Distorted Mass Edges at LHC from supersymmetric Leptoquarks

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Introduction
  Sample model setup
  P&D of exotics

Distortion of Edges
  Exotic fermion characteristics
  Physiognomy of edges
  Robustness of effect

Conclusions
Sample model setup

Some model facts

- $E_6$ SUSY GUT w/ two-step unification
- NMSSM-like $\mu$-problem solution
- Higgs-matter unification
- solution of doublet-triplet splitting problem:
- existence of TeV scale exotics contained in 27: colored iso-singlet scalars and fermions
- more on $E_6$ in e.g. Antonio Morais talk (PS 9)

Decomposition of the fundamental 27

<table>
<thead>
<tr>
<th></th>
<th>$SU(3)_C$</th>
<th>$SU(2)_L$</th>
<th>$U(1)_Y$</th>
<th>$U(1)'$</th>
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</thead>
<tbody>
<tr>
<td>$\hat{Q}$</td>
<td>3</td>
<td>2</td>
<td>1/3</td>
<td>$Q'_Q$</td>
</tr>
<tr>
<td>$\hat{u}^c$</td>
<td>$\bar{3}$</td>
<td>1</td>
<td>-4/3</td>
<td>$Q'_u$</td>
</tr>
<tr>
<td>$\hat{d}^c$</td>
<td>$\bar{3}$</td>
<td>1</td>
<td>2/3</td>
<td>$Q'_d$</td>
</tr>
<tr>
<td>$\hat{L}$</td>
<td>1</td>
<td>2</td>
<td>-1</td>
<td>$Q'_L$</td>
</tr>
<tr>
<td>$\hat{e}^c$</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>$Q'_e$</td>
</tr>
<tr>
<td>$\hat{H}^u$</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>$Q'_{H^u}$</td>
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<tr>
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<td>1</td>
<td>2</td>
<td>-1</td>
<td>$Q'_{H^d}$</td>
</tr>
<tr>
<td>$\hat{D}$</td>
<td>3</td>
<td>1</td>
<td>-2/3</td>
<td>$Q'_D$</td>
</tr>
<tr>
<td>$\hat{D}^c$</td>
<td>$\bar{3}$</td>
<td>1</td>
<td>2/3</td>
<td>$Q'_{D^c}$</td>
</tr>
<tr>
<td>$\hat{\nu}^c$</td>
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<td>1</td>
<td>0</td>
<td>$Q'_{\nu^c}$</td>
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<tr>
<td>$\hat{S}$</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>$Q'_S$</td>
</tr>
</tbody>
</table>
Production and decay of exotic fermions

- dominant decays to sfermion/sm-fermion pair
- scalar/gaugino mode suppressed due to typically heavier scalar mass
- all figures & numbers using WHIZARD (projects.hepforge.org/whizard)

- x-secs @ LHC14: $10^{-3}$ fb $\rightarrow 10^{5}$ fb
- single production dominant for high masses (ps effect)
- but: dependence on coupling ($\lambda = e \approx 0.312$)

Leptoquarkino production channels

Leptoquarkino Branching Fraction

Decays of $\tilde{D}$
- $\tilde{D} \rightarrow \tilde{e}_{L} + u$
- $\tilde{D} \rightarrow \tilde{e}_{R} + u$
- $\tilde{D} \rightarrow \tilde{u}_{L} + e$
- $\tilde{D} \rightarrow \tilde{u}_{R} + e$
- $\tilde{D} \rightarrow \tilde{d}_{L} + \nu_{e}$
- $\tilde{D} \rightarrow \tilde{\nu}_{L} + d$
Final state selection

- sfermion/fermion decay of exotics dominate
- final states of pair production: $2 \text{ jet} + 2 \text{ lepton} + \text{MET}$
- (single production: $1 \text{ jet} + 2 \text{ lepton} + \text{MET}$)
- backgrounds include gluino pair, associated gluino-squark and squark pair production
- former two under fairly good control through cuts ($p_T (\text{jet}) > 100 \text{ GeV}$ on parton level)
- $\sigma$-secs of backgrounds roughly of comparable size ($10^{-1} \text{ fb} \rightarrow 10^6 \text{ fb}$)
Some exotic fermion characteristics

