Neutrino source searches and a realtime neutrino alert stream in the southern sky with IceCube starting tracks

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Neutrino Parallel
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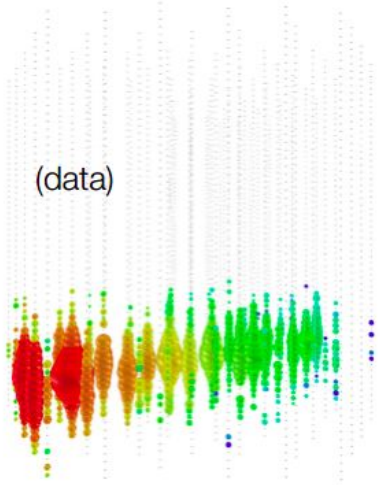
Common IceCube neutrino event morphologies

Use array of optical modules (DOMs) in antarctic ice

Wait for neutrinos to interact

Observe **Cherenkov light** from charged, relativistic particles created in interactions

Charged-current ν_μ

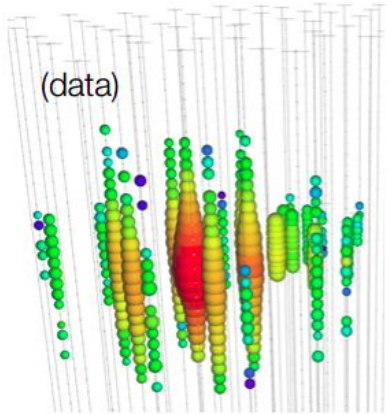


Track

Factor ~2 energy resolution

<1 degree angular resolution

Neutral-current / ν_e



Cascade

15% deposited energy resolution

5-20 degree angular resolution

DOM hit time

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IceCube and rejecting atmospheric neutrinos

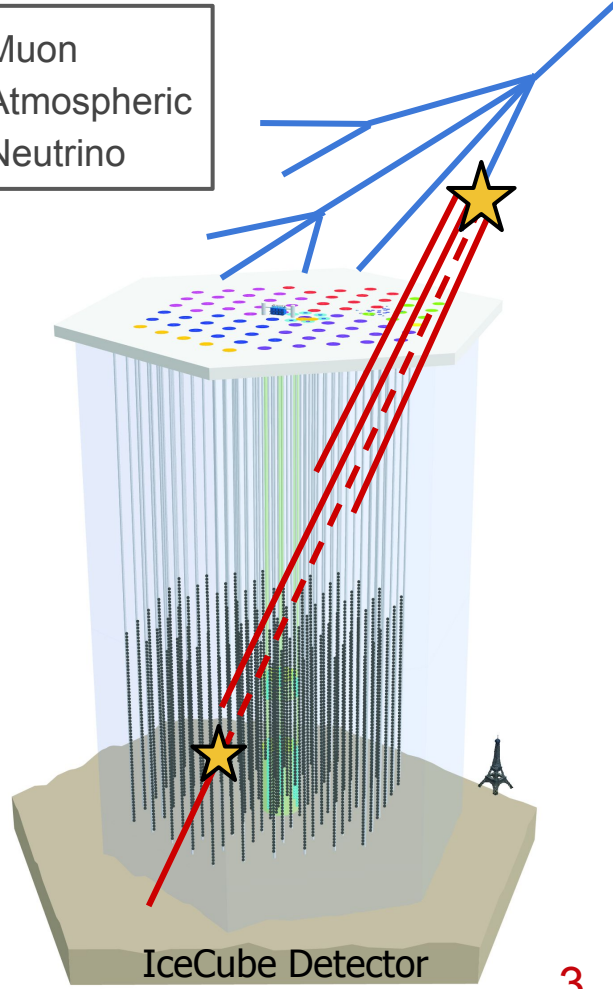
IceCube is looking for **astrophysical neutrinos** as evidence of **hadronic acceleration** in our universe

IceCube trigger dominated by cosmic ray muons

Use energy and zenith angle to distinguish atmospheric and astrophysical neutrinos

Can find **neutrinos in southern sky** by looking for **starting muon tracks** using a veto region

Reject atmospheric neutrinos using light from muons created in the same air shower

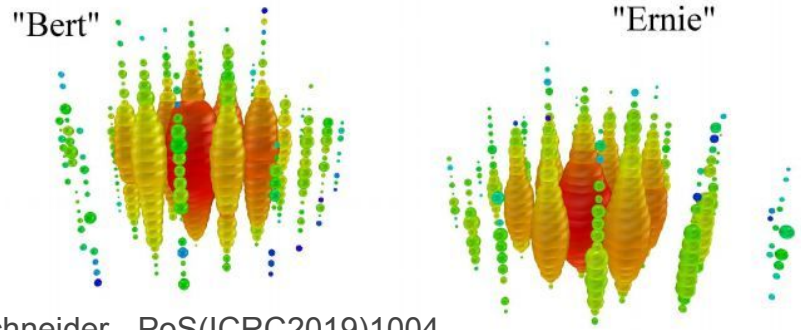


Starting tracks versus previous starting selections

(Existing) Starting Event Selections

Use **predefined veto regions** of detector to find starting events

- Detector volume restricted
- Cascade dominated selection



Schneider - PoS(ICRC2019)1004

(New) Starting Track Selection

Selection Goal: Observe **starting tracks**

- High astrophysical muon neutrino purity in southern sky
- Good pointing resolution

