Cosmic Positron Signature from Dark Matter in the Littlest Higgs Model with T-parity

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Introduction

WMAP (Wilkinson microwave anisotropy probe)

cold dark matter candidate
  • Neutral
  • Stable
  • Massive (100 GeV – 1TeV)

WINP (Weakly Interacting Massive Particle)

No WINP in SM $\iff$ beyond SM (WINP)

- Supersymmetric Model (neutralino)
- Little Higgs Model with T-parity (heavy photon)

H-C. Cheng and I. Low (‘03)
Dark Matter Search

- **indirect**
- **direct**

### Dark Matter
- **annihilation**
  - Gamma rays
  - Neutrino
  - antiprotons
  - **positrons**

- from Galactic center
- halo

### Dark matter scatter off of a detector

- Search the positron flux

### Future experiments

- **HEAT**
  - (High Energy Antimatter Telescope)
  - Energy range (positron)
  - ~30 GeV

- **PAMELA**
  - (Payload for Antimatter Exploration and Light-nuclei Astrophysics)
  - ~270 GeV

- **AMS-02**
  - (Alpha Magnetic Spectrometer)
  - ~ a TeV
1. Littlest Higgs Model with T-parity
2. Relic abundance of the dark matter
3. Positron signature
4. Summary
Littlest Higgs Model with T-parity
Low energy cutoff scenario

- Solve the problem of fine-tuning around a TeV
- Constrained by EW Precision Test

\[ \Lambda \gtrsim 5 \text{ TeV} \]

R. Barbieri and A. Strumia ('00)

Little Hierarchy Problem

Little Higgs Model can also solve

\[ m_0^2 + \delta m^2 \]

\[ \delta m^2 \sim \Lambda^2 \]

cutoff scale

Higgs: a pseudo Nambu-Goldstone boson

Higgs mass: protected at 1-loop quadratic divergence
New particles are constrained by EW Precision Test

\[ Z_f \]

constraint

\[ m_z \] has to be raised

reintroduce fine-tuning

T-parity (Z\(_2\) symmetry)

SM Particles → T-even
New Particles → T-odd

provide

Dark matter Candidate
Littlest Higgs Model

- SU(5)/SO(5) non-linear sigma model

\[
\Sigma = e^{2i\Pi/f} \sum_0
\]

\[
\Pi = \frac{1}{\sqrt{2}} \begin{pmatrix}
0 & H & \sqrt{2}\Phi \\
H^\dagger & 0 & H^T \\
\sqrt{2}\Phi^\dagger & H^* & 0
\end{pmatrix}
\]

\[
\Sigma_0 = \begin{pmatrix}
0 & 0 & 1 \\
0 & 1 & 0 \\
1 & 0 & 0
\end{pmatrix}
\]

New triplet Higgs boson       SM Higgs doublet

\[
\text{SU}(5) \supset [\text{SU}(2) \times \text{U}(1)]^2 \quad \text{(gauged)}
\]

\[
[\text{SU}(2) \times \text{U}(1)] \quad \text{(SM)}
\]
Kinetic Term

\[ \frac{f^2}{8} \text{Tr} D_\mu \Sigma (D^\mu \Sigma)^\dagger \]

\[ D_\mu \Sigma = \partial_\mu \Sigma - i \sum_j \left[ g_j W_j^a (Q_j^a \Sigma + \Sigma Q_j^{aT}) + g'_j B_j (Y_j \Sigma + \Sigma Y_j) \right] \]

gauge couplings of the SU(2) and U(1)

\[ W_L^a = sW_1^a + cW_2^a \]
\[ W_H^a = -cW_1^a + sW_2^a \]
\[ B_L = s'B_1 + c'B_2 \]
\[ B_H = -c'B_1 + s'B_2 \]
Littlest Higgs Model with T-parity

T-parity

B_1(W_1) \Leftrightarrow B_2(W_2)

\Pi \Leftrightarrow - \Omega \Pi \Omega

\Omega = \text{diag.}(1,1,-1,1,1)

Spectrum

10

T-even

Φ

W_H, Z_H

1

T-odd

h

A_H

Lightest T-odd

0.1

W, Z

Dark matter candidate

m_{A_H} \approx \frac{g'}{\sqrt{5}} f
Relic Abundance of Dark Matter
There are s-channel poles

If $m_{AH} > m_h$

J. Hubisz and P. Meade (‘05)

Relic density $\Omega h^2$ depends on $m_{AH}$, $m_h$
contour plot of the relic abundance

S-channel pole line
\[ m_h = 2m_{A_H} \]

Cross section is very large
Relic density is very small

Allowed region for WMAP at 2σ level

\[ 0.094 < \Omega h^2 < 0.129 \]

Relic density
\[ \frac{1}{\langle \sigma v \rangle} \]
cross section
Indirect Detection of the Dark Matter Using Cosmic Positrons
solve the diffusion eq.

positron flux $\Phi_{e^+} \square f_{e^+} \times BF$

Number density of positrons per unit energy

( in the inflationary universe )

$2 \sim 5$ V.Berezinsky et al ('03)

Effect of inhomogeneity

Boost Factor
In a wide region of the parameter $f$, $m_h$ space

1. Calculate the production rate of $e^+$

2. Solve the diffusion equation

   Obtain the flux of the **signal positrons**

3. Think of the **Background** which are obtained by simulations

   E.A. Baltz and J. Edsjo

   ('99)

   **positron fraction** $\frac{\Phi_{e^+}}{(\Phi_{e^+} + \Phi_{e^-})}$
positron fraction

$$\Phi_{e^+} / (\Phi_{e^+} + \Phi_{e^-})$$

in 7 sample points

(On the allowed region for WMAP)
\[ \chi^2 = \sum_i \frac{(N_i^{(\text{Obs})} - N_i^{(\text{BG})})^2}{N_i^{(\text{Obs})}} \]

- the number of positron events observed in the i-th bin
- the number of events expected from the background contribution in the i-th bin.

\( \chi^2 \) is proportional to BF^2

Acceptance of PAMELA
- 20.5 cm\(^2\)sr

Acceptance of AMS-02
- 450 cm\(^2\)sr

Assuming three years of data-taking
contour plot of $\chi^2$

In the PAMELA

with $BF = 5$

$\chi^2 = 33.9 \rightarrow$

95% confidence level

In the AMS-02

with $BF = 2$
χ² Plot

χ² plot (along with the U- and L-branch) within WMAP constraint

χ² depends on BF and m_h
95% confidence level contour within WMAP constraint

**Possibility to Detect the Signal**

**PAMELA**
- \( f < 830 \text{GeV} \)
- \( m_{AH} < 120 \text{GeV} \)
- BF > 5

**AMS-02**
- Wide range of the parameter space including the region BF = 1
Impact of Higgs Phenomenology

Invisible width

in the U-branch

\( m_h > 2m_{A_H} \)

\[ h \rightarrow A_H A_H \]

up to 5 %

LHC and ILC

The measurement might be possible at a future muon collider
We have studied the possibility to detect the $A_H$ dark matter in the littlest Higgs model with T-parity.

In the PAMELA experiment, the dark matter signal may be detected when $f < 830 \text{GeV}$ ($m_{A_H} < 120 \text{GeV}$) and $BF > 5$.

In AMS-02 experiments, The dark matter signal may be detected even if there is no enhancement from the boost factor.