Indirect detection of supersymmetric particles with neutrino telescopes

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Starting point:

- *Neutrino Telescopes as a Direct Probe of Supersymmetry Breaking*, Ivone. F. M. Albuquerque, Gustavo Burdman and Z. Chacko, Physical Review Letters, 92, 221802 (2004);
- *Direct detection of supersymmetric particles in neutrino telescopes*, Ivone. F. M. Albuquerque, Gustavo Burdman and Z. Chacko, Physical Review D 75, 035006 (2007);

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Goal

Extend the results for a complementary Supersymmetry Breaking Energy Scale:

$$10^7\,GeV \lesssim \sqrt{F} \lesssim 10^{10}\,GeV \longrightarrow 10^5\,GeV \lesssim \sqrt{F} \lesssim 10^7\,GeV$$

Outline

- Theoretical context;
- Interactions – cross sections, energy loss and ν flux;
- What was already done – study of the direct detection of the NLSPs signals;
- **What is new** – study of the indirect detection of the NLSPs signals.

Introduction

Weak scale supersymmetry (SUSY) as an extension of the Standard Model of particle physics;

R-parity $\rightarrow$ neutral and stable
lightest supersymmetric particle (LSP);

The supersymmetry must be broken $\rightarrow \sqrt{F}$:

- If $\sqrt{F} \lesssim 10^{10}\,GeV \rightarrow$ Gravitino LSP;
- If $\sqrt{F} \gtrsim 10^{10}\,GeV \rightarrow$ Neutralino LSP.

Gravitino LSP Scenarios

Processes that have to be considered:

$$\nu N \rightarrow \tilde{l}_L \tilde{q}$$

$\tilde{l}_L \tilde{q}$ promptly decay to $2\tilde{l}_R + SM$ particles

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- $\tilde{l}_R$: typically the $\tilde{\tau}_R \rightarrow$ Next to lightest supersymmetric particle (NLSP);
- $\tilde{\tau}_R$ lifetime can be very large $\rightarrow$ can travel very long distances before decaying:

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

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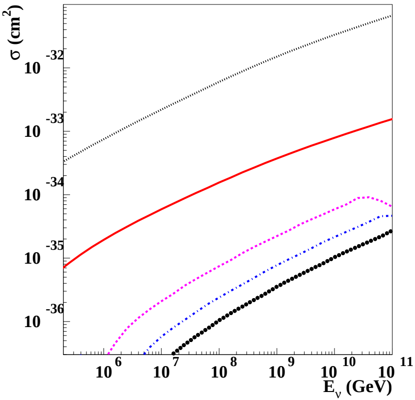
- $10^7\,GeV \lesssim \sqrt{F} \lesssim 10^{10}\,GeV \Rightarrow$ direct detection ($\tilde{\tau}_R$ doesn't decay inside the Earth);
- $10^5\,GeV \lesssim \sqrt{F} \lesssim 10^7\,GeV \Rightarrow$ indirect detection ($\tilde{\tau}_R$ decays inside the Earth).

ν-nucleon cross-sections

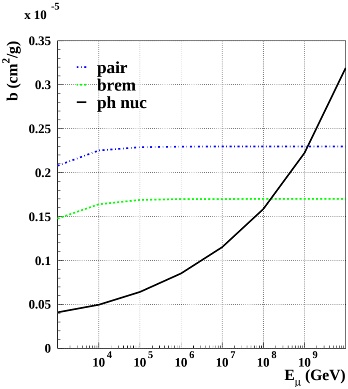


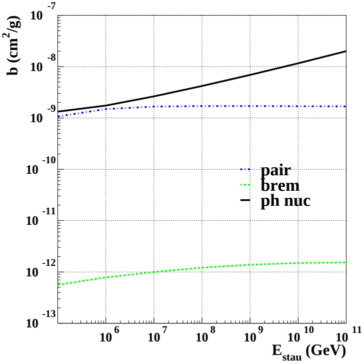
The three lower curves correspond to $m_{\tilde{\ell}_L} = 250$ GeV, $m_{\tilde{w}} = 250$GeV; and for squark masses $m_{\tilde{q}} = 300$ GeV (dashed) , 600 GeV (dot-dashed) and 900 GeV (dotted). The top curve corresponds to the SM charged current interactions and the middle one to the di-muon background.

