A combined Flavor composition measurement of astrophysical neutrinos using multi-sample IceCube data

Neha Lad[1,2] for the IceCube Collaboration

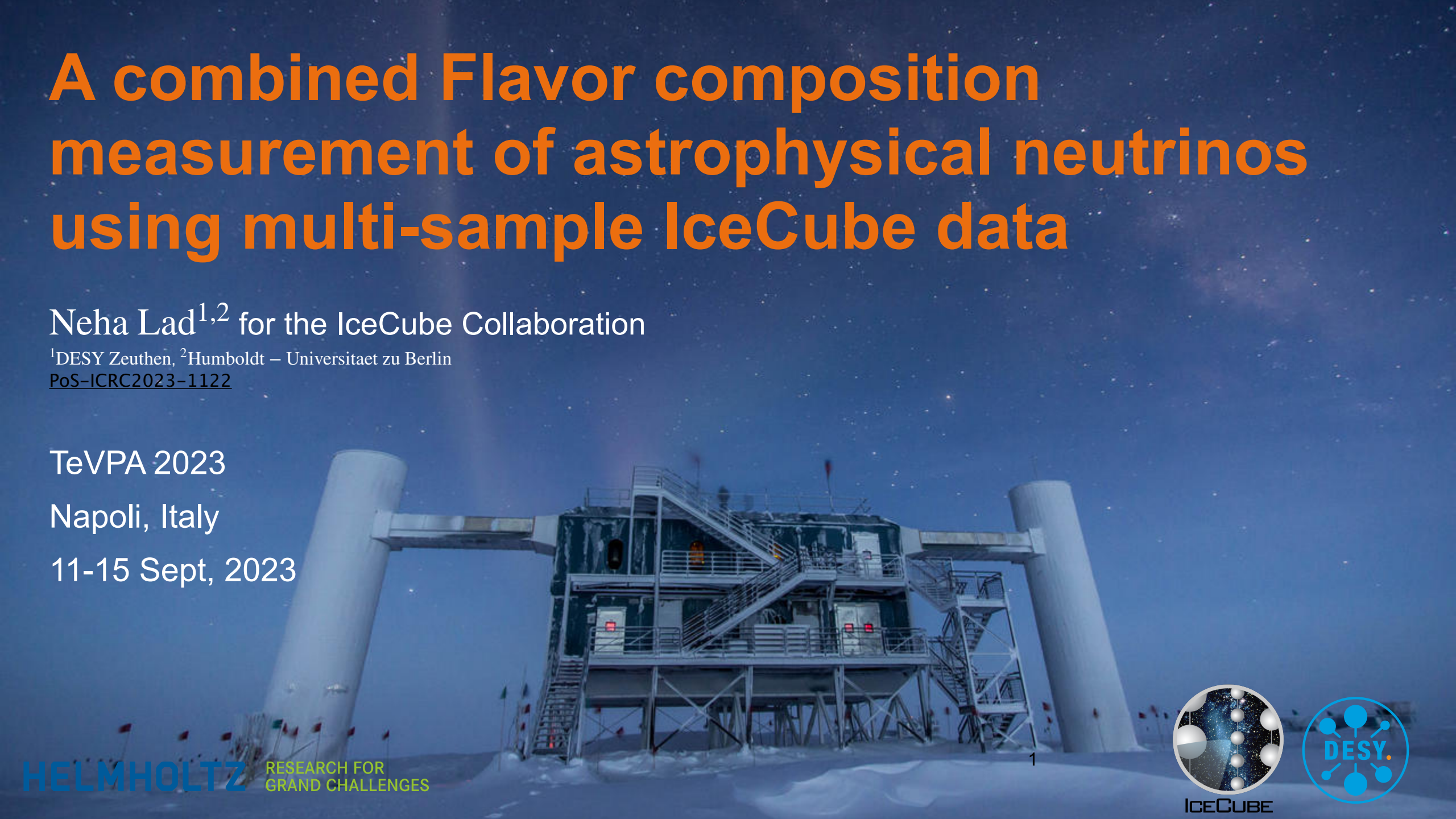
[1]DESY Zeuthen, [2]Humboldt – Universitaet zu Berlin

PoS-ICRC2023-1122

TeVPA 2023

Napoli, Italy

11-15 Sept, 2023



HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

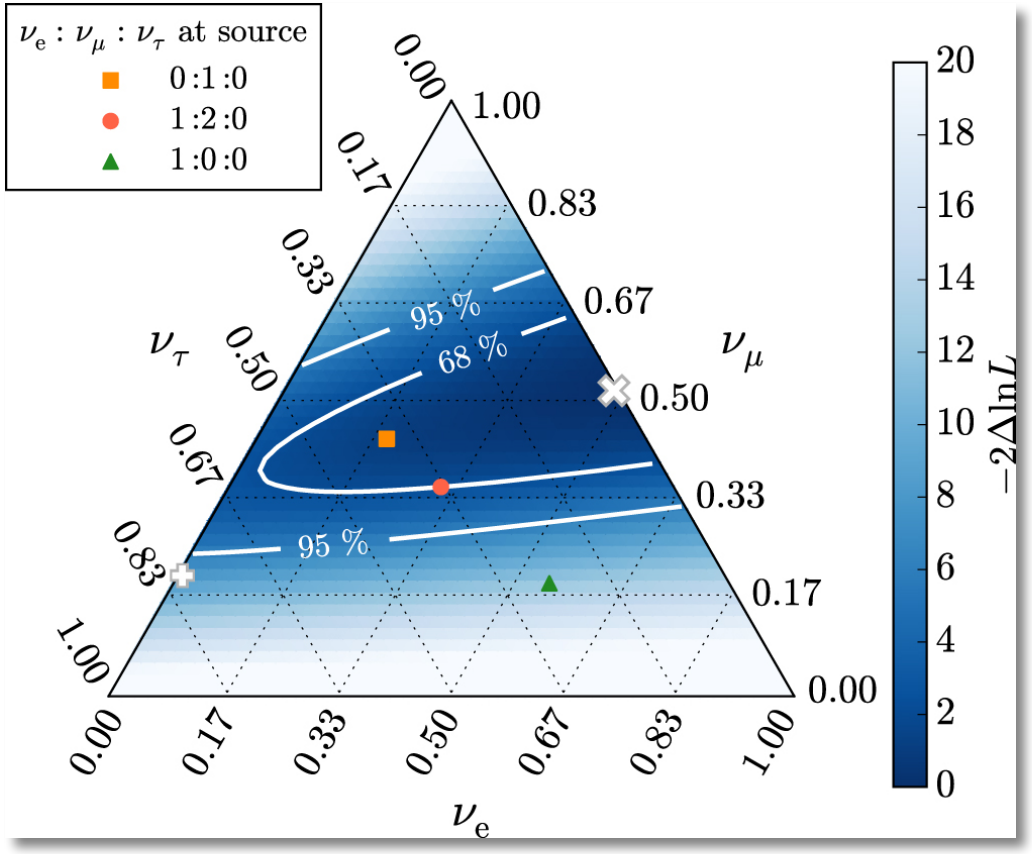
ICECUBE

DESY.

