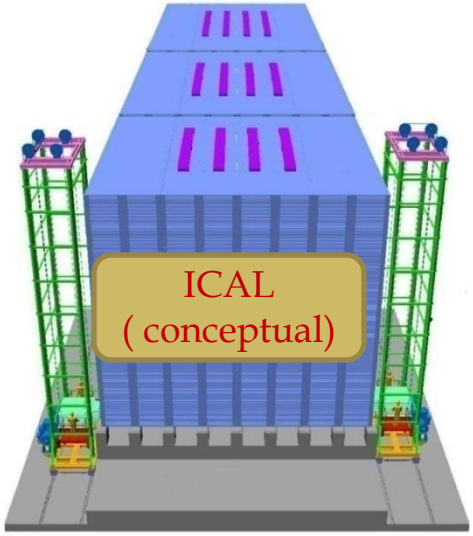
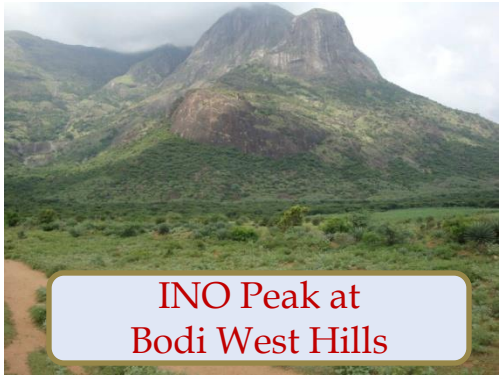
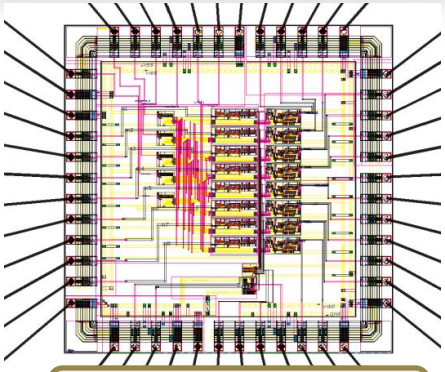
India-Based Neutrino Observatory (INO)







Y.P. Viyogi
DAE Raja Ramanna Fellow
VECC Kolkata
for INO collaboration

INO: a brief history

- MoU signed by Directors of seven DAE Institutions in 2002, for the exploration of sites, R&D on detectors and preparation of a detailed project report as part of the feasibility study.
- DAE allocated funds for feasibility study and detector R &D. Disbursed through TIFR.
- DST agreed to participate in the project and provided seed funding to 12 university groups.
- Site selection : Two alternatives (a) PUSHEP near Masinagudi in Nilgiri mountains in Tamilnadu (b) Rammam in the Darjeelimng hills in West Bengal. Preferred PUSHEP.
- Got trapped in environmental issues, lost four years of time, finally shifted to Bodi West Hills in Tamilnadu

INO : Salient Features

- A unique facility for non-accelerator nuclear and particle physics in the country with multi-institutional initiative.
- Underground laboratory with ~1 km all-round rock cover accessed through a 1.9 km long tunnel. A large and several smaller caverns to facilitate many experimental programs.
- The magnetized Iron Calorimeter (ICAL) detector, with its charge identification ability, to address frontline neutrino issues e.g., mass parameters and other properties, in a manner complementary to ongoing efforts worldwide.
- Will support several other experiments when operational. Neutrino-less Double Beta Decay and Dark Matter Search experiments foreseen in the immediate future.
- Welcome International participation.

INO Project Components

- Construction of an underground laboratory and surface facilities near Pottipuram village in Theni district of Tamil Nadu.
- Construction of a massive 50 kton magnetised Iron Calorimeter (ICAL) detector to study properties of neutrinos.
- Construction of the INO Centre- The Inter-Institutional Centre for High Energy Physics (IICHEP) at Madurai.
- Human Resource Development (INO Graduate Training Program)

Financial Issues

- Cost of the project : 1500 Crores
  - Surface facilities, tunnel and cavern : ~500 Crores
  - IICHEP at Madurai : ~ 50 Crores
  - ICAL ~ 950 Crores
- Status : AEC approved last month, now goes to Cabinet
- Sharing between DAE and DST
  - DAE funds civil infrastructure and 50% of ICAL, supports DAE groups
  - DST funds 50% of ICAL, supports non-DAE groups
- A 100 Crore project for development of site infrastructure (roads, water supply, electricity etc.) and construction of 1/8 size Engineering Module of ICAL already approved.

ICAL: The physics goals

- Accurate determination of the atmospheric parameters (θ_{23} octant, deviation of θ_{23} from maximality)
- Determination of neutrino mass hierarchy (large θ_{13} is good news !)
- Nonstandard interactions, CPT violation, long range forces, ultrahigh-energy muon fluxes, ...
- Far detector for a future neutrino factory

Physics goals to be complementary to other experiments worldwide. There is a growing realization that both atmospheric and accelerator experiments are needed to obtain best values of the parameters.

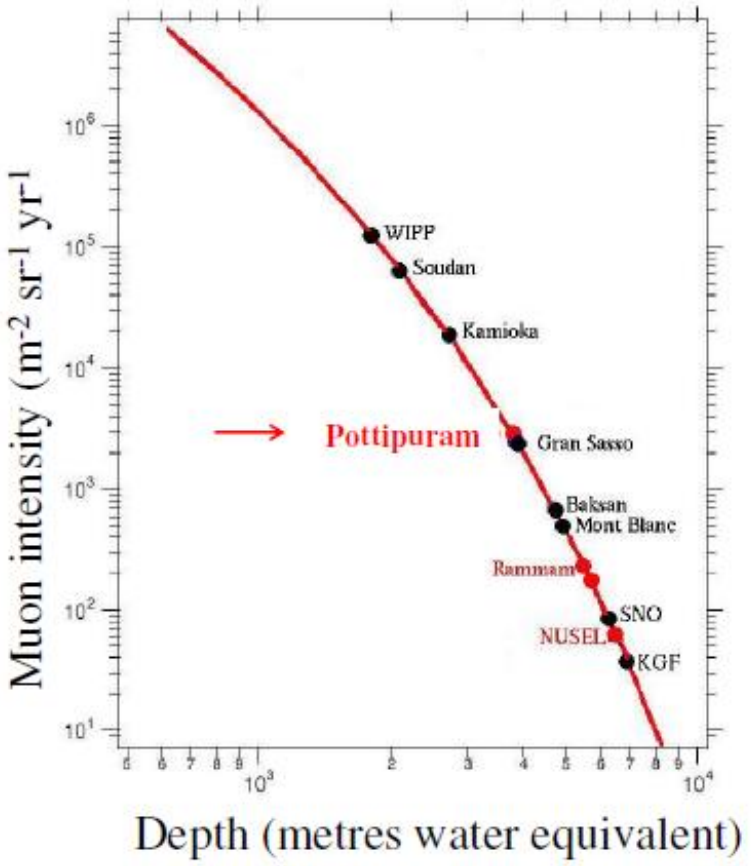
- Accelerators : narrow range of L,E; high precision
- Atmospheric : Large range of L,E, not-so-high precision

INO: the location

Madurai –the nearest major city

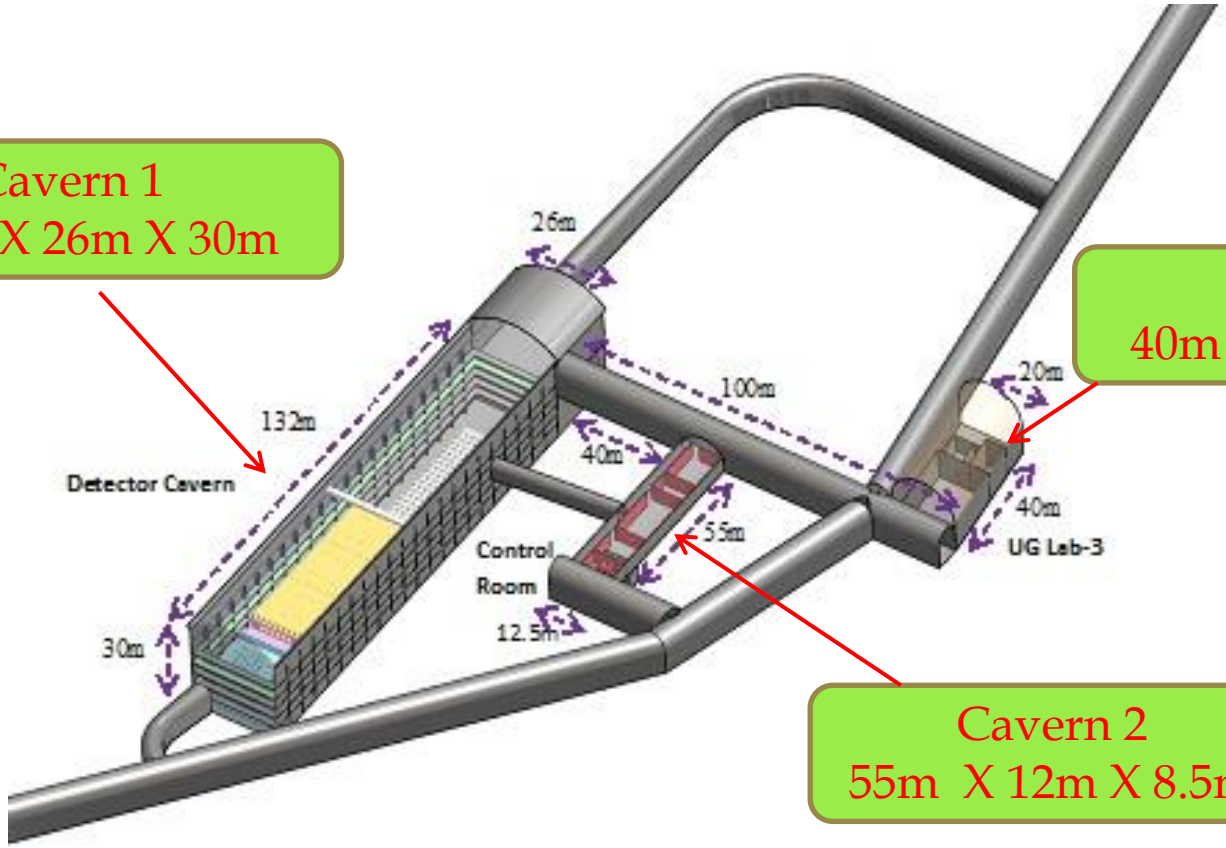
- INO site is located 115 km west of the temple city Madurai in the Theni district of Tamil Nadu close to the border the between Tamil Nadu & Kerala.
- Madurai has an international airport.
- IICHEP to be setup at Madurai

INO site : Bodi West Hills



- 9^0 58’ N, 77^0 16’ E
- Pottipuram Village
- Theni District
- Tamil Nadu State

Underground Laboratory Layout



- The cavern-1 is set under 1589 m peak with vertical rock cover of 1289 m.
- Accessible through a 1.9 km long tunnel
- Cavern -1 will host 50 kt ICAL detector. Space available for additional 50 kt.
- Cavern-2 & 3 available for other experiments (NDBD, Dark Matter ….).

Inter-Institutional Centre for High Energy Physics (IICHEP)

- To be located on a 13 Ha land very close to the Madurai Kamraj University in the city of Madurai.
- Will act as the nodal centre for all INO activities.
- Will have a major detector development laboratory.
- INO Graduate Training program will move to IICHEP when ready.

Site and infrastructure development

- 26 hectares of land provided free by Tamil Nadu state government for setting up surface facilities near portal location at Pottipuram village.
- 13 hectares of land acquired at Madurai for IICHEP.
- Survey work and fencing work at both sites in progress.
- Water supply work by Tamilnadu Water and Drainage (TWAD) Board in progress
- Master Plan for IICHEP site is ready.
- Architectural design of the first building to house Detector hall and 1/8 Scale ICAL Engineering Module is ready
- Tendering very soon

Activity at the INO site at Pottipuram : construction of a temporary bridge for carrying material

Supplying water to INO Project

River Mullaiperiyar

TWAD engineers by the side of the river

Transporting water supply pipes

Unloading of water pipes near site

Survey work in progress at IICHEP site Madurai

The rocky site

Surveyors in action

Temporary shed being erected

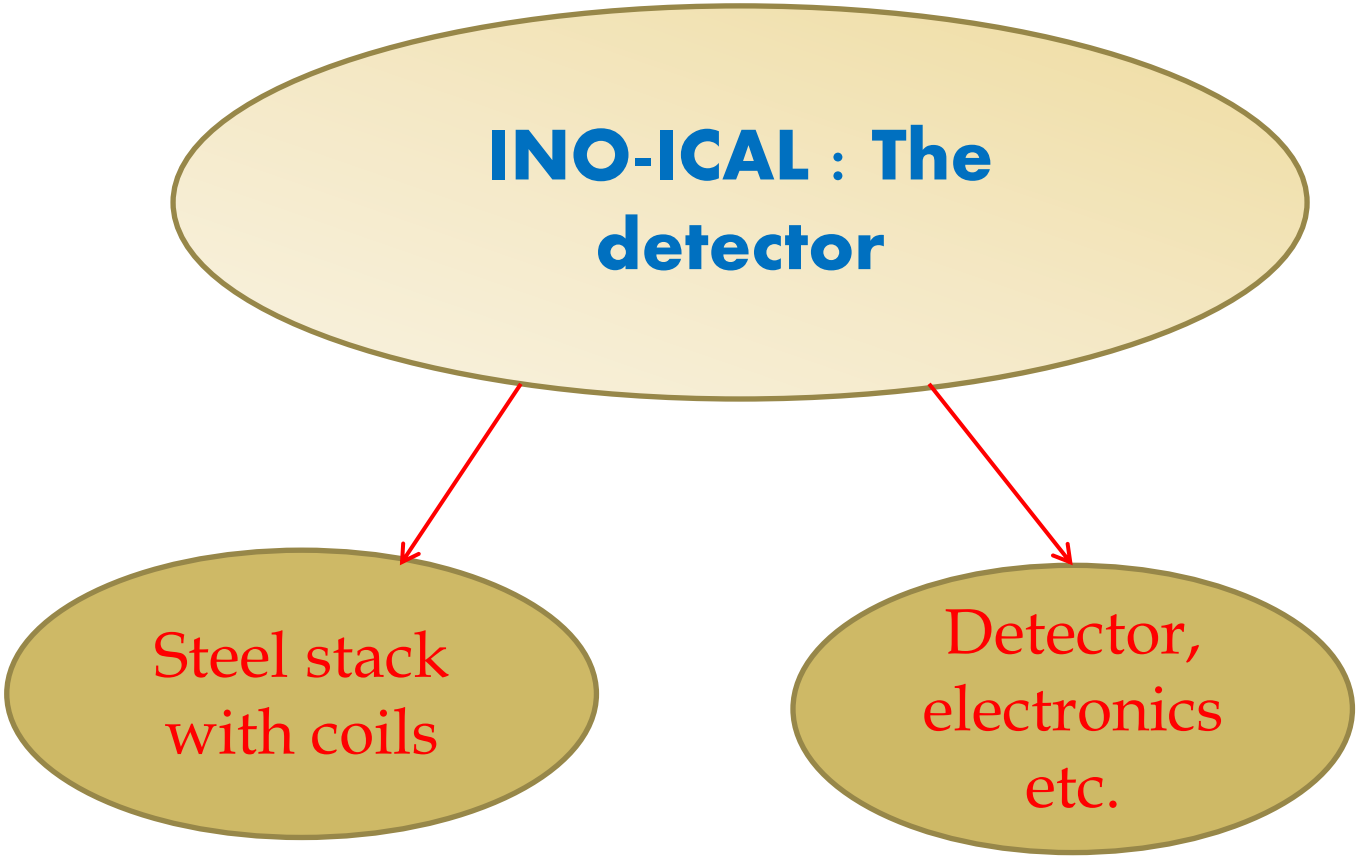
IICHEP@Madurai

Started operating from the rental building at Vadapalanchi, Madurai South.

