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

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Work done with AseshKrishna Datta, and Biswarup Mukhopadhyaya

(arXiv:0708.2427, JHEP 10(2007)080)

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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 $\longrightarrow$ SUSY GUT $\longrightarrow$ Non-universal gaugino masses at M_{GUT}.

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

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

- Intention $\longrightarrow$ distinguish them at LHC.

- To do so $\longrightarrow$ 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 $\longrightarrow$ Non-universal scalar masses at M_{GUT}
- Non-universal scalar masses $\longrightarrow$ alters scalar mass heirarchy $\longrightarrow$ alters decay branching fractions.
- Intention $\longrightarrow$ distinguish scalar mass scenarios at LHC.
- To do so $\longrightarrow$ 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 $\longrightarrow$

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

    - Analytic function of chiral superfields Φ_i.
    - Transforms as $\longrightarrow$ symmetric product of the adjoint representation

Non-universal gaugino mass: (Model contd.)

- Part of the N=1 supergravity lagrangian *containing kinetic energy and mass terms for gauginos and gauge bosons*

$$
\begin{aligned}
e^{-1}\mathcal{L} &= -\frac{1}{4} Re f_{\alpha\beta}(\phi)(-1/2\bar{\lambda}^{\alpha} \not{D} \lambda^{\beta}) \\
&- \frac{1}{4} Re f_{\alpha\beta}(\phi) F^{\alpha}_{\mu\nu} F^{\beta\mu\nu} \\
&+ \frac{1}{4} e^{-G/2} G^{i}((G^{-1})^{j}_{i})[\partial f^{*}_{\alpha\beta}(\phi^{*})/\partial\phi^{*j}]\lambda^{\alpha}\lambda^{\beta} + h.c
\end{aligned}
$$

where

- $G^i = \partial G/\partial\phi_i$ and $(G^{-1})^i_j$ is the inverse matrix of $G^j{}_i \equiv \partial G/\partial\phi^{*i}\partial\phi_j$,
- λ^α is the gaugino field, and
- ϕ is the scalar component of the chiral superfield Φ.

Non-universal gaugino mass: (Model contd.)

- In terms of the non-singlet Φ^N fields :

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

where

  - f_0 and ξ^N are functions of chiral singlet superfields and
  - $M = M_{Pl}/\sqrt{8\pi}$.

- Contribution to $f_{\alpha\beta}$ from Φ^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 Φ^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 $\longrightarrow$ replace Φ^S and Φ^N by their vev's and get $\langle f_{\alpha\beta} \rangle$.

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

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

- If symmetry breaking occurs via gauge singlet fields only $\longrightarrow f_{\alpha\beta} = f_0 \delta_{\alpha\beta} \longrightarrow \langle f_{\alpha\beta} \rangle = f_0 \longrightarrow$ Universal

Non-universal gaugino mass: (Model contd.)

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

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

Representation	$M_3 : M_2 : M_1$ at M_{GUT}	$M_3 : M_2 : M_1$ at M_{EWSB}
1	1:1:1	6:2:1
24	2:(-3):(-1)	12:(-6):(-1)
75	1:3:(-5)	6:6:(-5)
200	1:2:10	6:4:10

Non-universal gaugino mass: (Model contd.)

- Considered only the lowest representation (54) of SO(10).

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

Representation	$M_3 : M_2 : M_1$ at M_{GUT}	$M_3 : M_2 : M_1$ at M_{EWSB}
1	1:1:1	6:2:1
54(i): $H \rightarrow SU(2) \times SO(7)$	1:(-7/3):1	7:(-5):1
54(ii): $H \rightarrow SU(4) \times SU(2) \times SU(2)$	1:(-3/2):(-1)	7:(-3):(-1)

(Chamoun et al. Nucl.Phys.B 624(2002)81)

Choice of SUSY parameters: Two options explored

- pMSSM: A phenomenological model
  - low-energy scalar masses phenomenological $\longrightarrow$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}.

