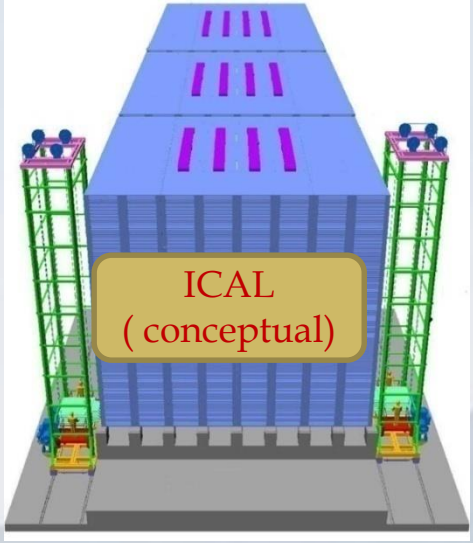
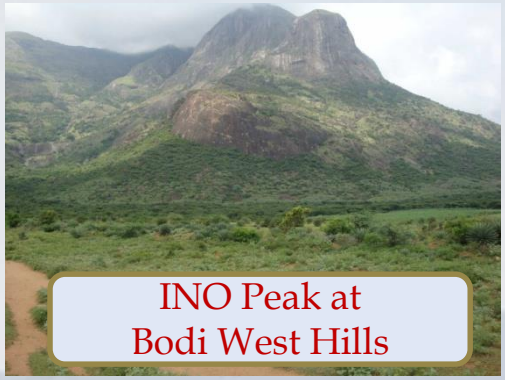

ICAL
(conceptual)

India-Based Neutrino Observatory (INO)


INO Peak at
Bodi West Hills

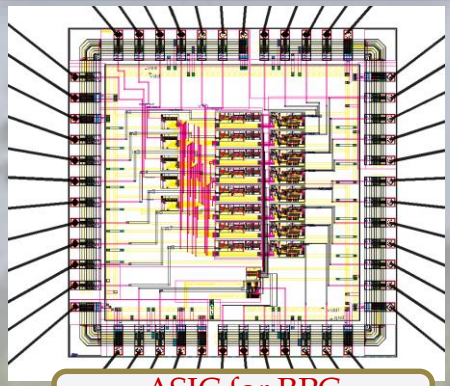

RPC Test stand at
TIFR

Naba K Mondal,
TIFR, Mumbai
For INO collaboration

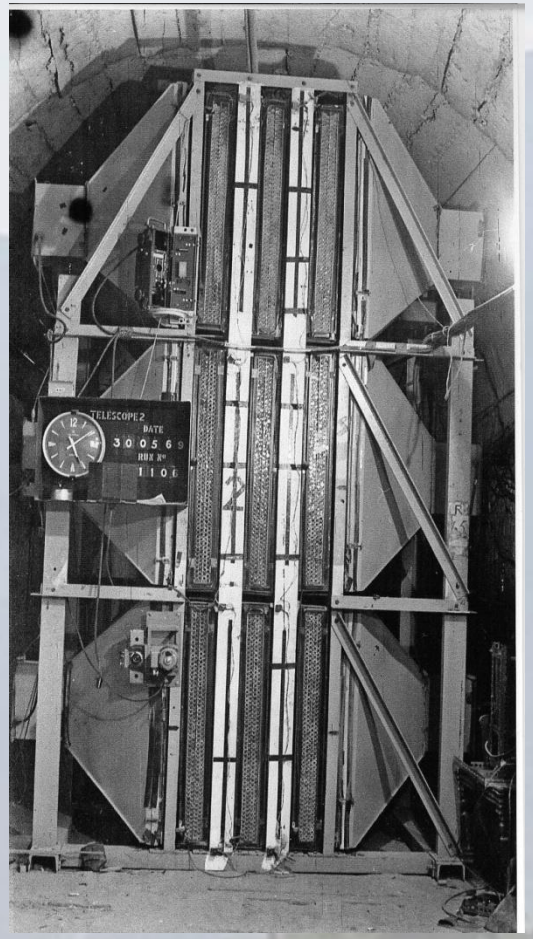
2nd International Meeting for Large Neutrino Infrastructure
Fermilab, 20-21 April, 2015


2mX2m RPC Test Stand at
TIFR

Prototype ICAL at VECC


ASIC for RPC
designed at BARC

Atmospheric neutrinos – 50 years



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

INO Collaboration

Ahmedabad: Physical Research Laboratory
Aligarh: Aligarh Muslim University
Allahabad: HRI
Bhubaneswar: I OP, Utkal University
Calicut : University of Calicut
Chandigarh: Panjab University
Chennai : IITM, IMSc
Delhi : Delhi University
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

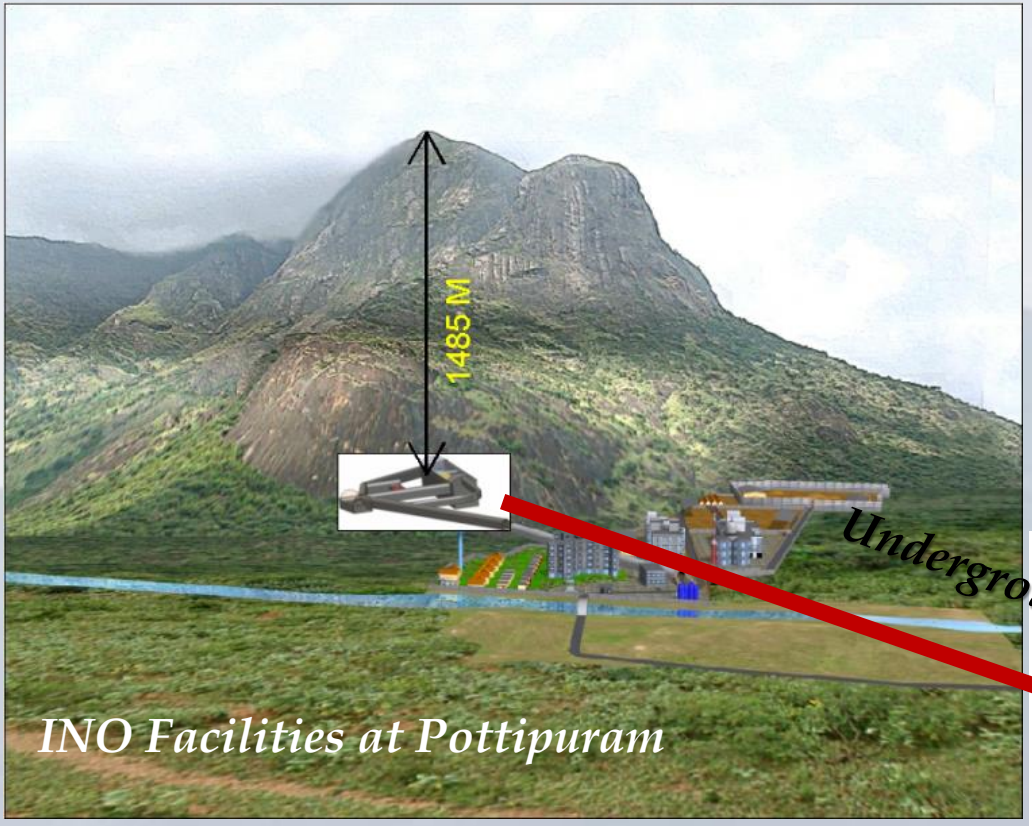
INO Project components

- *Construction of an underground laboratory and surface facilities near Pottipuram village in Theni district of Tamil Nadu.*
- *Construction of the 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)*
- *Detector R & D*

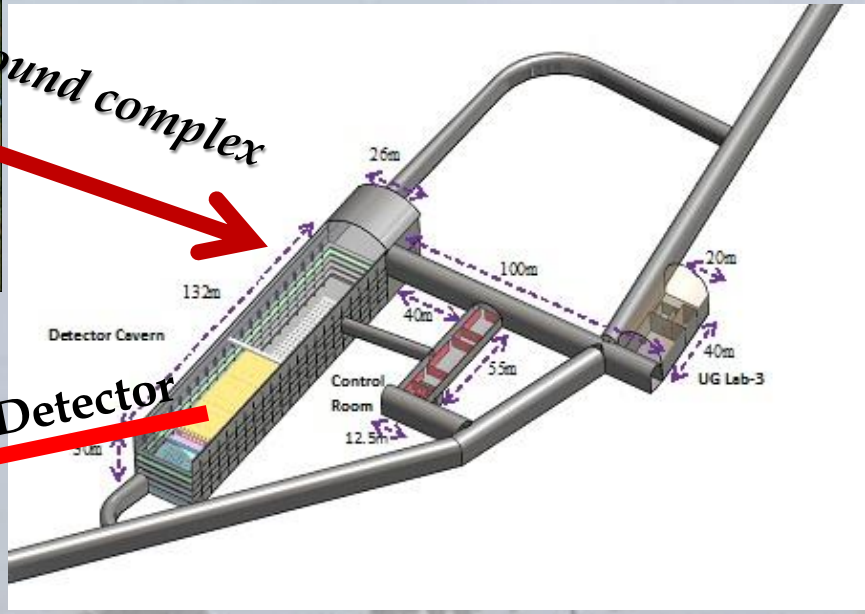
Financial approval from Govt. of India received in January, 2015

ICAL: The physics goals

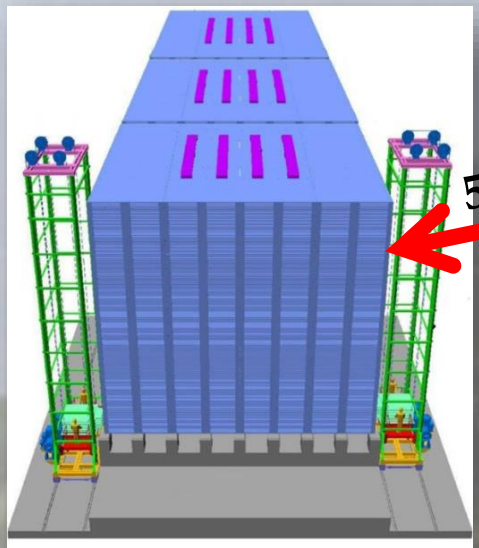
- *Improved precision of atmospheric oscillation parameters*
- *Determine neutrino mass hierarchy using matter effects via charge discrimination*
- *Measure the deviation of 2-3 mixing angle from its maximal value and its octant*
- *Test bed for various new physics like NSI, CPT violation, long range forces*
- *Detect Ultra High Energy Neutrinos, Cosmic Muons, Indirect searches of DM*



