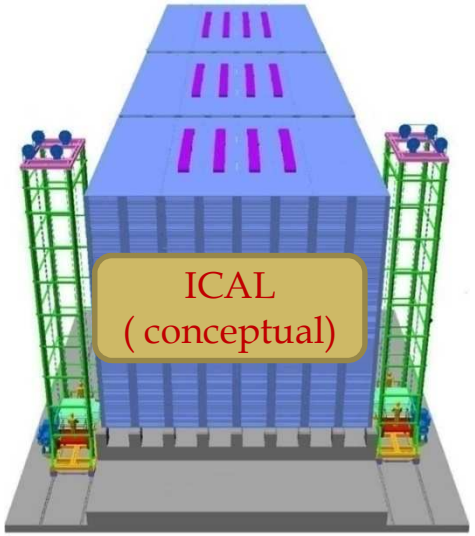
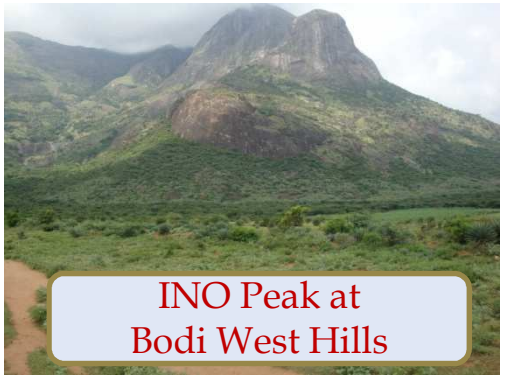
India-Based Neutrino Observatory (INO)

Naba K Mondal
TIFR, Mumbai

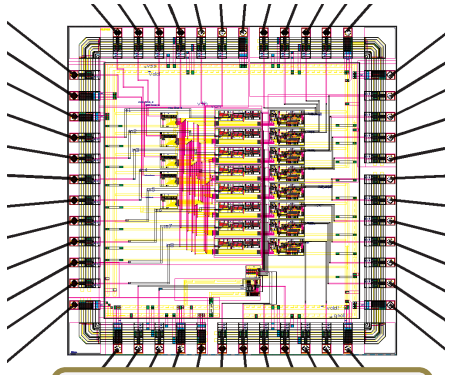

ICAL
(conceptual)


INO Peak at
Bodi West Hills


RPC Test stand at
TIFR


2mX2m RPC Test Stand at
TIFR

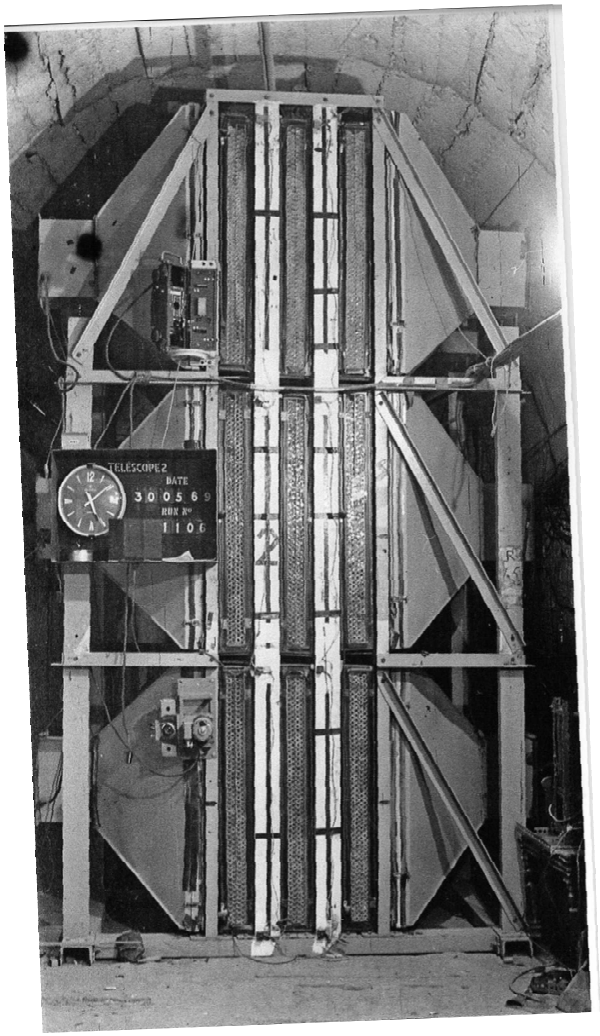

Prototype ICAL at VECC


ASIC for RPC
designed at BARC

Kolar Gold Fields Underground Laboratory

- *India had a long tradition of carrying out experiments deep underground.*
- *KGF laboratory was the deepest underground laboratory during the period 1951-1992.*
- *First atmospheric neutrino was detected at KGF at a depth of 2.3km way back in 1965 by the TIFR-Osaka-Durham group.*
- *During late 70s & early 80s dedicated detectors were setup at KGF by TIFR-Osaka collaboration to look for proton decay.*
- *KGF mines closed its operation in 1992.*

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

Nucleon Decay Experiments at KGF during 80s

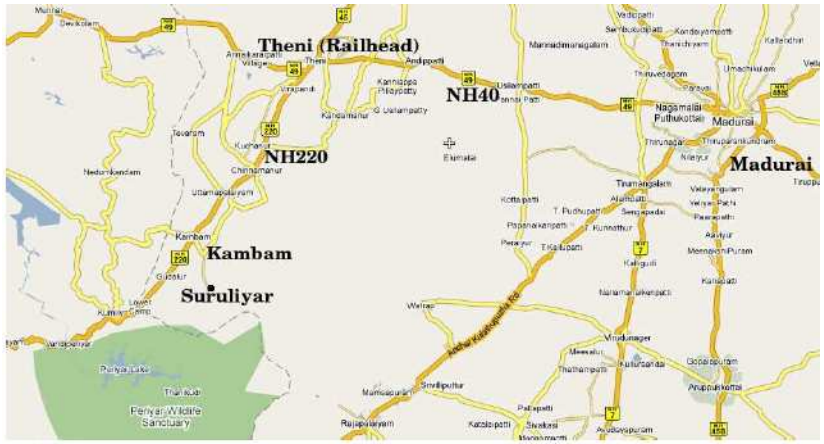
INO : Salient Features

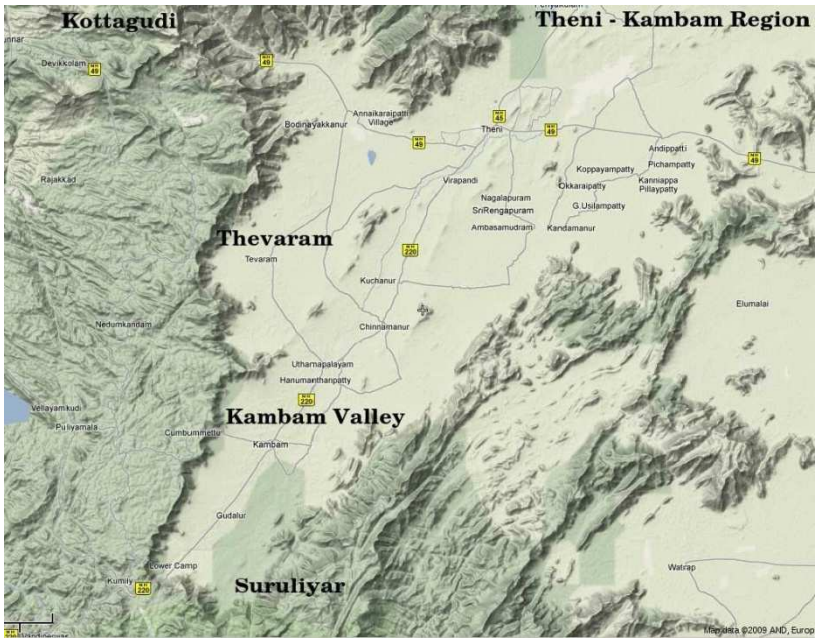
- *Underground laboratory with ~1 km all-round rock cover accessed through a 2 km long tunnel. A large and several smaller caverns to facilitate many experimental programmes.*
- *Frontline neutrino issues e.g., mass parameters and other properties, will be explored in a manner complementary to ongoing efforts worldwide.*
- *The ICAL detector, with its charge identification ability, will be able to address questions about the neutrino mass ordering.*
- *Distance from CERN (Switzerland) and JPARC (Japan) ~ 7000 km, close to "magic baseline" for experiments with neutrino beams in a few decade from now*
- *Will support several other experiments when operational. Neutrino-less Double Beta Decay and Dark Matter Search experiments foreseen in the immediate future.*
- *INO facility will be available for international community for setting up experiments.*

Projects approved by Indian funding agencies

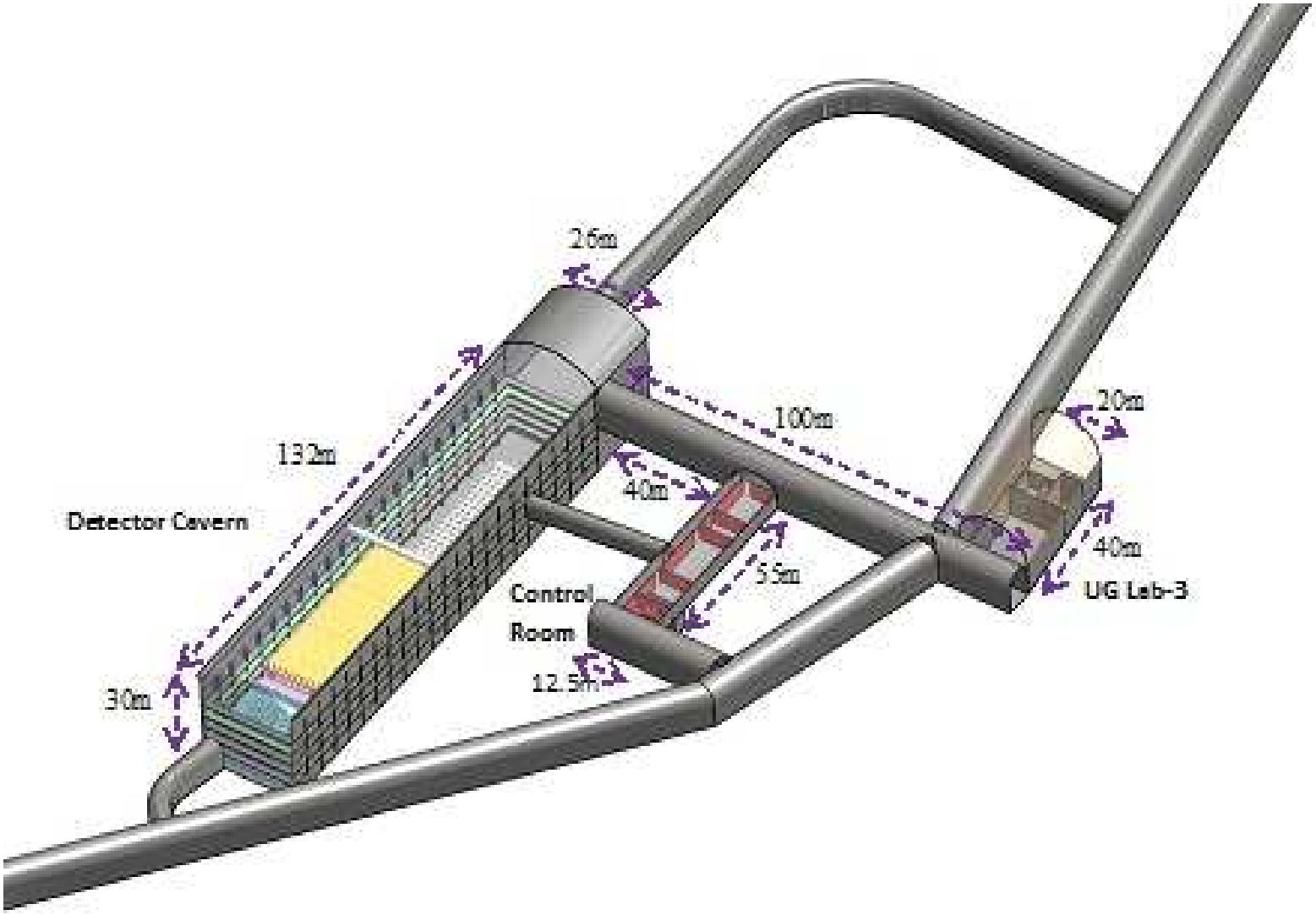
- ***Construction of an underground laboratory and surface facilities near Pottipuram village in Theni district of Tamil Nadu.***
- ***Construction of the 50 kton magnetised Iron calorimeter (ICAL) detector to study properties of neutrinos.***
- ***Construction of the INO centre- The National Centre for High Energy Physics (NCHEP) at Madurai.***
- ***Human Resource Development (INO Graduate Training Program)***
- ***Detector R & D***

INO site at Pottipuram





Underground Laboratory Layout



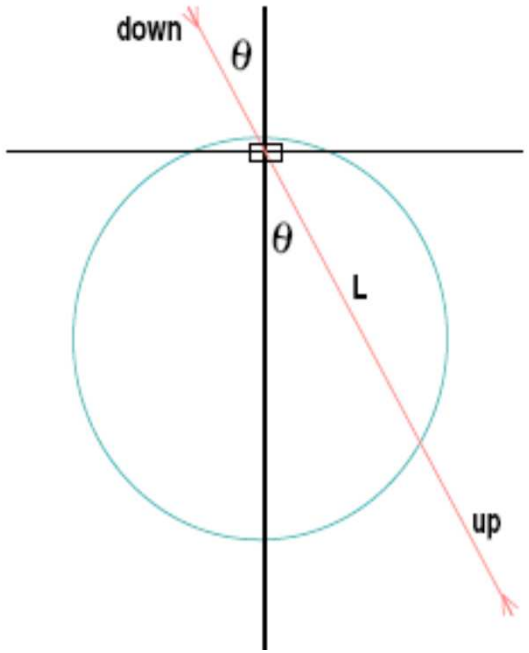
INO-ICAL Experiment

A large mass detector with charge identification capability

Physics goal:

