Disentangling Charm and Astrophysical Neutrino Fluxes in IceCube

Primary author: Jakob van Santen, University of Wisconsin, Madison

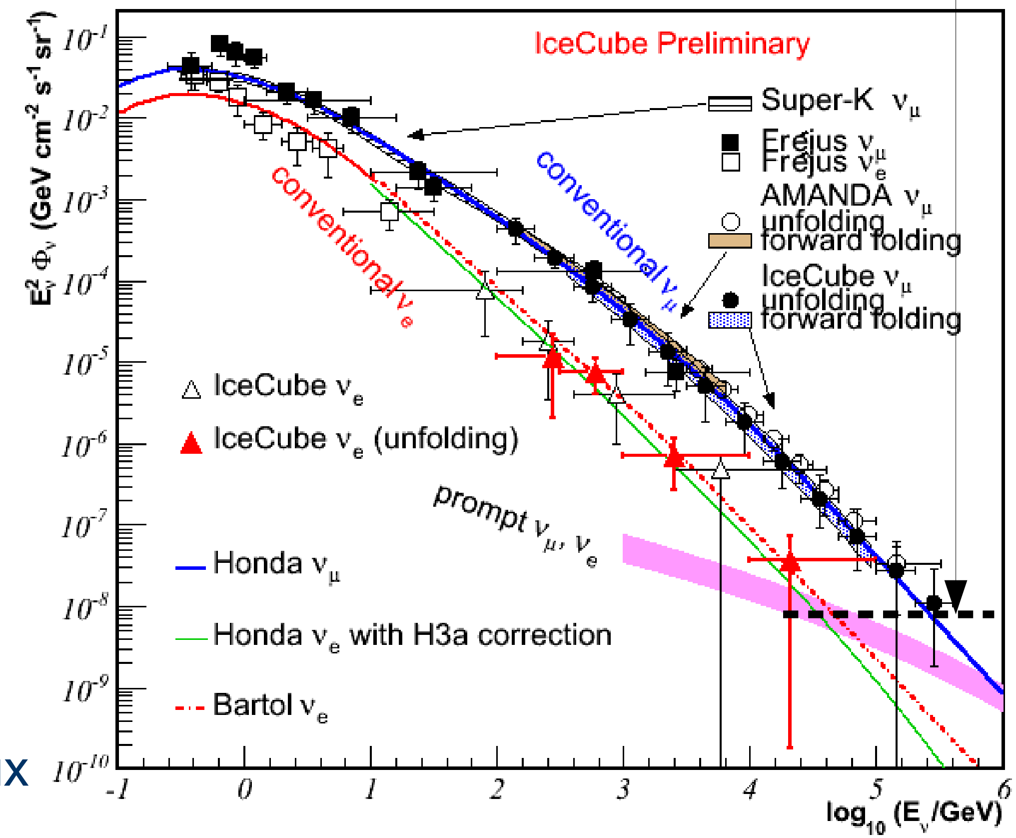
Gary Binder, Lawrence Berkeley National Laboratory

MANTS, 20 September 2014

Atmospheric Neutrinos

Current best-estimate of astrophysical E^{-2} flux

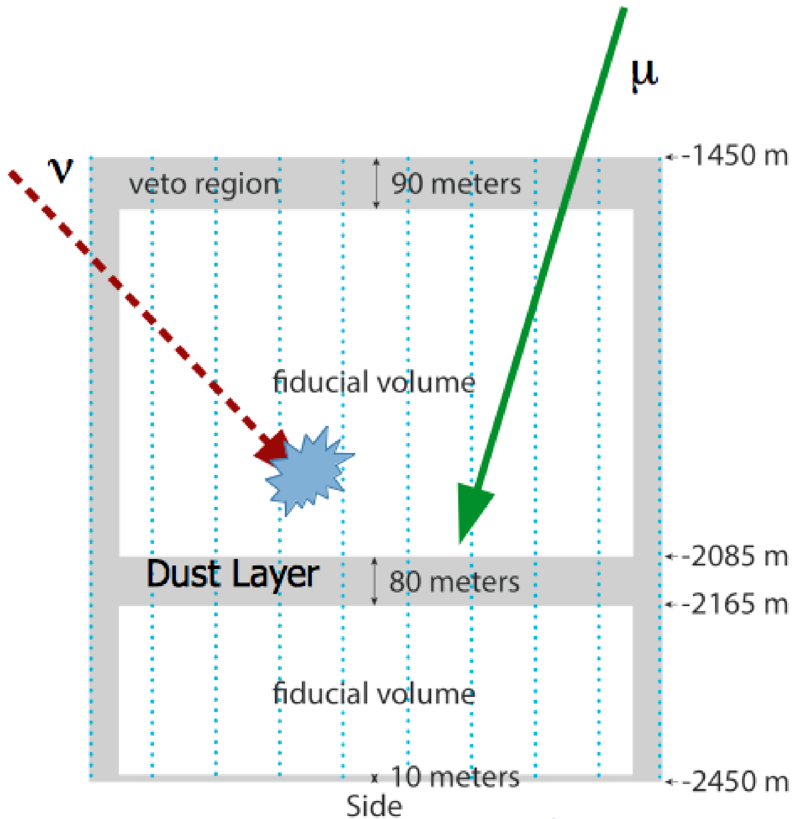
- Conventional neutrinos
  - Pion/kaon decay
  - $\sim E^{-3.7}$
  - Peaked at horizon
  - Mostly ν_μ
- Prompt neutrinos
  - Charm decay
  - $\sim E^{-2.7}$
  - Isotropic
  - Nearly equal flavor
  - Calculated normalization of flux varies widely
  - Unobserved background for astrophysical neutrino searches



