Neutrino Oscillations in IceCube Deep Core

By Gerardo Giordano

The Pennsylvania State University,
University Park, PA

PENNSTATE

1855

IceCube Deep Core

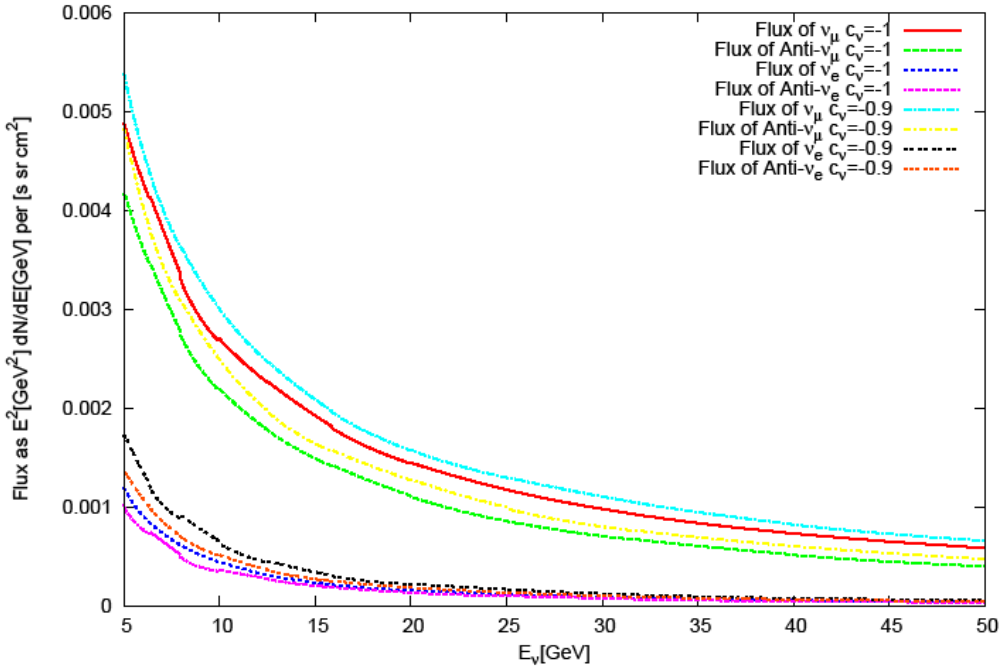
- IceCube Deep Core (ICDC) consists of 6 + 2 densely instrumented strings in the center of IceCube (IC)
  - 7 m between modules on a string
  - 15 Mton instrumented volume
  - Also, includes 7 nearest strings of IC
- ICDC can measure cascade and track energies much lower than IC (IC down to ~100GeV)
- Opens up neutrino oscillation studies of atmospheric neutrinos
  - Very high event rate

