Studying Gaugino Mass Unification at the LHC

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Setup

- Assume SUSY discovered early on at LHC
- Want to determine broad characteristics of underlying theory
  - → Can we determine if gaugino masses are universal independent of actual model?
- Assume MSSM with gaugino masses obeying Mirage pattern

$$M_1 \, : \, M_2 \, : \, M_3 \, \simeq \, (1 + 0.66\alpha) \, : \, (2 + 0.2\alpha) \, : \, (6 - 1.8\alpha)$$

- Can we demonstrate $\alpha \neq 0$ using a relatively small amount of luminosity?
- Approach: determine observables which are sensitive to small changes in α with other SUSY soft terms held fixed
- Won't assume measurement of sparticle masses, will assume knowledge of soft term inputs (need to start somewhere)

Method

- SUSY "base model" defined via low scale soft terms and choice of α

$$\left\{ \begin{array}{c} \tan\beta,\ m^2_{H_u},\ m^2_{H_d} \\ M_3,\ A_t,\ A_b,\ A_\tau \\ m_{Q_{1,2}},\ m_{U_{1,2}},\ m_{D_{1,2}},\ m_{L_{1,2}},\ m_{E_{1,2}} \\ m_{Q_3},\ m_{U_3},\ m_{D_3},\ m_{L_3},\ m_{E_3} \end{array} \right\}$$

  - * Vary α from -0.5 to 1 in steps $\Delta\alpha = 0.05$
  - * M_1 and M_2 determined relative to M_3 via Mirage ratio
- Each point of α line generate 100k events ($\sim 5\ \mathrm{fb}^{-1}$)
- Model point data generated via `PYTHIA 6.4 + PGS4` using level 1 triggers
- SM background sample: 5 fb^{-1} of top, bottom, dijets and gauge boson production (both single and double)
- Appropriately weight SM background to include with each signal sample

Method cont'd

- Initial object level cuts

Object	Minimum p_T	Minimum $\|\eta\|$
Photon	20 GeV	2.0
Electron	20 GeV	2.0
Muon	20 GeV	2.0
Tau	20 GeV	2.4
Jet	50 GeV	3.0

- Event level cuts
  - * $\not{E}_T > 150$ GeV
  - * Transverse sphericity $S_T > 0.1$
  - * $H_T > 600$ GeV or 400 GeV (events with ≥ 2 leptons) $H_T = \not{E}_T + \sum_{\text{jets}} p_T^{\text{jet}}$
- Signatures found using `ROOT` based analysis package `Parvicursor`

  `http://www.atsweb.neu.edu/ialtunkaynak/heptools.html#parvicursor`
- Start with hundreds of signatures → remove redundancies → 128 sigs

Signatures

- Initial set of 128 signatures = 46 counting + 82 kinematic distributions
  - Signatures applied to specific final state event topologies
    i.e. [≥ 2 b-jets], [≥ 1 leptons, ≤ 4 jets], etc
  - Counting: OS dilepton, trileptons, 2 b-jet, etc
  - Kinematic distributions: p_T, M_{inv}, M_{eff}
  - Integrate distributions over appropriately chosen ranges to obtain counts
- Minimum luminosity required to separate two models using n sigs at confidence level p:

$$L_{\mathrm{min}} = \frac{\lambda_{\mathrm{min}}(n,p)}{R_{AB}} \qquad R_{AB} = \sum_i (R_{AB})_i = \sum_i \frac{\left(\sigma_i^A - \sigma_i^B\right)^2}{\sigma_i^A + \sigma_i^B}$$

- Want to select set of n sigs so $L_{\mathrm{min}}(p)$ is small as possible over wide array of model pairs A and B
- Need to do our best to ensure signatures minimally correlated

Best Signatures

- For an α line can we distinguish $\alpha \neq 0$ from "data", i.e. $\alpha = 0$?
  - $\longrightarrow$ For two models A & B compute $\left(R_{AB}\right)_i$ for 128 signatures
  - $\longrightarrow$ Select signatures which best detect changes in α for this model pair
- Determine best signatures for other model pairs
- Average over ensemble of models to determine which sigs best at tracking changes in α across different model inputs
- Partition data according to final state topologies to minimize correlations:

$$
\begin{gathered}
N_{\text{jets}} \leq 4 \text{ versus } N_{\text{jets}} \geq 5, \\
N_{\text{leptons}} = 0 \text{ versus } N_{\text{leptons}} \geq 1.
\end{gathered}
$$

Optimal Lists

- Ultimately form 3 lists which best track changes in α
- Single most effective signature to distinguish models

	Description	Min Value	Max Value
1	$M_{\mathrm{eff}}^{\mathrm{any}} = \not{E}_T + \sum_{\mathrm{all}} p_T^{\mathrm{all}}$ [All events]	1250 GeV	End

