Neutrino Oscillations with the IceCube/ DeepCore

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IceCube/DeepCore and Neutrino Oscillations

- Sensitivity to $\Delta m^2(atm) \sim 10^{-3}$, requiring $L(km)/E(GeV) \sim 10^3$

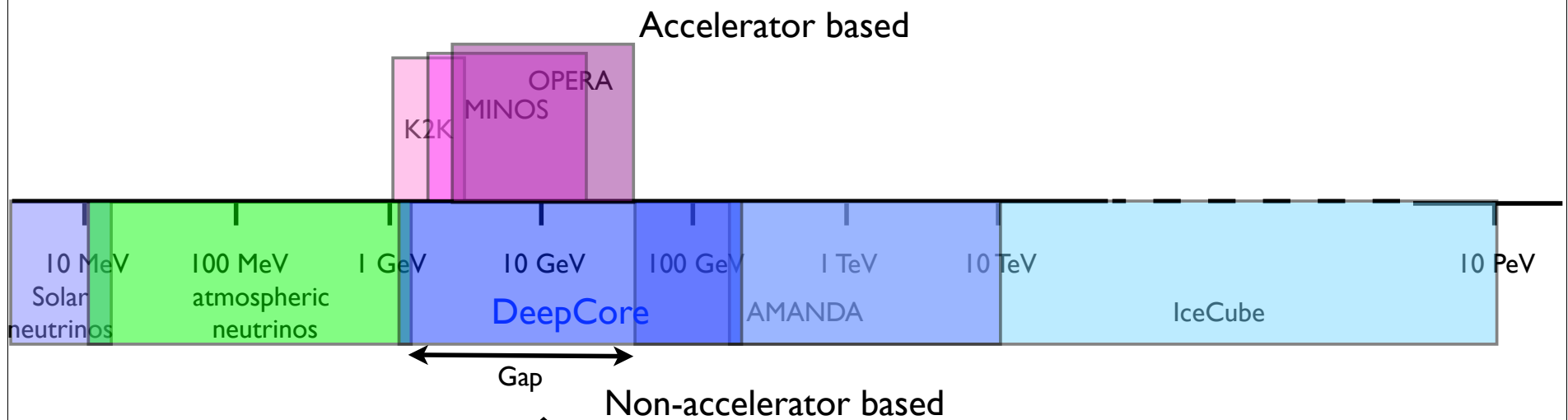- With design sensitivity near $E_\nu \sim 1$ TeV, IceCube needs $L \sim 10^6$ km.

  (There are no TeV neutrino sources at this distance)

