Miami 2007

Cosmogenic Neutrinos and Quasi-stable Supersymmetric Particle Production*

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*M.H. Reno, I. Sarcevic and J. Uscinski, Phys. Rev. D76, 123009 (2007)

- Neutrinos are highly stable, neutral particles ⇒ Thus cosmic neutrinos point back to astrophysical point sources and bring information from processes otherwise obscured by a few hundred gm of a material.

- Interaction length of a neutrino is

$$\mathcal{L}_{\text{int}} \equiv \frac{1}{\sigma_{\nu N}(E_\nu)\cdot N_A}$$

Interaction length of 1TeV neutrino is 250 kt/cm^2 or column of water of 2.5 million km deep.

- Neutrino astronomy ⇒ a unique window into the deepest interiors of stars and galaxies
(HE photons get absorbed by a few hundred gm of a material).

- UHE Cosmic Neutrinos: Probes of Particle Physics and Astrophysics
  - ⋆ Energy Much Higher than Available in Colliders
  - ⋆ Escape from Extreme Environments
  - ⋆ Point Back to Sources
  - ⋆ A New Window to the Universe

Cosmic Neutrinos

- ⋆ **Cosmic Neutrino Background** ($T \sim 1.9K$, **i.e.** $E_\nu \sim 10^{-4} eV$)
- ⋆ **Solar Neutrinos (MeV energies)**
- ⋆ **SN 1987A (MeV energies)**
- ⋆ **Atmospheric Neutrinos (GeV to TeV energies)**
- ⋆ **Extragalactic Neutrinos (Cosmogenic, AGN, GRB, etc; GeV to EeV energies)**

Neutrino Flavors

- **source:** π **decays** $\Rightarrow \nu_e : \nu_\mu : \nu_\tau = 1 : 2 : 0$

- **propagation towards Earth: neutrino oscillations**

  $\star$ ν_μ **and** ν_τ **maximally mixed** $\Rightarrow \nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$

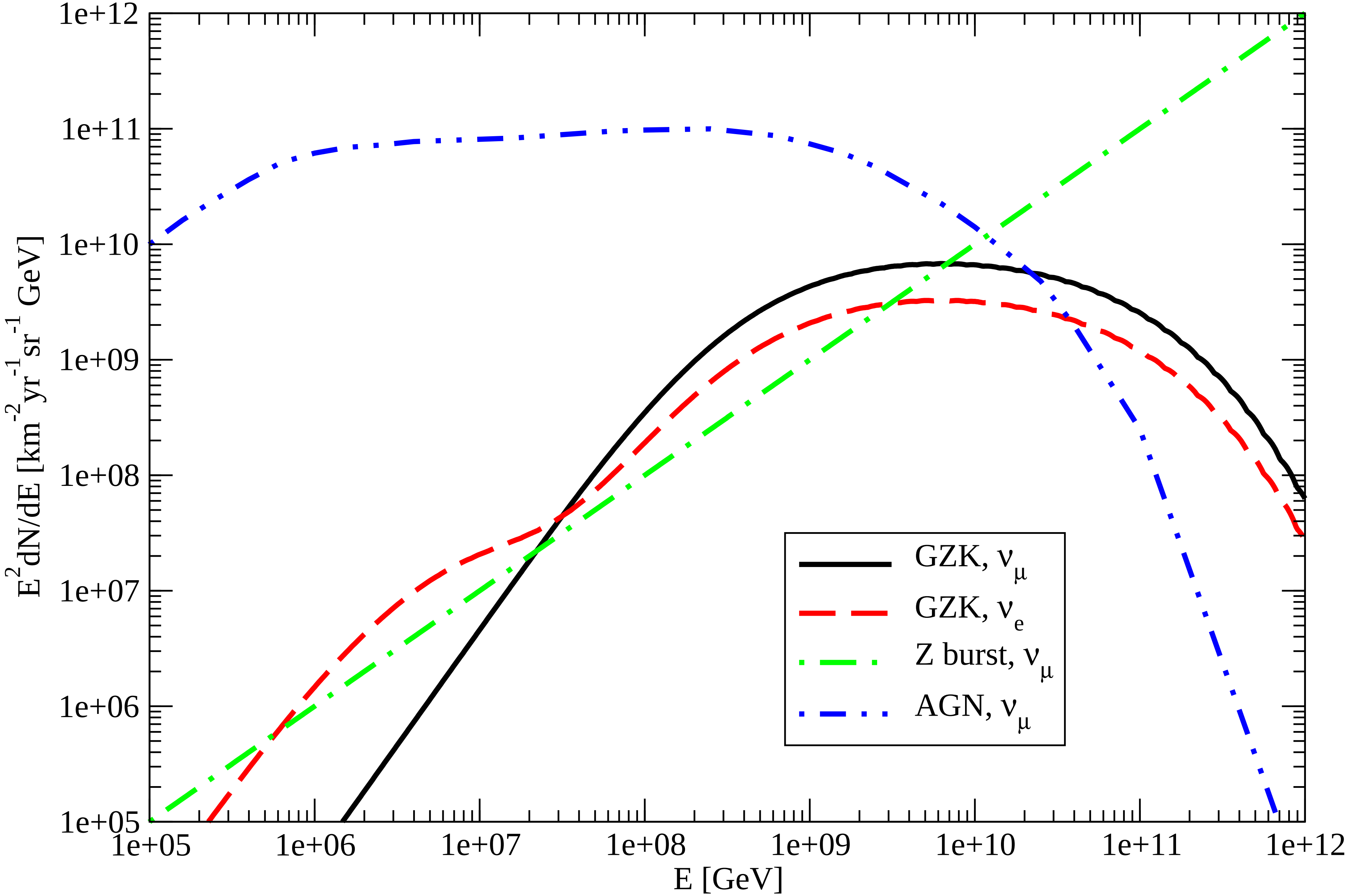
- **If** $F^0_{\nu_e} : F^0_{\nu_\mu} : F^0_{\nu_\tau} \neq 1 : 2 : 0$ **then three flavor mixing is relevant**

$$F_{\nu_e} \quad = \quad F^0_{\nu_e} - \frac{1}{4}\sin^2 2\theta_{12}(2F^0_{\nu_e} - F^0_{\nu_\mu} - F^0_{\nu_\tau})$$

$$F_{\nu_\mu} \quad = \quad F_{\nu_\tau} = \frac{1}{2}(F^0_{\nu_\mu} + F^0_{\nu_\tau}) + \frac{1}{8}\sin^2 2\theta_{12}(2F^0_{\nu_e} - F^0_{\nu_\mu} - F^0_{\nu_\tau})$$

Jones, Mocioiu, Reno and Sarcevic, PRD 69 (2004)

- **Three flavor mixing is important for cosmogenic neutrinos. These neutrinos originate from cosmic ray protons interacting with the cosmic microwave background. Since both the cosmic ray flux and the 3K microwave background have been measured, cosmogenic neutrino flux is a “guaranteed” neutrino flux.**


1e+12
1e+11
1e+10
1e+09
1e+08
1e+07
1e+06
1e+05
1e+05
1e+06
1e+07
1e+08
1e+09
1e+10
1e+11
1e+12
$E^2 dN/dE$ [km^{-2} yr^{-1} sr^{-1} GeV]
E [GeV]
GZK, ν_μ
GZK, ν_e
Z burst, ν_μ
AGN, ν_μ

- Detection of HE neutrinos with neutrino telescopes depends strongly on neutrino interactions and their cross section:
- Event rates for *downward* charged particles (leptons/sleptons) from neutrino interactions:

$$R_\nu = V \int dE_\nu \;\; \sigma(E_\nu) \;\; F_\nu(E_\nu)$$

- Event rates for *upward* charged tracks (leptons/sleptons) from neutrino interactions:

$$R_\nu = A N_A \int dE_\nu R(E_\nu, E_l) \sigma(E_\nu) S(E_\nu) F_\nu(E_\nu, X)$$

where $R(E_\nu, E_l)$ is the lepton/slepton range and $S(E_\nu)$ is the neutrino attenuation factor.

Experiments

- **AMANDA/ICECUBE/ICECUBE-PLUS/HYPERCUBE**
- **ANTARES, NESTOR**
- **RICE**
- **ANITA**
- **PIERRE AUGER**
- **EUSO, OWL**
- **SalSA, LOFAR ...**

Probing Particle Physics with UHE Neutrinos

- UHE cosmic neutrinos present unique opportunity to study the interactions of elementary particles at energies beyond current or planned colliders.

- Cosmic neutrinos with energies E_ν above 10^{17} eV probe neutrino-nucleon scattering at center-of-mass (c.m.) energies above

$$\sqrt{s_{\nu N}} \equiv \sqrt{2 m_N E_\nu} \simeq 14 \left(\frac{E_\nu}{10^{17}\ \mathrm{eV}} \right)^{1/2} \mathrm{TeV}$$

- These energies are beyond the proton-proton c.m. energy $\sqrt{s_{pp}} = 14$ TeV of the LHC, and Bjorken-x values below $\simeq 2 \times 10^{-4}$

Probing SUSY with UHE Cosmic Neutrinos

- In most SUSY scenarios, particle produced in high energy collisions decay immediately into the lightest one and are thus hard to detect.
- In some low-scale SUSY models in which gravitino is the lightest supersymmetric particle (LSP), the next-to-lightest particle (NLSP) is the charged super-partner of the right-handed tau, the stau.
- The cross section for the production of staus in neutrino-nucleon scattering is several orders of magnitude smaller than neutrino charged-current or neutral-current cross section.

I. Albuquerque, G. Burdman, Z. Chacko, PRL **92** (2004); PR **D75** (2007)
M. Ahlers, J. Kersten and A. Ringwald, JCAP **0607** (2006)

- **However, due to its weak coupling to the gravitino, the stau is a long-lived particle. For the SUSY breaking scale, $\sqrt{F} > 5 \times 10^6$ GeV, the long-lived stau could potentially travel long distances before decaying into gravitino.**
- **Stau lifetime depends on the gravitino mass (or SUSY breaking scale) and the stau mass, i.e.**

$$c\tau = \left(\frac{\sqrt{F}}{10^7 GeV}\right)^4 \left(\frac{100GeV}{m}\right)^5 10km$$

- **Limits on stau mass are about 100GeV (from nonobservation in accelerator experiments)**
- **Stau with energy of 10^6GeV and mass of 100GeV, could potentially travel 10^4 km before decaying**

- Detection of staus depend on their initial production and on stau range (charged tracks), and on stau interactions in the detector/ice (showers).
- Stau interactions are important for detection:
  - ⋆ Stau range depends on its energy loss as it traverses the earth. Photonuclear interactions of staus is a dominant process at high energies. However, weak interactions, depending on the mixing angle of righ-handed and left-handed staus, could suppress the stau range at high energies. On the other hand, detectors which cannot detect charged tracks rely on the stau producing showers (weak interactions).

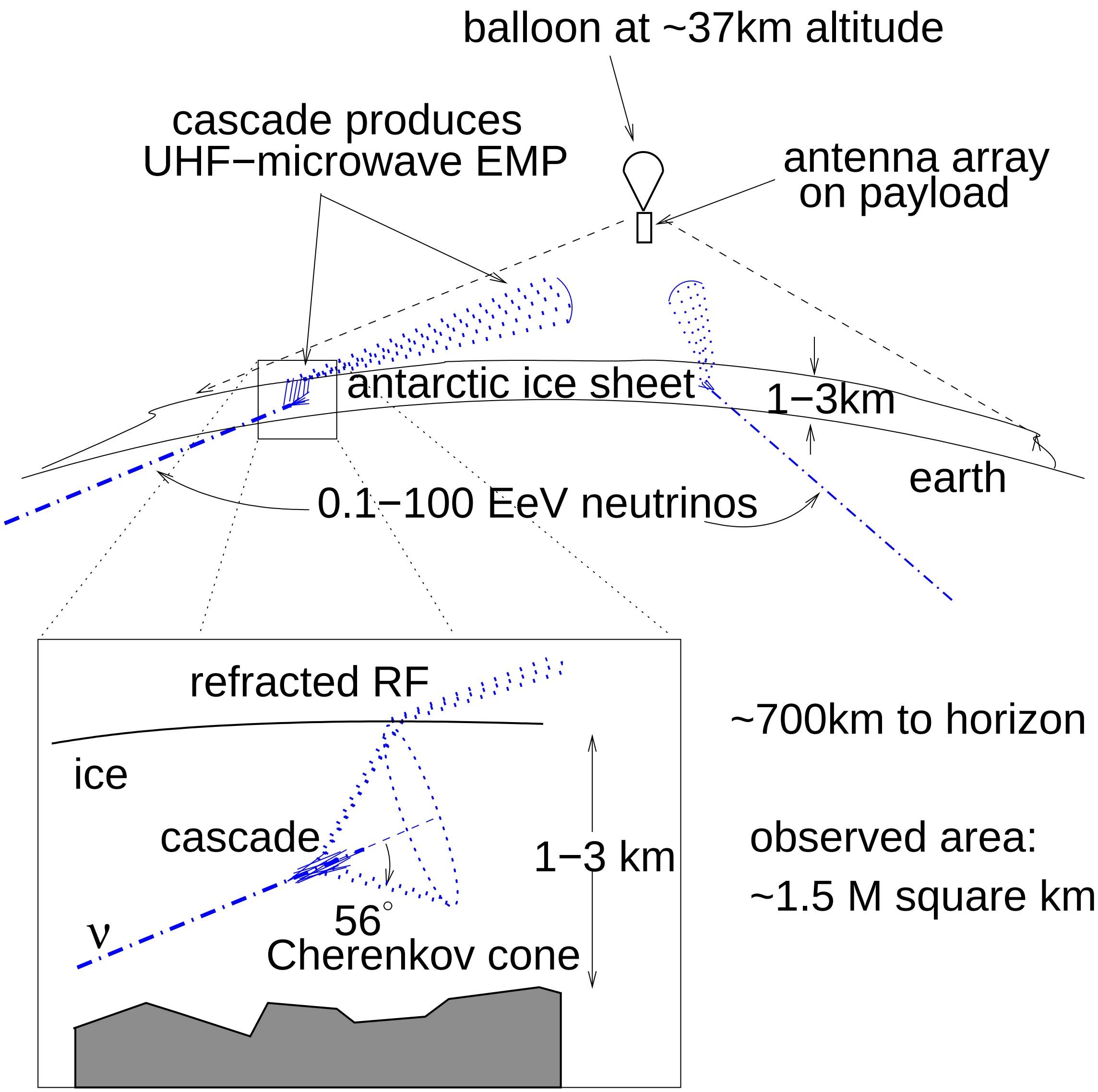
M.H. Reno, I.S. and S. Su, Astropart. Phys. 24 (2005)
M.H. Reno, I.S. and J. Uscinski, Phys. Rev. D74 (2006)
M.H. Reno, I.S. and J. Uscinski, Phys. Rev. D76 (2007)

- Neutrino telescopes (ICECUBE, ANITA, ARIANNA) have unique ability to provide the first evidence for supersymmetry at weak scale.

