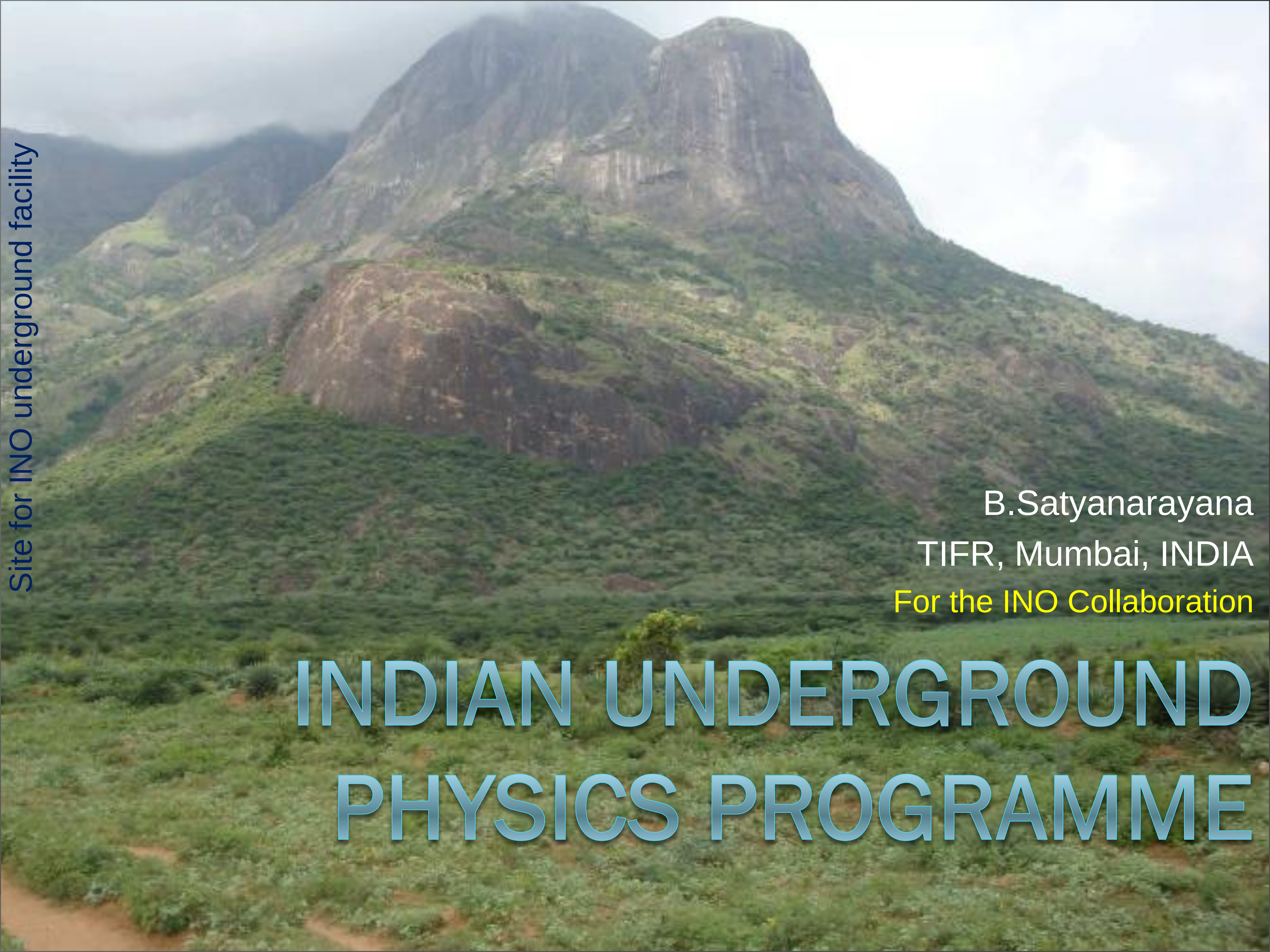


Site for INO underground facility

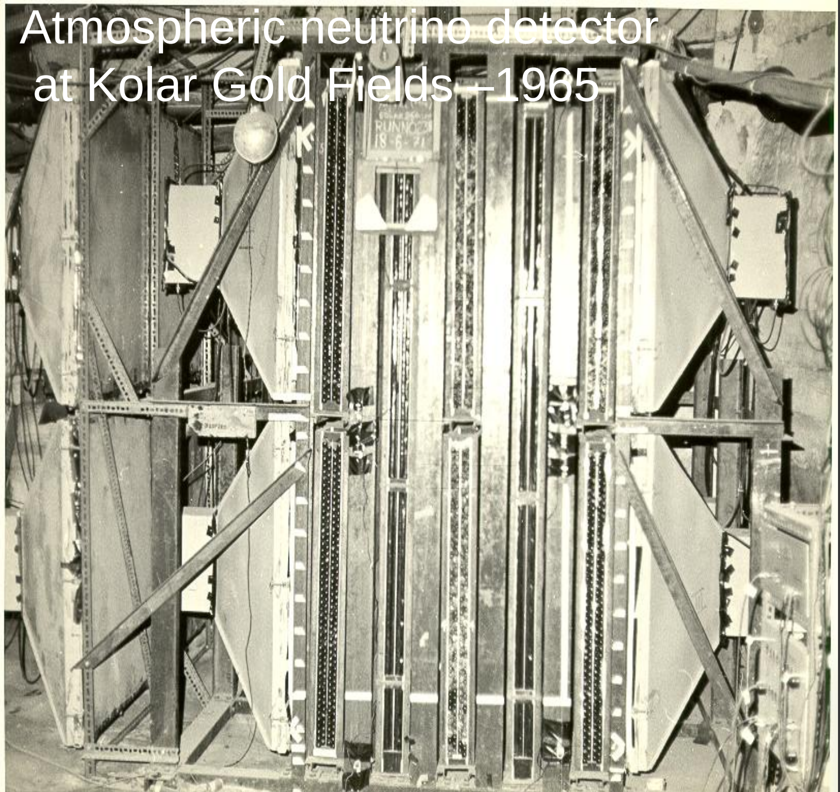
INDIAN UNDERGROUND PHYSICS PROGRAMME

B.Satyanarayana
TIFR, Mumbai, INDIA
For the INO Collaboration

Plan of the talk

- Introduction
- India-based Neutrino Observatory project
- Underground laboratory
- Goals and possibilities with ICAL detector
- Design of and prototyping ICAL detector
- Physics with NDBD detector
- Design of and prototyping NDBD detector
- NCHEP and other possibilities
- Summary and outlook

Tradition of underground physics



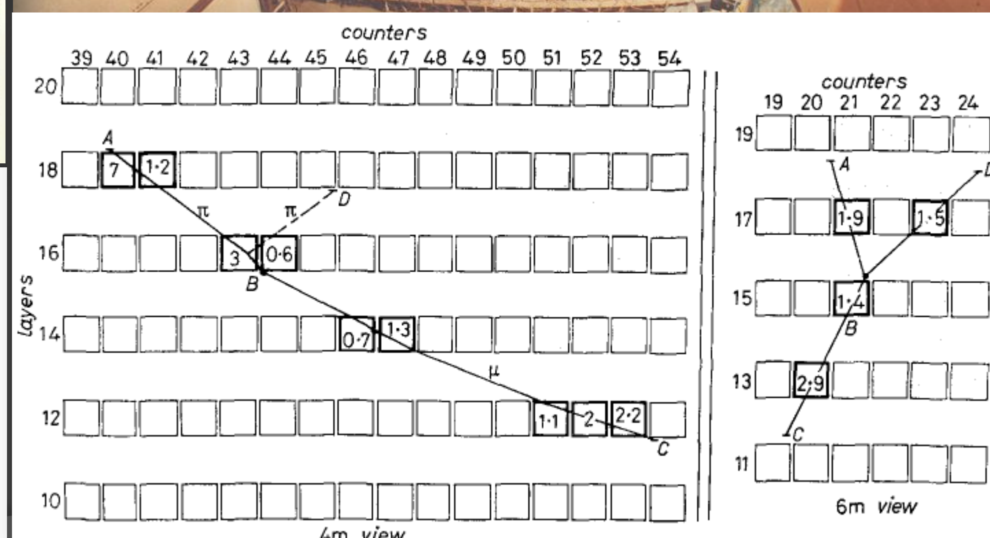
DETECTION OF MUONS PRODUCED BY COSMIC RAY NEUTRINO DEEP UNDERGROUND

C. V. ACHAR, M. G. K. MENON, V. S. NARASIMHAM, P. V. RAMANA MURTHY and B. V. SREEKANTAN,
Tata Institute of Fundamental Research, Colaba, Bombay

K. HINOTANI and S. MIYAKE,
Osaka City University, Osaka, Japan

D. R. CREED, J. L. OSBORNE, J. B. M. PATTISON and A. W. WOLFENDALE
University of Durham, Durham, U.K.

Received 12 July 1965



History of neutrino physics in India

- High Energy Physics research using underground detectors at Kolar Gold Fields during 1952-92.
- Muon intensities and angular distributions at various depths.
- Indian initiative in neutrino physics goes back to more than 35 years.
- Demonstrated for the first time the feasibility of doing neutrino experiment at KGF in south India.
- International collaboration experiment to detect atmospheric neutrinos started at KGF in 1964.
- Detection of atmospheric neutrino in 1965.
- KGF data during the proton decay era was used to look for ultra high energy neutrino sources in the sky.
- Bounds on neutrino masses using cosmological data.
- Estimation of atmospheric neutrino flux.

