Galactic and Extragalactic Southern Sky Neutrino Source Searches with IceCube Starting Track Events in the 1 to 100 TeV Energy Range.

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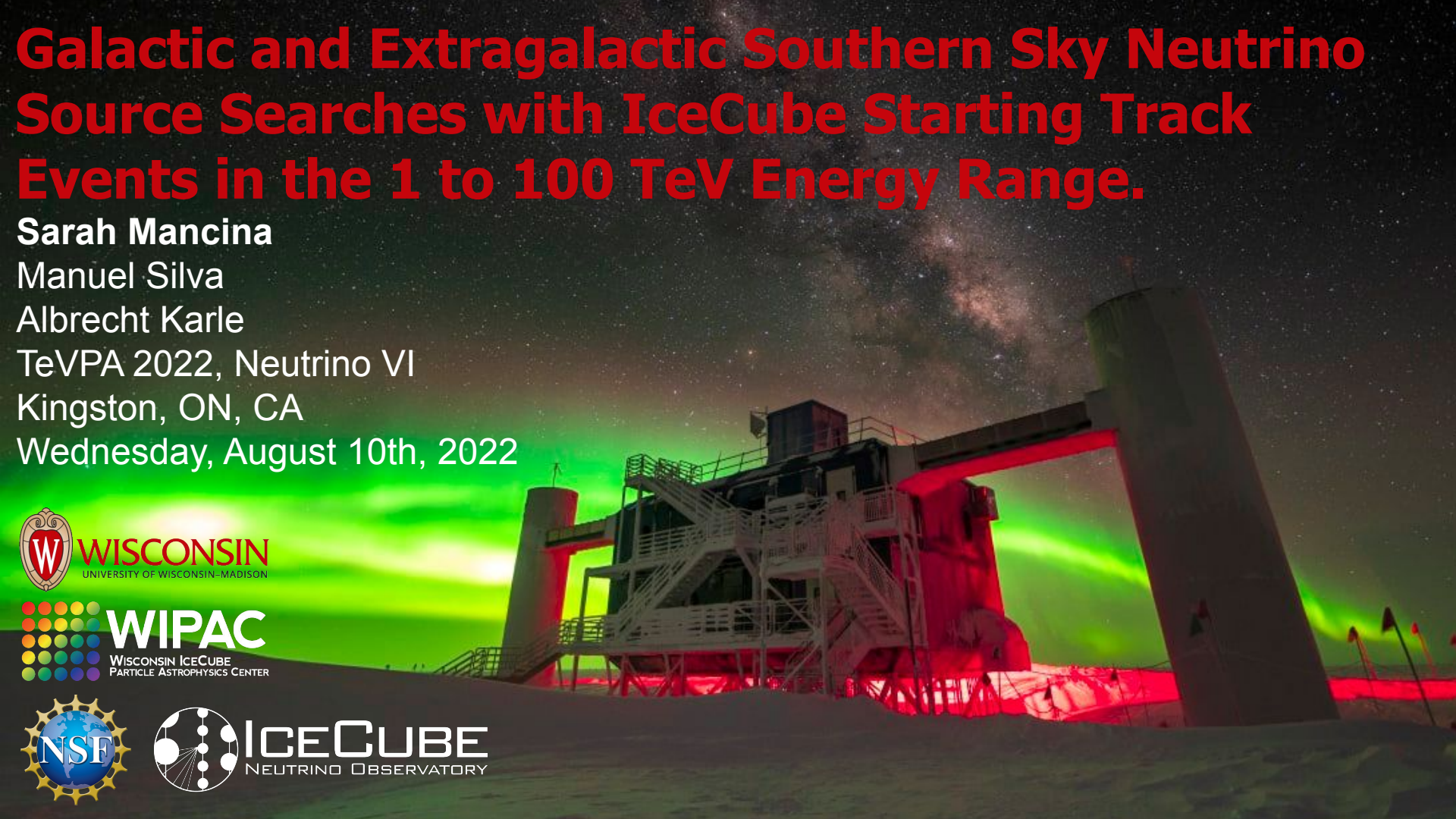


IceCube and Rejecting Atmospheric Neutrinos

IceCube is an array of PMT in the south pole ice that picks up Cherenkov Light from charged particles

