



Event Selections

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IceCube Summer
School 2023

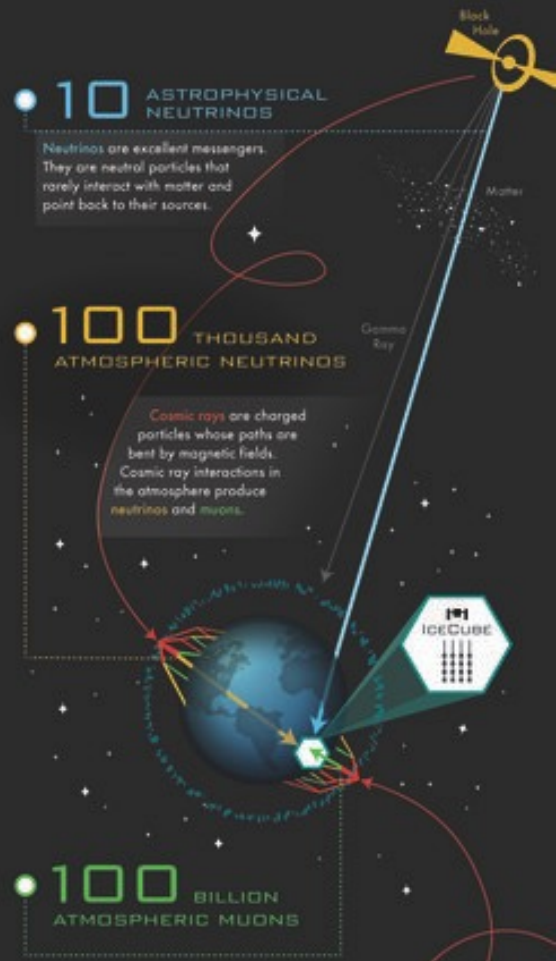
Heavily borrowed from Kayla Leonard DeHolton's talk from 2022

Event Selections

- Motivation
- General Considerations
- Examples in IceCube

COSMIC MESSENGERS

EVERY YEAR,
ICECUBE
DETECTS ABOUT...



Types of events

- Atmospheric muons
- Atmospheric neutrinos
- Astrophysical neutrinos

- Cascades
- Tracks
- ...

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→ Cosmic rays ...

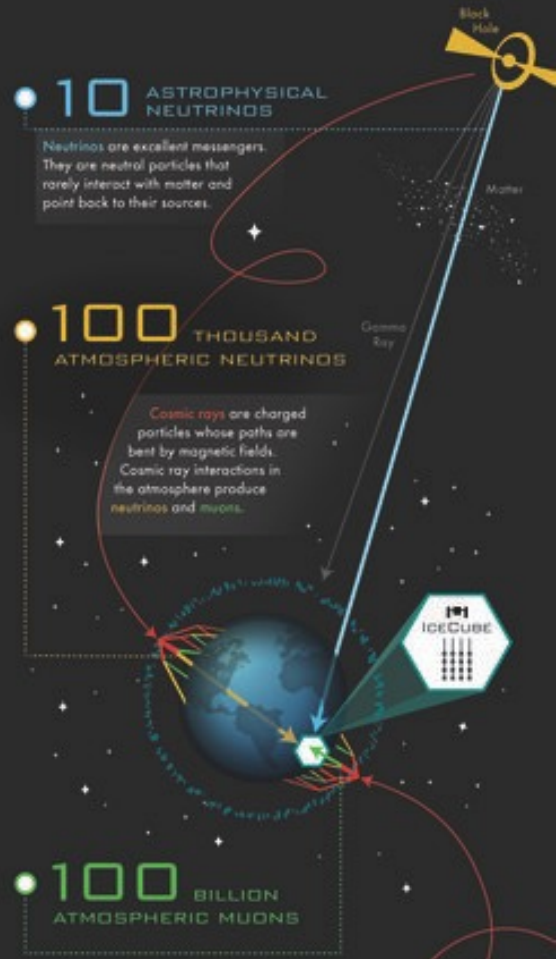
→ Neutrino oscillations ...

→ Cosmos ...

- Cascades
- Tracks
- ...

Different analyses care about different types of events. Many techniques are used to curate samples of a given event type for a given analyses.

EVERY YEAR,
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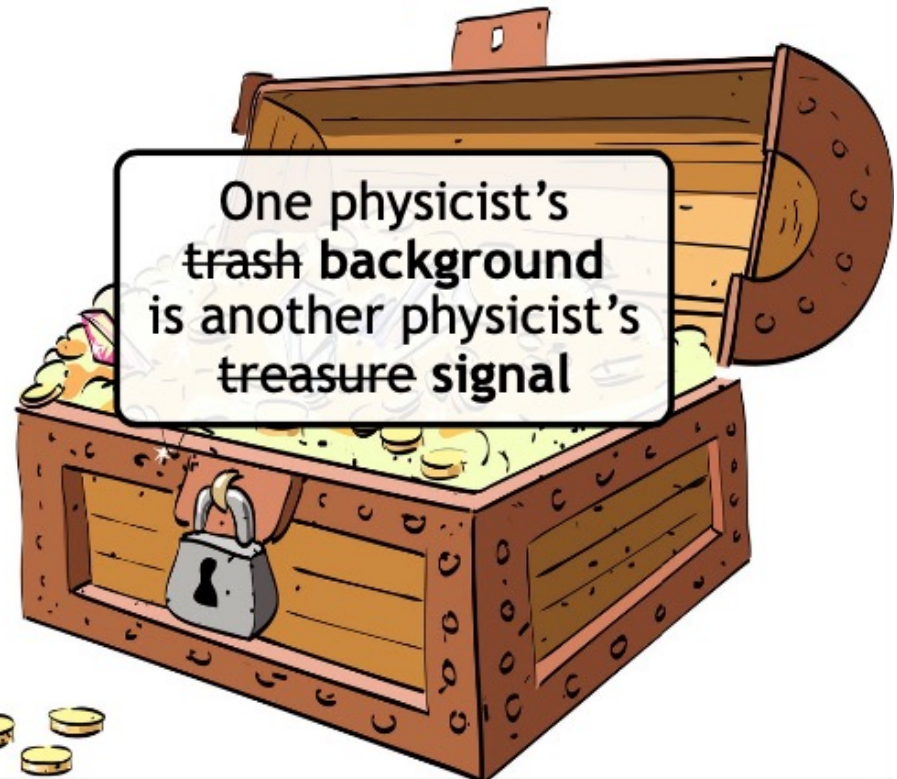


Types of events

- Atmospheric muons
- Atmospheric neutrinos
- Astrophysical neutrinos

- Cosmic rays ...
- Neutrino oscillations ...
- Cosmos ...

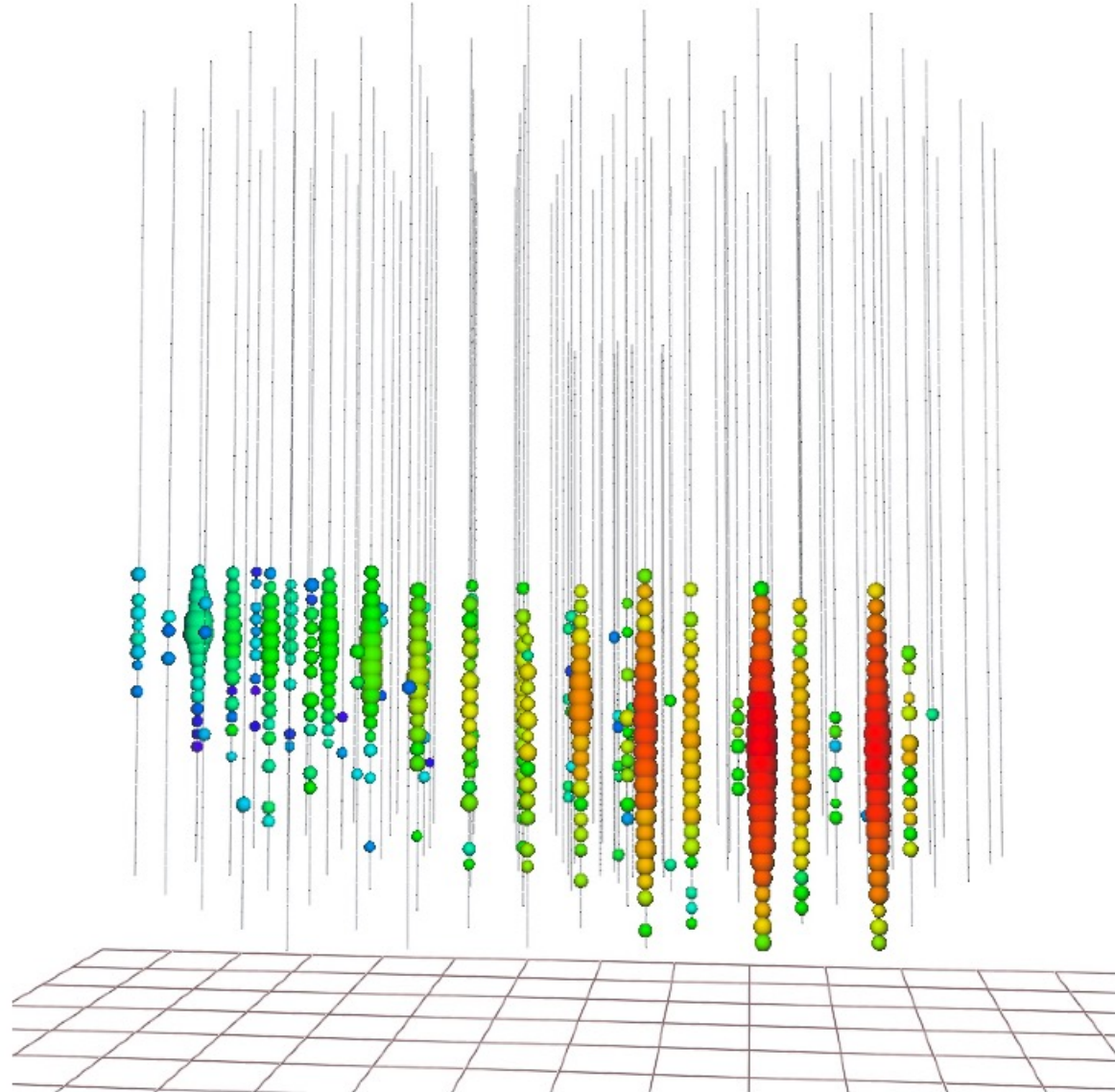
- Cascades
- Tracks
- ...



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IceCube events



Start with:

- Charge
- Time

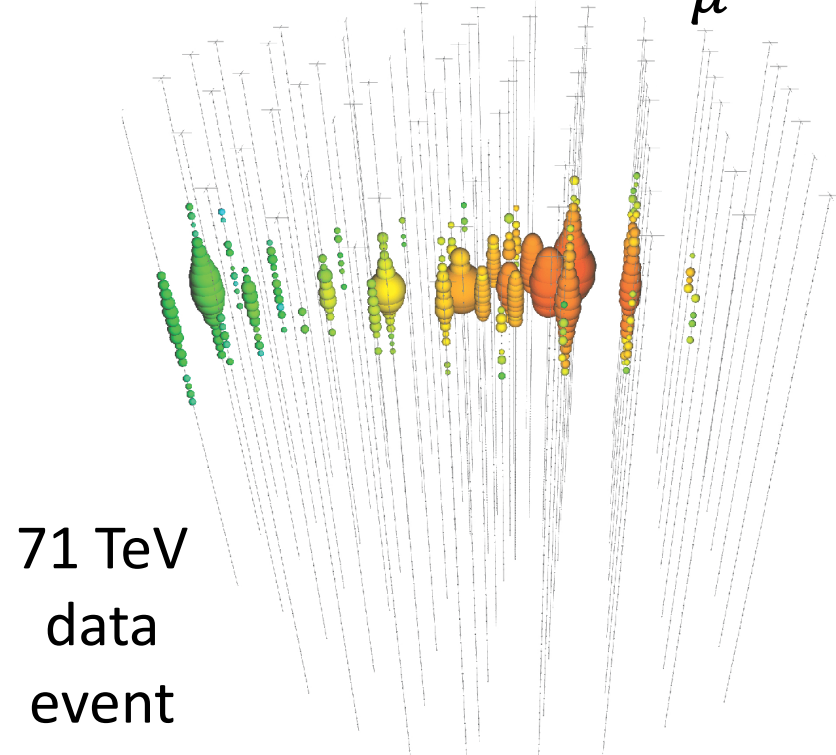
for every DOM in the detector

We want to determine what type of events they are *before* we apply sophisticated reconstructions

Apply filters that broadly classify events to find events one might be interested in (i.e. MuonFilter, CascadeFilter, ...)

