EVENT SELECTIONS IN ICECUBE

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Bootcamp 2019

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WISCONSIN

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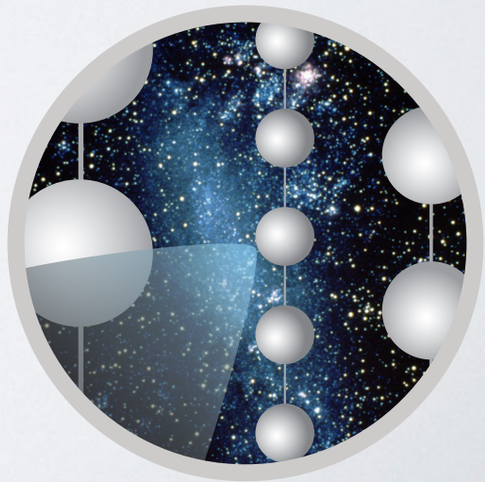
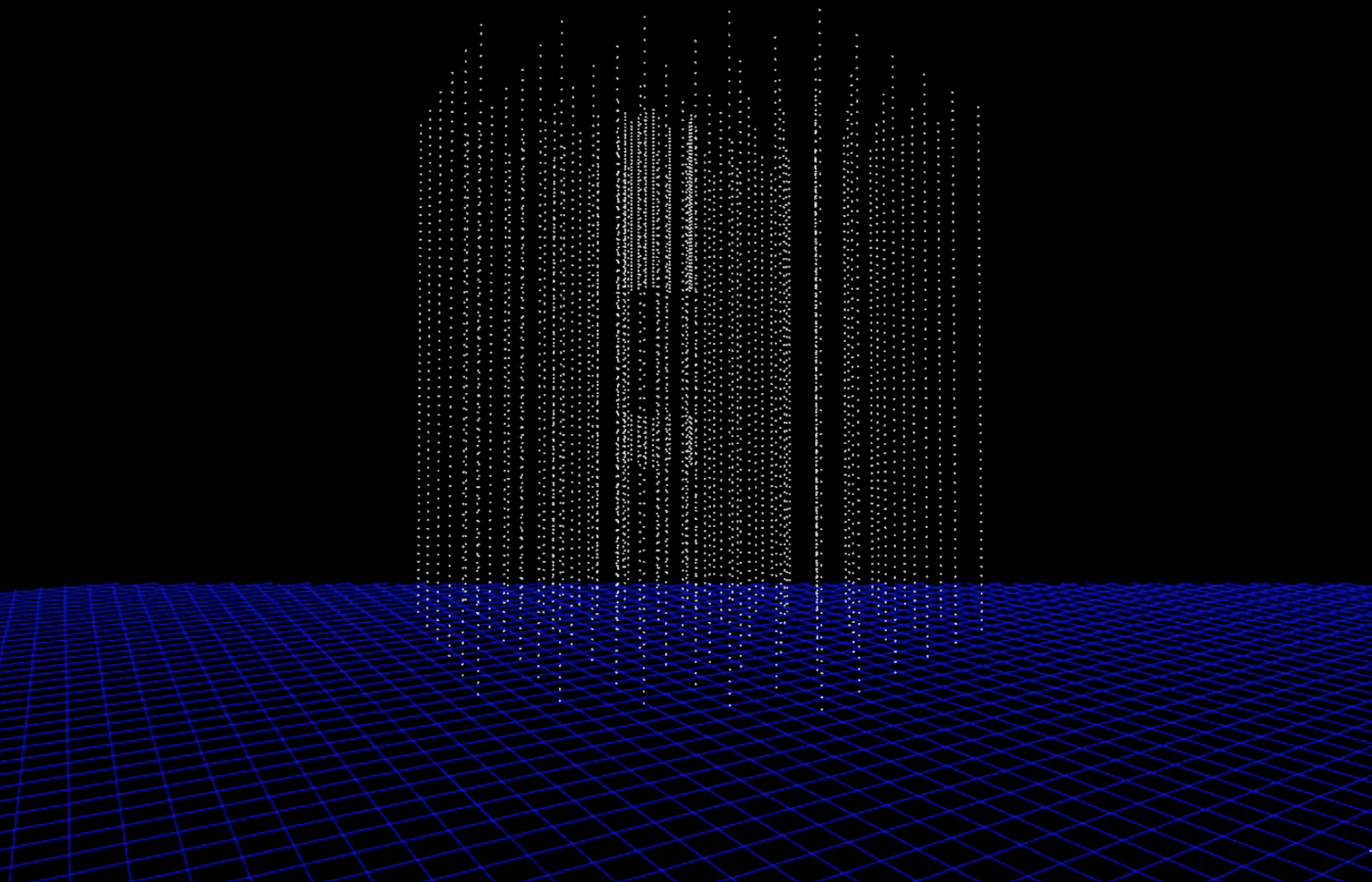


ICECUBE



INTRODUCTION

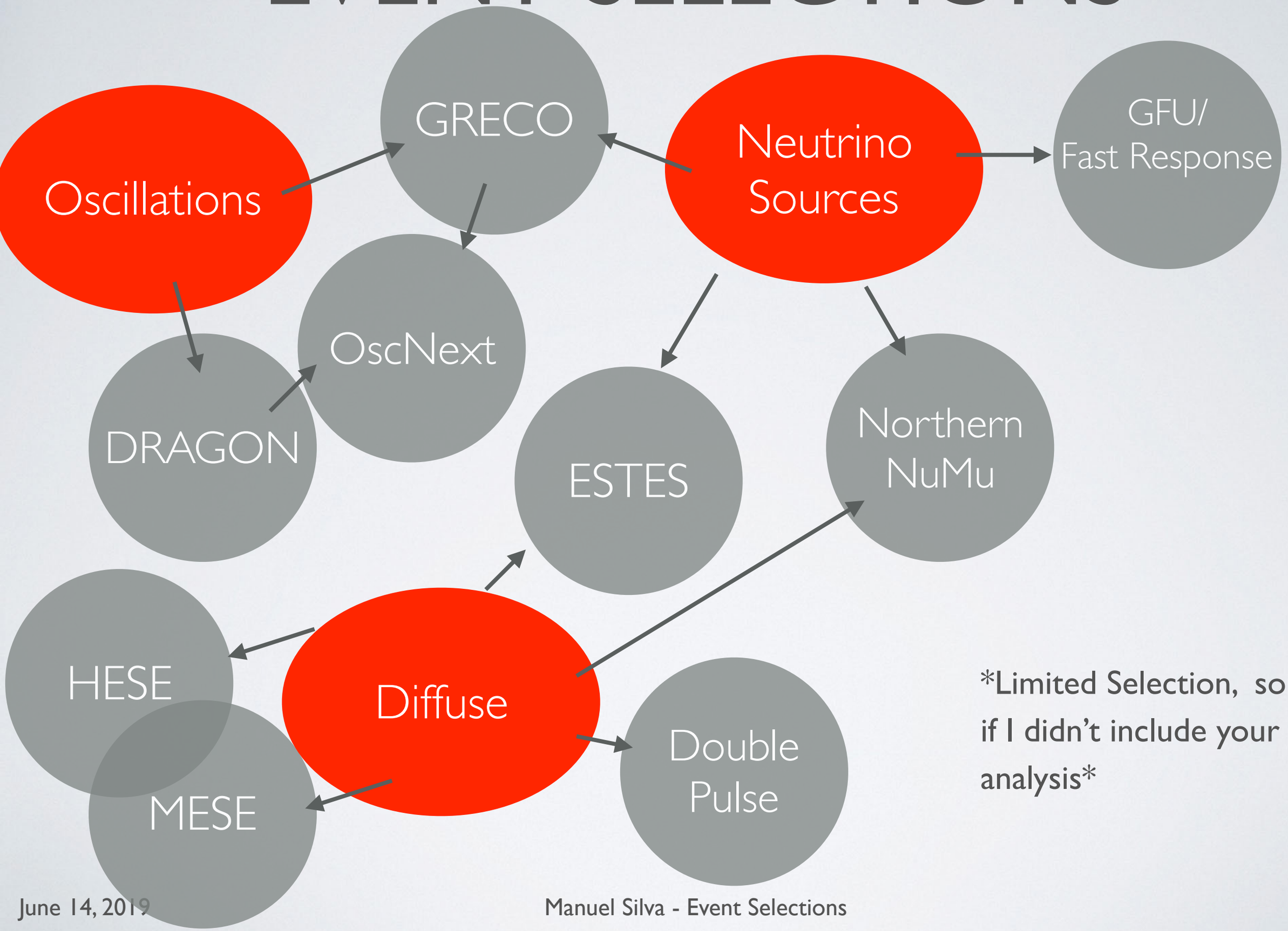
- IceCube takes "pictures" of all these events….
- But how do you differentiate a muon from a neutrino? Astrophysical Neutrino vs Atmospheric Neutrino?

Filters! Cuts! Vetos! BDTs!

What particles are they searching for? Energy range?

Do they have background contamination? What is this background?

EVENT SELECTIONS

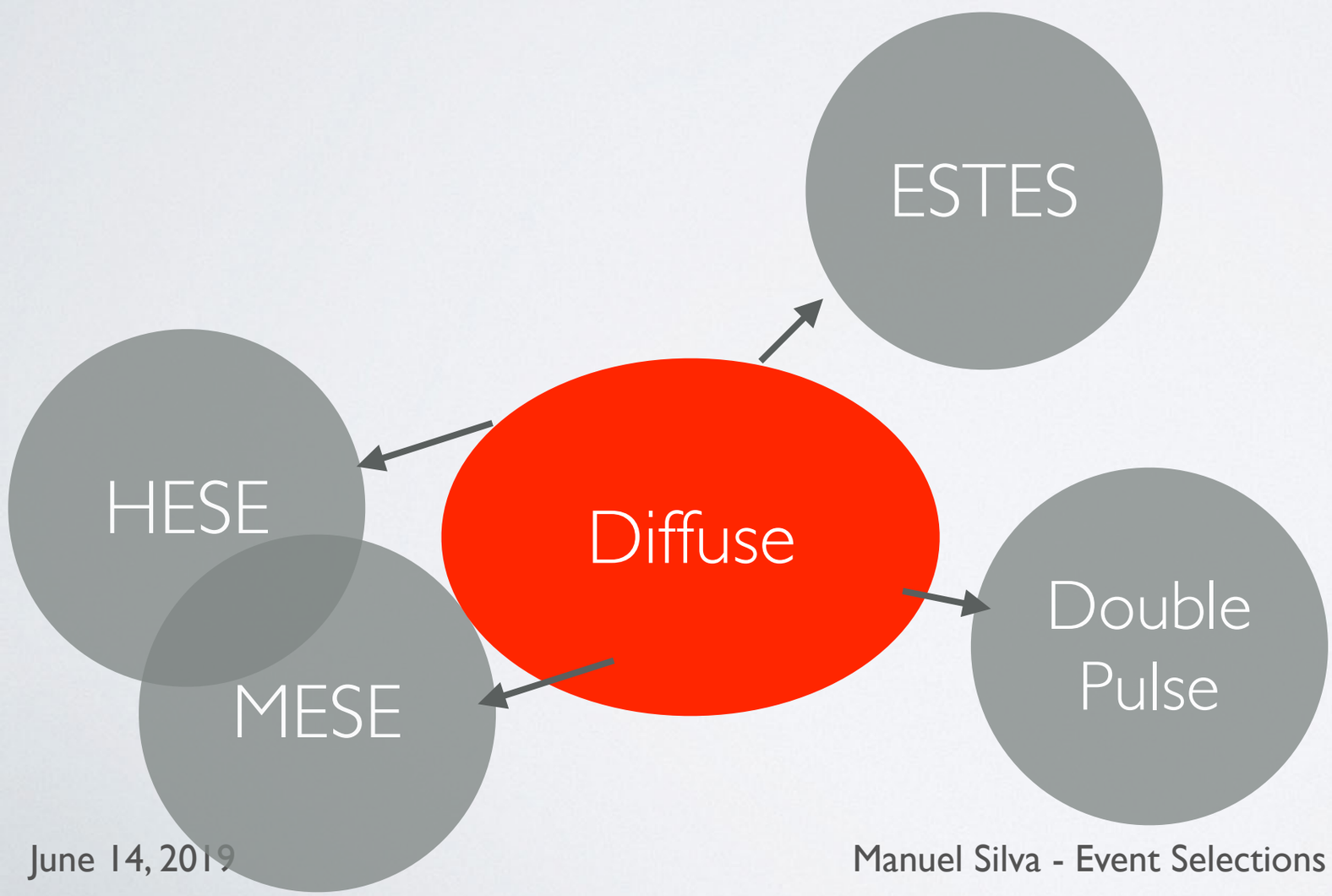


Limited Selection, sorry if I didn't include your analysis

DIFFUSE

- Goal of group is to identify and measure atmospheric and/or astrophysical neutrino properties

