A Posterior Analysis on IceCube Double Pulse Tau Neutrino Candidates

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Abstract

Astrophysical tau neutrinos can cause double pulse waveform signals in IceCube photon sensors. The previous 8-year analysis has found three tau neutrino candidates and the most promising one is located very near to the dust layer in the detector. We will present an *a posteriori* analysis on this event using a new ice model treatment with continuously varying parameters to do targeted-volume re-simulation for tau neutrinos and other background neutrino ensembles, which aims to explore the impact of different ice models on the expected signal and background statistics.

ν_τ Double Pulse Events in the IceCube Detector

❖ Astrophysical tau neutrinos can cause double pulse waveforms in Digital Optical Modules (DOMs) due to its charged current interaction and subsequent decay vertices.

$$\nu_\tau + N \to \tau^- + X \Rightarrow \begin{cases} \tau^- \to \nu_\tau + \text{hadrons}^- \ (64.8\%) \ \surd \\ \tau^- \to \nu_\tau + \bar{\nu}_e + e^- \ (17.8\%) \ \surd \\ \tau^- \to \nu_\tau + \bar{\nu}_\mu + \mu^- \ (17.4\%) \end{cases}$$

❖ The waveform read-out duration for a DOM is 422ns with 128 samples, 3.3ns per bin.

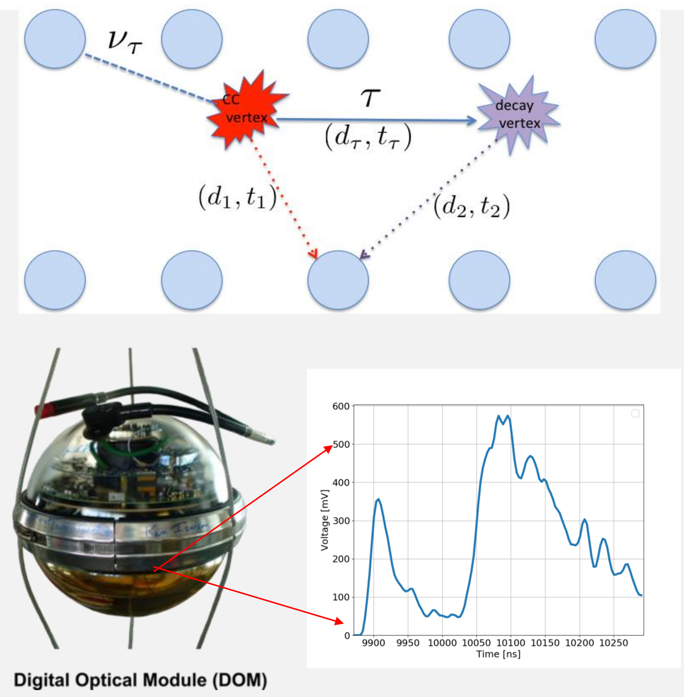

Fig 1: Event topology for a ν_τ and double pulse waveform in a DOM

Tau Neutrino Candidates and SnowStorm

❖ The most promising ν_τ candidate from previous double pulse analysis [1] is on top of a dust layer which might contain rapid shift in the ice's optical properties.

❖ A targeted re-simulation was performed with SnowStorm [2] which is a new ice model treatment with continuous variation of nuisance parameters.

