Physics potential of INO-ICAL

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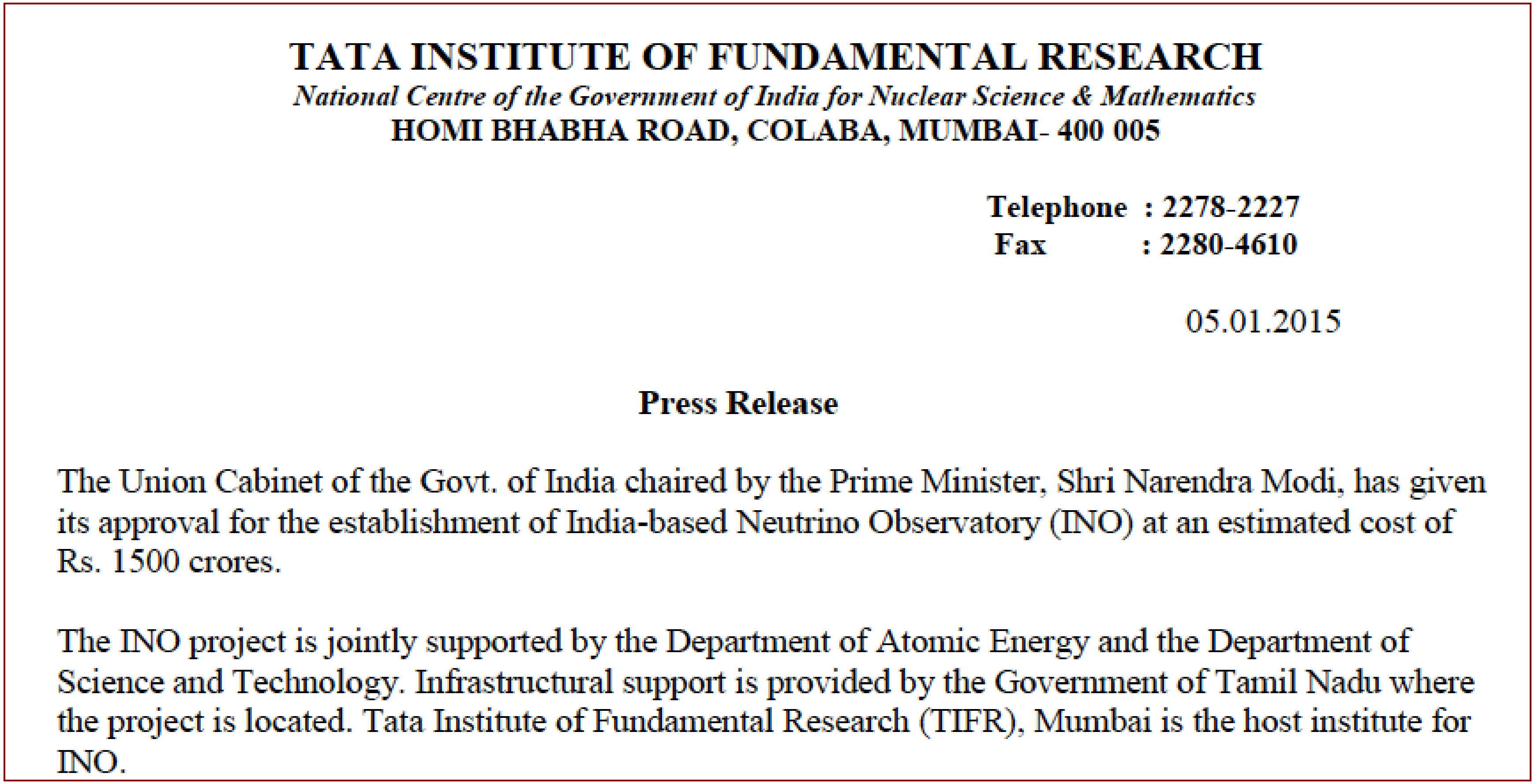
TIFR, Mumbai, India
(For the INO-ICAL Collaboration)

Workshop on neutrino programs with facilities in Japan, Aug 4-6th, 2015

Some good news started this year…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05.01.2015

Press Release

The Union Cabinet of the Govt. of India chaired by the Prime Minister, Shri Narendra Modi, has given its approval for the establishment of India-based Neutrino Observatory (INO) at an estimated cost of Rs. 1500 crores.

The INO project is jointly supported by the Department of Atomic Energy and the Department of Science and Technology. Infrastructural support is provided by the Government of Tamil Nadu where the project is located. Tata Institute of Fundamental Research (TIFR), Mumbai is the host institute for INO.

But there is a long way to go…..

The INO-ICAL White Paper

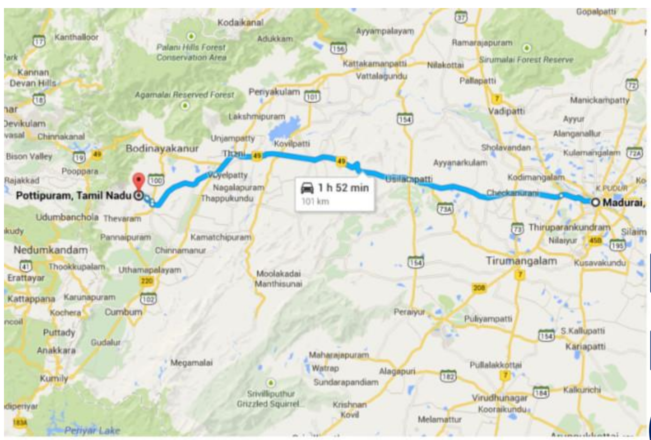
INO/ICAL/PHY/NOTE/2015-01

Physics Potential of the ICAL detector at the India-based Neutrino Observatory (INO)