- Atmospheric Neutrinos, with $L \sim 10^4$ km, could be used

  ...requires a detector sensitivity of $E_\nu \sim 10$ GeV

  ...enter DeepCore

DeepCore - closing the neutrino energy gap

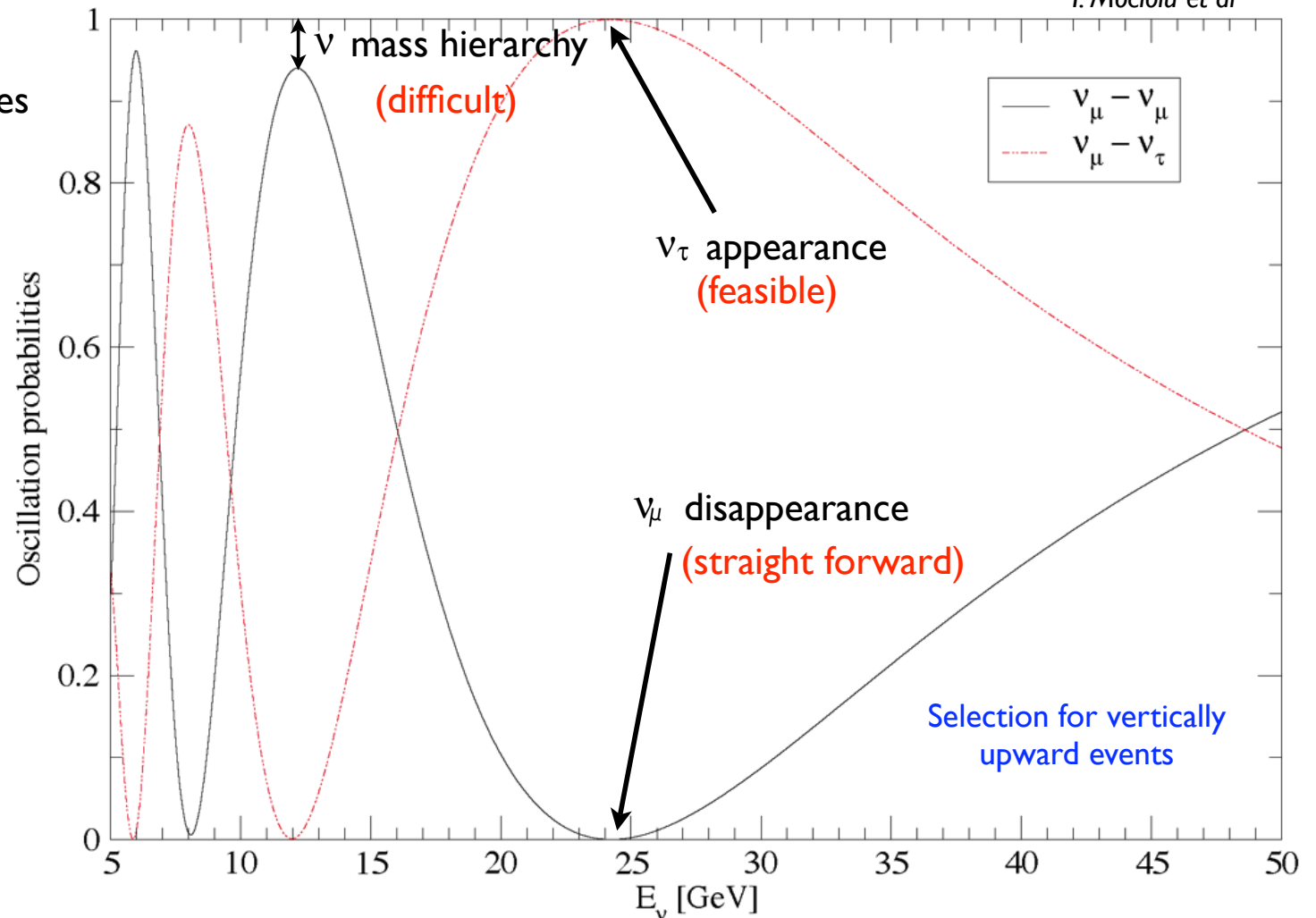Accelerator based

OPERA

MINOS

K2K

10 MeV	100 MeV	1 GeV	10 GeV	100 GeV	1 TeV	10 TeV	10 PeV

Solar neutrinos

atmospheric neutrinos

DeepCore

AMANDA

