What else can we learn about Dark Matter from neutrino telescopes?

Beatriz Cañadas del Río

Departamento de Física Teórica and Instituto de Física Teórica
UAM - CSIC
INFN - Roma Tor Vergata

March 2010

Based on work in collaboration with

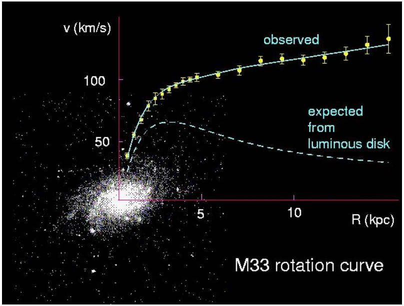
D.G.Cerdeño, C.Muñoz and S.Panda

Outline

The Dark Matter problem

- 85% of the matter density of the Universe is made of some kind of non-luminous dark matter (DM) whose nature is still unknown.

- Evidence of DM comes from gravitational effects observed both at galactic and extragalactic scales.



- Astrophysical bounds,

$$0.1 \lesssim \Omega_{DM} h^2 \lesssim 0.3$$

- WMAP bounds,

$$0.097 \lesssim \Omega_{DM} h^2 \lesssim 0.122$$

[J.Dunkley et al. WMAP 5 year]

Dark Matter Candidates

Baryonic Matter

- Cold gas in the Intergalactic Medium
- Massive Compact Halo Objects (MACHOs)
- Jupiter-like objects, black holes...

Inconsistent with Big Bang Nucleosynthesis

Non-baryonic Matter

- Neutrinos were also proposed as Dark Matter candidate

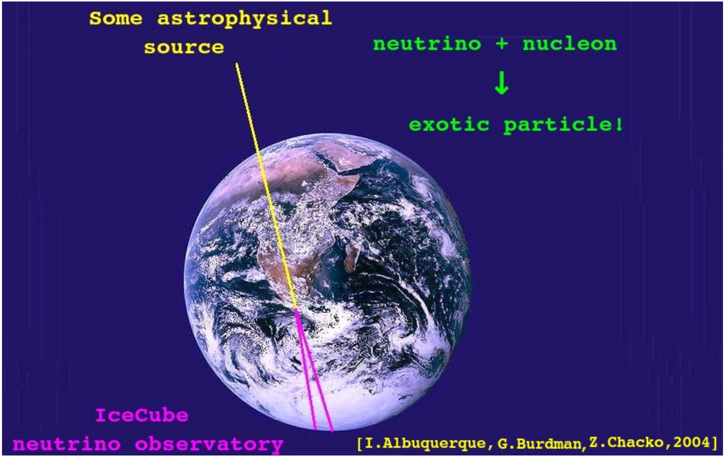
Hot Dark Matter implies different formation of large scale structures

Dark Matter Candidates

Beyond the Standard Model of Particle Physics

- Weakly Interacting Massive Particles (WIMPs)
  - Lightest Supersymmetric Particle
  - Lightest Kaluza Klein Particle
- Extra Weakly Interacting Massive Particles (e-WIMPS)
  - Supersymmetric Gravitino
  - Axion, Axino

What can we learn from Neutrino Telescopes?



Introduction

- Supersymmetry provides very well motivated candidates for dark matter which also allow long-lived NLSPs