What is the stau flux at the detector?

- Neutrino Flux from Astrophysical Sources
- Neutrino interactions in Earth (attenuation)
- Stau production ($\nu + N \rightarrow ...\tilde{\tau} + \tilde{\tau}$): small cross section
- Stau propagation and energy loss
- Stau weak interactions in the detector/ice

ANITA: Antarctic Impulsive Transient Antenna

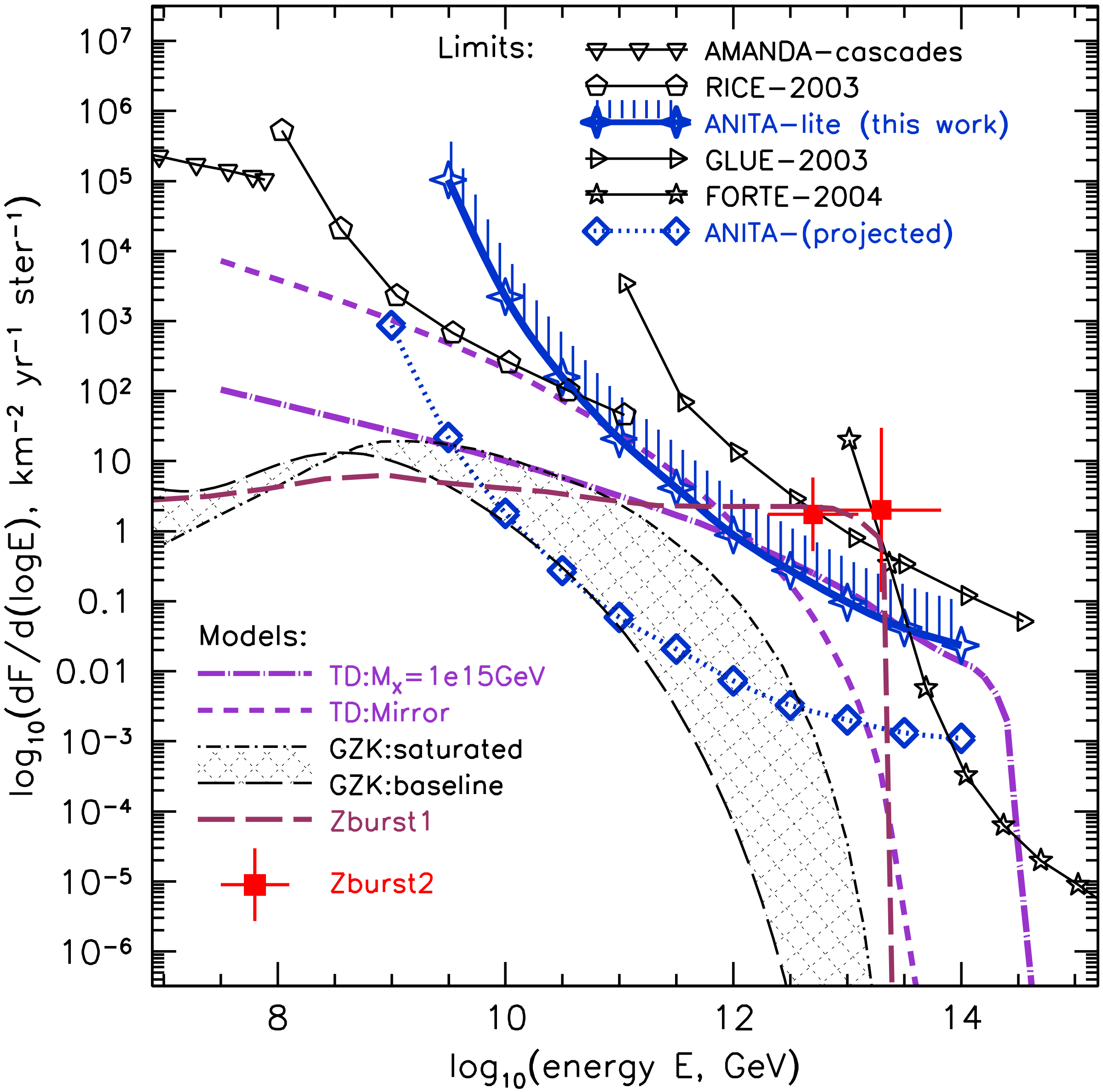


~700km to horizon

observed area:

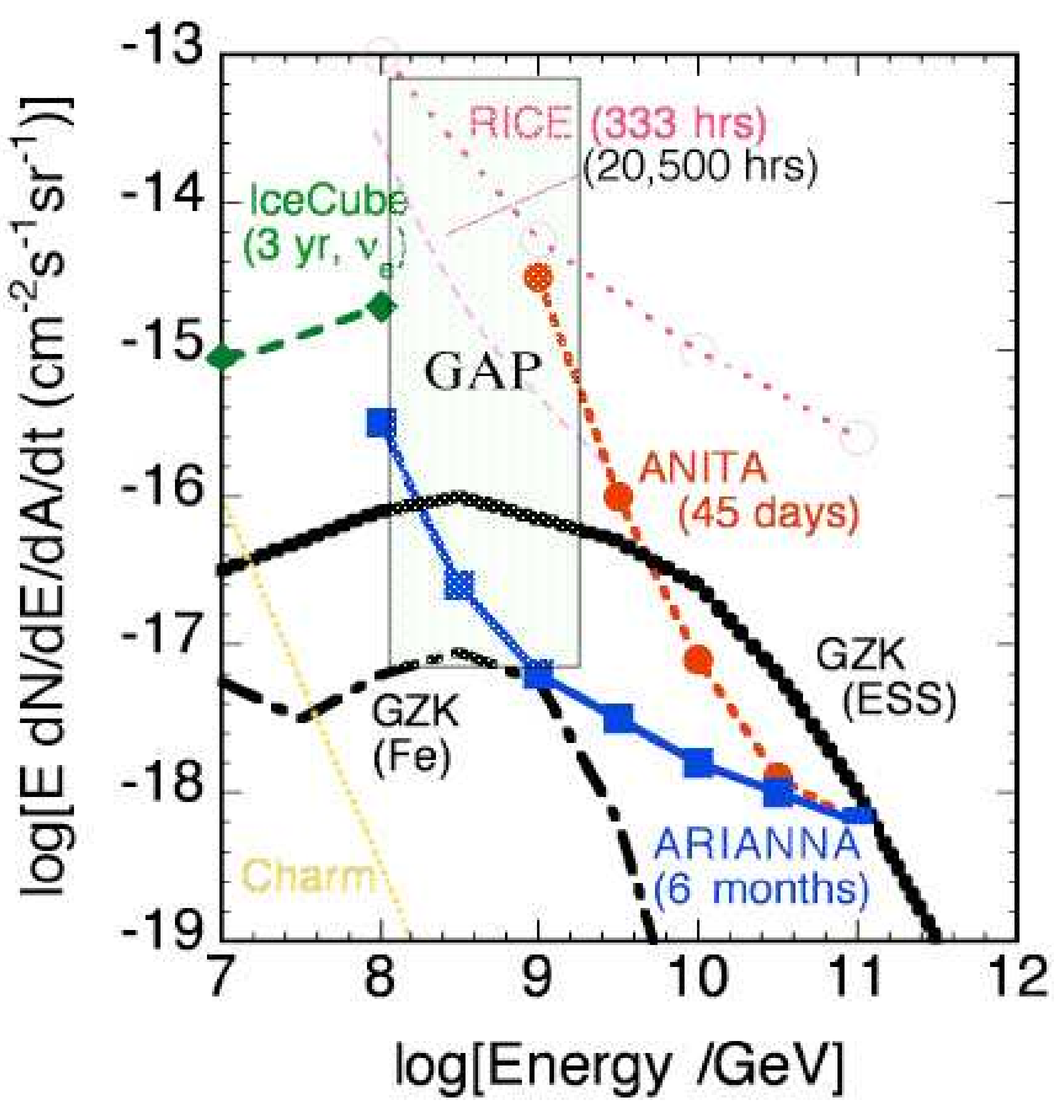
~1.5 M square km

Neutrino Flux limits (ANITA and ANITA-lite)



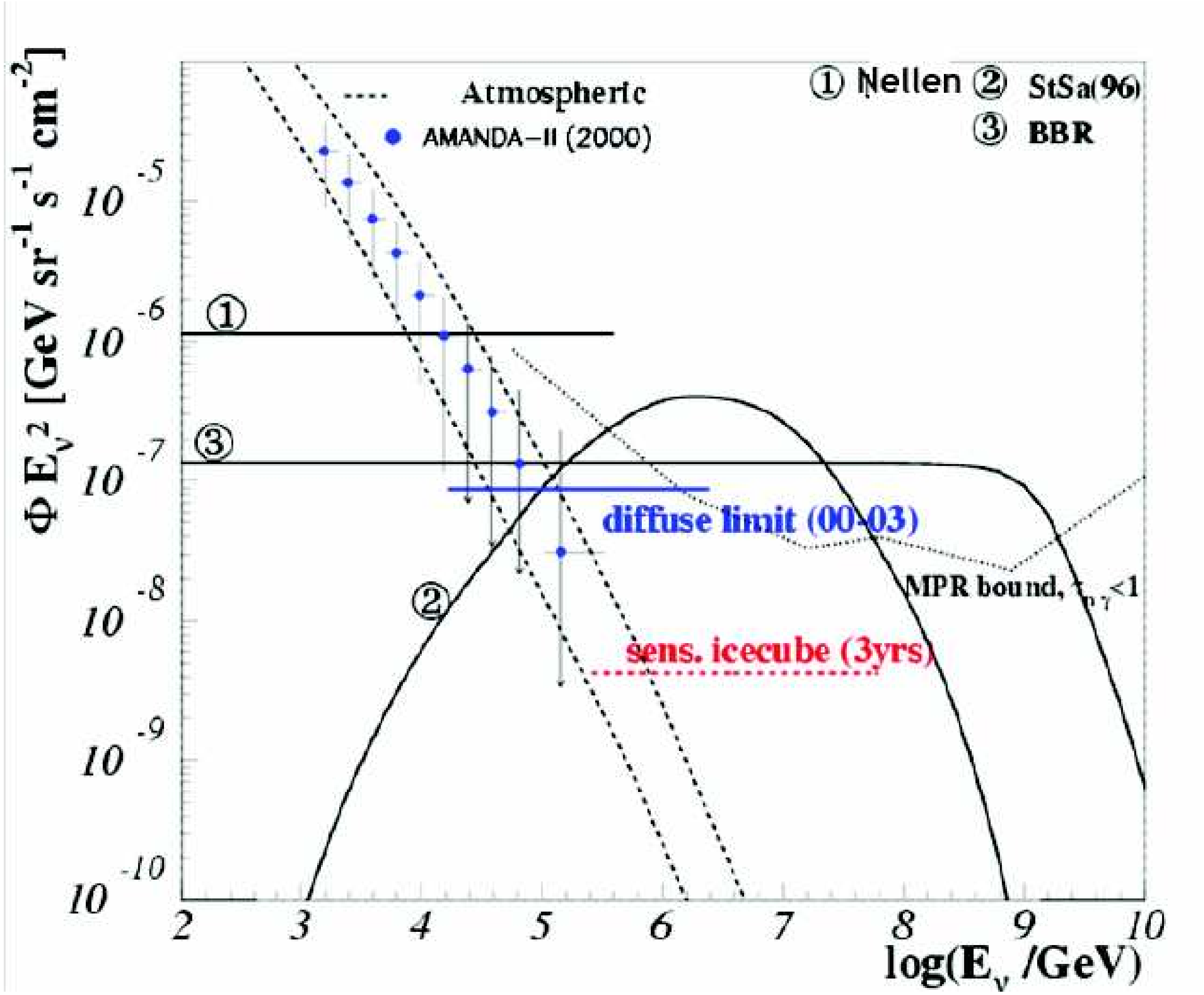
Anita Collaboration, PRL 96 (2006)