IceCube

Gap

Non-accelerator based

Region of relatively open neutrino oscillation parameter space

DeepCore neutrino oscillation signals...for your consideration

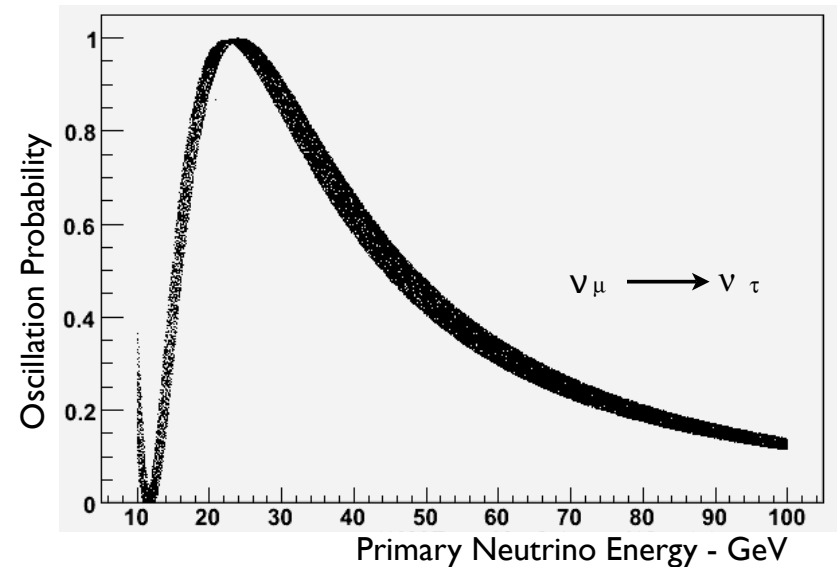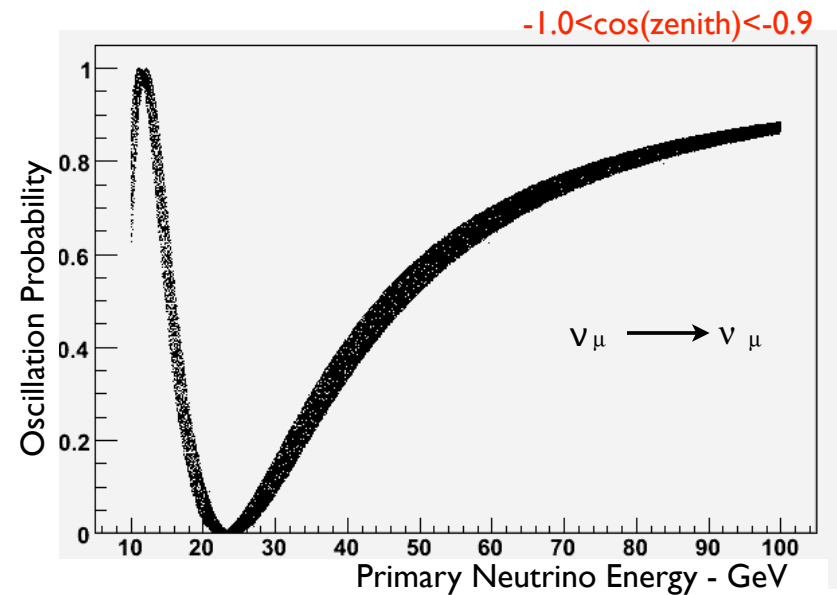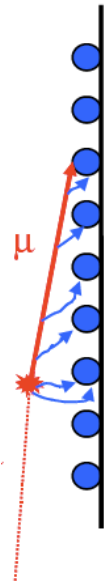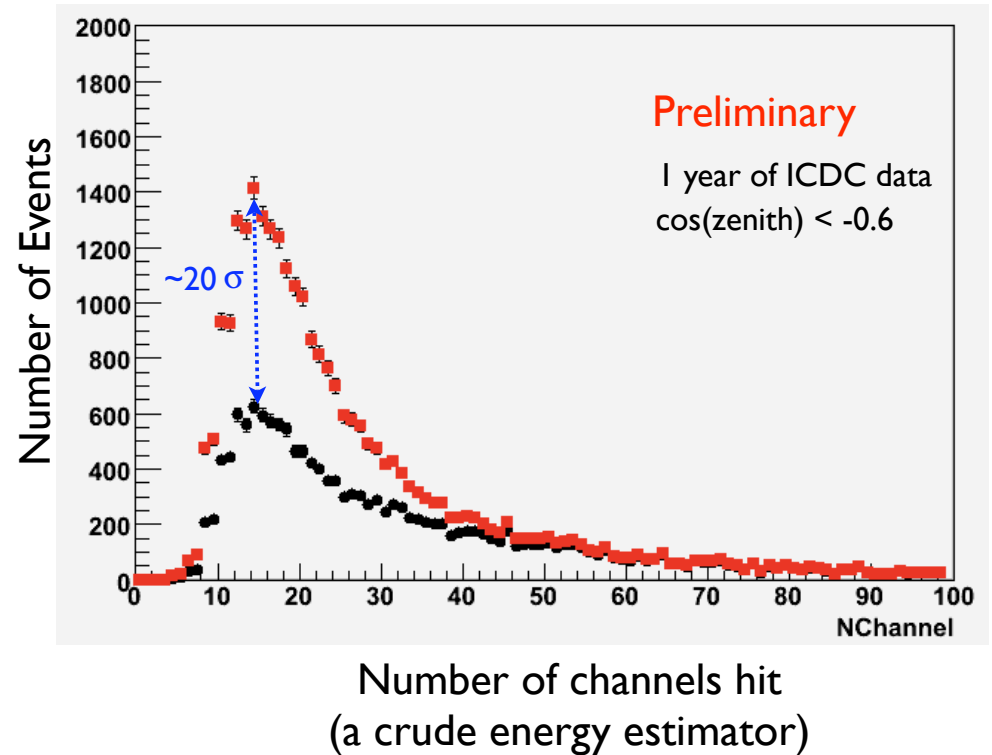# Monte Carlo of the DeepCore signal for Oscillation Studies

