Status of India-based Neutrino Observatory

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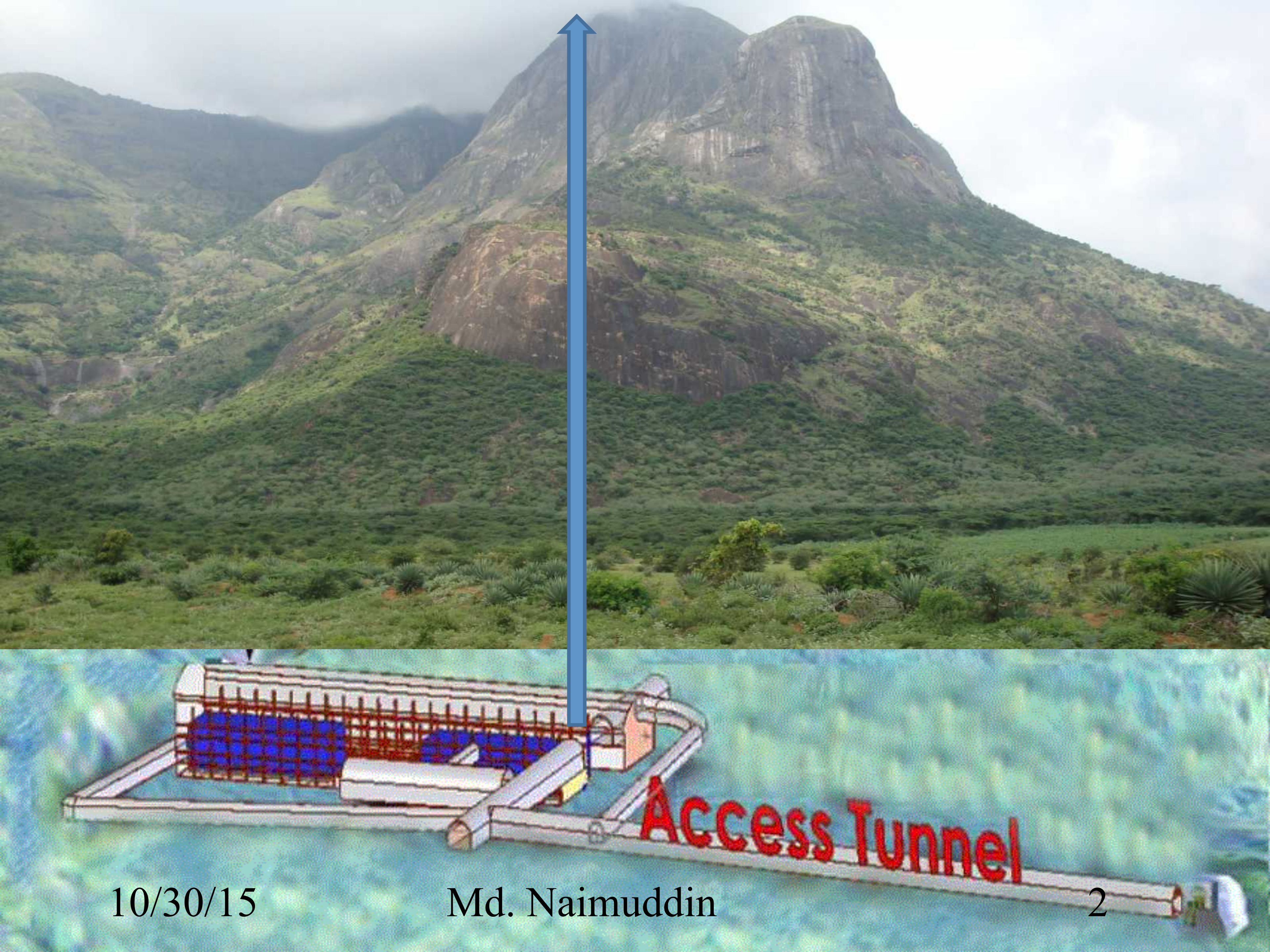
University of Delhi

NNN15

October 28 – 31, 2015

Stony Brook University, USA


Access Tunnel

INO and ICAL Detector

- At the beginning of this year, we received approval for building the INO facility near Madurai in south India.
- A cavern of dimensions 132m × 26 m × 32.5m will be constructed at the end of a 1.91 km long tunnel.
- INO will have a 50 kilotons magnetized Iron Calorimeter (ICAL) to detect the atmospheric muonic neutrinos and anti neutrinos interactions.
- Uniqueness of this experiment is its capability to differentiate between a positive charged muon and a negatively charged muon and thus between a muon neutrino and a muon anti-neutrino that produces it.

The INO-ICAL White Paper

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

Physics with INO

- Atmospheric neutrinos provide a wider range for E and L than any artificial neutrino source.

- An ability to discriminate between neutrinos and anti-neutrinos enables efficient determination of neutrino mass ordering independent of CP phase.

- Accurate determination of the atmospheric parameters (θ_{23} octant, deviation of θ_{23} from maximality)

- Determination of neutrino mass hierarchy (large θ_{13} helps)

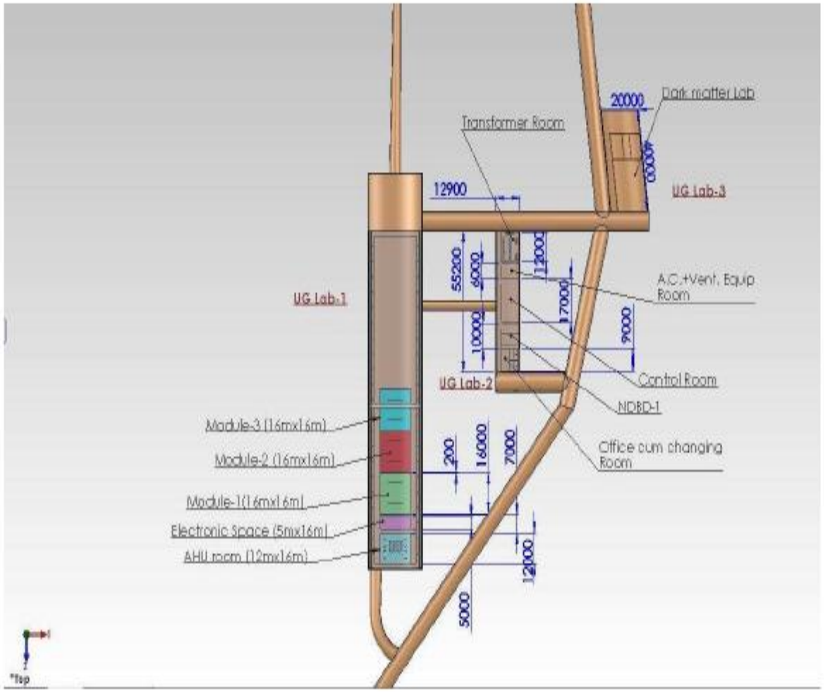
Physics with INO

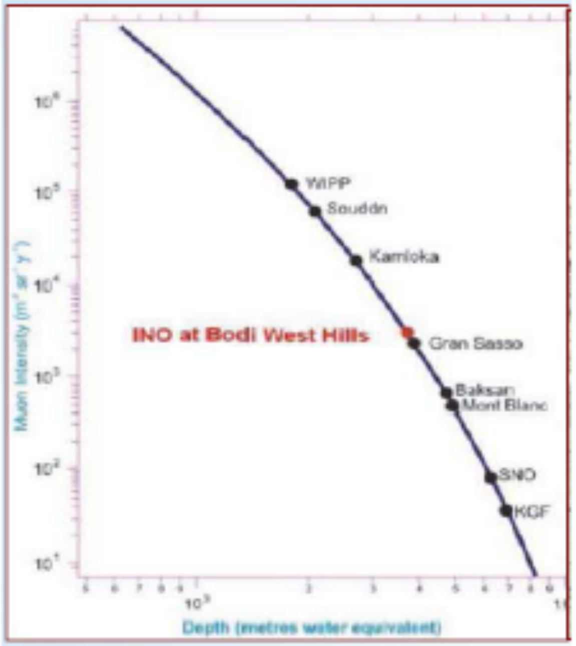
- Determination of CP violation in the lepton sector

- Nonstandard interactions, CPT violation, long range forces, ultrahigh energy muon fluxes, ...

- Hadron shower reconstruction allows access to neutrino energy and high energy cosmic rays

