

Measurement of neutrino events above 1 TeV with contained vertices

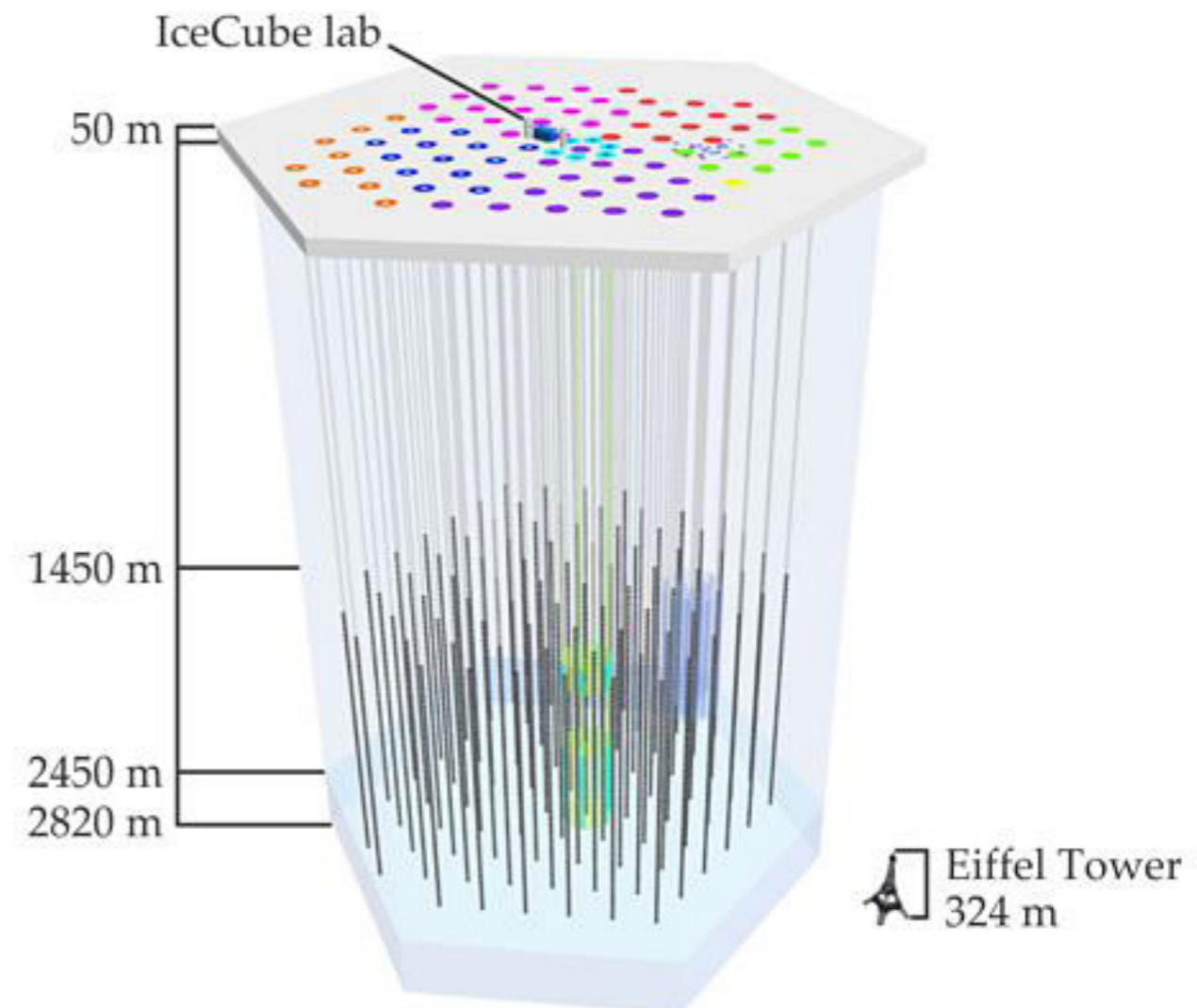
Nancy Wandkowsky for the IceCube Collaboration
TeVPA, August 8, 2017
Columbus, OH, USA

Contents

- Introduction
- High energy starting events 2010-2015
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- Summary & Conclusion

IceCube: South Pole Neutrino Observatory

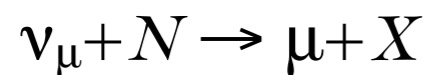
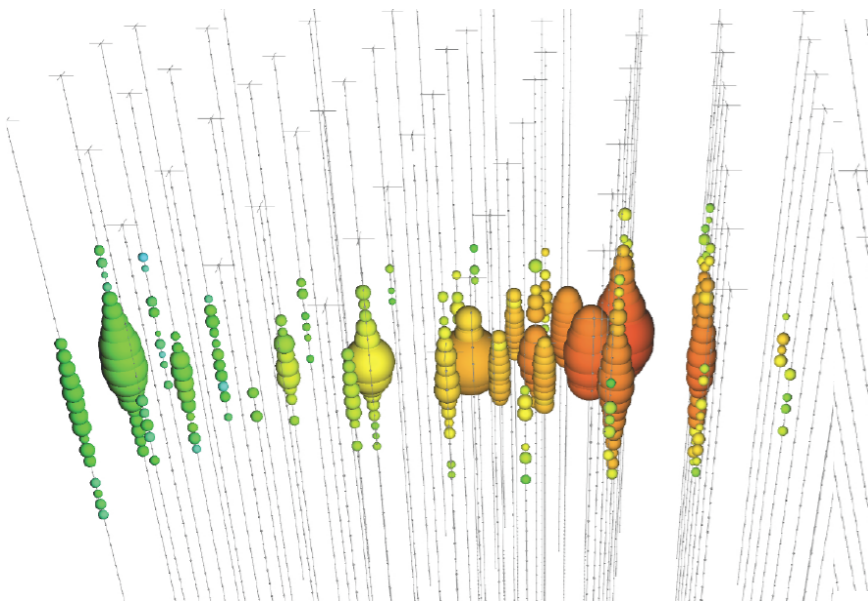
- 5160 Digital Optical Modules (DOMs) on 86 strings
- 1 km³ volume
- 17 m vertical spacing
- 125 m horizontal spacing
- Completed in 2010



Neutrino event signatures

CC muon neutrino

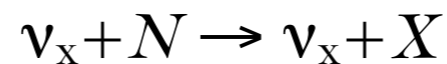
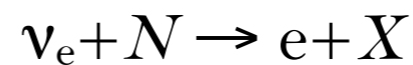
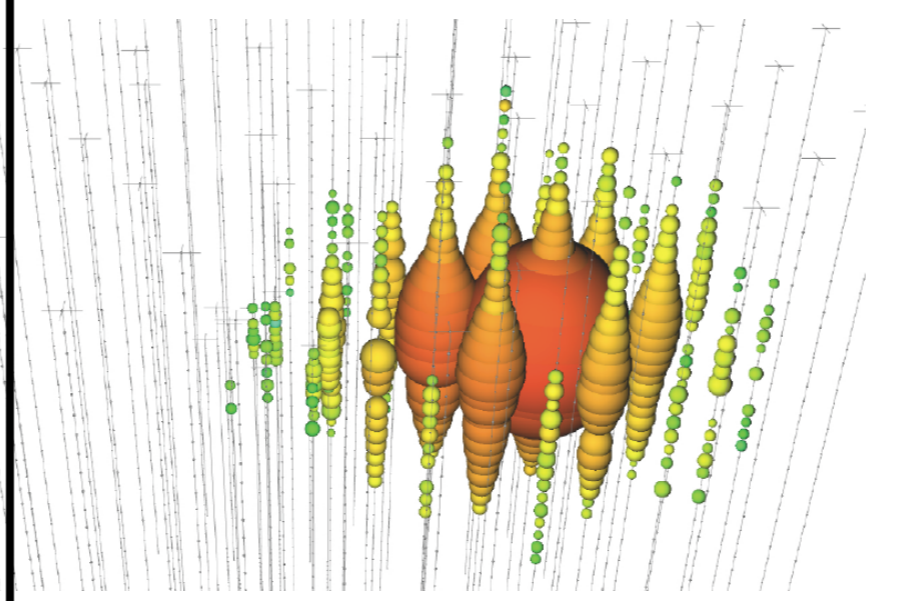
“track”



factor ~ 2 energy resolution
 $< 1^{\circ}$ angular resolution

NC/electron neutrino

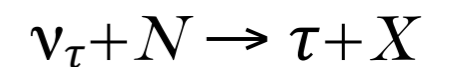
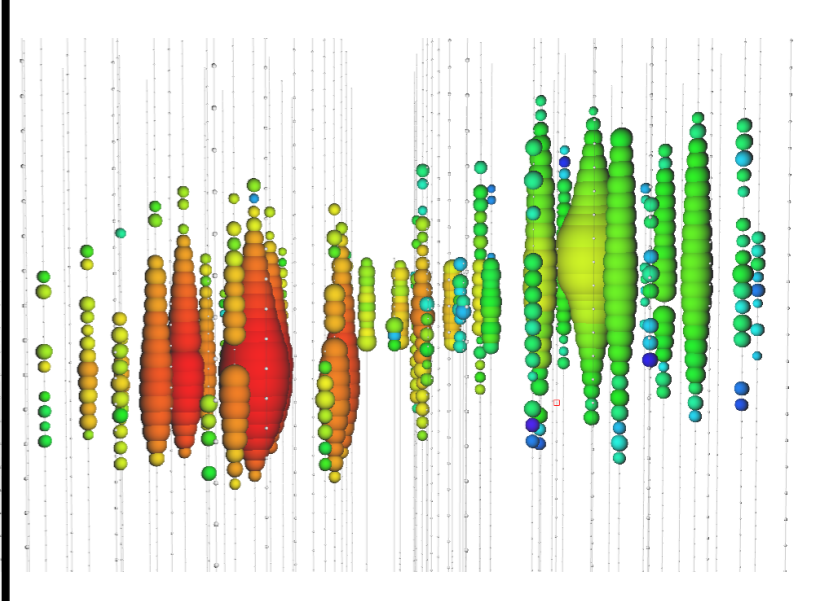
“cascade”



