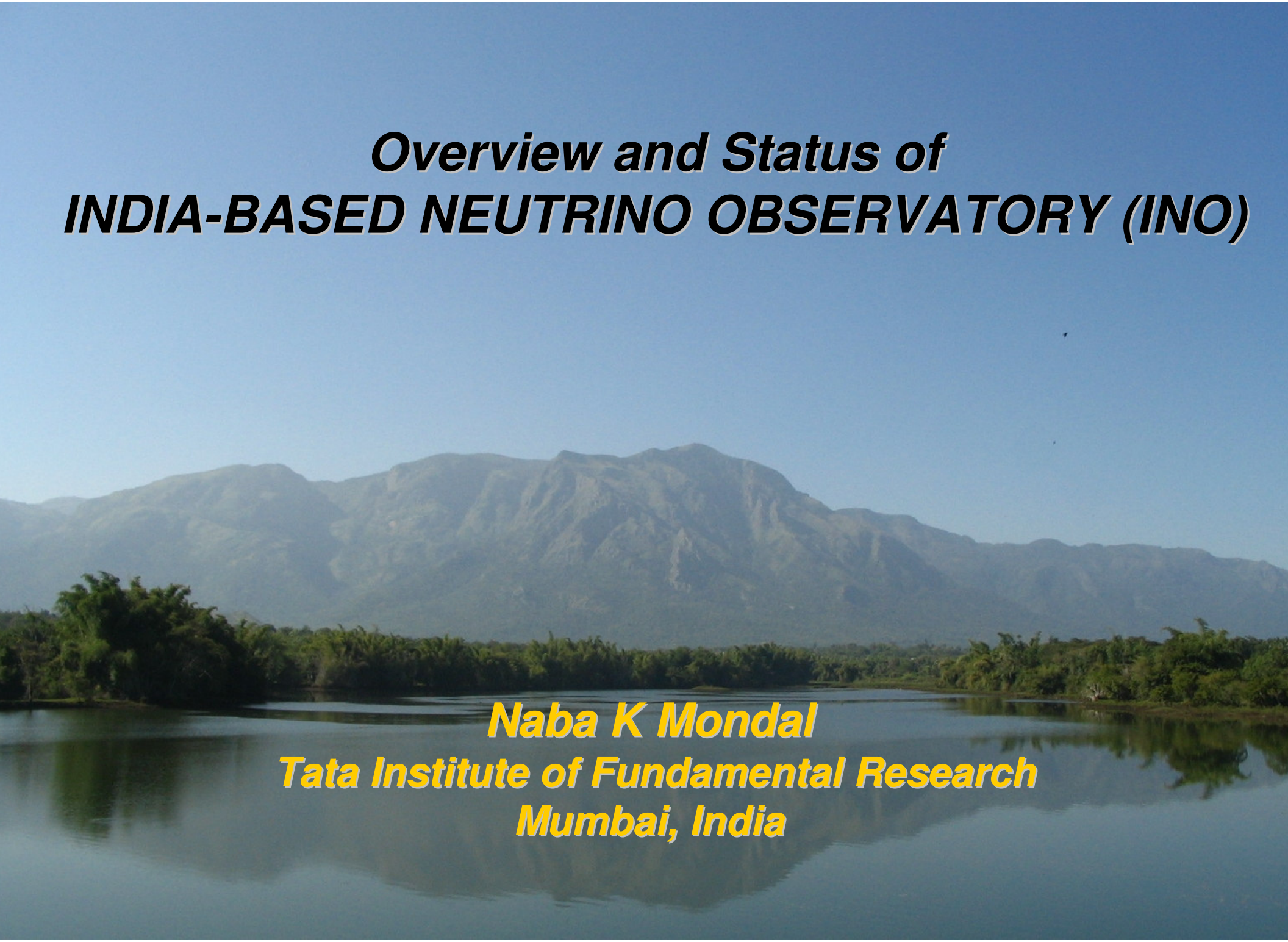


Overview and Status of INDIA-BASED NEUTRINO OBSERVATORY (INO)

Naba K Mondal

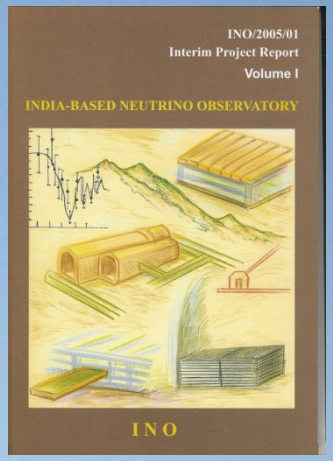
Tata Institute of Fundamental Research

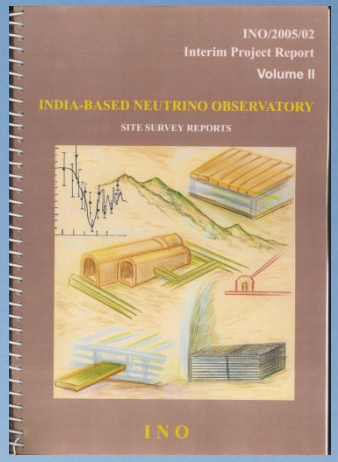
Mumbai, India

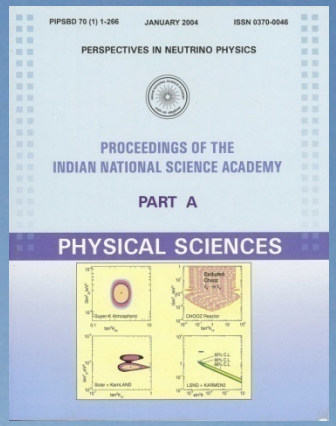
INO project

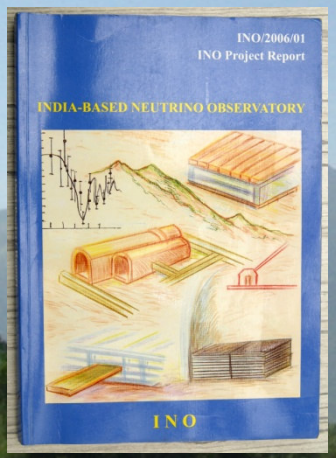
- *India-based Neutrino observatory is a Mega Science Project funded by Dept. of Science & Technology and Dept. of Atomic Energy, Govt. of India . The project will lead to:*
- *Creation of a world class underground laboratory in the country for carrying out research in the emerging field of neutrino physics. Will develop into a full fledged underground laboratory over the years for other studies in physics, biology & geology.*
- *Involvement of Universities in a big way for carrying out large basic science projects- healthy development of University-Research lab partnership.*
- *A Centre for particle physics and detector technology and its varied applications in areas like medical imaging.*
- *INO graduate training program will lead to Ph.D. in particle physics and more importantly creating highly skilled scientific manpower for experimental high energy and nuclear physics. Hands on training on all aspect of experiments with strong emphasis on detector development.*

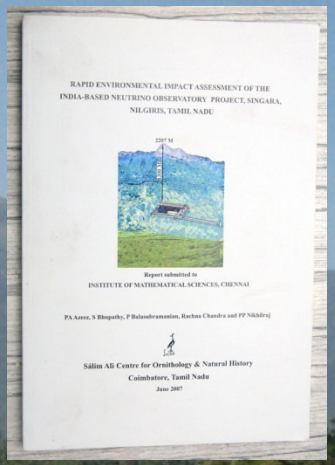
1st May, 2005

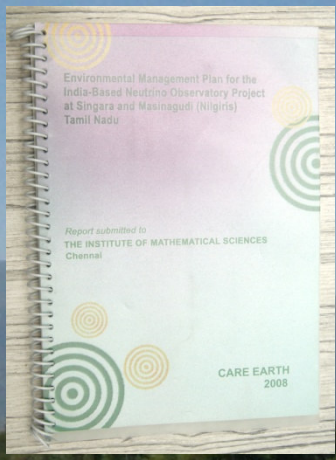












Plus several other smaller documents

TIFR-ASET colloquia series on INO

Overview and status of INO & ICAL : Naba K Mondal

Mechanical Structure of ICAL Detector : Piyush Verma

ICAL Magnet Design : Vivek Datar

Gas Systems for the ICAL Detector : Suresh Kalmani

DAQ system for ICAL Prototype : Suresh Upadhya

VLSI and ASIC designs: V.B.Chandratre

DAQ System for ICAL detector : B.Satyanarayana

Generator, simulation and reconstruction: Gobinda Majumder

Online Analysis tools : Deepak Samuel

Web utilities & online tools : P.Nagaraj

INO Collaboration

- *Aligarh Muslim University*
- *Banaras Hindu University*
- *Bhabha Atomic Research Centre*
- *Calcutta University*
- *Delhi University*
- *Harish Chandra Research Institute*
- *University of Hawaii*
- *Himachal Pradesh University*
- *Indian Institute of Technology, Chennai*
- *Indian Institute of Technology, Guwahati*
- *Indian Institute of Technology, Mumbai*
- *Indira Gandhi Center for Atomic Research,*
- *The Institute of Mathematical Sciences*
- *Institute of Physics*

- *University of Jammu*
- *Jamia Millia Islamia University*
- *University of Kashmir*
- *University of Mysore*
- *Panjab University*
- *Physical Research Laboratory*
- *Saha Institute of Nuclear Physics*
- *Sambalpur University*
- *Sikkim Manipal Institute of Technology*
- *Tata Institute of Fundamental Research*
- *Variable Energy Cyclotron Centre*

25 institutions currently in INO collaboration

Physics using atmospheric neutrinos at INO

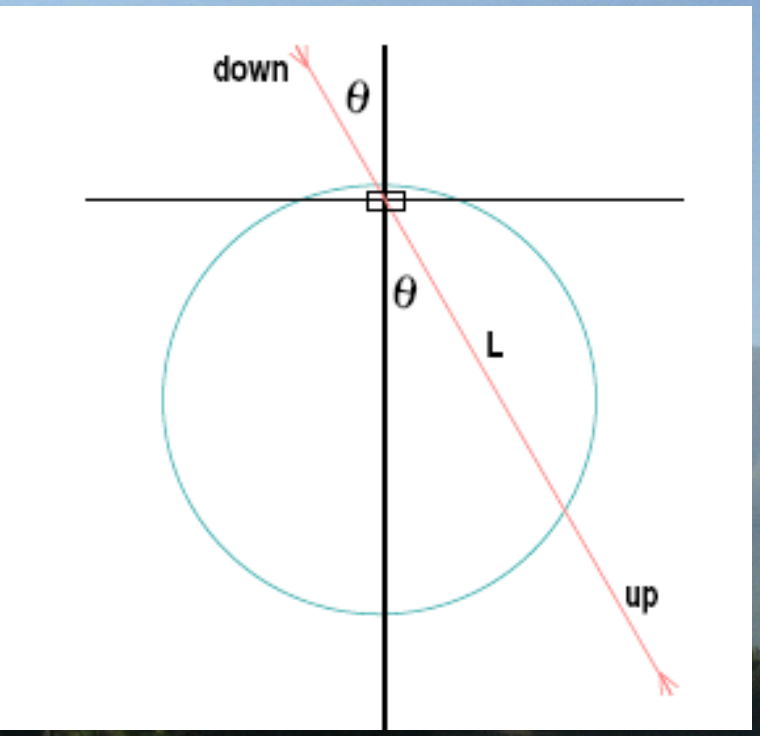
- *Reconfirm atmospheric neutrino oscillation*
- *Improved measurement of oscillation parameters*
- *Search for potential matter effect in neutrino oscillation*
- *Determining the sign of Δm^2_{23} using matter effect*
- *Measuring deviation from maximal mixing for θ_{23}*
- *Probing CP and CPT violation*
- *Constraining long range leptonic forces*
- *Ultra high energy neutrinos and muons*

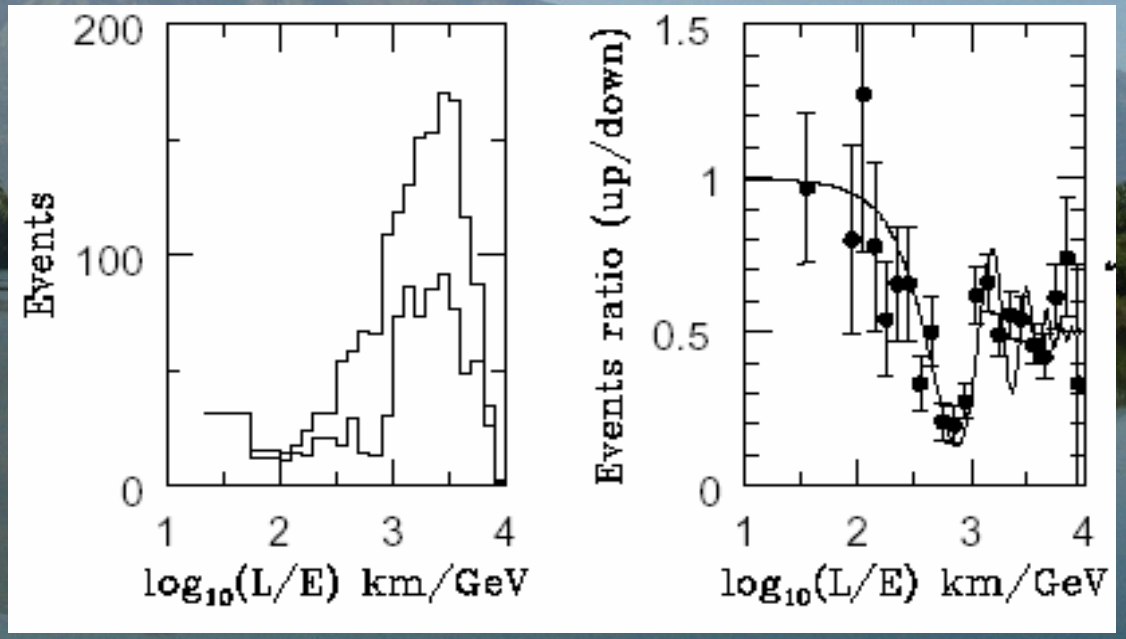
Disappearance of ν_μ Vs. L/E

The disappearance probability can be measured with a single detector and two equal sources:

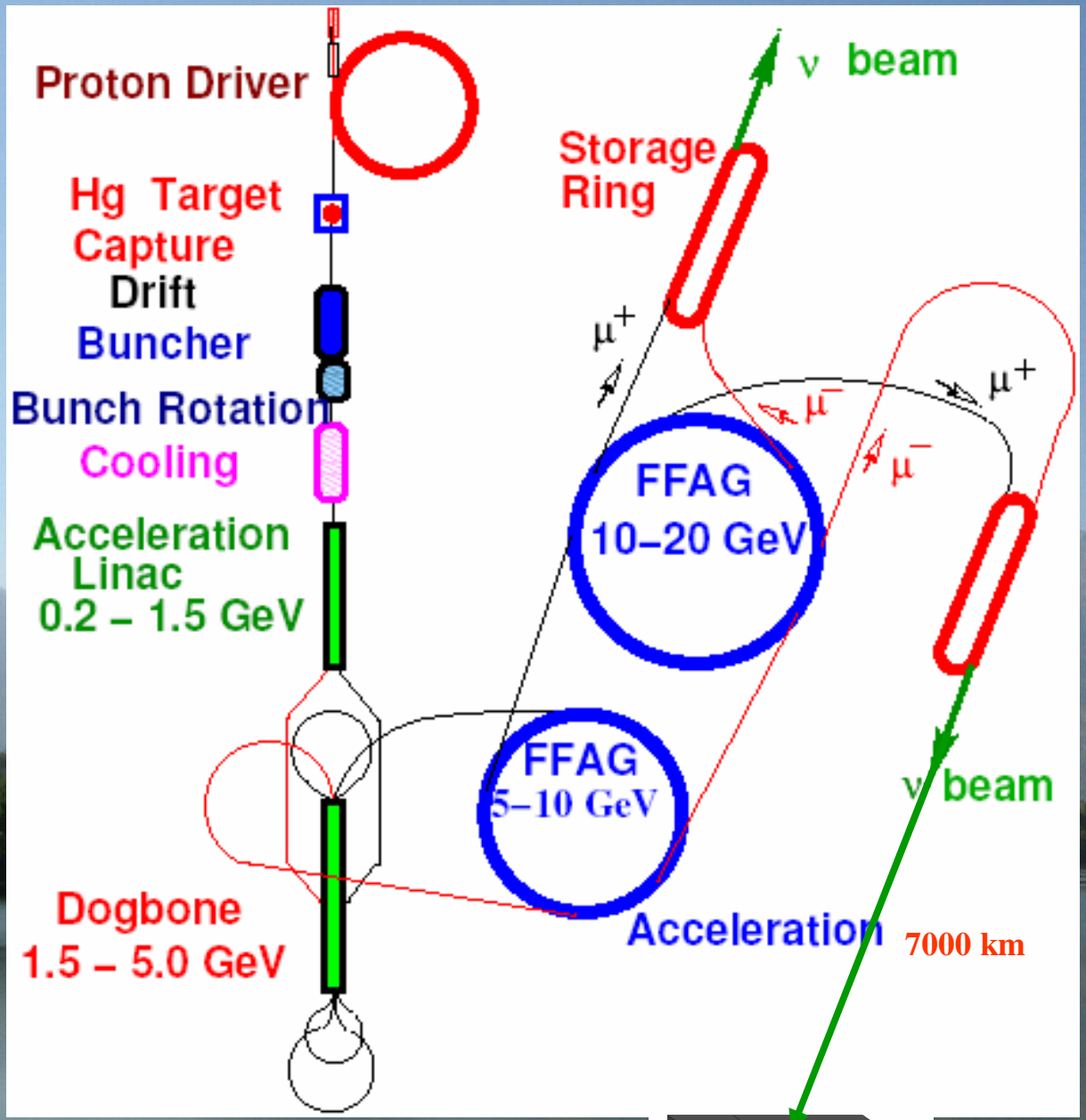
$$\frac{N_{up}(L/E)}{N_{down}(L'/E)} = P(\nu_\mu \rightarrow \nu_\mu; L/E)$$

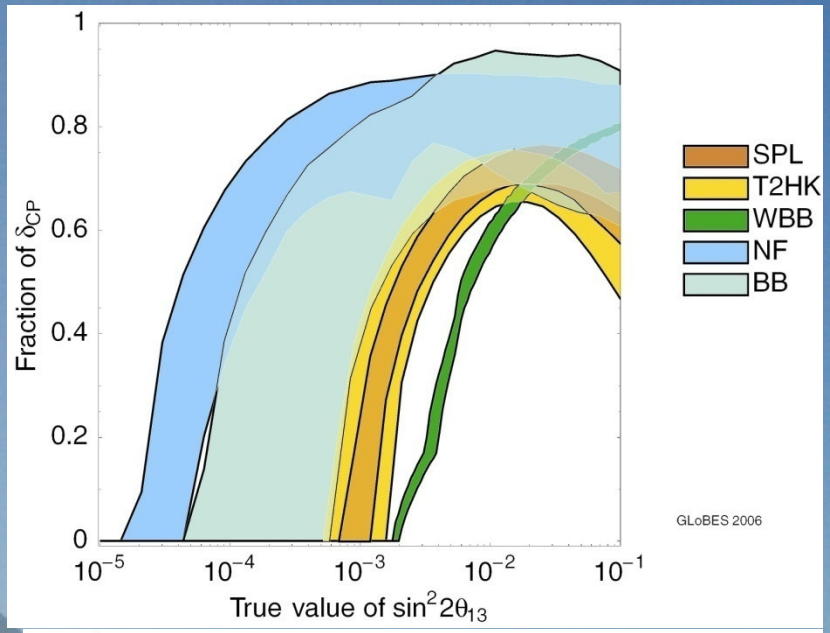
$$= 1 - \sin^2(2\Theta)\sin^2(1.27\,\Delta m^2\,L/E)$$

