

Supersymmetric dark matter after LUX

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Based on:

MB, Marek Olechowski, Pawel Szczerbiak

arXiv:1705.00227

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Neutralino as a thermal relic

- Dark matter particle should be stable (at least at cosmological time scales)
- The simplest SUSY models predict that the lightest sparticle (LSP) is stable
- SUSY WIMP miracle: the lightest neutralino has (roughly) the right relic abundance to account for DM
- But the devil is in details... and experimental constraints

Relic abundance of neutralinos

- In MSSM there are 4 neutralinos:

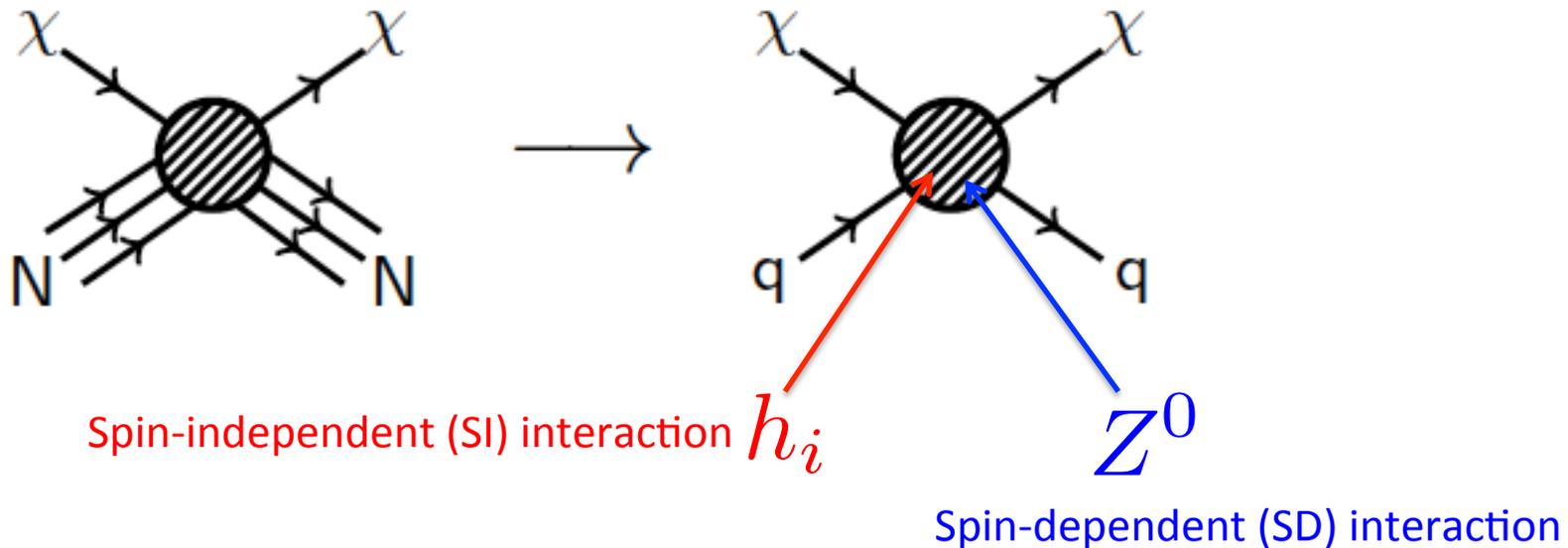
$$\begin{pmatrix} \text{Bino } M_1 & 0 & -M_Z \sin\theta_W \cos\beta & M_Z \sin\theta_W \sin\beta \\ 0 & \text{Wino } M_2 & M_Z \cos\theta_W \cos\beta & -M_Z \cos\theta_W \sin\beta \\ -M_Z \sin\theta_W \cos\beta & M_Z \cos\theta_W \cos\beta & 0 & -\mu \\ M_Z \sin\theta_W \sin\beta & -M_Z \cos\theta_W \sin\beta & -\mu & \text{Higgsinos } 0 \end{pmatrix}$$

- Pure Bino: generically $\Omega h^2 \gg 1$ (due to lower limits on sfermion masses)
- Pure Higgsino: $\Omega h^2 \approx 0.12 \Rightarrow m_{\text{LSP}} \approx 1 \text{ TeV}$
- Pure Wino: $\Omega h^2 \approx 0.12 \Rightarrow m_{\text{LSP}} \approx 3 \text{ TeV}$ (but strong tension with indirect detection exp.)
- The most viable option:** mixed (well-tempered) Bino-Higgsino DM with mass from 100 GeV to 1 TeV

