technische universität dortmund

WIPAC Wisconsin IceCube Particle Astrophysics Center

TDLI 李政道研究所

Search for Astrophysical Tau Neutrinos using IceCube Waveforms

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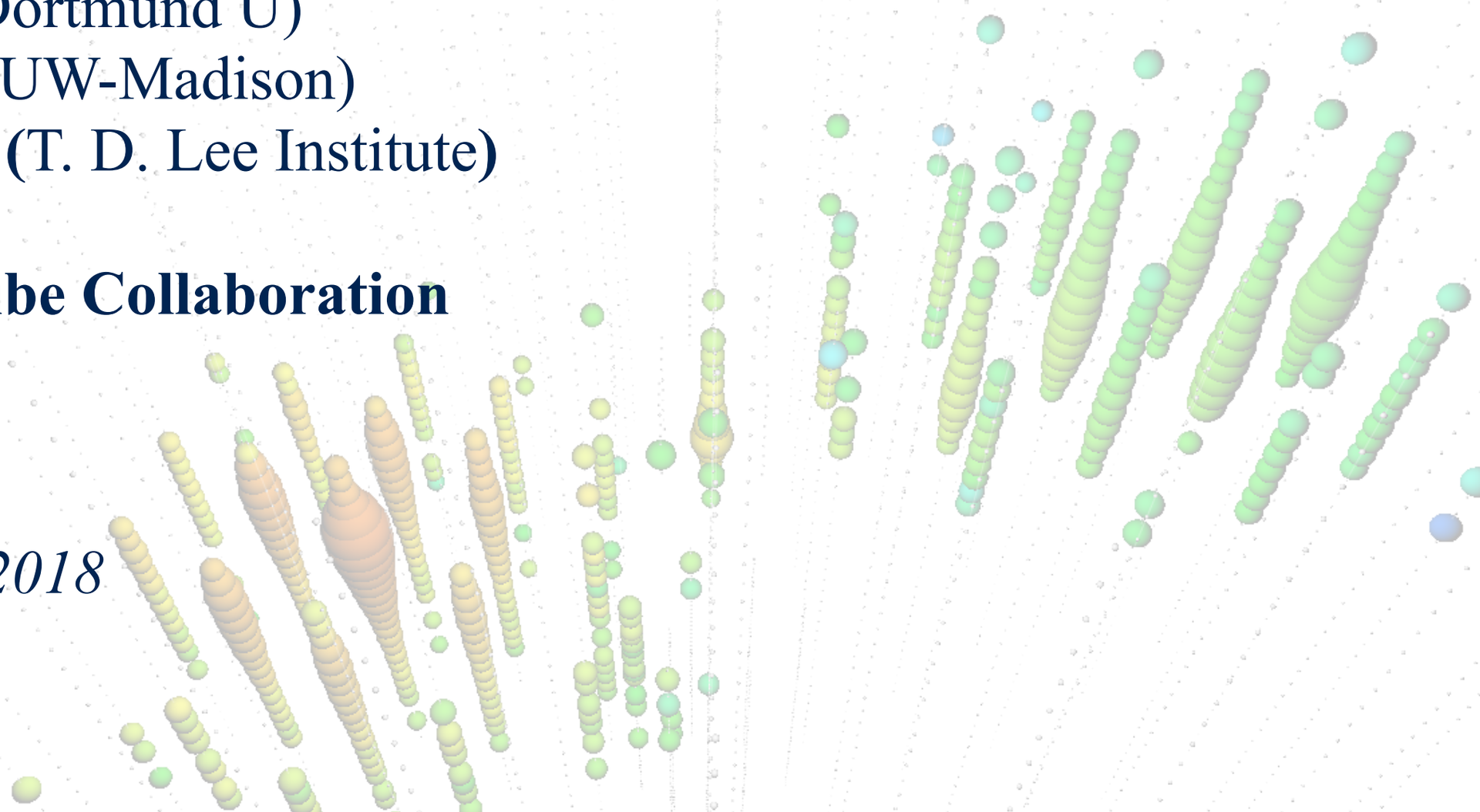
Logan Wille (UW-Madison)
Donglian Xu (T. D. Lee Institute**)**

for the IceCube Collaboration



VLVnT 2018
October 2-4, 2018
Dubna,Russia

Outline

Implication of identifying astrophysical tau neutrinos

Tau Neutrino Signatures / Observables in IceCube

- “Double Cascades” and “Double Pulses”

Waveform-based tau neutrino identifications in IceCube

- Event selection with straight cuts
- Event selection with machine learning techniques

Summary

Why is it important?

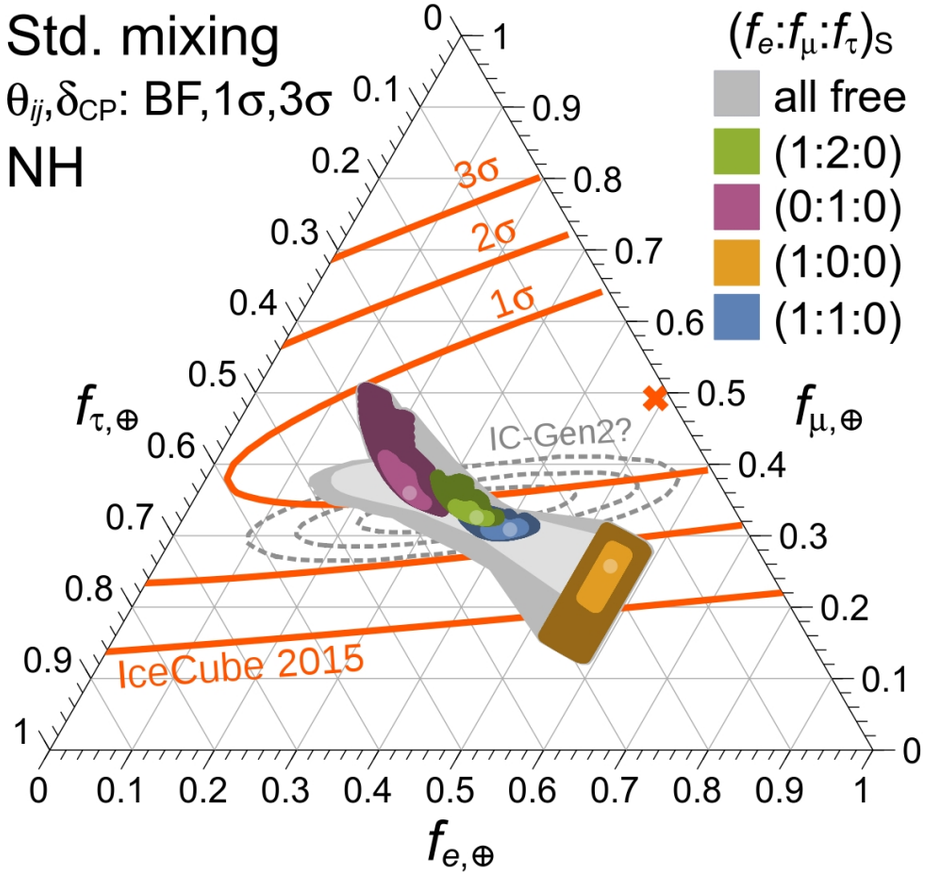
Atmo. ν_τ production is negligible, one ν_τ event can be 5σ astrophysical

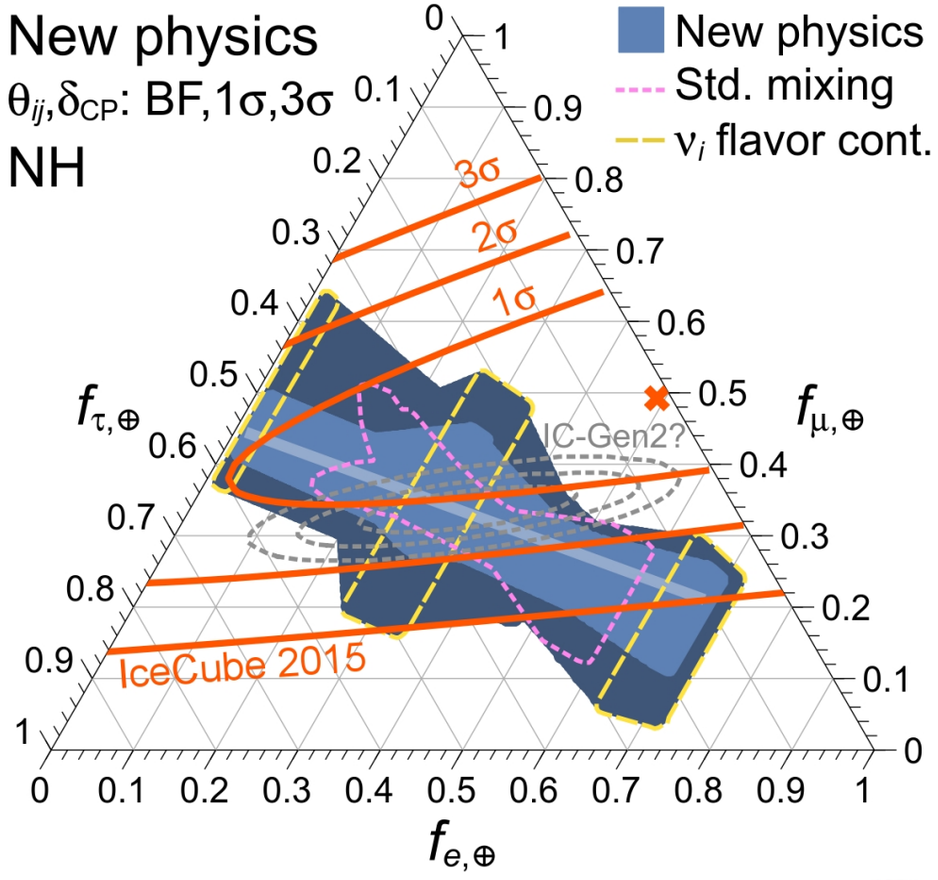
Essential in precision measurement of **neutrino flavor ratio at Earth**