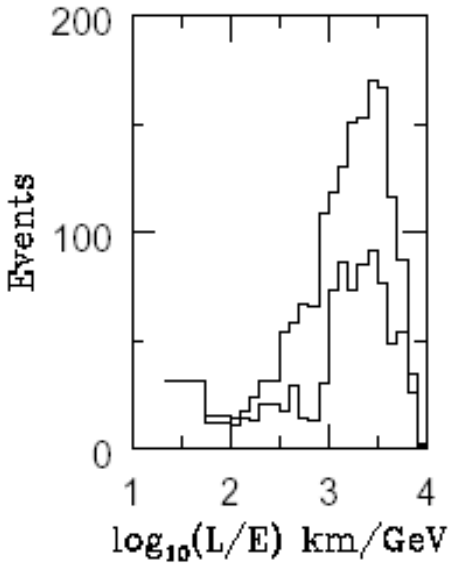
- ***Improved measurement of oscillation parameters.***
- ***Search for potential matter effect in neutrino oscillation.***
- ***Determining the sign of Δm^2_{23} using matter effect***
- ***Measuring deviation from maximal mixing for θ_{23}***
- ***Probing CP and CPT violation.***
- ***Constraining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

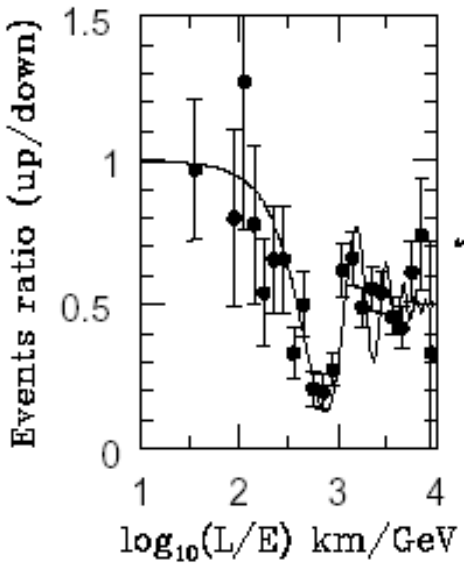
Disappearance of ν_μ Vs. L/E



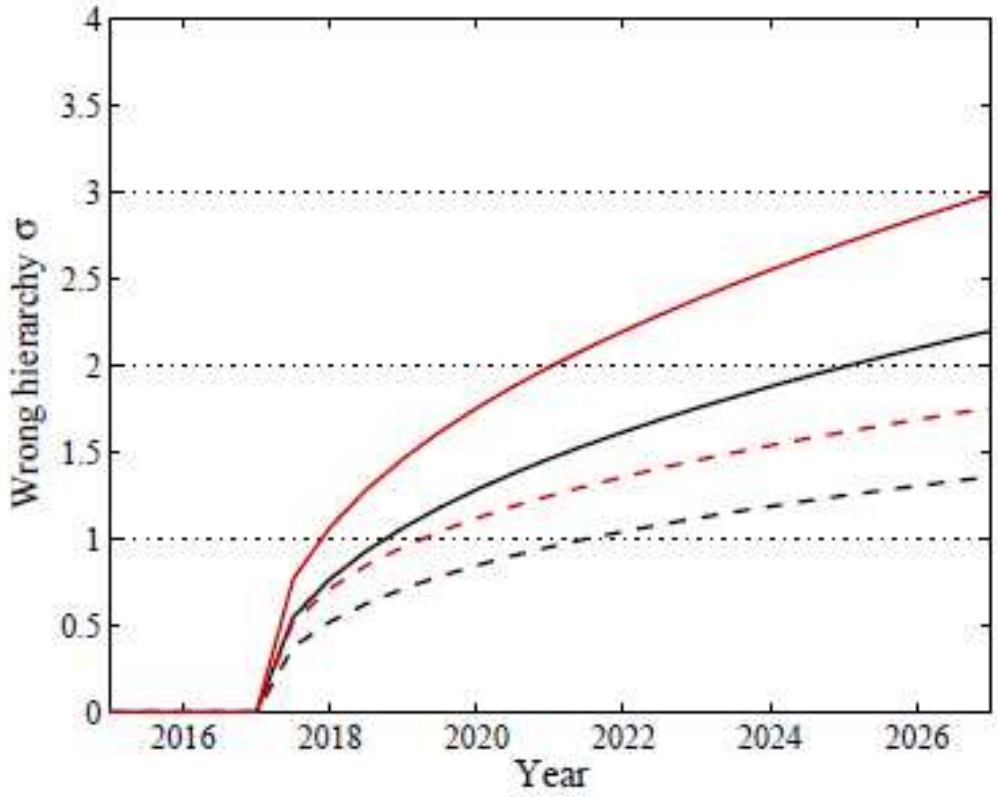
$$\frac{N_{up}(L/E)}{N_{down}(L'/E)} = P(\nu_\mu \rightarrow \nu_\mu; L/E)$$

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



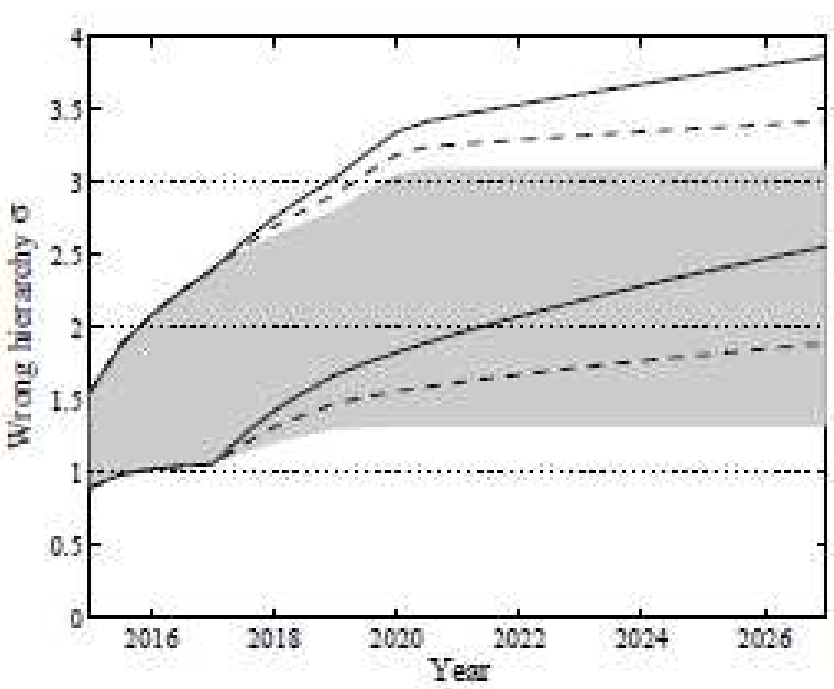


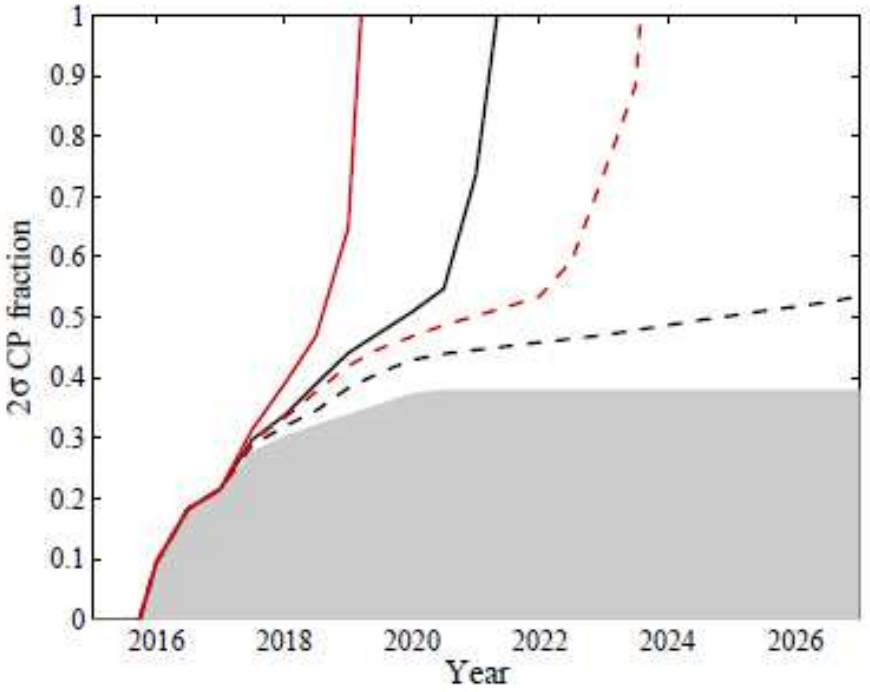
Neutrino mass ordering sensitivity of INO



Blennow & Schwetz 2012

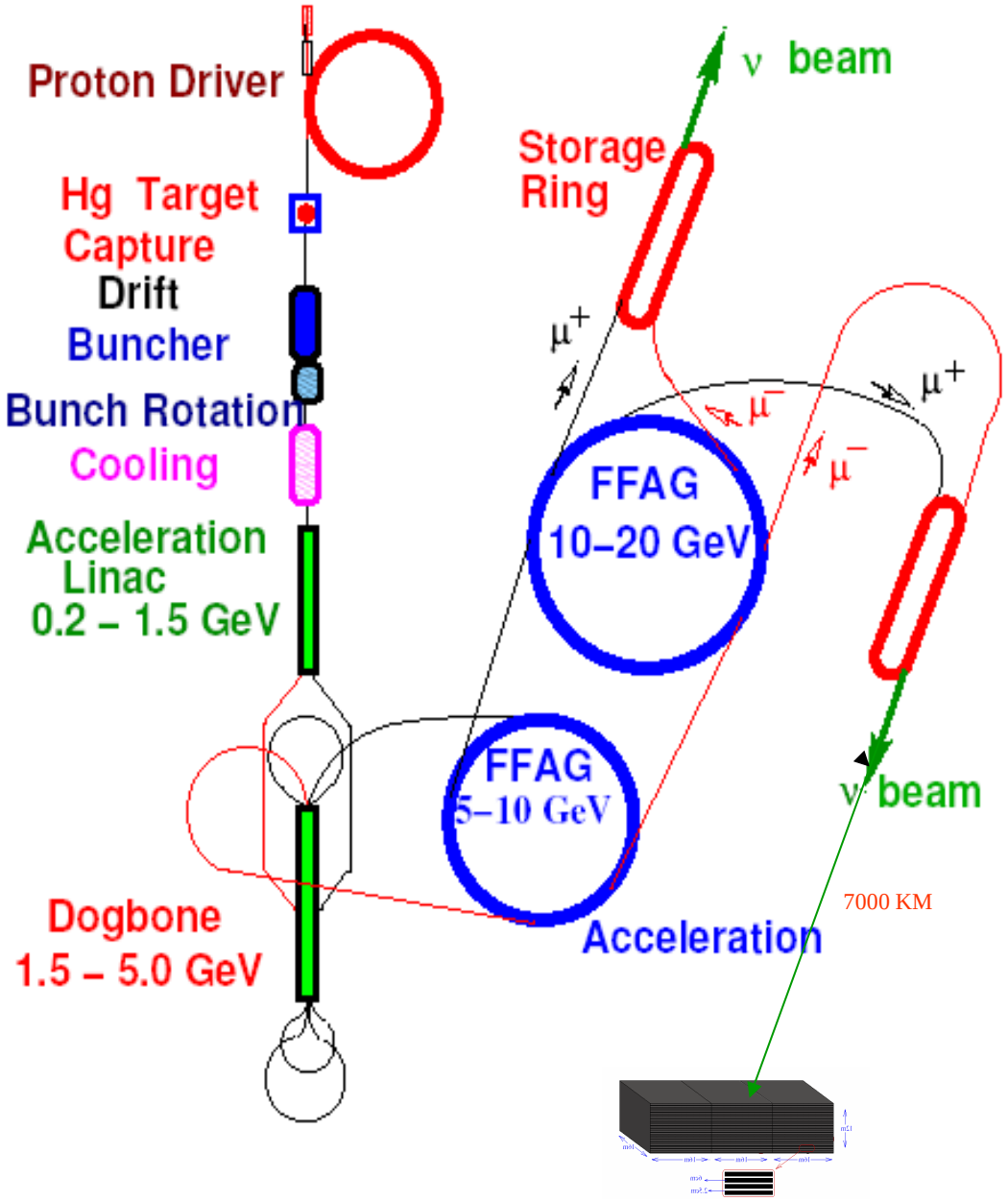
INO Mass ordering sensitivity (combined with NOvA & T2K)