$\pm 15\%$ energy resolution
 $\sim 10^{\circ}$ angular resolution

CC tau neutrino

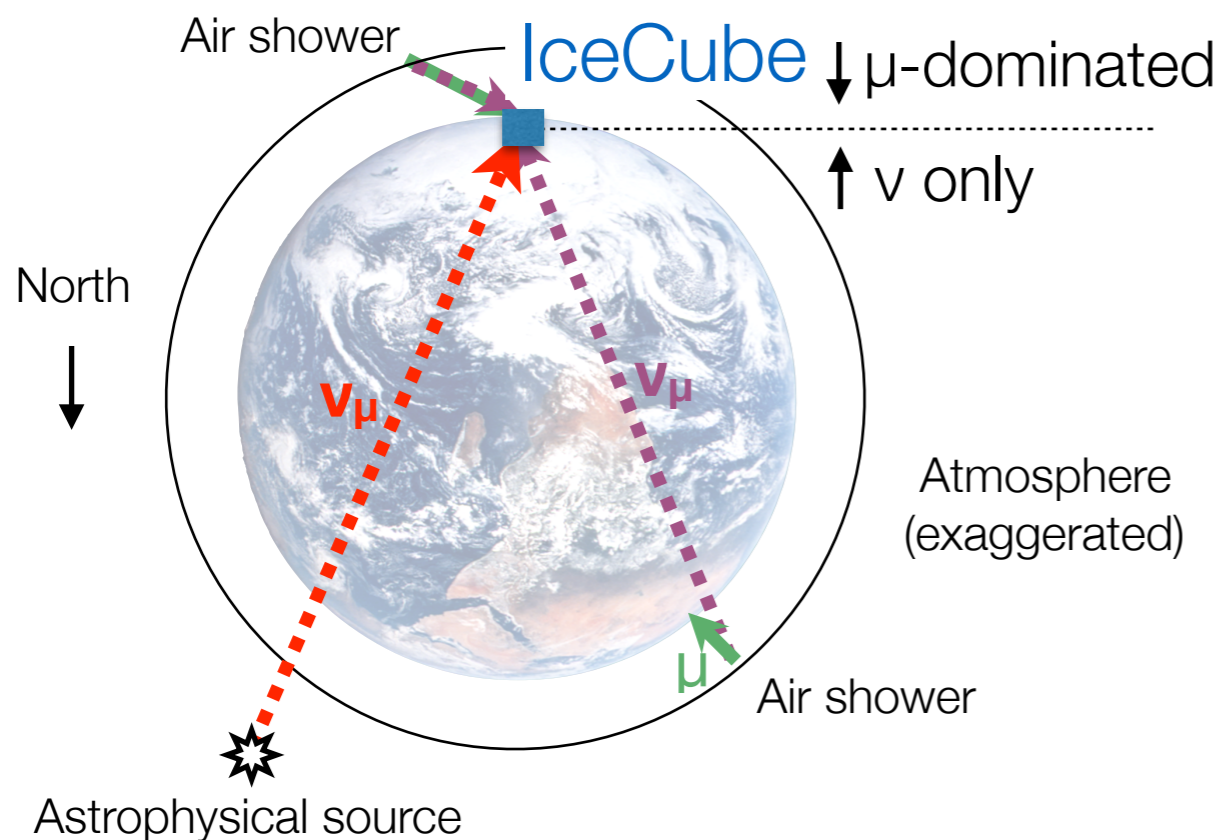
“double bang”



not observed yet
 τ decay length: 50 m/PeV

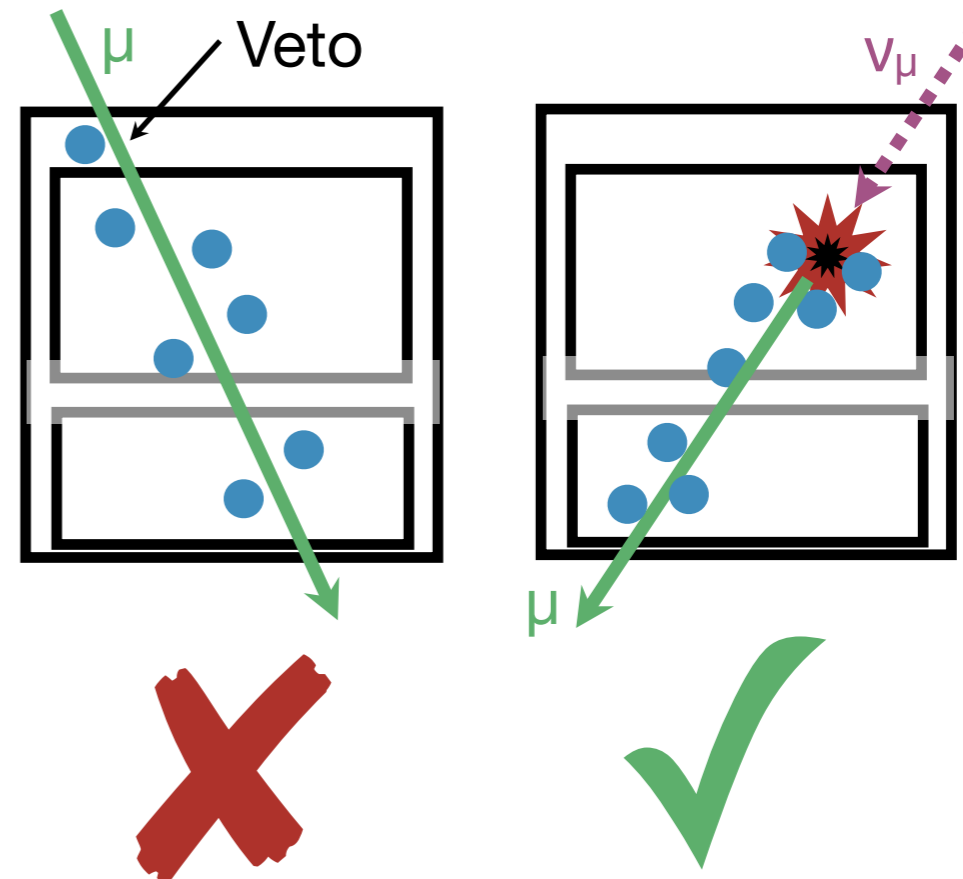
Isolating neutrino events

Up-going tracks



Earth stops penetrating muons
Effective volume larger than detector
sensitive to ν_μ , northern sky only

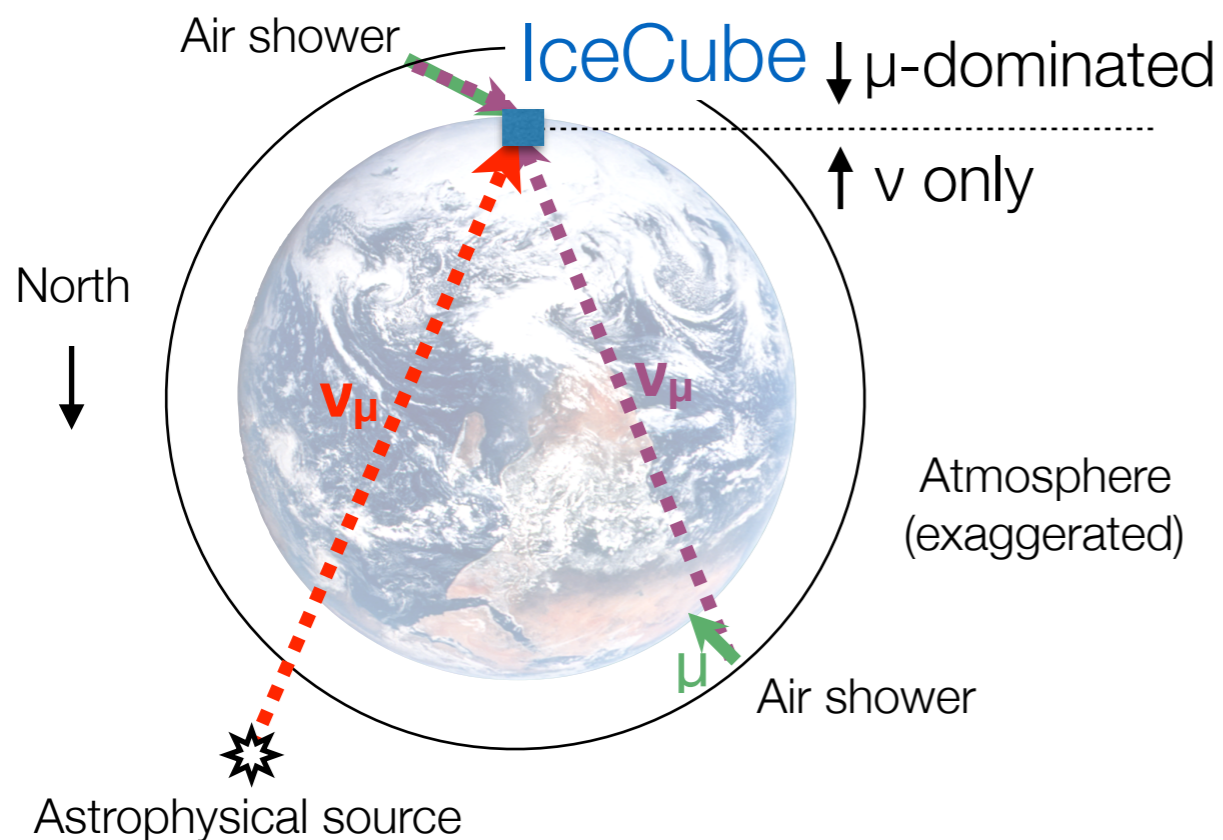
Active veto



Veto detects penetrating muons
effective volume smaller than detector
sensitive to all flavors, entire sky