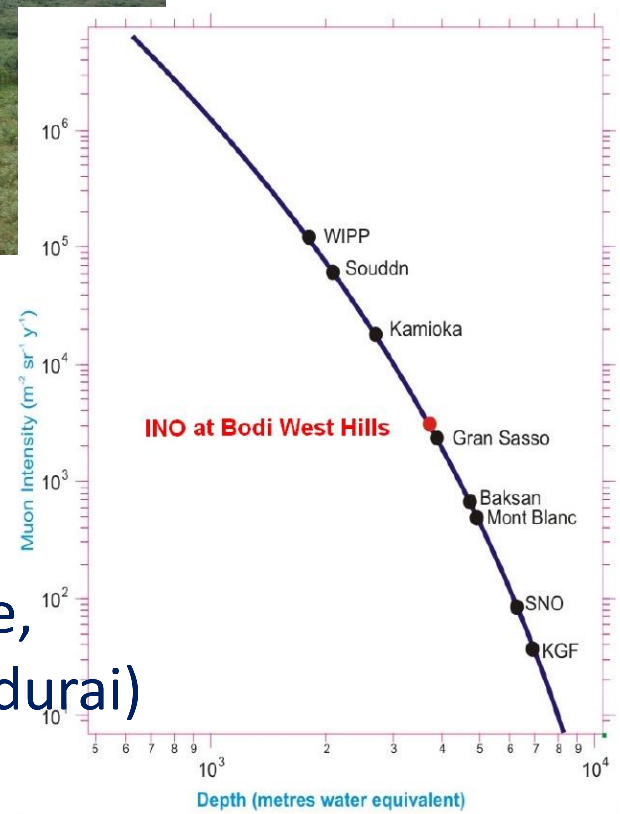
The ICAL Collaboration

arXiv:1505.07380v1 [physics.ins-det] 27 May 2015

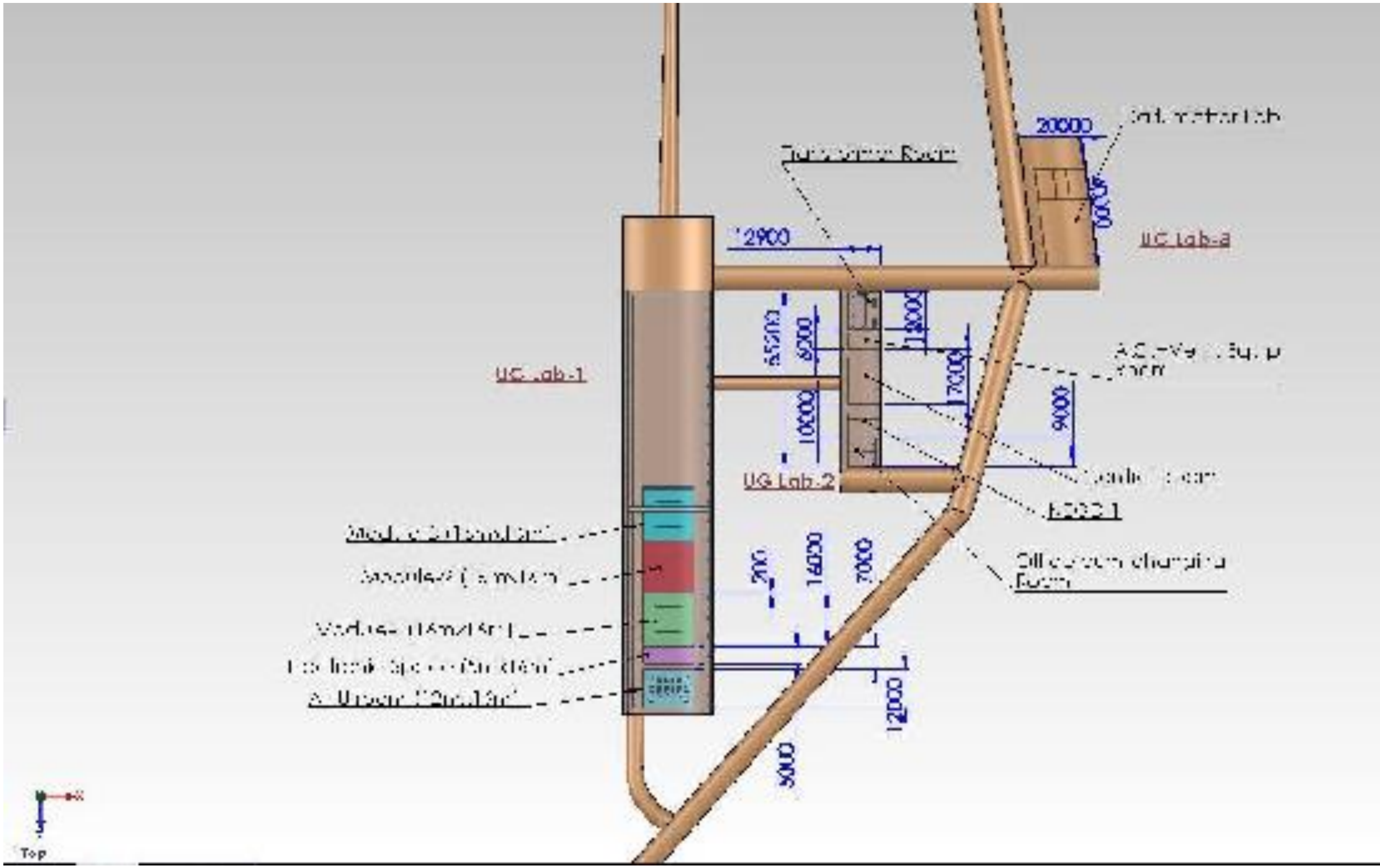
The location of INO



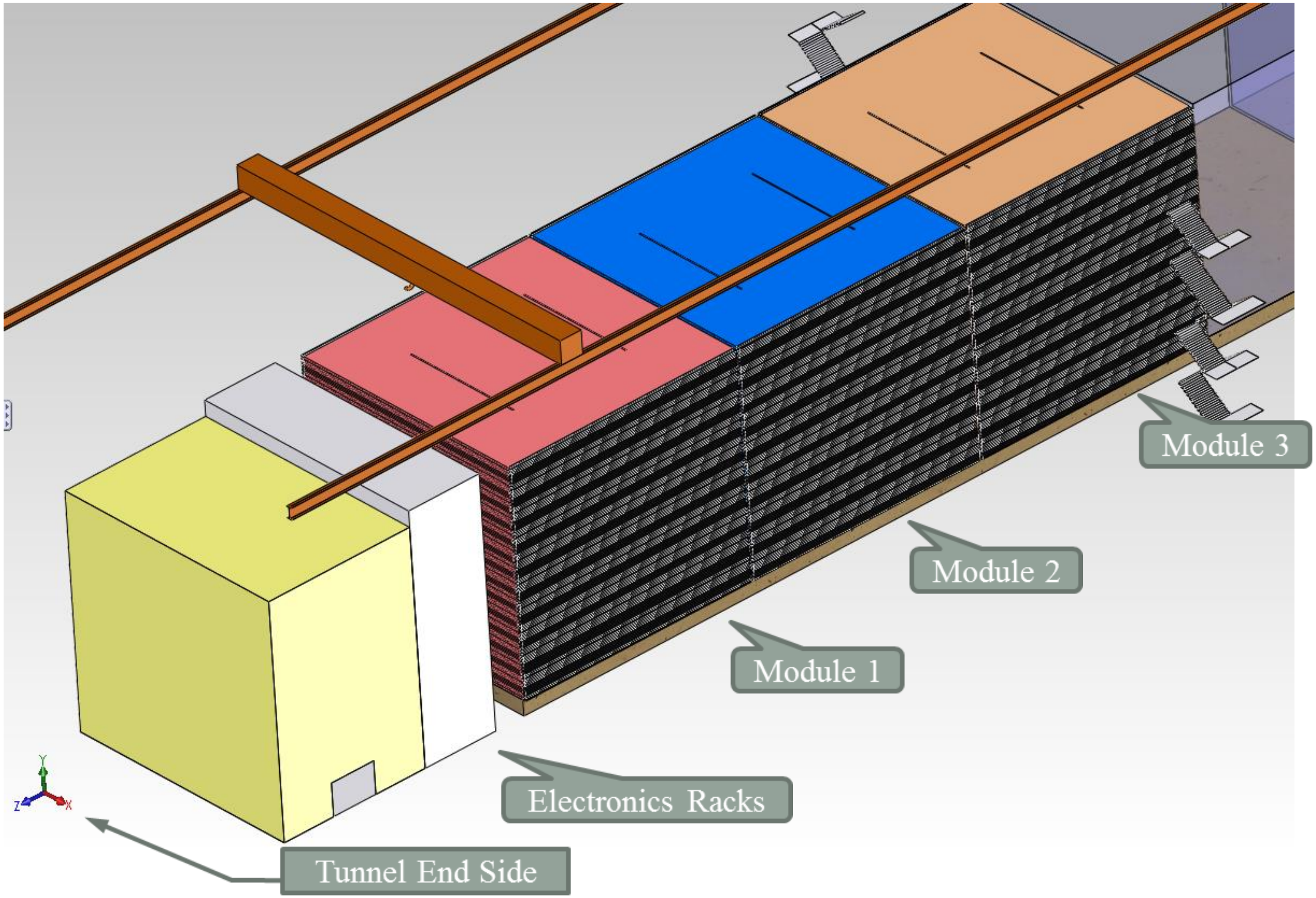
Bodi West Hills,
Pottipuram Village,
(100 km from Madurai)
Tamil Nadu State



The cavern


20000
12900
UG Lab-1
UG Lab-2
10000
9000
16000
7000
12000
5000
Top

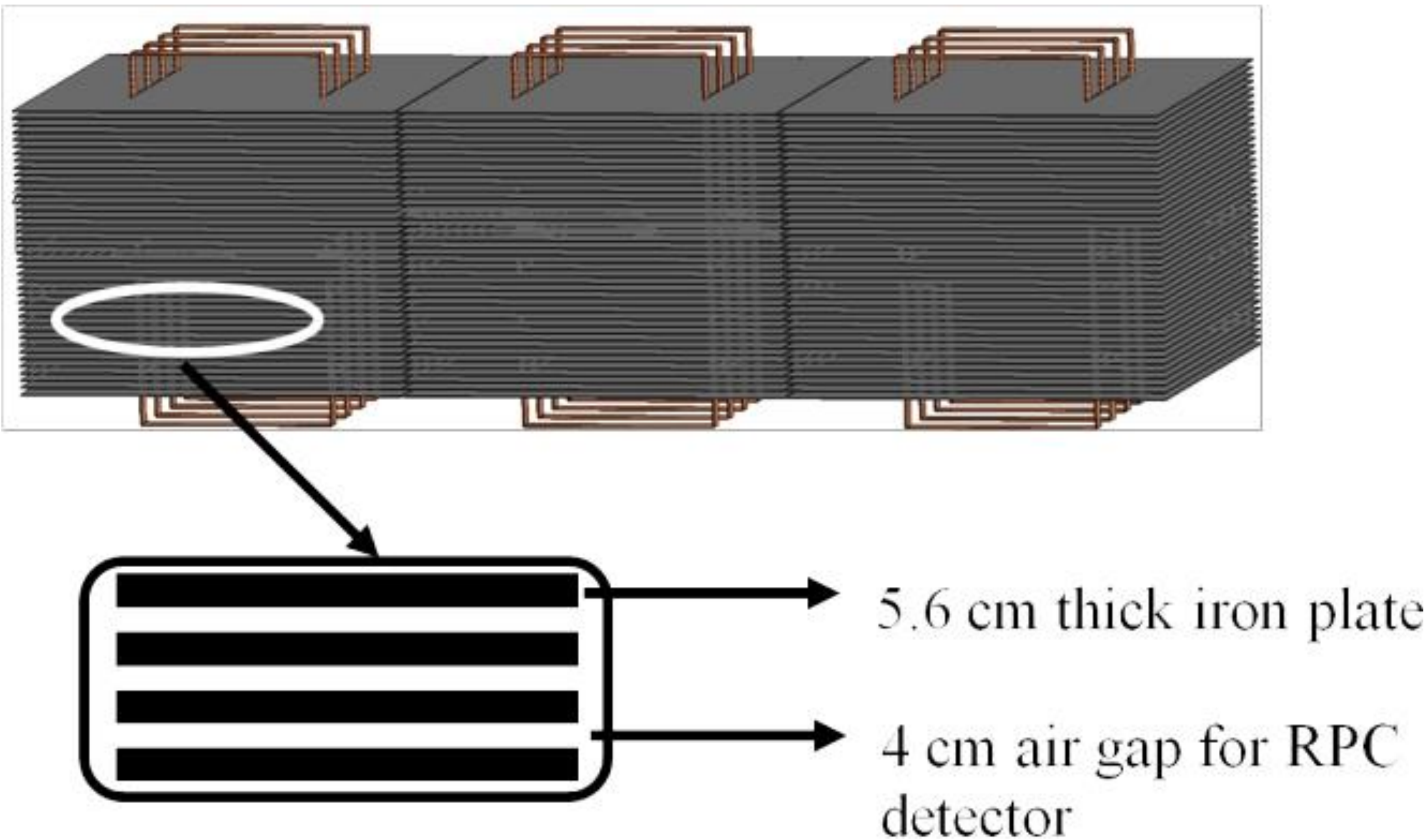
ICAL Modules in the main cavern



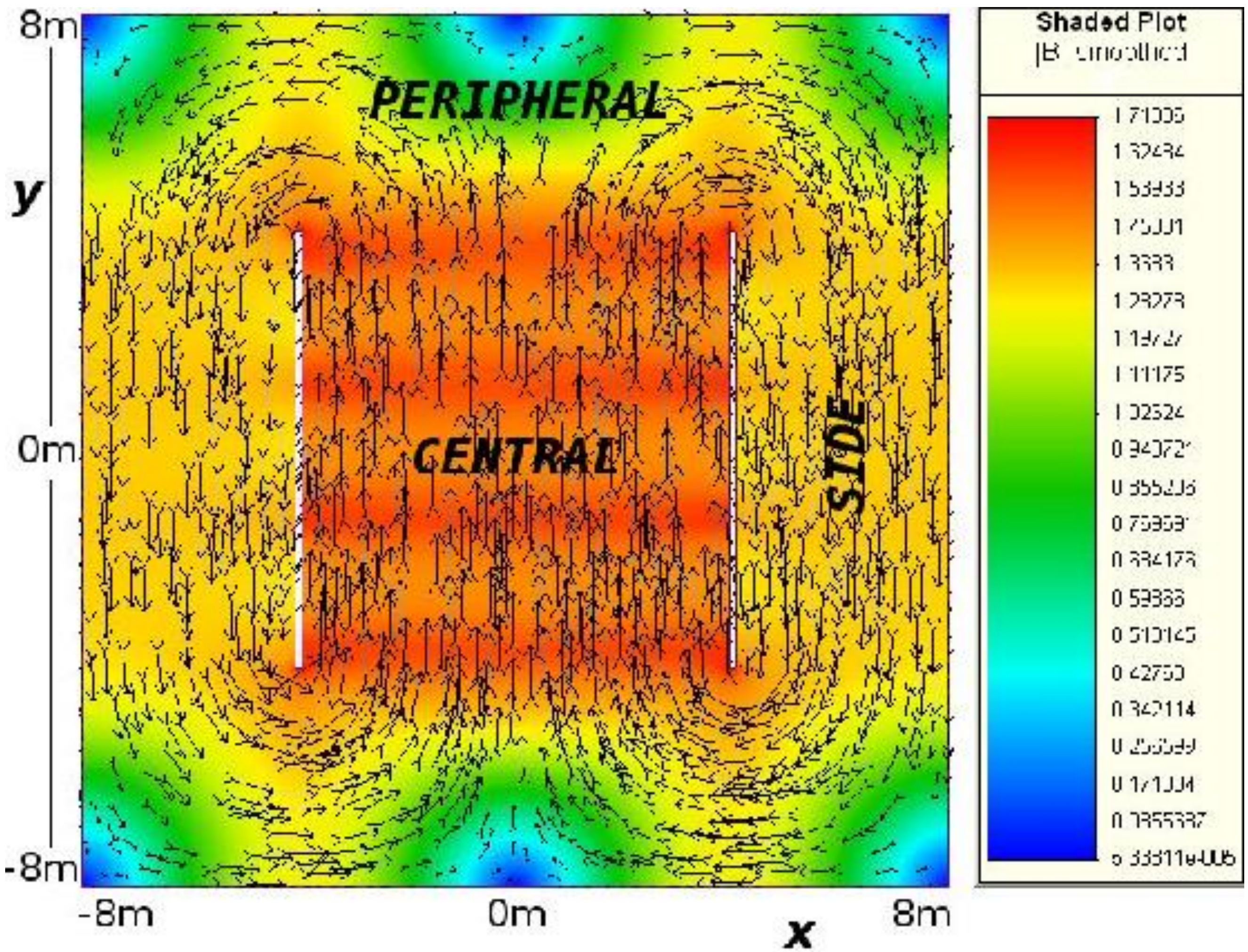
The ICAL detector: desiderata

- ***Large target mass*** *(50 – 100 kt)*
- ***Good tracking and Energy resolution***
  (Tracking calorimeter)
- ***Good directionality for up/down discrimination***
  (Nano-second time resolution)
- ***Charge identification capability***
  (uniform, homogeneous magnetic field)
- ***Ease of construction & Modularity***
- ***Complementarity to the other existing / proposed detectors***

