Tue Jan 3 03:34:01 2012

Results from IceCube Contained Event Search

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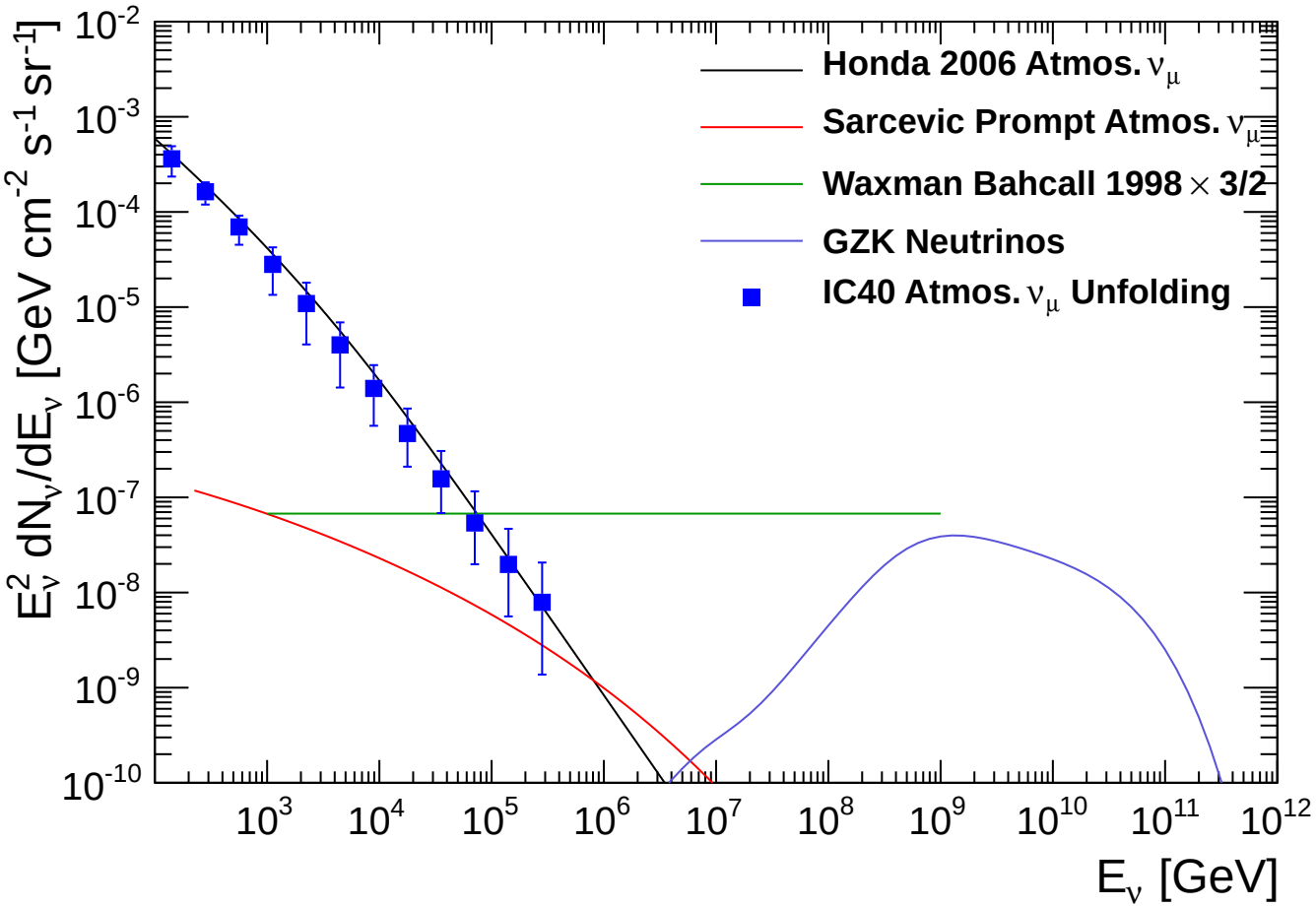
The Neutrino Landscape above 1 TeV



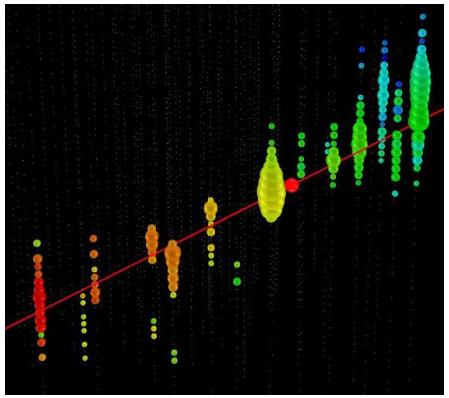
- π/K Atmospheric Neutrinos (dominant $<$ 100 TeV)
- Charm Atmospheric Neutrinos ("prompt", visible $\sim$ 100 TeV)
- Astrophysical Neutrinos (maybe dominant $>$ 100 TeV)
- Cosmogenic Neutrinos ($> 10^6$ TeV)

Event Signatures

Muon Neutrino CC (data)

< 1 degree angular resolution

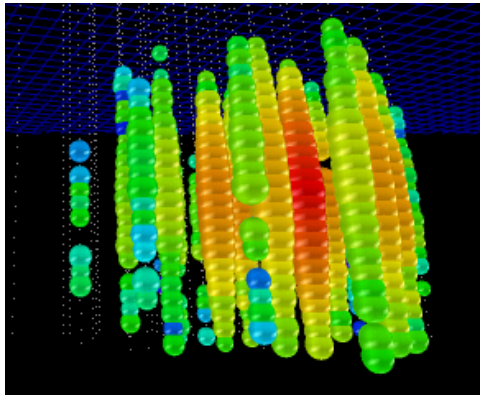
factor of 2 resolution of muon energy



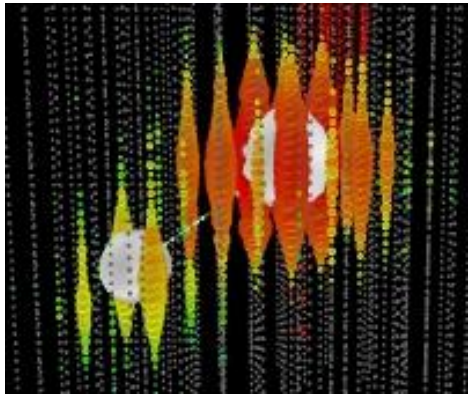
Neutral Current or Electron Neutrino (data)

10 degree angular resolution (high energy)

$\sim 15\%$ deposited energy resolution



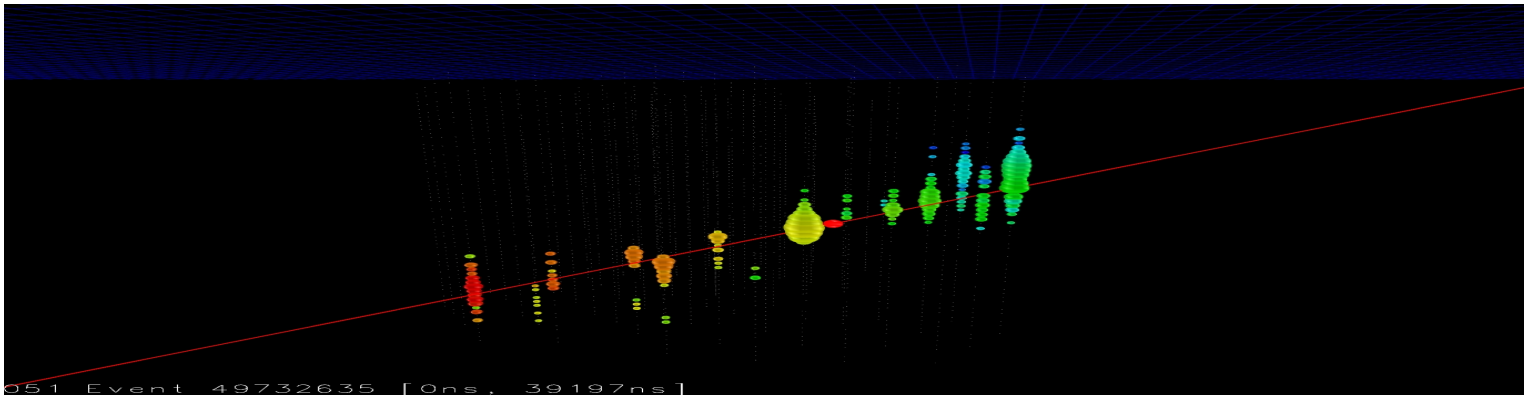
Tau Neutrino CC (simulation)



Neutrino Identification

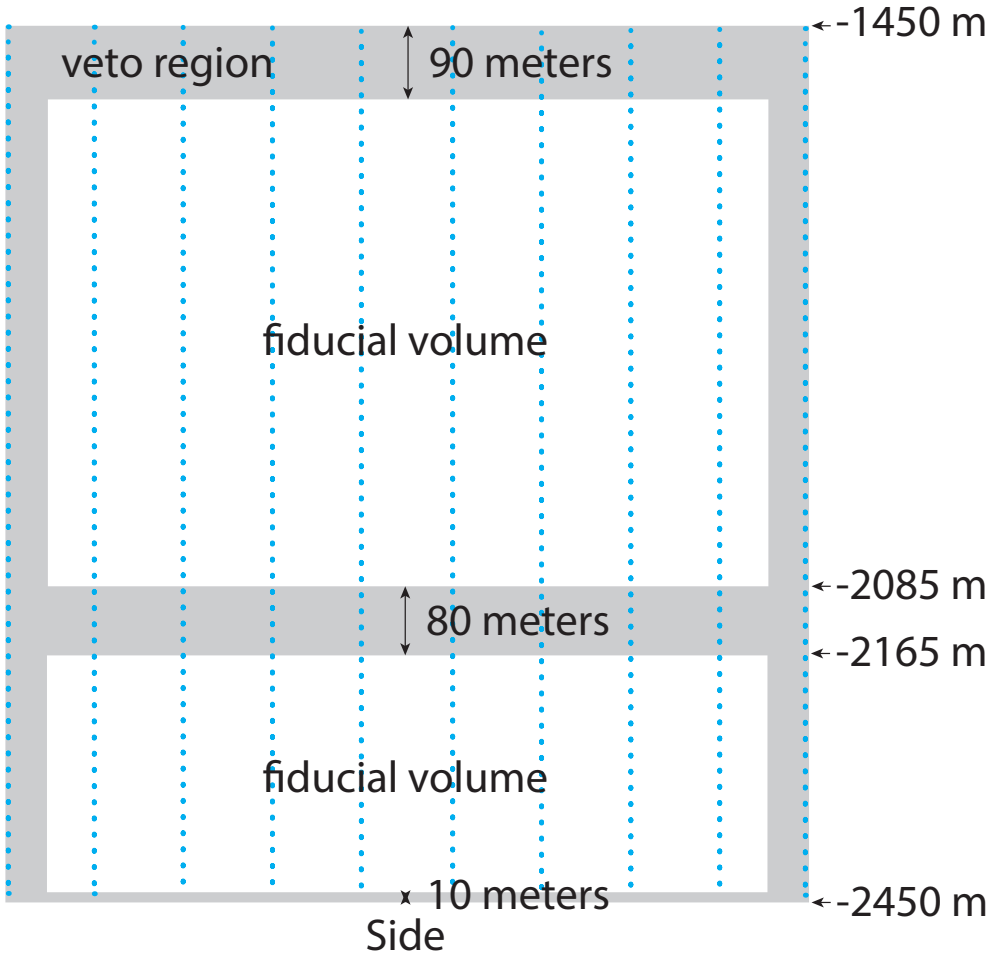
How to identify neutrinos?

