Color-octet scalars of N=2 SUSY at the LHC

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based on Choi, Drees, Kalinowski, JMK, Popenda, and Zerwas
arXiv:0812.3586

Outline

Introduction

Minimal Supersymmetric Standard Model (MSSM)

- One fermionic generator is assumed. (N=1)
  $\Rightarrow$ Each SM particle (+one more Higgs) has its superpartner ($\leftarrow$ supermultiplet)
- R-parity conservation is assumed.
  $\Rightarrow$ · Pairwise production of superparticles!
  · Lightest Supersymmetric Particle (LSP) stable!
- Electrically neutral, colorless Majorana fermion is assumed to be the LSP.
- SUSY breaking sector is manifested as free parameters.
  $\Rightarrow$ Different parameter set gives different collider signals.
- Typical LHC signals are [e.g. The ATLAS Collaboration, arXiv:0901.0512]:
  Pairwise production of $\tilde{q}, \tilde{g} \rightarrow$ cascade decays
  $\rightarrow$ 2-4 hard jets (+softer QCD jets) + missing $\mathrm{E_T}$ from LSP.

N=1/N=2 Hybrid Model

- Motivations: Demands for Dirac gaugino [Choi, Drees, Freitas, Zerwas]; “Supersoft” SUSY breaking [Fox, Nelson, Weiner]; String-inspired Brane models [Antoniadis et al.]; ...
- Matter fermions are chiral
  $\Rightarrow$ We adopt N=1/N=2 hybrid scheme; i.e. N=2 mirror (s)fermions to be very heavy, and expanding N=2 only in the gauge sector.
- N=2 QCD hypermultiplet: $\hat{g}(\{g_\mu, \tilde{g}\}) + \hat{g}'(\{\sigma, \tilde{g}'\})$

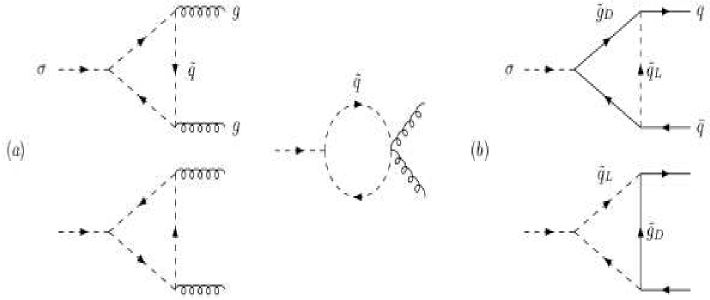
Furthermore, we assume

- pure Dirac gluino;
- Degenerate scalar/pseudoscalar component of σ.

Color-octet Scalar **gluon**, σ

- R-parity even $\Rightarrow$ single production possible (..in principle)!
- Mass given by
  superpotential: $W \supset \frac{1}{2} M_3' \hat{g}'^a \hat{g}'^a$
  + soft breaking terms: $\mathcal{L} \supset -m_\sigma^2 |\sigma^2| - m_{\sigma\sigma}^2 \sigma\sigma$.
- Interactions are
  SUSY breaking trilinear interaction with squarks:
  $\mathcal{L} \supset -g_S M_3^D \sigma^a \frac{\lambda_{ij}^a}{\sqrt{2}} \sum_q (\tilde{q}_{Li}^* \tilde{q}_{Lj} - \tilde{q}_{Ri}^* \tilde{q}_{Rj})$
  + Gauge interaction with gluons/gluinos: E.g.
  $\mathcal{L} \supset -\sqrt{2} i g_S f^{abc} \overline{\tilde{g}_{DL}^a} \tilde{g}_{DR}^b \sigma^c$
  $\Rightarrow$ At tree level, decays to gluino or squark pairs!

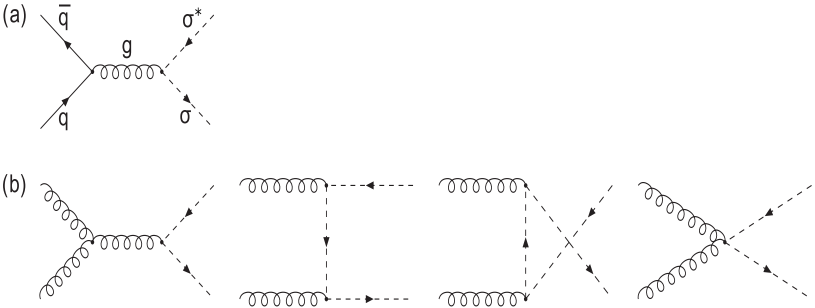
Coupling to gluons/quarks through triangle loop: E.g.