Underground complex

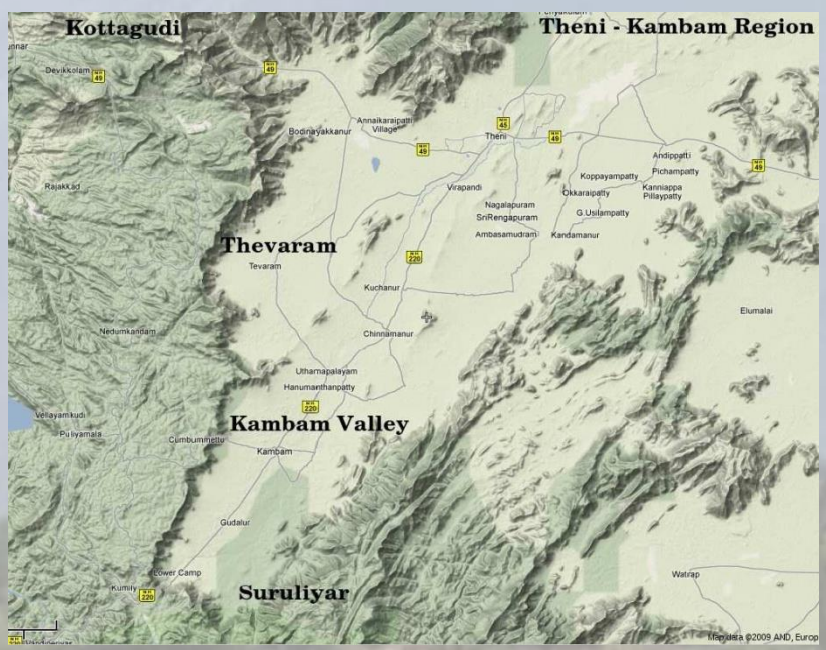


50 kton ICAL Neutrino Detector




INO: the location

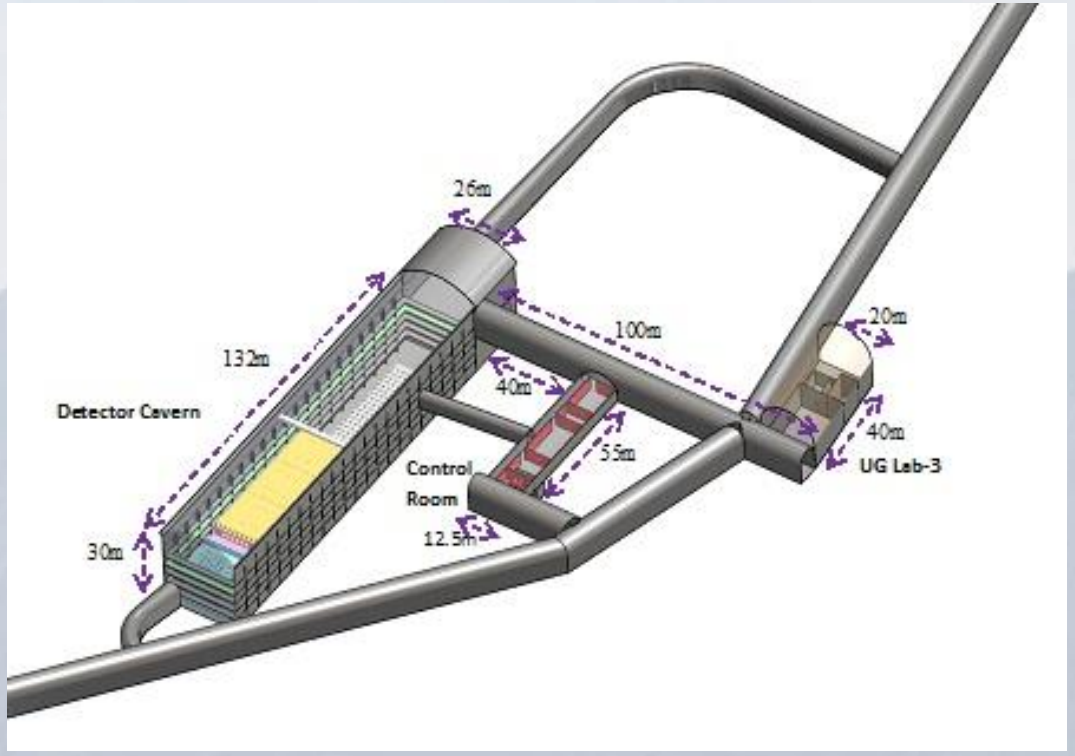
INO site : Bodi West Hills



Contact us:

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

Underground Laboratory Layout



- *The cavern-I 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 ….).*

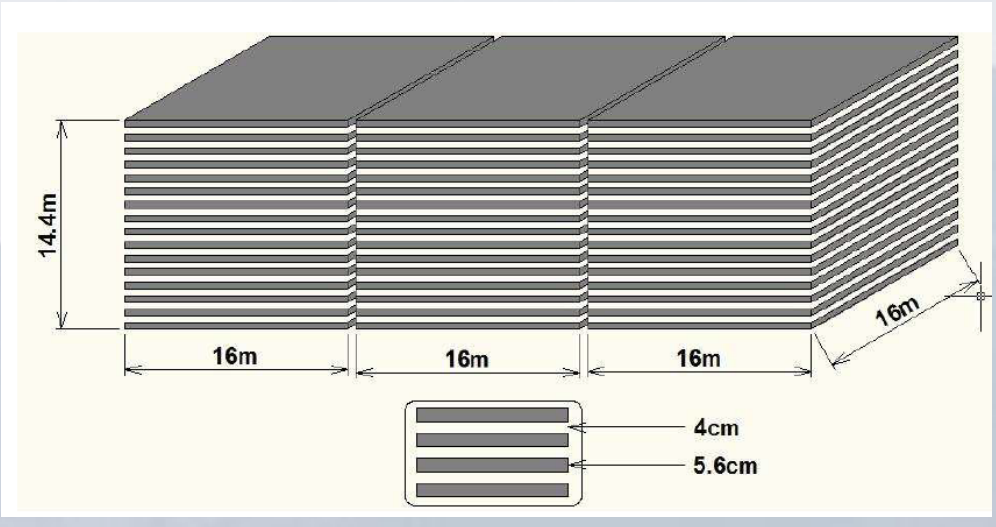
INO Site@ Pottipuram

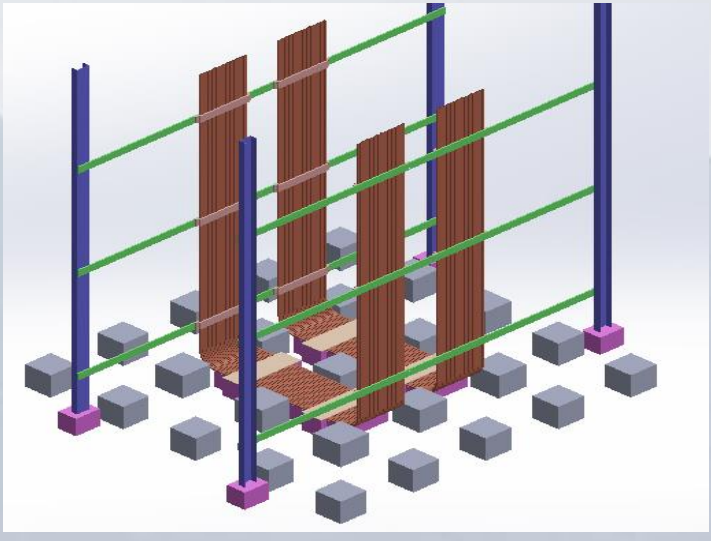
Site for Inter-Institutional Centre for High Energy Physics (ICHEP)

- *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.*

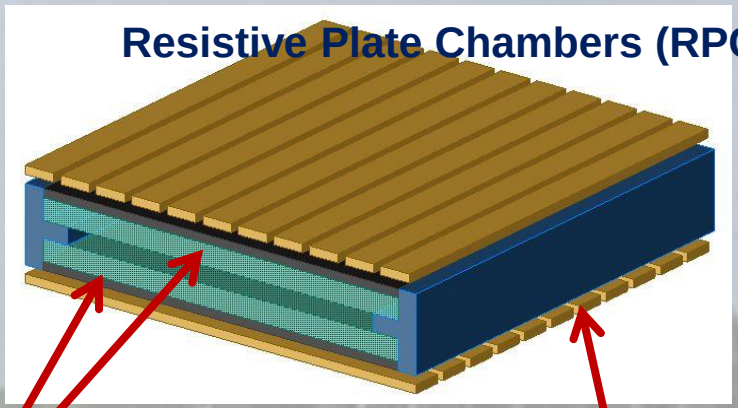
INO-ICAL : The detector

INO-ICAL Detector



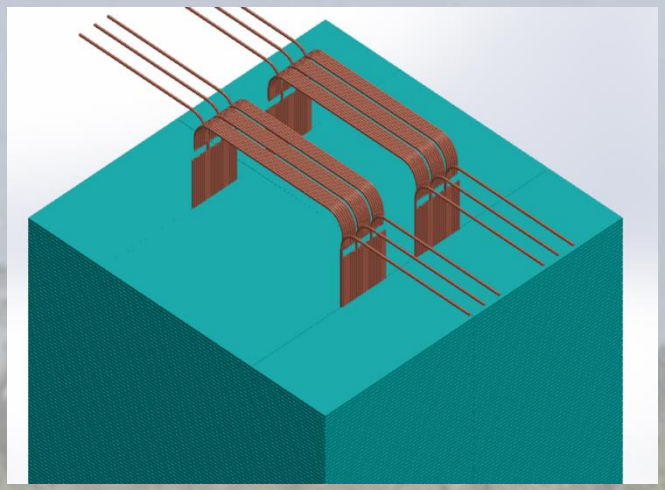


Resistive Plate Chambers (RPC)