Motivation

Flavor Composition Measurement of Diffuse Astrophysical Neutrinos

- Understanding neutrino production at high energy sources through flavor measurements
- Standard 3-flavor oscillations yield nonzero ν_τ fraction



M. G. Aartsen *et al* 2015 *ApJ* **809** 98

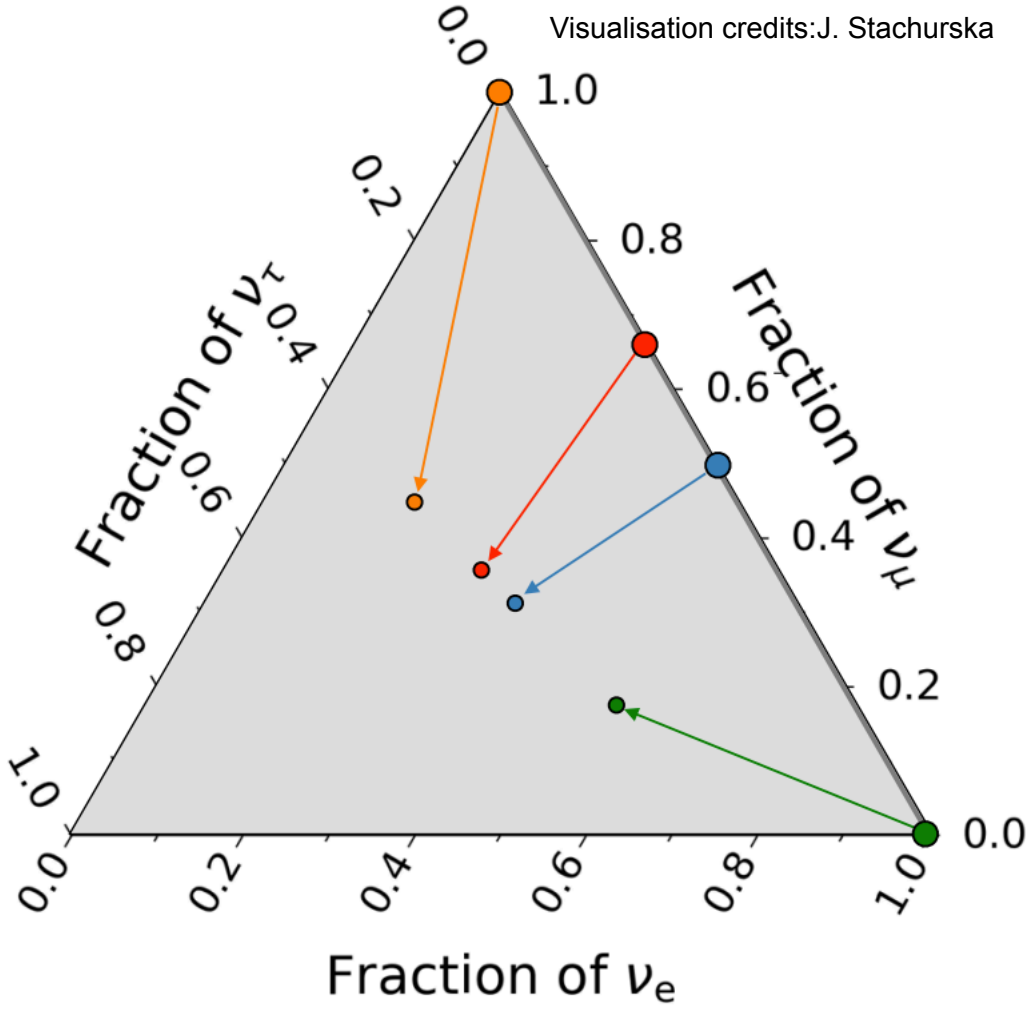
Motivation

What is Flavor Composition Measurement of Diffuse Astrophysical Neutrinos?

	At the Source $\nu_e : \nu_\mu : \nu_\tau$	At large distance (eg: Earth)
Pion-production scenario	1 : 2 : 0	0.30 : 0.36 : 0.34
Muon-damped scenario	0 : 1 : 0	0.17 : 0.45 : 0.37
Neutron-beam scenario	1 : 0 : 0	0.55 : 0.17 : 0.28
Charm-production scenario	1 : 1 :0	0.36 : 0.31 : 0.33

See Astropart.Phys.34:205-224,2010 for more details

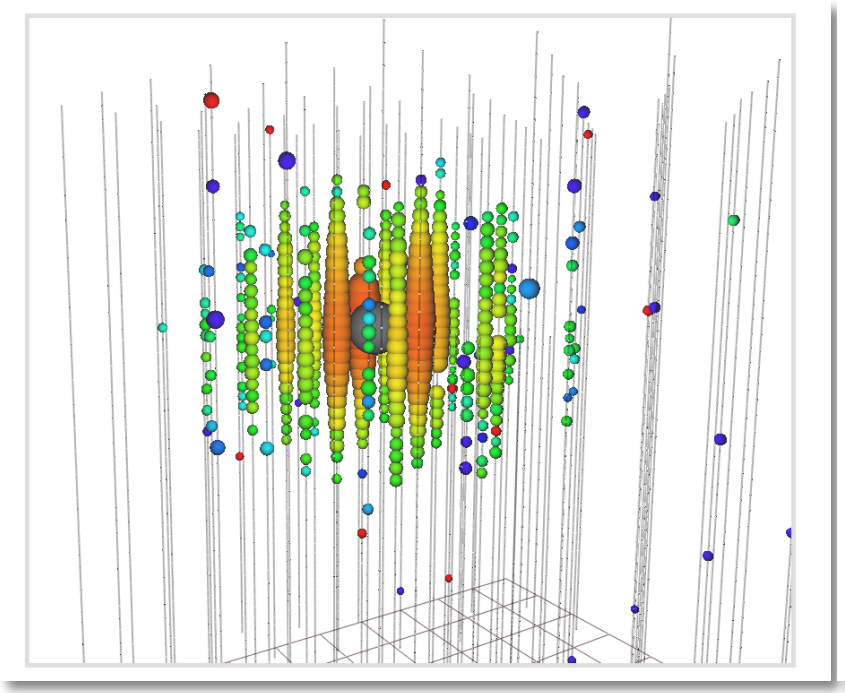
Visualisation credits:J. Stachurska



Neutrino Oscillations!

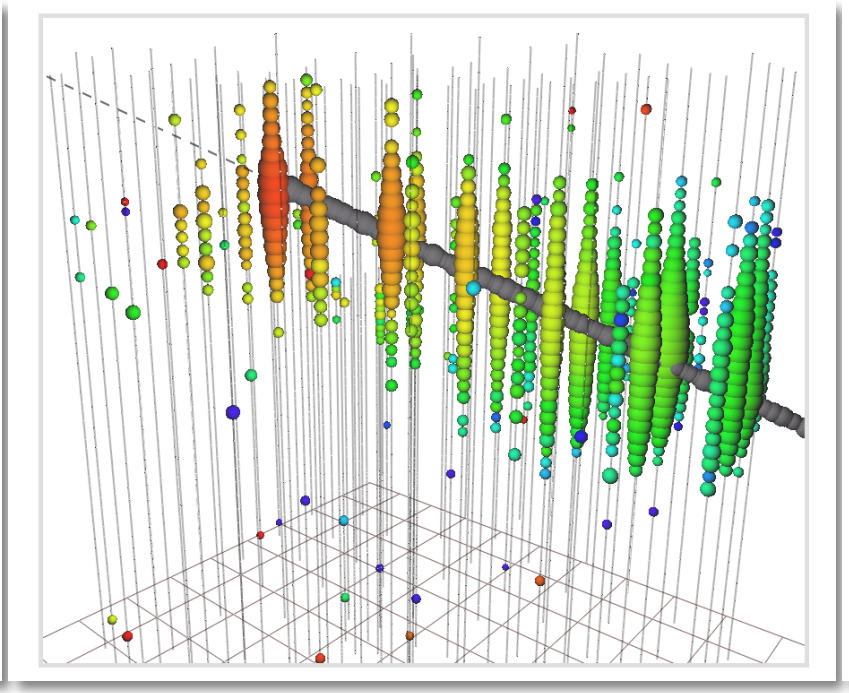
Particle Identification to tag all flavors is necessary..