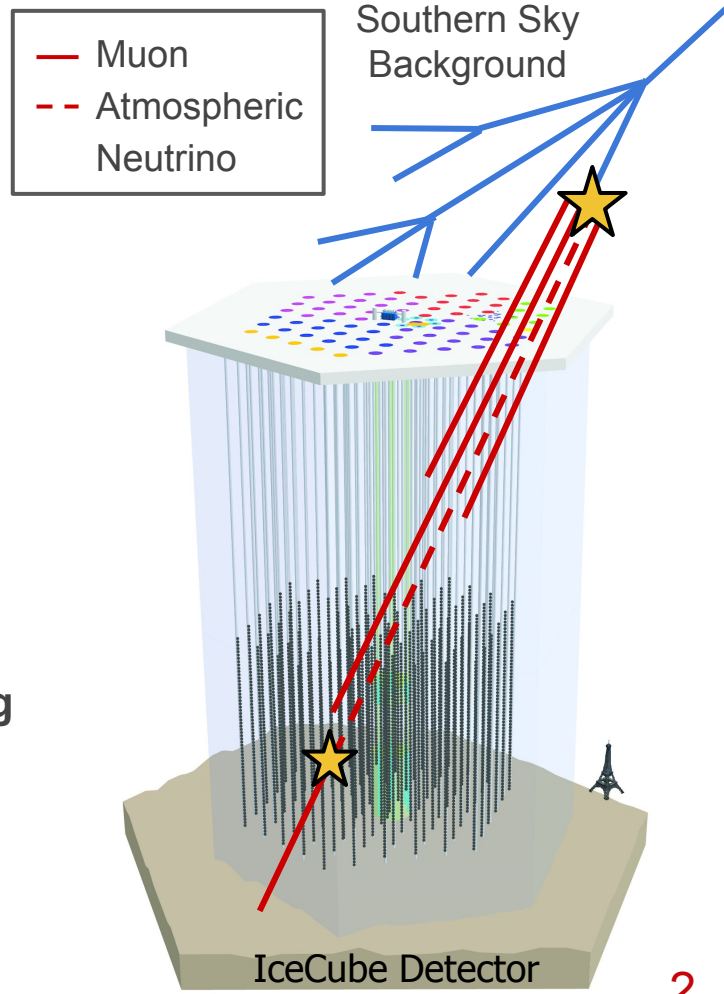
IceCube looks for **astrophysical neutrinos** as evidence of **hadronic acceleration** in our universe

IceCube trigger is dominated by cosmic ray muons from the southern sky

We traditionally use energy and zenith angle to distinguish atmospheric (background) and astrophysical (signal) neutrinos

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

IceCube can reject atmospheric neutrinos using light from muons created in the same air shower



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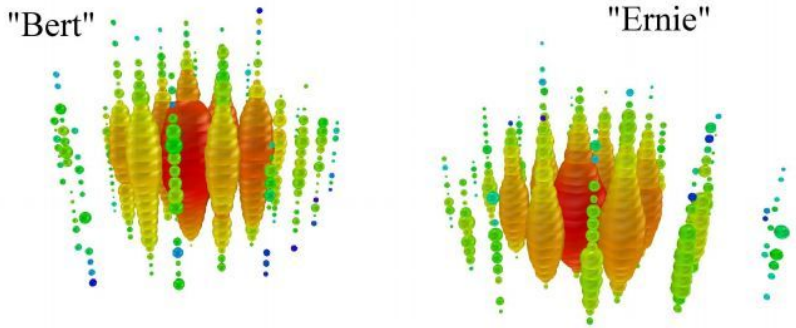
Starting Tracks and Previous Starting Selections

(Existing) Starting Event Selections

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

- Detector volume restricted
- Cascade dominated selection

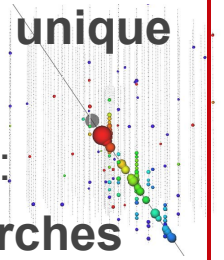


(New) Starting Track Selection

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**



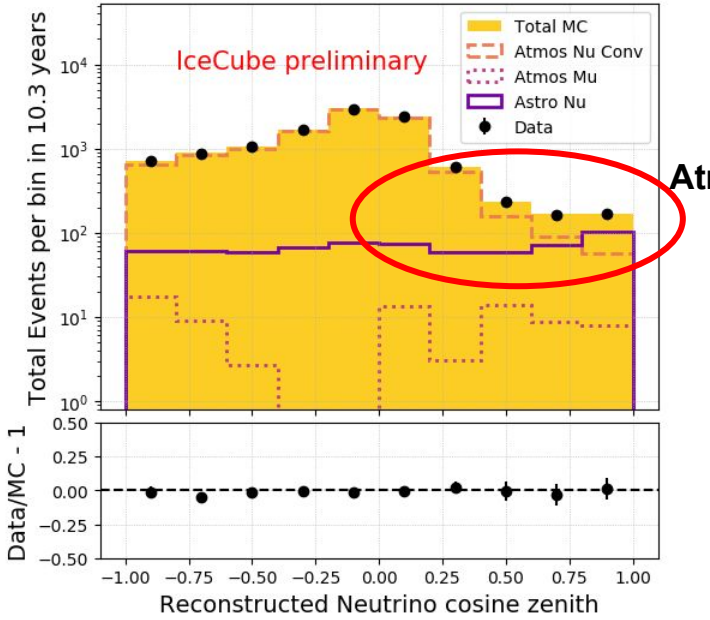
Can use starting track events for:

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

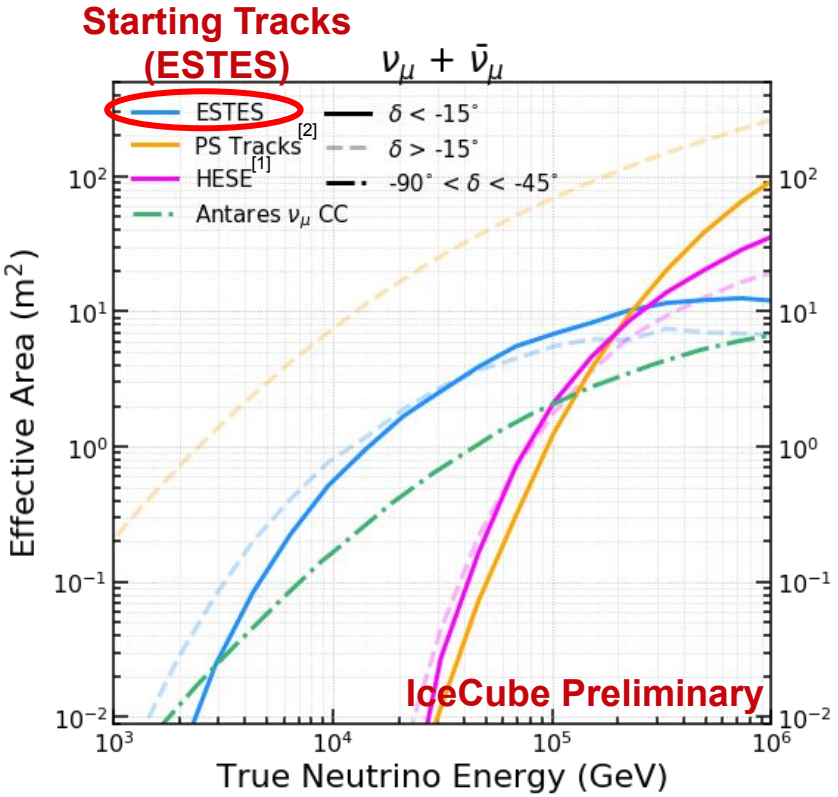
***M. Silva in Nu V:** Measurement of the Astrophysical Diffuse Flux Spectrum using Muon Neutrino Events with a Contained Vertex in IceCube

Event Rates and Effective Area

Per year rates	Astro. $\nu_{\text{all flavor}}$	Atmos. ν_μ	Atmos. μ
North ($\theta \geq 80°$)	24.9	856.9	1.2
South ($\theta < 80°$)	**13.3**	**91.4**	**6.7**



Atmospheric Nu Self-Veto



1. HESE 7.5 Year (arXiv:2011.03545)
2. ANTARES (Phys. Rev. D 96, 082001 (2017))

Search for Neutrino Sources

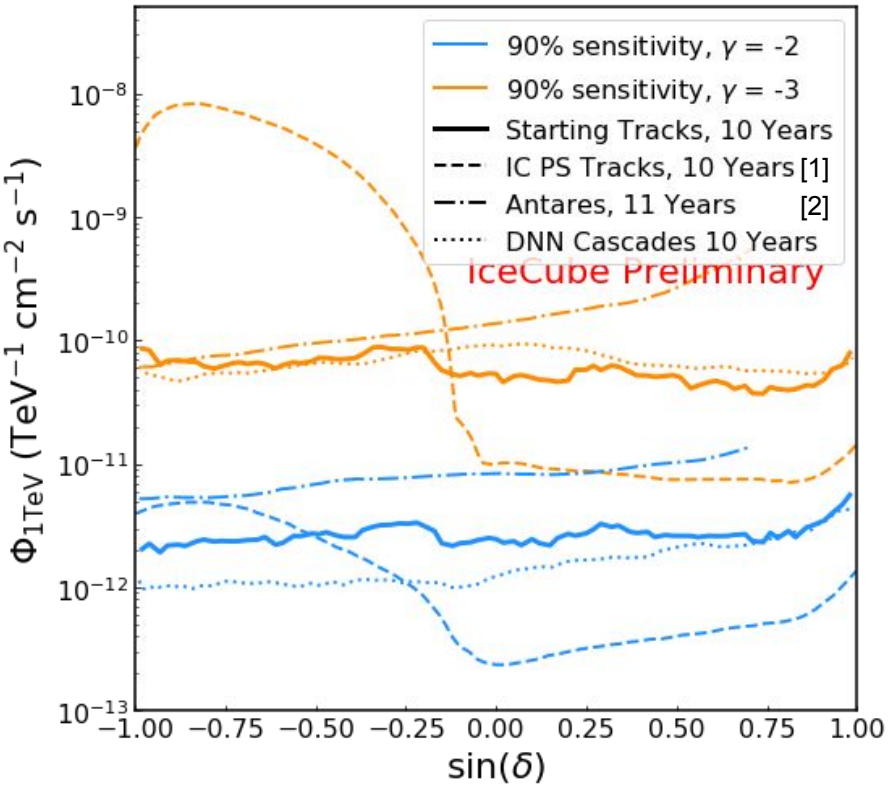
Time-integrated searches:

- All-sky search
- Single Source List
- Catalog stacking
- Galactic plane template