Isolating neutrino events

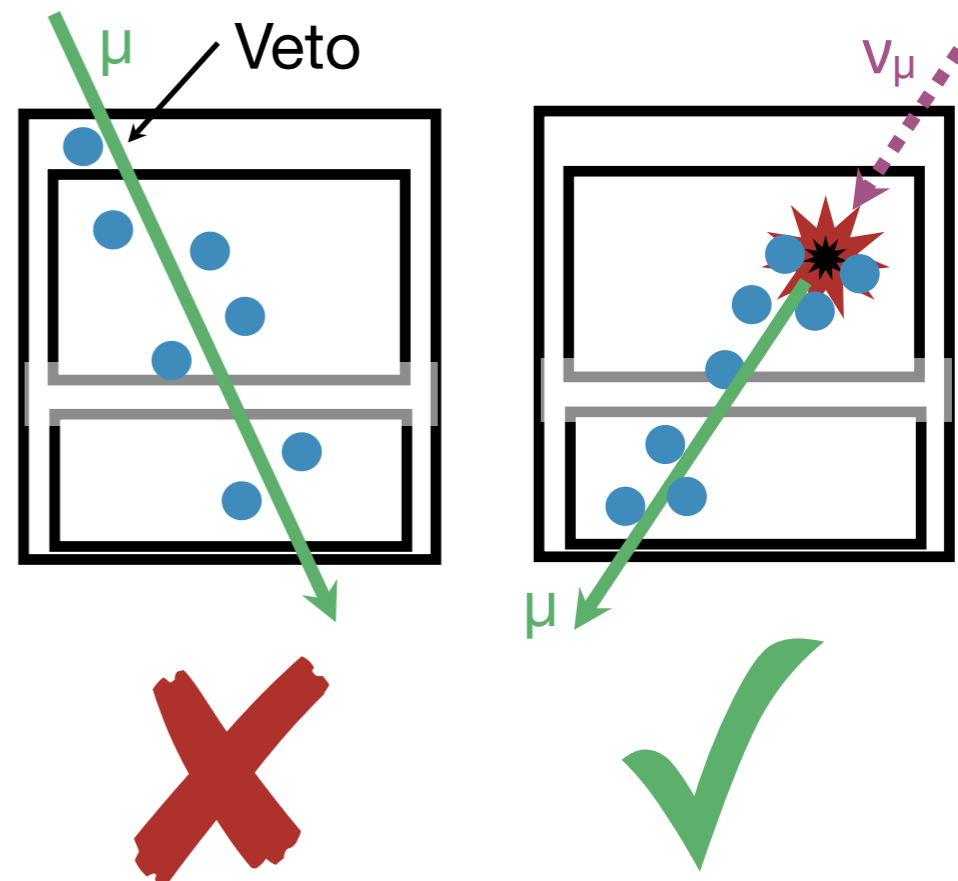
Up-going tracks



Earth stops penetrating muons
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sensitive to ν_μ , northern sky only

this talk!

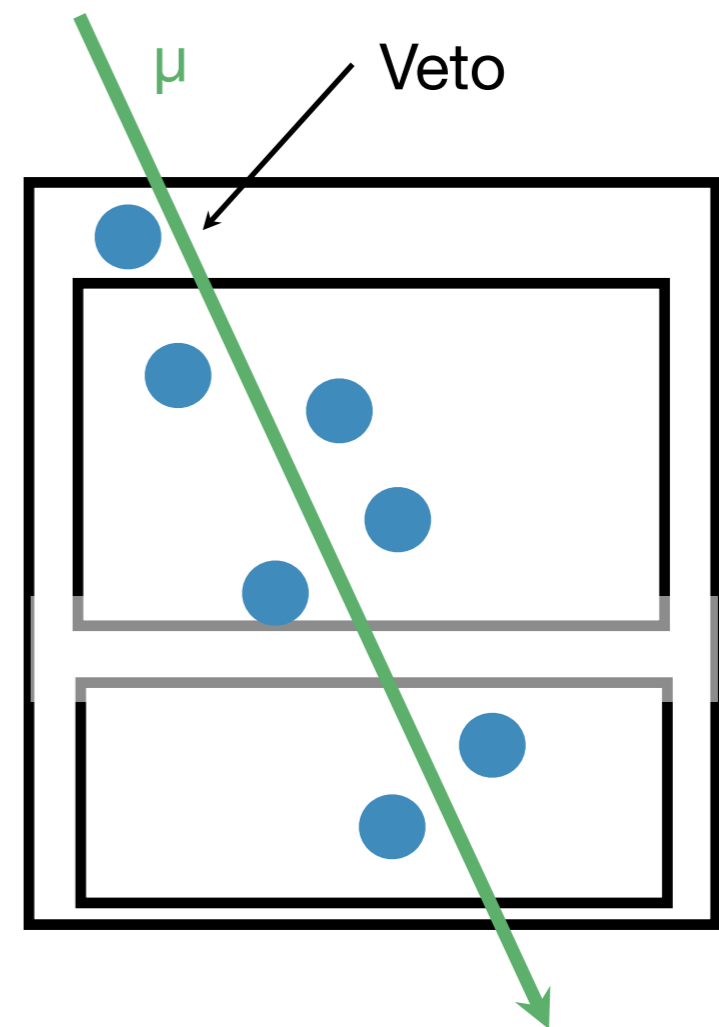
Active veto



penetrating muons detected in veto
effective volume smaller than detector
sensitive to all flavors, entire sky

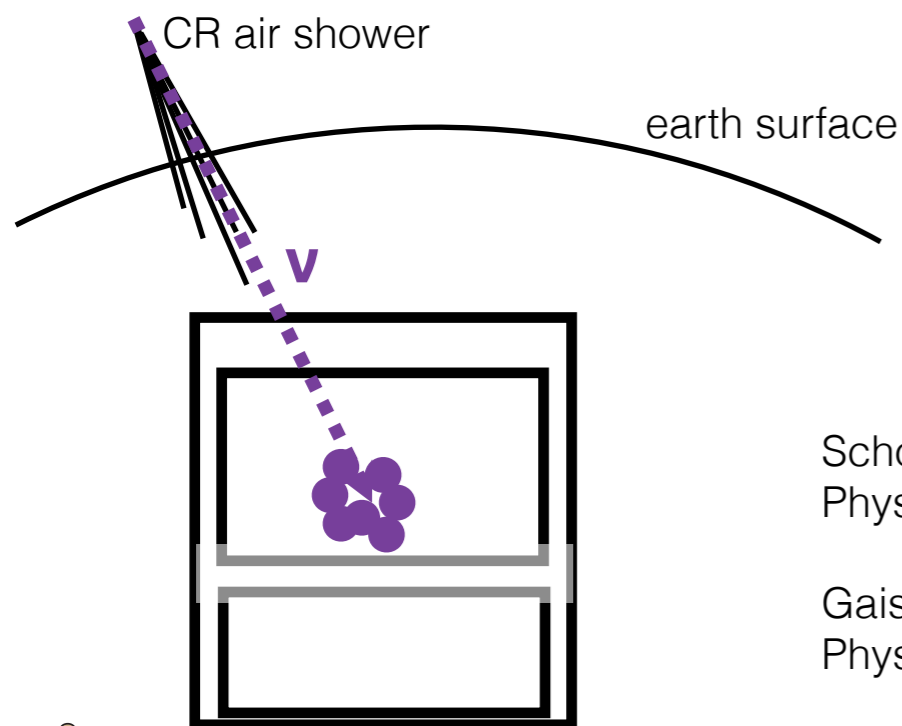
Background reduction

- Atmospheric muon veto: rejects events entering the detector
- remaining atm. muon background estimated from data
- 400 Mton effective fiducial mass



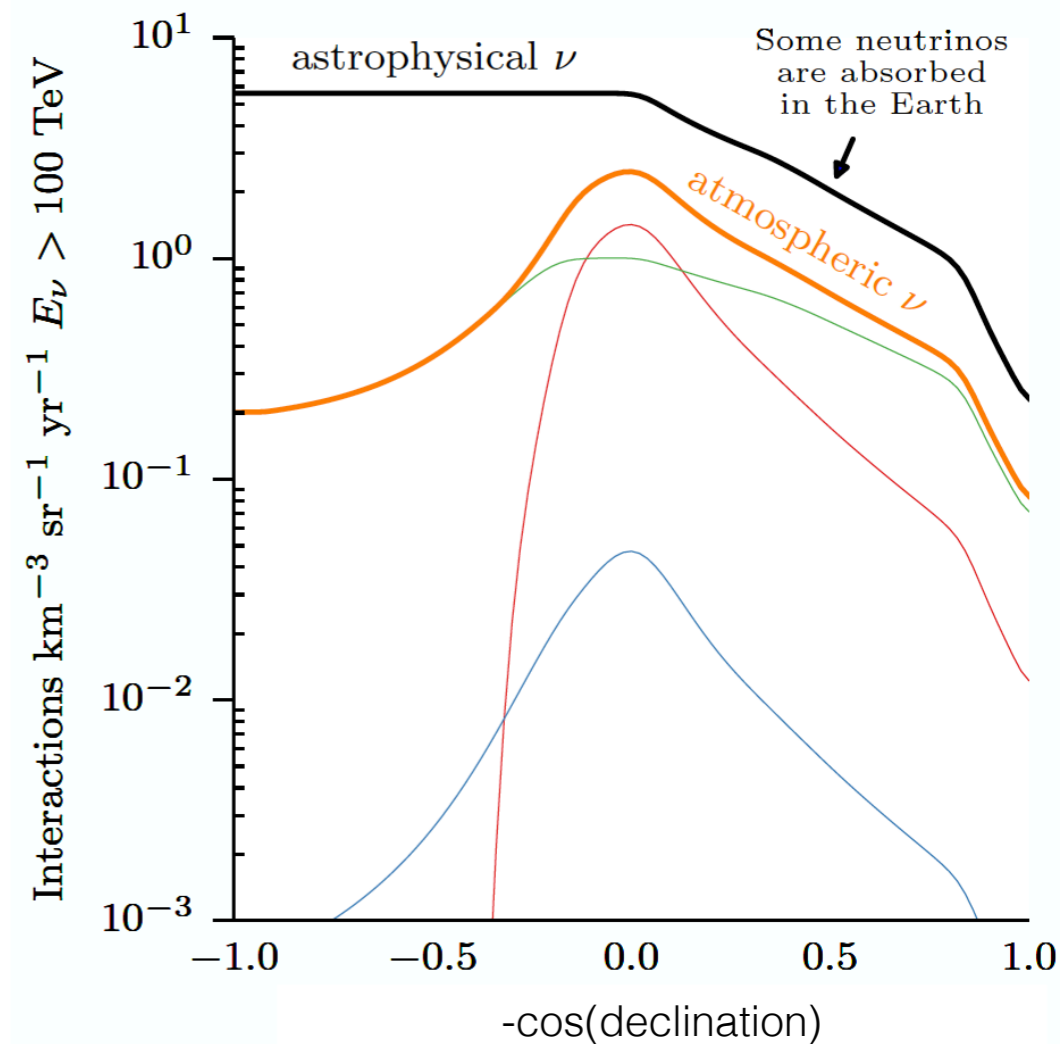
Background reduction

- Atmospheric muon veto
- Atmospheric neutrino “self-veto”:
analysis level correction:
 $N_{\text{atm.}\nu} = N_{\text{atm.}\nu} \times P(\text{self-veto})$
 $P(\text{self-veto})$: prob. that accompanying air shower is not rejected by atm. muon veto



