The First High-Energy Extragalactic Neutrinos

Dan Hooper

Particle Astrophysics Center

Fermi National Accelerator Laboratory

dhooper@fnal.gov

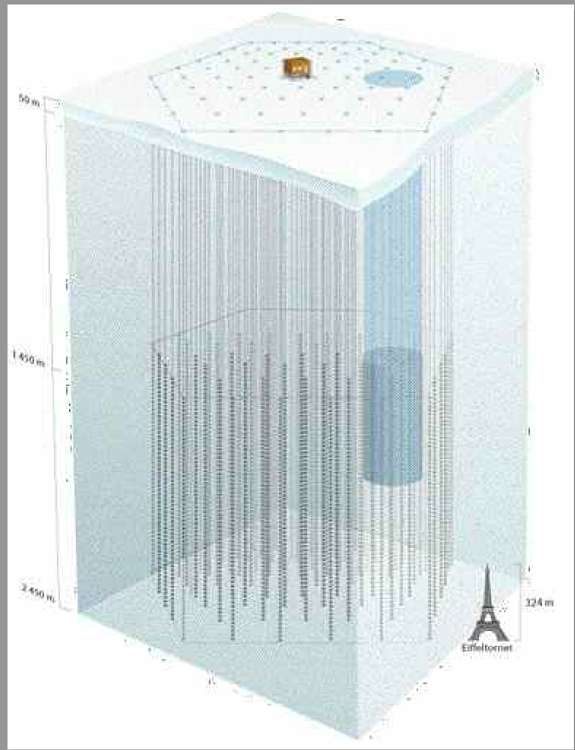
TeV Astrophysics III

Venice

August 2007

The Neutrinos Are Coming!

- To date, no (confirmed) sources of high or ultra-high energy neutrinos have been discovered
- This is likely to change soon
- Experimental sensitivity is rapidly approaching that needed to detect the first galactic and extra-galactic sources of high energy cosmic neutrinos



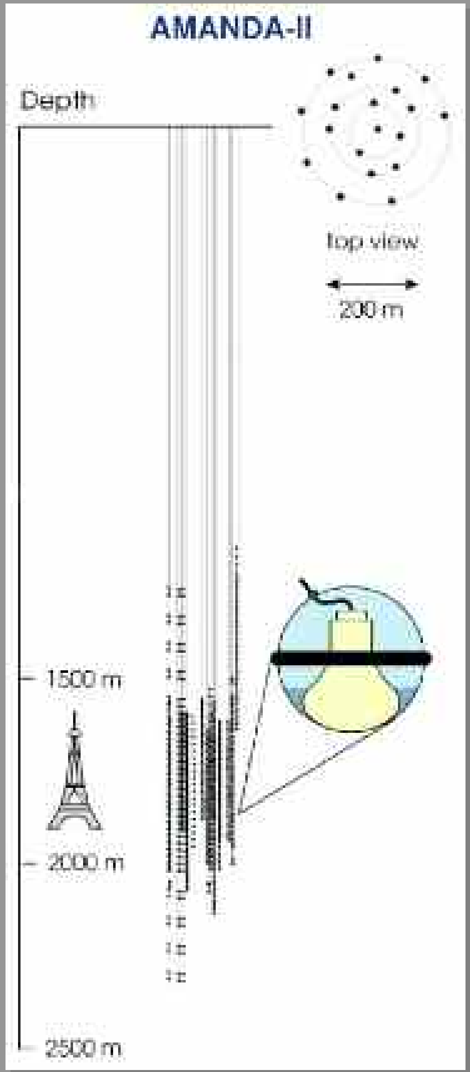
Tools of the Trade: The First Generation

AMANDA:

•Below ~2 kilometers of Antarctic ice
•Optical Cerenkov, $E_{\mu,th}$~30 GeV
•Effective Area of ~50,000 sq meters
•Sensitive to muons, EM/hadronic showers
•~7 years of data in current form

ANTARES:

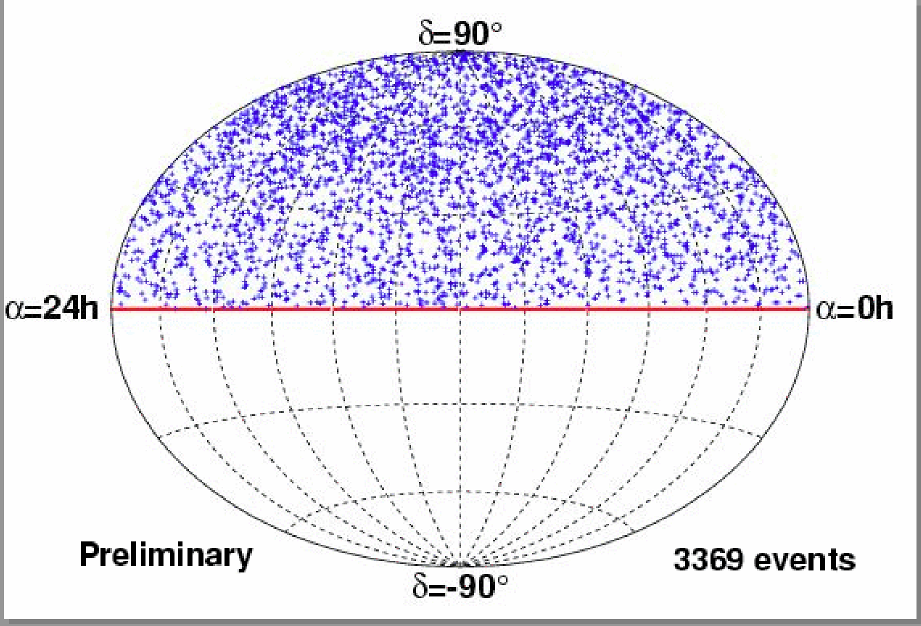
•Under construction in Mediterranean Sea
•Somewhat larger effective area, and lower energy threshold than AMANDA
•Northern hemisphere location

