# SUSY at the Pole

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

# Outline

# Idea

- Cosmic neutrinos reach energies $\gtrsim 10^{11}$ GeV
- Interactions with nucleons in the Earth:
  $\sqrt{s} \sim 1$ TeV for $E_\nu \sim 10^6$ GeV
- 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:

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

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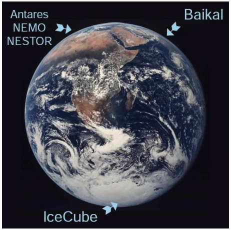
⇒ Can traverse the whole Earth

- 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

$\rightsquigarrow$ Bounds on gravitino mass and reheating temperature

More restrictive for unstable gravitino

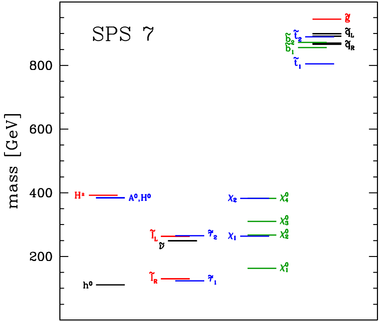
$\rightsquigarrow$ Favored scenario:

- Stable gravitino LSP
- Slepton NLSP

# SUSY Spectra

Consider 2 examples:

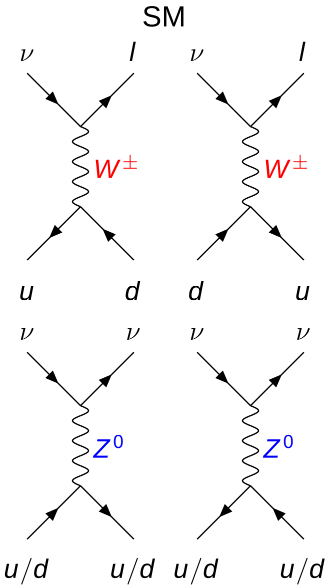
SPS 7 Benchmark (GMSB with $\tilde{\tau}$ NLSP)



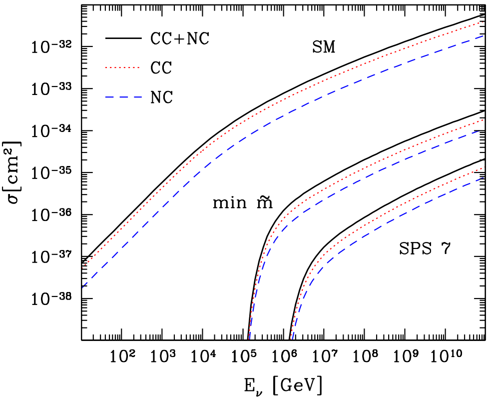

Toy Model with light superpartners:

- $\chi_i^{\pm}, \chi_i^0, \tilde{l}$ at 100 GeV
- $\tilde{q}$ at 300 GeV

# Neutrino Interactions in the Earth

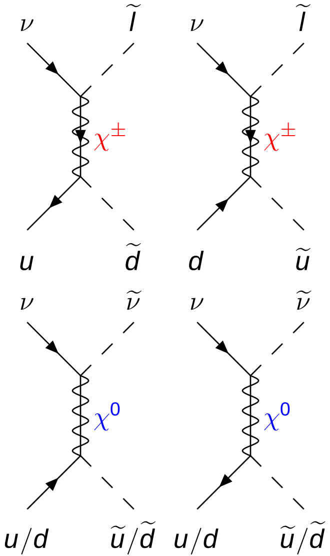



## Cross section



# Neutrino Interactions in the Earth

MSSM

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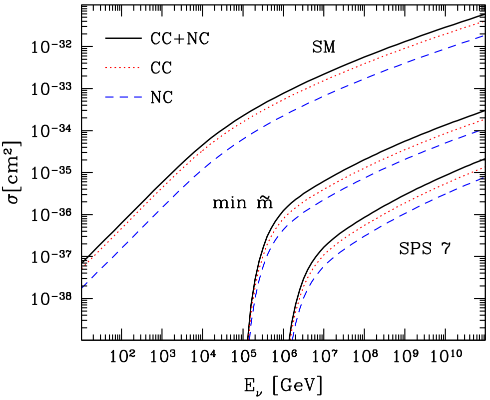

# Stau Energy Loss

$$-\left\langle \frac{\mathrm{d}E}{\mathrm{d}x} \right\rangle \propto \alpha + \beta E$$

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

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- $\alpha$ due to ionization
- $\beta$ due to radiative processes
- $\beta E \gg \alpha$ for muons with $E \gtrsim 500$ GeV
- $\beta_{\tilde{\tau}} \approx \frac{m_\mu}{m_{\tilde{\tau}}} \beta_\mu \Rightarrow$ Stau range much larger
  $\Rightarrow$ Can compensate for smaller production cross section
- Detailed calculation: Reno, Sarcevic, Su, Astropart. Phys. **24** (2005)