- Best hope to find prompt flux is to focus on ν_e-induced cascades

Finding Neutrinos

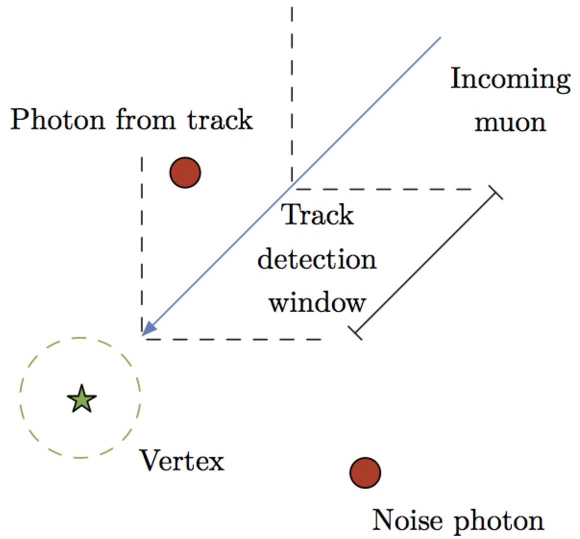
- Use an outer layer to veto incoming muons and select events starting in the detector
- Same method as in earlier 2(3) year IceCube results that found 28(37) events above ~60 TeV
- Since most muons and conventional neutrinos are track-like, focusing on cascades brings the energy threshold down to ~10 TeV
- Would like to go to even lower energies

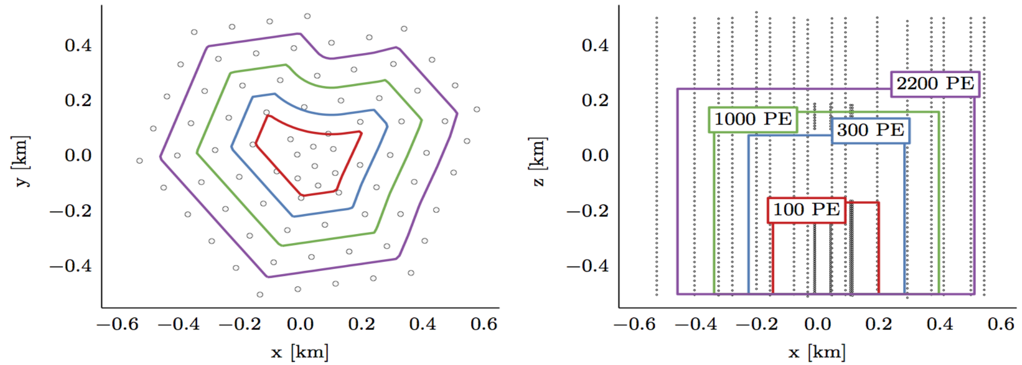


Science 342, 1242856 (2013)

