The Enhanced Starting Track Event Selection (ESTES)

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IPA Neutrino Astronomy Session 3

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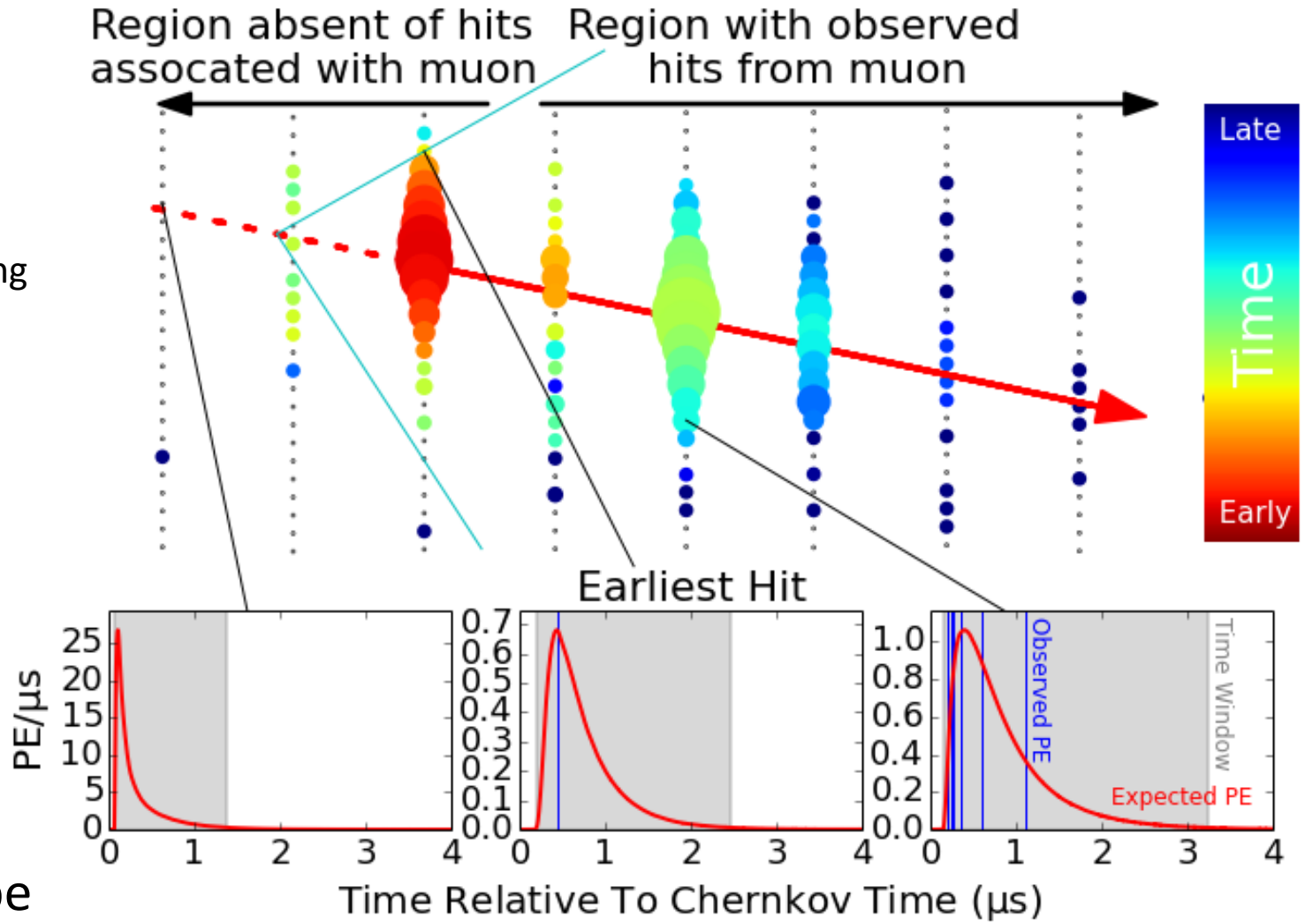
ESTES Overview

- Goal: Observe starting tracks
  - Starting tracks from the southern sky benefit from the atmospheric self-veto
  - Clear astrophysical events above 10 TeV
- Uses the StartingTrackVeto to identify when unhit DOMs along tracks are significant
  - Rejects incoming muons while keeping starting tracks
- Expects less than one incoming muon event a year
  - Allows ESTES to be used for diffuse and point source measurements
- IceCube has measured the astrophysical flux with a number of analyses, I will refer to 3
  - HESE: 4 year results from the Observation of Astrophysical Neutrinos in Four Years of IceCube Data
    - https://pos.sissa.it/archive/conferences/236/1081/ICRC2015_1081.pdf
  - MESE: 2 year results from Atmospheric and Astrophysical Neutrinos above 1 TeV Interacting in IceCube
    - https://arxiv.org/pdf/1410.1749.pdf
  - Up-going muon neutrinos: Observation and Characterization of a Cosmic Muon Neutrino Flux from the Northern Hemisphere using six years of IceCube data
    - https://arxiv.org/pdf/1607.08006.pdf

Veto Definition

- Starting tracks
  - Identifiable start to the event
    - DOMs missing hits given a through-going hypothesis
- Need to assess what hits are associated with the event
  - Noise hits vs hits from event
- We have photon tables which provide per time expected yield for all track →DOM combinations
- We don’t know what the event’s properties are, so choose the basic hypothesis that the region where you observe the muon can be described by a uniform light yield
  - First need to find the region of the identified muon
    - Search for section of track which has hits predicted by the minimum ionizing muon table
      - Uses direct Cherenkov radiation by default, can use other options
  - Event can be higher in light output than minimum ionizing muon so a normalization needs to be set



