Search for Diffuse Astrophysical Muon Neutrinos with Two Years of IceCube Data

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TAUP 2013

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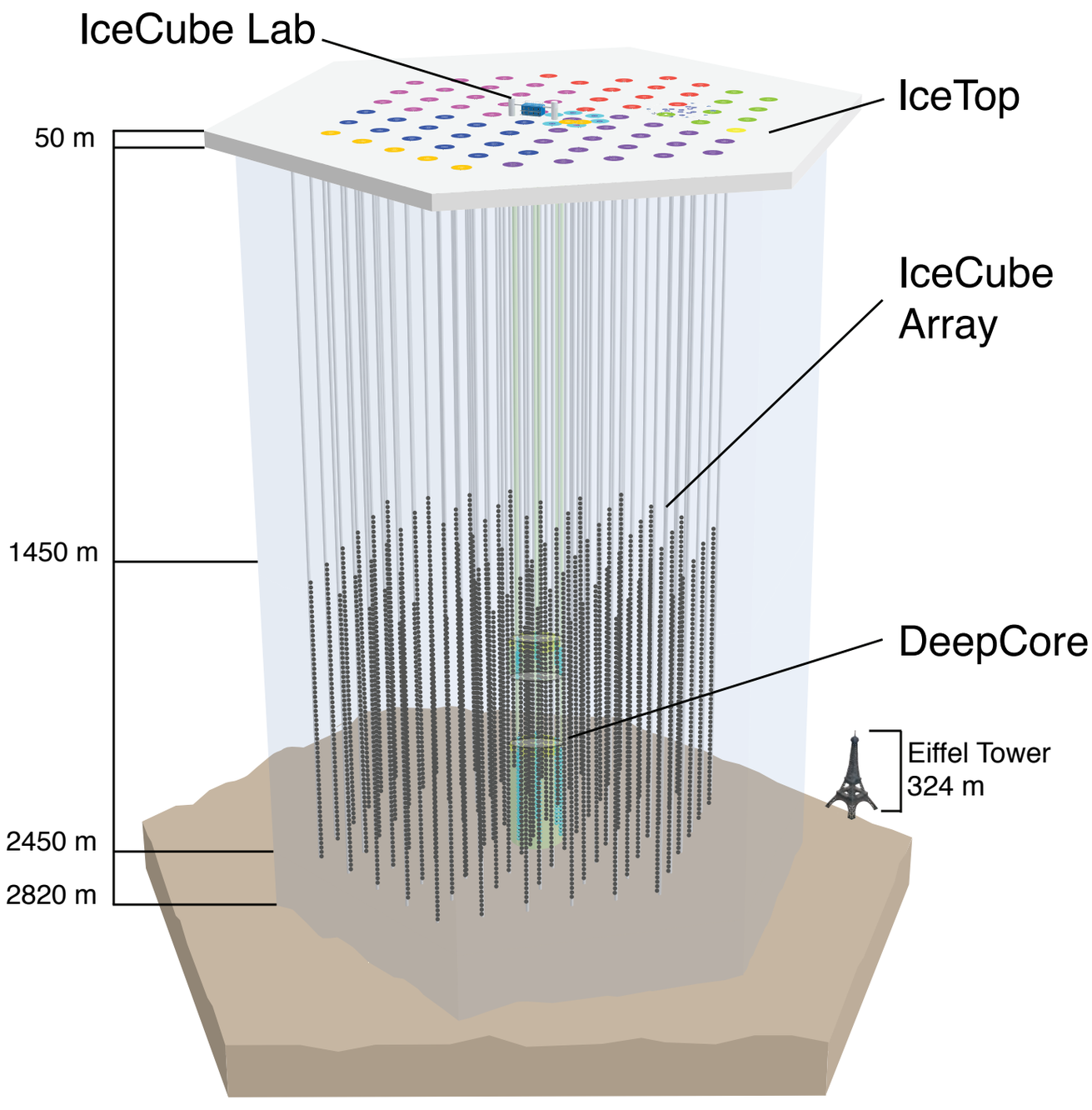
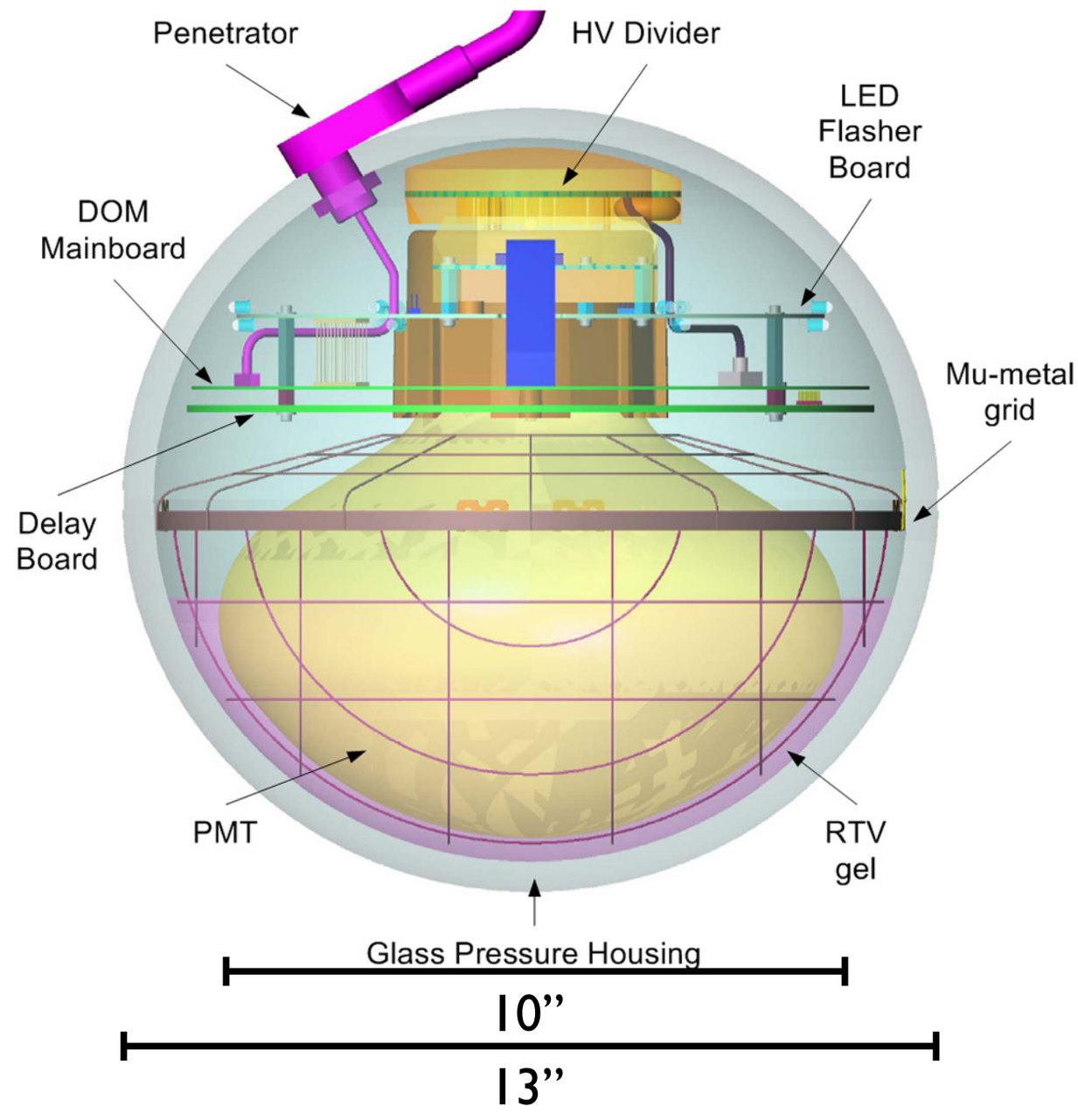
The IceCube Detector





Why Search for a Diffuse Astrophysical Flux? (and how?)

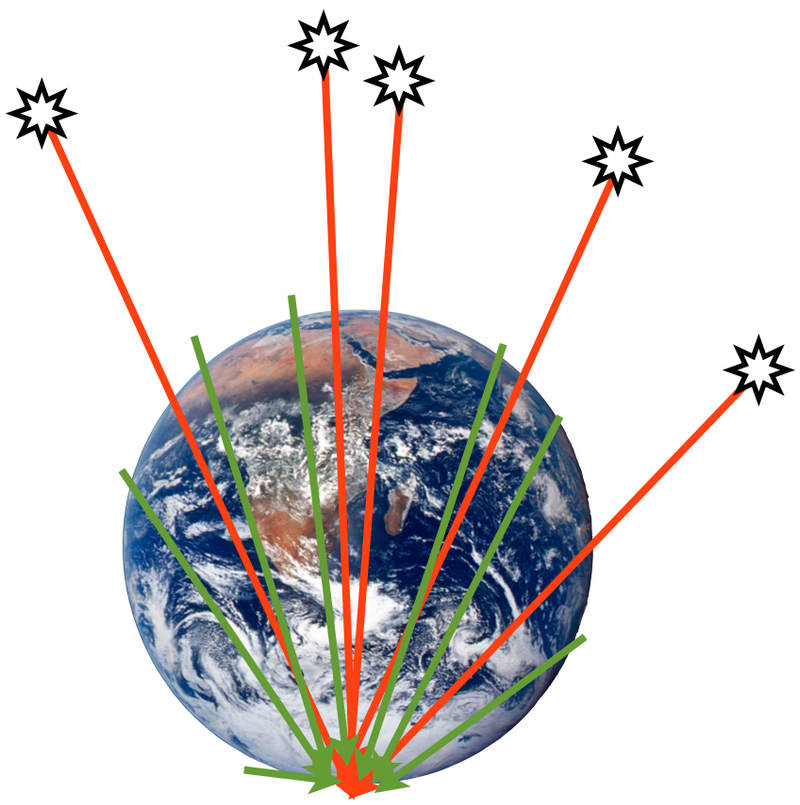
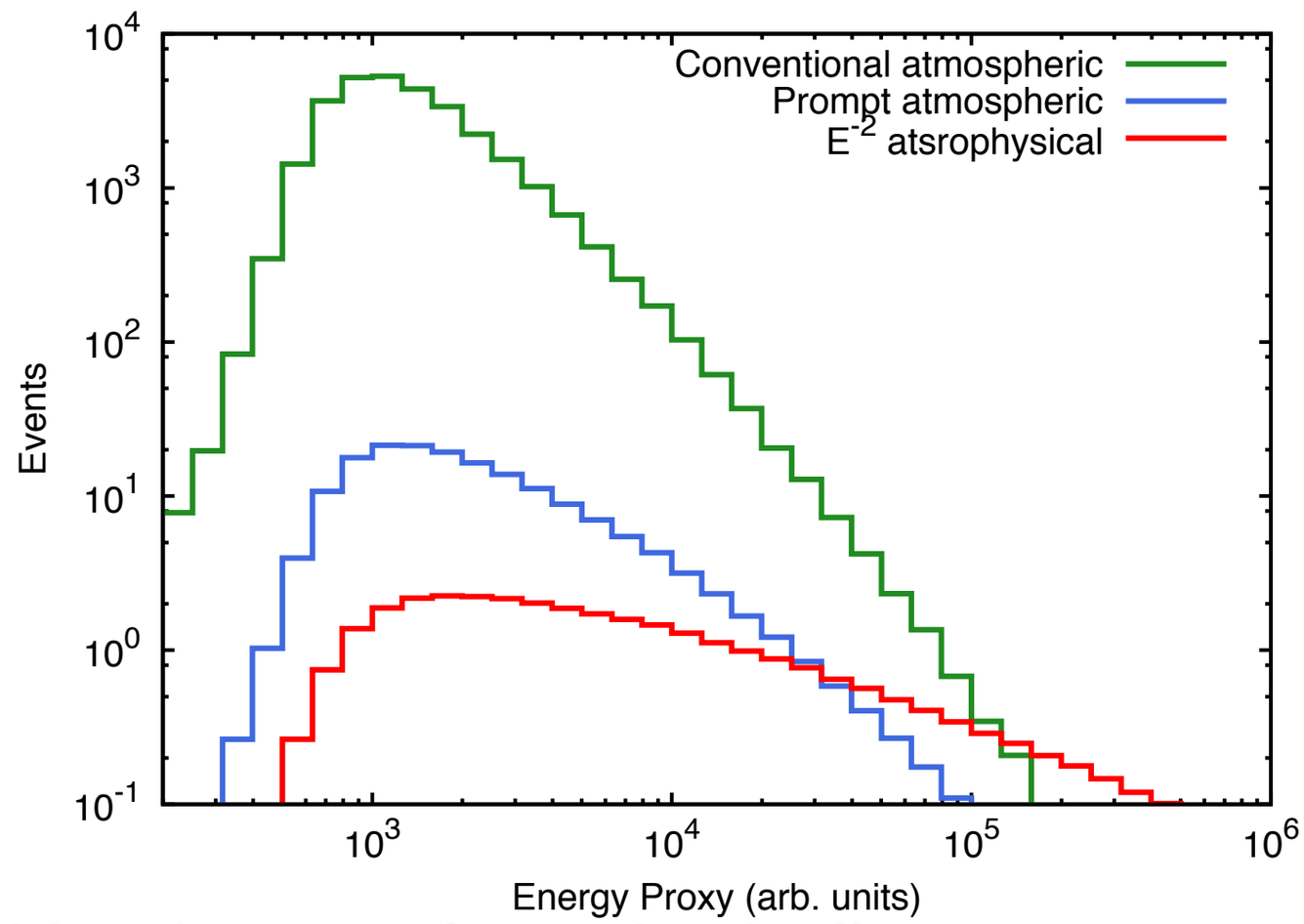
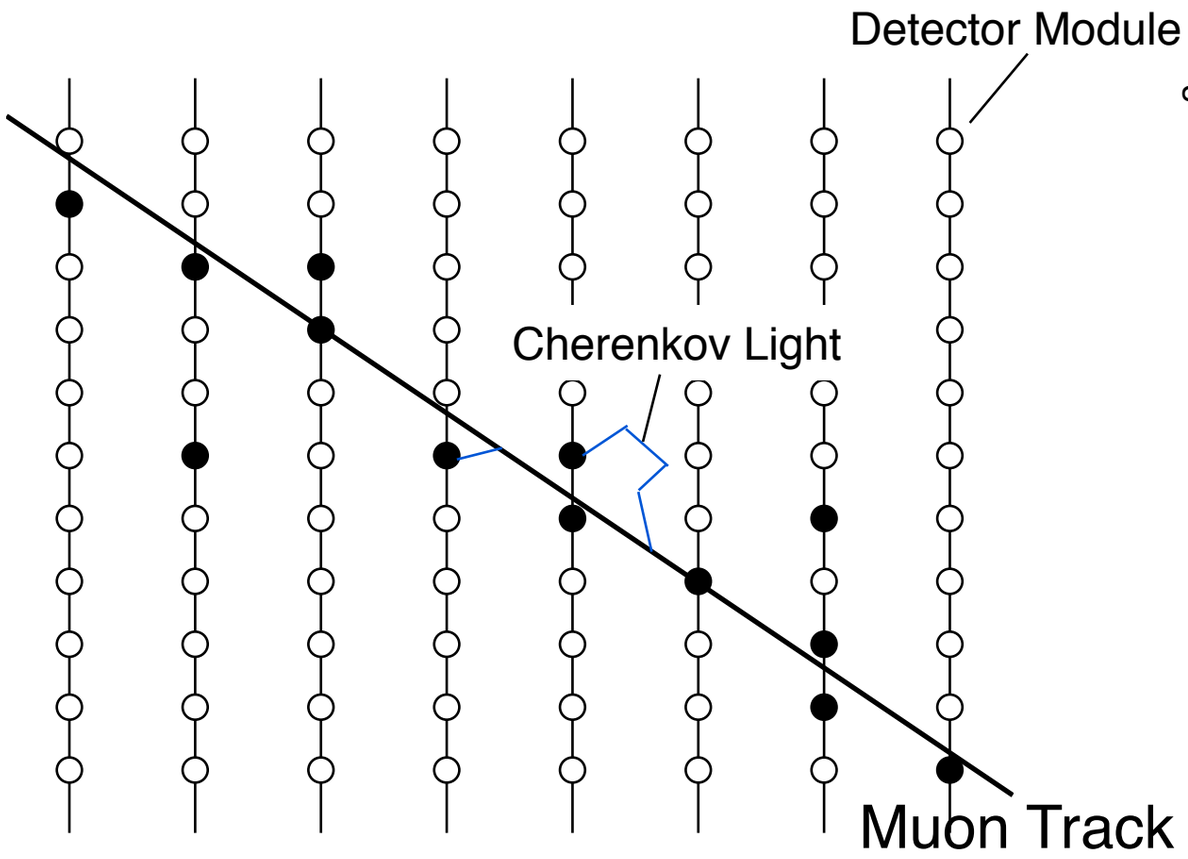