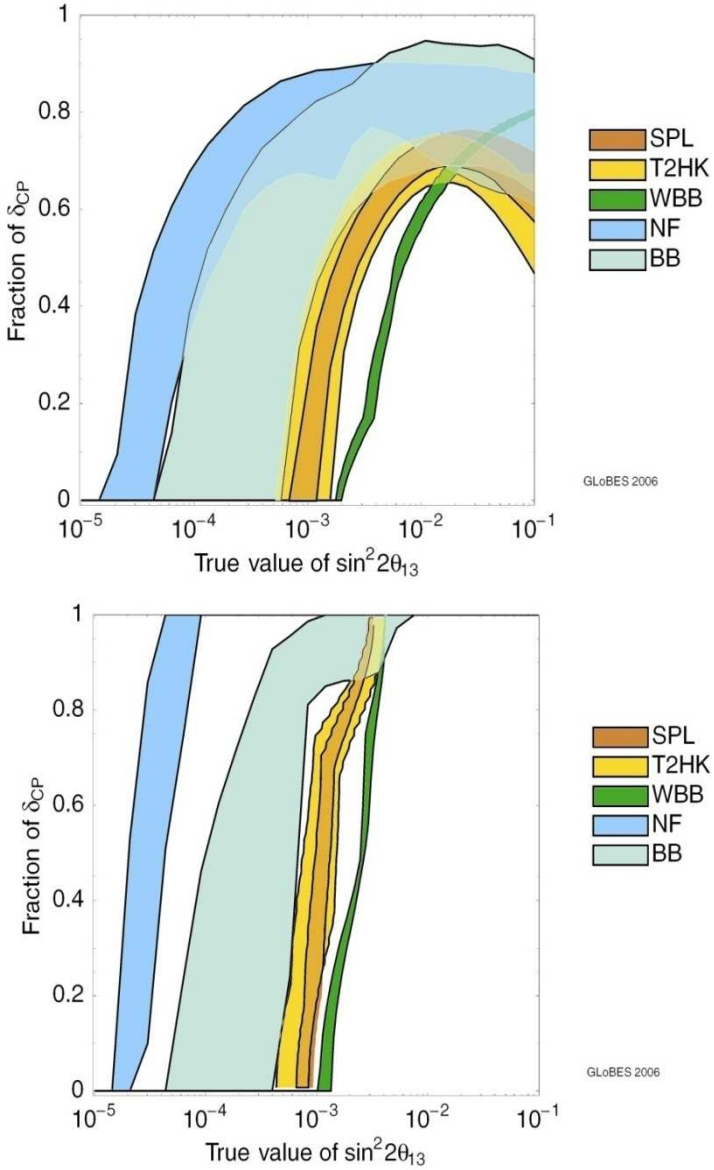




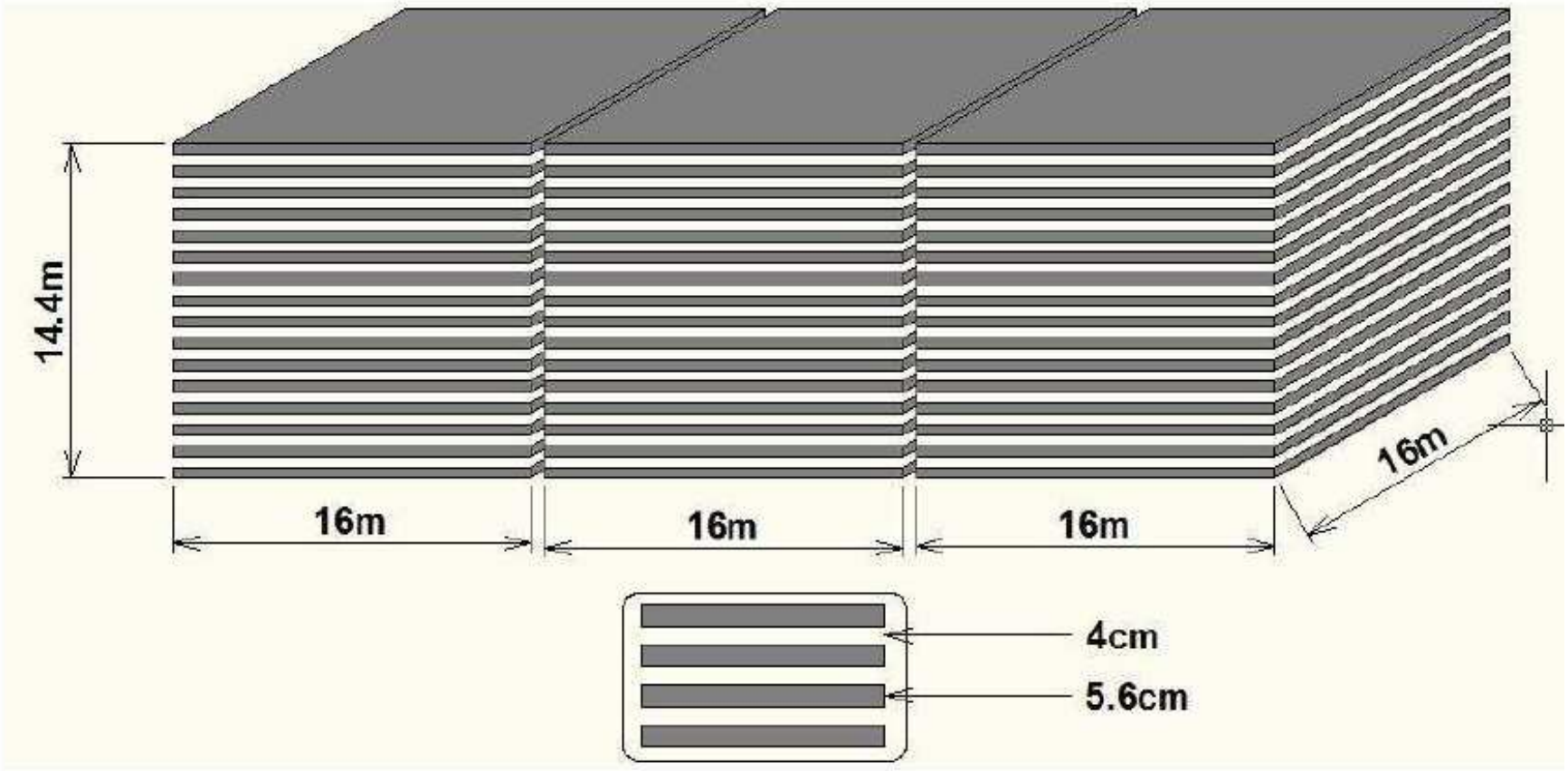
Blennow & Schwetz 2012

Beyond Superbeam - Neutrino Factory

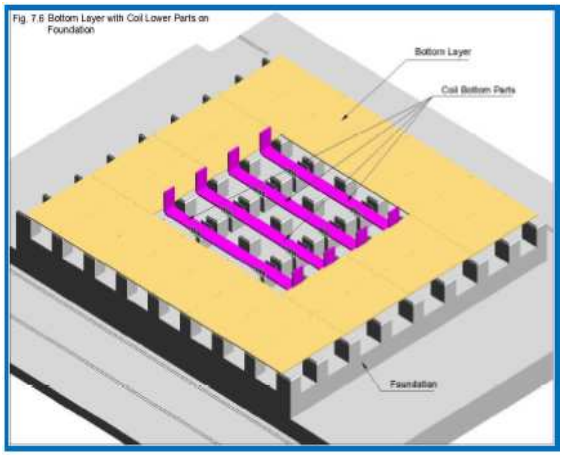


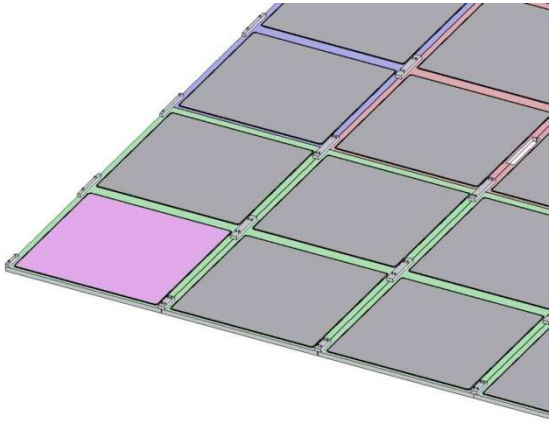


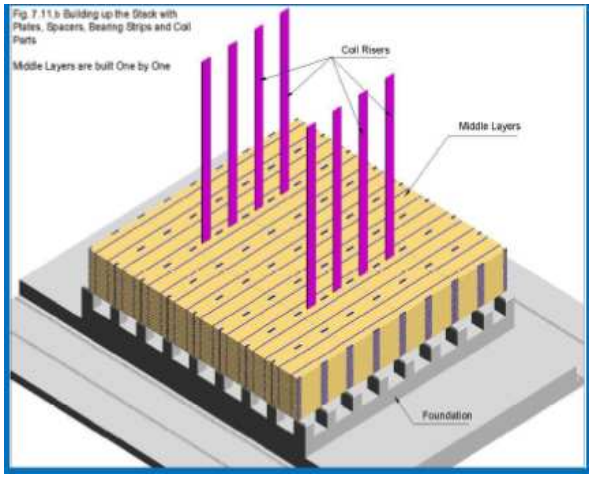
INO-ICAL Detector

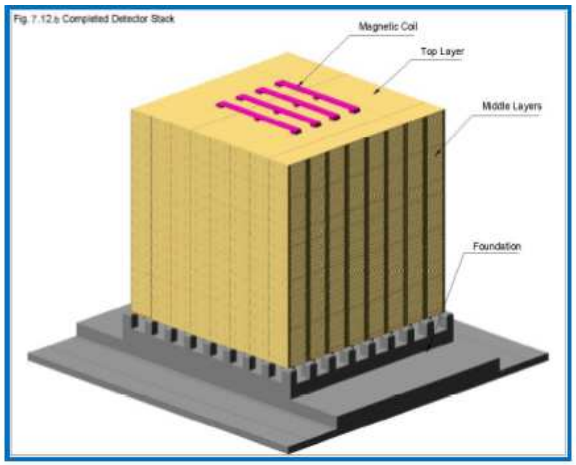


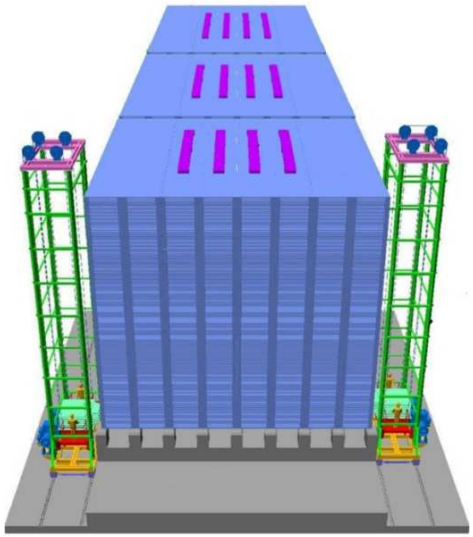
Construction of the ICAL detector

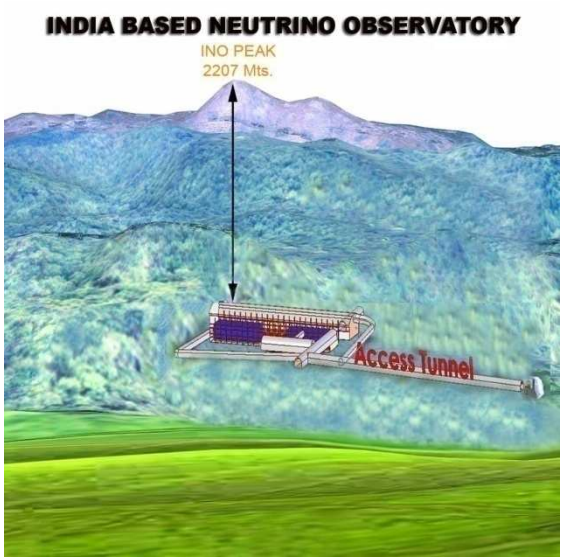








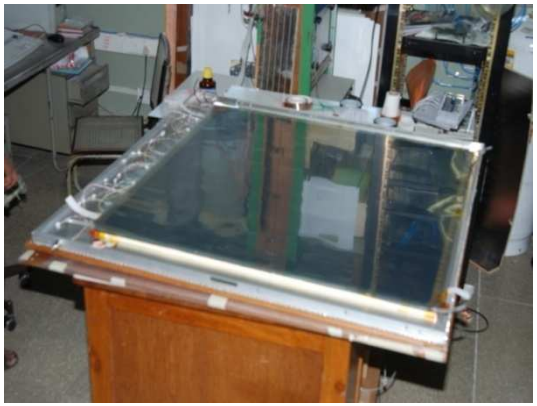




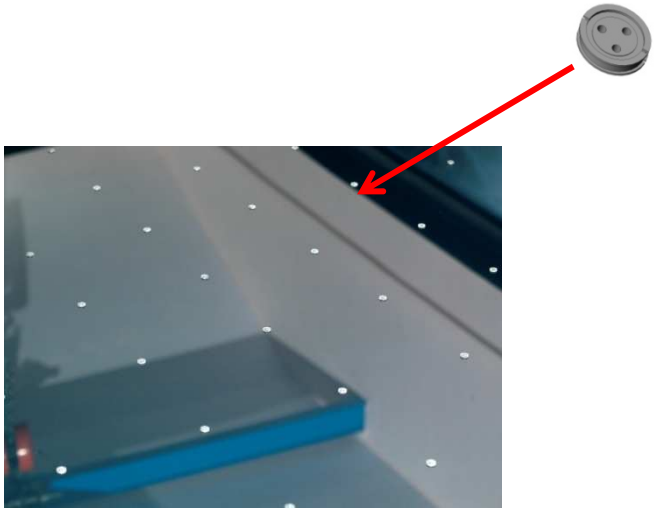
Largest Basic Science Project in India

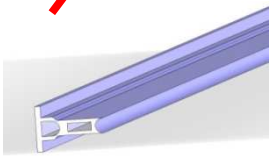
No of modules	*3*
Module dimension	*16 m X 16 m X 12 m*
Detector dimension	*48 m X 16 m X 12 m*
No of layers	*140*
Iron plate thickness	*6 cm*
Gap for RPC trays	*2.5 cm*
Magnetic field	*1.5 Tesla*
RPC unit dimension	*2 m X 2 m*
Readout strip width	*2 cm*
No. of RPCs/Road/Layer	*8*
No. of Roads/Layer/Module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

Fabrication of 1m x 1m RPCs



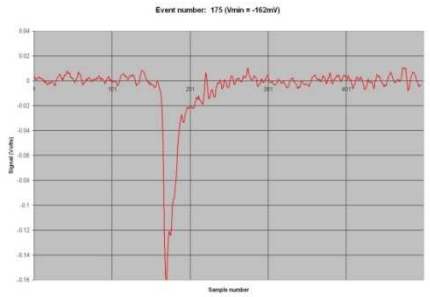
Making of 2m x 2m RPCs

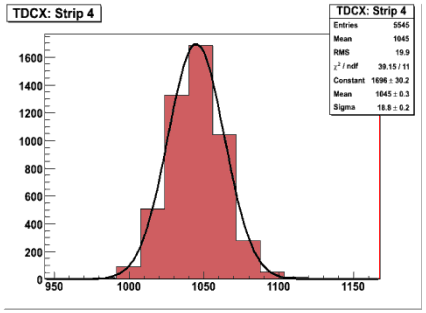


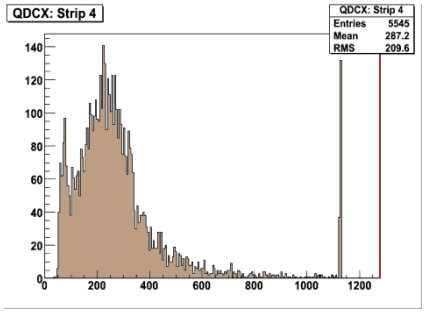


RPC fabrication at Asahi Float Glass Co.

