The Passage of Ultrarelativistic Neutralinos through Matter

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SUSY08, Seoul

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based on `hep-ph/0603162` and `0704.3934`

Outline

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:

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

Questions:

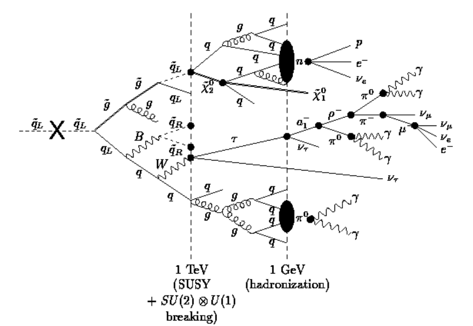
- B.-U. models: are there objects which have sufficiently large $B \cdot L$?
- are the arrival directions of UHE events homogeneously distributed? $\Rightarrow$ exclusion of one or a few local point sources
- are there local sources? AUGER indicates correlation between nearby AGNs and the origin of UHE events (arXiv: 0712.2843)

One possible source: 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)

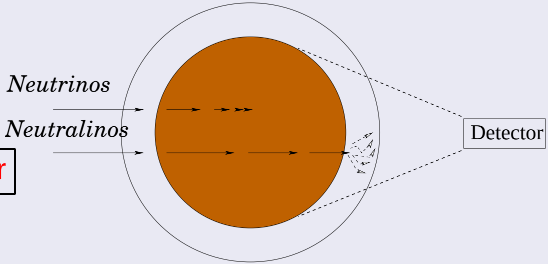
$\Rightarrow$"smoking gun" for TDMs:
Detection of $\tilde{\chi}_1^0$

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

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

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

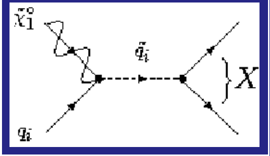
⇒ Using the Earth as a filter



Necessary tools:

- calculation of total & differential cross section (⇒ 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).

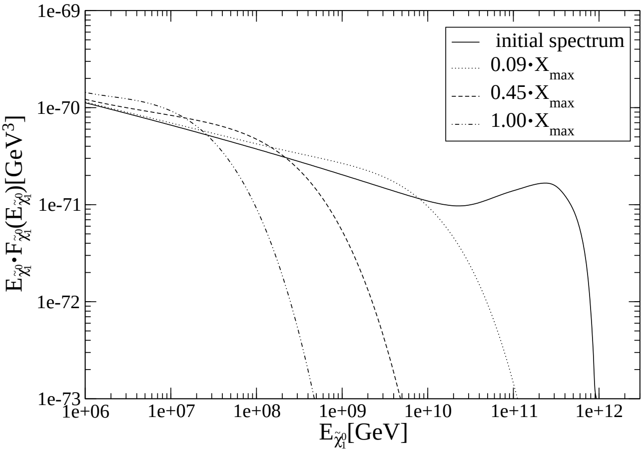
Check of the results:

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

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

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

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

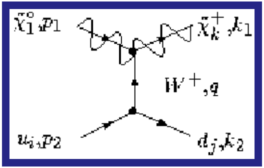


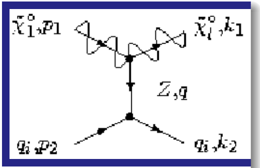
x_{max} : maximal column depth of the Earth

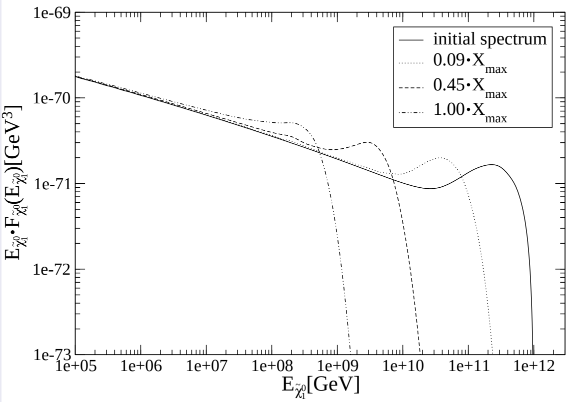
$\frac{X}{X_{\max}}$	$\frac{\Phi_{\tilde{\chi}_1^0}(X)}{\Phi_{\tilde{\chi}_1^0}(0)}$
0.09	1.000
0.45	1.000
1.00	1.001

