Tue Jan 3 03:34:01 2012

Recent Highlights from IceCube

Nathan Whitehorn
for the IceCube Collaboration

University of Wisconsin - Madison

March 4, 2013
Rencontres de Moriond 2013 Electroweak

Why are High Energy Neutrinos Interesting?

$$p + \gamma/p \rightarrow \pi^0 + X$$
$$\hookrightarrow \gamma + \gamma + p$$

Gammas

$$\rightarrow \pi^+ + X$$
$$\hookrightarrow \mu^+ + \nu_\mu + X$$
$$\hookrightarrow e^+ + \nu_{\bar{\mu}} + \nu_e + \nu_\mu + X$$

Neutrinos

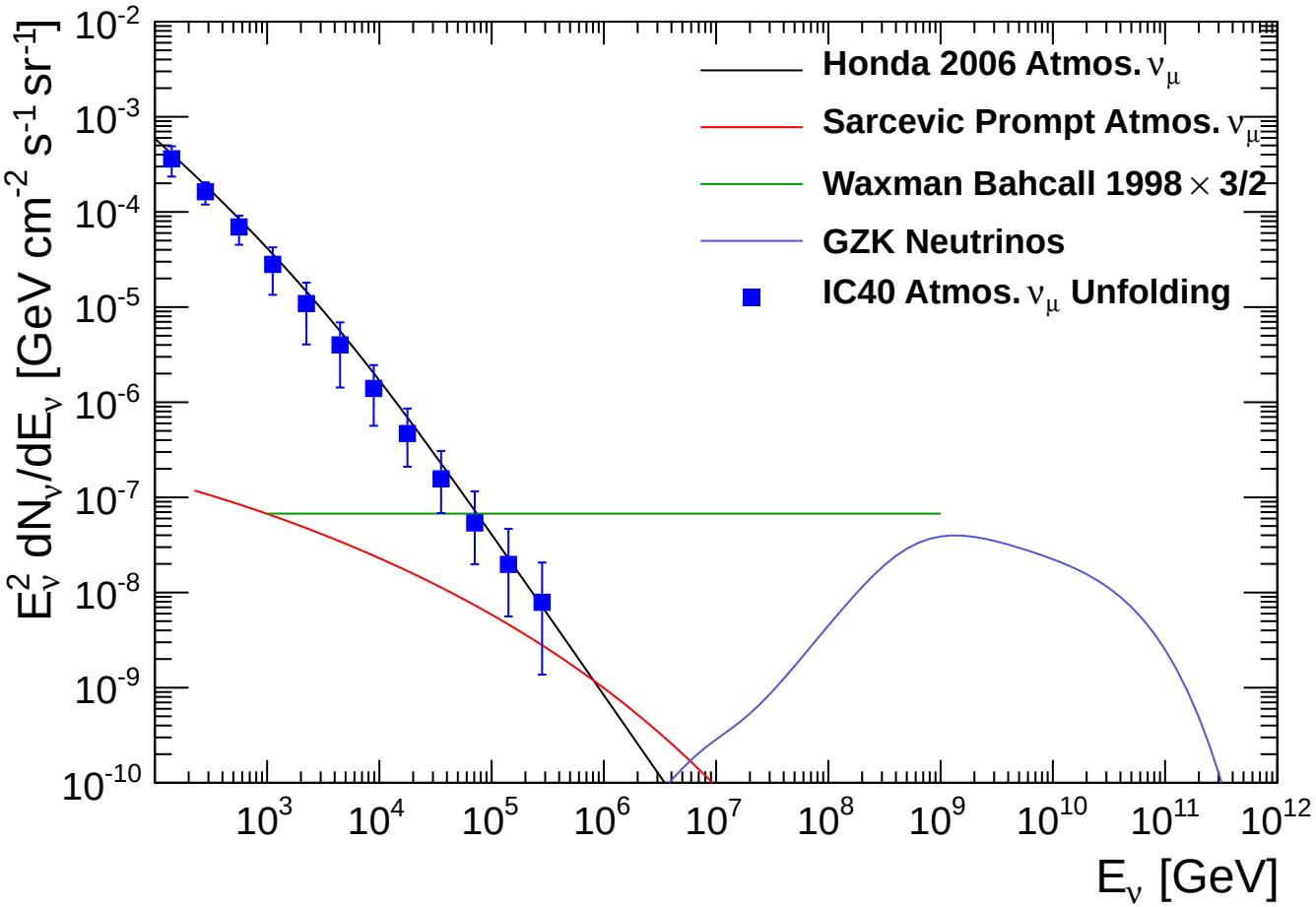
Neutrinos from cosmic ray interactions in:

- Atmosphere
- Cosmic Microwave Background
- Cosmic-ray acceleration sites

Also from:

- Exotic physics (e.g. WIMP annihilation)
- ?

A Neutrino Taxonomy at 1 GeV and Up



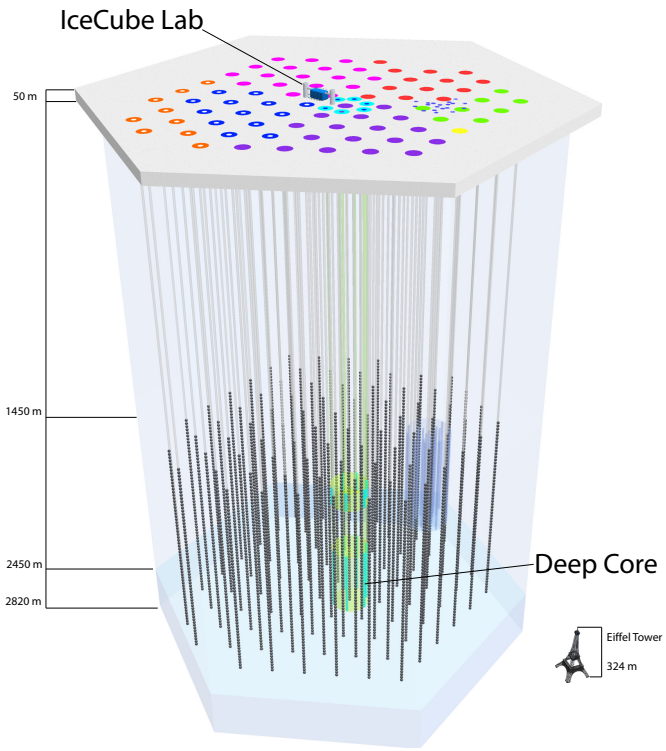
- π/K Atmospheric Neutrinos (dominant $<$ 100 TeV)
- Charm Atmospheric Neutrinos ("prompt", 300 TeV)
- Astrophysical Neutrinos (maybe dominant $>$ 100 TeV)
- Cosmogenic Neutrinos (10^6 TeV)