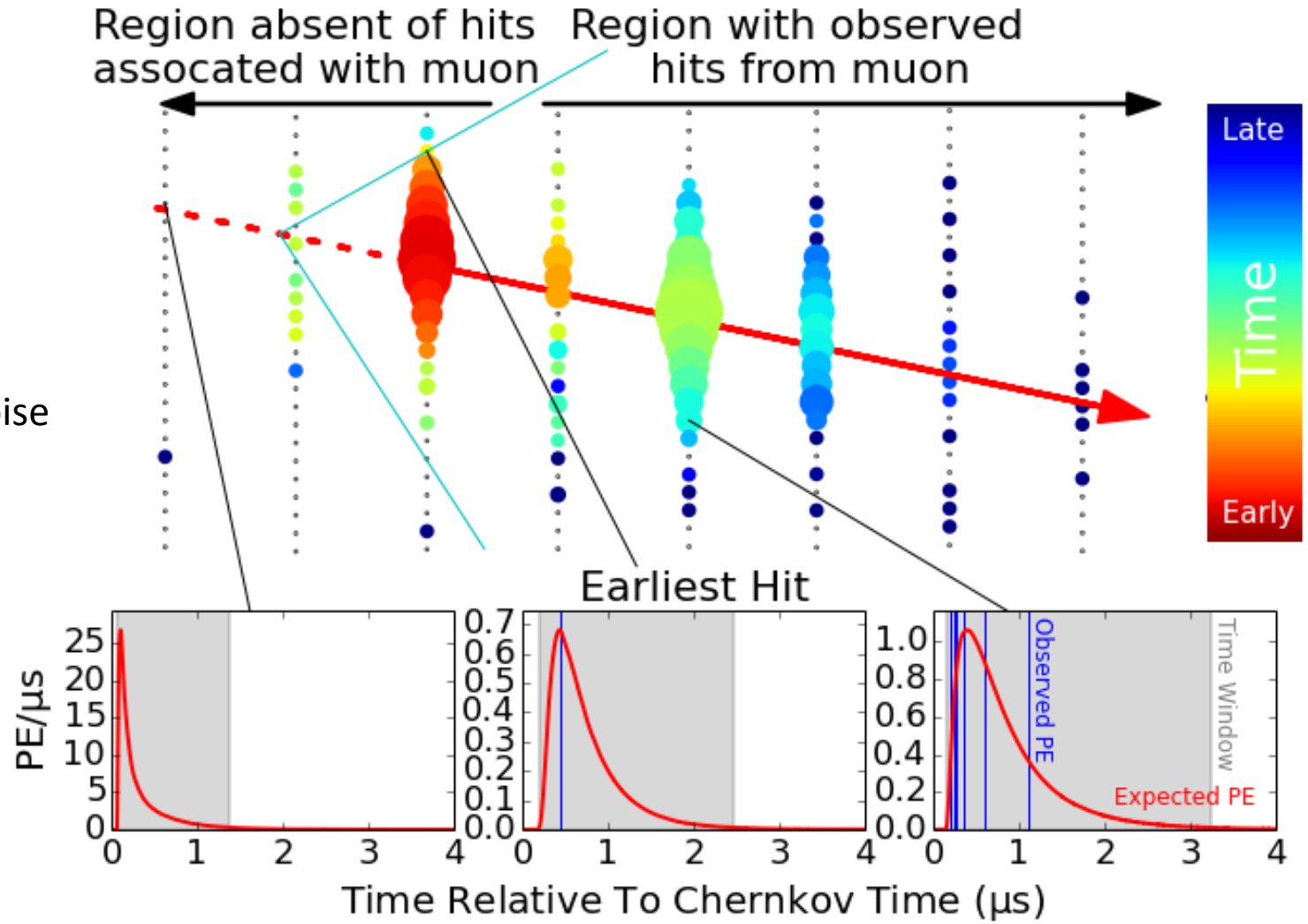
Veto Definition

- In the unscaled case
- Model each observation as a Poisson probability

$$p(\lambda, k) = \frac{\lambda^k e^{-\lambda}}{k!}$$

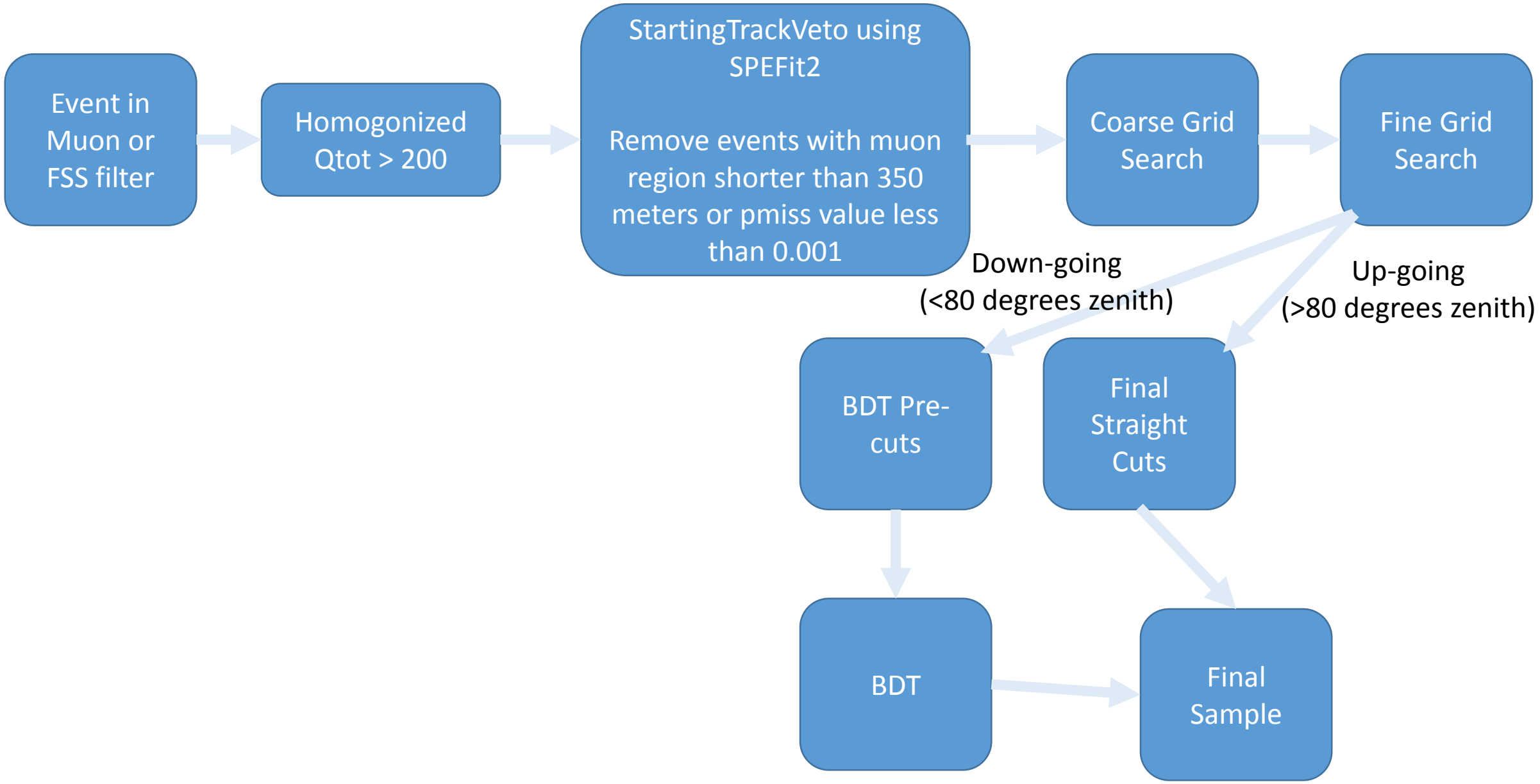
λ is the expected number of PE → table yield + noise
k is the observed number of PE

$$LLH = \sum_i \log(p(\lambda_i, k_i)) \; where \; \lambda_i = \lambda_{e_i} + \lambda_{b_i}$$



- We know λ is not calibrated for the event
  - Introduce a scaling factor a making $\lambda_i = a\lambda_{e_i} + \lambda_{b_i}$
- By finding the value of a which minimizes the LLH we have obtained the scaled yield which best represents our hypothesis
  - Every DOM in muon region, hit or otherwise, provides information and is used
- The assumption that the event can be described by a uniform light output is inappropriate if
  - A DOM is close to the track, thus making an estimate in a rapidly changing region
  - Large stochastics dominate the light yield
- A special mode is used to mitigate these effects

