Status of ν_τ appearance search in IceCube and PINGU

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Measuring ν_τ appearance

- From theory: "2-3 osc" is $\nu_\mu \to \nu_\tau$
  - measured by OPERA (5 events)
  - also observed by SK at $\sim 4\sigma$
- Precise measurement of ν_τ appearance allows verification of unitarity of mixing matrix
- ν_τ CC x-sec turns on at a few GeV
  - need as high ν energy as possible
- However $\nu_\mu \to \nu_\tau$ oscillation maximum at much lower energies at typical oscillation baselines
  - maximum at 25 GeV for ν traveling through Earth's diameter

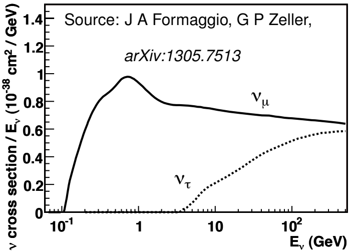
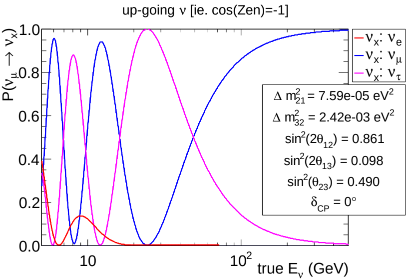
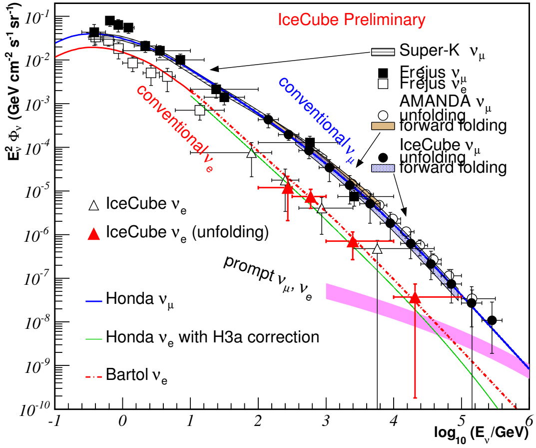


FIG. 10 Plot comparing the total charged current ν_μ (solid) and ν_τ (dashed) per nucleon cross sections divided by neutrino energy and plotted as a function of neutrino energy.



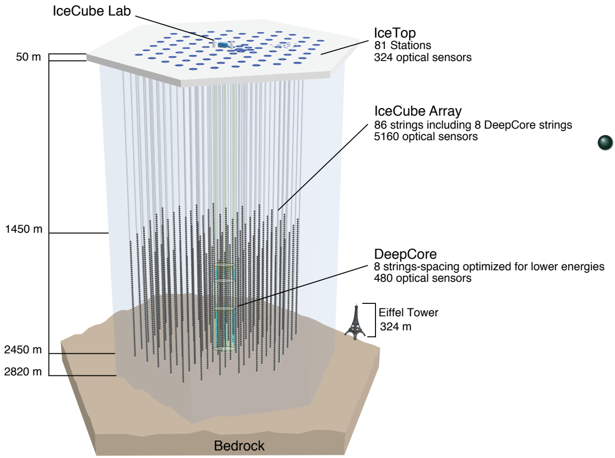
Atmospheric neutrinos

- Neutrinos from different baselines and energies
  - Baselines vary between ~20 km to ~12760 km

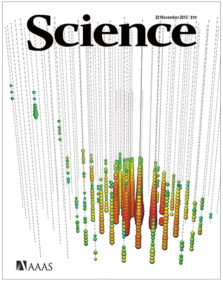


- Large volume detectors needed for large statistics
- $\sim 10^4$ ν_μ expected per year at analysis level in DeepCore

IceCube

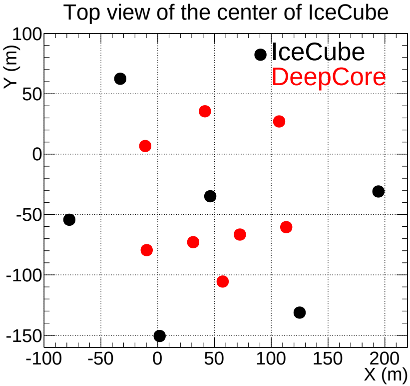


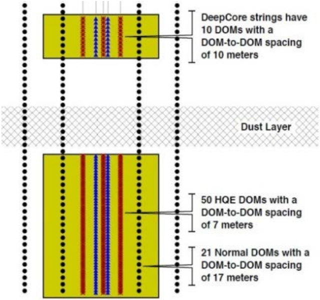
- Without DeepCore:
  78 strings,
  125 m string spacing,
  17 m module z-spacing
- Optimized for (very)
  High Energy neutrinos