Starting track selection defines a **unique "dark" region for each event**

Can use starting track events for:

- **Neutrino point source searches**
- **Realtime neutrino event stream**
- Diffuse muon neutrino spectrum fit

Silva - PoS(ICRC2019)1010

Creating the dark and muon regions

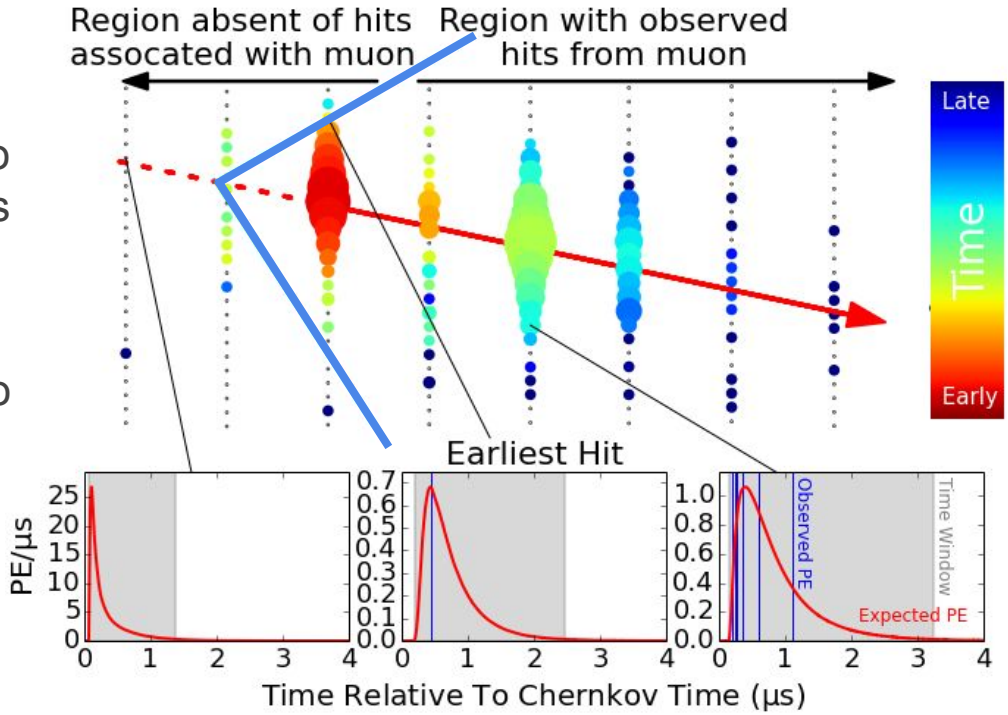
Assume an infinite track hypothesis

Predict light yield at optical modules (DOMs) to find earliest hit consistent with track hypothesis

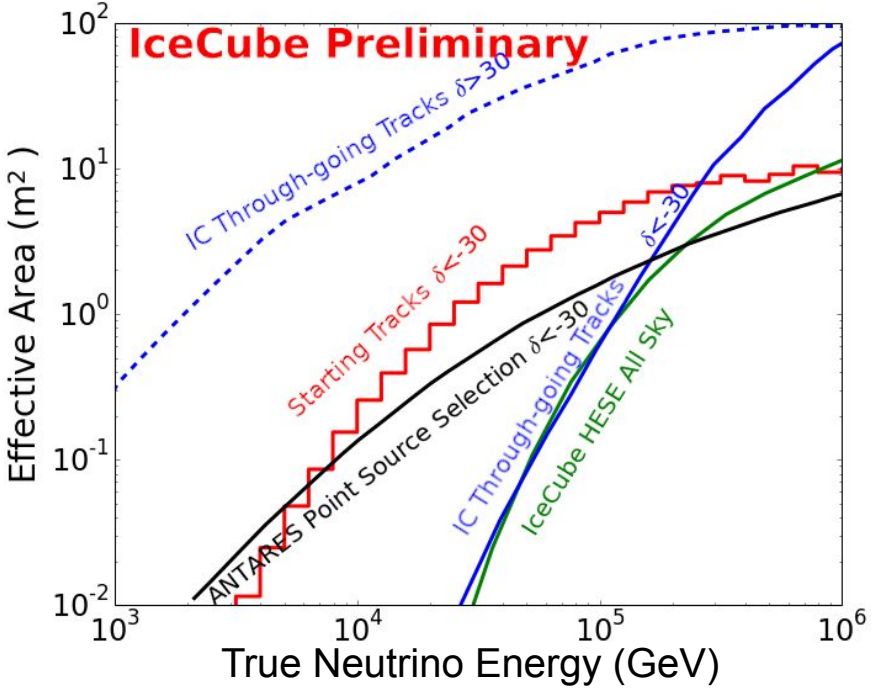
Define **muon region** and **dark region**

