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- Detection of UHE neutrinos requires minimal knowledge of the neutrino cross section
- Future observations will allow one to *measure* the neutrino-nucleon cross section at an unprecedented energy, $\sqrt{s} \sim 10^6$ GeV, and compare σ to the Standard Model prediction (*Frichter, McKay, Ralston; Gandhi, Reno, Quigg, Sarcevic*)

AK and T.J.Weiler, Phys.Rev.Lett.88:161101,2002

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- Calibration at $\sqrt{s} = 1$ GeV yields unexpected results: UHECR
- Prospects for future measurements of the neutrino-nucleon cross section at $\sqrt{s} \sim 10^6$ GeV.

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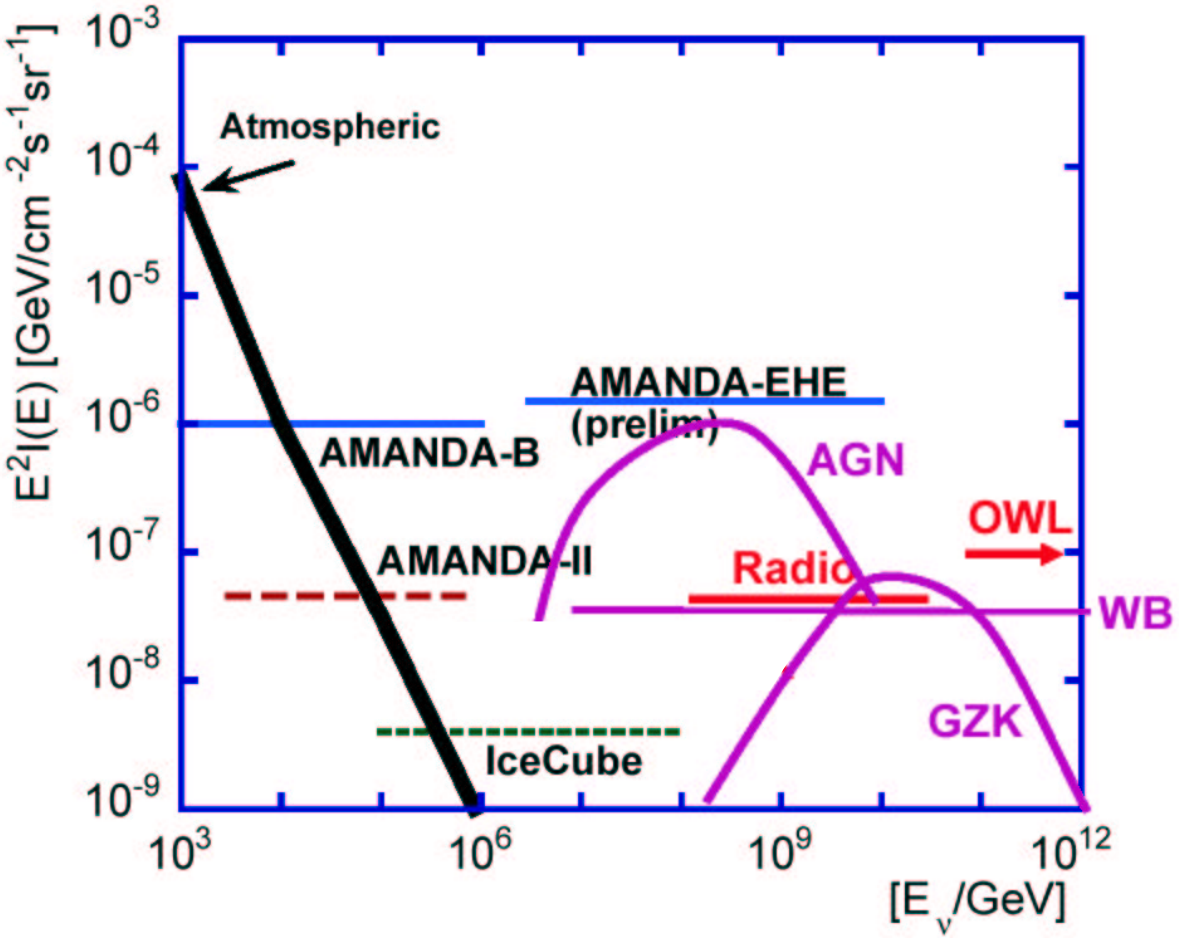
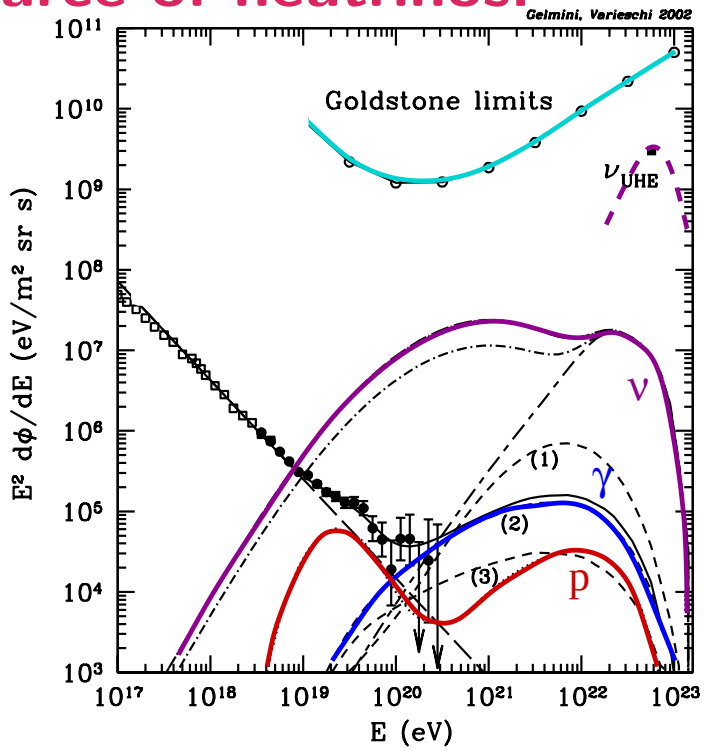
- Astrophysical sources: AGN, GRB, etc.
- Z-bursts [Weiler, Fargion *et al.*], TDs $\Rightarrow$ **a lot of neutrinos**

Predictions and limits



Z-bursts as a source of neutrinos:



Gelmini and Varieschi; Kalashev *et al.*

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- **Additional sources can provide additional flux.**

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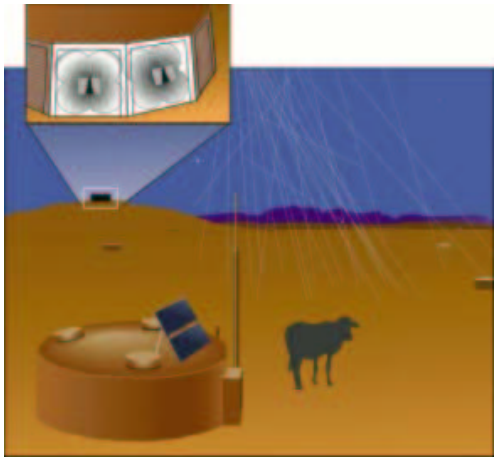
- Pierre Augere experiment 