- Test standard oscillation over astronomical baselines
- Probe dominant emission processes at source
- Constrain new physics models

M. Bustamante, J. F. Beacom, and W. Winter, Phys. Rev. Lett. 115, 161302 (2015).

C. A. Argüelles, T. Katori, and J. Salvado, Phys. Rev. Lett. 115, 161303 (2015).





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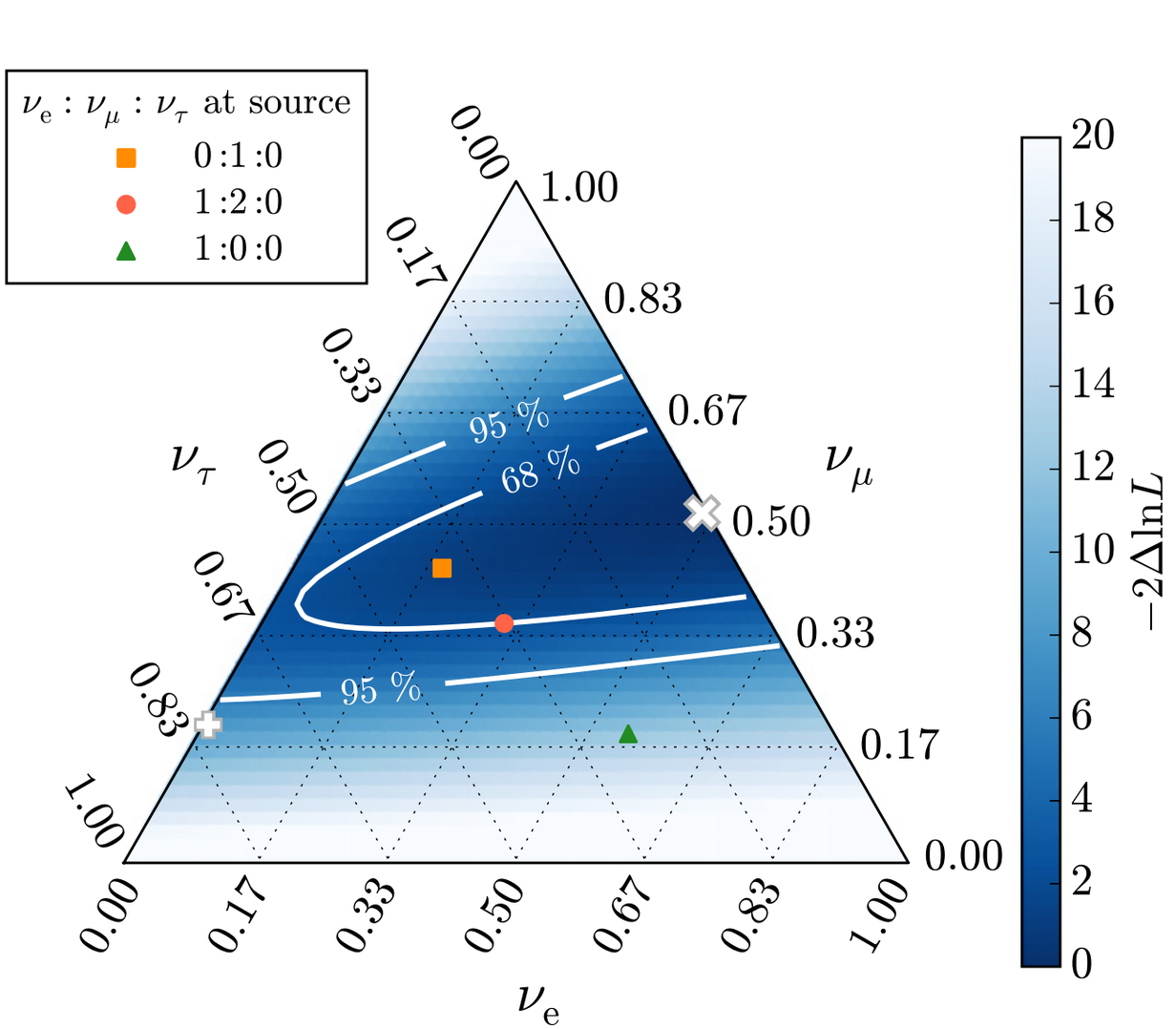
Astro. Neutrino Flavor Composition Measurement

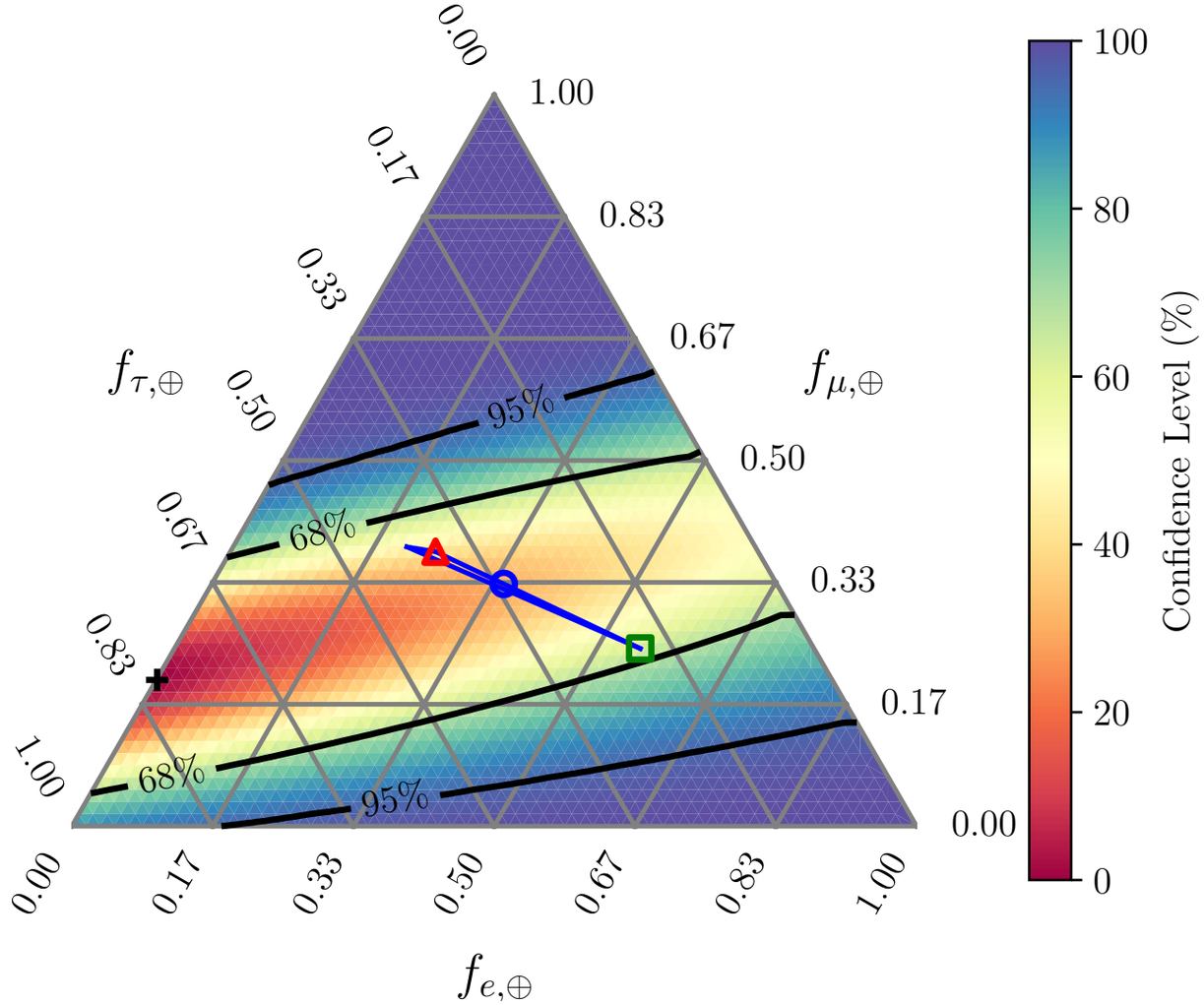
Previous effort to find taus … w/o explicitly sensitive observables

High degeneracy between ν_τ and ν_e in the cascades



Combined fit:
through-going tracks + cascades

ApJ 809, 98 (2015)



Combined fit:
starting tracks + cascades

arXiv:1808.07629
Phys. Rev. Lett. 114, 171102

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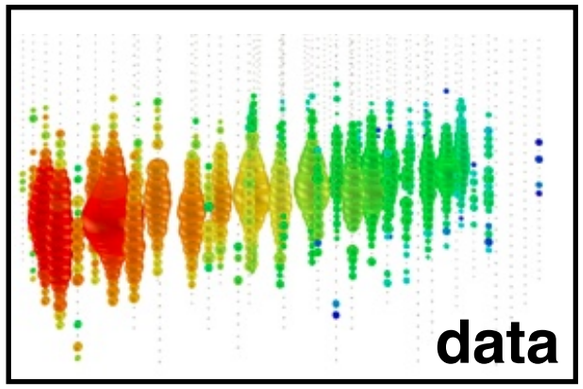
Event Signatures in IceCube