Event Selection Overview

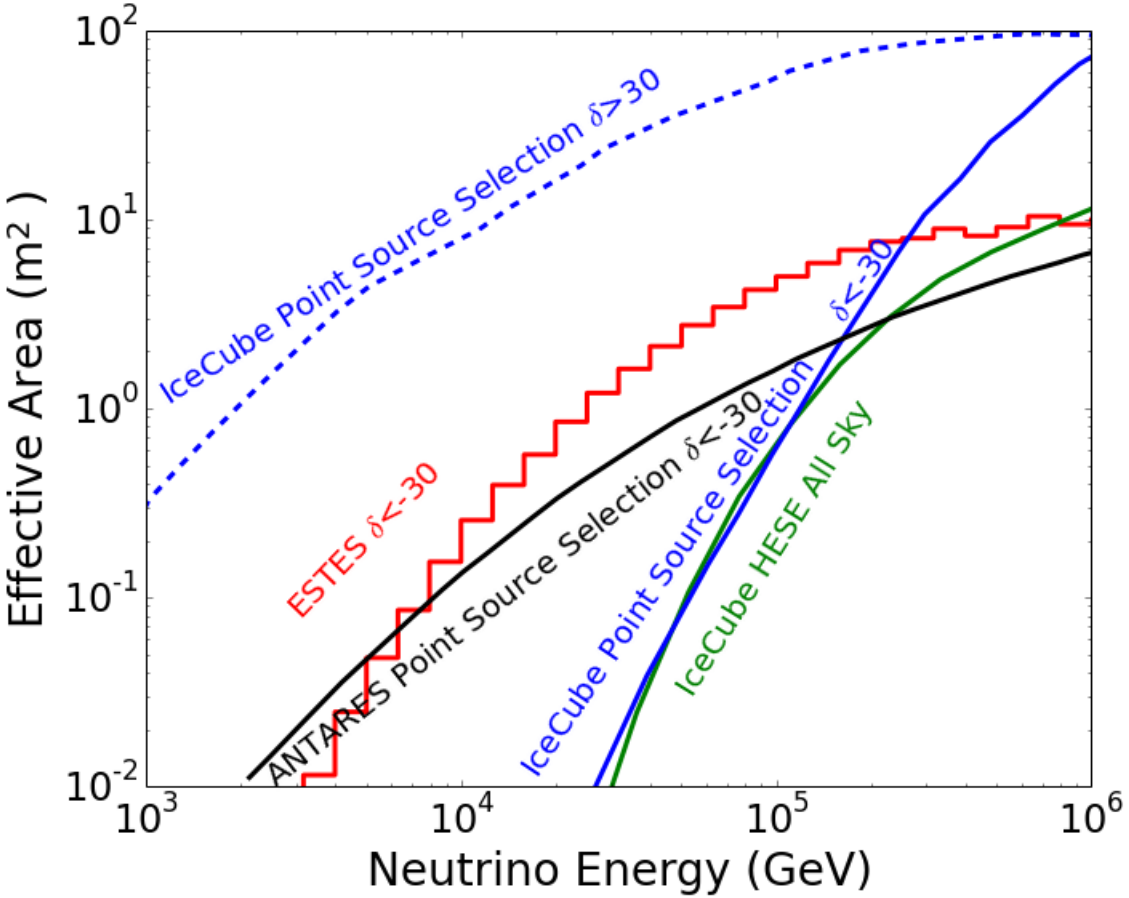


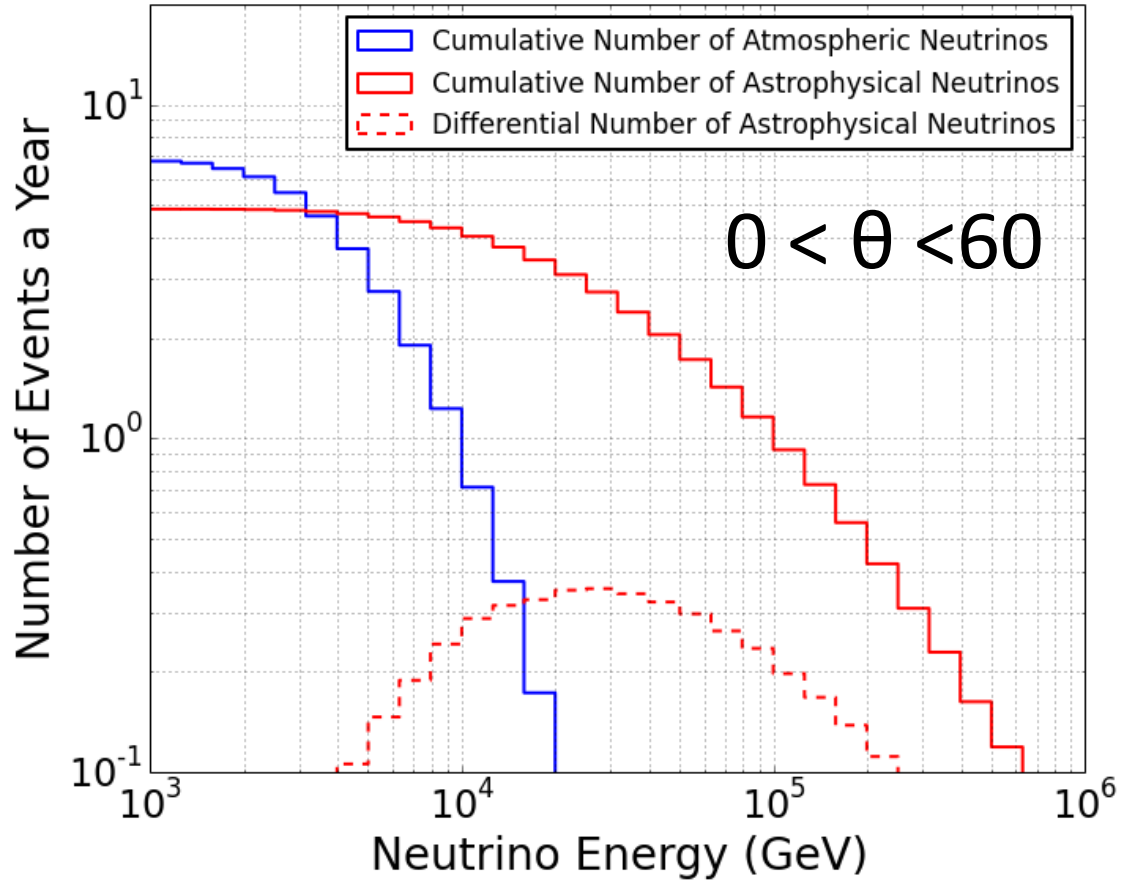
Effective Area and per Year Event Expectations From Diffuse Flux

Assuming Medium Energy Starting Event Best Fit Flux

$$\Phi = 2.06 \times 10^{-18} \left(\frac{E_\nu}{10^5 \mathrm{GeV}}\right)^{-2.46} \mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{sr}^{-1}\mathrm{s}^{-1}$$

