Present status and Physics prospects at INO and mini-ICAL and feasibility of shallow depth ICAL

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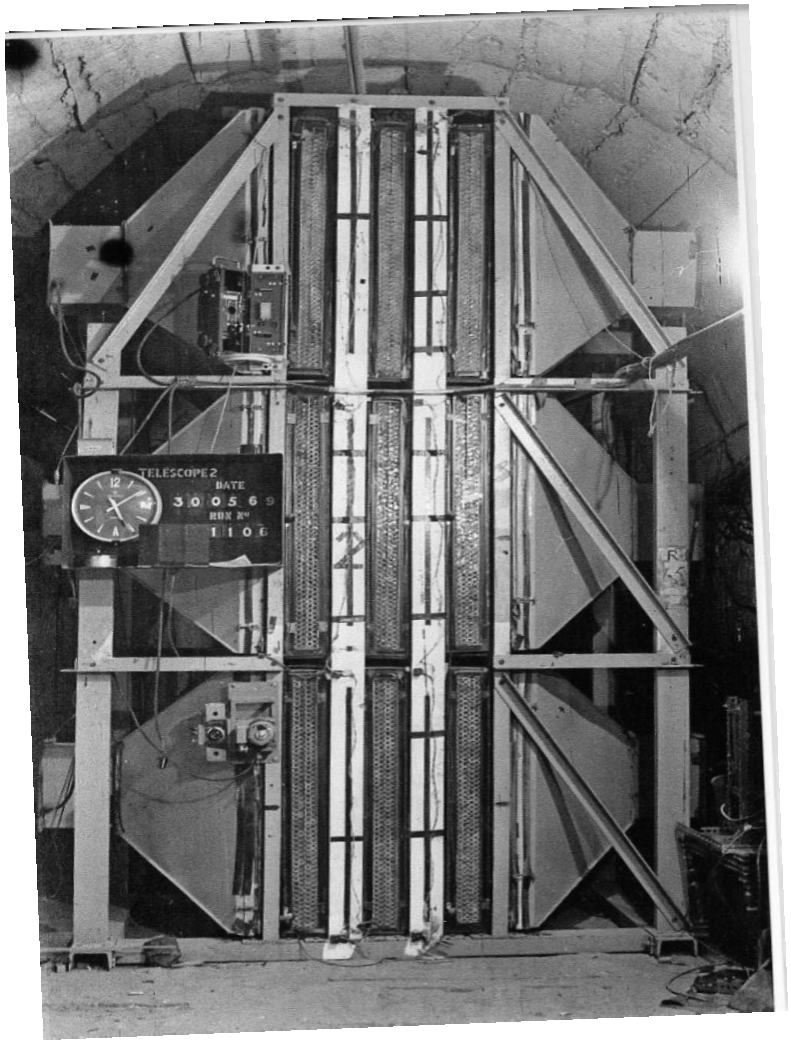
Mumbai

PANE 2018 @ ICTP Trieste (30 May 2018)

Atmospheric neutrino detection in 1965



Atmospheric neutrino detector at Kolar Gold Field –1965

DETECTION OF MUONS PRODUCED BY COSMIC RAY NEUTRINO DEEP UNDERGROUND

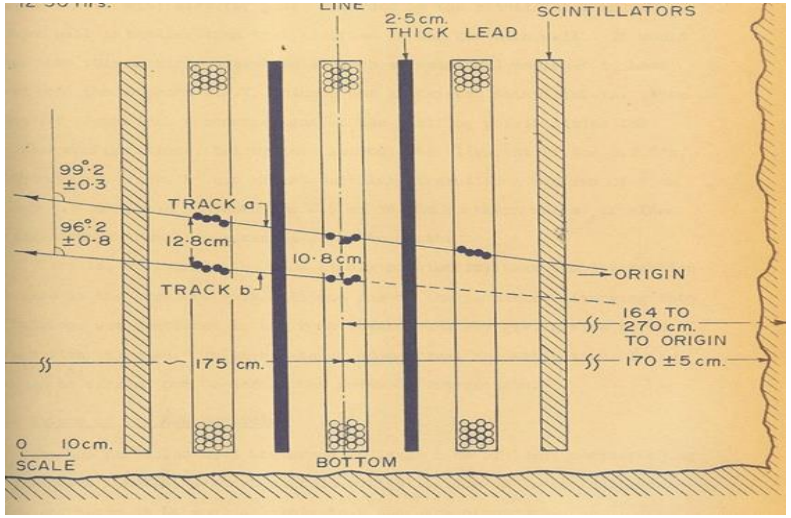
C. V. ACHAR, M. G. K. MENON, V. S. NARASIMHAM, P. V. RAMANA MURTHY and B. V. SREEKANTAN,
Tata Institute of Fundamental Research, Colaba, Bombay

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.

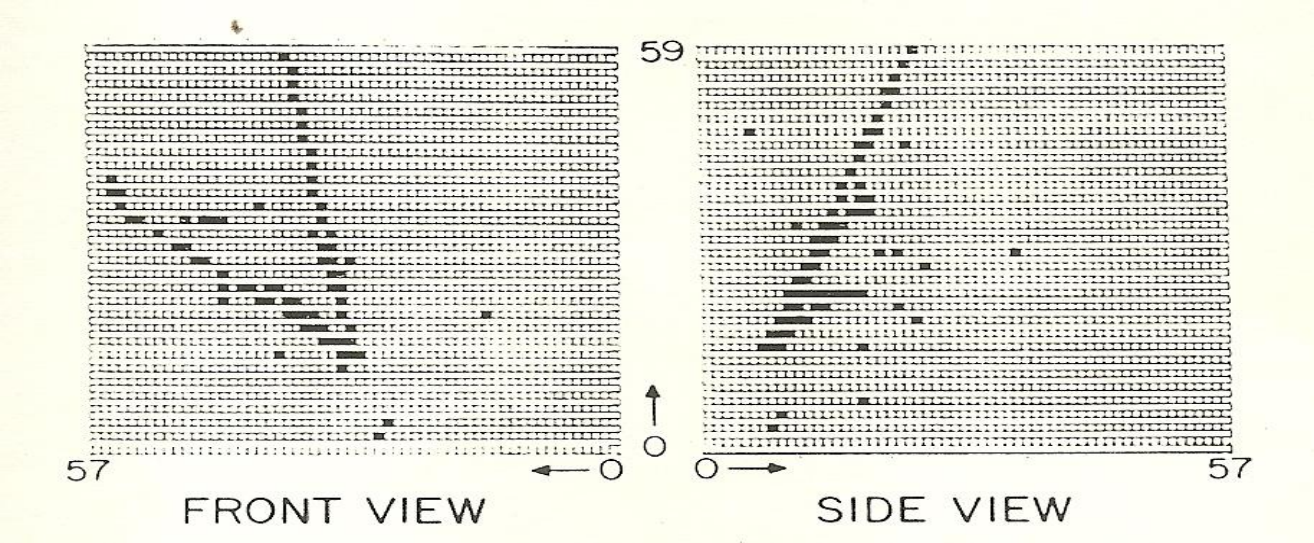
Received 12 July 1965

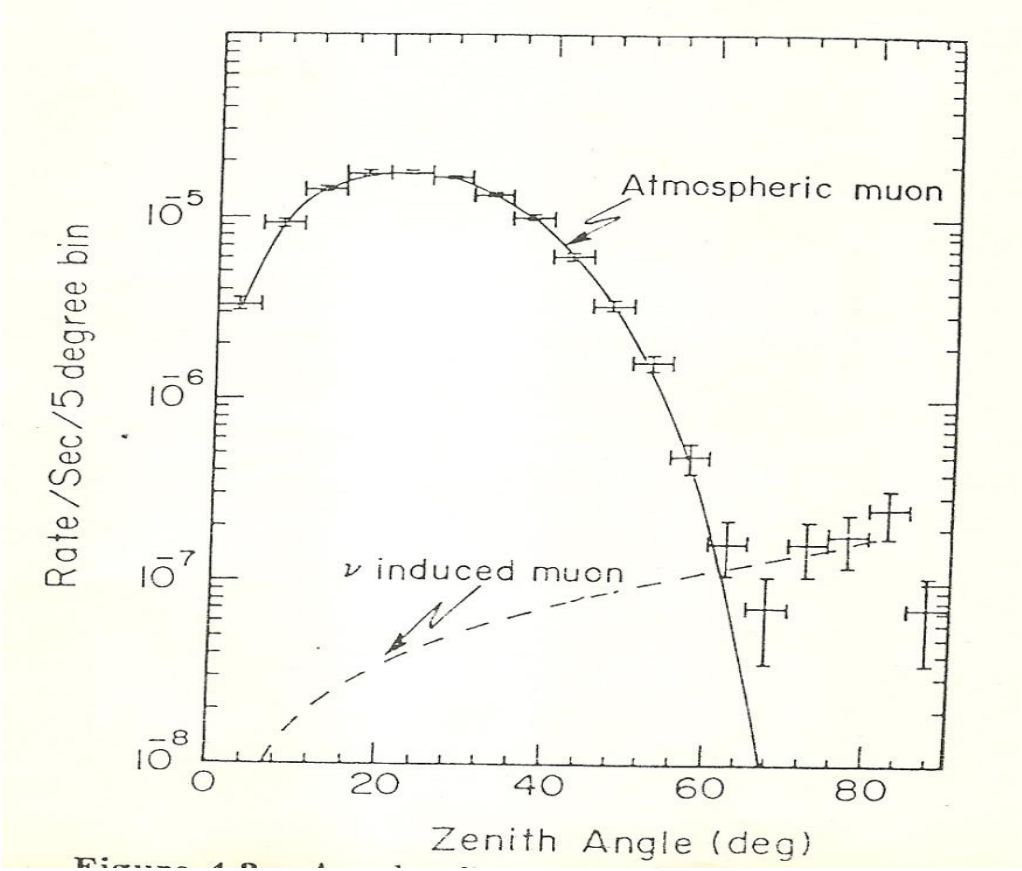
Physics Letters **18**, (1965) 196, dated 15th Aug 1965



