Supersafe Supersymmetry with a Dirac gluino

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mainly: 1203.4821 with Adam Martin (CERN/Notre Dame);
plus 1208.2784 with Adam Martin, Ricky Fok (York), Yuhsin Tsai (UC Davis)
and work-to-appear with Nirmal Raj (Oregon)
Outline

1. Brief Intro

2. Dirac Gluino and “Supersoft Supersymmetry”

3. Colored Superpartner Production @ LHC

4. Simplified Models

5. Jets + missing searches for supersymmetry @ LHC
   a) ATLAS; CMS $\alpha_T$; (CMS MHT; CMS “razor”)
   b) Comparisons

6. Generalizations (“mixed gauginos”)

7. Summary
Introduction

Weak Scale Supersymmetry @ LHC
In this talk, focus on "jets + MET" sqark and gluino production.

Many Searches!
Supersymmetry @ LHC

Squark-gluino-neutralino model, \( m(\tilde{\chi}^0_1) = 0 \) GeV

**ATLAS Preliminary**

- Combined
  - CL\(_s\) observed 95% C.L. limit
  - CL\(_s\) median expected limit
  - Expected limit ±1\(\sigma\)

ATLAS EPS 2011

\[
\int L \, dt = 4.71 \text{ fb}^{-1}, \sqrt{s} = 7 \text{ TeV}
\]

\( \sigma_{\text{SUSY}} = 1 \text{ fb} \)

\( \sigma_{\text{SUSY}} = 10 \text{ fb} \)

\( \sigma_{\text{SUSY}} = 100 \text{ fb} \)

1st+2nd generation squark mass

 gluino mass [GeV]
If weak scale supersymmetry...

1st, 2nd generation heavy (> 1.5-2 TeV), if LSP light (< 200-300 GeV)

LSP heavier (at least 300-400 GeV)

Too simplified a model (cascades)

R-parity violation. LSP decays, no missing energy.

Too simplified a model (compressed)
Dirac Gluino in Supersymmetry
Dirac Gluino

Solve EDMs (Hall, Randall)

Supersoft Supersymmetry (Fox, Nelson, Weiner)

R-Symmetric Supersymmetry -- Flavor safe! (Kribs, Poppitz, Weiner)

“Supersafe” -- Suppressed $\sigma$’s (Kribs, Martin)

Reduced Fine-Tuning (Kribs, Martin)
Dirac Gauginos in Supersymmetry

SUSY breaking to gauginos communicated through D-term spurions:

\[ W'_\alpha = \theta_\alpha D \]

Dirac gaugino masses arise from:

\[
\int d^2\theta \sqrt{2} \frac{W'_\alpha W^\alpha_j A_j}{M}
\]

giving

\[ \mathcal{L} \supset -m_D \lambda_j \tilde{a}_j \]

Polchinski, Susskind (1982)
Hall, Randall (1991)
Fox, Nelson, Weiner (2002)
...

\[ m_D = D'/M \]
Dirac Gauginos in Supersymmetry II

Dirac gaugino masses require extending the MSSM with chiral adjoint superfields:

\[
\begin{align*}
A_j & \quad j = 1 \ldots 8 & \text{color octet} \\
A_j & \quad j = 1 \ldots 3 & \text{weak triplet} \\
A_j & \quad j = 1 & \text{singlet}
\end{align*}
\]

Gauge coupling unification... (for those who still care)

...still perturbative, but requires unifons.
Dirac Gauginos in Supersymmetry III

Scalar masses could arise from:

$$\int d^4 \theta \frac{(W'^\alpha W'_\alpha)^\dagger W'^\beta W'_\beta}{M^6} Q^\dagger Q$$

which is finite! This is because the only counterterm

$$\int d^4 \theta \frac{\theta^2 \bar{\theta}^2 m_D^4}{M^2} Q^\dagger Q$$

is suppressed by $1/M^2$.

