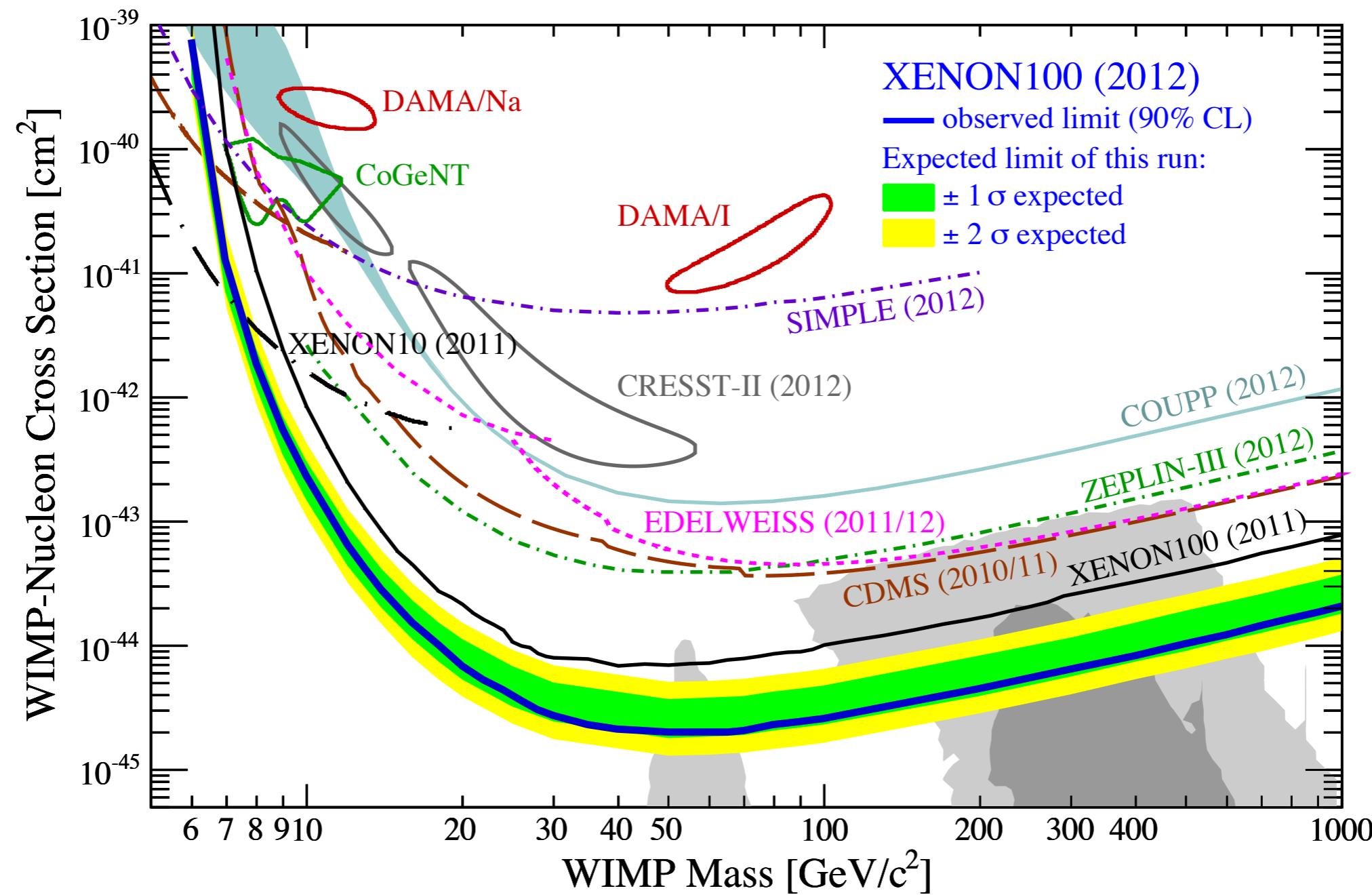


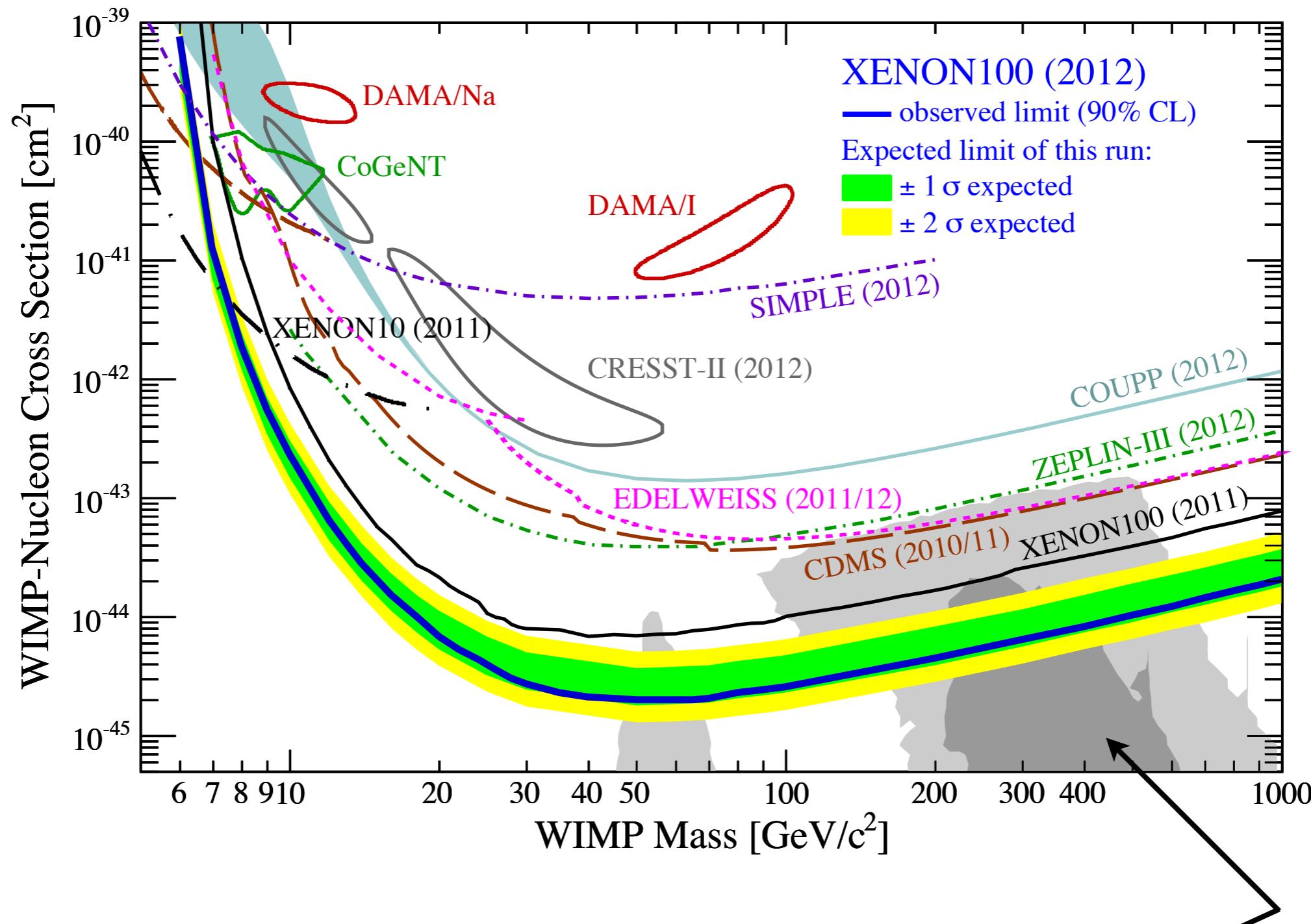
# Prospects and Blind Spots for Neutralino Dark Matter

TeVPA 2013, UC Irvine, 8/29

David Pinner

Clifford Cheung, Lawrence Hall, DP, and Josh Ruderman    1211.4873





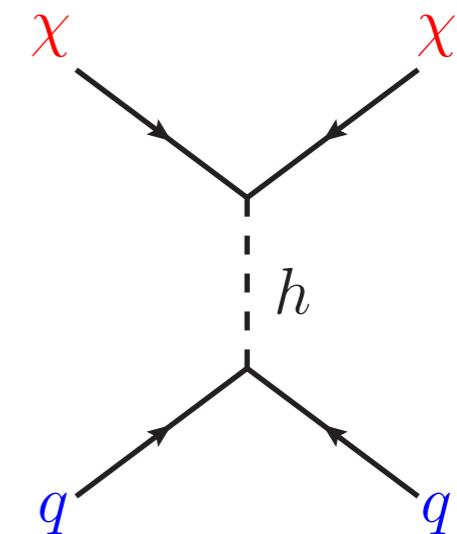
What does this mean for SUSY DM?

# elastic scattering

I. spin-independent:  $\bar{\chi}\chi \bar{N}N$

$$\mathcal{L} \supset c_h \bar{\chi}\chi h$$

$$\sigma_p^{SI} \approx 6 \times 10^{-45} \text{ cm}^2 \left( \frac{c_h}{0.1} \right)^2$$



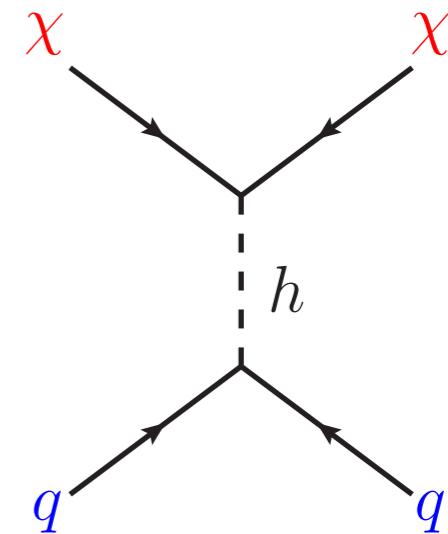
# elastic scattering

I. spin-independent:

$$\mathcal{L} \supset c_h \bar{\chi} \chi h$$

$$\sigma_p^{SI} \approx 6 \times 10^{-45} \text{ cm}^2 \left( \frac{c_h}{0.1} \right)^2$$

$$\bar{\chi} \chi \bar{N} N$$

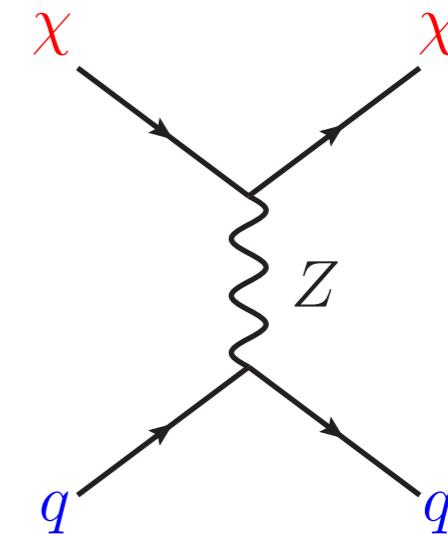


2. spin-dependent:

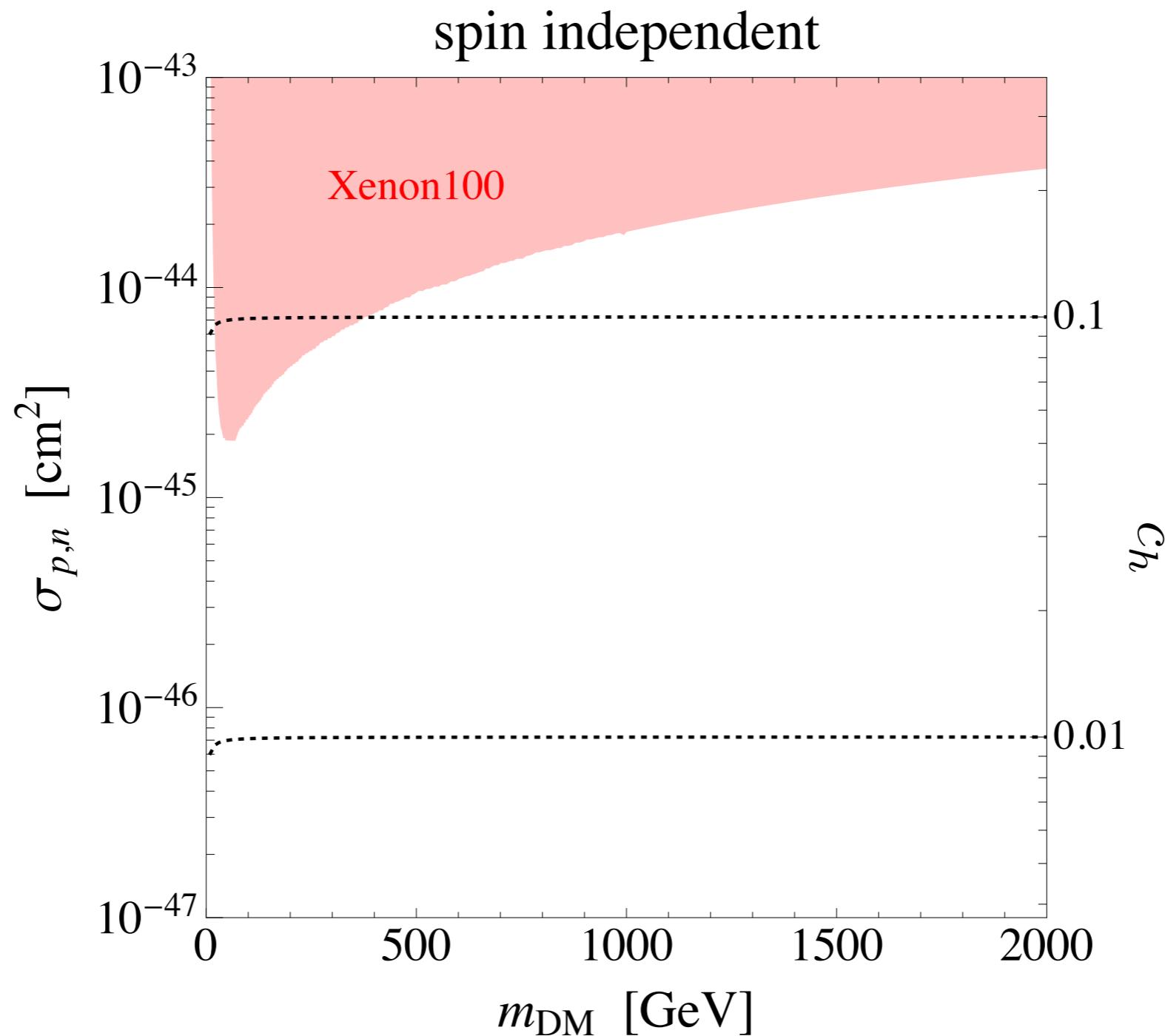
$$\bar{\chi} \gamma^\mu \gamma^5 \chi \bar{N} \gamma_\mu \gamma^5 N$$

$$\mathcal{L} \supset c_Z \bar{\chi} \gamma^\mu \gamma^5 \chi Z_\mu$$

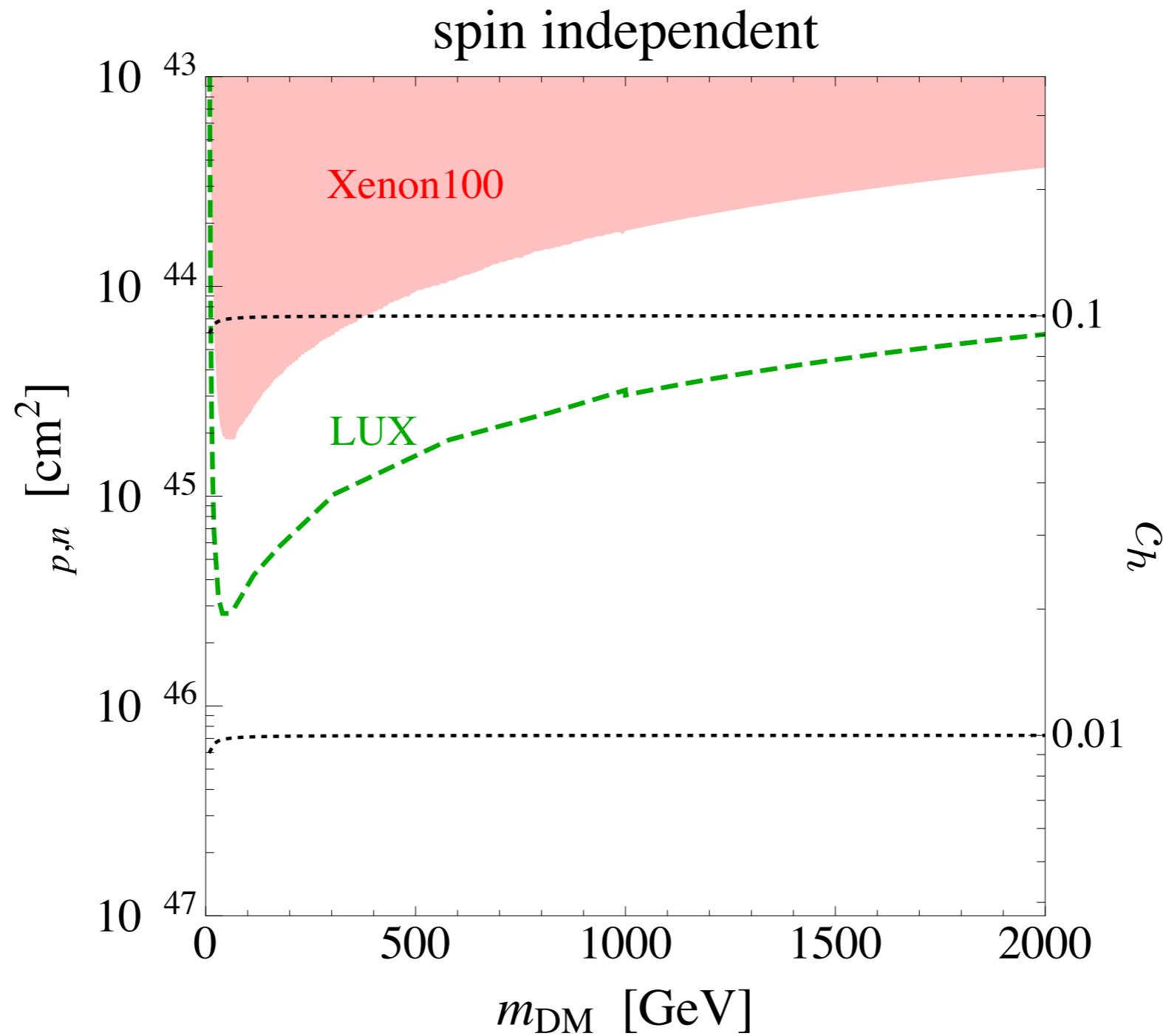
$$\sigma_p^{SD} \approx 3 \times 10^{-39} \text{ cm}^2 \left( \frac{c_Z}{0.1} \right)^2$$