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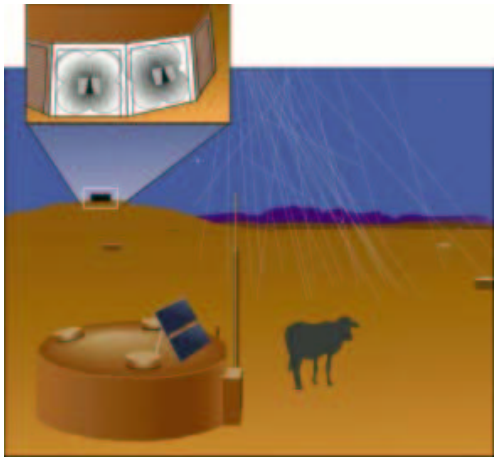
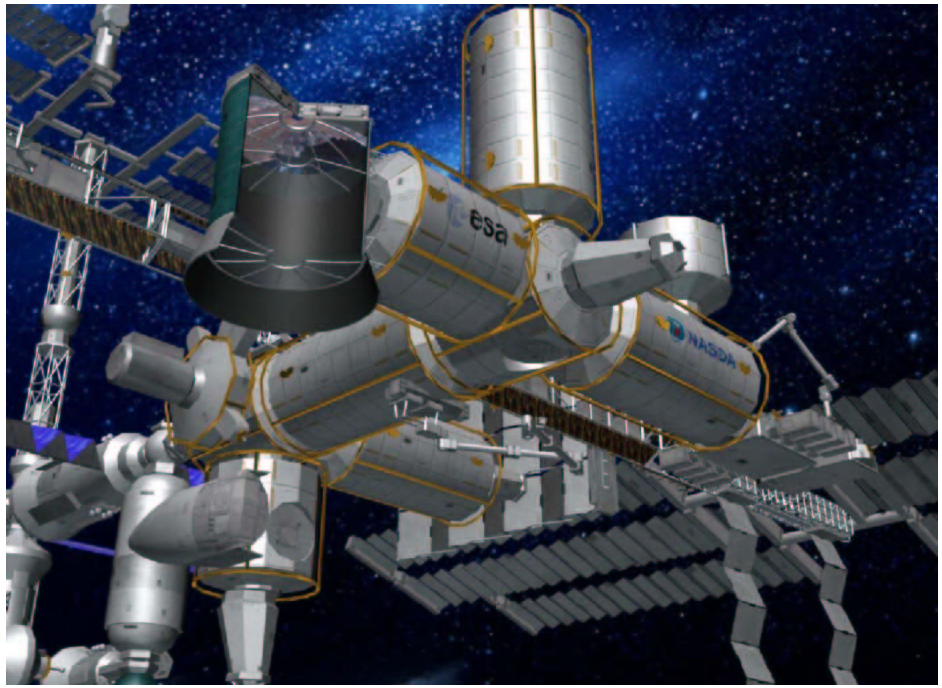
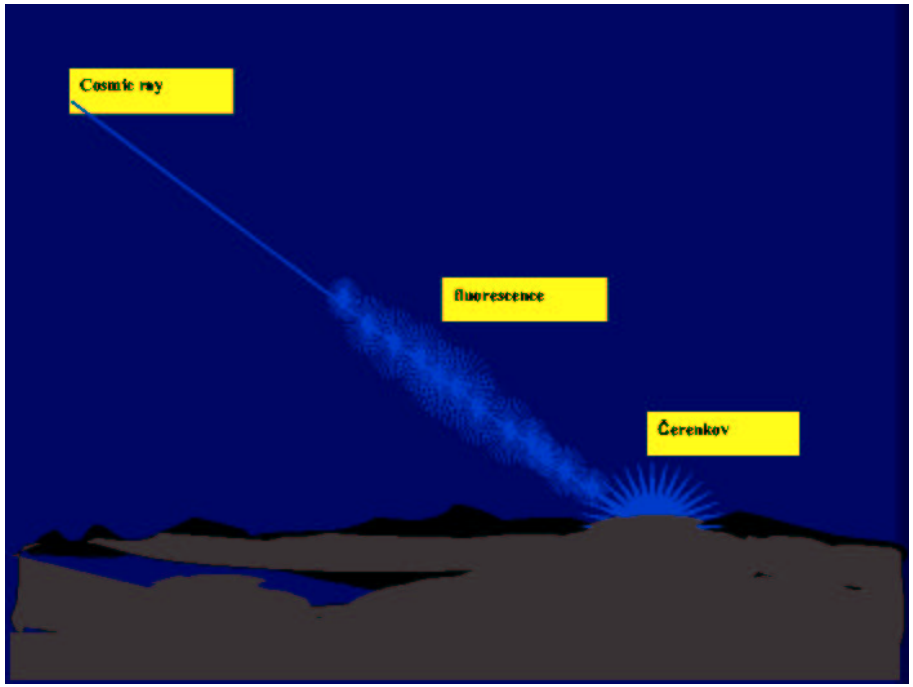
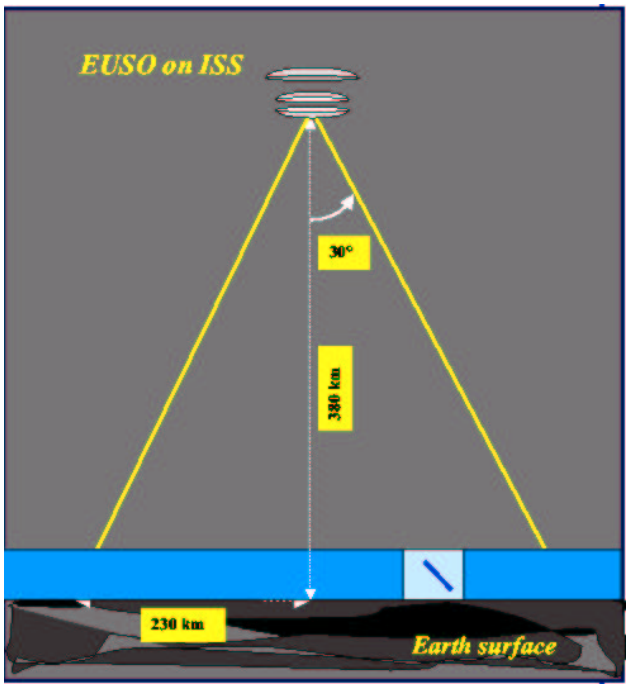
- Pierre Augere experiment 
- Future EUSO, OWL, TA,...