Scalar masses are “supersoft”

Fox, Nelson, Weiner (2002)
Squark/Slepton Masses

One-loop contributions:

\[ M_f^2 = \sum_i \frac{C_i(f) \alpha_i M_i^2}{\pi} \log \frac{\tilde{m}_i^2}{M_i^2} \]
Squark/Slepton Masses

One-loop contributions:

\[ M_f^2 = \sum_i \frac{C_i(f)\alpha_i M_i^2}{\pi} \log \frac{\tilde{m}_i^2}{M_i^2} \]

Would-be log divergence is cutoff by adjoint scalar contribution.

Adjoint Scalars

Gauginos married off with fermionic components of chiral adjoint superfields:

\[ A_j = \begin{pmatrix} \tilde{a}_j \\ a_j \end{pmatrix} \]

Also contain scalars in adjoint representation (e.g. “sgluons”).

\[
\int d^2 \theta \sqrt{2} \frac{W'_\alpha W^\alpha_j A_j}{M} \quad \text{also} \quad \mathcal{L} \supset -m_D^2 (a_j + a_j^*)^2
\]

Additional contributions

\[
\int d^2 \theta \frac{W'_\alpha W'^\alpha_j}{M^2} A_j^2
\]

Masses for \(\text{Re}[a_j]\) and \(\text{Im}[a_j]\) (opposite signs)
Finite Squark Masses from Dirac Gauginos

\[ M_f^2 = \sum_i \frac{C_i(f)\alpha_i M_i^2}{\pi} \log \frac{\tilde{m}_i^2}{M_i^2} \]

Plugging in numbers:

\[ M_{\tilde{q}}^2 \simeq (700 \text{ GeV})^2 \left( \frac{M_3}{5 \text{ TeV}} \right)^2 \frac{\log \tilde{r}_3}{\log 1.5} \]

or

\[ M_{\tilde{q}}^2 \simeq (760 \text{ GeV})^2 \left( \frac{M_3}{3 \text{ TeV}} \right)^2 \frac{\log \tilde{r}_3}{\log 4} \]

Dirac gluino \( \simeq (5-7) \times \text{ squark mass} \)
Naturalness I: Gluino

MSSM

one-loop

$$\delta m_{H_u}^2 = -\frac{3\lambda_t^2}{8\pi^2} M_t^2 \log \frac{\Lambda^2}{M_t^2}$$

two-loop

$$\delta m_{H_u}^2 = -\frac{\lambda_t^2}{2\pi^2} \frac{\alpha_s}{\pi} |\tilde{M}_3|^2 \left( \log \frac{\Lambda^2}{\tilde{M}_3^2} \right)^2$$

evaluate

$$\delta m_{H_u}^2 \big|_{\text{MSSM}} \simeq -\left( \frac{\tilde{M}_3}{4} \right)^2 \left( \frac{\log \Lambda/\tilde{M}_3}{3} \right)^2$$
Naturalness I: Gluino

### MSSM

**one-loop**

\[ \delta m_{H_u}^2 = -\frac{3\lambda_t^2}{8\pi^2} M_t^2 \log \frac{\Lambda^2}{\tilde{M}_t^2} \]

**two-loop**

\[ \delta m_{H_u}^2 = -\frac{\lambda_t^2}{2\pi^2} \frac{\alpha_s}{\pi} |\tilde{M}_3|^2 \left( \log \frac{\Lambda^2}{\tilde{M}_3^2} \right)^2 \]

**evaluate**

\[ \delta m_{H_u}^2 \big|_{\text{MSSM}} \simeq -\left( \frac{\tilde{M}_3}{4} \right)^2 \left( \log \frac{\Lambda}{\tilde{M}_3} \right)^2 \]

### Supersoft

**one-loop**

\[ \delta m_{H_u}^2 = -\frac{3\lambda_t^2}{8\pi^2} M_t^2 \log \frac{\tilde{M}_3^2}{M_t^2} \]

**two-loop** (finite)

**evaluate using mstop and:**

\[ M_{\tilde{q}}^2 \simeq (700 \text{ GeV})^2 \left( \frac{M_3}{5 \text{ TeV}} \right)^2 \log \frac{\tilde{r}_3}{\log 1.5} \]

\[ \log \frac{M_3^2}{M_t^2} \simeq \log \frac{3\pi}{4\alpha_s} \]

\[ \delta m_{H_u}^2 \big|_{\text{SSSM}} \simeq -\left( \frac{M_3}{22} \right)^2 \log \frac{\tilde{r}_3}{\log 1.5} \]

**Dirac gluino** can be substantially heavier than Majorana gluino while just as natural.
Naturalness II: Dirac Electroweak Gauginos?

