Event Selections

IceCube
Summer School
2024

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Heavily borrowed from Marjon Moulai, Kayla Leonard DeHolton, Steve Sclafani

Event Selections

What are they?

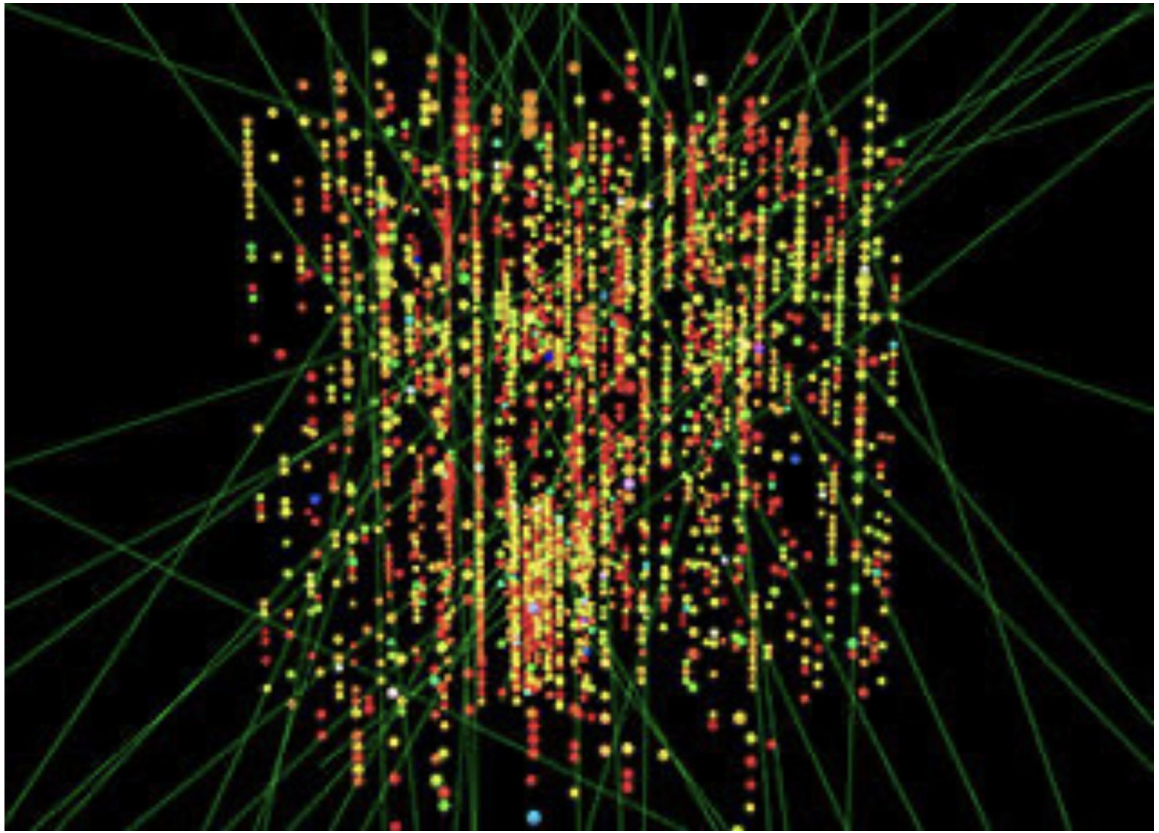
General Techniques

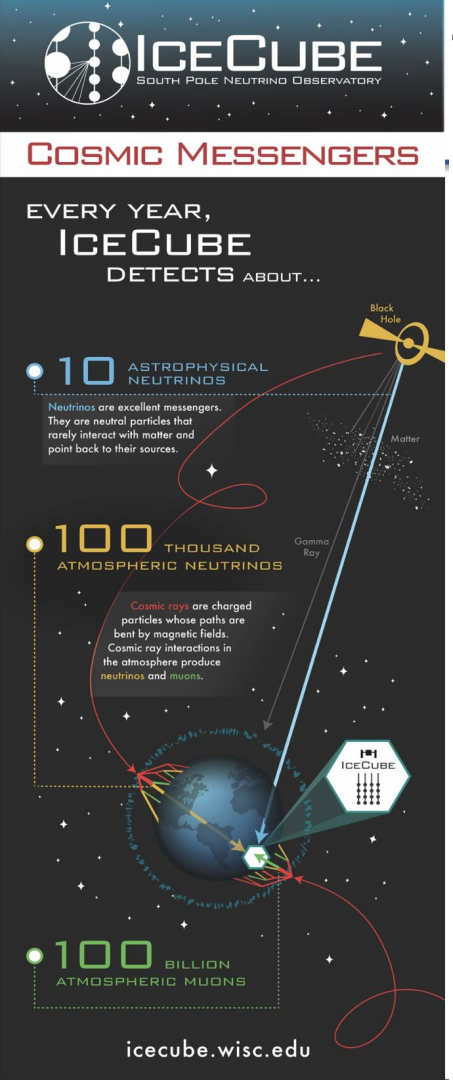
Case Studies

What is an IceCube event?

- An event is just a series of **pulses**: charge and timing information from each DOM
- Detector is always taking data of events
- After cleaning and before ‘selecting’ events, roughly **4 million events** seen in the detector **per day**

a few microseconds in IceCube → looks like a mess

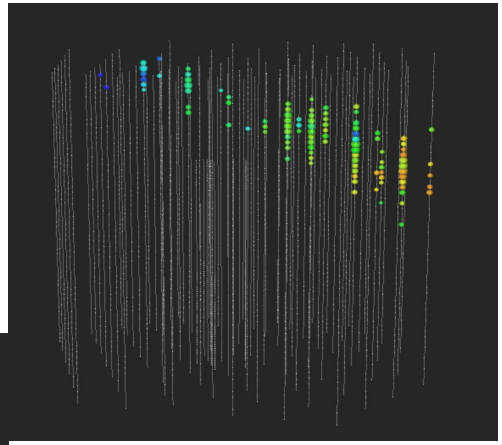




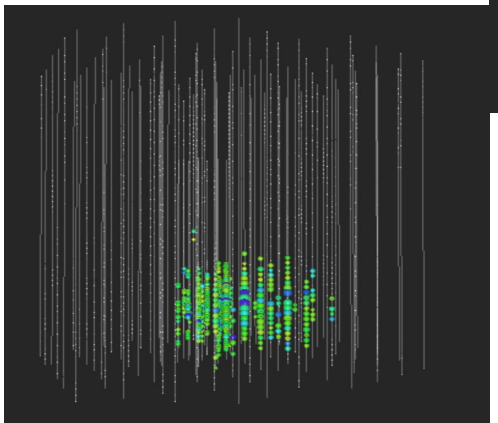
Types of Events

- Atmospheric Muons 100 Billion
- Atmospheric Neutrinos 100 Thousand
- Astrophysical Neutrinos 10

Track Event →
(angular res.)



- Cascades
- Tracks



← Cascade Event
(energy res.)