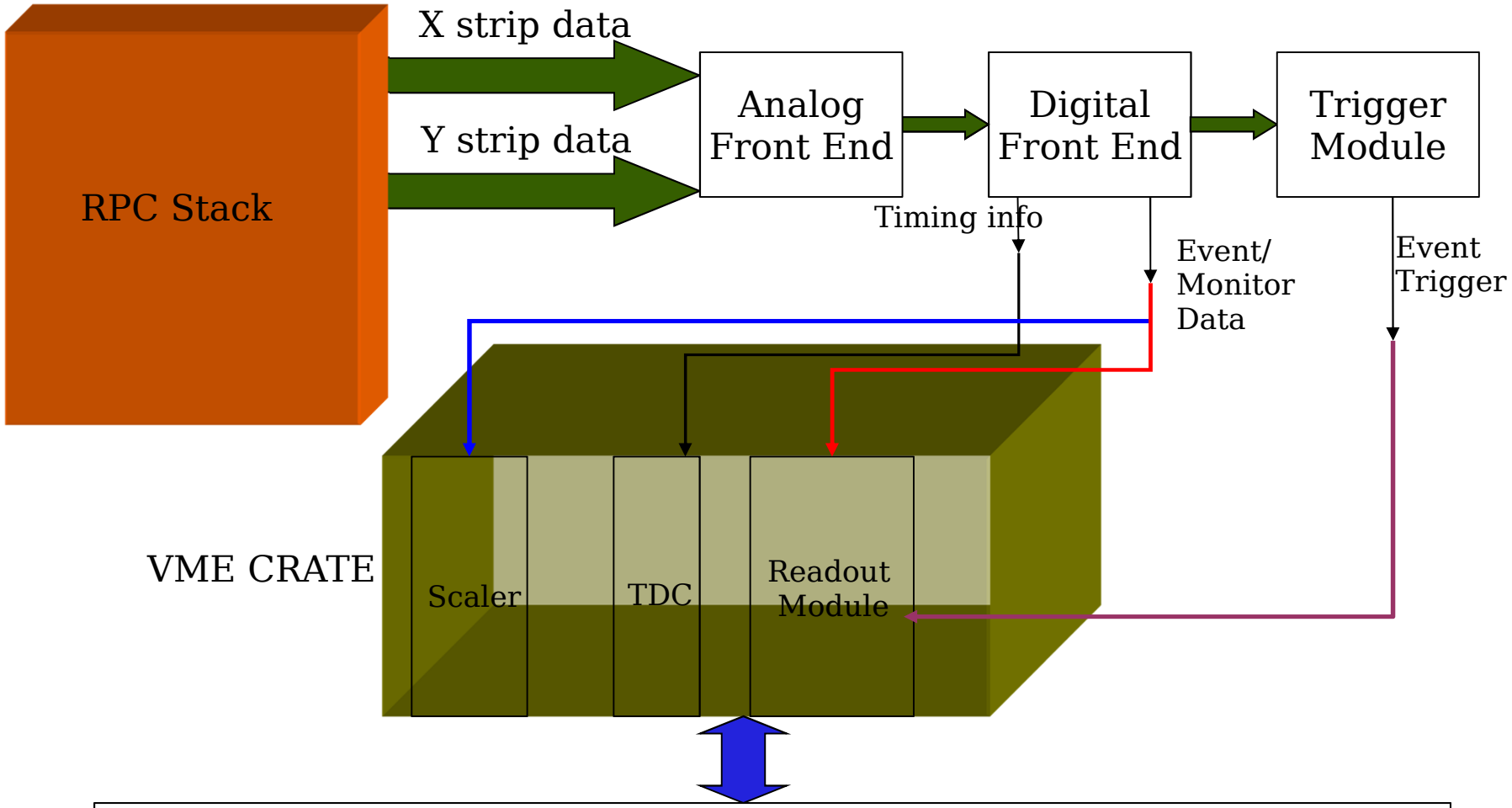
Prototype Glass RPC Stack at TIFR tracking Muons







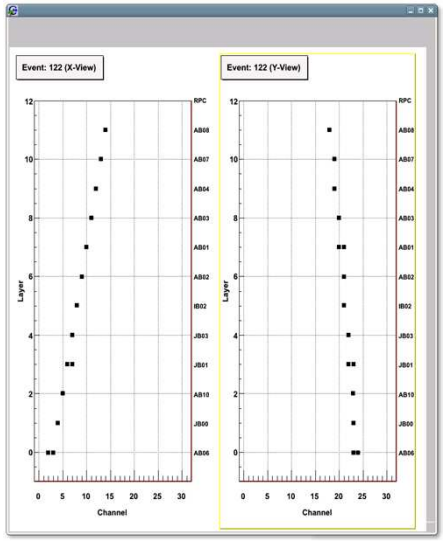
VME BASED DAQ SETUP

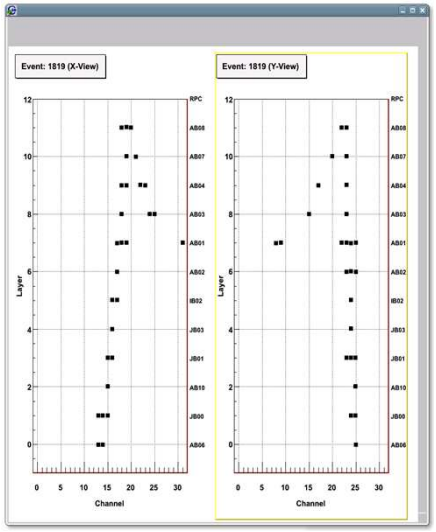


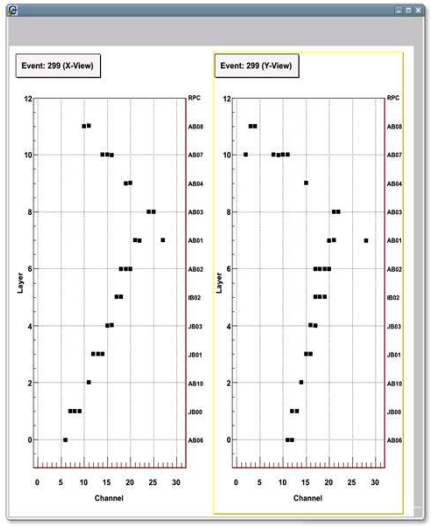
Linux based DAQ software (C++, Qt, ROOT)

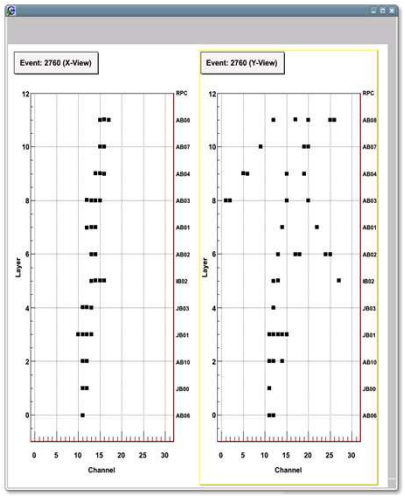
- ✓Interrupt Based
- ✓Multi-Threaded
- ✓Graphical User Interface
- ✓Online 2D/3D Event Display
- ✓RPC Strip Monitoring
- ✓Online Error Reporting

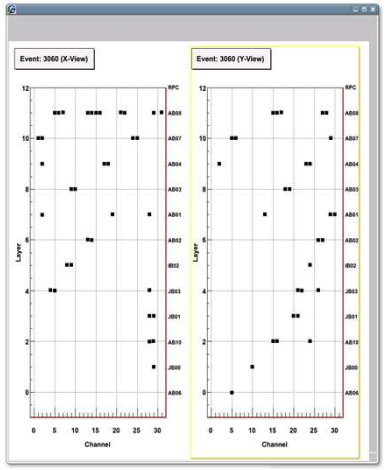
Some interesting cosmic ray tracks



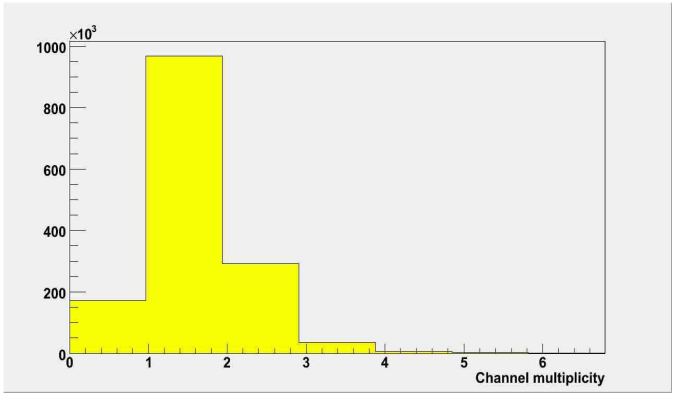




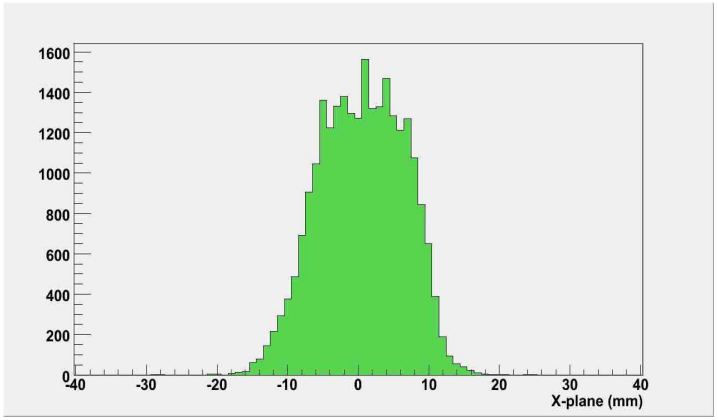




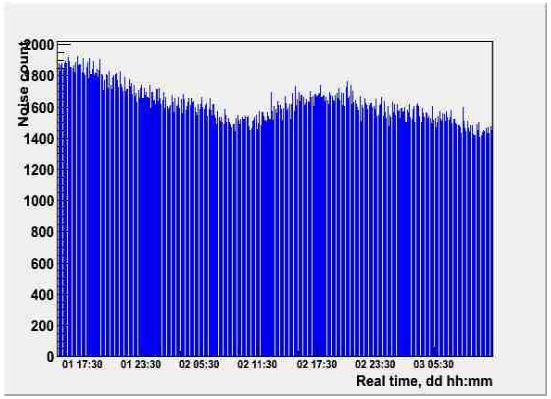
Study of RPC performance using cosmic muons