- A full IceCube/DeepCore detector MC simulation is completed for the atmospheric neutrino signal (ν_μ and ν_e)

- Code for 3-neutrino MSW oscillations (thanks I. Mocioiu), utilizing the PREM Earth Model to numerically integrate the layers which a neutrino of given energy and direction will traverse is written into an IceCube data processing module

- Module inputs include oscillation parameters such as Δm^2, mixing angles, CP violation...

- Output of the module are the oscillation probabilities for a neutrino at the IceCube detector location

-1.0<cos(zenith)<-0.9

$\nu_\mu \longrightarrow \nu_\mu$

Oscillation Probability

Primary Neutrino Energy - GeV

$\nu_\mu \longrightarrow \nu_\tau$

Oscillation Probability

Primary Neutrino Energy - GeV

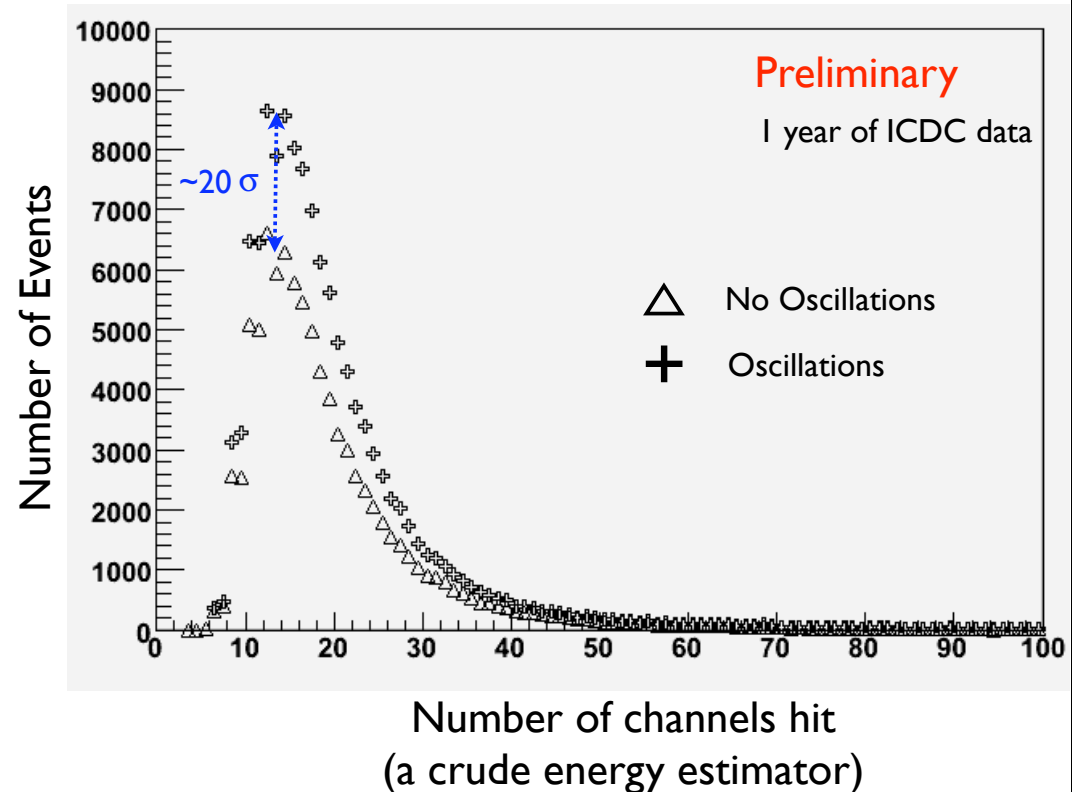# DeepCore ν_μ Disappearance (The Old Curiosity Shop)

