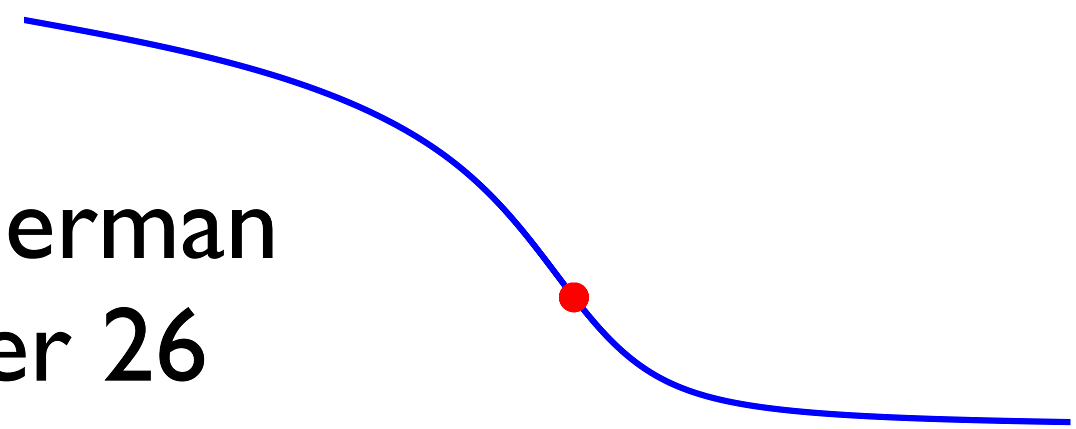
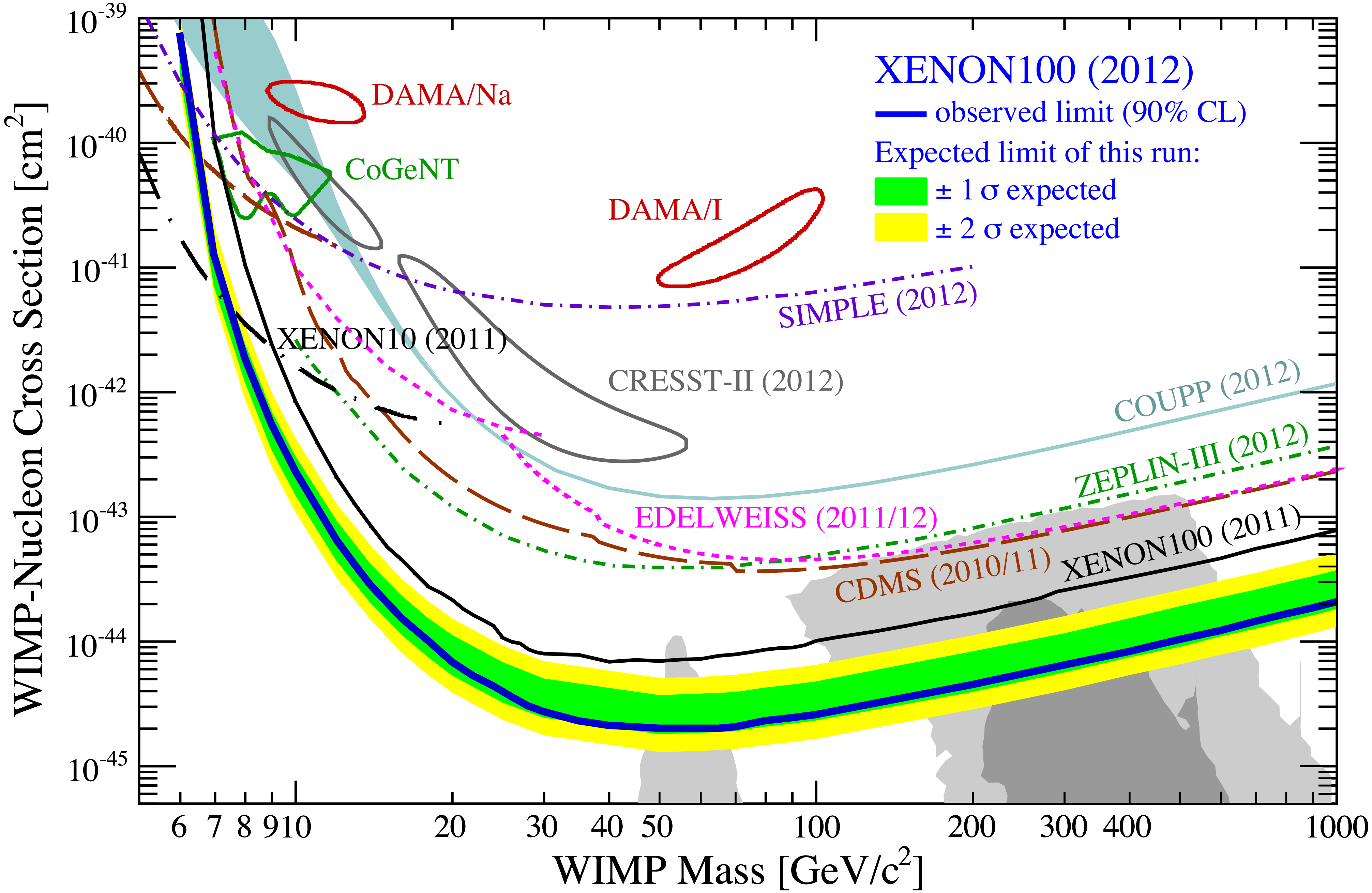
Prospects and Blind Spots for Neutralino Dark Matter

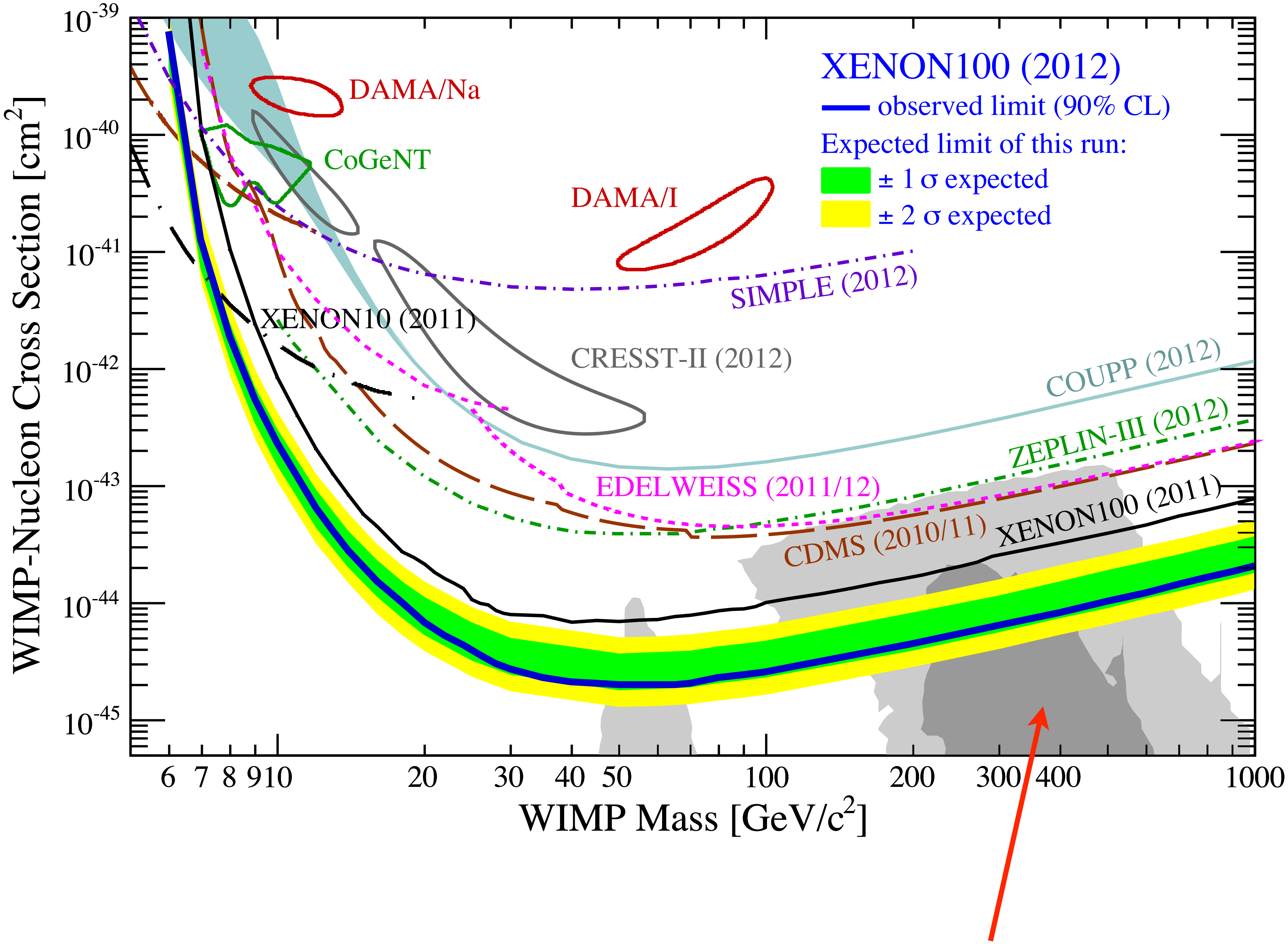
Josh Ruderman
October 26
GGI 2012



Cliff Cheung, Lawrence Hall, David Pinner, JTR
1211.xxxx



XENON100 (2012)
observed limit (90% CL)
Expected limit of this run:
± 1 σ expected
± 2 σ expected
DAMA/Na
CoGeNT
DAMA/I
SIMPLE (2012)
XENON10 (2011)
CRESST-II (2012)
COUPP (2012)
ZEPLIN-III (2012)
EDELWEISS (2011/12)
XENON100 (2011)
CDMS (2010/11)
WIMP-Nucleon Cross Section [cm²]
WIMP Mass [GeV/c²]
10⁻³⁹
10⁻⁴⁰
10⁻⁴¹
10⁻⁴²
10⁻⁴³
10⁻⁴⁴
10⁻⁴⁵
6 7 8 9 10 20 30 40 50 100 200 300 400 1000

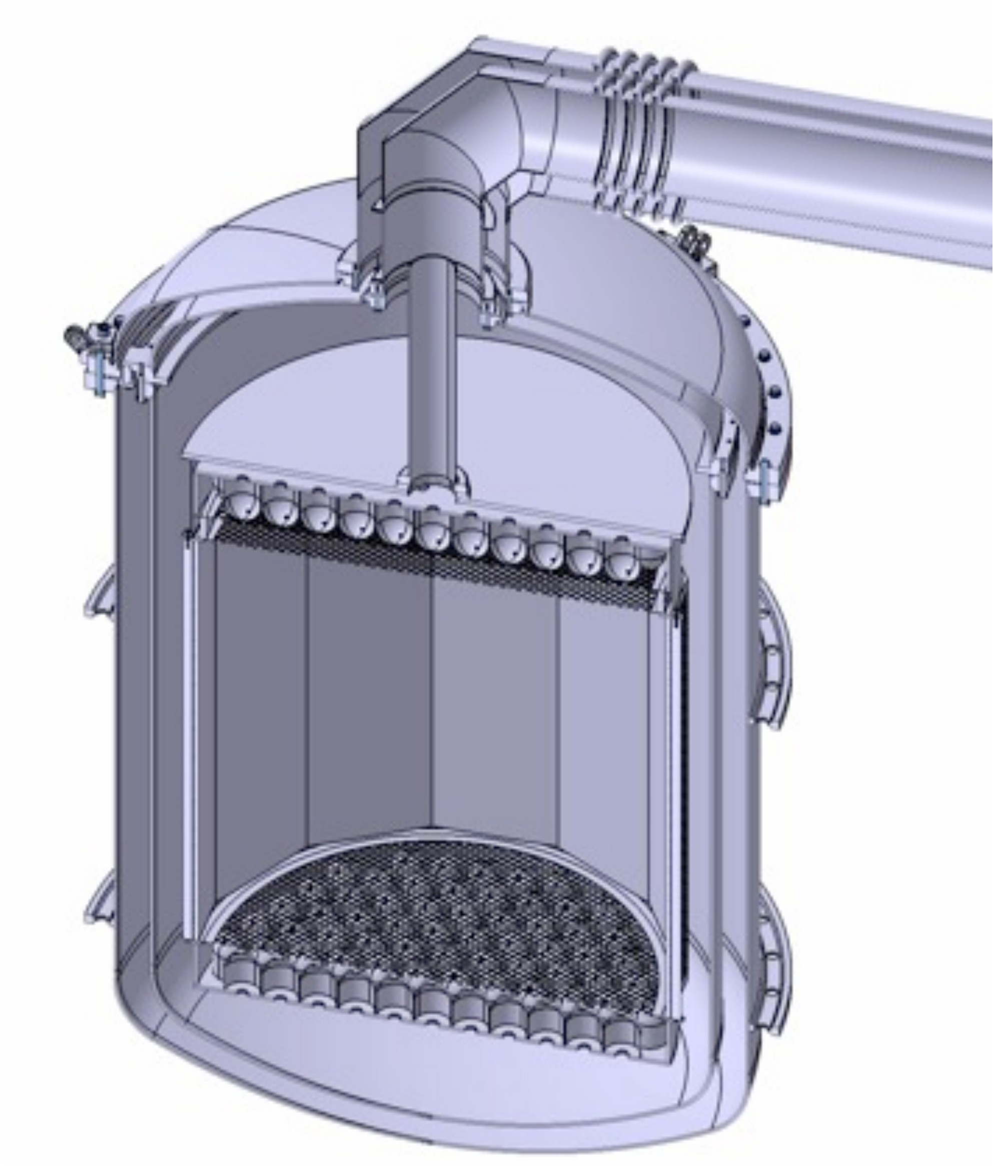


what is status of SUSY DM?

the plan

1. experimental status
2. neutralino DM in SUSY
3. bino-higgsino
4. bino-wino-(higgsino)

experimental status

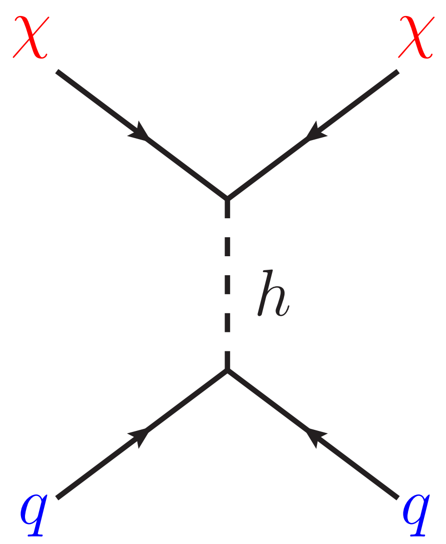


types of scattering:

1. spin independent: $\bar{\chi}\chi\bar{N}N$

$y\,\bar{\chi}\chi h$

$$\sigma_{SI} \approx 8 \times 10^{-45}\,\mathrm{cm}^2 \left(\frac{y}{0.1}\right)^2$$



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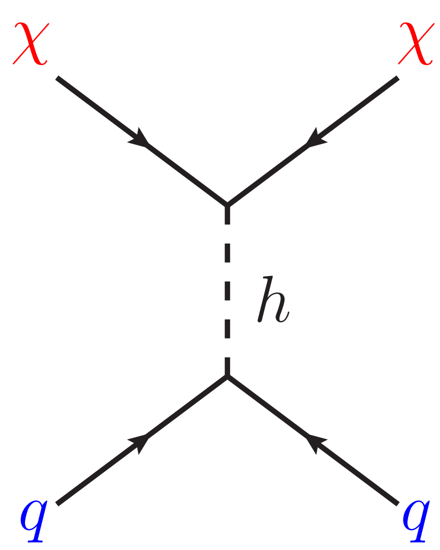
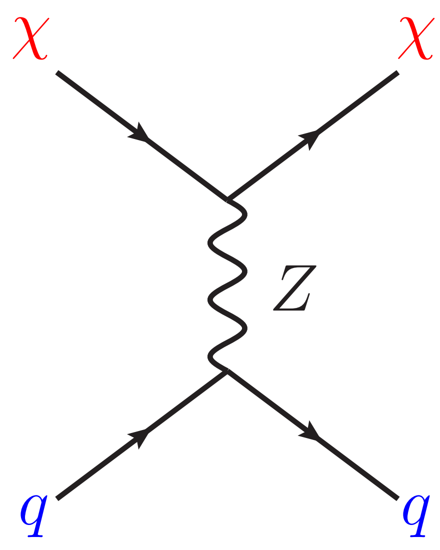


