Cosmic neutrino oscillations and τ neutrinos in IceCube

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Update of survival/oscillation probabilities for cosmic neutrinos

$$P_{\ell\ell'} = \sum_i |U_{i\ell}|^2 |U_{i\ell'}|^2 = P_{\ell'\ell}$$

Three parameters (P_0, P_1, P_2) for $P_{\ell\ell'}$:

$$P_{\ell\ell'} = \begin{pmatrix} 1/3+2P_0 & 1/3-P_0+P_1 & 1/3-P_0-P_1 \\ & 1/3+P_0/2-P_1+P_2 & 1/3+P_0/2-P_2 \\ & & 1/3+P_0/2+P_1+P_2 \end{pmatrix}$$

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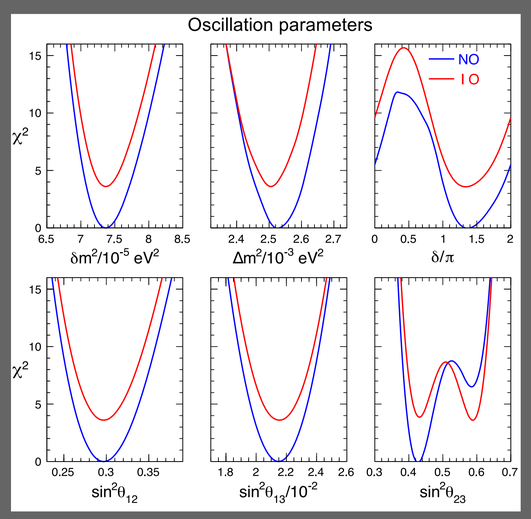

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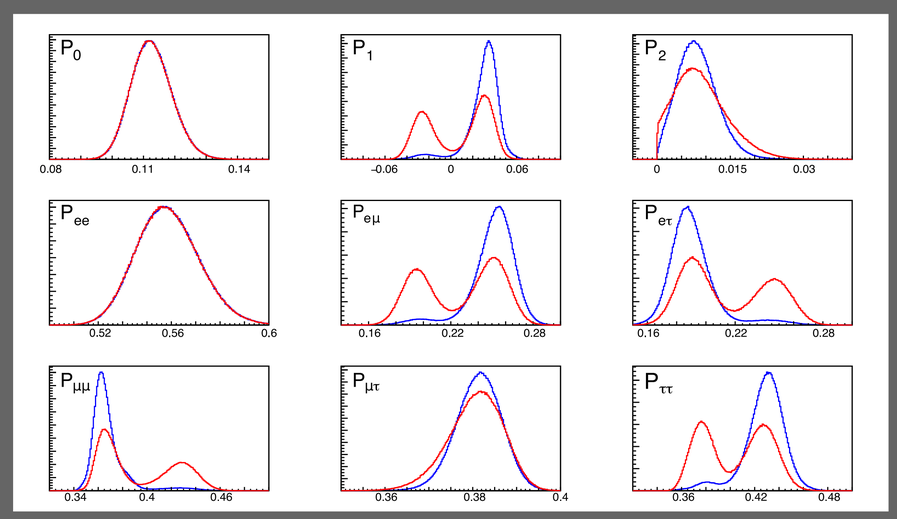


Obtain $P_{\ell\ell'}$ from sampling the oscillation parameters according to their distributions

Cosmic τ neutrinos can be precisely predicted!

Assumptions:

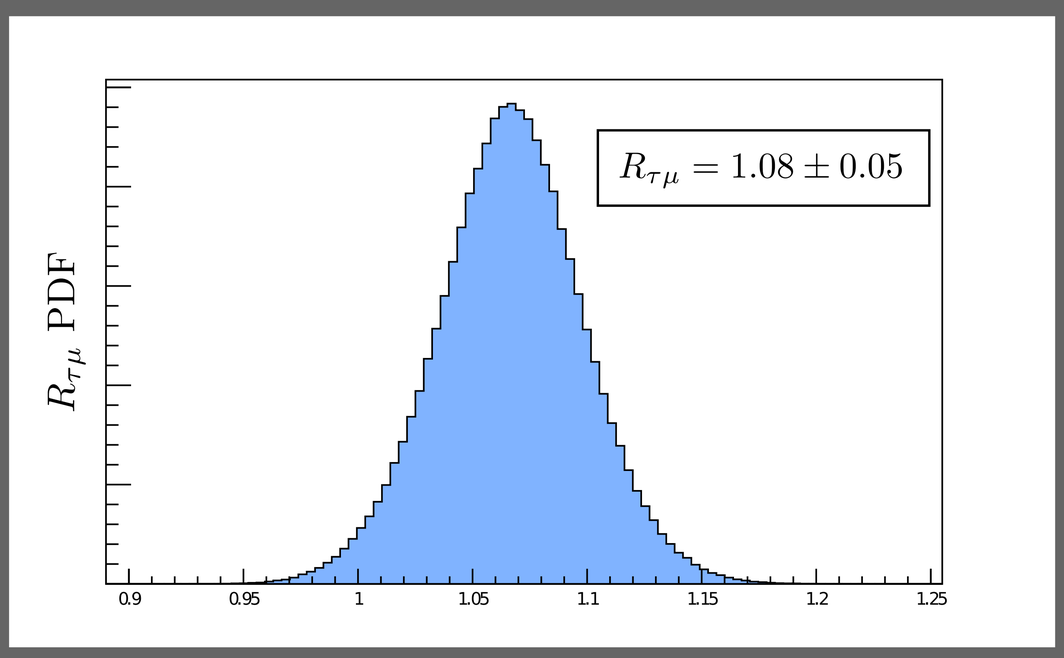
- Three-flavour neutrino oscillations
- Generic production mechanism
- No τ neutrinos at the source