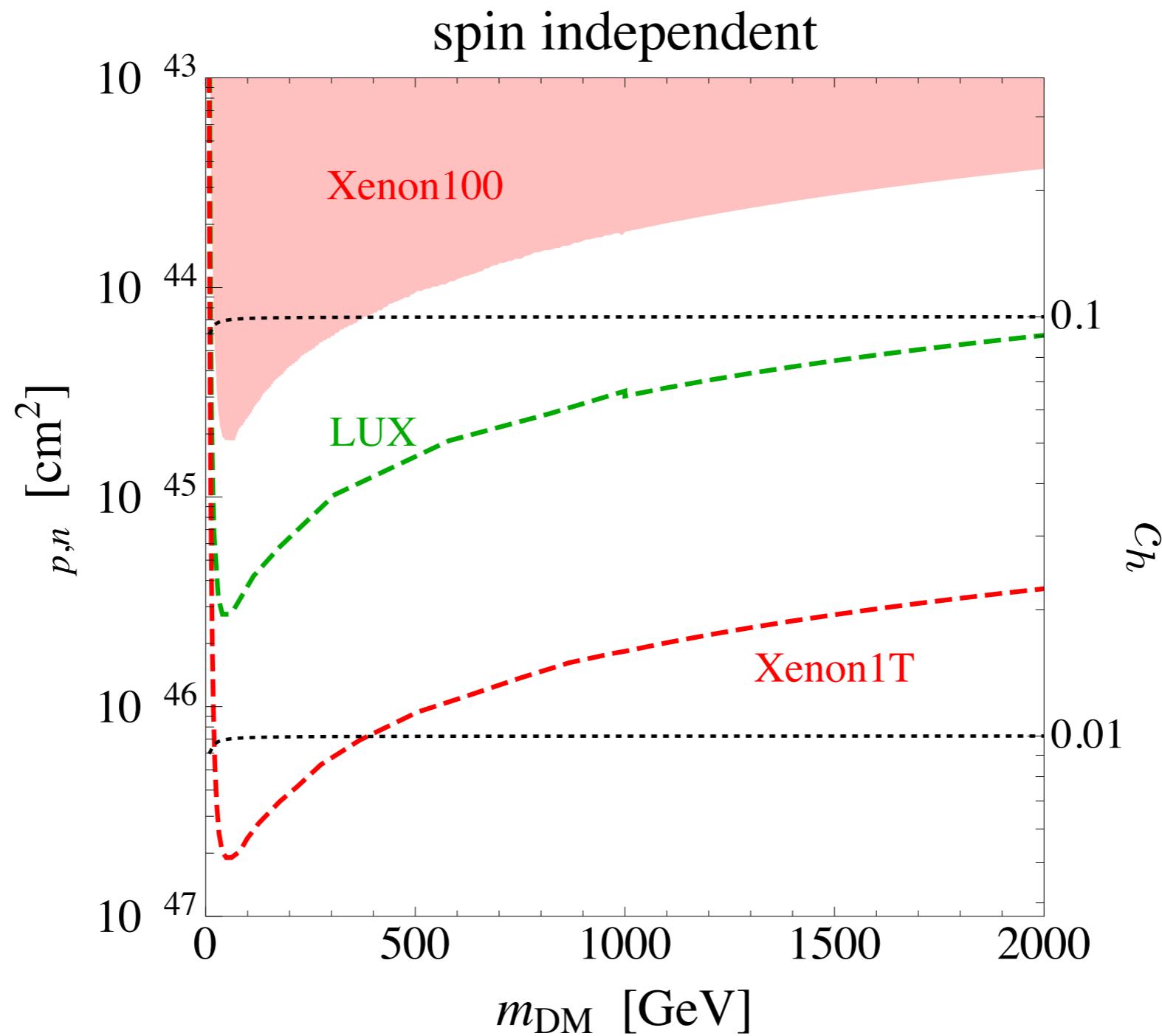
# direct detection limits



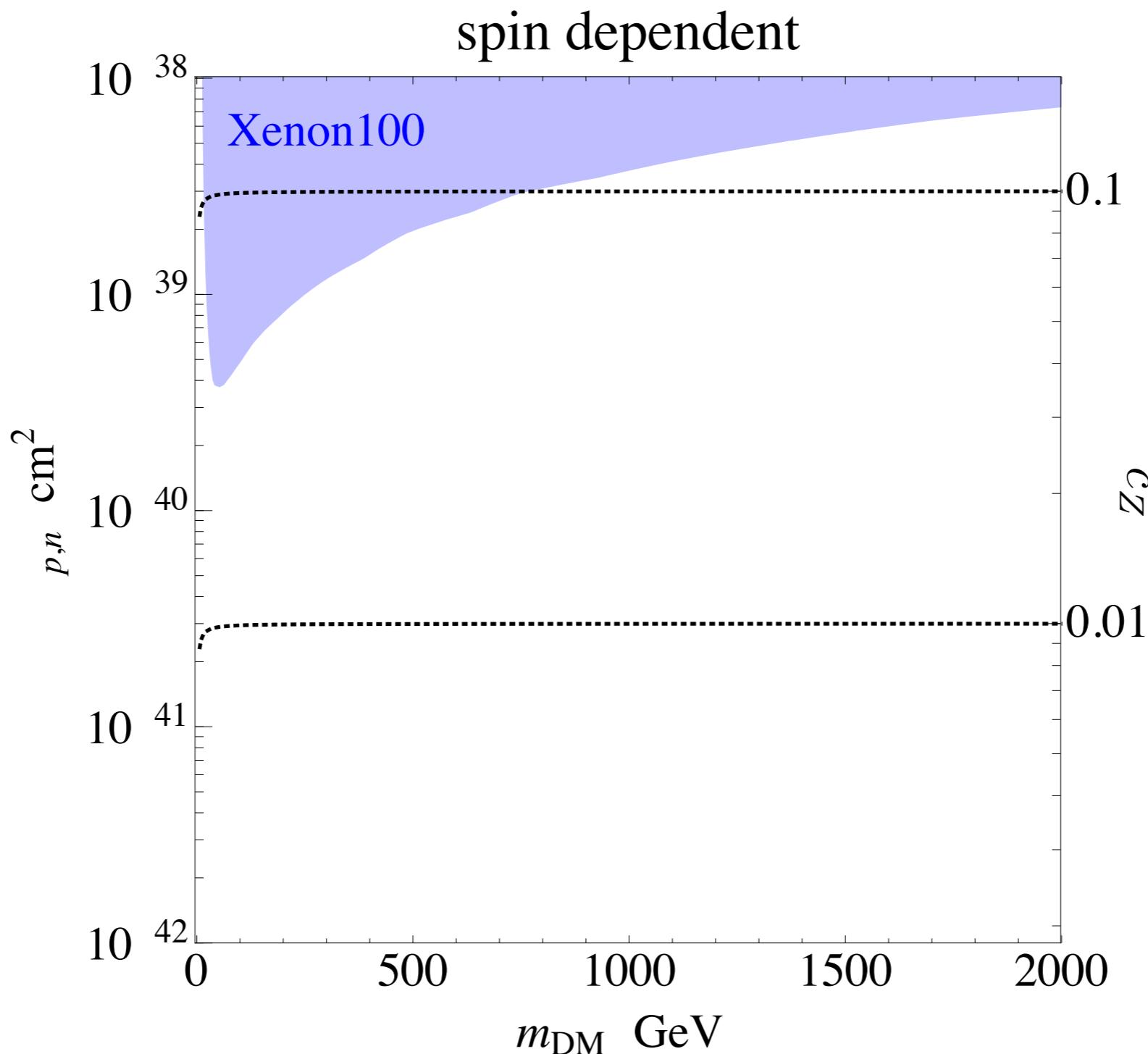
# direct detection limits



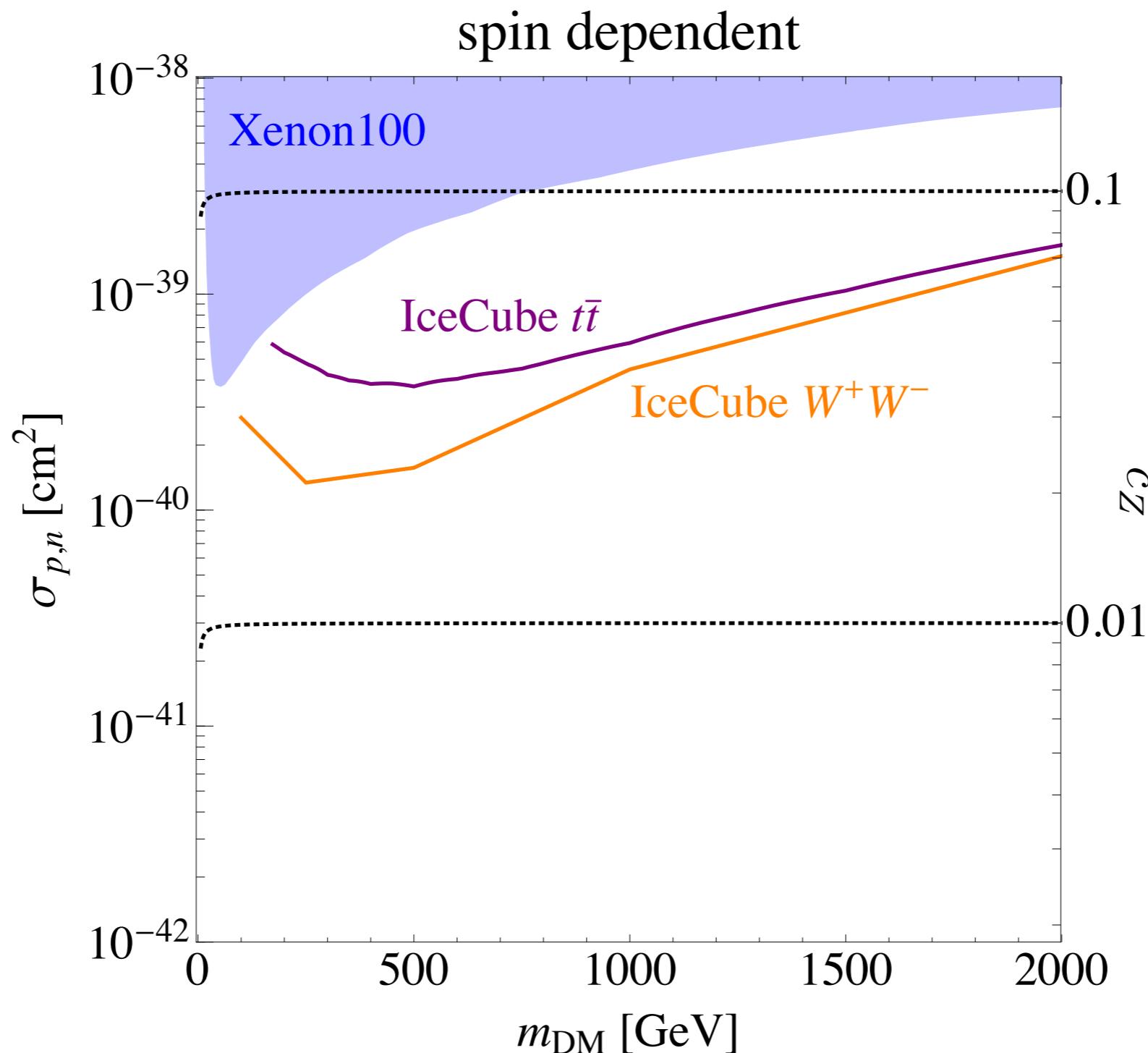
# direct detection limits



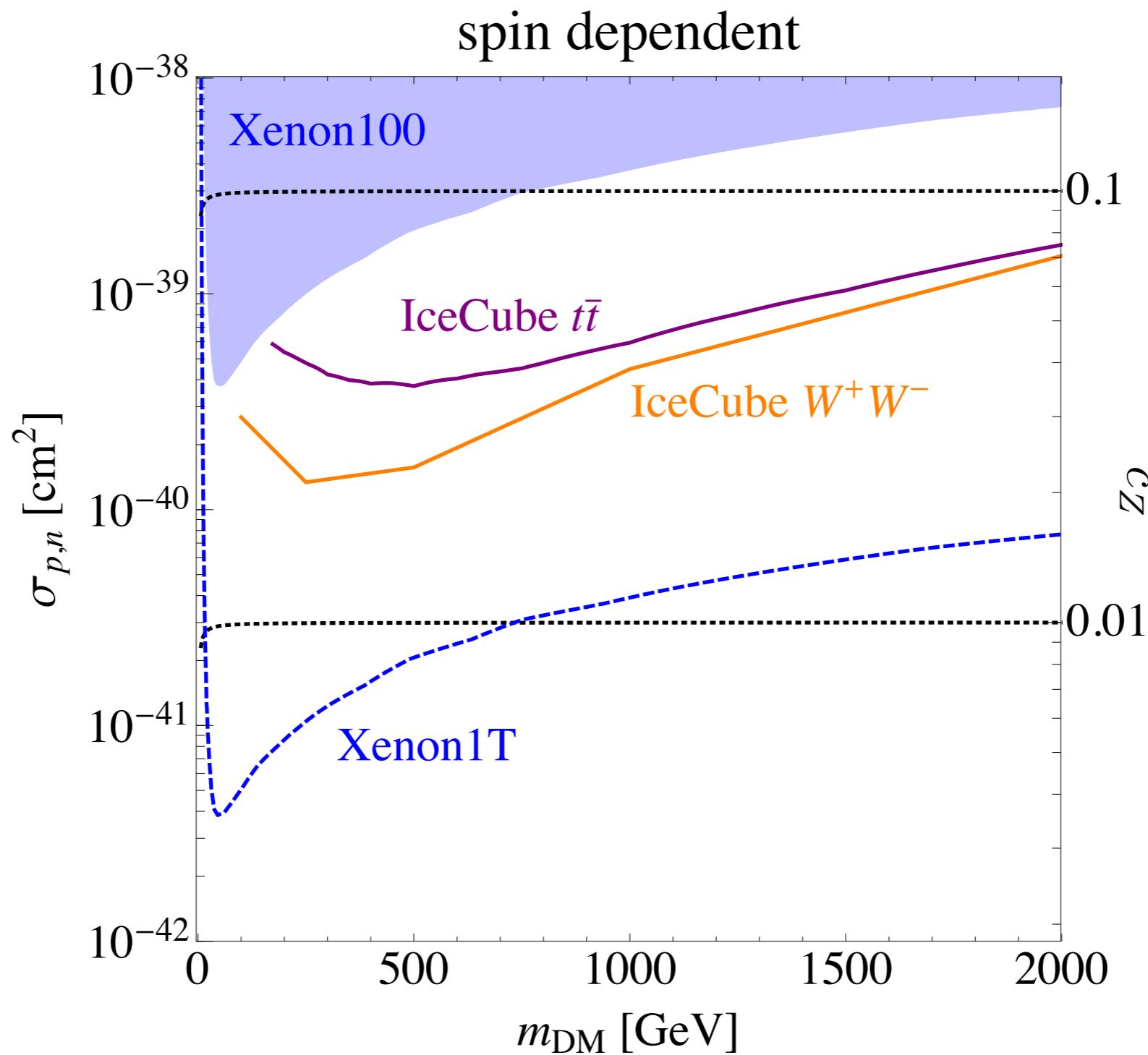
# direct detection limits



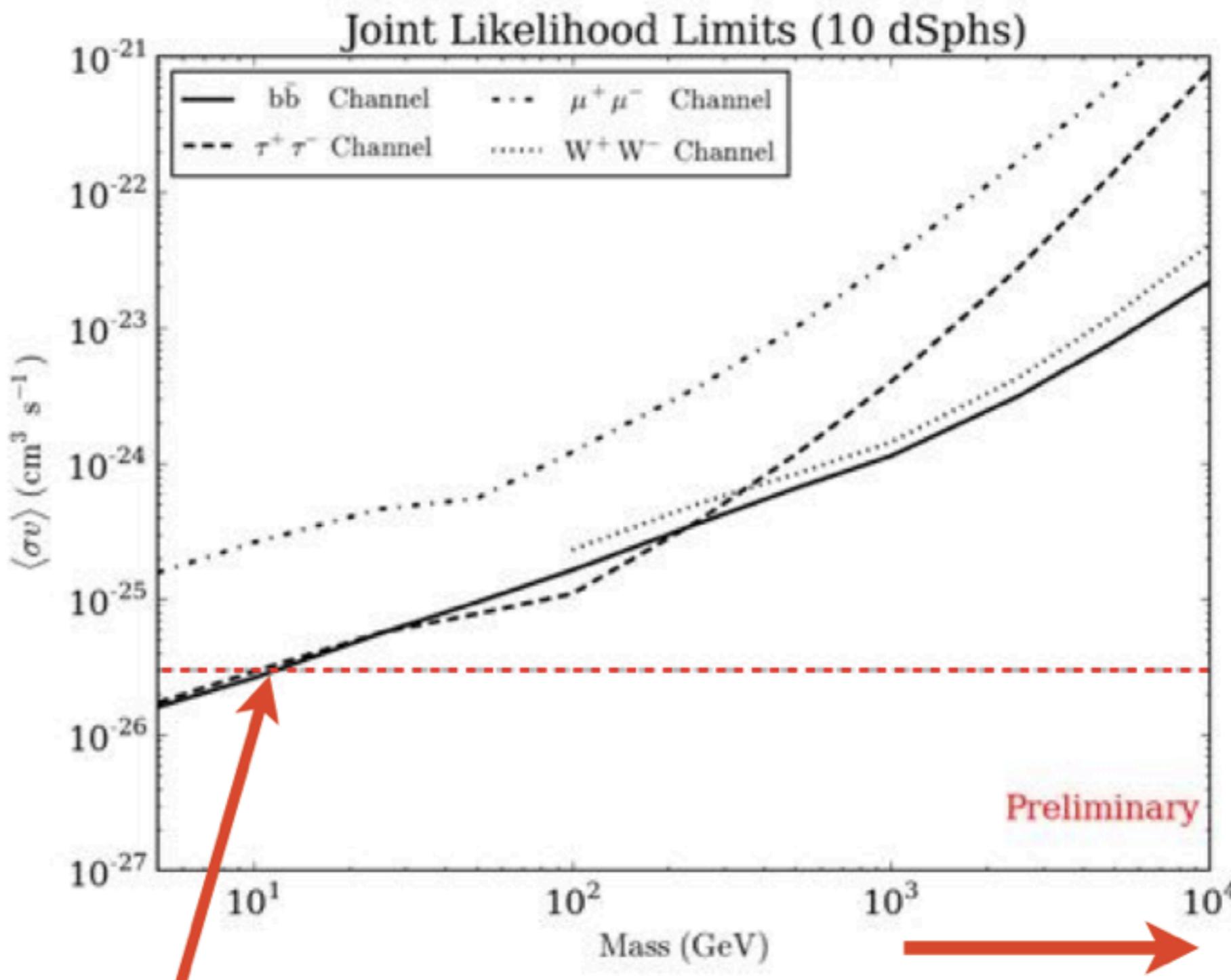
# direct detection limits



# direct detection limits



# indirect detection



- Fermi-LAT: 1108.3546

[http://fermi.gsfc.nasa.gov/science/mtgs/symposia/  
2012/program/fri/ADrlica-Wagner.pdf](http://fermi.gsfc.nasa.gov/science/mtgs/symposia/2012/program/fri/ADrlica-Wagner.pdf)

**Extended to 10 TeV**

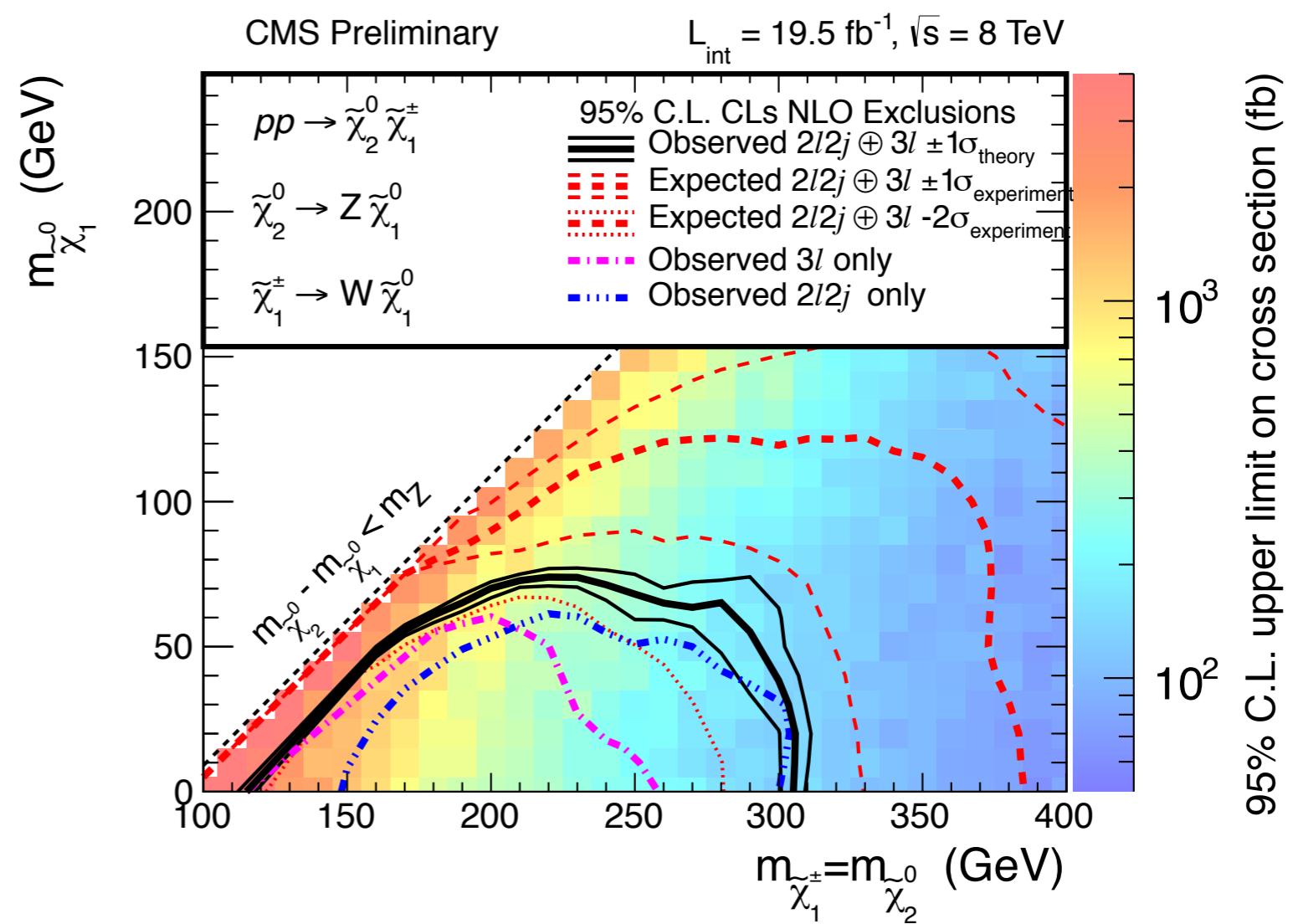
# collider limits

LEP:

$$m_{\chi^\pm} \gtrsim 100 \text{ GeV}$$

$$\implies \mu, M_2 \gtrsim 100 \text{ GeV}$$

LHC:



# neutralino DM

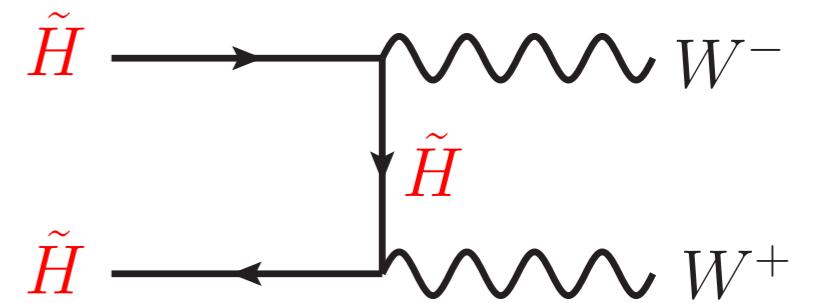
- $SM + \tilde{b}, \tilde{w}, \tilde{h}_{u,d}$
- decoupled scalars
- CP conservation
- parameters:  $M_1, M_2, \mu, \tan \beta \equiv v_u/v_d$

# neutralino DM in SUSY

- unnatural models, e.g. split SUSY, with decoupled scalars
- natural models, like the NMSSM, with  $\theta_{\tilde{s}} \ll 1$
- We'll be agnostic about tuning

