mini-ICAL status and feasibility of shallow depth ICAL

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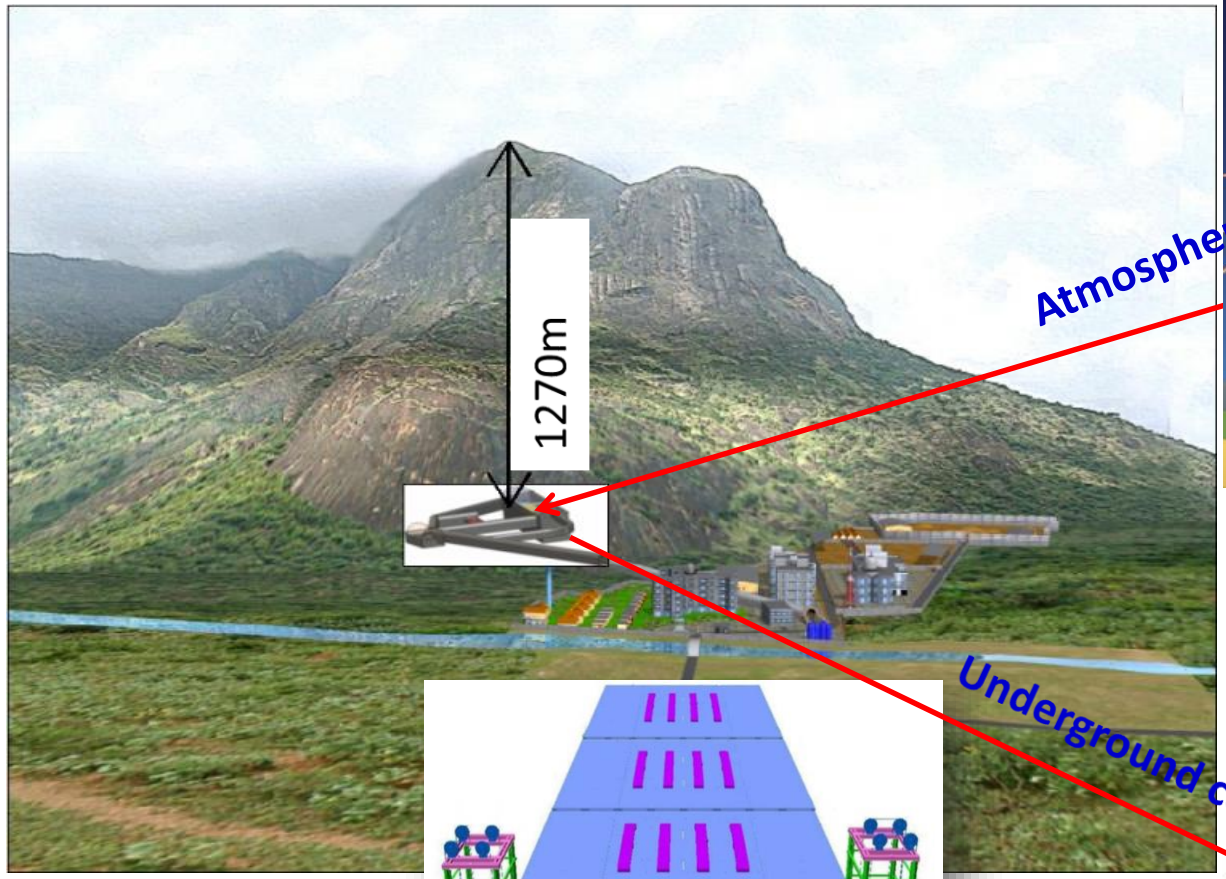
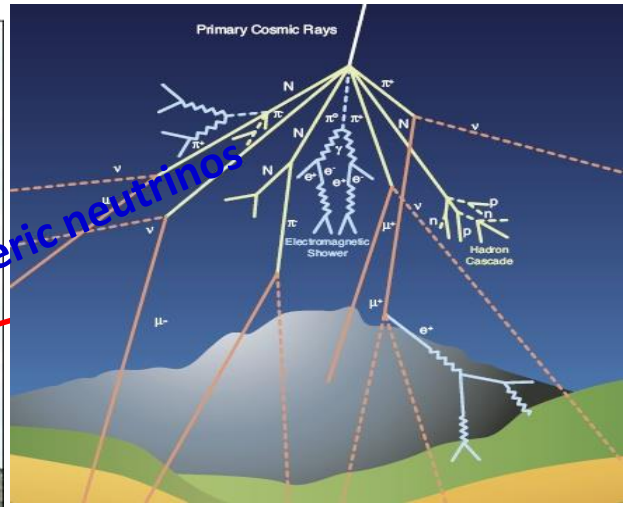
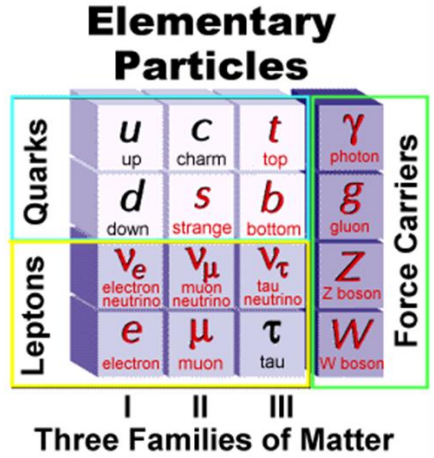
INO Cell

DHEP annual meeting (8-9 May 2018)

India based Neutrino Observatory at Pottipuram (Theni)

