Measurement of the Diffuse Muon Neutrino Spectrum using IceCube Starting Track Events

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Introduction

Measured flux from Fermi, IceCube, and Auger suggest **common source** of high energy photons, neutrinos, and cosmic rays. IceCube measurements targeting different energies have shown tension in measurement between TeV and PeV neutrinos. This might be an indication that there is structure in the astrophysical diffuse neutrino spectrum. We use starting tracks to provide a **unique measurement** using a dataset that is **inclusive** of both **lower** energy **and higher energy** astrophysical neutrinos.

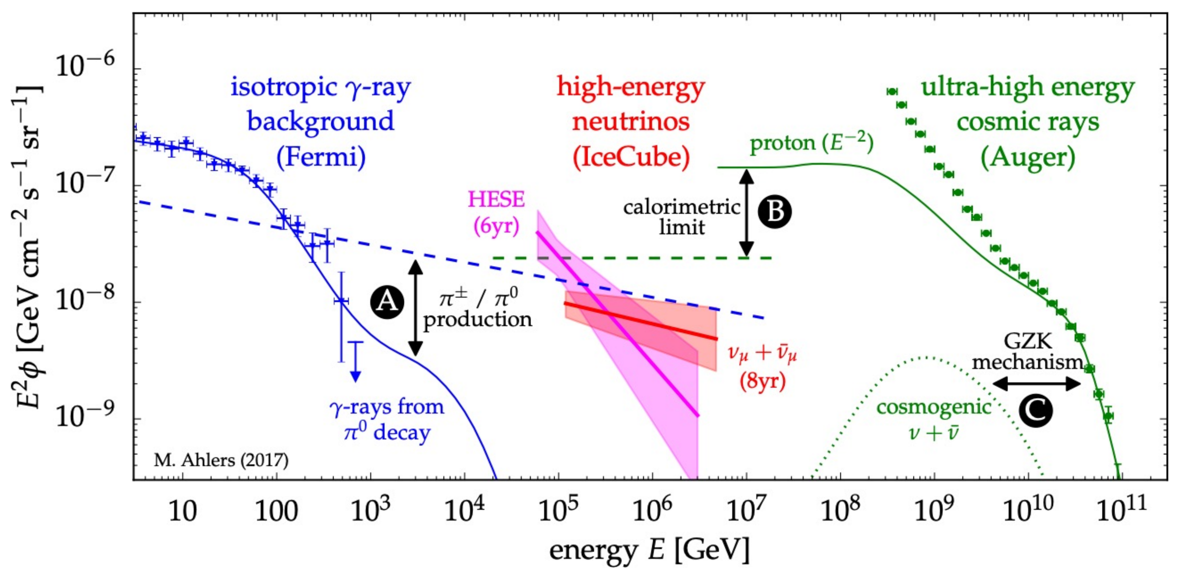


Figure 1: Production mechanism of pions (charged and neutral) leads to the emission of gamma-rays and neutrinos. CR emission models suggest a "maximal flux" of neutrinos (calorimetric limit). [1]

Starting Track Events

Starting Track events are **muon neutrinos** undergoing a **charged-current interaction** within the volume of the detector (figure 2)

The exiting **muon track** is used to **point backwards** and form the "dark region", this region is where **neutrino travelled** and **no Cherenkov light** *should be* detected

We then compute the **probability** of being a **real starting track** event (equation 1)

$$p(\lambda, k=0) = \frac{\lambda^k e^{\lambda}}{k!}, \; p_{miss} = \prod_{i=1}^{DarkRegion} p(\lambda_i, k_i = 0)$$

Equation 1a: Probability of observing no light (k=0) assuming a muon track emitted Cherenkov light λ. 1b: Total probability for all IceCube modules in dark region.