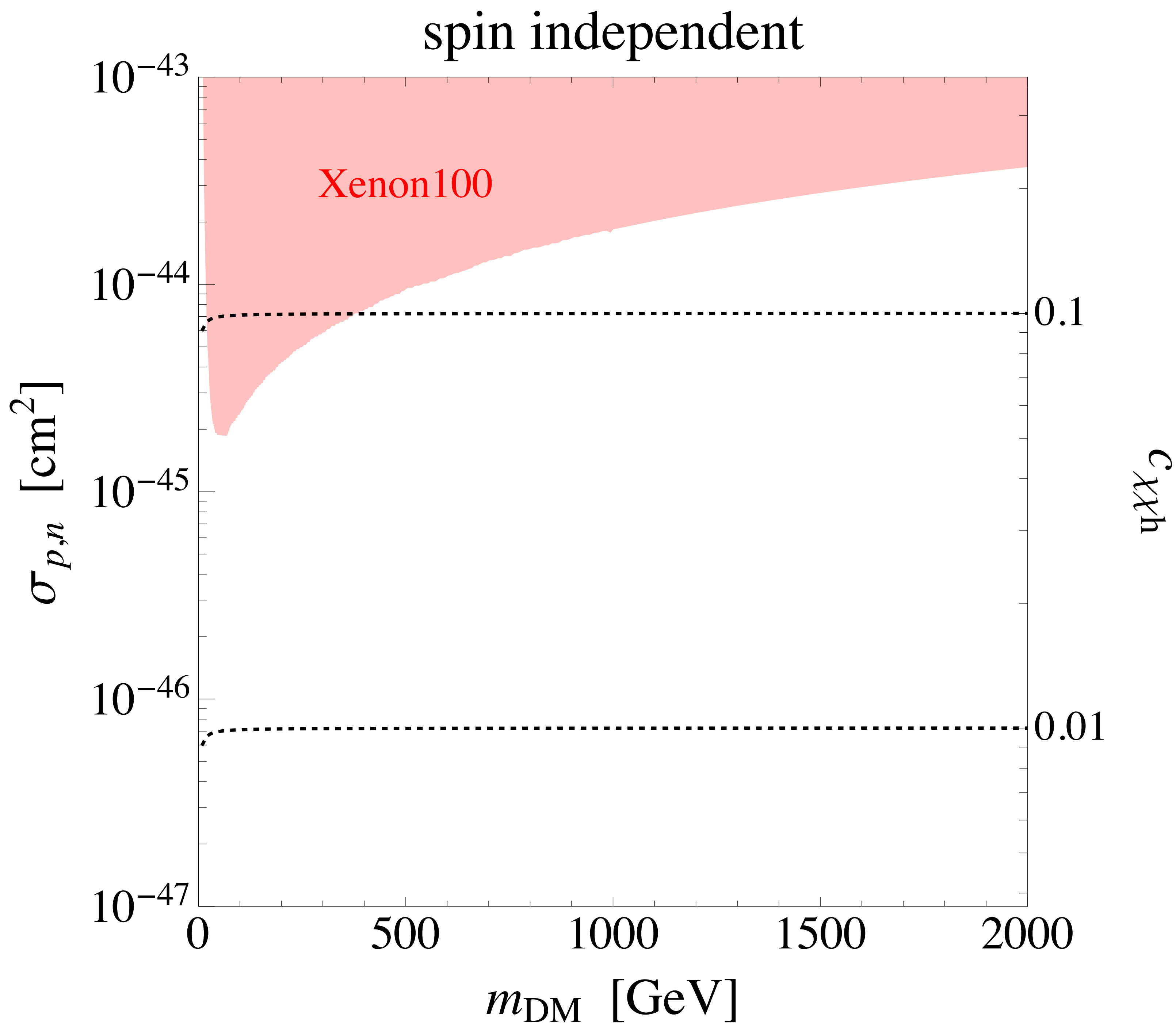
2. spin-dependent: $\bar{\chi}\gamma^\mu\gamma^5\chi\ \bar{N}\gamma_\mu\gamma^5 N$

$c\,\bar{\chi}\gamma^\mu\gamma^5\chi\, Z_\mu$

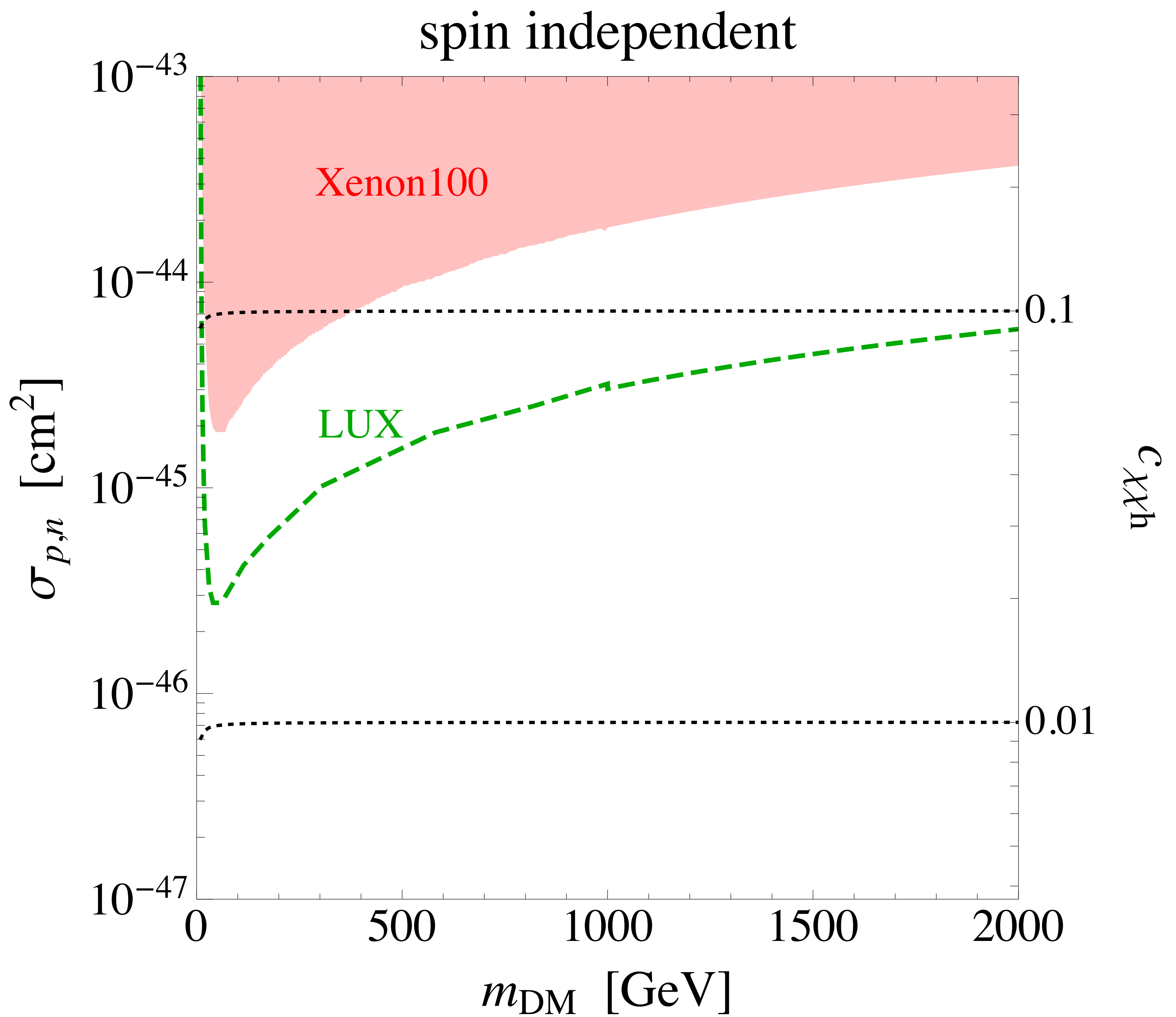
$$\sigma_{SD} \approx 3 \times 10^{-39}\,\mathrm{cm}^2 \left(\frac{c}{0.1}\right)^2$$



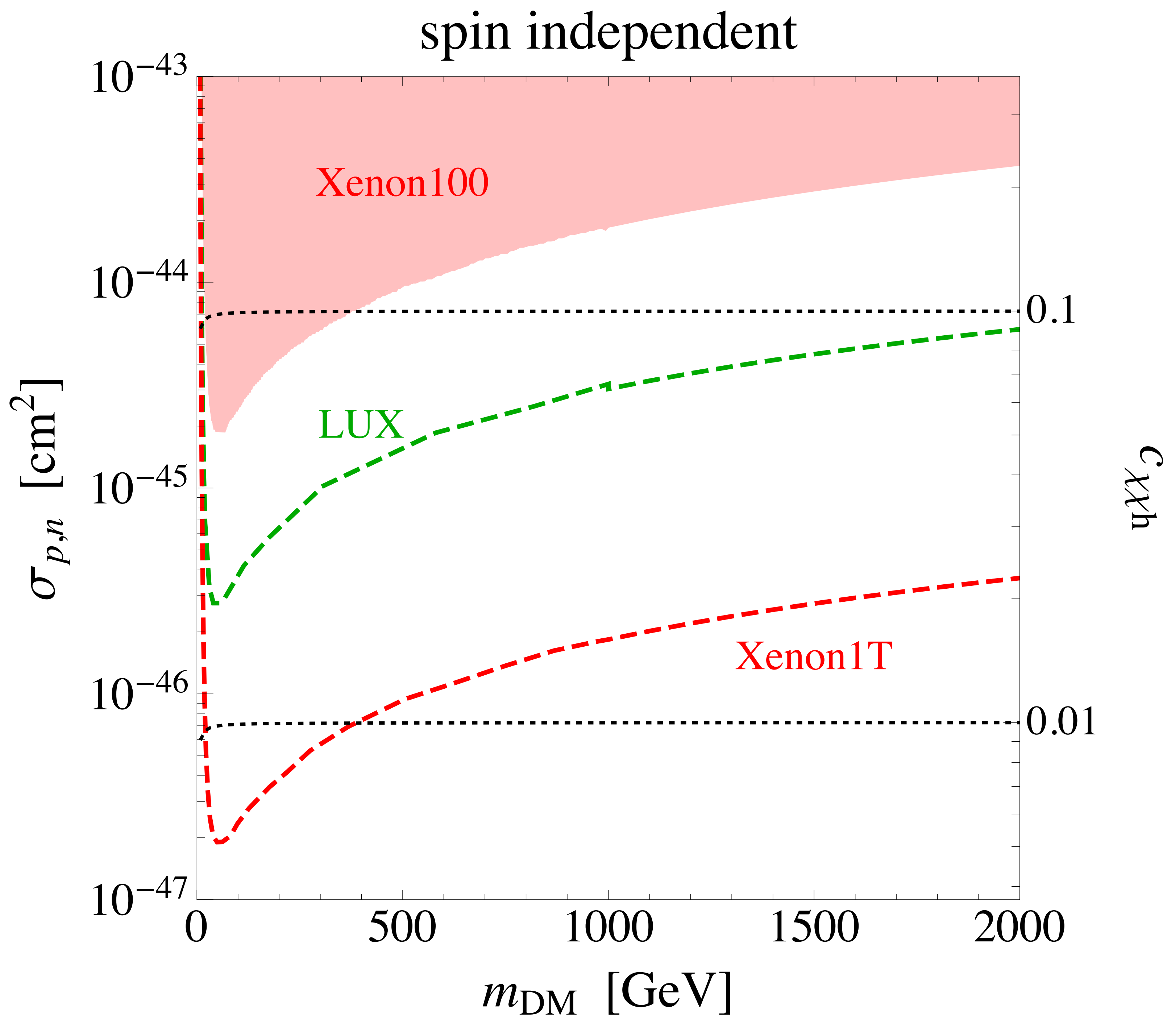
spin independent status



spin independent status



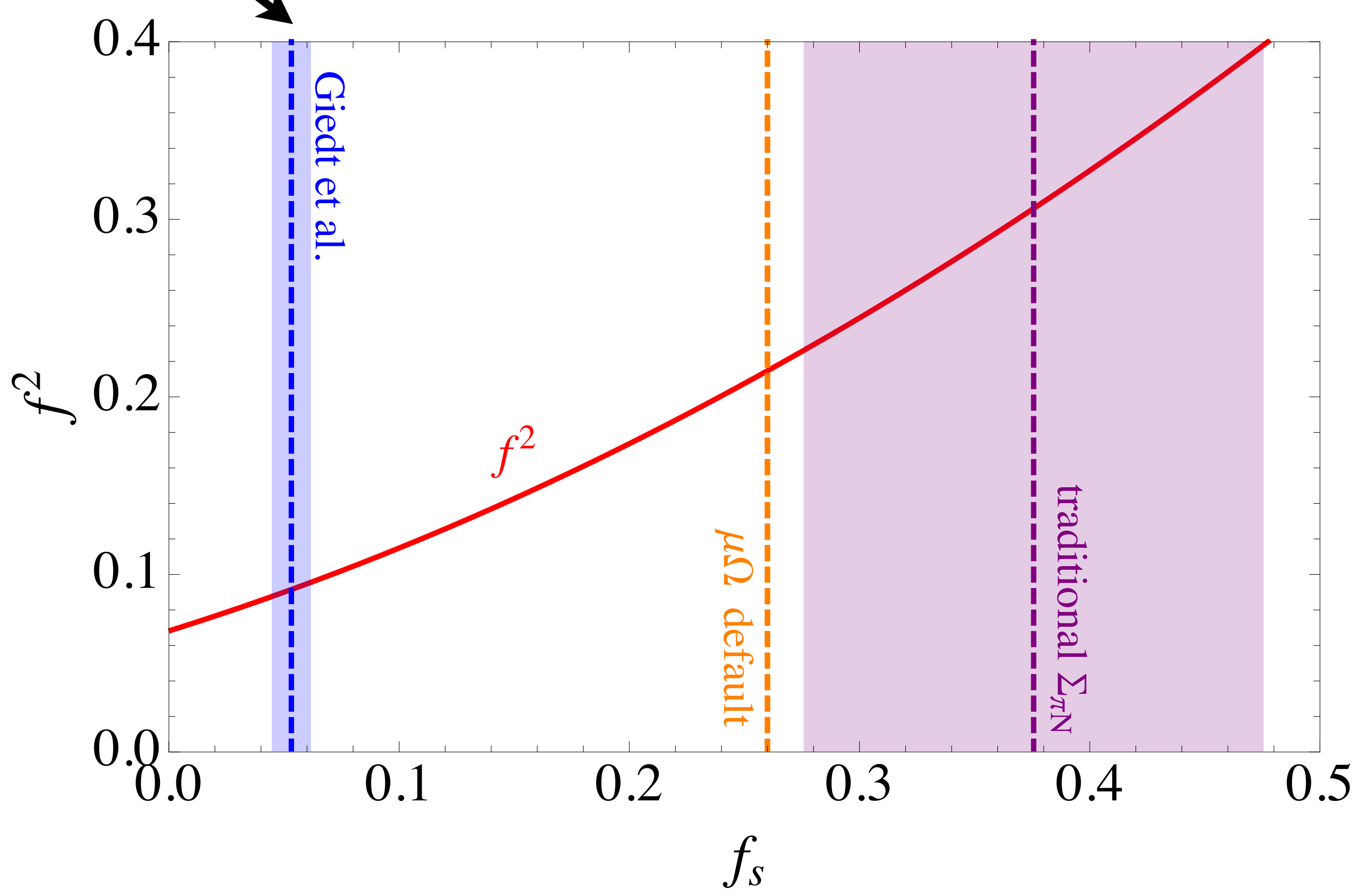
spin independent status



what about the strange quark?

