Ultrahigh energy cosmic rays fluxes and cosmogenic neutrinos

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The possible detection of cosmogenic neutrinos can affect the interpretation of the spectrum and the composition of the ultrahigh energy cosmic rays. Currently the two active detectors, the Auger Observatory in Argentina and the Telescope Array in Utah, USA, do not agree in their treatment of the chemical composition.

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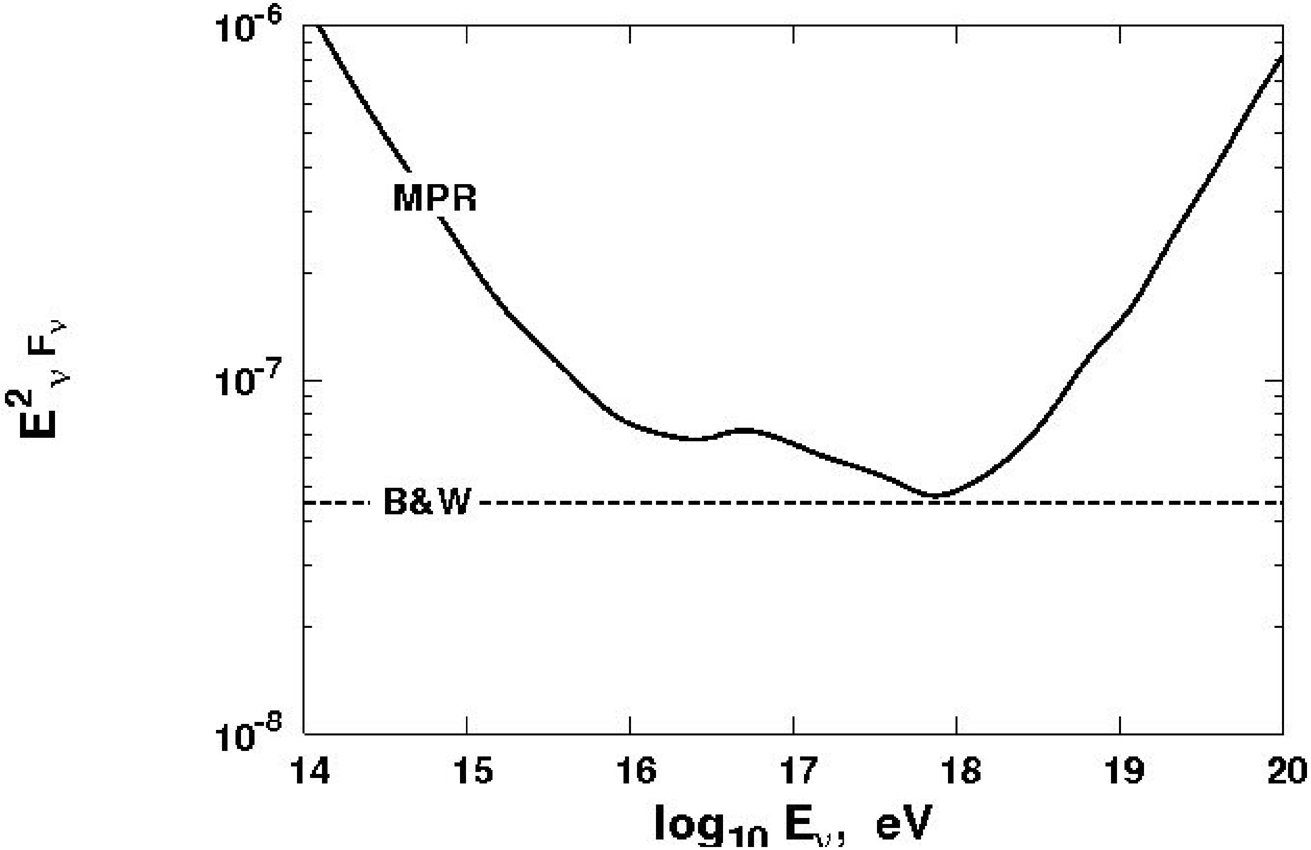


Very high energy neutrinos have always been predicted to come from the sources of UHE cosmic rays, as first stated by Waxman and Bahcall. The upper limits of Waxman&Bahcal and of Manheim, Protheroe & Rachen are shown here. These are neutrinos generated in the the UHECR sources.

Cosmogentic neutrinos are neutrinos from the propagation of extragalactic cosmic rays in the Universe. These neutrinos were first proposed and their flux was calculated in 1969 by Berezinsky&Zatsepin and independently by Stecker in 1973.
In 1983 Hill & Schramm did a calculation and used the non-detection by Fly's Eye of neutrino induced air showers to set limits on the cosmological evolution of the CR sources.
The main difference with the processes in AGN and GRB is that the main photon target is the microwave background (2.75^{o}K) of much lower temperature than the photon emission of these sources. This raises the proton photoproduction threshold to very high energy:

$$E_p^{min} \simeq \frac{m_\Delta^2 - m_p^2}{2(1-cos\theta)\varepsilon} \simeq \frac{5 \times 10^{20}}{(1-cos\theta)} \text{ eV}$$

Actually the proton photoproduction threshold in the CMB is about 3.10^{19} eV. There is also production in the isotropic infrared/optical background.

Photoproduction interactions

p + γ = N + π + ...

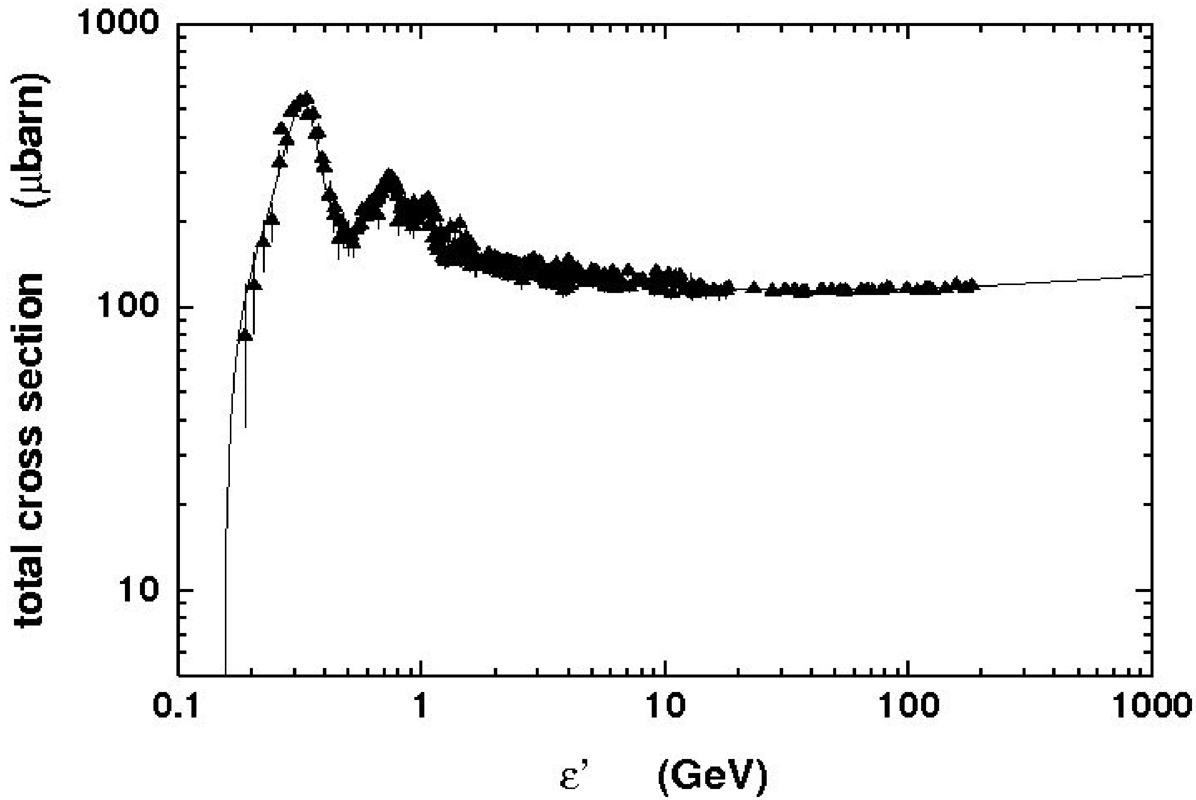
$$s = m_p^2 + 2E_p\epsilon(1 - \beta_p \cos\theta)$$

