Event Selections in IceCube

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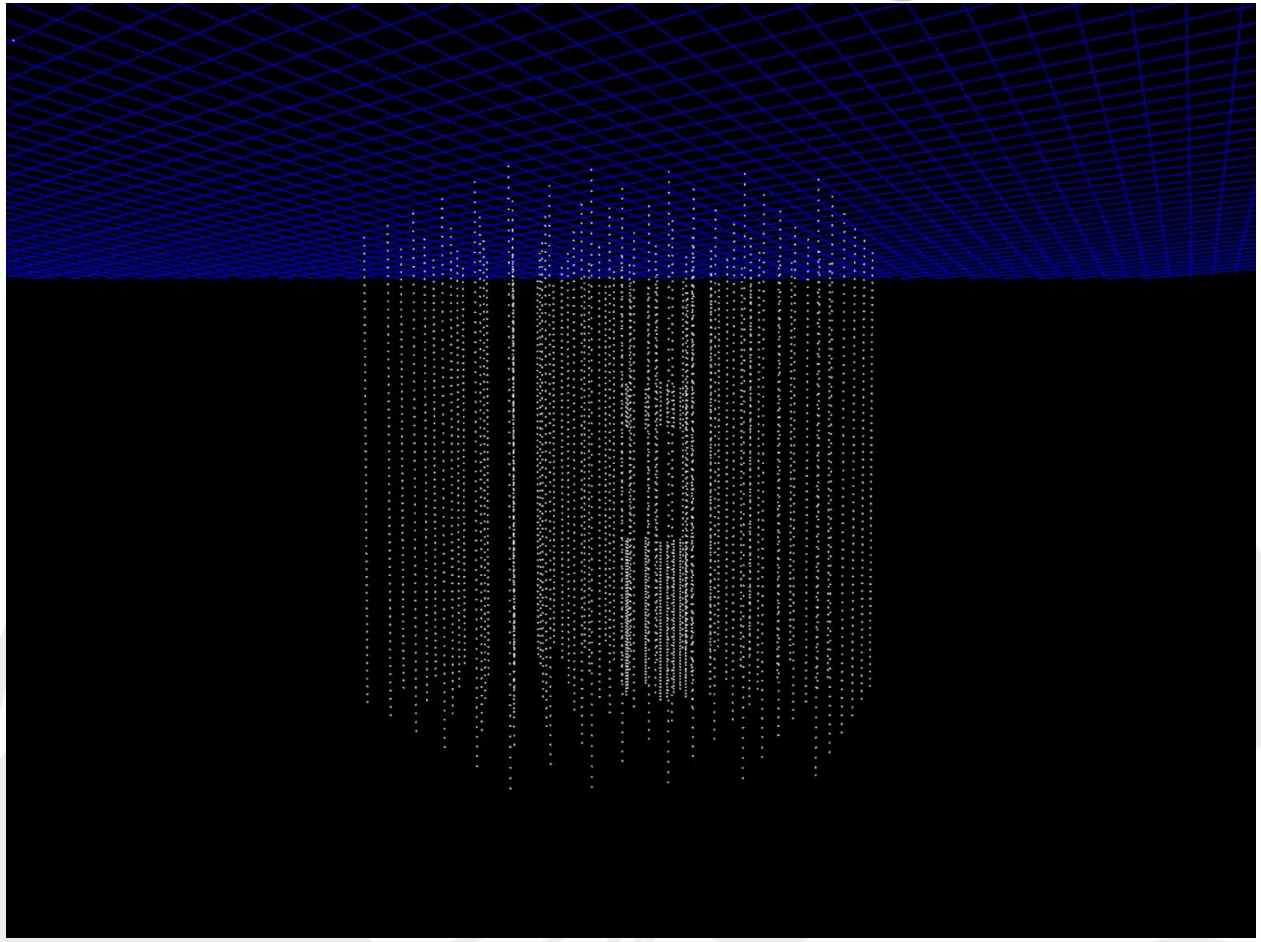
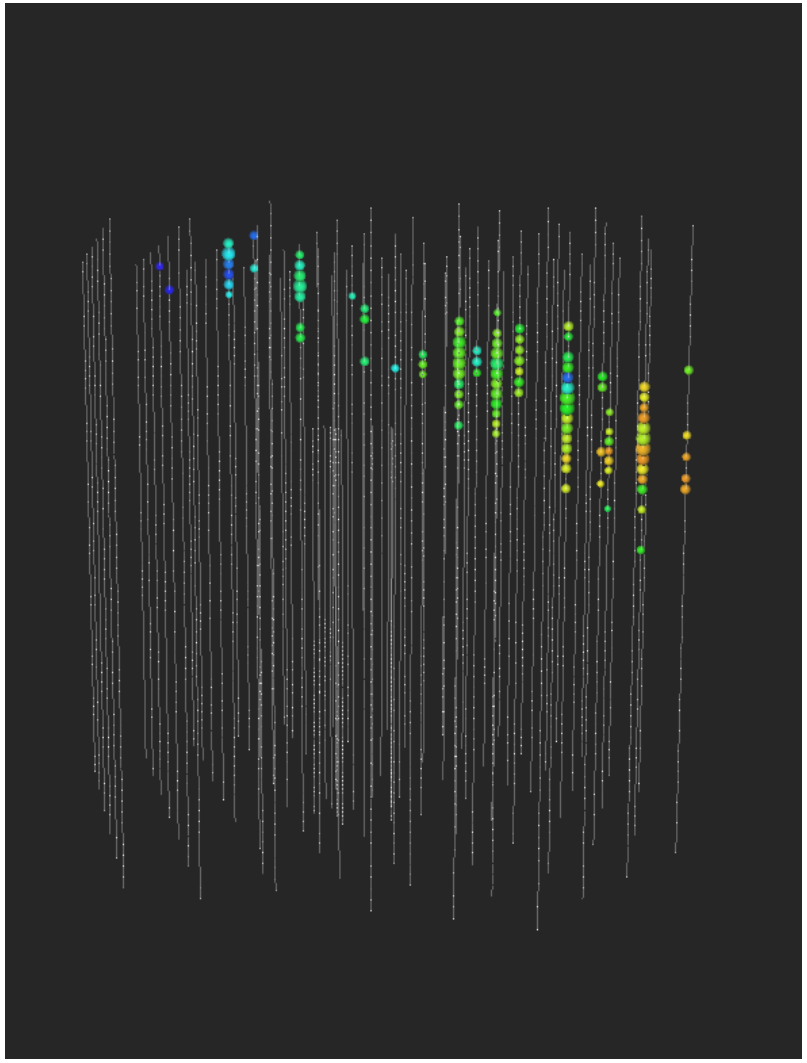
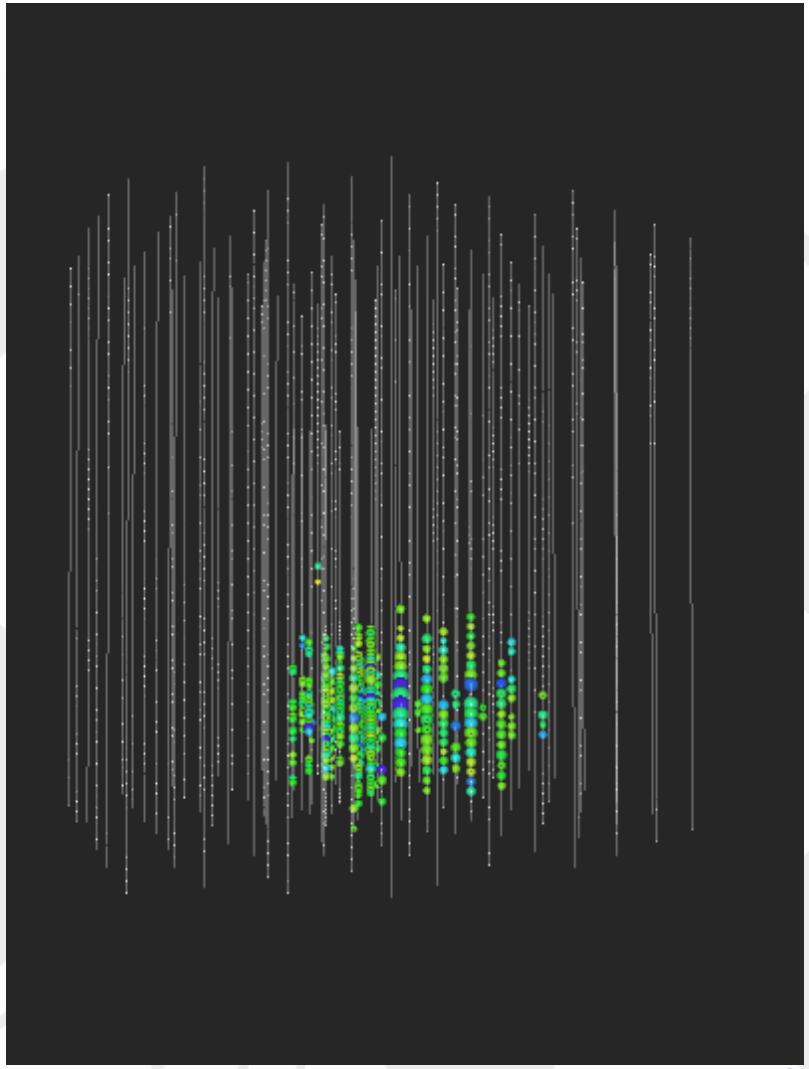
IceCube Events

- Each event is a series of pulses from byproducts of one interaction. We are interested in the properties of the primary particle.
- IceCube is hit with lots of events of many varieties – and takes data continuously.
- 10ms of data shows the detector lit up with downgoing atmospheric muons and muon bundles
- Starting point after cleaning around 50 events / second (~4 million / day)



Which is the “good” Event?





