Dark Matter Implications of the First CMS and ATLAS SUSY Results

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Discussed Papers

- Based On Papers
  - **arXiv: 1103.1197**:
    Sujeet Akula, Ning Chen, Daniel Feldman, Mengxi Liu, Zuowei Liu, Pran Nath, GP
  - **arXiv:1103.5061**:
    SA, DF, ZL, PN, GP
- With Collaborators at
  - C.N. Yang Institute for Theoretical Physics at Stony Brook University
  - Michigan Center for Theoretical Physics at University of Michigan
  - Northeastern University

Outline

1. Motivation: LHC SUSY Results
2. Reach Dependence on A_0 and $\tan\beta$
3. Implications of LHC Results for mSUGRA Parameter Space
4. Dark Matter/LHC Implications for mSUGRA and NUSUGRA
5. Conclusion

Quick Review of mSUGRA Parameters

Framework of analysis is mSUGRA

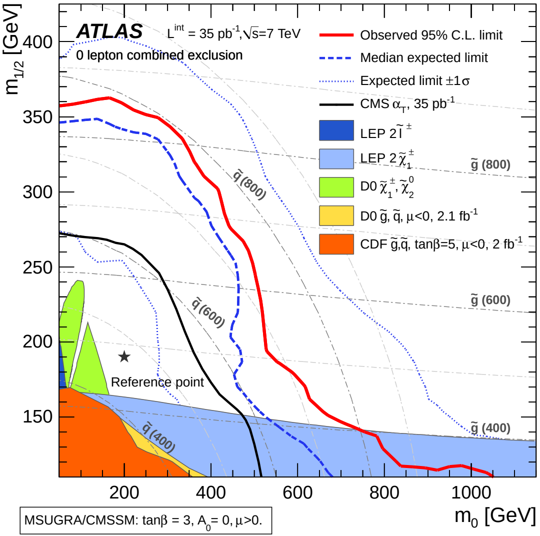
Model Parameters

- m_0: scalar mass at GUT scale
- $m_{1/2}$: gaugino mass at GUT scale
- A_0: Trilinear soft breaking parameter at GUT scale
- $\tan\beta$: ratio of the Higgs VEVs
- $\mathrm{sign}(\mu)$: sign of the Higgs mixing parameter

mSUGRA with R-parity supplies a dark matter candidate, which is the lightest neutralino

Exp. Results: Reach for fix A_0 and $\tan\beta$

- How does the LHC reach change for different values of A_0 and $\tan\beta$?
- How much of the SUSY space has now been constrained?
- What is the effect on the dark matter direct detection search?



LHC SUSY Searches:

arXiv:1101.1628 (**CMS**)

arXiv:1102.2357 (**ATLAS**)

arXiv:1102.5290 (**ATLAS**; exhibited to right)

CMS α_{T} Search

Identification (and Trigger) Criteria

- $H_T = \sum_{i=1}^{N_{jet}} p_T(j_i) > 250\ \mathrm{GeV}$
- Jets (j_i): $p_T > 50\ \mathrm{GeV}$ and $|\eta| < 3$
  - $|\eta(j_1)| < 2.5$
  - $p_T(j_1) > 100\ \mathrm{GeV}$
  - $p_T(j_2) > 100\ \mathrm{GeV}$
- Leptons (e, μ): $p_T > 10\ \mathrm{GeV}$
- Photons: $p_T > 25\ \mathrm{GeV}$

Event Selection

- $n(\ell) = 0$
- $n(\gamma) = 0$
- $n(j) \geq 2$
- $H_T > 350\ \mathrm{GeV}$
- $\alpha_{\mathrm{T}} = p_T^{\tilde{j}_2} / M_T > 0.55$
  - If $N_{jet} > 2$ then two pseudo-jets, $\tilde{j}$
  - $\tilde{j}$ is the scalar sum of jets such that the p_T difference between $\tilde{j}$ is minimized
- $\Delta R_{ecal} > 0.3$ and $\Delta\phi^* \left(j, \not{E}_T^{reco}\right) > 0.5$
- $R_{miss} = \not{E}_T^{reco} / \not{E}_T^{cal} < 1.25$

arXiv: 1101.1628

ATLAS 1 Lepton Search

Identification Criteria

- Leptons: $p_T > 20$ GeV
  - $|\eta^e| < 2.47$ and vetoed if $1.37 < |\eta^e| < 1.52$
  - if $\Delta R(x, \mu) < 0.2$ then $p_T^x < 1.8$ GeV
  - $|\eta^\mu| < 2.4$
- Jets: $p_T > 20$ GeV and $|\eta| < 2.5$
  - jet discarded if $\Delta R(j, e) > 0.2$
  - $\Delta R(j, \ell) > 0.4$
- $\not{E}_T^{reco} > 125$ GeV
  - η^j extended to $|\eta^j| < 4.9$