Glass plates

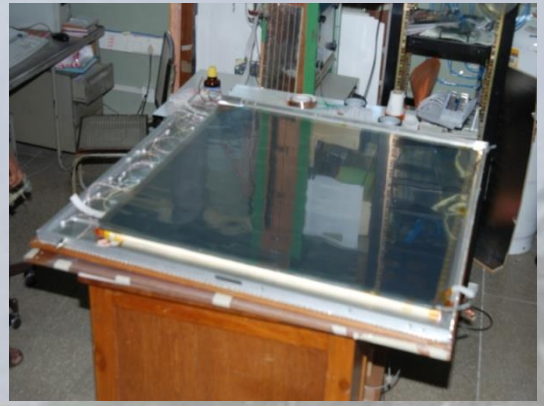
Pickup strips



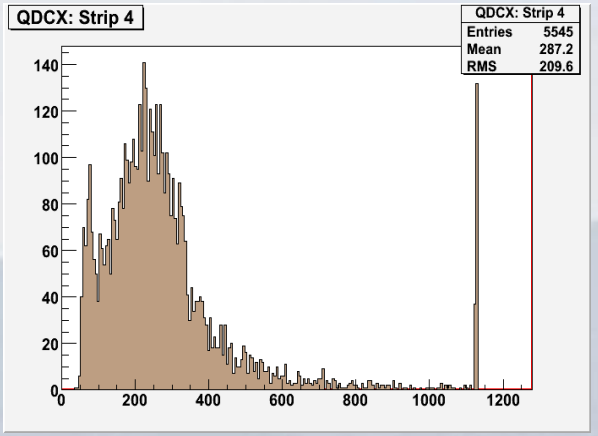
ICAL factsheet

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	*$3.7 X 10^6$*

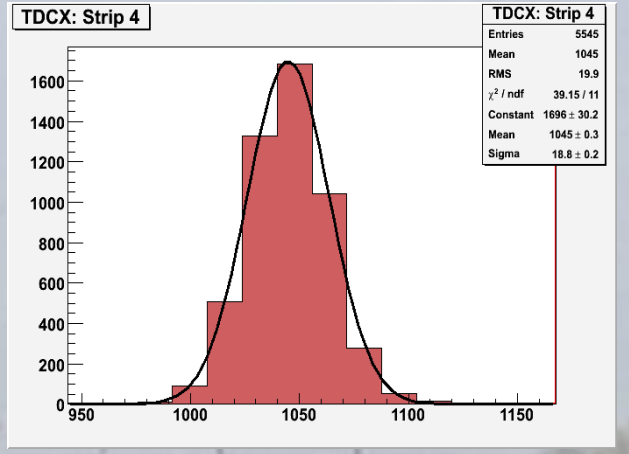
Fabrication of 1m x 1m RPCs



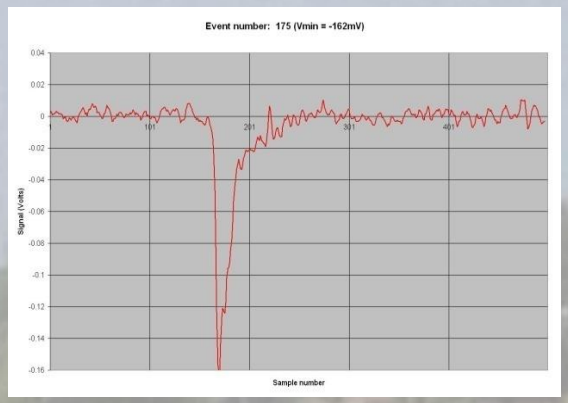
Prototype RPC Stack at TIFR tracking Muons



Charge spectrum

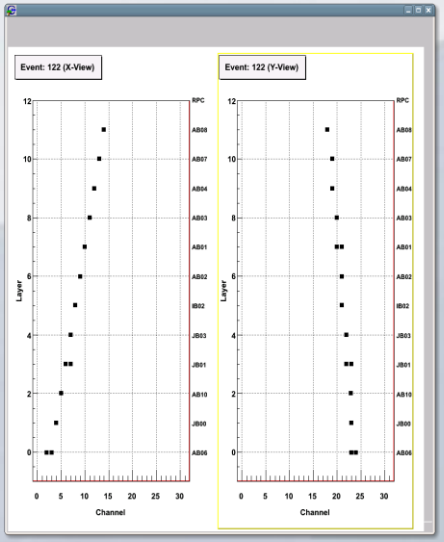


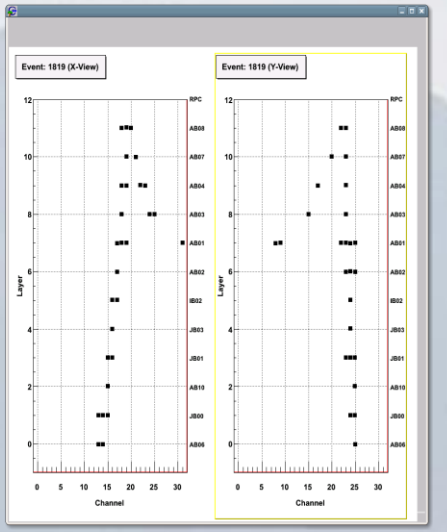
Time resolution

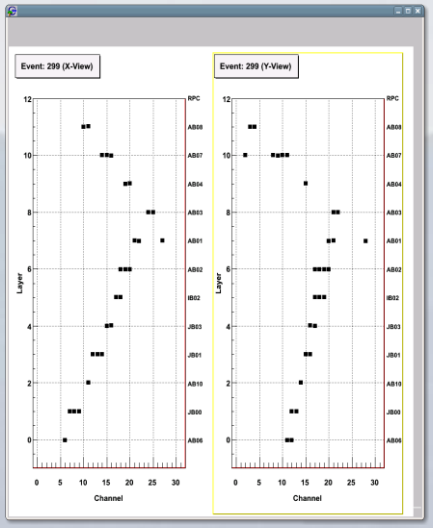


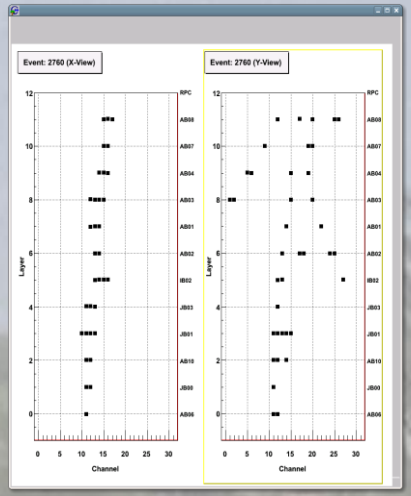
Analog signal due to muon

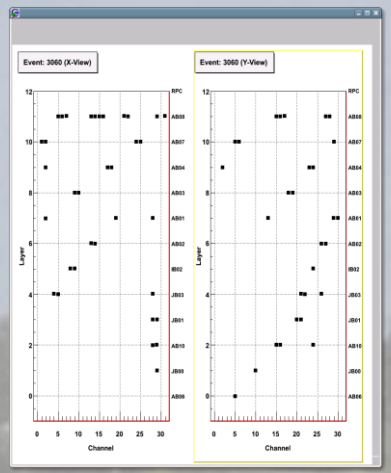
cosmic ray tracks in the RPC stand





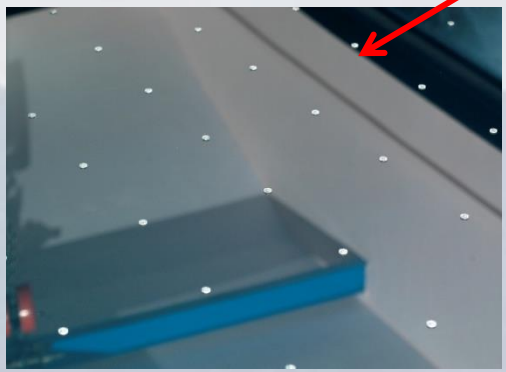


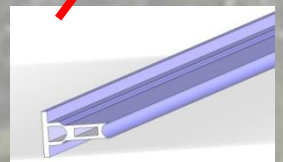




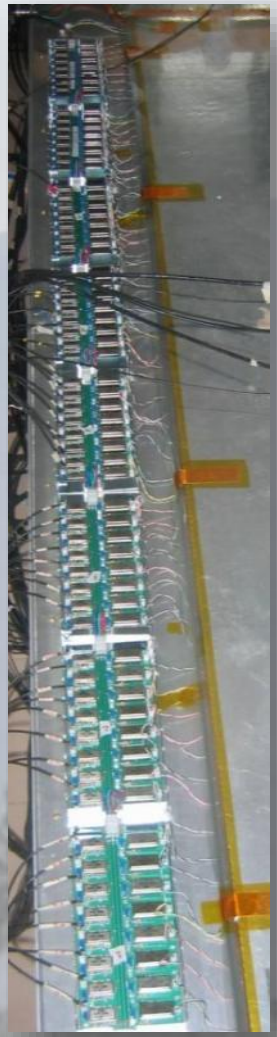
Demonstrate the Tracking Capability of the RPC system