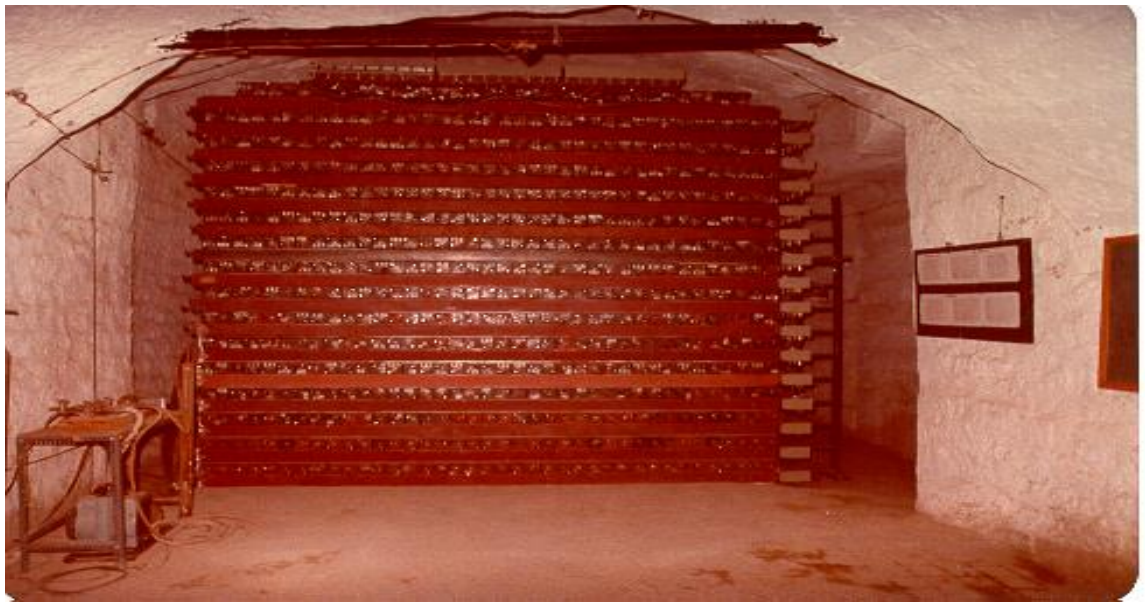
Neutrino Events

Detector depth ~ 2.3 km





KGF Phase-I Nucleon Decay Detector



1. India based Neutrino Observatory (INO)

- First discussed at Workshop on High Energy Physics Phenomenology at Chennai (2000)
- MoU between 6 DAE institutions signed (2002)
- INO Report submitted to Chairman DAE (2006)
- Detailed Project Report on INO site by TNEB (2010)
- MoEF – Govt. of India Environmental Clearance (EC) for Pottipuram site (2010)
- Financial sanction by Central Cabinet, GoI (Jan 2015)
- PILs in Madurai bench of Madras HC, NGT SZ at Chennai (2015)
- Fresh EC from MoEF in March 2018; PIL in NGT Delhi by same NGO
- Awaiting clearances from National Board of Wildlife clearance, TN Pollution Control Board

The INO Collaboration

• INO Collaborating Institutions

Collaborating Institutions:

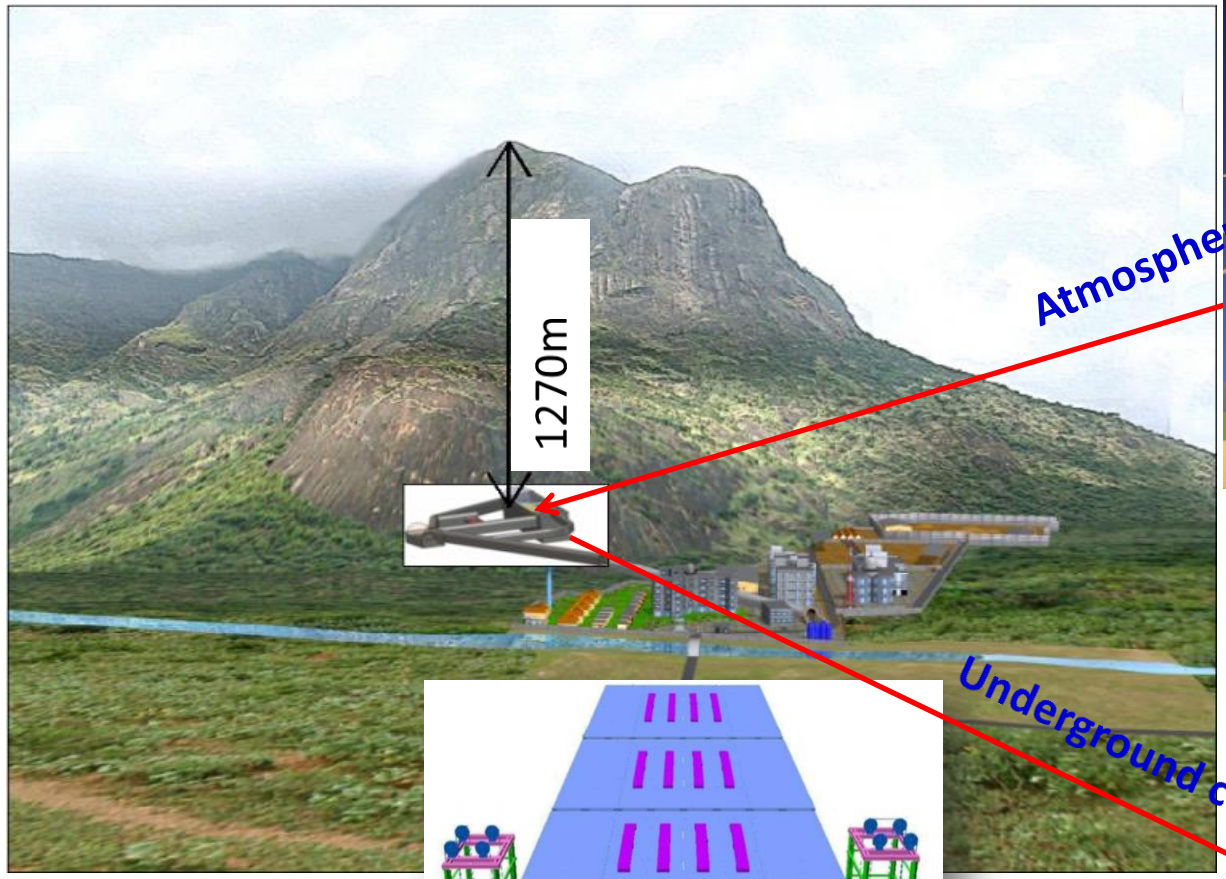
- AMU
- BARC
- BHU
- CU
- DU
- HNBGU
- HPU
- HRI
- IGCAR
- IITB
- IITG
- IITM
- IMSc
- IOP
- JU
- KU
- MU
- NBU
- PRL
- PU
- SINP
- SMIT
- SU
- TIFR
- UoH
- VECC

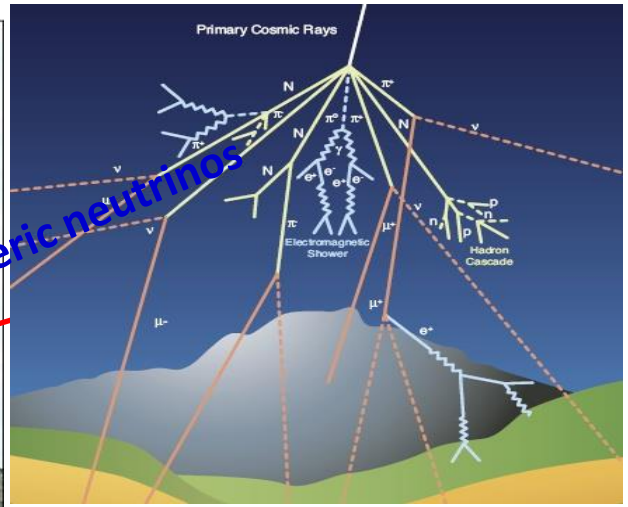
+IISER (Mohali), American College , Tezpur Univ, CKU (Gulbarga)

Participants of the INO Collaboration meeting at Madurai Kamaraj University (22-23 March 2018)

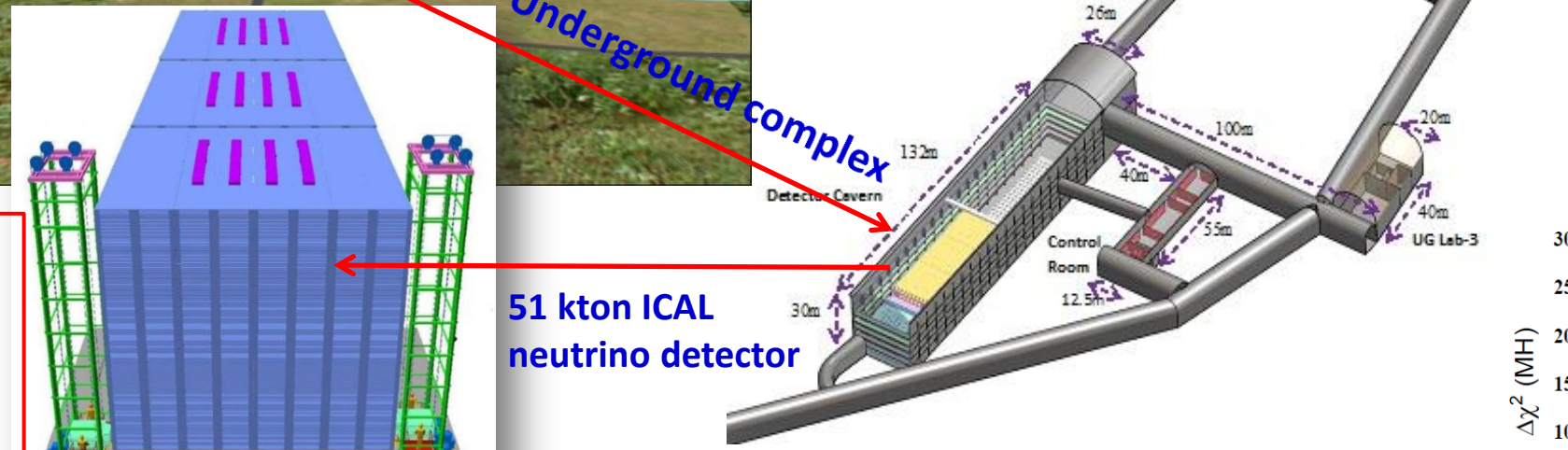
~28 institutions (national labs, Universities, IITs) participating

India based Neutrino Observatory at Pottipuram (Theni)





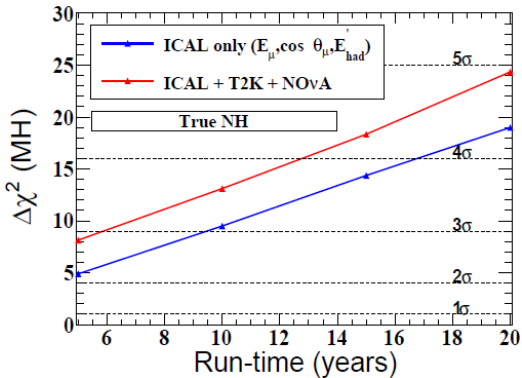
Collaboration of ~28 institutions (research centres, Universities, IITs)



51 kton ICAL neutrino detector

Will be largest electromagnet in the world – 51,000 tons. ~30000 glass RPCs (**×3 world total**)