- Effect is strongest and easiest to measure using nearly vertical up-going ν_μ induced muons

- Study for trigger level only (4 channels hit in the DeepCore fiducial volume)

- Only statistical errors are shown

- Utilizes 3-neutrino mixing and the PREM Earth model

Preliminary

1 year of ICDC data
cos(zenith) < -0.6

~20 σ

Number of channels hit
(a crude energy estimator)

Event Selection: muon track events with a starting vertex inside the DeepCore fiducial volume.

DeepCore ν_τ Appearance (Our Mutual Friend)

- Low energy cascade events that need to be identified from the track events of similar energy

- Study for trigger level only (6 hits in the DeepCore fiducial volume)

- Utilizes 3-neutrino mixing and the PREM Earth model

Preliminary

1 year of ICDC data

△ No Oscillations

+ Oscillations

~20 σ

Number of Events

Number of channels hit
(a crude energy estimator)

Event Selection: ν_e CC (interaction vertex + interaction particle) and NC (interaction vertex)

ν_μ CC (interaction vertex + muon) and NC (interaction vertex) E<10GeV

w/Oscillations - ν_τ CC (interaction vertex + decay particle) and NC (interaction vertex)

Neutrino Mass Hierarchy (Great Expectations)

Neutrino mass hierarchy extraction using atmospheric neutrinos in ice

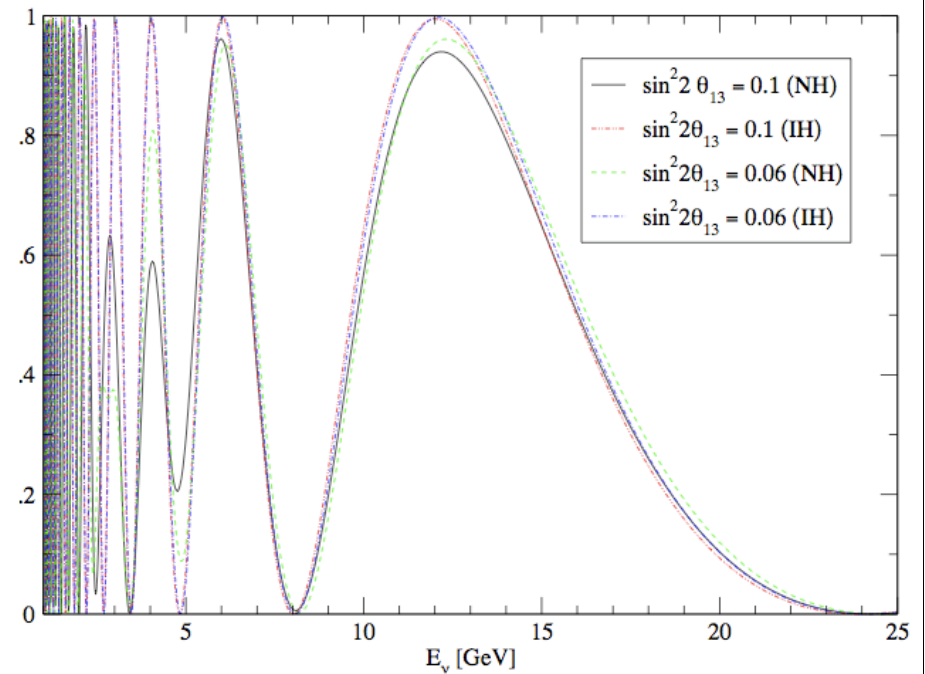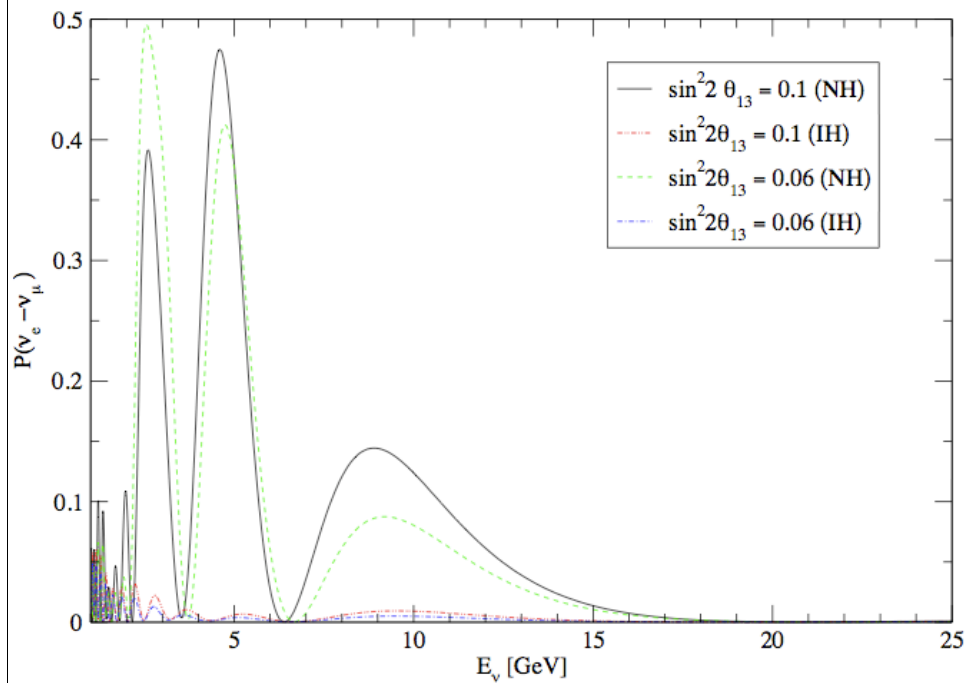Olga Mena[1,2], Irina Mocioiu[3] and Soebur Razzaque[4]

[1] INFN Sez. di Roma, Dipartimento di Fisica, Università di Roma "La Sapienza", P.le A. Moro, 5, I-00185 Roma, Italy
[2] Institute of Space Sciences (IEEC-CSIC), Fac. Ciencies, Campus UAB, Bellaterra, Spain
[3] Department of Physics, Pennsylvania State University, University Park, PA 16802, USA and
[4] Space Science Division, Code 7653, U.S. Naval Research Laboratory, Washington DC 20375, USA

(Dated: August 24, 2008)

Neutrino Mass Hierarchy (Great Expectations)

arXiv:0803.3044 (March 2008)

Neutrino mass hierarchy extraction using atmospheric neutrinos in ice

Olga Mena[1,2], Irina Mocioiu[3] and Soebur Razzaque[4]

