Towards a last word on neutralino DM

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SUSY Dark Matter

$$\tilde{\chi}_i^0 = N_{ij}(\tilde{B}, \tilde{W}^0, \tilde{H}_u^0, \tilde{H}_d^0) \qquad \tilde{\chi}_i^\pm = V_{ij}(\tilde{W}^\pm, \tilde{H}^\pm)$$

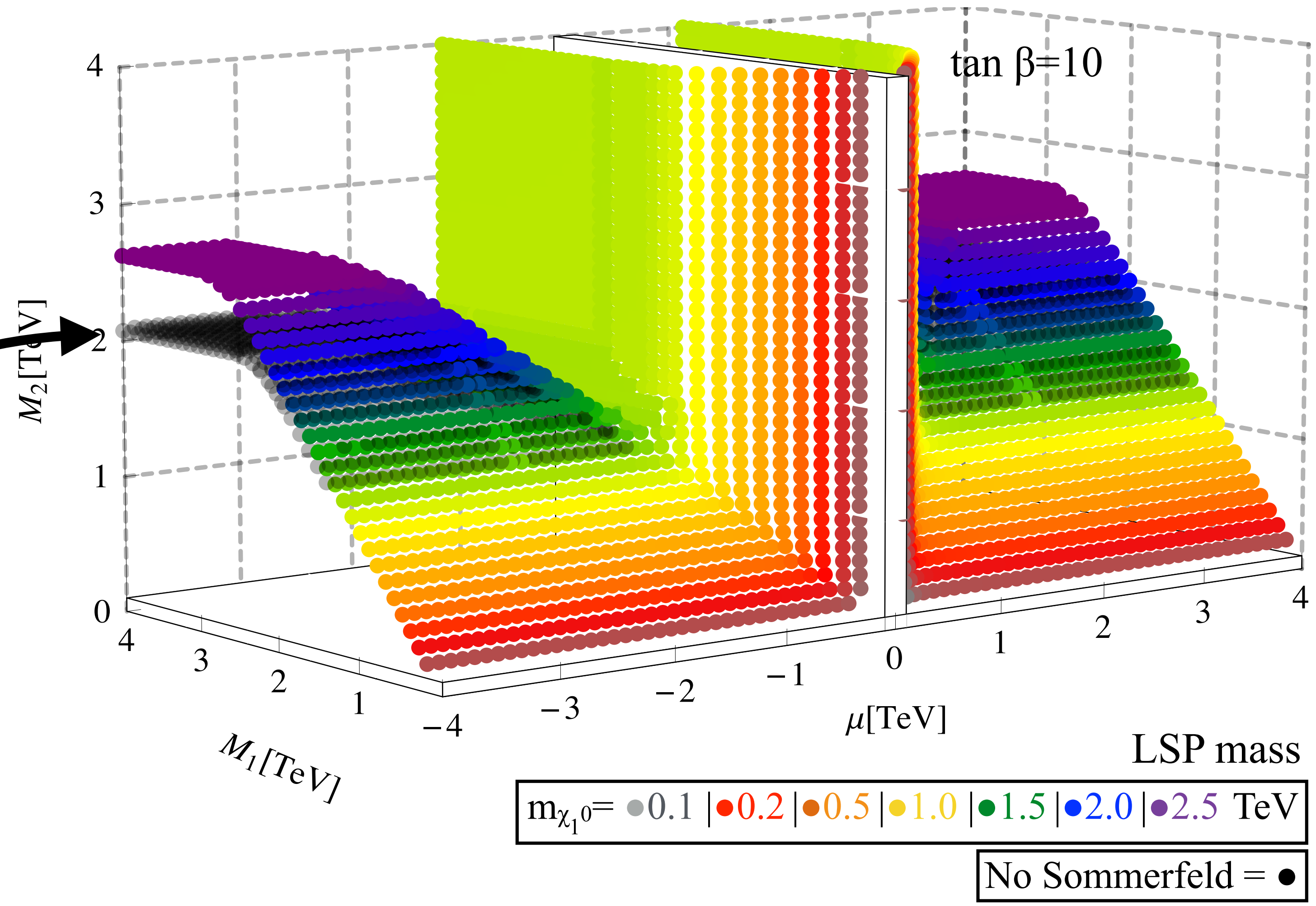
$$M_1,\ M_2, \mu,\ \text{and}\ \tan\beta$$

- Find parameter space that gives the right relic density (ignore effects of sfermions)
- Look at Direct/Indirect/Collider constraints (both present and future expectations)

Relic surface with SE

$$\Omega h^2 = 0.120 \pm 0.005$$

No S.E.



$$\Omega_{\tilde{W}} h^2 \simeq 0.12 \left(\frac{m_{\tilde{\chi}}}{2.1\ \mathrm{TeV}}\right)^2 \xrightarrow{\mathrm{SE}} 0.12 \left(\frac{m_{\tilde{\chi}}}{2.6\ \mathrm{TeV}}\right)^2 .$$

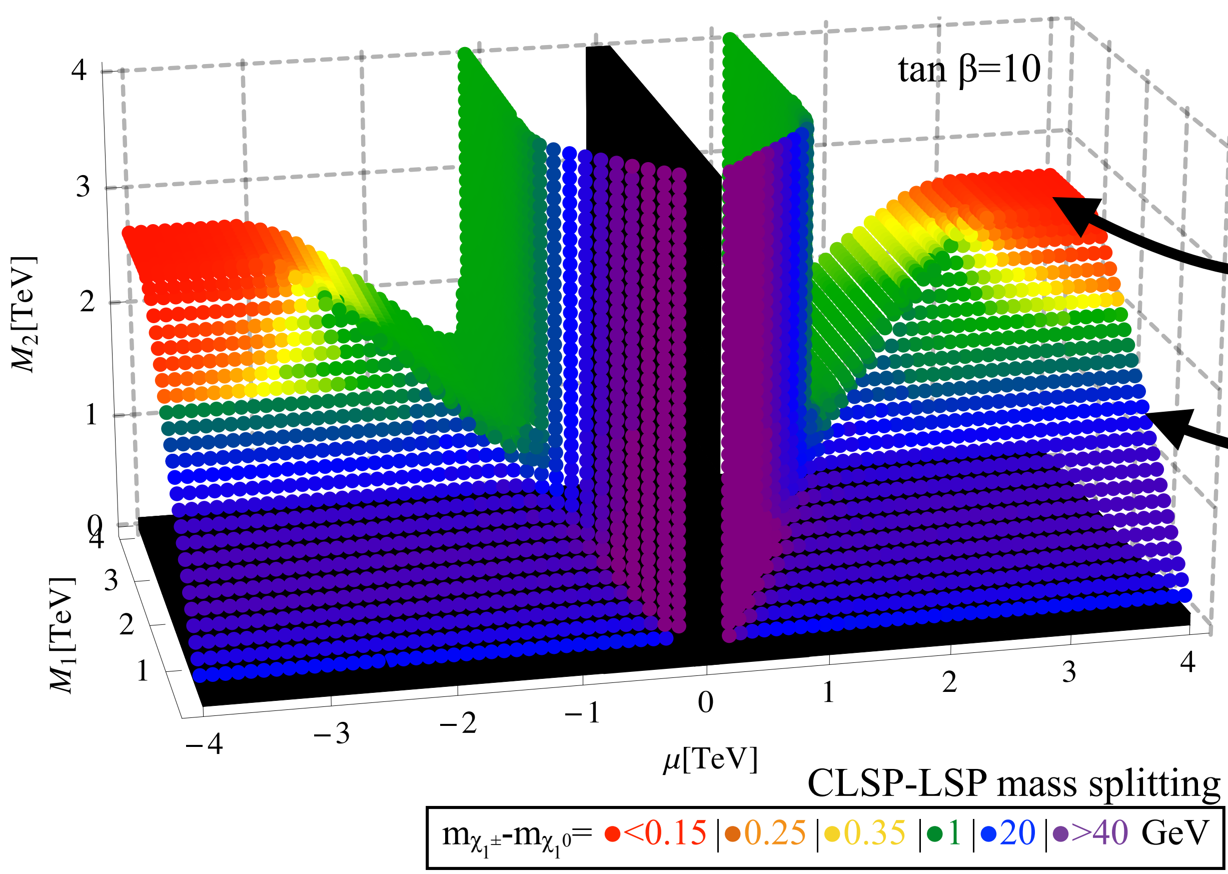
$$\Omega_{\tilde{H}} h^2 \simeq 0.12 \left(\frac{m_{\tilde{\chi}}}{1.13\ \mathrm{TeV}}\right)^2 \xrightarrow{\mathrm{SE}} 0.12 \left(\frac{m_{\tilde{\chi}}}{1.14\ \mathrm{TeV}}\right)^2 .$$

