Evolution of the INO

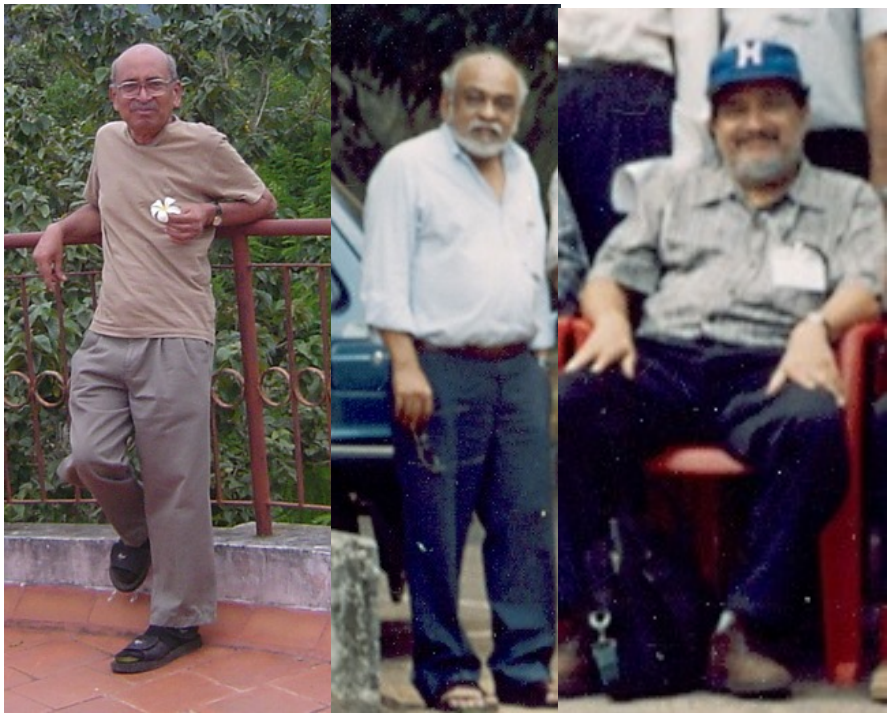
Mundur V N Murthy

Dedicated to the memory of

C V K Baba

R S Raghavan

Sandip Pakvasa



The “We” in this presentation refers to all the members of the INO collaboration

Every member has contributed in multiple ways to INO which is still evolving:

Doing phenomenology, simulations, designing the components of detectors
Participating in the civil, structural and electrical engineering aspects
Surveying for the appropriate site walking through many difficult terrains
Talking to the people, students, activists, officials and politicians
Presenting the project to multiple agencies involved in giving permissions
…….

Multi-tasking is assumed and most members are contributing to more than just one or two activities

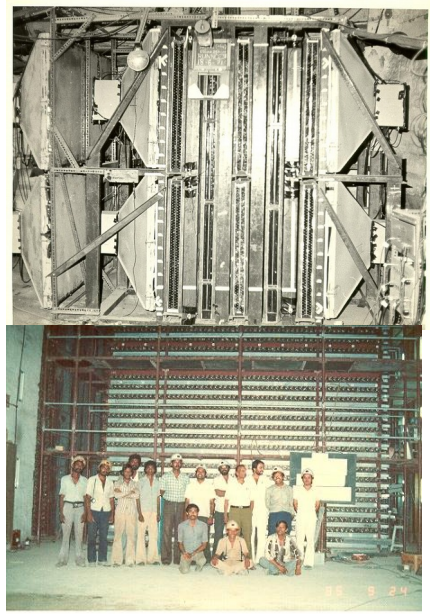
Many members continue to actively contribute well after their formal association With INO-project has ended

Pre-history: KGF Underground Laboratory

1960- Experiments measuring cosmic muon intensity up to a depth of 3000m
1965- Detection of atmospheric neutrino event for the first time
1970-80s- Consolidation of neutrino event data using large scale proton decay detectors,
1970-80s- Observation of anomalous events- unexplained! Could it be due to Dark Matter?

One of the leading underground laboratories in the world at the time.

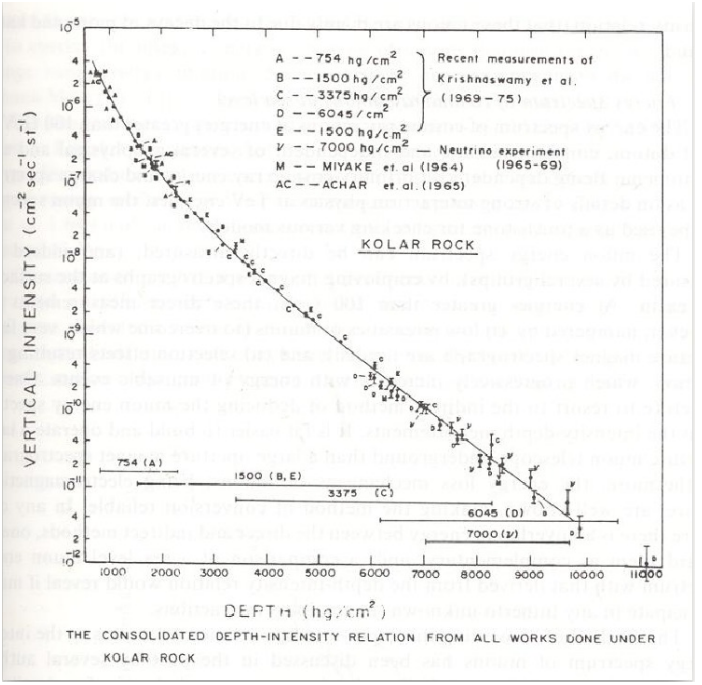
Unfortunate closure by the 90s! Could have been converted to a National Underground Facility- a missed opportunity!



