A new IceCube starting track event selection and realtime event stream

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SOUTH POLE NEUTRINO OBSERVATORY

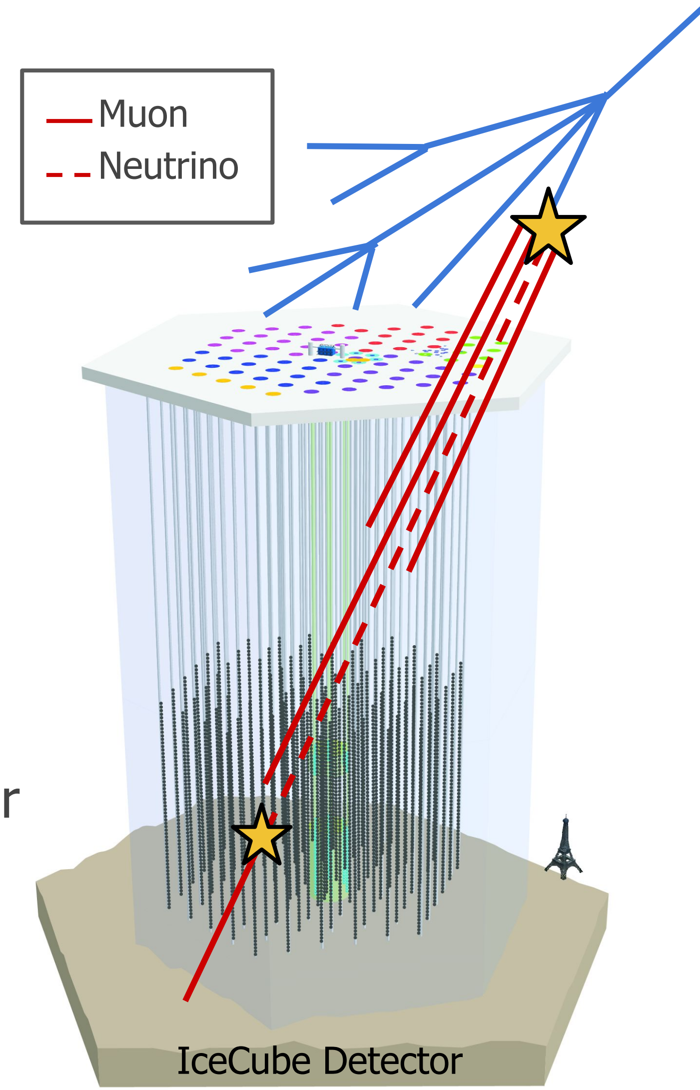
IceCube and Atmospheric Neutrino Self-Veto

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 by light from their sibling muons created in the same air shower

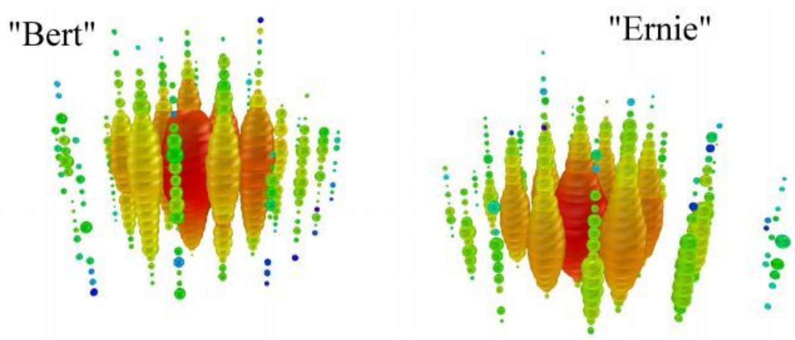


Enhanced Starting Track Event Selection (ESTES)

(Existing) Starting Event Selections

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

- Restrict detector volume
- Optimized for cascades



(New) ESTES

Selection Goal: Observe starting tracks

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

Starting track selection defines a **unique veto region for each event**

Can use starting track events for:

- Diffuse astrophysical spectrum fit
- Point source searches
- Realtime event stream