Mission of event selection → gather <u>your</u> events

Atmospheric Muons 100 Billion → Cosmic Ray WG
Atmospheric Neutrinos 100 Thousand → Oscillations, Diffuse
Astrophysical Neutrinos 10 → Diffuse Spectrum

Cascades
Tracks

Different analyses care about different types of events

Most of the job is →

- keeping as many of your events as possible
- <u>developing/implementing techniques</u> to differentiate events
- identifying events to answer your <u>physics question</u>
- a LOT <u>harder</u> than it sounds

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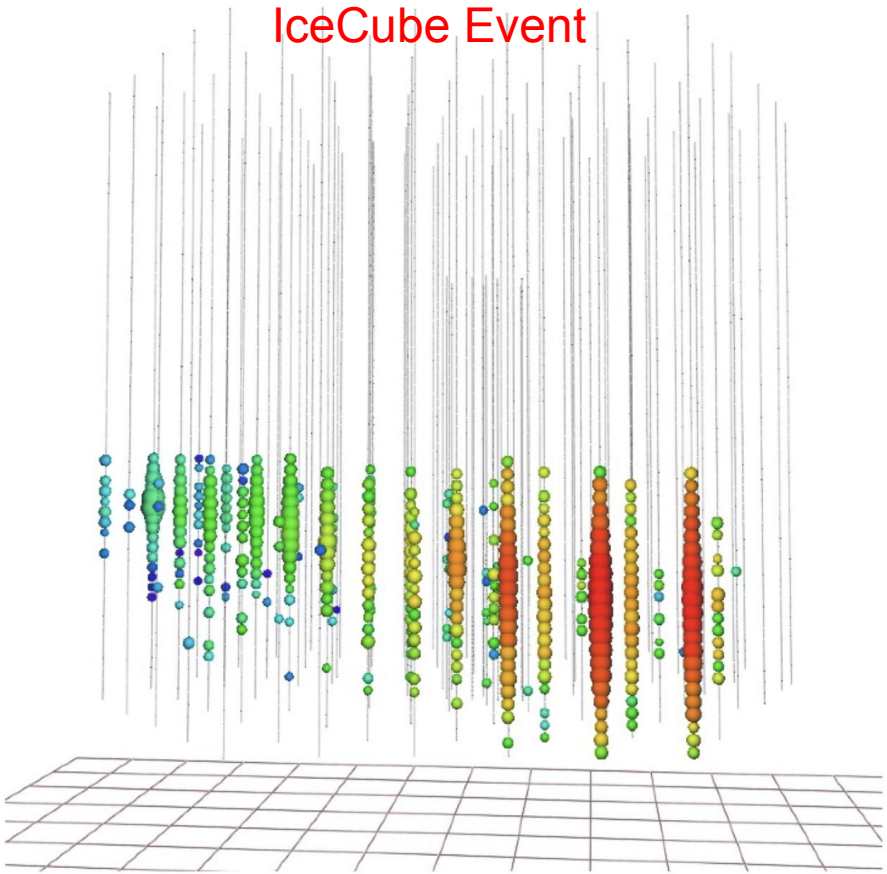
Filtering – The First Step



For each event:

- Charge
- Time

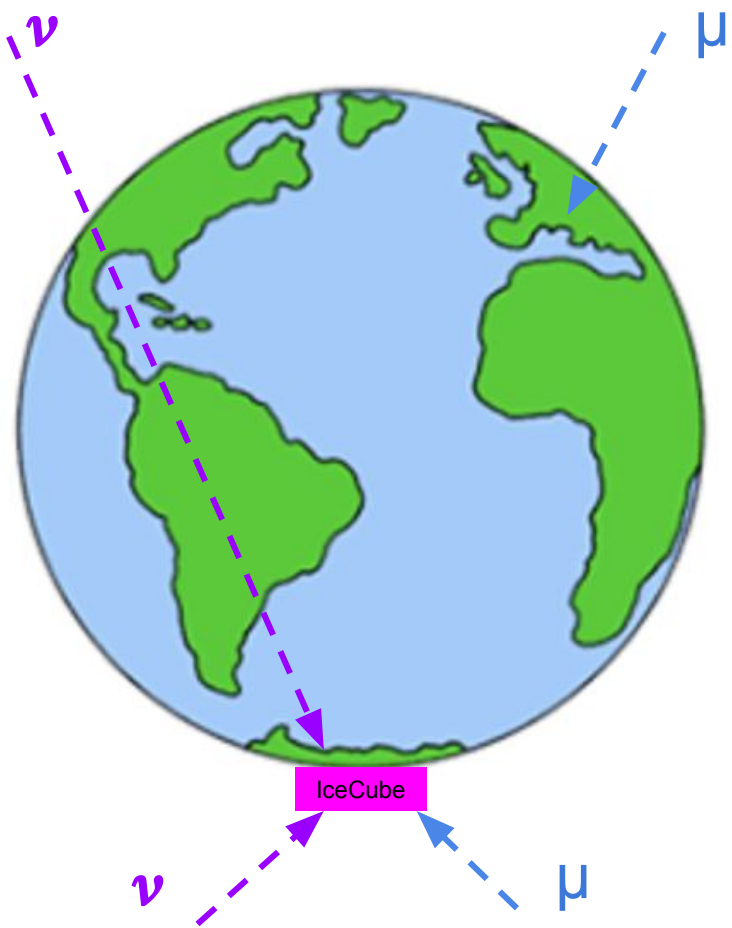
For each DOM in detector

Can broadly identify event types

Some examples:

- Cascade Filter
- Muon Filter
- Deepcore Filter

Post Filtering → Find the Neutrinos: Using Earth (event zenith)



Southern Sky:

- IceCube is on southern surface
- neutrinos **and** muons reach detector

Northern Sky:

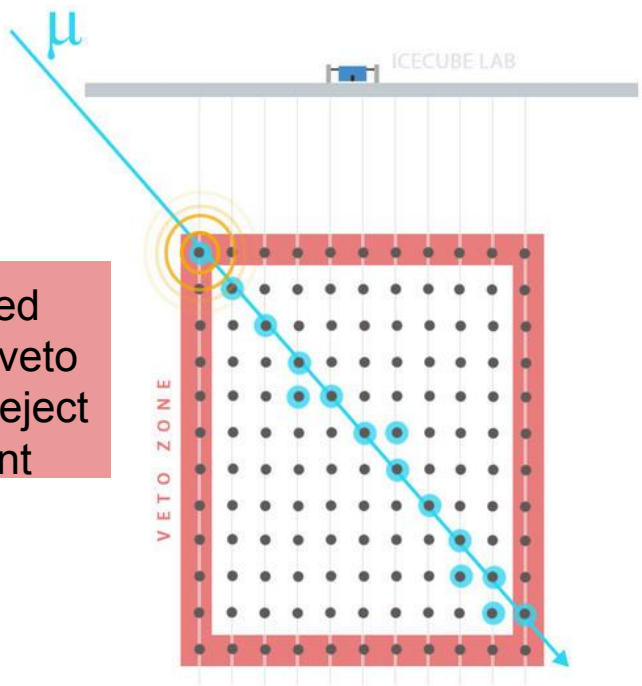
- Earth is a muon shield
- Only neutrinos reach IceCube

Looking at Northern sky only → eliminates most muons from your sample

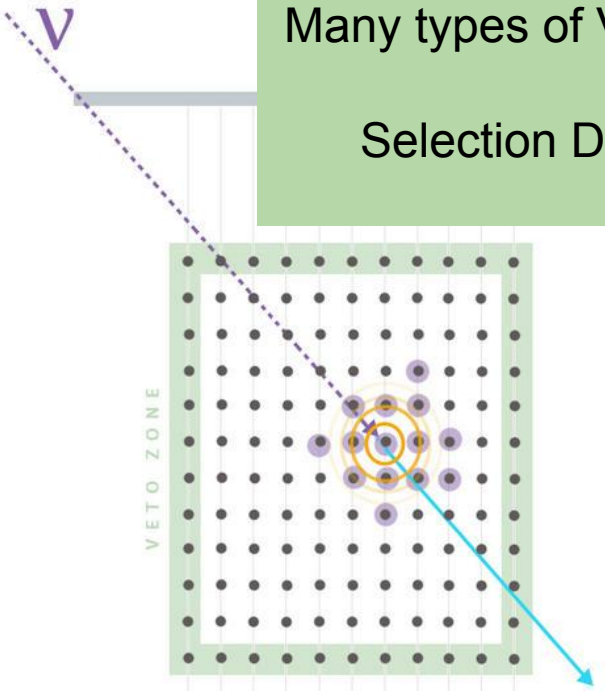
If you want to include Southern sky…

Find the Neutrinos: Veto Regions

- Muons leave light along entire path of travel (energy losses) → track-like
- Look for events that don't do ^^ → more likely to be neutrinos