ARIANNA: Antarctic Ross Iceshelf ANtenna Neutrino Array



S. Barwick, arXiv:astro-ph/0610631

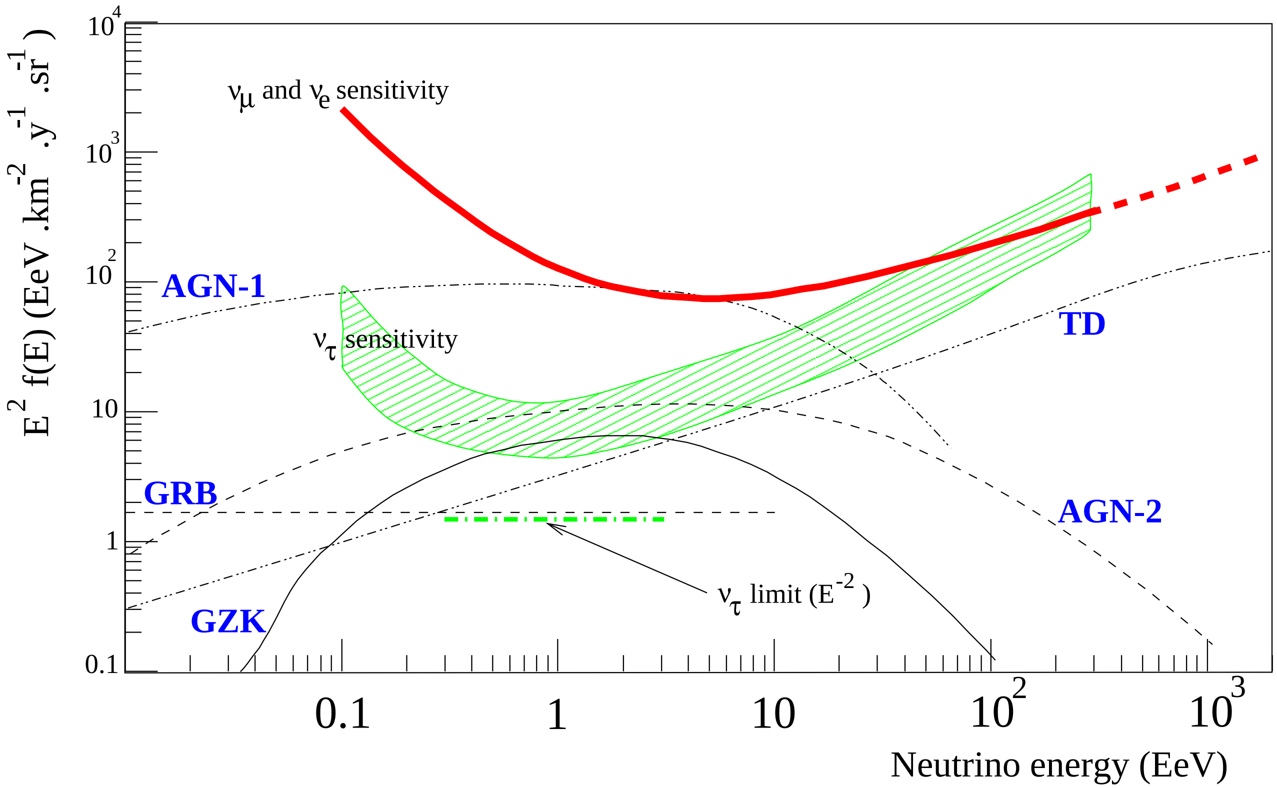
Amanda neutrino flux limit and IceCube sensitivuty



IceCube Collaboration, presented at TeV Particle Astrophysics

Workshop, Madison, August 2006

Auger neutrino flux sensitivity



X. Bertou et al., Astropart. Phys. 17 (2002)

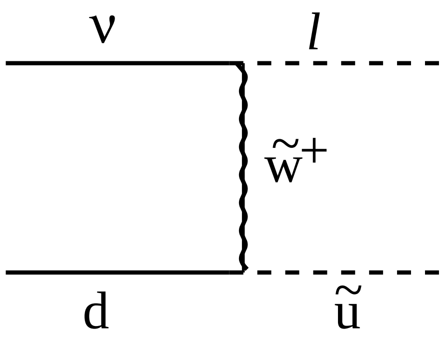
Stau Flux at the Detector

Flux of charged staus reaching the detector is given by

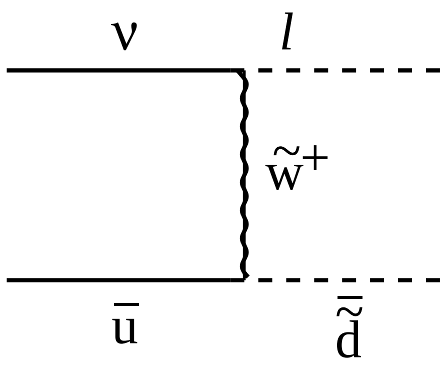
$$\frac{dN_{\tilde{\tau}}(E_{\tilde{\tau}}, \cos\theta, \phi)}{dE_{\tilde{\tau}}\, d\cos\theta\, d\phi} = \frac{1}{2\pi}\int dE_\nu \frac{dN_\nu(E_\nu)}{dE_\nu} K(E_\nu, \theta; E_{\tilde{\tau}})$$

- $\frac{dN}{dE_\nu}$ - initial neutrino flux
- $K(E_\nu, \theta; E_{\tilde{\tau}})$ - probability that neutrino entering Earth with energy E_ν and nadir angle θ will produce stau that reaches detector with energy $E_{\tilde{\tau}}$
  - ⋆ the probability of neutrino surviving a distance z in the Earth
  - ⋆ probability that neutrino converts to a stau
  - ⋆ probability that the created stau reaches the detector
  - ⋆ the stau's energy and position when produced are such that it reaches the detector with energy $E_{\tilde{\tau}}$.

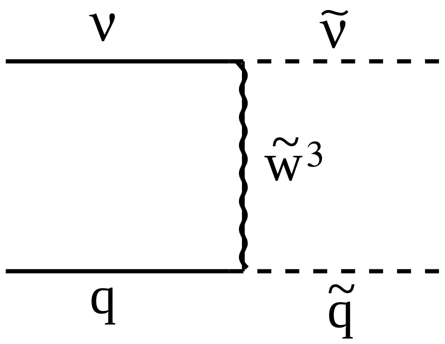
Stau Production in Neutrino Interactions



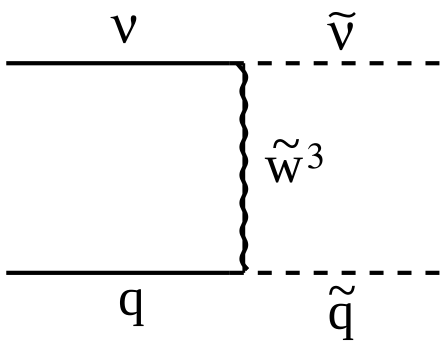
(a)



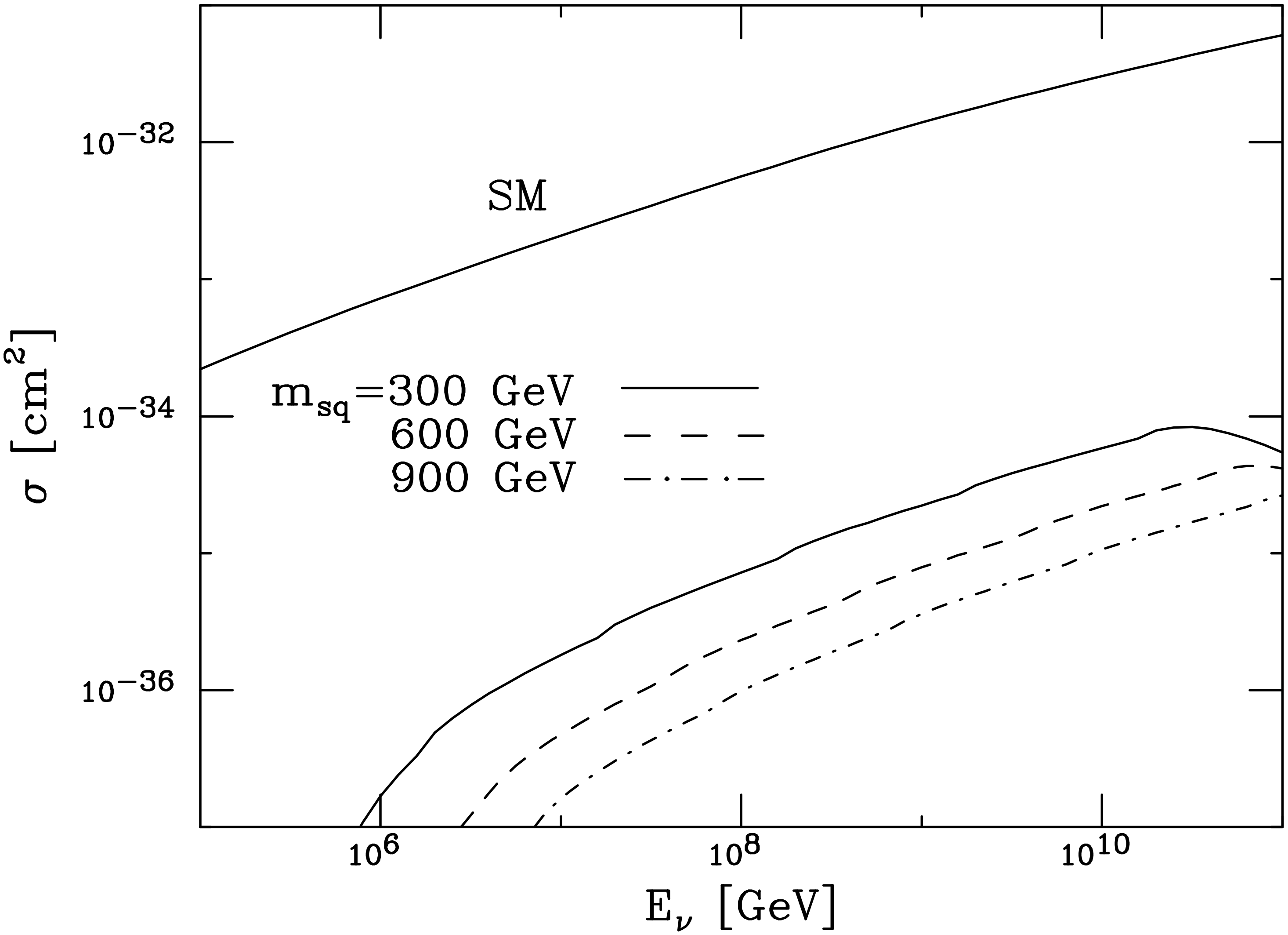
(b)



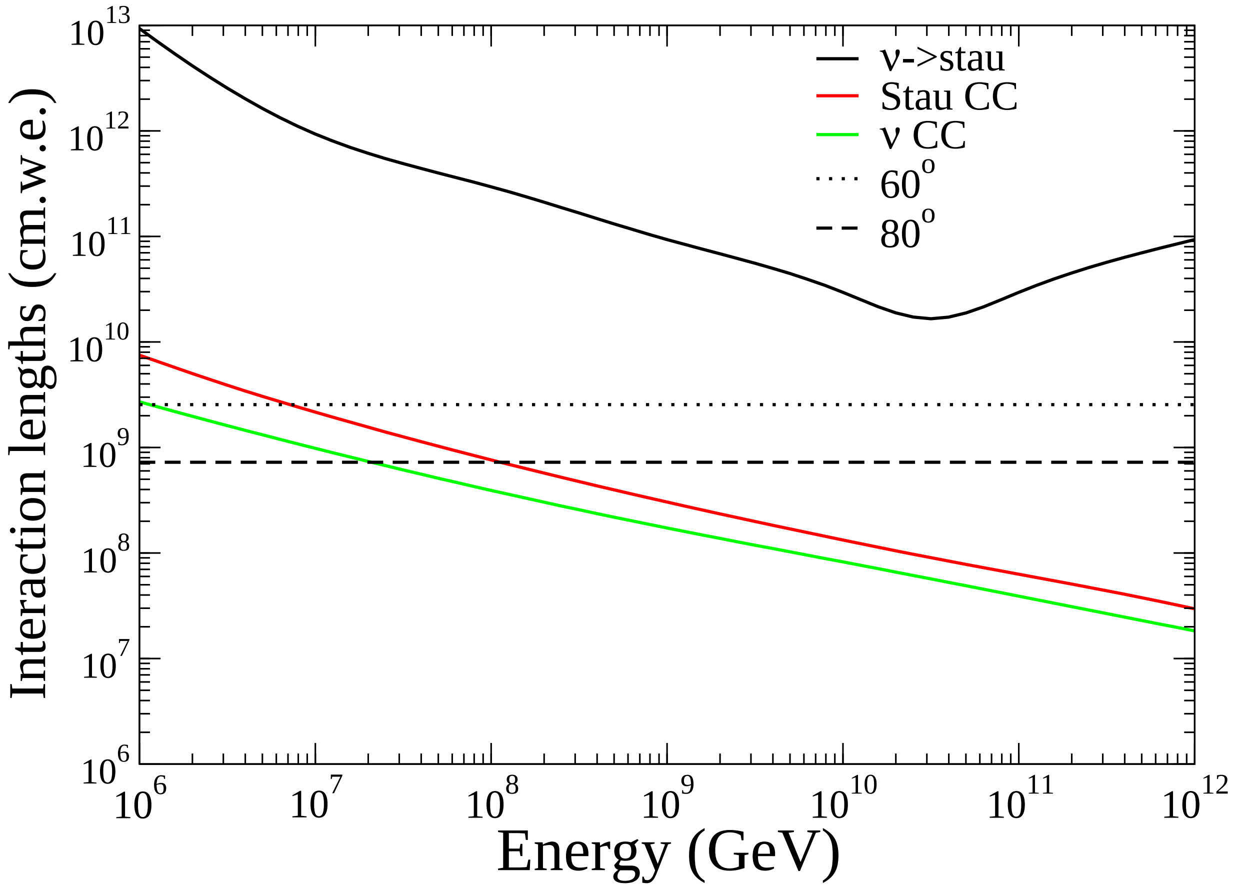
(c)



(d)