Use standard unbinned maximum likelihood analysis

Improvement to IceCube sensitivity in southern sky

Better sensitivity for softer spectrums due to energy range of events



1. PS Tracks (PRL 123, 051103)
2. IceCube + Antares (ApJ 892 (2020) 92)

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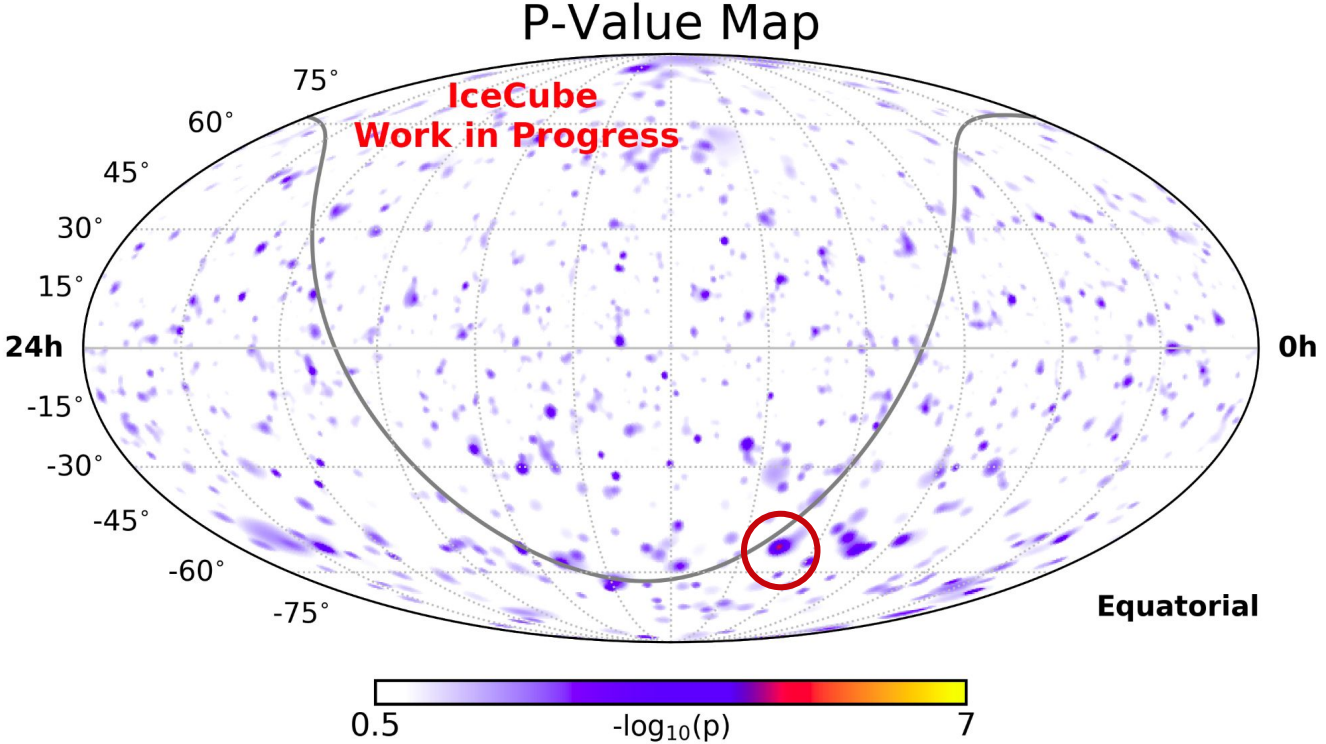
Preliminary Allsky Scan Results



Results of untriggered allsky scan looking for significant clustering

Hot spot not significant after post-trial corrections

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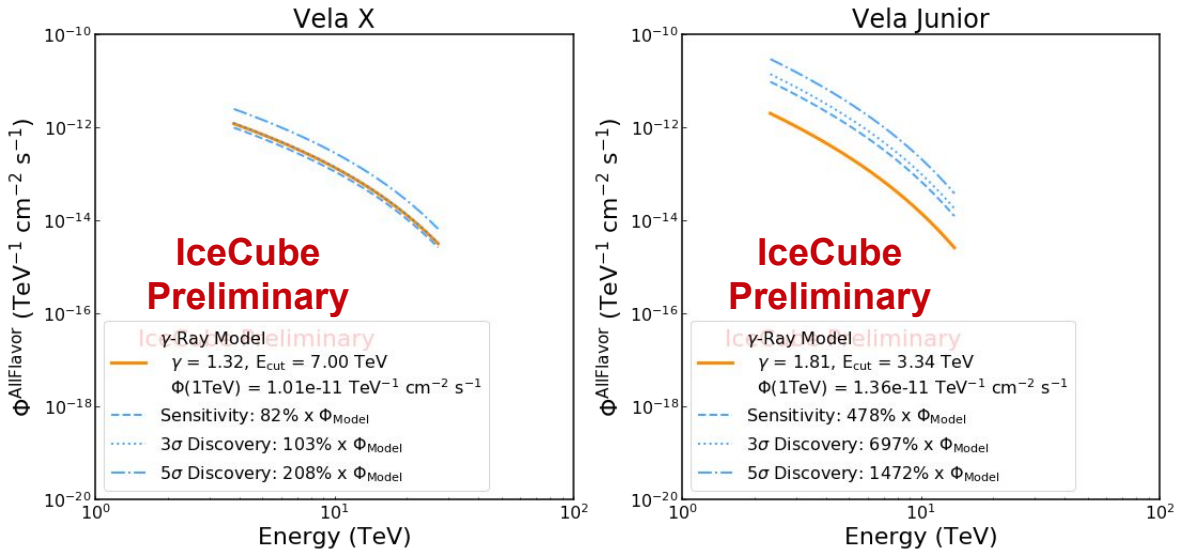
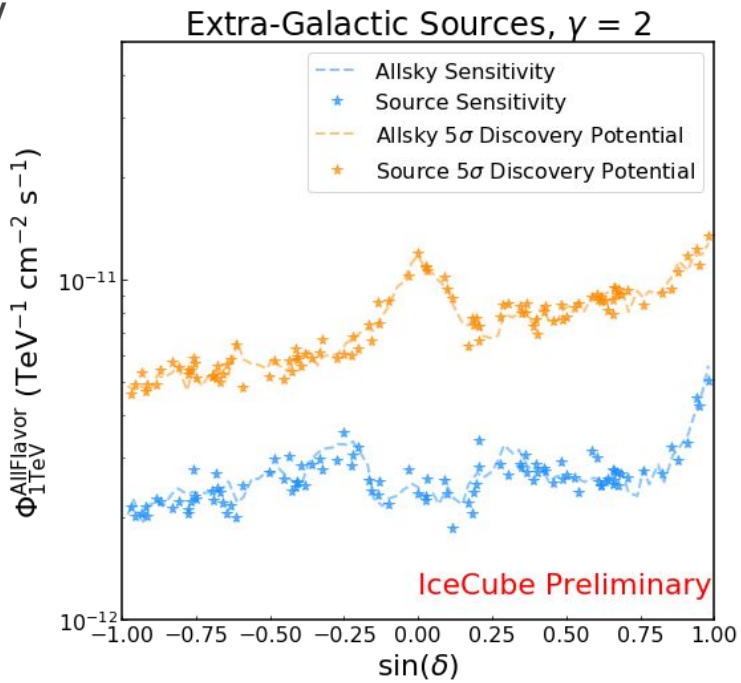
Single Source List Analysis

