Numerical Relativity Workshop at ICTS

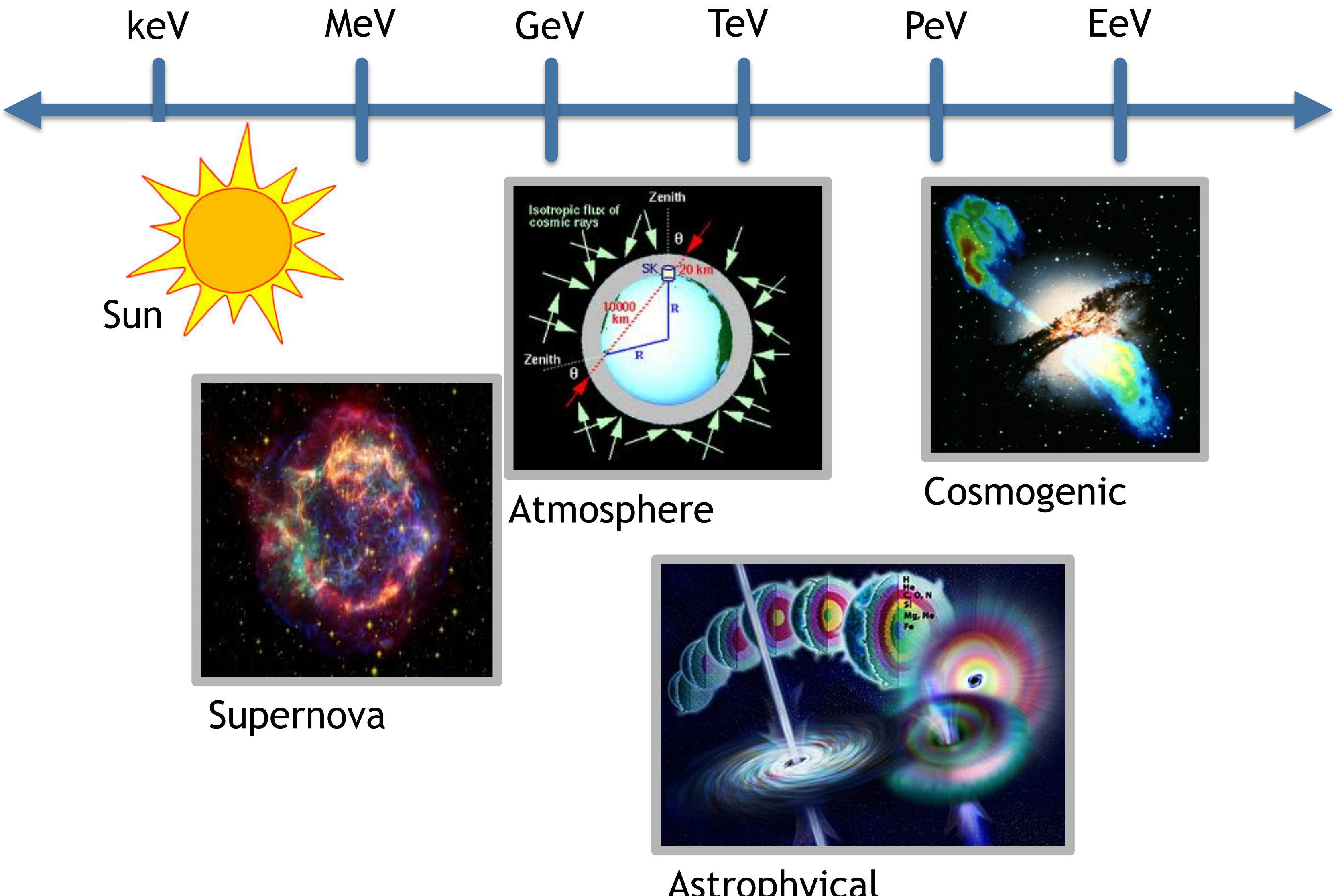
4 July 2013

Neutrino Astronomy and its Synergies with GW Astronomy

Basudeb Dasgupta

ICTP, Trieste

The Neutrino Sky



Anatomy of IceCube

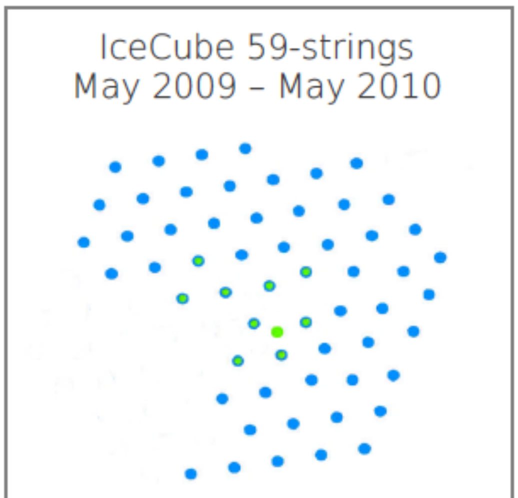
The IceCube Neutrino Observatory

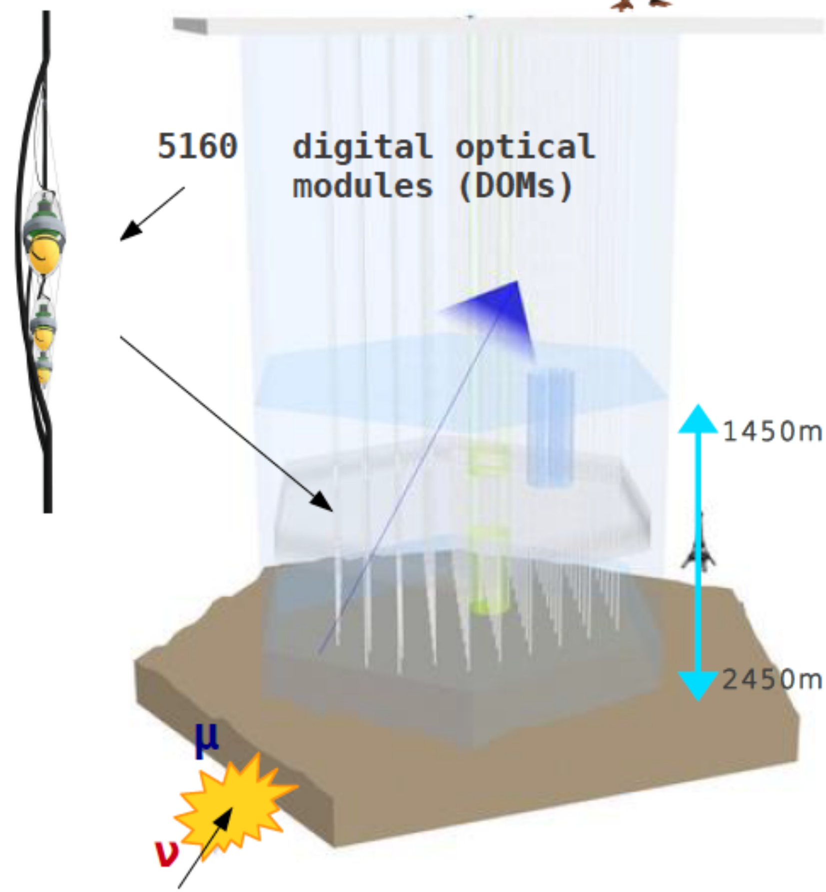
(not to scale)

Detection of high energy neutrinos via Cherenkov light emitted by secondary leptons.

The first km^3 ν detector .

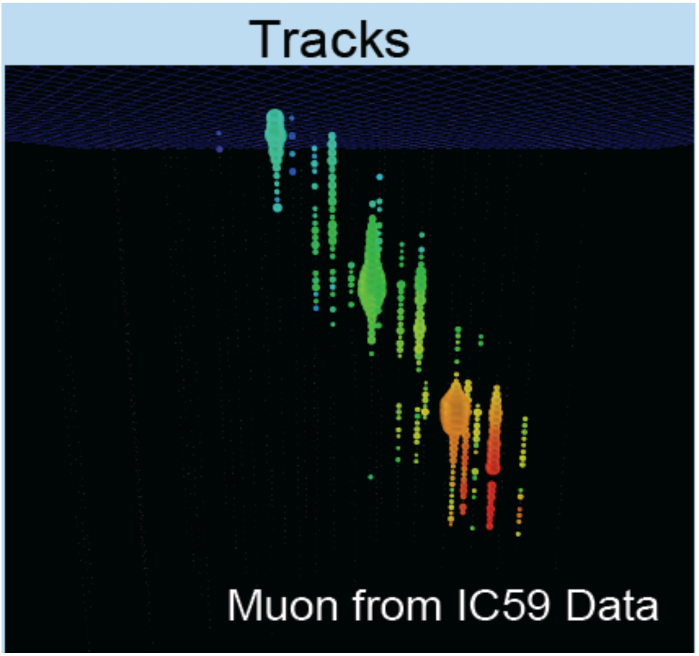
Completed in Dec. 2010!