❖10-100 MC events for each set of ice model parameters

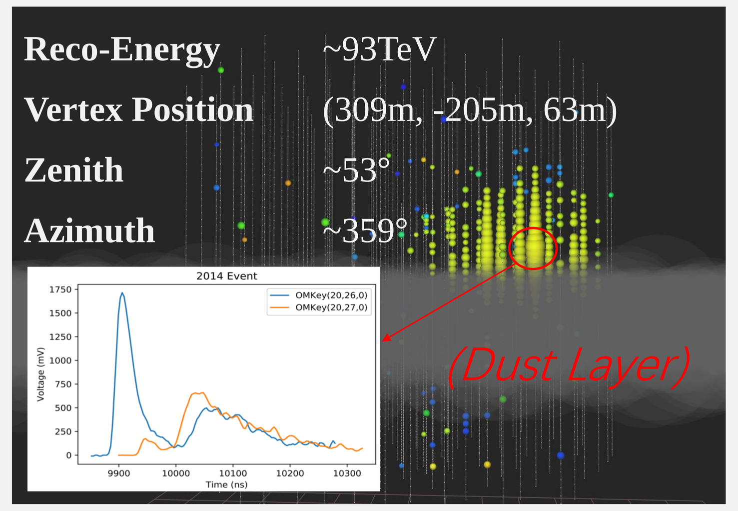

Fig 2: Two identified double pulse waveforms of the 2014 ν_τ candidate

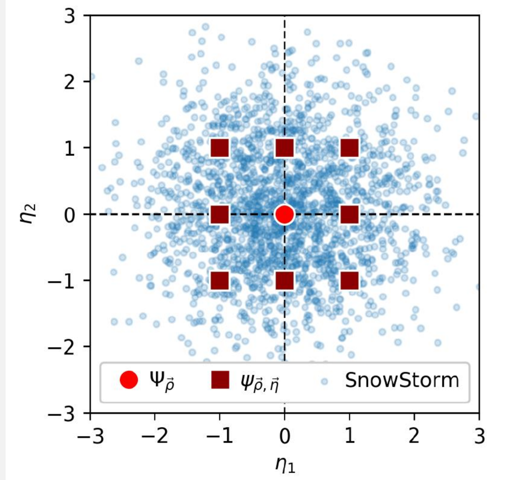

Fig 3: An illustration of SnowStorm sampling on ice models

Re-simulation Chain with SnowStorm and Parameter Settings

LeptonInjector → Propagator → SnowStorm → Detector Simulation → Standard L1&L2 → LeptonWeighter → Double Pulse Selection (DP)

Simulation Parameters	Settings
Flavor	ν_τ , ν_μ , ν_e
Generated Energy (TeV)	[50,250], [250,500], [500,1000]
Injected Center	(309m, -205m, 63m)
Injected Volume	Radius =25m, Height =50m
Zenith	[20°,80°]
Azimuth	[0°,360°]

Table 1: LeptonInjector [4] Settings

Ice Properties	Sampling Type	Range
IceWavePlusModes	Gaussian	Default
Absorption	Gaussian	$\mu = 1.0, \sigma = 0.05$
Scattering	Gaussian	$\mu = 1.0, \sigma = 0.05$
DOM Efficiency	Gaussian	$\mu = 1.0, \sigma = 0.05$
Anisotropy	Gaussian	$\mu = 1.0, \sigma = 0.1$
HoleIce Forward	Delta	[0.1016, -0.0493]

Table 2: SnowStorm Settings

Flavor	DPA Passing Rates		
	[50,250]	[250,500]	[500,1000]
ν_τ	5785/200k	29425/200k	41698/200k
ν_μ	161/200k	1036/200k	2137/200k
ν_e	32/200k	47/200k	53/200k

Table 3: Double Pulse Passing Rates

Expected Double Pulse Event Rates with MC Data

❖With the settings, the main background is ν_μ, ν_e have modest impacts.

❖ Background ν_μ around 100TeV seem to have higher possibility to pass DP selection, but ν_τ signals are still dominant with 10 times higher rate.

