Some novel physics with ICAL at INO and a possible cryogenic Indium detector for solar neutrinos

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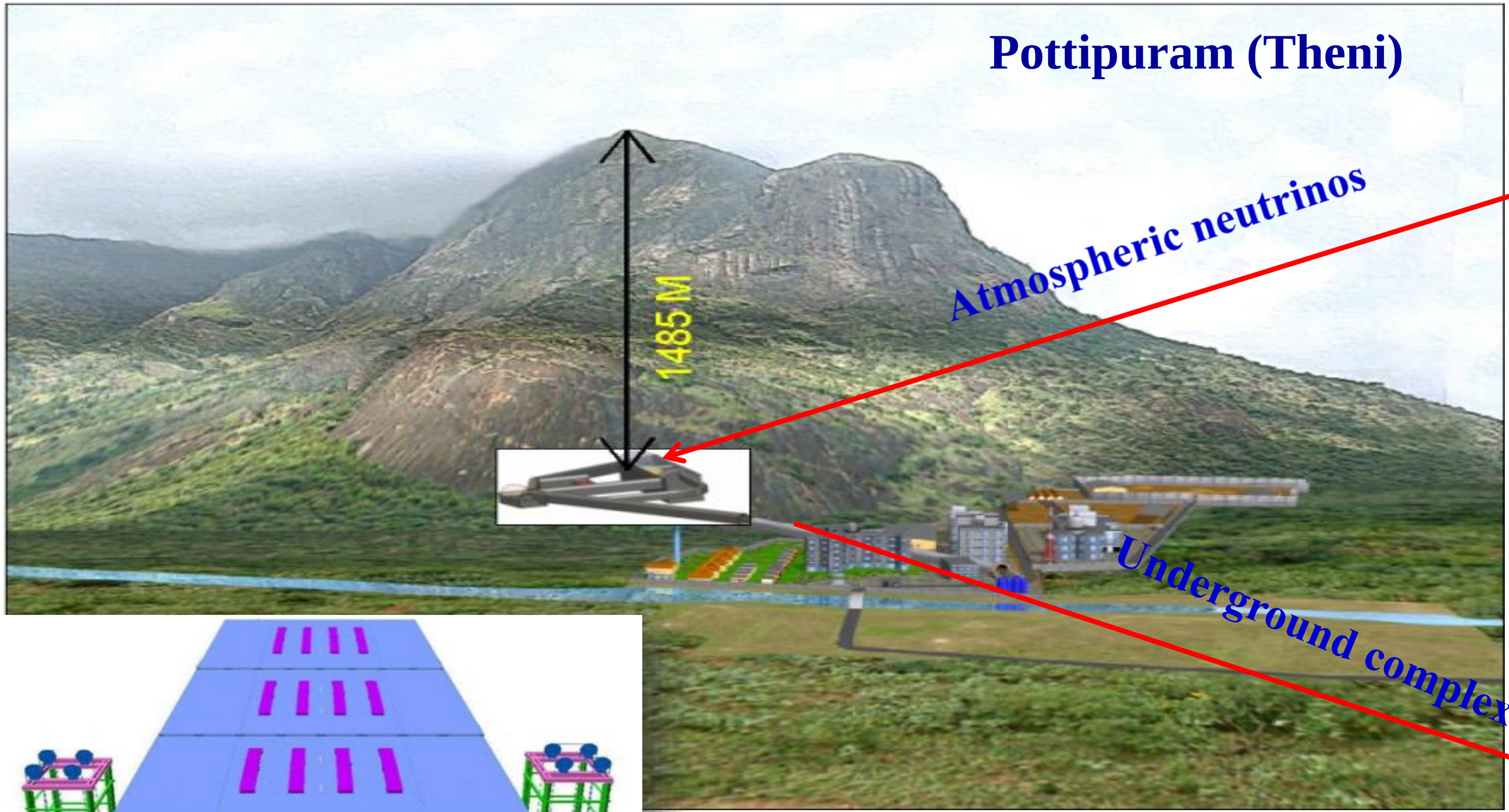
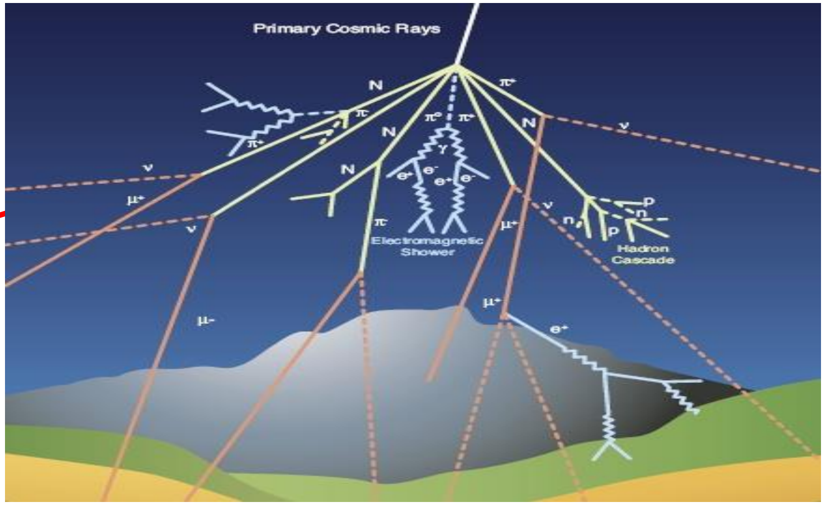
ASET Colloquium, TIFR (2 Sept 2016)

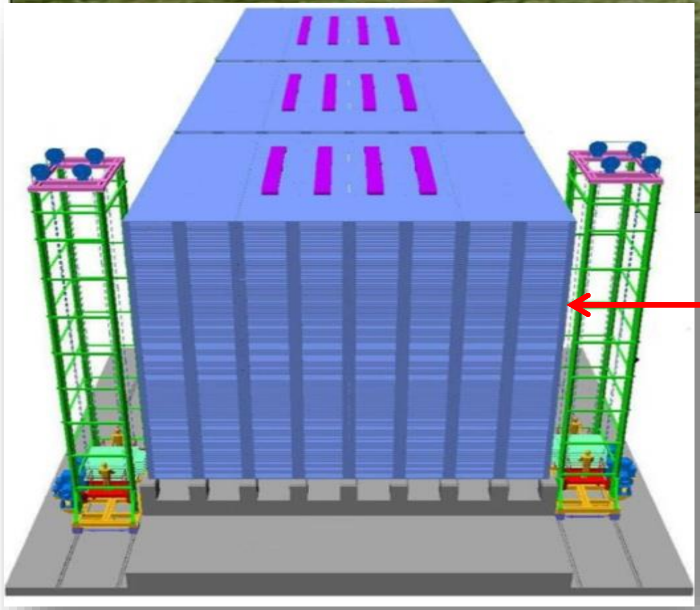
Topics

1. Introducing ICAL at INO
2. Searching for magnetic monopoles with ICAL
3. Searching for anomalous KGF events at ICAL /Dark Matter particle decays to muons
4. Sensitivity of ICAL to sterile-active neutrino mixing using atmospheric neutrinos
5. A possible cryogenic In detector for solar neutrinos

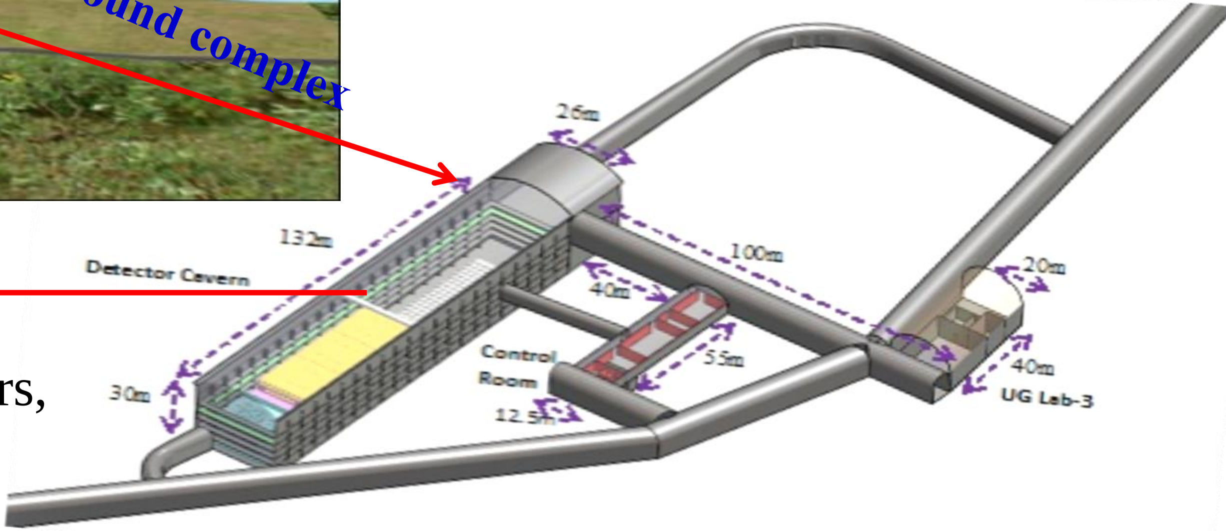
1. Introducing ICAL at INO







51 kton ICAL Detector



- ν oscillation parameters, ν mass hierarchy
- Search MMs, DMP decay

Physics reach of Iron Calorimeter detector

ICAL will measure atmospheric muon neutrinos and muon-antineutrinos

Energy range: 1 GeV $\leq E_\nu \leq$ 20 GeV

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

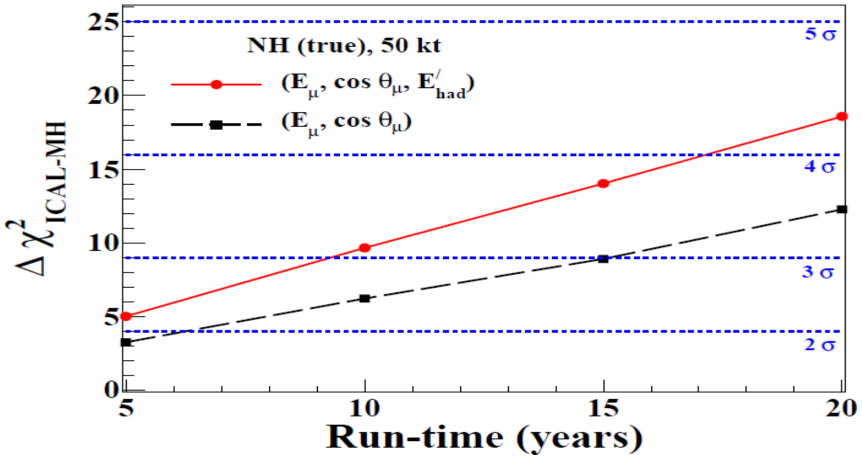
- Neutrino mass hierarchy – normal or inverted
- Neutrino mixing parameters (Δm_{23}^2, θ_{23})
- Non-standard interactions
- Ultra high energy cosmic muons