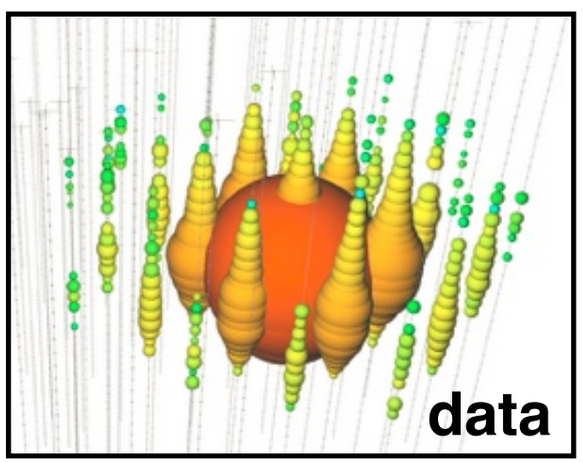
(1) Track: charged current ν_μ

- **<1° Angular resolution**
- **Factor ~ 2 energy resolution**

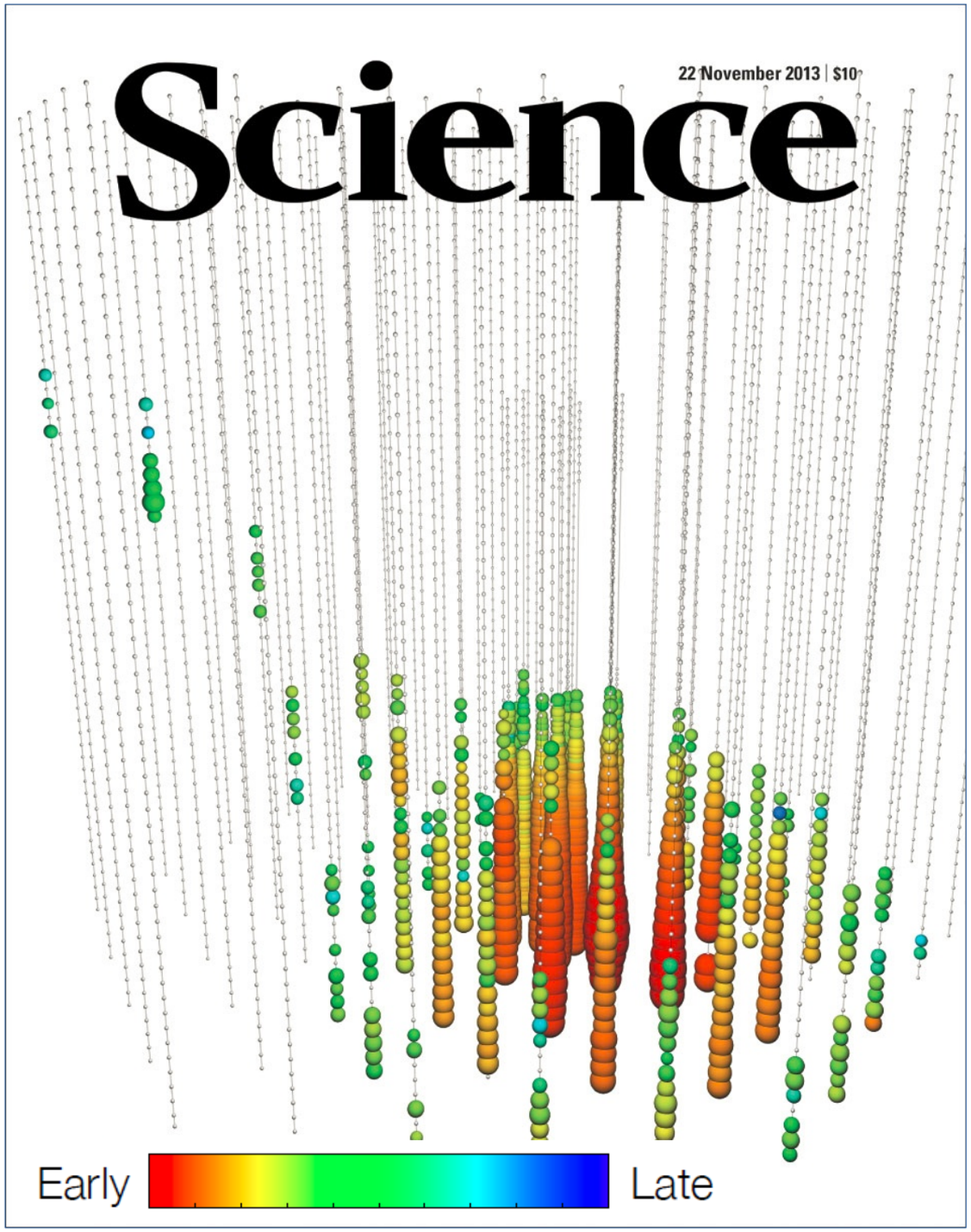


(2) Cascade / Shower: all neutral current, charged current ν_e, low-E charged current ν_τ

- **10° Angular resolution above 100 TeV**
- **15% energy resolution on deposited energy**



“high degeneracy”



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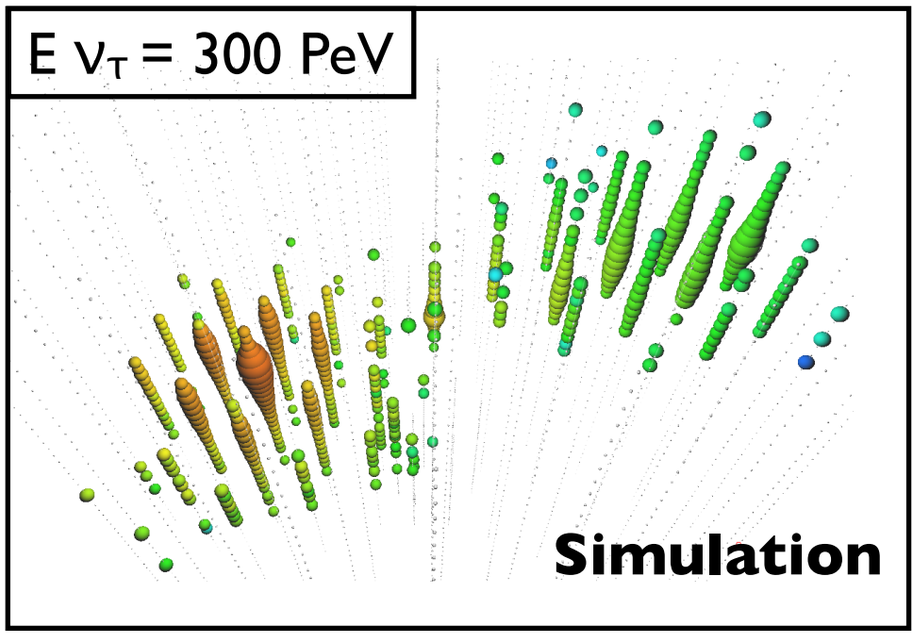
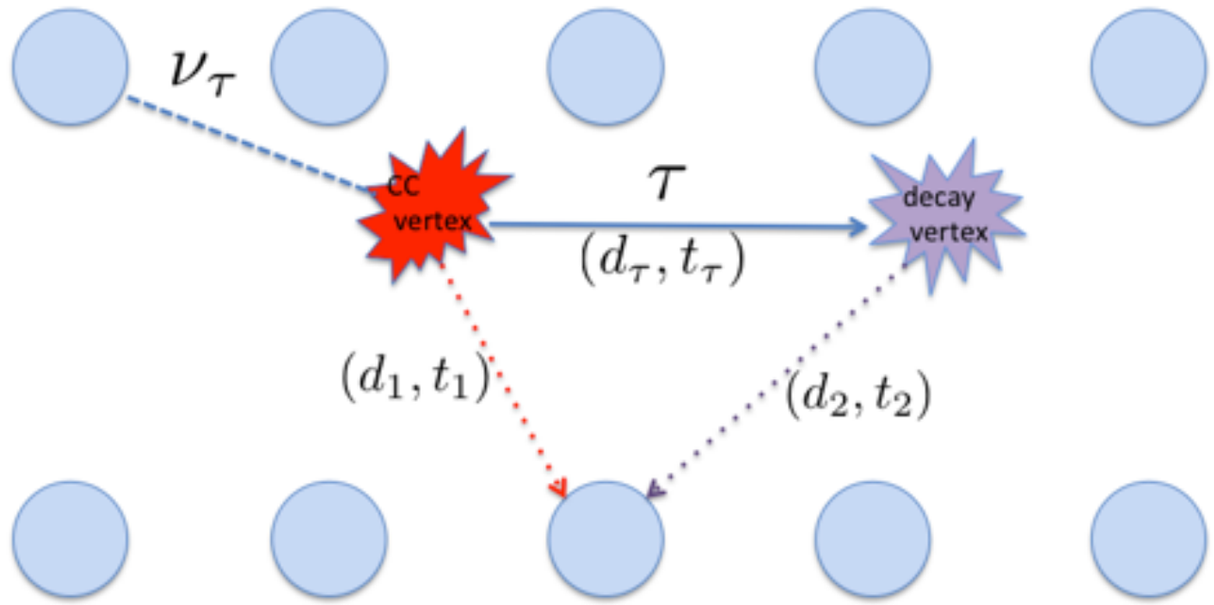
(3) Double Cascades: High-E ν_τ charged current