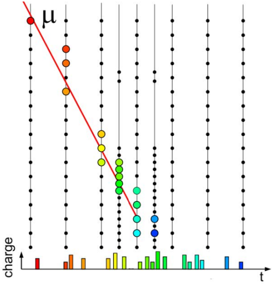
IceCube-DeepCore

- 78 strings, 125 m string spacing
- 17 m modules z-spacing
- 8 strings, 40-75 m string spacing
- 7 m modules z-spacing



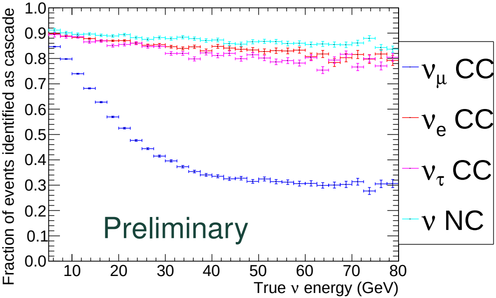


Measurement strategy



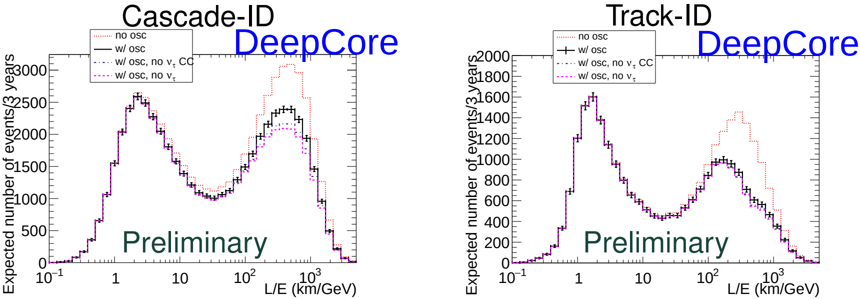
- Huge background from atmospheric μ
  - Use IC as veto to reject atm μ events
  - Same as done for ν_μ disappearance analysis
    - see J. Hignight's talk
- Reconstruct ν energy and direction
  - oscillation distance (L) given by zenith

- Separate ν events with clear muons from rest
  - only $\sim$18% of τ decay have μ
  - ν_μ CC is main background to analysis
- Cannot currently separate different types of "cascade"



What is the signal in IceCube-DeepCore?

- The oscillation formalism does not relate to how the ν interacts
  - in that sense, ν_τ CC and NC are both signal
- But, uncertainties on the x-sec would affect more ν_τ CC rate
  - in that case using signal as only ν_τ CC would simplify interpretation

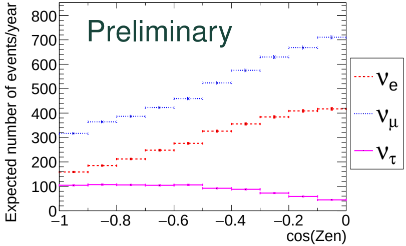


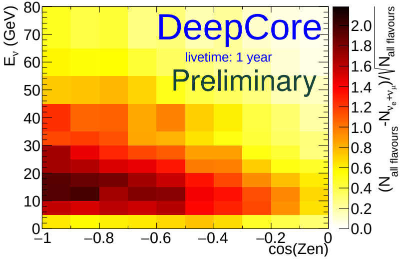
- Currently both ν_τ CC and NC considered signal.
  - In future plan to present results in both scenarios

What is the signal in IceCube-DeepCore?

- But fit is not done in L/E, but in $E \times \cos\theta_z$
  - Most signal in cascade channel
  - Pattern in $E \times \cos\theta_z$ helps reduces impact of systematics