Making of 2m x 2m RPCs

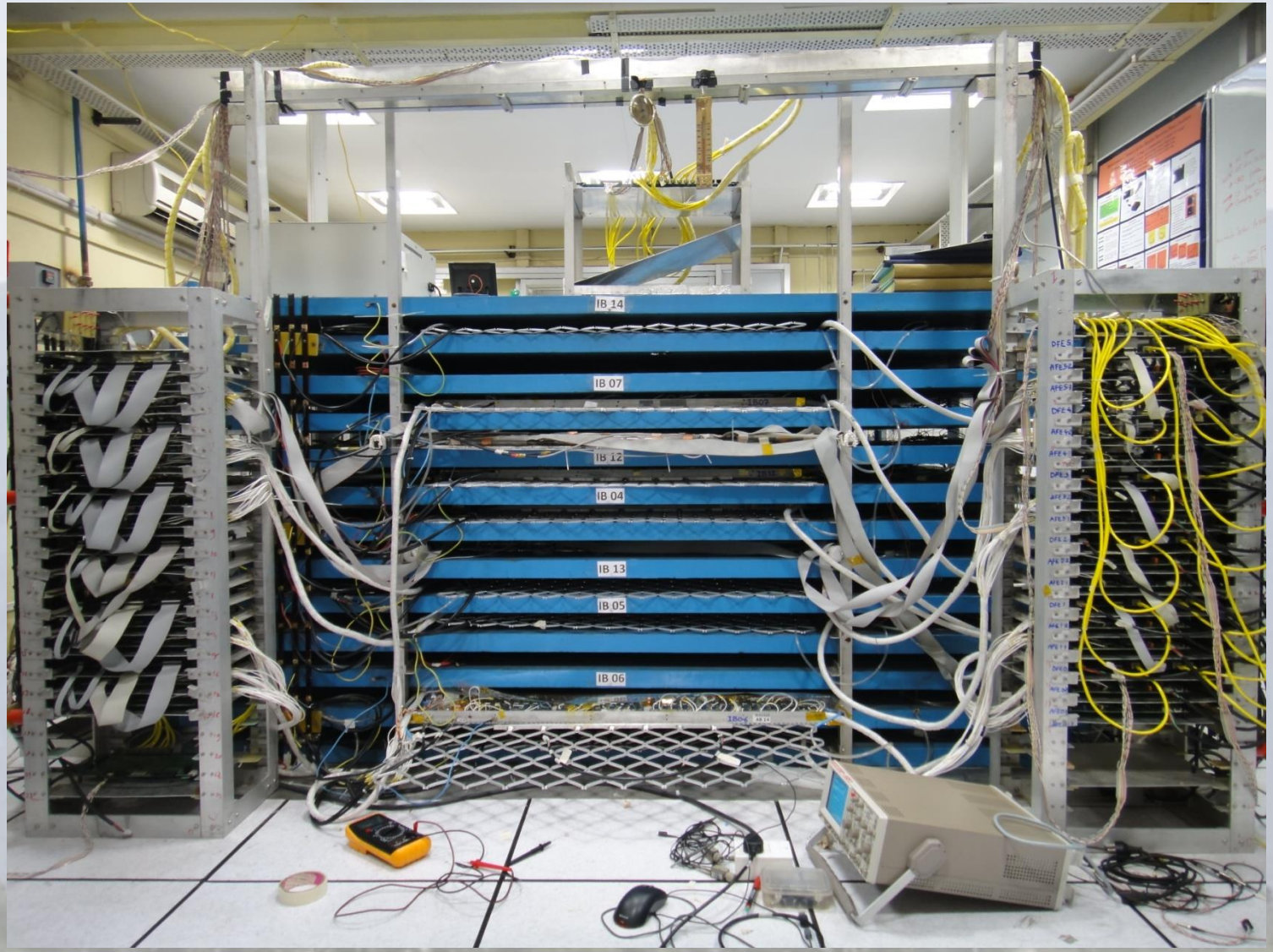




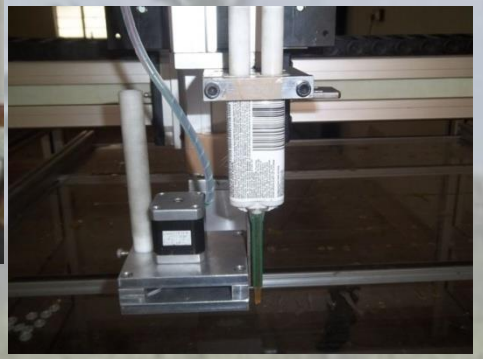
2m x 2m glass RPC test stand



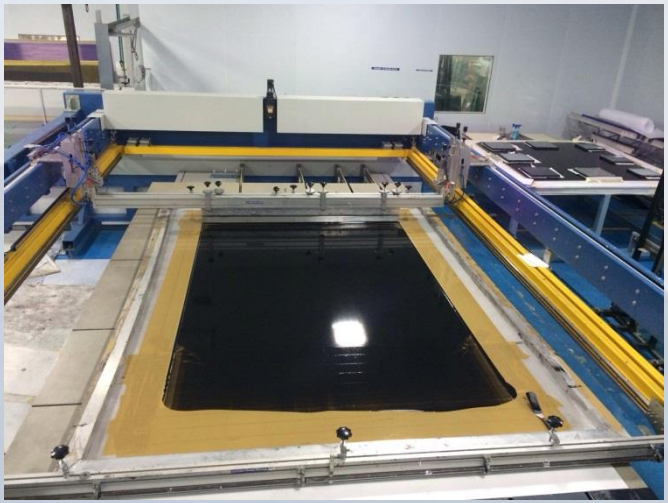
Prototype Magnet with RPC layers



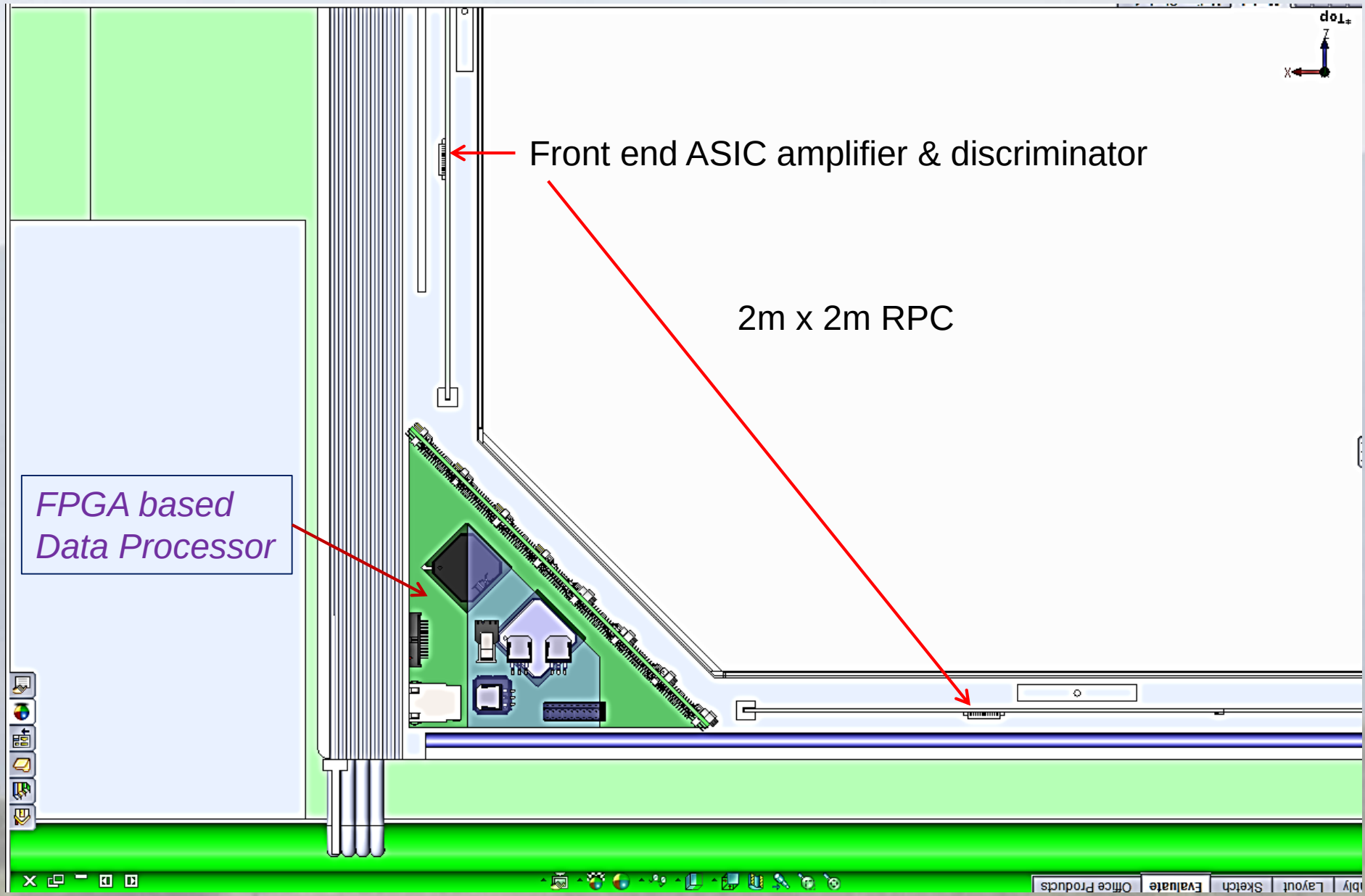
Automatic RPC gap making setup



RPC production at Saint Gobain, Chennai

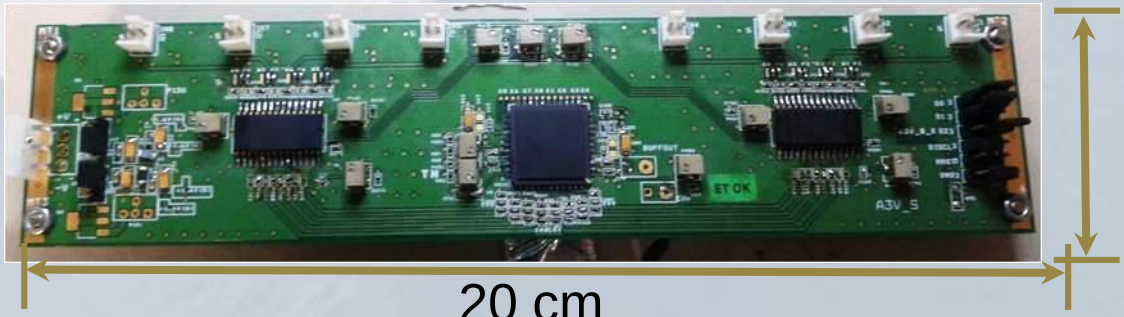


Details of the RPCDAQ



INO FRONTEND: PRESENT STATUS

✓A compact 8-channel FE board with dimension 45 mm x 20 cm designed, fabricated and tested in lab. Testing with RPC detector at TIFR in progress.