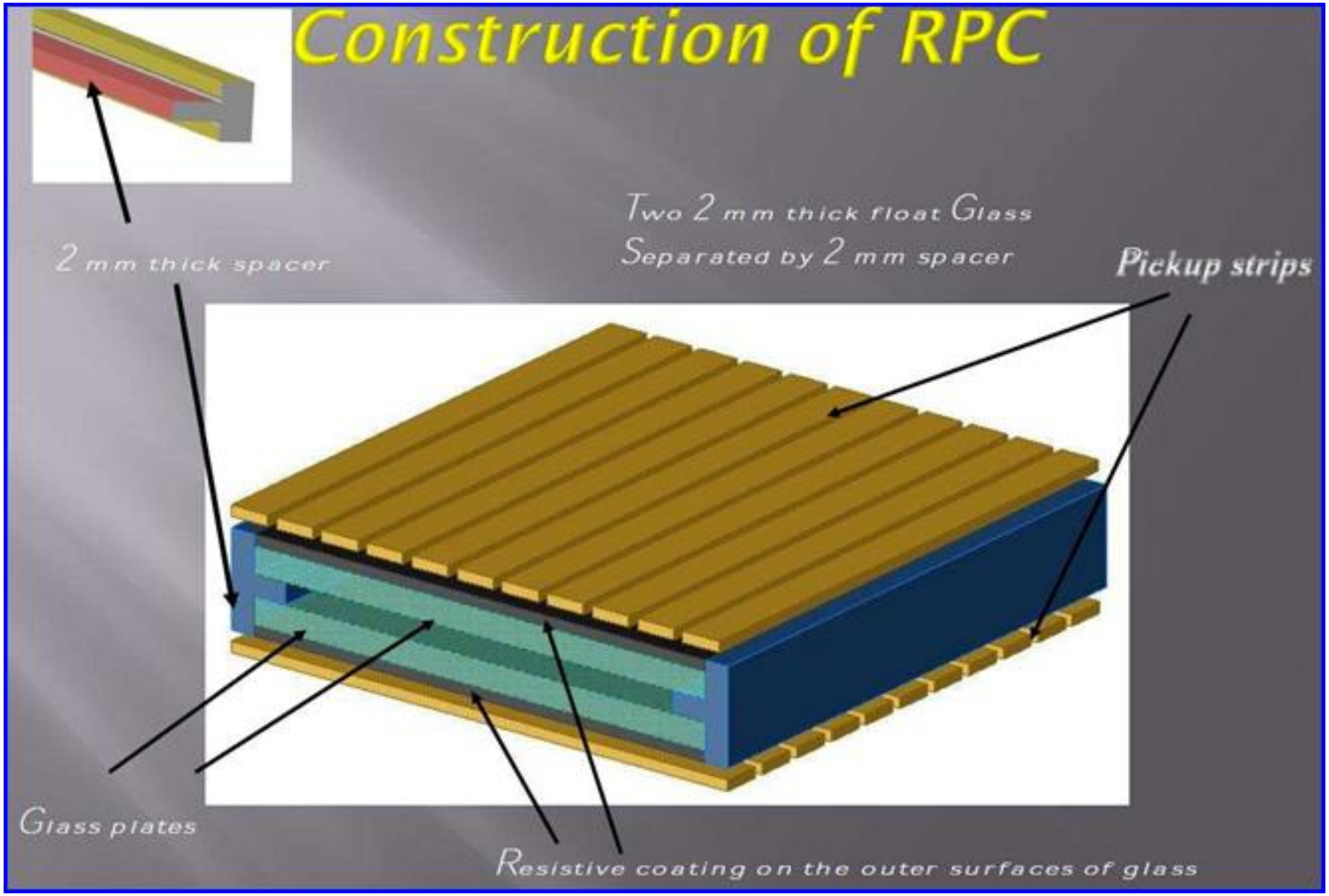
The ICAL detector



The magnetic field



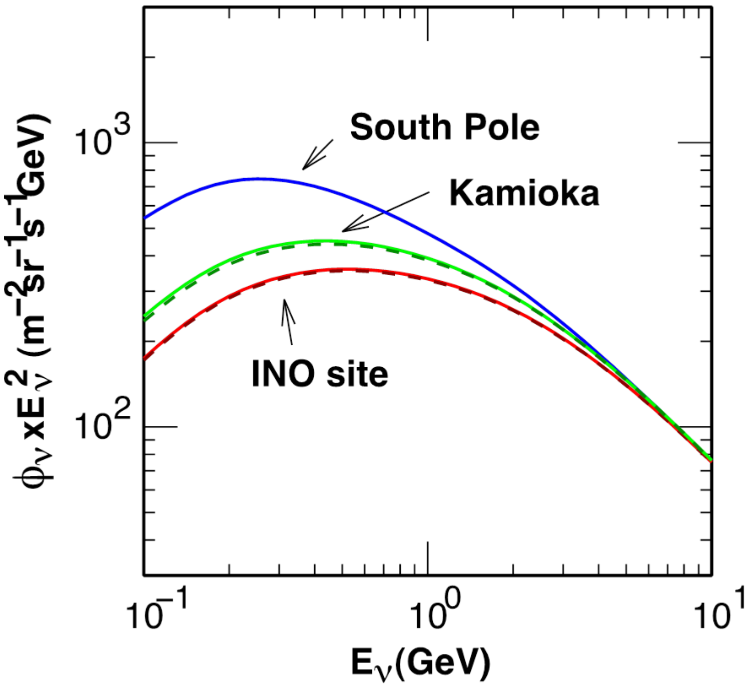
The active detector: RPC

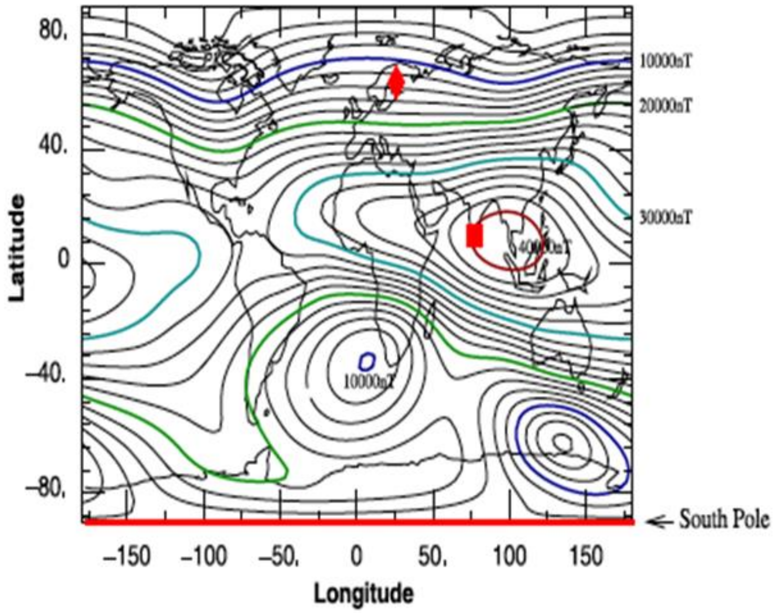


The detector specifications

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	*$3.7 X 10^6$*

Atmospheric neutrino flux





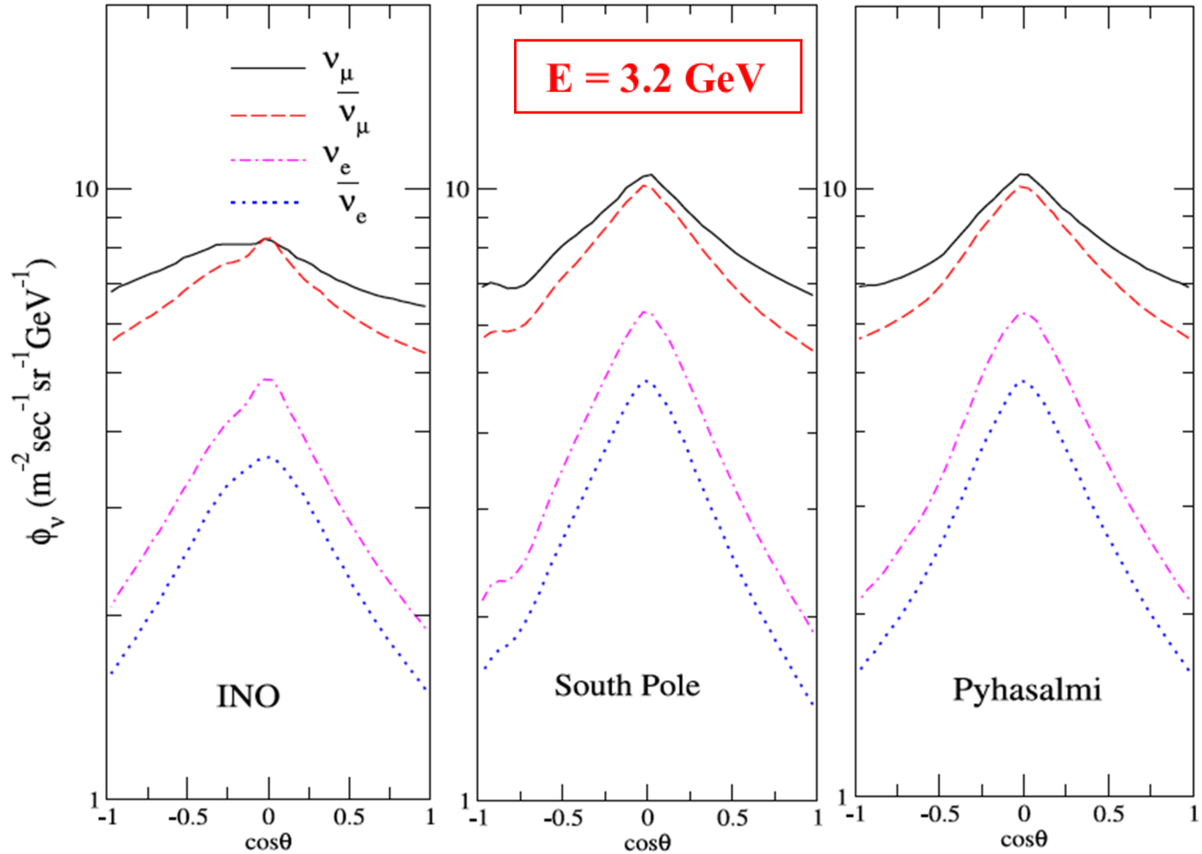
Horizontal component of the geomagnetic field

Magnitude at the Earth's surface ranges from 25 to 65 microtesla

Averaged over all directions
Summed over all flavors of neutrino and anti-neutrino

Athar, Honda, Kajita, Kasahara, Midorikawa, arXiv:1210.5154 [hep-ph]

