On the Correlation Between the Spin-Independent and Spin-Dependent Direct Detection of Dark Matter

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Outline

- WMAP has given us a very precise measurement of the relic density of dark matter:

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- Now we just have to figure out what it is.
- For this work we will assume that dark matter is a weakly interacting massive particle (WIMP).
- We would like to explore the near term prospects for the direct detection of WIMP dark matter.

- The simplest weak interaction is

$$\mathcal{O}_{\text{vector}} = (\bar{\chi}_{\text{D}}\, \gamma^{\mu}\, \chi_{\text{D}})\, Z^{0}_{\mu}$$

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- If the dark matter is Majorana, this operator trivially vanishes.
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- This in turn must be proportional to electroweak symmetry breaking.
- Hence, the following operators will naively be non-vanishing:

$$\begin{aligned} \mathcal{O}_{\rm Higgs} &= (\bar{\chi}\, \chi)\, h \\ \mathcal{O}_{Z^0} &= (\bar{\chi}\, \gamma^{\mu} \gamma^{5}\, \chi)\, Z^0_{\mu} \end{aligned}$$

- $\mathcal{O}_{\rm Higgs}$ and $\mathcal{O}_{Z^0}$ lead to spin-independent and spin-dependent scattering off of nuclei respectively.

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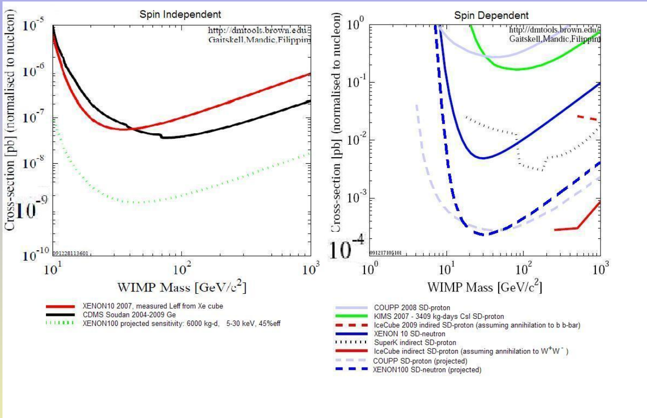
- This is in tension is with LEP due to bounds on the slepton masses.
- However, this tension is alleviated if one considers a mixed (well-tempered) neutralino with $m_{\mathrm{DM}} > m_W$.
- We will show that well-tempering can naturally imply spin-independent and spin-dependent signals for the next generation of experiments.

Outline

- The best limits on dark matter with $m_{\mathrm{DM}} > m_W$ are given by



- Define "large" cross sections as $\sigma_{\mathrm{SI}}^{\mathrm{large}} > 5 \times 10^{-9}$ pb and $\sigma_{\mathrm{SD}}^{\mathrm{large}} > 10^{-4}$ pb, motivated by the near term projections of currently running experiments.

- The following operator leads to spin-independent scattering:

$$\mathcal{O}_q^{\mathrm{SI}} = c_q\,(\bar{\chi}\,\chi)\,(\bar{q}\,q),$$

- In the MSSM (with heavy squarks) the coefficients of the spin-independent operator in the decoupling and large $\tan\beta$ limits is:

$$\begin{aligned} c_u &\sim \frac{(Z_W - t_w\,Z_B)Z_{H_u}}{m_h^2} \\ c_d &\sim c_u\left(1 - t_\beta \frac{m_h^2}{m_H^2}\frac{Z_{H_d}}{Z_{H_u}}\right) \end{aligned}$$

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- with typical size

$$\sigma_{\mathrm{SI}}^{\mathrm{MSSM}}(\chi\,N \to \chi\,N) \approx 5\times 10^{-9}\,\mathrm{pb}\left(\frac{(Z_W - t_w\,Z_B)\,Z_{H_u}}{0.1}\right)^2$$

- Note that this requires neutralino mixing to be non-vanishing.

- The following operator leads to spin-dependent scattering:

$$\mathcal{O}_q^{\rm SD} = d_q\,(\bar{\chi}\,\gamma^\mu\gamma^5\,\chi)(\bar{q}\,\gamma_\mu\gamma^5\,q).$$

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$$\sigma_{\rm SD}^{\rm MSSM}(\chi\,p \to \chi\,p) \approx 4\times 10^{-4}\,{\rm pb}\,\left(\frac{|Z_{H_d}|^2 - |Z_{H_u}|^2}{0.1}\right)^2$$

- Note that this also requires neutralino mixing to be non-vanishing.

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- In the limit of Mostly Bino (or Wino) with some Higgsino one can approximate this value by

$\frac{c_{2\beta}\, s_w^2\, m_Z^2}{\mu^2 - M_1^2}$ for $|M_1|$, $|\mu|$, $|\mu| - |M_1| > m_Z$, $M_2 \to \infty$

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- In the limit of a very mixed Bino-Higgsino or Wino-Higgsino one can approximate this value by

$$\frac{(s_\beta - c_\beta)\, s_w\, m_Z}{2\sqrt{2}\,|\mu|} \quad \text{for } |M_1| = |\mu| > m_Z,\ M_2 \to \infty$$
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- It is the limit of Wino-Higgsino which leads to the largest spin-dependent cross sections for the neutralino.

