The Passage of Ultrarelativistic Neutralinos through Matter

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based on `hep-ph/0603162`

Outline

1. Introduction/Motivation
2. Transport equations
3. Event rates
4. Summary

Experiments...

- have shown the existence of ultra high energy (UHE) cosmic rays with $E \gtrsim 10^{11}$ GeV
- indicate that most UHE events are caused by protons

Protons with $E \gtrsim 5 \cdot 10^{10}$ GeV lose energy through inelastic scattering:

$$\begin{aligned} p + \gamma_{2.7K} &\rightarrow n + \pi^+ \\ &\rightarrow p + \pi^\circ \end{aligned} \quad \Longrightarrow \quad \text{proton energy loss length} \sim 50 \text{ Mpc} \quad \Longrightarrow \text{local sources}$$

Problems:

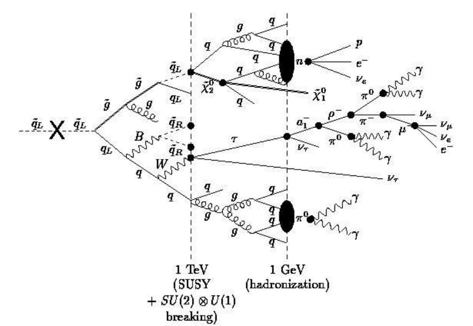
- there are no known local sources
- arrival directions of UHE are homogeneously distributed
- existence of objects which have sufficiently large $B \cdot L$

One possible solution: Top-Down Models (TDMs)

- existence and decay of very massive, long-lived X-particles ($M_X > 10^{12} GeV$) $\Rightarrow$ UHE events
- X-particles could be associated with a Grand Unified Theory

Signature for Top-Down Models

Decay chain in the framework of R-parity conserving SUSY:



(M.Drees and C.Barbot)

Stable particles:

- photons
- neutrinos ν
- electrons
- protons
- neutralinos $\tilde{\chi}_1^0$(LSPs)

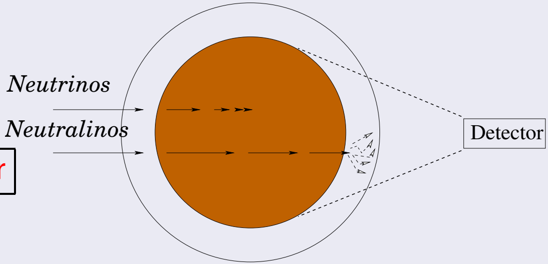
$\Rightarrow$"smoking gun" for TDMs: Detection of $\tilde{\chi}_1^0$

Discrimination between ν and $\tilde{\chi}_1^0$?$\Rightarrow$

Possible measurement method for $\tilde{\chi}_1^0$:

Cross section for $\tilde{\chi}_1^0$ interactions with matter is smaller than that of ν

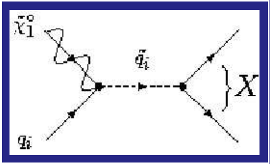
$\Rightarrow$ Using the Earth as a filter



Necessary tools:

- calculation of total & differential cross section ($\Rightarrow$ hep-ph/0603162)
- solution of the transport equations
- calculation of event rates

Transport equation for $s-$channel scattering (bino-dominated $\tilde{\chi}_1^0$)



$$\frac{\partial F_{\tilde{\chi}_1^0}(E,X)}{\partial X} = \underbrace{-\frac{F_{\tilde{\chi}_1^0}(E,X)}{\lambda_{\tilde{\chi}_1^0}(E)}}_{\text{decrease}} + \underbrace{\frac{1}{\lambda_{\tilde{\chi}_1^0}(E)} \int_0^{y_{\max}} \frac{dy}{1-y} K_s(E,y) F_{\tilde{\chi}_1^0}(E_y,X)}_{\text{increase due to } \tilde{\chi}_1^0+q_i\to\tilde{\chi}_1^0+q_i},$$

$F_{\tilde{\chi}_1^0}(E,X)$: differential $\tilde{\chi}_1^0$ flux where
E: $\tilde{\chi}_1^0$ energy and
X: matter depth.
$\lambda_{\tilde{\chi}_1^0}(E)^{-1} = N_A \sigma^{\text{tot}}_{\tilde{\chi}_1^0 N}(E)$: interaction length
$K_s(E,y) = \sigma_s^{\text{tot}}(E)^{-1} d\sigma_s(E_y)/dy$: kernel
$E_y : E/(1-y)$

mSUGRA scenario with $m_{\tilde{g}} > m_{\tilde{q}} \Longrightarrow$
$\sigma_s^{\text{tot}}(\tilde{\chi}_1^0 + q_i \to X) \approx$
$\sigma_s^{\text{tot}}(\tilde{\chi}_1^0 + q_i \to \tilde{\chi}_1^0 + q_i)$

Solution method...

based on the first order Taylor expansion:

$$F_{\tilde{\chi}_1^0}(E, X + dX) = F_{\tilde{\chi}_1^0}(E, X) + dX \frac{\partial F_{\tilde{\chi}_1^0}(E, X)}{\partial X} + \cdots \text{ where}$$

the boundary condition $F_{\tilde{\chi}_1^0}(E, 0)$ is given by the incident $\tilde{\chi}_1^0$ flux (e.g. SHdecay: hep-ph/0211406).