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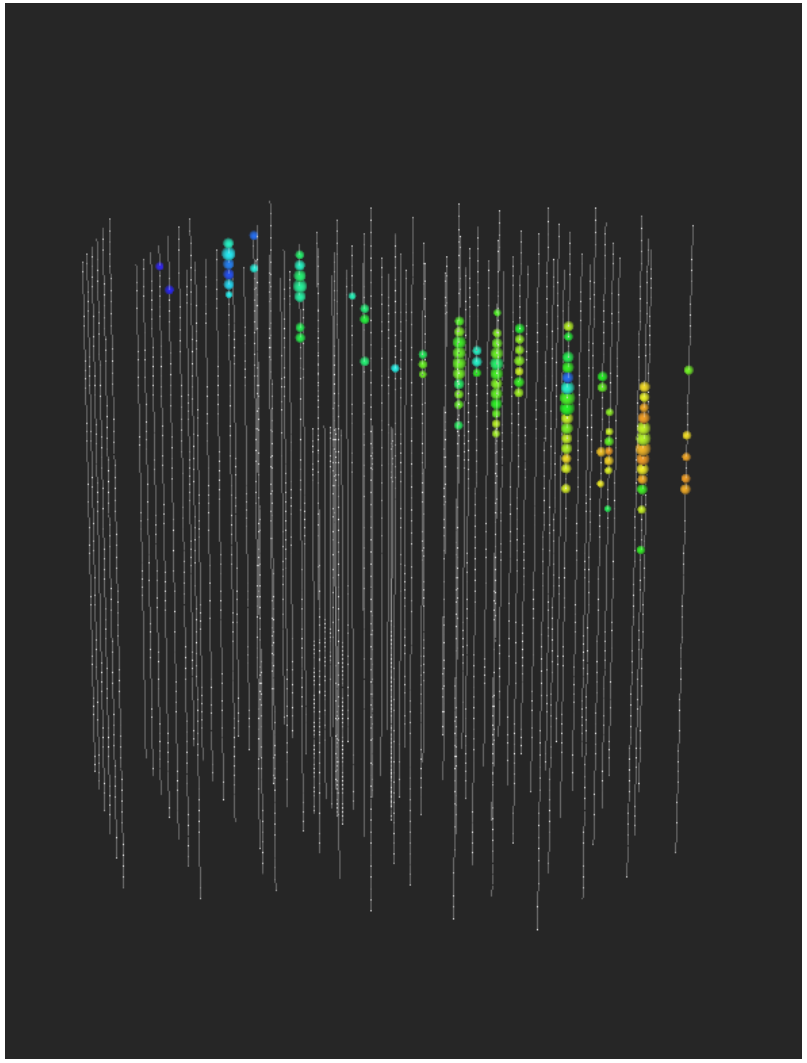

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Track Event
Upgoing
Medium to High Energy
Starting Outside the detector

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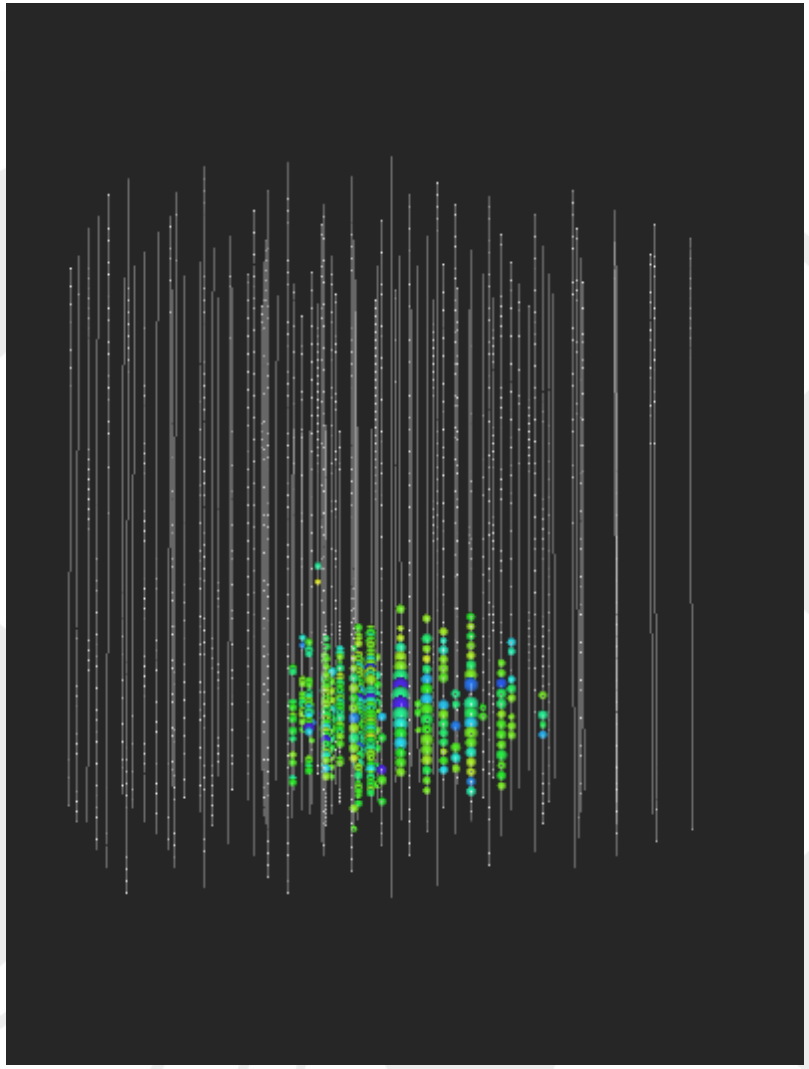
Cascade Event
Difficult to see direction
Medium to High Energy
Contained within the detector



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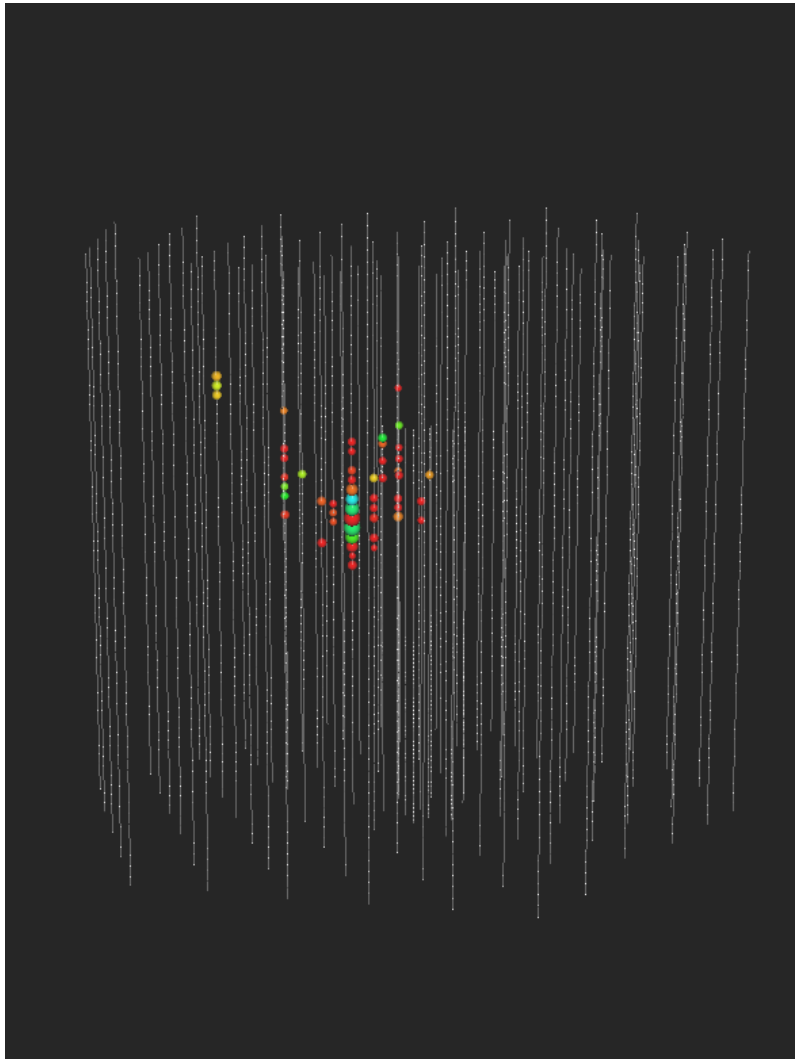