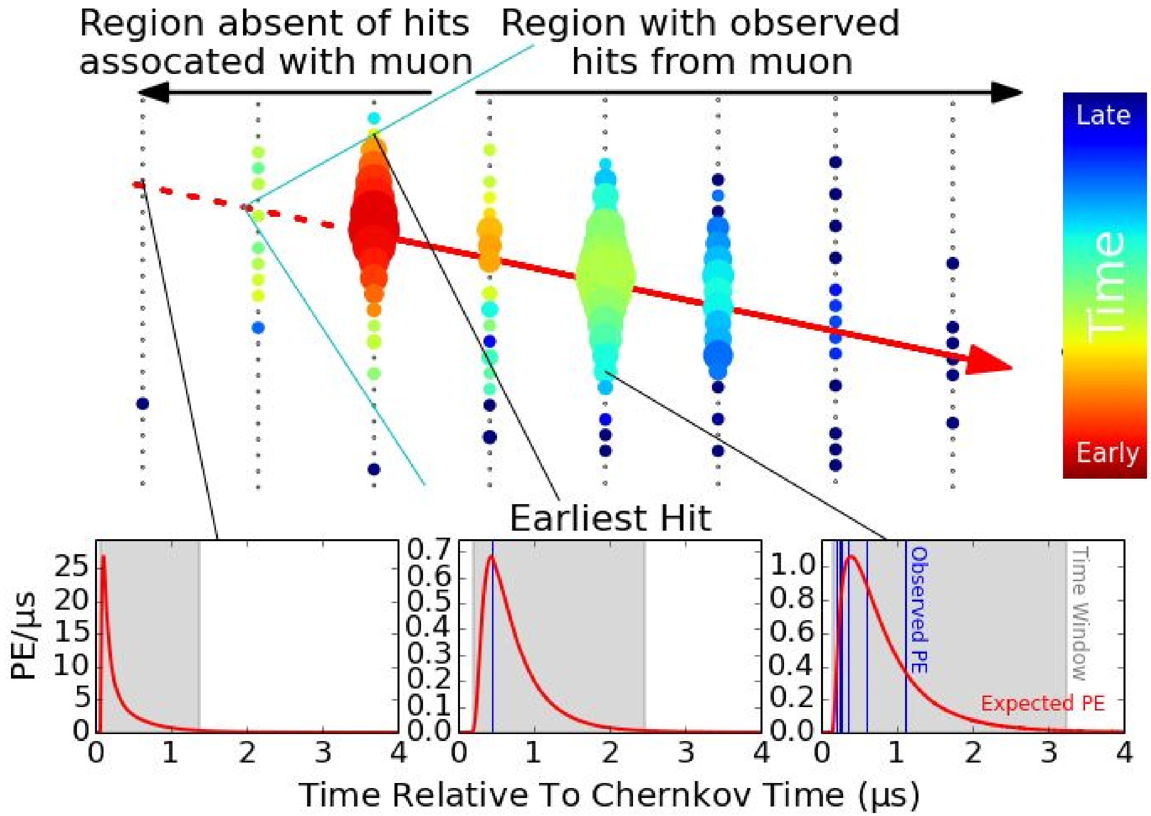
Veto region selection

Assume an infinite track hypothesis

Predict light yield at optical modules (DOMs)

Find earliest hit consistent with track hypothesis

Define **muon region** and **veto region**



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

- Product of poisson probability that DOMs in veto region saw no hits

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

Full starting track selection

	Atmo μ (per year)	Atmo v (per year)	Astro v (per year)
South pole filters and total charge cut	9.0×10^8	1.7×10^4	1.2×10^3
Starting track veto (cuts on p_{miss})	5.6×10^6	3.4×10^3	150
Sneaking track grid search with starting track veto	1.6×10^4	910	50
Up-going (θ > 80°) Straight cuts / Down-going (θ < 80°) Straight cuts + BDT	**<1**	**160**	**14**