Signature List A

- Best signatures with maximum correlation of 10%

	Description	Min Value	Max Value
1	$M_{\mathrm{eff}}^{\mathrm{jets}}$ [0 leptons, $\geq$ 5 jets]	1100 GeV	End
2	$M_{\mathrm{eff}}^{\mathrm{any}}$ [0 leptons, $\leq$ 4 jets]	1450 GeV	End
3	$M_{\mathrm{eff}}^{\mathrm{any}}$ [$\geq$ 1 leptons, $\leq$ 4 jets]	1550 GeV	End
4	p_T(Hardest Lepton) [$\geq$ 1 lepton, $\geq$ 5 jets]	150 GeV	End
5	$M_{\mathrm{inv}}^{\mathrm{jets}}$ [0 leptons, $\leq$ 4 jets]	0 GeV	850 GeV

Signature List B

Optimal Lists

- Allow correlations as high as 30%
- First instance of true counting signatures

	Description	Min Value	Max Value
	Counting Signatures		
1	N_ℓ [≥ 1 leptons, ≤ 4 jets]		
2	$N_{\ell^+\ell^-}$ [$M_{\mathrm{inv}}^{\ell^+\ell^-} = M_Z \pm 5\ \mathrm{GeV}$]		
3	N_B [≥ 2 B-jets]		
	[0 leptons, ≤ 4 jets]		
4	$M_{\mathrm{eff}}^{\mathrm{any}}$	1000 GeV	End
5	$M_{\mathrm{inv}}^{\mathrm{jets}}$	750 GeV	End
6	$\not{E}_T$	500 GeV	End
	[0 leptons, ≥ 5 jets]		
7	$M_{\mathrm{eff}}^{\mathrm{any}}$	1250 GeV	3500 GeV
8	r_{jet} [3 jets $>$ 200 GeV]	0.25	1.0
9	p_T(4th Hardest Jet)	125 GeV	End
10	$\not{E}_T / M_{\mathrm{eff}}^{\mathrm{any}}$	0.0	0.25
	[≥ 1 leptons, ≥ 5 jets]		
11	$\not{E}_T / M_{\mathrm{eff}}^{\mathrm{any}}$	0.0	0.25
12	p_T(Hardest Lepton)	150 GeV	End
13	p_T(4th Hardest Jet)	125 GeV	End
14	$\not{E}_T + M_{\mathrm{eff}}^{\mathrm{jets}}$	1250 GeV	End

Signature List C

$$r_{\mathrm{jet}} \equiv \left(p_T^{\mathrm{jet3}} + p_T^{\mathrm{jet4}}\right) / \left(p_T^{\mathrm{jet1}} + p_T^{\mathrm{jet2}}\right)$$

Results: Benchmark Model B

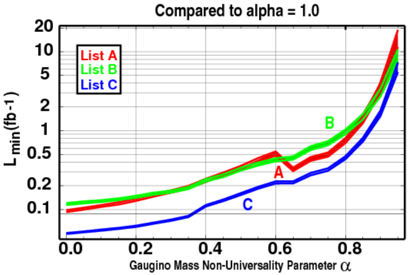
- Predicts $\alpha \simeq 1$

  dominant processes

  $qg \to \widetilde{q}\widetilde{g}$, $gg \to \widetilde{t}_1\overline{\widetilde{t}}_1$

$m_{\widetilde{N}_1}$	338.7	$m_{\tilde{t}_1}$	379.9
$m_{\widetilde{N}_2}$	440.2	$m_{\tilde{t}_2}$	739.1
$m_{\widetilde{N}_3}$	622.8	$m_{\tilde{u}_L}$	811.7
$m_{\widetilde{N}_4}$	634.3	$m_{\tilde{u}_R}$	793.3
$m_{\widetilde{C}_1^{\pm}}$	440.1	$m_{\tilde{b}_1}$	676.8
$m_{\widetilde{C}_2^{\pm}}$	635.0	$m_{\tilde{b}_2}$	782.4
$m_{\tilde{g}}$	818.0	$m_{\tilde{d}_L}$	815.4
μ	625.2	$m_{\tilde{d}_R}$	793.5
m_h	119.5	$m_{\tilde{\tau}_1}$	500.4
m_A	807.4	$m_{\tilde{\tau}_2}$	540.4
m_{H^0}	806.8	$m_{\tilde{e}_L}$	545.1
$m_{H^{\pm}}$	811.1	$m_{\tilde{e}_R}$	514.6

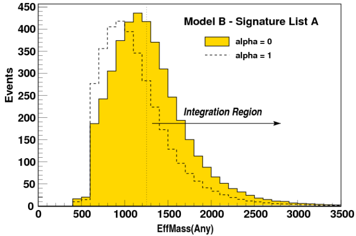
spectra [GeV] at $\alpha = 1$



Model B

Model B List A and C

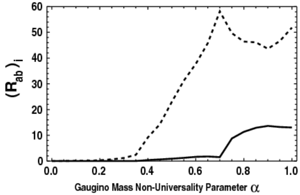
- List A



$M_{\mathrm{eff}}^{\mathrm{any}} = \not{E}_T + \sum_{\mathrm{all}} p_T^{\mathrm{all}}$ [All events]

