CCAPP The Ohio State University's Center for Cosmology and AstroParticle Physics

THE OHIO STATE UNIVERSITY

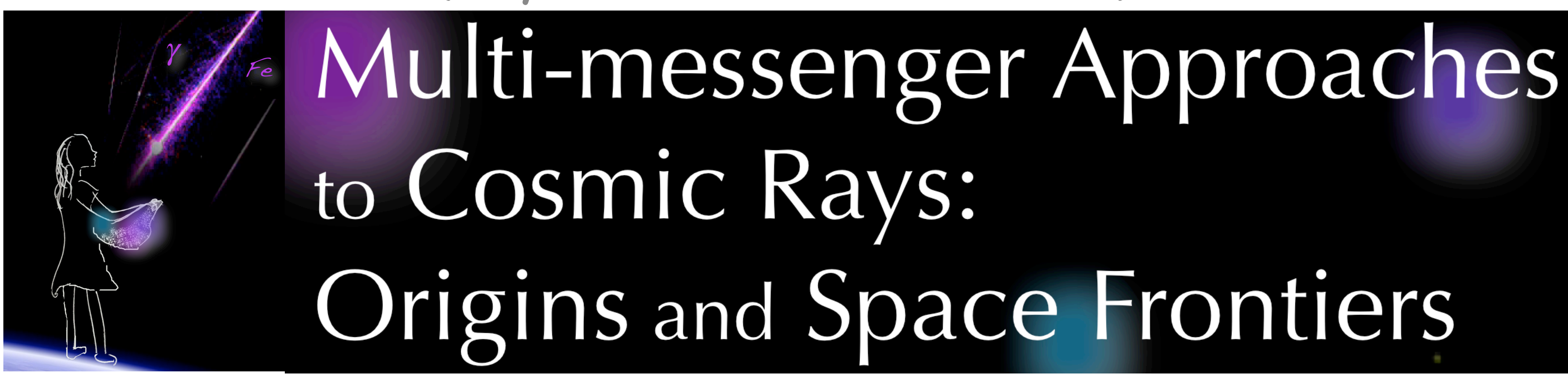
PeV cascades in IceCube: Less is more

Ranjan Laha

Ohio State University

arXiv: 1306.2309

(Phys. Rev. D 88, 043009)



Thanks to my collaborators: J Beacom, B Dasgupta, S Horiuchi, K Murase

Neutrino Astrophysics

J Bahcall in Neutrino Astrophysics (1989)

"The title is more of an expression of hope than a description of the book's contents....the observational horizon of neutrino astrophysics may grow ... perhaps in a time as short as one or two decades"

IceCube at the forefront of this new field

Has IceCube finally seen astrophysical neutrinos?

Contents

- IceCube introduction & types of neutrino events
- A quick introduction to the PeV events
- Questions that arise from these events
- What kind of spectrum is favored?
- How is it possible to find out about the spectrum in the quickest possible time?
- Connection of this work to the new ~100 TeV events

