ASPEN DARK MATTER WORKSHOP
LHC / MODEL BUILDING DISCUSSION
SUSY DARK MATTER CANDIDATES

• Jonathan Feng: SUSY Now
• Leszek Roszkowski: CMSSM/MSSM/NMSSM Dark Matter after LHC 8 TeV and XENON 100
• Genevieve Belanger: LHC Constraints on Light Neutralinos
• Yael Shadmi: Dark Matter from SUSY Hidden Sectors
SUSY NOW

- LHC has not yet discovered BSM physics, so what’s the status of weak-scale SUSY now? Recall its main motivations.

- Gauge Coupling Unification

- Dark Matter

Insensitive to superpartner masses
Thermal neutralino DM is still viable
• Naturalness

Highly subjective, but a standard procedure is to express the $Z$ mass in terms of the fundamental SUSY parameters of a given model and require that there not be large cancelations

\[ N_i \equiv \left| \frac{\partial \ln m_Z^2}{\partial \ln a_i^2} \right| = \frac{a_i^2}{m_Z^2} \frac{\partial m^2_Z}{\partial a_i^2} \]

\[ m_Z^2 = 2m_{H_d}^2 - m_{H_u}^2 \frac{\tan^2 \beta}{\tan^2 \beta - 1} - 2\mu^2 \]

\[ M_1(m_{\text{weak}}) = 0.41M_1 \]
\[ M_2(m_{\text{weak}}) = 0.82M_2 \]
\[ M_3(m_{\text{weak}}) = 2.91M_3 \]
\[ -2\mu^2(m_{\text{weak}}) = -2.18\mu^2 \]
\[ -2m_{H_u}(m_{\text{weak}}) = 3.84M_3^2 + 0.32M_3M_2 + 0.047M_1M_3 - 0.42M_2^2 \]
\[ +0.011M_2M_1 - 0.012M_1^2 - 0.65M_3A_t - 0.15M_2A_t \]
\[ -0.025M_1A_t + 0.22A_t^2 + 0.0040M_3A_b \]
\[ -1.27m_{H_u}^2 - 0.053m_{H_d}^2 \]
\[ +0.73m_{Q_3}^2 + 0.57m_{U_3}^2 + 0.049m_{D_3}^2 - 0.052m_{L_3}^2 - 0.053m_{E_3}^2 \]
\[ +0.051m_{Q_2}^2 - 0.110m_{U_2}^2 + 0.051m_{D_2}^2 - 0.052m_{L_2}^2 + 0.053m_{E_2}^2 \]
\[ +0.051m_{Q_1}^2 - 0.110m_{U_1}^2 + 0.051m_{D_1}^2 - 0.052m_{L_1}^2 + 0.053m_{E_1}^2 \]

\[ m_{\tilde{H}} \lesssim 640 \text{ GeV} \left( N_{\text{max}/100} \right)^{1/2} \]
\[ m_{\tilde{B}} \lesssim 3.4 \text{ TeV} \left( N_{\text{max}/100} \right)^{1/2} \]
\[ m_{\tilde{W}} \lesssim 1.2 \text{ TeV} \left( N_{\text{max}/100} \right)^{1/2} \]
\[ m_{\tilde{q}} \lesssim 1.4 \text{ TeV} \left( N_{\text{max}/100} \right)^{1/2} \]
\[ m_{\tilde{t}_L,\tilde{b}_L} \lesssim 1.0 \text{ TeV} \left( N_{\text{max}/100} \right)^{1/2} \]
\[ m_{\tilde{t}_R} \lesssim 1.1 \text{ TeV} \left( N_{\text{max}/100} \right)^{1/2} \]
\[ m_{\tilde{b}_R} \lesssim 4.1 \text{ TeV} \left( N_{\text{max}/100} \right)^{1/2} \]
\[ m_{\tilde{\tau}_L,\tilde{\tau}_R} \lesssim 4.0 \text{ TeV} \left( N_{\text{max}/100} \right)^{1/2} \]
\[ m_{\tilde{\tau}_L,\tilde{\tau}_R} \lesssim 4.0 \text{ TeV} \left( N_{\text{max}/100} \right)^{1/2} \]
\[ m_{\tilde{c}_L,\tilde{s}_L,\tilde{u}_L,\tilde{d}_L} \lesssim 4.0 \text{ TeV} \left( N_{\text{max}/100} \right)^{1/2} \]
\[ m_{\tilde{c}_R,\tilde{u}_R} \lesssim 2.7 \text{ TeV} \left( N_{\text{max}/100} \right)^{1/2} \]
\[ m_{\tilde{s}_R,\tilde{d}_R} \lesssim 4.0 \text{ TeV} \left( N_{\text{max}/100} \right)^{1/2} \]
\[ m_{\tilde{\mu}_L,\tilde{\tau}_L,\tilde{\nu}_L} \lesssim 4.0 \text{ TeV} \left( N_{\text{max}/100} \right)^{1/2} \]
\[ m_{\tilde{\mu}_R,\tilde{e}_R} \lesssim 4.0 \text{ TeV} \left( N_{\text{max}/100} \right)^{1/2} \]

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EXPERIMENTAL CONSTRAINTS

- Collider constraints (see below)
- Flavor constraints are famously stringent, but are elegantly satisfied in some frameworks (e.g. gauge-mediated SUSY breaking).
- Higgs boson mass

\[
\left( \frac{2.5 \text{ TeV}}{m_{\tilde{t}_i}} \right)^2 \left| \mu M_2 \right| \tan \beta \sin \theta_{\text{CP}} \leq \frac{1.05 \times 10^{-27} \text{ e cm}}{10} \\
\left( \frac{1.7 \text{ TeV}}{m_{\tilde{q}}^2} \right)^2 \left| \mu M_2 \right| \tan \beta \sin \theta_{\text{CP}} \leq \frac{2.9 \times 10^{-26} \text{ e cm}}{10}
\]

- EDMs

- Requires multi-TeV 1st generation squarks and sleptons if phases $\sim 1$
SUMMARY OF CONSTRAINTS

For details, see 1302.6587
MODELS: MORE MINIMAL SUSY

- Heavy 1\textsuperscript{st}/2\textsuperscript{nd} generation, light 3\textsuperscript{rd} generation. Requires maximal stop mixing or new fields (e.g., NMSSM) to raise Higgs mass. See also Effective SUSY, U(1)-mediated SUSY, Superheavy SUSY, Natural SUSY, …
• All scalars heavy, sfermions light. Requires parameter correlations to be natural or give up on naturalness. See also PeV SUSY, Split SUSY, Spread SUSY, String-Motivated SUSY, Mini-Split SUSY, …
• Reduce missing $E_T$, so all superpartners can be light. Requires maximal stop mixing or new fields (e.g., NMSSM) to raise Higgs mass, and small phases to satisfy EDM constraints. See also RPV SUSY, Stealth SUSY, …