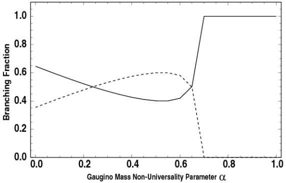
Demonstrates choice of integration region used to track α variations

- List C



solid: N_ℓ [≥ 1 leptons, ≤ 4 jets]

dash: N_B [≥ 2 B-jets]



solid: $\widetilde{N}_2 \longrightarrow \widetilde{N}_1 Z$

dash: $\widetilde{N}_2 \longrightarrow \widetilde{N}_1 h$

Controlled Sample

- 1449 model points varied in a controlled manner

Input Parameter Range	Variation
$400\ \mathrm{GeV} \geq M_3 \geq 800\ \mathrm{GeV}$	5 steps
$400\ \mathrm{GeV} \geq \mu \geq 1000\ \mathrm{GeV}$	5 steps
$300\ \mathrm{GeV} \geq (m_{\tilde{e}_{L,R}}, m_{\tilde{\tau}_{L,R}}) \geq 700\ \mathrm{GeV}$	5 steps
$500\ \mathrm{GeV} \geq (m_{\tilde{Q}_L}, m_{\tilde{q}_L}, m_{\tilde{t}_{L,R}}, m_{\tilde{b}L,R}) \geq 1000\ \mathrm{GeV}$	5 steps
$\tan\beta = 10$	Fixed
$m_A = 1000\ \mathrm{GeV}$	Fixed
$A_\tau,\ A_t,\ A_b,\ A_e,\ A_u,\ A_d = 0$	Fixed

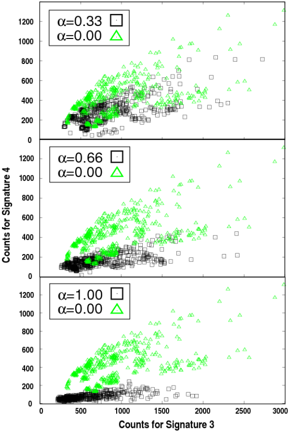
Largest Production Channel

Mode	$\alpha = 0$	$\alpha = 0.33$	$\alpha = 0.66$	$\alpha = 1.0$
$gg \to \tilde{g}\tilde{g}$	44.6%	45.2%	42.9%	44.8%
$fg \to \tilde{q}_R\tilde{g}$	31.1%	30.2%	33.1%	35.7%
$fg \to \tilde{q}_L\tilde{g}$	24.3%	25.5%	23.9%	19.4%

Second Largest Production Channel

Mode	$\alpha = 0$	$\alpha = 0.33$	$\alpha = 0.66$	$\alpha = 1.0$
$gg \to \tilde{g}\tilde{g}$	2.7%	2.1%	2.8%	1.4%
$fg \to \tilde{q}_R\tilde{g}$	42.0%	48.8%	47.5%	45.2%
$fg \to \tilde{q}_L\tilde{g}$	42.0%	47.1%	49.6%	53.3%
$f_i f_j \to \tilde{\chi}_2^0\tilde{\chi}_1^\pm$	13.2%	1.9%	-	-

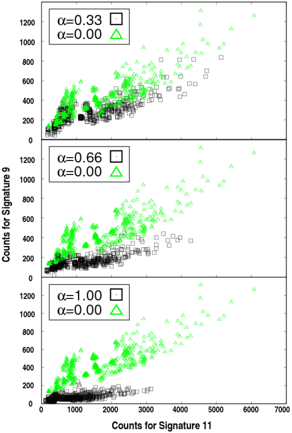
C.S. Footprints



List B

$$B_4 = p_T(\#1\ \ell)\ [\geq 1\ \ell,\ \geq 5\ j]$$

$$B_3 = M_{\mathrm{eff}}^{\mathrm{any}}\ [\geq 1\ \ell,\ \leq 4\ j]$$



List C

$$C_9 = p_T(\#4\ j)\ [0\ \ell,\ \geq 5\ j]$$

$$C_{11} = \not{E}_T / M_{\mathrm{eff}}^{\mathrm{any}}\ [\geq 1\ \ell,\ \geq 5\ j]$$