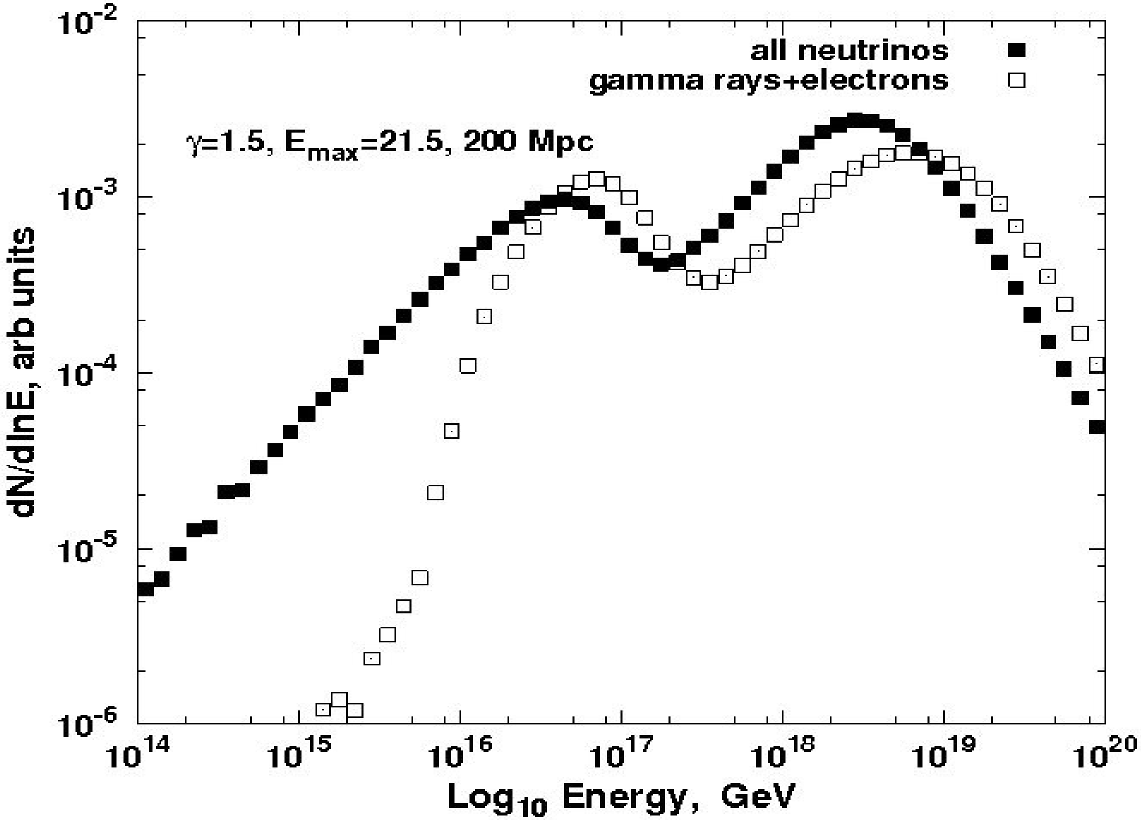
$$E_p = \frac{m_{\pi^0}}{4\epsilon}(2m_p + m_{\pi^0}) \simeq 10^{20}\ \mathrm{eV}\ .$$

Δ^+ dominates the cross section at threshold

ε' is the photon Energy in the proton frame, where the energy threshold is 0.13 GeV

$\varepsilon' = (s - m_p^2)/2m_p$





Cosmogenic gamma rays have higher energy at production for a simple reason: one neutral pion decays in two gamma rays while a charged pion decays into three neutrinos. For the same reason the neutrino flux is higher. It is difficult, though, to use the γ-ray background to limit the neutrino flux because of the extragalactic magnetic fields.

The important astrophysical parameters for the shape and magnitude of the cosmogenic neutrino fluxes are:

Emissivity of UHECR sources

Maximum acceleration energy

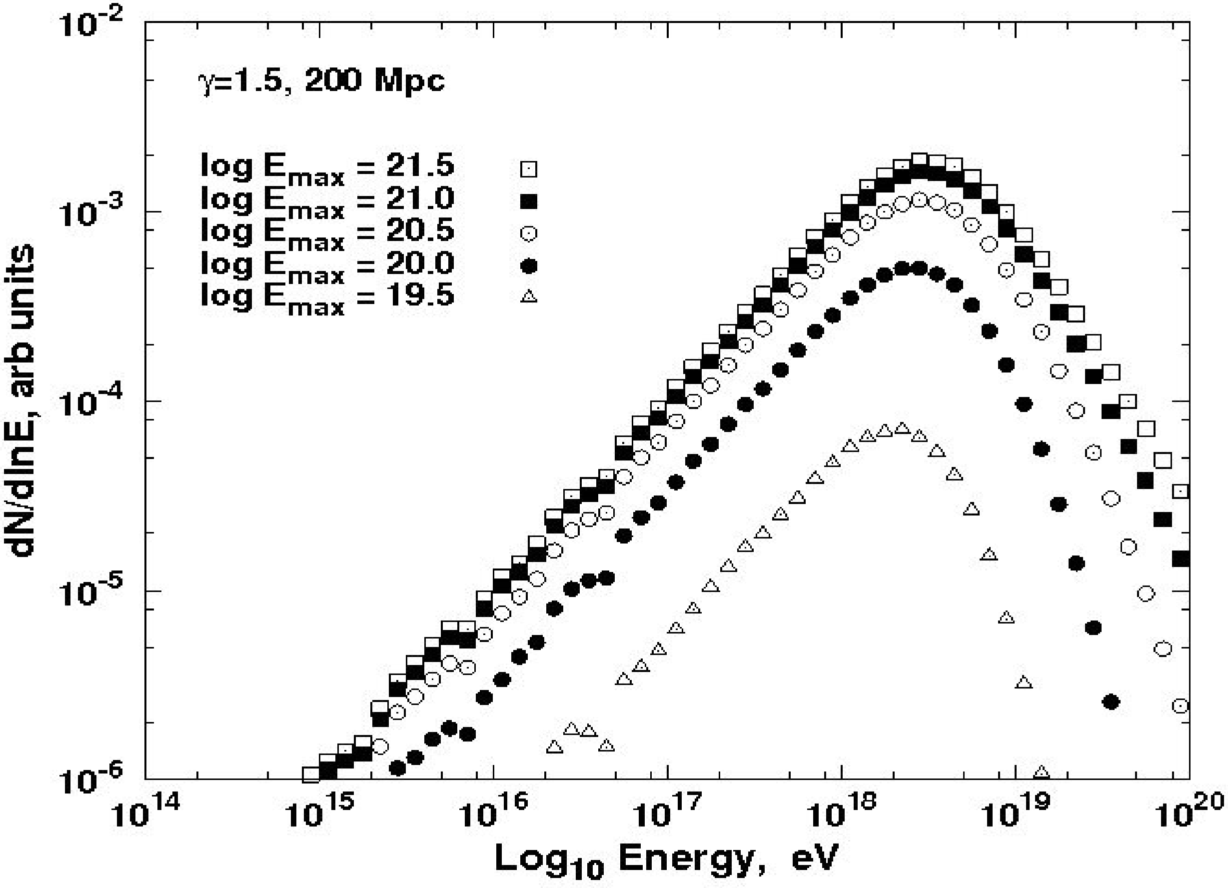
Energy spectrum at acceleration

Cosmological evolution of the UHECR sources

Composition of UHECR at acceleration

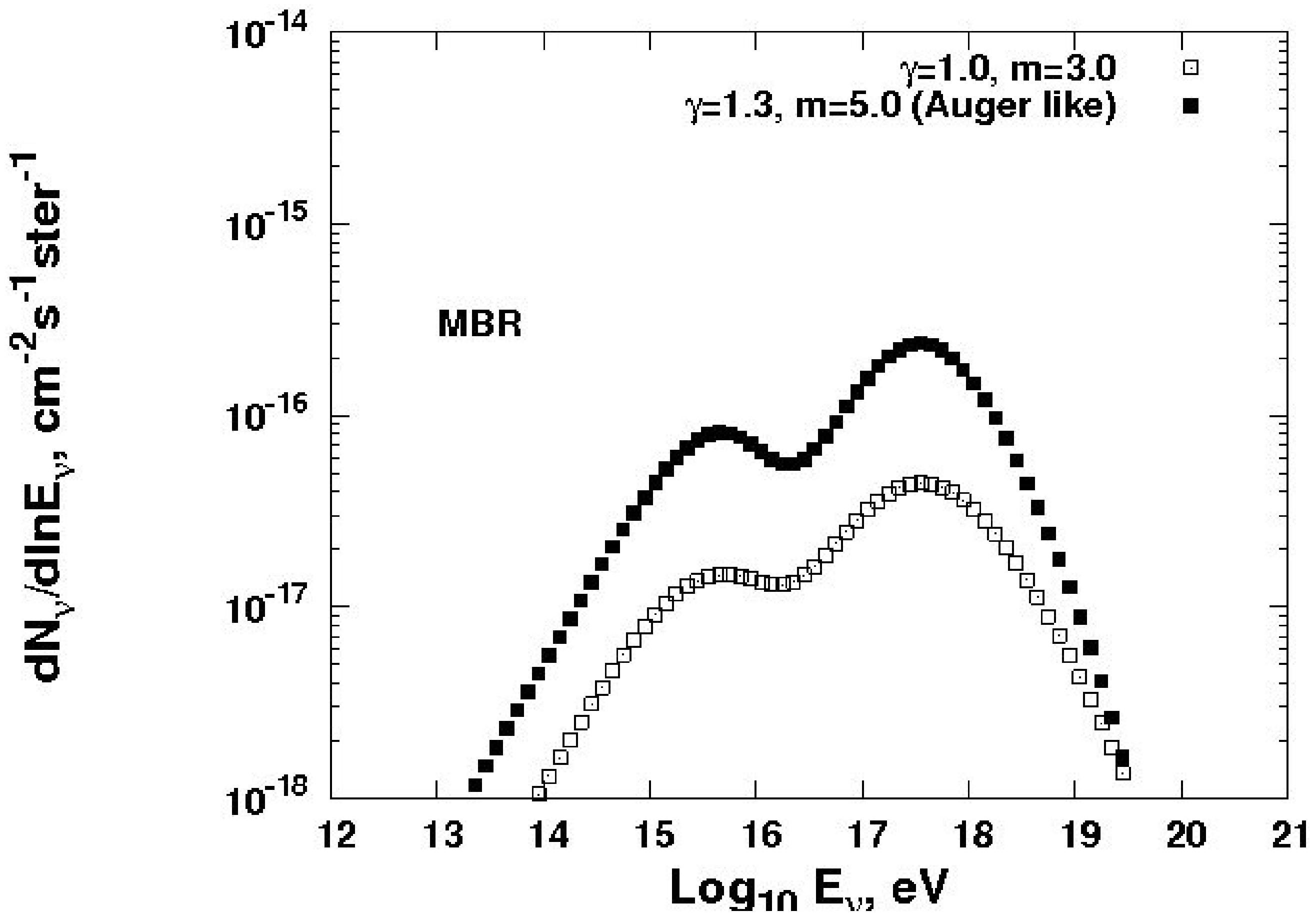
Distribution of these sources in the Universe

Most of these parameters are correlated with each other



The maximum acceleration energy of the UHE protons is one of the most important astrophysical parameters for the estimate of the cosmogenic neutrino flux. Only muon neutrinos and antineutrinos shown here.

What can we expect after the current measurements of the UHECR flux? We can use some of the `proton' fits of the Auger spectrum. The emissivity of the UHECR sources is corrected (it is a linear effect, a coefficient). We use now ½ of the emissivity of W&B.