India-based Neutrino Observatory project

- The primary goal of INO is neutrino physics.
- A national collaboration of scientists from more than 20 groups belonging to DAE institutions, IITs and Universities.
- The total cost of the project is expected to be about $300M.
- The project includes:
  - construction of an underground laboratory and associated surface facilities,
  - construction of a Iron Calorimeter (ICAL) detector for neutrinos,
  - setting up of National Centre for High energy Physics (NCHEP).
- The project is expected to be completed within six years beginning April 2011.
- A successful INO-Industry interface developed because of the large scale of experimental science activity involved.
- INO Graduate Training Programme (GTP) under the umbrella of Homi Bhabha National Institute (HBNI) - a deemed-to-be University within DAE is in its third year.

INO Collaboration

Spokesperson: N.K. Mondal, TIFR, Mumbai
Home page: http://www.ino.tifr.res.in

Ahmedabad: Physical Research Laboratory (PRL)
S. Goswami, A.S. Joshipura

Aligarh: Aligarh Muslim University (AMU)
S. Ahmed, M. Sajjad Athar, R. Hasan, S.K. Singh

Allahabad: Harish Chandra Research Institute (HRI)
S. Choubey, R.Gandhi, A.Raychaudhuri

Calicut: University of Calicut (UC)
B.R.S. Babu, A.M. Vinodkumar

Chandigarh: Panjab University (PU)
V.K. Bhandari, V. Bhatnagar, M.M. Gupta, A. Kumar, J.S. Shahi, B. Singh, J.B. Singh

Chennai: Indian Institute of Technology, Madras (IITM)
N. Chandrachoodan, N. Krishnapurna, J. Libby, A. Prabhakar

Chennai: The Institute of Mathematical Sciences (IMSc)
D. Indumathi, H.S. Mani, M.V.N. Murthy, G. Rajasekaran, N.Sinha

Delhi: Delhi University (DU)
S.K. Chamoli, B.C. Choudhary, D. Choudhury, D. Kaur, A. Kumar, S. Kumar, S. Mandal, Md. Naimuddin, Shahnawaz, S. Verma, S.K. Verma

Guwahati: Indian Institute of Technology (IITG)
B.Bhuyan, P. Paulose, A. Sil

Hawaii (USA): University of Hawaii (UHW)
S. Pakvasa

Indore: Indian Institute of Technology (IITI)
S. Rakshit

Jammu: University of Jammu (JU)
A. Bhasin, A. Gupta, R. Gupta, S. Mahajan, S.S. Sambyal

Kalpakkam: Indira Gandhi Center for Atomic Research (IGCAR)
J. Jayapandian, C.S. Sundar

Kolkata: Ramakrishna Mission Vivekananda University (RMVU)
Abhijit Samanta

Kolkata: Saha Institute of Nuclear Physics (SINP)
P. Bhattacharya, S. Bhattacharya, Kamales Kar, D. Majumdar, S. Saha

Kolkata: University of Calcutta (CU)
S. Bandyopadhyay, A. Banerjee, D. Jana, G. Gangopadhyay

Kolkata: Variable Energy Cyclotron Centre (VECC)
R.K. Bhandari, S. Chattopadhyay, A.K. Dubey, S.A. Khan, S. Muhuri, T.K. Nayak, S. Saha, J. Saini, P.R. Sarma, R.N. Singaraju, V. Singhal, S.K. Thakur, Y.P. Viyogi

Lucknow: Lucknow University (LU)
Jyotsna Singh

Madurai: American College (AC)
S.P.M. Deborrah, K. Gnanasekar, S.R. Inbanathan, K. Moorthy

Mumbai: Bhabha Atomic Research Centre (BARC)
V. Arumugam, Anita Behere, M.S. Bhatia, V.B. Chandratre, V.M. Datar, M.P. Diwakar, G. Gouthaman, Suresh Kumar, P.K. Mukhopadhyay, L.M. Pant, B.J. Roy, K. Srinivas, V. Sugadan

Mumbai: Indian Institute of Technology, Bombay (IITB)
Basanta Nandi, S. Uma Sankar, Raghav Varma

Mumbai: Tata Institute of Fundamental Research (TIFR),
B.S. Acharya, S. Banerjee, M.Bhuyan, A. Dighe, K.S. Gothe, S.D. Kalmani, S. Lahamge, G.Majumder, N.K. Mondal, P. Nagaraj, B.K. Nagesh, S.K. Rao, L.V. Reddy, A. Redij, D. Samuel, M. Saraf, B. Satyanarayana, S. Upadhya, P. Verma

Mysore: University of Mysore (MU)
S. Krishnaveni, C. Ranganathaiah, H.B. Ravikumar

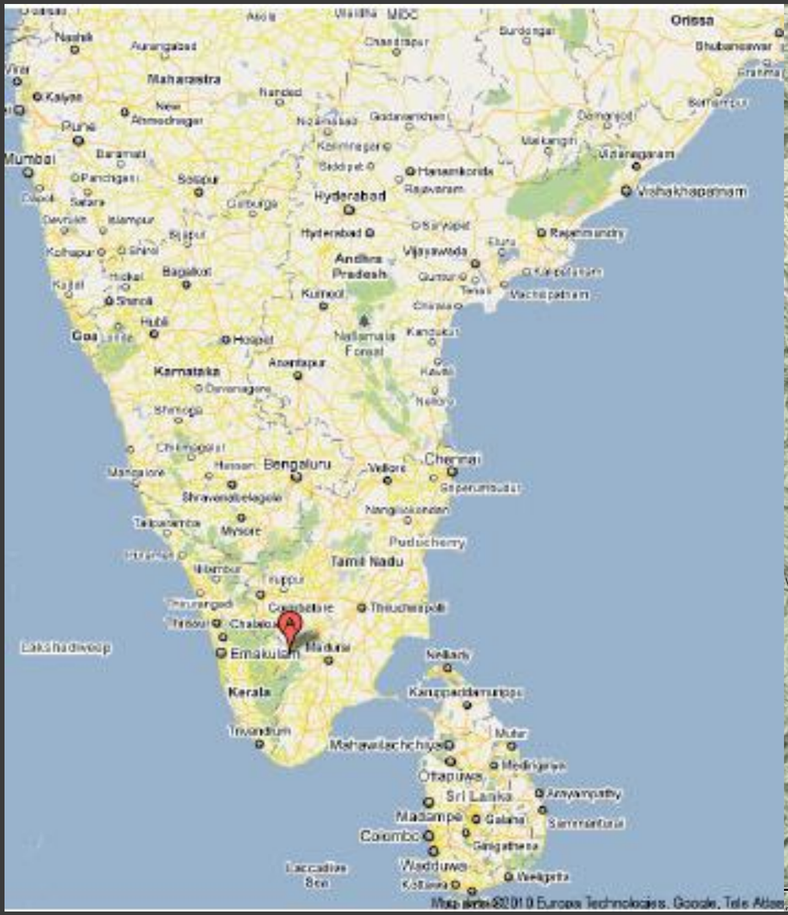
Sambalpur: Sambalpur University (SU)
S. N. Nayak