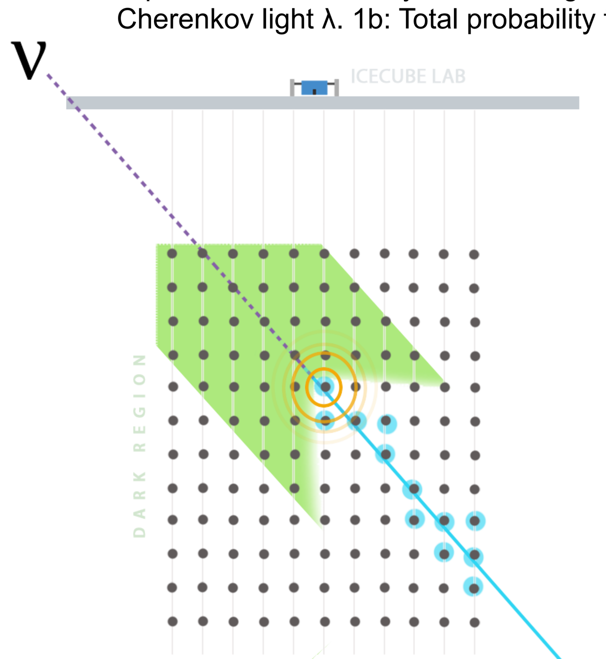


Figure 2: Diagram outlining a starting track event. The neutrino (dashed line) enters the detector and undergoes a CC interaction (circle). The muon track (solid line) is then used to "point-backwards" and form our dark region.

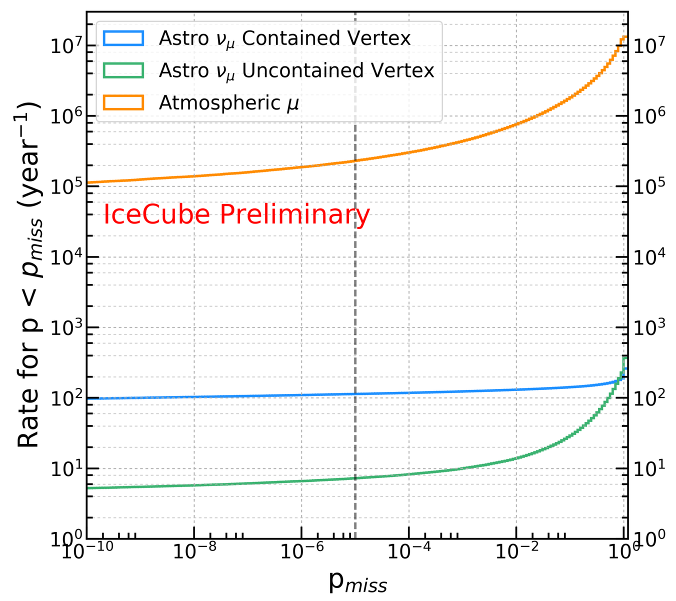


Figure 3: Cumulative distribution for p_{miss} and chosen cut (dashed line). The astrophysical muon neutrinos are broken down into events where the vertex takes place within the detector or not (contained vs uncontained).

Boosted Decision Tree

eXtreme Gradient Boosting Decision Tree algorithm (**BDT**) [4] used to **reduce the atmospheric muon** background to **negligible** quantities

The **BDT score** represents a **probability** for a particular event to be an **astrophysical muon neutrino** (figure 4)

Most **important variables** are shown in ref [11]

The events surviving the p_{miss} and BDT cuts are used for the remainder of this presentation