$\Rightarrow$ At one-loop level, decays to top-quarks or gluon pairs!

σ production

The relevant Feynmann diagrams:



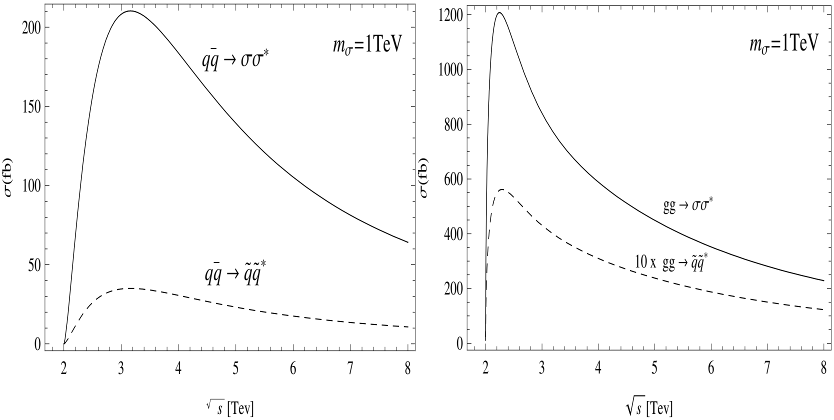
$\Rightarrow$ Identical (modulo color factors) to squark-pair production.

The $\sigma\sigma^*$ cross sections exceed those of squarks:

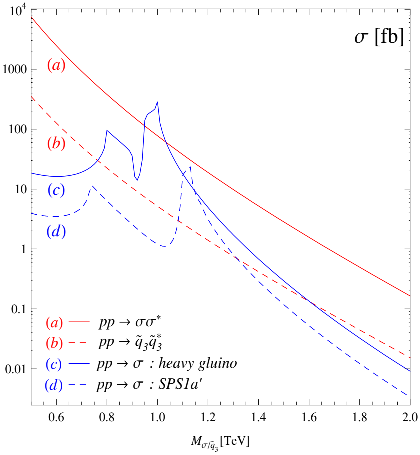
$$\frac{\sigma[gg \to \sigma\sigma^*]}{\sigma[gg \to \tilde{q}_3\tilde{q}_3^*]} = \begin{cases} \frac{\mathrm{tr}(\{F^a, F^b\}\{F^a, F^b\})}{\mathrm{tr}(\{\frac{\lambda^a}{2}, \frac{\lambda^b}{2}\}\{\frac{\lambda^a}{2}, \frac{\lambda^b}{2}\})} = \frac{216}{28/3} \simeq 23 \\ \quad \text{for } \beta \to 0, \\ \frac{\mathrm{tr}(2F^aF^bF^bF^a + F^aF^bF^aF^b)}{\mathrm{tr}(2\frac{\lambda^a}{2}\frac{\lambda^b}{2}\frac{\lambda^b}{2}\frac{\lambda^a}{2} + \frac{\lambda^a}{2}\frac{\lambda^b}{2}\frac{\lambda^a}{2}\frac{\lambda^b}{2})} = \frac{180}{10} = 18 \\ \quad \text{for } \beta \to 1, \end{cases}$$

$$\frac{\sigma[q\bar{q} \to \sigma\sigma^*]}{\sigma[q\bar{q} \to \tilde{q}_3\tilde{q}_3^*]} = \frac{\mathrm{tr}(\frac{\lambda^a}{2}\frac{\lambda^b}{2})\,\mathrm{tr}(F^aF^b)}{\mathrm{tr}(\frac{\lambda^a}{2}\frac{\lambda^b}{2})\,\mathrm{tr}(\frac{\lambda^a}{2}\frac{\lambda^b}{2})} = \frac{12}{2} = 6 \quad \text{for any } \beta.$$

The partonic branching ratio:



σ productions at the LHC:



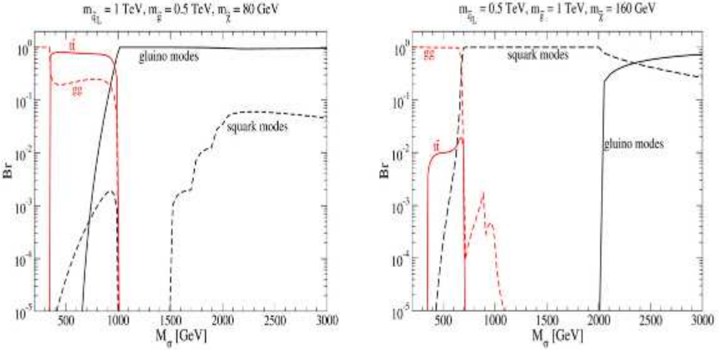
$\Rightarrow$ Sizable σ event rate can be generated!