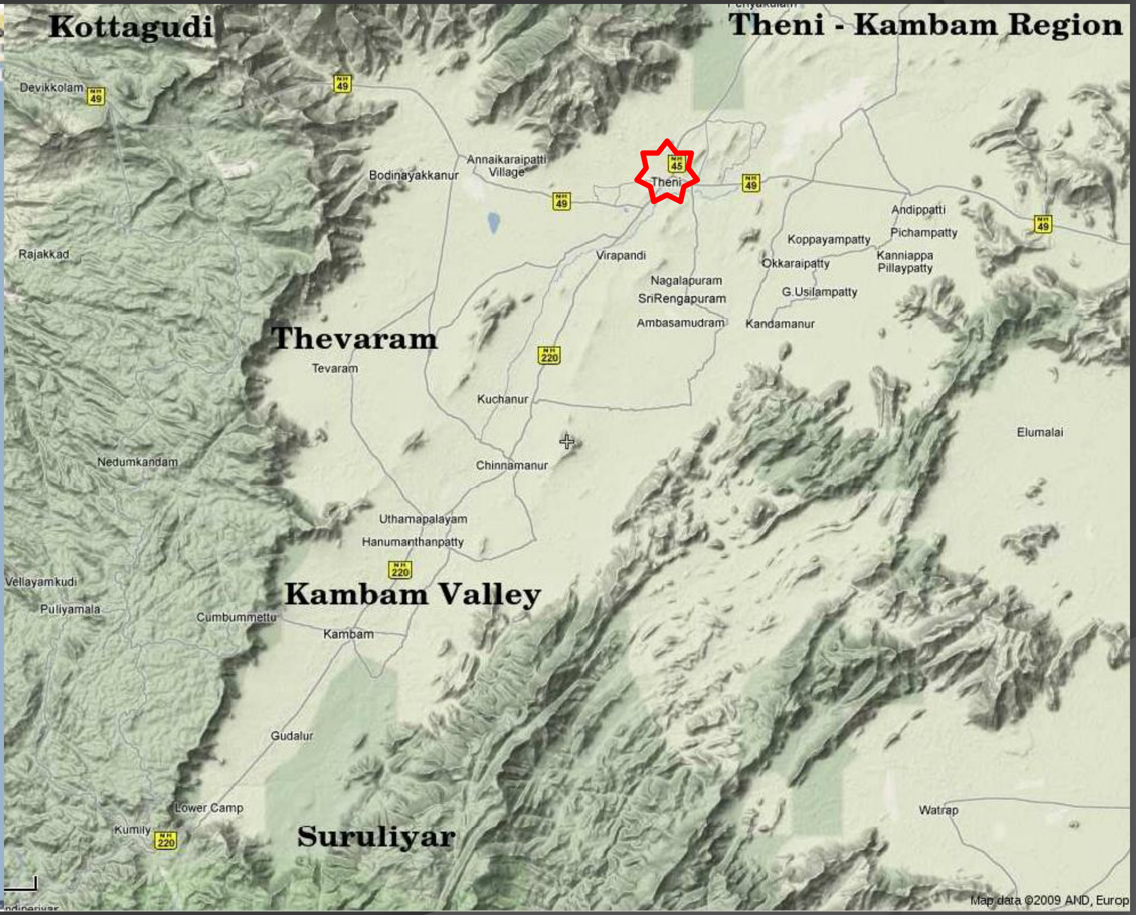
Srinagar: University of Kashmir (UK)
W. Bari, N. Iqbal

Varanasi: Banaras Hindu University (BHU)
B.K. Singh, C.P. Singh, V. Singh

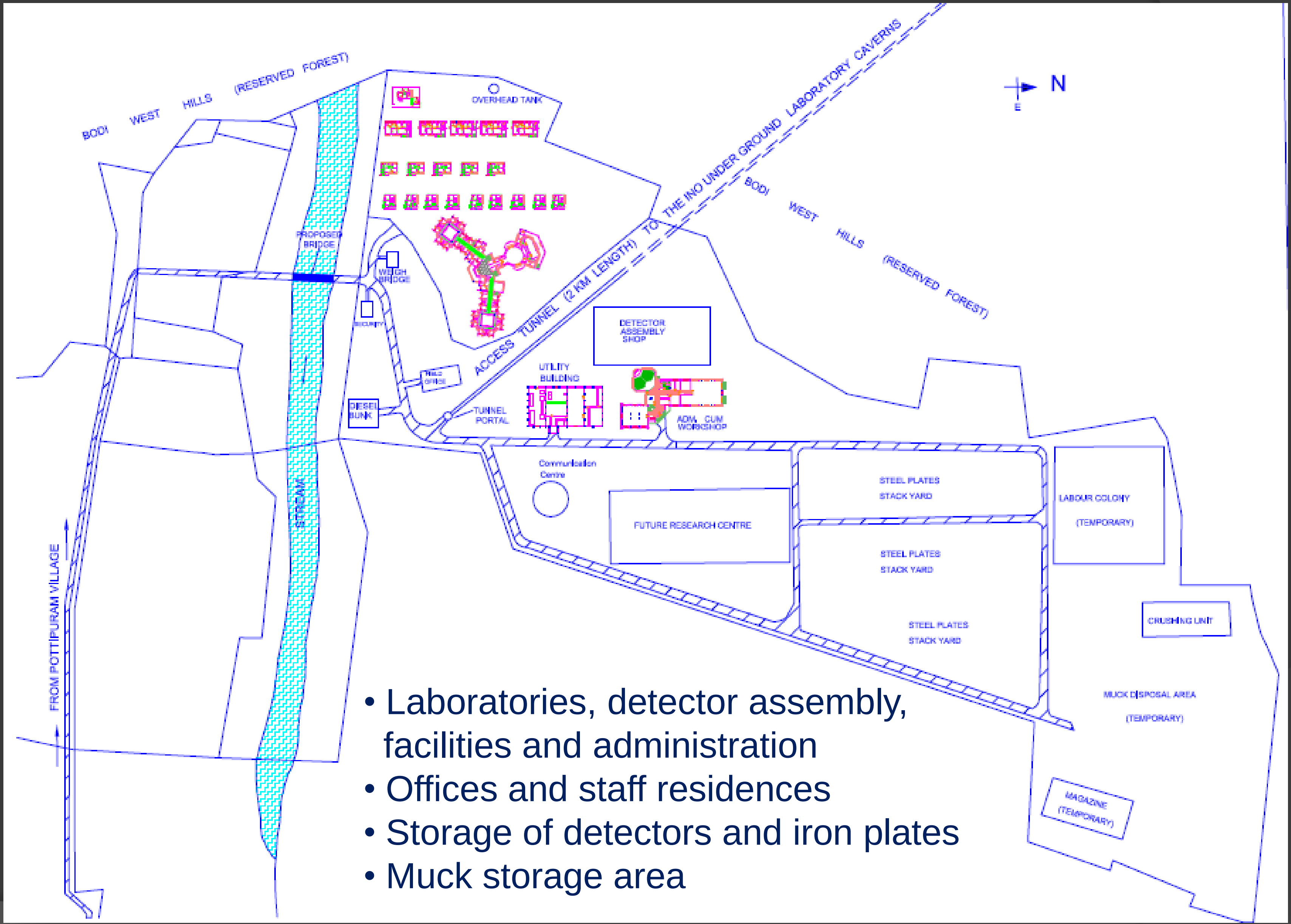
Location of INO underground lab

Location: 9°58′ North; 77°16′ East, 110km from Madurai (South India)



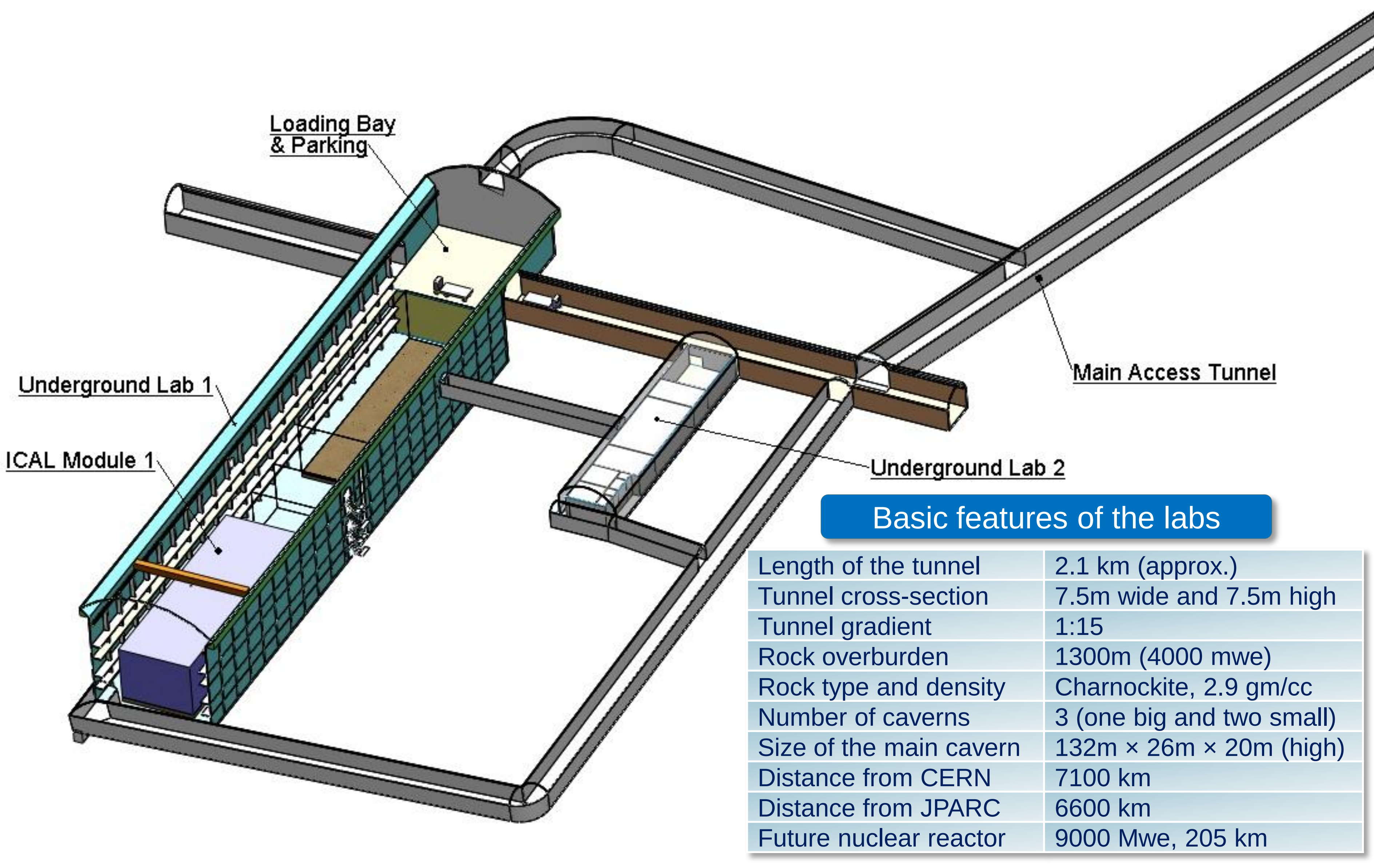


Layout of the surface lab utilities



- Laboratories, detector assembly, facilities and administration
- Offices and staff residences
- Storage of detectors and iron plates
- Muck storage area