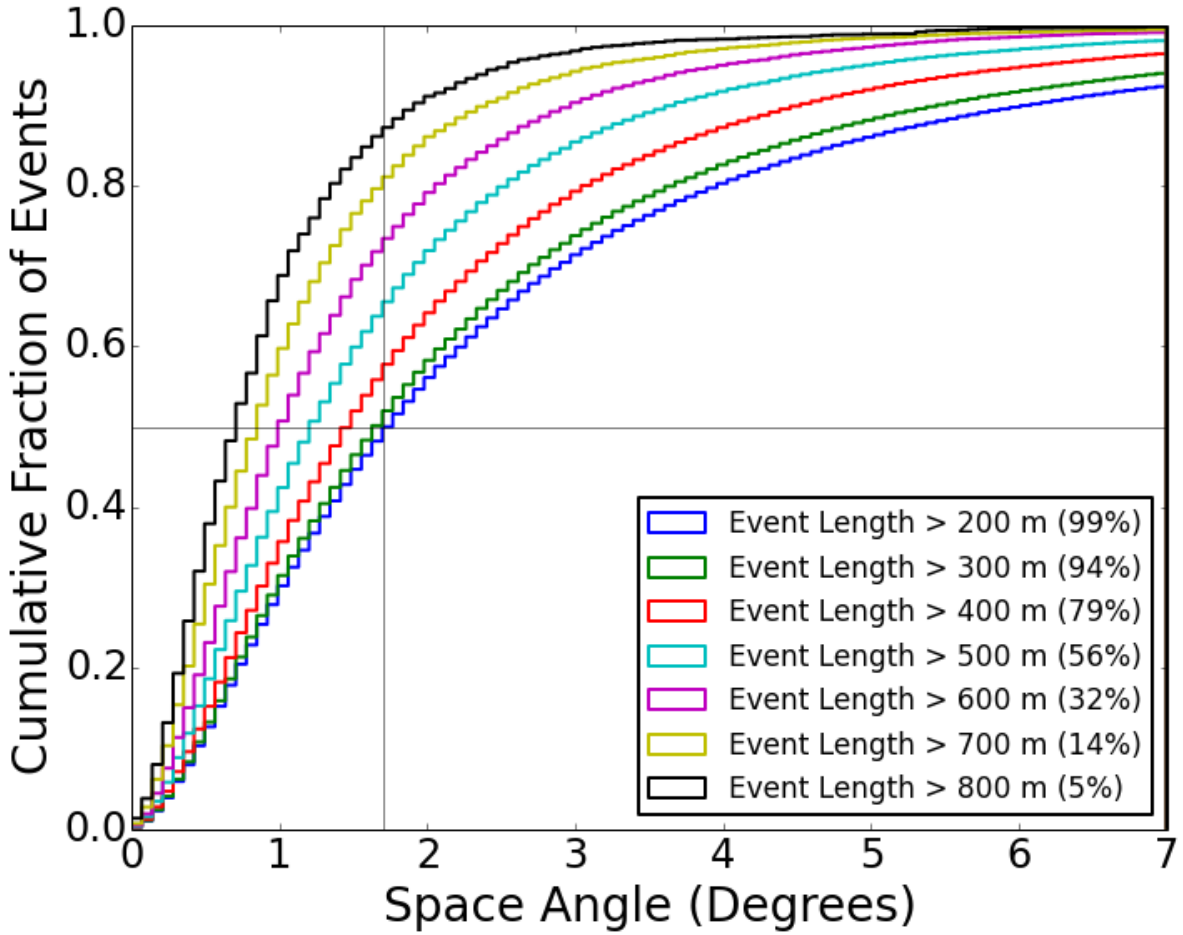
arXiv:1410.1749

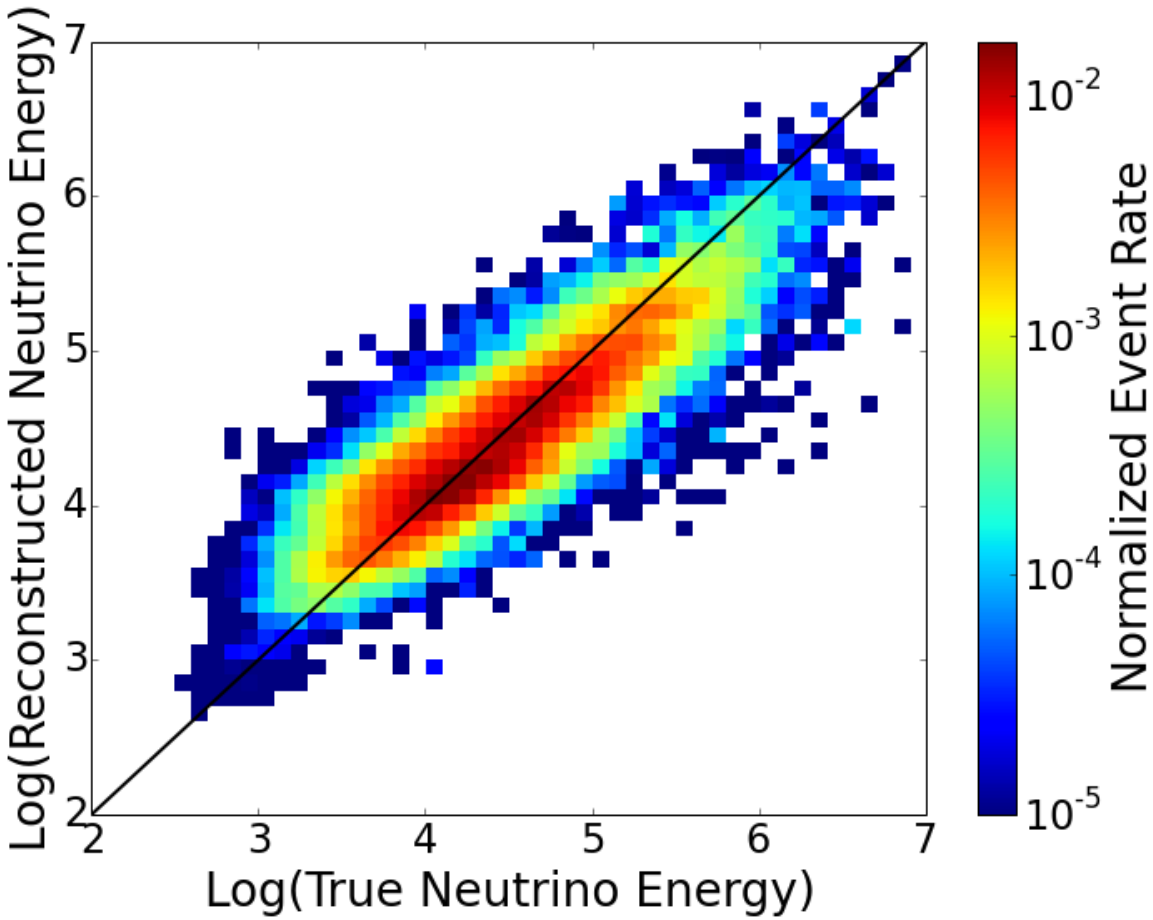




- Largest effective area in southern sky starting at ~8 TeV and ending at ~200 TeV
  - < 1 incoming muon event per year
- Views over half of the Galactic Plane
  - Including Galactic Center
- Expect 2-10 events per year depending on input flux

Angular and Energy Resolution



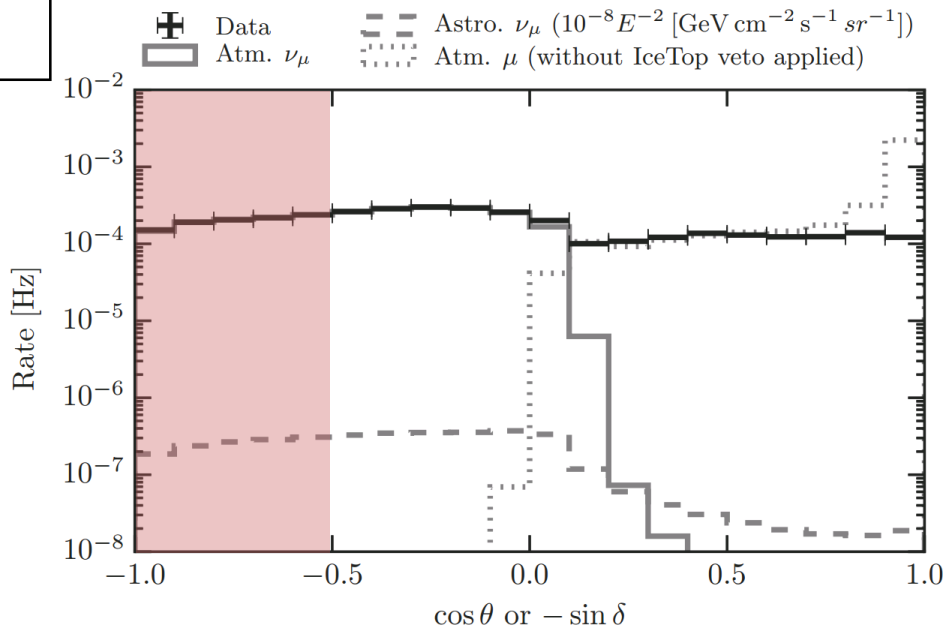


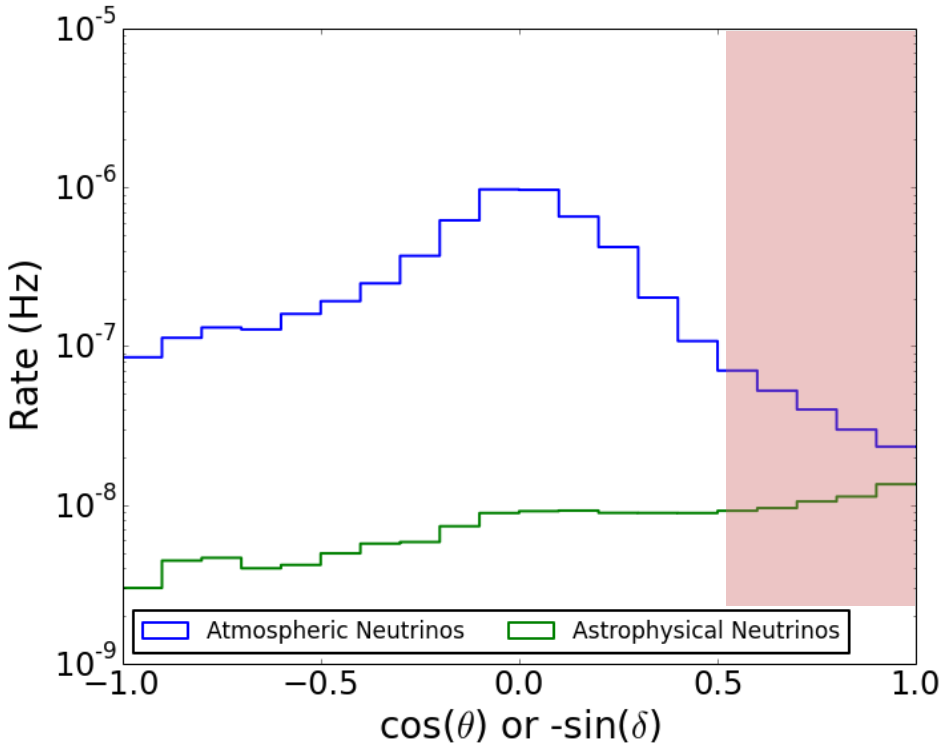
- Average angular error around 1.7 degrees for entire sample
- Energy resolution around .25 in log space across all energies