- All neutrino flavors of various energies

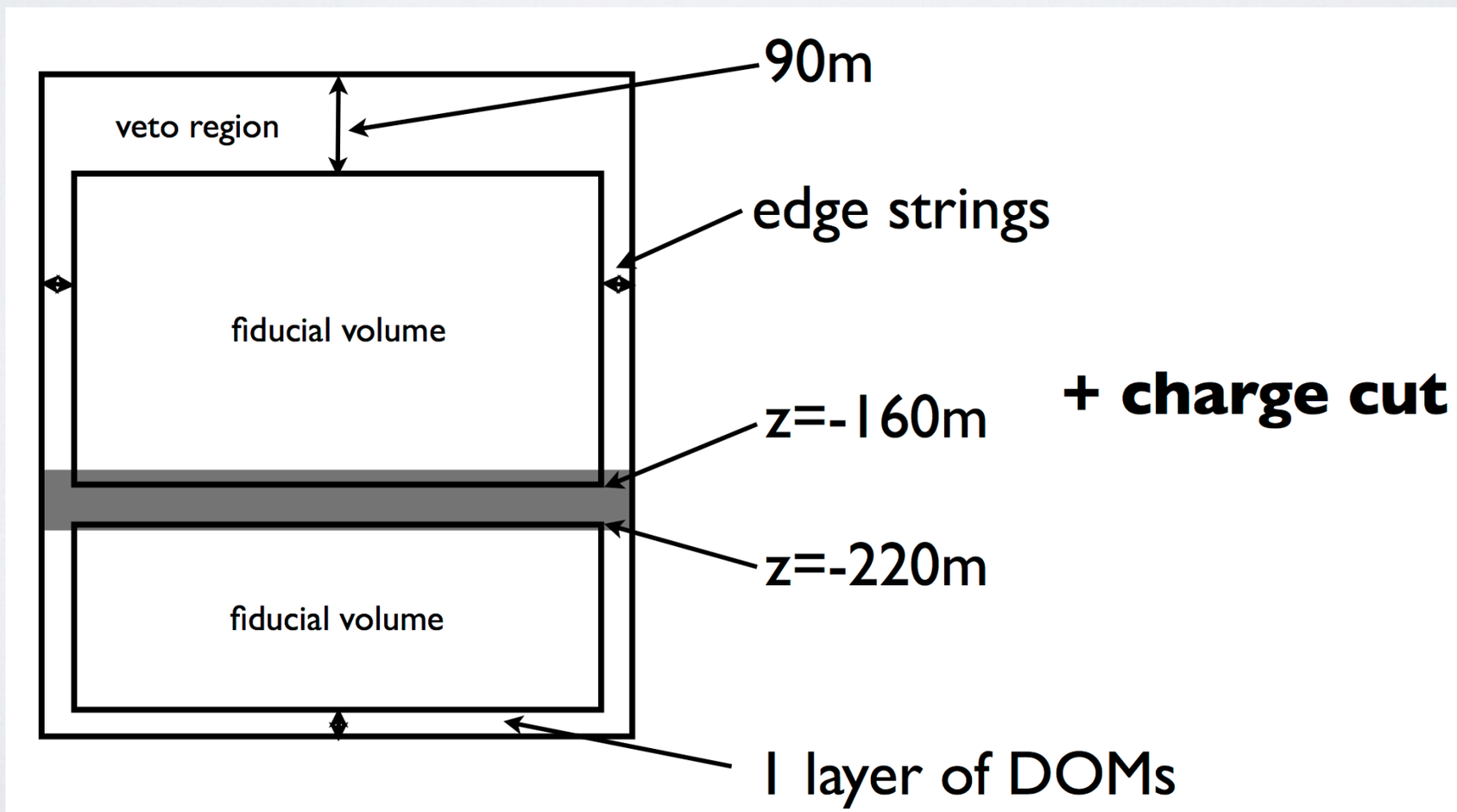


- Requires different techniques for Northern vs southern sky

- Etc…

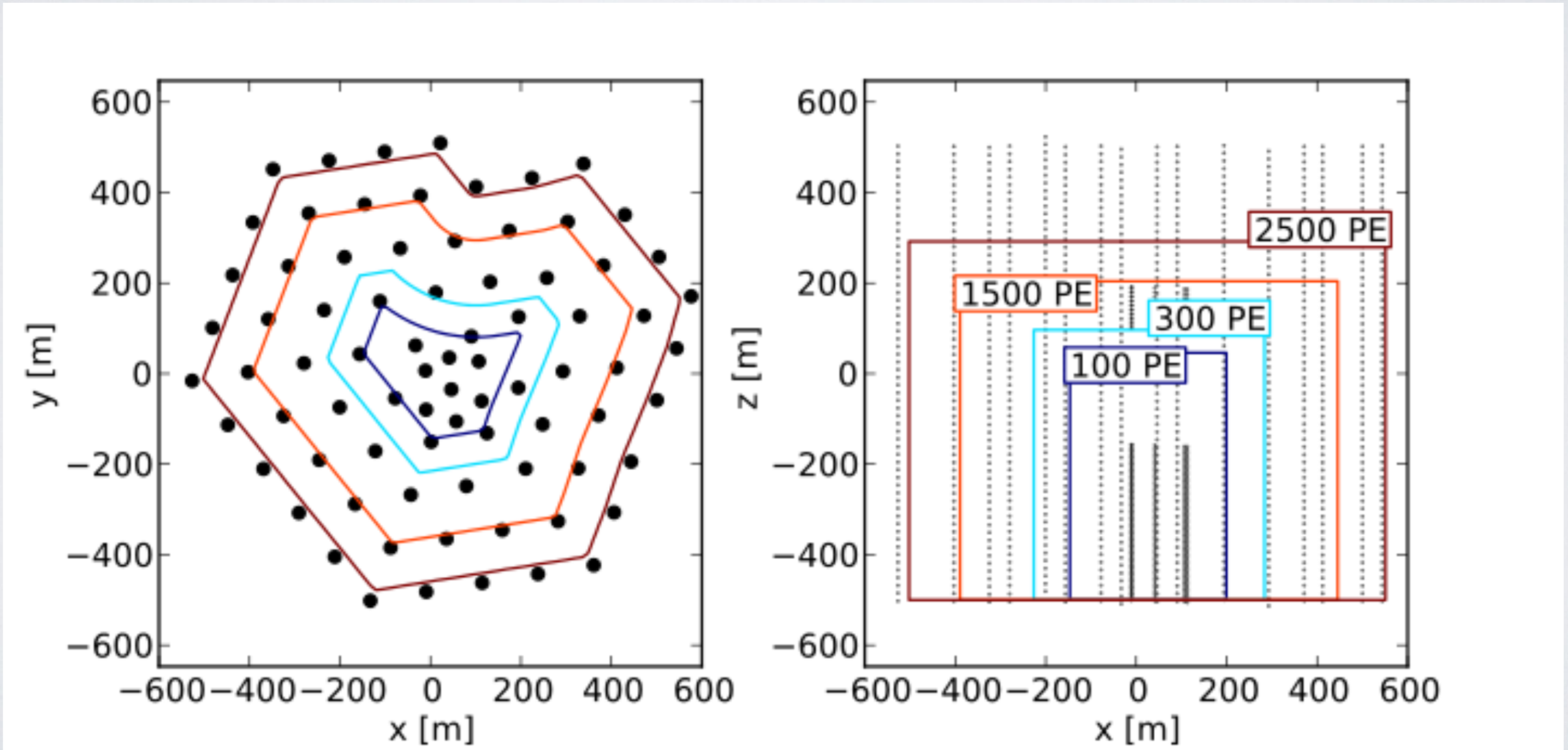
HESE

- High Energy (HE) Cut, Q_{tot} > 6000 PE
- Use outer layer of DOMs as veto region, cut on Starting Events (SE)



MESE

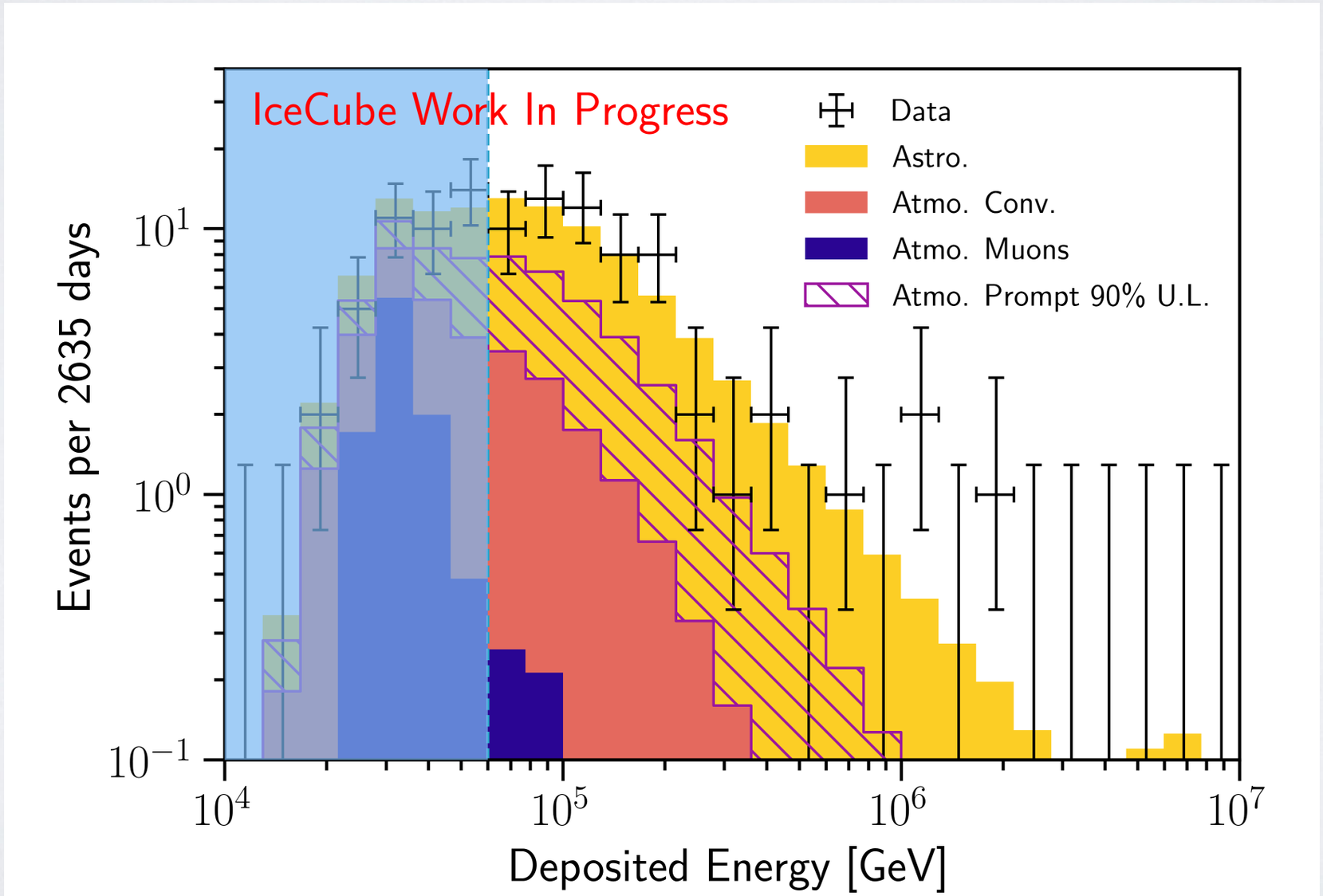
- Similar to HESE, but now add more veto layers for medium energies (ME)
-



HESE RESULTS

- High energy neutrinos, high astrophysical purity, equal preference for all flavors