Schematic of the underground labs



Basic features of the labs

Length of the tunnel	2.1 km (approx.)
Tunnel cross-section	7.5m wide and 7.5m high
Tunnel gradient	1:15
Rock overburden	1300m (4000 mwe)
Rock type and density	Charnockite, 2.9 gm/cc
Number of caverns	3 (one big and two small)
Size of the main cavern	132m × 26m × 20m (high)
Distance from CERN	7100 km
Distance from JPARC	6600 km
Future nuclear reactor	9000 Mwe, 205 km

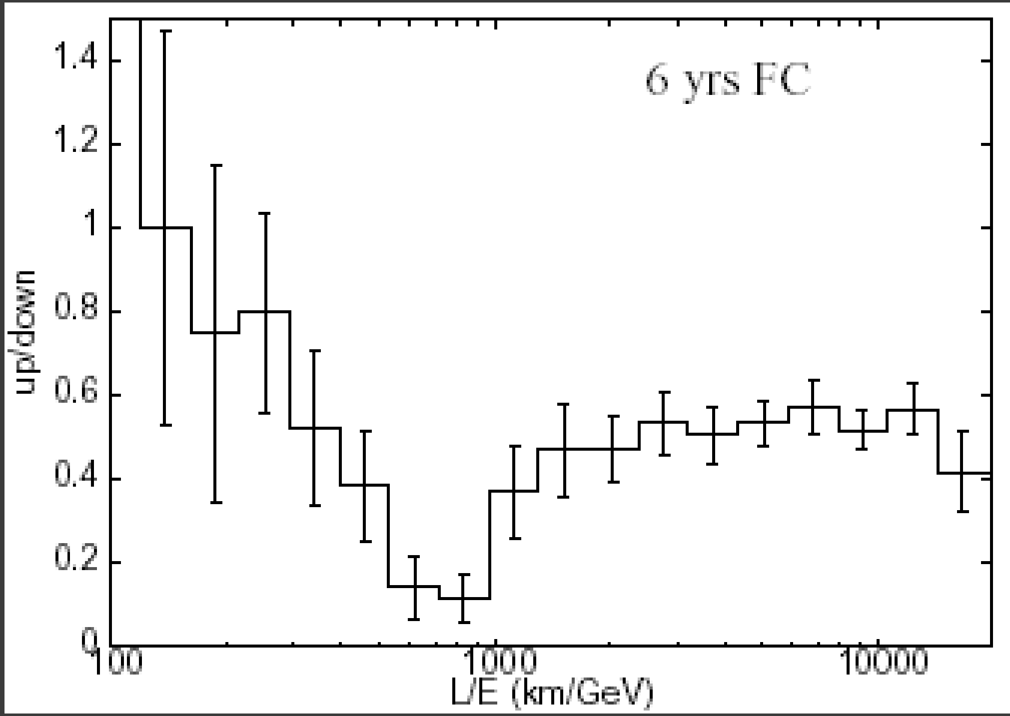
Main physics goals of ICAL

- Reconfirmation with greater statistical significance the first oscillation dip in *L*/*E* of the atmospheric neutrinos, and measure precisely $|\Delta_{32}| \approx |\Delta m^2_{atm}|$ and $\sin^2 2\theta_{23}$.
- Determine the sign of Δ_{32} and hence the neutrino mass hierarchy using matter effect.
- Measure the deviation of θ_{23} from maximality, and resolve the octant ambiguity.
- Distinguish $\nu_\mu \leftrightarrow \nu_\tau$ from $\nu_\mu \leftrightarrow \nu_s$ oscillation from muon-less events.
- Search for CPT violation.
- Best scenario if Daya Bay or D-CHOOZ or MINOS or T2K find sign of non-zero θ_{13} (Ref: Shoji Nagamiya's plenary talk today)

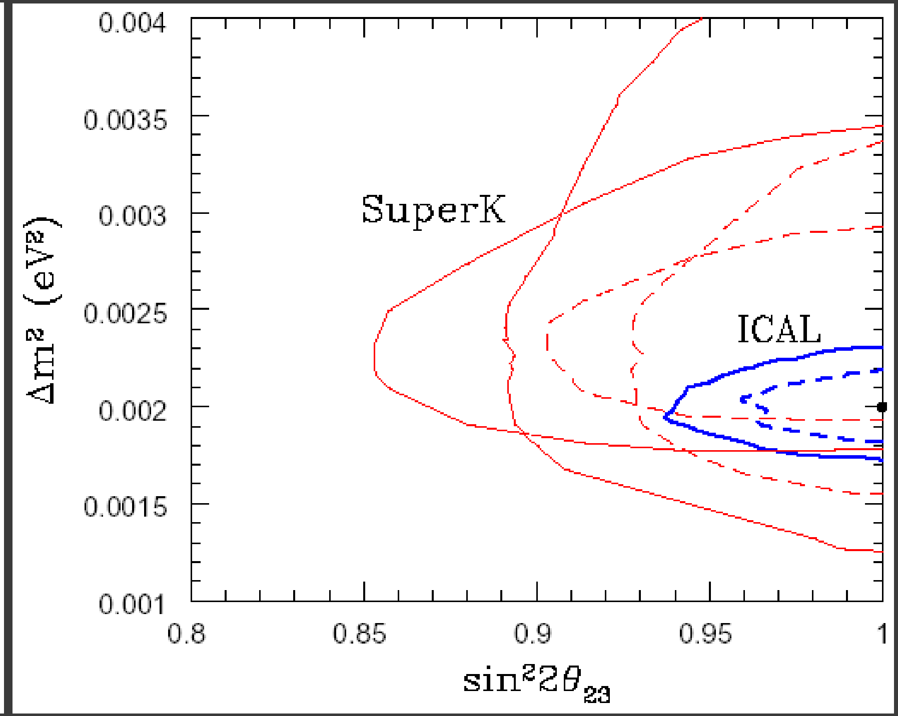
Physics possibilities with ICAL

- ICAL detector is expected to play a significant and pioneering role in the global experimental particle physics program over the next several decades.
- ICAL is capable of shedding light on the neutrino mass hierarchy, or the ordering of neutrino masses, due to its unique capability to identify lepton charge.
- Determining the hierarchy would be a crucial pointer to the physics that lies beyond the Standard Model.
- ICAL can significantly aid in improving the precision of the atmospheric mass squared difference and the associated mixing angle.
- Using effects primarily due to earth's matter, it can also shed light on the octant of the atmospheric mixing angle.
- ICAL's capability to set bounds on the violation of CPT has also been explored.
- Its sensitivity to new long range forces has been studied.
- ICAL is capable of substantially adding to our present knowledge of very high energy cosmic ray muons due to its unique capability to access hitherto unexplored energy regions in this sector.
- Several studies have also explored ICAL's capabilities as an end detector for a neutrino factory or a beta beam. This would allow precise measurements of very important parameters like the CP phase and the small mixing between two of the neutrino mass states.
- Extensive simulation studies are under progress to refine and sharpen the physics capabilities ICAL.

Using atmospheric neutrinos



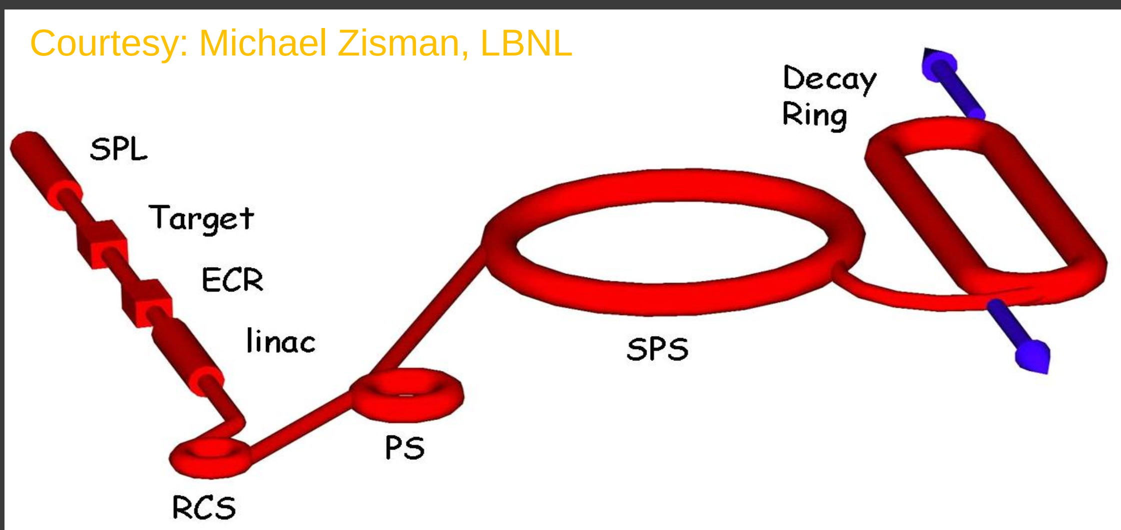
Up/down ratio of fully contained muon events as a function of *L/E* obtained from GEANT simulated data for an exposure of 6 years at INO.