Deposited charge in veto region → reject the event



Many types of Veto Regions

Selection Dependent

Find the Neutrinos: Veto Regions

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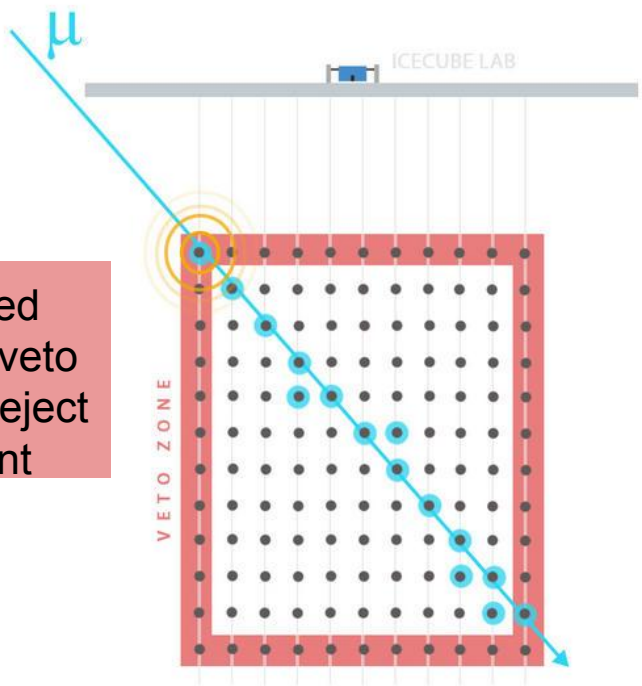

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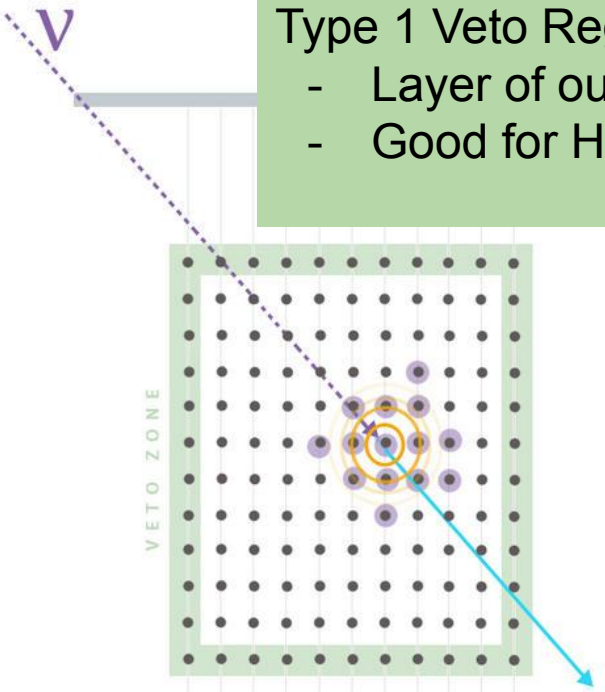

Type 1 Veto Region:
- Layer of outer volume
- Good for HE Cascades

Find the Neutrinos: Veto Regions

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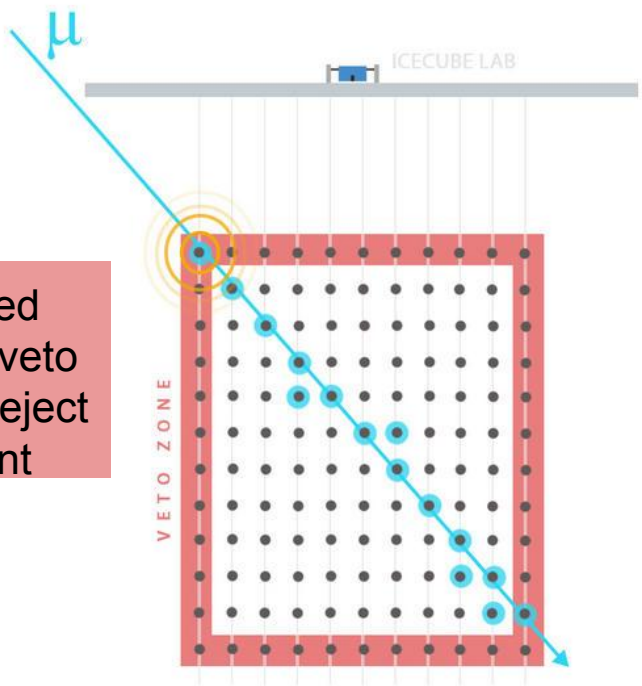
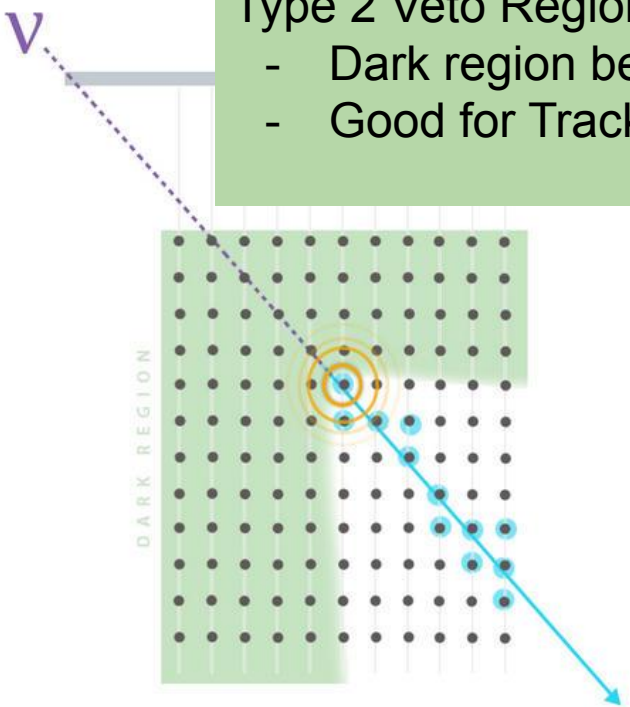


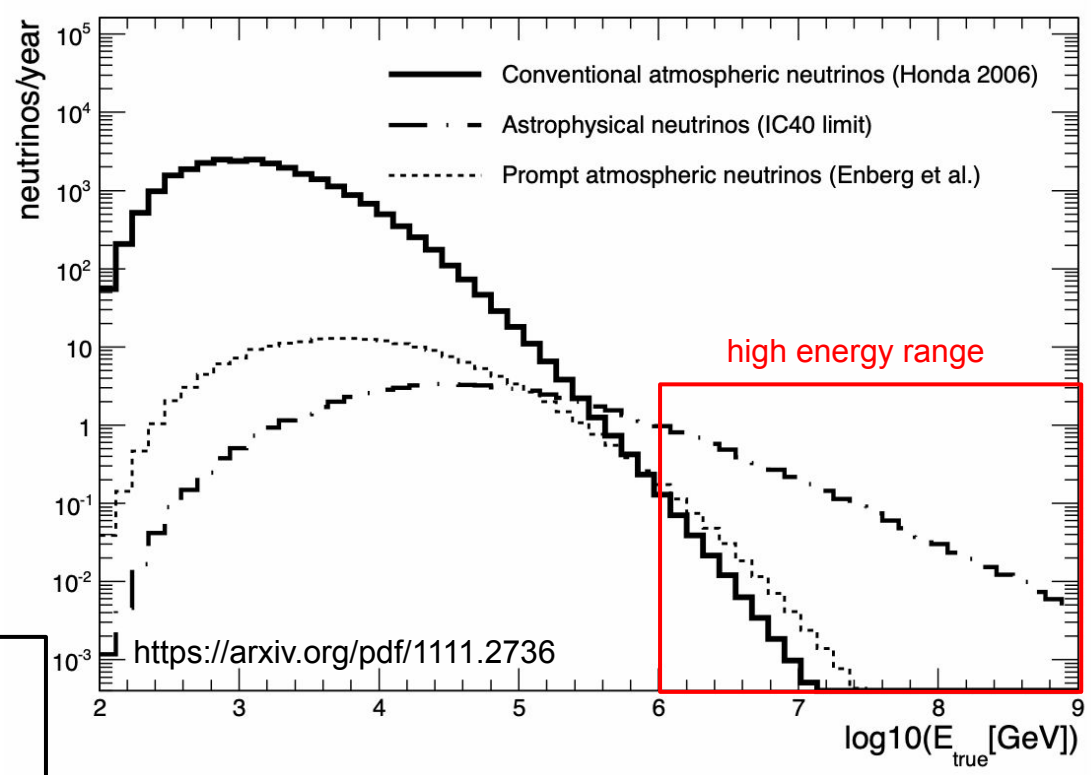
Type 2 Veto Region:
- Dark region behind vertex
- Good for Tracks