σ decays

Recall: $\exists$ SUSY breaking trilinear interaction with squarks + gauge interaction with gluinos.

- At tree level
  - $\sigma \to \tilde{g}\tilde{g}(\to qq\tilde{q}\tilde{q} \to qqqq + \tilde{\chi}\tilde{\chi})$, with $\Gamma[\sigma \to \tilde{g}_D \bar{\tilde{g}}_D] = \frac{3\alpha_s M_\sigma}{4} \beta_{\tilde{g}} \left(1 + \beta_{\tilde{g}}^2\right)$.
  - $\sigma \to \tilde{q}\tilde{q}(\to qq + \tilde{\chi}\tilde{\chi})$, with $\Gamma[\sigma \to \tilde{q}\tilde{q}^*] = \frac{\alpha_s}{4} \frac{|M_3^D|^2}{M_\sigma} \beta_{\tilde{q}}$.
- At one-loop level:
  - $\sigma \to t\bar{t}(\to b\bar{b}W^+W^-)$, with $\Gamma(\sigma \to q\bar{q}) = \frac{9\alpha_s^3}{128\pi^2} \frac{|M_3^D|^2 m_q^2}{M_\sigma} \beta_q \left[\left(M_\sigma^2 - 4m_q^2\right) |\mathcal{I}_S|^2 + M_\sigma^2 |\mathcal{I}_P|^2\right]$. ($\mathcal{I}_S$, $\mathcal{I}_P$: effective scalar (S), pseudoscalar (P) couplings.)
  - $\sigma \to gg$, with $\Gamma(\sigma \to gg) = \frac{5\alpha_s^3}{384\pi^2} \frac{|M_3^D|^2}{M_\sigma} \left|\sum_q \left[\tau_{\tilde{q}_L} f(\tau_{\tilde{q}_L}) - \tau_{\tilde{q}_R} f(\tau_{\tilde{q}_R})\right]\right|^2$. ($\tau_{\tilde{q}_{L,R}} = 4m_{\tilde{q}_{L,R}}^2/M_\sigma^2$; $f(\tau) = -\frac{1}{2}\int_0^1 \frac{dx}{x} ln(1 - 4x(1-x)/\tau)$.)

The decay branching ratios:



$(m_{\tilde{q}_R} = 0.95 m_{\tilde{q}_L}; m_{\tilde{t}_L} = 0.9 m_{\tilde{q}_L}; m_{\tilde{t}_R} = 0.8 m_{\tilde{q}_L})$

- Two-body final states dominate.
- Above thresholds, the partial width into gluinos always dominate.

Signals at the LHC

- Above all thresholds:
  pp $\to \tilde{g}\tilde{g}\tilde{g}\tilde{g} \to$ (isotropically distributed, hard) 8 jets + 4 LSP's.
  $\Rightarrow$ Easily distinguishable!
- If $m_{\tilde{q}} \lesssim m_{\tilde{g}}$ & $\exists$significant L-R mixing:
  pp $\to \tilde{t}_1\tilde{t}_1\tilde{t}_1^*\tilde{t}_1^* \to$ 4 LSP's + many hard jets.
- If $M_\sigma > 2m_{\tilde{g}} \gtrsim 2m_{\tilde{q}}$:
  pp $\to \tilde{q}\tilde{q}^*\tilde{g}\tilde{g} \to$ 4 LSP's + many hard jets.
- If kinematically allowed:
  pp $\to tt\bar{t}\bar{t}$
  $\Rightarrow$ Direct M_σ reconstruction might be possible!

Summary

- N=2 gauge hypermultiplet includes color-octet scalar, σ.
- The signals at the LHC from σ are very different from those of MSSM.
- Depending on the mass spectra, either multi-jet with high sphericity and large missing $\mathrm{E_T}$, or four top quarks should be observed.