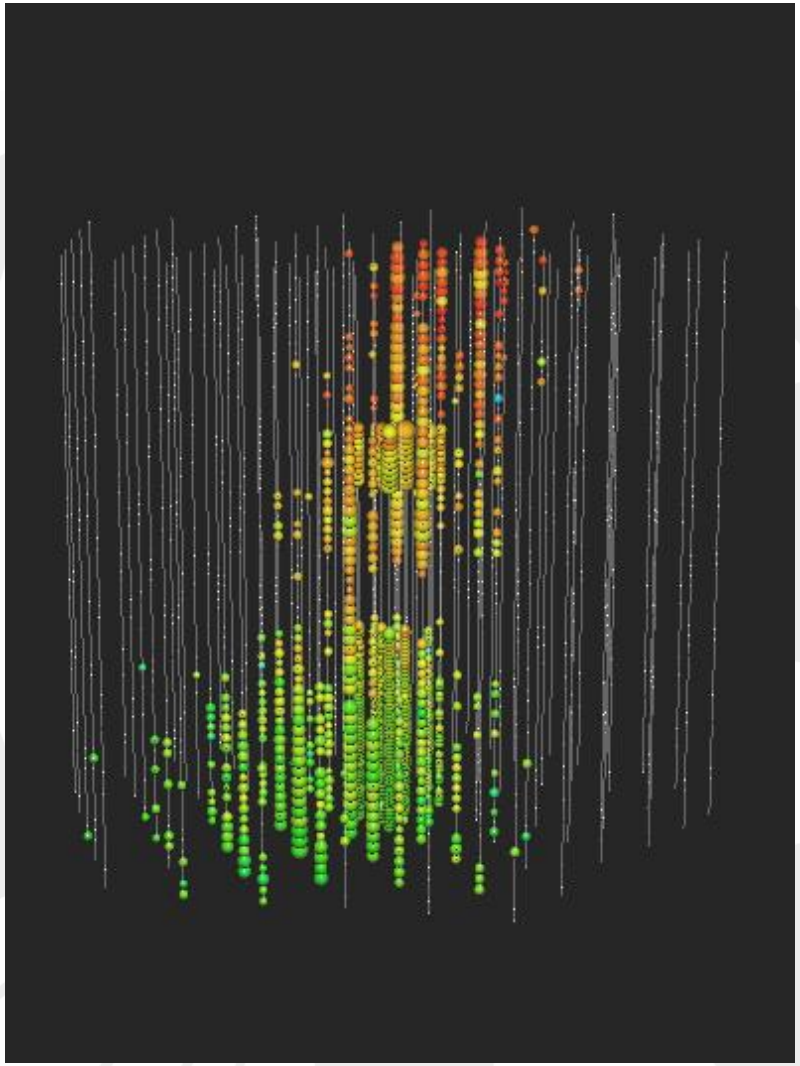

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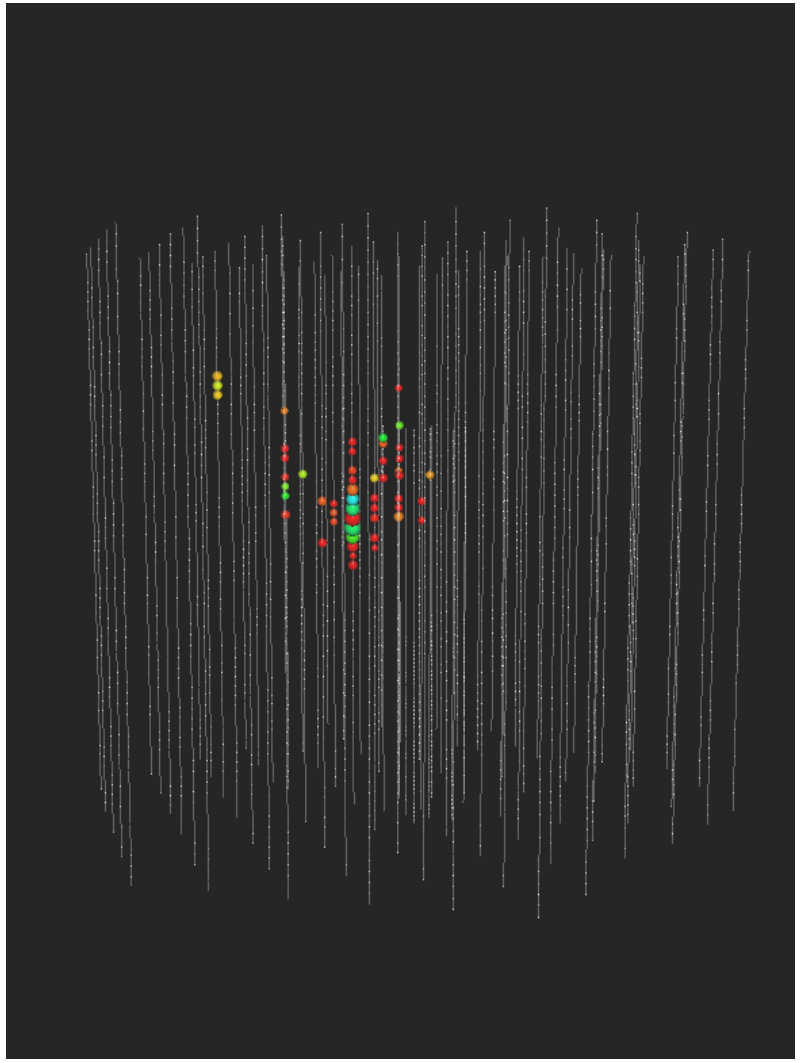

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Starting Track
Upgoing
Low to Medium Energy

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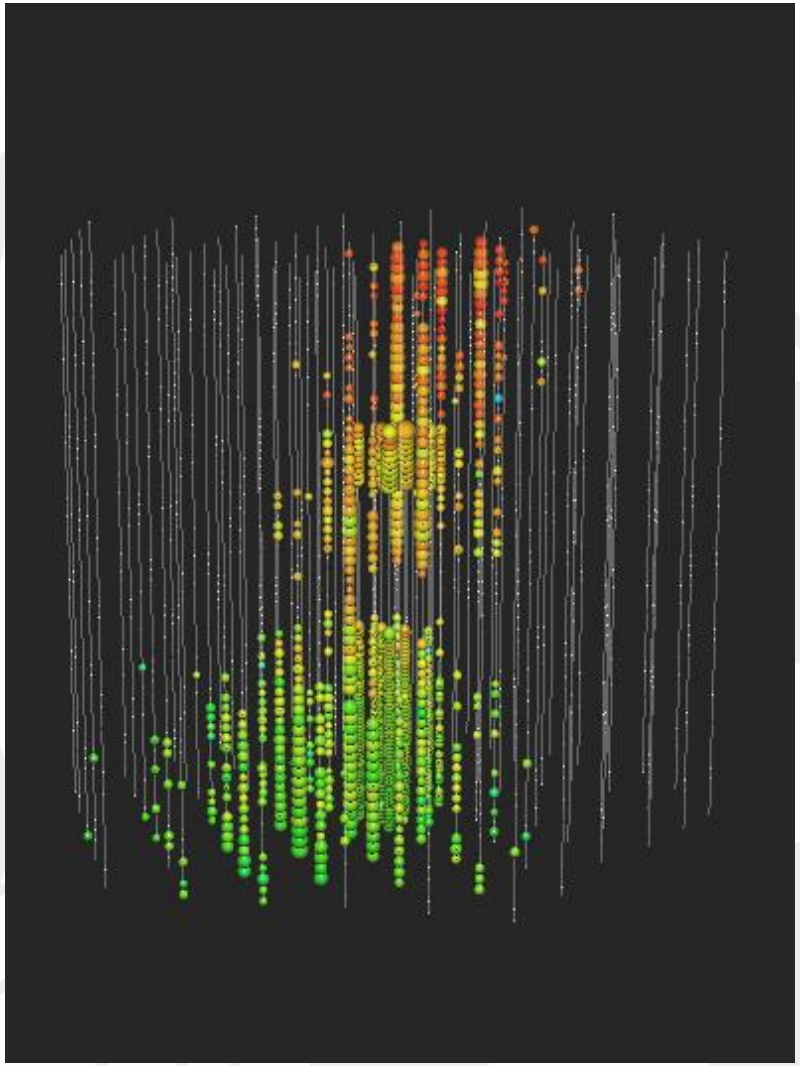
Track Event
Downgoing
Very High Energy

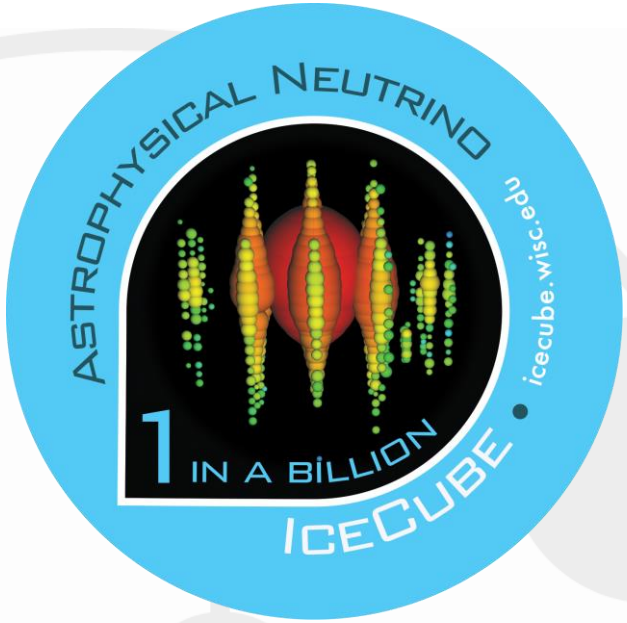


Which is a "good" event

- All events can be useful for some analysis, but each analyses focuses on collecting specific event types into a single dataset.
- Lots of times we only show the most extreme examples of an event type. Typically, there is a lot of gray areas between classification.
- This is a lot of work, usually done with machine learning, the resulting dataset can be shared and used for lots of physics
- Since every selection is different – and they often take years, I will try and give an overview of what kinds of selections exist and what makes them unique

What kind of events are you looking for?

- **Muon vs Neutrino**
- Atmospheric neutrino vs Astrophysical neutrino
- Contained vs uncontained vs partially contained
- Starting or through-going (or exiting)
- Energy range?
- How much and what types of background is acceptable?