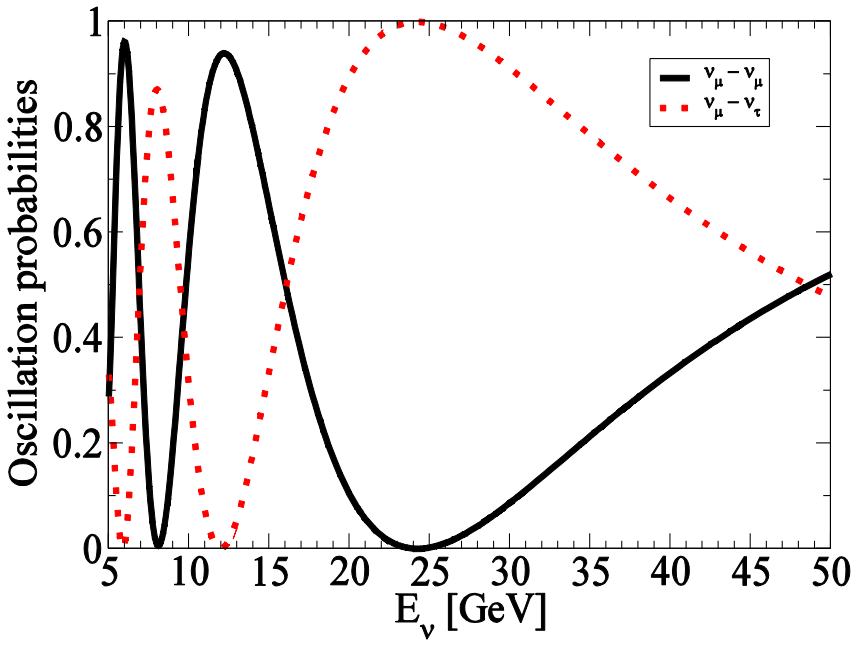
Atmospheric ν's in ICDC

- IC & ICDC optimized for detecting μ-tracks, but cascades are also possible
  - Directional information for cascades…not so good
  - Energy resolution for cascades…great
  - Focus on counting events
- Types of Cascade Events
  - ν_e Charged Current (CC)
  - ν_{any} Neutral Current (NC)
  - Electromagnetic (EM) and Hadronic (Had) decays of τ from ν_τ

ν_τ in ICDC: Motivation

- ICDC is good news for counting ν_τ
  - τ leptons come from ν_τ from $\nu_\mu \rightarrow \nu_\tau \rightarrow \tau$
  - Atmospheric ν_e and anti-ν_e fluxes much lower than ν_μ and anti-ν_μ at these energies
  - ICDC energy range corresponds to max $\nu_\mu \rightarrow \nu_\tau$ and min ν_μ survival
  - Unlike SK, τ threshold production effects are small (threshold of 3.5GeV)



