Neutrino Oscillations with the IceCube/DeepCore

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The Pennsylvania State University

Workshop on “Low Energy” Neutrino Physics and Astrophysics with IceCube
IceCube/DeepCore and Neutrino Oscillations

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

- 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

Region of relatively open neutrino oscillation parameter space
DeepCore neutrino oscillation signals...for your consideration

Mass hierarchy measurement assumes $\sin^2(2\Theta_{13}) = 0.1$
Monte Carlo of the DeepCore signal for Oscillation Studies

- A full IceCube/DeepCore detector MC simulation is completed for the atmospheric neutrino signal ($\nu_\mu$ and $\nu_e$)

- 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 $\Delta m^2$, mixing angles, CP violation...

- Output of the module are the oscillation probabilities for a neutrino at the IceCube detector location
DeepCore $\nu_\mu$ Disappearance (The Old Curiosity Shop)

- Effect is strongest and easiest to measure using nearly vertical up-going $\nu_\mu$ 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

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

Event Selection:

$\nu_e$ CC (interaction vertex + interaction particle) and NC (interaction vertex)
$\nu_\mu$ CC (interaction vertex + muon) and NC (interaction vertex) $E<10$GeV
$w/Oscillations$ - $\nu_\tau$ CC (interaction vertex + decay particle) and NC (interaction vertex)
Neutrino Mass Hierarchy (Great Expectations)

Neutrino mass hierarchy extraction using atmospheric neutrinos in ice

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(Dated: August 21, 2008)
Neutrino Mass Hierarchy (Great Expectations)

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Neutrino mass hierarchy extraction using atmospheric neutrinos in ice

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(Dated: August 21, 2008)
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 with full PREM Earth model

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

Number of Events

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<th>Energy of detected muon (GeV)</th>
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Preliminary
5 years of ICDC data
\[ \cos(\text{zenith}) < -0.6 \]
\[ \sin^2(2 \Theta_{13}) = 0.1 \]

circles = inverted; squares = normal
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:
  - $\nu_\mu$ disappearance ($>20\sigma$ statistical measurement with 1 year of ICDC data). Sensitive to overlap energies of SuperK and long-baseline experiments and opens to primarily unexplored region $>10\text{GeV}$.
  - $\nu_\tau$ appearance ($\sim20\sigma$ statistical measurement with 1 year of ICDC data). Directly competitive with OPERA accelerator experiment.
  - Neutrino Mass Hierarchy ($\sim10\sigma$ 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 $\theta_{13}$ at Daya Bay, for example.