Event Signatures in IceCube



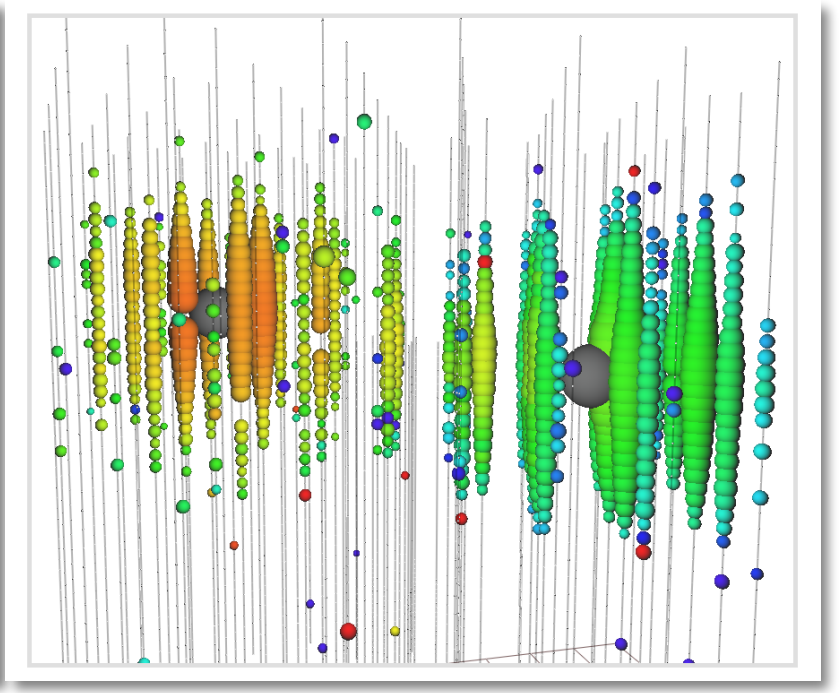
Cascade Event

ν_e- CC and all flavor NC interactions



Track Event

ν_μ- CC and atmospheric muons



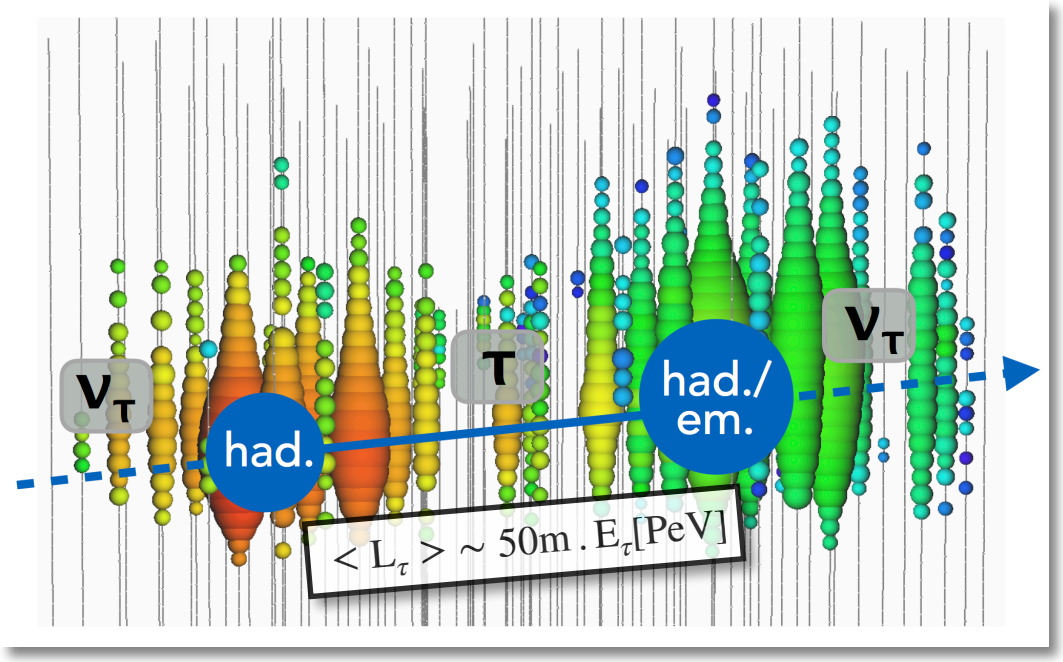
Double Bang Event

ν_τ-CC interactions

Event Signatures in IceCube

ν_τ-CC Double Bang Events

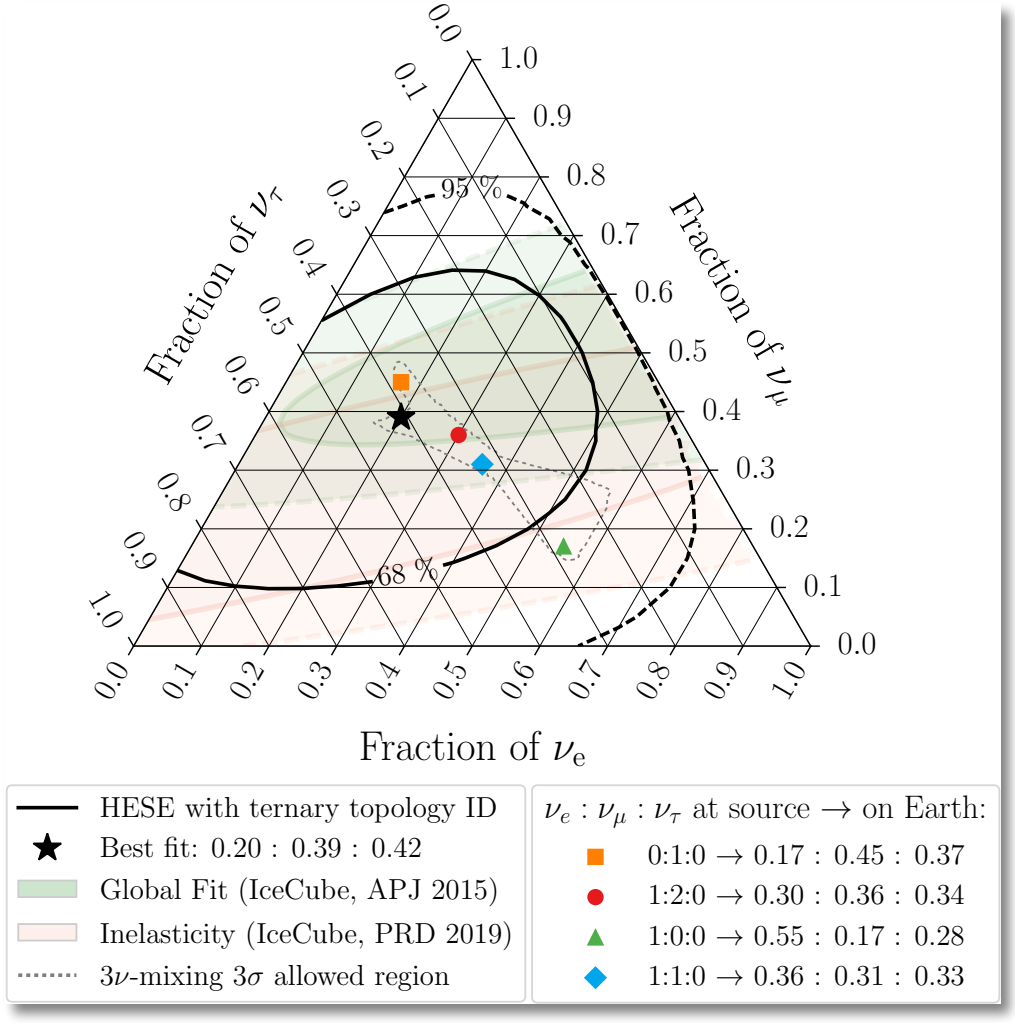
- Challenging to detect
- Low expectation rate (highly depends on spectral features)
- Detection methods in IceCube: Double Cascades (likelihood-based reconstruction) and Double Pulse (CNN search for double pulse structure in IceCube DOMs)
- The event must be fully contained in the detector