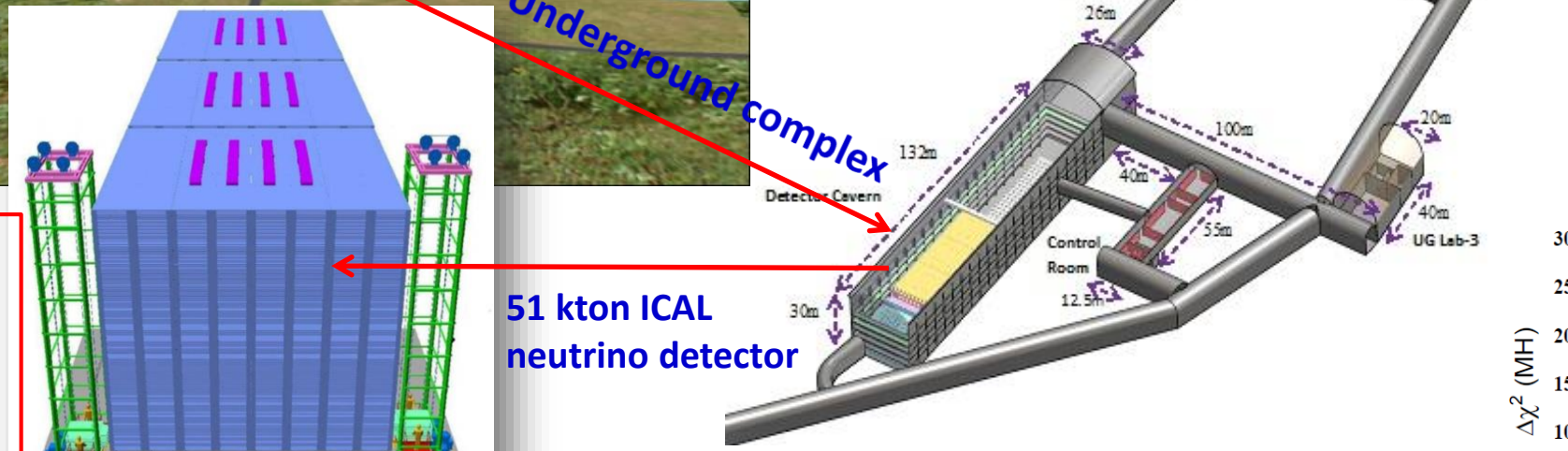




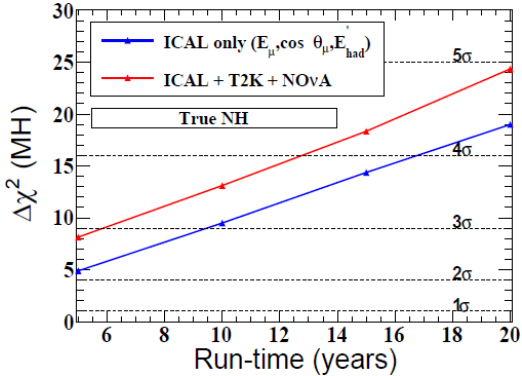


+ H^0

Higgs boson



Mass ordering of ν



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

51 kton ICAL neutrino detector

Why 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 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)
- Proof of principle test of cosmic muon veto detector

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
- After hooking up trigger system , first muon tracks with I=800A seen yesterday
- All 10 RPCs expected to be in place in another week

Powering up mini-ICAL, magnetic field measurements

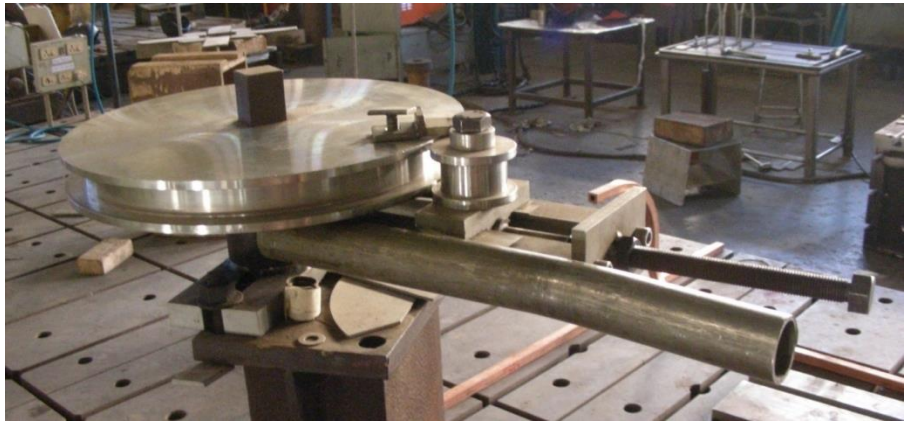
- Low conductivity chilled water circulation system for Magnet PS and OFHC Cu coils of magnet (80 LPS, 8 bar)
- Magnet PS from VECC, Kolkata and set up in its shed (30V, 1500A. linear)
- Multi-core Cu cable ($2\times400mm^2 \times 45m$ each way) for MPS-coil connection
- Magnetic field measurement system from 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 ns) on L1 show B_{max}~1.2 T @800A