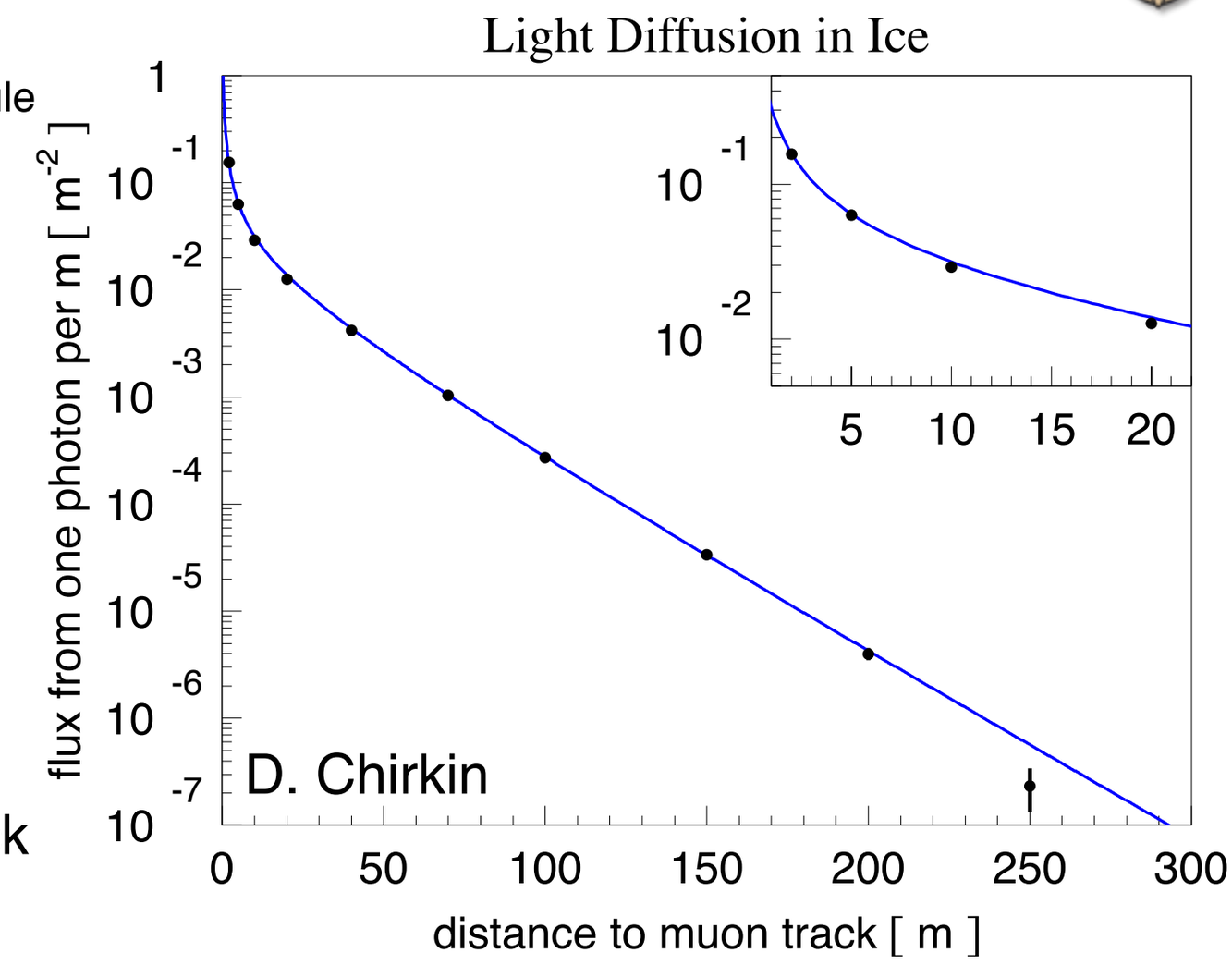
Image courtesy NASA Johnson Space Center



- Sources may be numerous and hard to resolve individually
- A harder energy spectrum can give away the presence of an astrophysical flux even when mixed with atmospheric background
- A typical guess is an E^{-2} powerlaw

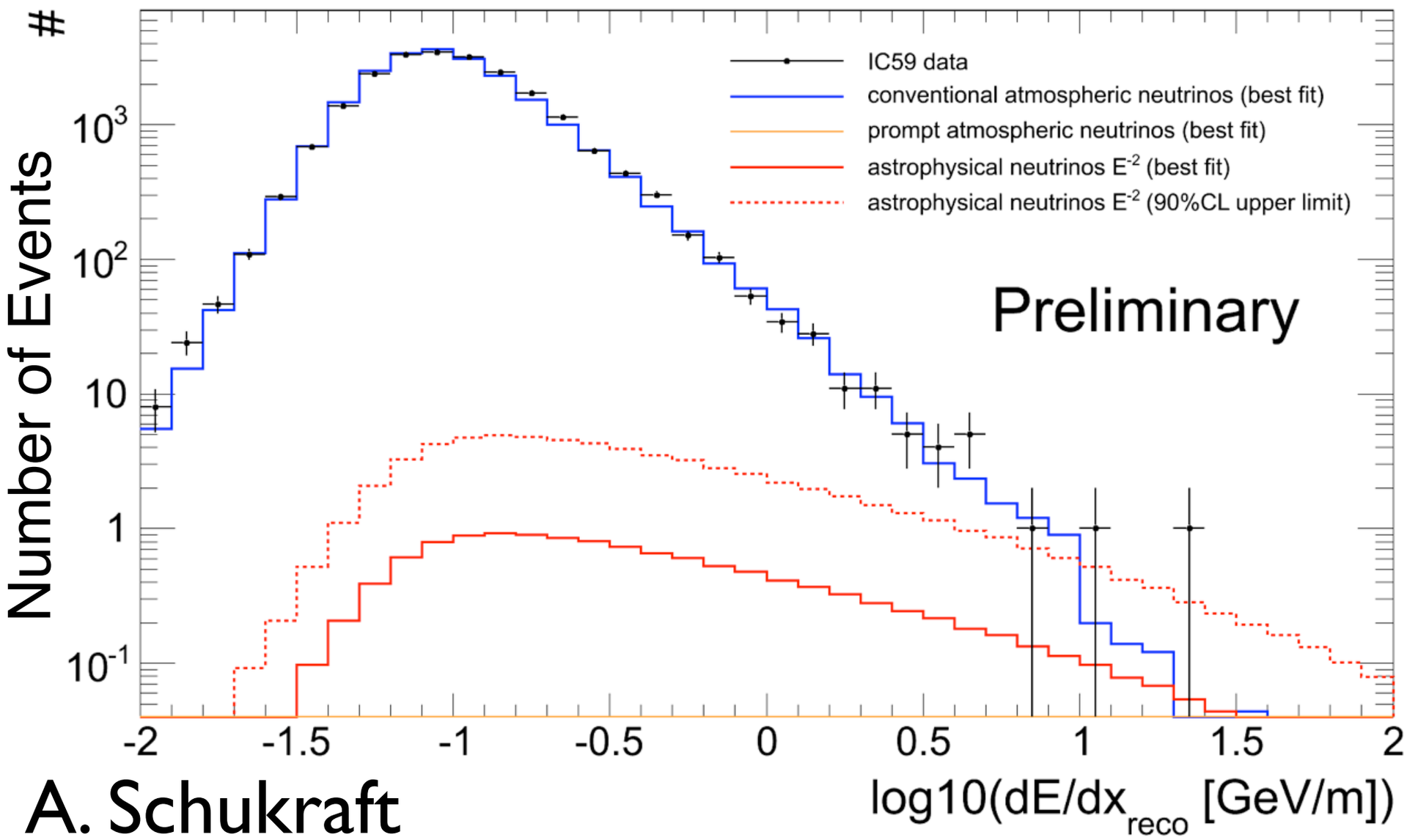
Muon Energy Measurement





- Energy is reconstructed by matching the expected light yield for a muon to the observed amount of light
- Only energy deposited in (or near) the detector can be measured
- Muons may travel long distances, losing energy in the process, so only a high energy muon at the detector is proof of a high energy neutrino