Select ~100 brightest sources relative to our sensitivity

Use TeV gamma ray data for galactic

Use GeV gamma ray data for extra-galactic



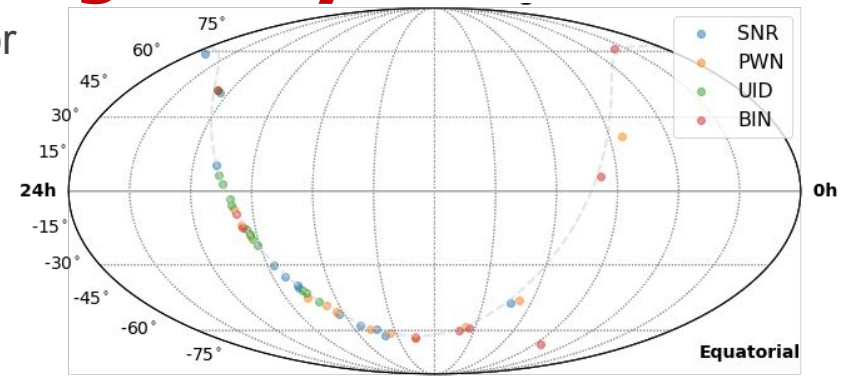


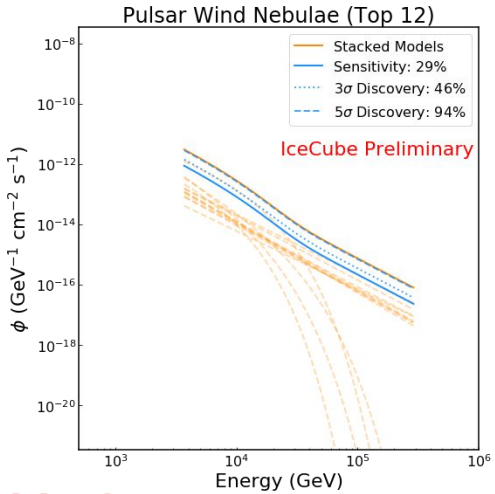
Galactic Plane Source Stacking Analysis

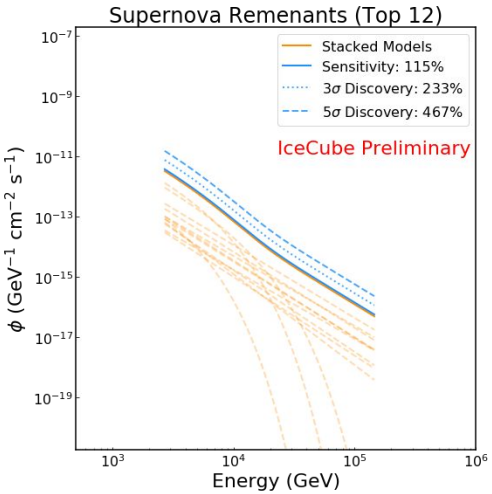
Select top 12 brightest sources in TeV Gamma Rays for PWN, SNR, and UID GP and combine test statistics