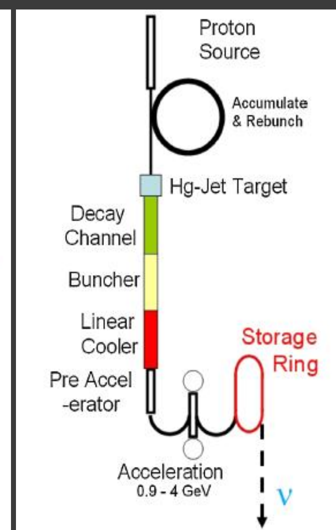


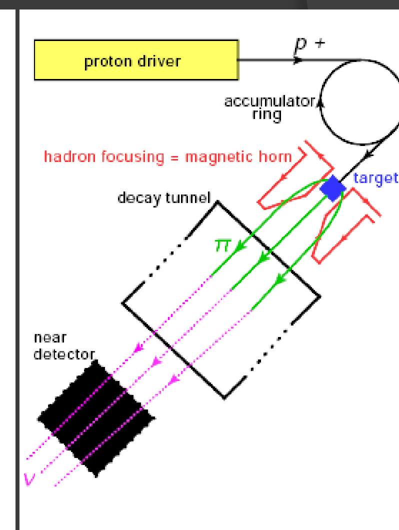
Exclusion plot of Δm^2 and $\sin^2 2\theta_{23}$ from ICAL and its comparison with the SK results

Accelerator-produced neutrinos

- Beta Beam facility is based on decays of a stored beam of beta-unstable ions. Produces low energy neutrinos.
- Neutrino Factory is based on the decays of a stored muon beam. Produces high energy neutrinos. Precursor to eventual Muon Collider.
- Superbeam facility is based on the decays of an intense pion beam.

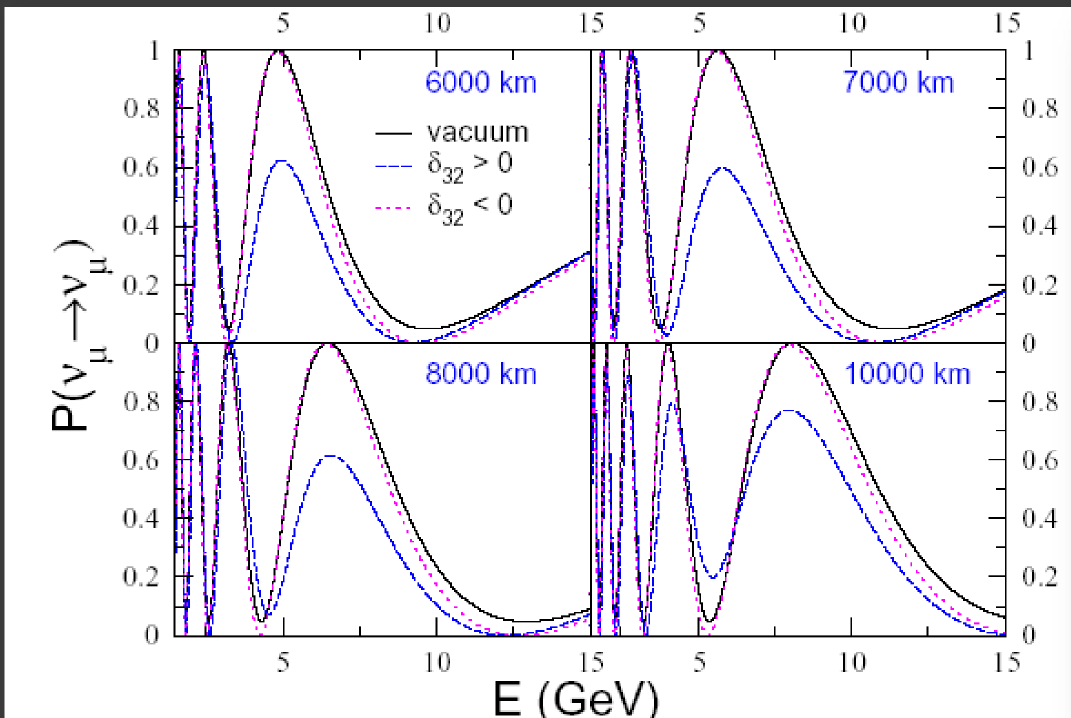




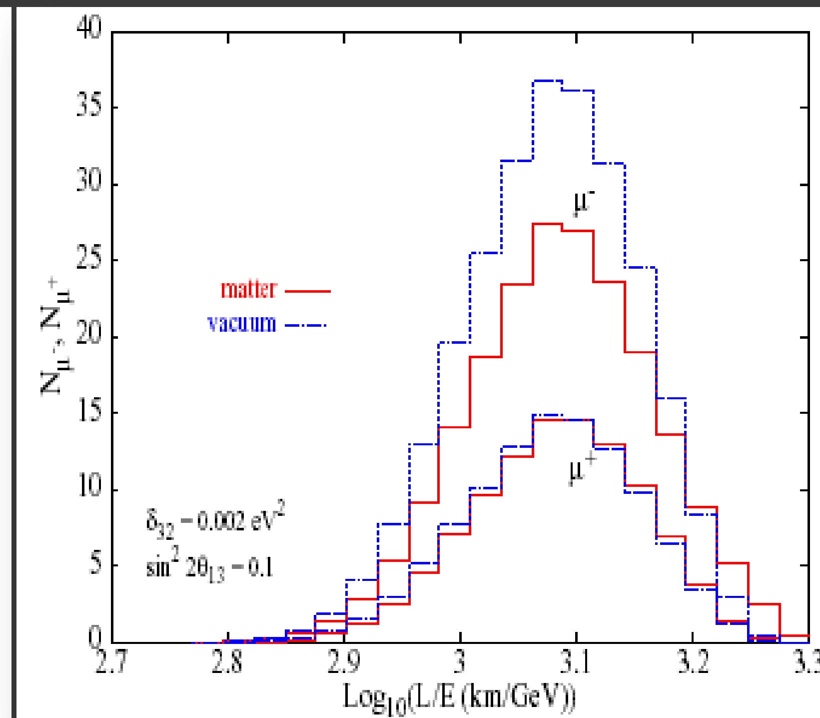


The 4th Plenary Meeting for International Design Study for a Neutrino Factory, October 12-14, 2009
12th International Workshop on Neutrino Factories, Super beams and Beta Beams, October 20-25, 2010
Tata Institute of Fundamental Research, Mumbai, INDIA

Using long-baseline neutrinos



The muon neutrino survival probability in vacuum and in matter for both signs of Δ_{23} plotted against the neutrino energy for different values of baseline lengths