Current Results

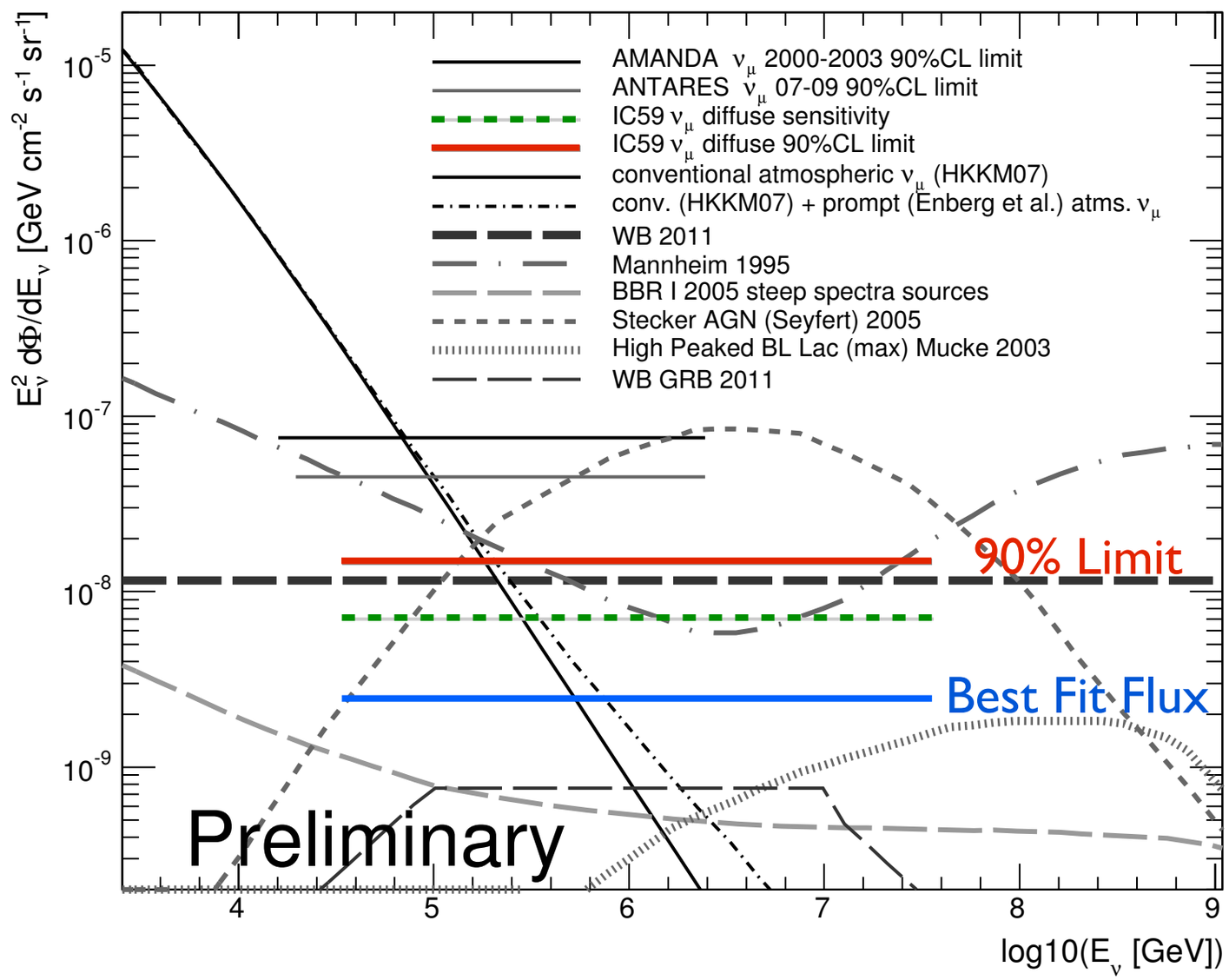


A. Schukraft

- Data from **3/4 complete** IceCube detector, with 348 days of livetime
- Best fit E-2 flux is nonzero (2.4×10^{-9} GeV cm^{-1} s^{-1} sr^{-1}), but is **not significant** (incompatible with background at only 1.8 σ)

Current Results

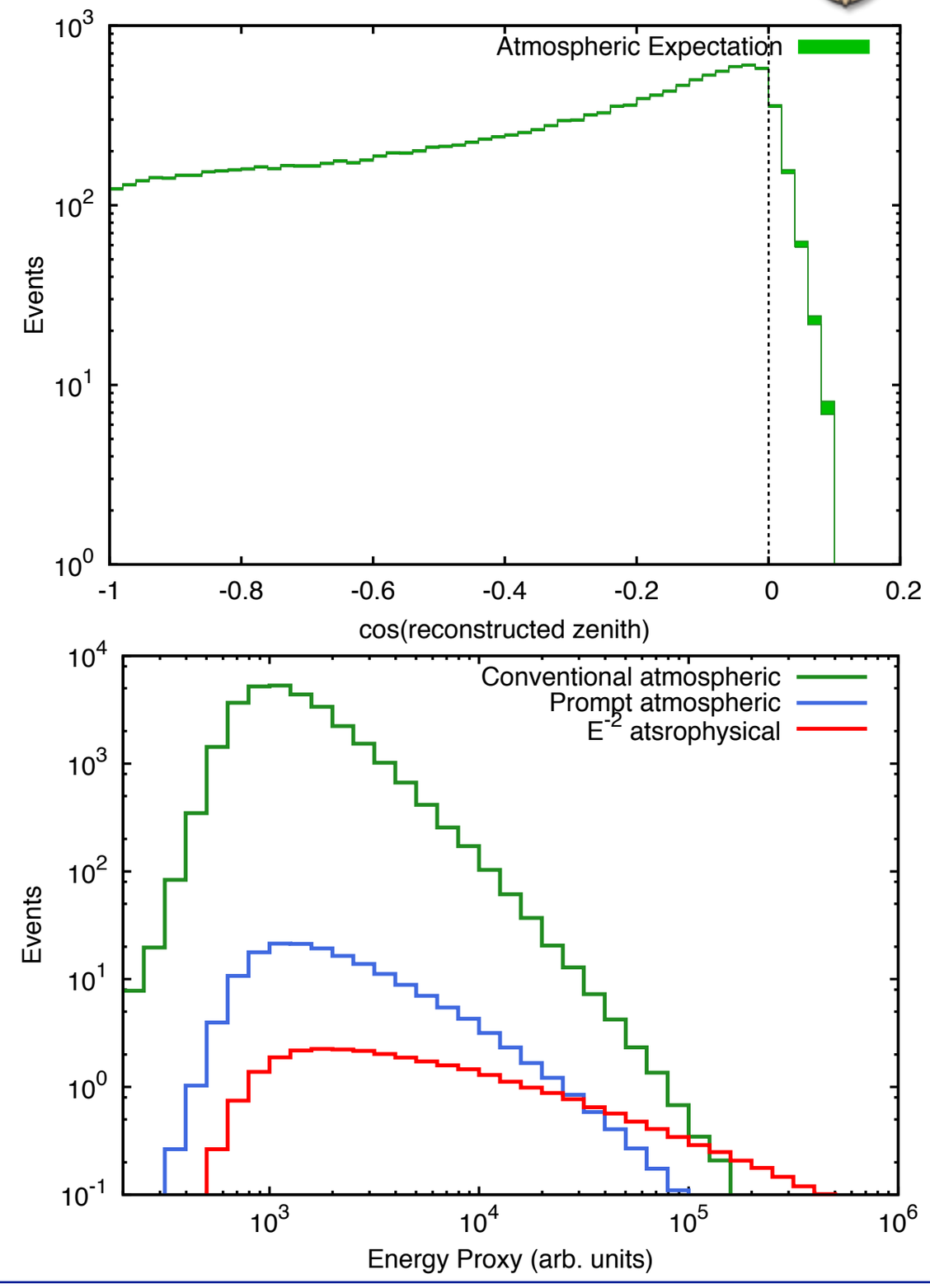
- Estimated Sensitivity: 7.6×10^{-9}
  - (This is the 'expected' limit if no signal exists)
- Limit (90%) from data: 1.4×10^{-8}
- Best-fit flux: 2.5×10^{-9}
- Significance over background-only hypothesis: 1.8σ



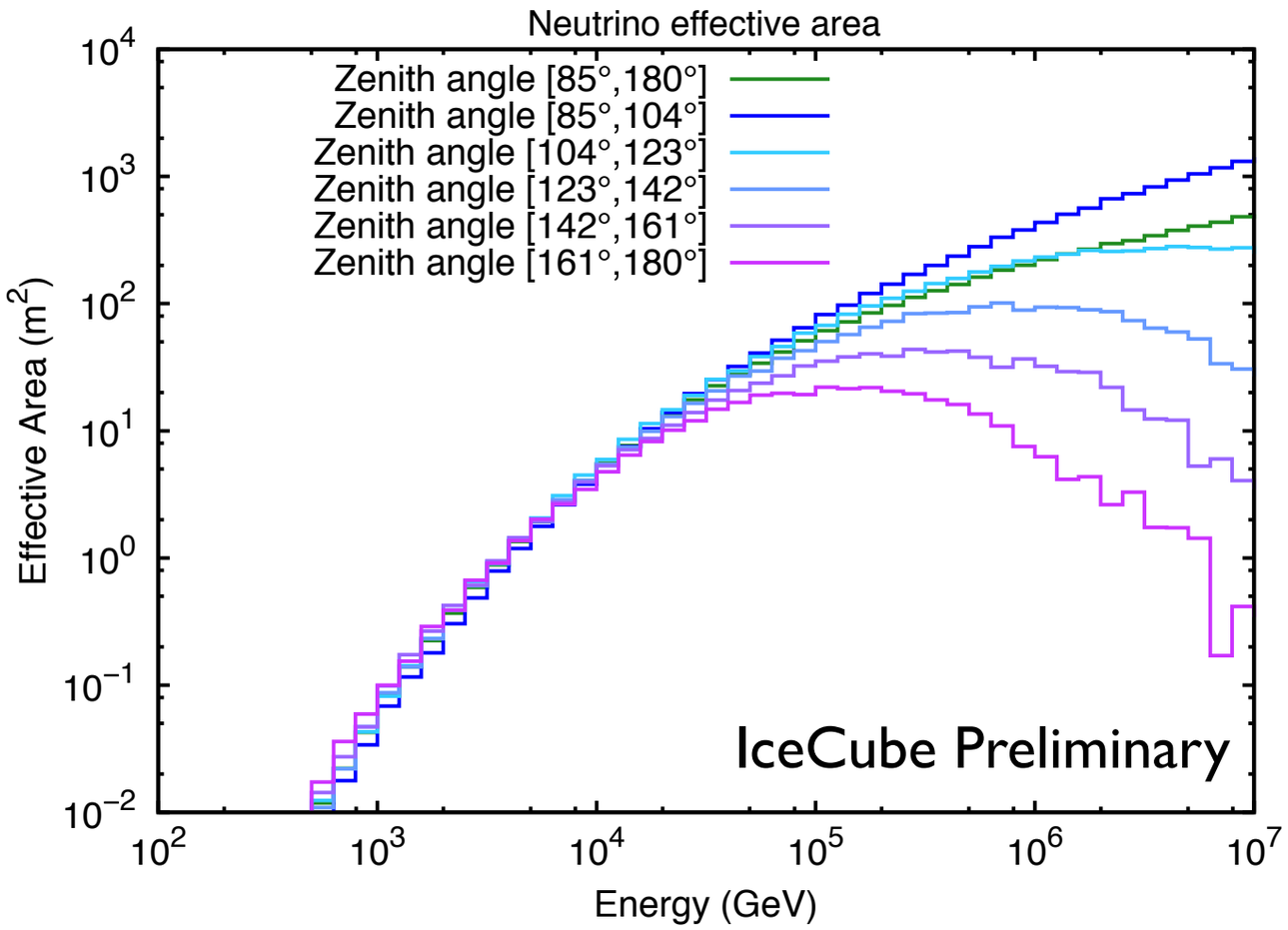
A. Schukraft, http://arxiv.org/abs/1302.0127

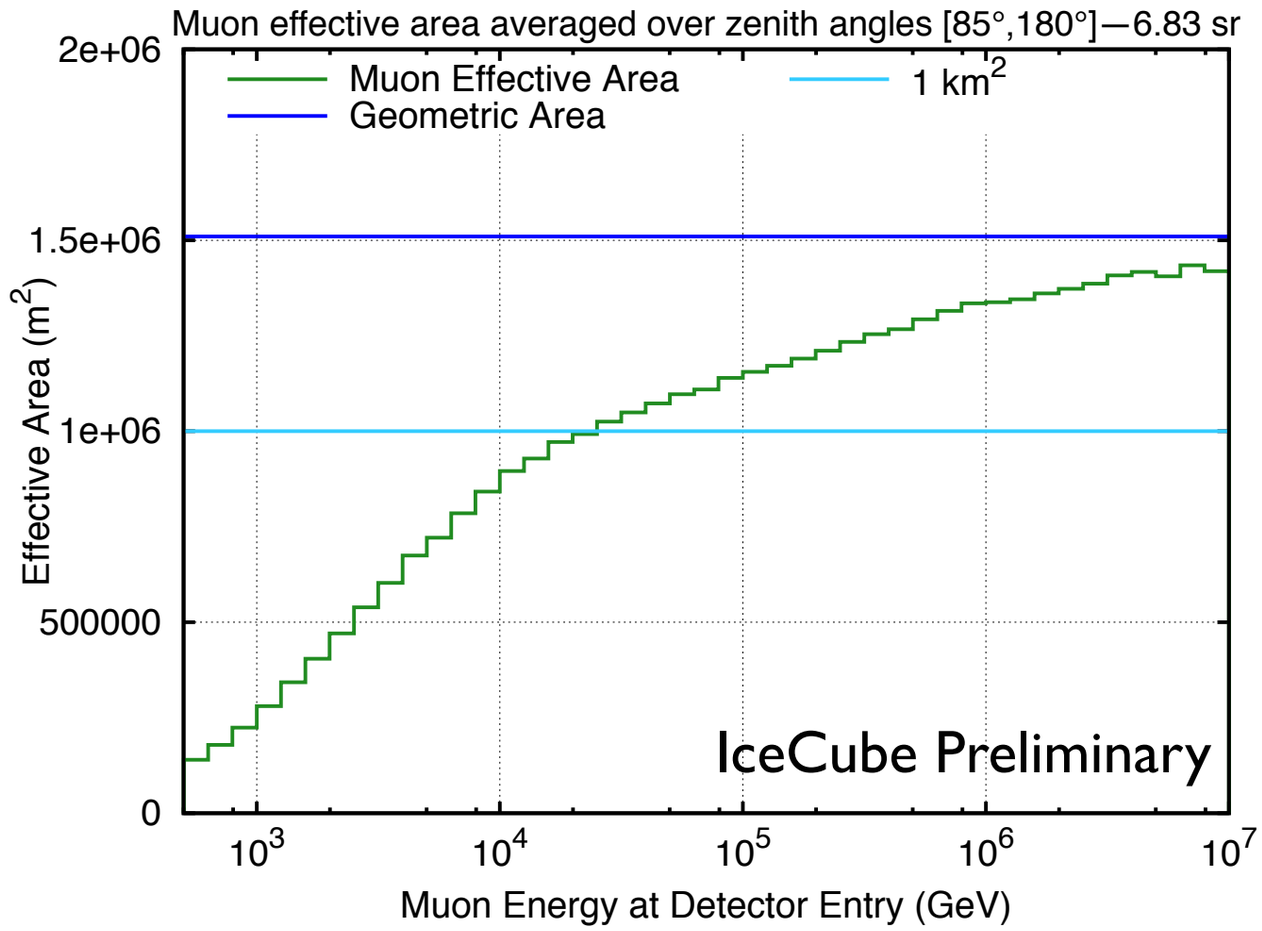
Analysis Method

- Event selection
  - Choose up-going muons, so that the Earth works as a shield against non-neutrinos
  - Require high quality geometric reconstruction—prerequisite for good energy reconstruction
  - Also keep some down-going muons near the horizon—exploit ice overburden
- Forward-Folding Maximum-Likelihood Fit
  - Allow the multiple hypothesis components to float to explain the data
  - Also include some systematics as nuisance parameters in the fit
  - (other systematics estimated by repeating the fit)



