Blind Spots for Dark Matter Direct Detection in MSSM

Based on work with Carlos Wagner, arXiv:1404.0392

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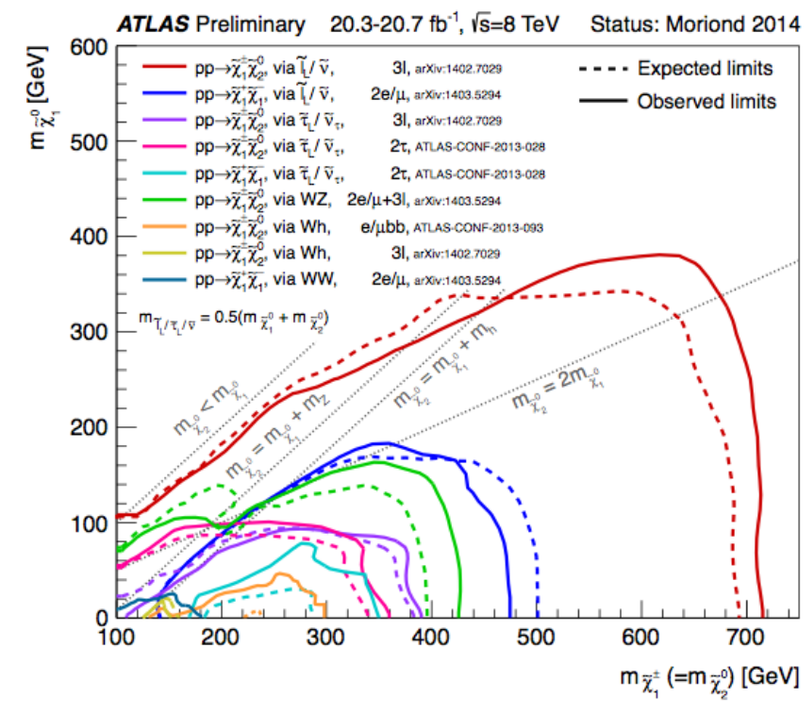
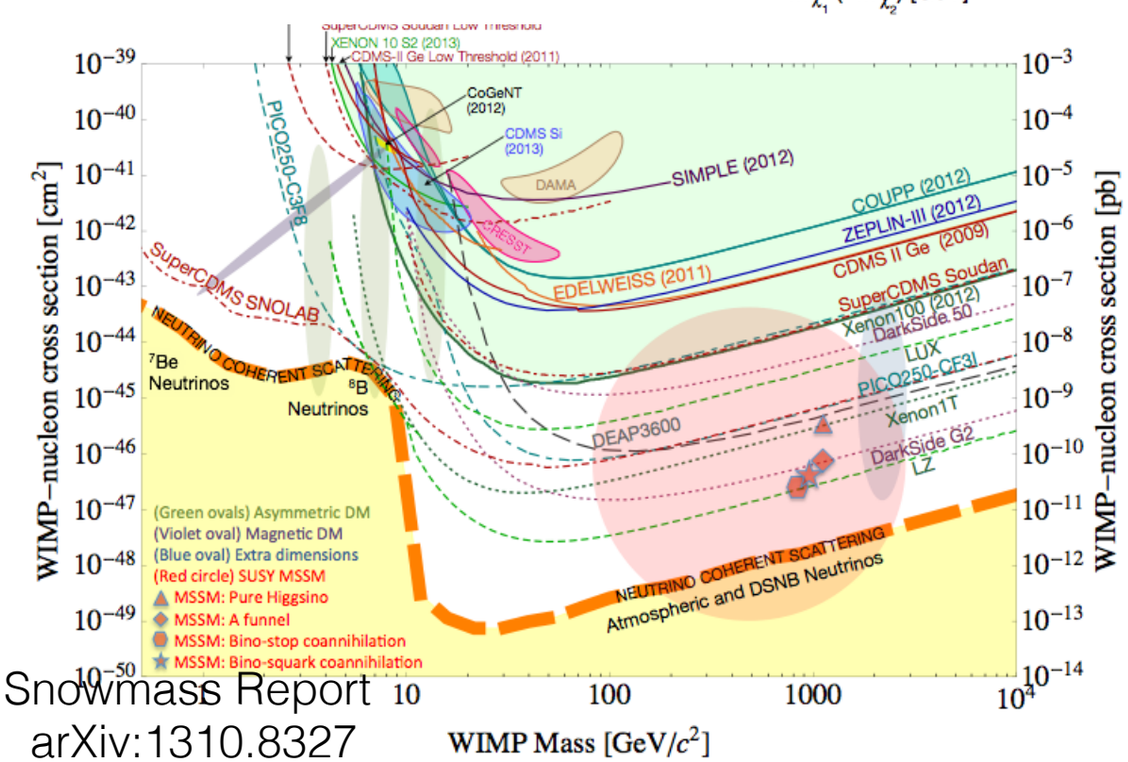
Neutralino Dark Matter