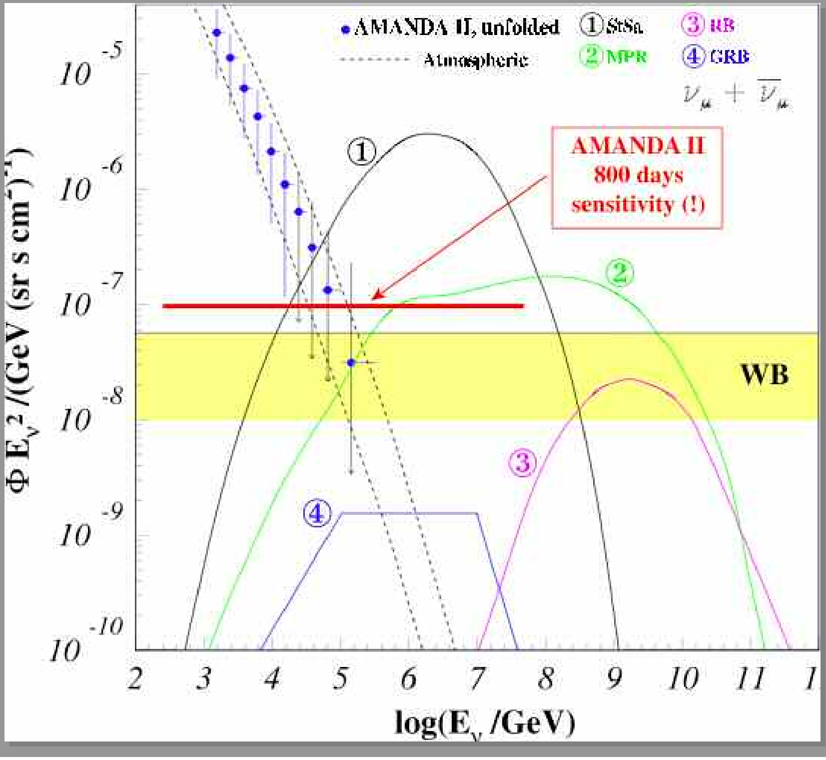


Tools of the Trade: The First Generation

The Successes of AMANDA

- 800 live days analyzed (over 4 years); atmospheric neutrino spectrum measured to ~100 TeV; consistent with theoretical expectations
- Sensitivity to diffuse neutrino flux in 100 GeV-100 PeV range approaching 10^{-7} GeV cm^{-2} s^{-1} sr^{-1}
- Limits on point sources at the level of $6x10^{-8}$ GeV cm^{-2} s^{-1}





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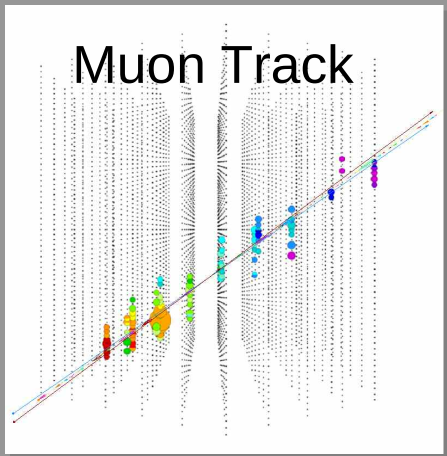
Tools of the Trade: The Next Generation

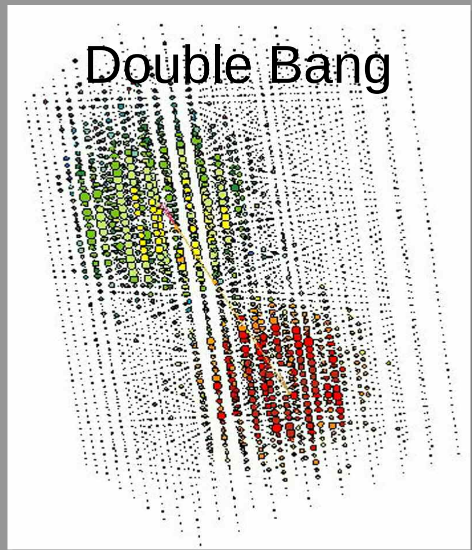
IceCube

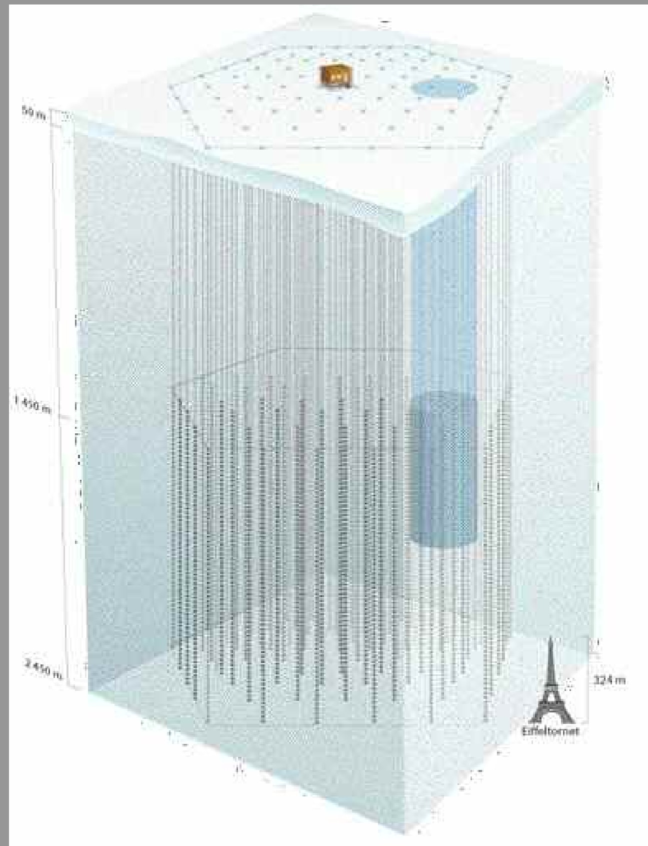
•Full Cubic Kilometer Instrumented Volume