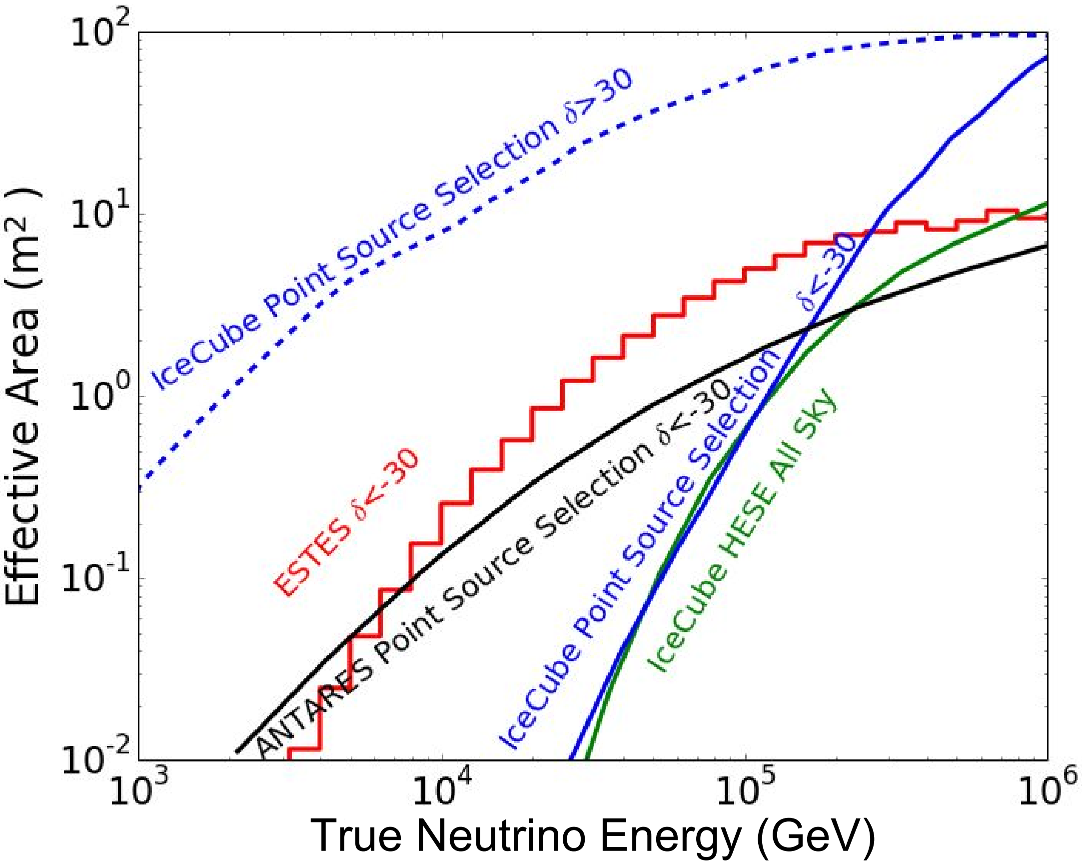
Final Level

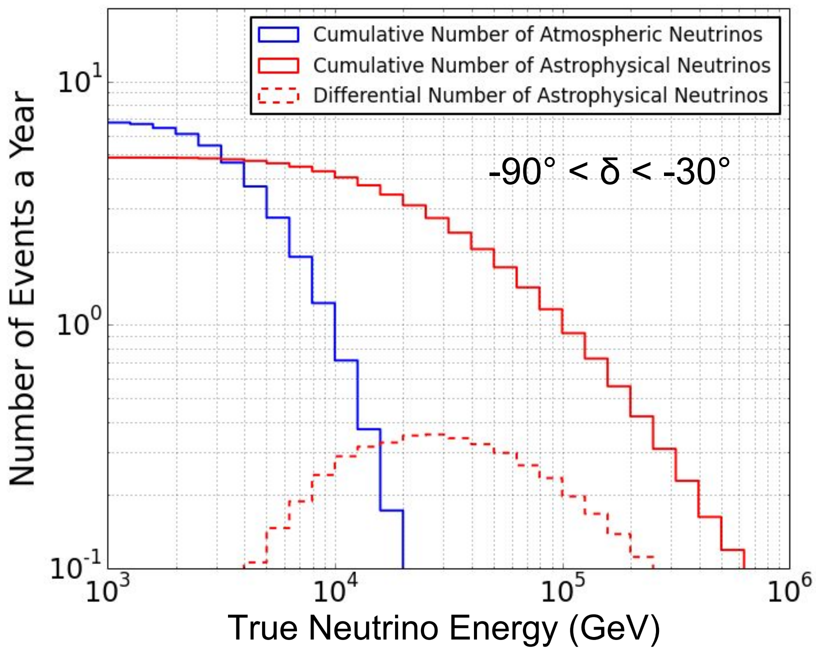
Numbers for all sky

Astrophysical flux assumed throughout this talk (PRD 91 (2015)):

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

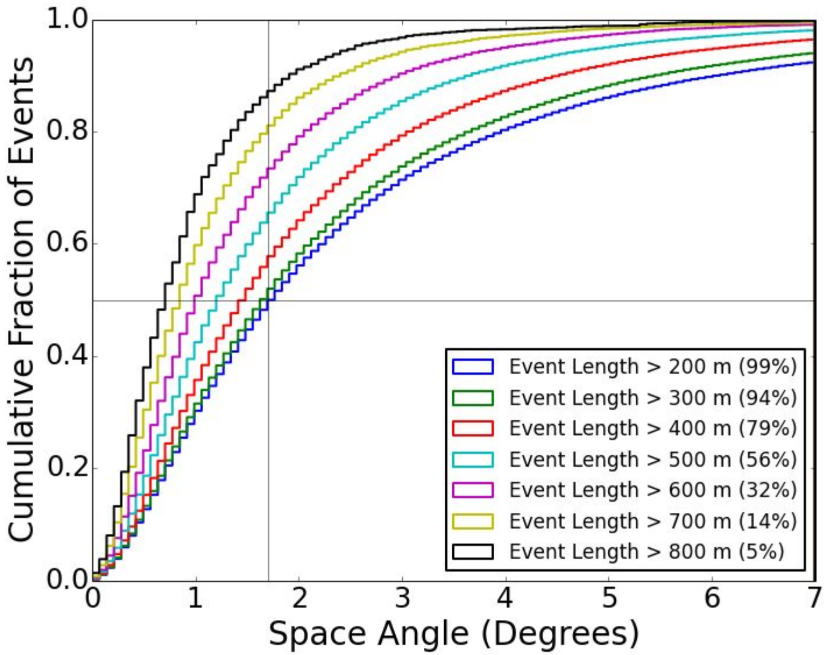
Effective area and per year event expectations

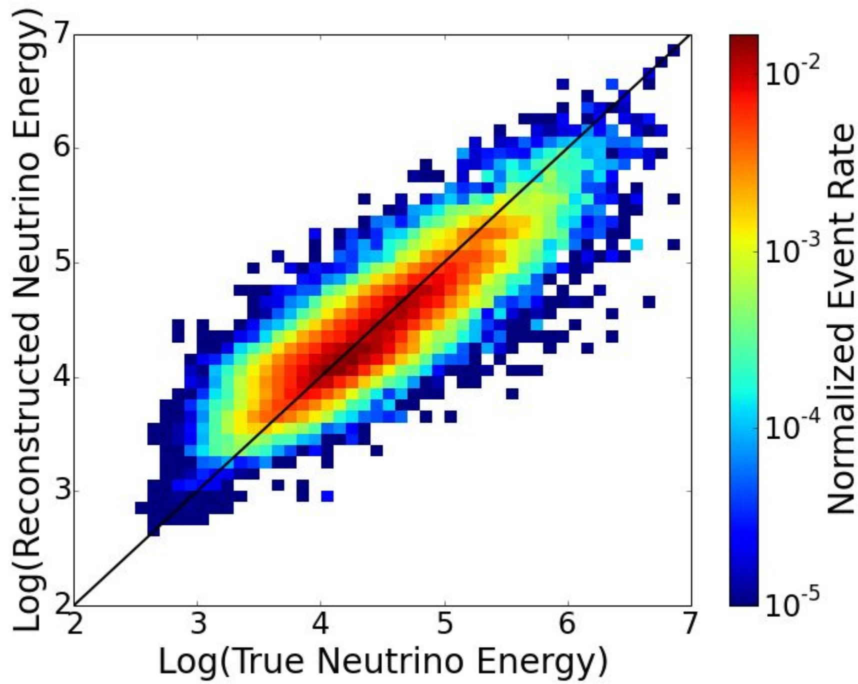




Astrophysical flux: PRD 91 (2015)