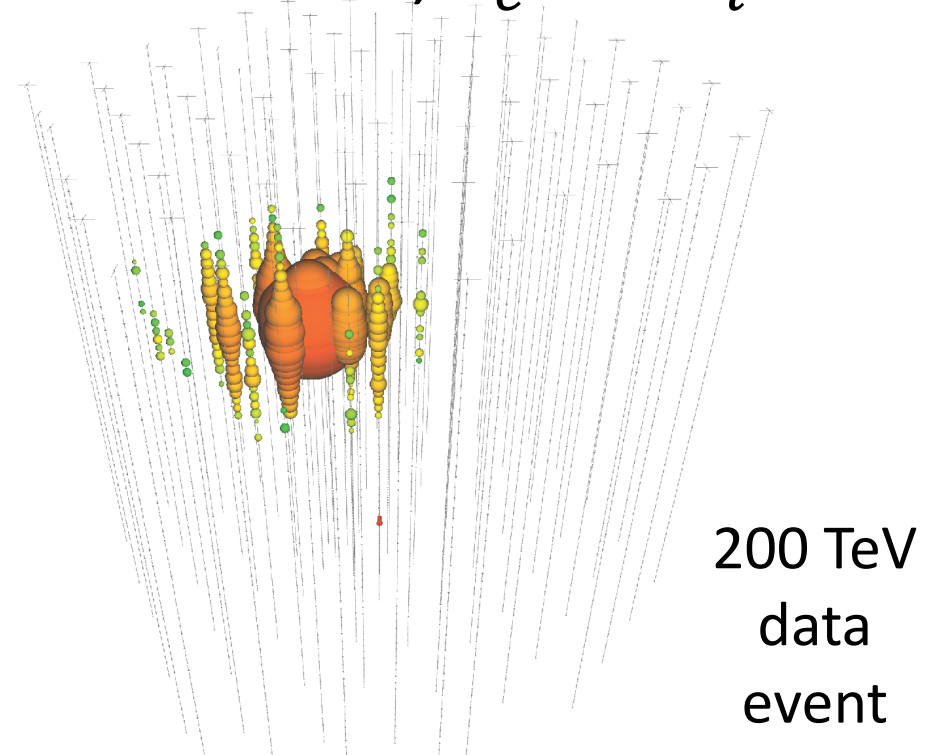
Two main morphologies

Muon Tracks: ν_{μ}^{CC}

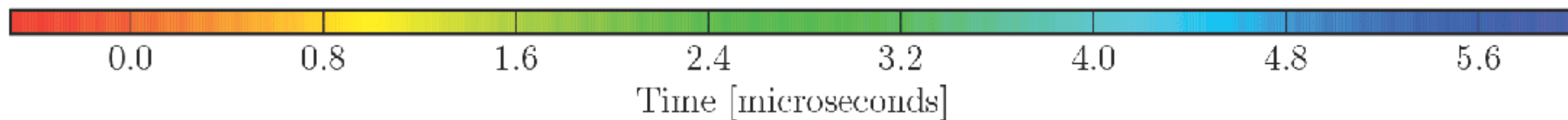


Good directional resolution ($<1^{\circ}$)

Cascades: ν^{NC} , ν_e^{CC} & ν_{τ}^{CC}



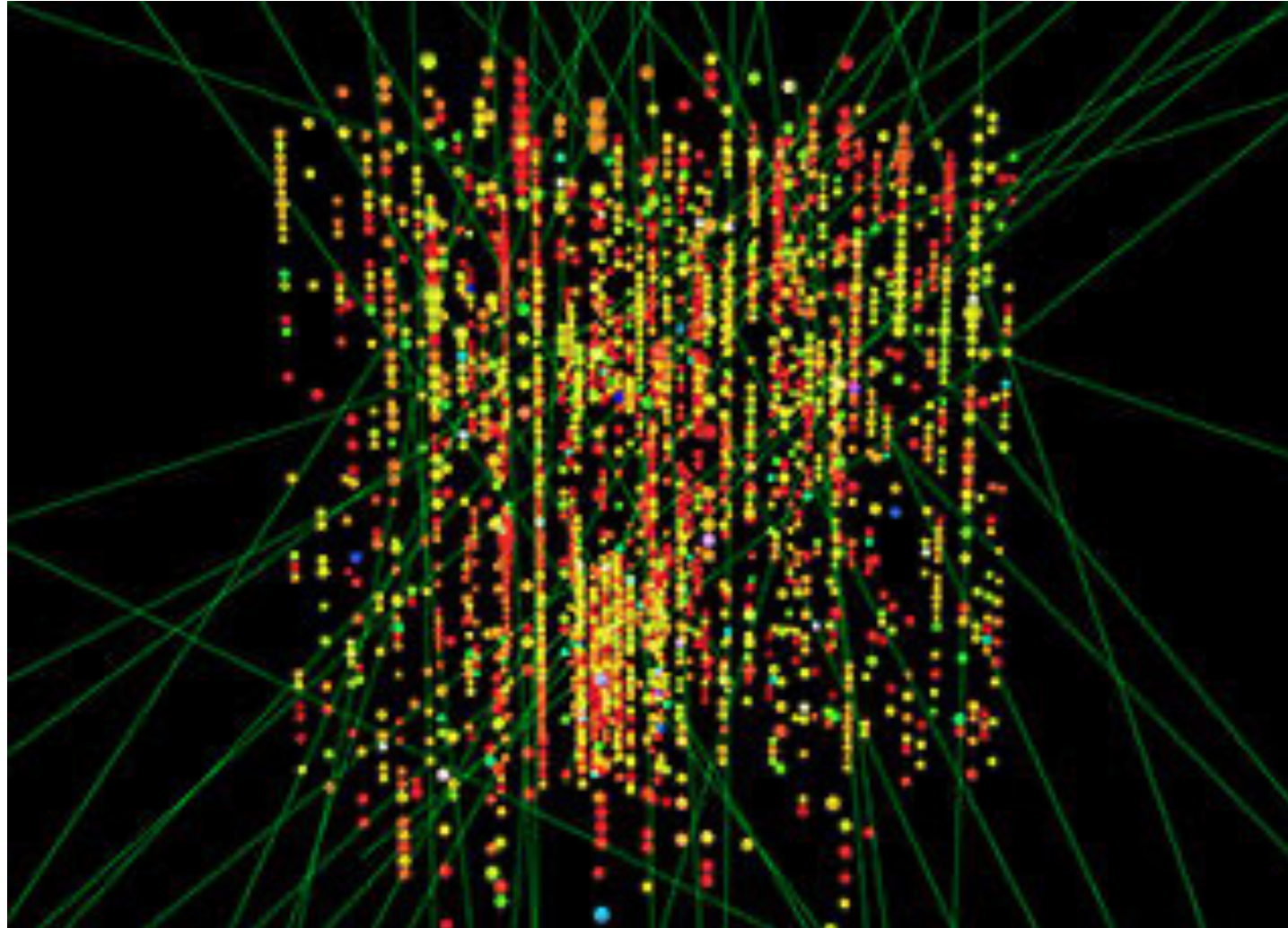
Good energy resolution



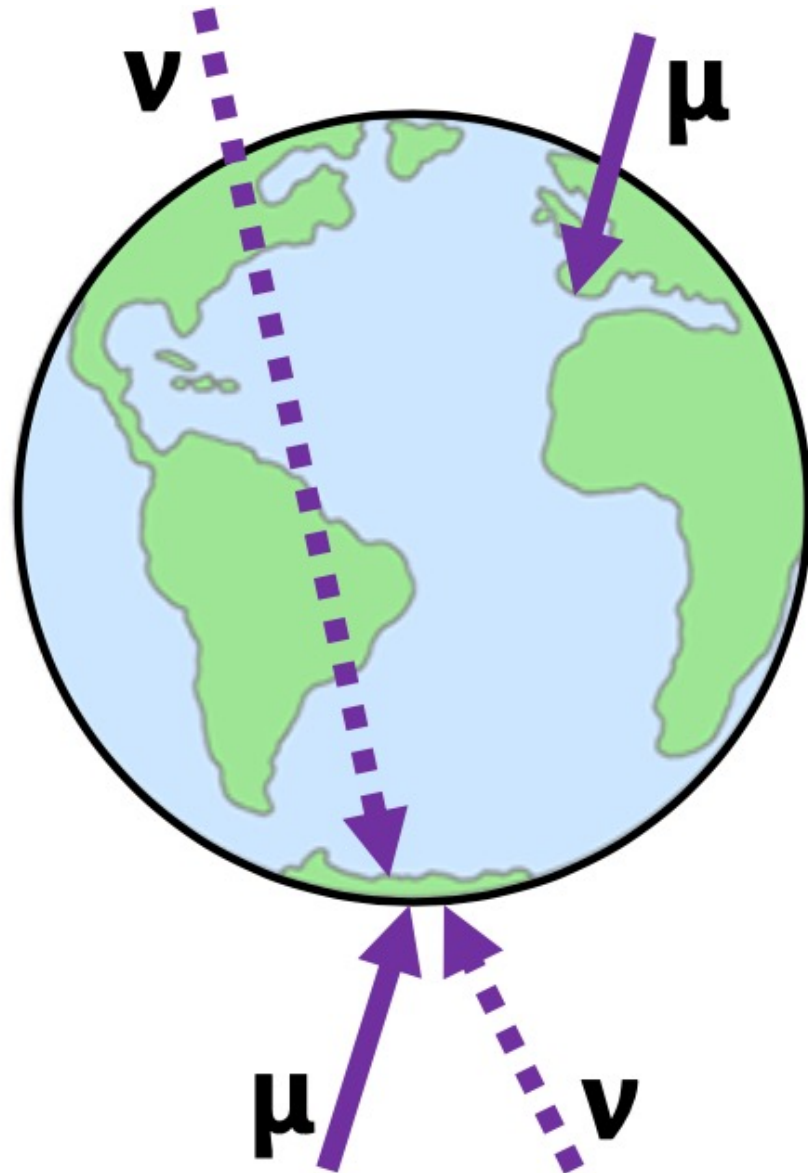
Billions of muons a year

→ Need strategies to pick out neutrino events

Events in a few microseconds in IceCube



Look down!

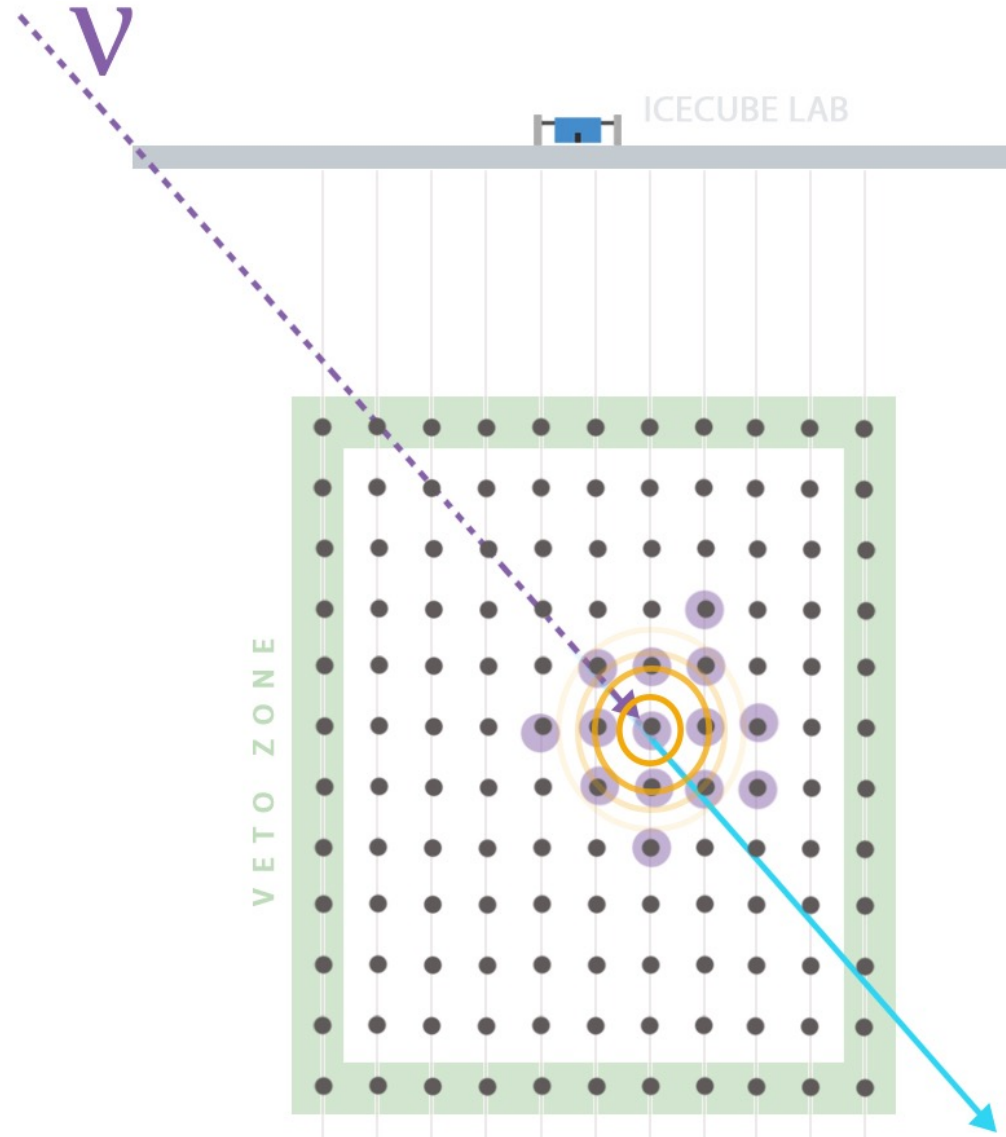
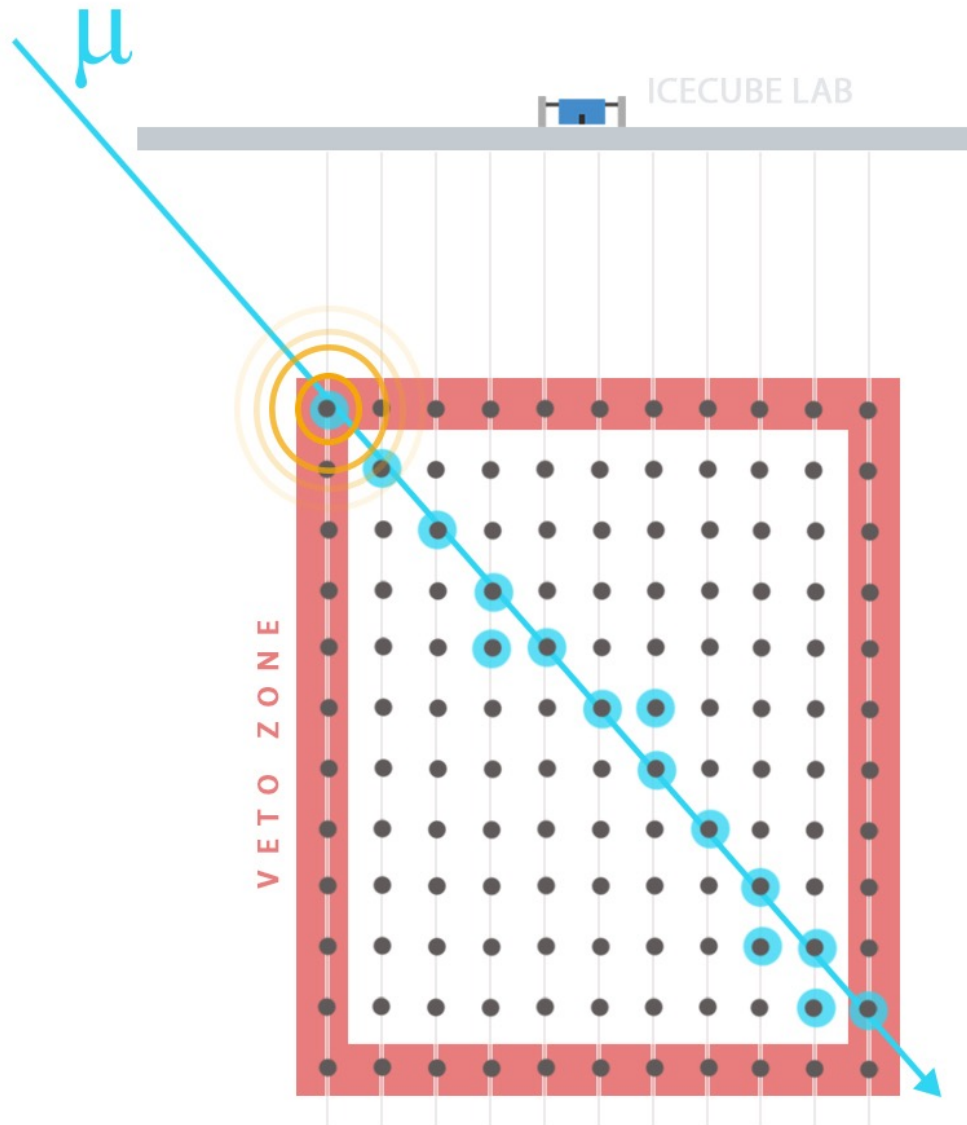