Strip Multiplicity due to crossing muons



Track residue in mm



Strip noise rate vs time

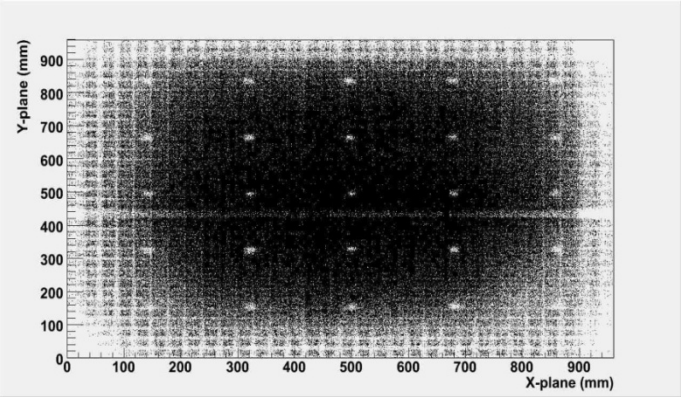
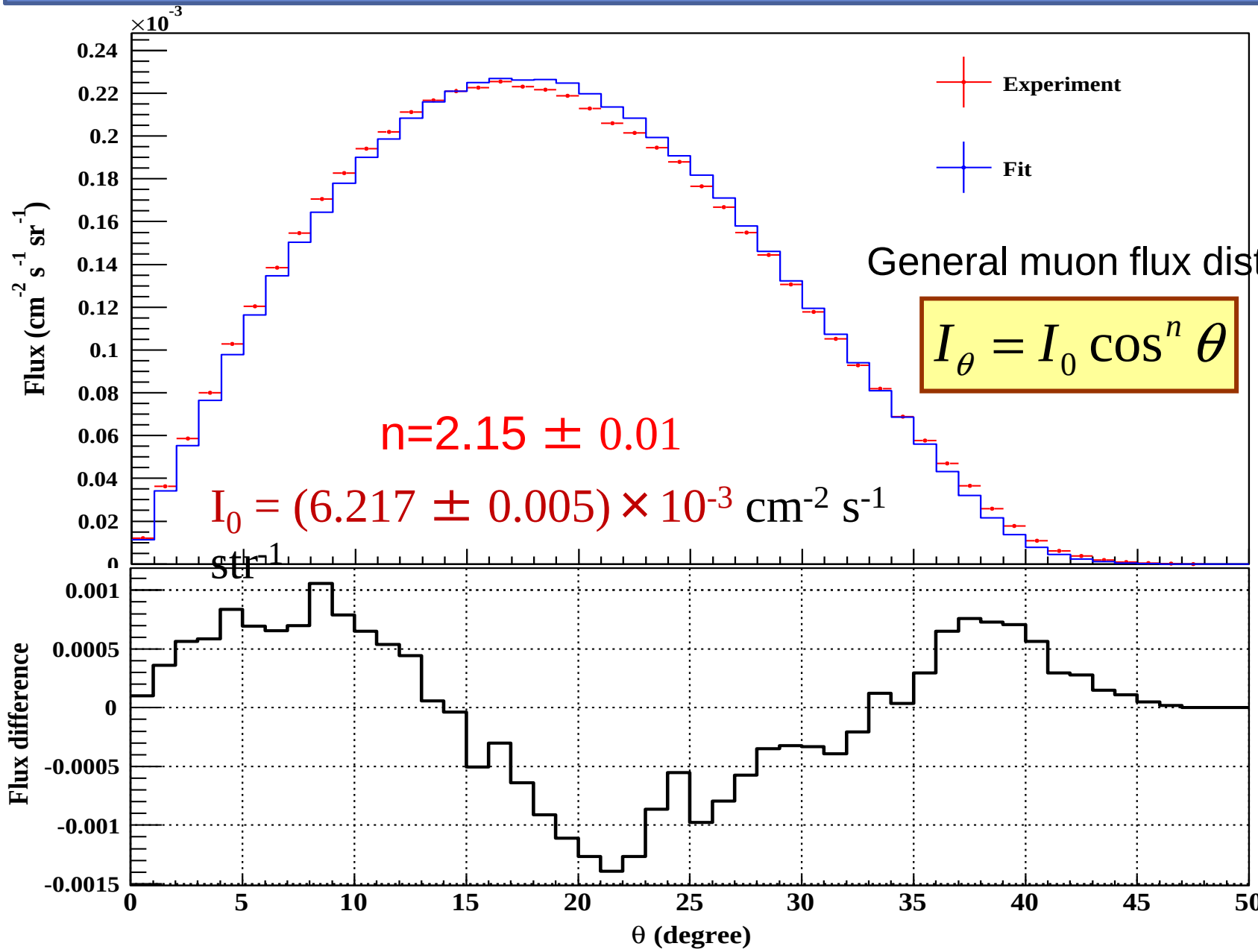


Image of a RPC using muons

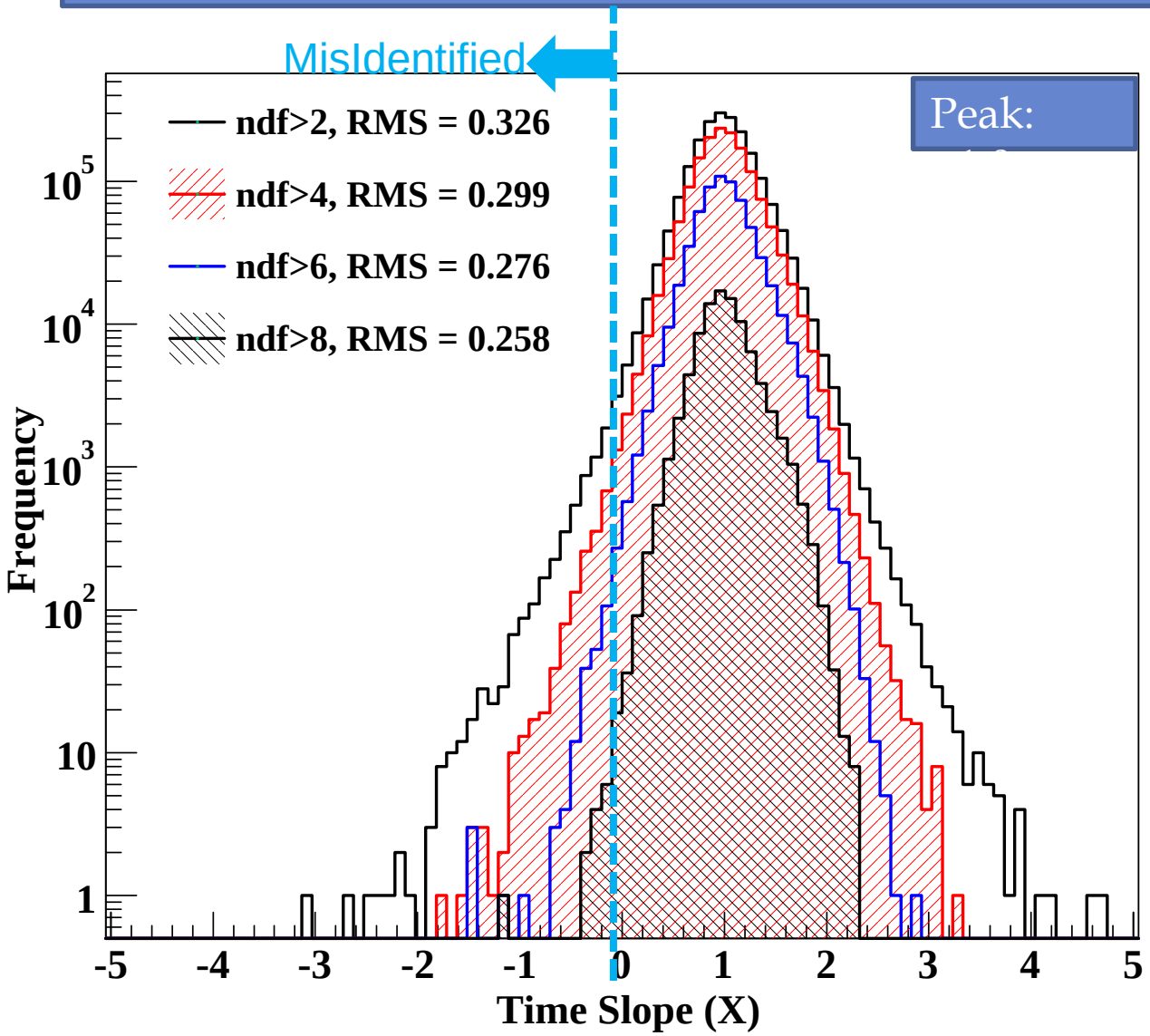
Muon flux measurement at sea level & at lower latitude (18



General muon flux distribution

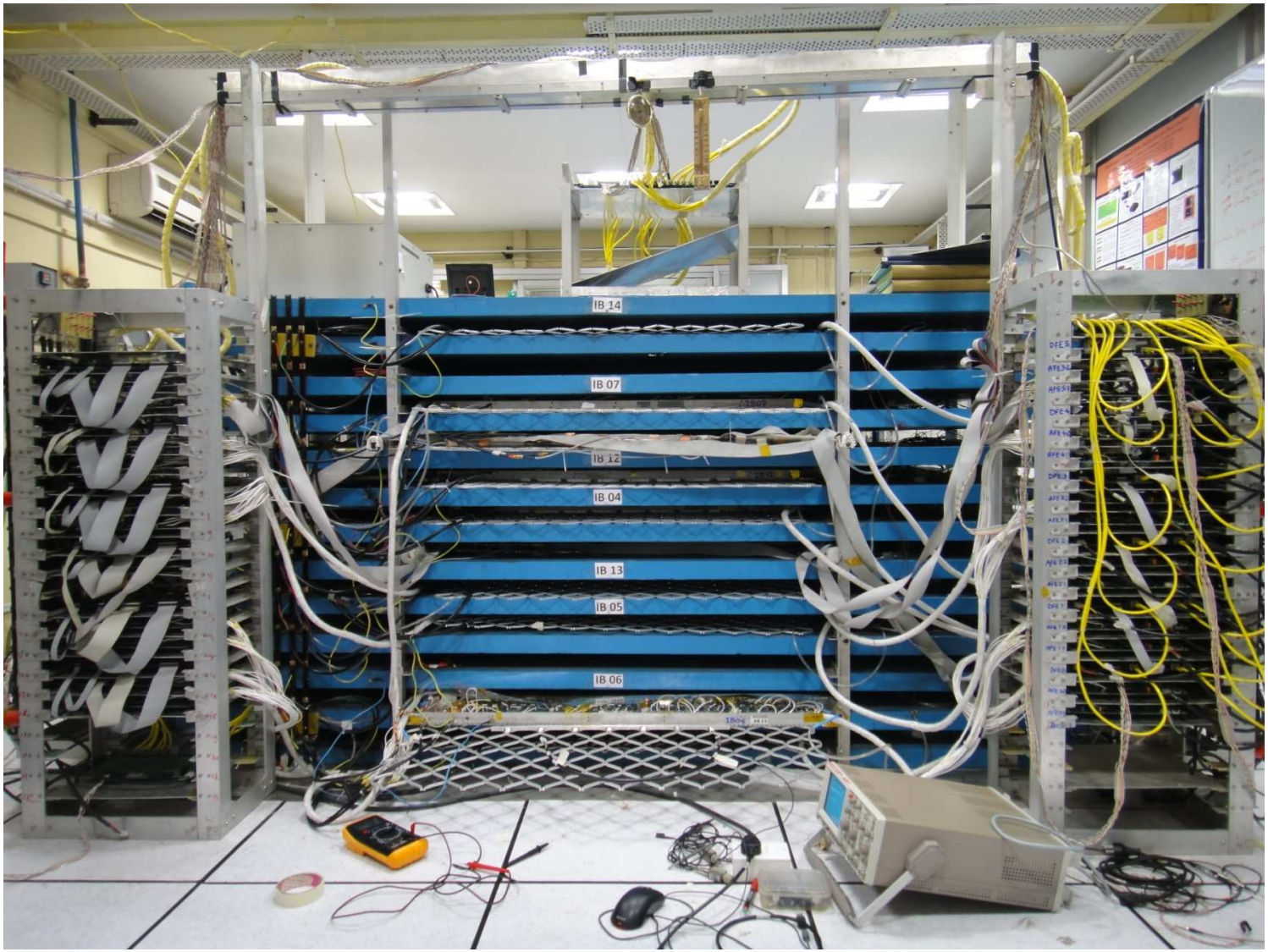
$$I_\theta = I_0 \cos^n \theta$$

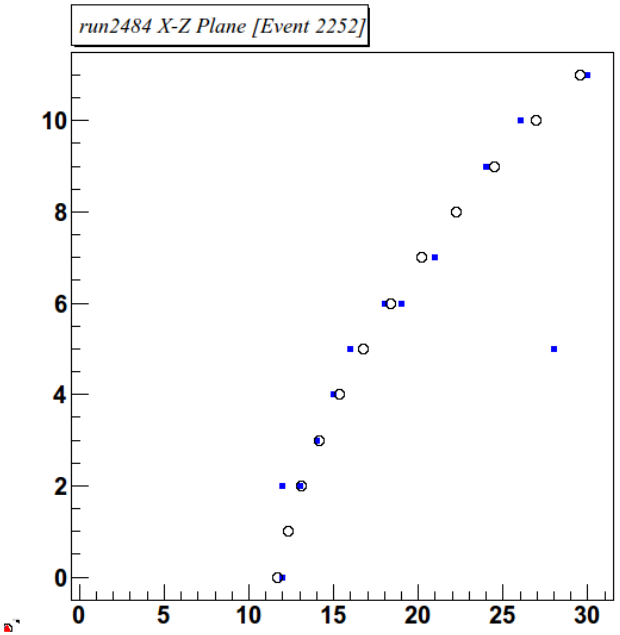
Directionality Distribution

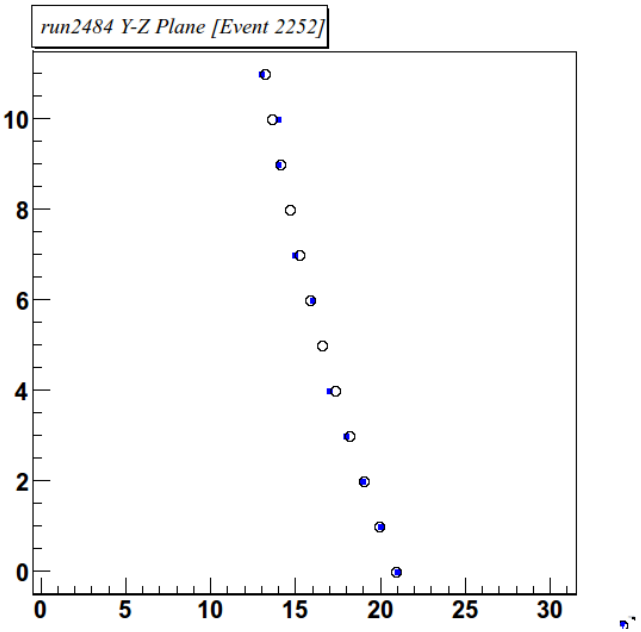


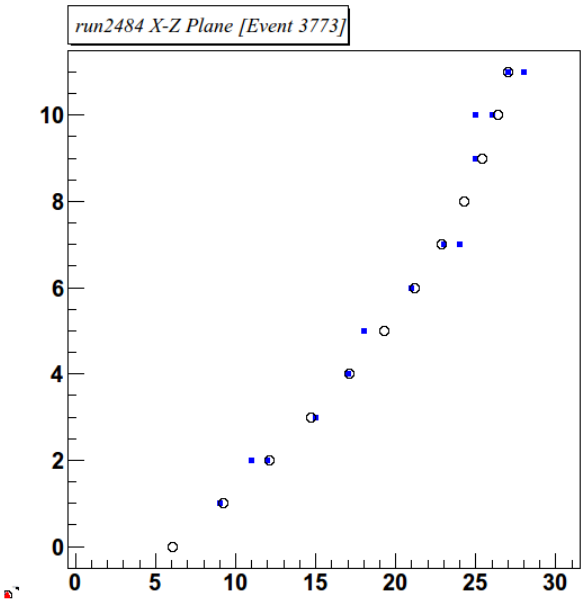
- For a constant time resolution of 1.5 ns for all layers, 1σ for time fit slope for a vertical track is ~0.3.
- Data gives 1σ = 0.326 for ndf>2. *This says misidentification in directionality is ~0.3% within 5σ limit*