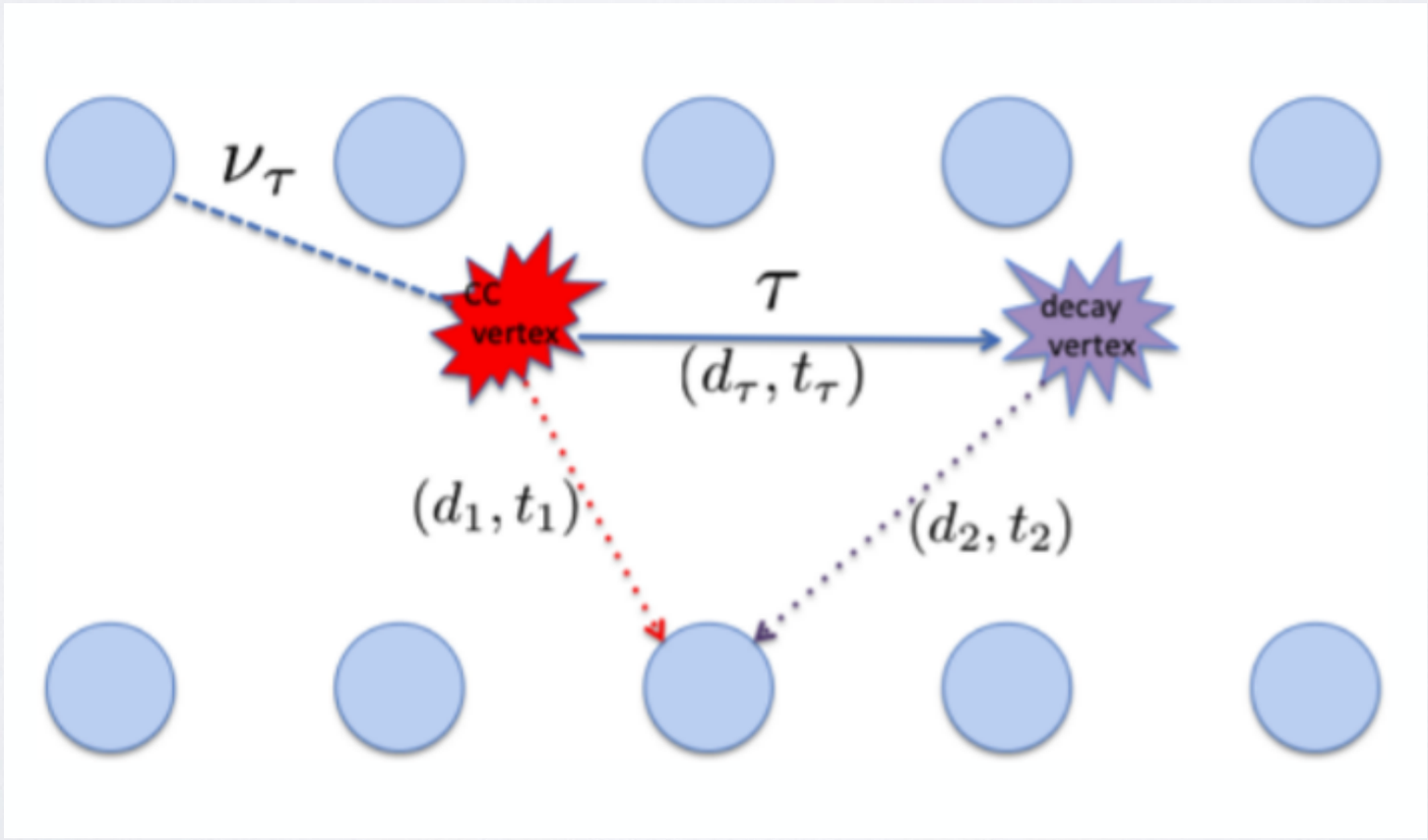
-



DOUBLE PULSE

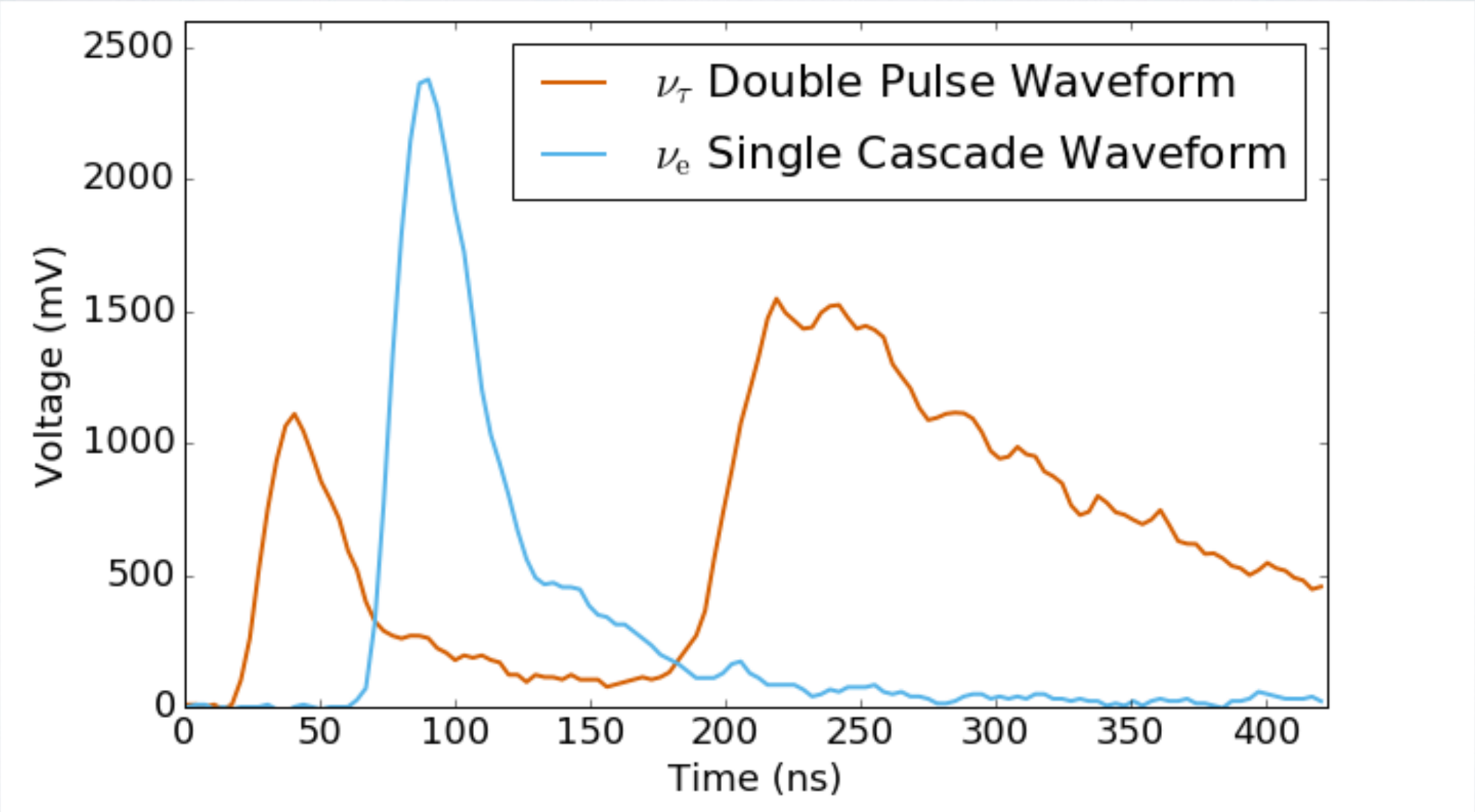
- Tau neutrino interacts within IceCube and produces a tau lepton

- Tau lepton travels before decaying, 2nd vertex

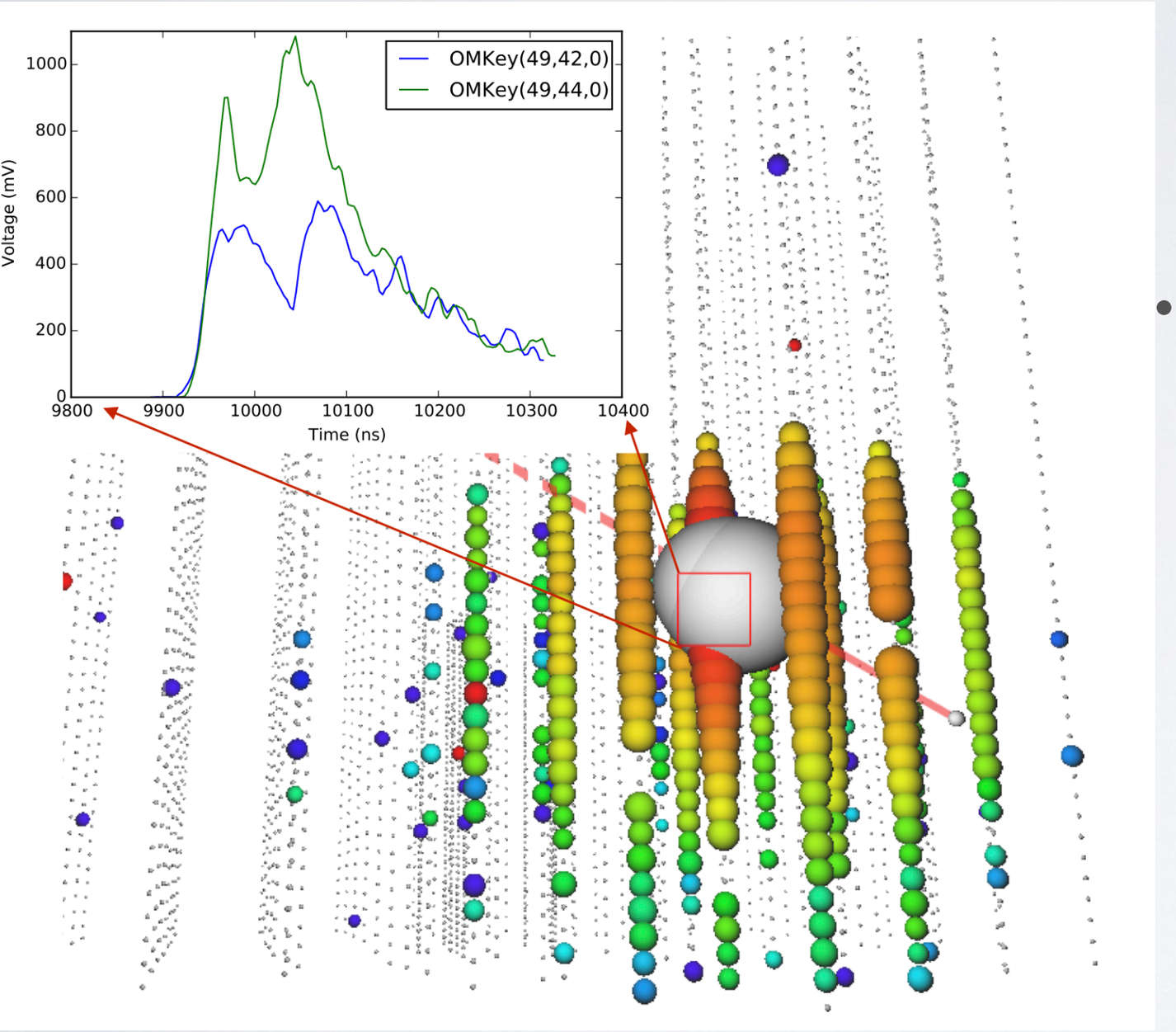


DOUBLE PULSE

- Use waveform from DOMs, apply series of cuts on the shape of the waveform



DOUBLE PULSE RESULTS



- **IceCube found tau neutrinos!!**

- 2 additional techniques underway to validate each other

  - Double Cascade Analysis

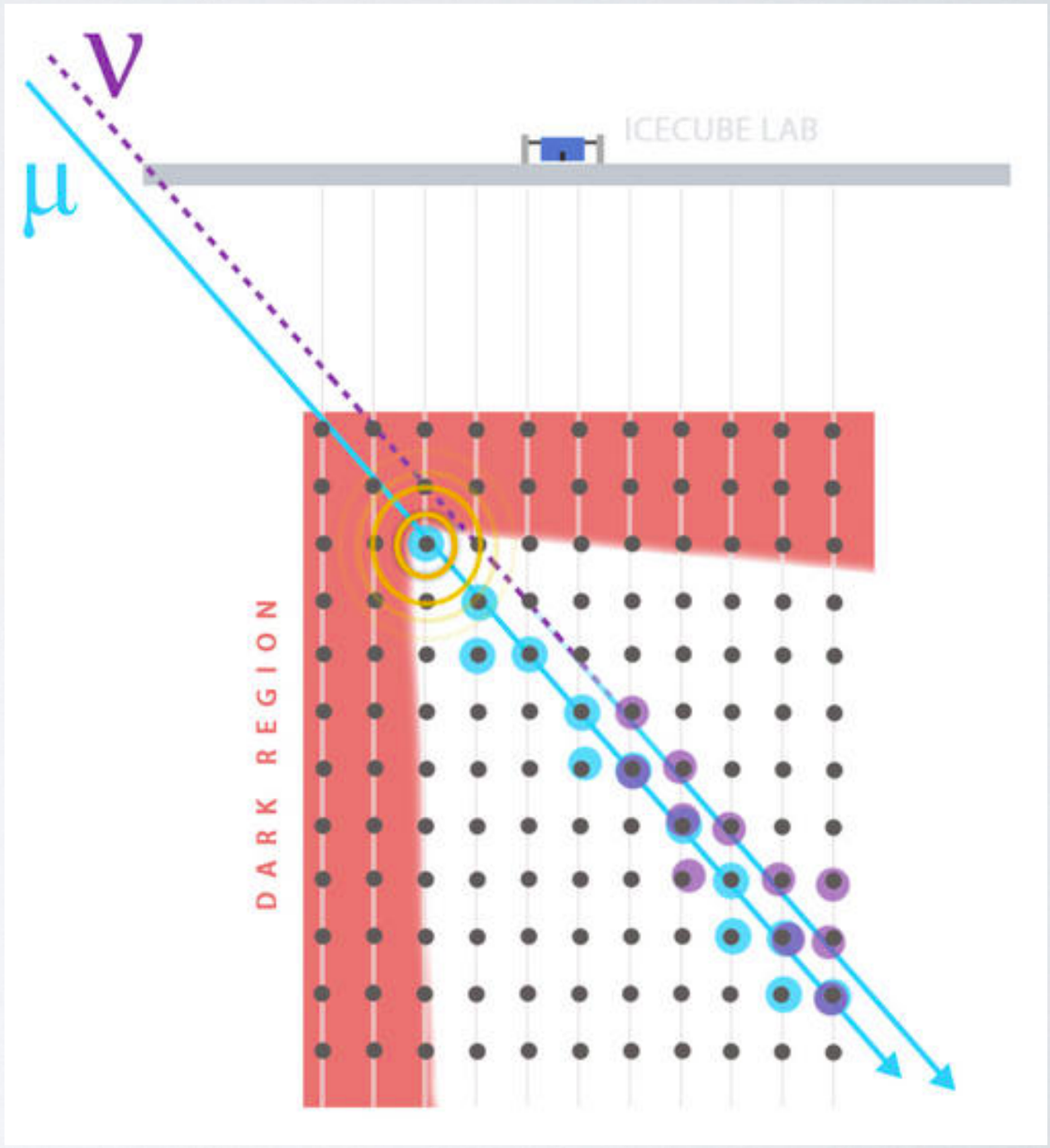
  - Deep Neural Network Analysis

ESTES

- **E**nhanced **S**tarting **T**rack **E**vent **S**election

- Prefer downgoing muon neutrinos, will need to veto atmos. muons

- DOM with first PE combined with track create the “dark region”



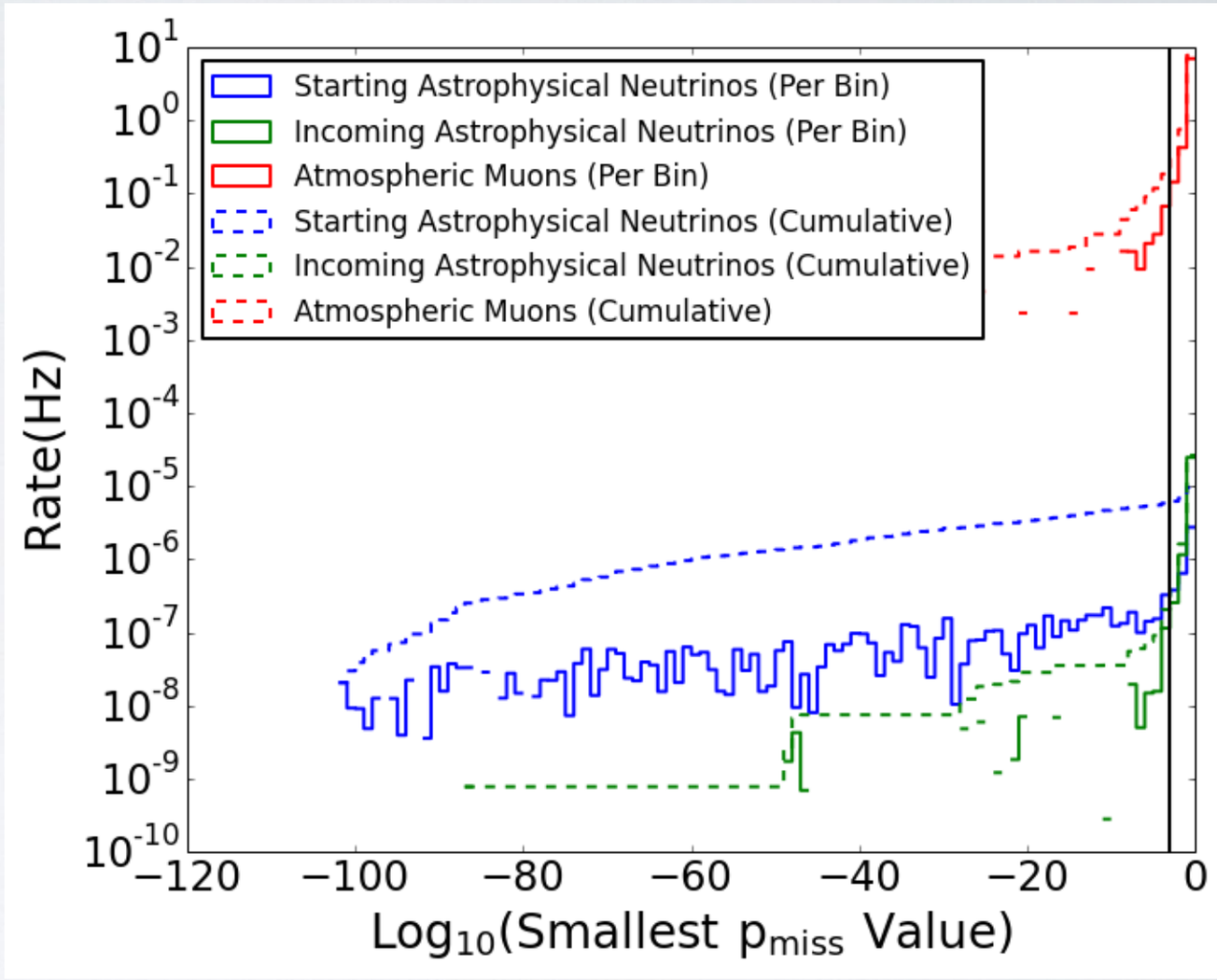
ESTES

- Probability to not see any PE in the dark region, p_{miss}

$$log(p_{miss}) = \sum_{i}^{All\ Veto\ Region\ DOMs} log(p(\lambda_i(\hat{a}, 0))$$