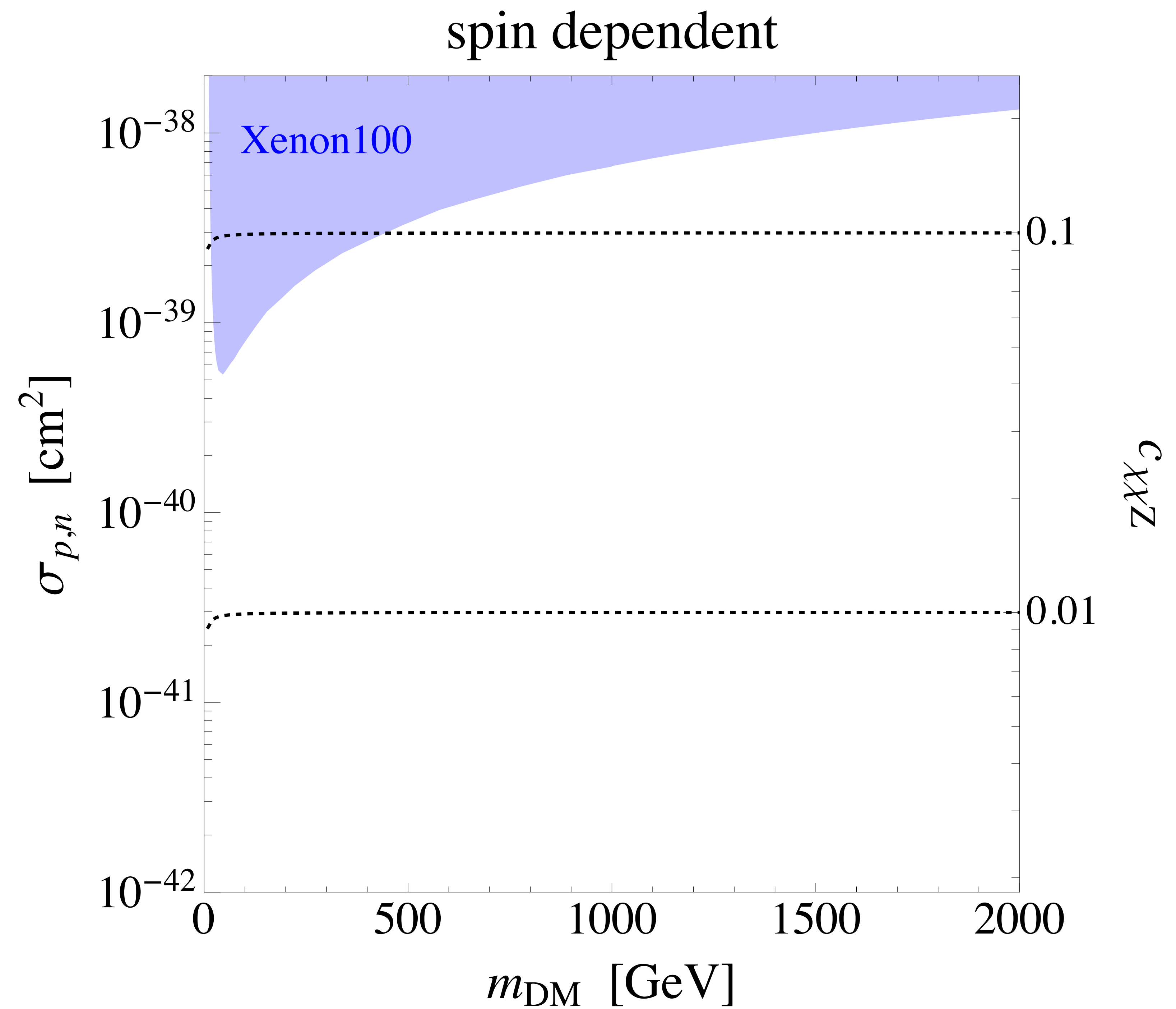
$$f_q = \frac{m_q}{m_N} \langle N|\, q\bar{q}\, |N\rangle \qquad \sigma \propto f^2 \qquad f = \Sigma_q f_q$$

lattice

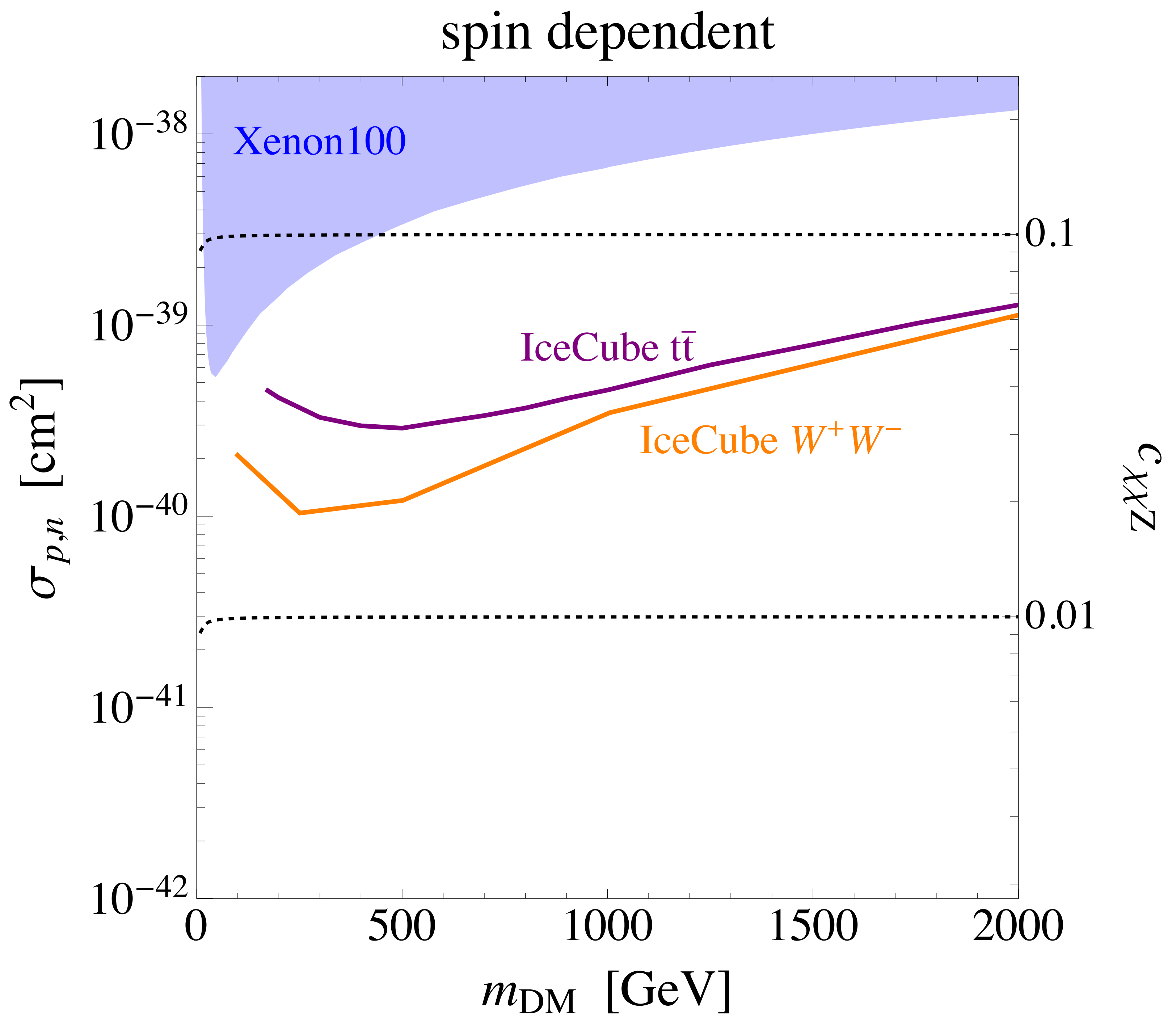


- Giedt, Thomas, Young 0907.4177

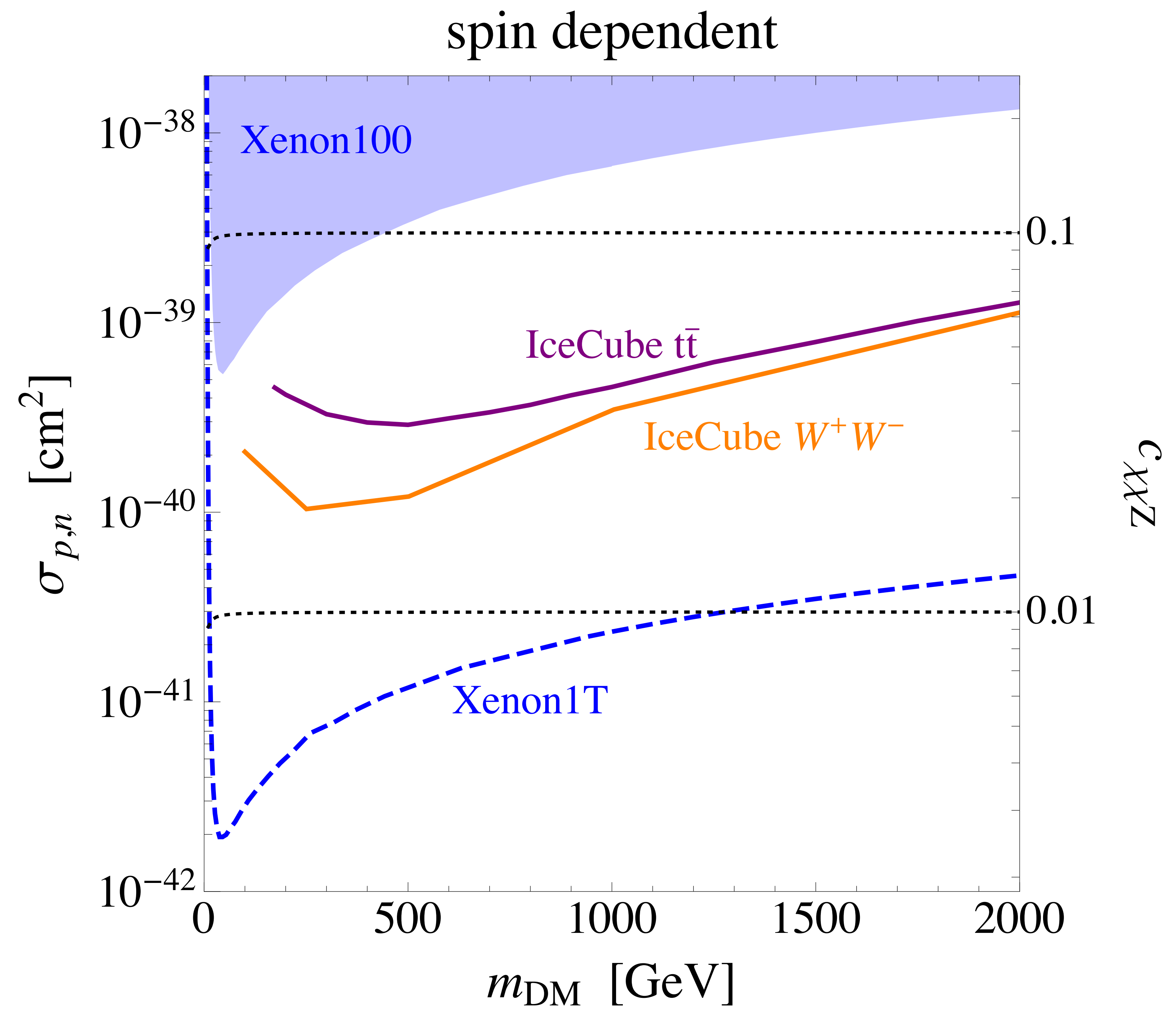
spin dependent status



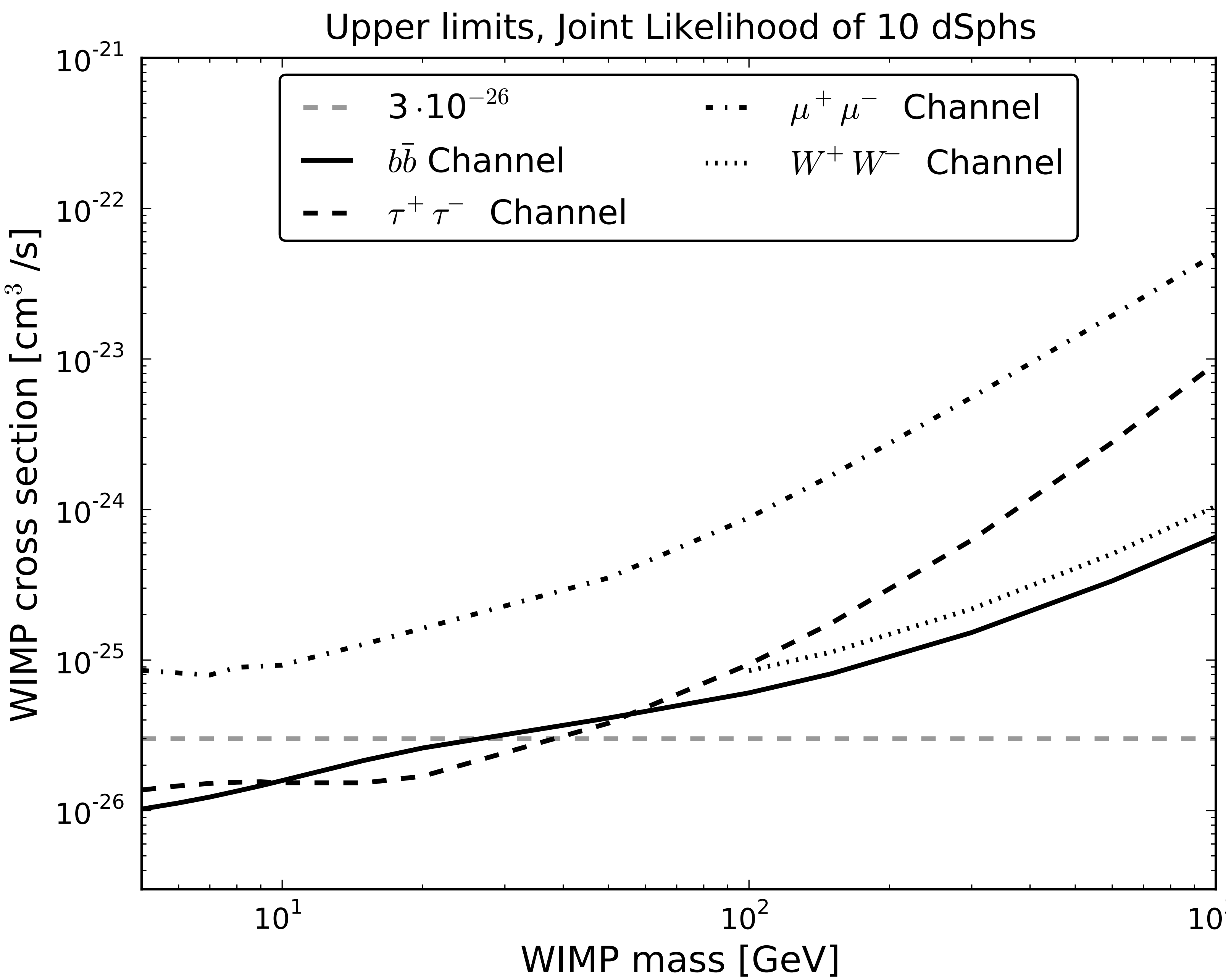
spin dependent status



spin dependent status

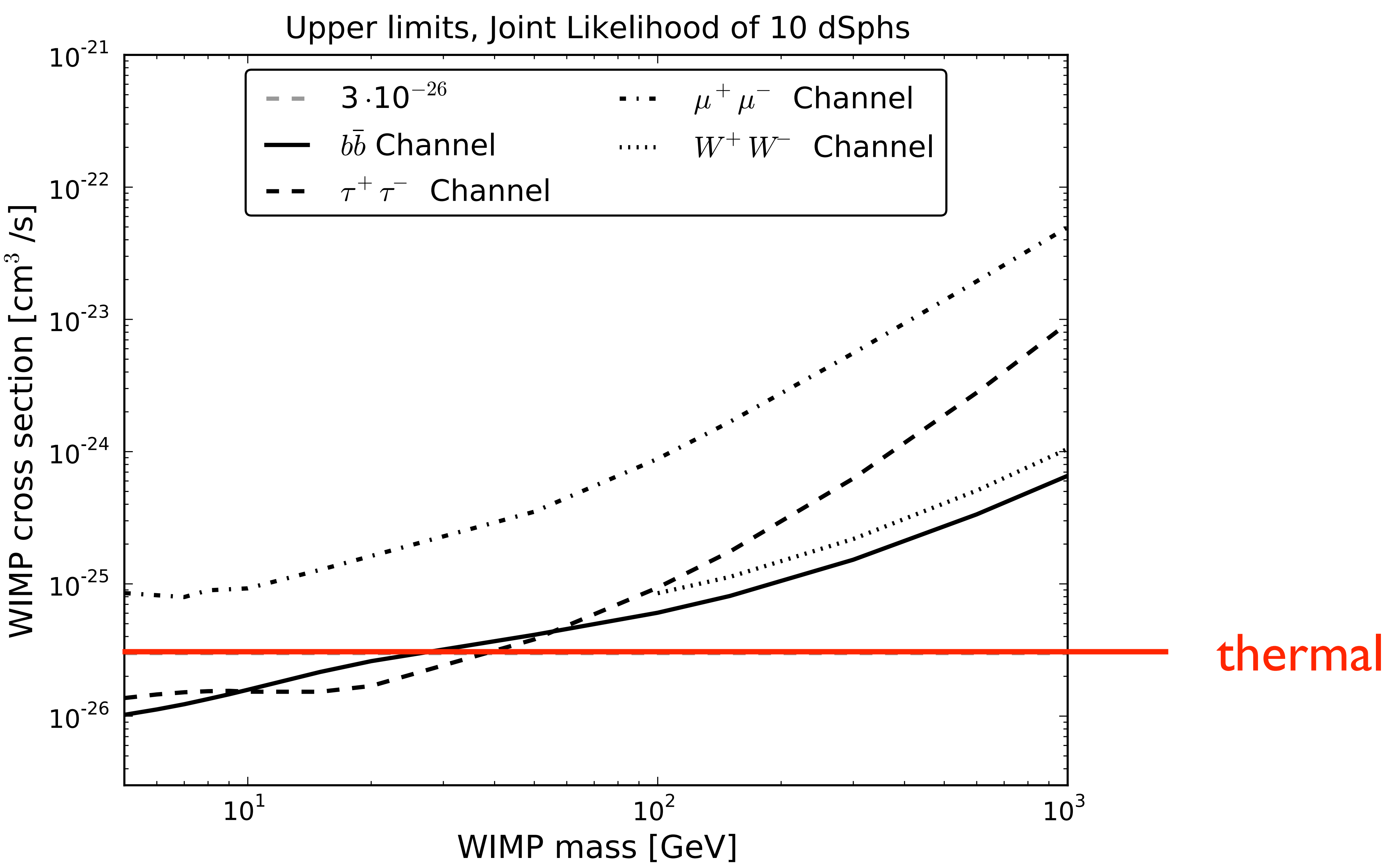


indirect



Upper limits, Joint Likelihood of 10 dSphs
$3 \cdot 10^{-26}$
$b\bar{b}$ Channel
$\tau^+\tau^-$ Channel
$\mu^+\mu^-$ Channel
W^+W^- Channel
WIMP cross section [cm^3 /s]
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{1}
10^{2}
10^{3}
WIMP mass [GeV]

indirect



Upper limits, Joint Likelihood of 10 dSphs
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$b\bar{b}$ Channel
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WIMP cross section [cm^3 /s]
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{1}
10^{2}
10^{3}
WIMP mass [GeV]
thermal

