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# Weak Interactions of Supersymmetric Staus at High Energies*

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*Huang, Reno, Sarcevic, and Uscinski, hep-ph/0607216

# Motivation

- **Probing SUSY with neutrinos***
  - ⋆ **Ultrahigh energy neutrinos interact with nucleons in Earth producing supersymmetric charged sleptons**
  - ⋆ **SUSY models where supersymmetric breaking scale is $> 5 \times 10^6$ GeV, LSP is gravitino and NLSP is charged slepton (stau)**
  - ⋆ **Stau has long lifetime, can travel large distances through Earth and be detected in neutrino telescopes**
- **Propagation and energy loss of stau important for detection**

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*I. Albuquerque, G. Burdman and Z. Chacko, Phys. Rev. Lett. 92, 221802 (2004), I. Albuquerque, G. Burdman and Z. Chacko, hep-ph/0605120, M. Ahlers, J. Kersten and A. Ringwald, hep-ph/0604188.

# Energy Loss

**The energy loss is given by**

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

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

*S. Iyer Dutta, M. H. Reno, I. Sarcevic and D. Seckel, Phys. Rev. D63, 094020 (2001)

# Different Processes

**Energy loss parameter $\beta$ has contributions from different processes**

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

**y is fraction of slepton energy loss**

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

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

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*M. H. Reno, I. Sarcevic and S. Su, Astropart. Phys. 24, 107 (2005).