Arkani-Hamed, Delgado, Giudice '06

Direct detection of neutralinos

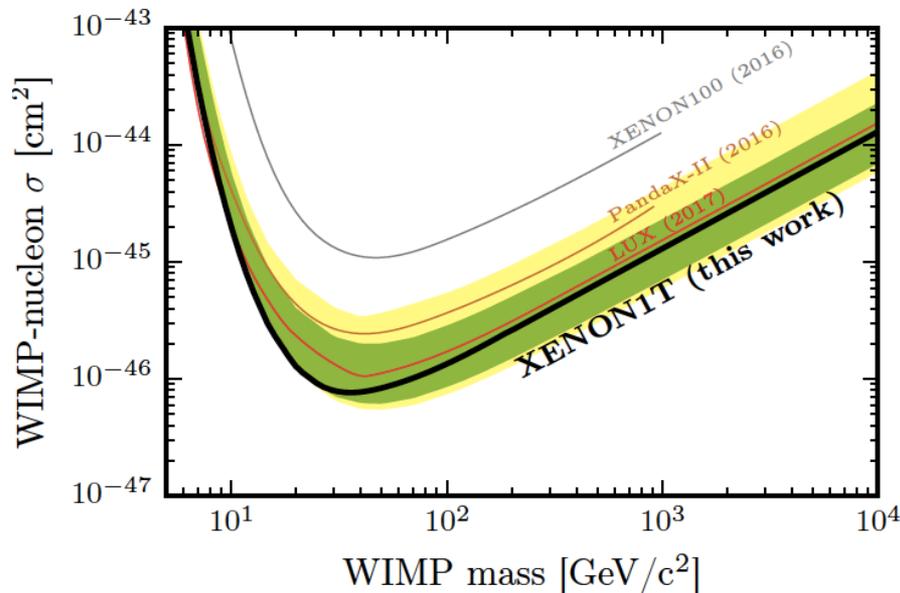
- Neutralinos interact with nucleons via exchange of Higgs boson(s) and Z boson



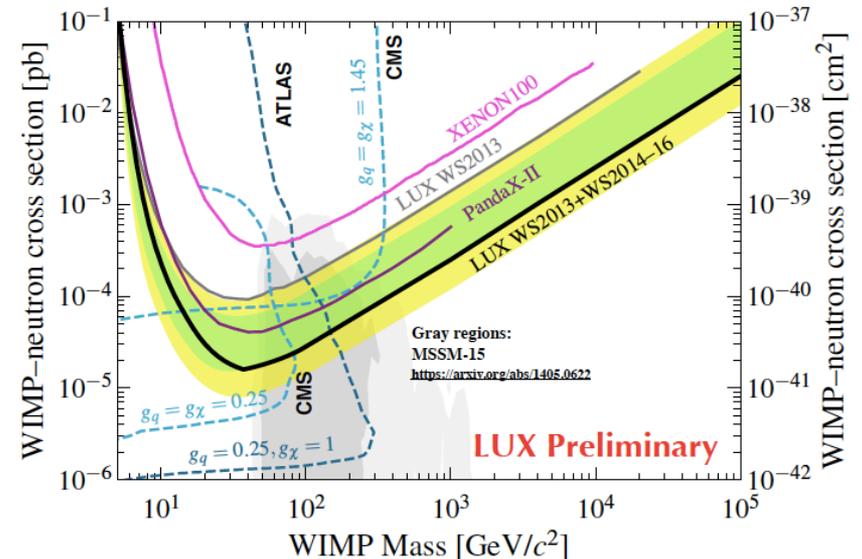
Limits on WIMP scattering off nuclei

- The strongest constraints from LUX (Xenon1T only slighter better in SI so far)