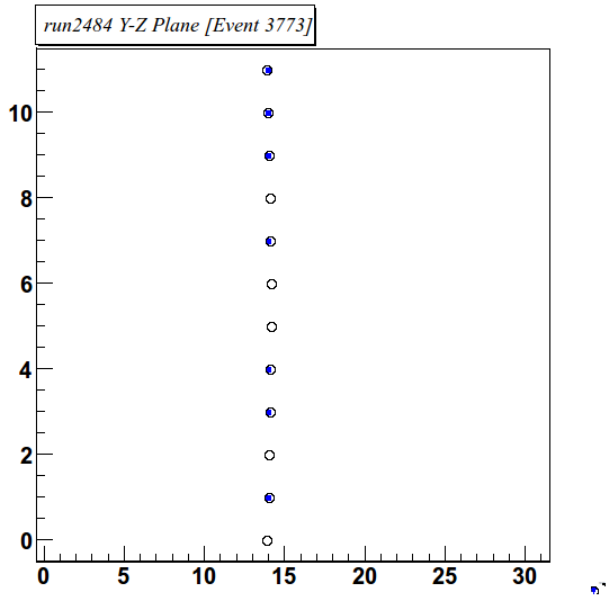
Prototype Magnet & RPC setup at VECC, Kolkata



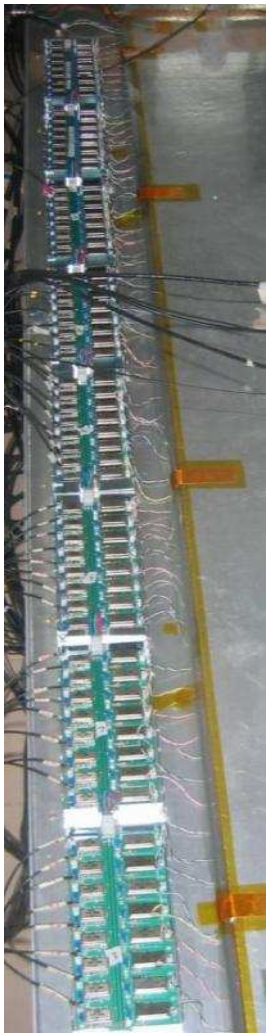

run2484 X-Z Plane [Event 2252]
0
2
4
6
8
10
0
5
10
15
20
25
30


run2484 Y-Z Plane [Event 2252]
0
2
4
6
8
10
0
5
10
15
20
25
30


run2484 X-Z Plane [Event 3773]
0
2
4
6
8
10
0
5
10
15
20
25
30


run2484 Y-Z Plane [Event 3773]
0
2
4
6
8
10
0
5
10
15
20
25
30

2m x 2m glass RPC test stand

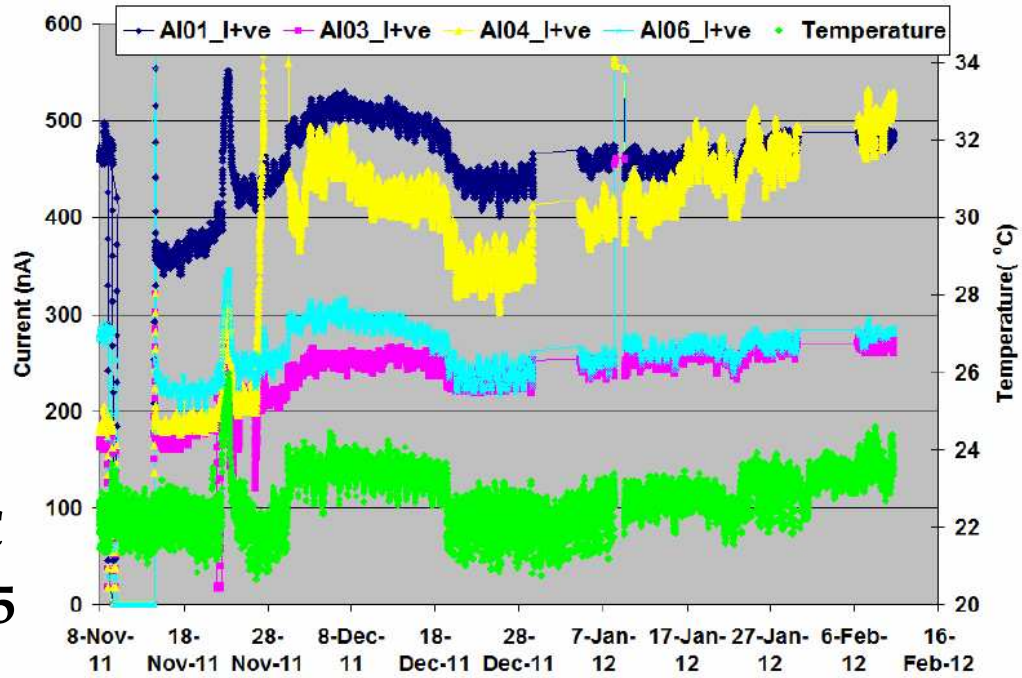


Gas optimisation studies

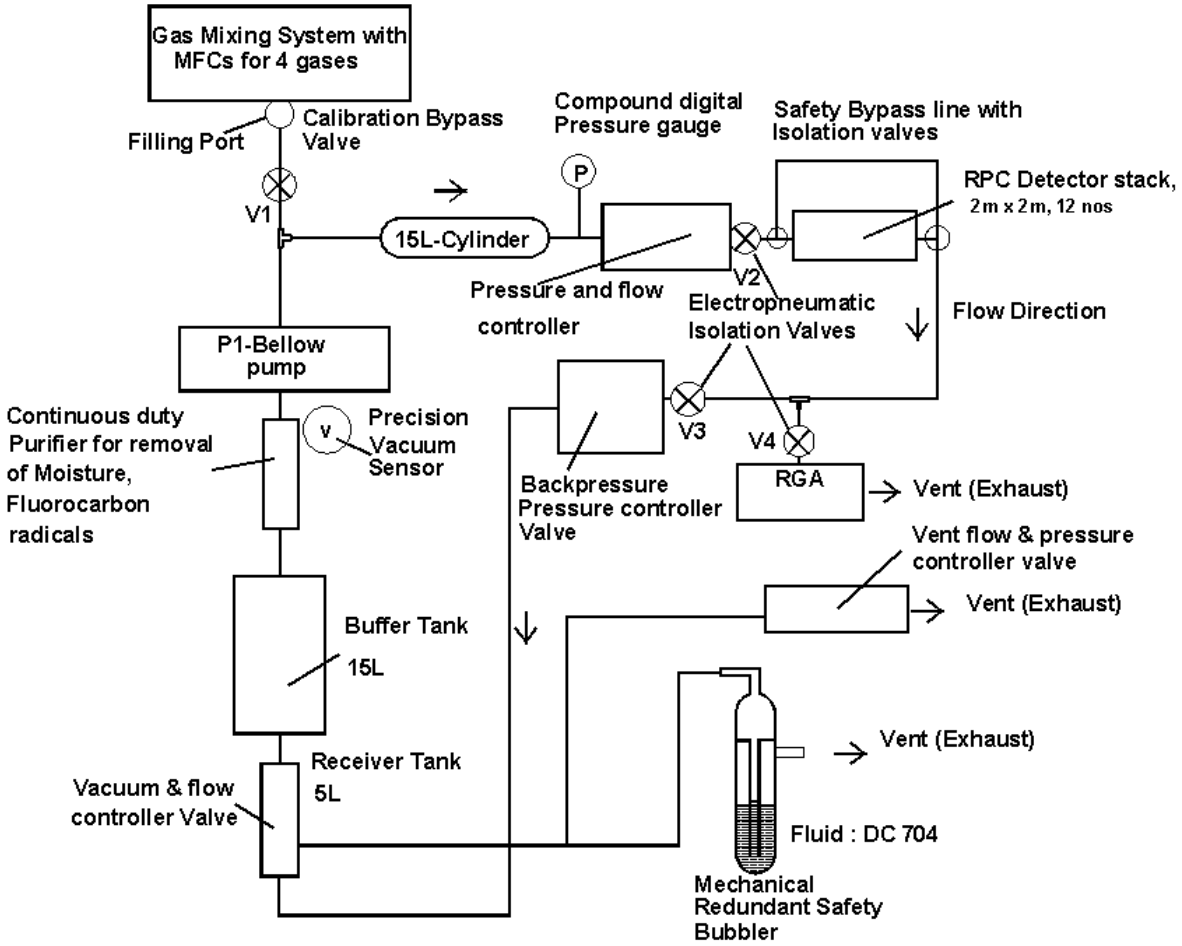
Gas flow for five RPCs (2m×2m) in new lab is reduced to 0.29 SCCM (1 volume change per 19 days).

Long-term performance studies on these RPCs is in progress.

At present, gas flow for the RPC (1mx1m) stack in C217 lab is 2.25 SCCM (1.6 volume change per day) i.e. 1 volume change per 0.62 days.