Improved Veto Techniques

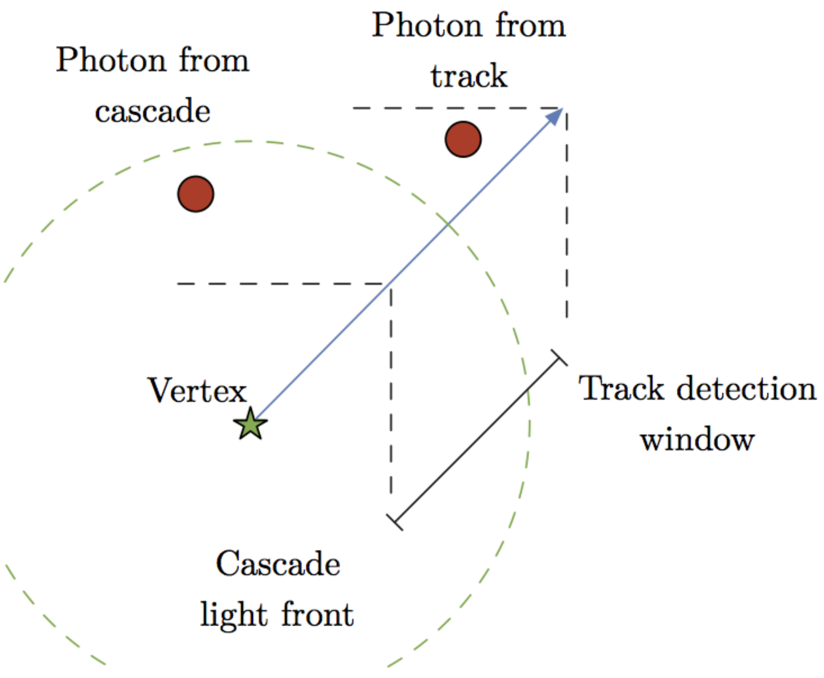
- Additionally, look for any hits (not just in the veto layer) consistent with a track entering the reconstructed vertex
- Scale fiducial volume with deposited charge of event to have a better chance of finding vetoing hits for low energy events





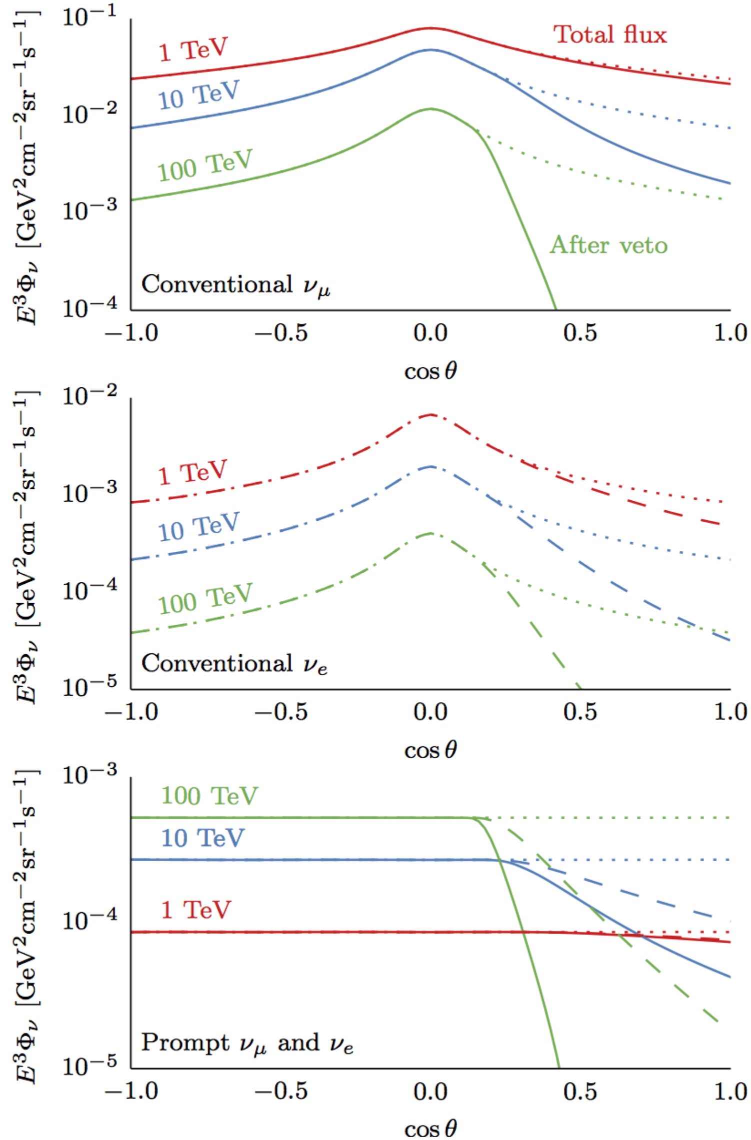
Cascade/Track Classification

- Reversing the muon track detection step also acts to identify starting track events, i.e charged-current ν_μ
- An event with > 10 hits following the vertex is classified as a track
- ~35% (60%) of astrophysical (conventional) ν_μ CC events identified as cascades