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

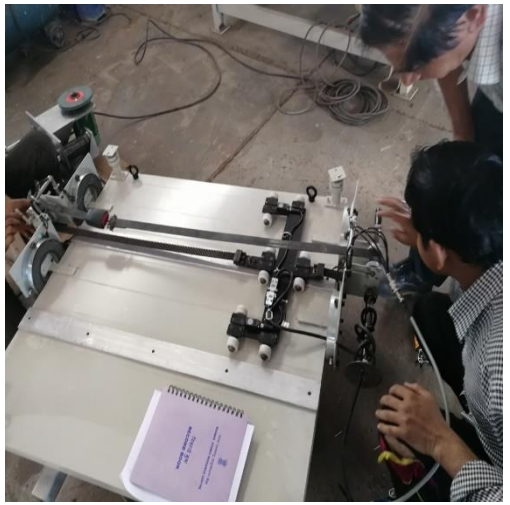
Induction brazing machine

Induction brazing in progress

Associated systems

Brazing joint pressure test

RPC Gap measurement system



Mock-up test set-up

Magnet assembly in progress

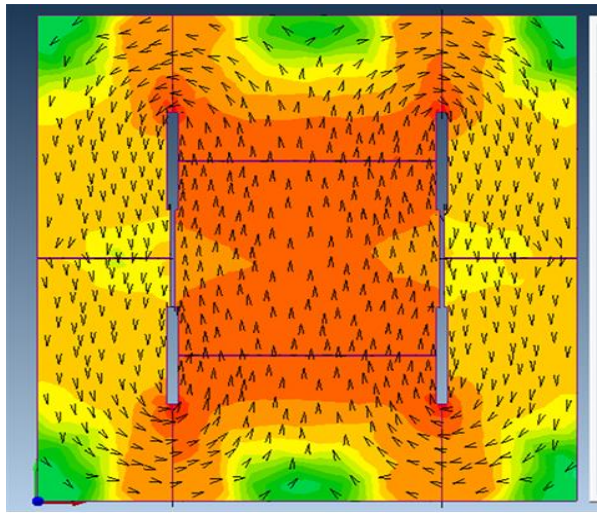
Spacer, Al guide & G-10 bracket

Layers in assembly

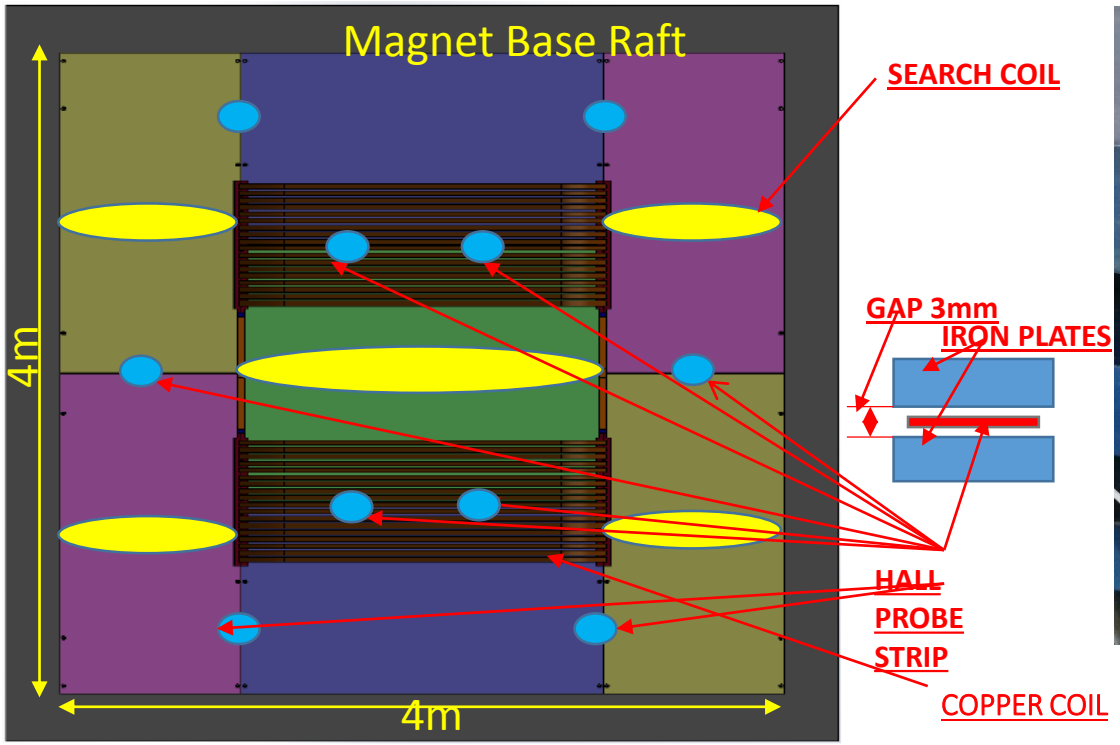
Coil Brazing

Coil hydrostatic pressure test

Low conductivity water cooling system for magnet & power supply



Field map at 26kAT

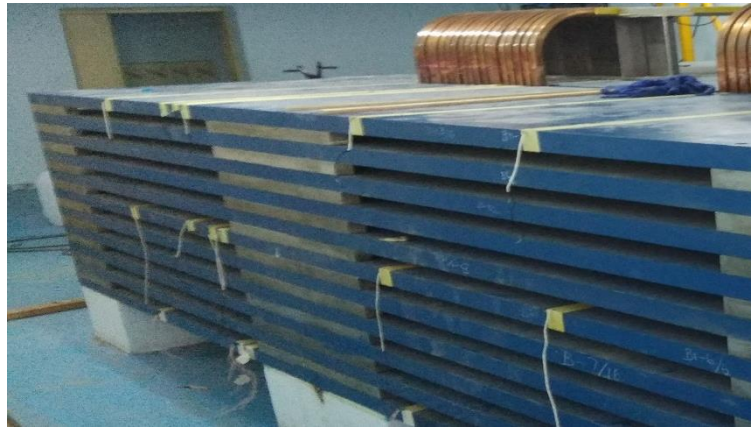


Magnetic measurement system
(1st ,6th , 11th layer)