Calculate the probability, p_{miss}, of DOMs in veto region missing light from an incoming muon

Use p_{miss} as main parameter in determining if starting track



Starting tracks effective area and per year event expectations



Final Level (per year)	Atmo μ	Atmo ν_μ	Asto ν_μ*
Up-Going (δ > -20°)	0	127	9
Down-going (δ < -20°)	0.8	33	**9**

*Assuming flux from PRD 91 (2015) for rest of talk

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

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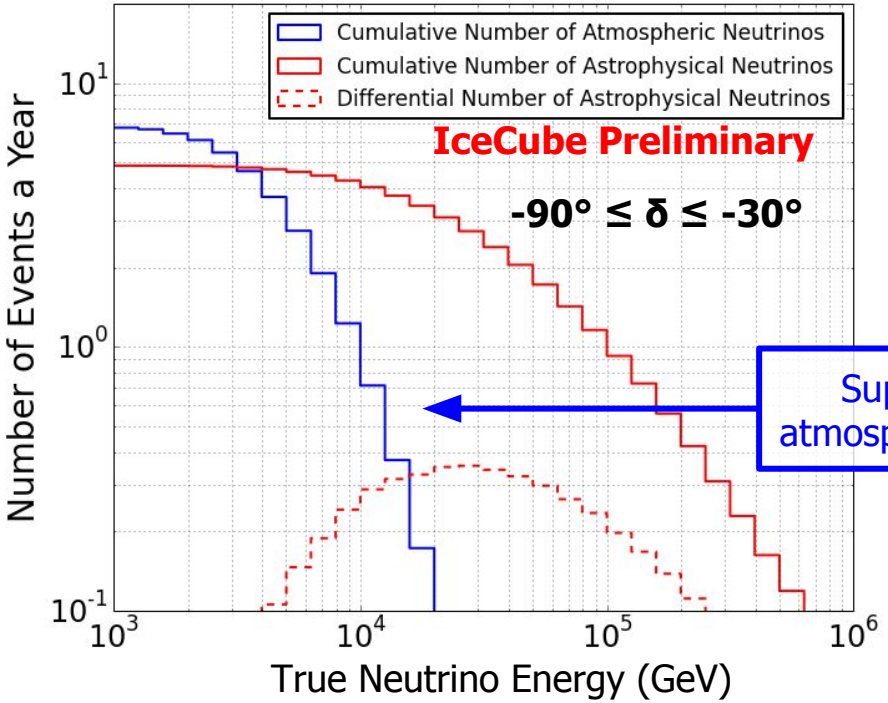
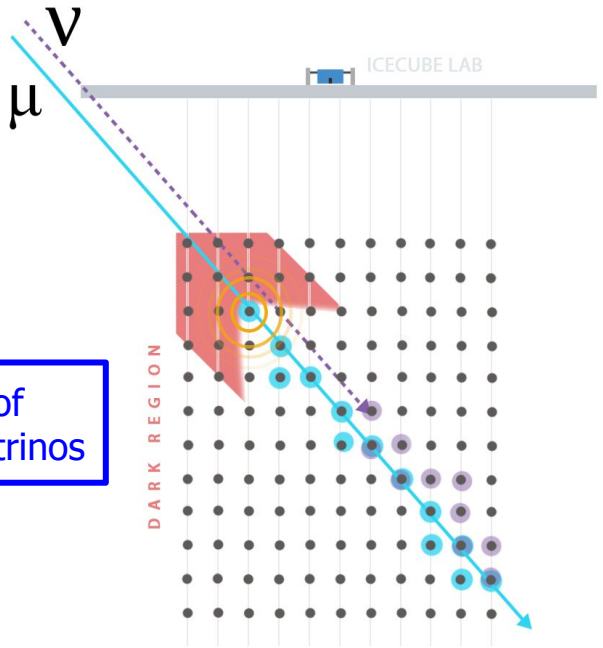
Southern sky per year event expectations