Neutrinos: Atmospheric vs. Astrophysical (Energy)

- Looking only at neutrino events → cannot differentiate atmospheric vs. astrophysical

- Simplest case → Look at high energy range
  - Atmospheric neutrinos are lower in energy
  - high energy neutrinos are much more likely to be astrophysical



If you want to include lower energy range…

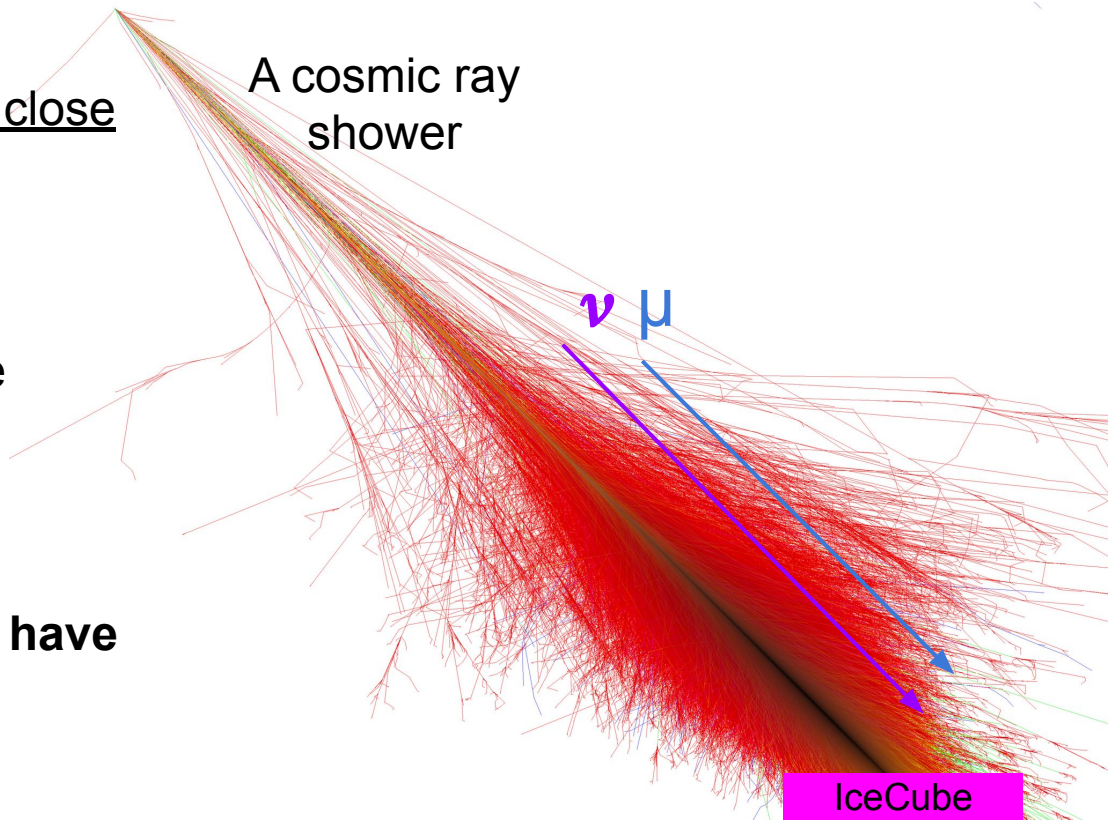
Neutrinos: Atmospheric vs. Astrophysical (Self Veto)

Cosmic Ray Showers : atmospheric neutrinos <u>with accompanying muons</u> reach IceCube

Neutrino and muons arrive <u>very close together in time</u>

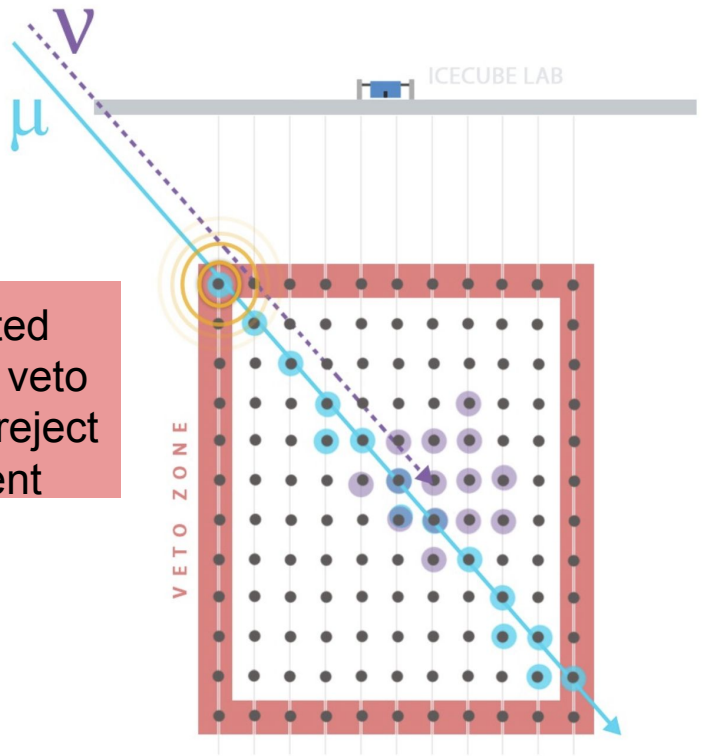
Atmospheric neutrinos can have accompanying muons

Astrophysical neutrinos **will not have** accompanying muons



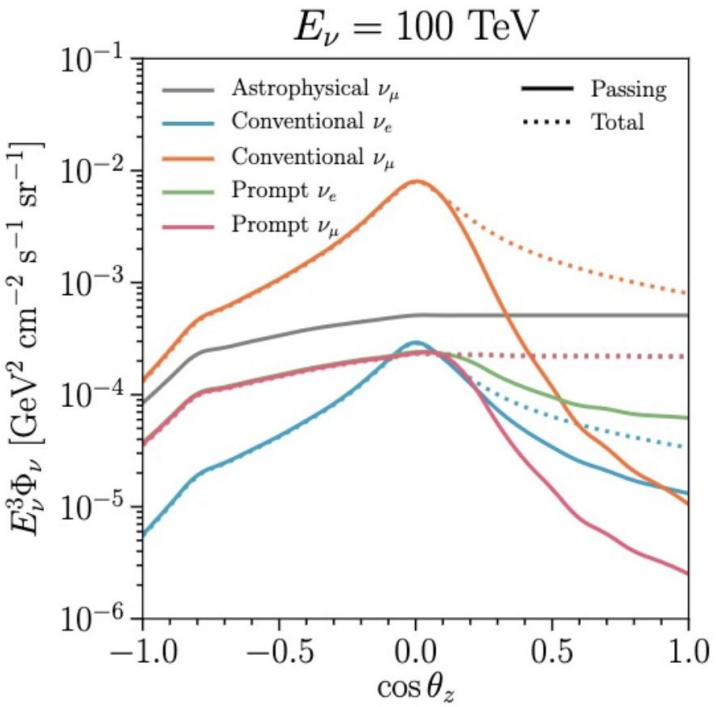
Neutrinos: Atmospheric vs. Astrophysical (Self Veto)