Hall probe PCB in the gap

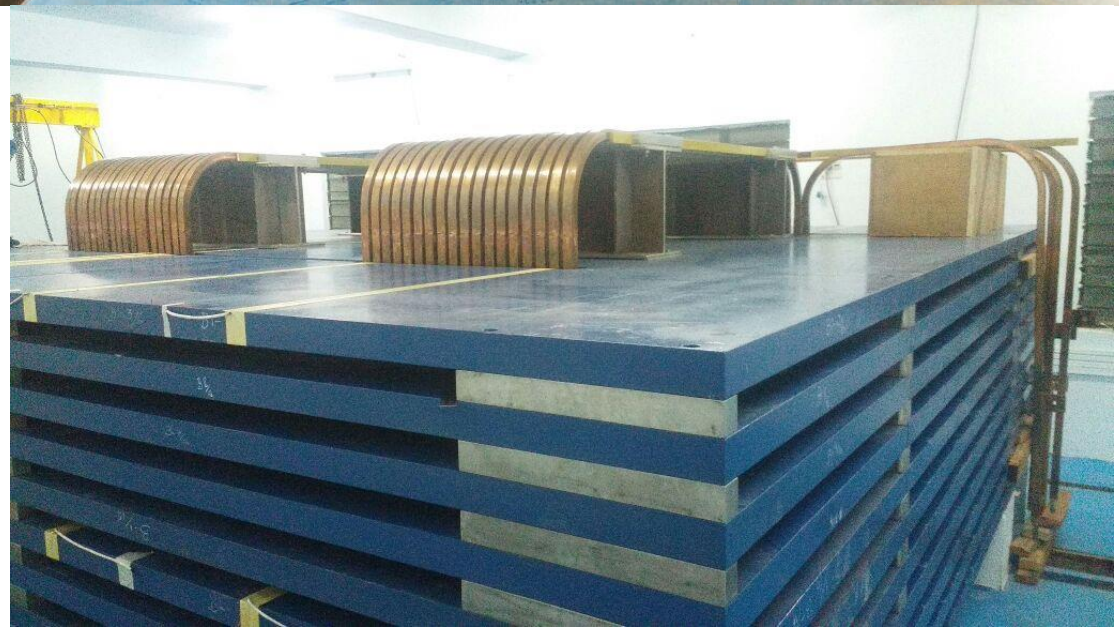
Magnet power supply
30V DC, 1200 AMP

Hall probe PCB strip



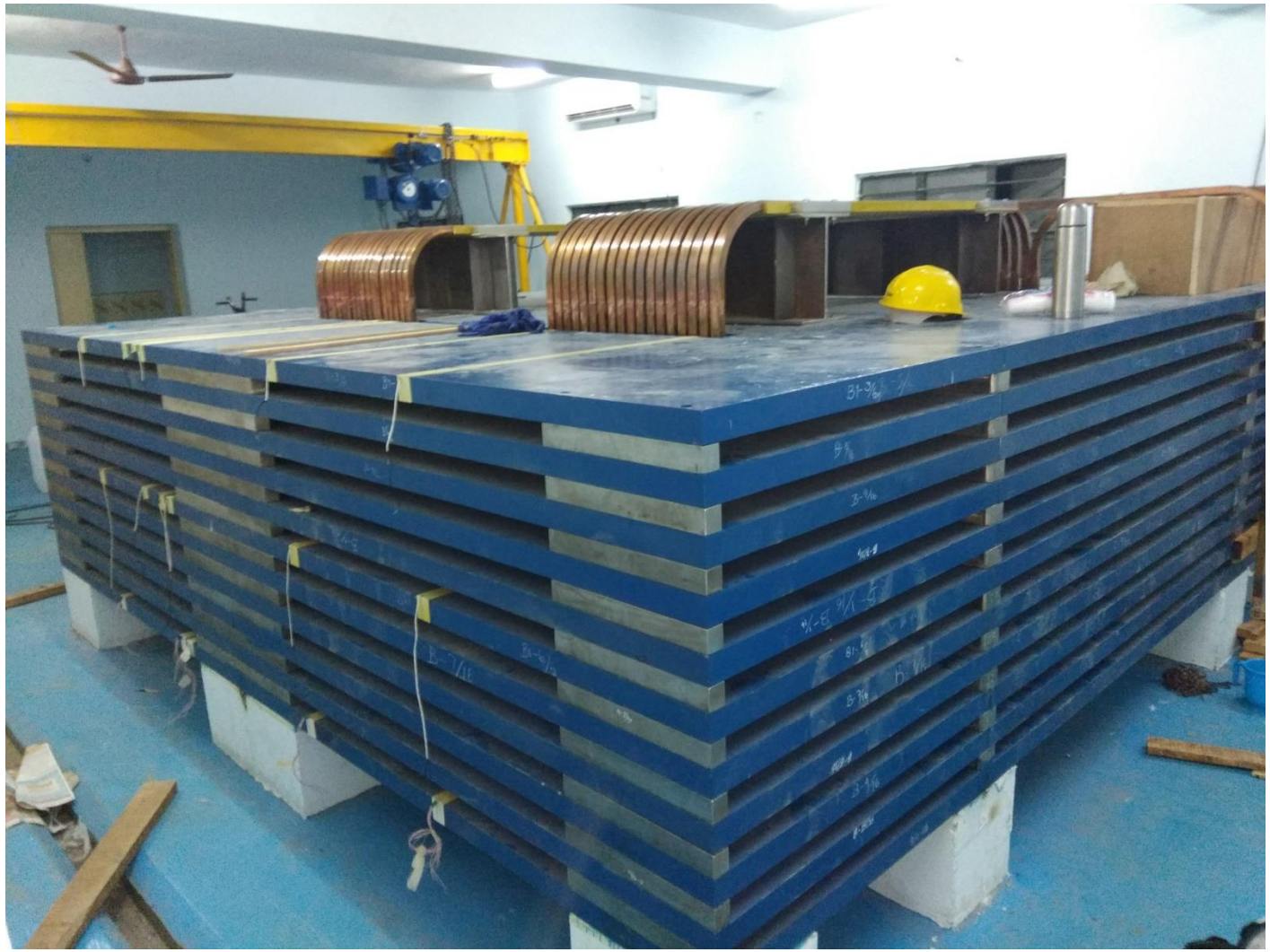
Search coils for flux measurement