# gauge eigenstates

- bino overcloses
- higgsino  $\mu \approx 1 \text{ TeV}$
- wino  $M_2 \approx 2.7 \text{ TeV}$

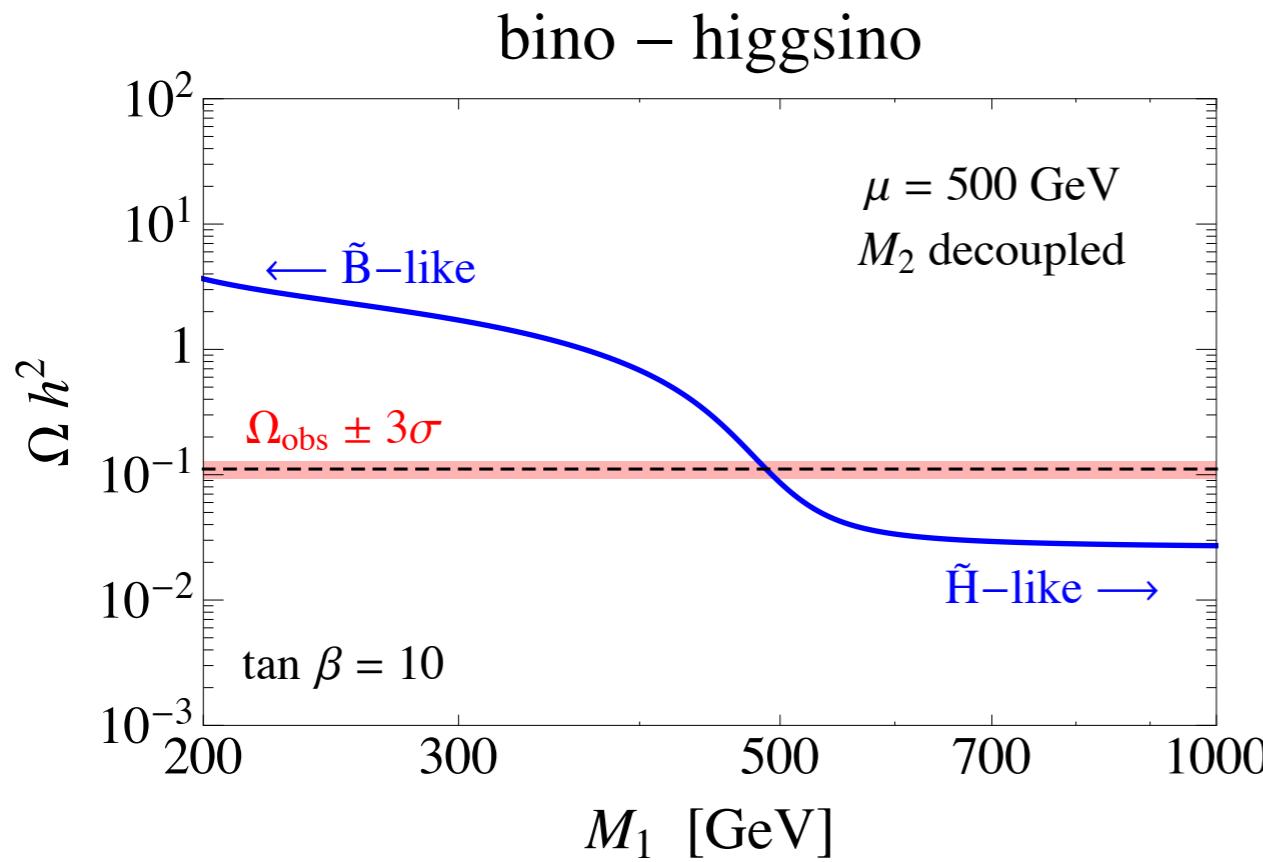


# well-tempering

$$\frac{1}{2} \tilde{\chi}^0 \mathcal{M}_N \tilde{\chi}^0 = \frac{1}{2} \begin{pmatrix} \tilde{b} & \tilde{w}_3 & \tilde{h}_d & \tilde{h}_u \end{pmatrix} \begin{pmatrix} M_1 & 0 & -g'v_d/\sqrt{2} & g'v_u/\sqrt{2} \\ 0 & M_2 & gv_d/\sqrt{2} & -gv_u/\sqrt{2} \\ -g'v_d/\sqrt{2} & gv_d/\sqrt{2} & 0 & -\mu \\ g'v_u/\sqrt{2} & -gv_u/\sqrt{2} & -\mu & 0 \end{pmatrix} \begin{pmatrix} \tilde{b} \\ \tilde{w}_3 \\ \tilde{h}_d \\ \tilde{h}_u \end{pmatrix}$$

# well-tempering

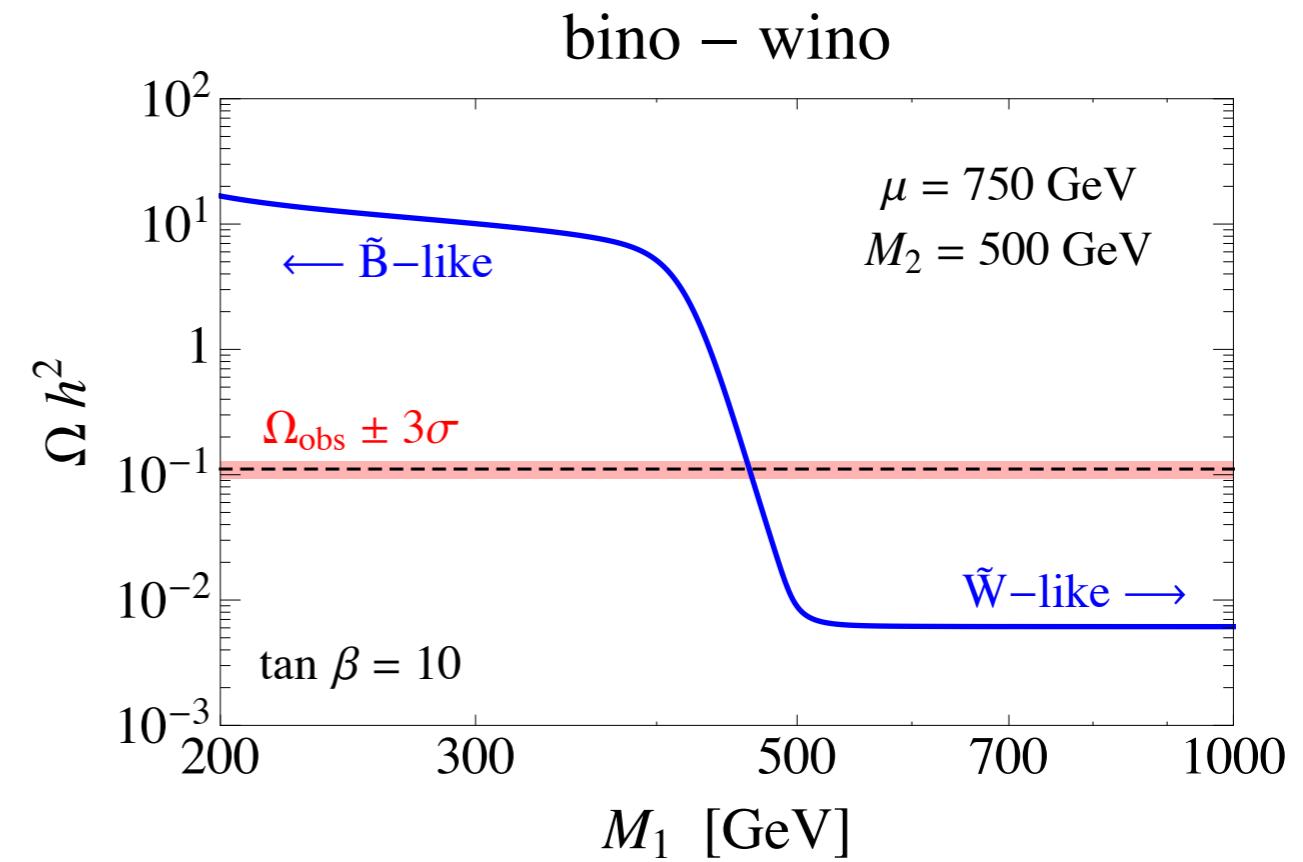
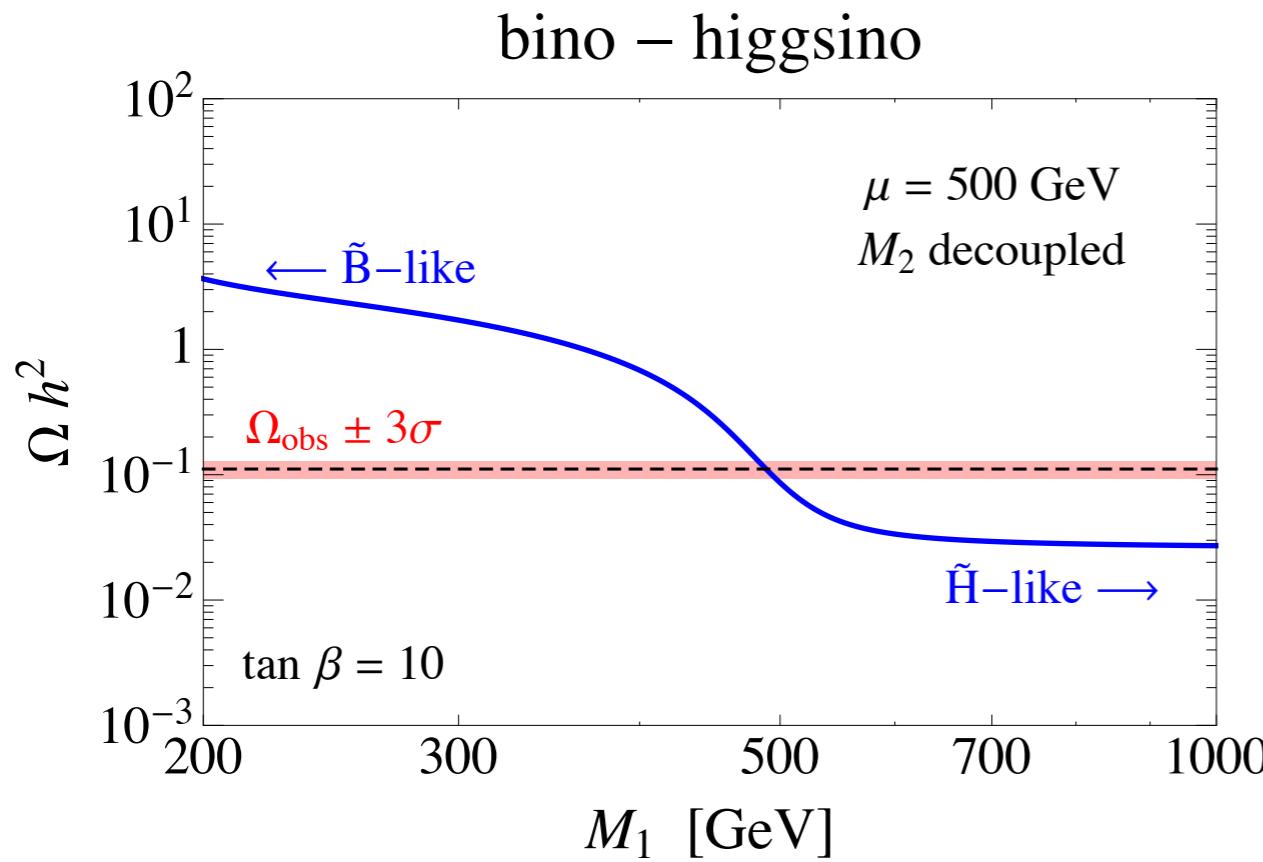
$$\frac{1}{2}\tilde{\chi}^0 \mathcal{M}_N \tilde{\chi}^0 = \frac{1}{2} \begin{pmatrix} \tilde{b} & \tilde{w}_3 & \tilde{h}_d & \tilde{h}_u \end{pmatrix} \begin{pmatrix} M_1 & 0 & -g'v_d/\sqrt{2} & g'v_u/\sqrt{2} \\ 0 & M_2 & gv_d/\sqrt{2} & -gv_u/\sqrt{2} \\ -g'v_d/\sqrt{2} & gv_d/\sqrt{2} & 0 & -\mu \\ g'v_u/\sqrt{2} & -gv_u/\sqrt{2} & -\mu & 0 \end{pmatrix} \begin{pmatrix} \tilde{b} \\ \tilde{w}_3 \\ \tilde{h}_d \\ \tilde{h}_u \end{pmatrix}$$