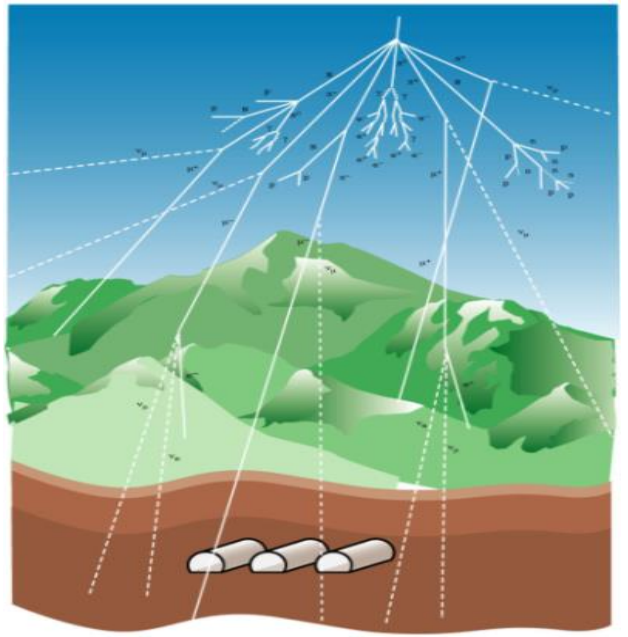
Mass ordering of ν



Experiments planned at INO

- **Atmospheric neutrinos @ ICAL (NH/IH), KGF events**, **MM,** …
- **Neutrinoless Double Beta Decay in ^{124}Sn** using a cryogenic bolometric detector – TINTIN (TIFR led collab.)
- **Dark Matter** search using a cryogenic scintillator for WIMPs - DINO (SINP led collab.)
- **Low energy accelerator for nuclear reaction cross sections ~ Gamow energy** of astrophysical interest (IUC-DAEF + Univ., IIT groups)

Iron Calorimeter (ICAL) detector



- Atmospheric neutrinos – provide a range of energies (E_ν~1-10 GeV) and matter propagation lengths ~ 1 – 13000 kms (**free!**)
- Measurements hitherto did not distinguish between muon **neutrinos** (ν_μ) and **anti-neutrinos** ($\overline{\nu}_\mu$)

ν_μ, $\overline{\nu}_\mu$ *identified via charged current interaction*

$\nu_\mu + n \rightarrow \mu^- + p$, $\overline{\nu}_\mu + p \rightarrow \mu^+ + n$ *an subsequent tracking of muons in B-field*

Physics reach of Iron Calorimeter detector

ICAL will measure atmospheric muon neutrinos and antineutrinos in

Energy range: $1\ \text{GeV} \leq E_\nu \leq 20\ \text{GeV}$

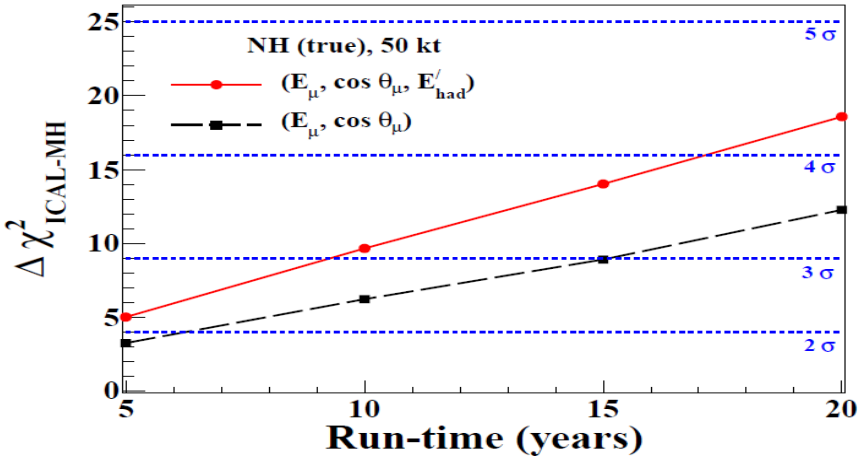
Zenith angles: $0^\circ \leq \theta_\nu \leq 70^\circ$, $110^\circ \leq \theta_\nu \leq 180^\circ$

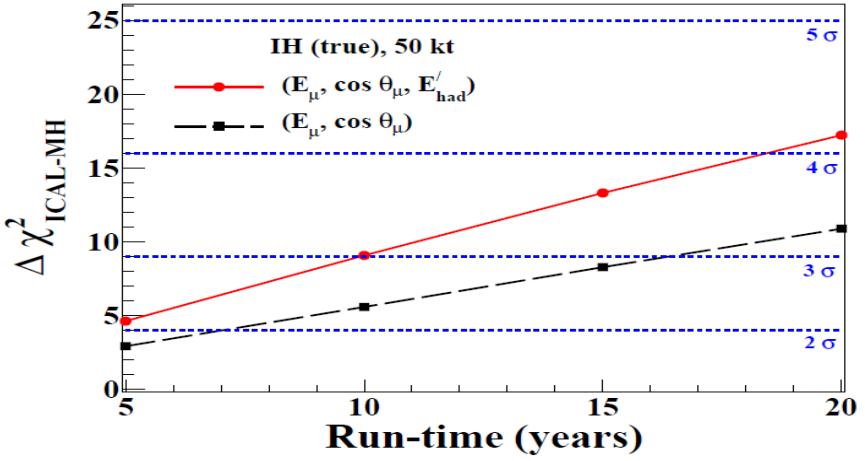
- Neutrino mass hierarchy – normal or inverted
- Neutrino mixing parameters, search for KGF events, magnetic monopole search, DM annihilation in sun, search for sterile neutrinos, NSI…

*White paper on Physics with ICAL : Pramana **88**, 79 (2017)*

Mass hierarchy of neutrinos – sensitivity of ICAL

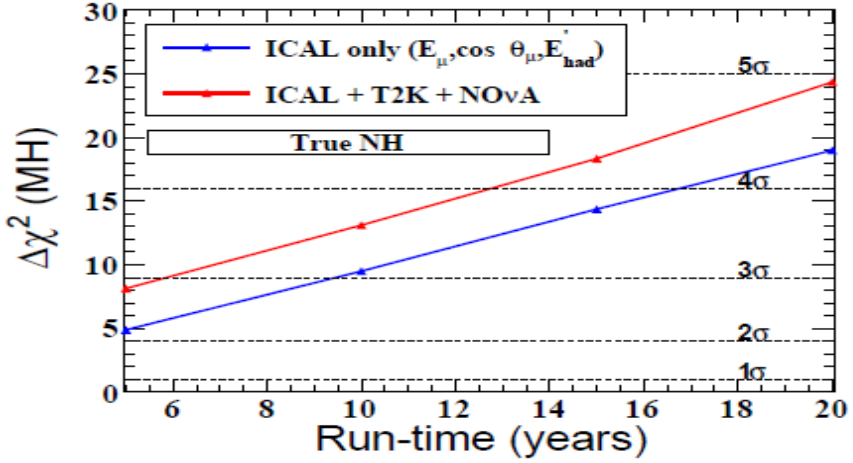
- $m_1 < m_2 < m_3$ (NH) or $m_3 < m_1 < m_2$ (IH) ?
- ICAL can identify mass hierarchy using atmospheric ν_μ , $\overline{\nu}_\mu$
- With accelerator based expts. can help in probing CP violation in ν-sector

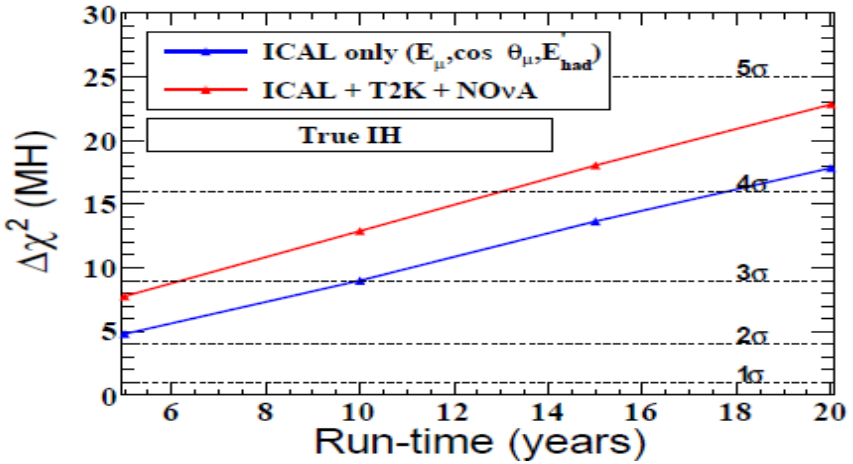




ICAL only

M.M. Devi et al, JHEP **1410**, 189 (2014)





ICAL + T2K + NovA

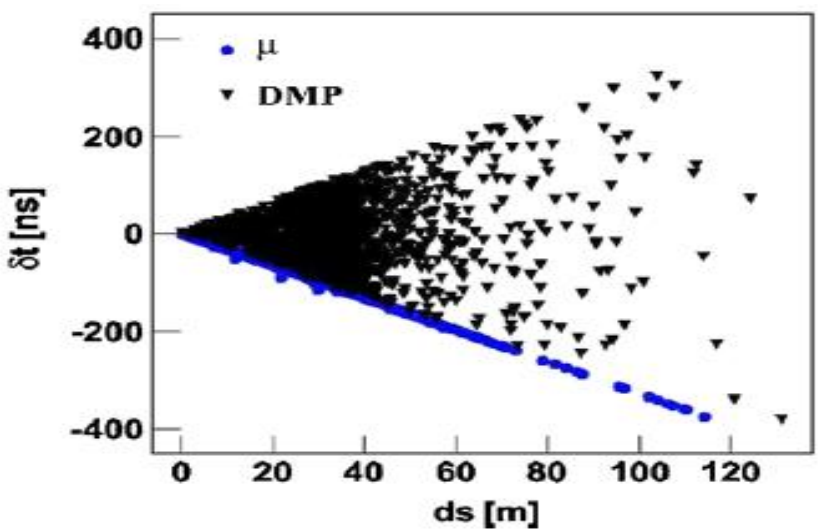
S. Agarwalla et al.

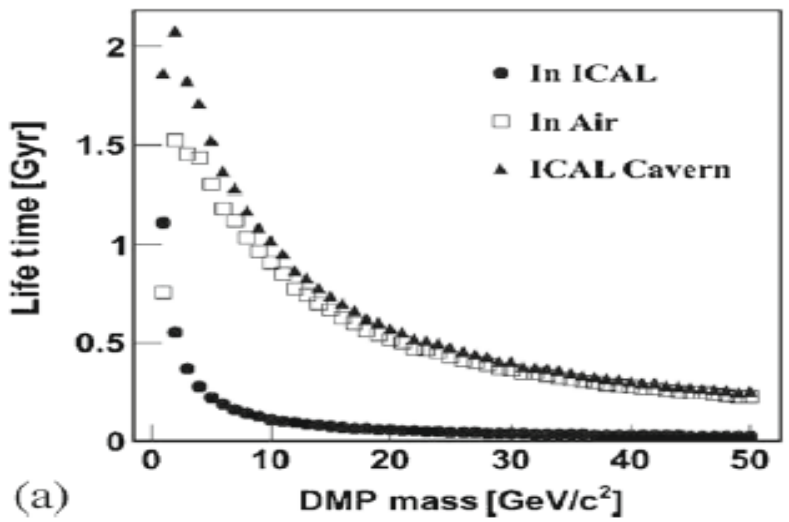
Searching for exotic particles at ICAL: Dark matter (DM) decay to $\mu^+\mu^-$

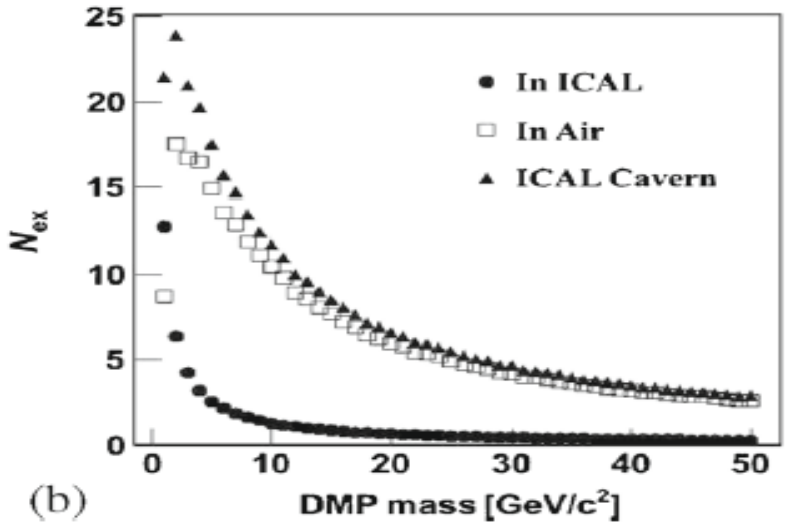
Anomalous events seen at KGF (5 ~1964-1975, 3 ~ 1980-1990) – from decay of light DM (Murthy, Rajasekaran 2014)?

