Long Lived Charged Particles

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PPC07

S. Su
Outline

Long lived charged particle
  * Collide search limit
  * Cosmological constraints

Connection to Dark Matter
  * Light gravitino dark matter (GMSB)
  * SuperWIMP dark matter
  * Cosmological implications
  * Collider implications
Long Lived Charged Particle in SM

**Proton** (stable): accidental global B and L symmetry

**Electron** (stable): gauge $U(1)_{EM}$

Stable particle appears when there is an unbroken symmetry

LSP in SUSY, LKP in UED, ...

**Muon** ($\tau = 2 \times 10^{-6}$ sec): $\Gamma \propto m_\mu^5/m_W^4$

Small coupling, small available phase space
Lots of candidates for long lived charged particle in BSM physics ...
<table>
<thead>
<tr>
<th>SMP</th>
<th>LSP</th>
<th>Scenario</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\tilde{\tau}_1)</td>
<td>(\tilde{\chi}_1^0)</td>
<td>MSSM</td>
<td>(\tilde{\tau}<em>1) mass (determined by (m</em>{\tilde{\tau}<em>{L,R}}^2, \mu, \tan \beta,) and (A</em>\tau)) close to (\tilde{\chi}_1^0) mass.</td>
</tr>
<tr>
<td>(\tilde{G})</td>
<td>GMSB</td>
<td></td>
<td>Large (N), small (M), and/or large (\tan \beta).</td>
</tr>
<tr>
<td>(\tilde{g})</td>
<td>MSB</td>
<td></td>
<td>No detailed phenomenology studies, see [23].</td>
</tr>
<tr>
<td>SUGRA</td>
<td></td>
<td></td>
<td>Supergravity with a gravitino LSP, see [24].</td>
</tr>
<tr>
<td>(\tilde{\tau}_1)</td>
<td>MSSM</td>
<td></td>
<td>Small (m_{\tilde{\tau}<em>{L,R}}) and/or large (\tan \beta) and/or very large (A</em>\tau).</td>
</tr>
<tr>
<td>AMSB</td>
<td></td>
<td></td>
<td>Small (m_0), large (\tan \beta).</td>
</tr>
<tr>
<td>(\tilde{\chi}_1^+)</td>
<td>(\tilde{\chi}_1^0)</td>
<td>MMSM</td>
<td>(m_{\tilde{\chi}<em>1^+} - m</em>{\tilde{\chi}<em>1^0} \gtrsim m</em>{\pi^+}). Very large (M_{1,2} \gtrsim 2) TeV (\gg</td>
</tr>
<tr>
<td>AMSB</td>
<td></td>
<td></td>
<td>(M_1 &gt; M_2) natural. (m_0) not too small. See MSSM above.</td>
</tr>
<tr>
<td>(\tilde{\chi}_1^0)</td>
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<td>MSSM</td>
<td>Very large (m_{\tilde{\chi}_1^0}^2 \gg M_3), e.g. split SUSY.</td>
</tr>
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<td>(\tilde{\chi}_1^0)</td>
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<td>MSSM</td>
<td>Very small (M_3 \ll M_{1,2}), O-II models near (\delta_{GS} = -3).</td>
</tr>
<tr>
<td>(\tilde{\chi}_1^0)</td>
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<td>MSSM</td>
<td>Non-universal squark and gaugino masses. Small (m_{\tilde{q}}^2) and (M_3), small (\tan \beta), large (A_t).</td>
</tr>
<tr>
<td>(\tilde{b}_1)</td>
<td></td>
<td>MSSM</td>
<td>Small (m_{\tilde{b}}^2) and (M_3), large (\tan \beta) and/or large (A_b \gg A_t).</td>
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Table 1
### Non-SUSY models