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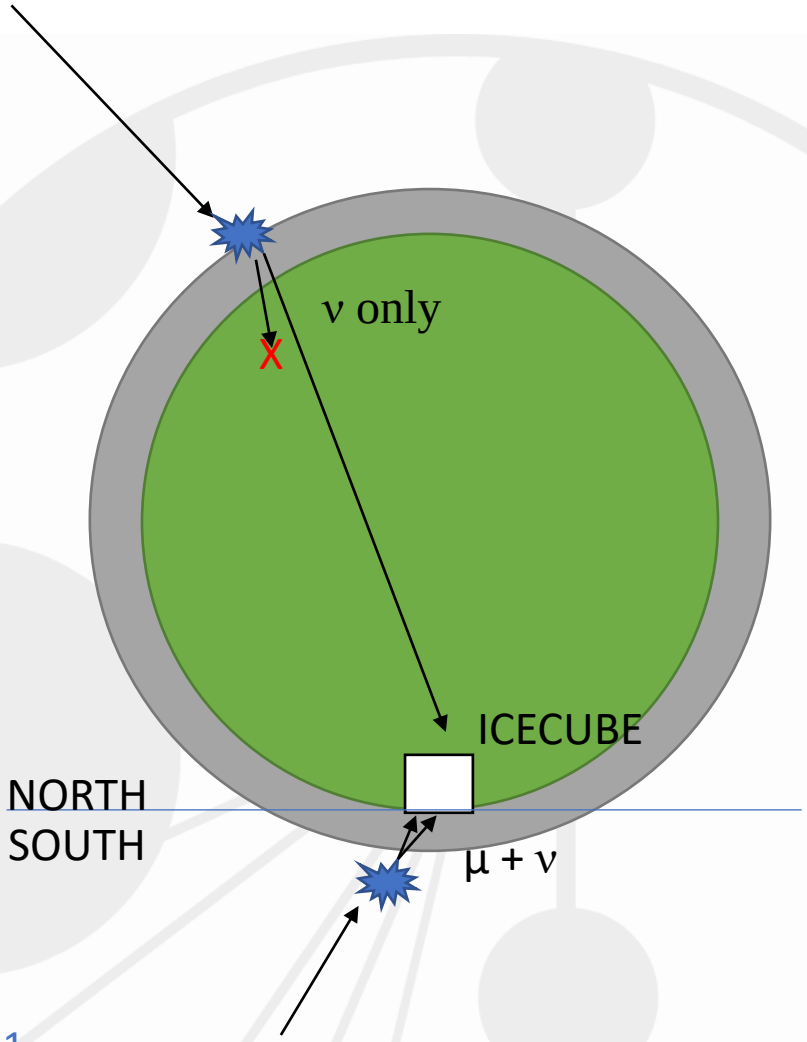
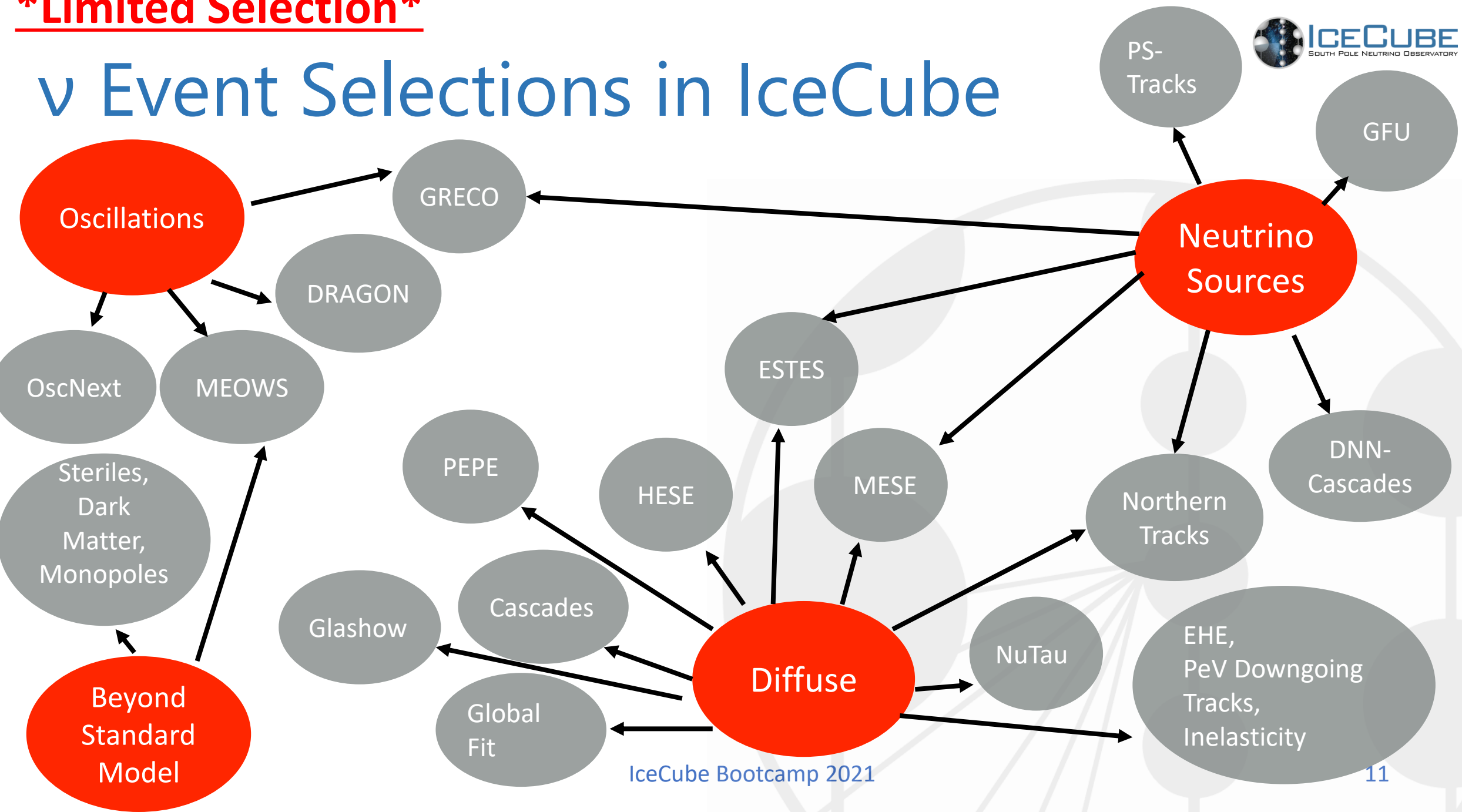


What else can we do?

- Look for events with higher energies. More likely to be Astrophysical Neutrino
- Look for events starting with the detector
- Look for cascades (they are only produced in IceCube from neutrinos)

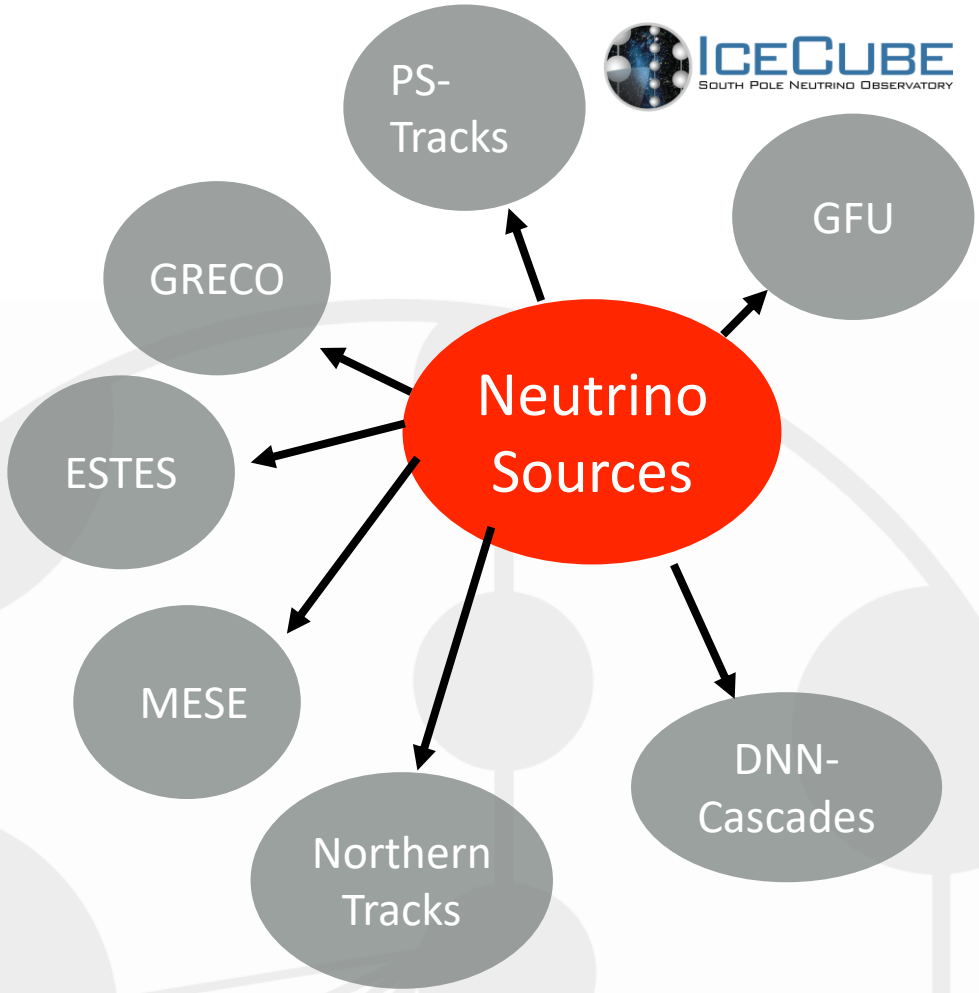
Limited Selection

ν Event Selections in IceCube



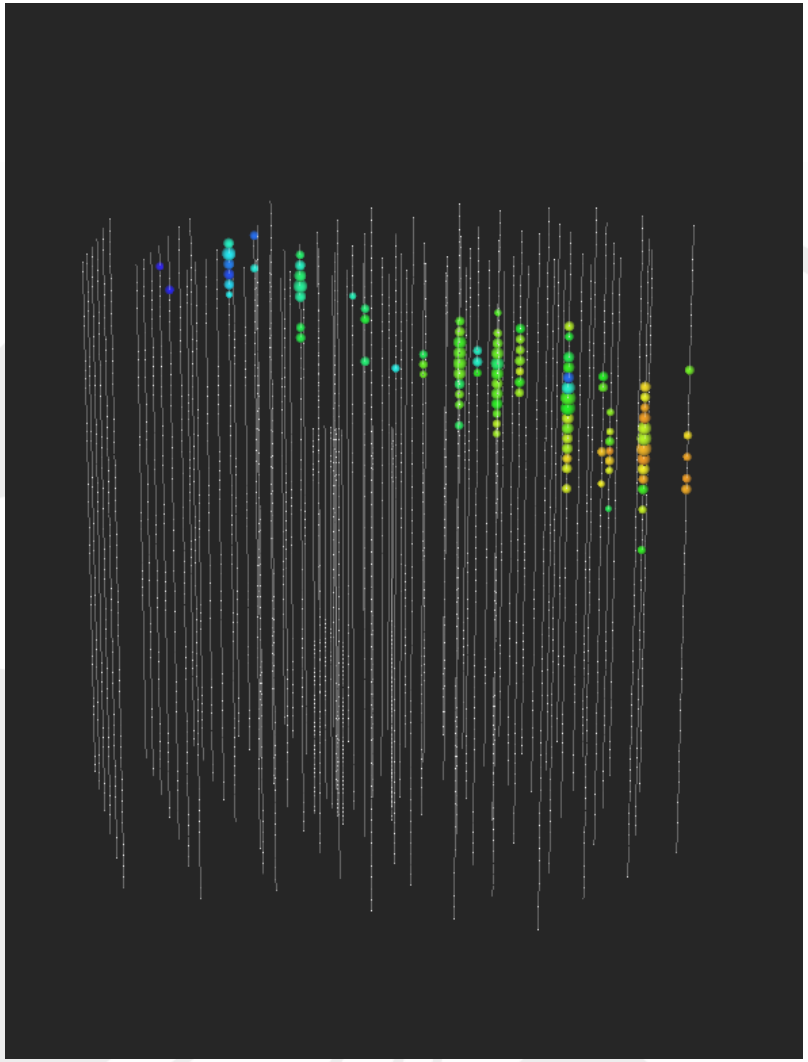
Neutrino Sources

- WG Goal: Identify sources of astrophysical neutrinos
- Look for correlations between our data and other stuff
- Typically want good pointing + high energy
- Traditionally can tolerate more background – higher data/mc disagreement
- https://wiki.icecube.wisc.edu/index.php/Nu_Sources_Datasets



