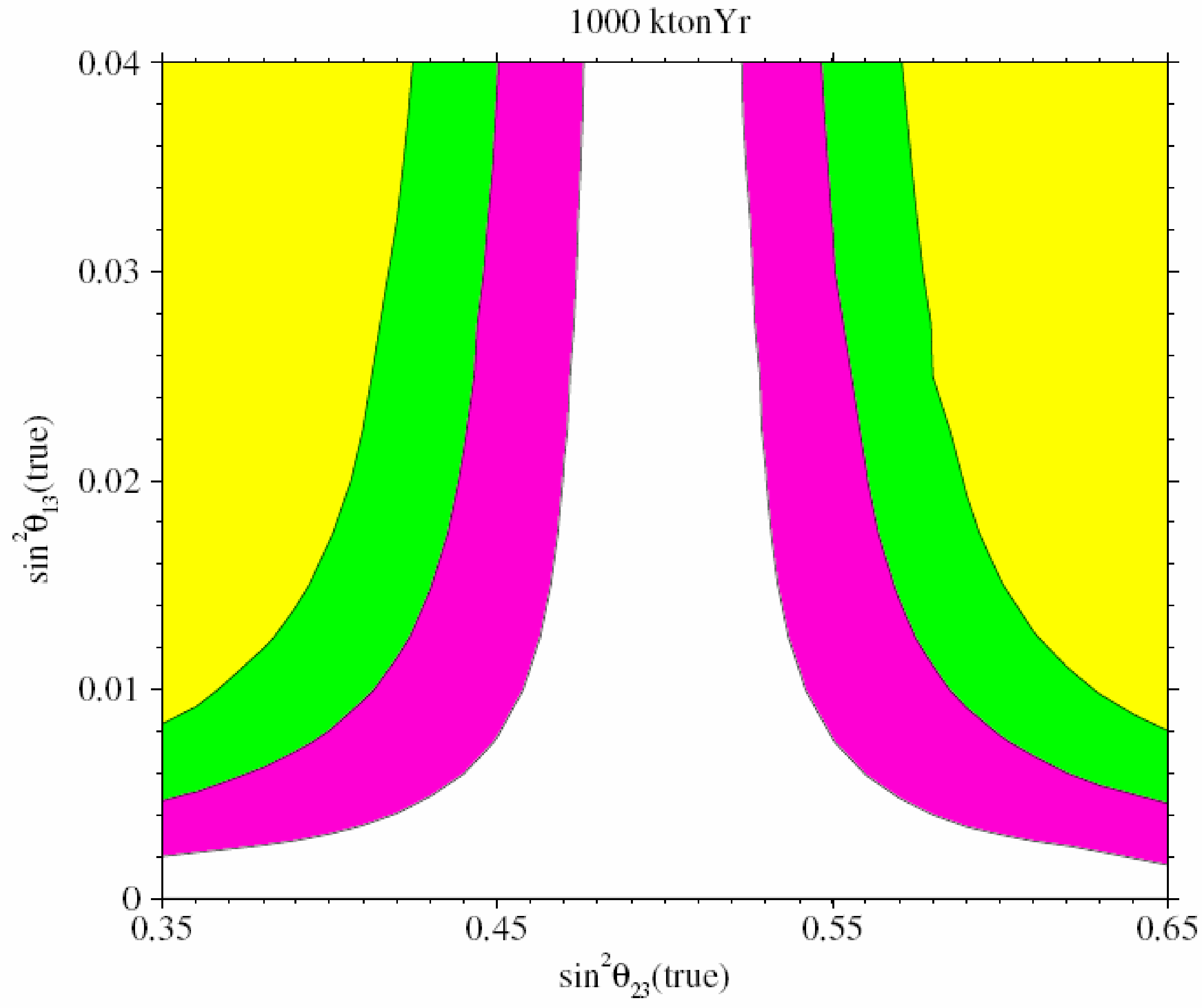
  - generally very positive and encouraging
- Site and infrastructure related Detailed Project Report (DPR) prepared by ETF & TNEB (June2007)
- ICAL prototype being assembled at VECC, Kolkata
- Design of 16 kT ICAL magnet module in progress
- R&D on glass RPC for longer lifespan in progress
- Vendor development (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