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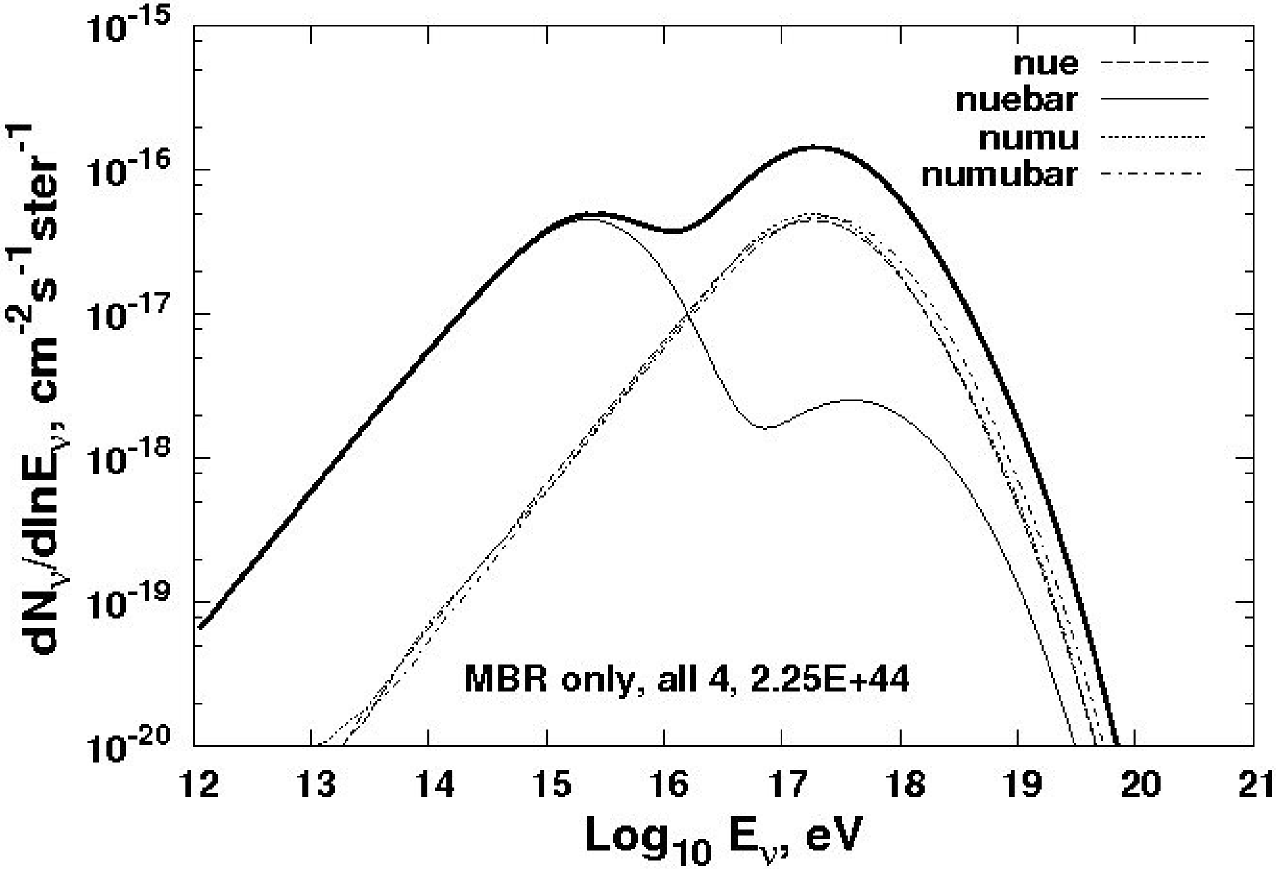
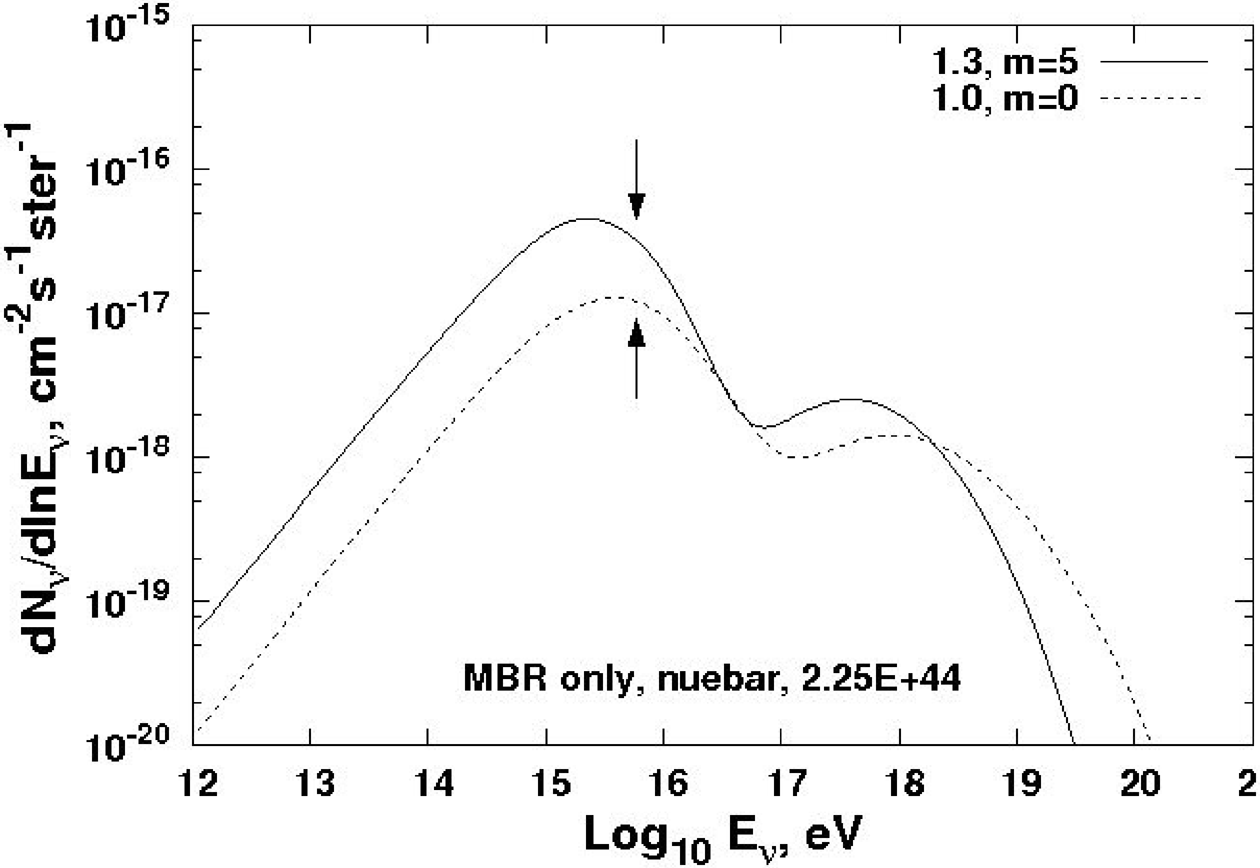
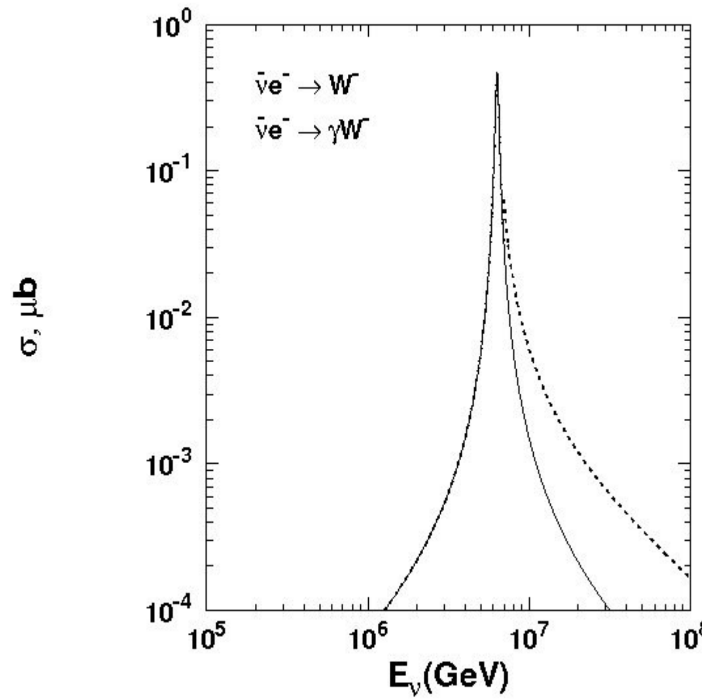
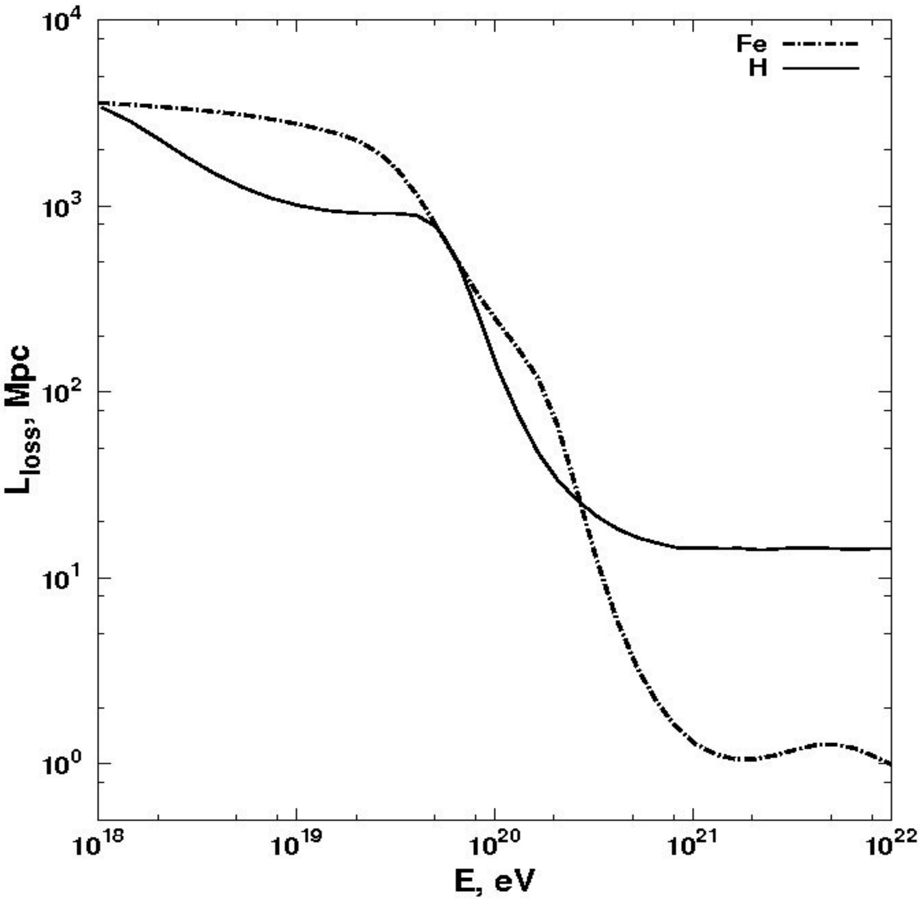