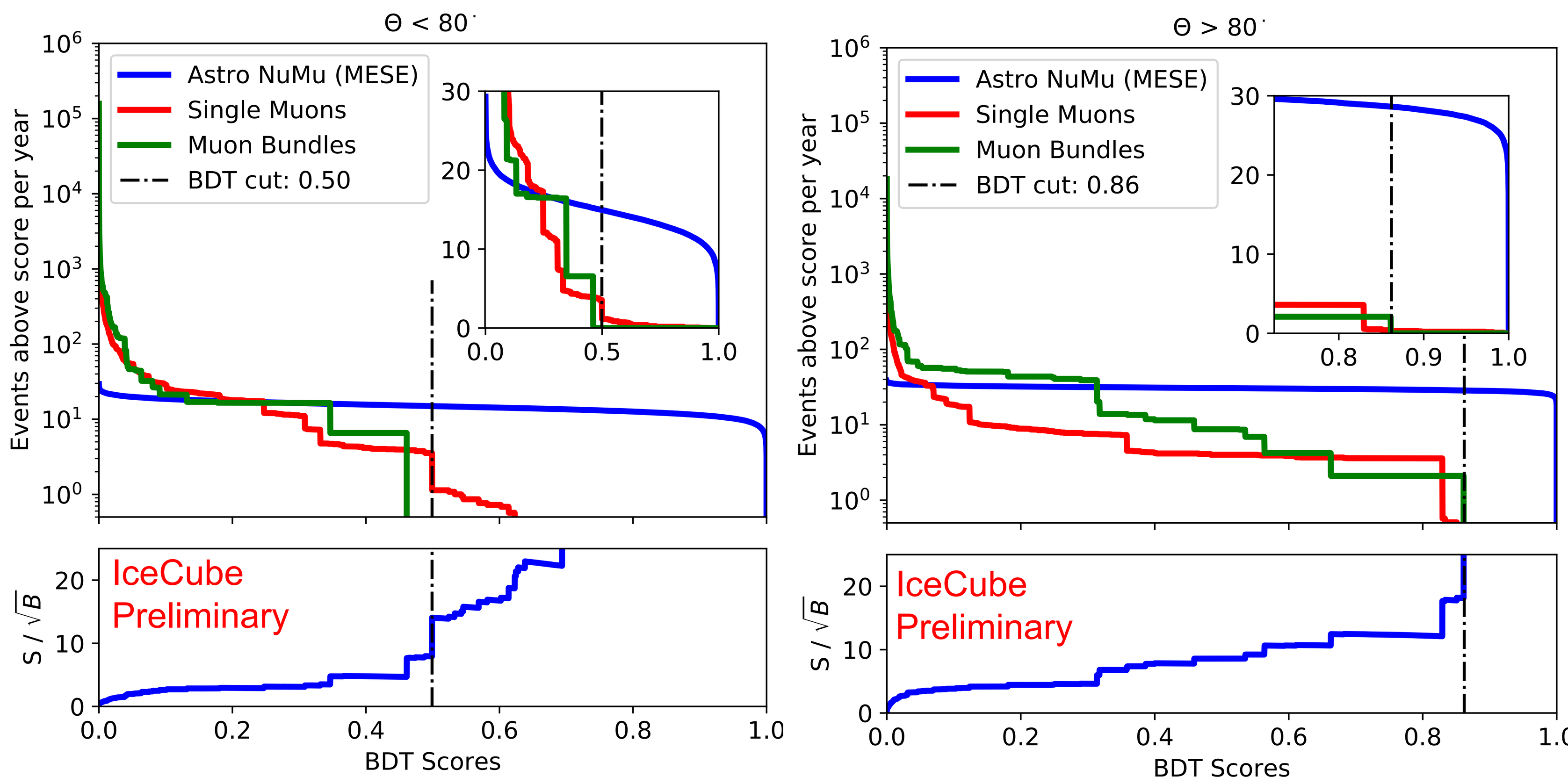


Figure 4: Cumulative BDT score distributions for zeniths < 80° (left) and zenith > 80°. Dashed line represents the cut chosen on BDT scores such that the atmospheric muon contribution is reduced to less than 1 expected per year. Astrophysical muon neutrinos (blue line) are simulated assuming the best-ft single power law flux from the MESE 2-year result [2]. Single Muons and Muon Bundles are simulated assuming the GaisserH4a Cosmic Ray flux [3].

Expected Rates

HKKMS cosmic-ray flux model [5] used for **atmospheric neutrinos** (Note: prompt flux is set to "0" for the duration of this work)

Self-veto effect [6] is applied as correction to HKKMS

Self-veto effect enables us to **select for** astrophysical muon **neutrinos** at **TeV energies**