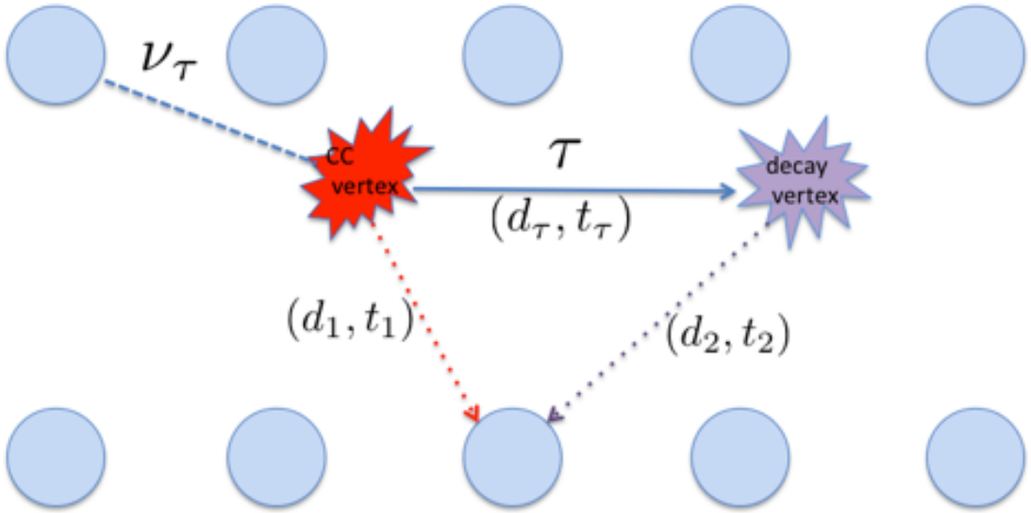
- **Tau decay length scales ~ 1PeV / 50m**
- **There is some hint… work in progress**

$$\nu_\tau + N \rightarrow \tau^- + X$$

$$\tau^- \rightarrow \nu_\tau + hadrons \quad (64.8\%) \checkmark$$
$$\tau^- \rightarrow \nu_\tau + \bar{\nu}_e + e^- \quad (17.8\%) \checkmark$$
$$\tau^- \rightarrow \nu_\tau + \bar{\nu}_\mu + \mu^- \quad (17.4\%)$$

Tau Neutrino Interaction with Double Pulse Waveforms

Schematic ν_τ CC interaction in IceCube



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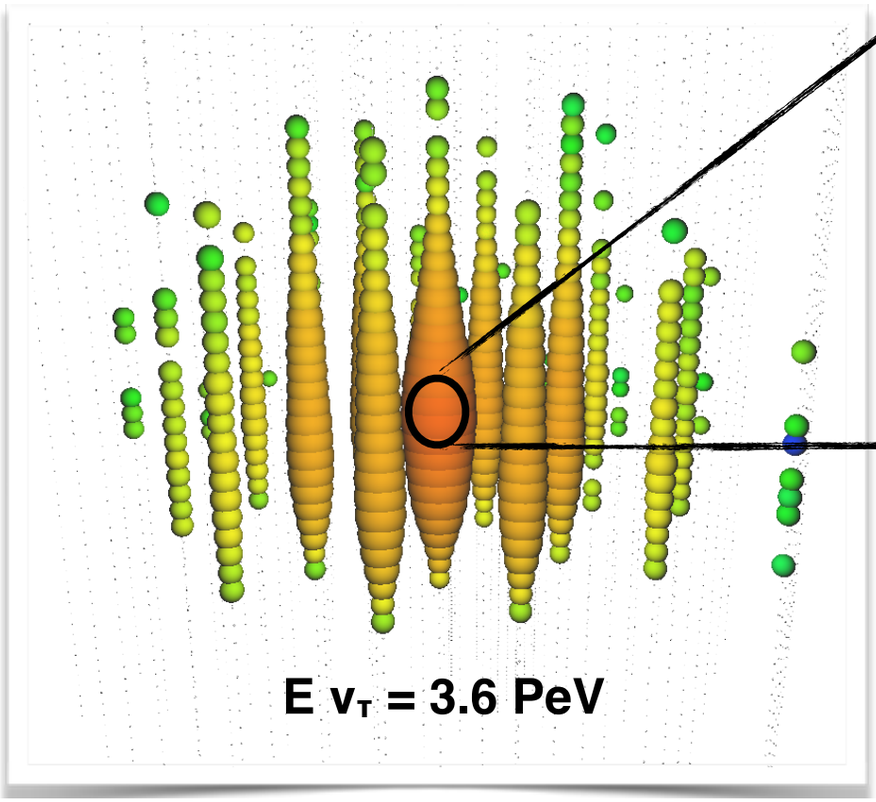
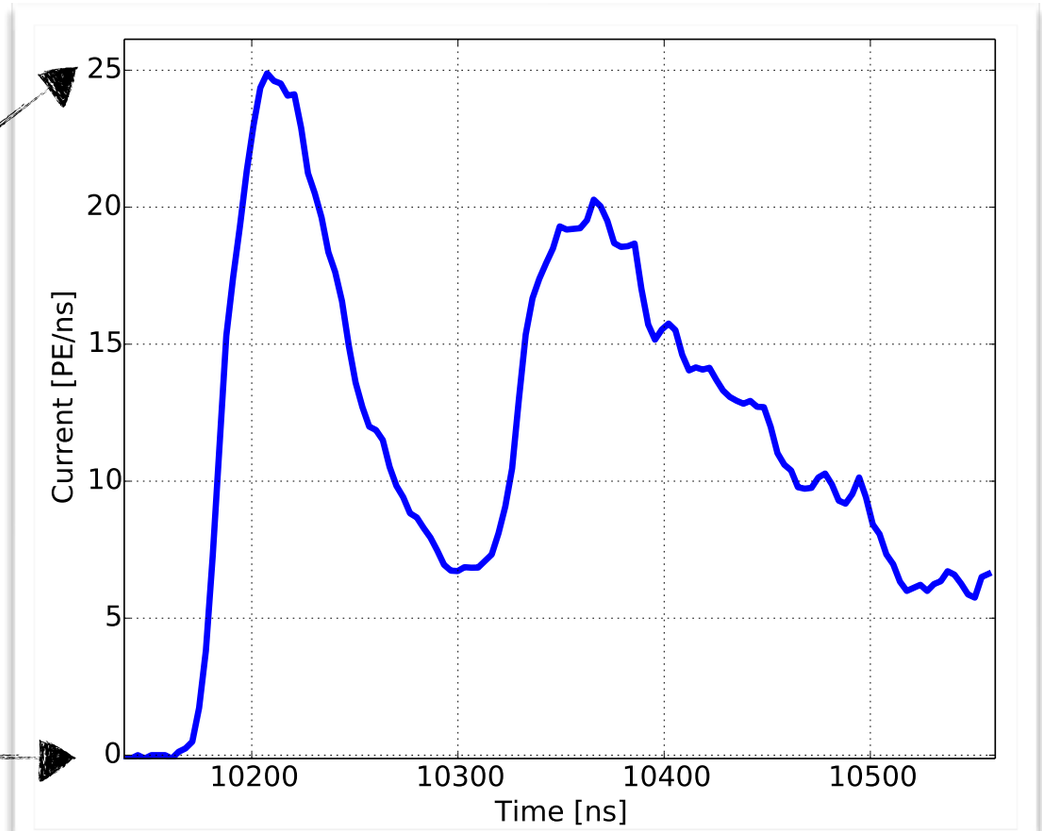