Master plan for IICHEP at Madurai

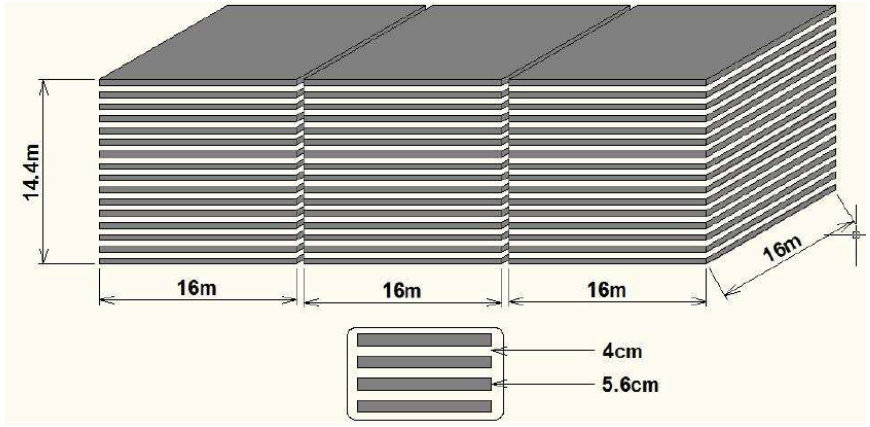
PROPOSED MASTER PLAN FOR IICHEP PROJECT AT MADURAI.

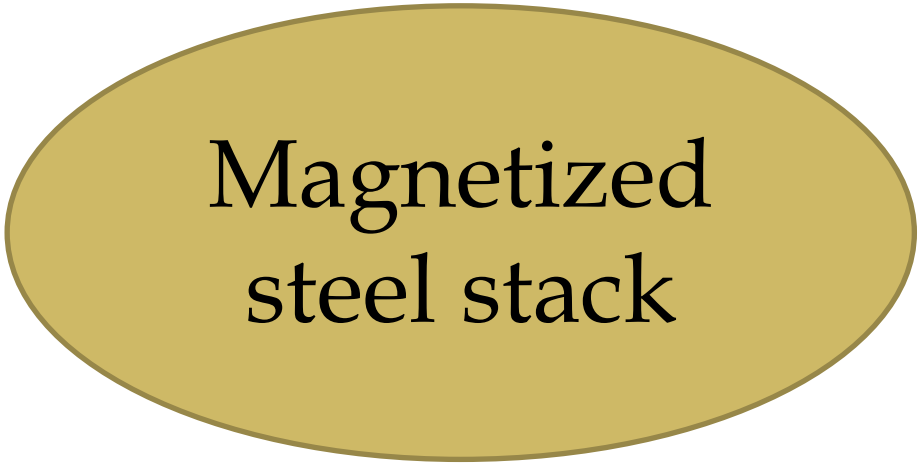
ARCHITECTURE SECTION, BARC.
T.K GHOSH, CHIEF ARCHITECT
S.S. KUMBHARE, ARCHITECT
R.K MENIA, ARCHITECT


INO-ICAL : The detector
Steel stack with coils
Detector, electronics etc.

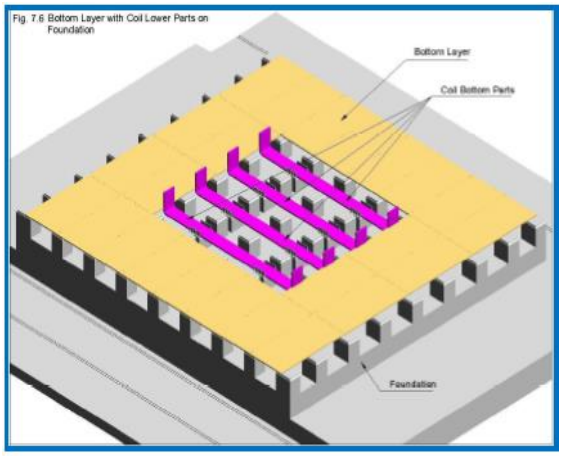
Magnetised Iron Calorimeter

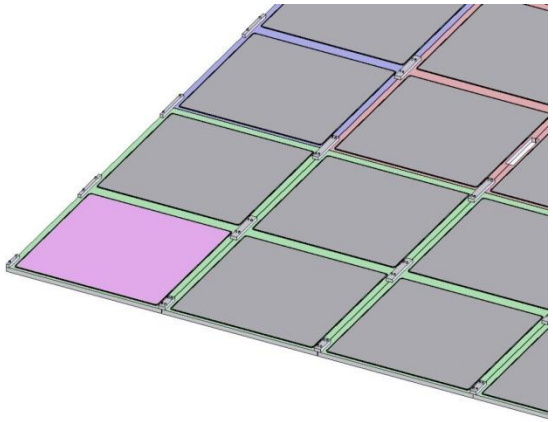
No of modules	3
Module dimension	16 m X 16 m X 14.4m
Detector dimension	48.4 m X 16 m X 14.4m
No of layers	150
Iron plate thickness	5.6cm
Gap for RPC trays	4 cm
Magnetic field	1.4 Tesla
RPC unit dimension	195 cm x 184 cm x 2.4 cm
Readout strip width	3 cm
No. of RPCs/Road/Layer	8
No. of Roads/Layer/Module	8
No. of RPC units/Layer	192
Total no of RPC units	28800
No of Electronic channels	3.7×10^6

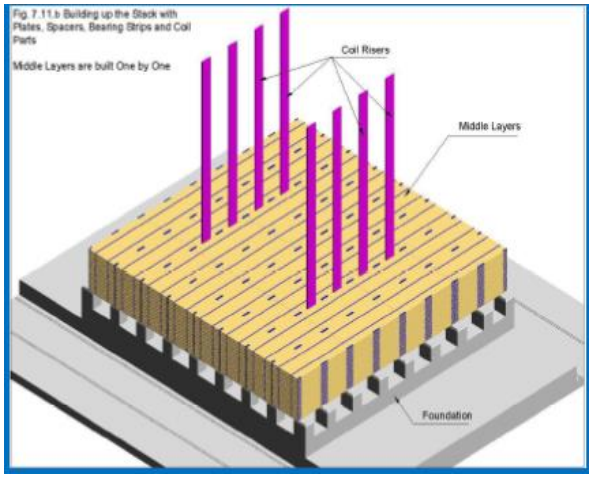


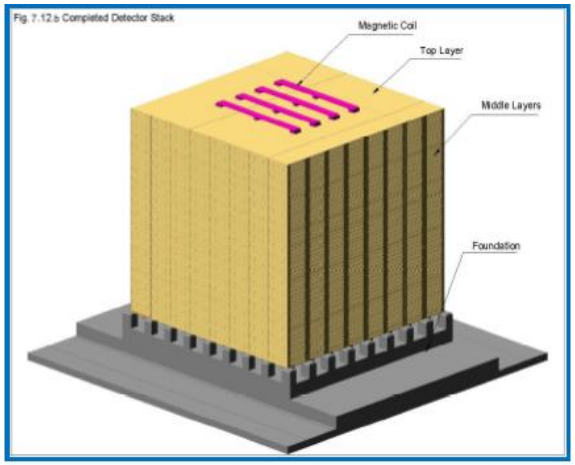

Magnetized
steel stack

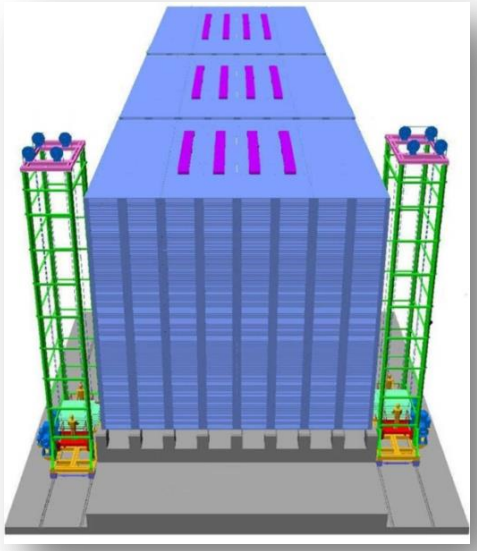
Construction of the ICAL detector

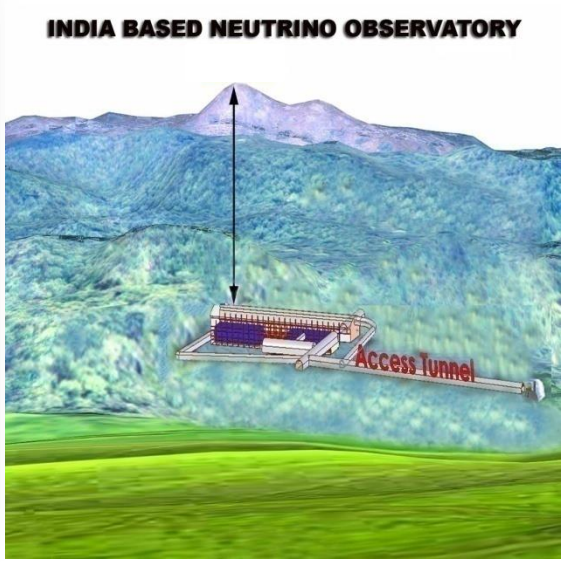






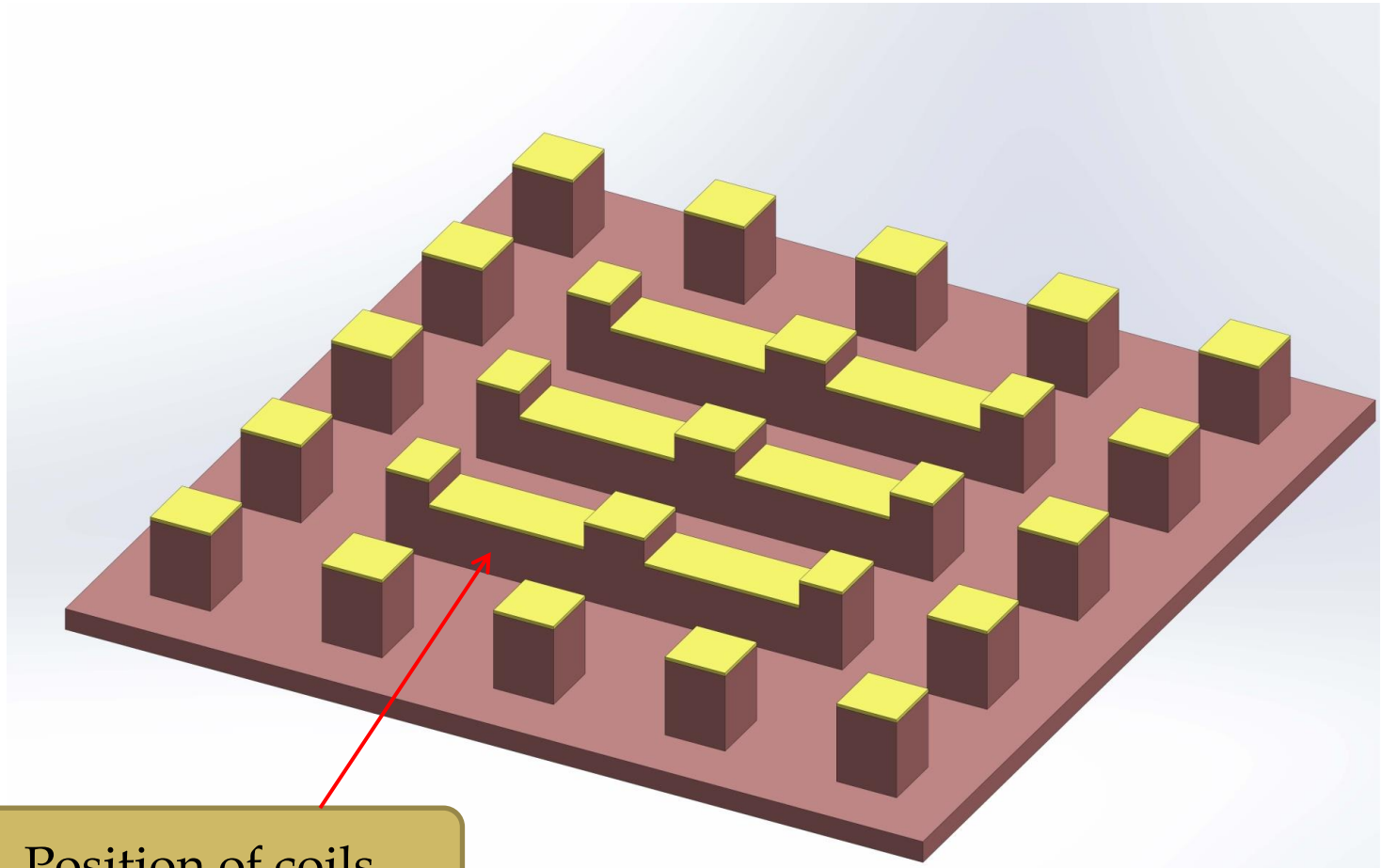






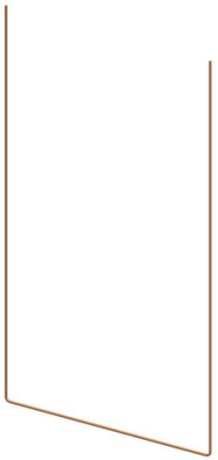
1/8 scale Engineering Module to be constructed first