- 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





Snowmass Report
arXiv:1310.8327

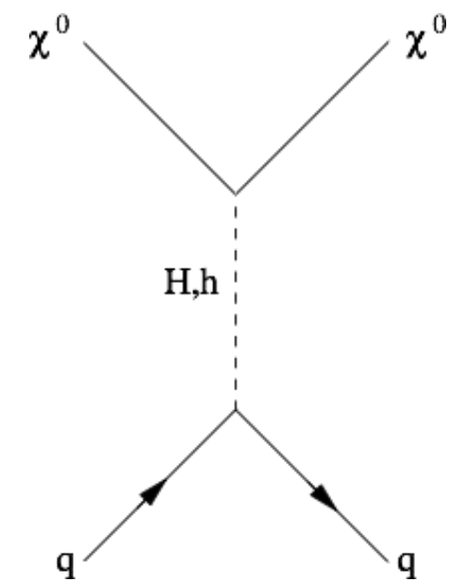
Outline

- 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_χ, higgsino mass μ, $\tan\beta$, 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

$$a_d \sim \frac{m_d}{\cos\beta}\left(\frac{-\sin\alpha\ g_{\chi\chi h}}{m_h^2} + \frac{\cos\alpha\ g_{\chi\chi H}}{m_H^2}\right).$$

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

Couplings

$$g_{\chi\chi h} \sim (g_1 N_{i1} - g_2 N_{i2})(-\cos\alpha\ N_{i4} - \sin\alpha\ N_{i3})$$
$$g_{\chi\chi H} \sim (g_1 N_{i1} - g_2 N_{i2})(-\sin\alpha\ N_{i4} + \cos\alpha\ N_{i3}).$$

Amplitude

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

Loop Effects

$$L = f_d \bar{d}_L d_R H_d^0 + \epsilon_d f_d \bar{d}_L d_R H_u^{0*} + h.c.$$

$$a_d \sim \frac{\bar{m}_d(g_1 N_{i1} - g_2 N_{i2})}{\cos\beta}\left[N_{i4}\sin\alpha\cos\alpha\left(\frac{1-\epsilon_d/\tan\alpha}{m_h^2}-\frac{1+\epsilon_d\tan\alpha}{m_H^2}\right)\right.$$
$$\left.+N_{i3}\left(\frac{\sin^2\alpha(1-\epsilon_d/\tan\alpha)}{m_h^2}+\frac{\cos^2\alpha(1+\epsilon_d\tan\alpha)}{m_H^2}\right)\right]$$

$$\bar{m}_d \equiv \frac{m_d}{1+\epsilon_d\tan\beta} \qquad \epsilon_d \approx \frac{2\alpha_s}{3\pi} M_3 \mu C_0(m_0^2, m_R^2, |M_3|^2)$$

$$C_0(X,Y,Z) = \frac{y}{(x-y)(z-y)}\log(y/x) + \frac{z}{(x-z)(y-z)}\log(z/x).$$

When 1st&2nd gen squarks are heavy, ϵ_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

$$< p|m_q q\bar{q}|p > \equiv m_p f_{Tq}^{(p)} \qquad f_{TG}^{(p)} = 1 - \sum f_{Tq}^{(p)}$$

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

Scattering cross section

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

$$F_u^{(p)} \equiv f_u^{(p)} + 2 \times \tfrac{2}{27} f_{TG}^{(p)} \approx 0.15 \qquad F_d^{(p)} = f_{Td}^{(p)} + f_{Ts}^{(p)} + \tfrac{2}{27} f_{TG}^{(p)} \approx 0.14$$

$$F_u^{(n)} \approx 0.15 \qquad F_d^{(n)} \approx 0.14$$

Blind Spots

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

Contribution from SM-like higgs vanishes

$$m_\chi + \mu \sin 2\beta = 0$$

Cheung, Hall, Pinner and Ruderman

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

$$(F_d^{(p)} + F_u^{(p)})(m_\chi + \mu \sin 2\beta)\frac{1}{m_h^2} \simeq F_d^{(p)} \ \mu \tan\beta \cos 2\beta \frac{1}{m_H^2}$$