Suppression of atmospheric neutrinos

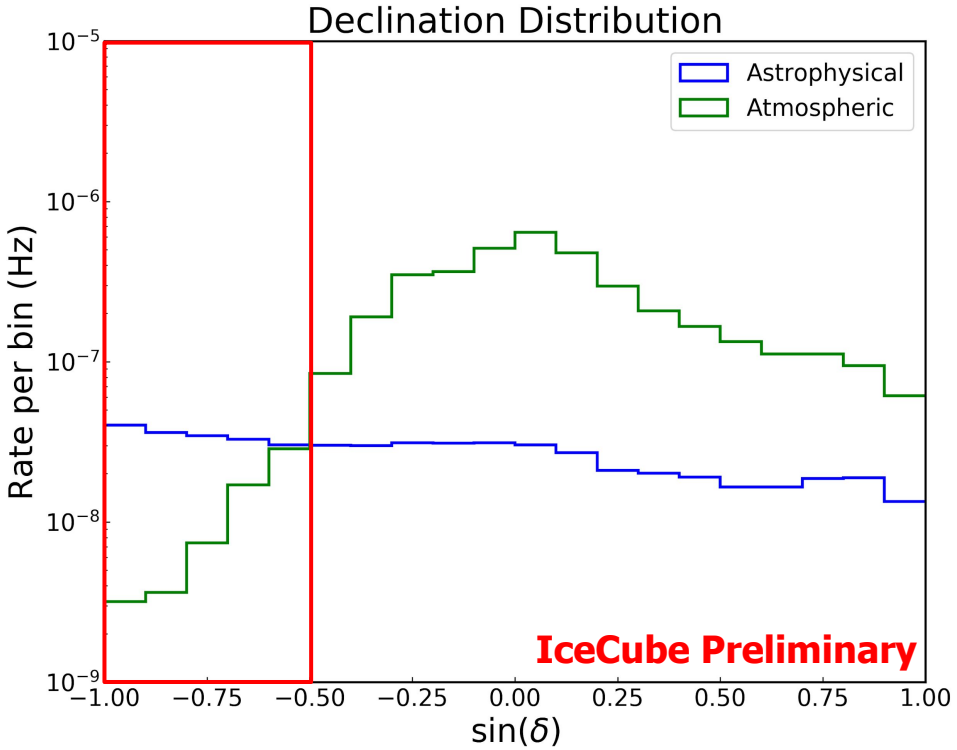


Point sources and astrophysical purity in the southern sky

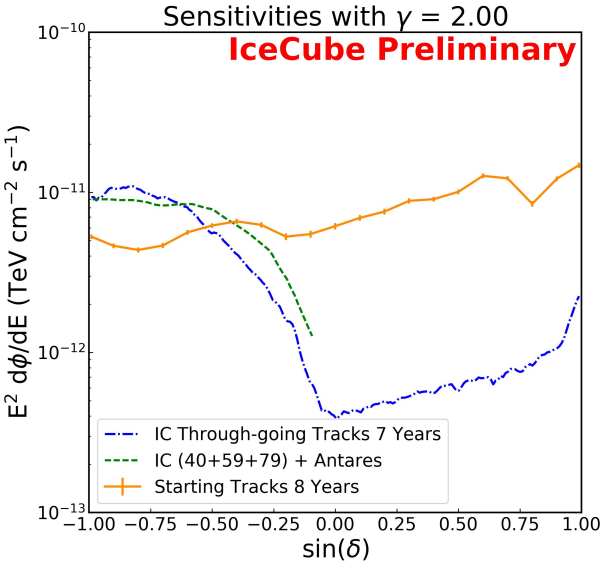
High astrophysical purity in southern sky

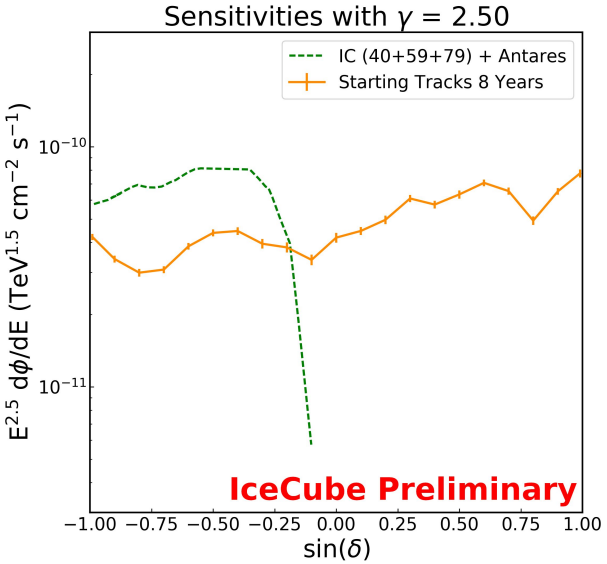
Only need a few events to be sensitive to source

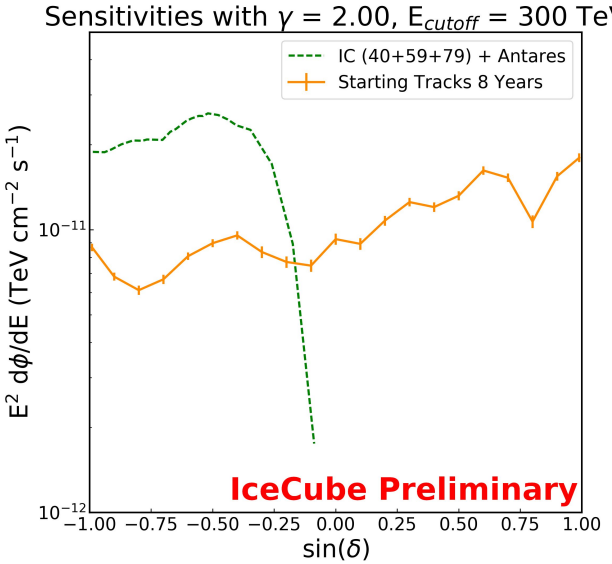
Use standard IceCube likelihood approach for point source searches