•22 (of 80) strings currently deployed (13 this season)

•Sensitive to muon tracks, EM/hadronic showers, and tau-unique events (above ~PeV)







•Similar prospects for KM3Net

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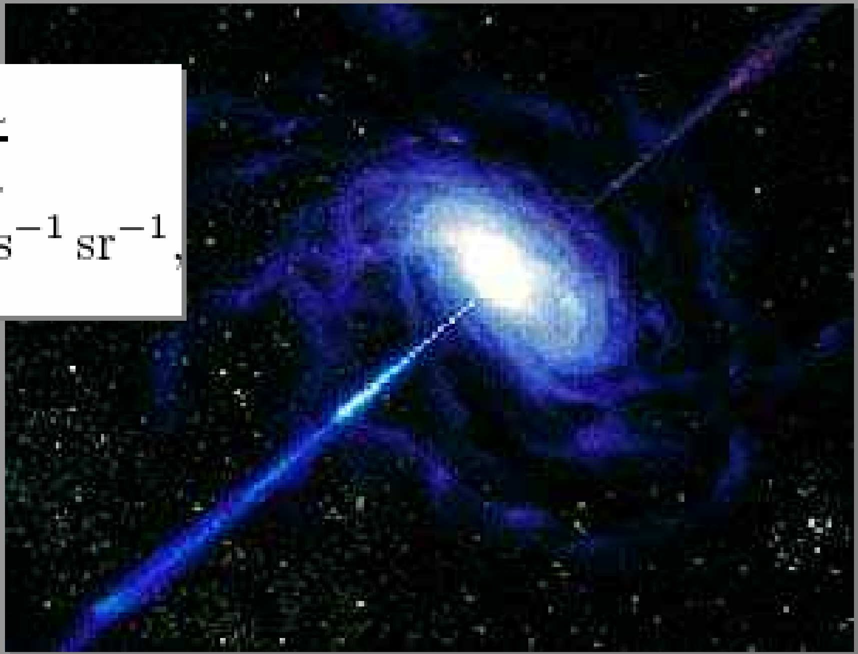
- "Waxman-Bahcall" Argument:

$$[E_\nu^2 \Phi_\nu]_{\rm WB} \approx (3/8)\, \xi_Z\, \epsilon_\pi\, t_{\rm H}\, \frac{c}{4\pi}\, E_{\rm CR}^2 \frac{d\dot{N}_{\rm CR}}{dE_{\rm CR}}$$
$$\approx 2.3 \times 10^{-8}\, \epsilon_\pi\, \xi_Z\, {\rm GeV\, cm^{-2}\, s^{-1}\, sr^{-1}},$$



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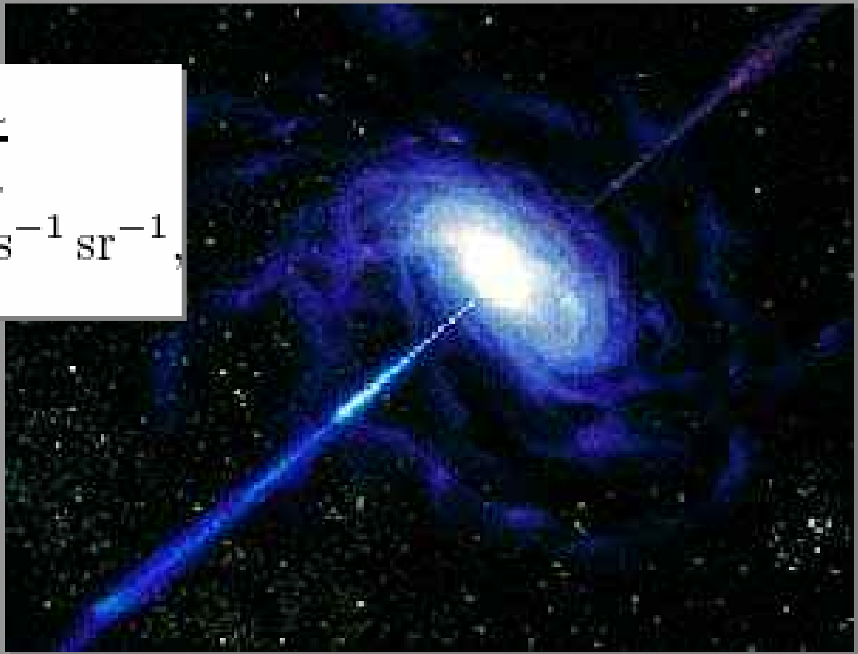
Fraction of proton energy to pions (ϵ_π)

Accounts for source evolution, etc. (~1) (ξ_Z)



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Extragalactic Neutrino Flux

•IceCube will reach well below the predicted levels for $\varepsilon_\gamma \sim 1$ (*ie*. the Waxman-Bahcall "Flux")

