Signatures of non-universal Gaugino and Scalar masses at the Large Hadron Collider (LHC)

Subhaditya Bhattacharya

**RECAP**
Harish-Chandra Research Institute, Allahabad, India

Work done with AseshKrishna Datta, and Biswarup Mukhopadhyaya


(arXiv:0804.4051)
Plan of the talk

- Basic ideas behind the work.
- Non-universal gaugino masses
  - Model
  - Choice of Parameters
  - Collider simulation
  - Results
- Non-universal Scalar masses
  - Squark-Slepton non-universality
  - Third family scalar non-universality
  - Scalar non-universality for $SO(10)$ $D$ – term
Basic ideas behind the work: Gaugino mass non-universality

- Theoretical prediction $\rightarrow$ SUSY GUT $\rightarrow$ Non-universal gaugino masses at $M_{GUT}$.

- Non-universality of gaugino masses $\rightarrow$ affects the chargino-neutralino mass composition.

- Collider signature $\rightarrow$ should get altered for various gaugino non-universal ratios.

- Intention $\rightarrow$ distinguish them at LHC.

- To do so $\rightarrow$ perform collider simulation for 'multichannel search' over a wide region of parameter space.
Basic ideas behind the work: Scalar mass non-universality

- Theoretical SUSY GUT & Various phenomenological models → Non-universal scalar masses at $M_{GUT}$

- Non-universal scalar masses → alters scalar mass hierarchy → alters decay branching fractions.

- Intention → distinguish scalar mass scenarios at LHC.

- To do so → perform collider simulation for ’multichannel search’ over a wide region of parameter space
Non-universal gaugino mass: Model

- Theoretical framework: N=1 Supergravity embedded in SU(5) or SO(10) GUT group.

- Gaugino masses depend crucially on $f_{\alpha\beta}(\Phi)$.

  - Gauge kinetic function $f_{\alpha\beta}(\Phi)$.

  - Analytic function of chiral superfields $\Phi_i$.

  - Transforms as symmetric product of the adjoint representation.
Non-universal gaugino mass: (Model contd.)

Part of the \( N=1 \) supergravity lagrangian containing \textit{kinetic energy and mass terms for gauginos and gauge bosons}

\[
e^{-1} \mathcal{L} = -\frac{1}{4} \text{Re} f_{\alpha\beta}(\phi)(-1/2\bar{\lambda}^\alpha \partial \lambda^\beta) \\
- \frac{1}{4} \text{Re} f_{\alpha\beta}(\phi) F^\alpha_{\mu\nu} F^{\beta\mu\nu} \\
+ \frac{1}{4} e^{-G/2} G^i \left( G^{-1} \right)_i^j \left[ \partial f_{\alpha\beta}^*(\phi^*) / \partial \phi^*^j \right] \lambda^\alpha \lambda^\beta + h.c
\]

where

\( G^i = \partial G / \partial \phi_i \) and \( (G^{-1})_i^j \) is the inverse matrix of \( G^j_i \equiv \partial G / \partial \phi^*^i \partial \phi^*_j \),

\( \lambda^\alpha \) is the gaugino field, and

\( \phi \) is the scalar component of the chiral superfield \( \Phi \).
Non-universal gaugino mass: (Model contd.)

- In terms of the non-singlet $\Phi^N$ fields:

$$f_{\alpha\beta}(\Phi^j) = f_0(\Phi^S)\delta_{\alpha\beta} + \sum_N \xi_N(\Phi^S) \frac{\Phi^N_{\alpha\beta}}{M} + \mathcal{O}\left(\frac{\Phi^N}{M}\right)^2$$

where

- $f_0$ and $\xi^N$ are functions of chiral singlet superfields and

- $M = \frac{M_{Pl}}{\sqrt{8\pi}}$.

- Contribution to $f_{\alpha\beta}$ from $\Phi^N$ 'has to come' through symmetric products of the adjoint representation of associated GUT group.
Non-universal gaugino mass: (Model contd.)

- For SU(5) possible non-singlet irreducible representations (to which $\Phi^N$ can belong):

\[(24 \times 24)_{symm} = 1 + 24 + 75 + 200\]

- For SO(10):

\[(45 \times 45)_{symm} = 1 + 54 + 210 + 770\]
Non-universal gaugino mass: (Model contd.)

- To obtain low energy effective theory replace $\Phi^S$ and $\Phi^N$ by their vev’s and get $\langle f_{\alpha\beta} \rangle$.