1. Upgoing muon tracks
   - Filter out CR muons with bulk of Earth
   - Unknown vertex – hard to measure energy
2. Contained vertex
   - Filter out CR muons using detector edge for anticoincidence
   - All charged particles seen
3. Excess over background
   - Works only for extremely bright/high energy sources



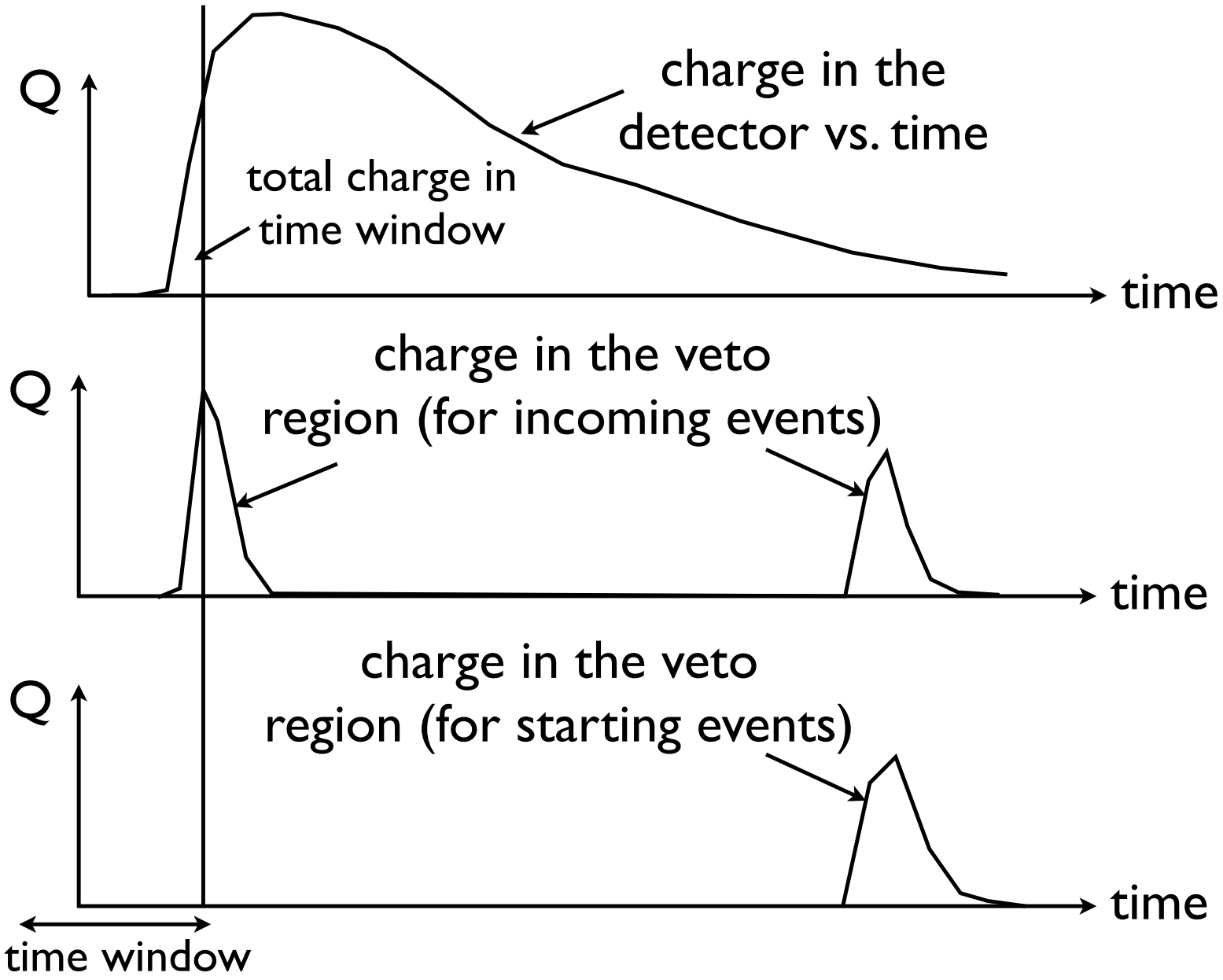
Event Selection For Contained Events

- Define a fiducial volume and a veto region
- Make sure first hits are not on boundary
- Go to high energy (> 6000 PE) to make sure significant numbers of photons expected on boundary
- Topology/direction independent sample
- NB: This is effective because of large degree of scattering