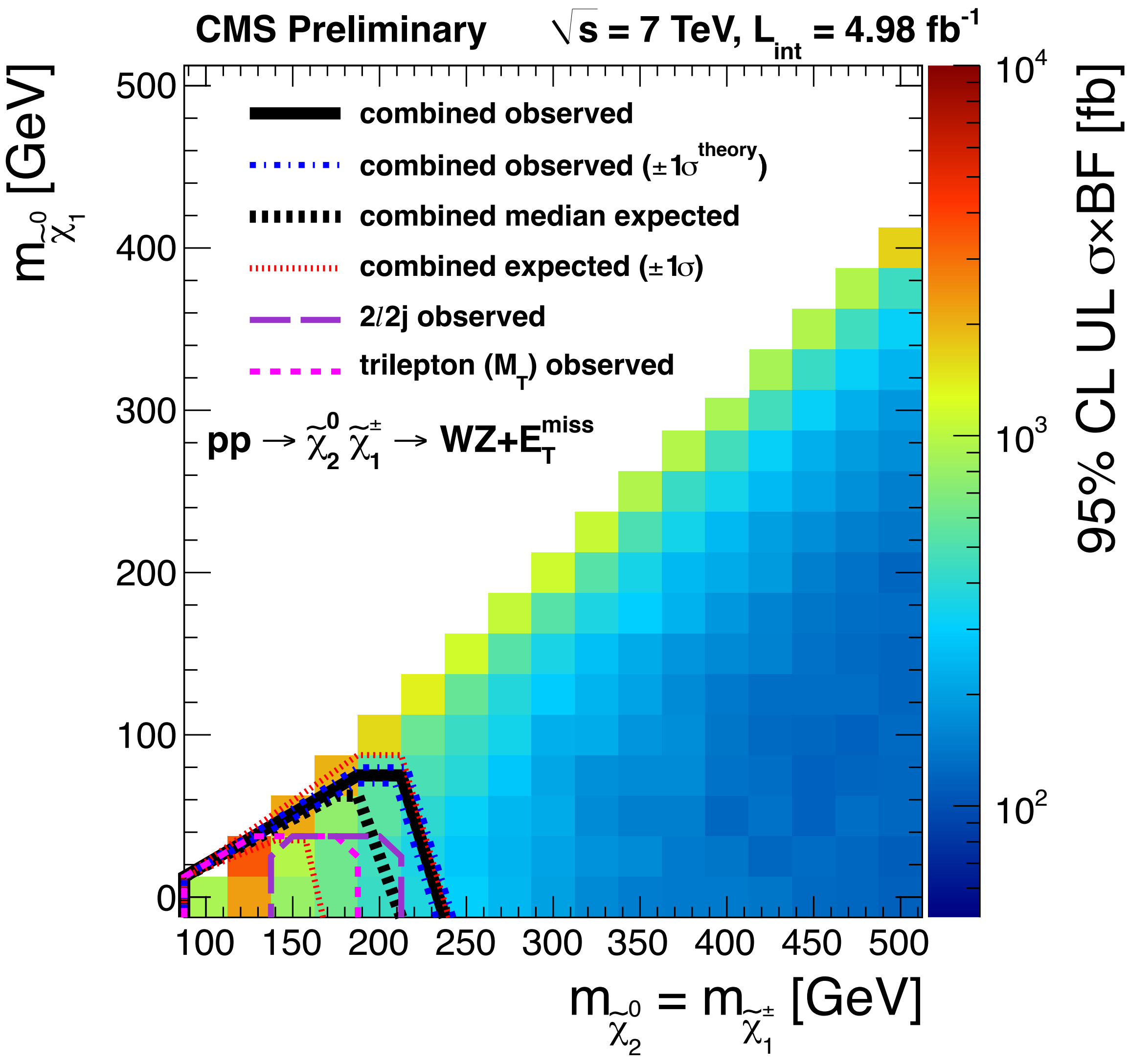
collider

LEP:

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

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

LHC:



neutralino DM in SUSY

fermionic dark matter

- $SM + \tilde{B}, \tilde{W}, \tilde{H}$

- assume scalar superpartners can be decoupled when computing: $\sigma_{\chi N}, \Omega$

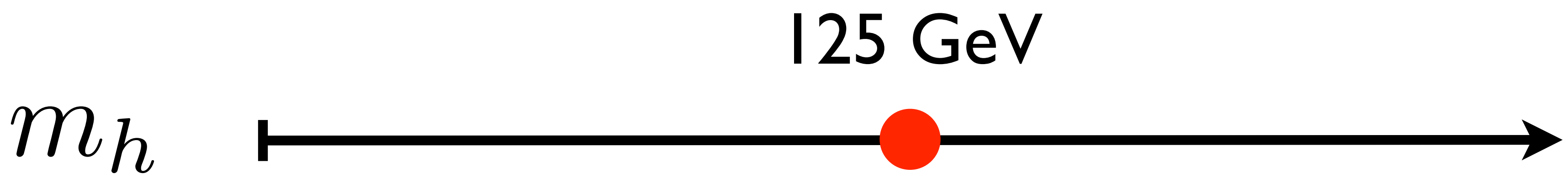
- assume CP

- parameters:

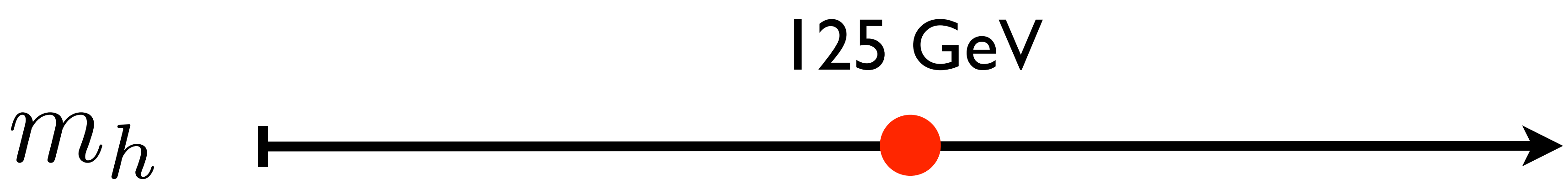
$$M_1, M_2, \mu, \tan\beta$$

is the weak scale natural?

is the weak scale natural?

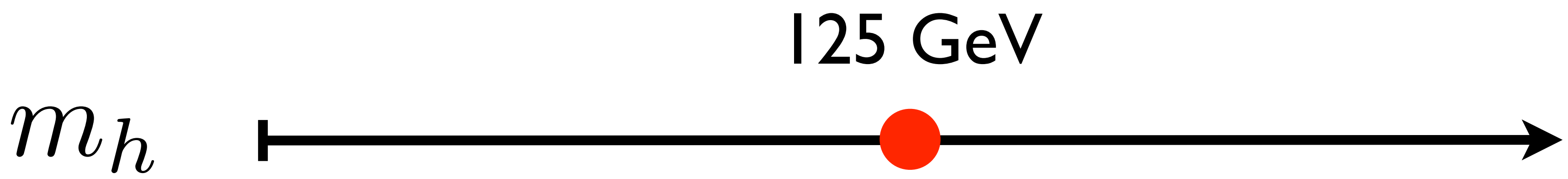


is the weak scale natural?



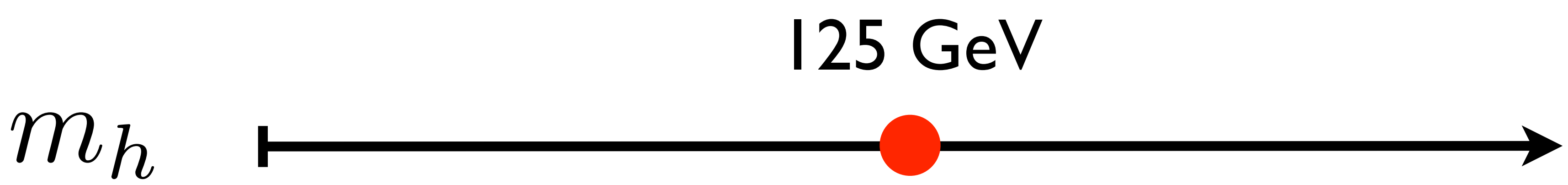
natural | unnatural

is the weak scale natural?



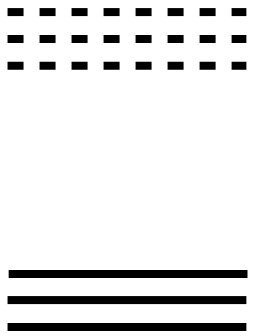
natural	unnatural
$\lambda S H_u H_d$	

is the weak scale natural?

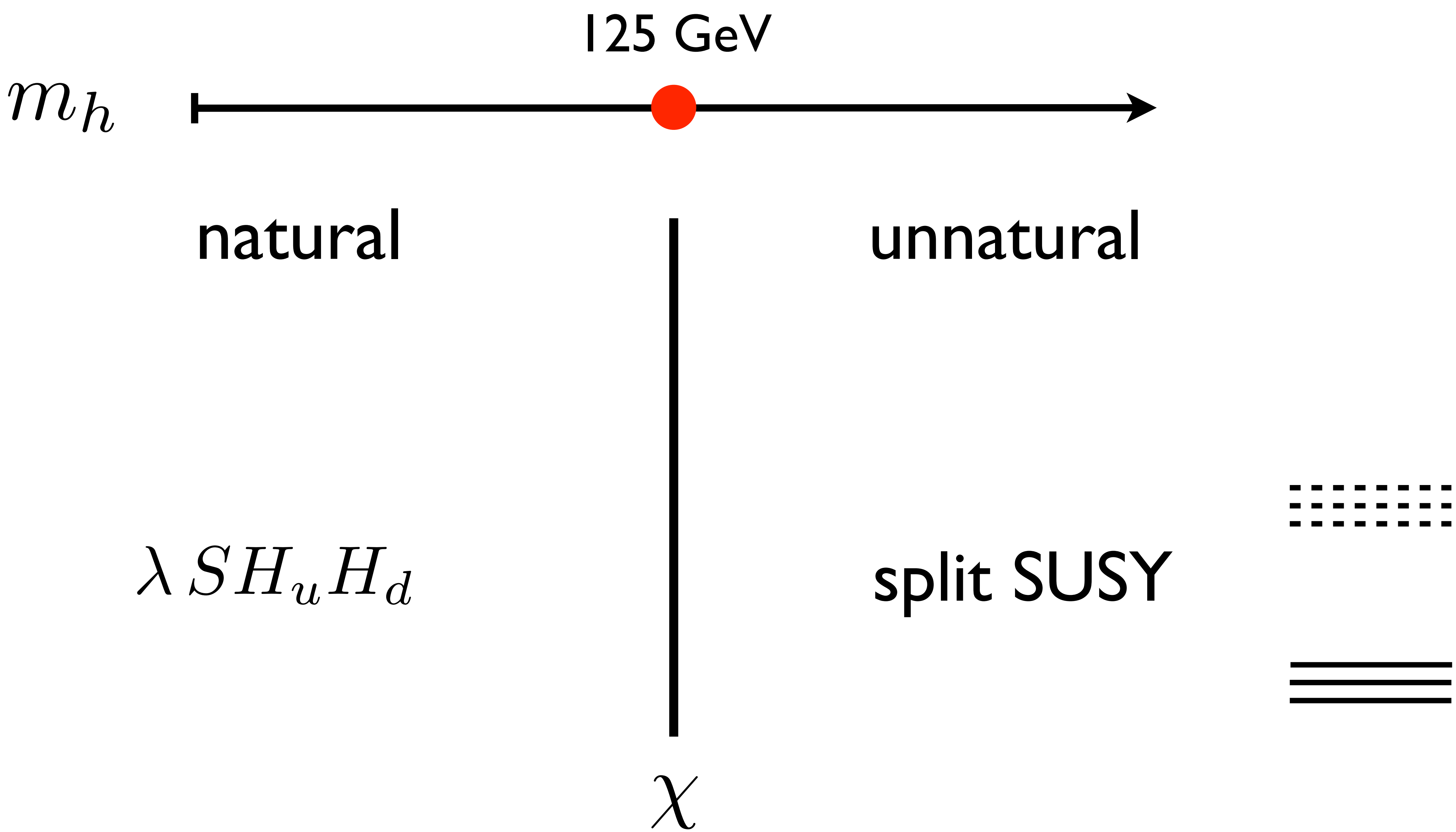


natural | unnatural

$\lambda S H_u H_d$ | split SUSY



is the weak scale natural?



neutralino DM interesting for both!

fermionic DM in unnatural SUSY

- the LSP is at the weak scale to avoid overclosure

$$\Omega \sim \frac{1}{\sigma} \sim m_{\tilde{N}}^2$$

- the DM mass is crucial for LHC observability

$$m_{\tilde{g}} > m_{\chi}$$

fermionic DM in natural SUSY

- fermionic DM is a simplified limit of natural SUSY

$$\left(\frac{m_Z}{\tilde{m}}\right)^4$$

- we assume any physics that raises the Higgs mass does not modify DM properties

$$\theta_{\tilde{N}_1 \tilde{S}} \ll 1$$

- DM mass is important for naturalness:

$$\mu \gtrsim m_\chi \qquad \longrightarrow \qquad \Delta \gtrsim \frac{2m_\chi^2}{m_h^2}$$

Ω

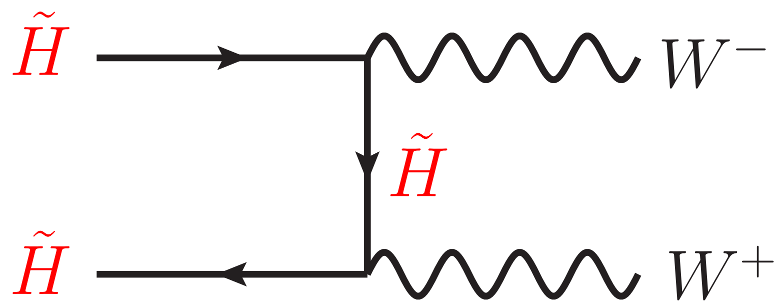
in this talk I'll consider two cases:

1. non-thermal $\Omega_{freezeout} \neq \Omega_{dm}$

2. thermal $\Omega_{freezeout} = \Omega_{dm}$

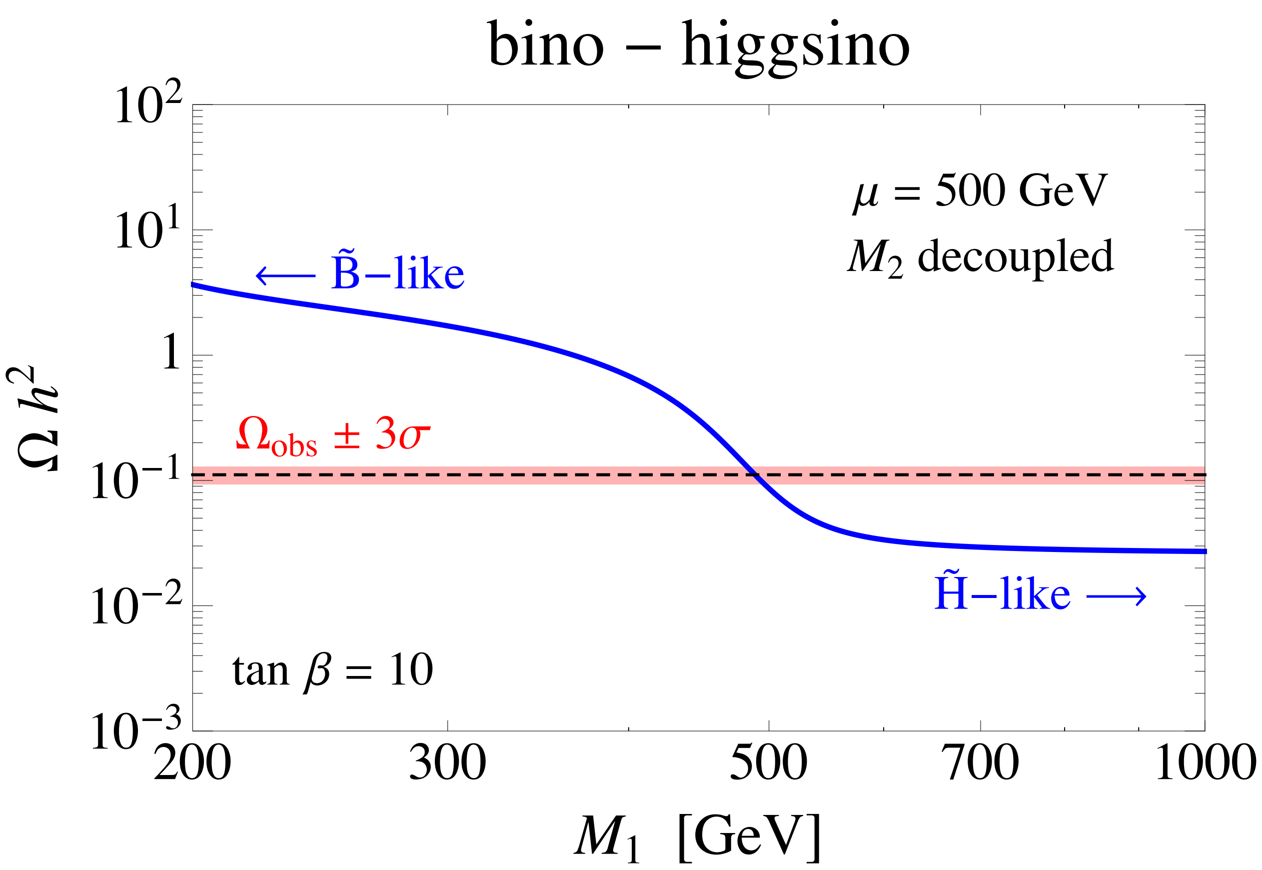
pure eigenstate DM

- bino — overcloses
- higgsino — $m_{\tilde{H}} \approx 1 \text{ TeV}$



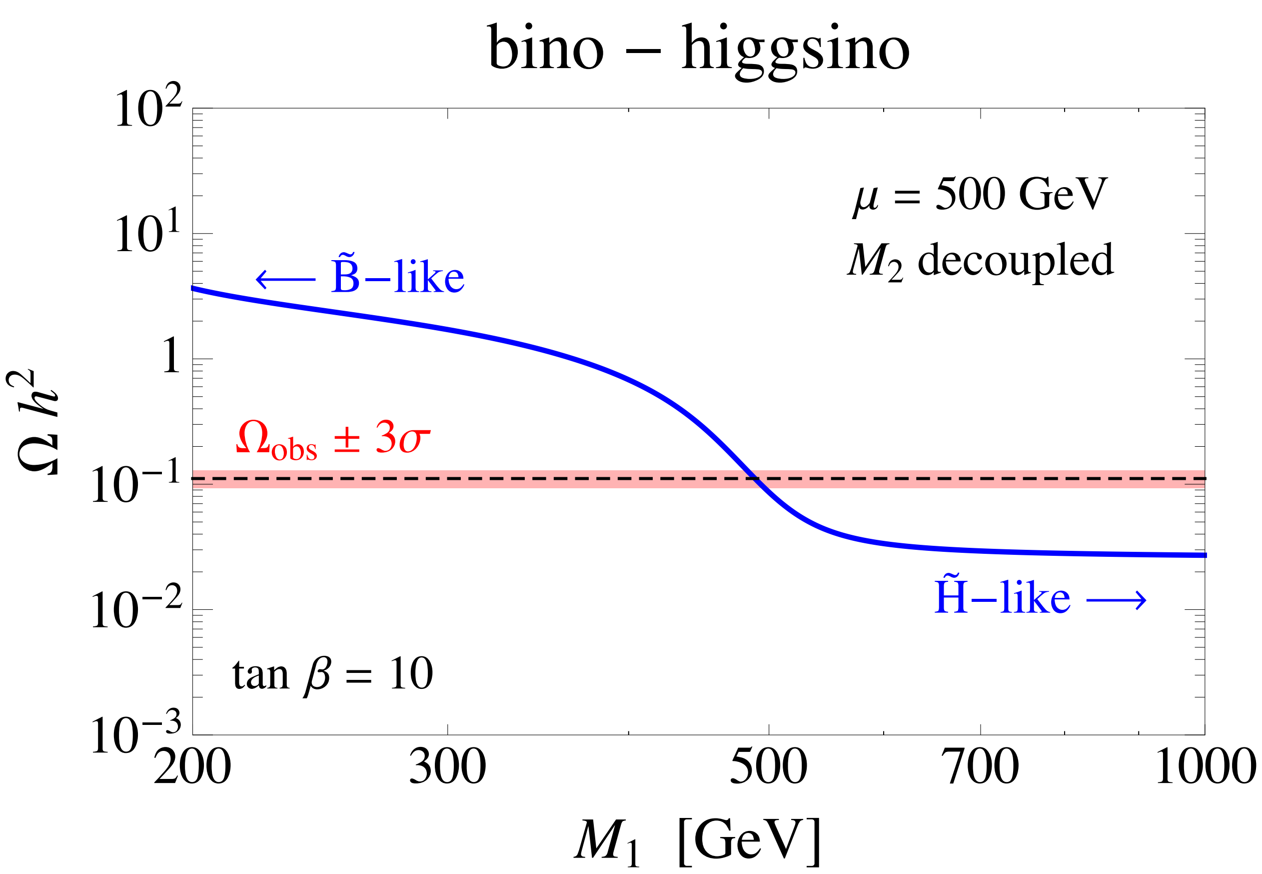
- wino — $m_{\tilde{W}} \approx 2.7 \text{ TeV}$

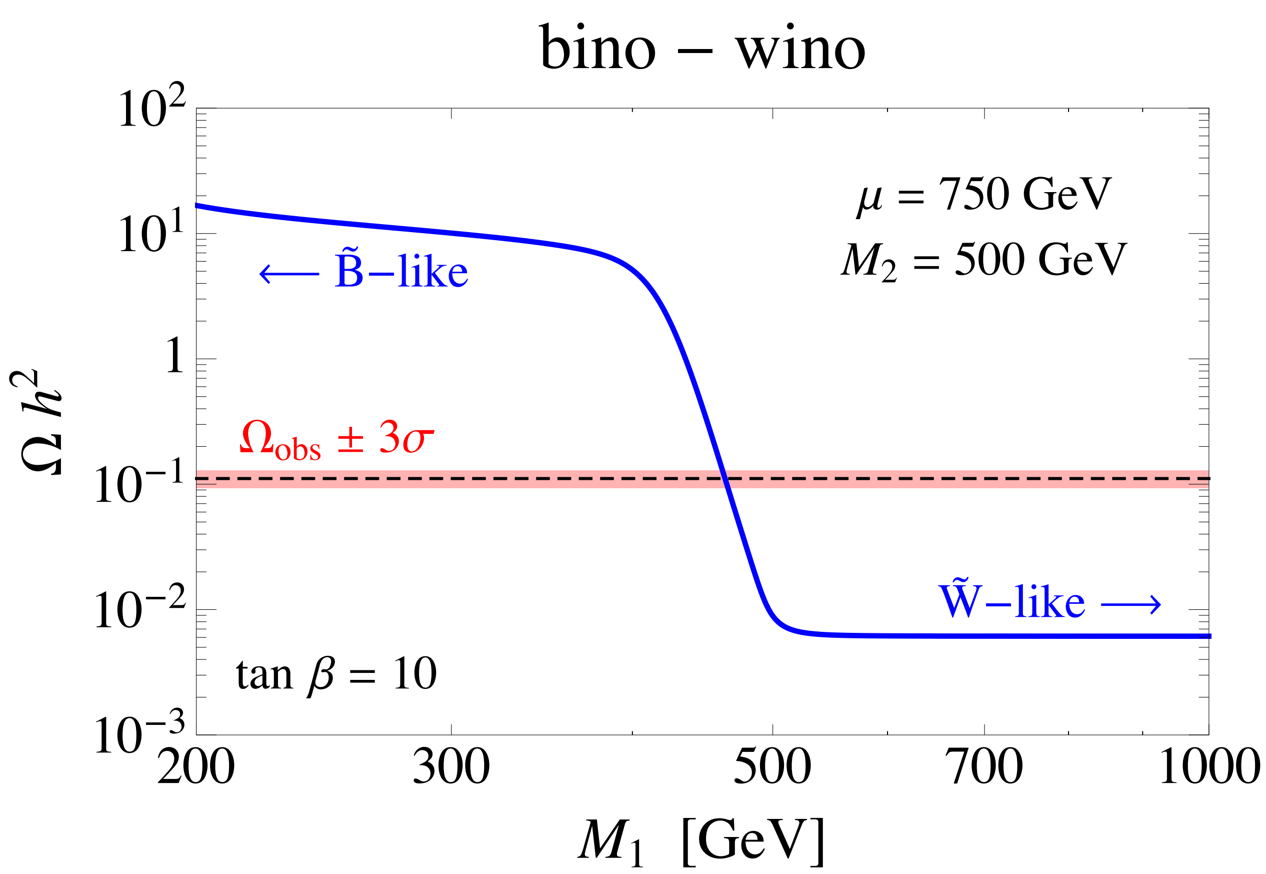
well-tempered neutralino



N. Arkani-Hamed, A. Delgado, G. Giudice 0601041.

well-tempered neutralino





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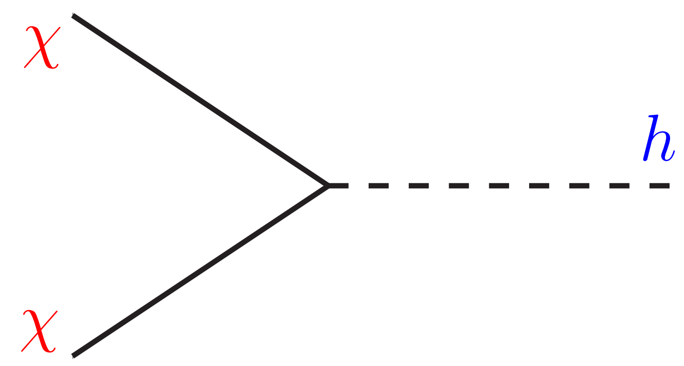
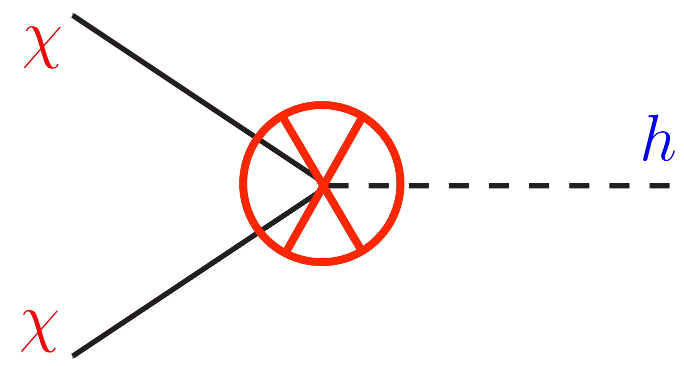
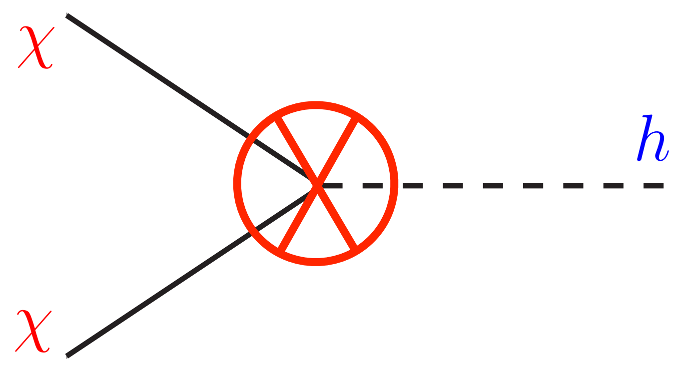
hidden dark matter



hidden dark matter



hidden dark matter



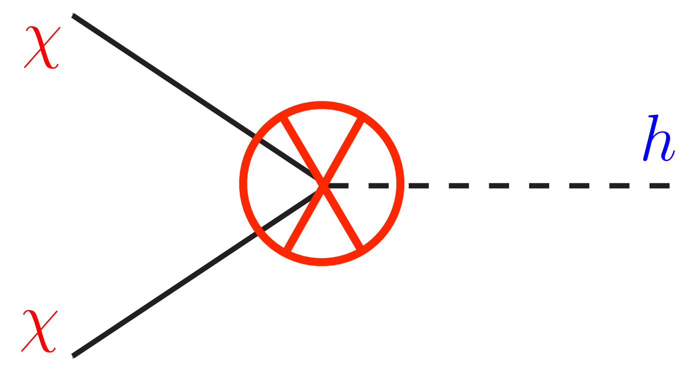
1. purity

$$\chi \to \tilde{B}, \tilde{W}, \tilde{H}$$

$$y_{\chi\chi h} \to 0$$

turn off mixing by decoupling higgsinos or gauginos

hidden dark matter



1. purity

$$\chi \to \tilde{B}, \tilde{W}, \tilde{H}$$

$$y_{\chi\chi h} \to 0$$

decouple higgsinos or gauginos

2. blindspots

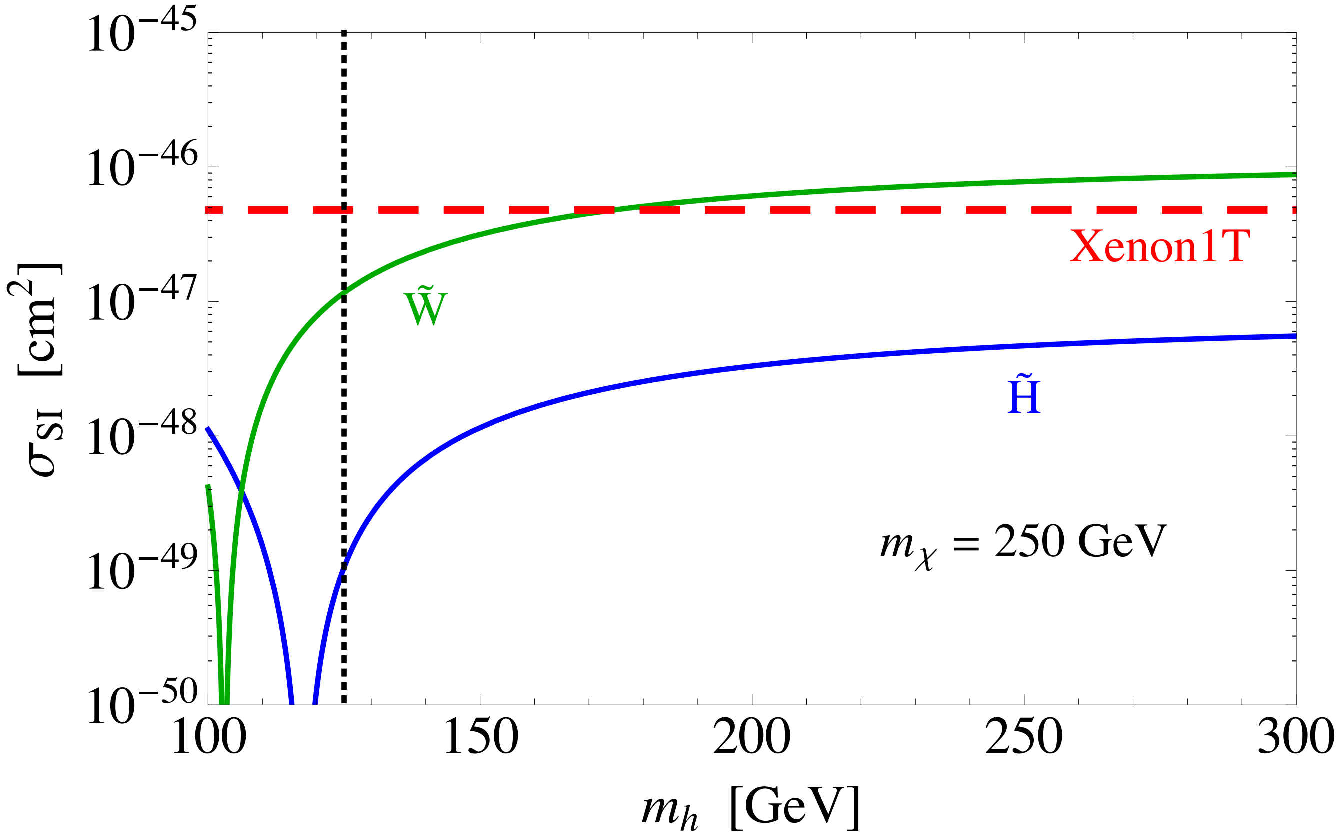
$$y_{\chi\chi h} = 0$$

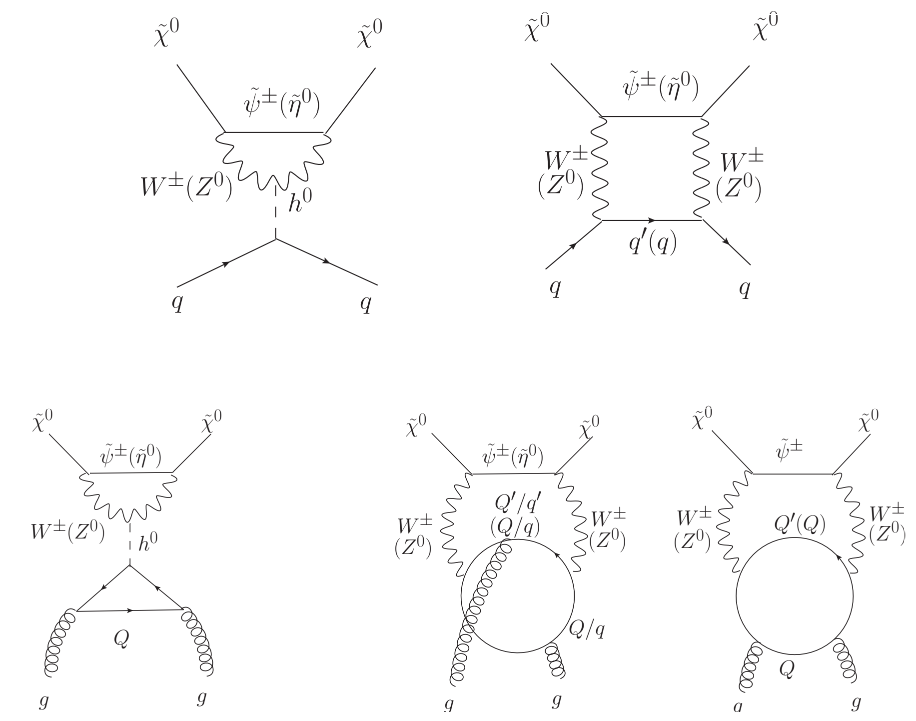
due to cancellation

purity

- tree-level Higgs coupling vanishes for pure higgsino or Wino

- loop contribution smaller than expected





- Hisano, Ishiwata, Nagata, Takesako 1104.0228
- Hill, Solon 1111.0016

blindspots

$$y_{\chi\chi h} = 0$$

blindspots

$$y_{\chi\chi h} = 0$$

- bino $m_\chi = M_1$ | $M_1 + \sin 2\beta\,\mu = 0$

blindspots

$$y_{\chi\chi h} = 0$$

- bino $\quad m_\chi = M_1$
- higgsino $\quad m_\chi = -\mu$

1

$$M_1 + \sin 2\beta\, \mu = 0$$

2

$$\tan\beta = 1$$

$$\mathrm{sign}(\mu) = -\mathrm{sign}(M_1)$$

blindspots

$$y_{\chi\chi h} = 0$$

- bino $\quad m_\chi = M_1$
- higgsino $\quad m_\chi = -\mu$
- wino $\quad m_\chi = M_2$