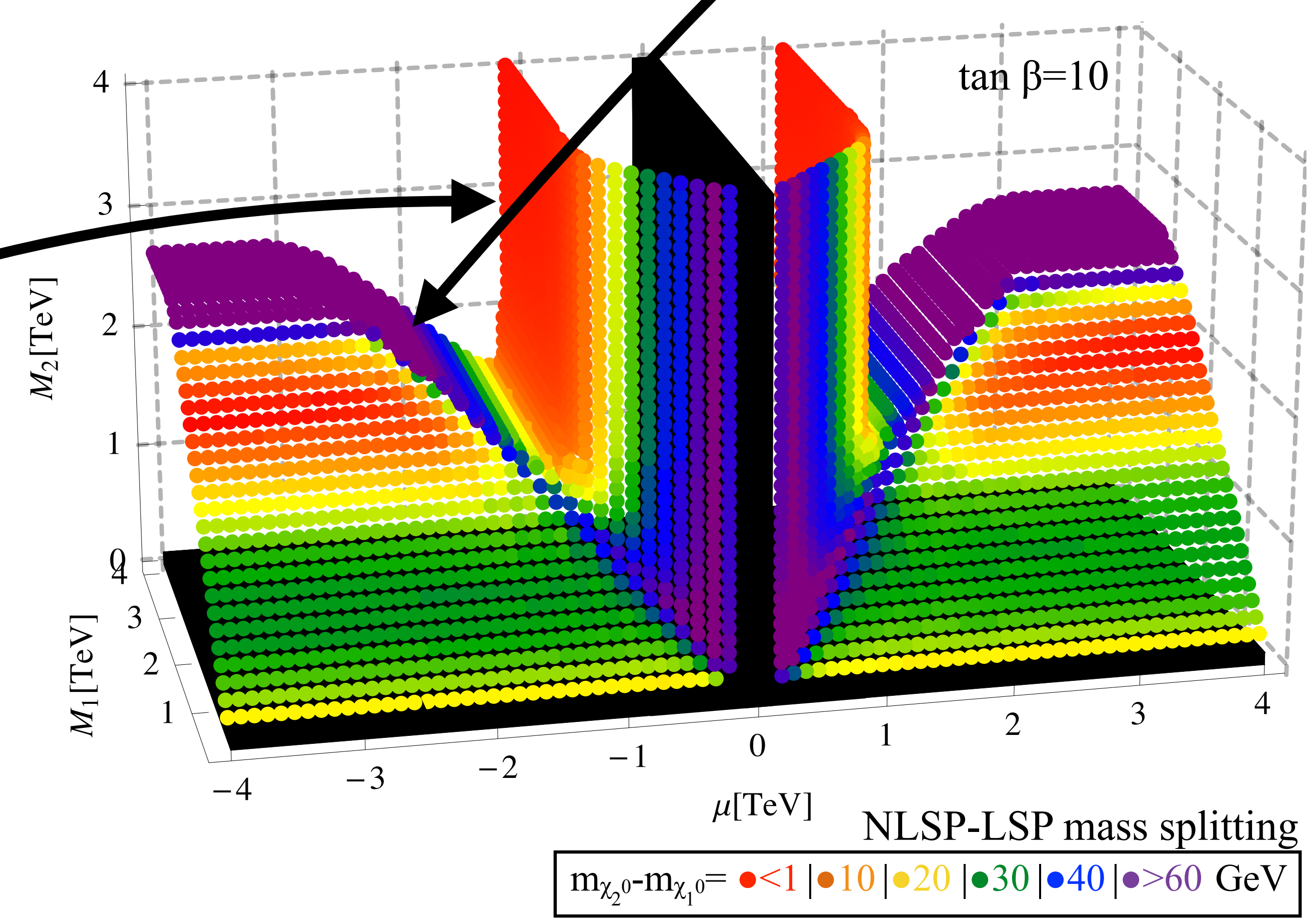
Mass Splitting

pure Wino => co-annihilation with chargino

Wino-Higgsinos

Bino-Winos





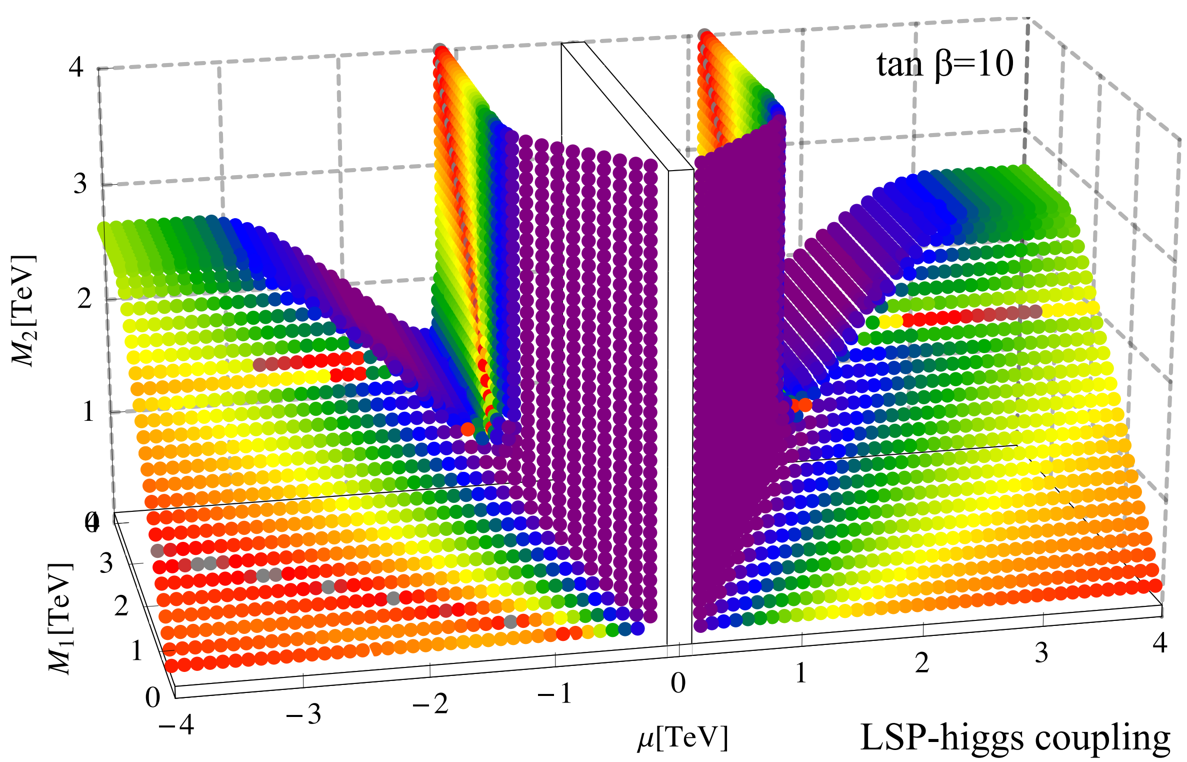
pure Higgsinos =>
co-annihilation with second neutralino + chargino

Couplings

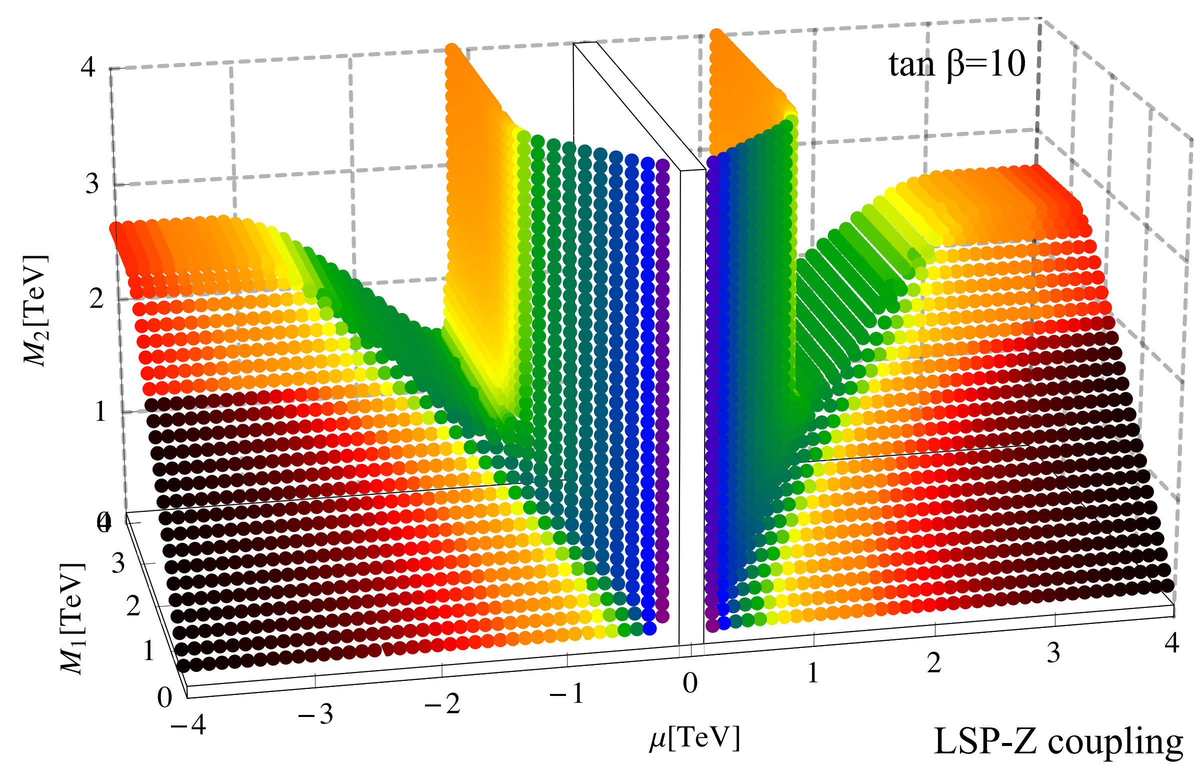
$$g_{Z\tilde{\chi}_1^0\tilde{\chi}_1^0} = \frac{g}{2\cos\theta_w}\ \left(|N_{13}|^2 - |N_{14}|^2\right)$$

$$g_{h\tilde{\chi}_1^0\tilde{\chi}_1^0} = \left(gN_{11} - g'N_{12}\right)\ \left(\sin\alpha\ N_{13} + \cos\alpha\ N_{14}\right)$$

$$g_{W\tilde{\chi}_1^0\tilde{\chi}_1^+} = \frac{g\sin\theta_w}{\sqrt{2}\cos\theta_w}\ \left(N_{14}V_{12}^* - \sqrt{2}N_{12}V_{11}^*\right)\ ,$$