Concrete Pedestal for the 8m X 8m X 7m Engineering Module (1/8 scale)

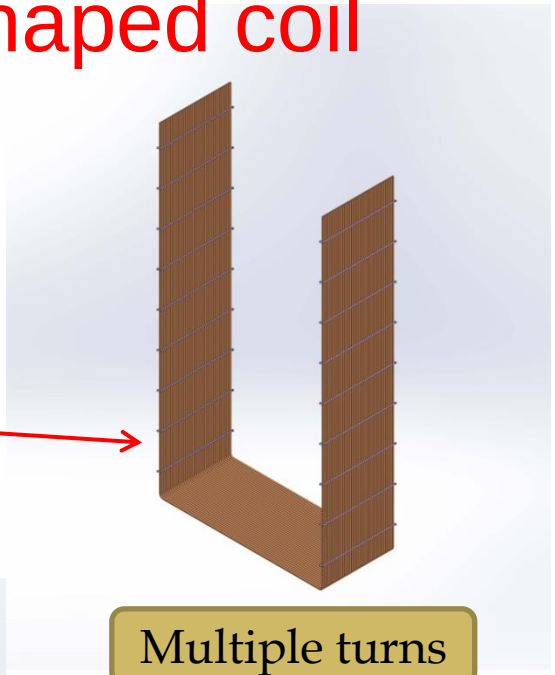


Copper conductor to U-shaped coil

The conductor
30mm cross-section
17 mm dia bore

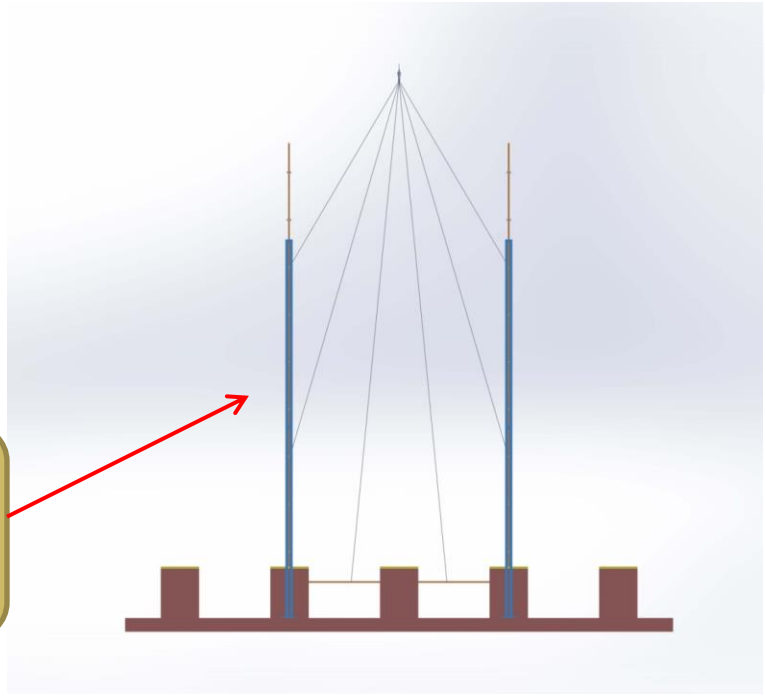


One turn



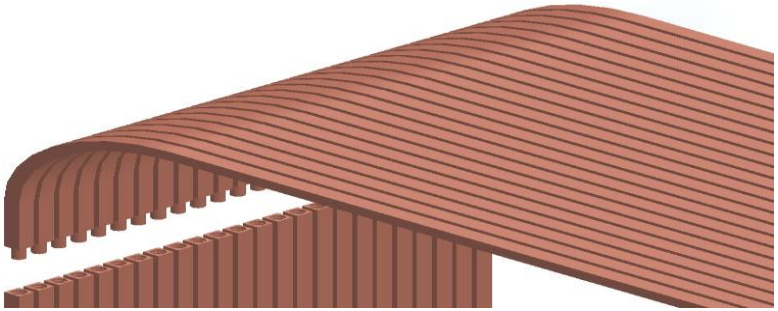
Multiple turns

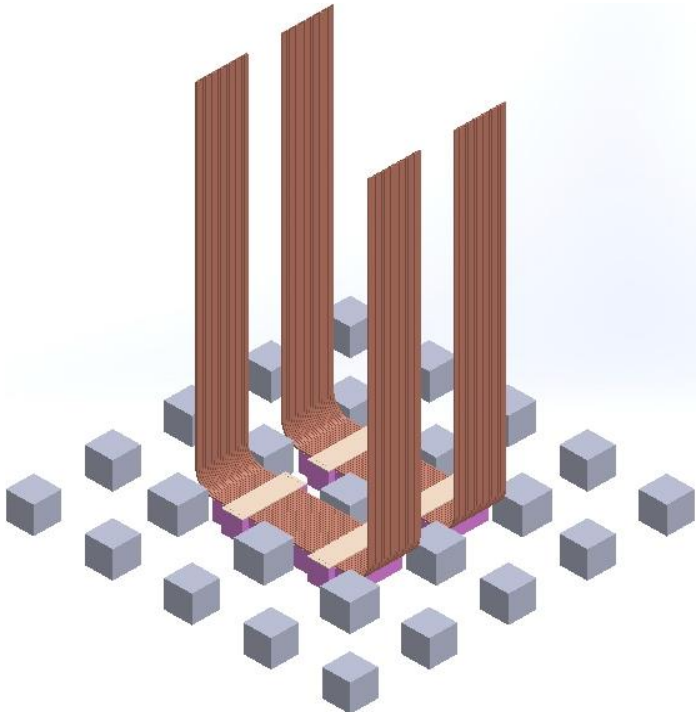
Avoid joints in the inaccessible region

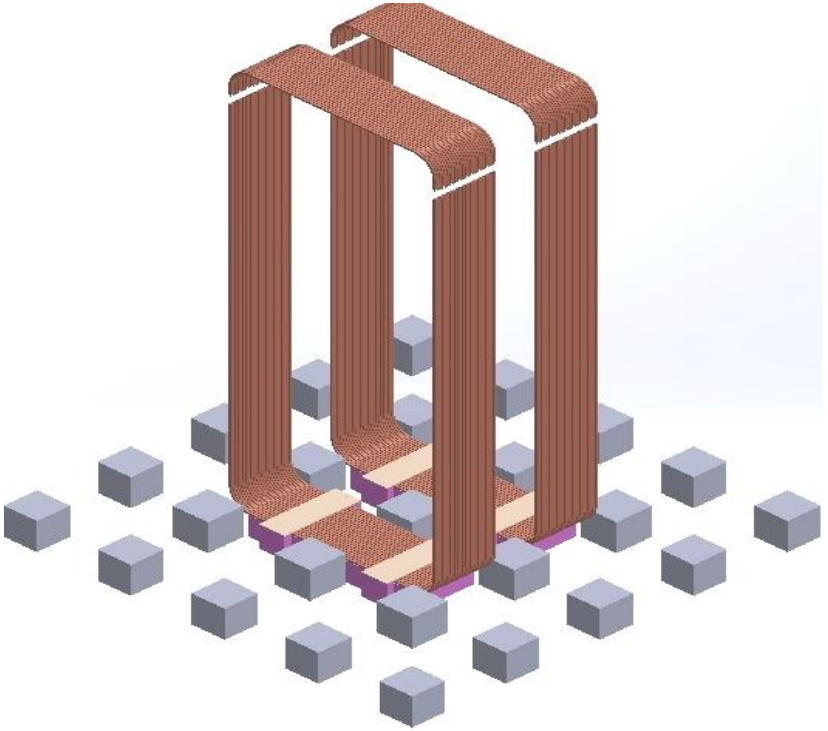


Coil suspension during plate insertion

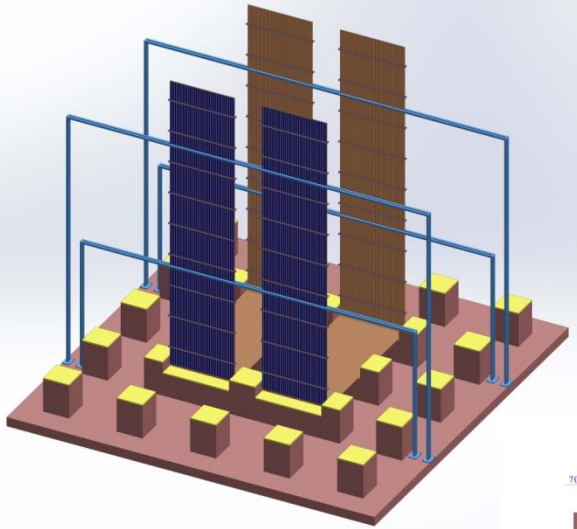
Connecting open ends of U-shaped coil

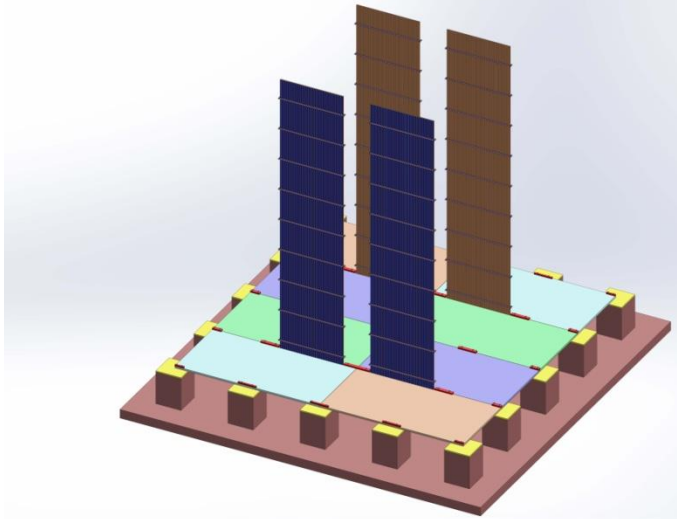


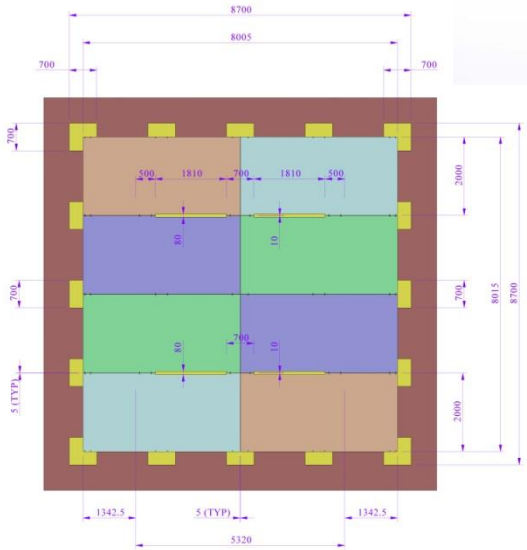




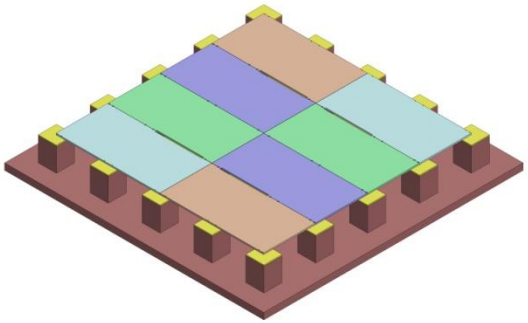
Laying out the steel plates after coil is erected