Extreme Universal Space Observatory (EUSO)

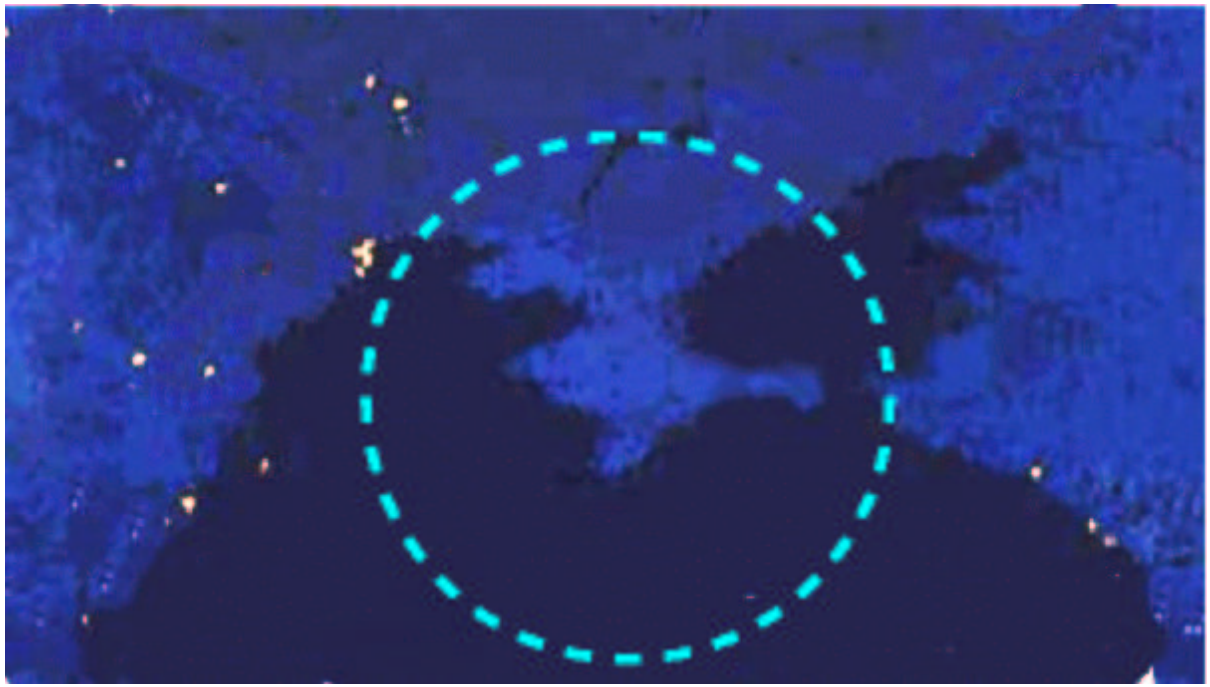


EUSO is designed to observe fluorescent air showers initiated by extremely high energy cosmic rays - and neutrinos

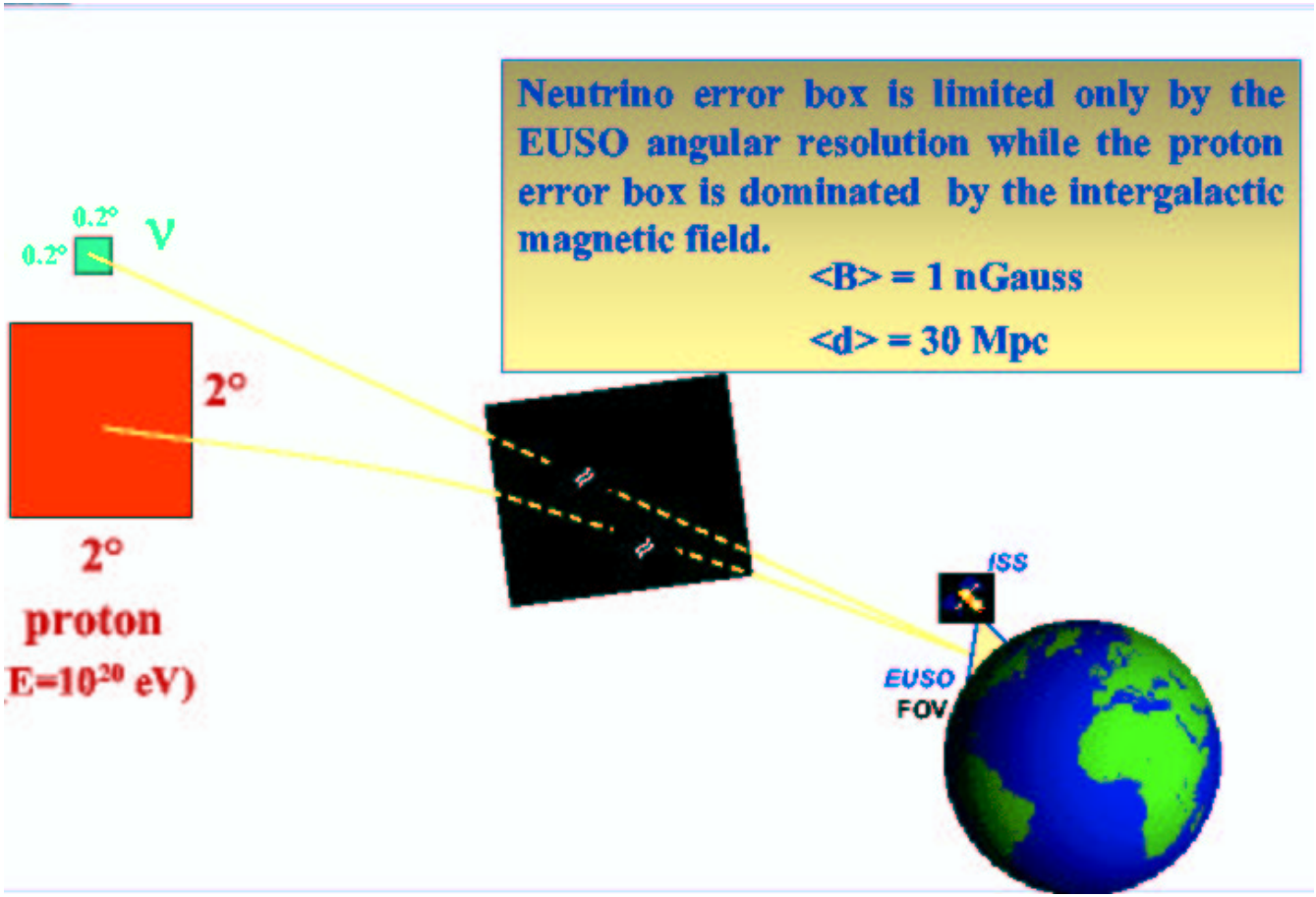




EUSO field of view



UHE neutrino astronomy



Cross sections

Several approved and proposed experiments plan to **detect UHE neutrinos** by observations of nearly **horizontal air showers**.

Neutrinos are the only particles that interact weakly enough to produce horizontal air showers (assuming the cross section $\sigma_{\nu N} \sim 10^{-31}\text{cm}^2$ at 10^{20}eV) Hence, particle ID is straightforward.

