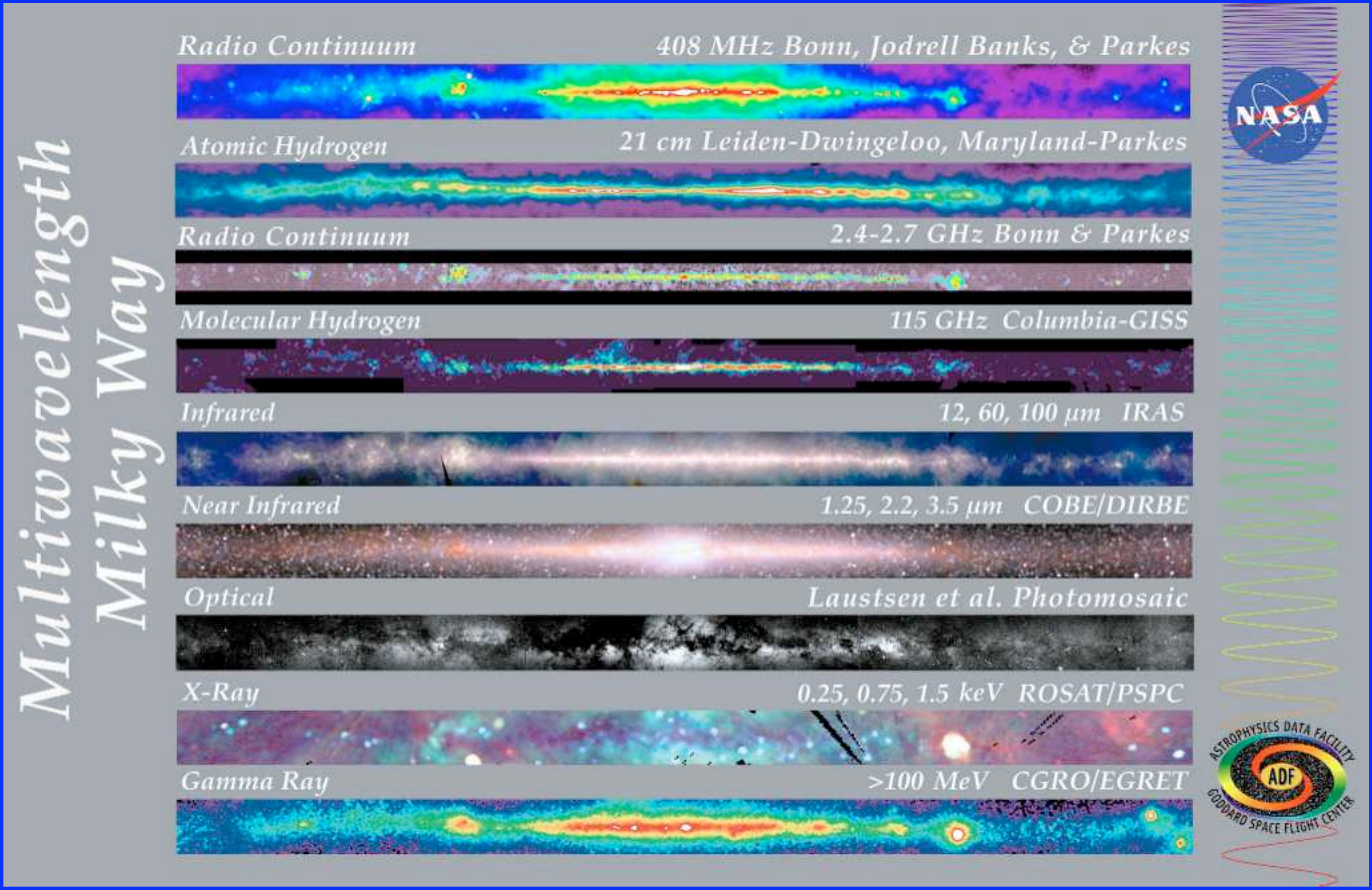
Quis custodiet ipsos custodes?
Who will neutrino the neutrinos?