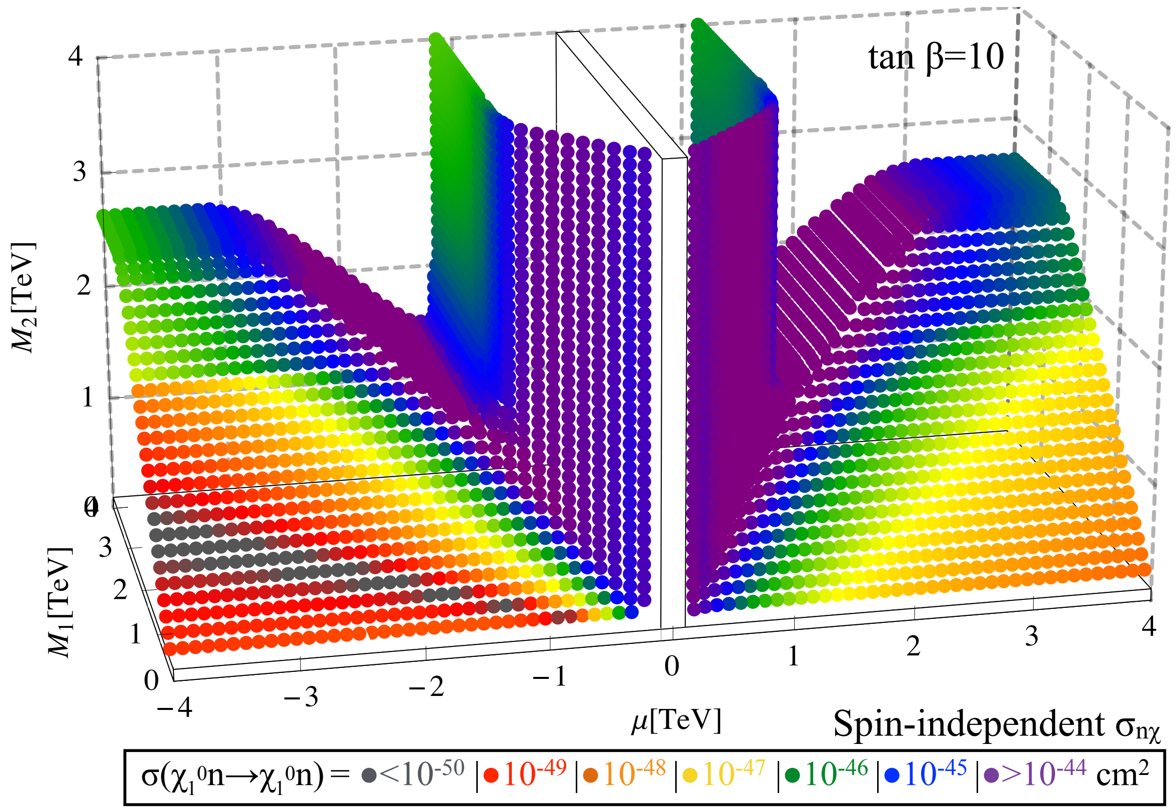


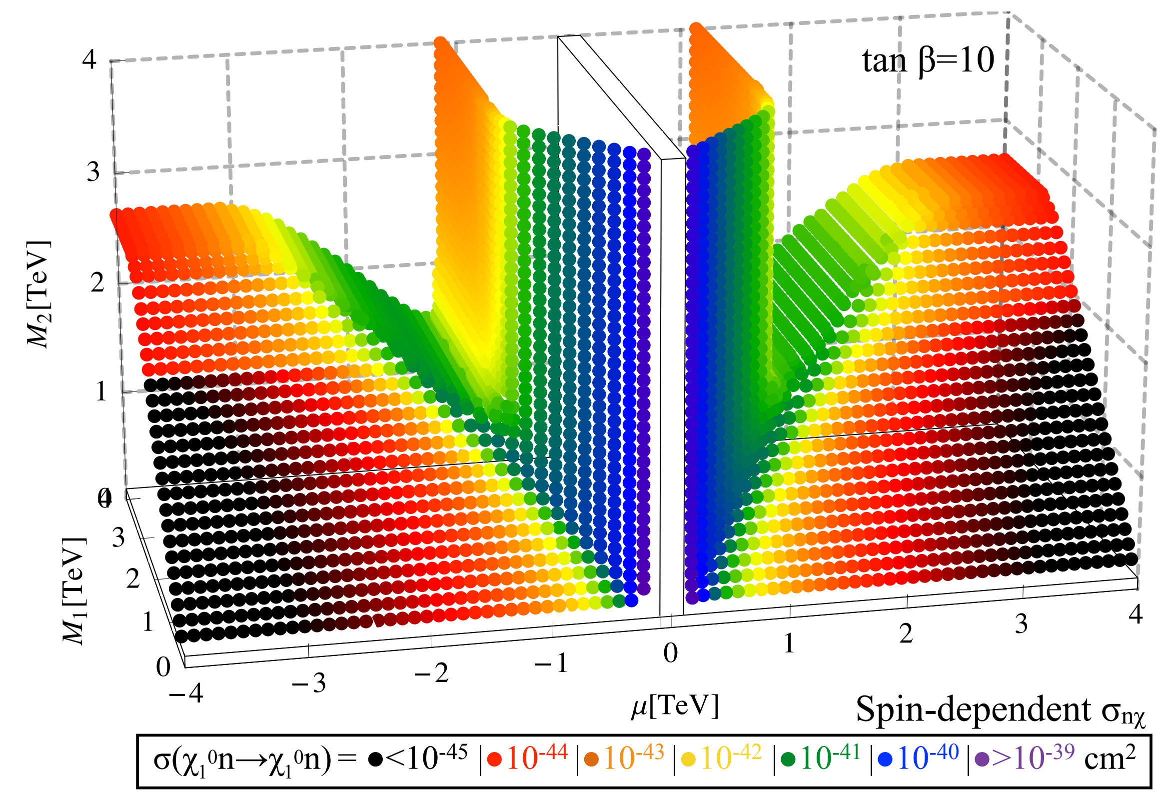
$(gN_{11}-g'N_{12})(s_\alpha N_{13}+c_\alpha N_{14})=$ ● 3×10^{-5} | ● 10^{-4} | ● 10^{-3} | ● 0.003 | ● 10^{-2} | ● 0.03 | ● 0.1



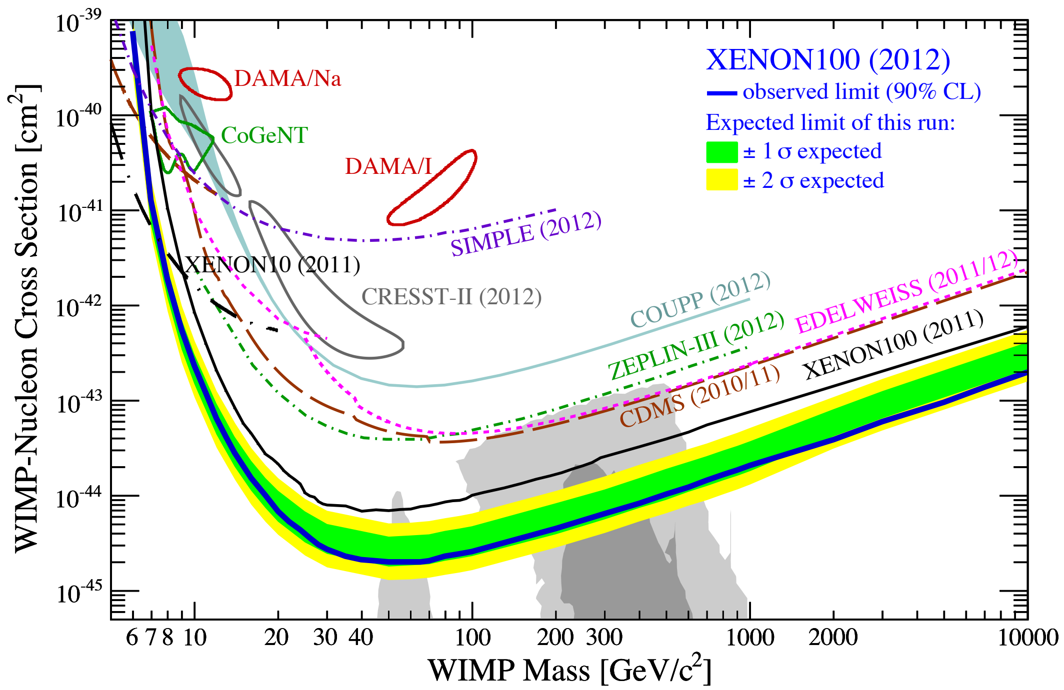
$|N_{13}|^2-|N_{14}|^2=$ ● 10^{-3} | ● 5×10^{-3} | ● 10^{-2} | ● 5×10^{-2} | ● 10^{-1} | ● 0.05 | ● 0.1