Simplified Comparison to IceCube Point Source Selection

Plot from
arXiv: 1609.04981

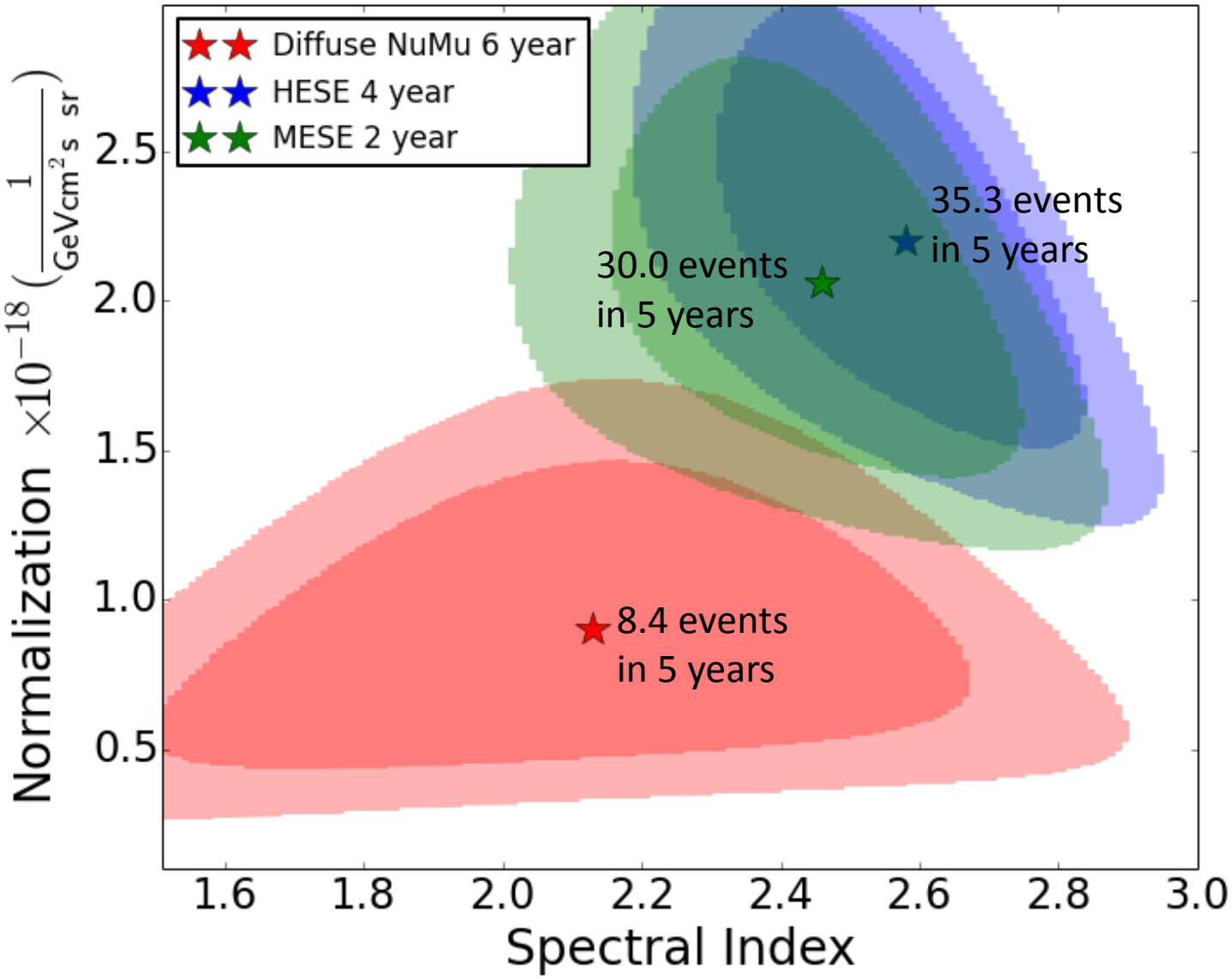
- Effective area for IceCube's point source selection in the Northern hemisphere at least 10 times larger than ESTES
  - Lacks self-veto
- How do they compare in a toy binned (4° x 4°) point source search?
  - 10 years
  - 1350 bins
  - $\Phi_\nu = 1 \times 10^{-8} E_\nu{}^{-2} \frac{\text{GeV}}{\text{cm}^2 \text{sr s}}$
  - No energy information
- Point Source
  - Atmospheric background events = 3.1 x 10^5
  - Astrophysical signal events = 4.0 x 10^2
  - ~5σ excess = 313 events -> 234.5 atmos. bkg + 79 astro. signal
  - 20% of total signal
- ESTES
  - Atmospheric background events = 68
  - Astrophysical signal events = 17
  - ~5σ excess = 3 events = 0.063 atoms. bkg + 3 astro. signal
  - 17% of total signal