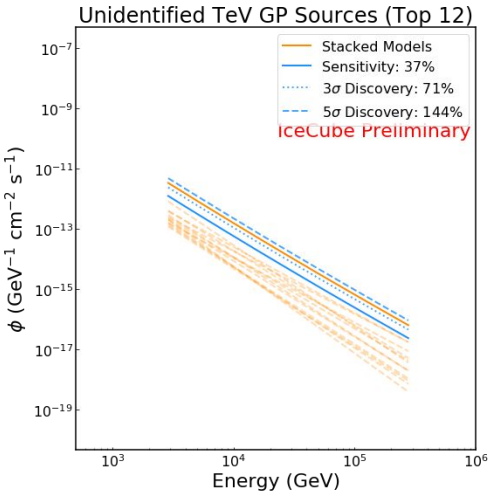
Also investigate TeV Binary objects

Sensitivities calculated assuming 100% of observed gamma ray flux from pion decay created by p-p interactions (optimistic model)









Gamma ray to neutrino flux conversion by Nahee Park (Queen's University)

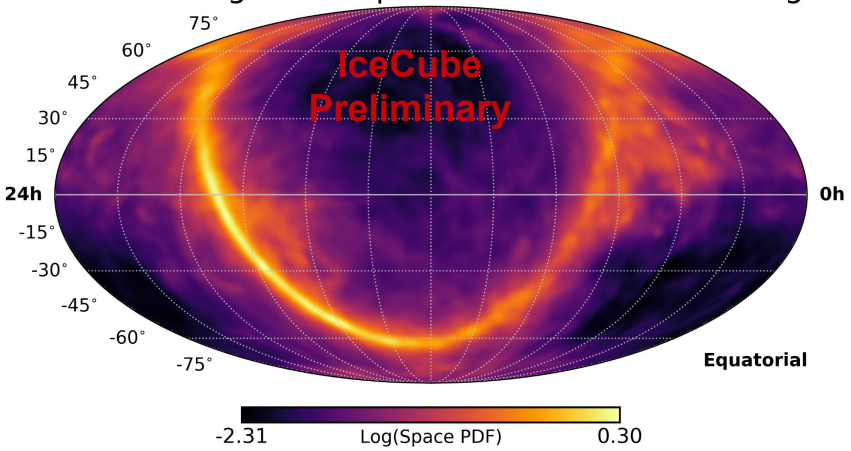
Galactic Plane Diffuse Emission Templates

Look for neutrinos generated by pion decay from cosmic ray interactions in the Galactic Plane medium

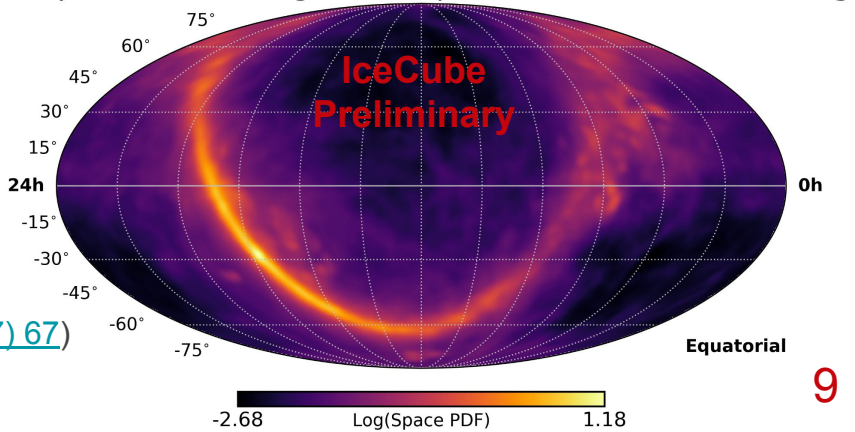
Simulation of 100% KRAγ model reveals 50% chance of significance ≥ 3.7σ for source hypothesis

	Fermi π^0 (γ = 2.5) (x 10^{-11} TeV cm^{-2} s^{-1})	KRAγ (5 PeV Cutoff) x KRAγ flux
Starting Tracks	**0.93**	**33%**
7 Year IC GP Paper [1]	2.97	-
IceCube Cascades [2]	2.5	87%
IC + Antares [3]	-	81%

Fermi π^0 signal acceptance with 1.4° smoothing



KRAγ 5PeV Cutoff signal acceptance with 1.4° smoothing



1. 7 Year IceCube GP PS Tracks (Ap.J. 849 (2017) 67)
2. IceCube Cascades (Ap.J. 886 (2019) 12)
3. IceCube + Antares (Ap.J., 868 (2018) L20)

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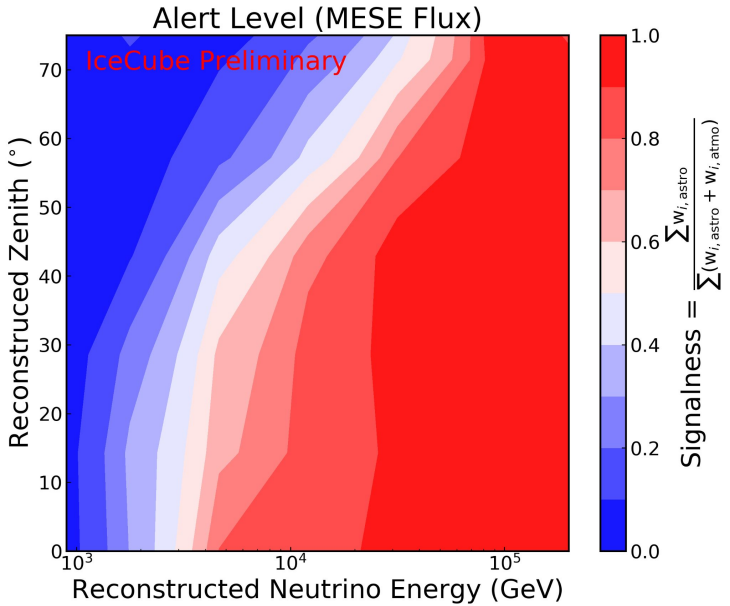
Starting Track Real-time Alerts