Event Selection

- $n(\ell) = 1$
- $n(j) \geq 3$
  - $p_T(j_1) > 60$ GeV
  - $p_T(j_2) > 30$ GeV
  - $p_T(j_3) > 30$ GeV
- $\Delta\phi\left(j_i, \not{E}_T^{reco}\right) > 0.2$
  - for $i \in \{1, 2, 3\}$
- $m_T\left(\ell, \not{E}_T^{reco}\right) > 100$ GeV
- $\not{E}_T^{reco} > 0.25 m_{eff}$
  - $m_{eff} = \sum_{i=1}^{3} p_T^{j_i} + p_T^{\ell} + \not{E}_T^{reco}$
- $m_{eff} > 500$
- Regions by m_T and $\not{E}_T^{reco}$

arXiv: 1102.2357

ATLAS 0 Lepton Search

Identification Criteria

- Leptons: $p_T > 10$ GeV
  - $|\eta^e| < 2.47$ and vetoed if $1.37 < |\eta^e| < 1.52$
  - if $\Delta R\,(x,\mu) < 0.2$ then $p_T^x < 1.8$ GeV
  - $|\eta^\mu| < 2.4$
- Jets: $p_T > 20$ GeV and $|\eta| < 2.5$
  - jet discarded if $\Delta R(j,e) > 0.2$
  - $\Delta R(j,\ell) > 0.4$
- $\not{E}_T^{reco} > 100$ GeV
  - η^j extended to $|\eta^j| < 4.9$

Event Selection

- $n(\ell) = 0$
- $n(j) \geq i$
  - Region A and B: $i = 2$
  - Region C and D: $i = 3$
- $p_T^{j_1} > 120$ GeV
- $p_T^{j_m} > 40$ GeV for $m \leq i$
- $\Delta\phi\left(j, \not{E}_T^{reco}\right) > 0.4$
- $\left(\not{E}_T^{reco}/m_{eff}\right)^{\{A;\{C,D\}\}} > \{0.3;\ 0.25\}$
- $(m_{eff})^{\{\{A,C\};D\}} > \{500\text{ GeV};\ 1000\text{ GeV}\}$
- $(m_{T2})^{\{B\}} > 300$ GeV

arXiv: 1102.5290

Calculating allowed contributions of new physics to the observed number of events, $N_{\rm obs}$

- Apply LHC cuts to SM background (b) and Signal (s)
- Calculate p-value; where $CL \equiv 1 - p$ and CL is the confidence level to upper limits
- α_T and 1 lepton search: apply a single-channel method
- 0 lepton search: we use a likelihood-based approach, which corresponds to a product of likelihoods of the form of Eq.(1) that is then maximized

$$p = \frac{\int_0^\infty dbds \sum_{n=0}^{N_{\rm obs}} G\left(s; N_s, \delta N_S\right) G\left(b; N_b, \delta N_b\right) P\left(n \mid b+s\right)}{\int_0^\infty db \sum_{n=0}^{N_{\rm obs}} G\left(b; N_b, \delta N_b\right) P\left(n \mid b\right)} \tag{1}$$

For more details see: arXiv:0901.0512; FERMILAB-CONF-00-048-E

p-value (Cont.)

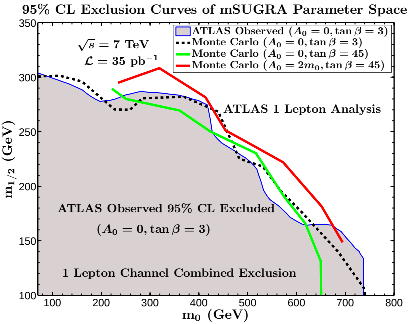
$$p = \frac{\int_0^\infty dbds \sum_{n=0}^{N_{\rm obs}} G\left(s; N_s, \delta N_S\right) G\left(b; N_b, \delta N_b\right) P\left(n \mid b+s\right)}{\int_0^\infty db \sum_{n=0}^{N_{\rm obs}} G\left(b; N_b, \delta N_b\right) P\left(n \mid b\right)}$$

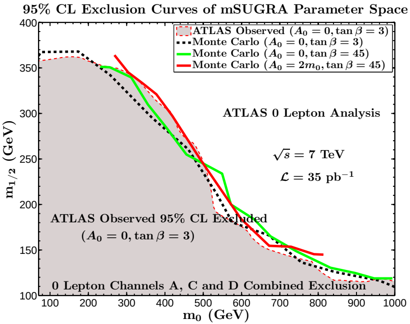
- $G\left(x; N_x, \delta N_x\right)$ is the Gaussian probability density function of observing N_x events with a standard deviation of δN_x
- $P\left(n \mid x\right)$ is the Poisson distribution of observing n events given the events x.

