Status of the India-based Neutrino Observatory

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(On behalf of the INO collaboration)

http://www.ino.tifr.res.in/ino/

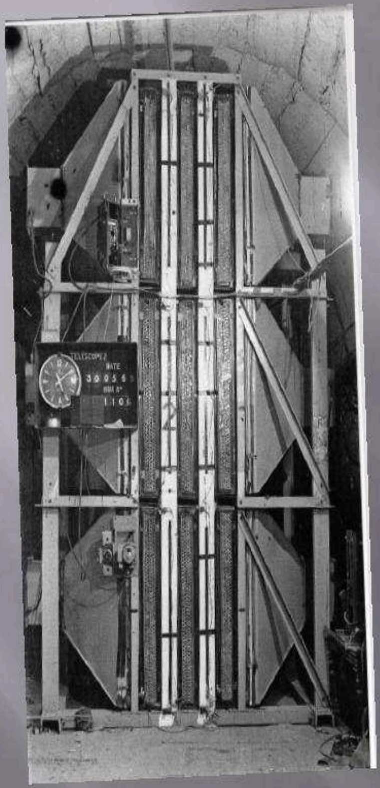
Dedicated to the memory of
Ramaswami (Raju) S. Raghavan
1937 - 2011

He was one of the first persons to encourage setting up INO and continued to take deep interest in the progress of the project

An Old Saga of Underground Laboratory in India

- *KGF: Deepest underground lab in world till 1992*
  > 6500 MWE
- *In 1965, at KGF at a depth of 2.3km, first atmospheric neutrino was observed by the TIFR-Osaka-Durham group*
- *During early 80s dedicated detectors were setup at KGF by TIFR-Osaka collaboration to look for proton decay*

Atmospheric neutrino detection in 1965



Atmospheric neutrino detector
at Kolar Gold Field -1965

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

Physics Letters 18, (1965) 196, dated 15th Aug 1965

EVIDENCE FOR HIGH-ENERGY COSMIC-RAY NEUTRINO INTERACTIONS*

F. Reines, M. F. Crouch, T. L. Jenkins, W. R. Kropp, H. S. Gurr, and G. R. Smith
Case Institute of Technology, Cleveland, Ohio

and

J. P. F. Sellschop and B. Meyer
University of the Witwatersrand, Johannesburg, Republic of South Africa
(Received 26 July 1965)

PRL 15, (1965), 429, dated 30th Aug. 1965

India Based Neutrino Observatory

- *A multi-institutional attempt to build a world-class underground facility to study fundamental issues in science with special emphasis being on neutrinos*
- *With ~1 km all-round rock cover accessed through a 2 km long tunnel. A large and several smaller caverns to pursue many experimental programs*
- *Complementary to ongoing efforts worldwide to explore neutrino properties*
- *A mega-science project (~250 M$) in India, jointly funded (50:50) by the Department of Atomic Energy and the Department of Science and Technology*
- *One of the largest basic science projects in India, involving nearly 100 scientists from 25 research institutes and Universities all over India*
- *INO facility is available for international community for setting up experiments like Neutrino-less Double Beta Decay, Dark Matter searches*

Recent Breakthroughs : Big News

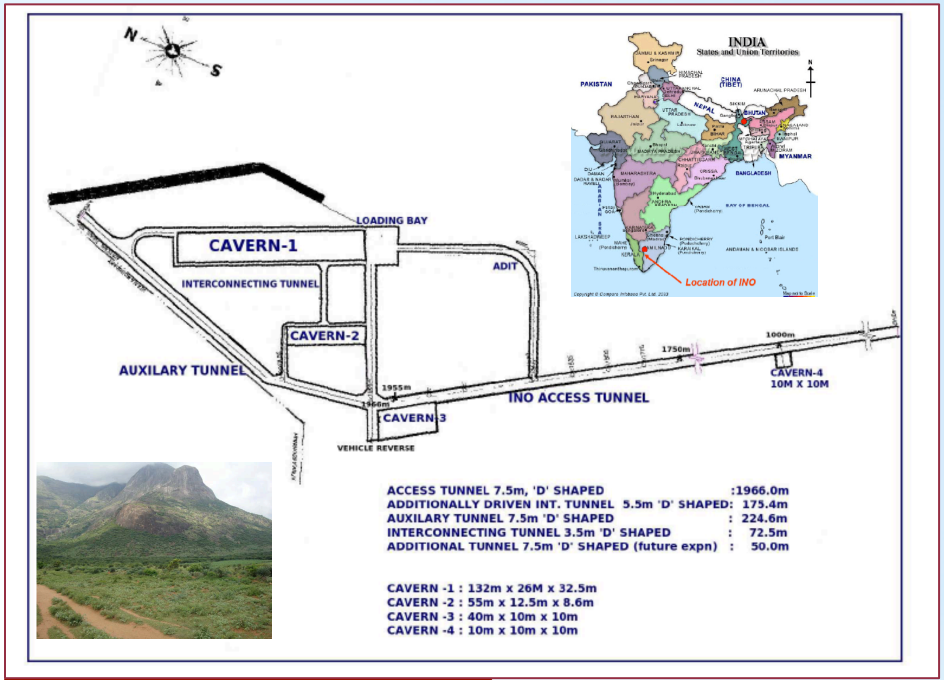
2011: A very productive year for INO reaching several milestones

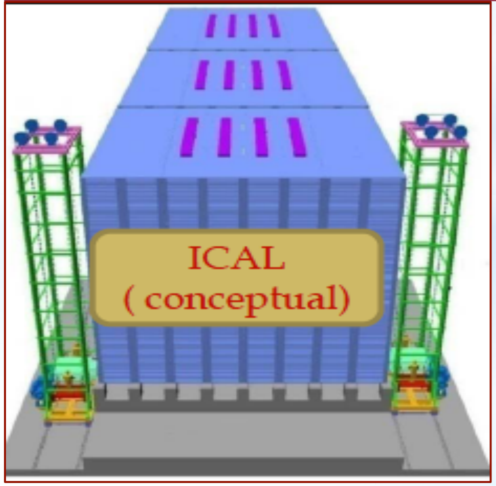
- ✓ *Environment & Forest clearances obtained in June*
- ✓ *Just few weeks back, Tamil Nadu Govt. has approved the request to allocate 26 Hectares of land at the Pottipuram village in Theni District to build the underground lab*
- ✓ *We expect to get the approval of 12 Hectares of land at Madurai soon to establish the INO centre – The National Centre for High Energy Physics (NCHEP)*

Now, finally we are all set to move ahead with the INO project

Approved projects under INO

- *To come up with an underground lab and surface facilities near Pottipuram village in Theni district of Tamil Nadu.*
- *To build massive 50 kt magnetized Iron calorimeter (ICAL) detector to study properties of neutrinos.*
- *Construction of the INO centre: The NCHEP at Madurai*
- *Human Resource Development (INO Graduate Training Program)*
- *Completely in-house Detector R&D with substantial INO-Industry interface*
  Projected Time Frame (2011-2017)