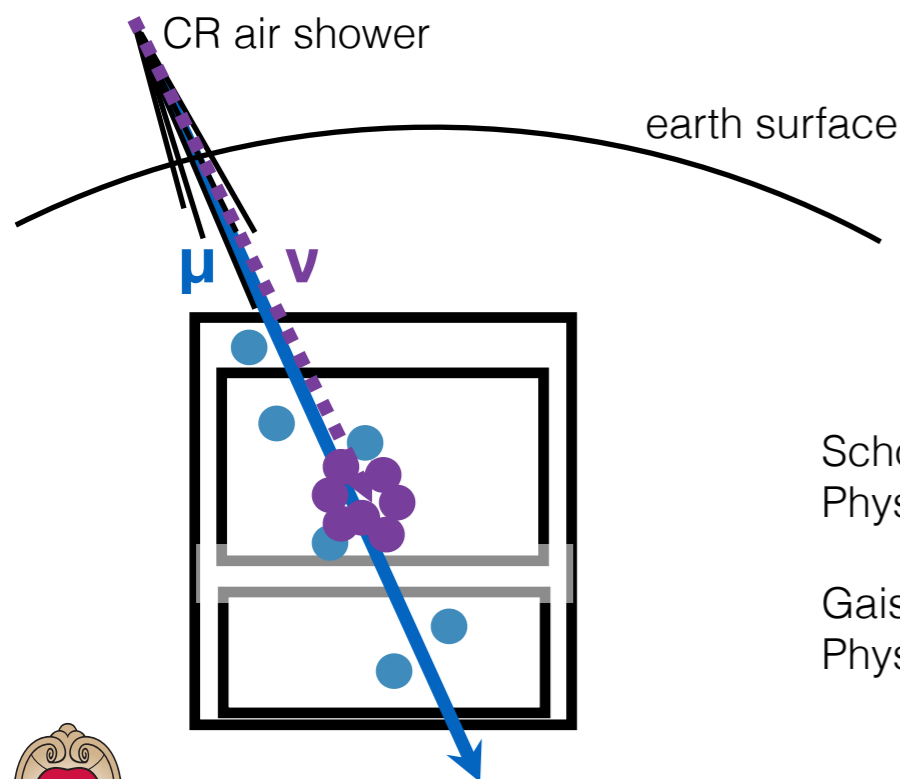
Schoenert, Gaisser, Resconi, Schulz,
Phys. Rev. D, 79:043009 (2009)

Gaisser, Jero, Karle, van Santen,
Phys. Rev. D, 90:023009 (2014)



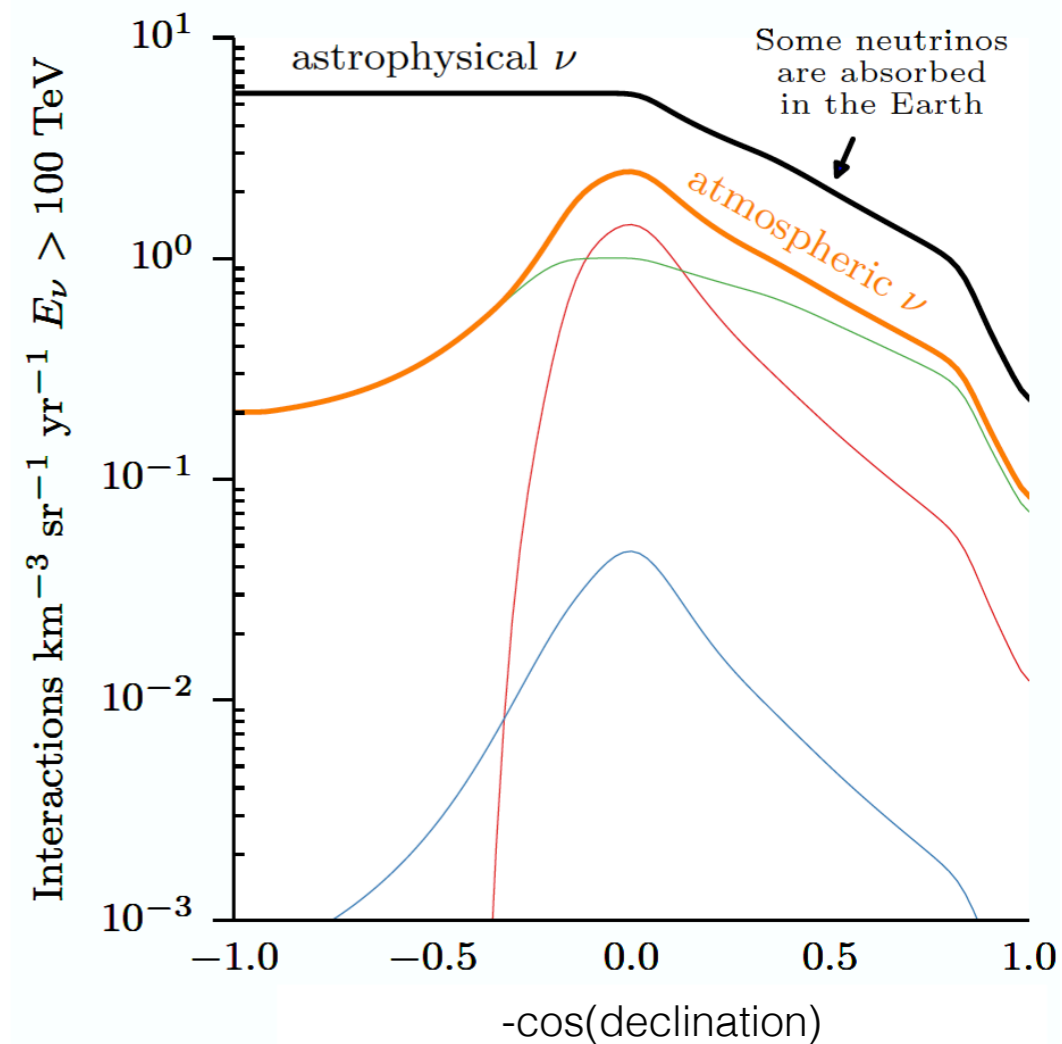
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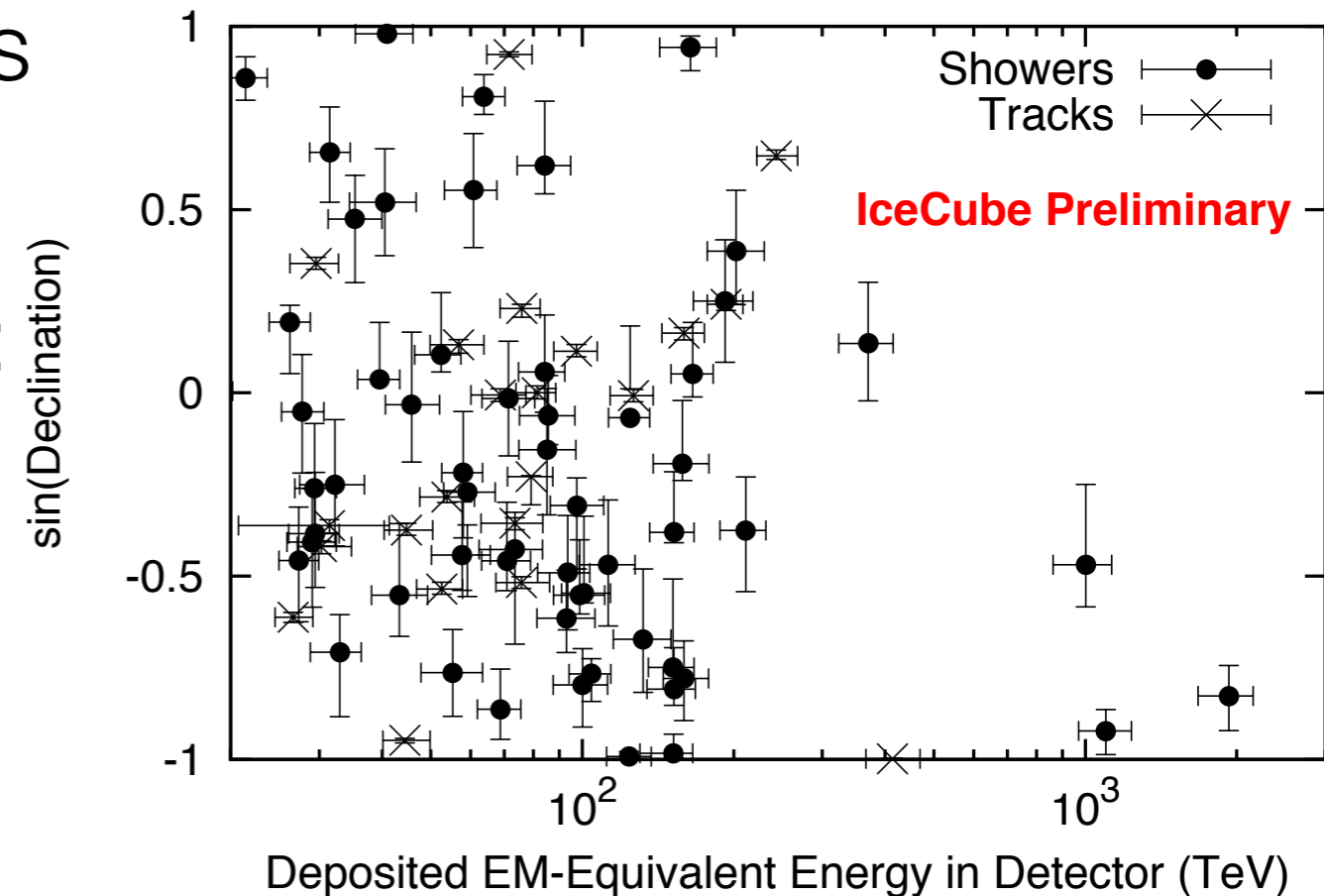