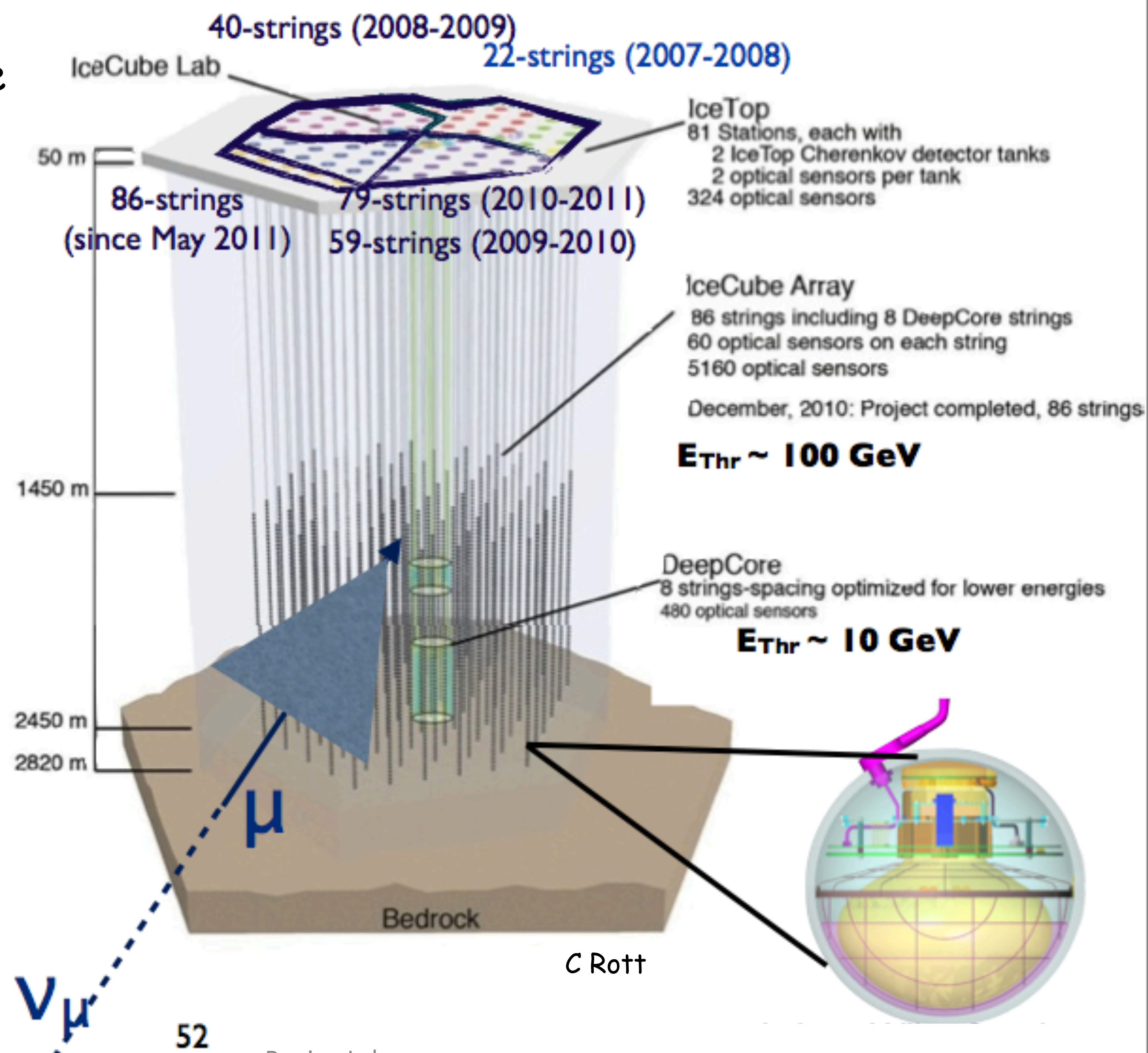
IceCube

Gigaton effective volume neutrino detector at South Pole

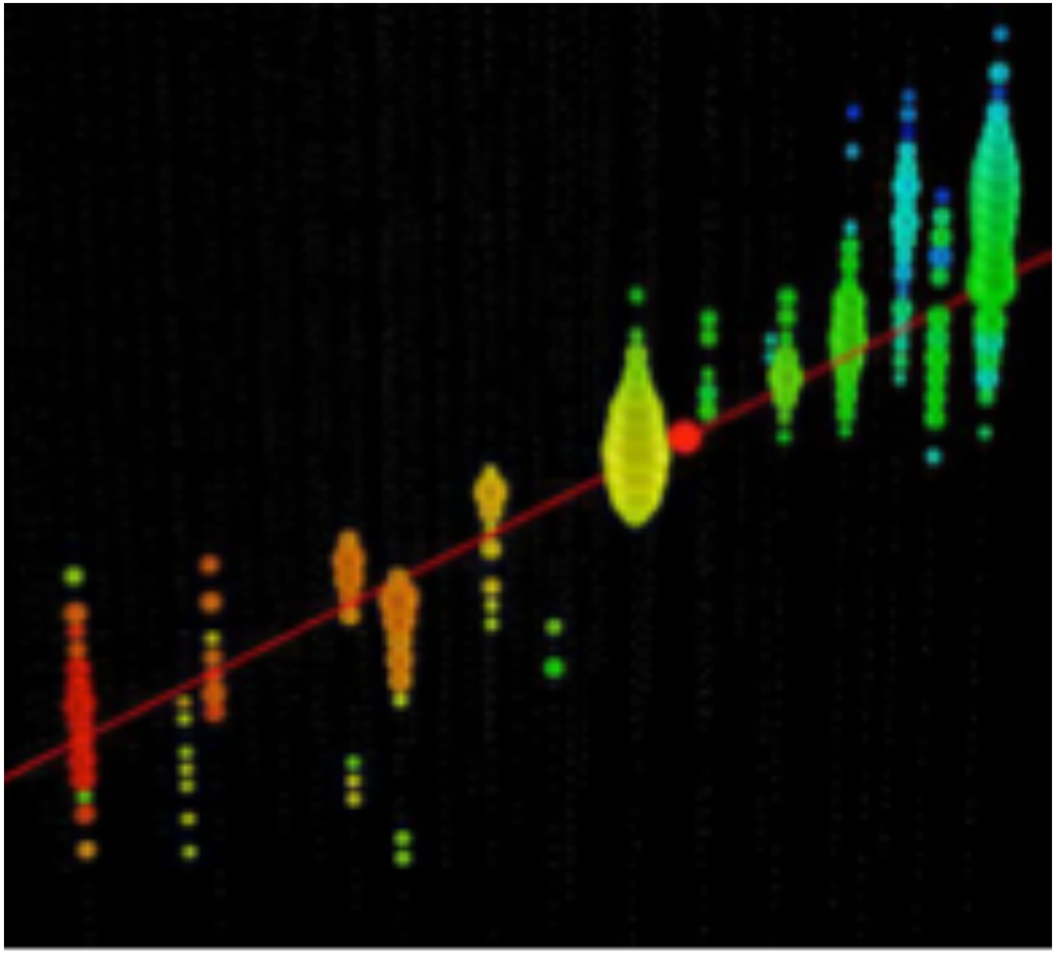
5160 Digital Optical Modules distributed over 86 strings

Completed in Dec 2010; data in full configuration from May 2011

Neutrino detected through Cherenkov light emission from charged particles produced due to neutrino CC/NC interactions



Neutrino detection - tracks



N Whitehorn IPA 2013

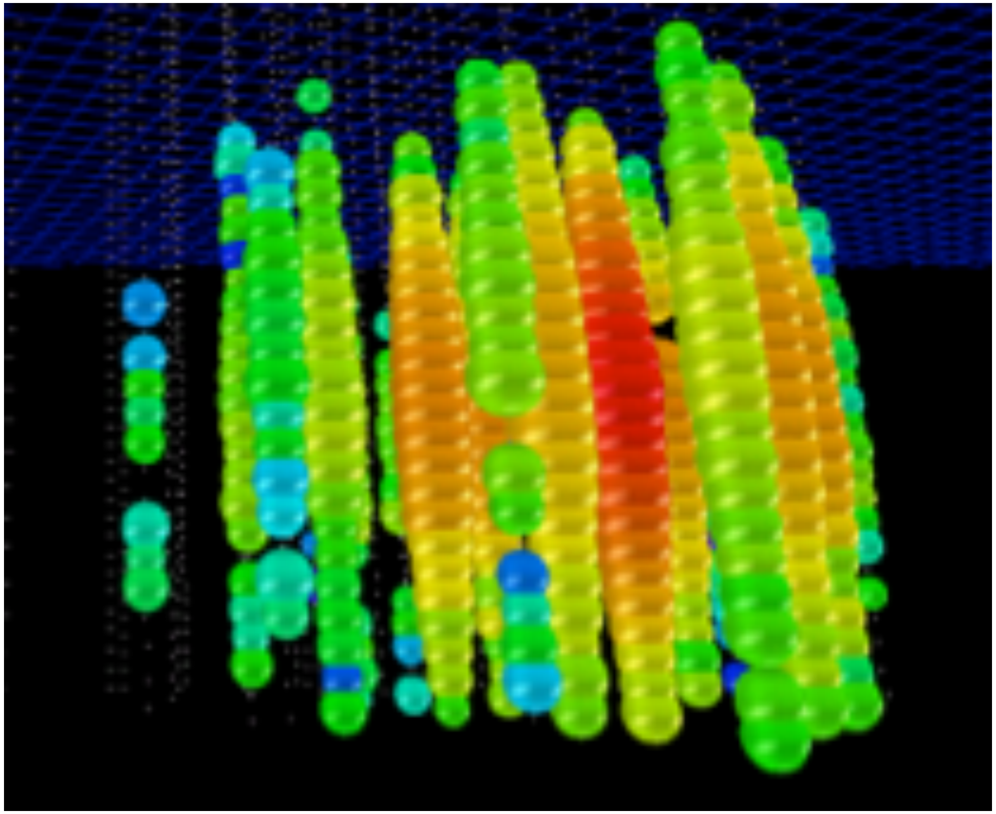
ν_μ charged current interaction produces a muon which produces track

+ Long range implies larger effective volume => can interact outside the detector and still make it inside the detector

+ Better Angular resolution ~ 1^o

- Higher conventional atmospheric neutrino backgrounds

Neutrino detection - cascades



N Whitehorn IPA 2013

ν_e charged current interaction produces an electron which produces an electromagnetic cascade

+ Calorimetric

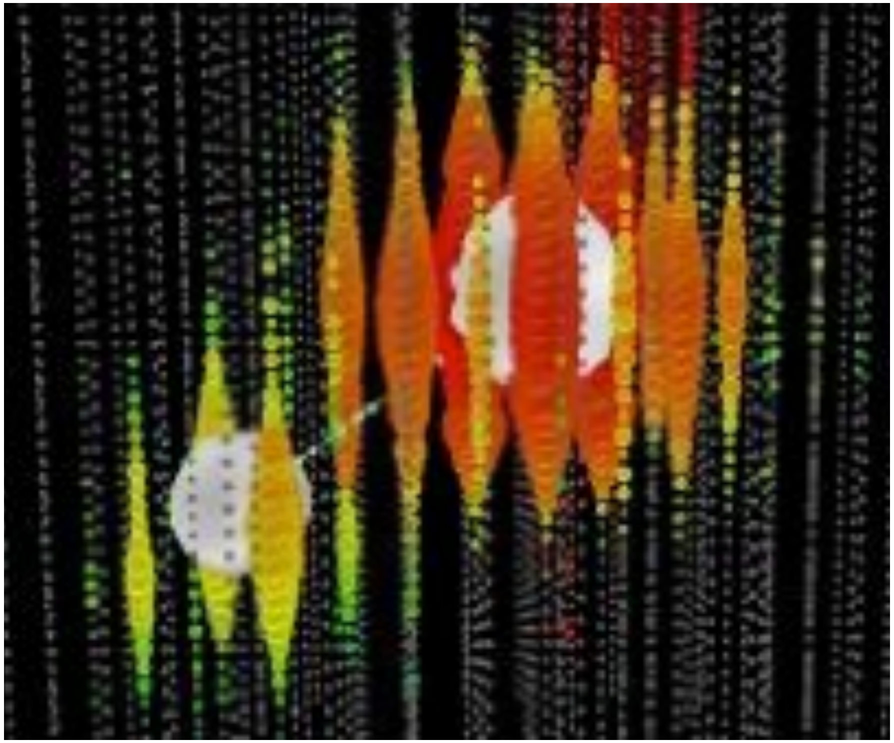
+ Lower atmospheric neutrino background

- Smaller effective volume

- Poor angular resolution ~ 30° (~10° at PeV)