<table>
<thead>
<tr>
<th>$Q_{em}$</th>
<th>$C_{QCD}$</th>
<th>$S$</th>
<th>Model(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>8</td>
<td>1</td>
<td>Universal Extra Dimensions (KK gluon)</td>
</tr>
<tr>
<td>±1</td>
<td>1</td>
<td>$\frac{1}{2}$</td>
<td>Universal Extra Dimensions (KK lepton)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fat Higgs with a fat top ($\psi$ fermions)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4th generation (chiral) fermions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mirror and/or vector-like fermions</td>
</tr>
<tr>
<td>±$\frac{4}{3}$</td>
<td>3</td>
<td>$\frac{1}{2}$</td>
<td>Warped Extra Dimensions with GUT parity (XY gaugino)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>5D Dynamical SUSY-breaking (xyon)</td>
</tr>
<tr>
<td>$-\frac{1}{3}$, $\frac{2}{3}$</td>
<td>3</td>
<td>$\frac{1}{2}$</td>
<td>Universal Extra Dimensions (KK down, KK up)</td>
</tr>
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<td>$\epsilon &lt; 1$</td>
<td>1</td>
<td>$\frac{1}{2}$</td>
<td>GUT with $U(1) - U(1)'$ mixing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Extra singlets with hypercharge $Y = 2\epsilon$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Millicharged neutrinos</td>
</tr>
<tr>
<td>$?$, $?$, $0/\frac{1}{2}$</td>
<td>1</td>
<td>“Technibaryons”</td>
<td></td>
</tr>
</tbody>
</table>
“Long Lived” and “Charged”

How long is long lived?

• < age of Universe ($10^{17}$ sec): Heavy isotope search
• > $10^{-8} - 10^{-7}$ sec: stable collider-wise

What charge?

• electric charge
• magnetic charge: magnetic monopole
• color charge: long lived gluinos (in split SUSY)
“Long Lived” and “Charged”

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- < age of Universe (10^{17} \text{ sec}): \text{ Heavy isotope search}
- > 10^{-8} \sim 10^{-7} \text{ sec}: \text{ stable collider-wise}

What charge?

- electric charge
  - magnetic charge: magnetic monopole
  - color charge: long lived gluinos (in split SUSY)
**Signature:**

slow, highly-ionizing, charged track

- large dE/dx
- time of flight
- Ring Imaging Cherenkov detection

S. Su
## Collider Searches

**charge = ± 1**

<table>
<thead>
<tr>
<th>Ecm (GeV)</th>
<th>Collision</th>
<th>Exp</th>
<th>Mass (GeV)</th>
<th>σ(pb)</th>
</tr>
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<tbody>
<tr>
<td>1800</td>
<td>p(\bar{p})</td>
<td>CDF</td>
<td>100-270</td>
<td>0.3-2</td>
</tr>
<tr>
<td>300</td>
<td>ep</td>
<td>H1</td>
<td>&lt;100</td>
<td>190</td>
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<tr>
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<td>e+e-</td>
<td>OPAL</td>
<td>45-102</td>
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- **Current Bound (LEP)** \(m_{\text{sl}} > 98\) GeV
- **Tevatron reach:** \(m_{\text{sl}} > 180\) GeV (10 \(fb^{-1}\), now?)
- **LHC reach:** \(m_{\text{sl}} > 700\) GeV for 100 \(fb^{-1}\)
charge = ± 1

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CDF Run II Preliminary

Stop Production cross section (NLO)

\[
\int L \, dt = 1.03 \, fb^{-1}
\]
### Collider Searches

**charge = ± 1**

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**CMB Constraints**

*CMB photon energy distribution*

\[ f_{\gamma}(E) = \frac{1}{e^{E/(kT)} + \mu - 1} \]

- **early decay:** \( \mu = 0 \)
  - thermalized through \( \gamma e \rightarrow \gamma e, eX \rightarrow eX\gamma, \gamma e \rightarrow \gamma\gamma e \)

- **late decay:** \( \mu \neq 0 \)
  - statistical but not thermodynamical equilibrium

\[ |\mu| < 9 \times 10^{-5} \]

Fixsen *et. al.*, astro-ph/9605054
Hagiwara *et. al.*, PDG
Big bang nucleosynthesis

Fields, Sarkar, PDG (2002)
Big bang nucleosynthesis

\[ \eta/10^{-10} = 6.1 \pm 0.4 \]

Fields, Sarkar, PDG (2002)
### Big bang nucleosynthesis

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>1</th>
<th>10</th>
<th>$10^2$</th>
<th>$10^3$</th>
<th>$10^4$</th>
<th>$10^5$</th>
<th>$10^6$</th>
<th>$10^7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hadronic Energy</td>
<td>$p + e \leftrightarrow n + \nu$</td>
<td>$n + p \rightarrow D \rightarrow ^4\text{He}$</td>
<td>$n + p \rightarrow D$</td>
<td>$n + ^4\text{He} \rightarrow D$</td>
<td>D overproduction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>Thermalizes through EM interactions</td>
<td>Constraints weak</td>
<td>$\gamma + D \rightarrow n + p$</td>
<td>D overdestruction</td>
<td>$\gamma + ^4\text{He} \rightarrow D + D$</td>
<td>D overproduction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall</td>
<td>No constraints</td>
<td>$^4\text{He}$ overproduction</td>
<td>D overproduction</td>
<td>Possible EM/had cancellation</td>
<td>D overproduction</td>
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### BBN Constraints

