Physics goals and status of INO
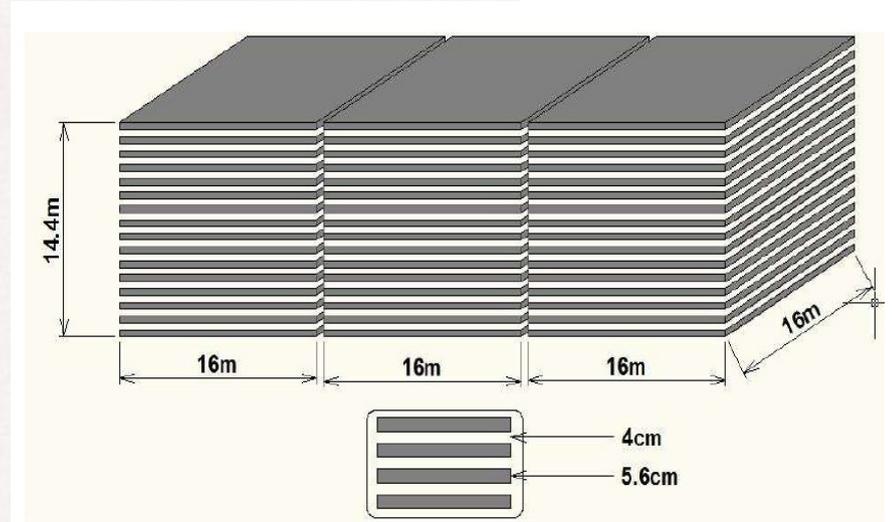
Amol Dighe
TIFR, Mumbai
(On behalf of the INO Collaboration)
http://www.ino.tifr.res.in/ino/

DAE-BRNS HEP Symposium
Santiniketan, Jan 2013

INO Collaboration

Ahmadabad: Physical Research Lab.

Aligarh: Aligarh Muslim University

Allahabad: HRI

Calicut : University of Calicut

Chandigarh: Panjab University

Chennai : IIT, Madras IMSc

Delhi : University of Delhi

Guwahati : IIT, Guwahati

Hawaii (USA) : University of Hawaii

Indore: IIT, Indore

Jammu : University of Jammu

Kalpakkam : IGCAR

Kolkata : Ramakrishna Mission Vivekananda University, SINP, VECC , University of Calcutta

Lucknow : Lucknow University

Madurai : American College

Mumbai : BARC

Mumbai : IIT, Bombay TIFR

Mysore : University of Mysore

Sambalpur : Sambalpur University;

Srinagar : University of Kashmir

Varanasi : Banaras Hindu University

INO: physics goals

Neutrino oscillations: current status

Parameter	Best Fit Value	1σ Range
$\sin^2\theta_{12}$	0.307	0.291-0.325
$\sin^2\theta_{23}$	0.386	0.365-0.410 (NH)
	0.392	0.370-0.431 (IH)
$\sin^2\theta_{13}$	0.0241	0.0216-0.0266 (NH)
	0.0244	0.0219-0.0267 (IH)
Δm^2_{21} (eV^2)	7.54×10^{-5}	$7.32\text{-}7.80 \times 10^{-5}$
$|\Delta m^2_{31}|$ (eV^2)	2.43×10^{-3}	$2.33\text{-}2.49 \times 10^{-3}$ (NH)
	2.42×10^{-3}	$2.31\text{-}2.49 \times 10^{-3}$ (IH)

sol

atm

Hot news 2012

sol

atm

Forero, Tortola, Valle, arXiv:1205.4018

4

Neutrino properties: key unknowns

- Precise values of neutrino parameters:

$$|\Delta m^2(atm)|, \ \Delta m^2(sol), \ \theta_{12}, \theta_{23}, \theta_{13}$$

- The sign of $\Delta m^2(atm)$, i.e. Neutrino mass hierarchy (MH)

- CP violation in the lepton sector

- Absolute masses of neutrinos

- Non-standard neutrino interactions

- ....

*An experiment should choose its own tools !*

INO: chosen materials and tools

- *Atmospheric neutrinos provide a wider range for E and L than any artificial neutrino source*

- *An ability to discriminate between neutrinos and antineutrinos enables efficient determination of neutrino mass ordering*

- *Magnetized iron calorimeter (ICAL): excellent muon energy measurement, muon direction reconstruction and charge identification*

- *Hadron shower reconstruction allows access to neutrino energy and high-energy cosmic rays*

INO: the physics goals

- *Accurate determination of the atmospheric parameters (theta23 octant, deviation of theta23 from maximality)*

- *Determination of neutrino mass hierarchy (large theta13 is good news !)*

- *Determination of CP violation in the lepton sector (with a future long baseline experiment with a neutrino factory)*

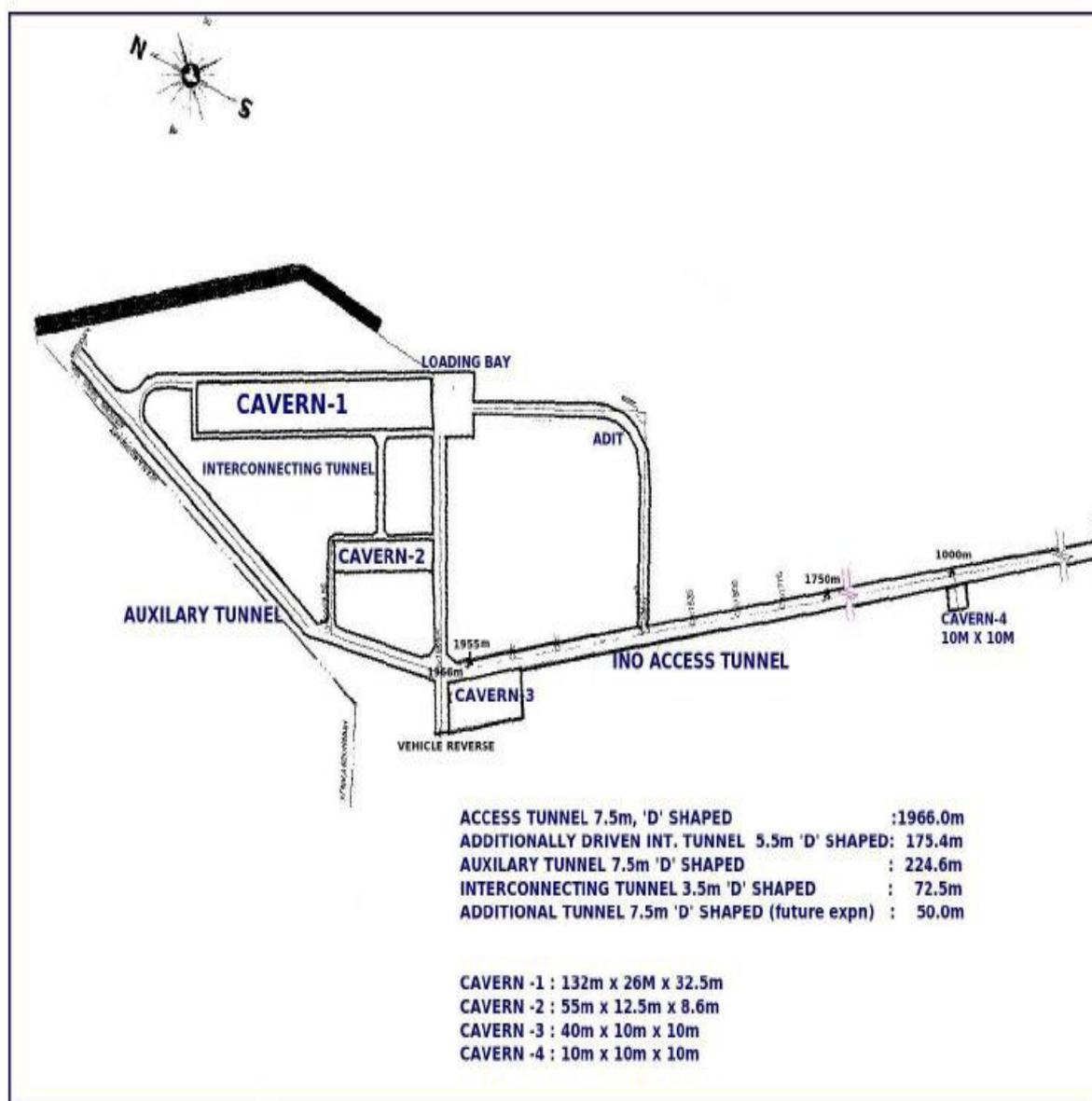- *Non-standard interactions, CPT violation, long range forces, ultrahigh-energy muon fluxes, ...*
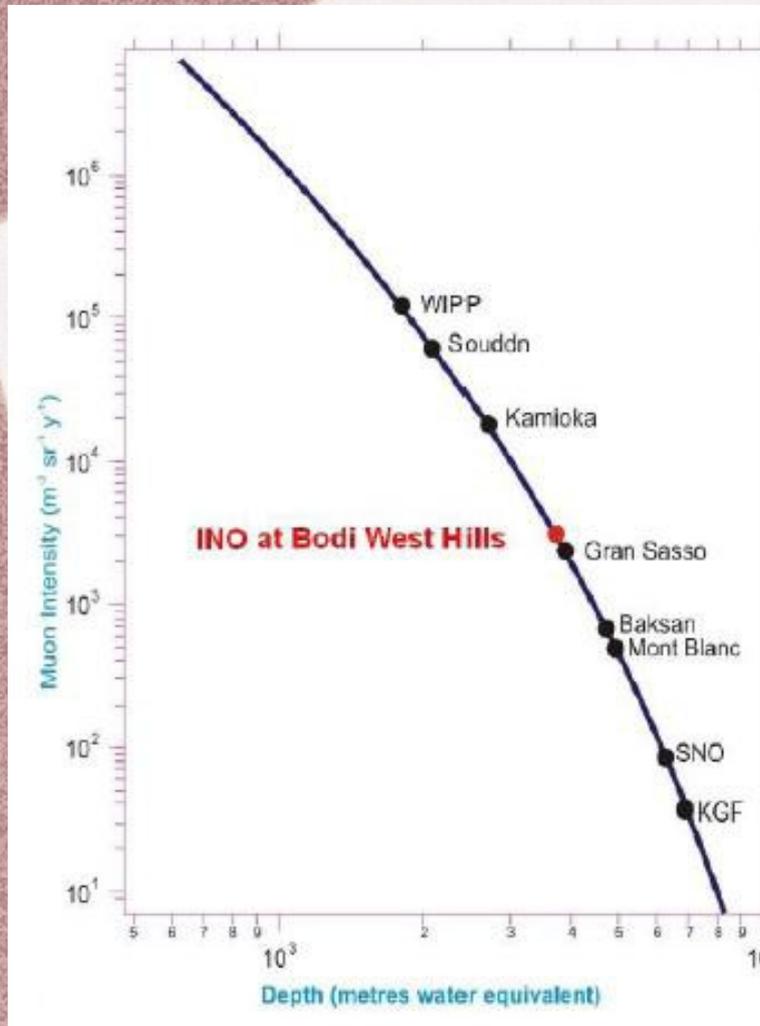
7