The lightest neutralino

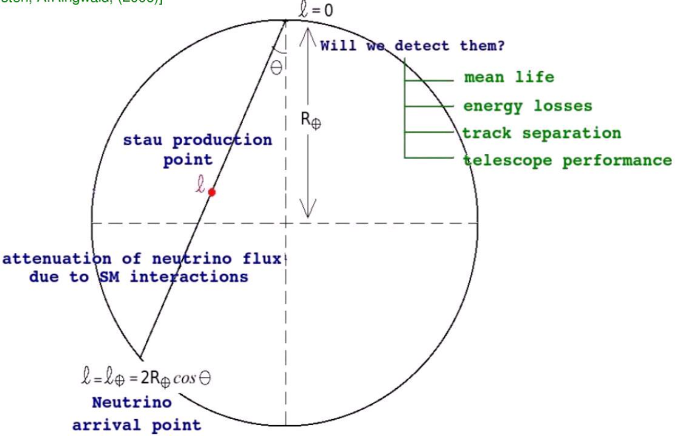
Stau NLSP in coannihilation region

The gravitino

Stau NLSP always long-lived

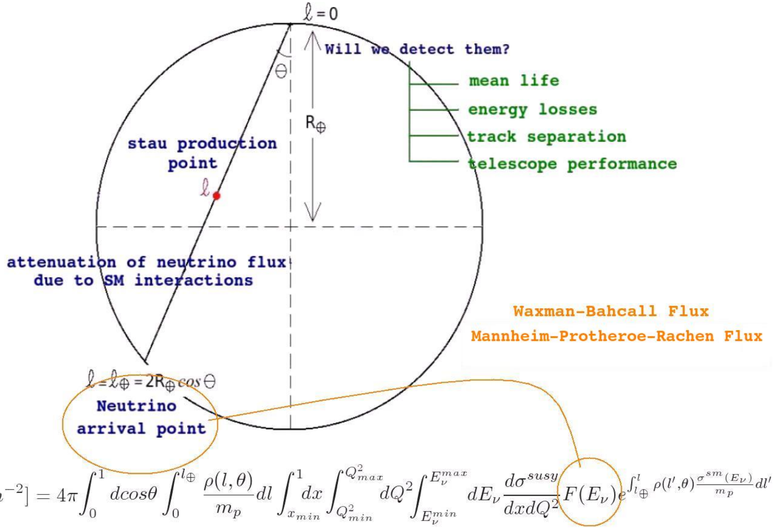
Detection rate

[I.Albuquerque, G.Burdman, Z.Chacko, (2004)]
[M.Ahlers, J.Kersten, A.Ringwald, (2006)]



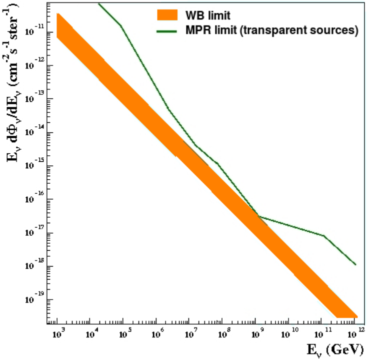
$$N[yr^{-1}][km^{-2}] = 4\pi \int_0^1 dcos\theta \int_0^{l_\oplus} \frac{\rho(l,\theta)}{m_p} dl \int_{x_{min}}^1 dx \int_{Q^2_{min}}^{Q^2_{max}} dQ^2 \int_{E_\nu^{min}}^{E_\nu^{max}} dE_\nu \frac{d\sigma^{susy}}{dx dQ^2} F(E_\nu) e^{\int_{l_\oplus}^{l} \rho(l',\theta) \frac{\sigma^{sm}(E_\nu)}{m_p} dl'}$$

Neutrino flux



$$N[yr^{-1}][km^{-2}] = 4\pi \int_0^1 dcos\theta \int_0^{l_\oplus} \frac{\rho(l,\theta)}{m_p} dl \int_{x_{min}}^1 dx \int_{Q^2_{min}}^{Q^2_{max}} dQ^2 \int_{E_\nu^{min}}^{E_\nu^{max}} dE_\nu \frac{d\sigma^{susy}}{dxdQ^2} F(E_\nu) e^{\int_{l_\oplus}^{l} \rho(l',\theta) \frac{\sigma^{sm}(E_\nu)}{m_p} dl'}$$

Neutrino flux



[I.Albuquerque, J.Lamoreux, G.F.Smoot (2002)]

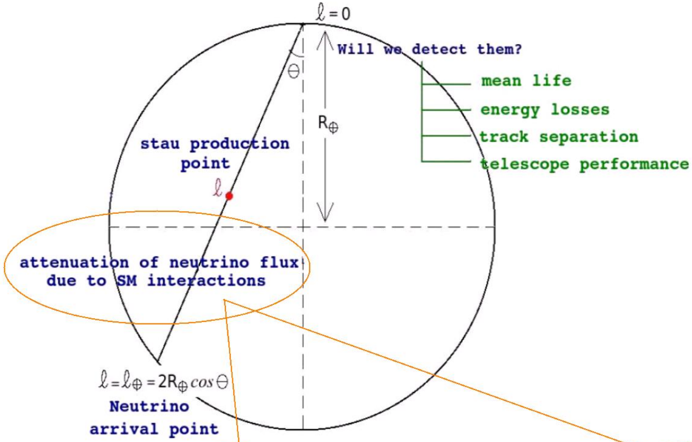
Waxman-Bahcall estimation

- Energy escaping astrophysical sources ≈ equally distributed between CRs γs and νs.
- Waxman and Bahcall placed a bound on the neutrino flux assuming a cosmic ray power spectrum $\propto E^{-2}$.