- Muons can travel kilometers through the Earth
- Atmospheric muons from the Northern sky are blocked by the Earth

Looking at the Northern sky (and cutting out the Southern sky) allows one to eliminate virtually all atmospheric muons from the sample

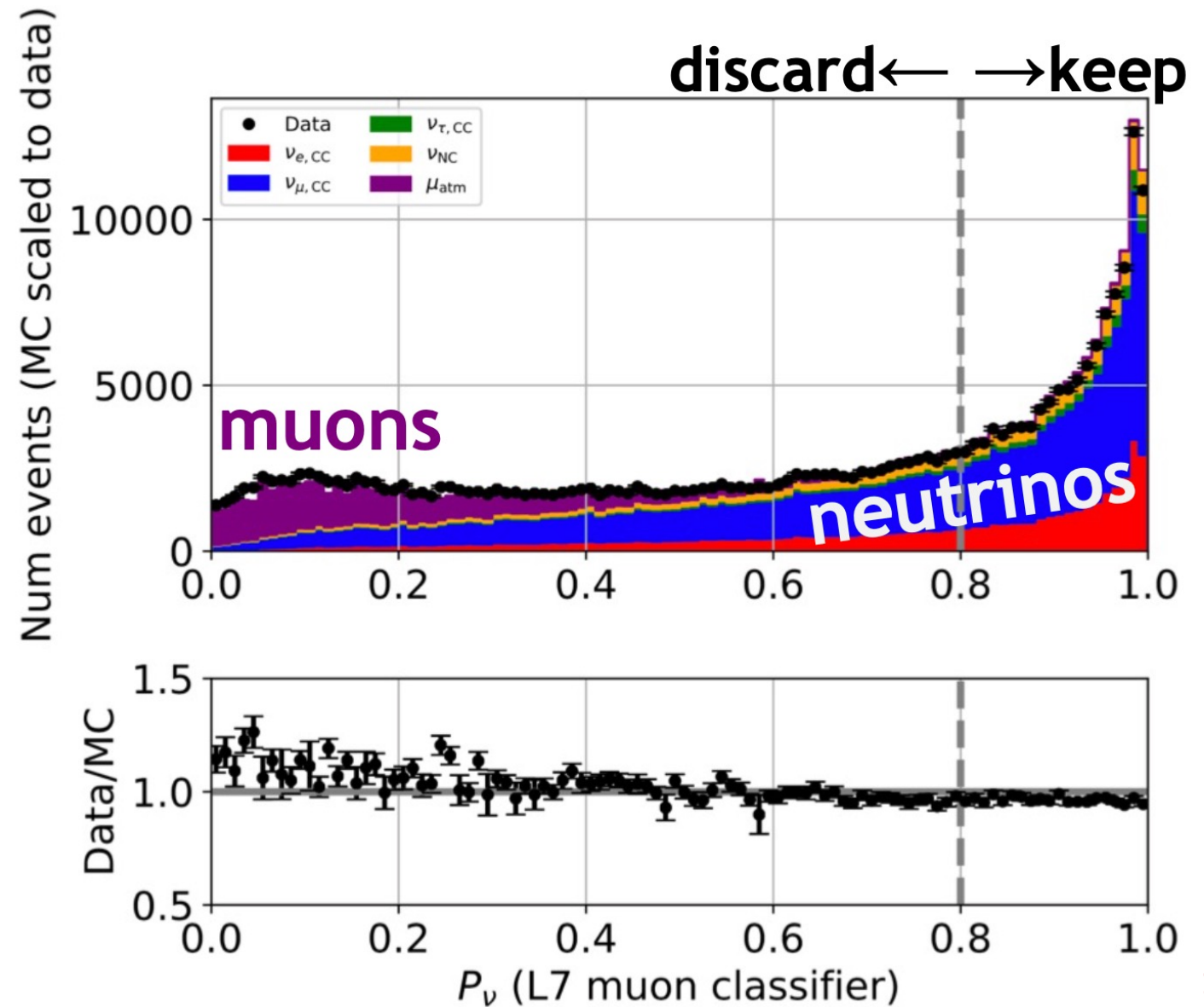


Veto atmospheric muons



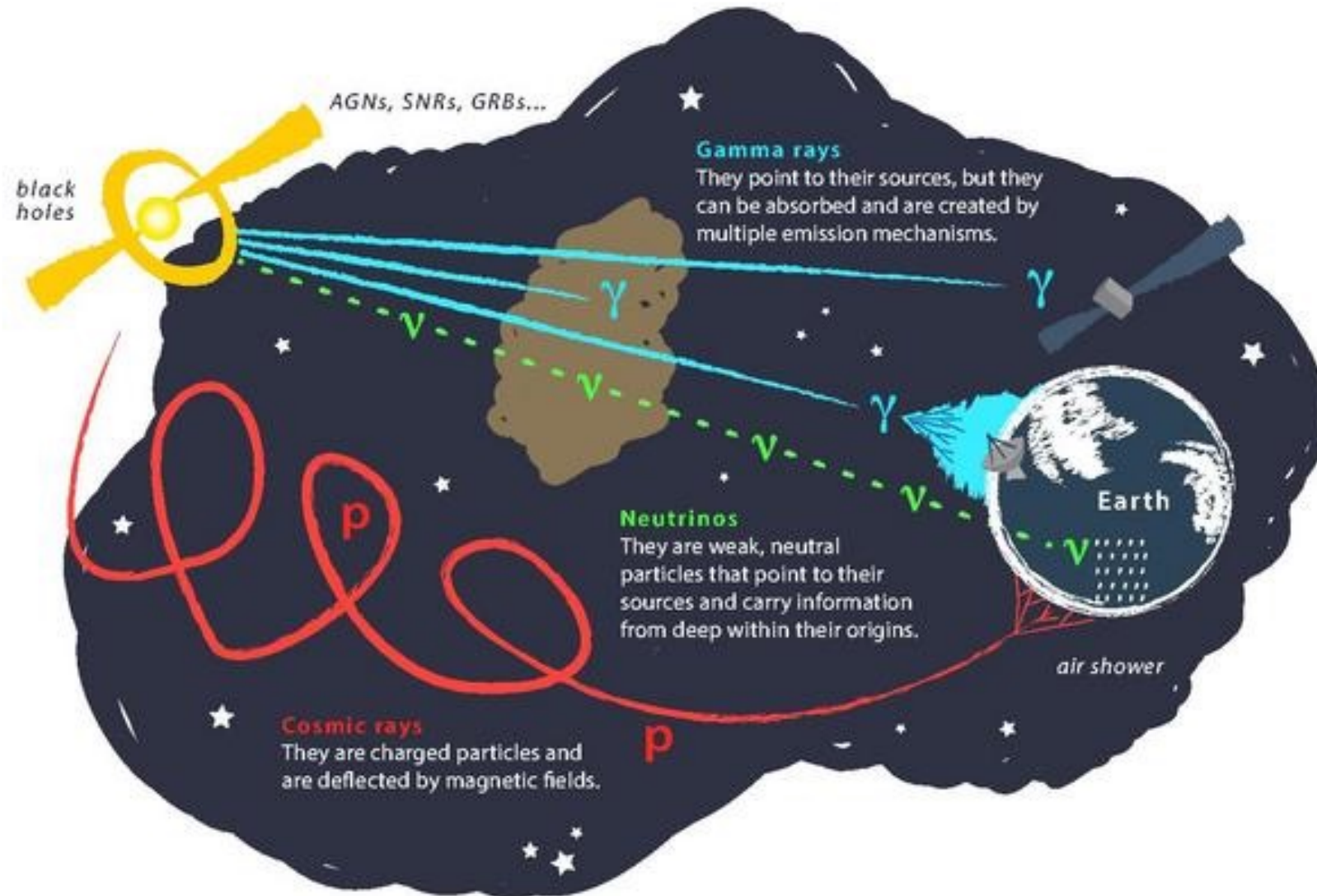
Machine Learning Classification

- BDTs and Neural Networks can be trained to differentiate between different event types
- Example of BDT from OscNext (Used for low-energy DeepCore events):
Returns output from 0 to 1 indicating how muon-like or neutrino-like an event is