INO: the location

The site: Bodi West Hills
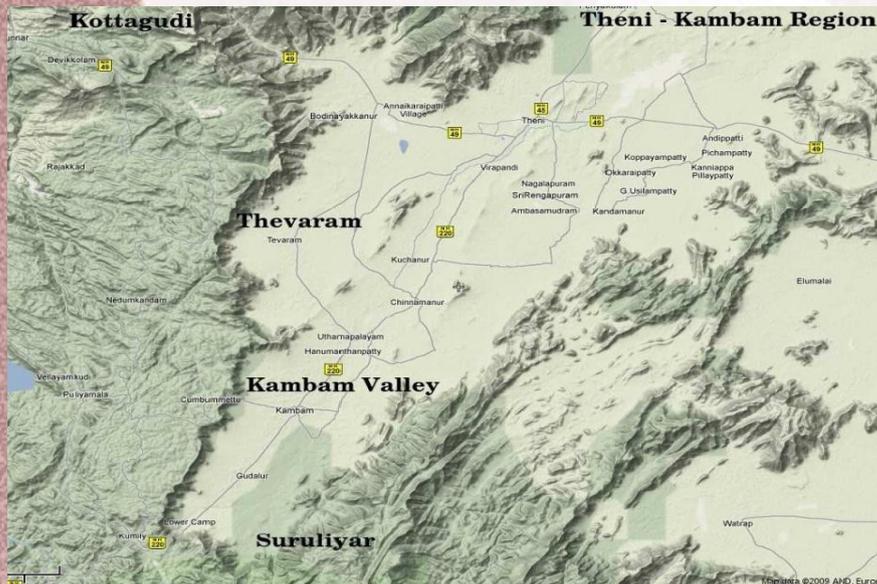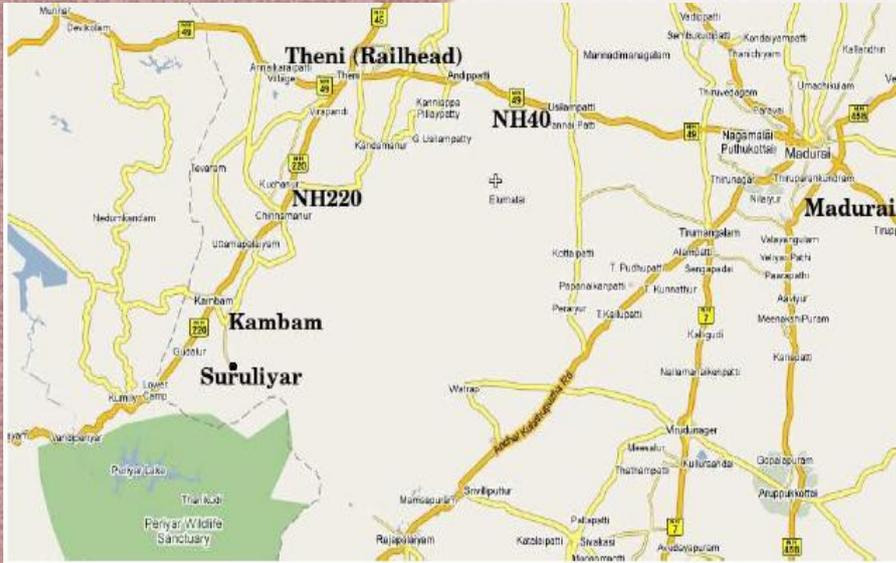
- *(9º 58' N, 77º 16' E)*
- *Pottipuram village*
- *Theni district*
- *Tamil Nadu state*
- *120 km from Madurai*

9

The caverns

- *Accessible through a 2km tunnel*

- *Cavern 1 will host 50kt ICAL (space for 100 kt)*

- *Other caverns available for multiple experiments (NDBD, dark matter, ...)*

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Geography of the site

- *Cavern set in Charnockite rock under the 1589 m peak*

- *Vertical cover: 1289 m, all-round cover ~1000m*

- *Warm, low-rainfall area, low humidity throughout the year, unusual wind speed in some seasons*
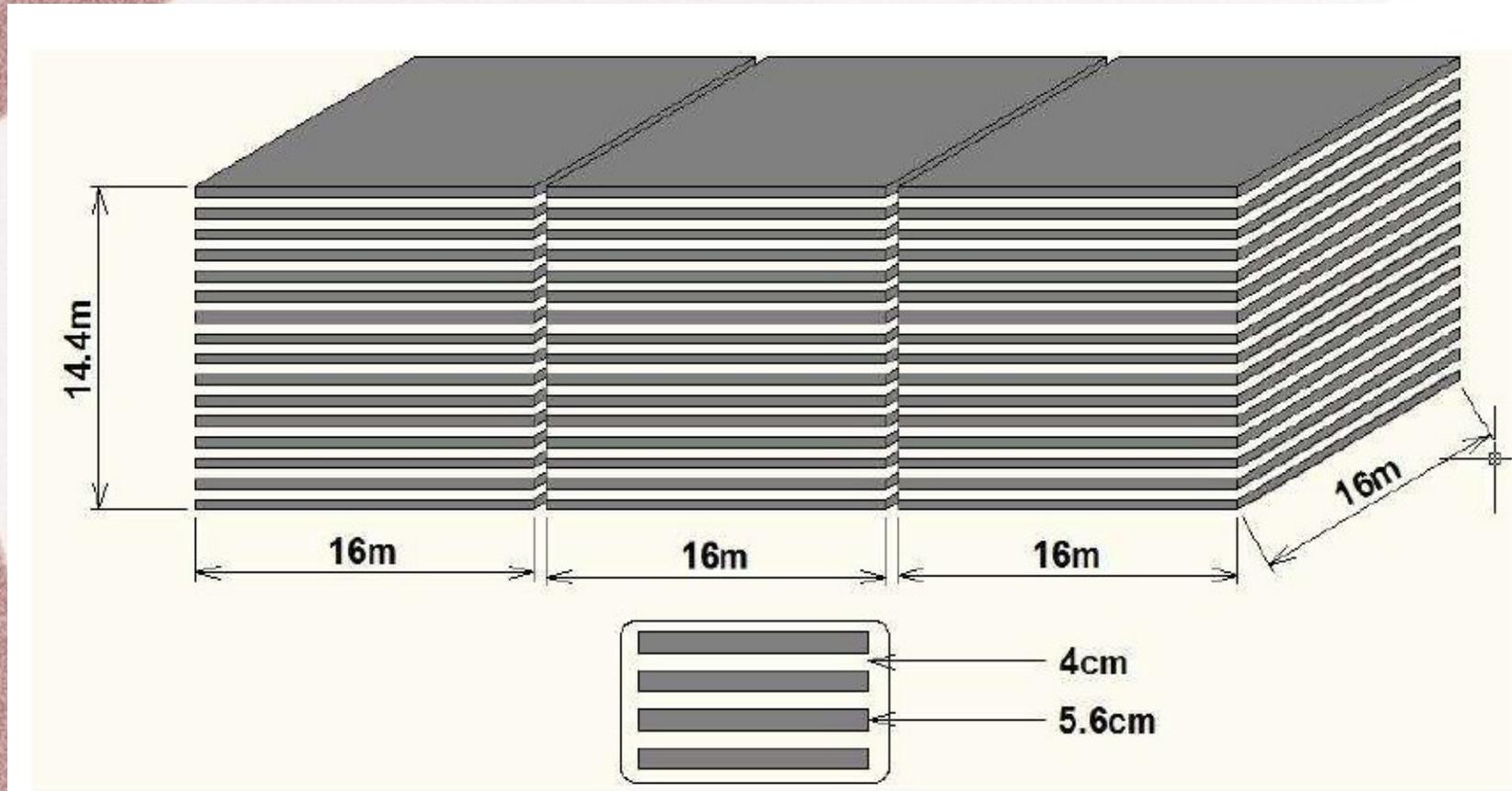
Organization at the site

- Flat terrain with good access to major roads

- All major components to be located underground , Small surface lab on the outside (Pottipuram)

- Tunnel and cavern under forest on the surface, but the portal outside the reserve forest boundary

- Surface facilities not on the forest land, so no forest clearing required.