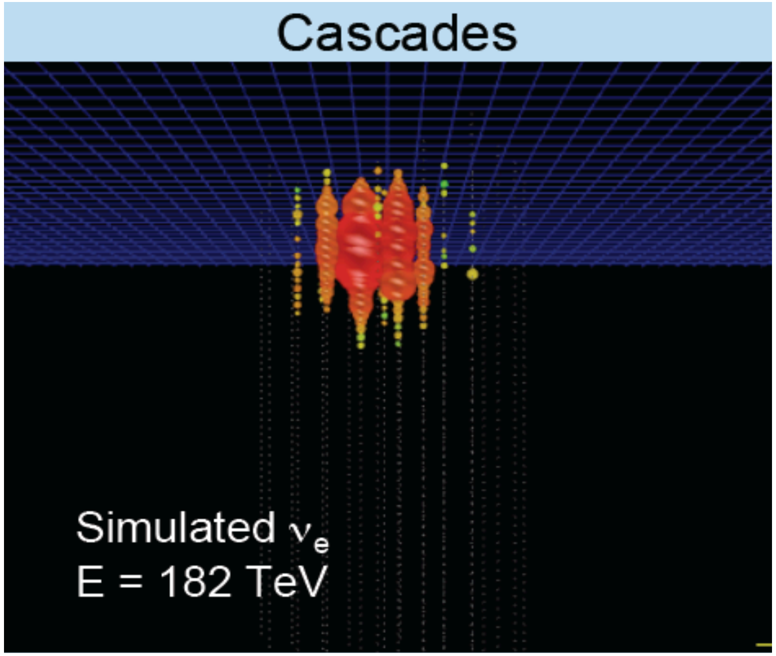




Anne Schukraft NOW2012 5

Two Types of Events





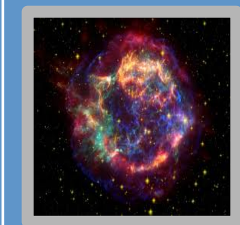
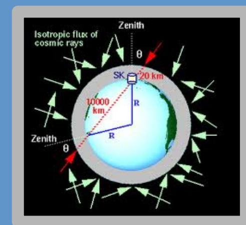
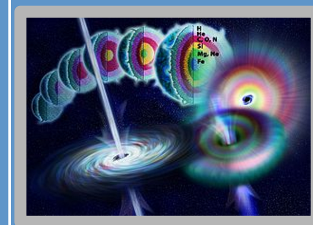
Good Directionality

Mostly muon neutrinos

Good Calorimetry

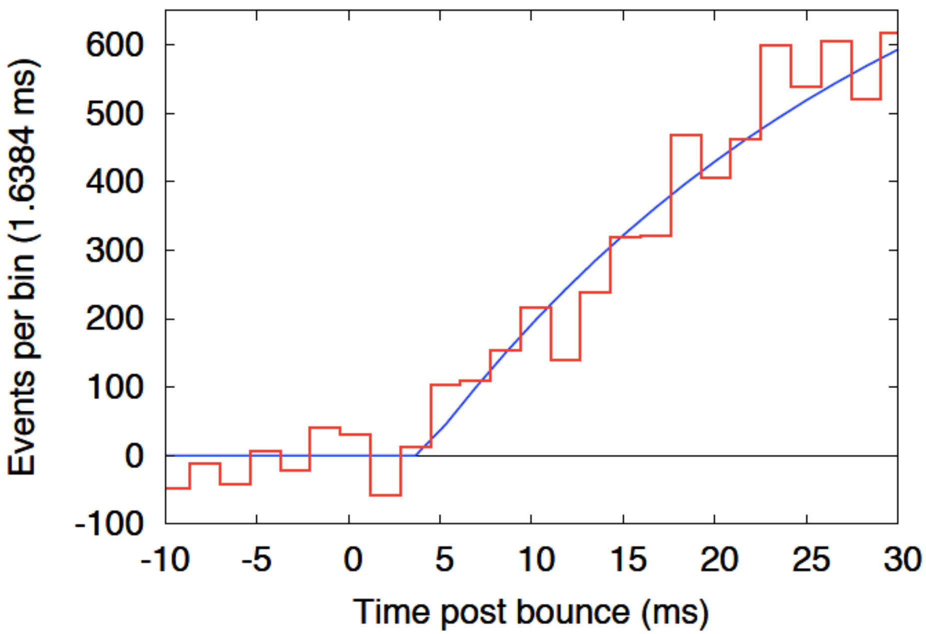
Mostly electron nus + all NC

Physics Universe of IceCube

					
Energy	~MeV	GeV - TeV	TeV - PeV	PeV - EeV	>EeV
Sources	Supernova	Atmospheric ν DM GRB	Atm.- Prompt GRB AGN Galaxies Clusters	GZK GRB AGN Galaxies Clusters	?
Signature	Increase in noise rate	Tracks (Up) Cascades	Tracks (Down) Cascades		

MeV Neutrino Astronomy

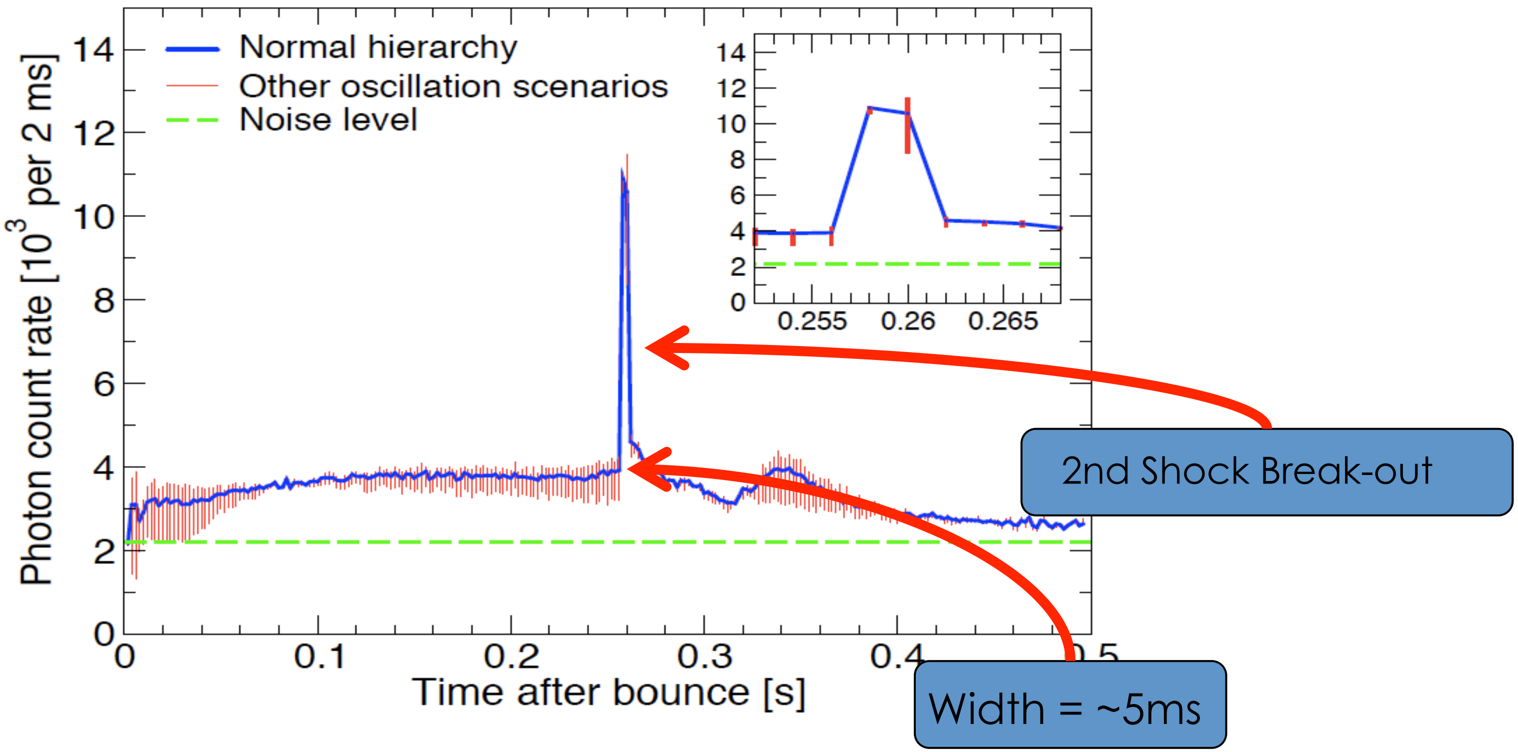
Timing and GW Coincidence



SN neutrino-curve is an excellent probe of the bounce time. This can be used to great advantage for coincidence measurement with gravitational wave detectors