•Models of gamma ray bursts,
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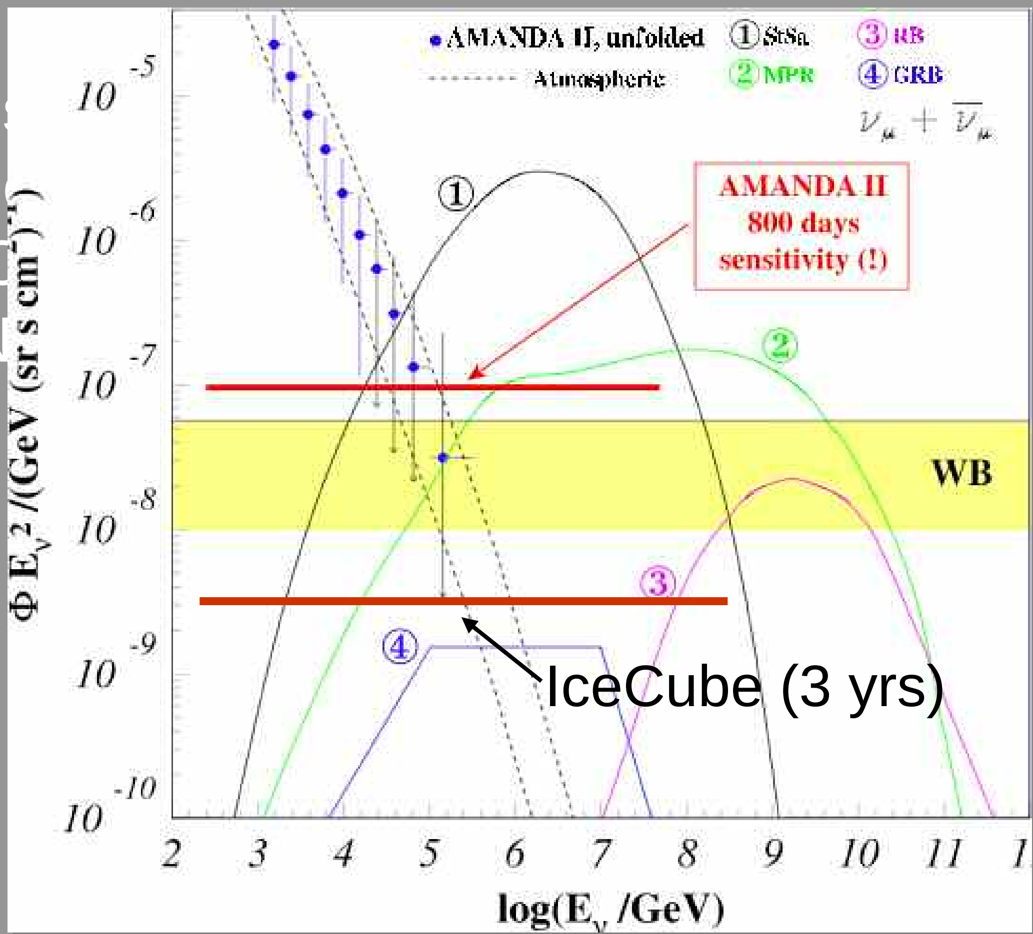

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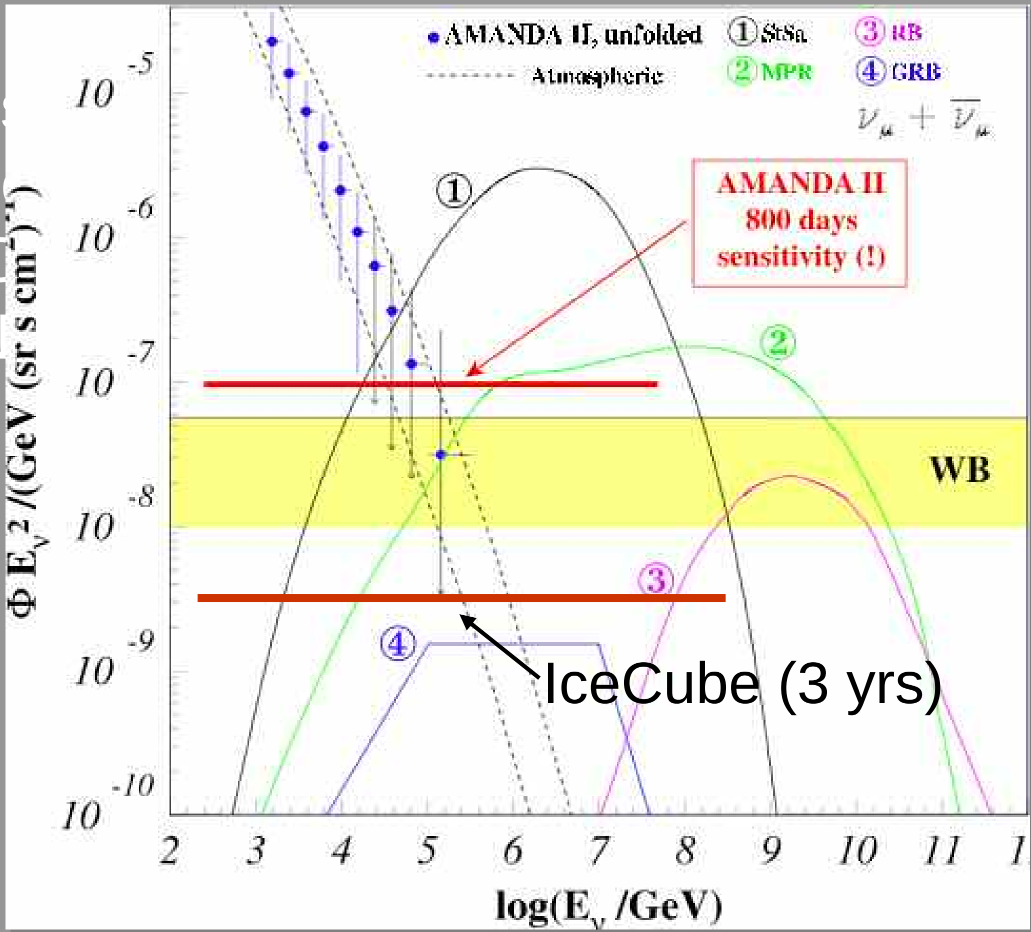
•Models of gamma ray bursts, active galactic nuclei, and starburst galaxies predict a flux of neutrinos within the reach of IceCube (or KM3NeT)



Likely to observe first cosmic high-energy neutrinos in coming years!