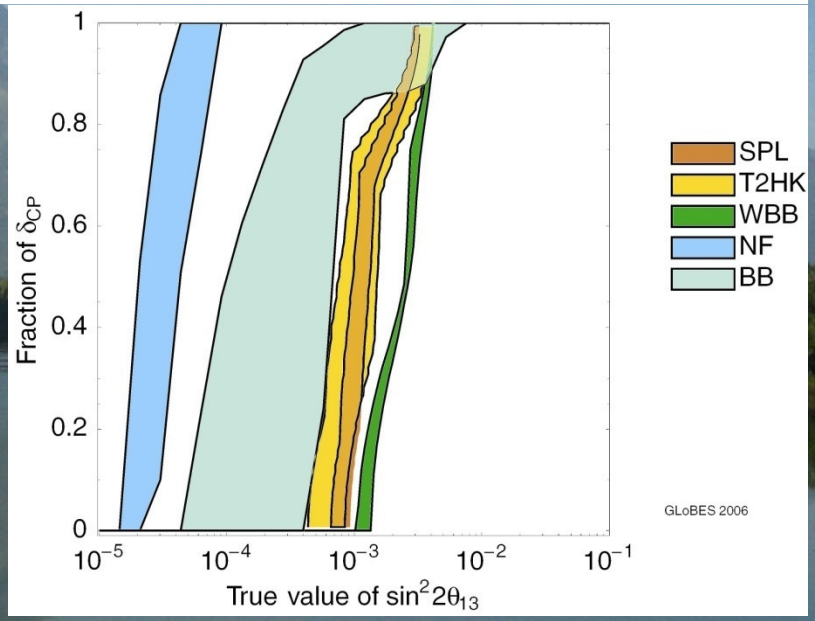


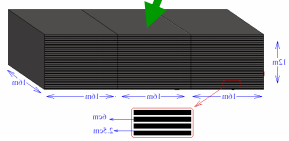


Beyond Superbeam - Neutrino Factory









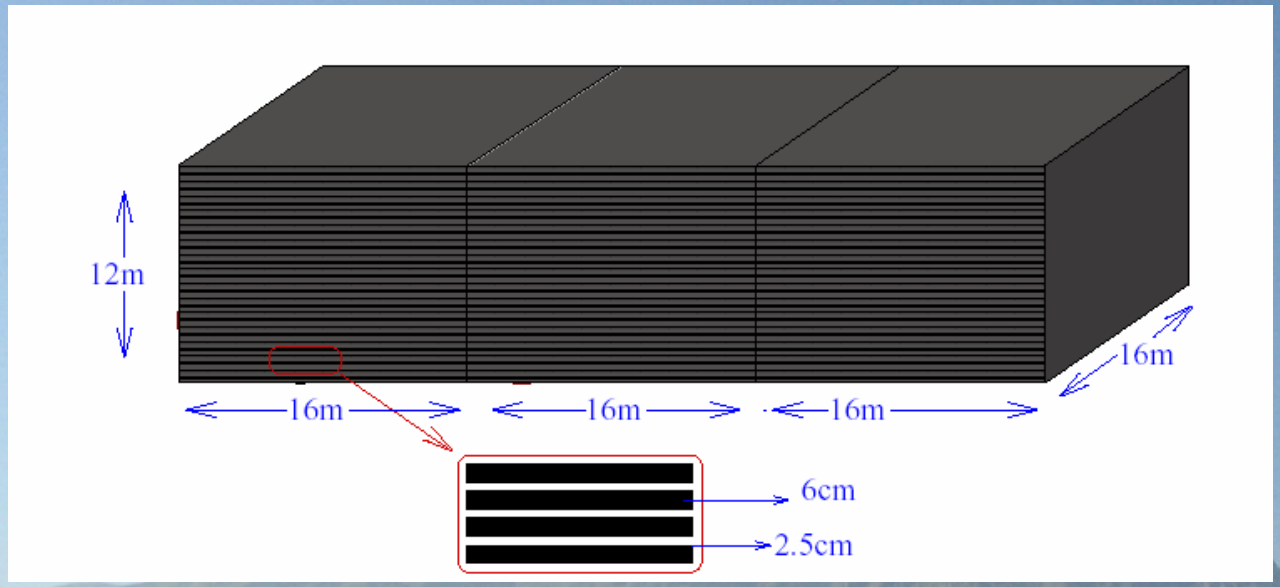
INO Phase 1

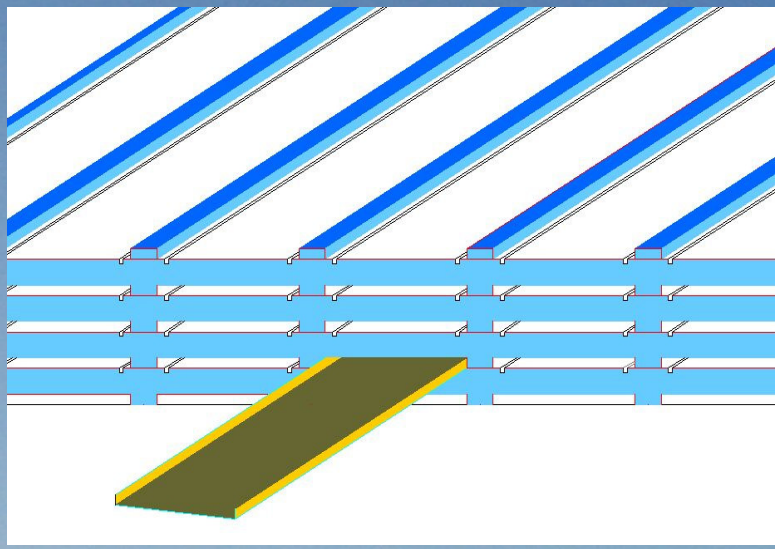
- *Neutrino Source*
  - *Need to cover a large L/E range*
    - *Large L range*
    - *Large E_ν Range*
  - *Use Atmospheric neutrinos as source*
- *Detector Choice*
    - *Should have large target mass (50-100 kT)*
    - *Good tracking and Energy resolution (tracking calorimeter)*
    - *Good directionality (<= 1 nsec time resolution)*
    - *Charge identification*
    - *Ease of construction*
    - *Modularity*
    - *Complimentarity with other existing and proposed detectors*
  - *Use magnetised iron as target mass and RPC as active detector medium*

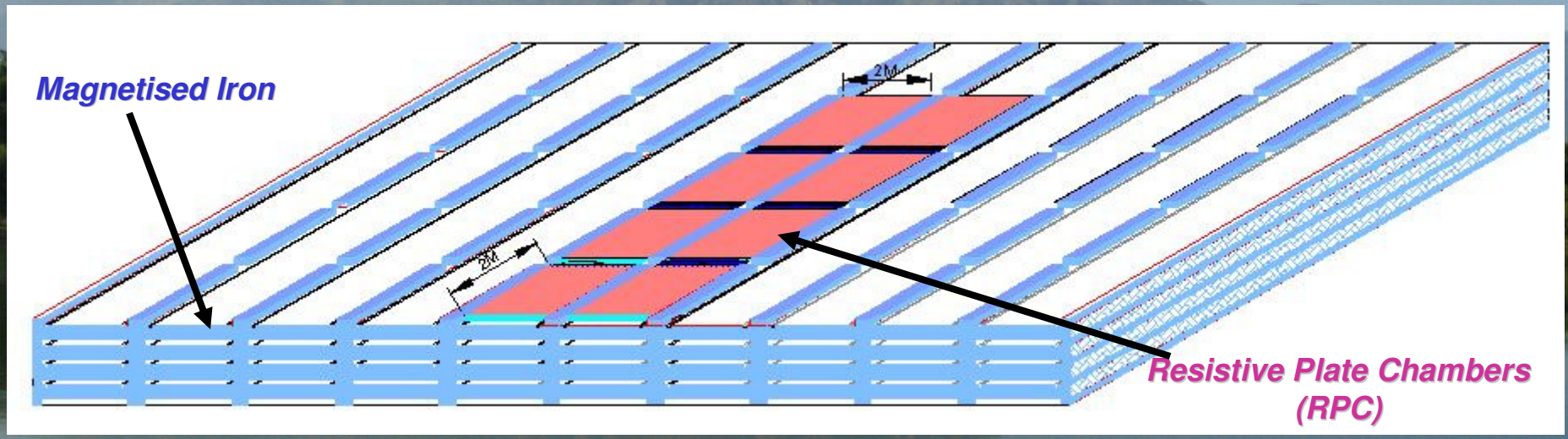
Ongoing INO R & D Activities

- *Development of various materials, processes, infrastructure and tools required for the detector R & D.*
- *Development of Resistive Plate Chambers (RPC).*
- *Development of Hybrid and ASIC based front end electronics & VME based Data Acquisition System.*
- *Design of a massive 50 kton magnet.*
- *Development of simulation and event reconstruction software packages.*
- *Development/setting up of WEB based tools for effective participation of remote collaborators in various R & D effort.*
- *INO Training school.*
- *Site selection.*

INO Detector Concept



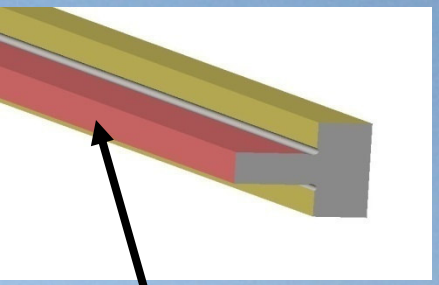




Largest Basic Science Project in the country

No of modules	3
Module dimension	16 m X 16 m X 12 m
Detector dimension	48 m X 16 m X 12 m
No of layers	140
Iron plate thickness	6 cm
Gap for RPC trays	2.5 cm
Magnetic field	1.5 Tesla
RPC unit dimension	2 m X 2 m
Readout strip width	2 cm
No. of RPCs/Road/Layer	8
No. of Roads/Layer/Module	8
No. of RPC units/Layer	192
Total no of RPC units	27000
No of Electronic channels	3.6×10^6