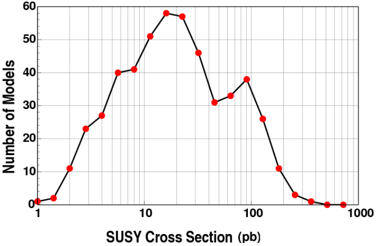
Ensemble of Models

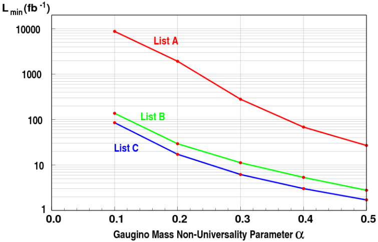
- How well do the lists fare on general SUSY models?
- To test procedure, apply to ensemble of 500 random models

  - Each model has $0 \leq \alpha \leq 0.5$ in steps of $\Delta\alpha = 0.1$

    $300 \leq m_{\tilde{\ell}},\ m_{\tilde{q}},\ M_3,\ \mu \leq 1200$ GeV

    $2 \leq \tan\beta \leq 50,\ m_A = 850$ GeV
  - Generate 100k events for each of 6 points along α lines



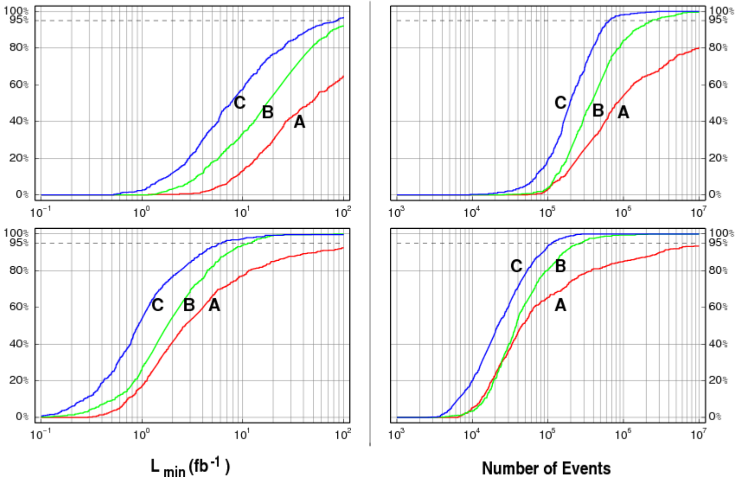


← $L_{\min}$ needed to detect $\alpha \neq 0$ for 95% of the random models

Ensemble of Models

Percentage of random models that can be distinguished

Top plots compare $\alpha = 0$ to $\alpha = 0.1$; bottom plots compare $\alpha = 0$ to $\alpha = 0.3$

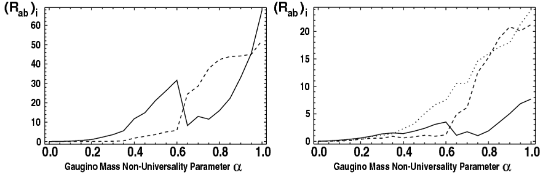


Outlook & Conclusions

- First step toward determining gaugino universality at LHC
- Demonstrated effectiveness of using targeted observables albeit in an artifical scenario
- Under our assumptions and framework LHC can determine gaugino mass non-universality
  - → 10% level with 25-50 fb^{-1} over 80% of investigated parameter space
  - → 30% level with 5-10 fb^{-1} over 95% of investigated parameter space
- Outlook and improvements
  - * Response of lists to other SUSY parameter variation
  - * Generalized gaugino mass parametrization
  - * Fully remove model dependence
  - * Include inclusive kinematic measurements: endpoints $(m_{\widetilde{N}_2} - m_{\widetilde{N}_1})$, m_{T2}, etc

Thank You!

Model B List B

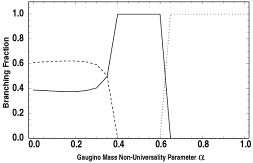


List B $(R_{AB})_i$

Left: solid $M_{\rm eff}^{\rm jets}$ $[0\ \ell, \geq 5\ j]$, dash $M_{\rm inv}^{\rm jets}$ $[0\ \ell, \leq 4\ j]$

Right: solid $M_{\rm eff}^{\rm any}$ $[0\ \ell, \leq 4\ j]$, dash $M_{\rm eff}^{\rm any}$ $[\geq 1\ \ell, \leq 4\ j]$,

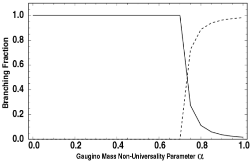
dot $p_T(\#1\ \ell)$ $[\geq 1\ \ell, \geq 5\ j]$



solid: $\widetilde{t}_1 \longrightarrow \widetilde{C}_1 b$

dash: $\widetilde{t}_1 \longrightarrow \widetilde{N}_1 t$

dot: $\widetilde{t}_1 \longrightarrow \widetilde{N}_1 c$



solid: $\widetilde{C}_1 \longrightarrow \widetilde{N}_1 W$

dash: $\widetilde{C}_1 \longrightarrow \widetilde{t}_1 \bar{b}$