Effective Area

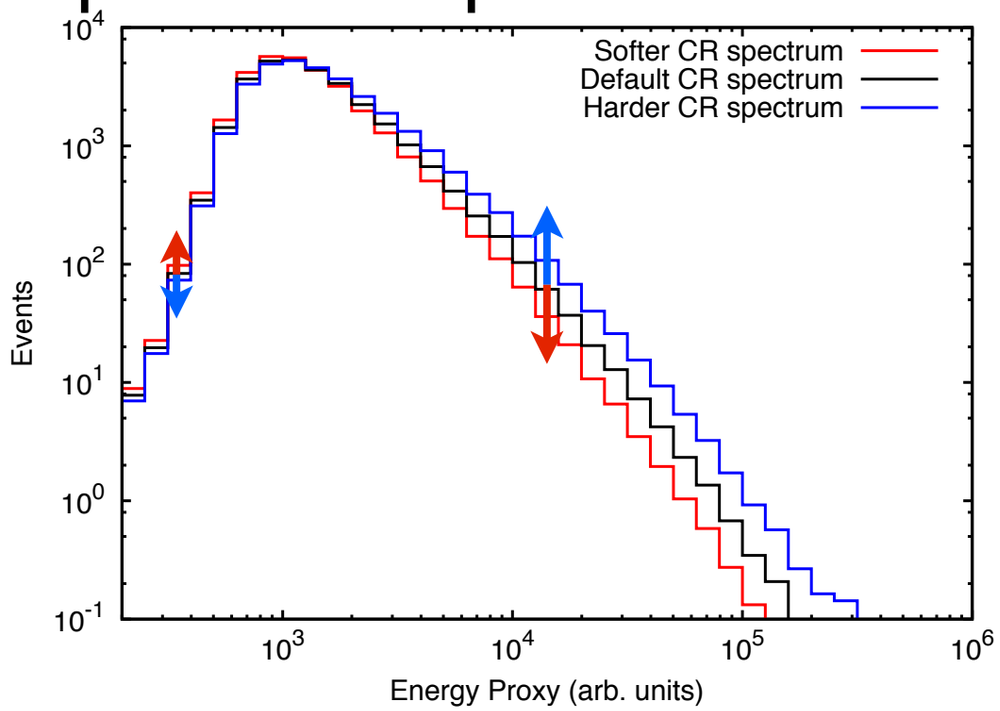


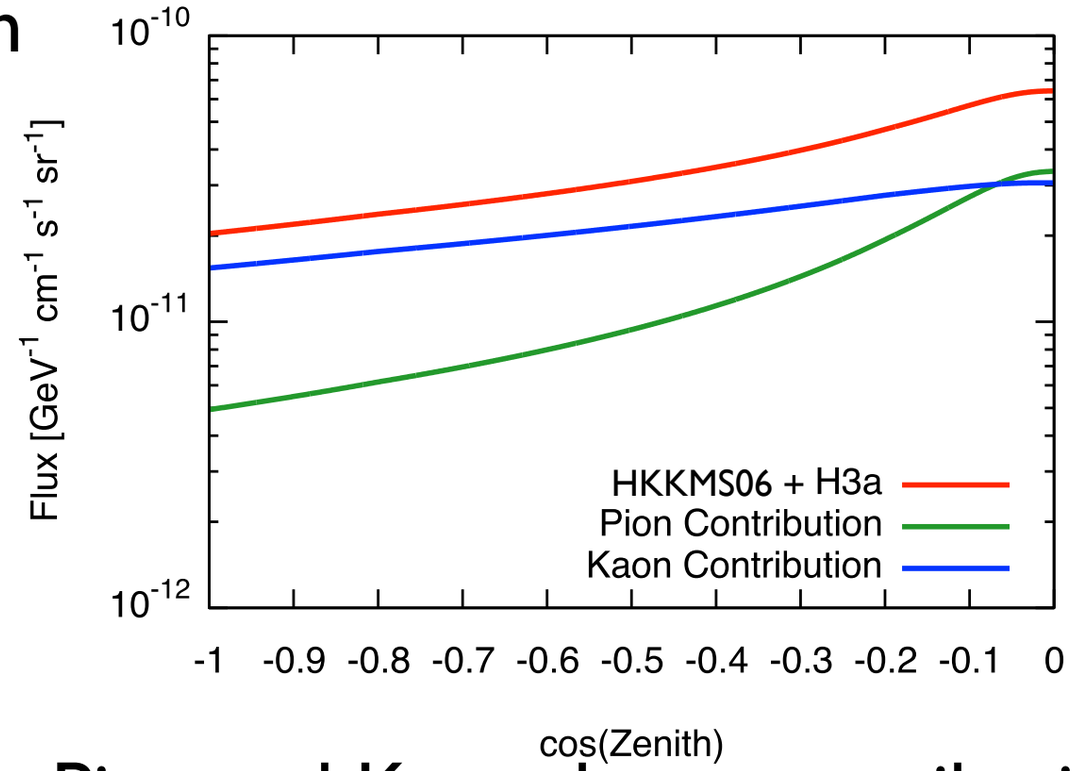


- Earth absorption has begins to have noticeable effects at ~100 TeV
- This makes the horizon region particularly valuable
- Muon range makes the neutrino effective area a misleading figure of merit —muon effective area describes detection and cut efficiency
- This selection is efficient for relevant muons