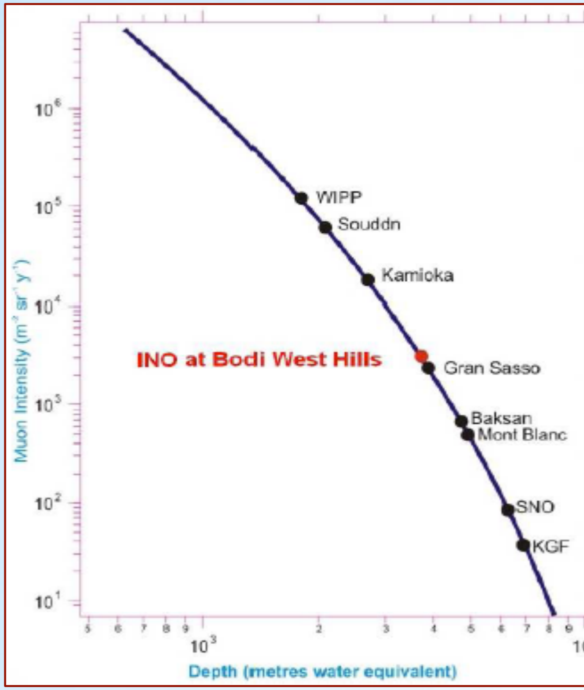


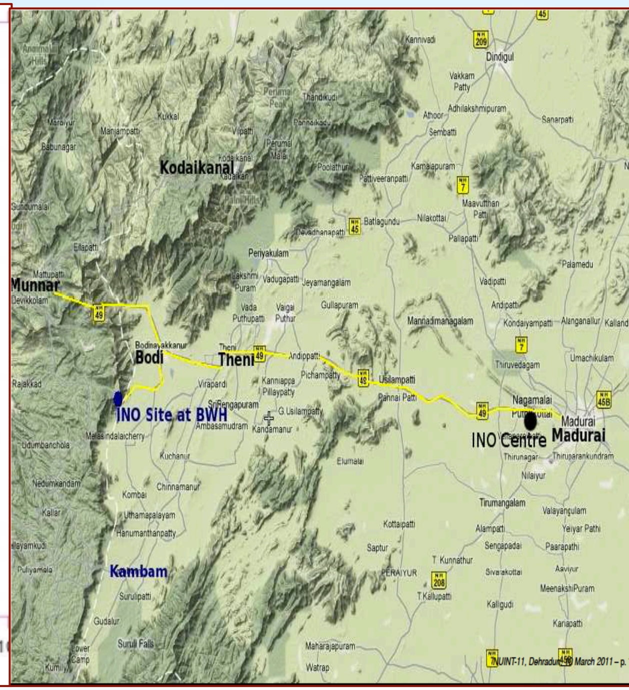


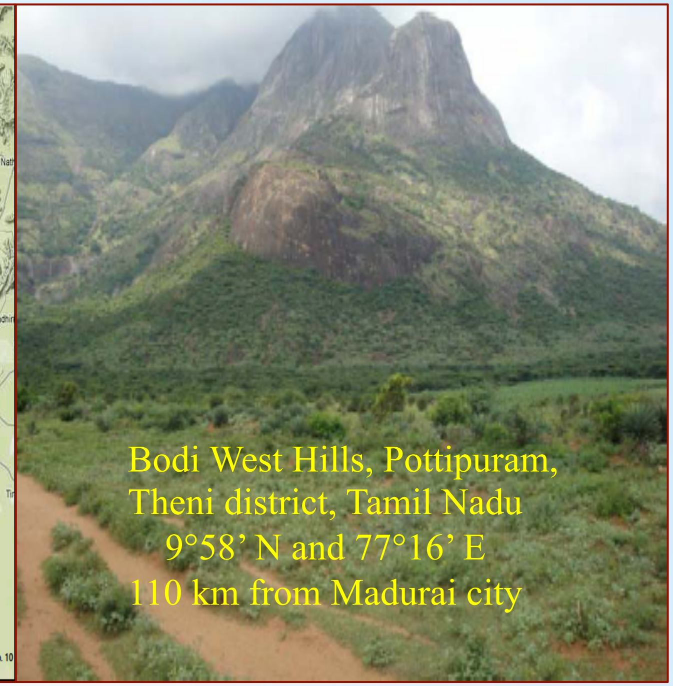
Spokesperson:
N.K. Mondal

Host Institute:
TIFR

Location of INO & Unique Features







- ***Transport:*** *Flat terrain with good access from major roads*
- ***Geotechnical Issues:*** *Good rock quality, Cavern set in massive Charnockite under the 1589 m peak, Vertical cover approx. 1289 m, Tunnel length 1.91 km*
- ***Environmental Issues:*** *Portal set outside the RF boundary, no disturbance to the forest. Surface facilities not on Forest Land. No clearing of forest*
- ***Weather :*** *Warm, low rainfall area, low humidity throughout the year*

INO Phase 1

Study Atmospheric neutrinos with a wide range of L/E

What do we want to achieve?

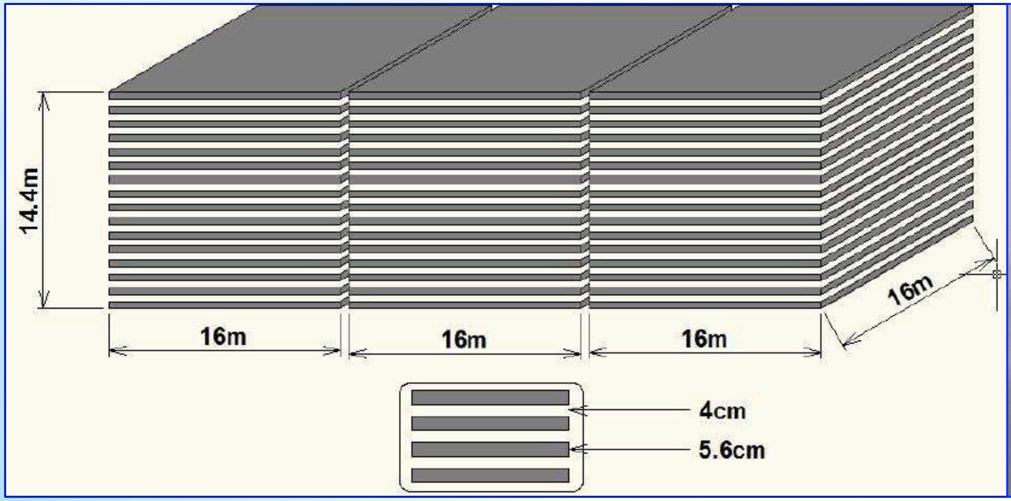
- ***Reconfirm neutrino oscillations using neutrinos and anti-neutrinos separately***
- ***Improved precision of oscillation parameters (*** $|\Delta m^2_{31}|$, $\sin^2 2\theta_{23}$ ***)***
- ***Determine the sign of*** Δm^2_{31} ***using matter effects via charge discrimination***
- ***Measure the deviation of*** θ_{23} ***from its maximal value and its octant***
- ***Test bed for various new physics like NSI, CPT violation, long range forces***
- ***Detect Ultra high energy Neutrinos and cosmic Muons***

What kind of Detector do we need?

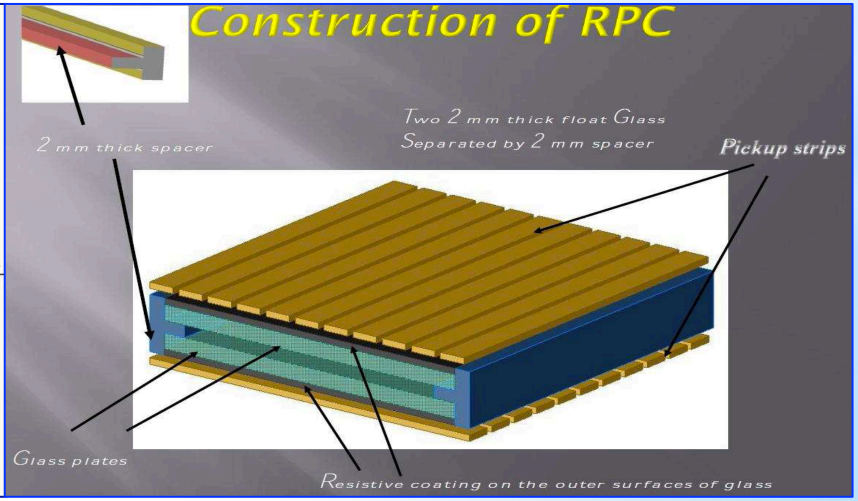
- Should have large target mass (50 - 100 Kton)
- Good tracking and Energy resolution (tracking calorimeter)
- Good directionality for up/down discrimination (nano-second time resolution)
- Charge identification (need to have uniform, homogeneous magnetic field)
- Ease of construction & Modularity
- Complementary to the other existing and proposed detectors

What is the ideal choice?