Neutral Current interaction of all neutrino flavors give hadronic cascade

Neutrino interactions ν_τ



N Whitehorn IPA 2013

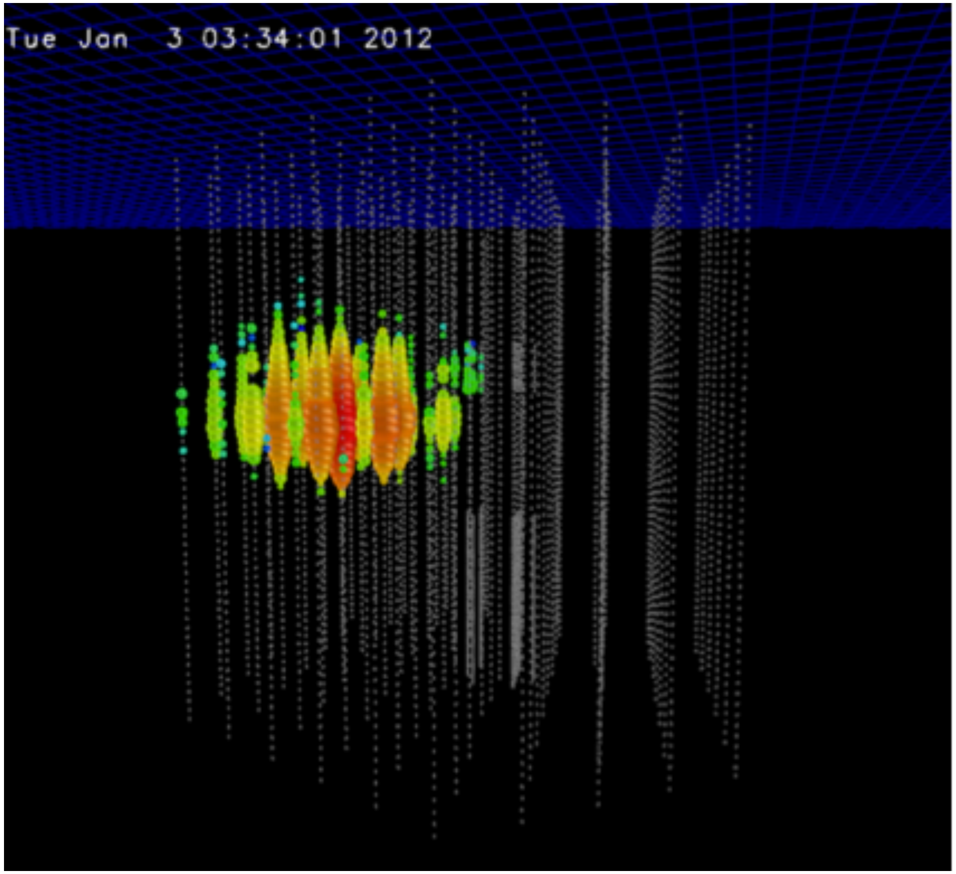
ν_τ charged current interaction produces either a cascade or distinct signatures ("lollypop", "single bang", "double bang"); the signature depends on energy

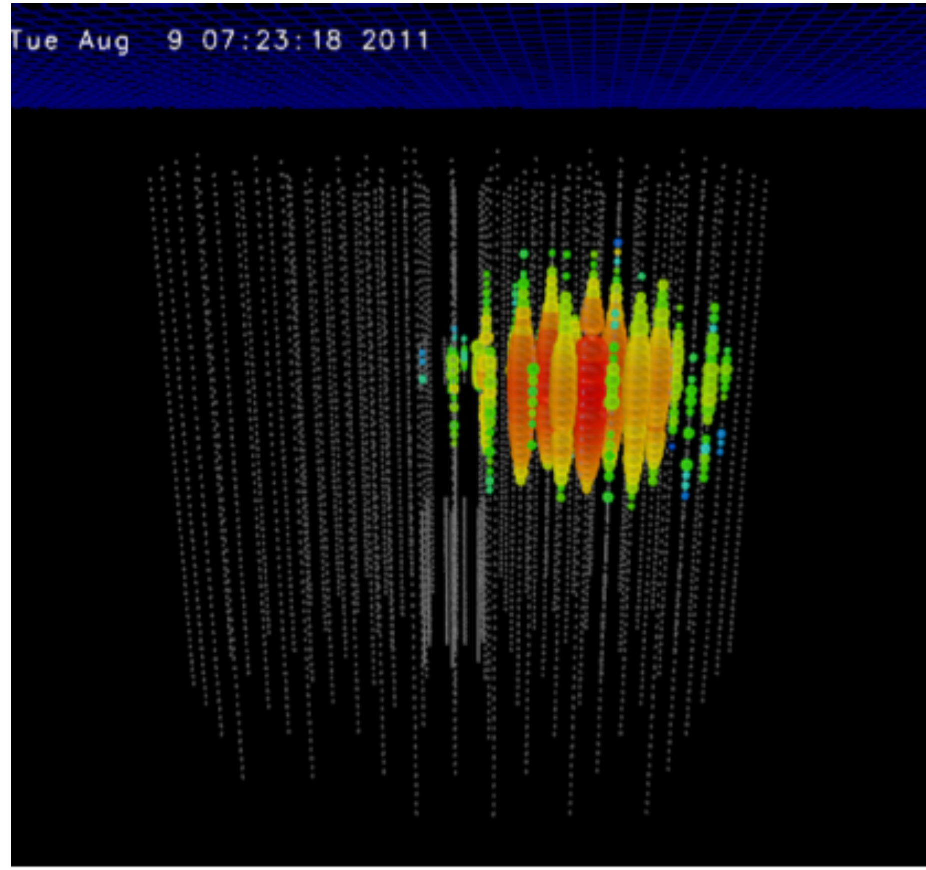
Cascades at < 1 PeV; distinct signatures at higher energies

+ Lower atmospheric neutrino background

Not yet seen

Two PeV events





N Whitehorn IPA 2013

Cascade events

PeV cascades in IceCube

Two cascade events of energy ~ 1 PeV - Highest energy neutrino ever detected - 10^6 times more energetic than a typical conventional atmospheric neutrino

Very near to the analysis threshold

From CC interactions of ν_e or NC interactions of all flavors

Widely separated in time

Does not coincide with a visible GRB/ AGN/ transient

Downgoing

No hits in IceTop

IceCube 1304.5356

Questions

Why are there no tracks in the analysis?

Why are the energies so close to each other?