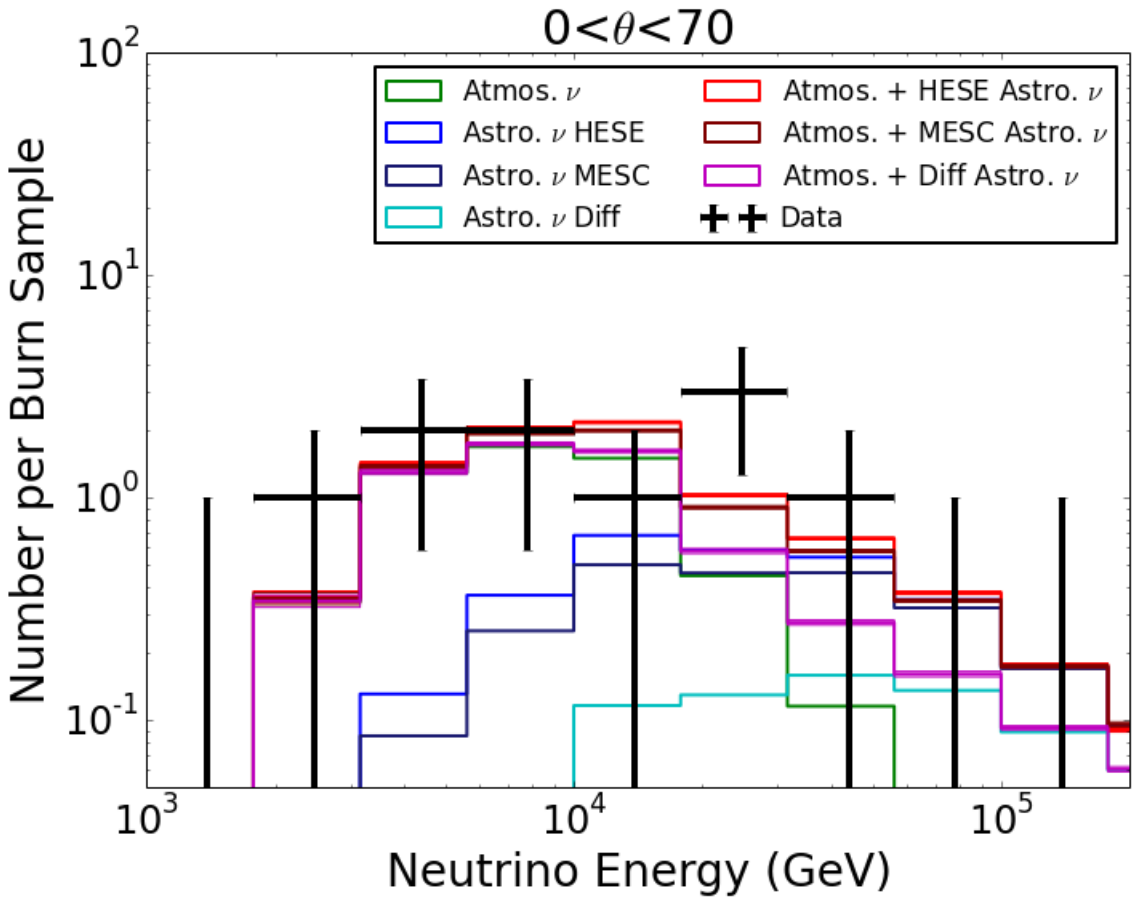


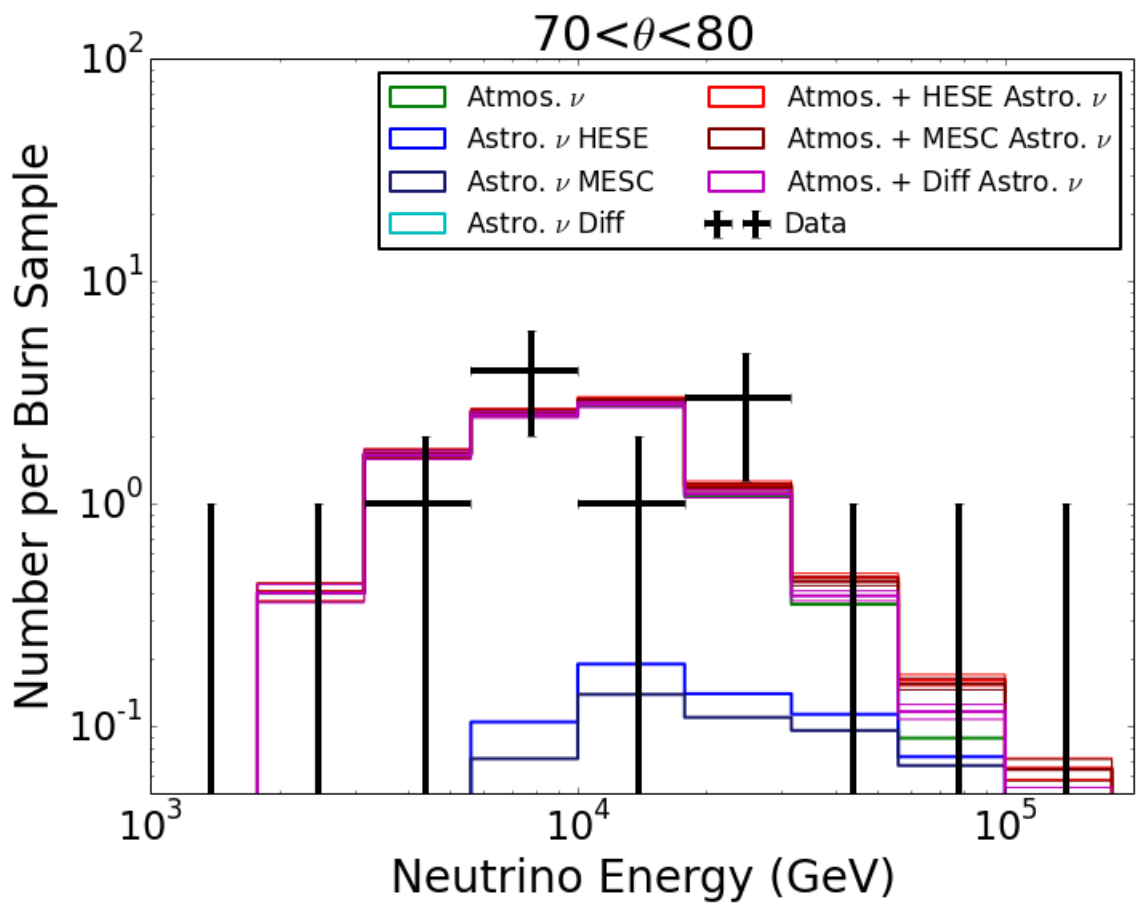
Diffuse Outlook

- The up-going NuMu flux is distinguishable from the softer cascade dominated fluxes at 1 sigma
- ESTES can play a role in determining properties of the astrophysical flux
- Measures interesting new events
  - Events from southern hemisphere
  - Muon neutrinos only