Radio Techniques

RICE

- Array of radio antennas co-deployed with AMANDA
- Effective Volume of ~1 km^3 at 100 PeV; several km^3 at 10 EeV
- Limits on diffuse neutrino flux in 200 PeV-200 EeV range
  of 6 $x10^{-7}$ GeV cm^{-2} s^{-1} sr^{-1}
- Future radio deployments with IceCube promising

ANITA-Lite, ANITA

- Balloon-based radio antennas
- ANITA-lite limit on diffuse flux
above ~EeV of $\sim 10^{-6}$ GeV/cm^2 s^1 sr^1
- 36 day ANITA flight ended Jan. 20

$\Rightarrow$sensitivity of $\sim 10^{-8}$ GeV/cm^2 s sr
observe the first UHE neutrino?

Ultra High Energy Cosmic Ray Experiments

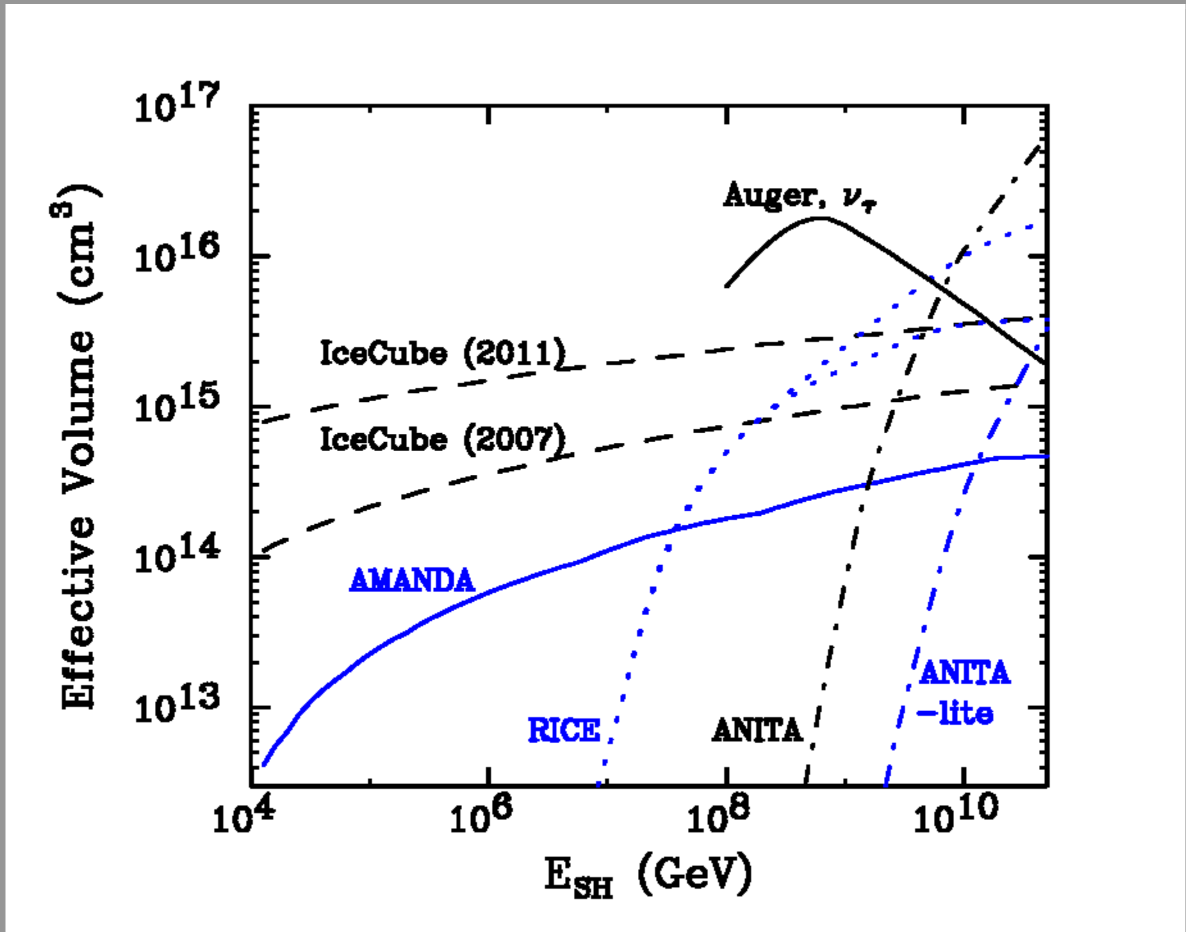
The Pierre Auger Observatory

•Southern cite currently under construction in Argentina
•First data released in 2005 (no neutrino data yet)
•Sensitive above 10^8 GeV, 3000 km^2 surface area
•Neutrino ID possible for quasi-horizontal showers and Earth-skimming, tau-induced showers
•AGASA experiment places limits on UHE neutrino fluxes

EUSO/OWL

•Satellite/space station based
•Enormous aperture
•Future uncertain

The Future of Ultra-High Energy Neutrino Astronomy



Neutrinos From Cosmic Ray Accelerators

•Hillas Criteron requires very extreme properties for the sources of the observed UHECRs, which few known objects possess

•Among the most promising possibilities are:

-Gamma Ray Bursts

-Active Galactic Nuclei

-Starburst Galaxies

•Could appear as a diffuse flux (up to WB bound), or as point sources (in space and/or time)