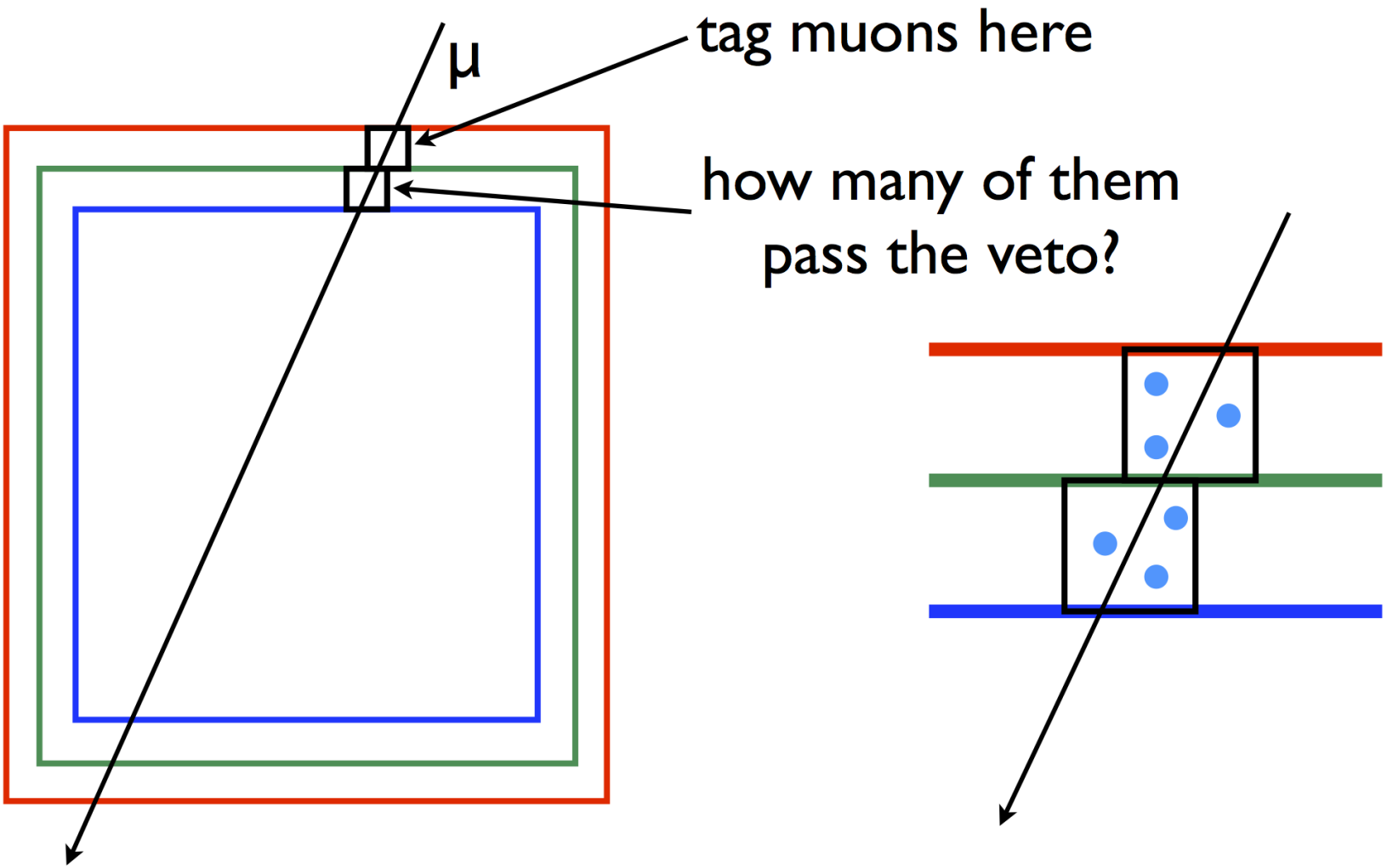


See talk by C. Kopper tomorrow

Event Selection



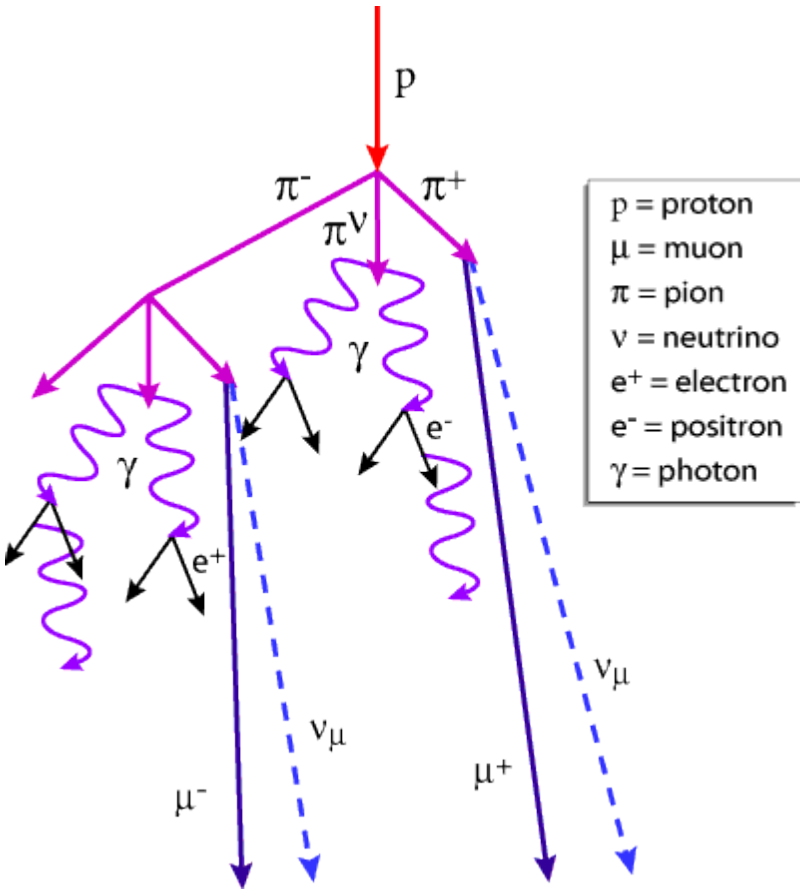
Estimation of Muon Background from Data



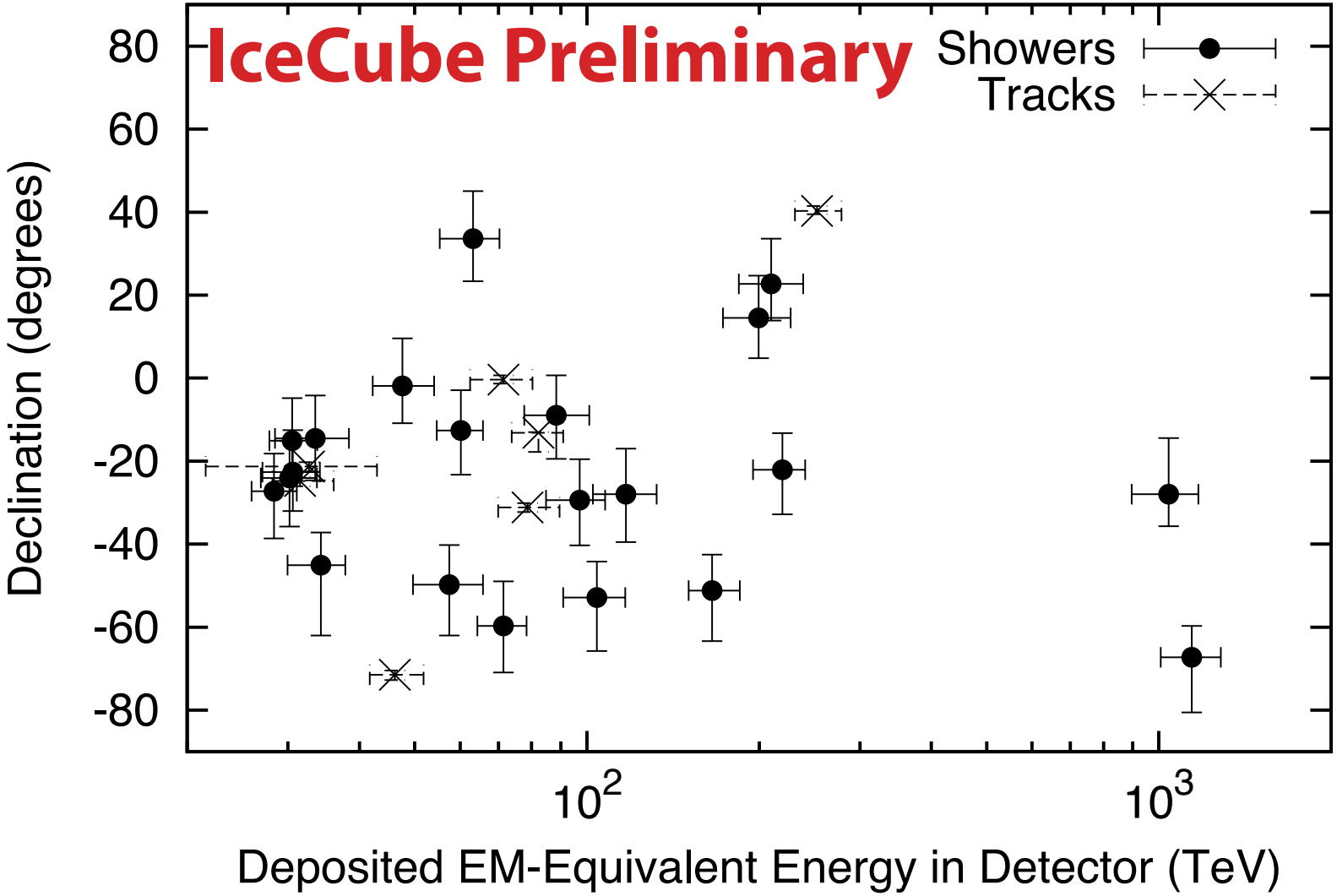
- Estimate Muon Background from Data
- Use outer tagging layer, see how many miss
- 3 ± 1.5 background events per year

Atmospheric Neutrinos

- Conventional well constrained: 2.3 ± 0.6 events per year
- Prompt not well constrained: upper limit (1σ) of 1.7 events per year
- Total: $2.3^{+1.9}_{-0.6}$ events per year



Results of Contained Vertex Event Search, 2010-2012



28 events (7 with visible muons, 21 without) on background of $10.6^{+5.0}_{-3.6}$

Observables of Interest

Spectral slope Separate extraterrestrial fluxes from atmospheric, probe properties of accelerator

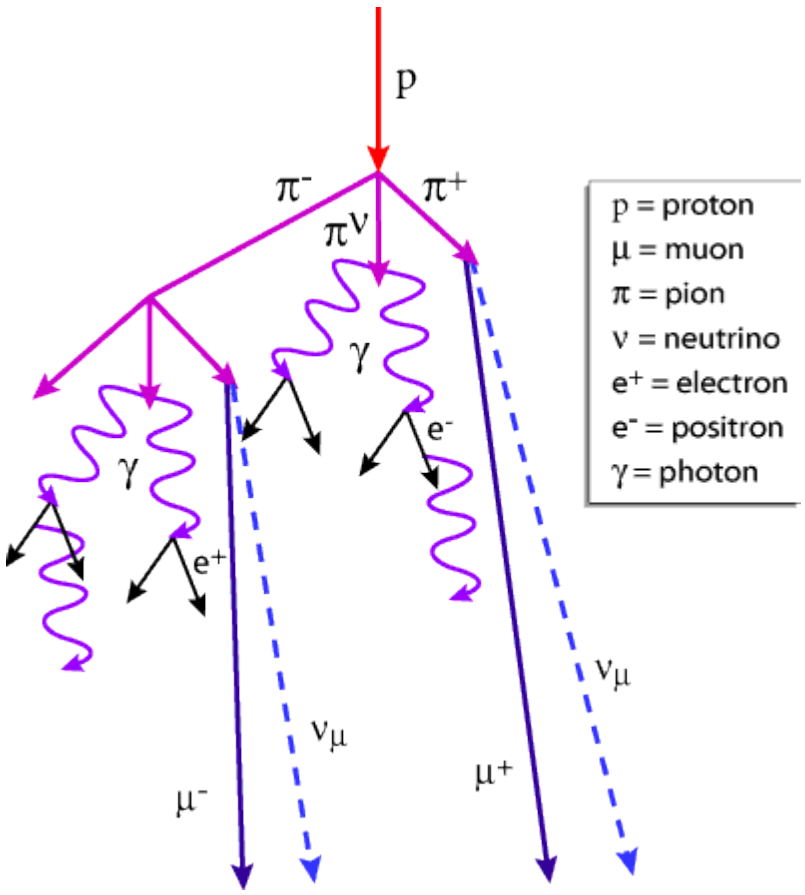
Spectral structure Cutoffs/slope changes may imply population changes

Flavor composition Discrimination against ν_μ dominated backgrounds, probes physics of production process

Zenith distribution Comparison to backgrounds, probes source locations

Vetoing Atmospheric Neutrinos: an Interesting Wrinkle

- Atmospheric neutrinos are made in air showers
- For downgoing neutrinos, the muons from the shower will likely not have ranged out when they arrive at IceCube
- Downgoing events that start in the detector are extremely unlikely to be atmospheric
- Note: optimal use requires *minimal* overburden to have the highest possible rate of cosmic ray muons



Schönert et al. arXiv:0812.4308

Signals and Backgrounds: Why This is Compelling

	Signal		Background		Data
✔	Cascade-dominated ($\sim 80\%$) from oscillations	✘	Track-like from CR muons and atmospheric ν_μ	•	21/28 are cascades
✔	High energy? Typically assume E^{-2}	✘	Soft spectrum ($E^{-3.7}$), $\lesssim 1$ event/year $>$ 100 TeV	•	Energies to above 1 PeV, 9 above 100 TeV
✔	Mostly (2/3) in southern sky from Earth absorption	✘	Muons in south, atmospheric neutrinos in north	•	24/28 from South, mostly cascades

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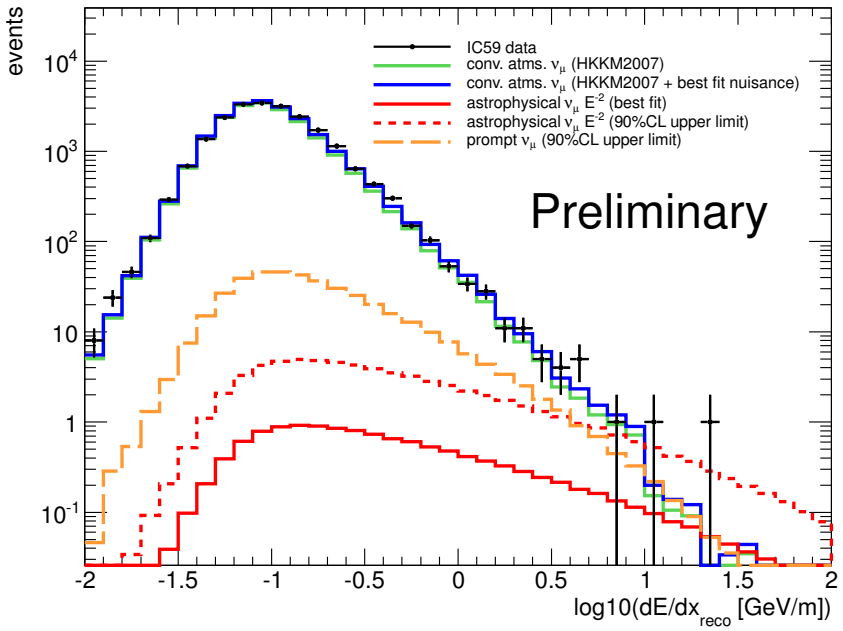
$\rightarrow 4\sigma$ evidence for astrophysical flux