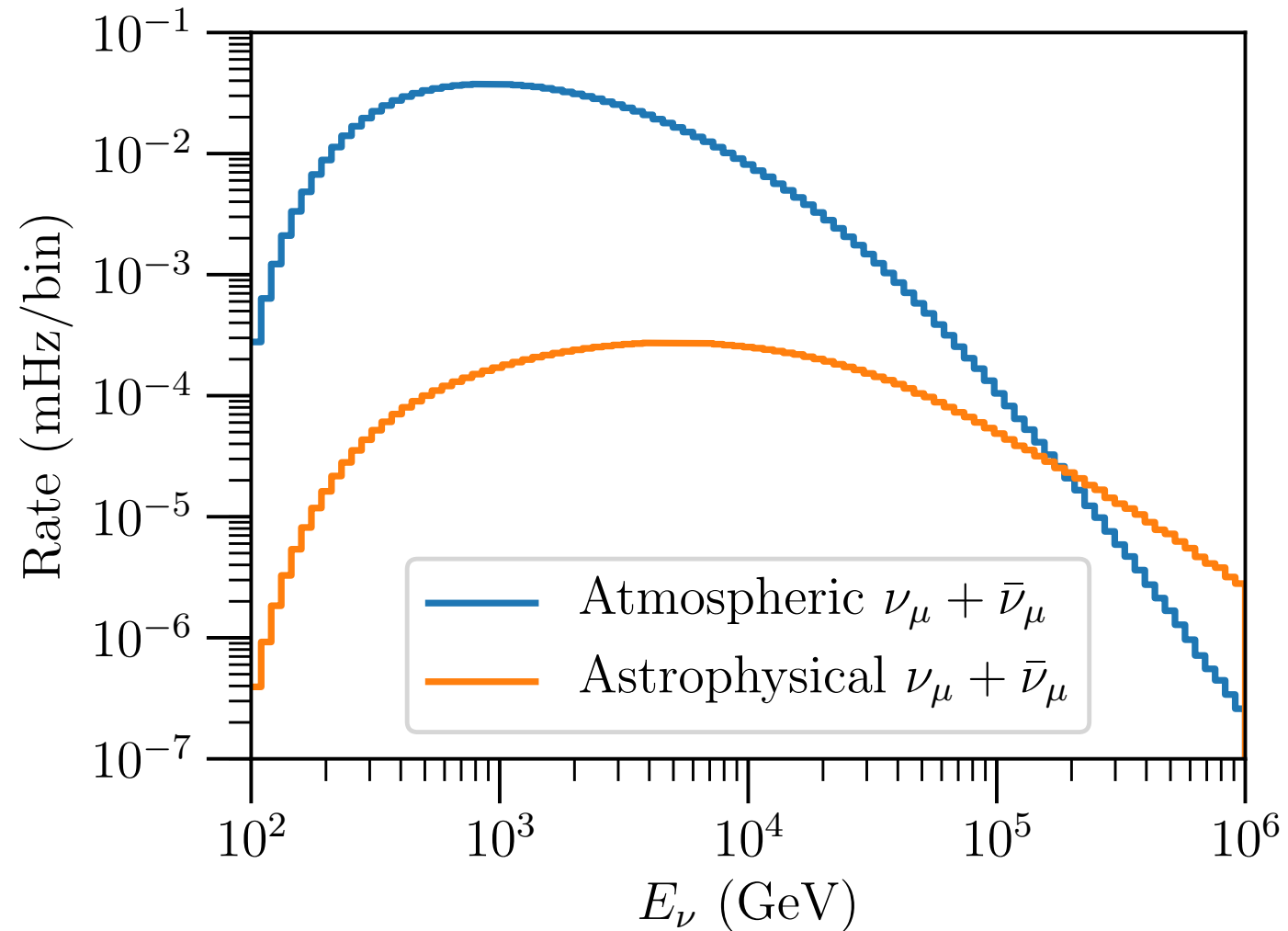


10000 atm. neutrinos to 1 astro. neutrino

→ Need strategies to measure astro. neutrinos



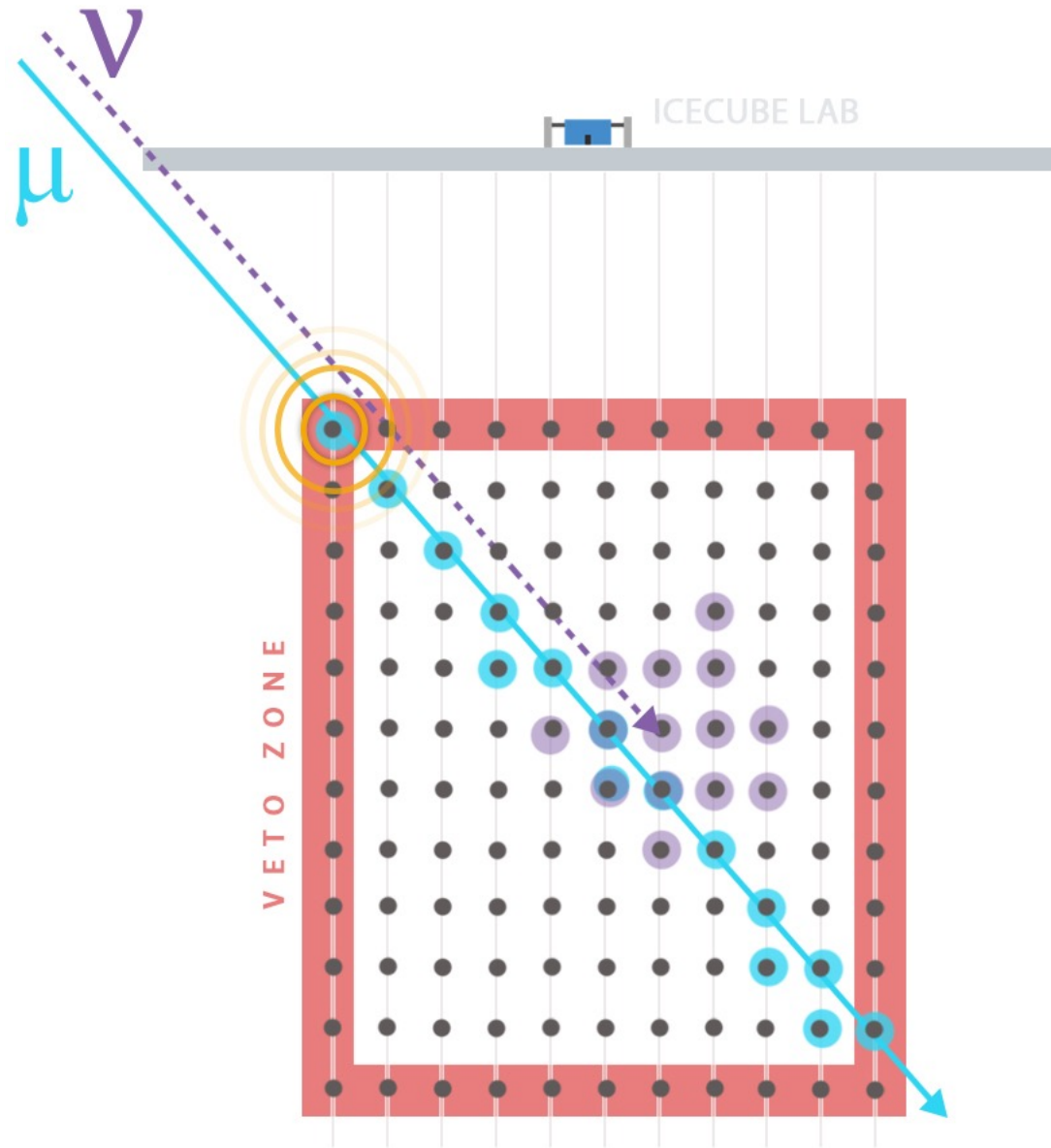
One strategy: focus at high energies



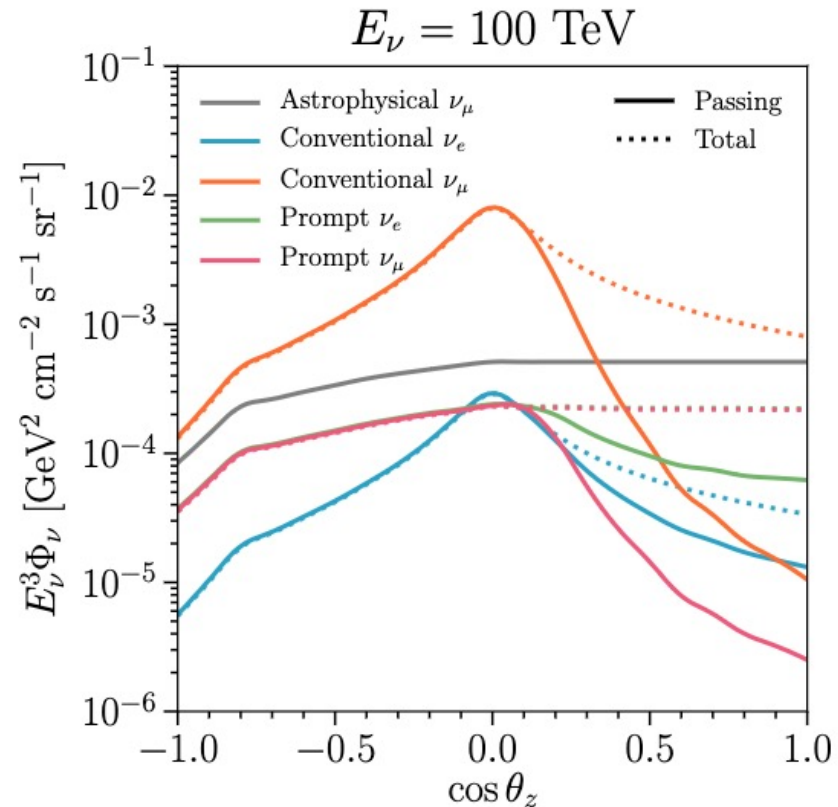
Atmospheric neutrinos
dominate up to a few
hundred TeV



Atmospheric neutrino self-veto



Higher % of astrophysical neutrinos in Southern sky due to self-veto



Event selection characteristics

- Effective area
- Field of view
- Energy range
- Energy resolution
- Angular resolution
- Flavor
- Background rate
- Livetime
- Real-time application

Physics motivation drives the event selection development

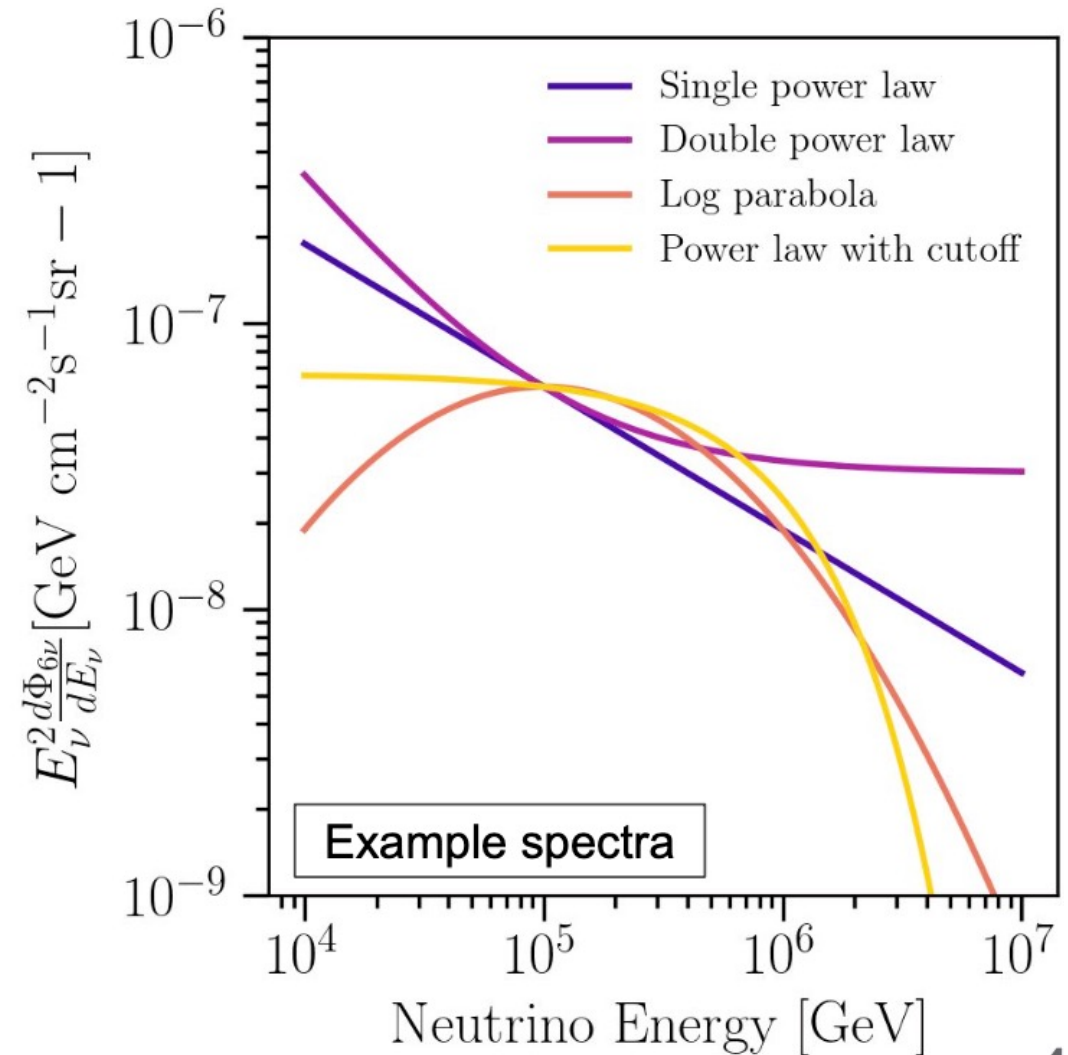


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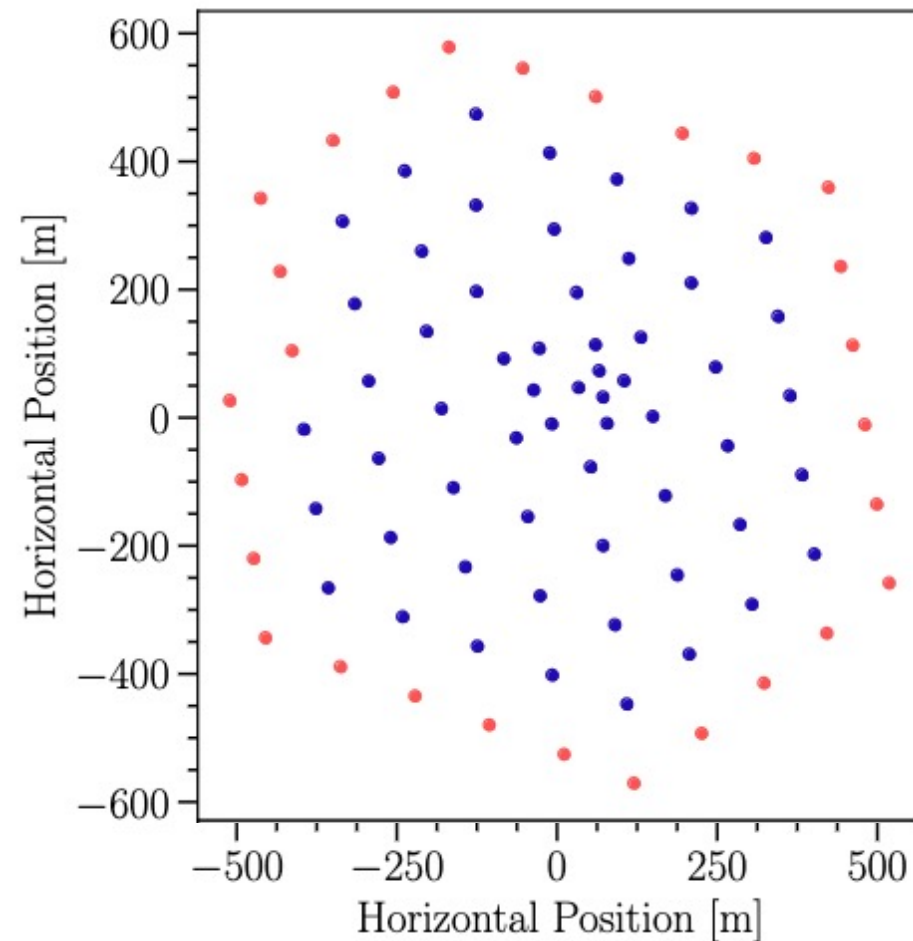
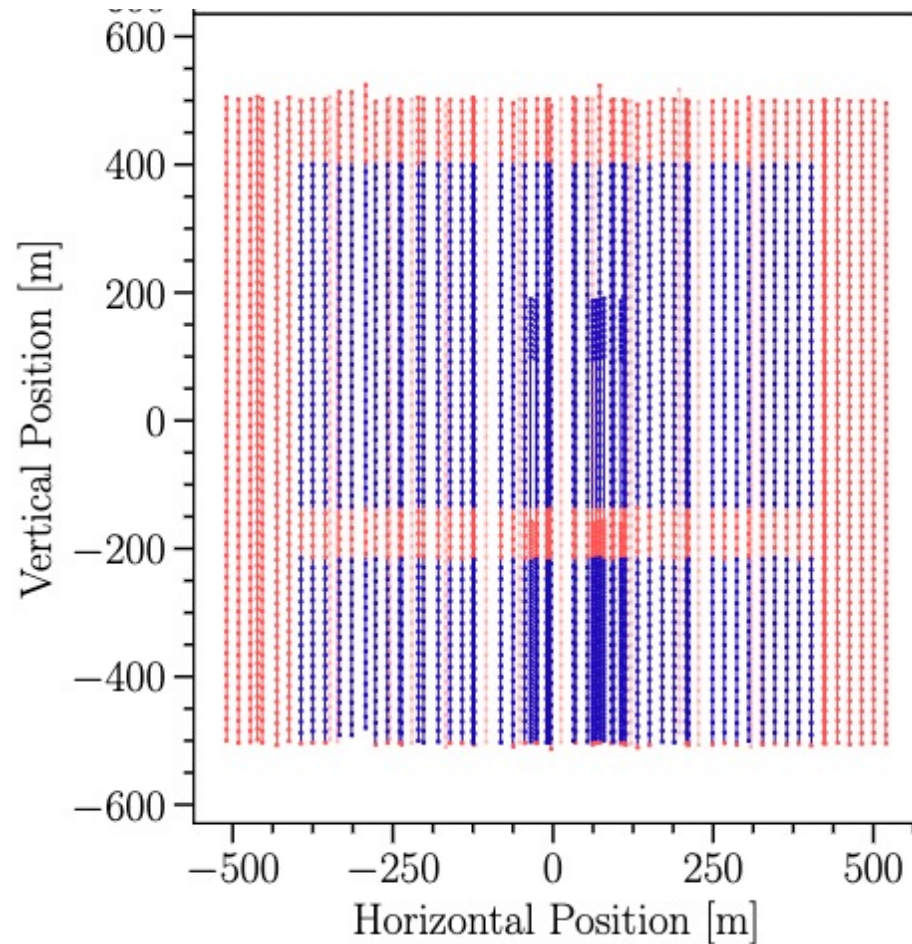
Physics aim: Characterize the astrophysical neutrino flux

