TeV Particle Physics and Physics Beyond the Standard Model

Ivone Albuquerque, Alex Kusenko, Tom Weiler

TeV Particle Astrophysics
Madison, 28-31 Aug, 2006
Probing Physics Beyond the SM with

\[ \lesssim \text{TeV} \ \nu_s, \ \gamma_s, \ \text{Cosmic Rays} \]

- Particle and astro experiments can be complementary
  - Together can better constrain models

- SUSY: NLSP detection in neutrino telescopes

- Dark Side:
  - DM, Black Holes
  - Squishing DM with Black Holes
Looking for SUSY in the Ice

- SUSY Breaking mechanism $\Rightarrow$ mass spectrum $\Rightarrow$ LSP
- LSP is determined by the scale of SUSY breaking ($\sqrt{F}$)

$10^3 \text{ GeV} < \sqrt{F} < 10^{12} \text{ GeV}$

- $\sqrt{F} > 10^{10} \text{ GeV} \Rightarrow$ LSP is neutralino
- $\sqrt{F} < 10^{10} \text{ GeV} \Rightarrow$ LSP is gravitino

in most of these cases: NLSP is charged slepton (typically the $\tilde{\tau}_R$ with $m = \vartheta(150 \text{ GeV})$

for $\sqrt{F} \gtrsim 10^6 \text{ GeV}$ and HE collisions, NLSPs travel long distances before decaying

I.A., G.Burdman, Z.Chacko - PRL 92 - 04
SUSY Cross Section

**SM $\sigma$**

- - - - - SUSY $\sigma (m(\tilde{q}) = 300)$ GeV
- - - - - SUSY $\sigma (m(\tilde{q}) = 600)$ GeV
- - - - - SUSY $\sigma (m(\tilde{q}) = 900)$ GeV

I.A., G.Burdman, Z.Chacko - PRL 92 - 04
Long Range Compensates Small XS

SUSY on the Rocks

\[ \nu_e, \mu, \tau \]

Signal strength depends on:

- production cross section
- branching ratio
- decay length
- energy loss

M. Ahlers
Rate of Charged NLSPs in Neutrino Telescopes

\[
E_\nu \frac{dN}{dE_\nu} \text{ (km}^2 \text{year}^{-1})
\]

I.A., G.Burdman, Z.Chacko
Flux of Staus and Muons

Staus at the detector may dominate over muons above $E \sim 10^5$ GeV, but with different energy loss properties!

Markus Ahlers (DESY Hamburg)  Long-lived Staus at Neutrino Telescopes  Madison, August 28-31, 2006
Table 1: Number of events per km$^2$ per year assuming the WB and MPR limits. The first column refers to upgoing di-muons. The last three columns correspond to upgoing NLSP pair events, for three different choices of squark masses: 300 GeV, 600 GeV and 900 GeV.

<table>
<thead>
<tr>
<th></th>
<th>$d\mu$</th>
<th>$m_{\tilde{q}} = 300$ GeV</th>
<th>600 GeV</th>
<th>900 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>WB</td>
<td>15</td>
<td>17</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>MPR</td>
<td>29</td>
<td>85</td>
<td>7</td>
<td>2</td>
</tr>
</tbody>
</table>
Stau Signature: 2 Tracks

I.A., G.Burdman, Z.Chacko
Rate of stau pairs for the Waxman–Bahcall flux at IceCube:

\[ \text{min } \tilde{m} : \quad \dot{N} \sim 5 \text{ per year} \quad \text{SPS 7} : \quad \dot{N} \sim 1 \text{ per decade} \]
Km$^3$ neutrino telescopes have the potential to discover the charged NLSP.

- Background (di-$\mu$) is small and 2 track NLSP signature is clear.

- Observation of the NLSP constitutes a direct probe of the scale of SUSY breaking.

- Complementary search to LHC.
Stau Energy Loss

Energy Loss - Range

- Electromagnetic energy loss:
  - ionization
  - bremsstrahlung
  - pair production
  - photonuclear

\[
\frac{dE}{dX} = - (\alpha + \beta E)
\]

- Weak interactions:
  - neutral current
  - charged current
  - decay

\[
\beta_{NC} \quad \text{removes particles}
\]

M.H. Reno
Stau Weak Interactions

![Graph showing the variation of X[km.w.e.] with E [GeV] for different values of \( \sin \theta_f \).](image)

- CC (\( \sin \theta_f = 0 \))
- CC (\( \sin \theta_f = 1 \))

\[ E_0 = 10^3 \text{ GeV} \]
\[ F^{1/2} = 10^7 \text{GeV} \]

M.H.Reno
Determining SUSY parameters using DArk Matter

The Lightest Neutralino

\[ \tilde{\chi}^0 = N_{11} \tilde{B} + N_{12} \tilde{W}^0 + N_{13} \tilde{H}_1 + N_{14} \tilde{H}_2 \]

Properties of the lightest neutralino can vary wildly depending on its composition.

The composition of the lightest neutralino will likely not be determined at the LHC.