N.Arkani-Hamed, A. Delgado, G. Giudice 060104I.

# well-tempering

$$\frac{1}{2} \tilde{\chi}^0 \mathcal{M}_N \tilde{\chi}^0 = \frac{1}{2} \begin{pmatrix} \tilde{b} & \tilde{w}_3 & \tilde{h}_d & \tilde{h}_u \end{pmatrix} \begin{pmatrix} M_1 & 0 & -g' v_d / \sqrt{2} & g' v_u / \sqrt{2} \\ 0 & M_2 & g v_d / \sqrt{2} & -g v_u / \sqrt{2} \\ -g' v_d / \sqrt{2} & g v_d / \sqrt{2} & 0 & -\mu \\ g' v_u / \sqrt{2} & -g v_u / \sqrt{2} & -\mu & 0 \end{pmatrix} \begin{pmatrix} \tilde{b} \\ \tilde{w}_3 \\ \tilde{h}_d \\ \tilde{h}_u \end{pmatrix}$$



N.Arkani-Hamed, A. Delgado, G. Giudice 060104I.

# blindsights

$$c_h = 0 :$$

$$\begin{aligned}\mathcal{L}_{h\chi\chi} &= \frac{1}{2}m_\chi(v+h)\chi\chi \\ &= \frac{1}{2}m_\chi(v)\chi\chi + \frac{1}{2}\frac{\partial m_\chi(v)}{\partial v}h\chi\chi + \mathcal{O}(h^2)\end{aligned}$$

$$\det(\mathcal{M}_N - \mathbb{1}m_{\chi_i}(v)) = 0$$

$$\frac{\partial m_{\chi_i}}{\partial v} = 0$$

$$\implies (m_{\chi_i}(v) + \mu \sin 2\beta) \left( m_{\chi_i}(v) - \frac{1}{2}(M_1 + M_2 + \cos 2\theta_W(M_1 - M_2)) \right) = 0$$

# blindsights

$$c_h = 0 :$$

- bino-like

$$m_\chi = M_1 \quad M_1 + \sin 2\beta \mu = 0$$

- higgsino-like

$$m_\chi = -\mu \quad \begin{aligned} \tan \beta &= 1 \\ \text{sign}(\mu) &= -\text{sign}(M_1) \end{aligned}$$

- wino-like

$$m_\chi = M_2 \quad M_2 + \sin 2\beta \mu = 0$$

$$M_1 = M_2 \quad \text{sign}(\mu) = -\text{sign}(M_1)$$

# bino-higgsino

- decouple wino

$$\mathcal{M}_N = \begin{pmatrix} M_1 & -g'v_d/\sqrt{2} & g'v_u/\sqrt{2} \\ -g'v_d/\sqrt{2} & 0 & -\mu \\ g'v_u/\sqrt{2} & -\mu & 0 \end{pmatrix}$$

- parameters:

$$M_1, \mu, \tan \beta$$

- non-thermal

$$\Omega_{\text{freezeout}} \neq \Omega_{\text{cdm}}$$

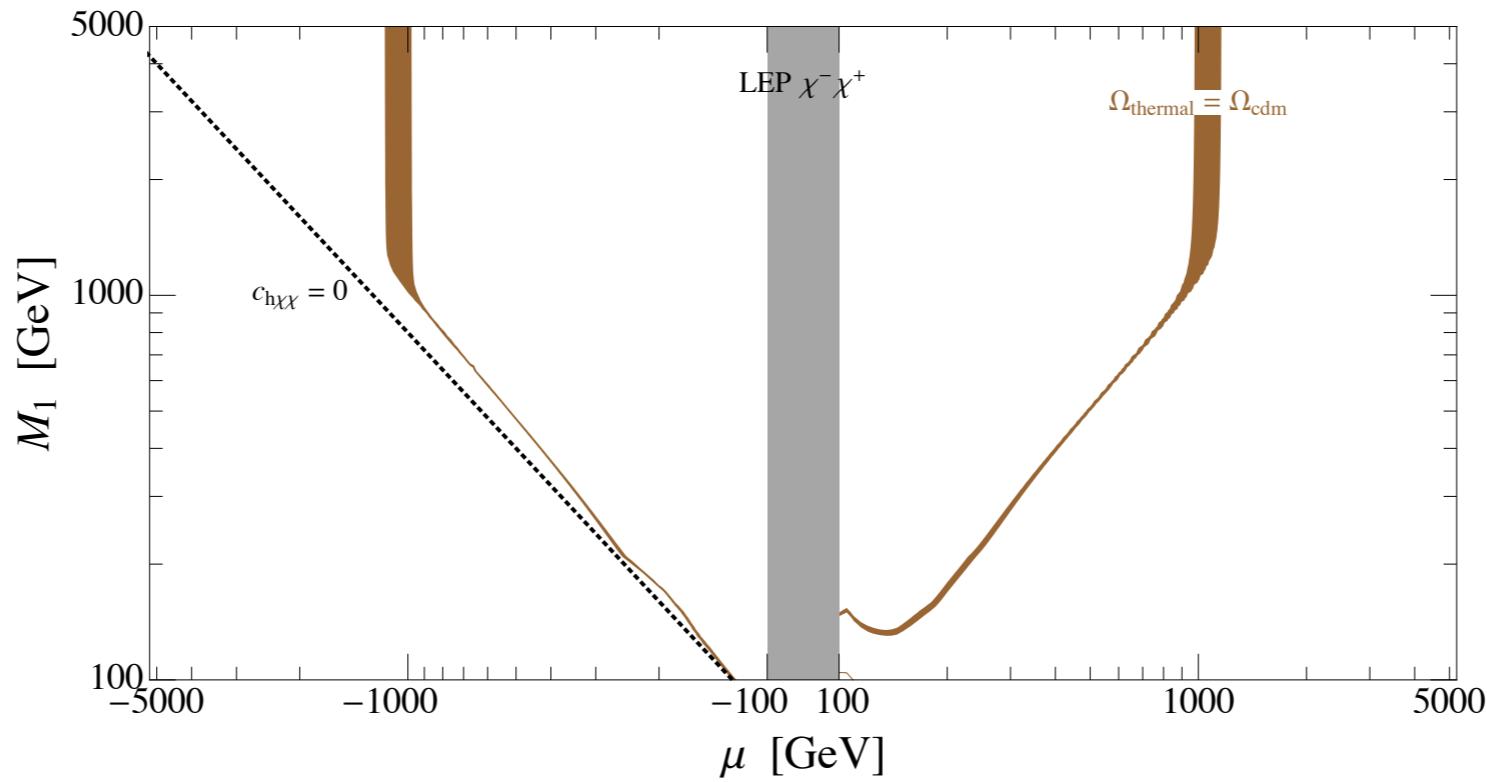
- well-tempered

$$\Omega(M_1, \mu, \tan \beta) = \Omega_{\text{cdm}}$$

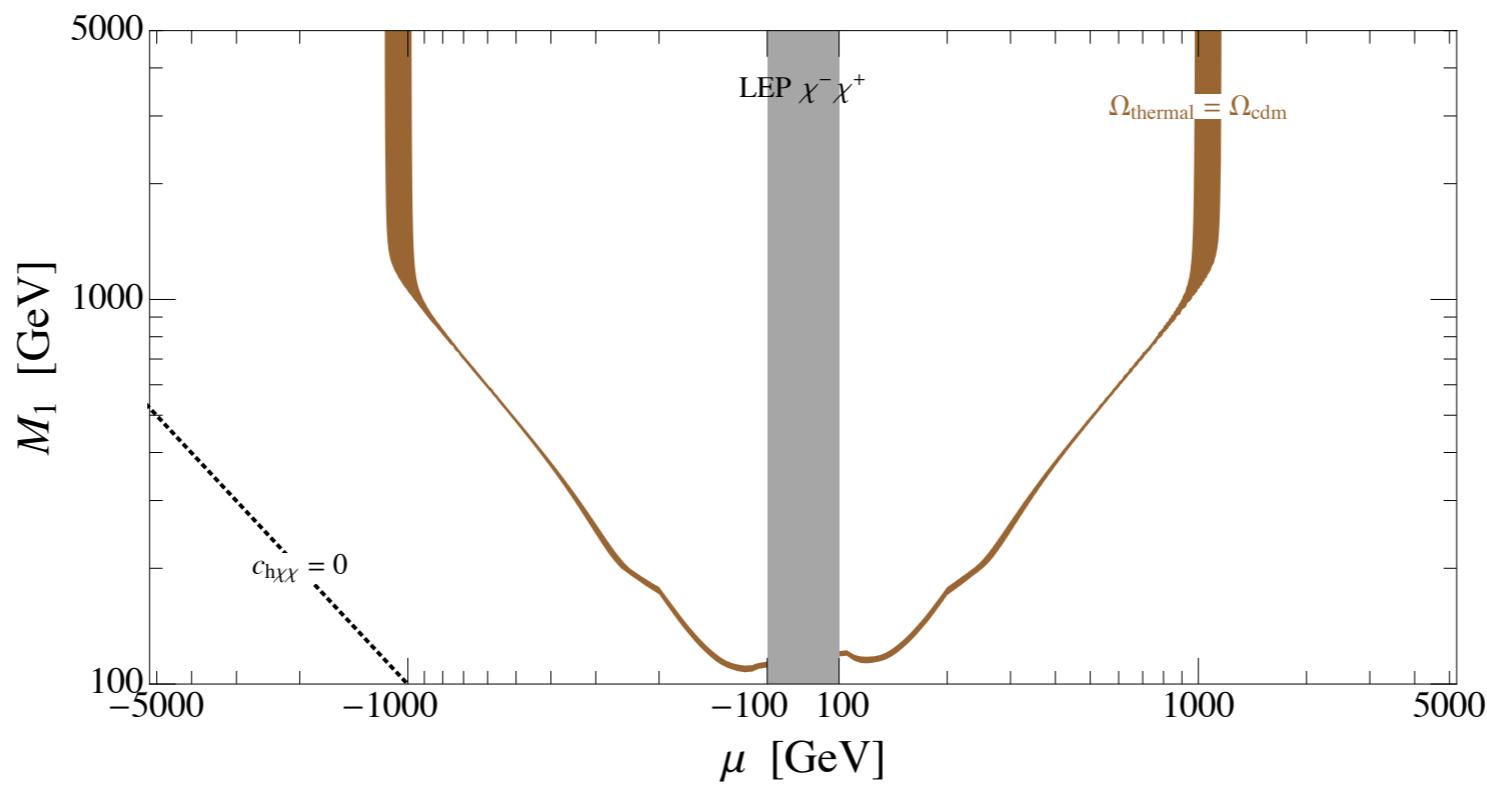
$$\implies M_1(\mu, \tan \beta)$$

# non-thermal

$\tan \beta = 2$

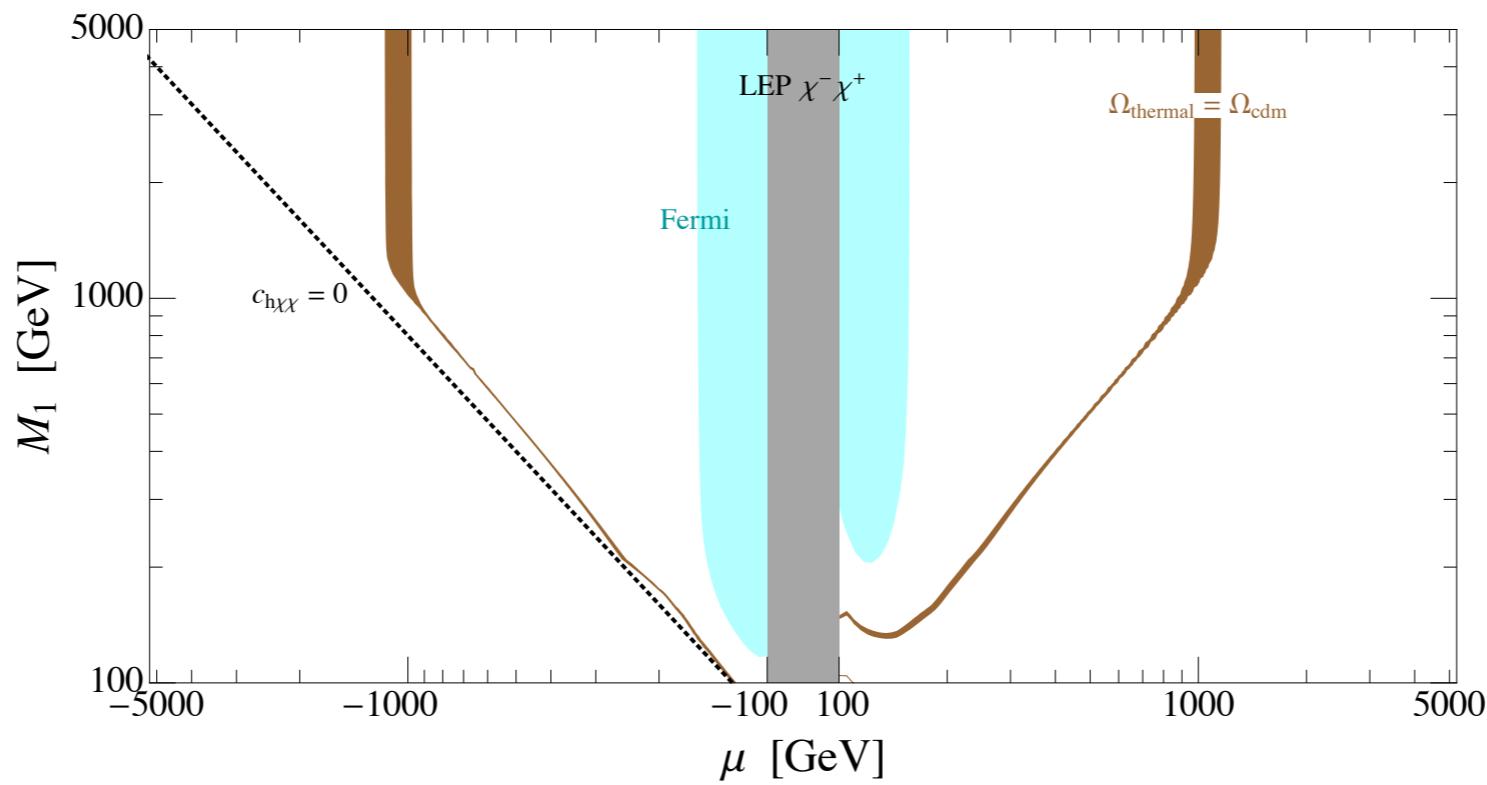


$\tan \beta = 20$

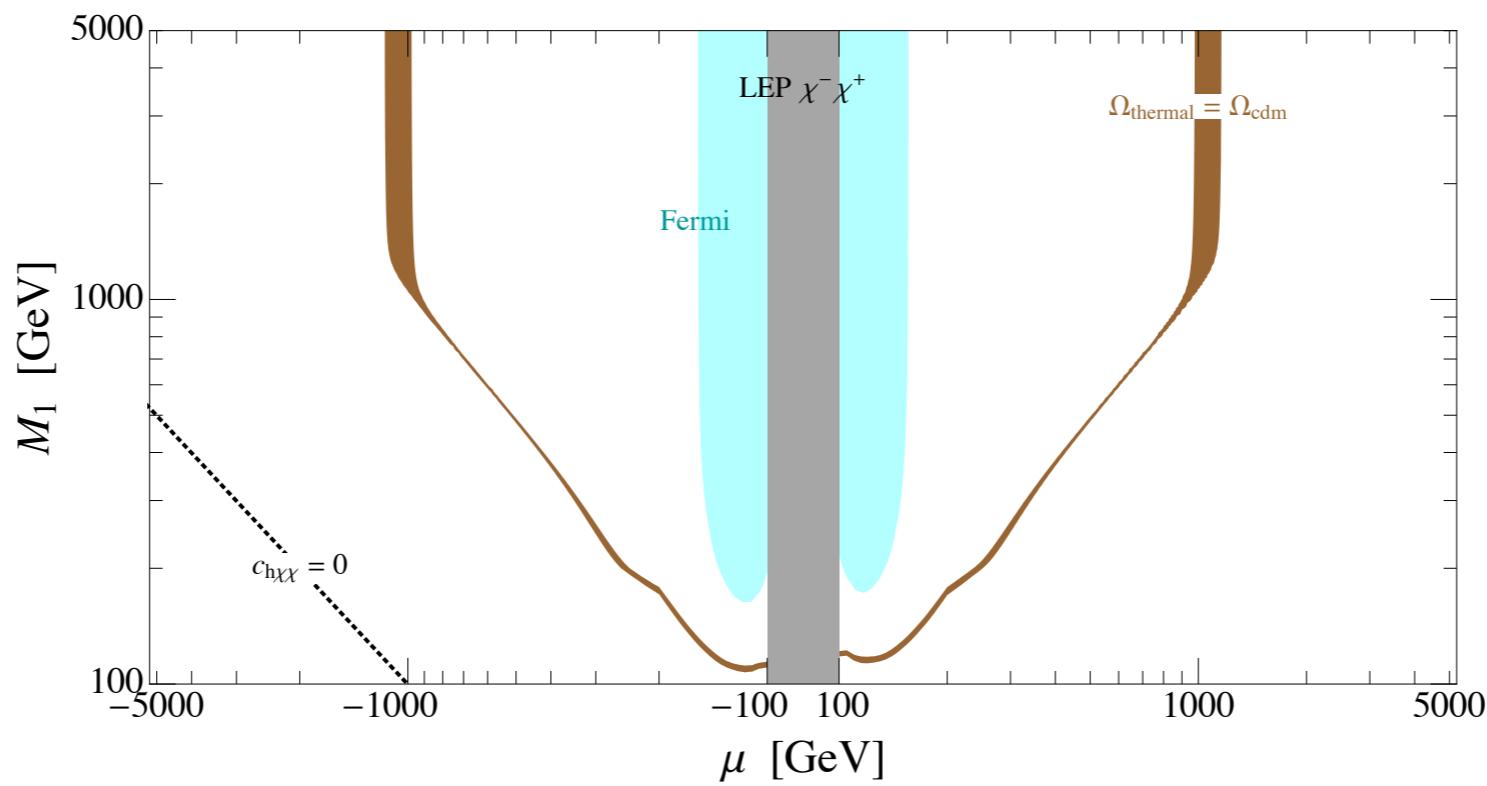


# non-thermal

$\tan \beta = 2$