Mannheim-Protheroe-Rachen estimation

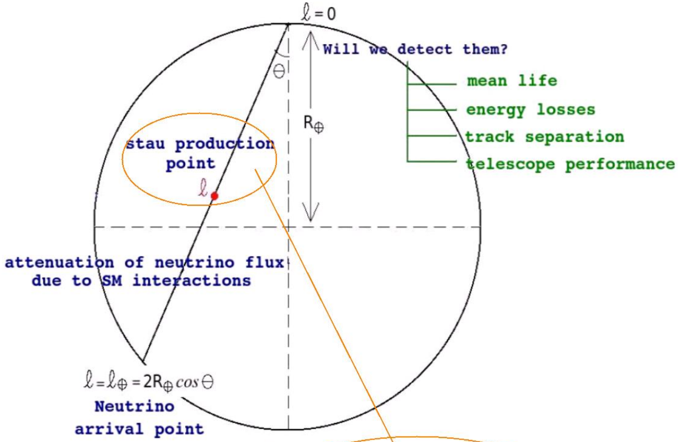
- They considered the same argument but a cosmic ray spectrum based on data at each energy.

Neutrino flux



$$N[yr^{-1}][km^{-2}] = 4\pi \int_0^1 dcos\theta \int_0^{l_\oplus} \frac{\rho(l,\theta)}{m_p} dl \int_{x_{min}}^1 dx \int_{Q^2_{min}}^{Q^2_{max}} dQ^2 \int_{E_\nu^{min}}^{E_\nu^{max}} dE_\nu \frac{d\sigma^{susy}}{dxdQ^2} F(E_\nu) e^{\int_{l_\oplus}^{l} \rho(l',\theta)\frac{\sigma^{sm}(E_\nu)}{m_p} dl'}$$

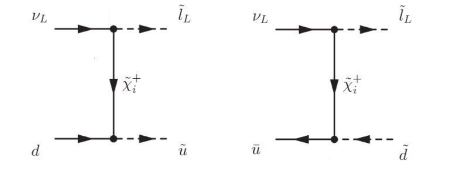
Stau production



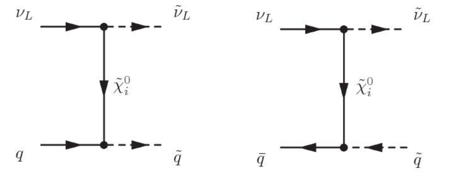
$$N[yr^{-1}][km^{-2}] = 4\pi \int_0^1 dcos\theta \int_0^{l_\oplus} \frac{\rho(l,\theta)}{m_p} dl \int_{x_{min}}^1 dx \int_{Q^2_{min}}^{Q^2_{max}} dQ^2 \int_{E_\nu^{min}}^{E_\nu^{max}} dE_\nu \frac{d\sigma^{susy}}{dxdQ^2} F(E_\nu) e^{\int_{l_\oplus}^{l} \rho(l',\theta)\frac{\sigma^{sm}(E_\nu)}{m_p}dl'}$$

Stau production

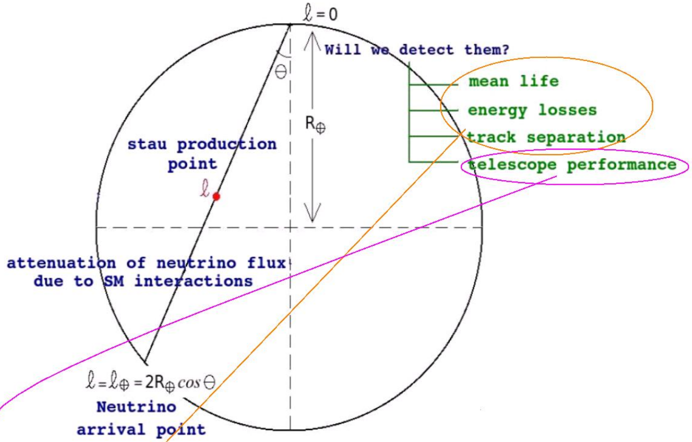
Chargino-mediated interactions



Neutralino-mediated interactions



Propagation and detection



$$N[yr^{-1}][km^{-2}] = 4\pi \int_0^1 dcos\theta \int_0^{l_\oplus} \frac{\rho(l,\theta)}{m_p} dl \int_{x_{min}}^1 dx \int_{Q^2_{min}}^{Q^2_{max}} dQ^2 \int_{E_\nu^{min}}^{E_\nu^{max}} dE_\nu \frac{d\sigma^{susy}}{dx dQ^2} F(E_\nu) e^{\int_{l_\oplus}^{l} \rho(l',\theta) \frac{\sigma^{sm}(E_\nu)}{m_p} dl'}$$