ESTES energy and angular resolution





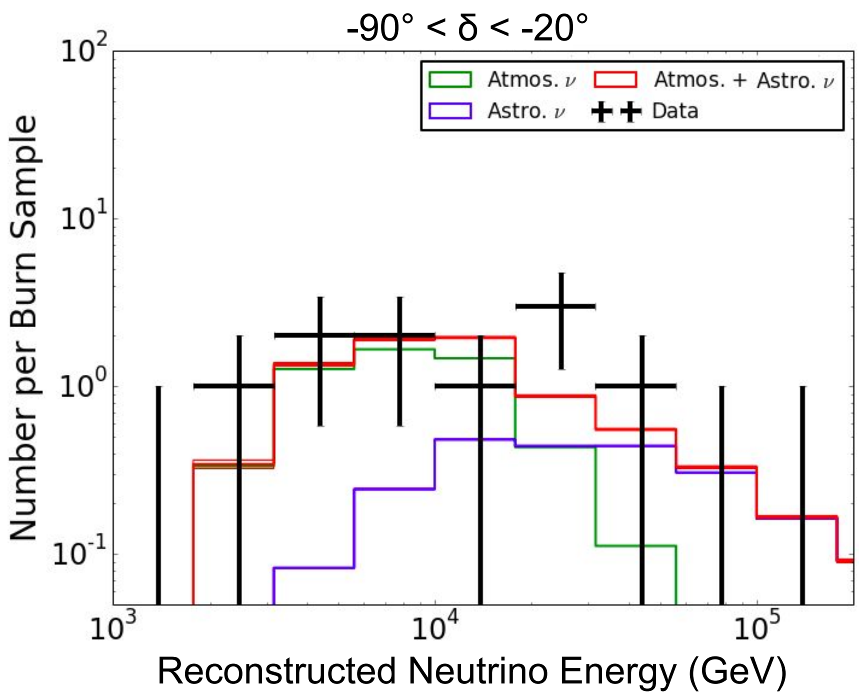
Average angular error around **1.7 degrees** for full sample

Angular error has little dependence on energy

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

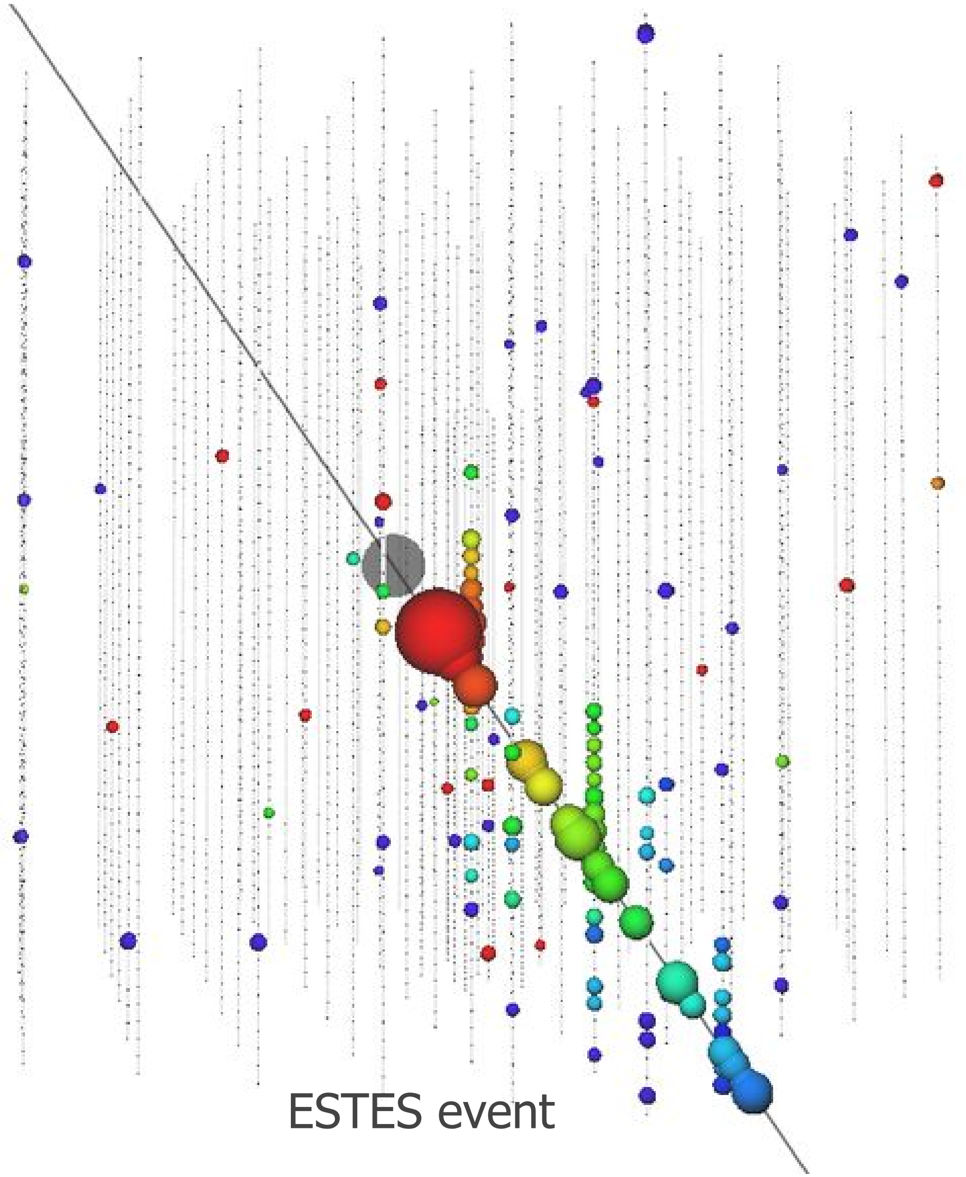
Neutrino energy resolution around 0.25 in log(Energy) across all energies