INO: Site at a Glance

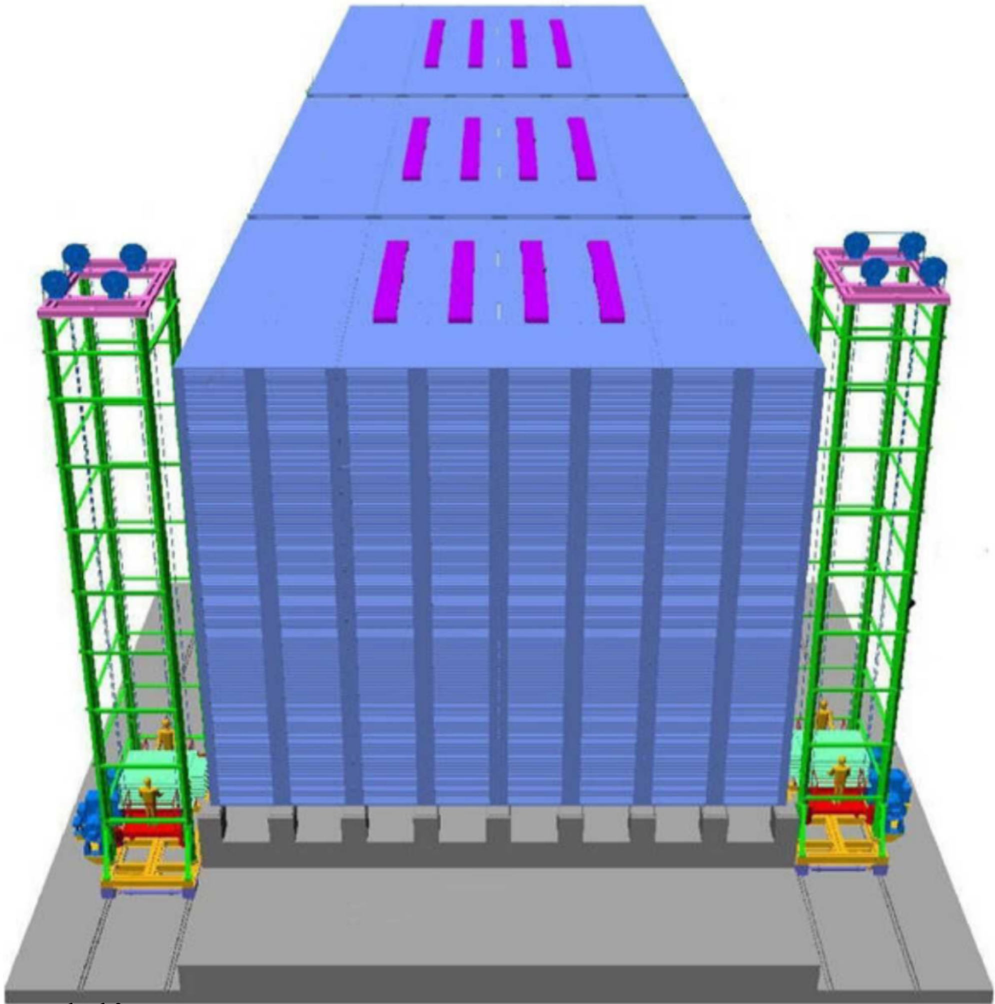


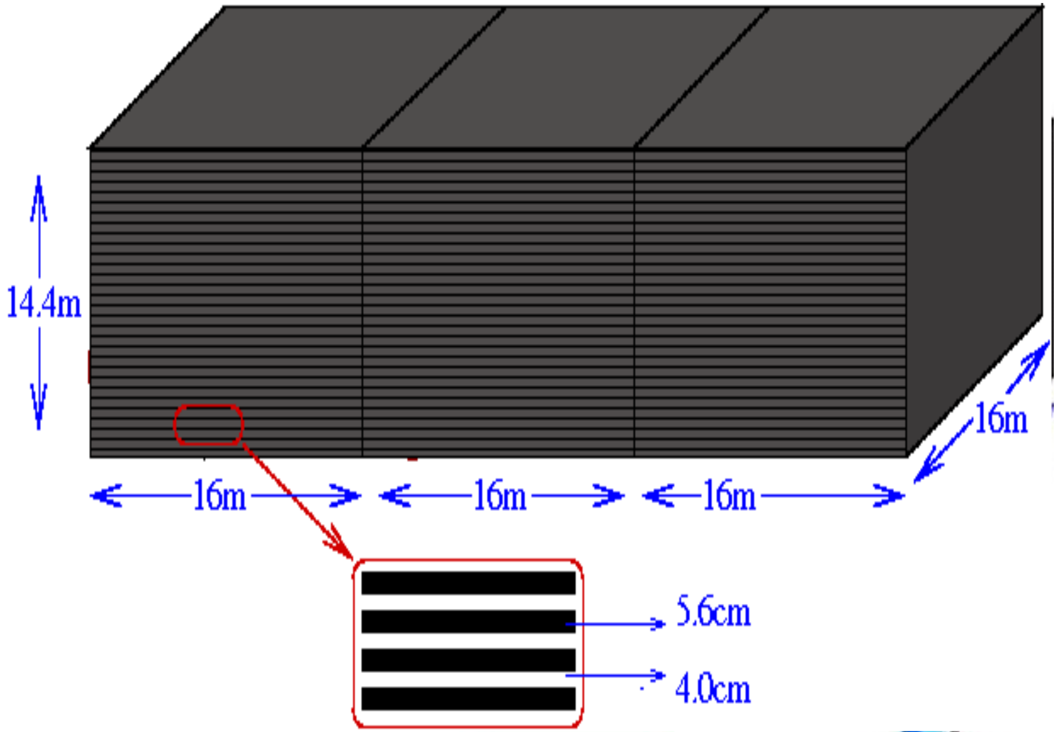


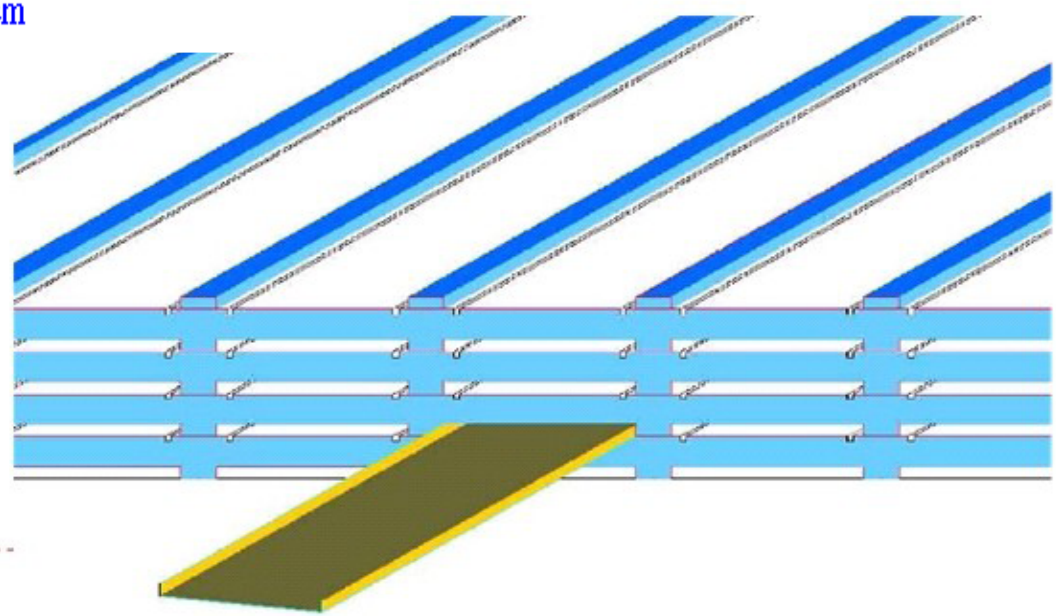
- Cavern set in Charkonite Rock under the 1589 m peak;
- Vertical cover 1289 m;
- Accessible through a 2 km tunnel
- Cavern 1 will host 50 kt ICAL (space for 100 kt);
- Other caverns for multiple experiments ($0\nu\beta\beta$, DM)

INO-Iron CALorimeter (ICAL) Detector

- Three modules, each of size 16m×16m×14.4m.
- In each module 151 layers of iron plates and RPC.
- 5.6 cm Thick iron plates are separated by 4.0cm gap for RPC, act as active detector element.
- Total mass of 51kton.
- Magnetic field applied 1~ 1.5T
- The readout of RPC is performed by external orthogonal pick up strips(X and Y strips).




14.4m
16m
16m
16m
16m
5.6cm
4.0cm



Construction of the ICAL detector

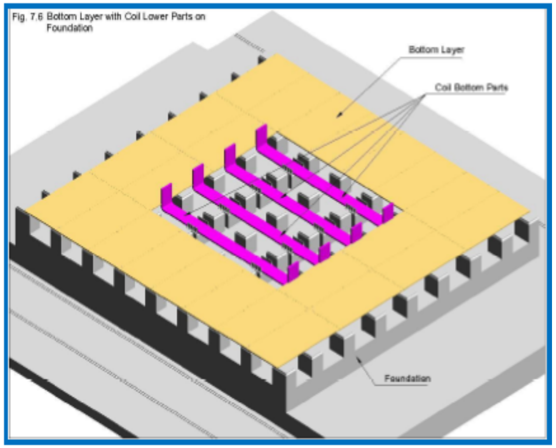


Fig. 7.6 Bottom Layer with Coil Lower Parts on Foundation

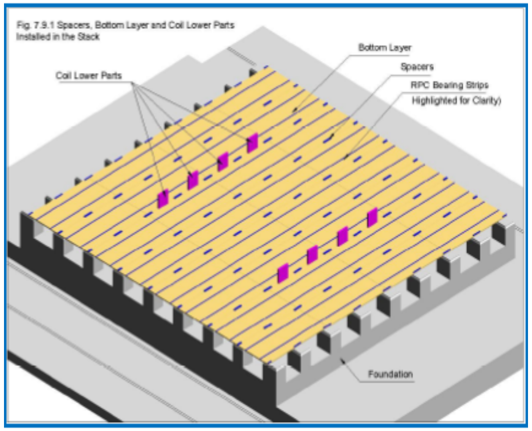


Fig. 7.9.1 Spacers, Bottom Layer and Coil Lower Parts Installed in the Stack

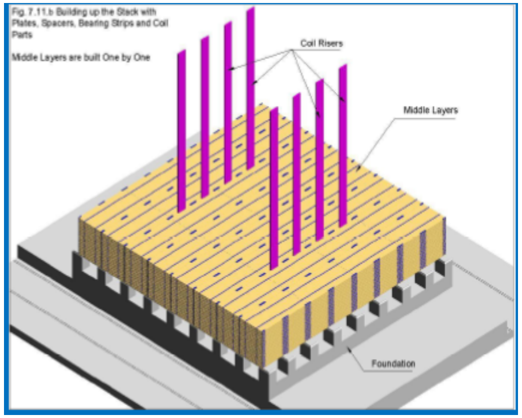


Fig. 7.11.b Building up the Stack with Plates, Spacers, Bearing Strips and Coil Parts