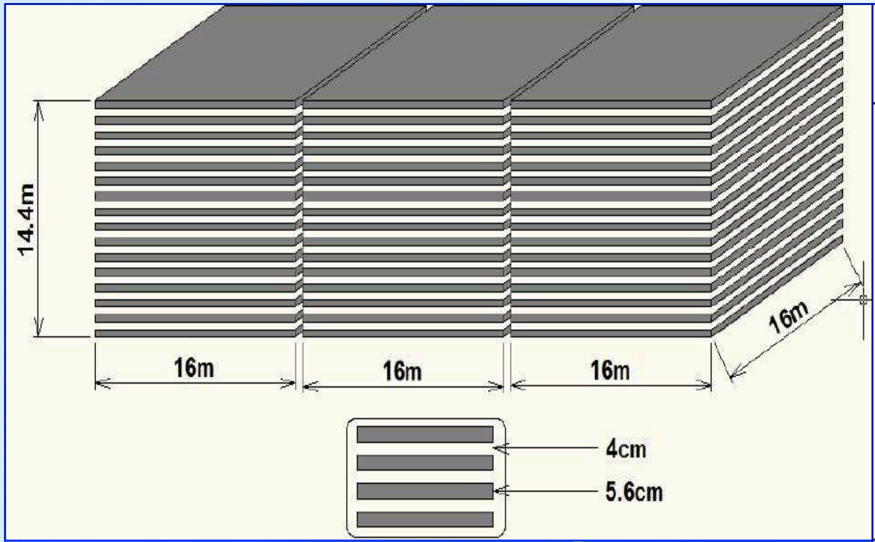
Magnetized iron (target mass): ICAL



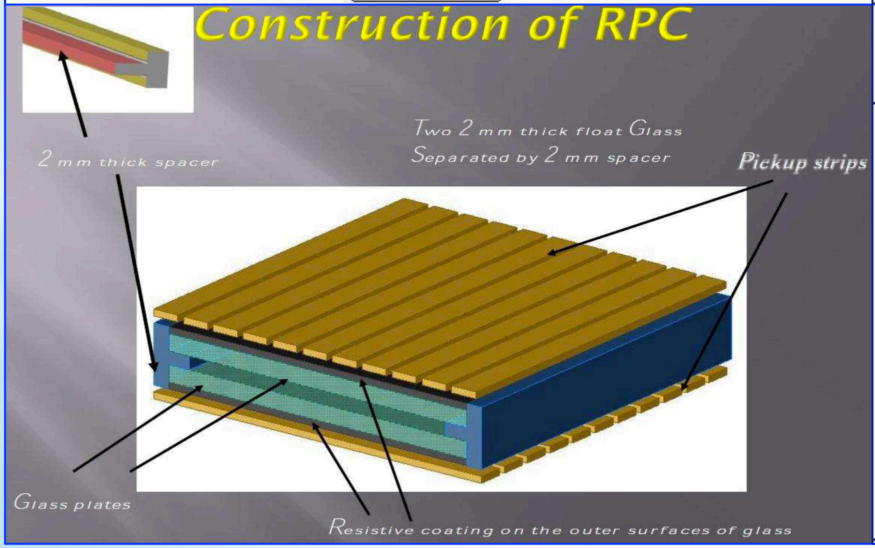
RPC (active detector element)



Specifications of the ICAL Detector

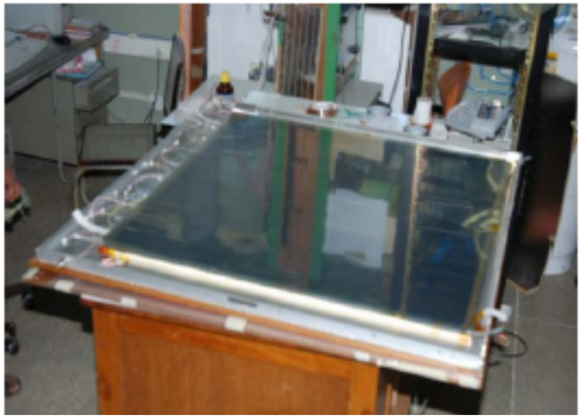


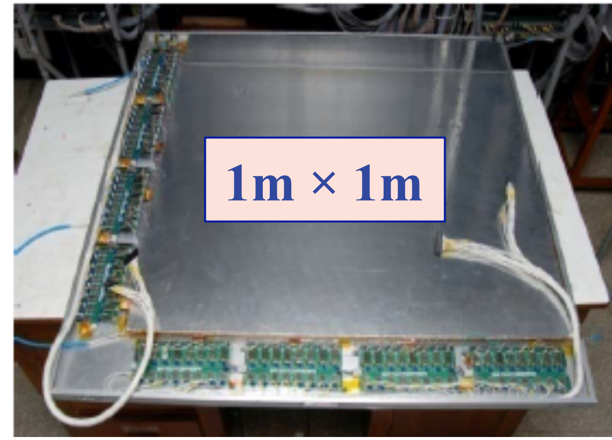
ICAL	
No. of modules	3
Module dimension	16 m × 16 m × 14.4 m
Detector dimension	48 m × 16 m × 14.4 m
No. of layers	150
Iron plate thickness	~ 5.6 cm
Gap for RPC trays	4.0 cm
Magnetic field	1.3 Tesla

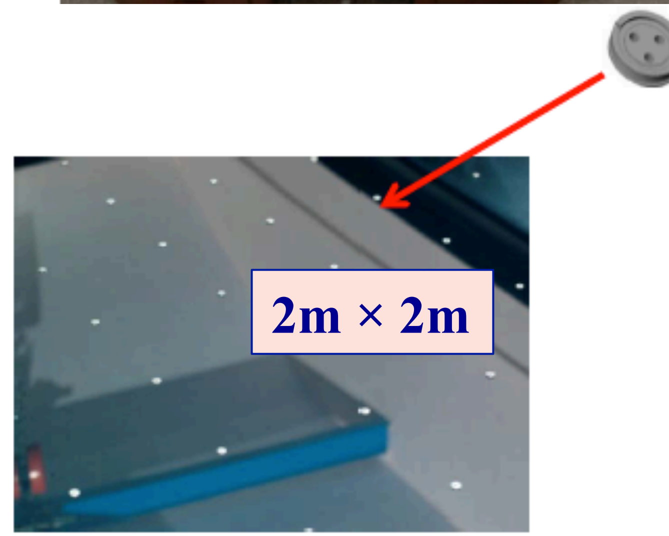


RPC	
RPC unit dimension	1.84 m × 1.84 m× 24mm
Readout strip width	3 cm
No. of RPC units/Road/Layer	8
No. of Roads/Layer/Module	8
No. of RPC units/Layer	192
Total no. of RPC units	~ 28800
No. of electronic readout channels	3.6864×10^6

Making of Glass RPCs at TIFR

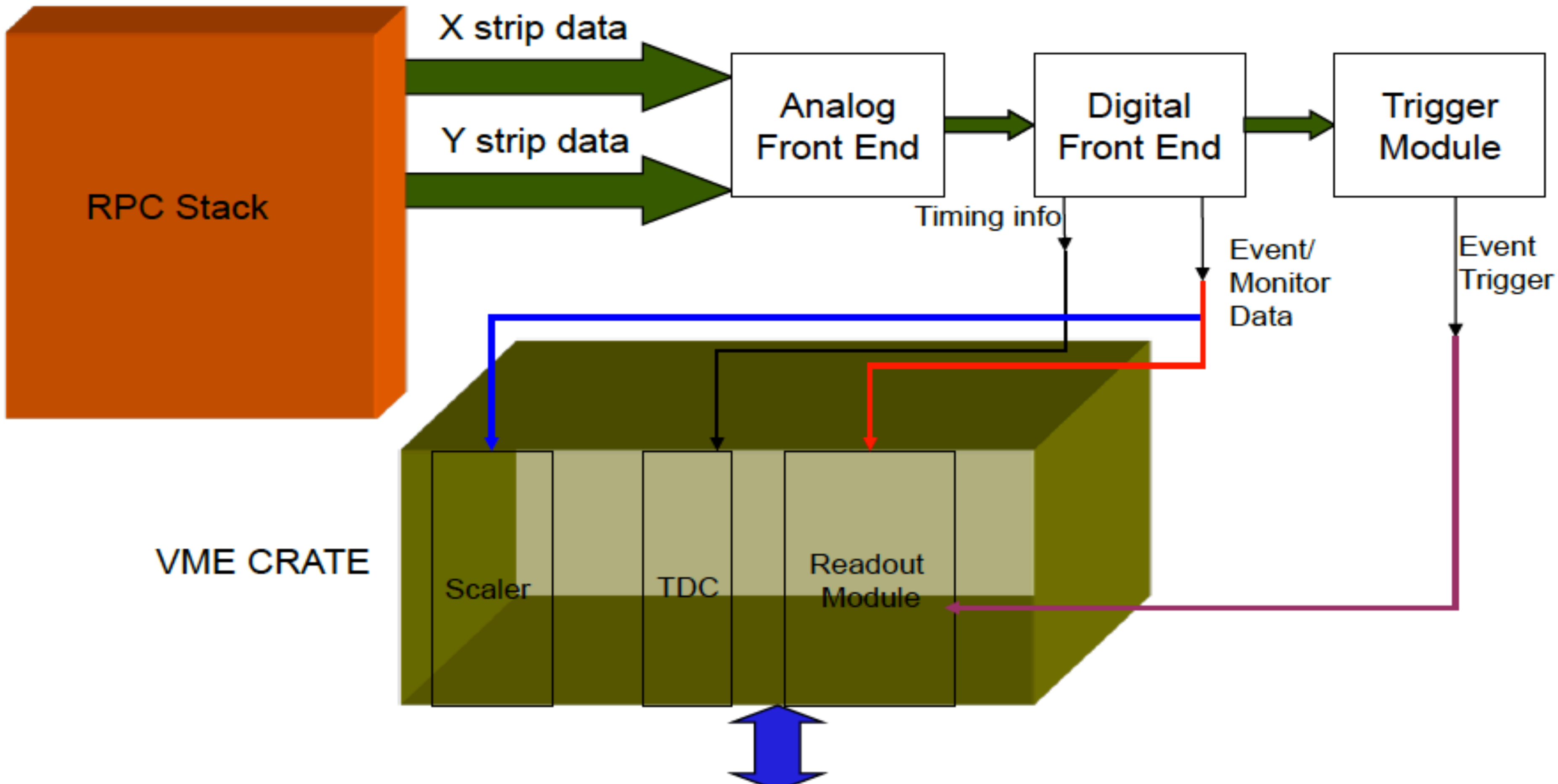






- *12 glass RPCs of 1m × 1m developed, tested for long in avalanche mode*
- *Recently 5 glass RPCs of 2m × 2m successfully assembled and tested*