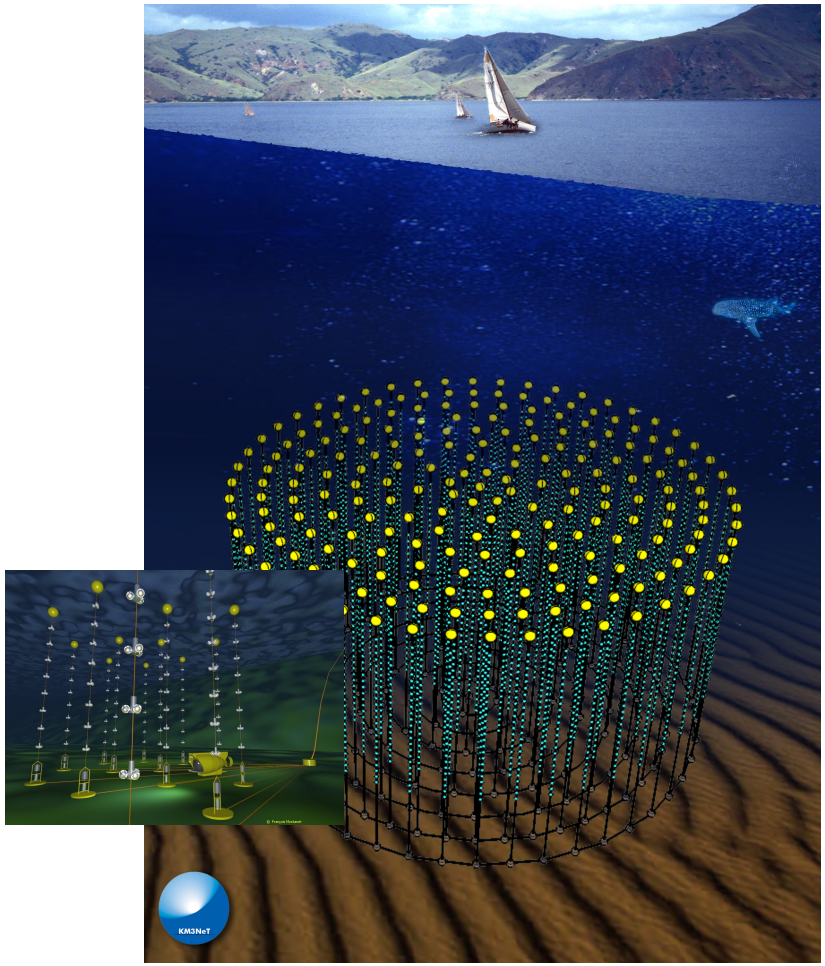
Challenges

- Neutrino cross-section is very small
- ...so are the fluxes
- Most of the TeV+ sources predict fluxes on the order of 1 event/gigaton/year
- Discrimination against background (cosmic ray muons, atmospheric neutrinos from π, K decay)

Gigaton Detectors

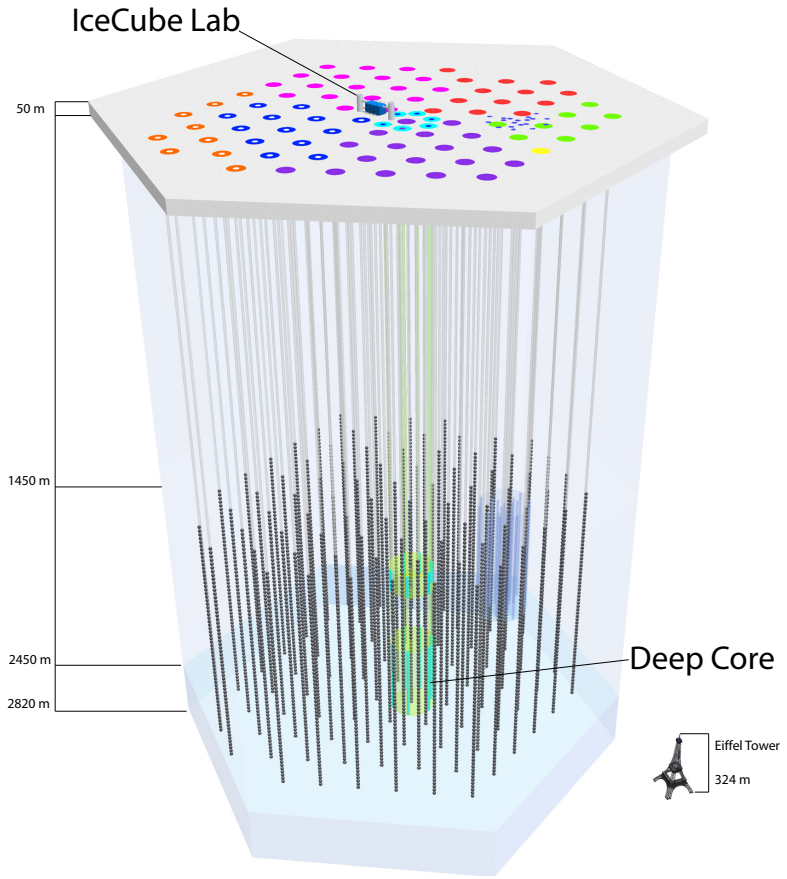
Need natural detectors: IceCube, KM3NET (future), ANTARES, Baikal