For more details see: arXiv:0901.0512; FERMILAB-CONF-00-048-E

Vary A_0 and $\tan\beta$

Using the cuts reported in arXiv:1102.2357 (left) and arXiv:1102.5290 (right) we see good agreement with $A_0 = 0$ and $\tan\beta = 3$

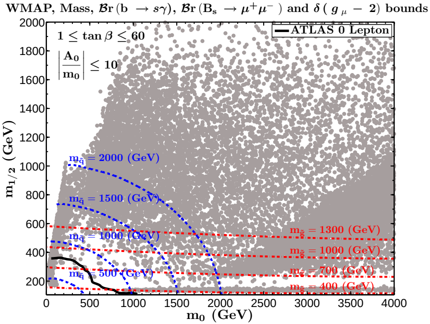




- Exclusion boundary does not change much when A_0 or $\tan\beta$ are varied
- Main changes are at the ends due to LEP, EWSB and $\tilde{\tau}_1$ LSP
- Consistent to use LHC exp. curve for random inputs

How does LHC data effect parameter space

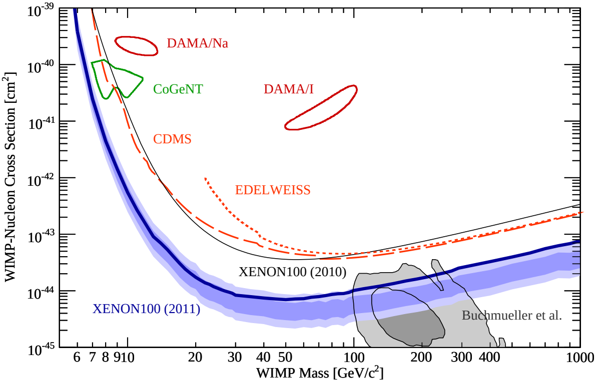
Previous results only needed to pass REWSB, so what if we apply (non-LHC) collider, flavor and astrophysics constraints? (K. Nakamura *et al.*, and arXiv: 1001.4538, hep-ph/0609232, hep-ph/0602001, 1006.3469, 0808.1297)



$$
\begin{aligned}
0.0896 < \quad & \Omega_\chi h^2 \quad < 0.1344 \\
m_h \quad & > \quad 93.5\ \text{GeV} \\
m_{\tilde{\tau}_1} \quad & > \quad 81.9\ \text{GeV} \\
m_{\tilde{\chi}_1^\pm} \quad & > \quad 103.5\ \text{GeV} \\
m_{\tilde{t}_1} \quad & > \quad 100\ \text{GeV}
\end{aligned}
$$

$$
\begin{aligned}
\mathcal{B}r\left(B_s \to \mu^+\mu^-\right) \quad & \le \quad 4.2 \times 10^{-8} \\
\left(-11.4 \times 10^{-10}\right) \le \quad \delta\left(g_\mu - 2\right) \quad & \le \left(9.4 \times 10^{-9}\right) \\
\left(2.77 \times 10^{-4}\right) \le \quad \mathcal{B}r\left(b \to s\gamma\right) \quad & \le \left(4.37 \times 10^{-4}\right)
\end{aligned}
$$

