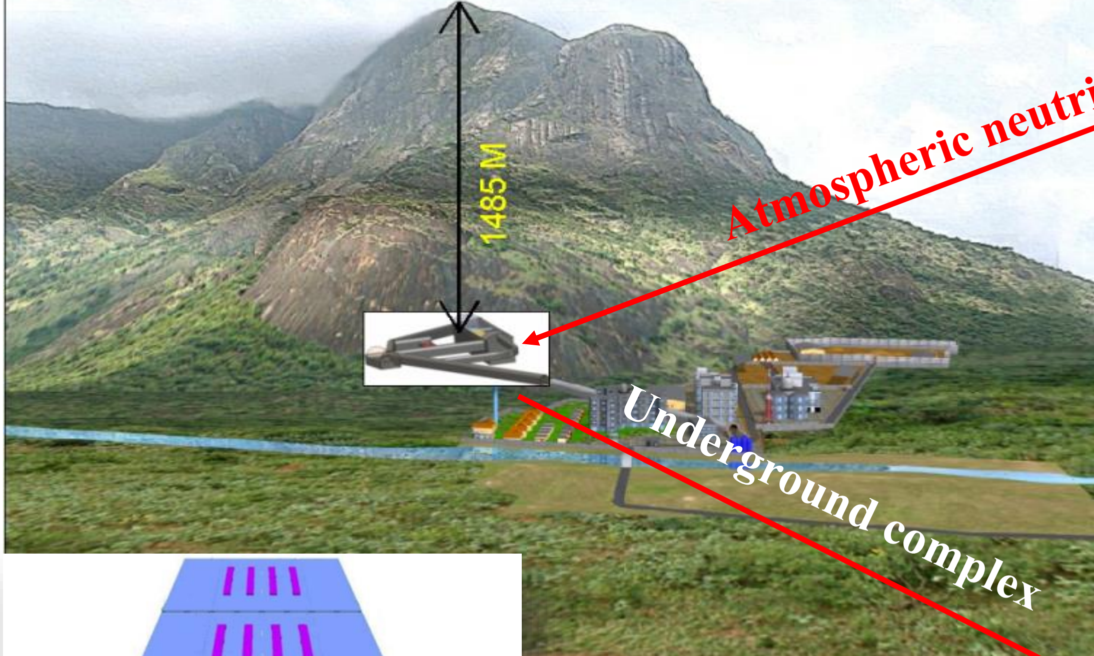
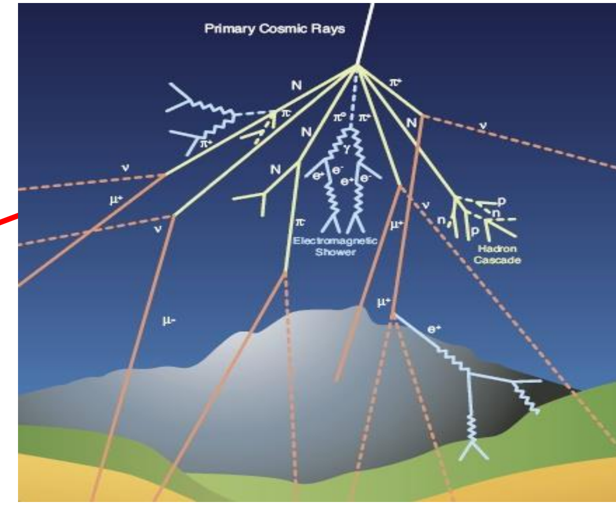
INO-ICAL Project

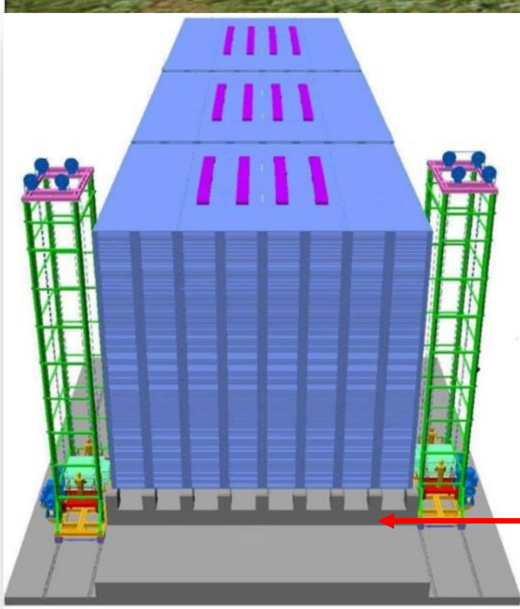
All major facilities are inside an underground cavern



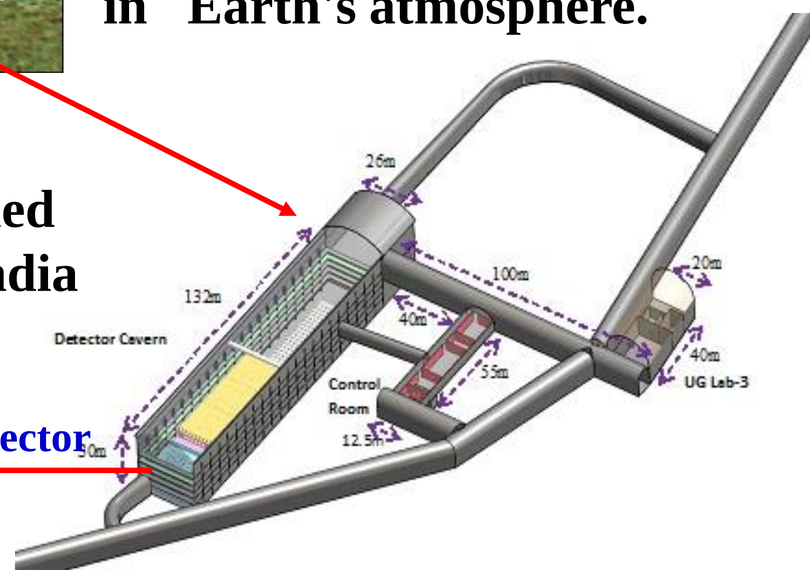


The magneised ICAL detector will study neutrinos naturally produced in Earth's atmosphere.

All components indigenously designed and to be built in India and many in TN



50Kton ICAL neutrino Detector



Salient Features of INO

- 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.
- 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.
- INO will support local college/univ students to learn world class experiments through a short or long term project at IICHEP/INO as well as in their experimental courses.
- Running a successful INO GTP with more emphasis on instrumentation.

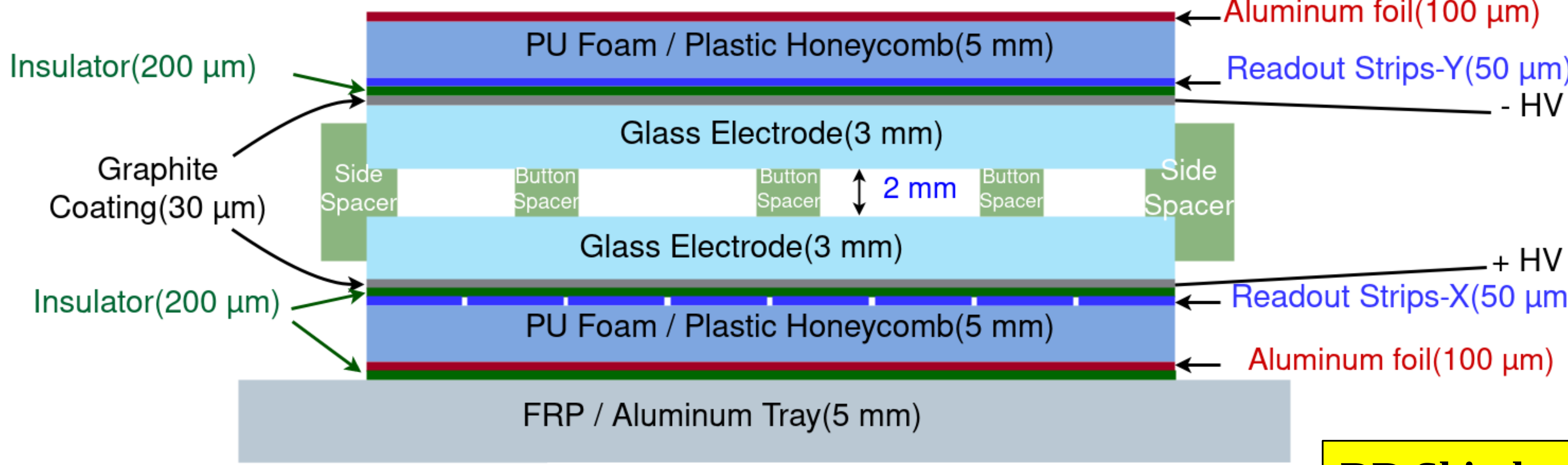
What science can INO-ICAL do ?

- **Only large magnetized neutrino detector which can study atmospheric ν_μ and $\bar{\nu}_\mu$ simultaneously over large E_ν, L**
- **Mass hierarchy (ordering) of neutrinos one of major goals.**

Competitors: JUNO (2023?), DUNE (2032). ICAL 3σ result in 10y stand-alone, 6 years using T2K, NovA.