Non-universal gaugino masses: Collider simulation

- The channels searched for: (ℓ stands for e or μ)
  - Opposite sign dilepton (OSD) :
    $(\ell^{\pm}\ell^{\mp}) + (\geq 2)\ jets\ + \not{E_T}$
  - Same sign dilepton (SSD) : $(\ell^{\pm}\ell^{\pm}) + (\geq 2)\ jets\ + \not{E_T}$
  - Single lepton* $(1\ell + jets)$: $1\ell\ + (\geq 2)\ jets\ + \not{E_T}$
  - Trilepton $(3\ell + jets)$: $3\ell\ + (\geq 2)\ jets\ + \not{E_T}$
  - Hadronically quiet trilepton* ((3ℓ)): $3\ell\ + 0\ jets\ + \not{E_T}$
  - Inclusive jet ($jets$): $(\geq 3)\ jets\ + \not{E_T}$

Non-univ gaugino masses: (Collider simulation contd.)

- $\not{E}_T \geq 100$ GeV.
- $p_{T\ell} \geq 20$ GeV and $|\eta_\ell| \leq 2.5$.
- An isolated lepton should have
  - lepton-lepton separation $\triangle R_{\ell\ell} \geq 0.2$
  - lepton-jet separation $\triangle R_{\ell j} \geq 0.4$
  - the energy deposit due to jet activity around a lepton E_T within $\triangle R \leq 0.2$ of the lepton axis should be ≤ 10 GeV.
- $E_{T\,jet} \geq 100$ GeV and $|\eta_{jet}| \leq 2.5$.

Non-univ gaugino masses: (Collider simulation contd.)

- 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 $300 fb^{-1} \longrightarrow$ specially marked with a '#'.

Non-universal gaugino masses: Results

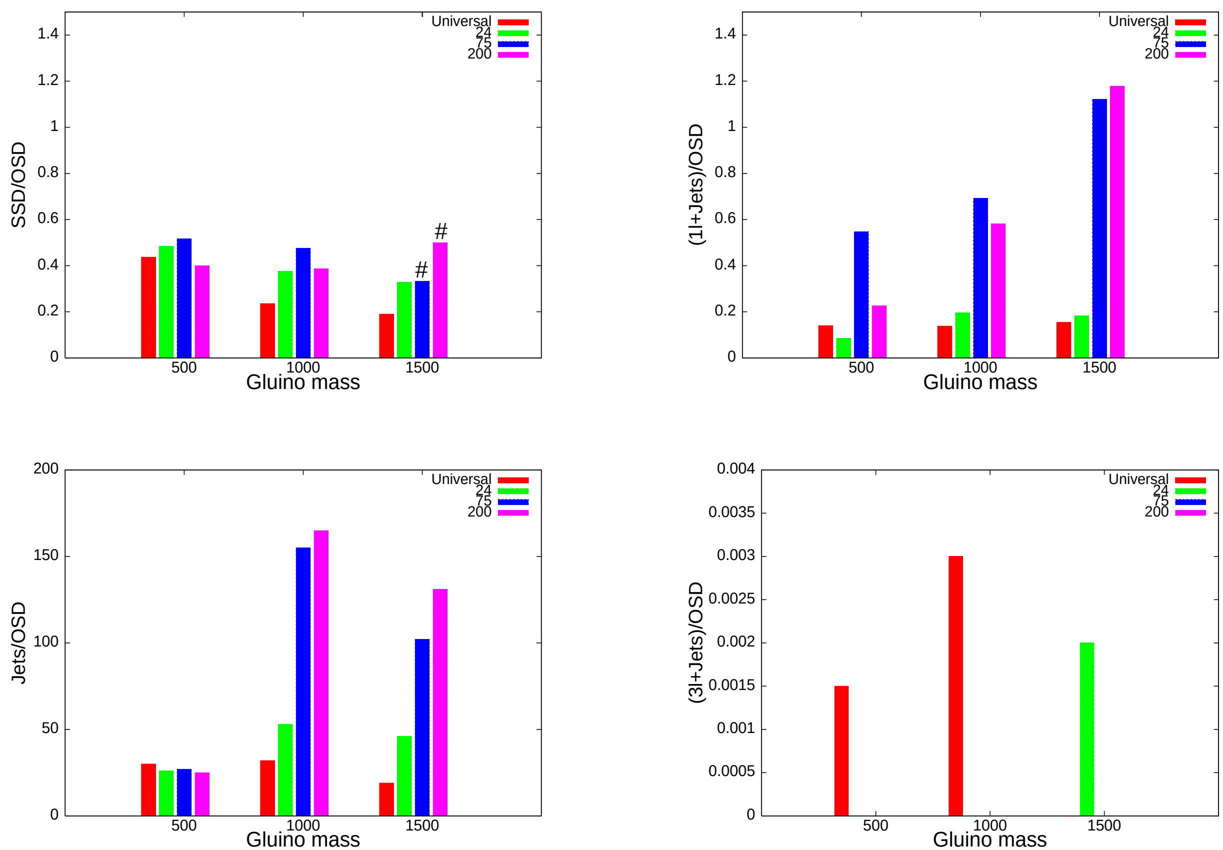

Figure 1: Event ratios for **pMSSM** in SU(5): $m_{\tilde{f}}$ =500 GeV, μ =300 GeV, $\tan\beta = 40$