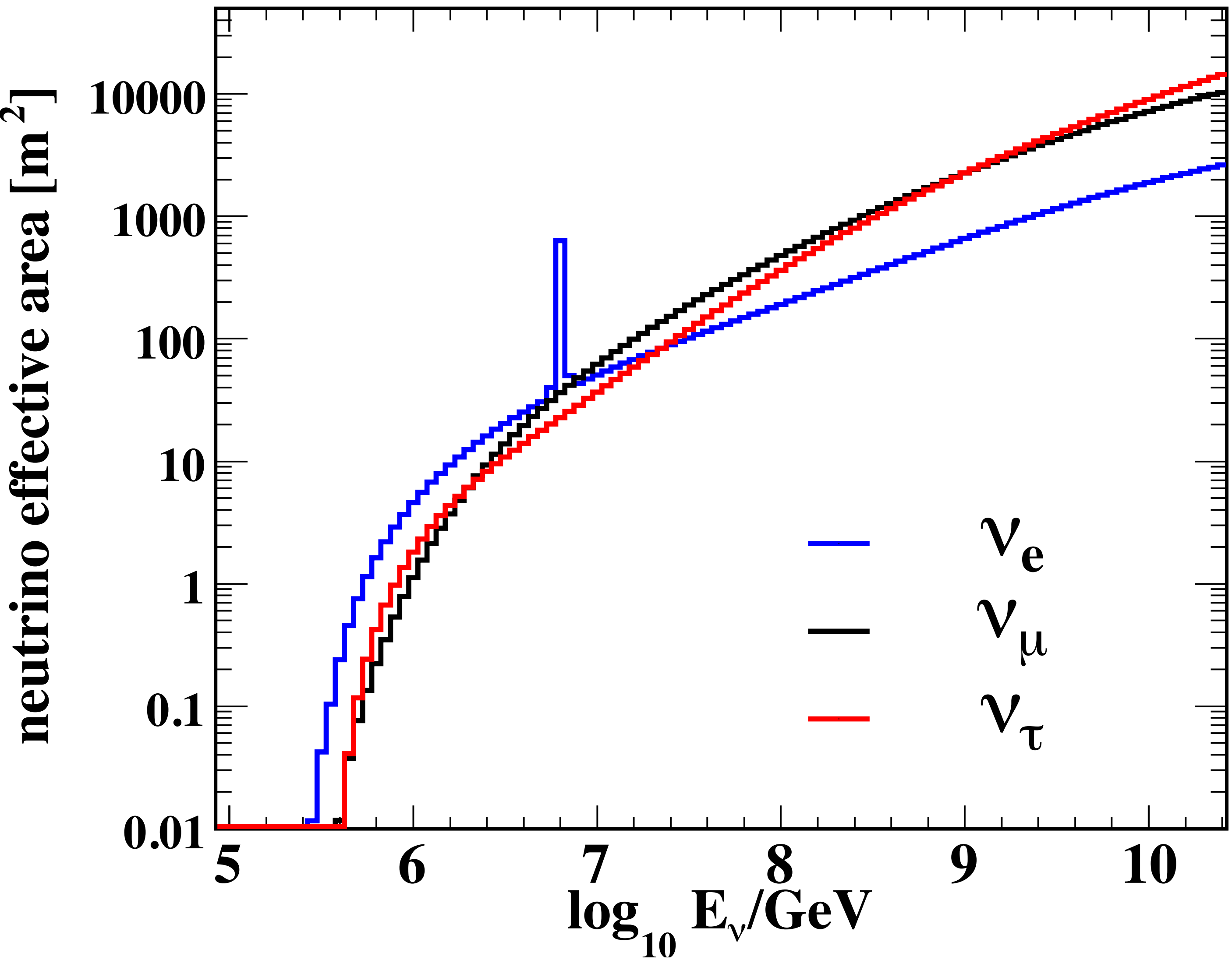
Where do the neutrinos come from?

Is the required flux consistent with previous constraints?

How to quickly distinguish between the source spectrum?

Why ν_e and not ν_μ ?

The search near 1 PeV is most sensitive to ν_e



IceCube 1304.5356

The signal cuts in this analysis are such that the exposure to muon neutrinos is lower than electron neutrinos around a PeV

Above ~10 PeV, the detection probability of muon neutrinos is enhanced

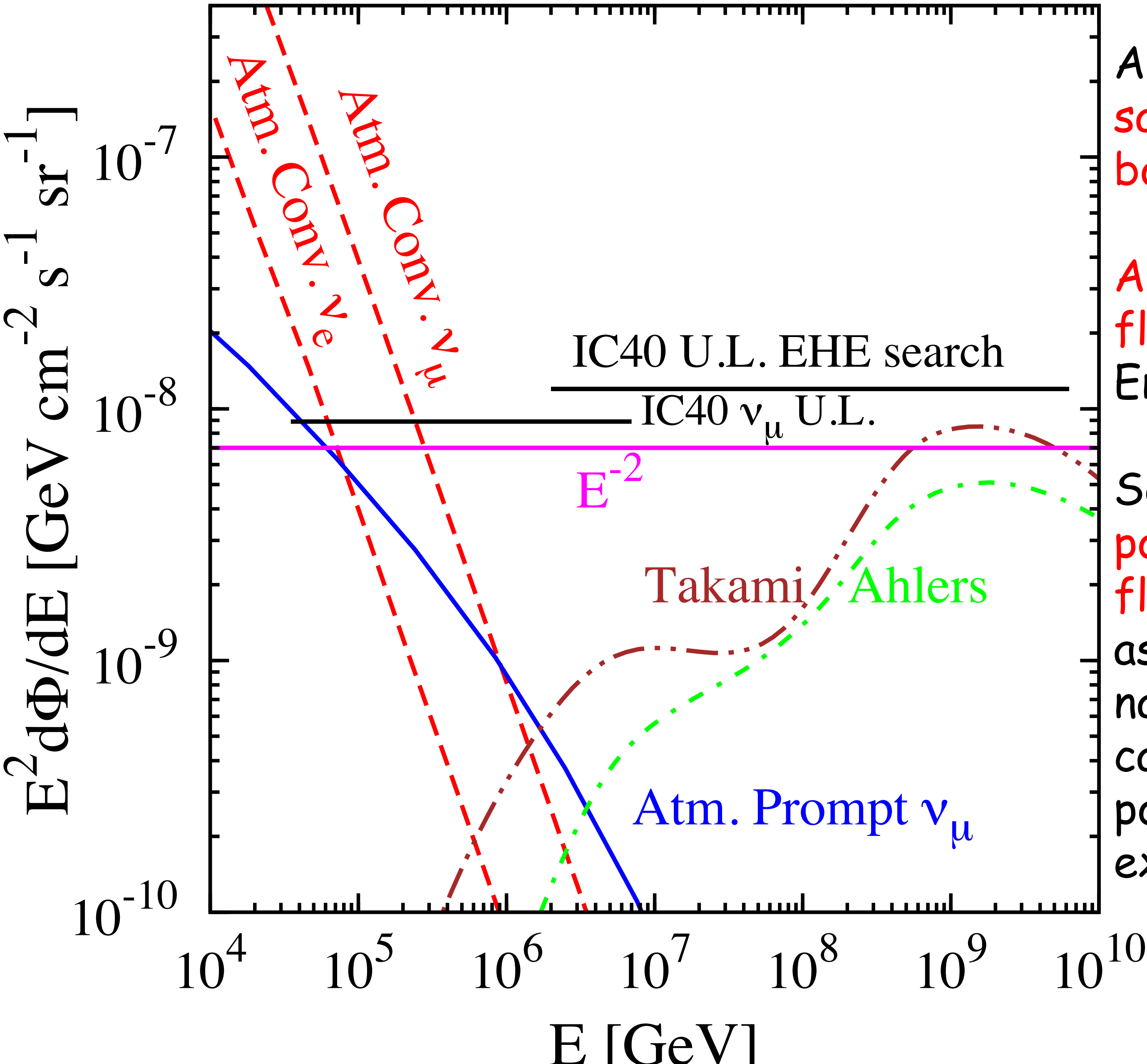
Why are the energies so close?