# Lifetime and Range

**Competing processes, decay and energy loss:**

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

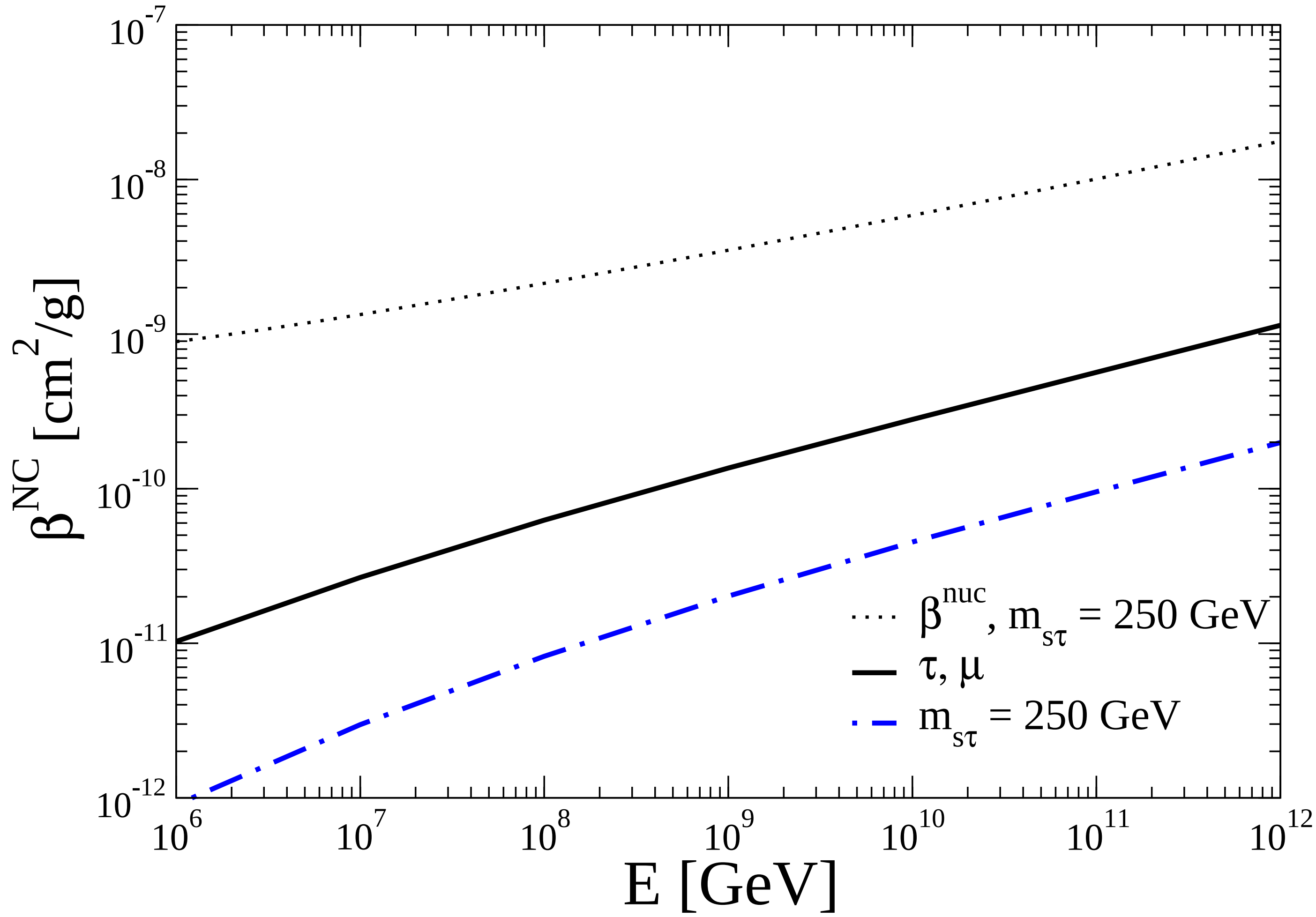
$$X(E, E_0) = \int dX' P(E, E_0, X')$$

**Without including weak interactions:**

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

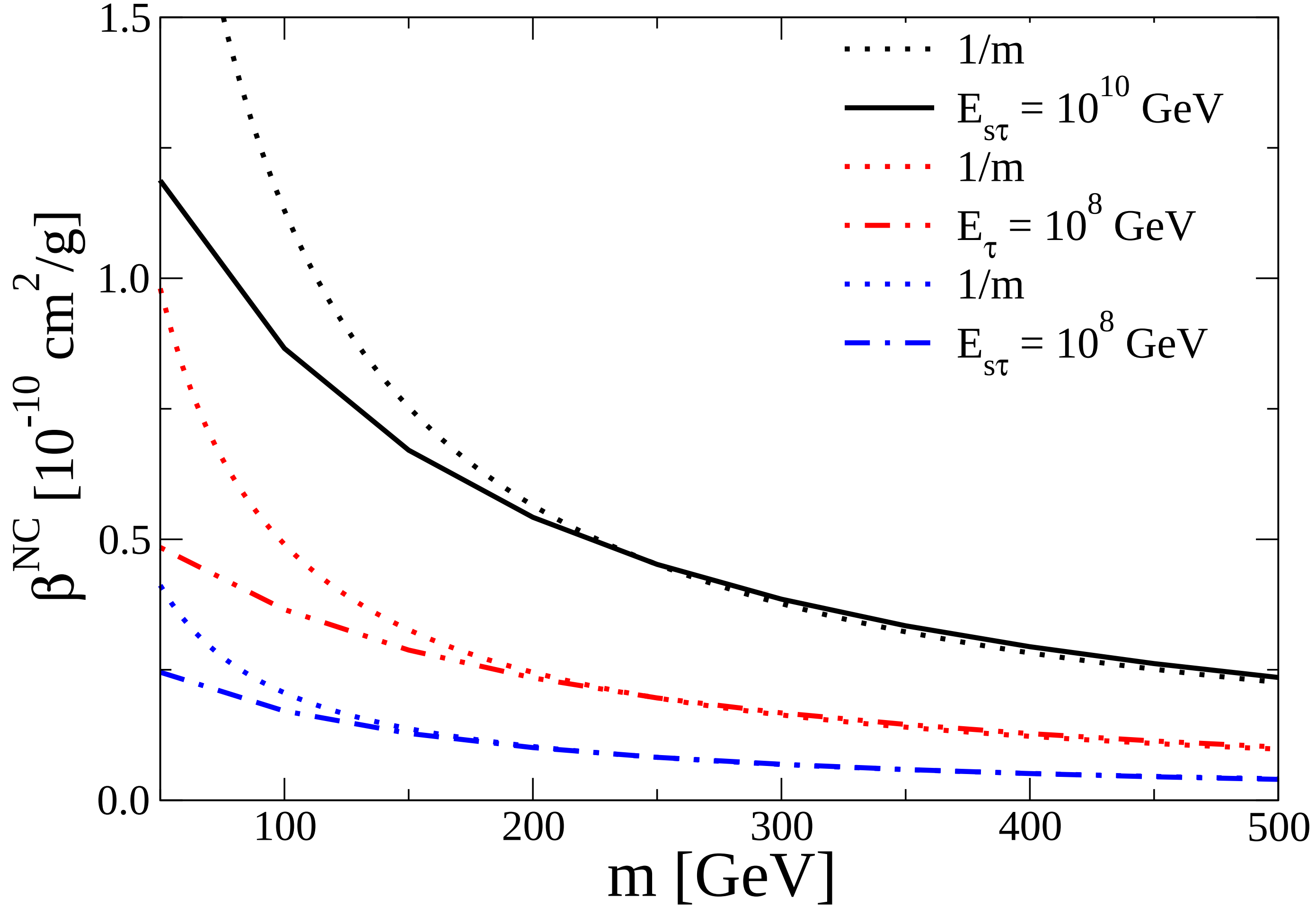
**Does weak interaction contribution to the energy loss have an effect on the range?**