Pagliaroni, Vissani, Coccia and Fulgione, arXiv:0903:1191 (PRL)
Halzen and Raffelt, arXiv:0908.2317 (PRD)

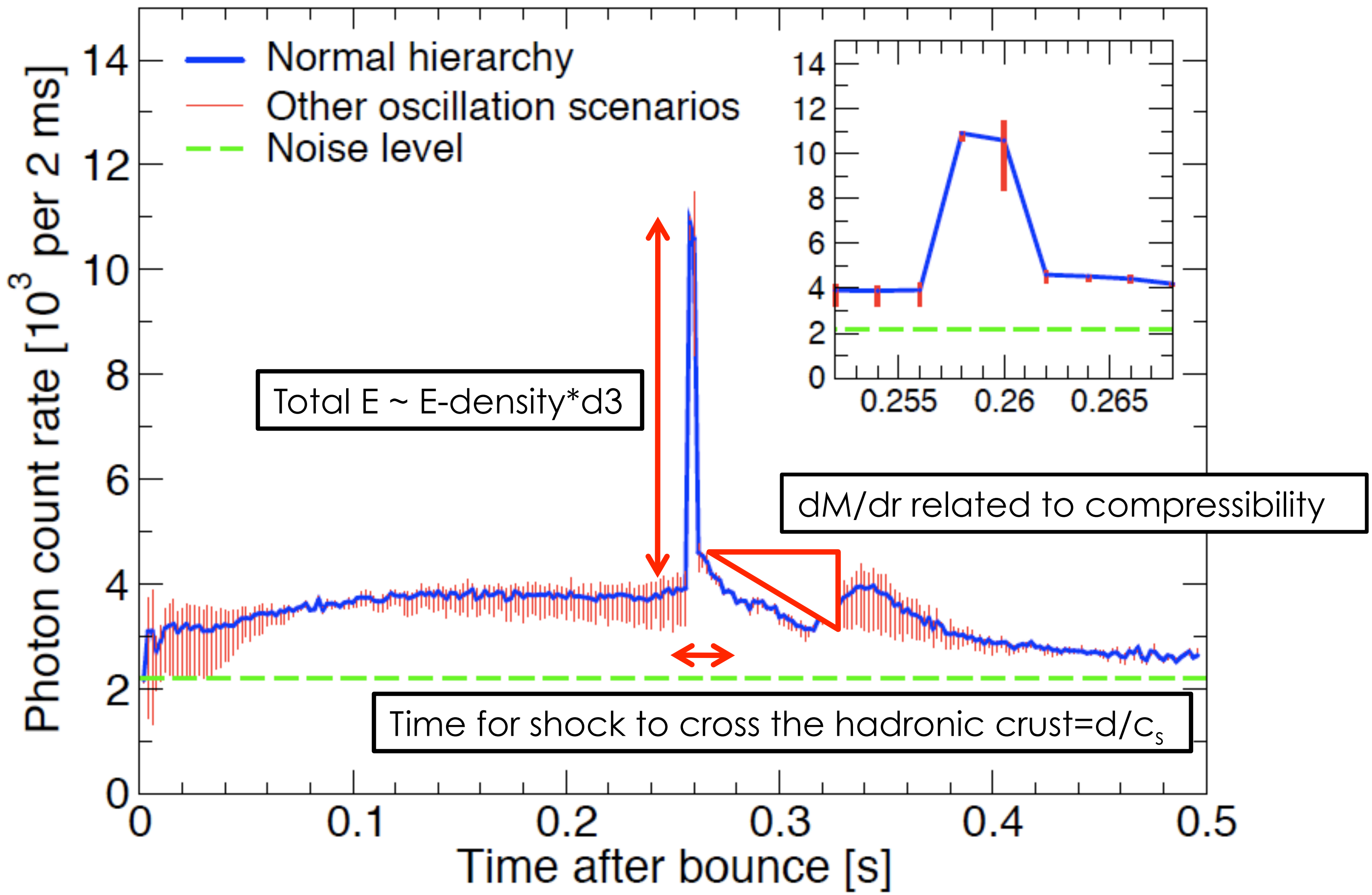
QCD Burst



Sagert, Fischer, Hempel, Pagliara, Schaffner-Bielich, Mezzacappa, Thielemann, and Liebendoerfer, arXiv:0809.4225 (PRL)

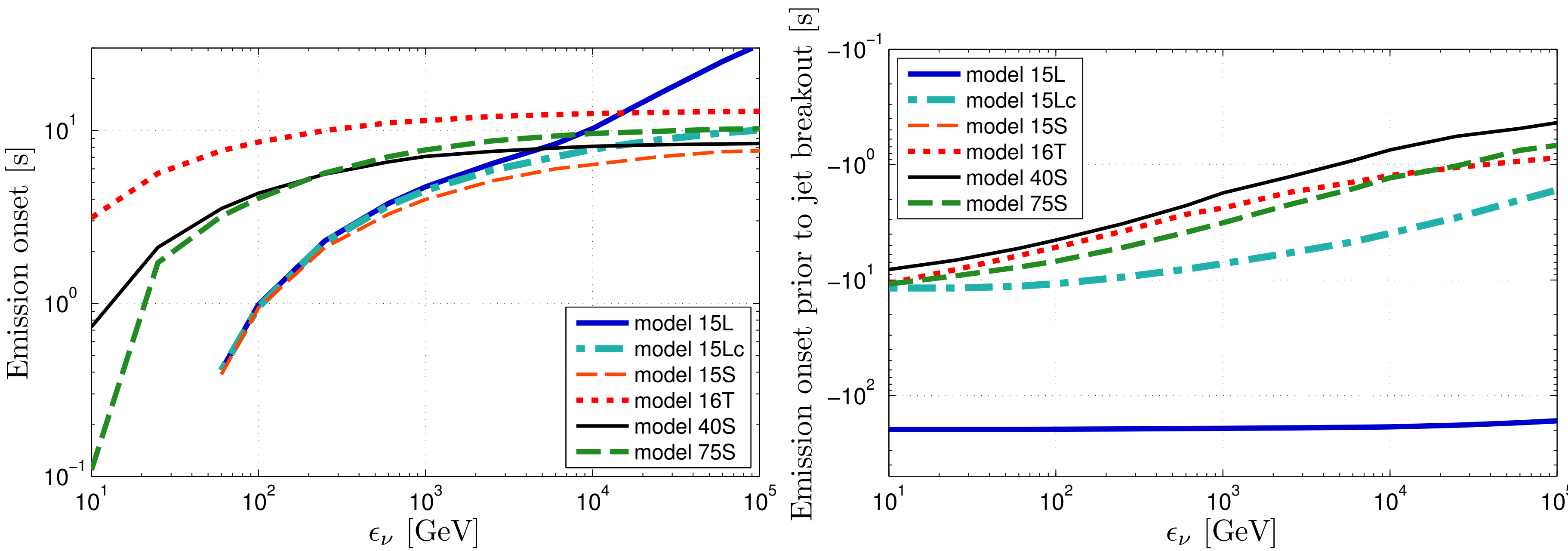
Dasgupta, Fischer, Horiuchi, Liebendorfer, Mirizzi, Sagert and Schaffner-Bielich arXiv:0912.2568 (PRD)

Probing Dense Matter



GeV - PeV Neutrino Astronomy

GRB Tomography



What can we say if we see only 1 or 2 events?