mini-ICAL assembly



RPC re-assembly

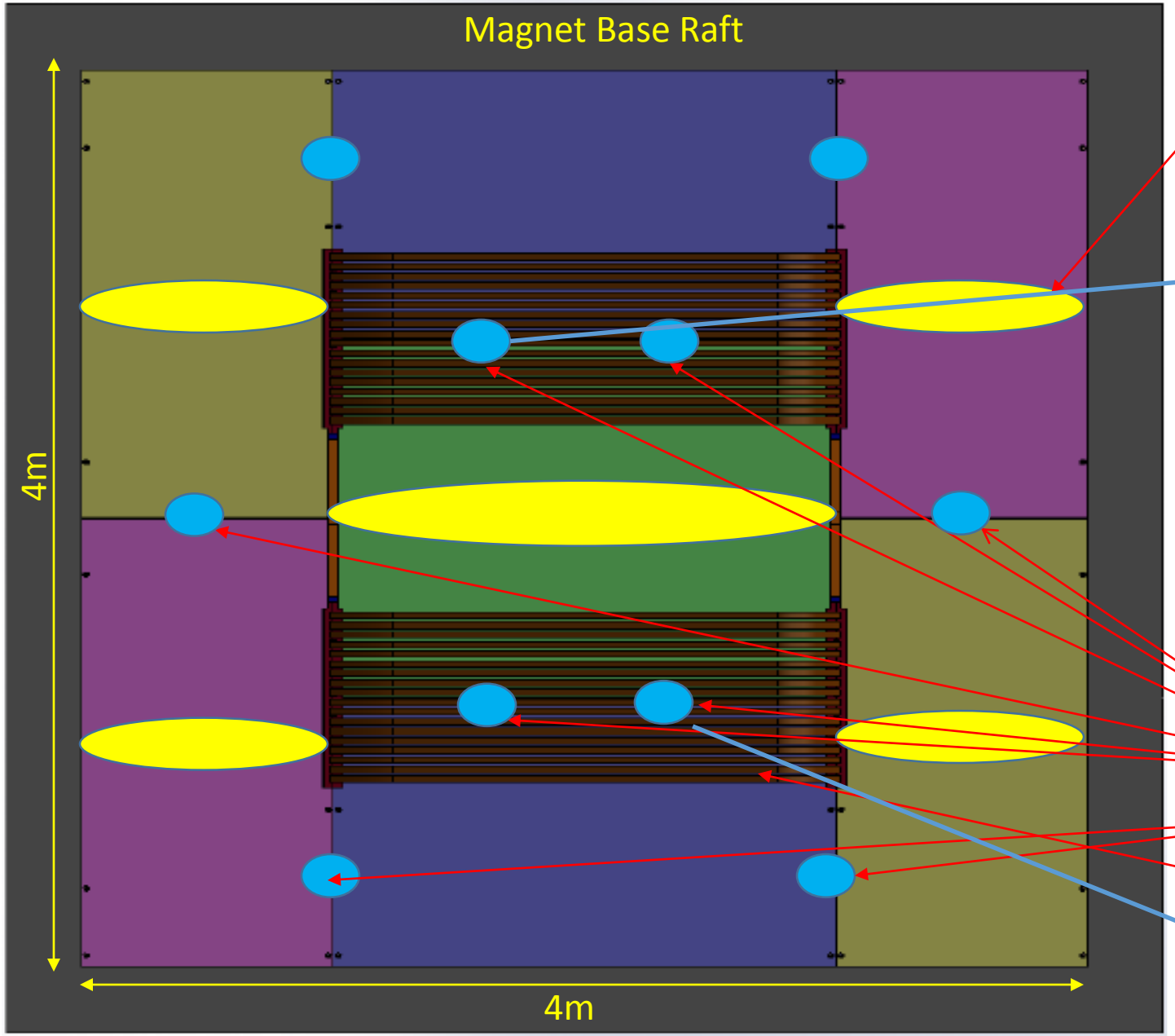
Magnetic Measurement System



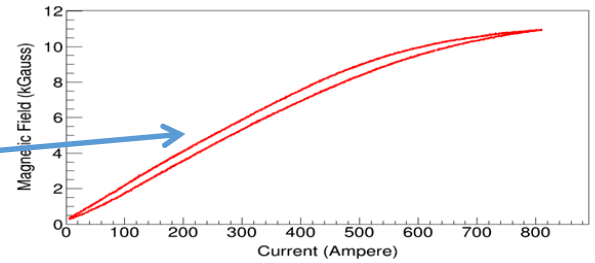
Search coils wrapped on 1st , 6th & 11th layer