IceCube

- 5160 PMTs with waveform readout
- ns time resolution
- 1 km^3 volume
- 86 strings
- 17 m PMT-PMT spacing per string
- 125 m string spacing
- DeepCore subarray lowers energy threshold to 10 GeV

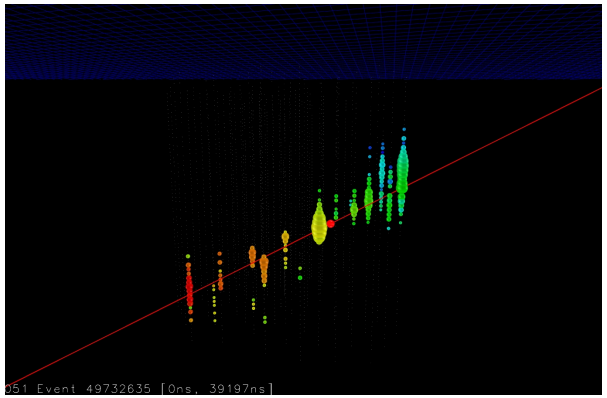


Event Signatures

Muon Neutrino CC (data)

< 1 degree angular resolution

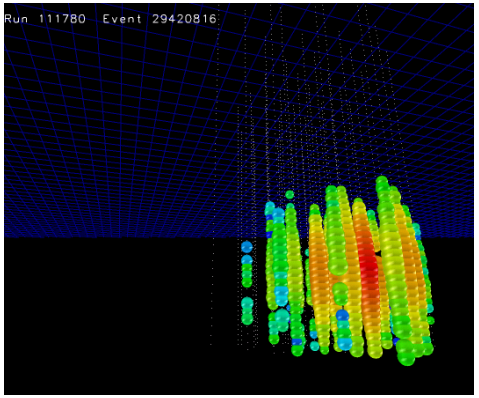
30% in log energy resolution



Neutral Current or Electron Neutrino (data)

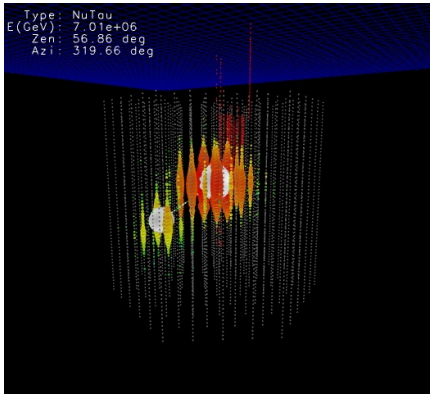
10 degree angular resolution (high energy)

$\sim 15\%$ energy resolution



Tau Neutrino CC (simulation)

Not yet observed



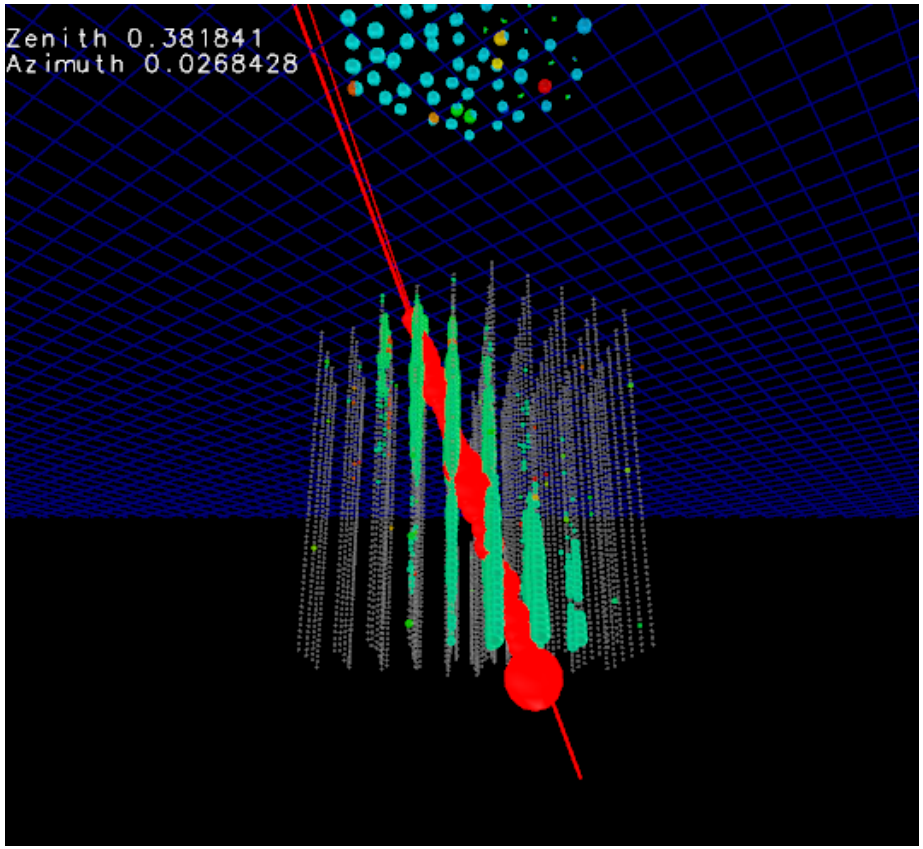
Challenges in Large-Volume Neutrino Detectors

Backgrounds:

- Cosmic Ray Muons (3000 Hz)
- Atmospheric Neutrinos (1 per 5 minutes)

Natural materials:

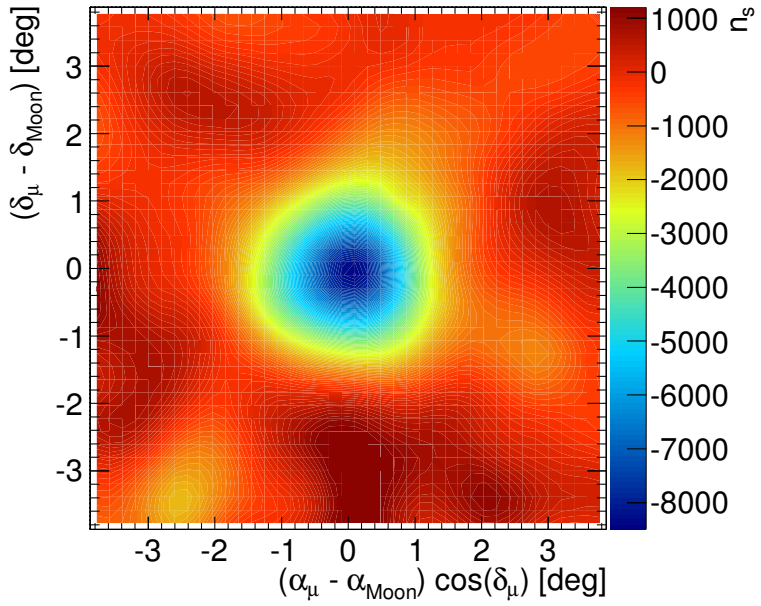
- Optical Properties of Ice measured In-Situ
- No Laboratory Calibration – must use cosmic rays



Calibration

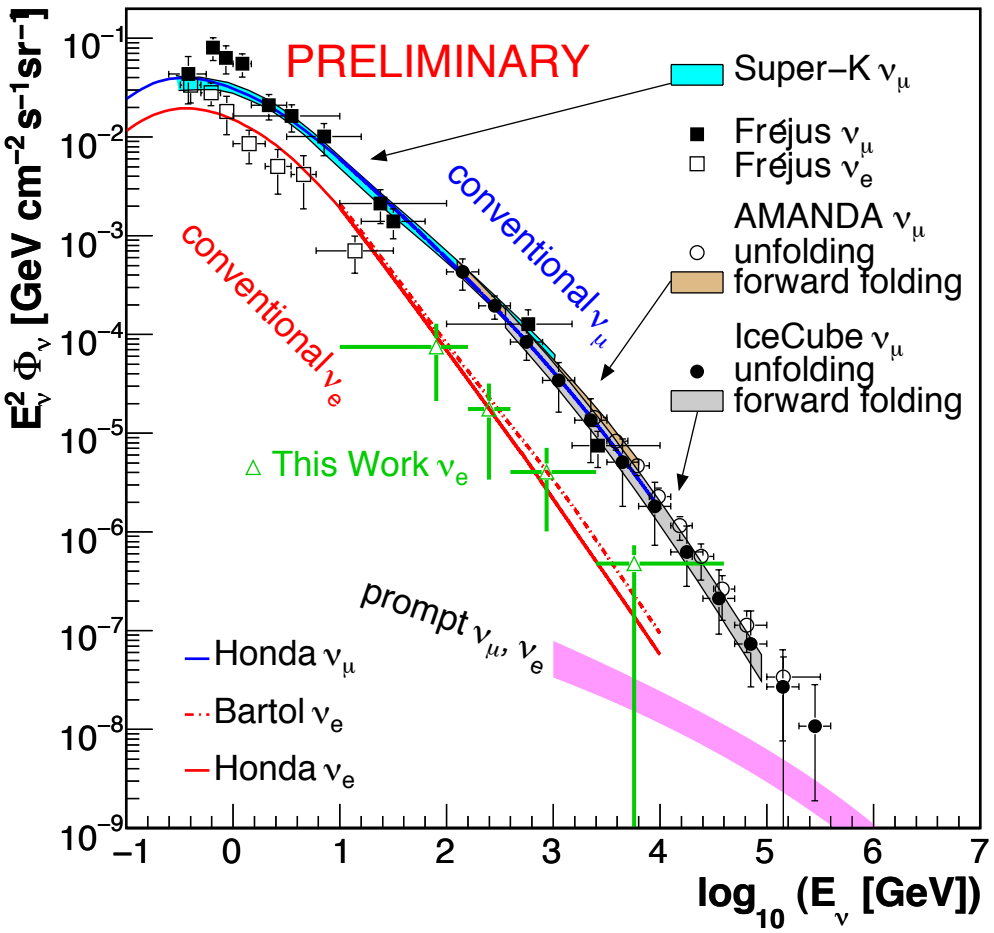
Calibration Sources:

- LED Flashers on each DOM
- In-Ice Calibration Laser
- Cosmic Ray Energy Spectrum
- Moon Shadow
- Atmospheric Neutrino Energy Spectrum
- Minimum-Ionizing Muons



Moon Shadow in Cosmic Ray Muons in IceCube (59 strings)