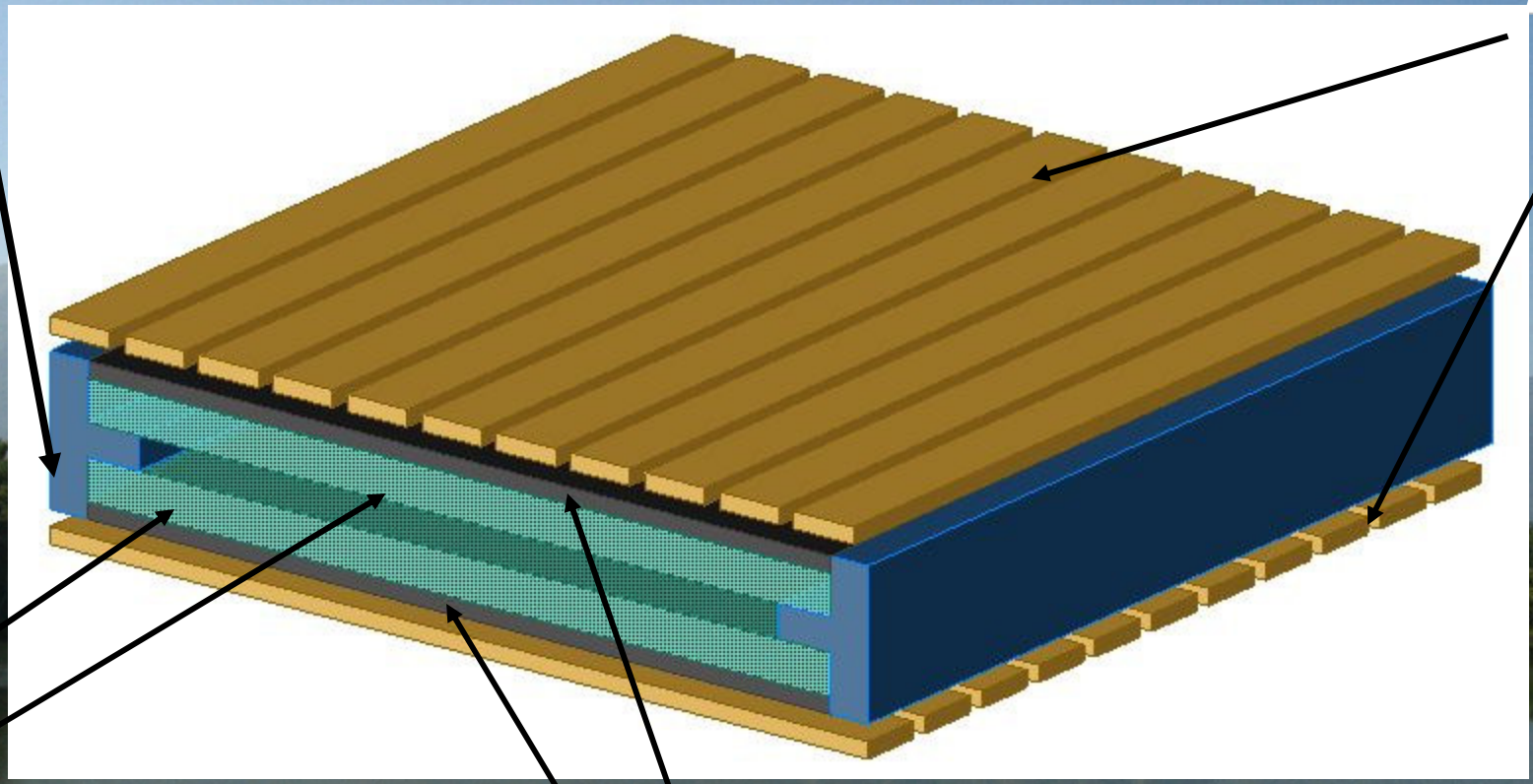
Construction of RPC



2 mm thick spacer

Two 2 mm thick float Glass
Separated by 2 mm spacer

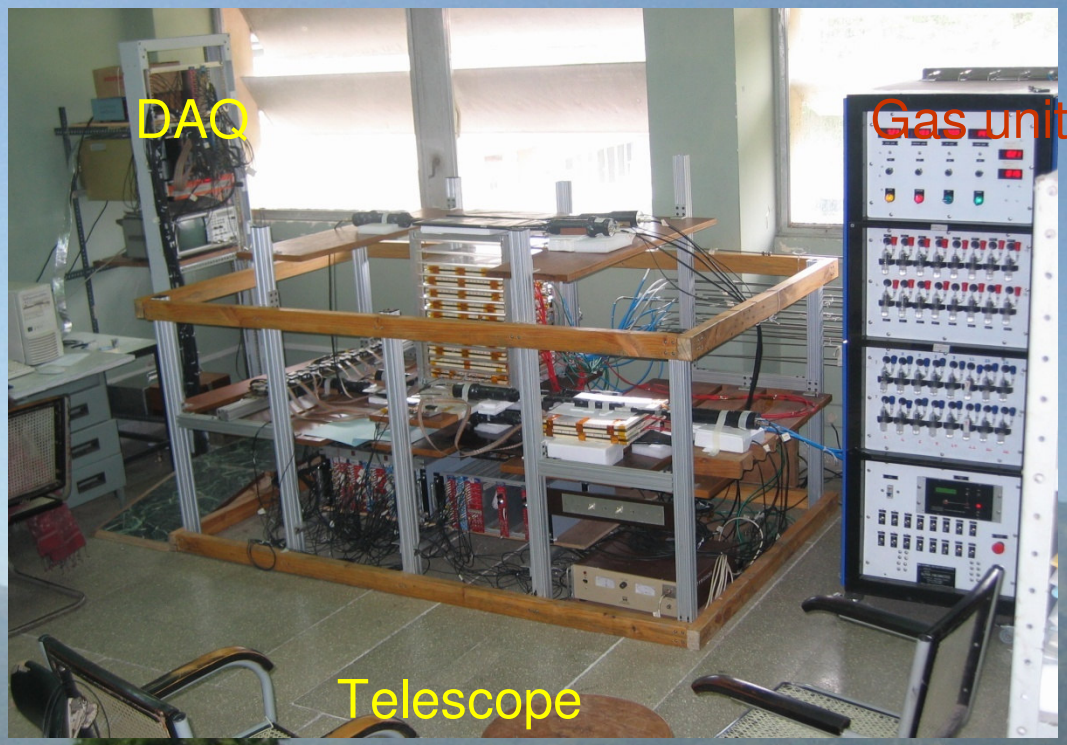
Pickup strips

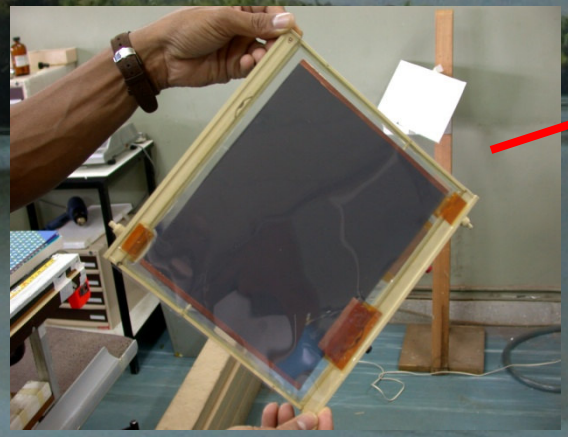


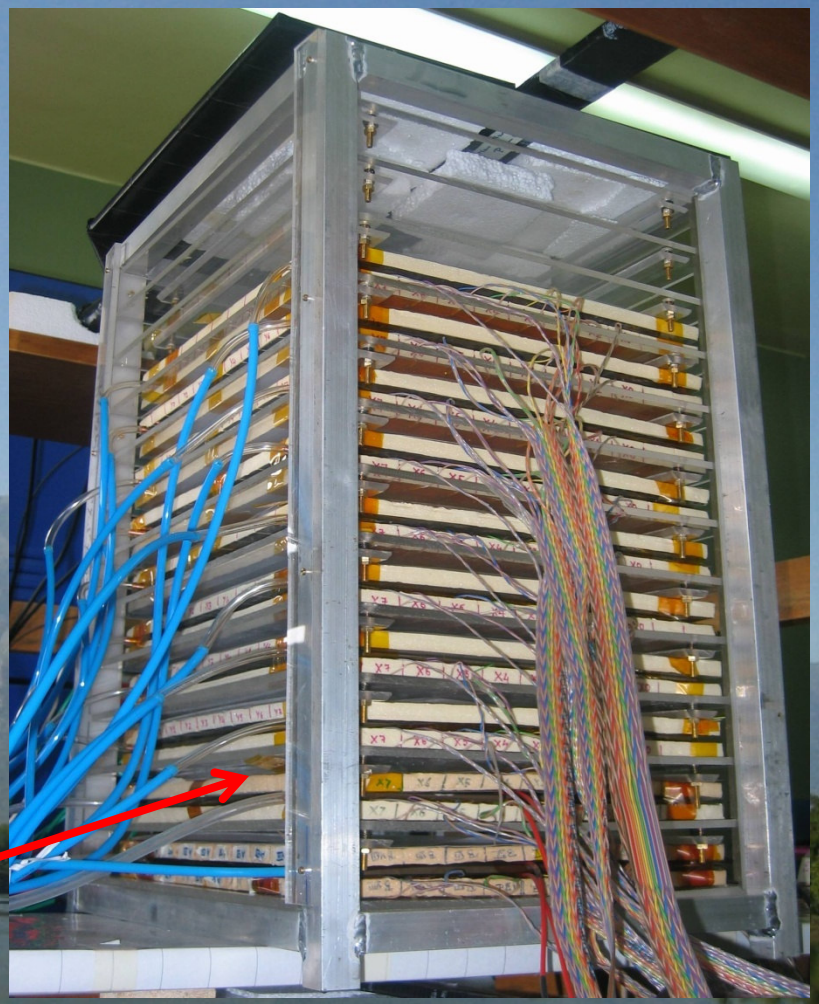
Glass plates

Resistive coating on the outer surfaces of glass

Cosmic Muon Test using small RPCs

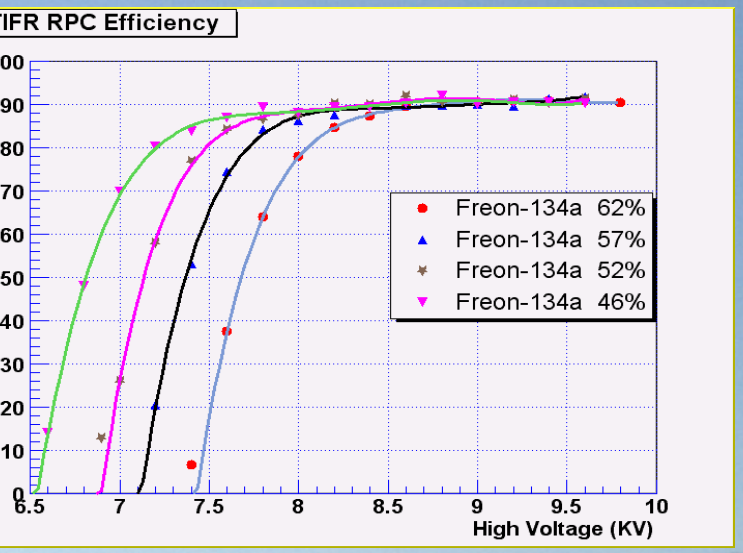


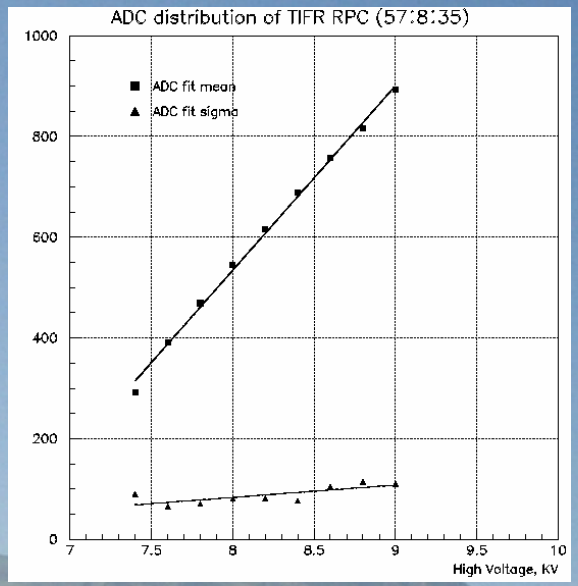


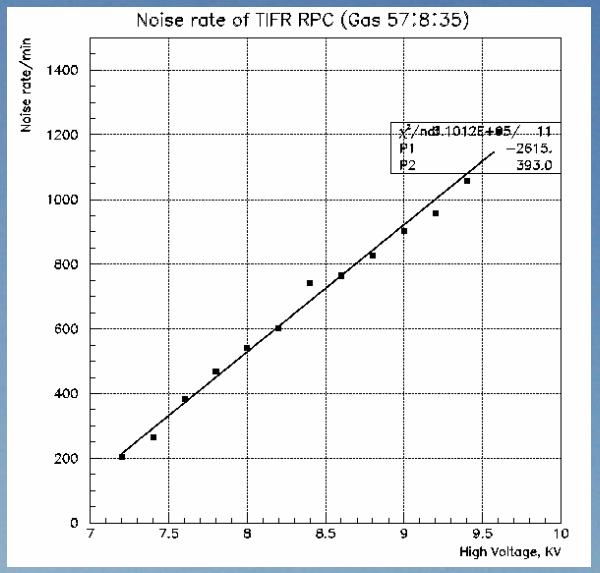


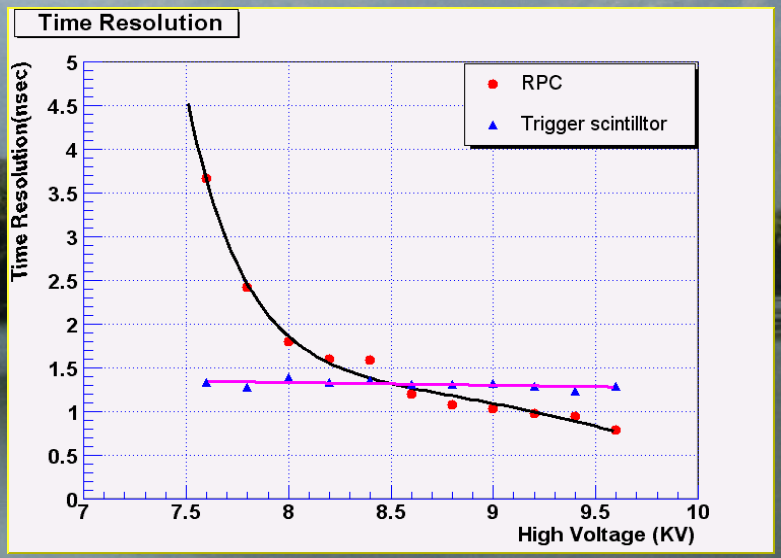
Stack of 10 RPCs

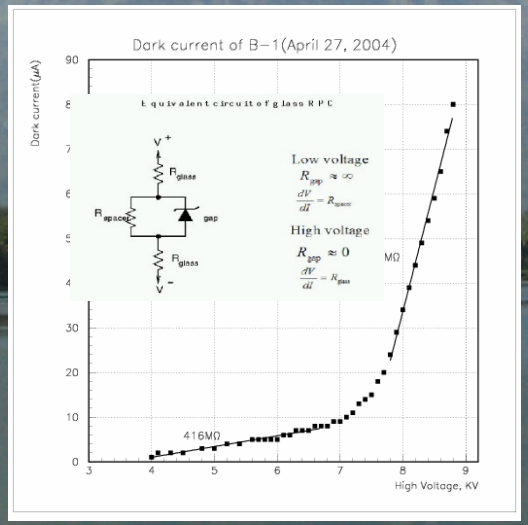
Early results





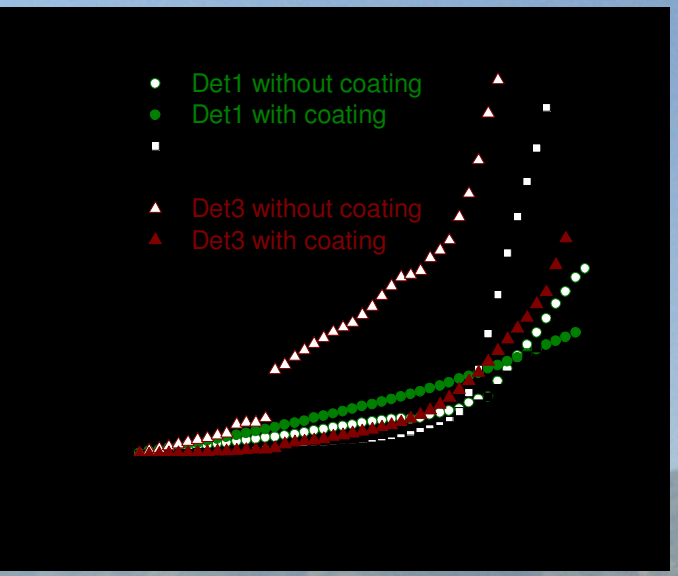


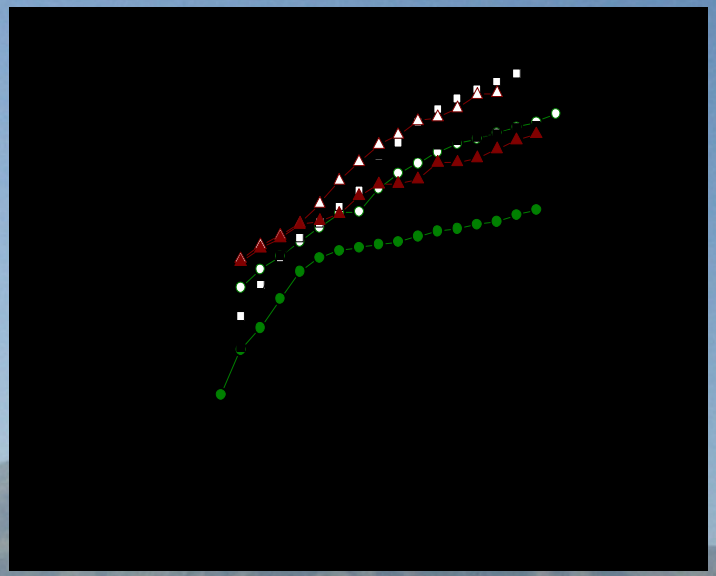


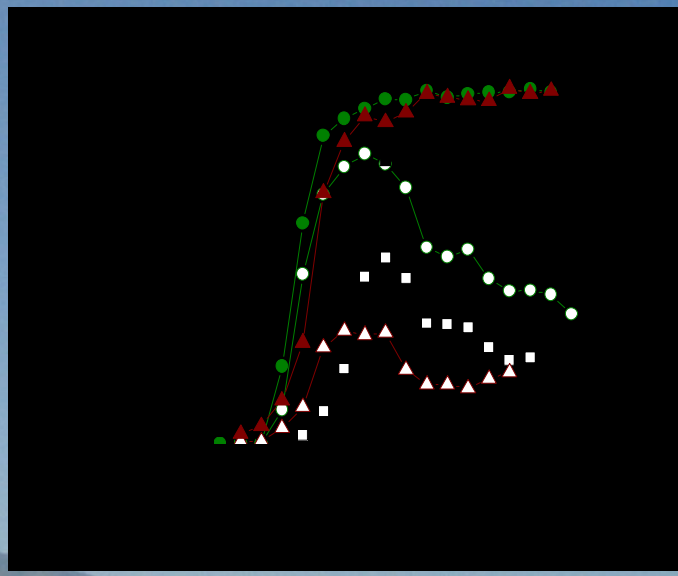


Gas Mixture	Tele window (mm)	Cross talk (%)
62:8:30	10	6.8
62:8:30	15	6.7
62:8:30	20	6.2
57:8:35	20	6.5
52:8:40	20	5.9
46:8:46	20	6.3

R & D on Bakelite RPC @ Kolkata





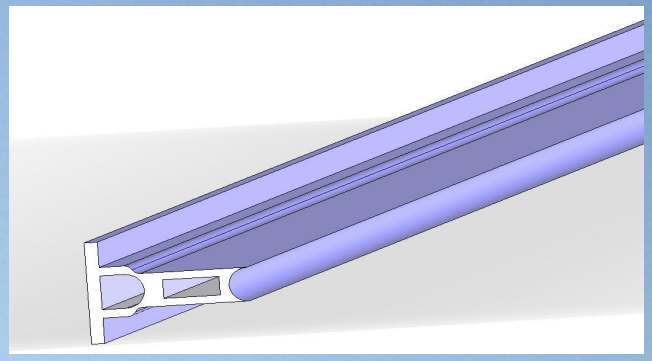


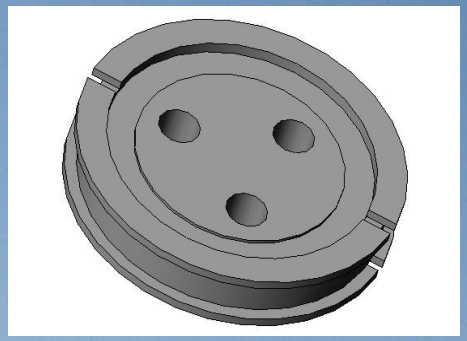
With silicone coating

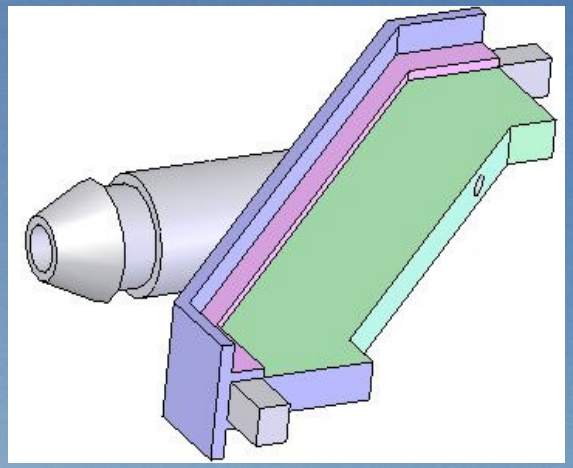
- *Efficiency plateau >96% obtained*
- *Counting rate decreased*
- *Current decreased*

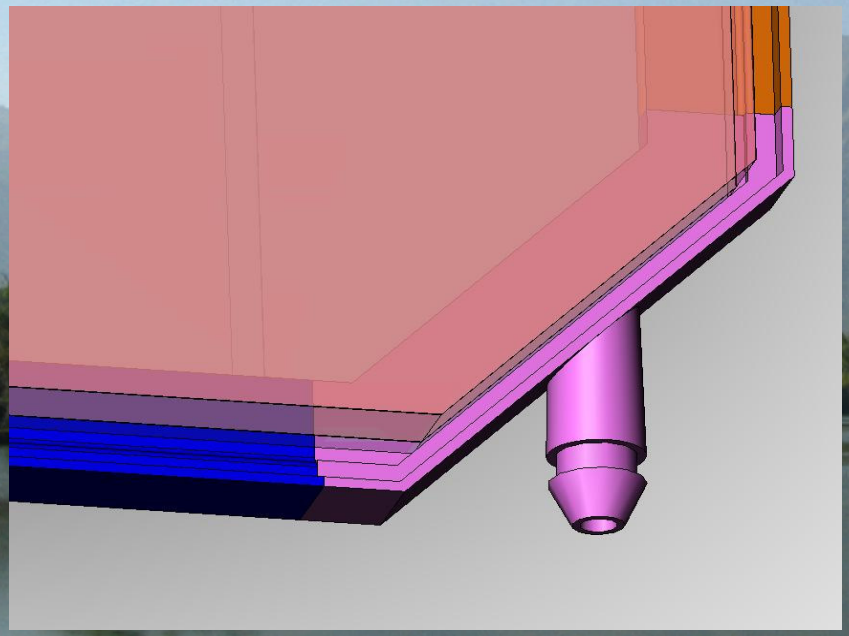
17

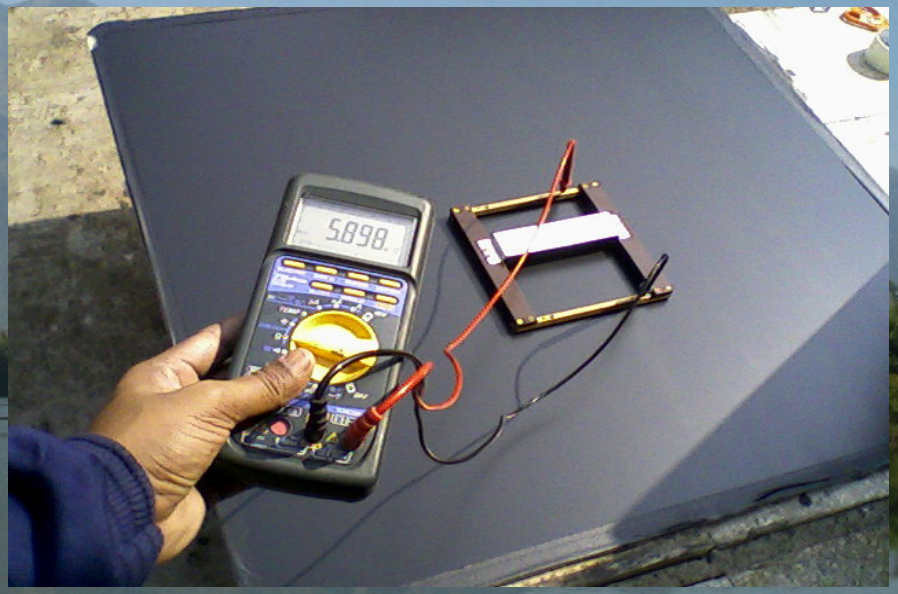
RPC building blocks



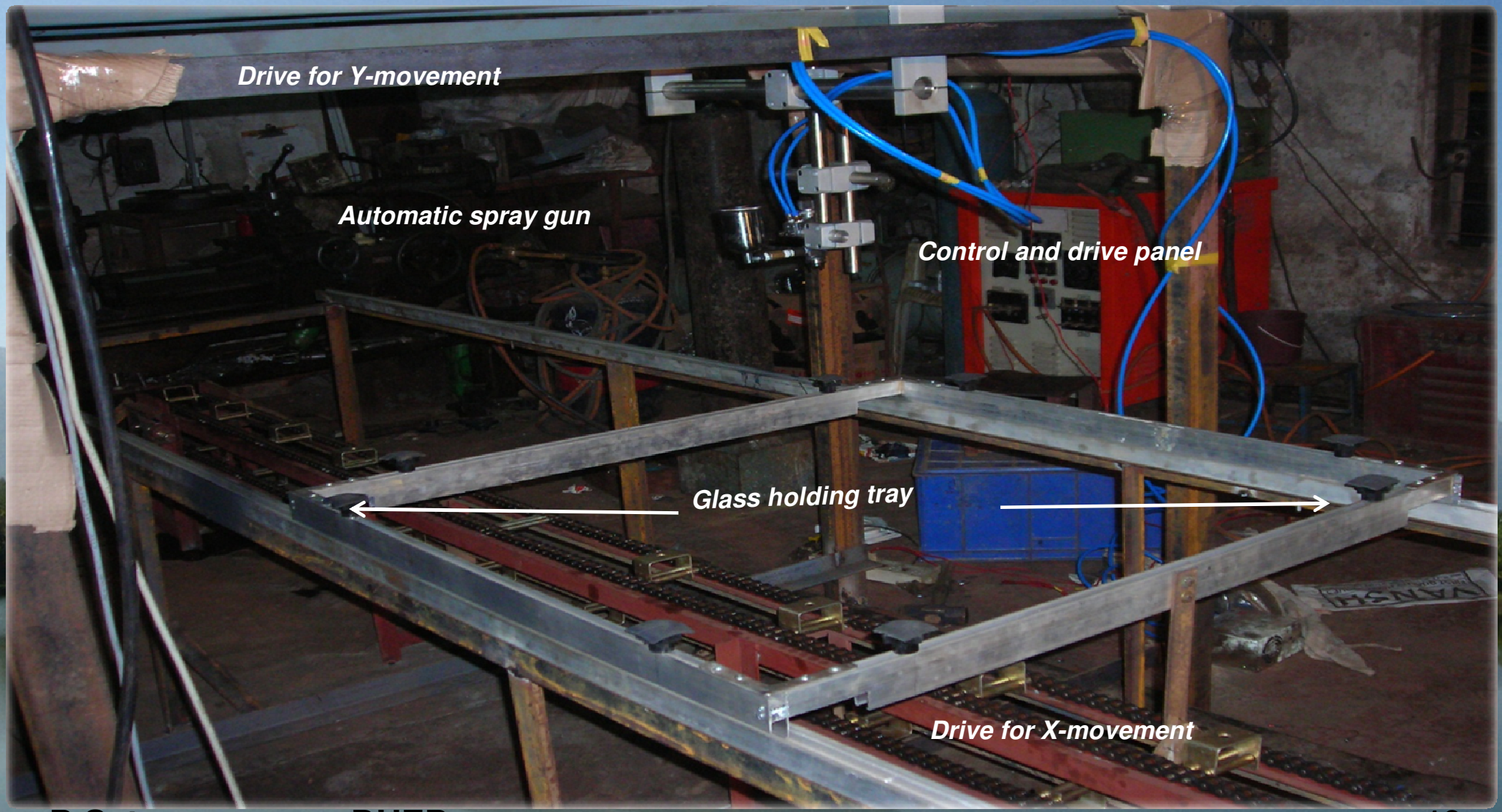








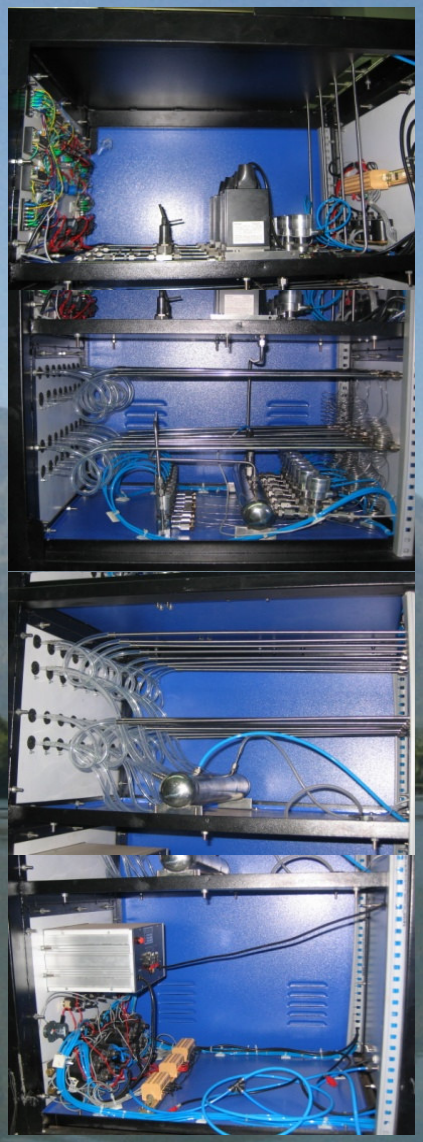
Automatic spray paint plant



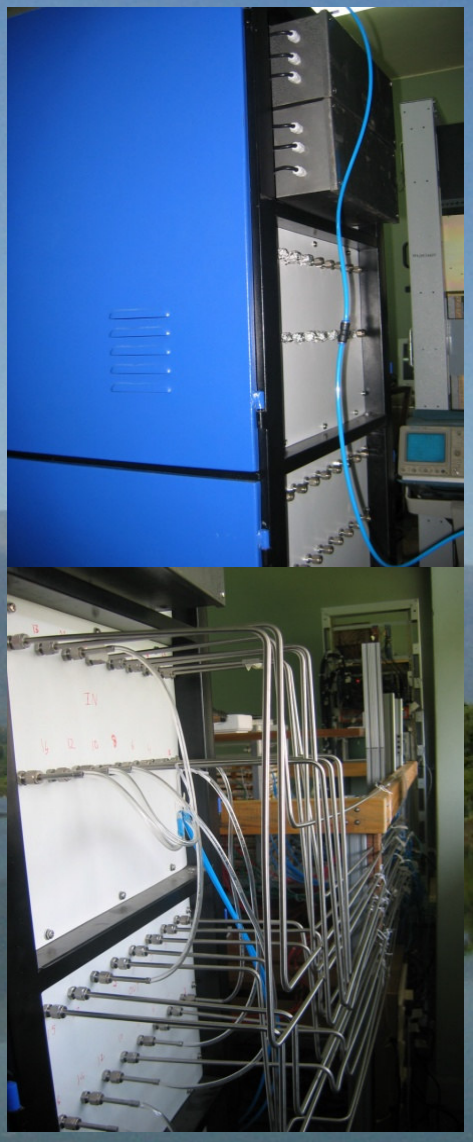
Constructional details of the gas system