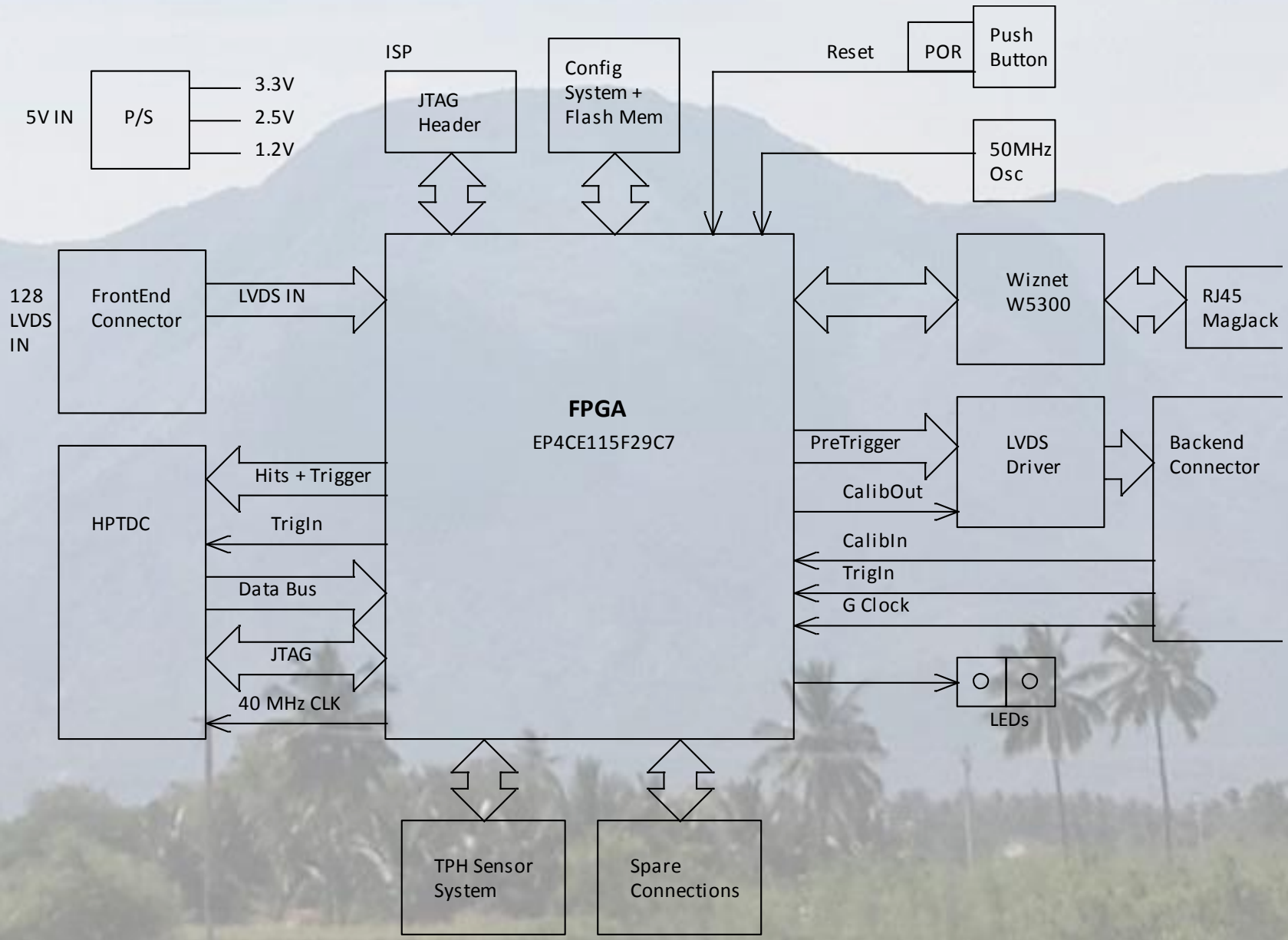


45 mm: min achievable FE board size with existing packages of Amplifier & Discriminator ASICs

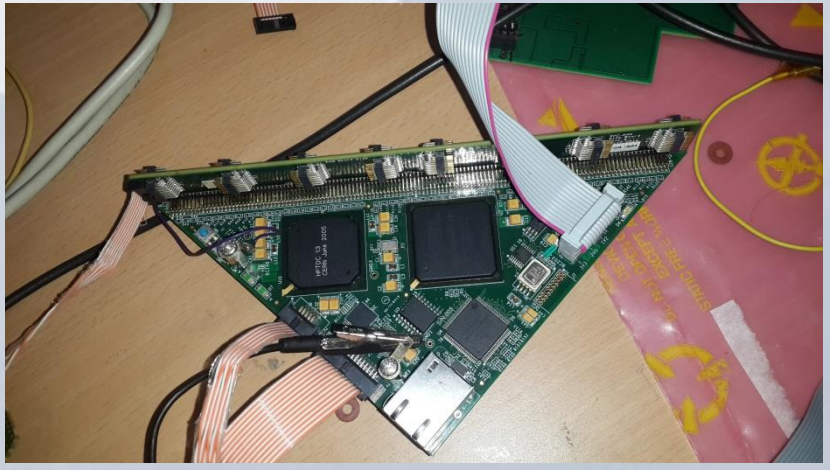
✓FE board size **could be further reduced only with low profile packages like QFN (difficult to assemble)**; **Amplifier & Discriminator performance with new package need to be verified before going for production**.

✓ **DFM** also need to be incorporated before production run.