Results from preliminary data



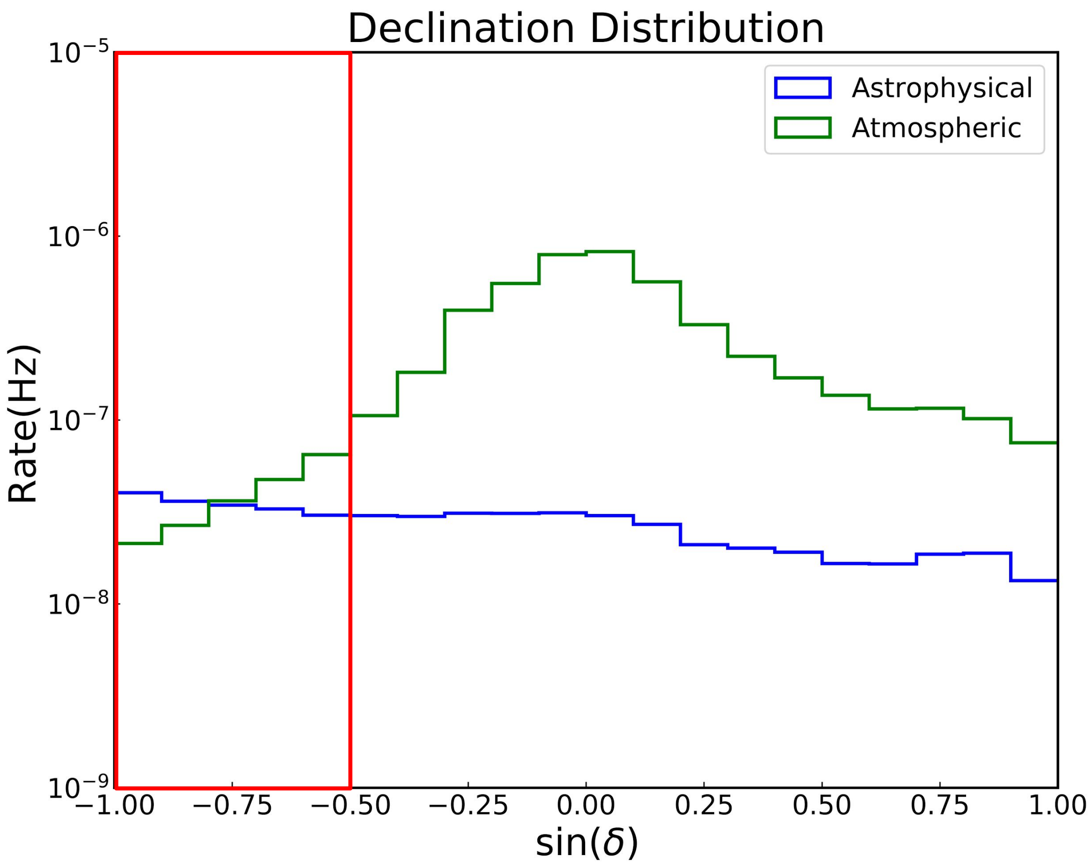
10% of 4 years of data

Will perform diffuse fit on data



ESTES event

Point sources and astrophysical purity in the southern sky



Astrophysical flux: [PRD 91 (2015)]

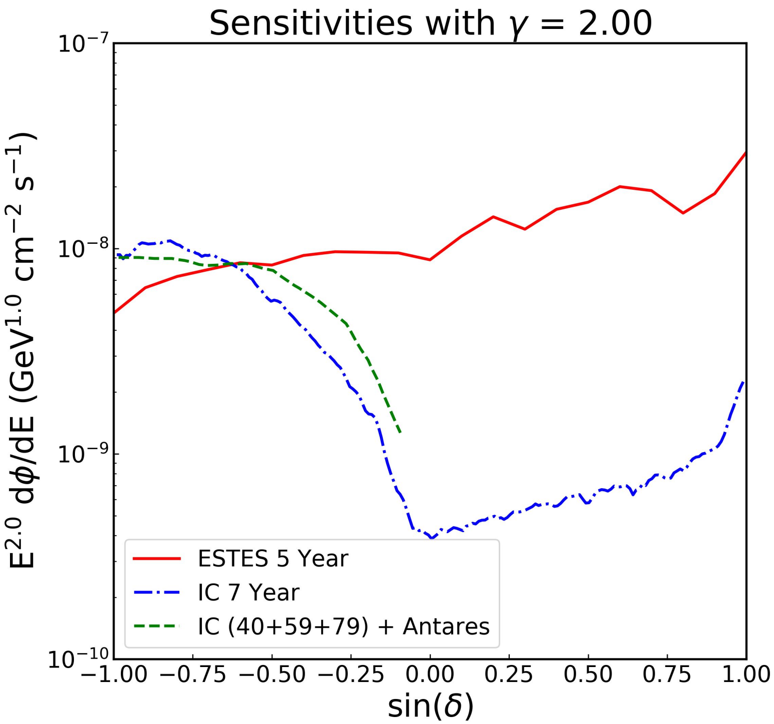
High astrophysical purity in southern sky

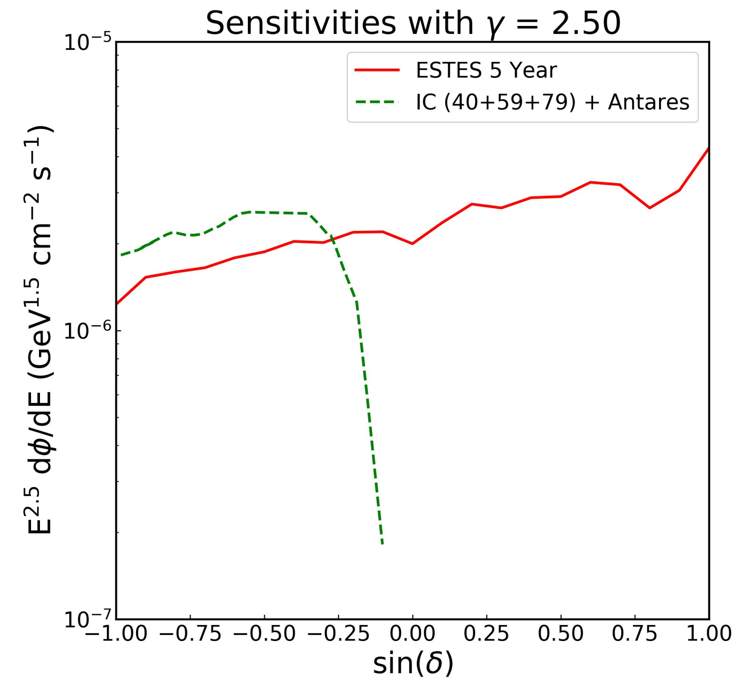
Only need a few events to be sensitive to source