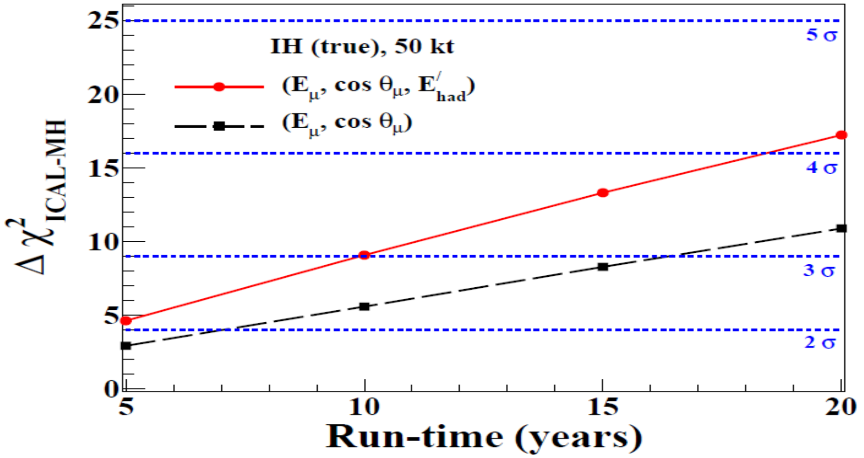
White paper on "Physics Potential of the ICAL detector at INO"

under review in Pramana (2016); arXiv:1505.07380

Mass hierarchy of neutrinos – sensitivity of ICAL

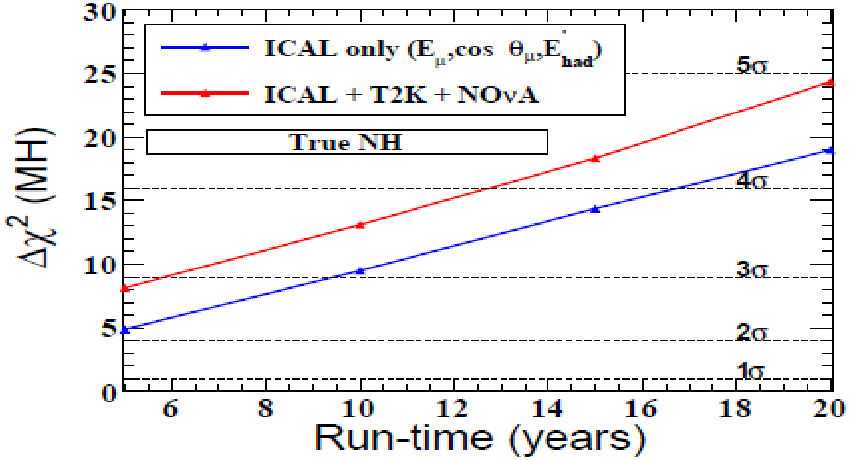
- $m_1 < m_2 < m_3$ (NH) or $m_3 < m_1 < m_2$ (IH) ?
- ICAL can identify mass hierarchy using atmospheric ν_μ , $\bar{\nu}_\mu$
- With accelerator based expts. can probe CP violation in ν-sector

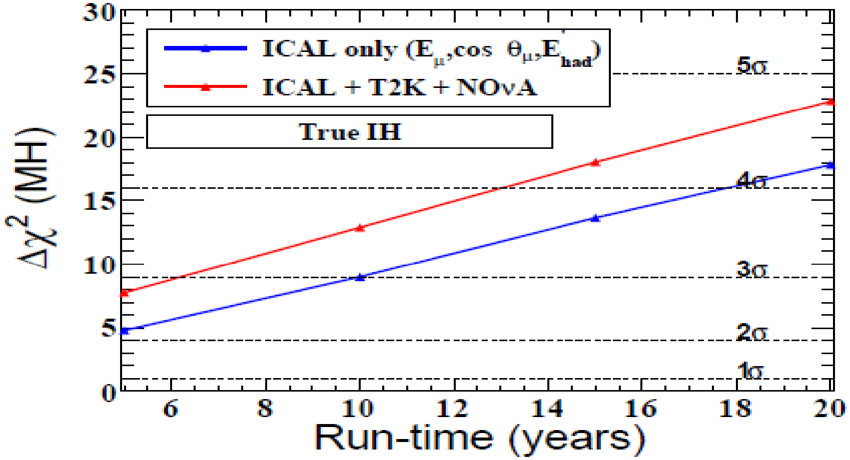




ICAL only

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

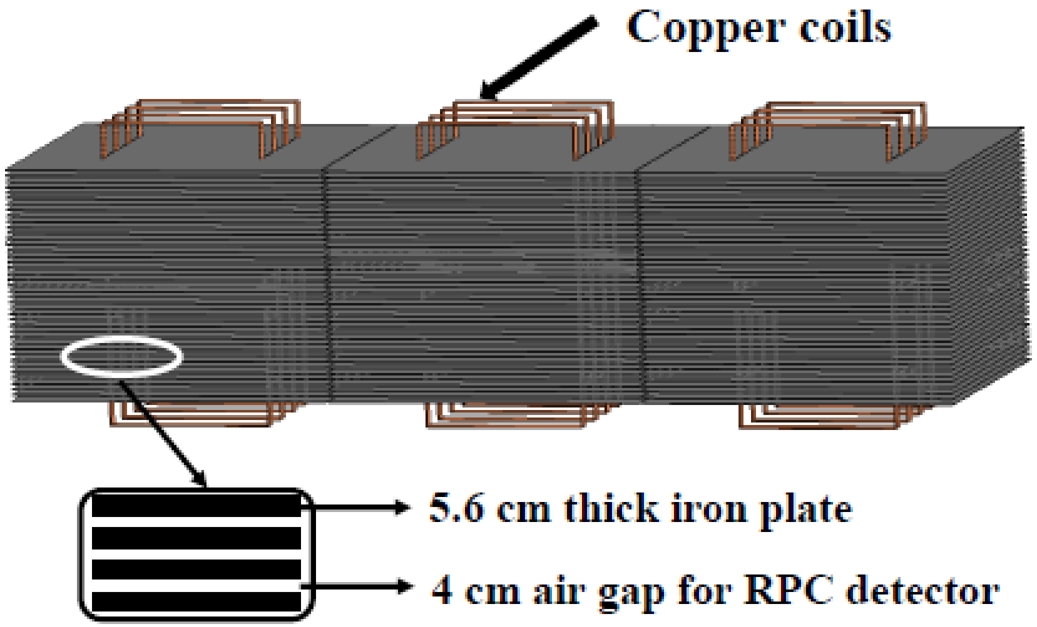




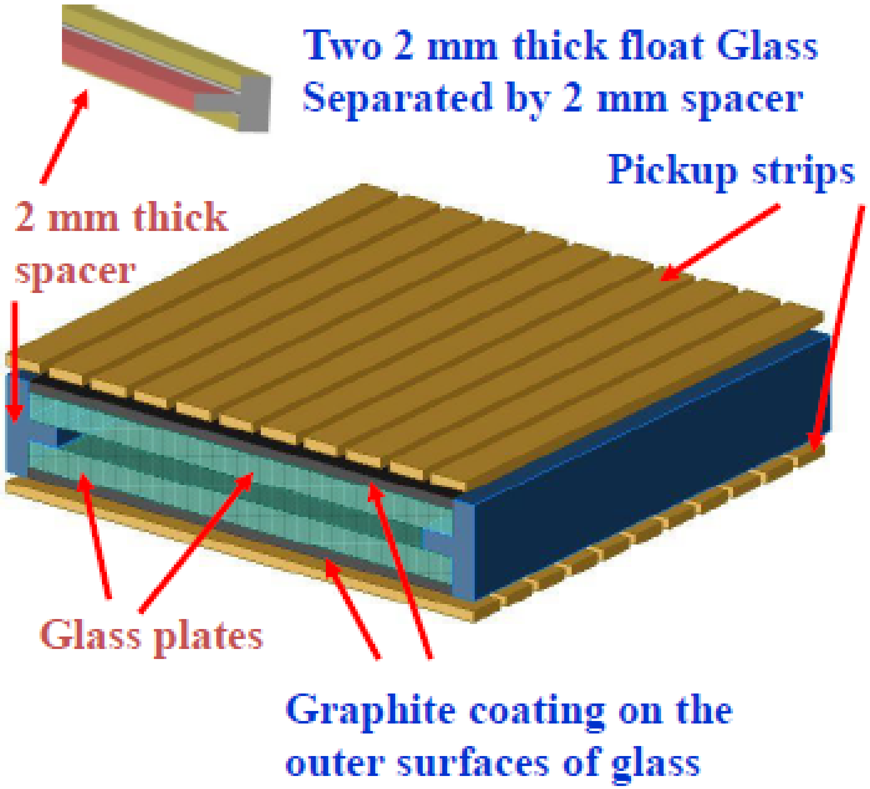
ICAL + T2K + NovA

S. Agarwalla, T. Thakore unpubl.

The INO ICAL detector



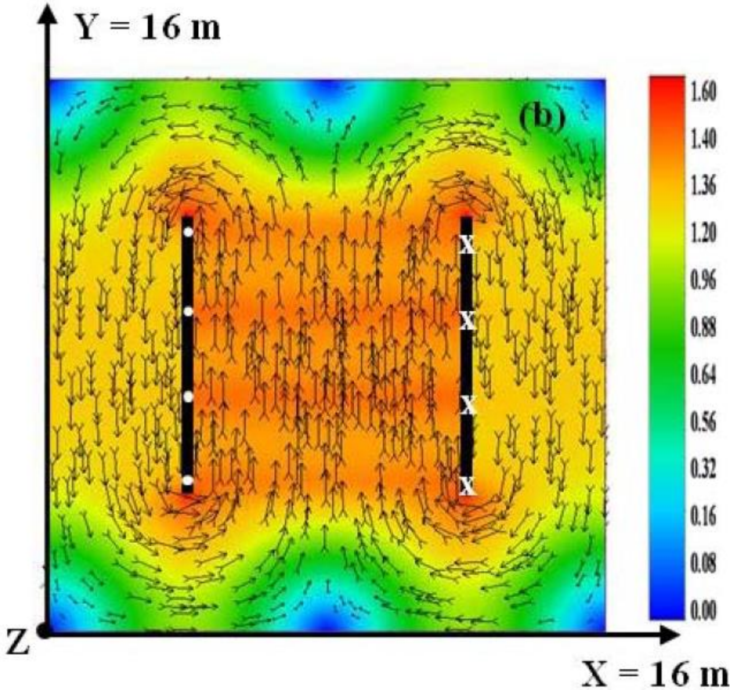
No of modules	3
Detector dimension	48 m × 16 m × 15 m
No. of layers	151
Module dimension	16 m × 16 m × 14.4 m
Iron plate thickness	5.6 cm
Mass	51 k-ton
Gap between each layers	4 cm