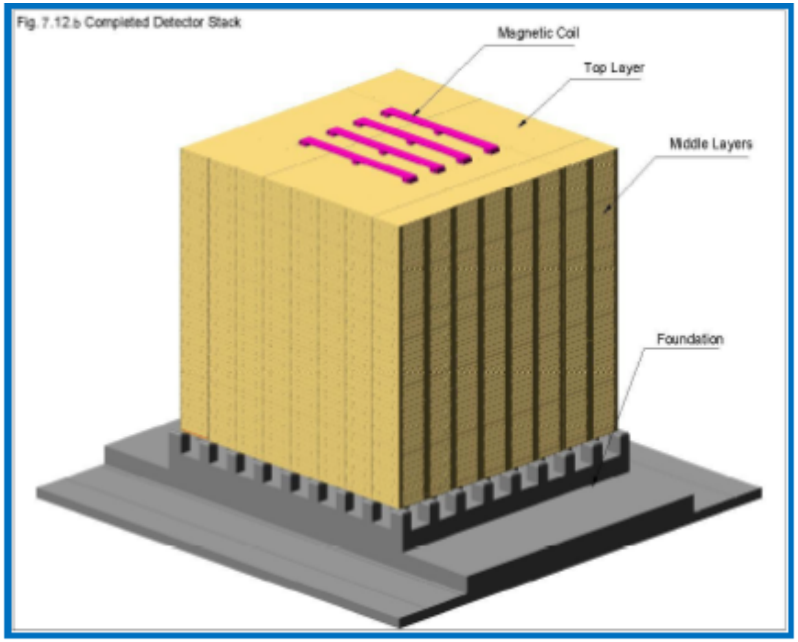


Fig. 7.12.b Completed Detector Stack

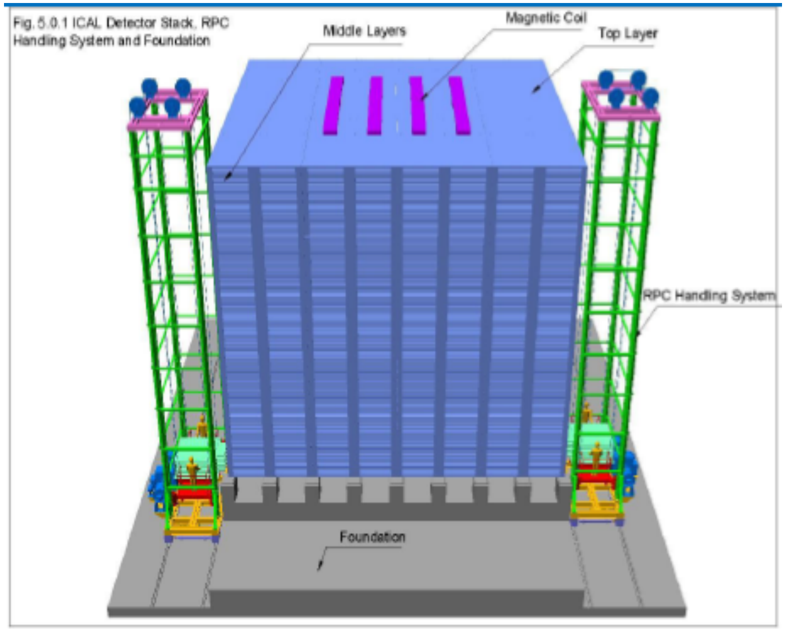
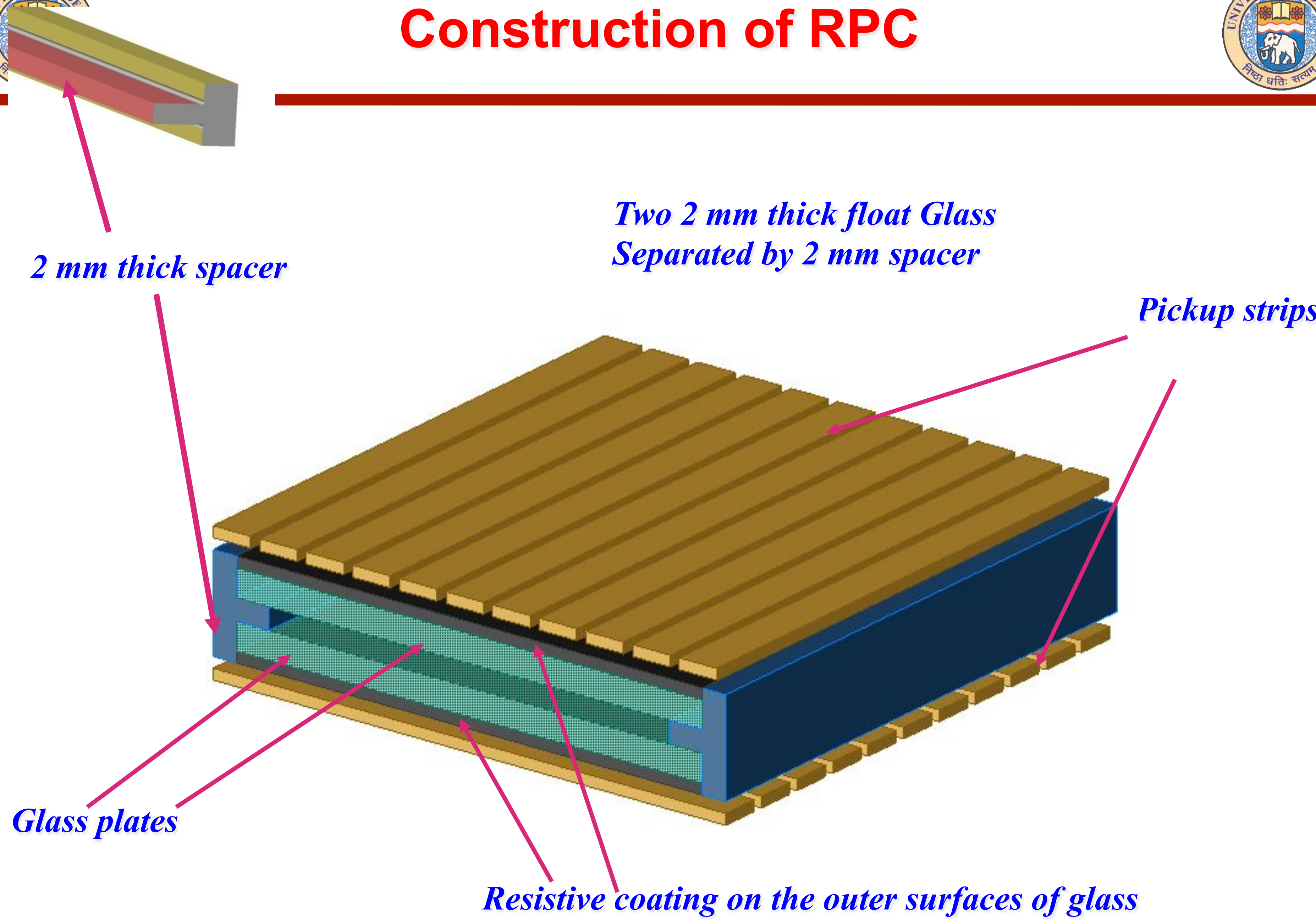
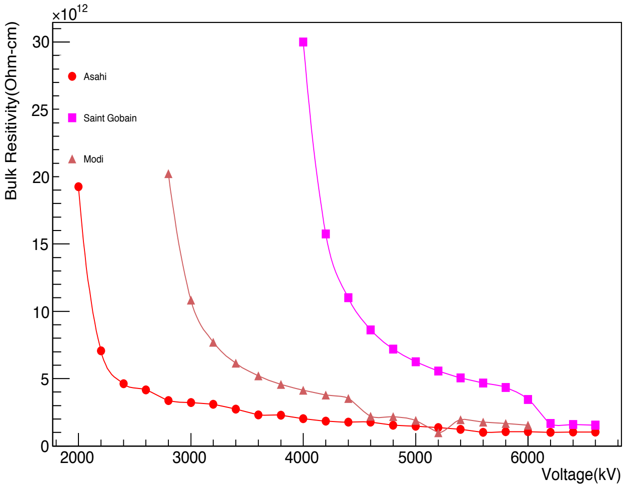


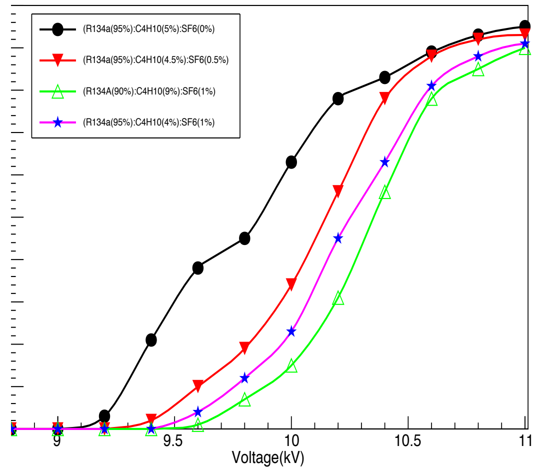
Fig. 5.0.1 ICAL Detector Stack, RPC Handling System and Foundation