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But how well do we **know** the neutrino-nucleon cross section?

Calculations of neutrino-nucleon cross section at $\sqrt{s} \sim 10^6$GeV

Calculations of $\sigma_{\nu N}$ at 10^{20}eV necessarily use extrapolations of PDF and standard model parameters.

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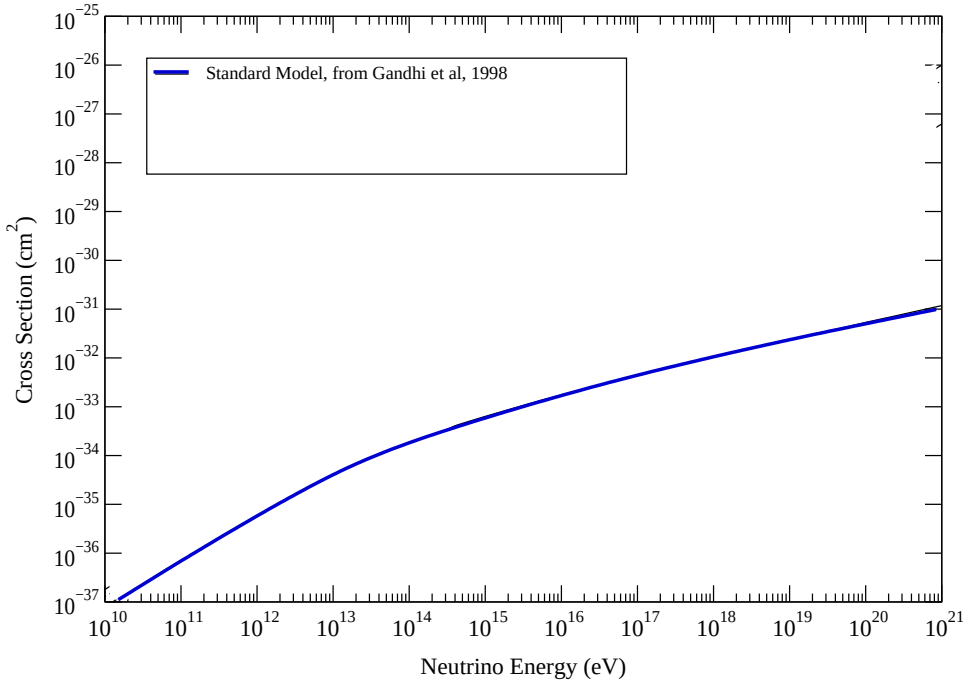

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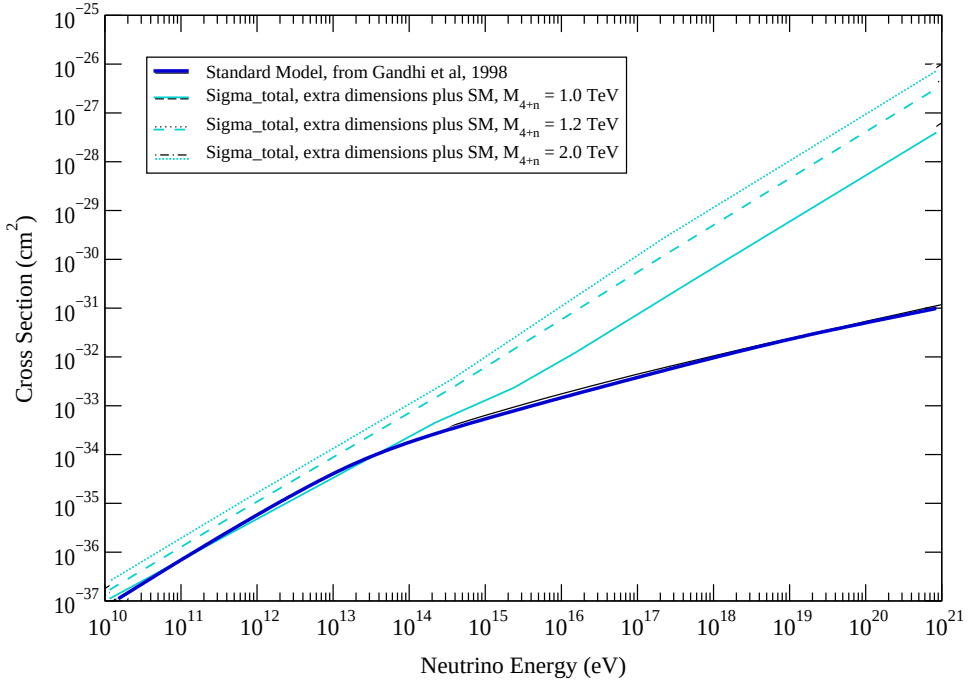

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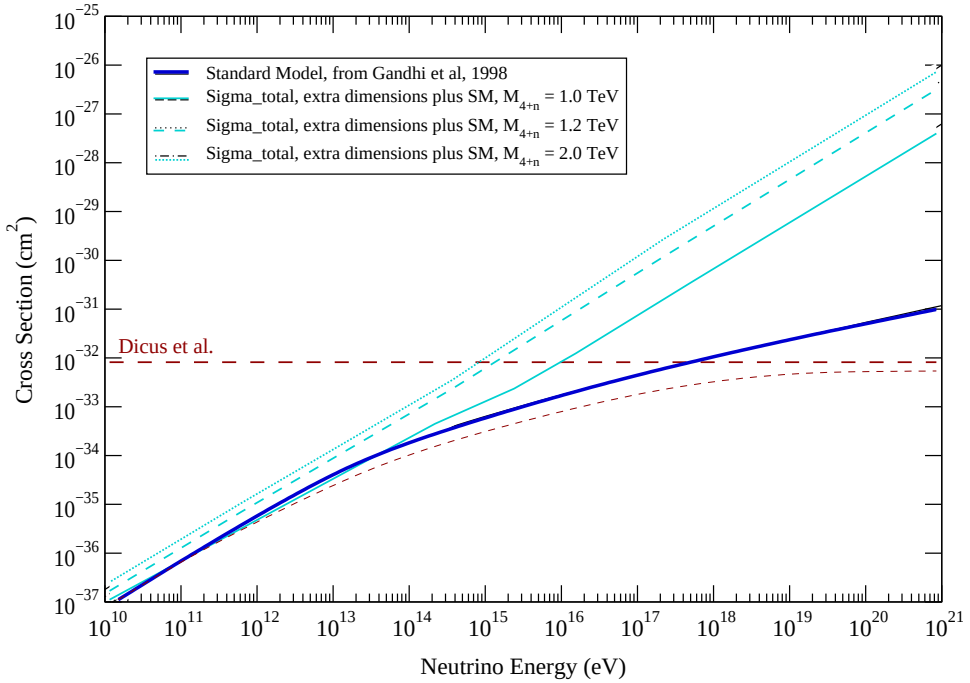