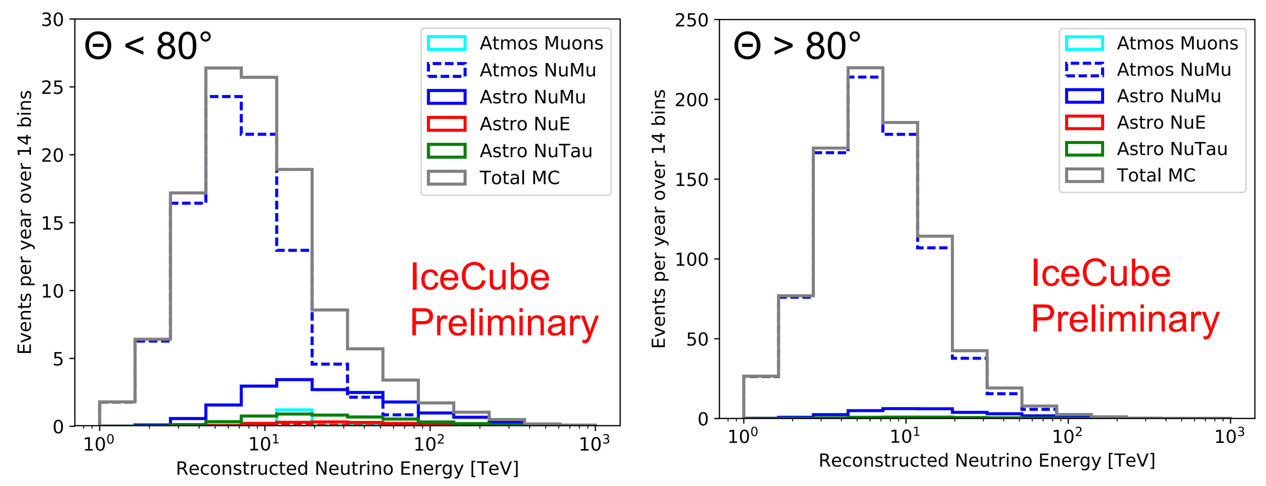


Figure 5: Each event surviving the STV and BDT are binned into 14 energy bins from 1 TeV to 1 PeV. This is further separated into zeniths < 80° (left) and zenith > 80°. The self-veto is most important for neutrinos with zeniths < 80°.