Event Signatures in IceCube

ν_τ-CC Double Bang Events

- Challenging to detect
- Low expectation rate (highly depends on spectral features)
- Detection methods in IceCube: Double Cascades (likelihood-based reconstruction)* and Double Pulse (CNN search for double pulse structure in IceCube DOMs)
- The event must be fully contained in the detector
- *Used in HESE-7.5[1] to find 2 Double Cascade candidates[2]



[1]PRD 104,[2]EPJ 82, 11

Search of ν_τ 'Double Cascades'

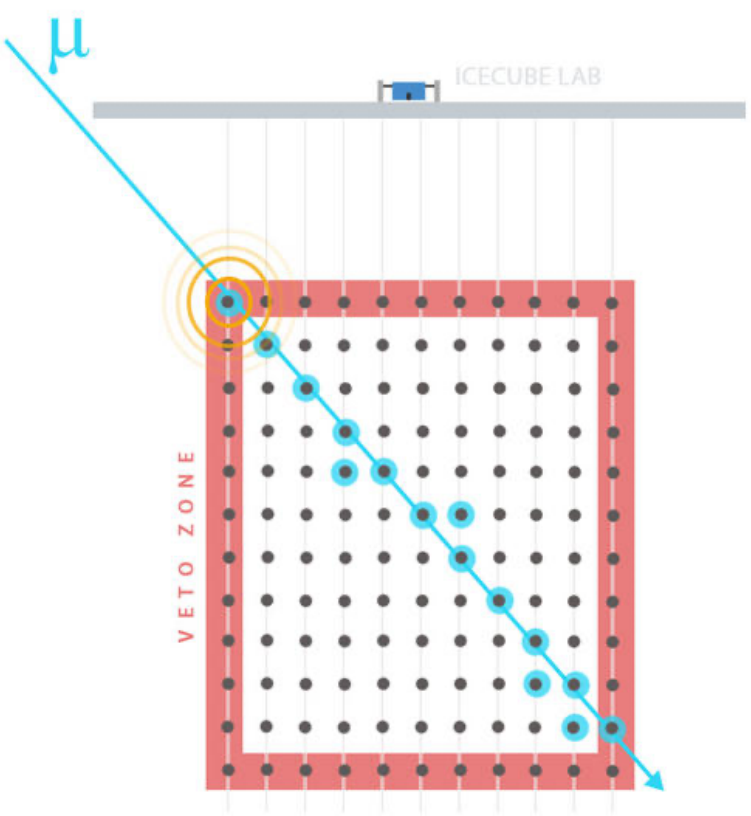
Analysis Concept - HESE - 12 , what is new?

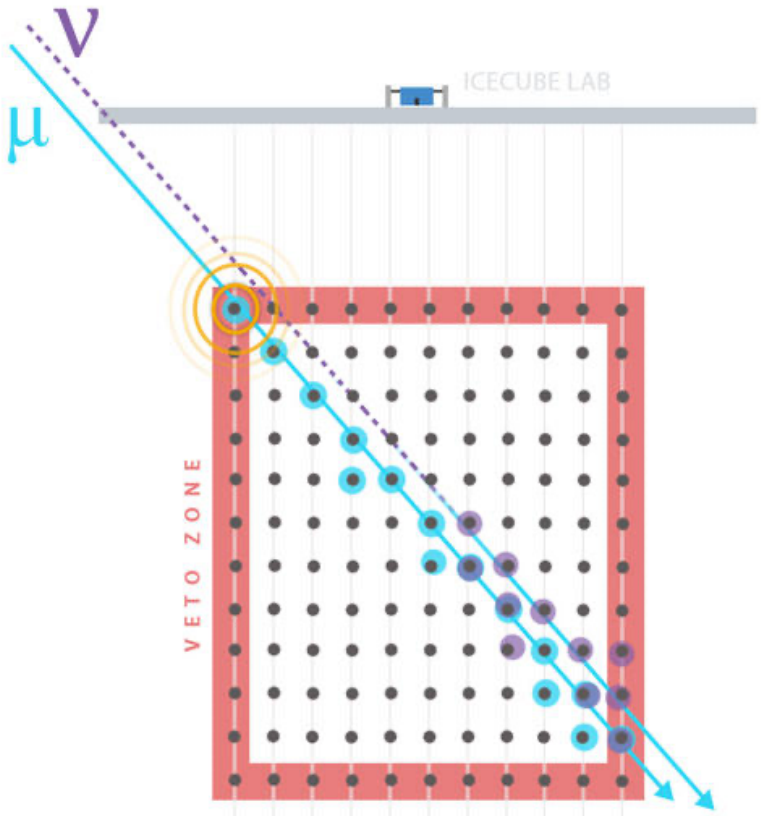
- Extend HESE (High Energy Starting Event) sample for ~4 years

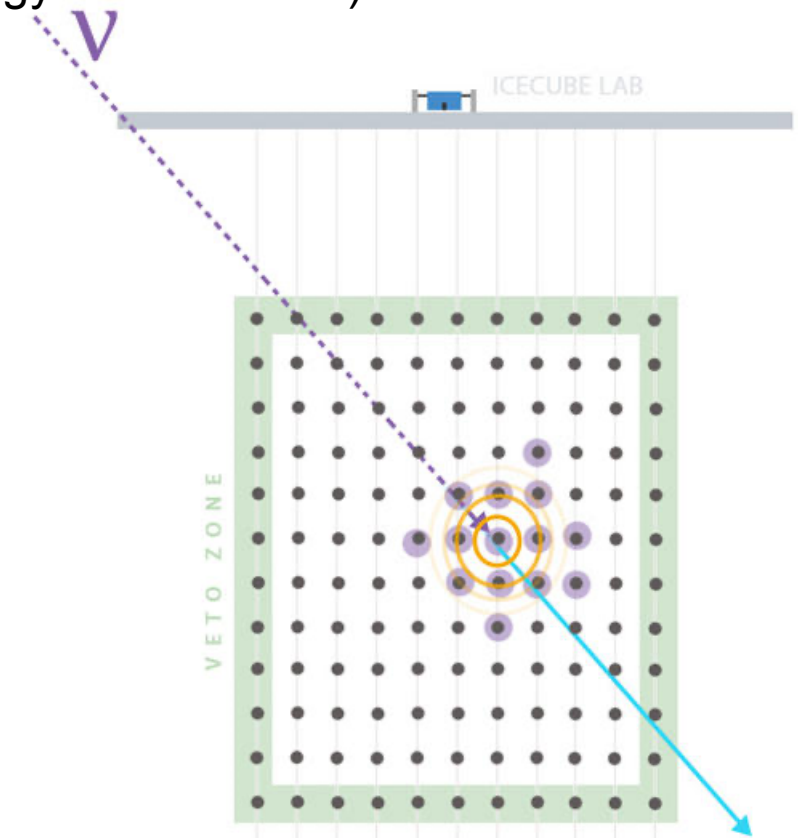
Search of ν_τ 'Double Cascades'

Speaking of HESE, What is it?