Can be simplified as

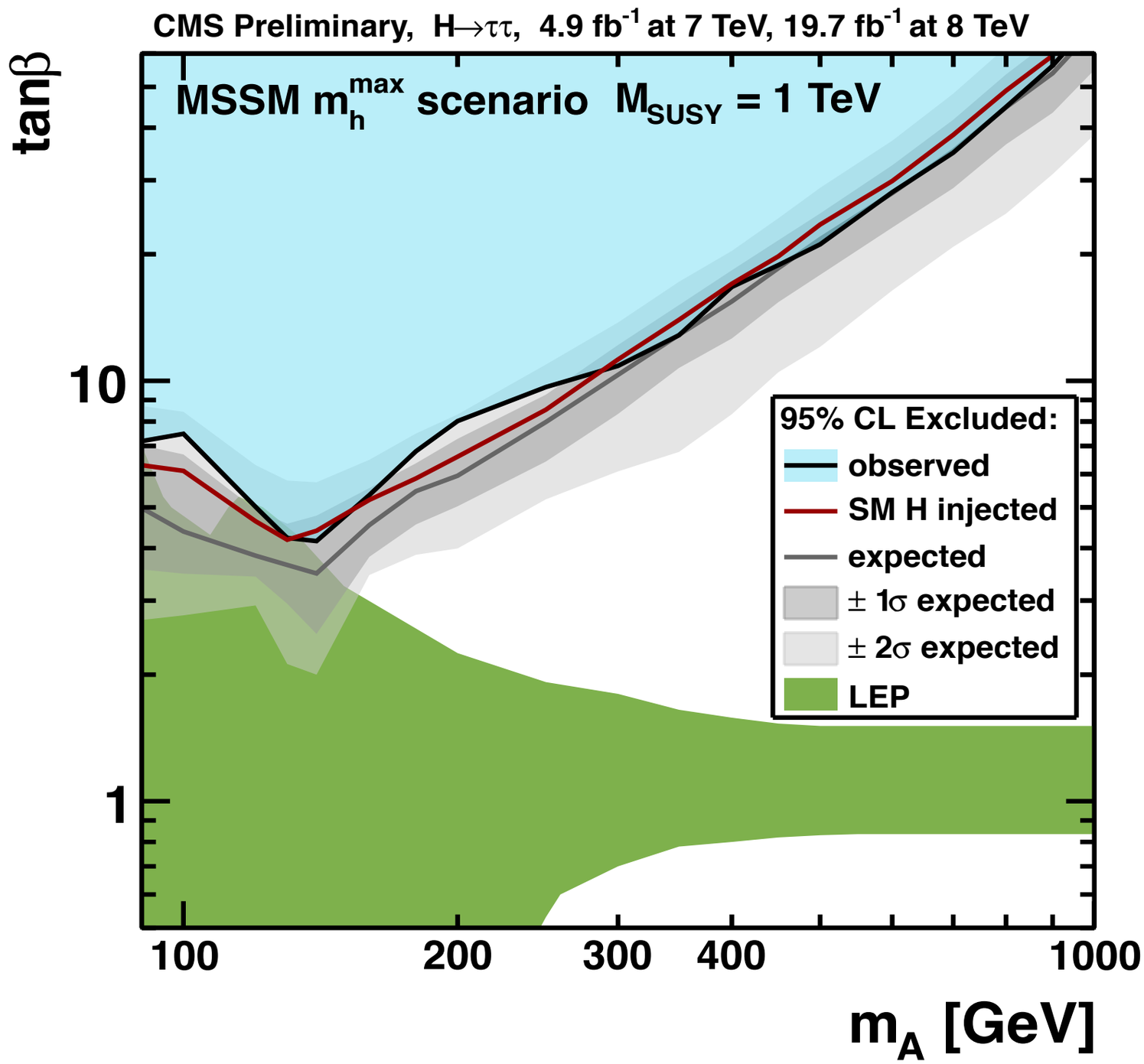
$$2\ (m_\chi + \mu \sin 2\beta)\frac{1}{m_h^2} \simeq -\ \mu \tan\beta \frac{1}{m_H^2}$$