- $\langle f_{\alpha\beta} \rangle$ get the form $f_\alpha \delta_{\alpha\beta} \rightarrow$ Non-Universal

- The value of $\langle f_{\alpha\beta} \rangle \rightarrow$ crucially depends on the specific representation responsible for the process.

- If symmetry breaking occurs via gauge singlet fields only $\rightarrow f_{\alpha\beta} = f_0 \delta_{\alpha\beta} \rightarrow \langle f_{\alpha\beta} \rangle = f_0 \rightarrow$ Universal
Non-universal gaugino mass: (Model contd.)

Simplify $\rightarrow$ Neglect the non-universal contributions to the gauge couplings at the GUT scale.

Table 1: Gaugino mass ratios for SU(5).

<table>
<thead>
<tr>
<th>Representation</th>
<th>$M_3 : M_2 : M_1$ at $M_{GUT}$</th>
<th>$M_3 : M_2 : M_1$ at $M_{EW,SB}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1:1:1</td>
<td>6:2:1</td>
</tr>
<tr>
<td>24</td>
<td>2:(-3):(-1)</td>
<td>12:(-6):(-1)</td>
</tr>
<tr>
<td>75</td>
<td>1:3:(-5)</td>
<td>6:6:(-5)</td>
</tr>
<tr>
<td>200</td>
<td>1:2:10</td>
<td>6:4:10</td>
</tr>
</tbody>
</table>
Considered only the lowest representation (54) of SO(10).

Table 2: Gaugino mass ratios for SO(10).

<table>
<thead>
<tr>
<th>Representation</th>
<th>$M_3 : M_2 : M_1$ at $M_{GUT}$</th>
<th>$M_3 : M_2 : M_1$ at $M_{EW_{SB}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1:1:1</td>
<td>6:2:1</td>
</tr>
<tr>
<td>54(i): $H \to SU(2) \times SO(7)$</td>
<td>1:(-7/3):1</td>
<td>7:(-5):1</td>
</tr>
<tr>
<td>54(ii): $H \to SU(4) \times SU(2) \times SU(2)$</td>
<td>1:(-3/2):(-1)</td>
<td>7:(-3):(-1)</td>
</tr>
</tbody>
</table>

Choice of SUSY parameters: Two options explored

- **pMSSM**: A phenomenological model
  - low-energy scalar masses phenomenological → degenerate squark and slepton mass with non-universal $M_i$ at $M_{GUT}$.

- **Non-universal SUGRA**:
  - Generated from $m_0$, $A_0$ and $sgn(\mu)$, with non-universal $M_i$ at $M_{GUT}$. 
The channels searched for: \((\ell \text{ stands for } e \text{ or } \mu)\)

- Opposite sign dilepton (OSD): 
  \((\ell^\pm \ell^\mp) + (\geq 2) \text{ jets} + E_T\)

- Same sign dilepton (SSD): 
  \((\ell^\pm \ell^\pm) + (\geq 2) \text{ jets} + E_T\)

- Single lepton* \((1\ell + \text{ jets})\): 
  \(1\ell + (\geq 2) \text{ jets} + E_T\)

- Trilepton \((3\ell + \text{ jets})\): 
  \(3\ell + (\geq 2) \text{ jets} + E_T\)

- Hadronically quiet trilepton* \(((3\ell))\): 
  \(3\ell + 0 \text{ jets} + E_T\)

- Inclusive jet \((\text{ jets})\): 
  \((\geq 3) \text{ jets} + E_T\)
Non-univ gaugino masses: (Collider simulation contd.)

- $E_T \geq 100$ GeV.
- $p_{T\ell} \geq 20$ GeV and $|\eta_\ell| \leq 2.5$.

An isolated lepton should have

- lepton-lepton separation $\Delta R_{\ell\ell} \geq 0.2$
- lepton-jet separation $\Delta R_{\ell j} \geq 0.4$
- the energy deposit due to jet activity around a lepton $E_T$ within $\Delta R \leq 0.2$ of the lepton axis should be $\leq 10$ GeV.

- $E_{T\text{jet}} \geq 100$ GeV and $|\eta_{\text{jet}}| \leq 2.5$. 
SM Background:

- All dominant standard model (SM) events generated.
- $t\bar{t}$ production most serious.