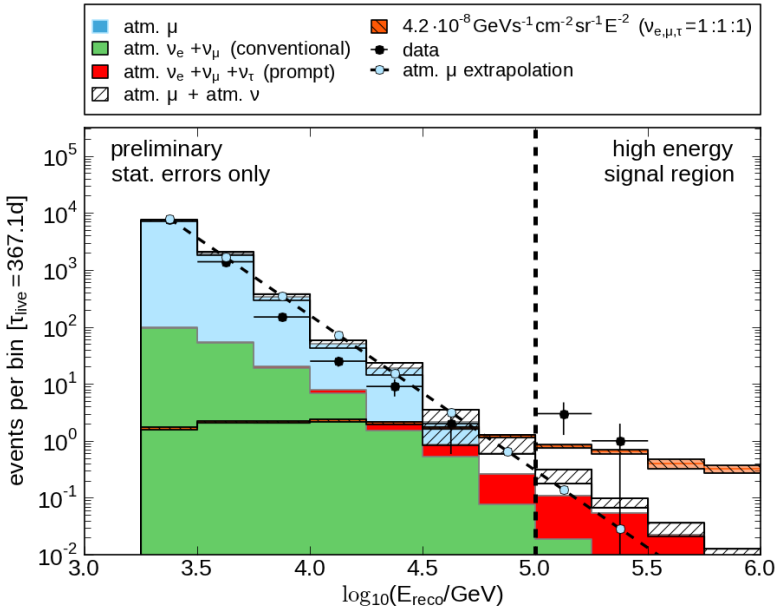
Hints in other channels

IC59 Northern ν_μ arXiv:1302.0127



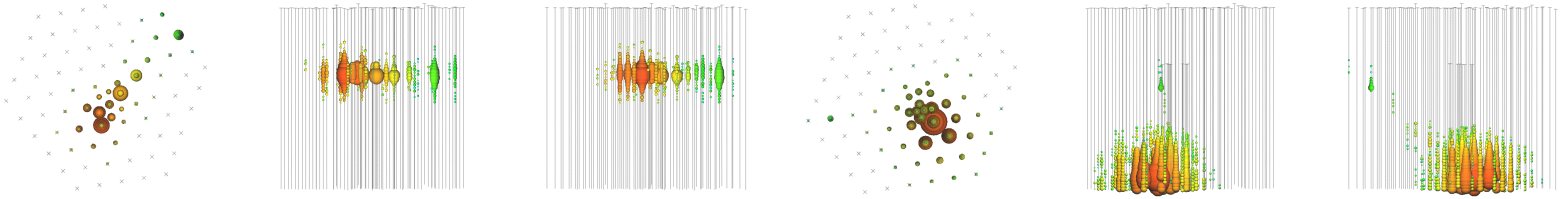
2009, 1.8σ

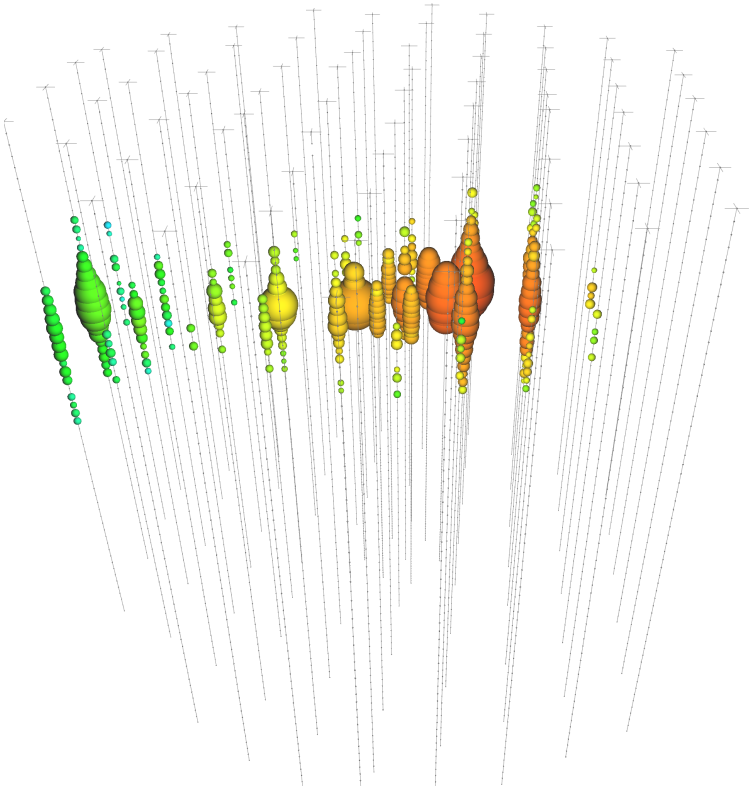
IC40 Cascades



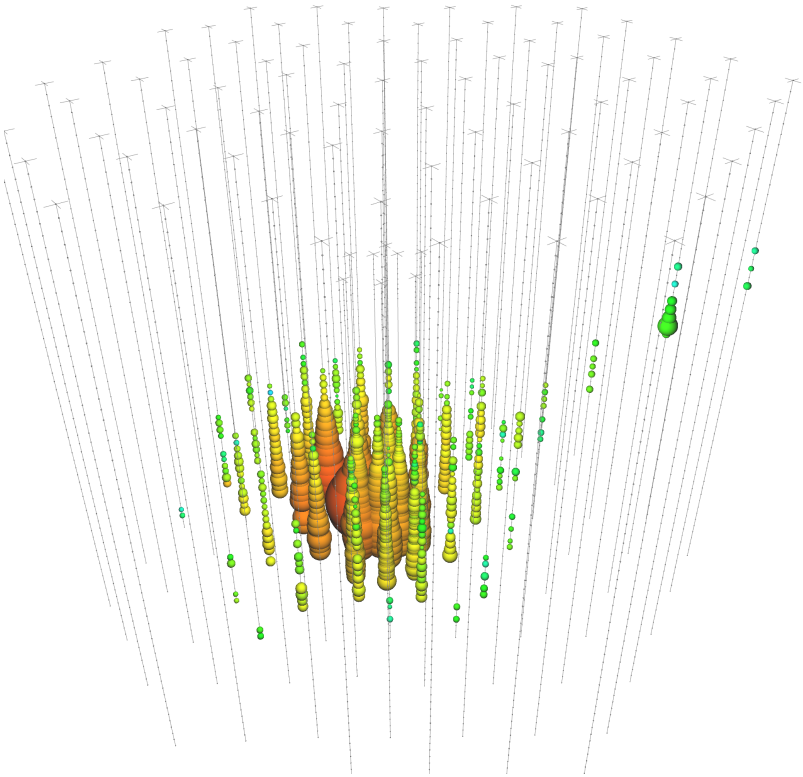
2008, 2.4σ

Some interesting events