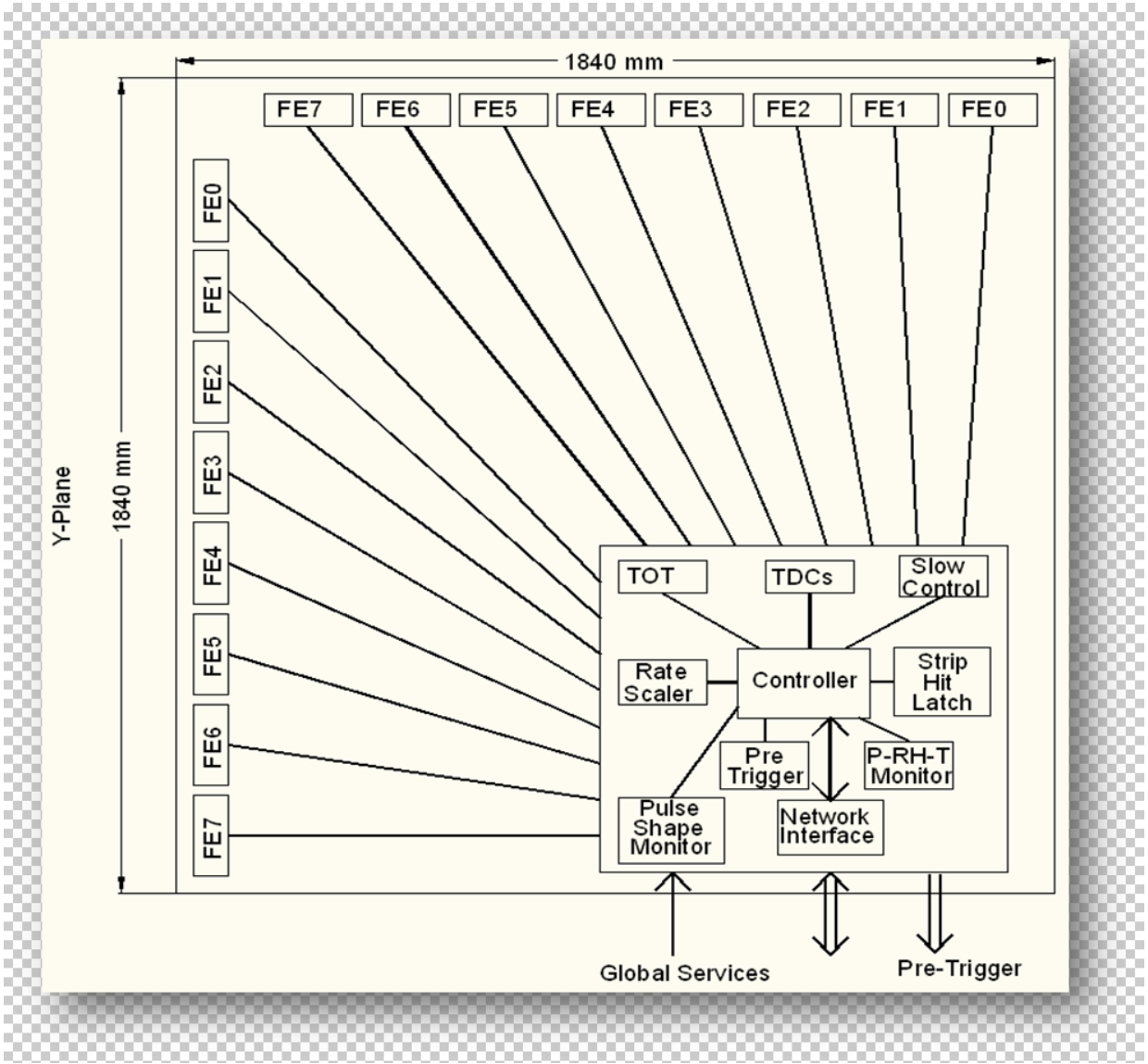


Closed loop gas system

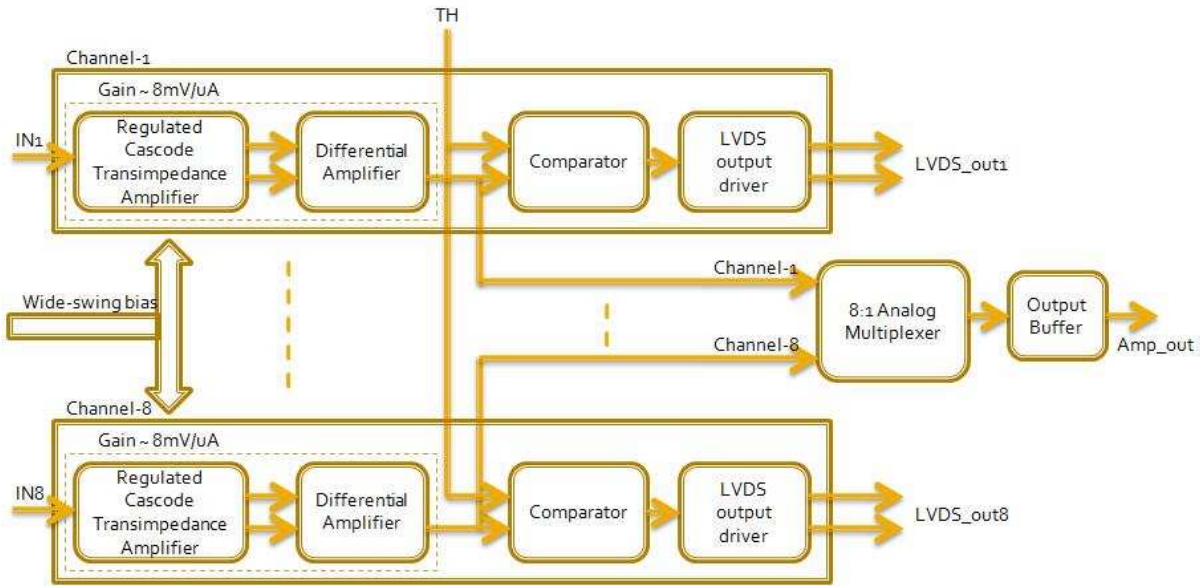


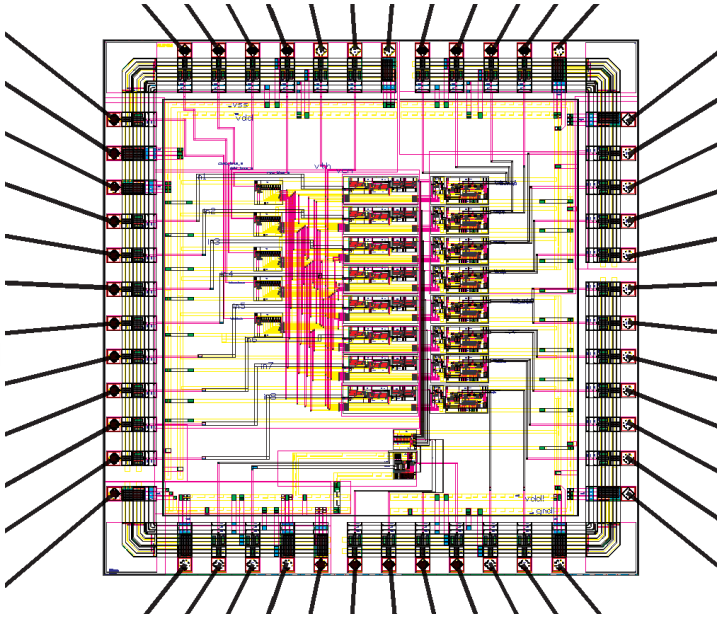
Schematic of Closed Loop Recirculation System

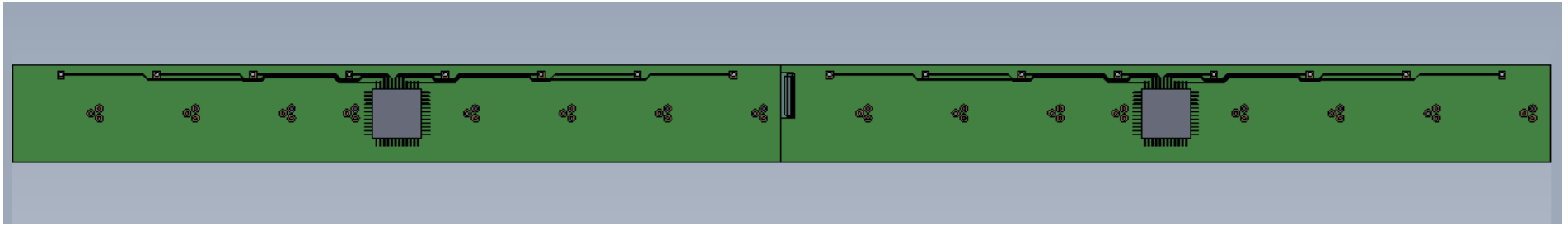
ICAL front-end electronics scheme

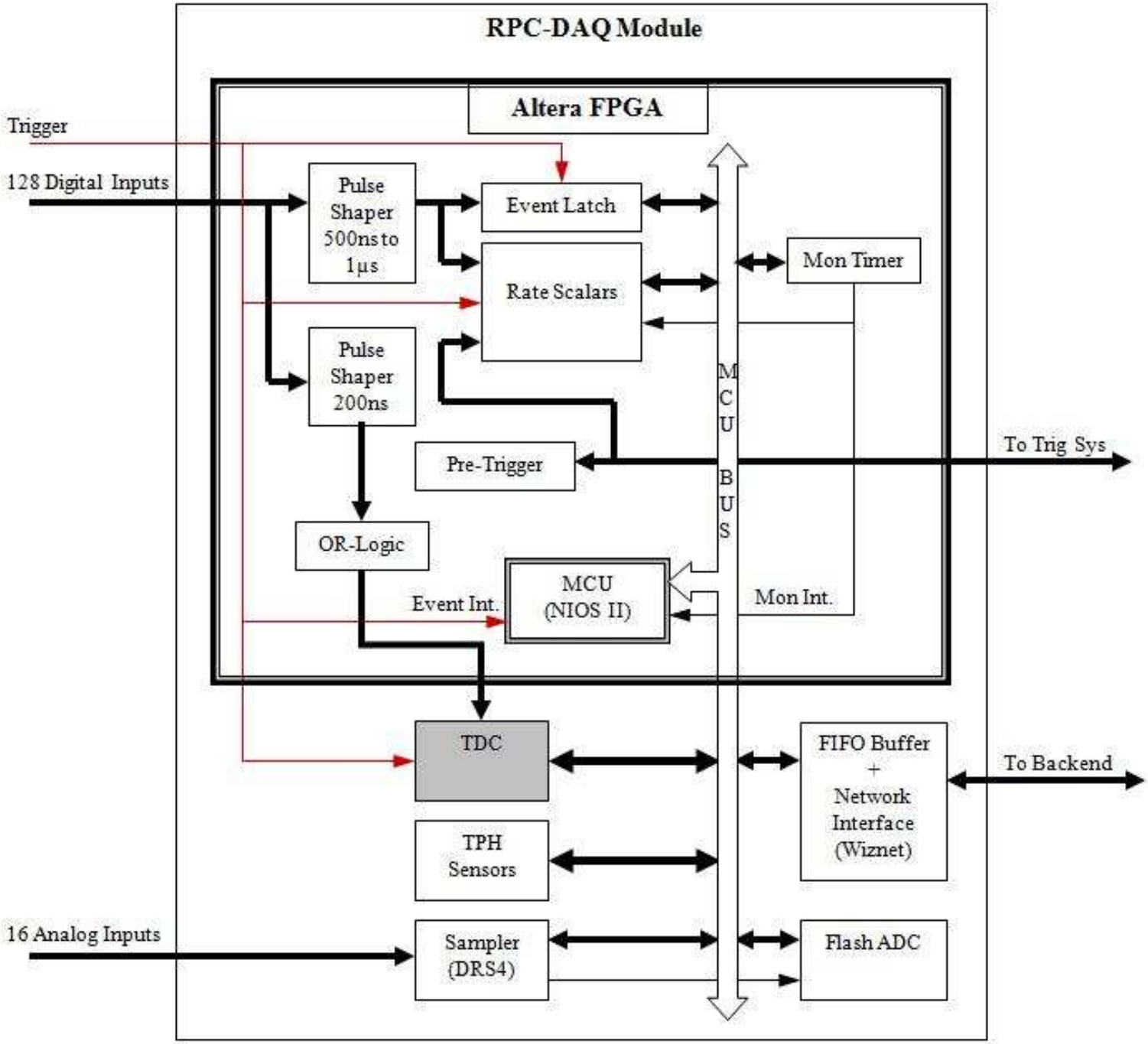


ICAL Front End Electronics



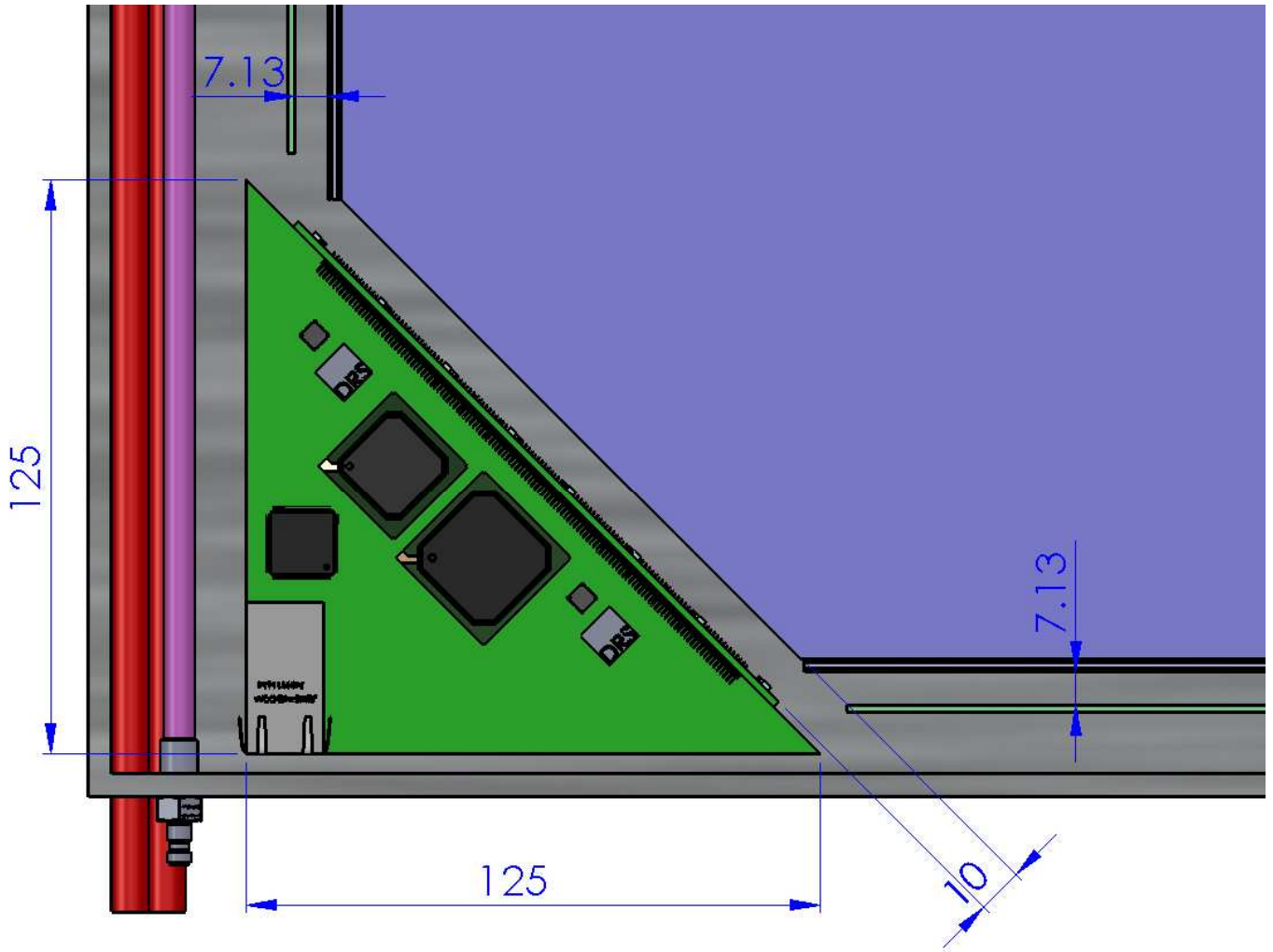






RPC DAq Block Schematic

Schematic of the DAQ card in RPC



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

GEANT4

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)

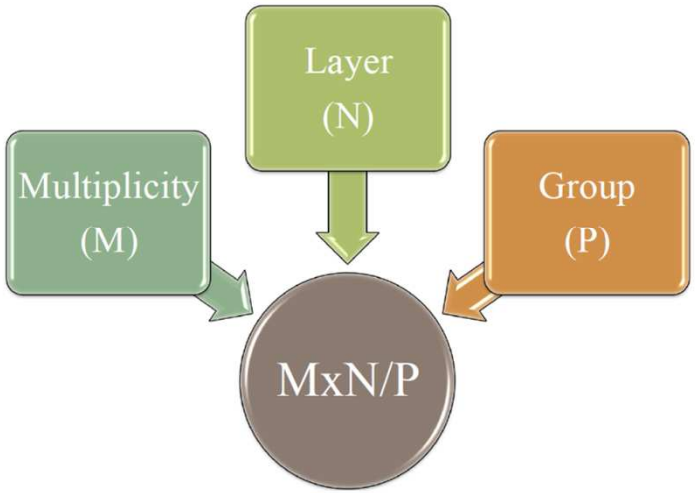
Event Reconstruction

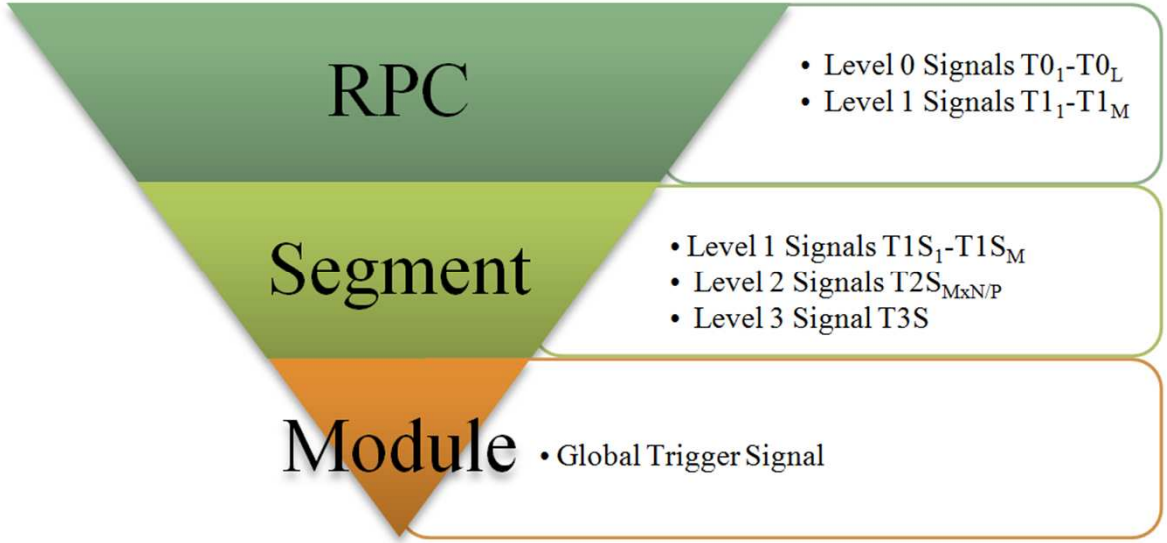
(E,p) of ν + X = (E,p) of A + B + ...