Some Results from KGF

Depth from surface in meters	Depth from the top of the atmosphere (mwe)	Time of observation: Hrs. Mins.	Number of counts observed	Counting rate in counts/hr
270	810	60 - 20	10,152	168.3 ± 1.7
800	1812	100 - 28	1,029	10.23 ± 0.32
1130	3410	211 - 45	142	0.67 ± 0.056
1415	4280	944 - 06	127	0.132 ± 0.012
2110	6380	2992 - 40	18	$(6.0 \pm 1.4) \times 10^{-3}$
2760	8400	2880 - 00	none	$< 3.47 \times 10^{-3}$

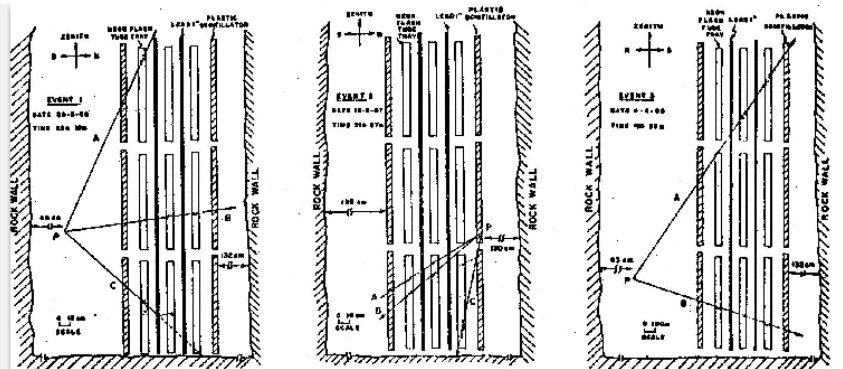
Table 1: Summary of muon measurements by MNR experiment in KGF mines.



THE CONSOLIDATED DEPTH-INTENSITY RELATION FROM ALL WORKS DONE UNDER KOLAR ROCK

Experiment	Live Time (Years)	No. of ν-induced muons	Background (atm. muons)
Phase I	8.41	139 ($55° - 125°$)	11.3
Phase II	5.53	182 ($60° - 120°$)	17.8
Total		321	29.1 ± 2.3

Table 3: Details of KGF data on neutrinos during 1980–90. The number of neutrino-induced muons includes includes up-going muons while the background is mostly from the first bin after the cut-off angle.



Outline of the Talk

- INO- Physics ideas and goals
- IICHEP- building a collaboration and human resources training and generation
- Site for underground observatory

WHEPP-2000 in Chennai

- Creation of an underground
- lab for experiments in Physics and Science in general
- Neutrino Physics in Particular taking advantage of its geographical position

Discussion on a possible neutrino detector located in India

Coordinators : M. V. N. MURTHY[1] and U. A. YAJNIK[7]

Participants and contributing authors: K.R.S. Balaji (1), G. Bhattacharyya (2), Amol Dighe (3), Shashikant Dugad (4), N.D. Hari Dass (1), P.K. Kabir (5), Kamales Kar (2), D. Indumathi (1), John G. Learned (6), Debasish Majumdar (2), N.K. Mondal (4), M.V.N. Murthy (1), S.N. Nayak (7), Sandip Pakvasa (6), Amitava Raychaudhuri (8), R.S. Raghavan (9), G. Rajasekaran (1), R. Ramachandran (1), Alak K. Ray (4), Asim K. Ray (10), Saurabh Rindani (11), H.S. Sharatchandra (1), Rahul Sinha (1), Nita Sinha (1), S. Umasankar (7), Urjit A. Yajnik (7)

(1) IMSc, Chennai (2) SINP, Calcutta (3) CERN, Geneva (4) TIFR, Mumbai (5) U. Virginia, Charlottesville (6) U. Hawaii, Honolulu (7) IIT Bombay, Mumbai (8) U. Calcutta, Calcutta (9) Bell Labs, Lucent Tech, Murray Hill (10) Viswa Bharati, Santiniketan (11) PRL, Ahmedabad

Abstract. We have identified some important and worthwhile physics opportunitites with a possible neutrino detector located in India. Particular emphasis is placed on the geographical advantage with a stress on the complimentary aspects with respect to other neutrino detectors already in operation.

Many Ideas

- Mega-Water Cerenkov detector (MWCD)
- Neutron detector embedded in rocks underground for detecting Supernova Neutrinos
- Space based Neutrino detector in an elliptic orbit to measure neutrino flux as a function of distance from the Sun- unique method to understand neutrino oscillations
- Basic goal was to have many experiments, even beyond physics in an underground location providing special background free environment.
- Possible Heavy Water Detector (similar to SNO) was also discussed little later.

Tentatively named India-based Neutrino Observatory (INO) until a location is found and an appropriate name is adopted. However, INO became a kind of brand name.

September 2000- N K Mondal agrees to lead the effort

January 28 2001-Letter from N K Mondal and G Rajasekaran

"On the Neutrino Detector initiative". Sent to all leading scientists in India as well as to the secretaries of DAE and DST, directors of Institutes seeking their support. Few respond positively, generally muted response initially.

February 21 2001- Symposium in honour of Rajaji becomes the First INO “collaboration” meeting

By summer 2001, Magnetised Iron Calorimeter (ICAL) becomes the main Detector-compact with RPC’s as the active detector elements, R&D begins in right ernest.

First report in 2002-January.

