

Tau neutrino measurement using track sample in IceCube

outline

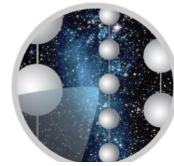
1. Introduction
2. Inelasticity
3. Selection
4. Status

Join us!

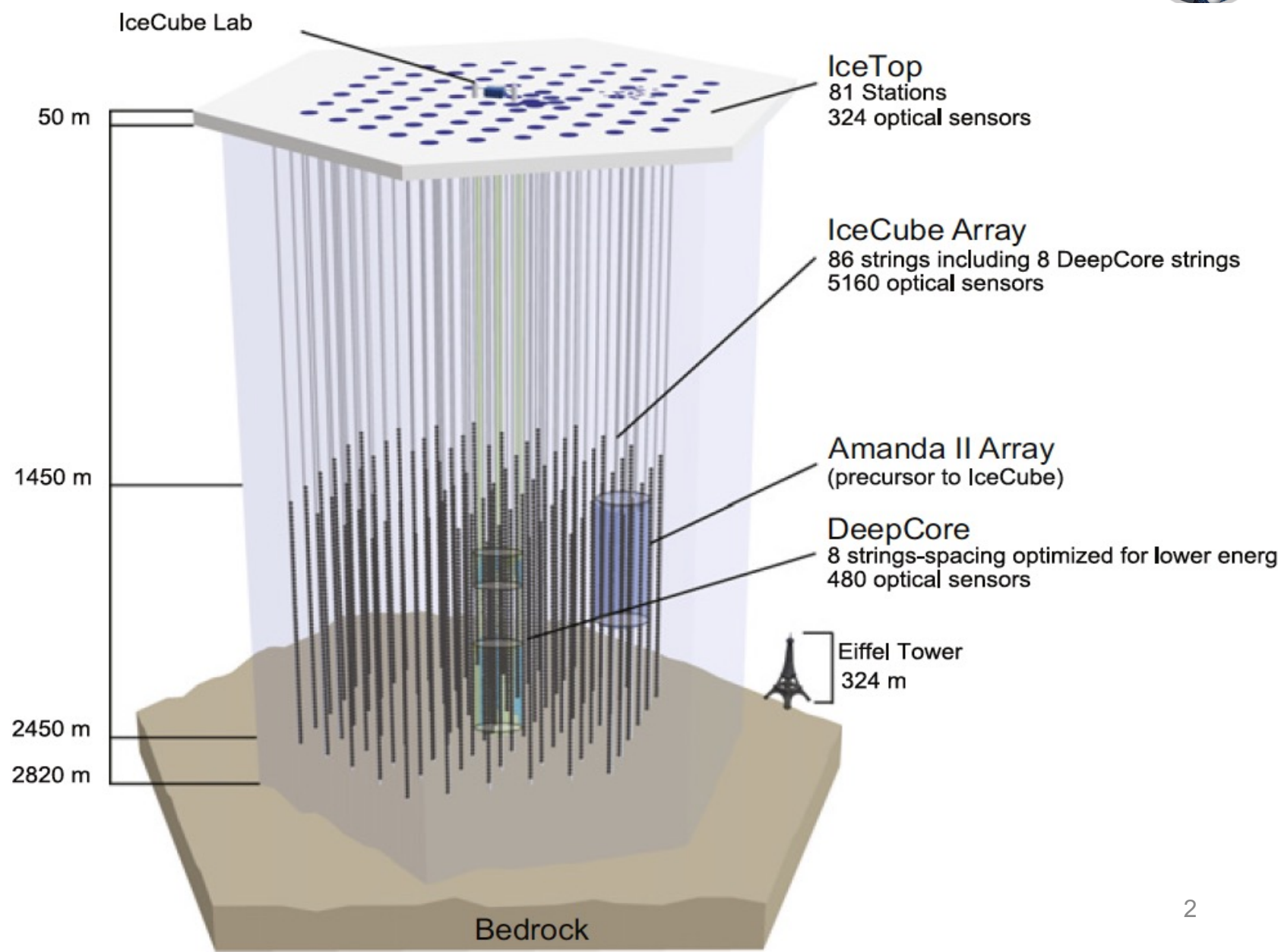
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Archie Millsop, Teppei Katori (King's College London)
Alex Wen, Carlos Argüelles (Harvard University)
IoP APP-HEPP conference, Cambridge, Apr. 7, 2025