When muon is rejected,
so is the atmospheric neutrino



Deposited charge in veto region → reject the event

Higher proportion of astrophysical neutrinos in southern sky due to self veto



More Identification Methods: Neural Networks and BDTs

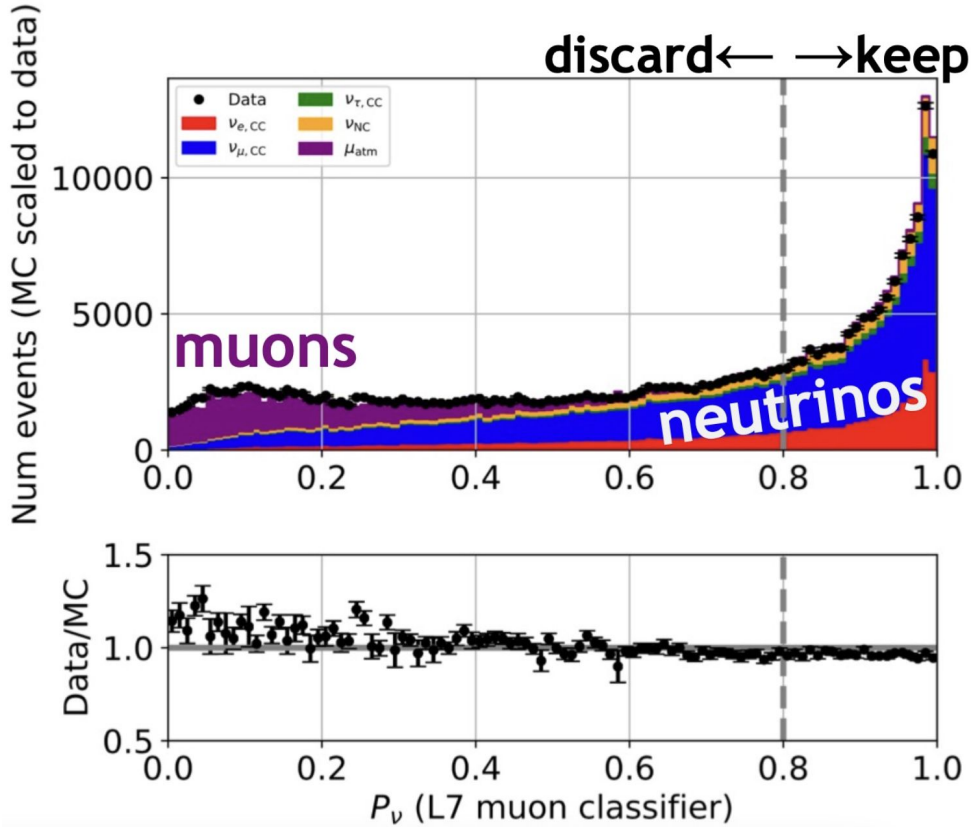
Can train neural networks and Boosted Decision Trees (BDTs) to differentiate between event types

Example BDT from OscNext (low energy deepcore events):

- Output 0 to 1
- More neutrino-y if ~1
- More muon-y if ~0
- Choose how strict you Want your classifier

LOTS of BDT classifiers in IceCube

They do all sorts of things



Event Selections

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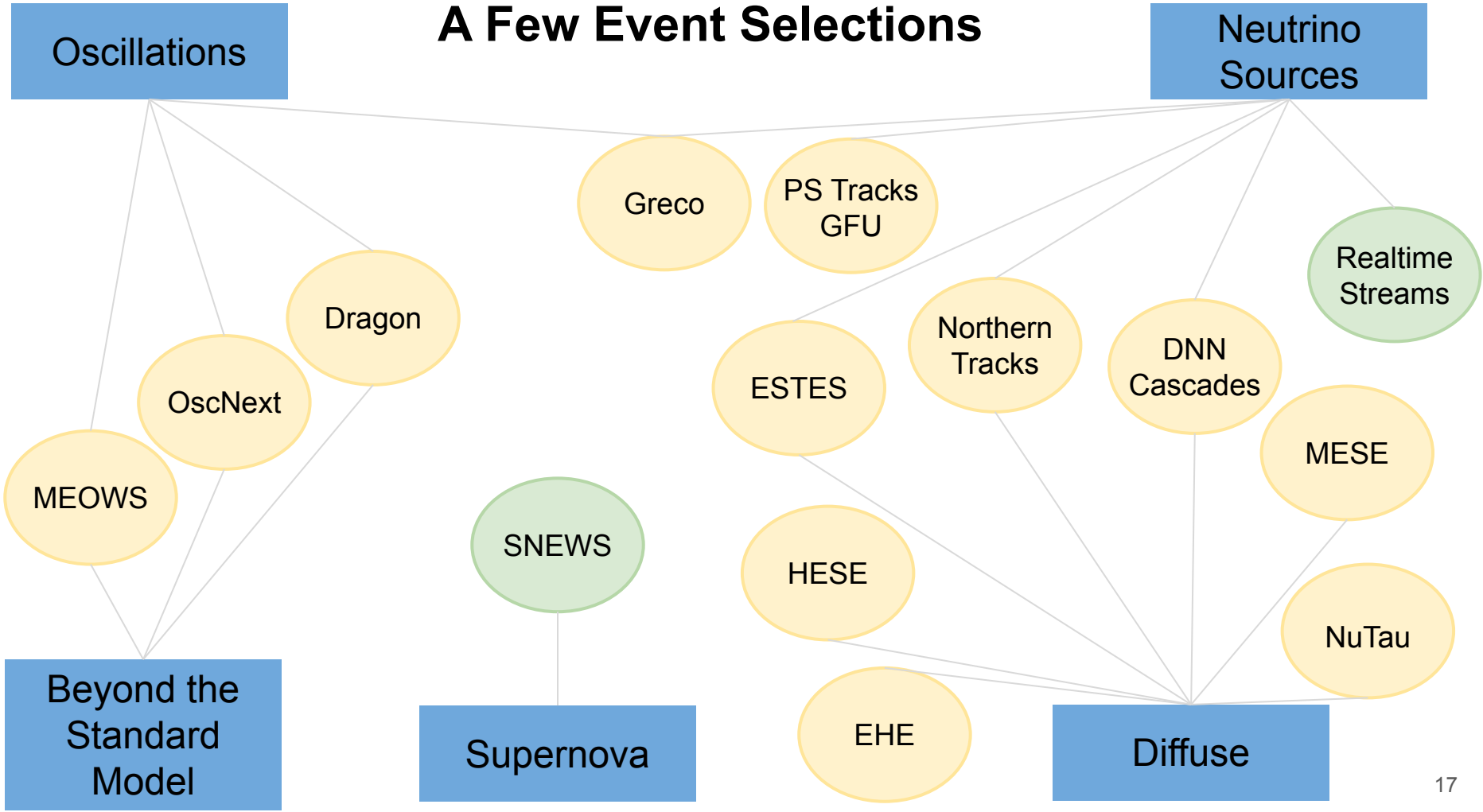
General Techniques
Case Studies