All Sky, All Flavor selection, high astrophysical Purity (Total Deposited Energy above 60TeV)



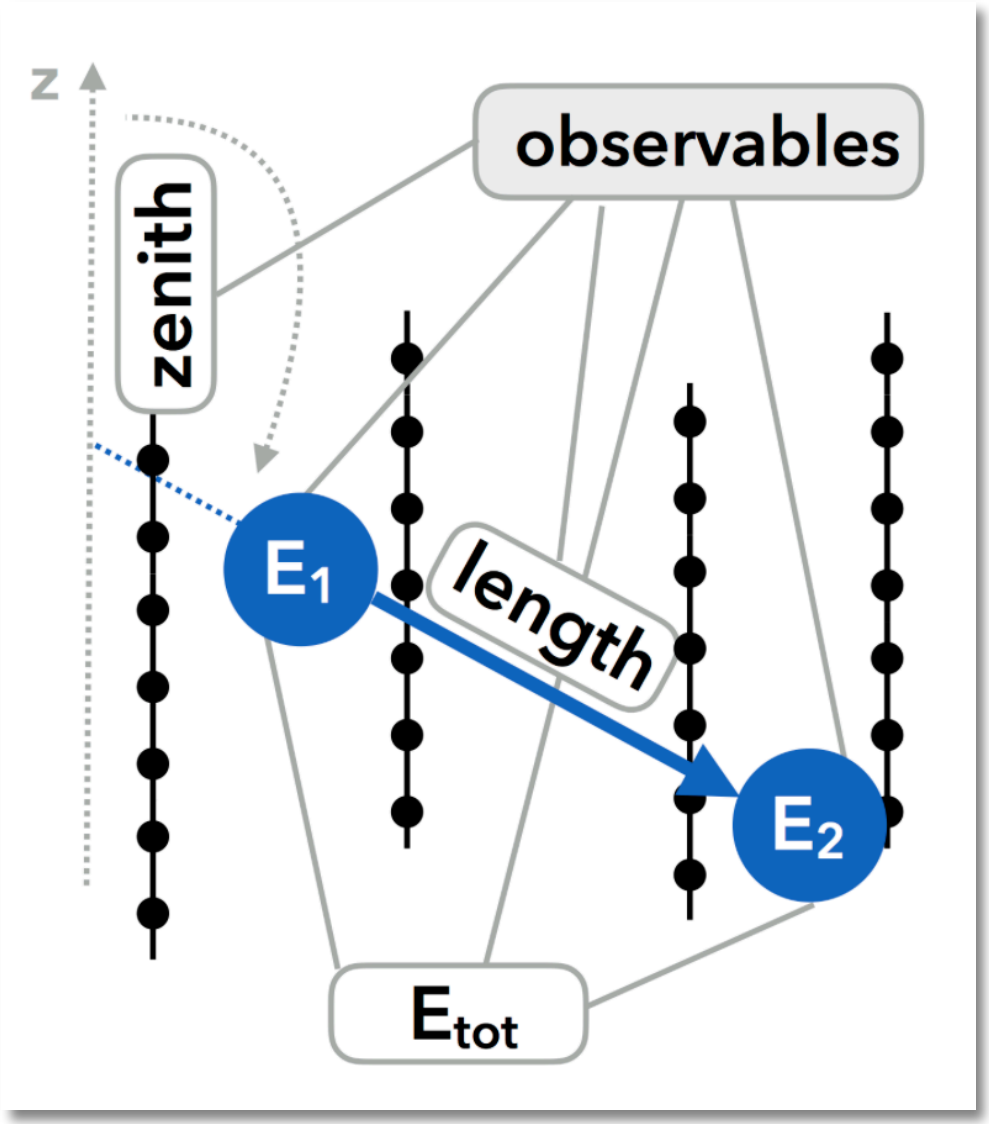




Search of ν_τ 'Double Cascades'

Analysis Concept - HESE - 12 , what is new?

- Extend HESE (High Energy Starting Event) sample for ~4 years
- All flavor neutrino Monte Carlo simulations
- Detector response modeled using the SnowStorm approach[1]
- Reconstructed Observables for PDFs:
  - Cascades and Tracks: Total Energy, Zenith angle
  - Double Cascades: Total Energy, Length, Energy Asymmetry*



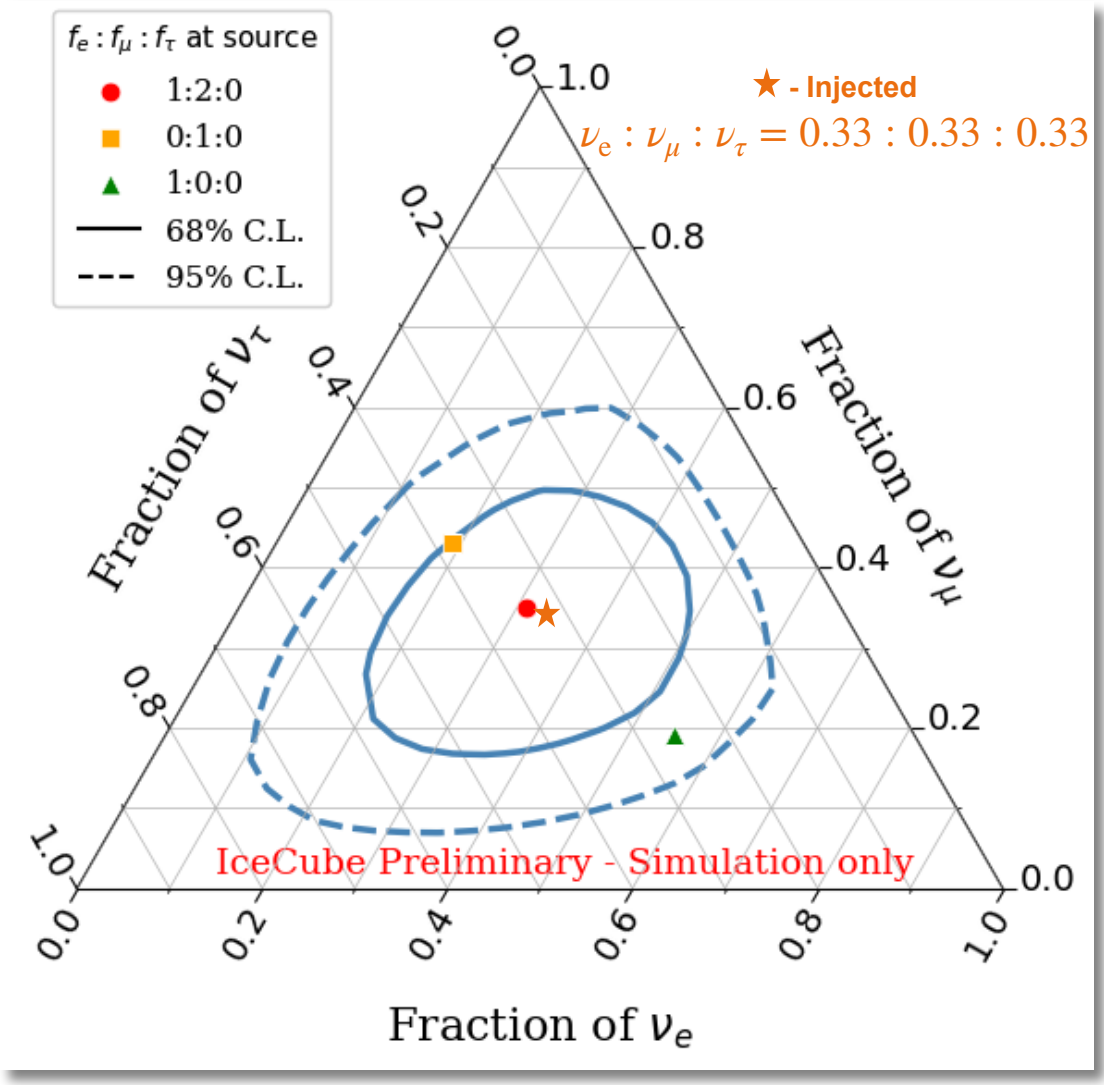
*The energy asymmetry is a measure of how the relative amount of deposited energy in each cascade is distributed

[1] JCAP10 (2019) 048

Flavor Composition Measurement

HESE-12 sensitivity

- Fit independent flavor normalizations
- Binned likelihood to perform a forward folding fit
- Asimov sensitivity assumes astrophysical neutrino spectrum* following a single power law (SPL) with, $\gamma_{\text{astro}} = 2.37$ and $\Phi^{\nu+\bar{\nu}}_{@100\text{TeV}} = 4.32$