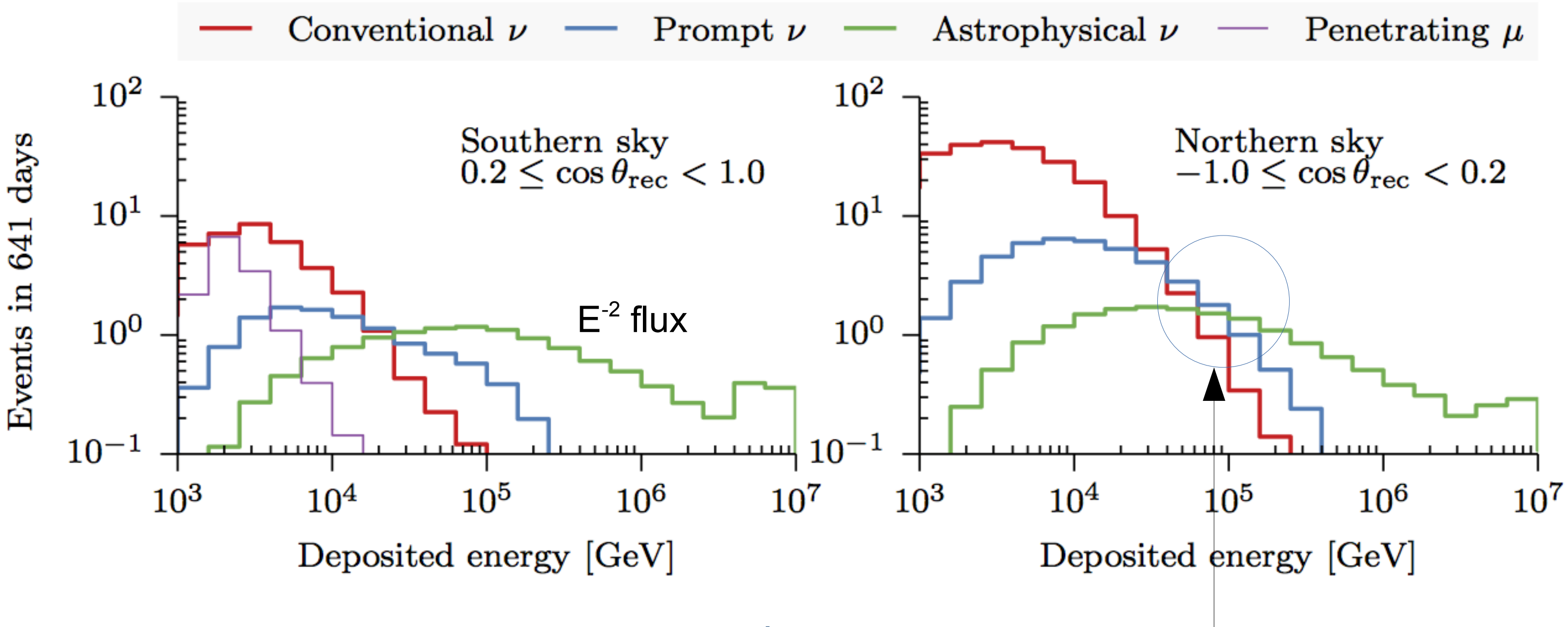
Self-Veto Probability

- At high energies and low zenith angles, atmospheric neutrinos will be accompanied by vetoing muons
- Leads to a suppression of the down-going atmospheric event rate
- Using latest analytic calculation by Gaisser et al.
  - Incorporates both correlated and uncorrelated muons in showers
  - See talk by K. Jero tomorrow



PRD 90, 023009 (2014)

Baseline Event Distributions



- Use energy, direction, and cascade/track ID information
- Perform a binned likelihood fit on these distributions to find the scaling of each atmospheric component and the index and normalization of a power-law astrophysical flux