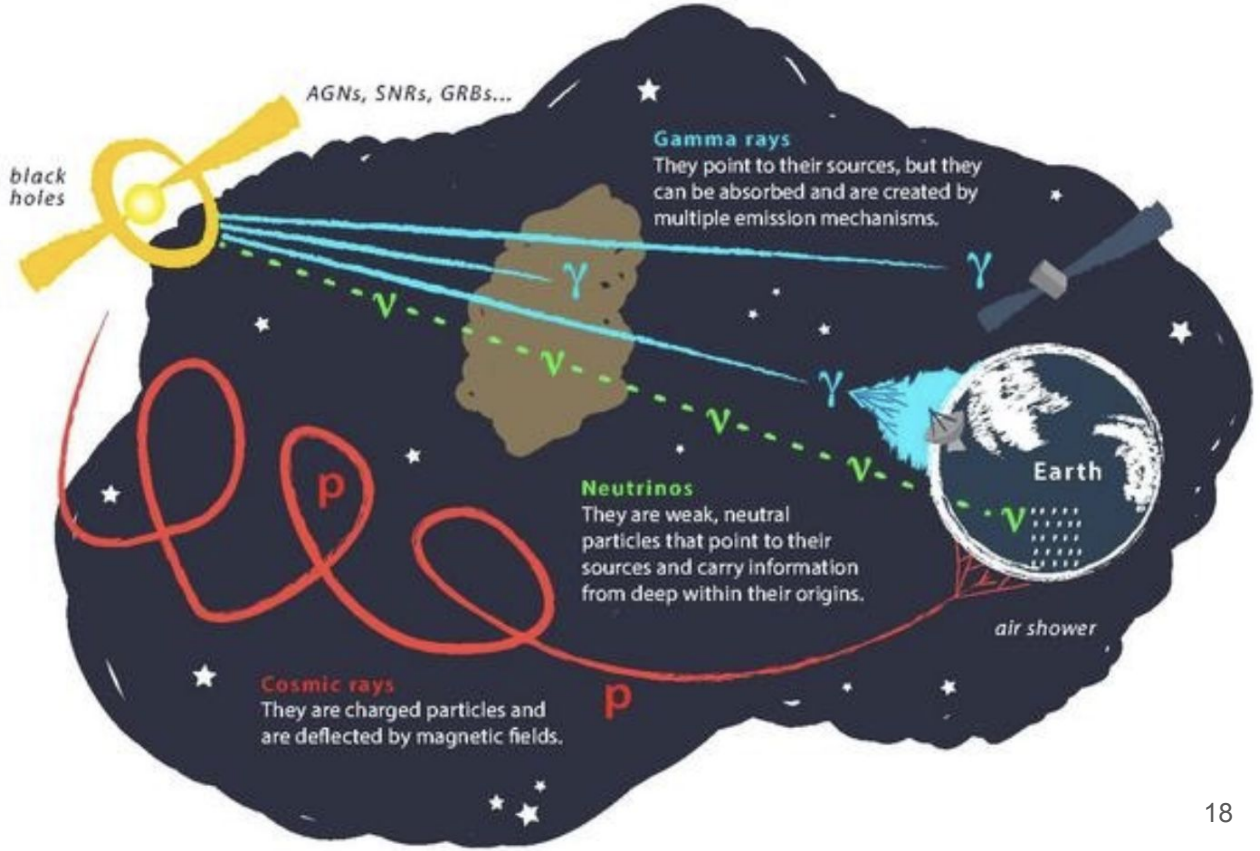
answering a physics question

A Few Event Selections



Physics Question:
Where do Astrophysical Neutrinos Come From?

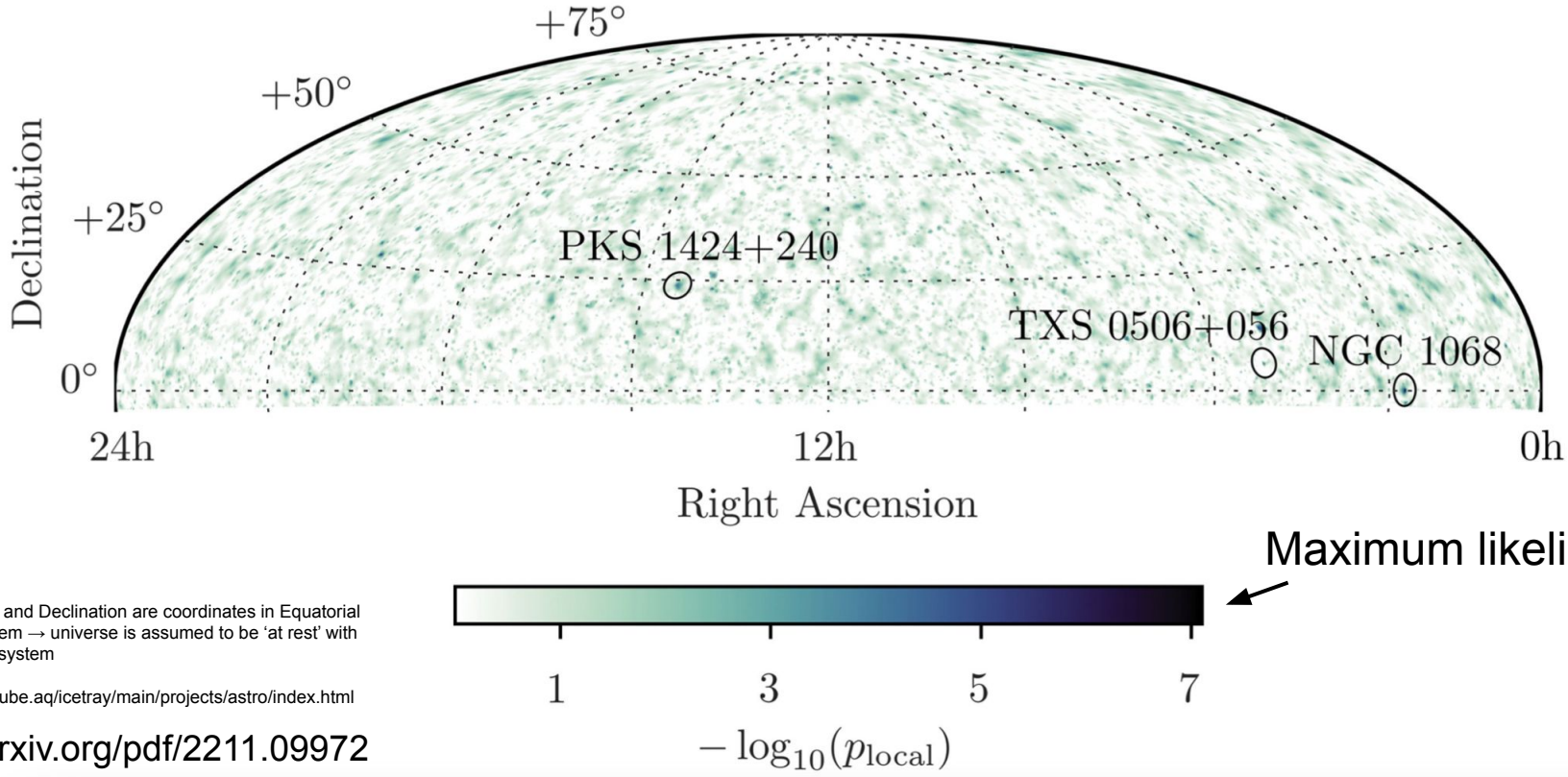
Potential Strategy → Use track events (good pointing/angular resolution)



Northern Tracks (Diffuse NuMu)

~76,000 events/yr

Goal: Identify neutrino emission from potential sources (galaxies, black holes, etc.)
Pinpointing likely sources by searching for <u>significant</u> neutrino excess



Right Ascension and Declination are coordinates in Equatorial Coordinate System → universe is assumed to be 'at rest' with respect to solar system

