Cosmological Connection of SUSY Models at the LHC

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We are about to enter into an era of major discovery

Dark Matter: we need new particles to explain the content of the universe

Standard Model: we need new physics

Supersymmetry solves both problems!

The super-partners are distributed around 100 GeV to a few TeV

LHC: directly probes TeV scale

Future results from PLANCK, direct and indirect detections, rare decays etc. experiments in tandem with the LHC will confirm a model

This talk: Can we establish SUSY models at the LHC? How accurately we can calculate dark matter density?
The signal:

jets + leptons + t’s + W’s + Z’s + H’s + missing $E_T$
SUSY at the LHC: Dilemma...
SUSY at the LHC

Final states $\rightarrow$ Model Parameters $\rightarrow$ Calculate dark matter density
Reconstruct sparticle masses, e.g.,

\[ \tilde{Q} \rightarrow q + l + \tilde{\chi}^0_1 \]
\[ \tilde{L} \rightarrow l + \tilde{\chi}^0_1 \]
\[ \tilde{\chi}^0_{2,3,4} \rightarrow Z, h, \bar{\ell} l + \tilde{\chi}^0_1 \] etc.

We may not be able to solve for masses of all the sparticles from a model

Solving for the MSSM : Very difficult

Identifying one side is very tricky!
SUSY at the LHC: Dilemma...
SUSY at the LHC Dilemma...

OS-LS Subtraction

![Graph showing counts and $M_{2\tau}$ distribution](image)
Extracting One side: $j\tau\tau$: BEST

OS-LS selection of ditaus selects $\tilde{\chi}_2^0$, but if we need to reconstruct the entire side.

We use the following subtraction scheme: **BEST**

The OS-LS $\tau$ pair has momentum related to the momentum of this Same Event Jet.

We collect all $2\tau+$ Jet pairs: get related pairs plus random pairs.

Using Jets from Previous Events: get only random pairs.

Normalize and perform the Same Jet - Previous Jet subtraction:

- **Random** pairs will cancel.
- Only the **related** pairs remain.

Bi Event Subtraction technique: **BEST**
BEST and SUSY Dilemma...
Event #n-1

Event #n

Background

Signal +Background

Dutta, Kamon, Kolev, Krislock,
arXiv:1104.2508 [hep-ph]
PLB’11
What BEST Looks Like...
Top reconstruction: BEST

Even with backgrounds, BEST triumphs.

- 7 TeV collision energy @ LHC, 2 fb$^{-1}$.
- ALPGEN - $t\bar{t}$ signal and $W$+jets background
- PYTHIA - shower
- PGS - detector

$m_W = 81.11 \pm 0.32$ GeV

$m_t = 170.5 \pm 1.5$ GeV
End Point Techniques with BEST

Even with backgrounds on top of SUSY, BEST triumphs.

- 14 TeV collision energy @ LHC, 100 fb$^{-1}$.
- nuSUGRA: $m_0 = 360$ GeV, $m_{1/2} = 500$ GeV, $\tan \beta = 40$, $A_0 = 0$, and $m_H = 732$ GeV.
- SM: $t\bar{t}$, $W+$Jets, and $Z+$Jets.

Significance improves 5 times with BEST
Determining mSUGRA Parameters

✓ Solved by inverting the following functions:

\[
M^{\text{peak}}_{j\tau\tau} = X_1(m_{1/2},m_0)
\]

\[
M^{\text{peak}}_{\tau\tau} = X_2(m_{1/2},m_0,\tan \beta,A_0)
\]

\[
M^{\text{peak}}_{\text{eff}} = X_3(m_{1/2},m_0)
\]

\[
M^{(b)\text{peak}}_{\text{eff}} = X_4(m_{1/2},m_0,\tan \beta,A_0)
\]