Methodology

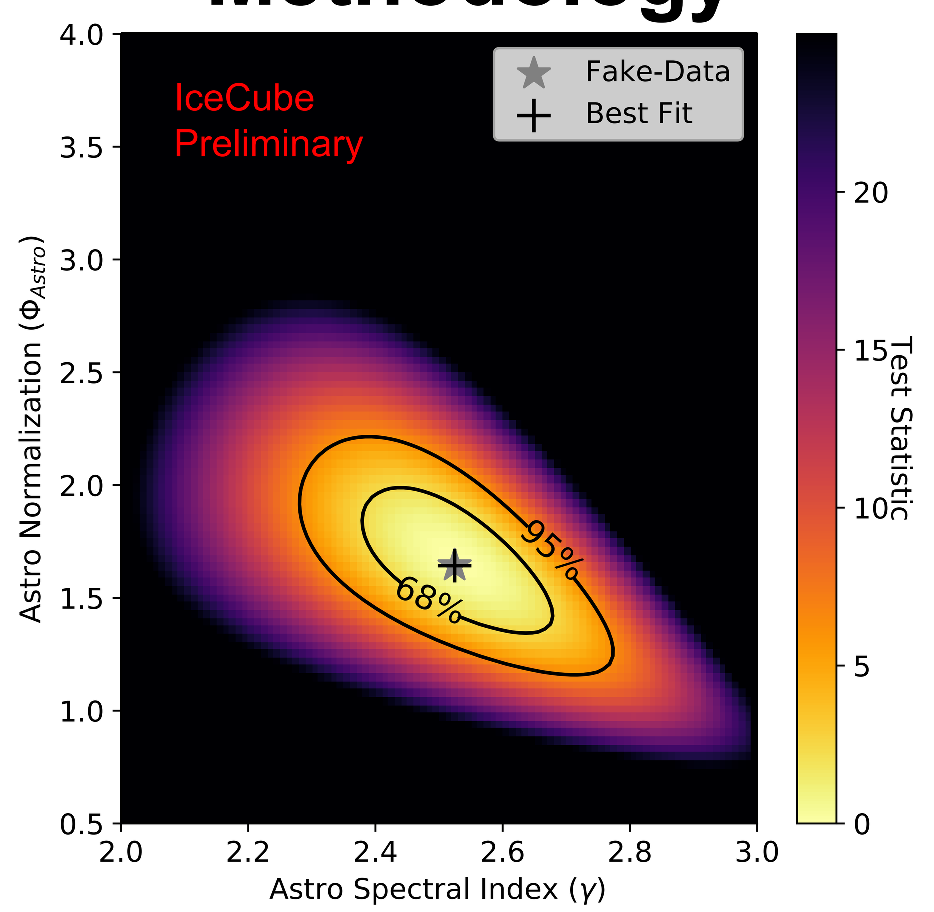


Figure 6: The "fake-data" point is directly from ref 5 (Best fit Φastro= 1.66, γ=2.53). 68 and 95% confidence intervals are shown as black contour lines.

A **binned likelihood** approach is used assuming **Poisson statistics** for each bin (eq 2)

An **example** of our result is shown in **fig 6** with the parameters of interest defined in eq 3

$$L = \prod_{bin-i} \frac{e^{-\lambda_i}\lambda_i^{k_i}}{k_i!}$$

Equation 2: Likelihood function for particular set of $\Phi_{atmos,0}$, Φ_{astro}, γ.

$$\Phi_{atmos} = \Phi_{atmos,0} \times HKKMS$$
$$\Phi_{astro}^{\nu+\bar{\nu}}(E)/\Phi_0 = \Phi_{astro} \times \left(\frac{E}{100TeV}\right)^{-\gamma}$$
$$\Phi_0 = 10^{-18} GeV^{-1} cm^{-2} s^{-1} sr^{-1}$$

Equation 3: Flux models used to simulate Asimov-data and the simulation. $\Phi_{atmos,0}$, Φ_{astro}, γ are the 3 parameters of interest for the studies shown in this presentation.

Results

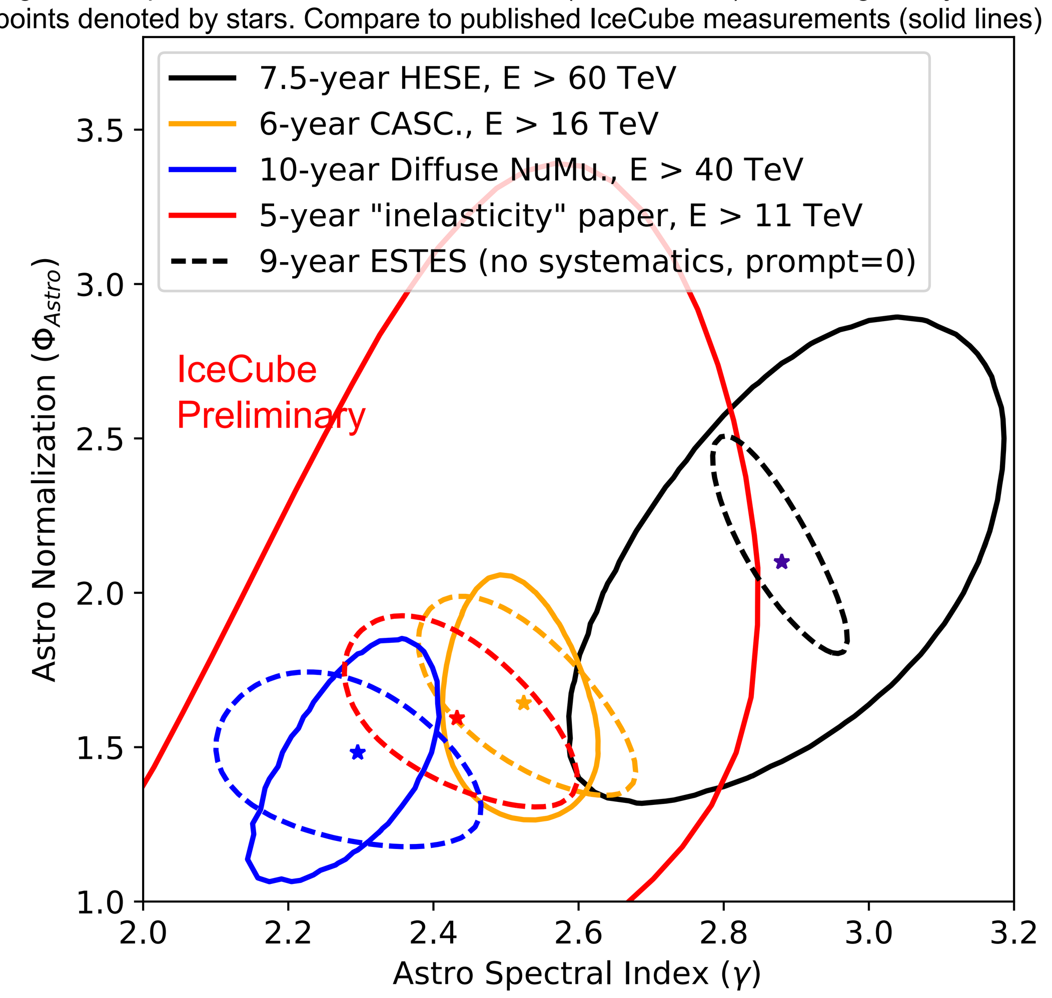
IceCube diffuse flux measurements in **figure 8** as solid lines