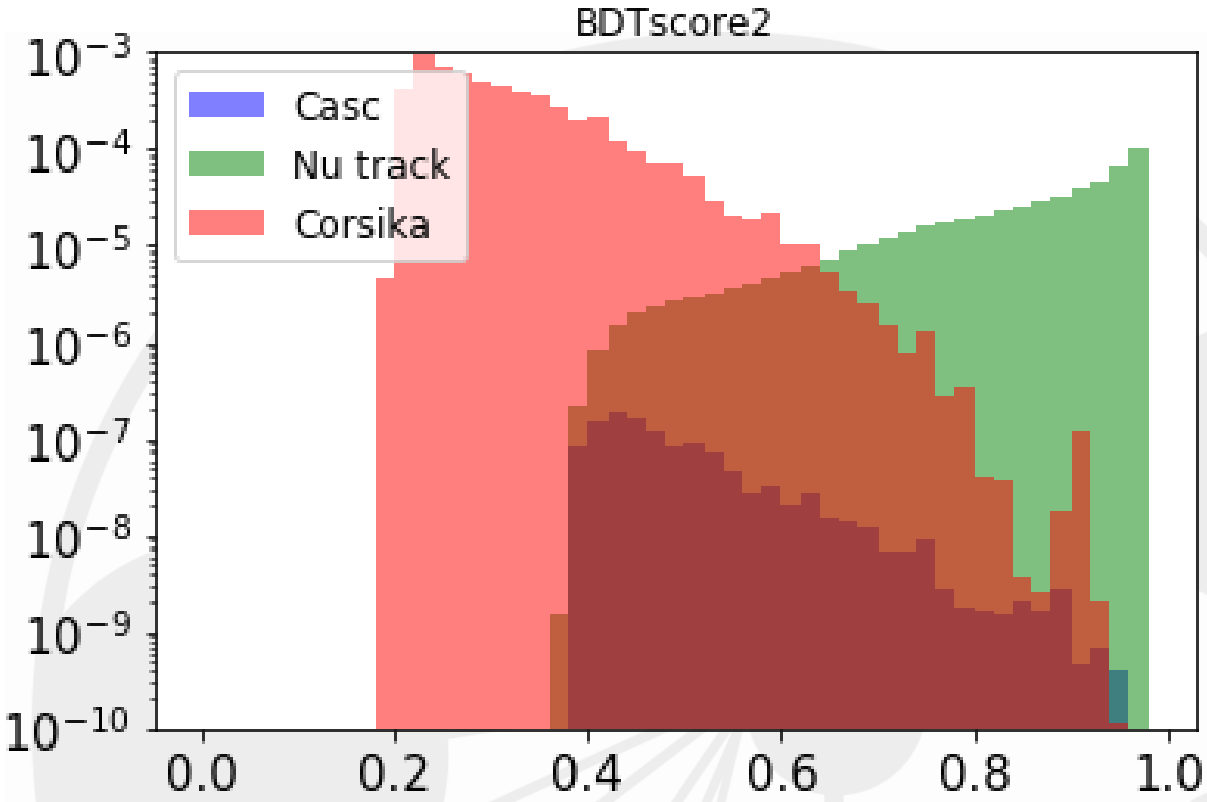
Point Source Tracks

- All Sky Tracks dataset
- Separate BDT to select events in north and south
- Southern Sky – impose a cut on energy to limit the muon background
- Sensitivity very different in North and South
- Final Event Rate ~340 events / day (More in the North)



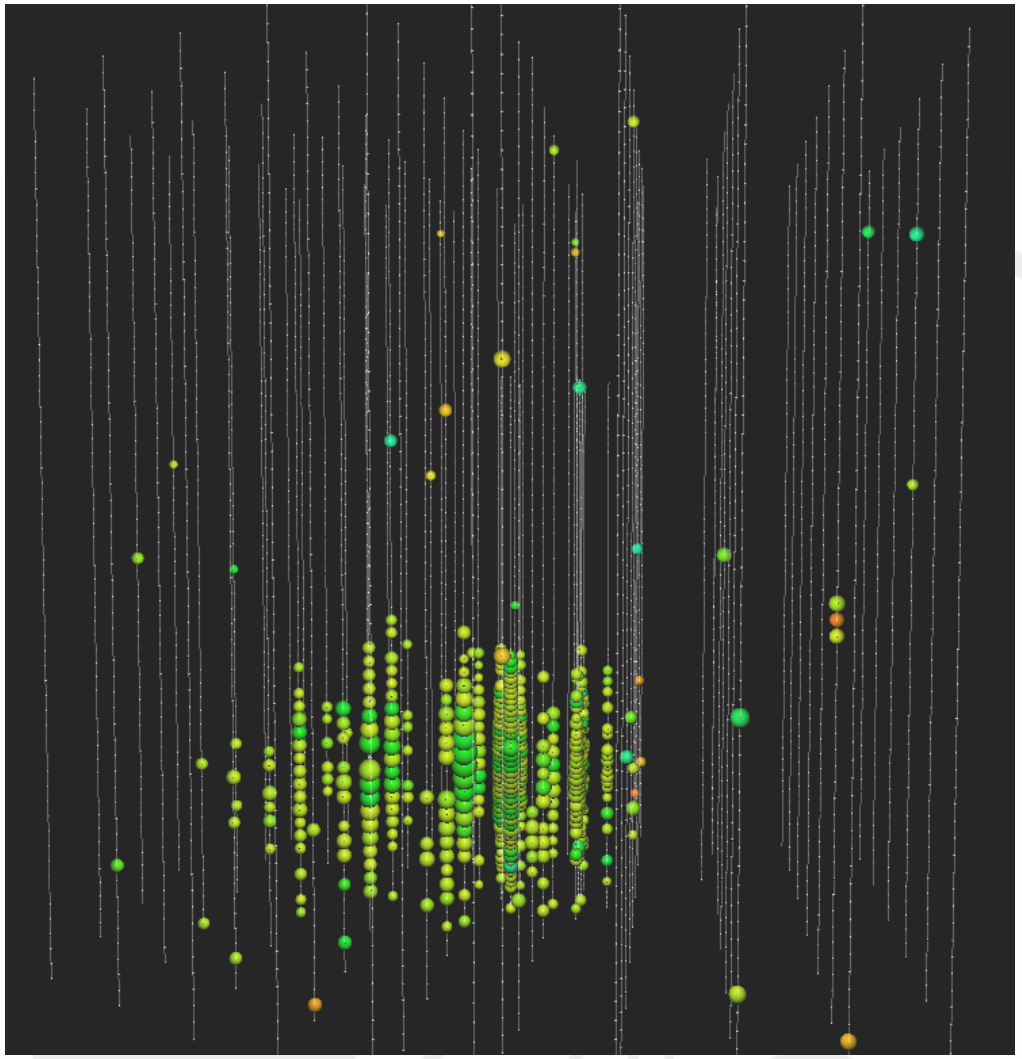
Point Source Tracks

- Input Parameters:
  - Track length
  - Reconstruction Confidence
  - Direction
  - Energy
- Upgoing Boosted Decision Tree classifier separating Background Muons (Corsika), Background Cascades (Casc) and Signal (Nu track)



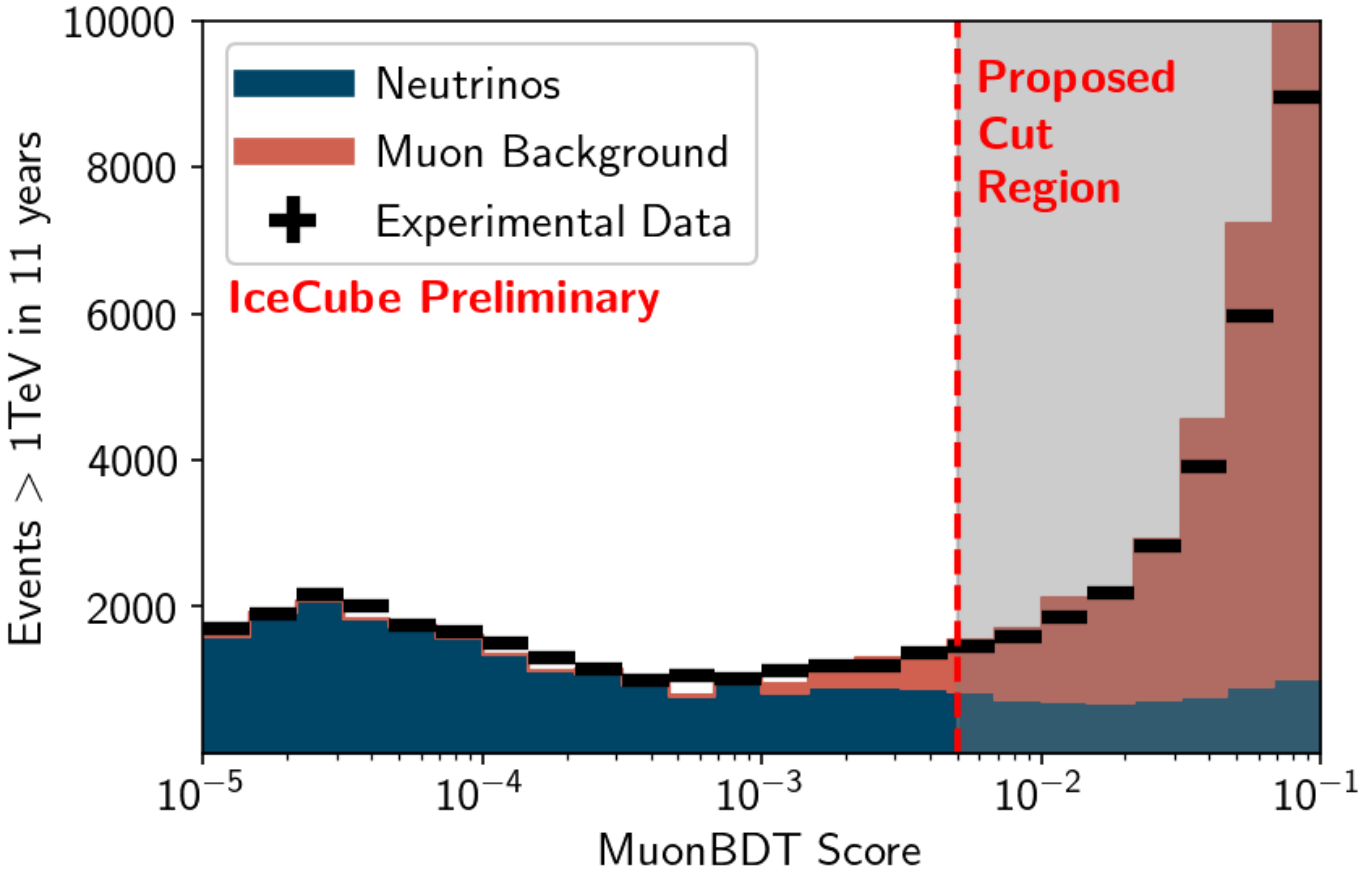
DNN Cascade

- All Sky Cascade Dataset
- Very low background even at lower energies
- Events are mostly contained
- Sensitivity is uniform throughout the sky
- Event pointing suffers
- Final Event Rate ~14 / day