$\Phi_{DM} \rightarrow \mu^+\mu^-$ $M_{DM} \sim 1 - 50$ GeV/c^2 : Sensitivity of ICAL$^+$ studied

However if $\Phi_{DM} \rightarrow \nu_\mu + \overline{\nu}_\mu$ lower bounds on DM lifetime from existing neutrino detectors much more stringent (Signal $\propto \int (4\pi\rho_{DM} r^2/r^2)\, dV$……)

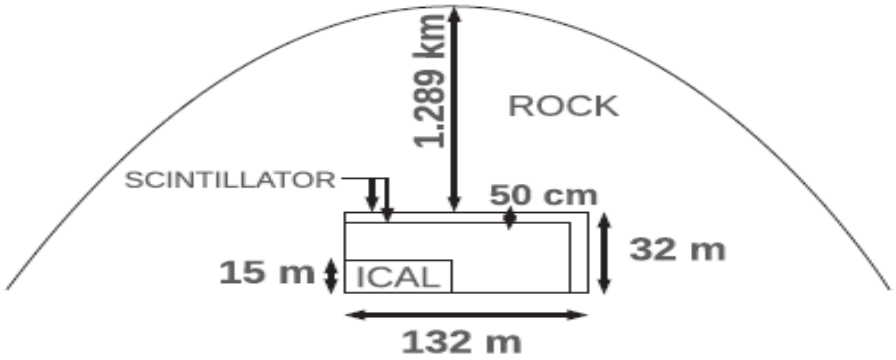


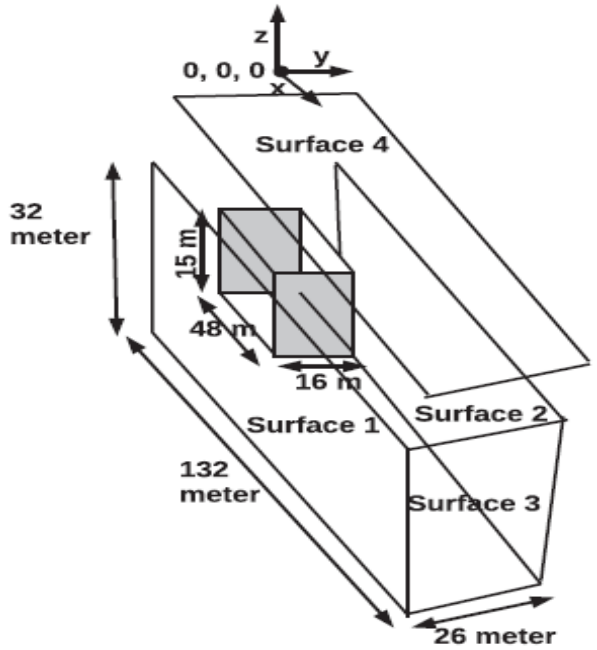


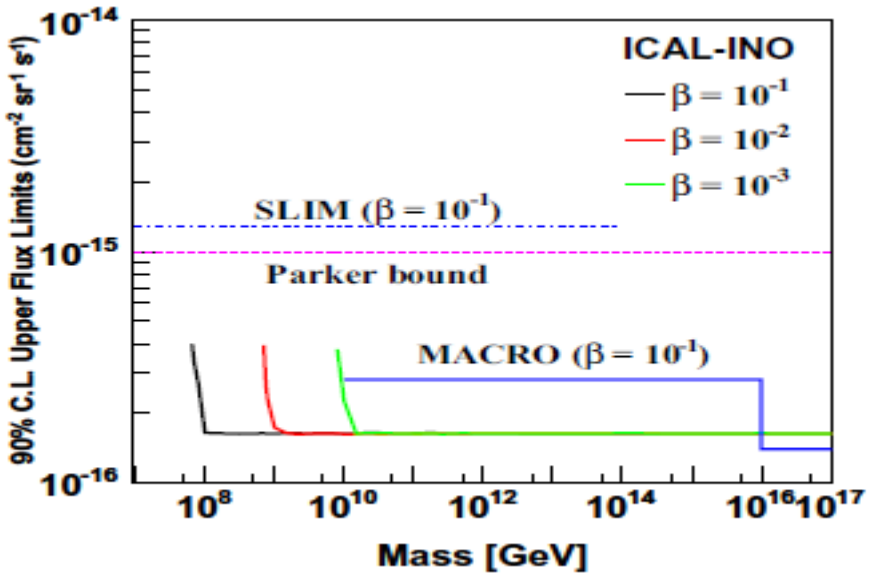


*N. Dash et al., Pramana **86**, 927 (2016)*

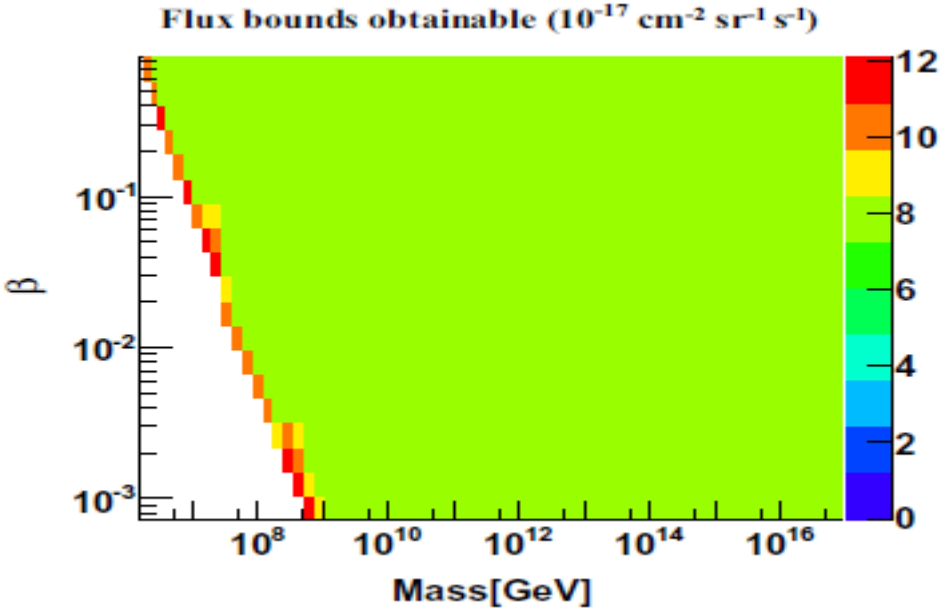
Searching for Magnetic Monopoles using ICAL





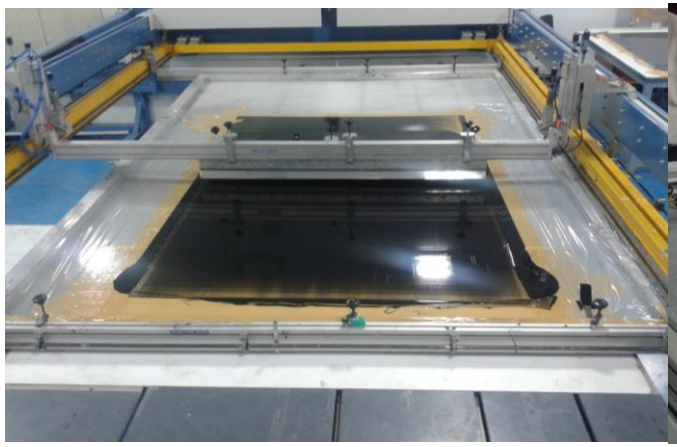


ICAL only

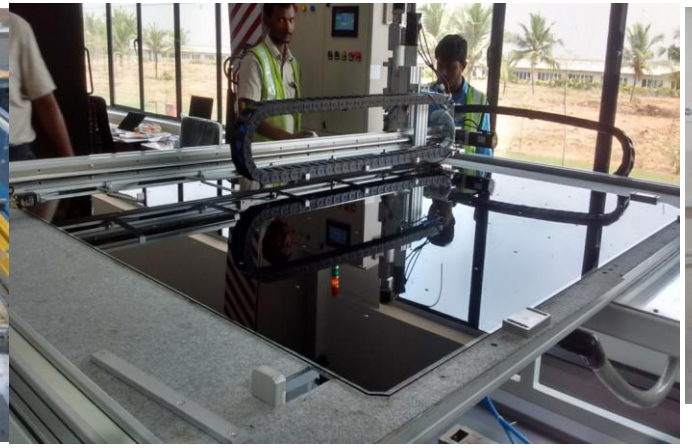


ICAL+

N. Dash et al., Astropart. Phys. ***70****, 33 (2015)*



Screen printing for graphite coating @ St. Gobain, Sriperumbudur)



Gluing spacer buttons with SPM (St. Gobain)

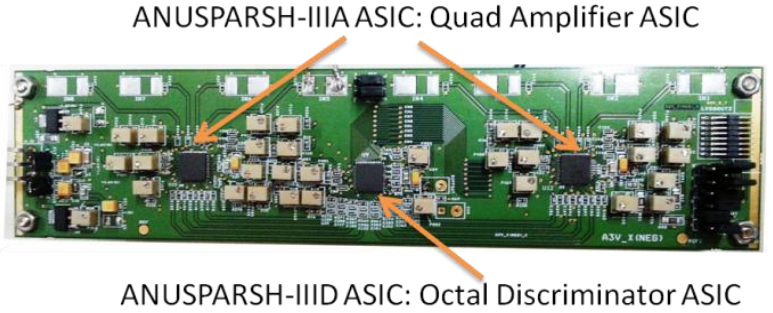
Stand for storing RPCs (IICHEP)