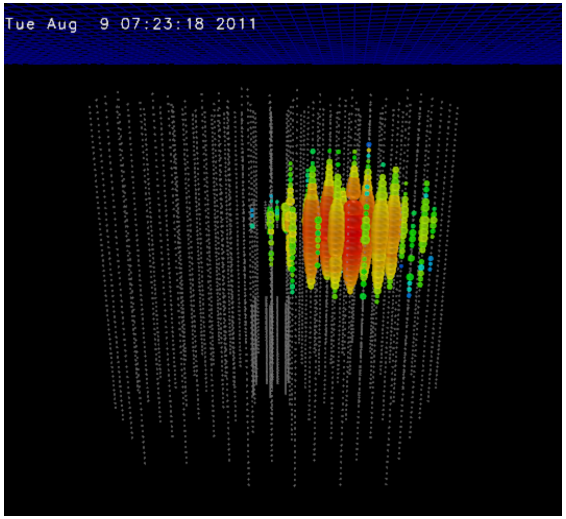
Razzaque, Meszaros, Waxman (many papers)
Bartos, Dasgupta, Marka, arXiv:1206.0764 (PRD)

TeV - PeV Neutrino Astronomy

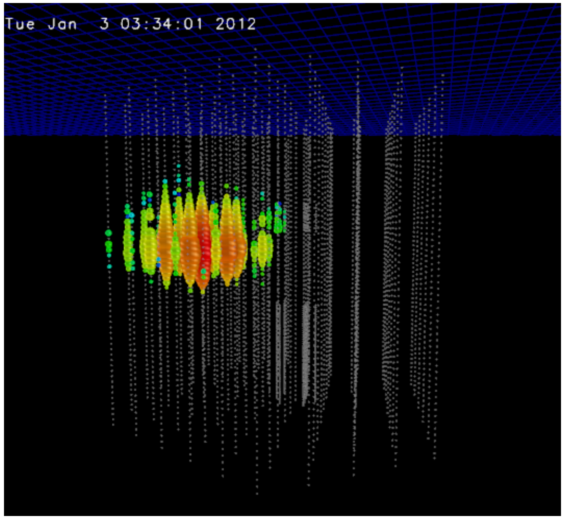
Two Events

Results (2.8σ)

Appearance of ~ 1 PeV neutrinos at lower energy threshold



"Bert"
~ 1050 TeV

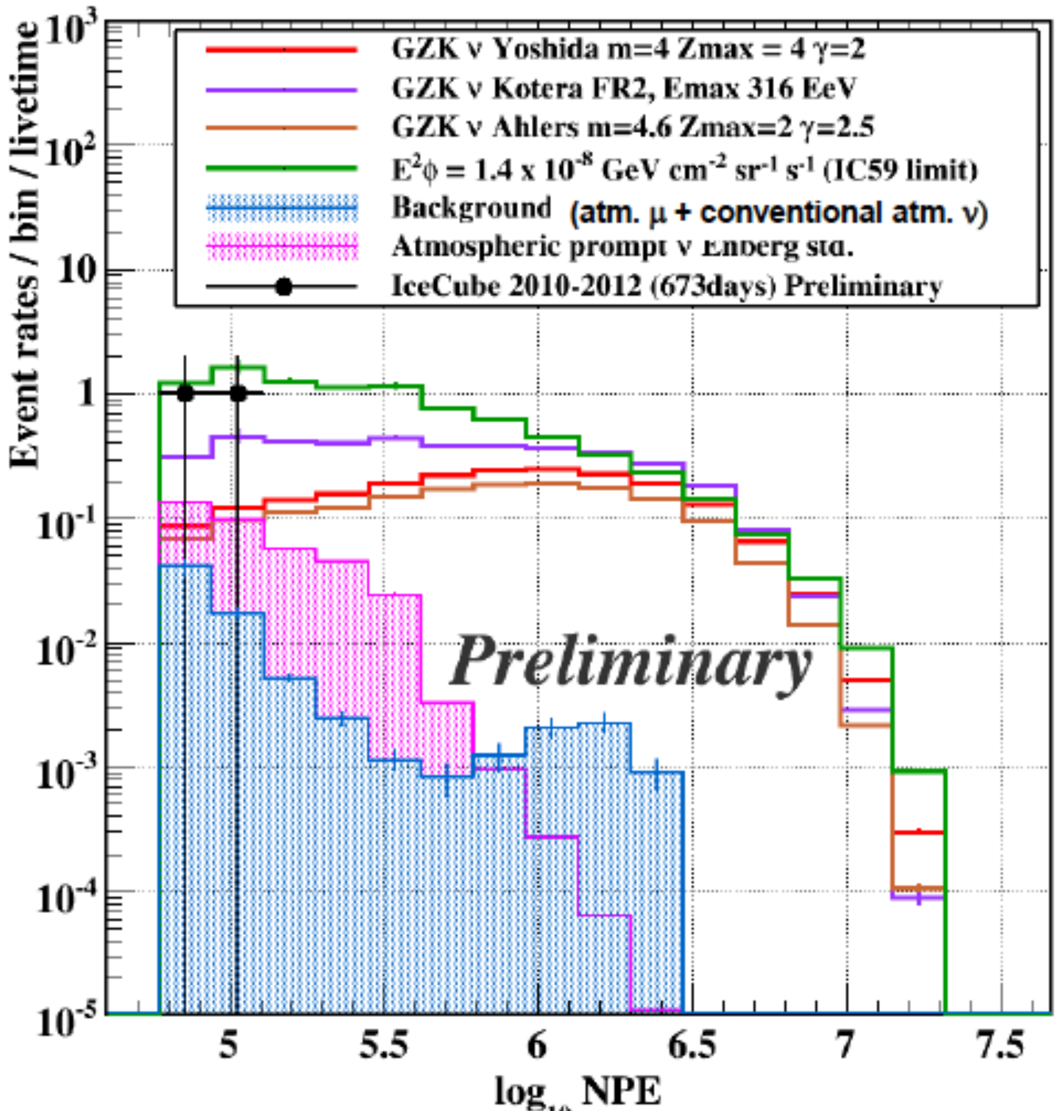


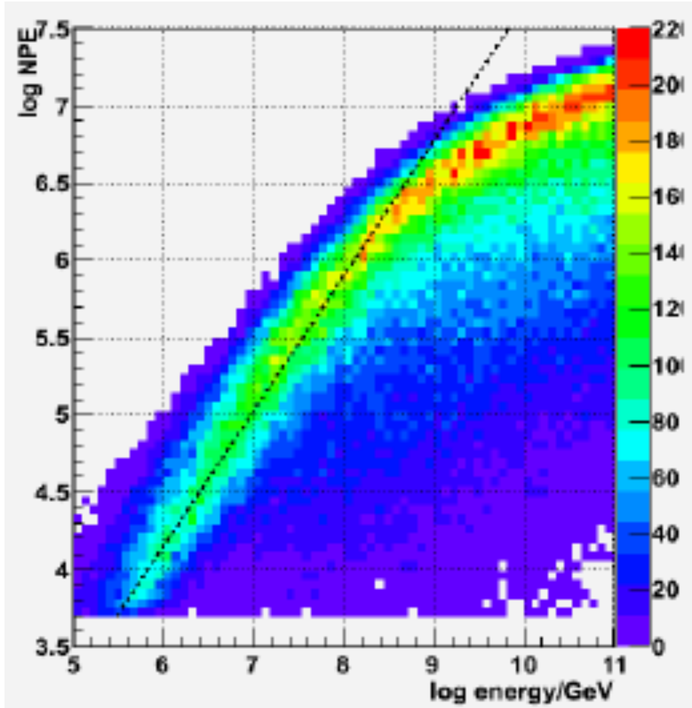
"Ernie"
~ 1150 TeV
arXiv:1304.5356

Run119316-Event36556705
Jan 3rd 2012
NPE 9.628×10^4
Number of Optical Sensors 312

Run118545-Event63733662
August 9th 2011
NPE 6.9928×10^4
Number of Optical Sensors 354

What are we seeing?