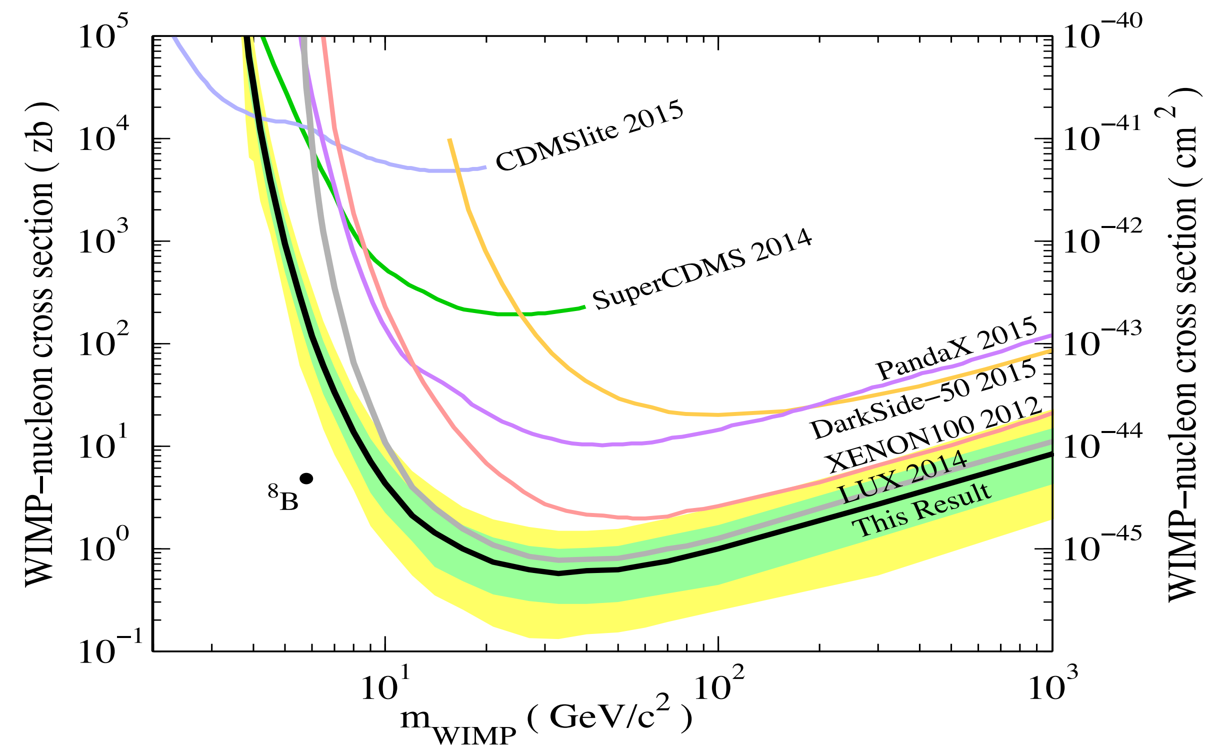
Direct Detection

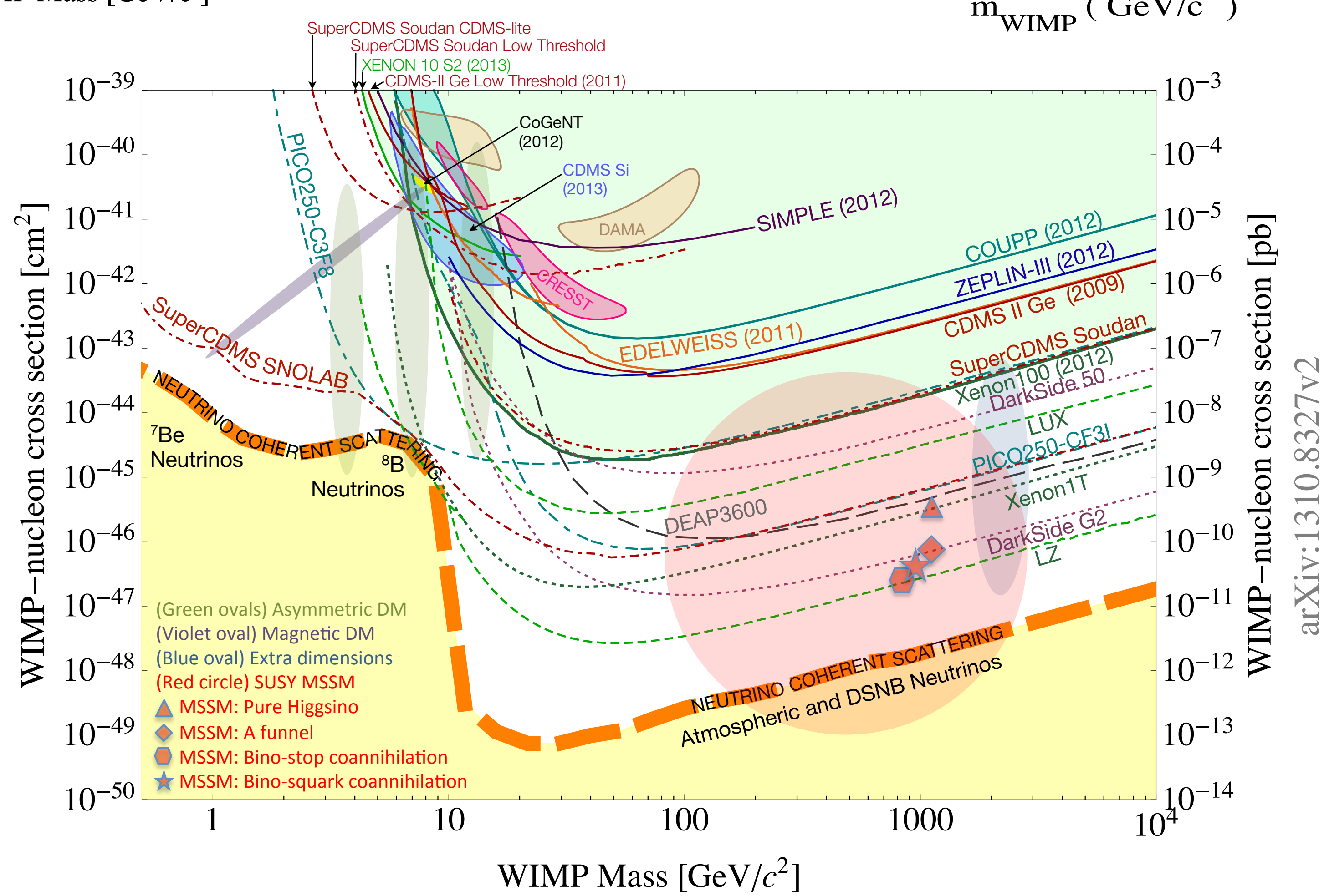




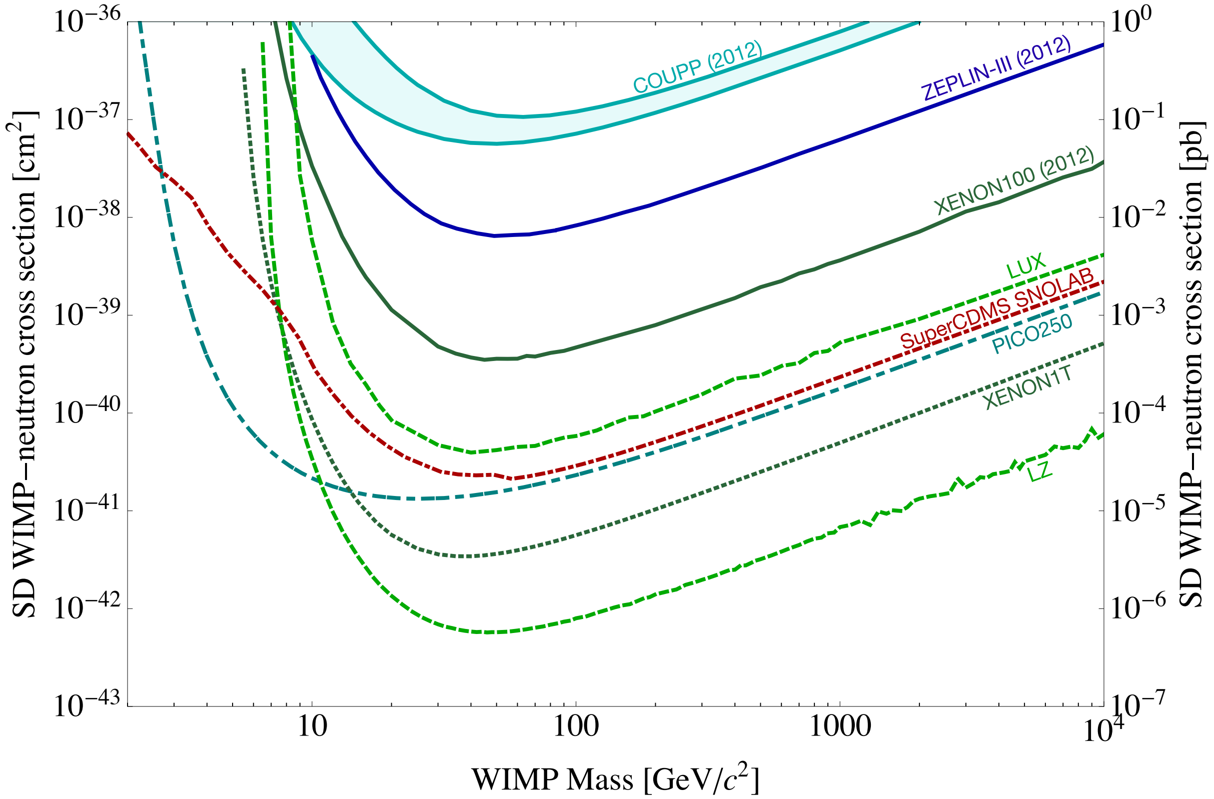
SI Direct Detection limits

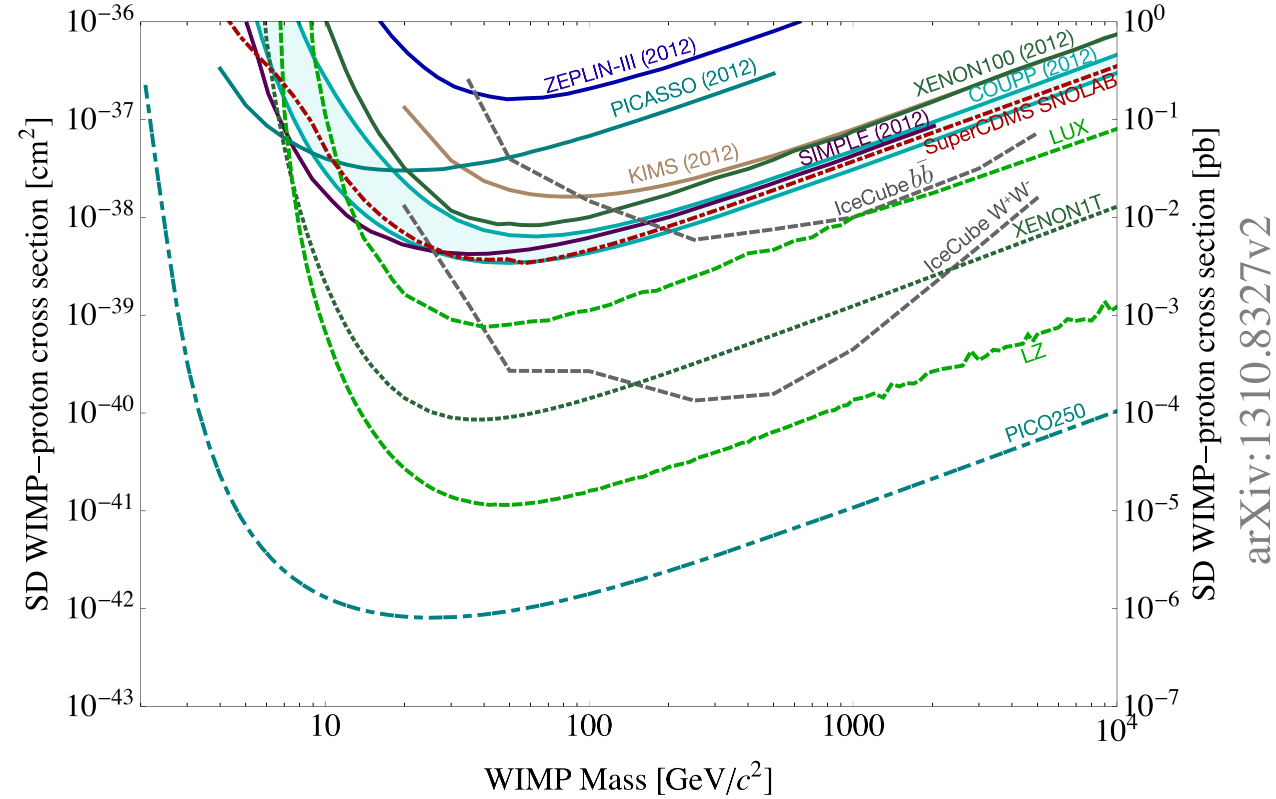