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Updates on the site front

- *INO project approved by DAE and DST*

- *Environmental and Forest Clearance for the site obtained. 26 hectars of land provided free by Tamil Nadu state government*

- *Site preparation works are being tendered.*

- *Funds have already been transferred to the Tamil Nadu government from the INO budget, for construction of approach roads and water connection to the INO site*

- *Construction of an INO Centre: National Centre for High Energy Physics (NCHEP) planned at Madurai, land has been acquired.*

- *The fencing of both, Pottipuram and Madurai lands, will start soon.*

13

INO-ICAL: The detector

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Magnetized Iron calorimeter (ICAL)

- *Iron plates separated by resitive plate chambers (RPCs): 150 layers*

Salient features of the detector

- *Magnetized iron as target mass and glass RPCs as the active detector*

- *Modularity and ease of construction*

- *Good energy measurement through tracking of muons bending in the magnetic field*

- *Directionality through tracking and timing (~1ns resolution)*

- *Charge identification through bending of muons*

- *Complementarity to existing and future detectors*

Detector factsheet

No. of modules	3
Module dimensions	16m × 16m × 14.5m
Detector dimensions	48.4m × 16m × 14.5m
No. of layers	150
Iron plate thickness	56mm
Gap for RPC trays	40mm
Magnetic field	1.3 Tesla
RPC dimensions	1,950mm × 1,840mm × 24mm
Readout strip pitch	3 0mm
No. of RPCs/Road/Layer	8
No. of Roads/Layer/Module	8
No. of RPC units/Layer	192
No. of RPC units	28,800 (97,505m²)
No. of readout strips	3,686,400

Construction of RPC
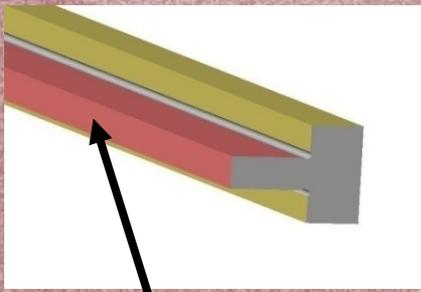
2 mm thick spacer

Two 2 mm thick float Glass Separated by 2 mm spacer

Pickup strips
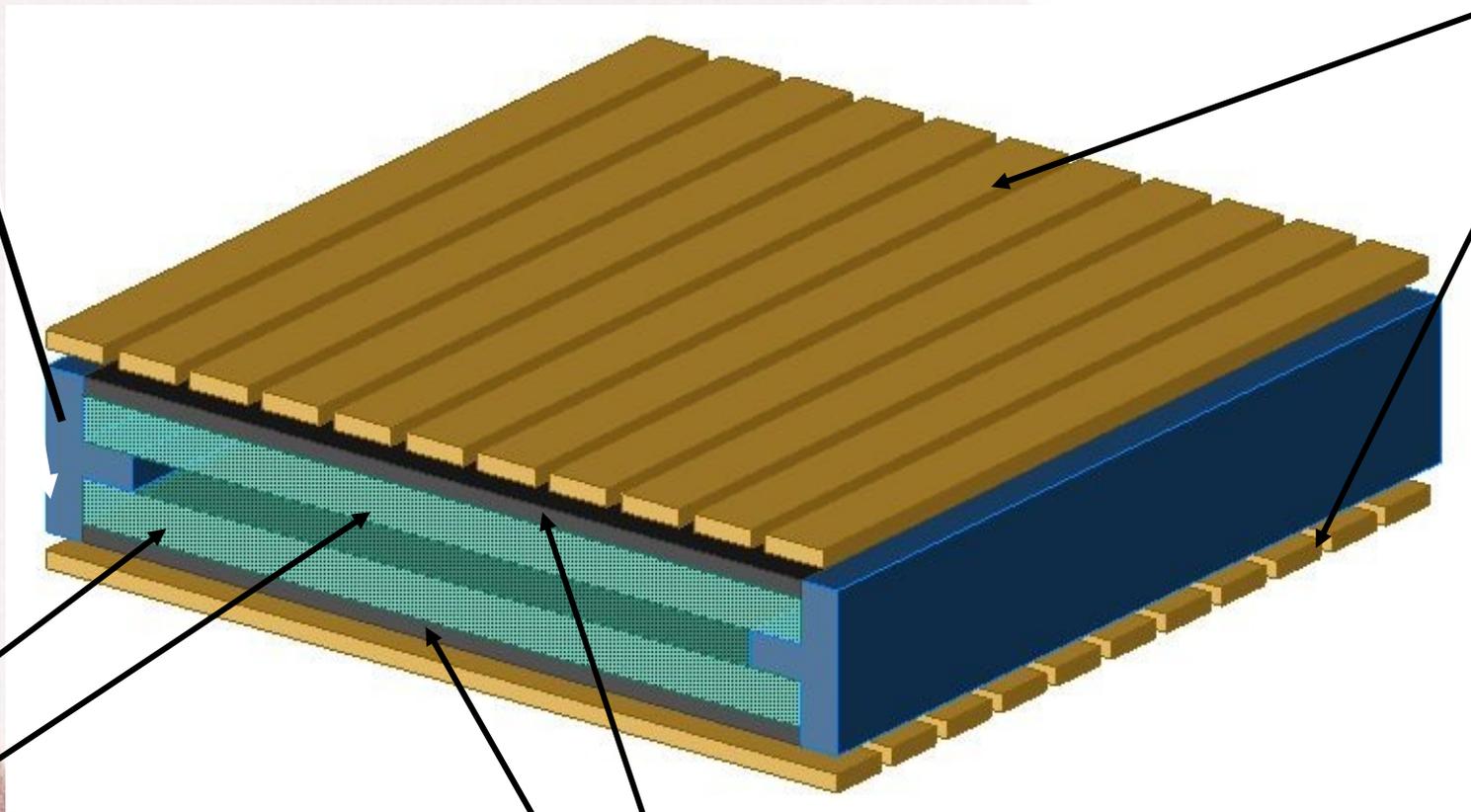
Glass plates

Resistive coating on the outer surfaces of glass

Construction of the ICAL

Fig. 7.6 Bottom Layer with Coil Lower Parts on Foundation
- Bottom Layer
- Coil Bottom Parts
- Foundation
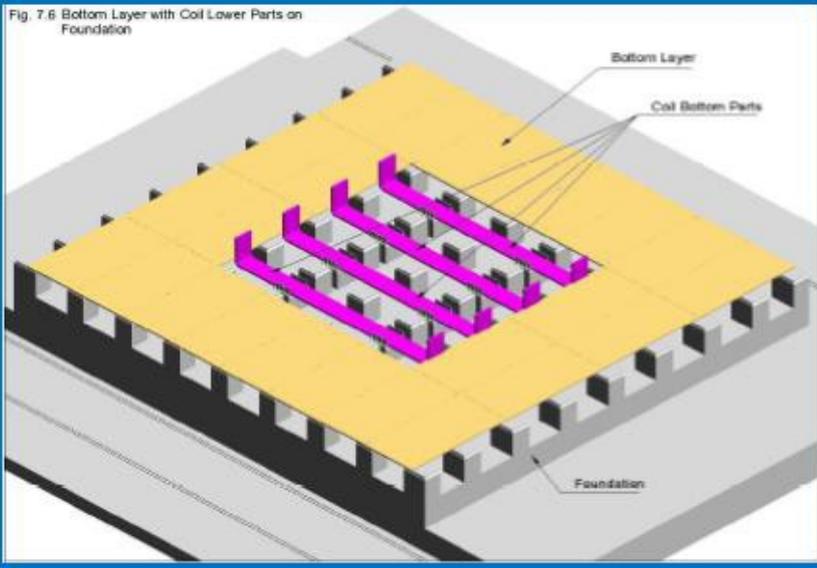
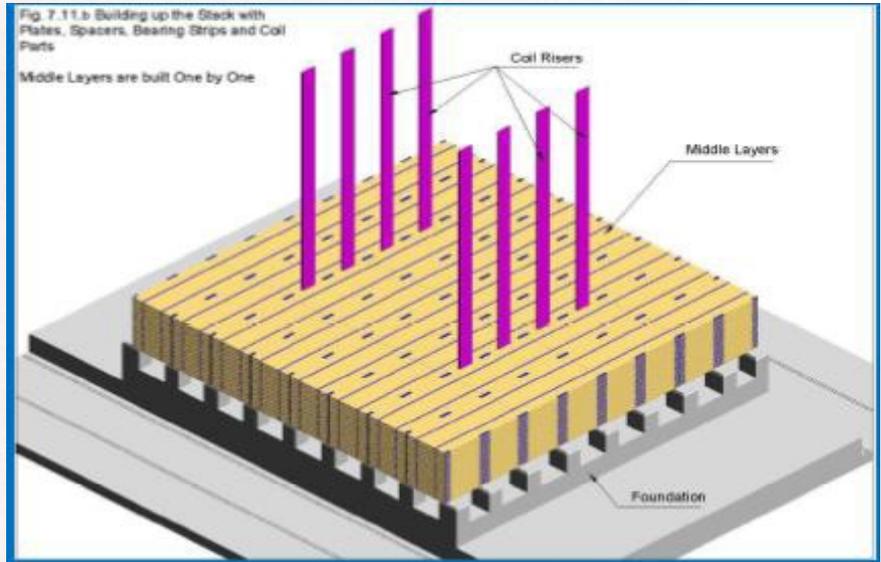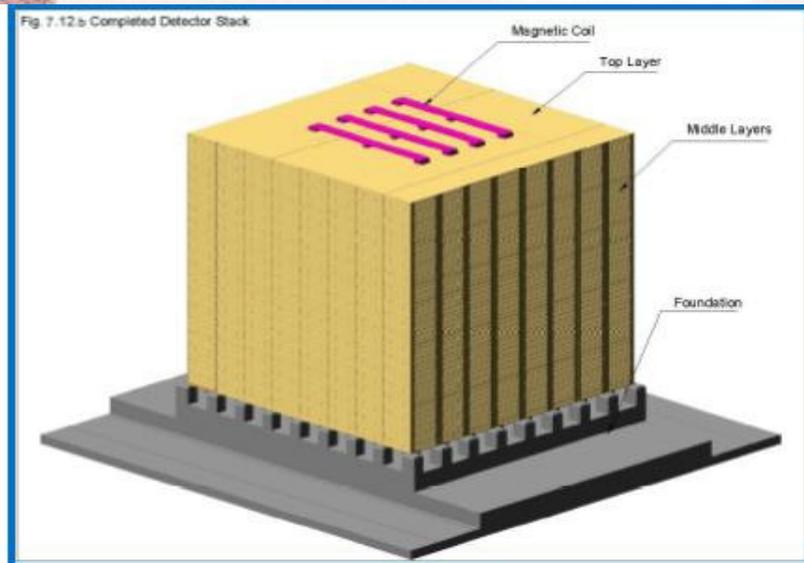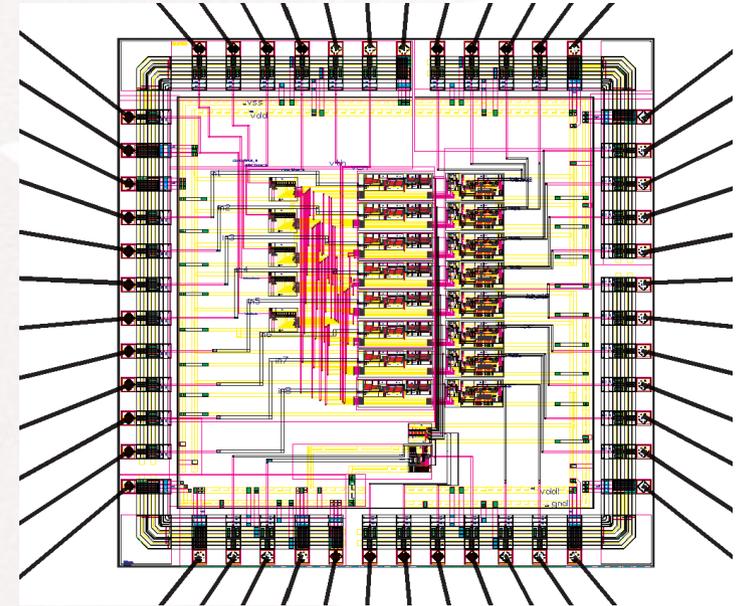Fig. 7.11.b Building up the Stack with Plates, Spacers, Bearing Strips and Coil Parts