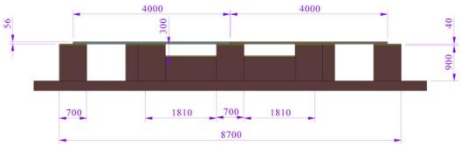




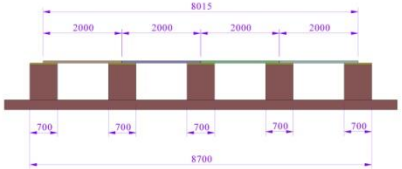


PLAN





ELEVATION



SIDE VIEW

INO (PROTOTYPE DOUBLE COLUMN)
ASSEMBLY OF FIRST LAYER OF IRON PLATE
ON PEDESTAL SHOWING SLOT DIMENSIONS
FOR MAGNET COIL

RPC Development, Electronics, Trigger and Daq

A journey through RPC road

200 cm x 200 cm glass RPC

RPC R&D

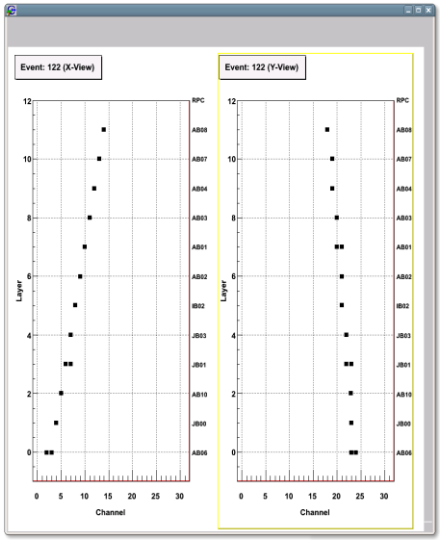
Glass RPCs : TIFR/BARC

Bakelite RPCs : VECC/SINP

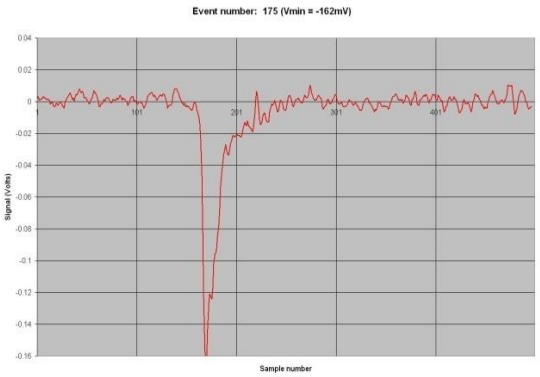
30 cm x 30 cm

100 cm x 100 cm

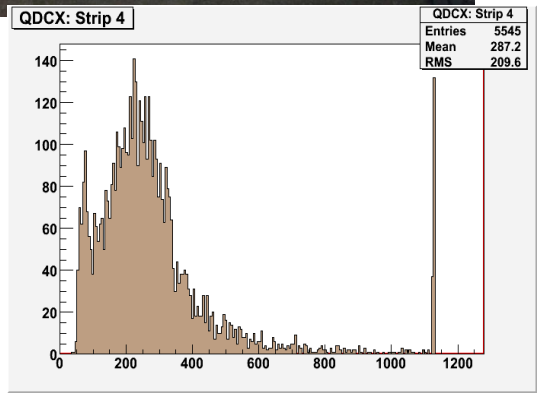
Prototype RPC Stack at TIFR tracking Muons



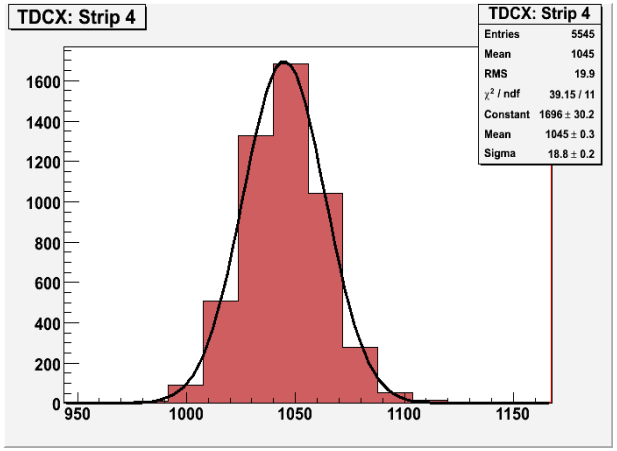
Cosmic ray tracks



Analog signal due to muon

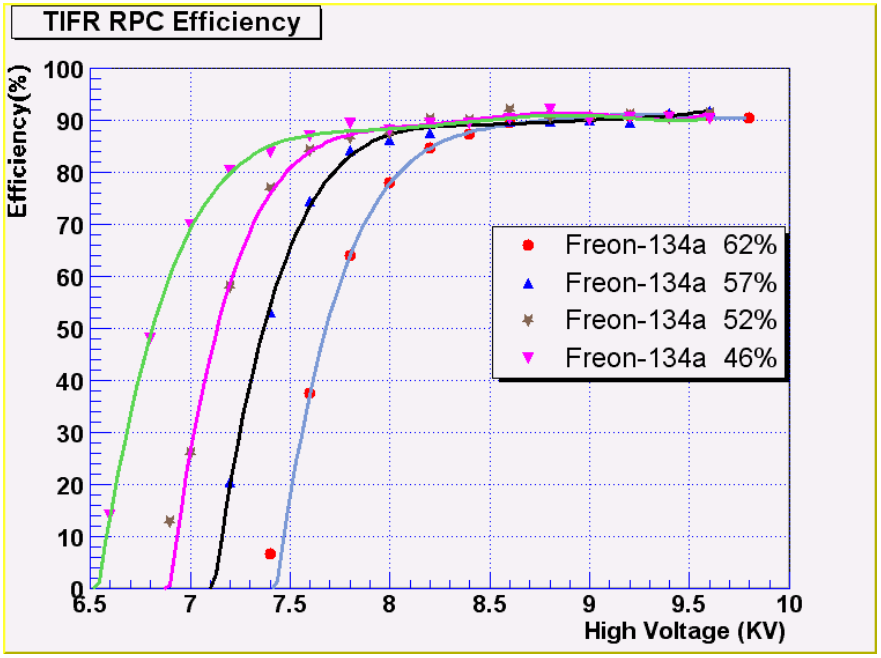


Charge spectrum

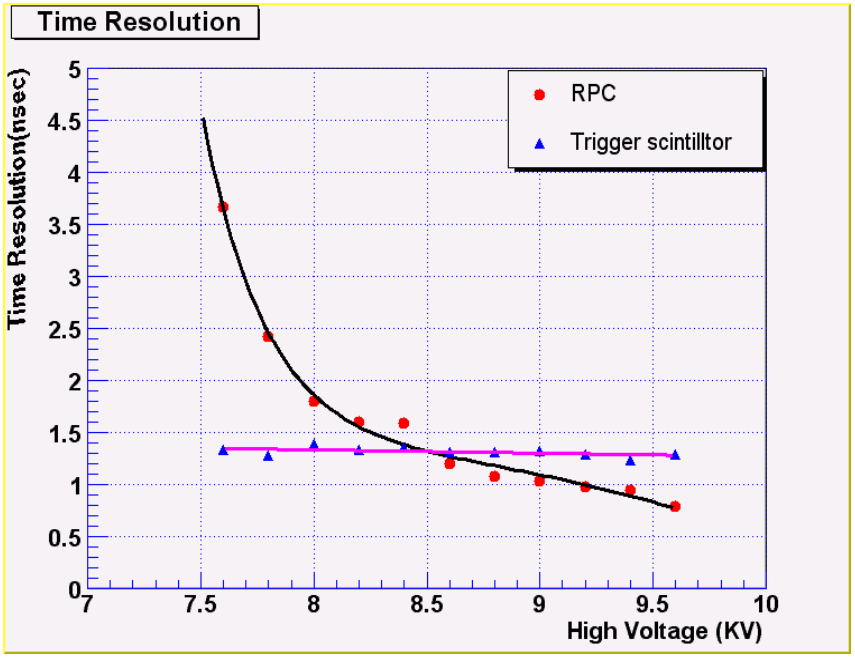


Time resolution

Glass RPC : efficiencies and time resolution

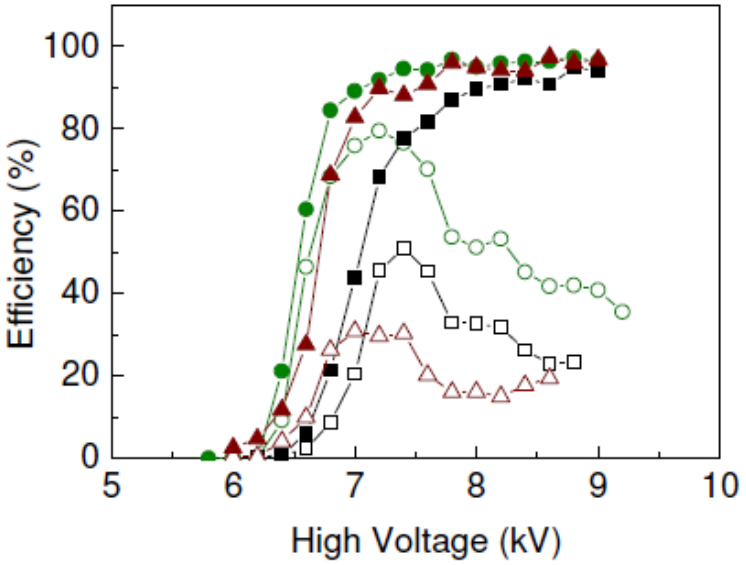


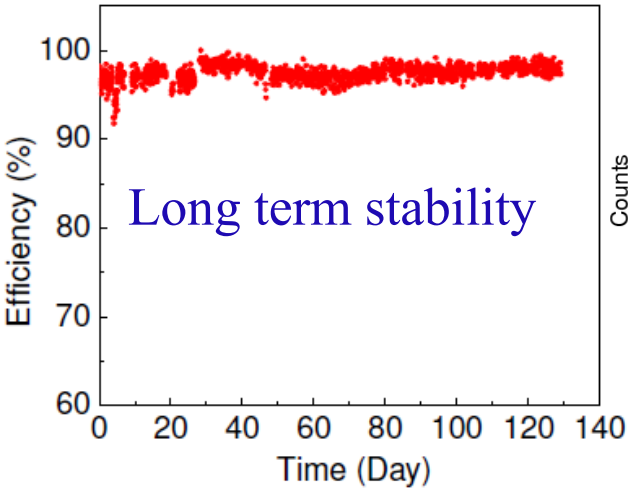
Efficiency

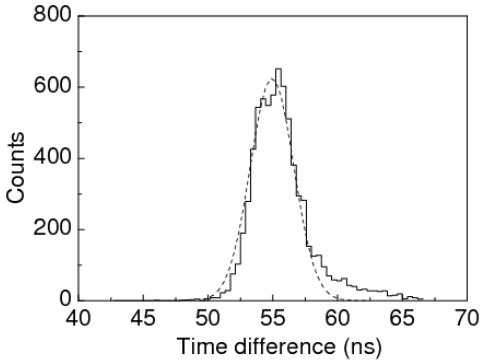


Time resolution

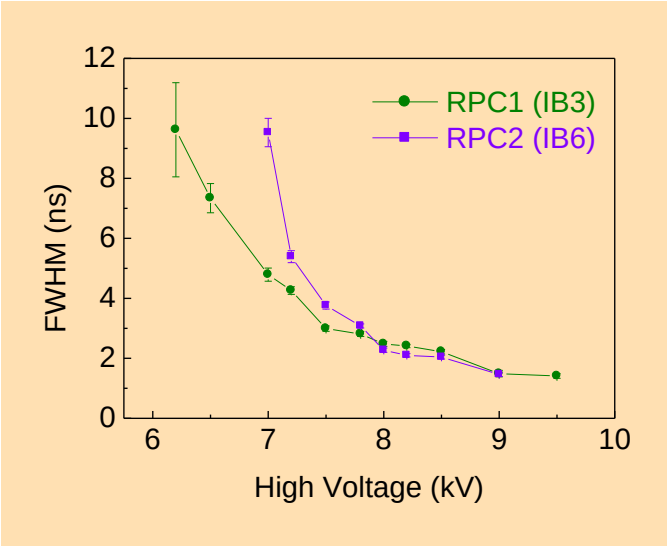
Bakelite RPC R&D at VECC/SINP Kolkata





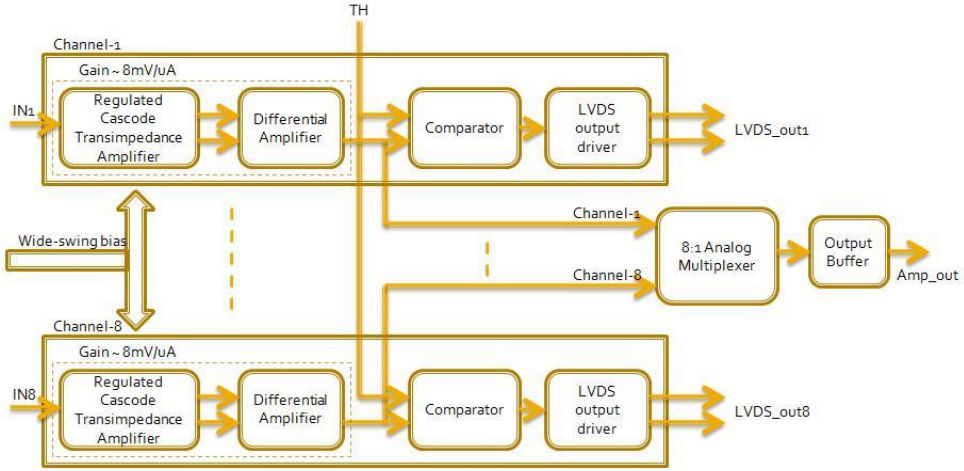


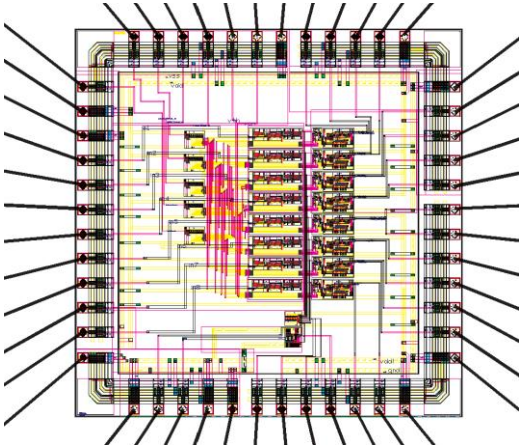
Time spectra of RPC

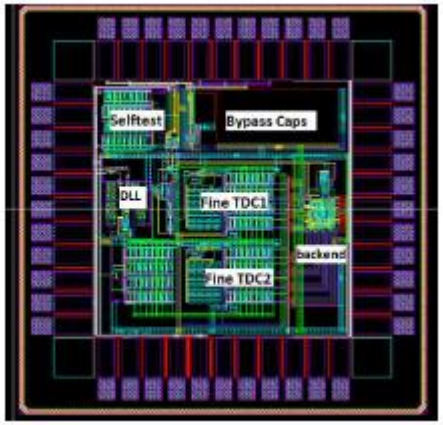


- Silicon coated P-120 grade Bakelite
- 30 cm X 30 cm and 1m X 1m RPCs
- Running in streamer mode
- Low counting rate ~0.1-0.2 Hz/cm^2
- Good time resolution ~ 2ns
- Good efficiency > 90%
- 1m X 1m RPCs running in the mini-ICAL
- R&D for large size chamber in progress