John Beacom, Ohio State University

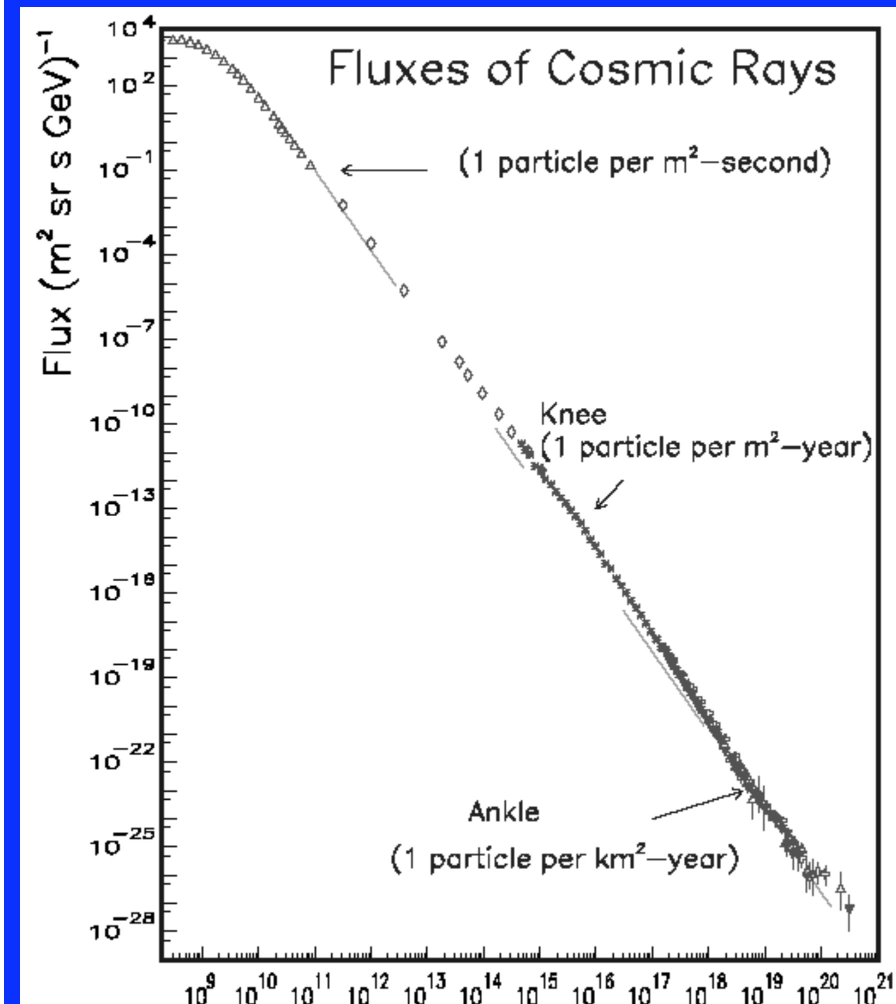
Introduction

Photon Windows



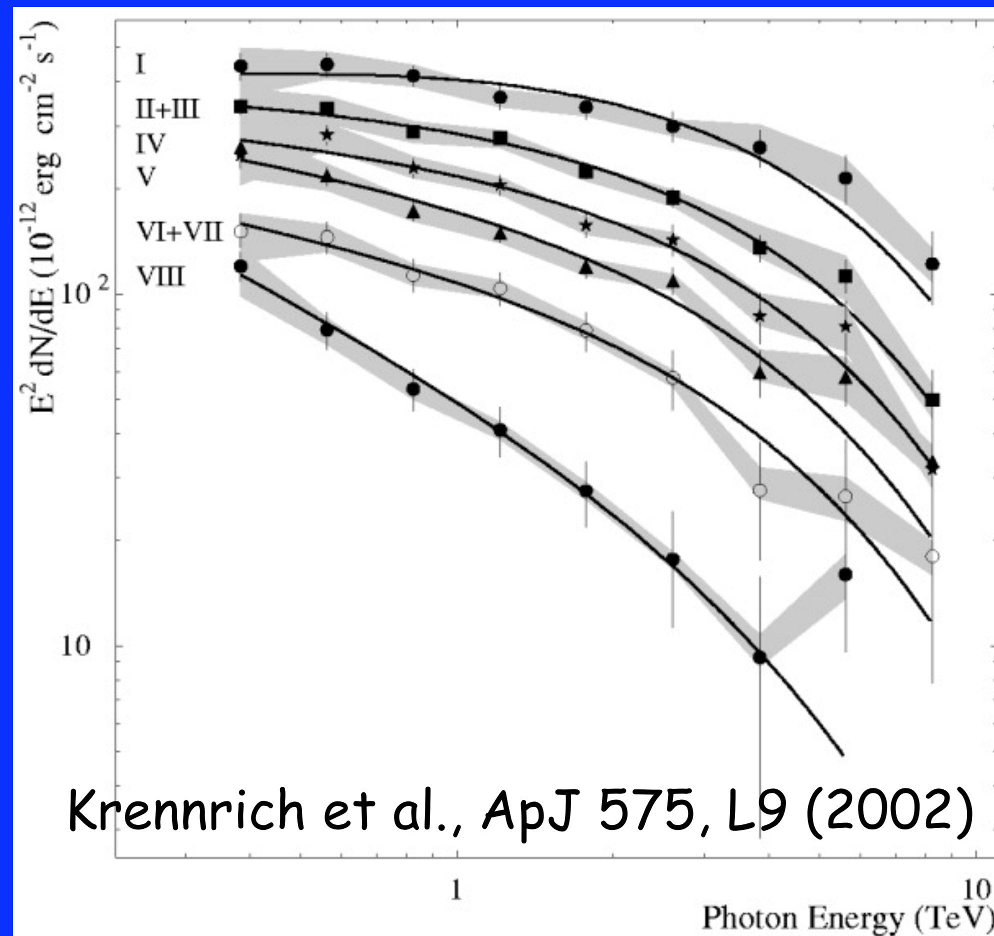
High Energy Messengers

Protons (diffuse)



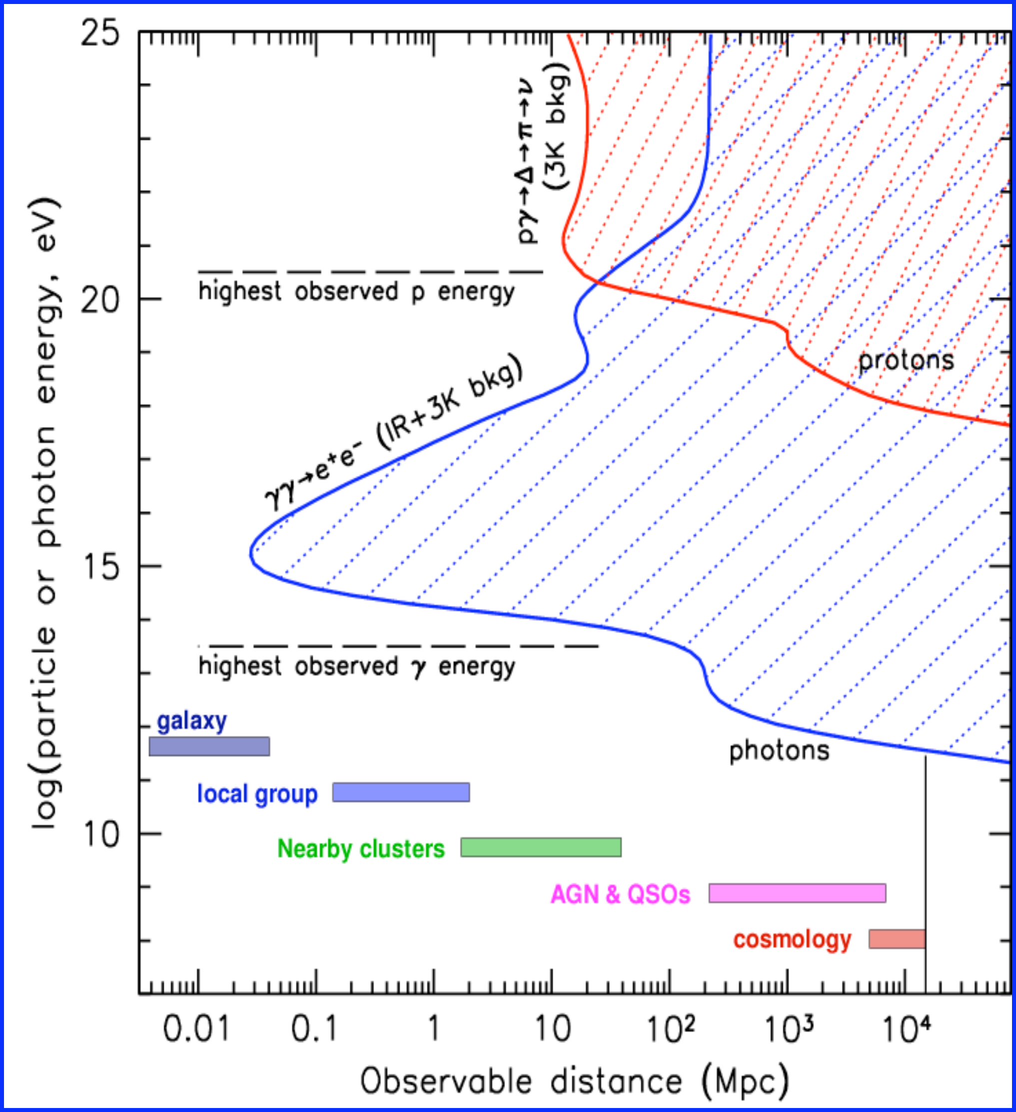
(Swordy)

Photons (Markarian 421)



Krennrich et al., ApJ 575, L9 (2002)

Beyond the Veil?



At high energies, the universe is opaque...

...except to neutrinos

(Peter Gorham)

Essential Points

- High-energy particle accelerators exist
- p + p or p + γ collisions can make a Δ resonance
- Neutral pions make gammas
- Charged pions make neutrinos
- Hence high-energy neutrinos exist, Q.E.D.
- But are they detectable? Usefully, reliably so?

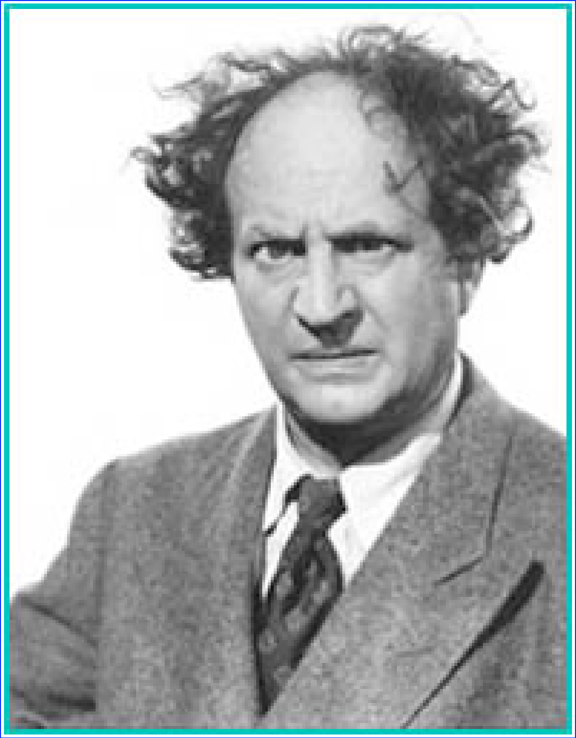
Neutrino Frontiers

E ~ MeV (micro-TeV)	E ~ TeV ~ erg (natural scale)	E ~ EeV (mega-TeV)
Visible Universe: Supernovae	*Nonthermal Universe*: AGN, GRB	*Extreme Universe*: UHE cosmic rays
Super-Kamiokande	IceCube, etc.	ANITA, etc.
Nucleosynthesis, dark matter	Black holes, dark matter	Energy frontier, dark matter