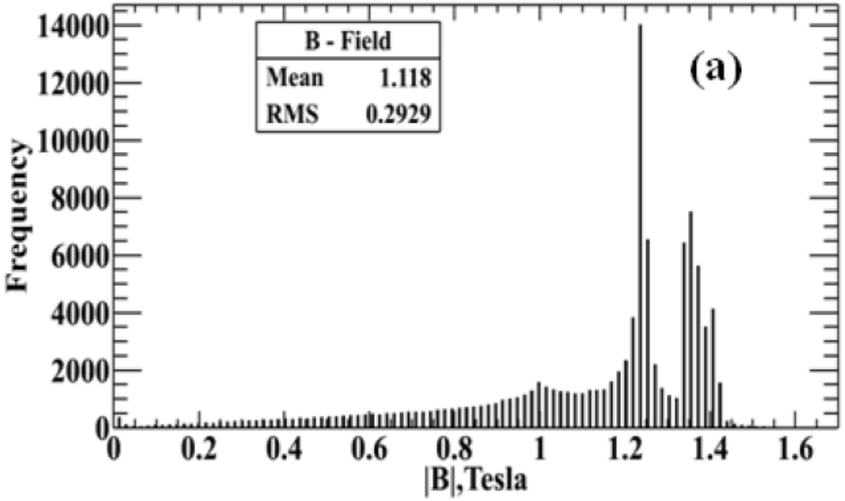


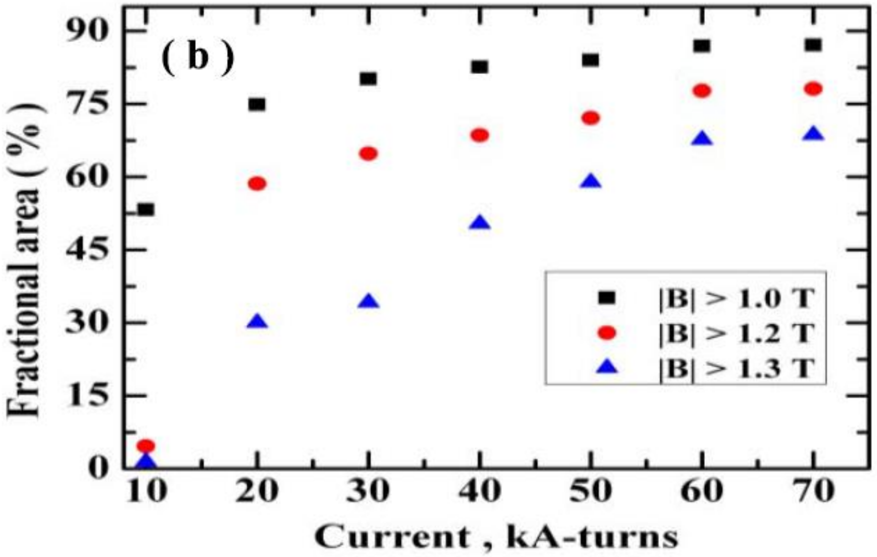
- Magnetized ICAL will identify $\mu^+/\ \mu^-$ and measure the momentum
- RPC will provide position and time information

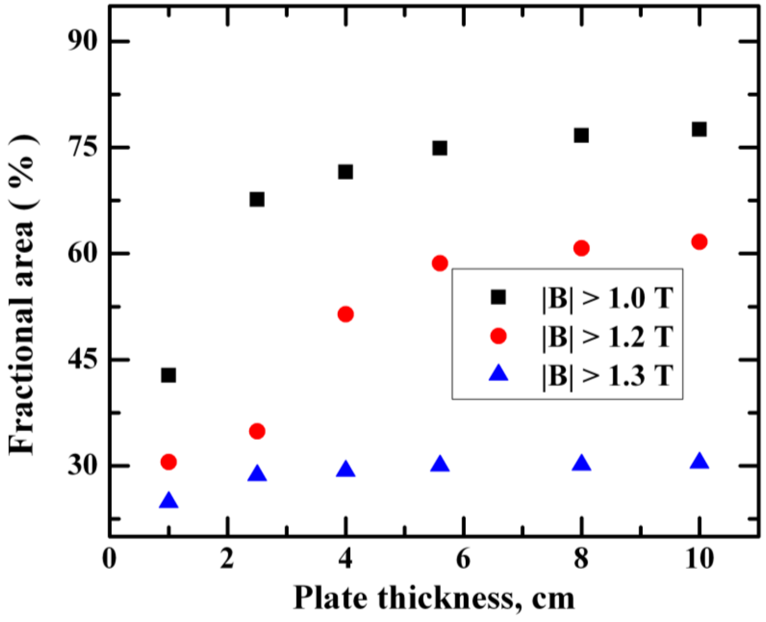
Electromagnetic simulation study of ICAL magnet

- B-field simulation using 3D finite element commercial software
- B-field uniformity studied for various plate thicknesses, tiling configurations, air gaps, slots (for Cu coils), coil configurations. *NI*, 2 low carbon steels
- Muon momentum response (from reconstructed trajectory) studied for a few coil currents, plate thicknesses