Electronics and Daq



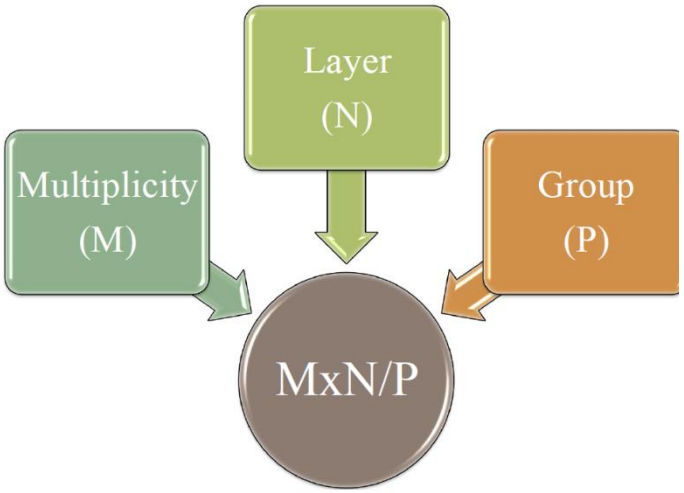


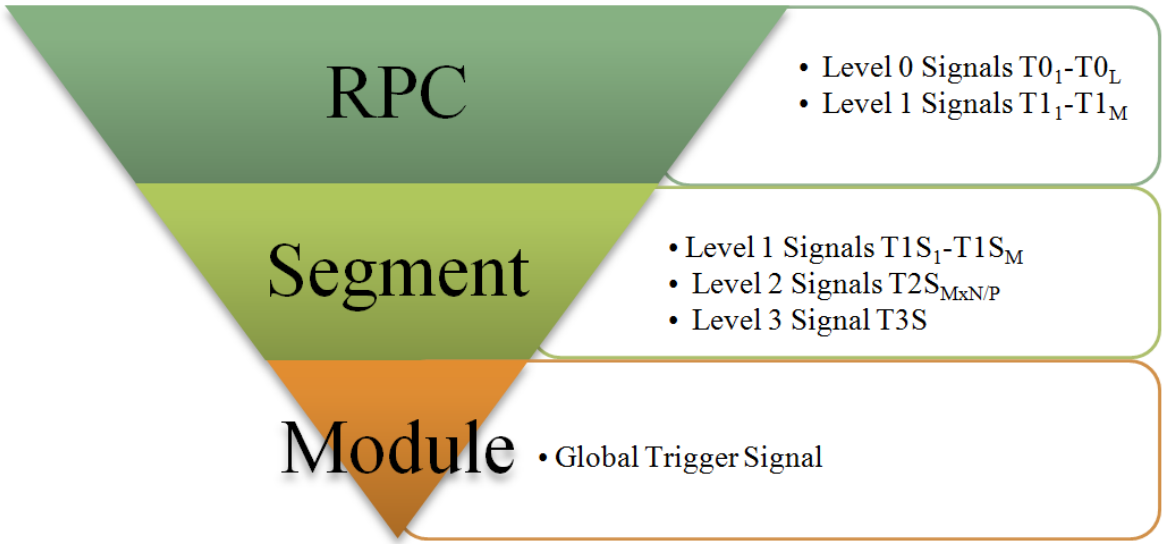


A TDC ASIC developed for INO project by IIT, Madras

- Front end 8-in-1 Amplifier-discriminator ASIC developed by BARC, 2nd version tested, soon to be finalized
- Overall electronics and DAQ architecture under design, various prototypes are under test
- High performance FPGA (featuring a µC softcore), TDC and waveform sampler based RPC-DAQ board is being prototyped.
- Data network architecture and hardware being designed.
- Integration of electronics and DAQ hardware with the RPC detector is being finalized.

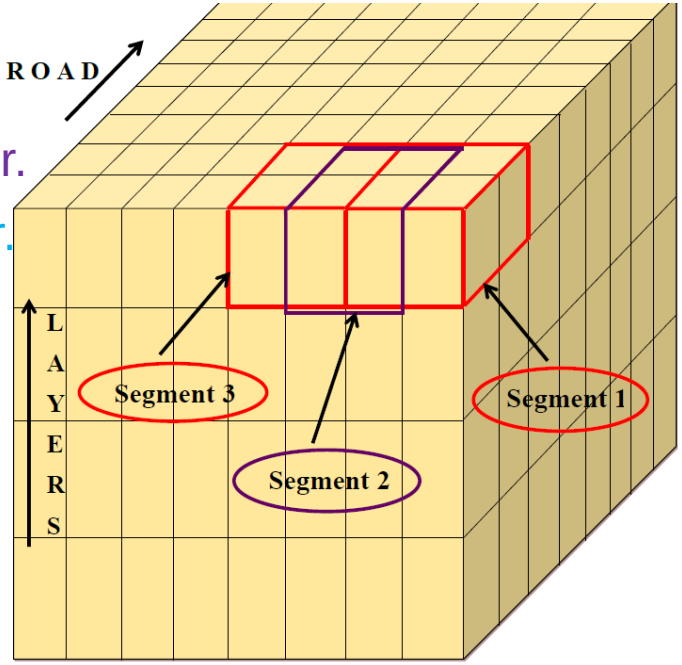
ICAL Trigger Scheme





- Trigger criteria based on event topology alone.
- Distributed and hierarchical architecture.
- Detector module segmented to generate local trigger.
- Combination of local triggers produces global trigger.
- Global trigger latches event data.

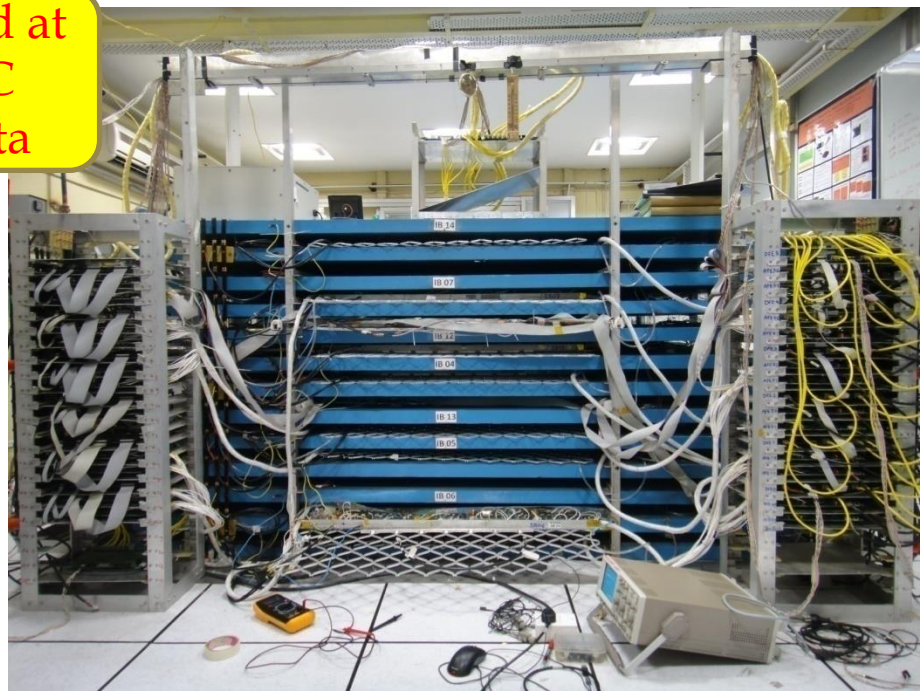
NIM, A678, 105 (2012) & NIM, A694, 126 (2012)



First version of ICAL Trigger Scheme in place, several implementation aspects tested, integration issues being addressed

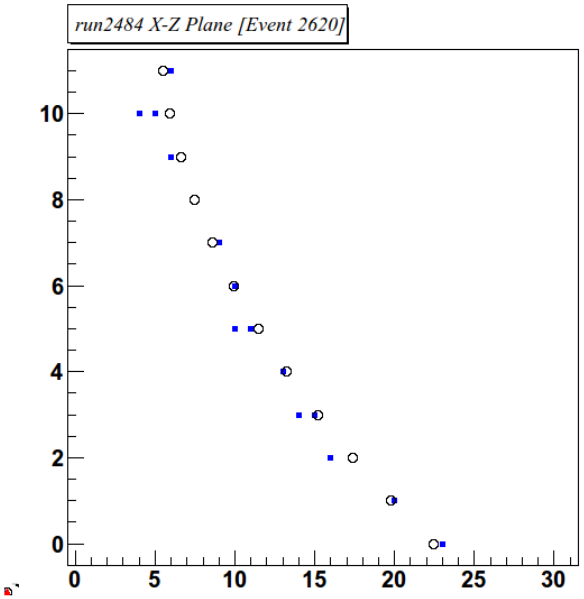
mini-ICAL : Prototype Magnet with RPC layers

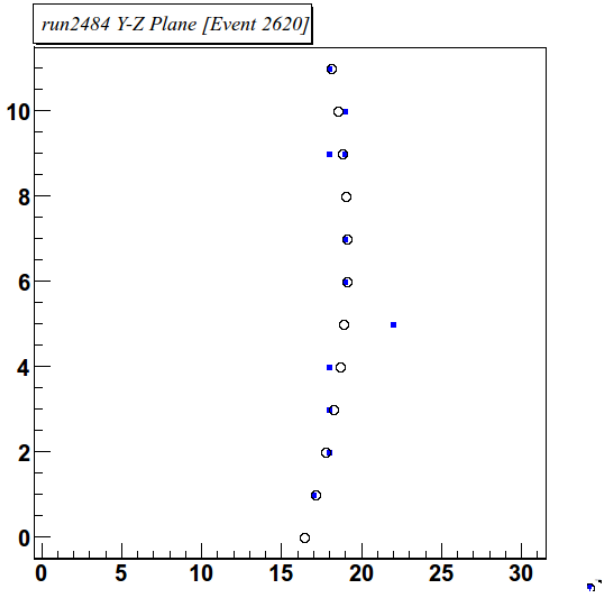
Installed at VECC Kolkata



- 35 Ton prototype with 12 gaps to house 1m x 1m RPCs
- Long term operational experience
- Operate both glass & Bakelite RPCs
- Muon track reconstruction with & without magnetic fields.
- Lab environmental condition studies and student training

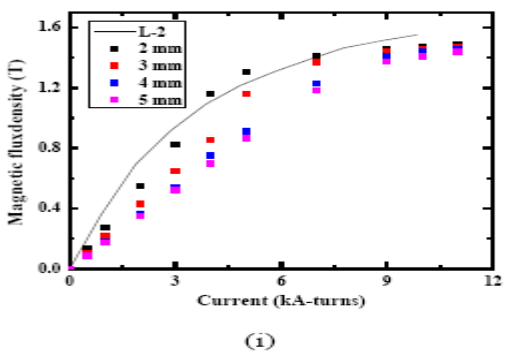
Cosmic muon tracks seen in the prototype



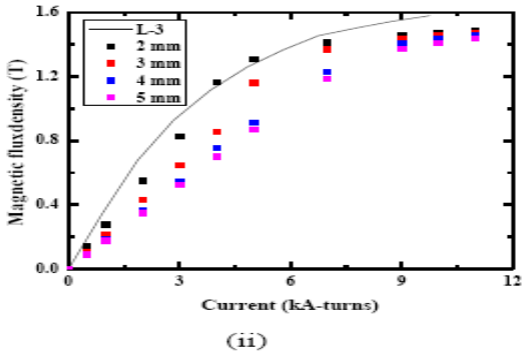


Hits and fitted points on a bent track for data taken with magnetic field ON condition

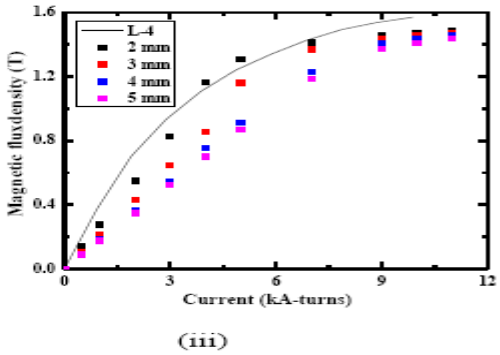
Magnetic field in the prototype
Comparisons of measured and simulated values



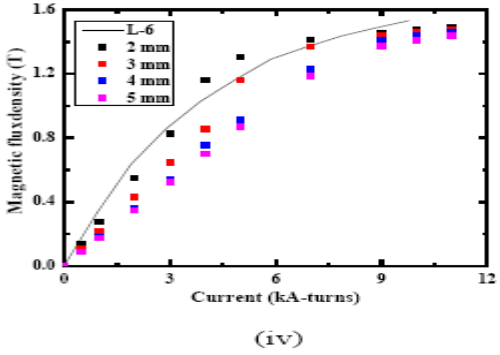
(i)



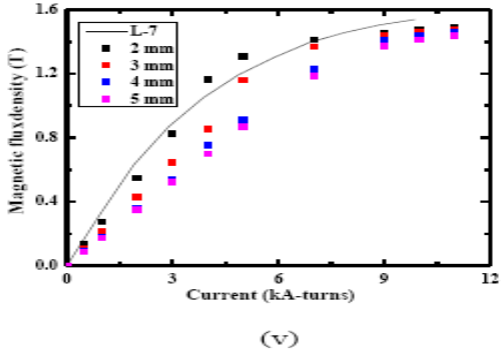
(ii)



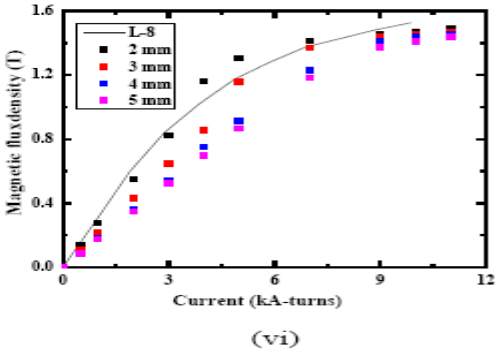
(iii)