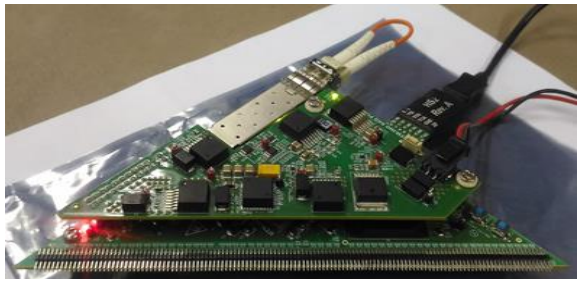
Closed loop gas system

RPC trolley (PCMT, Vellore)

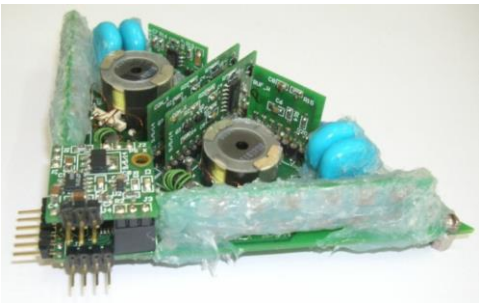
4m×2m steel plates (Essar, Hazira to IICHEP, Madurai) on truck

Inspection of machined steel plate at Essar





Front End RPC, DAQ boards



DC-DC HV supply

INO Graduate Training Programme (affiliated to HBNI, a deemed to be University)

- First batch with 5 students in 2008, now in 11th year (~3-8 students)
- 1 year courses preceding work on PhD thesis problem
- Lectures in morning, lab work on projects in afternoon
- Guides from institutes in INO collaboration affiliated to HBNI or with institutions having MoU with HBNI (IIT-B, IIT-M, JNU….)
- Ex-students doing well (faculty positions, PDFs in good labs)

2. mini-ICAL (80 ton, 4m × 4m × 11 layers of Fe)

- Performance of Magnet: Measured magnetic field (*using sense coils and Hall probes*) vs 3D FE simulation
- Performance over long period of RPC including DC-DC supply, FE electronics in fringe B-field, EMI, closed loop gas system…..
- Feasibility of Muon Spin Rotation (μSR) for information about B-field complementary to sense loop and Hall probe data
- Measure $\Phi(\mu^+)$, $\Phi(\mu^-)$ at Madurai (near equator) and compare with simulation (by Athar, Honda)
- Prototype cosmic muon veto detector for mini-ICAL

mini-ICAL magnet assembly

- Base support structure for 80 ton magnet
- Assembly of 3 ton gantry (max. plate weight 1.4 tons), Δz @ 3.8 ton load
- G-10 sheets on floor on which OFHC Copper “U-sections” placed in 2 sets (for 2 sets of current carrying coils)
- Assembly of magnet plates around “U”s including fixing of Aluminium RPC guide strips (3 nos), field measurement sense coils on layers 1,6, 11, 3mm shims for Hall probe insertion, inter-layer SS spacers, G-10 intra-coil spacers, induction brazing of “C”s and inlet & outlet pipes followed by leak testing at 10 bar

RPC re-assembly

- RPC tray delivery much delayed
- As some of the gaps are considerably smaller than their design value (due to bending of plates) it was decided that existing Al trays will be modified, pickup panels resized and FEE cards repositioned for use in mini-ICAL
- 6 completed trays are placed in mini-ICAL
- Mini-ICAL magnetic field measurements completed on layers 1, 11
- Closed loop gas system for RPCs working as expected
- First muon tracks with 8 RPCs in centre @ I=900A (B~1.4 Tesla) seen on 24/5
- All 10 RPCs expected to be in place by 1 June 2018

Powering up mini-ICAL, magnetic field measurements

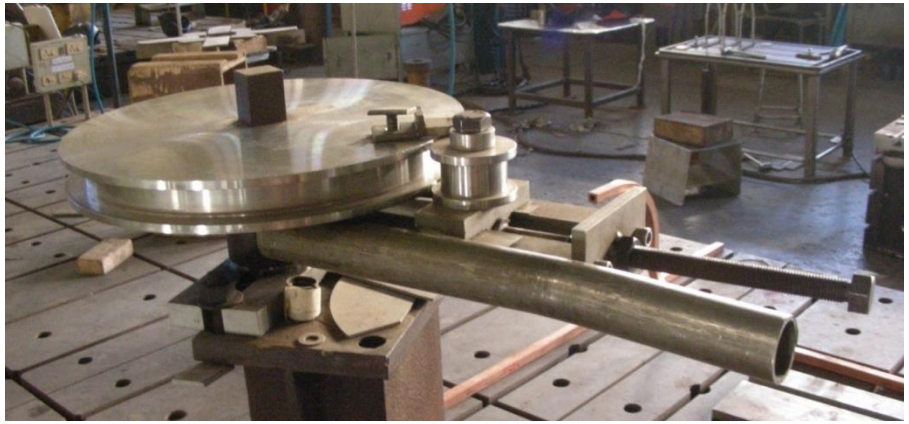
- Low conductivity chilled water circulation system for Magnet PS and OFHC Cu coils of magnet (80 LPS, 8 bar)
- Magnet PS from VECC, Kolkata and set up in its shed (30V, 1500A. linear)
- Multi-core Cu cable ($2\times400mm^2\times$ 45m each way) for MPS-coil connection
- Magnetic field measurement system f rom Pune vendor installed, working
- Electrical power supply modifications completed (control/distribution panel, wiring modifications, earth pits)
- Diesel generator (125 kVA) installation completed
- First measurements with Hall sensors (150 nos) on L1 show B_{max}~1.2 T @900A

Plate machining Job

Spacers and Pins

Copper Conductor Spool

Magnet Components (Core & Coil)



Conductor bending machine

Conductor straightening machine

Coil fabrication

More pictures of mini-ICAL assembly …..

Gantry Crane for plate handling

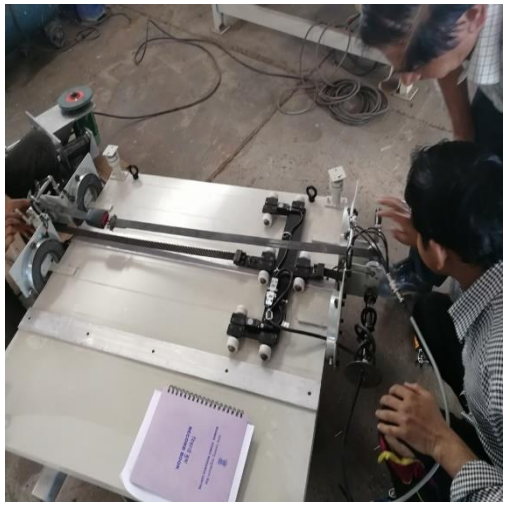
Induction brazing machine

Induction brazing in progress

Associated systems

Brazing joint pressure test

RPC Gap measurement system



Mock-up test set-up

Magnet assembly in progress

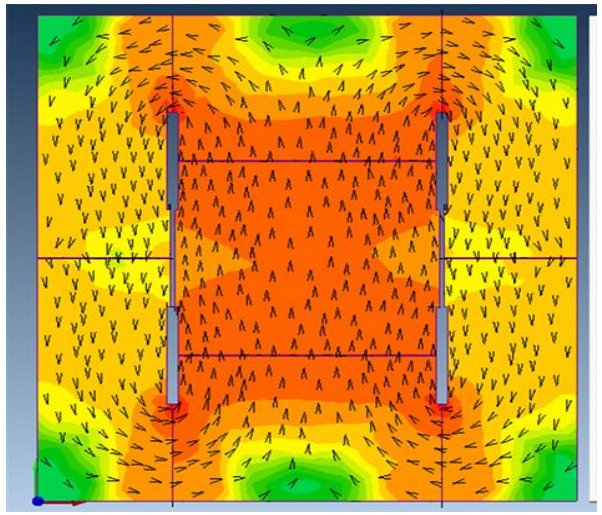
Spacer, Al guide & G-10 bracket

Layers in assembly

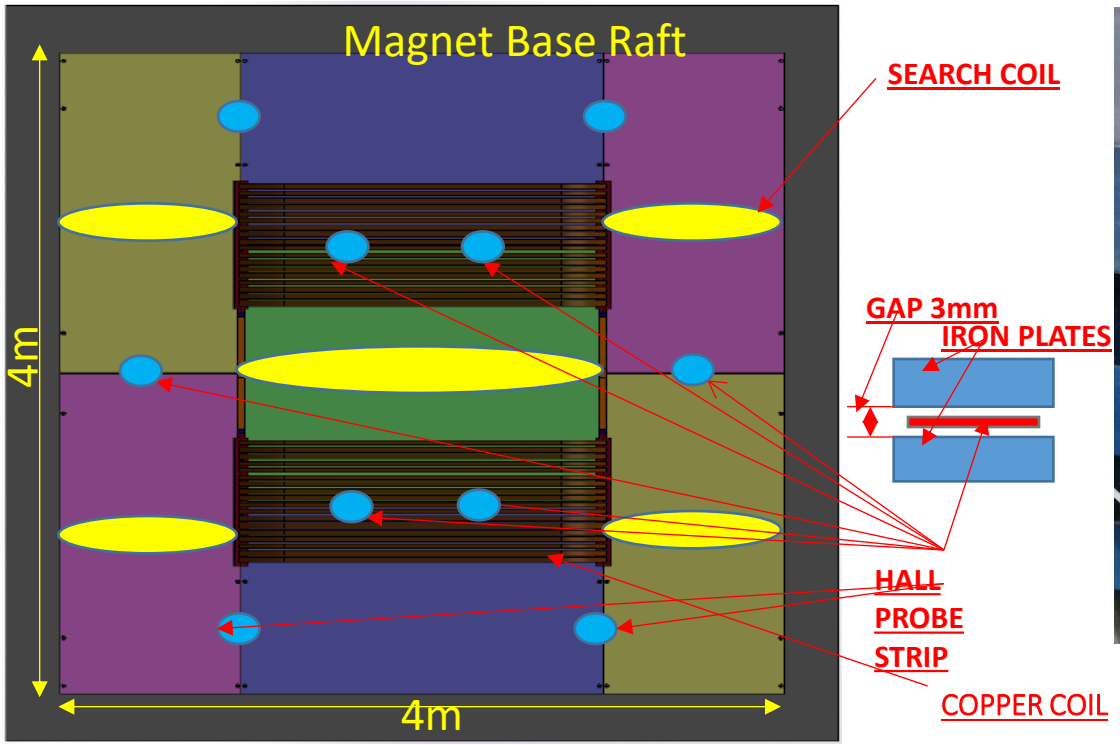
Coil Brazing

Coil hydrostatic pressure test

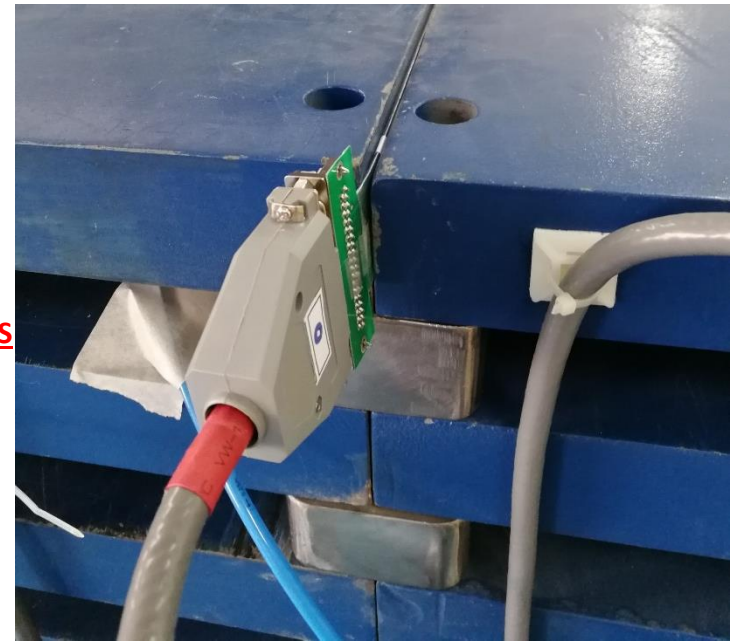
Low conductivity water cooling system for magnet & power supply