Ishihara, Neutrino 2012

We have two cascade events with ~1.04 PeV and ~1.14 PeV

Demystifying the PeV Cascades in IceCube: Less (Energy) is More (Events)

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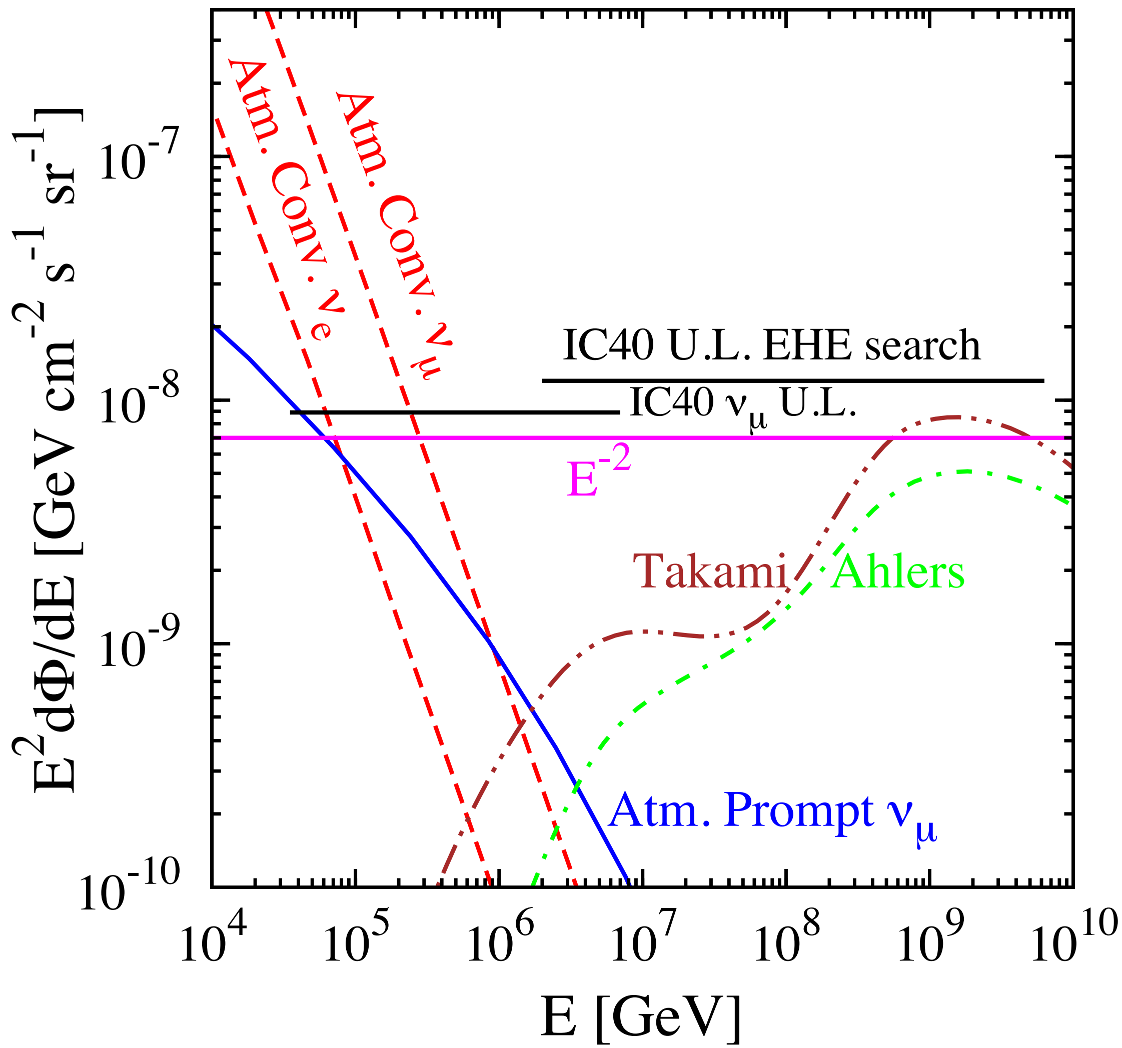
(Dated: June 2, 2013)

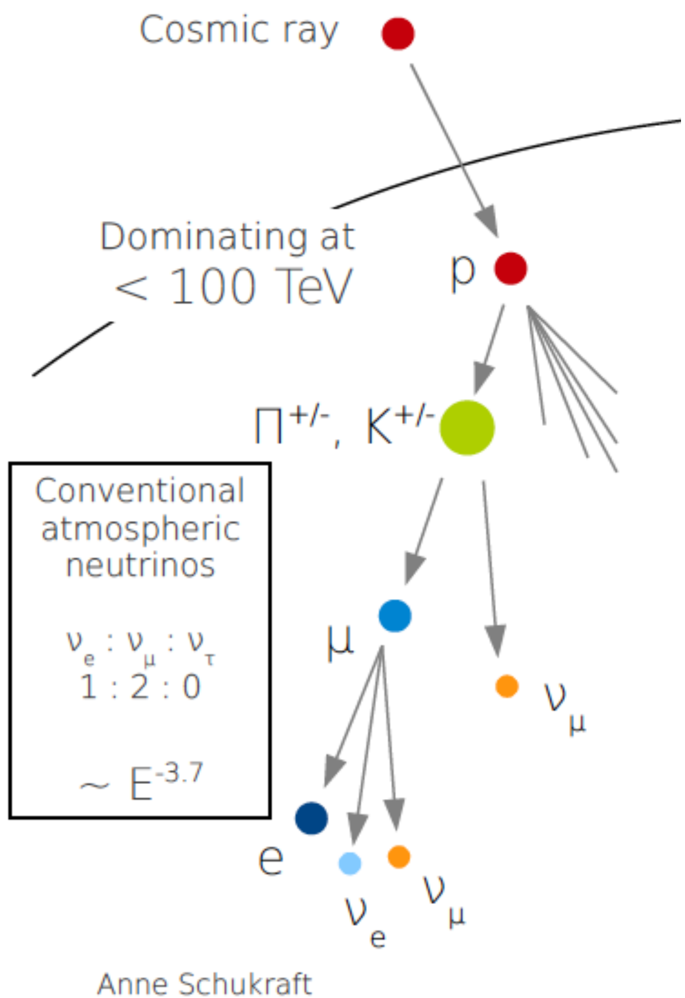
The IceCube neutrino telescope recently detected two cascade events with energies near 1 PeV. Without invoking new physics in the neutrino sector, we analyze the source of these neutrinos. We show that atmospheric conventional neutrinos and cosmogenic neutrinos (those produced in the propagation of ultra-high-energy cosmic rays) are strongly disfavored. For atmospheric prompt neutrinos or a diffuse background of neutrinos produced in astrophysical objects, the situation is less clear. We show that there are tensions with observed data, but that the details depend on the least-known aspects of the IceCube analysis. Likely, prompt neutrinos are disfavored and astrophysical neutrinos are plausible. We demonstrate that the fastest way to reveal the origin of the observed PeV neutrinos is to search for neutrino cascades in the range below 1 PeV, for which dedicated analyses with high sensitivity have yet to appear, and where many more events could be found.

arXiv:1306.2309 (submitted to PRD)

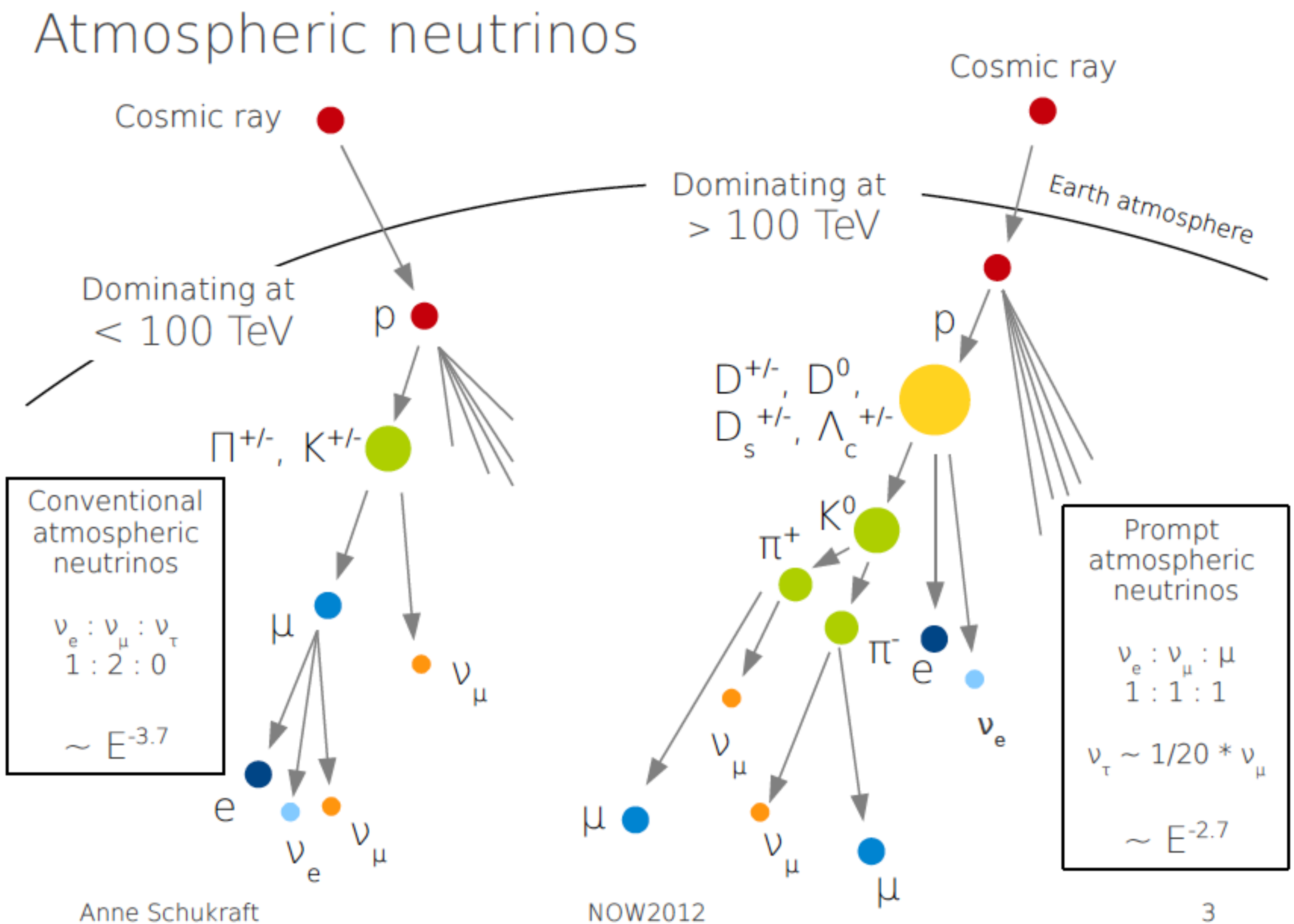
What are the relevant fluxes?