https://docs.icecube.aq/icetray/main/projects/astro/index.html

https://arxiv.org/pdf/2211.09972

Point Source (PS) Tracks

~120,000 events/yr

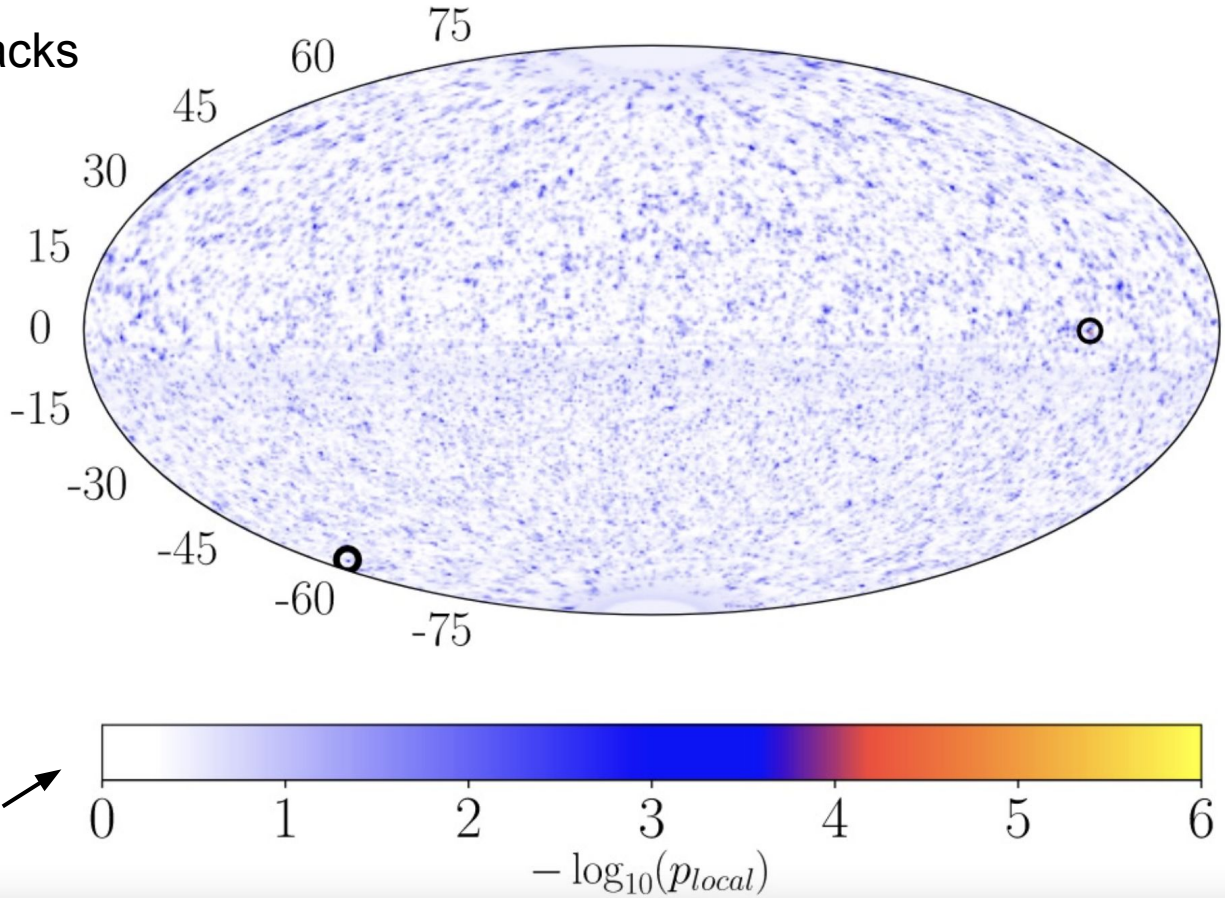
Goal: same as Northern Tracks

Includes:

- Southern Sky
- ‘All Sky’ sample
- More neutrino events per year

Harsh energy cut in southern sky to remove atmospheric muons

Maximum likelihood

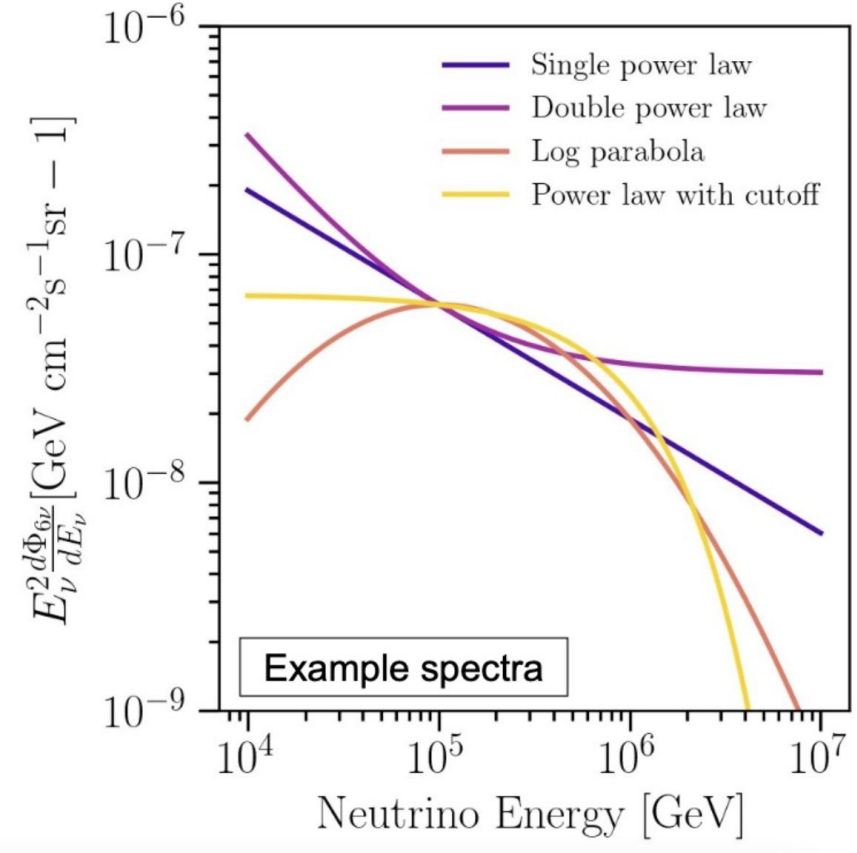


https://arxiv.org/pdf/1910.08488

Physics Question:
What does the Astrophysical Neutrino Flux Look Like?

Potential Strategy → Use events that start inside the detector

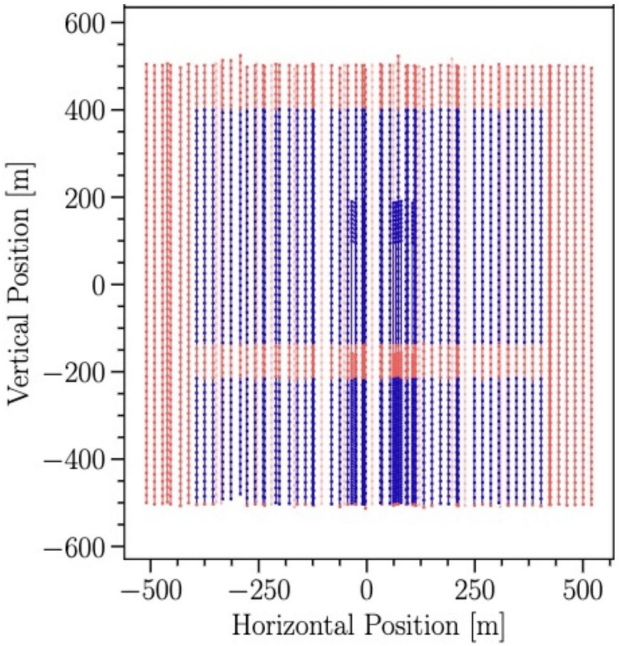
Starting Events have better energy resolution

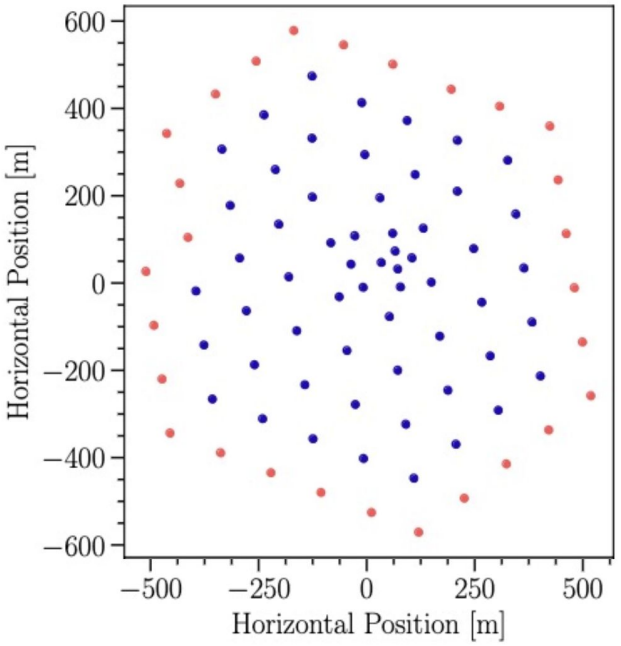


HESE: High Energy Starting Events

General Techniques Used:

- High energy only
- Outer layer veto (keep only events that start inside detector)
- Deposited charge > 6000 photoelectrons (help remove atmospheric background)