E ν_T = 3.6 PeV



Double Pulse Event Candidates

Signal

ν_τ

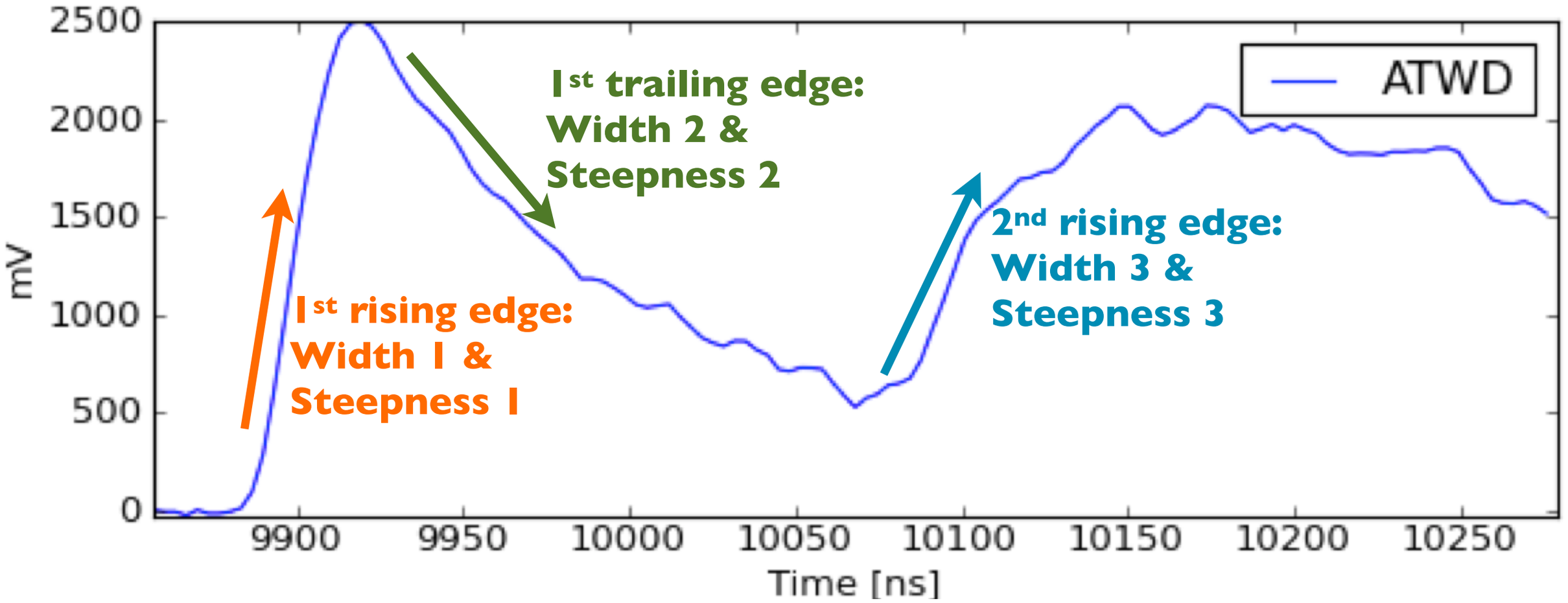
Backgrounds

Muons

ν_μ

TeV-scale stochastic losses ~O(10) meters near some DOM

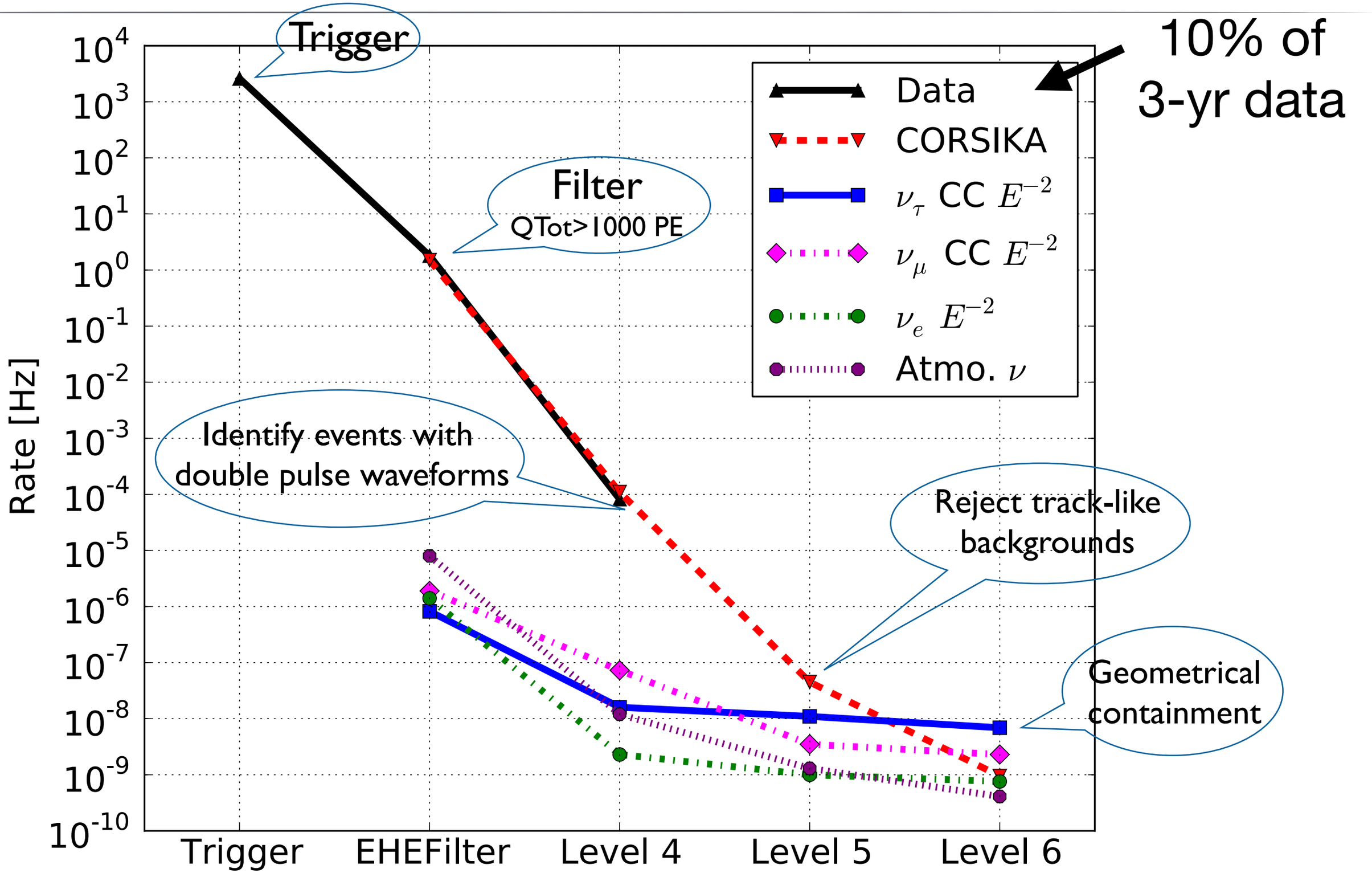
Identifying DP Waveforms with Straight Cuts



Note: DPA only runs on ATWD waveforms with accumulated charge > 432 PE

Method: *"Detecting Tau Neutrinos in IceCube with Double Pulses"*, arXiv:1309.7003

Initial results from analyzing 3 years of data…

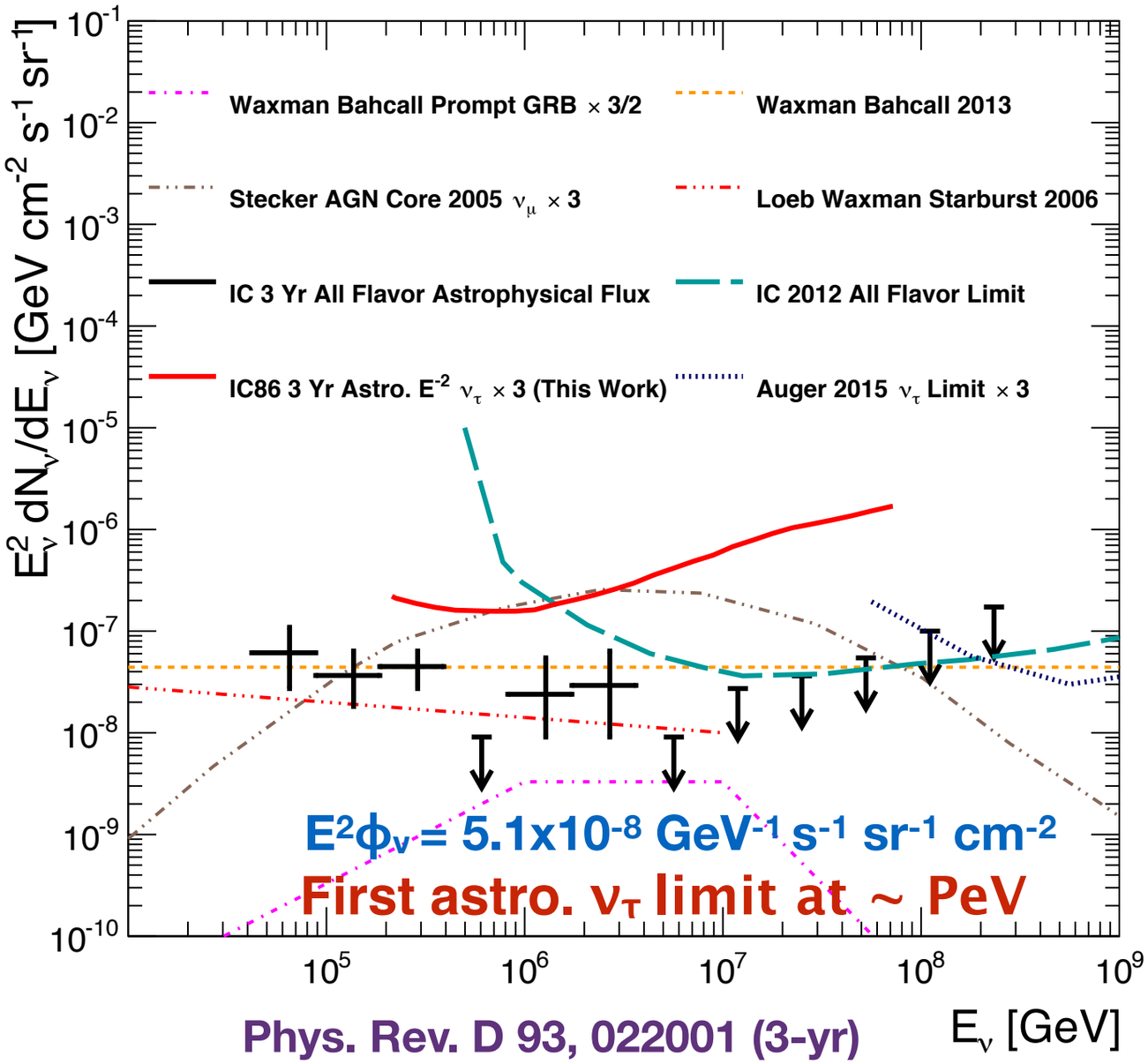


Phys. Rev. D 93, 022001 (3-yr)