- Straight cut on p_{miss}

- 100 million muons per year reduced to 10 thousand



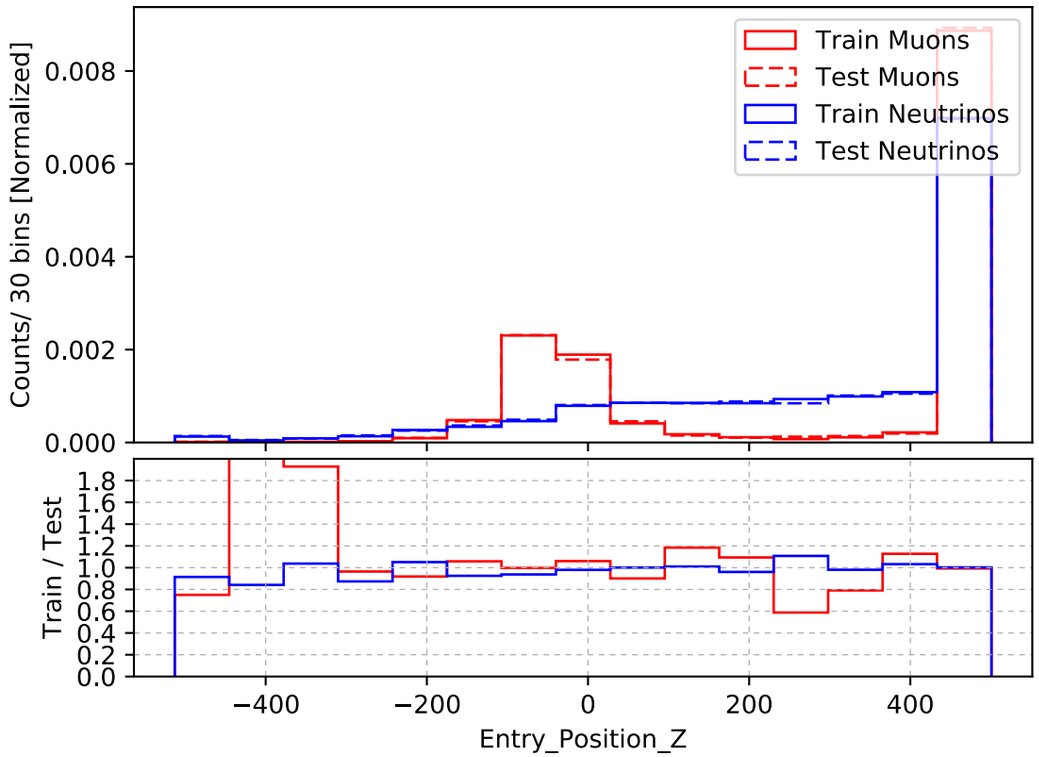
ESTES

- Use a Boosted Decision Tree (BDT) to minimize muons entering our final event selection

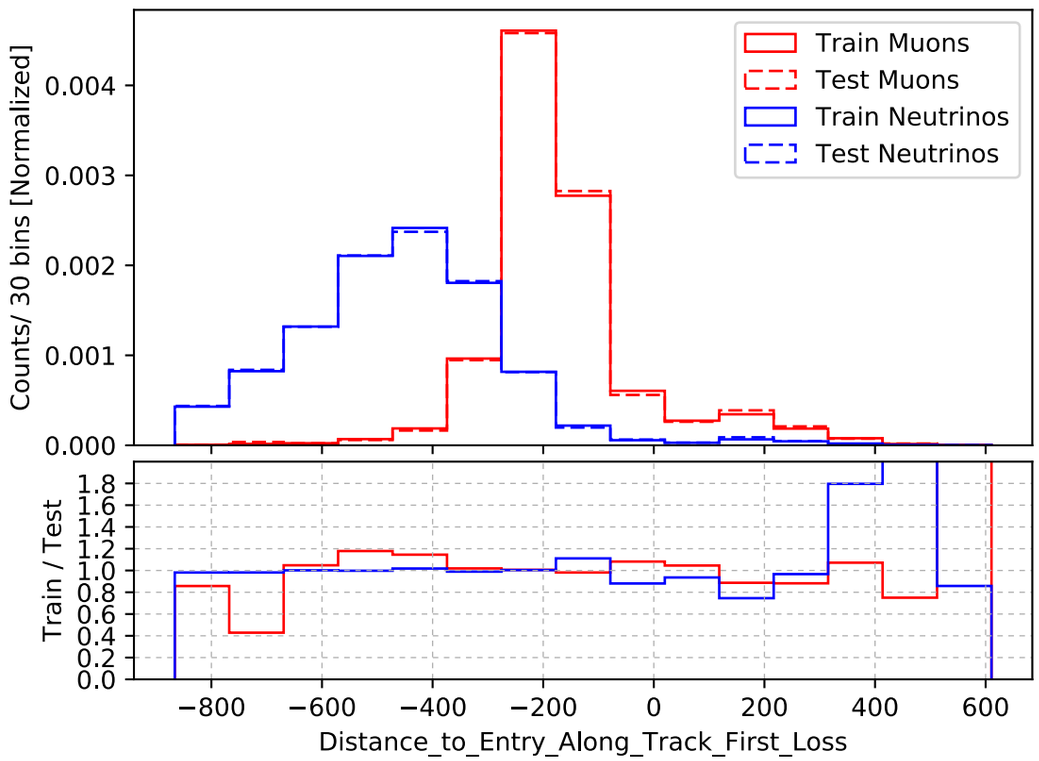
- Use 16 event properties as input to the BDT, in the end the BDT ranks them in order of "importance"

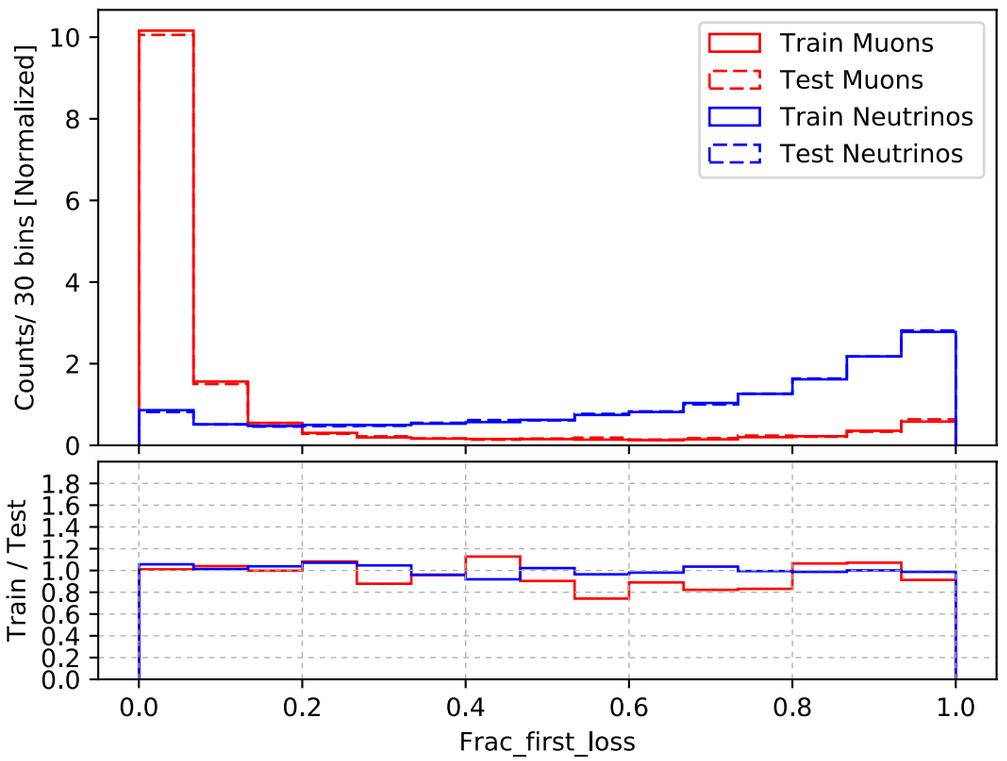
Z of entry position	Distance to from first millipede loss to edge (closest)	Fraction of energy in first millipede loss	Distance to edge along track	P_{miss} from segmented track calculation
Number of millipede losses	Total energy of millipede losses	Fraction of hits that are direct	Length of millipede losses	Millipede zenith angle
Fraction of charge on edge of detector	Number of fits tested in coarse search	LineFit speed	P_{miss} from Cherenkov calculation	Millipede ↔ LineFit space angle

ESTES



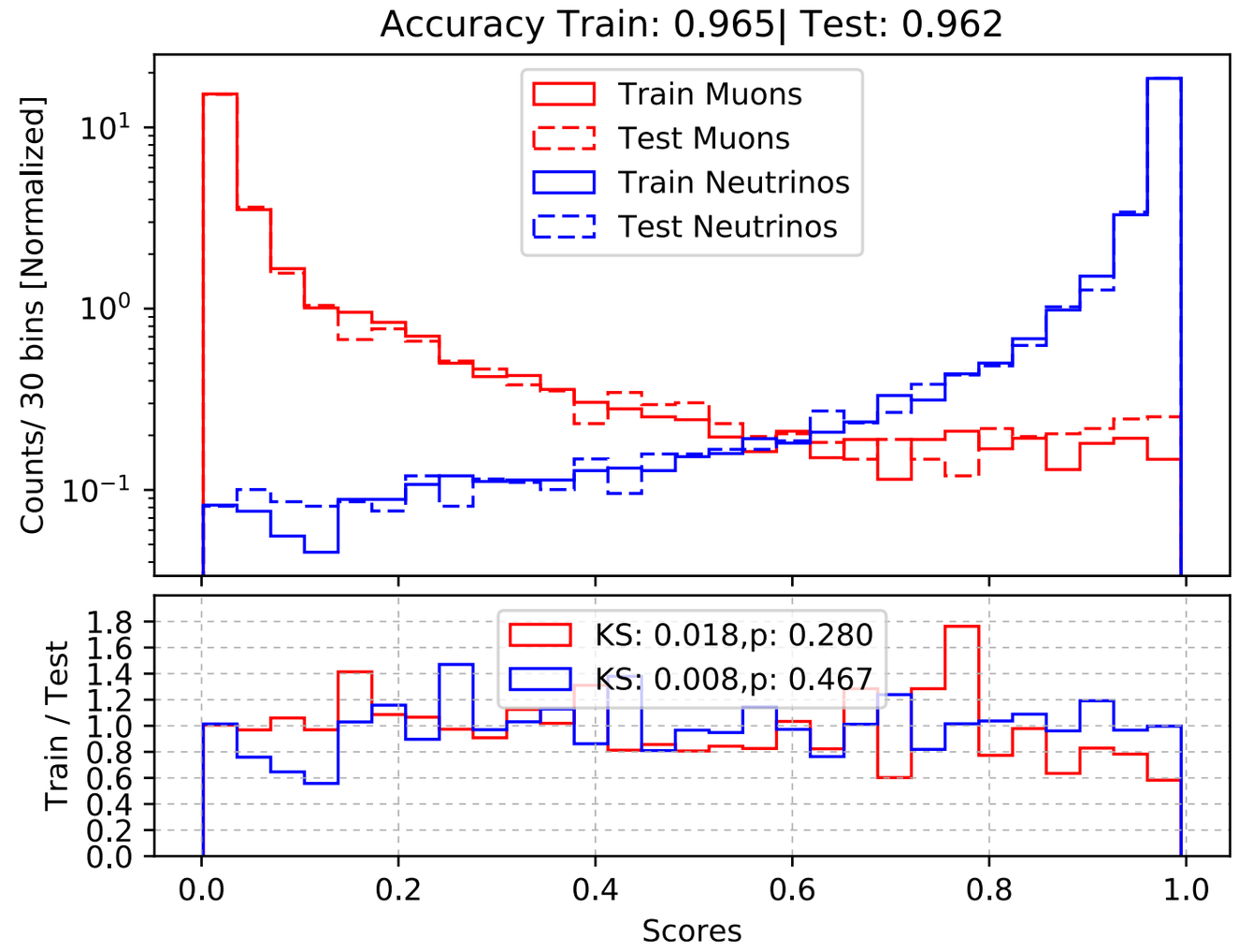
- Most important inputs according to the BDT shown here





ESTES

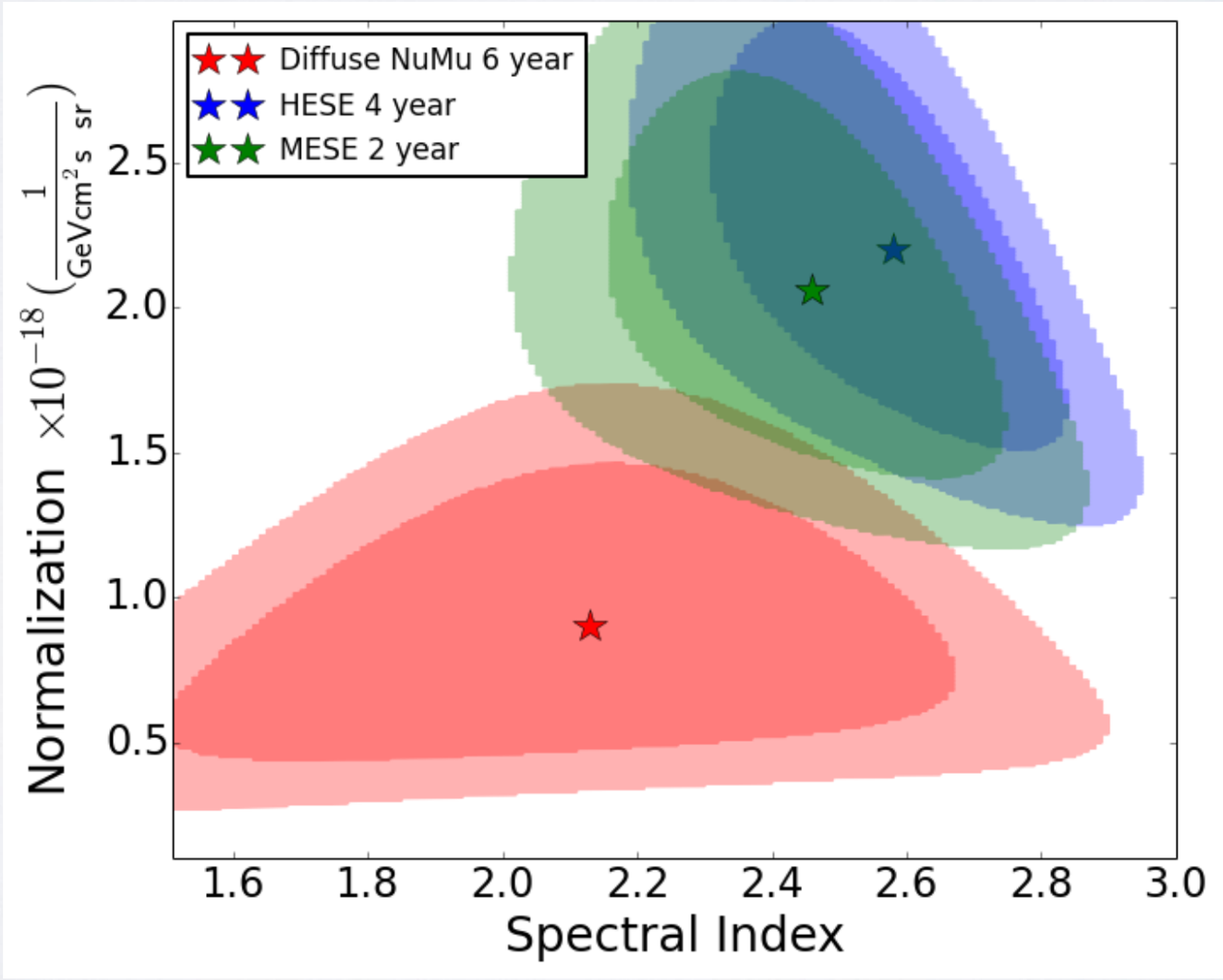
- The BDT assigns a probability of being a muon vs muon neutrino, apply a single cut now on BDT score