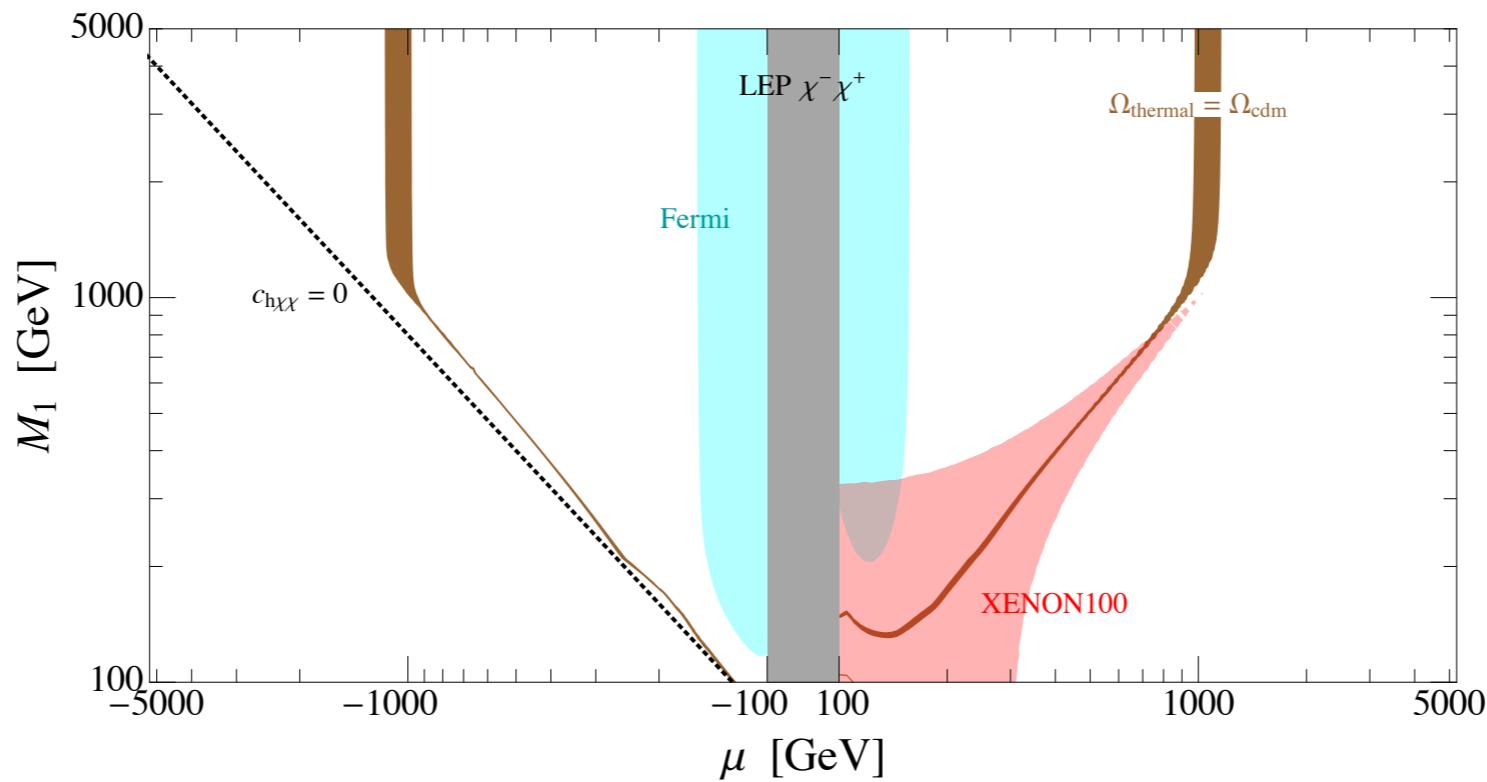


$\tan \beta = 20$

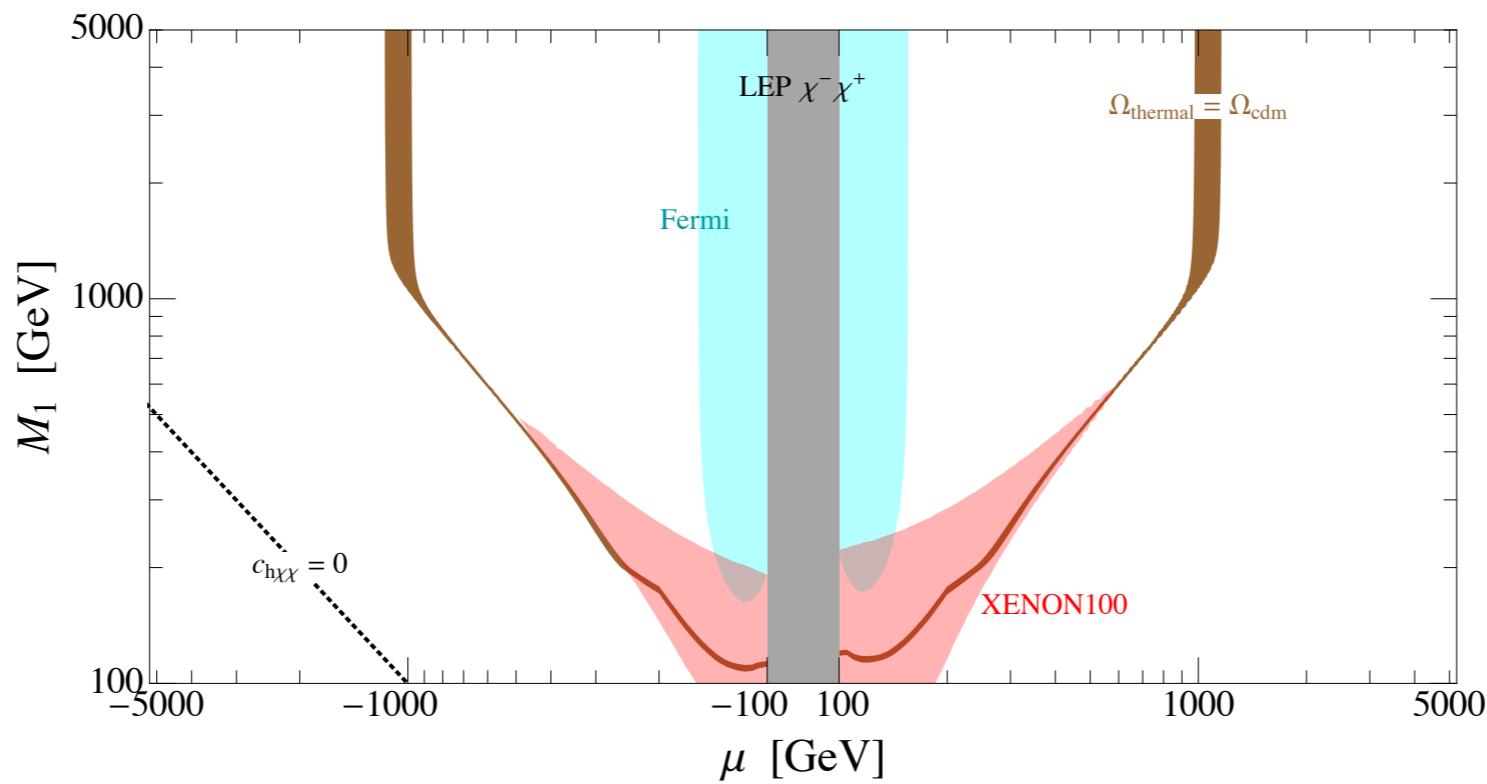


# non-thermal

$\tan \beta = 2$

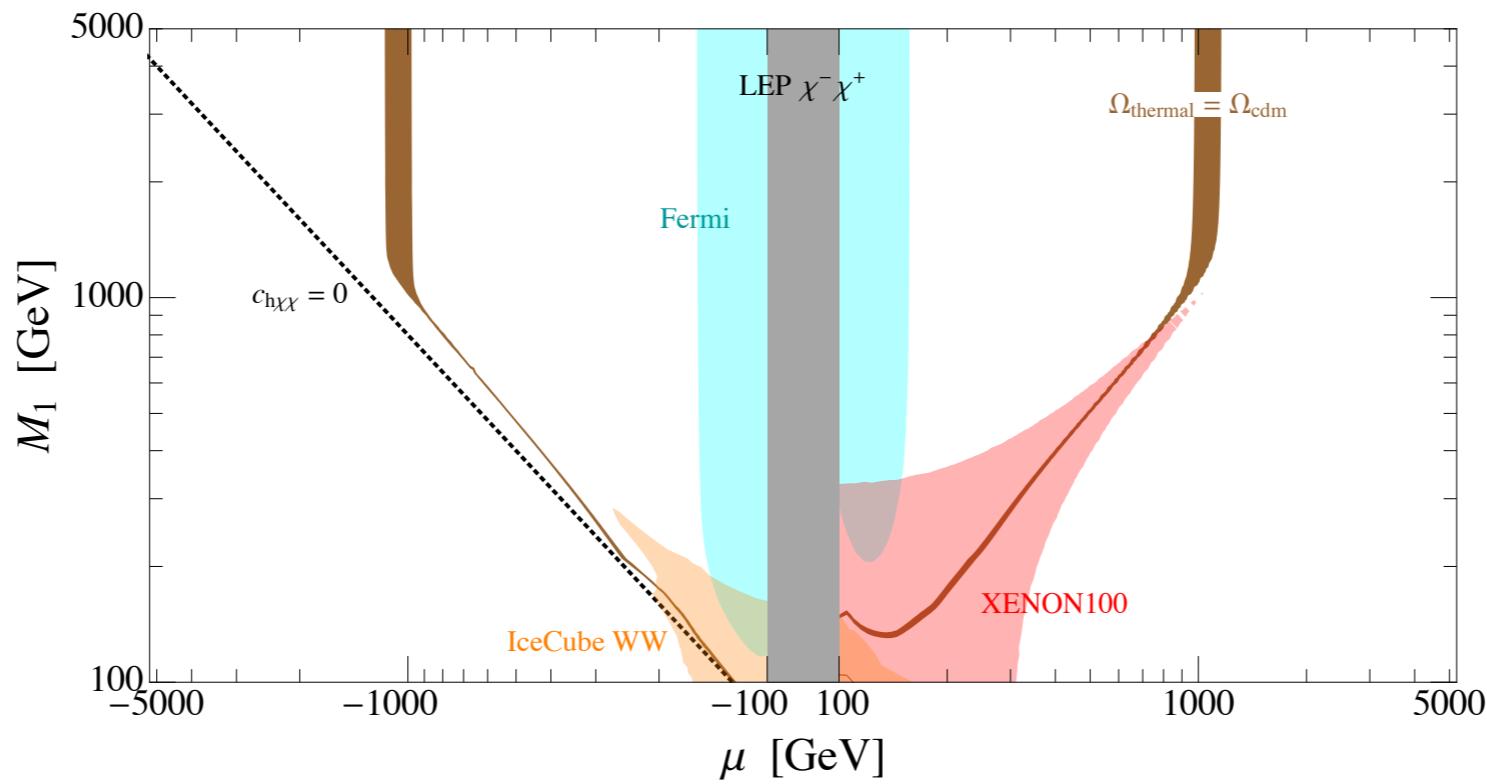


$\tan \beta = 20$

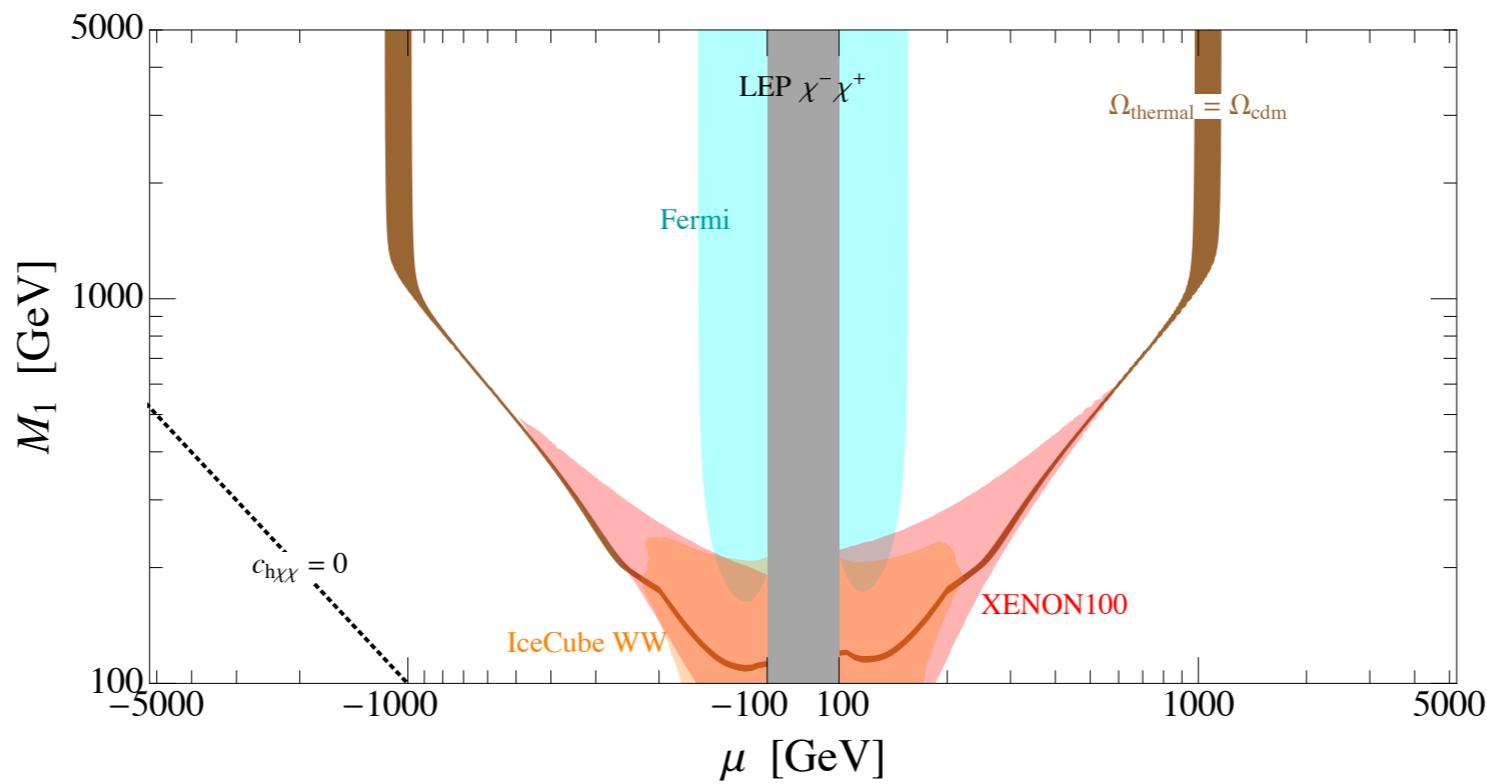


# non-thermal

$\tan \beta = 2$

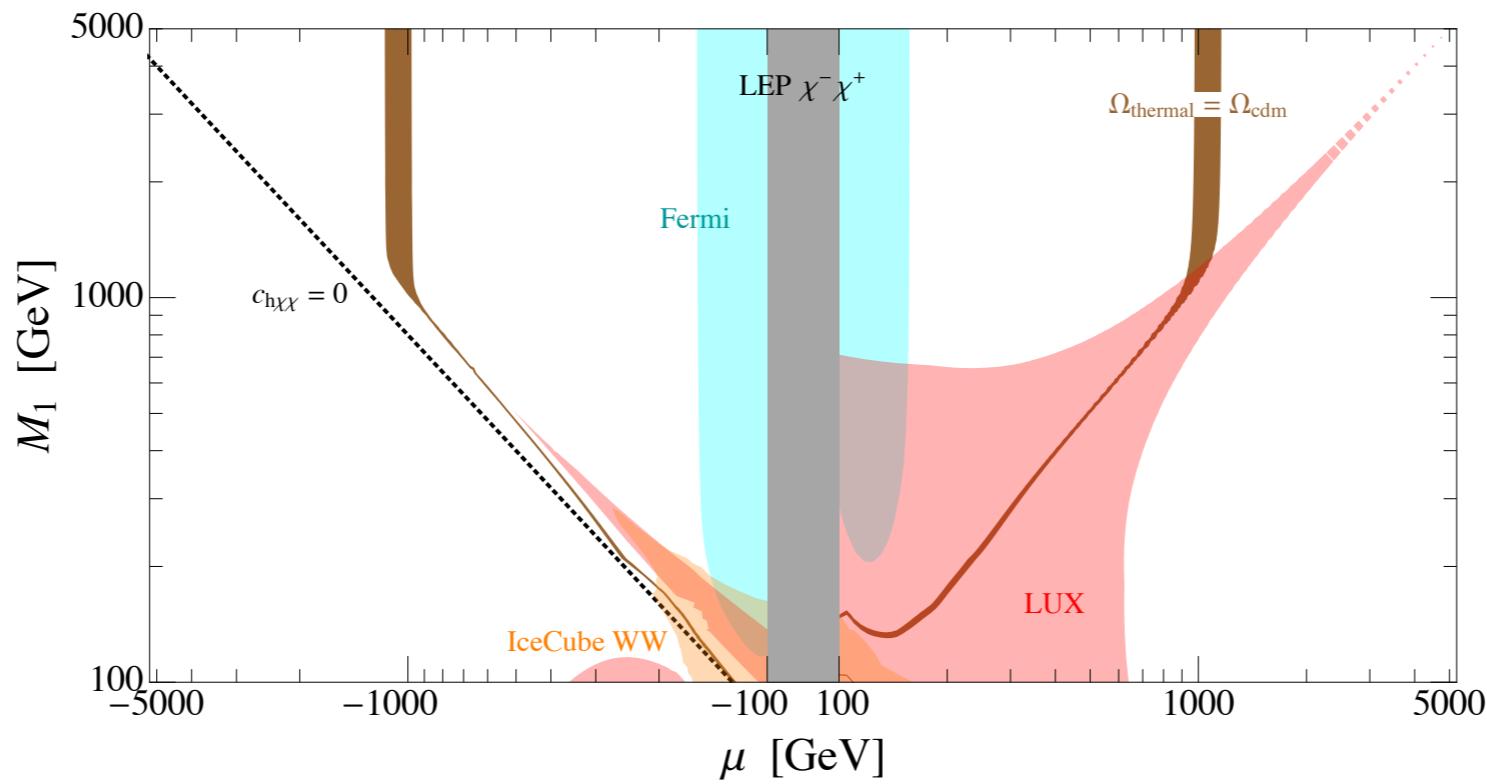


$\tan \beta = 20$

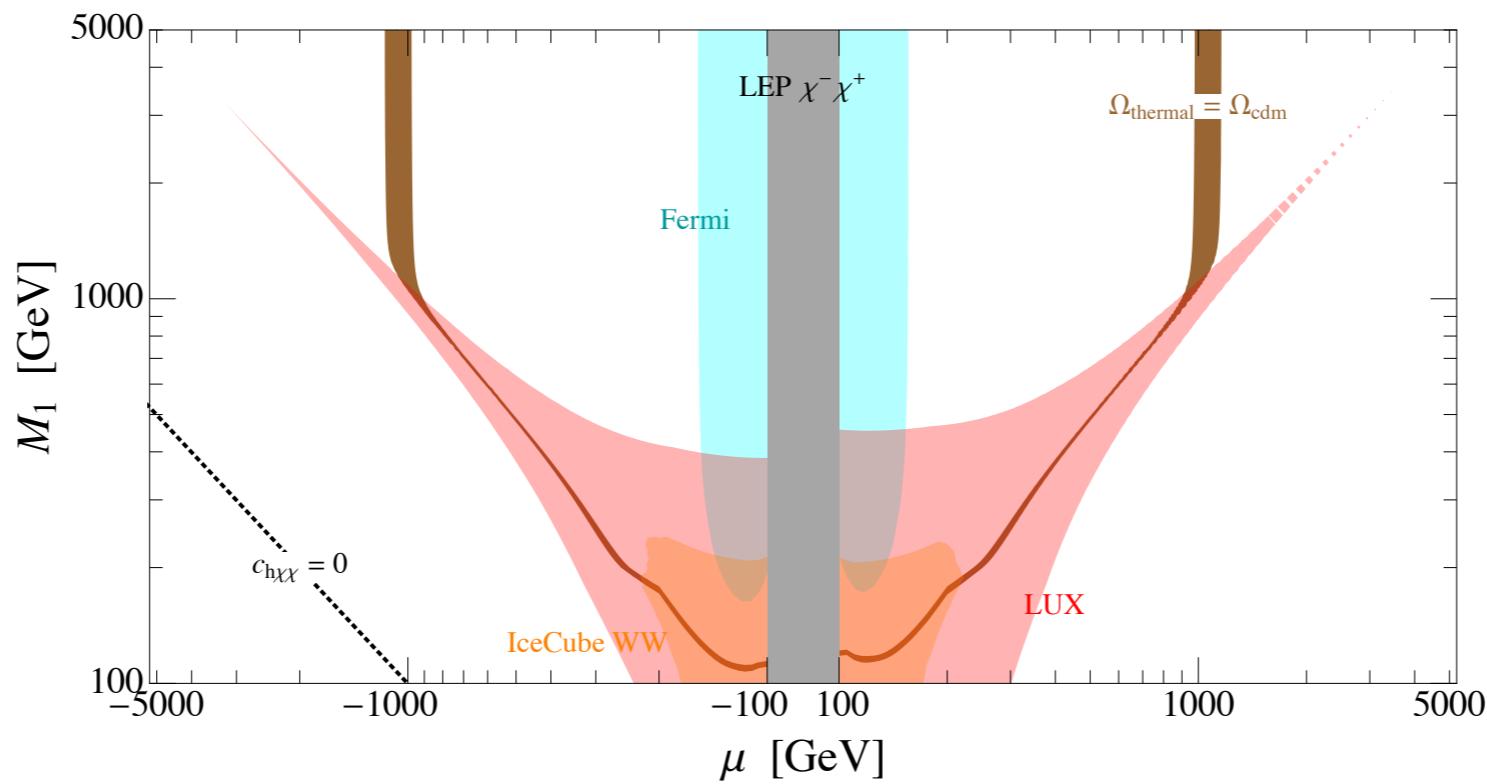


# non-thermal

$\tan \beta = 2$

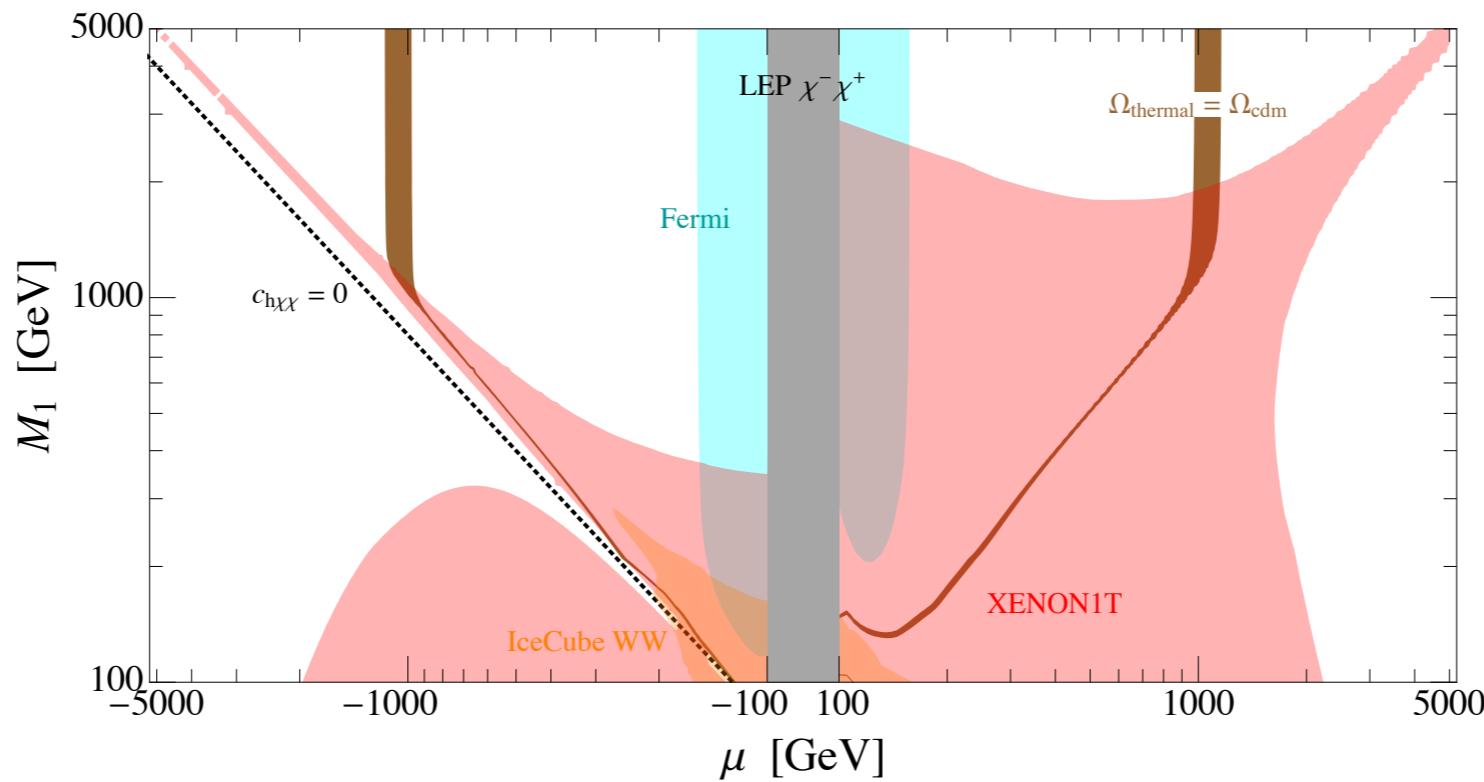


$\tan \beta = 20$