The threshold of the analysis is ~1 PeV

Due to threshold effect we are unable to infer any information about lower energy spectra

Lack of higher energy events suggest that the neutrino spectrum is steeply falling

Neutrino fluxes considered in this work

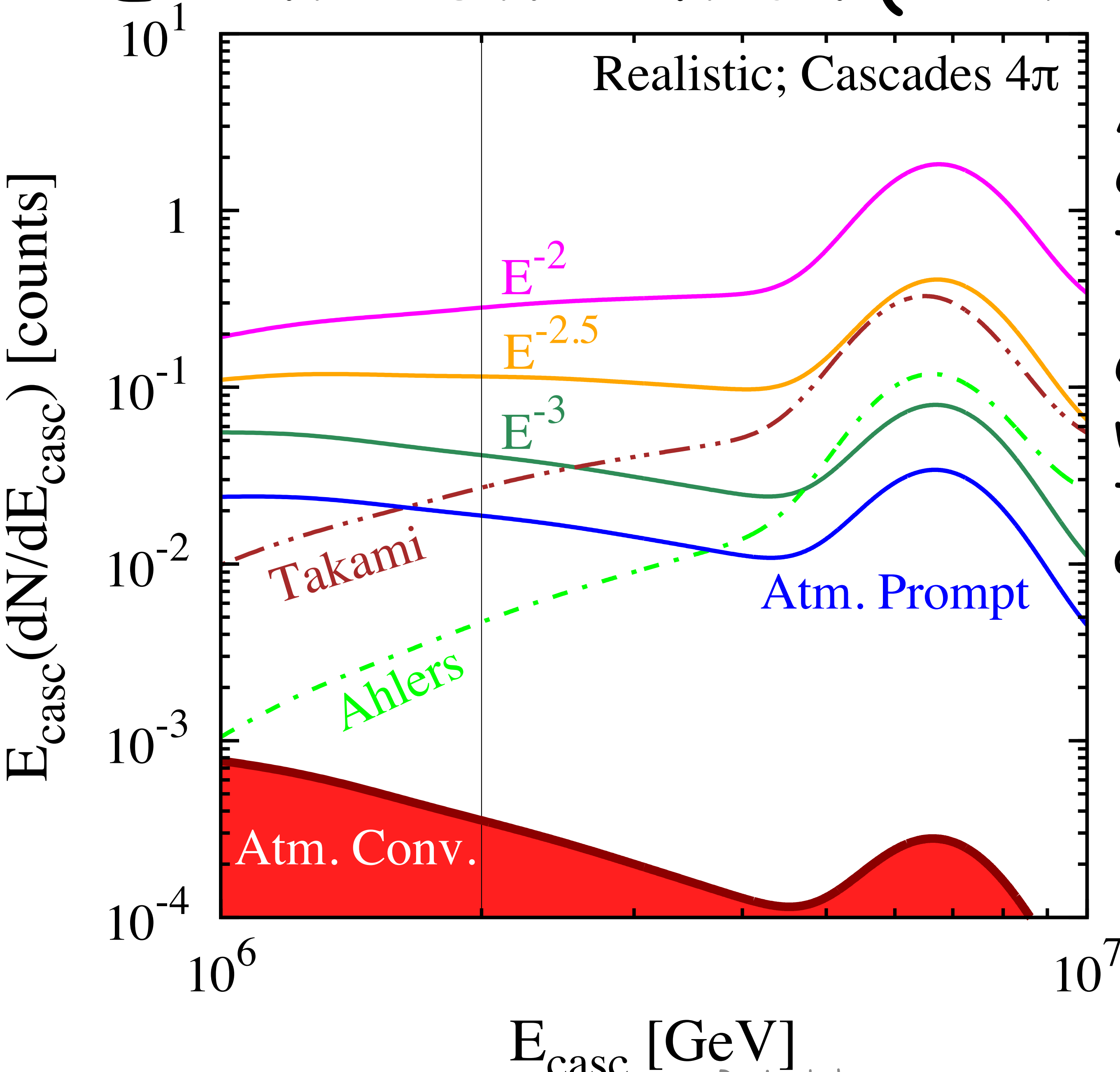


All fluxes chosen to satisfy the previous bounds from IceCube

Atmospheric prompt fluxes taken from Enberg etal

Some representative power law source fluxes taken -- we assume that over a narrow range all fluxes can be described by a power law, but exceptions exist

Event distribution (Real detector)



Atmospheric conventional flux too low

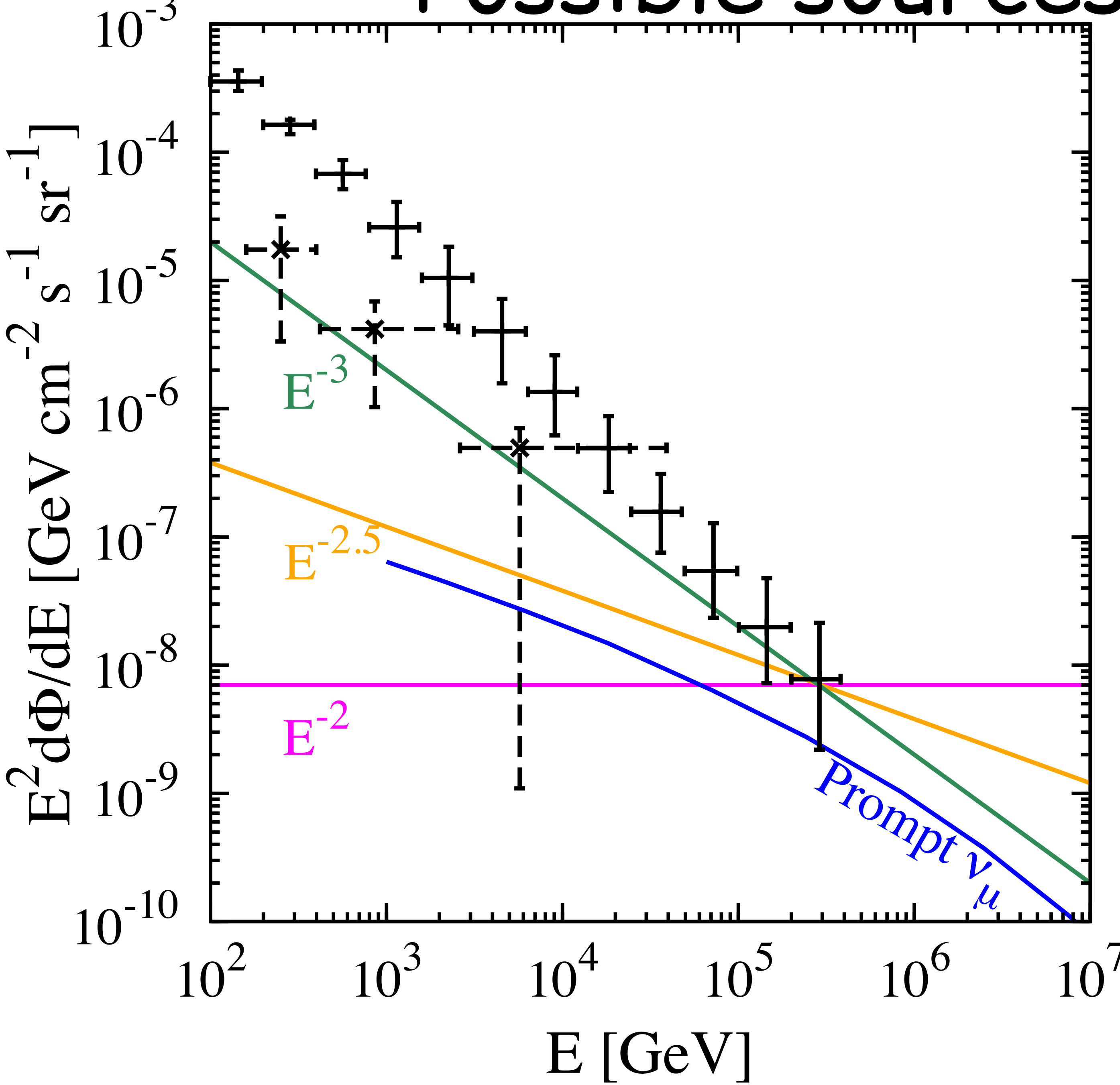
Cosmogenic fluxes will produce vastly too many events at higher energies