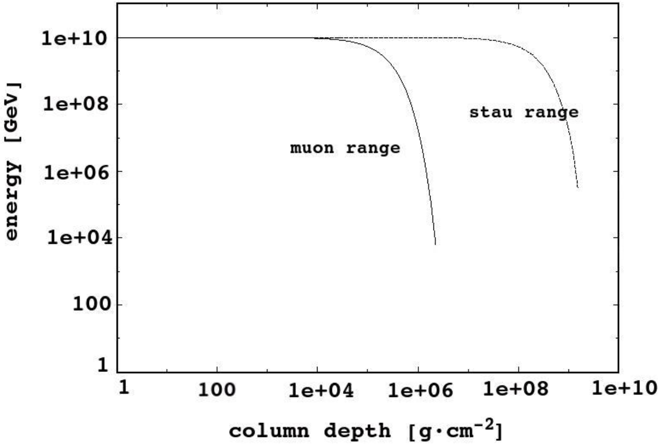
Energy losses

Average energy loss of a particle traversing a column depth Z

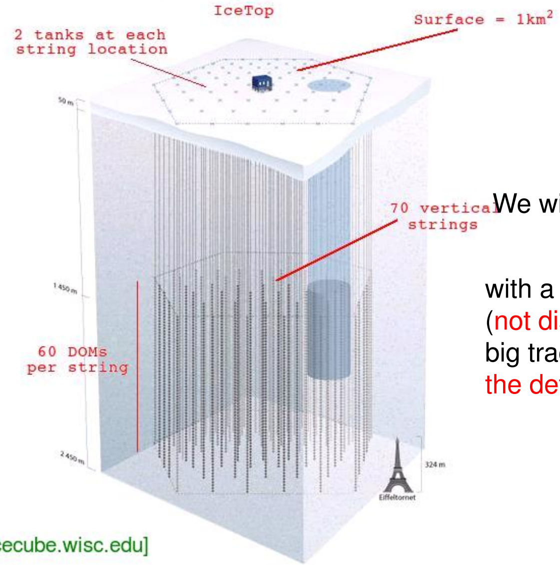
$$-\langle\frac{dE}{dZ}\rangle = \alpha + \beta E,$$

- α describes ionization energy losses
- β describes radiative energy loss. It depends on the mass of the particle and on its energy

β_μ is 3 orders of magnitude bigger than $\beta_{\tilde{\tau}}$ $\Rightarrow$ the muon range is much smaller.



Track separation



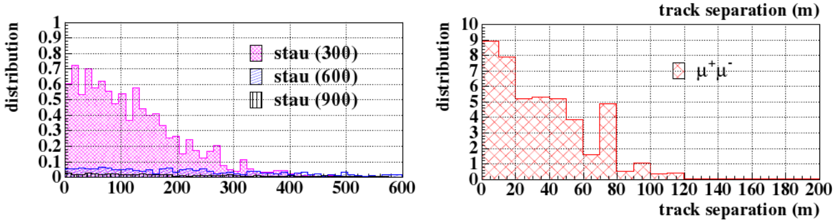
[icecube.wisc.edu]

We will discard particles arriving

with a too small track separation (not discriminated), and with a too big track separation (they will miss the detector).

Track separation

The separation of the two staus at the detector depends on the angle with which the two particles are produced, $\delta = \delta(Q^2,\ x,\ s)$, and on the point at which they are produced.



[I.Albuquerque, G.Burdman & Z.Chacko (2006)]

Framework

CMSSM parameters

- Universal scalar masses: m_0
- Universal gaugino masses: $M_{1/2}$
- Universal trilinear couplings: A_0
- $\tan\beta$
- $|\mu|^2$ fixed once EW symmetry breaking is imposed, but sign remains free

... + SUGRA

- Gravitino mass: $m_{\tilde{G}}$

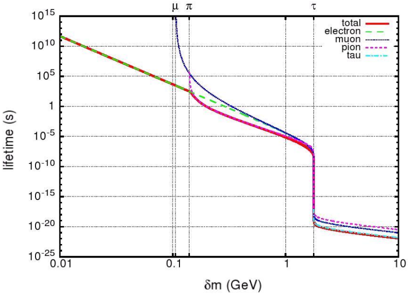
Framework

Experimental constraints

- Bounds on the Higgs mass
- Bounds on masses of supersymmetric particles
- Branching ratios of processes like $b \to s\gamma$, $B_s \to \mu^+\mu^-$, etc.