- **Discriminating vacuum & matter-modified ν-oscillations possible only by DUNE and ICAL**
- **MSW resonance can only be observed by ICAL**
- **Synergy with accelerator experiments for CP violation**
- **Tomography of the earth using matter effects**
- **BSM physics: NSI, $\nu_{sterile}$, magnetic monopole, DM decay/annihilation**

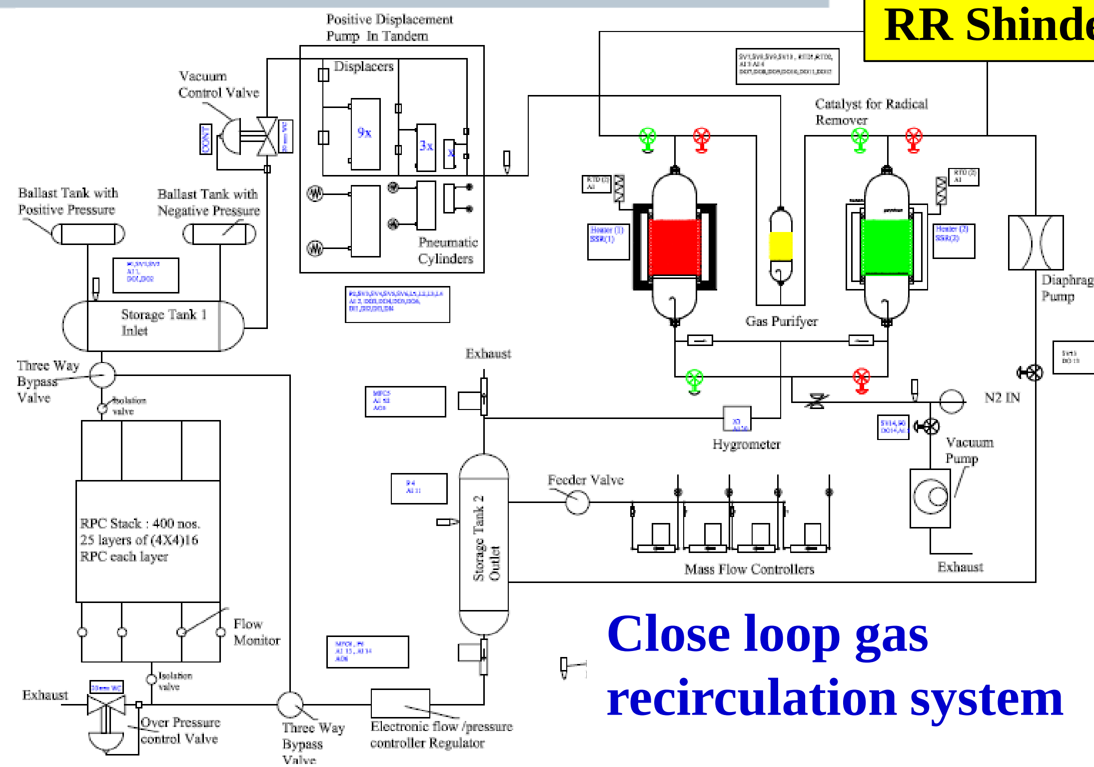
RPC : The main detector component



RR Shinde

HV supply. Output voltage range is 0 to ±6KV and upto 2μA current.

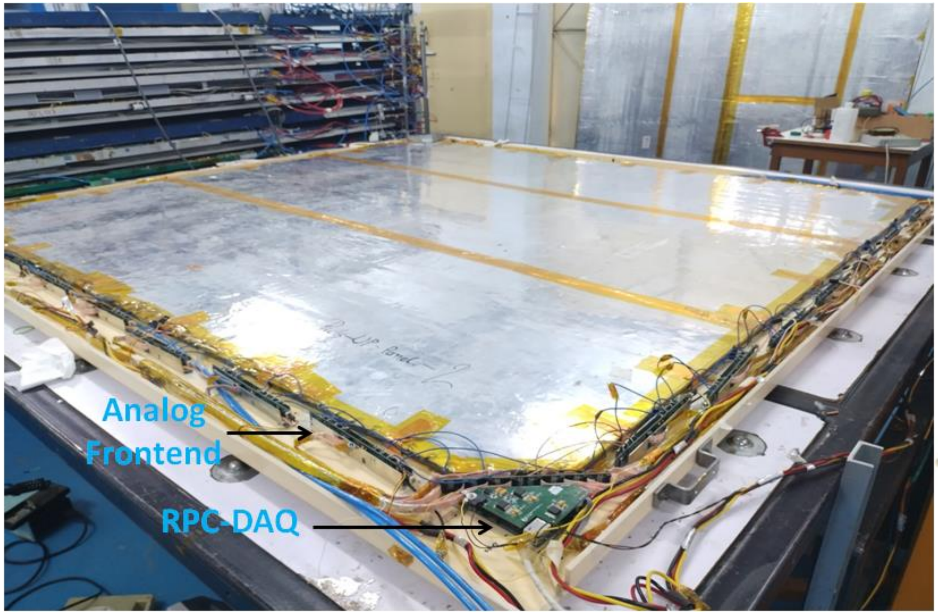
Developed by BARC



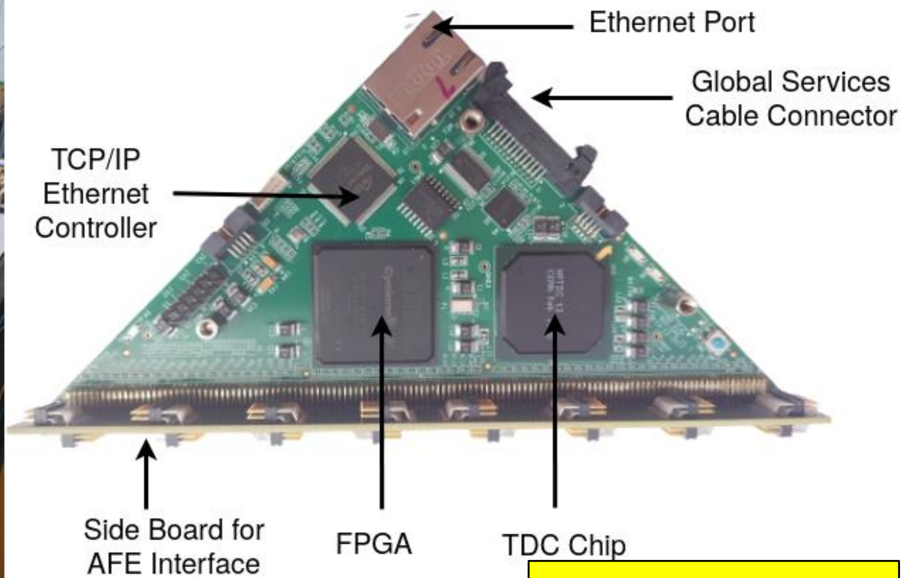
Close loop gas recirculation system

A fully assembled RPC with electronics

Assembled RPC on table

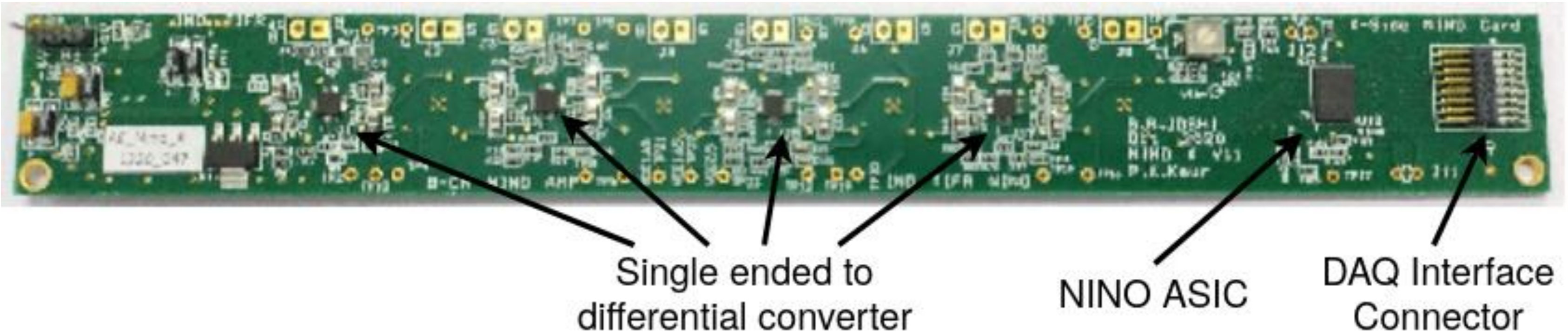


The digital Front-End Board



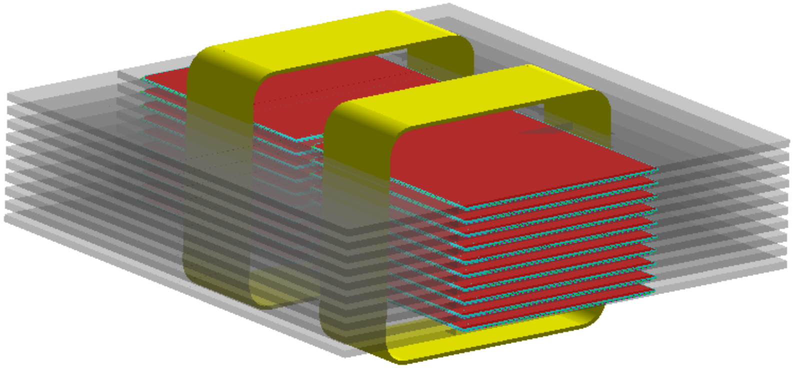
Aditya Deodhar

The analog Front-End Board (designed and developed by BARC)



HPTDC chip designed by IITM

The miniICAL detector



KC Ravindran

- Ran miniICAL (still running) to establish the electronics and other systems for the final production.
- Numerous abstracts sent to the national and international conferences.
- Based on all these works, there were many peer reviewed journal publications(submissions) during this period

Cosmic Muon Veto Detector around miniICAL, Madurai

Can one overcome the background due to cosmic rays?