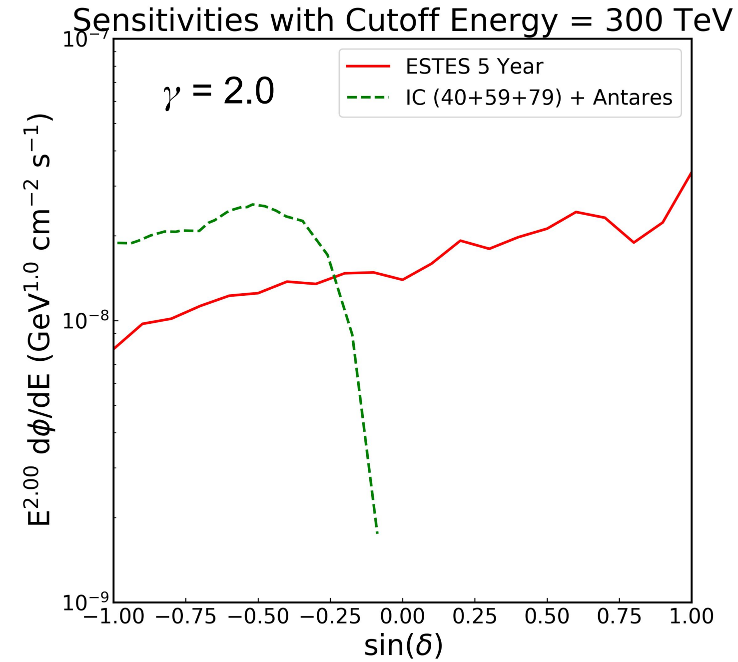
10 Years of starting tracks in southern sky:

- 68 background events
- 66 astrophysical events
- Events needed for 5σ point source: 3

Point source sensitivities





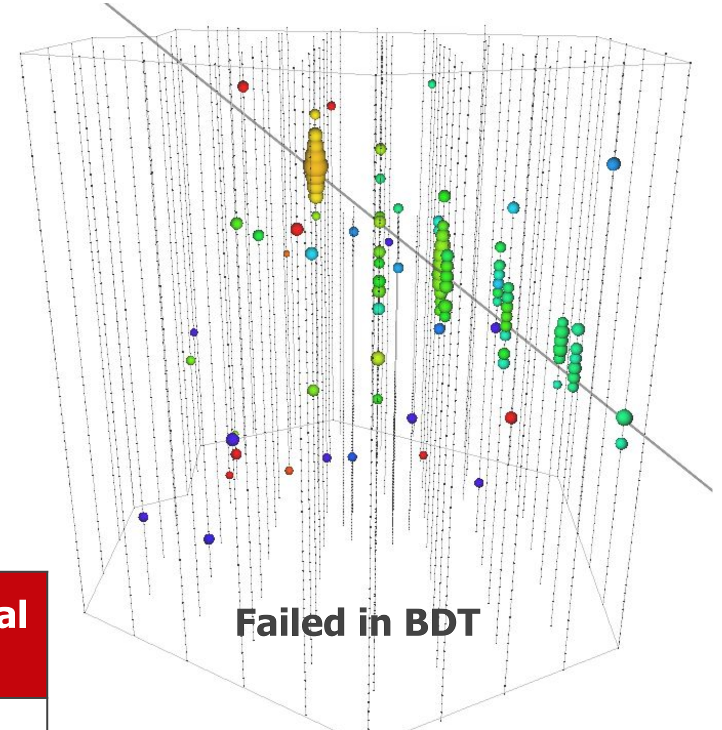


Starting track selection sensitive to southern sky

Competitive sensitivities especially when spectrum softer or energy cutoffs applied

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

ESTReS: ESTES near realtime event stream



Modified veto selection run in realtime at South Pole

- Higher energy
- Longer track length

Atmospheric μ	Atmospheric ν	Astrophysical ν (Total/Total at 50% purity)
1300 per year	7.5 per year	2.8/2.4 per year