Different neutrino flavors in a standard cosmogenuc neutrino Calculation. Electron antineutrinos are result of neutron decay. Have in mind that these neutrinos are generated very far away and at arrival at Earth the composition is bound to be close to 1:1:1.



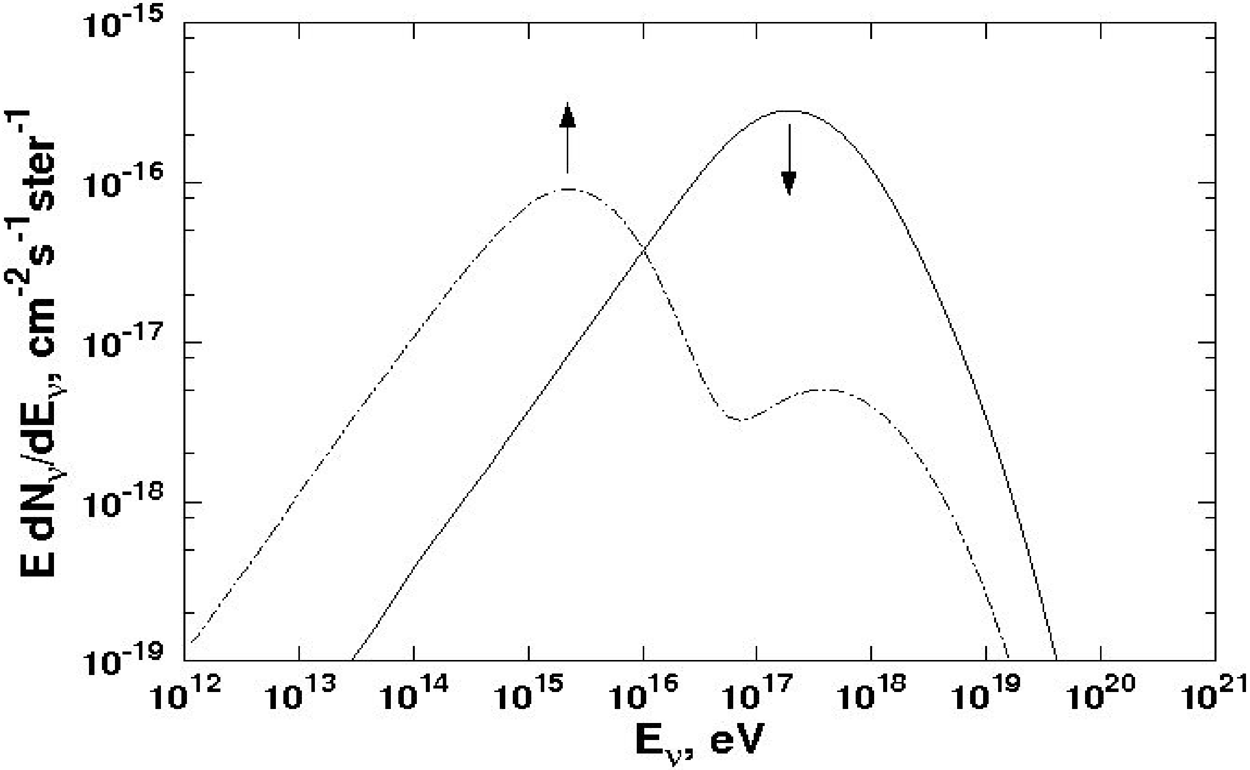


The highest possible cross section is at the Glashow resonance: $\bar{\nu}_e + e^- = W^-$ The decay products of the W^- would generate showers in a big detector. The resonance is however narrow and high rate is not expected.