Atmospheric Neutrino Measurement

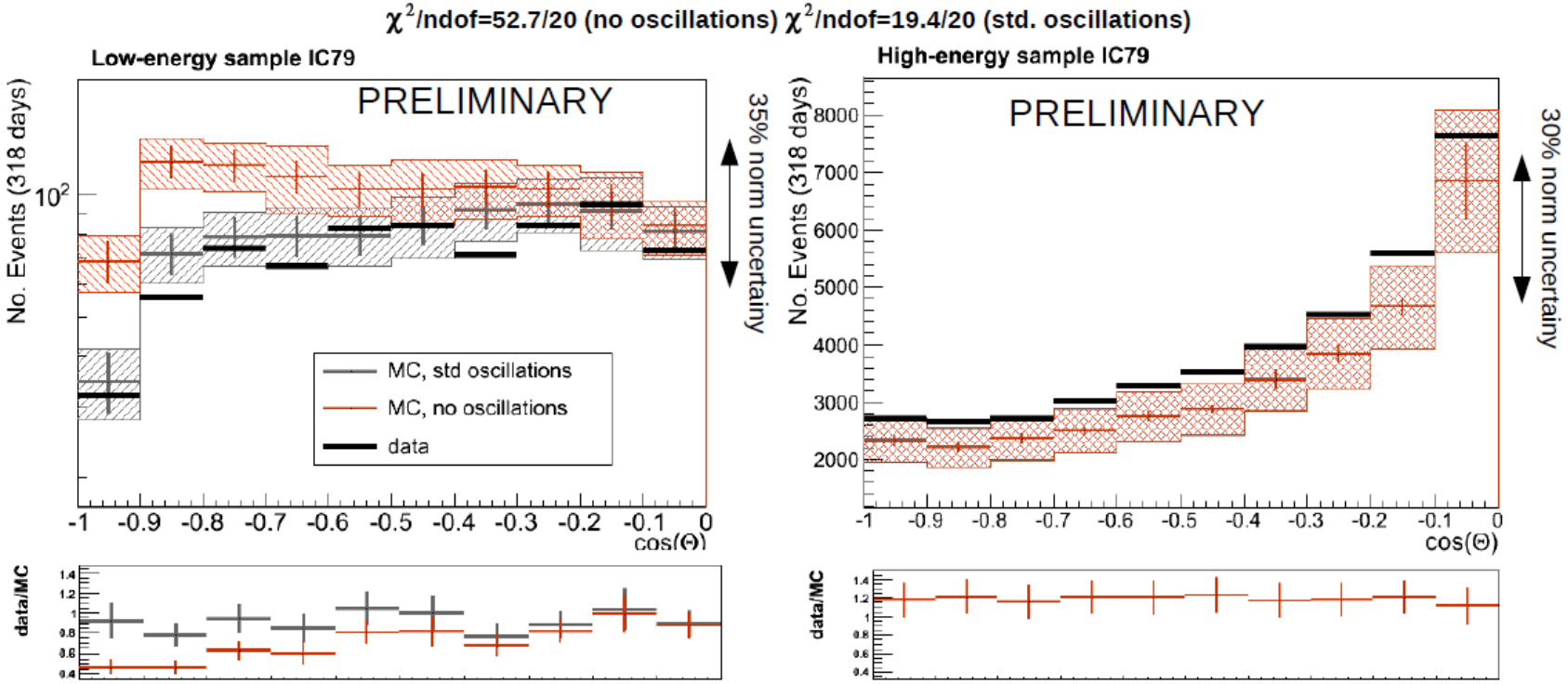


arXiv:1212.4760

- Largest-ever sample of atmospheric neutrinos: 100,000 events per year
- First measurement of atmospheric ν_e at TeV energies
- Approaching the ability to test prompt models

Neutrino Oscillations

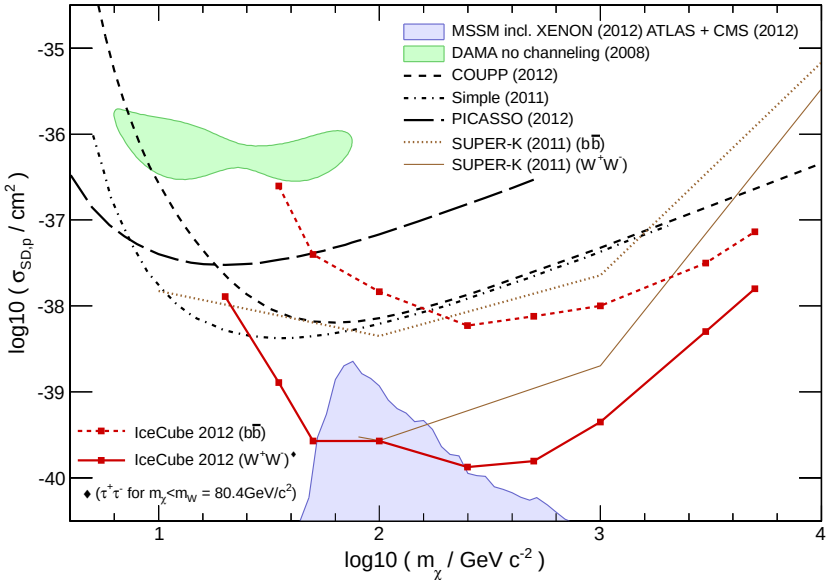
Sensitive to Θ_{23} over long baselines from atmospheric neutrinos – zenith-dependent suppression of CC ν_μ as different chords of the Earth are traversed.

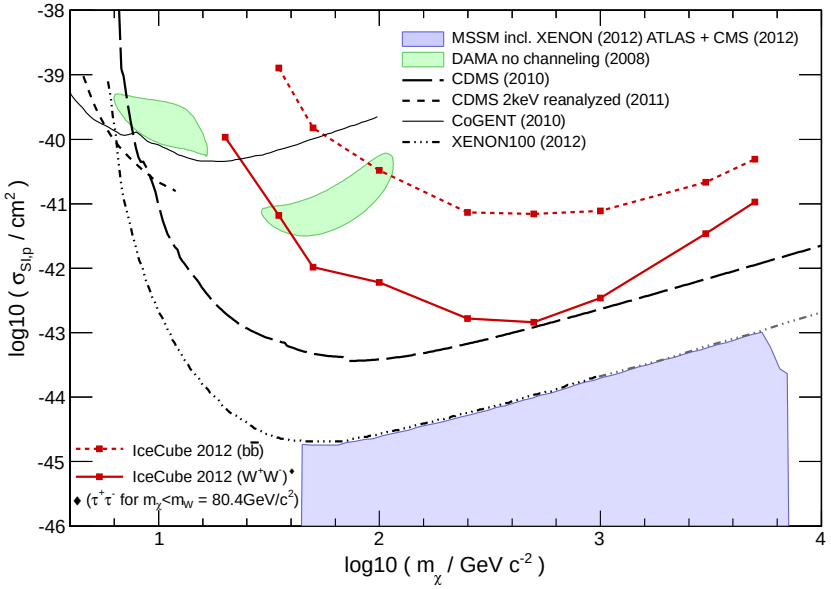


Extremely high statistics available with multi-megaton Deep Core subarray – first observation of neutrino oscillations in IceCube.