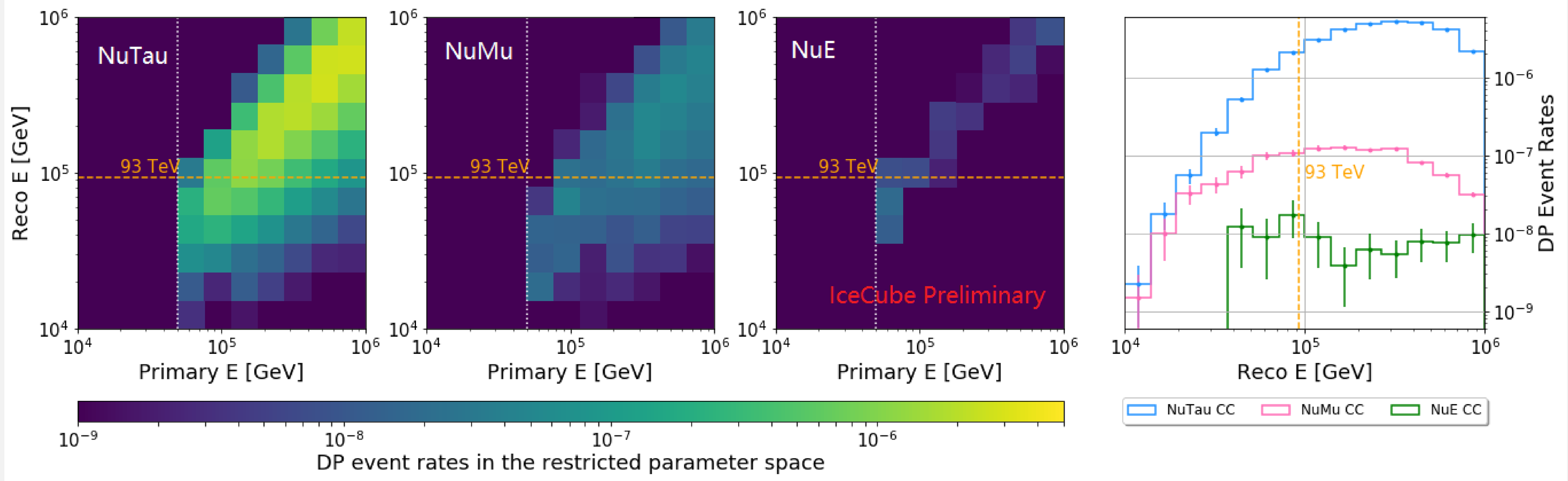

Fig 4: Expected double pulse event rates per year in targeted volume

Purity and Impact of Different Ice Models

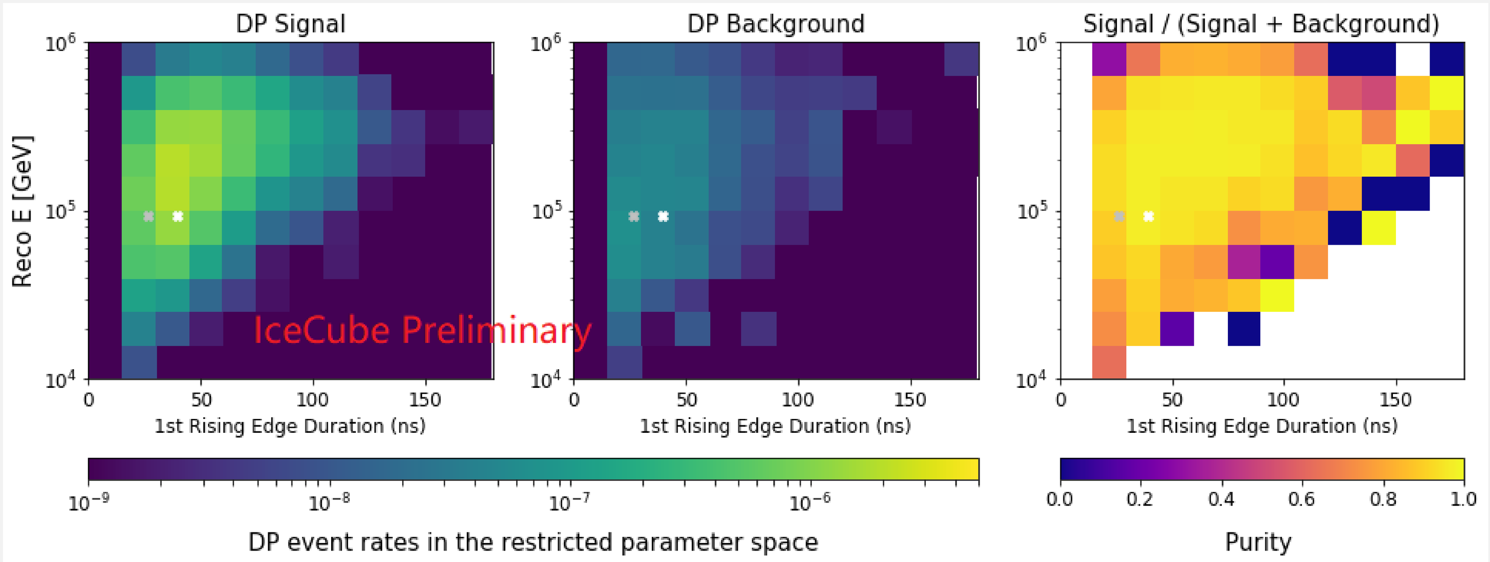

Fig 5: Expected event rates, purity and waveform observables of the candidate (two scatters)