VME Based DAQ Setup

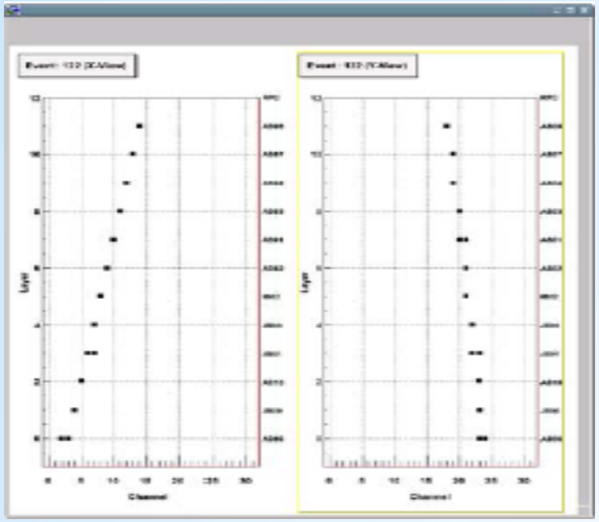


Linux based DAQ software (C++, Qt, ROOT)

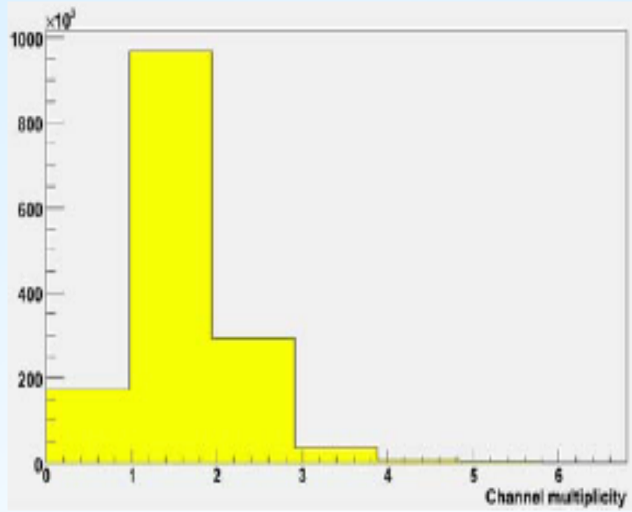
- Interrupt Based
- Multi-Threaded
- Graphical User Interface
- Online 2D/3D Event Display
- RPC Strip Monitoring
- Online Error Reporting

Performance of RPC using Cosmic Muons

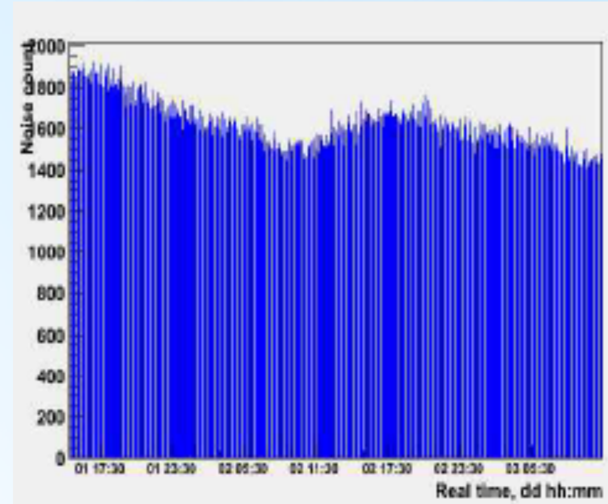
INO



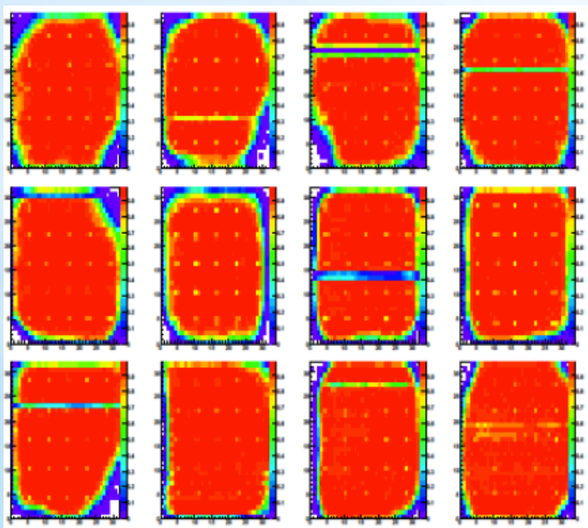
Cosmic Ray Tracks



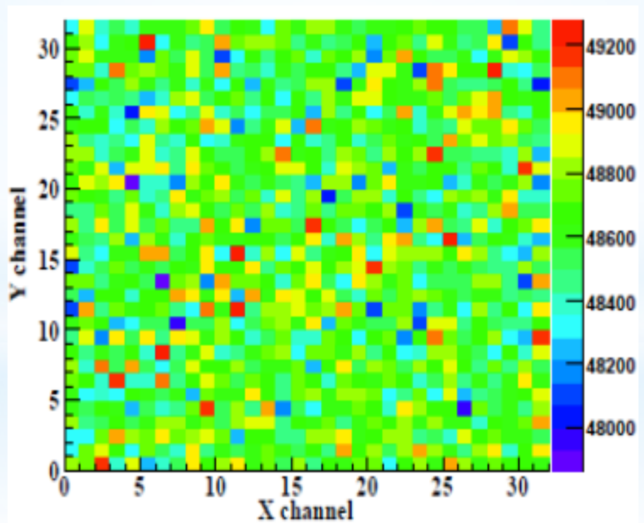
Strip multiplicity due to crossing muons



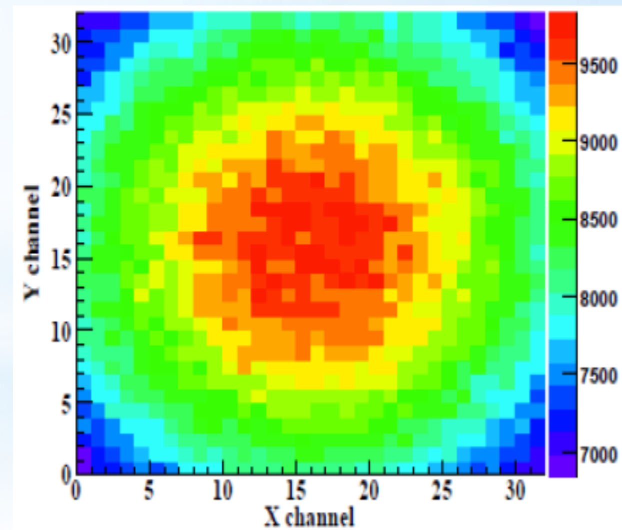
Strip noise rate .vs. time



Cosmic muon imaging



Hit distribution in top RPCs



Hit distribution in bottom RPCs

Efforts at VECC & SINP (Kolkata)

- ***Bakelite RPCs being developed, operating in streamer mode, innner surface coated with PDMS (silicone) for smooth surface, efficiency plateau over 96% with reduced noise rate and long term stability***

- ***ICAL@INO being modular in size, can use both glass as well as bakelite RPCs***

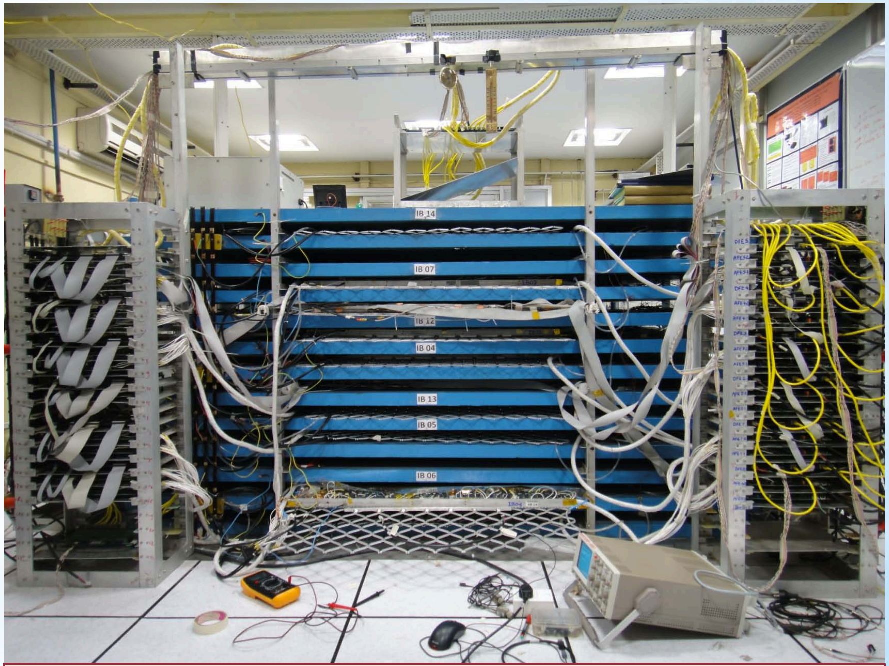
13 layers of soft iron
Each Iron Plate: 2.48m x 2.17m x 0.05m