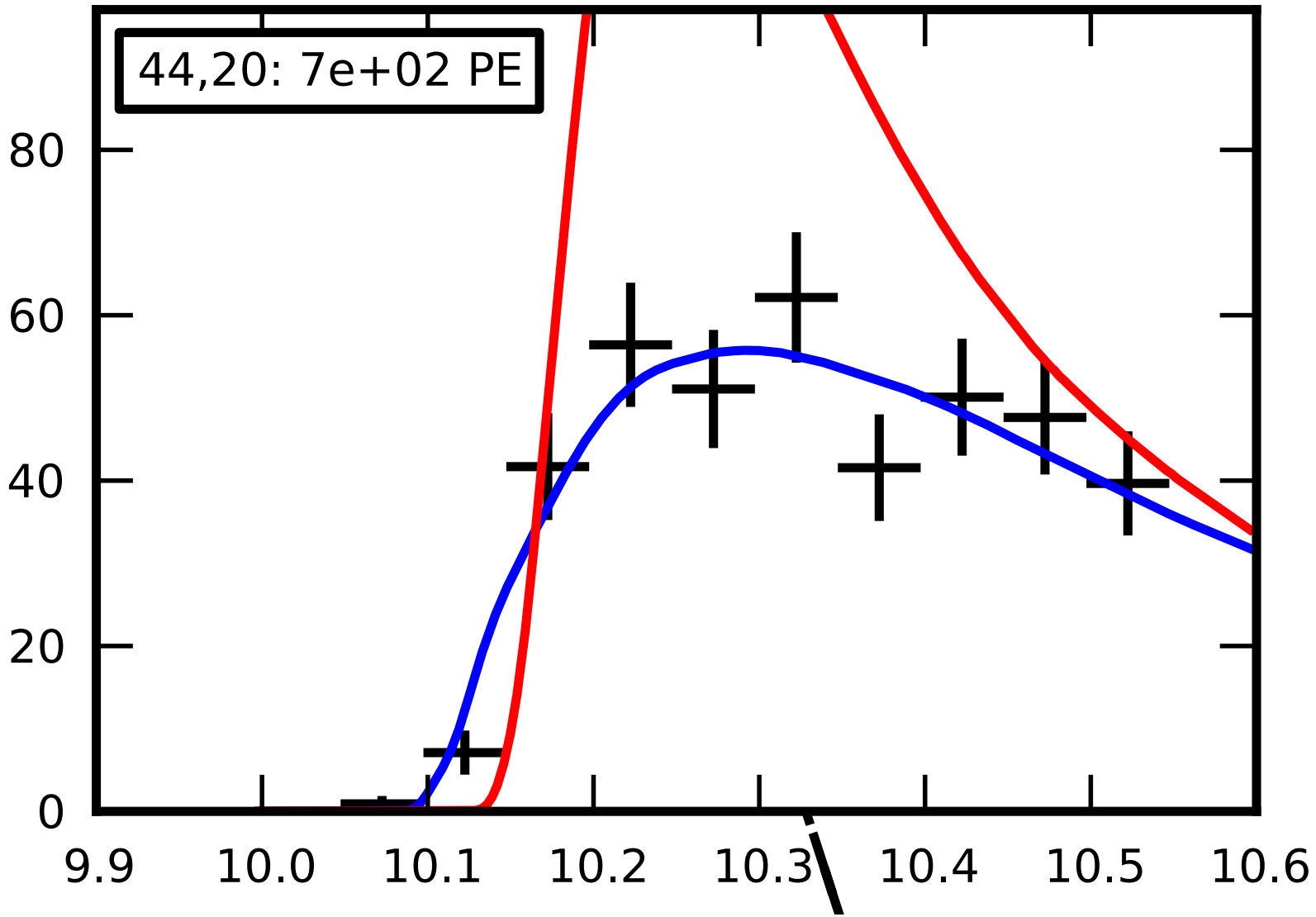


74.1 TeV, -0.4°

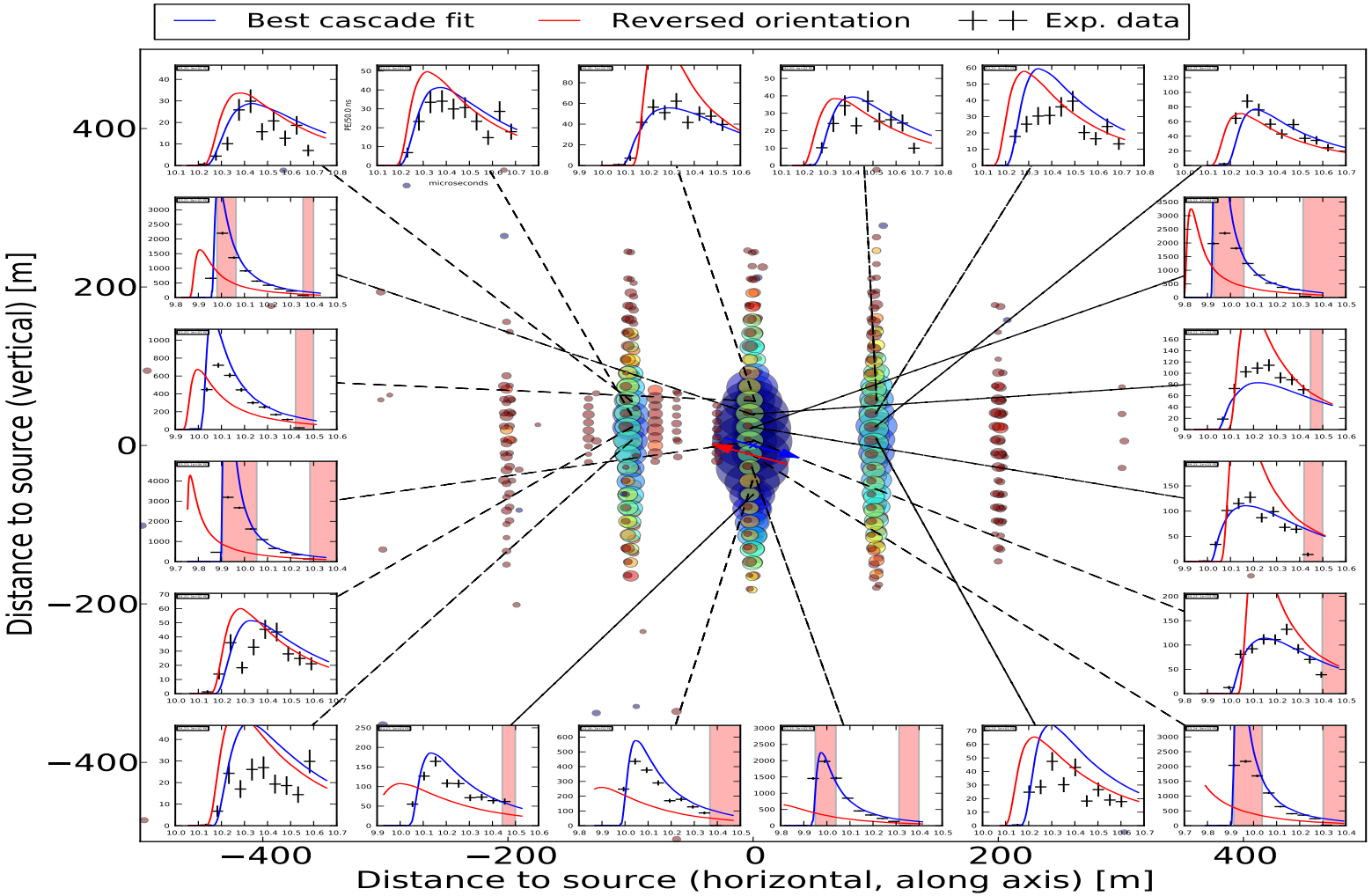


252.7 TeV, $+40^\circ$

Raw Data

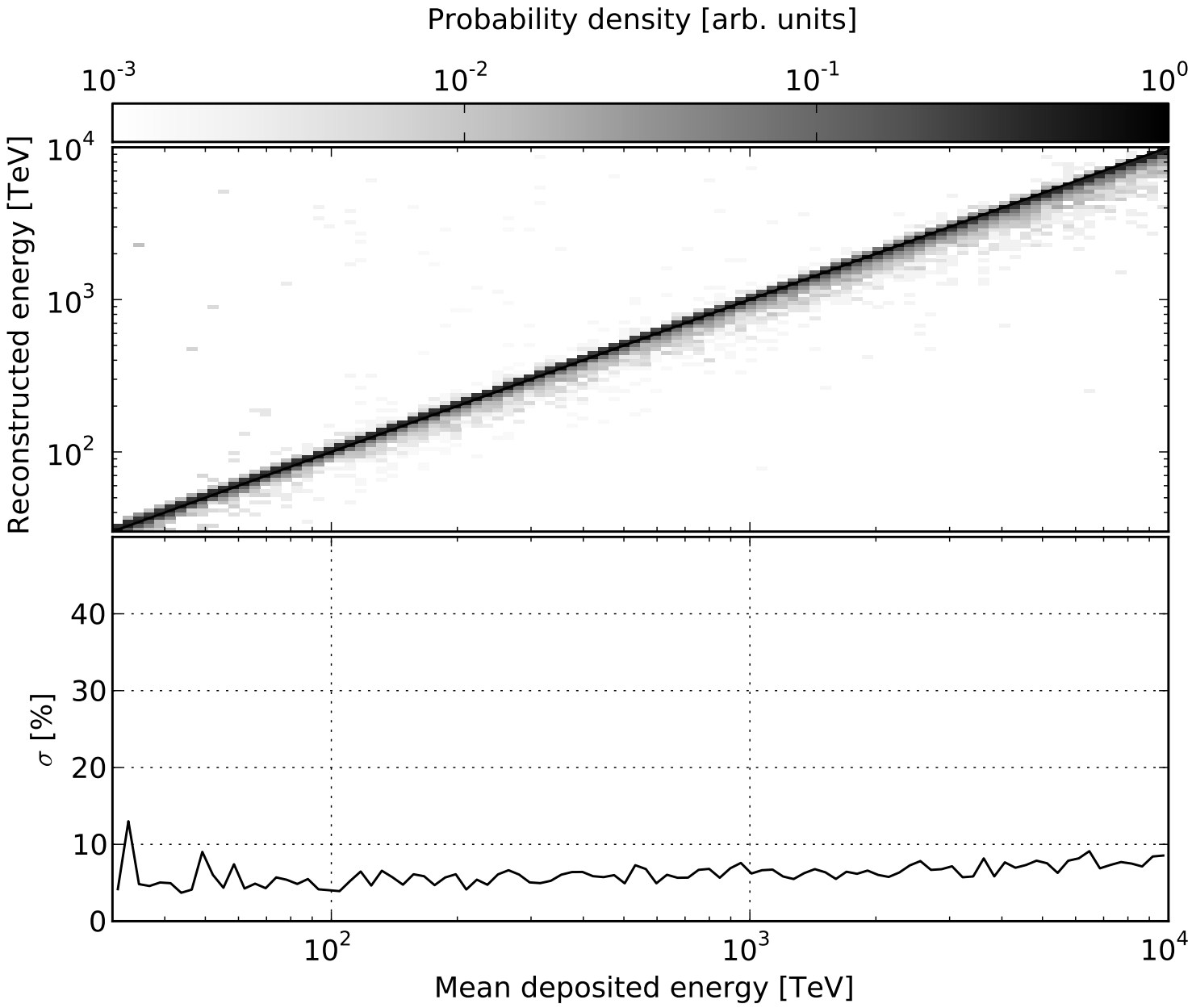


Raw Data


Best cascade fit
Reversed orientation
Exp. data
Distance to source (vertical) [m]
Distance to source (horizontal, along axis) [m]
microseconds