Initial results from analyzing 3 years of data…

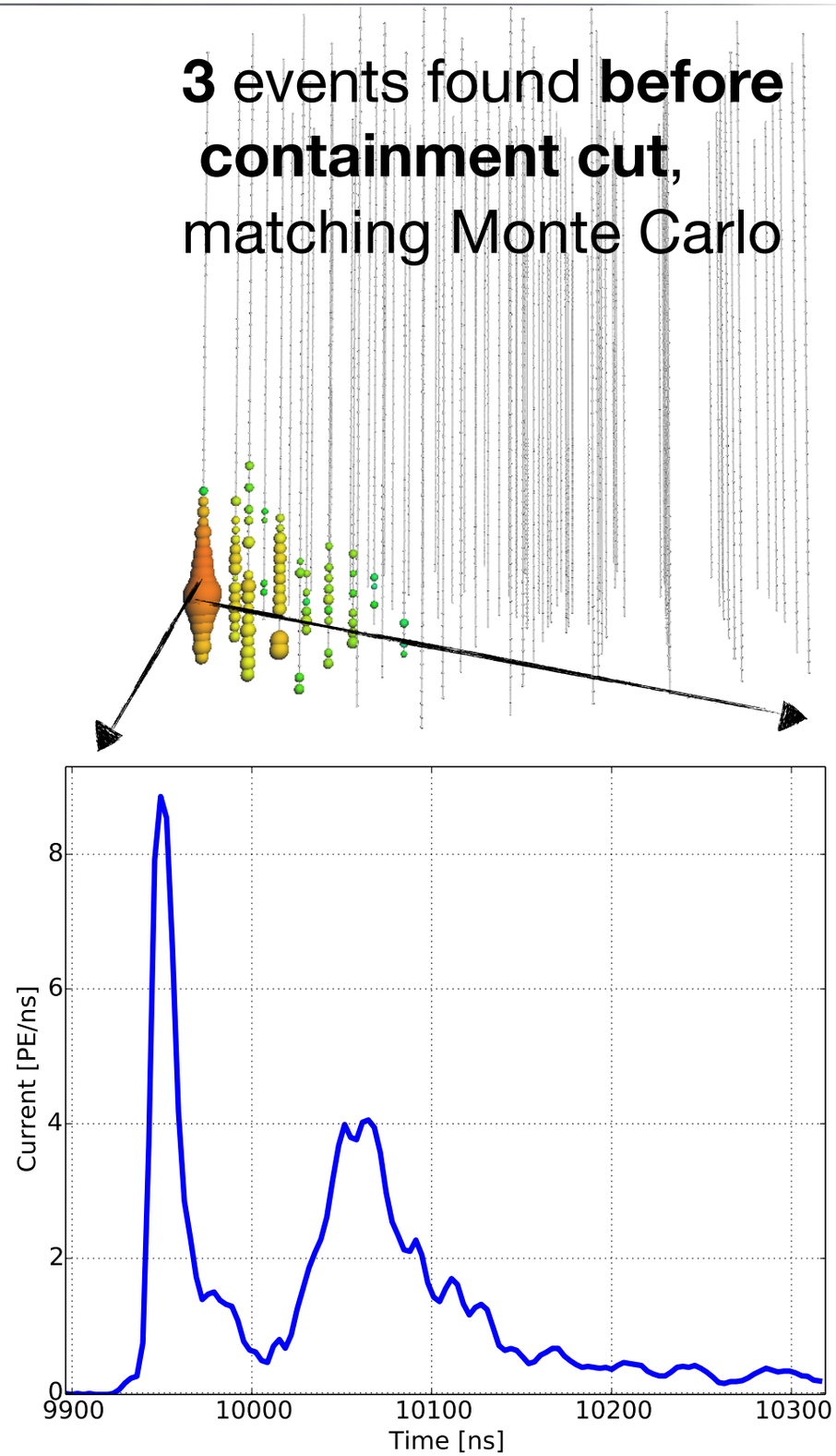
0.54 signal, 0.35 bg expected in 914 days

Zero events found at final cut



Phys. Rev. D 93, 022001 (3-yr)

3 events found **before containment cut**, matching Monte Carlo



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Improved Event Selection with Straight Cuts

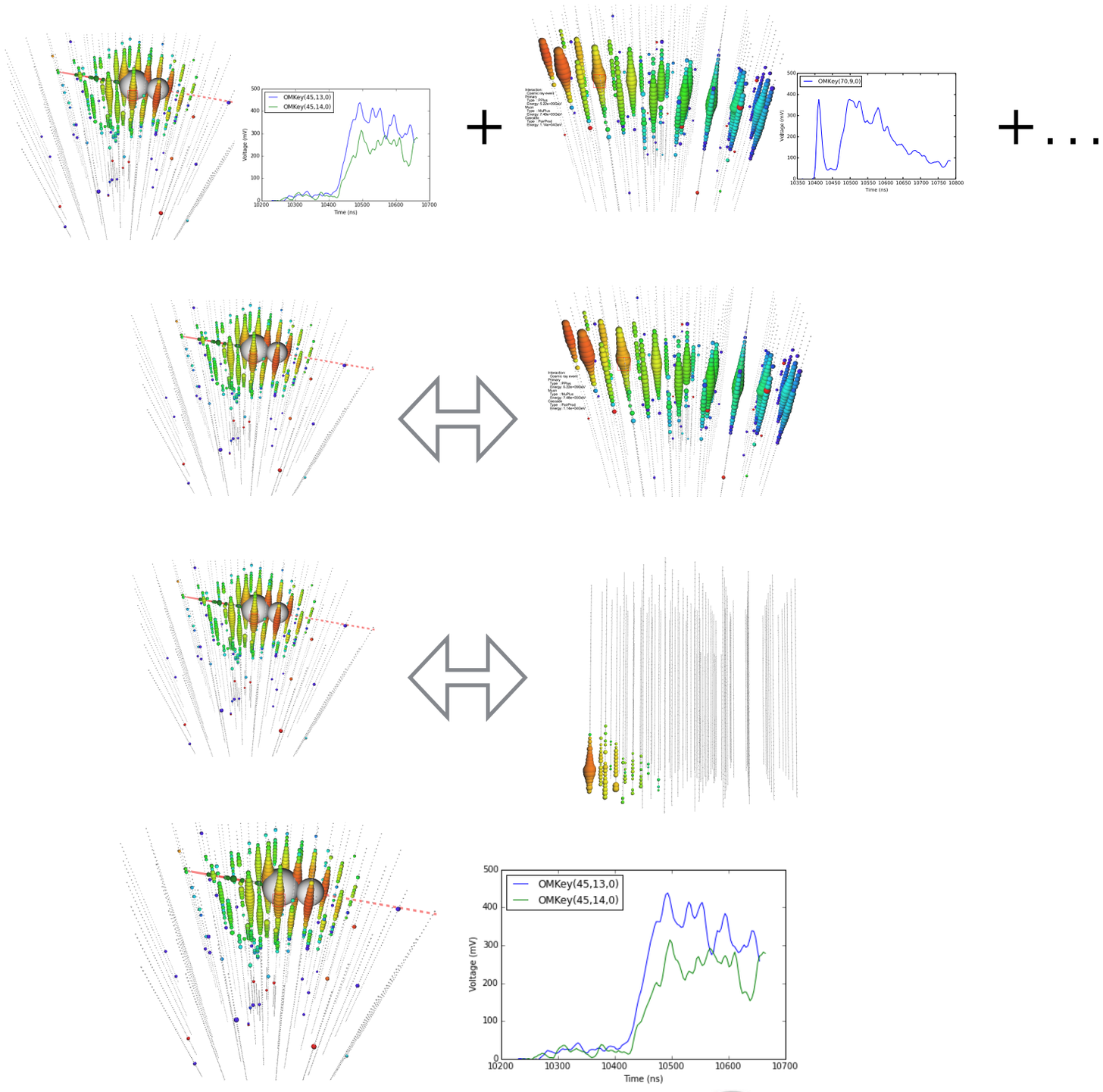
Trigger

L4: Double Pulse Events
New! Local Coincidence

L5: Particle Identification
Track VS Cascades

L6: Reject Corner Events
“Safeguard”

Forward Folding
measure flux or set limits



Improved Event Selection with Straight Cuts

The improved tau double pulse analysis **gains ~ a factor of 2 in effective areas**, comparing to the published results in PRD

We expect **1.8+/-0.023 NuTau** events and **1.6+/-0.11 background** events **in 8 years**

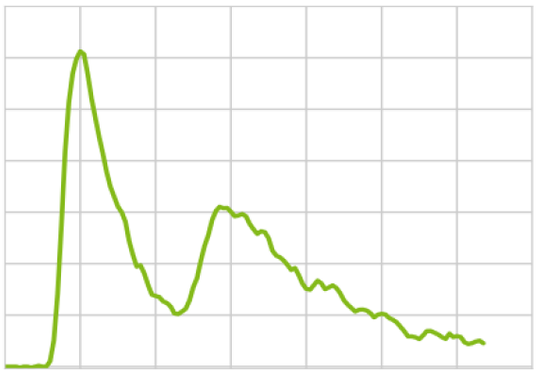
Sensitivity at 90% C.L. is:

$$\Phi_{\nu_\tau} = 1.49 \cdot 10^{-18}\,\mathrm{GeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1} \cdot \left(\frac{E}{100\,\mathrm{TeV}}\right)^{-2.13}$$