# NC Interactions



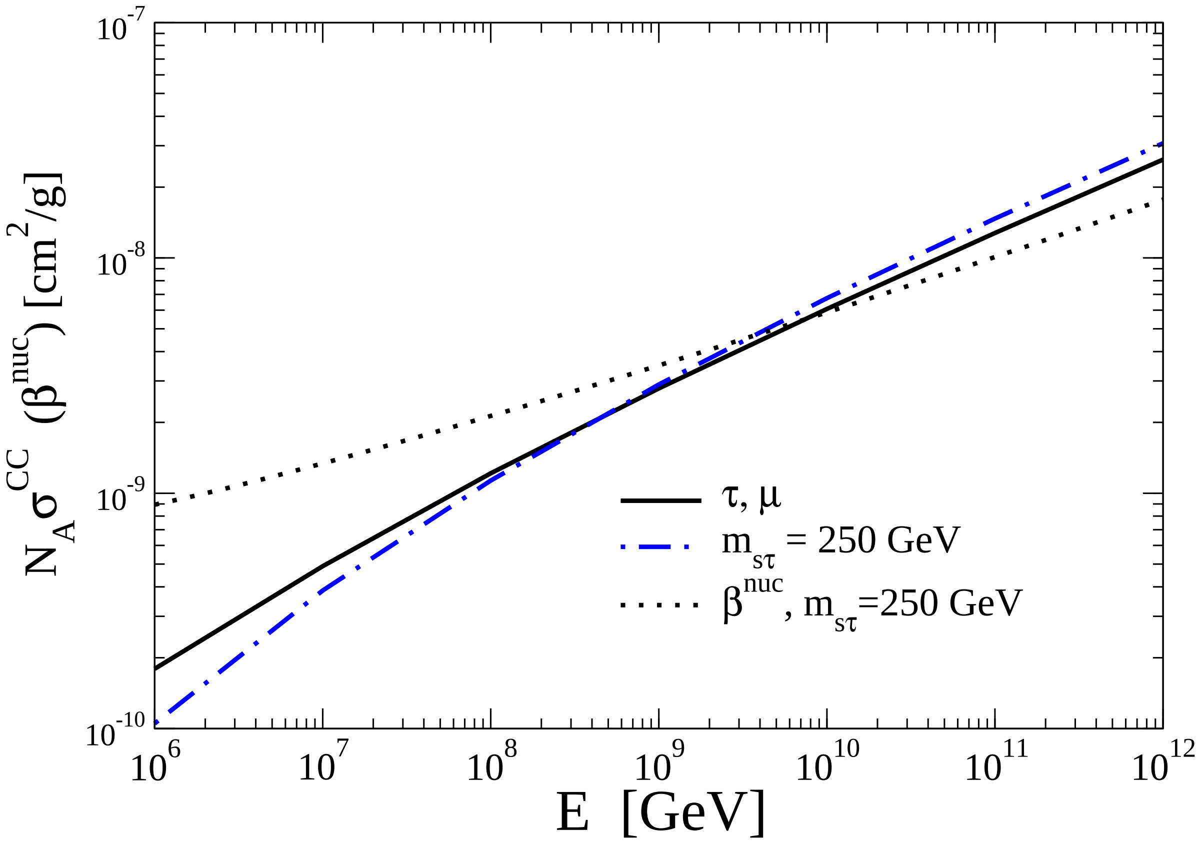

- $\beta^{NC}$ **is small when compared to** $\beta^{nuc} \sim 10^{-8}$ **cm$^2$/g**