Systematic Effects

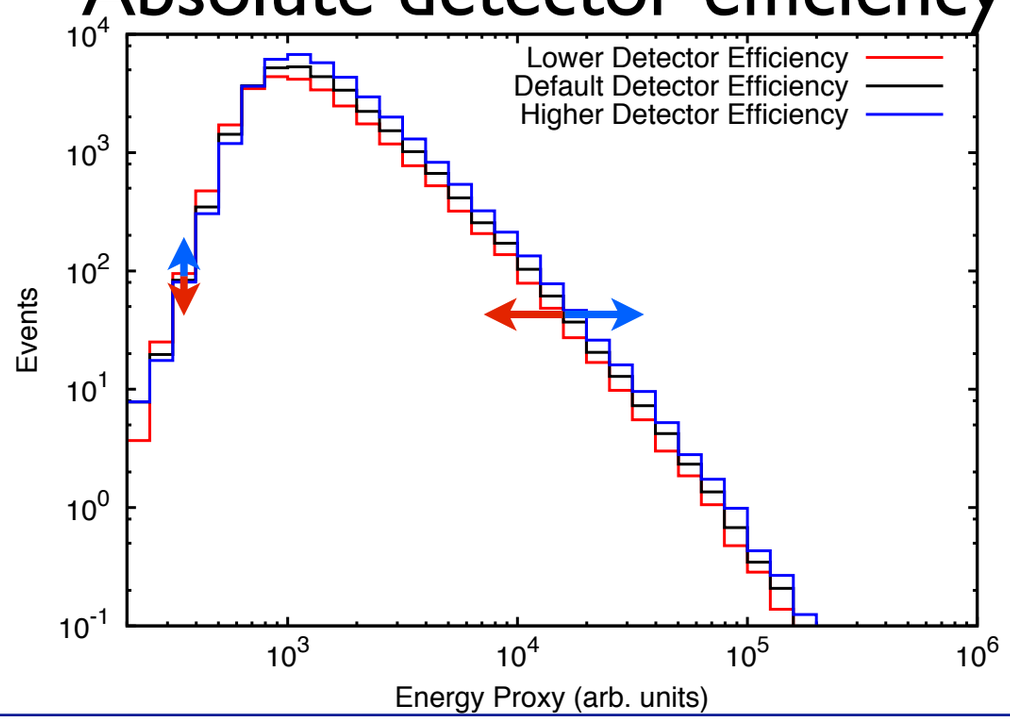
Slope of atmospheric neutrino spectrum





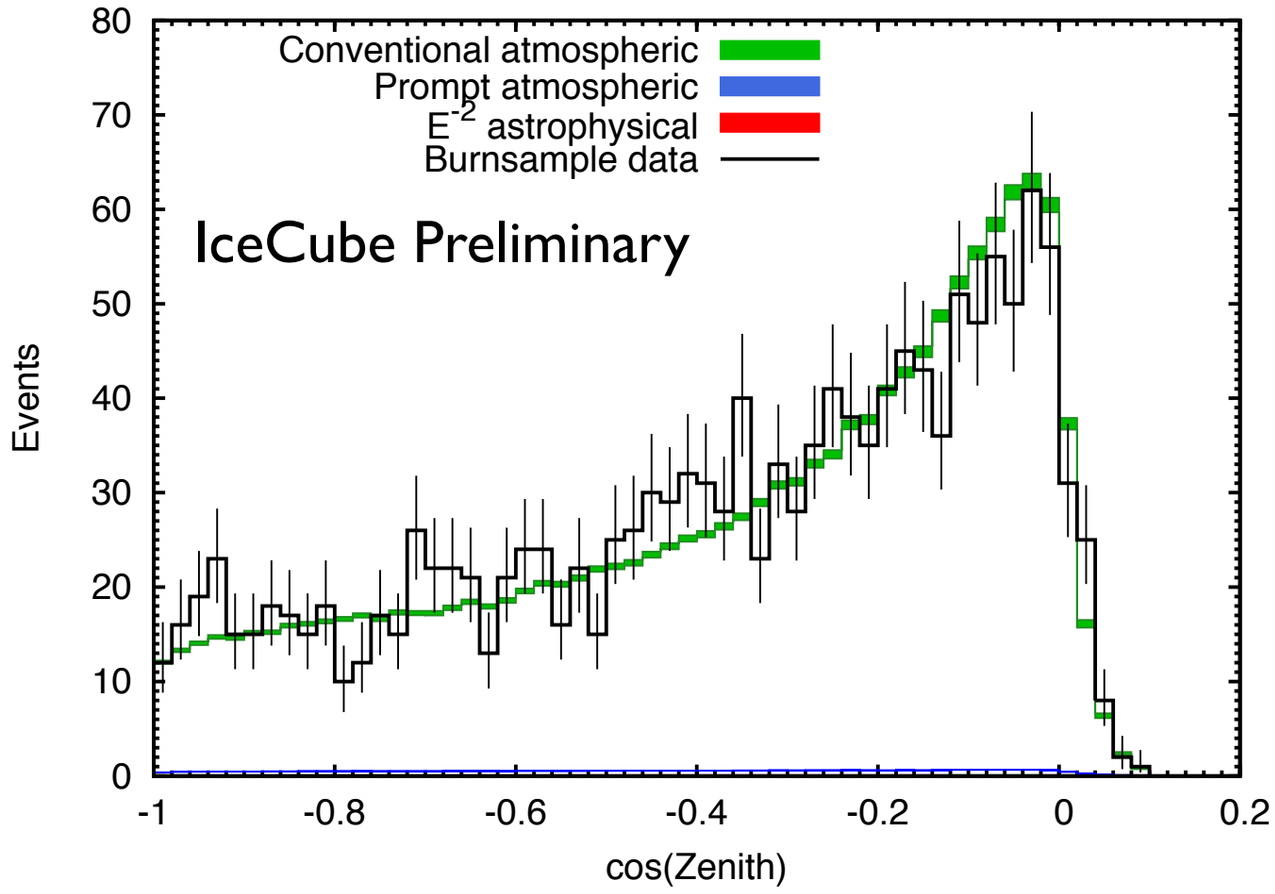
Pion and Kaon decay contributions

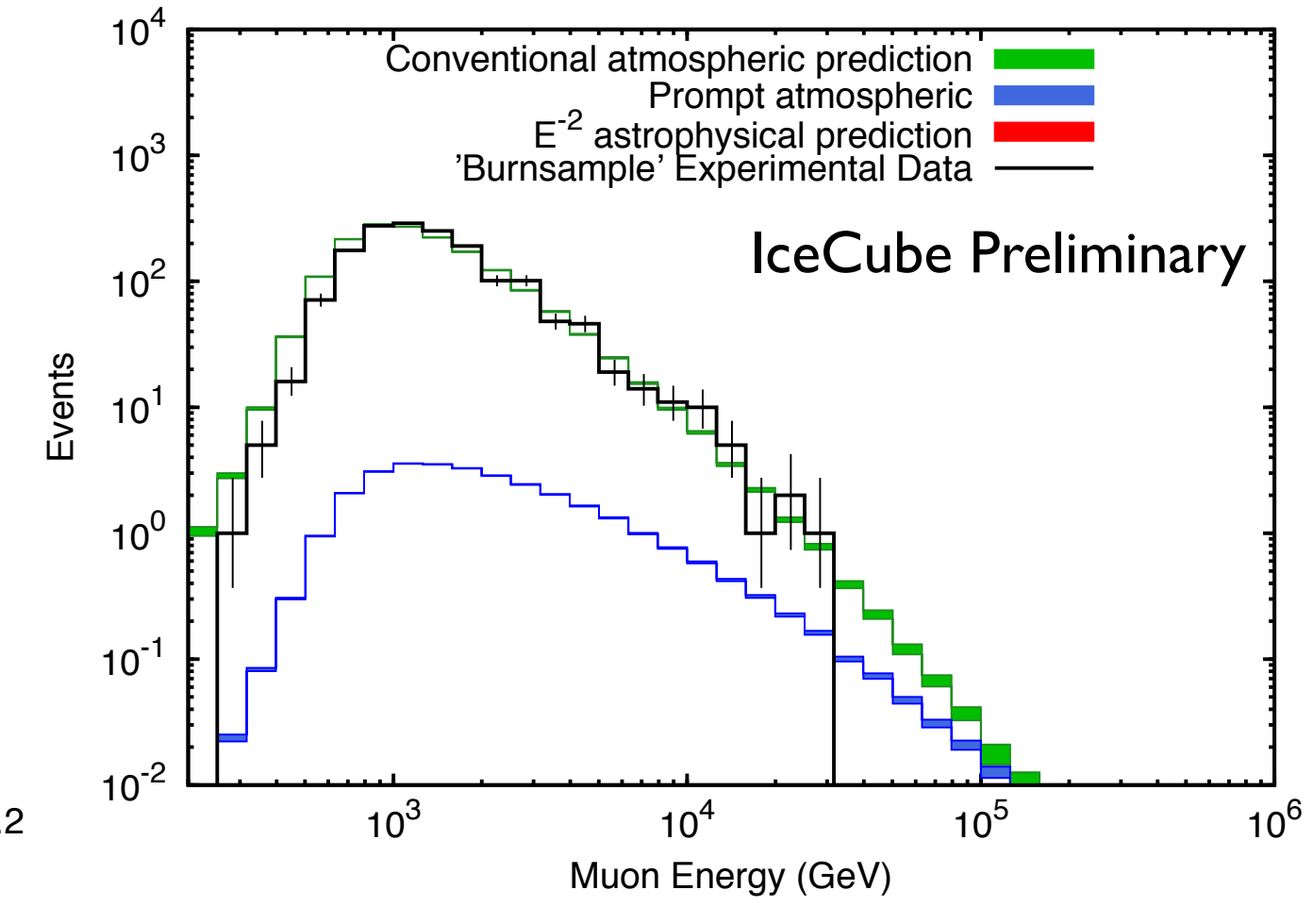
Absolute detector efficiency



- Not illustrated:
  - Ice Optics
  - ν_τ 'contamination'
  - the cosmic ray knee
  - neutrino cross sections

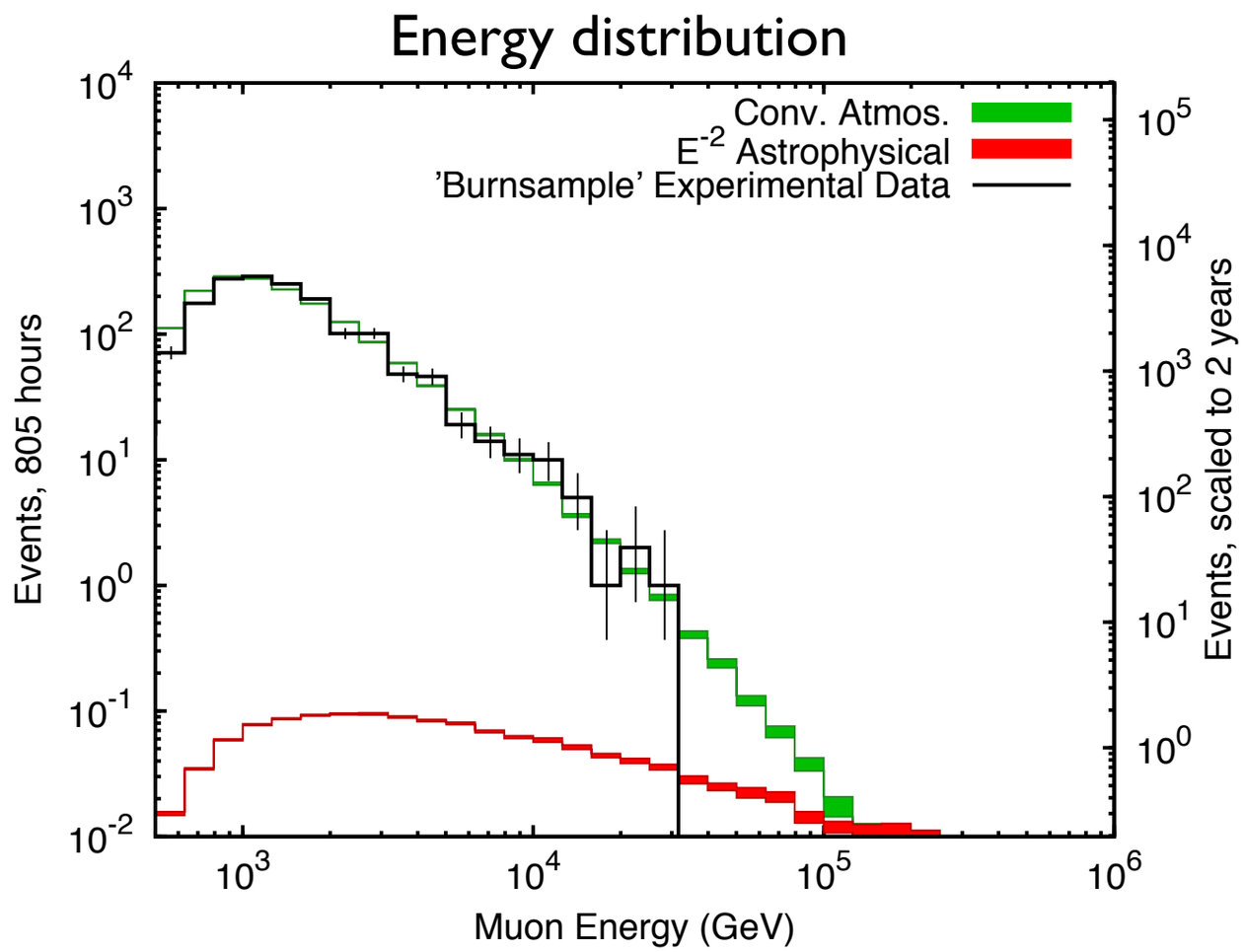
Test Results

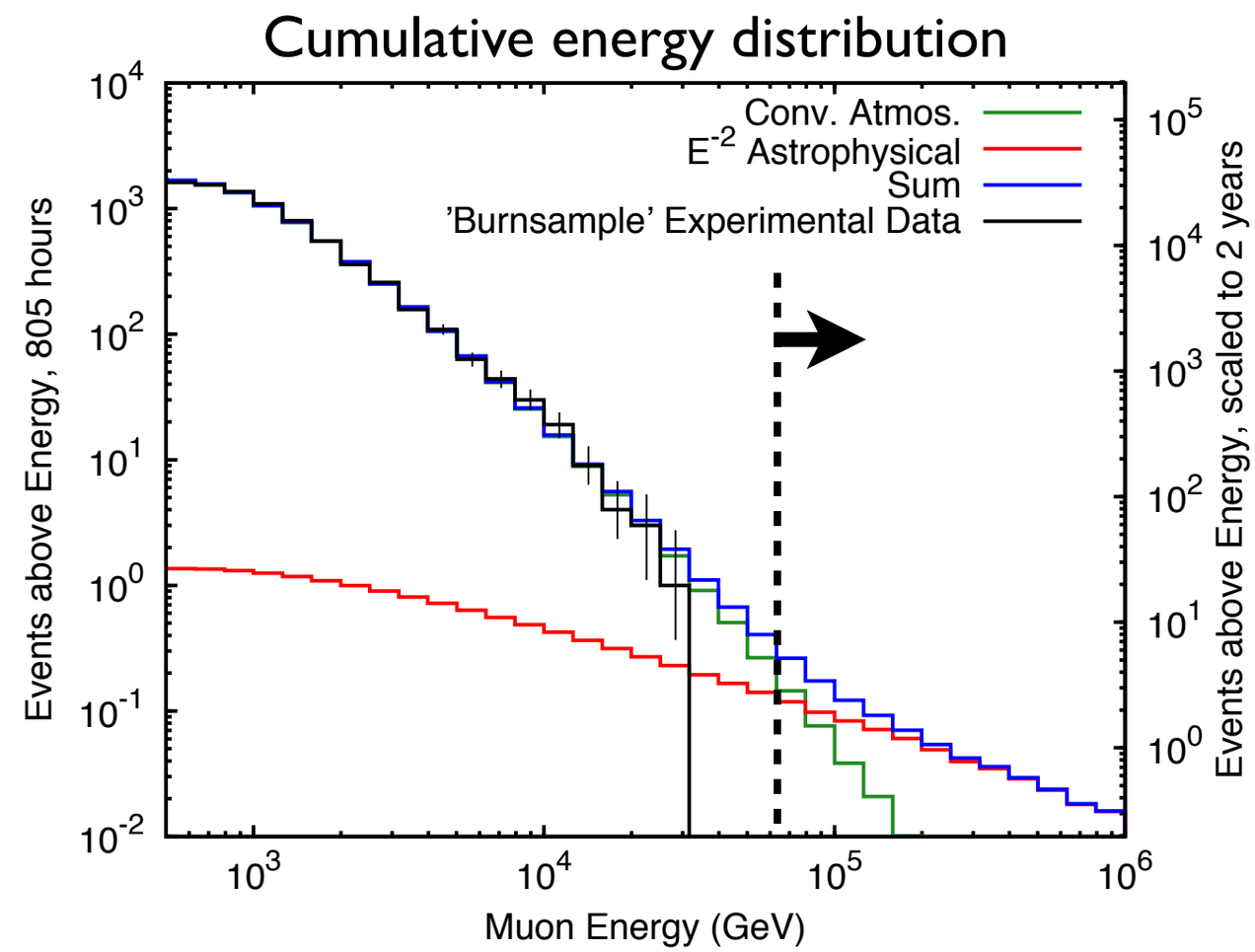




- Data from 805.5 hours of the ~complete detector
- Reasonable agreement with background expectations
- No evidence of an astrophysical signal
- Best-fit prompt contribution is non-zero, but ill-constrained