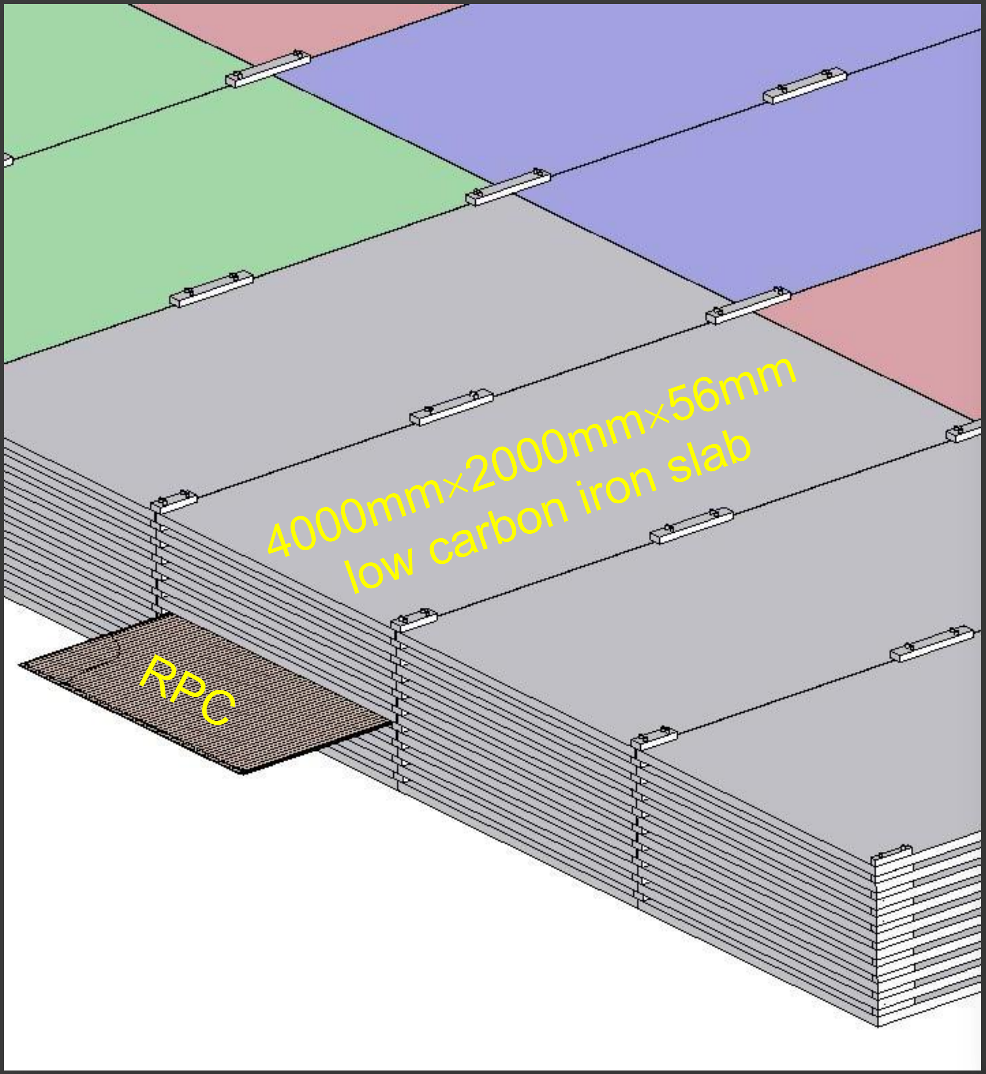


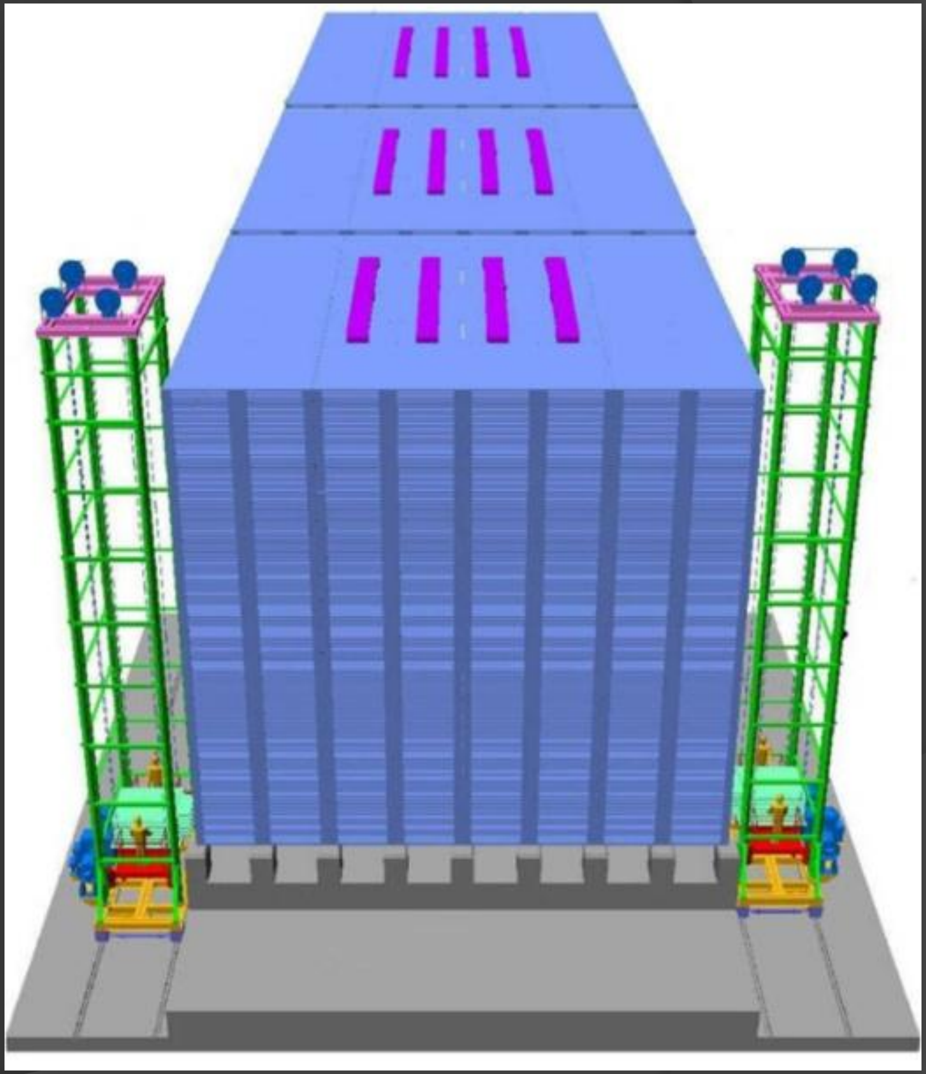
$\mu^{\pm}$ event rates for the normal mass hierarchy and an exposure of 1000 kton year for a restricted choice of *L* and *E* range

The choice of detector: ICAL

- Use (magnetised) iron as target mass and RPCs as active detector elements.
- Atmospheric neutrinos have large *L* and *E* range. So ICAL has large target mass: 50kton in its current design.
- Nearly 4π coverage in solid angle (except near horizontal).
- Upto 20 GeV muons contained in fiducial volume; most interesting region for observing matter effects in 2–3 sector is 5–15 GeV.
- Good tracking and energy resolution.
- ns time resolution for up/down discrimination; good directionality.
- Good charge resolution; magnetic field $\sim$1.5 Tesla.
- Ease of construction (modular; 3 modules of 17 kTons each).
- Note: ICAL is sensitive to muons only, very little sensitivity to electrons; Electrons leave few traces (radiation length 1.8 (11) cm in iron (glass)).

Assembly of ICAL detector

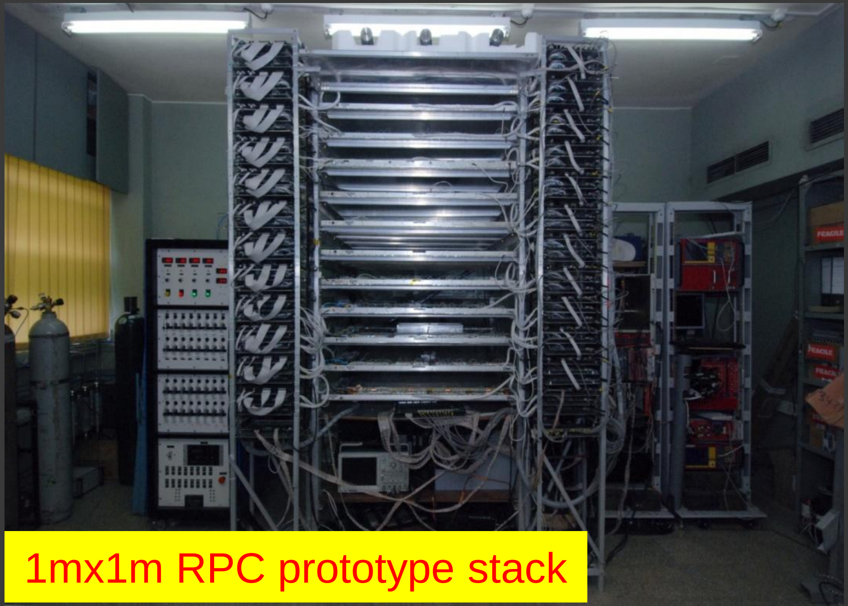




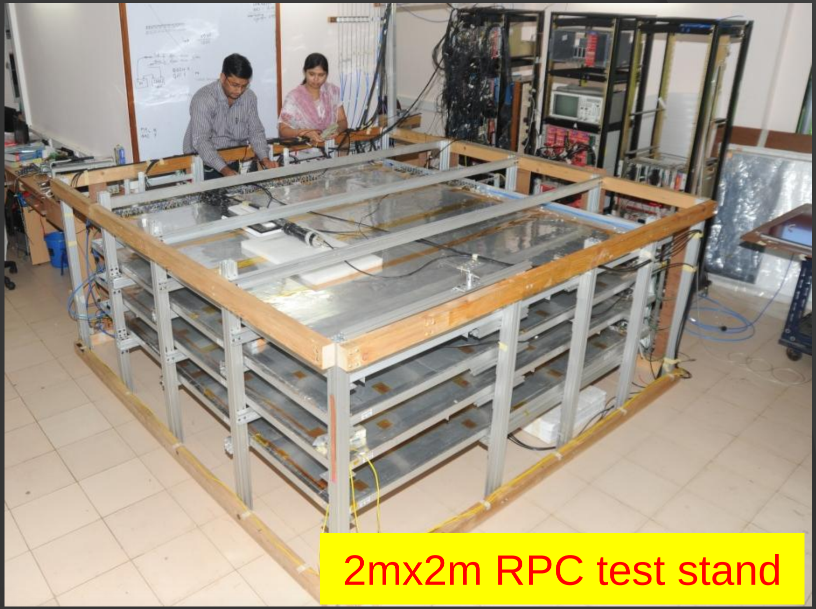
Factsheet of ICAL detector

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	1.3Tesla
RPC dimensions	1,840mm × 1,840mm × 24mm
Readout strip pitch	30mm
No. of RPCs/Road/Layer	8
No. of Roads/Layer/Module	8
No. of RPC units/Layer	192
No. of RPC units	28,800 (97,505m^2)
No. of readout strips	3,686,400