Modified veto selection run in realtime at South Pole

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

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

Great for transients in southern sky not powerful enough to generate 100 TeV neutrinos



Per year rates	Atmo μ	Atmo ν (>50% signalness)	Astro ν (>50% signalness)
Filter + Event Selection (Alert Level)	No surviving simulation	0.75	3.26

Signalness - ratio of signal to total events in MC at final level for events with similar reconstructed energy and declination (flux from PRD 91 (2015) assumed)

$$\phi = 2.06\times10^{-18}\left(\frac{E_\nu}{10^5\,\mathrm{GeV}}\right)^{-2.46}\,\mathrm{GeV}^{-1}\mathrm{cm}^{-2}\mathrm{sr}^{-1}\mathrm{s}^{-1}$$

Summary

Looking for starting events allows you to reject your atmospheric neutrino background

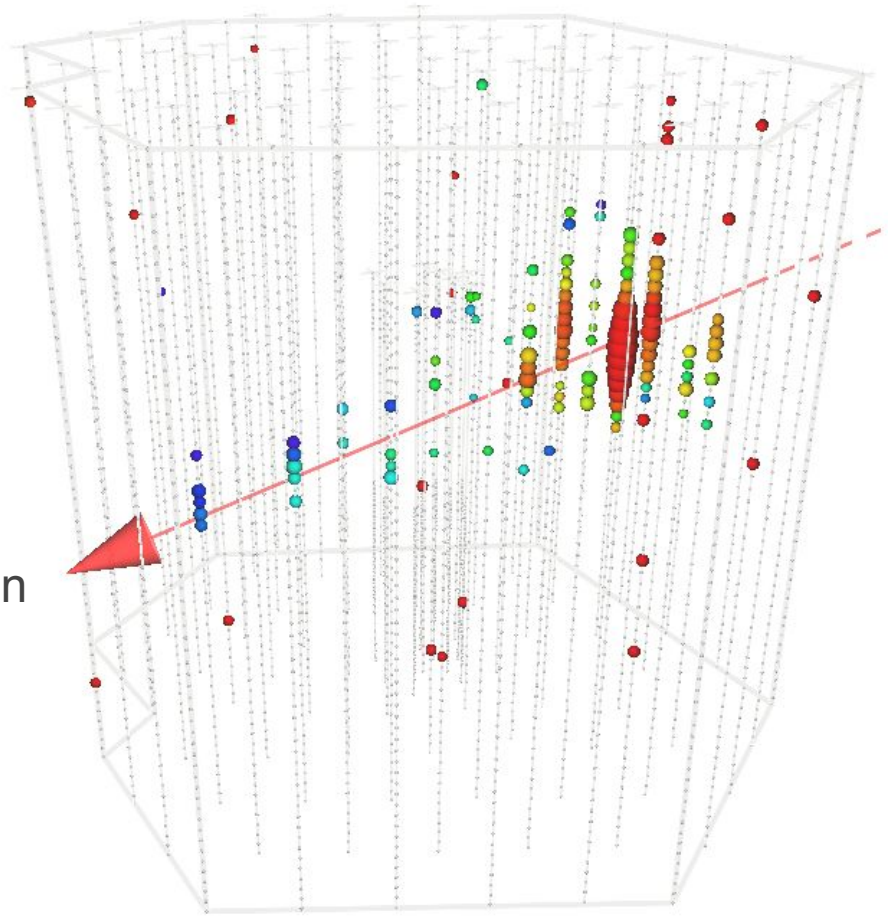
Increased purity allows IceCube to improve neutrino source sensitivity in the southern sky

No significant hotspot in untriggered allsky scan

Use new selection to probe the galactic plane

Can send out alert events with high signalness in the 10's of TeV range

Full results coming soon!



