SUSY at the Pole

Jörn Kersten

DESY, Hamburg

Based on
M. Ahlers, J.K., A. Ringwald, JCAP 07 (2006) 005
(hep-ph/0604188)
Idea

- Cosmic neutrinos reach energies \( \gtrsim 10^{11} \) GeV
- Interactions with nucleons in the Earth:
  \[ \sqrt{s} \sim 1 \text{ TeV} \text{ for } E_\nu \sim 10^6 \text{ GeV} \]
- Production of SUSY particles possible

\( \rightsquigarrow \) Detection of SUSY via cosmic ray observations?
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$\leadsto$ Detection of SUSY via cosmic ray observations?

Problem:

- Heavier particles decay to LSP immediately
- LSP neutral $\Rightarrow$ not observable
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Production of SUSY particles possible

$\rightsquigarrow$ Detection of SUSY via cosmic ray observations?

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Loophole: Long-lived charged NLSP ($\tilde{\tau}_1$)
The Scenario

- **Gravitino** is the LSP
- Only gravitational interaction

⇒ **Long-lived NLSP:**

\[
\frac{L}{2R_\oplus} \approx \left( \frac{m_{\tilde{\tau}}}{100 \text{ GeV}} \right)^{-6} \left( \frac{m_{3/2}}{400 \text{ keV}} \right)^{2} \left( \frac{E_{\tilde{\tau}}}{500 \text{ GeV}} \right)
\]

⇒ Can traverse the whole Earth
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\]

⇒ Can traverse the whole Earth

- R-parity ⇒ Staus produced in **pairs**
- High energy ⇒ Nearly **parallel tracks**, separation few m to few km

⇒ Detectable in **neutrino telescopes**

Albuquerque, Burdman, Chacko, PRL 92 (2004)
Motivation from Cosmology

Constraints on the LSP:
- Observed dark matter density
- Big Bang Nucleosynthesis
- Distortions of the Cosmic Microwave Background

\(\leadsto\) Bounds on gravitino mass and reheating temperature

More restrictive for unstable gravitino

\(\leadsto\) Favored scenario:
- Stable gravitino LSP
- Slepton NLSP
Consider 2 examples:

**SPS 7 Benchmark (GMSB with $\tilde{\tau}$ NLSP)**

**Toy Model** with light superpartners:
- $\chi_i^{\pm}, \chi_i^0, \tilde{l}$ at 100 GeV
- $\tilde{q}$ at 300 GeV
Neutrino Interactions in the Earth

SM

Cross section

\[ \nu + l \rightarrow W^\pm + u/d \]

\[ \nu + l \rightarrow Z^0 + u/d \]

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Neutrino Interactions in the Earth

MSSM

\[ \nu \rightarrow \tilde{l} \]

\[ \nu \rightarrow \tilde{\nu} \]

\[ \chi^\pm \]

\[ \chi^0 \]

\[ u \rightarrow \tilde{d} \]

\[ d \rightarrow \tilde{u} \]

Cross section

\[ \sigma [\text{cm}^2] \]

\[ E_\nu [\text{GeV}] \]

CC + NC

CC

NC

SM

min \( m \)

SPS 7
Stau Energy Loss

\[- \left( \frac{dE}{dx} \right) \propto \alpha + \beta E\]

- $\alpha$ due to ionization
- $\beta$ due to radiative processes
- $\beta E \gg \alpha$ for muons with $E \gtrsim 500$ GeV
Stau Energy Loss

\[-\left\langle \frac{dE}{dx} \right\rangle \propto \alpha + \beta E\]

- \(\alpha\) due to ionization
- \(\beta\) due to radiative processes
- \(\beta E \gg \alpha\) for muons with \(E \gtrsim 500\) GeV
- \(\beta_{\tau} \approx \frac{m_\mu}{m_{\tau}} \beta_\mu\) \(\Rightarrow\) Stau range much larger
  \(\Rightarrow\) Can compensate for smaller production cross section

Detailed calculation: Reno, Sarcevic, Su, Astropart. Phys. 24 (2005)
1. Introduction
2. Stau Production and Propagation
3. Stau Detection
4. Conclusions
Assume Waxman-Bahcall flux for cosmic neutrinos

\[ E_\nu^2 F(E_\nu) = 2 \cdot 10^{-8} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ GeV (per flavor)} \]

Waxman, Bahcall, Phys. Rev. D59 (1999)
Flux of Single Staus

Assume Waxman-Bahcall flux for cosmic neutrinos
\[ E^2 \nu \cdot F(E_{\nu}) = 2 \cdot 10^{-8} \, \text{cm}^{-2} \, \text{s}^{-1} \, \text{sr}^{-1} \, \text{GeV} \text{ (per flavor)} \]

Waxman, Bahcall, Phys. Rev. D59 (1999)
Assume Waxman-Bahcall flux for cosmic neutrinos

\[ E^2 \nu F(E_\nu) = 2 \cdot 10^{-8} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ GeV (per flavor)} \]

Waxman, Bahcall, Phys. Rev. D59 (1999)

⇒ Staus subdominant compared to muons in detected spectrum
Expected signature: 2 parallel muon-like tracks

Estimate for detection efficiency:
- Cutoff at low energy: $E_\tau > 500$ GeV
- $50 \text{ m} < \text{separation} < 1 \text{ km}$

Background:
- Coincident muons: $\sim 12$ orders of magnitude below muon flux
- Muon pairs from $\nu_\mu + N \rightarrow \mu + H \rightarrow \mu + \mu + \nu_\mu + H'$: Separation $< 50 \text{ m}$ due to small range of muons

Albuquerque, Burdman, Chacko, hep-ph/0605120
Stau Pair Event Rate

energy spectra at the detector
IceCube: A~1km² and 50m<x<1km

- $\mu$
- $\gamma+\gamma$ (min $\tilde{m}$)
- $\gamma+\gamma$ (SPS 7)
**Stau Pair Event Rate**

energy spectra at the detector
IceCube: A~1km² and 50m<x<1km

![Graph showing energy spectra at the detector](image)

**Number of events at IceCube for Waxman-Bahcall flux**

- $\min \tilde{m}$: 5 per year
- SPS 7: 1 per decade
For Comparison

Albuquerque, Burdman, Chacko, hep-ph/0605120

Number of events per km$^2$ with Waxman-Bahcall flux:
- $\sim \min \tilde{m}: 14$ (12?) per year
- $\sim$ SPS 7: 1 per year

Possible reasons for the discrepancy:
- Calculation of track separation
- Relation between stau energy and initial neutrino energy
- Neutrino propagation in the Earth
Stopped Staus

- Low-energy staus stop in the detector
- Decay later $\sim \tau$ cascade
- Correlation with track ending in the detector
- Observable at IceCube for lifetimes $\lesssim$ few hours
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- Low-energy staus stop in the detector
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![Energy spectra at the detector](image)
Stopped Staus

- Low-energy staus stop in the detector
- Decay later $\sim \tau$ cascade
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\[ \min \tilde{m}: \sim 1 \text{ event per century} \]
1. Introduction

2. Stau Production and Propagation

3. Stau Detection

4. Conclusions
Conclusions

- Gravitino LSP + stau NLSP attractive for cosmology
- Cosmic ray interactions in the Earth $\rightsquigarrow$ stau pairs
- Detectable in neutrino telescopes
- Small event rates in km$^3$ detector for “realistic” SUSY-breaking scenarios and cosmic neutrino flux
- Several events per year possible, if superparticles lighter or neutrino flux larger than expected
- LHC will probably discover SUSY earlier