12 layers of 1m × 1m RPCs
8 glass RPCs and 4 Bakelite RPCs

Total of 4 coils, each having 5 turns
perpendicular to the plane of the Fe (1.6 Tesla)

800 channels of preamp
timing discriminators for avalanche RPCs

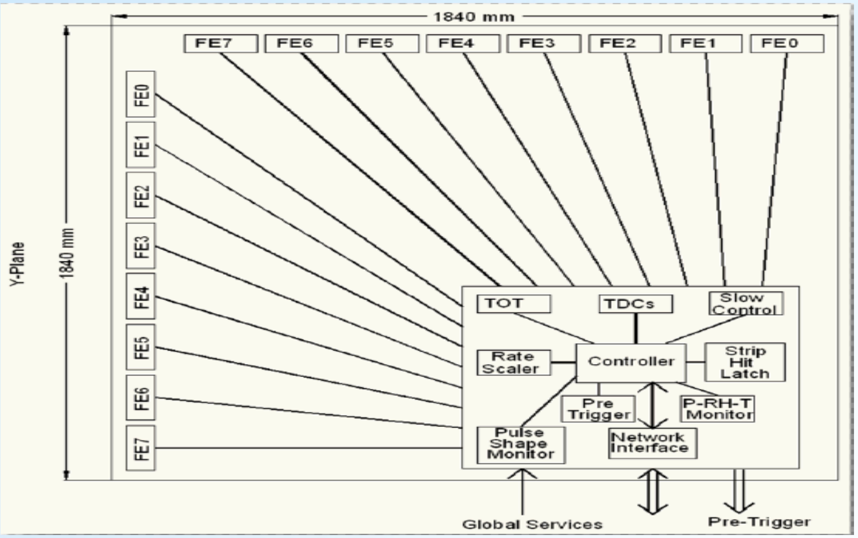
Designed to study the working behavior of RPCs together with the front end electronics in presence of magnetic field



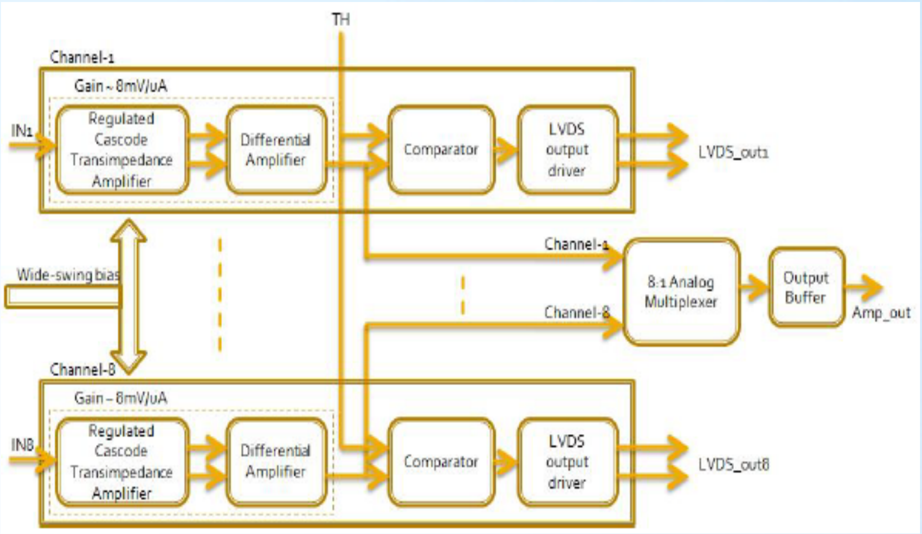
ICAL@INO Prototype Detector ~ 50 tons
Total Height 1.302 m

ICAL Front End Electronics

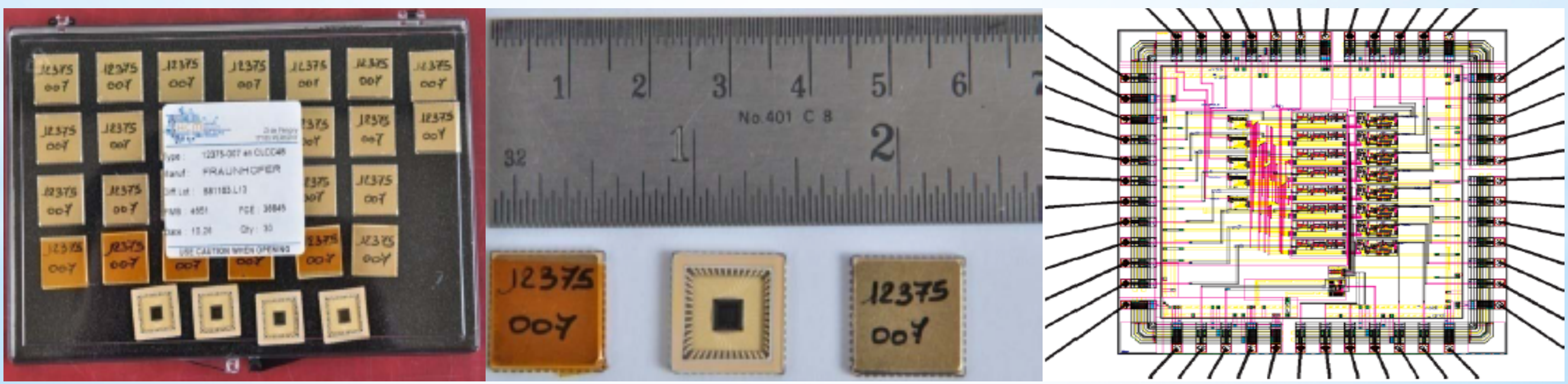
INO



The Scheme



Layout of the Electronics Chip



Electronics Chip developed at BARC Electronics division

Detector Simulation Strategy

INO

Simulation work is under progress

NUANCE

Neutrino Event Generation

$\nu_a + X \rightarrow A + B + \ldots$

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

GEANT

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

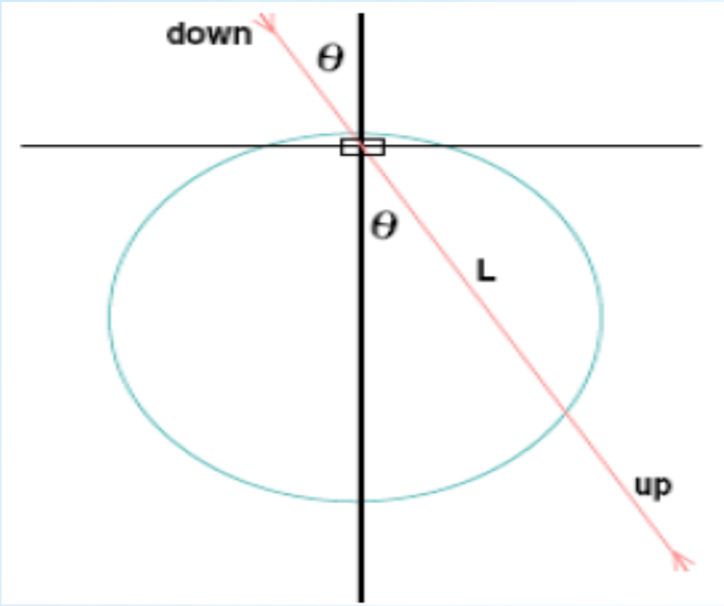
(E,p) of ν + X = (E,p) of A + B + ...

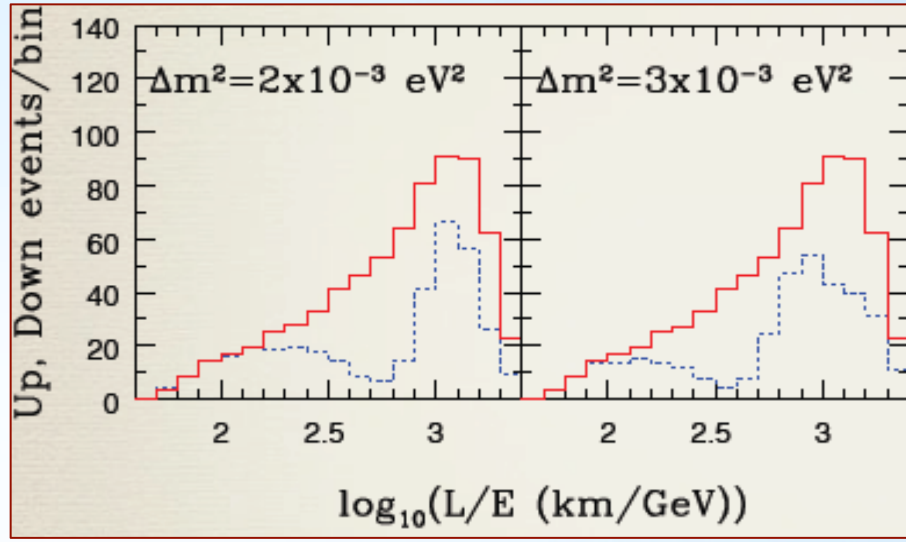
Fit the tracks of A + B + ... to get their energy and momentum.