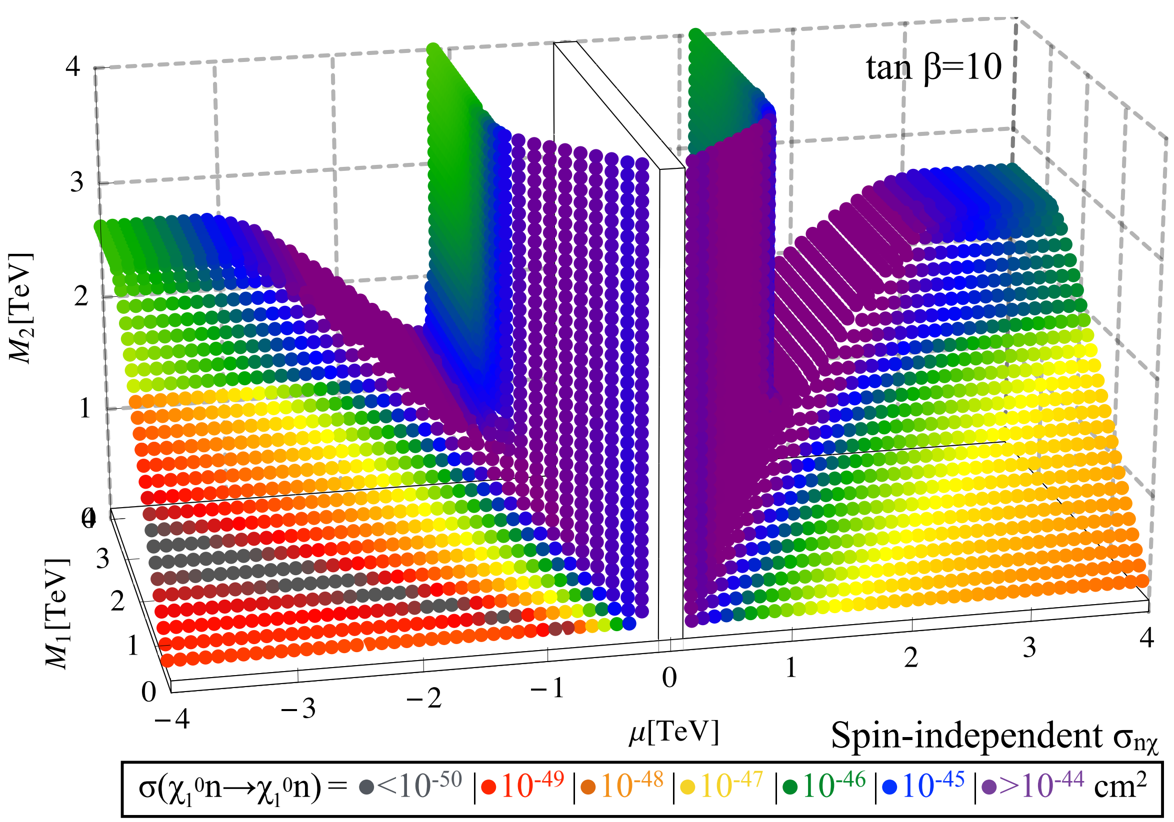


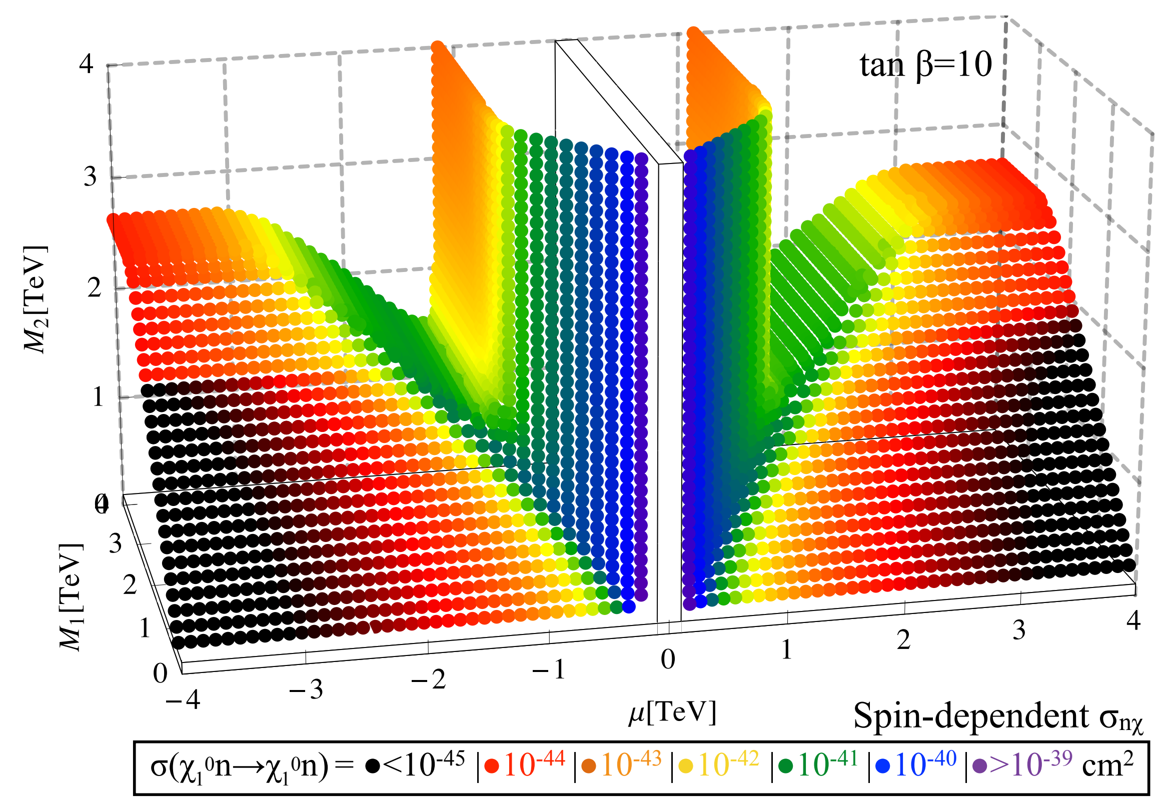
SD Direct Detection limits

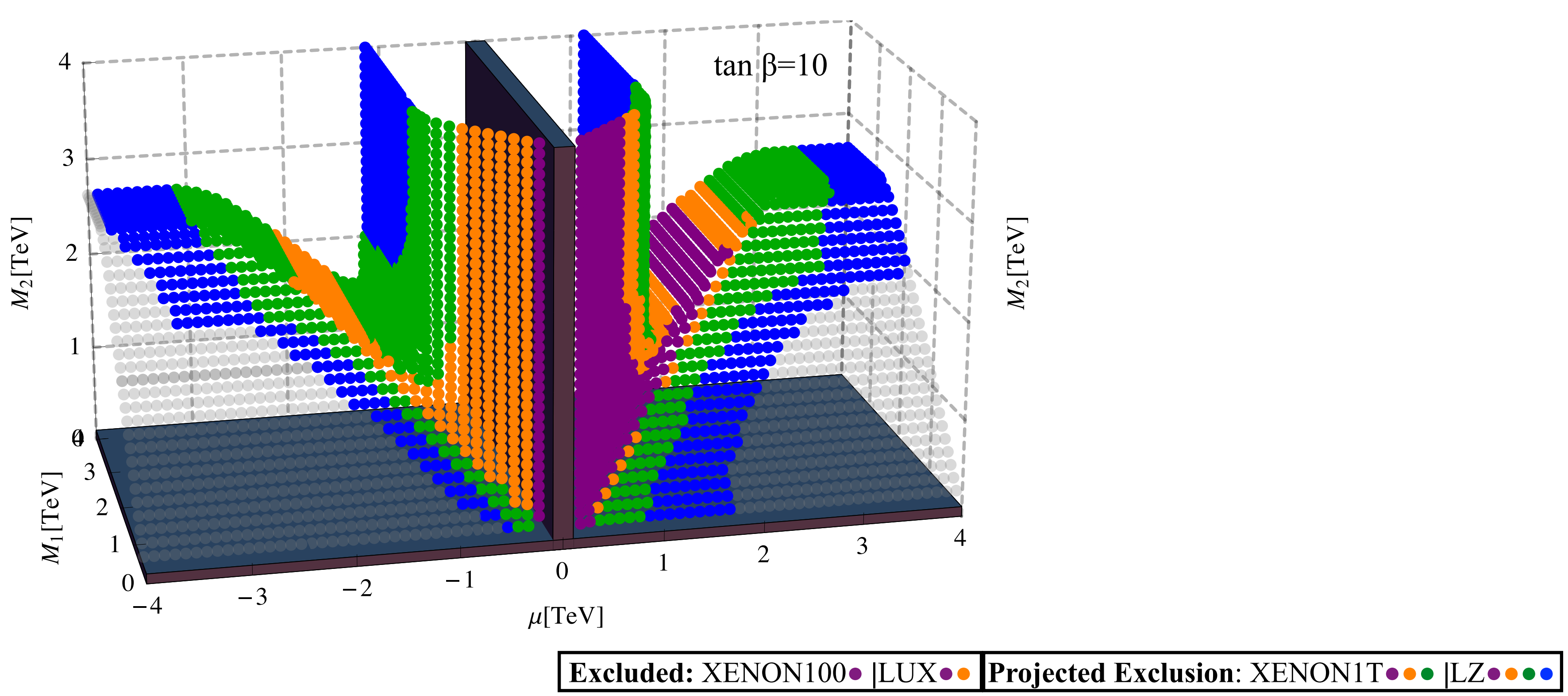




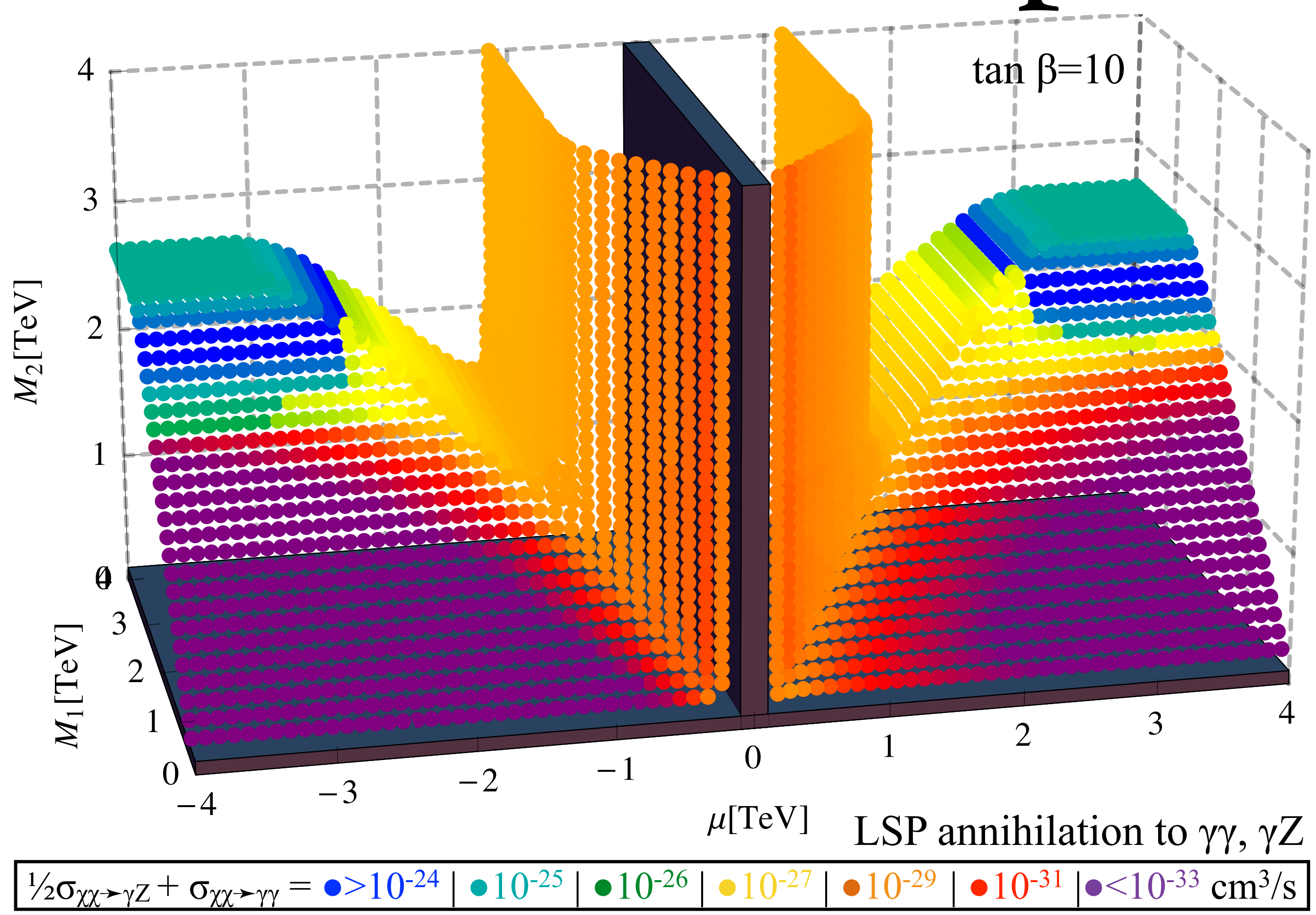
Direct Detection