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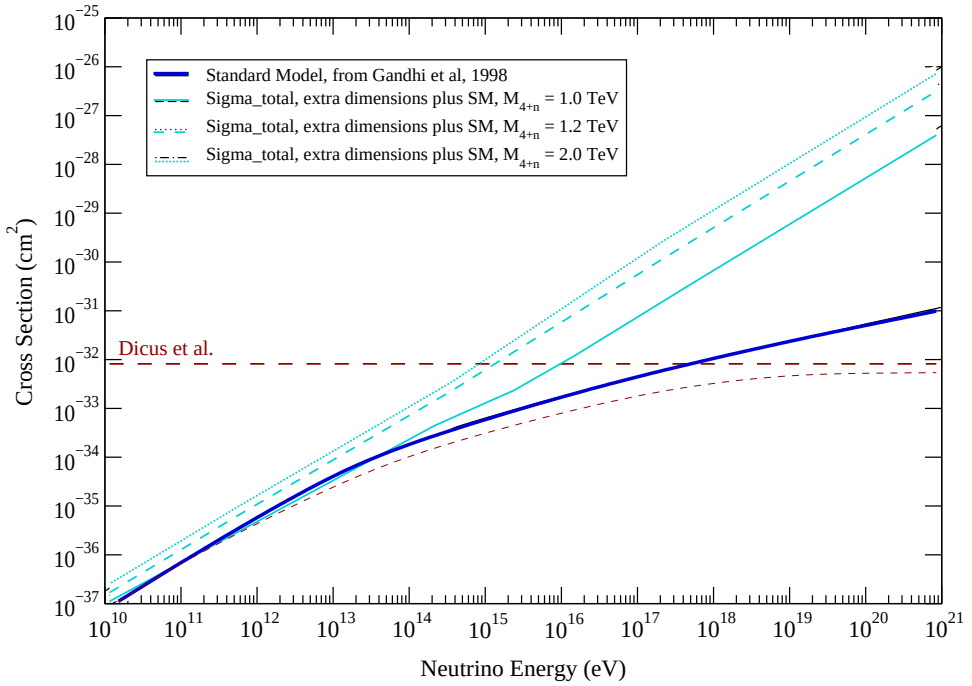

SM is probably right, but we want to **measure** this cross section.

NLO and saturation effects may lower the cross section [hep-phg/0208125]

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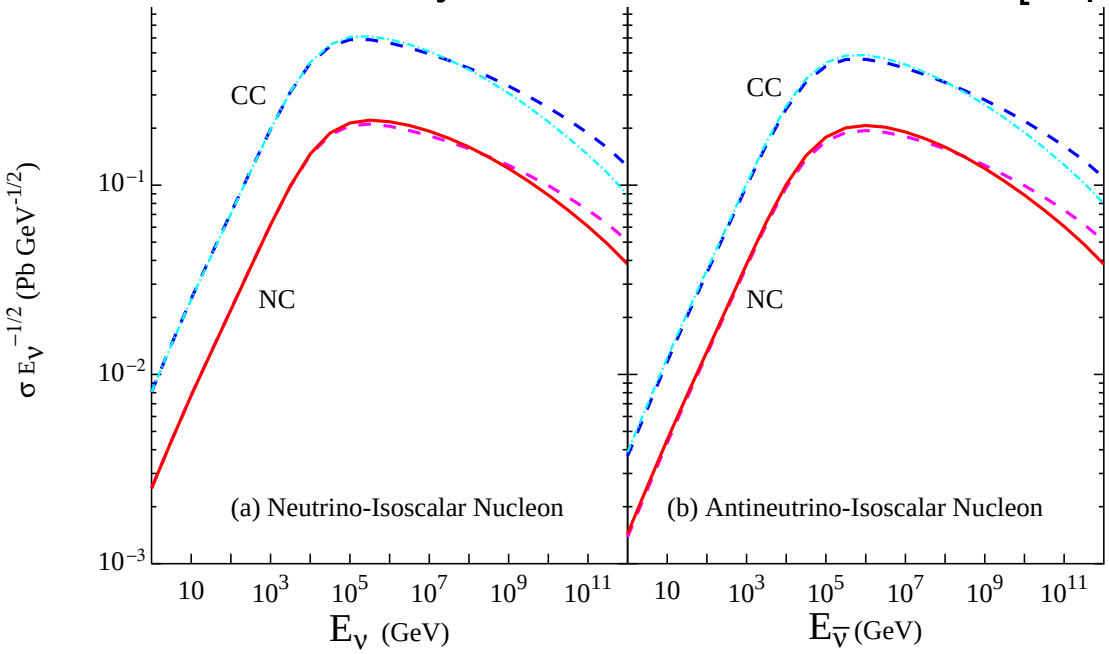

The solid (dashed) line represents the NLO (LO) cross sections.

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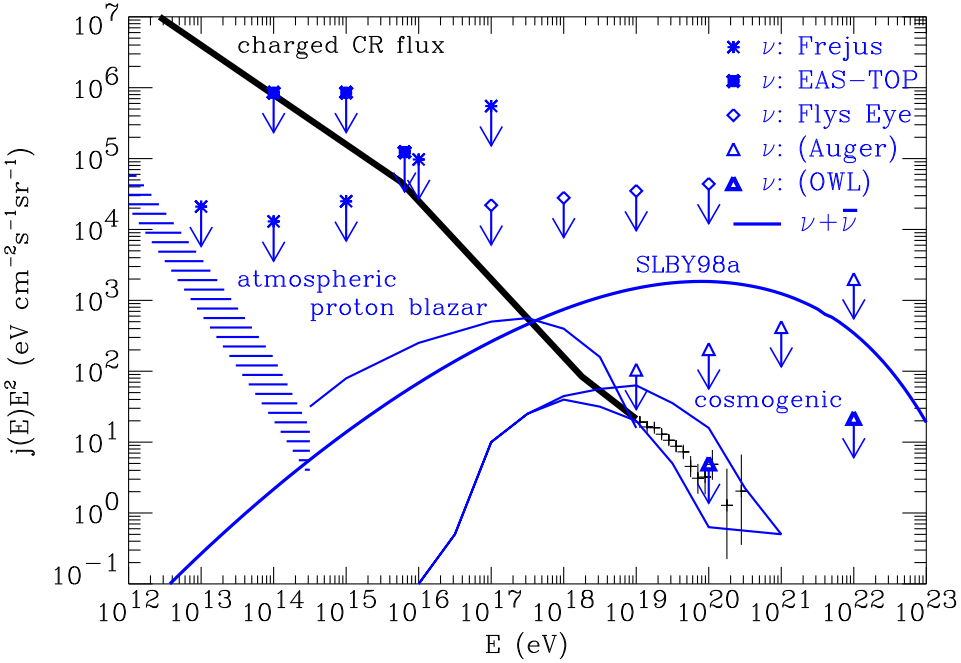
The cross section may be higher or lower than the Standard Model prediction...