"Inelasticity" paper [10] is most like this work, it **focused** on **starting track events**

We compute **1σ expected measurements** displayed in figured 8 as dashed lines assuming various models

This event selection is competitive to and will **improve** our current **understanding** of the **diffuse neutrino flux**

Figure 8: Expected 68% confidence intervals (dashed lines) assuming we inject the points denoted by stars. Compare to published IceCube measurements (solid lines)



Discussion and Outlook

Detector and ice **systematics** will **soon** be **implemented into** our **likelihood** in addition to atmospheric flux uncertainties. The role of prompt neutrino fluxes is expected to be non-negligible and will also be included

We expect to **observed ~1000 starting track events per year** and negligible atmospheric muons events

As-is, this **event selection** will be able to **contribute substantially** to our understanding of the diffuse neutrino flux

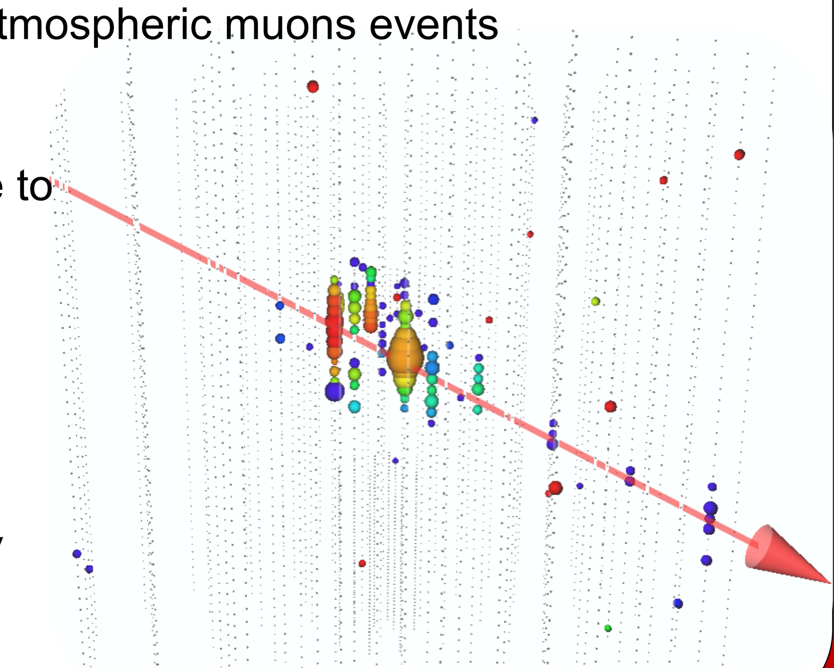


Figure 9: Event display of a starting track event with a reconstructed energy of 16 TeV and zenith of 66°. The estimated probability to be of astrophysical origin is at least 50%.

References

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