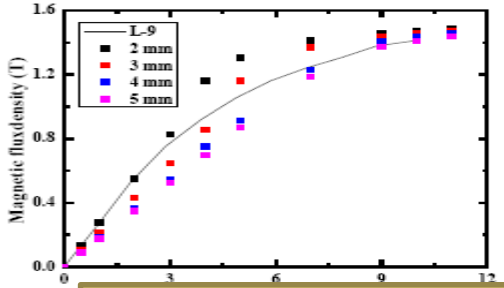
(iv)



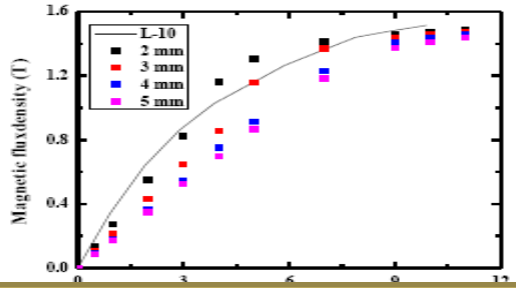
(v)



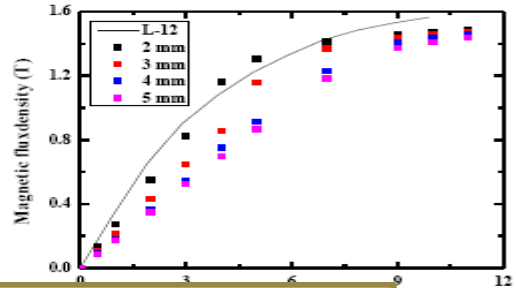
(vi)



(vi)



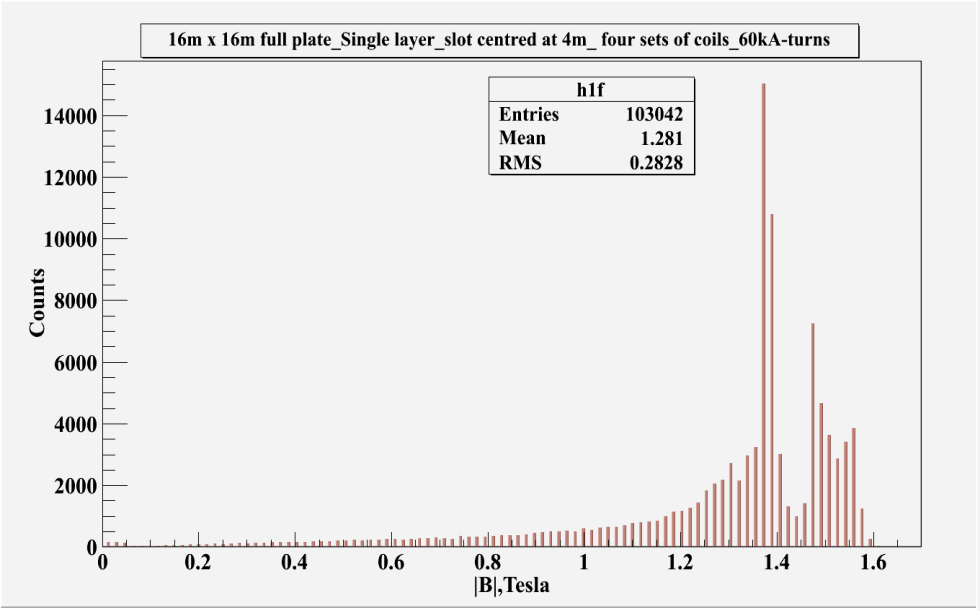
(vii)

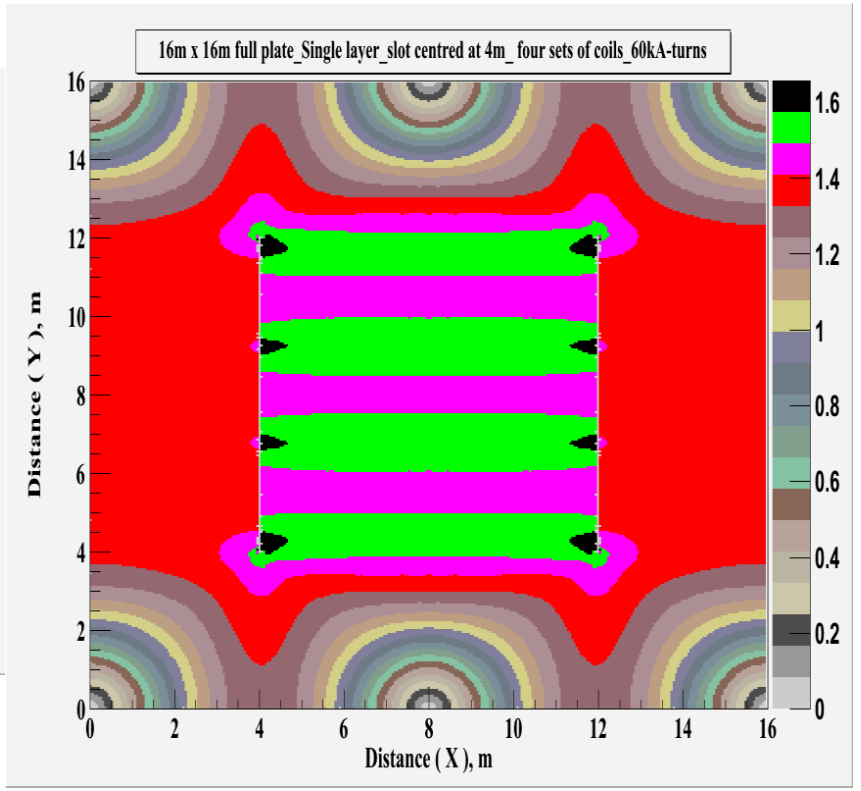


(viii)

Good agreement with assuming 2mm gap between plates

Magnet simulation : 16m module

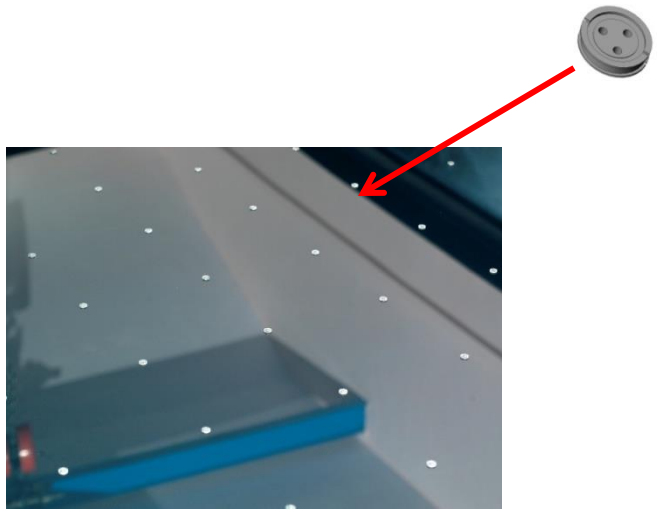


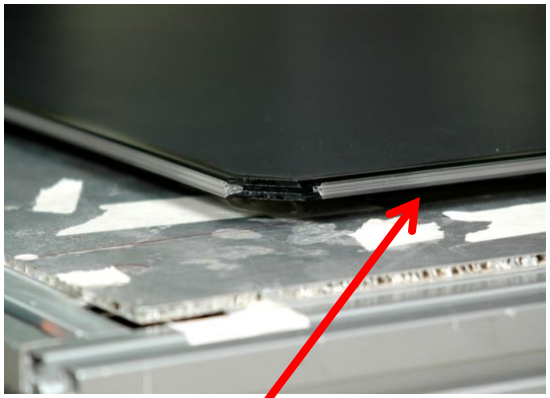


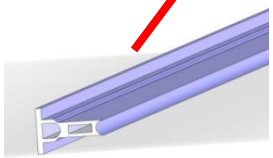
- Realistic geometry with gaps between plates
- Proper coil segments
- ~90% fiducial volume has B>1T
- Field profile now in GEANT code also

Production of glass RPCs

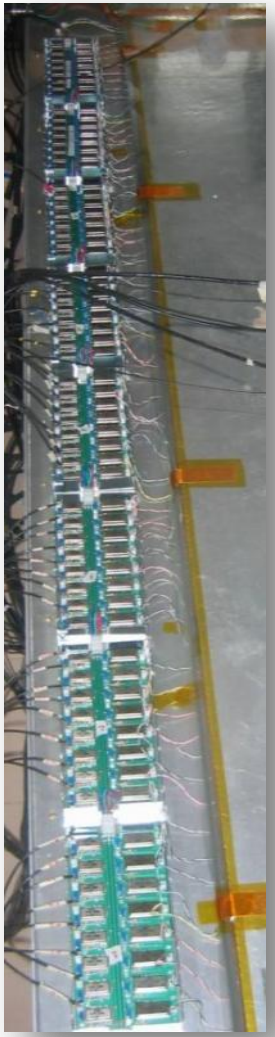
Fabrication of 2m x 2m RPCs



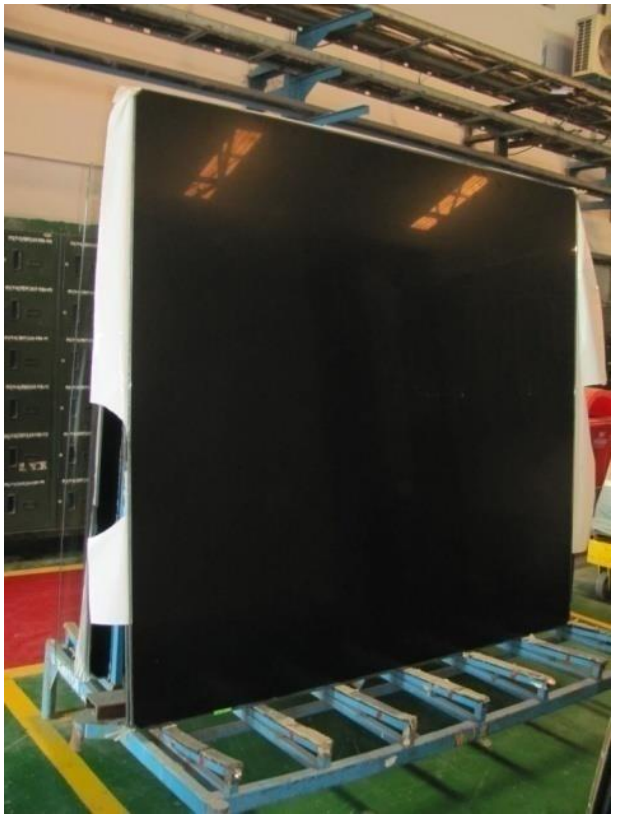




2m x 2m glass RPC test stand

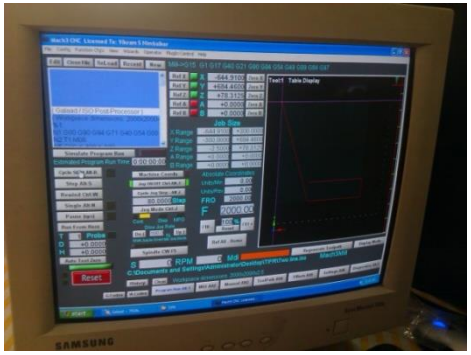


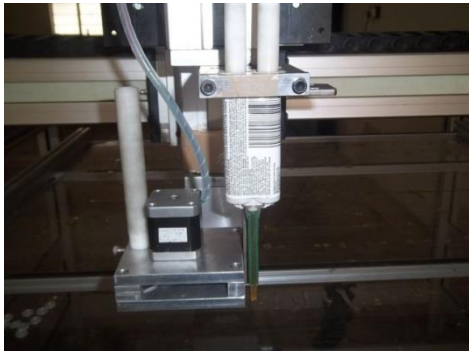
RPC fabrication at Asahi Float Glass



Painting/curing of glass plates

Automation of RPC gap making

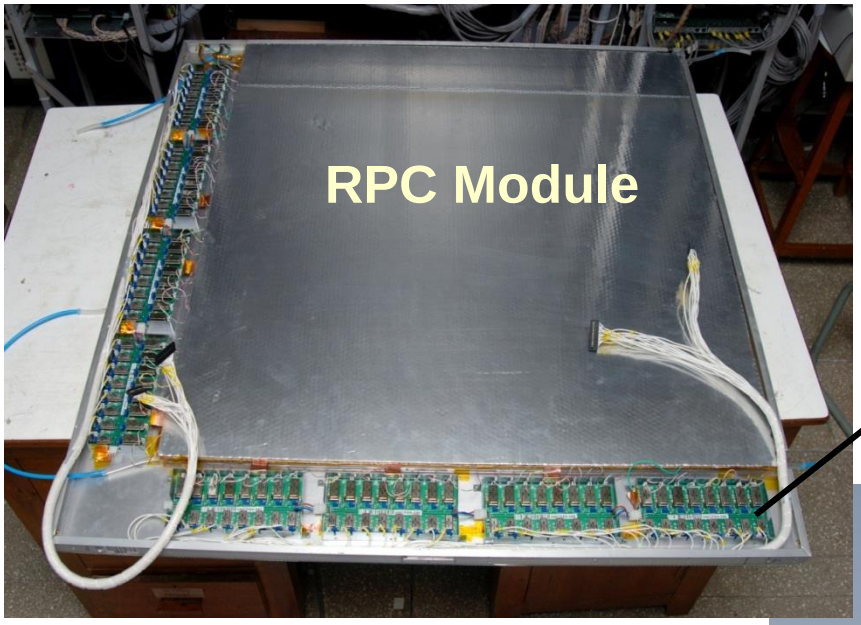




Gas recirculation system

- Prototype close loop gas recirculation system is under test at TIFR RPC lab.
- Design of system required for Engineering Module in progress