**Big bang nucleosynthesis**

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<tbody>
<tr>
<td>Hadronic Energy</td>
<td>Thermalizes through EM interactions</td>
<td>Interacts with background hadrons</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>$p + e \leftrightarrow n + \nu$</td>
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**Gamma Processes**

- $\gamma \gamma_{BG} \rightarrow e^+ e^-$
- $\gamma e_{BG} \rightarrow \gamma e$

**Energy Maximum**

$$E_{\text{max}} = \frac{m_e^2}{22T} = 12 \text{ MeV} \left[\frac{t}{10^6 \text{sec}}\right]^{1/2}$$
BBN constraints

- Decay lifetime \( T_{\text{NLSP}} \)
- EM/had energy release

\[ \xi_{\text{EM,had}} = \varepsilon_{\text{EM,had}} \cdot Br_{\text{EM,had}} \cdot Y_{\text{NLSP}} \]
BBN constraints

- Decay lifetime $\tau_{\text{NLSP}}$
- EM/had energy release

$$\xi_{\text{EM,had}} = \varepsilon_{\text{EM,had}} \text{Br}_{\text{EM,had}} Y_{\text{NLSP}}$$

$$Y_{\text{NLSP}} = \frac{n_{\text{NLSP}}}{n_\gamma} \approx 3.0 \times 10^{-12} \left[ \frac{\text{TeV}}{m_{\text{SWIMP}}} \right] \left[ \frac{\Omega_{\text{SWIMP}}}{0.23} \right]$$
BBN constraints

- Decay lifetime $\tau_{\text{NLSP}}$
- EM/had energy release

$$\xi_{\text{EM, had}} = \varepsilon_{\text{EM, had}} \cdot \text{Br}_{\text{EM, had}} \cdot Y_{\text{NLSP}}$$

**BBN constraints**

- **Decay lifetime** $\tau_{\text{NLSP}}$
- **EM/had energy release**

\[ \xi_{\text{EM,had}} = \epsilon_{\text{EM,had}} \, \text{Br}_{\text{EM,had}} \, Y_{\text{NLSP}} \]


Kawasaki, Kohri and Moroi, astro-ph/0402490
charged particles catalyze BBN

\[ ^4\text{He} \ X^- + d \rightarrow ^6\text{Li} + X^- \]

\( \text{constrain stau lifetime} < 10^4 \text{ sec} \)

Kaplinghat, Tajaraman (2006);
Kohri, Takayama (2006);
Cyburt, Ellis, Fields, Olive, Spanos (2006);
Hamaguchi, Hatssuda, Kamimura, Kino, Yanagida (2007);
Bird, Koopmans, Pospelov (2007);
Takayama (2007)
Connection to Dark Matter

- does not address dark matter

- **WIMP** dark matter
  - MSSM with stau NLSP and neutralino LSP coannihilation
  - decay inside the detector

- **non-WIMP** dark matter
  - does not relate to WIMP-miracle
    - e.g., GMSB stau NLSP with light gravitino LSP
  - relate to WIMP-miracle
    - **superWIMP** scenario
      - e.g., SUGRA stau NLSP with heavy gravitino LSP
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Gravitino

• Gravitino: superpartner of graviton
• Obtain mass when SUSY is spontaneously broken $m_G \sim F/m_{pl}$
• Stable when it is LSP - candidate of Dark Matter
GMSB with Light Gravitino

slepton NLSP decay

\[ c\tau_{\text{NLSP}} = 0.1 \left( \frac{100 \text{ GeV}}{m_{\text{NLSP}}} \right)^3 \left( \frac{m_\tilde{G}}{2.4 \text{ eV}} \right) \text{ mm} \]

\[ m_\tilde{G} = 2.4 c_{\text{grav}} \left( \frac{\sqrt{F}}{100 \text{ TeV}} \right)^2 \text{ eV} \]

stau could either decay or being stable inside the detector

gravitino relic density

\[ \Omega h^2 \sim (m_\tilde{G}/\text{keV}) (100/\text{g.}) \]