Magnetic Measurement System

Mini-ICAL hall entry door

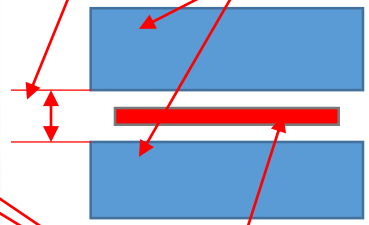


SEARCH COIL



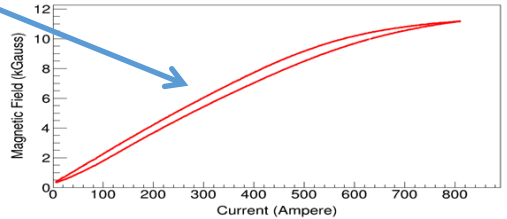
GAP 3mm

IRON PLATES



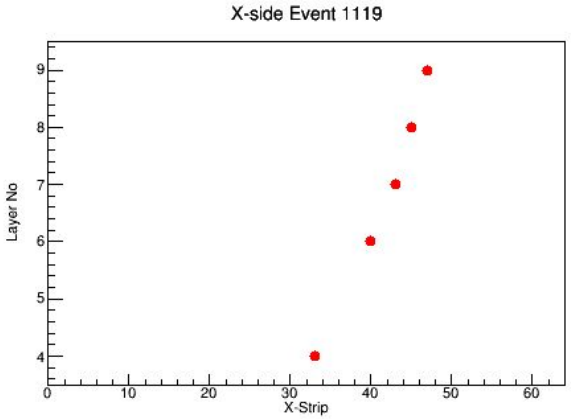
HALL PROBE STRIP

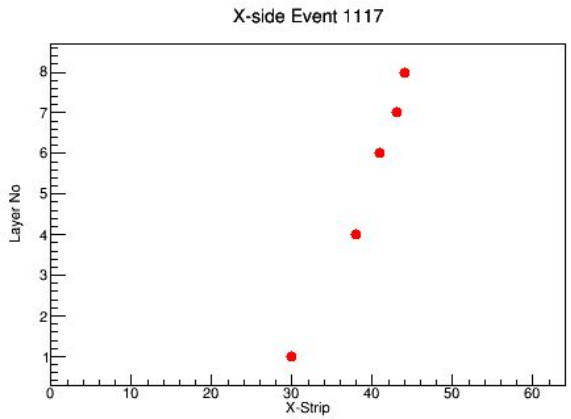
COPPER COIL

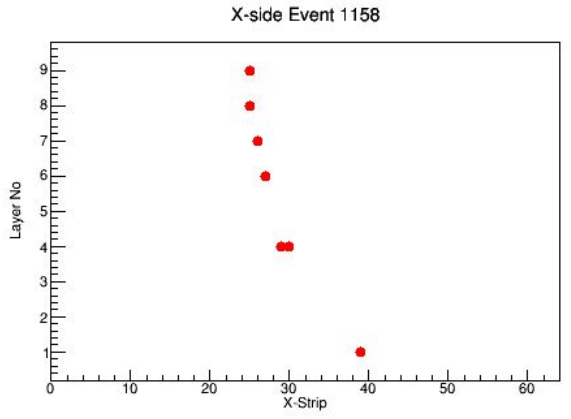


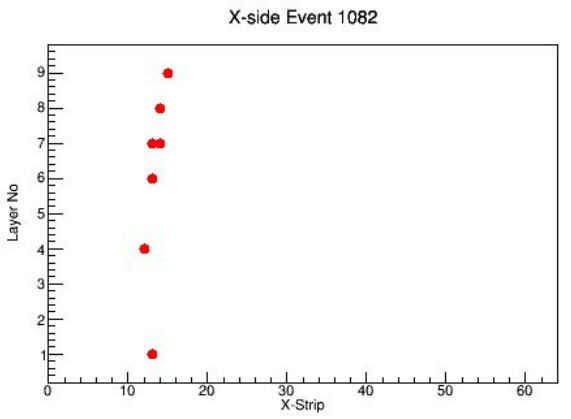
Positional view for search coil & Hall sensors

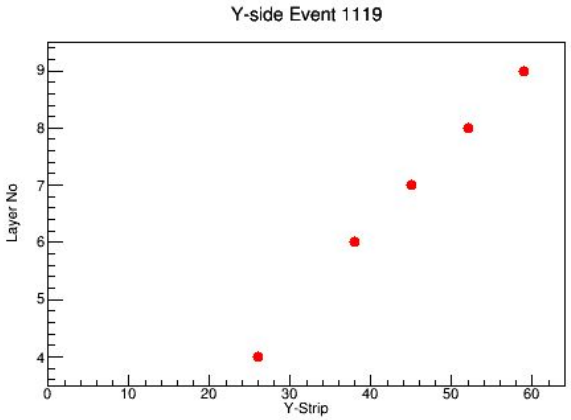
First muons seen in mini-ICAL (18:46 hrs, 8-5-2018)!

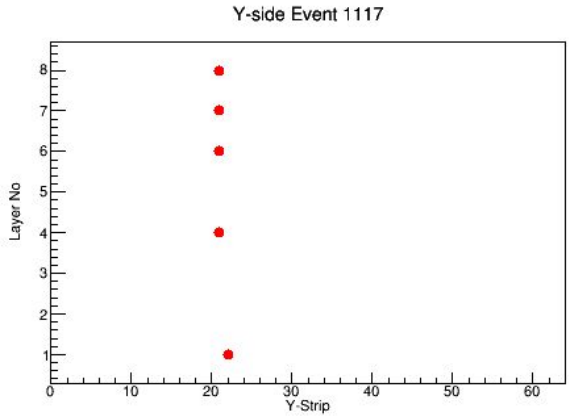


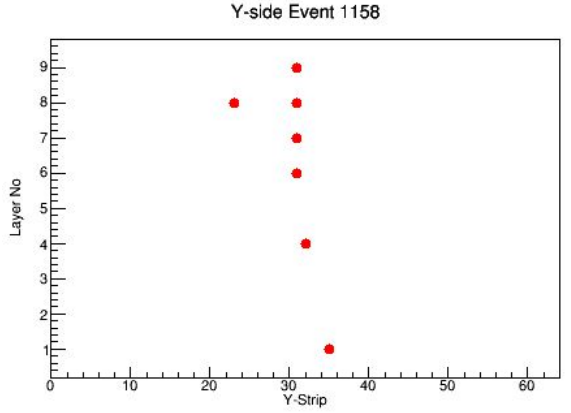


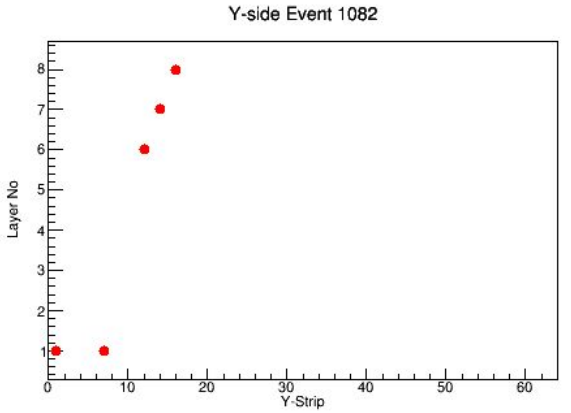












Is a shallow depth ICAL feasible?

Can one overcome the background due to cosmic rays?