What it cannot be

Conventional atmospheric neutrinos – the conventional electron neutrino flux is too low.

Cosmogenic/ GZK neutrinos – the flux peaks at 10^3 PeV – if we see one event in PeV range then we should see numerous events at higher energies

Possible sources



Either diffuse astrophysical source or atmospheric prompt neutrinos

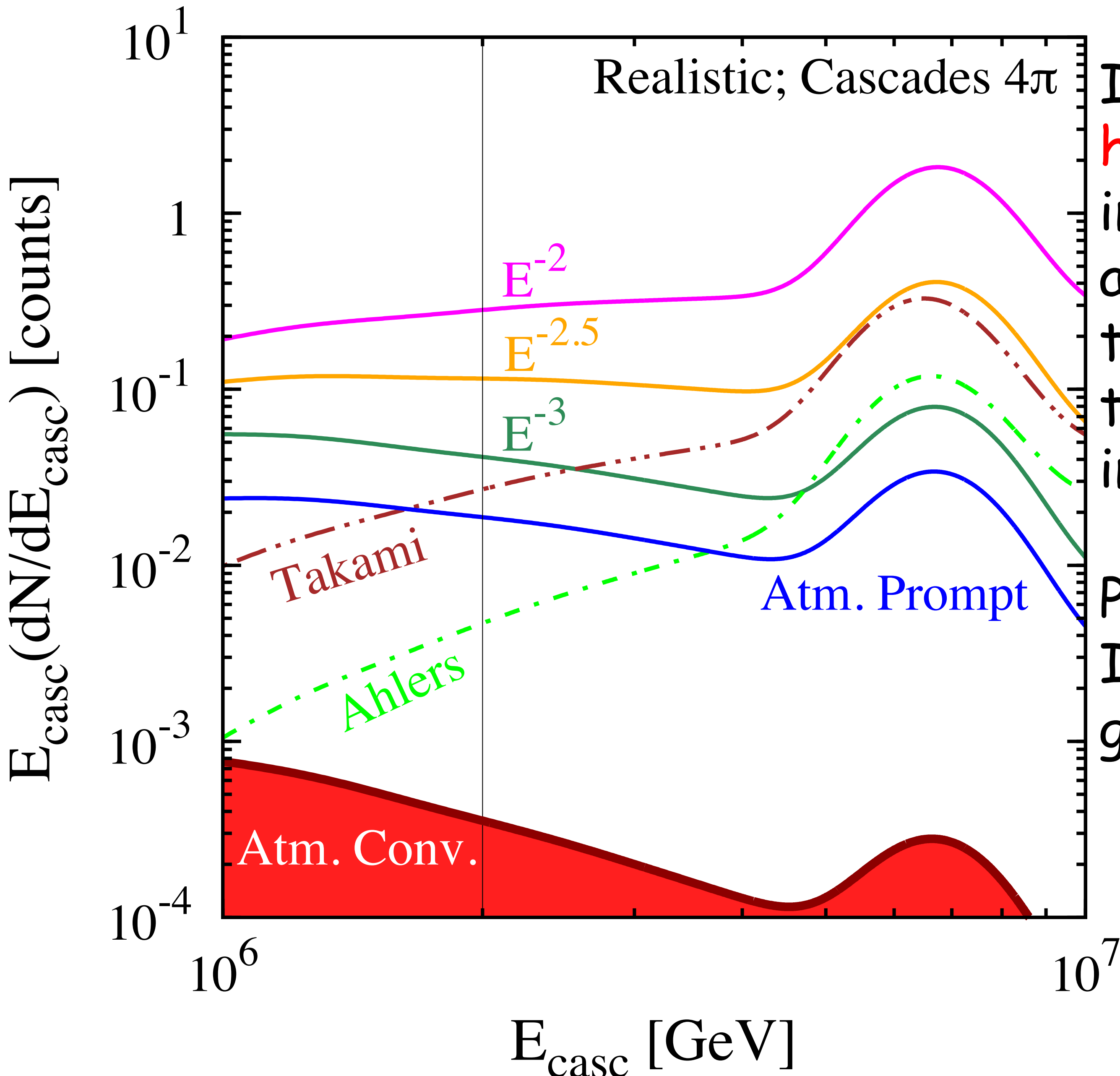
Atmospheric prompt neutrinos

Collisions of cosmic rays with atmospheric nuclei produces short-lived charmed mesons

Due to short lifetime, spectra harder than conventional neutrinos

Uncertain because of hadronic uncertainties, cosmic ray composition

Atmospheric prompt neutrinos



Indication of heavier composition in the cosmic rays at energies greater than 1 PeV disfavor the prompt interpretation

Presence of hits in IceTop is a smoking gun signature.