If the cross section is strong, GZK neutrinos may actually explain the UHECR events!



Berezinsky; Bordes *et al.*; Domokos, Nussinov; Nussinov, Shrock; Domokos, Kovesi-Domokos; Jain, McKay, Panda, Ralston; Sigl *et al.*

However, if the cross section is **lower than the Standard Model prediction**, the air horizontal showers may be too few to observe...

The rate of horizontal air showers is **proportional to $\sigma_{\nu N}$**. If the cross section is smaller than $10^{-31}\mathrm{cm}^2$, the horizontal air showers cannot be observed even by OWL and EUSO.

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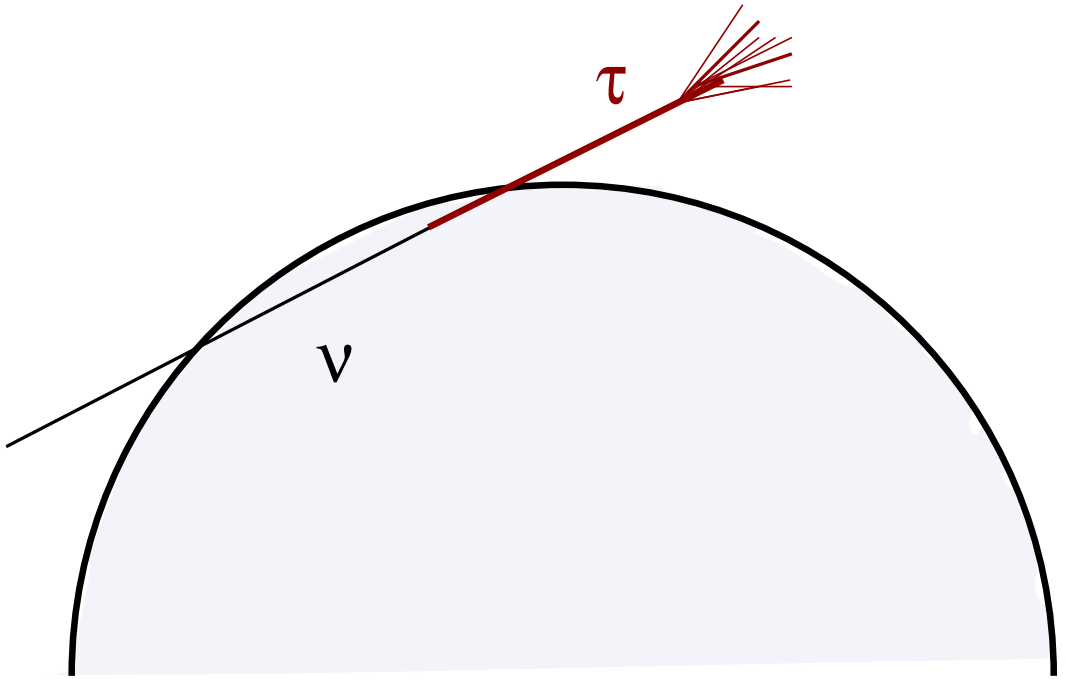
On the contrary, the smaller cross section is a boon!

[AK, Weiler, Phys.Rev.Lett.88:161101,2002]

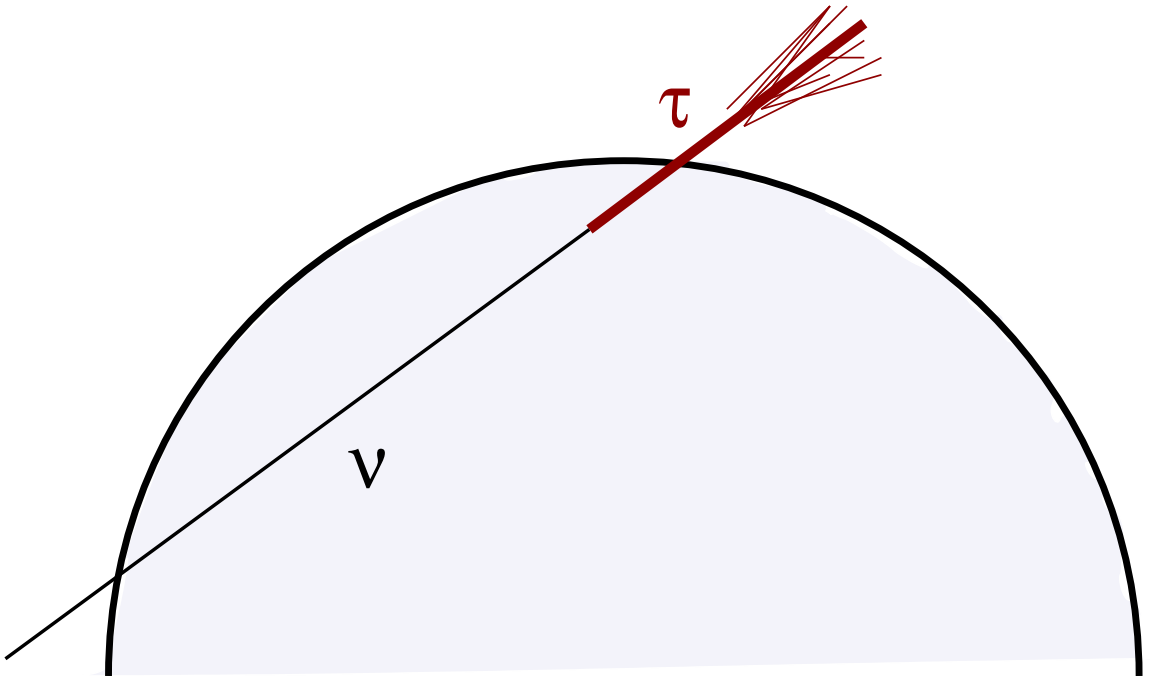
If the cross section is smaller, the Earth becomes more transparent to neutrinos. More neutrinos can get through the Earth, interact just below the surface and produce a charged lepton that originates an **up-going air shower (UAS)** .