We seek and welcome collaboration with members of the international physics community

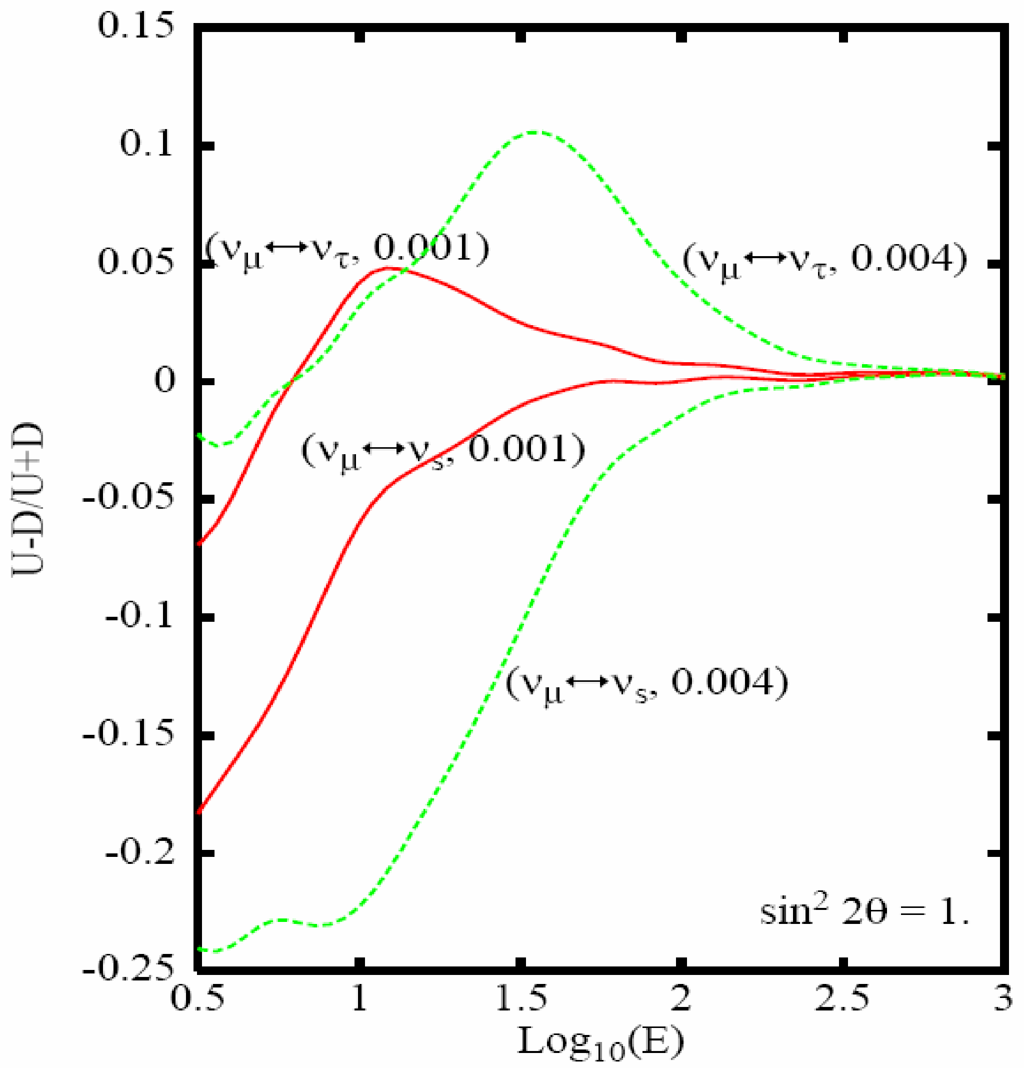
Thank you

Additional slides

Octant ambiguity at ICAL



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



From INO Report (May 2006)

"This is an open collaboration and it is hoped that many more physicists from within and outside the country will join in this effort. The success of this project crucially depends upon international participation and support."