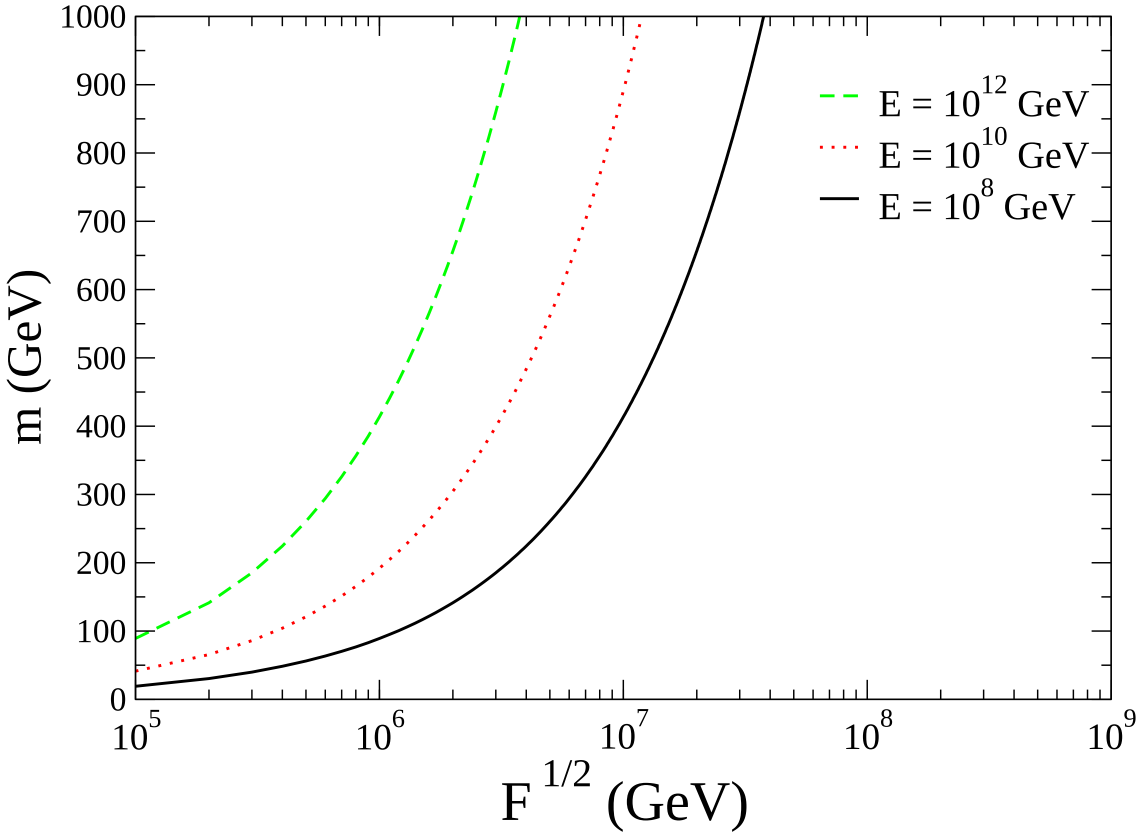

SM
m_{sq}=300 GeV
600 GeV
900 GeV
10^{-32}
10^{-34}
10^{-36}
σ [cm^2]
10^6
10^8
10^{10}
E_ν [GeV]

Stau Interactions Length



We use the stau cross section obtained with $m_{\tilde{q}} = 300$ **GeV,** $m_{\tilde{w}} = 250$ **GeV and** $m_{\tilde{l}_L} = 250$ **GeV.**

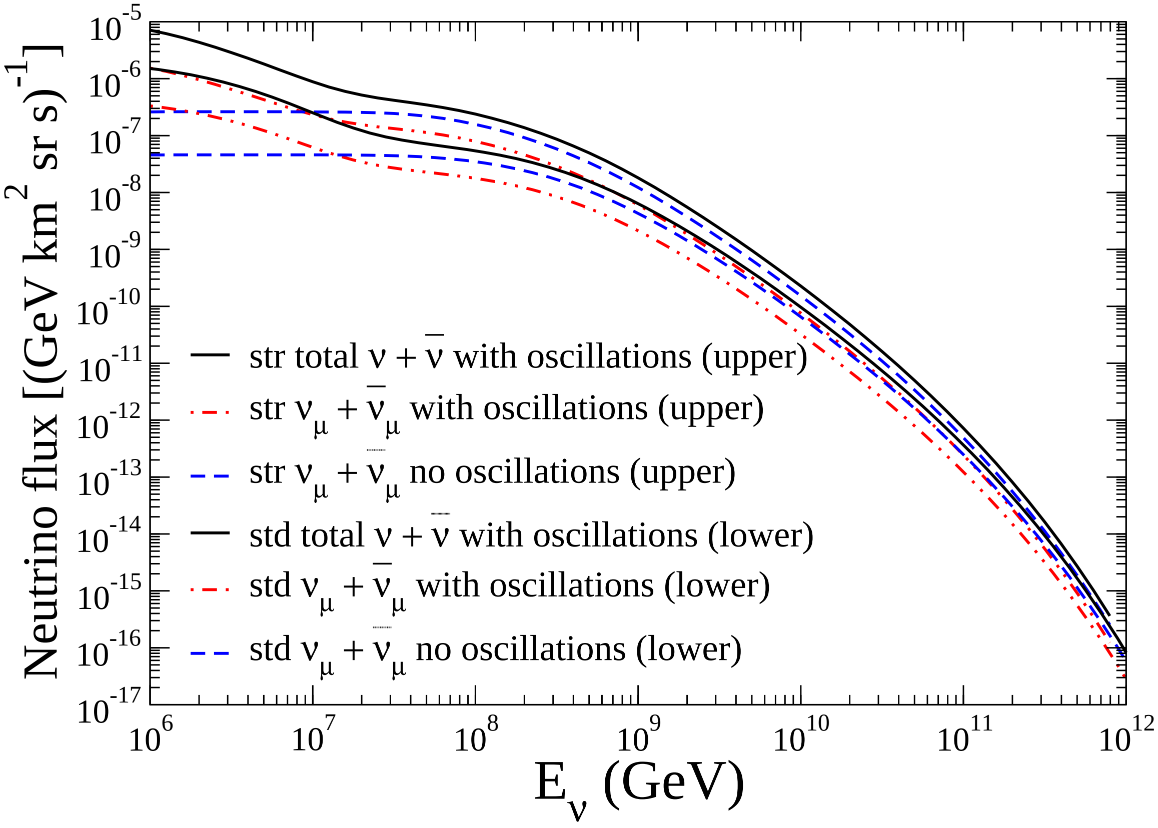
- **The parameter space ($m_{\widetilde{\tau}}$, $F^{1/2}$), probed by demanding that stau does not decay as it traverses the column depth of 10^7 cm w.e.**



Cosmogenic Neutrino Flux

- **Cosmogenic neutrino flux with “strong evolution” ($(1+z)^4$), or with the “standard evolution” ($(1+z)^2$)**

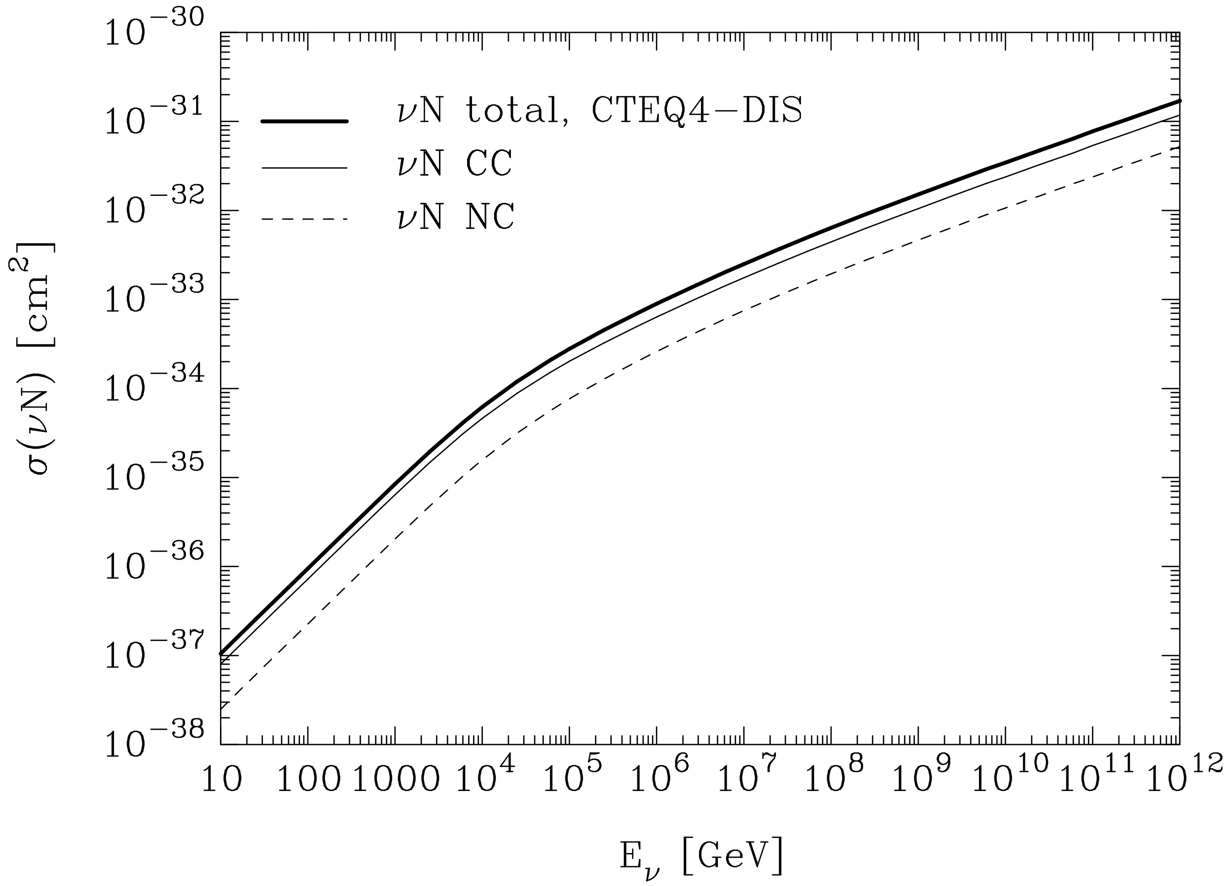
Engel, Seckel and Stanev, Phys. Rev. D64 (2001)



Reno, Sarcevic and Uscinski, Phys. Rev. D76 (2007)

Muon and Stau Fluxes

- **Muons are produced by $\nu_\mu N$ charged-current interactions**



R. Gandhi, C. Quigg, M.H. Reno and I.S., PRD58 (1998)

Muon Energy Loss

Charged particle (muon, tau, stau) energy loss is given by

$$-\frac{dE}{dX} = \alpha + \beta E$$

- **E - particle energy**
- **X - range of particle**
- α **- ionization energy loss** $\sim 2 \cdot 10^{-3}$ **GeV cm^2/g, dominant at low energies**
- β **- radiative energy loss, dominant at high energies**

Iyer Dutta, Reno, Sarcevic and Seckel, Phys. Rev. D63 (2001)

- **Energy loss parameter β is given by**

$$\beta^i(E) = \frac{N_A}{A} \int dy \; y \frac{d\sigma^i(y,E)}{dy}$$

y is the fraction of lepton (slepton) energy loss

$$y = \frac{E - E'}{E}$$

- **The radiative energy loss for muons due to bremsstrahlung, pair production and photonuclear scattering, characterized by β_μ, increases with energy from about $\simeq 4 \times 10^{-6}$ cm^2/g at $E_\mu \sim 10^3$ GeV to about $\simeq 5 - 6 \times 10^{-6}$ cm^2/g at $E_\mu \sim 10^9$ GeV. With $\alpha \simeq 2 \times 10^{-3}$ GeV cm^2/g for high energies,**

$$dE/dX \simeq -\beta_\mu E$$

- **Combined with effects of the finite muon lifetime on the survival probability $P_{\rm surv}$,**

$$\frac{dP_{\rm surv}}{dX} = -\frac{P_{\rm surv}}{c\tau\rho E/m}$$

leads to

$$P_{\rm surv} = \exp\left[-\frac{m_\mu}{c\tau_\mu\beta_\mu\rho}\left(\frac{1}{E_\mu} - \frac{e^{-\beta_\mu(L-X)}}{E_\mu}\right)\right] .$$

- **Muon flux produced by incident ν_μ, for column depth L**

$$\begin{aligned} F_\mu(E_\mu, L) &\simeq \int_0^L dX \int dE_\nu e^{-X\sigma_{CC}(E_\nu)N_A} F_{\nu_\mu}(E_\nu, 0) \\ &\times N_A\sigma_{\nu\to\mu}(E_\nu)\delta(E_\mu - 0.8E_\nu e^{-\beta_\mu(L-X)}) \\ &\times \exp\left[-\frac{m_\mu}{c\tau_\mu\beta_\mu\rho}\left(\frac{1}{E_\mu} - \frac{e^{-\beta_\mu(L-X)}}{E_\mu}\right)\right] \end{aligned}$$

- **We have approximated the neutrino-nucleon charged current differential cross section by**

$$\frac{d\sigma_{\nu\to\mu}(E_\nu,\ E'_\mu)}{dE'_\mu} \simeq \sigma_{\nu\to\mu}(E_\nu)\delta(E'_\mu - 0.8E_\nu)$$

where E'_μ is the energy of the produced muon. This is the energy of the muon before it loses energy via electromagnetic interactions.