Non-universal gaugino masses: Results

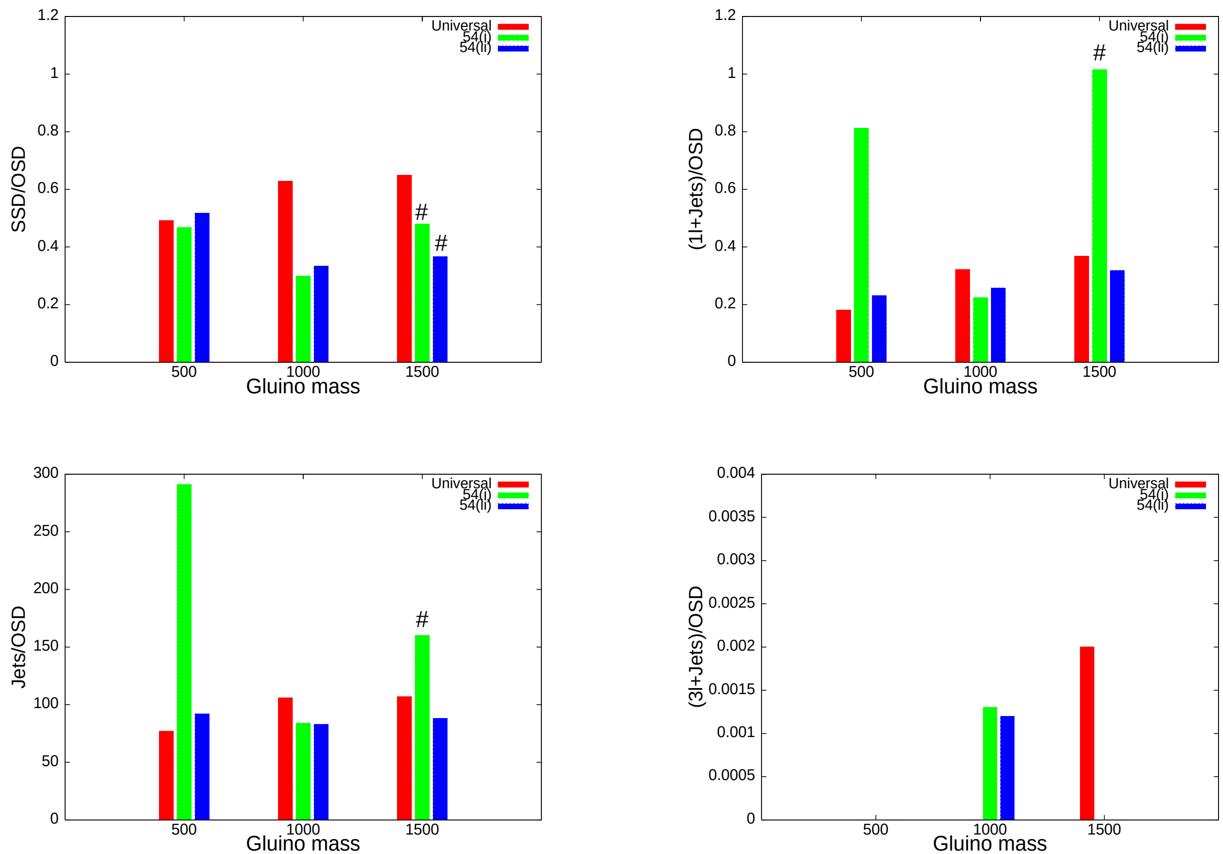

Figure 2: Event ratios for **pMSSM** in SO(10): $m_{\tilde{f}}$ =1000 GeV, μ =1000 GeV, $\tan\beta = 5$

Non-universal gaugino masses: Conclusions

- In a substantial region of the parameter space $\longrightarrow$ **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 $\longrightarrow$ distinction is relatively difficult.
- Trilepton channel is the most efficient discriminator.
- Extraction of μ in pMSSM kind of framework is a challenging task. $\longrightarrow$ important.