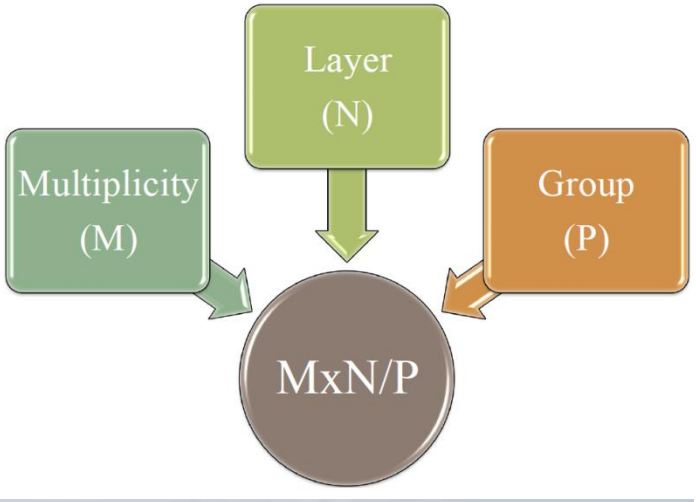
Block diagram of RPCDAQ

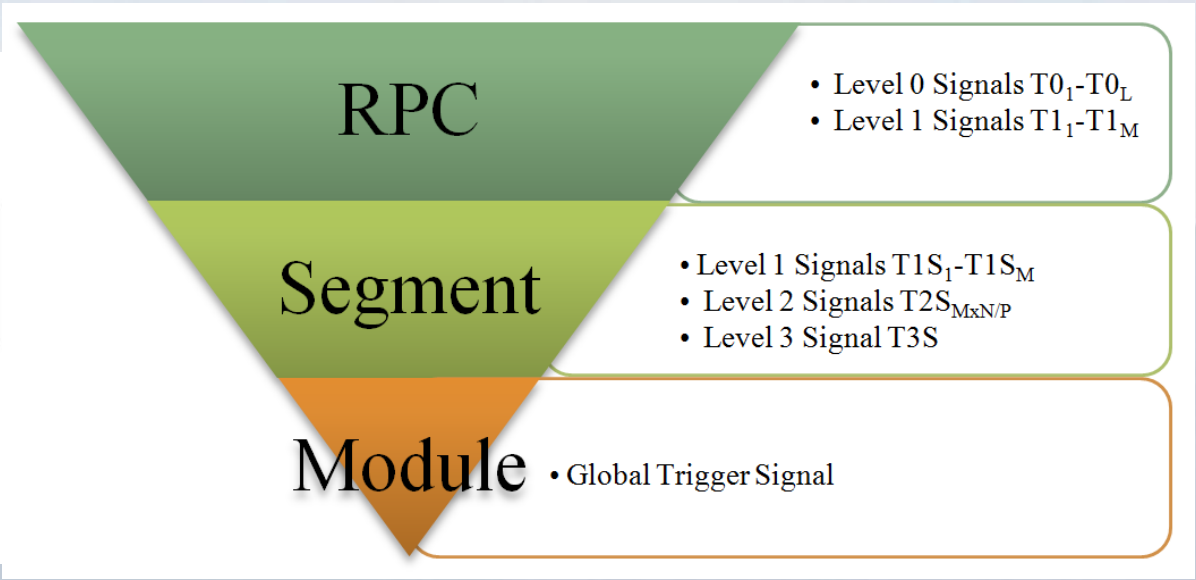


RPC-DAQ Board

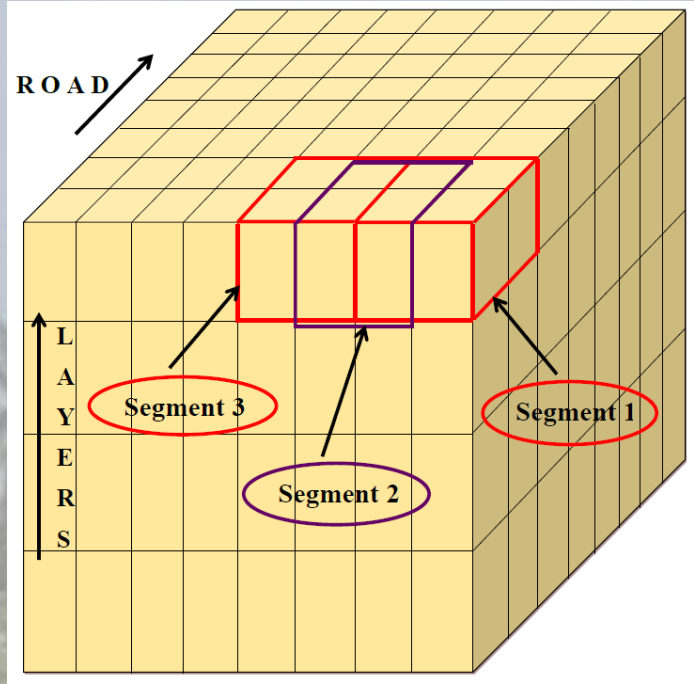


ICAL Trigger Scheme

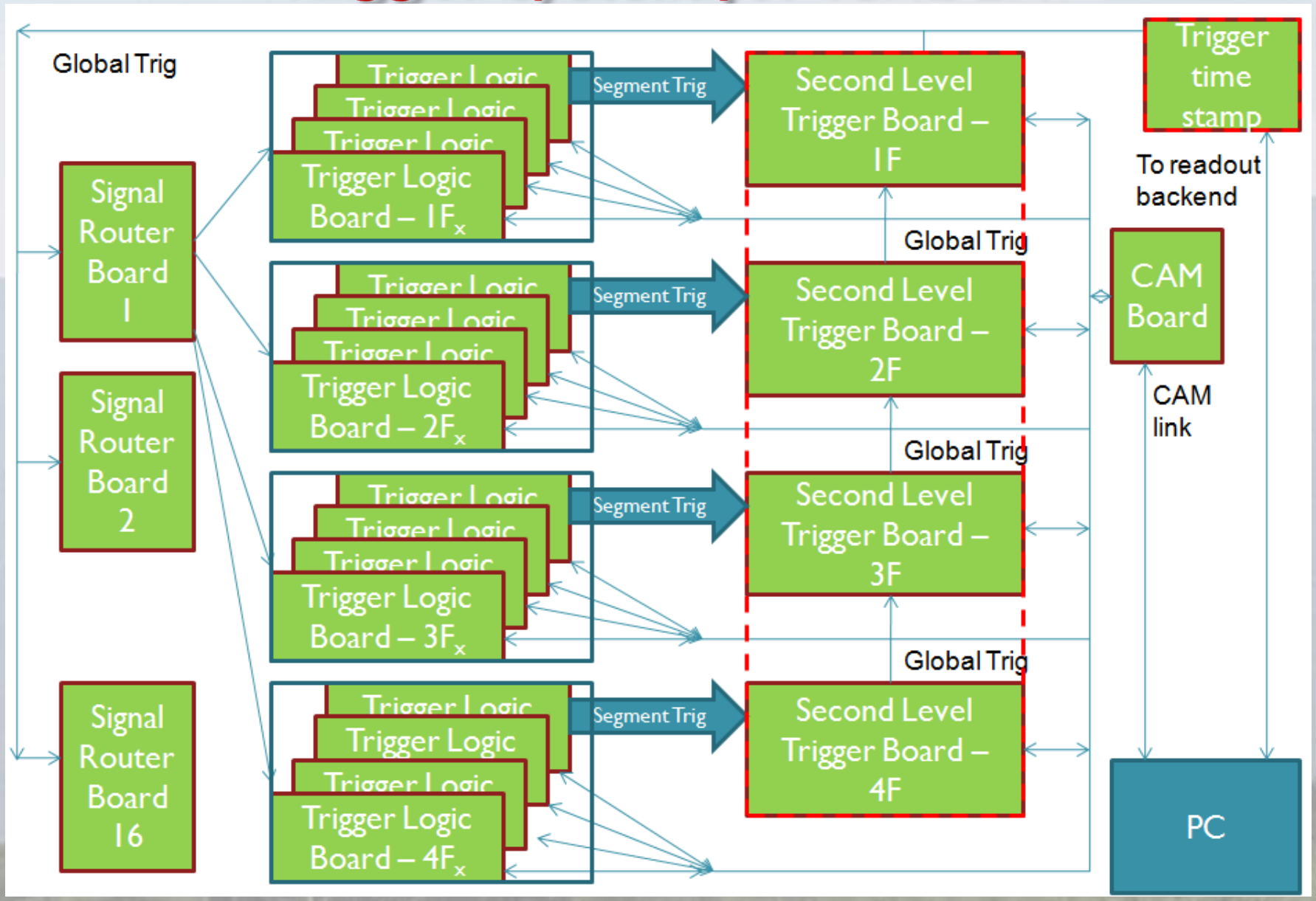




- ***Trigger criteria based on event topology alone.***
- ***Distributed and hierarchical architecture.***
- ***Detector module segmented to generate local trigger.***
- ***Combination of local triggers produces global trigger.***
- ***Global trigger latches event data.***



Trigger system for ICAL-EM



INO: Simulation & Physics sensitivity studies

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 4

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)

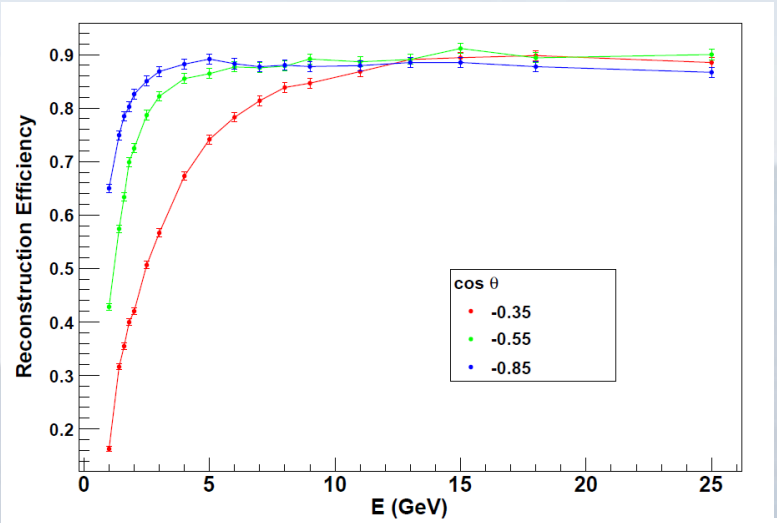
Event Reconstruction

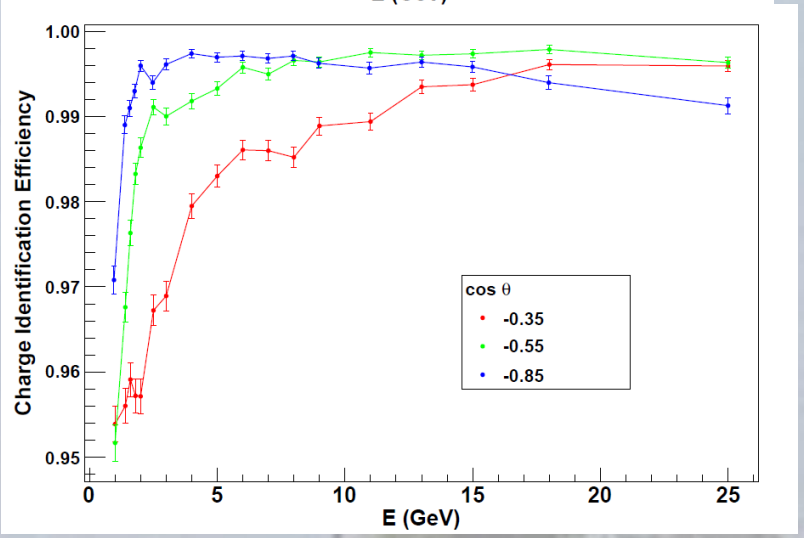
(E,p) of v + X = (E,p) of A + B + ...

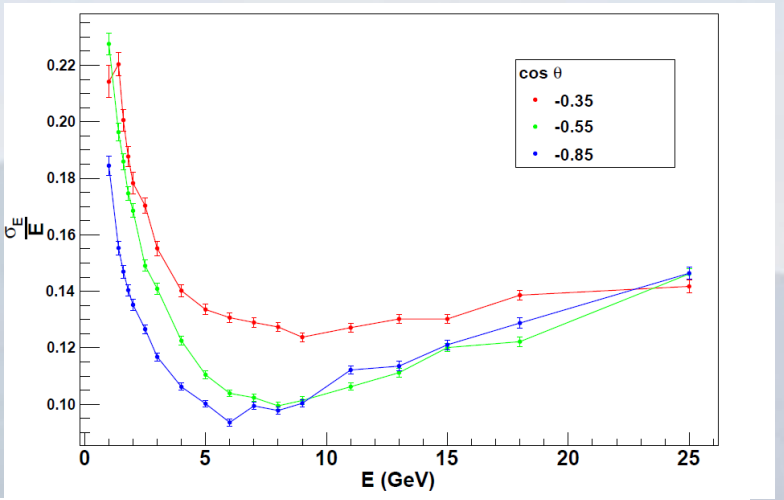
Fit the tracks of A + B + ... to get their energy and momentum.

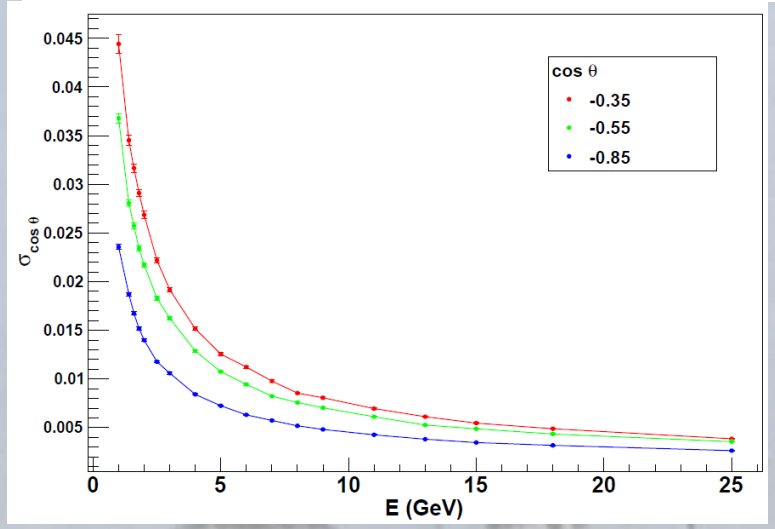
Output:
i) Energy & Momentum of the initial particles