Moroi, Murayama and Yamaguchi, PLB303, 289 (1993)

- \( m_\tilde{G} \sim \text{keV} \): warm Dark Matter
- \( m_\tilde{G} > \text{keV} \): problematic! gravitino dilution necessary
  \[ \Rightarrow \text{stringent bounds on reheating temp.} \]

no direct connection between stau and gravitino relic density
Boltzmann equation

\[
\frac{dn}{dt} + 3Hn = -\langle \sigma v \rangle (n^2 - n_{eq}^2)
\]

expansion \( \chi\chi \to ff \), \( ff \to \chi\chi \)

Graphical representation showing the change in comoving number density with respect to the parameter \( x = m/T \) (time →). The graph indicates increasing \( <\sigma_A v> \) over time.
Boltzmann equation

\[ \frac{dn}{dt} + 3Hn = -\langle \sigma v \rangle (n^2 - n_{eq}^2) \]

Thermal equilibrium

$\chi \leftrightarrow ff$

$\chi \rightarrow ff$

$ff \rightarrow \chi\chi$

WIMP

Comoving Number Density

$N_{EQ}$

Increasing $\langle \sigma_A v \rangle$

$x = m/T$ (time $\rightarrow$)
**WIMP**

**Boltzmann equation**

\[
\frac{dn}{dt} + 3Hn = -\langle \sigma v \rangle (n^2 - n_{eq}^2)
\]

- expansion
- $\chi \chi \rightarrow ff$
- $ff \rightarrow \chi \chi$

**Universe cools:**

\[n = n_{EQ} \sim e^{-m/T}\]

**Graph:**

- Comoving Number Density
- $N_{EQ}$
- $x = m/T$ (time $\rightarrow$)

Increasing $<\sigma_A v>$
**Boltzmann equation**

\[
\frac{dn}{dt} + 3Hn = -\langle \sigma v \rangle (n^2 - n_{eq}^2)
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- **expansion**
- \(\chi\chi \rightarrow ff\)
- \(ff \rightarrow \chi\chi\)

Freeze out, \(n/s \sim \text{const}\)

**Graph:**
- Comoving Number Density vs. \(x = m/T\) (time →)
- \(N_{EQ}\)

S. Su
WIMP

Boltzmann equation

\[ \frac{dn}{dt} + 3Hn = -\langle \sigma v \rangle (n^2 - n_{eq}^2) \]

expansion\ 
\( \chi \chi \rightarrow ff \) \ 
\( ff \rightarrow \chi \chi \)

Increasing \( \langle \sigma_A v \rangle \)
\textbf{WIMP: Weak Interacting Massive Particle}

- \( m_{\text{WIMP}} \sim m_{\text{weak}} \)
- \( \sigma_{\text{an}} \sim \alpha_{\text{weak}}^2 m_{\text{weak}}^{-2} \)

\[
\Omega h^2 \sim \frac{2.6 \times 10^{-10} \text{GeV}^{-2}}{\langle \sigma_A v \rangle} \quad \langle \sigma_A v \rangle \sim \frac{\alpha^2}{m_{\text{weak}}^2} 0.1 \sim 10^{-9} \text{GeV}^{-2}
\]

\[ \Rightarrow \Omega h^2 \sim 0.3 \]
**WIMP - Miracle**

**WIMP: Weak Interacting Massive Particle**

- $m_{\text{WIMP}} \sim m_{\text{weak}}$
- $\sigma_{\text{an}} \sim \alpha_{\text{weak}}^2 m_{\text{weak}}^{-2}$

\[
\Omega h^2 \sim \frac{2.6 \times 10^{-10} \text{GeV}^{-2}}{\langle \sigma_A v \rangle} \quad \langle \sigma_A v \rangle \sim \frac{\alpha^2}{m_{\text{weak}}^2} 0.1 \sim 10^{-9} \text{GeV}^{-2}
\]

\[\Rightarrow \Omega h^2 \sim 0.3\]

- appear in particle physics models motivated independently by attempts to solve Electroweak Symmetry Breaking
- relic density are determined by $m_{\text{pl}}$ and $m_{\text{weak}}$
  - naturally around the observed value
  - no need to introduce and adjust new energy scale
WIMP $\rightarrow$ superWIMP + SM particles

Feng, Rajaraman and Takayama (2003)