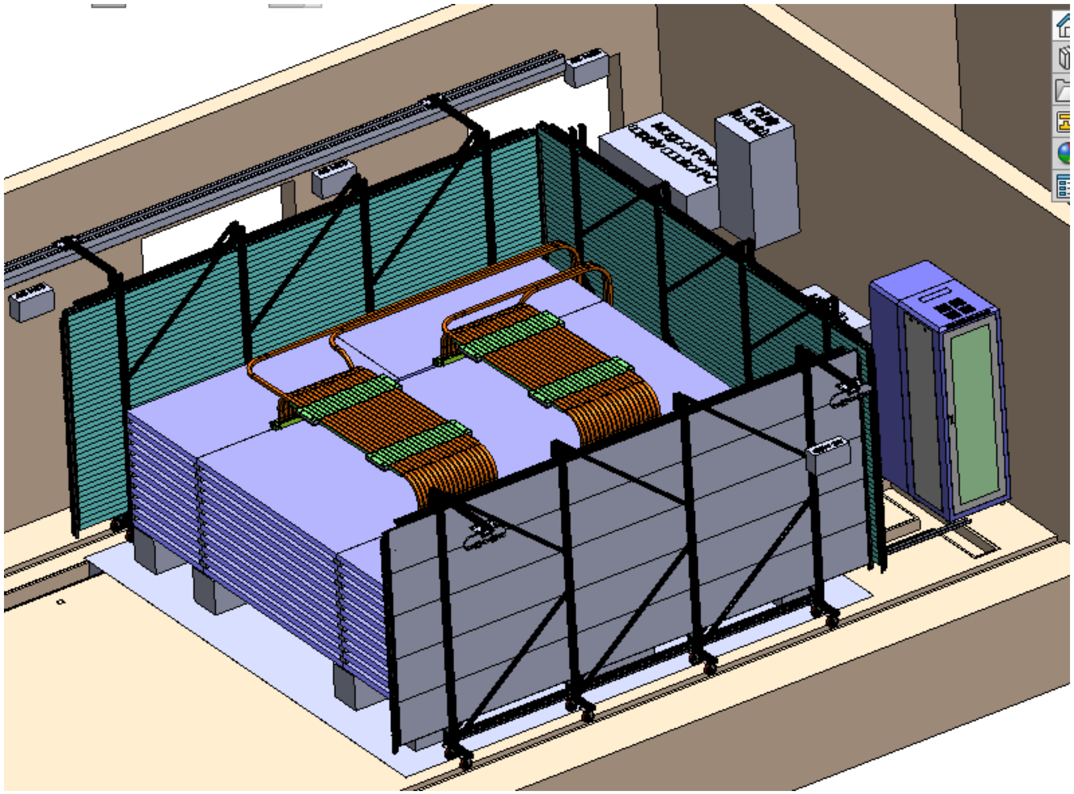
- **Muons : primary and secondary**
- **Primary γ-rays, *p*, *n*, will not survive at ~100m depth (λ_{em} ~ 0.15m, λ_{had} ~ 0.3m)**

A cosmic muon veto (CMV) detector with ε ≥ 99.99% needed

On three sides/top of miniICAL detector, there will be three/four layers of extruded scintillator

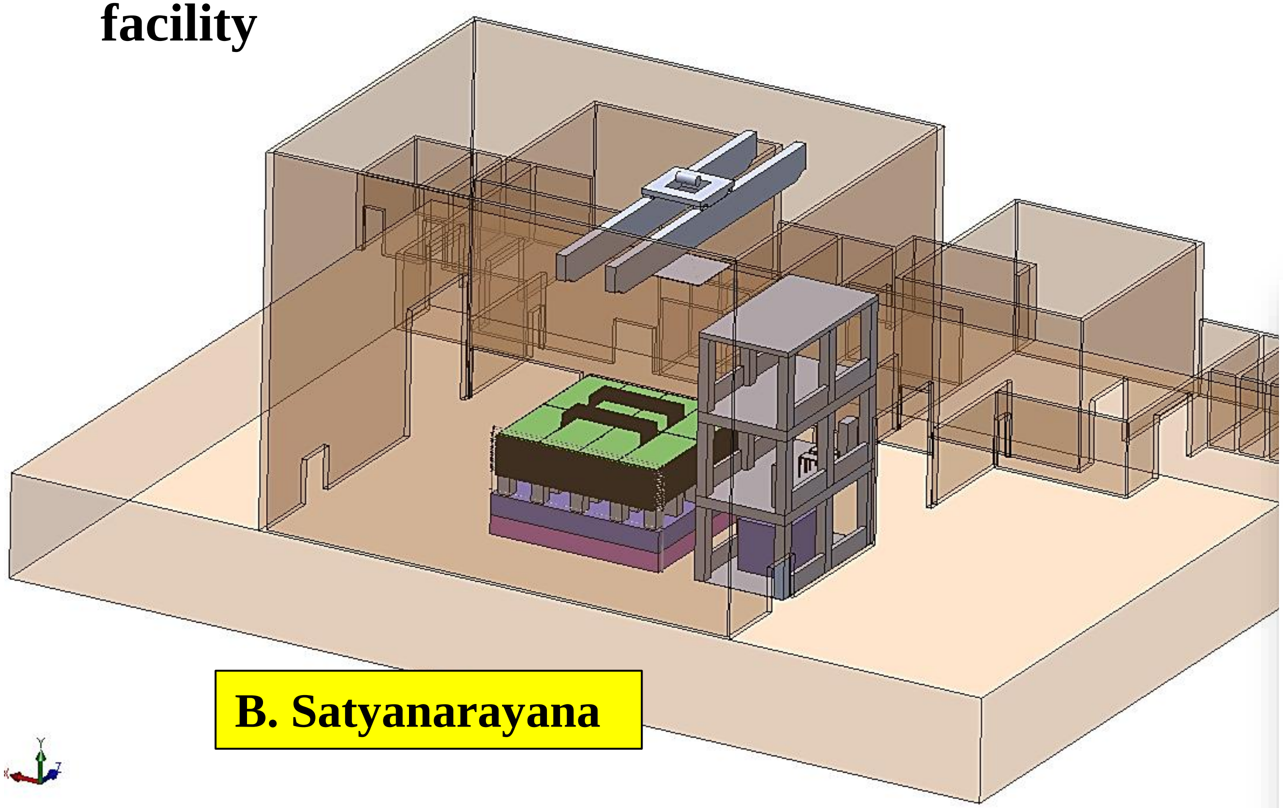
Feasibility study for the identification of cosmic muon at shallow depth

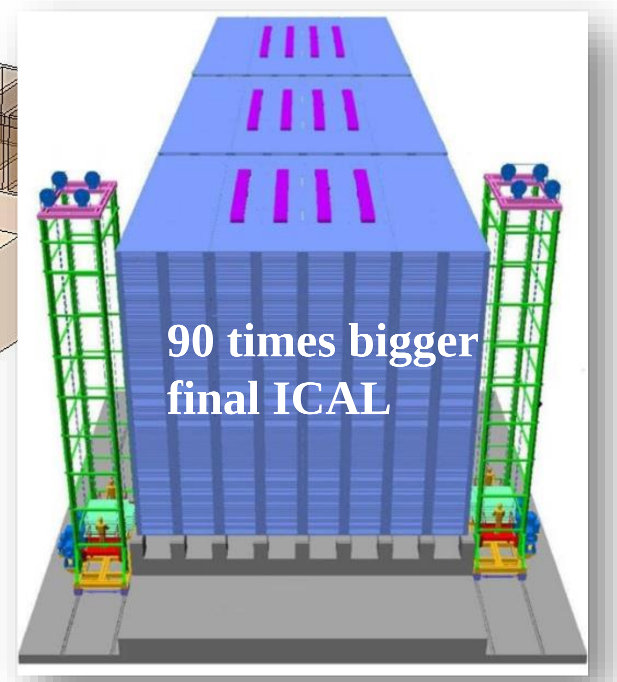
Mandar Saraf & Poster : Piyush Verma



Activities

- **Running miniICAL**
- **Commissioning of Cosmic Muon Veto Detector**
- **Preparation for the Engineering Module**
  - **With a common goal : A succesfull INO experiment at the underground facility**

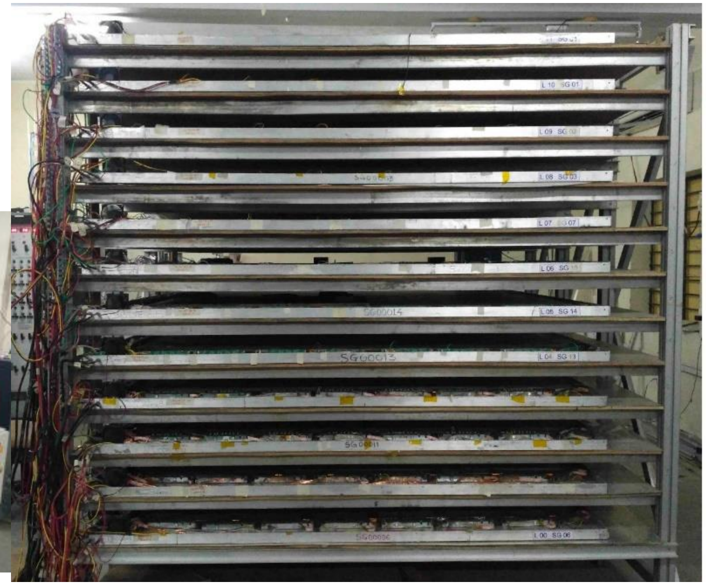


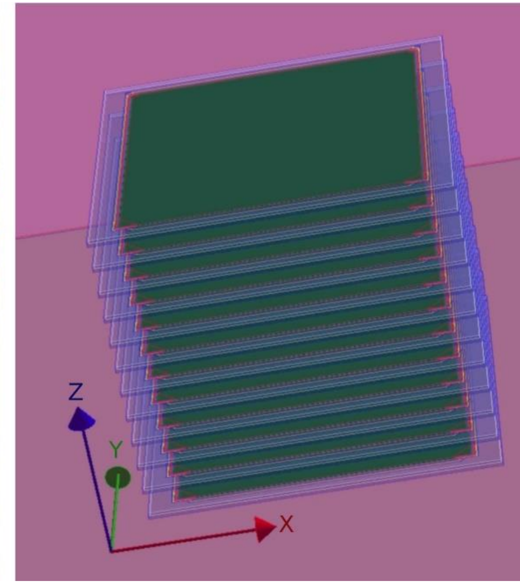


Only 20 layers of RPC, but iron in 23 layer, but the lab is able to accommodate upto 70 layers