Field map at 26kAT



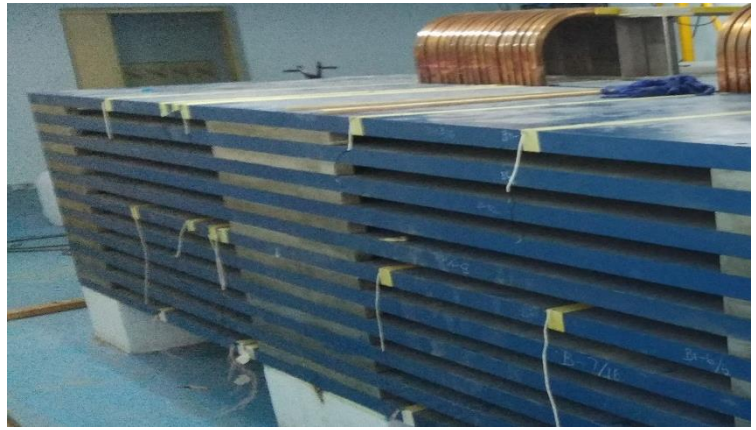
Magnetic measurement system
(1st ,6th , 11th layer)



Hall probe PCB in the gap

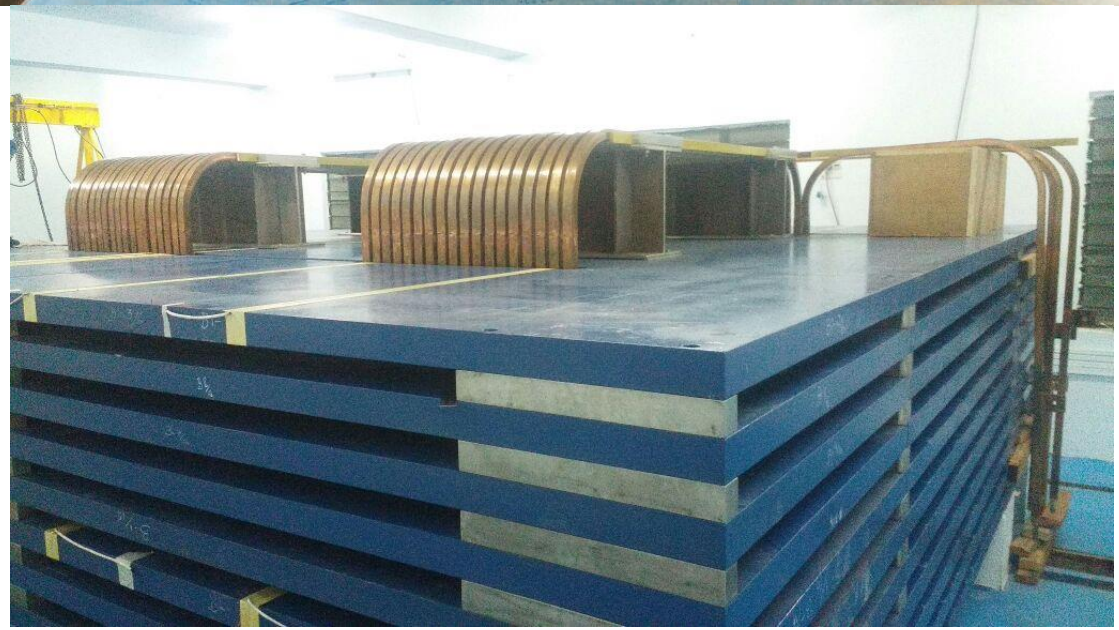
Magnet power supply
30V DC, 1200 AMP

Hall probe PCB strip



Search coils for flux measurement

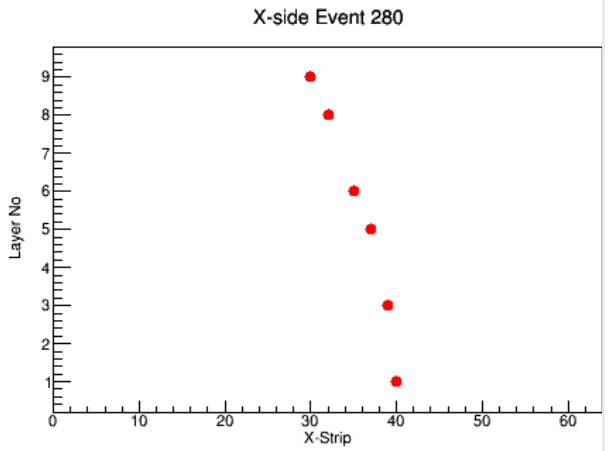
mini-ICAL assembly

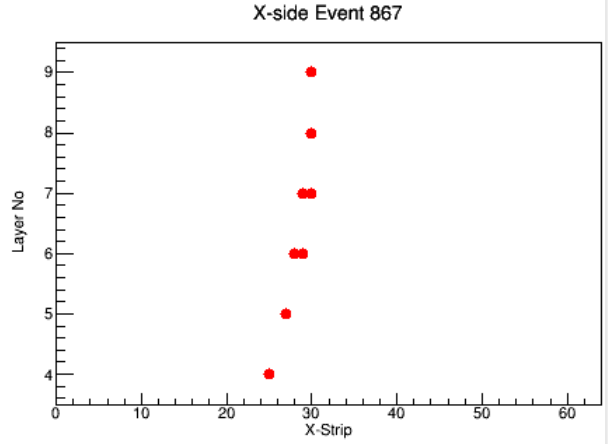


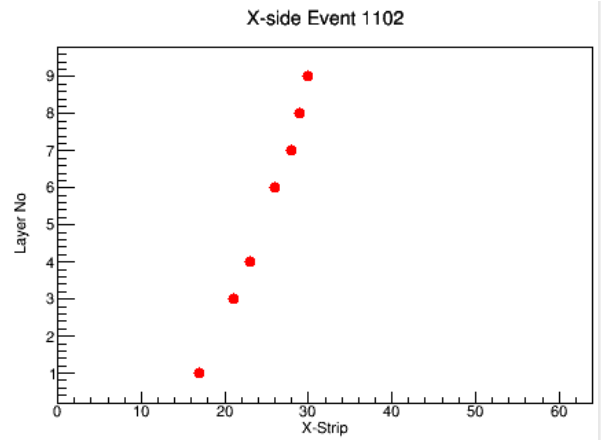
RPC re-assembly

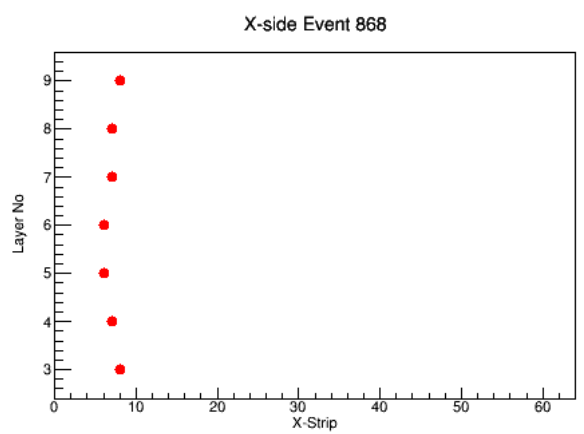
First muons seen in mini-ICAL on 8-5-2018 (6 RPCs on edge)