Feng, Rajaraman, Takayama (2003);
Bi, Li, Zhang (2003);
Ellis, Olive, Santoso, Spanos (2003);
Wang, Yang (2004);
Feng, Su, Takayama (2004);
Buchmuller, hamaguchi, Ratz, Yanagida (2004);
Roszkowski, Ruiz de Austri, Choi (2004);
Brandenburg, Covi, hamaguchi, Roszkowski, Steffen (2005);
...
\[ \text{WIMP} \rightarrow \text{superWIMP} + \text{SM particles} \]

Feng, Rajaraman and Takayama (2003)

\begin{align*}
\text{Comoving Number Density} & = N_{\text{EQ}} \\
\text{x=m/T (time \rightarrow)} & = 1, 10, 100, 1000
\end{align*}
**superWIMP**

**WIMP → superWIMP + SM particles**

Feng, Rajaraman and Takayama (2003)

$10^4 \text{ s} < t < 10^8 \text{ s}$
\[ \text{WIMP} \rightarrow \text{superWIMP} + \text{SM particles} \]

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WIMP → superWIMP + SM particles

Feng, Rajaraman and Takayama (2003)

$10^4 \text{s} < t < 10^8 \text{s}$

$N_{\text{EQ}}$

$x = \frac{m}{T} (\text{time} \to)$
**WIMP → superWIMP + SM particles**

Feng, Rajaraman and Takayama (2003)

\[ 10^4 \text{ s} < t < 10^8 \text{ s} \]

\[ \Omega_{\text{SWIMP}} = \frac{m_{\text{SWIMP}}}{m_{\text{WIMP}}} \Omega_{\text{WIMP}} \]

![Diagram showing comoving number density over time](image)

- Increasing \( <\sigma_A v> \)
- **X**-axis: \( x = m/T \) (time →)
- **Y**-axis: Comoving Number Density

S. Su
$\text{WIMP} \rightarrow \text{superWIMP} + \text{SM particles}$

$10^4 \text{ s} < t < 10^8 \text{ s}$

$\Omega_{\text{SWIMP}} = \frac{m_{\text{SWIMP}}}{m_{\text{WIMP}}} \Omega_{\text{WIMP}}$

Feng, Rajaraman and Takayama (2003)
$WIMP \rightarrow \text{superWIMP} + \text{SM particles}$

Feng, Rajaraman and Takayama (2003)

$10^4 \text{ s} < t < 10^8 \text{ s}$

$\Omega_{\text{SWIMP}} = \frac{m_{\text{SWIMP}}}{m_{\text{WIMP}}} \Omega_{\text{WIMP}}$

SuperWIMP

- e.g. Gravitino LSP
- LKK graviton

WIMP

- neutral
- charged
superWIMP in SUSY

SUSY case

WIMP $\rightarrow$ superWIMP + SM particles
**superWIMP in SUSY**

**SUSY case**

WIMP $\rightarrow$ superWIMP + SM particles

*Charged slepton*

Superpartner of lepton
**SuperWIMP in SUSY**

**SUSY case**

\[ \text{WIMP} \rightarrow \text{superWIMP} + \text{SM particles} \]

- **Charged slepton**
  - Superpartner of lepton

- **Gravitino**
  - Superpartner of graviton
**superWIMP in SUSY**

**SUSY case**

WIMP $\rightarrow$ superWIMP + SM particles

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  - Superpartner of graviton

EM, had. cascade

$\Rightarrow$ change CMB spectrum

$\Rightarrow$ change light element abundance predicted by BBN

**Strong constraints !**
**superWIMP in SUSY**

**SUSY case**

WIMP $\rightarrow$ superWIMP + SM particles

- **Charged slepton**
  - Superpartner of lepton

- **Gravitino**
  - Superpartner of graviton

- **EM, had. cascade**
  - $\Rightarrow$ change CMB spectrum
  - $\Rightarrow$ change light element abundance predicted by BBN

- Strong constraints!