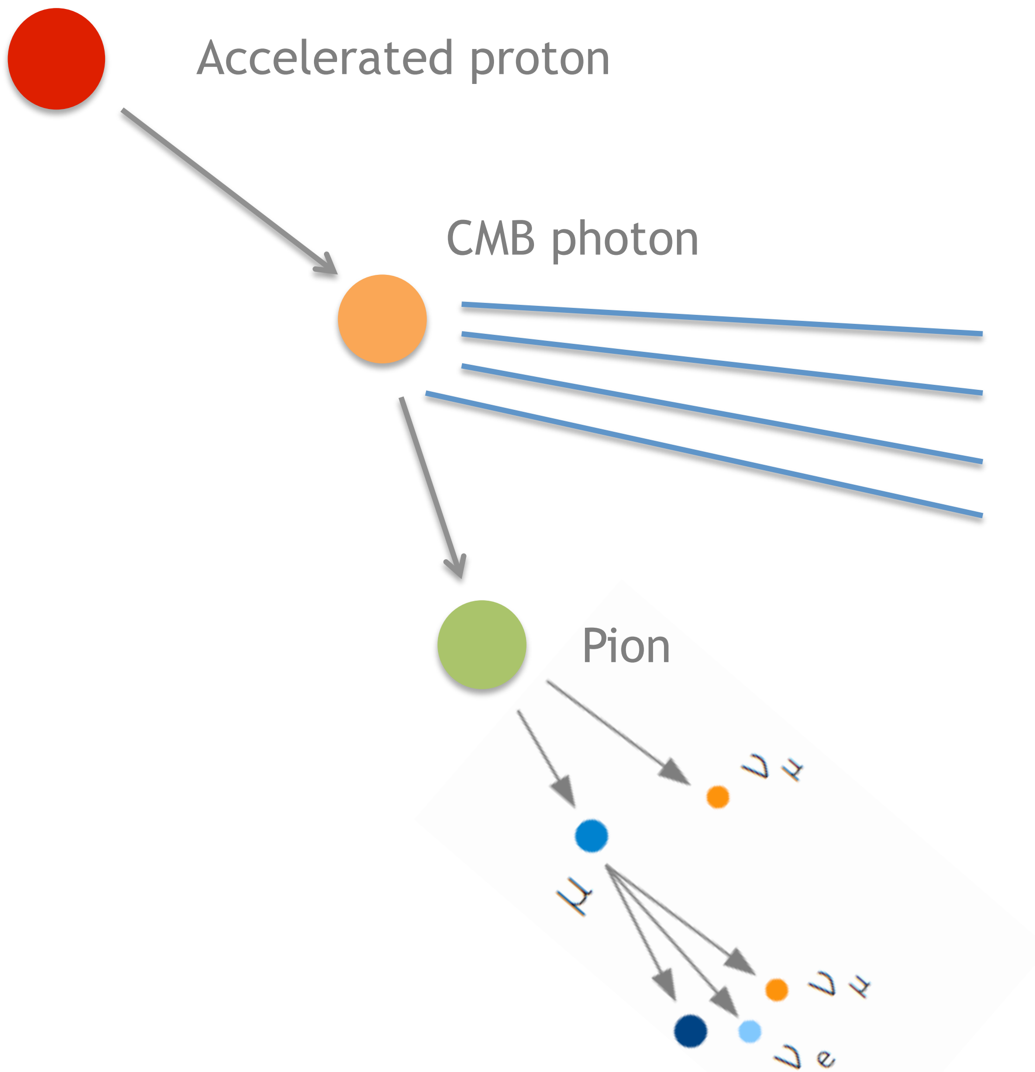
Atmospheric Neutrinos



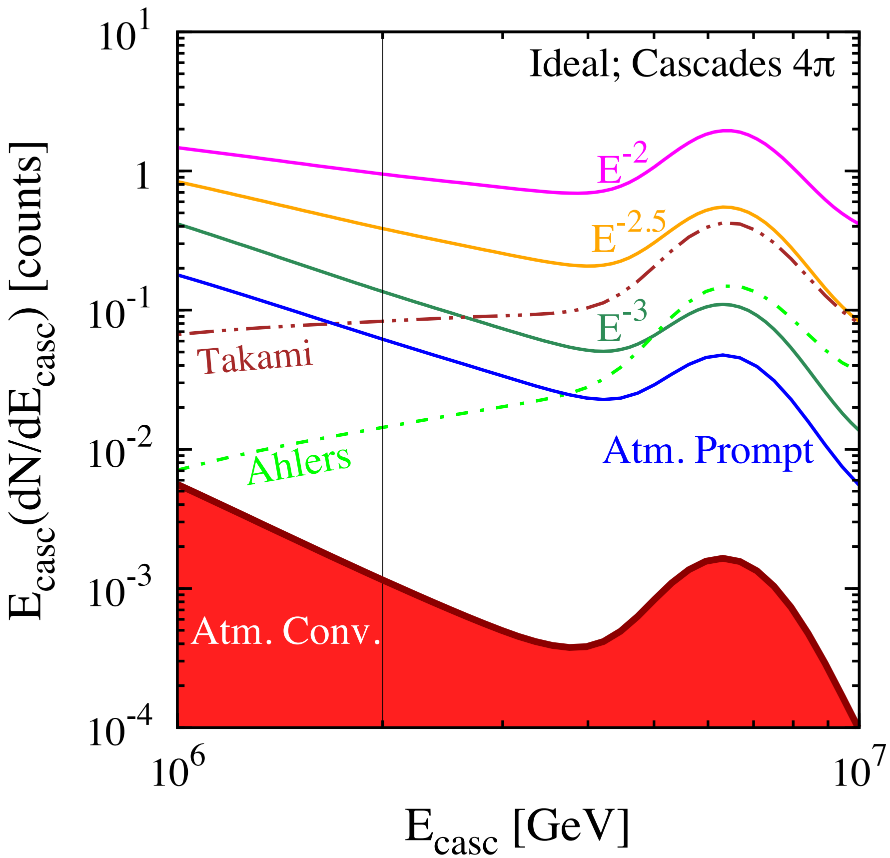
Prompt Atmospheric Neutrinos

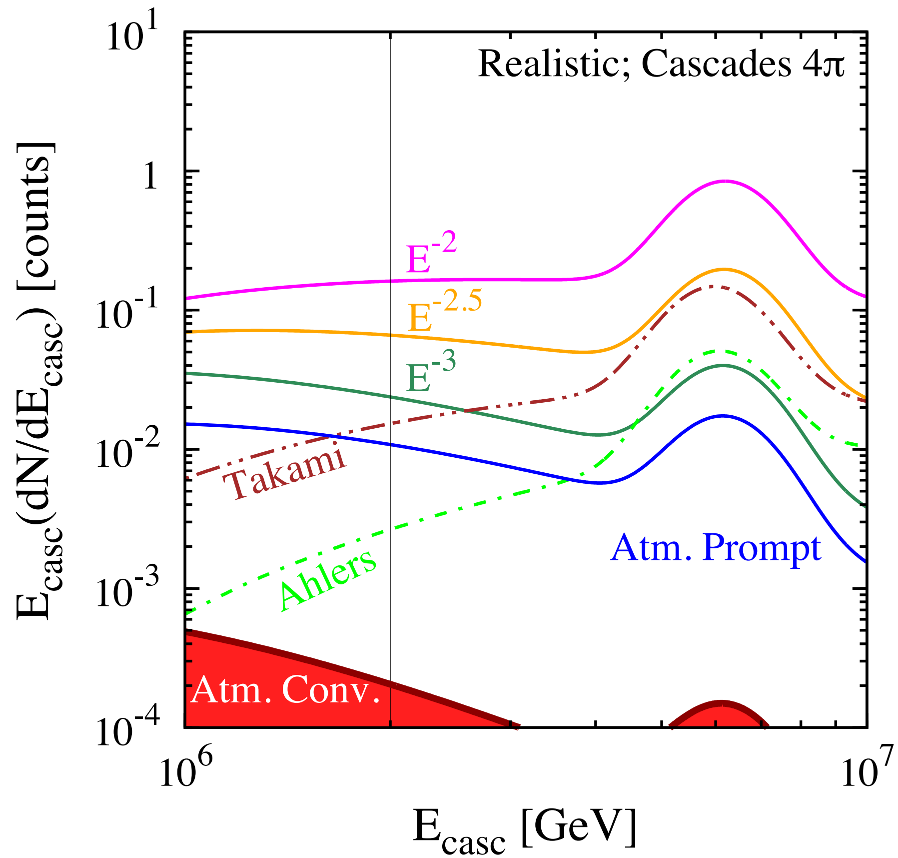


Cosmogenic Neutrinos



Theory vs Experiment



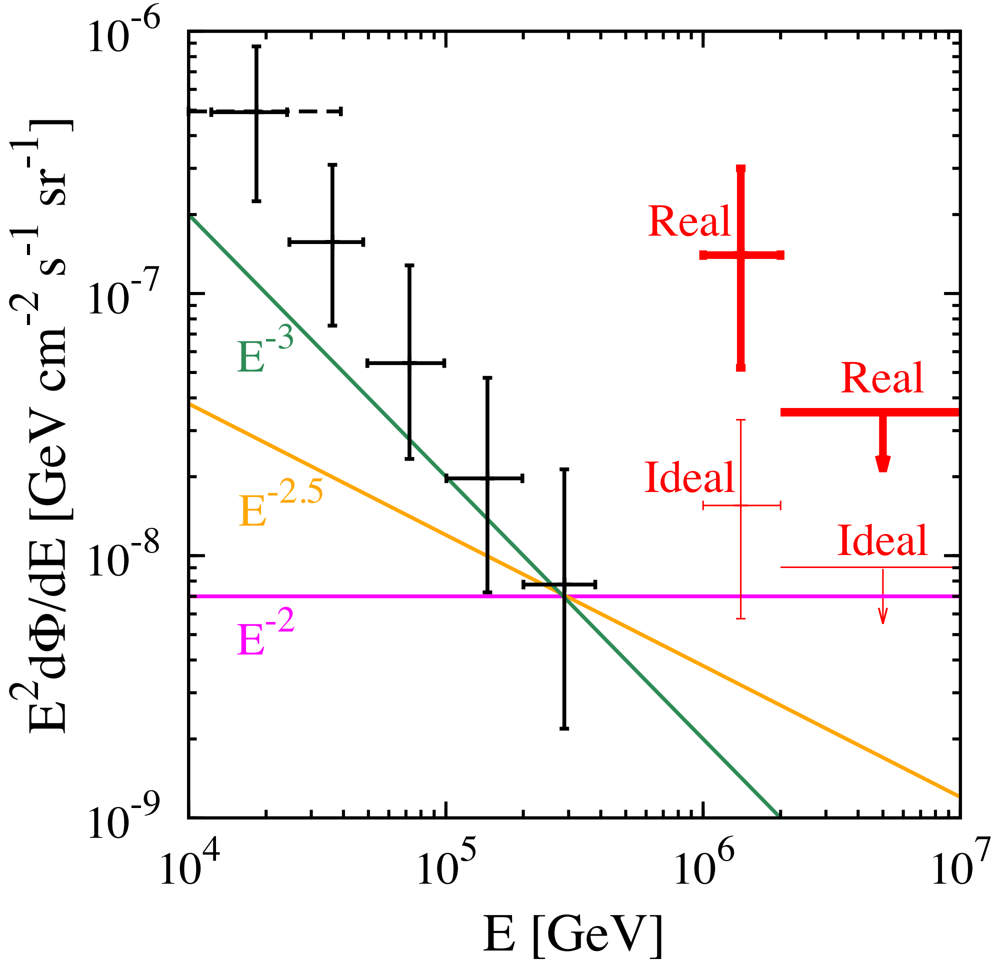


How many events were expected?

TABLE I. Expected numbers of cascade events in the two energy bins, obtained by integrating the curves in the right panel (the realistic approach using the effective area) of Fig. 3. These numbers are typically a factor of ~ 10 below those for the left panel (the ideal case or "theorist's approach").