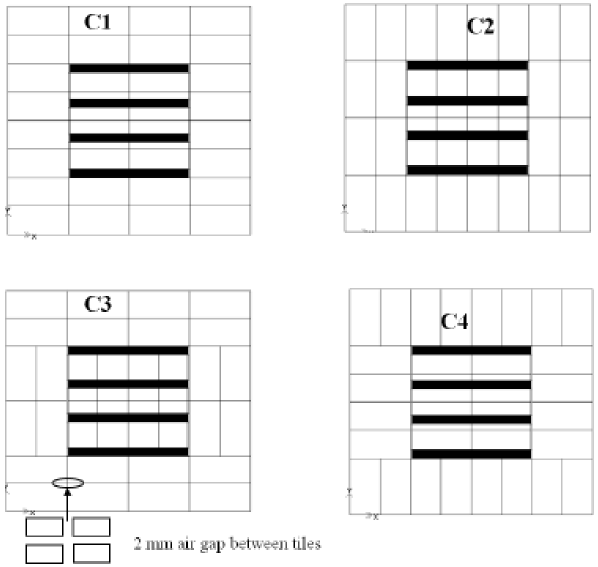


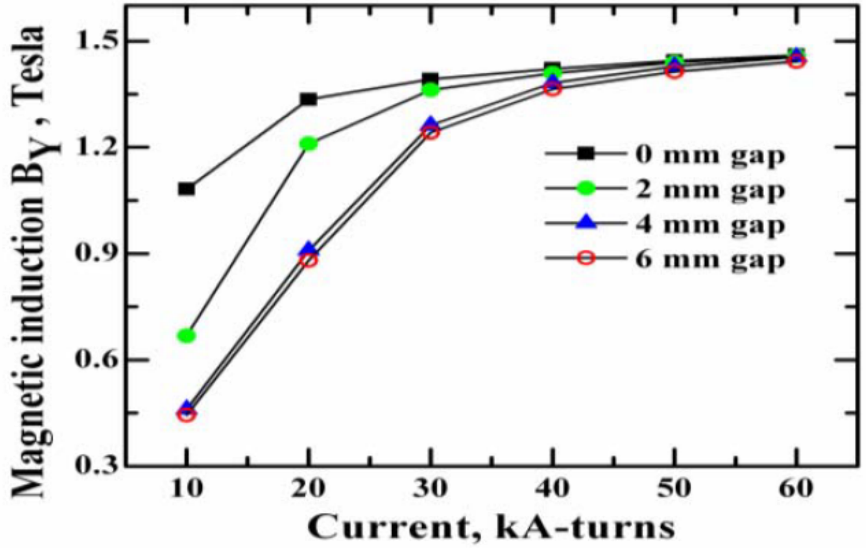




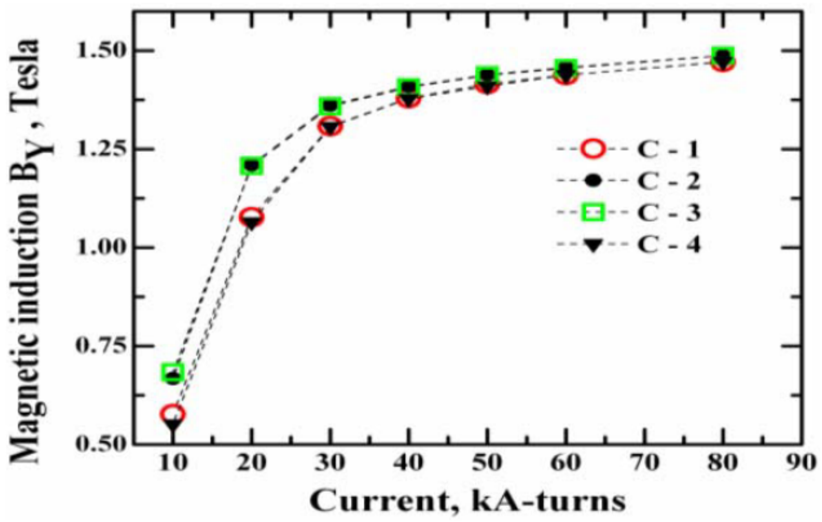


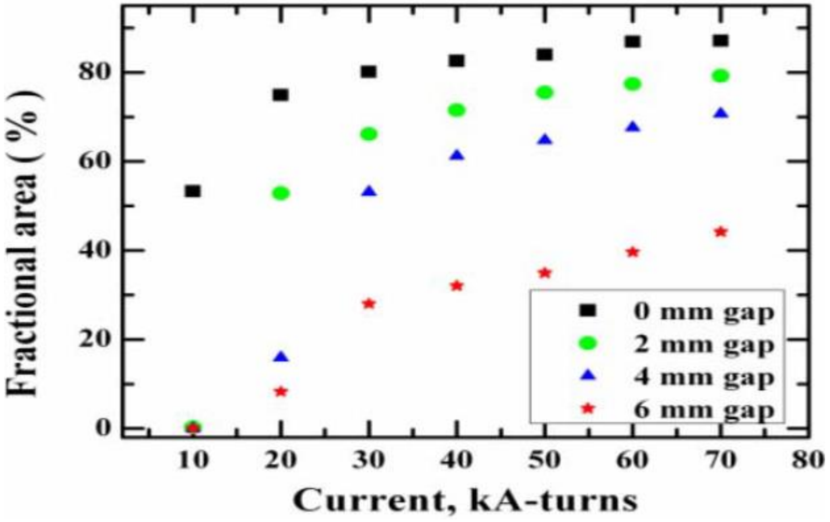
B-field uniformity for NI=20 kA.turns





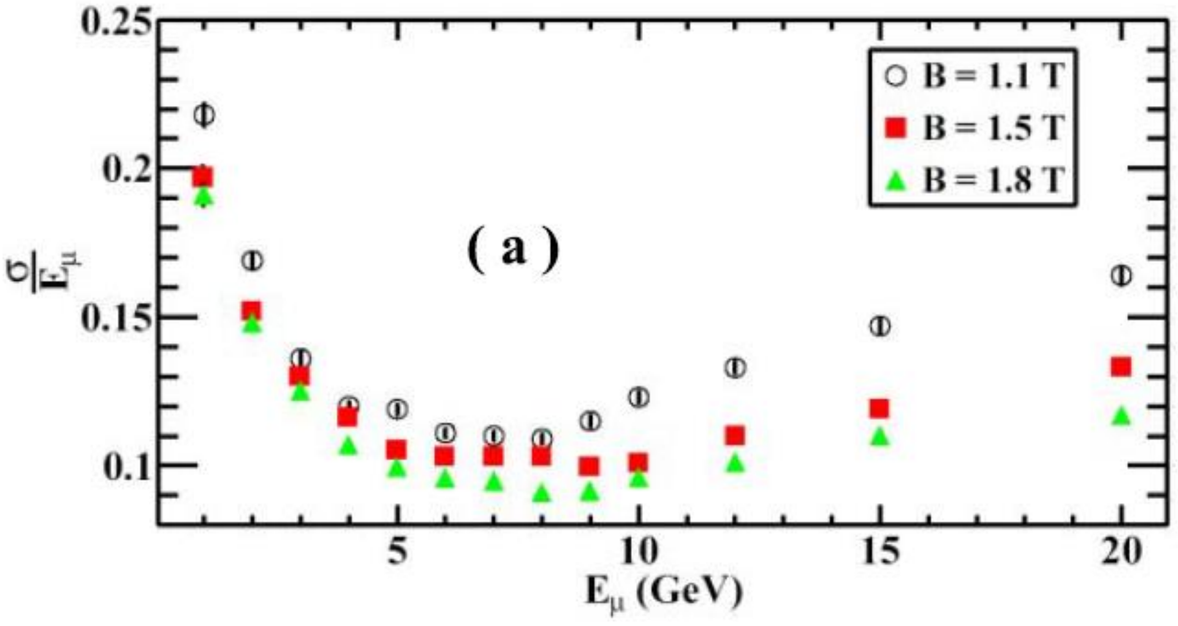
C2 for different gaps

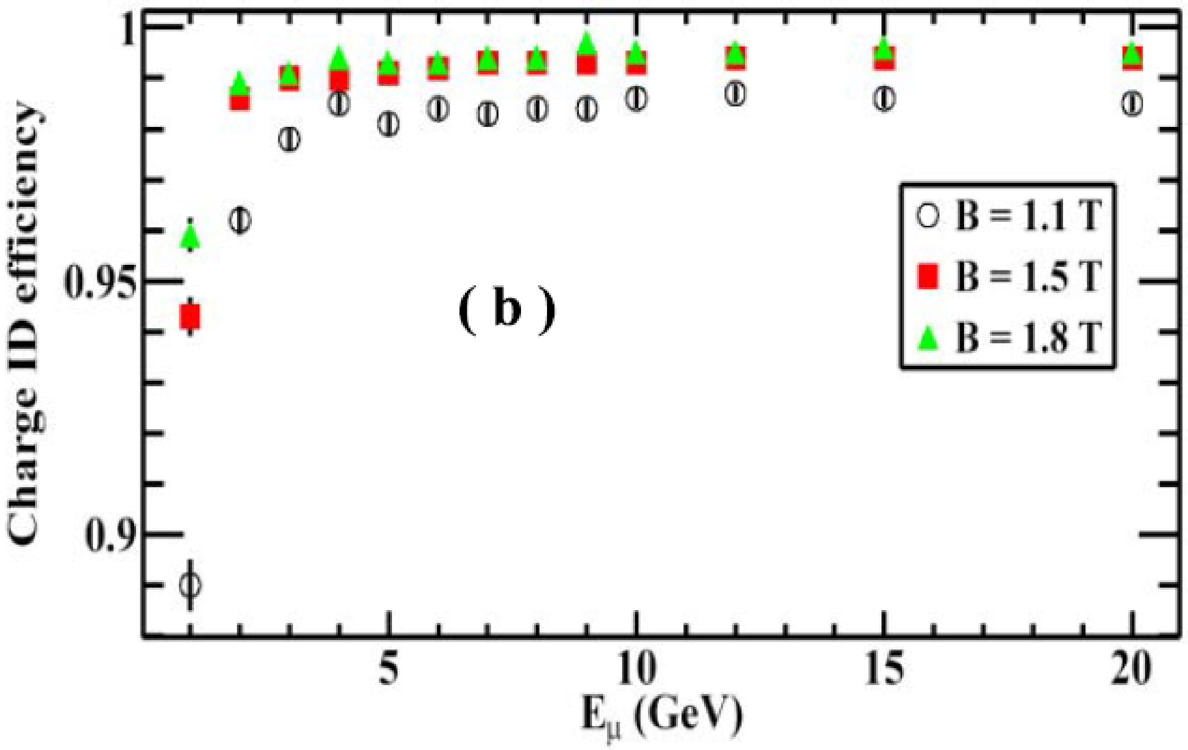




Fractional area with B > 1 T

Muon response of ICAL for various B-field strengths





S.P. Behera et al., IEEE Magnetics **51**, 7000409 (2015)

2. Searching magnetic monopoles at ICAL@INO

- Dirac (1931) attempt to understand quantization of electric charge led to idea of magnetic monopole with magnetic charge $g_M = n(\hbar c/2e)$ [g_1=(137/2) e]
- t'Hooft (1974), Polyakov (1974) showed that certain kinds of Grand Unified Theories (GUT) $\Rightarrow m_{\mathrm{MM}} \sim 10^{16}$ GeV/c^2
- Rubakov (1981), Callan (1982) showed that GUT MMs can ***catalyze*** proton decay in its passage through matter with $\sigma_{\mathrm{MM}} \sim \sigma_{\mathrm{nucl}} \sim 100$ mb $\Rightarrow \lambda \sim 1m$

  MM passing through matter would lead a series of *p* decays in path

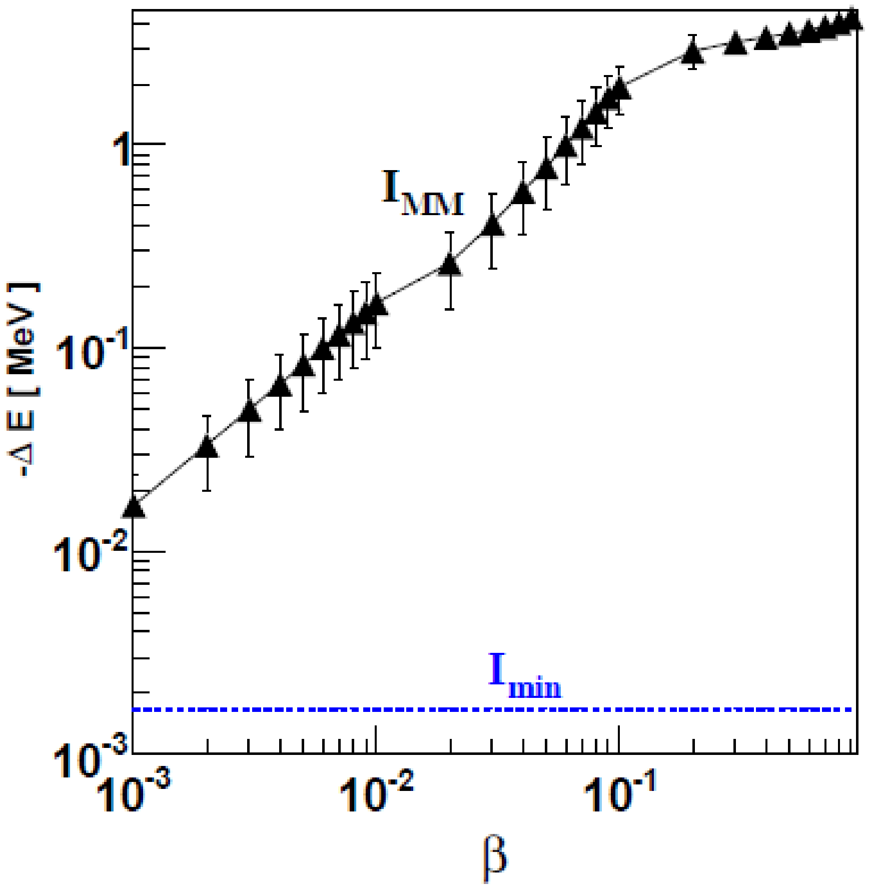
  Wilczek (1982): σ_{MM} could be σ_{weak}

- Parker (1970) showed that light MMs will gain energy from galactic magnetic field (~ 0.3 nT or ~10^{-5} B_{earth})

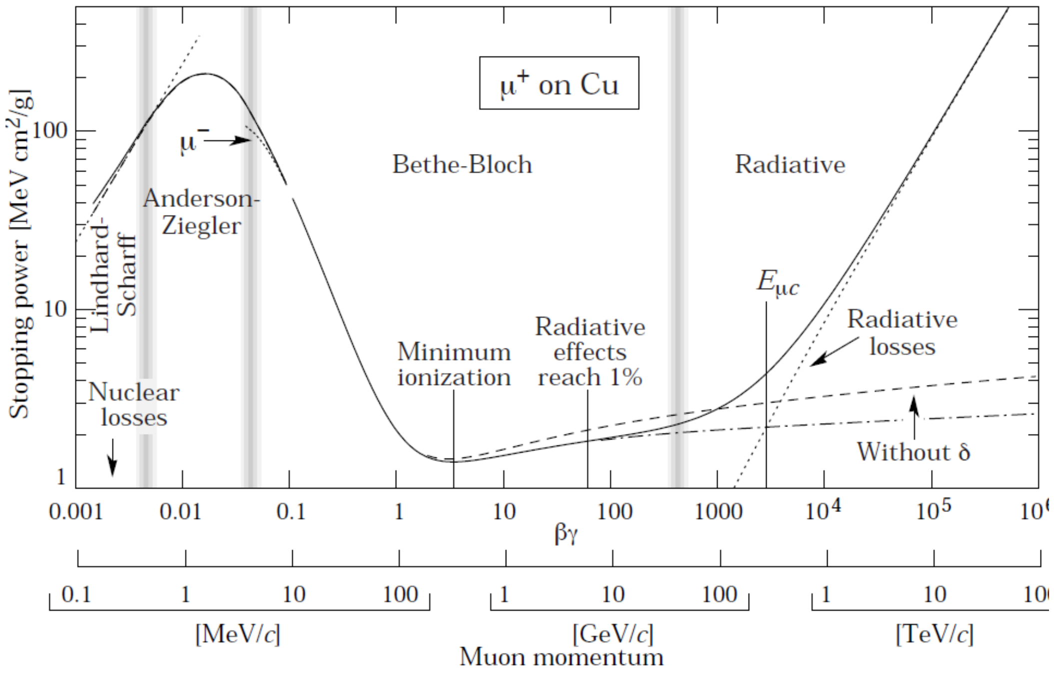
  MM flux ≤ 10^{-15} cm^{-2} s^{-1} sr^{-1} for $m_{MM} < 10^{17}$ GeV/c^2 (Parker bound)
- Experimental searches for GUT magnetic monopoles in cosmic rays and light MMs at accelerators use *ionization* or *current induced in a loop*
- KGF collab. $\Phi_{MM} < 3\times 10^{-14}$, MACRO at Gran Sasso, SLIM, IceCube, ANTARES, Baikal and Kamiokande
- Cabrera (1982) at Stanford found one event in a SC loop. In 1990 his group reported an upper bound 2000 times smaller.
- CDF at Fermilab : $\sigma\,(p\bar{p} \rightarrow MM + X) < 0.2$ pb

- Magnetic charge $g_M = n\,(\hbar c/2e) \approx (137/2)\,e$ *for* $n = 1$
- Energy loss of MM increases with velocity (compare with muon)