Angular distribution of neutrino flux

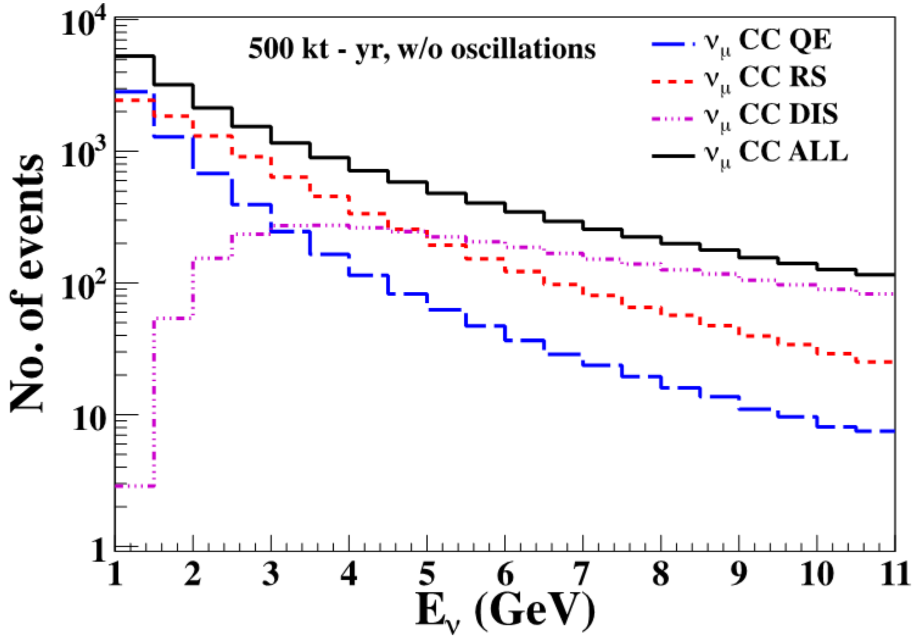


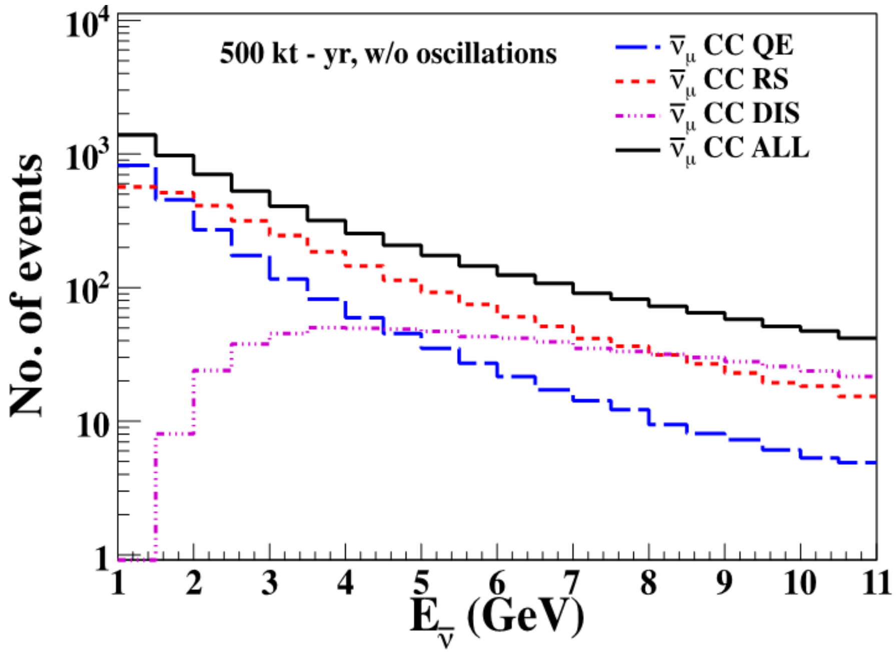
Athar, Honda, Kajita, Kasahara, Midorikawa, arXiv:1210.5154 [hep-ph]

Simulation framework

NUANCE	**Neutrino Event Generation** $\nu_\ell + N \rightarrow \ell + X$. Generates particles that result from a random interaction of a neutrino with matter using theoretical models for both neutrino fluxes and cross-sections.	**Output:** (i) Reaction Channel (ii) Vertex and time information (iii) Energy and momentum of all final state particles
GEANT	**Event Simulation** $\ell + X$ through simulated ICAL Simulates propagation of particles through the ICAL detector with RPCs and magnetic field.	**Output:** (i) x, y, z, t of the particles as they propagate through detector (ii) Energy deposited (iii) Momentum information
DIGITISATION	**Event Digitisation** (X, Y, Z, T) of final states on including noise and detector efficieny Add detector efficiency and noise to the hits.	**Output:** (i) Digitised output of the previous stage
ANALYSIS	**Event Reconstruction** $(E, \vec{p})$ of ℓ, X (total hadrons) Fit the muon tracks using Kalman filter techniques to reconstruct muon energy and momentum; use hits in hadron shower to reconstruct hadron information.	**Output:** (i) Energy and momentum of muons and hadrons, for use in physics analyses.

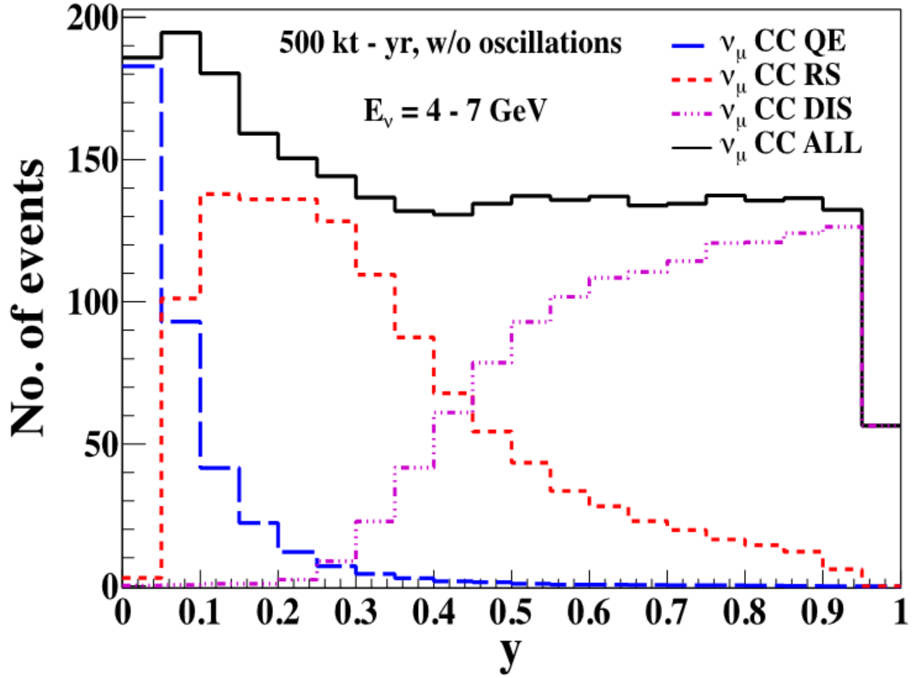
Event distribution (NUANCE)

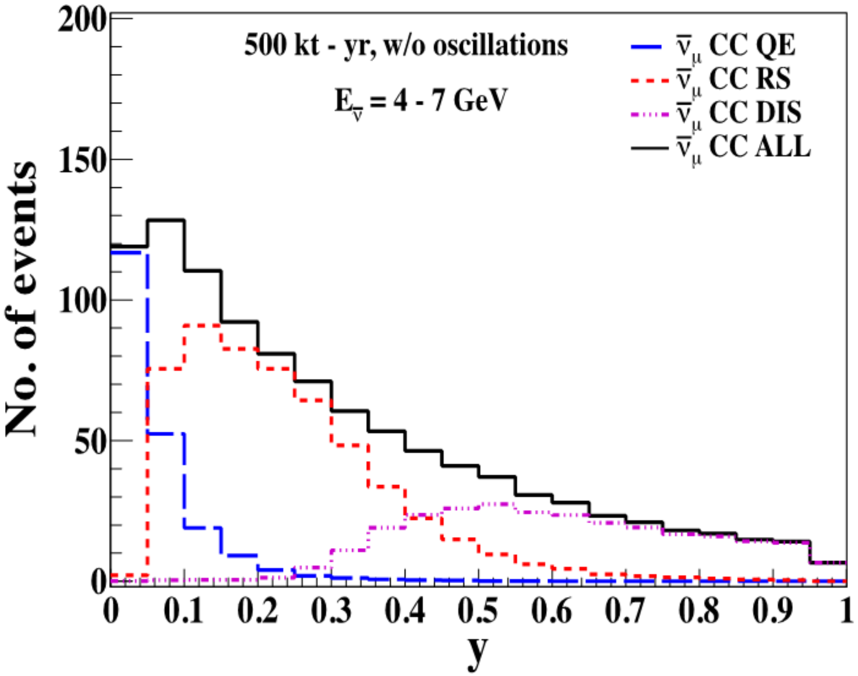




Relative contributions of three cross-section processes to the total events in the absence of oscillation and without detector efficiency and resolutions