All sky point source sensitivities







Starting track selection sensitive to southern sky

Improved sensitivities especially when spectrum softer or energy cutoffs applied

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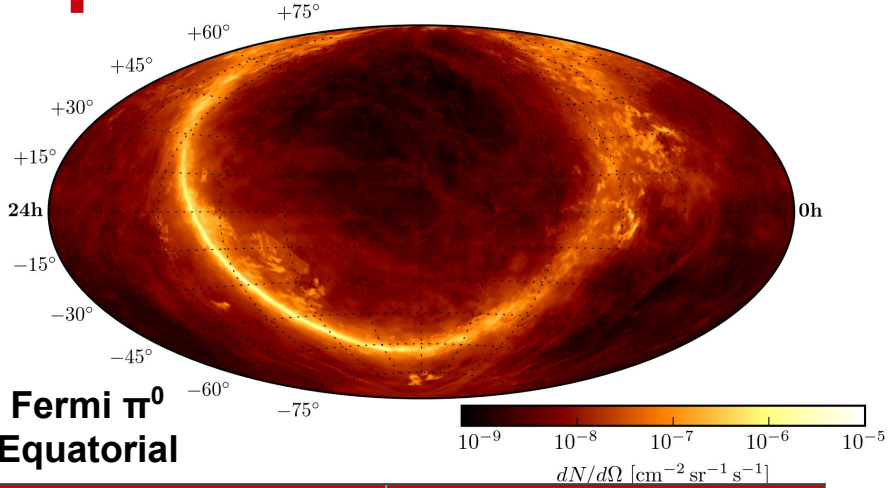
IC 7 Year: arXiv:1609.04981 IC (40+59+79) + Antares: arXiv:1511.02149v1

Galactic plane emission templates sensitivities

Look for neutrino emission from cosmic rays interacting with galactic plane matter

Use two models: Fermi π^0 and KRAγ

Sensitivity to each model shown below



Fermi π^0 Equatorial

	Fermi π^0 (γ = 2.5)	KRAγ (5 PeV Cutoff)	KRAγ (50 PeV Cutoff)
Starting track selection 8 years	2.45 x 10^{-11} TeV cm^{-2} s^{-1} 13.37 +/- 0.22 Events	45.9% x KRAγ 6.60 +/- 0.11 Events	35.1% x KRAγ 6.39 +/- 0.10 Events
7 Year Galactic Plane Paper*	2.97 x 10^{-11} TeV cm^{-2} s^{-1}	-	79% x KRAγ

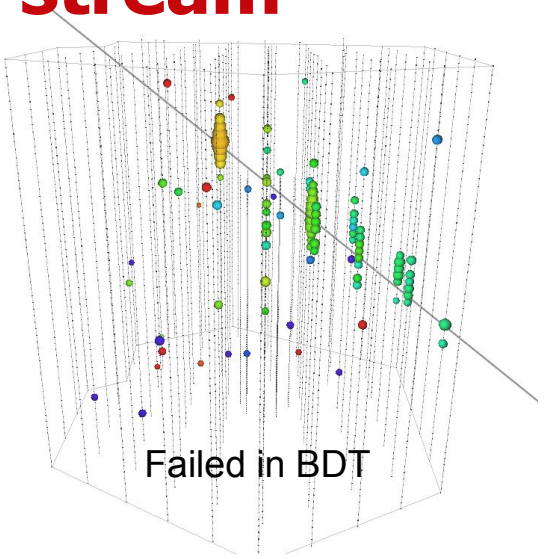
*7 Year Galactic Plane Paper: Astrophys.J. 849 (2017) 67

Starting track near realtime event stream

Modified veto selection run in realtime at South Pole

- Higher energy
- Longer track length

	Atmo μ	Atmo ν	Astro ν (with >50% signalness)
Modified Filter	7200 per year	17.9 per year	**5.5 per year**



Events sent north to have whole event selection run on them in ~5 minutes

Signalness calculated comparing ratio of signal to total events in MC at final level for events with similar reconstructed energy and declination