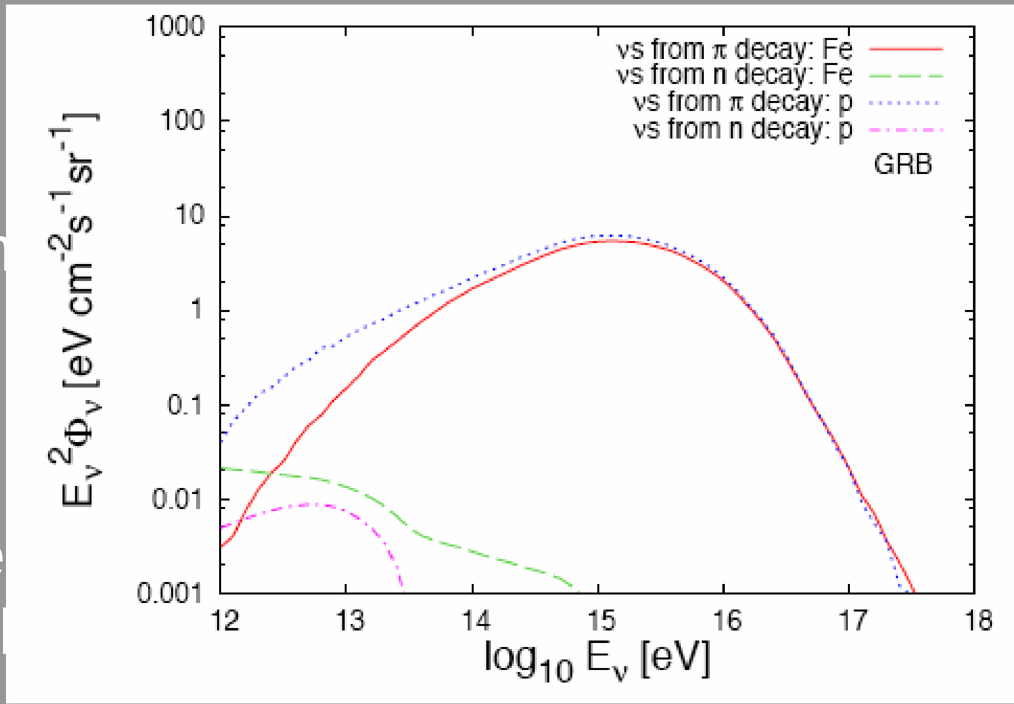
Gamma Ray Bursts

•Total observed (gamma ray) luminosity in all GRBs is remarkably similar to the total flux of cosmic rays above the ankle

•If GRBs accelerate the highest energy cosmic rays, then they will also produce pions and neutrinos, the flux of which can be straightforwardly calculated/estimated

•Around ~10 (PeV) neutrinos per year are expected in a kilometer-scale experim

•Analysis in conjunction with gamma ray astronomy (*ie*. Swift) can be use remove essential



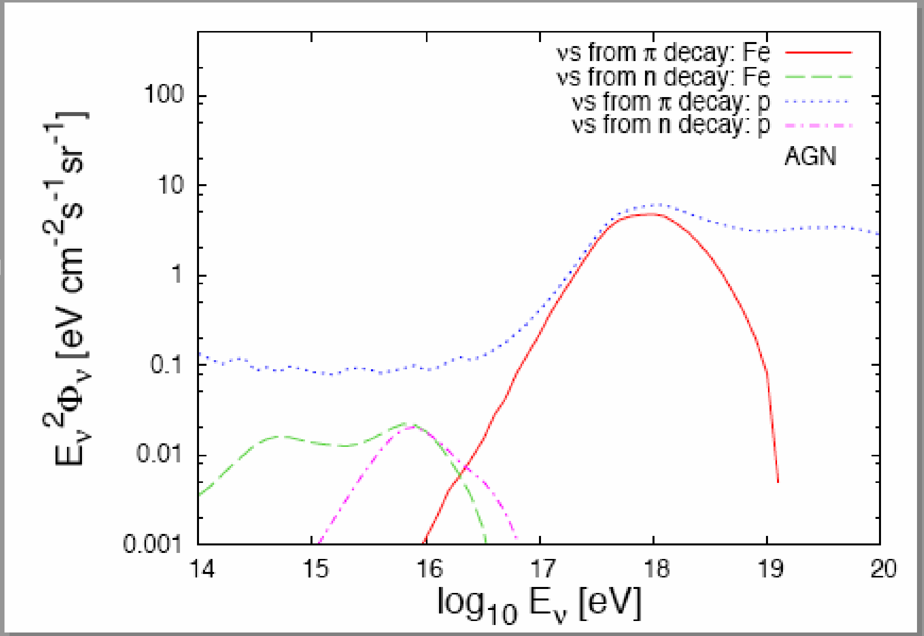
(See talk by Andrew Taylor)

Active Galactic Nuclei

•Along with GRBs, AGN are one of the few classes of astrophysical objects that can potentially accelerate particles to 10^{20} eV (AGN are the most energetic sources in the universe)

•If AGN are the sources of the UHECRs, then it is plausible that they will also produce an observable flux of EeV neutrinos ($\sim$1 event/year in a km^3 experiment - but estimates vary!)