- Leptoquarkino w/ intrinsic negative R-parity $\rightarrow$ sparticle-like decay through long cascades
- Dependent upon SUSY breaking / spectrum, there is a special feature:
- Kinematic endpoint of $M_{ql}$ is equivalent to vanilla MSSM-like dilepton edge: no spin correlation between quark and lepton due to intermediate scalar
- Dirac instead of majorana fermion

$$m_{ql}^{max} = \left[ \frac{(m_{\tilde{e}R(L)}^2 - m_{\tilde{\chi}_1^0})(m_D^2 - m_{\tilde{e}R(L)}^2)}{m_{\tilde{e}R(L)}^2} \right]^{1/2}$$

Diagram:

- $\tilde{D}$
- $\tilde{l}_R$
- $\tilde{\chi}_1^0$
- $\tilde{l}^\pm$
- $\tilde{\chi}_1^0$
- $q$
- $l^-$
Example of a typical event

- consider e.g. 2 jet + 2 lepton + MET final state
- comparison yields fundamentally different nature of intermediate state(s)
- strong phenomenological implications arise
Physiognomy of edges I

- exotics have baryon & lepton numbers → concentrate on jet/lepton variables
- best guess is $m_{lq}$, direct observation yields:

![Invariant Mass Distribution of (q,l)](image)

- Inability to experimentally combine correct jet/lepton pair requires intro of $m_{ql, high}$ and $m_{ql, low}$

$$m_{ql, high} = \max\{m_{ql^+}, m_{ql^-}\}$$

$$m_{ql, low} = \min\{m_{ql^+}, m_{ql^-}\}$$
Physiognomy of edges II

- speciality: maximization over lepton pair yields uncorrelated jet/lepton pairs from two ’sides’ of decay cascades for signal
- result: tail in $m_{q_l,\text{high}}$ (compared to tail-less vanilla MSSM)
- important: not to be misidentified as squark analysis with wrong combinatorics!
alternative jet/lepton variables including endpoint features are e.g. $m_{ql}^*$ or $m_{qll}$

• bonus: definition of $m_{ql}^*$ intrinsically free of combinatorical issues (but still suffering from admixture of uncorrelated leptons)

\[ m_{ql}^* = m(\min_E \{j_1, j_2\}, \max_E \{l^+, l^-\}) \]
Digging out the Signal

Use difference in lepton correlation:
- In vanilla MSSM signal correlation yields clear endpoint structure
- Exotic signal leptons mostly uncorrelated
- Cut above edge drastically reduces standard SUSY backgrounds
Robustness of effect

- In the following, we show impact of 4 exotic masses embedded into two different SPS spectra (mSUGRA (SPS3) + GMSB (SPS7))
- effect is stable and hardly dependent upon scenario
- only relative mass difference to underlying spectrum is relevant
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Mass scans w/ SPS3

$\text{m}_{q_1,\text{low}}$

$\text{m}_{q_1,\text{high}}$

$\text{m}_{q_{ll}}$

$\text{m}_{q_1}^*$
Distortion features

- $m_{ql,\text{low}}$ not particularly useful to disentangle exotic signals
- $m_{ql,\text{high}}$ and $m^*_{ql}$ show most promising distortions
- notice steplike endpoint feature due to multiple possible intermediate states (here: sleptons)
- deviation dominates for $M_D \ll M_{\tilde{q}}$ and naturally washes out for $M_D \gg M_{\tilde{q}}$
Mass scans w/ SPS7

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- Most B(MS)SM models introduce new particles, which may distort *standard* kinematic observables
- Origin of effect is model independent: difference in spin of intermediate particle
- Misidentified combinatorical issues in e.g. squark analyses are able to (re)produce similar effect \(\rightarrow\) careful and elaborate study necessary!
- After all: discovery of such exotic matter content could provide a handle on underlying GUT scale structure
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