With just D-term spurion

\[
\int d^2 \theta \sqrt{2} \frac{W'_\alpha W^\alpha_j A_j}{M}
\]

in components:

\[
\mathcal{L} \ni -m_D \lambda_j \tilde{a}_j - \sqrt{2} m_D (a_j + a_j^*) D_j - D_j \left( \sum_i g_k q_i^* t_j q_i \right) - \frac{1}{2} D_j^2
\]

Integrate out massive Re\[a_j\], forces \[D_j = 0\], hence tree-level quartic vanishes.

\[
m_h^2 = m_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2} \cos^2 \alpha y_t^2 m_t^2 \ln \frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}
\]

Naively...a DISASTER! Only stop loop contributions to Higgs mass. (Requires \[\gg 10\ TeV\] mass stops.)
Naturalness II: Higgs Mass

“Pure” Supersoft (Dirac gauginos; D-term & no F-terms) dead.

Need either Majorana winos and binos, or other additional contributions to Higgs mass, e.g.

- NMSSMology
- R-symmetric contributions ($\lambda$ couplings)
- Composite stops (Csaki, Randall, Terning)
- ...

I’m not directly concerned with Higgs mass. Arguably, the MSSM needs to be extended anyway to minimize EW tuning...
Example: R-Symmetric with $\lambda$ couplings

In an R-Symmetric model, a tree-level quartic is generated by “mu” terms and “$\lambda$” terms:

$$W \supset \mu_u H_u R_u + \mu_d R_d H_d$$

$$W \supset \lambda_B^u \Phi_B H_u R_u + \lambda_B^d \Phi_B R_d H_d$$

$$+ \lambda_W^u \Phi_W^a H_u \tau^a R_u + \lambda_W^d \Phi_W^a R_d \tau^a H_d$$

Example (not optimized for maximal Higgs with minimal stops):

$$M_2 = 1 \text{ TeV}$$

$$\mu_u = \mu_d = 200 \text{ GeV}$$

$$m(\tilde{t}_{L,R}) = 3 \text{ TeV}$$

Fok, Martin, Tsai, GK
LHC Squark & Gluino Production
LHC

ALICE

ATLAS

LHCb

CMS
Squark Production

Gluino exchange diagrams ought to dominate LHC production of (1st generation) squarks

But for heavier gluino...
Majorana versus Dirac

Requires Majorana mass insertion. Scales as $1/M$

Dirac and Majorana. Scales as $|p|/M^2$

Suppressed
Suppression of t-channel Dirac Gluino

![Graph showing suppression of t-channel Dirac Gluino]

- Squark masses at which the cross-section of the final state $s q_L, s q_R$ surpasses that of the final state $s q_L/R, s q^*_L/R$.  

Red: Both generations, blue: just the first generation.

Sunday, November 11, 2012

Kribs & Raj
Squark and/or gluino production (LO)
Squark and/or gluino production (LO)
with heavy gluino