6-yr data sample (all)

- 80(+2) events observed (2 events with coincident atm. muons removed)
- Background (full sample):
 - $15.6^{+11.4}_{-3.9}$ atm. neutrinos
 - 25.2 ± 7.3 atm. muons
 - no “prompt” contribution:
90%CL UL $\sim 1 * \text{ERS}^{(1)}$
- updated cross-section model (“CSMS”⁽²⁾)

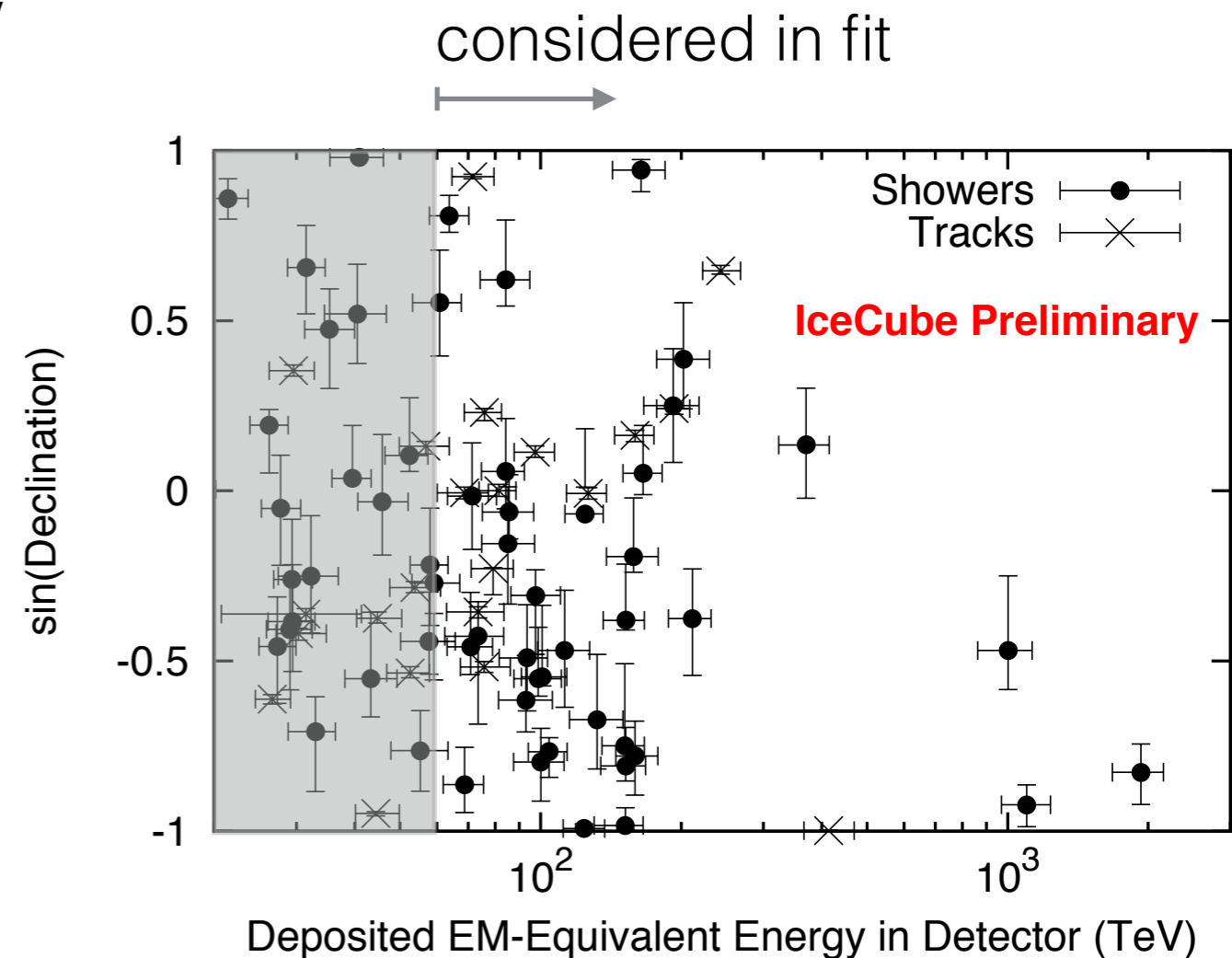
(1) Enberg, Reno, Sarcevic, Phys. Rev. D, 78:043005 (2008)

(2) Cooper-Sarkar, Mertsch, Sarkar, JHEP08(2011)042



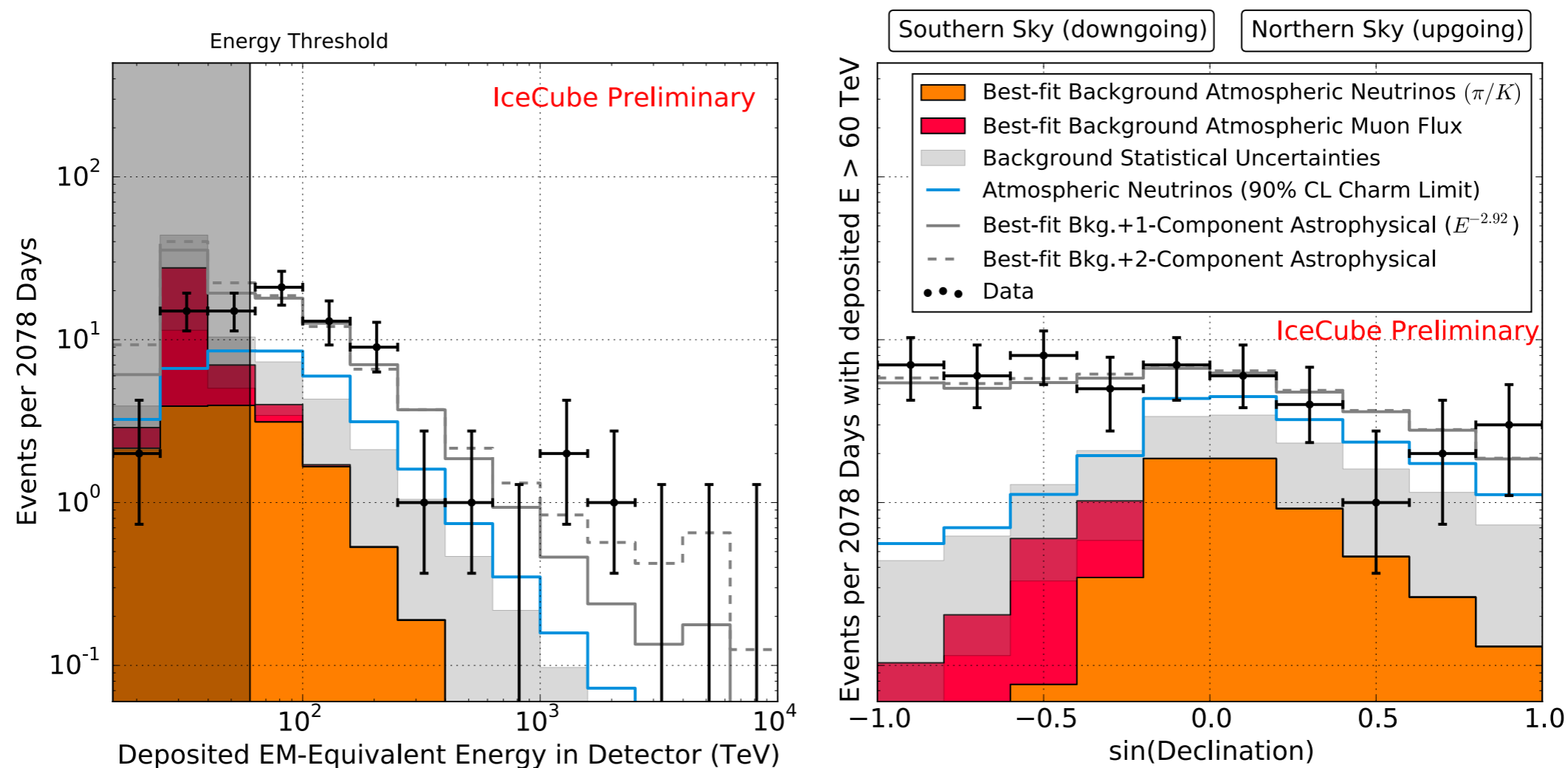
6-yr data sample (considered in fit)

- 80(+2) events observed (2 events with coincident atm. muons removed)
- 49 events with $E_{\text{dep}} > 60$ TeV
- Background (>60 TeV):
 - $8.5^{+9.4}_{-2.9}$ atm. neutrinos
 - 1.4 ± 0.4 atm. muons