Front view

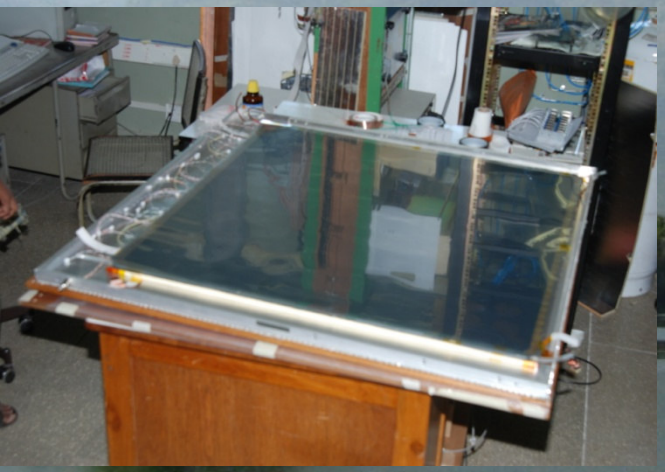
Internal view



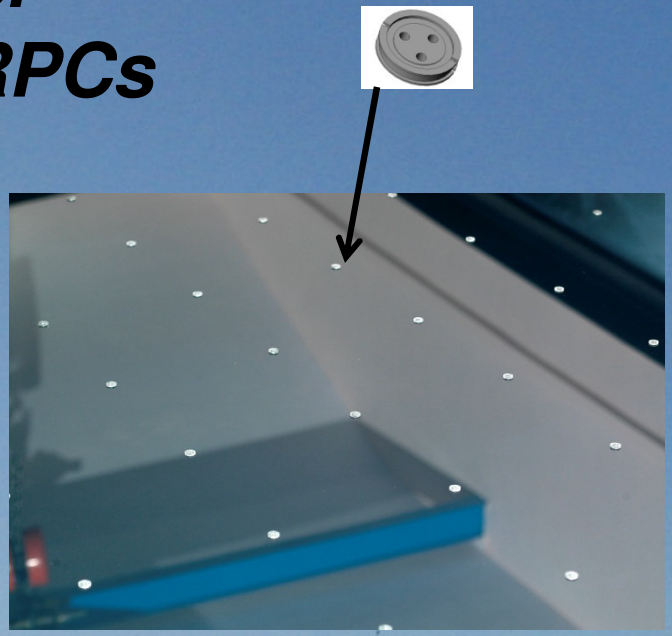
Rear view

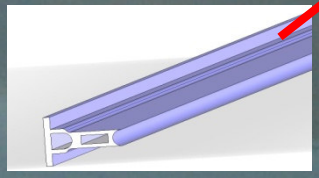


Fabrication of 1m x 1m RPCs



Final RPC Frontier
making of 2m x 2m RPCs





A journey through RPC road

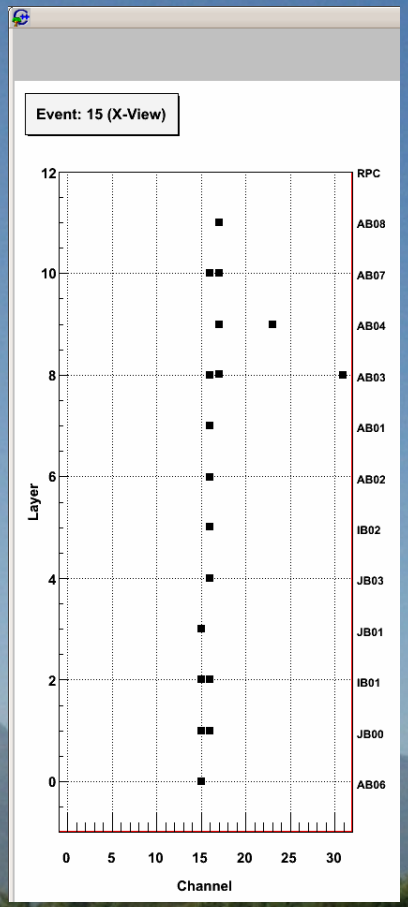
200 cm x 200 cm

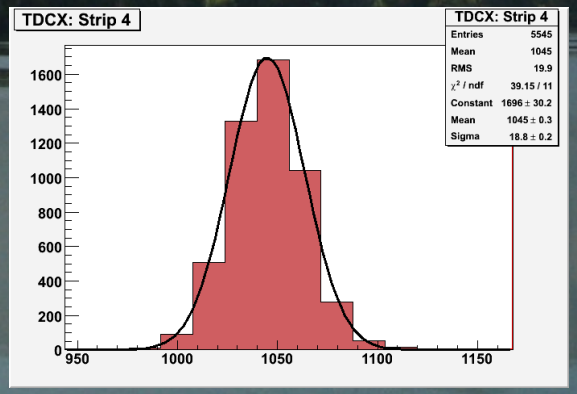
30 cm x 30 cm

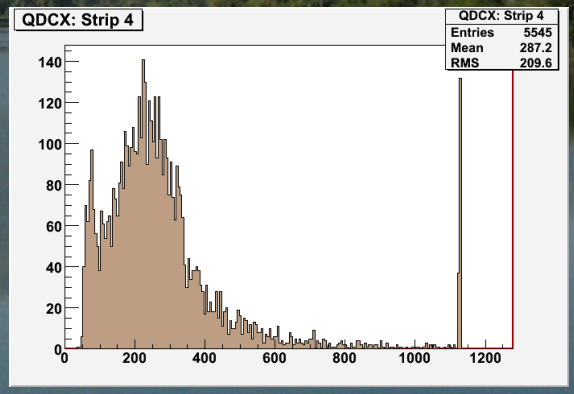
10 cm x 30 cm

100 cm x 100 cm

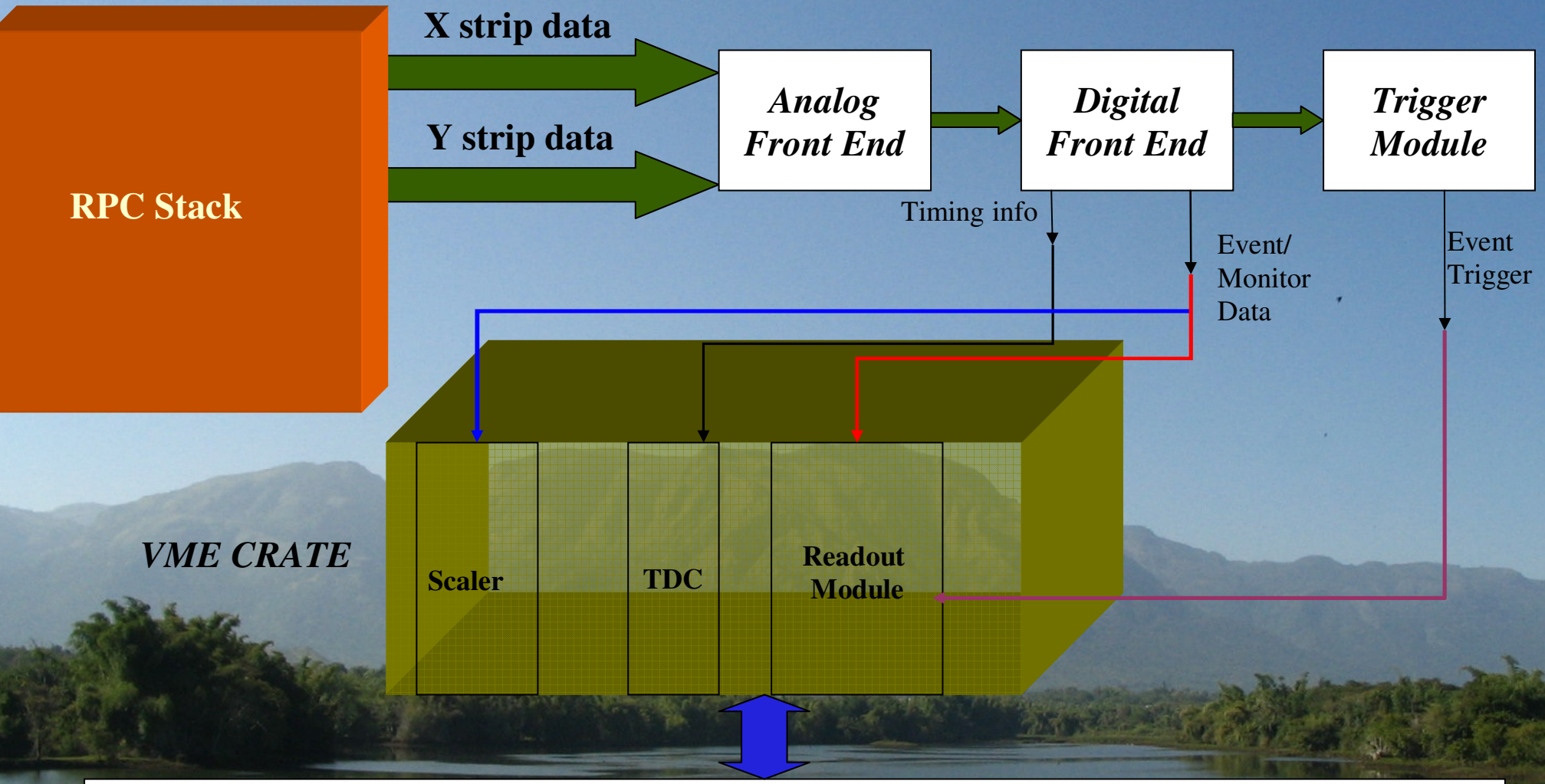
Prototype RPC Stack at TIFR tracking Muons







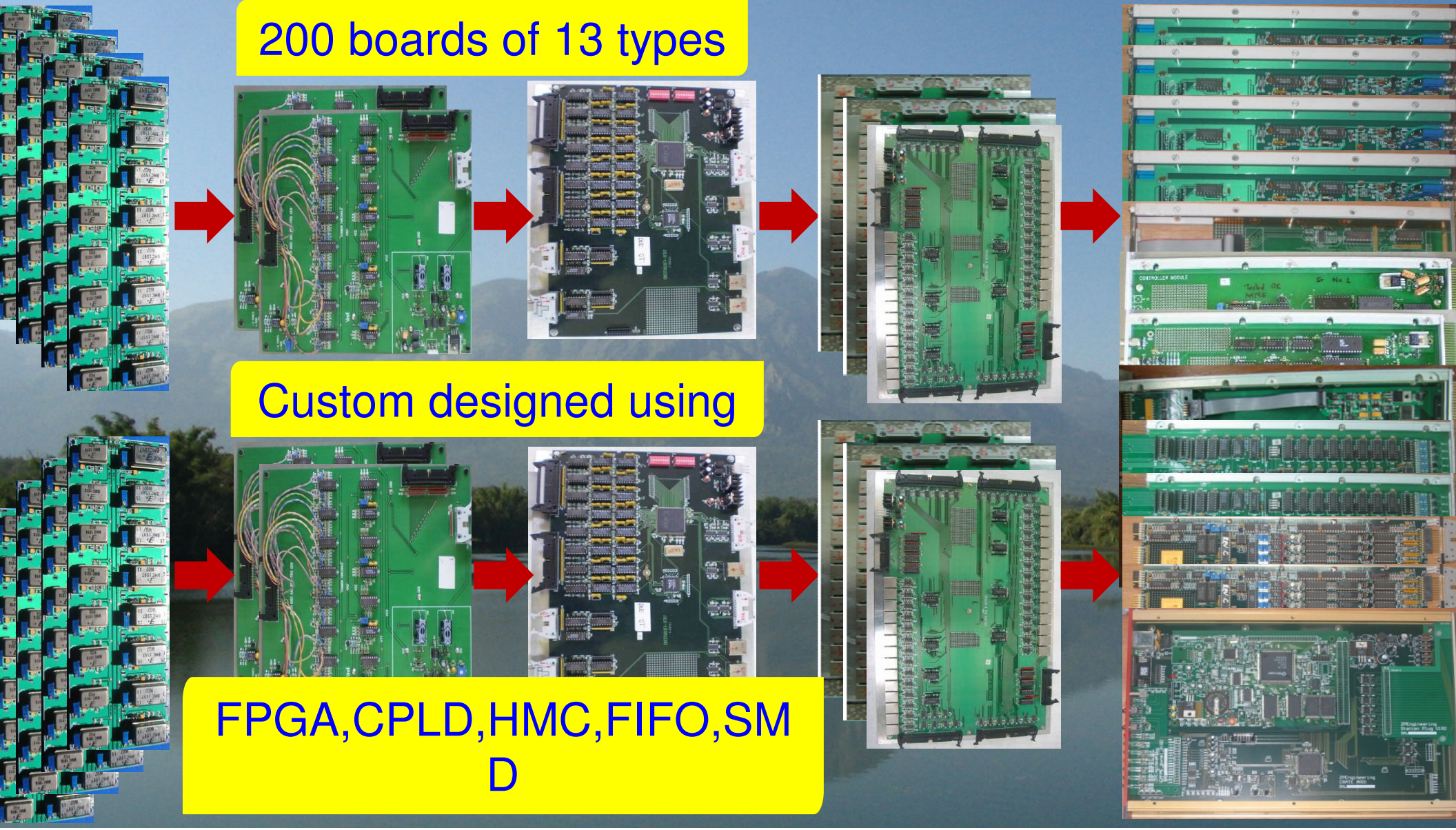
VME BASED DAQ SETUP



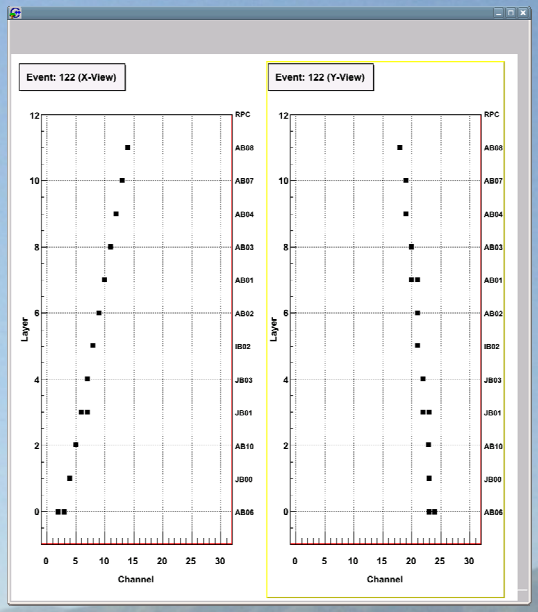
Linux based DAQ software (C++, Qt, ROOT)

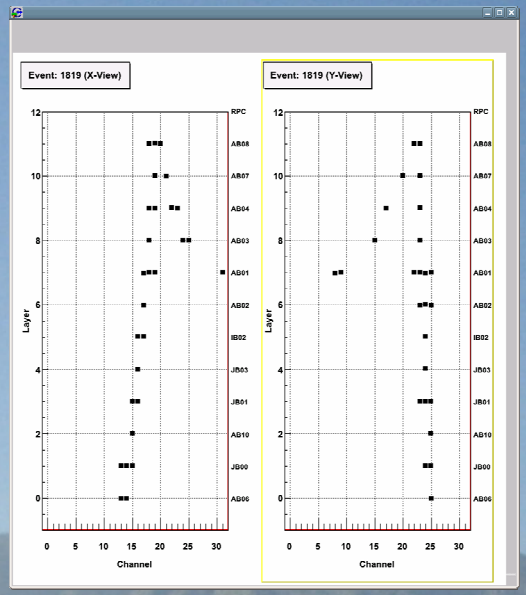
- ✓*Interrupt Based*
- ✓*Multi-Threaded*
- ✓*Graphical User Interface*
- ✓*Online 2D/3D Event Display*
- ✓*RPC Strip Monitoring*
- ✓*Online Error Reporting*

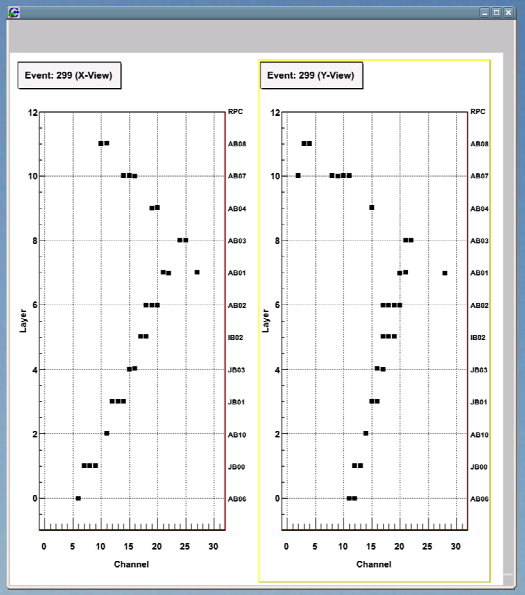
Design and implementation of the data acquisition system

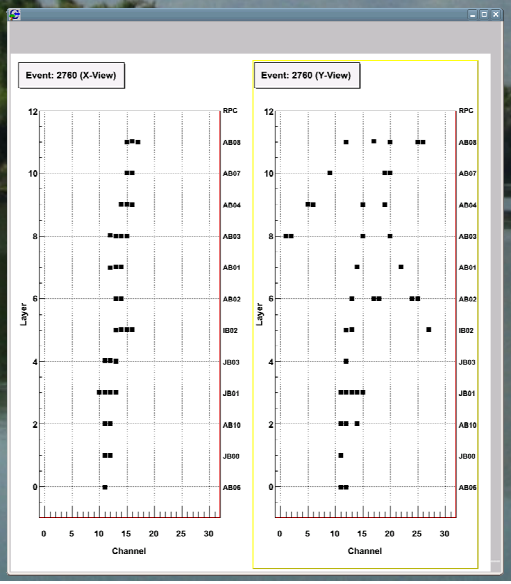


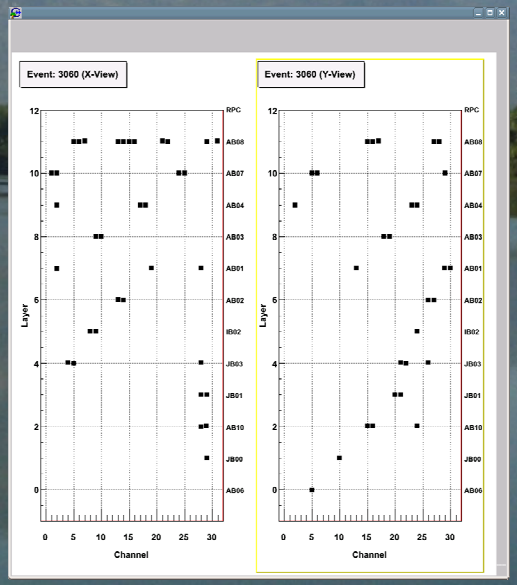
Some interesting cosmic ray tracks



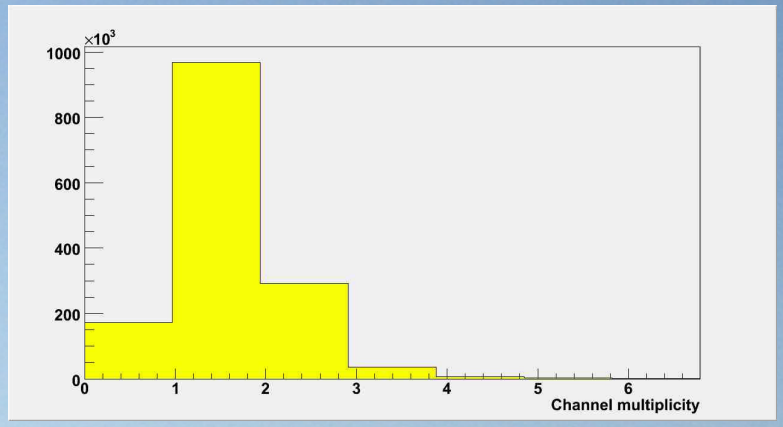




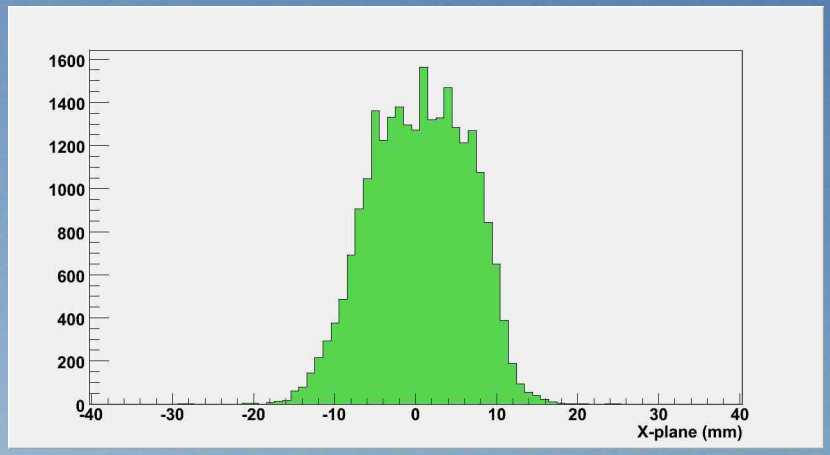




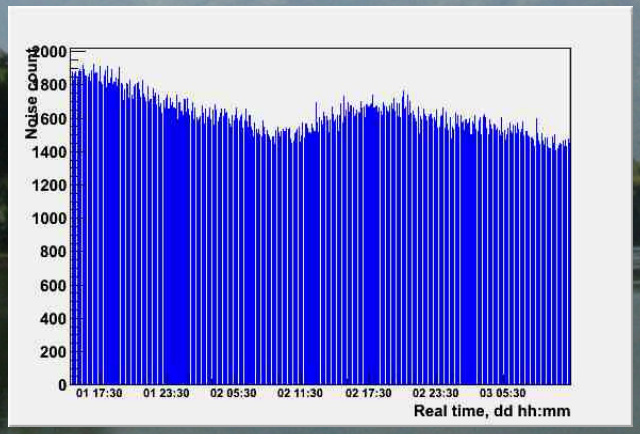
Study of RPC performance using cosmic muons