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

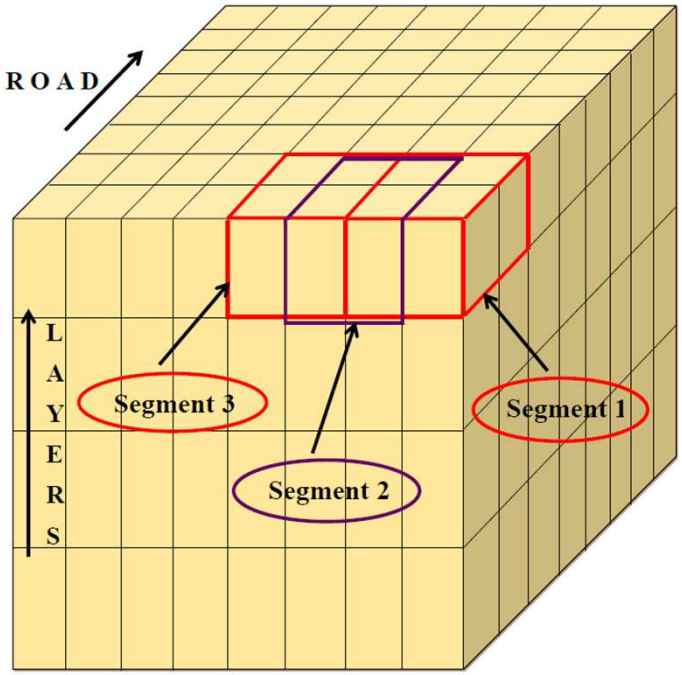
Output:
i) Energy & Momentum of the initial neutrino

ICAL Trigger Scheme

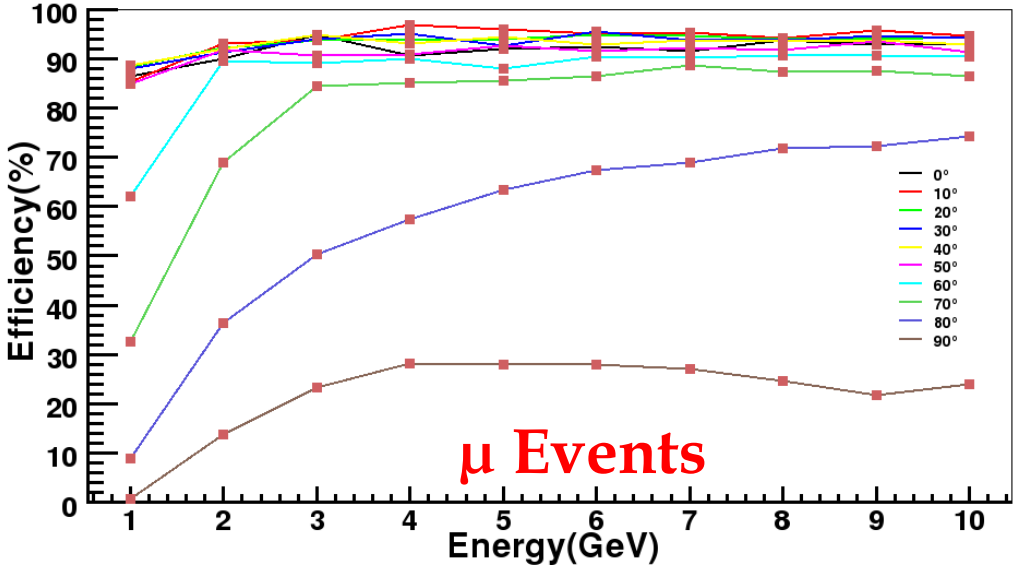




- **Trigger criteria based on event topology alone.**
- **Distributed and hierarchical architecture.**
- **Detector module segmented to generate local trigger.**
- **Combination of local triggers produces global trigger.**
- **Global trigger latches event data.**



Simulation Results

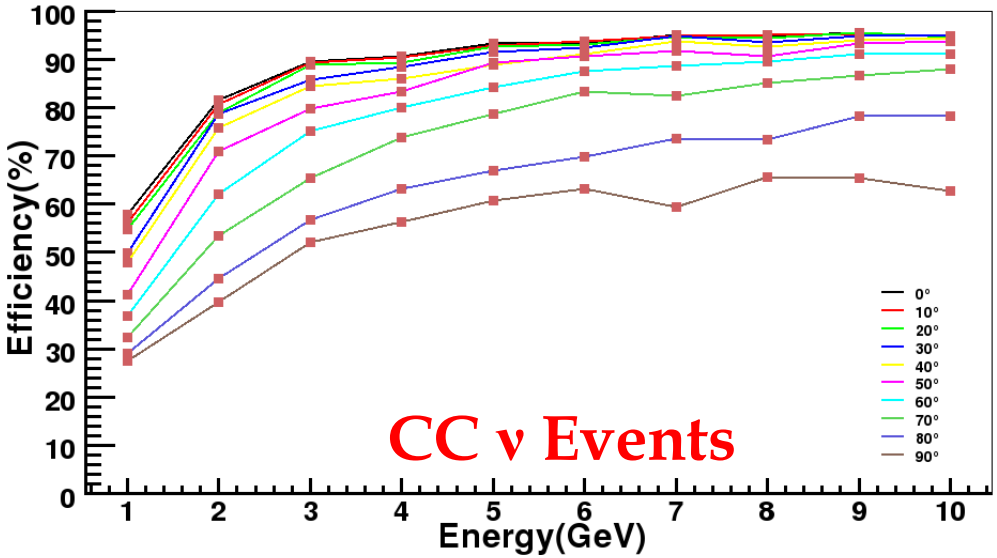


➢ Muon events and neutrino events are generated with event vertices randomly distributed over the fiducial volume of the detector.

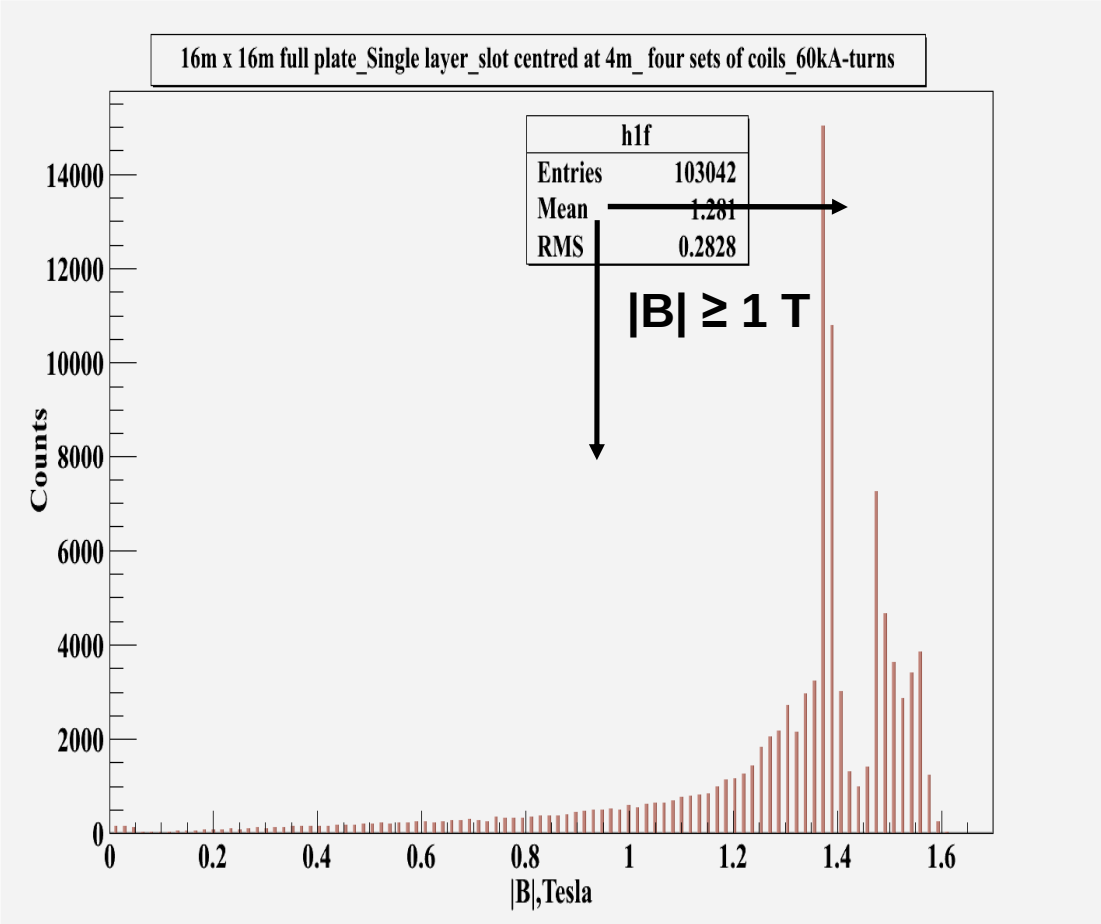
➢ Events are simulated using the INO-ICAL simulation code and the *Digitization* output is used to determine the trigger efficiency.

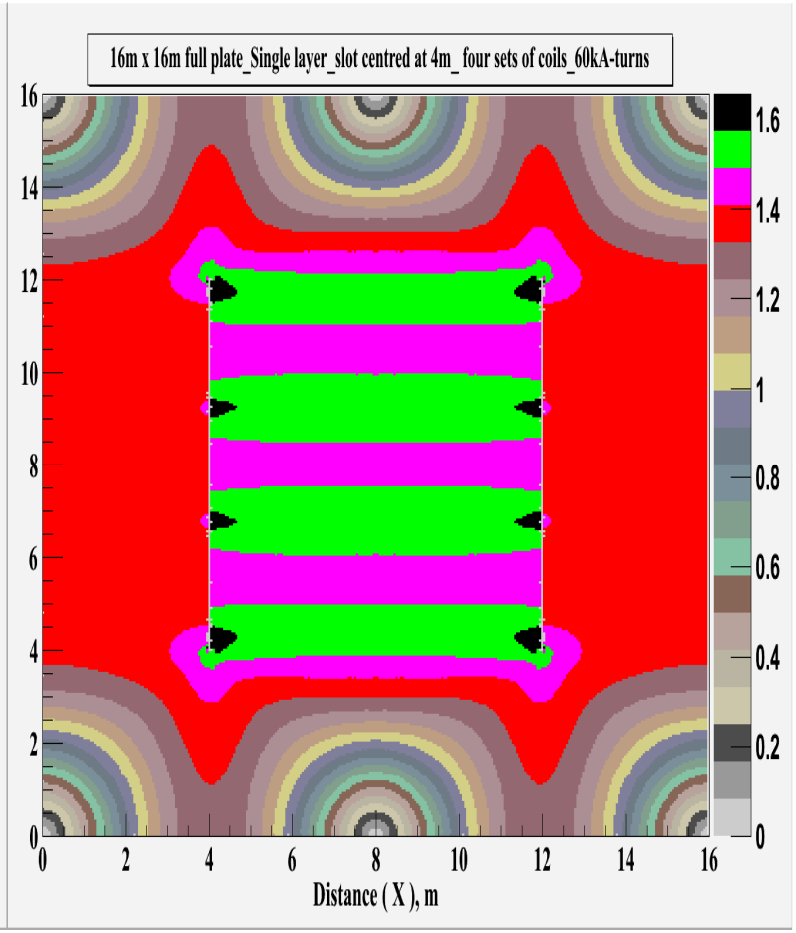
➢ **Analysis algorithm complies with the architecture of the trigger system.**

➢ **Trigger efficiency is determined for**
- **Segment size 4m x 4m x 4m.**
- **Trigger criteria**
  - ✓ **1x5/8**
  - ✓ **2x4/8**
  - ✓ **3x3/8**
  - ✓ **4x2/8**



Magnet simulation





Surface plot of |B|

Human Resource development & Training

INO Training School:

- ***We have already started INO graduate training program 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.***
- ***Being attached to Ph.D. guides at various collaborating institutions for a Ph. D. degree after completion of coursework***

Current status

- ***RPC development -***
  - *Full size RPCs (2m X 2m) are now being fabricated not only in our lab but also by the Industry.*
- ***Electronics-***
  - *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.*
- ***Magnet-***
  - *Prototype magnet at VECC/SINP, Kolkata is running. 2nd Engineering module will be fabricated during next 2 years.*
- ***Human Resource-***
  - *Graduate Training Programme for the last three years within HBNI*
- ***INO Site-***
  - *Environment & Forest clearances obtained.*
  - *26 Hectares of land at Pottipuram provided by TN Govt. free of cost.*
  - *12 Hectares at Madurai will be provided by TN Govt. against payment.*

PERT CHART

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						◄——►

Thank You