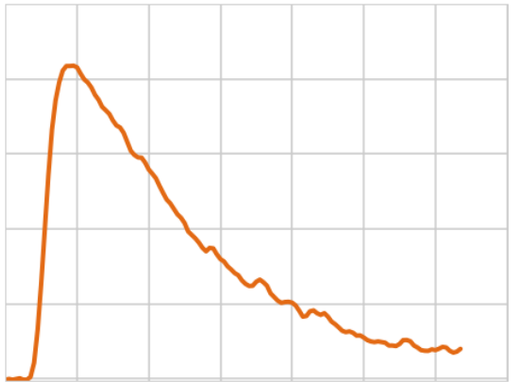
Improved Event Selection with Machine Learning

Double Pulse waveform identification

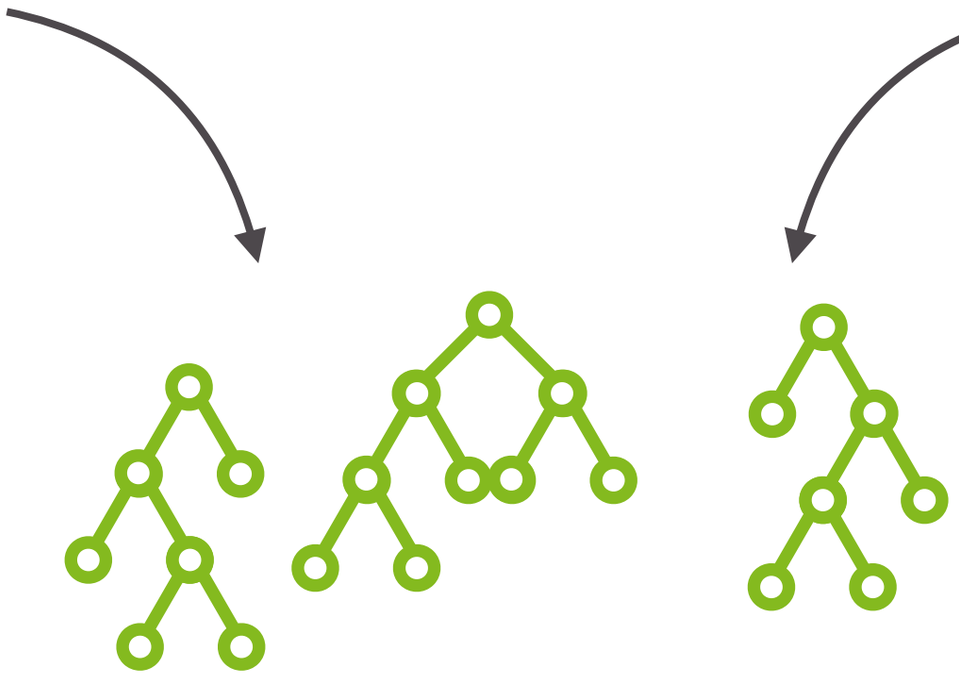
Signal



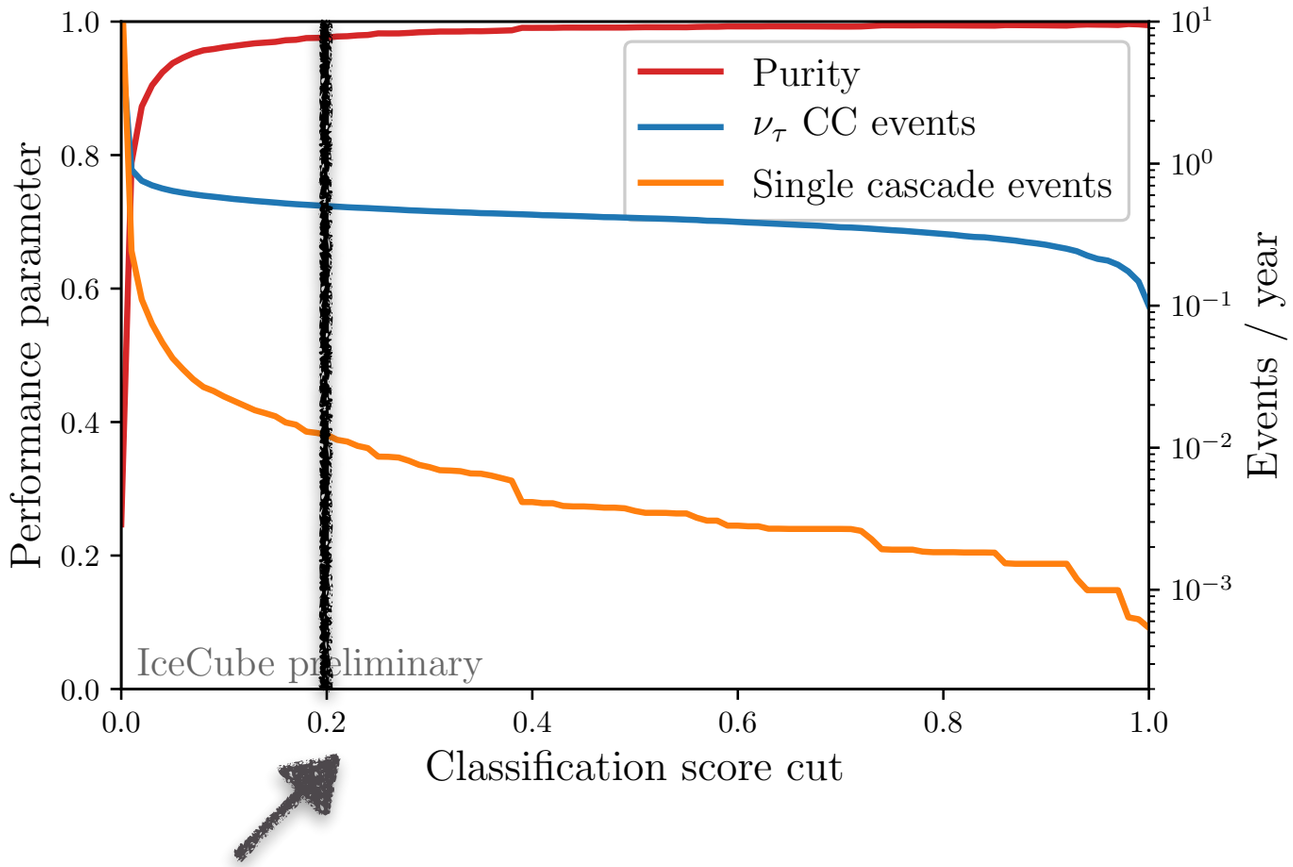
Background



Describe each waveform with O(10) observables



- Train a Random Forest to distinguish double pulse waveforms from single cascade waveforms
- Relatively pure sample of events with double pulse waveforms
- Signal still overwhelmed by atmos. muons