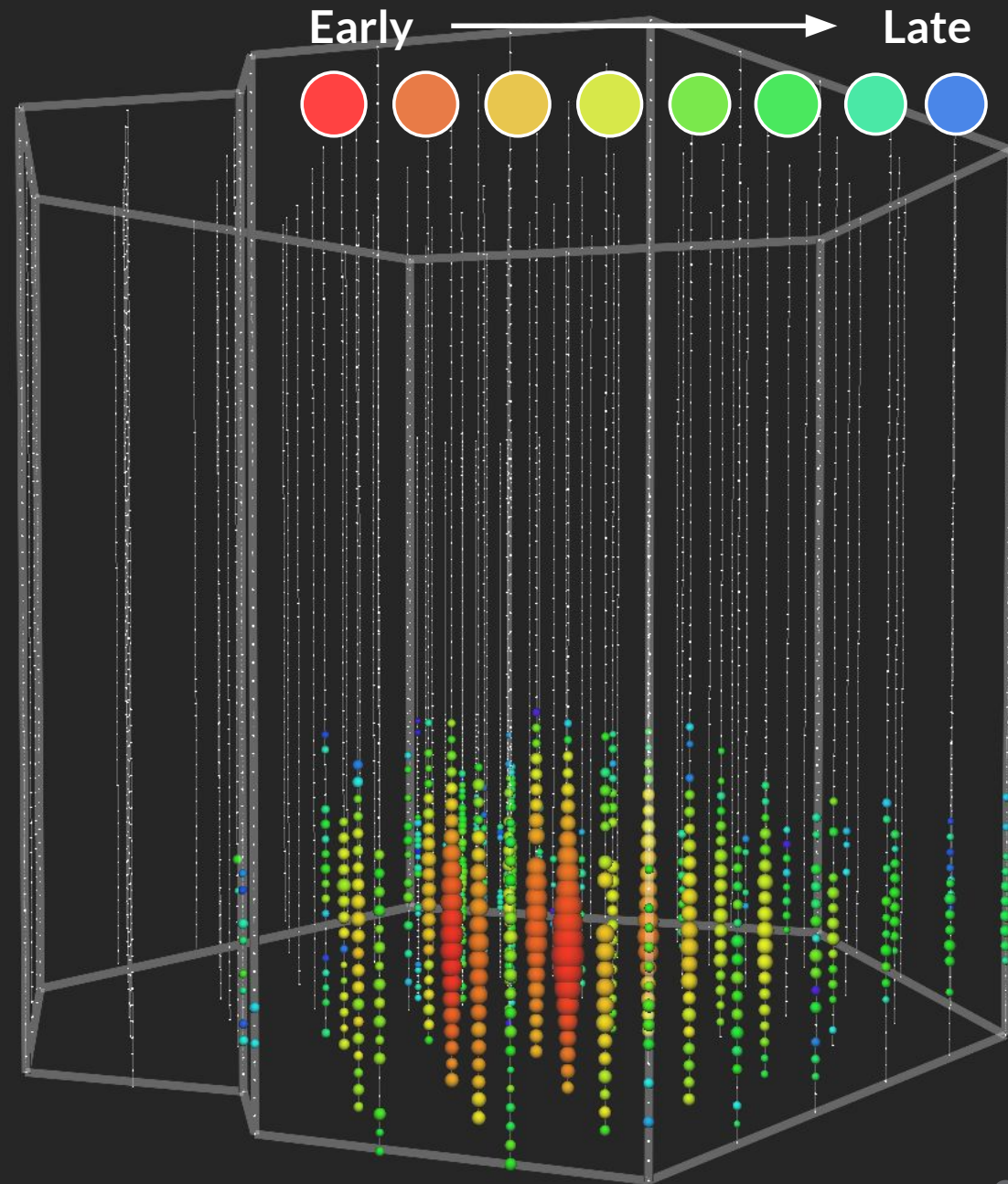
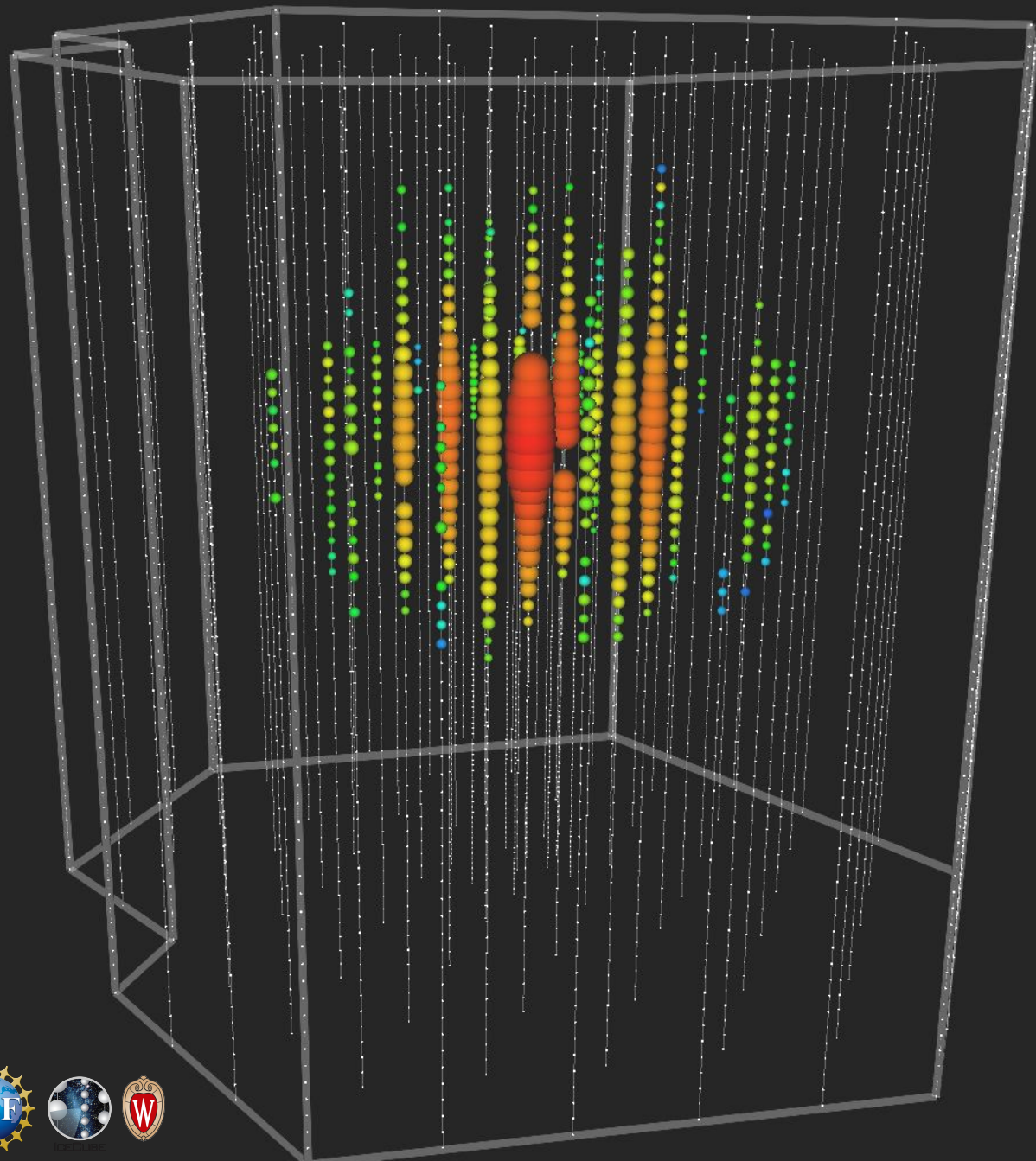
- One strategy:
 - Use events that start in the detector
- Starting events have better energy resolution
 - Cascades
 - Starting tracks



High Energy Starting Events (HESE)

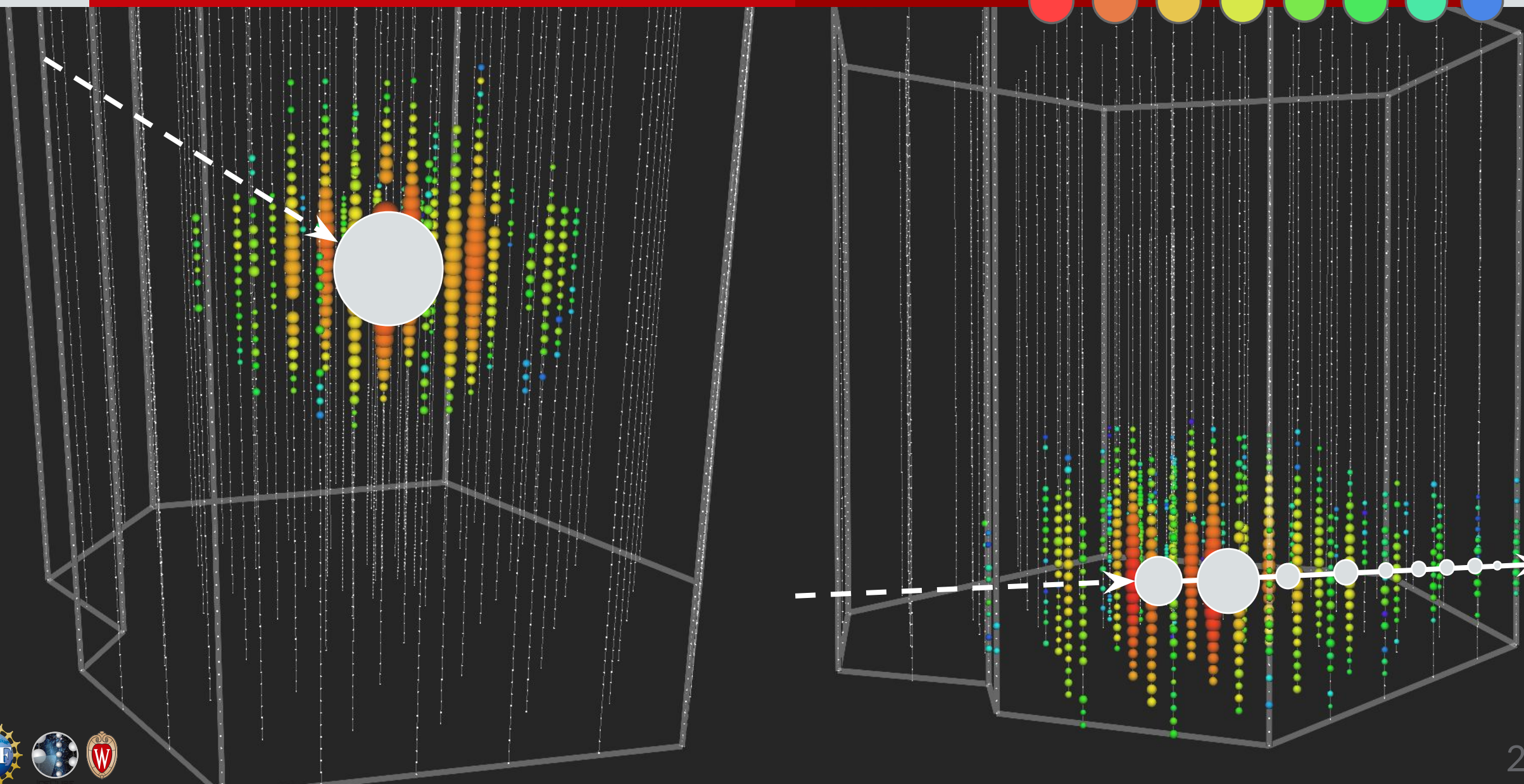
- Use the outer layer of the detector to veto events
- Require total charge ≥ 6000 photoelectrons