Jan 2002, Interim Report

INTERIM REPORT

On The Feasibility Study for

AN INDIA-BASED NEUTRINO OBSERVATORY (INO)

The Indian Neutrino Consortium[1]

B.S. Acharya[1], C.V.K. Baba[2], Sudeshna Banerjee[1], P.N. Bhat[1], Pratap Bhattacharya[3], Sudeb Bhattacharya[3], Subhasish Chattopadhyay[4], Sukalyan Chattopadhyay[3], V.M. Datar[5], Anindya Datta[6], S.R. Dugad[1], Raj Gandhi[6], P. Ghosh[1], Asimananda Goswami[3], M.M. Gupta[11], S.K. Gupta[1], D. Indumathi[7], Kamales Kar[3], N. Krishnan[1], Naba K. Mondal[1] **(Spokesperson)**, G.S.N. Murthy[4], M.V.N. Murthy[7], Tapan Nayak[4], Biswajit Paul[1], A.K. Ray[1], Amitava Raychaudhuri[8], Amit Roy[2], Satyajit Saha[3], Manoj Sharan[3], S.D. Sharma[12]

Scientific Advisors:

Ramanath Cowsik[9], H.S. Mani[10], V.S. Narasimham[1], G. Rajasekaran[7], Bikash Sinha[3]

[1]Tata Institute of Fundamental Research, Mumbai, India
[2]Nuclear Science Centre, New Delhi, India
[3]Saha Institute of Nuclear Physics, Kolkata, India
[4]Variable Energy Cyclotron Centre, Kolkata, India
[5]Bhabha Atomic Research Centre, Mumbai, India
[6]Harishchandra Research Institute, Allahabad, India
[7]The Institute of Mathematical Sciences, Chennai, India
[8]Dept. of Physics, University of Calcutta, Kolkata, India
[9]Indian Institute of Astrophysics, Bangalore, India
[10]S.N. Bose Centre for Basic Sciences, Kolkata, India
[11]Panjab University, Chandigarh, India
[12]Himachal Pradesh University, Shimla, India

Contents

Ical flagship detector

Transparent operation

2001-02-INO website started operating in IMSc, later moved to TIFR. All reports Were made public from the very beginning. A first for any project in India at the time

Important Events:

26-27 March 2002- INO collaboration meeting in TIFR with DAE Chairperson And DST representative present.

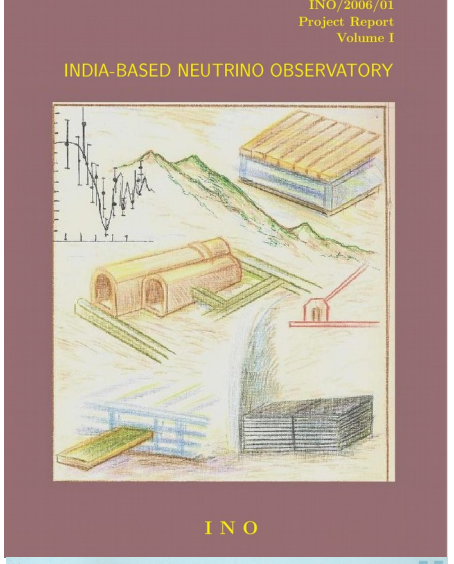
30 August 2002- MOU signed for the formation of INO collaboration and its Program management committee

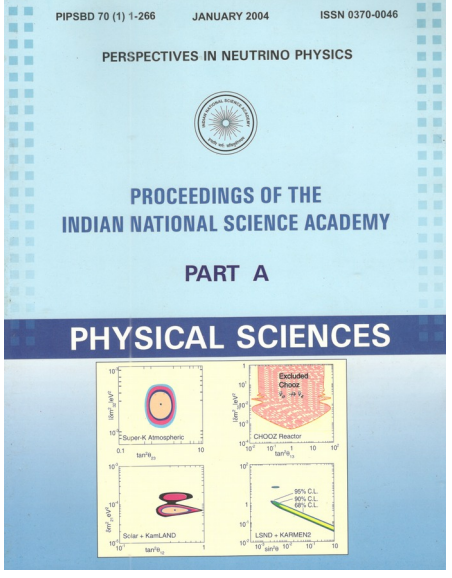
Dec 2002- After meeting with Dave Casper at NUINT-2 Irvine, ICAL detector simulations begin with NUANCE neutrino Generator and GEANT

2002- Meeting to pursue neutrino less double beta decay NDBD – an NDBD Group is formed

2004- INSA came forward to publish perspectives on neutrino Physics with emphasis on INO related activities

2005-2006 The first definitive report on ICAL and other activities at INO was released and submitted to various agencies.





The ICAL @ INO Collaboration in2006: Nearly 100 people in 30 Institutions

The INO Collaboration[1]