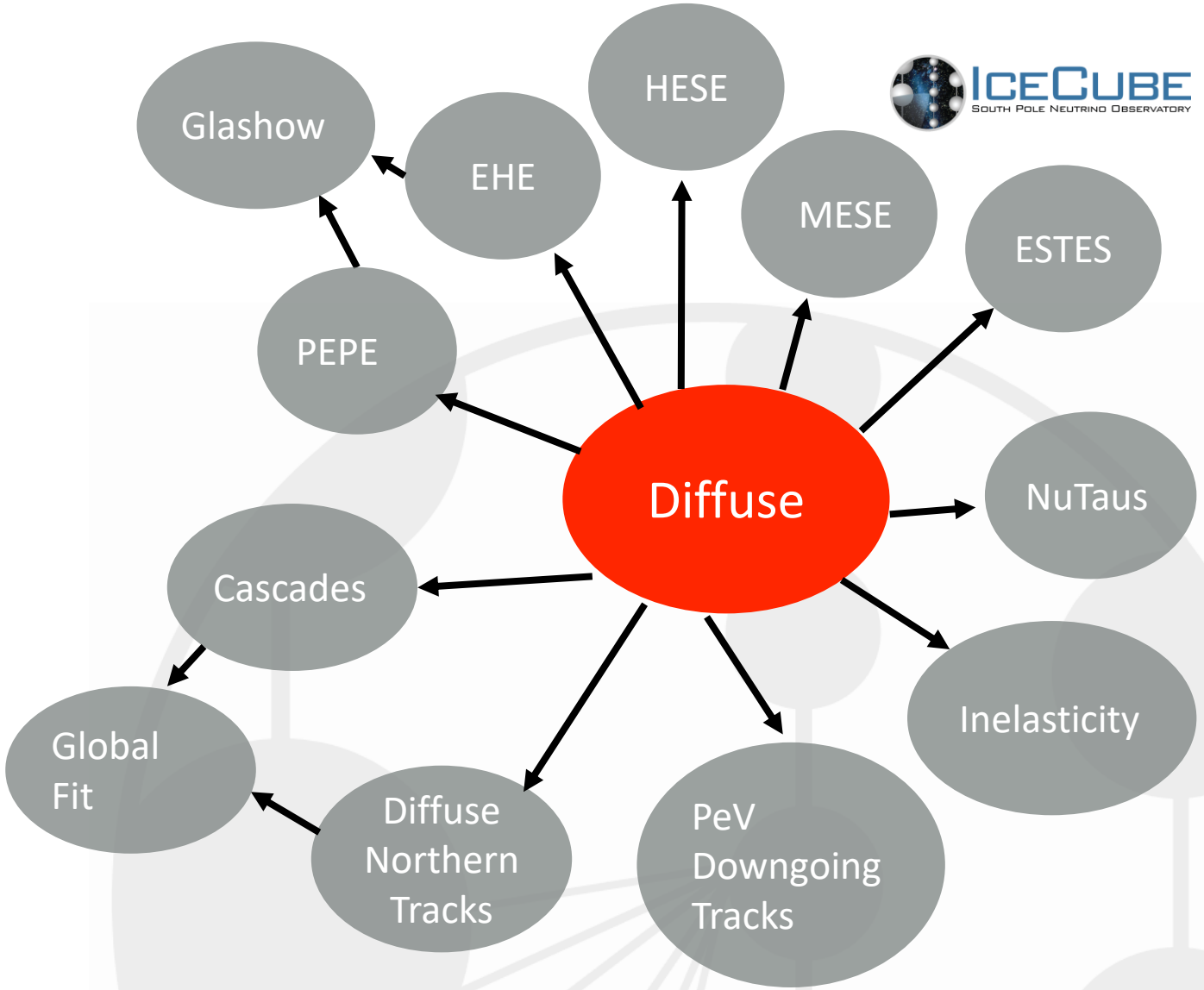
Selection Steps

- Run Many Small Deep-Neural-Net Classifiers and Regressors
- Take the results of these and a reconstruction – use as inputs to 2 BDT Classifiers
- **Classifier 1 – MuonBDT**
- Classifier 2 – CascadeBDT
- Selection is very fast



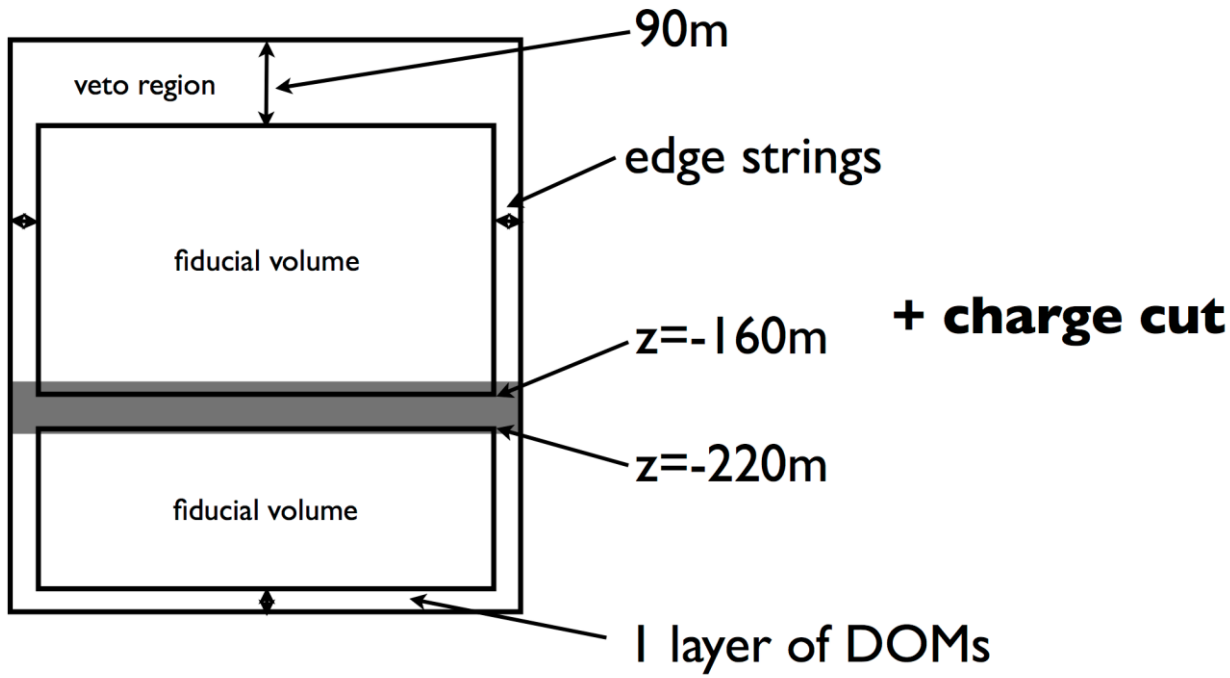
Diffuse

- WG Goal: Measure the astrophysical flux and understand the details of that measurement
- Also includes analyses focused on atmospheric neutrino fluxes
- Lots of different selections to do individual analyses / measurements
- Focused only on our data and don't care about pointing that much
- Good energy resolution is important
- Traditionally low background (and want to understand what background we see)
- Requires Good Data / MC agreement
- https://wiki.icecube.wisc.edu/index.php/Diffuse_Cosmic_and_Atmospheric_Neutrinos



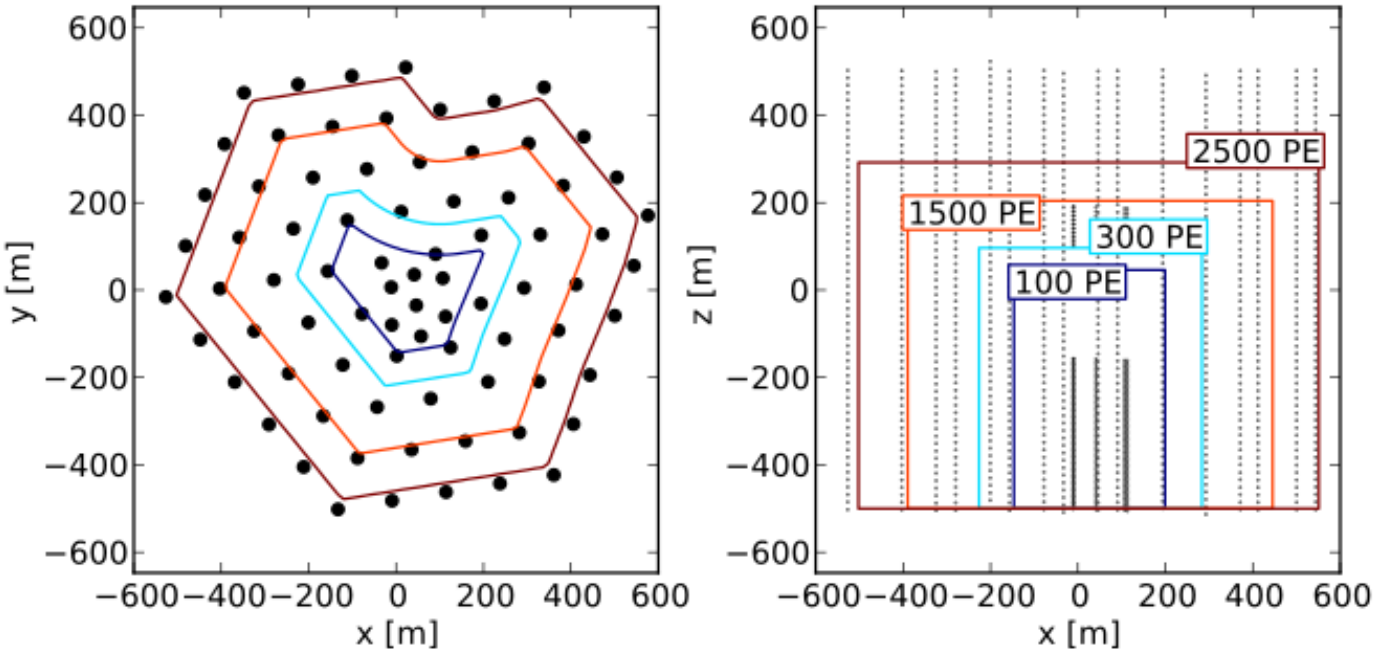
High Energy Starting Events (HESE)