The Neutrino Universe Awaits Us

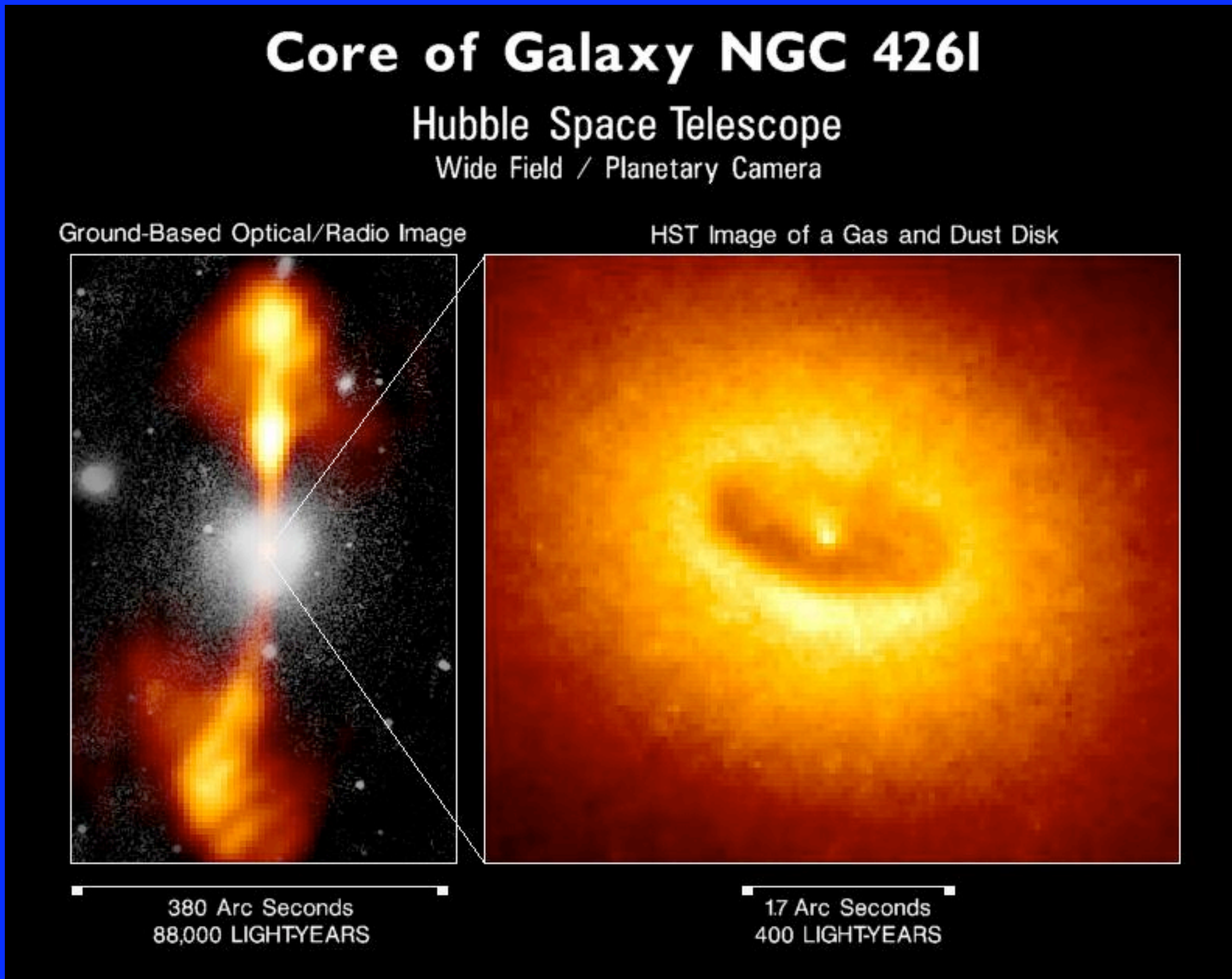
Round Up the Usual Suspects

protons	photons	neutrinos
energetic	direct	revealing
divertable	stoppable	untrustworthy?



Neutrino Point Sources

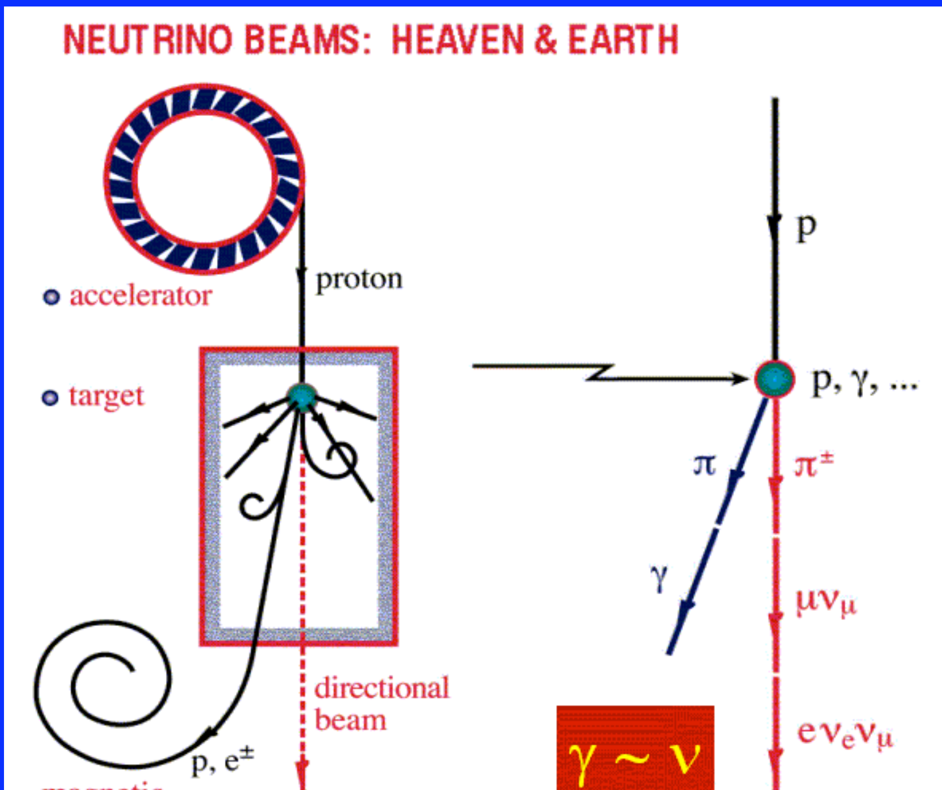
Active Galaxies



Standard Case

$$\pi^0 \rightarrow \gamma\gamma$$

$$\pi^+ \rightarrow \mu^+ \nu_\mu \,,\; \mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$$



(graphic from Francis Halzen)

initial fluxes are

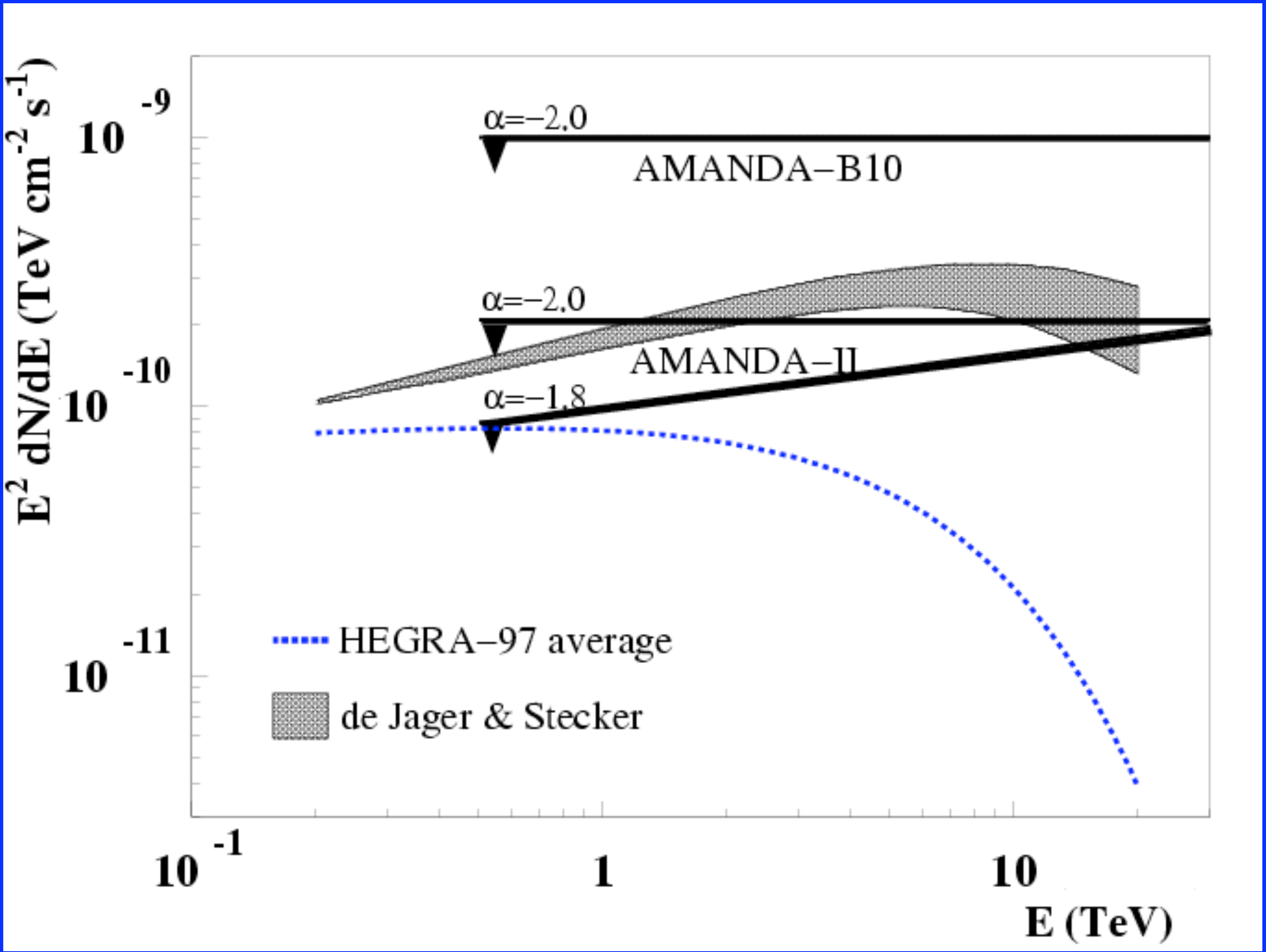
$$\varphi_{\nu_e} : \varphi_{\nu_\mu} : \varphi_{\nu_\tau} = 1:2:0$$