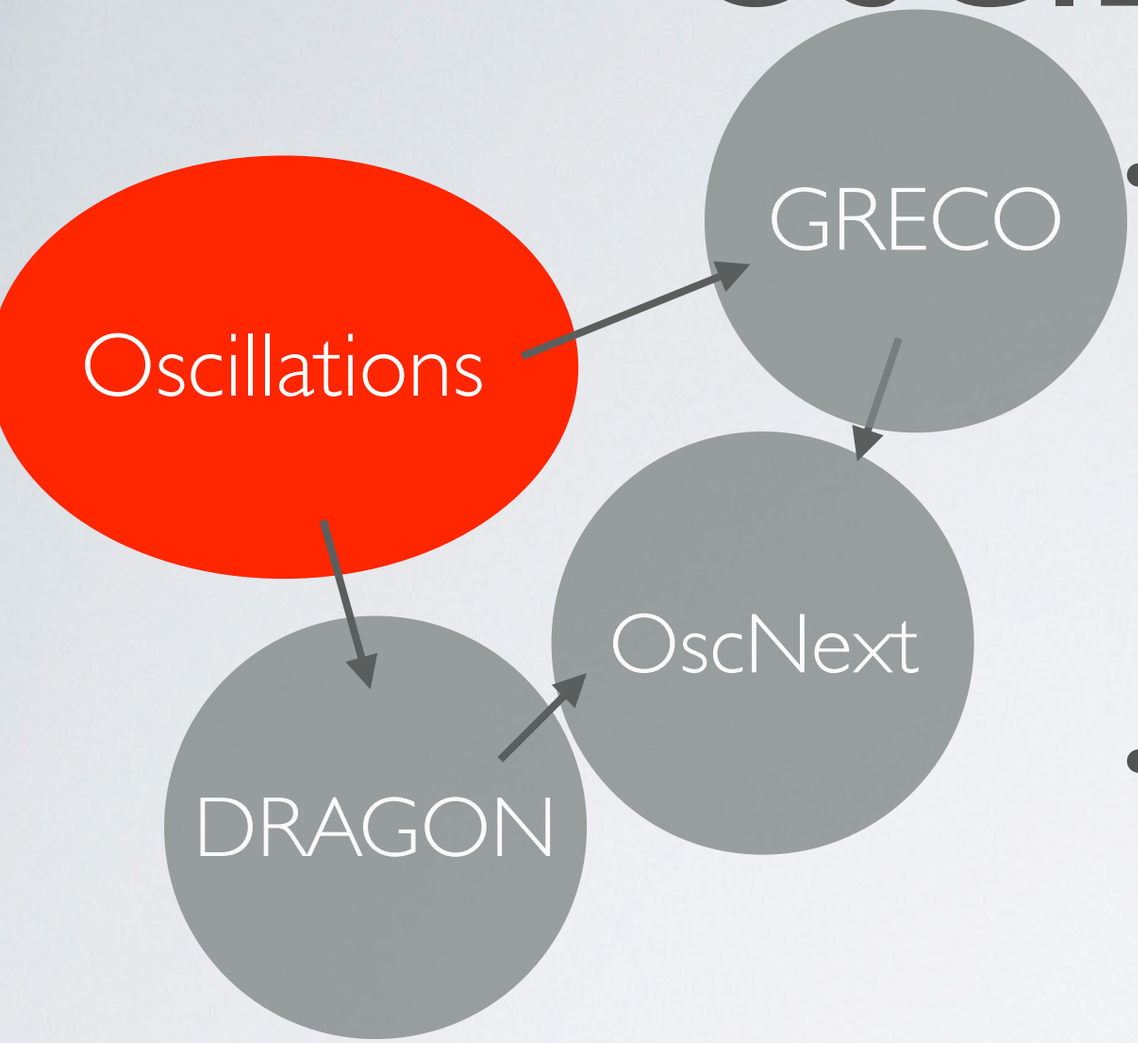
- Cut on score such that muon rate is < 1 muon per year

ESTES - RESULTS

- ESTES was able to validate 3 different published diffuse measurements



OSCILLATIONS



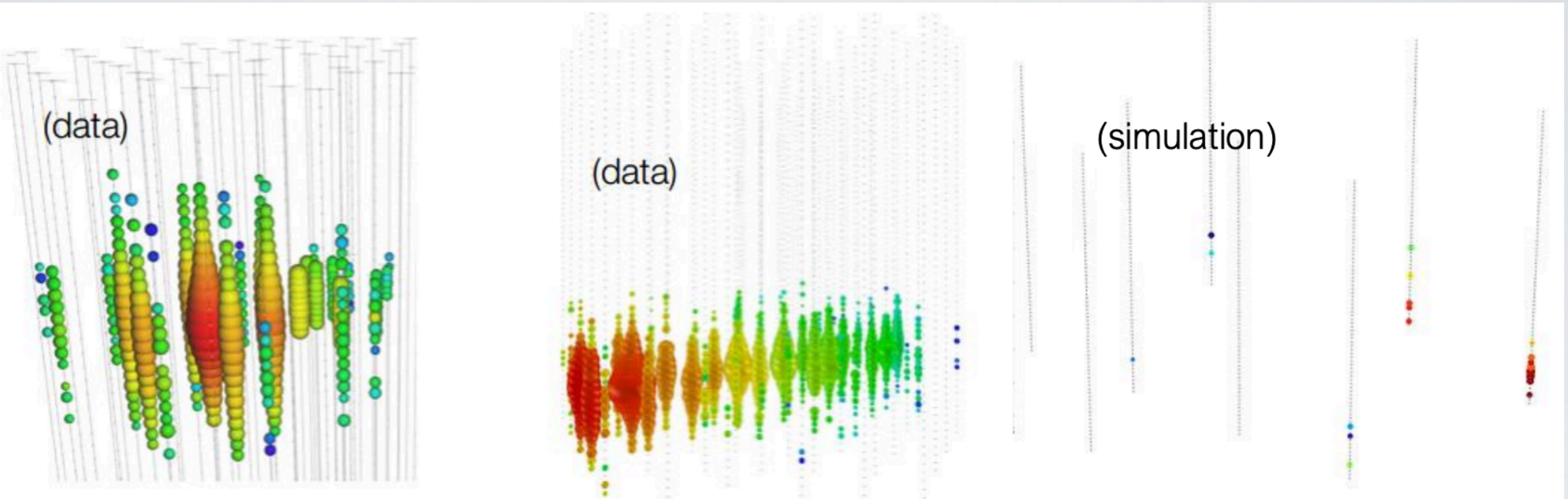
- 2 different event selection used up to 2019, <u>different physics goals</u>

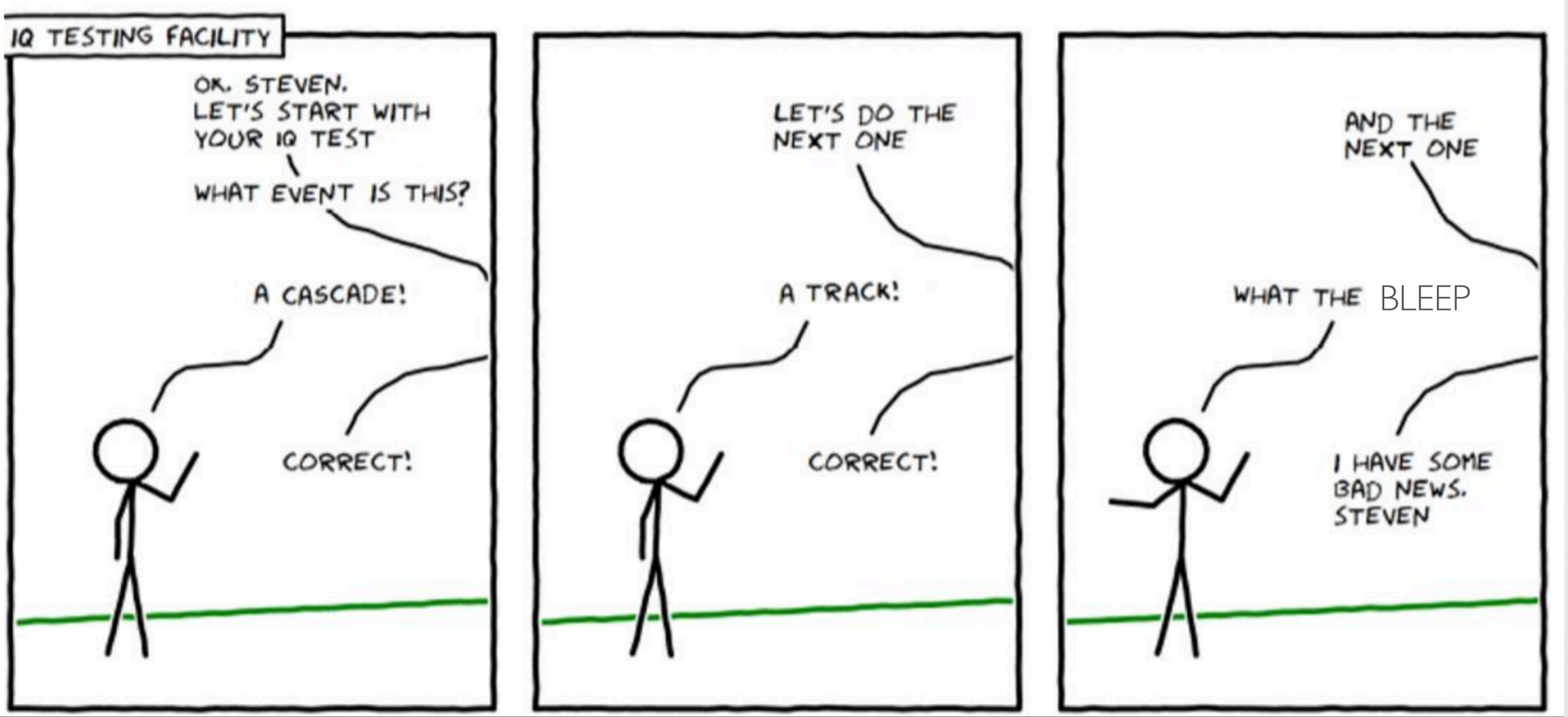
- GRECO and DRAGON now united under **OscNext framework**

- Low energy neutrinos, primarily atmospheric

Cred:
Jan Weldert

OSCNEXT





OSCNEXT

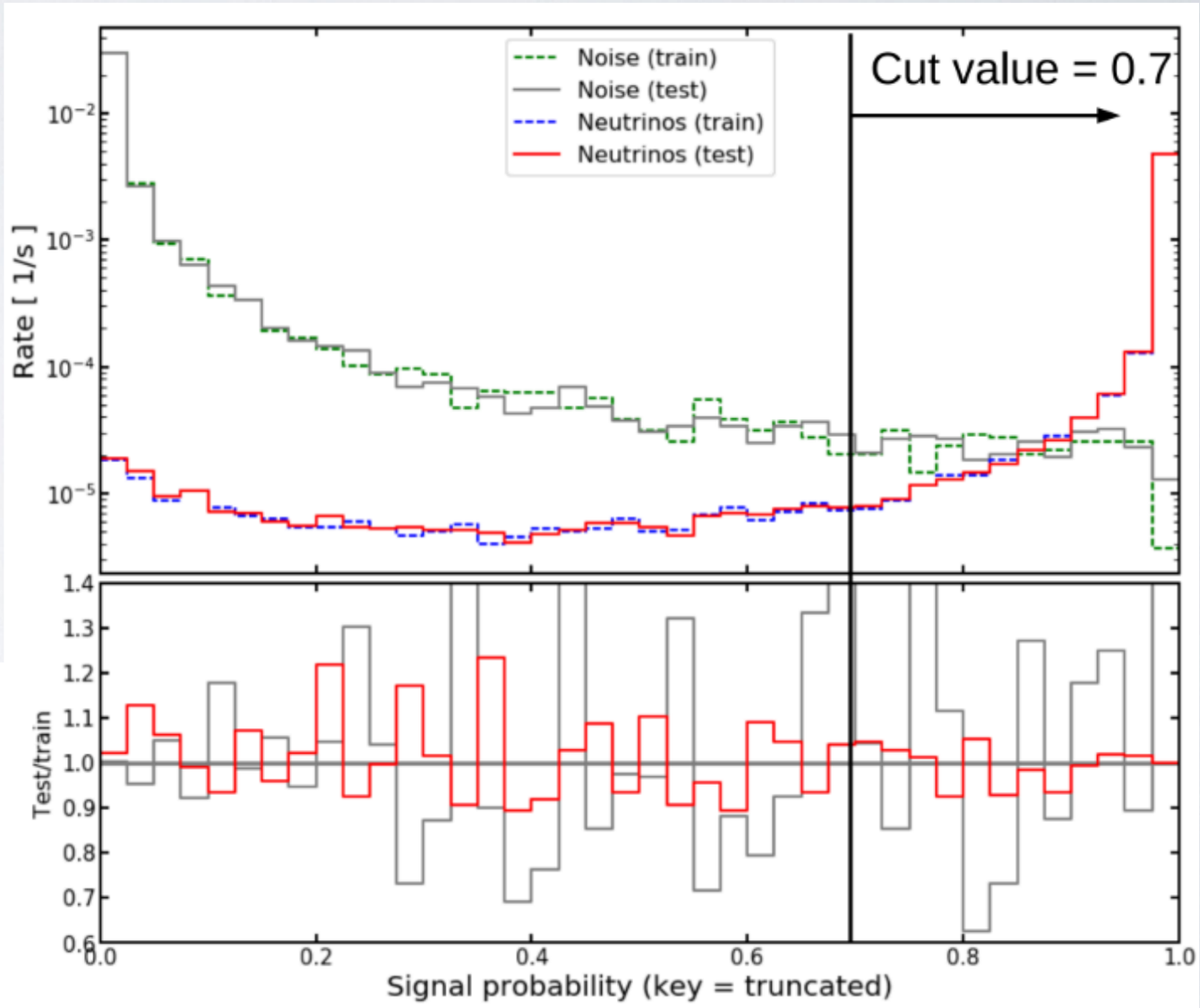
- Few strings in DeepCore means “noise” can accidentally be interpreted as a muon
- Simple Cut on time between pulses in adjacent DOMS
  - Time between pulses < 5 μs
- Two BDTs now required to filter muons
  - Level 4 and 5

LEVEL 4

- DOMs have noise that can be interpreted as low energy event

- Use 5 variables as input

- Cut = 0.7 **reduces noise** rate by **over 100**



- IC2018_LE_L3_Vars.NchCleaned
- L4_micro_count.STW_m3500p4000_DTW200
- L4_iLineFit.speed
- L4_fill_ratio.fillratio_from_mean
- IC2018_LE_L3_Vars.FullTimeLengthRatio

LEVEL 5

- Primary background are now “clean” muons, time to filter them out!!