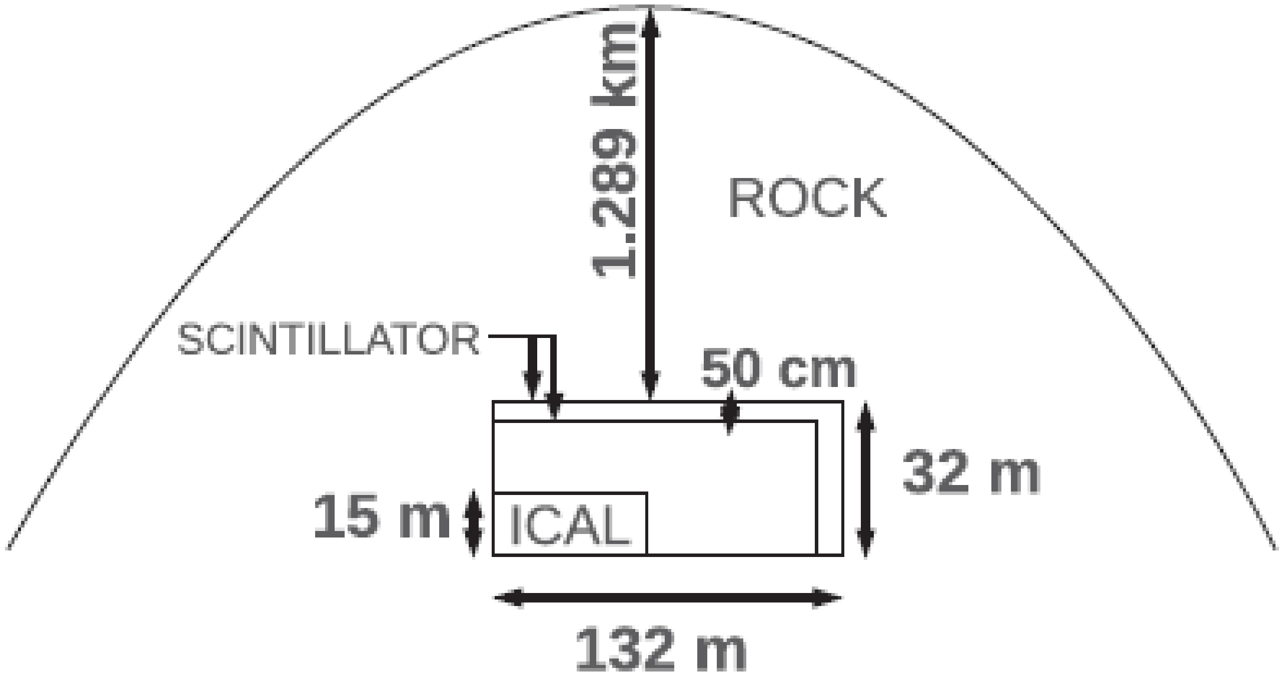
Mag. Monopole in RPC gas

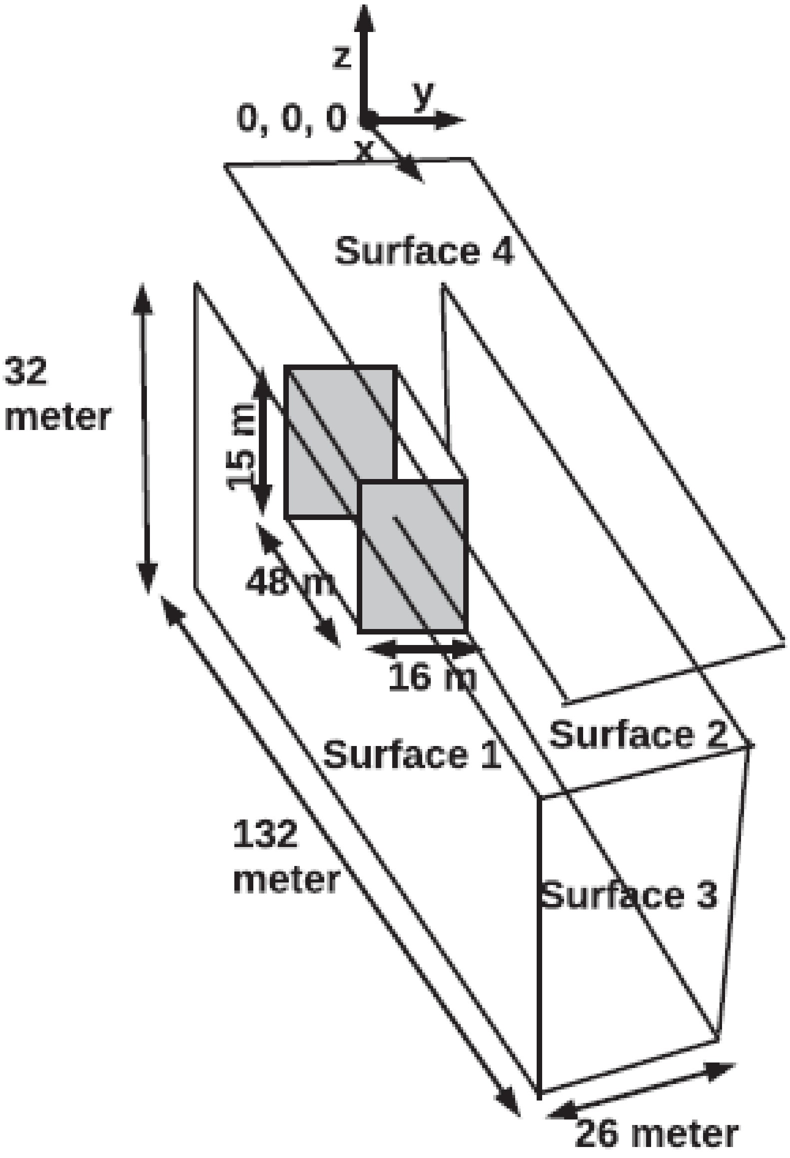


Muon



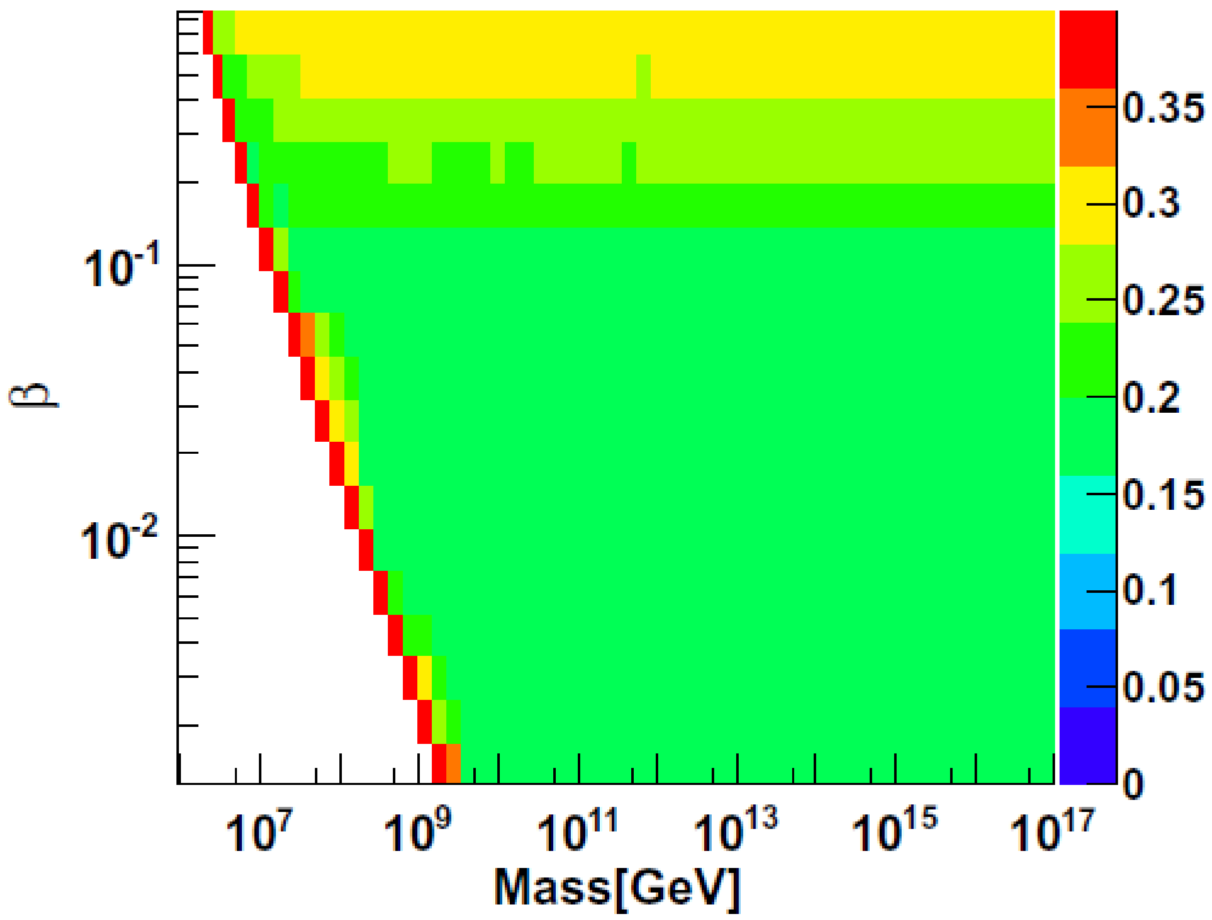
ICAL at underground site (schematic)



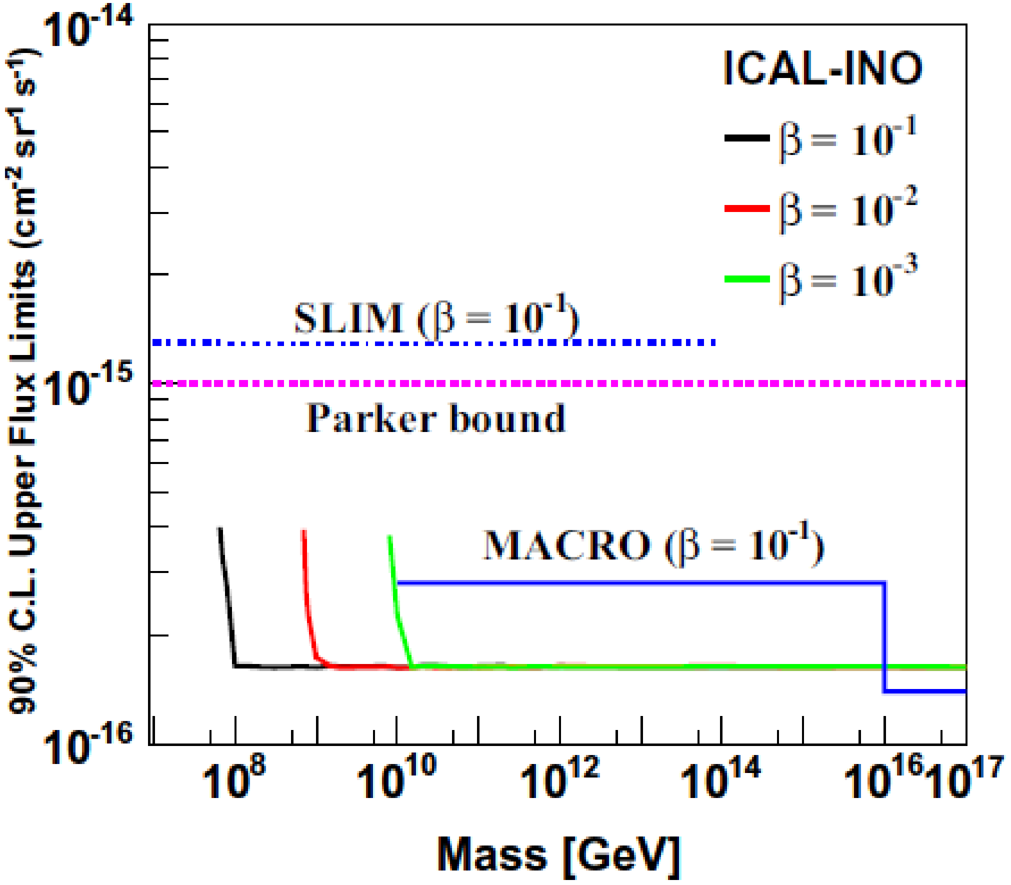


- Use track information (long) and time-of-flight information (slow) to discriminate against muons (TOF ~ 3.3 μsec/m for v_{MM} = 300 km/sec)
- Heavier MMs with typical inter-galactic speeds easily penetrate 1 km rock. Here flux from upper hemisphere considered ($\Delta\Omega = 2\pi$ sr).
- Upper bounds from 10 years running for heaviest MMs lower than MACRO by ~ 2
- With additional detectors on 4 of 6 sides of cavern, this is further lowered by ~ 2

Upper bound on MM flux for 10 yrs of ICAL (10^{-15} cm^{-2}.s^{-1})