Small window for prompt to appear

BERKELEY LAB

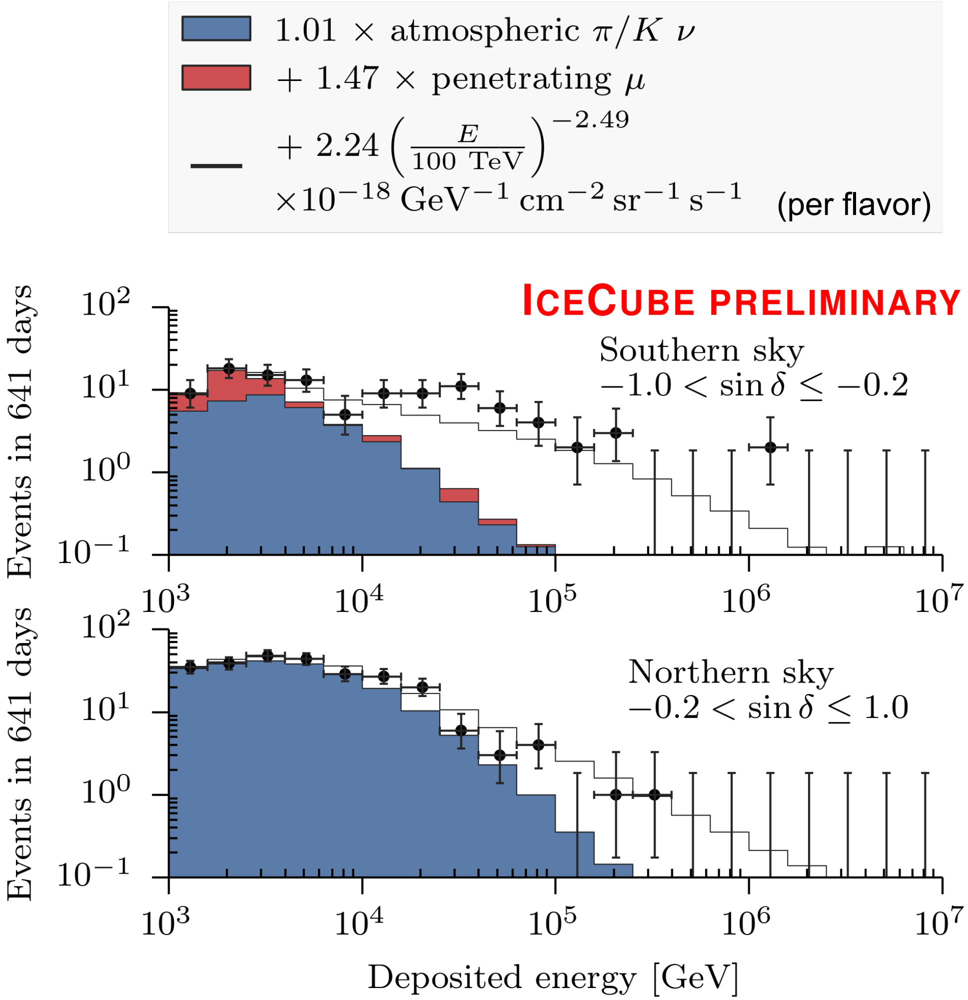
Component Signatures

Component	Energy	Zenith	Topology
Muons	Low	Down-going	Mostly tracks
Conventional	Low, $\sim E^{-3.7}$	Peaked at horizon, down-going suppressed	Mostly tracks
Prompt	Medium, $\sim E^{-2.7}$	Isotropic, down-going suppressed	Cascades and tracks
Astrophysical	High, $\sim E^{-2}$(?)	Isotropic(?)	Mostly cascades (1:1:1 flavor ratio)

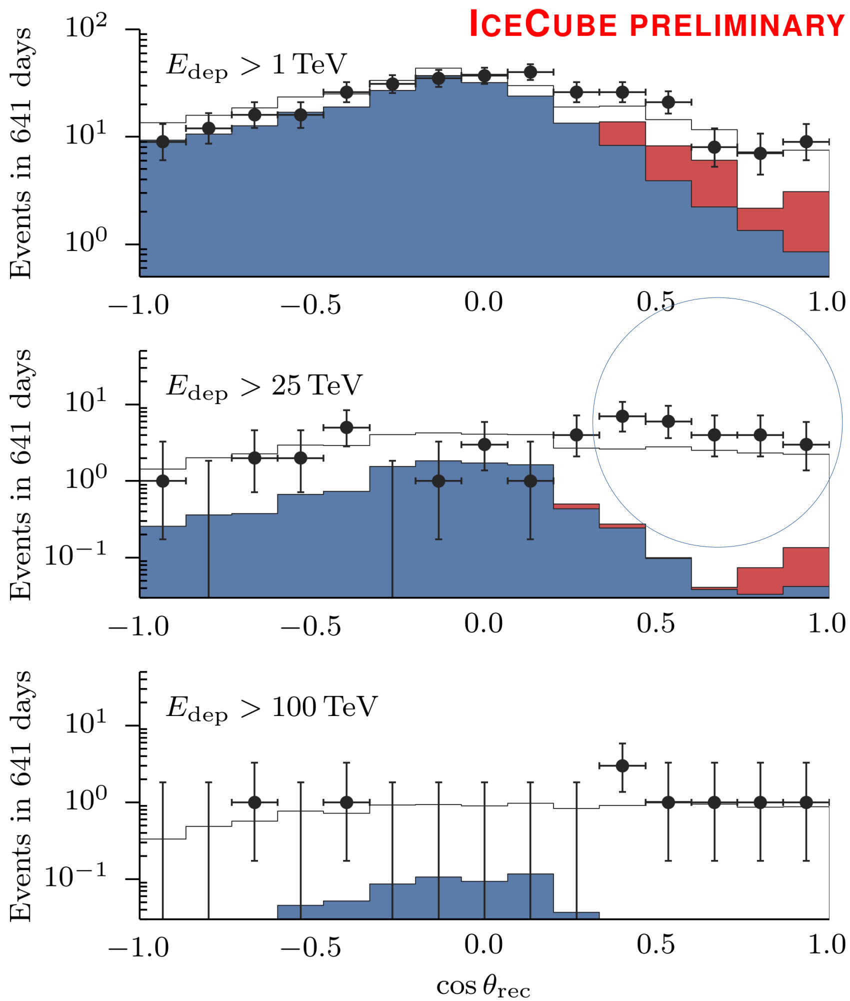
- Each component has a unique imprint on the distribution of events