- Use **real data** and **train against simulated neutrinos** using BDT

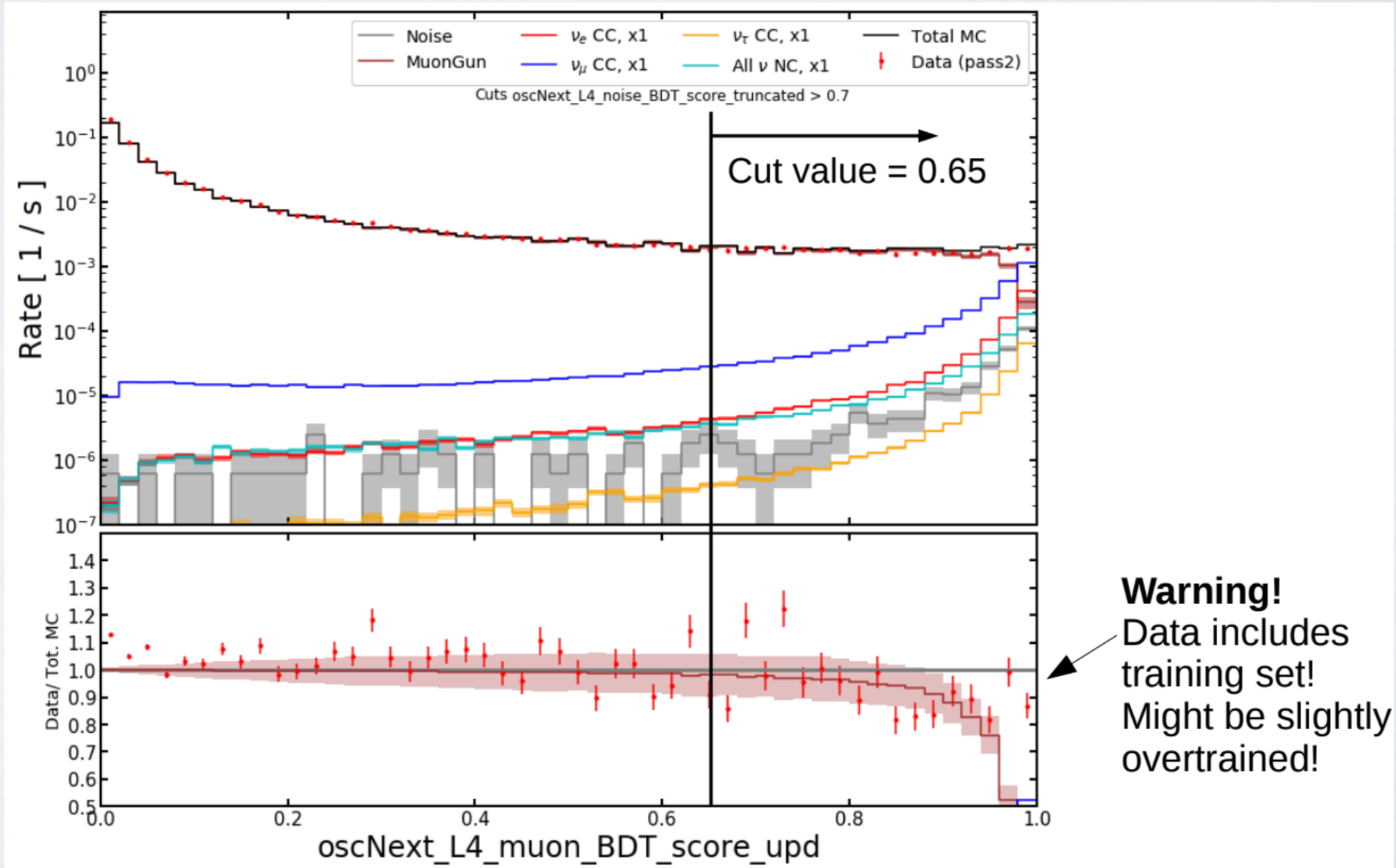
-

- IC2018_LE_L3_Vars.ICVetoHits
- IC2018_LE_L3_Vars.NAbove200Hits
- IC2018_LE_L3_Vars.RTVeto250Hits
- IC2018_LE_L3_Vars.NchCleaned
- L4_VICH_nch
- L4_accumulated_time
- L4_first_hlc_rho
- SRTTWOfflinePulsesDCHitStatistics.cog_z
- SRTTWOfflinePulsesDCHitStatistics.z_sigma
- SRTTWOfflinePulsesDCHitStatistics.z_travel

LEVEL 5

- Extract probabilities and apply single cut

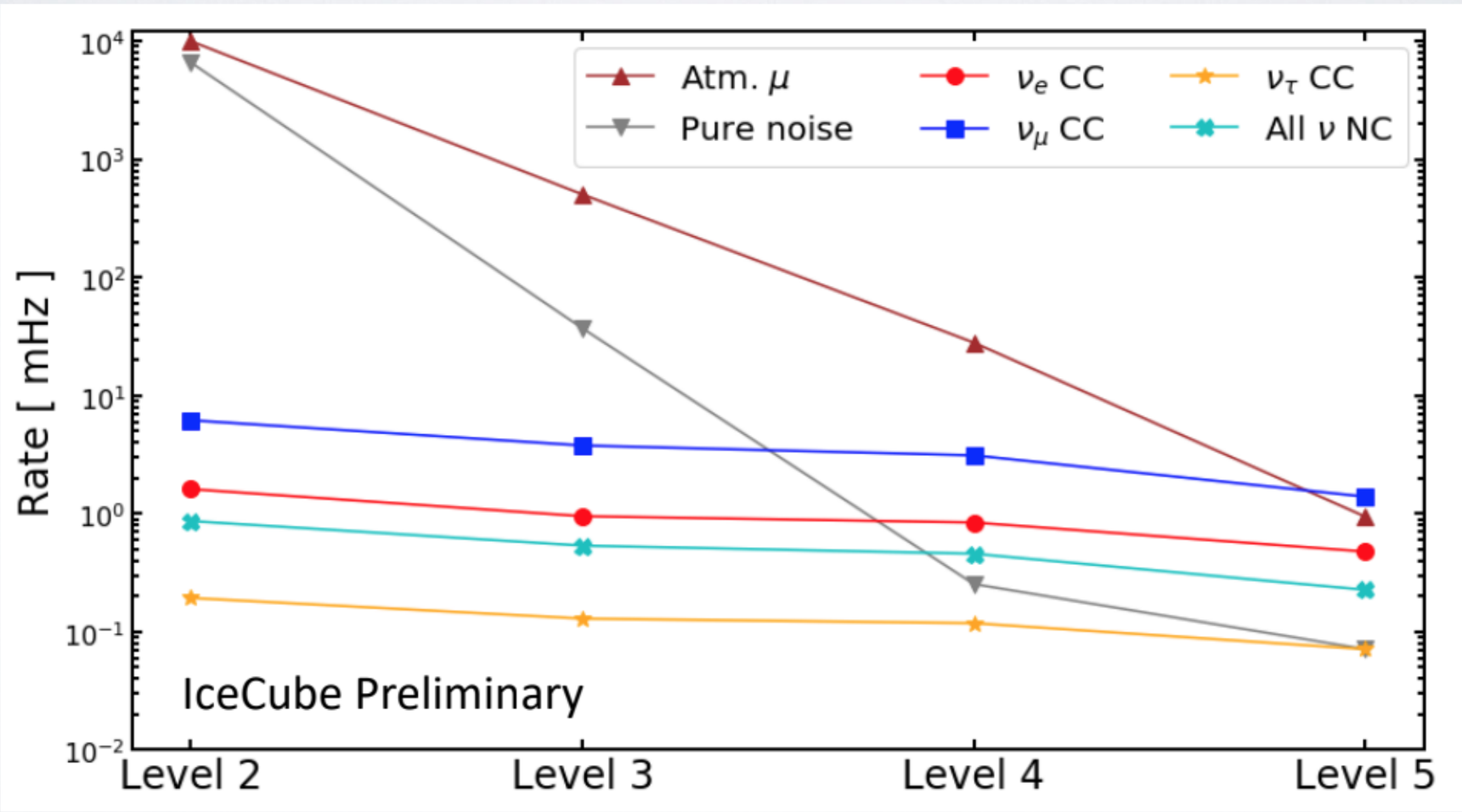
- Note: **overtraining** is sometimes an issue when using BDTs, always consult your resident machine learning expert



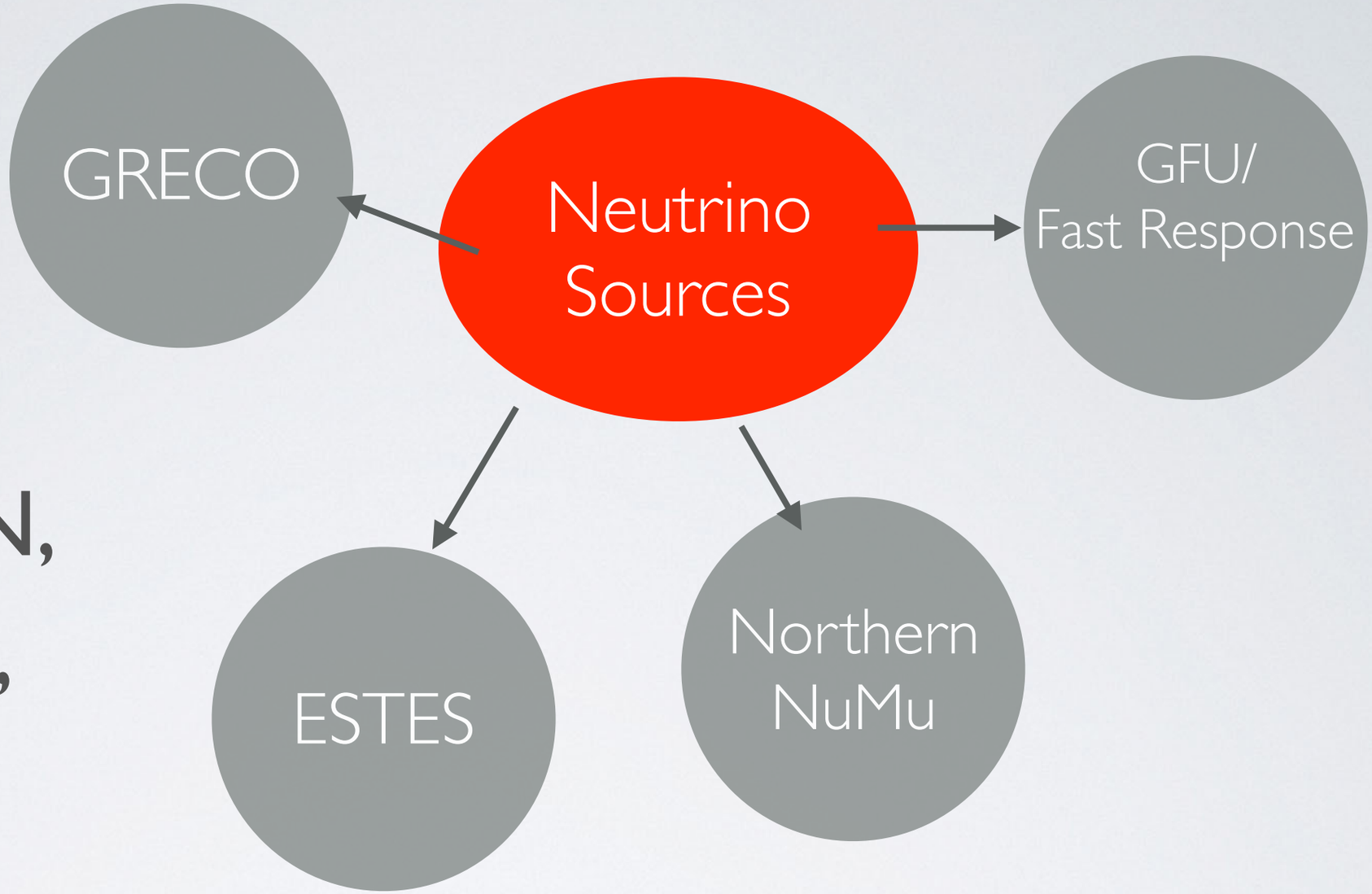
OSCNEXT - STATUS

- Muon rates decreased from ~10^4 to ~1 per millisecond, neutrino rates barely affected

- Still much work to do in Oscillations group!!