Other activities

- **Physics with twelve 2m×2m RPC stack at Madurai**

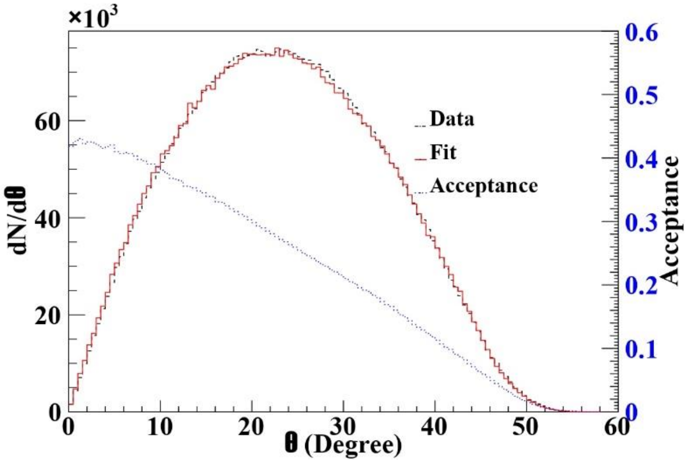


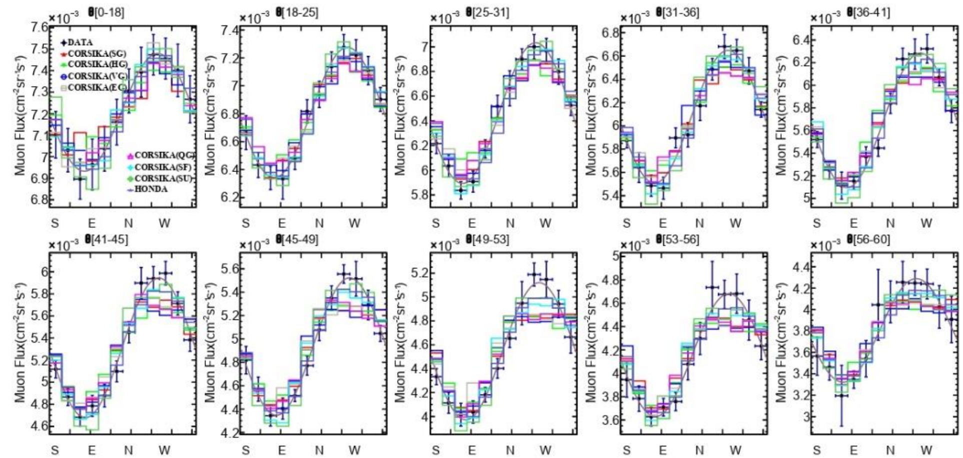


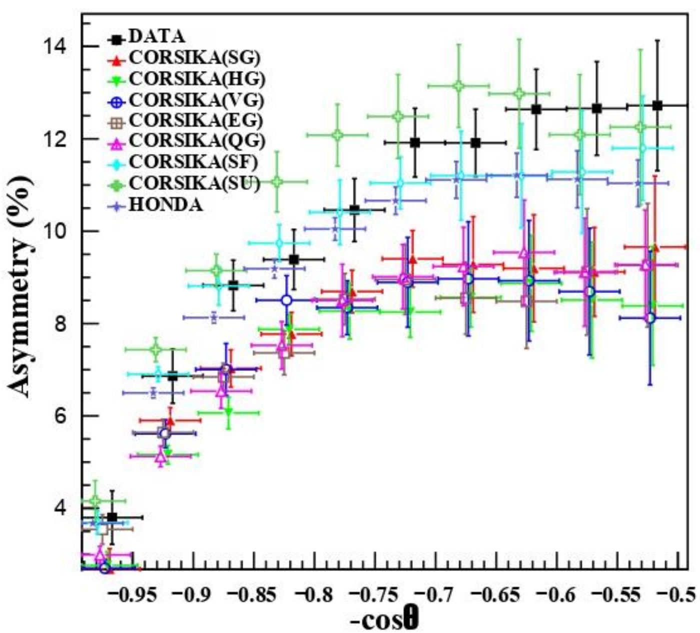
- **Running twelve 1m×1m RPC stack mainly for the development study of electronics**

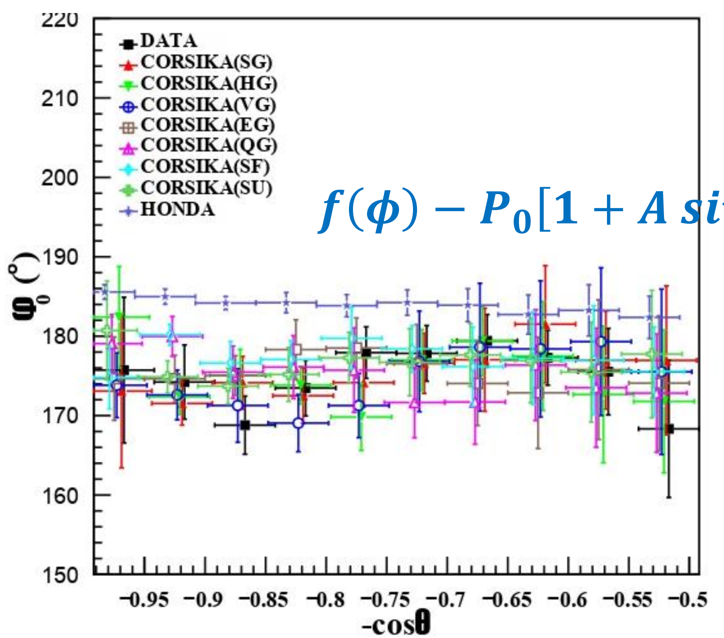
Polar & Azimuthal angle of Muon :

Exper. Astronomy 49 (2020) 3, 141-157







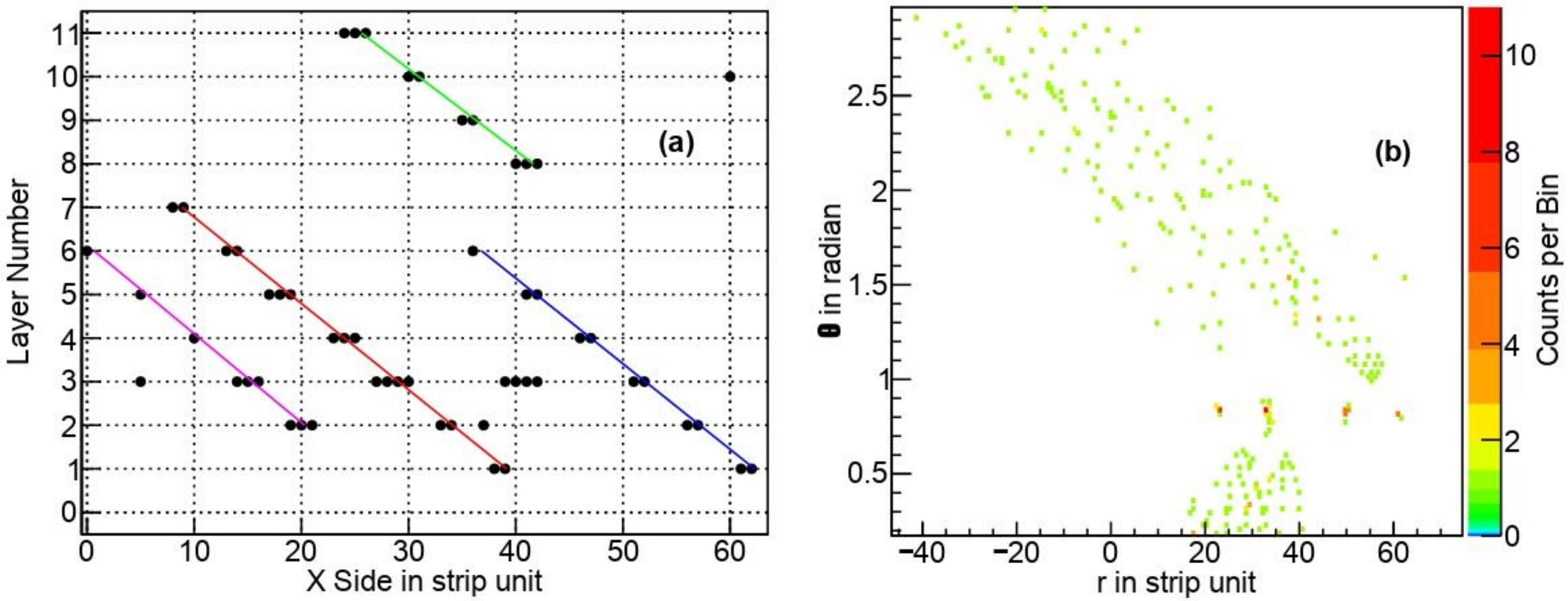


$$f(\phi) - P_0[1 + A\sin(-\phi + \phi_0)]$$

- **It has a power to distinguish hadronic models**

Muon multiplicity : Exper. Astronomy 51 (2021) 1, 17-32

2m × 2m RPC stacked were triggered by muon and most of the events were of single muon.