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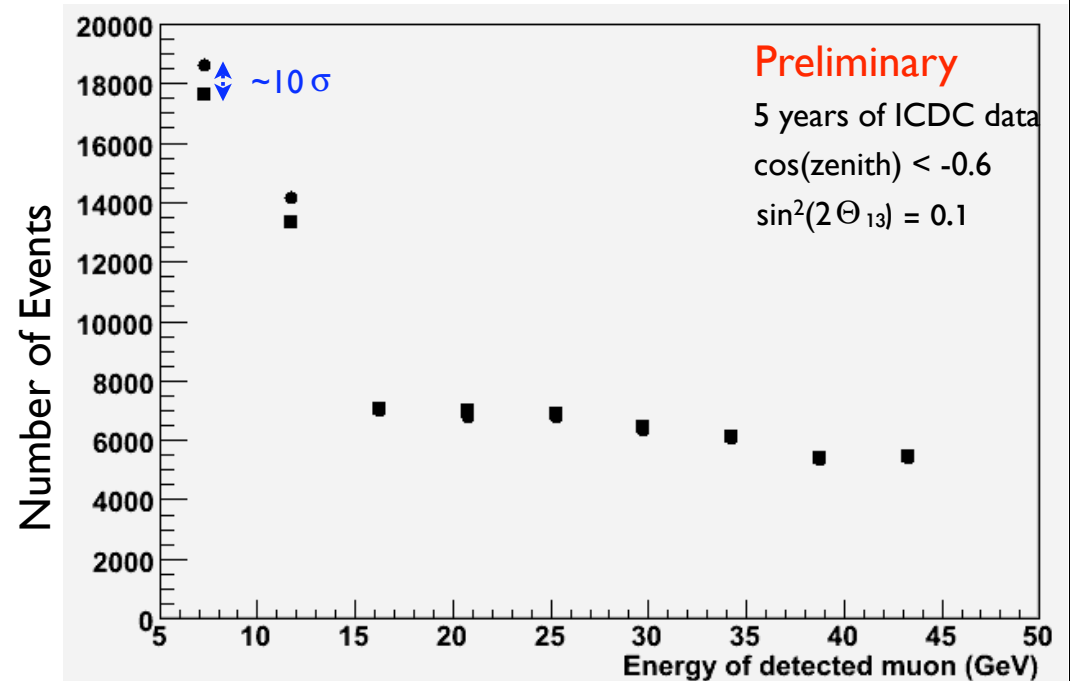
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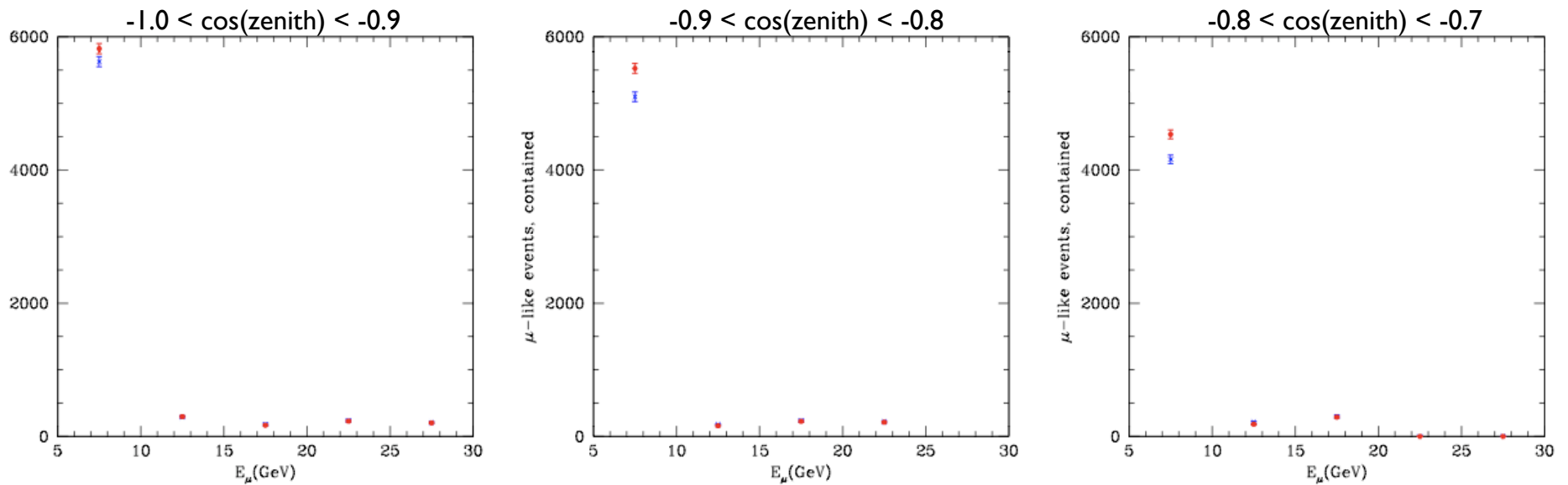
Neutrino Mass Hierarchy (Great Expectations)