Middle Layers are built One by One
- Coil Risers
- Middle Layers
- Foundation

Fig. 7.12.b Completed Detector Stack
- Magnetic Coil
- Top Layer
- Middle Layers
- Foundation

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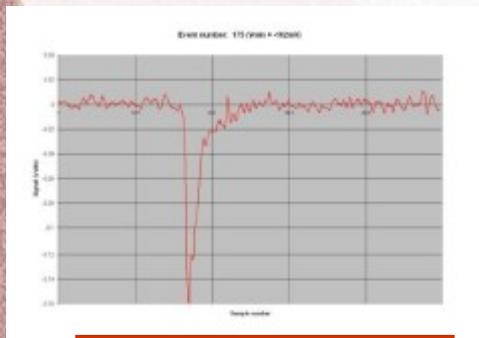# ICAL Front End Electronics chip developed at BARC Electronics Division
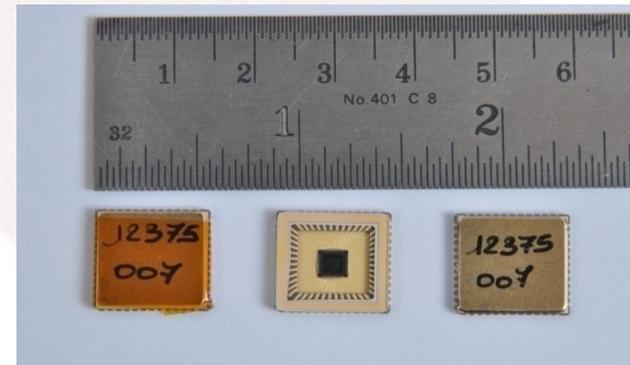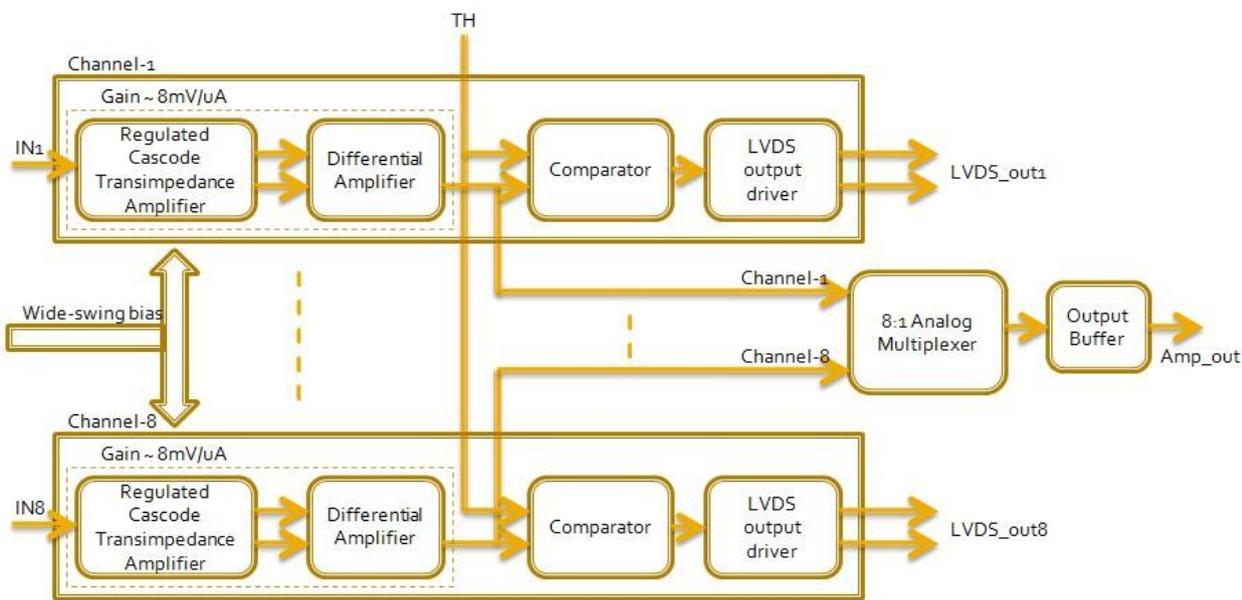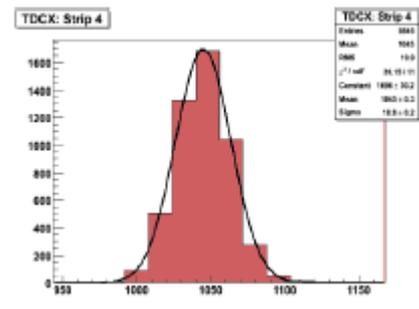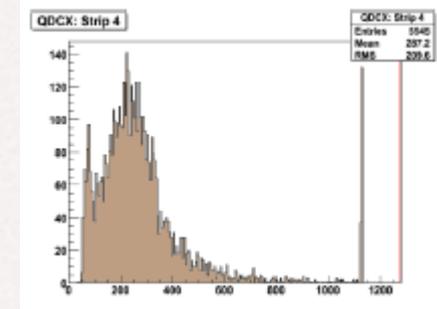

(Poster by B. Satyanarayana)