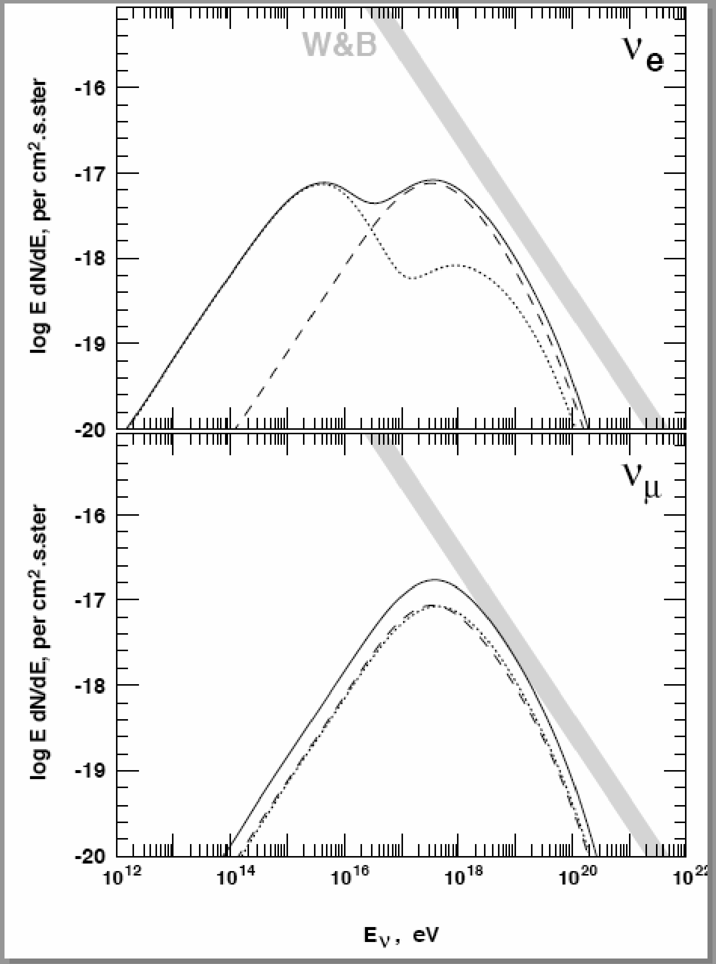
•Known locations (point sources) along with flaring periods can be used to remove/reduce BG



(See talk by Andrew Taylor)

Cosmogenic Neutrinos

- Ultrahigh energy protons interaction with the CMB, producing pions, and subsequently neutrinos
- The resulting neutrino spectrum - the cosmogenic neutrino flux - has long been considered to be a “guaranteed” source of UHE neutrinos
- Event rate of ~1/yr is predicted at a kilometer-scale neutrino telescope

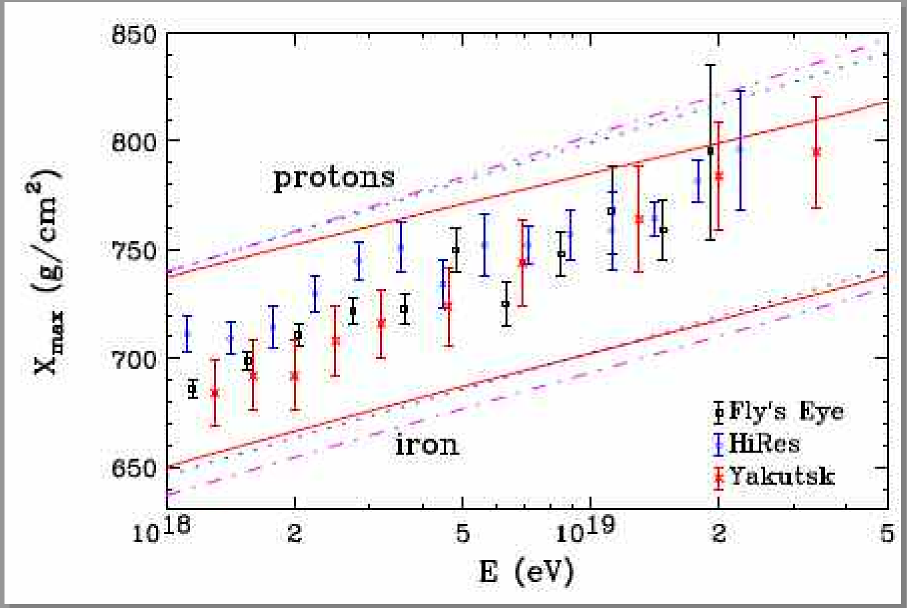


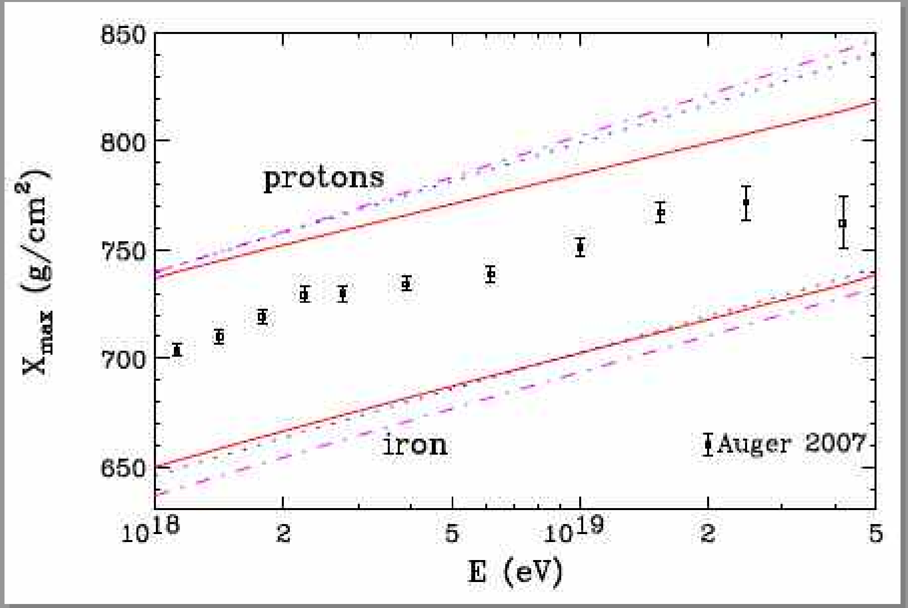
Engle, Seckel, and Stanev, PRD, astro-ph/0101216

Cosmogenic Neutrinos And UHECR Nuclei

Motivations for nuclei domination in the UHECR spectrum:

1) Hillas criterion for the maximum energy produced in a cosmic ray accelerator scales with electric charge, Z
2) Magnetic fields effect nuclei more strongly, helping to explain the lack of identified UHECR point sources
3) New data from Auger strongly favors a mixed proton-heavy nuclei composition ***Important implications for neutrino astronomy!***





(See yesterday's talk by Angela Olinto)

Cosmogenic Neutrinos And UHECR Nuclei

- In the of case nuclei UHECRs, UHE neutrinos are produced very differently than with protons

- For example:

$Fe^{56} + \gamma_{CMB/CIRB} \rightarrow Mn^{55} + p$

$Mn^{55} + \gamma_{CMB/CIRB} \rightarrow Mn^{54} + n$

$n \rightarrow p \, e \, \bar{\nu}_e$

… etc.