\[
\begin{align*}
 m_0 &= 210 \pm 5 \\
 m_{1/2} &= 350 \pm 4 \\
 A_0 &= 0 \pm 16 \\
 \tan \beta &= 40 \pm 1
\end{align*}
\]

\[
\Omega_{\tilde{\chi}_1^0 h^2} = Z(m_0,m_{1/2}\tan \beta,A_0)
\]

\[
\frac{\delta \Omega_{\tilde{\chi}_1^0 h^2}}{\Omega_{\tilde{\chi}_1^0 h^2}} = 6.2\% \ (30 \text{ fb}^{-1})
\]

\[
\frac{\delta \sigma_{\tilde{\chi}_1^0 - p}}{\sigma_{\tilde{\chi}_1^0 - p}} \approx 7\% \ (30 \text{ fb}^{-1})
\]

Arnowitt, Dutta, Gurrola, Kamon, Krislock and Toback’PRL, 08
NUSUGRA: Relic Density

Non Universal SUGRA Model: 

\[ m_{Hu}^2 = m_0^2 (1 + \delta_u^2), \quad m_{Hd}^2 = m_0^2 (1 + \delta_d^2), \]

- \( M_{\text{eff}}^{\text{peak}} = f_1(m_{1/2}); \)
- \( M_{\text{eff}}^{(b, \text{no } W) \text{ peak}} = f_2(m_{1/2}); \)
- \( M_{j_\gamma}^{\text{end}} = f_3(m_{1/2}, m_H); \)
- \( M_{j_\gamma}^{\text{peak}} = f_4(m_{1/2}, m_H, m_0); \)
- \( M_{\tau \tau}^{\text{end}} = f_5(m_{1/2}, m_H, m_0, A_0); \)
- \( M_{j_\gamma}^{\text{end}} = f_6(m_{1/2}, m_H, m_0, A_0, \tan \beta). \)

\[
\begin{array}{|c|c|c|c|c|c|c|c|}
\hline
\mathcal{L} (\text{fb}^{-1}) & m_{1/2} (\text{GeV}) & m_H (\text{GeV}) & m_0 (\text{GeV}) & A_0 (\text{GeV}) & \tan \beta & \mu (\text{GeV}) & \Omega_{\chi_0 h^2} \\hline
1000 & 500 \pm 3 & 727 \pm 10 & 366 \pm 26 & 3 \pm 34 & 39.5 \pm 3.8 & 321 \pm 25 & 0.094^{+0.107}_{-0.038} \\hline
100 & 500 \pm 9 & 727 \pm 13 & 367 \pm 57 & 0 \pm 73 & 39.5 \pm 4.6 & 331 \pm 48 & 0.088^{+0.108}_{-0.072} \\hline
\text{Syst.} & \pm 10 & \pm 15 & \pm 56 & \pm 66 & \pm 4.5 & \pm 48 & +0.175_{-0.072} \\hline
\end{array}
\]

Dutta, Kamon, Kolev, Krislock, Oh, PRD ‘10
Mirage Mediation

• We have moduli mediation plus anomaly mediation

• Using observables like: $M_{\text{eff}}, M_{\tau\tau}, P_t, M_{j_{\tau\tau}}$, it is possible to reconstruct the gaugino masses to check the gaugino unification scale

Input from the experimental measurements

Dutta, Kamon, Sinha, Wang, to appear

Values of the masses at the GUT scale

$@ 10 \text{ fb}^{-1}$
Conclusion

- Signature contains missing energy (R parity conserving) many jets and leptons: Discovering SUSY should not be a problem!
- Once SUSY is discovered, attempts will be made to measure the sparticle masses (highly non trivial!), establish the model and make connection between particle physics and cosmology
- Different cosmologically motivated regions of the SUGRA models have distinct signatures.
- Use the signatures and BEST to construct a decision tree
- It is possible to determine model parameters and the relic density based on the LHC measurements
- non-universal model parameters (Higgs non-universality)----Can be determined
- Mirage mediation models? ----Can be determined