- **We have also approximated the attenuation of the neutrino flux in transit through a column depth X by the shadow factor**

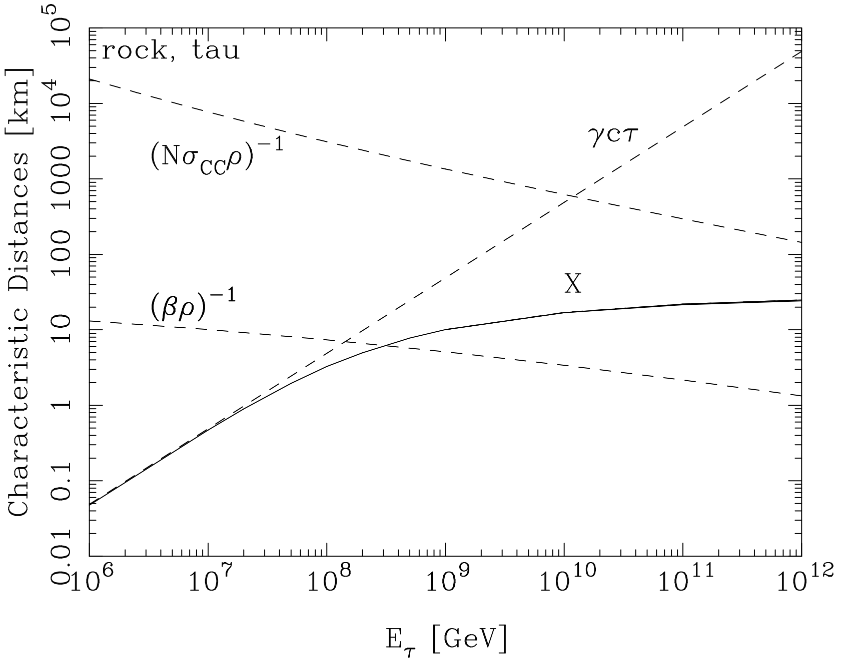
$$S \equiv \exp\left(-\sigma_{CC}^{\nu N}(E_\nu)N_A X\right)\ .$$

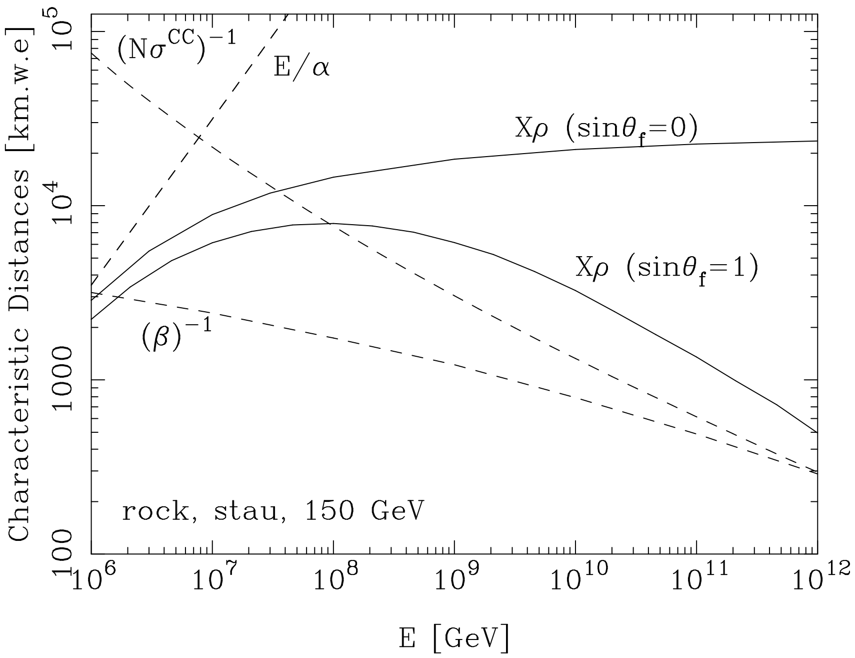
Stau Energy Loss Processes

- **Bremsstrahlung:** $\tilde{\tau} Z \rightarrow \gamma \tilde{\tau} Z$
- **Pair production:** $\tilde{\tau} Z \rightarrow \tilde{\tau} Z e^+ e^-$
- **Photonuclear:** $\tilde{\tau} N \rightarrow \tilde{\tau} X$ → **dominant for E >** 10^6 **GeV, scales as** $\frac{1}{m}$
- **Neutral current:** $\tilde{\tau} N \rightarrow \tilde{\tau} X$
- **Charged current:** $\tilde{\tau} N \rightarrow \tilde{\nu} X$ → **removes particle**

M. H. Reno, I. Sarcevic and S. Su, Astropart. Phys. 24 (2005)
M. H. Reno, I. Sarcevic and J. Uscinski, PRD 74 (2006)

Tau and Stau Range





M.H. Reno, I.S. and S. Su, Astropart. Phys. 24 (2005)

Lifetime and Range

Competing processes, decay and energy loss:

$$c\tau = \left(\frac{\sqrt{F}}{10^7 GeV}\right)^4 \left(\frac{100GeV}{m}\right)^5 10km$$

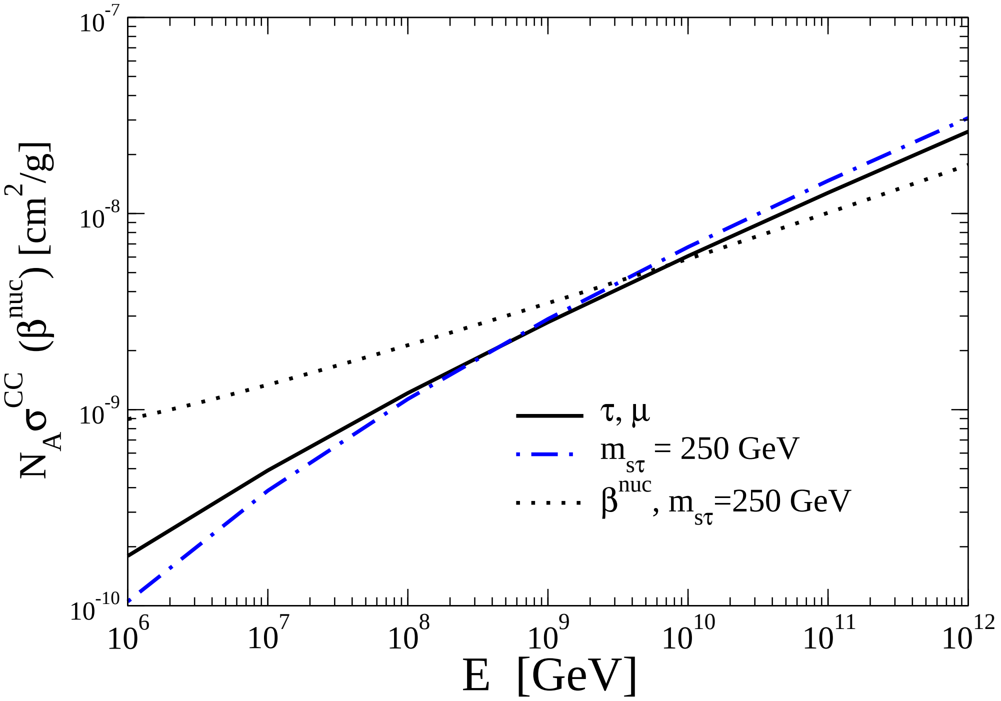
$$X(E, E_0) = \int dX' P(E, E_0, X')$$

Without including weak interactions:

- **Characteristic range for staus is 10^4 km**
- **Characteristic range for taus is 10 km (for comparison)**

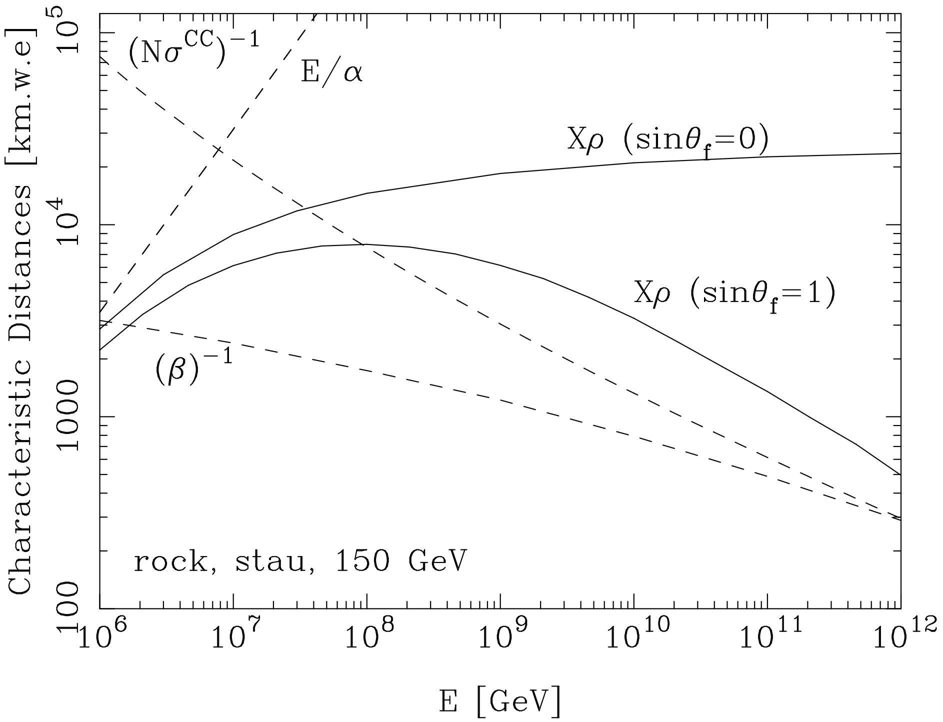
Does weak interaction contribution to the energy loss have an effect on the range?

CC Interactions



- **Stau cross section is roughly equal to lepton case $\cdot$ sin$^2\theta_f$ - indicates mixing of LH and RH staus.**
- **CC interactions become significant at higher energies**
- β^{NC} **is small when compared to** $\beta^{nuc} \sim 10^{-8}$ **cm^2/g**

Characteristic Distances: Stau



- **At low energies, ionization energy loss dominates**
- **For energies $\sim 10^8$ GeV, CC interaction dominates for $\sin\theta_f = 1$**

M.H. Reno, I.S. and J. Uscinski, PRD74 (2006)

Stau Flux

- **The stau flux that reaches the detector depends on initial production cross section and its energy loss.**
- **We consider two limiting cases: staus with no weak interactions, and staus with maximal weak interactions.**
- **The stau energy loss parameter $\beta_{\tilde{\tau}}$, without weak interactions, can be parametrized as**

$$\begin{aligned} \beta_{\tilde{\tau}} &= b_0 + b_1 \ln(E/E_0) \ , \\ b_0 &= 5 \times 10^{-9} \ \mathrm{cm}^2/\mathrm{g} \ , \\ b_1 &= 2.8 \times 10^{-10} \ \mathrm{cm}^2/\mathrm{g} \ , \\ E_0 &= 10^{10}\mathrm{GeV} \end{aligned}$$

- **When there are no weak interactions of staus, the relation between the initial stau energy, $E^i_{\widetilde{\tau}}$, and the final stau energy, $E_{\widetilde{\tau}}$, as a function of distance is given by**

$$E^i_{\widetilde{\tau}}(E_{\widetilde{\tau}}) \quad = \quad E_0 \exp\left[\left[\frac{b_0}{b_1}\left(1 - e^{-b_1(L-X)}\right) + \ln\frac{E_{\widetilde{\tau}}}{E_0}\right] e^{b_1(L-X)}\right]$$

- **The stau survival probability is given by**

$$P_{\rm surv}(E_{\widetilde{\tau}}, E^i_{\widetilde{\tau}}) = \exp\left(\frac{m_{\widetilde{\tau}} b_1}{c\tau\rho b_0^2}\left[\frac{1}{E_{\widetilde{\tau}}}(1 + \ln(E_{\widetilde{\tau}}/E_0) - \frac{1}{E^i_{\widetilde{\tau}}}(1 + \ln(E^i_{\widetilde{\tau}}/E_0)\right]\right) \times \exp\left[-\frac{m_{\widetilde{\tau}}}{c\tau b_0 \rho}\left(\frac{1}{E_{\widetilde{\tau}}} - \frac{1}{E^i_{\widetilde{\tau}}}\right)\right]$$