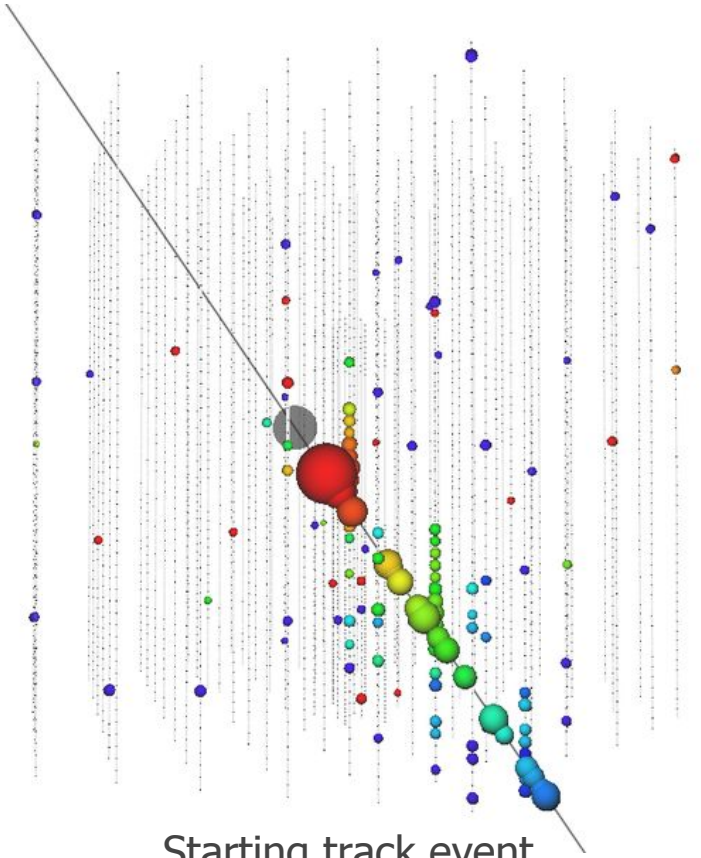
In the future, if **event passes full selection, send out an alert**

Summary

Selection provides a sample of muon neutrinos with high astrophysical purity in the southern sky

Selection has a competitive sensitivity in the southern sky for point source searches

Starting track alert stream will begin soon and send out alerts for southern sky events



Starting track event

Backup Slides

Veto and p_{miss} definition in detail

Each DOM has a poisson probability of observing photons elections (PE)

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

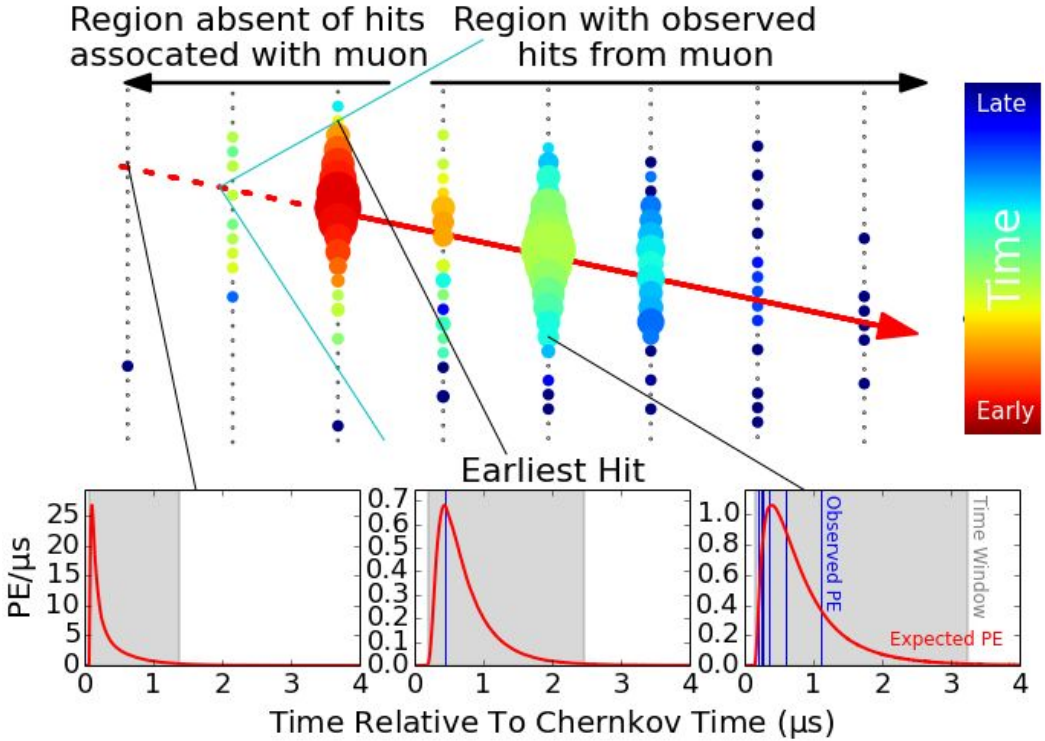
λ is expected number of PE

K is observed number of PE

p_{miss} is the product of probabilities that DOMs in the veto region saw no charge