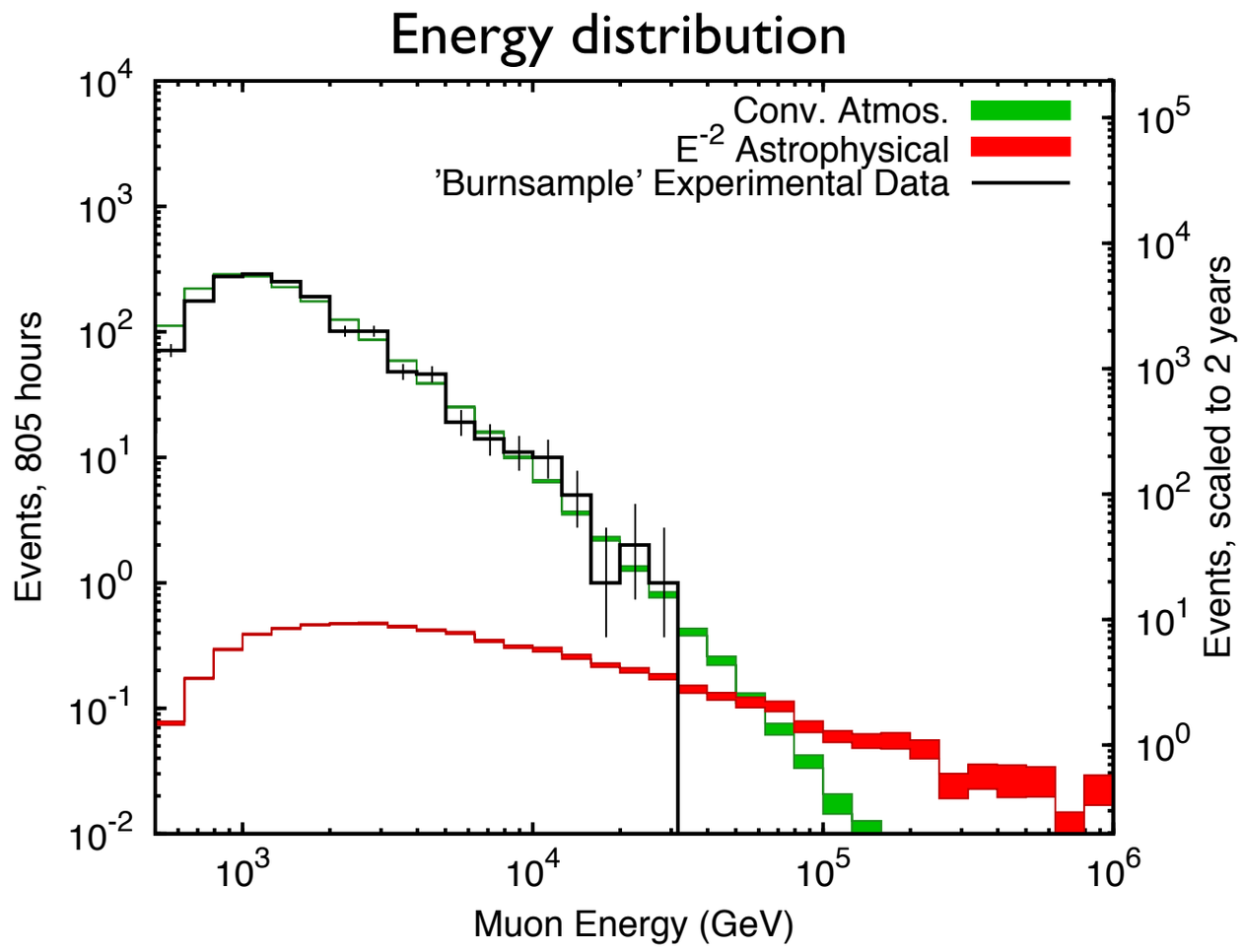
Performance Estimates

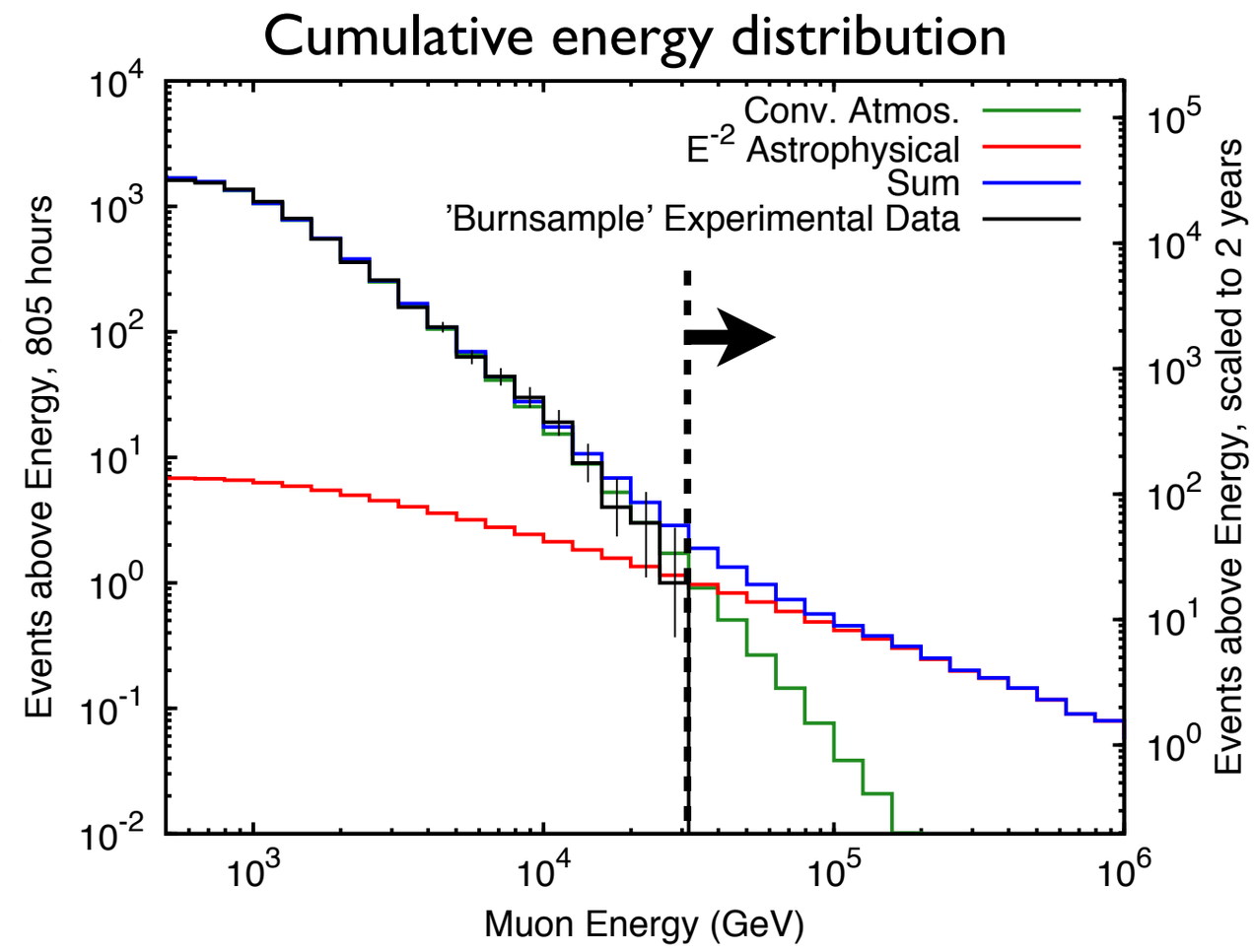




- What if there is a flux matching the existing ν_μ result?
- Simple 'cut-and-count' would see ~5.2 events on a background of ~2.8

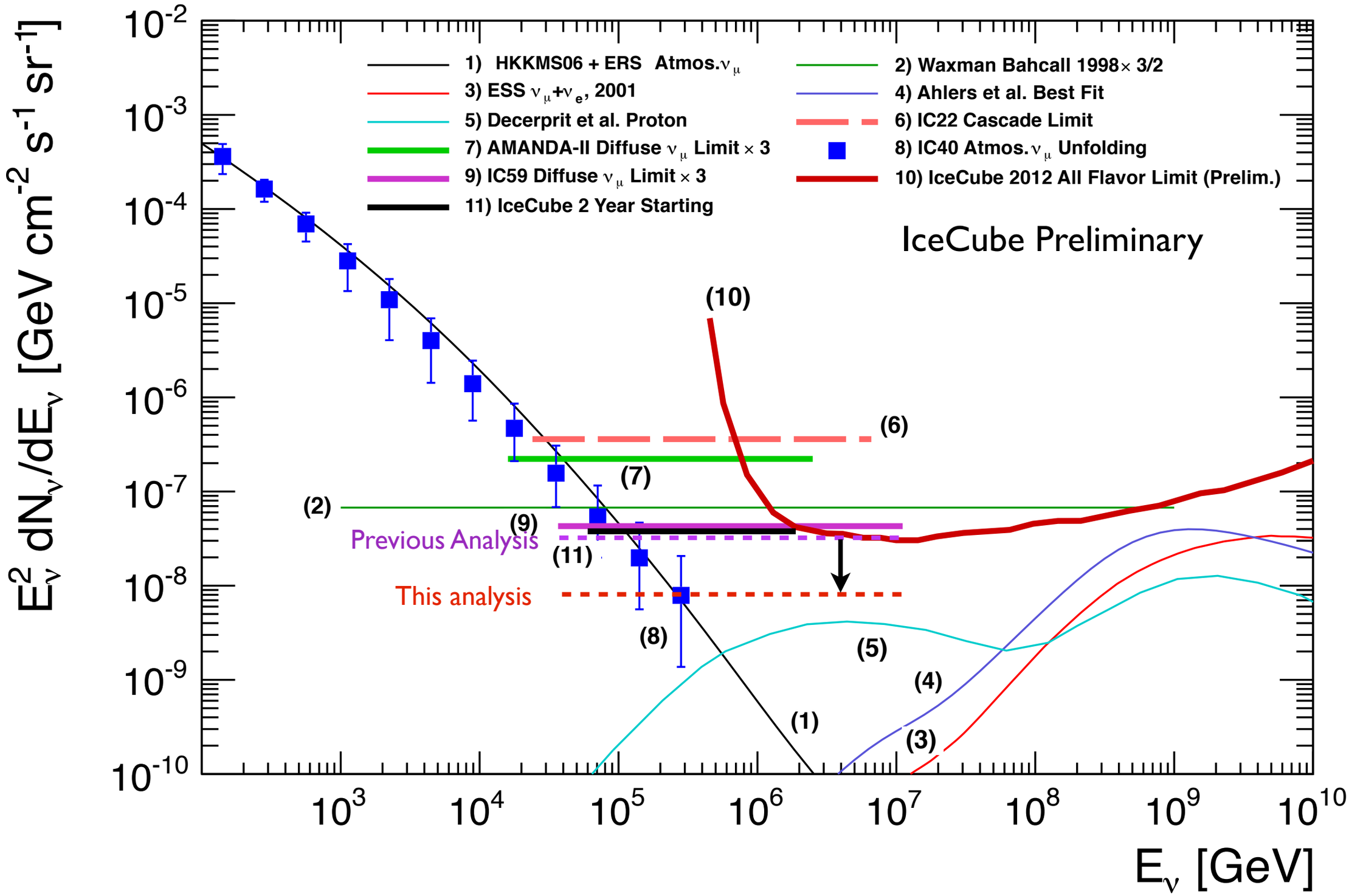
Performance Estimates





- There are other, more optimistic estimates: IceCube high energy starting events suggest ~1.2×10^{-8} flux
  - see talk by C. Kopper in High Energy Astrophysics II
- 'cut-and-count': ~37 on ~17.9
- Shape analysis improves significance ~3.9σ to ~4.5σ

Sensitivity

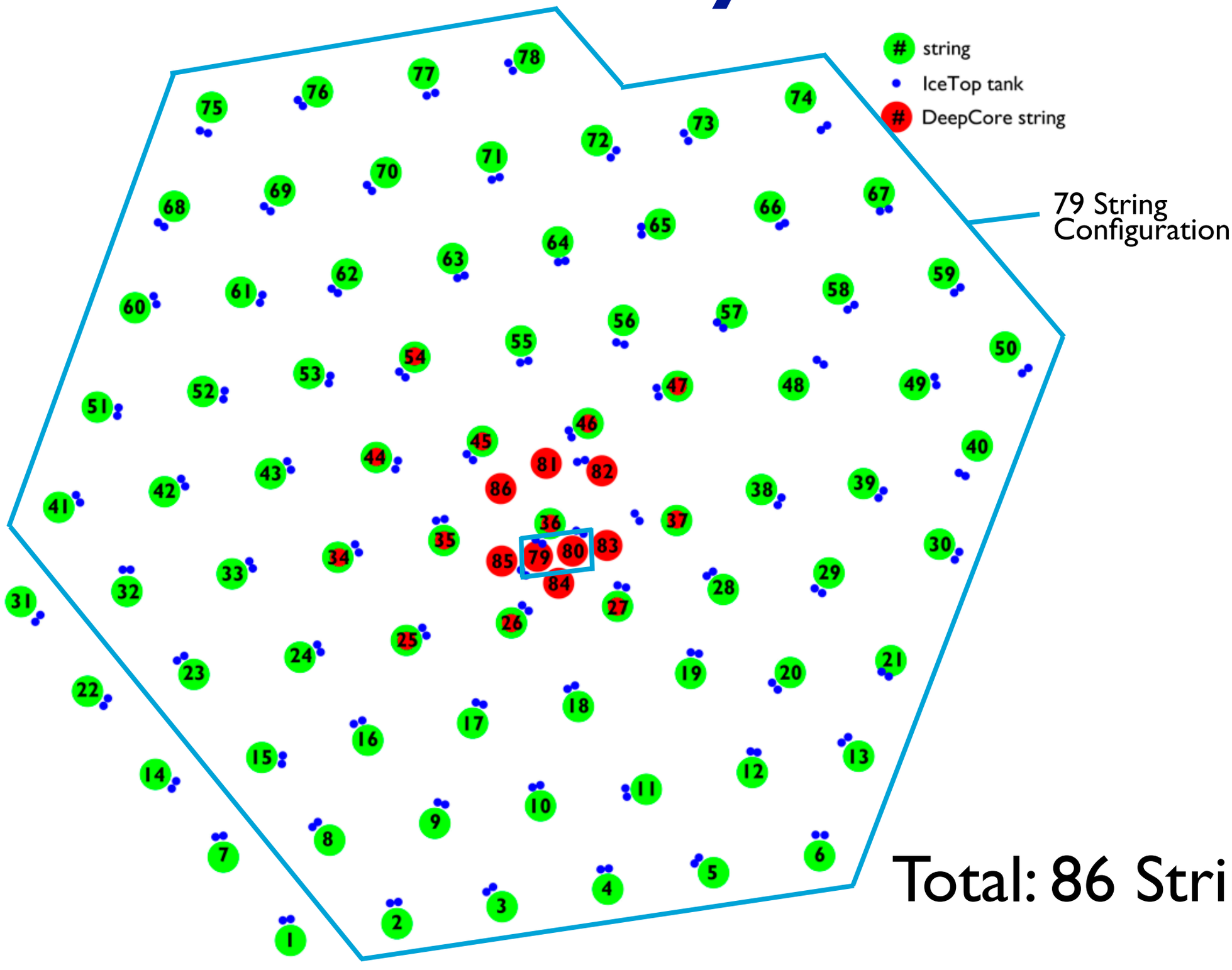


Status and Conclusions

- Analysis is under way—we are in the process of unblinding this data
- This is a very exciting time for diffuse neutrinos
  - Cascades (and other contained events) are starting to show a signal
  - There may be a hint of a signal in through-going muons
  - Will sources soon become apparent?