Strip Multiplicity due to crossing muons



Track residue in mm



Strip noise rate vs time

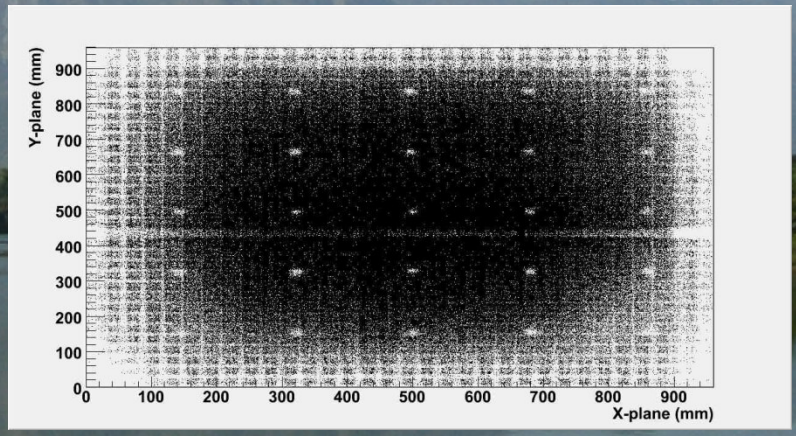
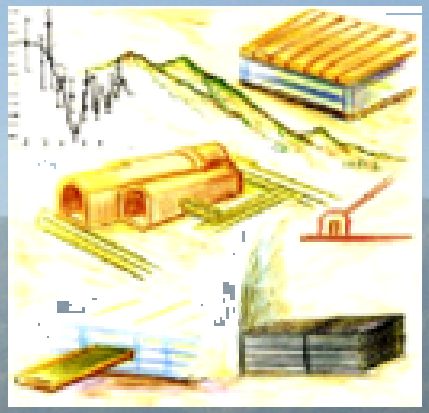


Image of a RPC using muons

RESISTIVE PLATE CHAMBERS AND RELATED DETECTORS (RPC2007)

Proceedings of the 9th International Workshop on Resistive Plate Chambers and Related Detectors

Tata Institute of Fundamental Research, Mumbai, India
13–16 February 2008



UNCORRECTED PROOF

Editors

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TIFR, India

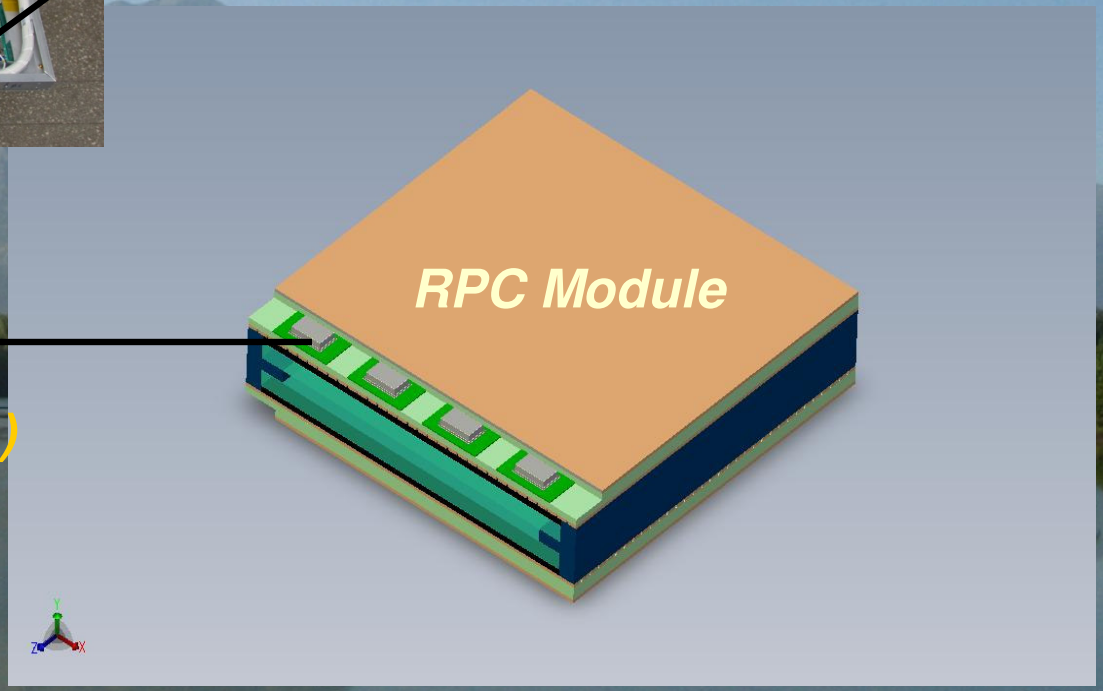
S.R. Ratti
Pavia, Italy

R. Santonico
University of Rome Tor Vergata, Rome, Italy

Miniaturization of front end electronics

Hybrid Preamplifier

(What we have now)



ASIC

(Where we want to go)

Fast Pre-Amplifier Cascade stage 0.35 µ

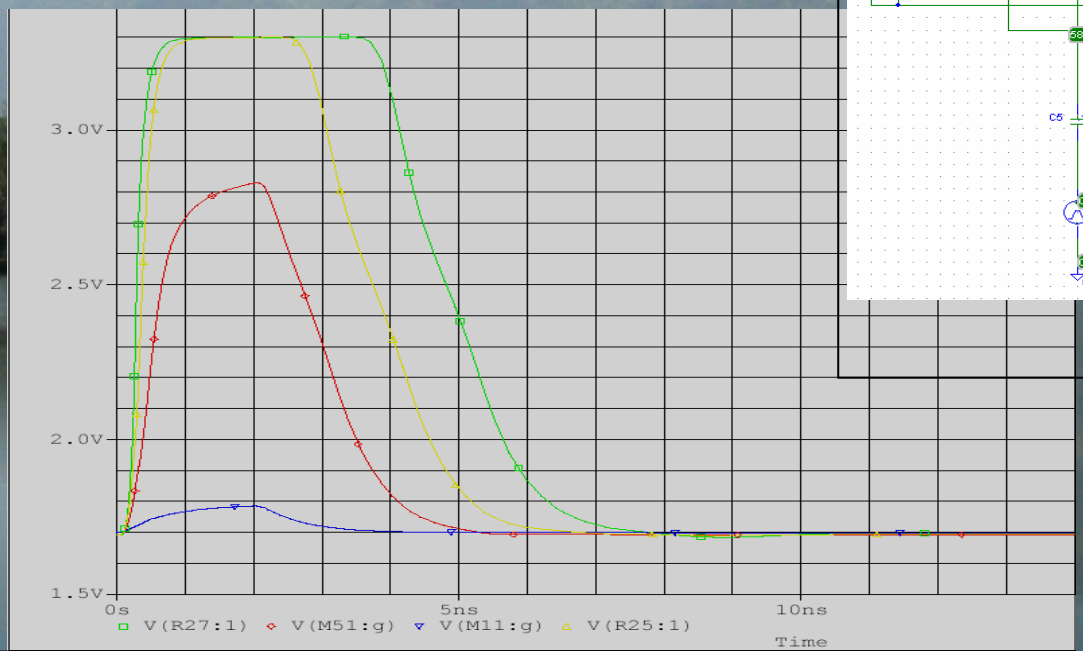
Solution in ASIC …

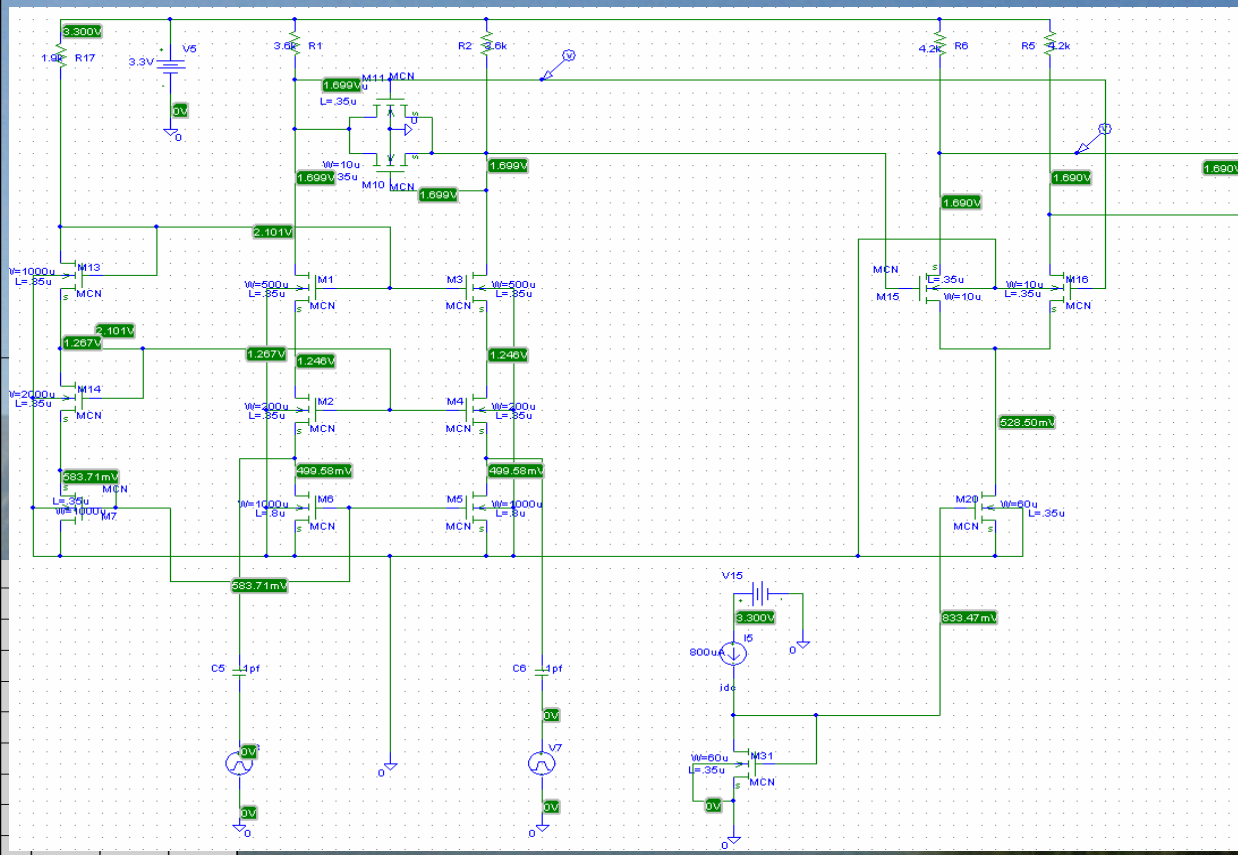
improved further

Key Features =>

- *Rise Time : < 1 nsec*
- *Power Consumption :100mw*
  ~ Now ~10mW
- *Power Supply : 3.3V*
- *Technology : 0.35u process*

Simulated Results …





50ff -350ff

FAST Comparator ~
1.2ns
Tr,Tf Tp

INO FE: Improved Architecture Regulated Cascade

(Preamp: 0.18u process)

Regulated cascade input stage

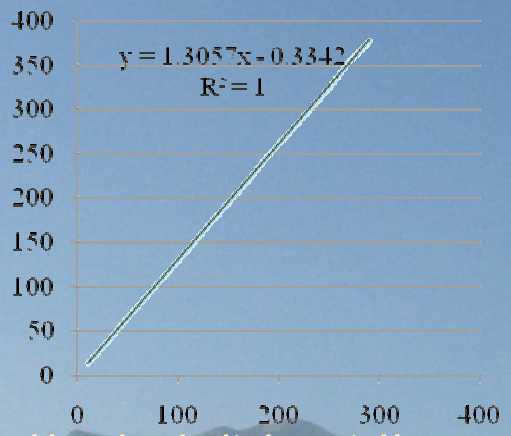
Rise time < 0.5ns

I/p Impedance : 50 ohm @ 350MHz
(s11 < -10dB upto 1GHz)

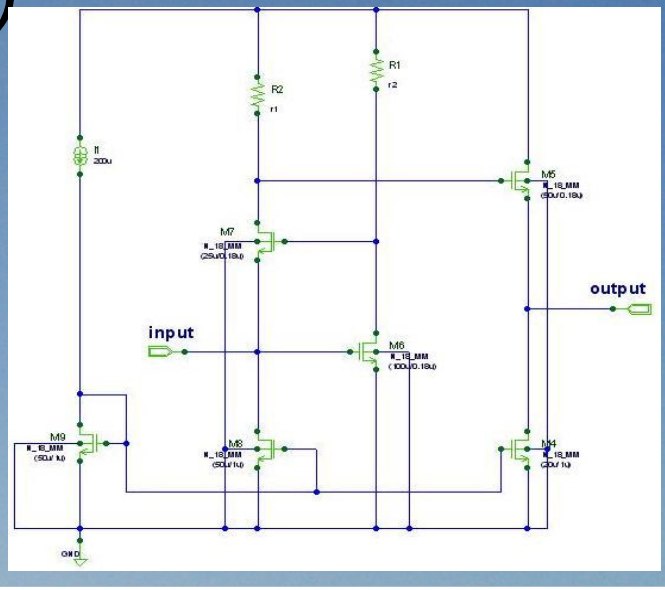
Gain : 62 dB

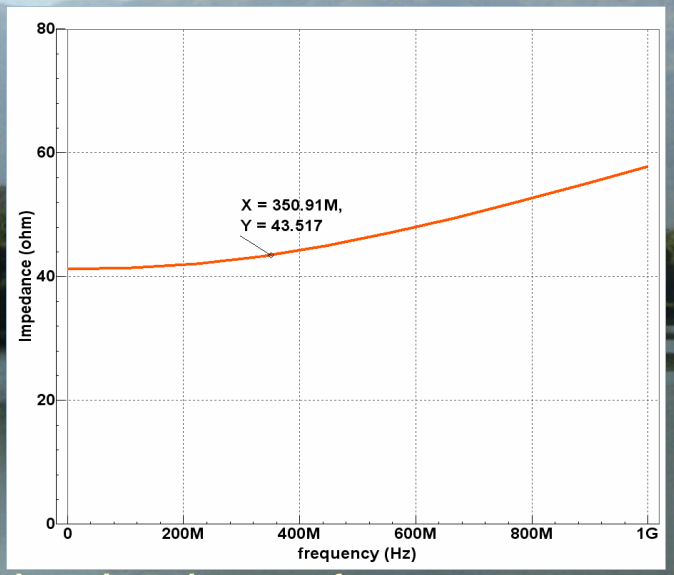
3-dB Bandwidth : 1.5 GHz

Power Consumption : 4mW (approx)

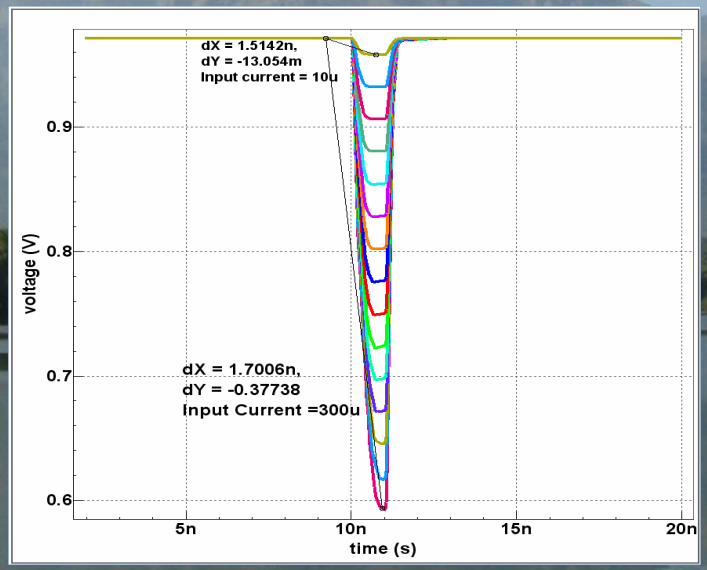


Linearity plot i/p I vs. o/p V

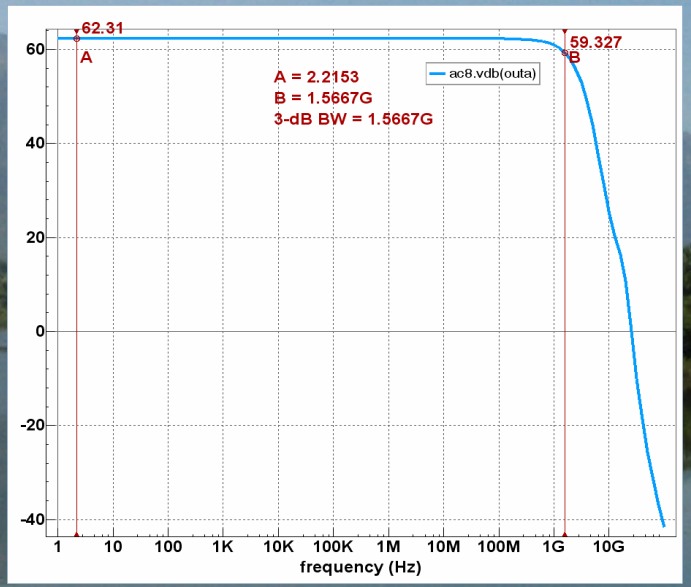




Input Impedance vs. frequency



Input current varied from 10u to 300u



FE gain vs. Frequency

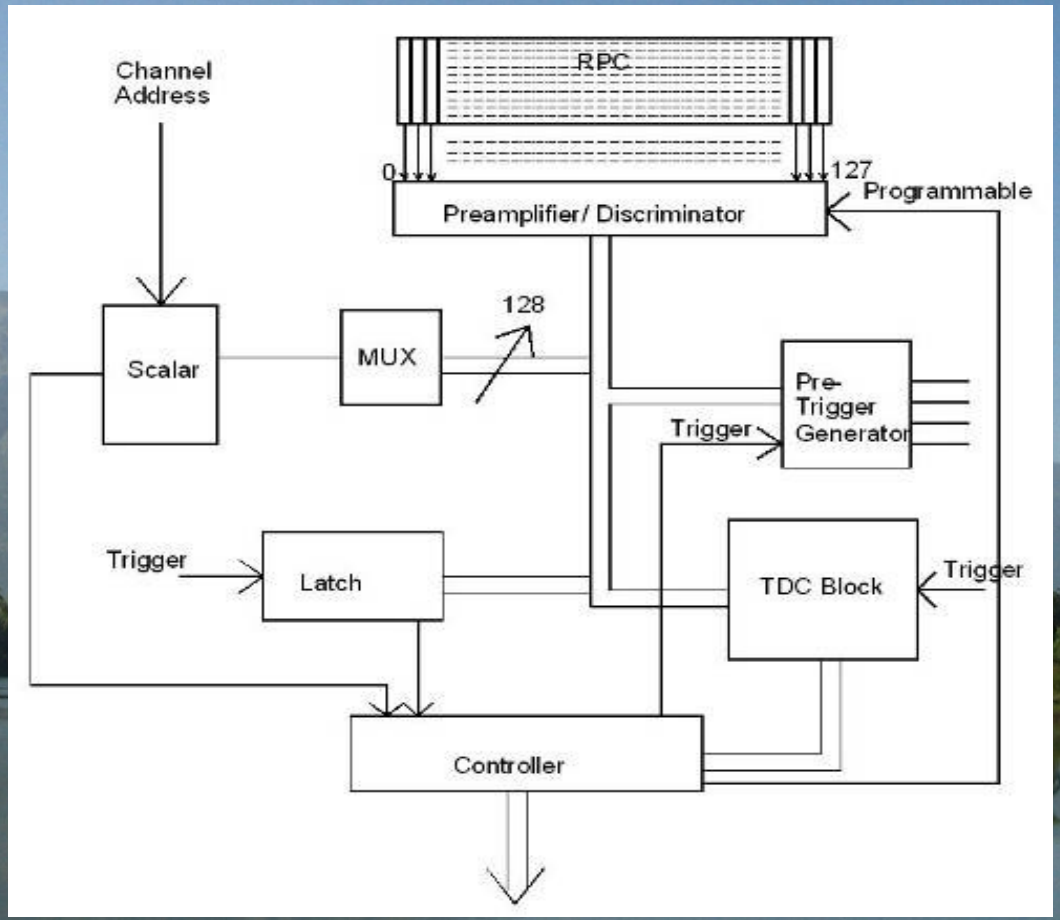
Fabrication of ASIC in the country

- **On 1st June, while delivering his 1st TIFR Foundation Day Talk, Dr. Kakodkar reminded us about missing the Micro-electronics revolution in India.**
- **We need to be at par in ASIC design and Fabrication with rest of the world.**
- **We do have within the DAE family the necessary design expertise.**
- **Need latest VLSI fabrication facility in the country.**