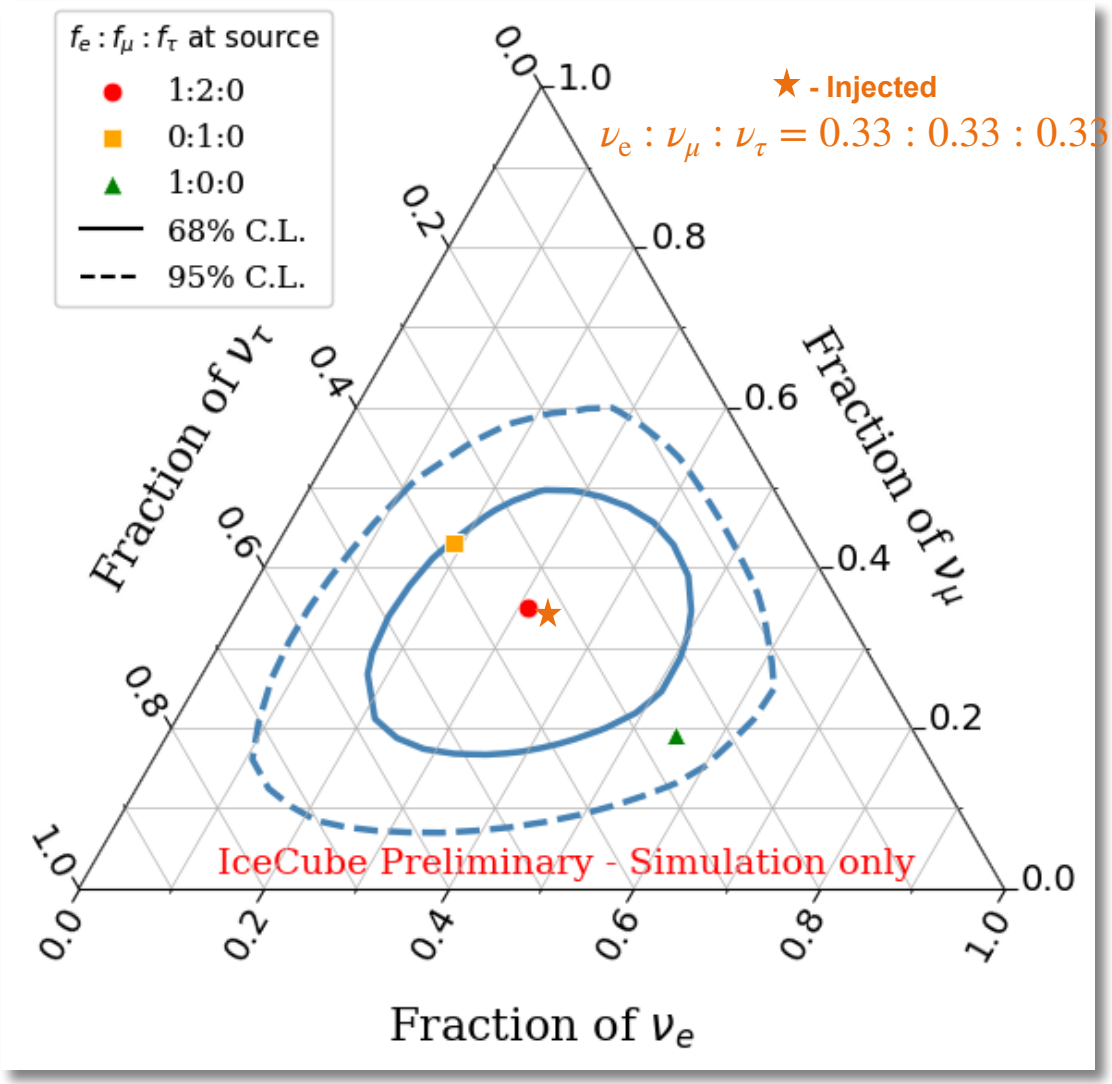
*BestFit SPL from [1]ApJ 928, 50,

Flavor Composition Measurement

HESE-12 sensitivity

- Fit independent flavor normalizations
- Binned likelihood to perform a forward folding fit
- Asimov sensitivity assumes astrophysical neutrino spectrum* following a single power law (SPL) with, $\gamma_{\text{astro}} = 2.37$ and $\Phi^{\nu+\bar{\nu}}_{@100\text{TeV}} = 4.32$

Can the contours shrink even more?



*BestFit SPL from [1]ApJ 928, 50,

Combined Flavor Composition Measurement

Analysis Concept - Combined Fit (aka GlobalFit)

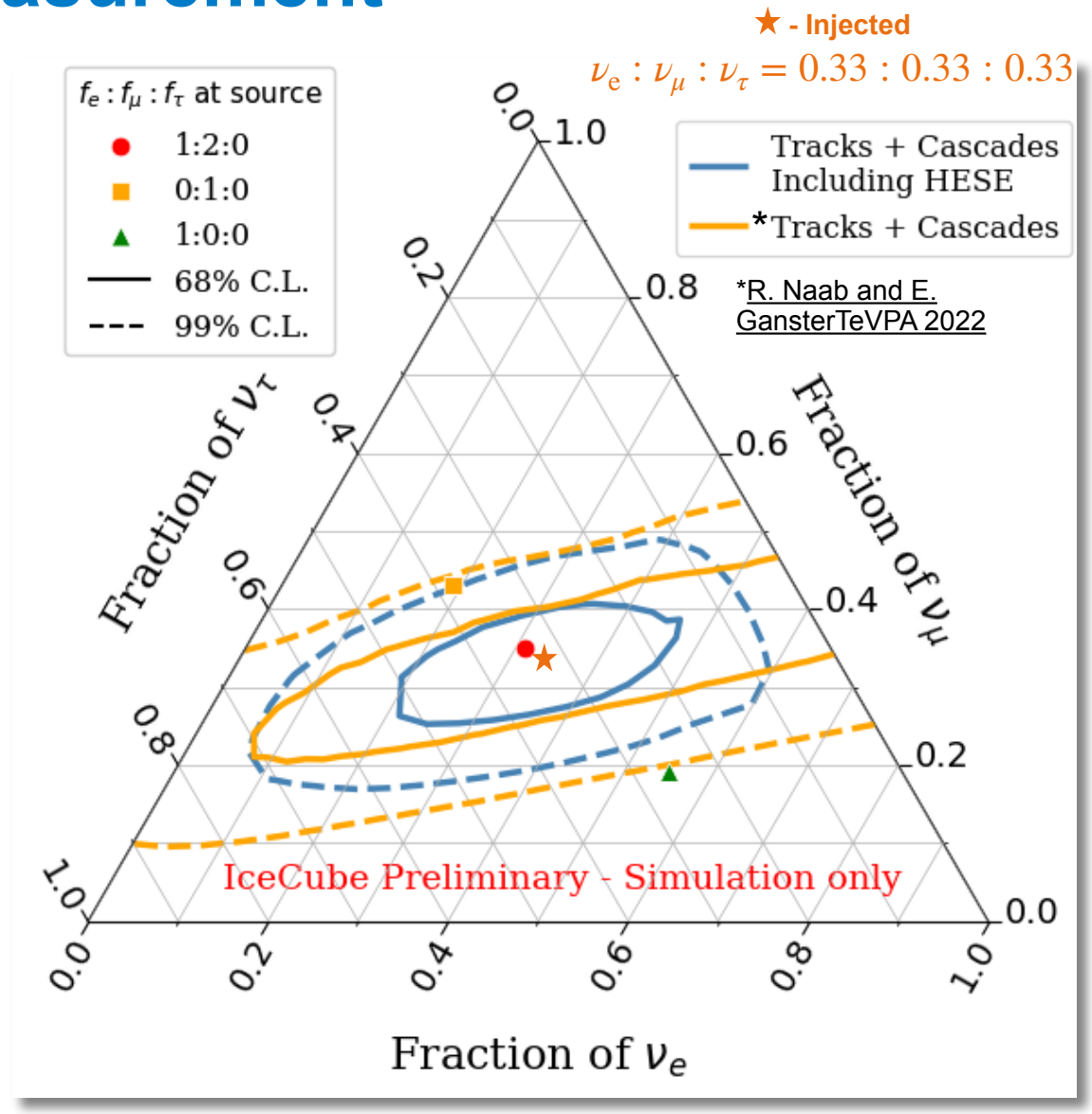
- Answer : YES! Combined Fit of multiple samples!
- Combine HESE-12 sample with IceCube GlobalFit[1] containing Cascades and Tracks
- No dedicated ν_τ identifier yet in GlobalFit
- De-Correlate samples in case of overlaps
- Consistent treatment of all nuisance parameters (atmospheric neutrino spectra, detector responses etc)