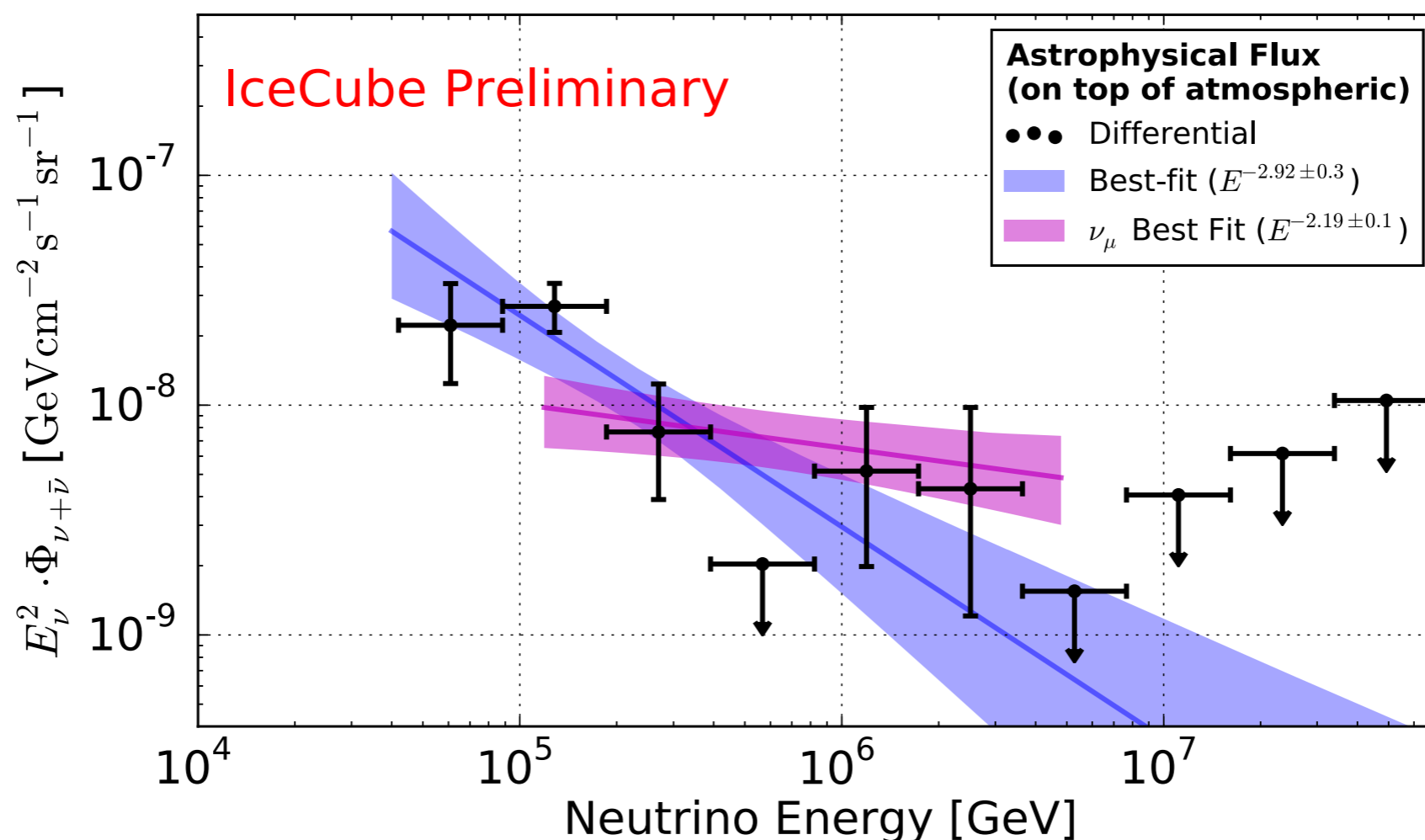
6-yr astrophysical

- Best-fit: $\phi = 2.46 \pm 0.8 \times 10^{-18} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$, $\gamma = -2.92 \pm 0.3$
- Background-only hypothesis rejected by $\sim 8\sigma$



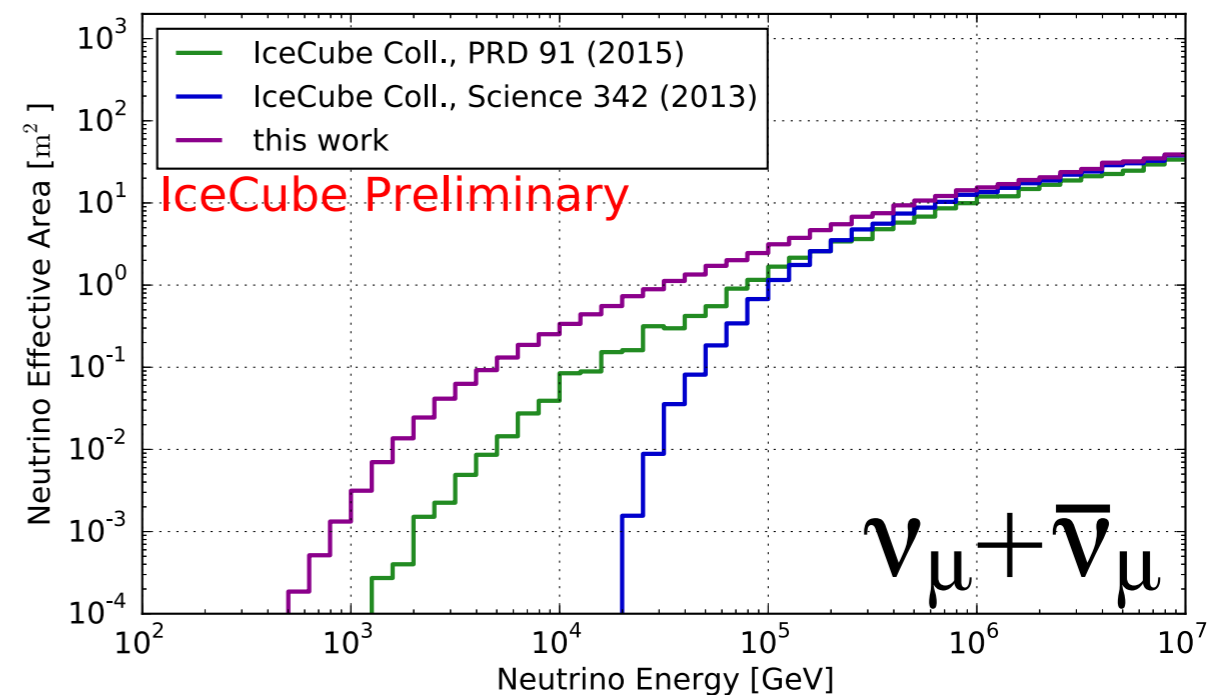
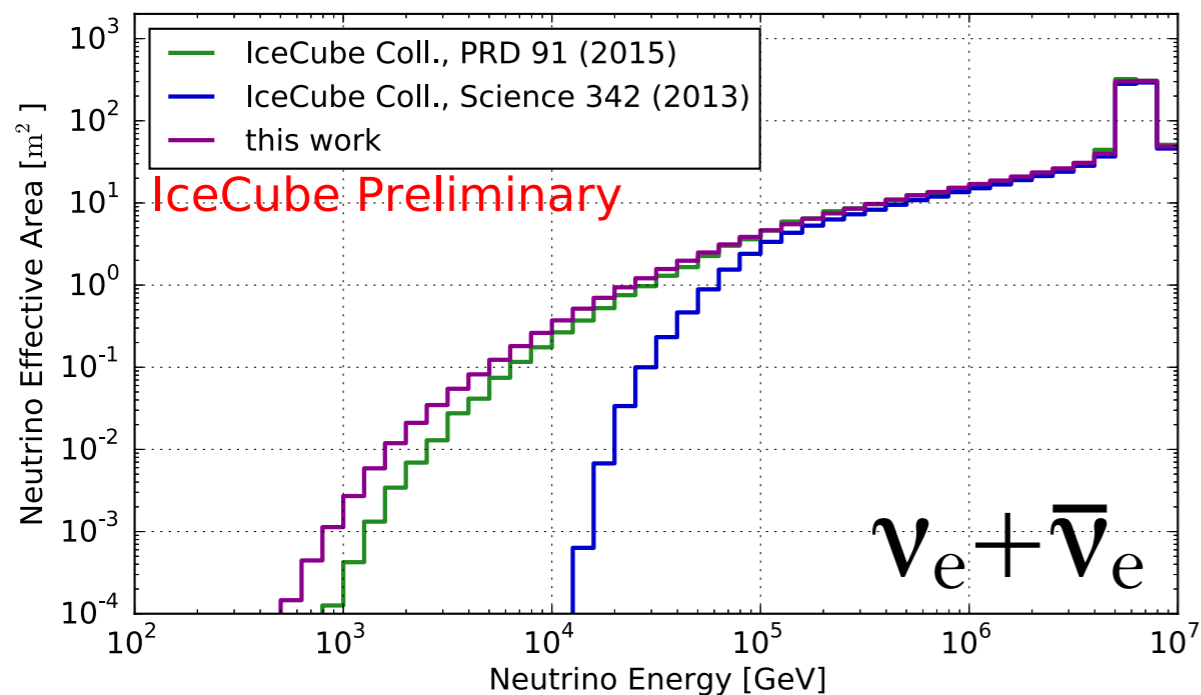
6-yr unfolding

- Unfolding to neutrino energy:
 - assume isotropic flux, $\nu_e:\nu_\mu:\nu_\tau=1:1:1$, $\nu:\bar{\nu}=1:1$
 - compatible with through-going muons in sensitive energy range