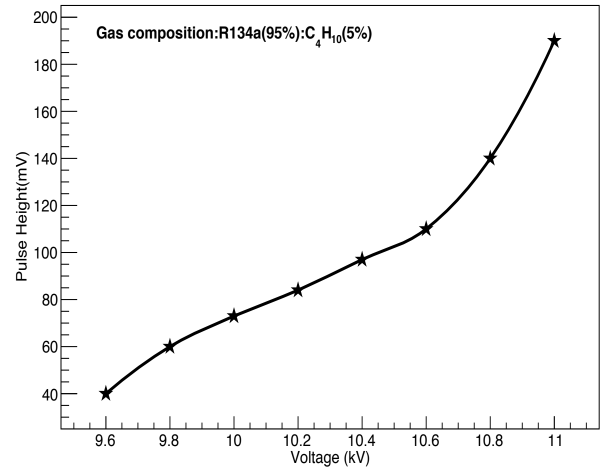
Construction of RPC

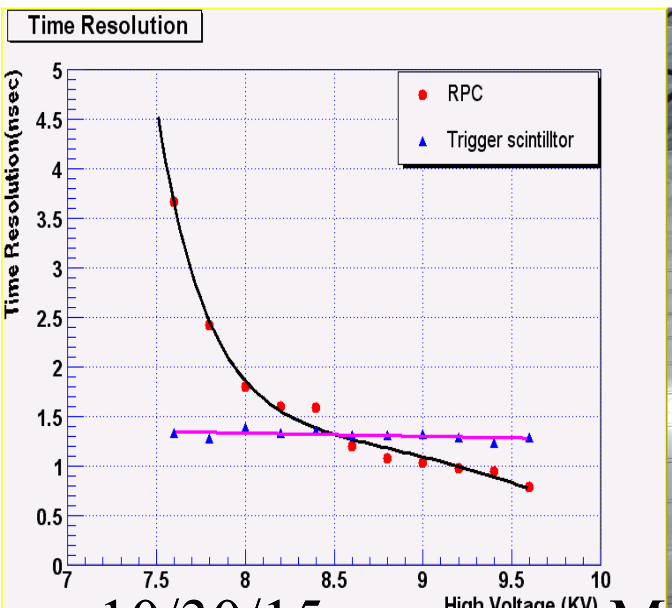


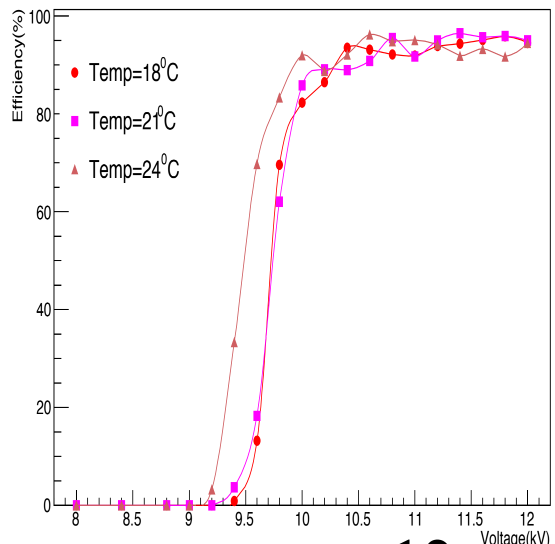
RPC Characteristics











Simulation Framework

NUANCE	**Neutrino Event Generation** $\nu_\ell + N \to \ell + X$. 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.

Particle Detection in ICAL

- Neutrinos interact within ICAL detector and produce associated lepton and hadronic shower.

- For muon neutrino , neutrino energy (E_ν) will be the sum of muon energy (E_μ) and hadronic energy (Eh):

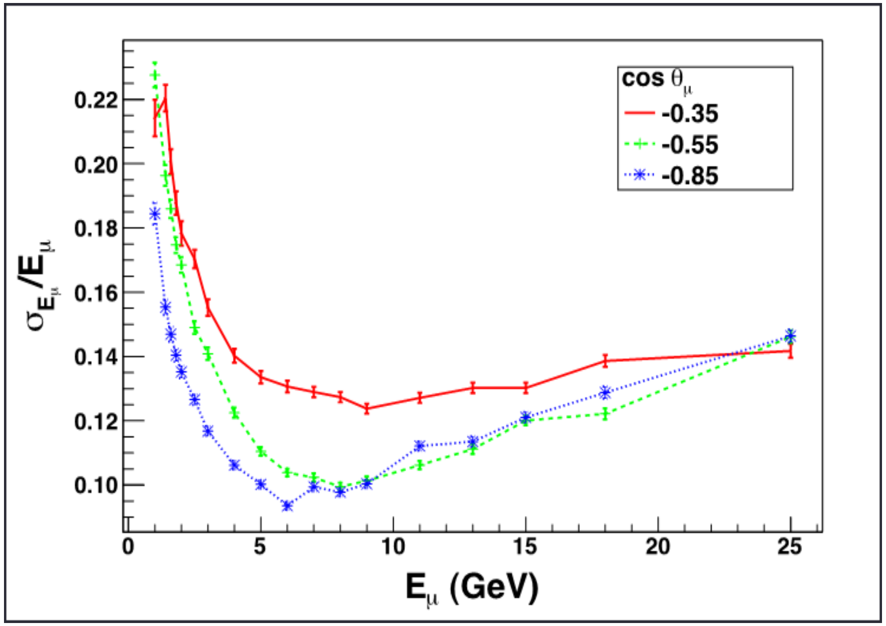
$$E_\nu = E_\mu + E_h$$

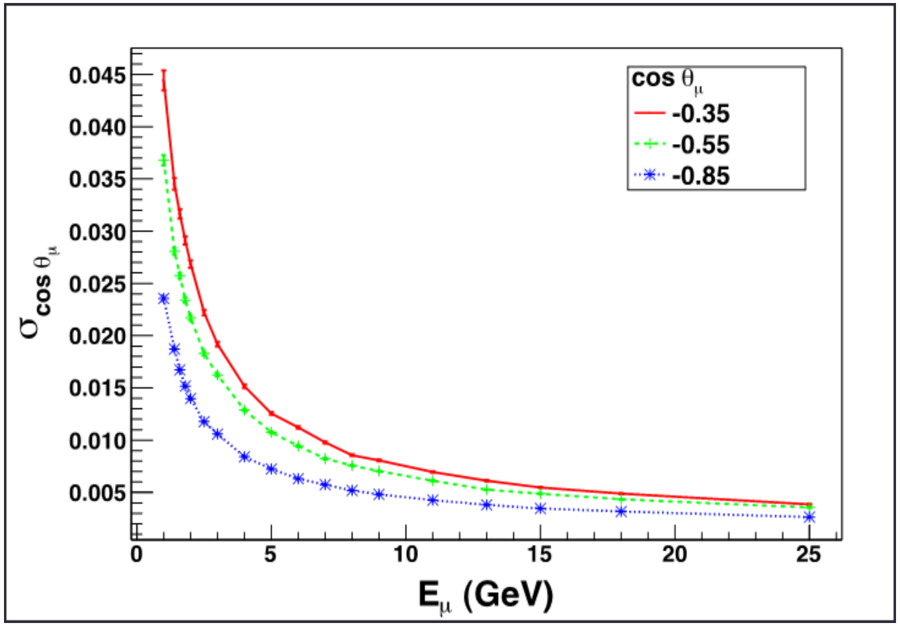
- To reconstruct the E ν precisely both muon energy and hadron energy have to be measured very precisely

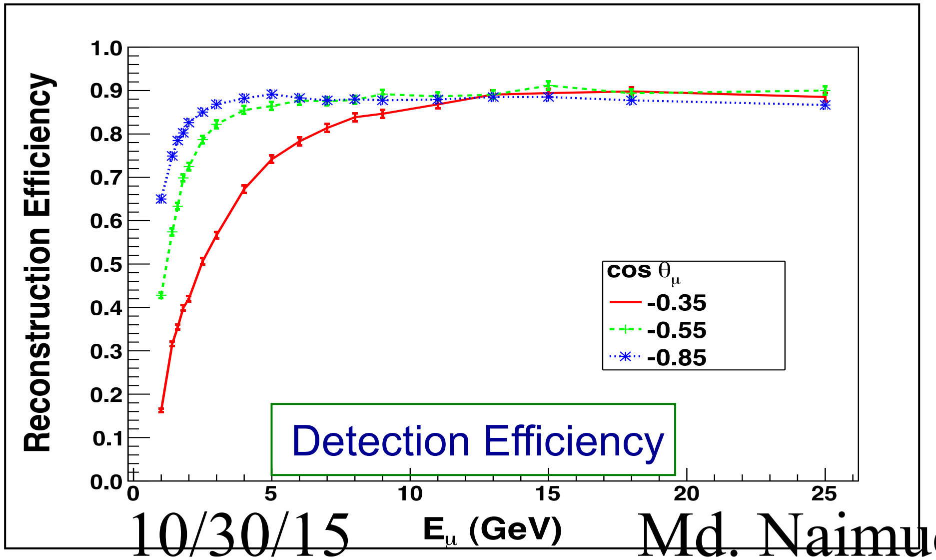
- Muons give a clear track inside detector, Energy of muons can be reconstructed from the track length in the detector.

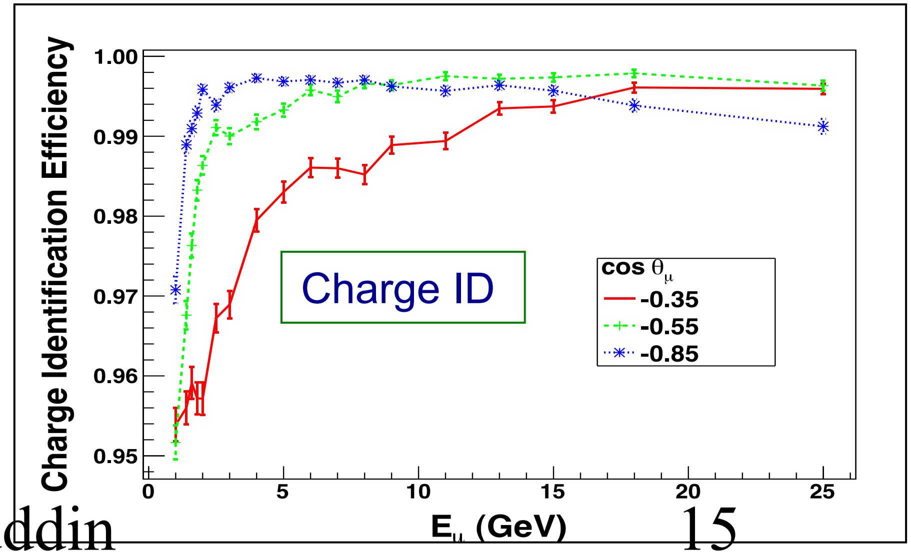
- The energy of hadrons can be calibrated as a function of number of total hits.