Upper bound on MM flux for 0 observed events



N. Dash et al., Astroparticle Physics **70**, 33 (2015)

3. Searching for anomalous KGF events at ICAL

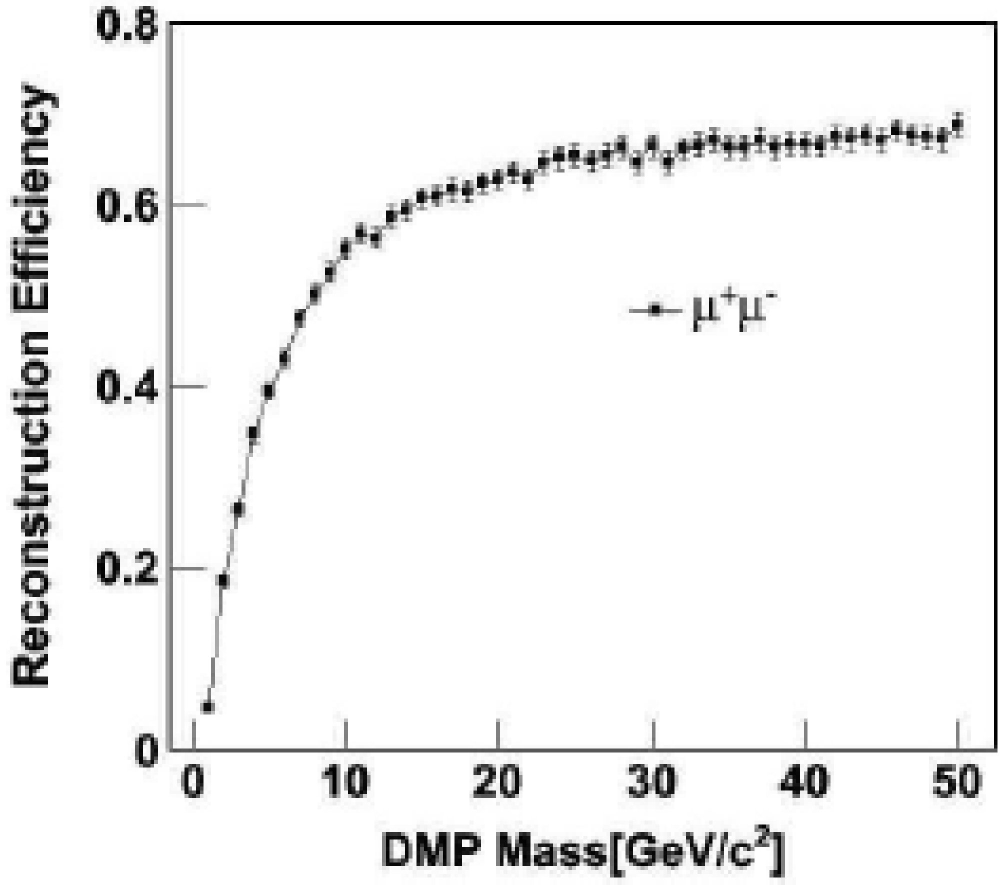
- About 7 anomalous events found during 25 years of running the proton decay experiment – multiple tracks leading back to an **origin not in detector or rock but in air**
- Is it due to a short lived particle produced in neutrino – rock interaction (KVL Sarma, G. Rajasekaran)? Ruled out by accelerator experiments!
- Rajasekaran, Murthy propose a light 5-10 GeV Dark Matter particle solution to KGF anomaly

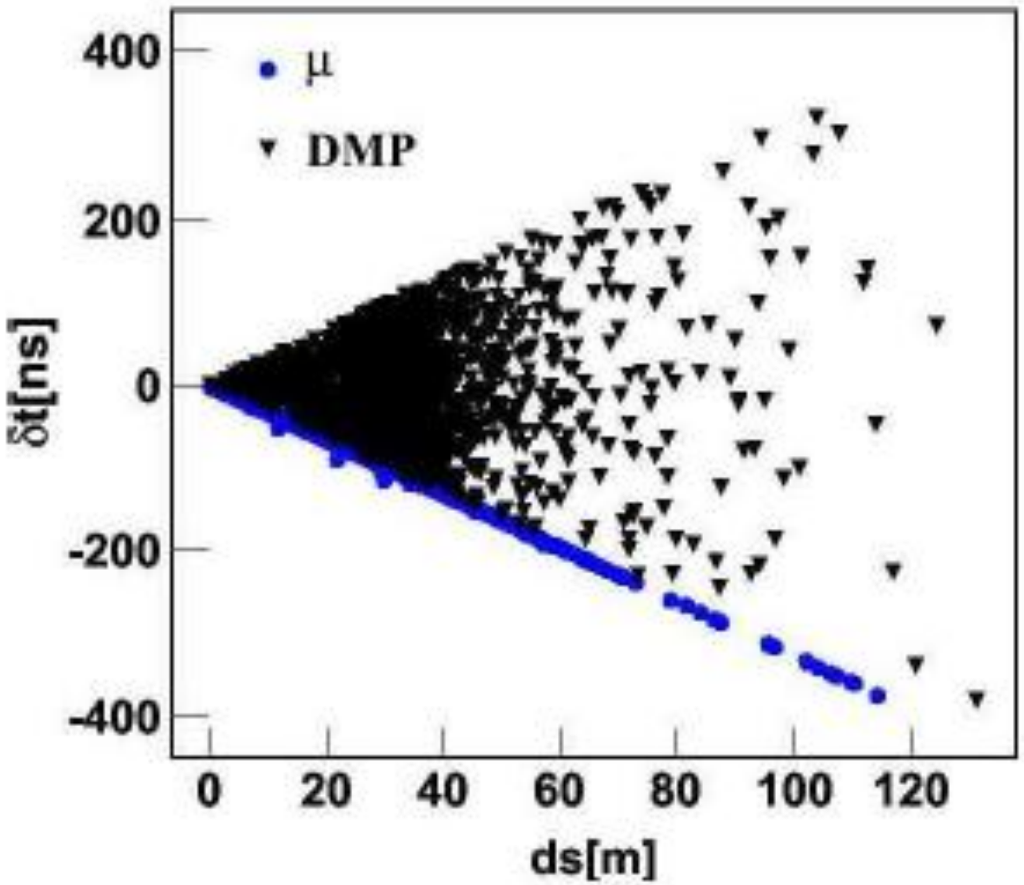
- DMP decay to leptons would imply that neutrinos from the cosmos should have been seen in large neutrino detectors

  $N_{dec} \propto R^3$ but $\varepsilon_{det} \propto R^{-2}$ so stringent bounds have ben derived
- However if KGF events are genuine, we should see many more with ICAL as cavern & detector ~ 10 times larger
- With additional detectors on 4 sides, should be able to provide data for/against KGF events in 2-3 years of running time