Proposed Front End Electronics: Triggered scheme

RPC , a unit for front-end processing

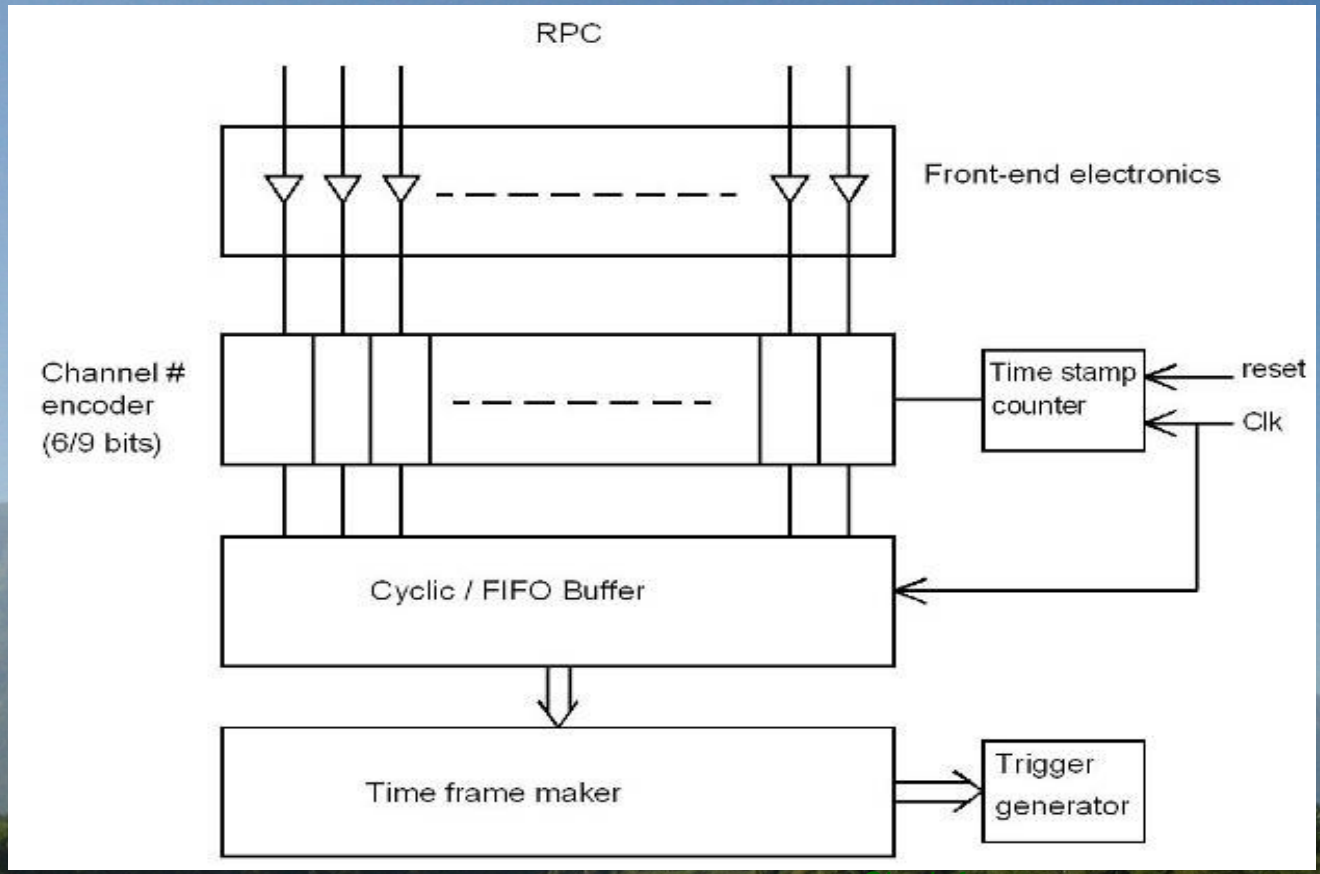
- *Conventional architecture*
- *Dedicated sub-system blocks for performing various data readout tasks*
- *Need for Hardware based on-line trigger system*
- *Trigger latency issues and how do we take care in implementation*
- *Synchronisation of trigger/global clock signals*



Trigger-less scheme

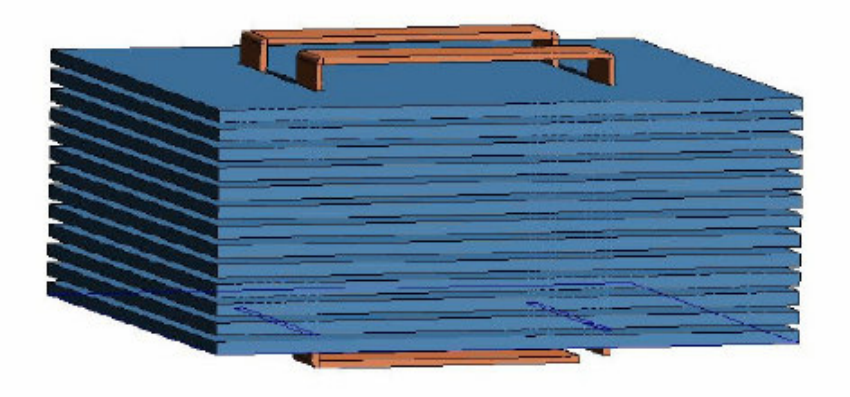
Suitable for low event rate and low background/noise rates

On-off control and V_{th} control to disable noisy channels

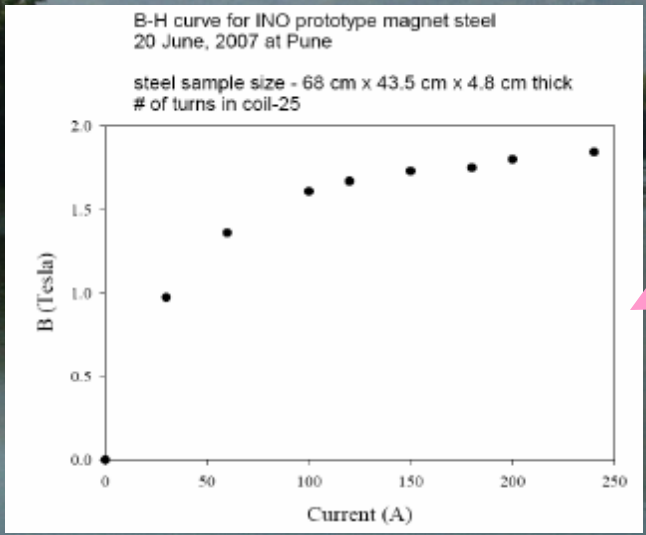


Clock frequency considerations

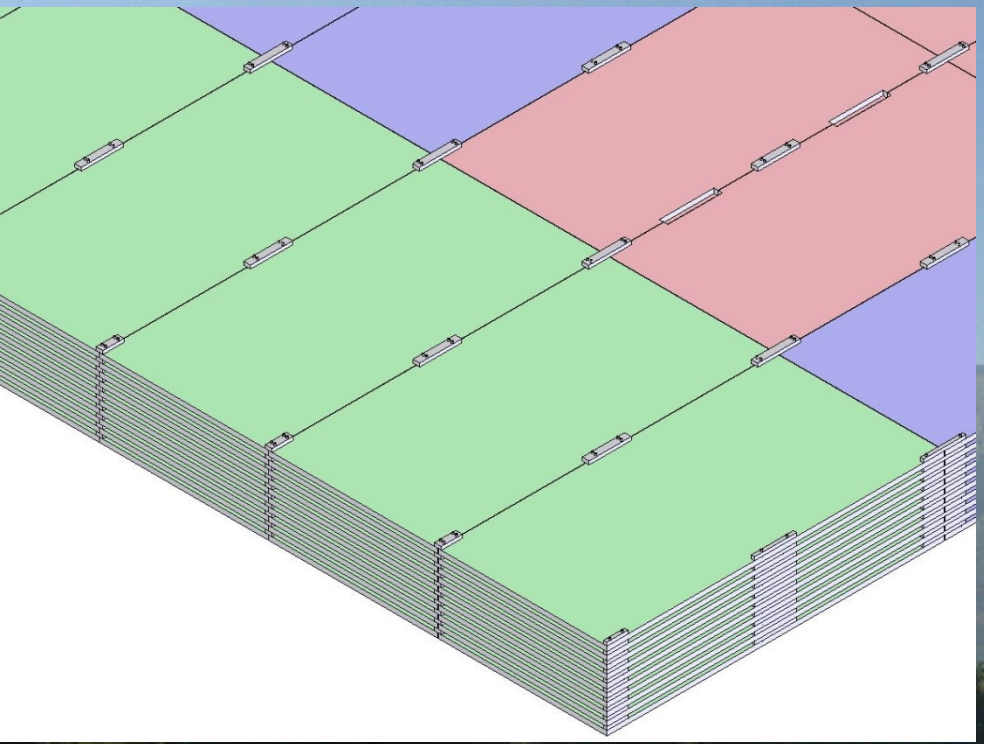
INO Prototype Magnet now at VECC

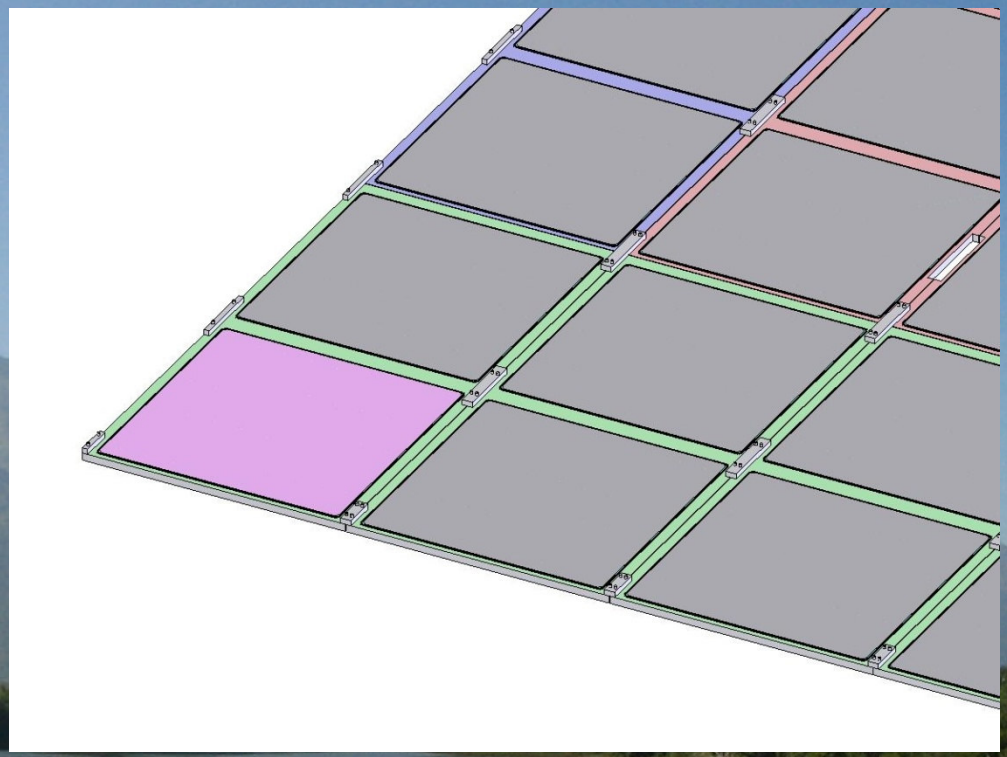


- *12, 1m^2 RPC layers*
- *13 layers of 5 cm thick magnetised iron plates*
- *About 1000 readout channels*
- *RPC and scintillation paddle triggers*
- *Hit and timing information*