Results

- 283 cascades, 105 tracks in 2 years
- Soft astrophysical index of 2.5 and zero charm is the best fit
- 90% upper limit on charm is 1.4 x ERS prediction
- Minor excess around 30 TeV in the southern sky is consistent with a statistical fluctuation
  - Goodness-of-fit: 15%
  - Correlated excess like this happens ~5% of the time



Zenith Distribution

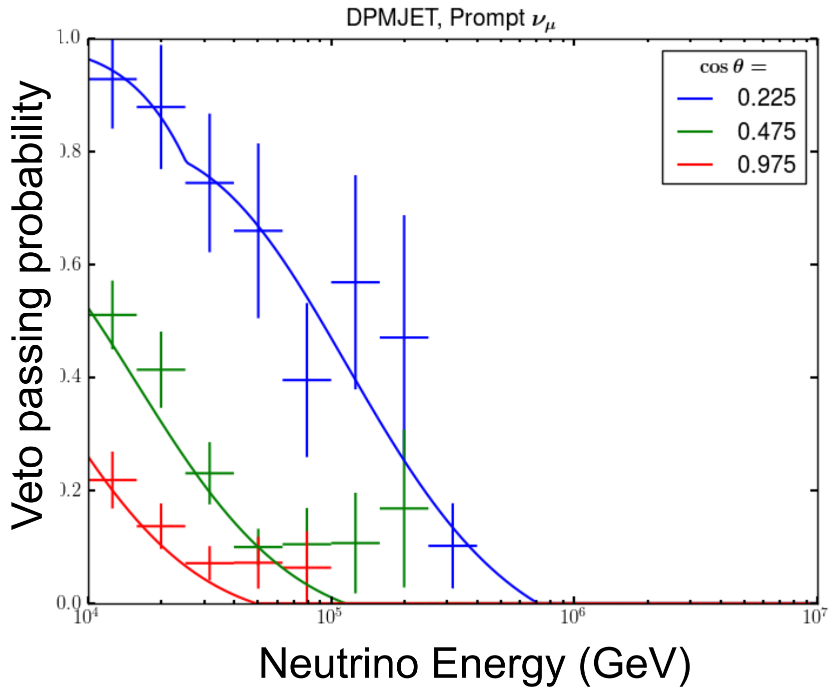


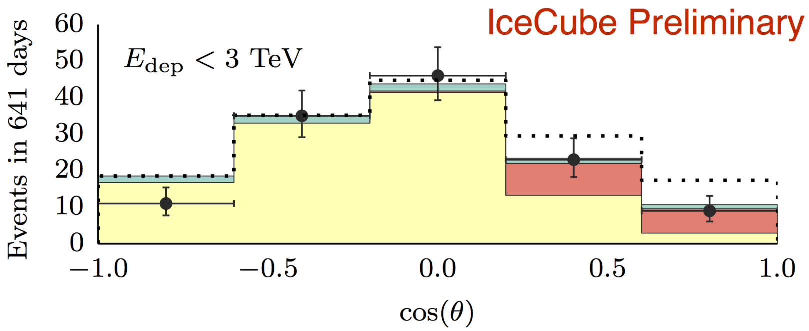
- How does the astrophysical index fit to such a soft value?
  - Could some of this be charm?
- Zenith distribution doesn't show the characteristic down-going suppression if a charm component were present
- Can we trust the calculation of self-veto probability?