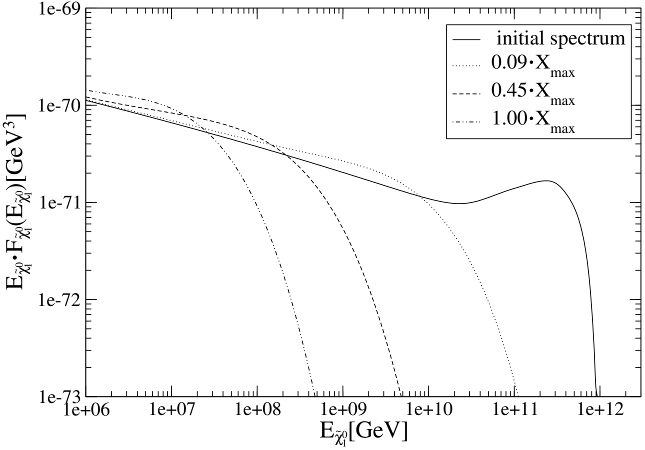
Check of the results:

For s- and t-channel: $\tilde{\chi}_1^0 + q_i \to \cdots \to \tilde{\chi}_1^0 + X$

$\Longrightarrow \Phi_{\tilde{\chi}_1^0} = \int_{m_{\tilde{\chi}_1^0}}^{E_{\rm max}} F_{\tilde{\chi}_1^0}(E, X) = \text{const.}$

- $F_{\tilde{\chi}_1^0}(E, 0) = 0$ for $E > E_{max}$
- independent of X

Transport equation for s−channel scattering (bino-dominated $\tilde{\chi}_1^0$)

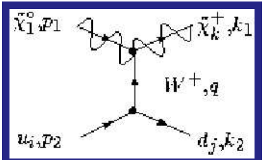


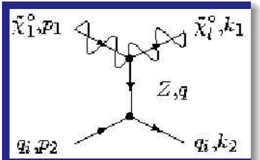
x_{max} : maximal column depth of the earth

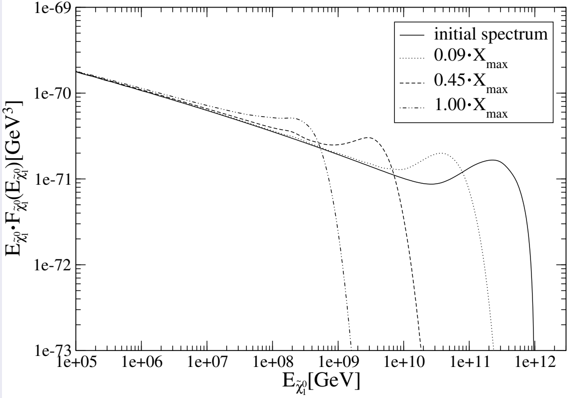
$\frac{X}{X_{\max}}$	$\frac{\Phi_{\tilde{\chi}_1^0}(X)}{\Phi_{\tilde{\chi}_1^0}(0)}$
0.09	1.000
0.45	1.000
1.00	1.001

(integrated from 10^3 to 10^{12} GeV)

Transport equation for $t-$channel scattering (higgsino-dominated $\tilde{\chi}_1^0$)







x_{max} : maximal column depth of the earth

$\frac{X}{X_{\max}}$	$\frac{\Phi_{\tilde{\chi}_1^0}(X)}{\Phi_{\tilde{\chi}_1^0}(0)}$
0.09	1.002
0.45	1.002
1.00	1.004

(integrated from 10^5 to 10^{12} GeV)

Event rates...

can be calculated with the help of $F_{\tilde{\chi}_1^0}(E, X)$. For the s-channel:

$$N = \int_{E_{\min}}^{E_{\max}} dE_{\mathrm{vis}} \int_{X_{\min}}^{X_{\max}} dX \int_0^{y_{\max}} \frac{dy}{y} \frac{d\sigma_s(\frac{E_{\mathrm{vis}}}{y})}{dy} F_{\tilde{\chi}_1^0}(\frac{E_{vis}}{y}, X) V_{\mathrm{eff}} \epsilon_{dc} t$$

V_{eff}: w.e. effective volume

ϵ_{dc}: duty cycle

t: measurement period

Event rates s-channel			
$E_{\tilde{\chi}_1^0} \geq 10^6$ GeV, $m_X = 10^{12}$ GeV	N_{D1}	N_{D2}	N_{D3}
$q\bar{q}$	0.0176	0.0175	0.0110
$q\tilde{q}$	0.0405	0.0440	0.0324
$l\tilde{l}$	0.1067	0.1487	0.1460
$5 \times q\tilde{q}$	0.4091	0.4168	0.2719

Event rates t-channel		
$E_{\tilde{\chi}_1^0} \geq 10^6$ GeV, $m_X = 10^{12}$ GeV	$N_{\tilde{\chi}_1^0}$	N_{ν_τ}
$q\bar{q}$	0.51	0.36
$q\tilde{q}$	1.63	0.65
$l\tilde{l}$	23.03	1.31
$5 \times q\tilde{q}$	13.71	4.14

- integrated from 10^6 to 10^{12} GeV
- target volume: 1Tt
- m. period: 1y
- duty cycle: 10%

Summary:

- there are cosmic rays with $E \gtrsim 10^{11}$ GeV
- possible explanation within the scope of TDMs
- detection of $\tilde{\chi}_1^0$ would be a "smoking gun" for TDMs
- detection of $\tilde{\chi}_1^0$ might be possible with aid of future satellite experiments