Muon Resolutions

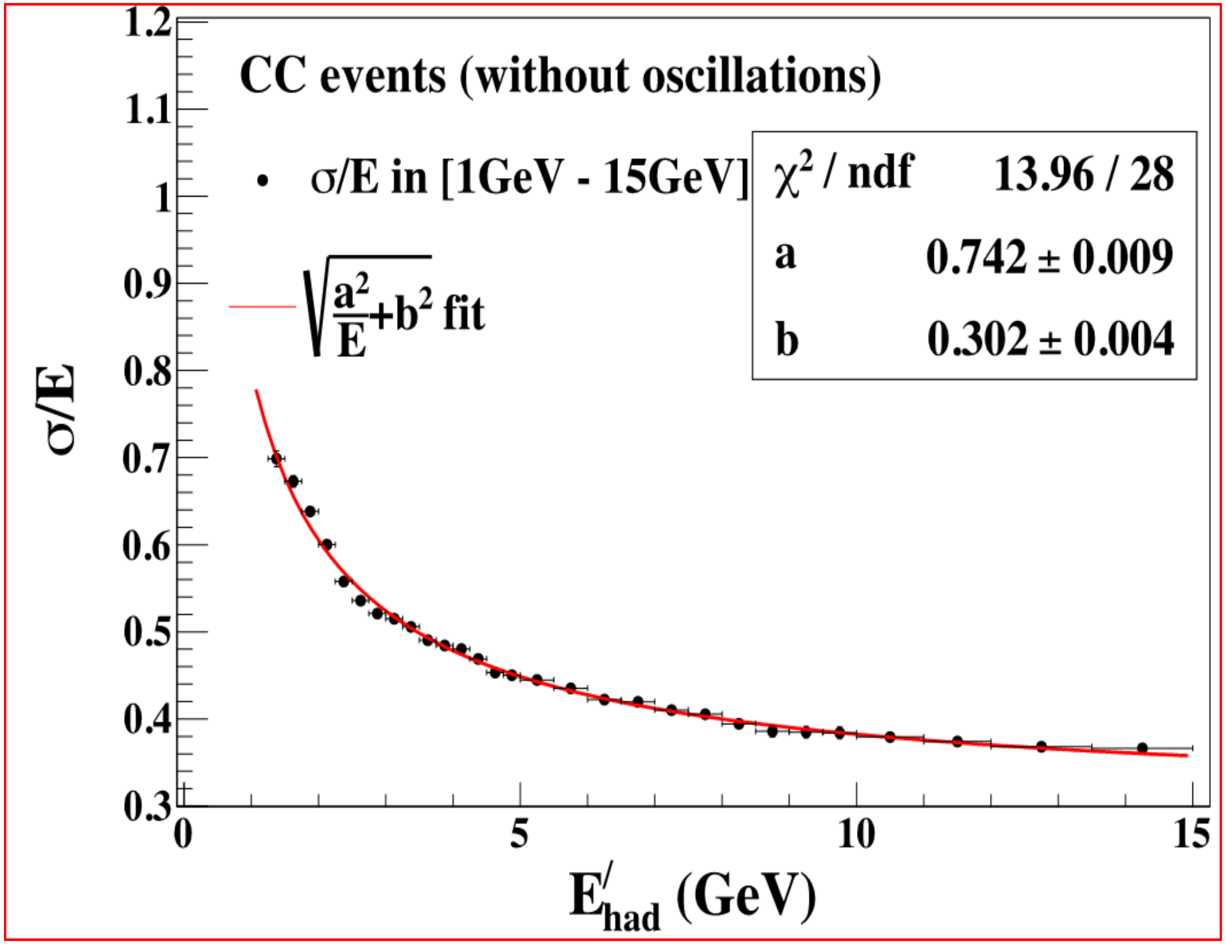








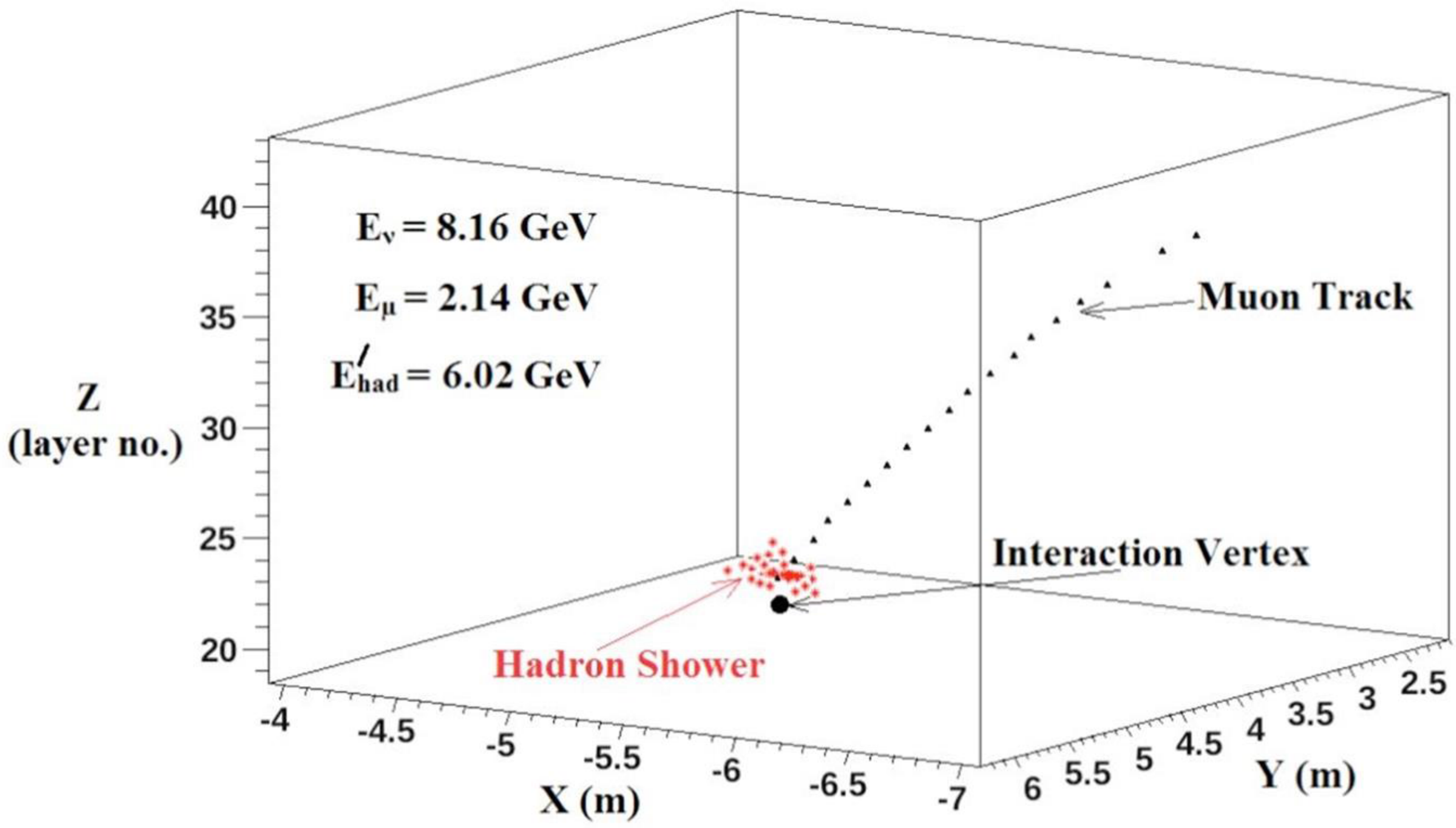
Hadron Resolution



Resolution for 2GeV energy is approximately 60% and 15 GeV is approx. 36%.

$E`_h = E_\nu - E_\mu$ (from hadron hit calibration)

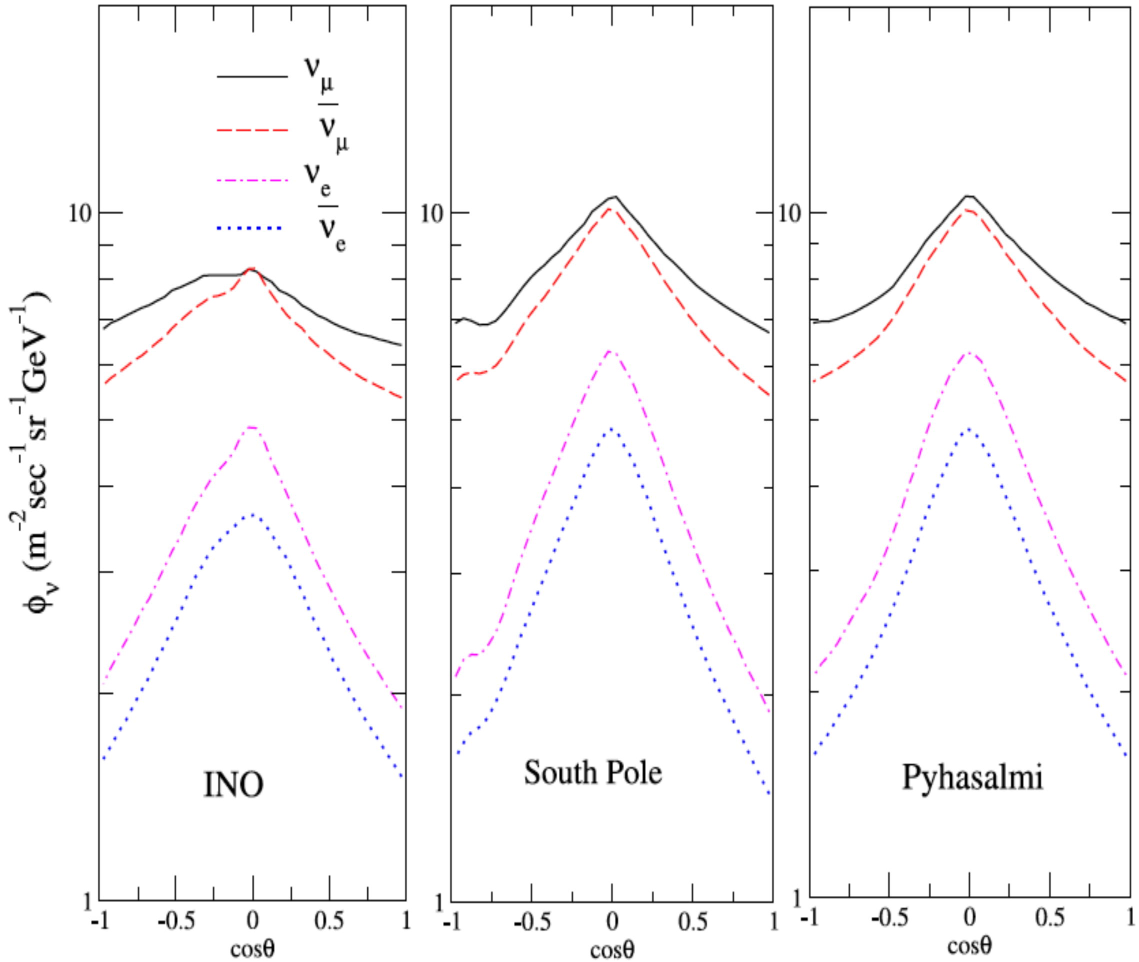
A Typical Event in ICAL



From GEANT4 Simulation

Atmospheric Neutrino Flux

- Atmospheric neutrino flux has been generated with NUANCE using Honda 3d fluxes for the Kamioka site in Japan.
- The Honda atmospheric fluxes at the INO site to be finalized soon.