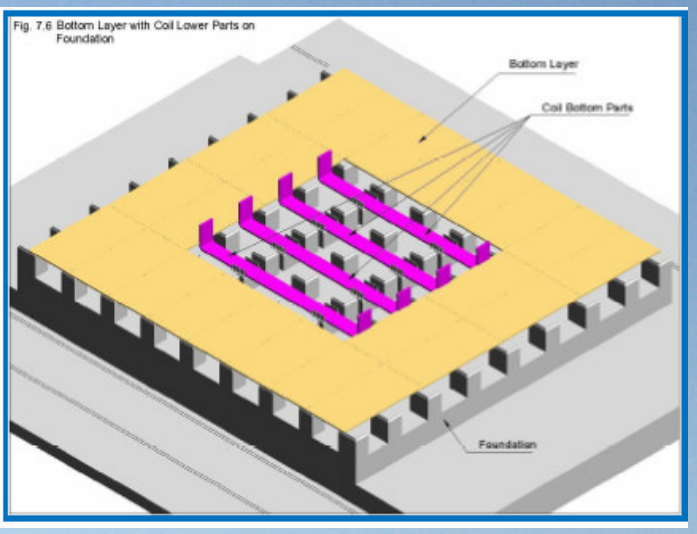


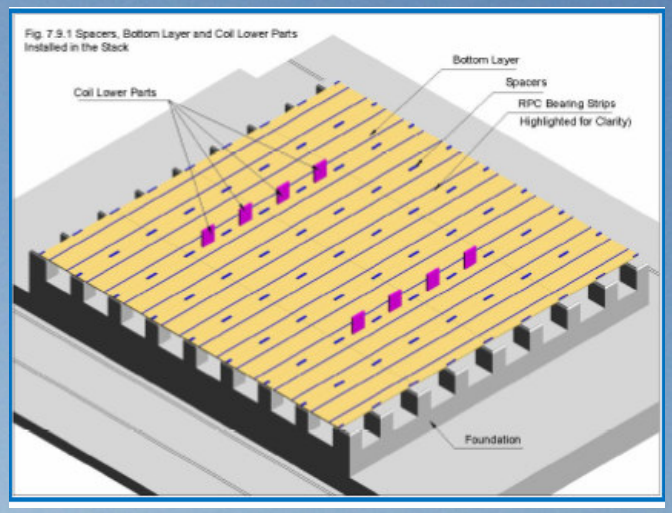
Construction of the INO-ICAL

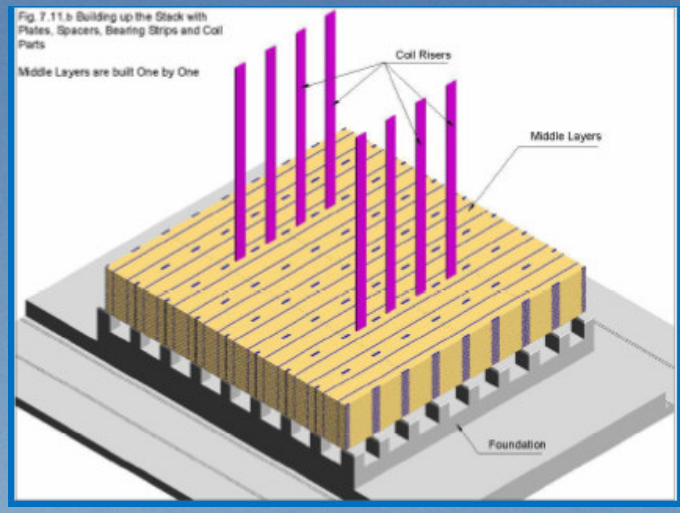


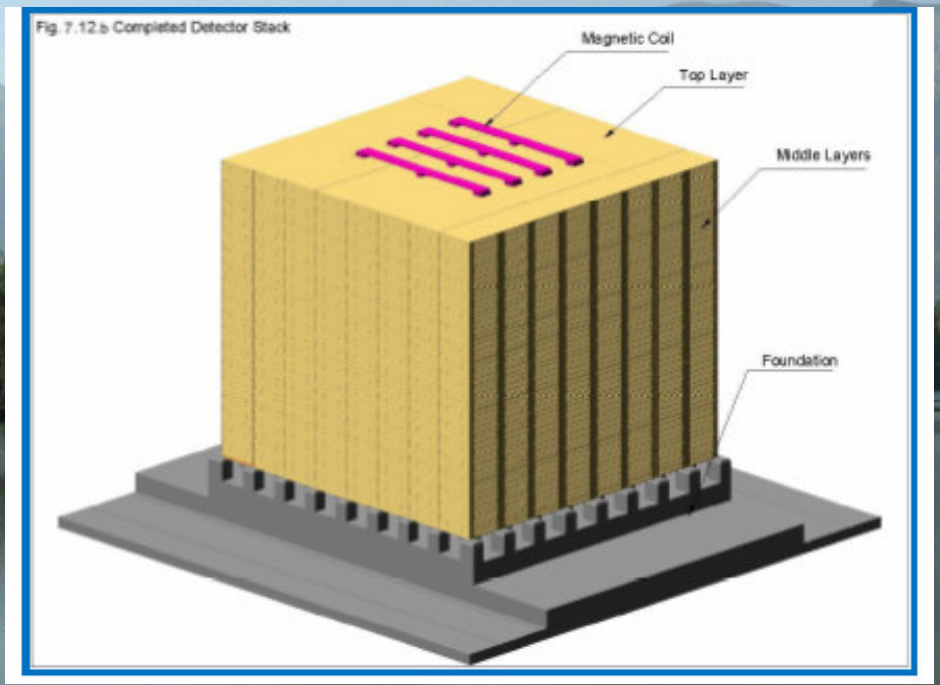


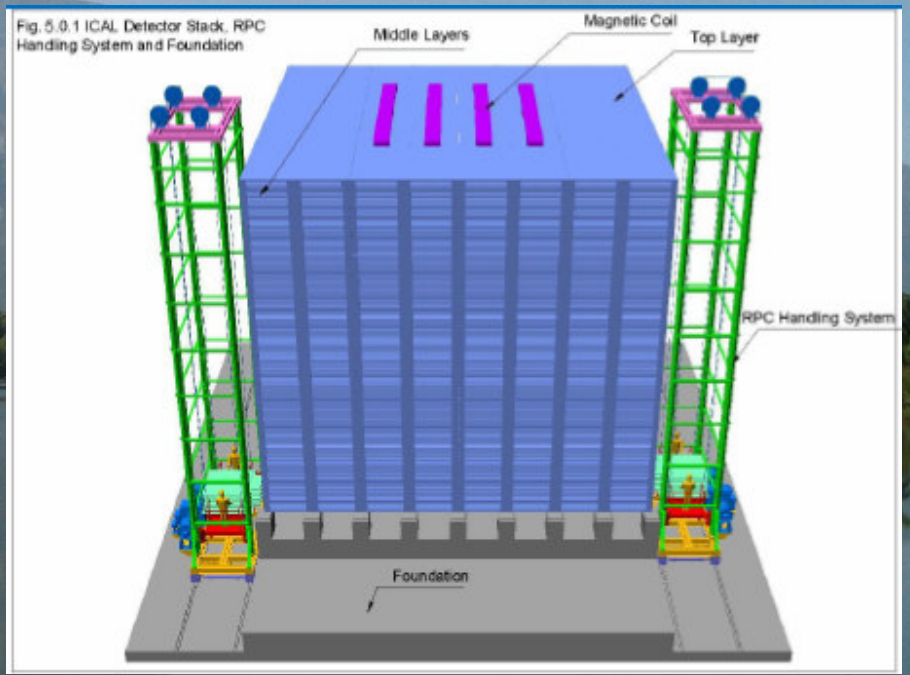
Construction of the ICAL detector





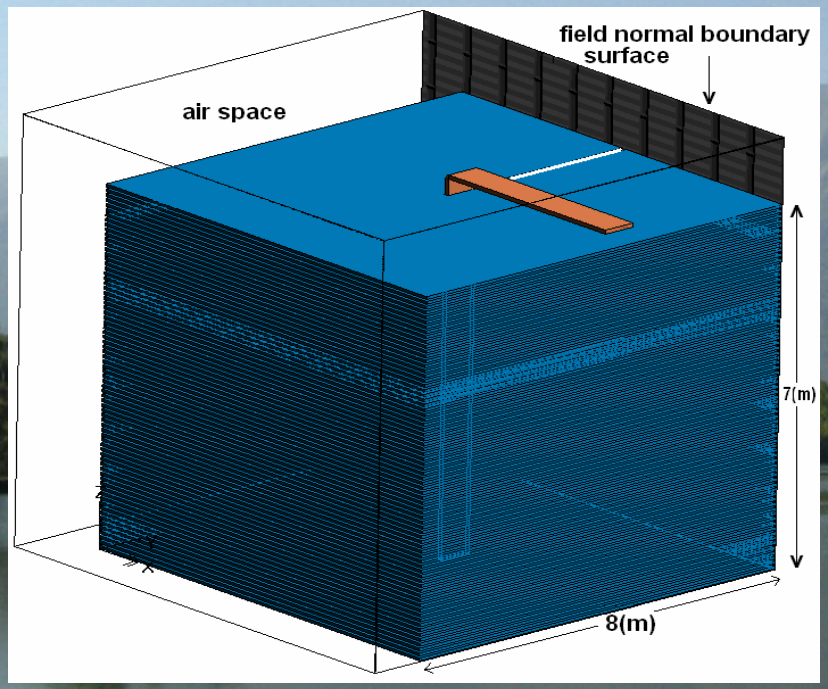


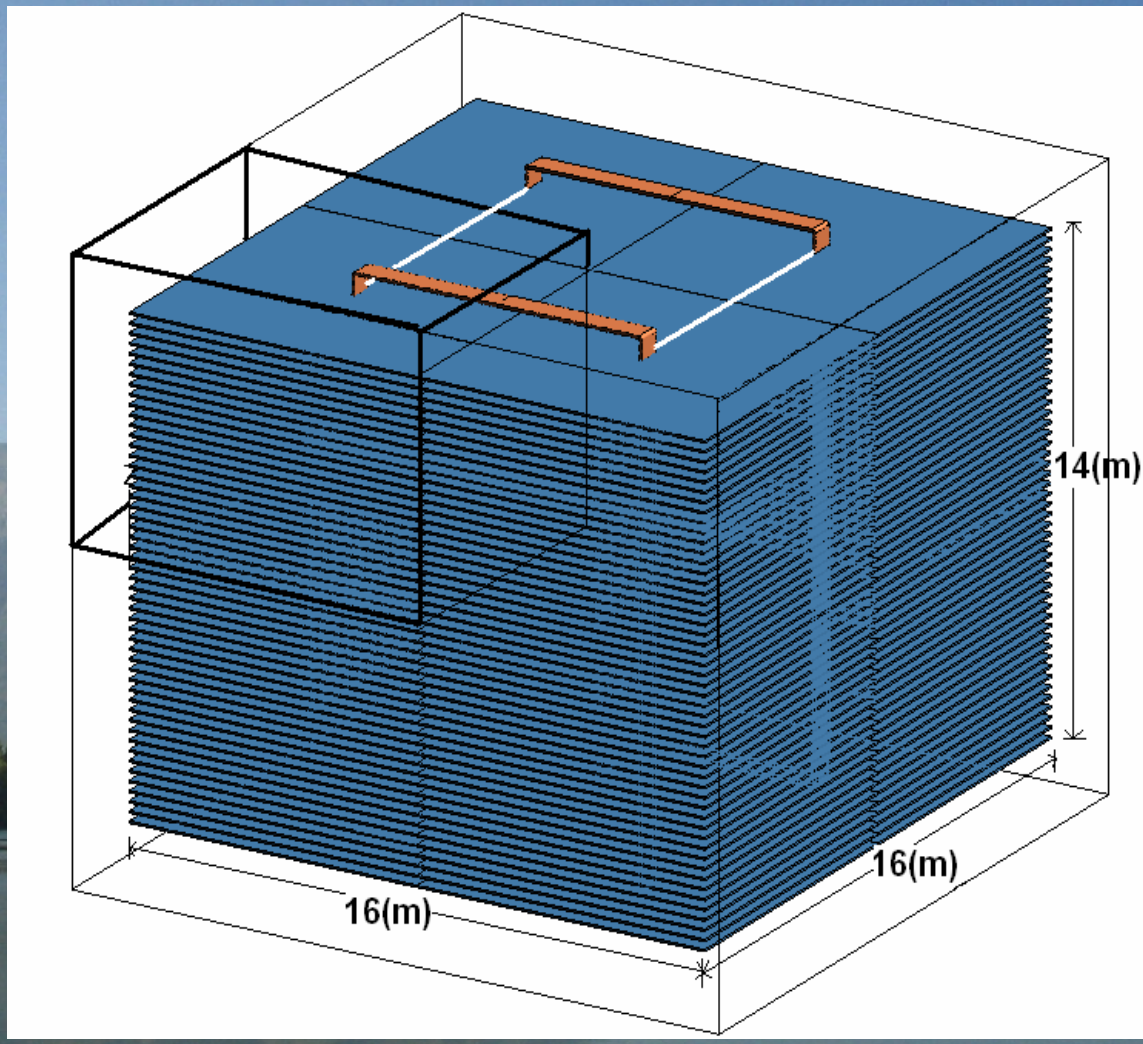




Full scale INO Magnet

The simulation is done with commercial software ***Magnet 6.26 (infolytica)****. Here the figure shows the 1/8th part continuous slot model (8 X 8 X 7) of full detector(16 X 16 X 14).*

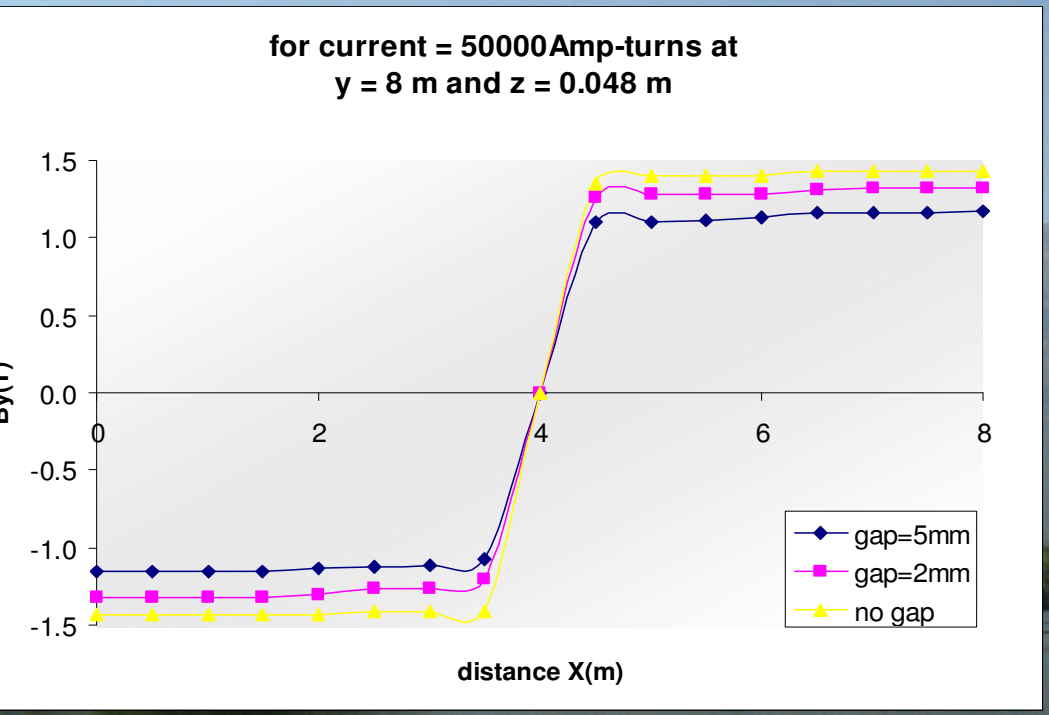


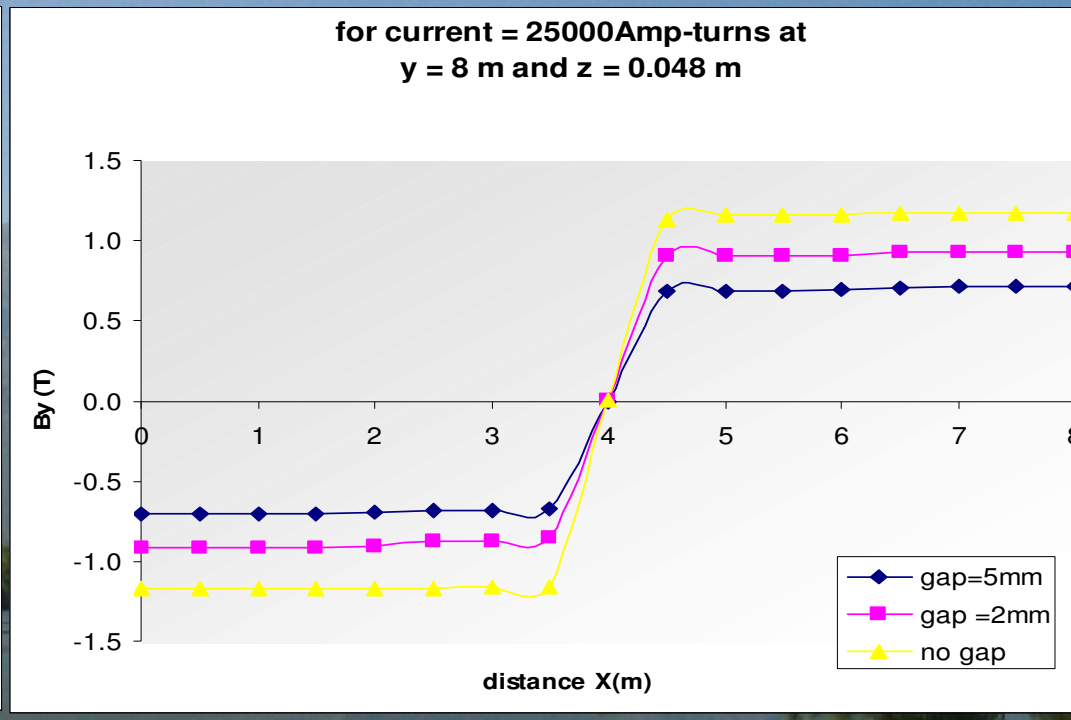


For continuous slot magnet plates, effect of gap in steel plates (air gap in between components of same plate) 0mm : 2mm : 5mm in B_y component (T) with

1) Total coil current 50000 Amp-turns is 1.42(T) : 1.31(T) : 1.16(T).

2) Total coil current 25000 Amp-turns is 1.17(T) : 0.92(T) : 0.71(T).





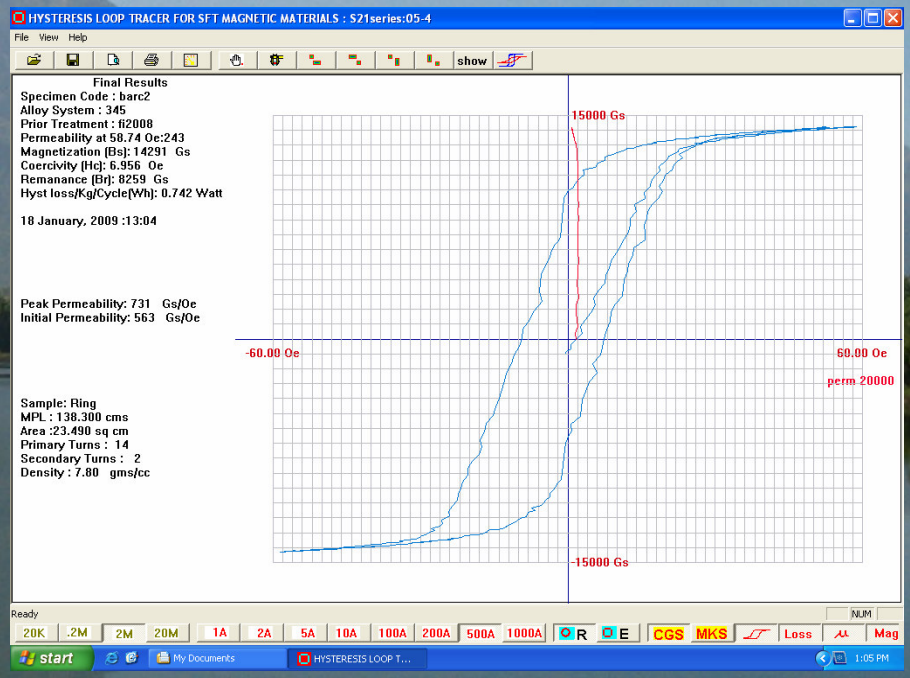
Magnet field using low carbon steel with coil current I = 50000Amp-turns (By = 1.4 (T))

Engineering studies…

- **Material studies …**

  exploit the composition/ magnetic characteristics relation in soft iron steels.

  We have procured a B-H curve tracer for macroscopic sample testing.



Simulation Framework

NUANCE

Neutrino Event Generation

ν_a + X -> 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

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

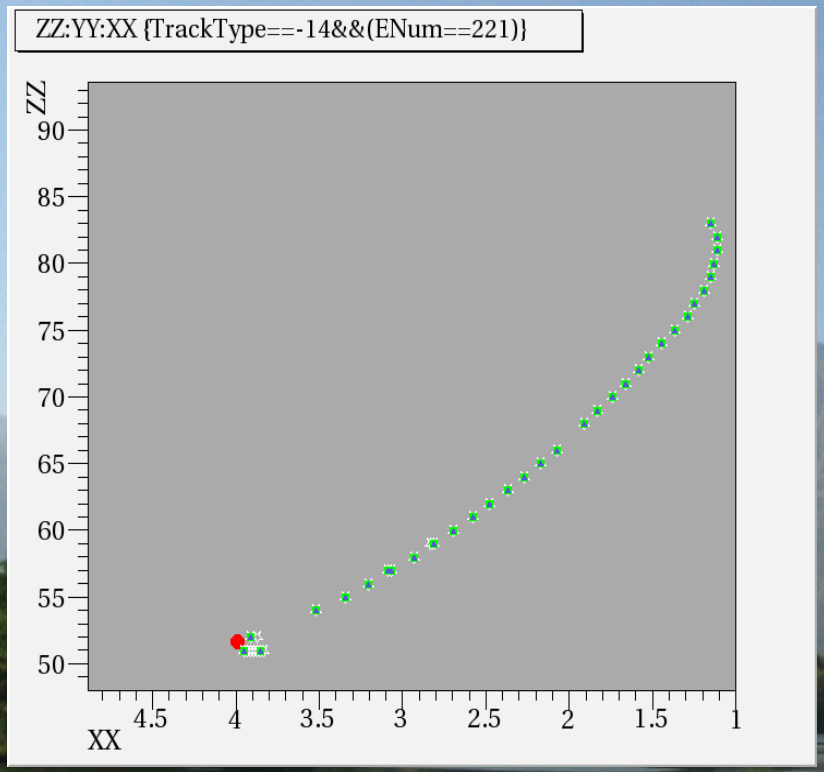
(E,p) of v + X = (E,p) of A + B + ...

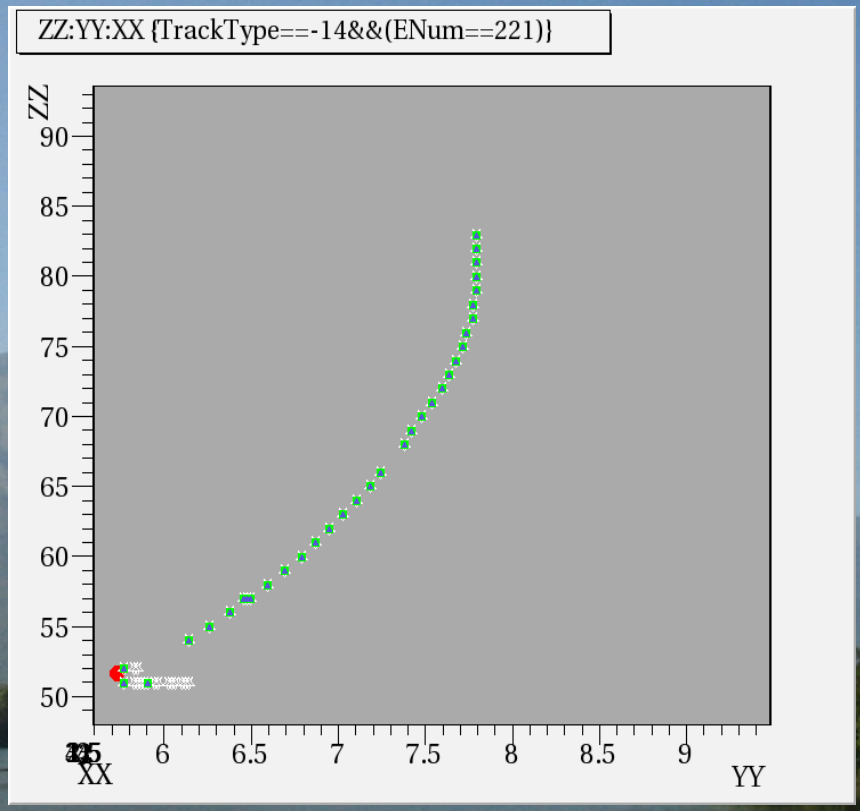
Fit the tracks of A + B + ... to get their energy and momentum.

Output:

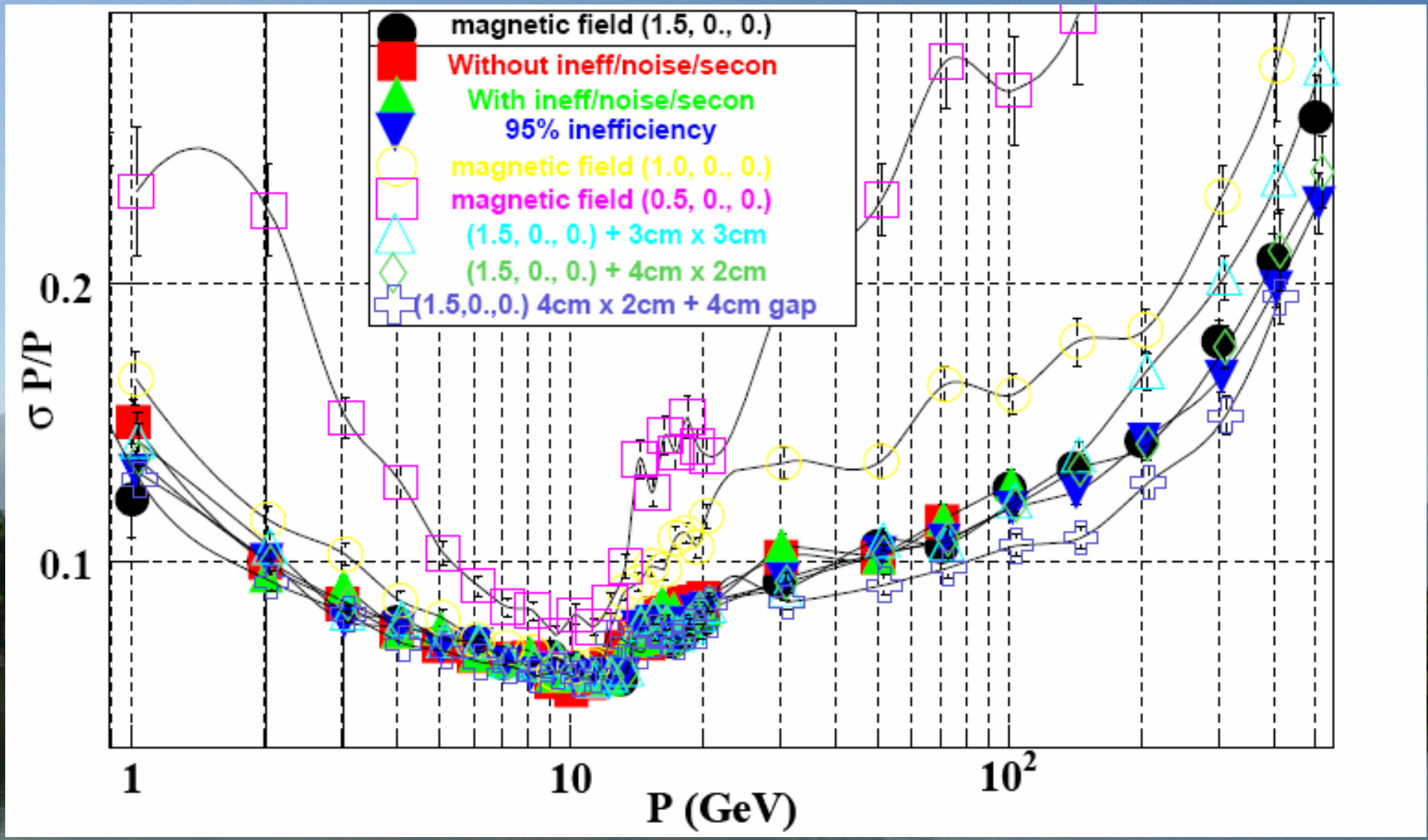
i) Energy & Momentum of the initial neutrino