Possible Source	N(1 – 2 PeV)	N(2 – 10 PeV)
Atm. Conv. [48]	0.0002	0.0002
Cosmogenic–Takami [36]	0.007	0.07
Cosmogenic–Ahlers [35]	0.001	0.03
Atm. Prompt [49]	0.01	0.01
Astrophysical E^{-2}	0.1	0.5
Astrophysical $E^{-2.5}$	0.04	0.13
Astrophysical E^{-3}	0.02	0.03

What the spectrum must be

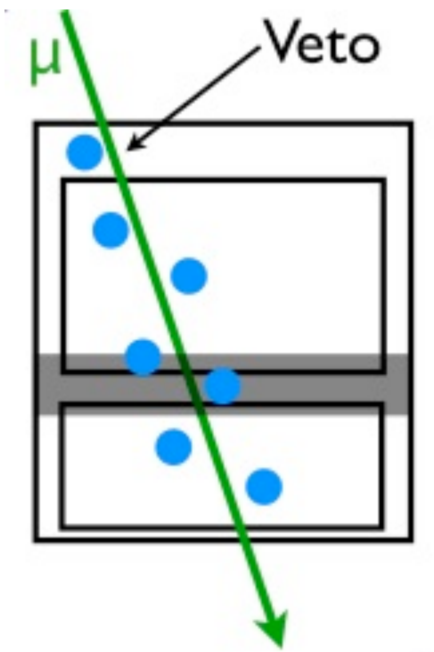


Predictions at lower energies

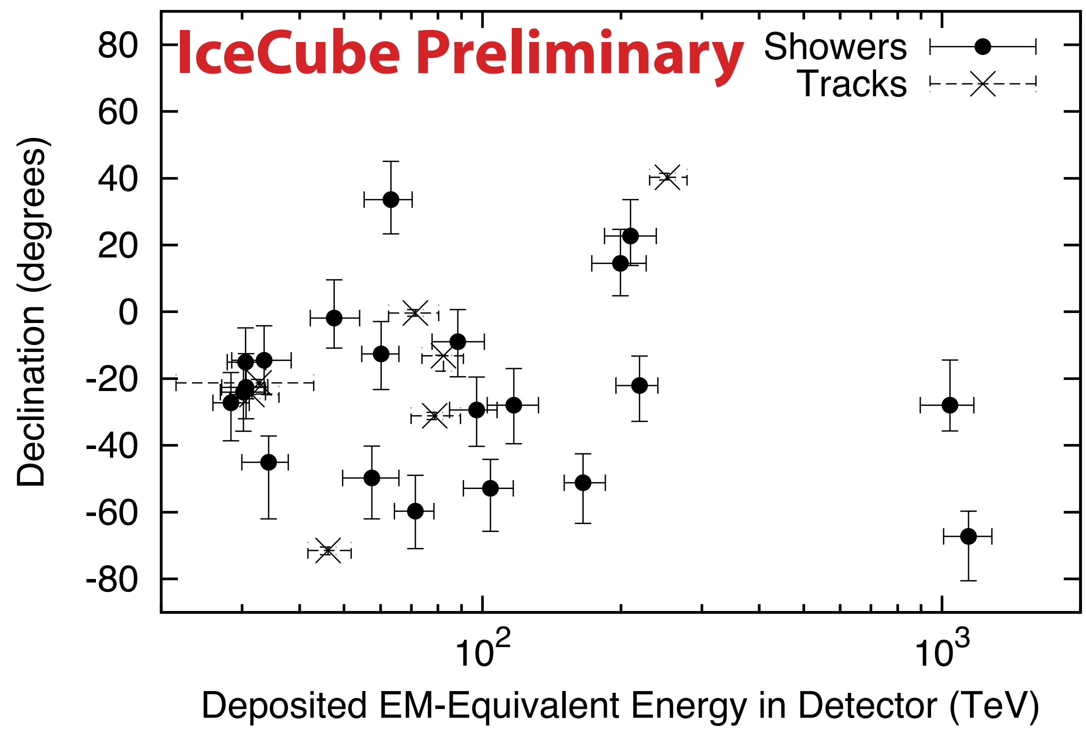
TABLE II. Expected numbers of track and cascade events (ideal case or "theorist's approach"), obtained by integrating the curves in each panel of Fig. 5 over the range 0.1–1 PeV.