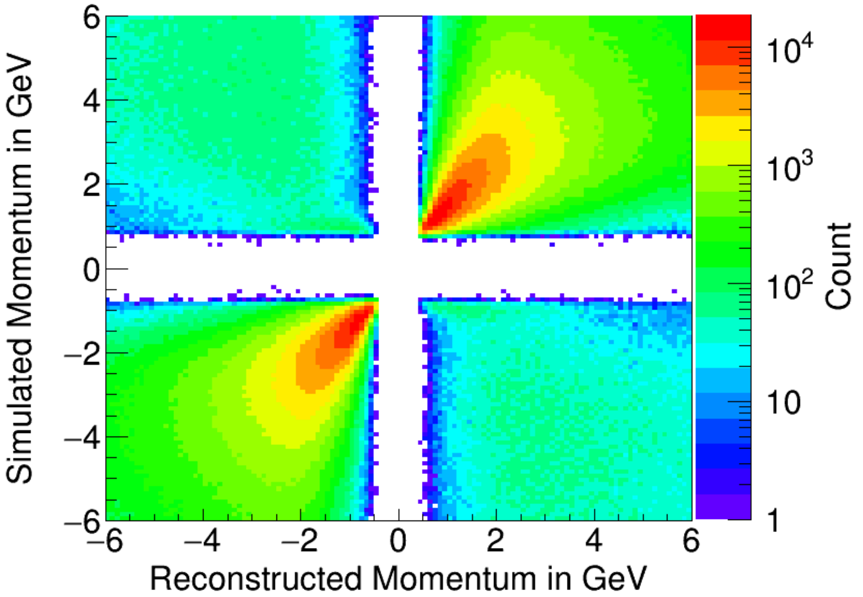


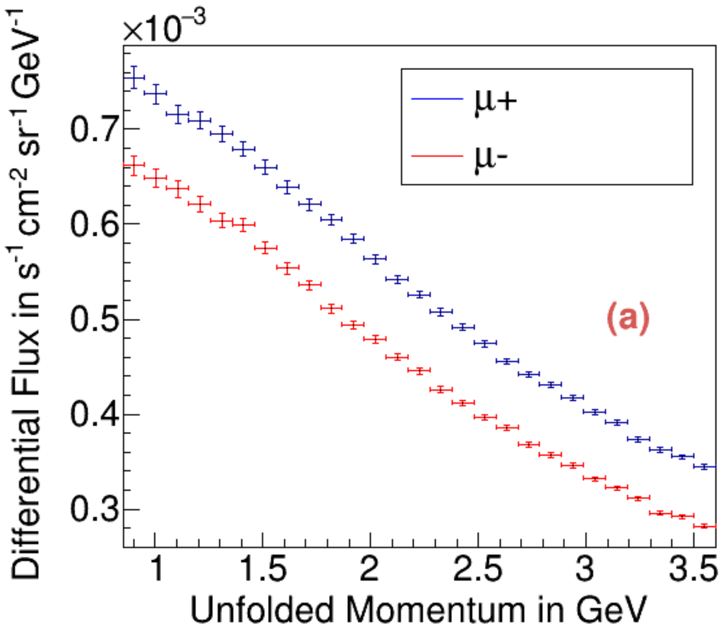
No of Tracks	Data	QGSJET-II-04	QGSJET01d
2	$6.35 \pm 0.05 \times 10^{-5}$	$2.35 \pm 0.10 \times 10^{-5}$	$2.36 \pm 0.10 \times 10^{-5}$
3	$5.80 \pm 0.50 \times 10^{-7}$	$1.20 \pm 0.10 \times 10^{-7}$	$1.20 \pm 0.10 \times 10^{-7}$
4	$2.00 \pm 1.00 \times 10^{-8}$	$3.00 \pm 1.00 \times 10^{-9}$	$2.40 \pm 0.60 \times 10^{-9}$

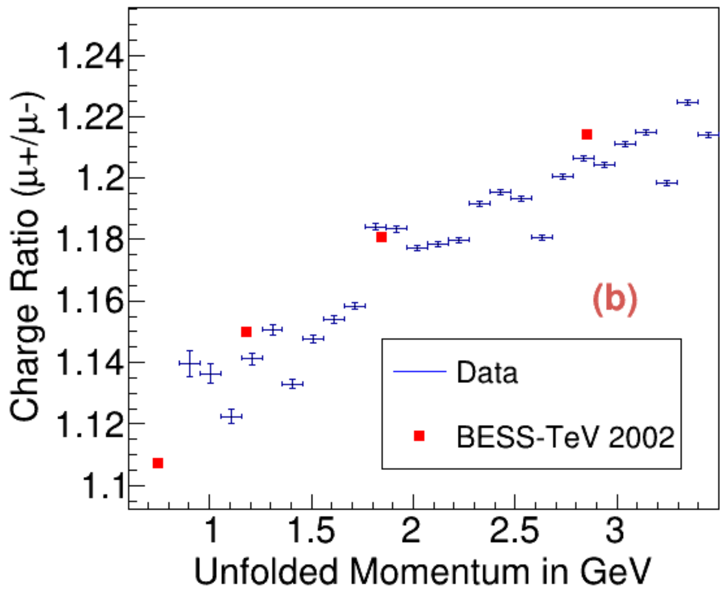
- **Observed multiplicities in data is more than MC, observed in other underground experiments also, but no proper explanation on prediction except to doubt the hadronic shower models.**

Muon charge ratio

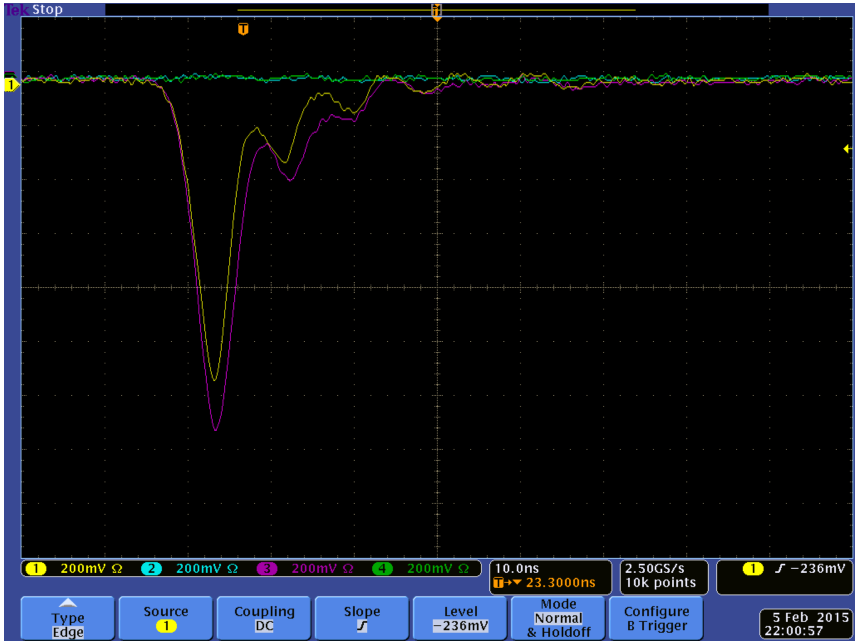
- The main goal is to put this input in neutrino event generators for the better prediction of neutrino flux.
  - Conference proceedings, will submit soon to journal