Non-universal scalar mass: Model1

- Model 1: Squark-Slepton Non-universality
  - Squarks and sleptons evolved from $\longrightarrow$ mutually uncorrelated mass parameters $m_{0\tilde{q}}$ and $m_{0\tilde{l}}$ respectively.

Squark-slepton Non-universality: Results

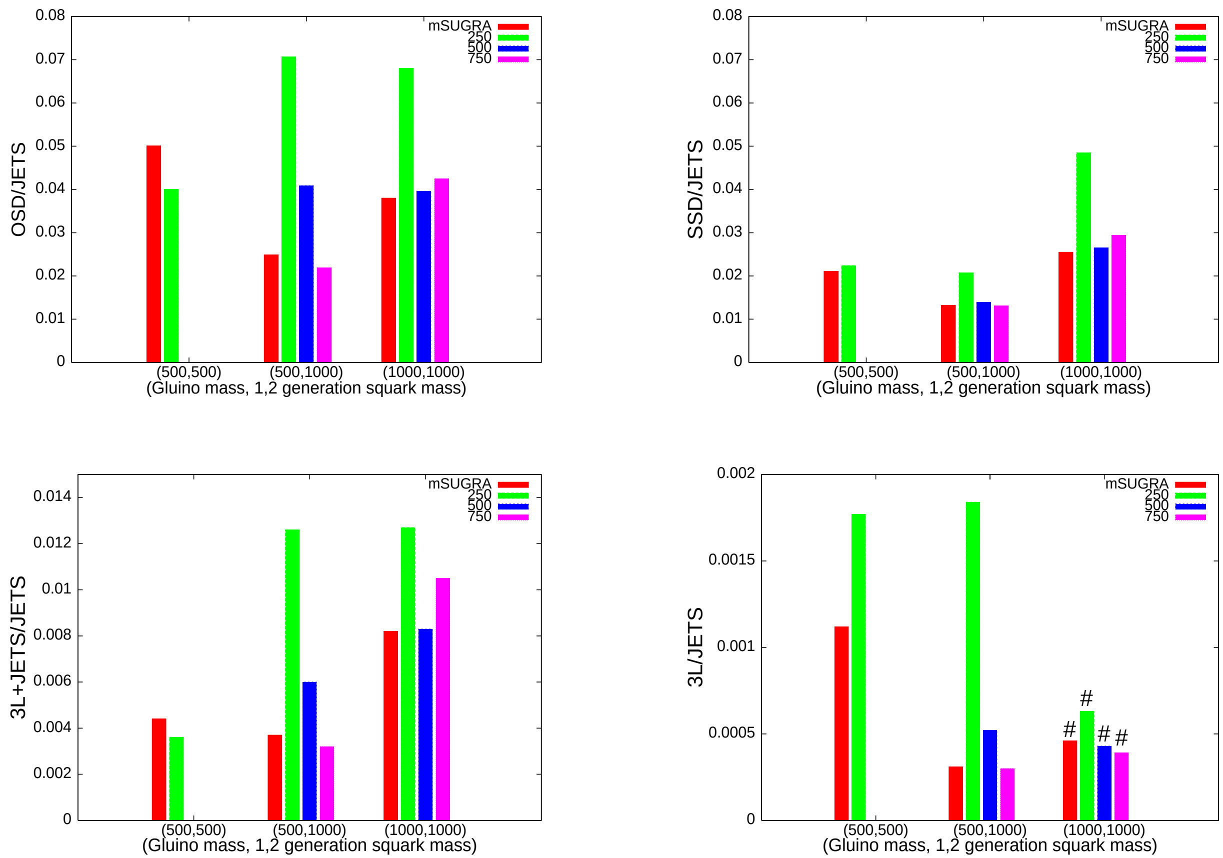

Figure 3: Event ratios for Squark-slepton Non-universality: $\tan\beta = 5$

Squark-slepton Non-universality: Results

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

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

- Cases with $m_{\tilde{l}1,2} = 500$ GeV $\longrightarrow$ 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