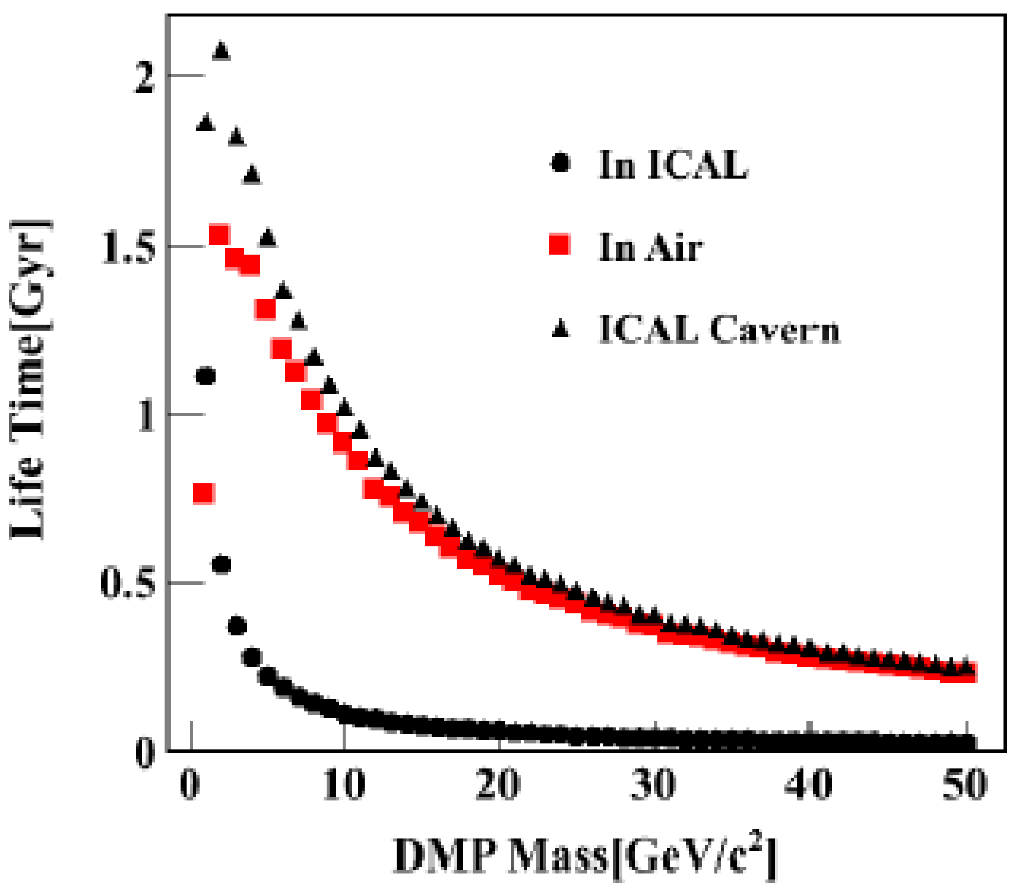
Muon reconstruction efficiency in ICAL

Time of flight between wall & ICAL detectors

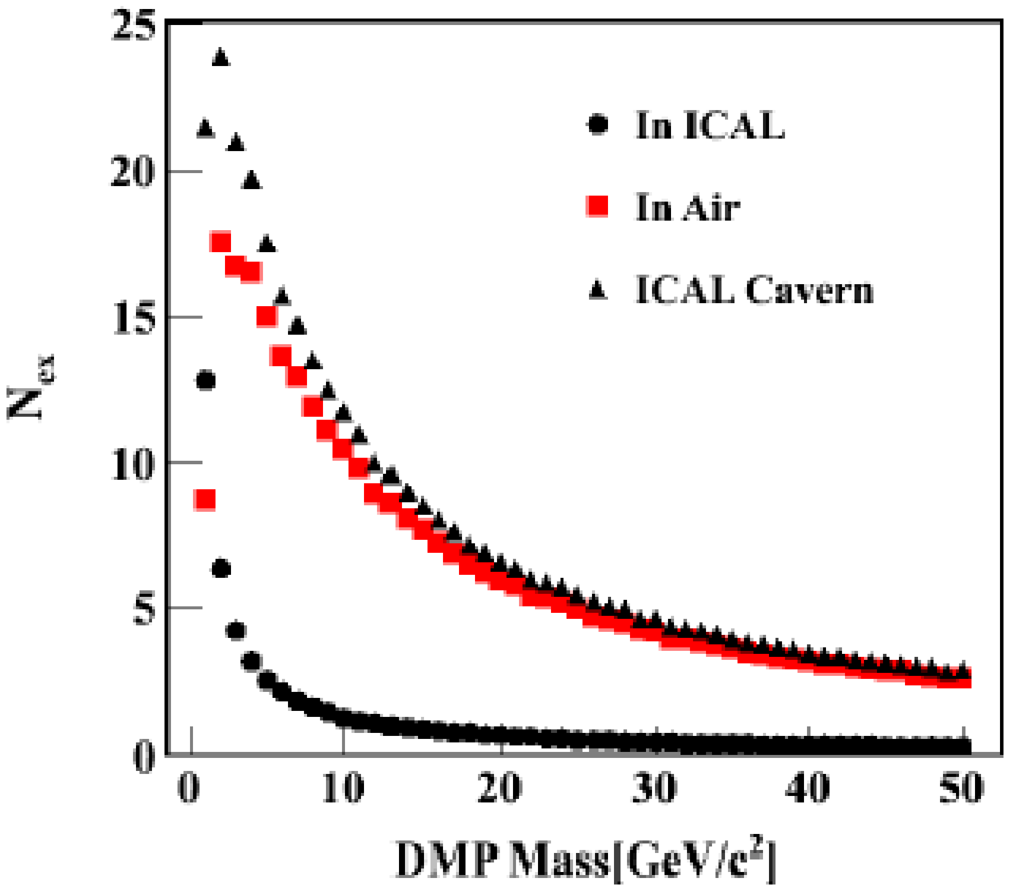




Lower bound on DM lifetime

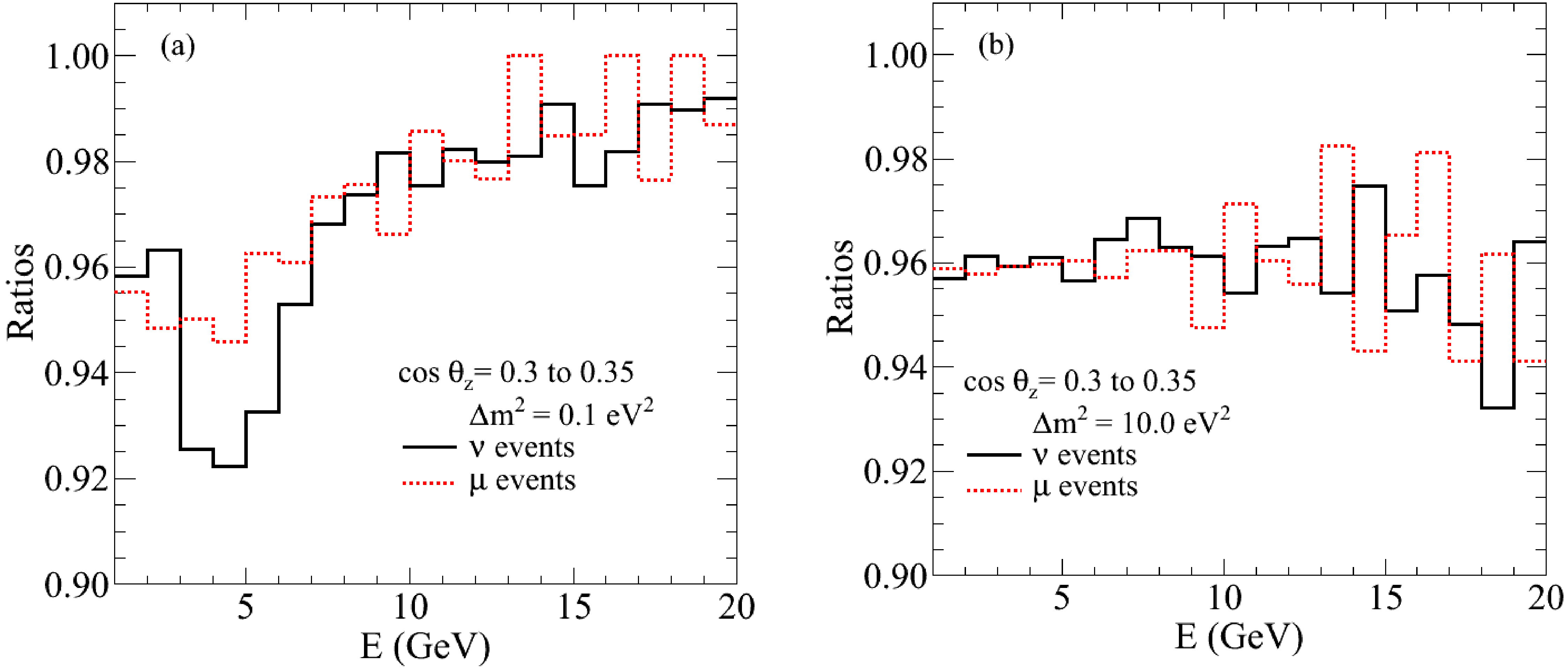


Events observed for τ = 2 Gyr

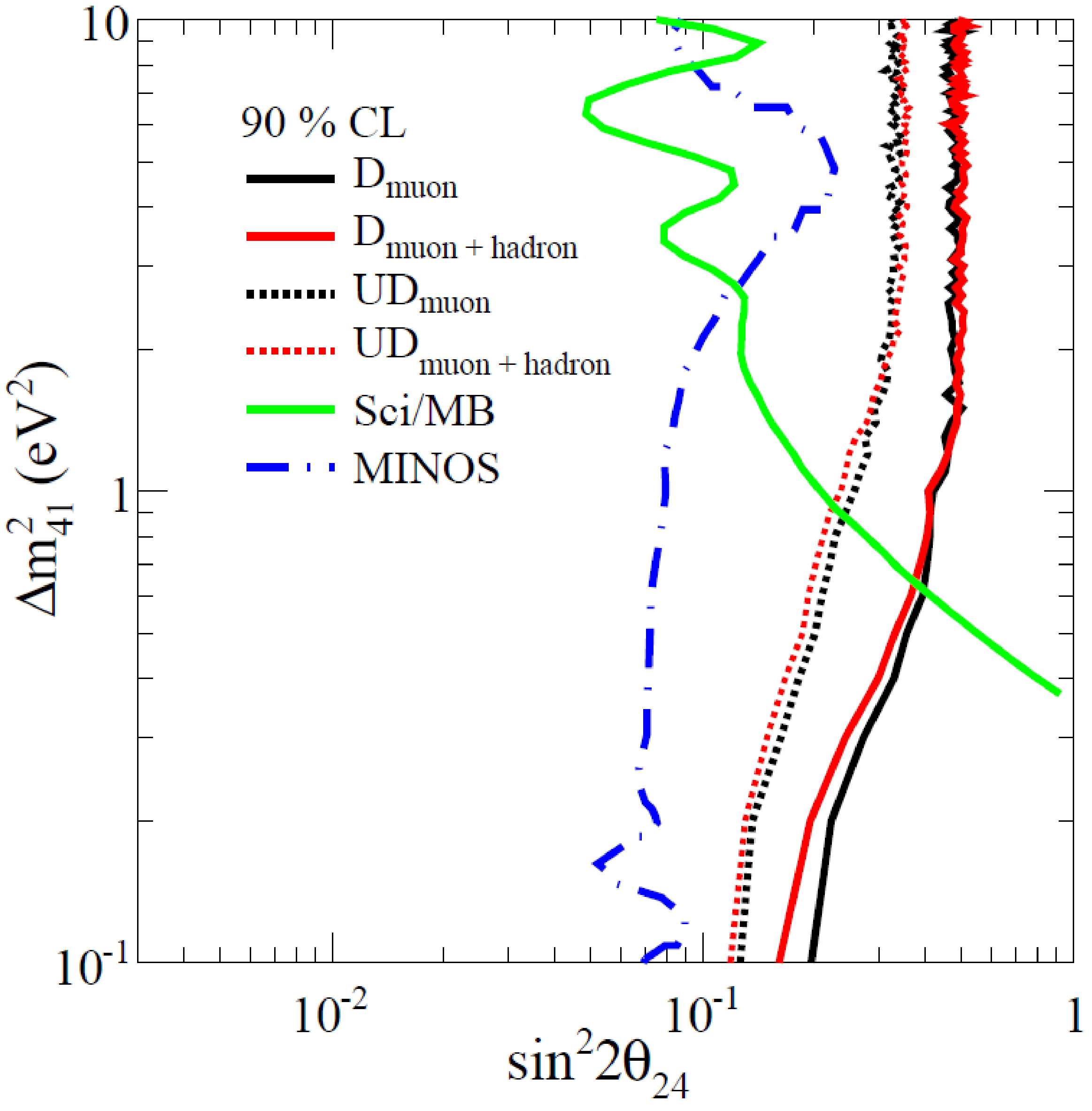


N. Dash et al., Pramana **86**, 927 (2016)

4. Sterile neutrino mixing at ICAL using atmospheric neutrinos

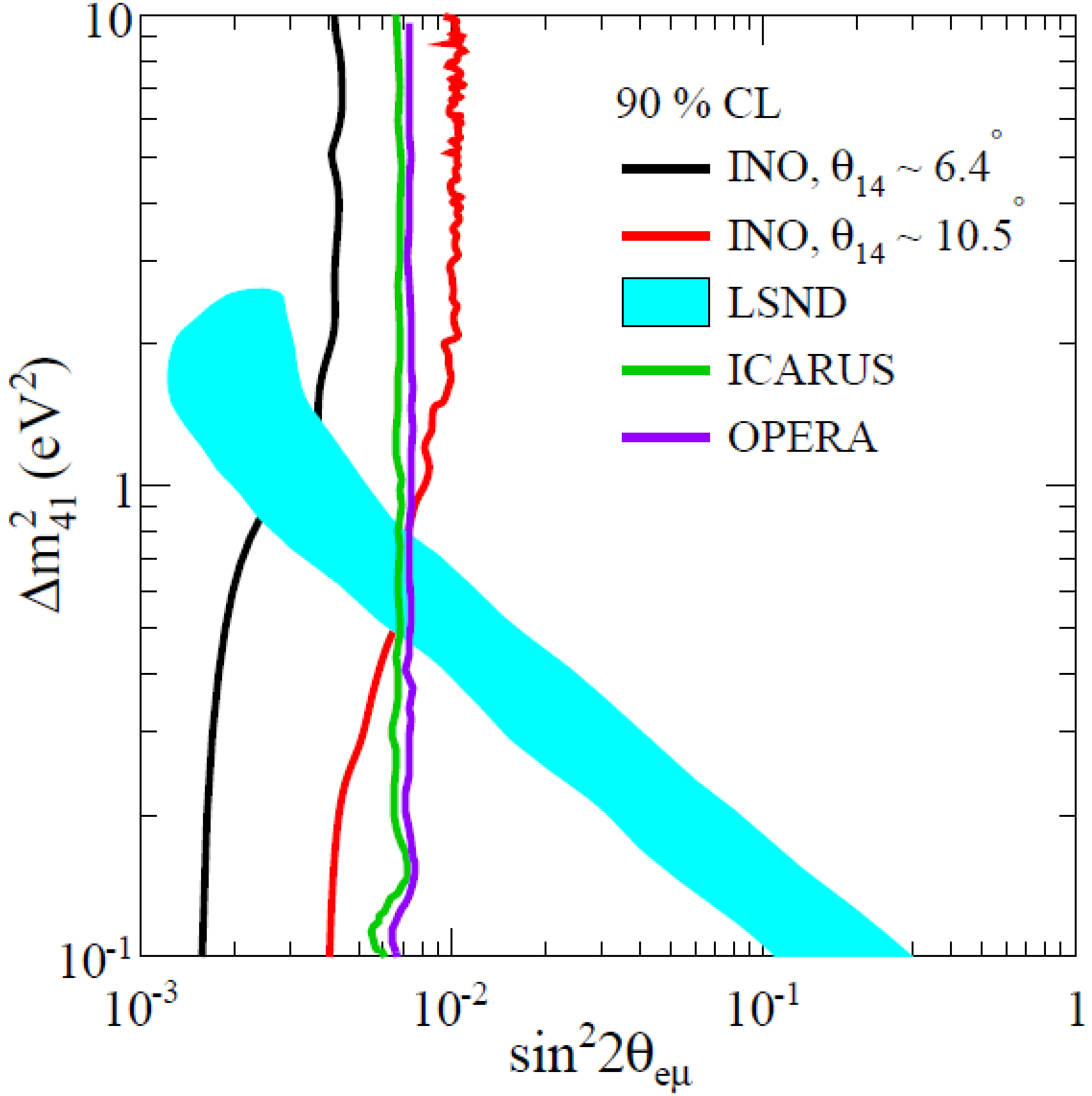


Ratio of events with and without sterile neutrino mixing (3+1)



Exclusion plot in Δm^2_{41} – $\sin^2 2\theta_{24}$ plane for 1 Mton.year exposure. Here other mixing angles assumed to be 0.