1. IceCube detector

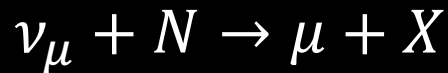




1. IceCube event morphology

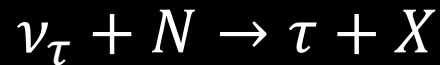
Track

ν_μ CC



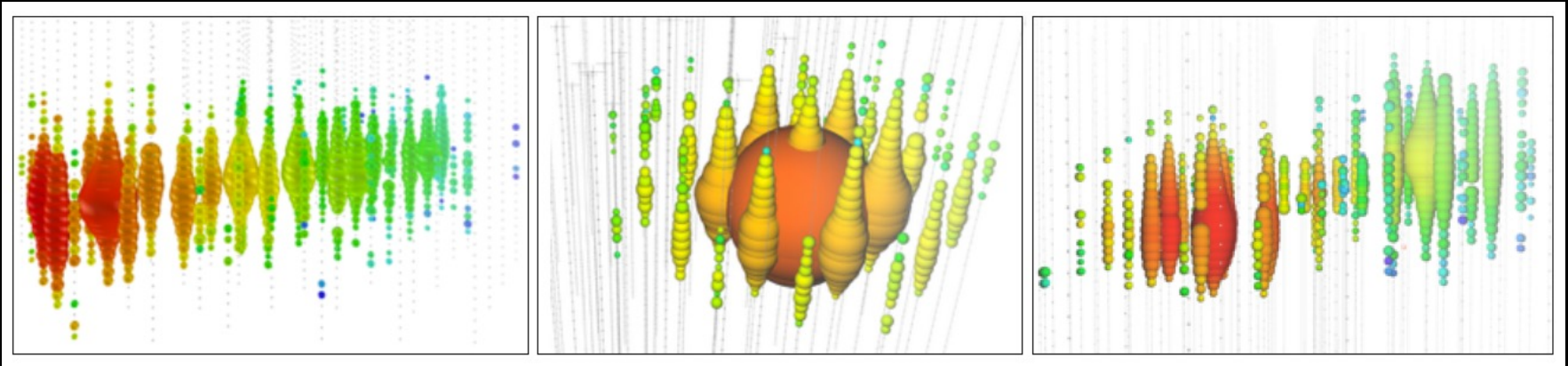
Cascade

ν_e CC, ν_τ CC, NC



Double cascade

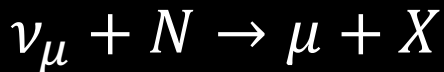
ν_τ CC ($L \sim 50m \cdot E/PeV$)



1. Inelasticity-based PID

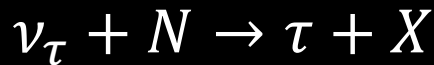
Track

ν_μ CC



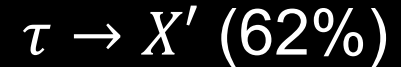
Cascade

ν_e CC, ν_τ CC, NC



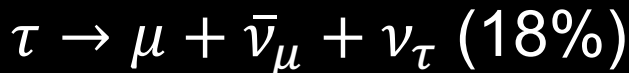
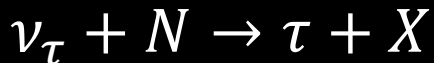
Double cascade

ν_τ CC (L~50m•E/PeV)



Tau decay muon track

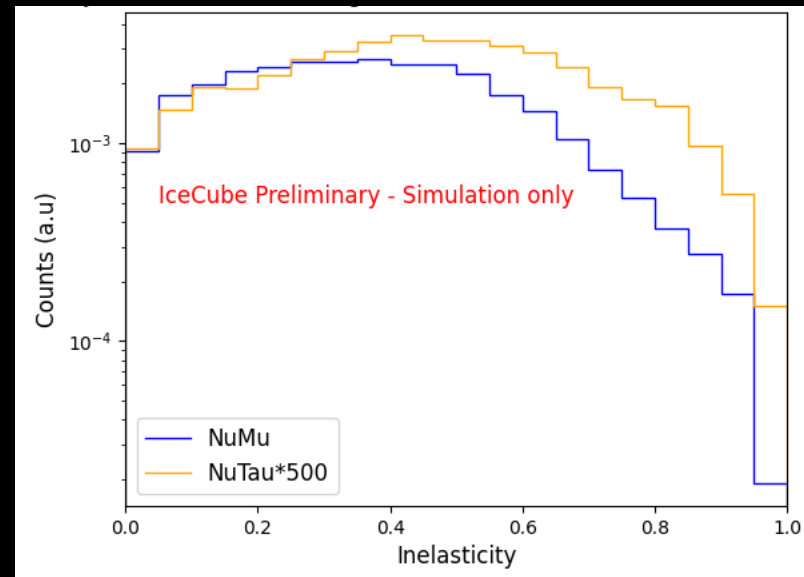
ν_τ CC



Relatively smaller track energy due to neutrino emissions.

→ Larger inelasticity

Tau decay track can be statistically separated





1. Tau neutrino measurements in IceCube

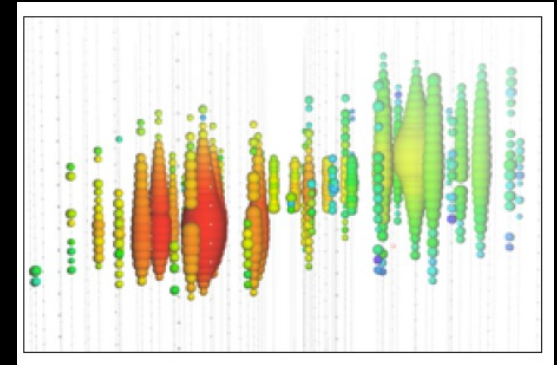
Atmospheric neutrino oscillation length ~ 12700 km (earth diameter) at ~ 35 GeV
→ no tau neutrinos from conventional atmospheric neutrinos above ~ 35 GeV

Tau neutrino sources

1. Astrophysical tau neutrinos
2. Charm-decay tau neutrino (prompt atmospheric neutrino)
→ haven't observed yet
3. exotic process (new physics)

So far, tau neutrinos are only identified in cascade samples.