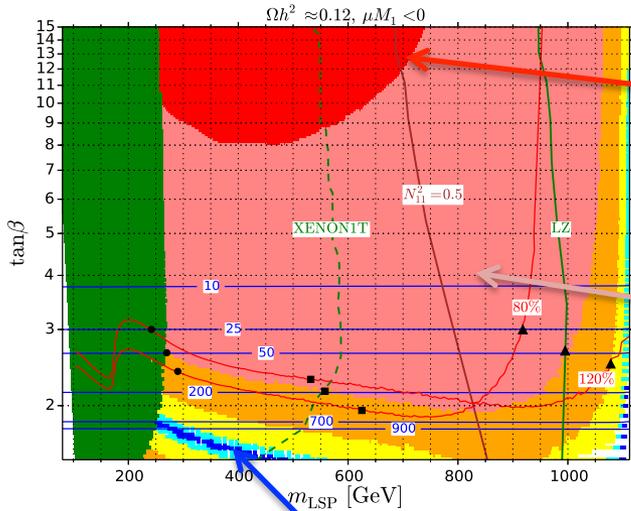
Spin-independent (SI) cross-section



Spin-dependent (SD) cross-section



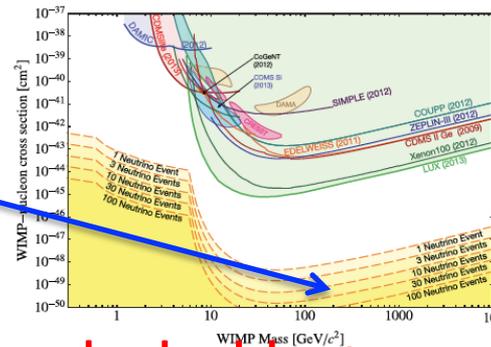
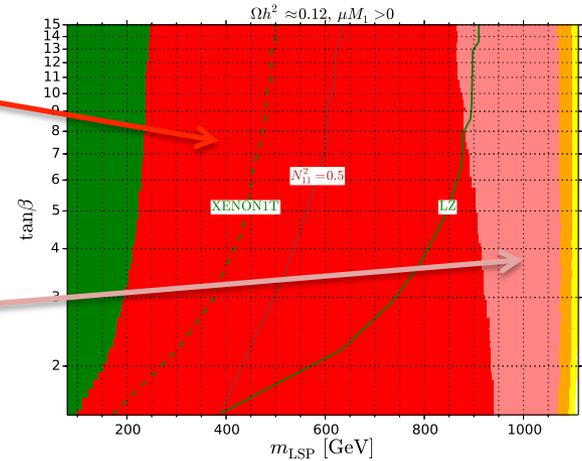
LUX Limits on Bino-Higgsino



Excluded by SI LUX2013

Excluded by SI LUX2016

SI x-sec below neutrino background



- Most parameter space excluded but small $\tan \beta$ still allowed

Blind spots for SI direct detection: vanishing Higgs-LSP coupling

- In parts of parameter space (**blind spots**) the SI LSP-nucleon effective coupling vanishes
- If only Higgs mediates this interaction SI blind spot occurs at $\frac{M_1}{\mu} = -\sin(2\beta)$ Cheung, Hall, Pinner, Ruderman '13
- $\Omega h^2 \approx 0.12$ requires large bino-higgsino mixing:
$$M_1 \sim \mu \Rightarrow \tan \beta \lesssim 2$$
- 125 GeV Higgs mass requires very heavy stops (big fine-tuning of the EW scale) in MSSM

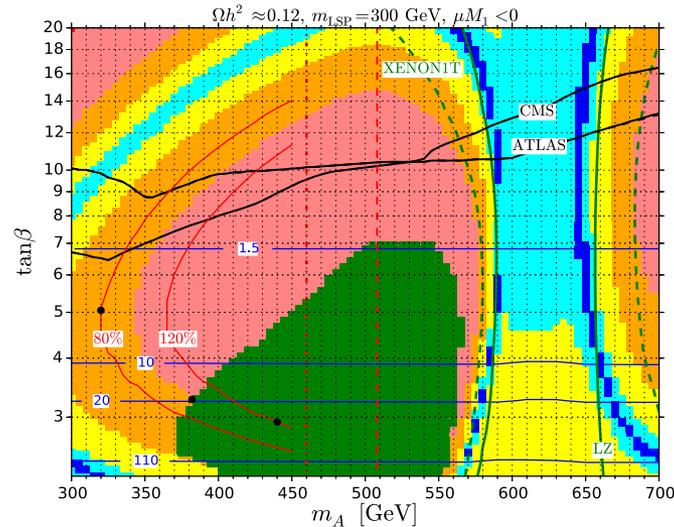
Blind spots for SI direct detection: interference with heavy Higgs H

- If H is light SI blind spot is modified Huang, Wagner '14

$$\frac{M_1}{\mu} \approx -\sin(2\beta) - \frac{m_h^2 \tan \beta}{m_H^2 2}$$

- $\Omega h^2 \approx 0.12$ may be obtained also for large $\tan \beta$
- But the LHC lower mass limits on m_H are strong, especially for large $\tan \beta$