In the histograms where any of the entries in the ratio has $\sigma = S/\sqrt{B} \leq 2$ for $300 fb^{-1} \rightarrow$ specially marked with a ’#’. 
Non-universal gaugino masses: Results

Figure 1: Event ratios for pMSSM in SU(5): $m_{\tilde{g}} = 500$ GeV, $\mu = 300$ GeV, $\tan \beta = 40$
Non-universal gaugino masses: Results

Figure 2: Event ratios for pMSSM in SO(10): $m_{\tilde{f}} = 1000$ GeV, $\mu = 1000$ GeV, $\tan \beta = 5$
Non-universal gaugino masses: Conclusions

- In a substantial region of the parameter space $\rightarrow 75$ and $200$ of SU(5) and $54$ (i) of SO(10) easily distinguishable.

- $24$ of SU(5), $54$(ii) of SO(10) and the universal case $\rightarrow$ distinction is relatively difficult.

- Trilepton channel is the most efficient discriminator.

- Extraction of $\mu$ in pMSSM kind of framework is a challenging task. $\rightarrow$ important.
Non-universal scalar mass: Model 1

Model 1: Squark-Slepton Non-universality

Squarks and sleptons evolved from $m_{0\tilde{q}}$ and $m_{0\tilde{l}}$ respectively.
Figure 3: Event ratios for Squark-slepton Non-universality: $\tan \beta = 5$
Squark-slepton Non-universality: Results

- Cases with $m_{\tilde{l}_{1,2}} = 250$ GeV, is fairly distinguishable $\rightarrow$ especially for squark masses on the higher side.

- The $3\ell + jets$ events distinguish $m_{\tilde{l}_{1,2}} = 750$ GeV $\rightarrow$ more prominent for high gluino mass and large $\tan \beta$.

- Cases with $m_{\tilde{l}_{1,2}} = 500$ GeV $\rightarrow$ difficult to differentiate from universal case.
Non-universal scalar mass: Model2

- **Model 2**: Third family scalar non-universality

- Third family scalars evolve from separate mass parameter \( m_0^3 \) from that of first two families \( m_0^{(1,2)} \).

- 1,2 families scalars may be very heavy \( \longrightarrow \) so called ‘inverted hierarchy’ \( \longrightarrow \) suppresses FCNC.
3rd family scalar Non-universality: Results

Figure 4: Event ratios for 3rd generation scalar Non-universality: $\tan \beta = 5$
3rd family scalar non-universality: Results

- The ratios are significantly higher for $m_{\tilde{q}^1,2} = 10$ TeV $\rightarrow$ Distinguishable.

- The ratios are significantly smaller for $m_{\tilde{q}^1,2} = 1$ TeV $\rightarrow$ Distinguishable.

- Unlike the other cases $\rightarrow$ very little dependence on the value of $\tan \beta$. 
Non-universal scalar masses: Model 3

**Model 3: Non-universality due to $SO(10)$ $D$-term**

- Matter fields belong to rep $16$ further classified into submultiplets depending on the representations of $SU(5)$ to which they belong.

- $\bar{5}(D^c & L)$ or $10(E^c, U^c & Q)$.

- Breakdown of $SO(10)$ to SM gives different $D$-terms for different $SU(5)$ rep.

- Respectively for $\bar{5}$ and $10$:

\[
m_{\bar{5}}^2 = m_0^2 - 1.5Dm_0^2 \quad (\text{for } D^c & L)
\]
\[
m_{10}^2 = m_0^2 + 0.5Dm_0^2 \quad (\text{for } E^c, U^c & Q)
\]
Figure 5: Event ratios for Scalar Non-universality due to $SO(10)\ D$ – term: $\tan\beta = 5$
Scalar Non-universality due to $SO(10)$ $D$ - term : Results

- For $m_{\tilde{g}} = 1$ TeV and 1.5 TeV $\rightarrow$ distinction between $D = 0.5$, -0.5 and -1.25 $\rightarrow$ difficult from the ratio plot.

- For $m_{\tilde{g}} = 500$ GeV $\rightarrow$ $D = 0.5$ and $D = -1.25$ easily distinguishable from the ratios.

- The hadronically quiet trilepton $\rightarrow$ largely washed out by backgrounds excepting for $m_{\tilde{g}} = 500$ GeV.
Non-universal scalar mass: Conclusions

- Unlike gaugino non-universality → schemes of scalar non-universality more non-uniform.

- Easiest identification → 1,2 family very heavy → ’inverted hierarchy’.

- Most difficult → Various D-terms, particularly for high gluino mass.
Thank You