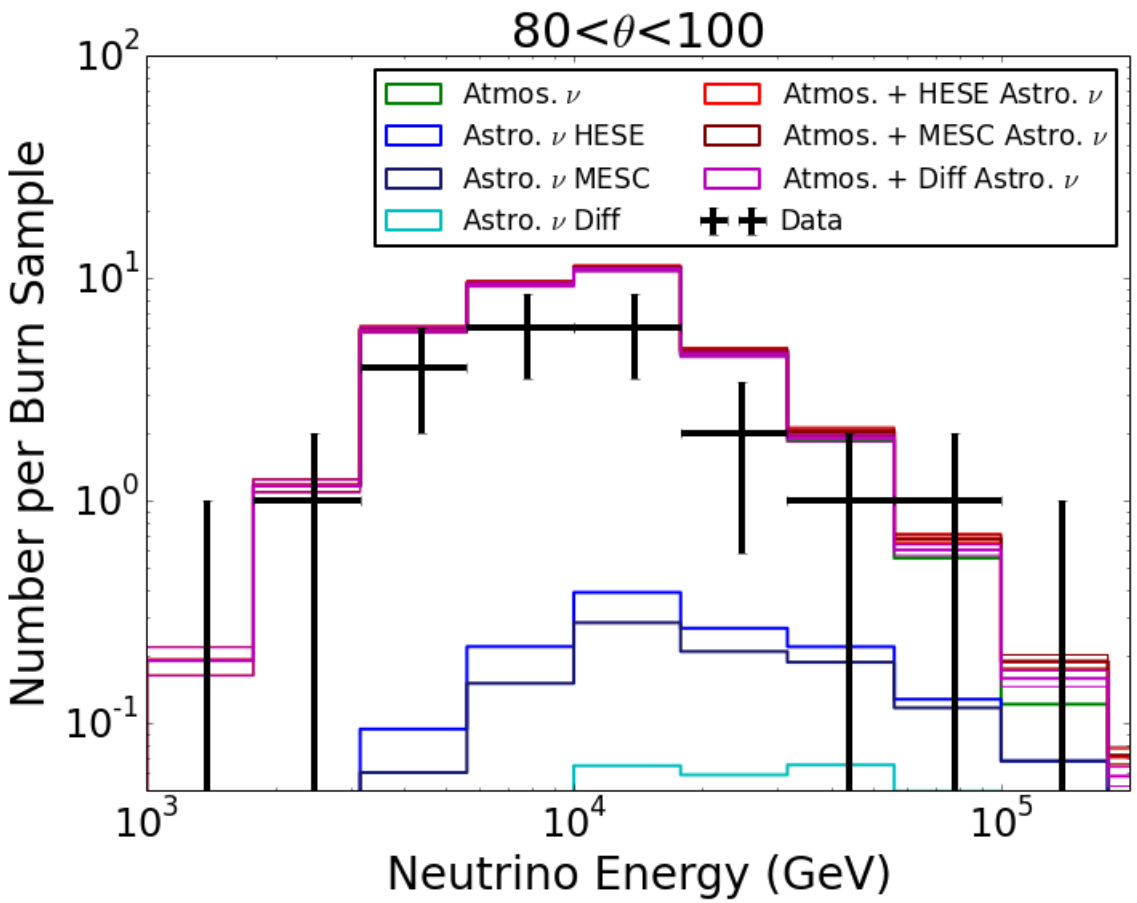
Burn Sample Results

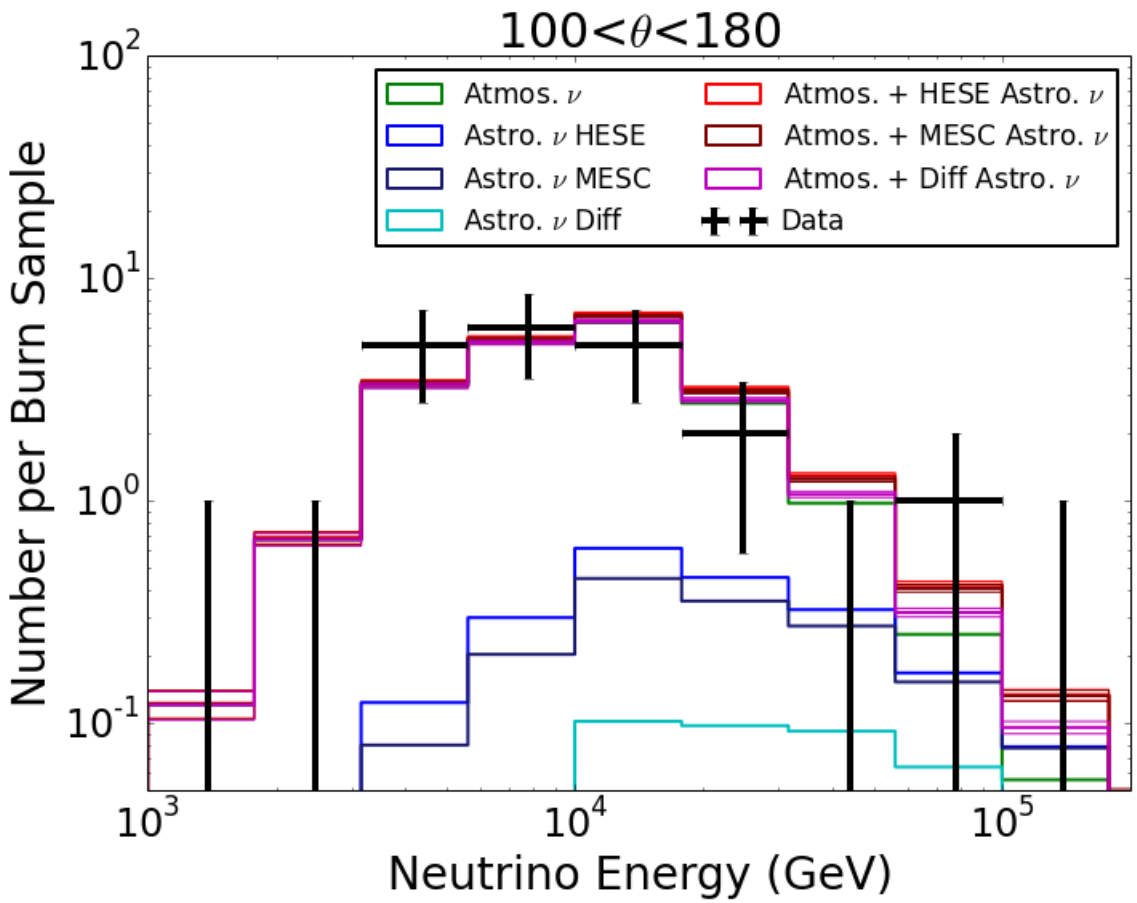




- Burn sample has a few events that are consistent with a soft astrophysical flux
- Consistent with existing atmospheric + astrophysical measurements indicates

Burn Sample Results





- Exploring the origin of the discrepancy in horizontal bins

Conclusions

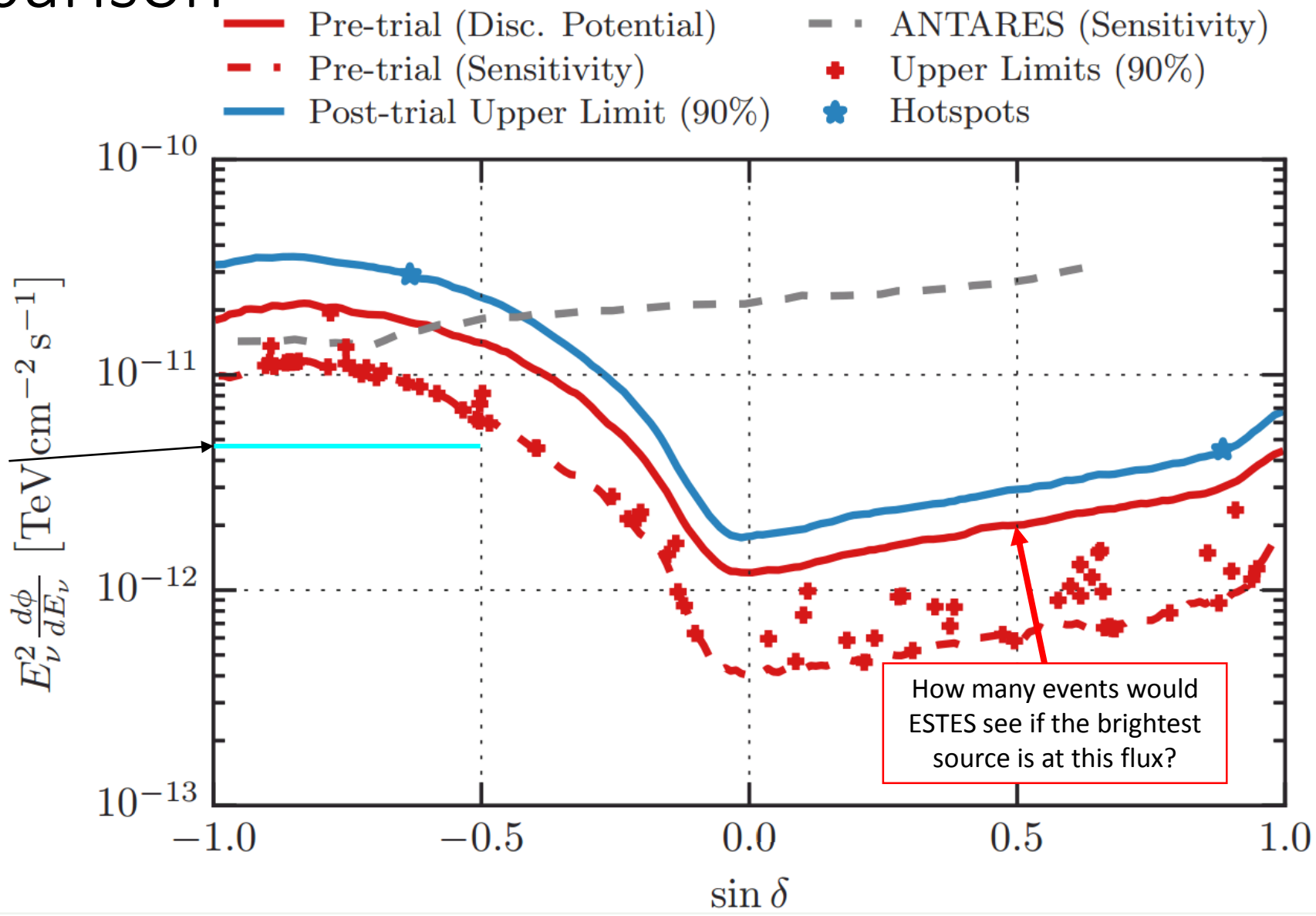
- ESTES is a new event selection in IceCube designed to obtain a diffuse purity sample
- Largest effective area for a track event selection in it's energy regime
  - The selection observes 59 starting tracks in the burn sample
- Will attempt to measure point sources
- Will measure diffuse astrophysical flux if at level of previous measurements