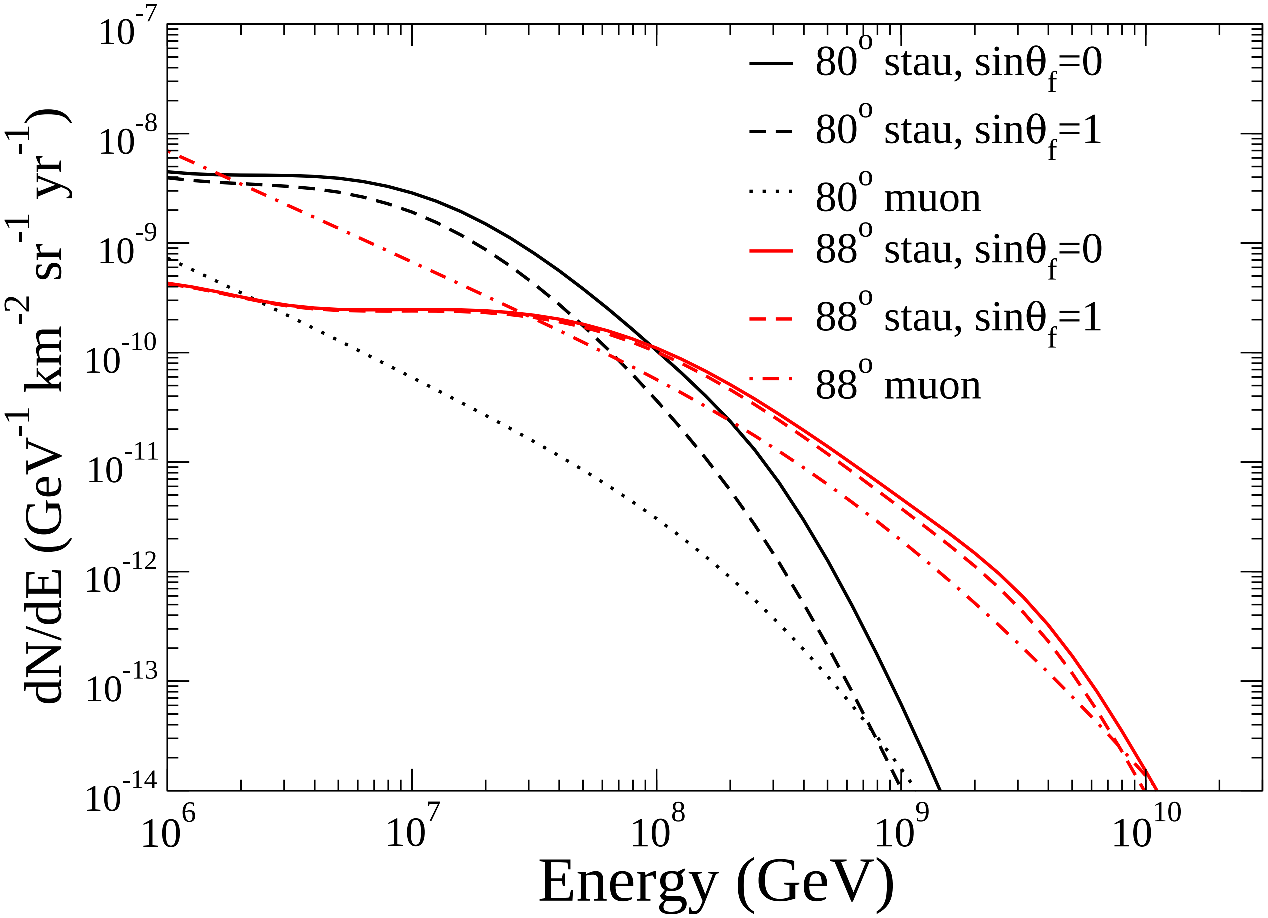
- This leads to a stau flux of

$$\begin{aligned} F_{\widetilde{\tau}}(E_{\widetilde{\tau}}, L) &\simeq 2\int_0^L dX \int dE_\nu e^{-X\sigma_{CC}(E_\nu)N_A} F_\nu(E_\nu, 0) \\ &\times N_A \sigma_{\nu\to\widetilde{\tau}}(E_\nu)\delta(E_{\widetilde{\tau}} - \frac{1}{6}E_\nu \frac{E_{\widetilde{\tau}}}{E^i_{\widetilde{\tau}}(E_{\widetilde{\tau}})}) \\ &\times P_{\mathrm{surv}}(E_{\widetilde{\tau}}, E^i_{\widetilde{\tau}}) \ . \end{aligned}$$

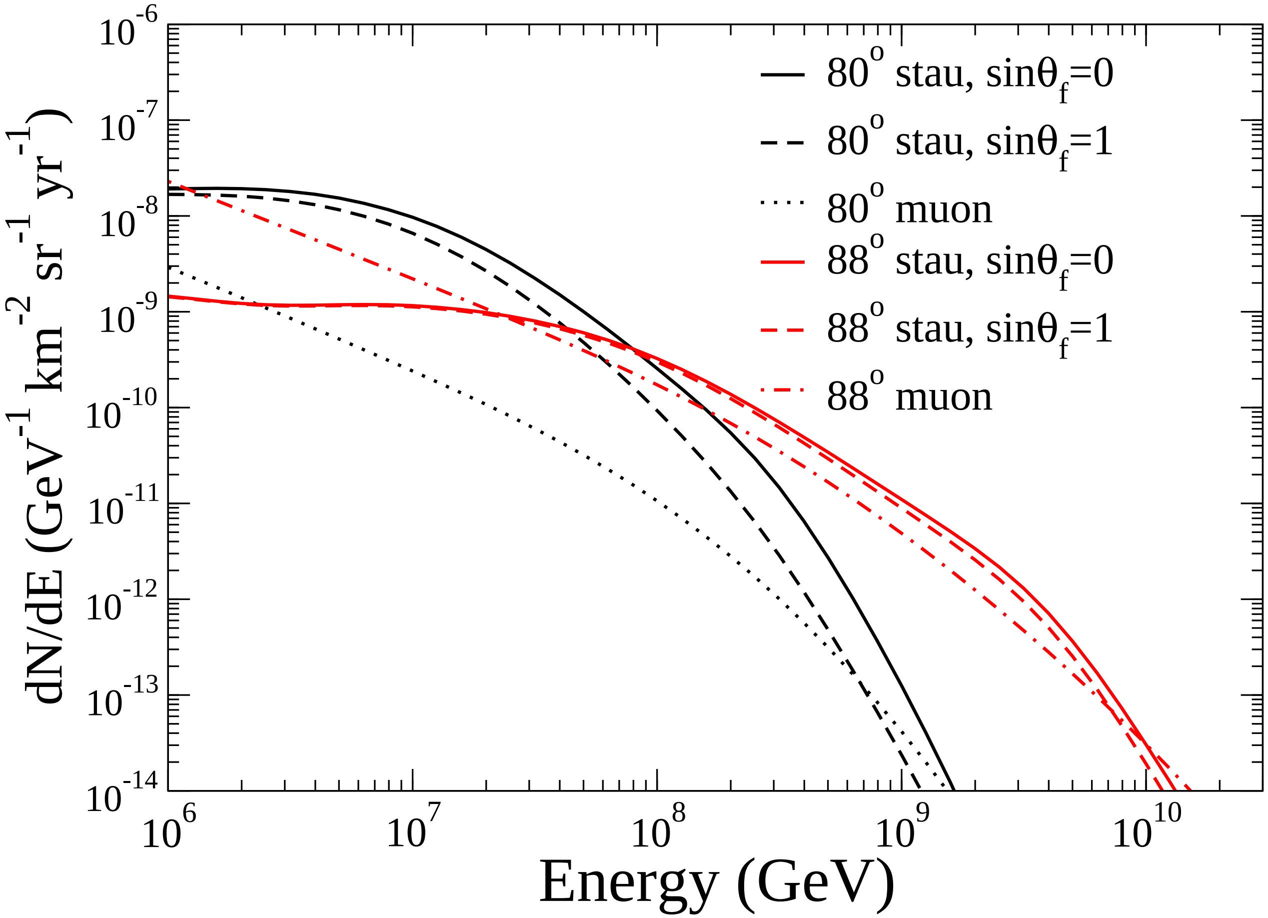
- The prefactor of 2 accounts for the fact that the staus appear in pairs, from decays of the initial squark and slepton.
- When weak interactions are included, there is an effect due to the attenuation of the staus themselves. The survival probability is modified and is given by

$$\begin{aligned} \frac{dP_{\mathrm{surv}}}{dX} &= -\frac{P_{\mathrm{surv}}}{\lambda_{\mathrm{eff}}} \\ \lambda^{-1}_{\mathrm{eff}} &= (c\tau\rho E/m_{\widetilde{\tau}})^{-1} + N_A\sigma^{CC}(\widetilde{\tau}N) \end{aligned}$$

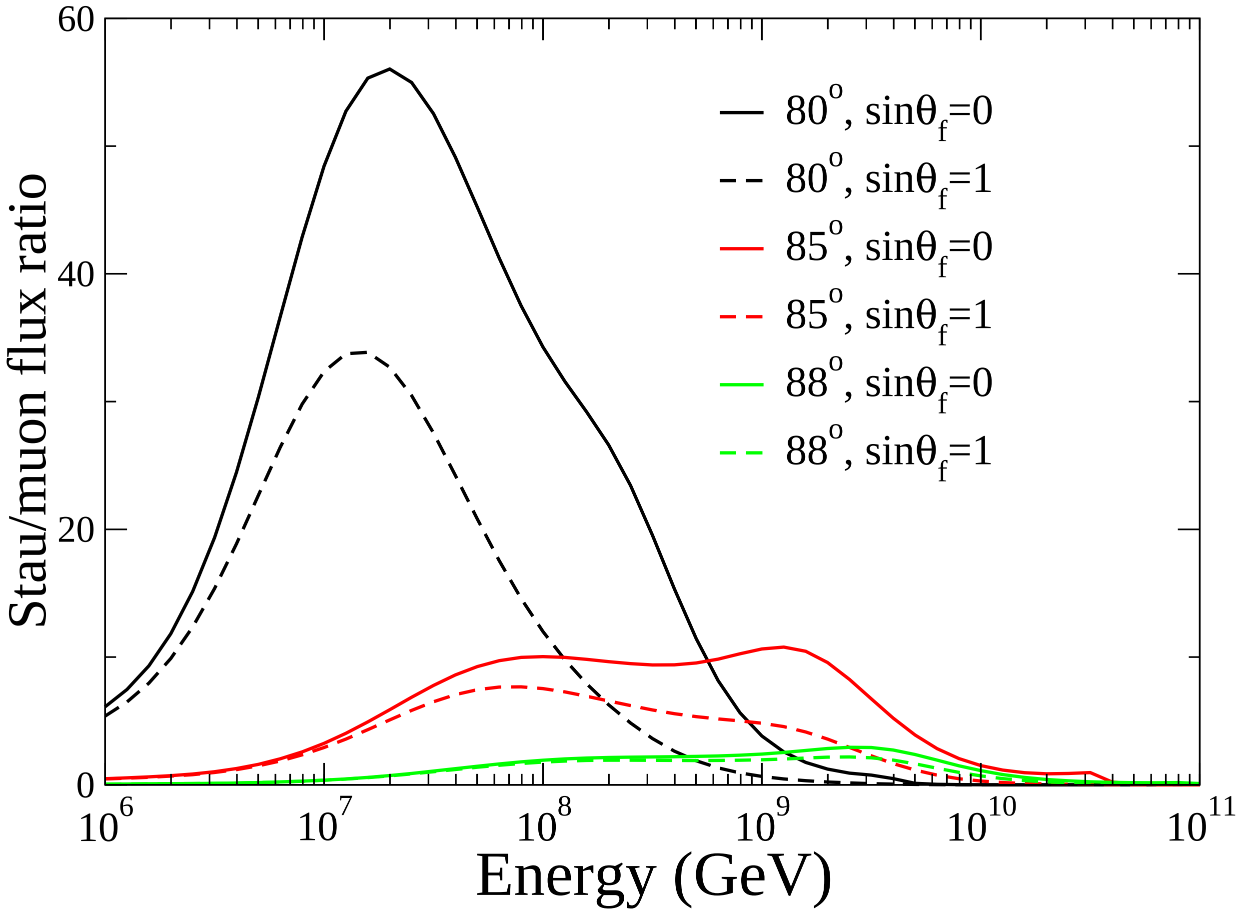
Stau and Muon Fluxes from Interactions of ("Standard") Cosmogenic Neutrinos



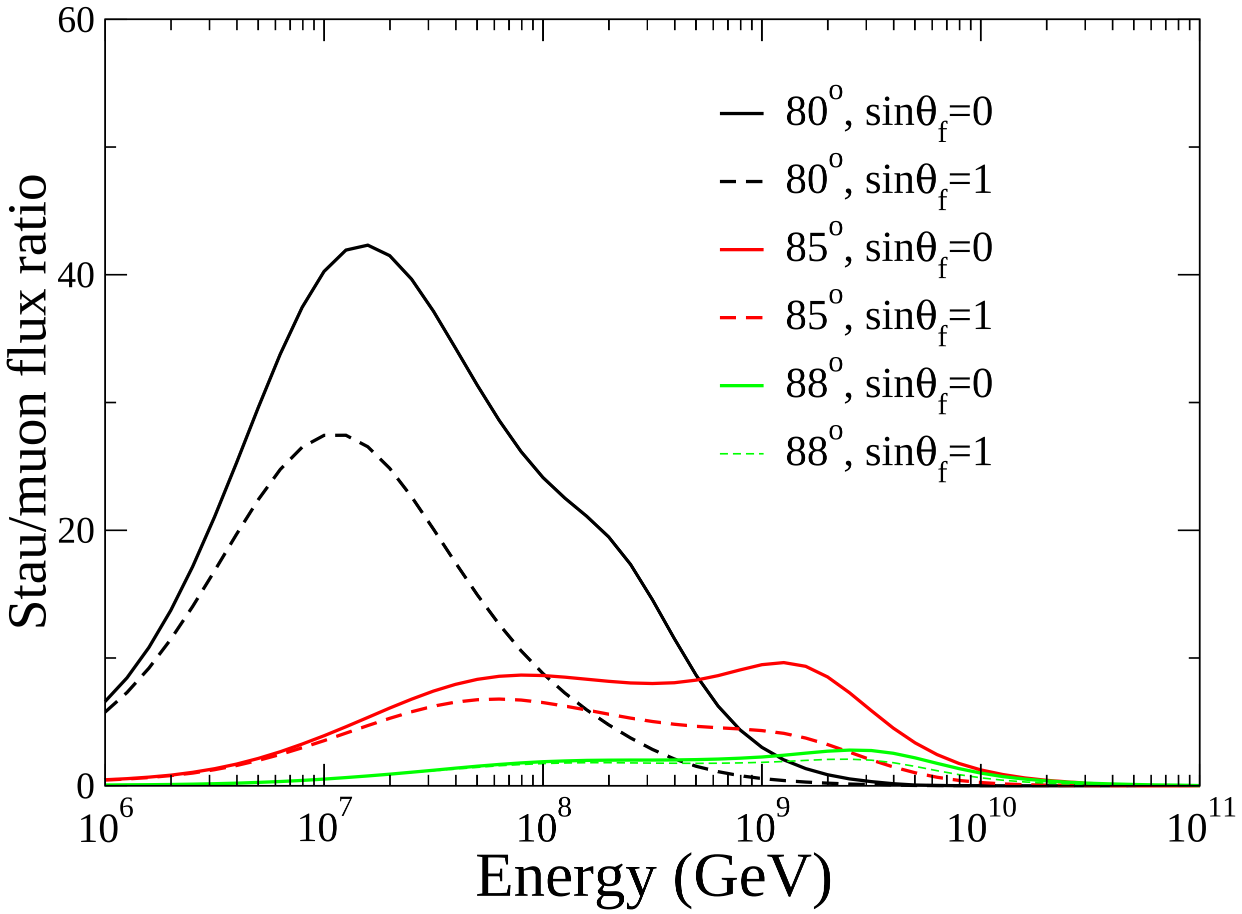
Stau and Muon Fluxes from Interactions of (“Strong”) Cosmogenic Neutrinos