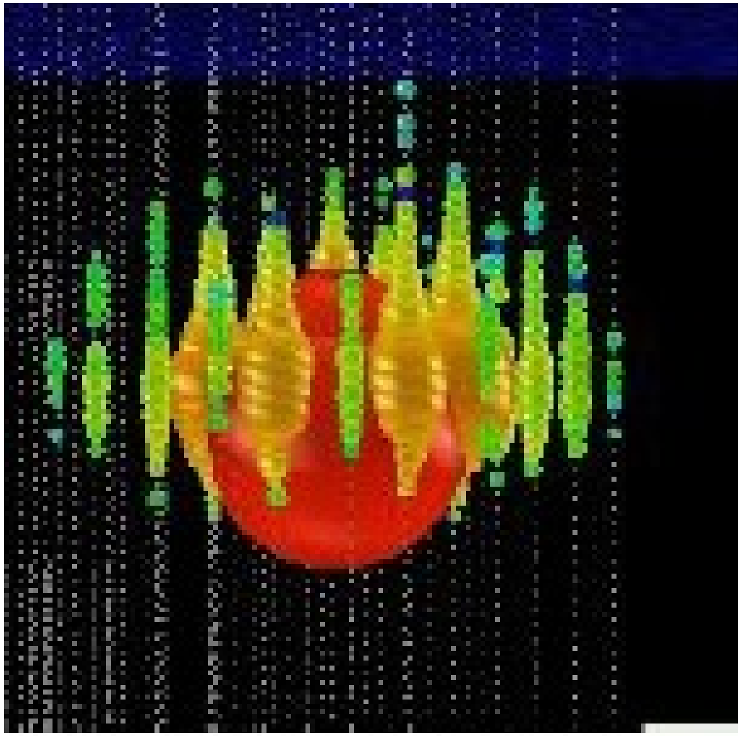
The depth of shower maxima of the HiRes and TA experiments suggest very light (H+He) UHECR composition while Auger measures an increasingly heavier composition at hery high energy

The energy loss length of Fe is close to that of protons but the main neutrino production is from neutron decay → mostly electron antineutrinos are created. Only when the energy per nucleon exceeds the threshold energy of 30 EeV other neutrino types are created.

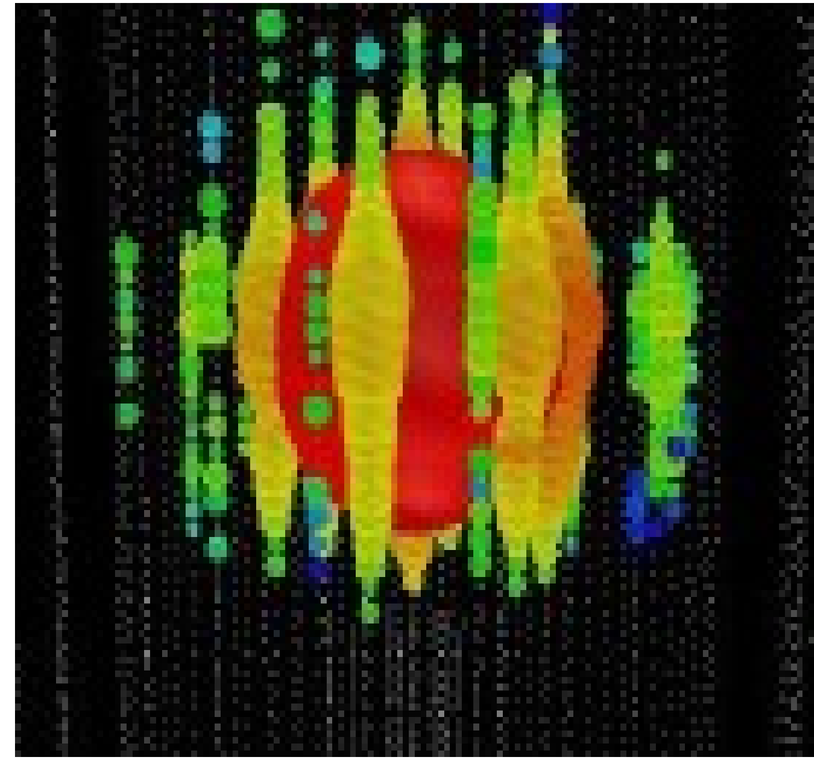


The general rule is that heavy composition would increase the flux of electron antineutrinos and decrease all others.

The heavier the UHE cosmic ray composition is, the higher is the flux of electron antineutrinos and the lower is the flux of all other flavors. Detection of the Glashow resonance would support heavy composition while the detection of 10^{18} eV neutrinos would support proton composition of UHECR.



312 DOMs



354 DOMs

Two neutrino events of energy above 10^{15} eV detected in IceCube were reported on Neutrino 2012 by **Aya Ishihara**. The first thought was that these events are produced by electron antineutrinos generating the Glashow resonance.