$$(\xi_e^0 : \xi_\mu^0 : \xi_\tau^0) = (x : 1-x : 0) \qquad \xi_\ell^0 = \Phi_{\nu_\ell}^0 / \Phi_\nu^0$$

Draw x (uniformly in [0,1]) and $P_{\ell\ell'}$ (PDFs above) to sample:

Ratio of τ neutrinos to μ neutrinos at Earth $\quad R_{\tau\mu} = \frac{P_{\tau e}x + P_{\tau\mu}(1-x)}{P_{\mu e}x + P_{\mu\mu}(1-x)}$

$R_{\tau\mu} \gtrsim 1 \Rightarrow$ **The flux of τ neutrinos is very close to that of μ neutrinos**

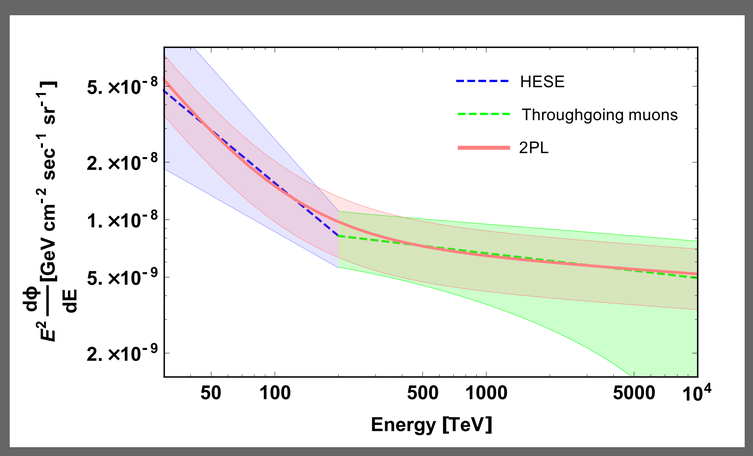


How many τ neutrinos? Look for $\nu_\tau + X \to \tau + Y \to \nu_\tau + Z$!

Model for the all-flavour flux: two-component power-law

- for E > 0.2 PeV, throughgoing muons compatible with one power-law
- for E < 0.2 PeV, HESE suggest a softer spectrum (see plot)

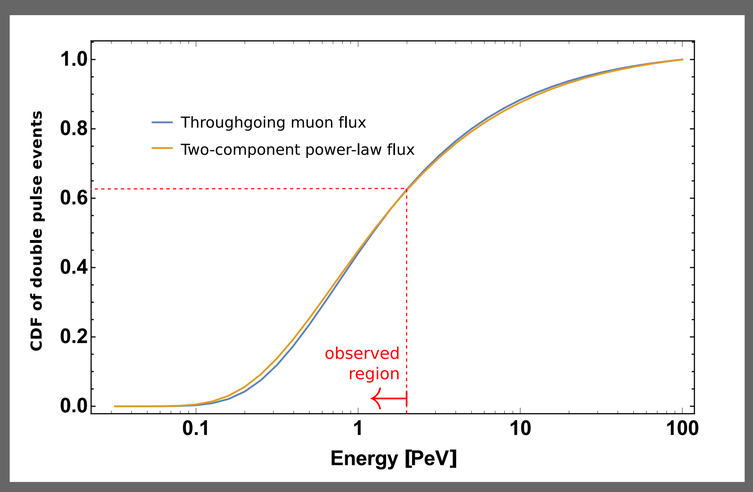
However, the latter gives only few observable τ neutrino events (see below)



Number of clear ν_τ-induced (double pulse) events in 5.7 years:

$$4\pi T \int_0^\infty \frac{\mathrm{d}\phi_{\nu_\tau}}{\mathrm{d}E} A_{2\mathrm{P}}(E)\, \mathrm{d}E = 0.65 \pm 0.24$$

- excellent agreement with IceCube [Phys. Rev. D **93** (2016) no.2, 022001]
- only neutrinos with E > 0.1 PeV contribute to double pulse events
- an energy cutoff would reduce such expectation
- ~60% of such events are produced by ν with E < 2 PeV - **already seen**



First double pulse signal is just around the corner!

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