Blind Spots: $\mu < 0$

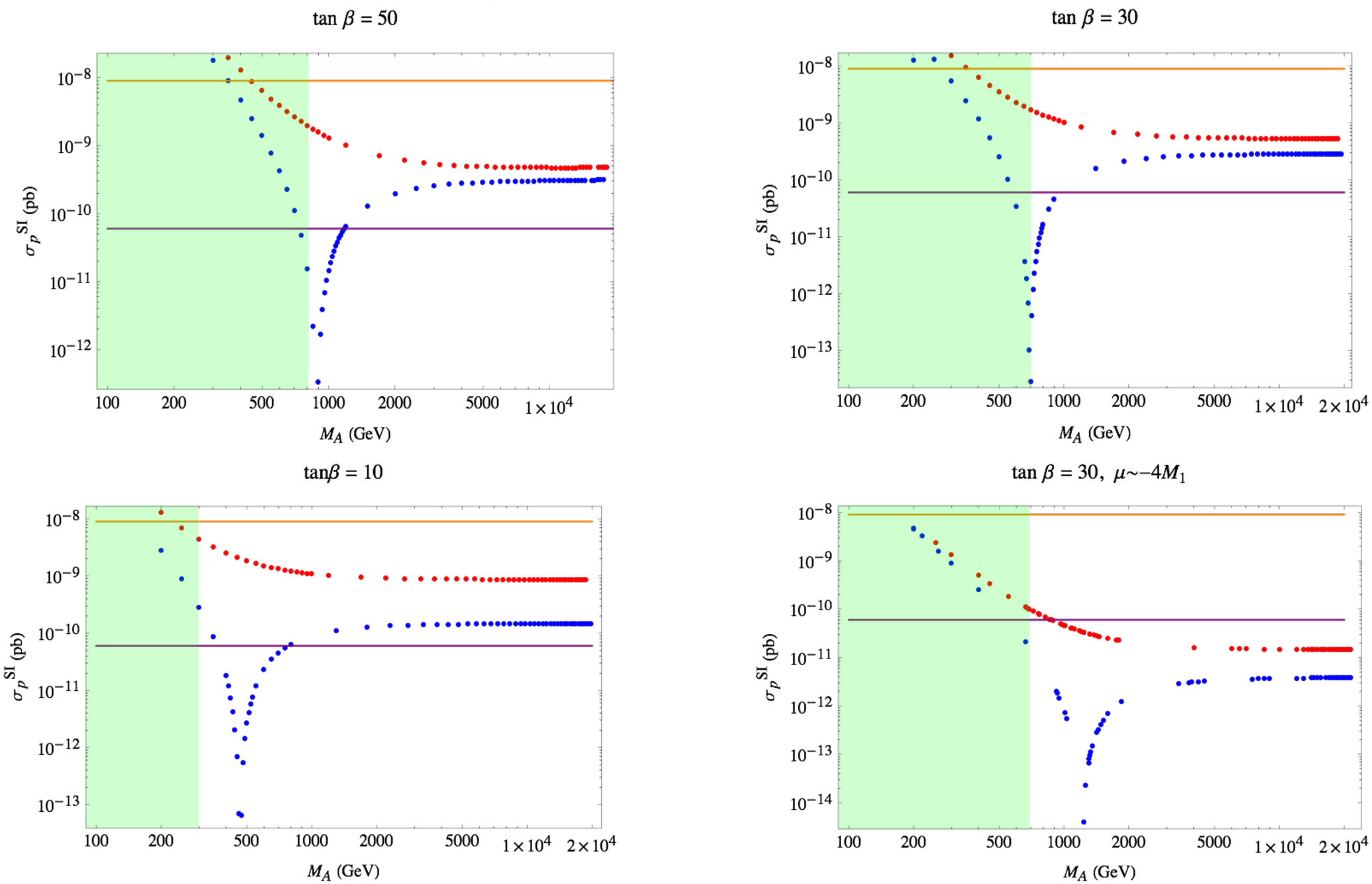
$$\sigma_p^{SI} \sim \left[(F_d^{(p)} + F_u^{(p)})(m_\chi + \mu \sin 2\beta)\frac{1}{m_h^2} + \mu \tan\beta \cos 2\beta(-F_d^{(p)} + F_u^{(p)}/\tan^2\beta)\frac{1}{m_H^2} \right]^2$$