- **Aligarh Muslim University, Aligarh:**
  M. Sajjad Athar, Rashid Hasan, S. K. Singh
- **Banaras Hindu University, Varanasi:**
  B. K. Singh, C. P. Singh, V. Singh
- **Bhabha Atomic Research Centre (BARC), Mumbai:**
  V. Arumugam, Anita Behere, M. S. Bhatia, V. B. Chandratre, R. K. Choudhury, V. M. Datar, M. P. Diwakar, M. G. Ghodgaonkar, A. K. Mohanty, A. W. Matkar, P. K. Mukhopadhyay, S. C. Ojha[2], L. M. Pant, K. Srinivas
- **Calcutta University (CU), Kolkata:**
  Amitava Raychaudhuri
- **Delhi University (DU), Delhi:**
  Brajesh Choudhary, Debajyoti Choudhury, Sukanta Dutta, Ashok Goyal, Kirti Ranjan
- **Harish Chandra Research Institute (HRI), Allahabad:**
  Sanjib K. Agarwalla, Sandhya Choubey, Anindya Datta, Raj Gandhi, Pomita Ghoshal, Srubabati Goswami, Poonam Mehta, Sukanta Panda, S. Rakshit, Amitava Raychaudhuri
- **University of Hawaii (UHW), Hawaii:**
  Sandip Pakvasa
- **Himachal Pradesh University (HPU), Shimla:**
  S. D. Sharma
- **Indian Institute of Technology, Bombay (IITB), Mumbai:**
  Basanta Nandi, S. Uma Sankar, Raghav Varma
- **Indira Gandhi Center for Atomic Research, Kalpakkam:**
  J. Jayapandian, C. S. Sundar
- **The Institute of Mathematical Sciences (IMSc), Chennai:**
  D. Indumathi, H. S. Mani, M. V. N. Murthy, G. Rajasekaran, Nita Sinha, D. V. Ramakrishna [3]
- **Institute of Physics (IOP), Bhubaneswar:**
  Pankaj Agrawal, D. P. Mahapatra, S. C. Phatak
- **North Bengal University (NBU), Siliguri:**
- **Panjab University (PU), Chandigarh:**
  Vipin Bhatnagar, M. M. Gupta, J. B. Singh
- **Physical Research Laboratory (PRL), Ahmedabad:**
  A. S. Joshipura, Subhendra Mohanty, S. D. Rindani
- **Saha Institute of Nuclear Physics (SINP), Kolkata:**
  Sudeb Bhattacharya, Suvendu Bose, Sukalyan Chattopadhyay, Ambar Ghosal, Asimananda Goswami, Kamales Kar, Debasish Majumdar, Palash B. Pal, Satyajit Saha, Abhijit Samanta, Abhijit Sanyal, Sandip Sarkar, Swapan Sen, Manoj Sharan
- **Sikkim Manipal Institute of Technology, Sikkim:**
  G. C. Mishra
- **Tata Institute of Fundamental Research (TIFR), Mumbai:**
  B. S. Acharya, Sudeshna Banerjee, Sarika Bhide, Amol Dighe, S. R. Dugad, P. Ghosh, K. S. Gothe, S. K. Gupta, S. D. Kalmani, N. Krishnan, Naba K. Mondal, P. Nagaraj, B. K. Nagesh, Biswajit Paul, Shobha K. Rao, A. K. Ray, L. V. Reddy, B. Satyanarayana, S. Upadhya, Piyush Verma
- **Variable Energy Cyclotron Centre (VECC), Kolkata:**
  R. K. Bhandari, Subhasish Chattopadhyay, Premomay Ghosh, B. Mohanty, G. S. N. Murthy, Tapan Nayak, S. K. Pal, P. R. Sarma, R. N. Singaraju, Y. P. Viyogi

Scientific Steering Committee

C. V. K. Baba, *Nuclear Science Centre, New Delhi*
Ramanath Cowsik, *Indian Institute of Astrophysics, Bangalore*
H. S. Mani, *The Institute of Mathematical Sciences, Chennai*
V. S. Narasimham, *Tata Institute of Fundamental Research, Mumbai*
G. Rajasekaran, *The Institute of Mathematical Sciences, Chennai*
Amit Roy, *Nuclear Science Centre, New Delhi*
Probir Roy, *Tata Institute of Fundamental Research, Mumbai*
Bikash Sinha, *Saha Institute of Nuclear Physics, Variable Energy Cyclotron Centre, Kolkata*

INO Spokesperson

Naba K Mondal,
Tata Institute of Fundamental Research,
Homi Bhabha Road, Mumbai 400 005, India

ICAL Physics potential using atmospheric neutrinos and antineutrinos

2001- mapping the complete period of the oscillation curve – soon SK did it- However doing it separately for nu and nubar was still attractive (Totsuka).

2005- Mass hierarchy of neutrinos as the main goal – still it is

Precision measurement of atmospheric neutrino parameters

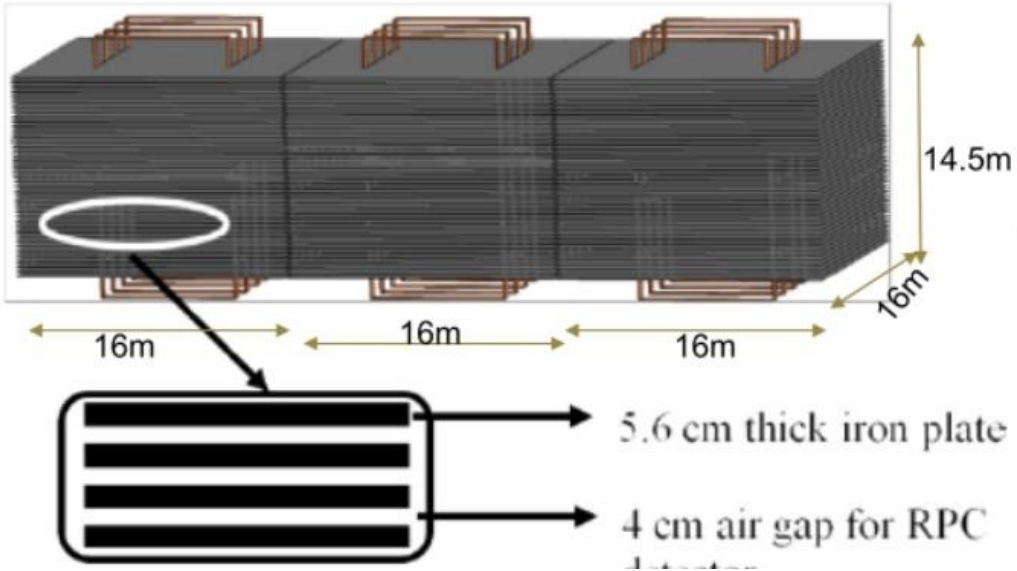
Non-maximal theta(23) – octant sensitivity

Synergy with other experiments: Better control when combined with Nova, T2K And other experiments to determine CP phase, octant, …

Exploring new physics: CPT Violation, Search for Magnetic Monopoles, Anomalous Kolar events -Search for Dark Matter …

There are bound to be unknowns and hence surprises.