1 $\quad M_1 + \sin 2\beta\, \mu = 0$

2 $\quad \tan\beta = 1$

$\mathrm{sign}(\mu) = -\mathrm{sign}(M_1)$

3 $\quad M_2 + \sin 2\beta\, \mu = 0$

4 $\quad M_1 = M_2$

$\mathrm{sign}(\mu) = -\mathrm{sign}(M_{1,2})$

bino-higgsino

bino-higgsino

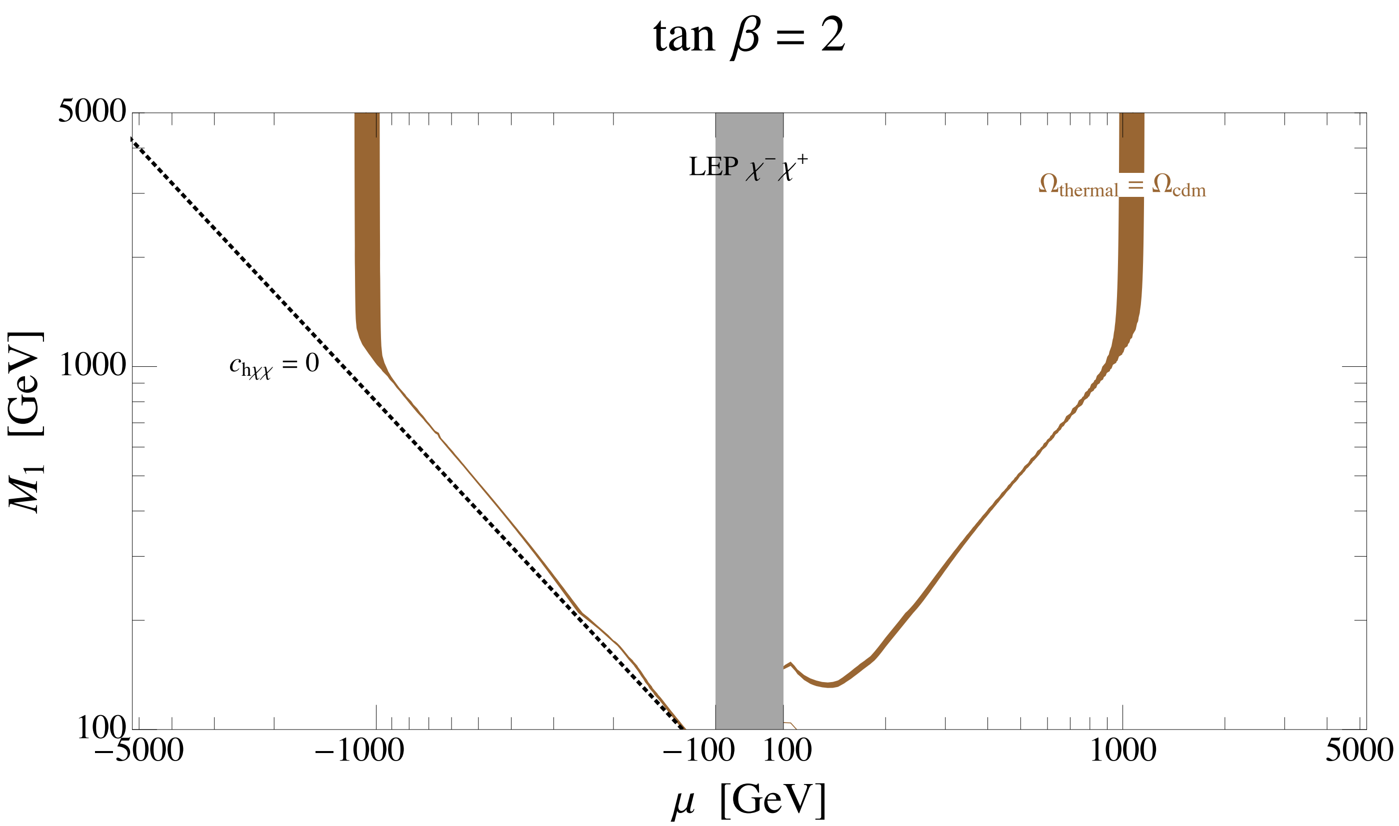
- decouple wino

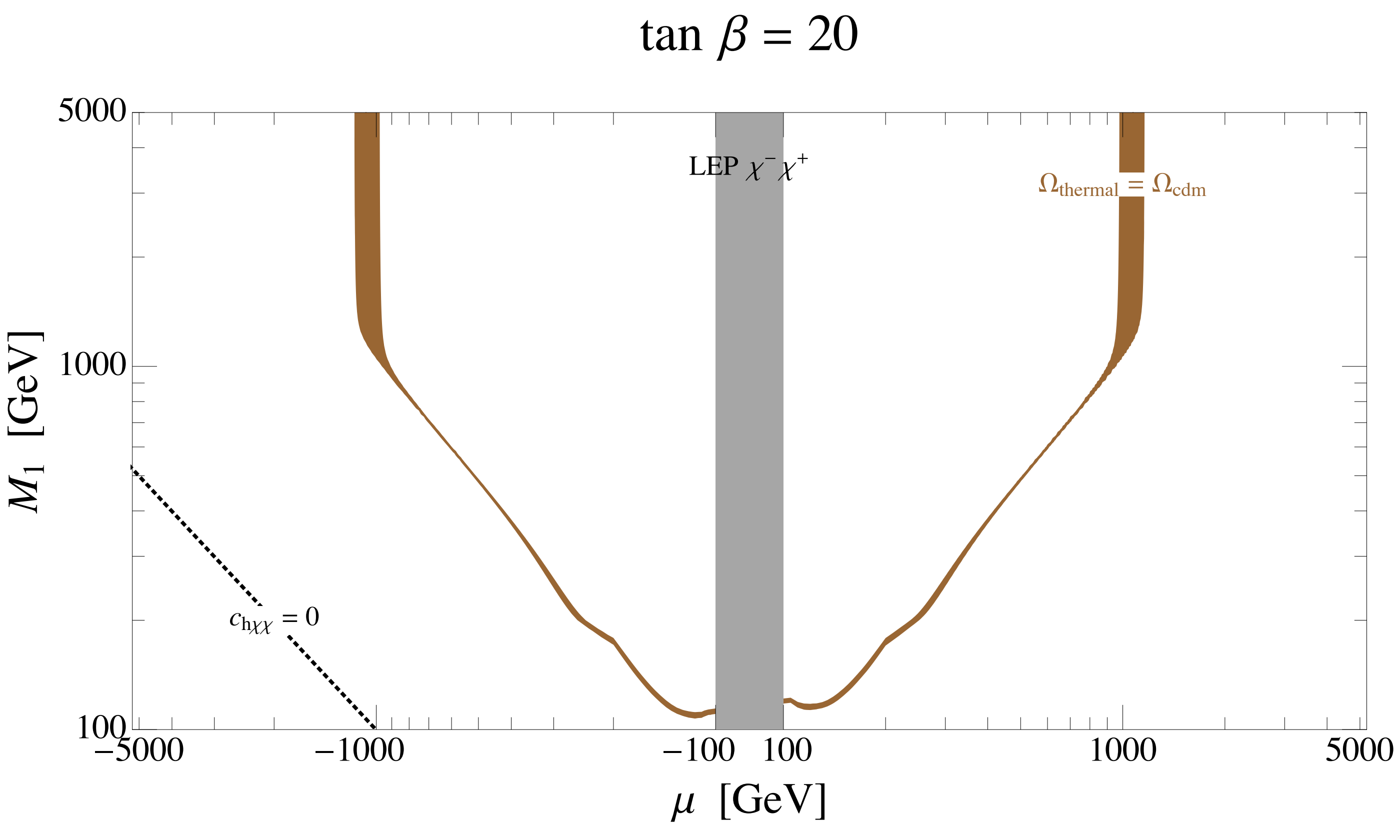
$$\begin{pmatrix} M_1 & -\frac{g' \cos\beta}{\sqrt{2}} v & \frac{g' \sin\beta}{\sqrt{2}} v \\ -\frac{g' \cos\beta}{\sqrt{2}} v & 0 & -\mu \\ \frac{g' \sin\beta}{\sqrt{2}} v & -\mu & 0 \end{pmatrix}$$

- parameters

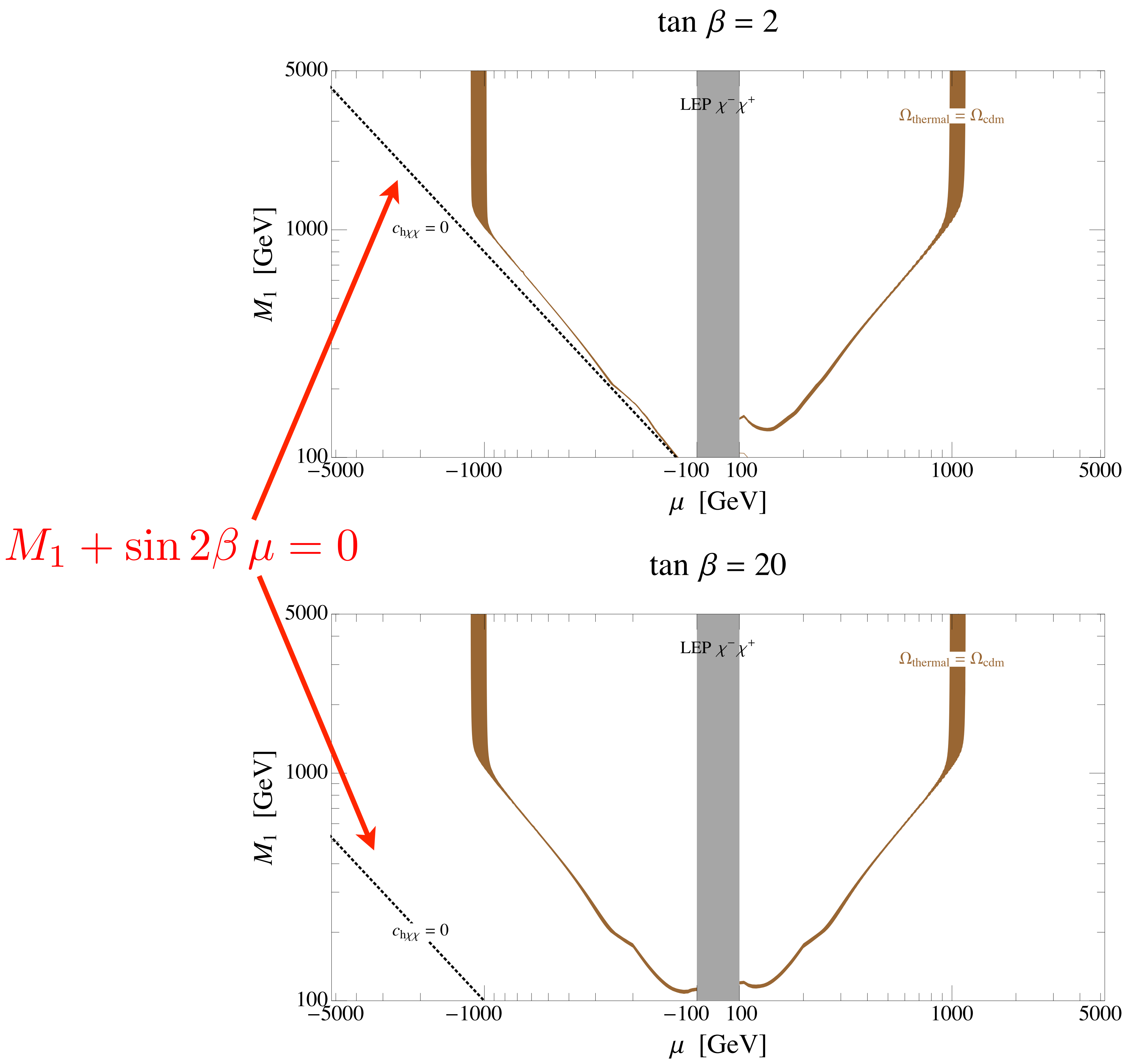
$$M_1,\ \mu,\ \tan\beta$$

non-thermal


tan β = 2
5000
1000
100
M1 [GeV]
LEP χ⁻χ⁺
Ωthermal = Ωcdm
chχχ = 0
−5000
−1000
−100
100
1000
5000
μ [GeV]


tan β = 20
5000
1000
100
M1 [GeV]
LEP χ⁻χ⁺
Ωthermal = Ωcdm
chχχ = 0
−5000
−1000
−100
100
1000
5000
μ [GeV]

non-thermal

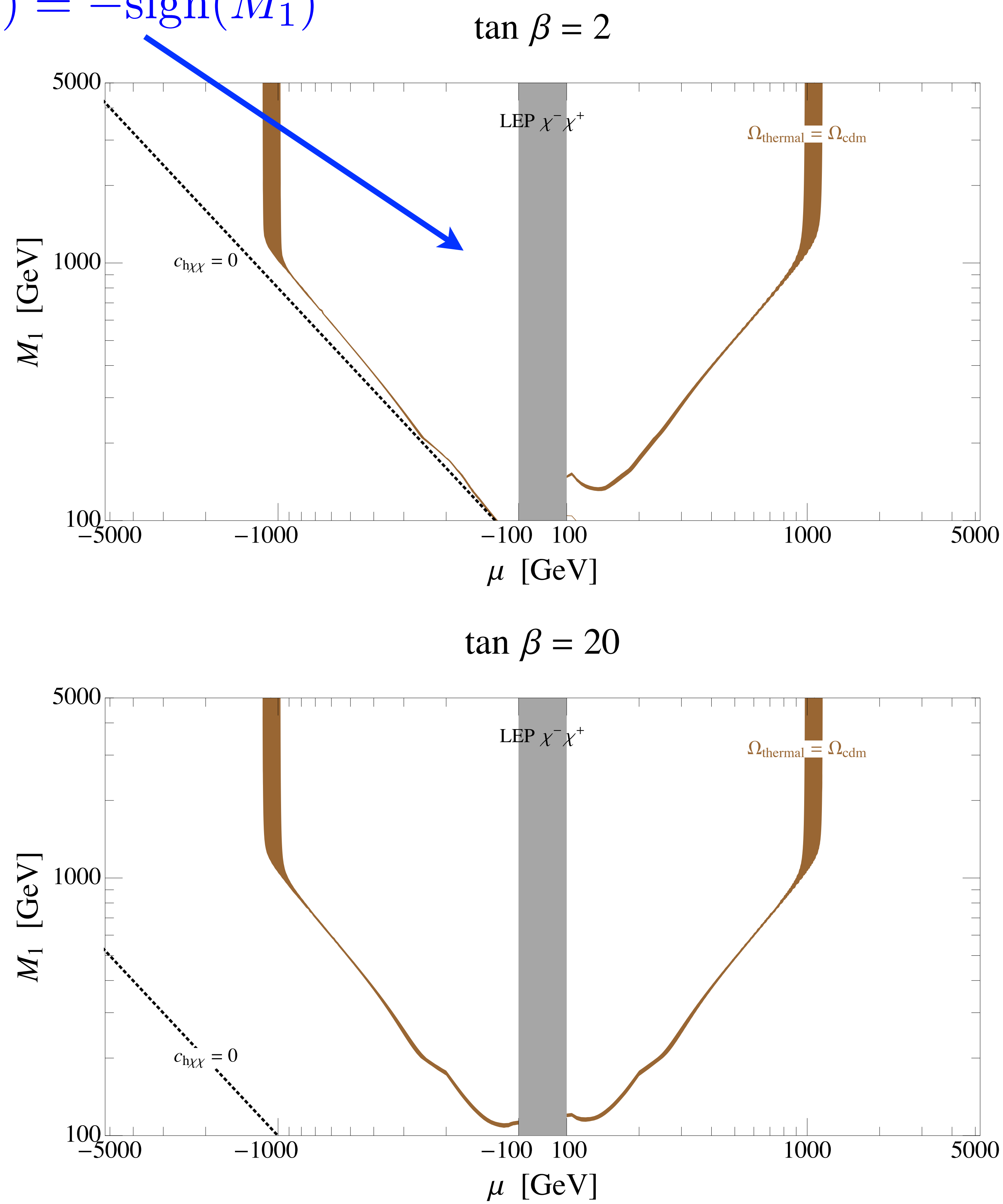


tan β = 2
LEP $\chi^-\chi^+$
$\Omega_{thermal} = \Omega_{cdm}$
$c_{h\chi\chi} = 0$
M_1 [GeV]
μ [GeV]
5000
1000
100
−5000
−1000
−100
100
1000
5000
$M_1 + \sin 2\beta\, \mu = 0$
tan β = 20
LEP $\chi^-\chi^+$
$\Omega_{thermal} = \Omega_{cdm}$
$c_{h\chi\chi} = 0$
M_1 [GeV]
μ [GeV]
5000
1000
100
−5000
−1000
−100
100
1000
5000

