The Passage of Ultrarelativistic Neutralinos through Matter

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in collaboration with M. Drees

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:

\[
p + \gamma_{2.7K} \rightarrow n + \pi^+ \\
\rightarrow p + \pi^o \\
\]

proton energy loss length $\sim 50$ Mpc $\Rightarrow$ 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:

Stable particles:

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

$\Rightarrow$ “smoking gun” for TDMs: Detection of $\tilde{\chi}_1^0$
Discrimination between $\nu$ 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 $\nu$

⇒ 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

S. Bornhauser (University of Bonn)
Transport equation for s–channel scattering (bino-dominated $\tilde{\chi}_1^0$)

$$\partial F_{\tilde{\chi}_1^0}(E, X) \over \partial X = -{F_{\tilde{\chi}_1^0}(E, X) \over \lambda_{\tilde{\chi}_1^0}(E)} + \left[1 \over \lambda_{\tilde{\chi}_1^0}(E)\right] \int_0^{y_{\text{max}}} dy \left. K_s(E, y) F_{\tilde{\chi}_1^0}(E_y, X) \right|_{y_{\text{max}} = 0} \right.$$ 

decrease 

increase due to $\tilde{\chi}_1^0 + q_i \rightarrow \tilde{\chi}_1^0 + q_i$

$F_{\tilde{\chi}_1^0}(E, X)$: differential $\tilde{\chi}_1^0$ flux where

$E$: $\tilde{\chi}_1^0$ energy and

$X$: matter depth.

$\lambda_{\tilde{\chi}_1^0}(E)^{-1} = N_A\sigma_{\tilde{\chi}_1^0 N}^{\text{tot}}(E)$: 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 $m_{\tilde{g}} > m_{\tilde{q}} \implies$

$\sigma_s^{\text{tot}}(\tilde{\chi}_1^0 + q_i \rightarrow X) \approx$

$\sigma_s^{\text{tot}}(\tilde{\chi}_1^0 + q_i \rightarrow \tilde{\chi}_1^0 + q_i)$
Solution method...

based on the first order Taylor expansion:

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

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: \( \tilde{\chi}_1^0 + q_i \rightarrow \cdots \rightarrow \tilde{\chi}_1^0 + X \)

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

- \( F_{\tilde{\chi}_1^0}(E, 0) = 0 \) for \( E > E_{\text{max}} \)
- independent of \( X \)
Transport equation for s–channel scattering (bino-dominated $\tilde{\chi}_1^0$)

$x_{\text{max}}$: maximal column depth of the earth

<table>
<thead>
<tr>
<th>$X_{\text{max}}$</th>
<th>$\Phi_{\tilde{\chi}_1^0}(X)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.09</td>
<td>1.000</td>
</tr>
<tr>
<td>0.45</td>
<td>1.000</td>
</tr>
<tr>
<td>1.00</td>
<td>1.001</td>
</tr>
</tbody>
</table>

(integrated from $10^3$ to $10^{12}$ GeV)
Transport equation for $t$–channel scattering (higgsino-dominated $\tilde{\chi}^0_1$)

$x_{\text{max}}$ : maximal column depth of the earth

<table>
<thead>
<tr>
<th>$\frac{X}{X_{\text{max}}}$</th>
<th>$\frac{\Phi_{\tilde{\chi}^0_1}(X)}{\Phi_{\tilde{\chi}^0_1}(0)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.09</td>
<td>1.002</td>
</tr>
<tr>
<td>0.45</td>
<td>1.002</td>
</tr>
<tr>
<td>1.00</td>
<td>1.004</td>
</tr>
</tbody>
</table>

(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:

\[
N = \int_{E_{\text{min}}}^{E_{\text{max}}} dE_{\text{vis}} \int_{X_{\text{min}}}^{X_{\text{max}}} dX \int_{0}^{y_{\text{max}}} dy \frac{d\sigma_{s}(E_{\text{vis}})}{dy} F_{\tilde{\chi}_1^0}(E_{\text{vis}}/y, X) V_{\text{eff}} \epsilon_{dc} t
\]

\( V_{\text{eff}} \): w.e. effective volume

\( \epsilon_{dc} \): duty cycle

\( t \): measurement period

### Event rates s-channel

\( E_{\tilde{\chi}_1^0} \geq 10^6 \text{ GeV}, m_X = 10^{12} \text{ GeV} \)

<table>
<thead>
<tr>
<th>( \bar{q}q )</th>
<th>( N_{D1} )</th>
<th>( N_{D2} )</th>
<th>( N_{D3} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{q}q )</td>
<td>0.0176</td>
<td>0.0175</td>
<td>0.0110</td>
</tr>
<tr>
<td>( q\bar{q} )</td>
<td>0.0405</td>
<td>0.0440</td>
<td>0.0324</td>
</tr>
<tr>
<td>( l\bar{l} )</td>
<td>0.1067</td>
<td>0.1487</td>
<td>0.1460</td>
</tr>
<tr>
<td>( 5 \times \bar{q}q )</td>
<td>0.4091</td>
<td>0.4168</td>
<td>0.2719</td>
</tr>
</tbody>
</table>

### Event rates t-channel

\( E_{\tilde{\chi}_1^0} \geq 10^6 \text{ GeV}, m_X = 10^{12} \text{ GeV} \)

<table>
<thead>
<tr>
<th>( \bar{q}q )</th>
<th>( N_{\tilde{\chi}_1^0} )</th>
<th>( N_{\nu\tau} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{q}q )</td>
<td>0.51</td>
<td>0.36</td>
</tr>
<tr>
<td>( q\bar{q} )</td>
<td>1.63</td>
<td>0.65</td>
</tr>
<tr>
<td>( l\bar{l} )</td>
<td>23.03</td>
<td>1.31</td>
</tr>
<tr>
<td>( 5 \times \bar{q}q )</td>
<td>13.71</td>
<td>4.14</td>
</tr>
</tbody>
</table>

- integrated from 10^6 to 10^{12} \text{ 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