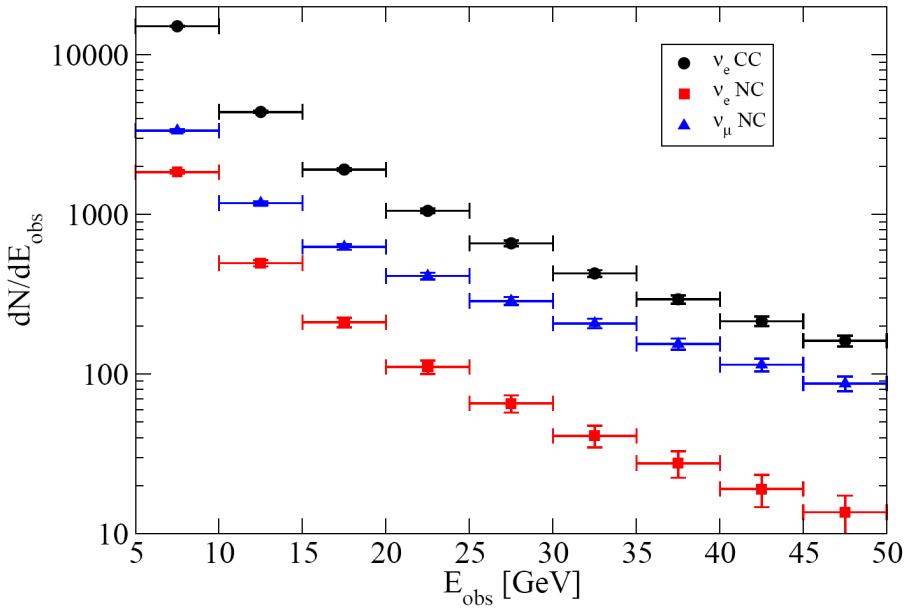


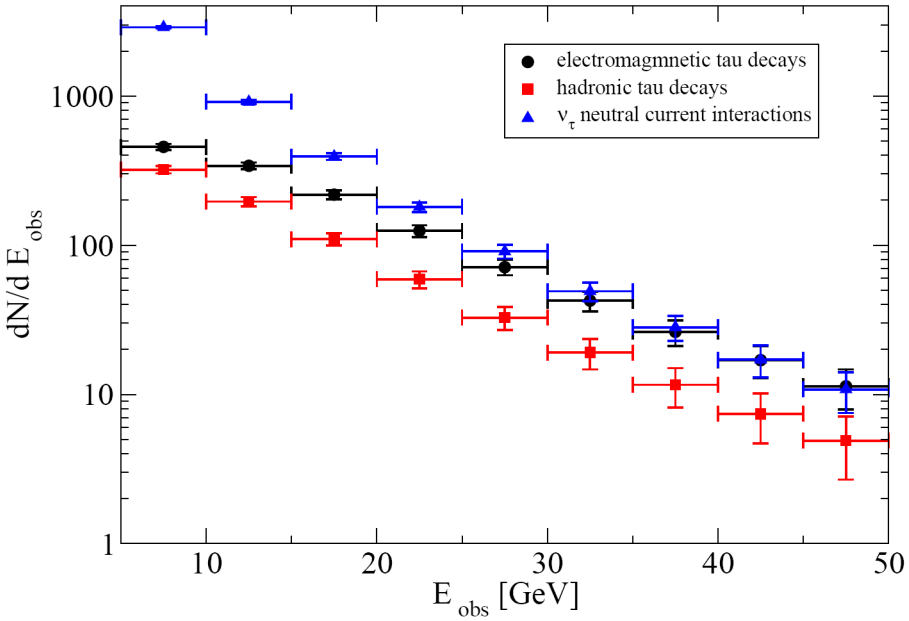
ν_τ in ICDC: Analysis

- Investigate ν's of energy 10 GeV to 100 GeV
- Integrate over all upward going angles
- Full three-flavor oscillations with matter effects
- Since low energy implies single string events usual cylinder of d=250m and h=350 now considered 6 cylinders of r=40m

ν_τ in ICDC: Results

- 3σ statistical significance in a few months BUT
  - At energies this low, μ-tracks are only 25m long
    - Look like cascades
    - Adds to systematics and increases time for statistical significance





G. G., O. M., & I. M., Phys. Rev. D 81: 113008 (2010)

ν_μ Disappearance in ICDC: Motivation

- Presently,
  - Δm_{31}^2 varies 2.18 - 2.64x10^{-3}eV^2…MINOS (2σ)
  - $\sin\theta_{23}$ varies 0.63 – 0.79…SK (2σ)
  - Can DC do better with high statistics?
- ICDC can detect tens of thousands of atmospheric events each year

ν_μ Disappearance in ICDC: Analysis

- Most events are from ν_μ CC interactions
  - Also, $\nu_e \rightarrow \nu_\mu$
  - Also, $\nu_\mu \rightarrow \nu_\tau \rightarrow \tau \rightarrow \mu$
  - Also, at low energy (~5GeV) tracks and cascades hard to distinguish
- Using surrounding IC, we limit study to neutrino interactions initiating inside the detector
  - Look at fully contained tracks
  - Look at μ allowed to exit (partially contained)
- Explore sensitivity to main oscillation parameters Δm_{31}^2 and θ_{23} using χ^2 statistical analysis

ν_μ Disappearance in ICDC: Uncertainties

- Angular reconstruction
- μ-track length reconstruction (relates to energy measurement)
- Modeling of light propagation
- Light detection efficiency of modules
- Flux, cross-section, total detector volume
- Consider overall error as fraction f_{sys} of number of events in each bin
  - f_{sys} 5% and 10% considered
- Analysis influenced by θ_{13}