- 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



Blind Spots, μ = -2M1

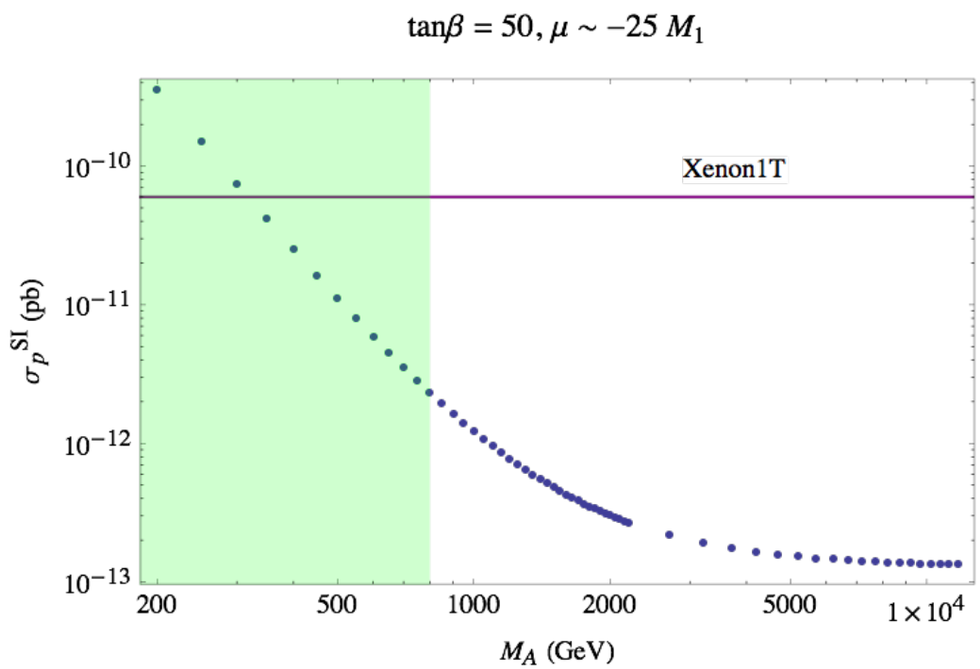


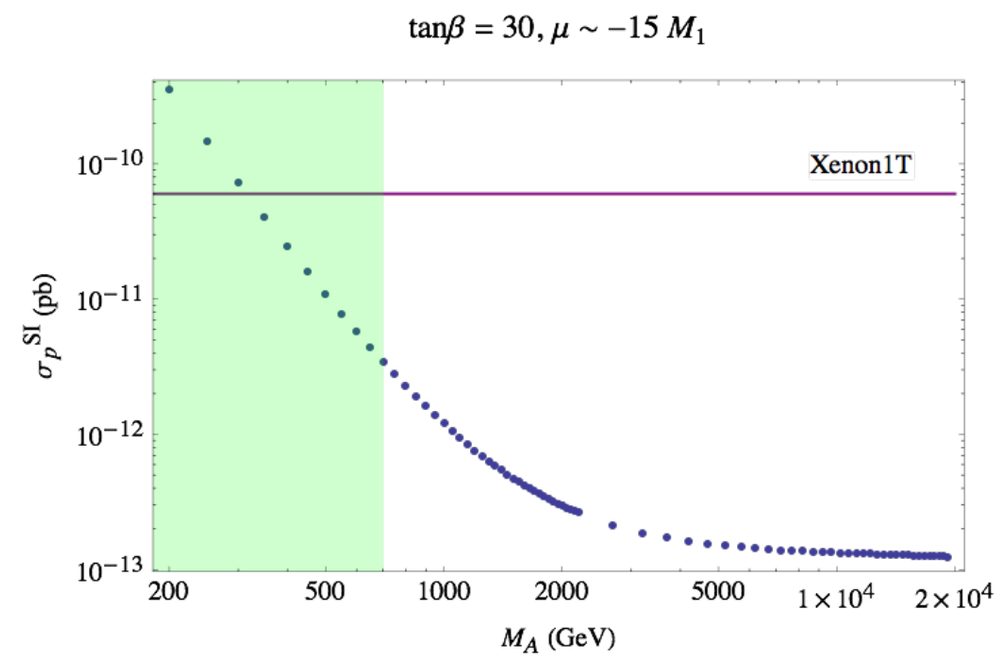
μ>0 μ<0 Lux Xenon1T, H/A->ττ