(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 example, the neutralino event rates for the s-channel are given by:

$$N = \int_{E_{\rm min}}^{E_{\rm max}} dE_{\rm vis} \int_{X_{\rm min}}^{X_{\rm max}} dX \int_0^{y_{\rm max}} \frac{dy}{y} \frac{d\sigma_s(\frac{E_{\rm vis}}{y})}{dy} F_{\tilde{\chi}_1^0}(\frac{E_{vis}}{y}, X)\mathcal{V}$$

$\mathcal{V} \propto V_{\rm eff}\epsilon_{dc}t$, where

$V_{\rm eff}$: w.e. effective volume,

ϵ_{dc}: duty cycle,

t: measurement period.

However: One will need at least teraton scale targets to detect neutralinos...

Future satellite experiments

- EUSO: stay on the ISS; monitors a surface area of $\mathcal{O}(10^5)$ km^2 $\Rightarrow$ target volume of $\approx$ 2.4 teratons
- OWL: two satellites; monitors a surface area of $\mathcal{O}(10^6)$ km^2 $\Rightarrow$ target volume of $\approx$ 10.0 teratons

Event rates for higgsino–like $\tilde{\chi}_1^0$

$E_{vis} \geq 10^6$ GeV, $M_X = 10^{12}$ GeV	$N_{\tilde{\chi}_1^0}$	N_{ν_τ}
$q\bar{q}$	0.19	3.87
$q\tilde{q}$	0.58	7.04
$l\tilde{l}$	7.37	14.17
$5 \times q\tilde{q}$	4.97	45.00

$E_{vis} \geq 10^9$ GeV, $M_X = 10^{12}$ GeV	$N_{\tilde{\chi}_1^0}$	N_{ν_τ}
$q\bar{q}$	0.0089	0.0001
$q\tilde{q}$	0.0608	0.0001
$l\tilde{l}$	2.5121	0.0003
$5 \times q\tilde{q}$	0.2624	0.0006

$E_{vis} \geq 10^6$ GeV, $M_X = 10^{16}$ GeV	$N_{\tilde{\chi}_1^0}$	N_{ν_τ}
$q\bar{q}$	0.0105	0.4448
$q\tilde{q}$	0.0078	0.3079
$l\tilde{l}$	0.0063	0.2917
$5 \times q\tilde{q}$	0.0124	0.4940

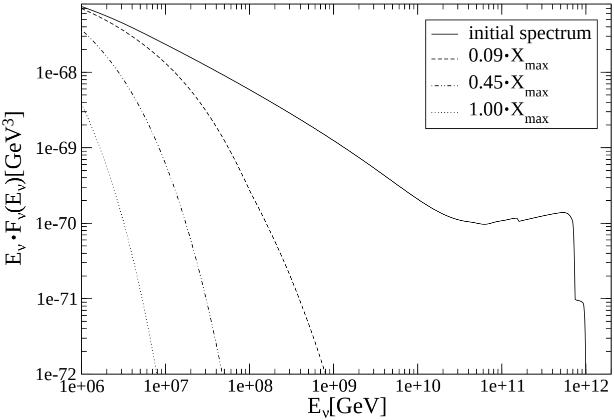
$E_{vis} \geq 10^9$ GeV, $M_X = 10^{16}$ GeV	$N_{\tilde{\chi}_1^0}$	N_{ν_τ}
$q\bar{q}$	0.000927	0.000007
$q\tilde{q}$	0.001258	0.000005
$l\tilde{l}$	0.001735	0.000005
$5 \times q\tilde{q}$	0.001807	0.000005

Parameters of the given results:

- target volume: 10Tt
- m. period: 1y
- duty cycle: 10%

Detectable if:

- mass of X particle close to its lower bound
- large ratio of neutralino and proton fluxes
- experiment must be able to detect Cerenkov light



Event rates for higgsino–like $\tilde{\chi}_1^0$		
$E_{\text{vis}} \geq 2 \cdot 10^7$ GeV, $M_X = 10^{12}$ GeV	$N_{\tilde{\chi}_1^0}$	N_{ν_τ}
$q\bar{q}$	0.10	0.18
$q\tilde{q}$	0.35	0.03
$l\tilde{l}$	5.41	0.67
$5 \times q\tilde{q}$	2.78	1.80

Higher lower bound for E_{vis} leads to higher reduction of $\tilde{\chi}_1^0$ fluxes compared to ν fluxes due to the softer neutrino spectra.