**Decay lifetime**

$\propto \frac{1}{m_{pl}^2/m_{G}^3}$
Neutralino LSP vs. Gravitino LSP

WIMP

\[ \tilde{\chi}, \tilde{l} \rightarrow \text{LSP} \]

SuperWIMP

\[ \tilde{\chi}, \tilde{\ell} \rightarrow \text{LSP} \]
The stau NLSP abundance is given by:

\[ Y_{\text{NLSP}} = \frac{n_{\text{NLSP}}}{n_\gamma} \approx 3.0 \times 10^{-12} \left( \frac{\text{TeV}}{m_\tilde{G}} \right) \left( \frac{\Omega_\tilde{G}}{0.23} \right) \]

Fix \( \Omega_\tilde{G} = 0.23 \)

200 GeV \leq \delta m \leq 400 \sim 1500 \text{ GeV}

\( m_\tilde{G} \leq 200 \text{ GeV} \)

Feng, SS and Takayama (2004)
\[ Y_{\text{NLSP}} = \frac{n_{\text{NLSP}}}{n_{\gamma}} \approx 3.0 \times 10^{-12} \left(\frac{\text{TeV}}{m_{\tilde{G}}}\right) \left(\frac{\Omega_{\tilde{G}}}{0.23}\right) \]

Feng, SS and Takayama (2004)

fix \( \Omega_{\tilde{G}} = 0.23 \)

200 GeV \( \leq \delta m \leq 400 \) ~ 1500 GeV
\( m_{\tilde{G}} \leq 200 \) GeV

solve \(^{7}\text{Li} \) anomaly
mSUGRA

 Ellis et. al., hep-ph/0312262
• SuperWIMPs are produced in late decays with large velocity (0.1 c - c)
• suppress small scale structure
• constant density cores in small mass halo
• reduce concentration in large mass halos
• warm DM with cold DM pedigree

Dalcanton, Hogan (2000);
Lin, Huang, Zhang, Brandenberger (2001);
Sigurdson, Kamionkowski (2003);
Profumo, Sigurdson, Ullio, Kamionkowski (2004);
Kaplinghat (2005);
Cembranos, Feng, Rajaraman, takayama (2005);
Strigari, Kaplinghat, Bullock (2006);
Bringmann, Borzumati, Ullio (2006)
Collider Production

\[ \Omega_{\text{WIMP}} \leq \Omega_{\text{SWIMP}} \leq \Omega_{\text{DM}} \]

- WIMP annihilate efficiently in early universe
- WIMP be produced efficiently at colliders

Upper bound on \( \Omega \)
Lower bound on rates

Birkedal, Matchev and Perelstein (2004)
Feng, SS and Takayama (2005)
superWIMP @ collider

Feng, SS and Takayama (2005)
• Decay life time
• SM particle energy/angular distribution ...

⇒ $m_{\tilde{G}}$

⇒ $m_{pl}$ ...
• Decay life time
• SM particle energy/angular distribution ...
  \[ \Rightarrow m_\tilde{G} \]
  \[ \Rightarrow m_{\text{pl}} \ldots \]

- Probes gravity in a particle physics experiments!
- BBN, CMB in the lab
- Precise test of supergravity: gravitino is a graviton partner
How to trap slepton?

- Decay life time
- *SM* particle energy/angular distribution ...
  
  \[ \Rightarrow m_{\tilde{G}} \]
  
  \[ \Rightarrow m_{\text{pl}} \] ...

- Probes gravity in a particle physics experiments!
- BBN, CMB in the lab
- Precise test of supergravity: gravitino is a graviton partner

How to trap slepton?
• Decay life time
• SM particle energy/angular distribution ...
  \[ \Rightarrow m_{\tilde{G}} \]
  \[ \Rightarrow m_{\text{pl}} \]

• Probes gravity in a particle physics experiments!
• BBN, CMB in the lab
• Precise test of supergravity: gravitino is a graviton partner

How to trap slepton?

Feng and Smith, (2004)
De Roeck et. al., (2005)
Slepton could live for a year, so can be trapped then moved to a quiet environment to observe decays.

- LHC: $10^6$ slepton/yr possible, but most are fast.
  Catch 100/yr in 1 kton water

Feng and Smith, hep-ph/0409278
Slepton trapping

Slepton could live for a year, so can be trapped then moved to a quiet environment to observe decays.

- LHC: $10^6$ slepton/yr possible, but most are fast. Catch 100/yr in 1 kton water.

- LC: tune beam energy to produce slow sleptons, can catch 1000/yr in 1 kton water.

Feng and Smith, hep-ph/0409278
Conclusions

- **Long lived charge particles appears in many BSM models**
- **Slow moving, highly ionization track at colliders**
- **Cosmological constraints from BBN, CMB, ...**
- **Link to dark matter: superWIMP scenario**
  - ✔ naturally obtain $\Omega$
  - ✔ solve BBN $^7$Li anomaly
  - ✔ small scale structure
  - ✔ could be tested at colliders