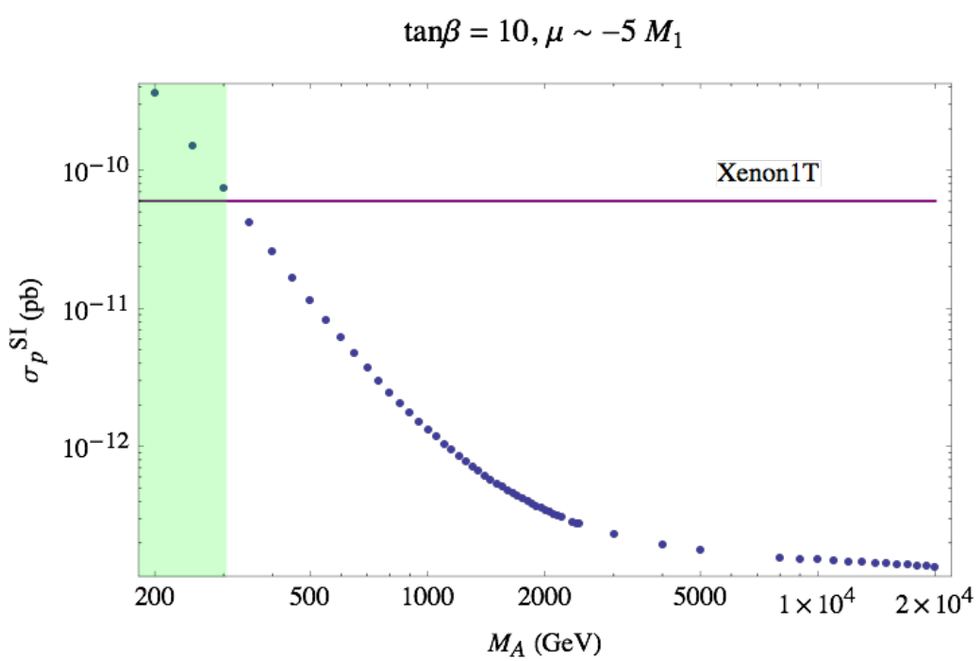
Traditional Blind Spot

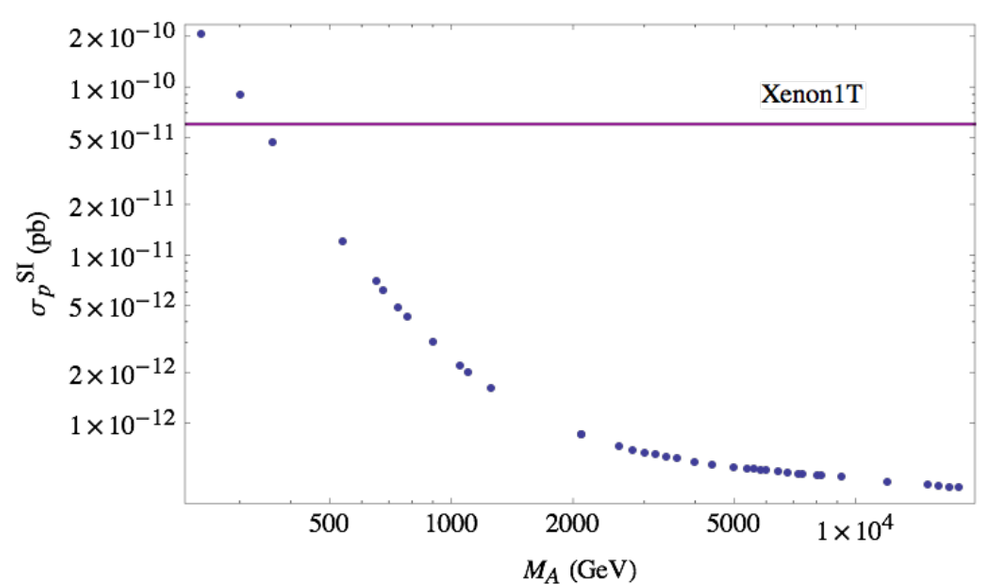
$$m_\chi + \mu \sin 2\beta = 0$$

H/A->ττ



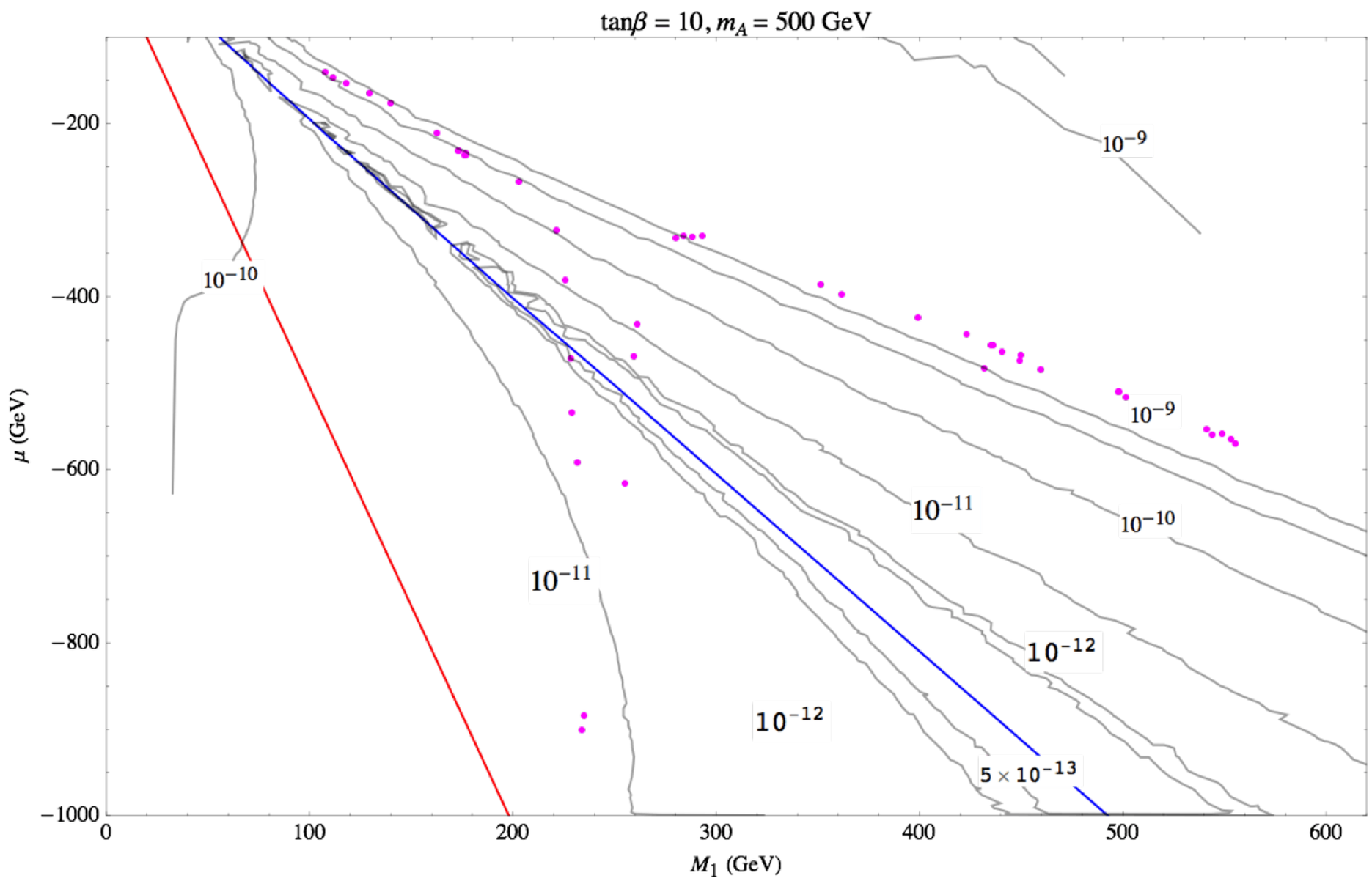