- **The increase in UAS rate compensates for the decrease in HAS.**
- **The comparison of the two rates allows a measurement of the cross section at 10^{11}GeV**
- **Angular distribution of UAS can provide an additional independent information about the cross section**

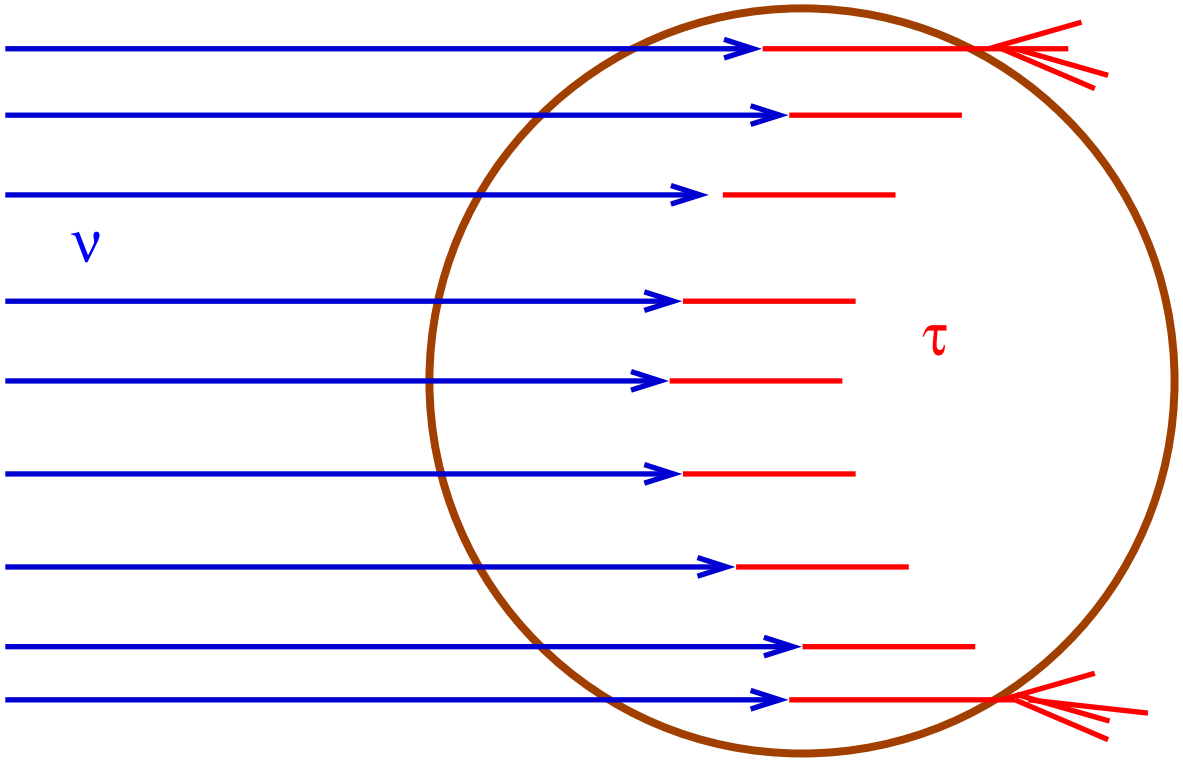
Earth-skimming events have been discussed in the literature



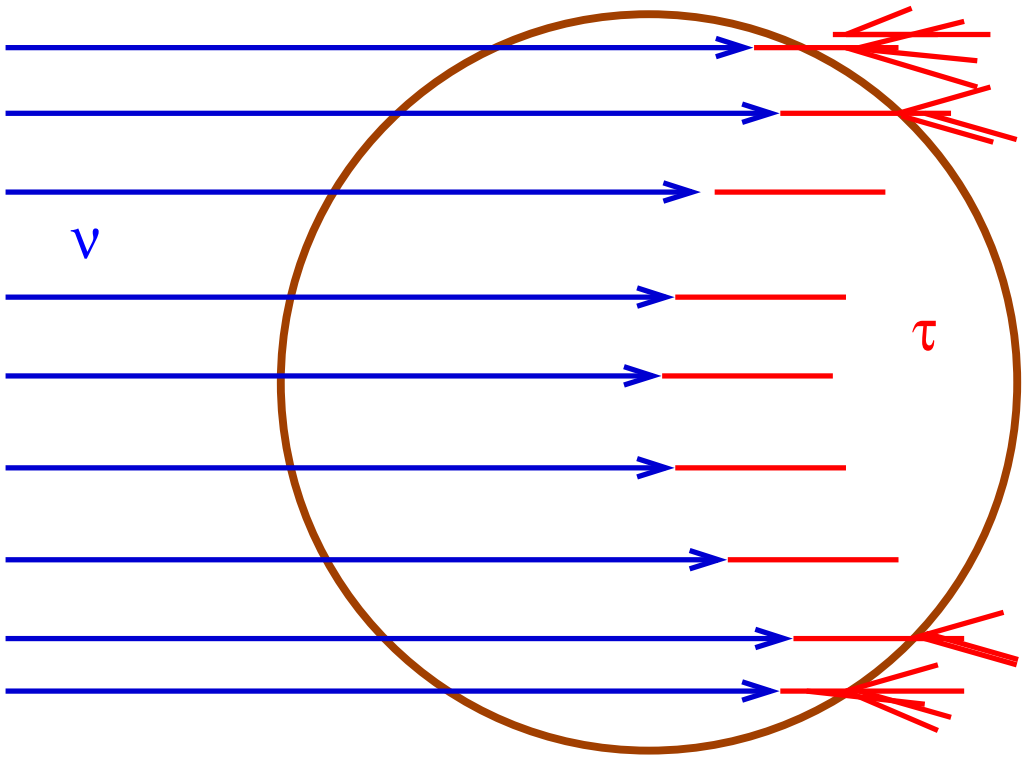
Domokos, Kovesi-Domokos, hep-ph/9805221; Fargion, astro-ph/0002453; Bertou *et al.*, astro-ph/0104452; Feng, Fisher, Wilczek, Yu, hep-ph/0105067



The probability of a neutrino conversion into an up-going τ grows with the mean free path λ_ν, for $\lambda_\nu < R_\oplus$, because the shadowing by the Earth decreases.



UAS requires a neutrino to interact and produce a τ below the surface.



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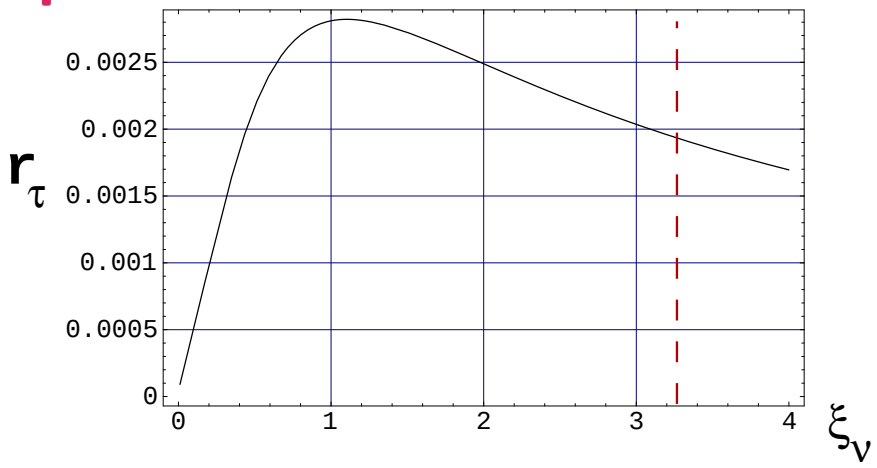
The number of UAS is higher for a smaller cross section.

How many τ's per neutrino?



