Blind Spots for Dark Matter Direct Detection in MSSM

Based on work with Carlos Wagner, arXiv:1404.0392

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Neutralino Dark Matter

- Everyone loves supersymmetry
- Squarks mass around TeV scale and chargino/neutralino mass around the order of weak scale is consistent with the higgs, and include a DM candidate, the lightest neutralino
- LHC limits on neutralinos are still weak
- Constrained by DDMD&IDMD experiments
Outline

- Identify the parameter space allowed by current experiments and understand the prospective for future experiments

- Identify the blind spots in DDMD analytically

- Relevant parameters: LSP mass $m_X$, higgsino mass $\mu$, $\tan \beta$, CP odd higgs mass $m_A$ and SM-like higgs mass $m_h$
Amplitude

In gauge eigenstates

\[ h = \frac{1}{\sqrt{2}} (\cos \alpha \, H_u - \sin \alpha \, H_d) \]
\[ H = \frac{1}{\sqrt{2}} (\sin \alpha \, H_d + \cos \alpha \, H_u). \]

Amplitude

\[ a_d \sim \frac{m_d}{\cos \beta} \left( -\sin \alpha \frac{g_{XXh}}{m_h^2} + \cos \alpha \frac{g_{XXH}}{m_H^2} \right). \]

\[ \tilde{\chi} = N_{i1} \tilde{B} + N_{i2} \tilde{W} + N_{i3} \tilde{H}_d + N_{i4} \tilde{H}_u \quad L \supset -\sqrt{2} g' Y_{H_u} \tilde{B} \tilde{H}_u H_u^* - \sqrt{2} g \tilde{W}^a \tilde{H}_u t^a H_u^* + (u \leftrightarrow d) \]

Couplings

\[ g_{XXh} \sim (g_1 N_{i1} - g_2 N_{i2})(-\cos \alpha \, N_{i4} - \sin \alpha \, N_{i3}) \]
\[ g_{XXH} \sim (g_1 N_{i1} - g_2 N_{i2})(-\sin \alpha \, N_{i4} + \cos \alpha \, N_{i3}). \]
When 1st&2nd gen squarks are heavy, $\epsilon_d$ is suppressed.
Amplitude

\[ a_d \sim \frac{m_d(g_1 N_{i1} - g_2 N_{i2})}{\cos \beta} \left[ N_{i4} \sin \alpha \cos \alpha \left( \frac{1}{m_h^2} - \frac{1}{m_H^2} \right) + N_{i3} \left( \frac{\sin^2 \alpha}{m_h^2} + \frac{\cos^2 \alpha}{m_H^2} \right) \right] \]

\[ N_{i3} \sim (m_\chi \cos \beta + \mu \sin \beta) \]

\[ N_{i4} \sim (m_\chi \sin \beta + \mu \cos \beta). \]

\[ \sin \alpha \approx -\cos \beta \]

\[ a_d \sim \frac{m_d}{\cos \beta} \left[ \cos \beta (m_\chi + \mu \sin 2\beta) \frac{1}{m_h^2} - \mu \sin \beta \cos 2\beta \frac{1}{m_H^2} \right] \]

\[ a_u \sim \frac{m_u}{\sin \beta} \left[ \sin \beta (m_\chi + \mu \sin 2\beta) \frac{1}{m_h^2} + \mu \cos \beta \cos 2\beta \frac{1}{m_H^2} \right] \]
SI Scattering Cross Section

\[ a_p = \left( \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{a_q}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{q=c,b,t} \frac{a_q}{m_q} \right) m_p \]

Form factors

\[ < p|m_qq\bar{q}|p > \equiv m_p f_{Tq}^{(p)} \quad f_{TG}^{(p)} = 1 - \sum f_{Tq}^{(p)} \]

\[ f_{Tu}^{(p)} = 0.017 \pm 0.008, \quad f_{Td}^{(p)} = 0.028 \pm 0.014, \quad f_{Ts}^{(p)} = 0.040 \pm 0.020 \text{ and } f_{TG}^{(p)} \approx 0.91 \]