Identifying tau neutrinos are difficult,
but tau neutrino measurement has many interesting topics!



2. Inelasticity

Inelasticity y is defined

$$y = \frac{\nu}{E}$$

Experimentally,

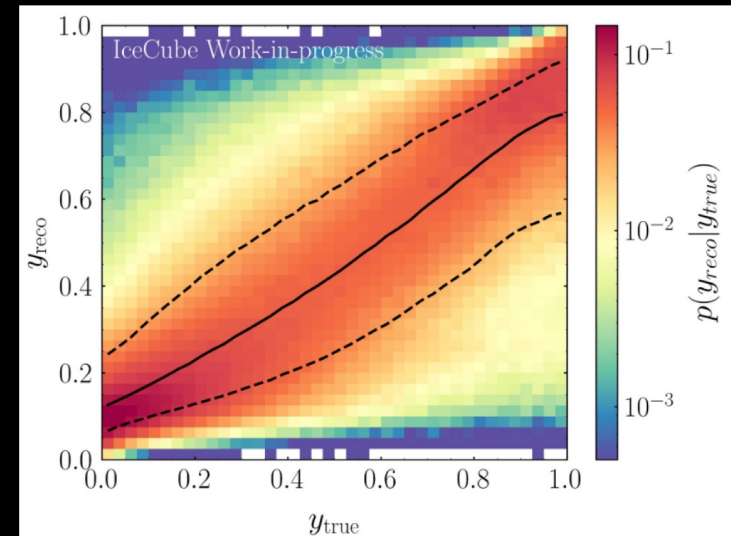
$$E = E_{vis} = E_{track} + E_{had}$$

$$\nu = E_{vis} - E_{track} = E_{had}$$

Effective y is defined

$$y_{eff} = \frac{E_{had}}{E_{vis}}$$

MAMBA-based y -reconstruction is underway
 - Inelasticity is also useful to $\nu/\bar{\nu}$ separation

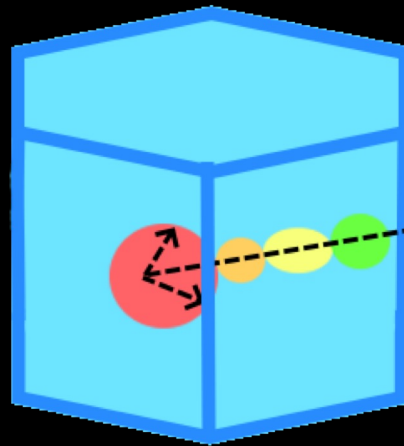


3. Selection

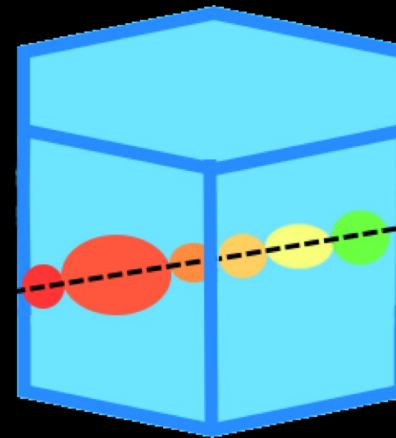
MEOWS (Matter-enhanced oscillations with steriles)

- Developed for sterile neutrino search analysis
- BDT-based selection
- 99.9% pure muon track sample
- 0.5-100 TeV
- $-1 < \cos\theta < 0$ (upgoing)
- Starting track $\sim 25\%$