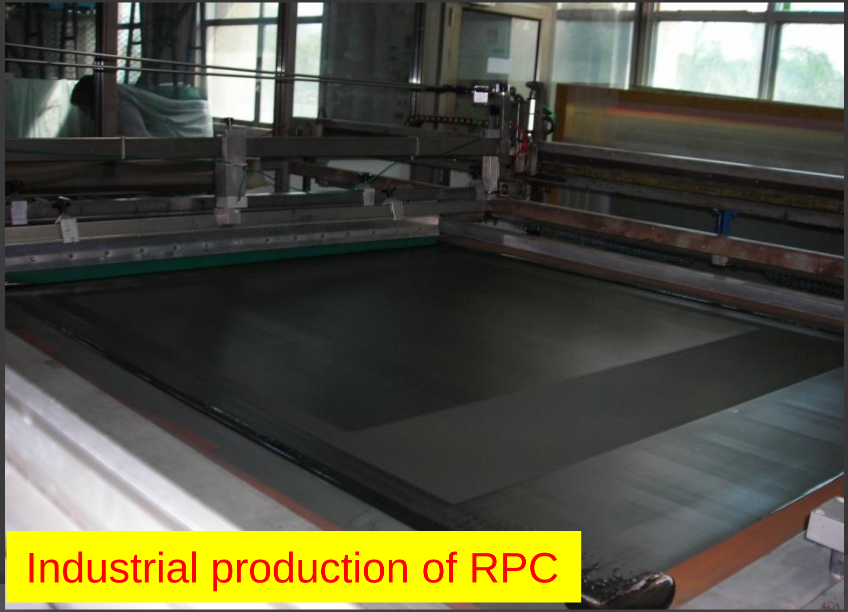
Prototyping of ICAL detector



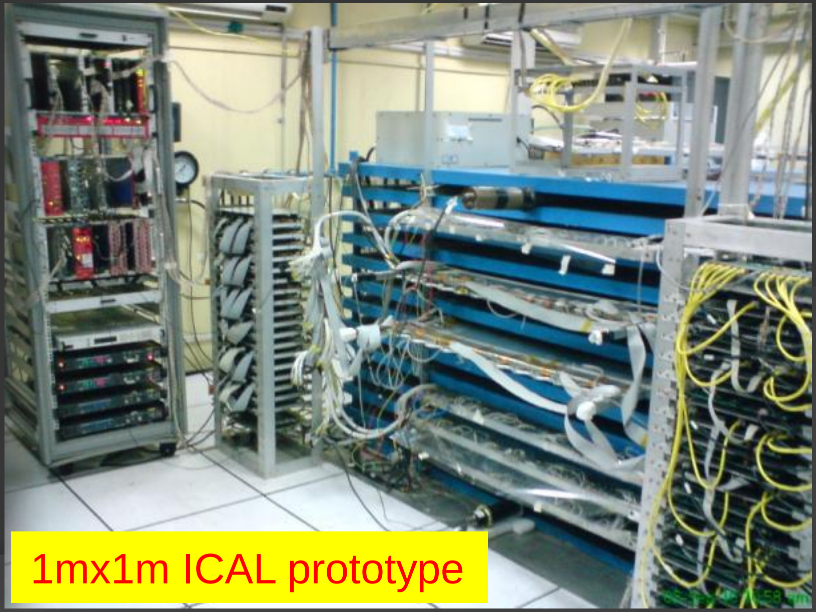
1mx1m RPC prototype stack



2mx2m RPC test stand

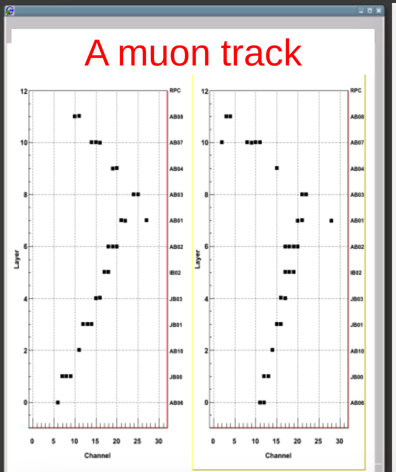


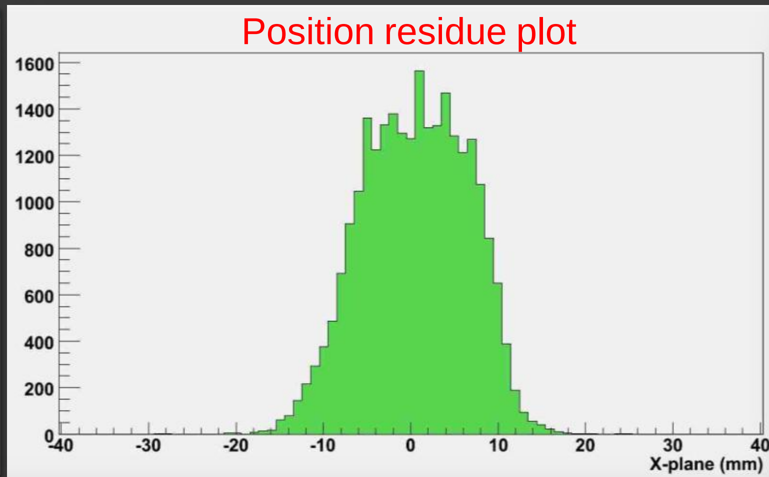
Industrial production of RPC

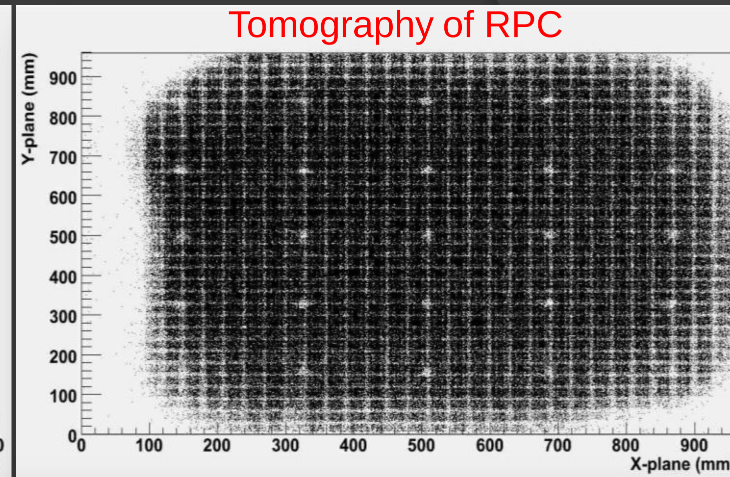


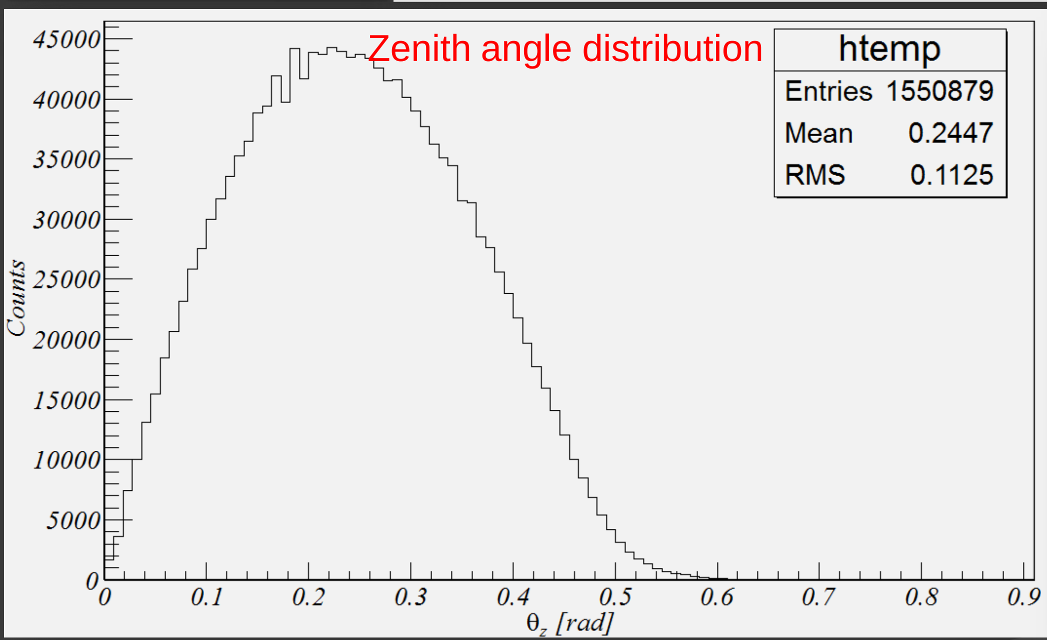
1mx1m ICAL prototype

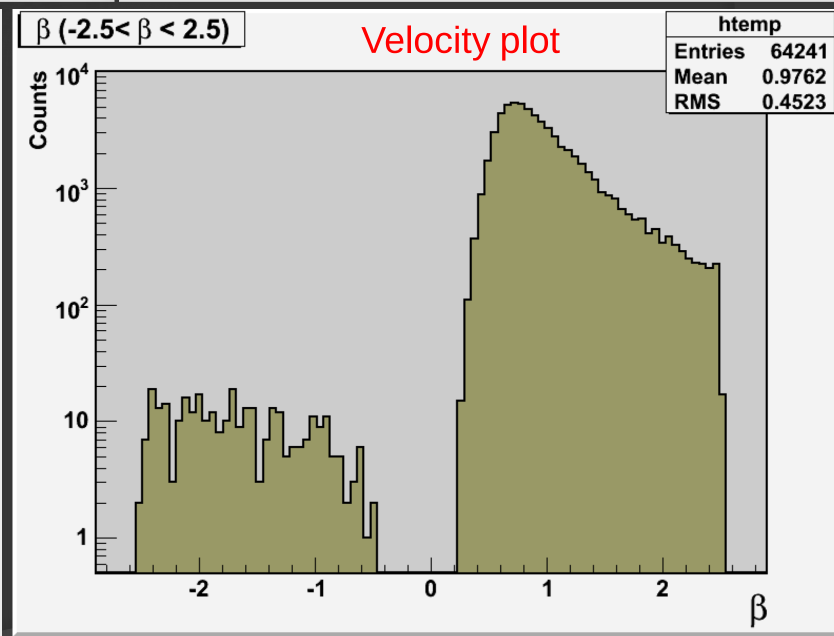
A few results from prototype stack











Numerical simulations and studies

- Neutrino interaction with ICAL material (predominantly iron) produces particles, which give signals in the RPCs placed inside the iron stacks. We need to find the energy and the direction of the incident neutrino from these signals.
- The simulation program for ICAL consists of the following four steps:
- GEN: Generation of neutrino events in the ICAL detector. We are using NUANCE event generator.
- SIM: All particles produced in a given neutrino event pass through the ICAL detector material, interact and lose energy through matter-particle interactions. We use GEANT4-toolkit.
- DIGI: Extract digitised signals for the aforesaid interactions, which could mimic the real detector signals. Proper detector noise, their inefficiencies, RPC strip multiplicities has been included in the software.
- RECO: Reconstruct neutrino four momenta from those digitized signals.
- Momentum resolution of fully confined charged track is ~6%, which is based on the measurement of path-length.
- Preliminary study shows that using reconstruction algorithm, one can identify the up-down ambiguity of a charge track.

Main physics goals of NDBD

- The mass and nature of neutrinos play an important role in theories beyond the Standard Model.
- The nuclear β decay and double beta decay can provide the information on absolute effective mass of the neutrinos.
- At present, neutrino-less double beta decay is perhaps the only experiment that can tell us whether the neutrino is a Dirac or a Majorana particle.
- Determining type of mass hierarchy (normal, inverted or quasi-degenerated).
- Probing CP violation in the leptonic sector.

The choice of detector: NDBD

- Crucial criterion for NDBD detector design is high energy resolution for a precision measurement of the sum energy of two electrons emitted in $0\nu\beta\beta$ decay.
- Low temperature bolometric detectors are ideally suited for this purpose.
- Active source experiments – where source itself serves as a detector, with candidates having large isotopic abundance are preferred.
- The low specific heat enables use of Sn (Q = 2.28 MeV, 5.8% abundance) as a bolometric detector; tin becomes superconducting below 3.7 K.
- Decay rate is proportional Q^5 and the interference from natural radioactive background is less at higher energies.
- In this experiment, the expected events are rare since the half-life for the decay is $\geq 10^{25}$ years.