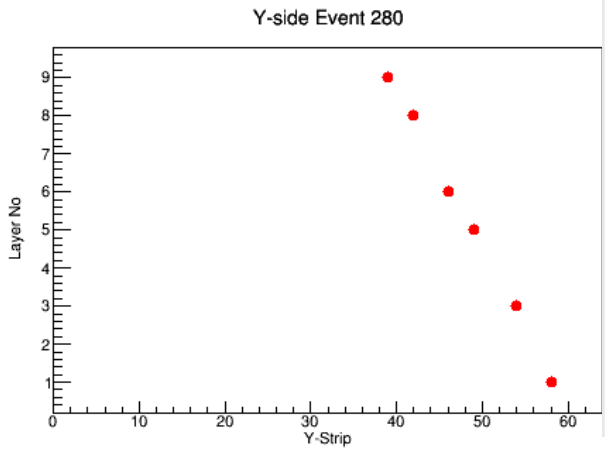
Uncorrected X-Y hit data

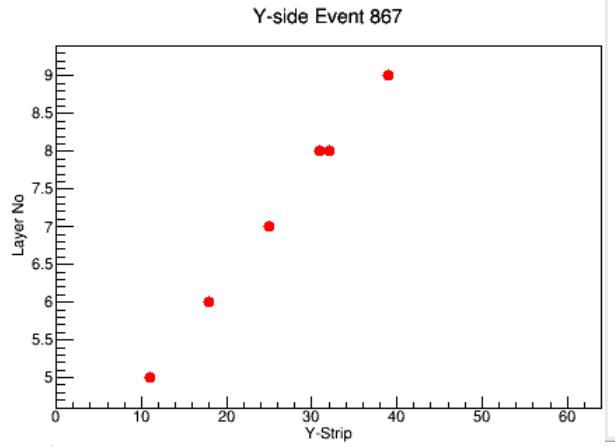


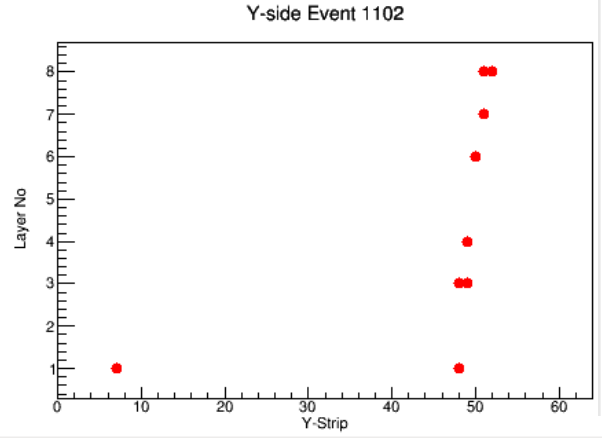


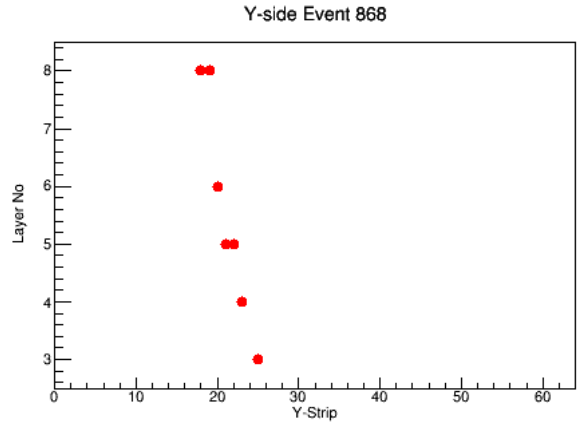






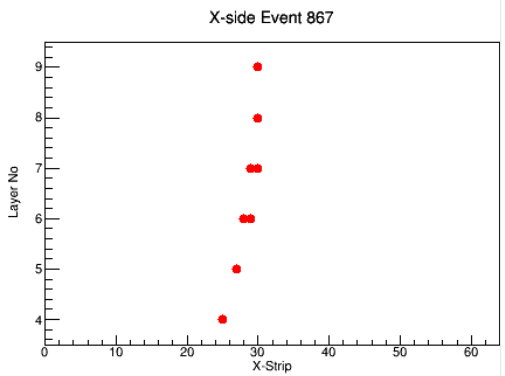


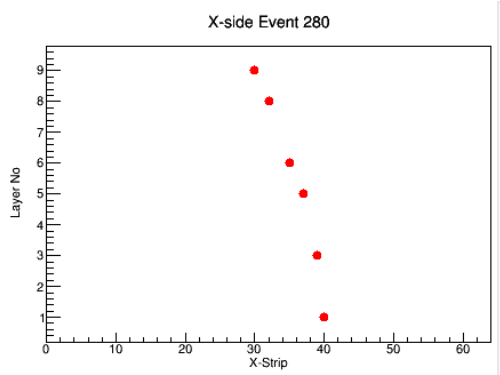


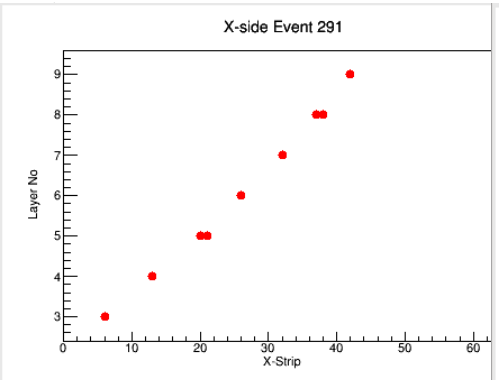


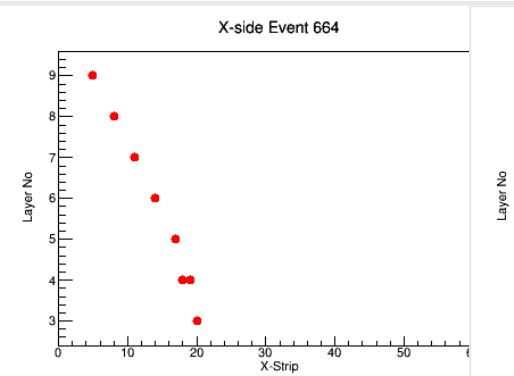
8 RPCs at centre of mini-ICAL (23-5-2018)

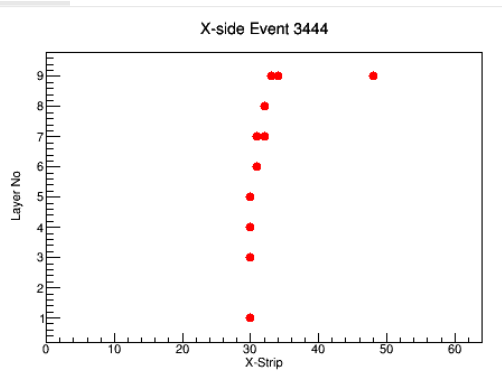
Offset corrected X-Y hit data

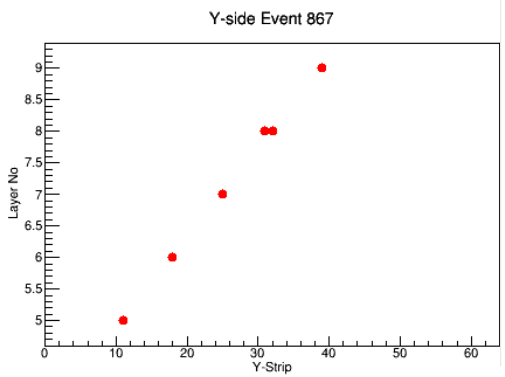


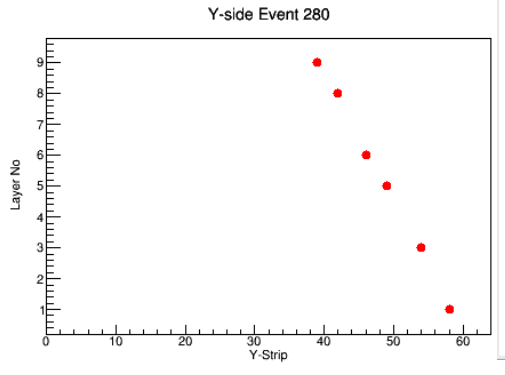


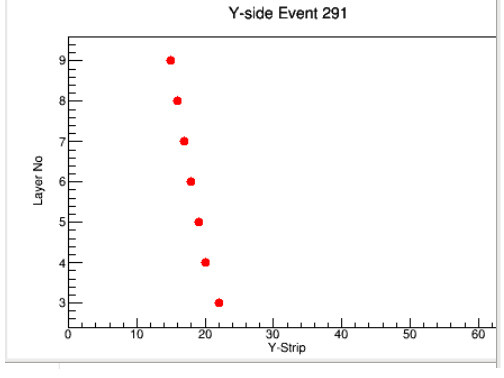


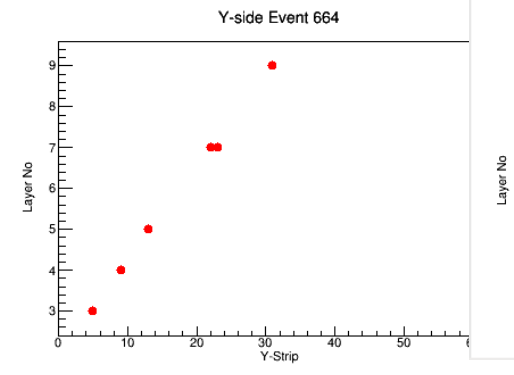


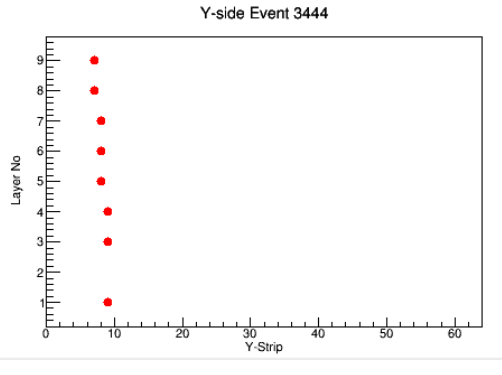












I = 900 A $\Rightarrow$ B ~ 1.4 Tesla

3. Is a Shallow depth ICAL feasible?

Can one overcome the background due to cosmic rays?

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

A cosmic muon veto (CMV) detector with $\varepsilon \geq 99.99\%$ needed

If SICAL at ~100m depth is feasible then

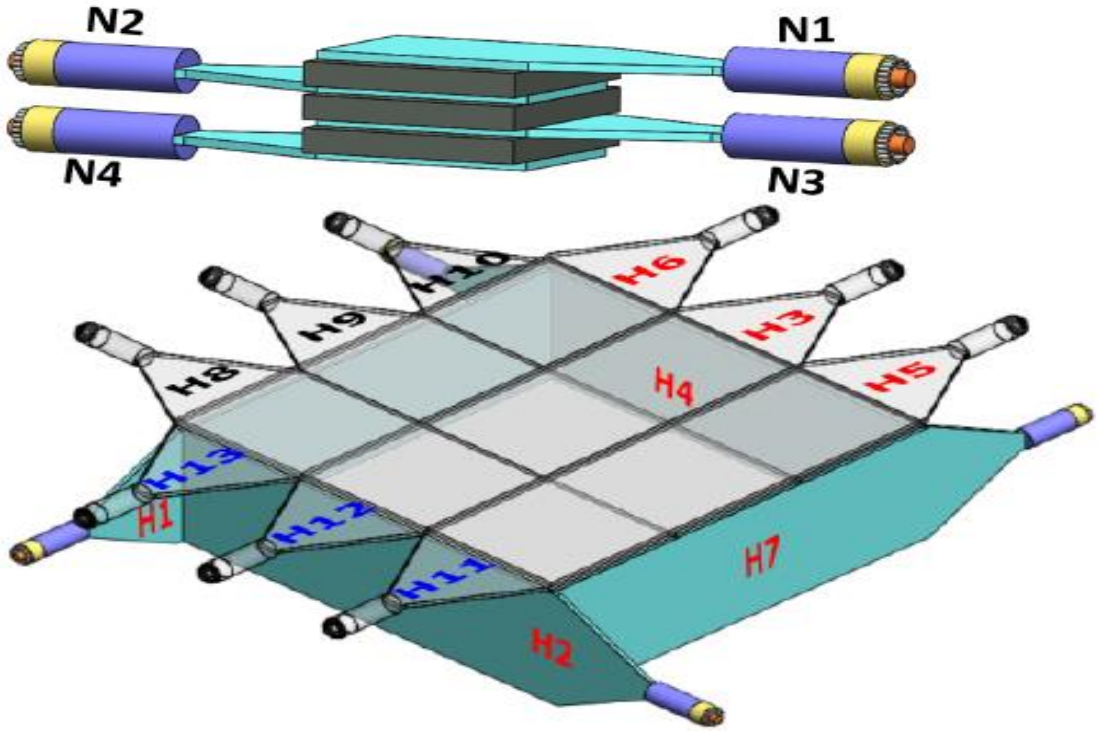
(a) can be sited almost ***anywhere***, access tunnel much shorter, cavern construction faster

(b) Larger caverns so much bigger detectors possible

(c) detector monitoring using cosmic muons

(d) information about B-field via Muon Spin Rotation.