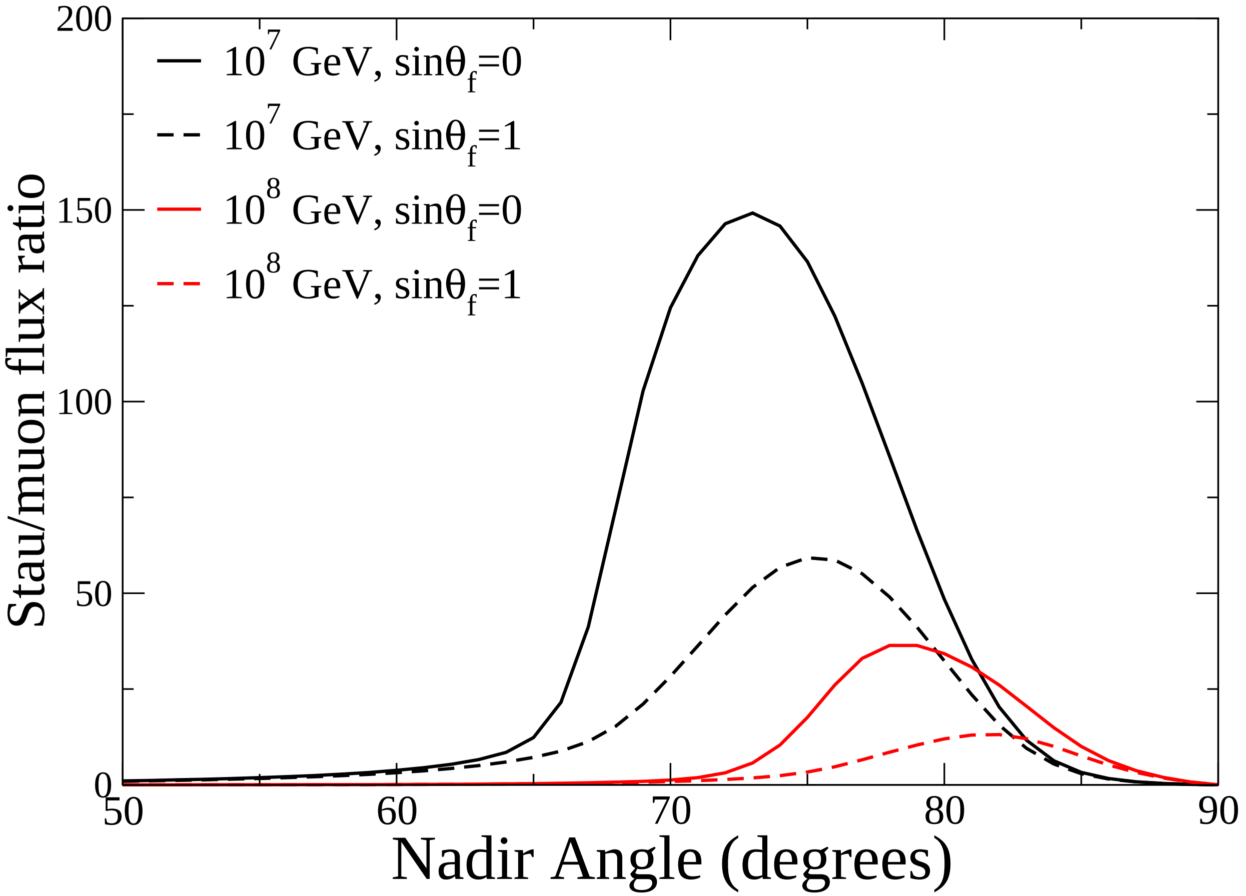
Stau to Muon Ratio for Cosmogenic Neutrino Flux with Standard Evolution



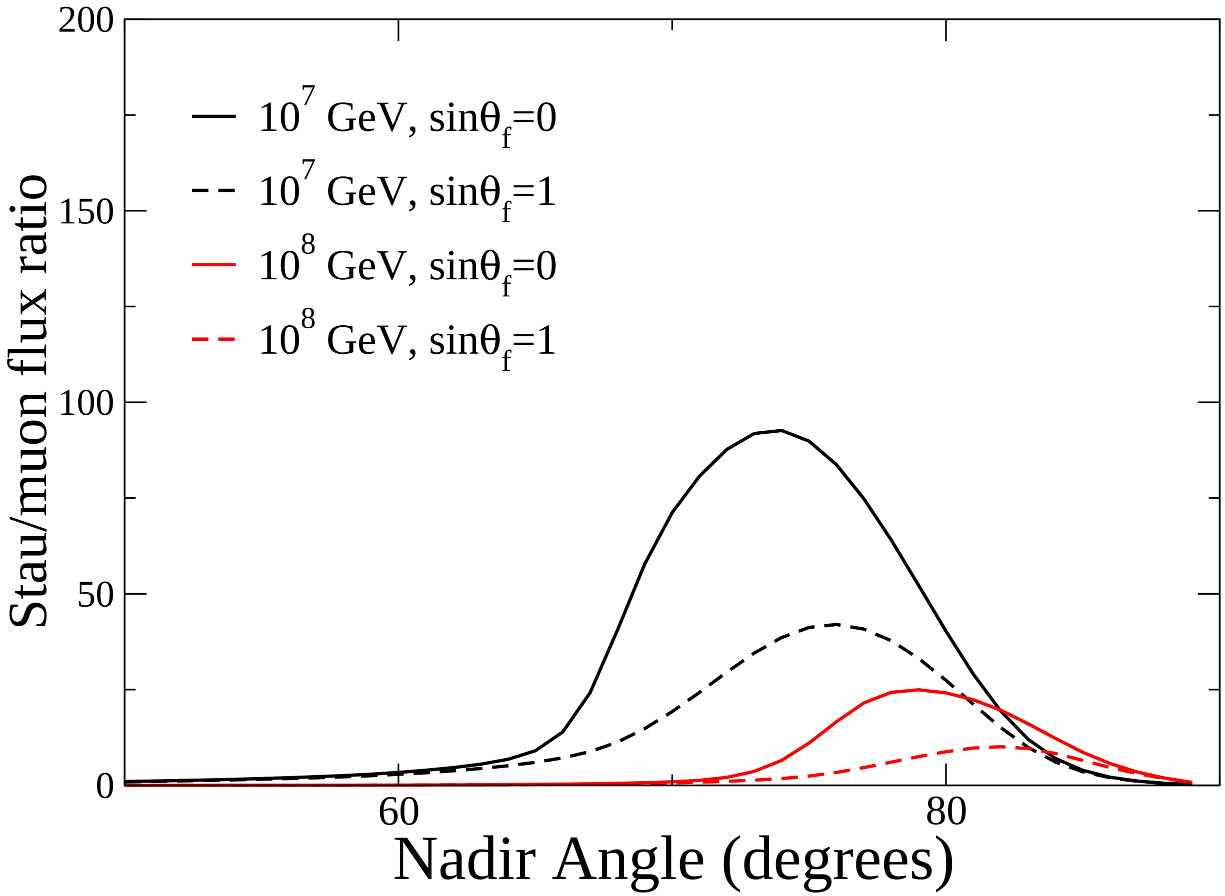
Stau to Muon Ratio for Cosmogenic Neutrino Flux with Strong Evolution



Ratio of Stau to Muon Flux from Cosmogenic Neutrinos with Standard Evolution



Ratio of Stau to Muon Flux from Cosmogenic Neutrinos with Strong Evolution



- **Stau production cross section is about three orders of magnitude smaller than the muon production cross section.**

- **Once staus are produced, they lose very little energy as they traverse the earth while muon energy loss is of the order 10^2-10^3 times greater. The stau range can be as high as 10^4 km w.e. for vanishing charged-current interactions or suppressed to about 10^3 km w.e. for maximal charged-current interactions.**

- **Neutrino attenuation has a large effect on the signals. It depletes more muons than staus, since muons must be created near the detector to be seen, whereas the staus can be produced farther away.**

- **Stau to muon ratio depends on the stau (muon) energy as well as the nadir angle. Including maximal charged-current interactions of the stau results in suppression of the signal to background ratio.**

- **As the nadir angle is decreased, there is an enhancement in the signal to background ratio until it reaches a maximum value and then it drops off when the neutrino attenuation begins to be a dominant effect for the signal.**

- **At lower energies, $E_{\tilde{\tau}} \sim 10^6$ GeV, the maximum signal to background ratio is 125 (at 70°) when stau maximum weak interactions are included and it is 280 without weak interactions. Signal to background ratio increases by another 50% when we include energy dependent muon energy loss.**

- **Potential problem is that stau tracks are "muon-like". The only difference is the energy loss. Number of interactions per km of ice for muons is significantly larger than for the stau – possible way to distinguish staus from muons.**

Stau Showers in Ice

- **Staus reaching the detector could interact in principle via weak interactions producing showers.**
- **Weak interactions of staus reduce its range, but provide an additional opportunity for its detection via interactions in ice which can provide a signal for detectors such as ANITA and ARIANNA.**
- **The stau showers for a given incident angle are determined the same way as the stau flux without weak interactions but modified to include the probability to produce showers in the ice,**

$$
\begin{aligned}
F_{\tilde{\tau},\mathrm{shr}}(E_{\mathrm{shr}}, L) &= \int_0^{z_{ice}} F_{\tilde{\tau}}(E_{\mathrm{shr}}, L - z') e^{-z'/\mathcal{L}^{\tilde{\tau}}_{CC}} \frac{dz'}{\mathcal{L}^{\tilde{\tau}}_{CC}} \\
&\simeq F_{\tilde{\tau}}(E_{\mathrm{shr}}, L)(1 - e^{-z_{ice}/\mathcal{L}^{\tilde{\tau}}_{CC}}) \ .
\end{aligned}
$$

- **We use the interaction length for maximal weak interactions. The pathlength through the ice, z_{ice}, for $\theta < 88.56^o$ is given by**

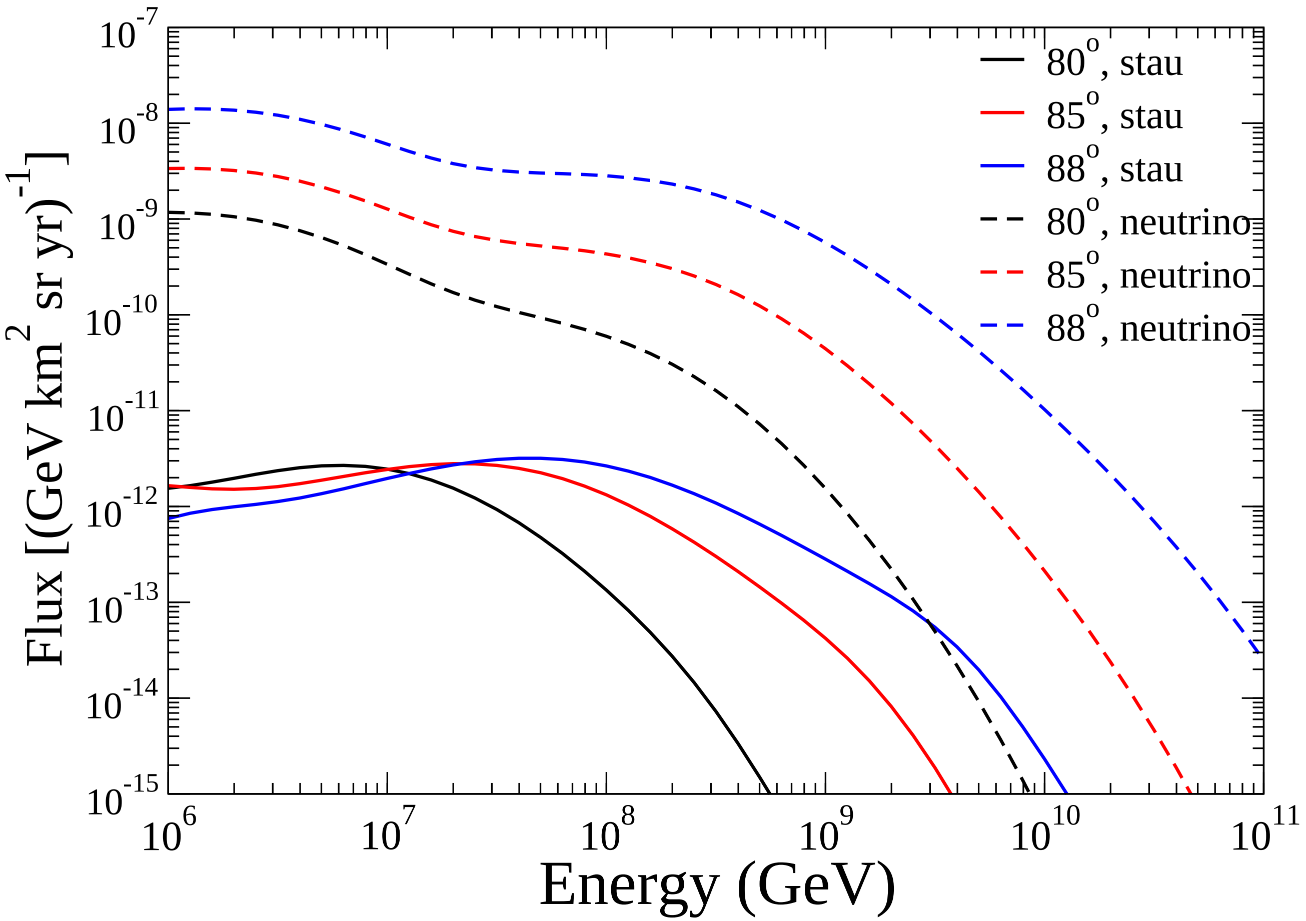
  $$z_{ice} = R_E \cos\theta - \sqrt{R_E^2 \cos^2\theta - 2R_E t + t^2},$$

  where R_E represents the radius of the earth and t the average ice thickness, taken to be 2 km.