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SOUTH POLE NEUTRINO OBSERVATORY

Backup Slides

Incoming Muon Veto

Assume an infinite track hypothesis

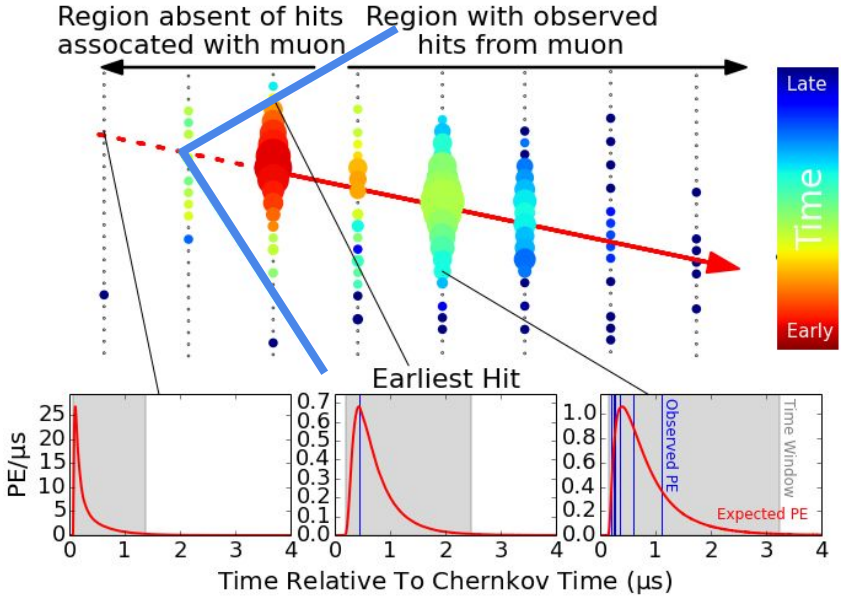
Predict light yield at optical modules (DOMs) to find earliest hit consistent with track hypothesis

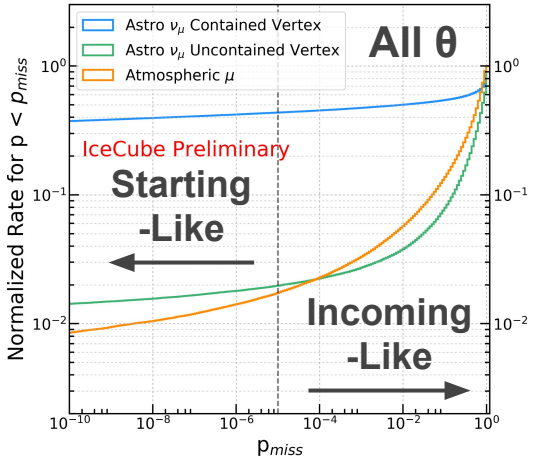
Define **muon region** and **dark region**

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

BDT cut at the end of selection to cut down to around 1 muon per year





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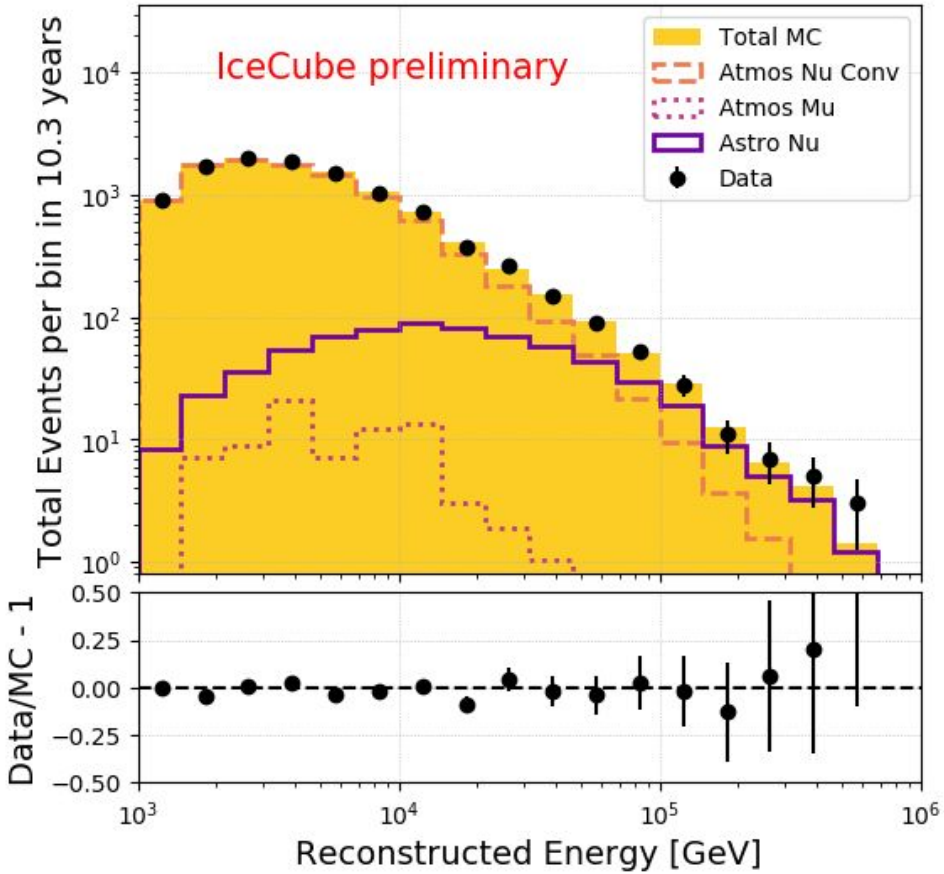
Event Rates in Energy



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Angular and Energy Reconstruction

Standard IceCube track reconstruction used, median all neutrino angular error 1.4°

Machine learning muon neutrino energy resolution at 25%