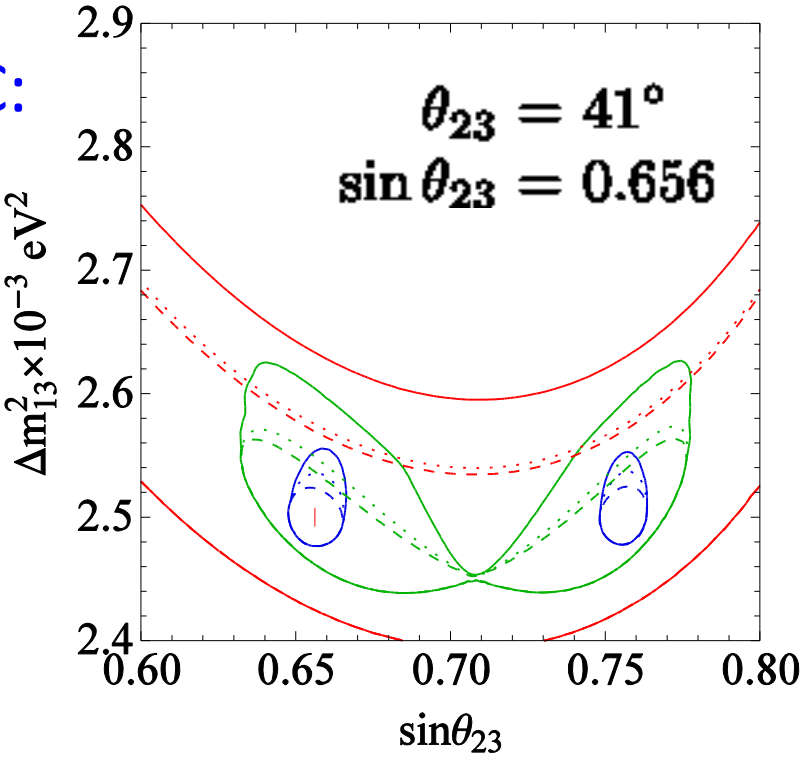
ν_μ Disappearance in ICDC: Results

Presently allowed values

$\Delta m^2_{32} \in (2.18 - 2.64)\,\mathrm{eV}^2 (2\sigma)$ (MINOS)

$\sin\theta_{23} \in (0.63 - 0.79)(2\sigma)$ (Super-Kamiokande)

ICDC:



Observable energies of 5 to 50 GeV

10 energy bins, 4 angular bins

vs.

1st energy bin, 1 angular bin +

9 energy bins, 4 angular bins

vs.

Exclude first 2 energy bins:

8 energy bins, 4 angular bins

$\theta_{13} = 0.01$ ----------

vs

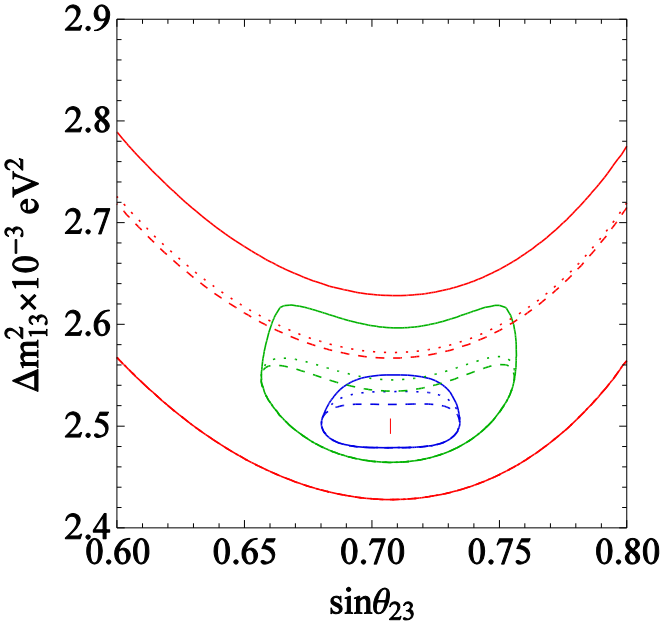
$\theta_{13} = 0.01 \pm 0.02$ .....