Figure: I. F. M. Albuquerque, et al, Physical Review D **75**, 035006 (2007).

Energy loss for muon and stau

Three main contributions – bremsstrahlung, pair production and photonuclear





Figures: M. H. Reno, I. Sarcevic and S. Su, Astroparticle Physics **24**, 107 (2005); Ivone F. M. Albuquerque, et al, Physical Review D **75**, 035006 (2007).

Neutrino flux

Waxman and Bahcall (WB) limit – the observed cosmic ray flux implies an upper bound on the high energy astrophysical neutrino flux.

$$\left(\frac{d\phi_\nu}{dE}\right)_{\mathrm{WB}} = \frac{(1-4)\times 10^{-8}}{E^2}$$

$$GeV\ cm^{-2}s^{-1}\ sr^{-1}$$

Mannheim, Protheroe and Rachen (MPR) limit – upper limit on the diffuse neutrino sources.

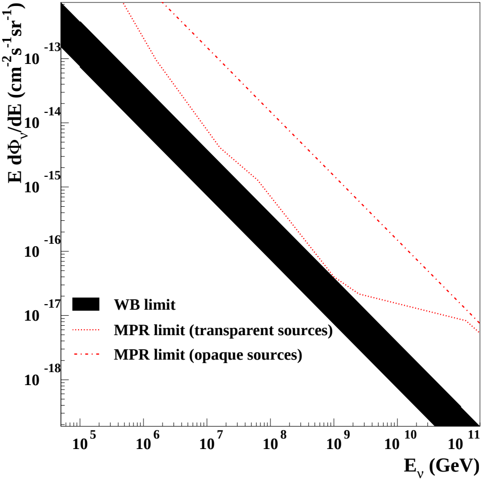


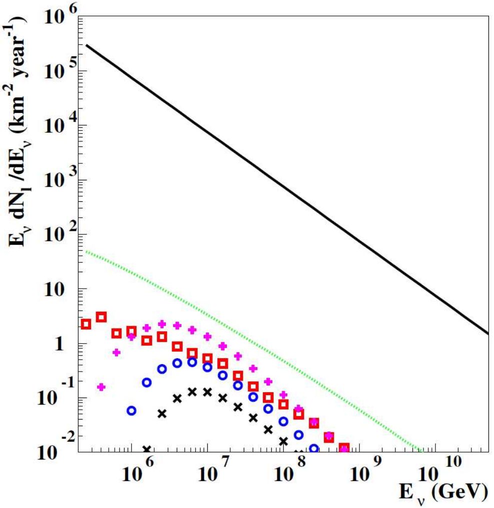
Figure: I. F. M. Albuquerque et al, arXiv:0803.3479v1[hep-ph]

Direct detection

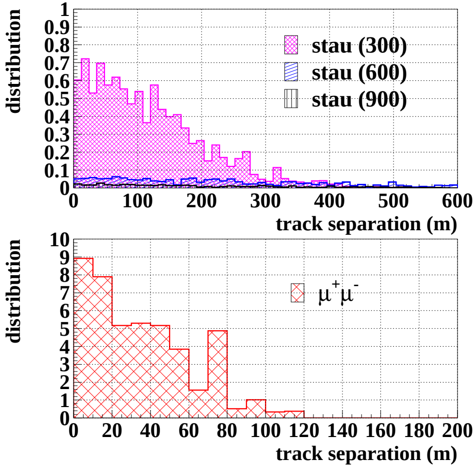
Direct detection – Energy spectrum

$\tilde{l}_R$ pair events per km^2, per year, at the detector. Curves that do not reach y axis; from top to bottom: $m_{\tilde{q}} = 300$, 600 and 900 GeV. Here, $m_{\tilde{l}_R} = 150$ GeV and $m_{\tilde{w}} = 250$ GeV. Also shown are the neutrino flux at earth and the μ and the di-muon flux through the detector (curves that reach y axis; from top to bottom respectively). In all cases we make use of the WB limit for the neutrino flux.

Figure: I. F. M. Albuquerque, et al, Physical Review D **75**, 035006 (2007).



For track separations above 100 m there should not be any significant contribution from the di-muon background.