- Make a cut on total energy
  - Qtot > 6000 PE
- Select Events starting inside veto region
- Event Rate 1 - 10 events / year (depending on how pure you want)
- Dataset can be used for various measurements



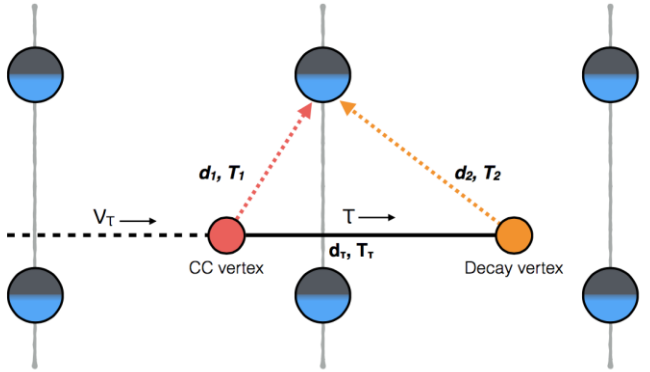
Medium Energy Starting Events (MESE)

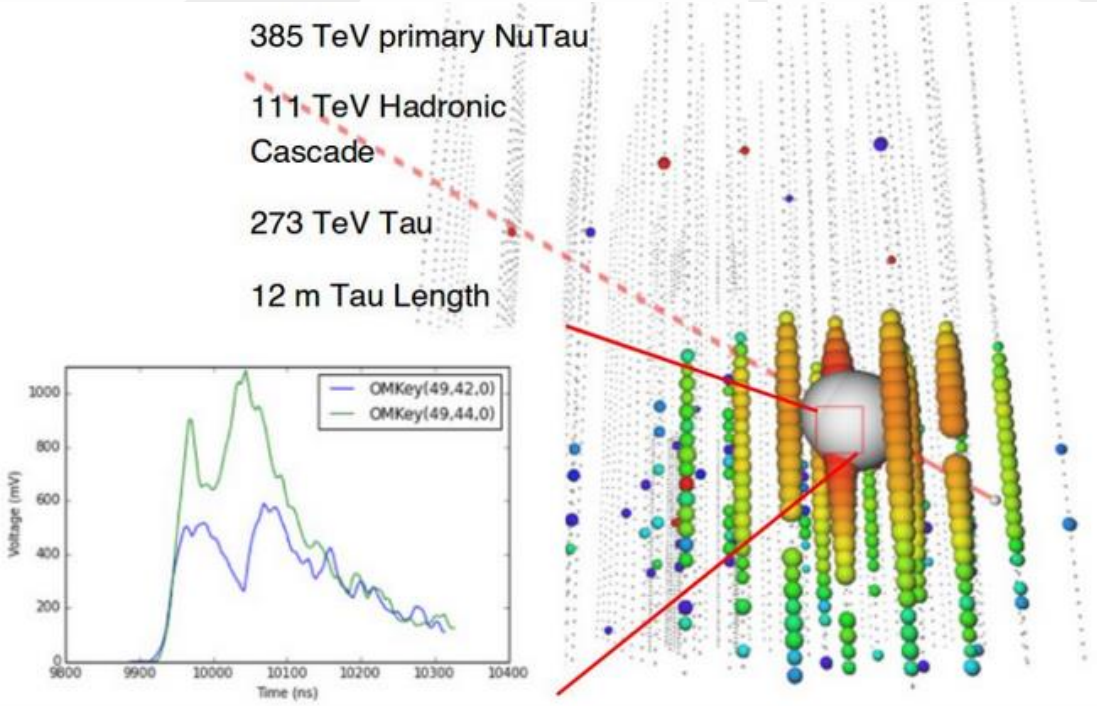
- We can loosen the cut on Energy if we are more sure the event didn't "sneak" into the detector
- Can use this technique to lower the required energy



NuTau Double Pulse

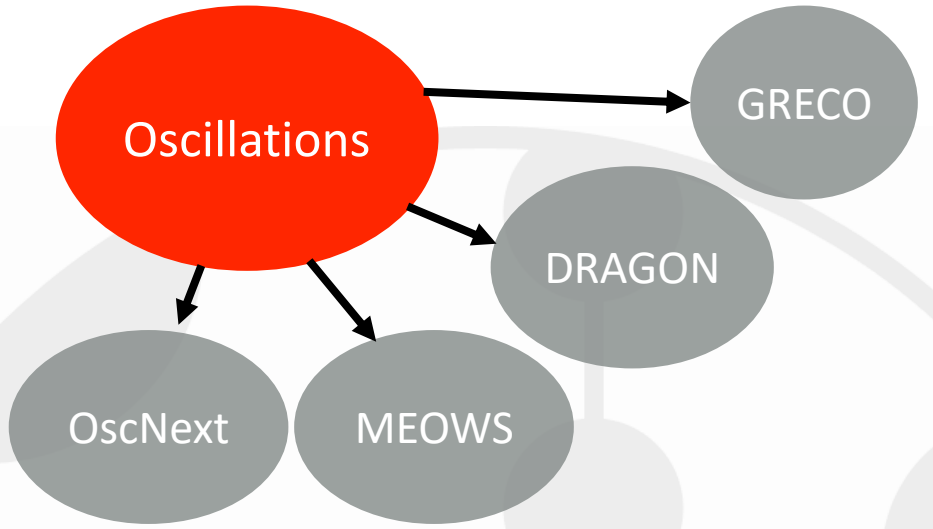
- Tau events are rare, but very useful in the measurement of the astrophysical flavor ratio
- Double Pulse looks for the signature from a nuTau CC interaction without needing the tau to travel far enough to be distinguishable from the first cascade
- Can use machine learning or more traditional cuts to identify
- Very Low final event rate. ~O(1)



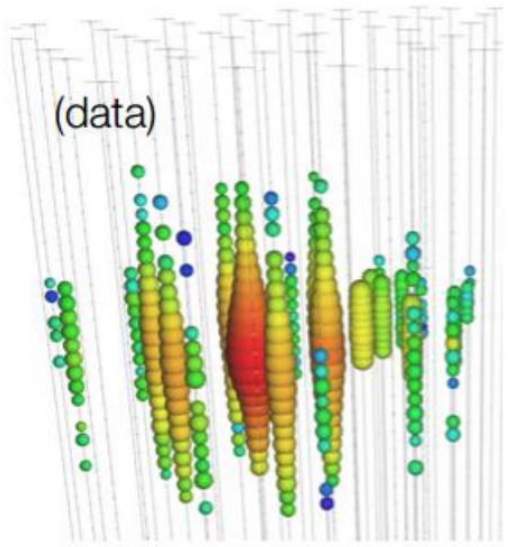


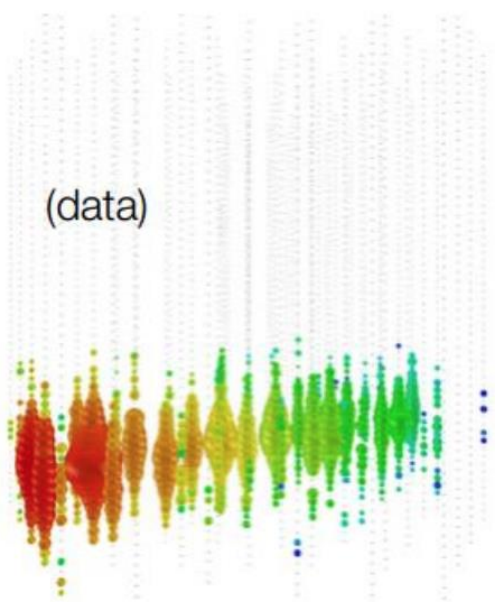
Oscillation

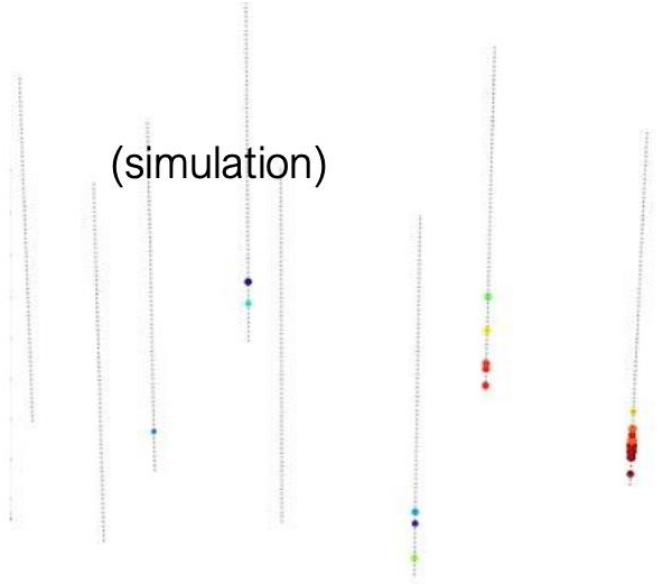
- Use low energy, atmospheric neutrinos to measure oscillation parameters of neutrinos
- Very different event regime than Diffuse or Nu-Sources
- https://wiki.icecube.wisc.edu/index.php/Neutrino_Oscillations_Working_Group_Page#Oscillations_data_samples