Testing the RPCs

RPC stack being used for cosmic ray measurements

Muon Pulse in RPC

RPC timing resolution
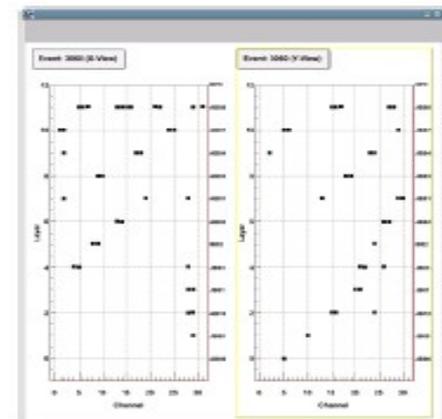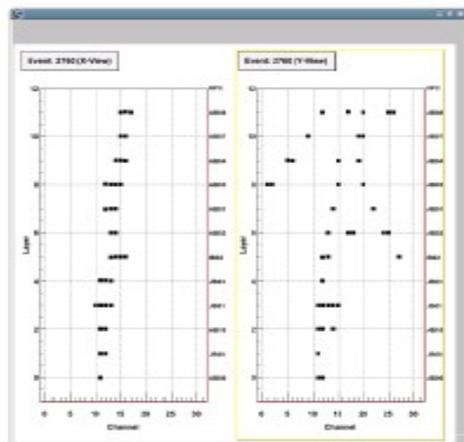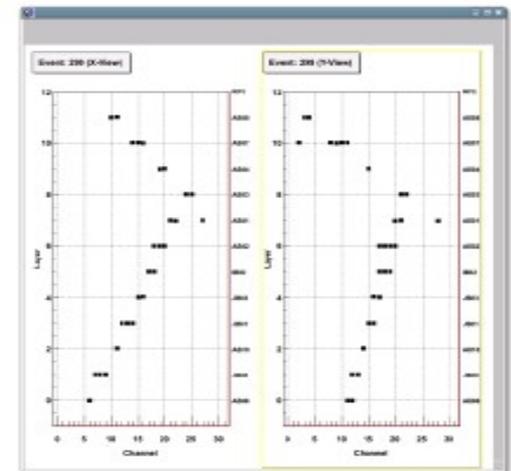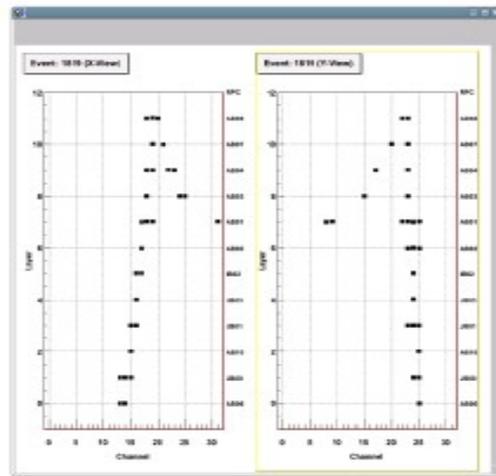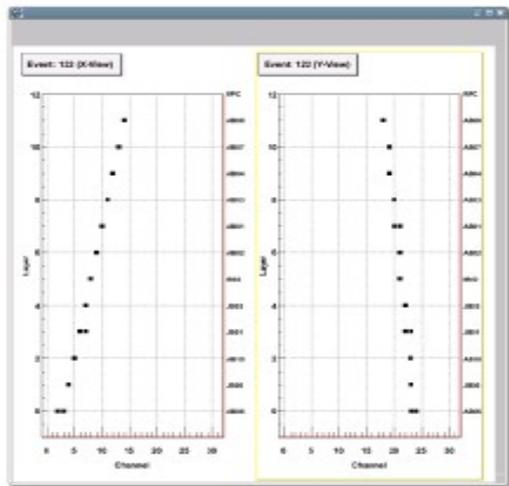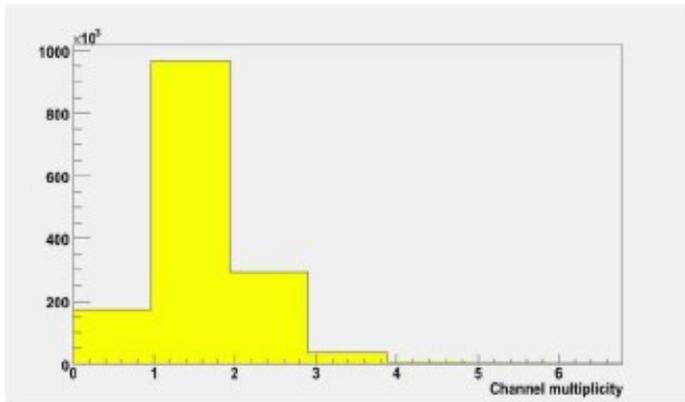

RPC Pulse ht. resolution

Cosmic ray tracks in the RPC stand

- *Demonstrates tracking capability of the INO RPC system*

RPC performance with cosmic rays

Strip Multiplicity due to crossing muons
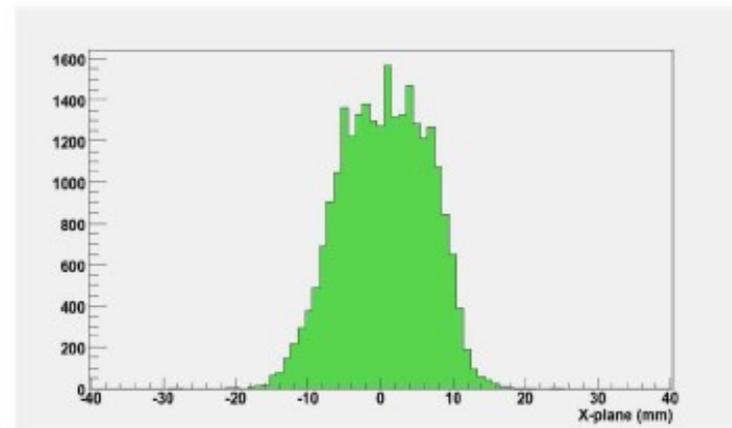
Track residue in mm
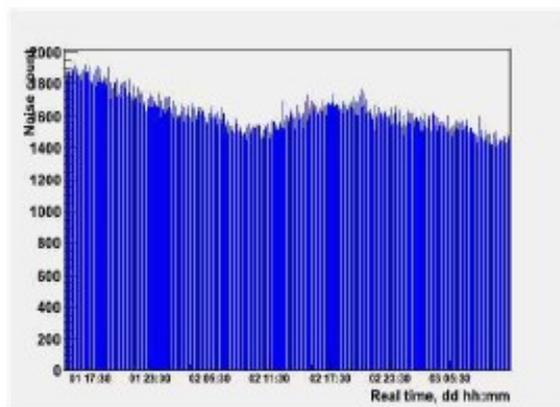
Strip noise rate vs time
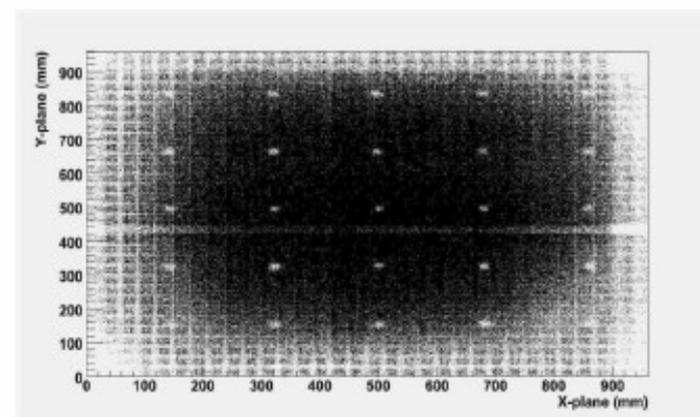
Image of a RPC using muons

Fabricating 2mx2m glass RPC in the lab
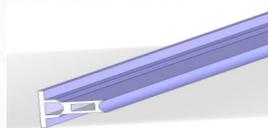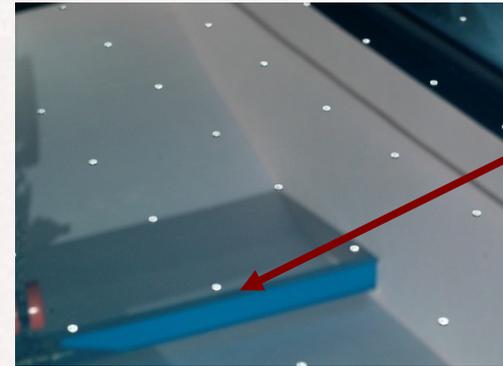
2m x 2m glass RPC test stand
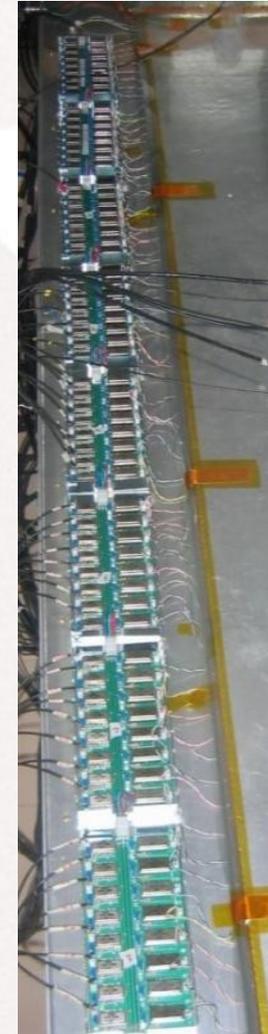
Bakelite RPC R&D