The relative normalization corresponds to the relative number of events for signal and background. Note the different horizontal scales, as well as different binning between the two figures.

Figure: I. F. M. Albuquerque, et al, Physical Review D **75**, 035006 (2007).

Indirect detection of NLSPs

Indirect detection of NLSPs

Now: considering the $\tilde{\tau}$ decay

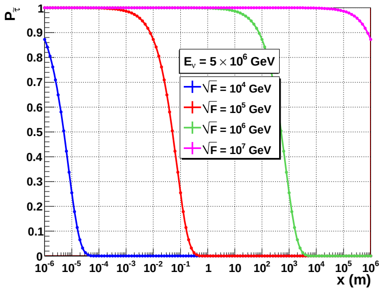
$\tilde{\tau}$ decay $\longrightarrow \tau +$ gravitino

τ regeneration:

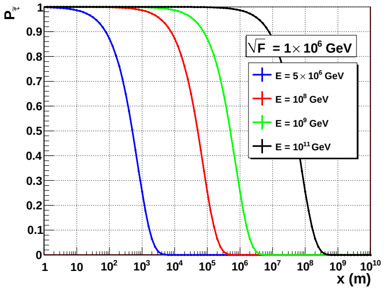
τ decay $\longrightarrow \nu_\tau + \mathrm{X}$

$\nu_\tau \, \mathrm{N} \xrightarrow{cc} \tau + \mathrm{X}$

$\tilde{\tau}$ survival probability (decay)



Different $\sqrt{F}$ (energy fixed).

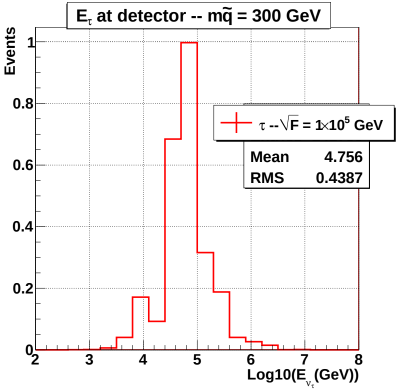


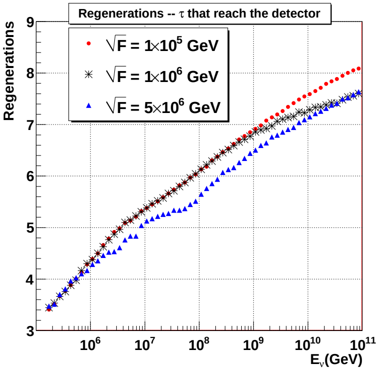
Different energies ($\sqrt{F}$ fixed).

IceCube

IceCube

τ energy at the detector and number of τ regenerations

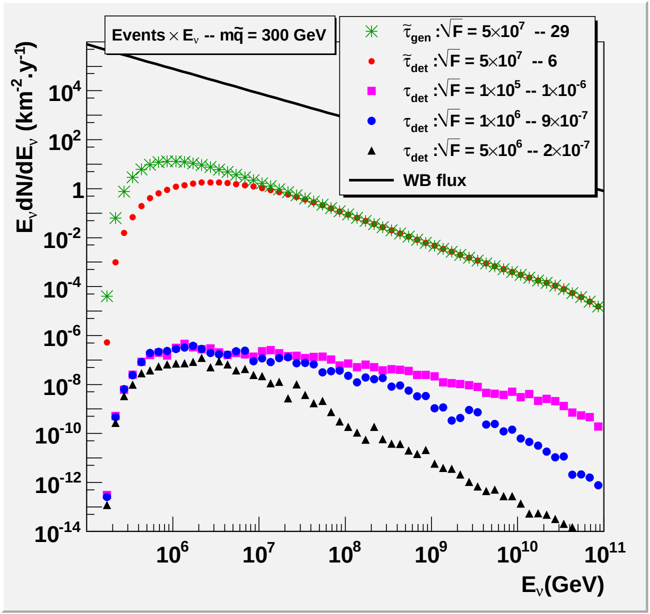




τ's flux at IceCube

$\sim 10^{-6}$ events

$\times$ km^{-2} $\times$ $year^{-1}$



Euso ($\sim 2 \times 10^5\ km^2$)