ICAL Detector



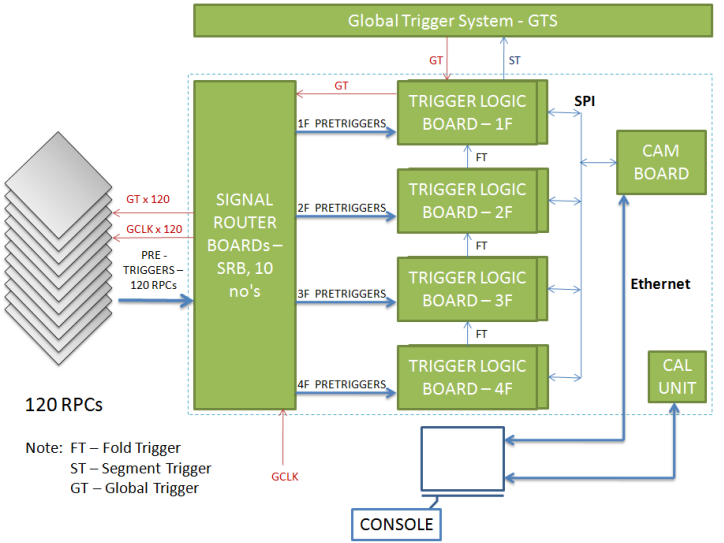
Excellent muon energy measurement, muon direction reconstruction and charge identification

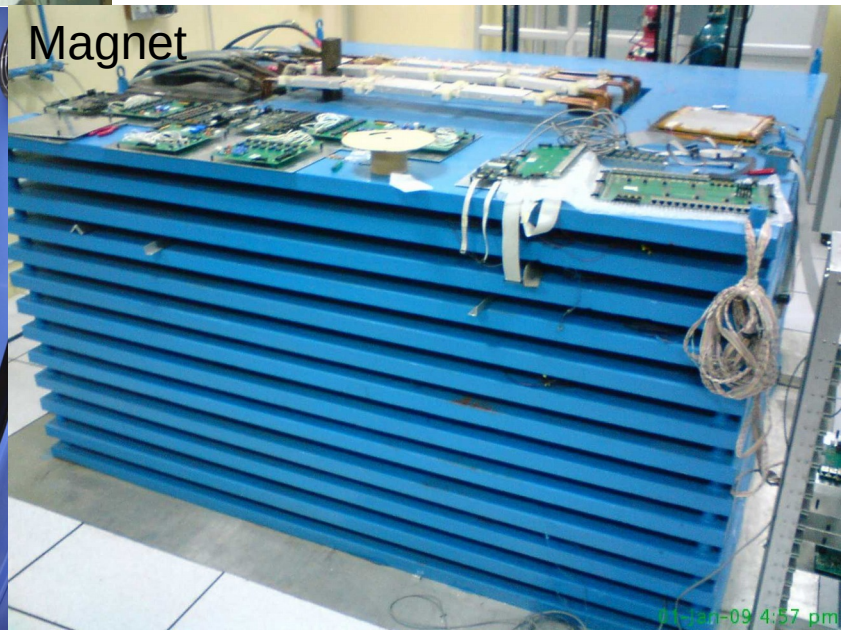
Hadron shower reconstruction allows access to neutrino energy and high energy cosmic rays

No. of Modules	3 (16 x16 x14.5 ms)
Detector dimension	48 x 16 x 14.5
No. of layers	151
Plate thickness	5.6cm
Gap between plates	4.0cm
Magnetic Field	1.5 Tesla

RPC unit dimension	2 x 2 m
Readout strip width	3cm
No. RPC / layer /mod	64
Total no of RPC units	30000
Electronic readouts	3.9 million

R&D in RPC, Gas system, electronics, magnet





Present Status

Pre-project activities started with an initial grant of around Rs. 80 crores

ICAL detector R&D complete – DPR for detector, DAQ systems ready
Gas system design finalised. Ready for Industrial production of all
Components of the detector.

Civil engineering DPR ready since 2010. Geotechnical studies completed

Construction of Engineering module to begin at the IICHEP in Madurai
To test all aspects of ICAL and logistics of operation.

Financial approval for the full project came in 2015 January

Delays due to various other, non-scientific, considerations.