after oscillations

$$\varphi_{\nu_e} : \varphi_{\nu_\mu} : \varphi_{\nu_\tau} = 1:1:1$$

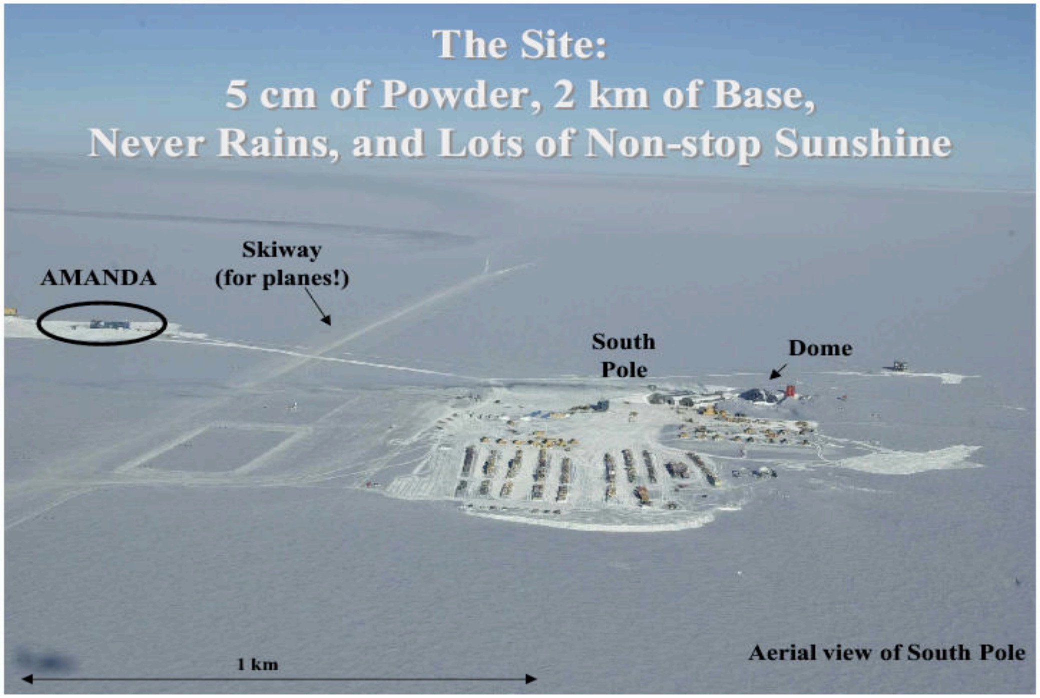
Earth opacity effects above E ~ 100 TeV

Neutrino-Gamma Connection

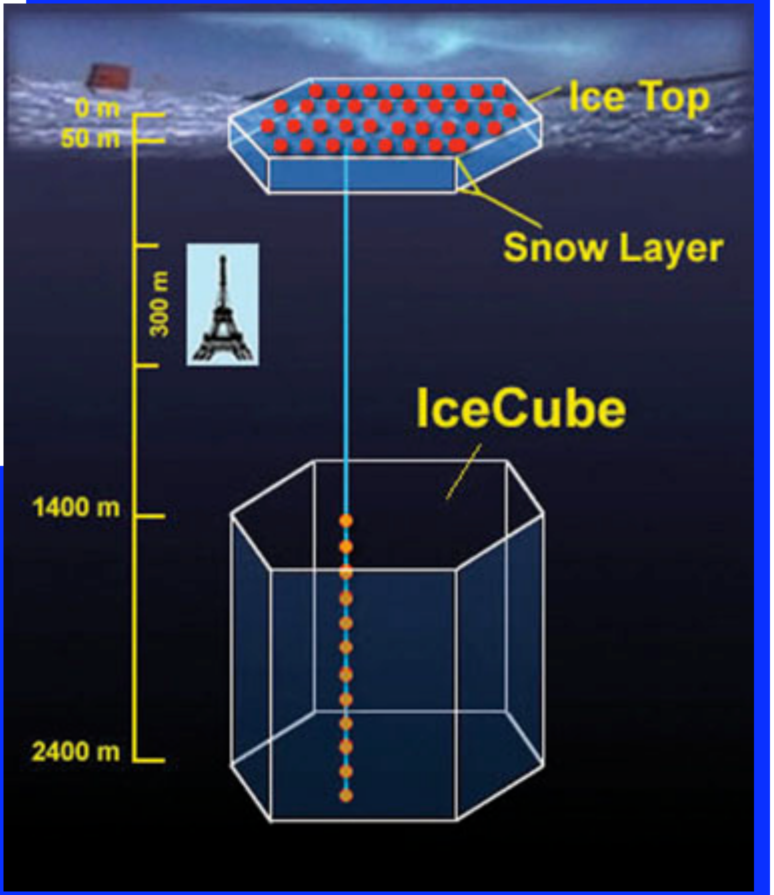


J. Ahrens et al. (AMANDA-II), astro-ph/0309585

ICECUBE

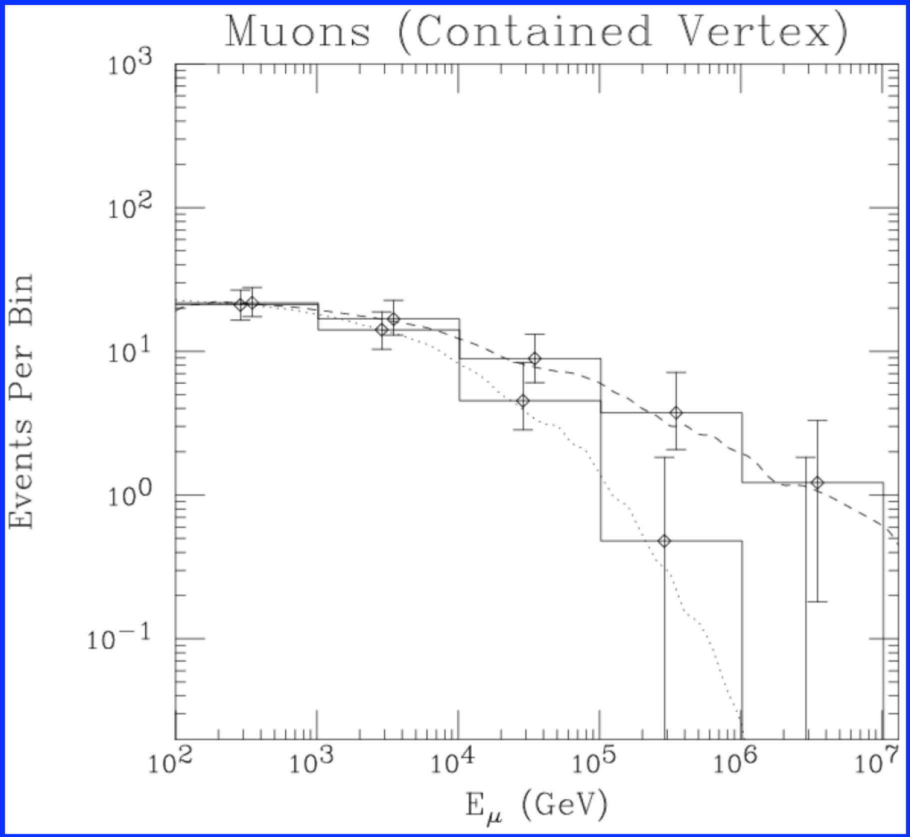


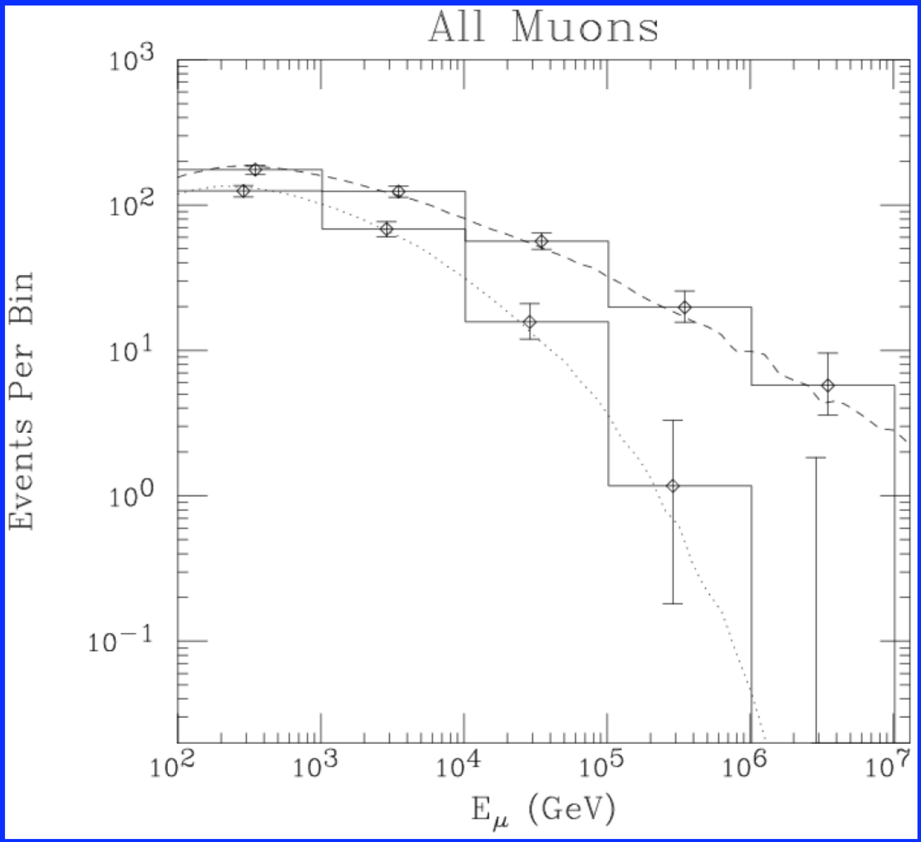
The Site:
5 cm of Powder, 2 km of Base,