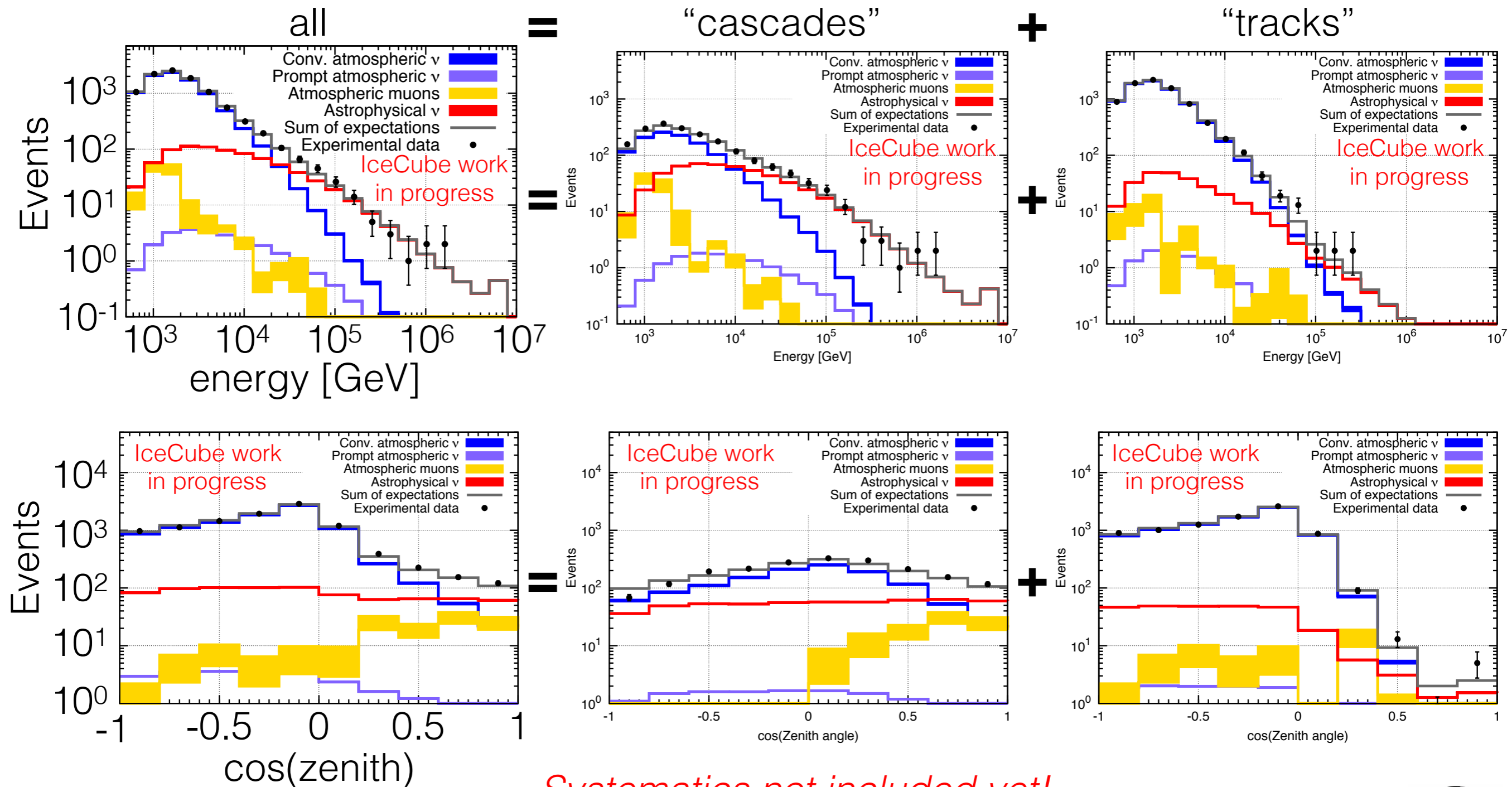


Low-threshold starting event selection

- Uses the veto approach, threshold lowered to 1 TeV (incl. high energy sample)
- Additional veto-based cuts to reduce atm. muon background to <10% of total rate (not using data-driven muon background estimate)
- Improved effective areas compared to previous selections utilizing an active veto (low-threshold starting events-cascade optimized, high energy starting events)



7-yr distributions

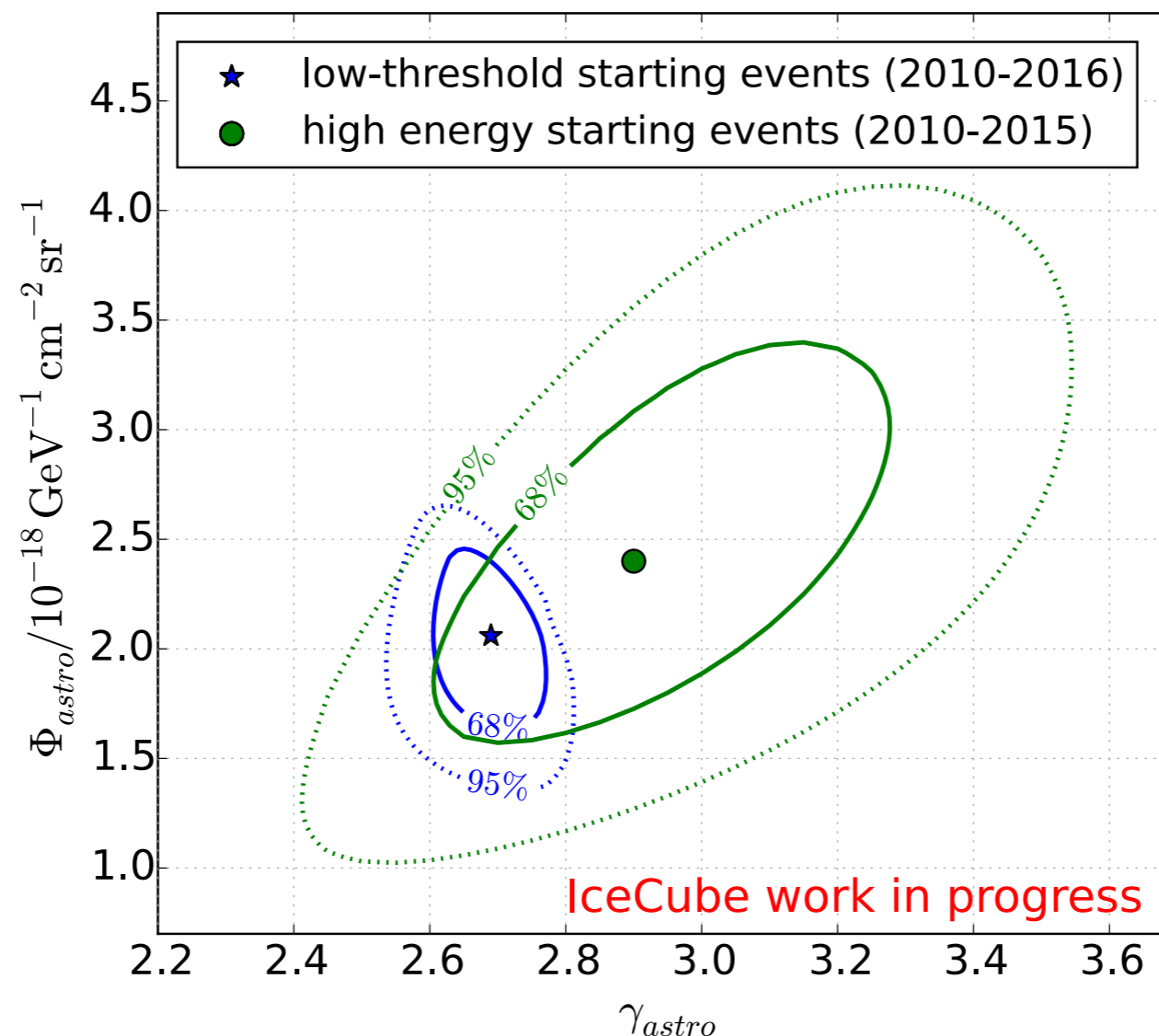


Systematics not included yet!

7-yr astrophysical

Systematics not included yet!

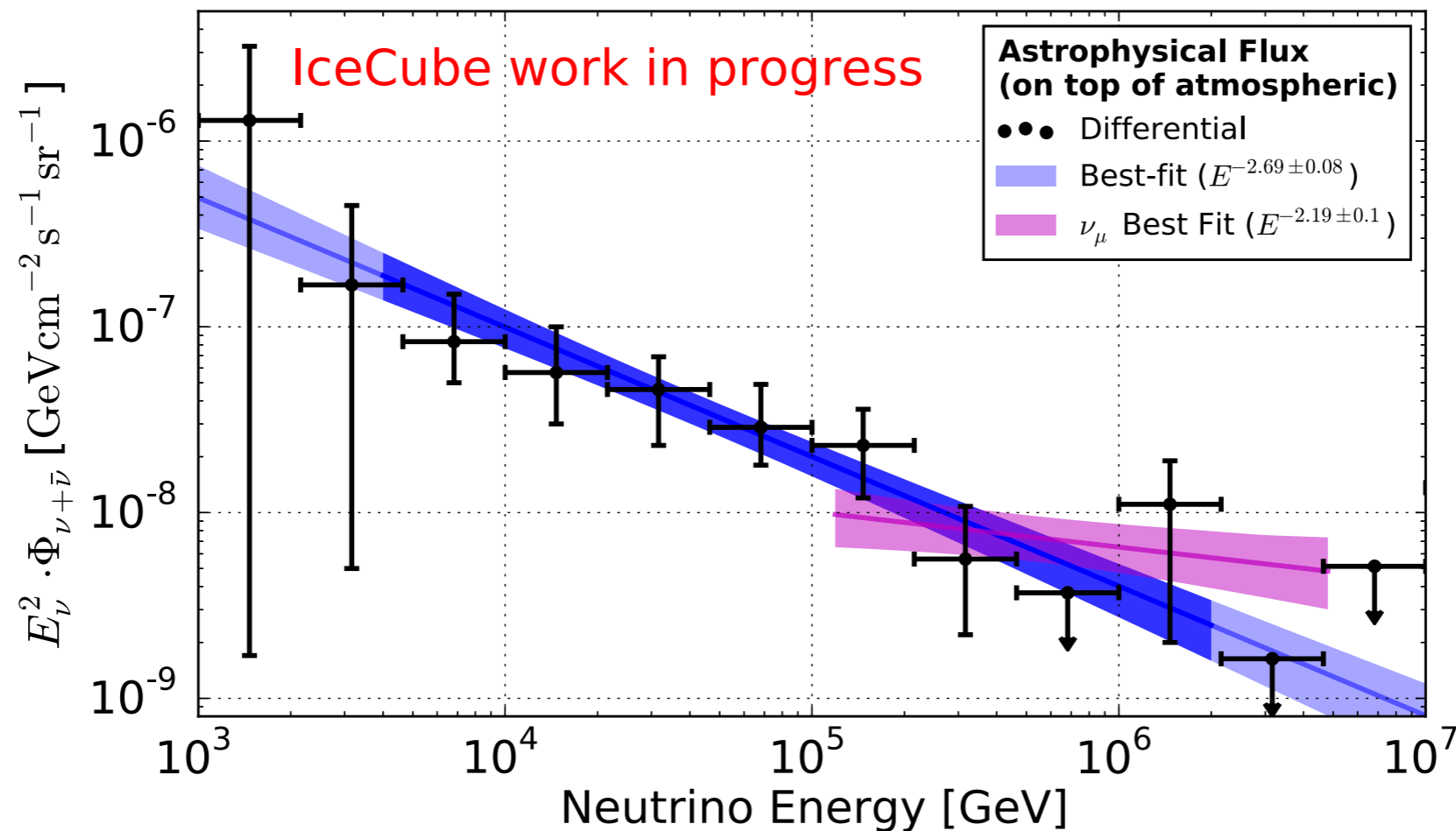
- Best-fit: $\phi = 2.1 \pm 0.3 \times 10^{-18} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ sr}^{-1} \text{ s}^{-1}$, $\gamma = -2.69 \pm 0.08$ ($\sim 6\sigma$)
- no evidence for a broken power-law astrophysical flux



7-yr unfolding

Systematics not included yet!