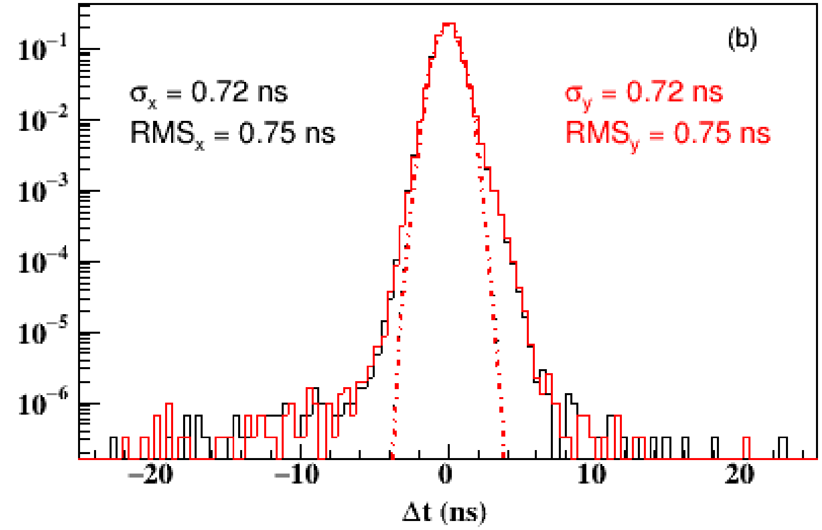


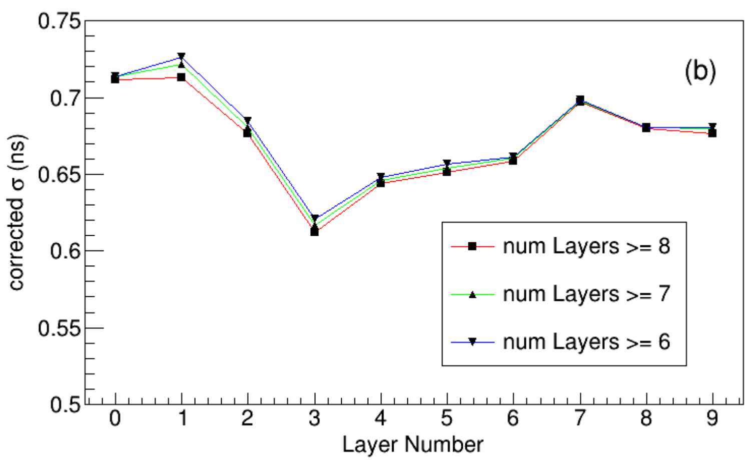


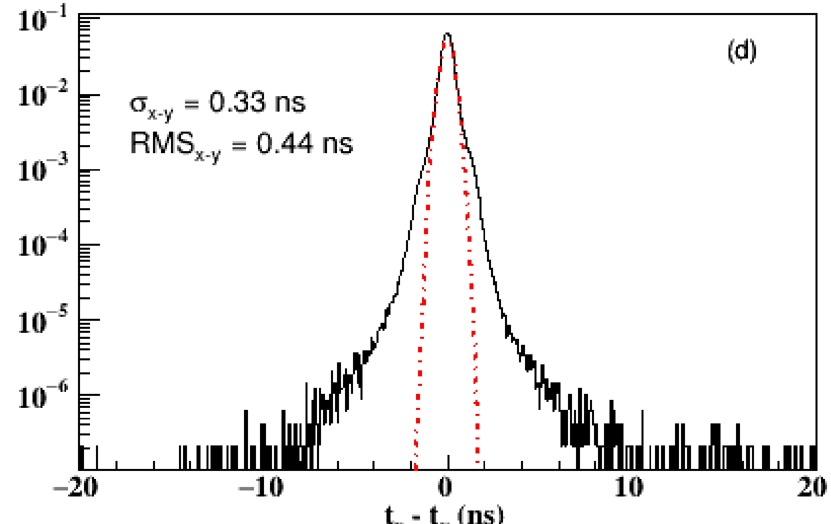


Time resolution using ToT : JINST 17 (2022) P04020







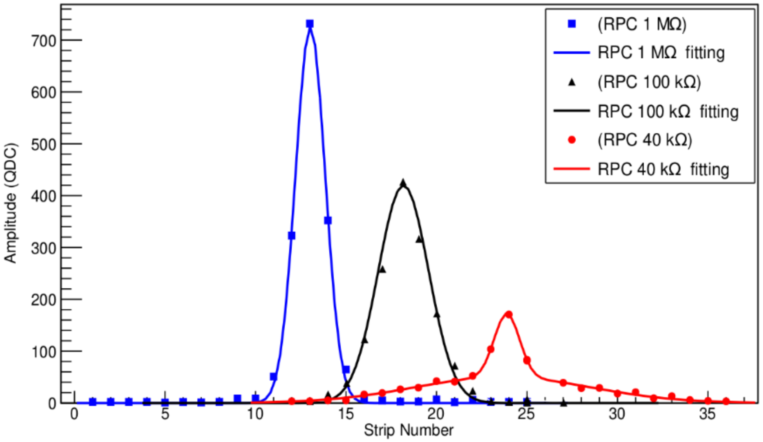


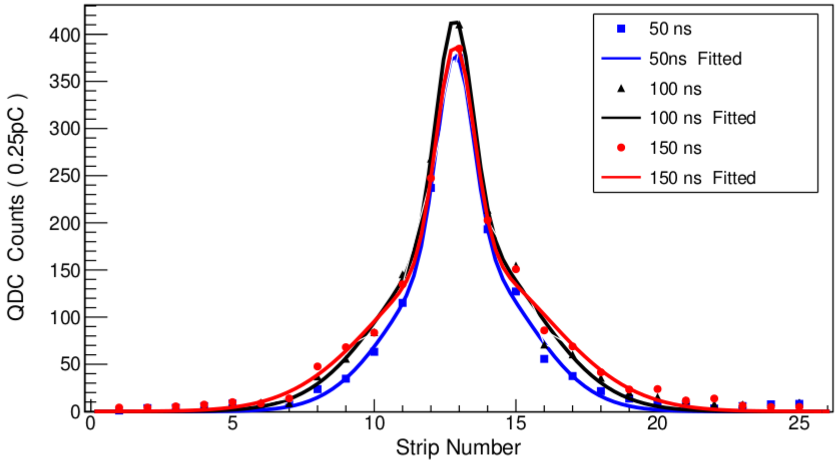
- **As far as we know, no other experiments achieved 600-700ps resolution from the conventional large size single gap RPC.**

Poster : Jim M John

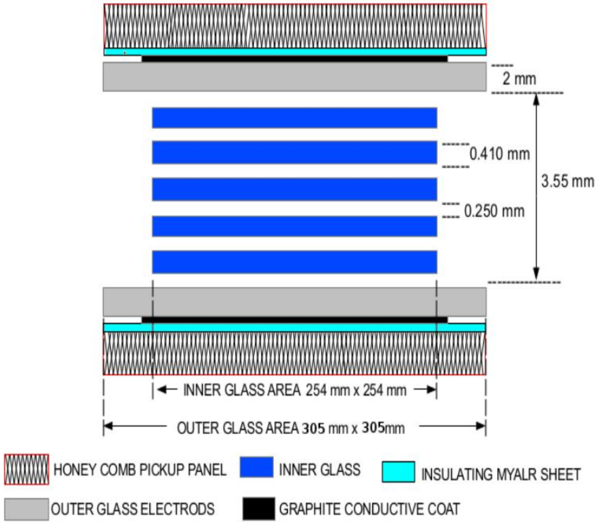
Various R&D with RPC detector

- **Effect of integration time on the induced charge and position resolution of the RPC detector. JINST 14 (2019) no.05, P05021**





- **Effect of electrode coat's surface resistivity of Resistive Plate Chamber on the space dispersion of induced charge. JINST 15 (2020) 09, T09010**

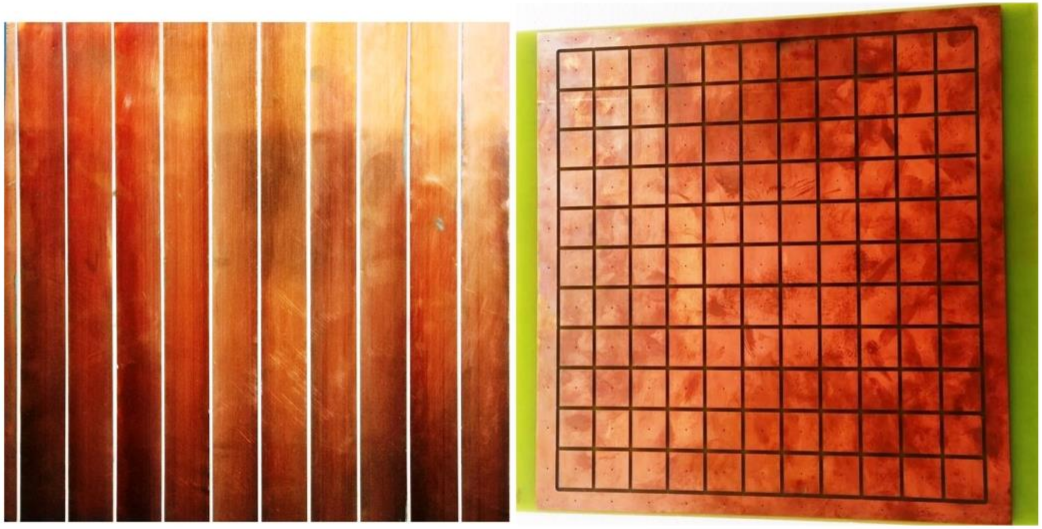


- **Development and characterization of six-gap glass MRPCs and feasibility study of a PET device**

Various R&D with RPC detector

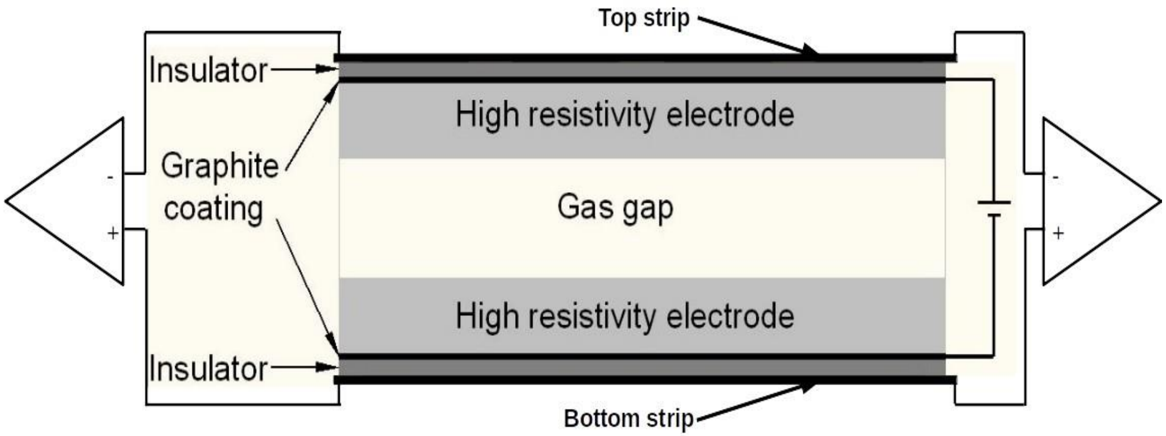
- **Study and characterisation of pad-based readout for RPC detector, Accepted in JINST**
  - **Useful for high multiplicity environment**