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

The χ^2 Analysis

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

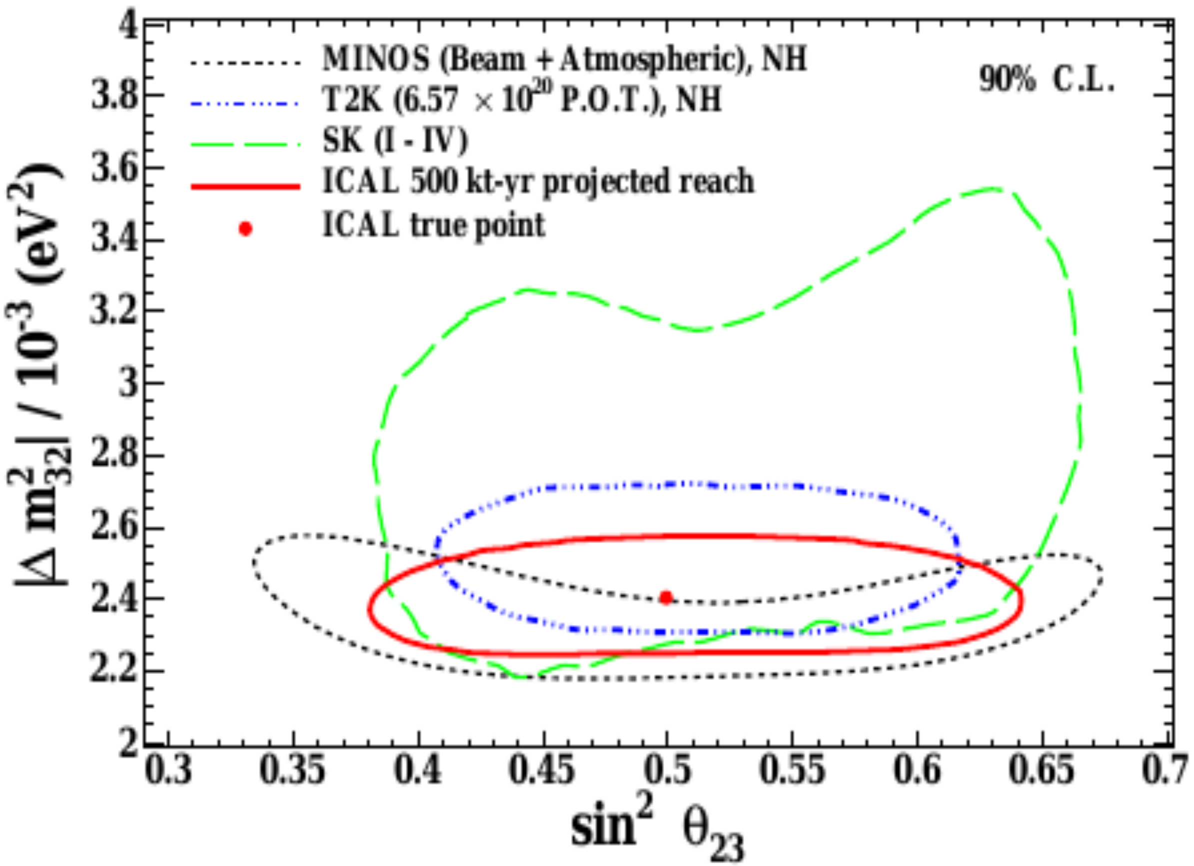
$$N_{ijk}^{\rm theory} = N_{ijk}^0 \left(1 + \sum_{l=1}^{5} \pi_{ijk}^l \xi_l\right) .$$

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:

$\Phi_\delta(E) = \Phi_0(E)\,[E/E_0]^\delta \approx \Phi_0(E)\,[1+\delta \ln E/E_0]$

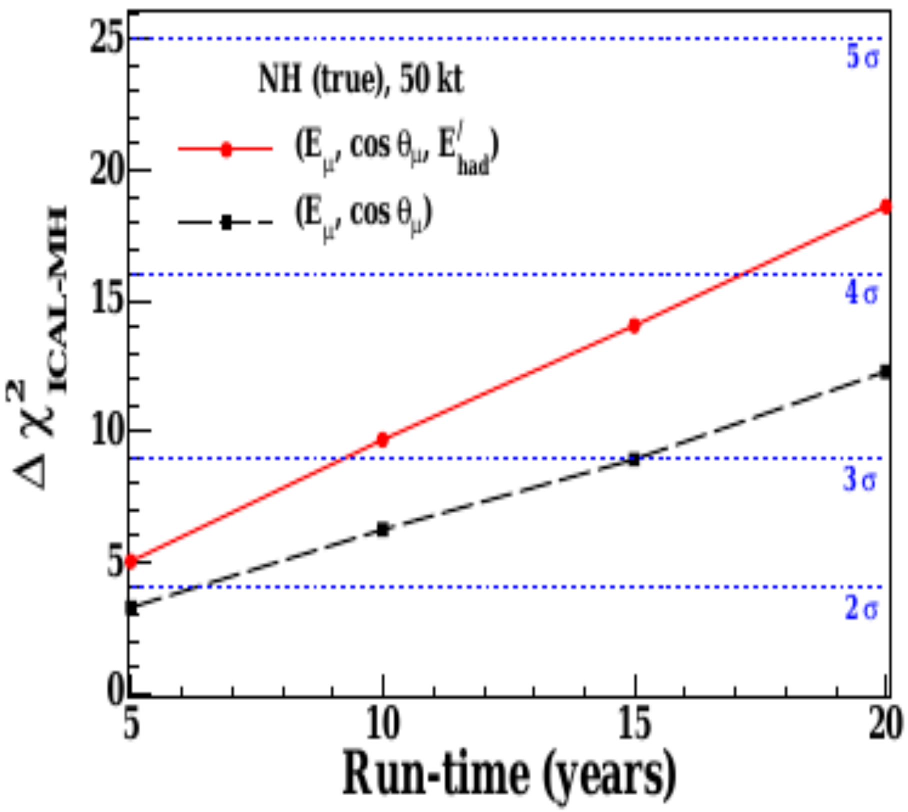
where $E_0 = 2$ GeV and δ is the 1σ systematic error of 5%

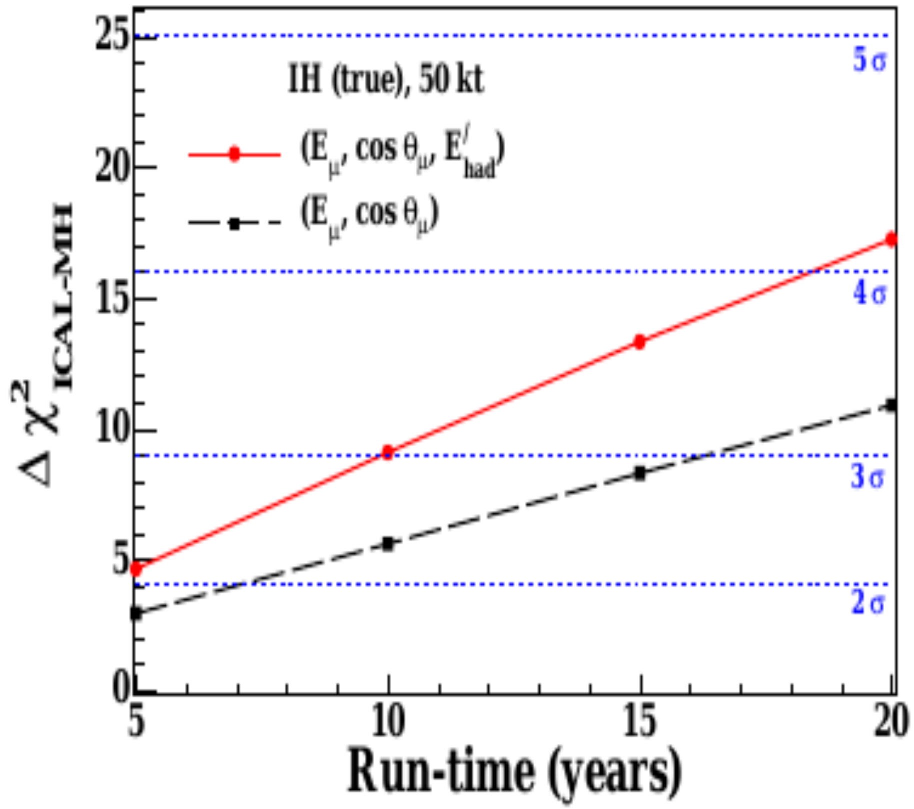
Oscillation Parameter Sensitivity



- Use priors on $|\Delta m^2_{atm}|$, θ_{23}, θ_{13} from LBL+ reactors projected reach