non-thermal

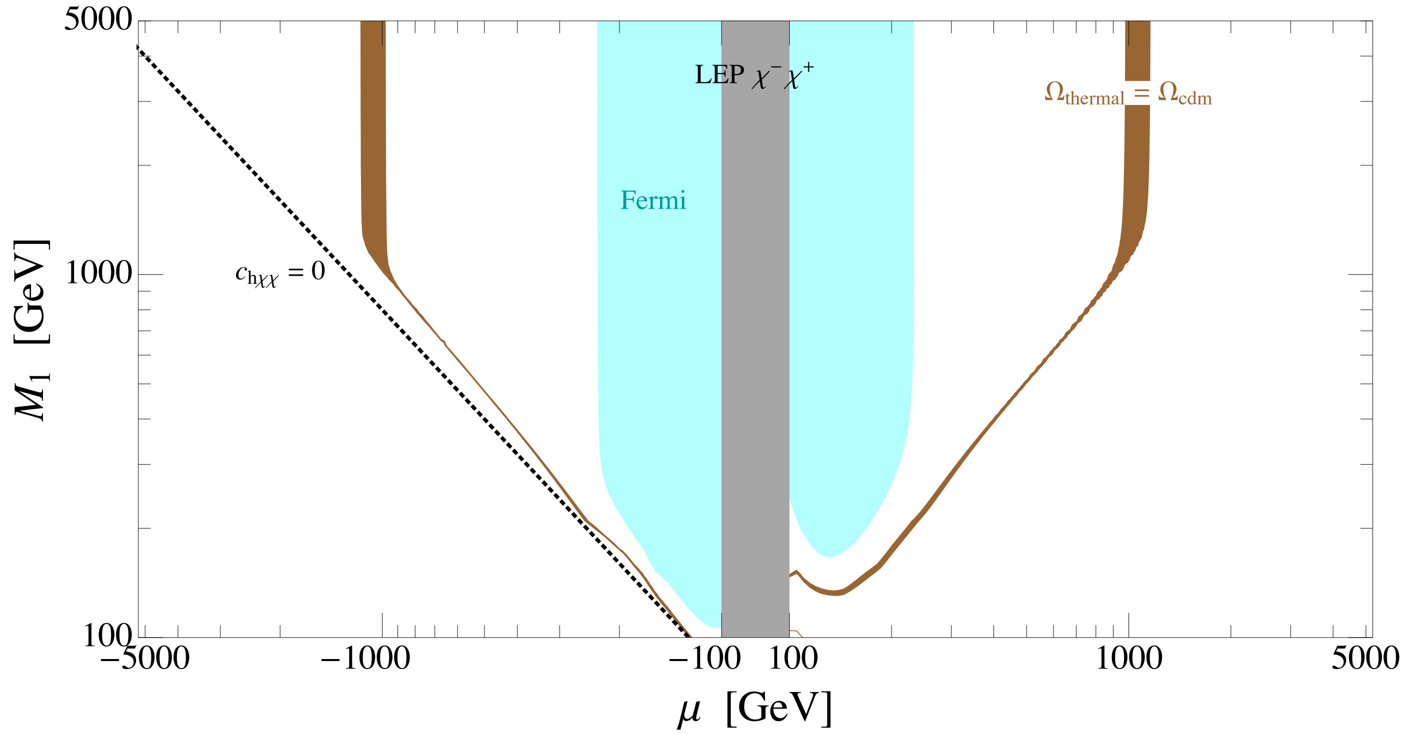
$\tan\beta \to 1$

$\mathrm{sign}(\mu) = -\mathrm{sign}(M_1)$

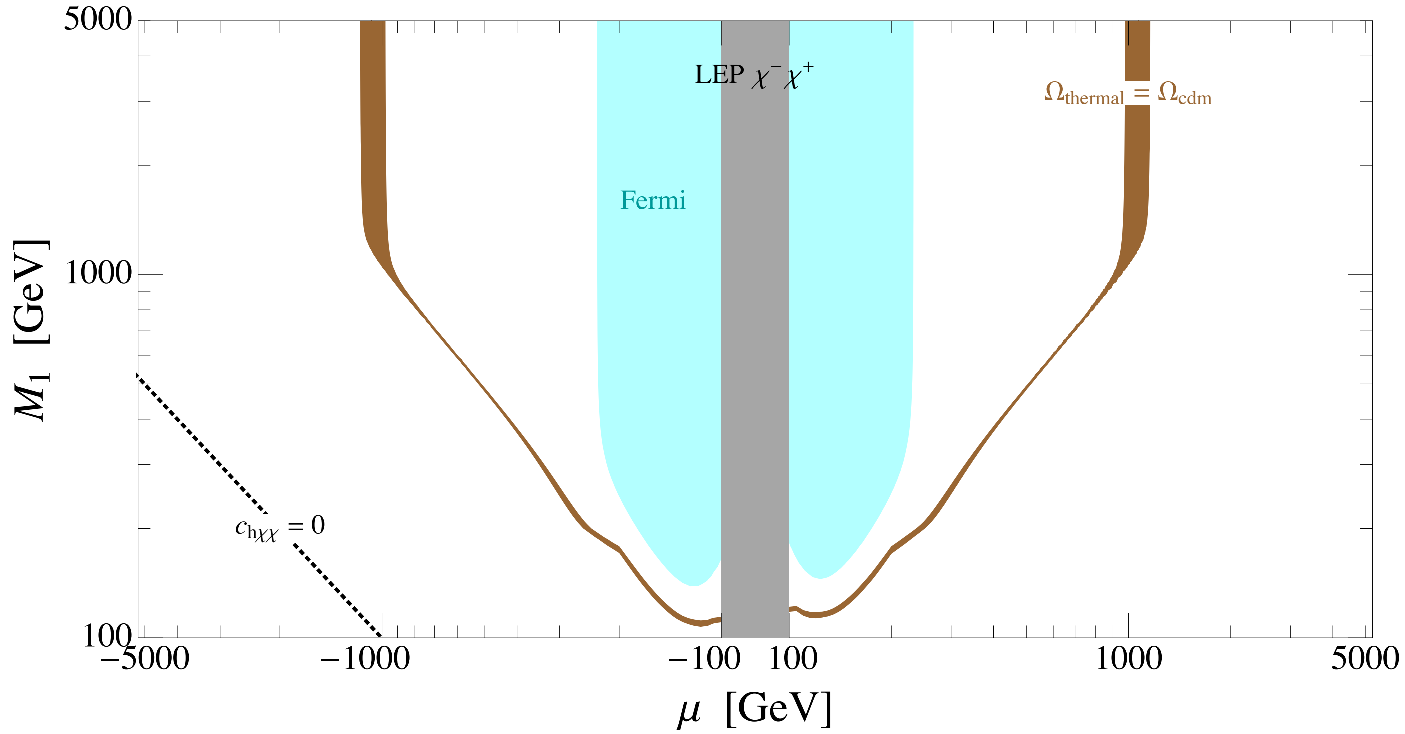


non-thermal

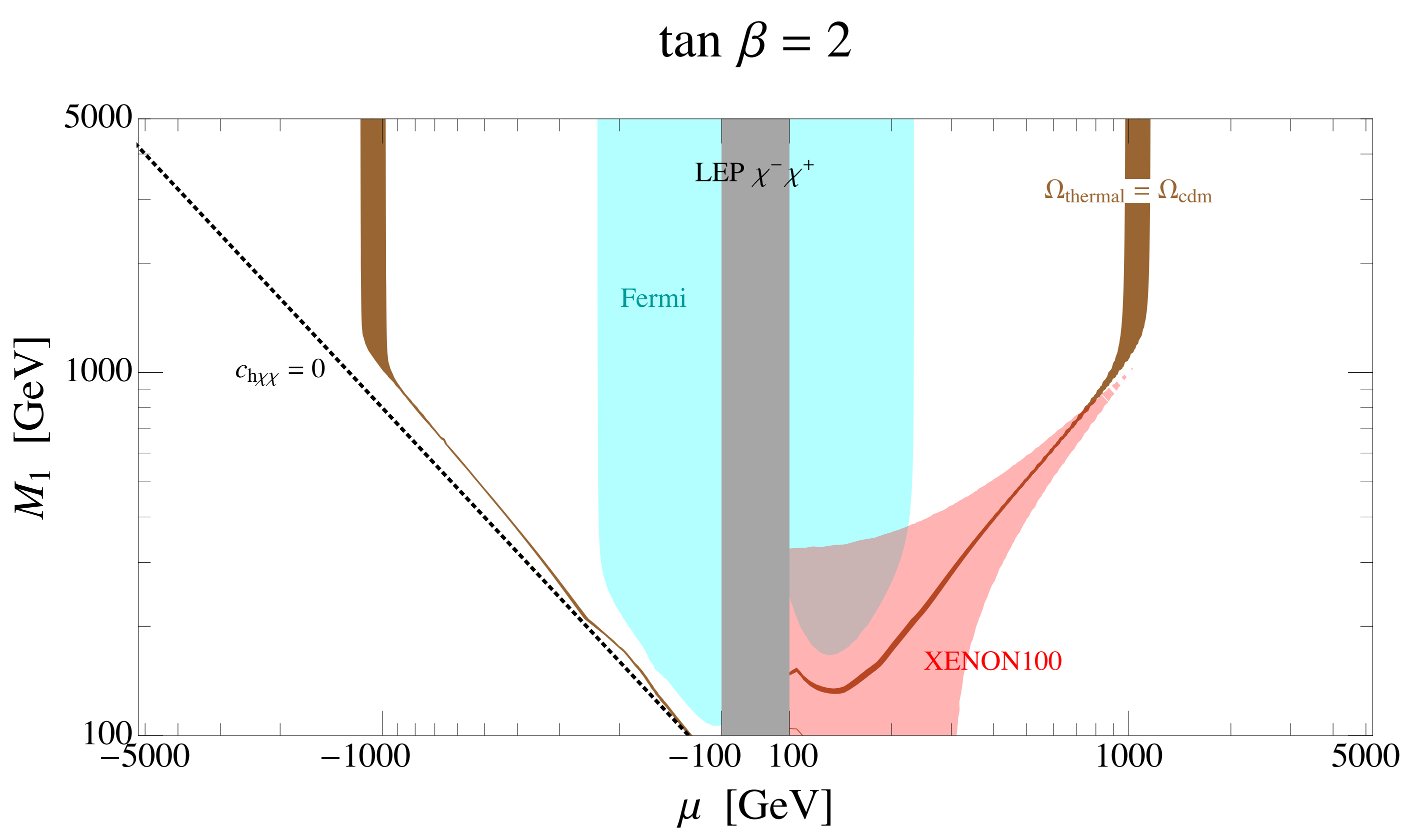
tan β = 2

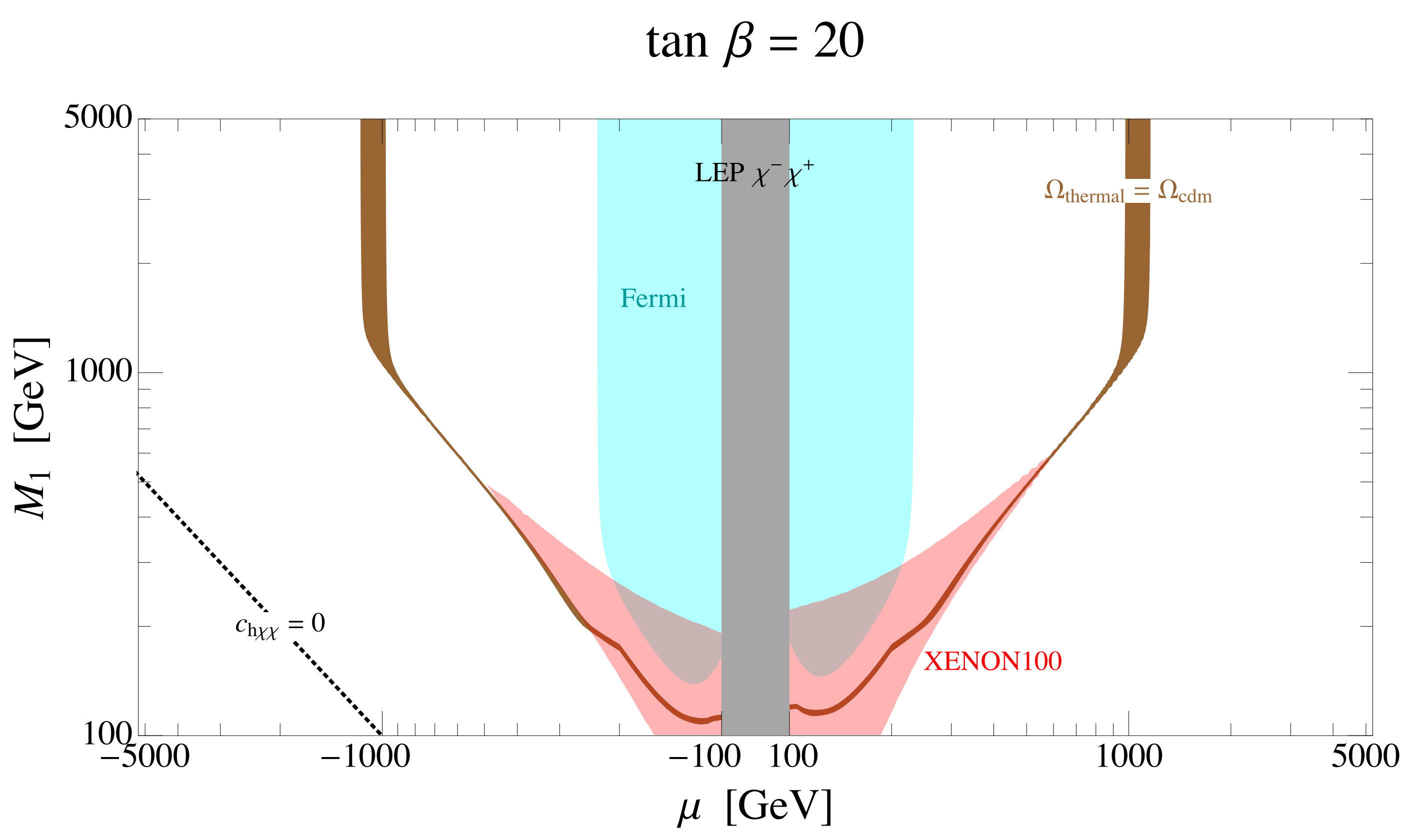


tan β = 20



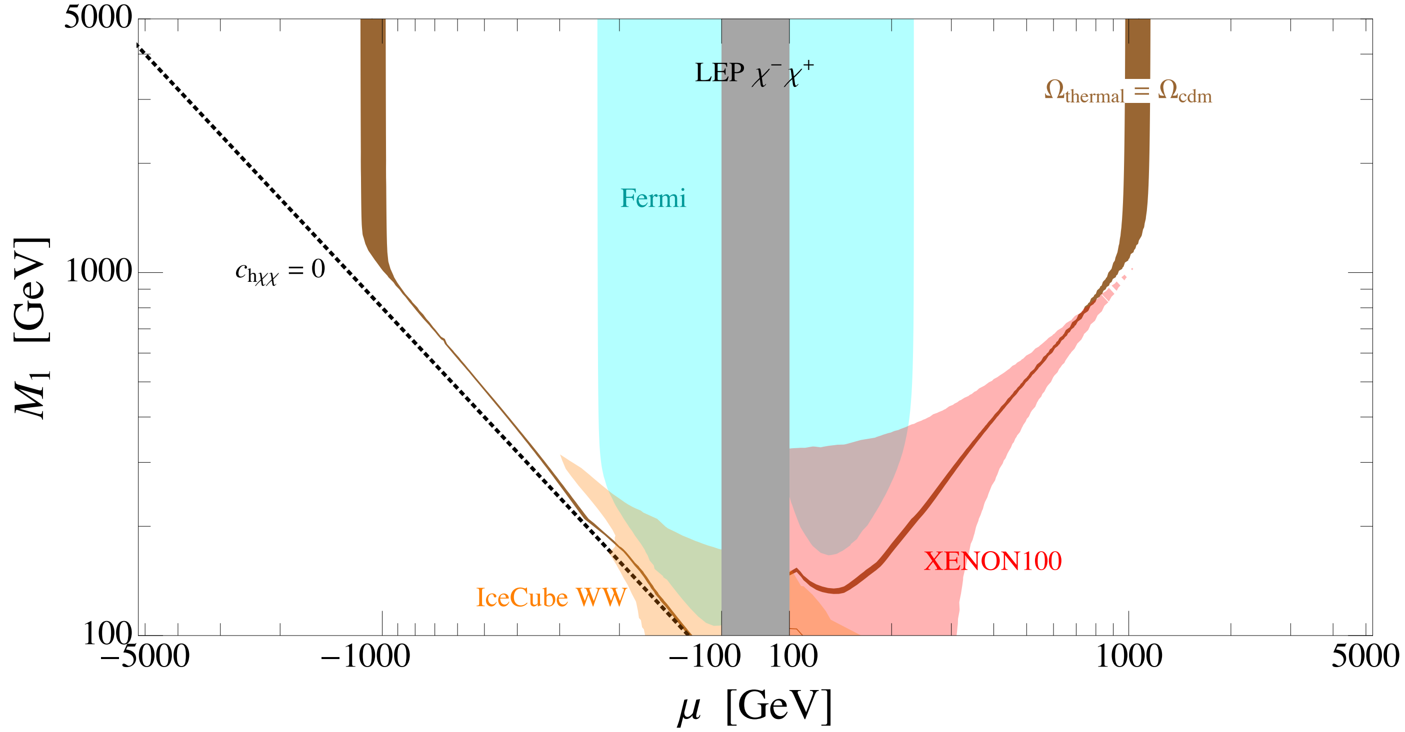
non-thermal


tan β = 2
LEP $\chi^- \chi^+$
$\Omega_{thermal} = \Omega_{cdm}$
Fermi
$c_{h\chi\chi} = 0$
XENON100
5000
1000
100
M_1 [GeV]
−5000
−1000
−100
100
1000
5000
μ [GeV]