- Unfolding to neutrino energy:
 - assume isotropic flux, $\nu_e:\nu_\mu:\nu_\tau=1:1:1$, $\nu:\bar{\nu}=1:1$
 - compatible with through-going muons in sensitive energy range



- High energy starting events (6yr): $\gamma_{\text{astro}} = -2.92 \pm 0.3$
- Low-threshold starting events (7yr): $\gamma_{\text{astro}} = -2.69 \pm 0.08$
- Low-threshold sample includes high energy sample, will supersede it in the future
- Both starting event samples compatible with single power law description...
- ...and with through-going muon result (PoS(ICRC2017)1005) in corresponding sensitive energy range (> 120 TeV)

- Current low-threshold starting event results do NOT fully include **systematics** yet, stay tuned!
- Detailed spectral features (e.g. possible “**30 TeV excess**” in low-threshold starting event sample) strongly depend on systematics - *work in progress!*
- Low-threshold starting event sample will be used in upcoming **multi-channel analysis** (PoS(ICRC2017)976)

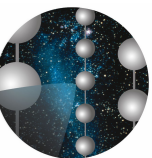
Thank you!



most photographs/timelapse: M. Wolf/NSF
<https://www.flickr.com/photos/135762220@N06/>



Nancy Wandkowsky, Measurement of neutrino events above 1 TeV with contained vertices

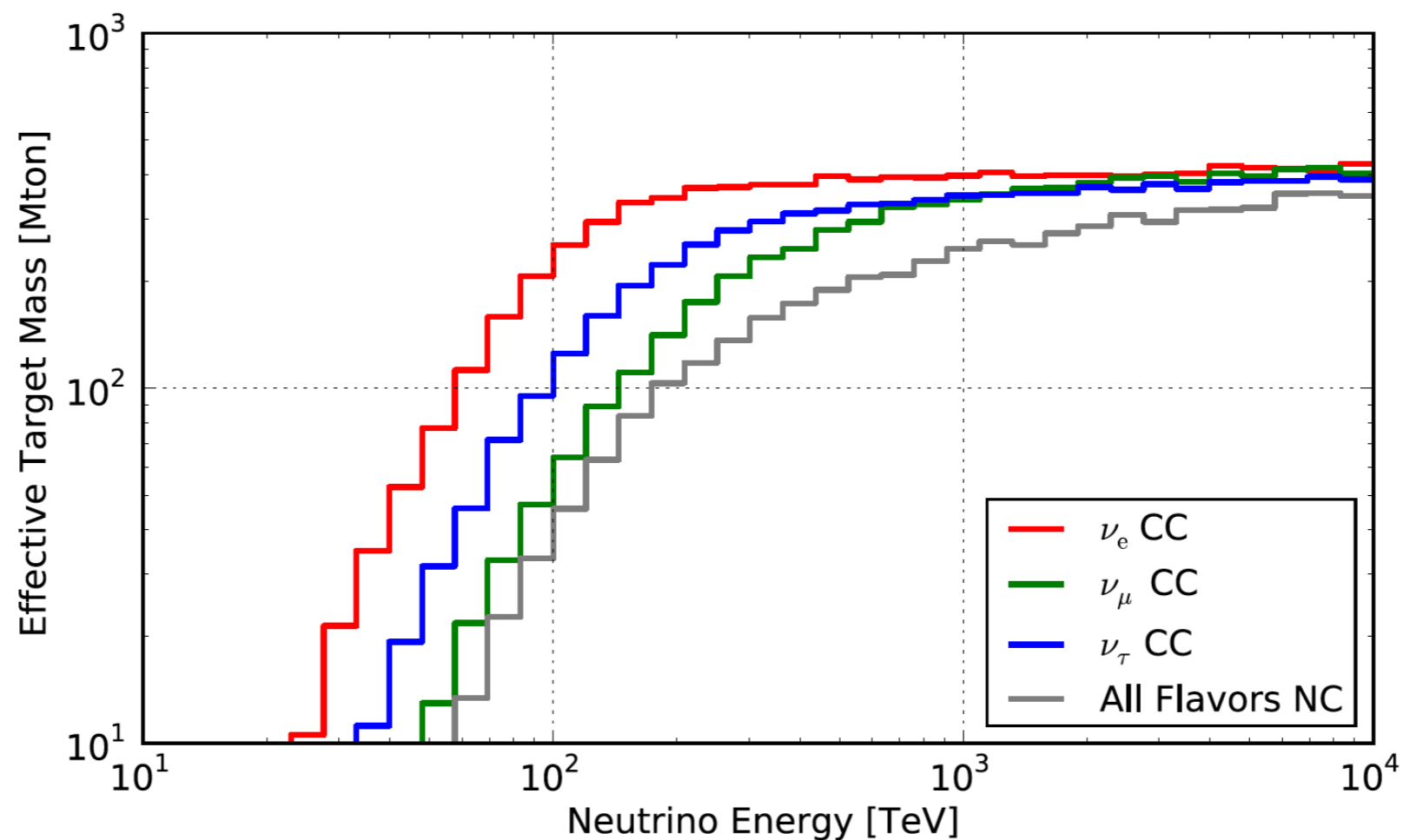


IceCube

High energy starting events (2010-2015)

Effective Fiducial Mass

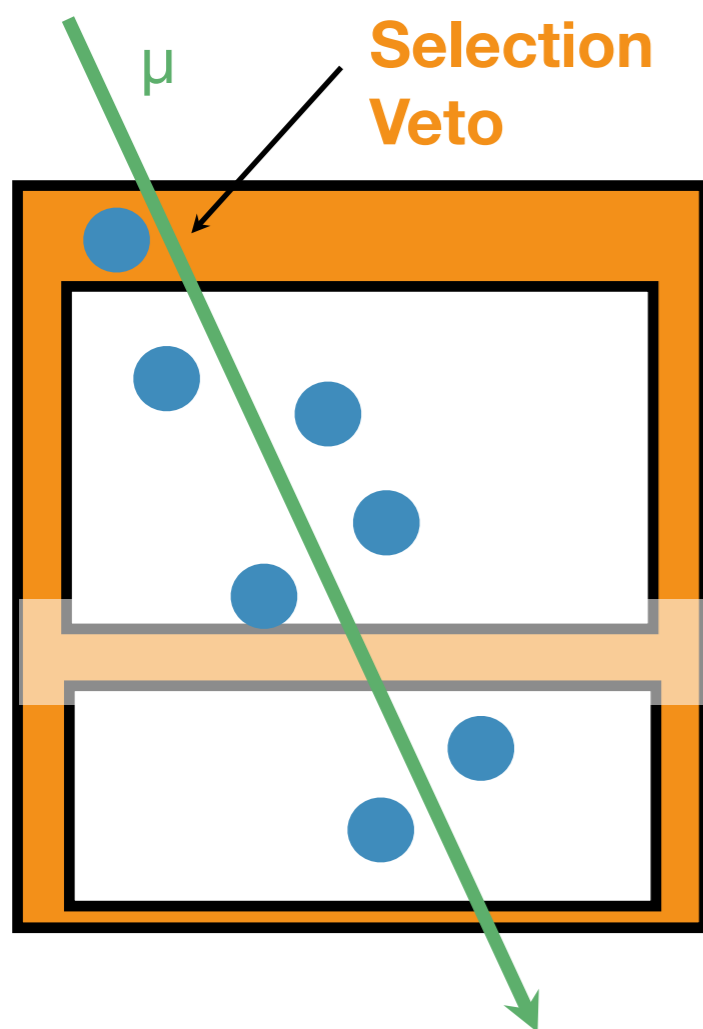
- Explicit search for events with contained vertices at high energies (>60 TeV)
- 400 Mton effective fiducial mass



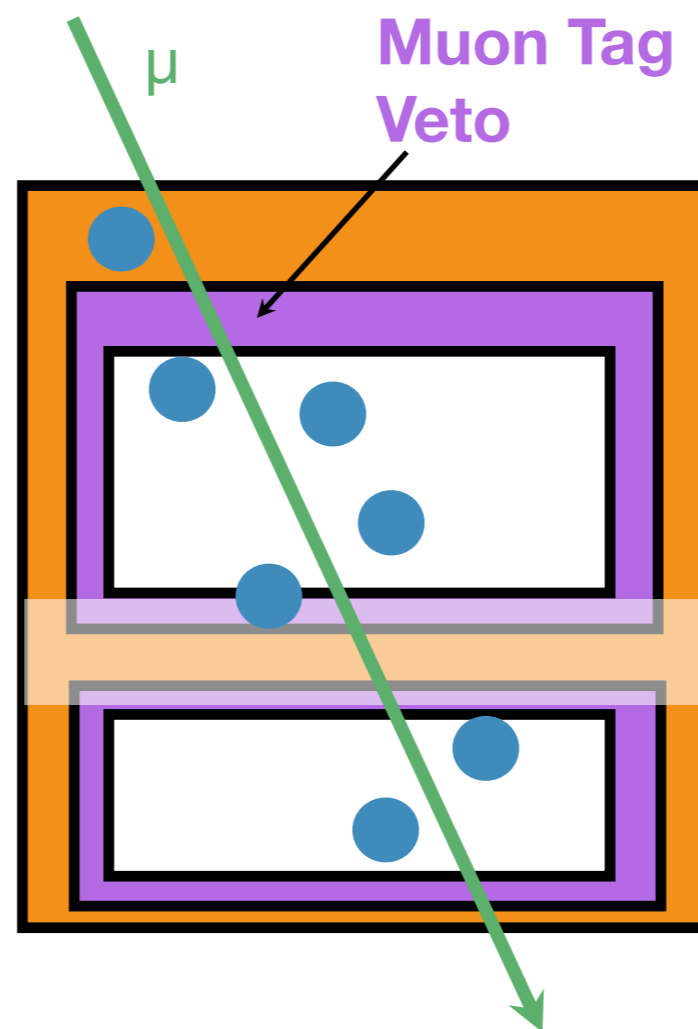
High energy starting events (2010-2015)

Data-driven background estimate

Selection Veto



Muon Tag Veto



define second veto layer
→ tag events that **fail the outer veto**, but **pass the inner veto**
(12 events in 6 yrs)
→ scale to full volume (factor 2.1)
→ 25.2 atm. muons expected in 6yrs

event fails atm. muon veto...
(i.e. not in neutrino sample)

but passes muon tag
(i.e. contributes to background estimate)

High energy starting events (2010-2015)

Test for possible 2-component astrophysical flux

- Use through-going muons as prior for “hard” astrophysical component
- No evidence for 2 components in this analysis