\begin{itemize}
    \item \begin{tikzpicture}[baseline=(current bounding box.center)]
        \draw[thick,->] (0,0) -- (1,0) node[midway,above] {$q$};
        \draw[thick,->] (1,0) -- (2,0) node[midway,above] {$g$};
        \draw[thick,->] (2,0) -- (3,0) node[midway,above] {$q$};
        \draw[thick,->] (3,0) -- (4,0) node[midway,above] {$\tilde{q}$};
        \draw[thick,->] (4,0) -- (5,0) node[midway,above] {$\tilde{q}$};
    \end{tikzpicture}
    \item \begin{tikzpicture}[baseline=(current bounding box.center)]
        \draw[thick,->] (0,0) -- (1,0) node[midway,above] {$\tilde{q}$};
        \draw[thick,->] (1,0) -- (2,0) node[midway,above] {$\tilde{q}$};
        \draw[thick,->] (2,0) -- (3,0) node[midway,above] {$\tilde{g}$};
    \end{tikzpicture}
    \item \begin{tikzpicture}[baseline=(current bounding box.center)]
        \draw[thick,->] (0,0) -- (1,0) node[midway,above] {$\tilde{q}$};
        \draw[thick,->] (1,0) -- (2,0) node[midway,above] {$\tilde{q}$};
        \draw[thick,->] (2,0) -- (3,0) node[midway,above] {$\tilde{g}$};
    \end{tikzpicture}
\end{itemize}
Squark production (LO)

LL, RR absent
LR suppressed $1/M^2$  

suppressed $1/M^2$ & PDFs
Bottom Line:

Colored Sparticle Production in Supersoft Supersymmetric Models
Substantially Suppressed at LHC

(numbers in 5 slides)
Simplified Models
Examples of Simplified Models Bounded @ LHC

- massless LSP
- bounds in (M3, Msq) plane
- gluino >> sq
- bounds in (Msq, LSP) plane
- sq >> gluino
- bounds in (M3, LSP) plane
Dirac versus Majororana Gluino Simplified Models

Construct a supersoft supersymmetric simplified model (SSSM) and perform apples-for-apples comparison against MSSM.

- **SSSM**
  - $M_3 = 5$ TeV
  - $M_\tilde{q} \sim \frac{M_3}{5 \rightarrow 10}$
  - $\ll M_\tilde{q}$ to $\approx M_\tilde{q}$

- **“equal MSSM”**
  - $\tilde{M}_3 = M_\tilde{q}$
  - $\tilde{g}$
  - $\tilde{q}_{L,R;1,2}$
  - $\ll M_\tilde{q}$

- **“intermediate MSSM”**
  - $\tilde{M}_3 = 2M_\tilde{q}$
  - $\tilde{g}$
  - $\tilde{q}_{L,R;1,2}$
  - $\ll M_\tilde{q}$

- **“heavy MSSM”**
  - $\tilde{M}_3 = 5$ TeV
  - $\tilde{g}$
  - $\tilde{q}_{L,R;1,2}$
  - $\ll M_\tilde{q}$

- $M_\tilde{g}$ is the gluino mass, $M_{\tilde{q}}$ is the squark mass, and $\tilde{g}$ is the mass of the LSP.
Simulations

Signal simulation | Depends only on squark mass!

- Pythia with NLO K-factors from Prospino
- CTEQ6L
- DELPHES

jet definitions appropriate to experiments

Backgrounds from ATLAS, CMS analysis notes.

Use simplified models of MSSM as cross checks that we are approximately matching expt analyses limits.
Colored Sparticle Cross Sections

The cross sections are shown for each of the simplified models as a function of squark mass. For each simplified model, the cross sections are shown in the figure for the SSS– model. The cross sections are calculated with NLO corrections. To incorporate these corrections, we feed the spectra into the event generator. To simulate the supersymmetric signal, we use PROSPINO [5] with appropriate settings. The distributions of events are shown in the figure for each of the simplified models. The cross sections are shown for each of the simplified models. The cross sections are shown as a function of squark mass.
Basic Jets Plus Missing Energy Searches

ATLAS  4.7/fb
CMS    1.1/fb
ATLAS jets + missing search strategy

0 leptons; all jets pT > 40 GeV

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_T^{miss}$ [GeV] &gt;</td>
<td>160</td>
</tr>
<tr>
<td>$p_T(j_1)$ [GeV] &gt;</td>
<td>130</td>
</tr>
<tr>
<td>$p_T(j_2)$ [GeV] &gt;</td>
<td>60</td>
</tr>
<tr>
<td>$p_T(j_3)$ [GeV] &gt;</td>
<td>60</td>
</tr>
<tr>
<td>$p_T(j_4)$ [GeV] &gt;</td>
<td>60</td>
</tr>
<tr>
<td>$p_T(j_5)$ [GeV] &gt;</td>
<td>40</td>
</tr>
<tr>
<td>$E_T^{miss}/m_{eff(Nj)} &gt;$</td>
<td>0.3 (2j)</td>
</tr>
<tr>
<td>$m_{eff}$ (incl.) [GeV] &gt;</td>
<td>1900/1400/</td>
</tr>
</tbody>
</table>