- **Muons (electrically charged) : primary and secondary**
- Primary γ-rays, *p, n*, will not survive at ~100m depth ($\lambda_{em} \sim 0.1$m, $\lambda_{had} \sim 0.4$m)

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

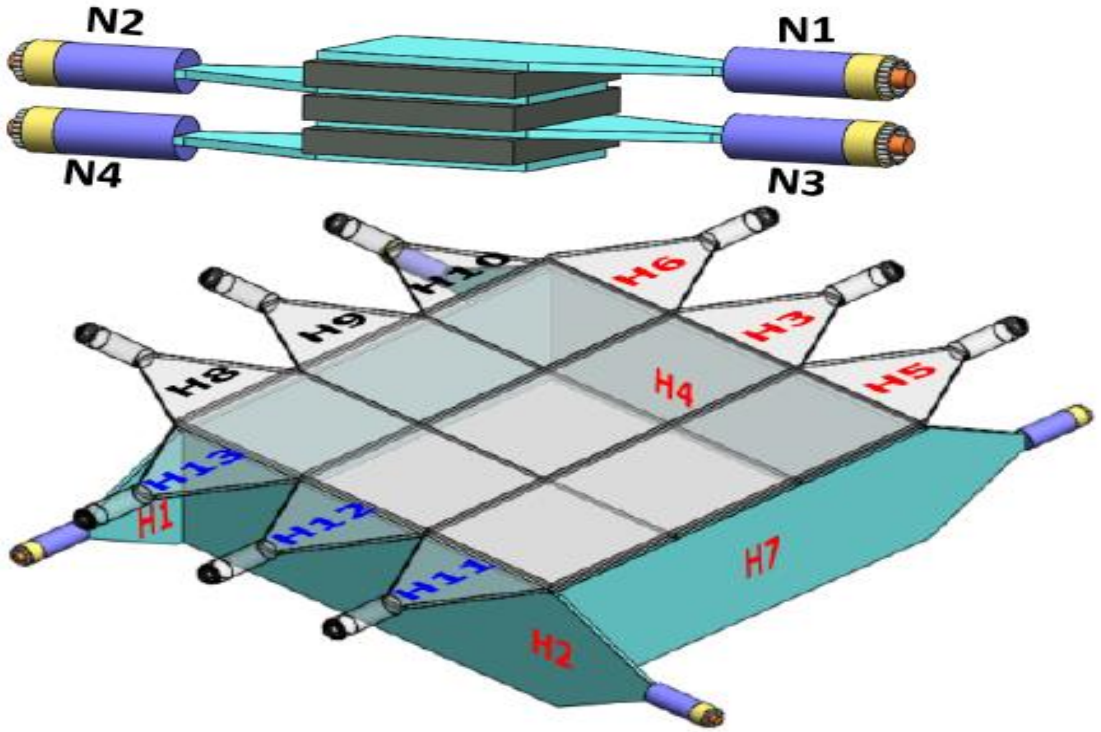
If SICAL at ~100m depth is feasible then

(a) can be sited almost ***anywhere***, much bigger detectors possible

(b) detector monitoring using cosmic muons

(c) 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)*

Proof-of-principle 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 and SiPM

Requirements for CMV detector for mini-ICAL

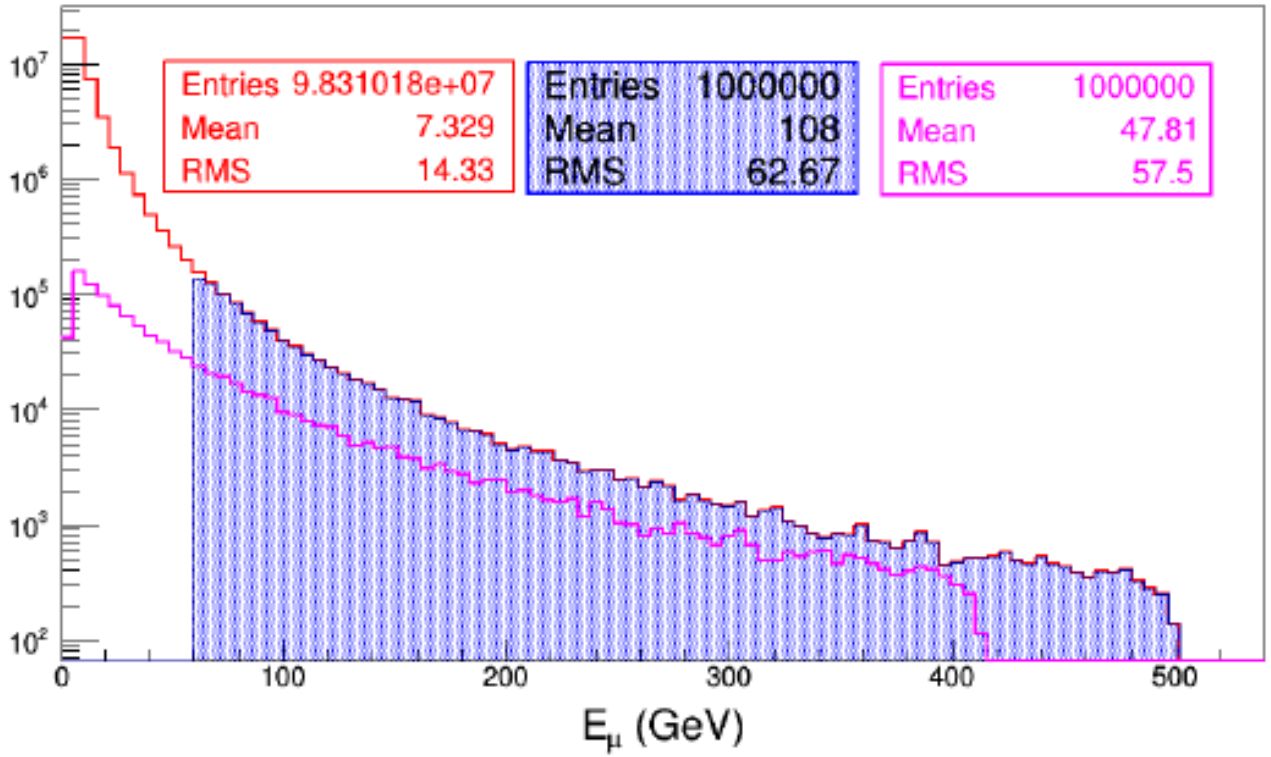
- Size of CMV detector ~ 5m × 5m × 2m
- No. of plastic scintillator (PS) layers : 3
- Extruded PS dimensions: 5cm (W) × 1cm (H) × 5m (L)
- 2 holes at centre 1.4 mm dia, 12.5 mm from side edge
- WLS fibre 1.4mm diameter read out by SiPM at either end
- WLS length ~ 8 km, 3200 SiPMs
- Electronics includes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