# $\beta^{NC}$ Mass Dependence



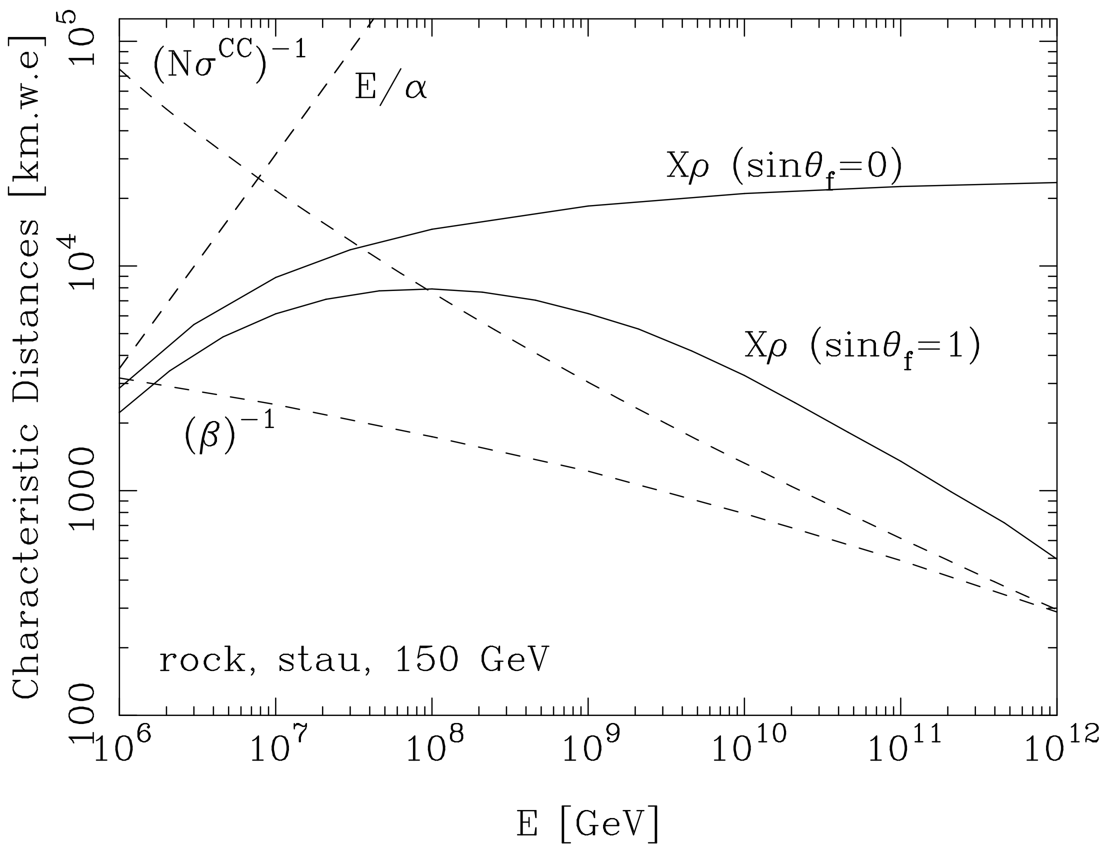

- **Mass dependence is weaker than $\frac{1}{m}$ for m $<$ 200 GeV**
- **For m $>$ 200 GeV, $\frac{1}{m}$ scaling**

# CC Interactions



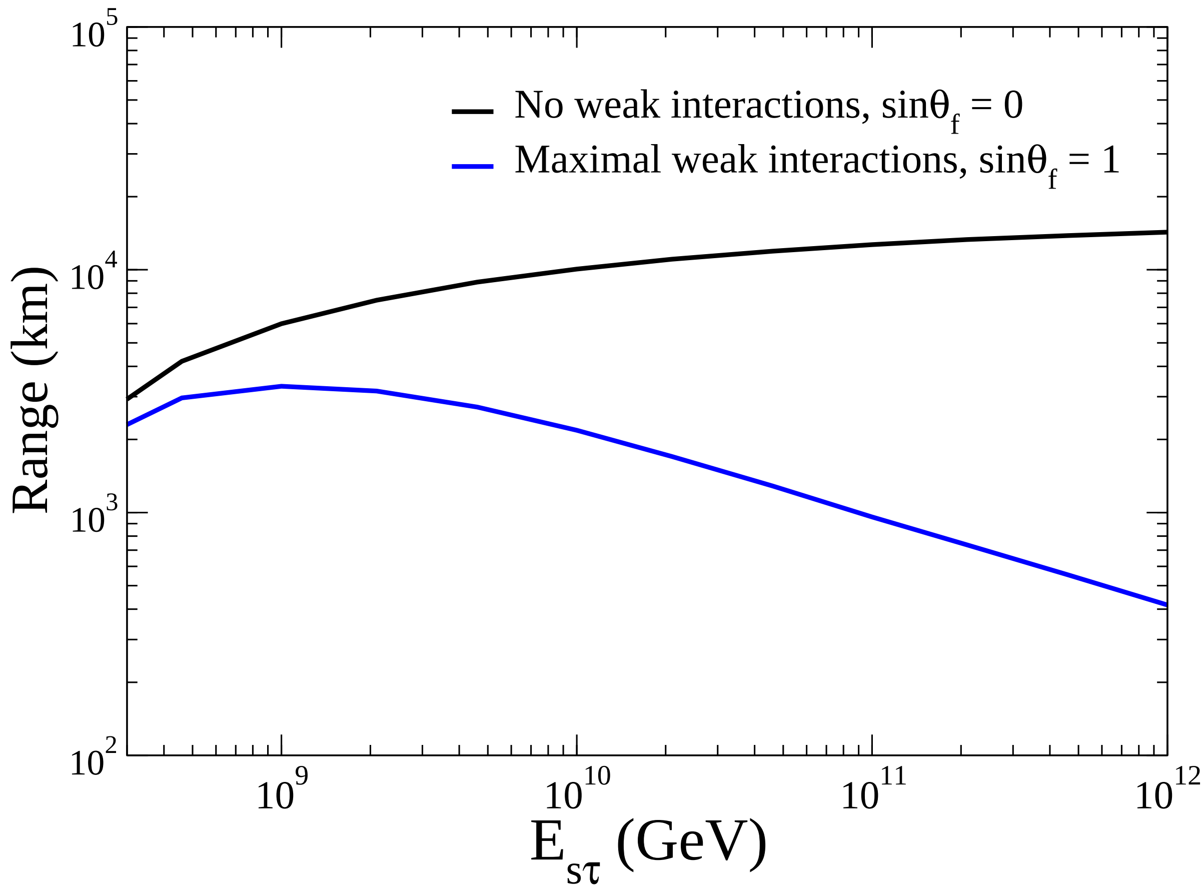

- **Stau cross section is roughly equal to lepton case $\cdot$ sin$^2\theta_f$ - indicates mixing of LH and RH staus. Take sin$\theta_f$ = 1, $m_{\tilde{\nu}} = m_{\tilde{\tau}}$ + 50 GeV**
- **CC interactions become significant at higher energies**

# Characteristic Distances: Stau




- $E_0 = 10^3$ **GeV**
- **At low energies, ionization energy loss dominates**
- **For energies** $\sim 10^8$ **GeV, CC interaction dominates for** $\sin\theta_f = 1$