Cascade-ID



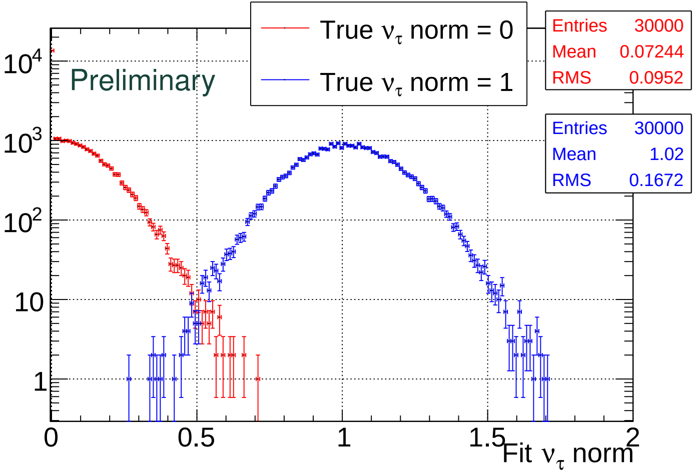


Systematic errors and fitting

	Gaussian prior	prior in fit?
ΔM^2	$(2.42 \pm 0.10) \cdot 10^{-3}$ eV^2	Yes
$\sin^2(\theta_{23})$	0.490 ± 0.055	Yes
ν overall normalization	$\pm 15\%$	No
Atmo. μ normalization	$1.34 \pm 20\%$	No
ν_e/ν_μ flux normalization	$\pm 2\%$	Yes
$\bar{\nu}/\nu$ flux normalization	$\pm 15\%$	Yes
Spectral index of ν_μ flux	± 0.05	Yes
DOM efficiency	$\pm 10\%$	Yes
Hole Ice	(0.02 ± 0.01) cm^{-1}	Yes

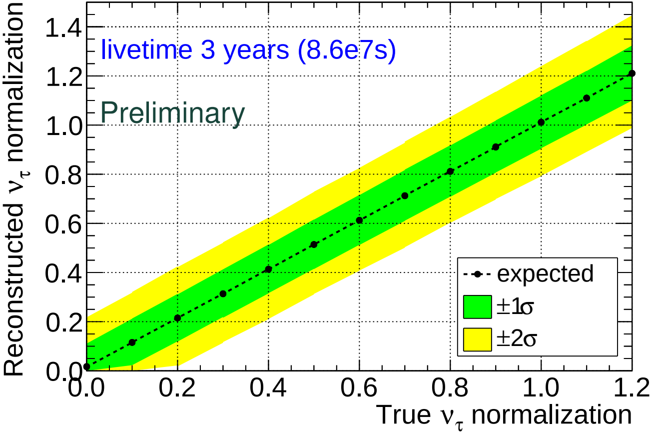
- Fit is done using Gaussian priors for most systematic errors and flat prior for ν_τ normalization (between 0.0 and 2.0)
  - in future will use more complicated prior for oscillation parameters
- For estimation of sensitivity, fit performed on several pseudo data generated from MC
  - When fit without prior, Gaussian prior is used for sampling of parameter used for pseudo-data creation.
- While main systematics already accounted for, still evaluating impact of other systematics

Reconstructed ν_τ normalization – 1 year



- Reasonable separation between default 3-flavour oscillation and no ν_τ appearance with 1 year DeepCore data
- Significance to exclude no ν_τ appearance: $\sim 6.5\sigma$ (Gaus approx)

Sensitivity for ν_τ normalization – “3 years”



- Significance to exclude no ν_τ appearance: $\sim 9.4\sigma$ (Gaus approx)
- 25% precision on ν_τ normalization

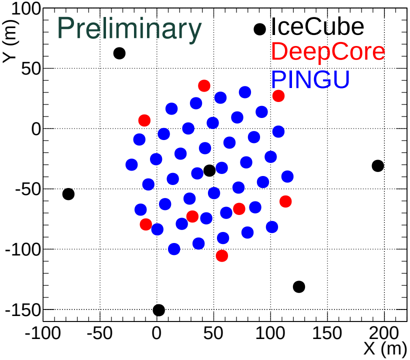
IceCube-DeepCore-PINGU

- 78 strings, 125 m string spacing
- 17 m modules z-spacing

- 8 strings, 75 m string spacing
- 7 m modules z-spacing

- 40 strings, 22 m string spacing
- 3 m modules z-spacing
  - all optical modules in clearest ice