Never Rains, and Lots of Non-stop Sunshine
AMANDA
Skiway
(for planes!)
South
Pole
Dome
1 km
Aerial view of South Pole



0 m
50 m
Ice Top
Snow Layer
300 m
IceCube
1400 m
2400 m

Neutrino Detection

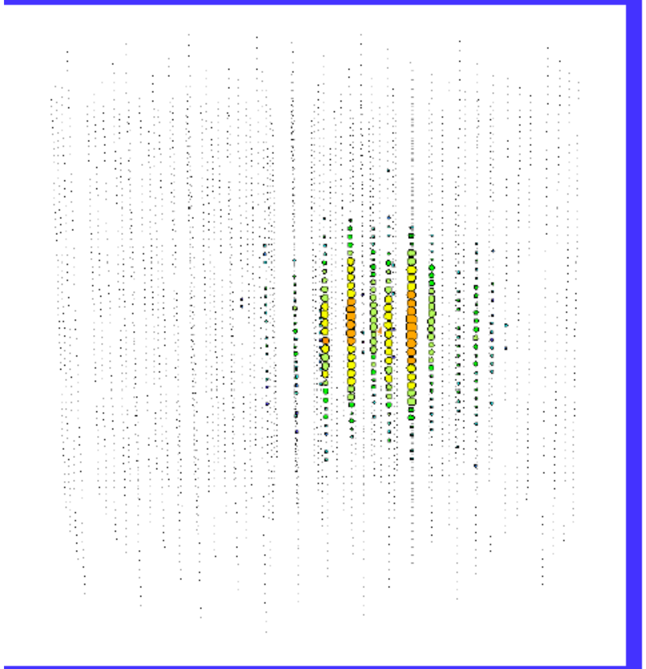
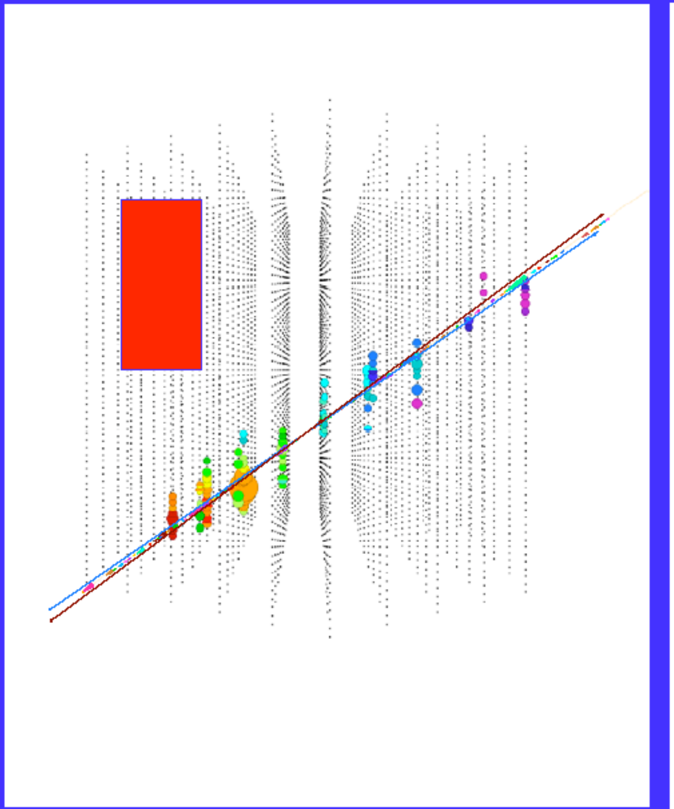
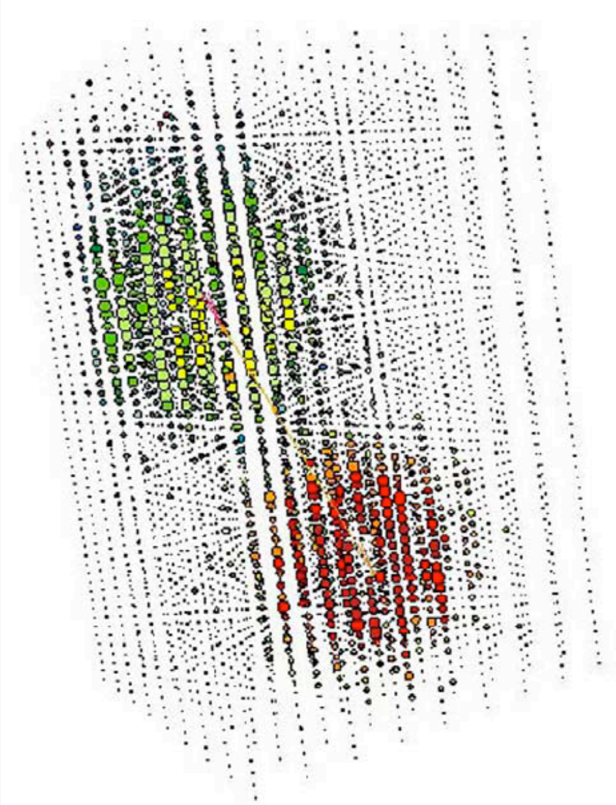




Beacom, Bell, Hooper, Pakvasa, Weiler, PRD 68, 093005 (2003) [+Erratum]