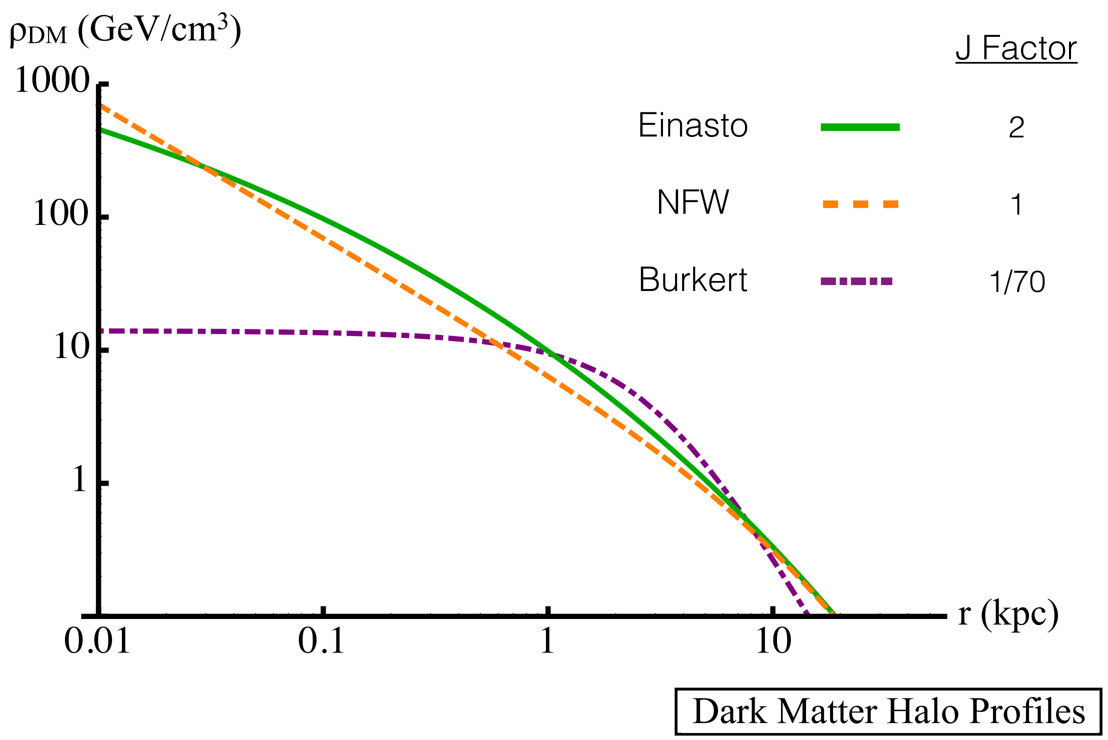






Indirect detection: Annihilation into photons



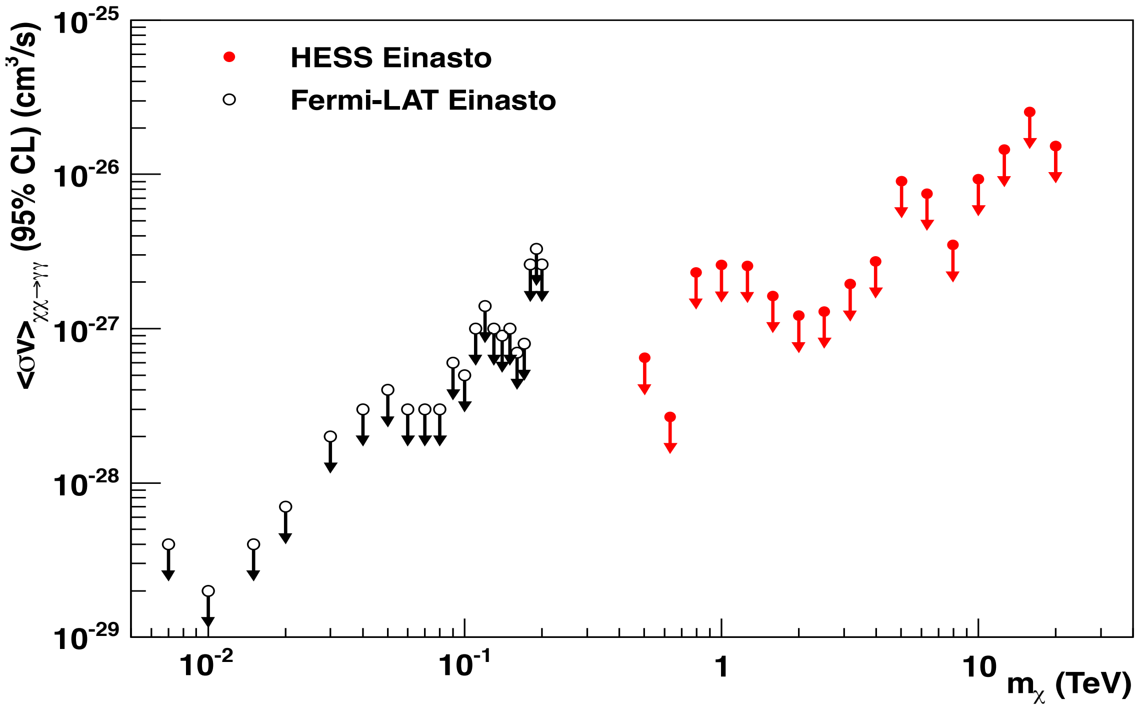


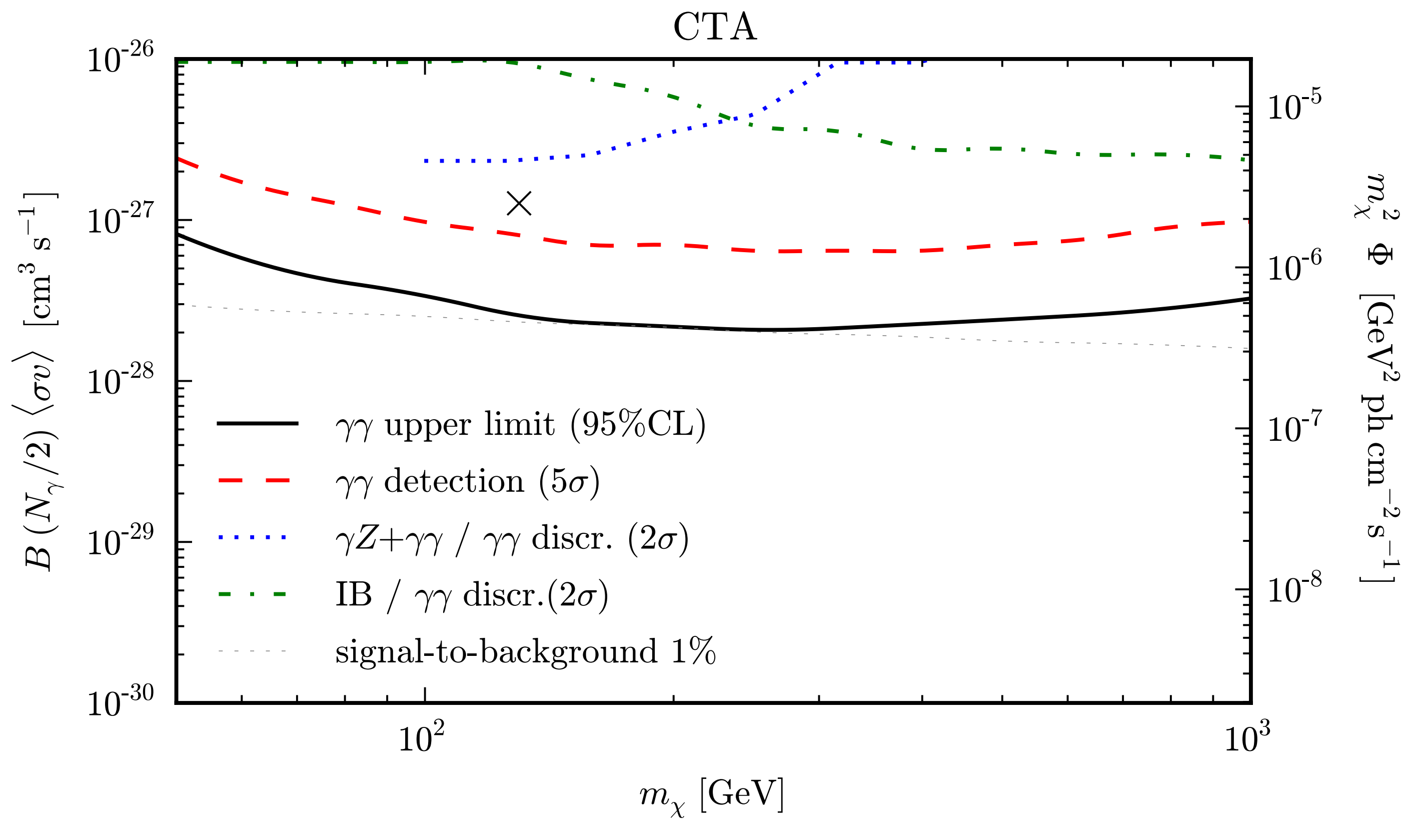
$$\rho_{\rm NFW}(r) = \frac{\rho_\odot}{(r/R)\,(1+r/R)^2},$$