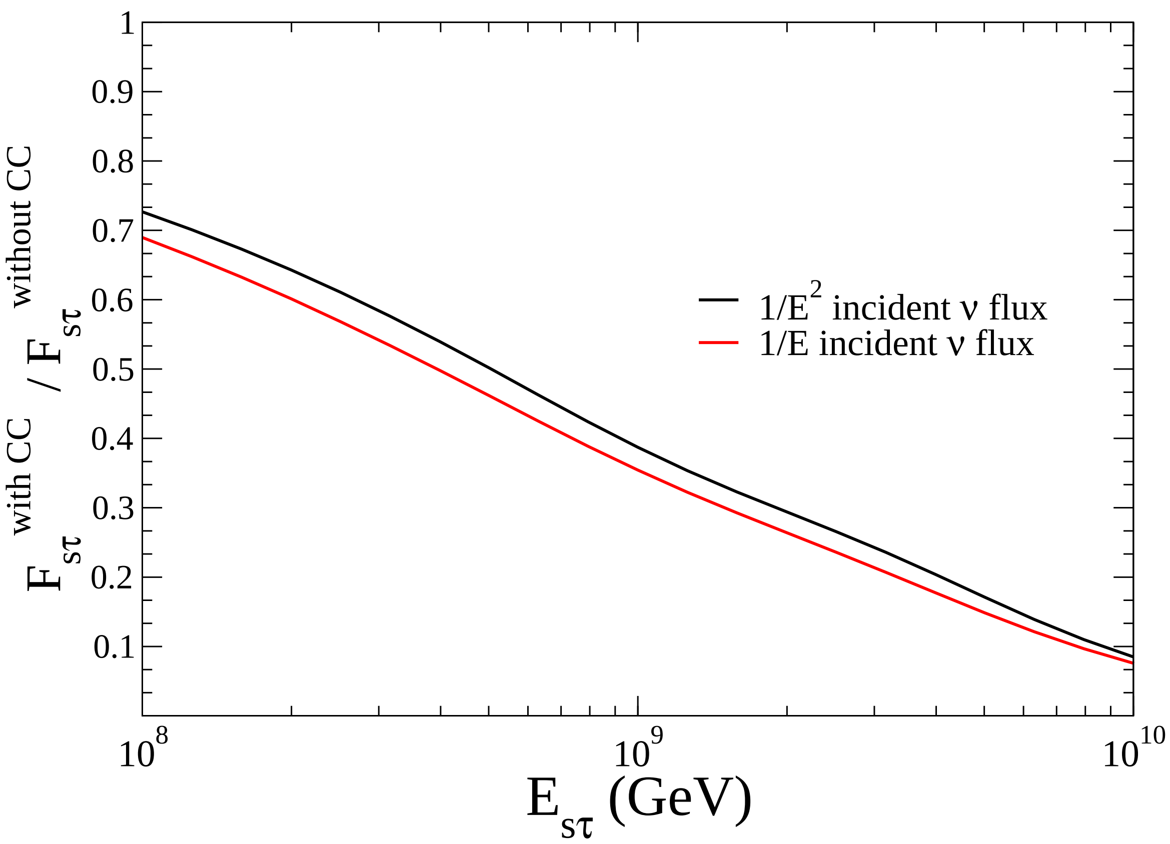
# Range: Stau, $E_0 = 10^8$ GeV




- $m_{\tilde{\tau}} = \mathbf{250\ GeV}$

# What is the stau flux at the detector?

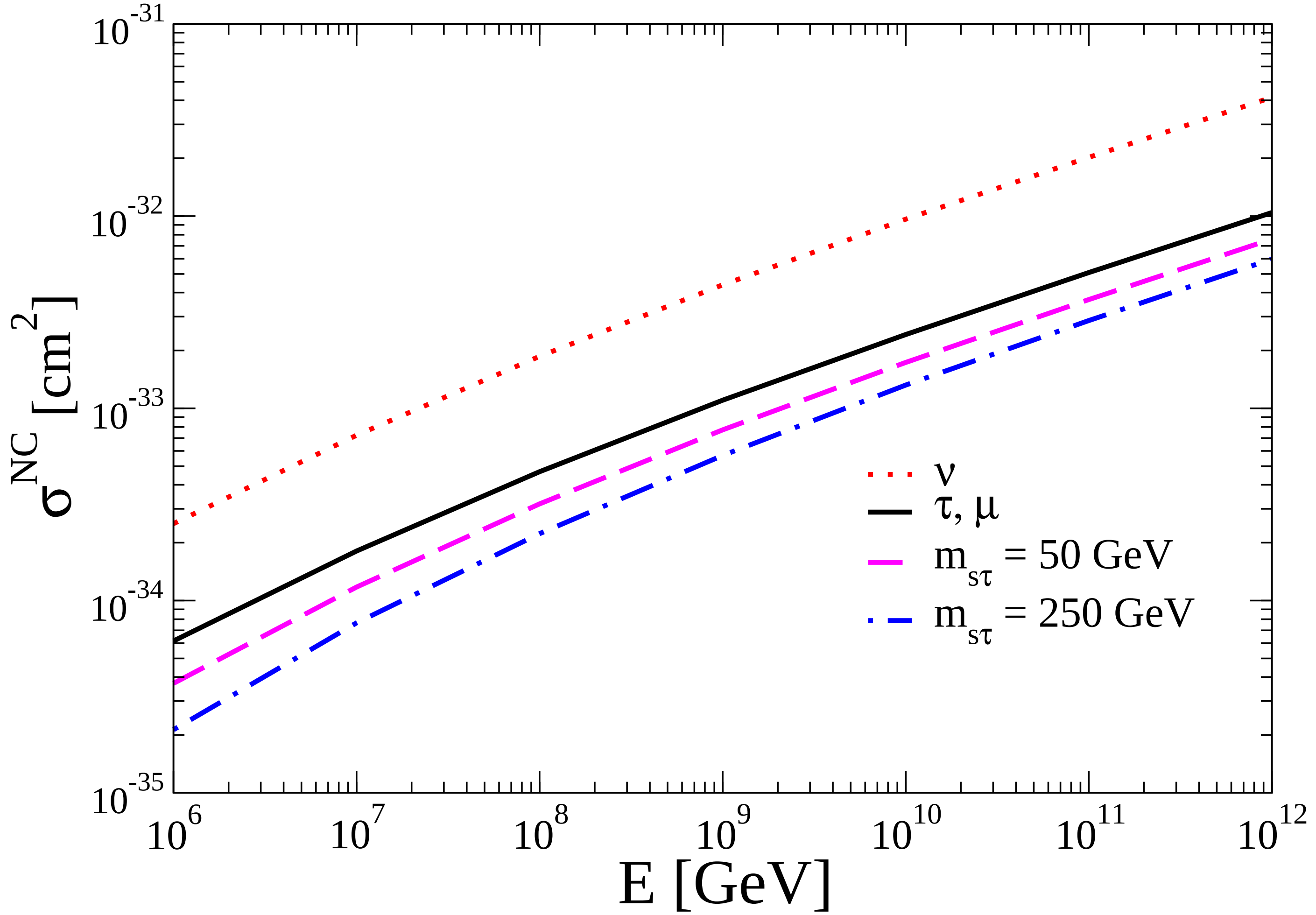
- **Astrophysical sources of neutrinos**
- **Neutrino interactions in Earth (attenuation)**
- **Stau production ($\nu + N \rightarrow ...\tilde{\tau} + \tilde{\tau}$): small cross section**
- **Stau propagation and energy loss**