These data are one way to measure the spectrum

Flavor Identification

$\sim$100 TeV ν_e $\sim$10 TeV ν_μ $\sim$10 PeV ν_τ

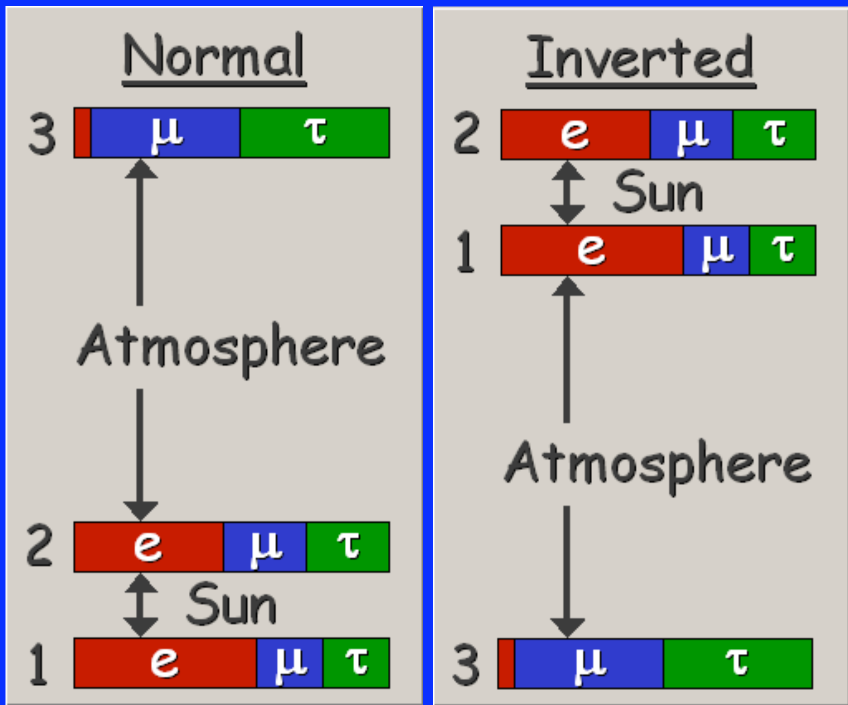
Could Neutrinos Decay?

- Neutrinos have mass, so they might decay
- But requires new interactions to invisible particles
- Surprisingly hard to limit this possibility

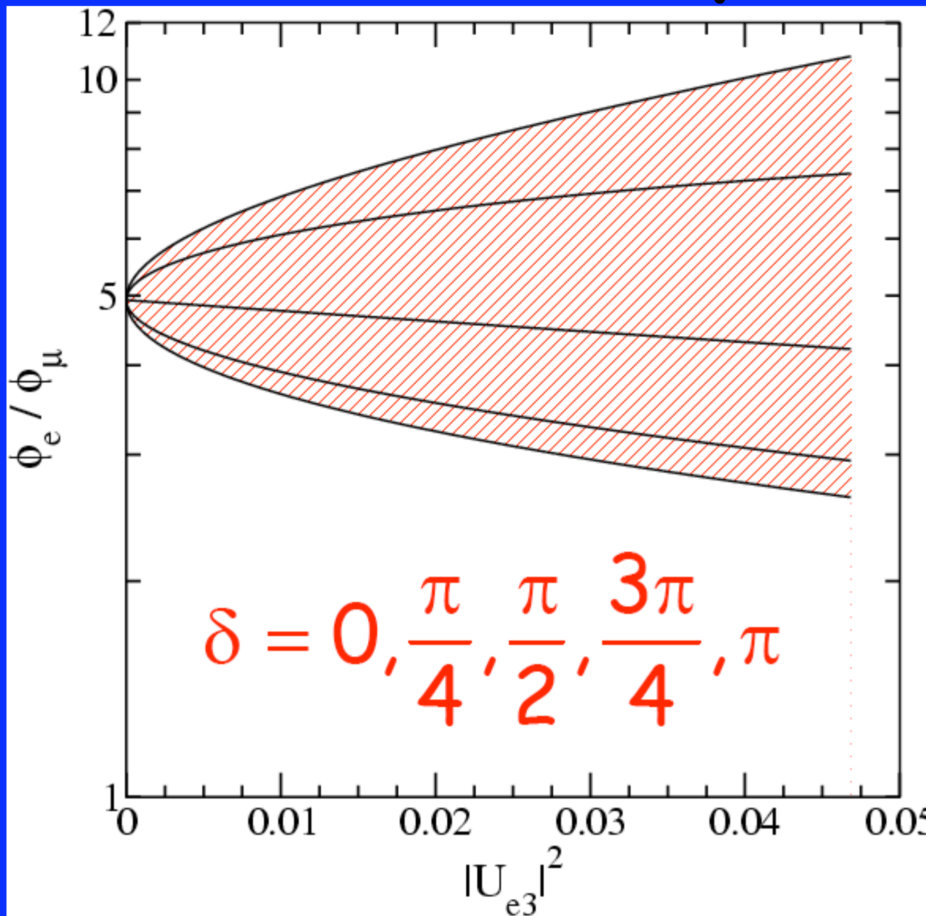
Neutrino source	L/E	τ/m (s/eV)
Accelerator	30 m/10 MeV	10^{-14}
Atmosphere	10^4 km/300 MeV	10^{-10}
Sun	500 s/5 MeV	10^{-4}
Supernova	10 kpc/10 MeV	10^5
AGN	100 Mpc/1 TeV	10^4

Beacom and Bell, PRD 65, 113009 (2002)

Effects of Neutrino Decay



~ 5:1:1 ~ 0:1:1



Possible direct measurement of CP phase δ too!

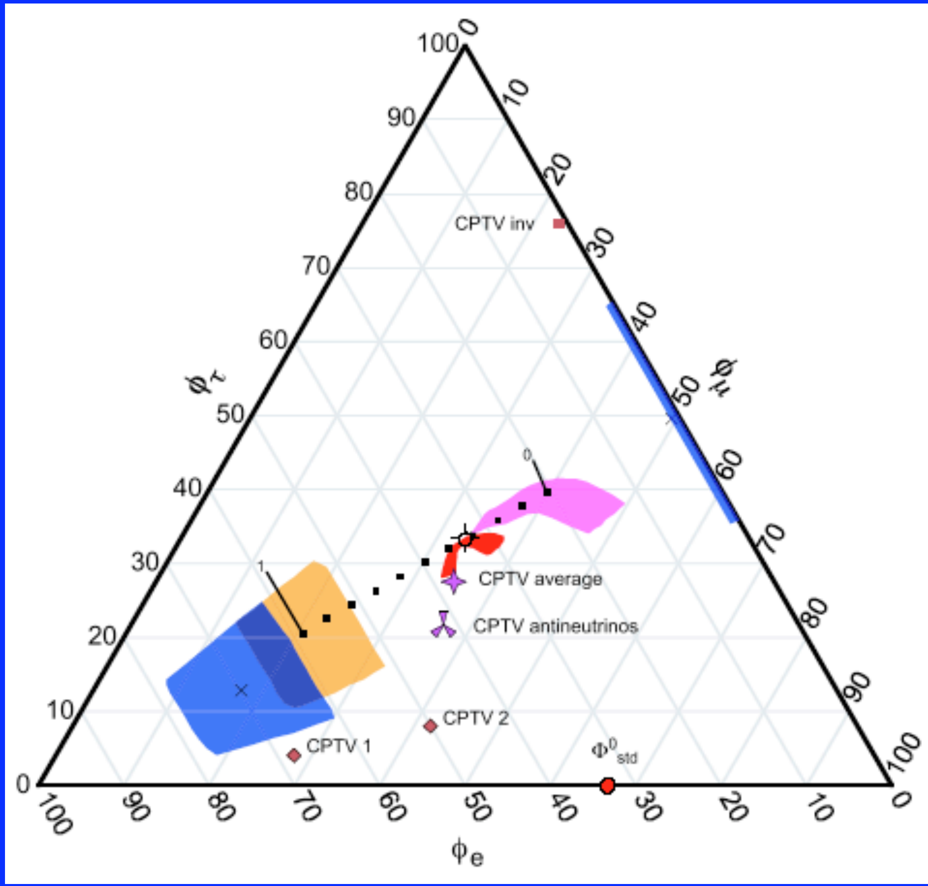
Beacom, Bell, Hooper, Pakvasa, Weiler, PRL 90, 181301 (2003);
Beacom, Bell, Hooper, Pakvasa, Weiler, PRD 69, 017303 (2004)

Neutrino Flavor Ratios

More general decay scenarios may occur (e.g., CPT-violating case)