Inelasticity distribution

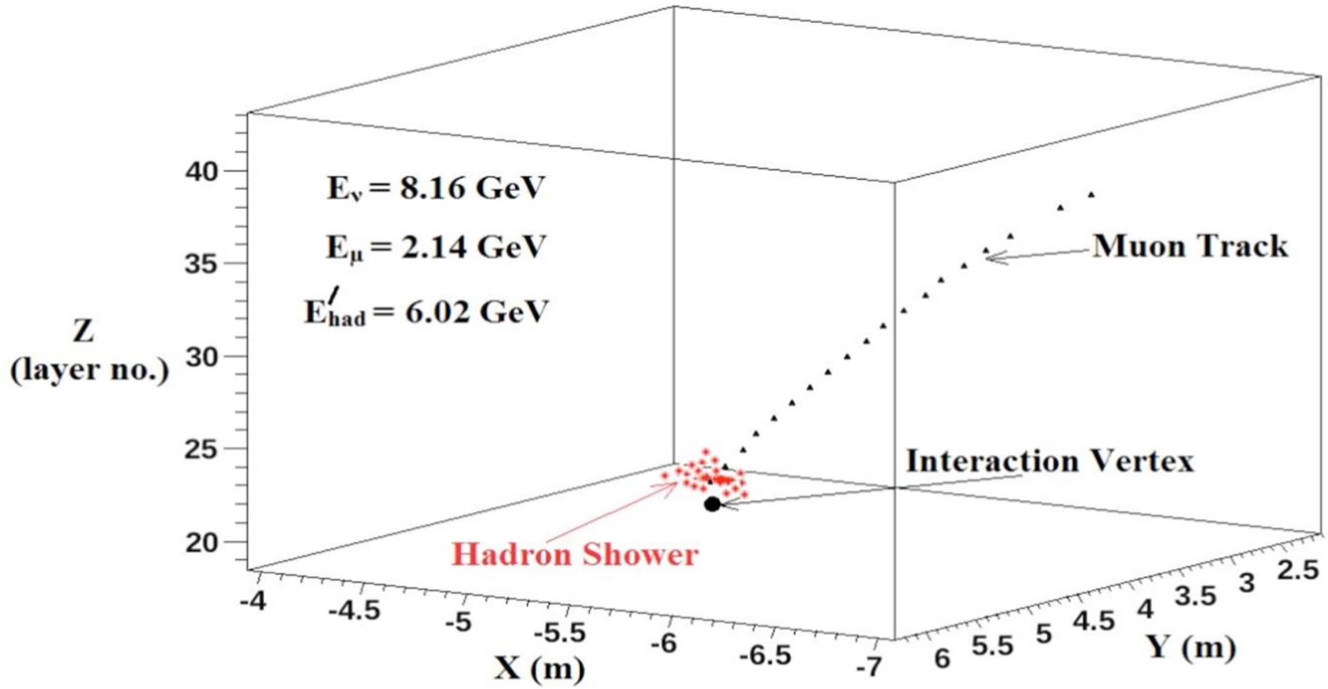




Inelasticities in individual events have a wide distribution

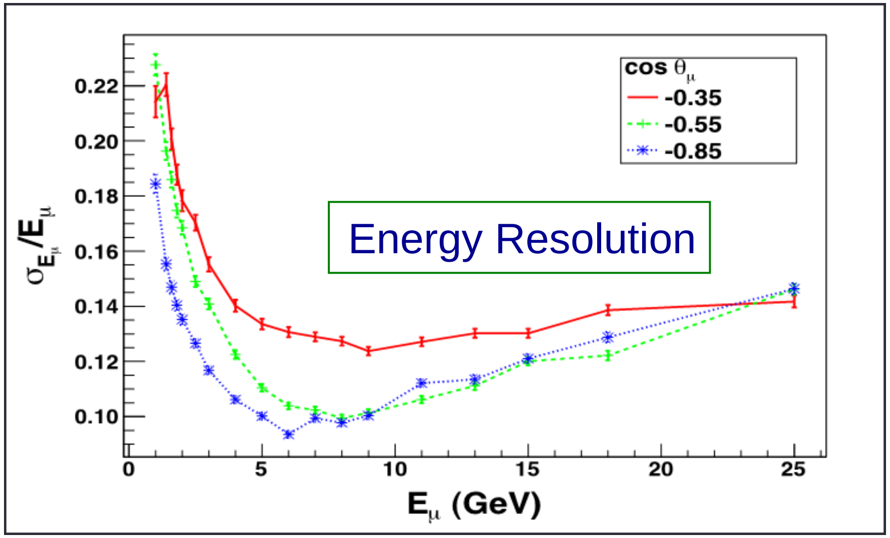
Important to measure inelasticity in individual events

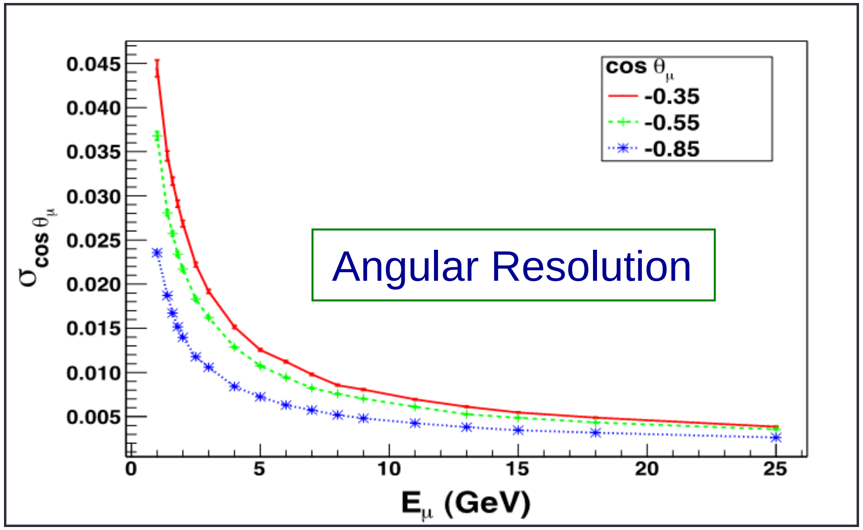
A typical CC event in ICAL

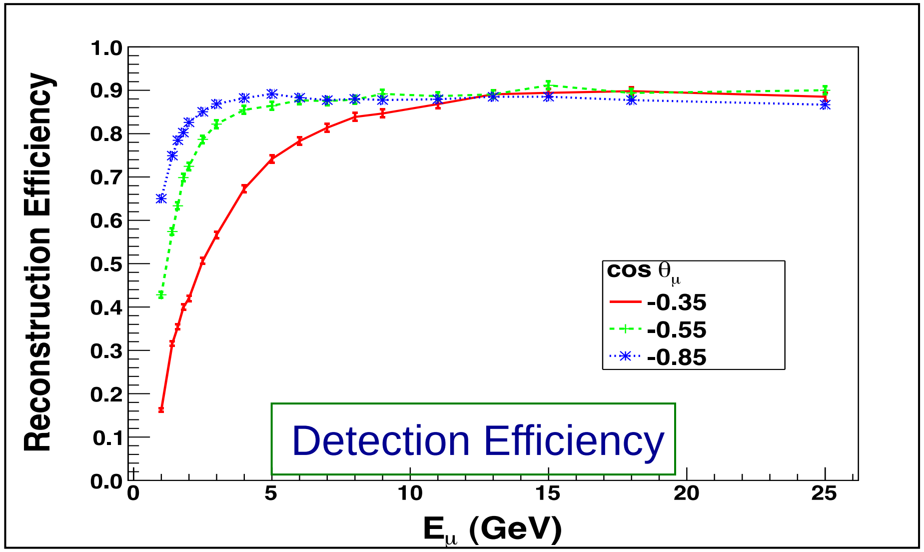


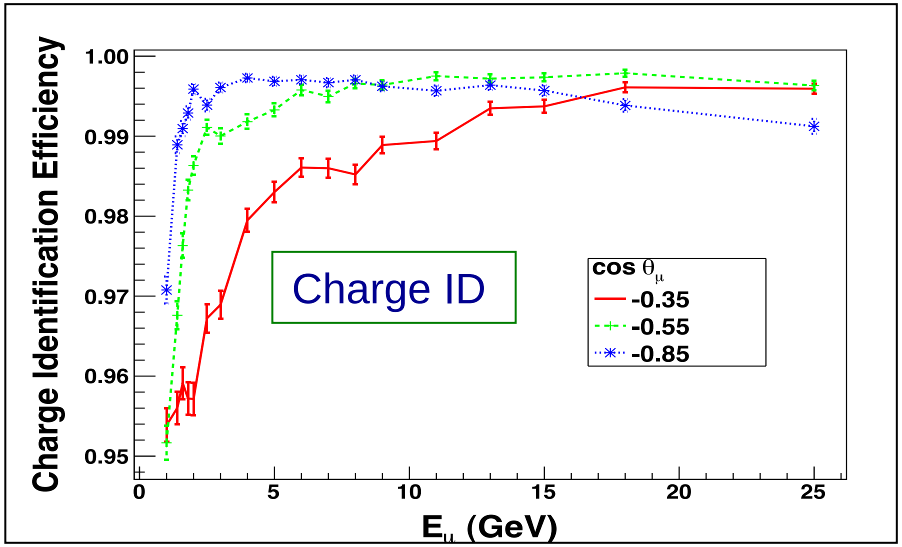
Using GEANT4 simulation

Detector response to muons

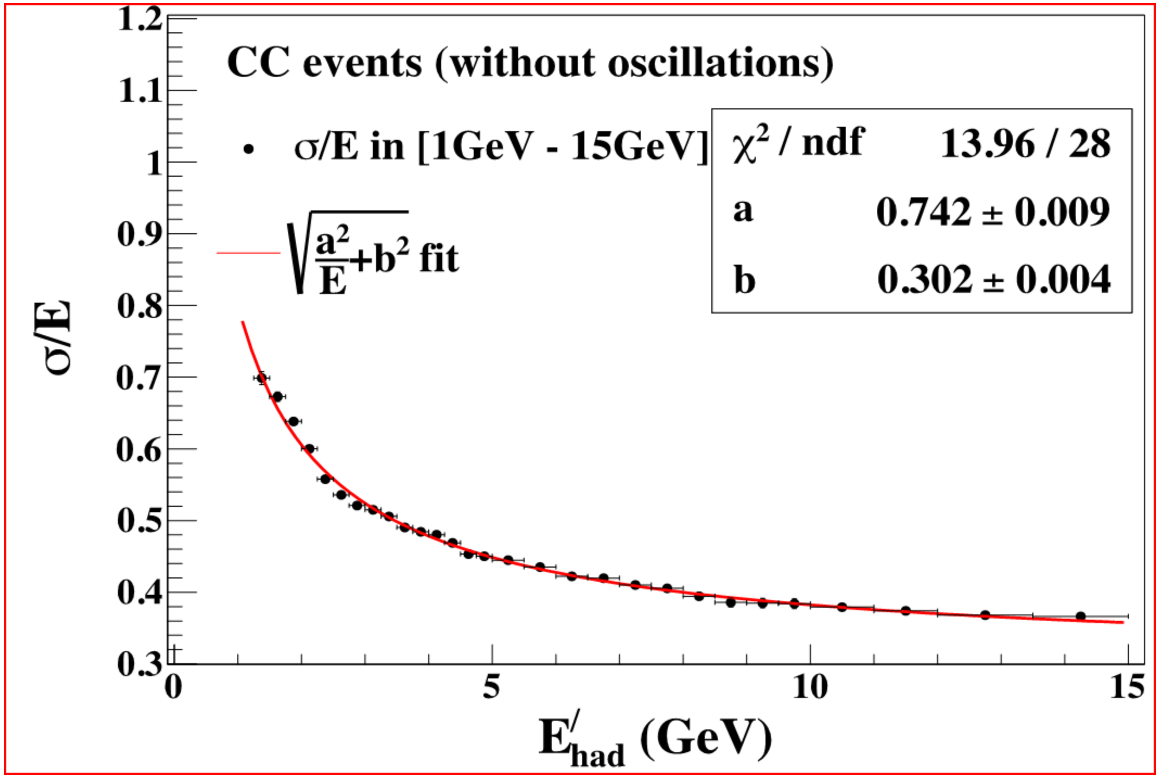








Detector response to hadrons



$E_h = E_\nu - E_\mu$ (from hadron hit calibration)

Hadron energy resolution: 85% at 1 GeV and 36% at 15 GeV

Moon Moon Devi, Anushree Ghosh, Daljeet Kaur, Lakshmi S. Mohan etal., JINST 8 (2013) P11003

Typical analysis technique

We define the Poissonian χ^2_- for μ^- events as :

$$\chi^2_- = \min_{\xi_l} \sum_{i=1}^{N_{E'_{\rm had}}} \sum_{j=1}^{N_{E_\mu}} \sum_{k=1}^{N_{\cos\theta_\mu}} \left[2(N_{ijk}^{\rm theory} - N_{ijk}^{\rm data}) - 2N_{ijk}^{\rm data} \ln\left(\frac{N_{ijk}^{\rm theory}}{N_{ijk}^{\rm data}}\right)\right] + \sum_{l=1}^{5} \xi_l^2 \,,$$

where

$$N_{ijk}^{\rm theory} = N_{ijk}^0 \left(1 + \sum_{l=1}^{5} \pi_{ijk}^l \xi_l\right) .$$