Event rates for bino–like $\tilde{\chi}_1^0$

$E_{\rm vis} \geq 10^6$ GeV, $M_X = 10^{12}$ GeV	N_{D1}	N_{D2}	N_{D3}
$q\bar{q}$	0.055	0.039	0.017
$q\tilde{q}$	0.130	0.099	0.051
$l\tilde{l}$	0.805	0.796	0.586
$5 \times q\tilde{q}$	1.294	0.944	0.434
$E_{\rm vis} \geq 10^9$ GeV, $M_X = 10^{12}$ GeV	N_{D1}	N_{D2}	N_{D3}
$q\bar{q}$	0.0005	0.0034	0.0055
$q\tilde{q}$	0.0021	0.0142	0.0234
$l\tilde{l}$	0.0381	0.2551	0.4321
$5 \times q\tilde{q}$	0.0145	0.0992	0.1571
$E_{\rm vis} \geq 10^6$ GeV, $M_X = 10^{16}$ GeV	N_{D1}	N_{D2}	N_{D3}
$q\bar{q}$	0.0026	0.0020	0.0010
$q\tilde{q}$	0.0020	0.0015	0.0007
$l\tilde{l}$	0.0018	0.0018	0.0007
$5 \times q\tilde{q}$	0.0032	0.0024	0.0012

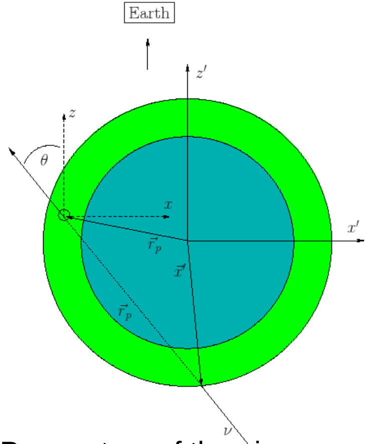
Squark masses:

- D1: 370 GeV
- D2: 580 GeV
- D3: 1000 GeV

Bino–like neutralino fluxes of many X decay scenarios remain invisible; even monitoring of the whole Earth's surface "only" leads to $V_{\rm eff}$ of 5000 teratons

Use of the Moon as a detector

- Moon's surface covered by regolith (homogeneous dielectric medium) up to a height of 10m
- UHE particles produce radio waves via Askarayan effect and the emission of Cerenkov light, respectively (Dagkesamanskii and Zheleznyk)



Event rates for ν and $\tilde{\chi}_1^0$		
$E_{\text{vis}} \geq 10^{10}$ GeV, $M_X = 10^{12}$ GeV	N_{total}^{ν}	$N_{\tilde{\chi}_1^0}$
$q\bar{q}$	2.46	0.10
$q\tilde{q}$	4.25	1.10
$l\tilde{l}$	65.04	60.10
$5 \times q\tilde{q}$	11.29	1.22
$E_{\text{vis}} \geq 10^{10}$ GeV, $M_X = 10^{16}$ GeV	N_{total}^{ν}	$N_{\tilde{\chi}_1^0}$
$q\bar{q}$	8.38	0.04
$q\tilde{q}$	5.52	0.05
$l\tilde{l}$	6.09	0.19
$5 \times q\tilde{q}$	4.97	0.07

Parameters of the given results:

- target volume: 320 Tt
- E threshold: 10^{10} GeV
- duty cycle: 40%

Summary:

- there are cosmic rays with $E \gtrsim 10^{11}$ GeV
- possible explanation within the scope of TDMs
- detection of $\tilde{\chi}_1^0$'s would be a "smoking gun" for TDMs
- detection of UHE $\tilde{\chi}_1^0$'s might be possible with aid of future satellite experiments like EUSO or OWL if:
  - neutralinos are higgsino–like
  - experiments can detect Cerenkov light
  - mass of X particle is near its lower bound
  - large ratio of neutralino and proton fluxes
- detection of UHE ν's and $\tilde{\chi}_1^0$'s might be possible through measurement of radio waves which are produced in the Moon's matter via the Askarayan effect