Oscillations to steriles with a tiny mass splitting also alters flavor ratios

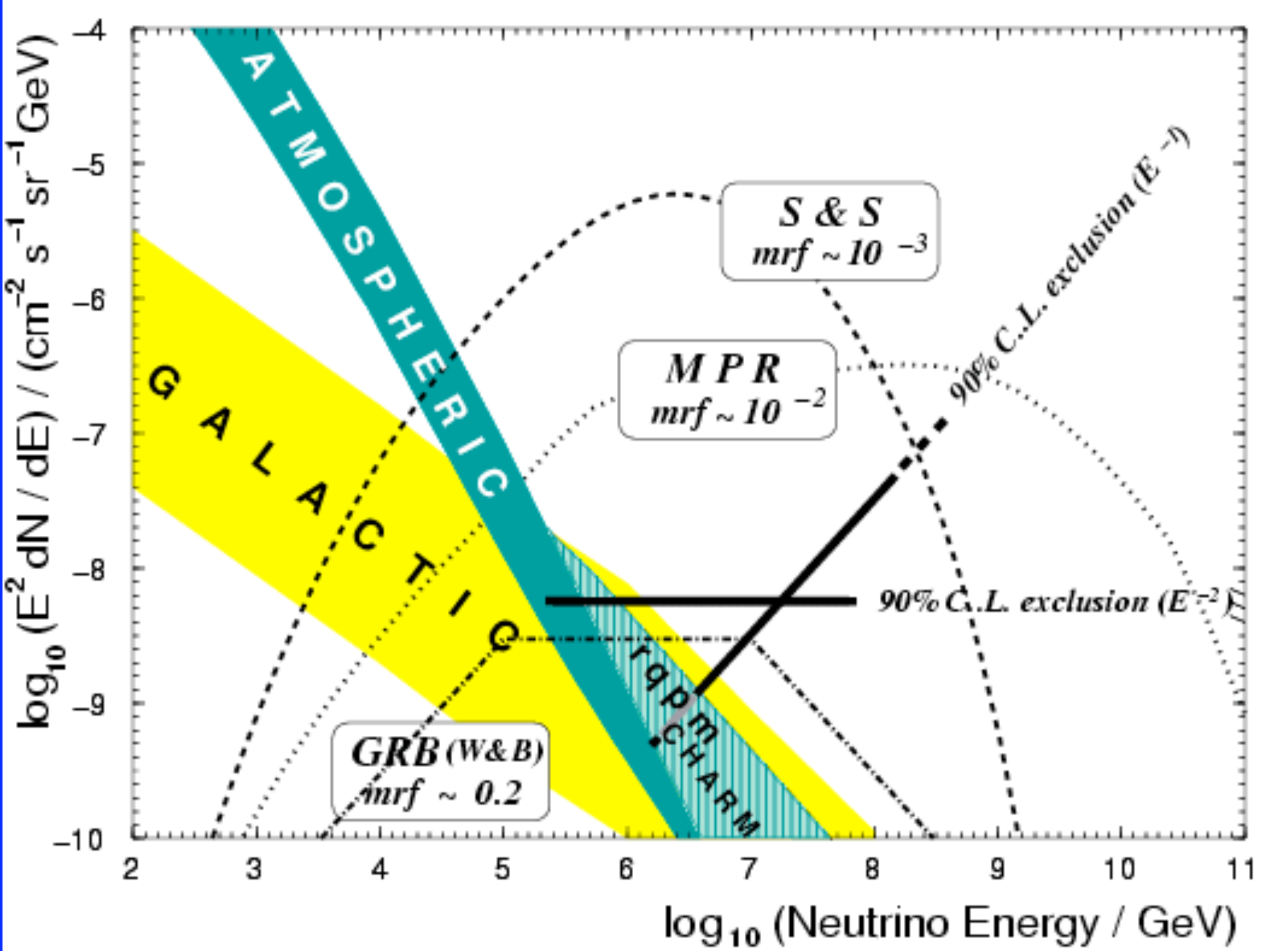
Muon cooling in the source can as well



Barenboim and Quigg, PRD 67, 073024 (2003)