Starting track



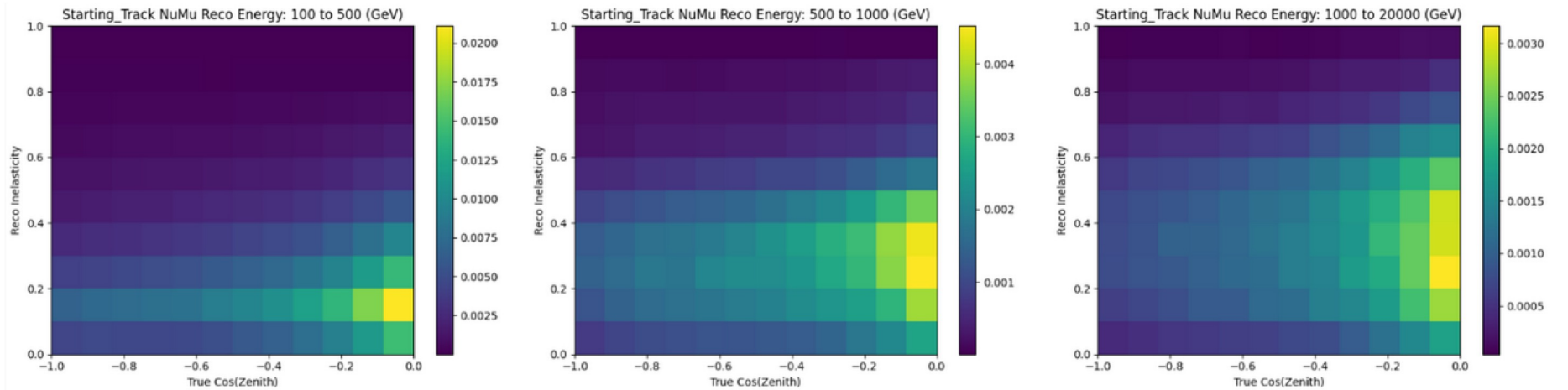
Through-going track



3. Selection

Muon neutrino MC sample

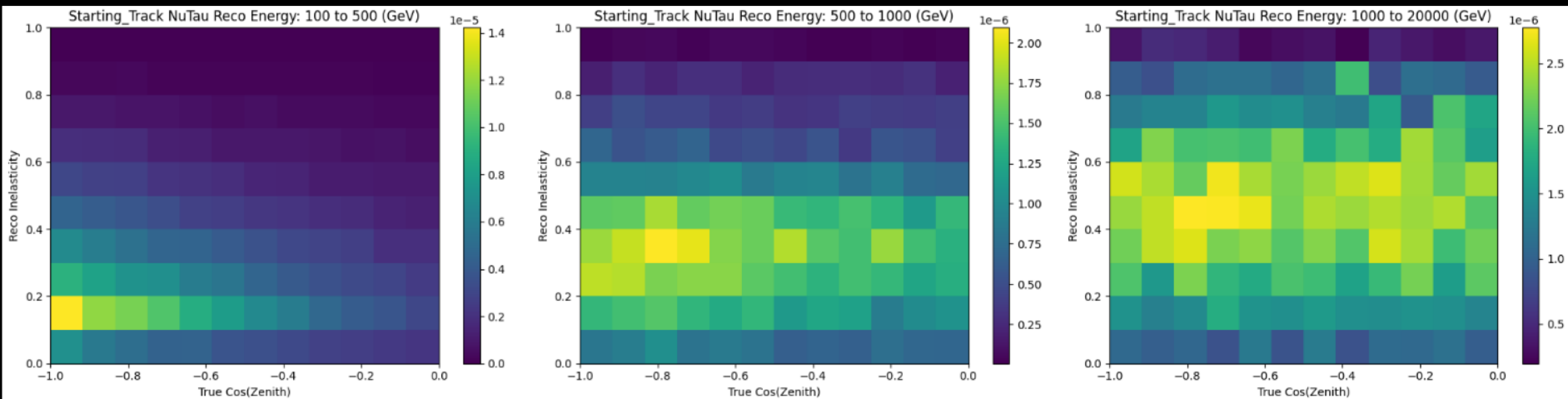
- Mostly horizontal events (=atmospheric neutrinos)
- Inelasticity peak at low



3. Selection

Tau neutrino MC sample

- From all direction (=atmospheric neutrinos)
- Inelasticity peak is higher
- Energy cut (1-20 TeV) for better reconstruction



3. Fit



GollumFit

- Developed for high-energy neutrino analysis
- soon-to-be public software of binned likelihood fit
- 3-dimension (energy, angle, PID)
- 37 nuisance parameters
 - atmospheric neutrino flux
 - astrophysical neutrino flux
 - Ice model

We added the 4th dimension (inelasticity) and a new nuisance parameter (numu/nutau ratio)



Key	Variable	Value \pm Width
Common to all neutrino telescopes		
convNorm	convNorm	1.0 \pm 0.2
ρ_{atm}	zenithCorrection	0.0 \pm 1.0
$\sigma_{\text{K-Air}}$	kaonLosses	0.0 \pm 1.0
K_{158G}^+	hadronicHEkp	0.0 \pm 1.0
K_{158G}^-	hadronicHEkm	0.0 \pm 1.0
π_{20T}^+	hadronicVHE1pip	0.0 \pm 1.0
π_{20T}^-	hadronicVHE1pim	0.0 \pm 1.0
K_{2P}^+	hadronicVHE3kp	0.0 \pm 1.0
K_{2P}^-	hadronicVHE3km	0.0 \pm 1.0
π_{3P}^+	hadronicVHE3pip	0.0 \pm 1.0
π_{3P}^-	hadronicVHE3pim	0.0 \pm 1.0
P_{2P}	hadronicVHE3p	0.0 \pm 1.0
n_{2P}	hadronicVHE3n	0.0 \pm 1.0
GSF ₁	cosmicRay1	0.0 \pm 1.0
GSF ₂	cosmicRay2	0.0 \pm 1.0
GSF ₃	cosmicRay3	0.0 \pm 1.0
GSF ₄	cosmicRay4	0.0 \pm 1.0
GSF ₅	cosmicRay5	0.0 \pm 1.0
GSF ₆	cosmicRay6	0.0 \pm 1.0
$\Phi^{\text{HE}}/10^{-18} \text{ GeV}^{-1} \text{ sr}^{-1} \text{ s}^{-1} \text{ cm}^{-2}$	astroNorm	0.787 \pm 0.36
$\Delta\gamma_1^{\text{HE}}$	astroDeltaGamma	0.0 \pm 0.36
$\Delta\gamma_2^{\text{HE}}$	astroDeltaGammaSec	0.0 \pm 0.36
$\log_{10}(E_{\text{break}}^{\text{HE}}/\text{GeV})$	astroPivot	5.0 \pm 1.0
promptNorm	promptNorm	1.0 \pm 1.0
$\nu/\bar{\nu}$	NeutrinoAntineutrinoRatio	1.0 \pm 1.0
ν Att	nuxs	1.0 \pm 0.1
$\bar{\nu}$ Att	nubarxs	1.0 \pm 0.1
IceCube Monte Carlo parameters		
DOM eff	domEfficiency	1.27 \pm 0.123
Hole Ice	holeIceForward	-1.0 \pm 10.0
Ice A ₀	icegrad0	0.0 \pm 1.0
Ice A ₁	icegrad1	0.0 \pm 1.0
Ice A ₂	icegrad2	0.0 \pm 1.0
Ice A ₃	icegrad3	0.0 \pm 1.0
Ice A ₄	icegrad4	0.0 \pm 1.0
Ice Phs ₁	icegrad5	0.0 \pm 1.0
Ice Phs ₂	icegrad6	0.0 \pm 1.0
Ice Phs ₃	icegrad7	0.0 \pm 1.0
Ice Phs ₄	icegrad8	0.0 \pm 1.0