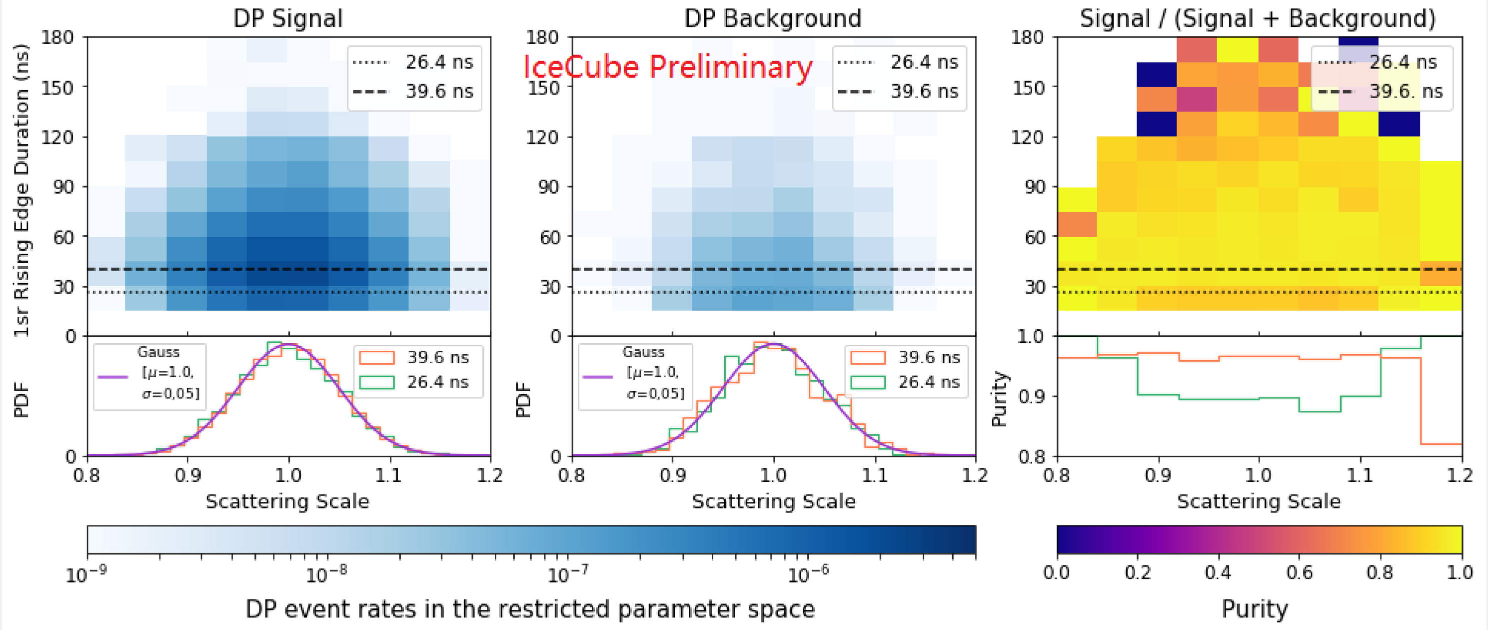

Fig 6: Purity *vs* first rising edge and scattering scale. Dashed and dotted lines indicate two waveforms of the candidate.

❖The purity around the dashed and dotted lines almost remains larger than 0.9 which means the impact of ice property uncertainties is not that significant.

Outlook

❖ Add atmospheric muon re-simulation

❖ Combine the machine learning method [5] to this posterior analysis

References

[1] IceCubeCollaboration, L. Wille and D. Xu, PoS(ICRC2019)1036 (2020).
[2] IceCubeCollaboration, M. G. Aartsen et al.,JCAP10(2019) 048
[4] IceCubeCollaboration, R. Abbasi et al.,Comput. Phys. Commun.266(2021) 108018.
[5]IceCubeCollaboration, M. Meier and J. Soedingrekso, PoS(ICRC2019)960 (2020)