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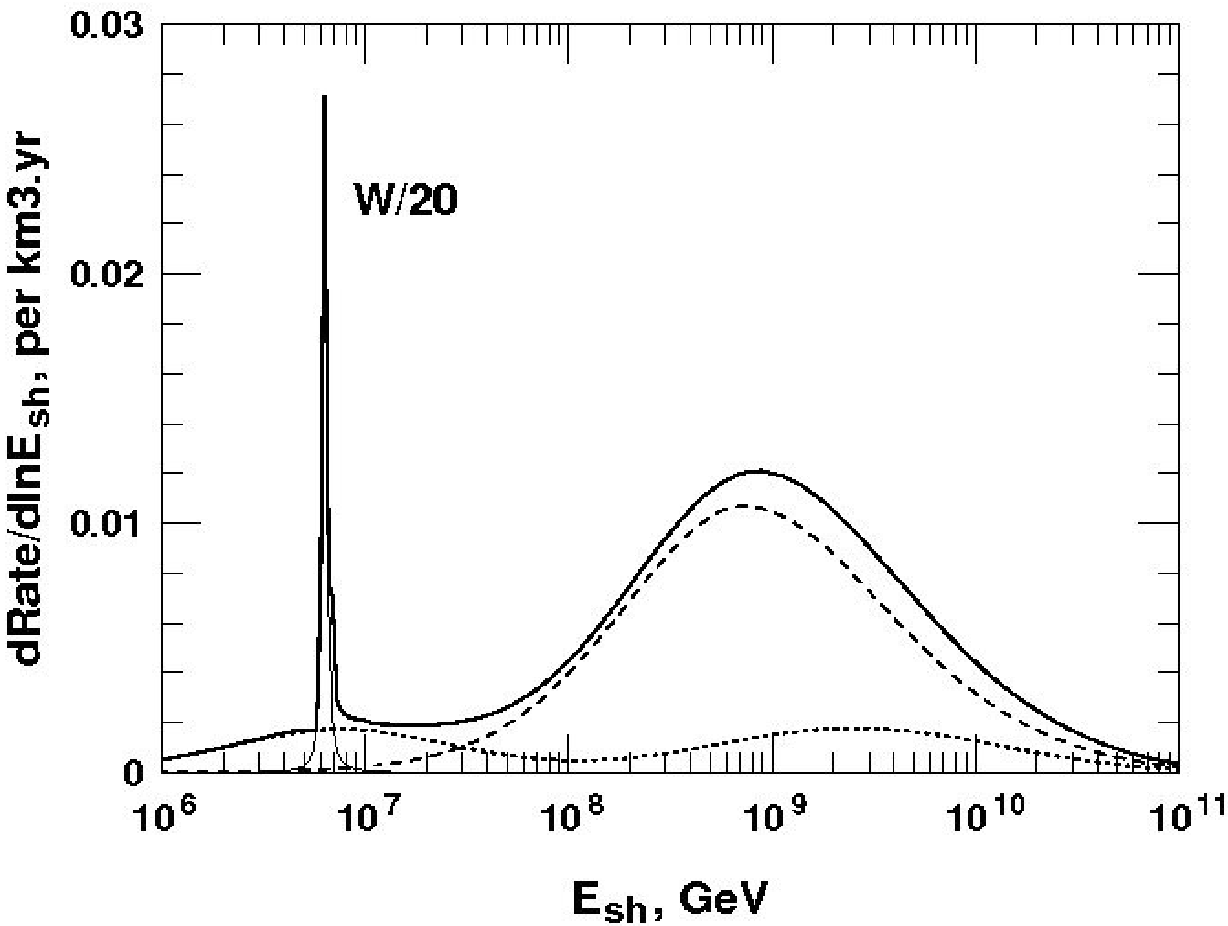

Theoretically expected (no efficiency) event rates from the production spectrum of cosmogenic neutrinos. Absorption in the Earth is included. Accounting for oscillations would decrease the rates by 2/3.