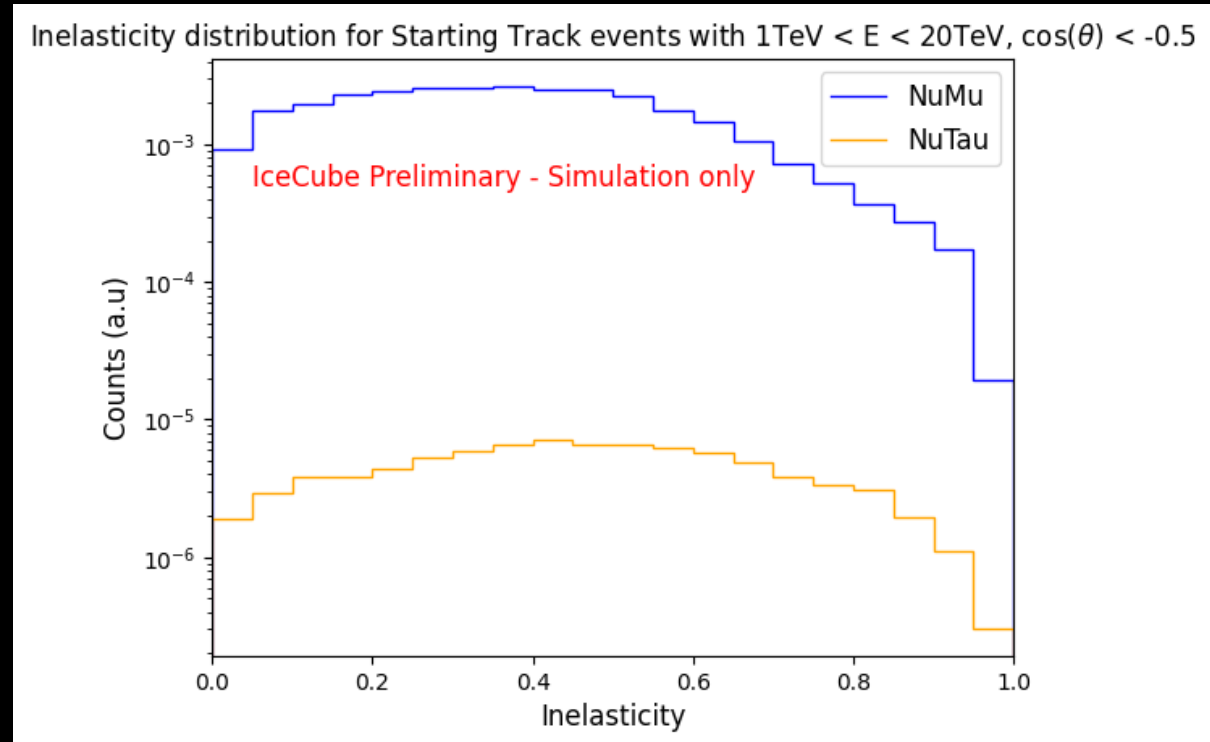
3. Fit

Inelasticity distribution

There are overwhelming amount of muon neutrinos

- Energy cut (1-20 TeV)
- Angle cut ($\cos\theta < -0.5$)

Expected tau neutrino events are $\sim 1\%$ of muon neutrino events.



Conclusion

New starting track sample selection is in progress, new inelasticity reconstruction is available soon

tau track PID is being made from a starting track sample

Thank you for your attention!