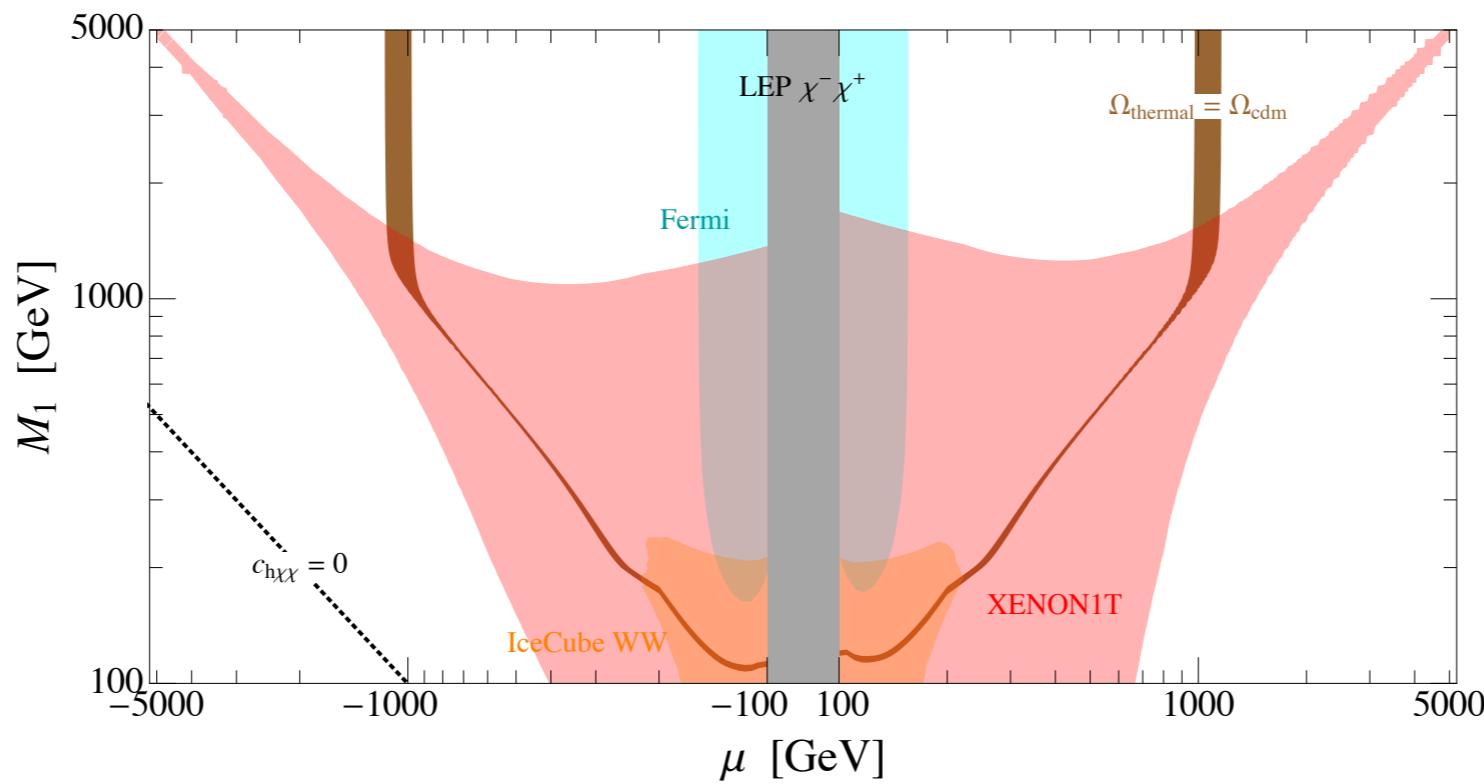


# non-thermal

$\tan \beta = 2$

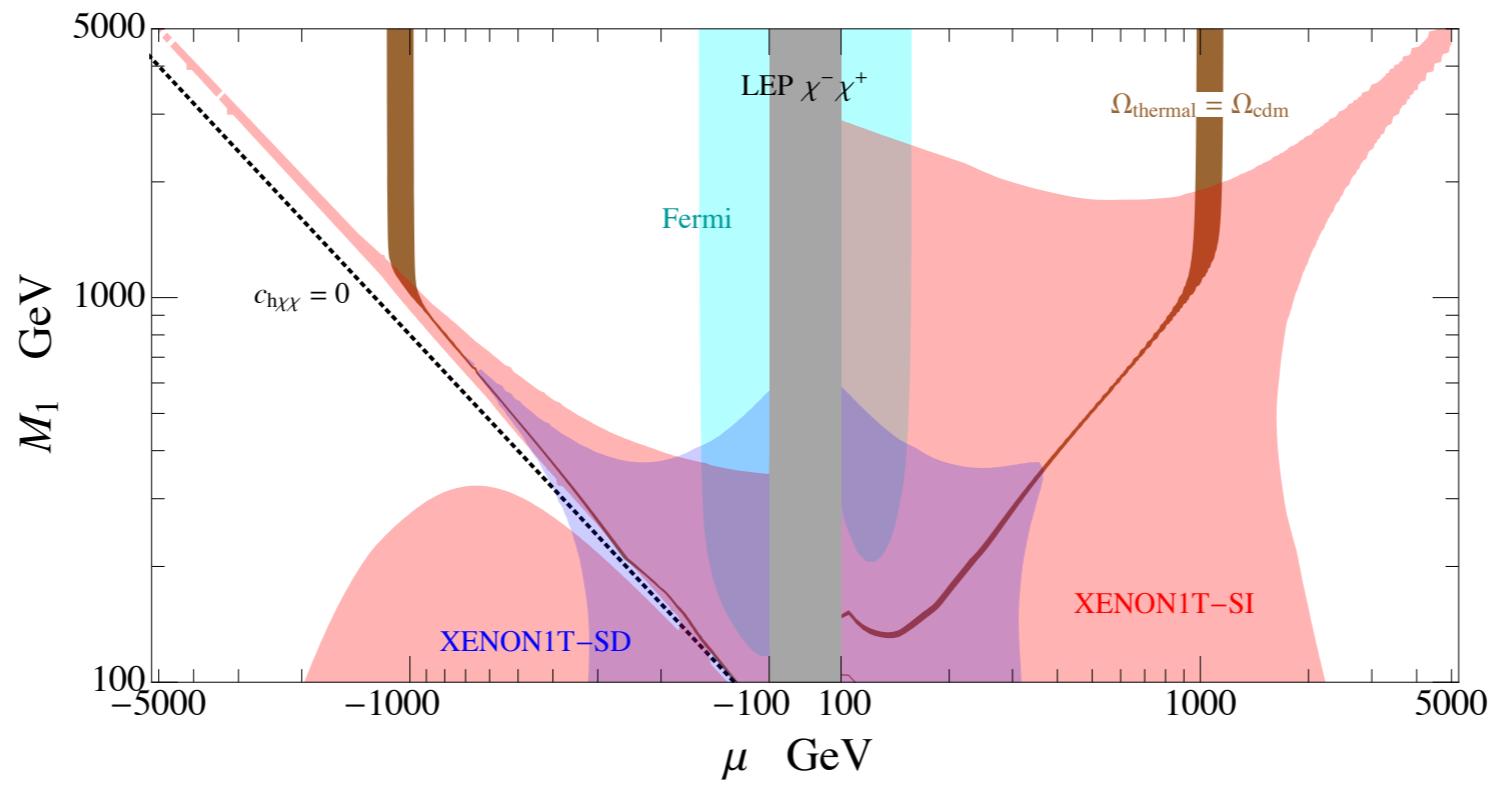


$\tan \beta = 20$

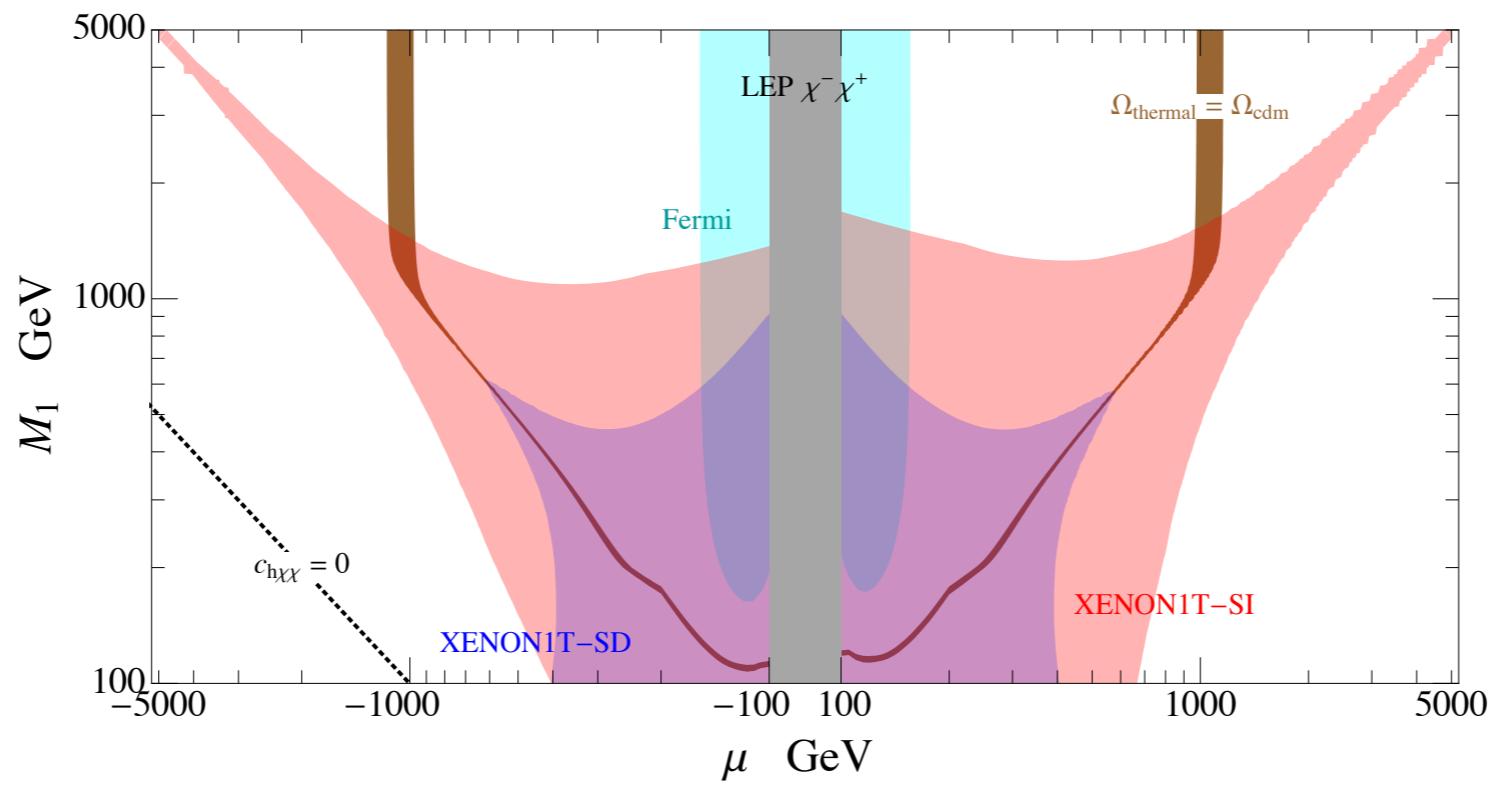


# non-thermal

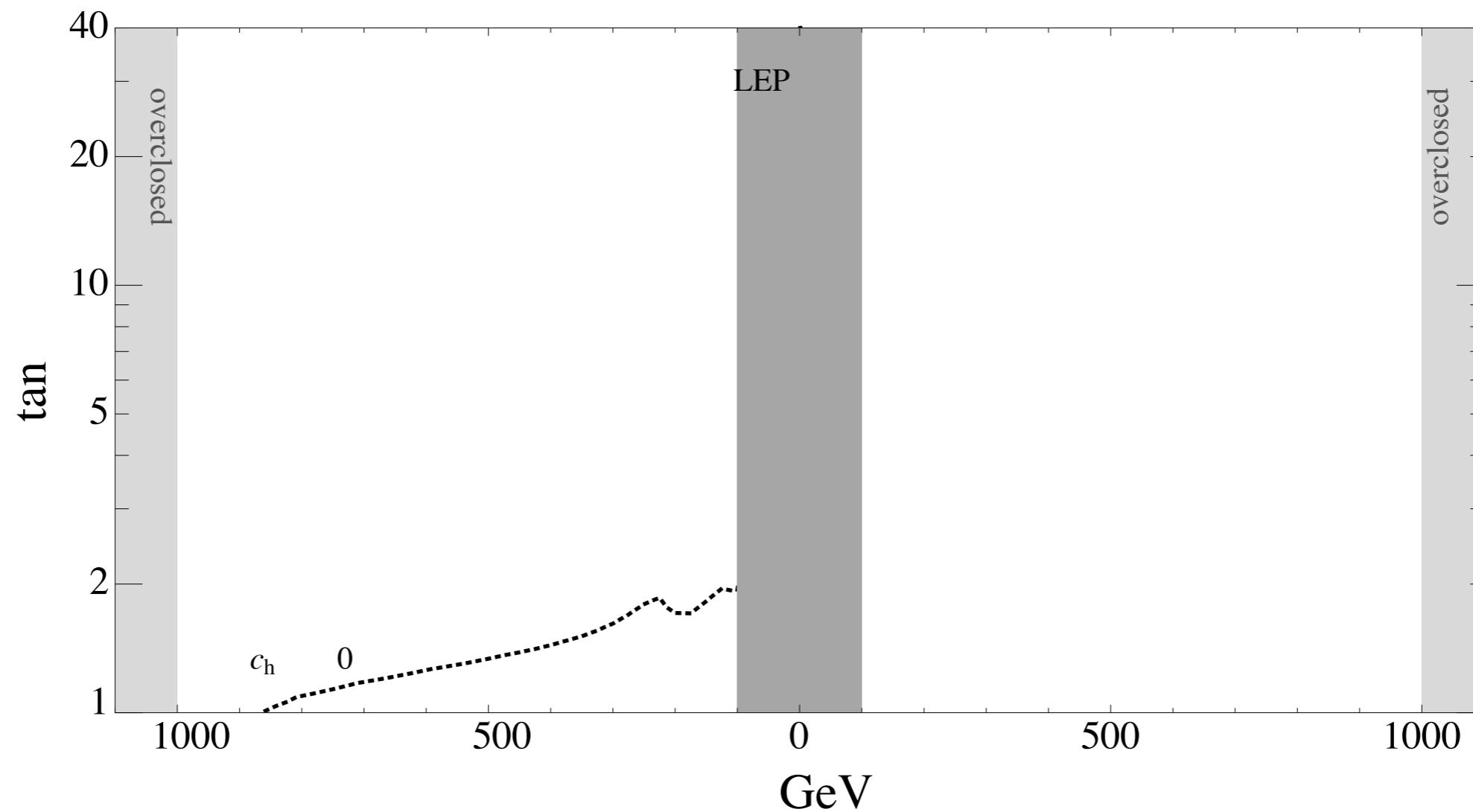
$\tan \beta = 2$



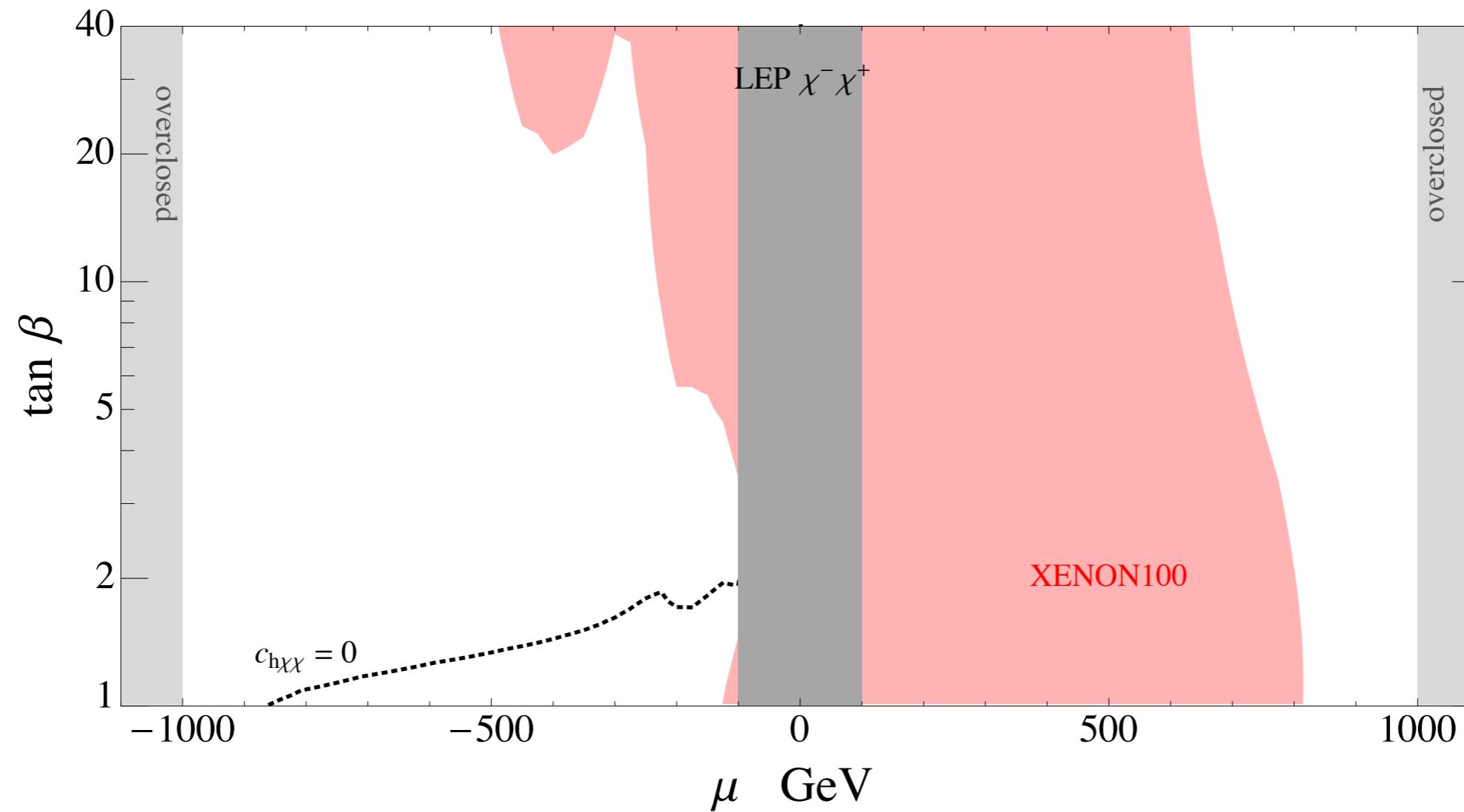
$\tan \beta = 20$



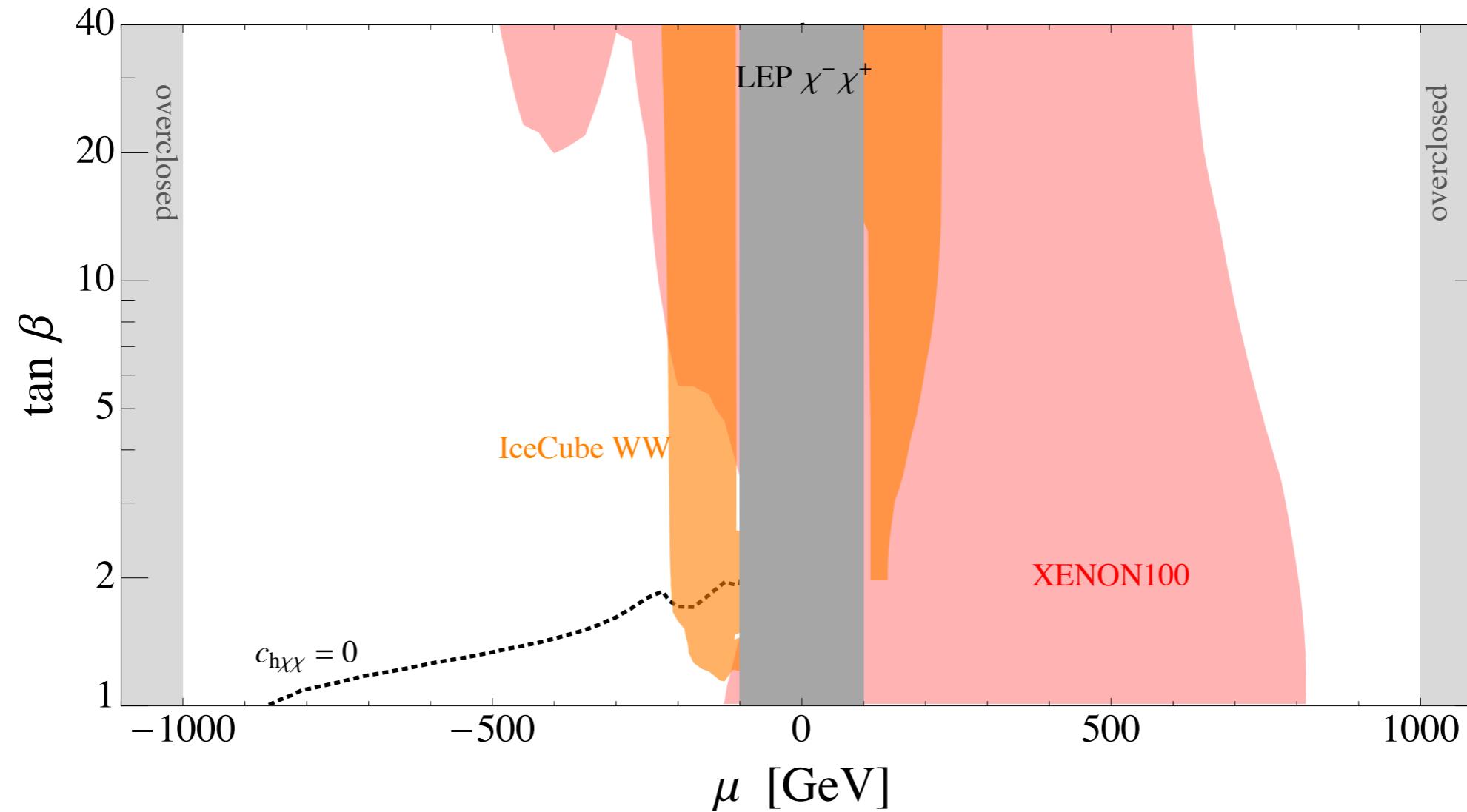
# well-tempered



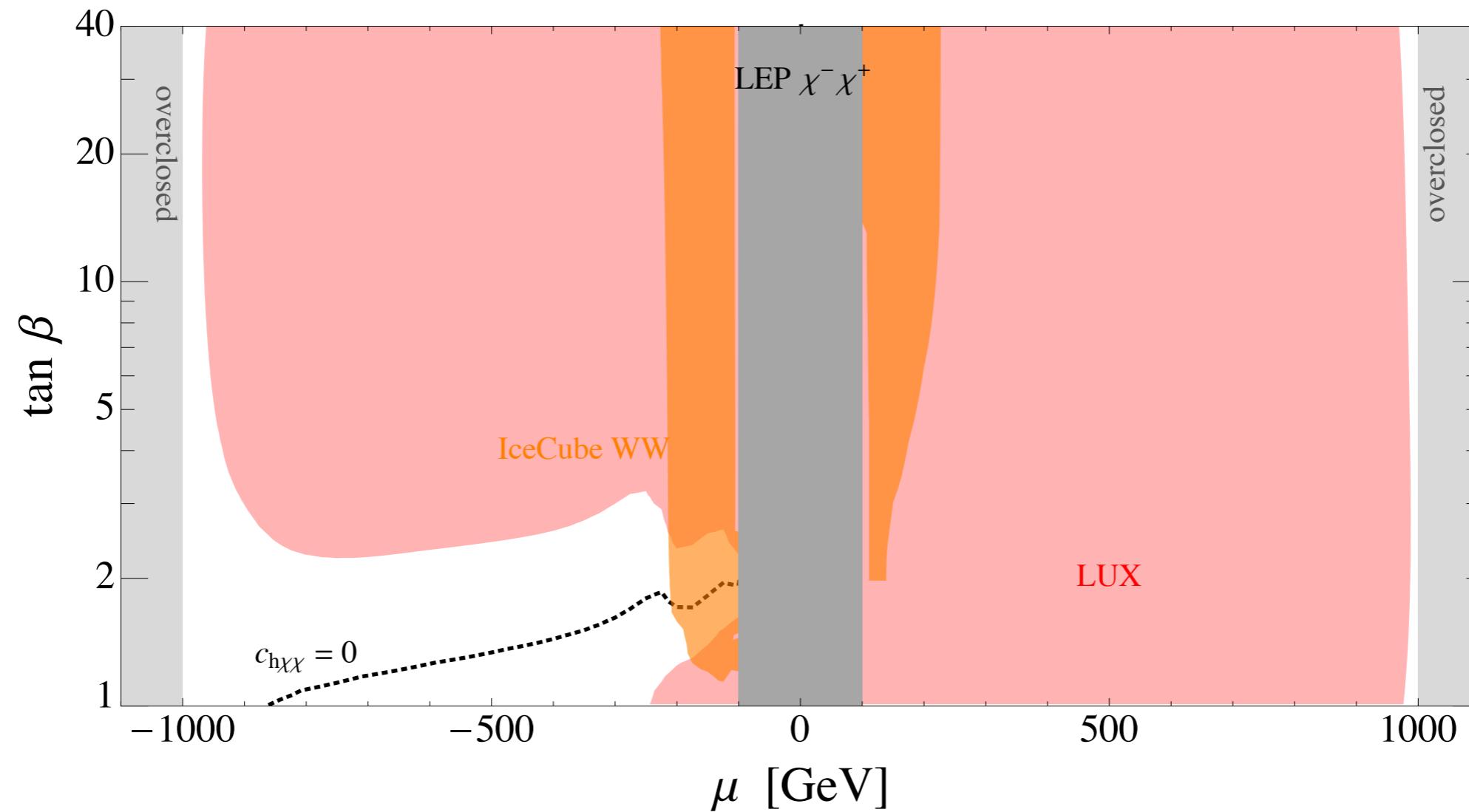
# well-tempered



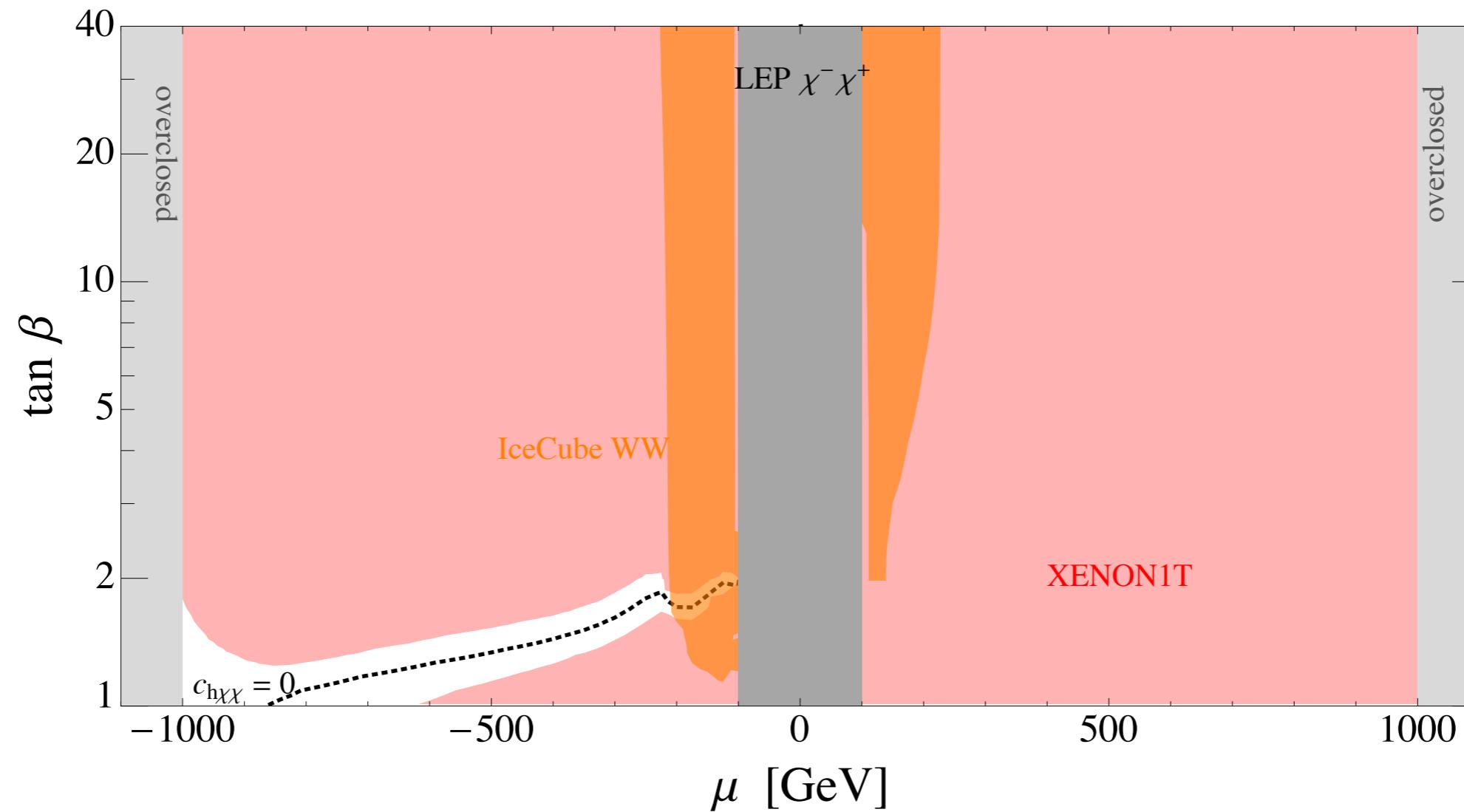