Poster : Umesh Shas



- **Improvement of position resolution of RPC with parallel strips readout**

Poster : Jones Panickier

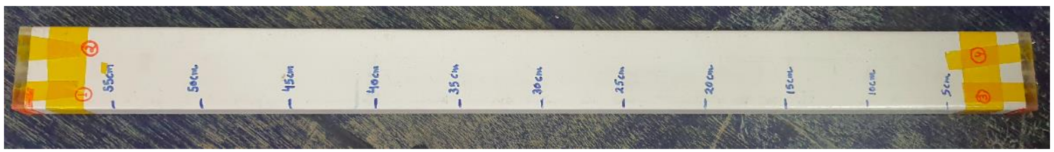


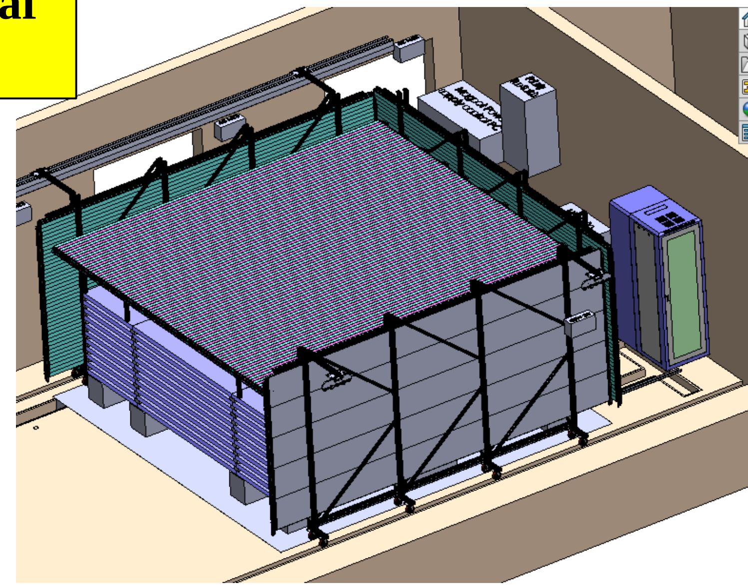
NB: Top and bottom strips aligned in the same direction
Alternate Readout Scheme Proposed

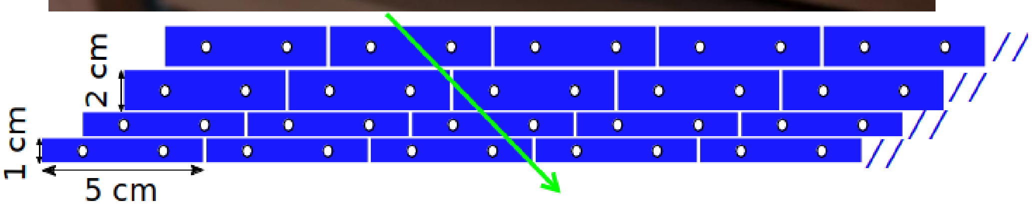
Scintillator and SiPM for CMVD

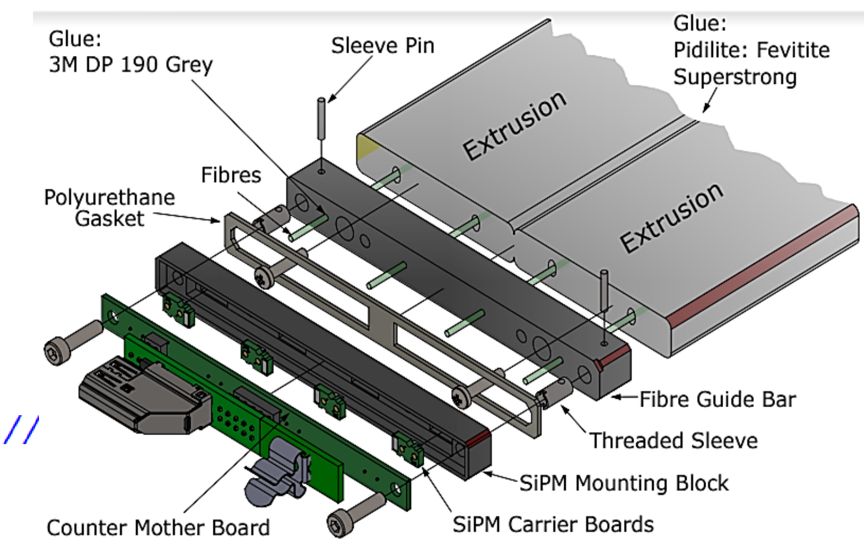
Mandar Saraf
E. Yuvaraj

- **Cosmic muon veto detector requires**
  - Total 712 extruded scintillator of size ~5m×5cm×1(1.8)cm
  - Total 2848 SiPM readout







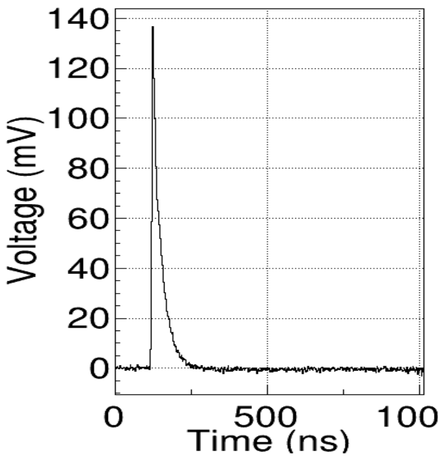


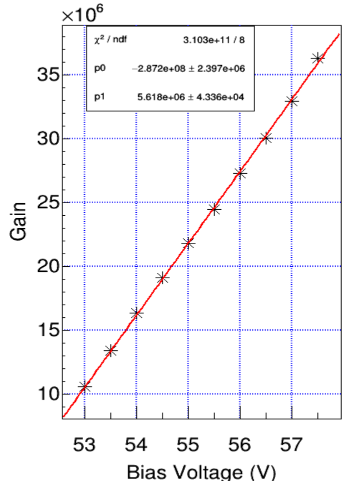
Tile making and testing of wall structures

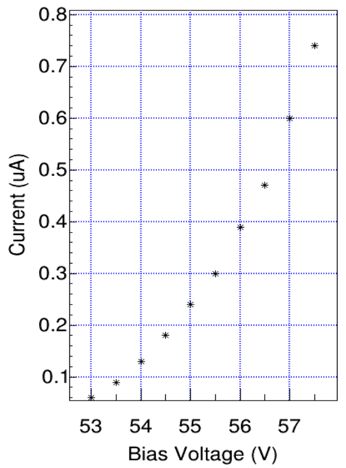
Poster : Pandi Raj Chinnappan

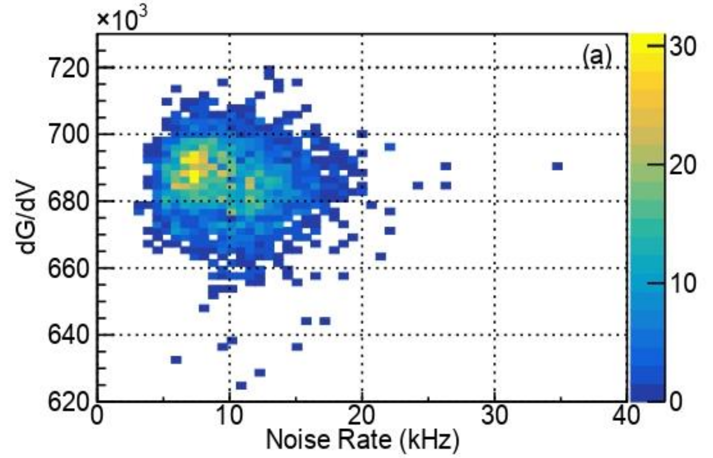
Mass testing of the SiPM and Scintillator