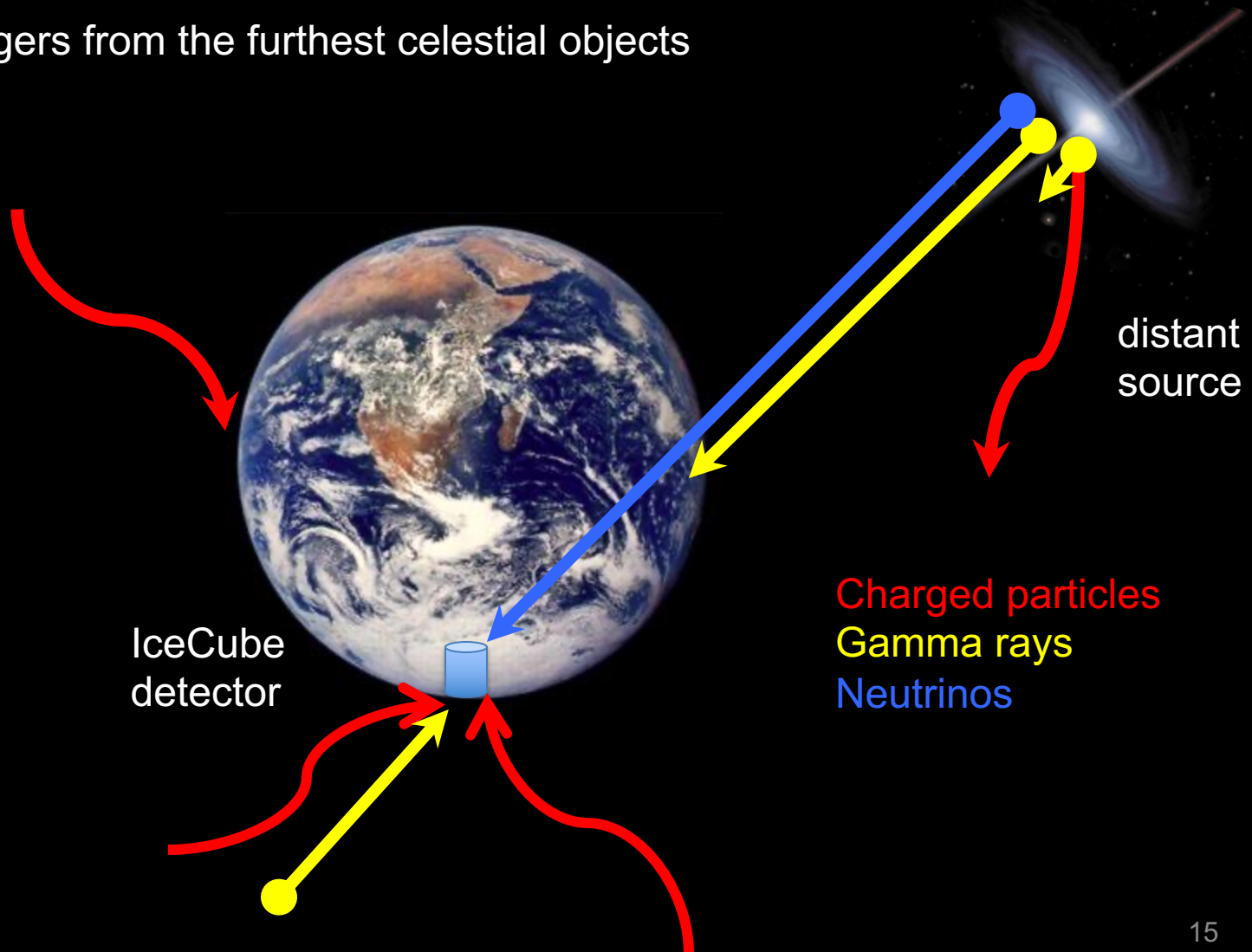


Backup



1. High-Energy Astrophysical Neutrinos

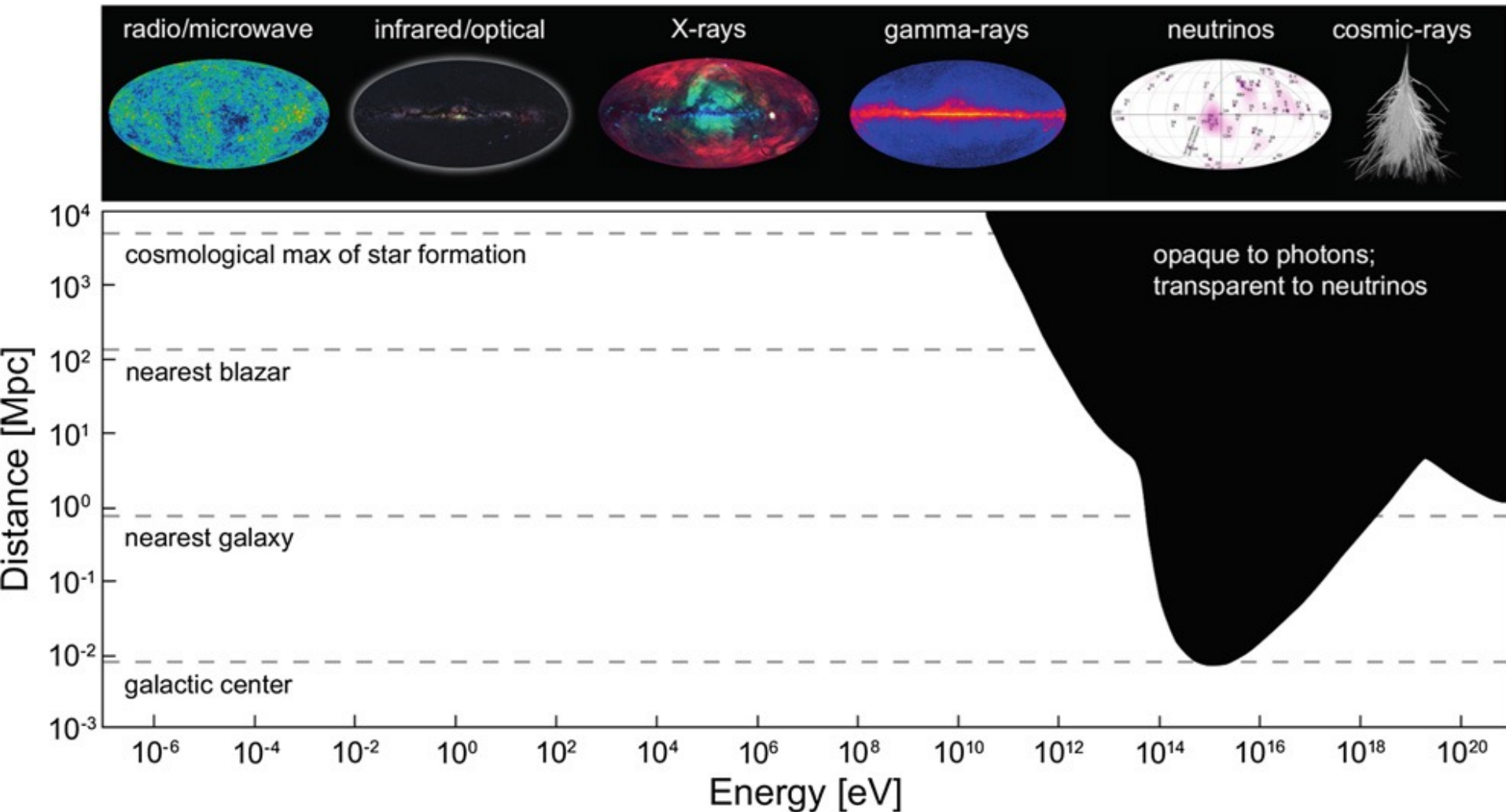
Direct messengers from the furthest celestial objects