The ratio r_τ of the upward going τ flux to the incident tau neutrino flux F_{ν_τ} as a function of $\xi = \lambda_\nu / R = 1/(\sigma_{\nu_N} n R)$, with fixed $\lambda_\tau / R = 3.5 \times 10^{-3}$, appropriate for events initiated by $\sim 10^{20}$ eV neutrinos. The value of ξ is limited from above by the weak-interaction cross section measured at HERA shown by a vertical dashed line.

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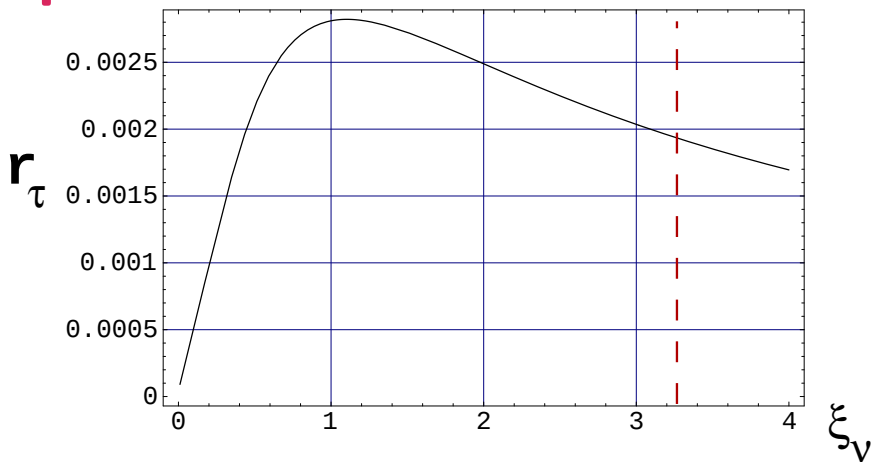

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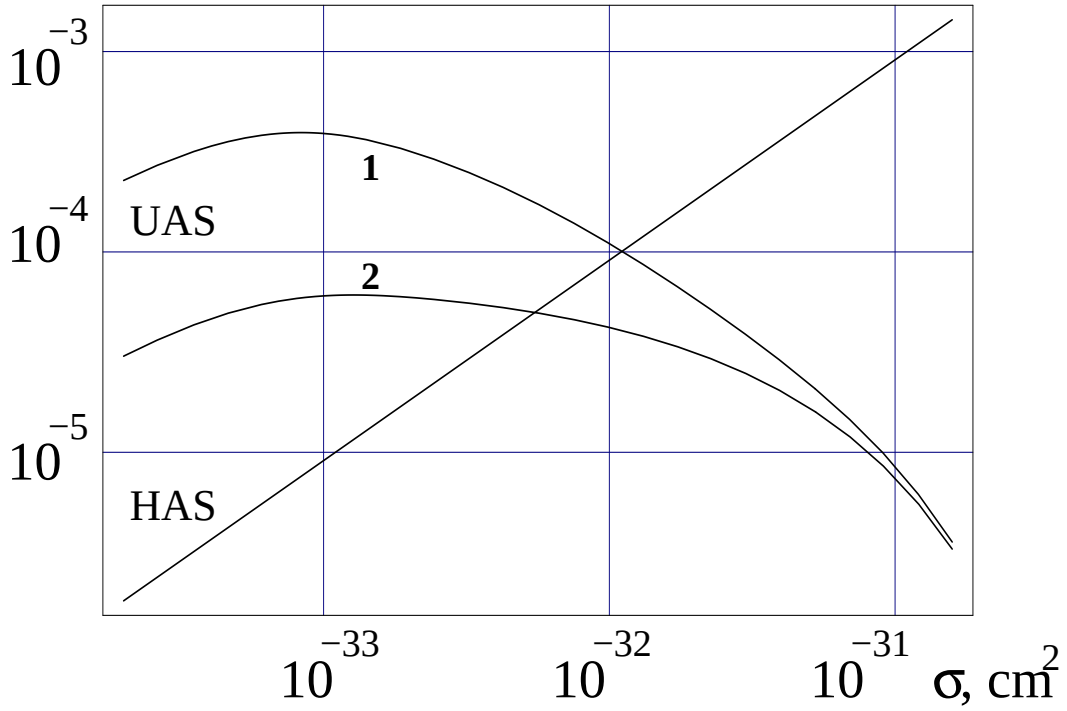
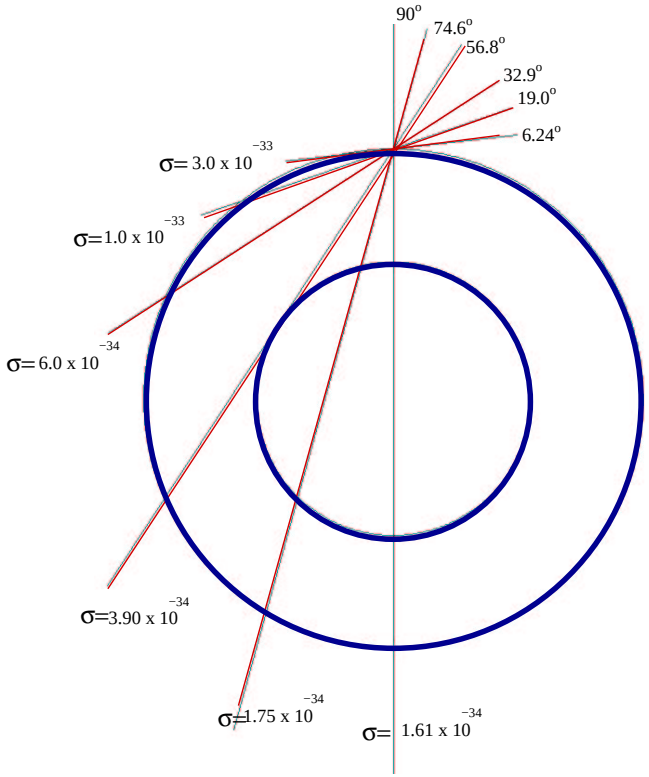
τ must decay in the atmosphere.

The shower probability per incident neutrino:



The energy threshold for detection of UAS was assumed $E_{\rm th} = 10^{18}$eV for curve 1 and $E_{\rm th} = 10^{19}$eV for curve 2. Additional UAS events, not included here, can be detected by EUSO or OWL via Cerenkov radiation of tau leptons.

In addition, the angular distributing depends on the cross section.



Most probable UAS corresponds to chord length close to mean free path

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Need ICE CUBE, EUSO, OWL, and more!

A side comment:

Bounds on the neutrino flux

- due to non-observation of neutrino-initiated HAS
- non-observation of radio signals from neutrino-initiated showers below the surface of the Moon

are weaker if the cross section is small.

Conclusion

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- future experiments can *measure* the neutrino cross section at an unprecedented energy scale $\sqrt{s} \sim 10^6$GeV.

- The *world's largest detector* will use the Earth.