R&D on Neutrinoless Double Beta Decay detector (NDBD) at INO

TIN.TIN Detector

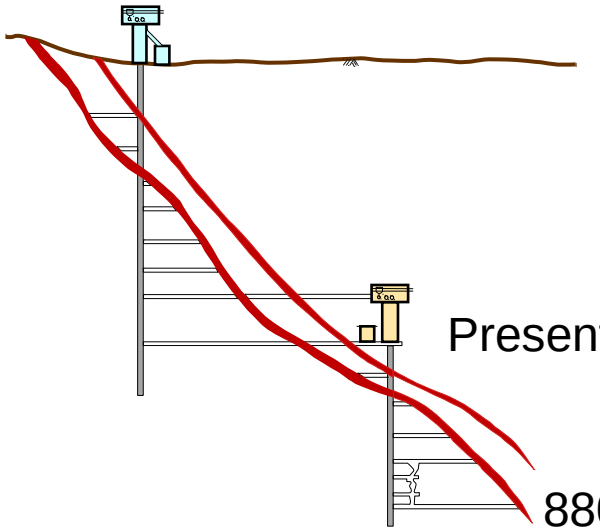
Nearly 25 people in 6 Institutions

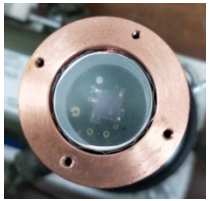
1. Tata Institute of Fundamental Research (TIFR), Mumbai, India
   - *V. Nanal, S.Ramakrishnan, V. M. Datar, R.Palit, S.Wategaonkar*
   - *Present Students / Post-docs : Dr. Ashif Reza, Dr. Rebecca Pachuau, Harisree Krishnamoorthy, Aparajita Mazumdar, Vishal Vatsa*
   - *Past Students / Post-docs : Dr. Abhijit Garai, Dr. Neha Dokania, Dr. S. Mathimalar, Dr. Vivek Singh, Dr. Yashwant Gowda*
2. Bhabha Atomic Research Centre (BARC), Mumbai, India
   - *A. Shrivastava, K.C.Jagadeesan, S.V.Thakare, K.G.Bhushan*
3. Indian Institute of Technology (IIT), Kharagpur and Ropar, India
   - *R. G. Pillay, P.K. Raina, Pushpendra Singh, Swati Thakur*
4. University of Lucknow, Lucknow, India
   - *P.K. Rath*
5. Variable Energy Cyclotron Centre (VECC), Kolkata, India
   - *Parnika Das*
6. Physical Research Laboratory (PRL), Ahmedabad, India
   - *V.K.B Kota*

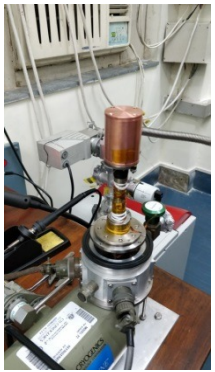
Feasibility study in progress for searching NDBD in Tin using Cryogenic bolometer.

The feasibility study for searching neutrinoless double beta decay in ^{124}Sn using cryogenic bolometer has been initiated. For this a custom-built cryogen-free dilution refrigerator, having a large cooling power of 1.4 mW at 120 mK, has been installed at TIFR, Mumbai, India.

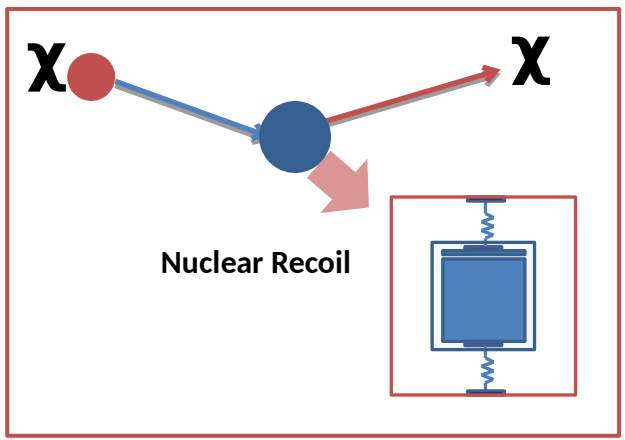
DINO at Jaduguda Underground Science Lab (JUSL)







Scintillator at Cryogenic temp at SINP



- Monitoring, understanding cosmic muons, gamma rays, radon level and neutron bg.
- R & D for setting up a direct dark matter search experiment (DINO*) using scintillators at millikelvin temperatures
- Detecting sub GeV WIMP by superheated liquid droplet detector (sub GeV WIMP
  Set up a medium size experiment (~ 20 kg) with scintillators at room temperature.
- High energy gamma rays from nuclear fission observed at low cosmic background.
- Simulation, theoretical estimates
- 4 papers published/archived/in prep, several conference presentations, 3PhD students working at JUSL at present.
- Lab at Jaduguda inaugurated in 2016.

Building a Collaboration

Human Resource Training and IICHEP

2001-2008 Many students were trained in collaborating institutions in areas such as phenomenology, simulations and detector hardware design and testing.

2008 Beginning of INO GTP program with 6 students- a well coordinated program which involves working on detector hardware, software as well as simulations and phenomenology. After a year of courses, the students are distributed in various collaborating institutions. In parallel students were recruited directly in collaborating Institutions too.

Recruitment of scientists/engineers through project mode.

Direct recruitment as faculty/scientists on a long-term basis is yet to happen – a serious draw-back.