NU SOURCES



- Search for blazar, AGN, supernovas, etc…
- Use muon tracks, need fast turn-around time
- All sky or northern/southern sky

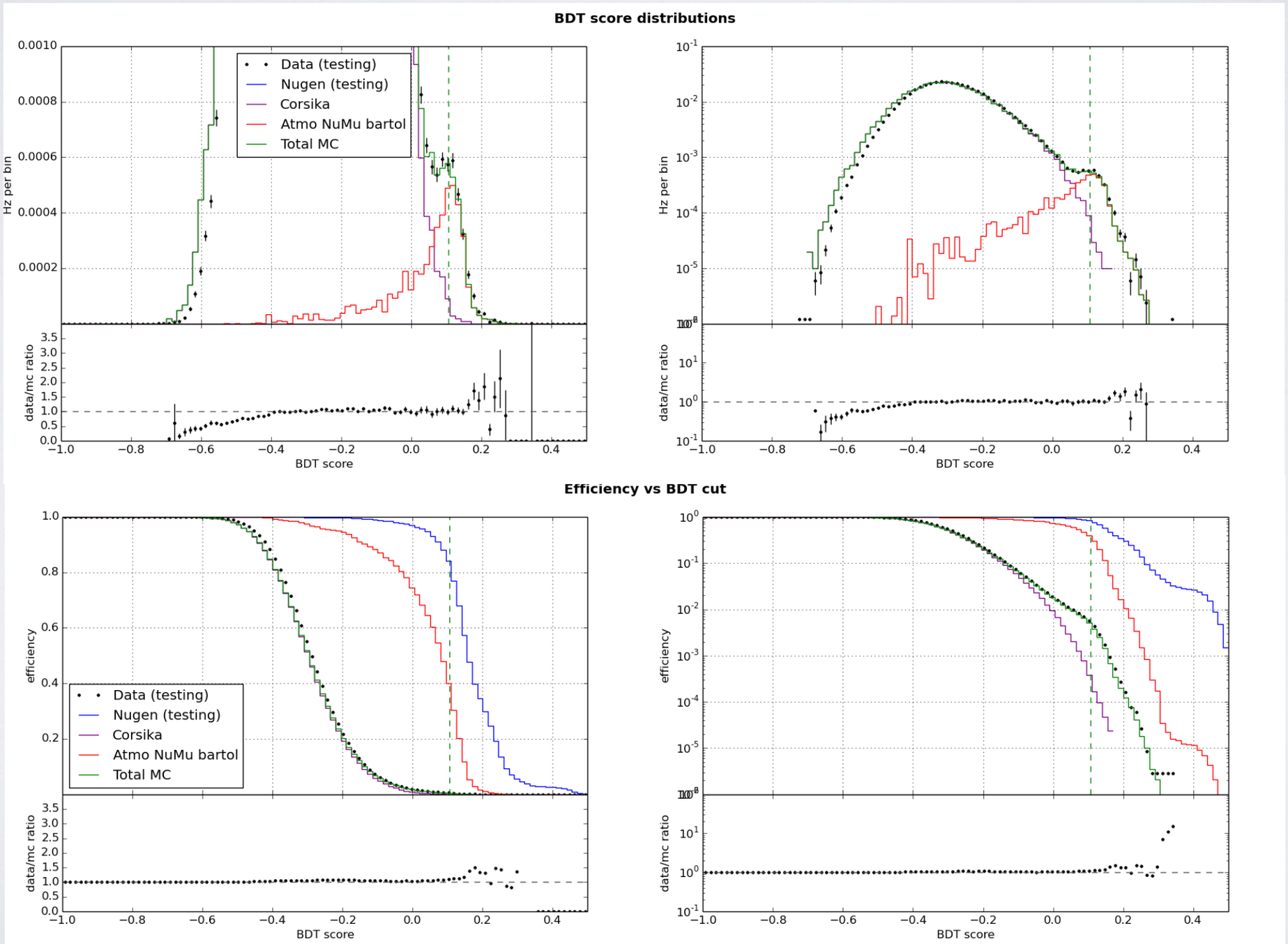
GFU/FAST RESPONSE

- We want a very high purity of astrophysical neutrinos
- BDT used for northern sky tracks, definitions found here
- Similar but fast response is faster

```
BayesLLHRatio
OnlineL2_BestFit_LineFit_DeltaAngle
MPE_ldirC
MPE_ndirC
LineFit_speed
OnlineL2_BestFit_zenith
logMuE
Plogl3p5
MaxSplitDelZenith
CosSplitMinZenith
Separation
LEmpty_divby_LDirC
Sall
log10QTot
Dist2COG
```

GFU/FAST RESPONSE

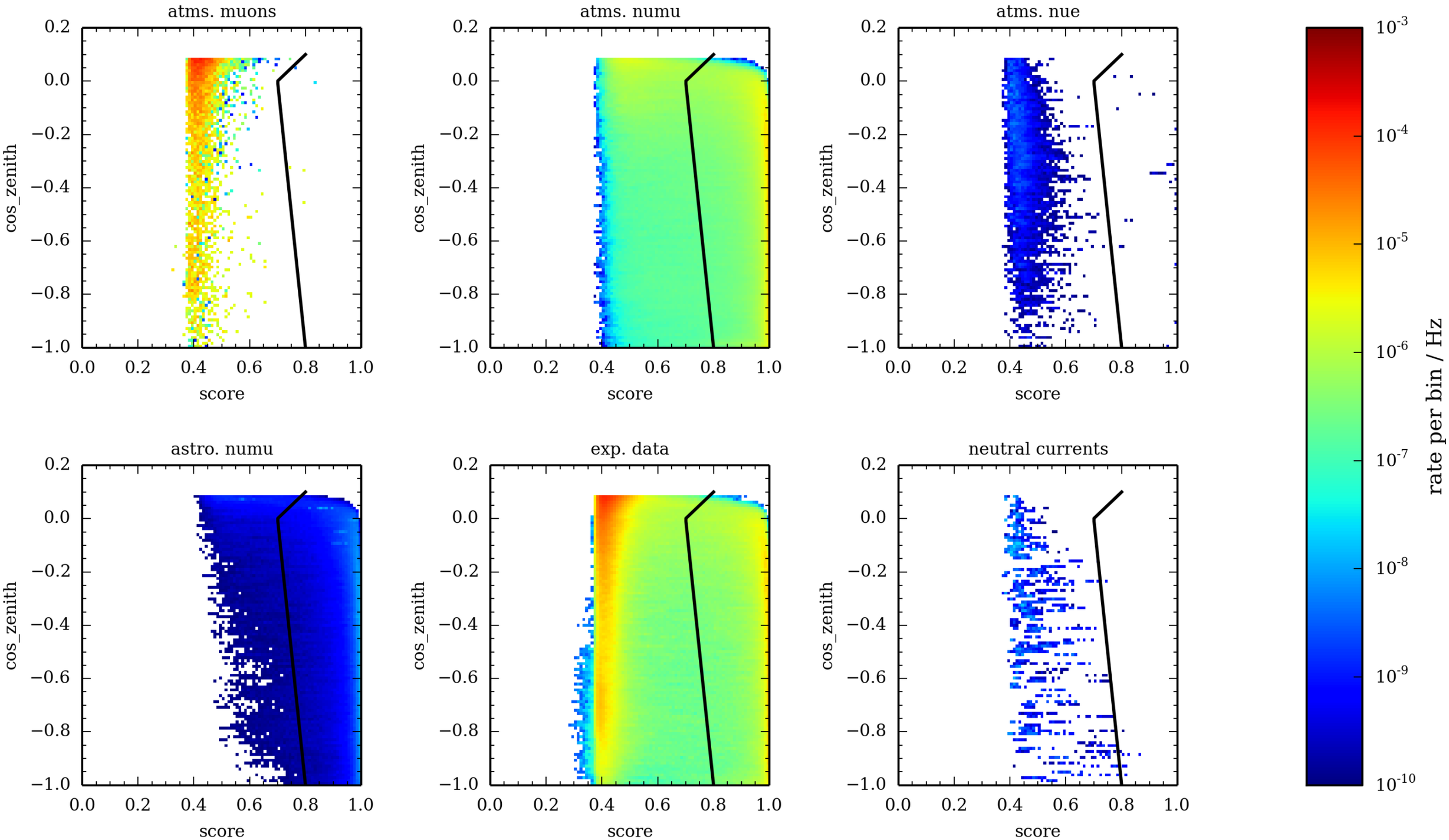
- Chose cut on BDT score, 80% efficiency astrophysical neutrinos



NORTHERN NUMU

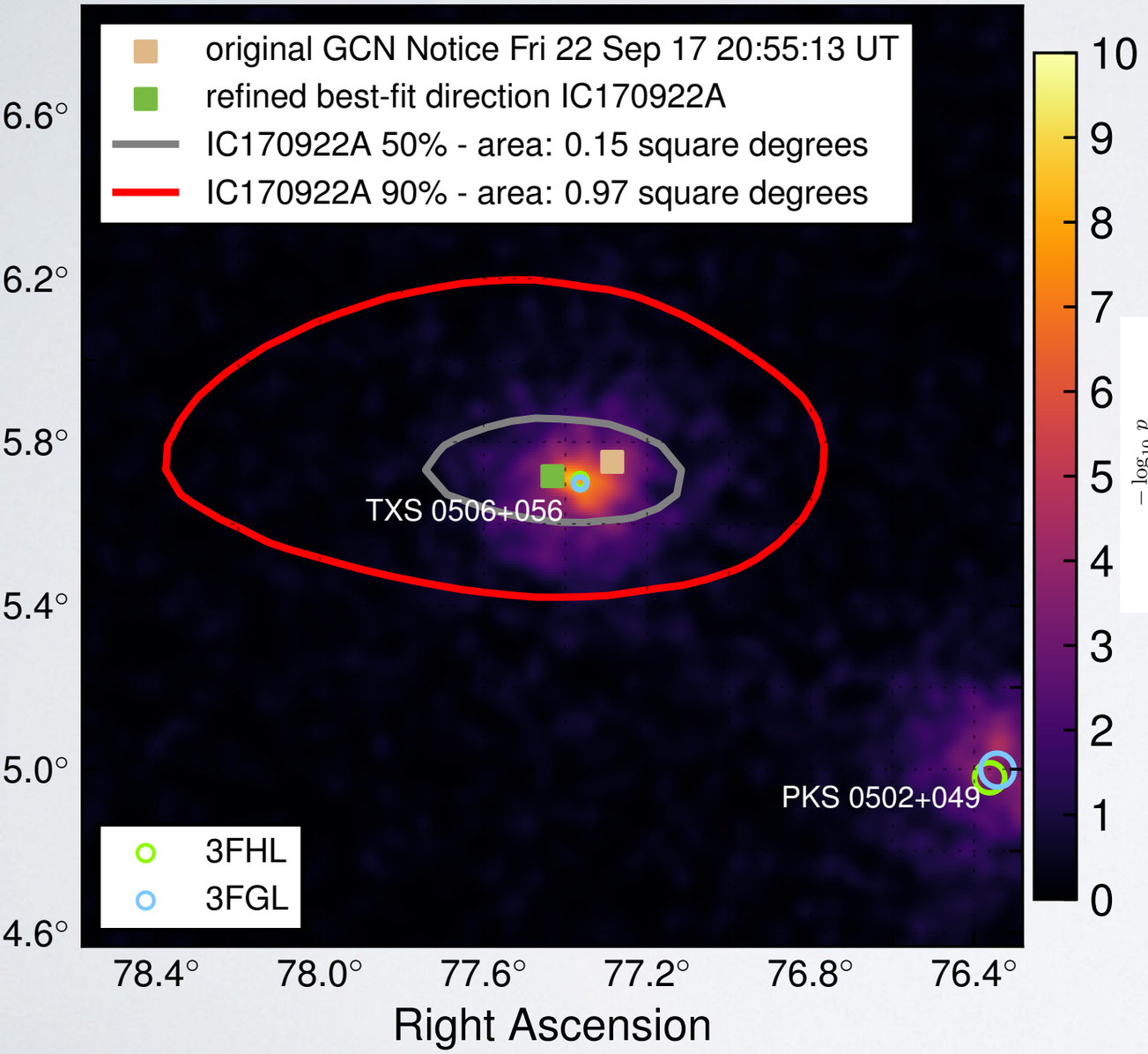
- Start at IceCube level3 data→wiki
- Use 10 variables as input to Adaptive Boosting BDT→wiki
- Cut on BDT score and cos(zenith), low statistics means that you have to do a little manual tuning yourself

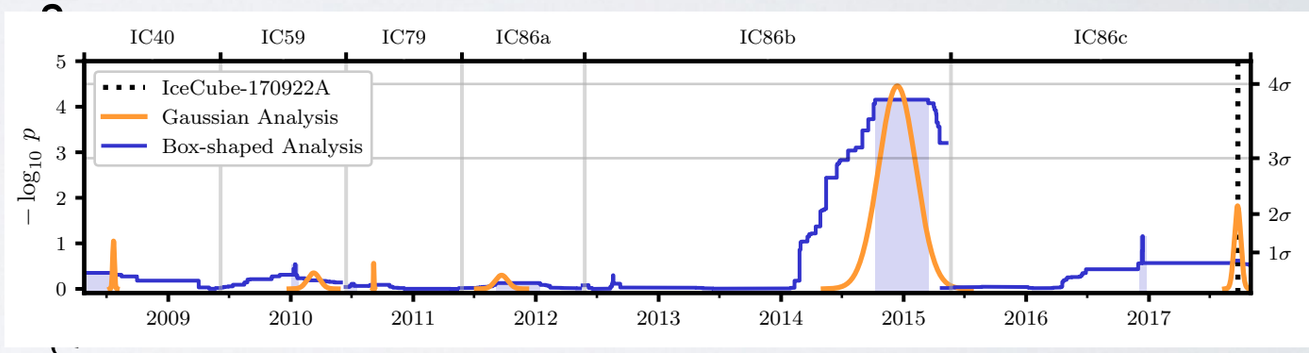
NORTHERN NUMU



NU SOURCES RESULTS

- **IceCube 3σ evidence blazers emit neutrinos**





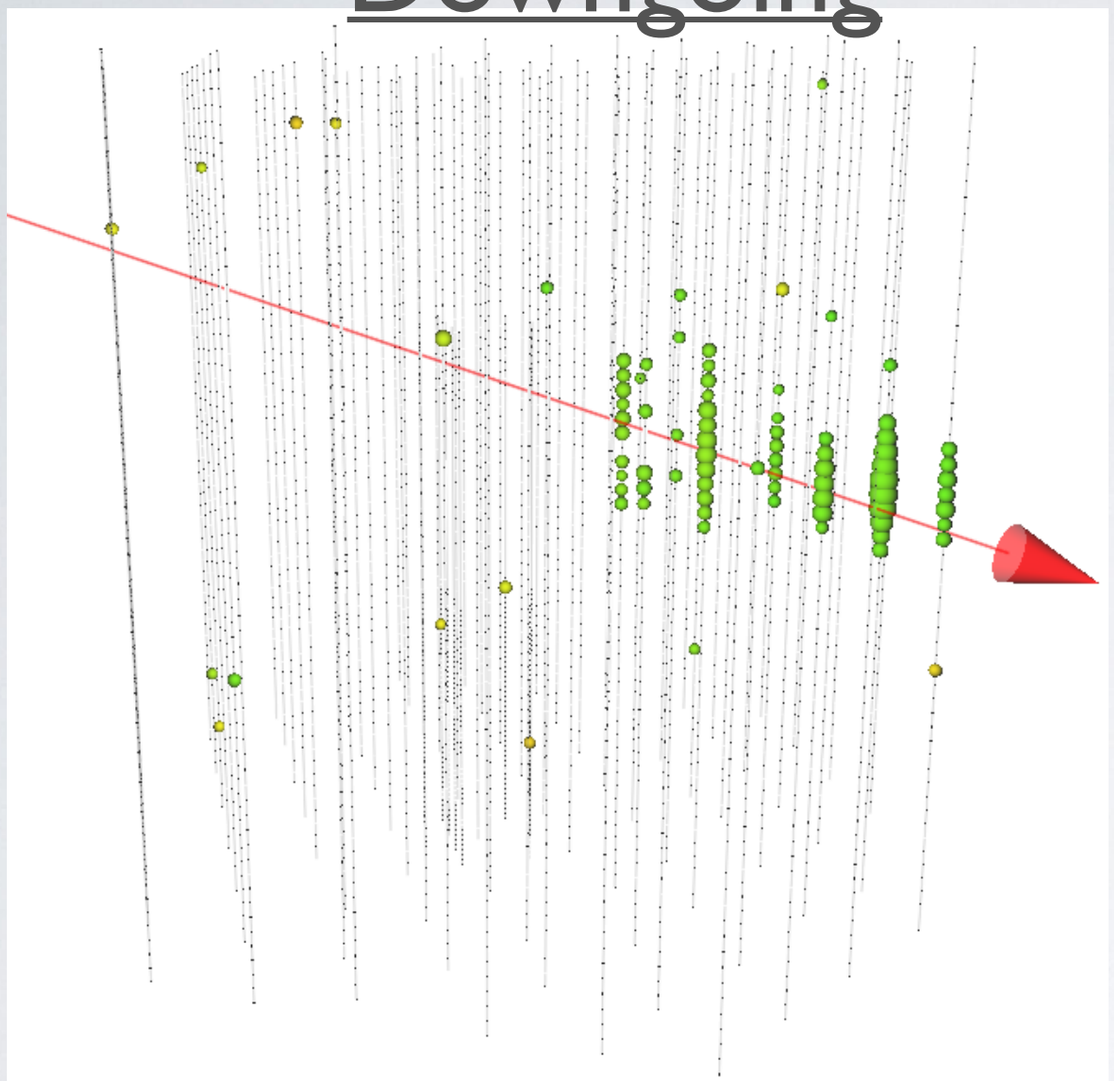
SUMMARY

- Various event selection techniques in IceCube
- Pick an event selection best suited for your particular analysis
- If it doesn't exist yet, make your own!!
  - Or contribute to ongoing efforts…