OscNext

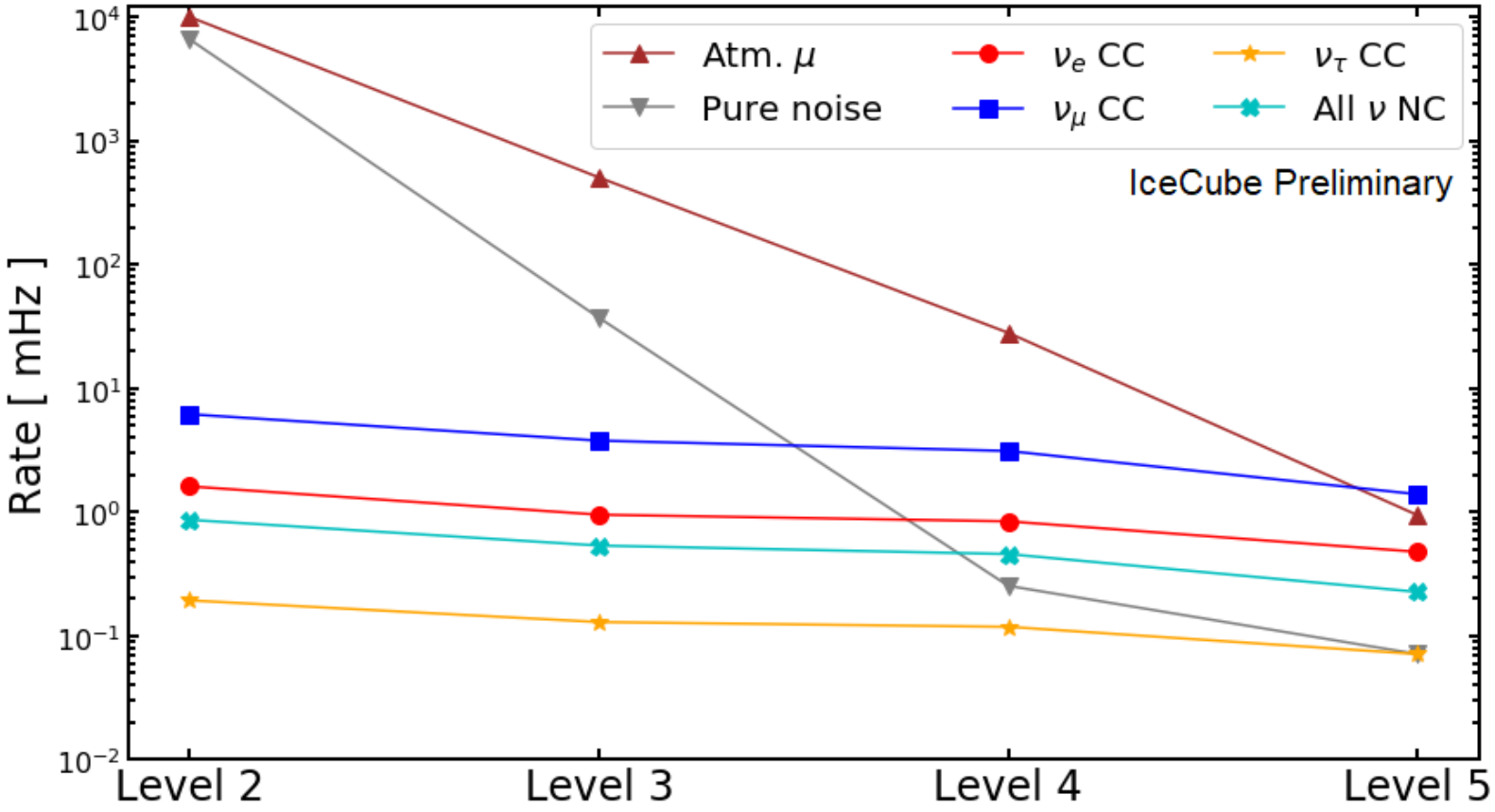






OscNext

- Level 4 and Level 5 BDTs to remove the background of noise hits and atmospheric muons
- Low event rate, ~80 events / day



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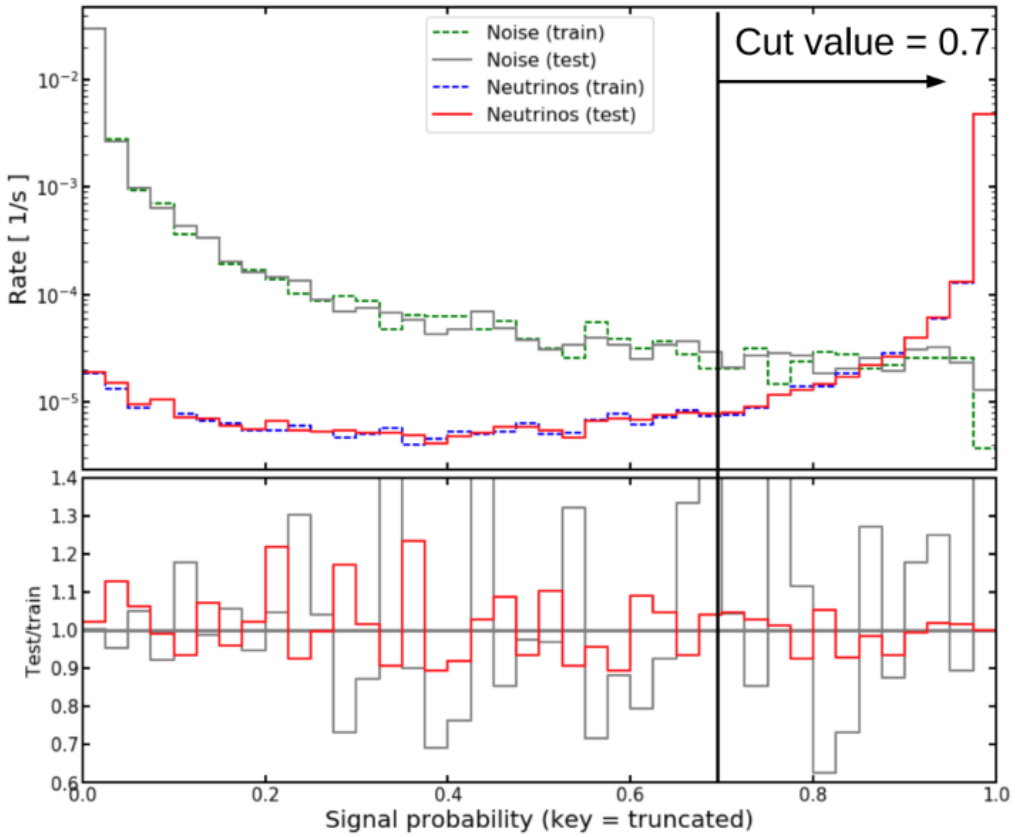
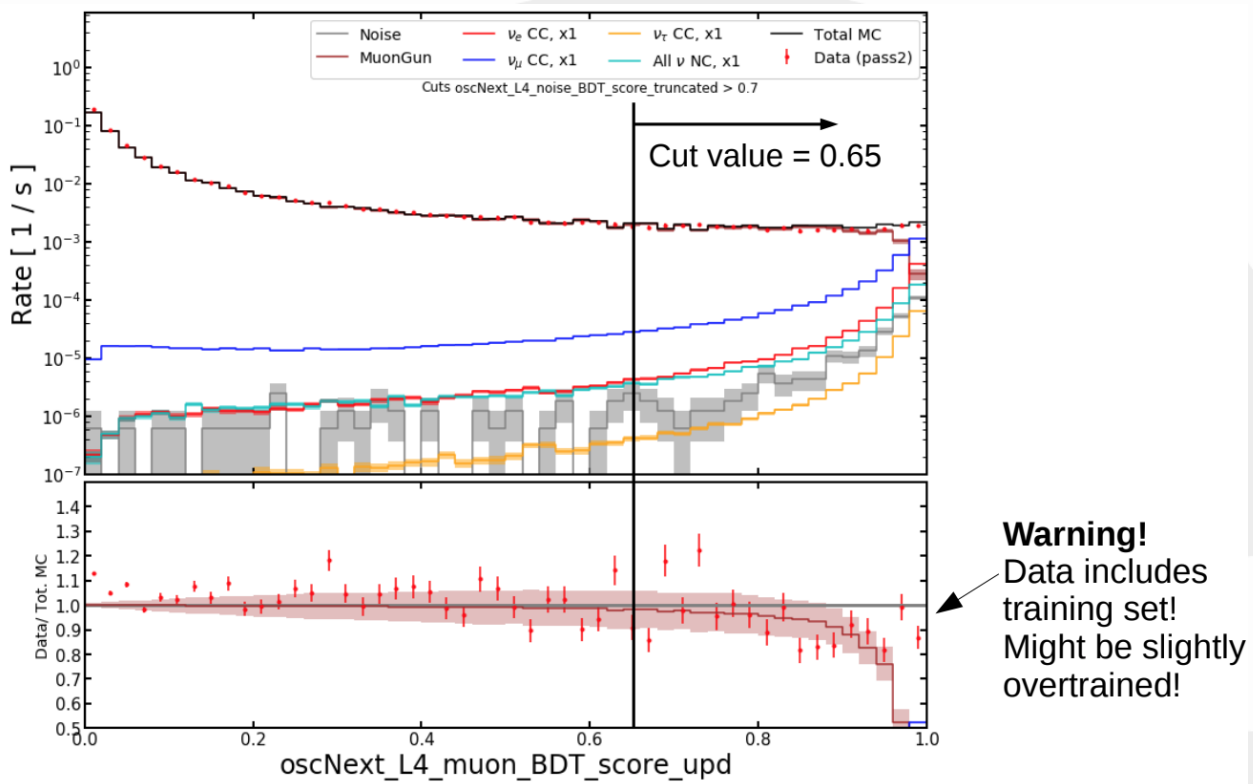


BDT Step 4 – remove Noise Hits keep Neutrinos



Warning!
Data includes training set!
Might be slightly overtrained!

BDT Step 5 – Remove Atmospheric Muons Keep Neutrinos

Conclusions

- Small slice of event samples
- Machine Learning is used a lot in this stage
- Any analysis requires a dataset, but they don't have to be done from scratch
- Good news is lots of the work is done – you can usually find a good starting point dataset already complete
- Working Groups should be able to point you in the right direction / recommend a dataset, etc.