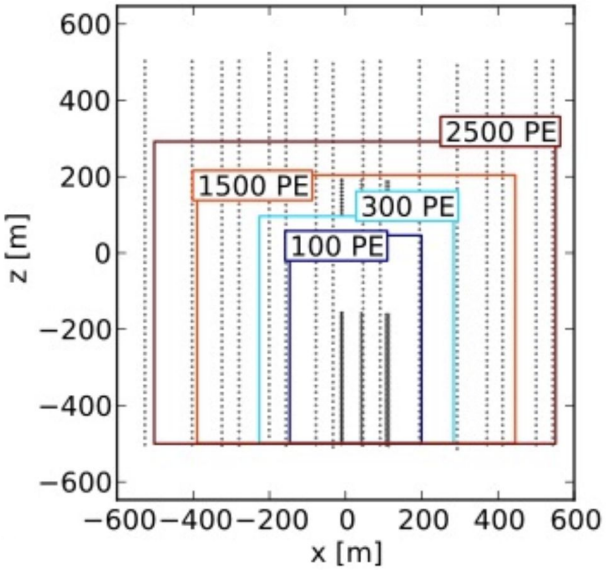


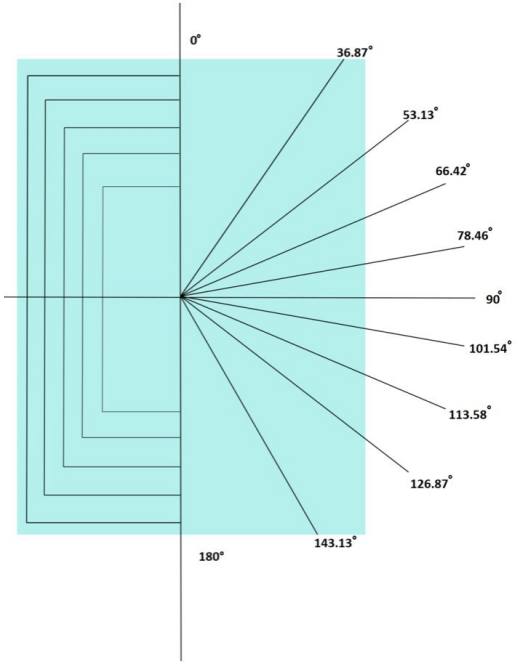


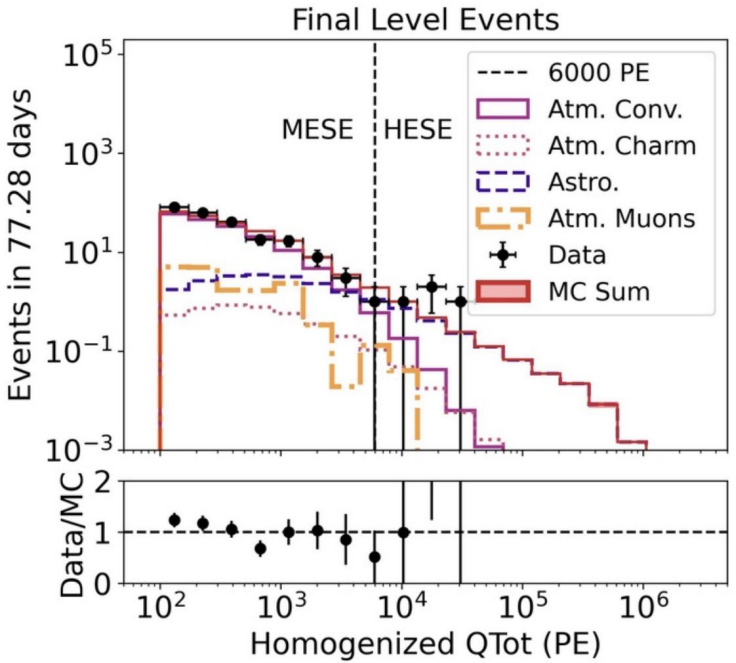
https://arxiv.org/pdf/2011.03545

MESE: Medium Energy Starting Events

- A sample with extended energy range compared to HESE
- Incorporates dynamic veto: energy and zenith dependent







https://wiki.icecube.wisc.edu/index.php/Medium_Energy_Starting_Events

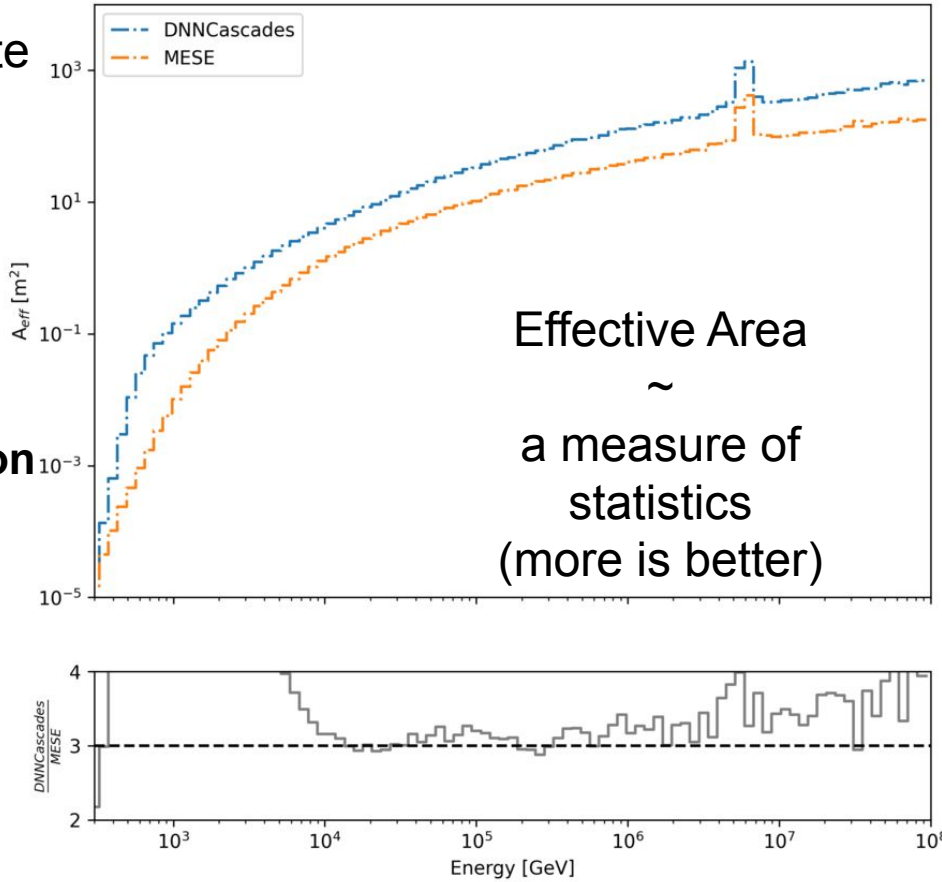
DNNCascades and Machine Learning Techniques:

NO veto layers → only BDTs to eliminate muon background

High statistics/sensitivity Cascades selection, especially at lower energies

Originally used to **detect neutrino emission from Galactic Plane**

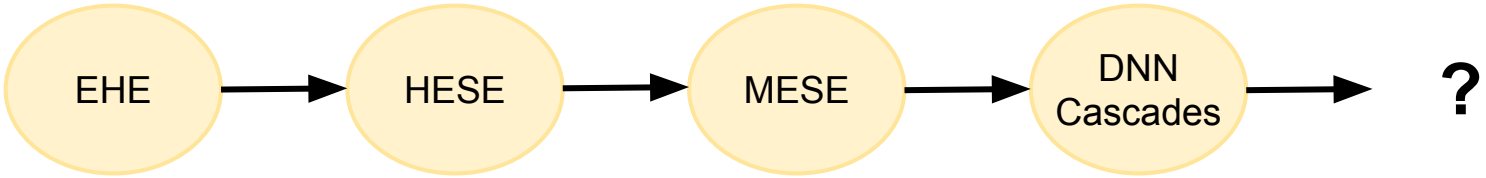
Zoë (me) Optimizing for Astrophysical Diffuse flux measurement



https://arxiv.org/pdf/2307.14842

In General: Event Selections

Start with a physics goal → build with developing technologies/modeling methods



Future of Event Selections: Combined Selections

- moving into an era where combined event selections will reveal physics information to us → <u>increased sensitivity, statistics, etc</u>.
- Updating existing event selections with newer techniques
- Learning to account for overlapping events in selections (complicated process)

Summary

- Lots of event types, and lots of ways to select your events of interest
  - Event distribution
  - Morphology (zenith, energy, etc.)
  - Neural Networking and Machine Learning

- Many existing event selections today
  - Always update techniques when you use an existing for your analysis
  - Create your own techniques using physics principles!
  - Combining event selections → next era of IceCube Physics