- *SINP and VECC groups in Kolkata developing bakelite RPCs in streamer mode*
- *Inner surface of bakelite coated with PDMS (silicone) to make the surface smooth*
- *Efficiency plateau over 96% obtained with reduced noise rate and long term stability*
- *INO-ICAL being modular, can use both, glass and/or bakelite RPCs*
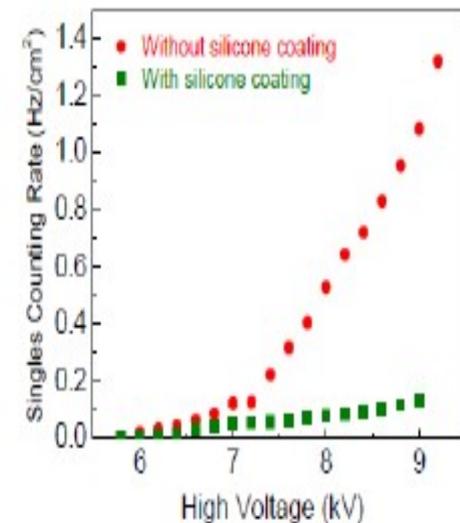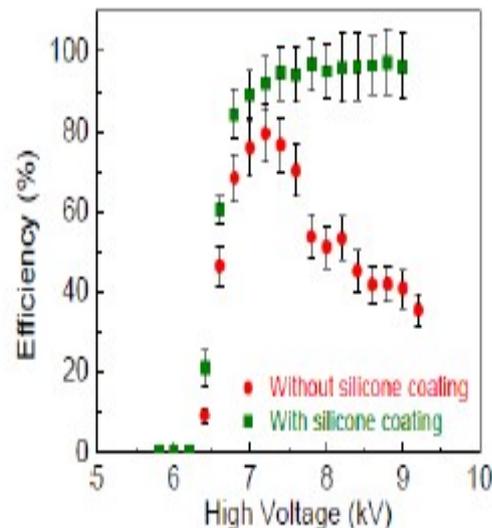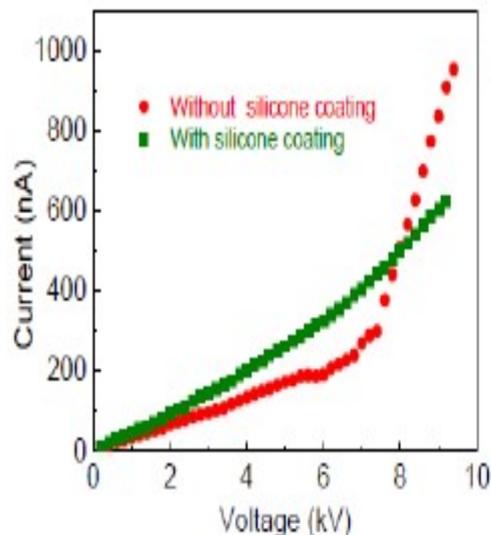
Detector prototype (40 ton) in Kolkata
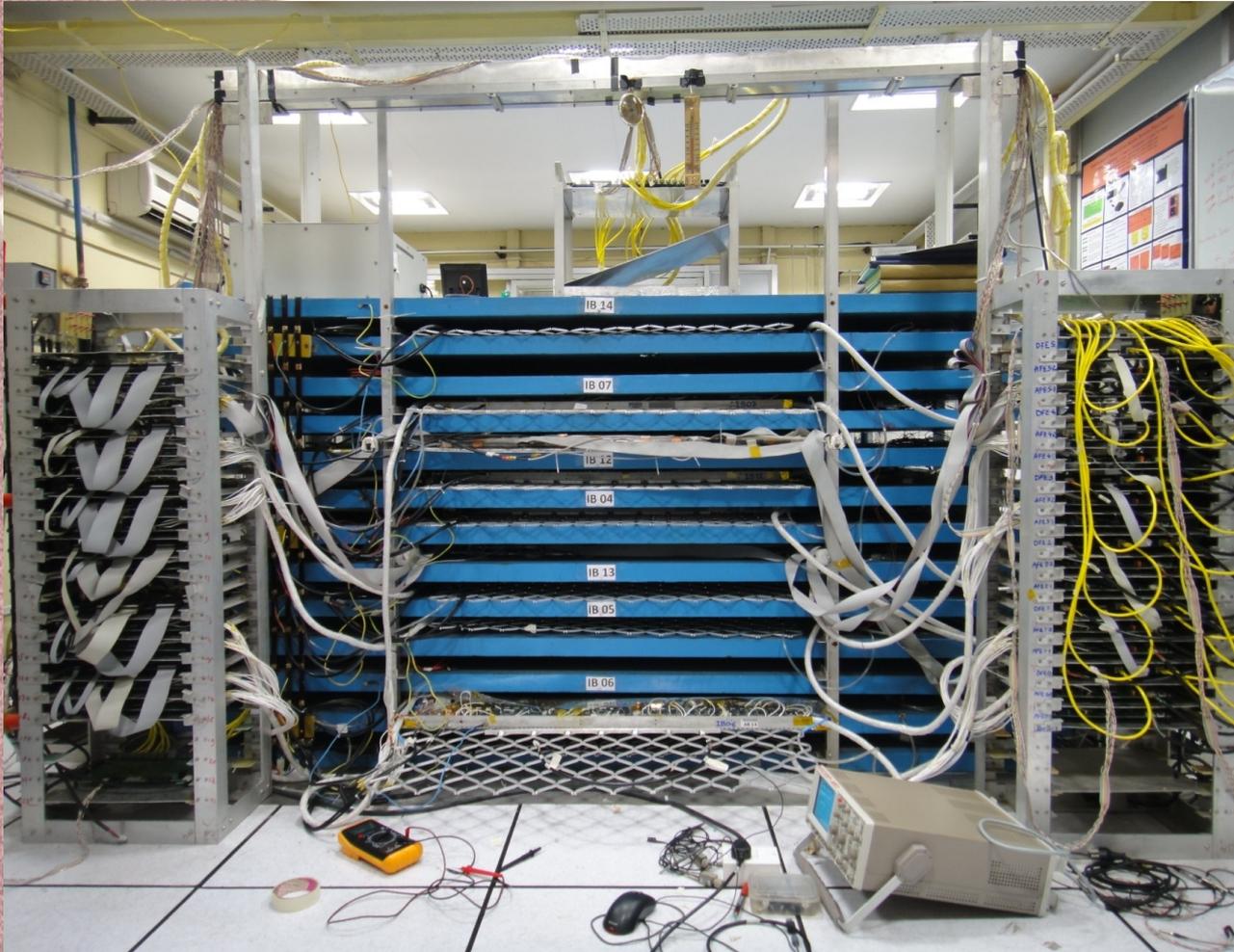
- *Both, glass and bakelite RPCs tested in this magnetized ICAL prototype*

(Talk by Sumanta Pal)

Status of detector development

- **RPC development for ICAL**:

  → R&D almost complete

  → Full size RPCs (2m X 2m) are being fabricated not just in the INO labs but also by the industry

  → Methods, machinery and production optzmisation for large scale production of RPCs are being developed with the help of an industry

- **Electronics for ICAL**

  → Design and prototyping of electronics, trigger and data acquisition systems progressing well.

  → First batch of ASIC front end designed by the INO electronics team & fabricated by Euro Practice IC Services being tested in the RPC lab

  → TDC ASIC developed at IIT Madras

- **Magnet for ICAL**

  → Prototype magnet running at VECC, Kolkata

8m x 8m x 20 layer engineering module (800 ton) being planned

INO: Simulations

Overview of simulation framework

Simulation Framework

NUANCE	**Neutrino Event Generation** $\nu_a + X \rightarrow A + B + ...$ Generates particles that result from a random interaction of a neutrino with matter using theoretical models .	**Output:** i) Reaction Channel ii) Vertex Information Iii) Energy & Momentum of all Particles
GEANT4	**Event Simulation** $A + B + ...$ through RPCs + Mag.Field Simulate propagation of particles through the detector (RPCs + Magnetic Field)	**Output:** i) x,y,z,t of the particles at their interaction point in detector ii) Energy deposited iii) Momentum information
	Event Digitisation (x,y,z,t) of $A + B + ...$ + noise + detector efficiency Add detector efficiency and noise to the hits	**Output:** i) Digitised output of the previous stage (simulation)
	Event Reconstruction (E,p) of $\nu + X$ = (E,p) of $A + B + ...$ Fit the tracks of $A + B + ...$ to get their energy and momentum.	**Output:** i) Energy & Momentum of the initial neutrino

The status of INO simulations

- MC code for generating atmospheric neutrino events at the INO site getting ready (talk by Indumathi). Current results use fluxes at SK.

- Complete detector geometry implemented in GEANT4, including the inhomogeneous magnetic field

- Muon track reconstruction: good understanding of energy and direction resolution, but improvements still possible (talk by Meghna)

- Hadron energy resolutions available, but not used in the physics analysis results yet. Optimization of iron plate thickness in progress (talk by Laxmi Mohan)

- Neutrino energy reconstruction using muon and hadron momenta possible (poster by Moon Moon Devi)

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Muon efficiencies and resolutions