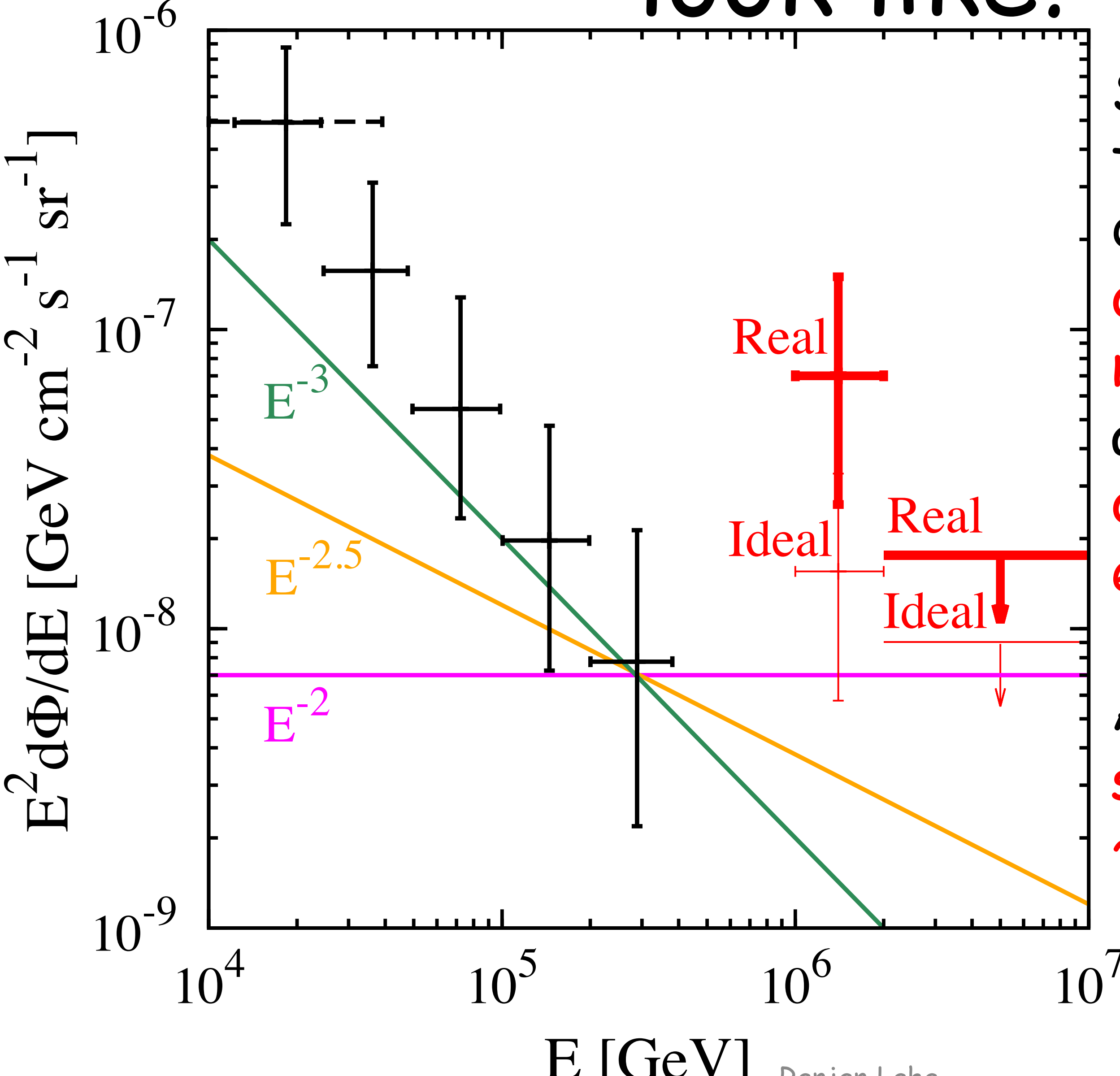
Neutrinos produced inside astrophysical sources

We take 3 representative spectra: E^{-2}, $E^{-2.5}$ & E^{-3}

Tension with the data for unbroken E^{-2} power law – steeper power law like E^{-3} favored

Broken E^{-2} power law which falls steeply beyond ~2 PeV is also favored

What can the neutrino spectrum look like?

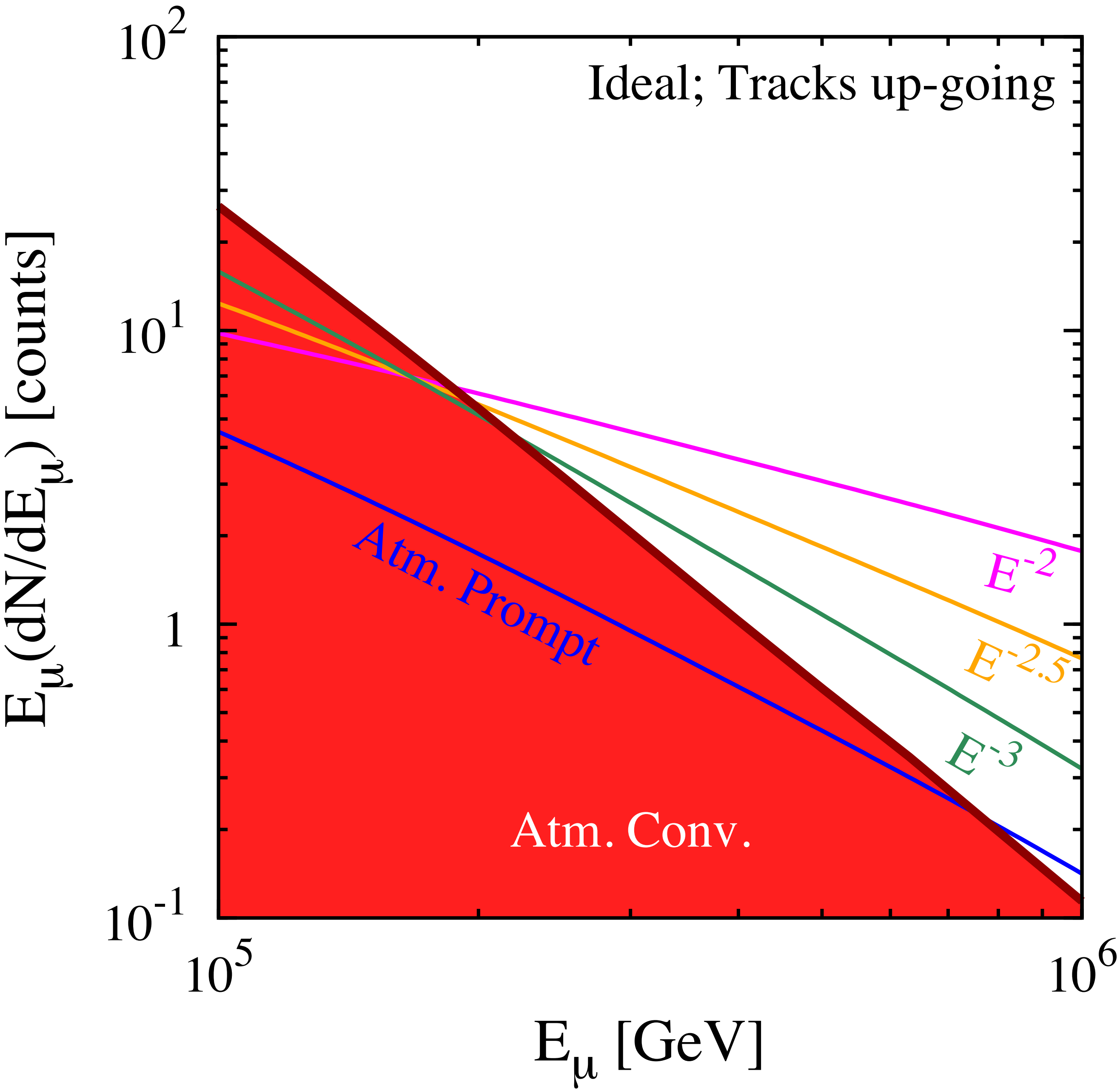


Strong constraints on the flux spectrum due to the observation of two neutrinos at ~ 1 PeV and non observation of neutrinos at higher energies