Indirect Dark Matter Detection in the Sun

- Dark Matter accumulates in the sun, annihilating to high-energy neutrinos
- Equilibrium annihilation related to solar capture rate $\rightarrow$ probes scattering cross-section
- High sensitivity to spin-dependent cross sections due to proton target
- Sensitive to 20 GeV $\lesssim m_\chi \lesssim$ 10 TeV
- Complementary to direct searches: fills out WIMP picture by testing other properties



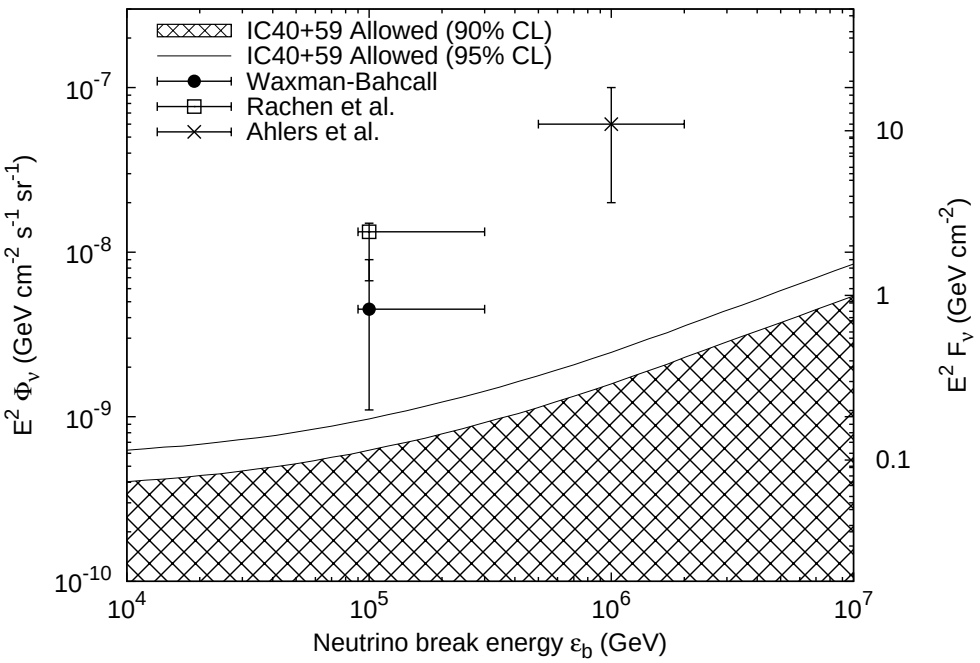


arXiv:1212.4097, accepted PRL

Gamma-ray Bursts

GRBs a leading candidate for acceleration of cosmic rays

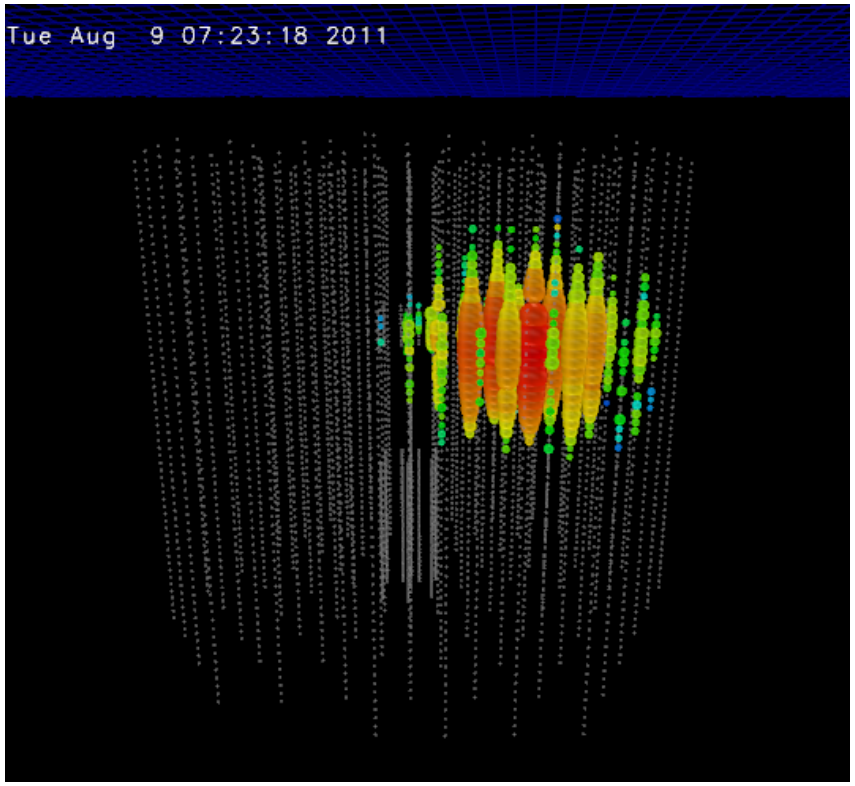
- High energy protons produce $\pi^+ \rightarrow \nu$ on ambient gammas in source
- Most GRB models where this happens excluded by IceCube
- All neutron-dominated models where this happens excluded by IceCube