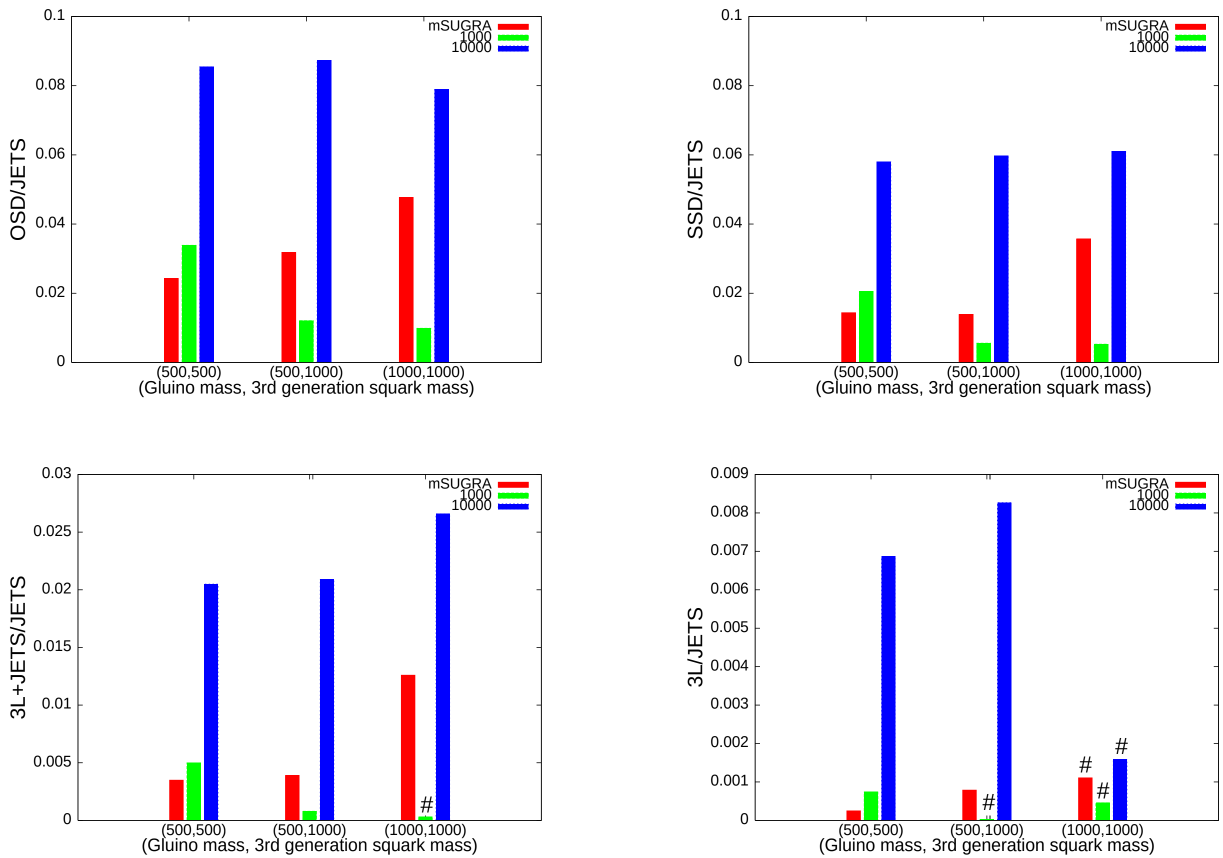

Figure 4: Event ratios for 3rd generation scalar Non-universality: $\tan\beta = 5$

3rd family scalar non-universality: Results

- The ratios are significantly higher for $m_{\tilde{q}^{1,2}} = 10$ TeV $\longrightarrow$ Distinguishable.
- The ratios are significantly smaller for $m_{\tilde{q}^{1,2}} = 1$ TeV $\longrightarrow$ Distinguishable.
- Unlike the other cases $\longrightarrow$ very little dependence on the value of $\tan\beta$.

Non-universal scalar masses: Model3

- Model 3: Non-universality due to $SO(10)$ D-term
  - Matter fields belong to rep **16** $\longrightarrow$ further classified into submultiplets $\longrightarrow$ depending on the representations of $SU(5)$ to which they belong.
  - $\bar{\mathbf{5}}(D^c \;\&\; L)$ or $\mathbf{10}(E^c, U^c \;\&\; Q)$.
  - Breakdown of $SO(10)$ to SM gives $\longrightarrow$ different D-terms for different $SU(5)$ rep .
  - Respectively for $\bar{5}$ and **10**:

$$m_{\bar{5}}^2 = m_0^2 - 1.5Dm_0^2 \quad (for\ D^c \;\&\; L)$$
$$m_{10}^2 = m_0^2 + 0.5Dm_0^2 \quad (for\ E^c, U^c \;\&\; Q)$$