Table 9: Cuts used to define each of the channels in the analysis. The Standard Model background processes contribute to the event counts in the signal regions. The largest part of the background from multi-jet processes.

The ATLAS jets + missing energy analysis is designed to search for supersymmetric particles, specifically squarks and gluinos, by excluding regions in the parameter space of supersymmetry.

The ATLAS experiment at the Large Hadron Collider at CERN has been carrying out these searches using proton-proton collisions at center-of-mass energies of 7 and 8 TeV. The analysis presented here is based on the ATLAS data taken with an integrated luminosity of 4.71 fb⁻¹.

The analysis uses a variety of control regions to study the background and to set limits on the production of supersymmetric particles. The signal regions are defined to be as far as possible the systematic uncertainties arising from extrapolation to the signal region. The analysis is optimised to maintain adequate statistical power while minimising the impact of background.

The ATLAS jets + missing energy analysis is a powerful tool for searching for new physics beyond the Standard Model, particularly in the context of supersymmetry.
This analysis aims to search for the production of heavy SUSY particles decaying into jets and neutralinos, with the latter creating missing transverse momentum ($E_T^{\text{miss}}$). Because of the high mass scale expected for the SUSY signal, the ‘effective mass’, $m_{\text{eff}}$, is a powerful discriminant between the signal and most Standard Model backgrounds. For a channel which selects events with N jets, $m_{\text{eff}}$ is defined to be the scalar sum of the transverse momenta of the leading N jets together with $E_T^{\text{miss}}$. The final signal selection uses cuts on $m_{\text{eff}}$(incl.) which sums over all jets with $p_T > 40$ GeV.
**ATLAS jets + missing search strategy**

![Graph showing squark-gluino-neutralino model with ATLAS Preliminary limits](image)

<table>
<thead>
<tr>
<th>Process</th>
<th>At</th>
<th>Am</th>
<th>Am'</th>
<th>Bt</th>
</tr>
</thead>
<tbody>
<tr>
<td>t\bar{t} + Single Top</td>
<td>0.22 ± 0.35 (0.046)</td>
<td>7 ± 5 (5.1)</td>
<td>11 ± 3.4 (10)</td>
<td>0.21 ± 0.33 (0.066)</td>
</tr>
<tr>
<td>Z/\gamma+jets</td>
<td>2.9 ± 1.5 (3.1)</td>
<td>31 ± 9.9 (34)</td>
<td>64 ± 20 (69)</td>
<td>2.5 ± 1.4 (1.6)</td>
</tr>
<tr>
<td>W+jets</td>
<td>2.1 ± 0.99 (1.9)</td>
<td>19 ± 4.5 (21)</td>
<td>26 ± 4.6 (30)</td>
<td>0.97 ± 0.6 (0.84)</td>
</tr>
<tr>
<td>Multi-jets</td>
<td>0 ± 0.0024 (0.002)</td>
<td>0.14 ± 0.24 (0.13)</td>
<td>0 ± 0.13 (0.38)</td>
<td>0 ± 0.0034 (0.0032)</td>
</tr>
<tr>
<td>Di-Bosons</td>
<td>1.7 ± 0.95 (2)</td>
<td>7.3 ± 3.7 (7.5)</td>
<td>15 ± 7.4 (16)</td>
<td>1.7 ± 0.95 (1.9)</td>
</tr>
<tr>
<td>Total</td>
<td>7 ± 0.999 ± 2.26</td>
<td>64.8 ± 10.2 ± 6.92</td>
<td>115 ± 19 ± 9.69</td>
<td>5.39 ± 0.951 ± 2.01</td>
</tr>
<tr>
<td>Data</td>
<td>1</td>
<td>59</td>
<td>85</td>
<td>1</td>
</tr>
<tr>
<td>local p-value (Gaus. \sigma)</td>
<td>0.98(-2.1)</td>
<td>0.65(-0.4)</td>
<td>0.9(-1.3)</td>
<td>0.95(-1.7)</td>
</tr>
<tr>
<td>UL on N_{BSM}</td>
<td>2.9(6.1^{+4.2}_{-2.7})</td>
<td>25(28^{20.39}_{60})</td>
<td>29(43^{12.52}_{460})</td>
<td>3.1(5.5^{3.8}_{8.3})</td>
</tr>
<tr>
<td>UL on \sigma_{BSM} /fb</td>
<td>0.62(1.3^{0.18}_{1.9})</td>
<td>5.3(6^{4.3}_{8.2})</td>
<td>6.2(9.2^{6.7}_{15})</td>
<td>0.65(1.2^{0.6}_{1.8})</td>
</tr>
</tbody>
</table>