Neutrinos!

$p + \gamma_{CMB} \rightarrow n + \pi^+$

$n \rightarrow p \, e \, \bar{\nu}_e$

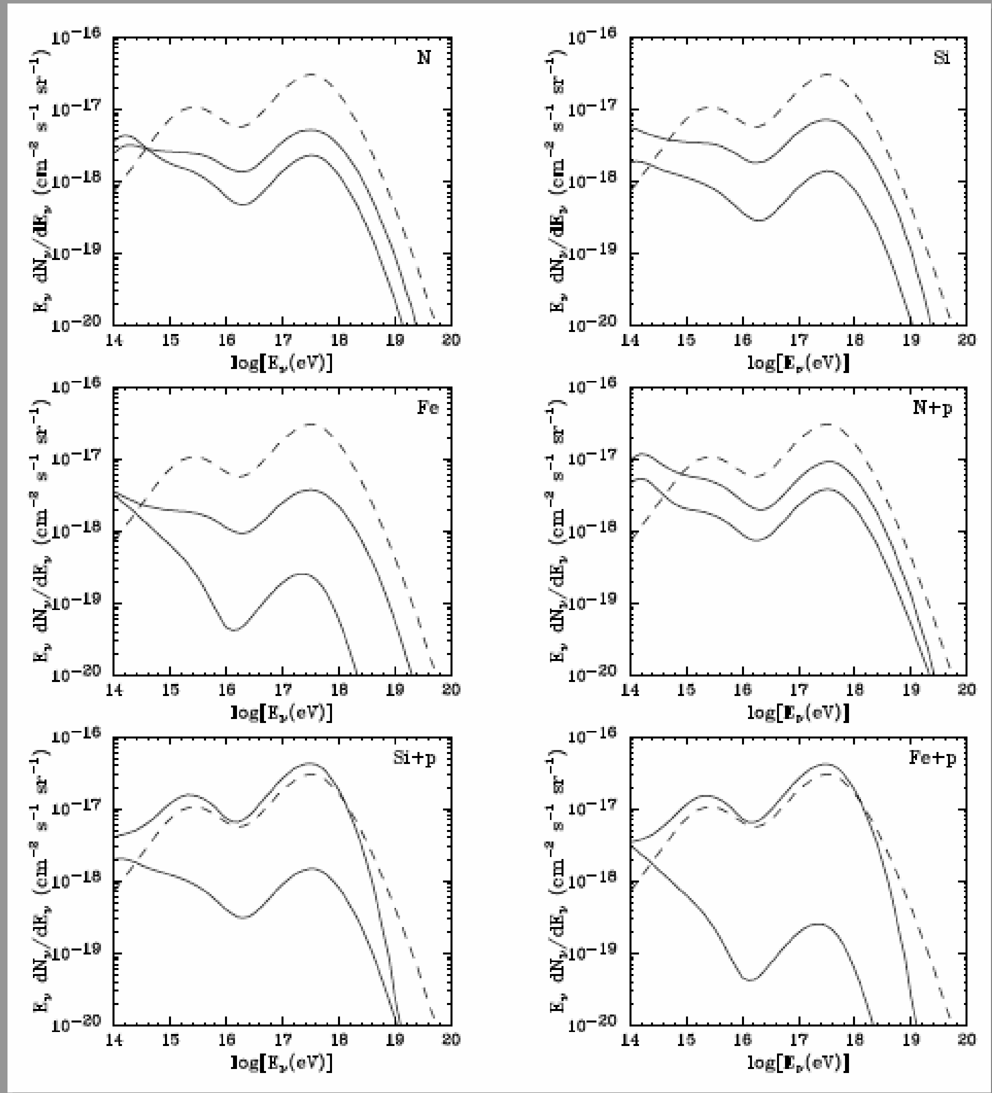
$\pi^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu \nu_\mu$

Cosmic Ray Nuclei and Cosmogenic Neutrinos

- If the UHECR compostion is a mixture of protons and heavy nuclei, the cosmogenic neutrino flux is only mildly affected

- If dominated by heavy/intermediate nuclei, however, the neutrino flux can be highly suppressed

- From Auger spectrum and composition measurements, we predict **1.4 to 0.015** events per year per km^3



Anchordoqui, Goldberg, Hooper, Sarkar and Taylor, in preparation

Conclusions

•The experimental status of neutrino astronomy is fast approaching the sensitivity expected to be required to observe the first high and ultrahigh energy cosmic neutrinos (IceCube, Anita, Auger, etc…)

•Would-be UHE cosmic ray accelerators such as gamma ray bursts or active galactic nuclei remain among the most promising sources for extragalactic cosmic neutrinos (best guess of ~1-10 events per year in km scale experiments)

•The prospects for observing cosmogenic neutrinos depend critically on the composition and spectrum of the UHE cosmic rays as they are injected by their sources (protons with only a small component of heavy nuclei can lead to as many as ~1 event/yr at IceCube or ~1 event per flight at Anita; Nuclei domination can lead to as little as 1 event per century)

THANKS!