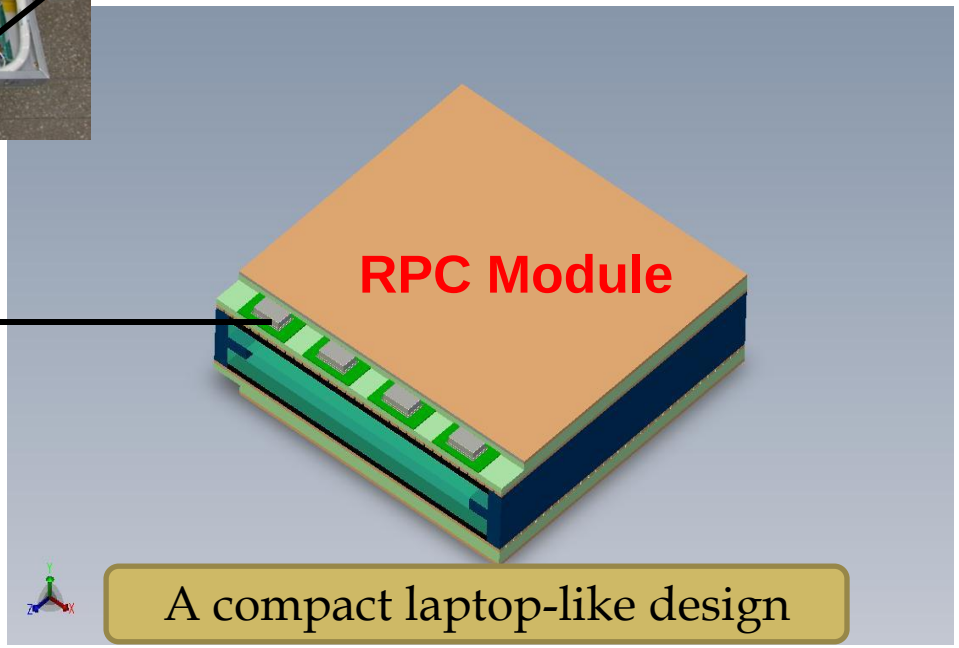
Compact Design of RPC and Electronics



Hybrid Preamplifier

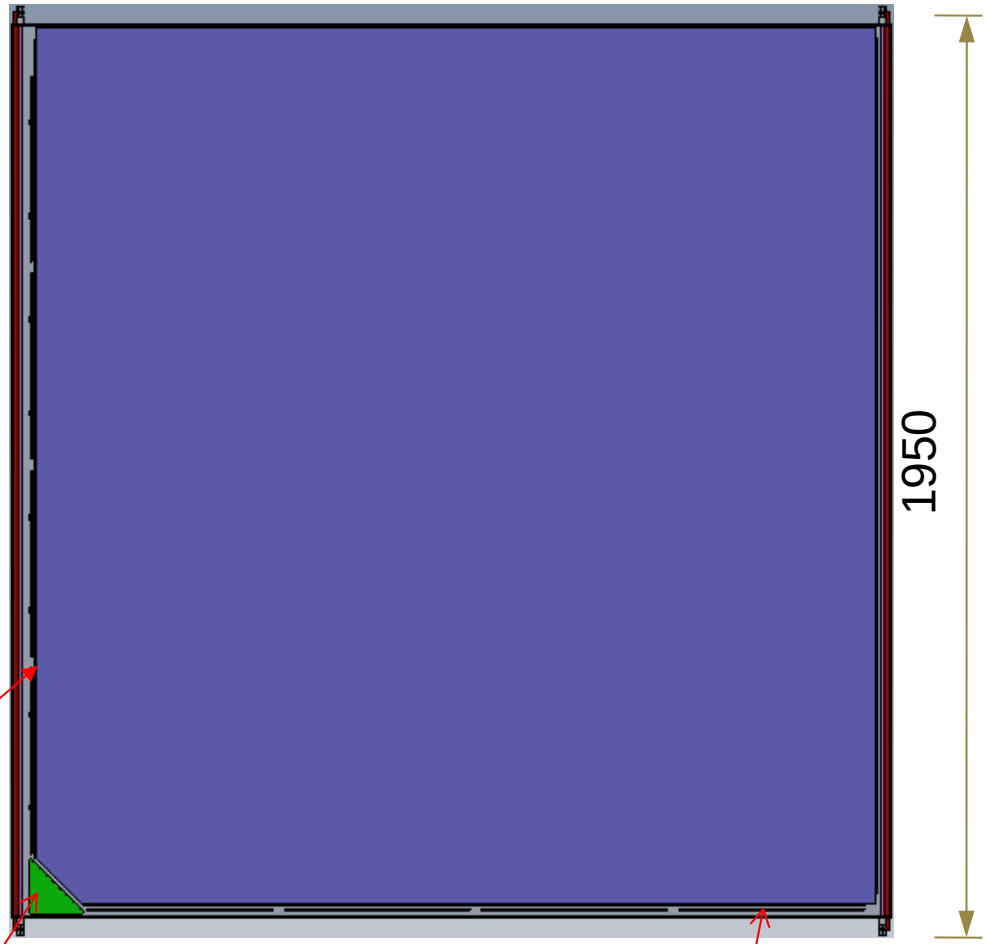
(What we have now)

(Where we want to go)