Backup

Point Source Comparison

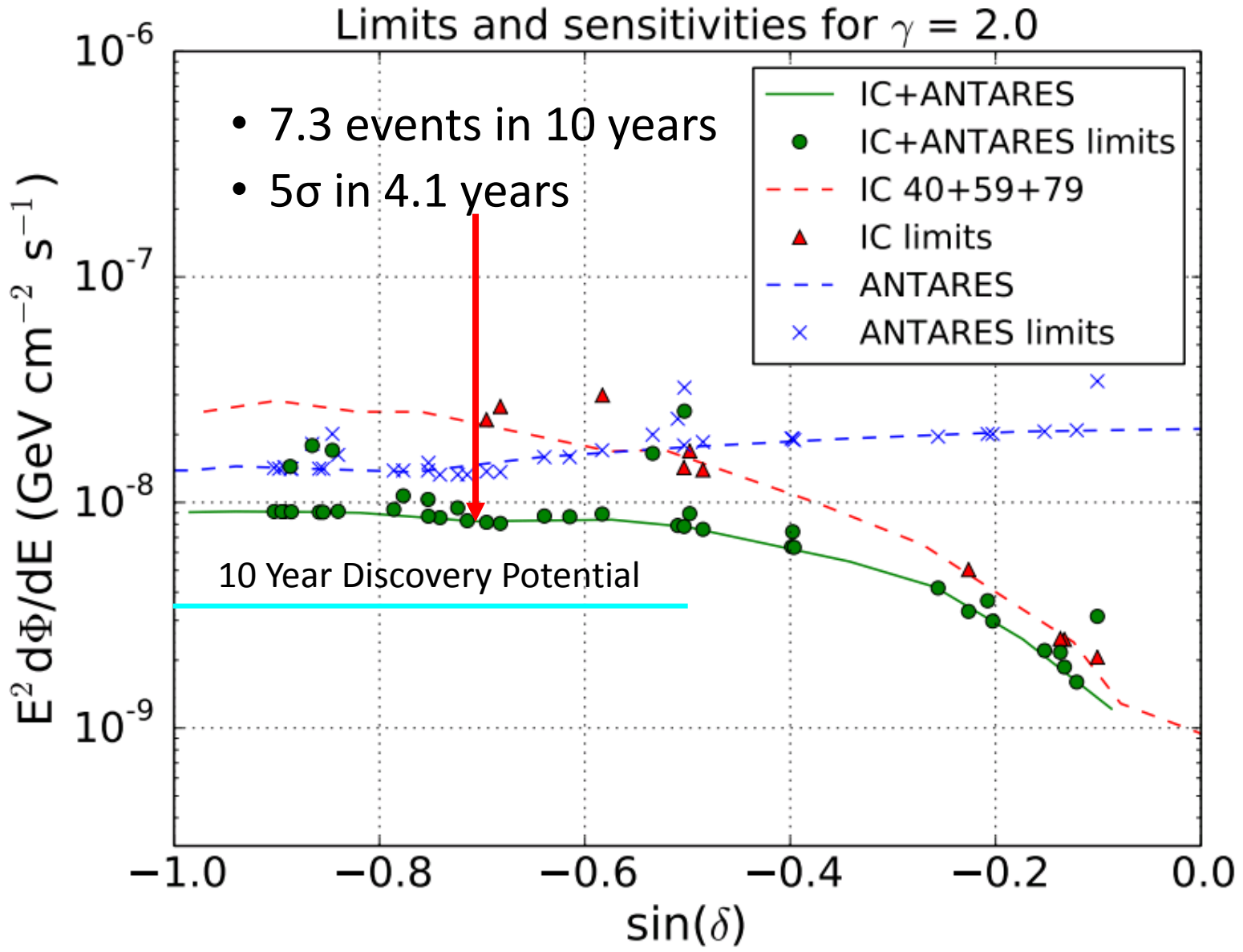
Plot and sensitivity numbers from IceCube 7 Year PS paper arXiv: 1609.04981

- E^{-2}
  - 1.8 events in 10 years
  - 5σ in 16.7 years
- What is the discovery potential of ESTES for E^{-2} sources in 7 years?



Point Source Outlook – Just missing the sources

Plot and sensitivity numbers from IceCube and ANTARES Collaborations
arXiv: 1511.02149



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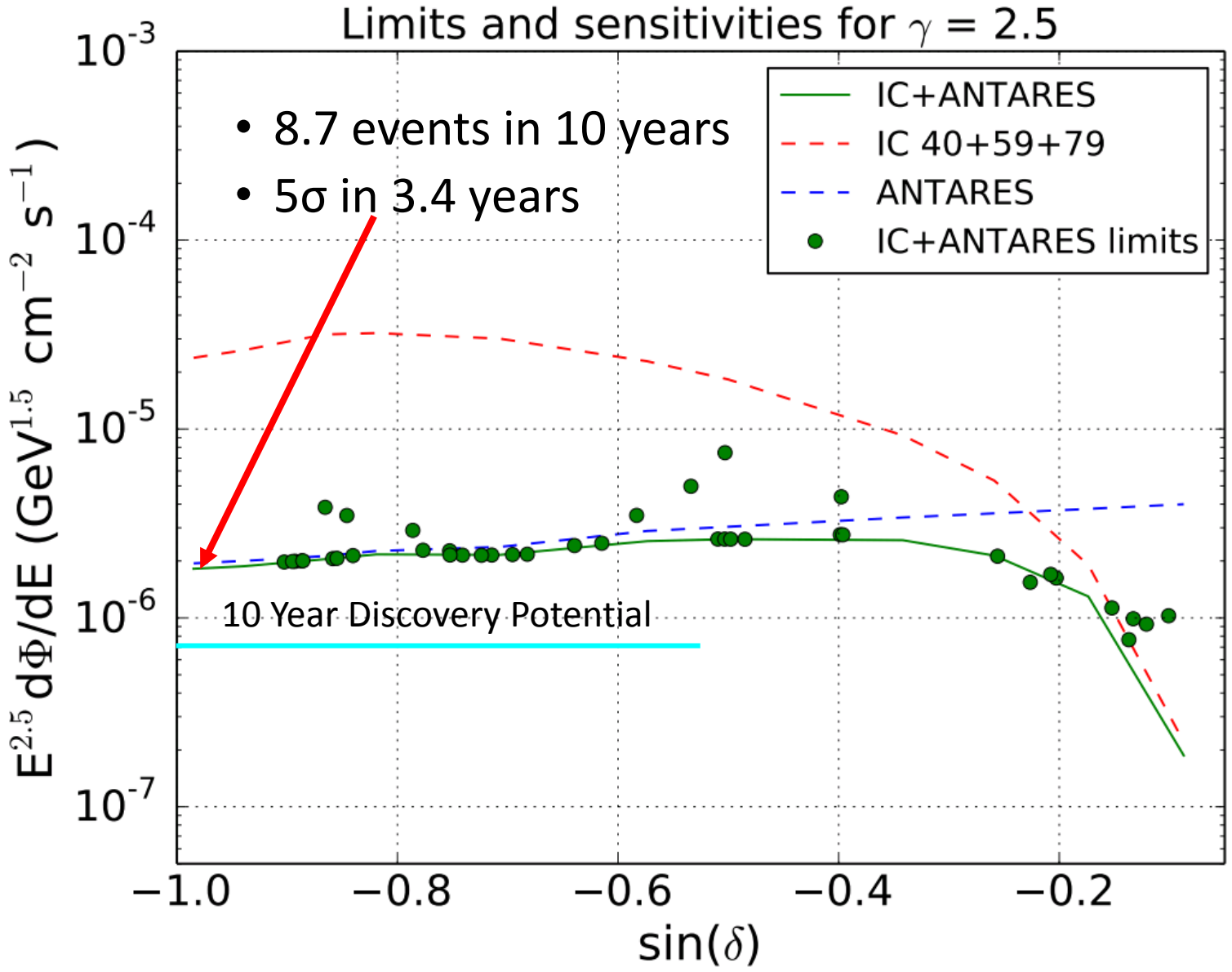

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