Motivation

- **WMAP** has measured the relic density of dark matter to a relative uncertainty of 6%.
- We hope to see a dark matter particle signature at the LHC.
- How accurately can we determine the relic density from the results of such an experiment?

**Relic Density:**
A measure of the density of dark matter left in the universe.
Relic Density Determination

\[
\left( \frac{\Omega}{\chi_1^0} \right)^{-1} \propto \left[ \begin{array}{cccc}
\chi_1^0 & h, H, A, Z & f_{\tilde{f}} & f_{\tilde{f}} \\
\chi_1^0 & \chi_1^0 & \chi_1^0 & \chi_1^0 \\
\chi_1^0 & \chi_1^0 & \chi_1^0 & \chi_1^0 \\
\chi_1^0 & \chi_1^0 & \chi_1^0 & \chi_1^0 \\
\end{array} \right] + \left[ \begin{array}{cccc}
\chi_1^0 & \tau & \tau & \gamma \\
\tilde{\chi}_1^0 & \tilde{\chi}_1^0 & \tilde{\chi}_1^0 & \tilde{\chi}_1^0 \\
\end{array} \right] e^{-\Delta M / 20}
\]

Griest, Seckel’91

\[\Delta M = M_{\tilde{\chi}_1^0} - M_{\tilde{\chi}_1^0} = 5 \sim 15 \text{GeV}\]

mSUGRA (Minimal Supergravity)

- \(m_{1/2}\): Universal gaugino mass at Grand Unified Scale (\(M_G\))
- \(m_0\): Universal scalar mass at \(M_G\)
- \(A_0\): Trilinear coupling at \(M_G\)
- \(\tan \beta\): \(<H_u> / <H_d>\) at the electroweak scale
- \(\text{sign}(\mu)\): Sign of Higgs mixing parameter \((W = \mu H_u H_d)\)

- These parameters are at the Grand Unified Scale
- To relate these parameters to particle masses at the Electroweak Scale, one must solve the Renormalization Group Equations.

A small \(\Delta M\) can be natural within mSUGRA
As an example consider, the selectron…
We could get a small mass difference.

For $\tan \beta = 5 \ldots$

$$m^2_{\tilde{e}_R} = m_0^2 + 0.15 m_{1/2}^2 + (37\text{GeV})^2$$

$$m^2_{\tilde{\chi}^0_1} = 0.16 m_{1/2}^2$$

Our base case…

$A_0 = 0 \quad \tan \beta = 40 \quad \text{sign} \mu = 1$

$m_0 = 210 \text{GeV} \quad m_{1/2} = 360 \text{GeV}$

$\Delta M = 10.6 \text{GeV}$

For expected experimental uncertainties (30fb$^{-1}$):

hep-ph/0608193

The uncertainties in mSUGRA parameters:

$\frac{\delta m_0}{m_0} \approx 4\% \quad \frac{\delta m_{1/2}}{m_{1/2}} \approx 6\%$
Relative Uncertainty in Relic Density

For expected experimental uncertainties:

\[ \frac{\delta M}{M} = 15\% \]

\[ \frac{\delta m_g}{m_g} = 6\% \]

The uncertainty in Relic Density:

\[ \frac{\delta \Omega_{\tilde{\chi}_1^0 h^2}}{\Omega_{\tilde{\chi}_1^0 h^2}} \approx 20\% \]

(WMAP’s is 6%)

Summary and Conclusion

- At 30fb\(^{-1}\) we expect to measure to the following relative uncertainties:
  \[ \frac{\delta \Delta M}{\Delta M} = 15\% \quad \frac{\delta m_g}{m_g} = 6\% \]
  hep-ph/0608193

- This results in uncertainties in mSUGRA parameters of:
  \[ \frac{\delta m_0}{m_0} = 4\% \quad \frac{\delta m_{1/2}}{m_{1/2}} = 6\% \]

- These result in an uncertainty in the relic density of:
  \[ \frac{\delta \Omega_{\tilde{\chi}_1^0}}{\Omega_{\tilde{\chi}_1^0}} = 20\% \]
  (WMAP error: 6%)
Ongoing Task: Testing Gaugino Universality

\[ M_{\tau\tau}^{\text{peak}} \propto \frac{1}{k} \sqrt{1-k^2} \sqrt{2\Delta M \cdot M_{\tilde{g}} \cdot k_1} \]

\[ k \approx \frac{M_{\tilde{\chi}_1^0}}{M_{\tilde{\chi}_2^0}} \quad k_1 \approx \frac{M_{\tilde{\chi}_1^0}}{M_{\tilde{g}}} \]

- \( M_{\tau\tau}, M_{\tilde{g}} \) from 2\( \tau \)/3\( \tau \) analysis.
- \( \Delta M \) from low energy tau transverse momentum.
- We can then find a relation between \( k_1, k \).

→ Test Gaugino Universality (a strong prediction of mSUGRA!)

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