**Table 7** Observed numbers of events in data and fitted background components in each SR. For the total background estimates, the quoted errors are evaluated for a single observation at a time. The last two lines show the upper limits on the excess number of events and the excess cross-section above the expected Standard Model (SM) background.

**ATLAS-CONF-2012-033**
ATLAS Search Bounds

SSSM
M3 = 5 TeV

MSSM
M3 = Msq

MSSM
M3 = 2 Msq

MSSM
M3 = 5 TeV

1st, 2nd generation squark mass

0 250 500 750 1000 1250 1500

AmAtAt'BtC'CnD'DEm  AmAtAt'BtC'CnD'DEm  AmAtAt'BtC'CnD'DEm  AmAtAt'BtC'CnD'DEm

Kribs & Martin
CMS $\alpha_T$ strategy

1.1/fb
To increase the sensitivity to higher mass states we carry out a shape analysis over the entire jets most likely to have given rise to the signal.

The jet-based estimate of the missing transverse energy are removed with the following procedure:

1. Events are required to satisfy $\Delta p_T > 5 \text{ GeV}$
2. The variable $\Delta p_T$ is used to select events which stem mainly from QCD multijet triggers.
3. Events with significant jet mismeasurements are protected against by requiring significant jet measurements.
4. The pseudorapidity of the jet with the highest $p_T$ is required to be less than 3.
5. The anti-$k_T$ variable in the lowest $p_T$ jet is required to be less than 3.
6. The transverse energy of each of the two leading jets is required to be greater than 1 GeV.
7. The transverse energy of each of the two leading jets is required to be greater than 1 GeV.
8. The ET of 2nd hardest jet is required to be greater than 1 GeV.
9. The ET of 2nd hardest jet is required to be greater than 1 GeV.
10. The ET of 2nd hardest jet is required to be greater than 1 GeV.

Finally, to protect against severe energy losses, events with significant jet mismeasurements are protected against by requiring significant jet measurements.

The $\alpha_T$ strategy combines $n > 2$ jets into 2 "pseudojets", then calculate:

$$\alpha_T = \frac{E_T^{jet_2}}{M_T} = \frac{E_T^{jet_2}}{\sqrt{\left(\sum_{i=1}^{2} E_T^{jet_i}\right)^2 - \left(\sum_{i=1}^{2} p_x^{jet_i}\right)^2 - \left(\sum_{i=1}^{2} p_y^{jet_i}\right)^2}}$$

where $E_T^{jet_2}$ is the ET of the 2nd hardest jet and $M_T$ is the invariant mass of the hardest 2 jets.

Cut on $\alpha_T \approx 0.5$ highly effective at suppressing QCD background.