# Flux of Single Staus

Assume Waxman-Bahcall flux for cosmic neutrinos

$E_\nu^2 F(E_\nu) = 2 \cdot 10^{-8}\, \mathrm{cm}^{-2}\, \mathrm{s}^{-1}\, \mathrm{sr}^{-1}\, \mathrm{GeV}$ (per flavor)

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

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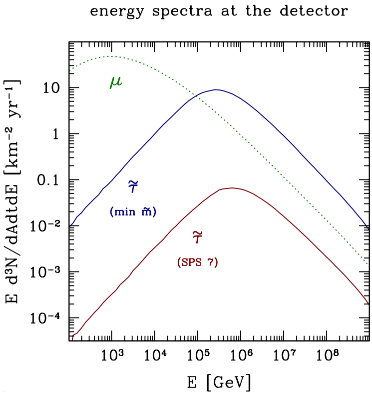

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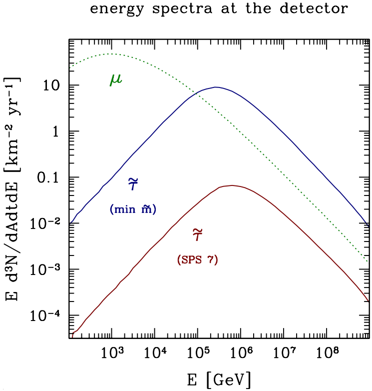


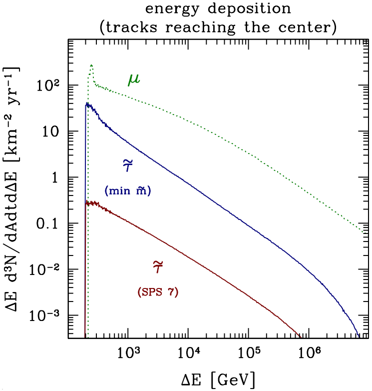


$\Rightarrow$ Staus subdominant compared to muons in detected spectrum

# Stau Pair Event Rate

- Expected signature: 2 parallel muon-like tracks
- Estimate for detection efficiency:
  - Cutoff at low energy: $E_{\tilde{\tau}} > 500\,\mathrm{GeV}$
  - $50\,\mathrm{m} <$ separation $< 1\,\mathrm{km}$
- Background:
  - Coincident muons:
    $\sim$ 12 orders of magnitude below muon flux
  - Muon pairs from $\nu_\mu + N \to \mu + H \to \mu + \mu + \nu_\mu + H'$:
    Separation $< 50\,\mathrm{m}$ due to small range of muons

Albuquerque, Burdman, Chacko, hep-ph/0605120

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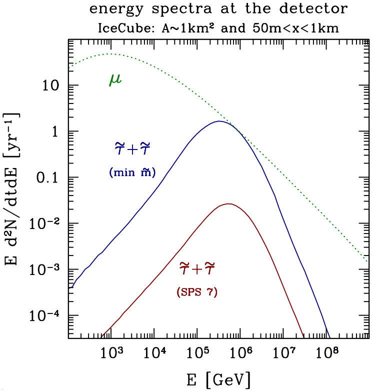

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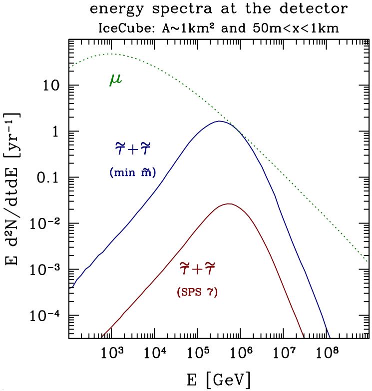


**Number of events at IceCube for Waxman-Bahcall flux**

min $\widetilde{m}$: 5 per year SPS 7: 1 per decade

# For Comparison

Albuquerque, Burdman, Chacko, hep-ph/0605120

Number of events per $\text{km}^2$ with Waxman-Bahcall flux:

- $\sim$ min $\widetilde{m}$: 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 $\rightsquigarrow$ $\tau$ cascade
- Correlation with track ending in the detector
- Observable at IceCube for lifetimes $\lesssim$ few hours

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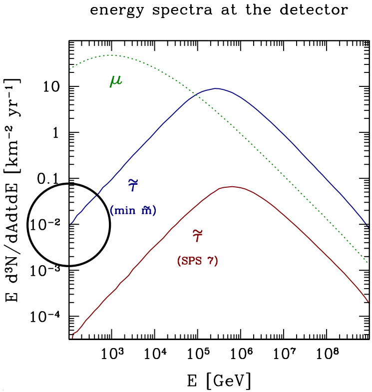

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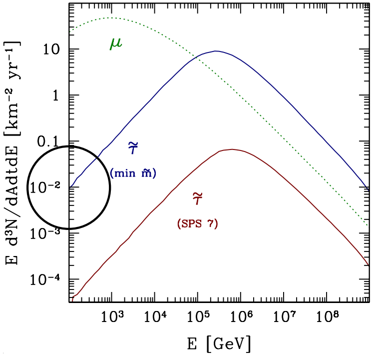
energy spectra at the detector




min $\tilde{m}$: $\sim$ 1 event per century

# 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