Blind Spot with Relic Density

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



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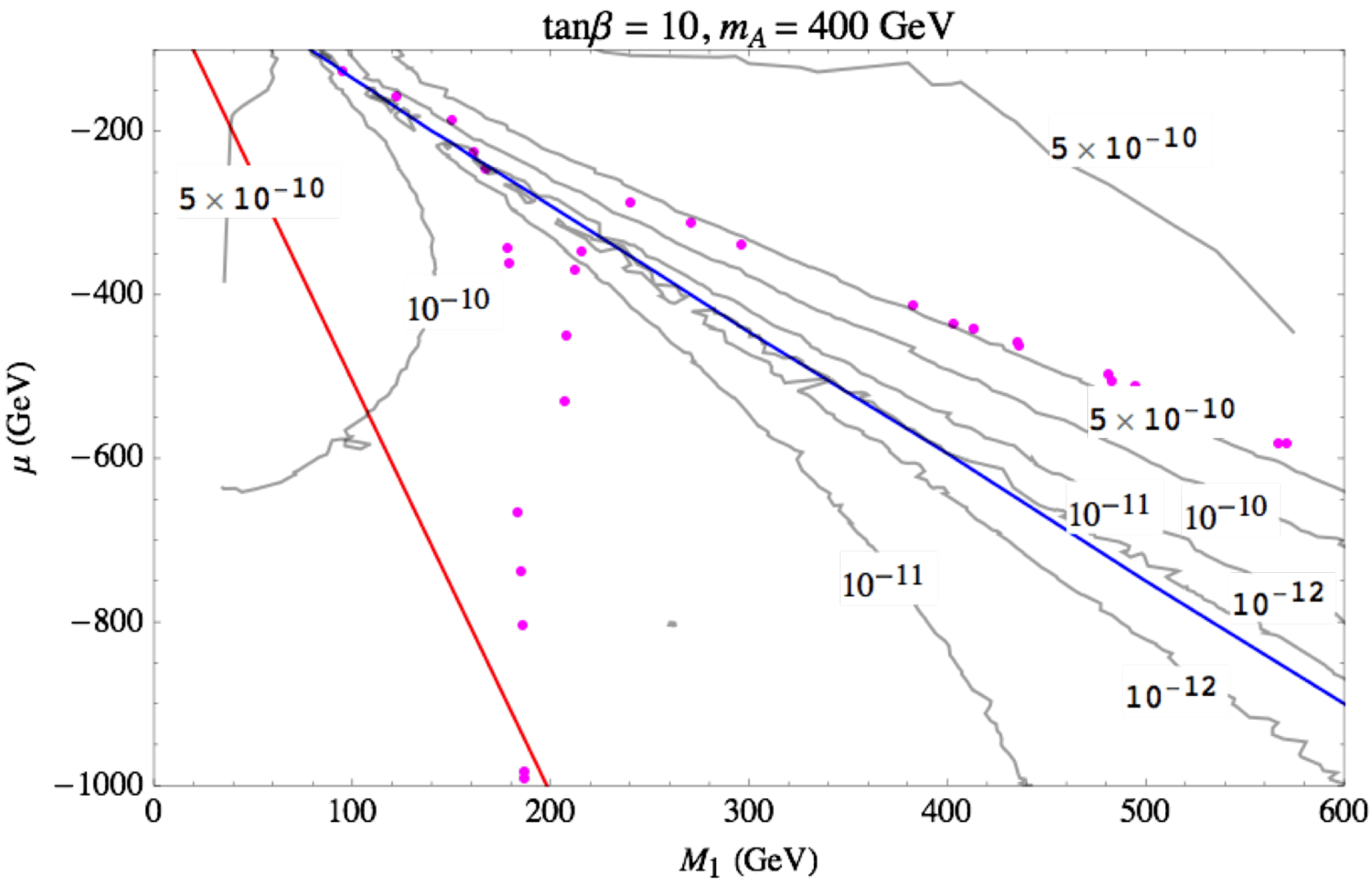