Detector Performances: Muons





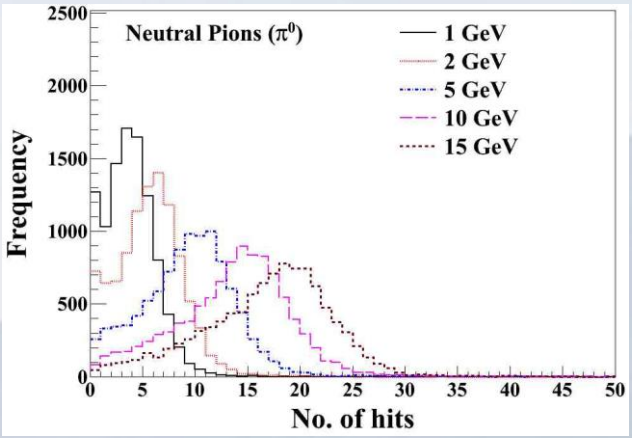


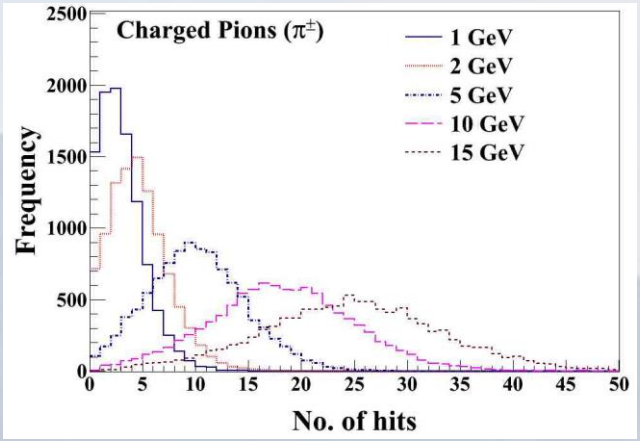


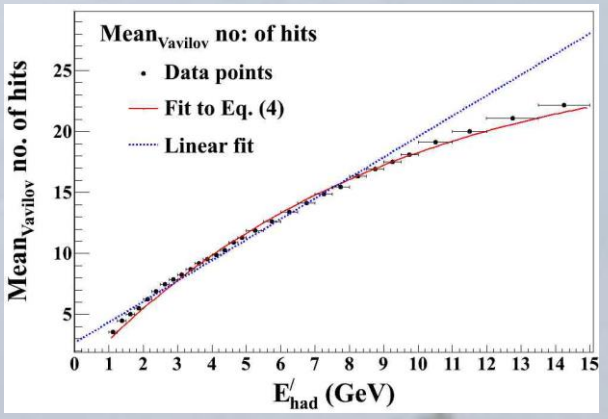
Reconstruction & Charge efficiencies

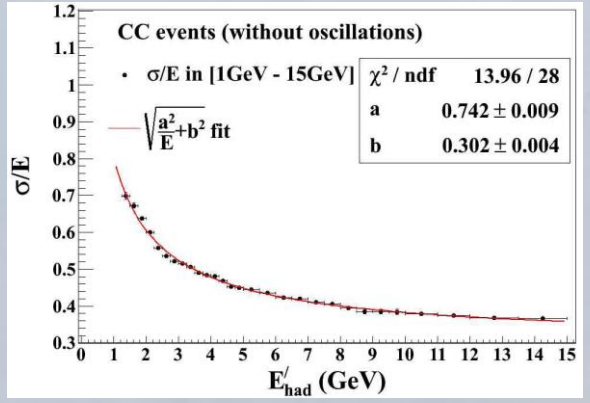
Energy & angular resolutions

Detector performances- hadrons







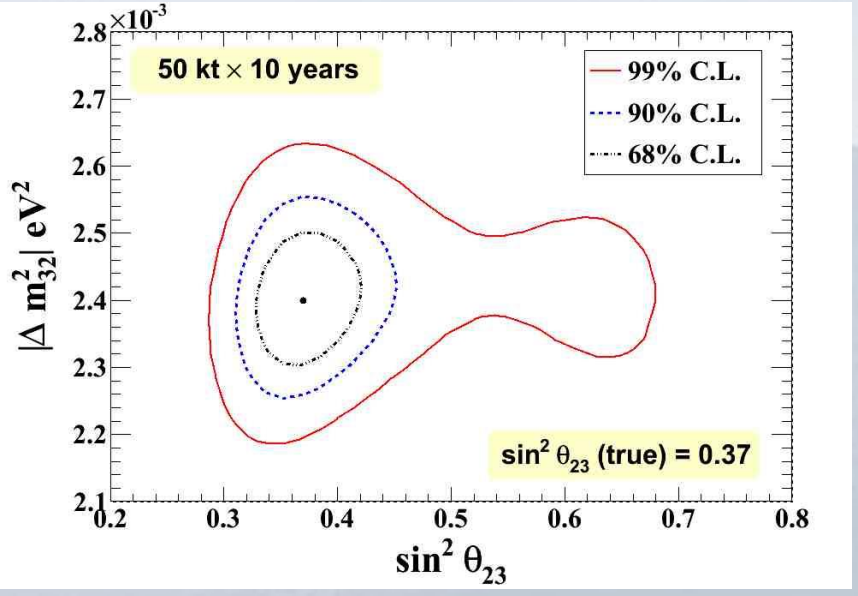


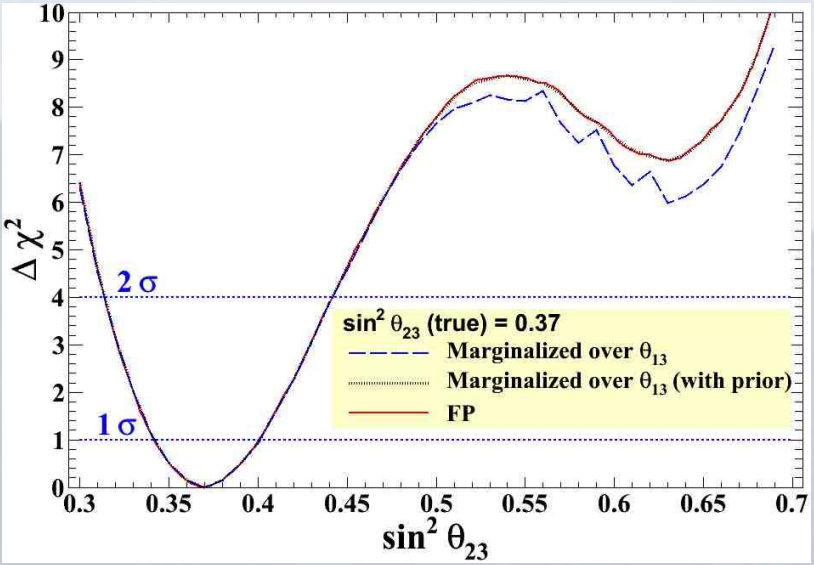
Calibration against $E'_{had} \equiv E_\nu - E_\mu$

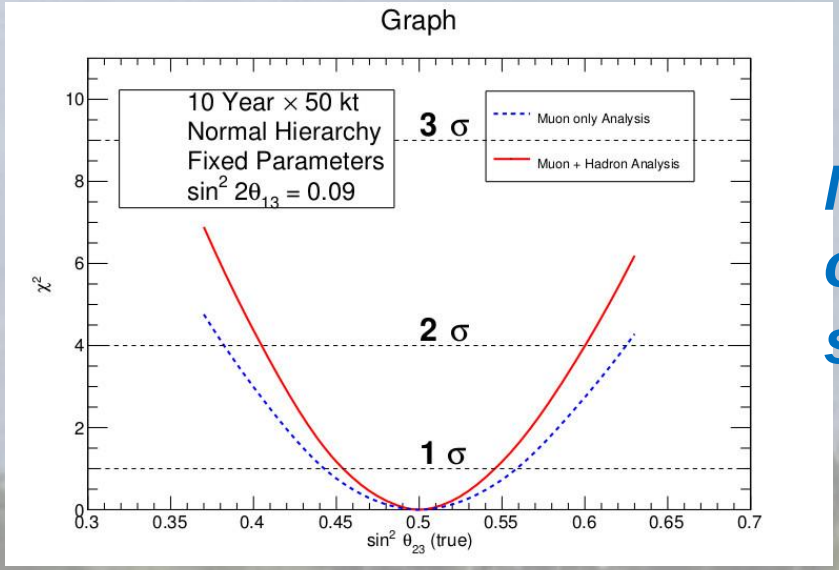
Vavilov distribution found to give a give good fit to the hit distribution

Hadron Energy resolution : $\frac{\sigma}{E} \approx \sqrt{\frac{(0.75)^2}{E} + (0.3)^2}$ ***85% at 1 Gev***