Neutralino LSP scenario

The mean life of the stau depends on $\delta m = m_{\tilde{\tau}} - m_{\chi}$



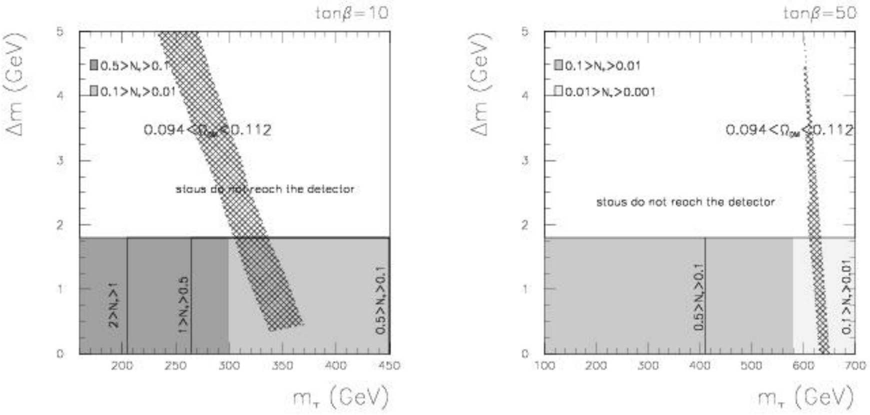
[T.Jittoh, J.Sato, T.Shimomura, M.Yamanaka, (2006)]

Note that the range of a particle

$$l = \gamma c\tau = \frac{E}{m} c\tau \quad \Rightarrow \tau_{min} \approx 10^{-9} s \quad \delta m_{max} \approx 2\ GeV$$

Very restrictive requirement!

Neutralino Results



[arXiv:0812.1067]

Gravitino LSP scenario

Long-lived staus

The stau is ensured to be long-lived in this case,

$$\tau_{\tilde{\tau}} \approx \Gamma^{-1}(\tilde{\tau} \to \tilde{G}\tau) = 48\pi M_P^2 \frac{m_{\tilde{G}}^2}{m_{\tilde{\tau}}^5} \left(1 - \frac{m_{\tilde{G}}^2}{m_{\tilde{\tau}}^2}\right)^{-4}$$

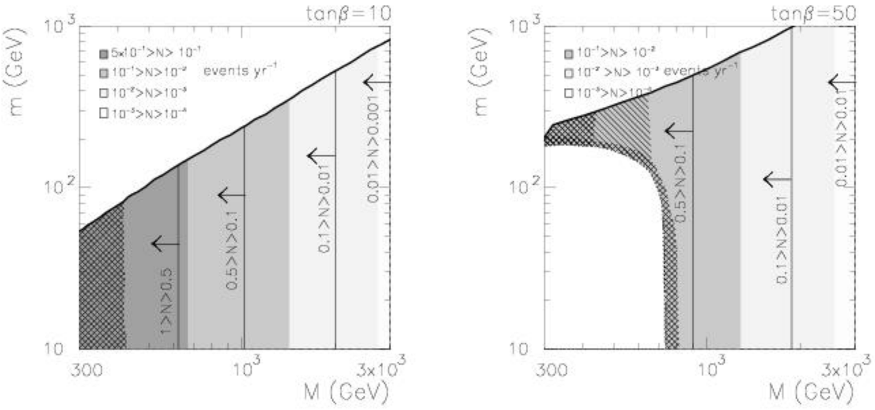
Gravitino LSP scenario

Additional Constraints

- NLSP decay to LSP produces electromagnetic + hadronic showers. If these decays take place after BBN, the products of the showers may alter abundances of light elements.
- Late injection of electromagnetic energy may distort the frequency dependence of the CMB
- Metastable charged particles may form bound states with light nuclei, enabling catalyzed BBN
  sorted out imposing $\tau_{\tilde{\tau}} < 5 \times 10^3$s

[M.Pospelov (2007)]

Gravitino Results



[arXiv:0812.1067]