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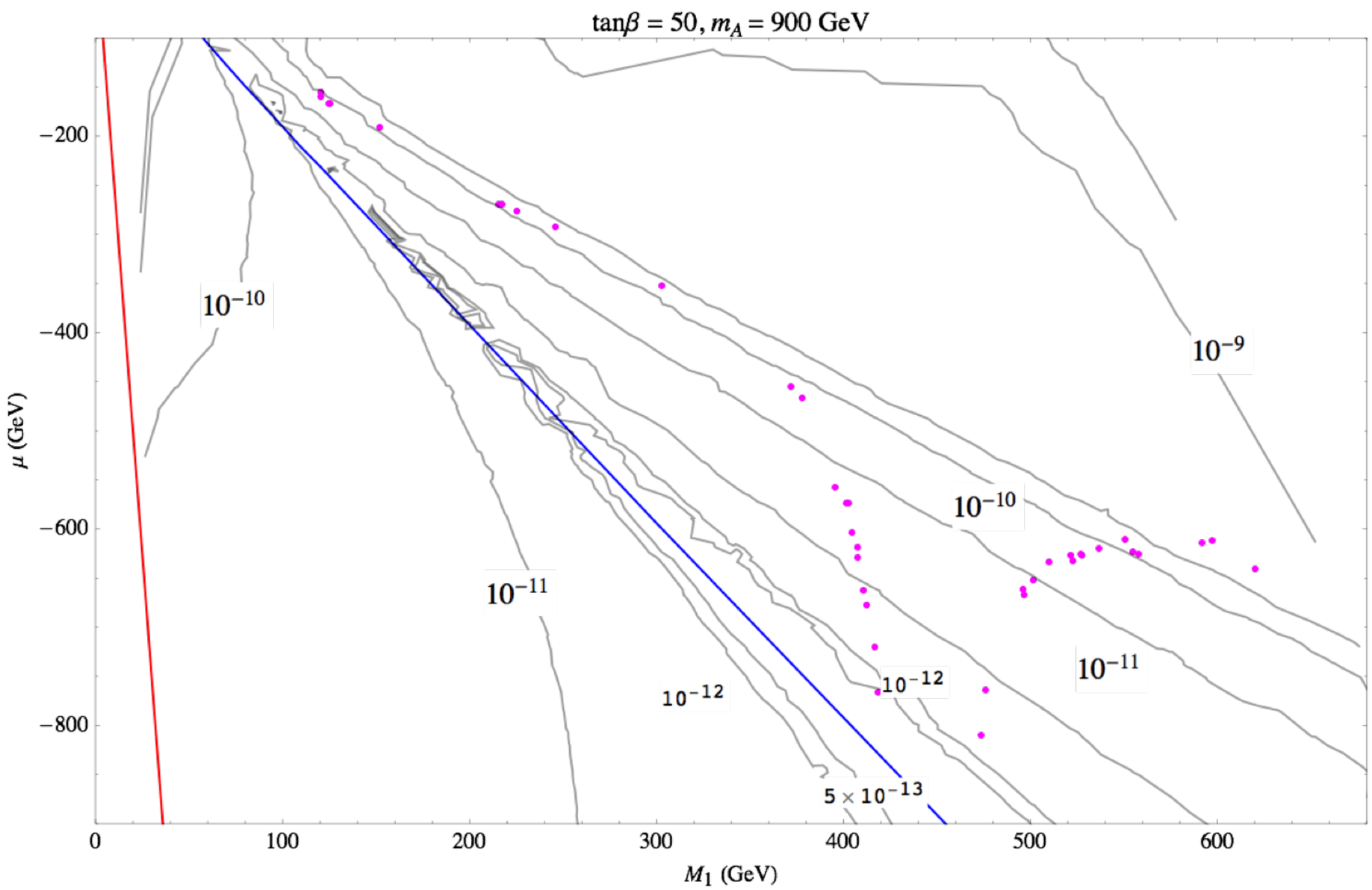

Conclusion

- SI DDMD cross section is suppressed for negative μ
- 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