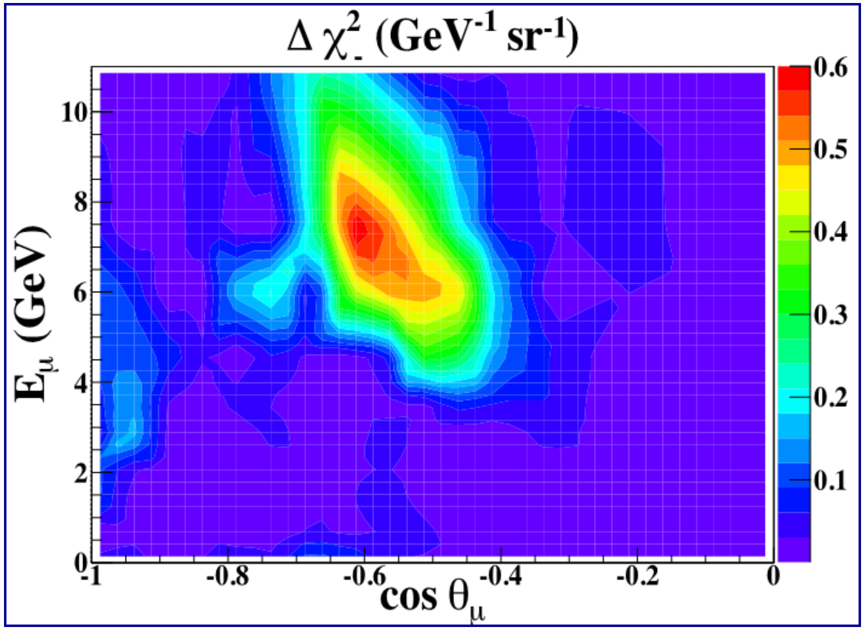
Observable	Range	Bin width	Total bins	
E_μ (GeV)	$[1,4)$	0.5	6	10
	$[4,7)$	1	3	
	$[7,11)$	4	1	
$\cos\theta_\mu$	$[-1.0,-0.4)$	0.05	12	21
	$[-0.4,0.0)$	0.1	4	
	$[0.0,1.0]$	0.2	5	
$E'_{\rm had}$ (GeV)	$[0,2)$	1	2	4
	$[2,4)$	2	1	
	$[4,15)$	11	1	

1) Overall 5% systematic uncertainty
2) Overall flux normalization: 20%
3) Overall cross-section normalization: 10%

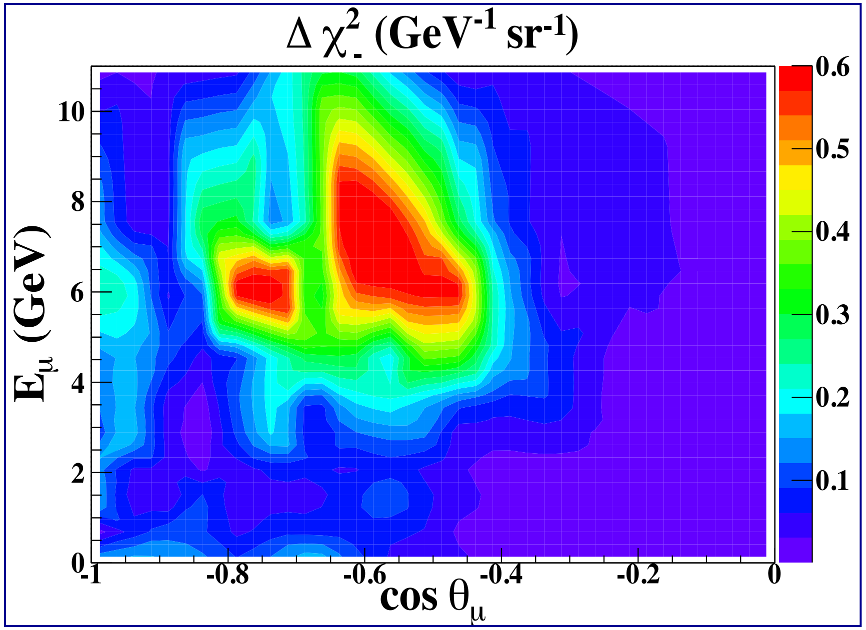
4) 5% uncertainty on the zenith angle dependence of the fluxes
5) Energy dependent tilt factor:
$\Phi_\delta(E) = \Phi_0(E)\,[E/E_0]^\delta \approx \Phi_0(E)\,[1+\delta \ln E/E_0]$
where E_0 = 2 GeV and
δ is the 1σ systematic error of 5%

Importance of hadron information

Distribution of $(\Delta\chi^2/\text{area})$ $[\chi^2(\text{IH}) - \chi^2(\text{NH})]$ for mass hierarchy discrimination considering μ^- events

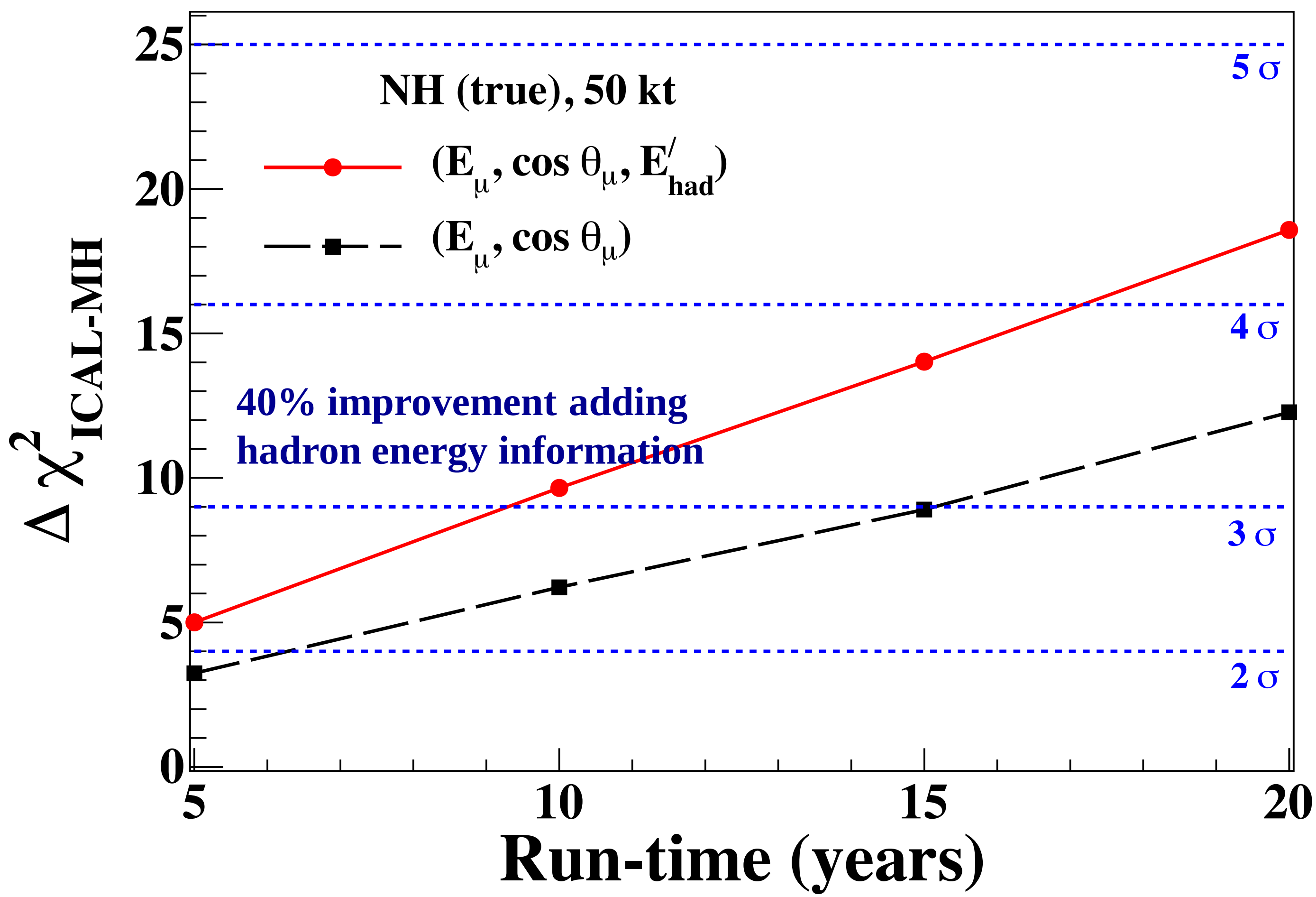


Hadron energy information not used



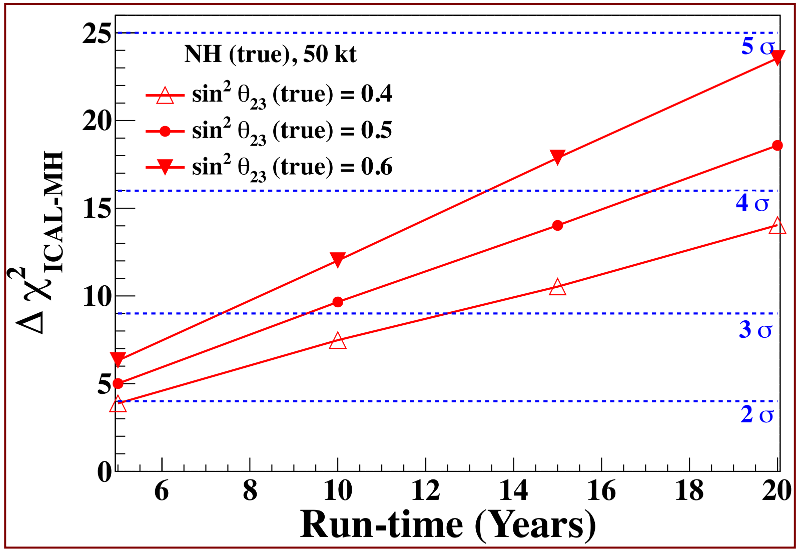
Hadron energy information used

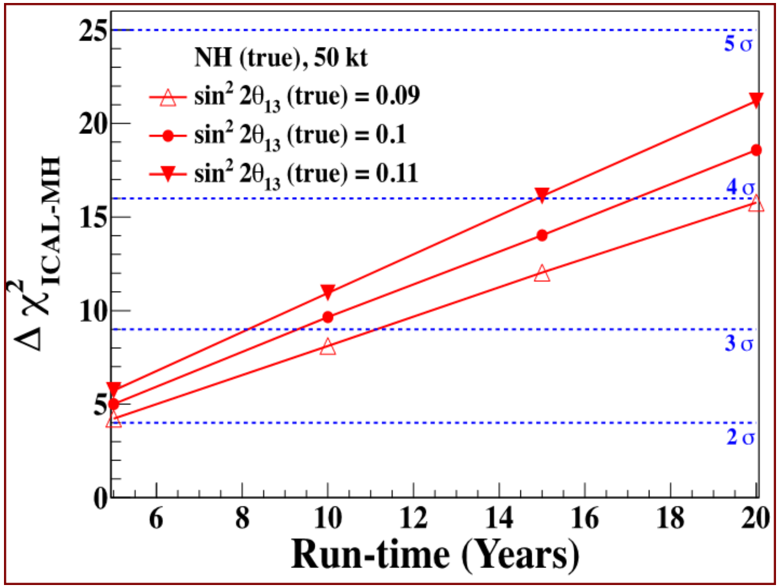
Mass hierarchy sensitivity: ICAL alone



Devi, Thakore, Agarwalla, Dighe, arXiv:1406.3689 [hep-ph]