Annihilation and elastic scattering cross sections with nucleons can vary very rapidly with magnitude depending on the composition and particle spectrum.\( \Rightarrow \text{tc} \)

By including astrophysical measurements with LHC data, it may be possible to determine the composition of the lightest neutralino.
Direct Detection:

- Models with large XS $\Rightarrow$ dominated by Higgs exchange, couplings to b and s quarks
- Squark exchange contribution is only substantial below $10^8$ pb
- Leads to correlation between neutralino composition, $\tan \beta$, $m_A$ and elastic scattering rate.
UHE $\nu$ and Physics Beyond SM

I. Sarcevic
Detection of Cosmic Neutrinos

- Muon tracks (ICECUBE, RICE)

- Electromagnetic and Hadronic Showers (ICECUBE, RICE, ANITA, Auger, OWL, EUSO)

- To determine the energy flux (muons or showers) that reaches the detector we need to consider propagation of neutrinos and leptons through the Earth and ice

- \( \nu_\tau \) give different contribution from \( \nu_\mu \) due to the very short \( \tau \) lifetime, i.e. the regeneration effect.

- New physics may be manifested via production of new particles in neutrino interactions, such as supersymmetric charged sleptons, staus, which after interactions with matter produce charge tracks similar to muons, or hardonic showers.

I. Sarcevic
Probing the Physics Beyond the Standard Model with EUSO

I. Sarcevic
Bounds on DM annihilation XS

Disappearance Means Appearance

- Dark matter is assumed to be the LSP
- Almost all SM states have gamma rays, and KKT require Br(gamma) < 10^{-10}
- The only “invisible” SM states are neutrinos
- We can bound the total cross section by assuming the worst case of Br(neutrino) = 100%
Signal and Background

- Angle-averaged (nu + nubar) flux in wide energy bins
- We are very conservative about the size of the required signal over background
- How well have we measured the background?

Beacom, Bell, Mack, astro-ph/0608090

J. Beacom
Cross Section Bounds

KKT model is strongly ruled out

KKT and unitarity bounds are greatly improved in a huge mass range

Cannot reach the natural scale for thermal relics yet

Beacom, Bell, Mack, astro-ph/0608090
Black Holes as DM annihilation “boosters”

ianfranco BERTONE
INFN, Padova
bertone@fnal.gov
http://home.fnal.gov/~bertone

/28/06
. Bertone  Hs as M nnihilation  oosters  eVPA  I Madison, WI
Adiabatic* growth of a Black Hole:
Hs s Annihilation Boosters

\[ \rho \propto r^{-\gamma} \]

\[ \rho \propto r^{-\gamma_{sp}} \]

\[ \gamma_{sp} = \frac{9-2\gamma}{4-\gamma} \]

*onserve Mass & Angular Momentum:
Gamma-Rays from DM Mini-spikes

Inserting typical values for the DM candidate and the spike, we find in scenario II

\[ \Phi(E, D) = \Phi_0 \frac{dN}{dE} \left( \frac{\sigma v}{10^{-26}\text{cm}^3/\text{s}} \right) \left( \frac{m_x}{100\text{GeV}} \right)^{-2} \left( \frac{D}{\text{kpc}} \right)^{-2} \left( \frac{\rho(r_{\text{sp}})}{10^2\text{GeVcm}^{-3}} \right)^2 \left( \frac{r_{\text{sp}}}{\text{pc}} \right)^{1/3} \left( \frac{r_{\text{cut}}}{10^{-3}\text{pc}} \right)^{-3} \]

\[ \Phi_0 = 9 \times 10^{-10}\text{cm}^{-2}\text{s}^{-1} \]

Note the normalization of the flux: each Black Hole would be as luminous in terms of annihilation radiation as the whole Galaxy!!

KEY POINT!
MBH Scenario 2 (10)

DENTICAL study sources

Smoaking gun!
Prospects for detection with neutrino telescopes

\[ N_{\text{BB}}(>R) \]

- ANTARES
- IceCube

\[ m_x = 1 \text{ TeV} \]
\[ \sigma v = 10^{-26} \text{cm}^3 \text{s}^{-1} \]
\[ E_{\mu}^{\text{th}} = 100 \text{ GeV} \]
Ann. channel $b\bar{b}$
CONCLUSIONS

Has an effectively oost he DM annihilation signal

Intermediate Mass Black Holes ay represent a unique opportunity to discover Dark Matter particles

LAST can rule out this scenario or prove it right. Importance of CTs MAGIC, HESS, VERITAS, ANGAROO in extending the search at higher energies

Eutrino telescopes CECube nd ANTARES might be able o detect neutrinos from mini-spikes

Further applications: see talks of S. Ando (gamma-ray background) and P. run anti-matter) in the DM session!
A New Method

- Based on a Very Simple Idea

- Look for the Higgs FIELD instead of the Higgs PARTICLE

- PROBLEM: Higgs is very massive $\Rightarrow$ very short range Higgs field

- A Particle very close to the Source of a Higgs Field will experience a Mass Adjustment

- Look at the Effect of Pairs of Massive Particles near Pair Threshold

Reucroft