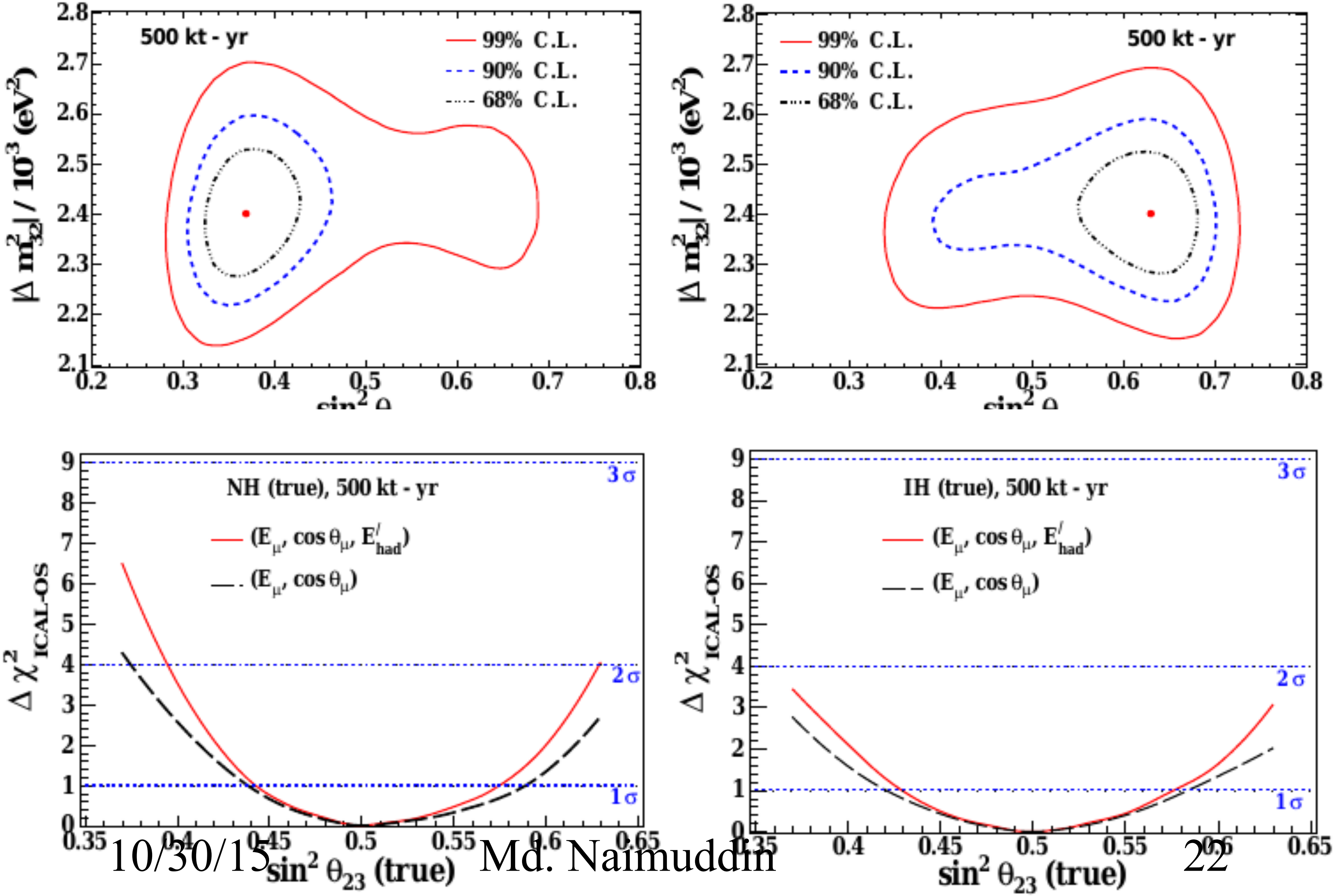
Mass Hierarchy sensitivity



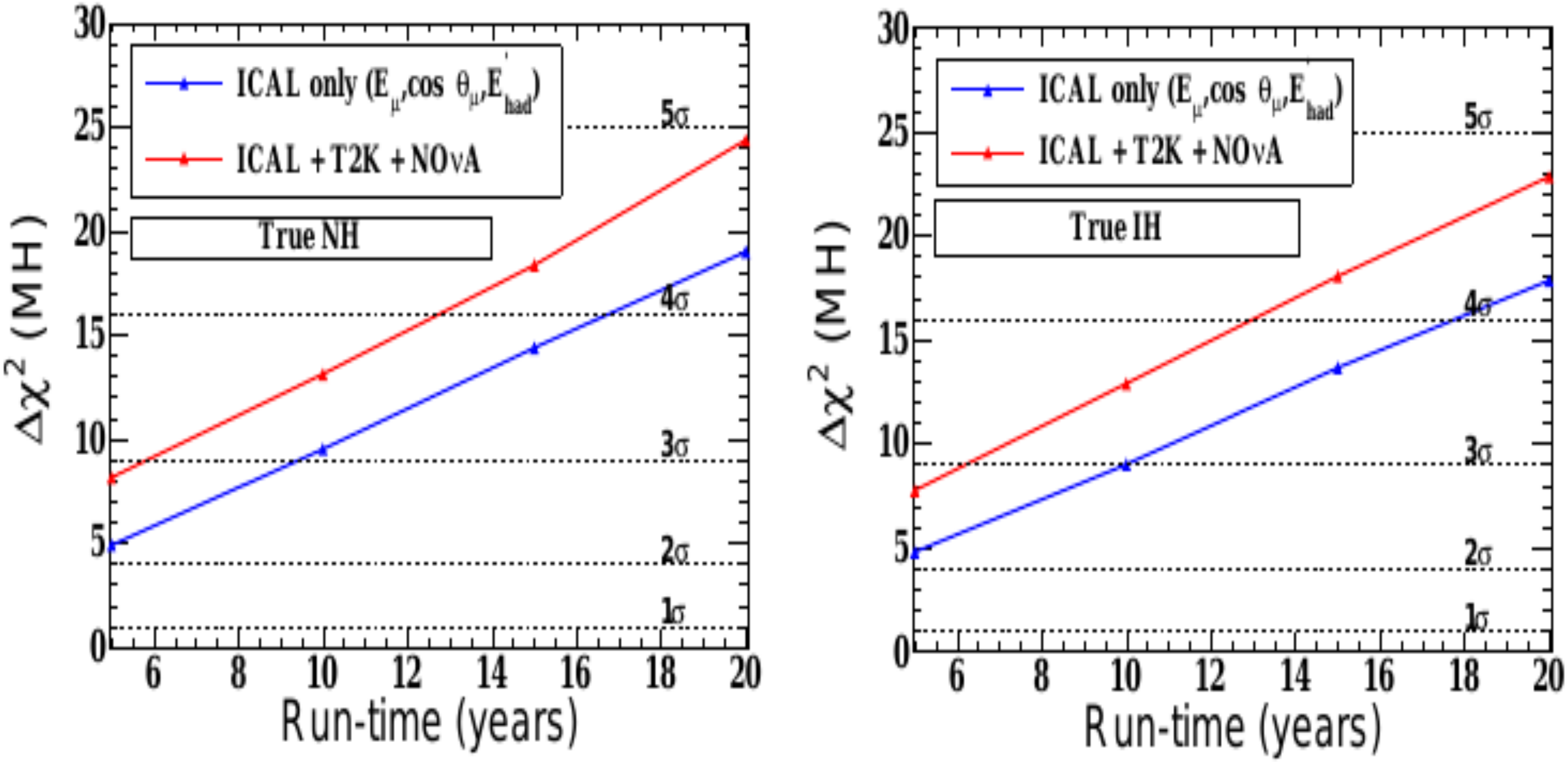


~2.3σ sensitivity for $\sin^2\theta_{23}$=0.5, $\sin^2 2\theta_{13}$=0.1 by 2025 (5 yrs)
~3σ sensitivity for $\sin^2\theta_{23}$=0.5, $\sin^2 2\theta_{13}$=0.1 by 2030 (10 yrs)

Octant Sensitivity



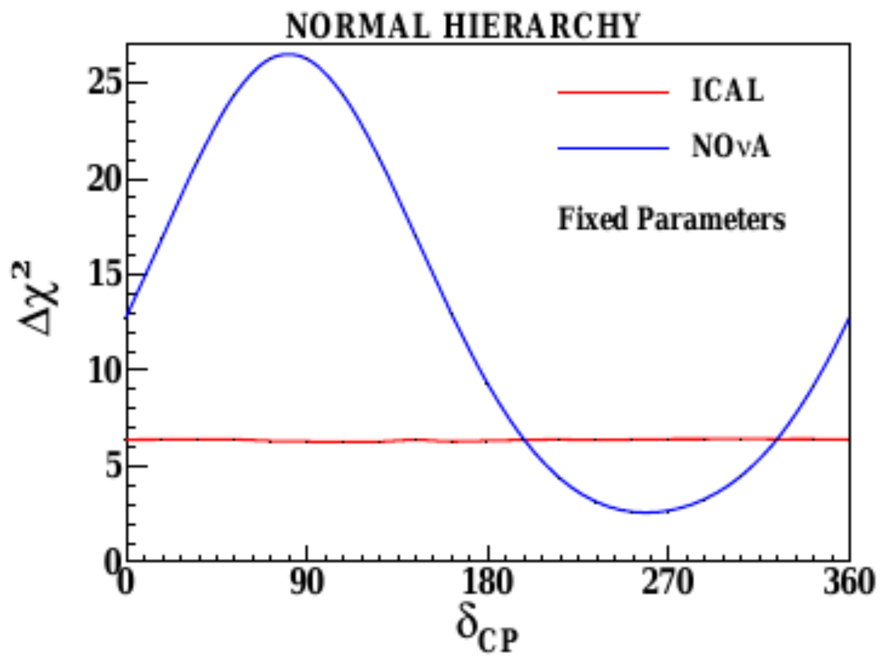
INO Combined with T2K and NOvA

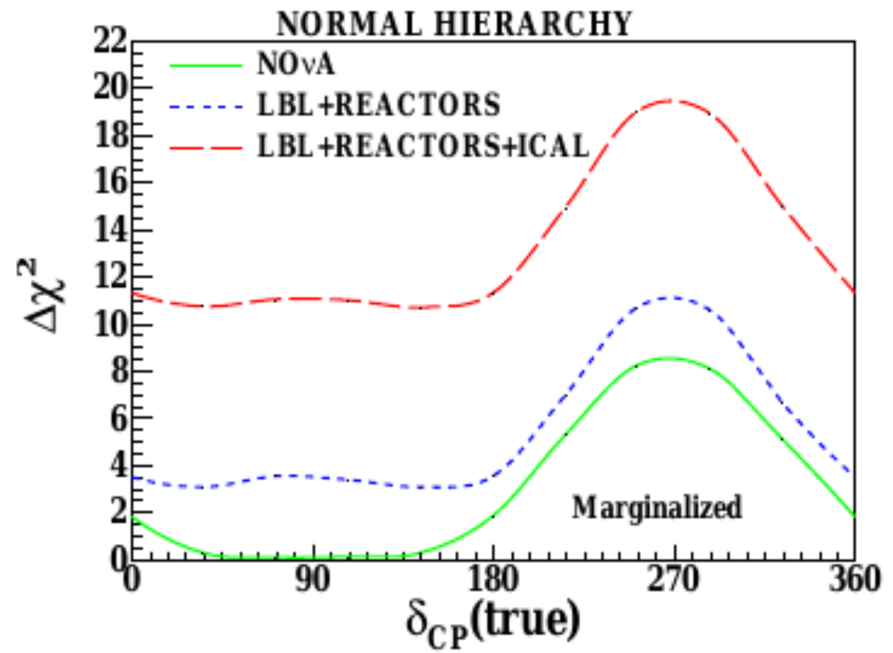


~3 σ sensitivity for $\sin^2\theta_{23}$=0.5, $\sin^2 2\theta_{13}$=0.1 in 6 yrs for NH.