Reconstruction eff

Charge-ID eff

Energy resolution

Cos θ resolution

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Talk by Meghna
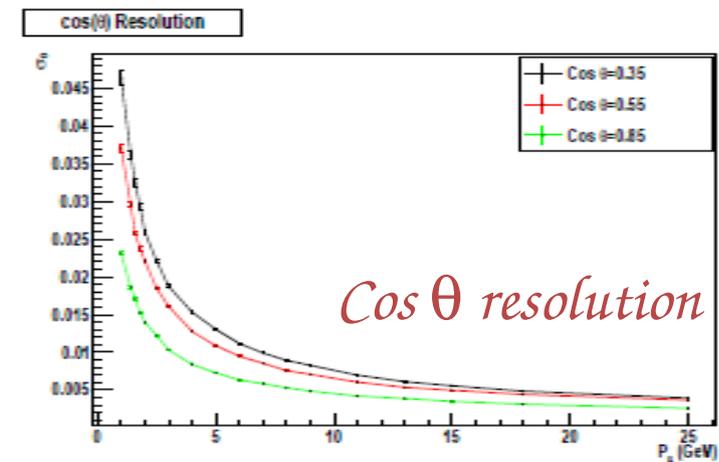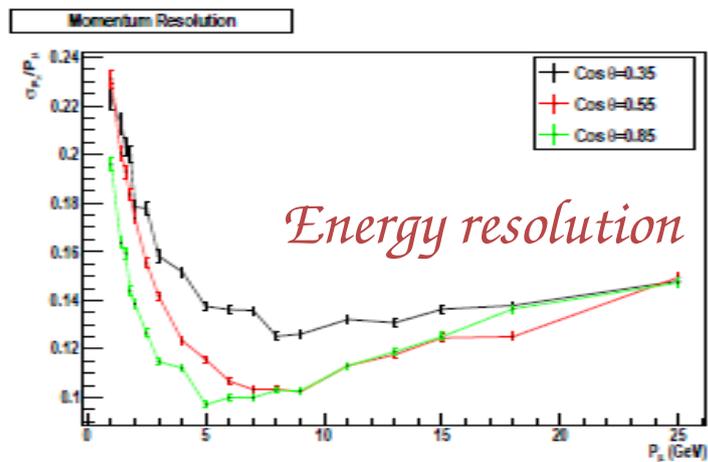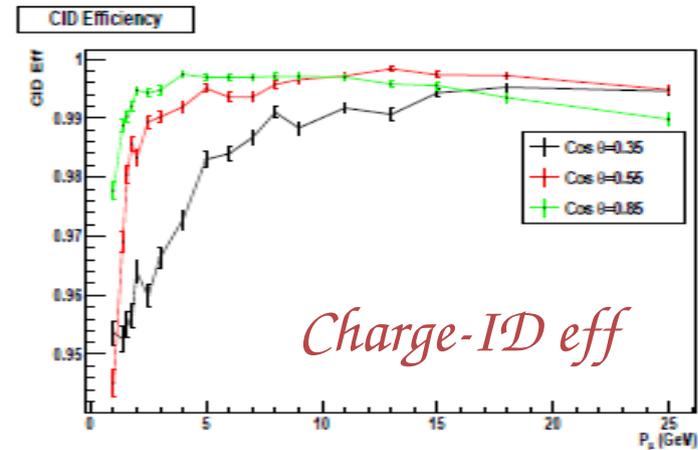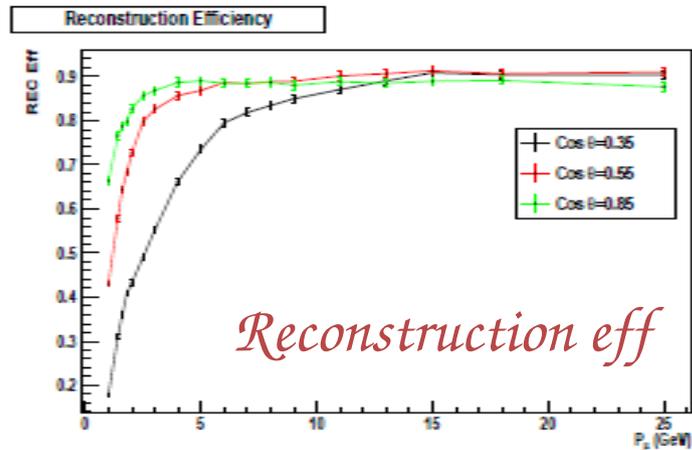
Hadron energy resolutions
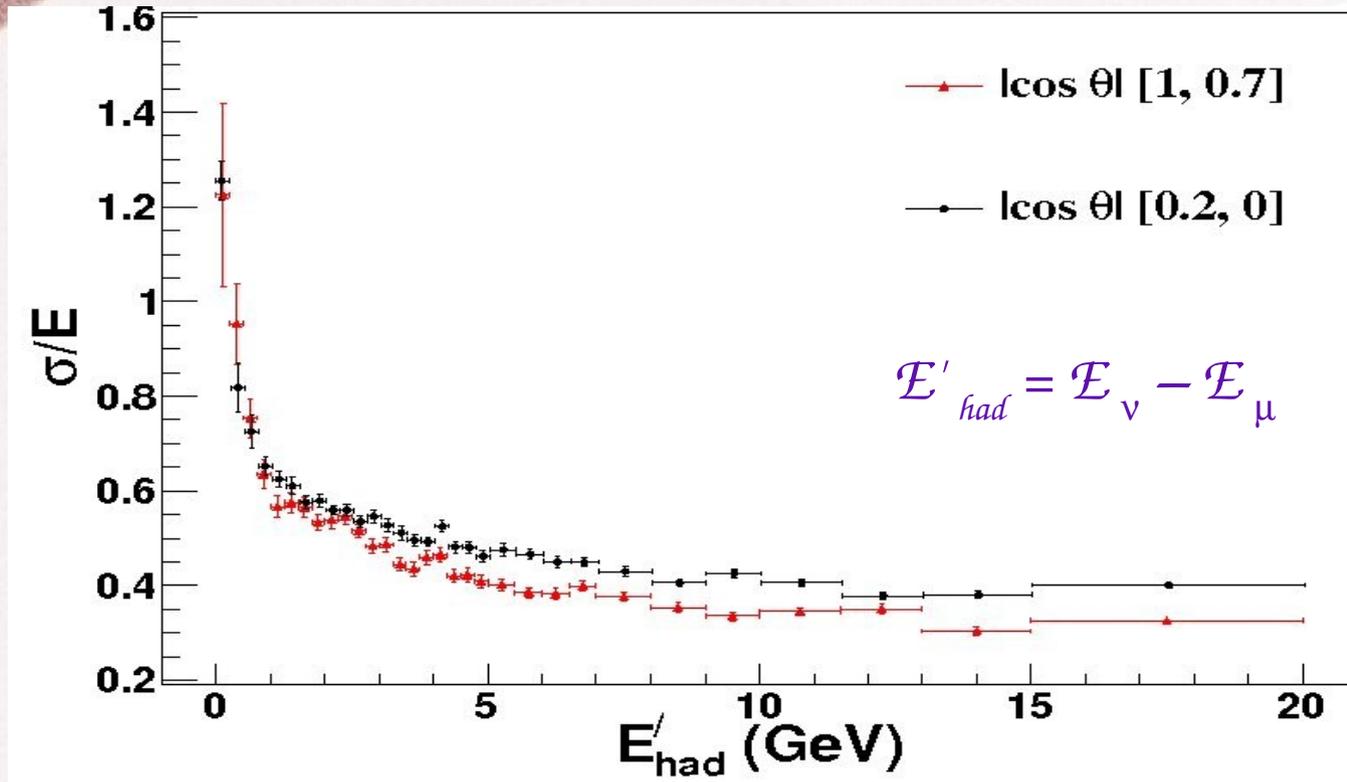
- *These can further be used for neutrino energy resolution*
  (Talk by Laxmi and poster by Moon Moon)

Mass hierarchy with INO-ICAL
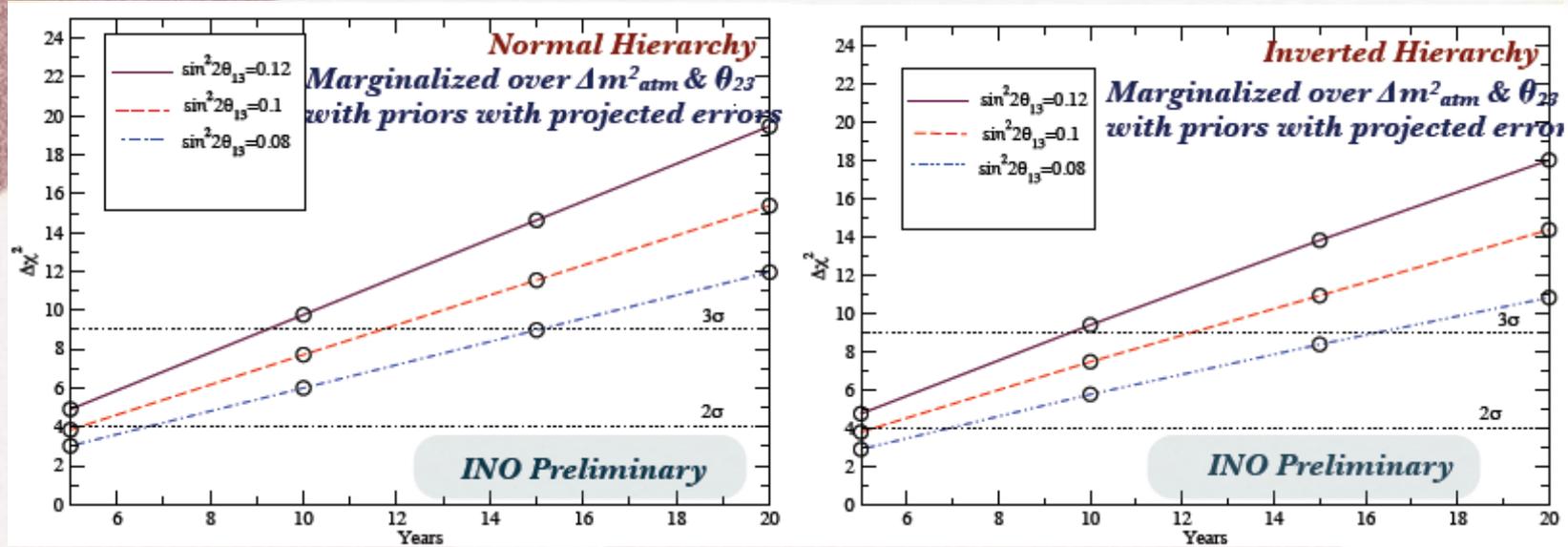
- *Events generated using NUANCE and ICAL resolutions in E and $\cos(\theta\_zenith)$*
- *Sensitivity independent of CP phase, as opposed to at the long baseline expts*
- *For $\sin^2(theta23)=0.5$, $\sin^2(2\,theta13)=0.1$:*

  In 5 years, 2 sigma sensitivity to MH, in 10 years (2027), 2.7 sigma

A. Ghosh, T. Thakore, S. Choubey, hep-ph/1212.1305, Talk by Anushree Ghosh

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Atmospheric parameters with INO-ICAL

INO Preliminary

90% CL
- MINOS All beam(14.1× 10²⁰ POT) + Atmospheric, Neutrino 2012
- SK L/E, Neutrino 2012
- SK Zenith, Neutrino 2012
- INO 5 Yr. (Simulation, Preliminary)
- INO 10 Yr. (Simulation, Preliminary)