1 Mton.yr exposure, θ_{34} assumed = 0



$\sin^2 2\theta_{e\mu} = 4\, U^2_{e4}\, U^2_{\mu 4}$

For $\Delta m^2_{41} \geq 0.1$ eV^2 ICAL data sensitive to $\theta_{24} > 10°$, θ_{14}, $\theta_{34} > 20°$

PhD thesis of Shiba Behera,

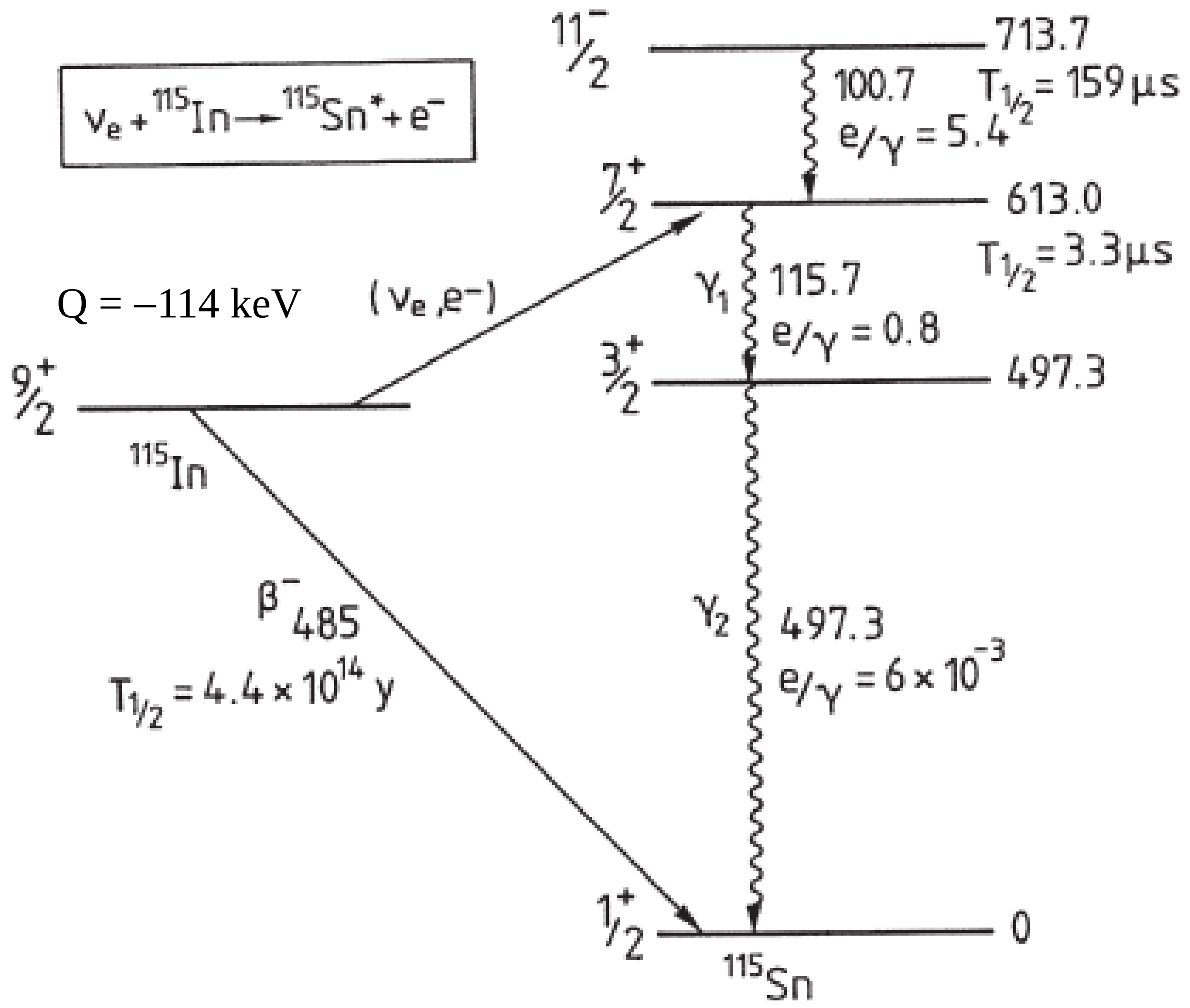
S.P. Behera et al., arXiv: 1605.08607 [hep-ph]

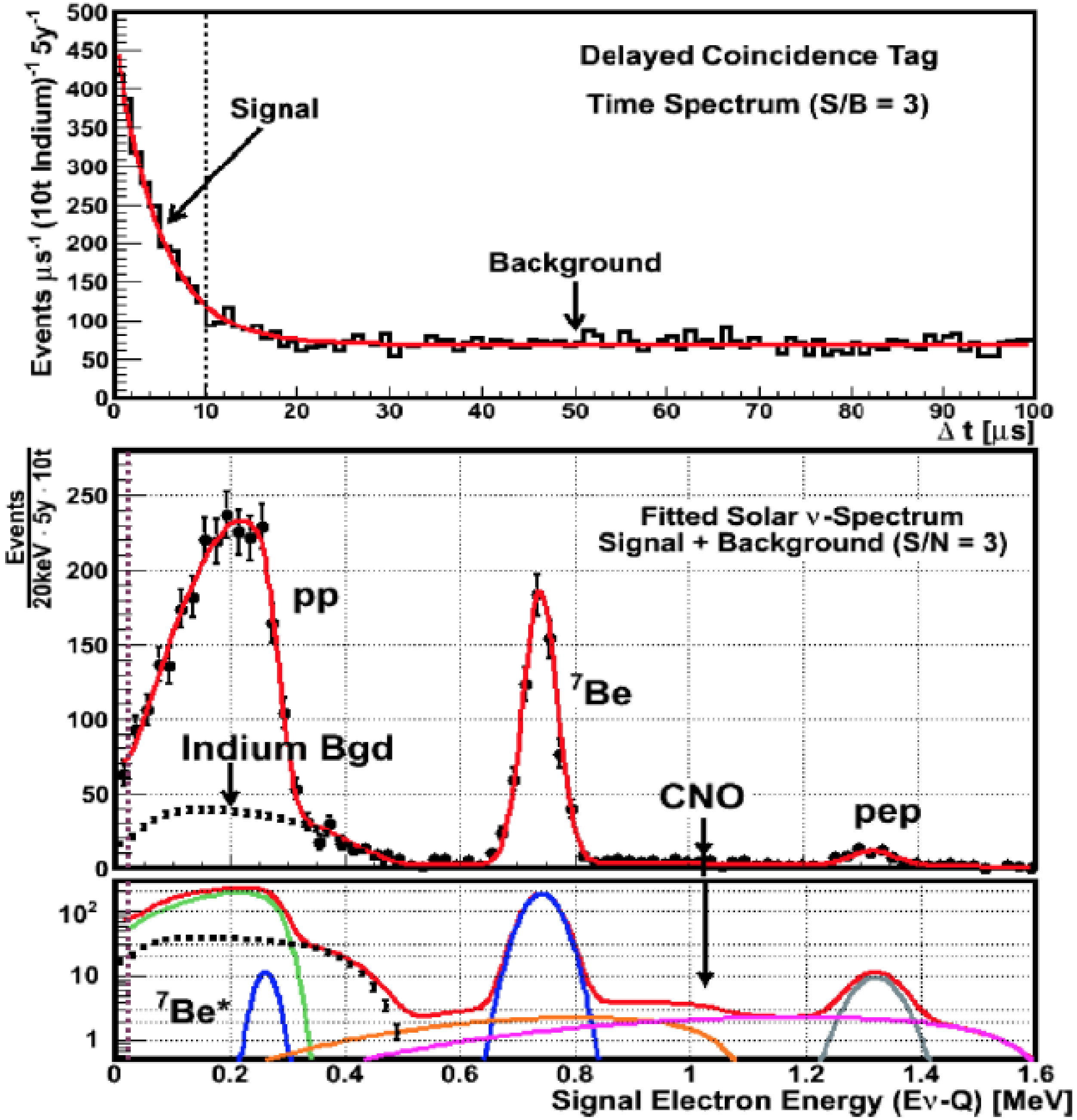
5. Cryogenic Indium detector for solar neutrinos

- Raghavan proposed an In detector for solar neutrinos (1976)

  ~2005 proposed segmented 8% In-loaded 100 ton LS detector
- Segmentation needed to reduce huge random background from natural β decay of ^{115}In (95% abundance) – "photon lattice" 3 in. resol. in X,Y, Z
- Booth (1987) explored possibility of measuring q-p in superconducting In
- How about a cryogenic bolometer of In metal (or a suitable compound)?

Levels excited in low energy ν_e CC interaction with ^{115}In





Ref. Raghavan's Physics Colloquium at BARC

- Measure E spectrum of *pp*, ^{7}*Be*, *pep* neutrinos (~50–1500 keV) in real time
- Measure core temperature of sun *directly* via Doppler broadening of ^{7}Be neutrinos [Bahcall] as well as the *p-p* neutrinos [Grieb, Raghavan 2007] *
- Search for a possible sterile neutrino-electron neutrino mixing using a radioactive ν_e source or one made online using a high current p/d beam on a suitable target [6].
- Search for neutrino-antineutrino oscillations using strong anti-ν_e source or one made online using a high current p/d beam on a suitable target.
- Search for dark matter (2-body) decay and/or annihilation through unidentified peak in neutrino spectrum.

- Potentially excellent energy resolution of cryogenic bolometer (~ few keV) using Indium especially suited for the items 2 and 5.
- Cryogenic detector (10 mK) needs segmentation into units of between 1-3 cm dimension (a full cost-benefit analysis necessary) with total mass 5-10 tons (Vol ~ $1 m^3$)
- 5-10 modules each with its own shielding. In view of the internal ^{115}In radioactivity the shielding could be placed *outside* the cryostat
- Each of the segments would have at least one T-sensor
- Timing < 1 μs needed. Bolometer may not be appropriate?

Acknowledgements

- ICAL magnet: Shiba Behera, M.S. Bhatia, Ajit Mohanty
- MM, DMP decay sensitivity of ICAL: Nitali Dash, Gobinda Majumder
- Sterile neutrino mixing with ICAL: Shiba Behera, Anushree Ghosh, Sandhya Choubey, Ajit Mohanty

Thank you

A view from Yosemite Valley

Lesser flamingoes @ mangroves near BARC, Mumbai

C. Grieb, R. Raghavan, PRL **98**, 141102 (2007)

TABLE I. Neutrino energies and thermal shifts.

	q(lab) keV	$+\Delta\langle E\rangle$ keV	$+\delta\langle E\rangle$ keV	$+\Delta E$ keV	$+\delta E$ keV
pp	420.2[a]	3.41[b]	1.6	5.2[c]	1.7
pep	1442.2	6.65[b]	4.54		
^{7}Be	861.8	1.29[b]	0.81		

[a] Q-value

[b] Mean energy shift (for *pp* in range 110-340 keV)

[c] Shift of max. energy in spectrum

$\delta\langle E\rangle$ Precision attainable in $\Delta\langle E\rangle$

⇐