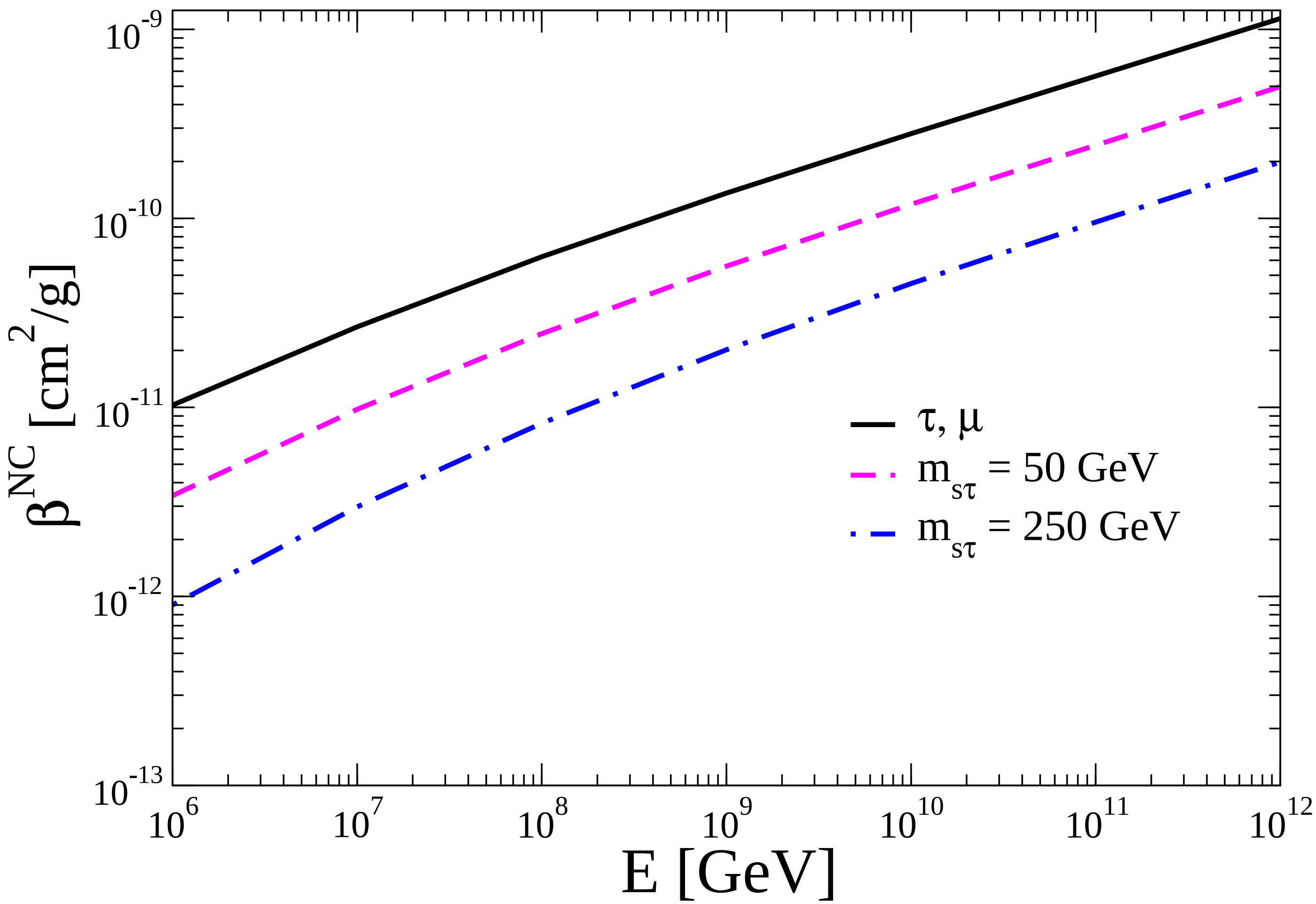
# Conclusions

- **NC interactions for staus do not have an effect on range for the masses and energies considered.**
- **Maximal values for sin$\theta_f$ in CC interactions for staus yield significant suppresion in range above $10^8$ - $10^9$ GeV, but parameter space is open.**
- **Implications for detecting staus in neutrino telescopes.**
  - ⋆ **IceCube - energy threshold $\sim 10^6$ GeV, maximal CC interactions does not affect range significantly**
  - ⋆ **ANITA - energy threshold is higher, $\sim 10^8$ GeV, maximal CC interactions decrease range**