$$\rho_{\rm Ein}(r) = \rho_\odot\ \exp\left[-\frac{2}{\alpha}\left(\left(\frac{r}{R}\right)^\alpha - 1\right)\right],$$

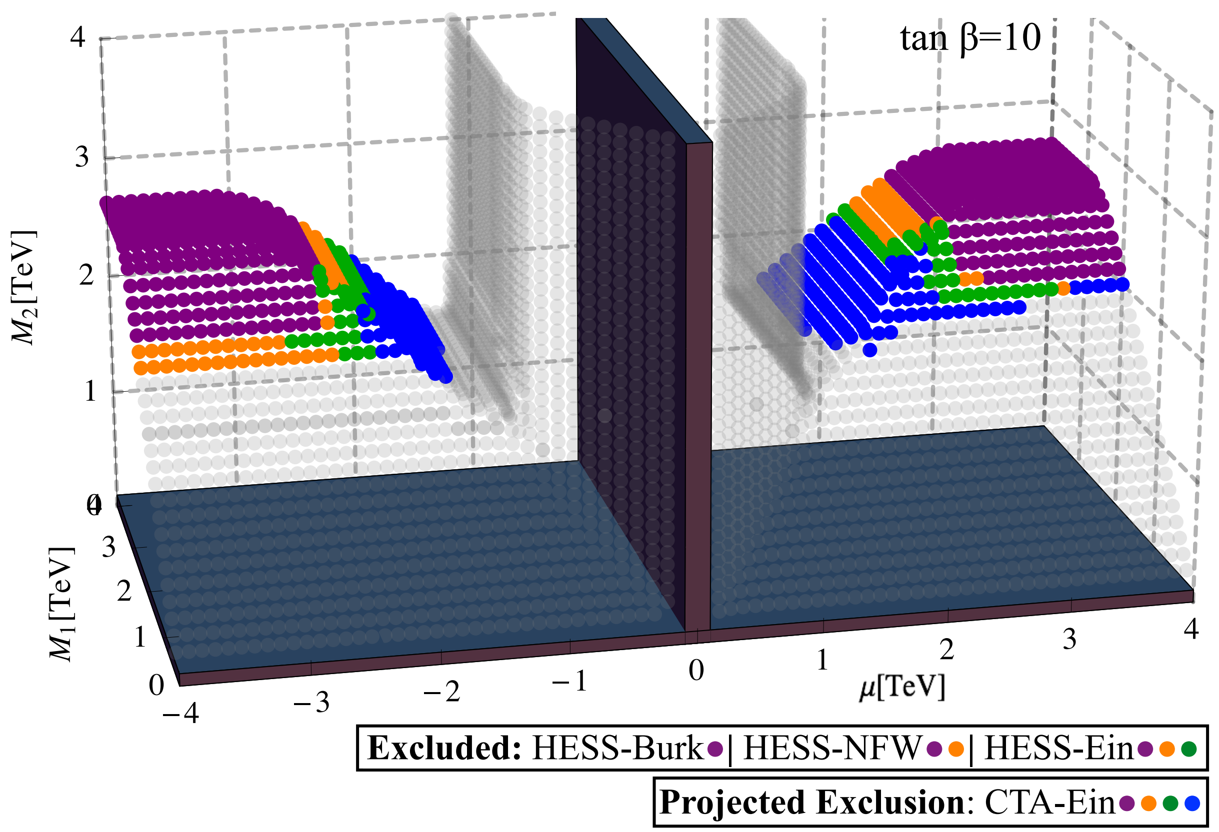
$$\rho_{\rm Burk}(r) = \frac{\rho_\odot}{(1+r/r_c)\,(1+(r/r_c)^2)},$$