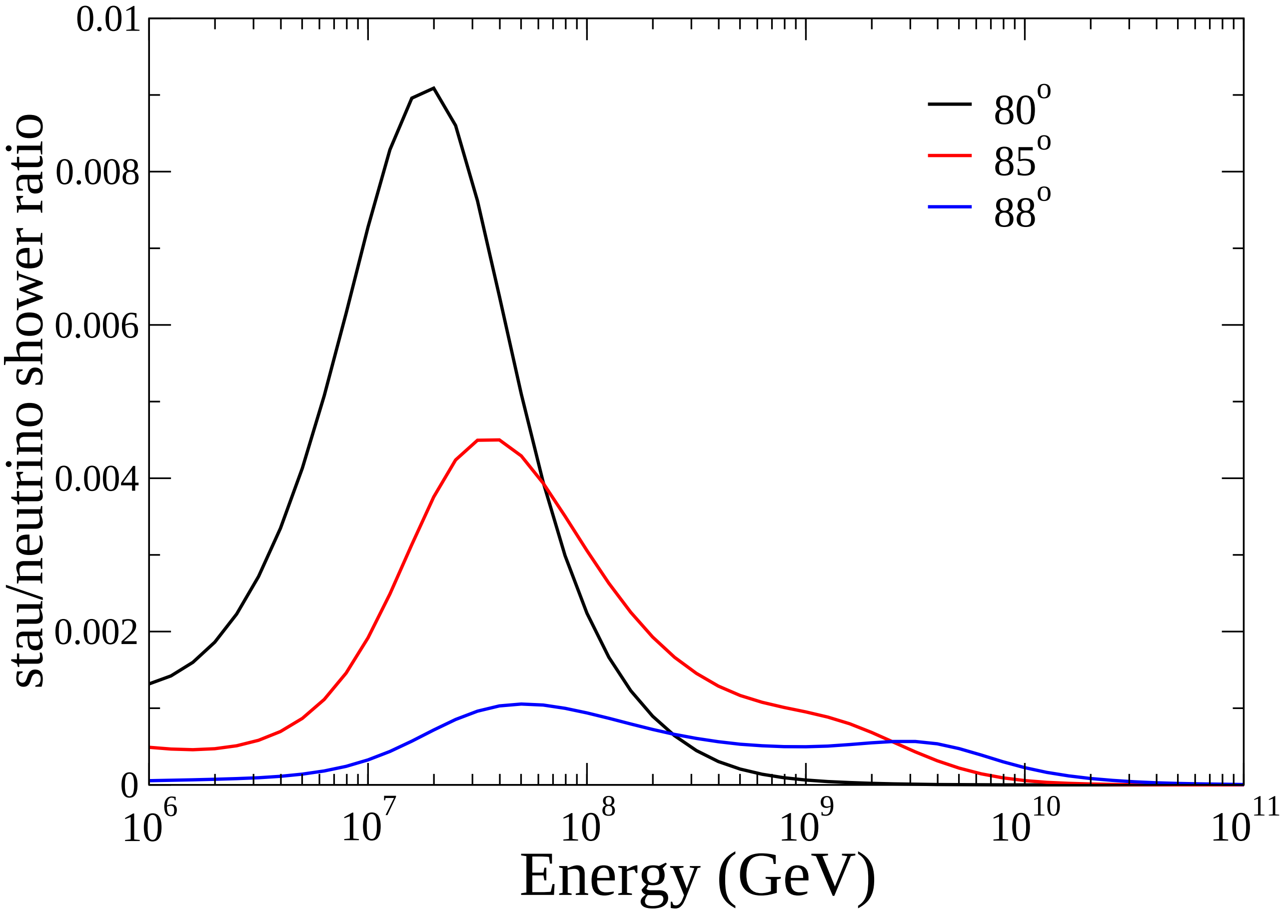
- **For comparison, showers due to neutrinos are found from the equation,**

  $$F_{\nu,\mathrm{shr}}(E_{\mathrm{shr}}, L) \simeq F_\nu(E_{\mathrm{shr}}, L)(1 - e^{-z_{ice}/\mathcal{L}^{\nu}_{CC}}) \ .$$

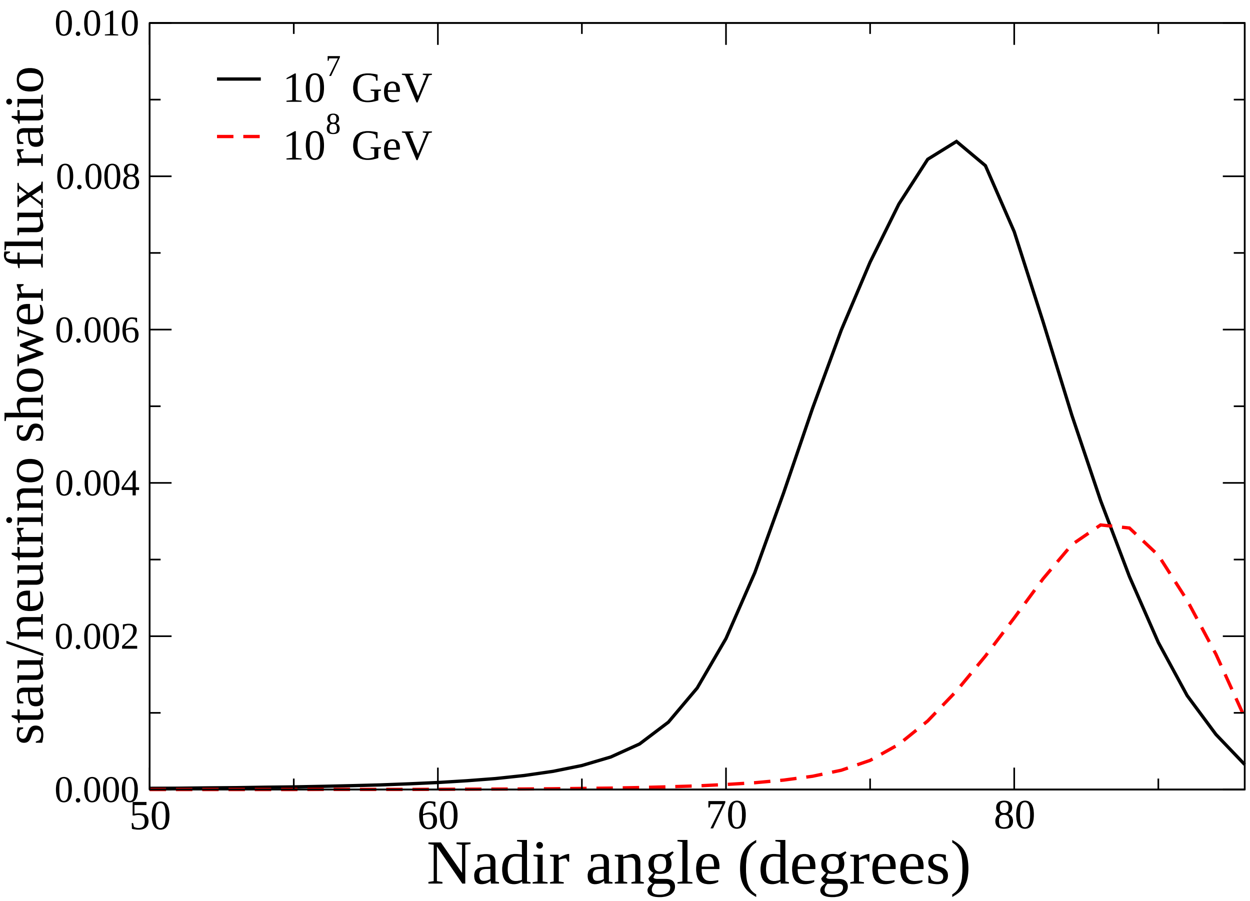
Shower Fluxes in the Detector



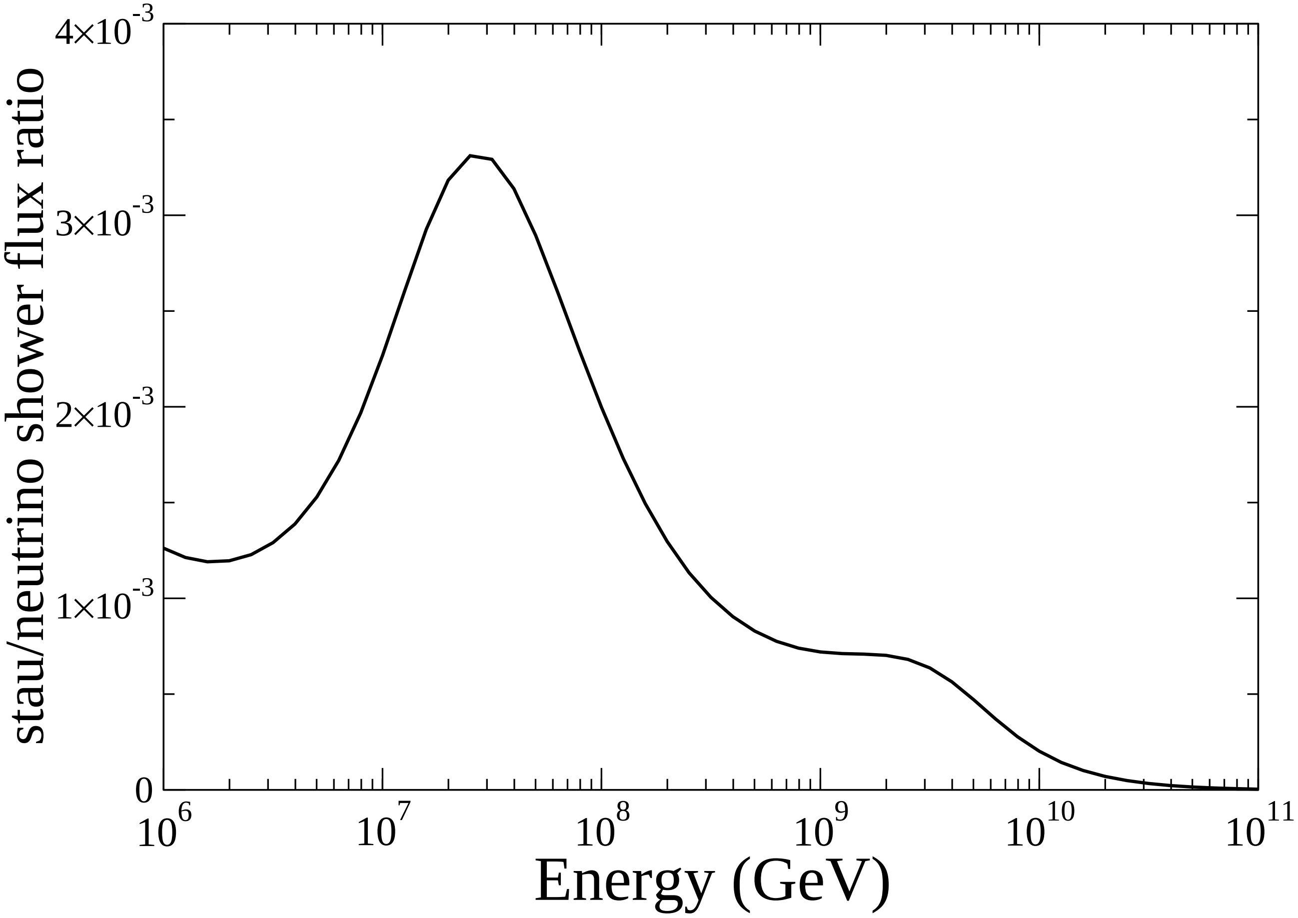
Ratio of Shower Flux from Staus and Neutrinos in the Detector



Ratio of Shower Flux from Staus and Neutrinos in the Detector for Different Nadir Angles



Ratio of Shower Fluxes Integrated over all Angles



- The showers due to neutrinos are of the order $10^3 - 10^4$ larger than staus. The input neutrino flux for the stau signal is at a higher energy than for the direct neutrino production of showers. The neutrino flux falls off as a function of energy so the ratio of stau to neutrino showers is suppressed in part due to this effect.
- In addition, the stau flux is suppressed due to the small stau production cross section. The probability of producing showers in the detector is roughly the same for neutrinos and for staus with maximal charged-current interactions, so the inclusion of the showers is not sufficient to make up for the suppression.
- The shape of the stau induced shower flux changes relative to the neutrino induced shower flux, so between $10^7 - 10^8$ GeV there is a peak in the ratio of stau to neutrino induced showers. The maximum stau/neutrino ratio occurs for an energy of 2.5×10^7 GeV and corresponds to a stau signal of about 0.33 % of the neutrino signal.

SUMMARY

- The stau flux at the detector depends on initial neutrino flux, stau production cross section and on stau energy loss as they traverse the earth.

- Weak interactions of staus are important for energies above 10^8 GeV. For large mixing angle, stau range is significantly reduced at ultrahigh energies

- Interactions of staus in ice, to produce showers, is predominantly via weak interactions – of relevance to ANITA and ARIANNA.

- We have considered signals for stau production: a) Showers produced by stau weak (CC) interactions in the ice and b) Stau Charged Tracks.

- **Showers:** The effects of stau weak interactions is to reduce its range, which combined with a small probability for stau production, gives very small signal relative to the background showers from neutrino CC and NC interactions.
- **Charged Tracks:** Stau flux at the detector is much larger than the muon flux for certain energies and nadir angles. However, stau tracks are “muon-like”. We have proposed a way to distinguish between stau and muon tracks by measuring the energy loss of muons via their interactions in the ice, and to use this method to reduce the background.
- Neutrino telescopes (ICECUBE, ANITA, ARIANNA) have unique ability to provide the first evidence for supersymmetry at weak scale.