# NC cross sections

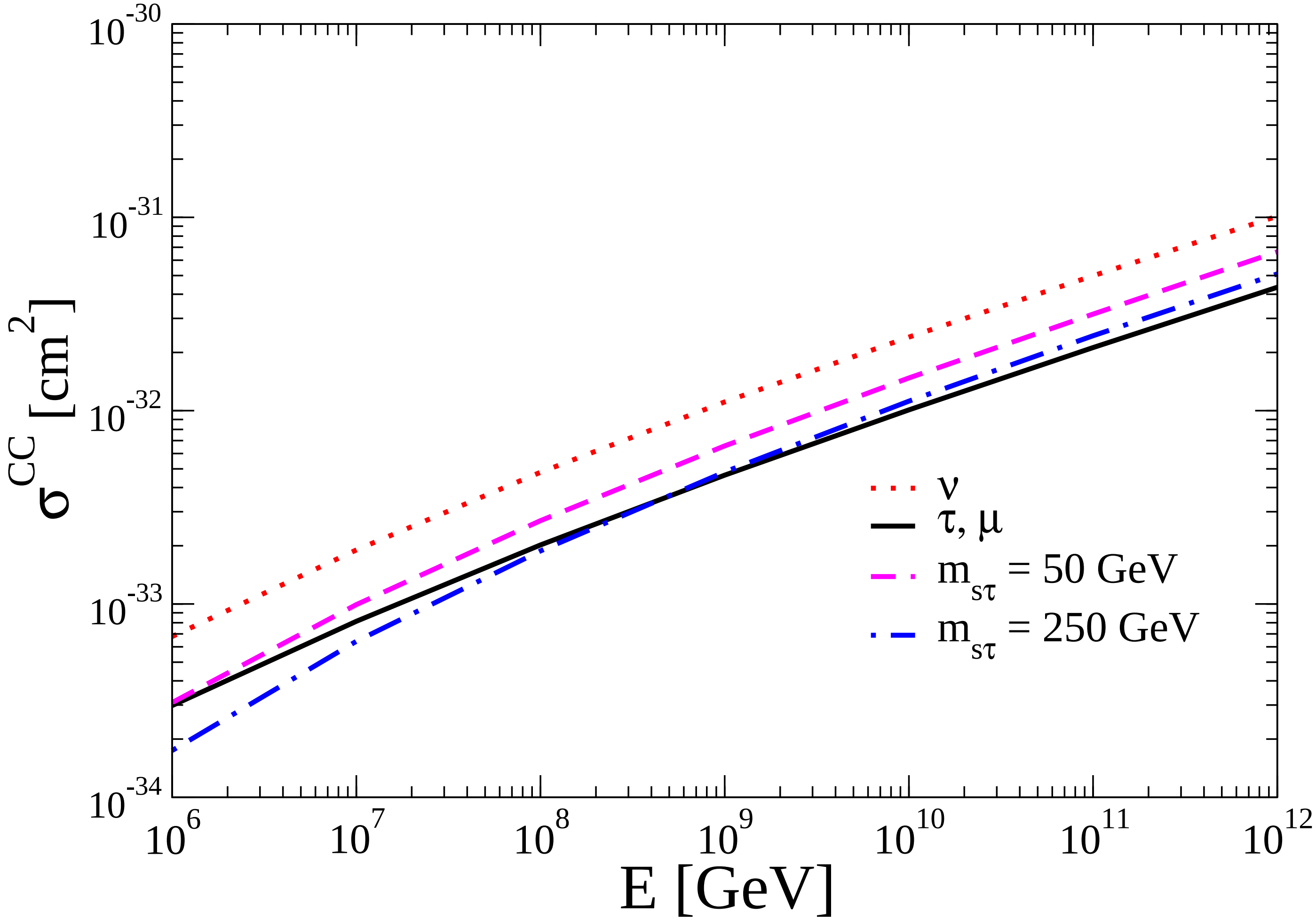


# NC beta

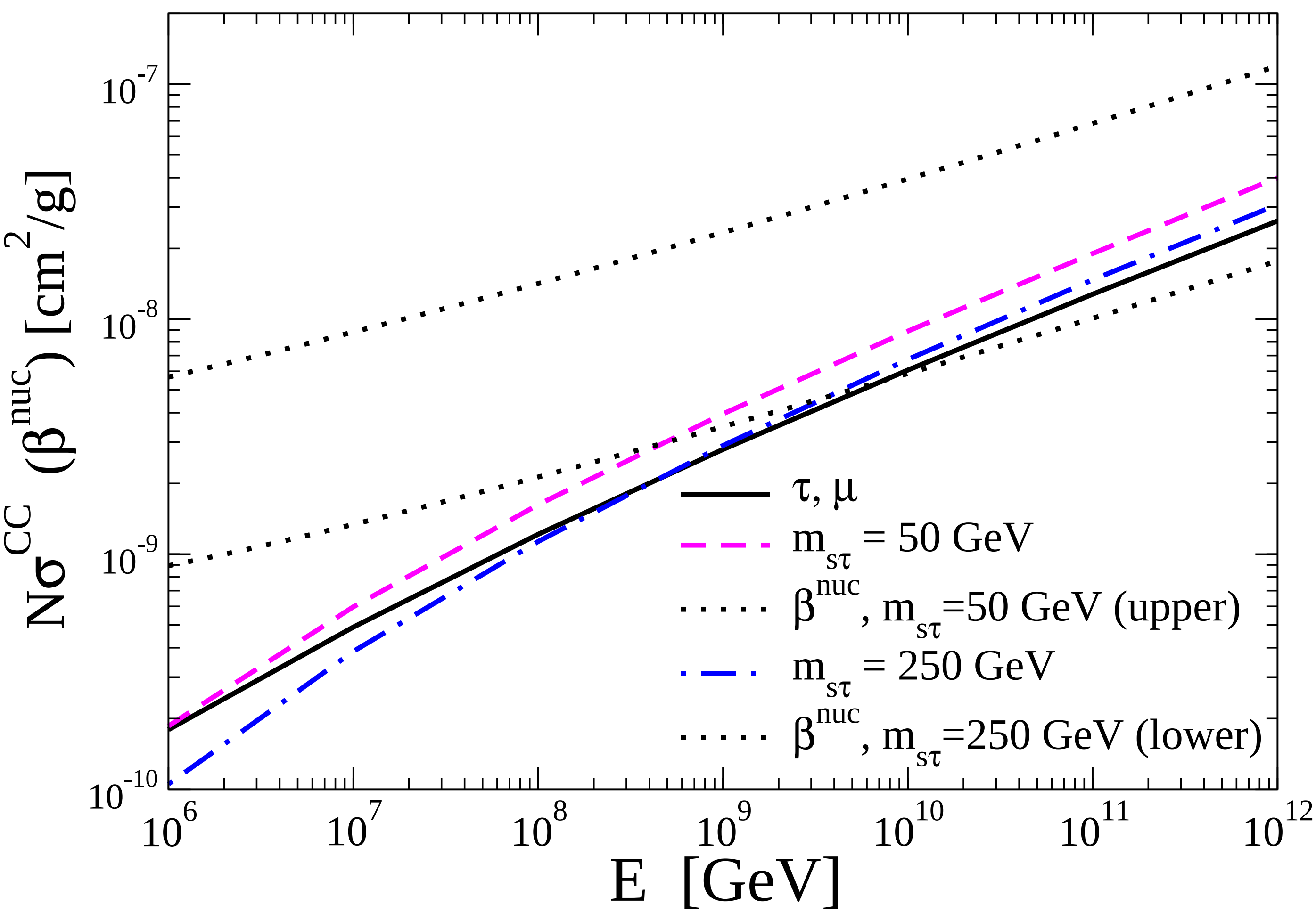


$\beta^{NC}$ [cm$^2$/g]
E [GeV]
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{6}$
$10^{7}$
$10^{8}$
$10^{9}$
$10^{10}$
$10^{11}$
$10^{12}$
τ, μ
$m_{s\tau}$ = 50 GeV
$m_{s\tau}$ = 250 GeV

# CC cross sections



# More CC



$N\sigma^{CC}$ $(\beta^{nuc})$ [cm$^2$/g]
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{6}$
$10^{7}$
$10^{8}$
$10^{9}$
$10^{10}$
$10^{11}$
$10^{12}$
E [GeV]
$\tau$, $\mu$
$m_{s\tau}$ = 50 GeV
$\beta^{nuc}$, $m_{s\tau}$=50 GeV (upper)
$m_{s\tau}$ = 250 GeV
$\beta^{nuc}$, $m_{s\tau}$=250 GeV (lower)

# Characteristic Distances: Tau