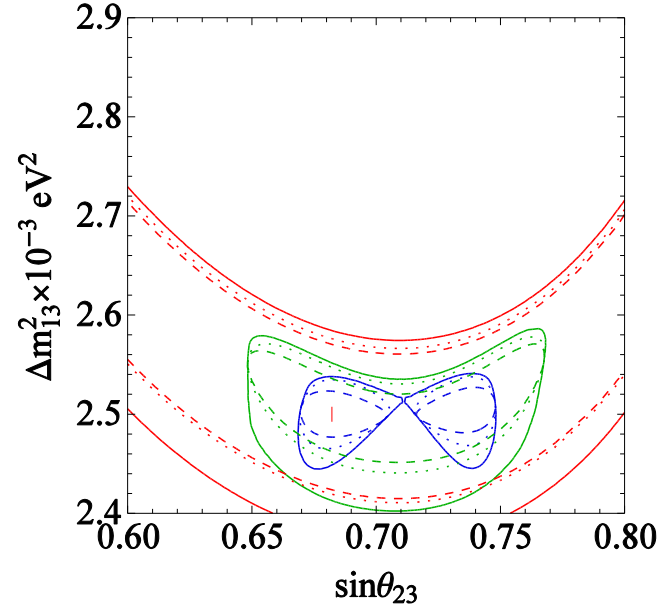
vs

θ_{13} completely free ——————

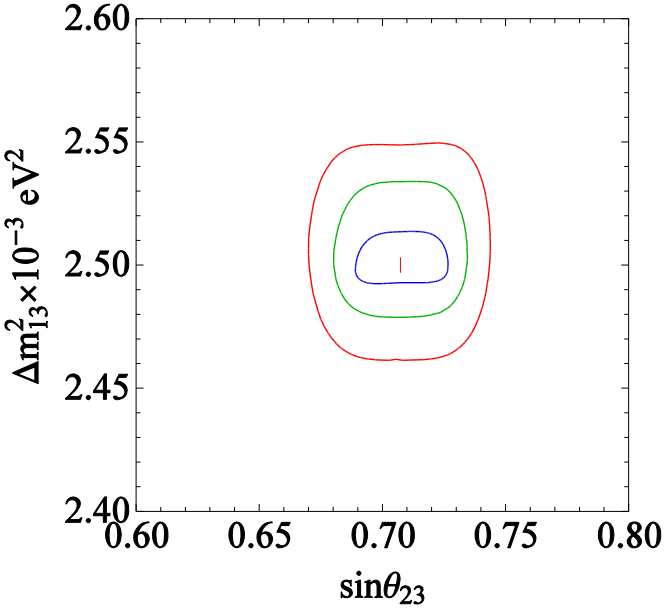
E. F-M, G. G., O. M. & I. M., Phys. Rev. D 82: 093011 (2010)

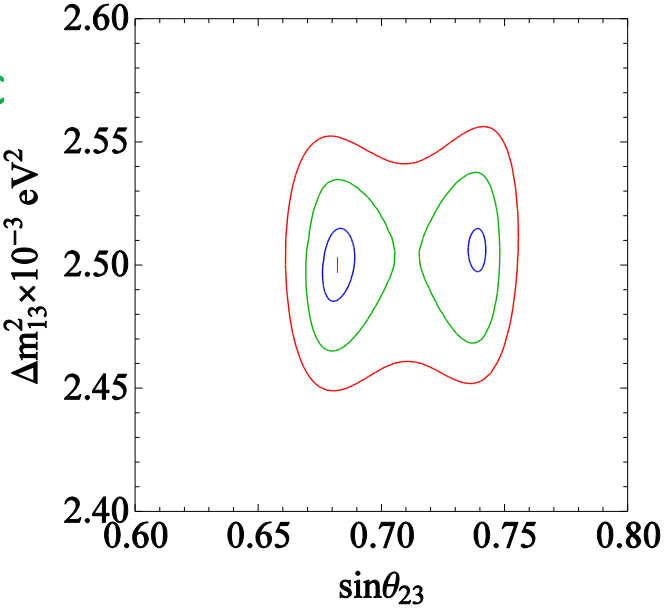
IceCube Deep Core





- Expected allowed regions depend on the true values of the parameters and control of systematic uncertainties





Outlook

- ICDC is already taking data
  - Looking galactic sources and dark matter annihilation
  - Atmospheric ν's are a background
- Their background is our signal
  - High statistics
  - Great for ν_τ appearance
  - Great for precision measurements of oscillation parameters