BERKELEY LAB

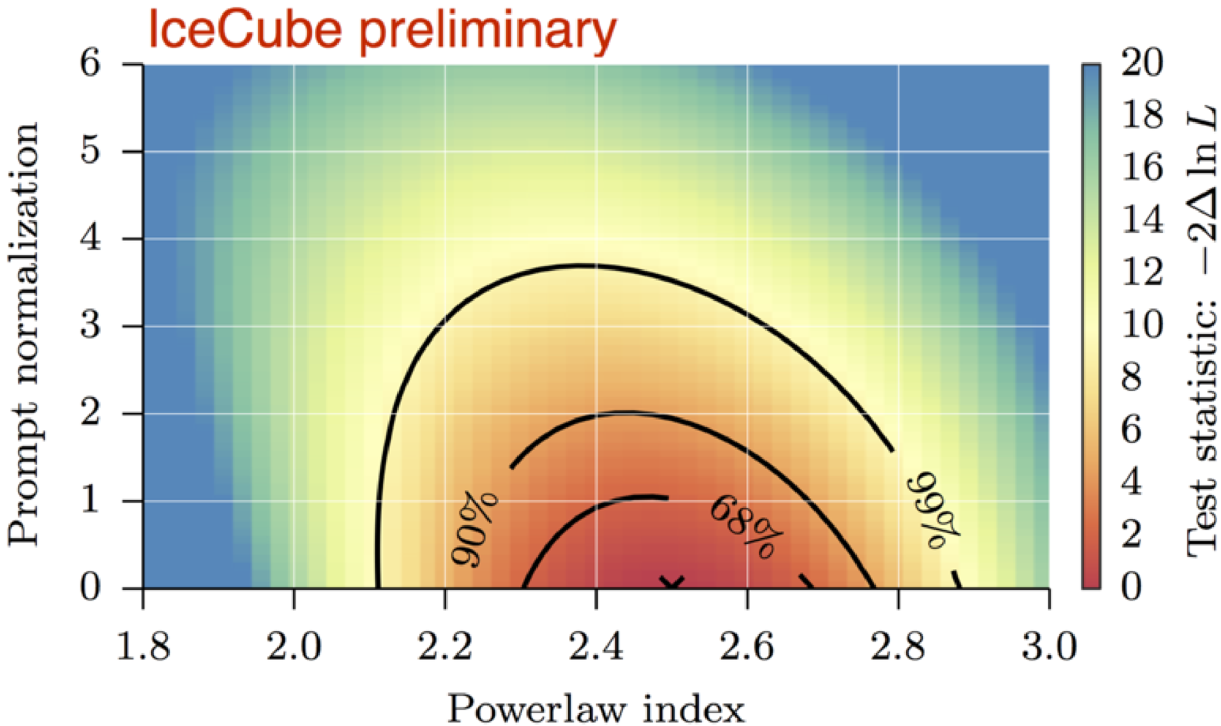
Self-Veto Probability Verification

- Neutrinos and muons in CORSIKA air showers with full detector response simulated
- The analytic calculation shows remarkably good agreement with the full simulation
- Veto suppression also visible in lowest energy data dominated by conventional neutrinos





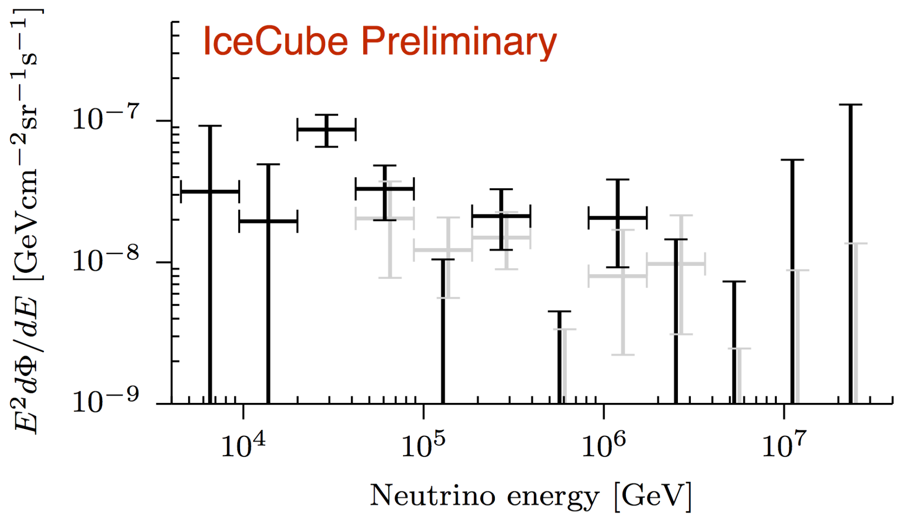
Likelihood contour



- Anti-correlation between astrophysical index and charm flux
- E^{-2} requires a large charm flux, and is disfavored at >99% confidence level