Output:
i) Energy & Momentum of the initial neutrino

Reconfirmation of L/E Dip

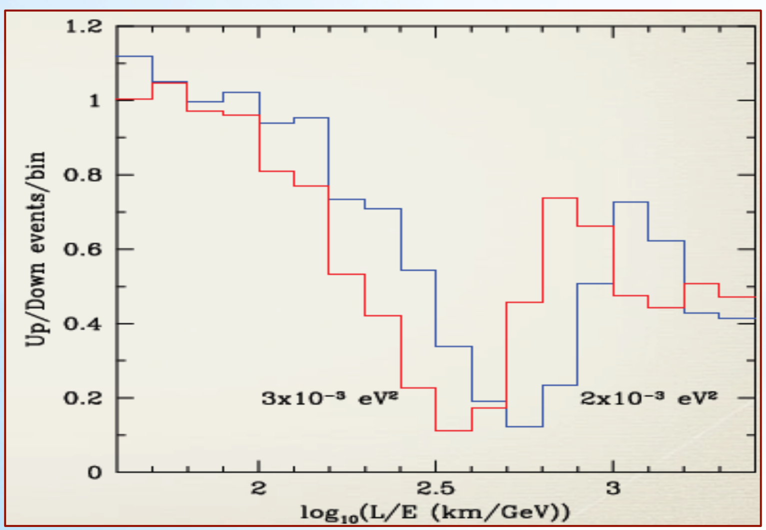
INO





Red: Downward μ **Blue: Upward μ**

250 kt.yr exposure



Observing fall and rise of up/down ν_μ

Crucial for Precision of $|\Delta m^2_{31}|$

Precision of atmospheric oscillation parameters

INO

θ_{23}	CL	Source
$42.9^\circ{}^{+4.1^\circ}_{-2.8^\circ}$	1σ	global-fit[2]
$35.7^\circ - 54^\circ$	3σ	global-fit[2]
$45^\circ{}^{+10^\circ}_{-7.8^\circ}$	99%	SK [4]
$45^\circ \pm 9^\circ$	90%	MINOS (ν) [4]
$34^\circ{}^{+6^\circ}_{-4^\circ}$ or $56^\circ{}^{+4^\circ}_{-6^\circ}$	90%	MINOS ($\bar{\nu}$) [5]
$39^\circ - 51^\circ$	2σ	T2K [32]
$36^\circ - 54^\circ$	2σ	NOνA [32]
$40^\circ - 50^\circ$	2σ	INO (1 Mton·yr)

$\Delta m^2_{32}(10^{-3}\text{eV}^2)$	CL	Source
$-2.36 \pm 0.07(\pm 0.36)$	1 (3)σ	global-fit [2]
$+2.47 \pm 0.12(\pm 0.37)$	1 (3)σ	global-fit [2]
$2.5^{+0.52}_{-0.60}$	99%	SK 3ν [4]
$2.35^{+0.11}_{-0.08}$	90%	MINOS ν [5]
$3.36^{+0.45}_{-0.40}$	90%	MINOS $\bar{\nu}$ [5]
2.5 ± 0.04	2σ	T2K [32]
$2.5^{+0.07}_{-0.04}$	2σ	NOνA [32]
2.5 ± 0.07	2σ	INO (1 Mton·yr)

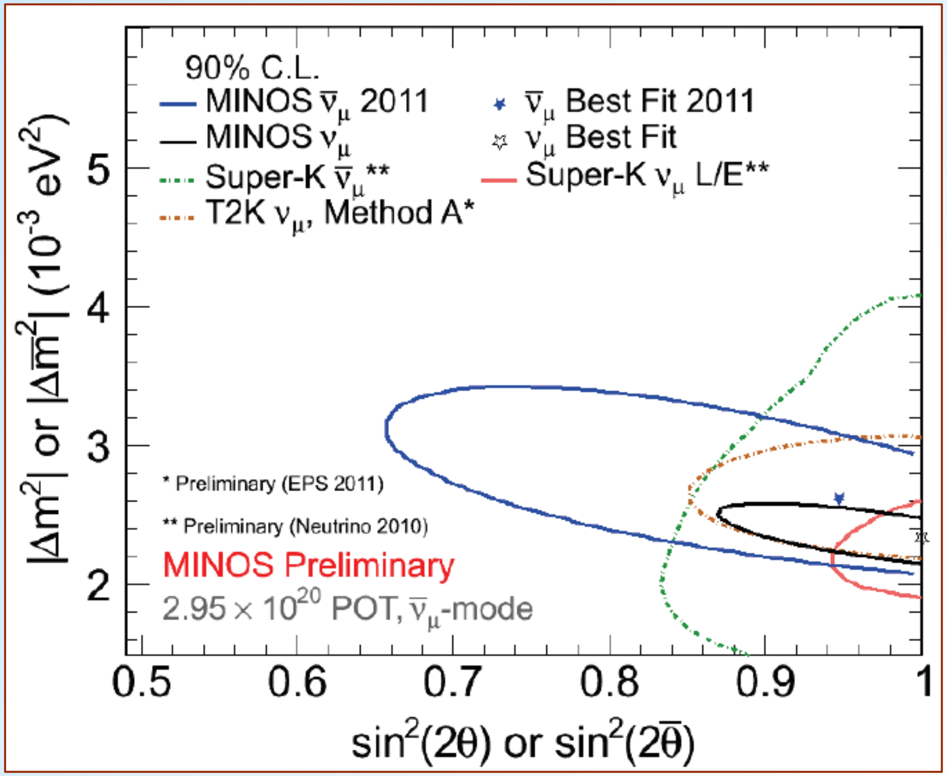
[2]: 1001.4524; [4]: hep-ex/0604011
[5]: 1103.0340; [32]: 0412133

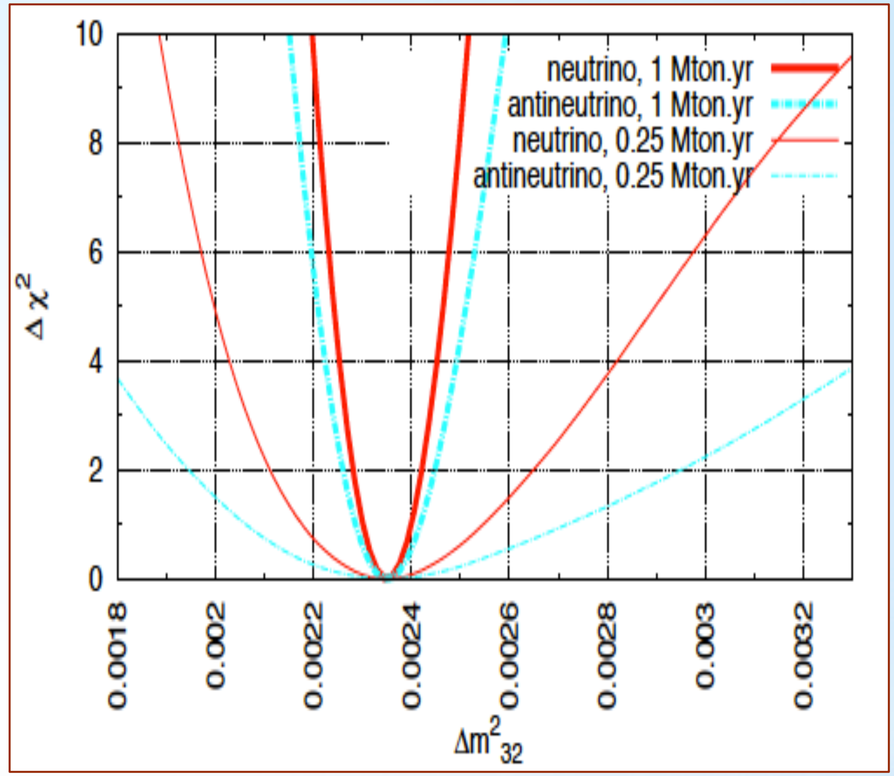
Samanta & Smirnov, 1012.0360
See also, Choubey & Roy, hep-ph/0509197

Improvement on the current precision might not be remarkable

Definitely the information will be complementary to other expts

Can we resolve MINOS anomaly?