Backup

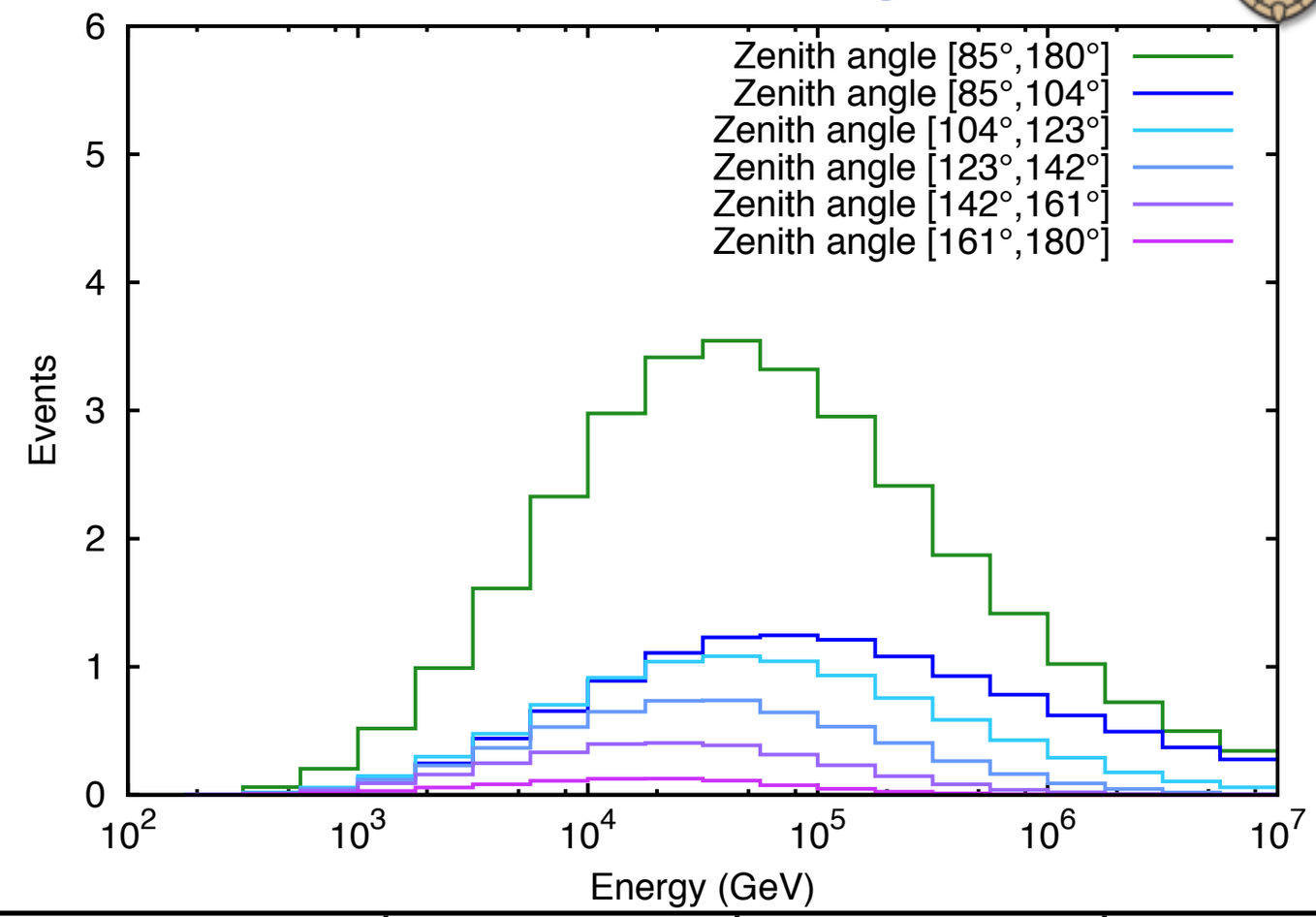
Detector Layout



Total: 86 Strings

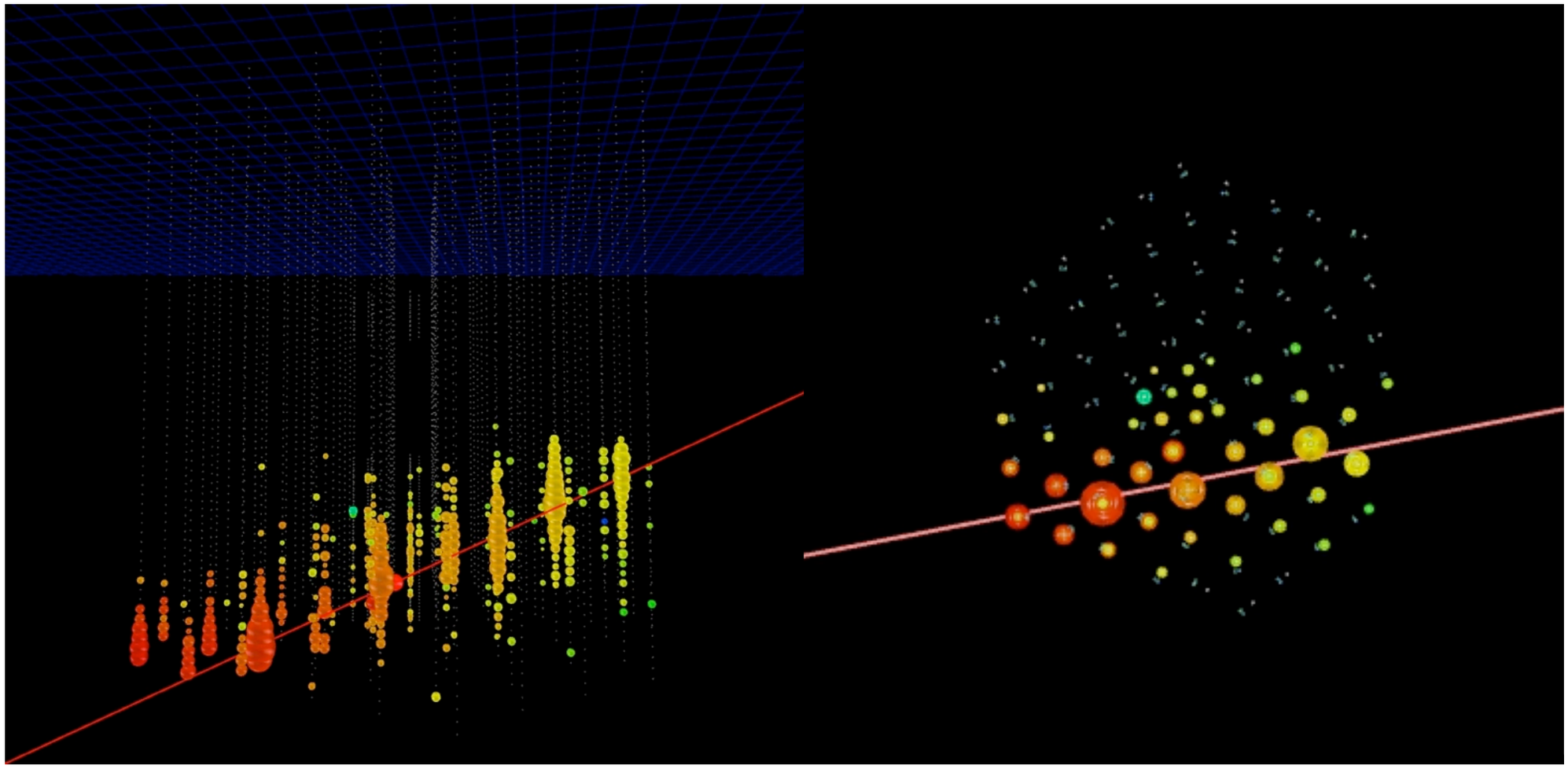
Impact of the 85°-90° Region

- Adding the slightly down-going region adds a small amount to the neutrino background and substantially to the signal
- Additional E^{-2} signal is biased toward high energies: median 300 TeV, rather than 50 TeV
- ~20% improvement in sensitivity



Flux	Up-going Expectation	Full Expectation	Increase
Conventional	29242	30364	3.8%
Prompt	168.1	173.7	3.3%
E^{-2}	28.6	31.1	8.7%
E^{-2} > 100 TeV	10.4	12.1	14.2%