$$p_{\text{miss}} = \prod_{i}^{\text{veto region DOMs}} p(\lambda_i, k = 0)$$

where $\lambda_i = a\lambda_{e_i} + \lambda_{n_i}$

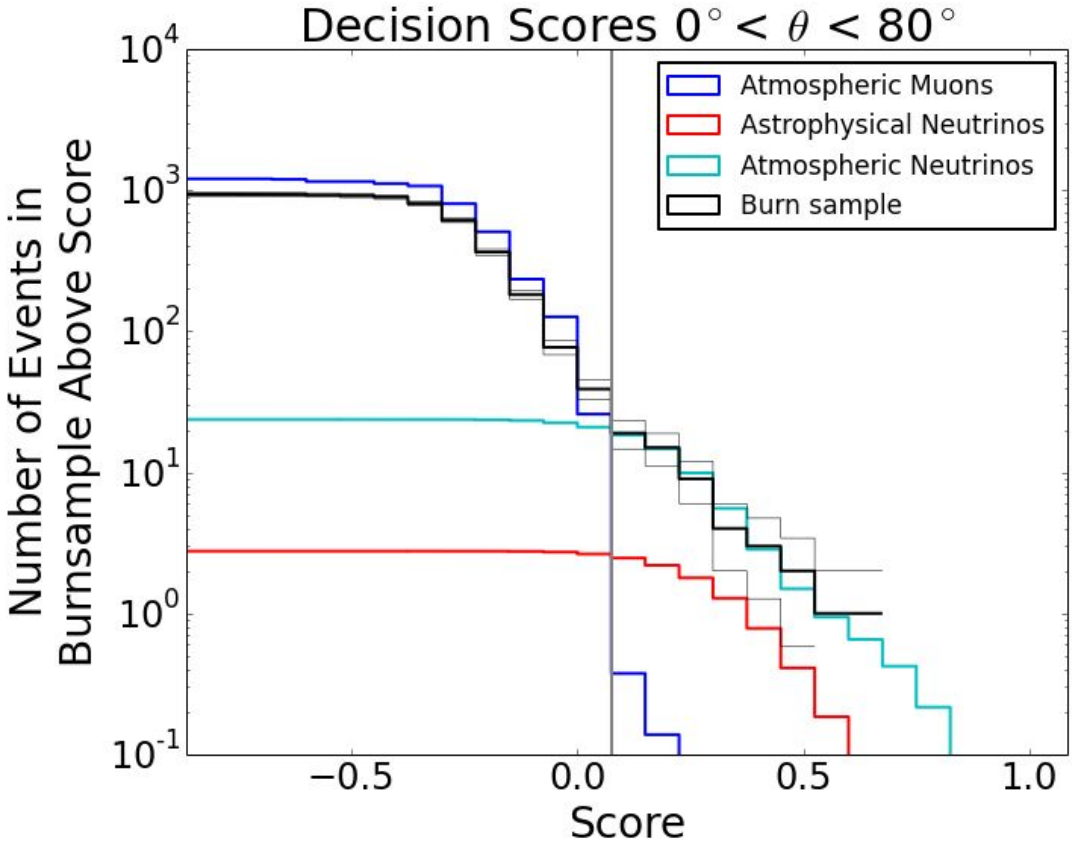


The scale factor, a, is calculated for each event with a maximum log likelihood fit using DOMs in the muon region

BDT Efficiency

Use BDT in southern sky

Efficient at removing cosmic ray muon background



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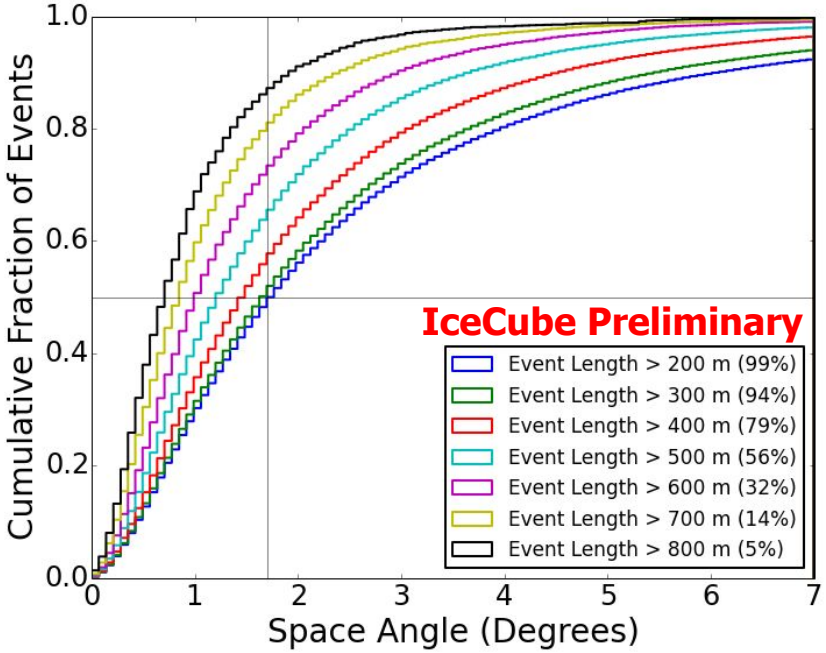
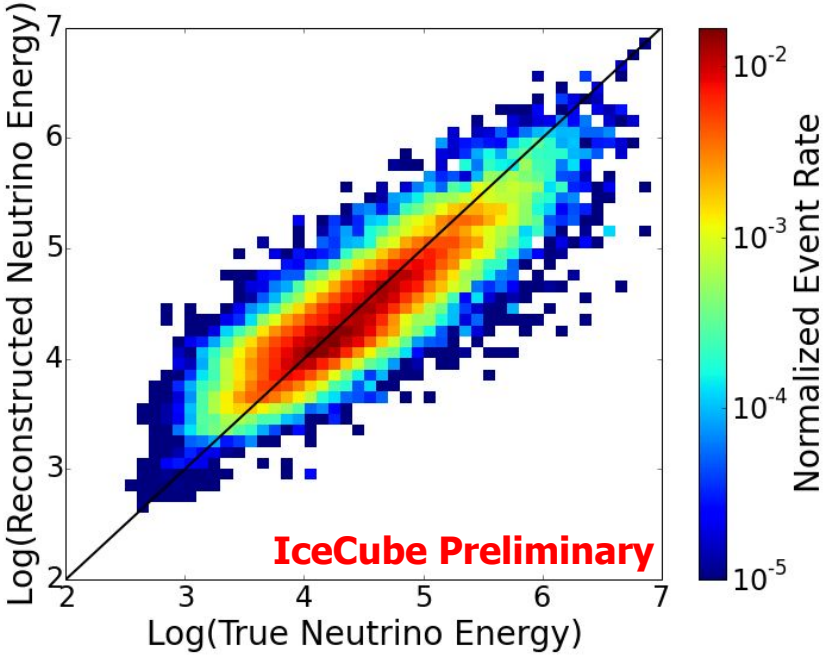
Starting tracks energy and angular resolution