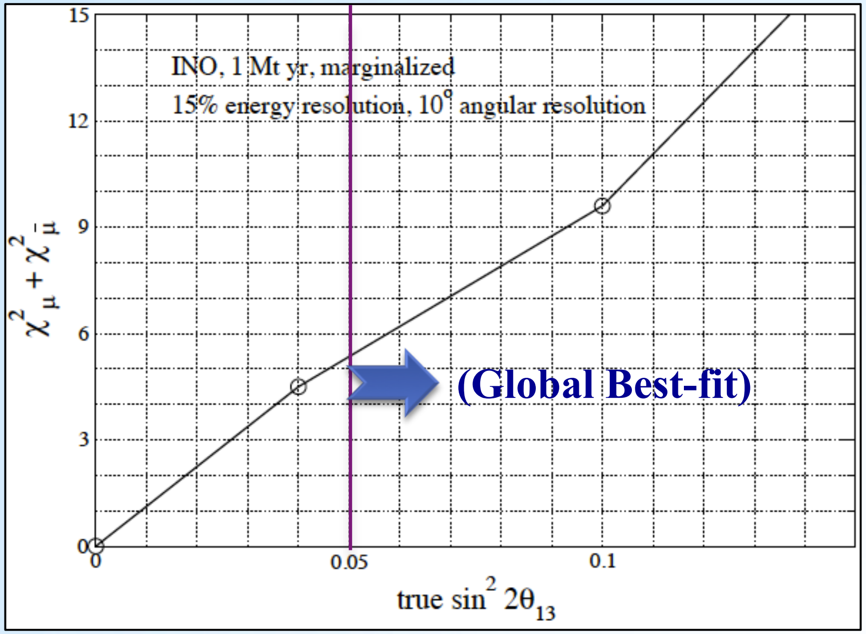
Samanta & Smirnov, 1012.0360

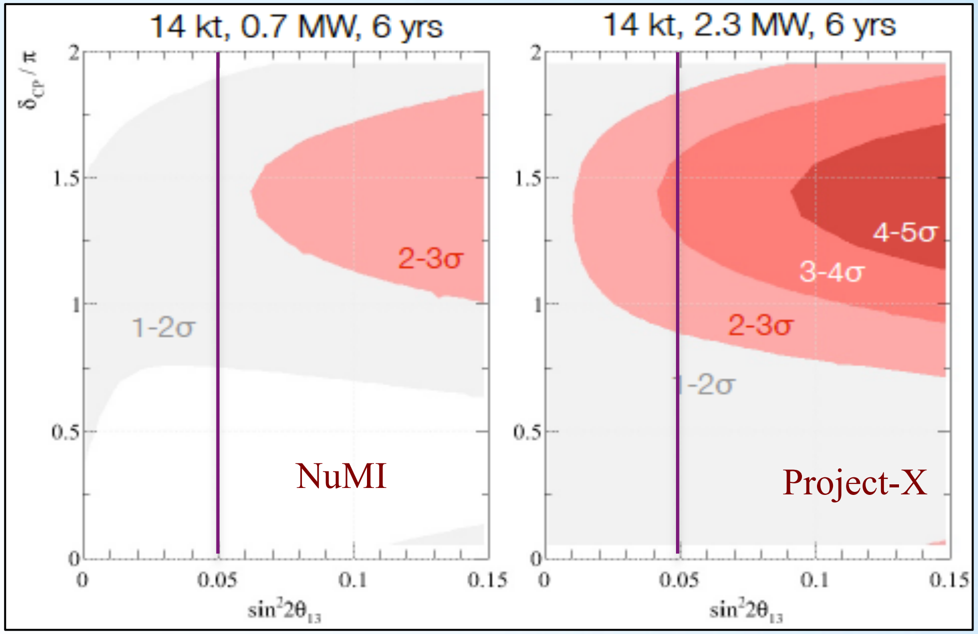
Charge Identification of ICAL is the key to have independent measurement of Atmospheric mass splitting with neutrinos & anti-neutrinos

MINOS Anomaly can be tested at > 3 sigma C.L.

Mass Hierarchy: ICAL@INO .vs. NOvA

INO





R. Gandhi etal., 0707.1723, Samanta 0907.3540 (see also: Indumathi etal, hep-ph/0407336)

M. Messier, Intensity Frontier workshop (24th Oct, '11)

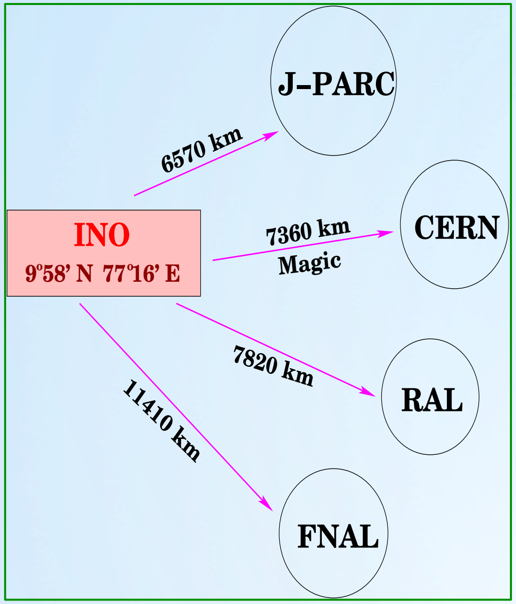
- *Large matter effects in ν_μ survival prob*
- *L = 6000 – 9000 km, E = 5 – 10 GeV*
- *Very mild dependence on CP phase*
- *MH possible > 2 sigma if* $\sin^2 2\theta_{13} = 0.05$

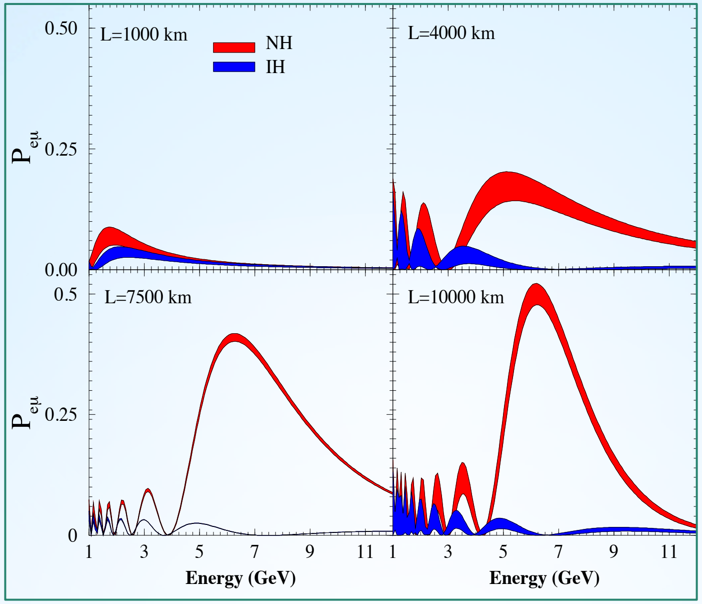
- *Depends on Platinum Channel, $P_{\mu e}$*
- *L = 810 km, E ~2 GeV*
- *Highly dependent on CP phase*
- *MH at 1-2 sigma for ~50% favorable values of CP phase if* $\sin^2 2\theta_{13} = 0.05$

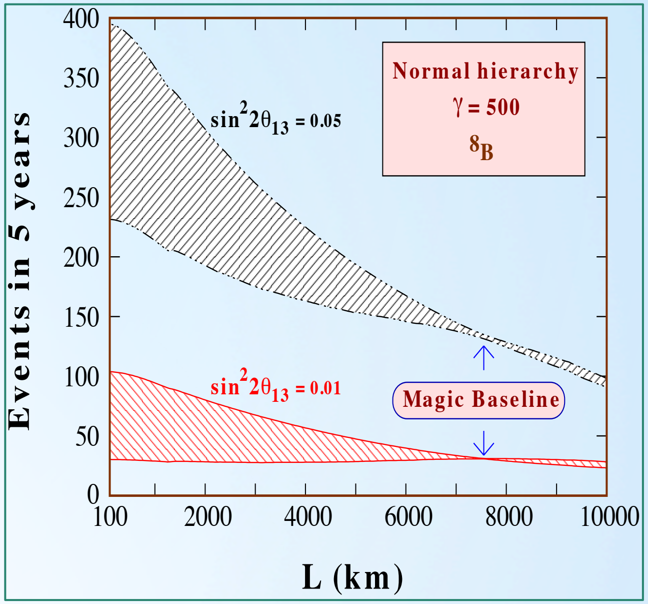
Disclaimer: For both the expts, systematics are very crucial, more study needed

Physics with Beams (INO Phase 2)