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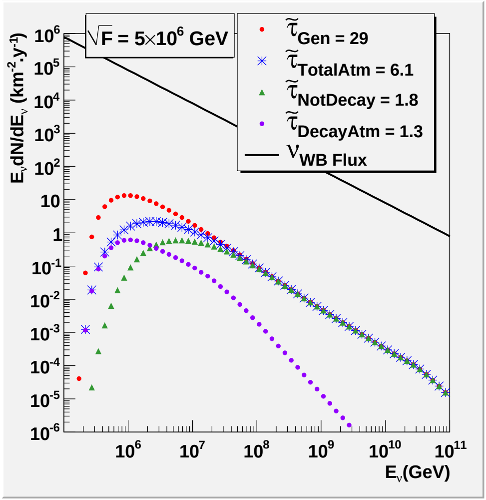
$\tilde{\tau}$ and τ at the atmosphere



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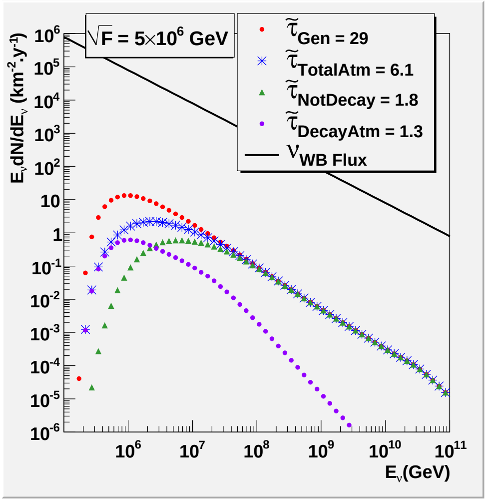


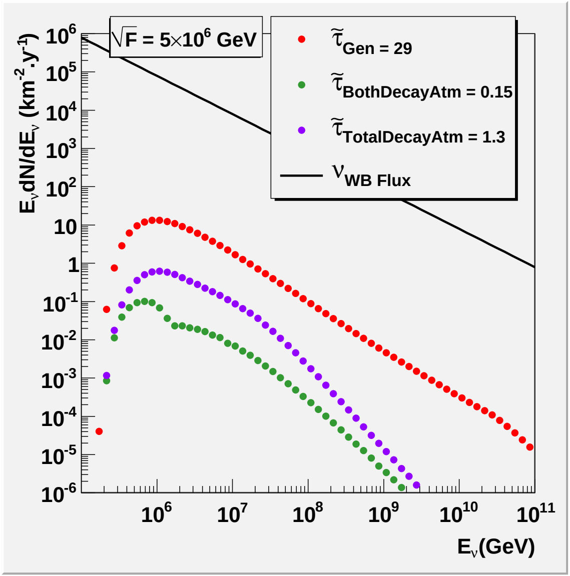
Problem: air fluorescence is related to the number of charged particles (N_e):

$$\frac{dN}{dx} = N_f N_e,$$

$N_f \sim 4.8$ photons $\times$ m^{-1} $\times$ (charged particle)$^{-1}$

$N_e \;=\; 1, 2$ ($\tilde{\tau}$ case)

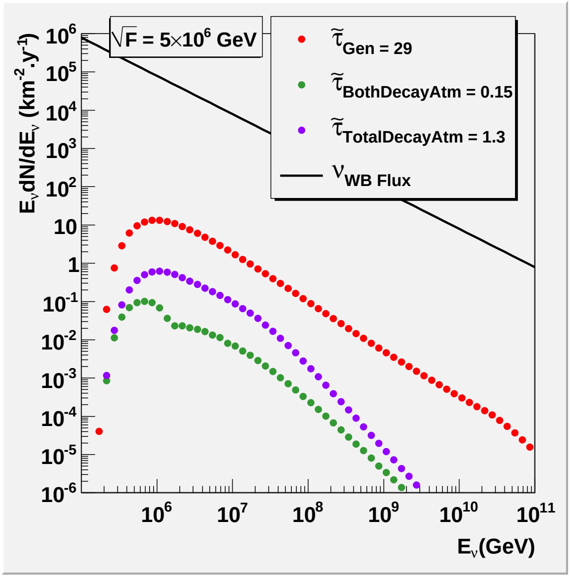
Checking the τ produced at the atmosphere:



Checking the τ produced at the atmosphere:

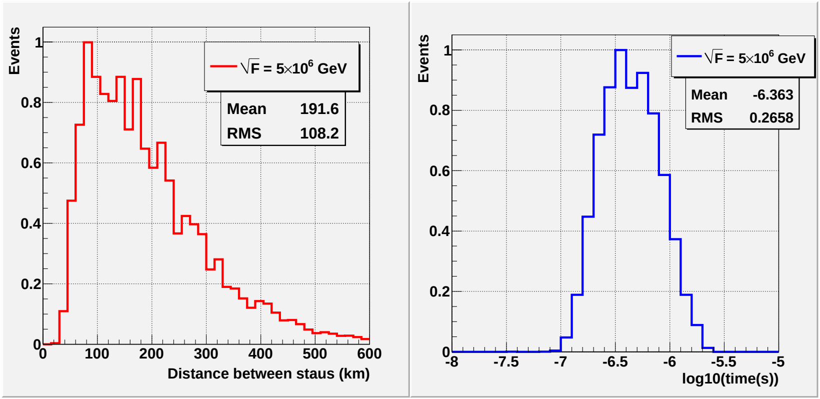
Flux with a good number of detectable showers:

$\sim 3 \times 10^4$ events $\times$ year^{-1} for the coincidence case.



$\tilde{\tau}$ pair decaying coincidently at the atmosphere

Distance between showers $\Rightarrow$ distinguishable signal with acceptable timming.



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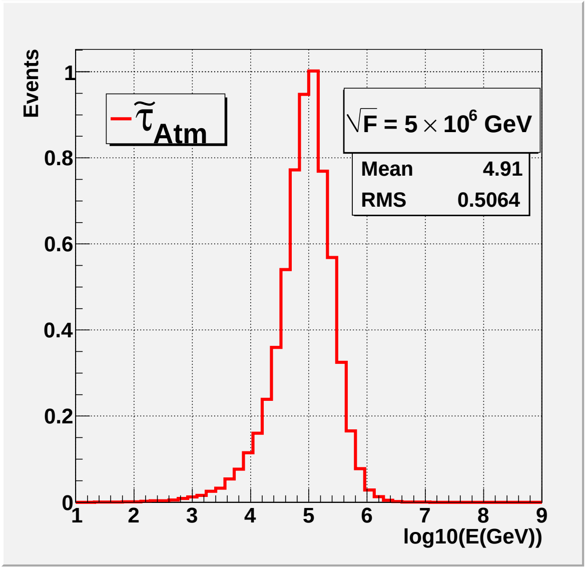
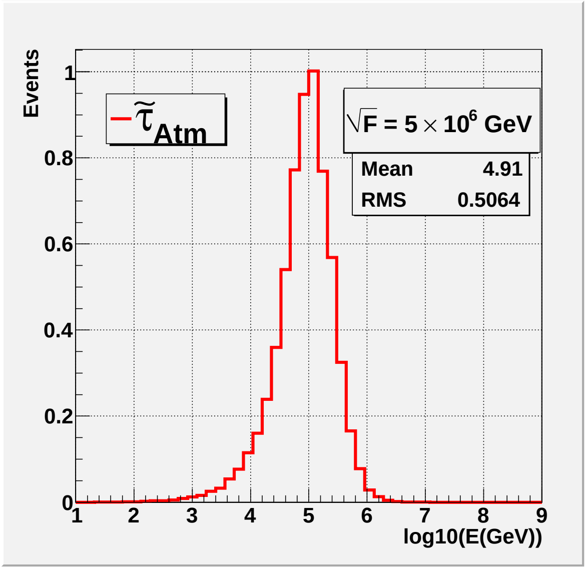


But, there is still a problem:

The (s)tau energy at the atmosphere is too low when compared with the detector threshold.



Conclusions

- The flux of τ (from $\tilde{\tau}$) at IceCube is too low. So, if the $\sqrt{F}$ is lower than $\sim 10^7$ GeV, the NLSP detection with this detector it is not possible;
- The number of showers produced at the atmosphere is enough for a detector with an area like the Euso's. The limitation is the energy threshold. Maybe a different experiment?

Thanks!