Scalar Non-universality due to $SO(10)\ D - term$: Results

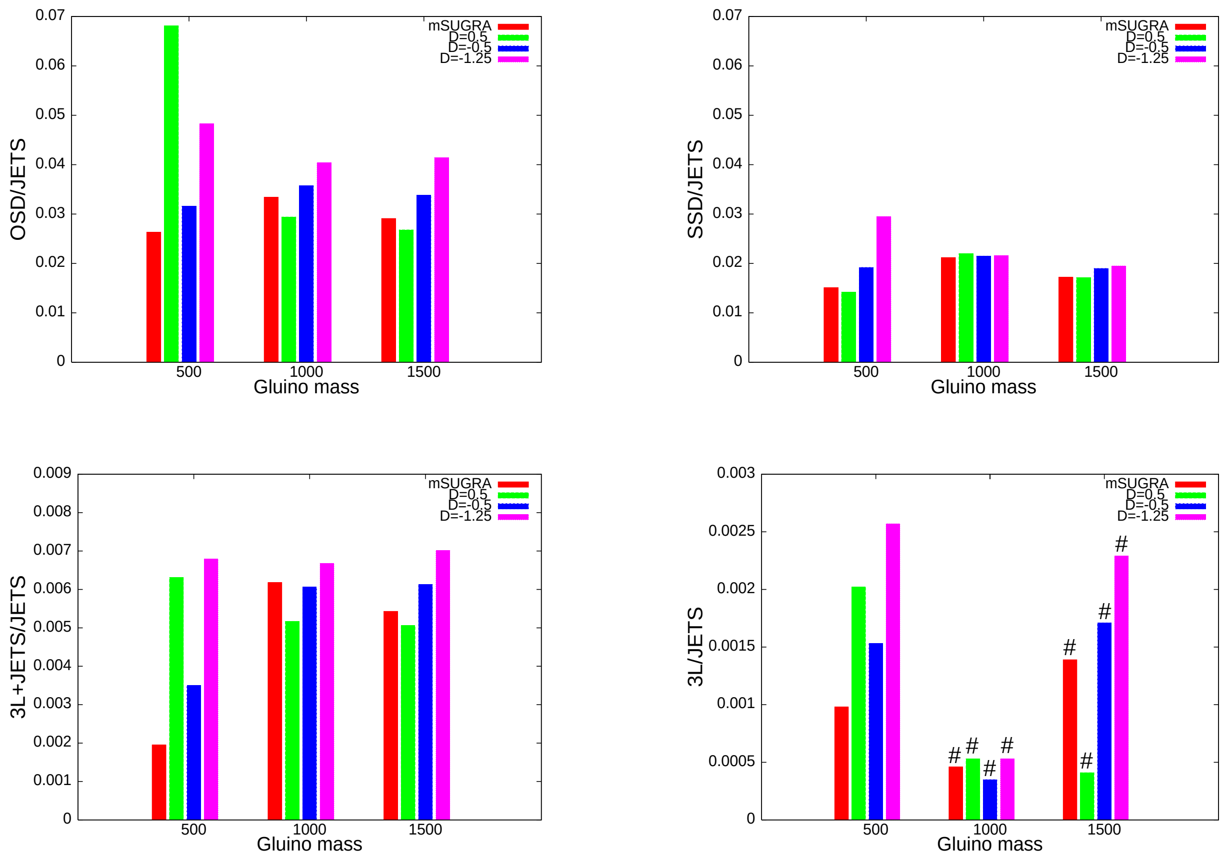

Figure 5: Event ratios for Scalar Non-universality due to $SO(10)\ D - term$: $\tan\beta = 5$

Scalar Non-universality due to $SO(10)\ D-term$: Results

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

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

- The hadronically quiet trilepton $\longrightarrow$ largely washed out by backgrounds excepting for $m_{\tilde{g}}$= 500 GeV.

Non-universal scalar mass: Conclusions

- Unlike gaugino non-universality $\longrightarrow$ schemes of scalar non-universality more non-uniform.
- Easiest identification $\longrightarrow$ 1,2 family very heavy$\longrightarrow$ 'inverted heirarchy'.
- Most difficult $\longrightarrow$ Various D-terms, particularly for high gluino mass.

Thank You