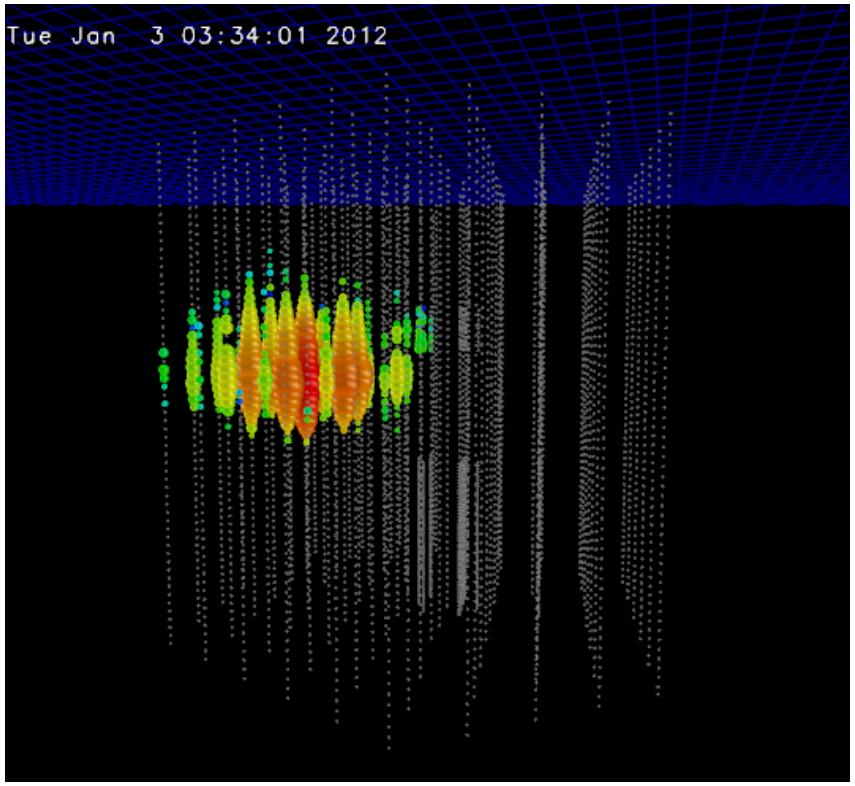
Nature 484 (2012), arXiv:1204.4219

A mystery: PeV neutrinos

Appearance of ~ 1 PeV neutrinos as an at-threshold background in cosmogenic neutrino search – should be $\ll 1$ atmospheric neutrinos per year at these energies