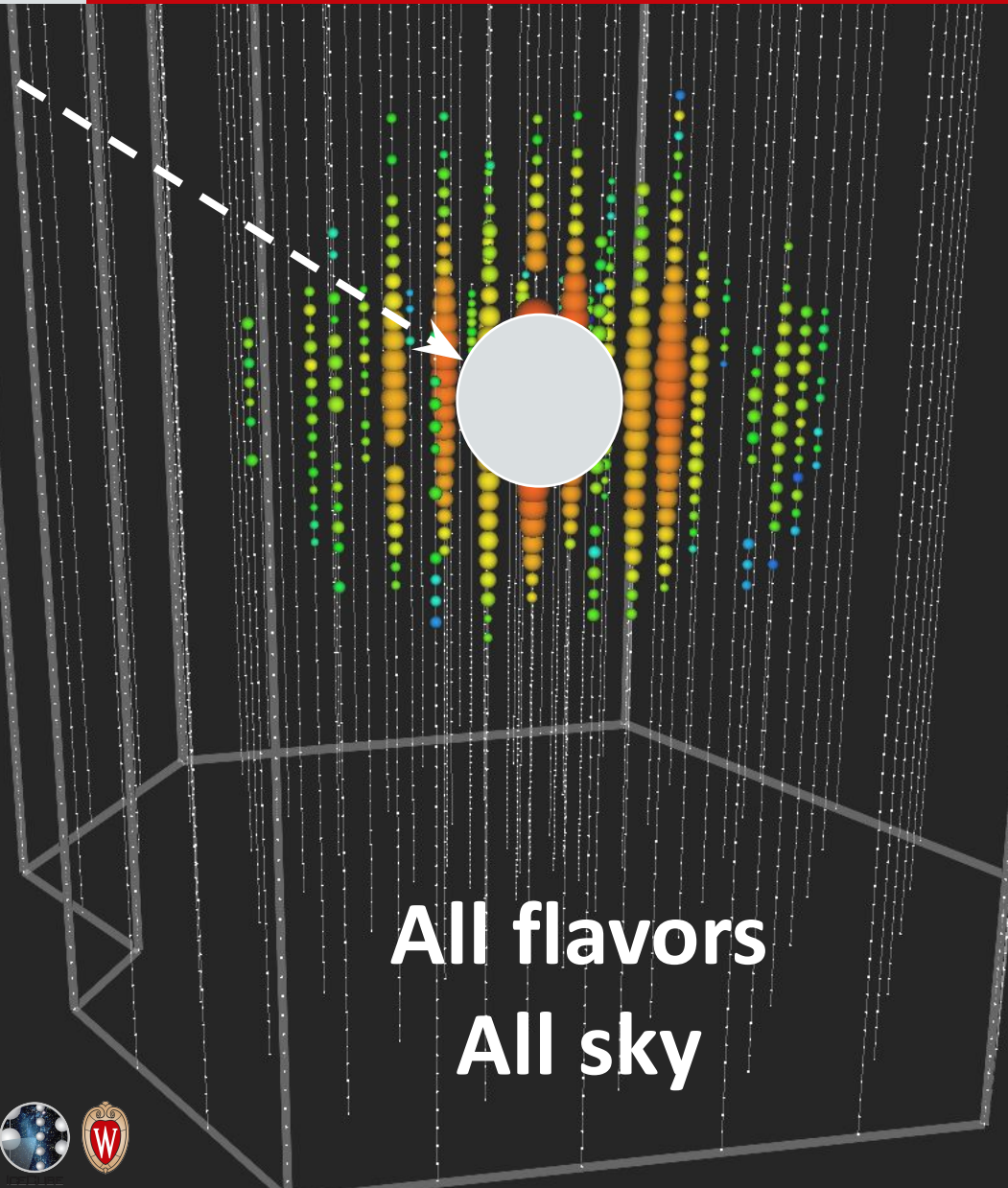
Reconstruction

Early → Late

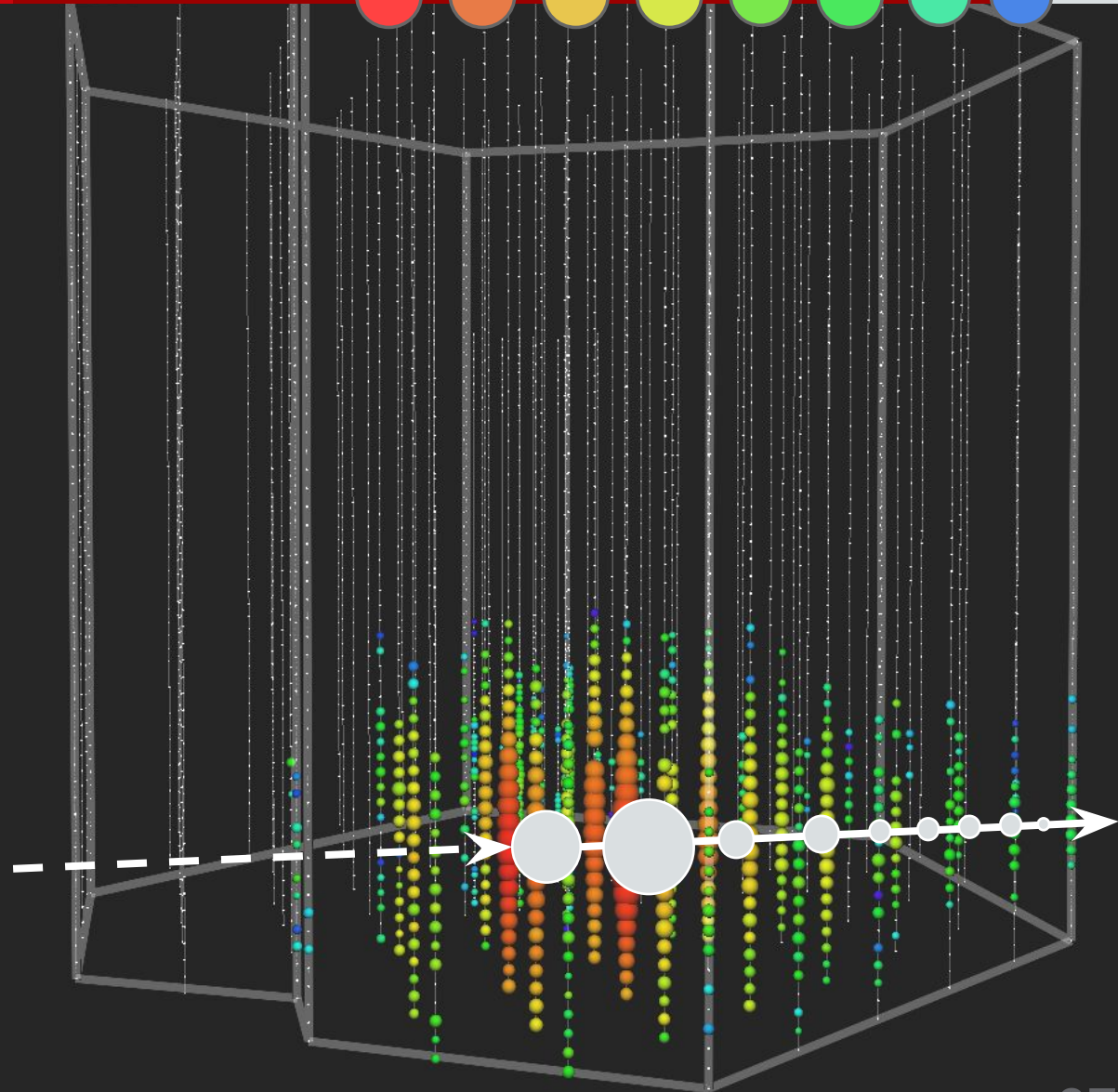


Reconstruction

Early → Late

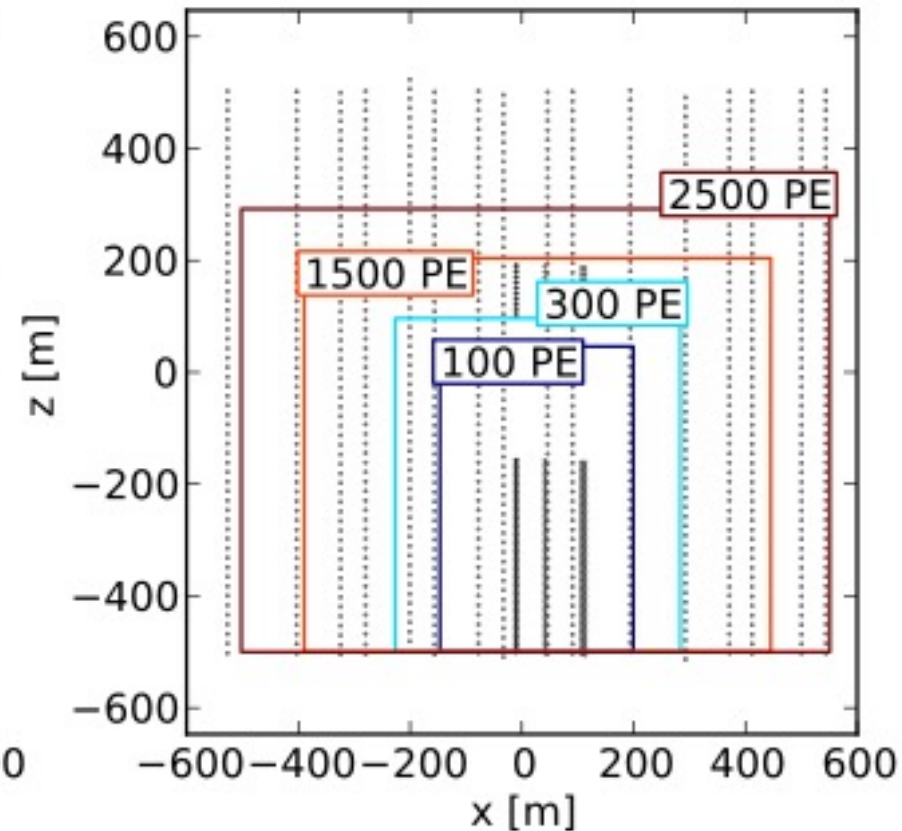
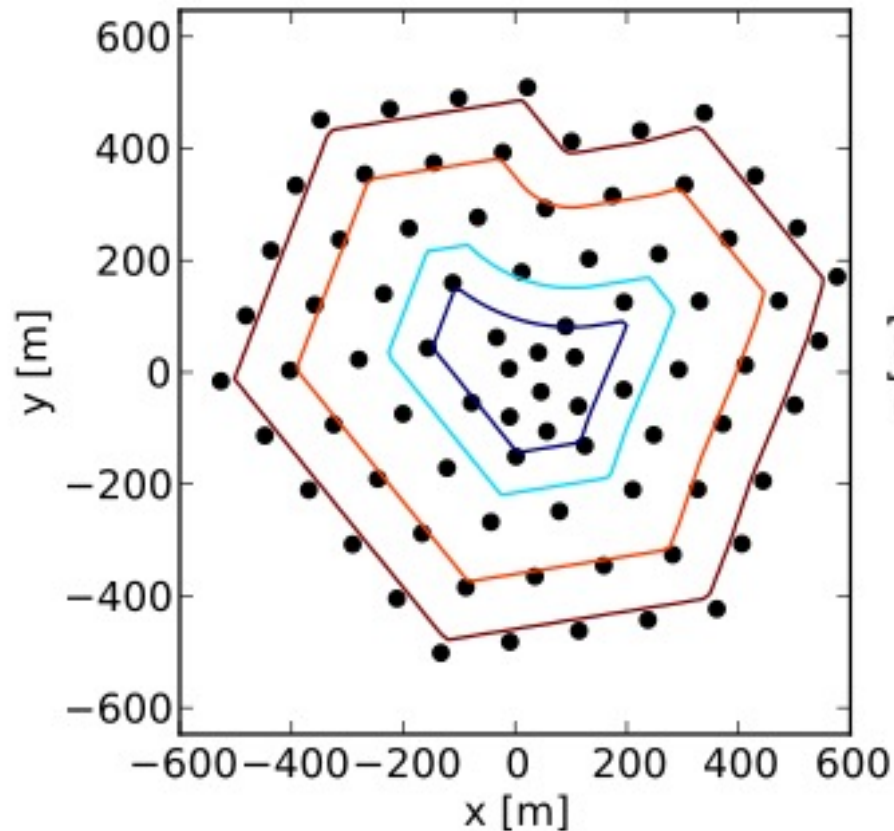


All flavors
All sky



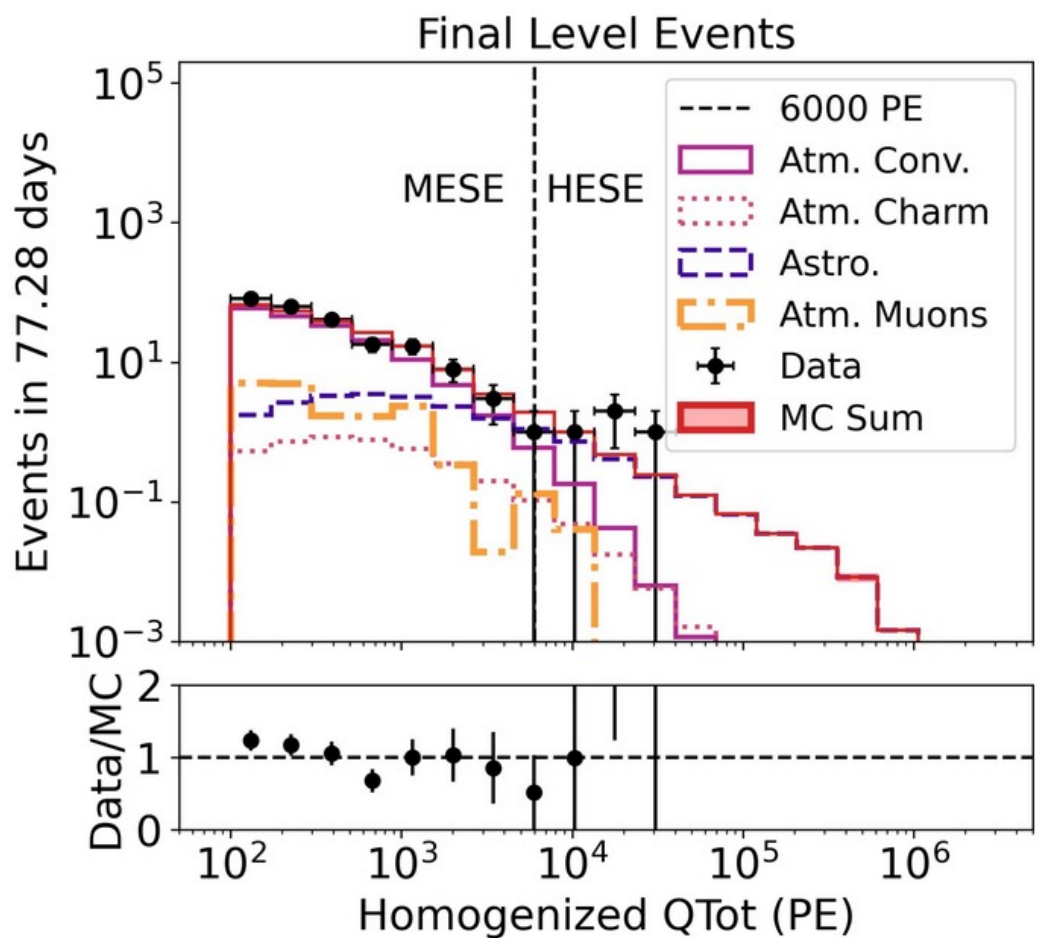
Medium Energy Starting Events (MESE)

- Use a dynamic veto that changes with energy
- Extends the HESE measurement down in energy