Average angular error around **1.7 degrees** for full sample

Angular error has little dependence on energy

Starting tracks use **hadronic shower** and **muon energy loss** to reconstruct energy

Neutrino energy resolution around 0.25 in log(Energy) across all energies

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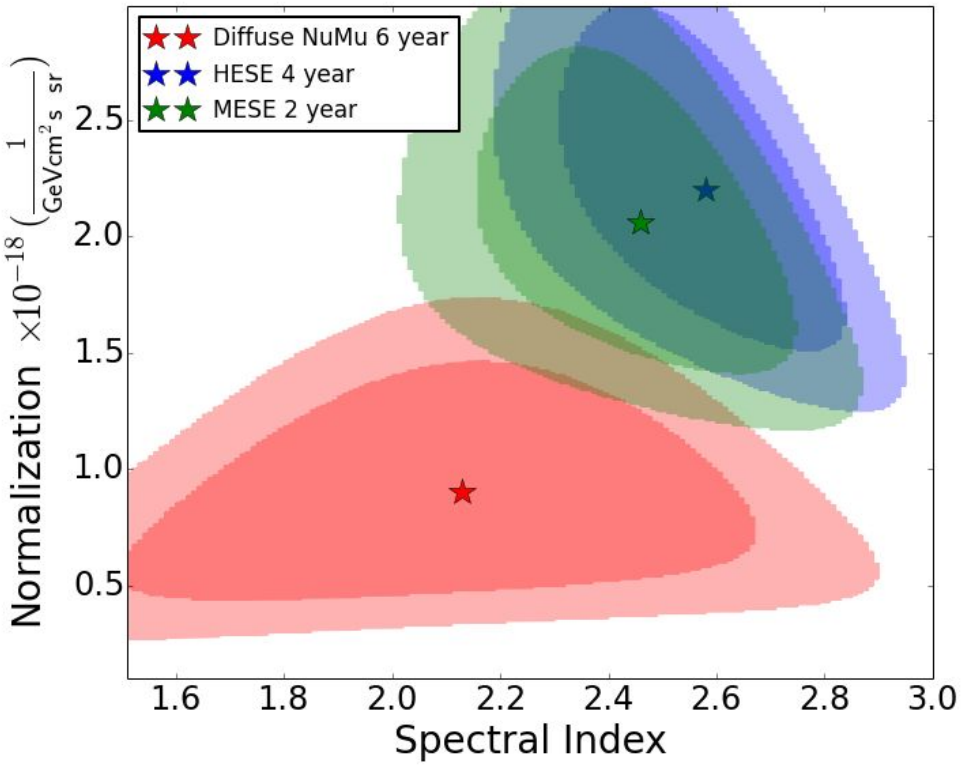
Diffuse astrophysical flux measurement outlook



Starting track selection fits to simulation of previous measurements

Up-going muon distinguishable from cascade dominated fluxes

HESE: 4 Year (cascade dominated)

- https://pos.sissa.it/archive/conferences/236/1081/ICRC2015_1081.pdf

MESE: 2 Year (cascade dominated)

- https://arxiv.org/pdf/1410.1749.pdf

Up-going muon neutrinos

- https://arxiv.org/pdf/1607.08006.pdf

Measure flux properties for southern sky muon neutrinos

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