MH sensitivity dependence on mixing angles

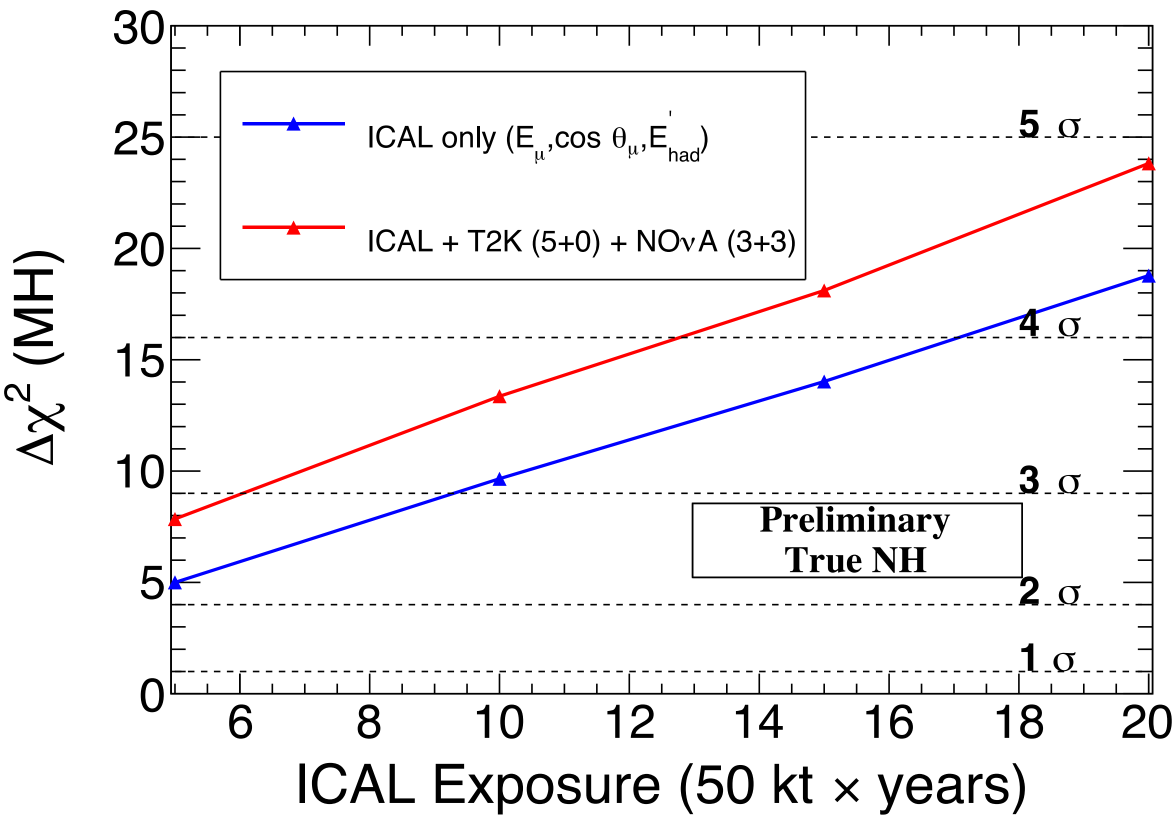




Devi, Thakore, Agarwalla, Dighe, arXiv:1406.3689 [hep-ph]

50 kt ICAL can rule out the wrong hierarchy with median $\Delta\chi^2 \approx 7$ to 12 depending on the true values of θ_{23} and θ_{13} in 10 years

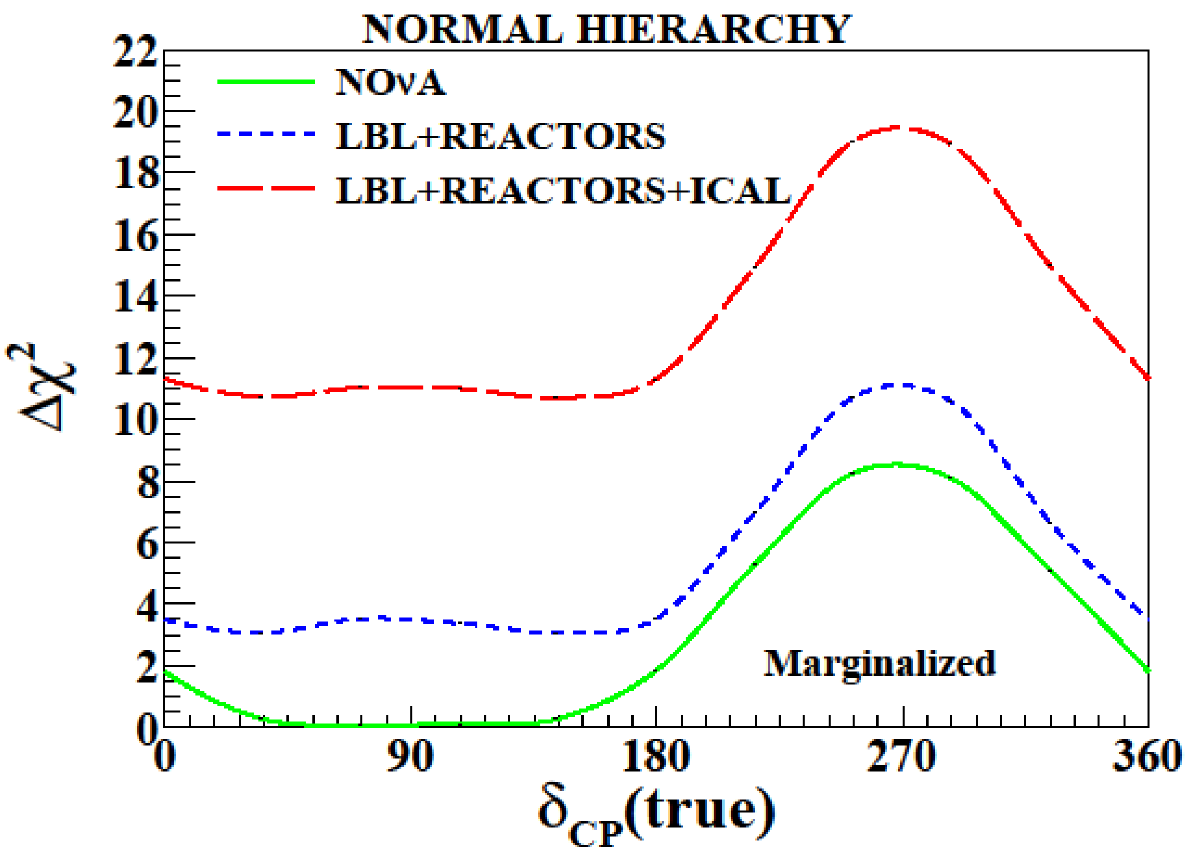
Synergy with T2K and NOvA (at deltaCP=0)



Thakore, Agarwalla, work in progress

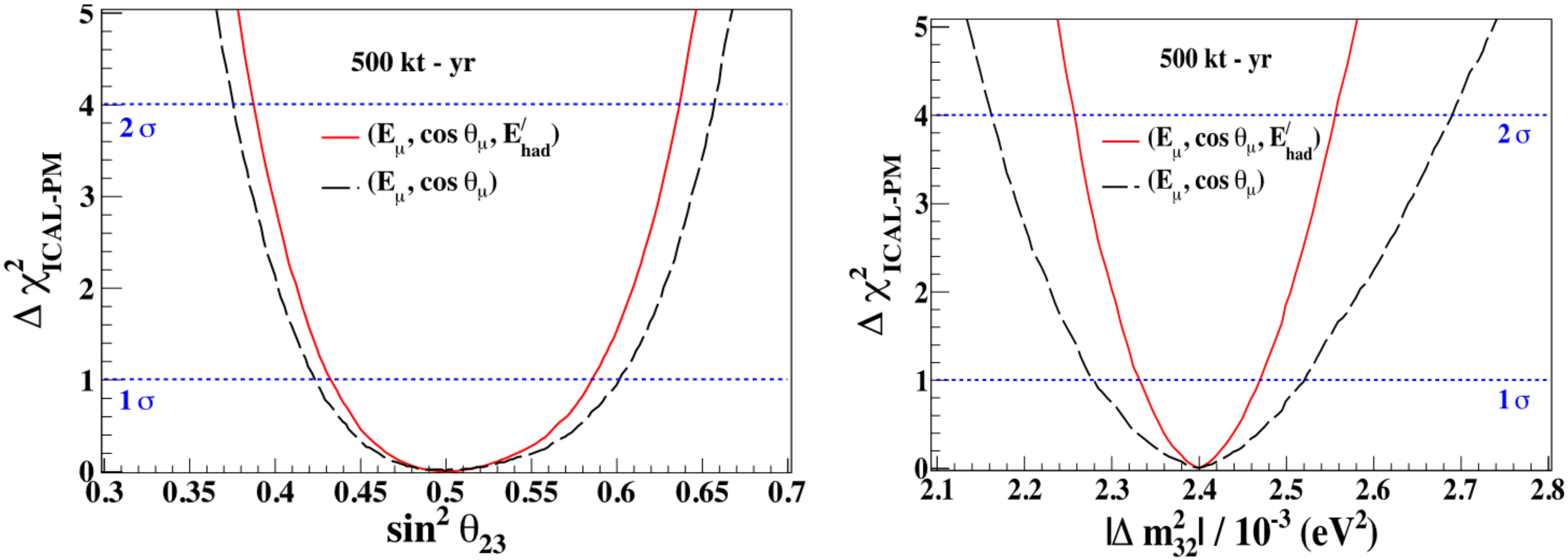
3σ median sensitivity can be achieved in 6 years (deltaCP=0)