Top view of the PINGU new candidate detector

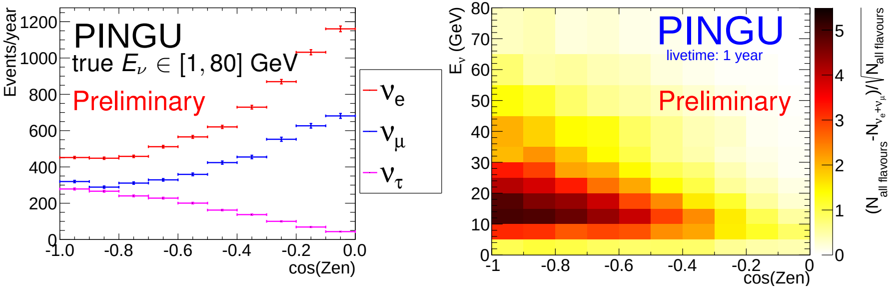


- For more on PINGU analysis see T. DeYoung's talk

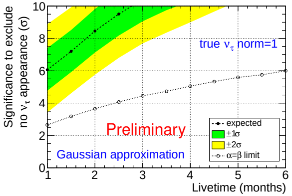
ν_τ appearance in PINGU

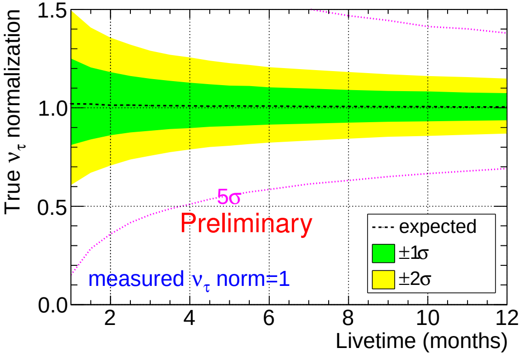
- Follow same procedure as for DeepCore
  - Denser array $\Rightarrow$ improved reconstruction and PID
- ν_τ composes larger part of final sample than in DeepCore

Cascade-ID



ν_τ appearance in PINGU – expected sensitivity





- 5σ exclusion of no ν_τ appearance after 1 month of data
- 10% precision in the ν_τ normalization after 6 months

Summary and outlook

- Atmospheric ν various baselines and energies permit measurement of ν_τ appearance
- IceCube-DeepCore should currently be able to statistically measure it with high significance
  - Progress being made towards this measurement
  - Expected 25% precision on normalization with already taken data
- PINGU should further increase sensitivity to ν_τ appearance
  - $<$ 10% precision on normalization after 1 year of data

The IceCube–PINGU Collaboration

International Funding Agencies

Fonds de la Recherche Scientifique (FRS–FNRS)
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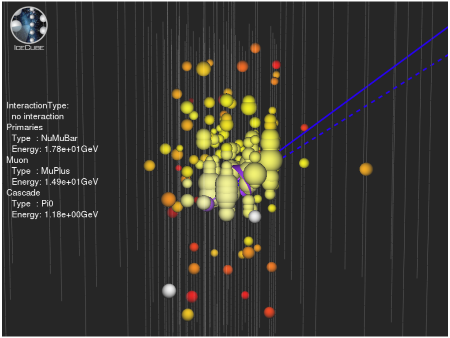
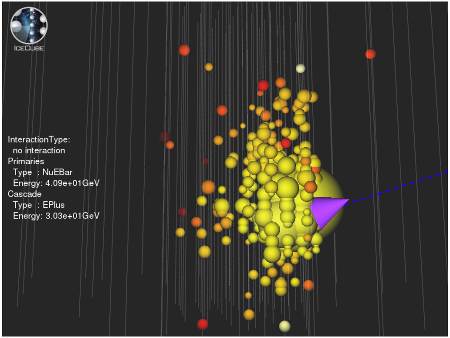
NSF–Physics Division
Swedish Polar Research Secretariat
The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

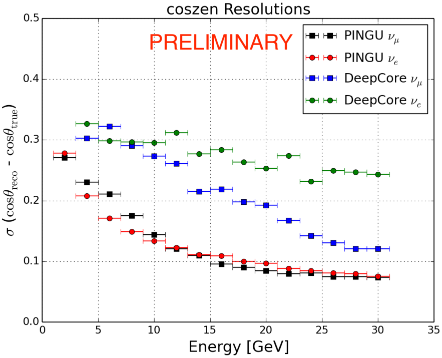
Backup slides

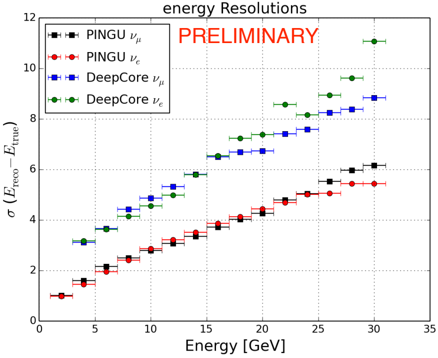
Event display at PINGU





Reconstruction resolutions





PINGU Particle identification