Weak Interactions of Supersymmetric Staus at High Energies*

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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

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 \(\sim 2 \cdot 10^{-3} \text{ GeV cm}^2/\text{g}\), dominant at low energies*
- \(\beta\) - radiative energy loss, dominant at high energies

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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:** $\tilde{\tau}Z \rightarrow \tilde{\tau}Ze^+e^-$
- **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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Lifetime and Range

Competing processes, decay and energy loss:

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

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

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?
\( \beta_{\text{NC}} \) is small when compared to \( \beta_{\text{nuc}} \sim 10^{-8} \text{ cm}^2/\text{g} \)
\( \beta^{NC} \) 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 \( \sin \theta_f = 1 \), \( m_{\tilde{\nu}} = m_{\tilde{\tau}} + 50 \text{ GeV} \)

- CC interactions become significant at higher energies
Characteristic Distances: Stau

- \( E_0 = 10^3 \text{ GeV} \)
- At low energies, ionization energy loss dominates
- For energies \( \sim 10^8 \text{ GeV} \), CC interaction dominates for \( \sin \theta_f = 1 \)
Range: Stau, $E_0 = 10^8$ GeV

- $m_{\tilde{\tau}} = 250$ GeV
What is the stau flux at the detector?

- Astrophysical sources of neutrinos
- Neutrino interactions in Earth (attenuation)
- Stau production ($\nu + N \rightarrow \ldots \tilde{\tau} + \tilde{\tau}$): 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 suppression 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

\[ \sigma_{NC}[\text{cm}^2] \]

\[ E [\text{GeV}] \]

- \( \nu \)
- \( \tau, \mu \)
- \( m_{s\tau} = 50 \text{ GeV} \)
- \( m_{s\tau} = 250 \text{ GeV} \)
$E \ [\text{GeV}]$

$\beta_{\text{NC}} \left[ \text{cm}^2/\text{g} \right]$

$\tau, \mu$

$m_{\tau} = 50 \text{ GeV}$

$m_{\tau} = 250 \text{ GeV}$
CC cross sections

\[ \sigma_{\text{CC}} \left[ \text{cm}^2 \right] \]

\( E [\text{GeV}] \)

- \( E \approx 10^6 \) GeV
- \( E \approx 10^7 \) GeV
- \( E \approx 10^8 \) GeV
- \( E \approx 10^9 \) GeV
- \( E \approx 10^{10} \) GeV
- \( E \approx 10^{11} \) GeV
- \( E \approx 10^{12} \) GeV

- \( \nu, \tau, \mu \)
- \( m_{s\tau} = 50 \text{ GeV} \)
- \( m_{s\tau} = 250 \text{ GeV} \)
More CC

\[ N\sigma_{CC}(\beta^{\text{nuc}}) \ \text{[cm}^2/\text{g]} \]

- \( \tau, \mu \)
- \( m_{\tau} = 50 \text{ GeV} \)
- \( \beta^{\text{nuc}}, m_{\tau} = 50 \text{ GeV} \) (upper)
- \( m_{\tau} = 250 \text{ GeV} \)
- \( \beta^{\text{nuc}}, m_{\tau} = 250 \text{ GeV} \) (lower)
Characteristic Distances: Tau

- $\gamma c \tau$
- $(N\sigma_{CC}\rho)^{-1}$
- $(\beta \rho)^{-1}$
- rock, tau

Characteristic Distances [km]

$E_\tau$ [GeV]