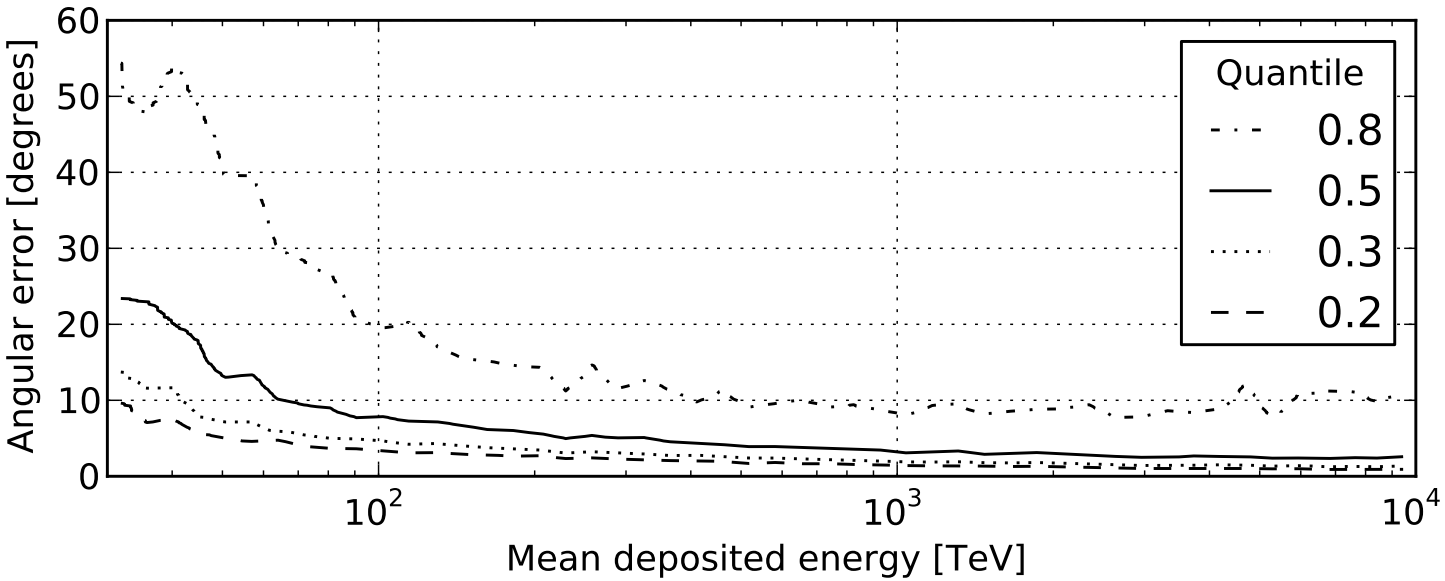
Shower Energy Resolution

Systematics limited above 10 TeV, typically 15%

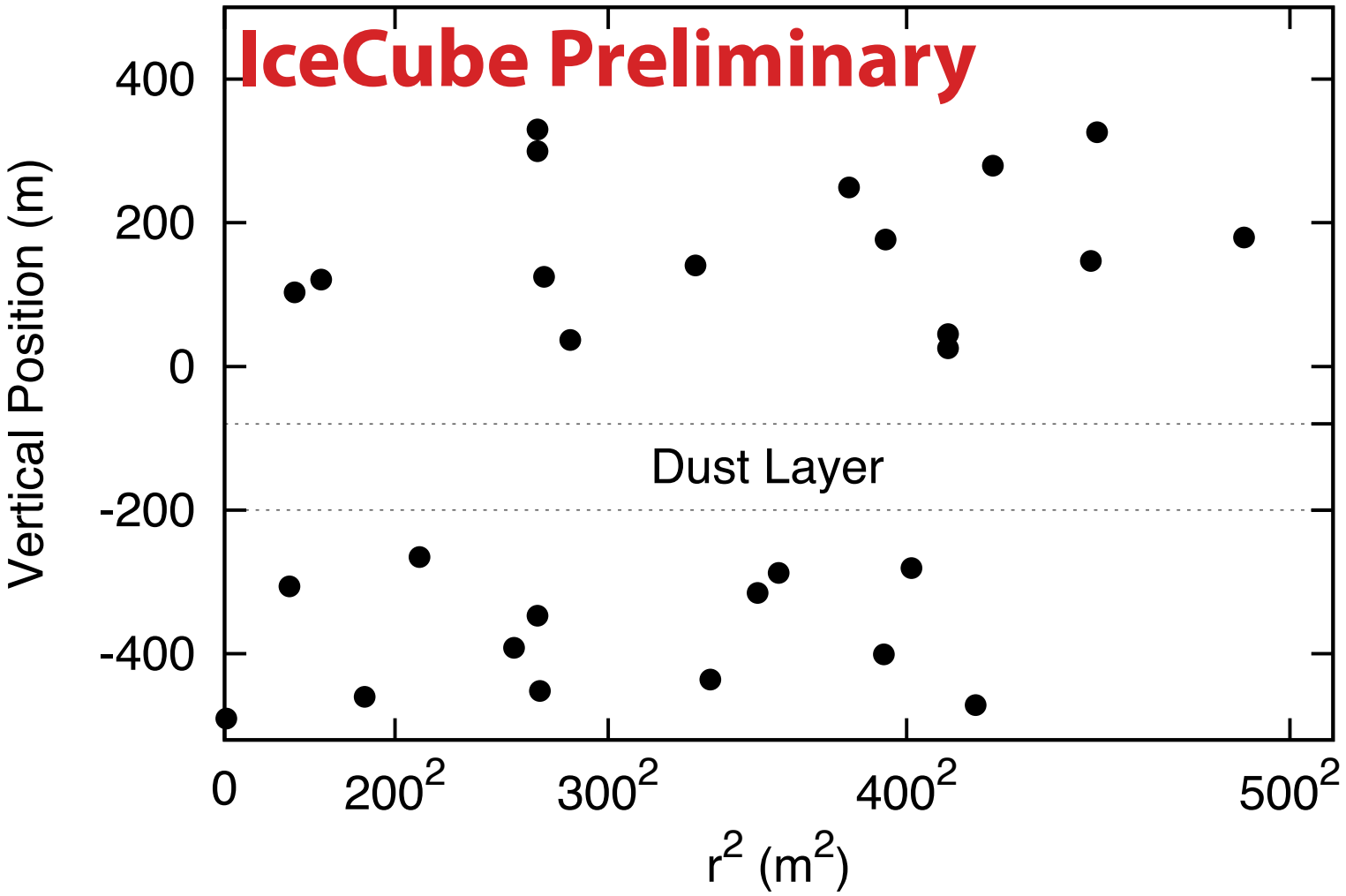


Shower Angular Resolution

Systematics limited above 10 TeV, typically 15°



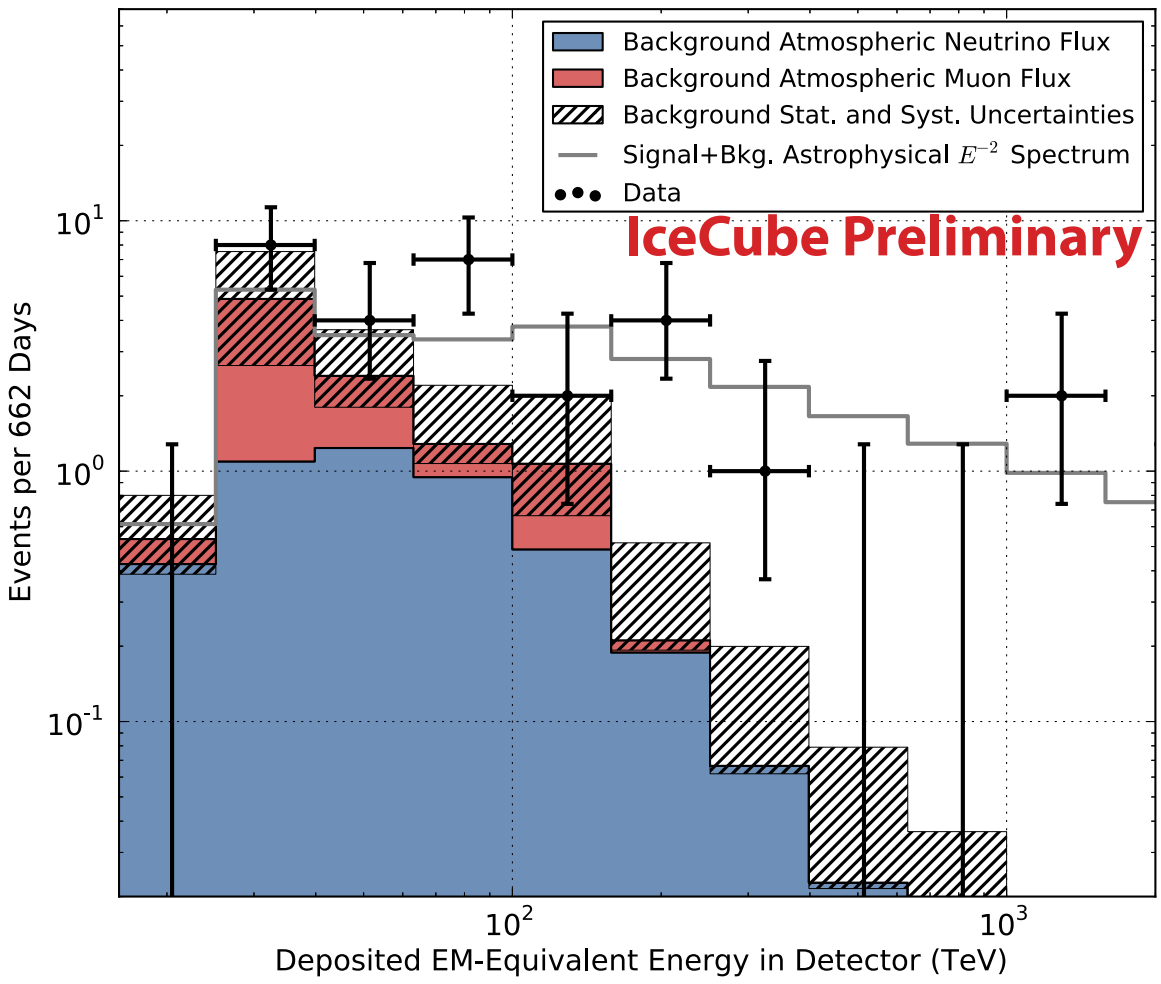
Event Distribution in Detector



Uniform in fiducial volume

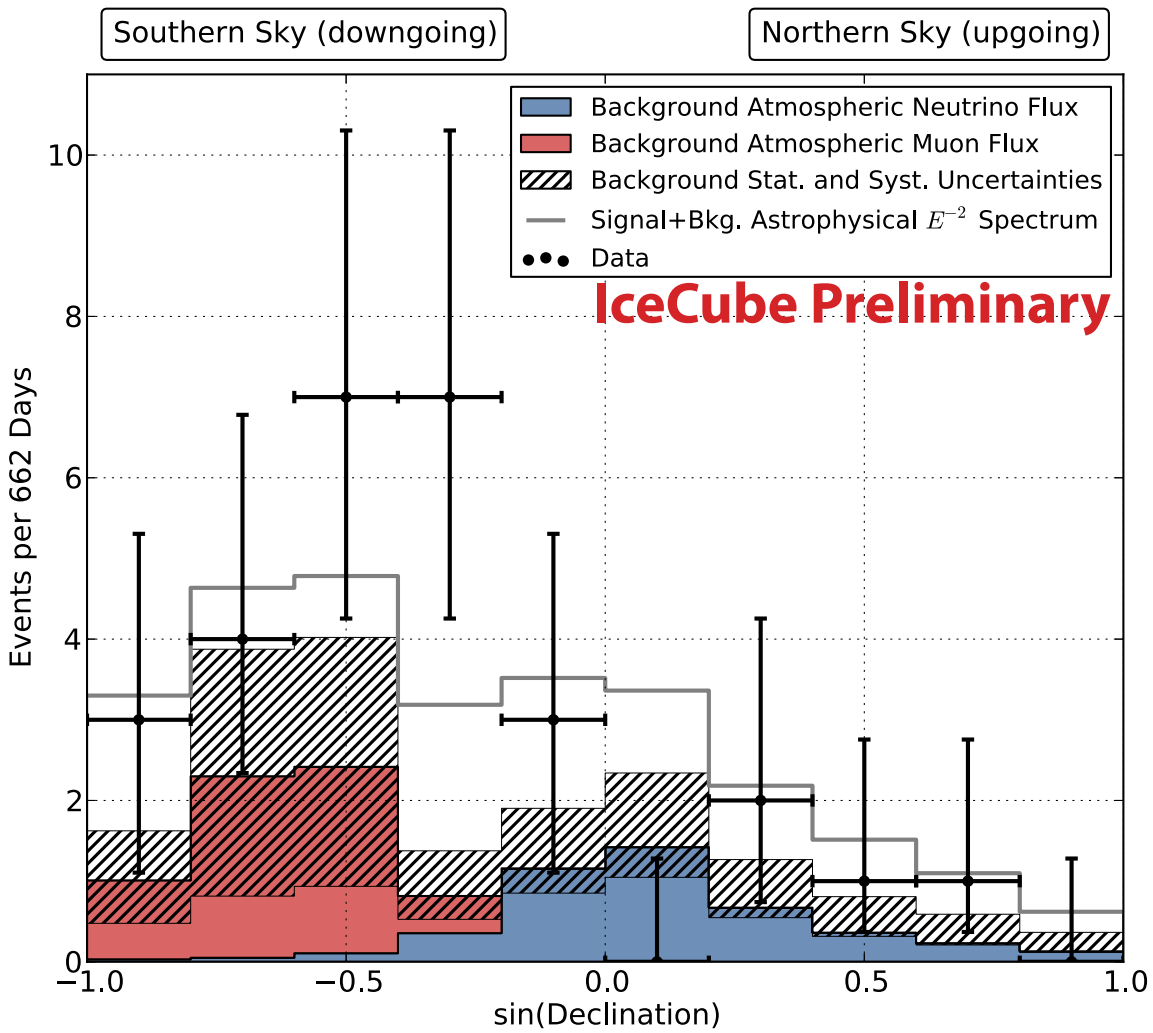
Energy Spectrum

- Harder than any expected atmospheric background
- Merges well into expected backgrounds at low energies
- Potential cutoff around 2 PeV if E^{-2}
- Too few events to measure spectrum well