INO



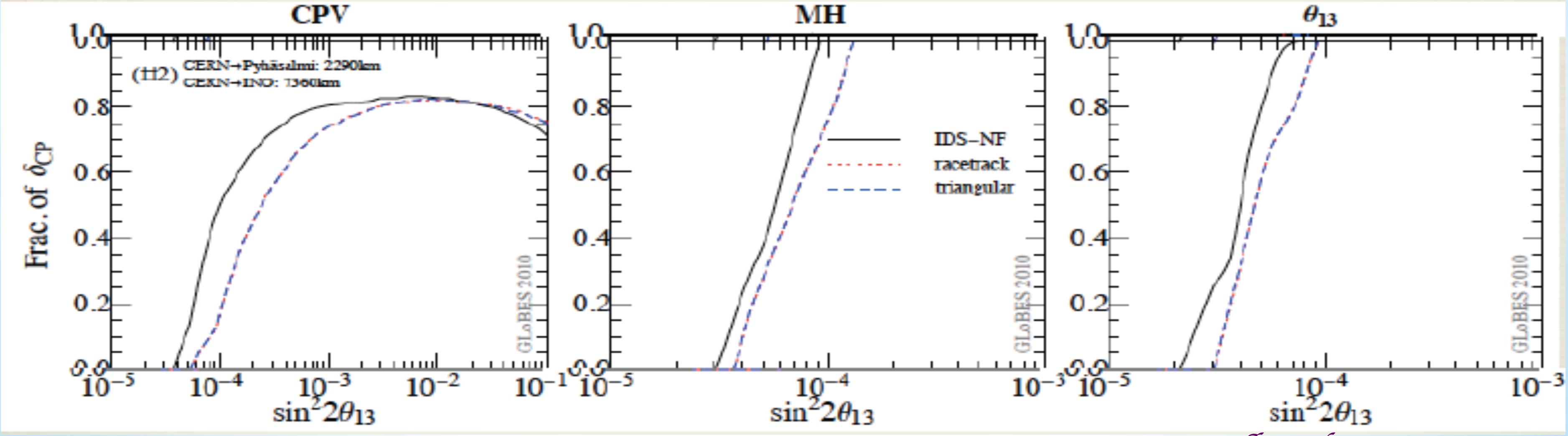




Near Resonant Matter Effect

Agarwalla etal., hep-ph/0610333

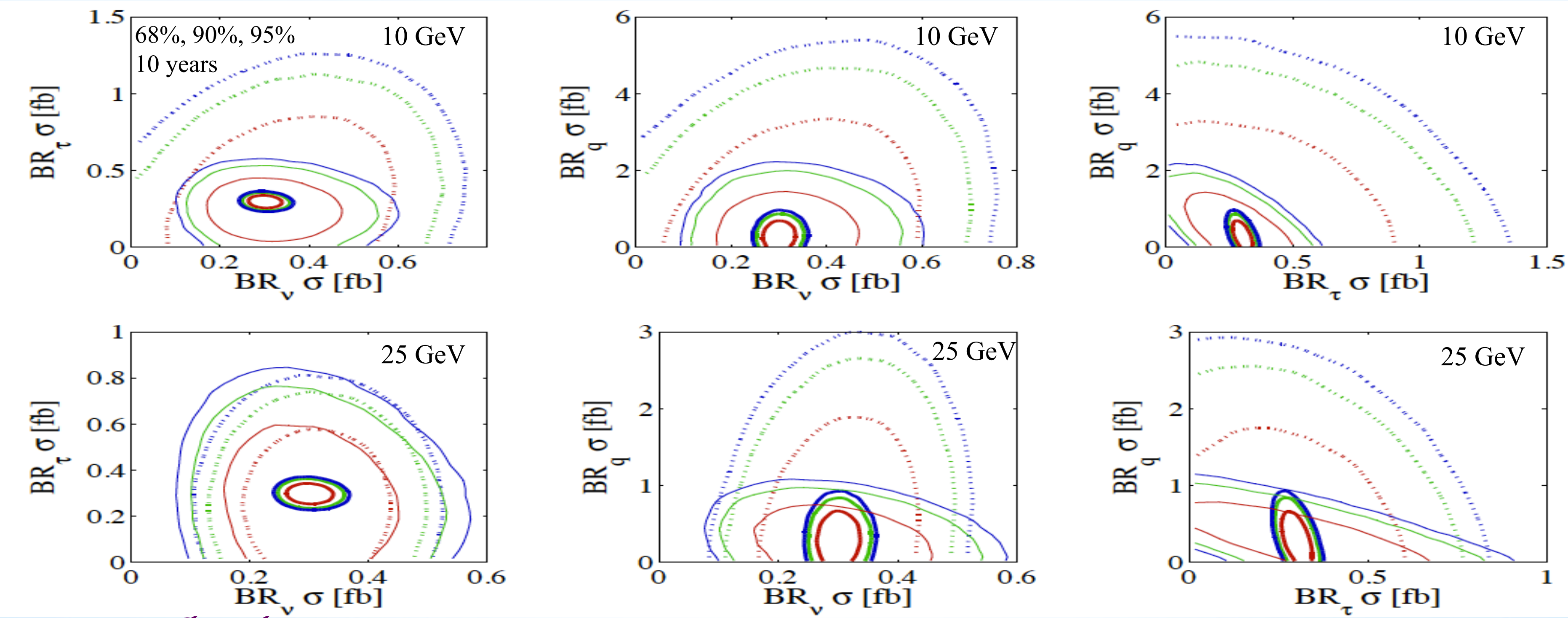
Agarwalla etal., arXiv:0711.1459



Agarwalla etal., arXiv:1012.1872

Indirect detection of Dark Matter with ICAL

INO



Agarwalla etal., arXiv:1105.4077

Dotted line: 100 kt ICAL   Thin line: 34 kt LAr   Thick line: 100 kt LAr

Experiment	DM mass	$BR_\tau \sigma$ [fb]	$BR_\nu \sigma$ [fb]	$BR_q \sigma$ [fb]
MIND (100 kt)	10 GeV	0.70	0.35	3.4
	25 GeV	0.34	0.15	1.7
LArTPC (34 kt)	10 GeV	0.15	0.11	0.73
	25 GeV	0.16	0.10	0.21
GLACIER (100 kt)	10 GeV	$1.5 \cdot 10^{-2}$	$6.4 \cdot 10^{-3}$	0.25
	25 GeV	$1.0 \cdot 10^{-2}$	$5.2 \cdot 10^{-3}$	0.19
Super-K data [5]	10 GeV	0.65	0.12	10
	25 GeV	0.45	0.19	5.0

Sensitivity to branching ratio × capture cross section at 90% C.L., 10 years data

DM particles gravitationally trapped inside the Sun may annihilate into SM particles, producing a flux of neutrinos

Energy & Angular resolution, crucial to suppress atmospheric background

More Physics Motivations with ICAL@INO

INO

Testing CPT violation ➔ hep-ph/0312027, arXiv:0802.0121, arXiv:1005.4851

Constraining Sterile Neutrinos ➔ arXiv:0709.0383, arXiv:1108.4360

Probing NSI ➔ hep-ph/0608034, arXiv:1105.5936

Impact of long range forces ➔ hep-ph/0310210, arXiv:1001.5344

Very High Energy Muons ➔ hep-ph/0512179

Intra-nuclear neutron-anti-neutron transformations inside an Fe nucleus. Signature will be the GeV energy pions. Existing SK limits can be improved using ICAL

work under progress....

Profile of the atm. ν flux at INO is very different from existing facility due to geomagnetic field, critical test for the calculation of the atmospheric neutrino flux

M. Honda, NUINT 2011, work under progress....

ICAL can study the cosmic ray muon asymmetry reported by IceCube, since this detector can see the galactic center as well

work under progres....

Where do we stand today?

- ***Full size RPCs (2m X 2m) are now being fabricated not only in our lab but also by the Industry***
- ***First batch of ASIC front end designed by the INO electronics team and fabricated by Euro Practice IC Services being tested in the lab using RPC pulses***
- ***Prototype magnet at VECC/SINP, Kolkata is running***
- ***Graduate Training Program for the last three years within HBNI***
- ***INO Site-Environment & Forest clearances obtained***
- ***Just few weeks back, Tamil Nadu Govt. approved the request to allocate 26 Hectares of land at the Pottipuram village in Theni District to build the underground lab***
- ***We expect to get the approval of 12 Hectares of land at Madurai soon to establish the INO centre – NCHEP***

Short term goals and Future Roadmap

- ***Prepare the Physics White paper with detailed Detector Simulation***
- ***Build a large 8m X 8m -20 layer detector with final specifications***
- ***Magnet & coil design & fabrication, Industrial production of RPCs***
- ***Final Electronics and DAQ, Pre-project activities at site***

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						

International collaboration most welcome

!! Stay Tuned for Exciting Discoveries at INO !!

Thank You