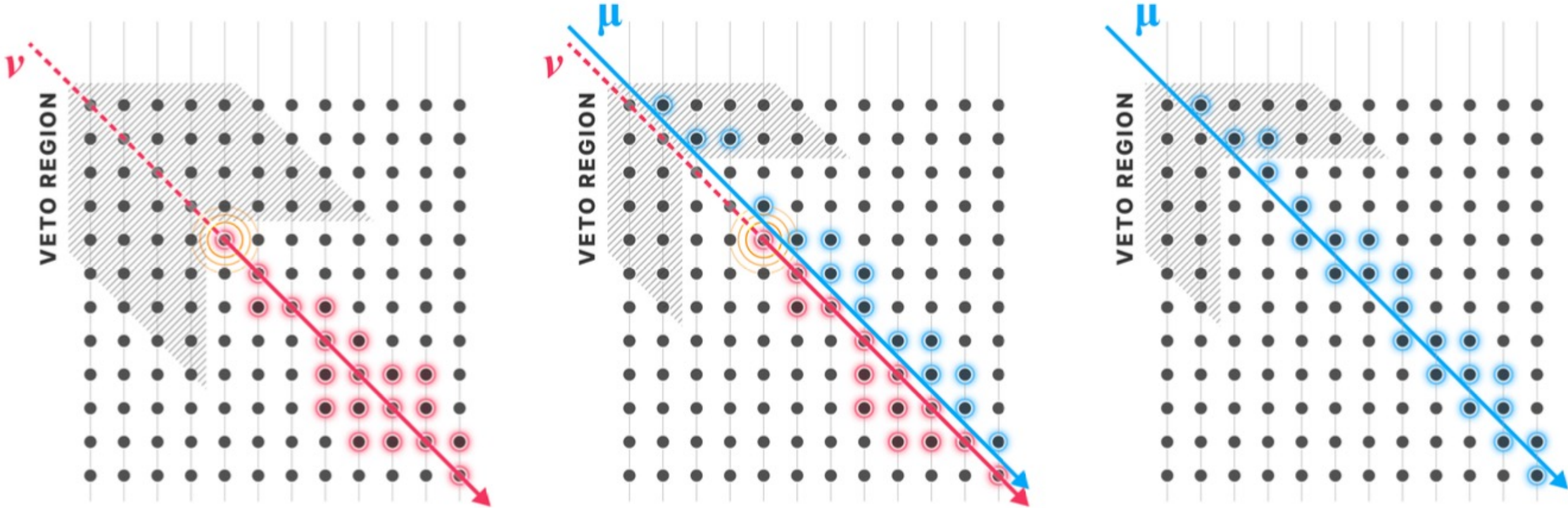


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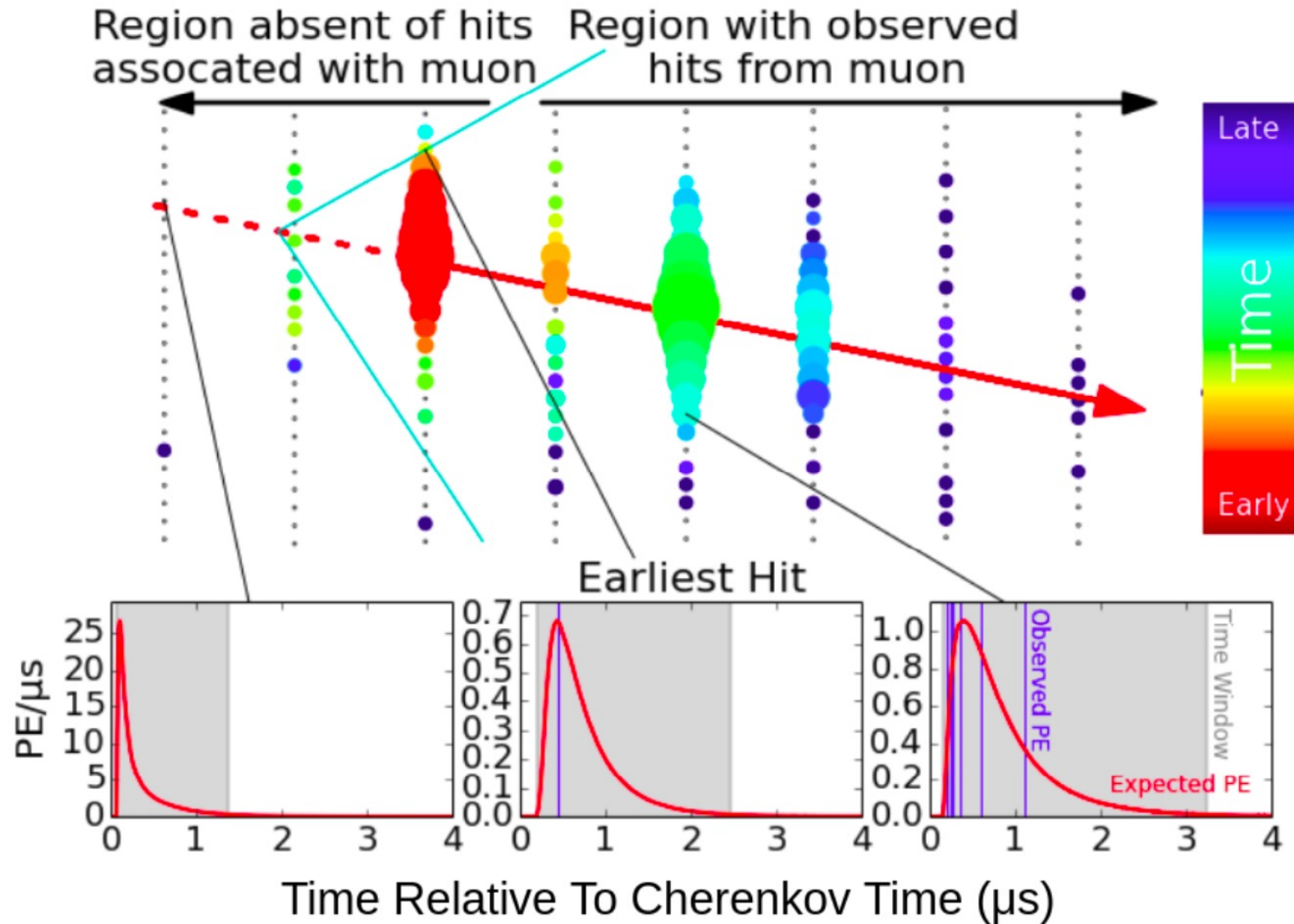
- Use a dynamic veto that changes with energy
- Extends the HESE measurement down in energy



Enhanced Starting Track Event Selection (ESTES)

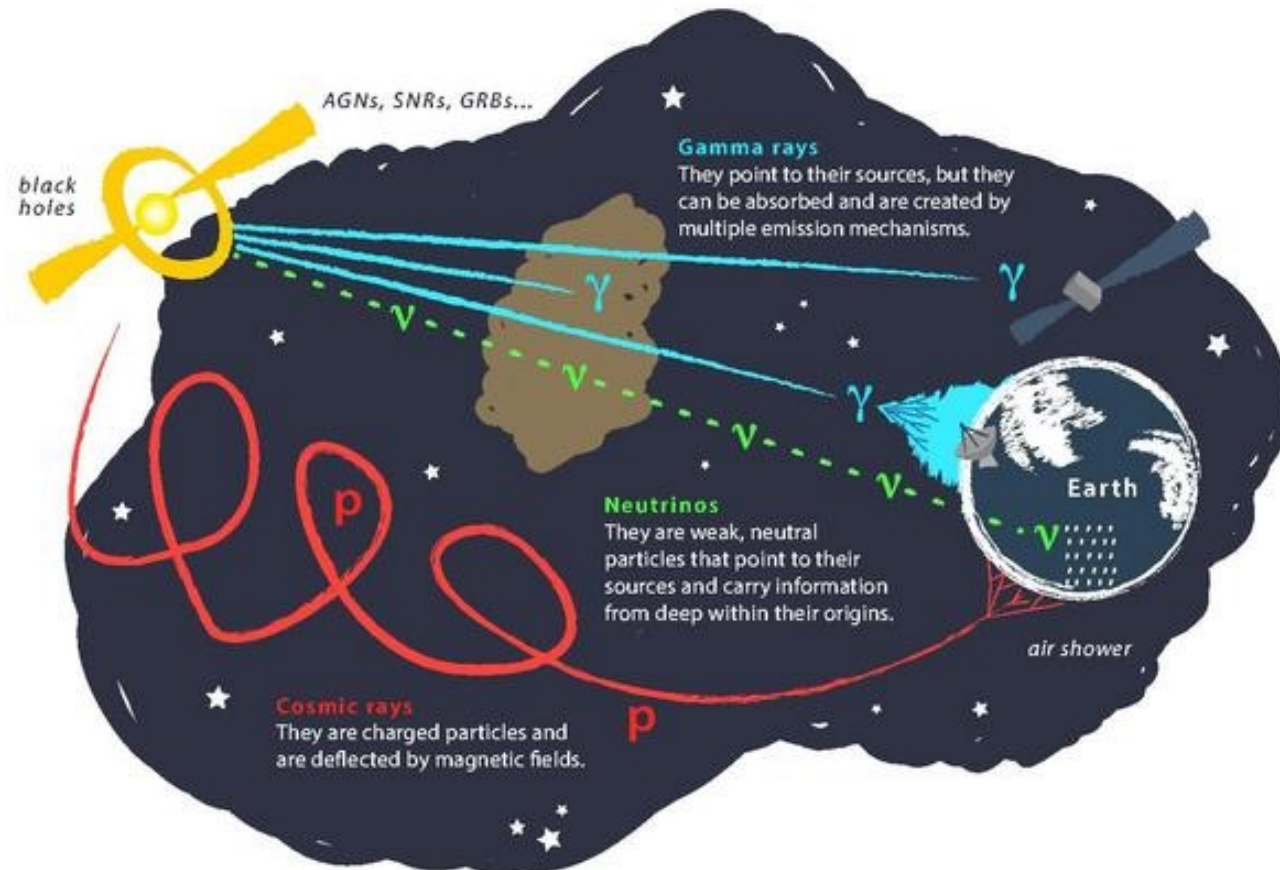


Enhanced Starting Track Event Selection (ESTES)

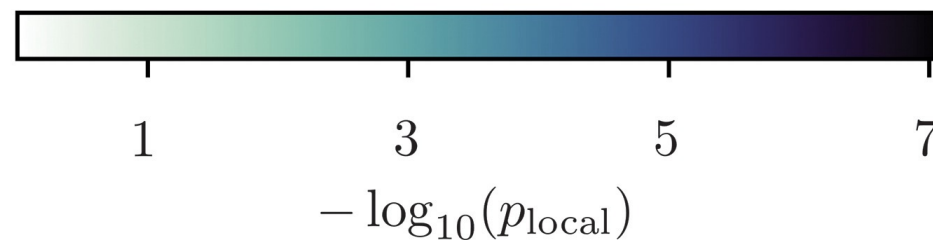
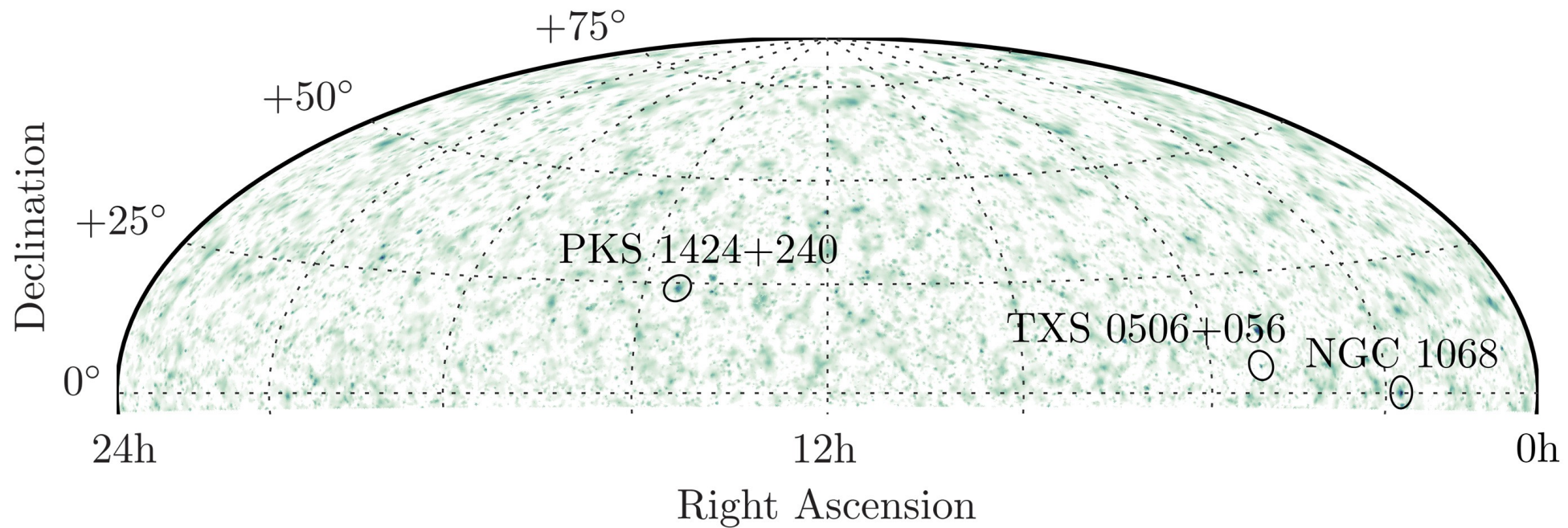


Physics Goal: Identify where astrophysical neutrinos come from

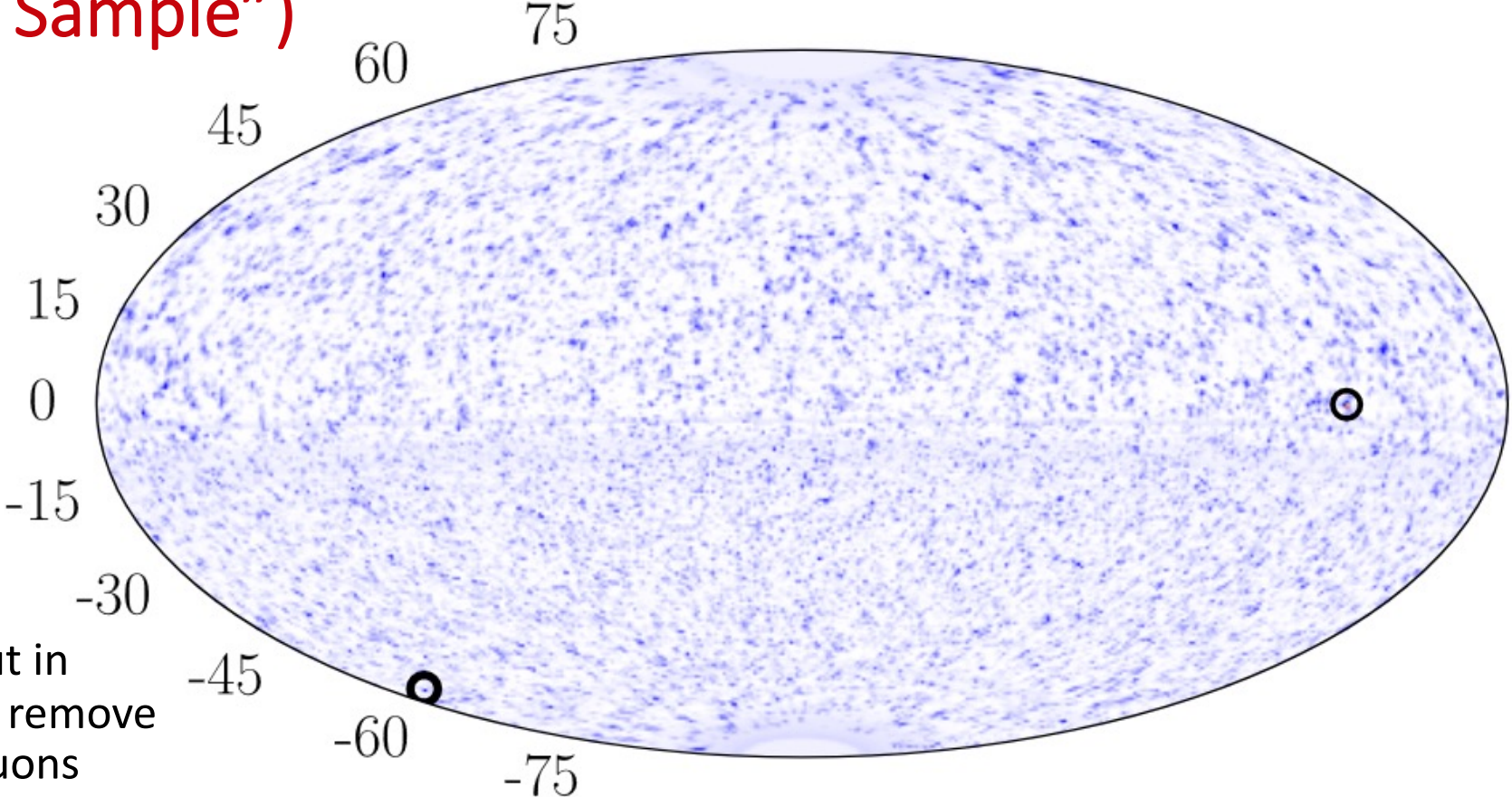
- One strategy: Use track events (ν_μ), which have good pointing resolution