Synergy at other DeltaCP values



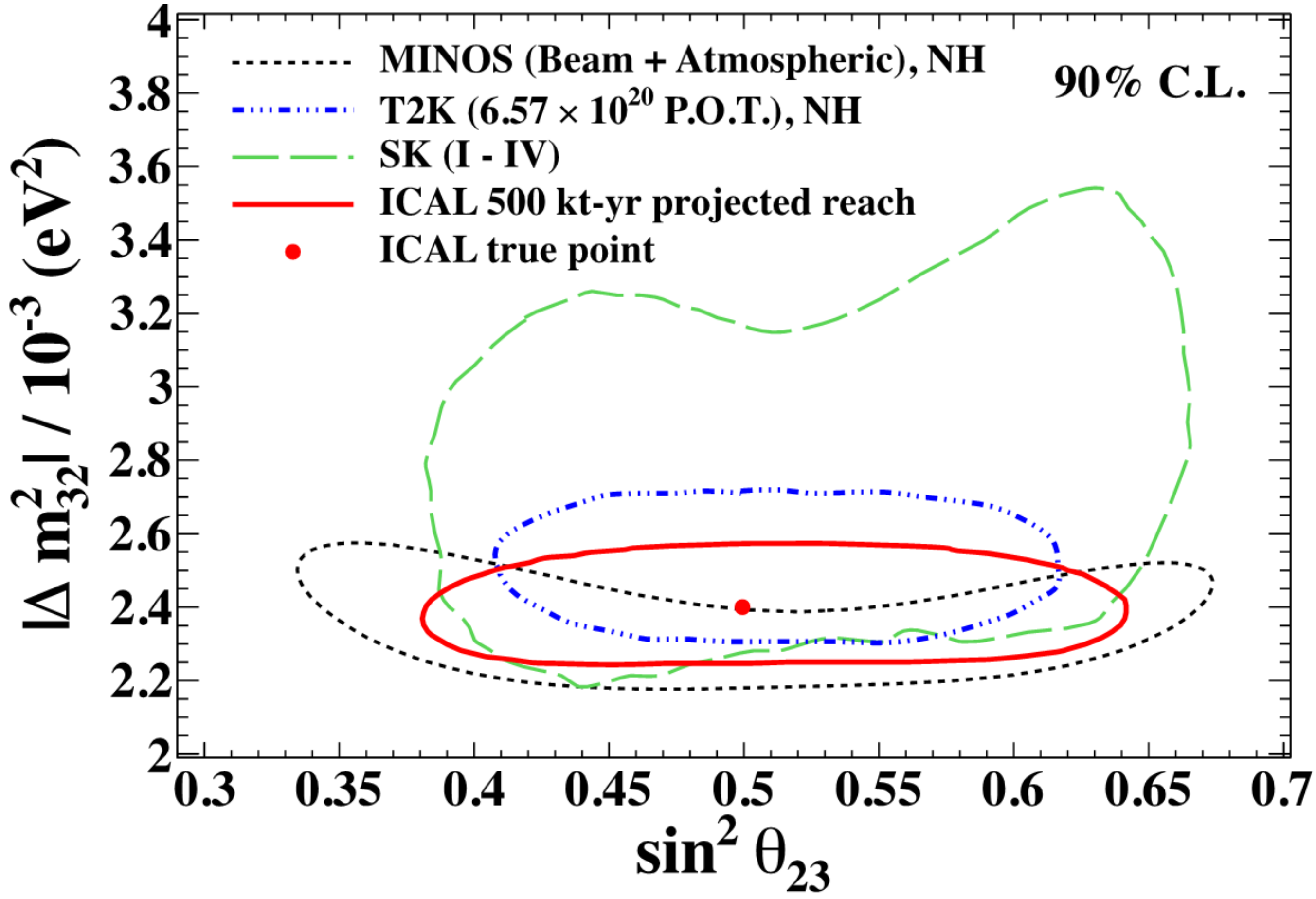
ICAL works even in the ``unlucky’’ deltaCP range….

Sensitivity to atmospheric mixing parameters

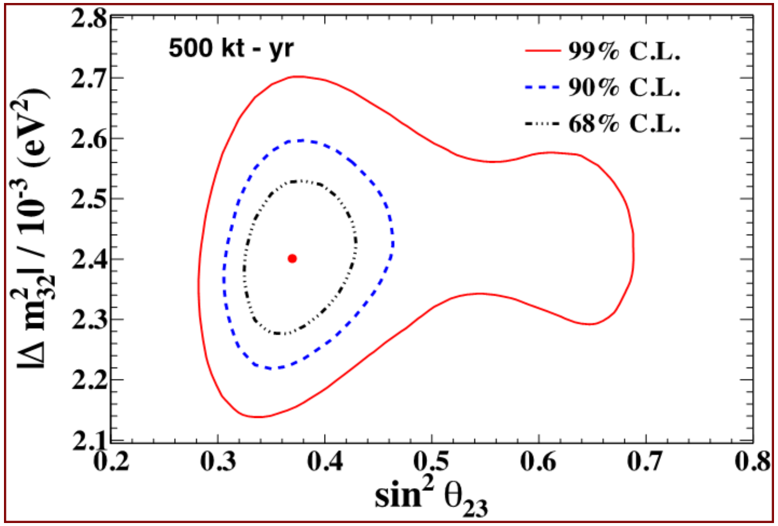


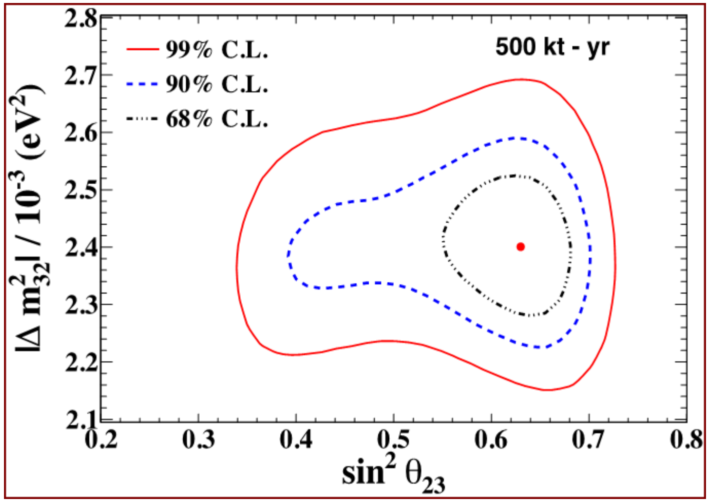
Significant improvement in the precision measurement of atmospheric mass splitting by adding hadron energy information with muon momentum

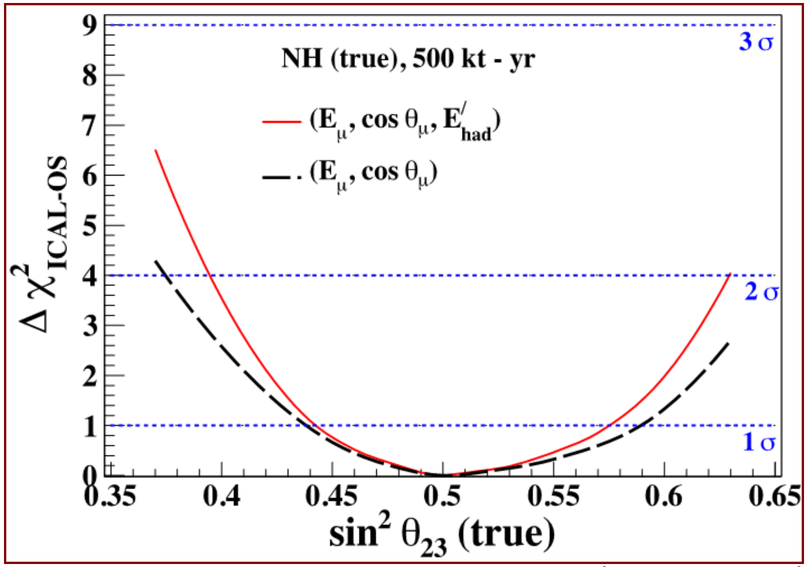
Reach for atmospheric mixing parameters



Octant sensitivity







Median 2σ discovery of θ_{23} octant is possible if θ_{23} is sufficiently away from maximal value

Other analyses in progress

- *Search for sterile neutrinos*
- *CPT violation and Non-Standard Interactions*
- *Search for magnetic monopoles*
- *Search for dark matter from the Sun*
- *Long range forces*
- *Exploiting NC events*
- *Possibilities of electron detection*
- ....

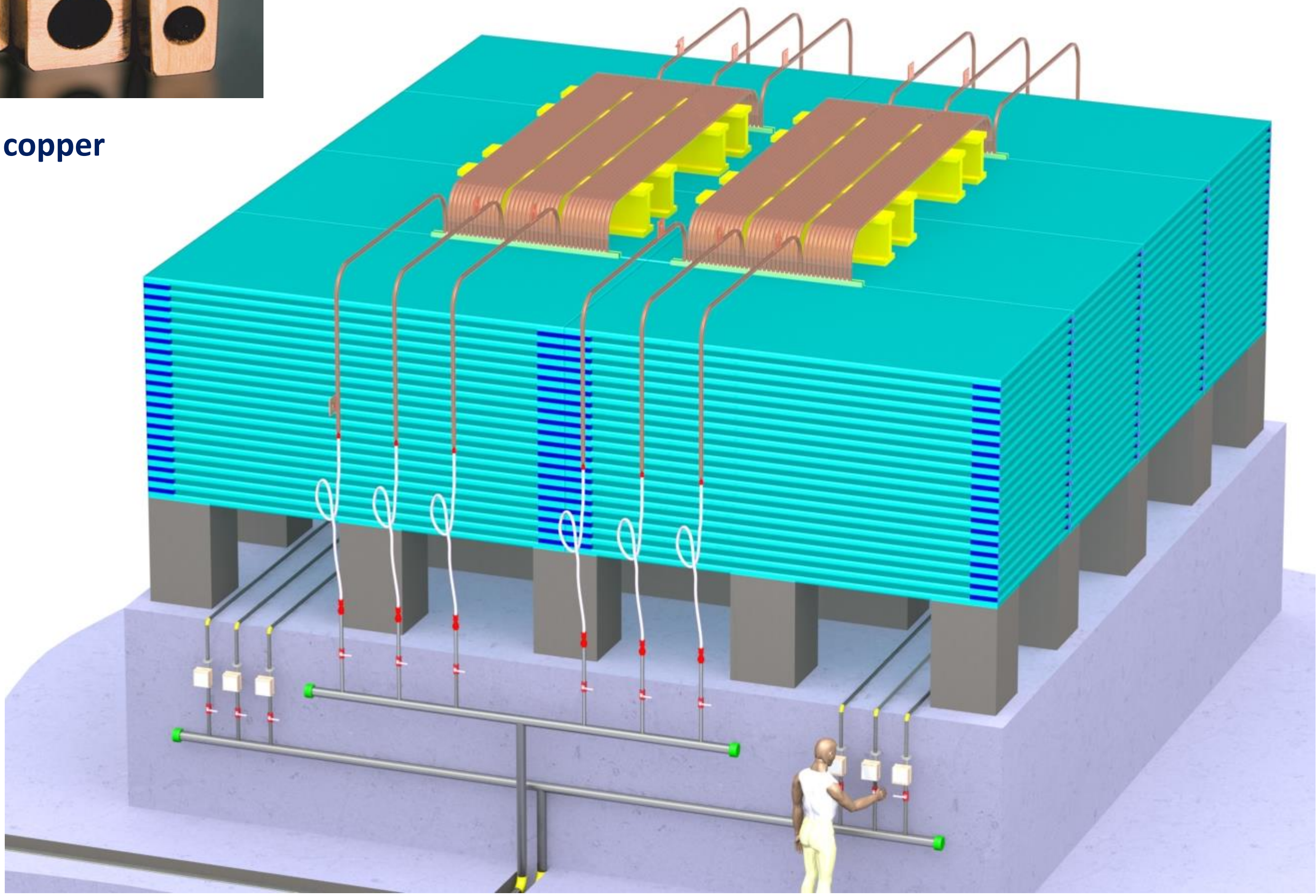
Current status of INO project

- **Site infrastructure development**
- **Development of INO centre at Madurai city (110 km from underground lab)**
  - Inter-Institutional Centre for High Energy Physics (IICHEP)
- **Construction of an 8m x 8m x 2.1 m engineering prototype module**

- **Detector R&D is now over**
- **Detailed Project Report for Detector and DAQ system is ready**
- **Soon go for industrial production of RPCs & associated front-end electronics**

Water cooled copper conductor

Prototype: the next step



The prospects

- Good muon tracking, charge ID and sensitivity to multi-GeV hadrons makes ICAL a unique multi-purpose detector
- Sensitive primarily to mass hierarchy, but also to many other new physics possibilities
- Synergy with ongoing and upcoming long baseline experiments
- Waiting for final go-ahead to start making the tunnel (t=0)
- The first module expected to start taking data at t=5 years

Thank You

- Collaborators are welcome…

http://www.ino.tifr.res.in/ino

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