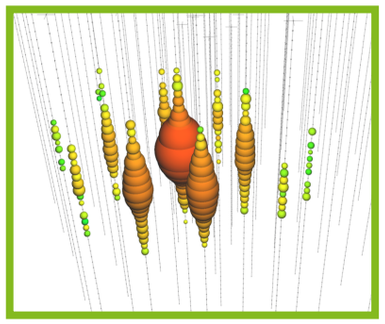


Keep events with at least one waveform score above 0.2

Improved Event Selection with Machine Learning

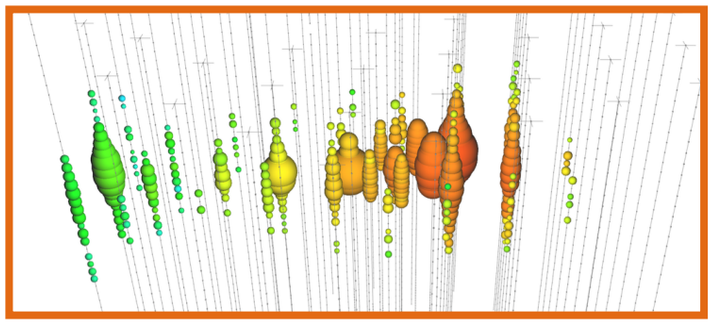
Track / Cascade separation

Signal

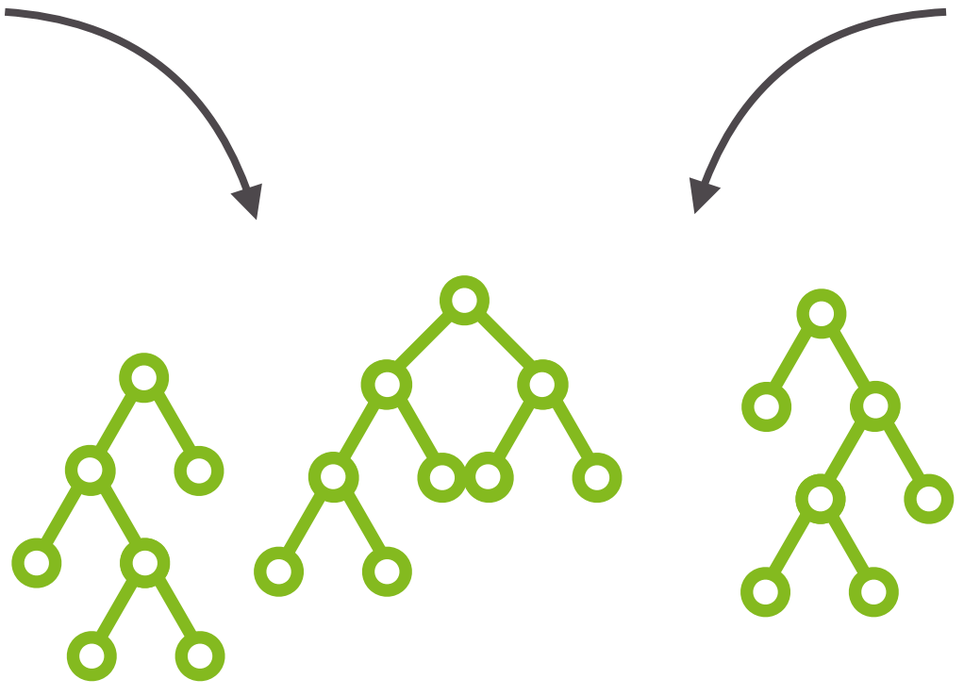


Contained $\nu\tau$ CC

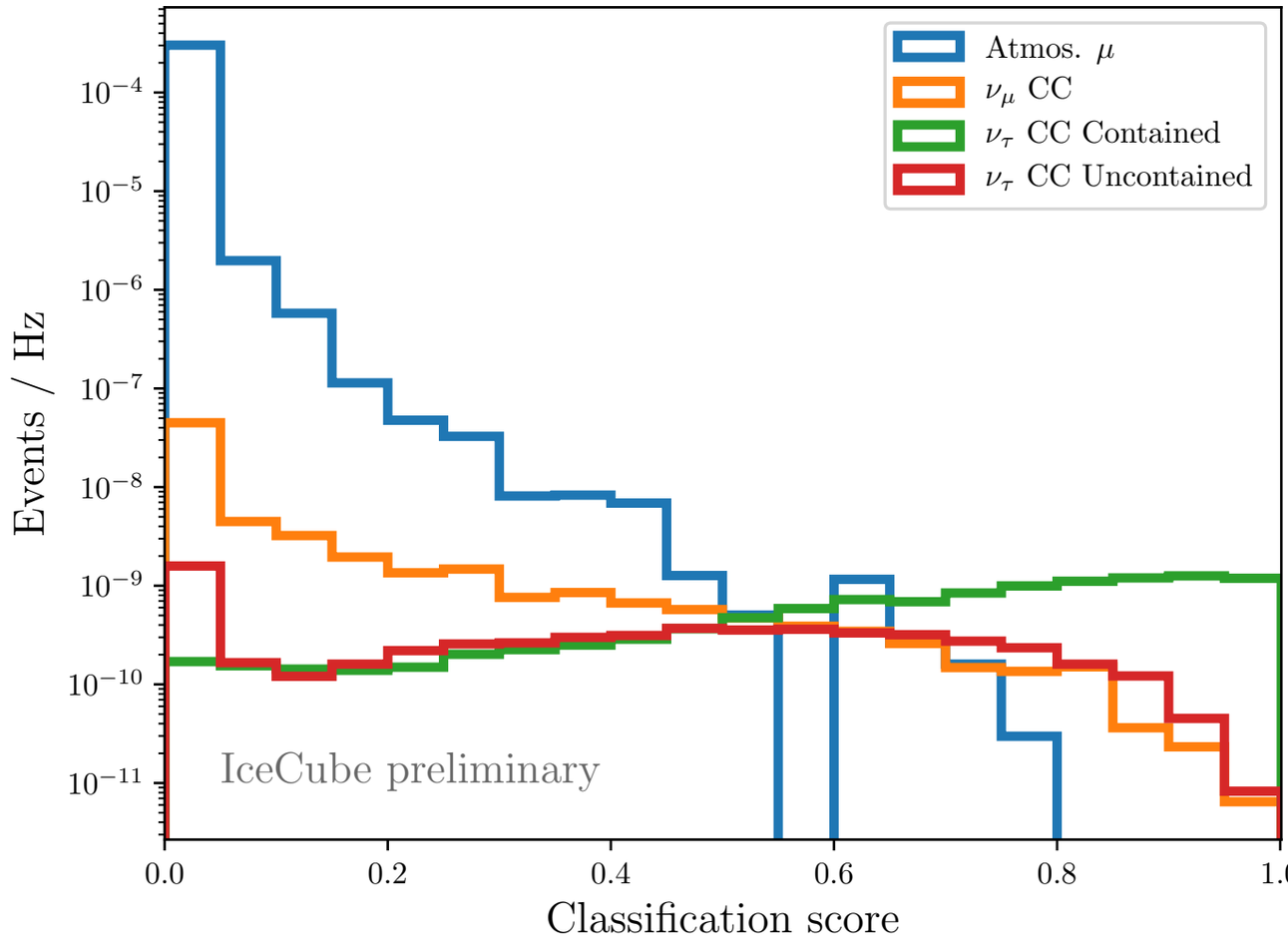
Background



$\nu\mu$ CC, atmospheric μ



- Train a 2nd Random Forest removing the track-like background events to obtain a tau-neutrino dominated sample
- Use the Model Rejection Factor to optimize the classification score cut



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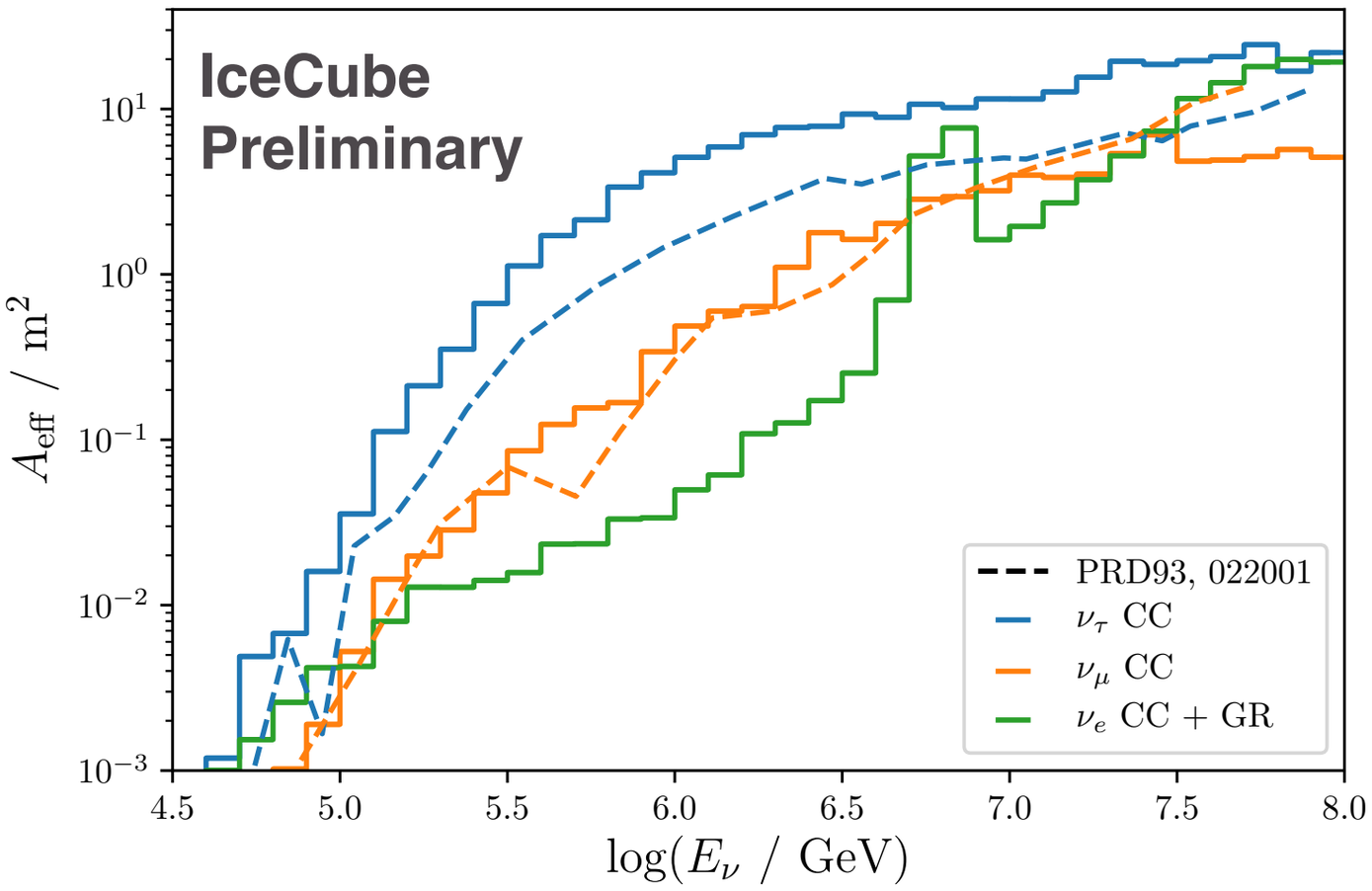
Improved Event Selection with Machine Learning

Analysis sensitivity

- Final cut event expectation: O(2.5) signal and O(1.2) background events in 7 years
- Signal effective area improved by a factor ~2 compared to the previously published double pulse analysis



- Average upper limit if there is no true signal present can be calculated from the Model Rejection Factor

Resulting sensitivity for 90% upper limits:

$$\Phi_{\nu_\tau} = 1.32 \cdot 10^{-18}\,\mathrm{GeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1} \cdot \left(\frac{E}{100\,\mathrm{TeV}}\right)^{-2.13}$$

Summary

- Improved event selections are finalized for tau neutrino double pulse analyses in IceCube with 8 years of collected data

- With improvements in event selection, ~a factor of 2 is gained in tau neutrino double pulse effective areas

- We expect to see ~ 2 – 3 tau neutrino double pulse events in 8 years

- Looking to unblind full sample soon, stay tuned!