Gravitino mass and reheating temperature

- To sort out limits on stau lifetime imposed by catalyzed BBN, the mass of the gravitino is constrained by an upper limit,

$$m_{\widetilde{G}} \leq 0.28 \left(\frac{m_{\widetilde{\tau}}}{100\,\mathrm{GeV}} \right)^{5/2} \mathrm{GeV}\,,$$

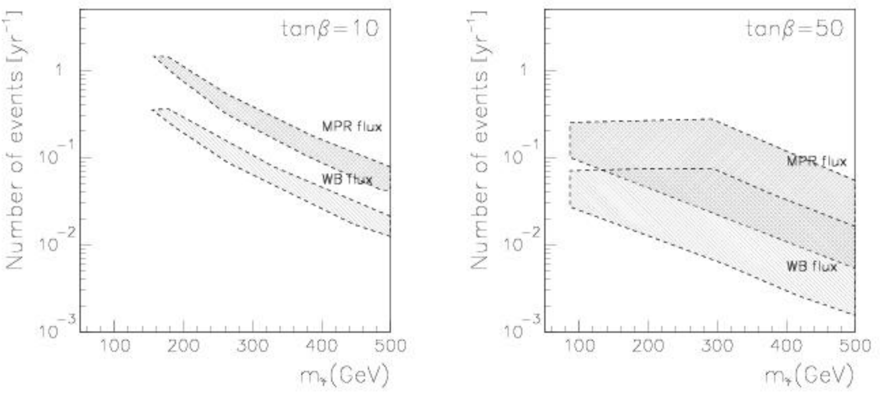
- The relic density is fully dominated by thermal production,

$$\Omega^{TP}_{m_{\widetilde{G}}} h^2 \approx 0.27 \left(\frac{T_R}{10^{10}\,\mathrm{GeV}} \right) \left(\frac{100\,\mathrm{GeV}}{m_{\widetilde{G}}} \right) \left(\frac{m_{\widetilde{g}}(\mu)}{1\,\mathrm{TeV}} \right)^2 ,$$

- Appropriate relic density can be recovered by an appropriate choice of the reheating temperature,

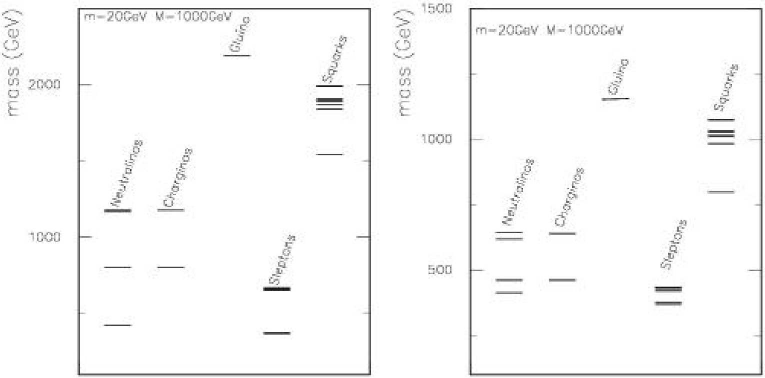
$$T_R \lesssim 5.2 \times 10^7 \left(\frac{m_{\widetilde{\tau}}}{100\,\mathrm{GeV}} \right)^{1/2} \mathrm{GeV}.$$

Number of pairs vs. stau mass

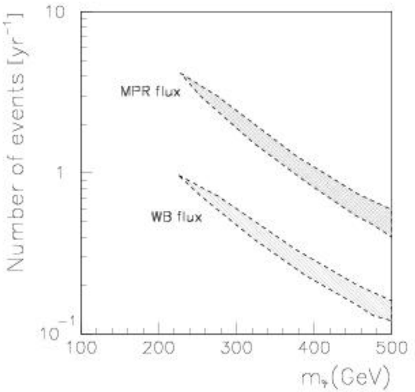


[arXiv:0812.1067]

Relaxing Universality Conditions



Relaxing Universality Conditions



[arXiv:0812.1067]

Conclusions

Neutralino LSP

- We need very tight degeneration between the stau and the neutralino in order to have a flux of staus arriving at IceCube telescope.
- Additionally, we need staus to be light for these fluxes to be observable.
- However, for the explored areas of the parameter space, this degeneration is only compatible with a correct Dark Matter relic abundance for high stau masses.

Gravitino LSP

DM relic density can be recovered in areas with higher stau flux by an appropriate choice of gravitino mass and reheating temperature.