Randall & Tucker-Smith 0806.1049
CMS $\alpha_T$ Search Strategy

Triggered $\geq$ 2 jets with 0 leptons and 0 photons.
- $E_T$: all jets $> 50$ GeV; leading 2 jets $> 100$ GeV
- Cut and count $H_T$ bins
  \[ H_T = \sum_{i=1}^{n} E_T^{\text{jet}_i} \]
- missing $E_T > 100$ GeV
- mild $\Delta \phi$ cut to reduce jet mismeasurement
### CMS Cuts and Counts

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
<th>f</th>
<th>g</th>
<th>h</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_T$ Bin (GeV)</td>
<td>275–325</td>
<td>325–375</td>
<td>375–475</td>
<td>475–575</td>
<td>575–675</td>
<td>675–775</td>
<td>775–875</td>
<td>875–∞</td>
</tr>
<tr>
<td>$p_T^{\text{leading}}$ (GeV)</td>
<td>73</td>
<td>87</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>$p_T^{\text{second}}$ (GeV)</td>
<td>73</td>
<td>87</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>$p_T^{\text{other}}$ (GeV)</td>
<td>37</td>
<td>43</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>$\alpha_T &gt; 0.55$</td>
<td>782</td>
<td>321</td>
<td>196</td>
<td>62</td>
<td>21</td>
<td>6</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>$\alpha_T &lt; 0.55$</td>
<td>$5.73 \cdot 10^7$</td>
<td>$2.36 \cdot 10^7$</td>
<td>$1.62 \cdot 10^7$</td>
<td>$5.12 \cdot 10^6$</td>
<td>$1.78 \cdot 10^6$</td>
<td>$6.89 \cdot 10^5$</td>
<td>$2.90 \cdot 10^5$</td>
<td>$2.60 \cdot 10^5$</td>
</tr>
<tr>
<td>$R_{\alpha_T}$ ($10^{-5}$)</td>
<td>$1.36 \pm 0.05_{\text{stat}}$</td>
<td>$1.36 \pm 0.08_{\text{stat}}$</td>
<td>$1.21 \pm 0.09_{\text{stat}}$</td>
<td>$1.21 \pm 0.15_{\text{stat}}$</td>
<td>$1.18 \pm 0.26_{\text{stat}}$</td>
<td>$0.87 \pm 0.36_{\text{stat}}$</td>
<td>$1.03 \pm 0.60_{\text{stat}}$</td>
<td>$0.39 \pm 0.52_{\text{stat}}$</td>
</tr>
</tbody>
</table>
CMS Bounds on Simplified Models

CMS Preliminary
$\sqrt{s} = 7 \text{ TeV} \ L = 1.1 \ \text{fb}^{-1}$

$pp \rightarrow \tilde{g} \tilde{g} \rightarrow q \ q \tilde{\chi}^0; \ m(\tilde{q})>>m(\tilde{g})$

$\sigma_{\text{prod}} = \sigma_{\text{NLO-QCD}}$

$\sigma_{\text{prod}} = 3 \times \sigma_{\text{NLO-QCD}}$

$\sigma_{\text{prod}} = 1/3 \times \sigma_{\text{NLO-QCD}}$

CMS-SUS-11-003
CMS $\alpha_T$ Search Bounds

- SSSM $M_3 = 5 \text{ TeV}$
- MSSM $M_3 = \text{Msq}$
- MSSM $M_3 = 2 \text{ Msq}$
- MSSM $M_3 = 5 \text{ TeV}$
Comparisons
Effectiveness of ATLAS strategy

\[ \sigma_{\text{pp} \to \text{colored superpartners}} \text{ (pb)} \]

- **MSSM, \( M_3 = M_{\tilde{q}} \)**
- **MSSM, \( M_3 = 2M_{\tilde{q}} \)**
- **MSSM, \( M_3 = 5 \text{ TeV} \)**
- **SSSM**

\[ M_{\tilde{q}} \text{ (GeV)} \]

Kribs & Martin
Effectiveness of CMS $\alpha_T$ strategy

The analyses we are interested in are broken into several squark masses. The number $N$ counting the number of supersymmetry events in each channel is the product of the cross section $\sigma$, luminosity $L$, and acceptance $A$.

In other analyses, one event can end up into several channels. For some analyses, the distribution of events is considered.