~4 σ sensitivity for $\sin^2\theta_{23}$=0.5, $\sin^2 2\theta_{13}$=0.1 in 13 yrs for NH.

Synergy with Other Experiments





- Though ICAL itself is rather insensitive to δ_{CP} , data from ICAL can still improve the determination of δ_{CP} itself, by providing input on mass hierarchy.
- This is especially crucial in the range $0 \leq \delta_{CP} \leq \pi$, precisely where the ICAL data would also improve the hierarchy discrimination of NOνA and other experiments

Other Analysis in Progress at ICAL

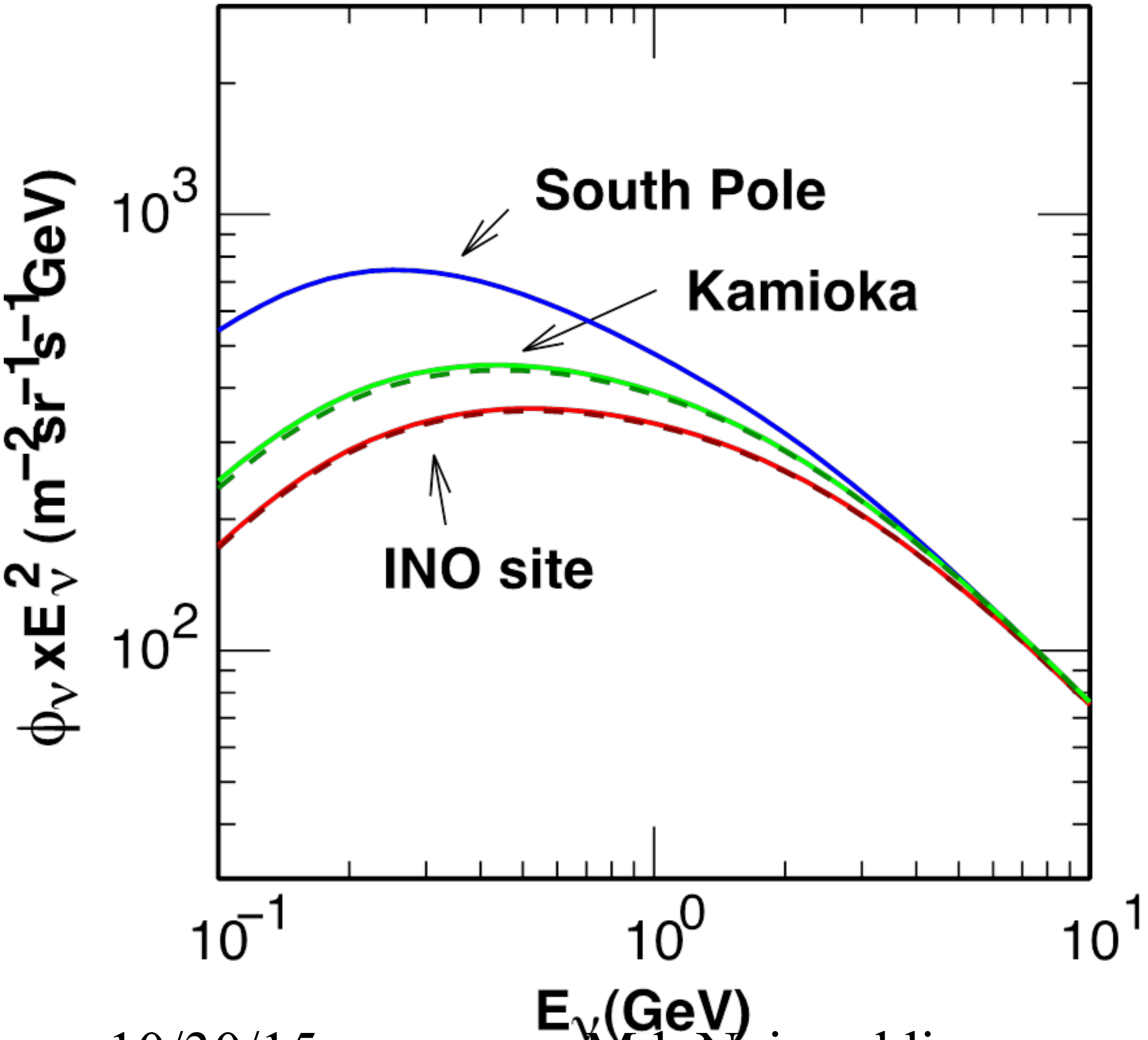
- ✓ Search for sterile neutrinos
- ✓ CPT violation and Non-Standard Interactions
- ✓ Search for magnetic monopoles
- ✓ Search for dark matter from the Sun
- ✓ Long range forces
- ✓ Exploiting NC events
- ✓ Possibilities of electron detection

Summary

- ✓ The land for the experimental site and surface facility at Madurai have been acquired.
- ✓ Detector R&D is almost complete for the base design. Further improvements are being pursued.
- ✓ Construction of an engineering module 8m X 8m X 2.1m is being initiated.
- ✓ The work is interrupted due to some litigations pending in courts of law regarding certain clearances.
- ✓ Still a long way to go……..

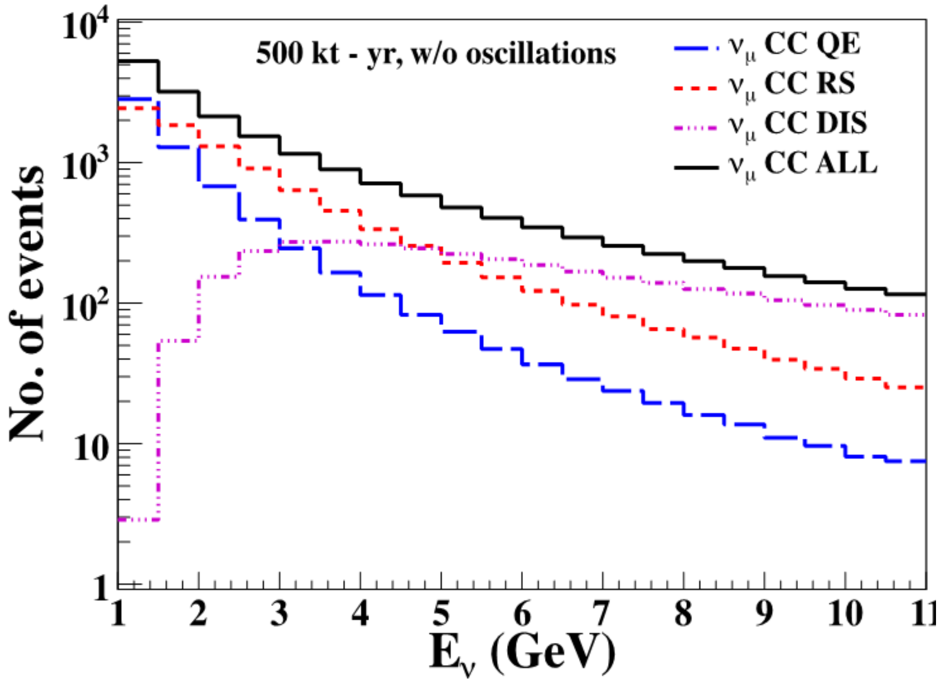
Thank you!

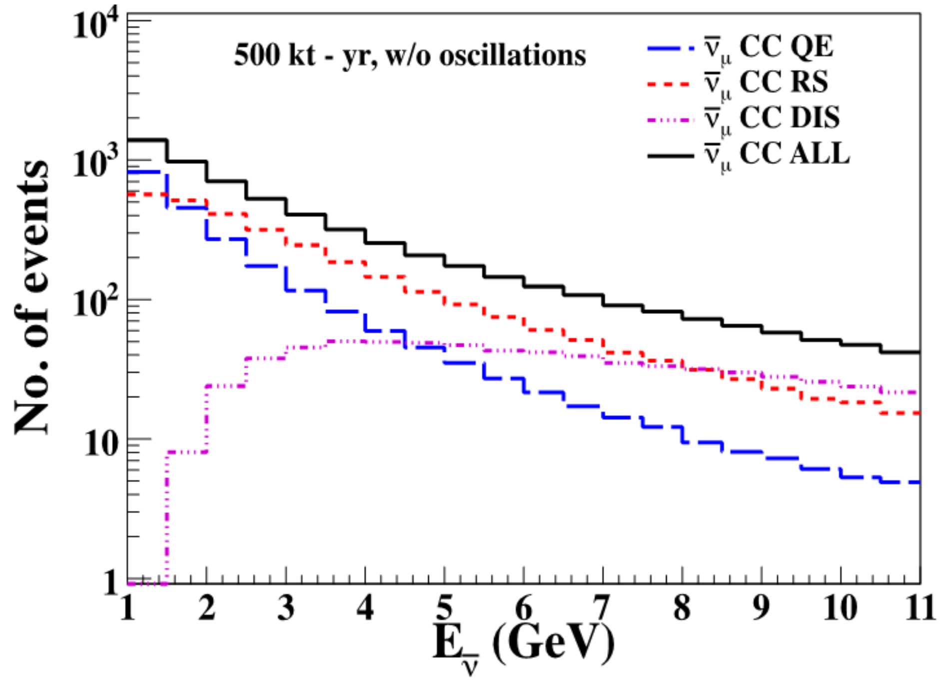
Atmospheric Flux



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

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