[1] PoS ICRC2023 1064

Combined Flavor Composition Measurement

Sensitivity for a Combined Flavor Fit

- Answer : YES! Combined Fit of multiple samples!
- Combine HESE-12 sample with IceCube GlobalFit[1] containing Cascades and Tracks
- No dedicated ν_τ identifier yet in GlobalFit
- De-Correlate samples in case of overlaps
- Consistent treatment of all nuisance parameters (atmospheric neutrino spectra, detector responses etc)



[1]PoS ICRC2023 1064

Combined Flavor Composition Measurement

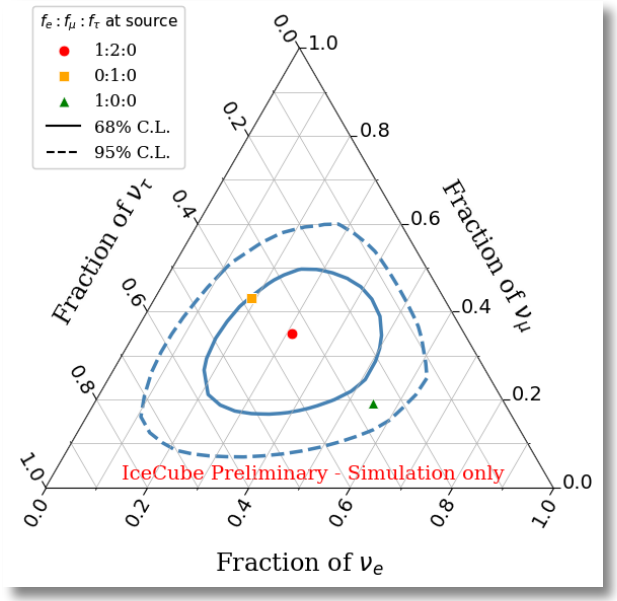
Results will be out soon!

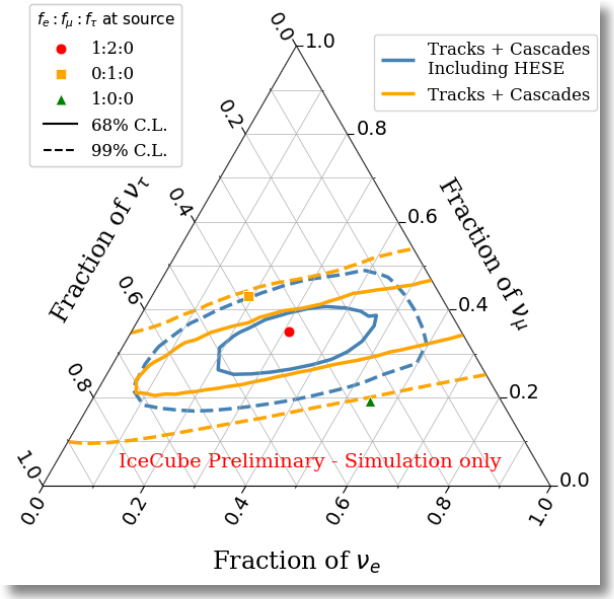
- Unblinded HESE data
- Post-unblinding checks are in the process
- Cascades + Tracks (GlobalFit) already unblinded[1]
- Stay tuned for exciting new results!

[1] for more details PoS ICRC2023 1064

Summary and Outlook

- Measurement of Flavor ratio of diffuse astrophysical neutrinos
- Revisit the HESE sample, an all-flavor, all-sky, astrophysically pure sample, with 12 years of data,
- Combine HESE with through-going tracks and Cascade sample, to perform a flavor GlobalFit
- Combining sample —> Significant gain in sensitivity
- HESE data unblinded, stay tuned for new results!