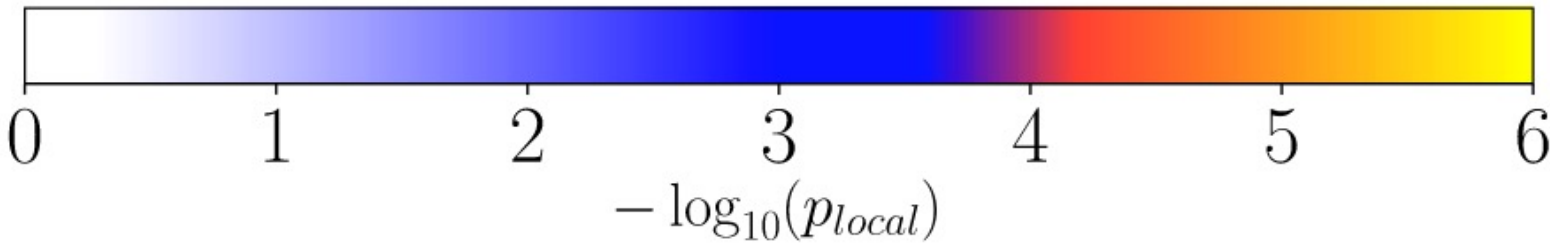
“Northern Tracks” (aka “Diffuse Numu”)



“Point Source (PS) Tracks” (aka “Tessa’s Sample”)



- All sky
- Harsh energy cut in Southern sky to remove atmospheric muons

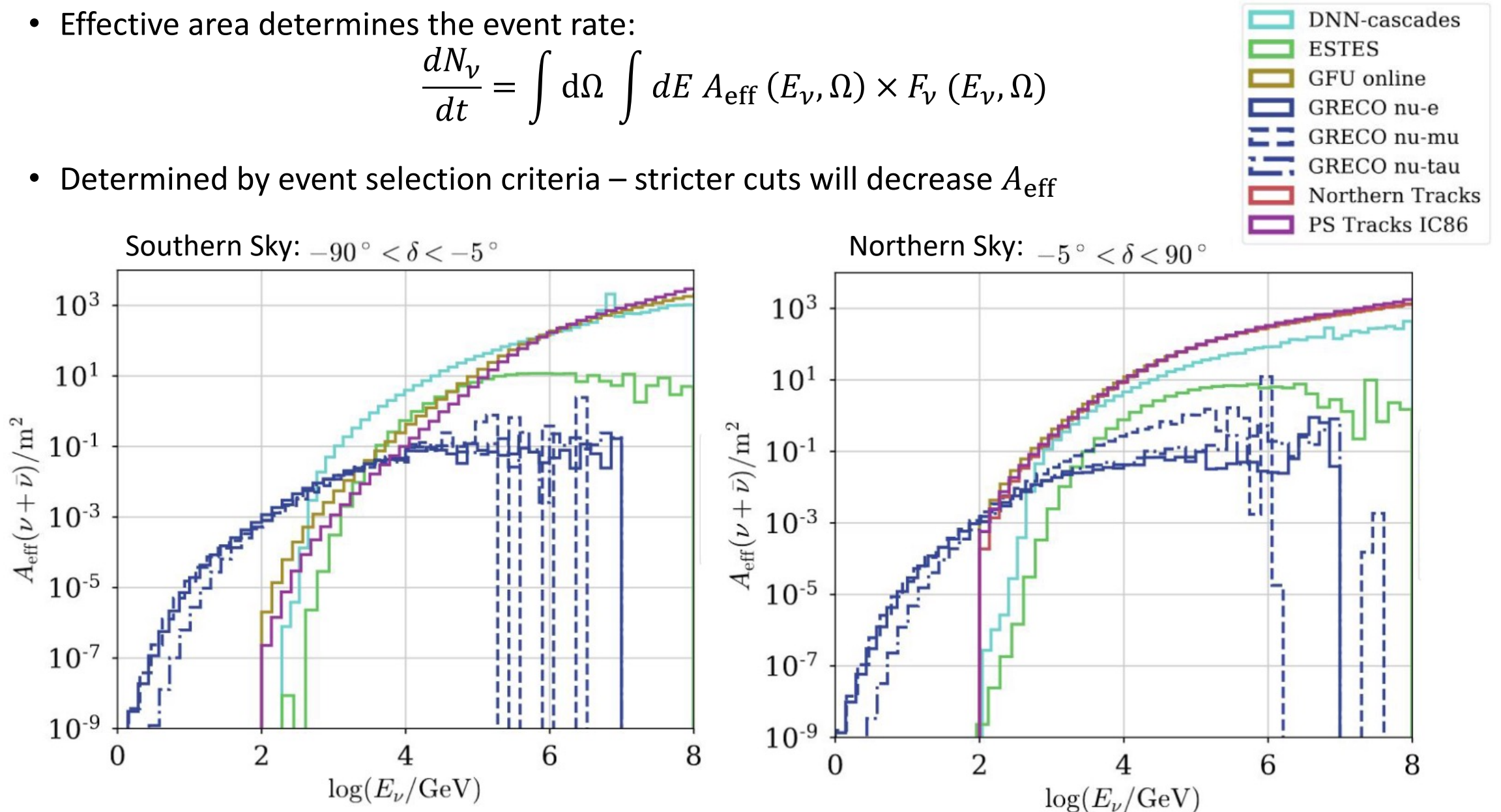


Effective area (A_{eff})

- Effective area determines the event rate:

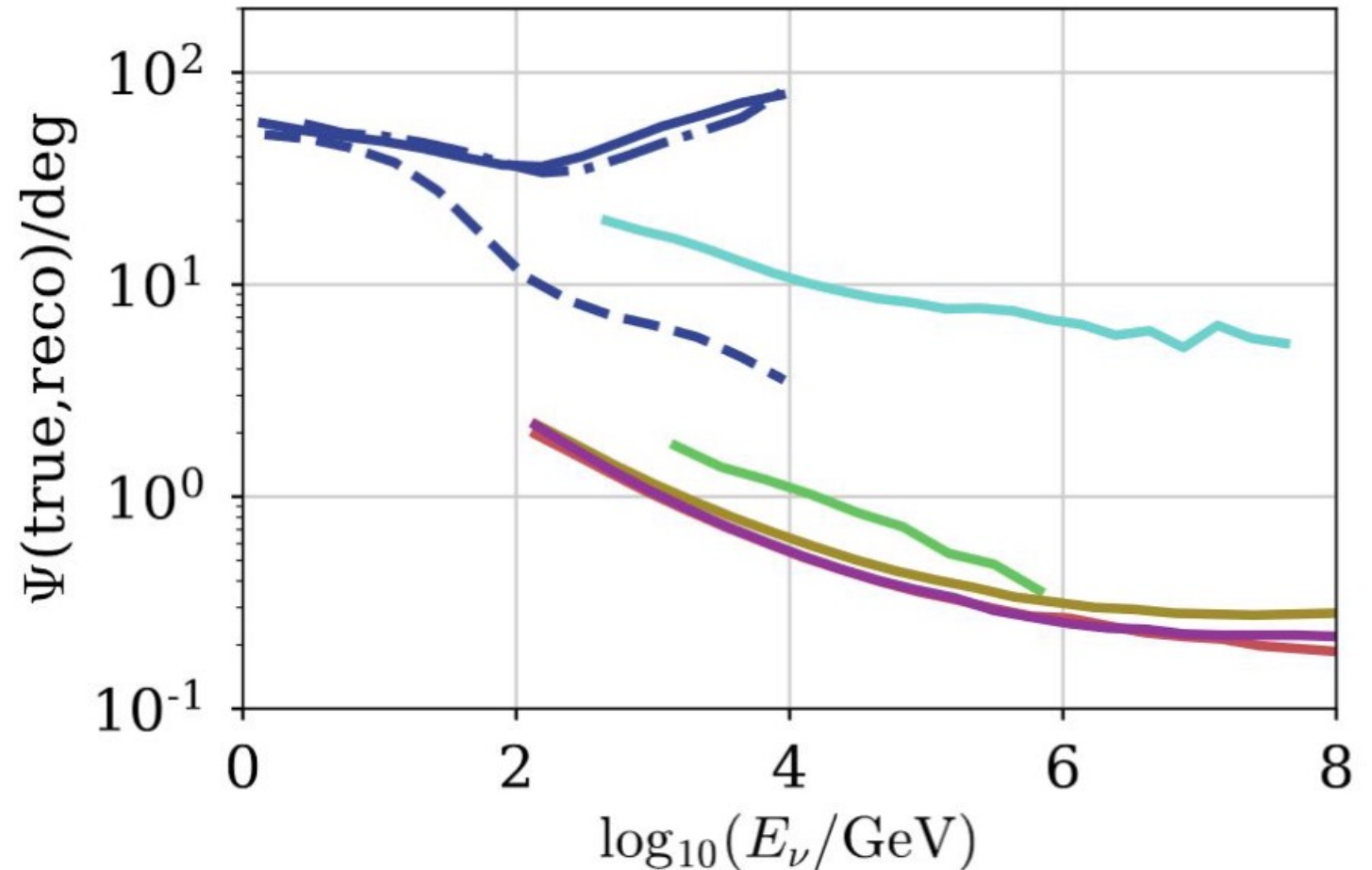
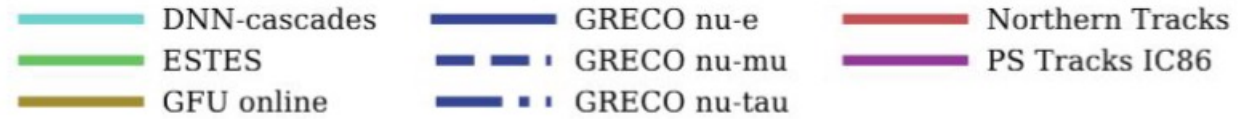
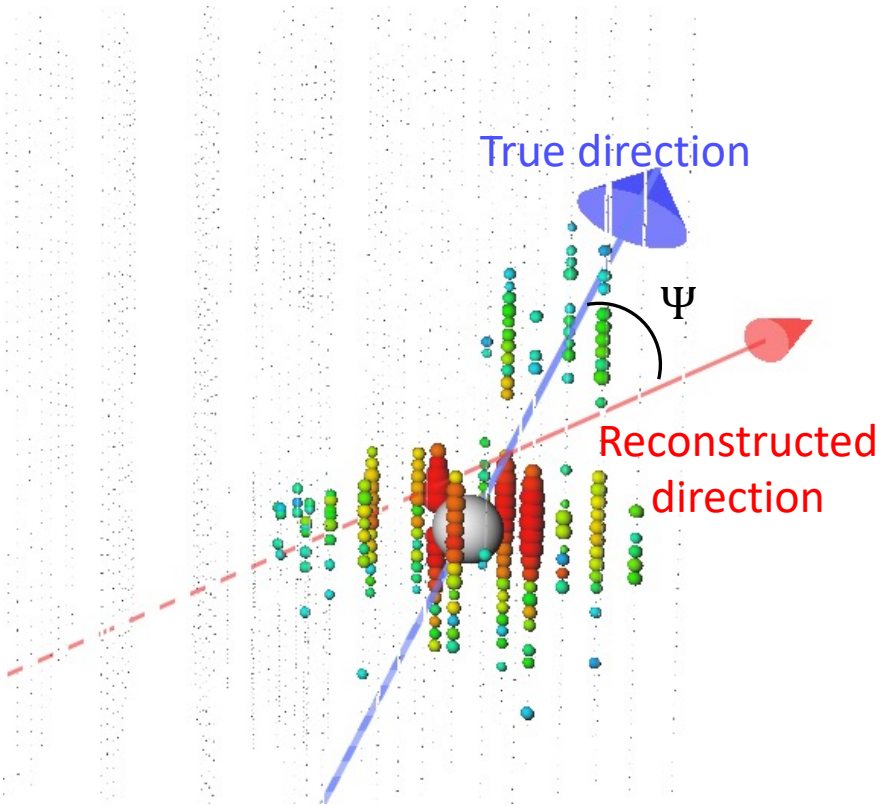
$$\frac{dN_\nu}{dt} = \int d\Omega \int dE A_{\text{eff}}(E_\nu, \Omega) \times F_\nu(E_\nu, \Omega)$$

- Determined by event selection criteria – stricter cuts will decrease A_{eff}



Angular resolution

- Smaller angular resolution \rightarrow better pointing ability



More IceCube event selections...

- Cascades
- DNN Cascades
- OscNext
- Greco
- MEOWS
- PEPE
- EHE

Too many to cover today!



Some last thoughts

- To select for different event types, you need to identify and exploit any differences in:
 - Morphology
 - Population distributions (i.e. energy or zenith angle)
- Most event selections rely on a combination of multiple cut types
- Event selections are often designed with a specific analysis in mind, but end up being used for many analyses