- The largest obtainable spin-dependent cross section in the MSSM is given by

$$\begin{aligned} |Z_{H_d}|^2 - |Z_{H_u}|^2 &< 0.4 \Rightarrow \\ (\sigma_{\rm SD}^{\rm SUSY}) &< 6 \times 10^{-3}\,{\rm pb} \end{aligned}$$

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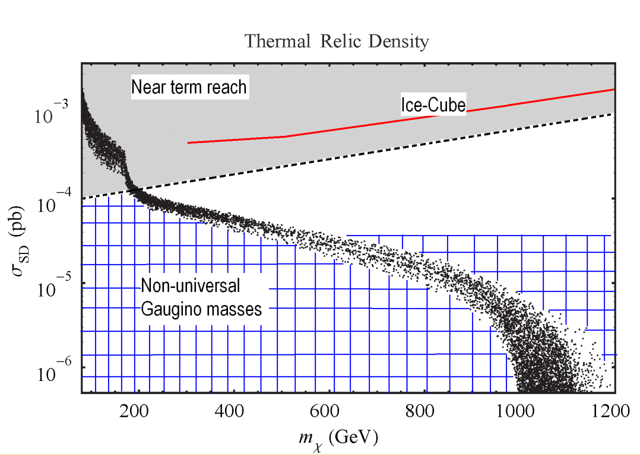
- If one imposes that the relic density is thermal

$$\begin{aligned} |Z_{H_d}|^2 - |Z_{H_u}|^2 &< 0.24 \Rightarrow \\ (\sigma_{\rm SD}^{\rm SUSY})_{\rm thermal} &< 2 \times 10^{-3}\,{\rm pb} \end{aligned}$$



- The points are for gaugino mass unification.

Outline

- Recall that

$$\frac{m_Z^2}{2} = -|\mu|^2 + \frac{m_{H_d}^2 - m_{H_u}^2 t_\beta^2}{t_\beta^2 - 1}$$

- Hence, small μ implies less fine-tuning in the Z^0 mass.

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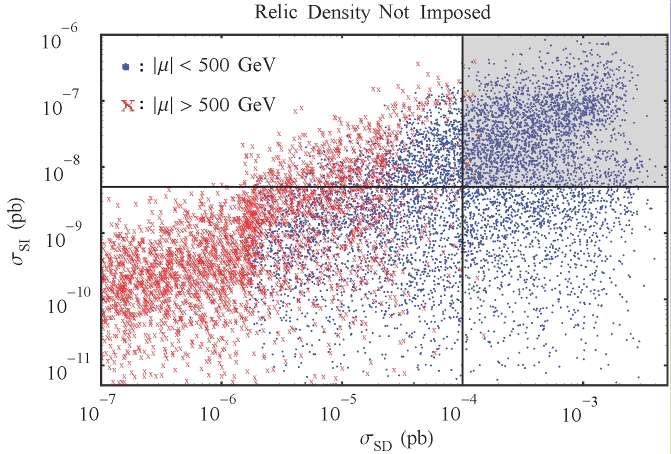
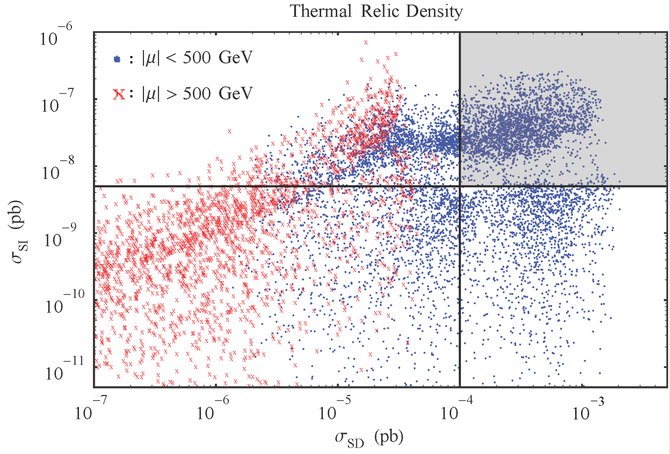
$$\frac{m_Z^2}{2} = -|\mu|^2 + \frac{m_{H_d}^2 - m_{H_u}^2 t_\beta^2}{t_\beta^2 - 1}$$

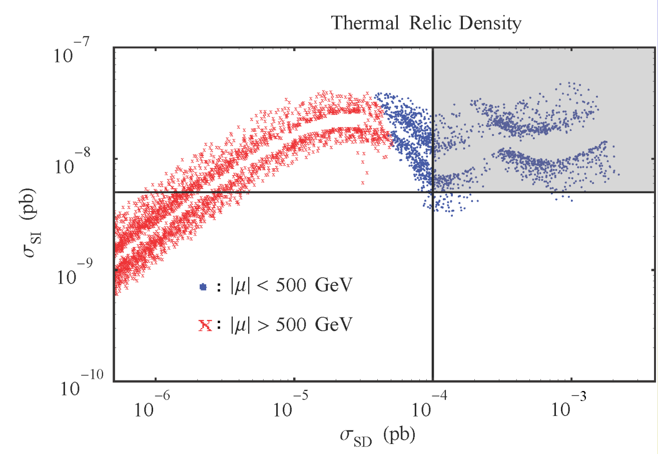
- Hence, small μ implies less fine-tuning in the Z^0 mass.
- In the plots that follow, the shaded region is "large:" much of the region with low fine-tuning will be probed in the near-term.
- Points with small spin-independent cross sections require either a pure neutralino or some sort of conspiracy, *e.g.* a cancellation between the contributions from the light and heavy Higgs.



- Here we make no assumptions about the *thermal* relic density.
- We still assume the neutralinos constitute the majority of the dark matter.



- Here we impose that the thermal relic density matches observation to within 3 σ.



- Here we impose a thermal relic density, gaugino mass unification and the decoupling limit.

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- Tension with LEP bounds points toward a mixed neutralino.
- This naively implies large spin-independent *and* large spin-dependent cross sections.
- Hence, dark matter direct detection experiments are beginning to probe a very interesting region of the parameter space.
- Maybe the detection of neutralino dark matter is right around the corner!!

Thank You

Are there any questions?