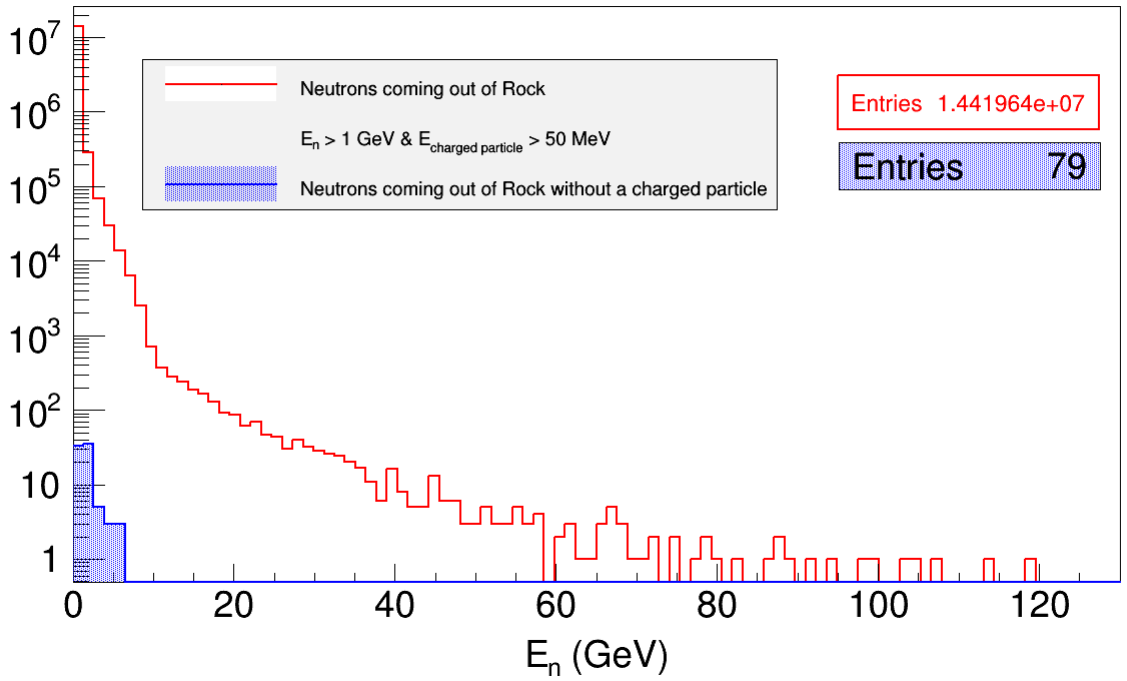
Simulating muon induced neutral particle production in rock (prelim. results)

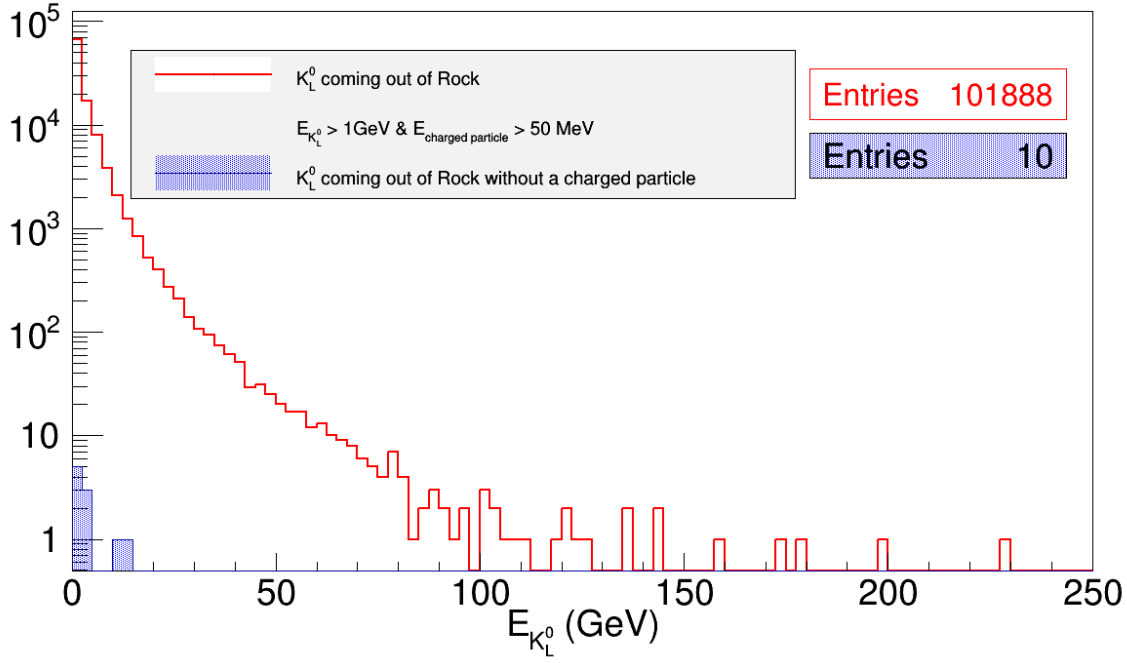
- Cosmic muons propagate through 100m rock undergoing only energy loss (10^{12})
- In next 3m muons allowed to undergo nuclear interactions ($\sigma_{int} \times 100$) and all particles propagated ($\lambda_{had} \sim 0.4$m)



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





For 10^{10} muons # of neutrals, with no accompanying charged particles (E > 50 MeV), leave rock & produce a track ($\geq$ 5 layers): $1.5\times10^{7}\times10^{-4}\times2\times10^{-3} = 3$

$\Rightarrow$ For ~10^8 muons/day on 100m deep ICAL bkgd events ~0.03/day, while $N_{atm\ \nu}$ ~ 3/day

Preliminary simulations show promise!

In summary…..

- Mini-ICAL close to being set up
- Shallow depth ICAL appears to be promising

Mini-ICAL team members:

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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) ….

Thank you