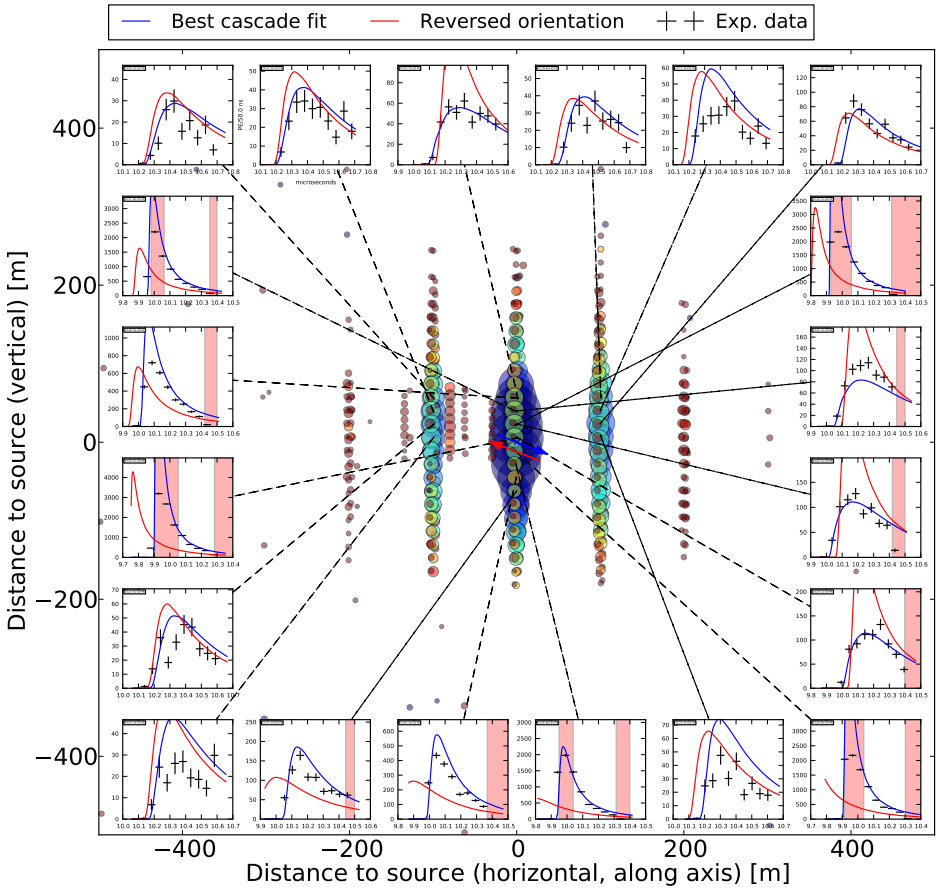
~ 1100 TeV



~ 1300 TeV

PRELIMINARY

A closer look at a PeV shower

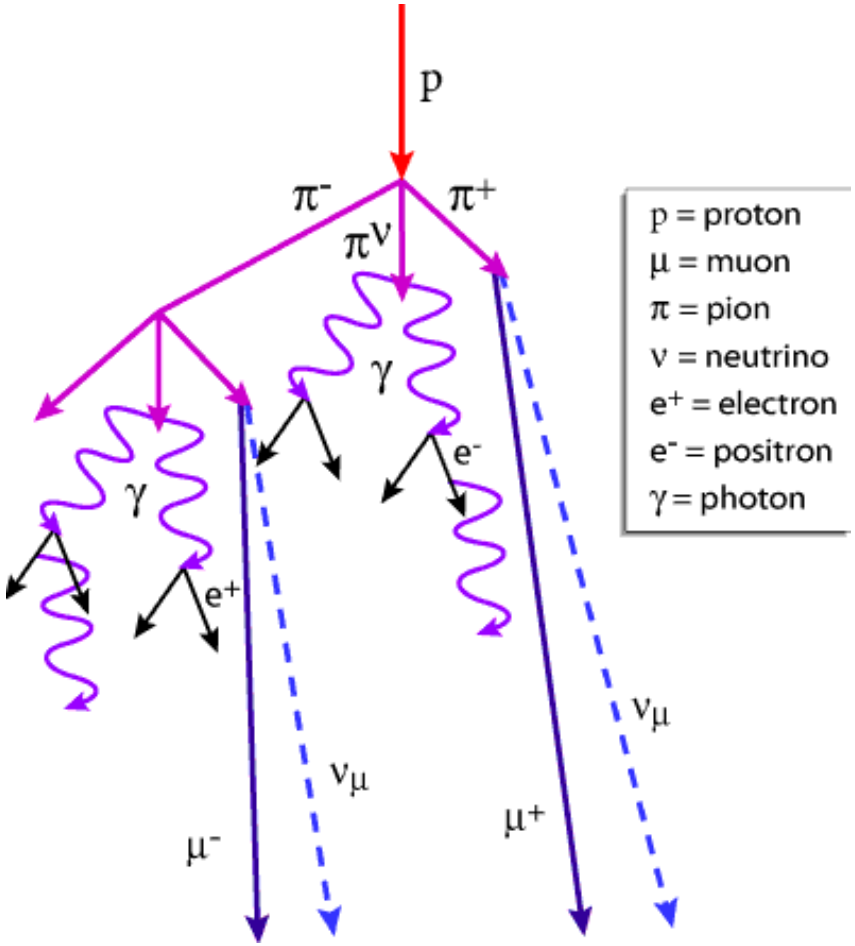


- Good absolute agreement with predictions for either ν_e or neutral-current
- Width of waveforms related to direction of Cherenkov cone
- Height proportional to energy
- Preliminary pointing established (blue arrow)
- Energy uncertainty of $^{+15\%}_{-13\%}$

PRELIMINARY

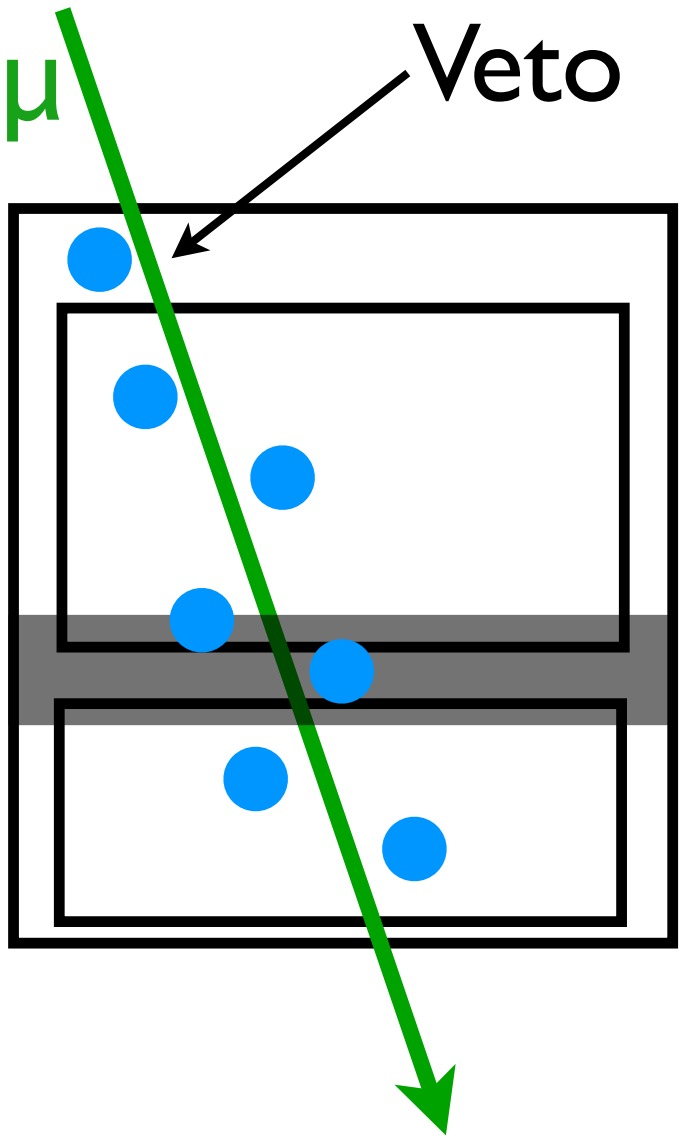
Atmospheric Neutrino Backgrounds

- Typically separated by energy, can also be separated by zenith angle: downgoing events should have associated showers
- 0.1 event/year at PeV energies
- Large uncertainties (factor of 5) in atmospheric spectrum at high energies – depends on composition of cosmic rays, very forward charmed meson production



Follow-up analysis to trace high-energy excess

- Events are in a tail of some distribution – what is the rest of the population?
- Energy spectrum, spatial distribution, and neutrino flavor ratios tell us about the source
  - Astrophysical events should oscillate to 1:1:1, may concentrate in sky
  - Charm signal $E^{-2.7}$, isotropic
  - Conventional Atmospheric $E^{-3.7}$, isotropic, ν_μ dominated
- Only ~ 1 event/year > 100 TeV predicted from existing models
- Probe entire 100 TeV - 1 PeV region, for all flavors and directions by vetoing entering muons (right)



Conclusions

- IceCube fully operational
- Detector performing extremely well
- Leading GRB models excluded
- Competitive constraints on WIMPs
- Neutrino oscillations observed
- PeV neutrinos observed as a background to GZK searches
- Not yet clear what they are: seem not to be atmospheric