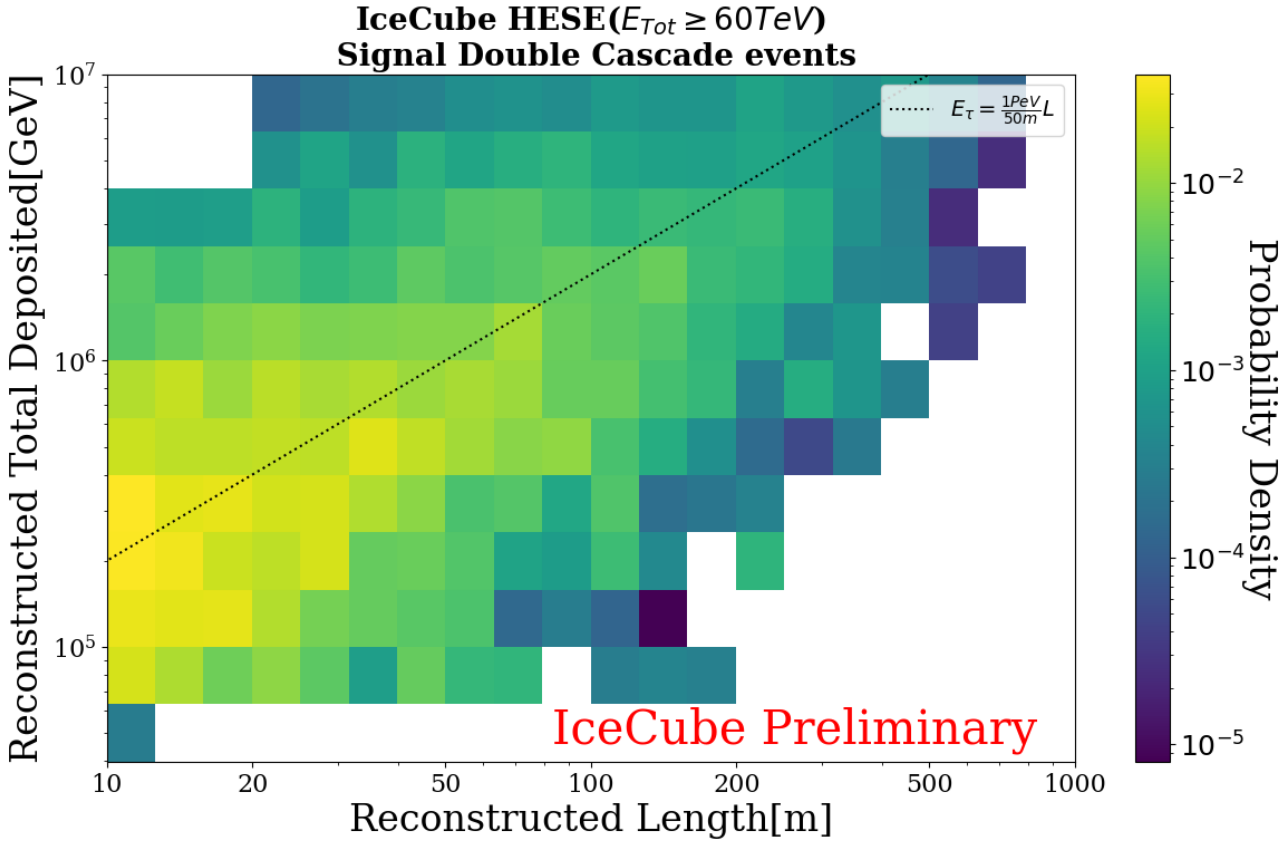


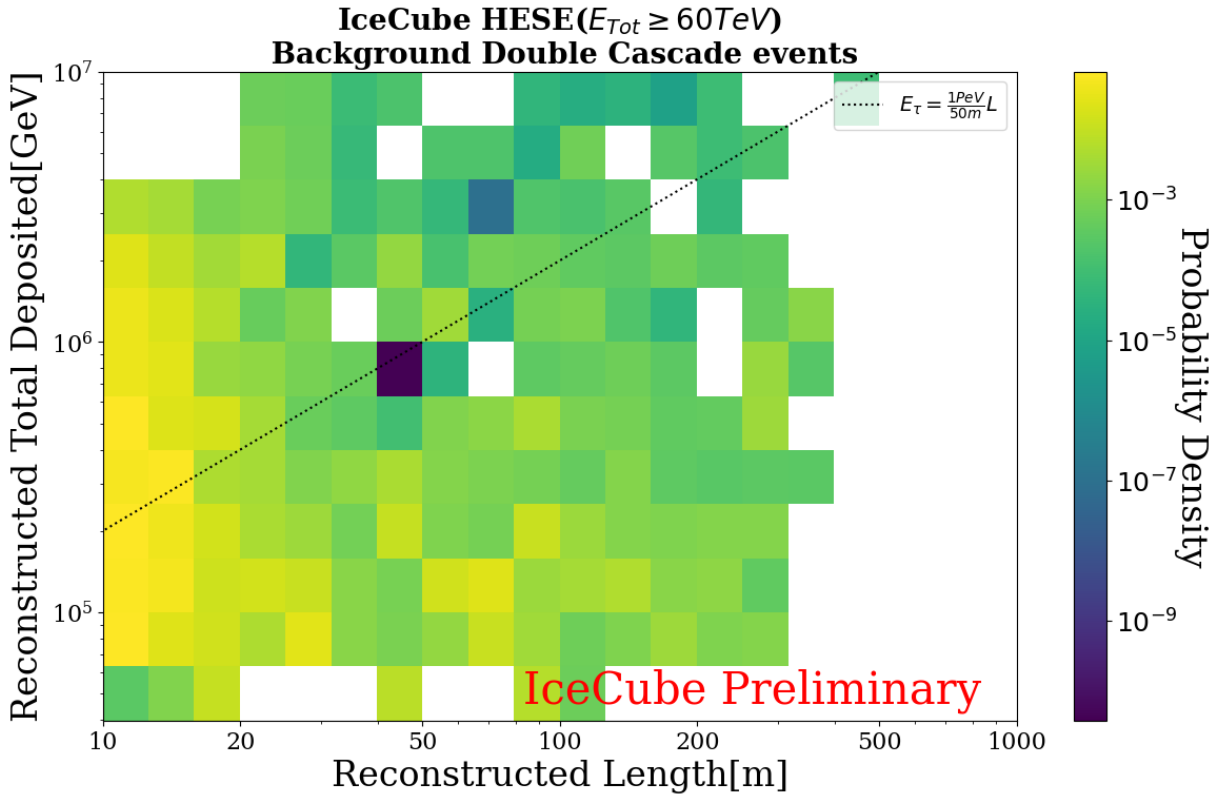


Back Up

Search of ν_τ 'Double Cascades'

Analysis Concept - Double Cascade PDFs (Total Energy vs Length)





Signal - Double Cascades from ν_τ

Background - Double Cascades from ν_e , ν_μ and (sneaky) atmospheric neutrinos

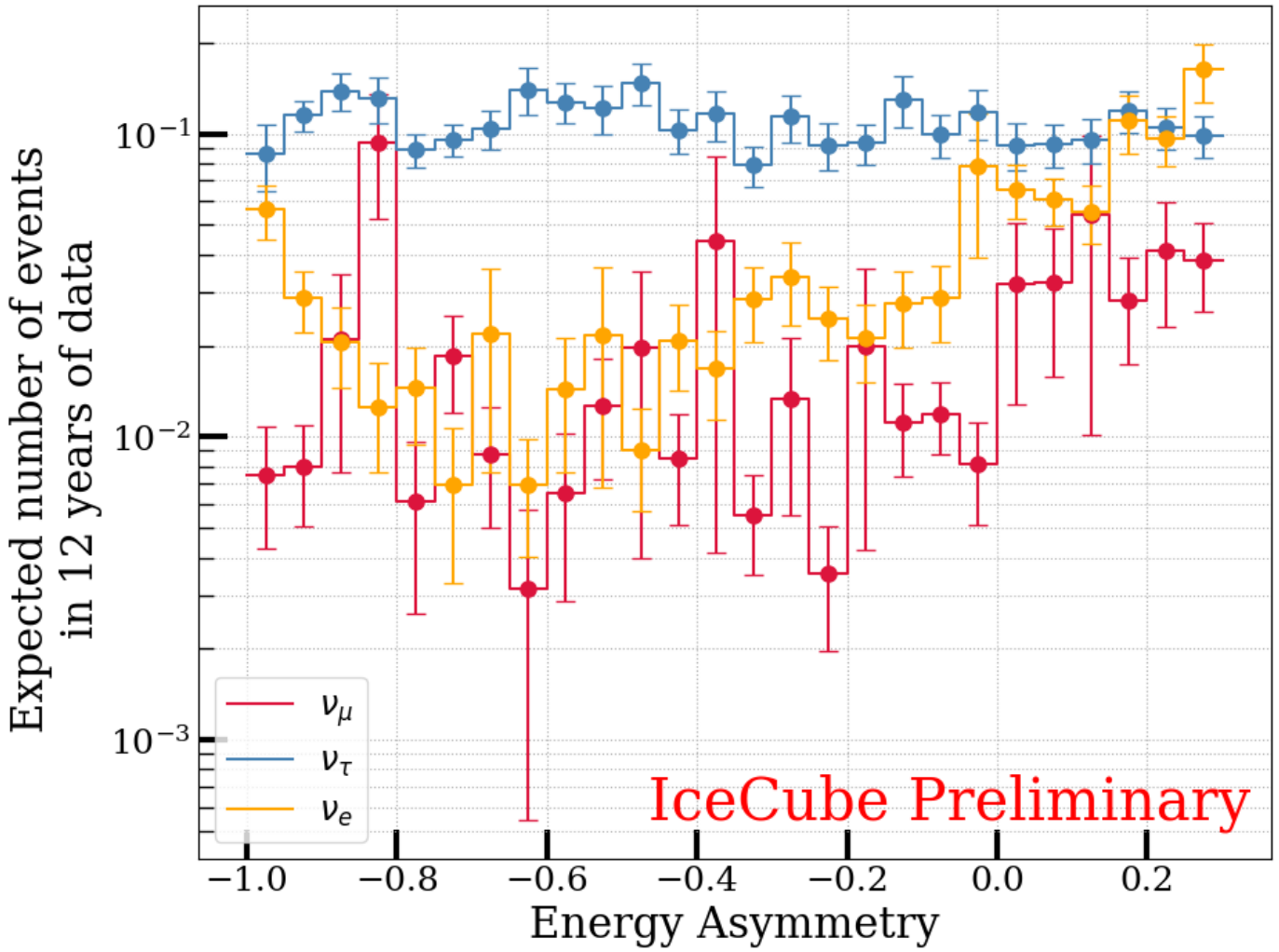
Search of ν_τ 'Double Cascades'

Analysis Concept - Double Cascade PDFs (Energy Asymmetry)

- The Energy Asymmetry (E_A) is a measure of how the relative amount of deposited energy in each cascade is distributed
- It is defined as,

$$E_A = \frac{E_1 - E_2}{E_1 + E_2}$$

- It is a good estimator to separate single cascades from double cascades



Contact

Deutsches Elektronen-
Synchrotron DESY

Neha Lad
neha.lad@desy.de

www.desy.de