Implications of LHC on Dark Matter Direct Detection

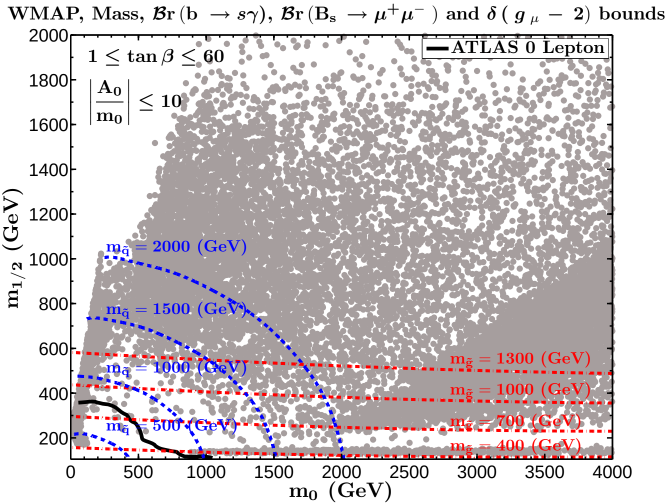


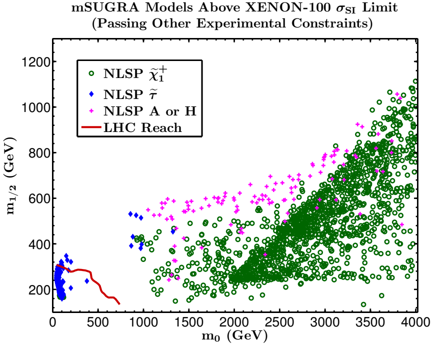
arXiv:1104.2549 (**XENON**)

What are the implications of the LHC Results on XENON-100?

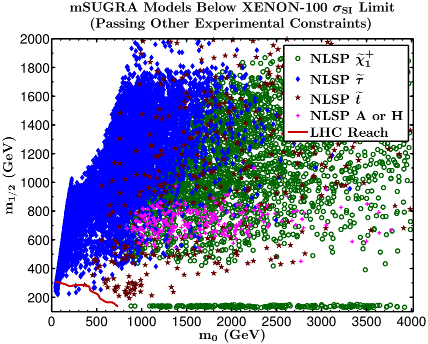
XENON-100 Results on mSUGRA Parameter Space

Before XENON-100 constraint is applied we have :





ABOVE XENON-100



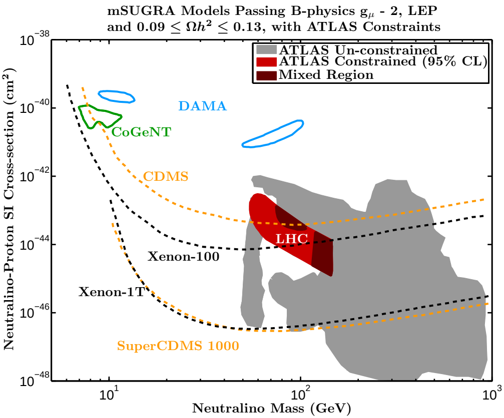
BELOW XENON-100

Models Most Constrained

- slepton coannihilation models (LHC and XENON)
- Hyperbolic Branch/Focus Point region (XENON)

There are significant uncertainties in the value of the strange quark form factors f_s as shown by arXiv:0907.4177. The uncertainty can give a significantly smaller σ_{SI} which would relax the constraints

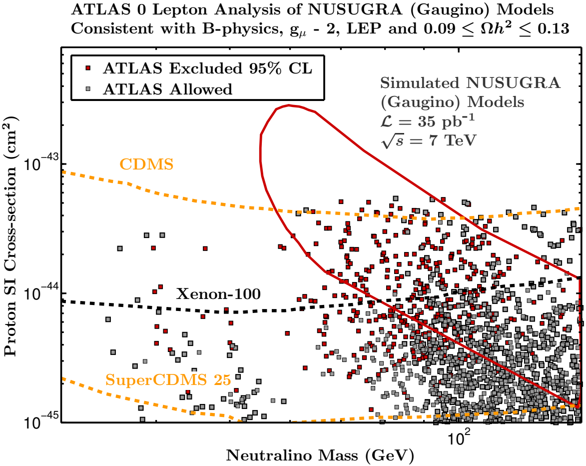
LHC Constraint on Dark Matter Direct Detection



LHC SUSY Search

- **Models** in the **Red Region** have been **constrained**
- $\sim$ **60%** of models in the **Maroon Regions** have been **constrained**
- **Models** in the **Gray Region** are **unconstrained**

ATLAS Excluded Region Repopulated by NUSUGRA



$$m_\alpha = m_{1/2}\,(1 + \delta_\alpha) \text{ for } \alpha \in \{1, 2, 3\} \text{ and } -1 < \delta_\alpha < 1$$