Octant sensitivity with hadron information

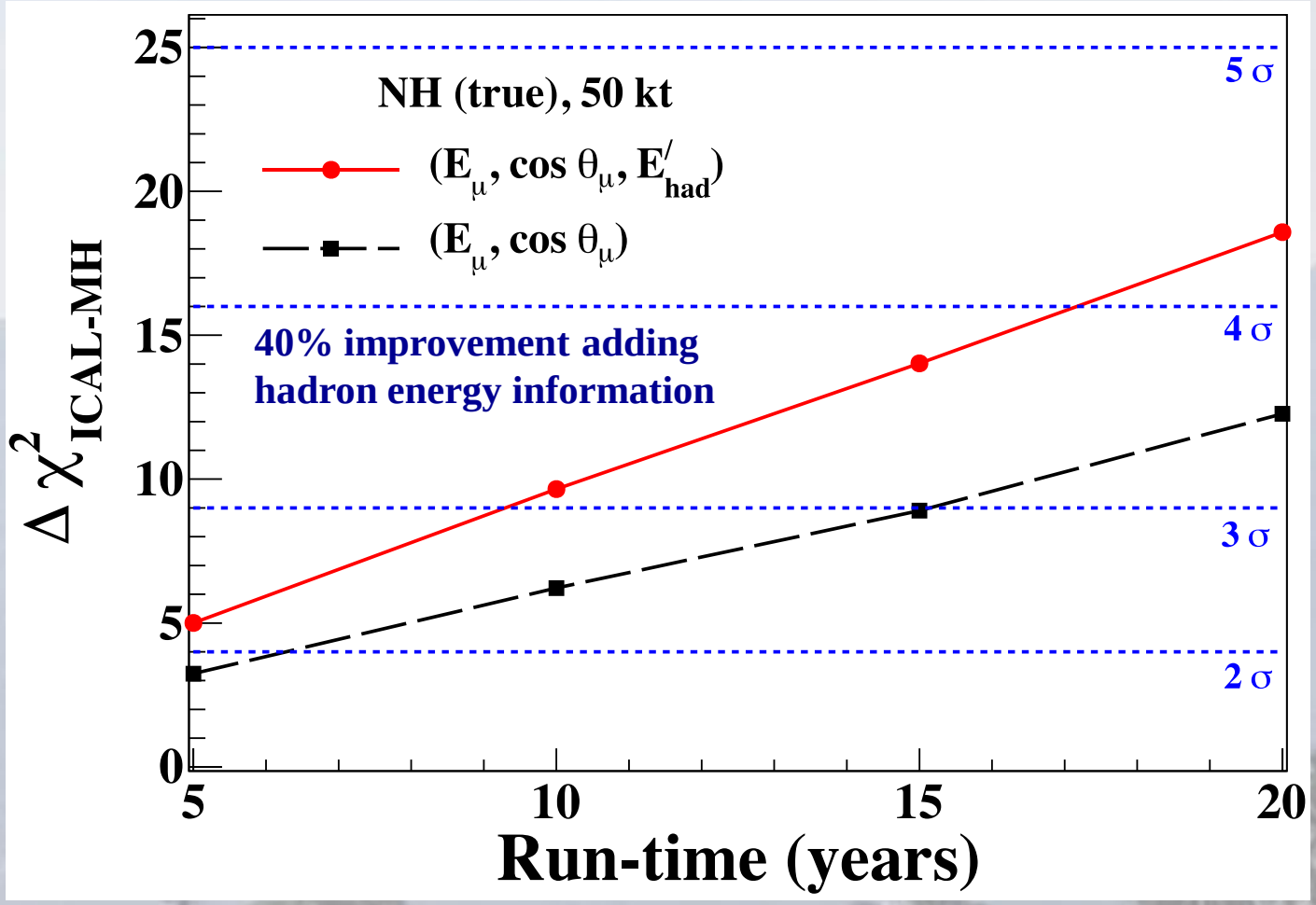






More than 2σ sensitivity to θ_{23} octant is possible if θ_{23} is sufficiently away from maximality

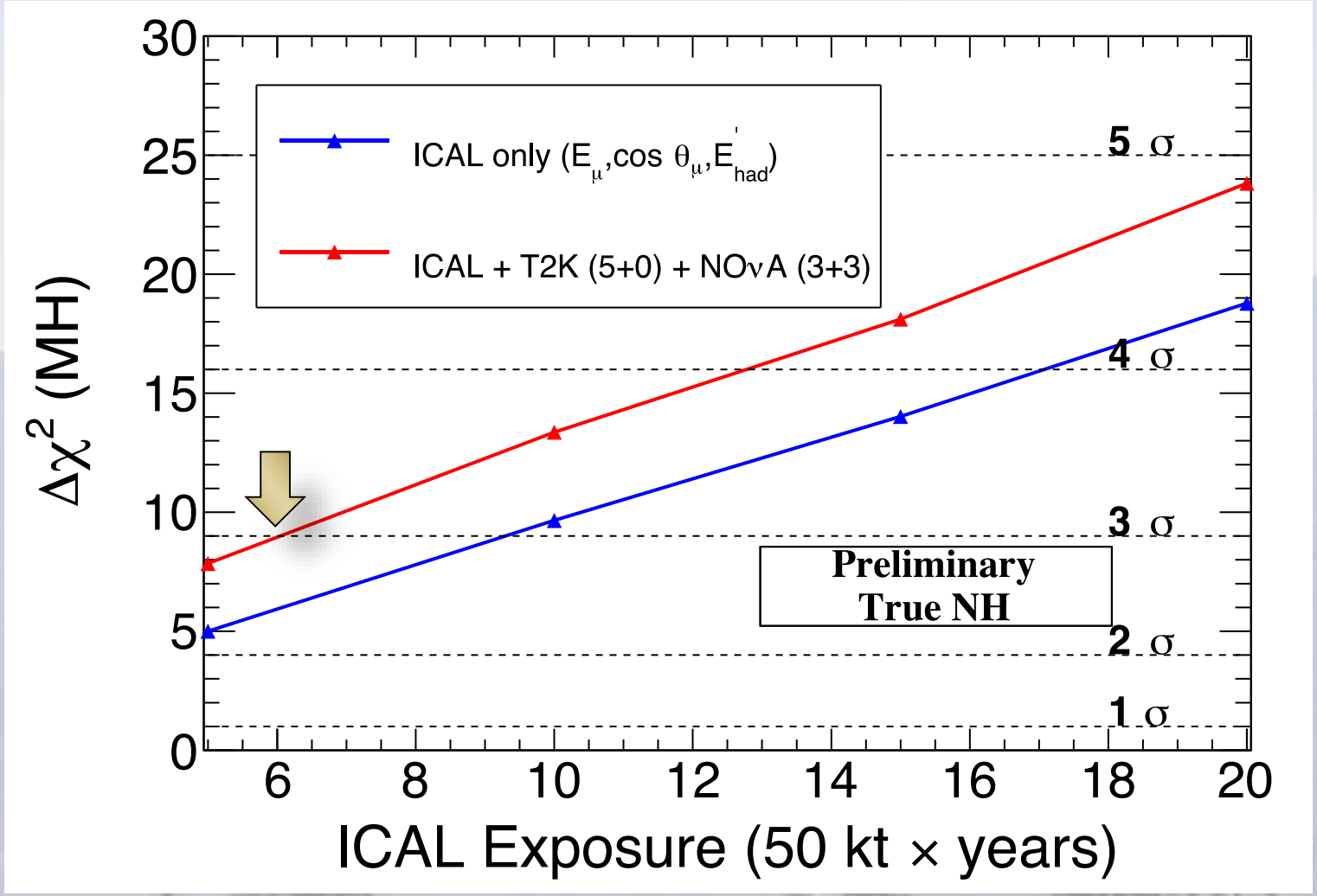
Identifying Neutrino Mass Hierarchy with INO-ICAL



Median Sensitivity

50 kt ICAL can rule out the wrong hierarchy with $\Delta\chi^2 \approx 9.5$ in 10 years

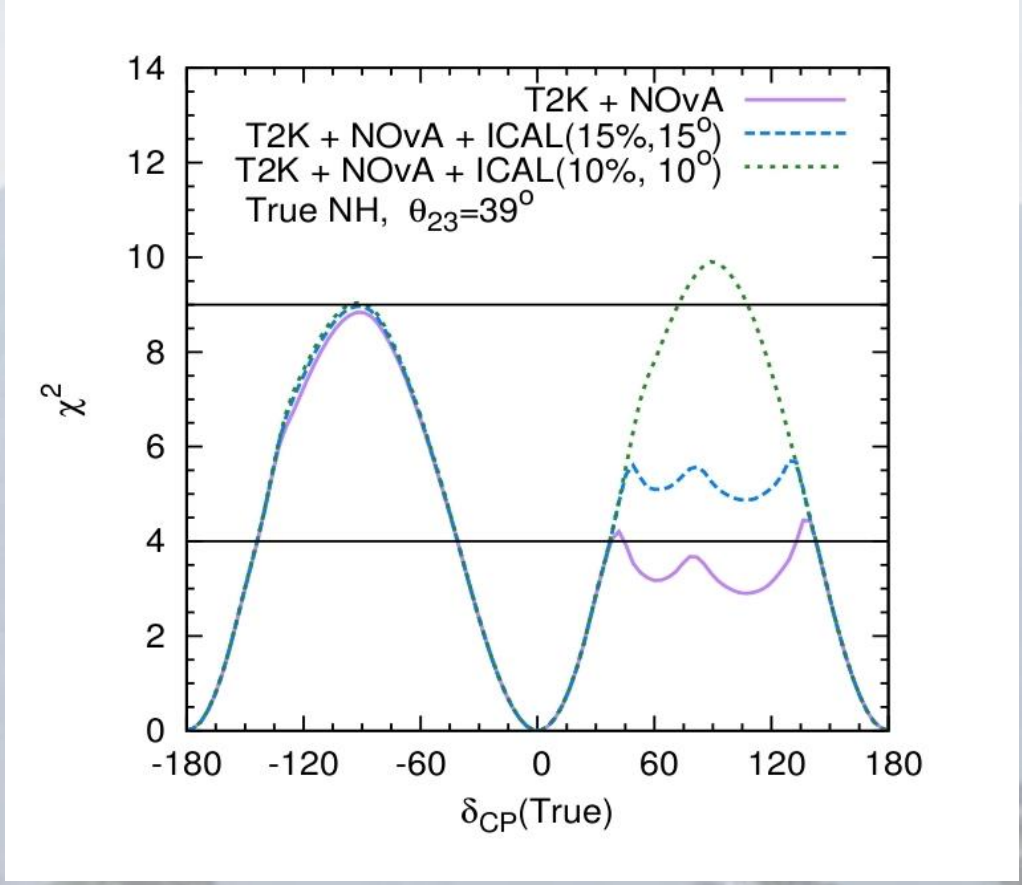
MH Discovery with ICAL+T2K+NOvA



work in progress (INO Collaboration)

3σ median sensitivity can be achieved in 6 years

Synergy with other experiments: CPV



Hierarchy information from INO-ICAL helps the detection of CP violation, though INO itself is not sensitive to CP violation

opposition

- *A PIL at Madurai branch of Madras High Court by a local Political leader.*
  - *Interim Order: We can not start construction until we obtained the TNPCB clearance.*
- *A case against INO by a green activist in the National Green Tribunal of Chennai.*

- *Not clear how quickly these problems will be solved.*

Summary

- *INO Project approved by the Govt. of India*
- *Pre-project activities started both at INO site & at Madurai city.*
- *Components for the Engineering Prototype are being procured.*
- *Some opposition from a political party and green activists has temporarily stopped our work.*
- *Trying to overcome these hurdles through enhanced public outreach program.*


Thank You for
your attention