1. High-energy astrophysics

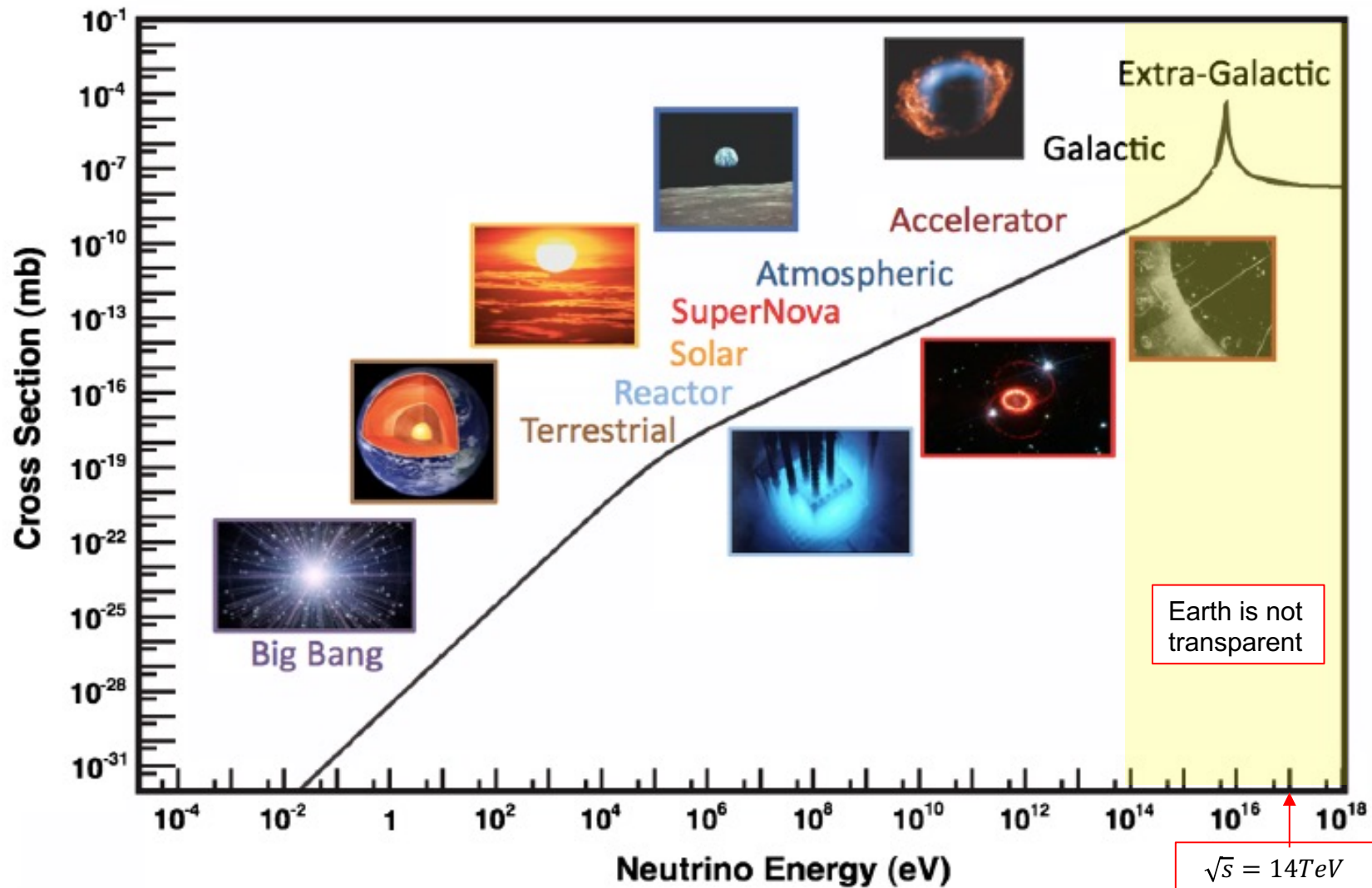
Above ~ 10 - 100 TeV neutrinos are only direct extra-galactic messengers