RPC Layout

403 mm X 23 mm
Preamp board

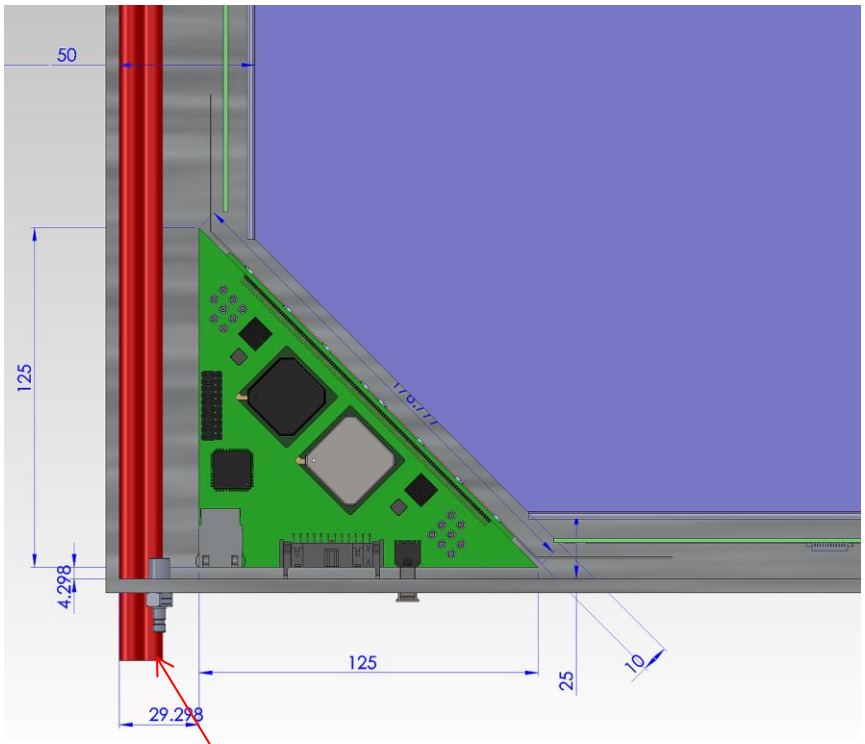


Preamp boards
in side channel

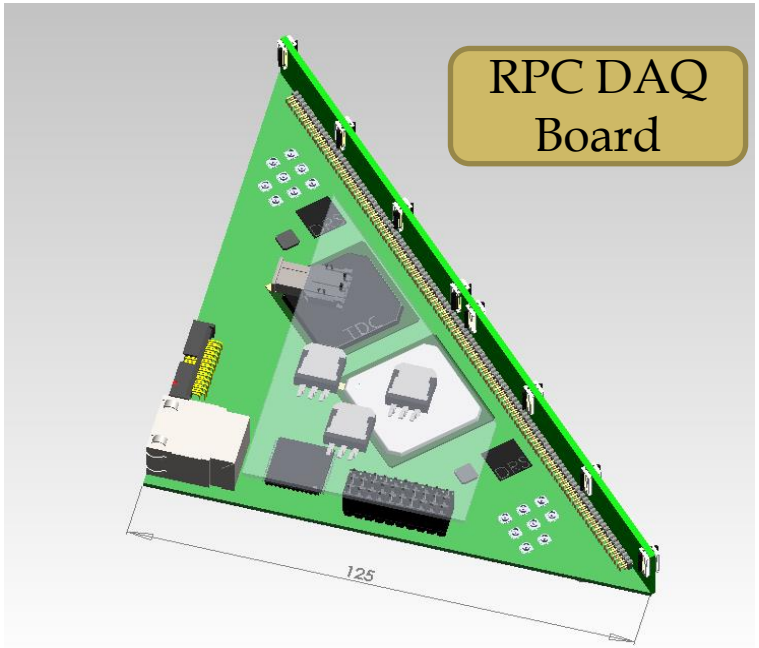
Cut corner for Daq board

Preamp boards
in side channel

DAQ Board in the RPC

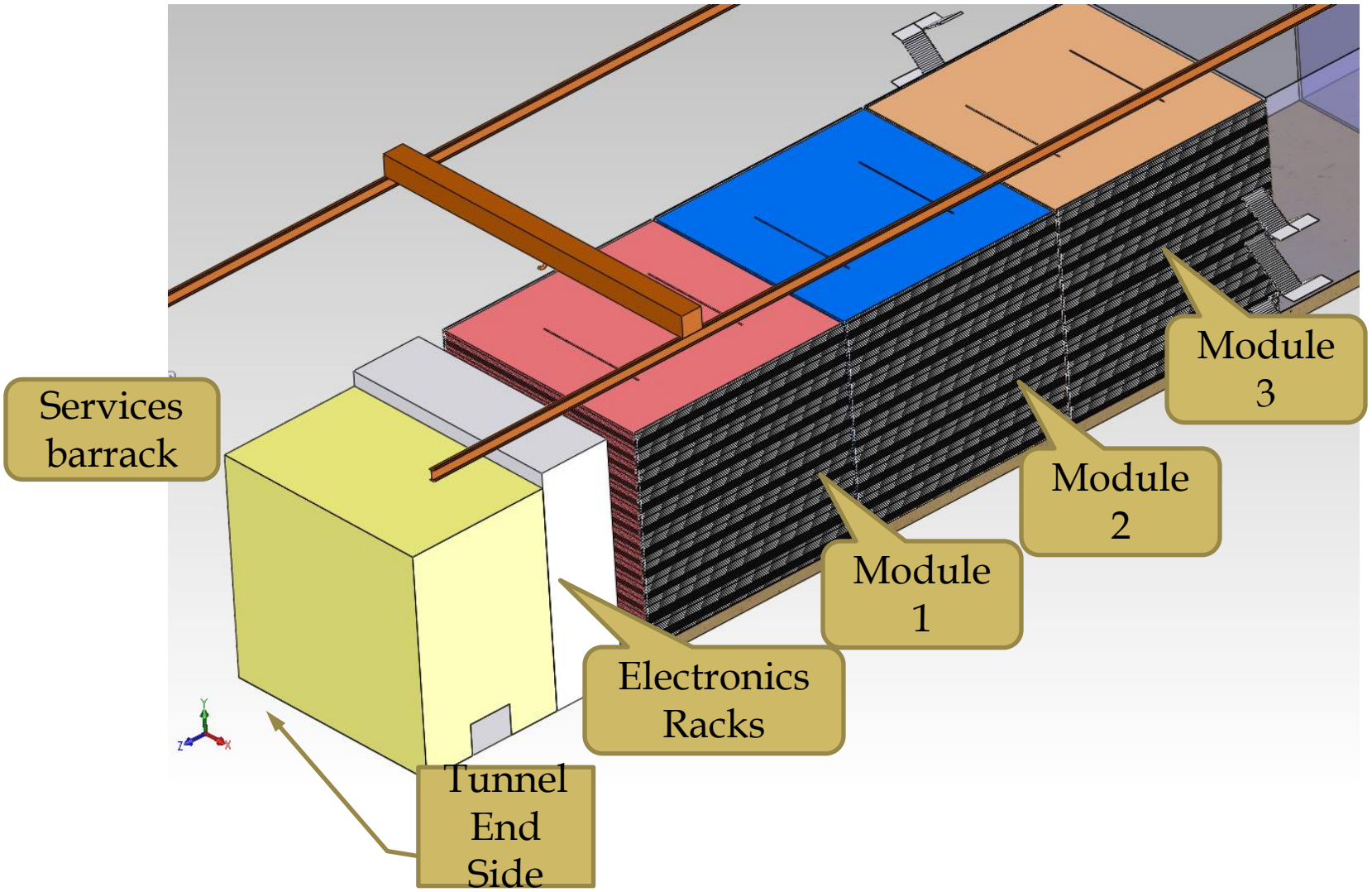


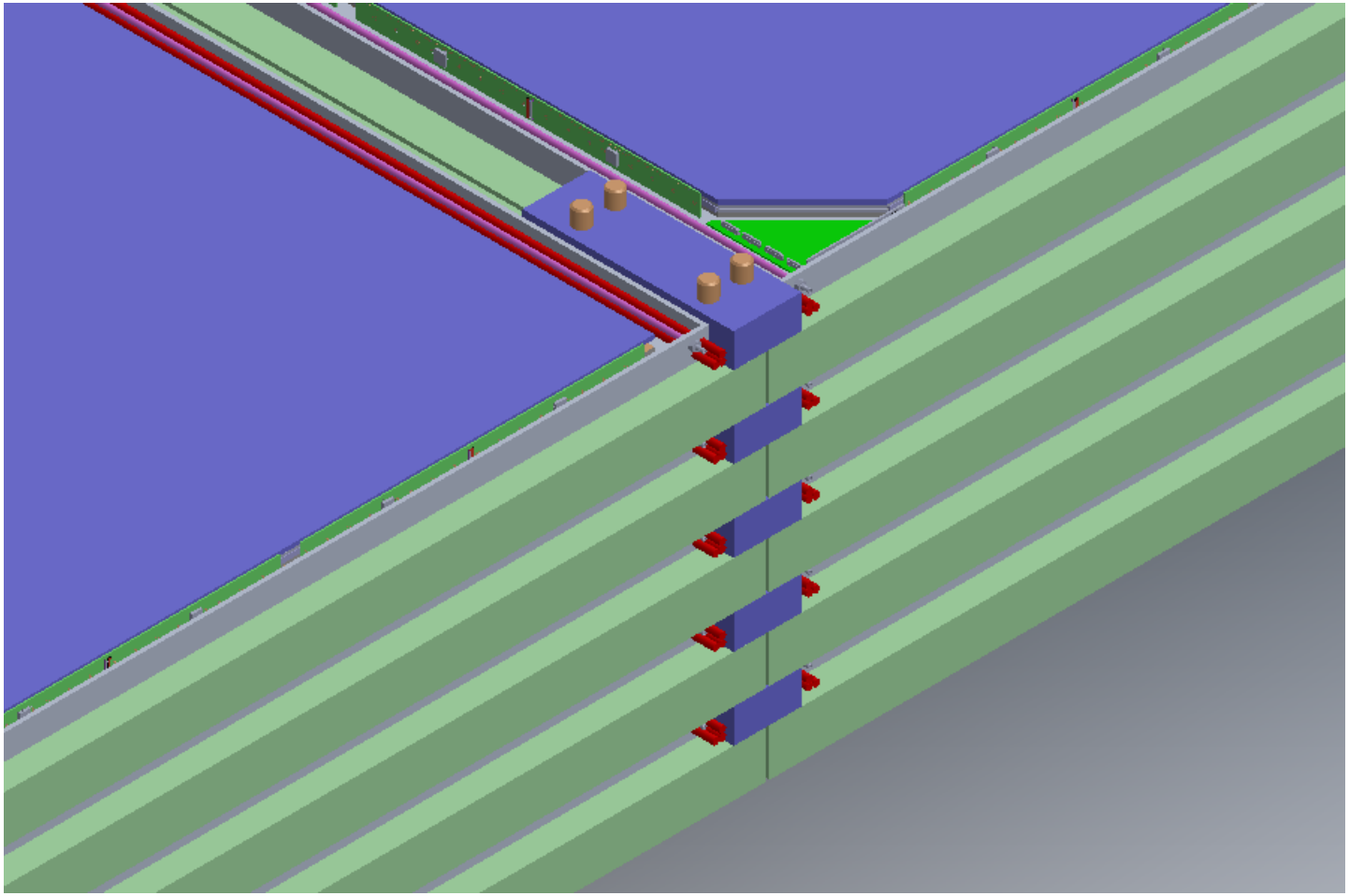
Service lines



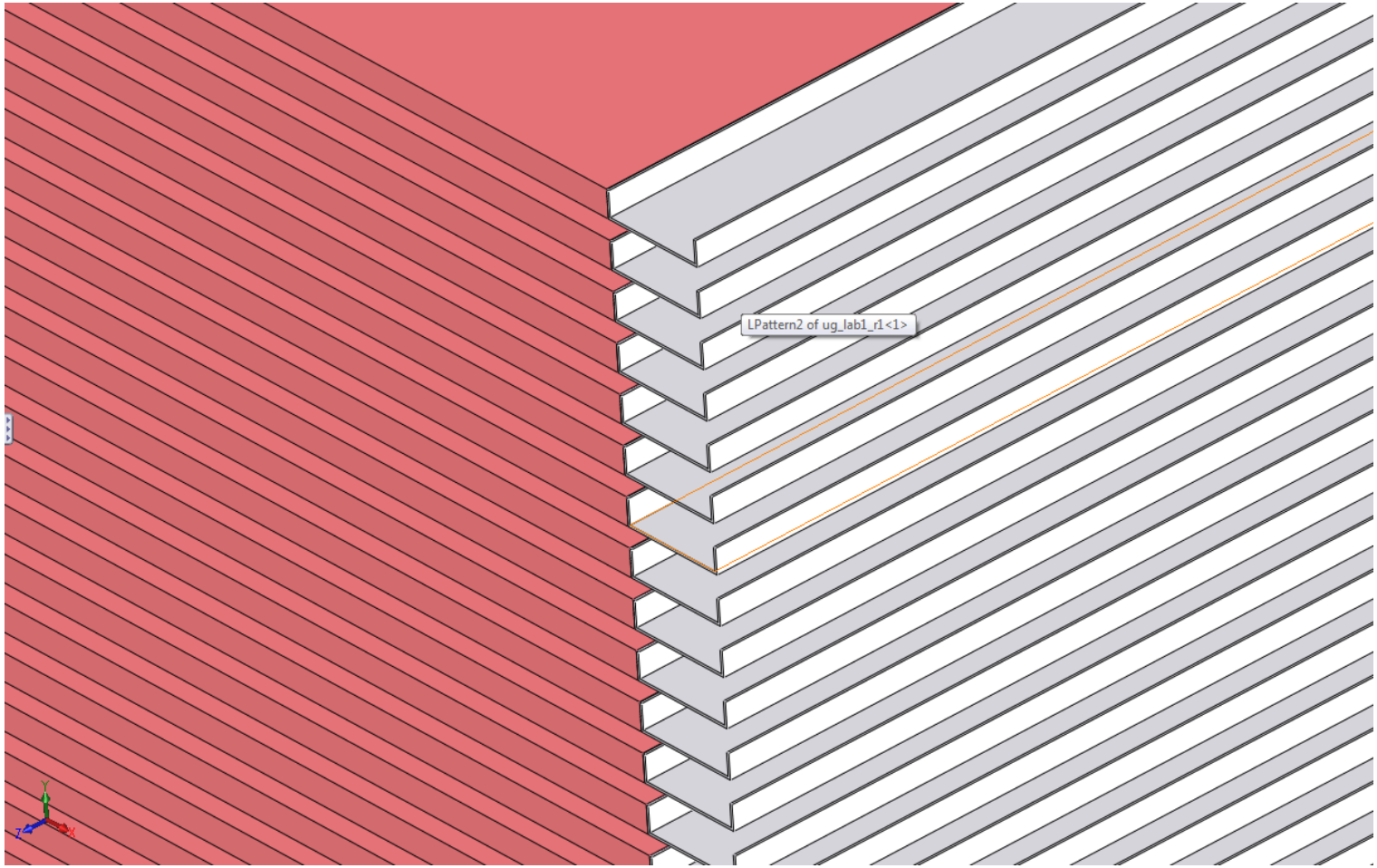
Prototyping in progress

ICAL Cavern : a closer look



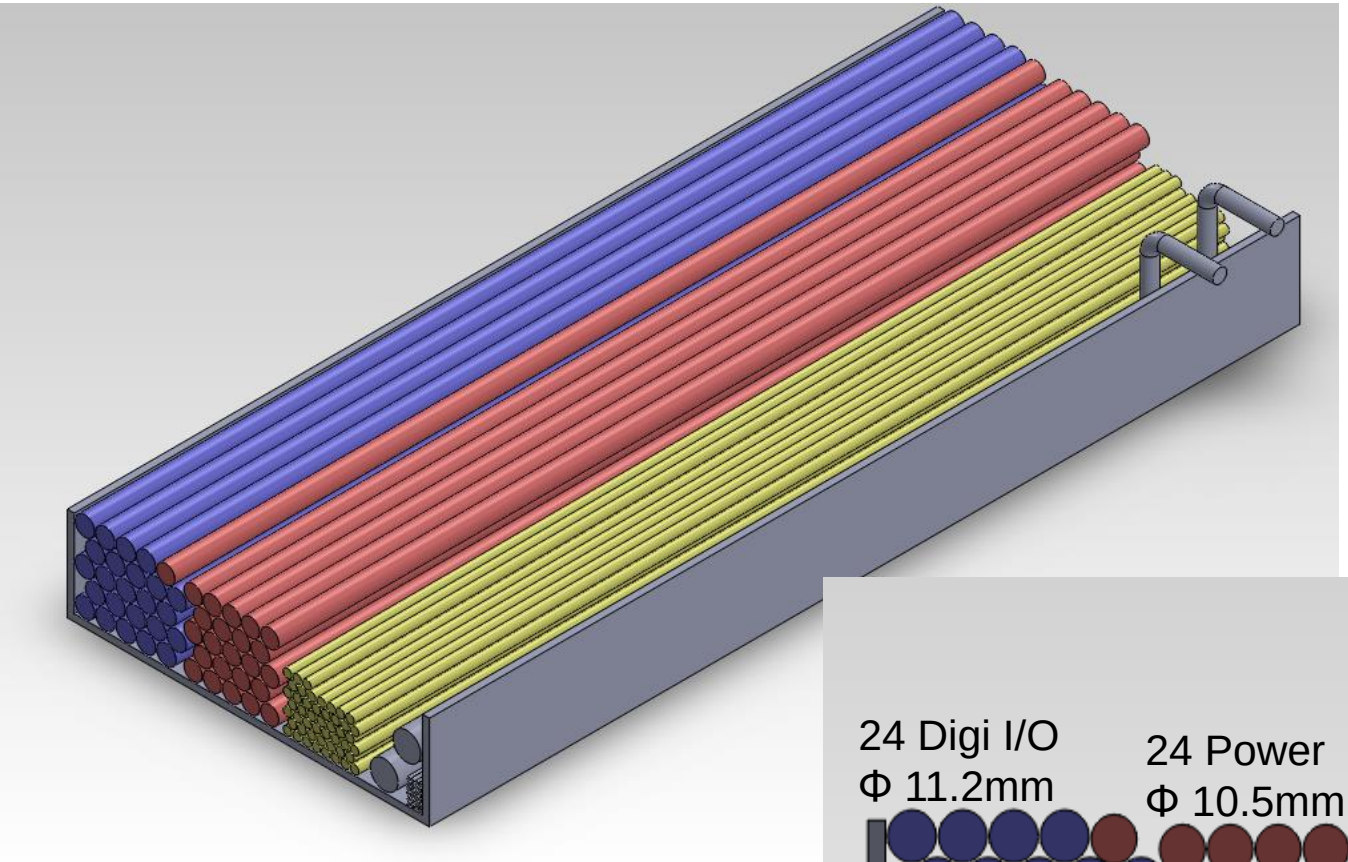


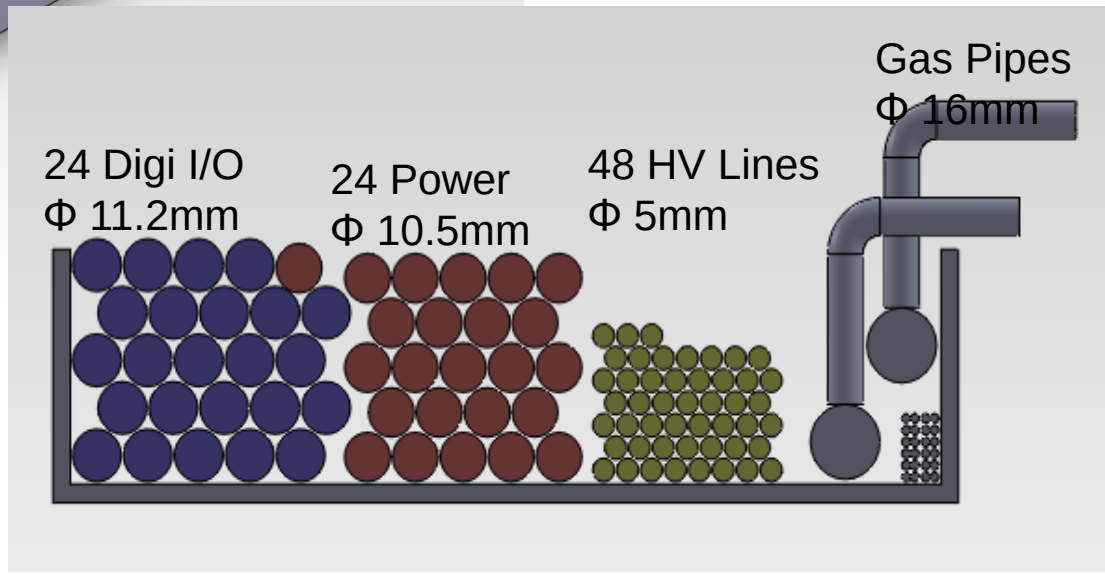
Cable Trays



Attached to spacer steel blocks, depth same as thickness of steel plates

Populating the ICAL Cable tray





Human Resource Development & Training

INO Graduate Training Programme

- Started in August 2008.
- Affiliated to HBNI.
- At present INO students are being trained for one year at TIFR, Mumbai in both experimental techniques and theory.
- Being attached to Ph.D. guides at various collaborating institutions for a Ph. D. degree after completion of coursework

Theses completed 4, in the pipiline : 3

Many Short/long term visits to RPC labs (Mumbai & Kolkata) of students and faculties from Universities in last several years.

INO Collaboration

Ahmedabad: Physical Research Laboratory
Aligarh: Aligarh Muslim University
Allahabad: HRI
Bhubaneswar : Utkal Univ.
Calicut : University of Calicut
Chandigarh: Panjab University
Chennai : IITM, IMSc
Delhi : Delhi University
Kalpakkam : IGCAR
Kolkata : SINP, CU, VECC
Lucknow : Lucknow University
Madurai : American College
Mumbai : BARC, IITB, TIFR
Mysore : University of Mysore
Srinagar : University of Kashmir
Varanasi : Banaras Hindu University

22 groups at present

Teams

Civil infrastructure :	BARC
ICAL Engineering :	BARC, TIFR, VECC
Detector and Physics :	All groups

Invitation : Come and join either the INO-ICAL Collaboration or any other experimental collaboration at INO. Come if you have ideas to setup an experiment in an underground laboratory in any branch of science.

Summary

- Project INO on firm footing
- INO graduate training programme attracting bright minds
- Work on site infrastructure and 1/8 scale Engineering Module in full swing
- Industrial production of 2m X 2m glass RPCs
  - Several vendors under development
  - Initial stages of automation completed
  - Order for first batch of large scale production soon
- Electronics, Trigger, Daq in advanced stages of development
- Work on Tunnel and cavern etc to be taken up after Cabinet approval of the main project


Thank You for
your attention