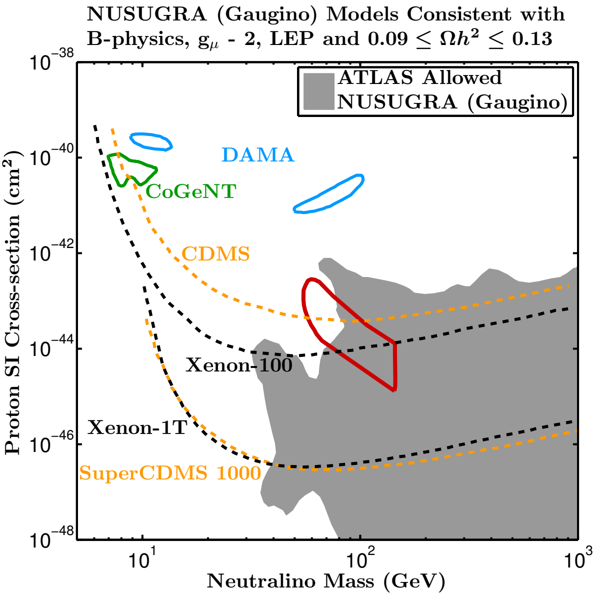
mSUGRA excluded region is now repopulated

Conclusion

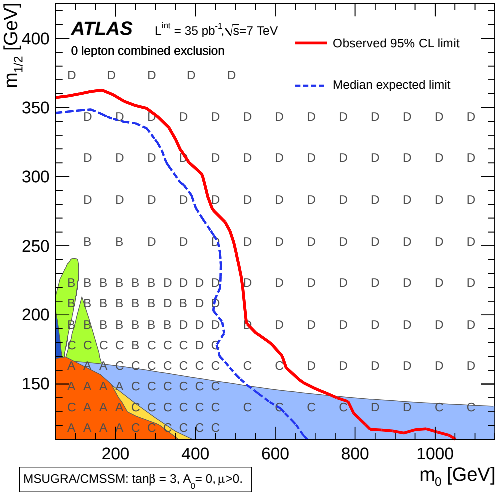
- With 35 pb^{-1} of integrated luminosity the LHC has probed a portion of the mSUGRA parameter space and has constrained a portion of the slepton coannihilation region
- Recent XENON-100 results have put additional constraints on the mSUGRA parameter space
  - Constrained mostly the HB/FP region
  - The neutralino-proton SI cross-section is sensitive to the strange quark form factors, which has large uncertainties.
- Repopulation of mSUGRA region excluded by LHC or direct detection experiments could hint at non-universalities

Additional Slides

NUSUGRA before LHC constraints are applied

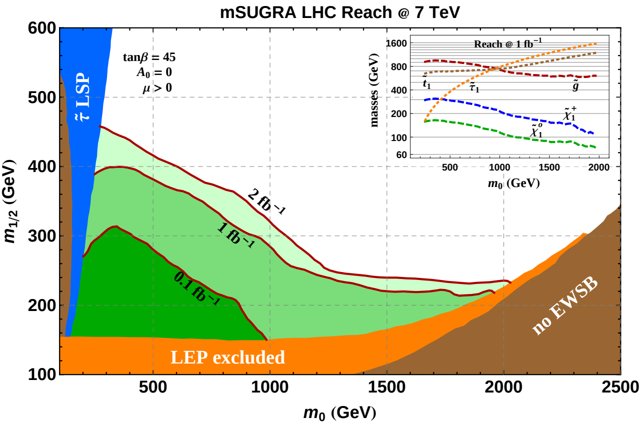


Points Marked By Channel that Best Excludes Region



http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/susy-0lepton_01

Projected Reach at 7 TeV



arXiv:1008.3423

LHC: SM Background

SM process	Cross section (fb)	SM process	Cross section (fb)
QCD $2,3,4$ jets	2.0×10^{10}	$t\bar{t}t\bar{t}$	0.5
$Z/\gamma + b\bar{b} + \leq 2$ jets	2.8×10^3	$t\bar{t}b\bar{b}$	1.2×10^2
$b\bar{b} + \leq 2$ jets	9.5×10^7	$b\bar{b}b\bar{b}$	2.2×10^4
$Z/\gamma + \leq 3$ jets	6.2×10^6	$W^\pm W^\pm$	2.0×10^3
$W^\pm + \leq 3$ jets	1.9×10^7	$W^\pm Z$	1.1×10^3
$W^\pm + t\bar{t} + \leq 2$ jets	70	$\gamma + \leq 3$ jets	1.5×10^7
$Z/\gamma + t\bar{t} + \leq 2$ jets	56	$t\bar{t} + \leq 2$ jets	1.6×10^5
$W^\pm + b\bar{b} + \leq 2$ jets	3.2×10^3	ZZ	7.3×10^2
$W^\pm + t\bar{b}\,(\bar{t}b) + \leq 2$ jets	2.4×10^2		

SM background was generated at 7 TeV using `MadGraph 4.4` (J. Alwall *et al.*).

For more detail see arXiv:1008.3423