Right-handed Sneutrinos at the TeV-scale

Hitoshi Murayama
ALCPG@SLAC 2004
January 9, 2004
Conclusions

SUSY Dark Matter does not need to be neutralino
Neutrinos may be light because of the small SUSY breaking scale ⇒ TeV-scale seesaw
right-handed sneutrino also TeV-scale
left- and right-handed sneutrinos mix
sneutrino LSP
Lepton-number violating $B$-term ⇒ inelastic dark matter
Can reconcile DAMA with other experiments
Collider signature confusing
LC can sort it out
Why are neutrinos light?
(Arkan-Hamed, Hall, HM, Smith, Weiner)

Standard seesaw mechanism:
\[
\mathcal{L} = \frac{1}{M} (LH_u)(LH_u) \rightarrow \frac{v^2}{M} \nu \nu
\]

Another way to get small neutrino mass from hidden sector SUSY breaking: sMajorana

\[
\langle X \rangle = m_I + \theta^2 m_I^2, \quad m_I = \sqrt{m_{3/2} M_P}
\]

\[
\mathcal{L} = \int d^2 \theta \frac{X}{M_P} LH_u N + \int d^4 \theta \frac{X^*}{M_P} NN
\]

\[
- \int d^2 \theta \left( \sqrt{\frac{m_{3/2}}{M_P}} LH_u N + m_{3/2} NN \right) + m_{3/2} \tilde{L}H_u \tilde{N}
\]

\[
m_\nu = \frac{m_{3/2}^2}{M_P}
\]
Sneutrinos Mix

\[ \mathcal{L} = \int d^2 \theta \frac{X}{M_P} L H_u N + \int d^4 \theta \frac{X^*}{M_P} N N - \int d^2 \theta \sqrt{\frac{m_{3/2}}{M_P}} L H_u N + m_{3/2} N N + m_{3/2} \tilde{L} H_u \tilde{N} \]

Large LR mixing \( \sim m_{3/2} \nu_2 \) despite small Yukawa \( \sim \sqrt{(m_{3/2}/M_P)} \)

Mass eigenstates: mixtures of left-handed and right-handed sneutrinos

Natural with \( R \)-charge \( N(2/3), X(4/3), L(0), H_u(0) \)
Bosonic LSP Dark Matter

Annihilation of mixed sneutrino is suppressed by the mixing angle

$$ \propto \sin^4 \theta_{LR} $$

Can suppress the annihilation cross section
⇒ viable dark matter candidate
Lepton-Number Violation

\[ \int d^4x \frac{X^*}{M_P} \left( 1 + \frac{XX^*}{M_P^2} \right) NN - \int d^2\theta m_{3/2} \tilde{N} \tilde{N} + \frac{m_{3/2}^{5/2}}{M_P^{1/2}} \tilde{N} \tilde{N} \]

\( B \)-term mixes right-handed sneutrino and anti-sneutrino à la neutral kaon

CP-even \( \tilde{\nu}_+ \) and CP-odd \( \tilde{\nu}_- \) states with

\( \Delta m \sim m_{3/2}^{3/2} / M_P^{1/2} \sim 100\text{keV} \)

(Inspired by Grossman-Haber)
Inelastic Dark Matter
(Hall, Moroi, HM)

The coupling to Z-boson off-diagonal because of the Bose symmetry

Scatters inelastically on nuclei
Kinetic energy $mv^2/2 \sim 10^6 m$ vs $\Delta m \sim 100$keV
Only a part of the phase space has enough energy

$$v^2 \geq 2\Delta m \frac{m + m_N}{mm_N}$$
DAMA

Residuals (cpd/kg/keV)

Time (day)

2-6 keV

6.3σ

Cross-section [cm²/nucleon]

WIMP Mass [GeV]
Recoinciling DAMA
(Smith, Weiner)

Larger phase space to satisfy the kinematic threshold for heavier nucleus

\[ \gamma^2 \geq 2 \Delta m \frac{m + m_N}{m m_N} \]

More phase space for I than Ge

Inelastic dark matter can reconcile DAMA with constraints from CDMS/Edelweiss/ZEPLIN-I

Annual modulation enhanced

Consistent (HM, Peña-Garay)
Reconciliation
Confusing Collider Signature
(de Gouvêa, Friedland, HM)

Acoplanar leptons
Sleptons? No, charginos

Lepton+jets+missing
Charginos? No, sleptons
**Spin Determination**

Threshold behavior

\[ \sigma \propto \beta \] (spin 1/2),  
\[ \sigma \propto \beta^3 \] (spin 0)

Polar angle distribution

\[ \frac{d\sigma}{d\cos \theta} \propto 1 + \cos^2 \theta \] (spin 1/2)  
\[ \frac{d\sigma}{d\cos \theta} \propto \sin^2 \theta \] (spin 0)

Azimuthal correlation in decay planes for charginos  
(HM, LCWS2000)
Parameter Measurements

Measure mixing angle
Both sneutrino masses
Slepton mass
Use $D$-term relation to cross check
Measure bino mass from selectron production
Calculate $\Omega h^2$
Conclusions

SUSY Dark Matter does not need to be neutralino
Neutrinos may be light because of the small SUSY breaking scale $\Rightarrow$ TeV-scale seesaw
right-handed sneutrino also TeV-scale
left- and right-handed sneutrinos mix
sneutrino LSP
Lepton-number violating $B$-term $\Rightarrow$ inelastic dark matter
Can reconcile DAMA with other experiments
Collider signature confusing
LC can sort it out