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

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

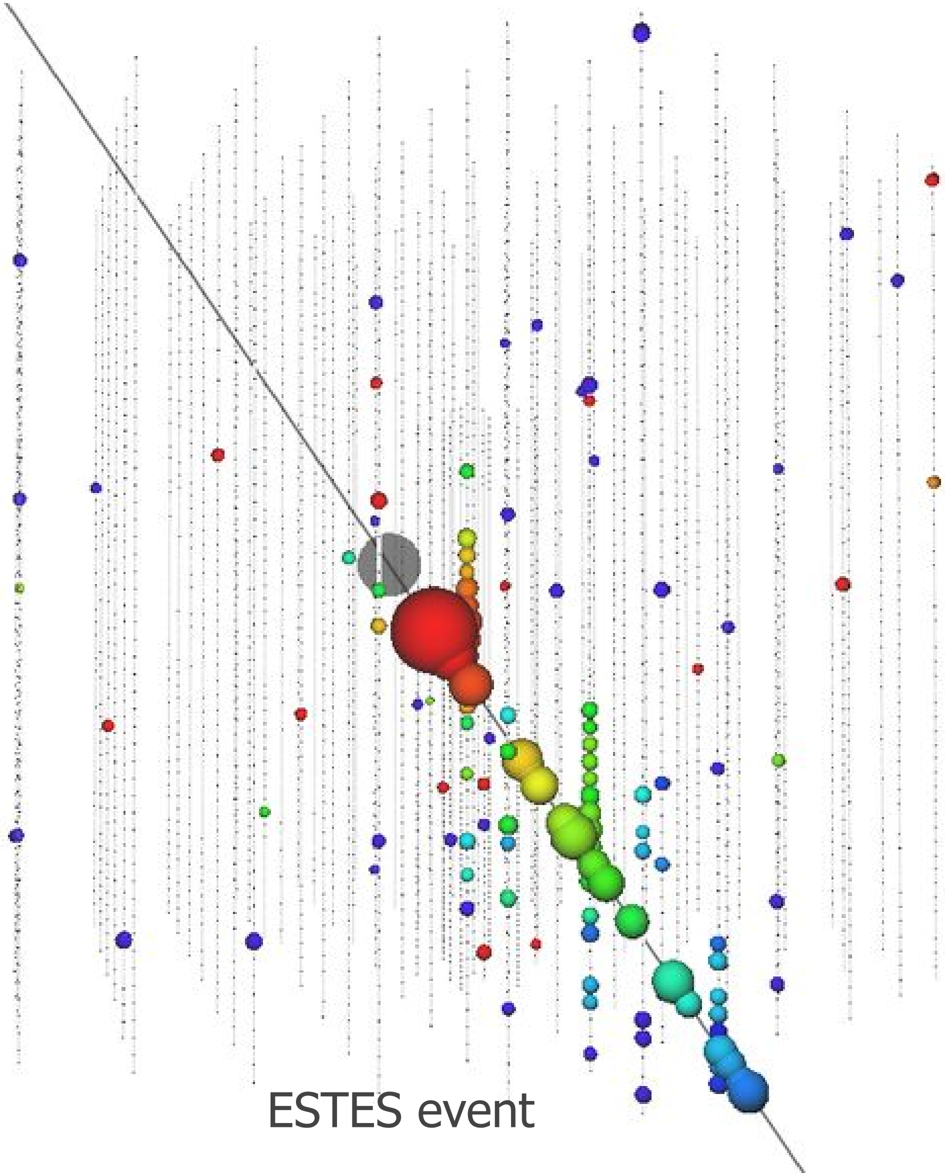
Conclusion and next steps

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

ESTES events have good energy and angular resolution

We have a competitive sensitivity in the southern sky for point source searches

Soon will start ESTReS alert system and send out alerts for southern sky events



ESTES event

Backup Slides

Veto and p_{miss} definition in detail

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