- Further, in case of NDBD detector , we need to optimize the detector module size and layout for separating α, β and γ.

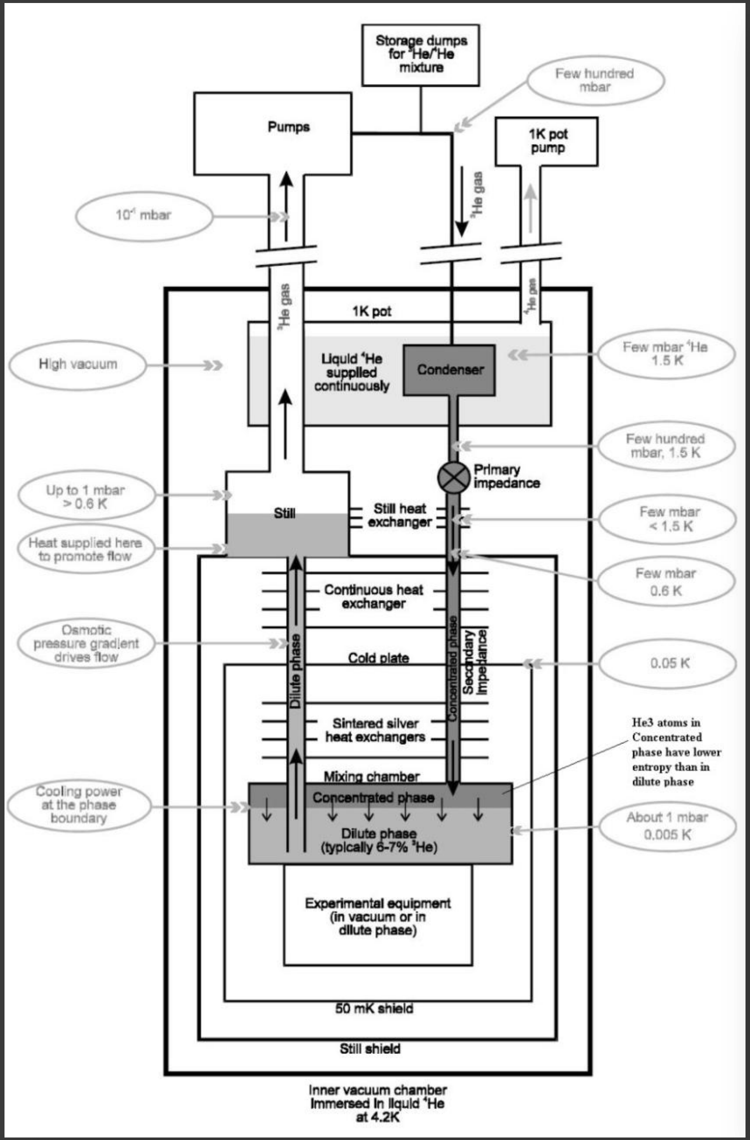
Factsheet of NDBD detector

- Assuming ~0.5% energy resolution with a background of ~0.2 cts/kev/yr, a detector of ~1 ton is being planned to achieve a sensitivity of m_{ν} ~200 MeV in 1 year of observation time.
- We envisage three labs for NDBD studies at the INO site.
- The main lab of about 5m × 5m × 7m in dimensions, will house the cryostat (~1m in diameter, 2m in height) .
- The cryostat can be mounted inside a 3m wide × 5m long × 2m deep pit.
- The second lab of 5m × 5m in area at the INO portal will house Helium liquefier, helium recovery, storage dewars etc.
- The third is an underground material processing laboratory of about 10m × 10m in area. This is essential to minimize the contamination due to n-induced reactions in the detector.

Prototyping NDBD detector

- Proposal to build a prototype bolometric detector of natural Sn of mass 0.5-1 Kg.
- Enrichment of ^{124}Sn using laser based isotope separation technique.
- $^{3}He-^{4}He$ dilution refrigerator with a cooling power of 20 μW at 30 mK is used; a test bench for qualifying mK thermometry.
- The lower is the detector temperature, higher is the temperature rise yielding a better signal to noise ratio.
- Commonly used low temperature sensors have large resistance at low temperature ≥ 10 KΩ.
- The superconducting transition edge sensors are very attractive option due to low power consumption and tuneable temperature range. Four probe measurement used.
- Estimated sensitivity with 1 kg natural Sn detector for an observation time of 1 year is 6×10^{20} years.

Setup of prototype NDBD detector



Possible new proposals at INO

- The INO facility will develop into a centre for other studies in physics, biology, geology, etc., which will exploit the special conditions existent deep underground.
- Low energy accelerator for experimental nuclear astrophysics studies; utilising the low back-ground environment inside the INO facility.

National Centre for HEP (NCHEP)

- To be setup in Madurai, close to the INO facility.
- Human resource development in basic experimental science research.
- Responsible for operation of the INO facilities.
- Will develop full-fledged manpower to operate and maintain the INO laboratory.
- Development of detector technology and its varied applications, such as in medical imaging, material science, industrial control and geological survey.

Summary and outlook

- ❖ Rich history of underground physics
- ❖ Expertise in building large scale experiments
- ❖ Skilled man power to build detectors, instrumentation and electronics
- ❖ INO is a mega science project conceived on an unprecedented scale in India
- ❖ Site approved, environment and forest clearance obtained, project approved by central government
- ❖ Construction work expected to start by April 2011
- ❖ ICAL physics data taking from 2017
- ❖ Will host many more experiments in future