➢ Results from a small (1m × 1m × 0.3m) CMV detector promising



Veto efficiency = 99.978 ± 0.003 %

*N. Panchal et al JINST **12**, T11002 (2017)*

Prototype CMV detector with 3 layers of 1 cm thickness 5m×5m×2m (~2 tons) for mini-ICAL will be built with extruded plastic scintillator (Fermilab), 1.2mm WLS fibre, SiPM and associated electronics

Requirements for CMV detector for mini-ICAL

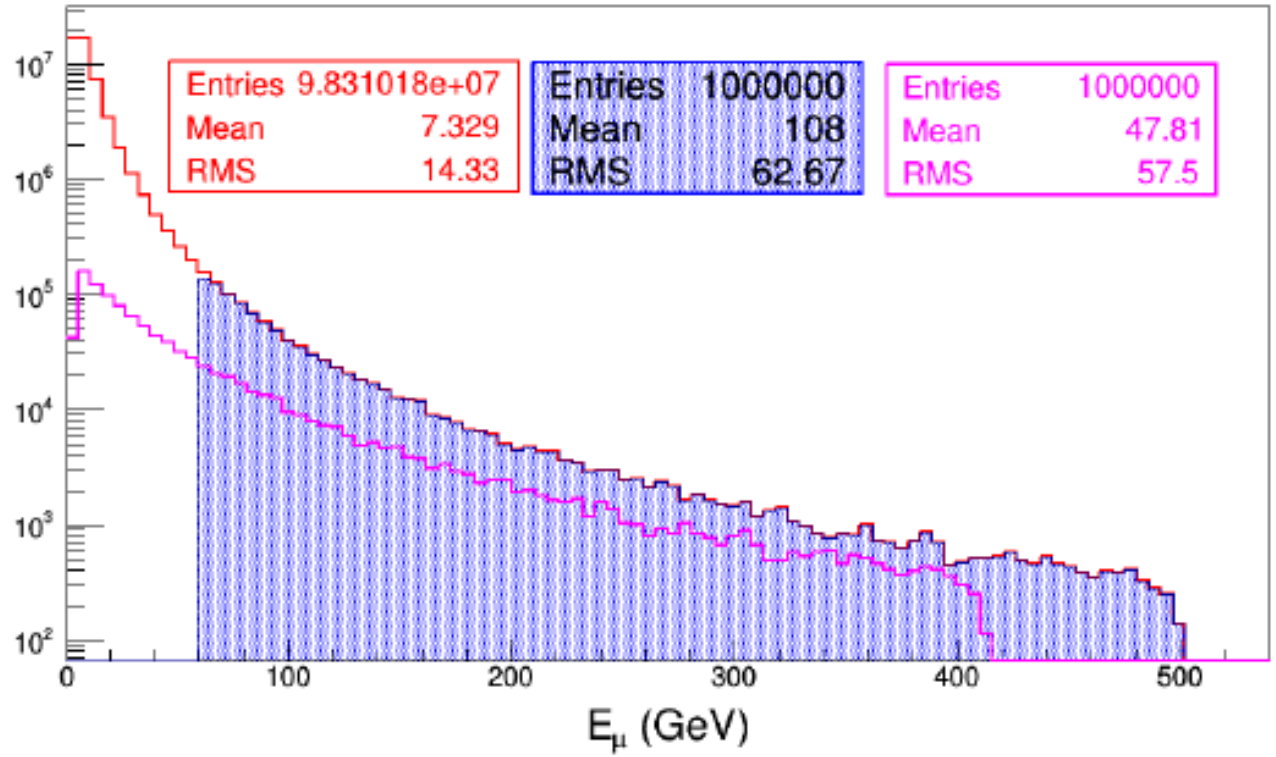
- Size of CMV detector ~ 5m × 5m × 2m
- No. of plastic scintillator (PS) layers : 3
- Extruded PS dimensions: 5cm (W) × 1cm (H) × 5m (L)
- 2 holes at centre 1.4 mm dia, 12.5 mm from side edge
- WLS fibre 1.4mm diameter read out by SiPM at either end
- WLS length ~ 8 km, 3200 SiPMs
- Electronics includes SiPM biasing, fast preamp and gain control

PS to be given at no cost for CMV detector by Fermilab, rest by INO

Quotes for SiPM (Hamamatsu), WLS (Kuraray) received.

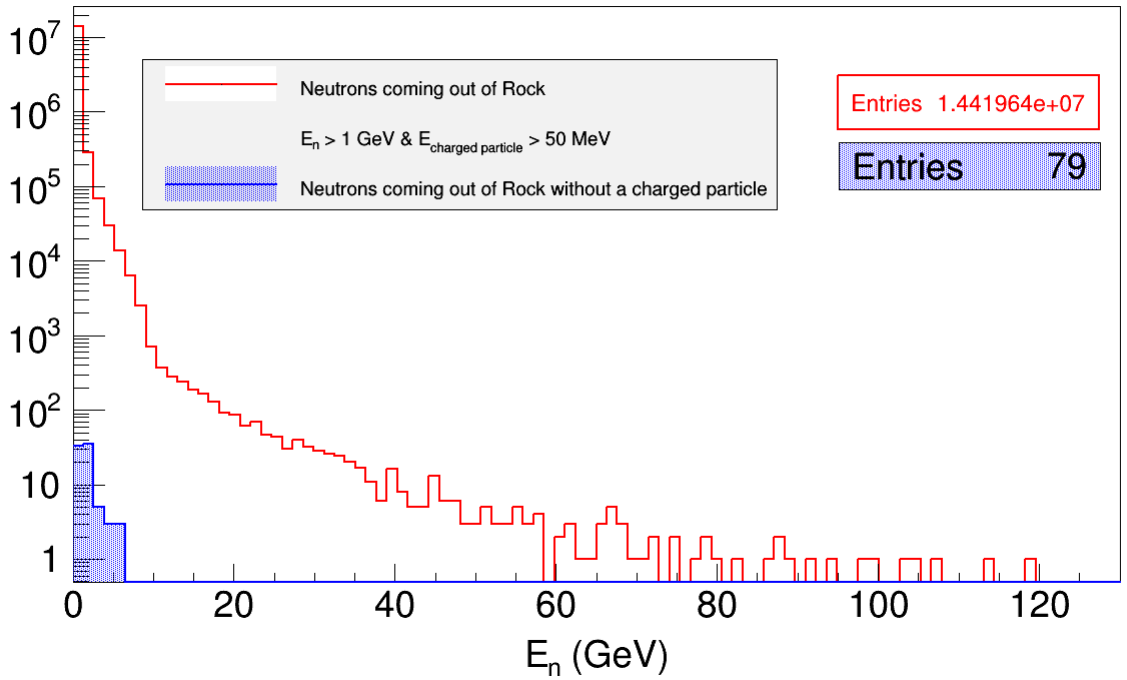
Simulating muon induced neutral particle production in rock (prelim. results)

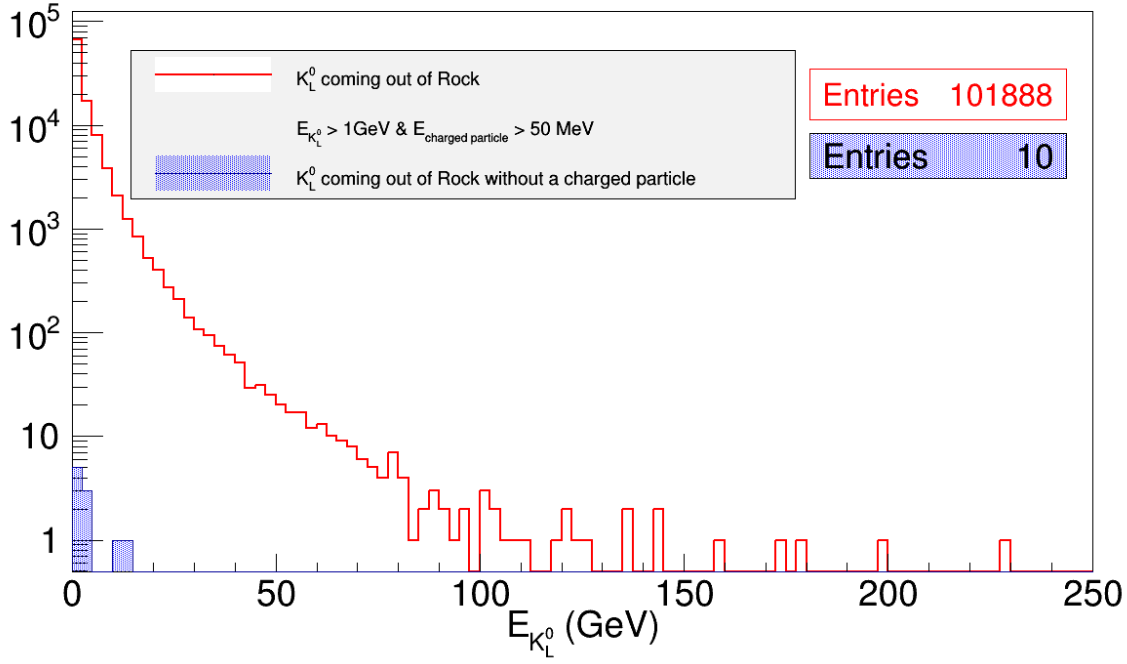
- Cosmic muons (MSL spectrum from CORSIKA) propagated through 100m rock undergoing only energy loss (10^{12})
- In next 3m muons allowed to undergo nuclear interactions ($\sigma_{int} \times 100$) and all particles propagated ($\lambda_{had} \sim 0.3$m) using GEANT4



Particles	Fraction (%)
n	47.8
p	24.5
π^+	12
π^-	11.7
π^0	0.5
K^0_L	0.2
K^0_S	0.3
K^+	0.3
K^-	2.3
μ^+	0.3
Σ^0	0.09
η^0	0.07

Energy spectra of neutrons and K^0_L





Simulation using 10^{10} muons after 100m rock (or 10^{10} at surface, secondaries producing muon track ($\geq$ 5 layers). For ~10^8 muons/day on 100m deep ICAL bkgd events ~0.0023/day, while $N_{atm\ \nu}$ ~ 3/day $\Rightarrow$ Preliminary results show promise!

Have to tackle false vetoes (Thanks Tianlu Yuan) next!

In summary…..

- Pushing for clearances in TN site
- Mini-ICAL close to being set up
- Shallow depth ICAL appears to be promising

Mini-ICAL team members:

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SINP: N.K.Mondal

TIFR: B.S. Acharya, Vishal Asgolkar, Rajkumar Bharathi, Apoorva Bhatt*, Santosh Chavan, S. Dasgupta, V.M. Datar, Upendra Gokhale, Darshana Gonji, S.R. Joshi, Suresh Kalmani, Puneet Kaur, A. Lokapure, G. Majumder, Suryanarayan Mondal*, P. Nagaraj, Neha*, Pathaleswar, S. Pethuraj*, K.C. Ravindran, Mandar Saraf, B. Satyanarayana, Ravindra Shinde, Dipankar Sil, Thoi Salam Singh, N. Sivaramakrishnan, Pavan V., L. Umesh, Suresh Upadhya, Piyush Verma, E. Yuvaraj

VECC: S.K. Thakur, A. Bera, A. Ghosh, Noor Mohamed

Mini-ICAL Design Safety Review Committee of BARC Safety Council for their suggestions

Essar Steel (steel plates), Green & Green (assembly), St. Gobain (RPC gaps), Ferrite India (Pune), BEC (Bhilai), Entech (B'luru) ….

* INO Graduate students

Thank you!

Lesser flamingoes @ mangroves near BARC, Mumbai

Green woodpecker @Corbett National Park