1. High-Energy Astrophysical Neutrinos

Above ~ 10 - 100 TeV neutrinos are only direct messengers



Earth is not transparent

$\sqrt{s} = 14 \text{ TeV}$

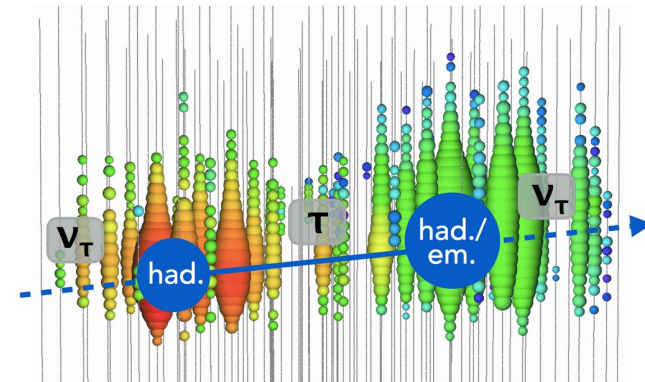
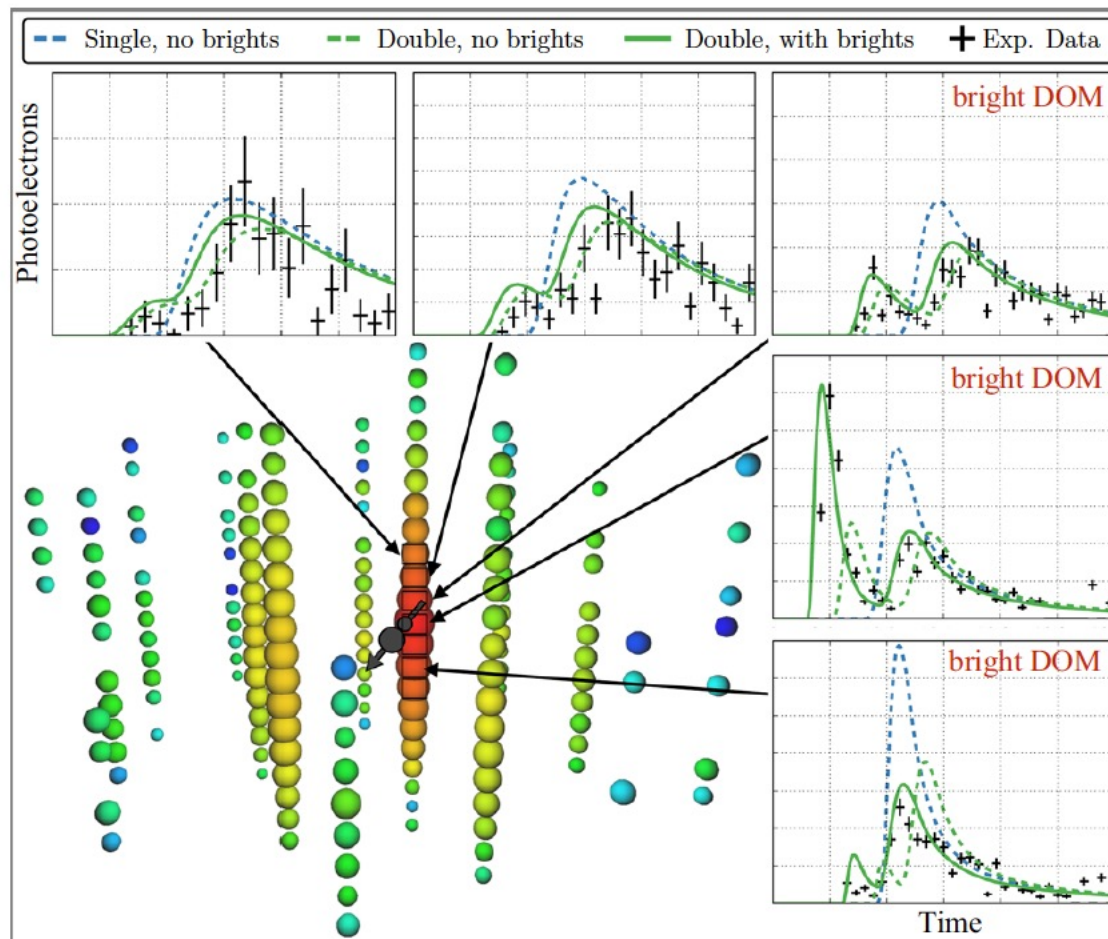


1. Astrophysical tau neutrinos

Double Double

- newly discovered tau neutrino candidate

“Double bang” is rare
($\sim 50m \cdot E / 1\text{PeV}$)



Double pulse can be found using timing information.

Improved tau PID algorithm is used for the flavour ratio