# well-tempered



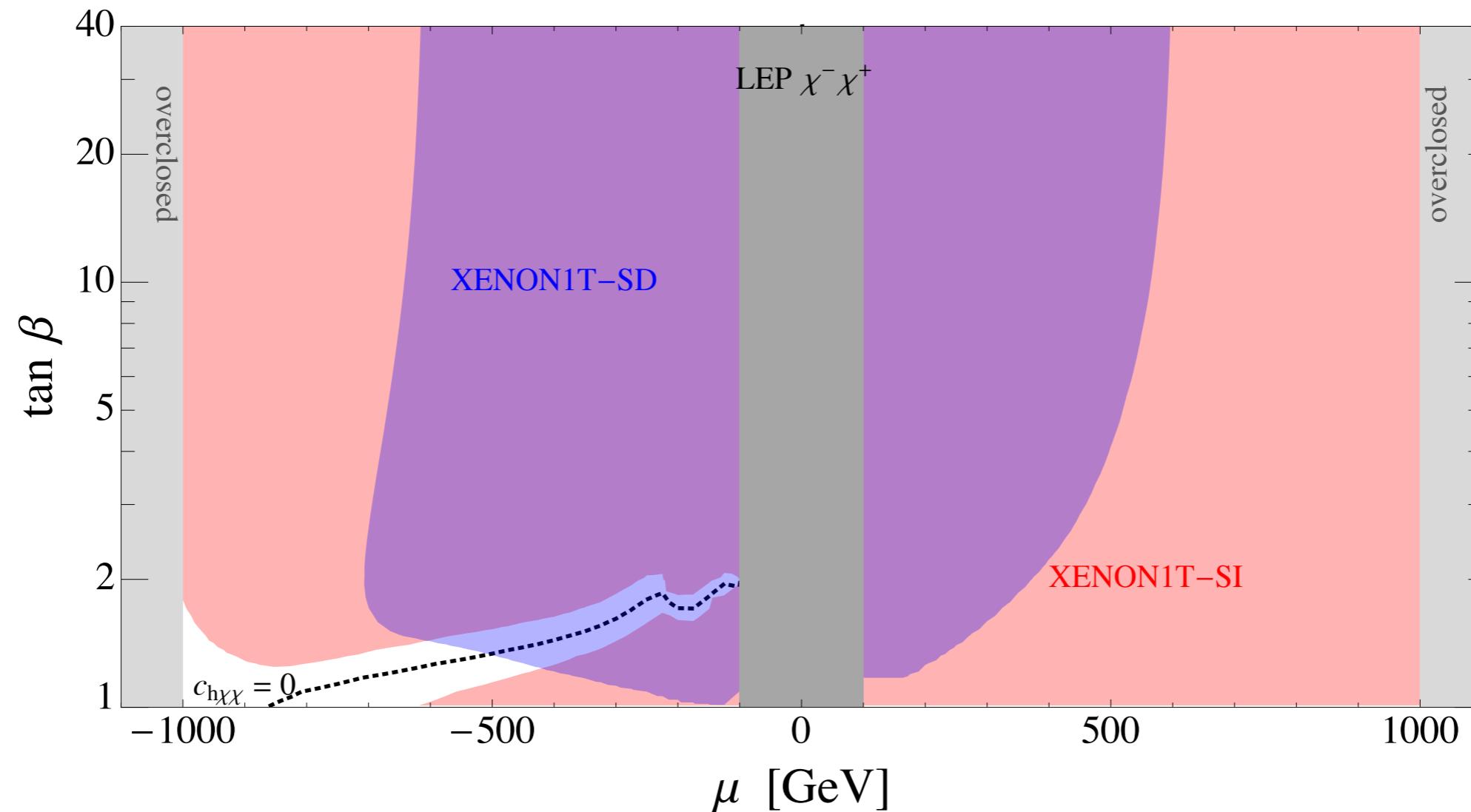
# well-tempered



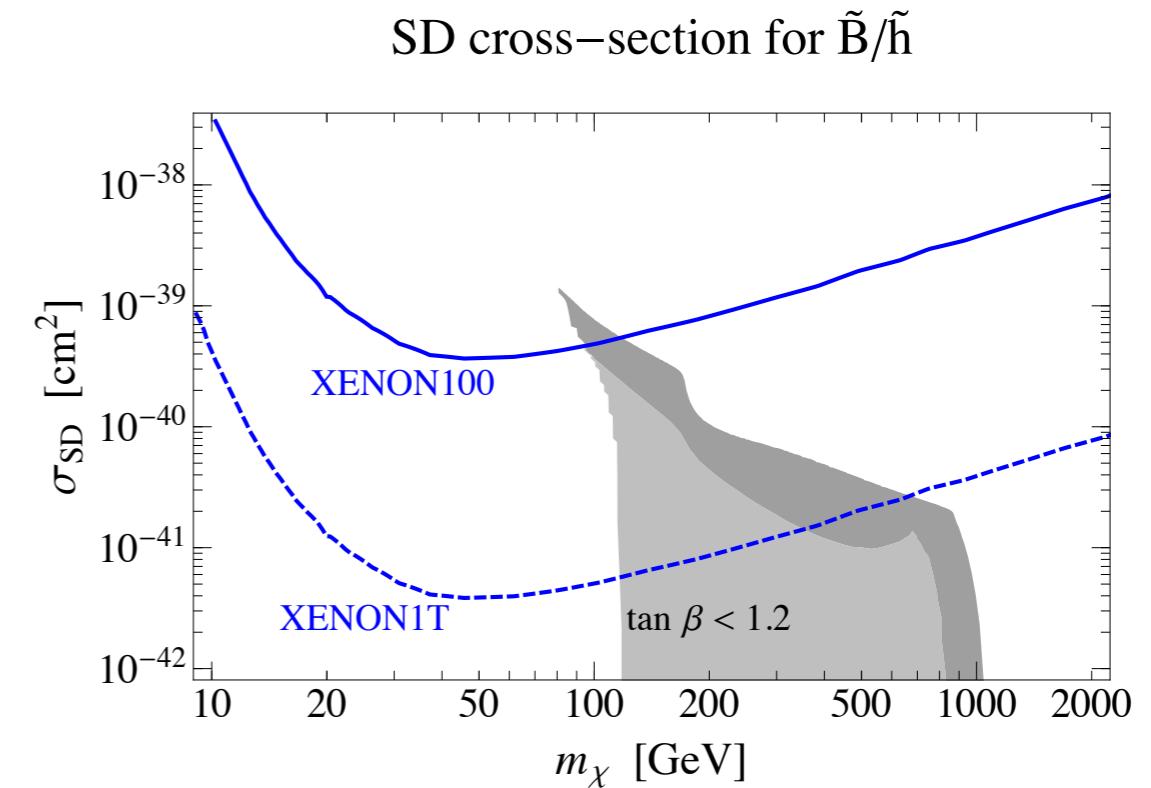
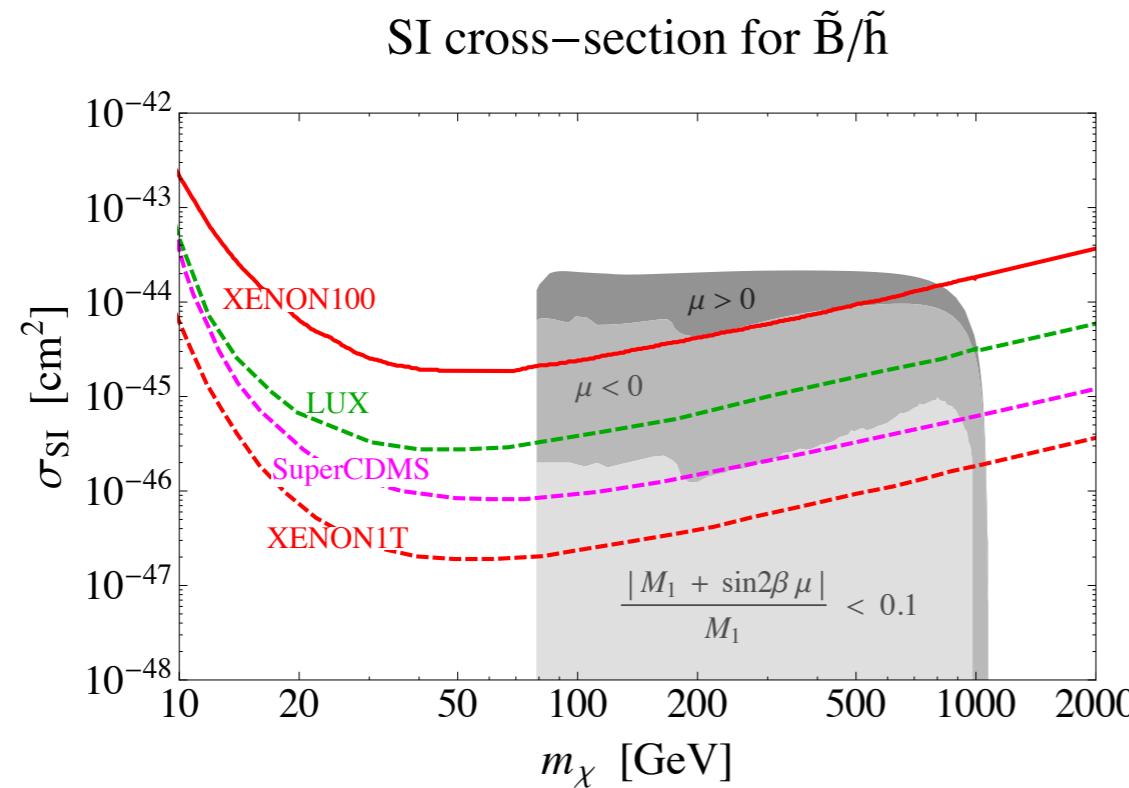
# well-tempered



# well-tempered



# more grey blobs



# conclusions

- direct detection is now probing interesting parts of neutralino DM parameter space
- large allowed region remains
- blindspots may still evade Xe IT
- blindspot tuning can be degenerate with EWSB or relic abundance tuning