- Full IceCube/DeepCore detector MC

- Study for trigger level only (4 hits in the DeepCore fiducial volume)

- Statistical errors considered only

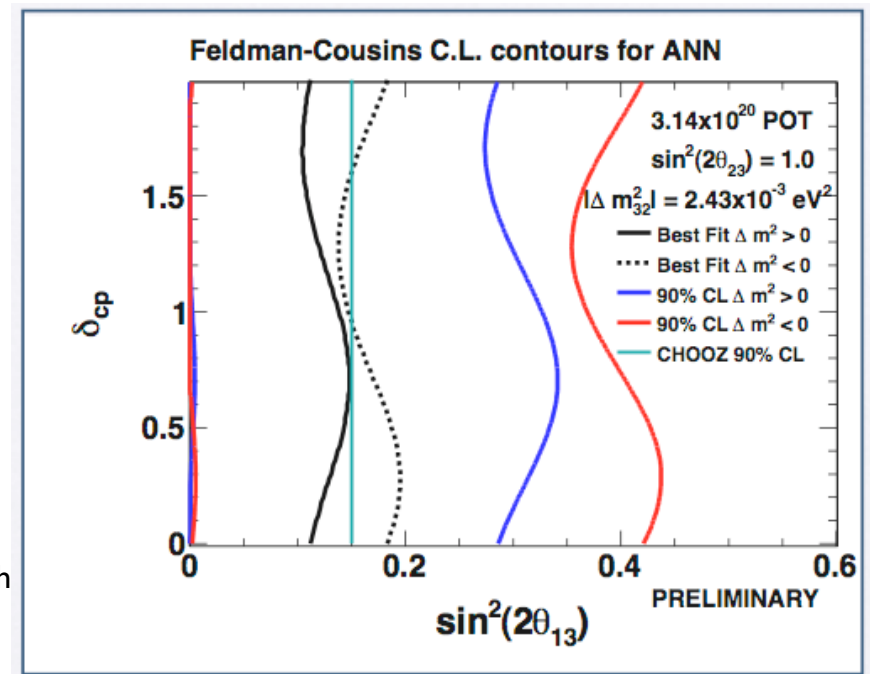- 3-neutrino oscillations w/ full PREM Earth model

Preliminary

5 years of ICDC data

cos(zenith) < -0.6

$\sin^2(2\Theta_{13}) = 0.1$

~10 σ

Number of Events

Energy of detected muon (GeV)

circles = inverted; squares = normal

Event Selection: muon track events with a starting vertex inside the DeepCore fiducial volume.

Neutrino Oscillation Conclusions

- Addition of DeepCore to the IceCube detector opens a window to a wealth of measurements utilizing atmospheric neutrino oscillations.

- Full detector MC studies have been completed for:

  - ν_μ disappearance (>20σ statistical measurement with 1 year of ICDC data). Sensitive to overlap energies of SuperK and long-baseline experiments and opens to primarily unexplored region >10GeV.

  - ν_τ appearance (~20σ statistical measurement with 1 year of ICDC data). Directly competitive with OPERA accelerator experiment.

  - Neutrino Mass Hierarchy (~10σ statistical measurement with 5 years of ICDC data and $\sin^2(2\Theta_{13}) = 0.1$). The first experiment with this sensitivity on the same time scale as a precision measurement of Θ_{13} at Daya Bay, for example.

First MINOS results