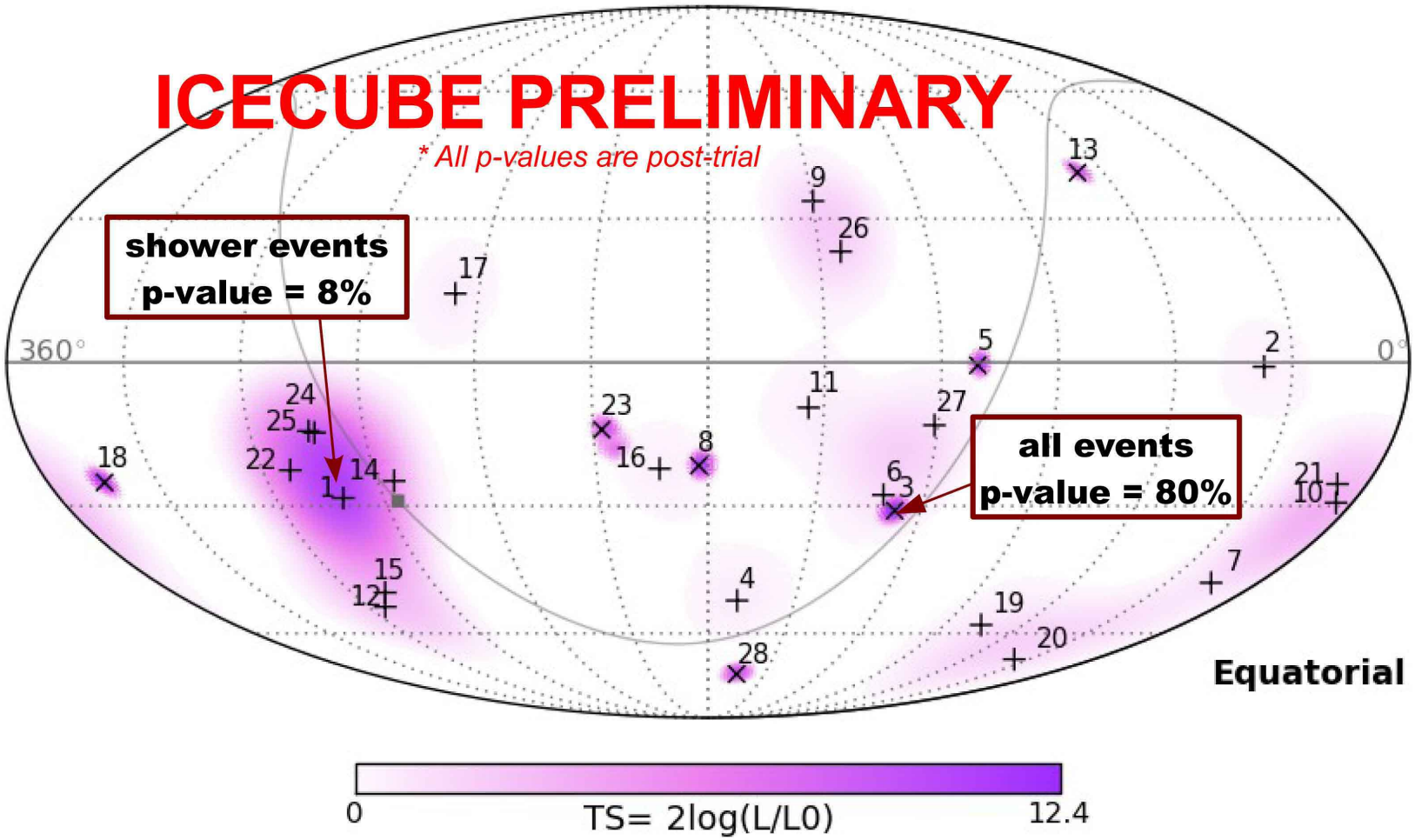


Zenith Distribution

- Compatible with Isotropic Flux
- Events from North absorbed in Earth
- Minor excess in south compared to isotropic, but not significant



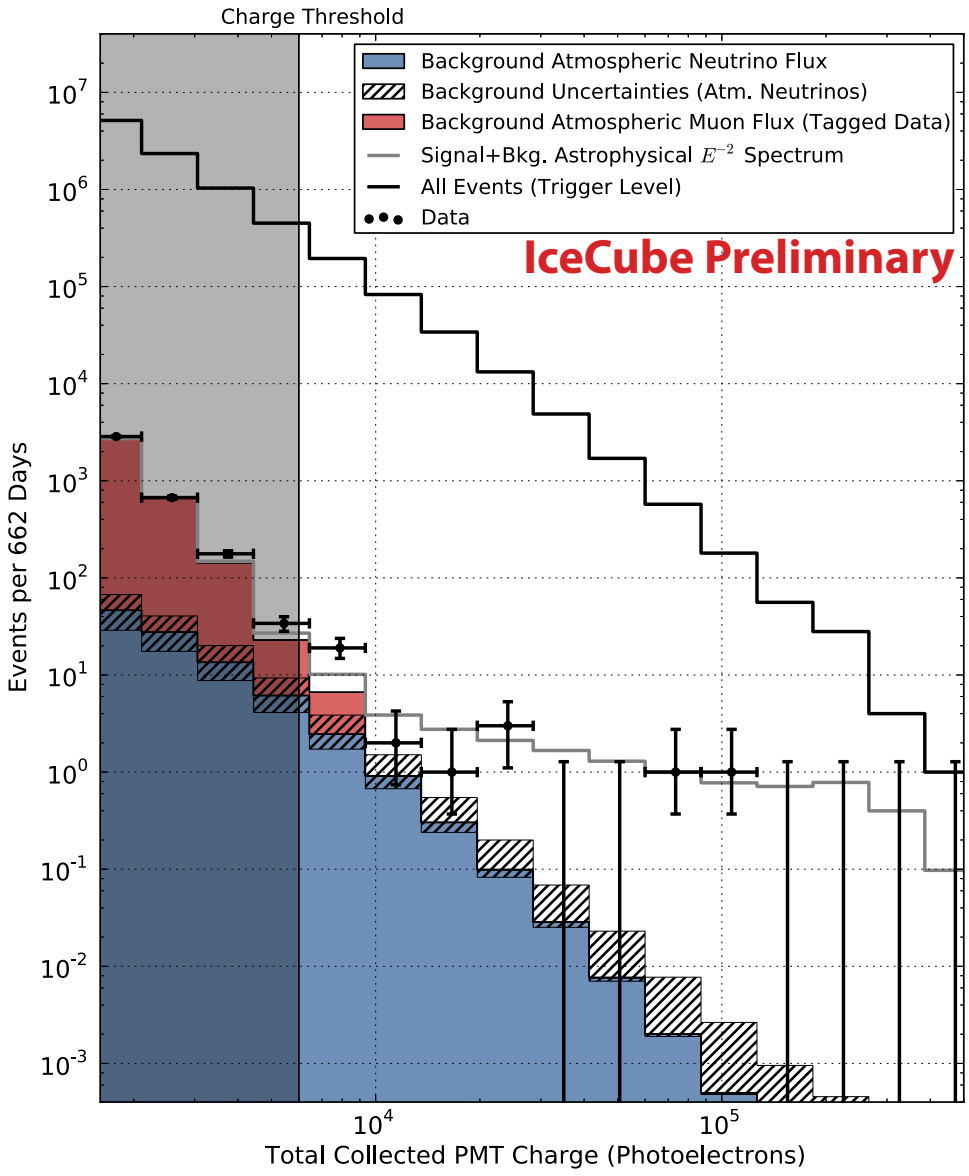
Skymap: Compatible with Isotropy



Too few events to evaluate isotropy or identify sources

Summary

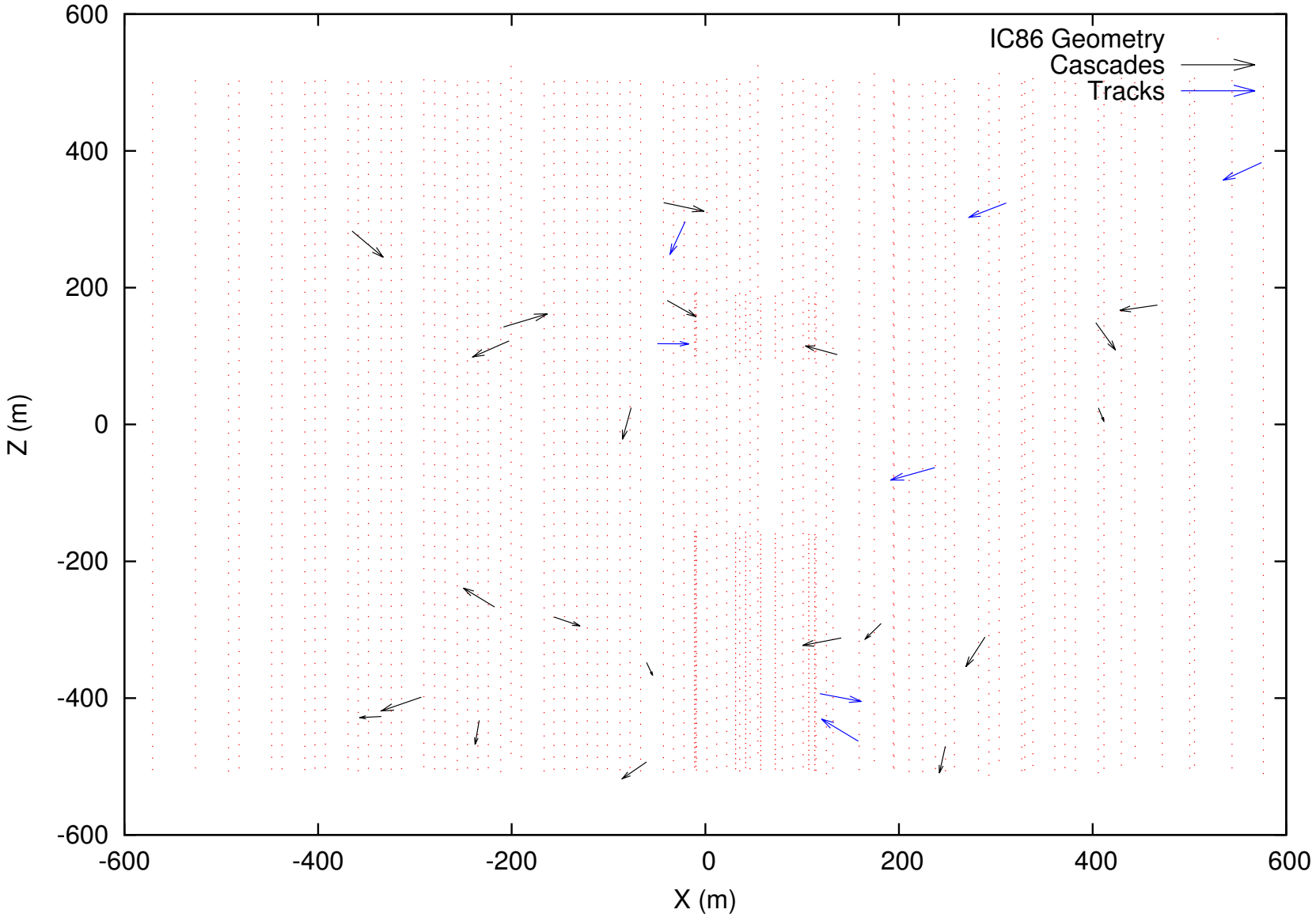
- Energy spectrum seems hard
- Flavor distribution consistent with 1:1:1
- Angular distribution makes atmospheric explanation hard: where are the air showers?
- Matches expectations for astrophysical flux
- Still no evidence for clustering
- Does not continue at E^{-2} past a few PeV
- Hard to characterize without more statistics