Simulated neutrino event in INO-ICAL

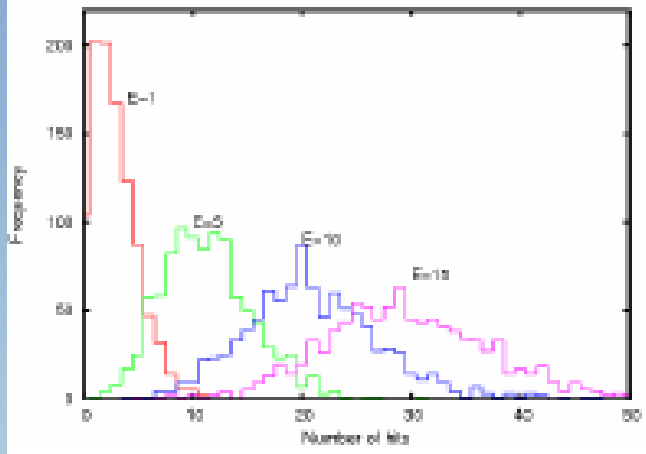


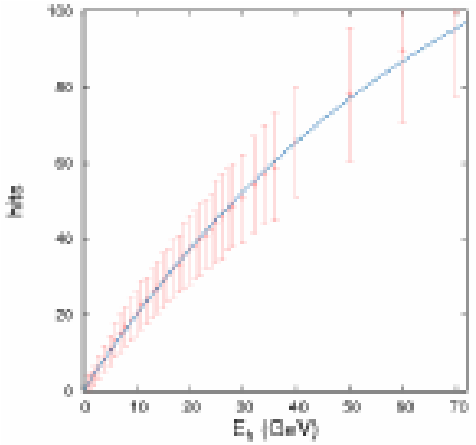


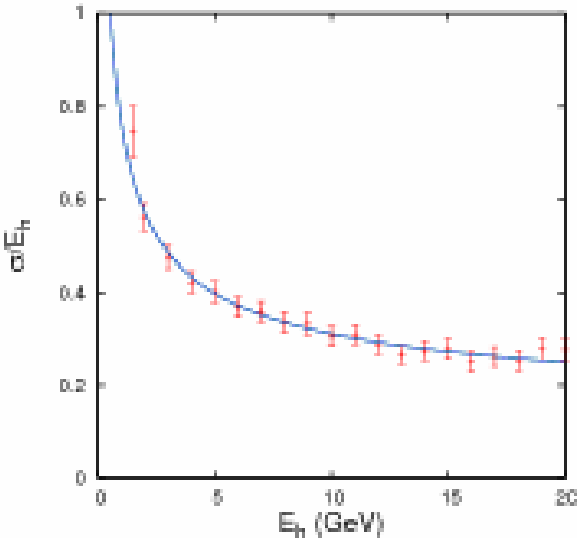
Track Resolution



Hadron Response

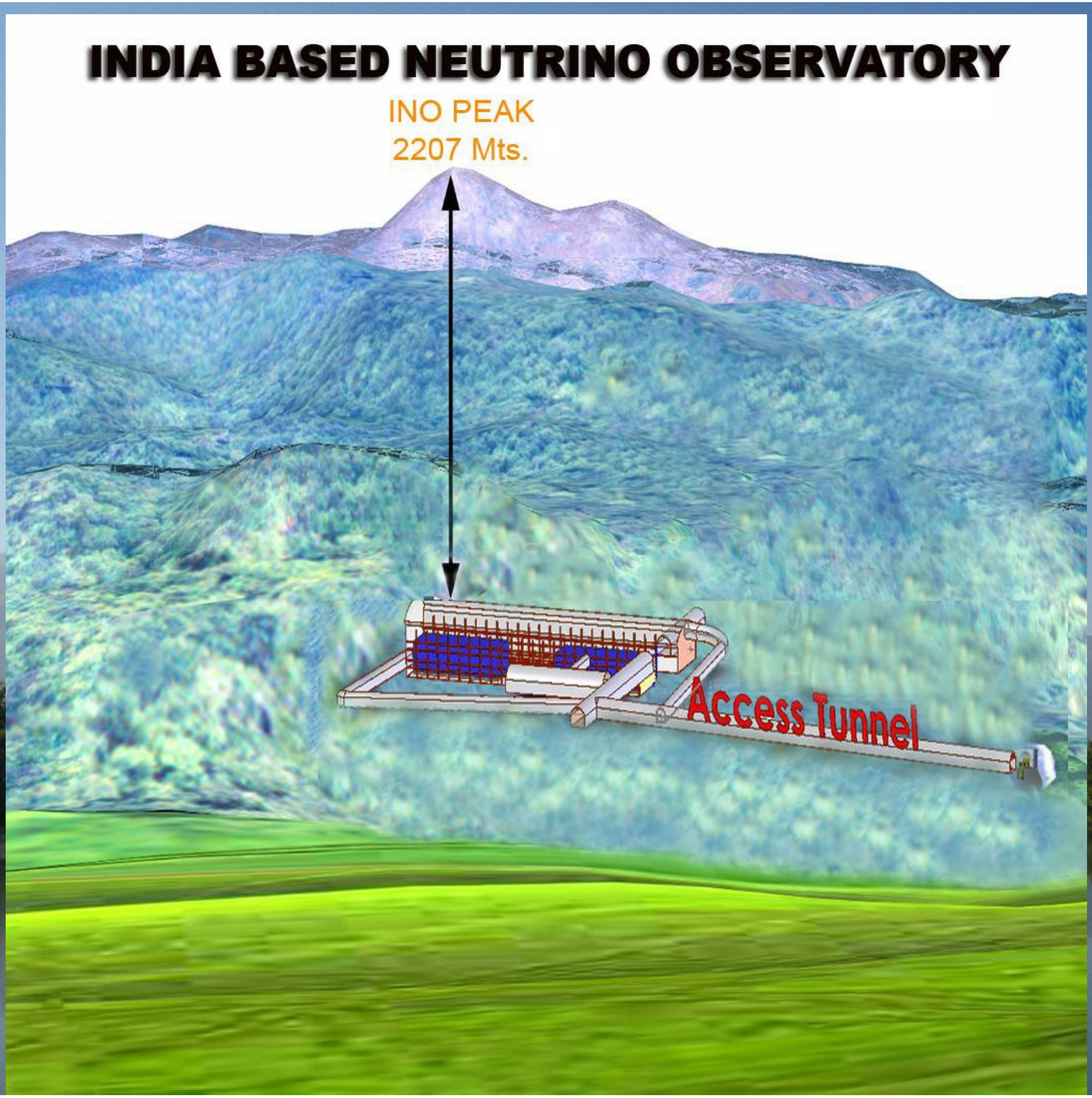






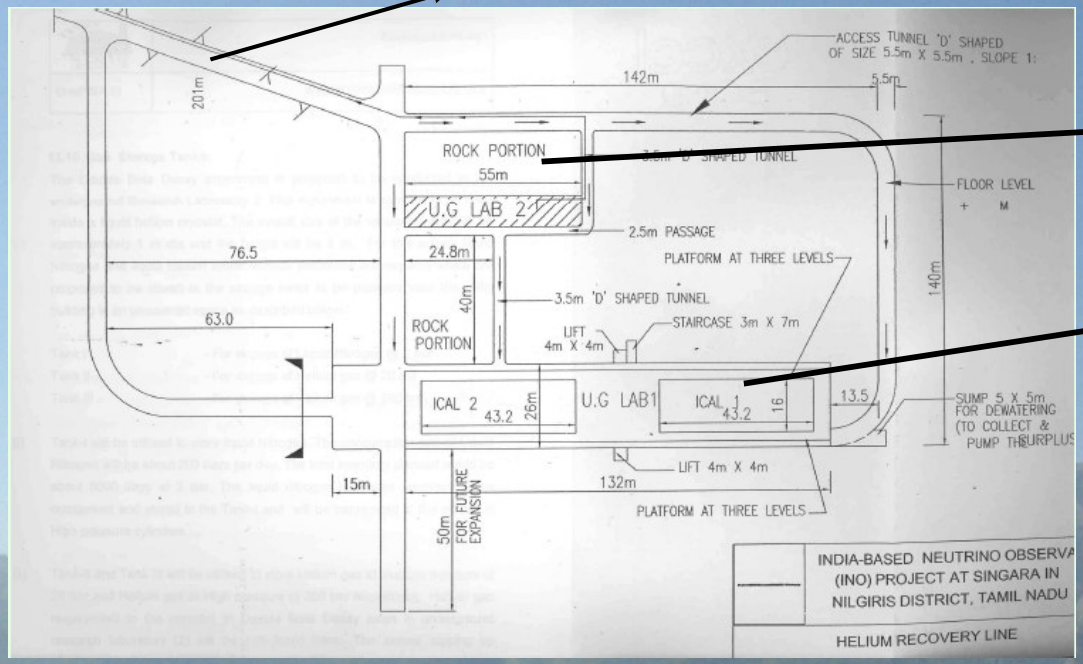
Pions of different fixed energies but random directions (1 K events)

INDIA BASED NEUTRINO OBSERVATORY



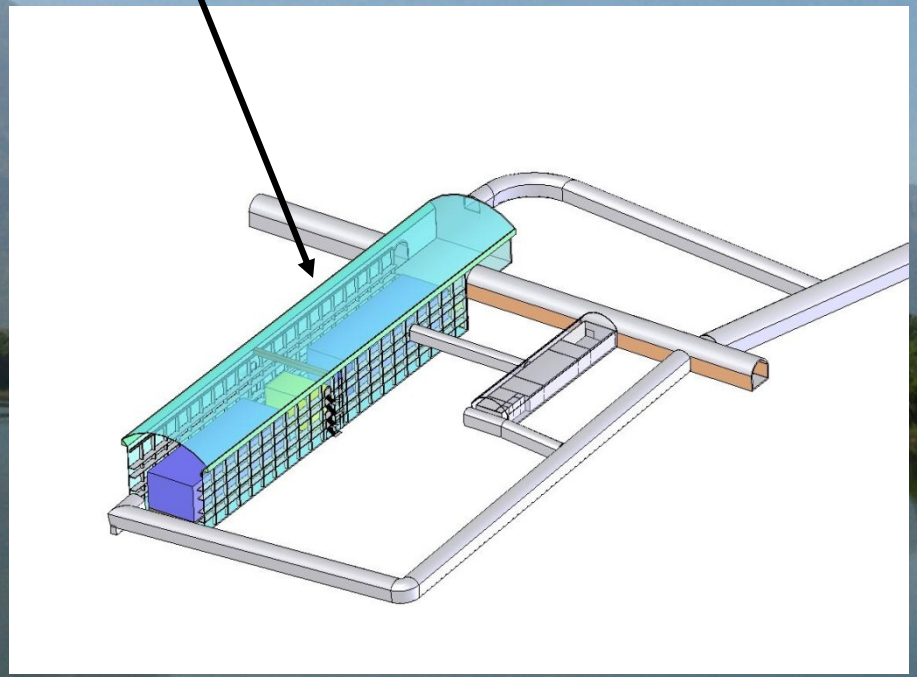
INO Underground Laboratory

2.2km long access tunnel



Cavern 2: 55m x 12.5m x 8.6m

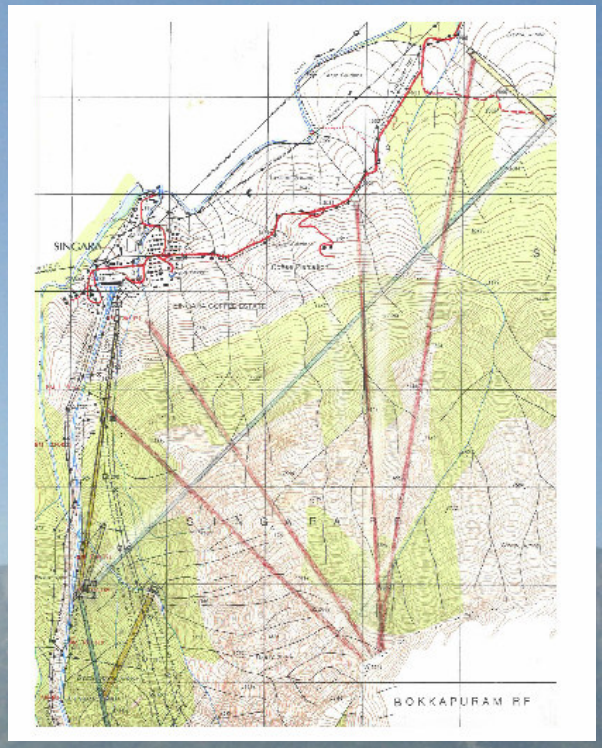
Cavern 1: 132m x 26m x 20m

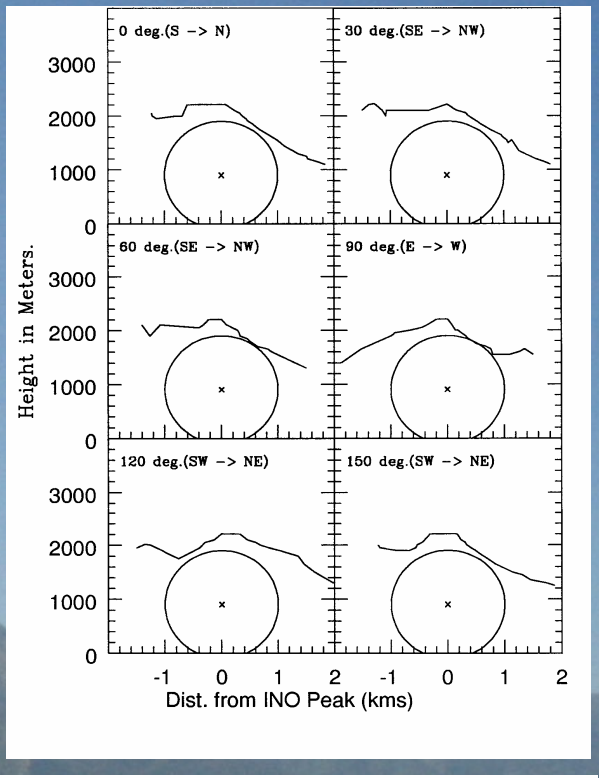


Vertical rock coverage : 1300 m

Possible tunnel alignments at PUSHEP

4 possible alignments of INO tunnel at PUSHEP





Alignment location	Length	Portal level	Cavern base	Vertical Cover	Cover at TRT
1. From access Tunnel 450 mm from PUSHEP portal	1867 mm	1019 mm	894 mm	1313 mm	+51 mm
2. Next to access Tunnel 187 mm east of PUSHEP portal	2129 mm	1050 mm	908 mm	1299 mm	+63 mm
3. South of Adit 4	2380 mm	1025 mm	867 mm	1340 mm	+61 mm
4. Around Adit 4 inlet	3194 mm	966 mm	753.5 mm	1453.5 mm	-18.9 mm

Tools for effective collaboration

- *Must make use of modern web based tools for effective collaboration.*
- ***INO Electronics Log Book :–*** *accessible through WEB.*
- ***INO Agenda Server:*** *to keep records of talks in meetings and to participate in video meetings. Anybody can upload their talks in the agenda server from anywhere in the world and participate- accessible through WEB.*
- ***INO-WIKI Page:*** *to produce various INO documents*
- ***INO Hypernews Discussion forum*** *: to participate in various INO related discussions and to share your ideas & thoughts with others within the collaboration- accessible through WEB.*

INO Center for Detector Development

- *Particle detectors developed by High Energy & Nuclear Physicists have found application in medical imaging, material science, industrial control, geological survey.*
- *Apart from exciting physics, detector development itself will be a major activity of this centre.*
- *Need a focused approach with a well coordinated group of people working on detector development.*
- *INO Centre can play the role of coordinating such activities through joint R & D efforts on detector development with other laboratories around the world.*
- *Need close interaction with industry.*

Human Resource development & Training

INO Training School:

- ***We have already started INO graduate training programme from August 2008.***
- ***Affiliated to HBNI.***
- ***At present INO students are being trained for one year at TIFR, Mumbai in both experimental techniques and theory.***
- ***Will be attached to Ph.D. guides at various collaborating institutions for a Ph. D. degree after completion of coursework***
- *Visiting students and Lab setup at Universities/IITs/IISER*
- ***Many long term visits of students and Faculty from Universities in last several years. Providing experimental kits to universities/IISER. Helping Universities to setup RPC test facilities .***

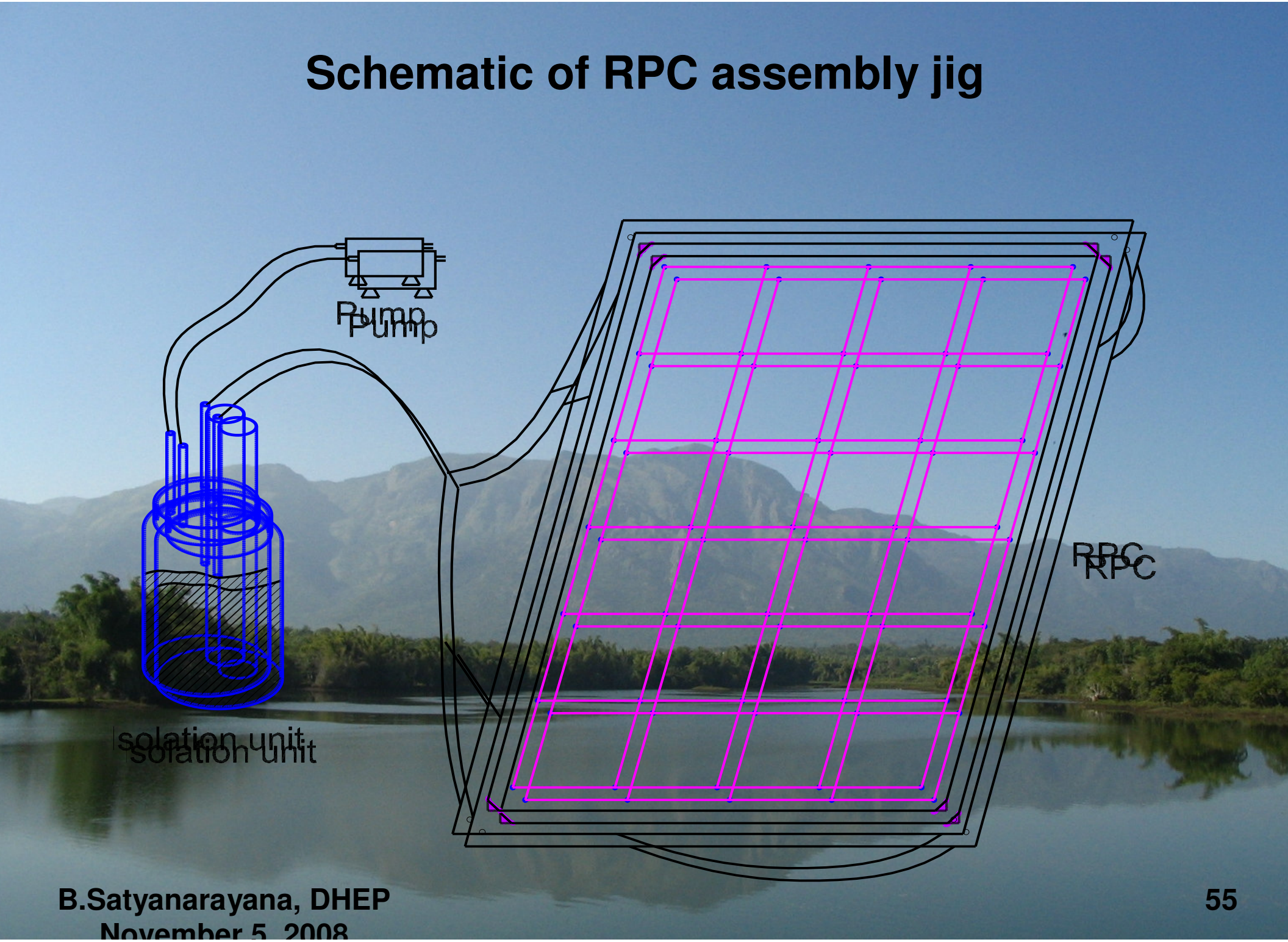
Talks, publications etc.

- *Ever increasing request for INO talks from every international conferences in the field.*
- *Around 30 publications on INO physics and instrumentation so far.*
- *Active partner of the International Design Study for a Neutrino Factory (IDS-NF) community.*
- *Next IDS-NF plenary meeting will be held at TIFR during 12-14 October, 2009.*
- *Direct interaction/collaboration with leading RPC team in Italy & Japan.*
- *Technical collaboration with KEK for electronics, magnet, RPC*

Project Status

- *A prototype RPC stack is now operational at TIFR. A second prototype with the magnet is getting ready at VECC.*
- *Electronics DAQ for the prototype is operational. Final electronics for the 50 Kton detector is under design.*
- *A gas purification & recirculation system is under test.*
- *Long term stability test of RPCs continuing.*
- *INO-Engineering task force has prepared a Detailed Project Report (DPR) on the INO cavern and surface lab .*
- *Detailed Project Report for the detector structure with all engineering details is ready.*
- *We have approached environment and forest departments for necessary clearances.*
  - *MOEF clearance obtained.*
  - *State forest clearance awaited.*
- *Environmental Impact Assesment & Enviornmental Management Plan for the INO lab at Singara, Masinagudi has been prepared by reputed enviornmental organisations.*
- *EMP compliance report submitted to TN Government.*
- *Identification of sources for various components needed for mass production of glass RPCs is in progress.*
- *Land for INO centre at Mysore will be provided by Karnataka Govt.*

INO team at RPC lab

Thank you for your support

Schematic of RPC assembly jig