The increased rate at $\tilde{z}_O$ through not the kinematic constraint $K$ on our reVersed $\tilde{z}_O$, we find the simplified models as a function of squark mass $M_q$ for each simplified model $P_d Q$. We restrict the processes appropriately and corporate these corrections. We feed the spectra into sizable next-to-leading order $P_{\tilde{z}_O}$ corrections. To investigate to make quantitative statements, we use $q_T z_o S$ or $q–S$ detector options and program using otzo $S$ or $q–S$.

The zSPT and all other superpartners are decoupled $P$ set. The analyses we are interested in are broken into several squark masses. The number $N$ counting the number of supersymmetry events in each channel is the product of the cross section $\sigma$, luminosity $L$, and acceptance $A$.

We use $q_T z_o S$ “parton distribution functions” and default scale choices. For event generation, we use Pythia without $\tilde{z}_O$ and rescale the cross section to match the spectrum. Statistical fluctuations have negligible effect on our recast $z_E [df]$. For event generation, we use PROSPINO with $\tilde{O}$ and $q–S$.

The simplified model is an existing $q–S$ simplified model $T^\prime$.

Gluino production $\tilde{O}$ note that our “heavy –SS–” simplified model as a function of squark mass $M_q$. For each simplified model $P_d Q$, we just recast $z_E [df] T$ restricting the processes appropriately and corporate these corrections. We feed the spectra into sizable next-to-leading order $P_{\tilde{z}_O}$ corrections. To investigate to make quantitative statements, we use $q_T z_o S$ or $q–S$ detector options and program using otzo $S$ or $q–S$.

The number of supersymmetry events in a particular channel is the product of the cross section $\sigma$, luminosity $L$, and acceptance $A$. The number $N$ counting the number of supersymmetry events in each channel is the product of the cross section $\sigma$, luminosity $L$, and acceptance $A$.

The number of signal events and background events are drawn from a $\mathcal{N}$ distribution centered on the number of expected $S–$ backVground events and

$$N_{\tilde{O}} = \frac{\sigma \times L \times A}{\mathcal{N}}$$

where $\mathcal{N}$ is the number of signal events and $\sigma \times L \times A$ is the expected number of background events.

The systematic error is the quoted systematic uncertainty $P$ taken directly from $[d“–db]$ whenever the systematic error is negligible. The number of signal events and background events are drawn from a $\mathcal{N}$ distribution centered on the number of expected $S–$ backVground events and

$$N_{\tilde{O}} = \frac{\sigma \times L \times A}{\mathcal{N}}$$

where $\mathcal{N}$ is the number of signal events and $\sigma \times L \times A$ is the expected number of background events.

For event generation, we use PROSPINO with $\tilde{O}$ and $q–S$.

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where $\mathcal{N}$ is the number of signal events and $\sigma \times L \times A$ is the expected number of background events.
“Mixed Gauginos”

(Dirac gluino and Majorana wino & bino)
FIG. 8: Impact of turning on electroweak gauginos at different masses, with $M_{\tilde{w}} = M_{\tilde{b}}$. The ratio $M_{\tilde{w}}/M_{\tilde{q}}$ is represented by the different colors; green: 1, black = .5, blue: .2, red = .1. The solid purple line is the QCD-only cross-section provided for comparison.
Contours showing the ratio of QCD-only XS over XS with gaugino interference. The wino mass = bino mass is on the Y axis, given as factors of squark mass.
Summary

* Heavy Dirac Gluino in “supersoft”, “R-symmetric” natural and suppresses colored sparticle production substantially

* Bounds on 1st,2nd generation squarks 680-750 GeV;
  (up to about 800 GeV with 12/fb @ 8 TeV CMS $\alpha_T$)

* Best search is $\alpha_T$ (Mar 2012); optimize over range of $H_T$ crucial
  (but, “razor” T2 confusion, for off-line...)

* Very high mass searches
  (e.g. ATLAS Meff > 1400-1900 GeV)
  not effective at constraining lighter squarks

* SUSY not ruled out yet...even models not tuned to avoid bounds!

* What is “minimally” necessary? (Majorana EW versus Dirac gluino...