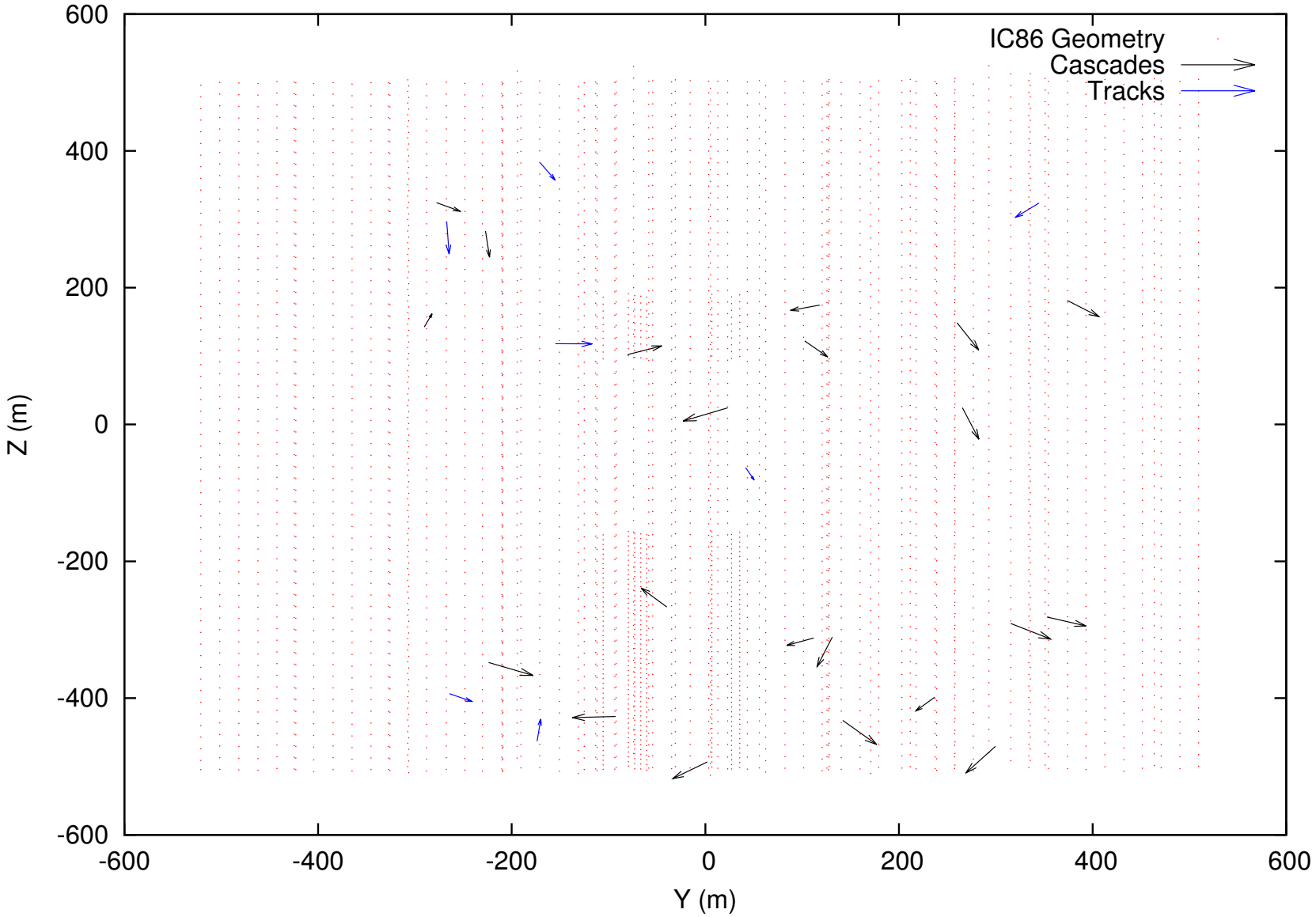


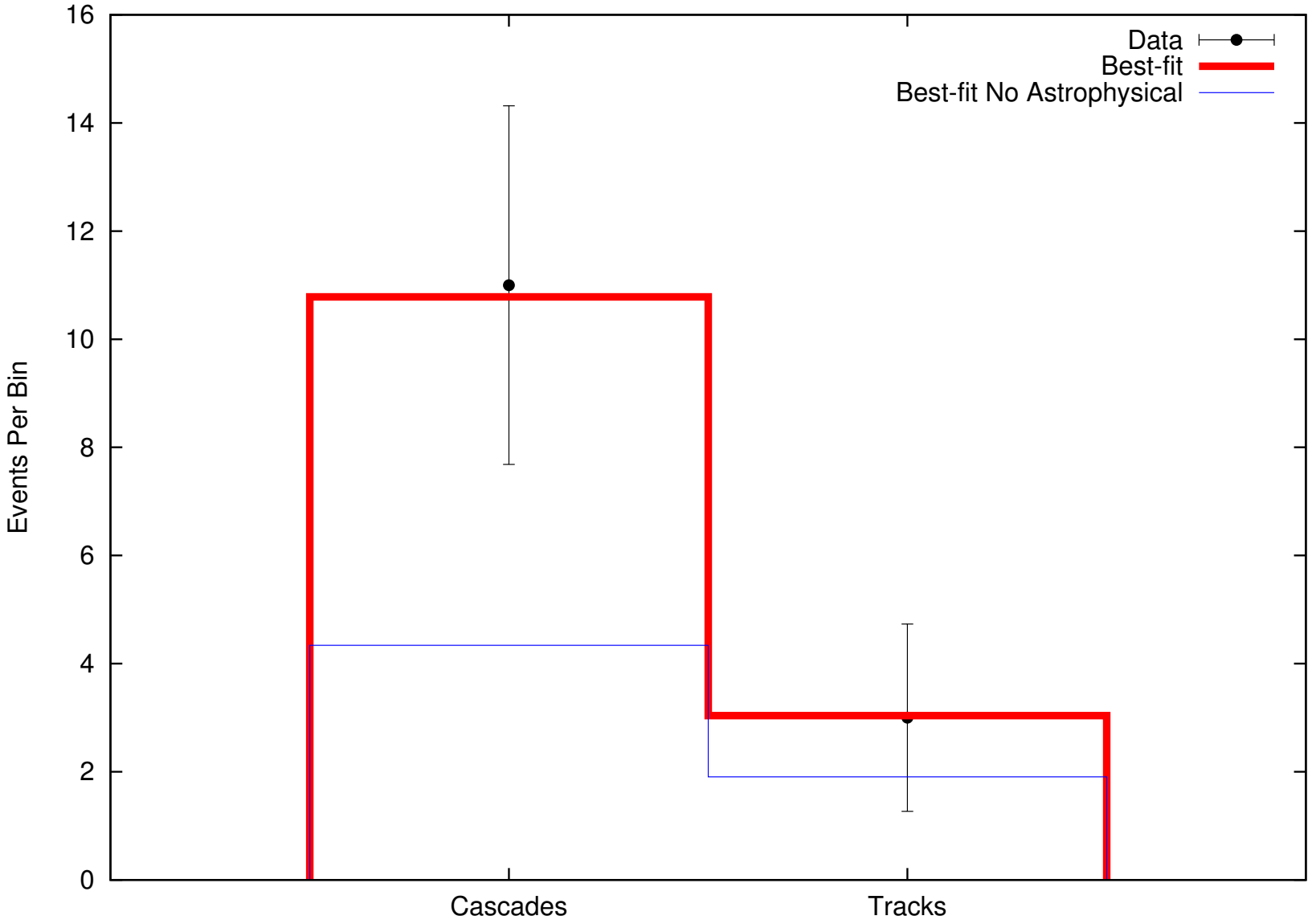
Parameters of the Future

- Atmospheric neutrino veto is a very powerful concept
- Dominant observable channel for astrophysical diffuse flux is 100 TeV - 1 PeV cascade events
- If an astrophysical flux, $\mathcal{O}(20)$ events per year per fiducial gigaton
- Analysis now gives $\mathcal{O}(100)$ events in IceCube in 10 years
- Angular resolution for cascades limited by modelling of light transport and sparse instrumentation
- Need $\mathcal{O}(10)$ events from a source to identify
- Flavor composition probes particle and astrophysics

Backup


IC86 Geometry
Cascades
Tracks
600
400
200
0
-200
-400
-600
Z (m)
-600
-400
-200
0
200
400
600
X (m)


IC86 Geometry
Cascades
Tracks
600
400
200
0
-200
-400
-600
Z (m)
-600
-400
-200
0
200
400
600
Y (m)


Data
Best-fit
Best-fit No Astrophysical
Events Per Bin
0
2
4
6
8
10
12
14
16
Cascades
Tracks