A break in the spectrum is needed at ~ 2 PeV

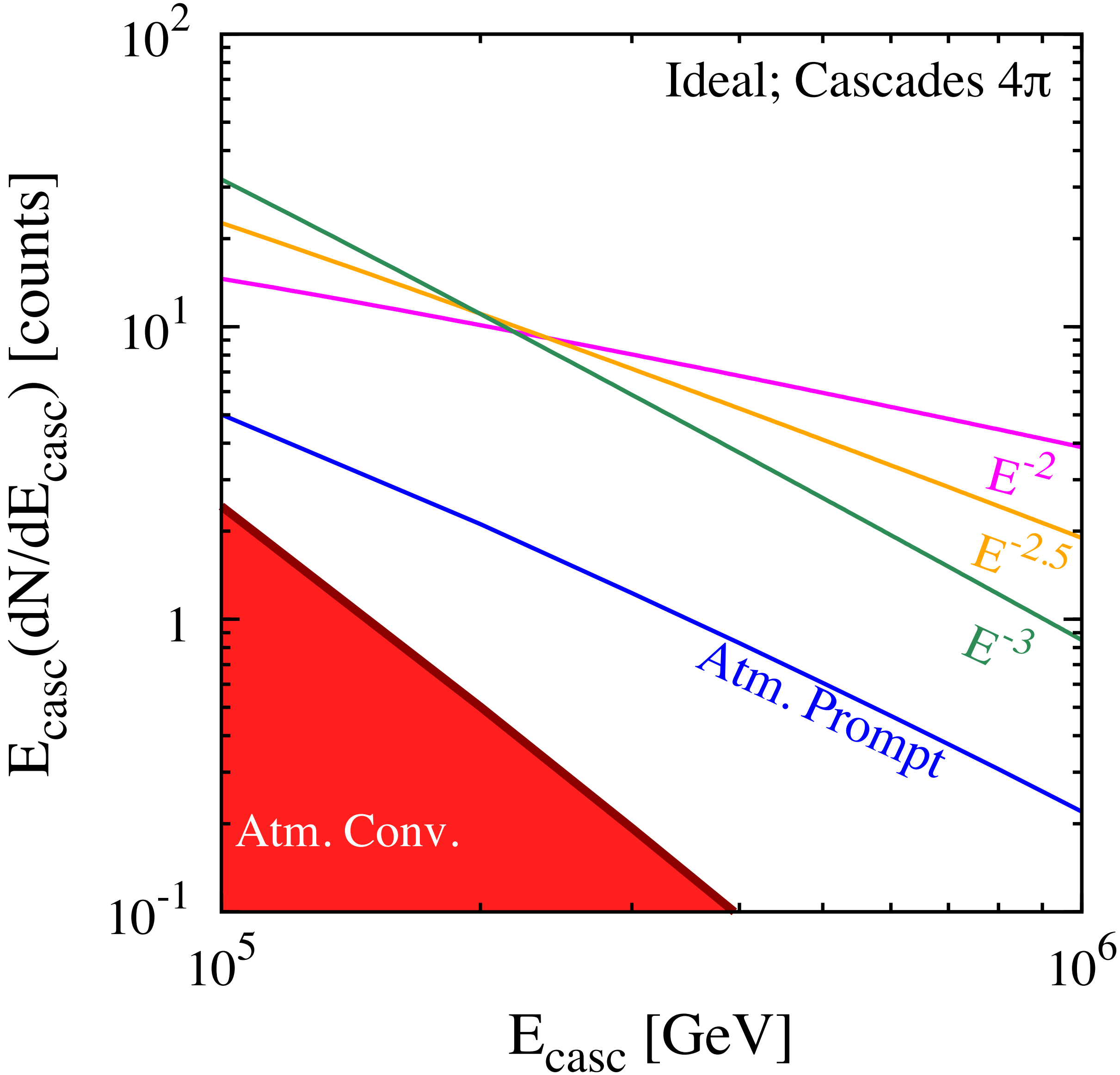
Ranjan Laha

How to know the neutrino spectrum?



Due to the large atmospheric neutrino background, searching for muon tracks is not the best idea – most of the flux is buried under the background

Search for cascades at lower energies

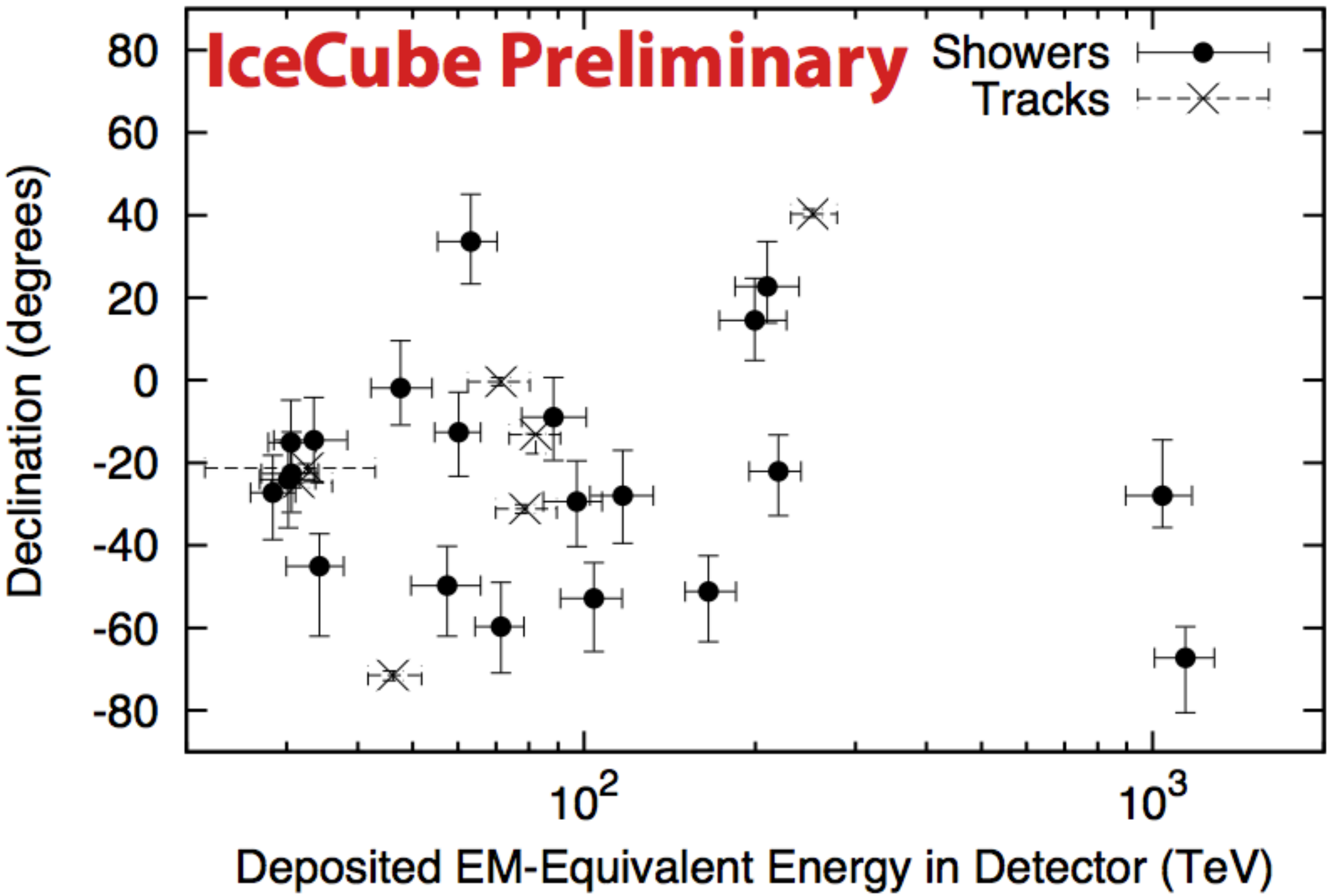


Due to lower atmospheric neutrino background, searching for cascades at lower energies offer the fastest way to distinguish between the spectra

IceTop can be useful for atmospheric prompt neutrino spectra

We estimate that ~ 2 years of data will robustly distinguish between the spectra

What did IceCube find in its new search?



N WHITE - HORN IPA 2013

Conclusions

PeV cascades in IceCube – entry of neutrino astrophysics to the PeV era

Neutrinos produced in astrophysical sources can be the PeV flux observed in IceCube. After the discovery of new events, prompts are disfavored

Searching for neutrinos in the lower energies with cascades will determine the source spectrum in the shortest amount of time