Possible Source	N_{track}	N_{casc}
Atm. Conv. [45]	11	1
Atm. Prompt [46]	3	4
Astrophysical E^{-2}	11	19
Astrophysical $E^{-2.5}$	10	20
Astrophysical E^{-3}	9	20

More data for contained events



Results of Contained Vertex Event Search (4.3σ)

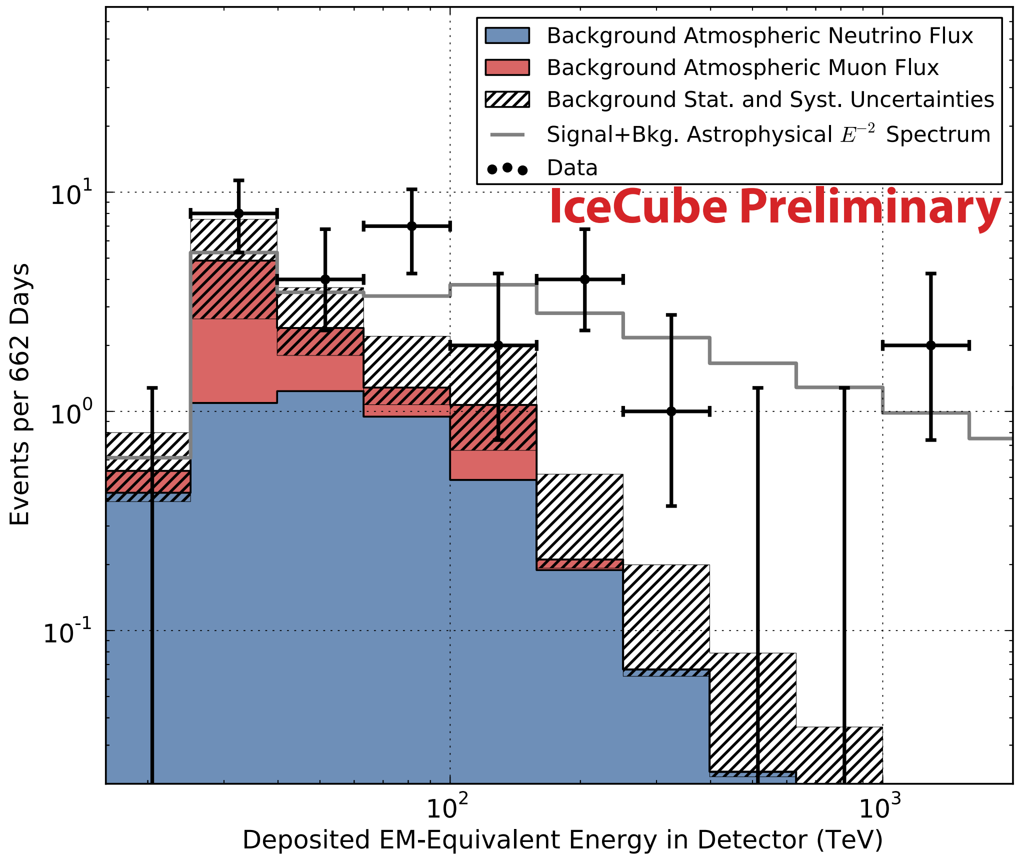


28 events (7 with visible muons, 21 without) on background of $10.6^{+4.5}_{-3.9}$ (12.1 ± 3.4 with reference charm model)

IceCube Talk at IPA

Energy Spectrum

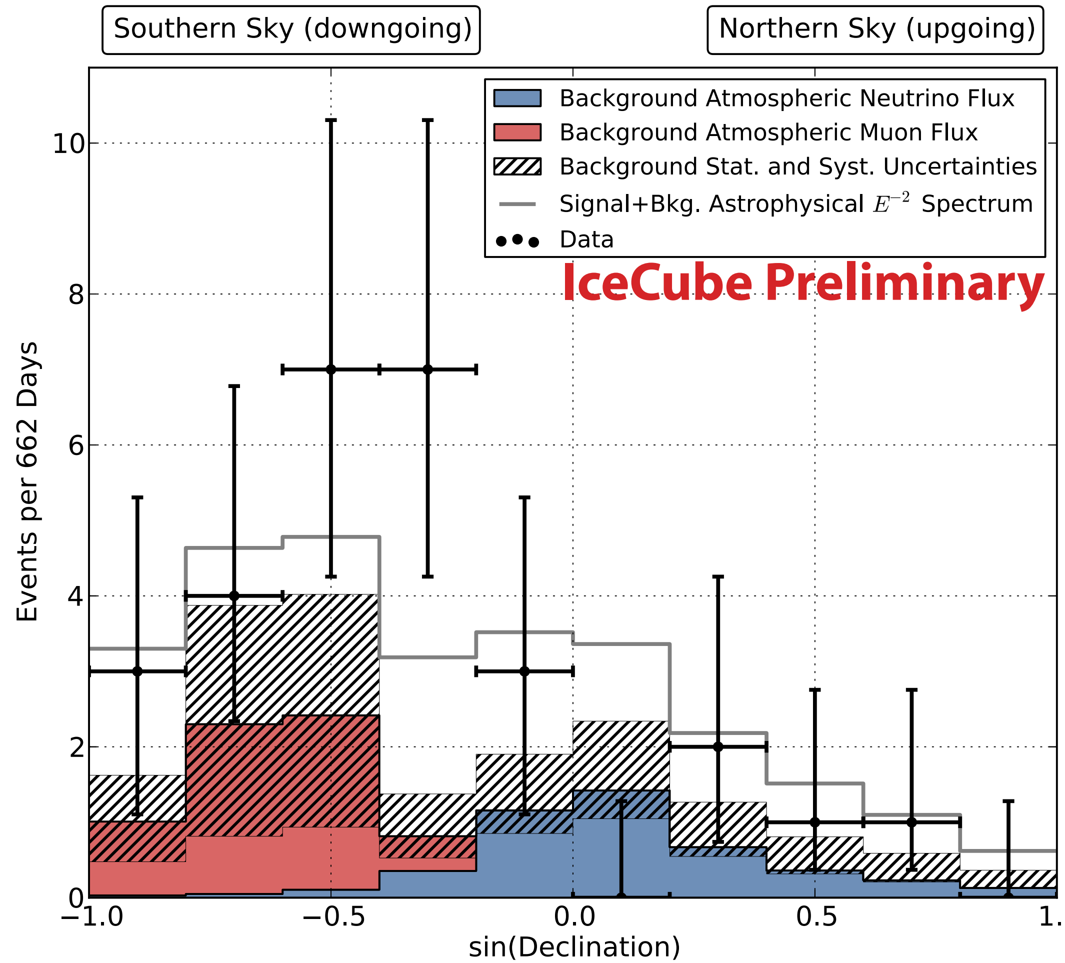
- Harder than any expected atmospheric background
- Merges well into expected backgrounds at low energies
- Potential cutoff at $1.6^{+1.5}_{-0.4}$ PeV



IceCube Talk at IPA

Directionality

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



IceCube Talk at IPA

What the astro sources could be

Source	Mechanism	Comments
AGN Jets	Proton-gamma	Peaks at 10-1000 PeV.
AGN Core	Proton-gamma	OK
GRB prompt	Proton-gamma	OK, but violates IC limit
GRB afterglow	Proton-gamma	Peaks at 10-1000 PeV
Starburst Galaxies	Proton-Proton	OK. Cutoff possible
Galaxy Clusters	Proton-Proton	OK. Break possible

Partners in Crime

Ranjan Laha

Shunsaku Horiuchi

John F. Beacom

Kenny Ng

Kohta Murase