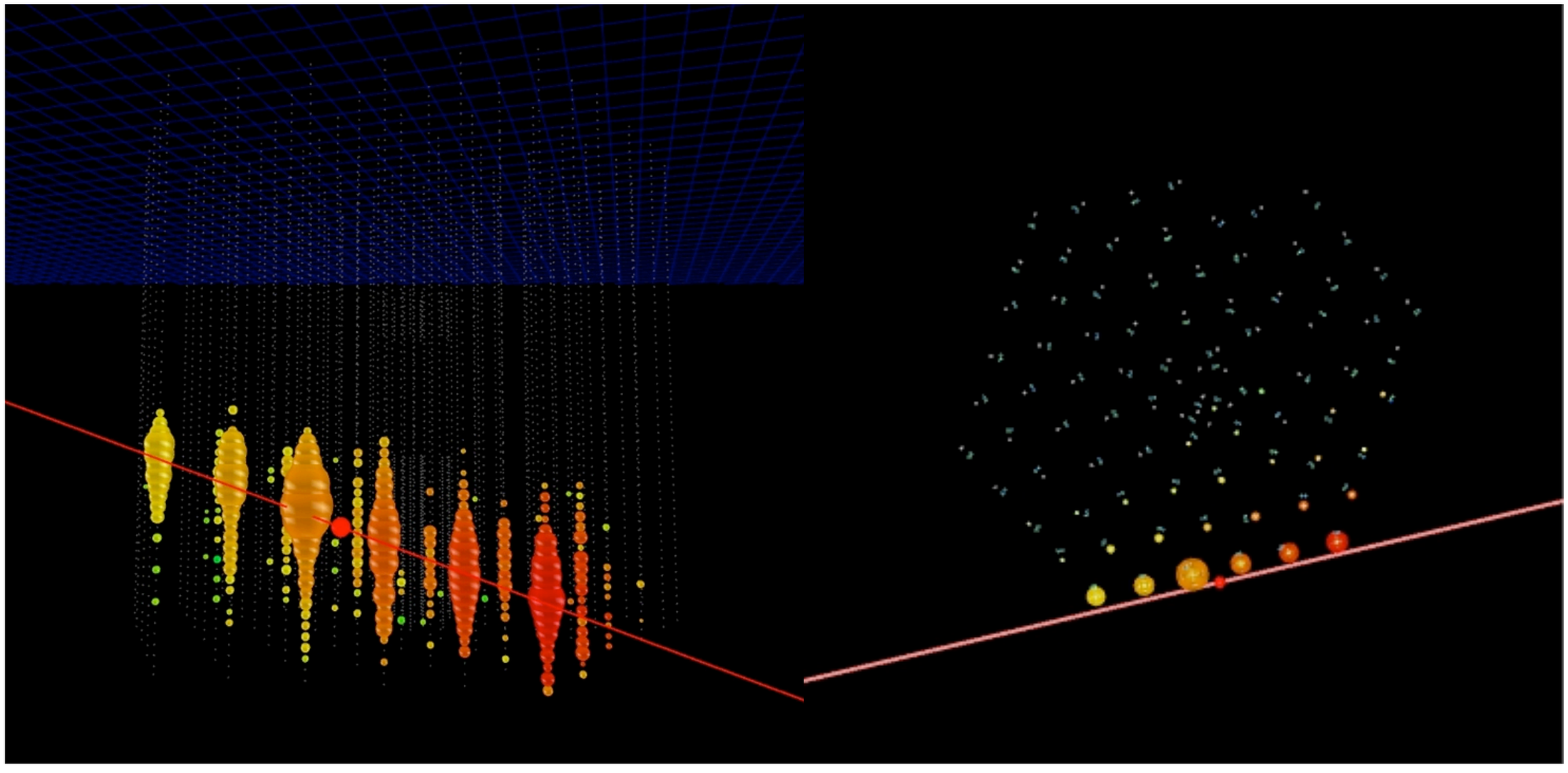
Highest Energy IC79 Burnsample Event



Side View Top View

- Reconstructed Zenith Angle 114°
- Estimated Muon Energy 28.9 TeV

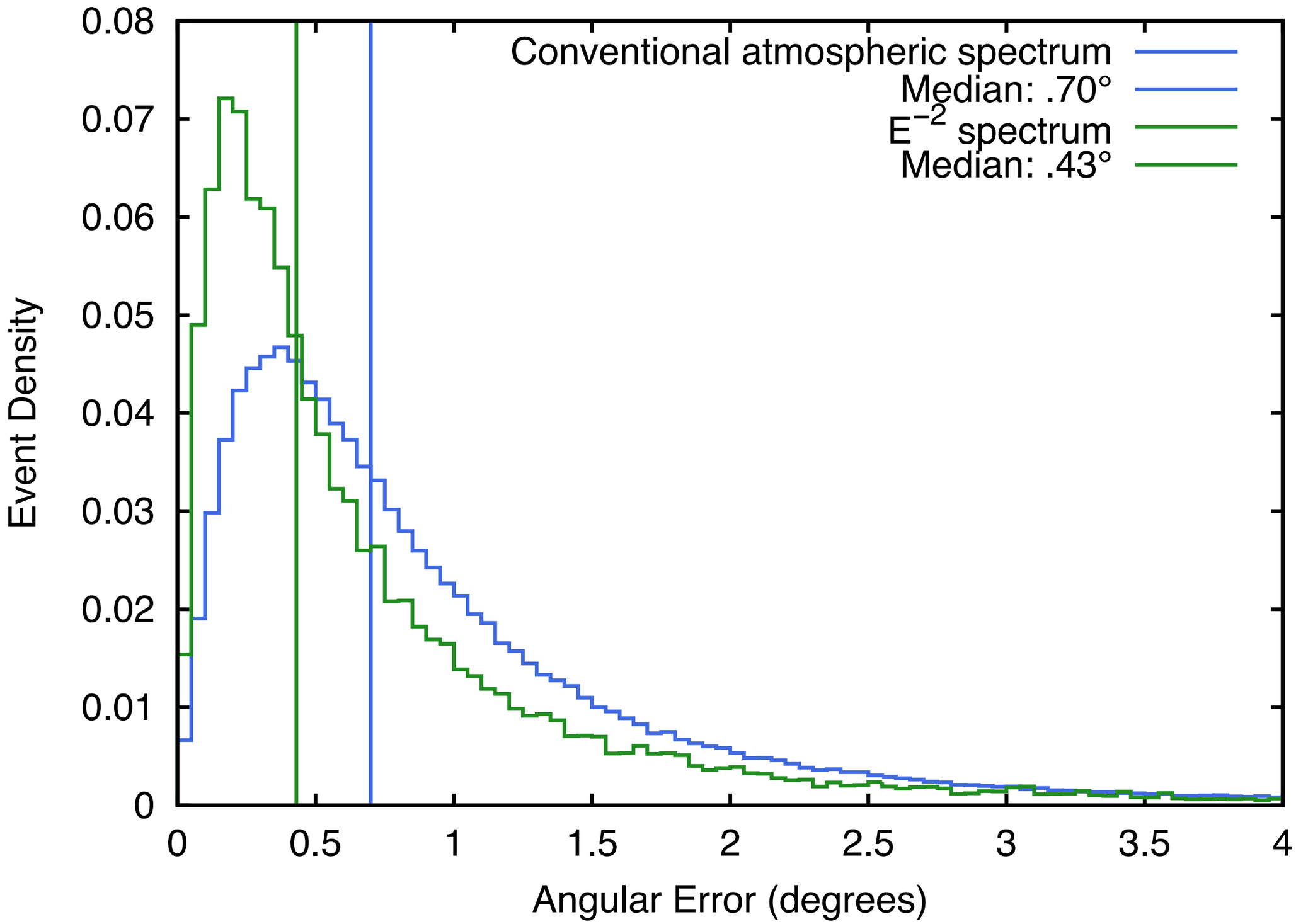
Highest Energy IC86 Burnsample Event



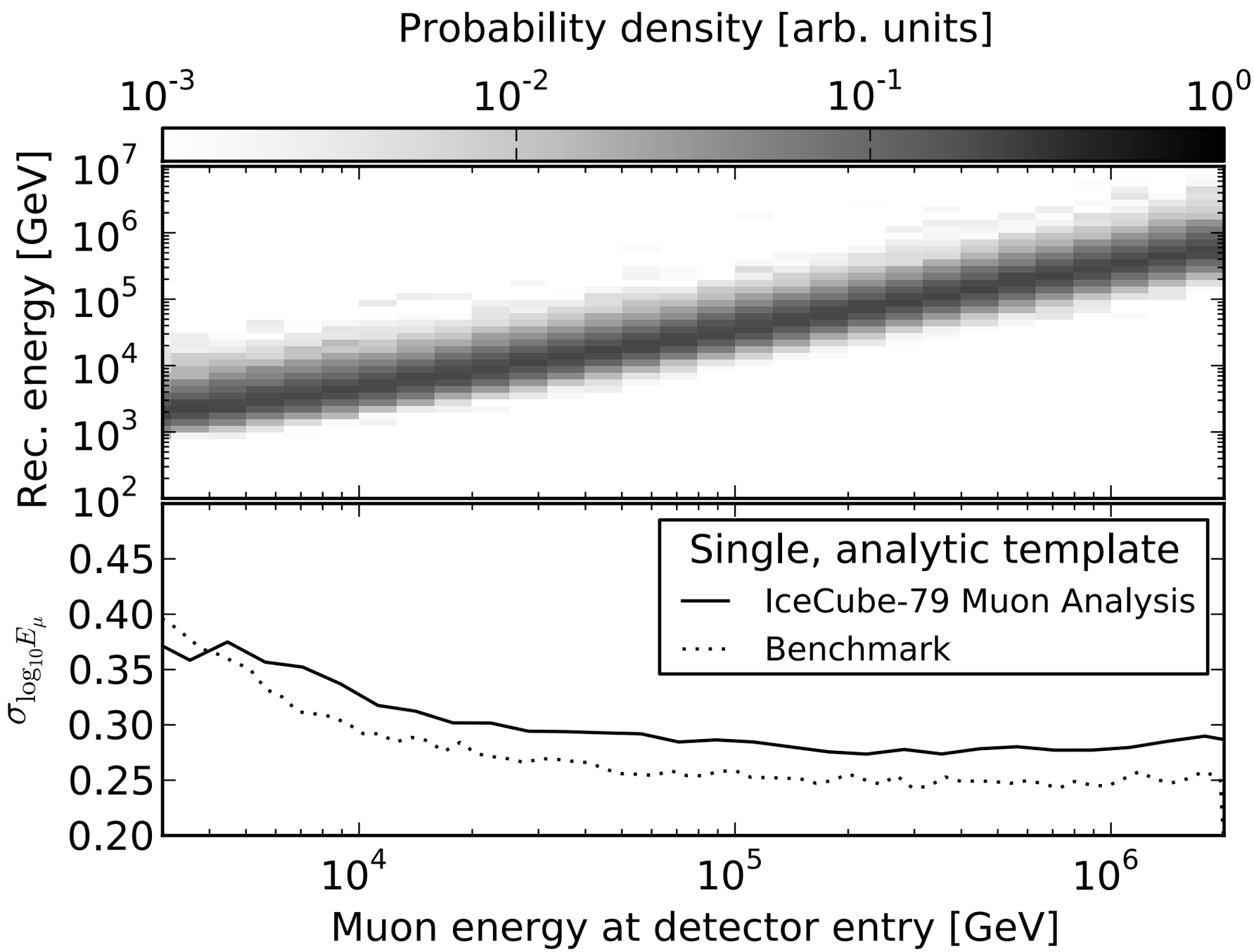
Side View Top View

- Reconstructed Zenith Angle 109°
- Estimated Muon Energy 107.4 TeV

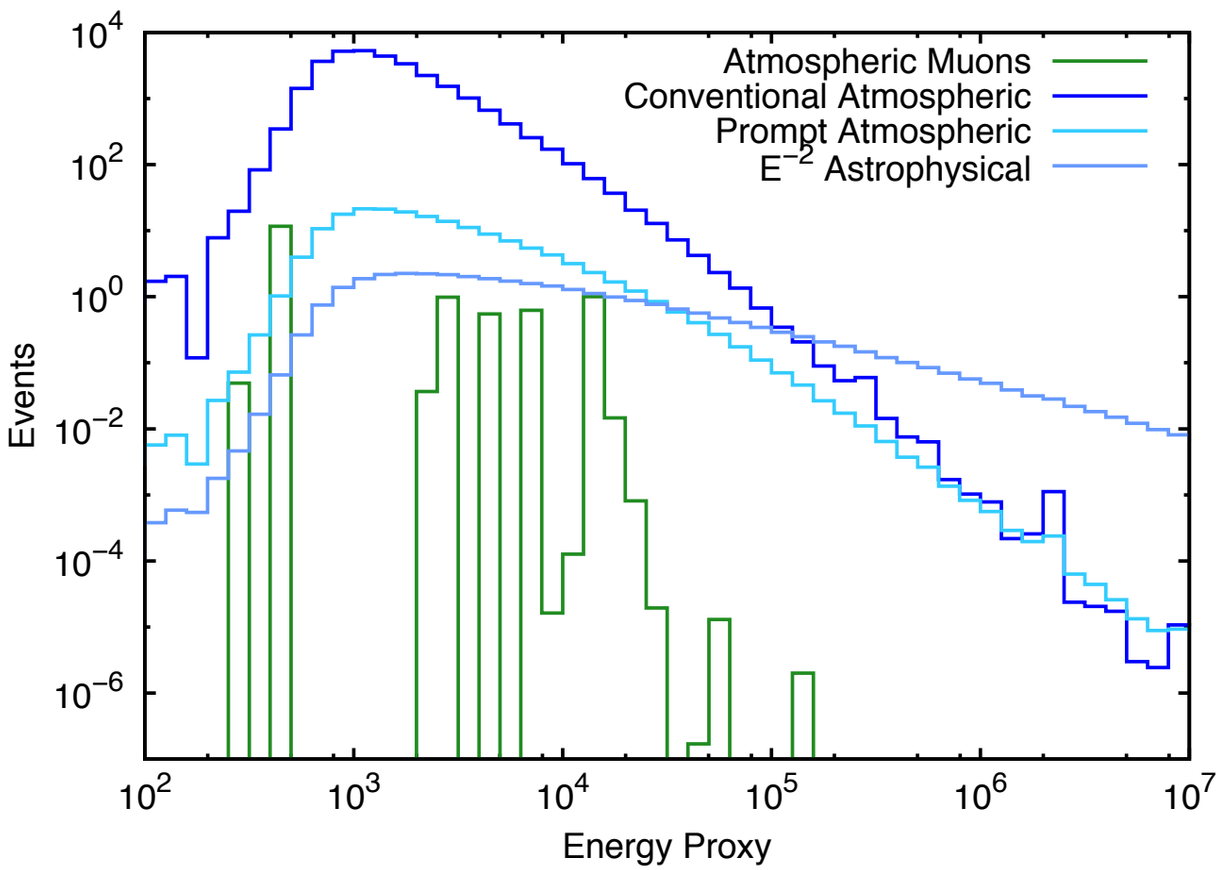
Angular Resolution

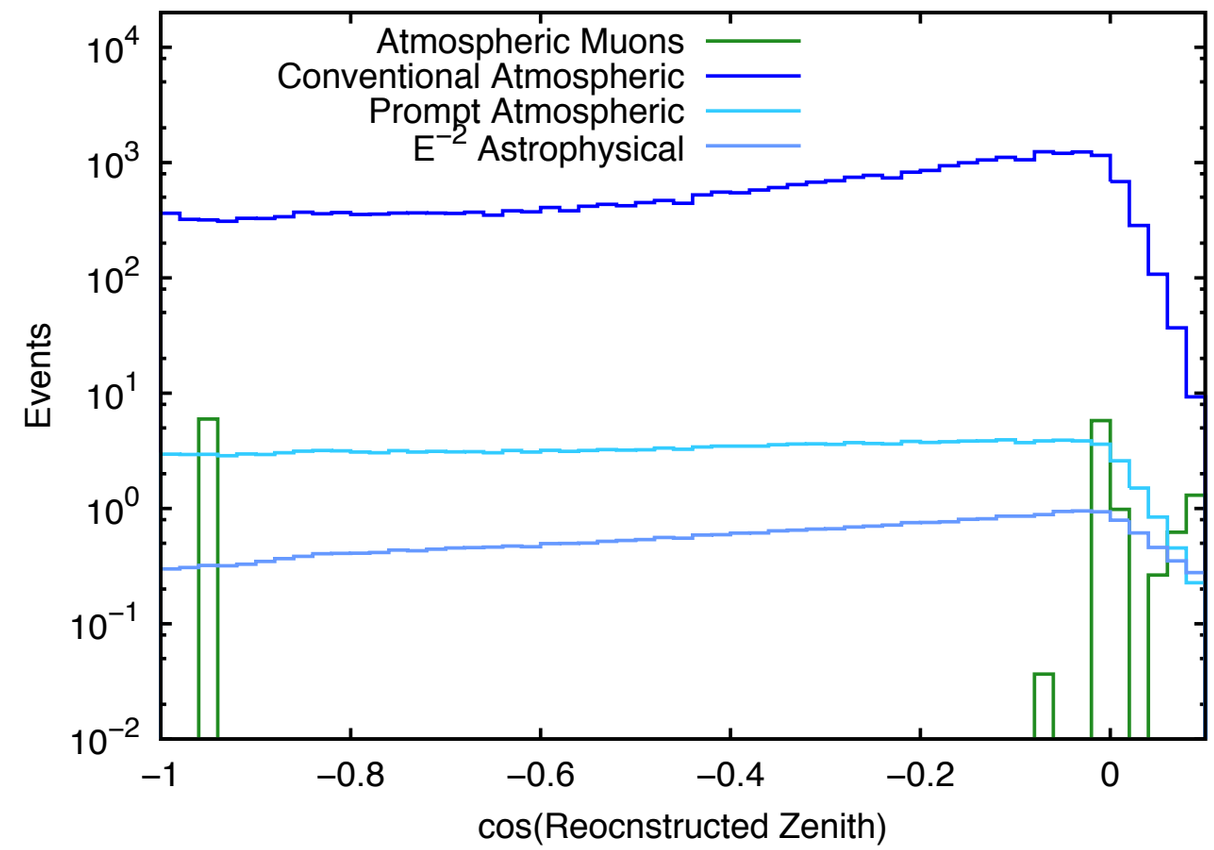


Energy Resolution



Background Contamination





Systematics

Effect	Handling
CR normalization	Included in likelihood
CR slope	Included in likelihood
CR knee	Repeat fit with different knee models
Pion/Kaon behavior	Included in likelihood
Tau neutrinos	Included in likelihood*
Neutrino cross sections	Repeat fit after reweighting neutrino simulation to match simulation with newer cross sections
Muon cross sections	No treatment
Spice-Mie Uncertainty	~Included in likelihood
Hole Ice	Repeat fit on data simulated without hole ice
Ice Anisotropy	Repeat fit on data simulated with Spice-Lea
DOM efficiency	Included in likelihood
Data/MC disagreement in cut variables	No treatment