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

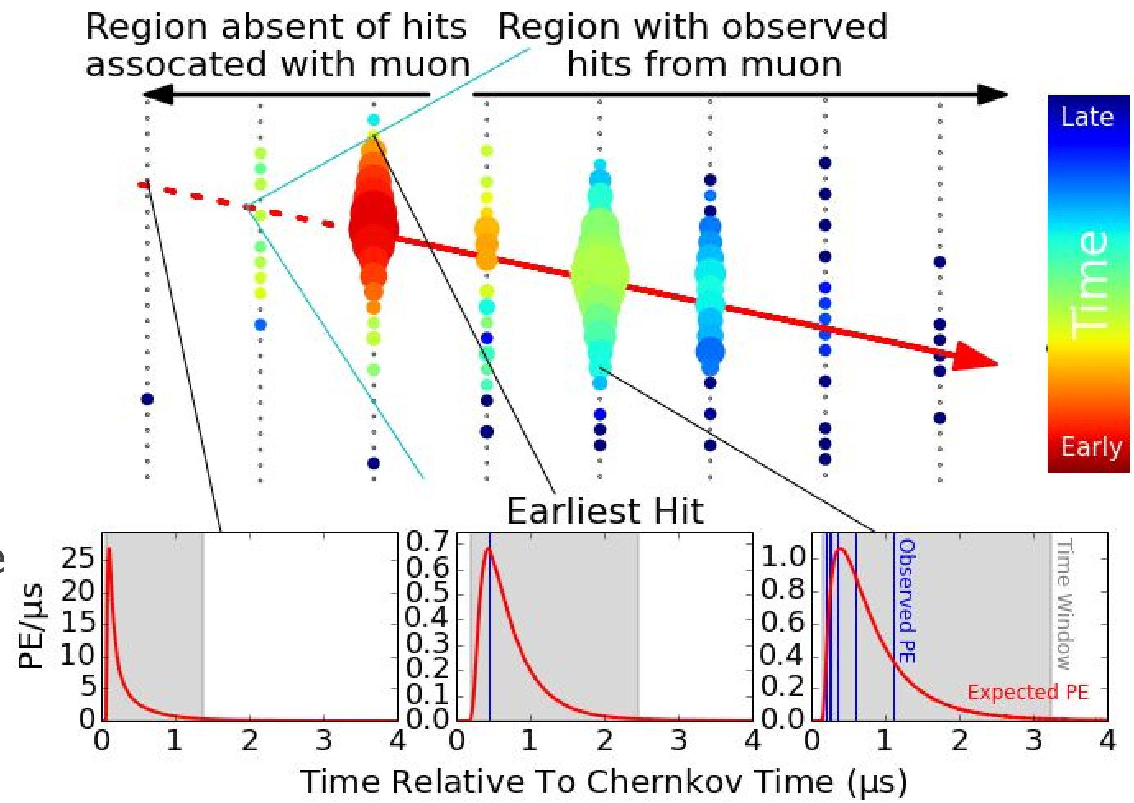
λ is expected number of PE

K is observed number of PE

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

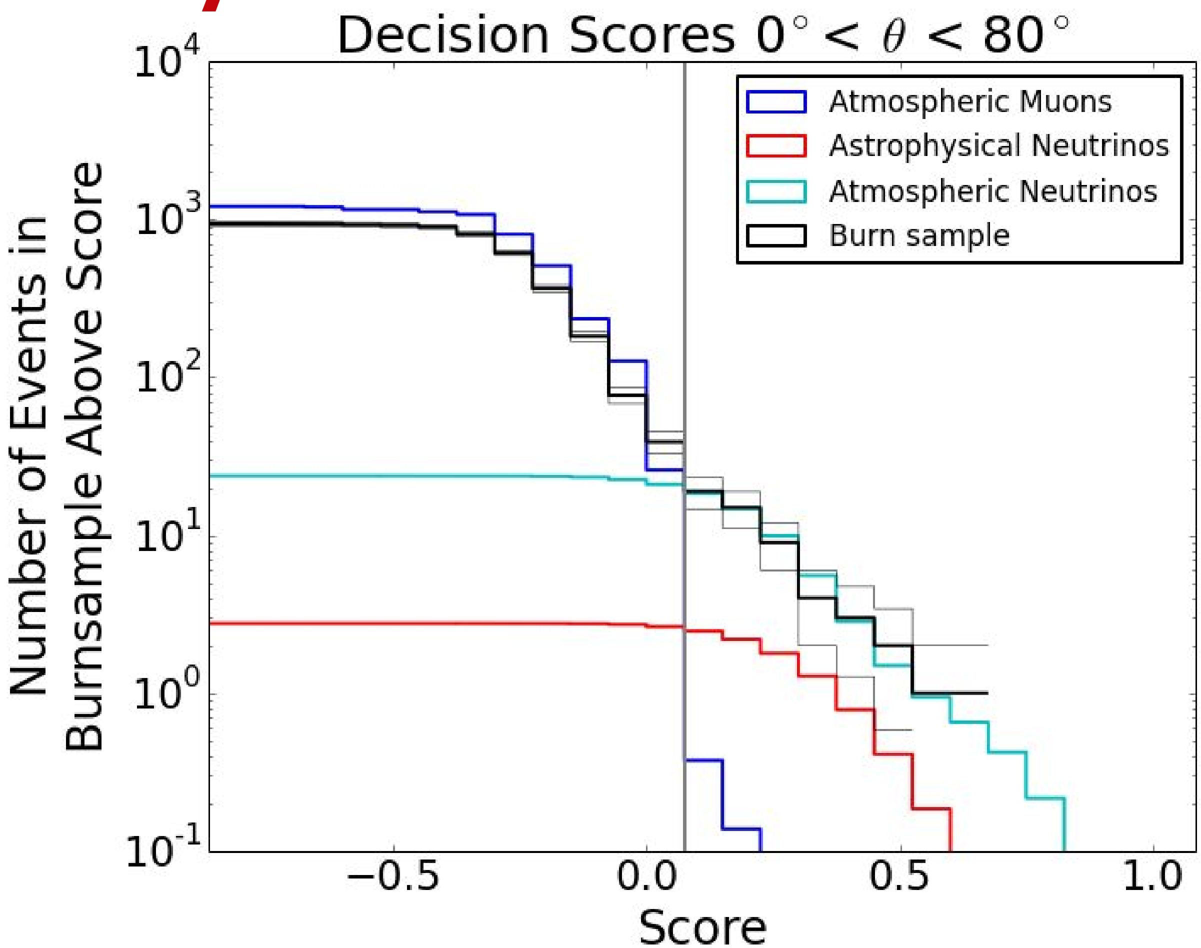
$$p_{miss} = \prod_{i}^{\text{veto region DOMs}} p(\lambda_i, k=0)$$

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

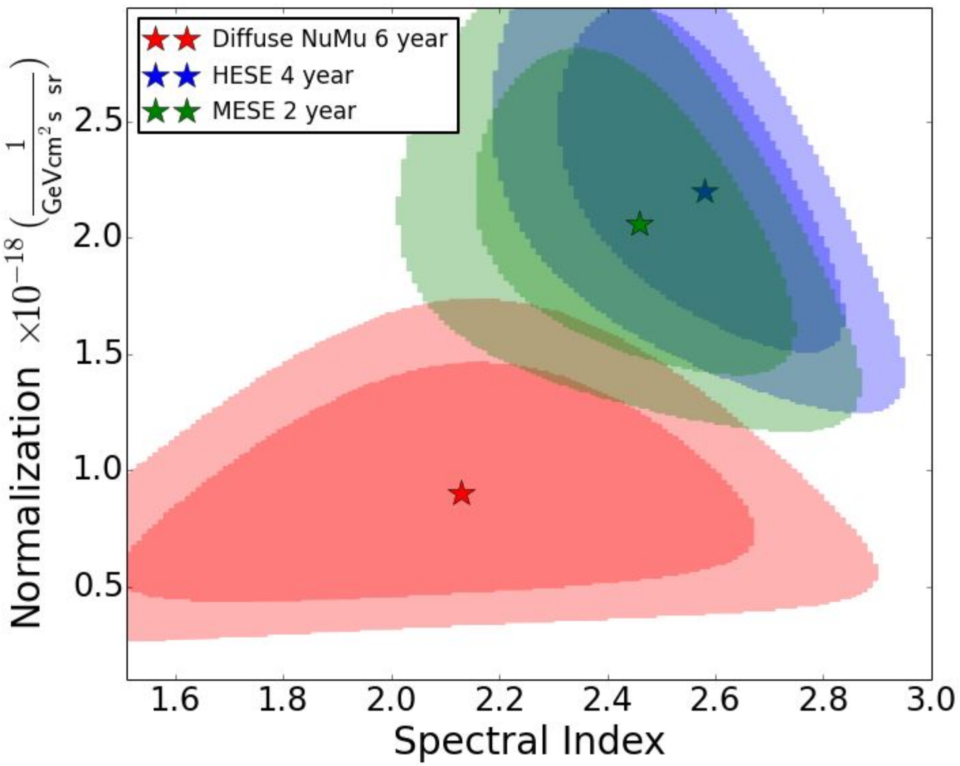
BDT Efficiency



Use BDT in southern sky

Efficient at removing cosmic ray muon background

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