Scattering cross section

\[ \sigma_{p}^{SI} \sim \left[ (F_d^{(p)} + F_u^{(p)})(m_\chi + \mu \sin 2\beta) \frac{1}{m_h^2} + \mu \tan \beta \cos 2\beta (-F_d^{(p)} + F_u^{(p)}/\tan^2 \beta) \frac{1}{m_H^2} \right]^2 \]

\[ F_u^{(p)} \equiv f_u^{(p)} + 2 \times \frac{2}{27} f_{TG}^{(p)} \approx 0.15 \quad F_d^{(p)} = f_{Td}^{(p)} + f_{Ts}^{(p)} + \frac{2}{27} f_{TG}^{(p)} \approx 0.14 \]

\[ F_u^{(n)} \approx 0.15 \quad F_d^{(n)} \approx 0.14 \]
Blind Spots

Contribution from SM-like higgs vanishes

\[
\sigma_p^{SI} \sim \left[ (F_d^{(p)} + F_u^{(p)}) (m_\chi + \mu \sin 2\beta) \frac{1}{m_h^2} + \mu \tan \beta \cos 2\beta (-F_d^{(p)} + F_u^{(p)}/\tan^2 \beta) \frac{1}{m_h^2} \right]^2
\]

Contribution from SM-like higgs and the heavy higgs cancels against each other

\[
(m_\chi + \mu \sin 2\beta) = 0
\]

Cheung, Hall, Pinner and Ruderman

Can be simplified as

\[
2 \left( m_\chi + \mu \sin 2\beta \right) \frac{1}{m_h^2} \simeq -\mu \tan \beta \frac{1}{m_H^2}
\]
Blind Spots: $\mu < 0$

\[ \sigma_{p}^{SI} \sim \left[ (F_{d}^{(p)} + F_{u}^{(p)})(m_{\chi} + \mu \sin 2\beta) \frac{1}{m_{h}^2} + \mu \tan \beta \cos 2\beta (-F_{d}^{(p)} + F_{u}^{(p)}/\tan^{2} \beta) \frac{1}{m_{H}^2} \right]^2 \]

- Suppress the couplings of lightest neutralinos to the light higgs boson
- Lead to a destructive interference between the light and heavy higgs exchange amplitudes
CMS H, A -> ττ Searches

CMS Preliminary, H -> ττ, 4.9 fb⁻¹ at 7 TeV, 19.7 fb⁻¹ at 8 TeV

MSSM mₜₐₓ scenario M_{SUSY} = 1 TeV

95% CL Excluded:
- observed
- SM H injected
- expected
- ± 1σ expected
- ± 2σ expected
- LEP

β tan

mₐ [GeV]

100 200 300 400 500 600 700 800 900 1000
Blind Spots, $\mu = -2M_1$

$\mu > 0, \mu < 0$ Lux Xenon1T, H/A $\rightarrow \tau\tau$
Traditional Blind Spot

\[ m_\chi + \mu \sin 2\beta = 0 \]

\[ \tan\beta = 50, \mu \sim -25 \, M_1 \]

\[ \tan\beta = 30, \mu \sim -15 \, M_1 \]

\[ \tan\beta = 10, \mu \sim -5 \, M_1 \]

\[ \tan\beta = 5, \mu \sim -2.6 \, M_1 \]

H/A - &gt; \tau\tau
Blind Spot with Relic Density

Traditional Blind Spot, Generalized Blind Spot, DDMD cross section, Right Relic Density
Blind Spot with Relic Density

Traditional Blind Spot, Generalized Blind Spot, DDMD cross section, Right Relic Density
Blind Spot with Relic Density

Traditional Blind Spot, Generalized Blind Spot, DDMD cross section, Right Relic Density
Conclusion

- SI DDMD cross section is suppressed for negative $\mu$
- Blind spots at $2 (m_\chi + \mu \sin 2\beta) \frac{1}{m_h^2} \simeq - \mu \tan \beta \frac{1}{m_H^2}$
- The blind spots can be consistent with the right relic density