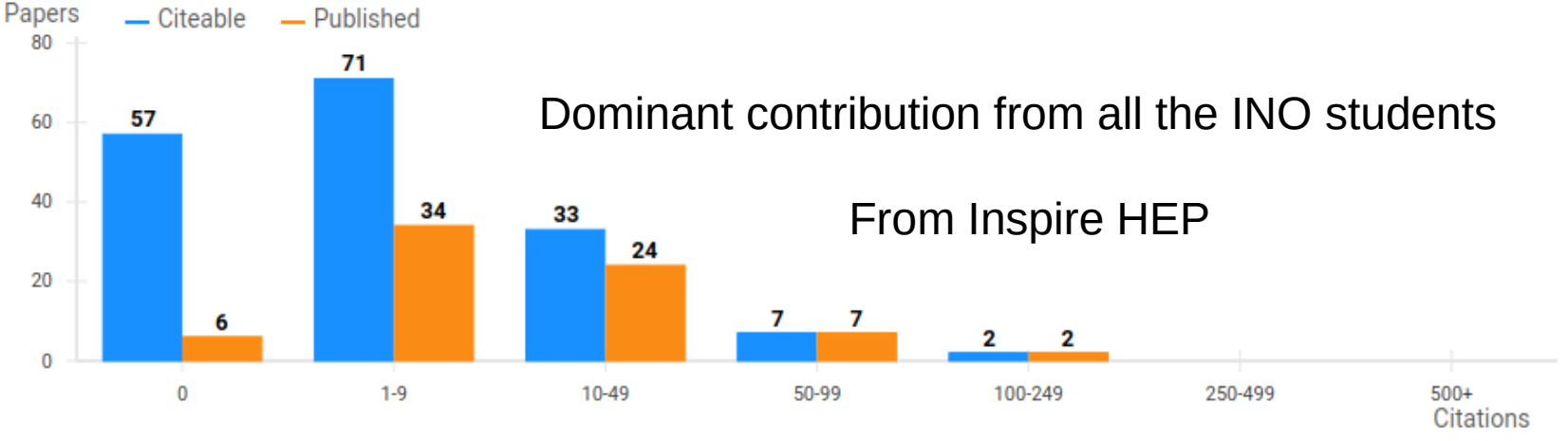
First batch of INO GTP students

Publication Statistics

Citation Summary

Exclude self-citations

	Citeable	Published
Papers	170	73
Citations	1,774	1,489
h-index	22	21
Citations/paper (avg)	10.4	20.4



Dominant contribution from all the INO students

From Inspire HEP

ICAL

192 publications

29 Ph.D thesis

100+ Authors

Tin.Tin (NDBD)

26 Publications (Refereed)

26 Conference Reports

5 Ph.D thesis

Inter-Institutional Centre for HEP

Conceived as a center for detector R&D for HEP, NP, Astrophysics in general
And INO in particular. There is no such dedicated experimental facility for HEP

IICHEP to be the place where many ideas may bloom, a place to incubate
Ideas, test them and pursue R&D if found exciting

A place where people from many institutions may come together to work on
Cutting edge detector technology.

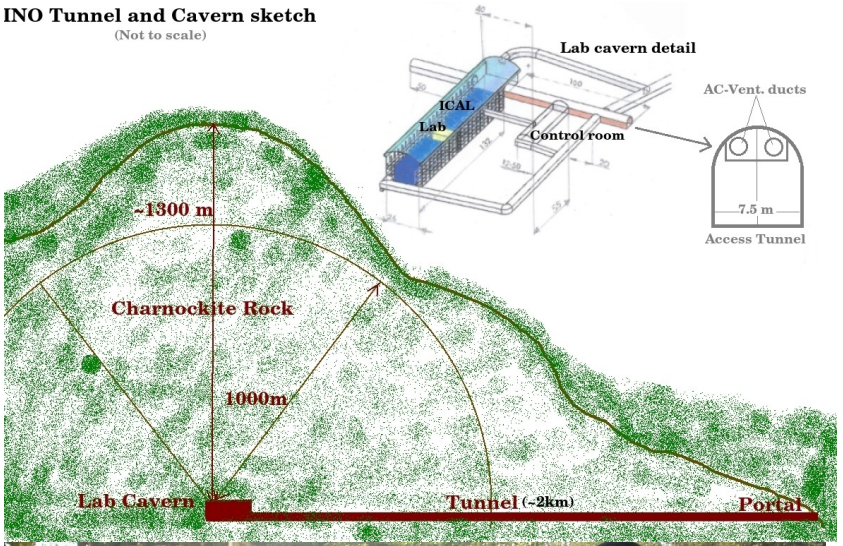
Presently working from a temporary building,
Moving soon to the new building on land
bought for the purpose, 1.5ha, in Madurai.

IICHEP mini-Ical @ Madurai

Training ground for students

Summer student, interns
Getting trained at IICHEP
Madurai

Locating a Site



Cover
Stability
Access
Infrastructure
Environment

Site for INO: Singara

2001- A visit to GSI in Chennai suggests the possibility of locating INO atSingara, northern slopes of Nilgiris- at PUSHEP project site. Nearly 13kms of tunnel already excavated.

2001-2003- Investigations complete offer of extending the project tunnel by another 800m to locate INO at a vertical depth of 900-1000m. Not considered.

Independent access with a 2km tunnel and lab at a vertical depth of 1300m below the peak proposed and studies completed.

2002-2005- Parallel site investigation at Rammam in Himalayas. Site selection committee recommends Singara considering the geology, access and Infrastructure.

2006-2007 – An Engineering Task Force along with TNEB prepares a detailed Project report. Voluntarily applied for environmental clearance.

Geologists of GSI
Engineers from DAE,
TNEB who helped
Throughout the site
Surveys

2008-The local people whole heartedly supported the project. The panchayat resolved to welcome INO project with some conditions.

Even though Environmental Clearance was granted, Forest clearance not given.

Many activists opposed the project on the ground that it is ecologically sensitive even though the Management plan prepared by a group of Environmental scientists declared that the project can go ahead by taking many precautionary measures.

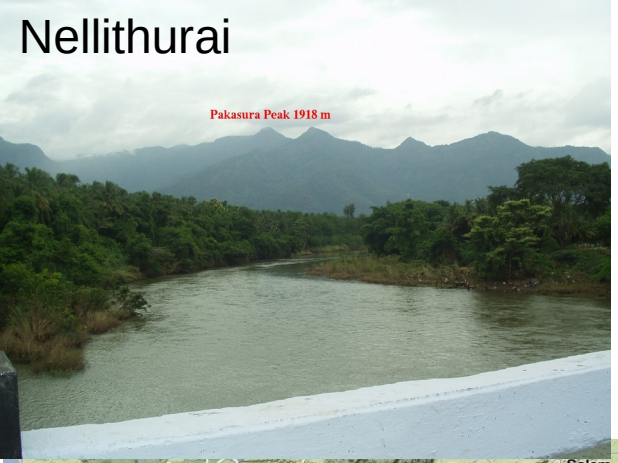
2008-The wild life sanctuary nearby was declared a Tiger reserve with a buffer zone.