Blind spots for SI direct detection: interference with heavy Higgs H



- Well-tempered LSP still requires quite small $\tan \beta$
- Strong resonant annihilation ($m_{\text{LSP}} \approx m_A/2$) may be out of reach of future SI direct detection experiments

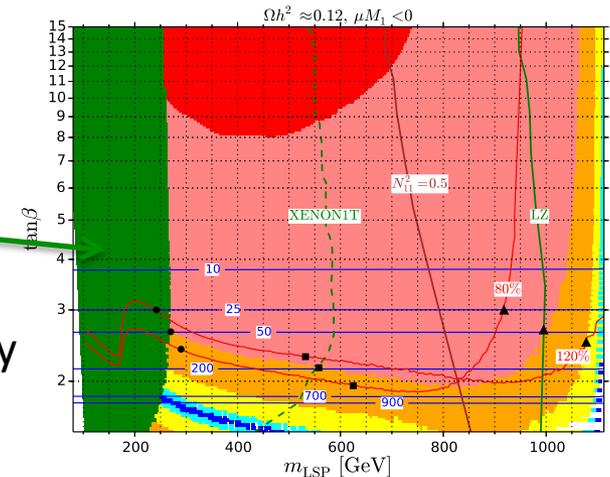
Testing SI blind spots with SD direct detection

- Neutralino SI blind spots can be efficiently probed using SD interaction with nucleons

- LUX provides lower mass limit for LSP of 250 GeV

- The limit is model-independent when LSP dominantly annihilates to $t\bar{t}$ via Z boson exchange

- The limits may be strongly improved by Xenon1T/LZ
- If no signal observed by LZ then direct detection exp. would be accommodated by:
 - Pure 1 TeV Higgsino
 - Pure Bino with fine-tuned spectrum of scalar masses (co-annihilations, resonant annihilation)



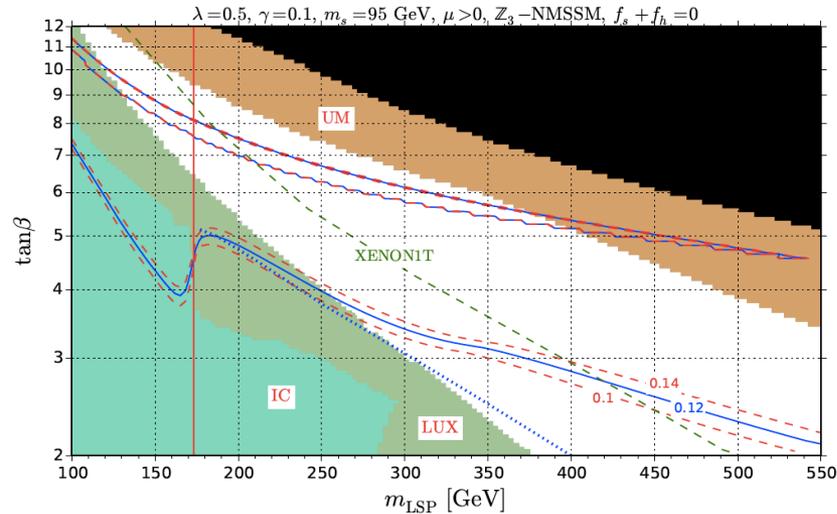
NMSSM: Beyond minimal SUSY

$$W = W_{\text{MSSM}} + \lambda S H_u H_d + \xi_F S + \frac{1}{2} \mu' S^2 + \frac{\kappa}{3} S^3$$

 New singlet scalar and fermion (singlino) introduced

- New DM candidate: (Higgsino-)Singlino
- Singlino similar to Bino except that it can strongly annihilate to singlet scalars
- SD constraints relaxed (due to smaller LSP-Z coupling required to get $\Omega h^2 \approx 0.12$)

NMSSM: Higgsino-Singlino DM



- SD constraints relaxed (due to smaller LSP-Z coupling required to get $\Omega h^2 \approx 0.12$)
- Future Xenon1T lower mass limit on Singlino-Higgsino LSP may be relaxed by 200-300 GeV as compared to the MSSM case

Conclusions

- Supersymmetric DM under pressure (as any other WIMP)
- Still, there are parts of parameter space consistent with the lack of observation
- Future results for SD scattering x-sec may close most of SI blind spots
- If there is no direct detection in next 5 years (LZ) the most viable scenario would be 1 TeV Higgsino or strong LSP annihilation to new light singlet scalars – cases for indirect DM detection

Acknowledgments

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