More than 3000 SiPM are tested and except one all are satisfied our QC criteria

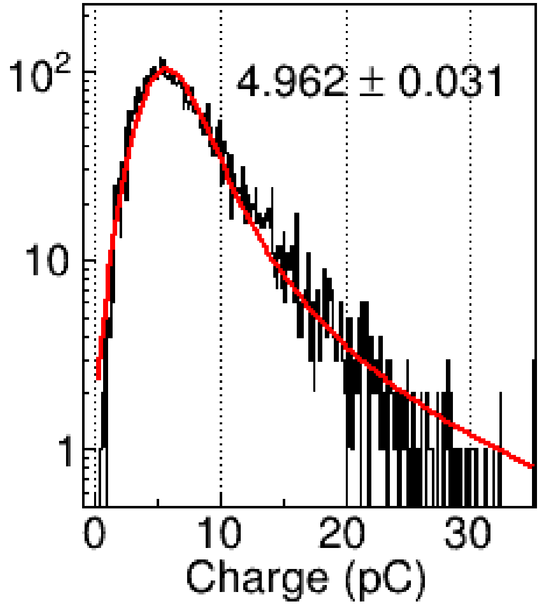






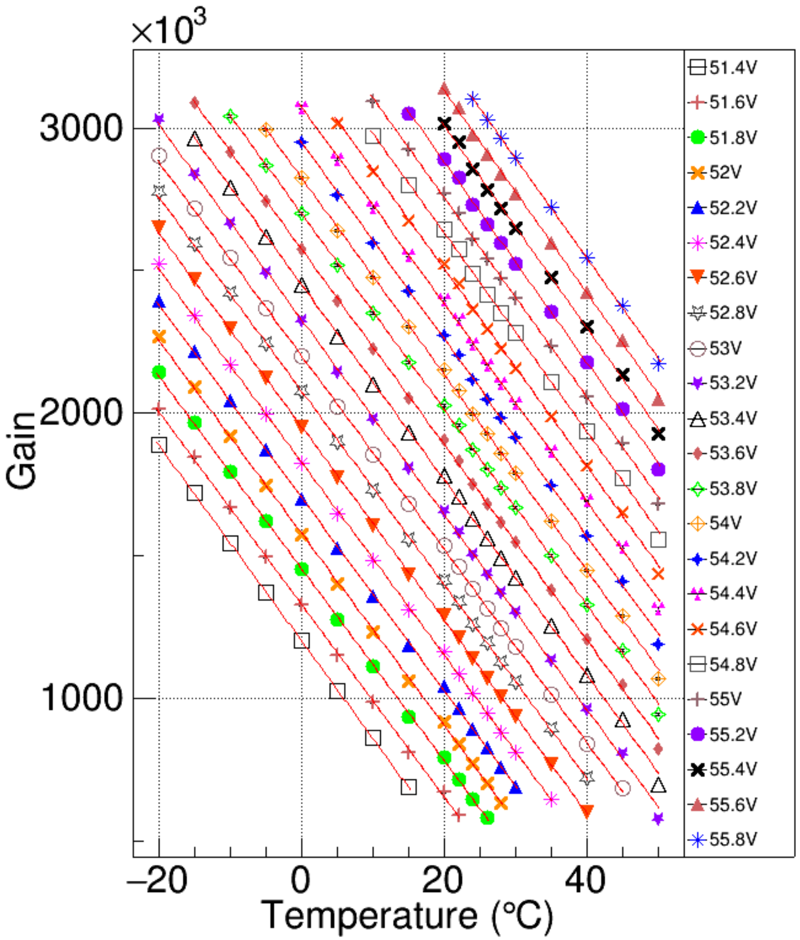


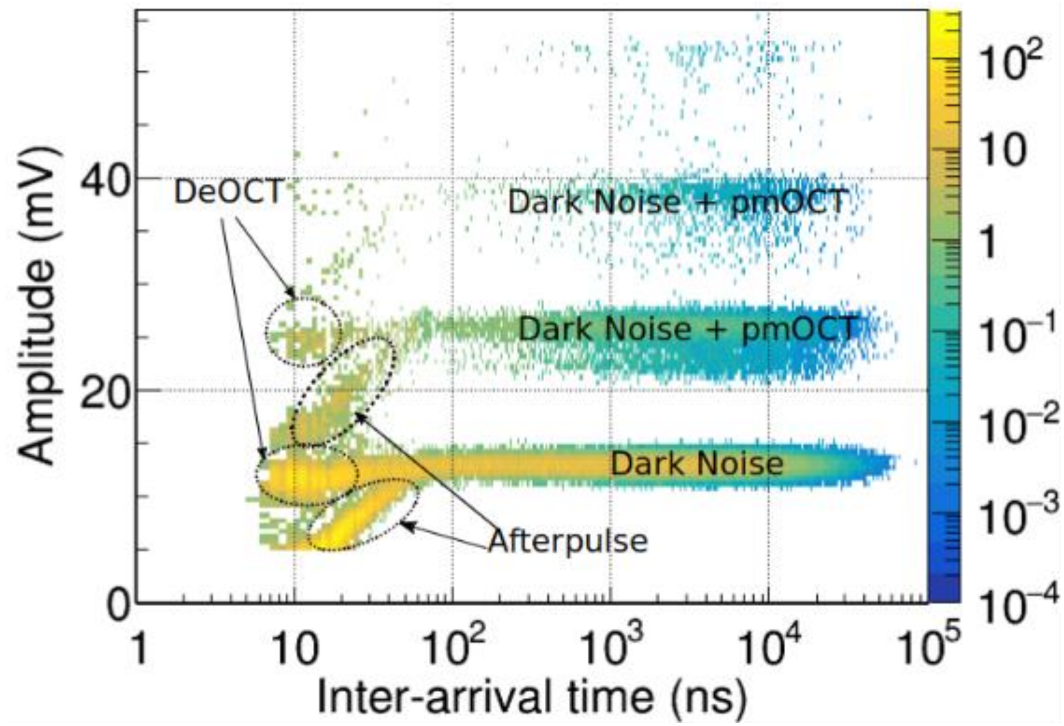
- Each fibre is test with cosmic muon signal before going to for tile production.



Some features of SiPM

- SiPM signal, cross talks as a function of HV/Temp



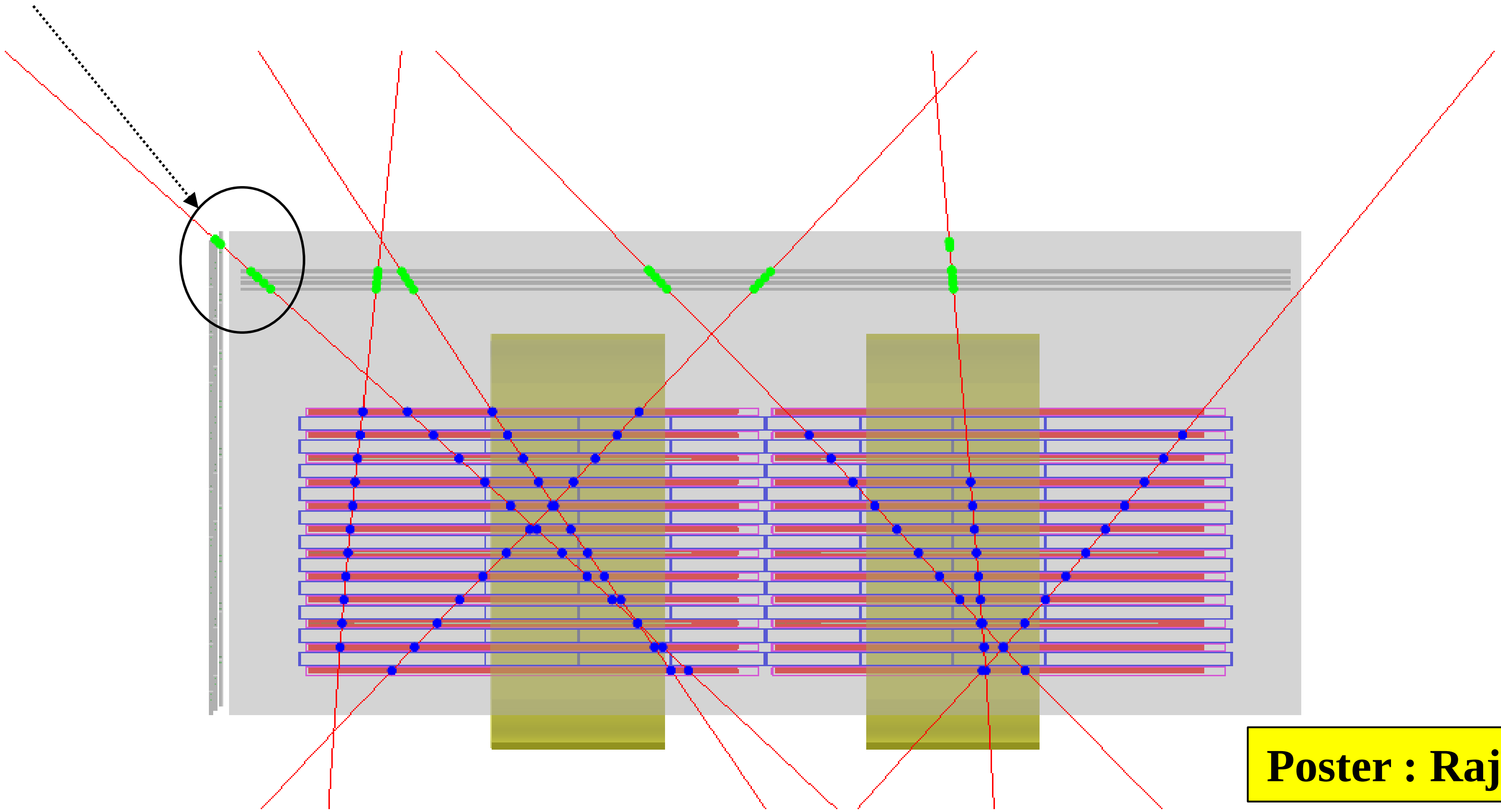


Poster :
Mamta Jangra
Mandar Saraf

- All these are initiated for the CMVD performance study,
- But, there are few unanswered observations also
- Already published/submitted one/one paper and another one in pipeline.

Expected Performance of the CMVD

- Muon trajectory is defined by the signal of RPCs and then extrapolate to scintillator layers of CMVD (both with and without magnetic field)
  - Providing input to the design of electronics
  - Expected performance (including the effect of multiple scattering and gap due to electronics



Poster : Raj Shah

List of INO talks on Friday Morning

- **9:30 – 9:45 : Preparation for the Engineering Module : B. Satyanarayana**
- **9:45 – 9:55 : MiniICAL operations : KC Ravindran**
- **9:55 – 10:05 : Close loop Gas system : Ravindra Shinde**
- **10:05 – 10:15 : Trouble shooting of RPCDAQ and noise studies : Aditya Deodhar**
- **10:15 – 10:30 : Overview of the Cosmic Muon Veto Detector : Mandar Saraf**
- **10:30 – 10:45 : Test of SiPM and scintillators for the CMVD : Mamta Jangra**
- **10:45 – 11:00 Frontend of Cosmic Muon Veto Detector : E. Yuvaraj**

List of INO posters

- **Mechanical Structure of the CMVD : Piyush Verma**
- **Infrastructure development for the CMVD : Pandi Rai Chinnappan**
- **Backend of miniICAL : P. Nagaraj**
- **Magnetic field measurements at miniICAL : Honey Kumari**
- **Time resolution of large scale RPC using ToT : Jim M John**
- **Pixelated RPC readout : Umesh Shas**
- **Position resolution of RPC with parallel strips : Jones J Panicker**
- **Choice of HV for a bad RPC : S Pethuraj**
- **Simulation of the CMVD : Raj Bhupen Shah**
- **Characterization of Silicon-Photomultipliers for CMVD : Mamta Jangra**
- **Qualification study of SiPMs on a large scale for the CMVD Experiment : Mandar Saraf**