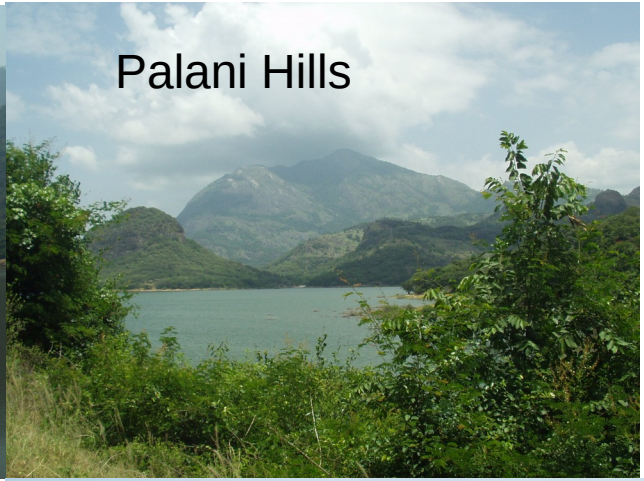
Even though INO site was clearly inside the PUSHEP project area not likely to affect the environment, the minister decided to revoke the clearance and asked us to find another suitable site.

> "I have interacted with scientists involved with the INO project and I have found them to be as mindful of environmental issues as the NGOs who are against the Project. However, I do think that, on balance, the decision must go against Singara" Minister of Environment and Forests, GOI, November 2009.

Back to square one!

Search for alternate sites begins! 2009-2011





Search ends with

INO @ Bodi West Hills

1.Forest clearance
2.Environment clearance
3.Land for surface facilities
4.Land for IICHEP in Madurai
5.Civil DPR report completed

Informal consent from local People through public Meeting
(not formally required)

Many outreach meeting to Convince the local people

Water supply completed
Fencing work completed in Bodi and Madurai.

Nov. 2009—June 2011: Period of Intense activity

Almost ready to go for construction by the end of 2011, but!



Many public outreach meetings at Pottipuram, Bodi, Theni and Madurai were held



But it was not to be!

Contributing factors: The delay in financial approval from 2012–2015

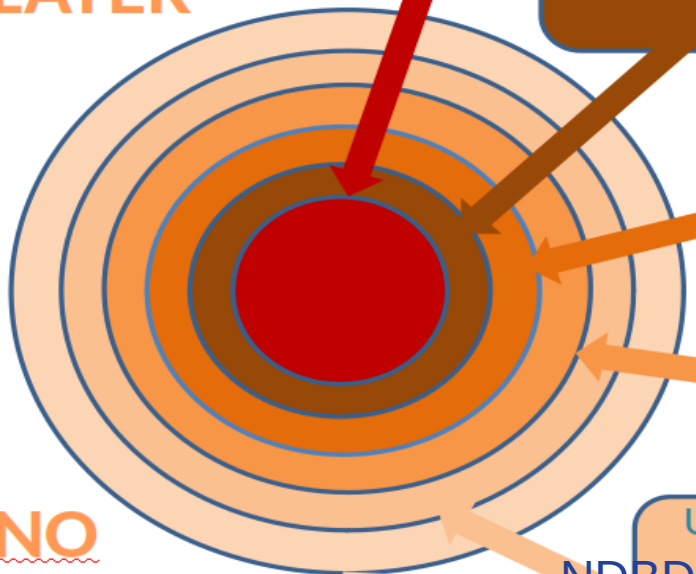
Beginnings of misinformed campaign since September 2012
--far more vicious than the campaign in Singara which was
Mainly related to Environmental issues.

Legal hurdles since 2015.

INO was conceived on a scale never contemplated for a science project in India before. Physics goals may change with time but the need to construct a deep underground laboratory for the flowering of many Ideas and Discoveries to be made remains.

This is some thing we owe to the future generation of students-- offer some thing exciting And concrete to dream of big things!

Concept of INO
In a nutshell



MULTI-LAYER

Determining neutrino mass ordering / Independent verification in neutrinos and antineutrinos / Detection of Earth matter effects

Measuring neutrino properties: Mixing parameters, Non-standard interactions, CPT violation, decay, decoherence, Sterile neutrinos, long range forces.
*Earth Tomography

Searching for physics beyond the Standard Model (beyond neutrinos): Magnetic monopoles, long-lived particles, dark matter annihilation

Act as a long-term detector looking for atmospheric and astrophysical phenomena: Searching for unknown,
*Multimessenger astronomy

ICAL @ INO

INO GOALS

Underground, radiation-free lab infrastructure useful for other experiments: High energy physics, Biology, Material Science, Geology.
*Readiness for future opportunities

NDBD
DINO...

A large scale international experiment running in India for development of Experimental physics human resource, Detector development expertise.
*Technology development, Education and training hub for students all over India

INO

Thank you


INO has found its Home!
The pursuit of science has often been compared to scaling of mountains...But who amongst us Can hope, even in imagination, to scale Everest and reach its summit when the sky is blue…But there is nothing mean or lowly in standing in the valley below and awaiting the sun to rise over Kanchenjunga."
S Chandrasekhar in Truth and Beauty: Aesthetics and motivtaions in Science.