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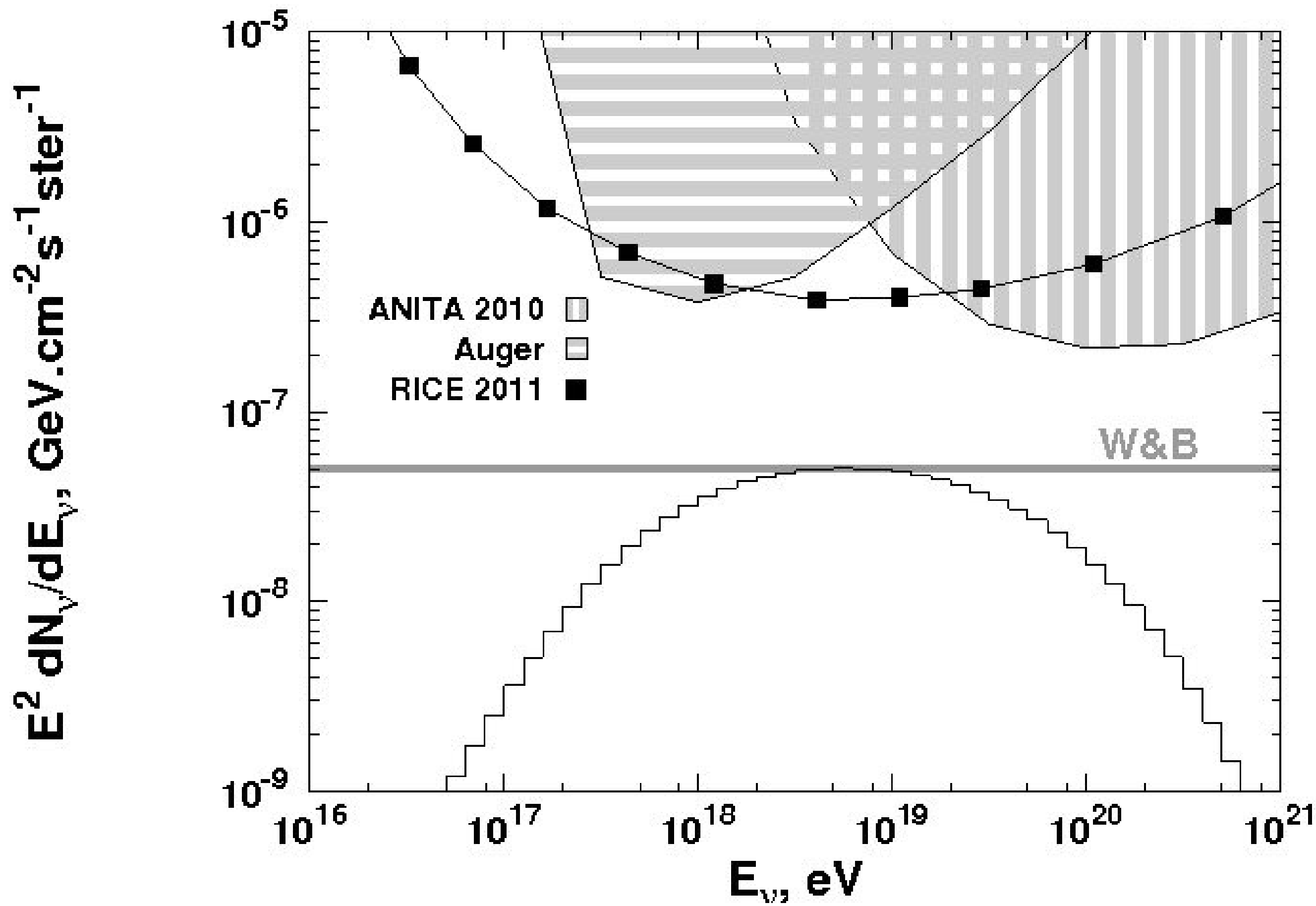
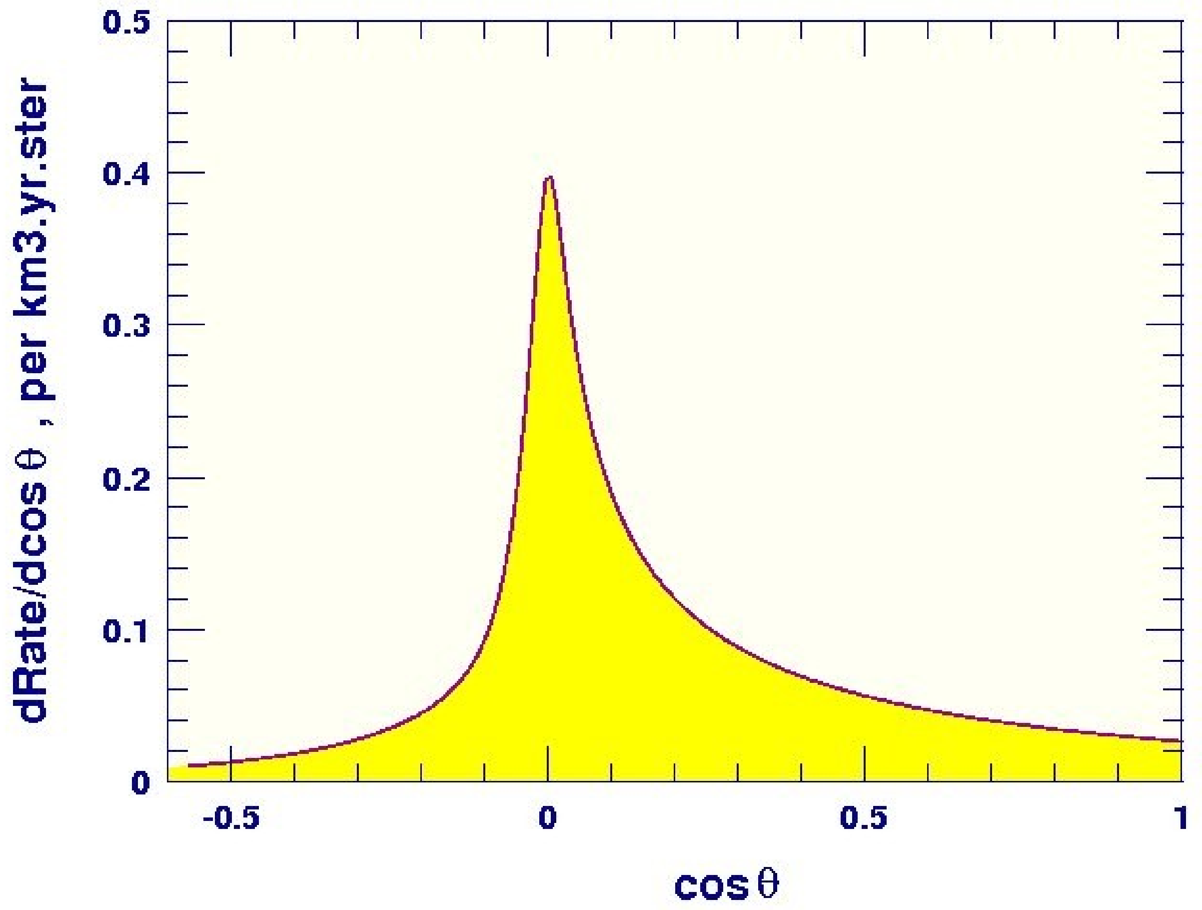
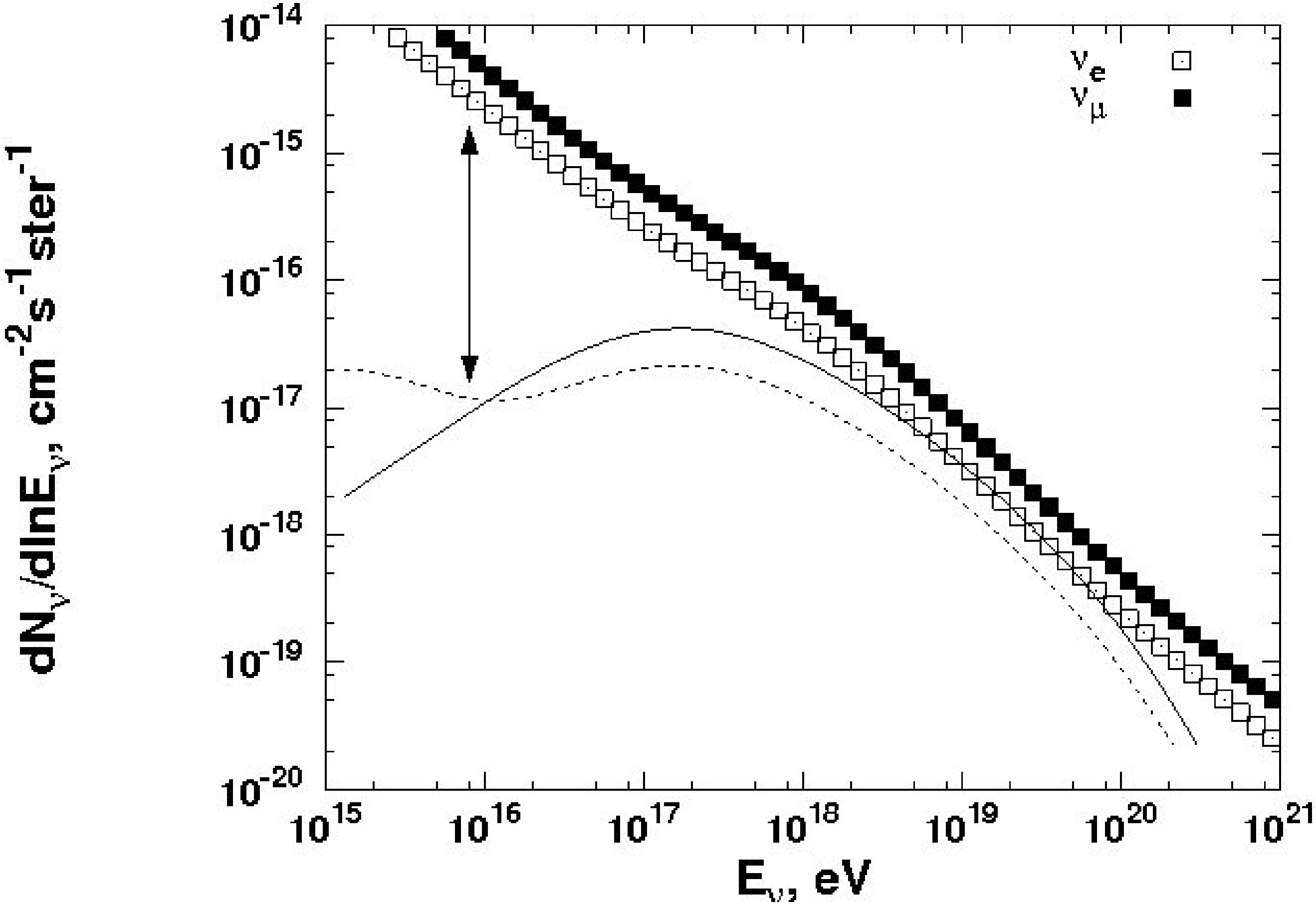
Current limits on the flux of high energy cosmogenic neutrinos.
Note it is plotted as E^2F so W&B limit is a straight line.
IceCube has a lower limit at lower energy.





Because of the structure of the atmosphere and the shadowing of the Earth all signals are concentrated in horizontal direction. This creates uniques signatures for Auger and other surace arrays and creates the most useful geometry (tracklength) for OWL/Airwatch.



Comparison of the W&B limit + cosmogenic neutrinos to only cosmogenic neutrinos.

It is easier to believe that the two PeV neutrino events in IceCube were generated at some of the cosmic ray sources rather than by UHECRs in propagation. The Glashow resonance cascades would have been of higher energy.

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