WELCOME

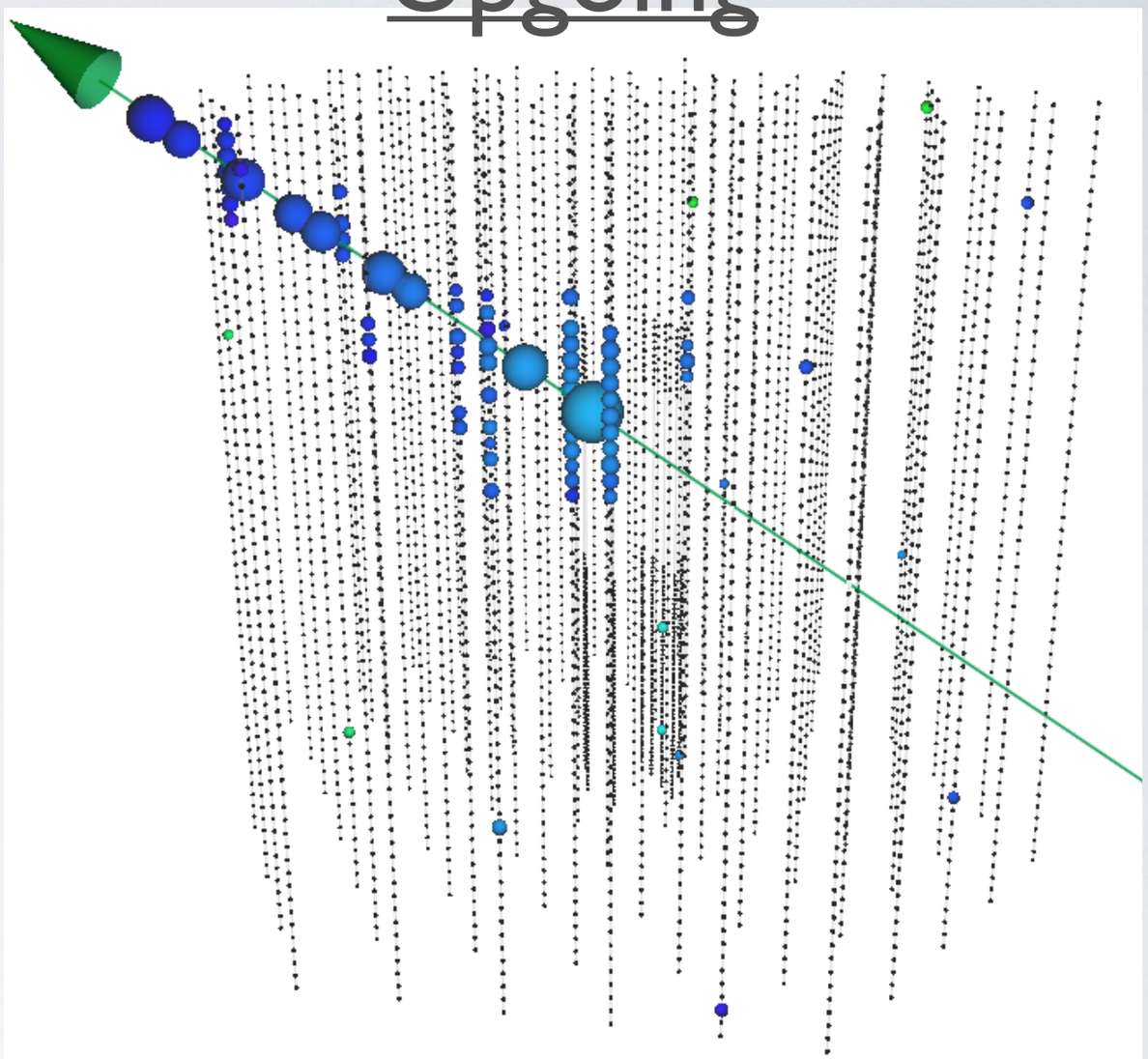
REFERENCE

Downgoing



- 1.5km of ice before reaching IceCube, **muon+neutrino rich**

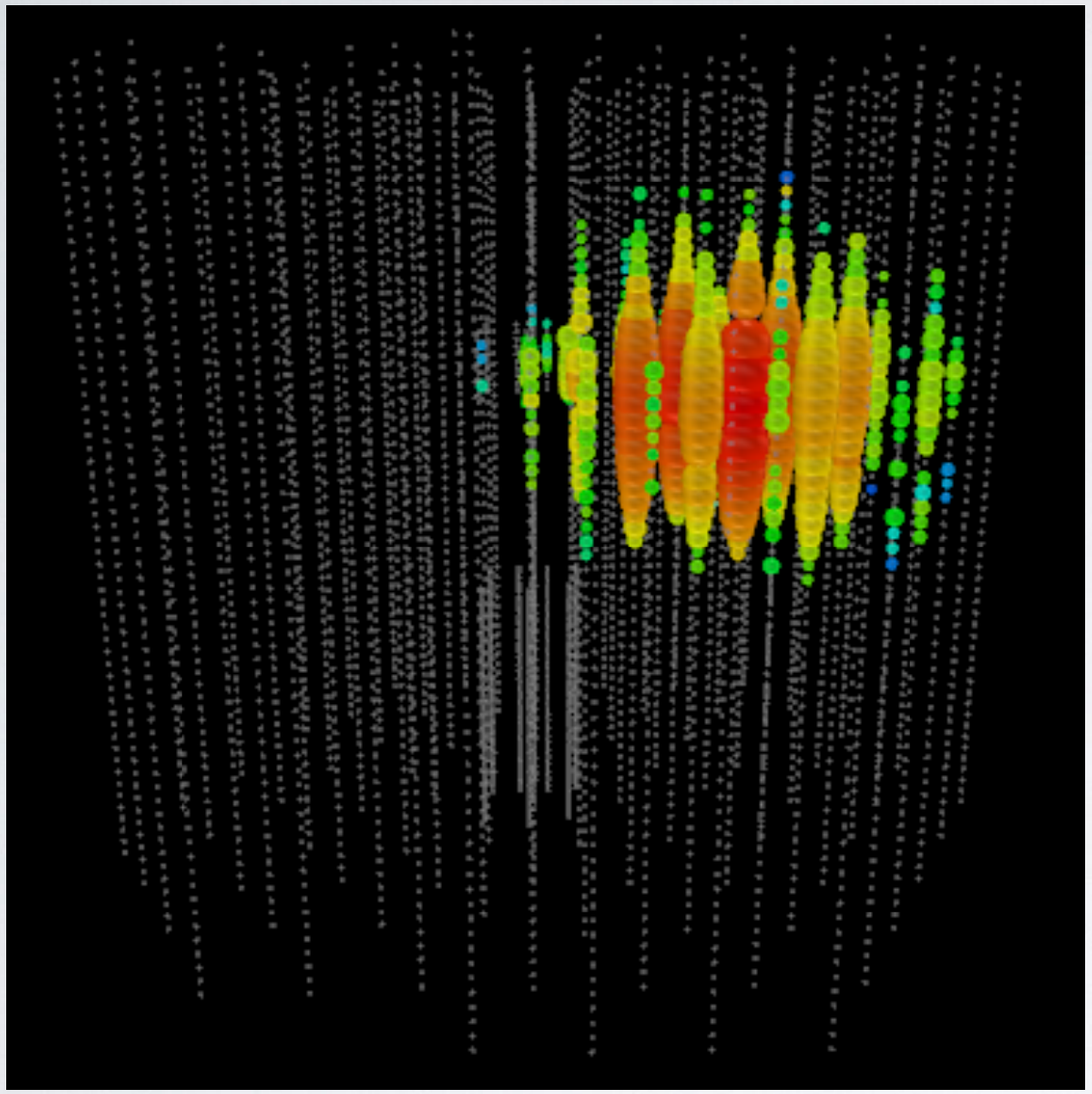
Upgoing



- Particles travel through the entire Earth before reaching IceCube, **neutrino rich**

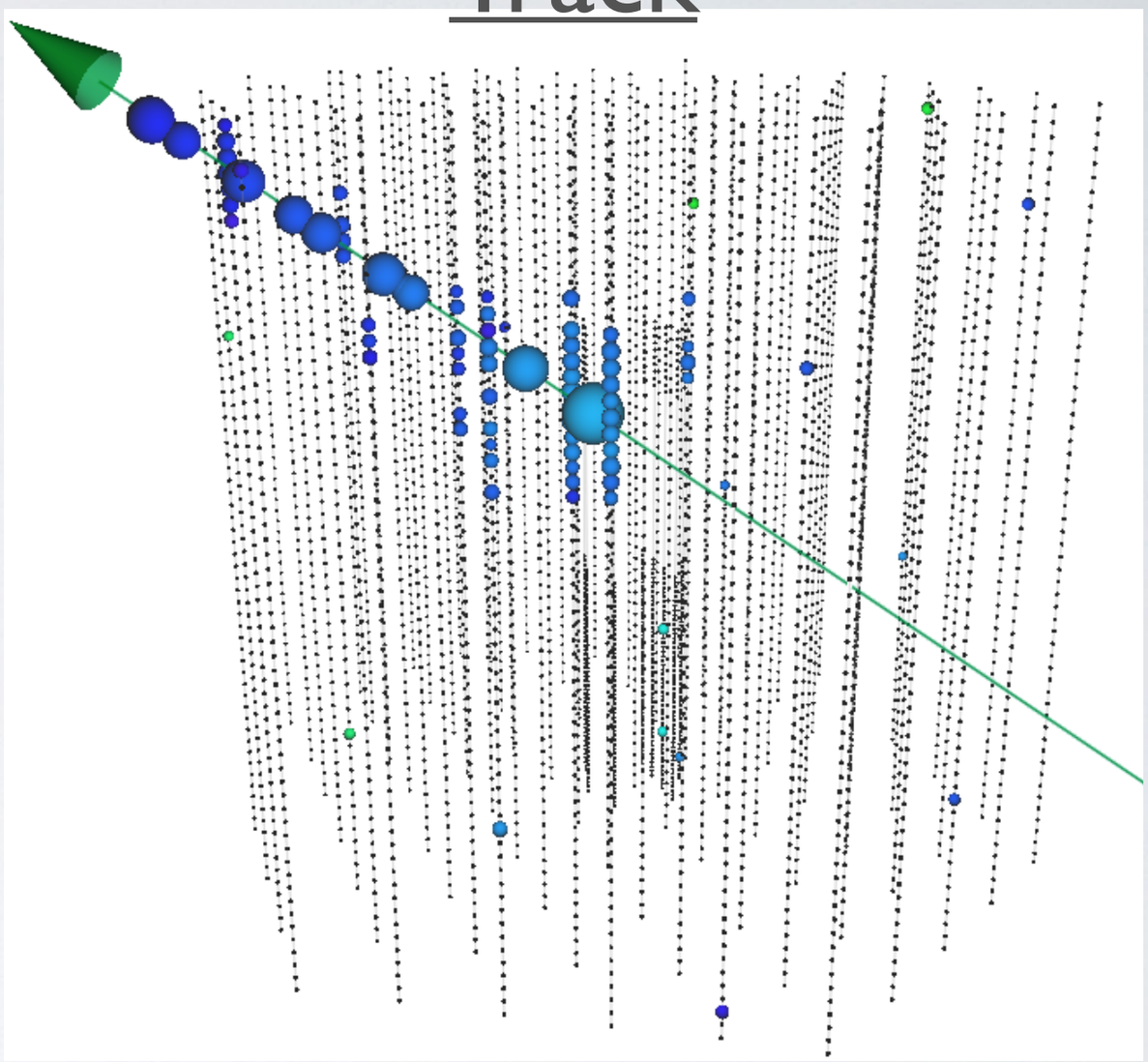
REFERENCE

Cascade



- Easy to classify as electron/tau neutrino, can also tag as neutral current

Track



- Easy to classify as muon neutrino undergoing charged current interaction

NEUTRINO SOURCES

- Full list of datasets already processed and ready for use
- Choose the “best” for your analysis

Dataset	Creator	Description
Point Source Tracks	S.Coenders, T.Carver	All-sky sample of numu tracks optimized for point sources (IC86 2012-2017 updated by T.Carver)
Gamma-ray Follow-up (GFU) with online reco	T.Kintscher	All-sky numu tracks designed for quick response analyses. Quick reco online.
Gamma-ray Follow-up (GFU) with offline reco	T.Kintscher	All-sky numu tracks designed for quick response analyses. Re-processed offline for better sensitivity.
Northern Tracks	R.Reimann	Northern sample of numu tracks, same as used for diffuse analysis of northern sky
Fast Response	K.Meagher	All-sky numu tracks designed for quick response analyses
Low Energy Starting Events	M.Richman	Low energy starting events
STeVE	M.Richman	Something with starting events
Transient Tracks	A.Pizzuto	Northern numu tracks designed for short timescale analyses like GRB/FRB
Gamma Rays	Z.Griffith	PeV scale gamma-ray events from IceCube & IceTop