Astrophysical Uncertainties

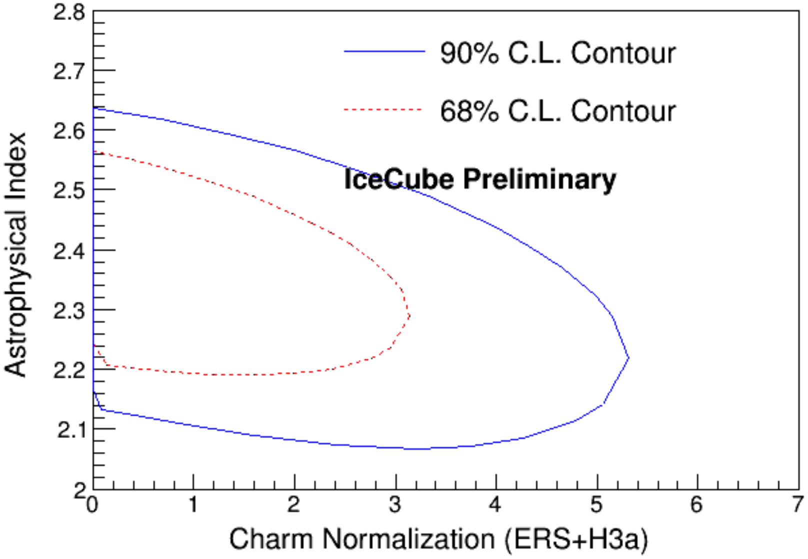
- What if the astrophysical spectrum is not well-described by a power law?
- Unfold the astrophysical spectrum as a piecewise function while also allowing atmospheric components to float
- 90% charm limit only slightly worsens: 1.4 → 1.5 x ERS
- Breaking the assumption of isotropy and allowing the flux in each hemisphere to float independently worsens the limit substantially: 1.5 → 3.6 x ERS

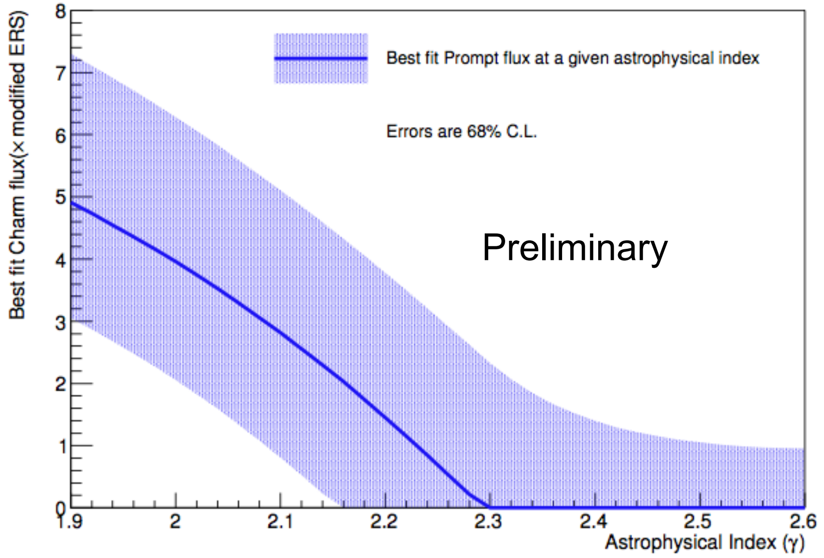


BERKELEY LAB

More data

- Several independent event selections reaching similar conclusions
- BDT event selection and particle identification with an even lower energy threshold has nearly identical results
  - See talk by C. Ha





Conclusions

- Methods developed to use maximal information in energy, angular, and flavor distributions to isolate atmospheric and astrophysical fluxes
- No evidence for charm neutrinos yet
  - Soft astrophysical power-law index of 2.5, zero charm is strongly preferred
    - Zenith distribution shows lack of self-veto suppression
  - Limits depend on the astrophysical model, but are nearing the ERS prediction
- Measurements in muons are needed!
- This is just one of many independent event selections in IceCube coming to the same conclusions
  - Several papers in the works!