



Status of ν_{τ} appearance search in IceCube and PINGU

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Measuring ν_{τ} appearance

- From theory: "2-3 osc" is $u_{\mu} \rightarrow
 u_{\tau}$
 - measured by OPERA (5 events)
 - \blacktriangleright 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 v energy as possible
- However $\nu_{\mu} \rightarrow \nu_{\tau}$ 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.



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Atmospheric neutrinos

- Neutrinos from different baselines and energies
 - $\blacktriangleright\,$ Baselines vary between ${\sim}20$ km to ${\sim}12760$ km



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

IceCube



- Without DeepCore: 78 strings,
 125 m string appairs
 - 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
 - \blacktriangleright 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 ~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
 - \blacktriangleright 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	$(2.42\pm0.10)\cdot10^{-3}~{ m eV^2}$	Yes
$\sin^2(\theta_{23})$	0.490 ± 0.055	Yes
u overall normalization	±15%	No
Atmo. μ normalization	$1.34\pm20\%$	No
ν_{e}/ν_{μ} flux normalization	±2%	Yes
$\bar{ u}/ u$ flux normalization	$\pm 15\%$	Yes
Spectral index of $ u_{\mu}$ flux	± 0.05	Yes
DOM efficiency	$\pm 10\%$	Yes
Hole Ice	$(0.02\pm 0.01)~{ m cm^{-1}}$	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 $u_{ au}$ appearance: \sim 6.5 σ (Gaus approx)

Sensitivity for ν_{τ} normalization – "3 years"



• Significance to exclude no ν_{τ} appearance: \sim 9.4 σ (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



• 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



ν_{τ} appearance in PINGU – expected sensitivity



- 5 σ 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</p>

The IceCube-PINGU Collaboration

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Backup slides

Event display at PINGU



Reconstruction resolutions



PINGU Particle identification