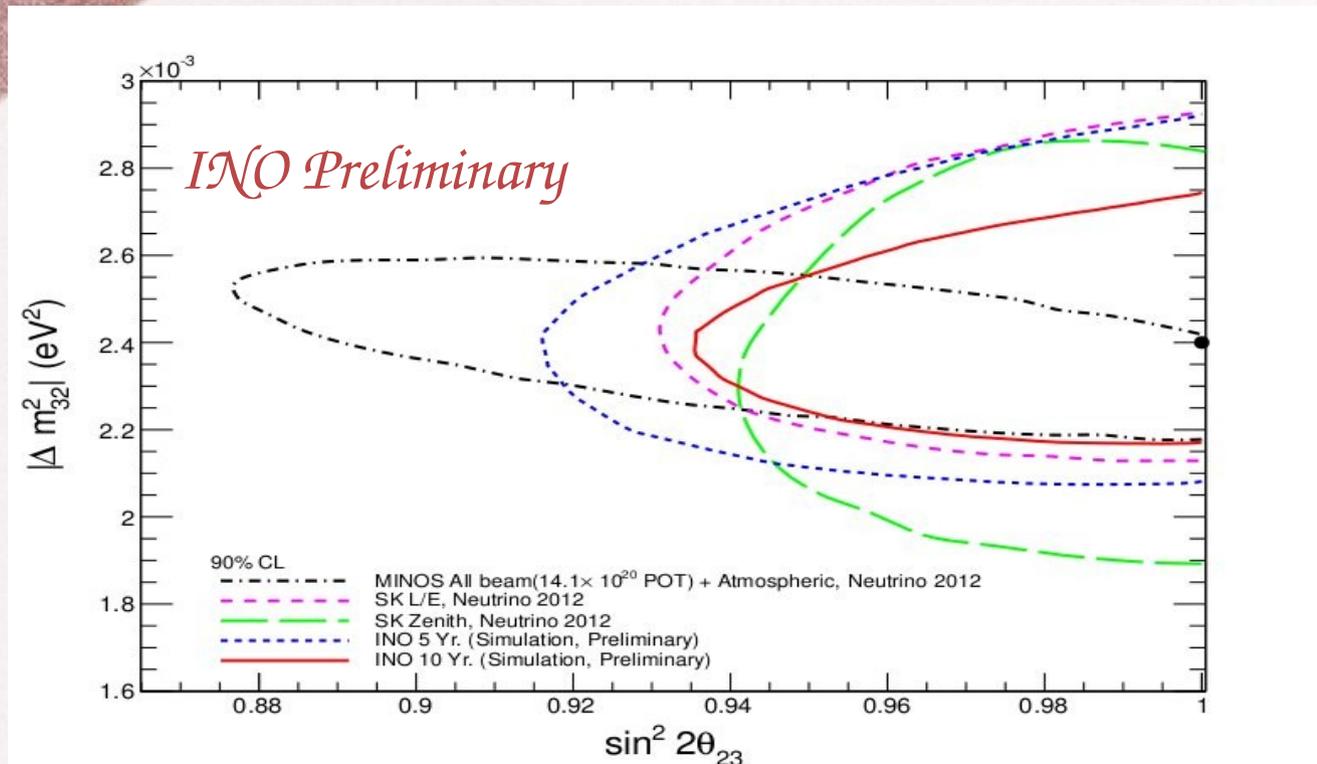- *Priors used on projected reach of* $|\Delta m^2_{32}|$, θ_{23}, θ_{13}

- *Precision complementary to LBL experiments:*
  better for θ_{23}, *but worse for* $|\Delta m^2_{32}|$

- *Performance comparable to SK with a similar exposure*

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T. Thakore, A. Ghosh, S. Choubey

θ_{13} octant and deviation from maximality
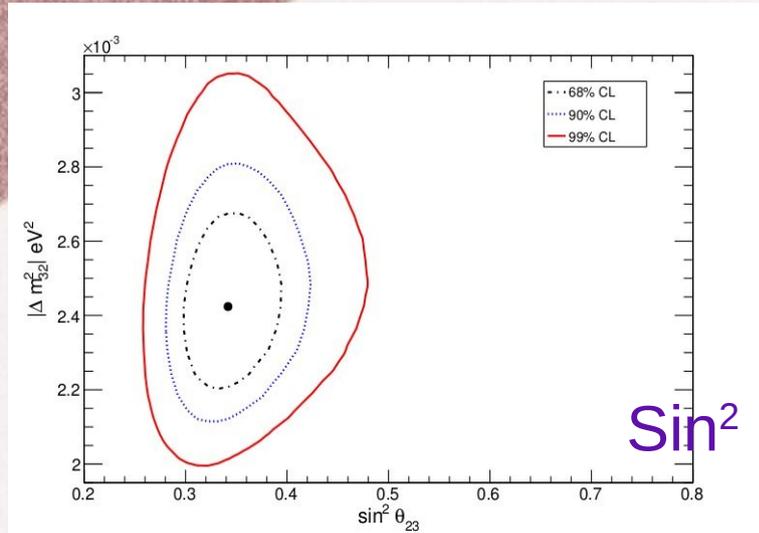
Sin^2 2θ_{23} = 0.9

First octant

Second octant

Sin^2 2θ_{23} = 0.95

INO Preliminary, T. Thakore, A. Ghosh, S. Choubey
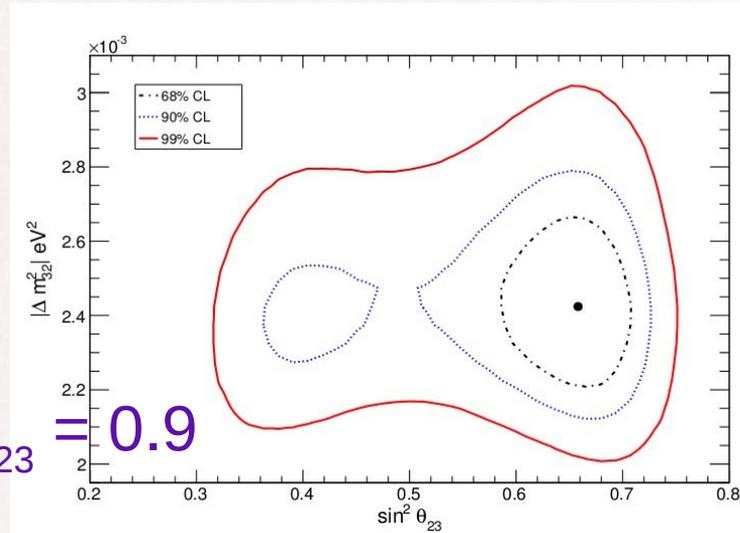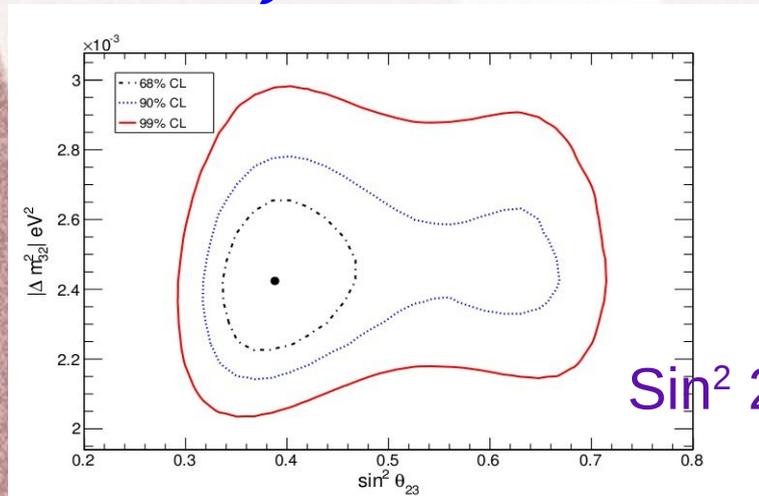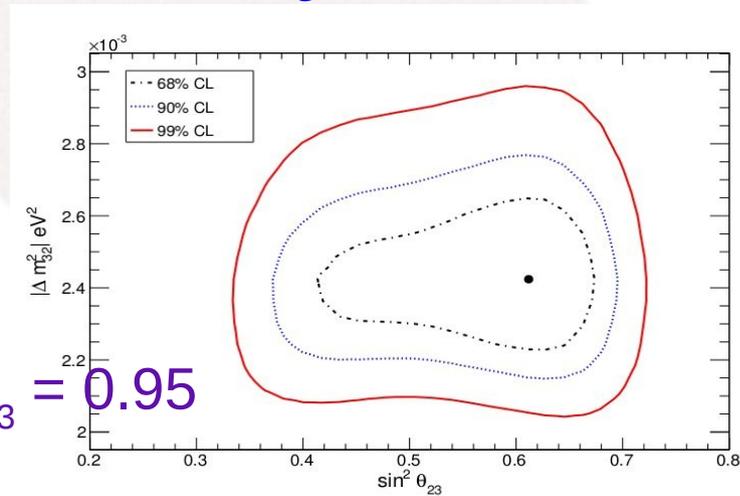
More analyses in progress

- *Improvement of Kalman-filter algorithm for muon track reconstruction (talk by Kolahal Bhattacharya)*

- *Sensitivity for CPT violating parameters (talk by Animesh Chatterjee)*

- *Analysis of upward-going muons produced from neutrino interactions in the surrounding rock (talk by Kanishka Rawat)*

- *Study of background from τ events (talk by Sumanta Pal)*

- *…*

INO: Timeline

INO-ICAL timeline

SN	Description of work	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
	Civil work at Pottipuram						
1	Land acquisition and pre-project work	↔					
2	Architectural and Engineering consultancy	↔					
3	Tendering and award of contracts	↔					
4	Mining of access portal		↔				
5	Excavation of tunnel		←———→				
6	Excavation of caverns				←———→		
7	Installation of services, cranes, lifts etc.					↔	
8	Civil work for magnet support bed					↔	
9	Surface facilities		←————————→				
	Magnet						
10	Procurement of steel plates			←——→			
11	Machining job for steel plates				←———→		
12	Transportation of machined plates at site					↔	
13	Procurement of copper coils					↔	
14	Assembly/erection of magnet (3 modules)					←———→	
	RPC						
15	Finalization of all design details, tendering	←———→					
16	Procurement of components		↔				
17	Fabrication and assembly of 30000 pcs		←——————————→				
18	Transportation to site and tests				←————→		
19	Procurement of electronics, gas handling			←———→			
20	Installation and commissioning					←———→	

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Human resource development and training

- INO Graduate Training Program from Aug 2008 (affiliated to HBNI)

- One year training in TIFR in both, experimental techniques and theory. After completion of coursework, attached to Ph.D. Guides in collaborating institutions

- Many short/long term visits to RPC labs (Mumbai and Kolkata) of students and faculty from universities in last several years.

2008

2009

Thank You

Collaborators are welcome !
http://www.ino.tifr.res.in/ino/