Annihilation into photons



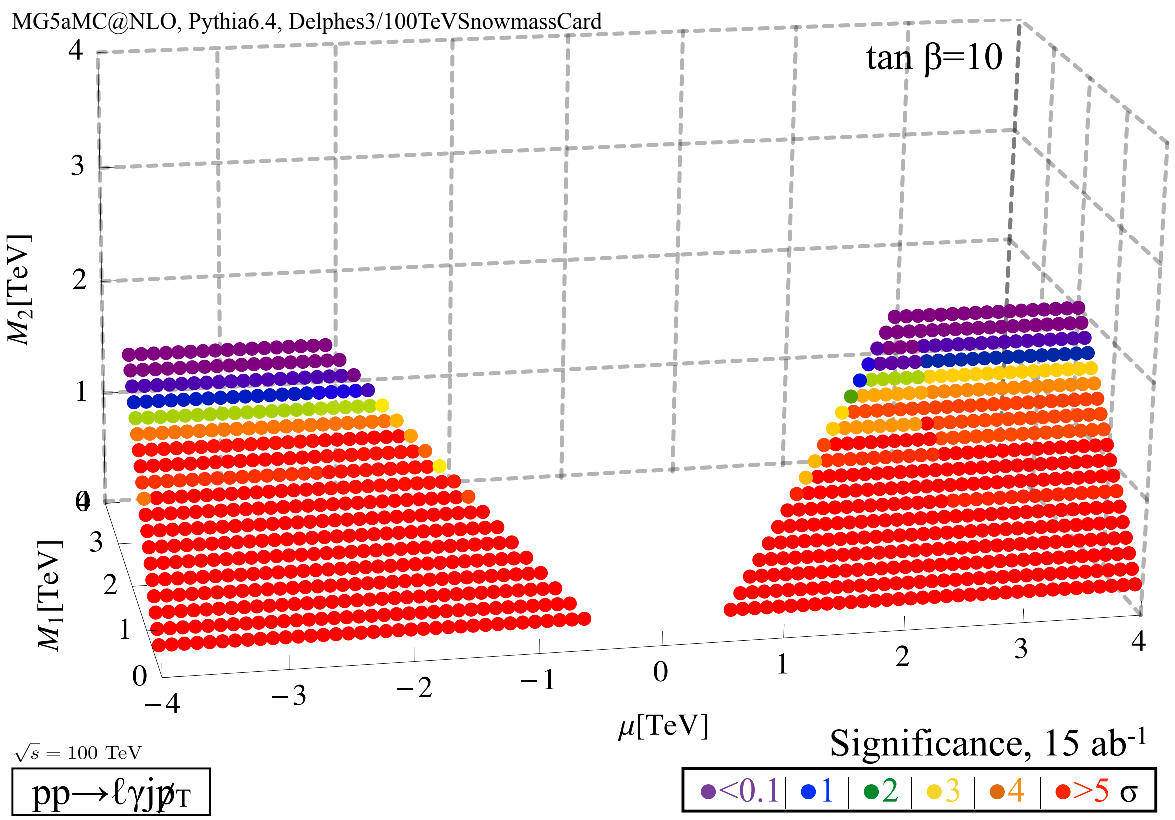


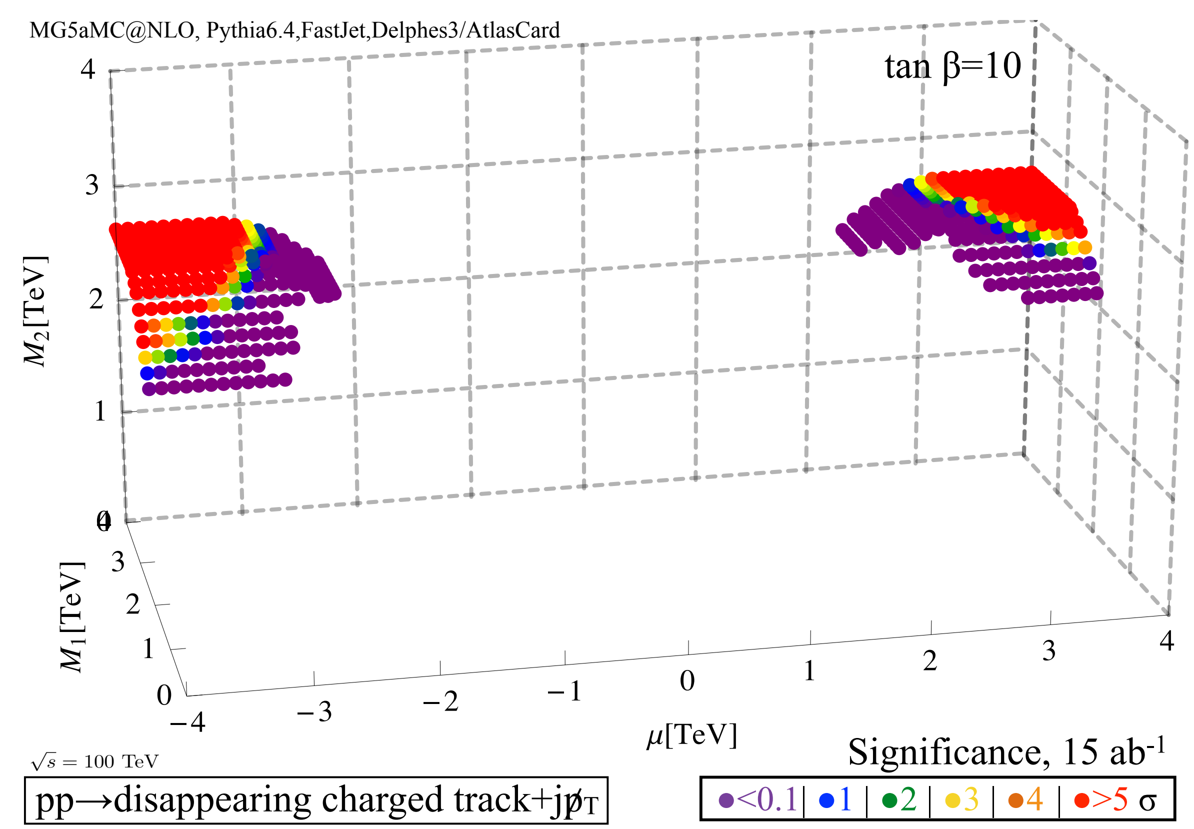
arXiv:1207.6773



(Potential) Collider Searches

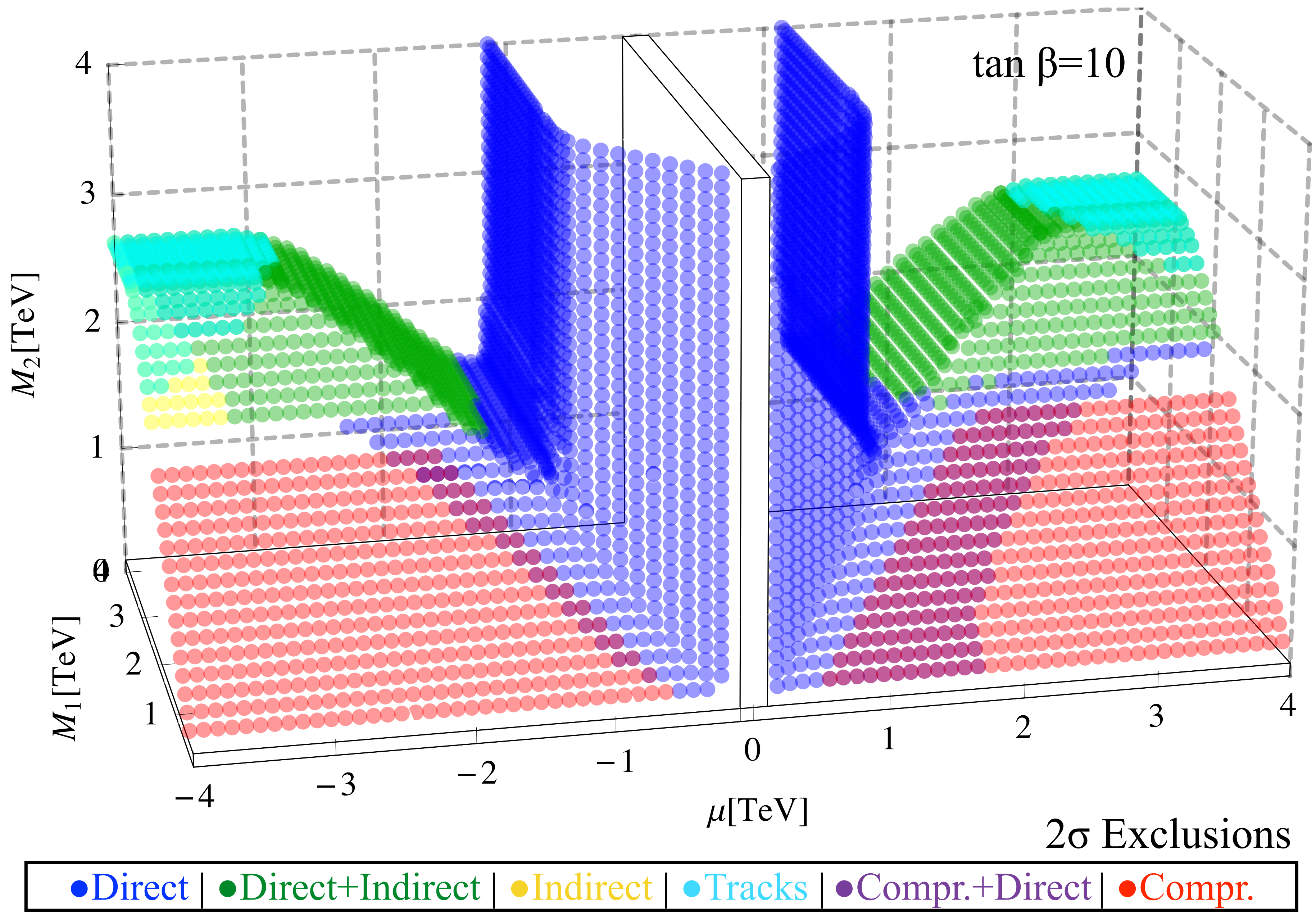
$$pp \to (\tilde{\chi}_2^0 \to \gamma \tilde{\chi}_1^0)\,(\tilde{\chi}_1^\pm \to \ell^\pm \nu_\ell \tilde{\chi}_1^0) j \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 \ell^\pm \nu_\ell \gamma j\ ,$$



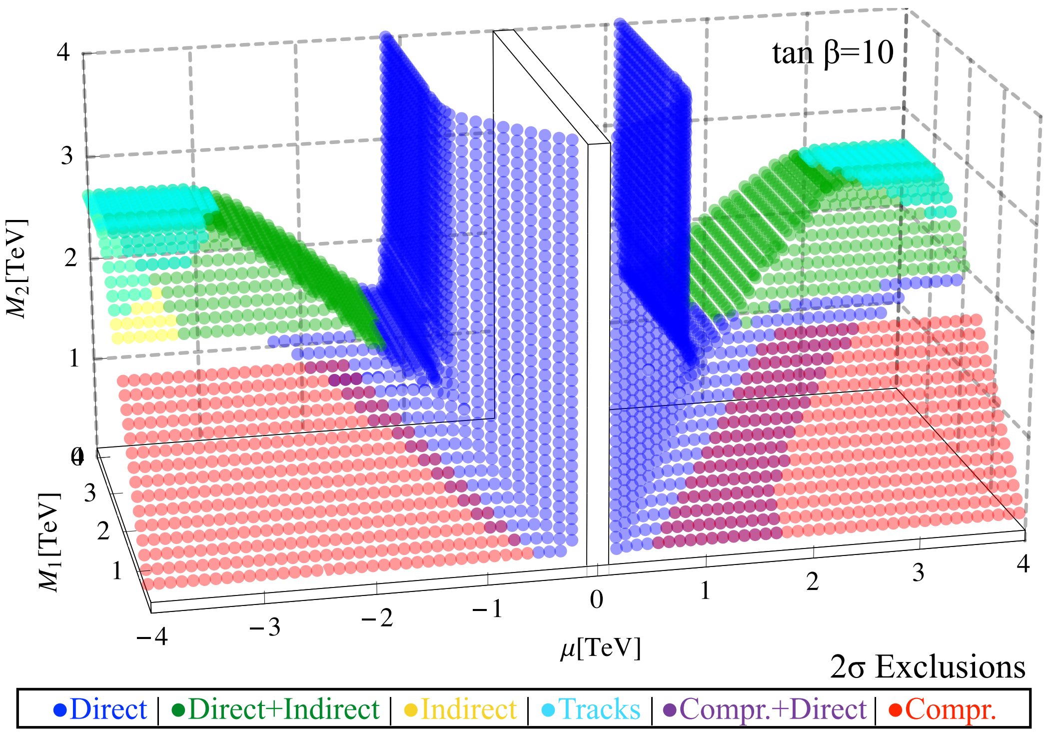


$$pp \to \chi_1^+ \chi_1^-,\ \chi_1^0 \chi_1^+$$

Putting it all together



Putting it all together



- Pure winos can best be detected with tracks + indirect detection
- Pure Higgsinos as well as Wino-Higgsinos can be detected with direct (and/or) indirect detection
- Bino-Winos can only be detected with collider searches

Almost all of SUSY DM can be detected within next 10-20 years!