Neutrino Diffuse Background

IceCube (Diffuse) Sensitivity

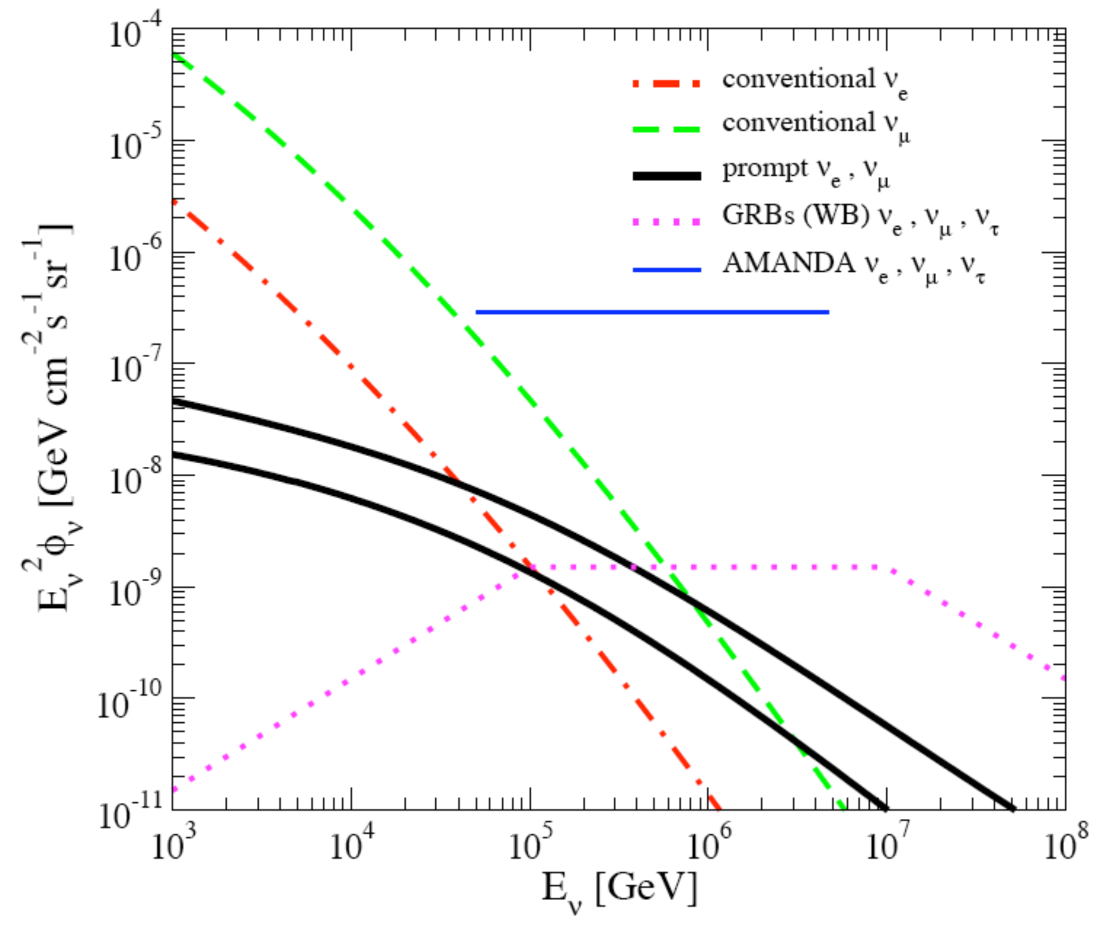


AMANDA-B10

AMANDA-II

J. Ahrens et al. (IceCube), astro-ph/0305196

Neutrino Spectra

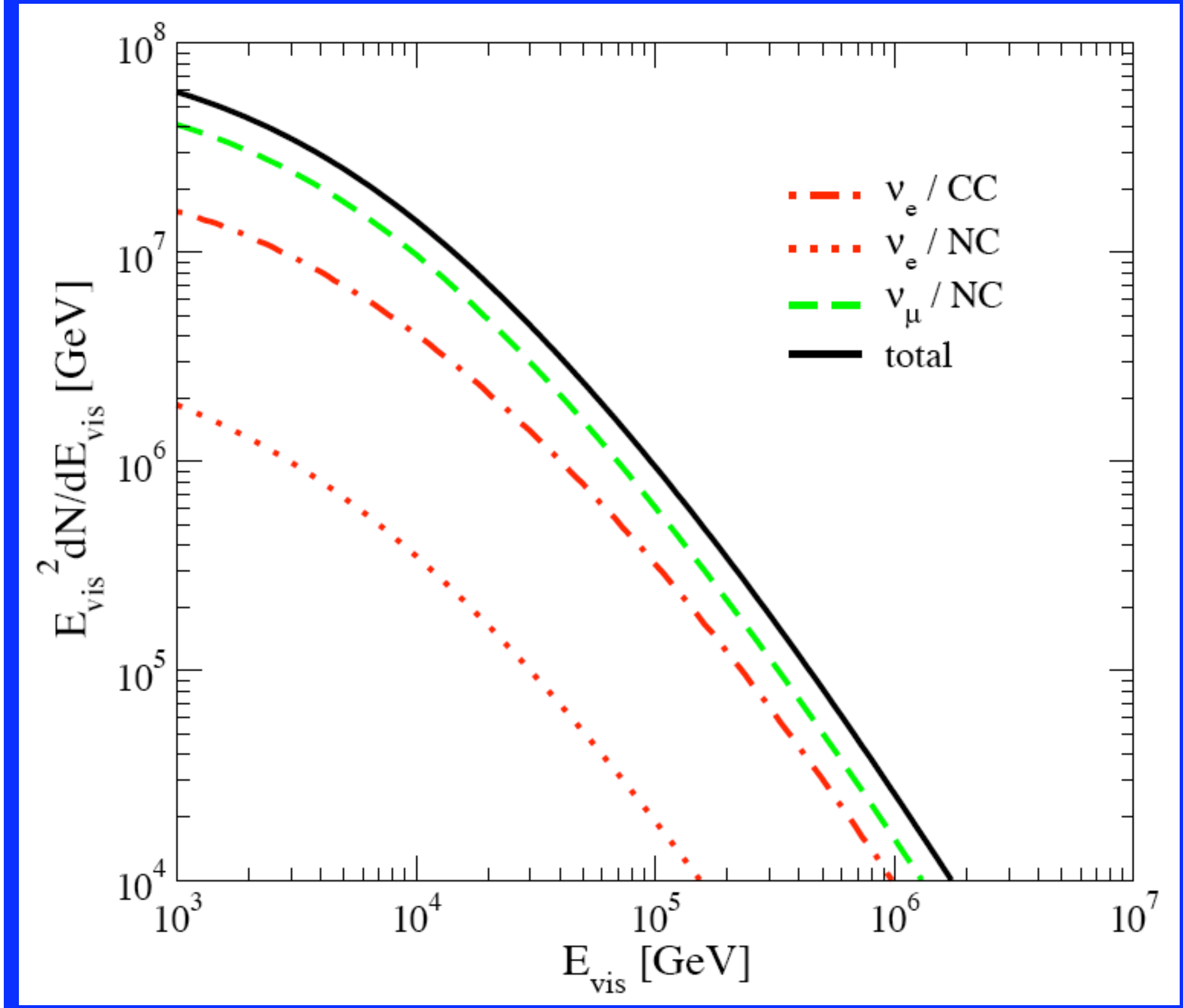


Nota Bene:
we assumed *small*
prompt atmospheric
and extragalactic
neutrino fluxes

Beacom and Candia,
JCAP 0411, 009 (2004)

Neutrino Flux	Flavors ($\nu_e : \nu_\mu : \nu_\tau$)	Angular Dependence
conventional atmospheric	$\frac{1}{20} : 1 : 0$	peaks at horizon
prompt atmospheric	$1 : 1 : \frac{1}{10}$	isotropic
Galactic	$1 : 1 : 1$	peaks at Galactic center
extragalactic	$1 : 1 : 1$	isotropic; point/transient sources

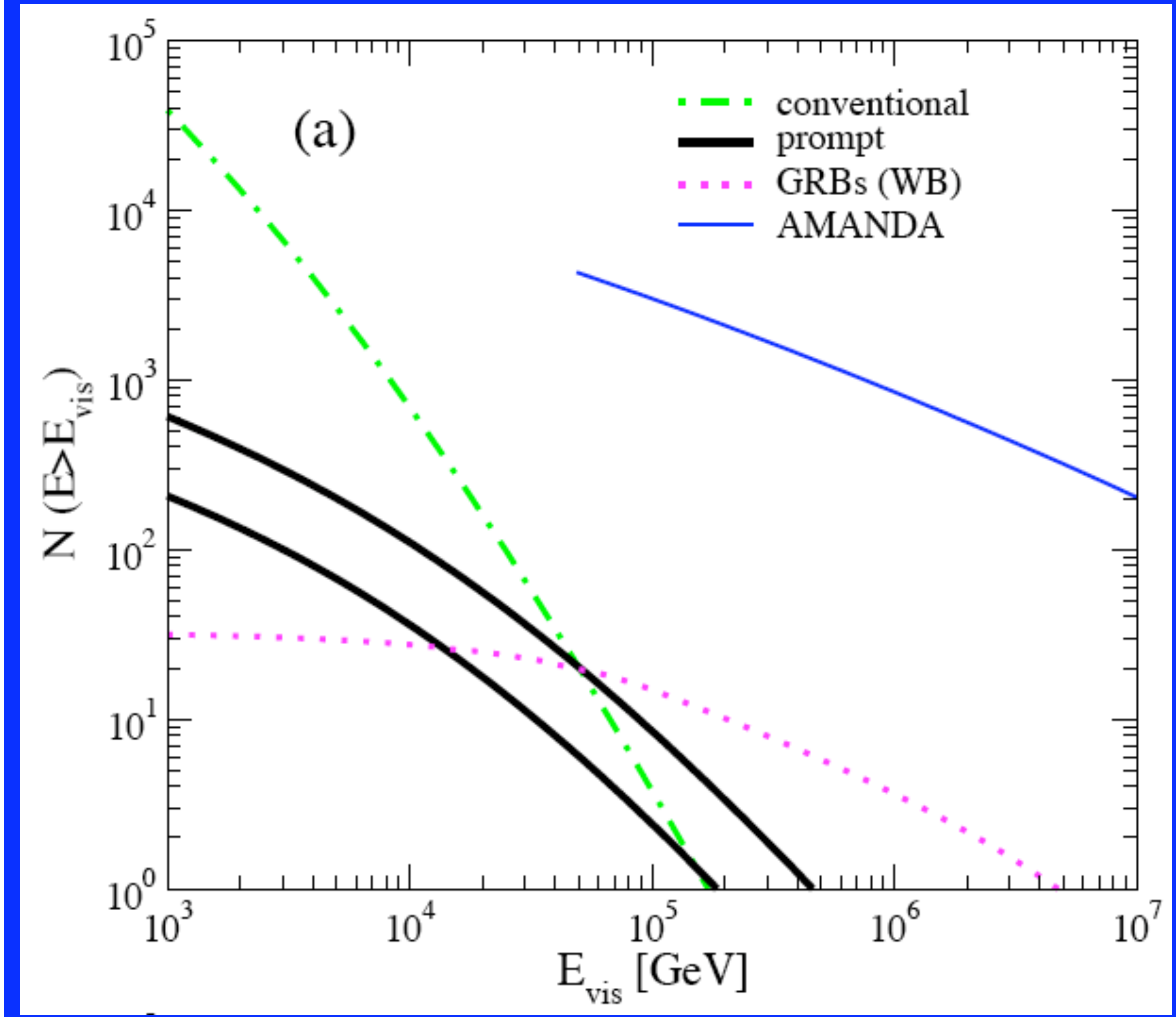
Visible Spectra



With muon tracks removed, the conventional background is much reduced

Beacom and Candia, JCAP 0411, 009 (2004)

Shower Power



Now focus is on 10^5 GeV instead of 10^6 GeV

Confirmed by Monte Carlo of Kowalski, JCAP 0505, 010 (2005)

Beacom and Candia, JCAP 0411, 009 (2004)

Conclusions

- No high energy astrophysical neutrinos detected
- However, the near-term prospects are very good
- Compelling motivation from proton, photon data
- But: neutrino properties not fully known
- But: separting signals and backgrounds hard
- Solution is to use all flavors of the neutrino

Further Reading

• "High-Energy Neutrino Astronomy: The Cosmic Ray Connection," Halzen and Hooper, Rept. Prog. Phys. 65, 1025 (2002)

• "High-Energy Neutrino Astrophysics," Learned and Mannheim, Ann. Rev. Nucl. Part. Sci. 50, 679 (2000)

• "High Energy Neutrino Astronomy: The Experimental Road," Spiering, J. Phys. G29, 843 (2003)

• "APS Neutrino Study: Report of the Neutrino Astrophysics and Cosmology Working Group,'' Barwick et al., astro-ph/0412544