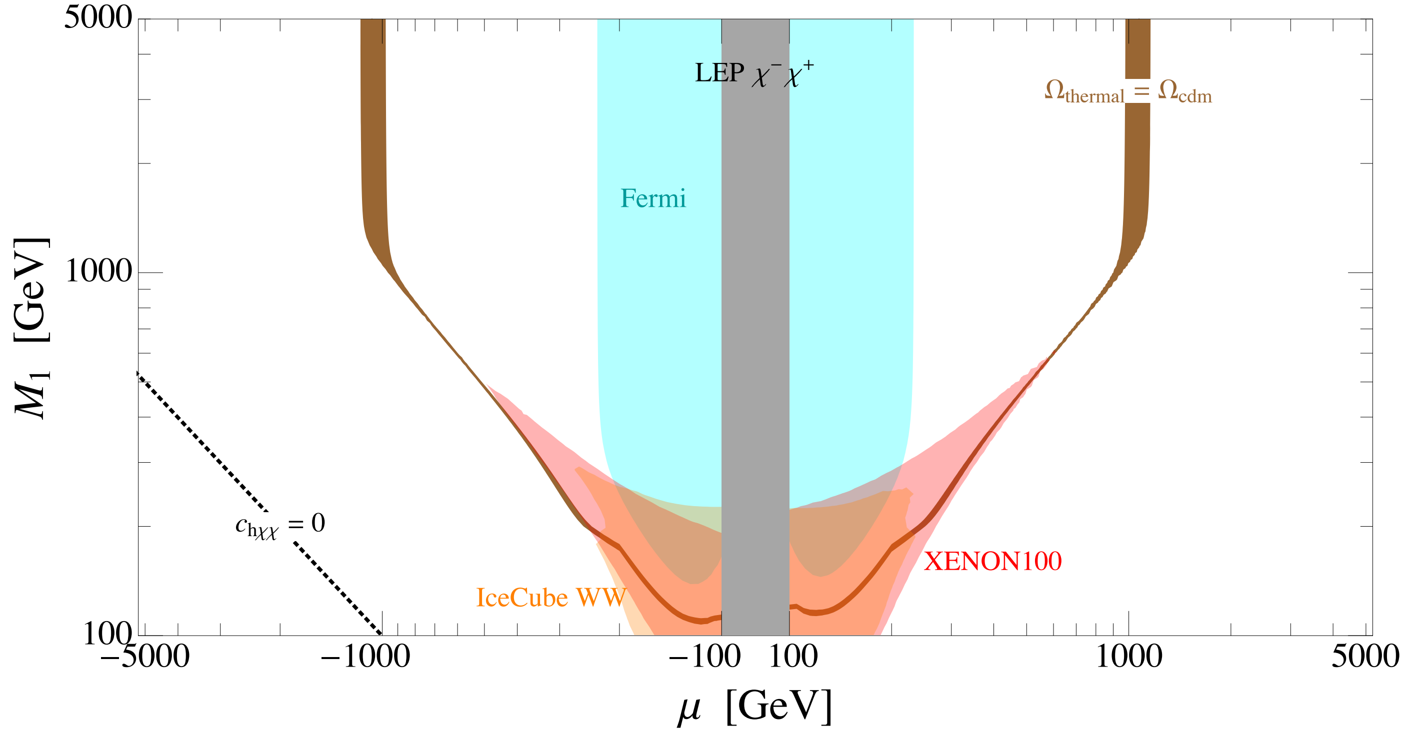

tan β = 20
LEP $\chi^- \chi^+$
$\Omega_{thermal} = \Omega_{cdm}$
Fermi
$c_{h\chi\chi} = 0$
XENON100
5000
1000
100
M_1 [GeV]
−5000
−1000
−100
100
1000
5000
μ [GeV]

non-thermal

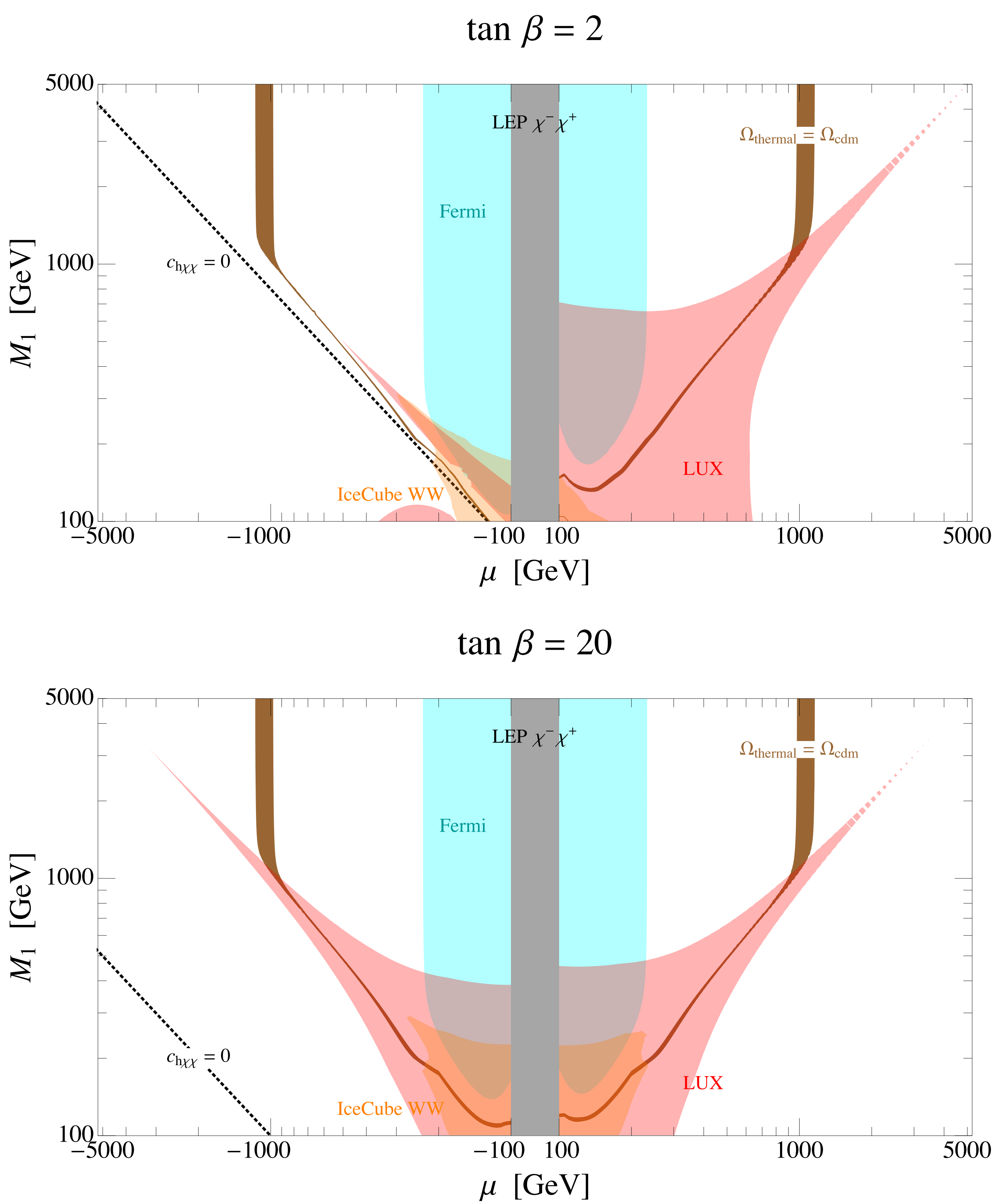
$\tan\beta = 2$



$\tan\beta = 20$

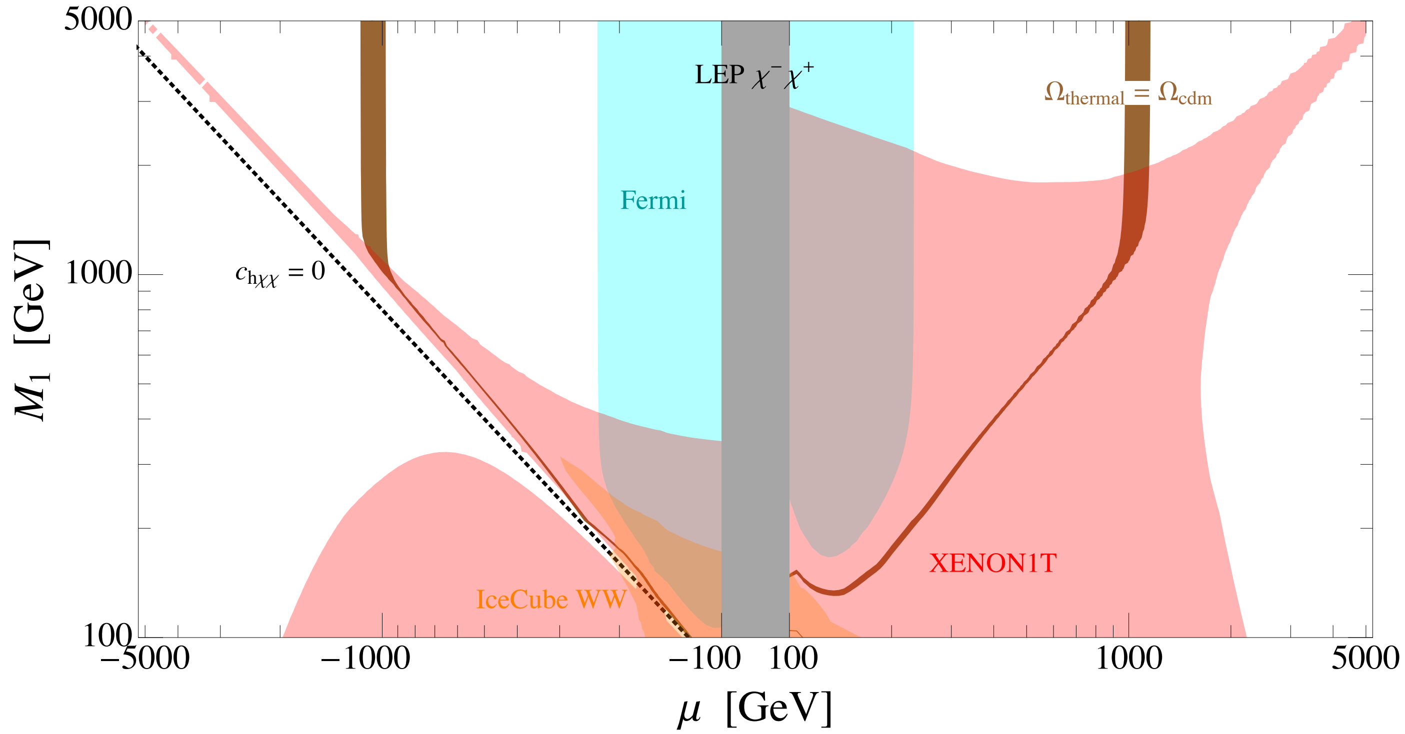


non-thermal

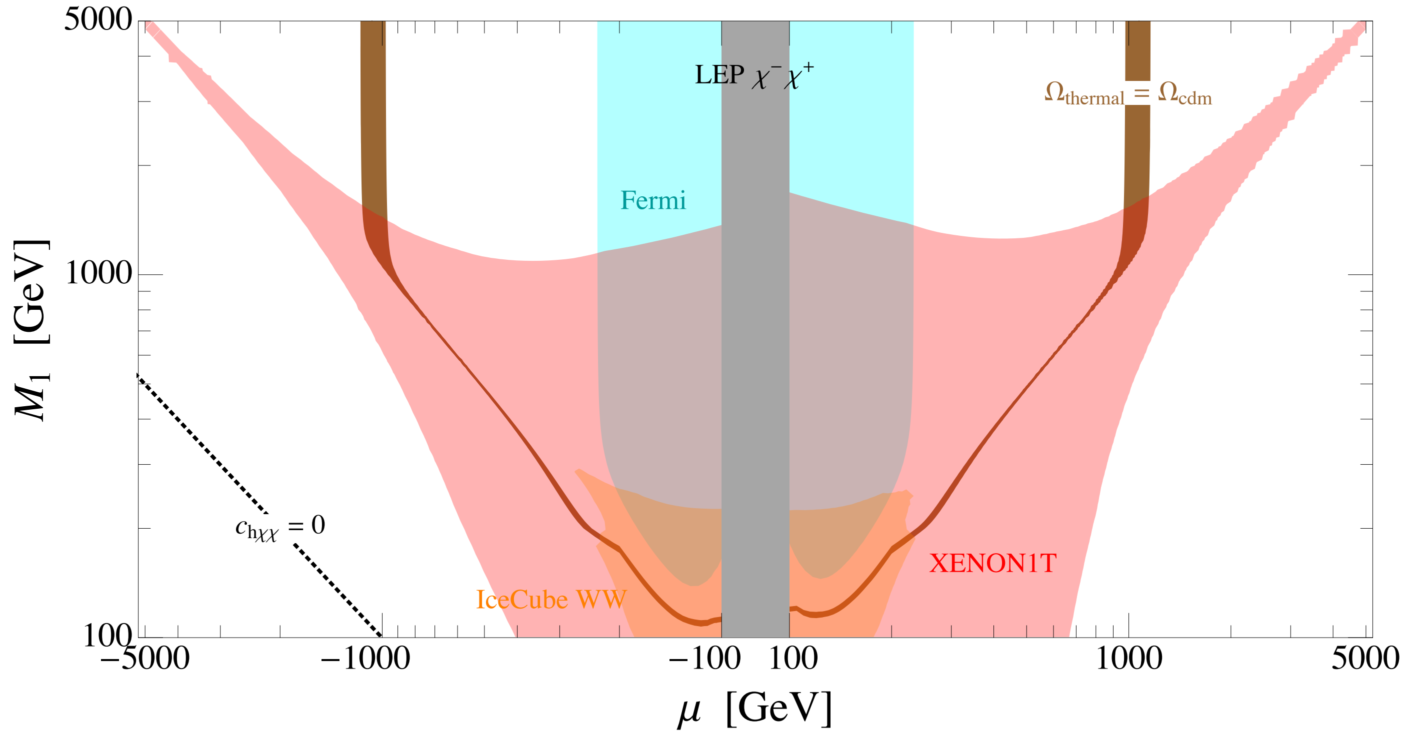

tan β = 2
LEP χ⁻χ⁺
Fermi
Ω_thermal = Ω_cdm
c_hχχ = 0
LUX
IceCube WW
M_1 [GeV]
μ [GeV]
5000
1000
100
−5000
−1000
−100
100
1000
5000
tan β = 20
LEP χ⁻χ⁺
Fermi
Ω_thermal = Ω_cdm
c_hχχ = 0
LUX
IceCube WW
M_1 [GeV]
μ [GeV]
5000
1000
100
−5000
−1000
−100
100
1000
5000

non-thermal

tan β = 2

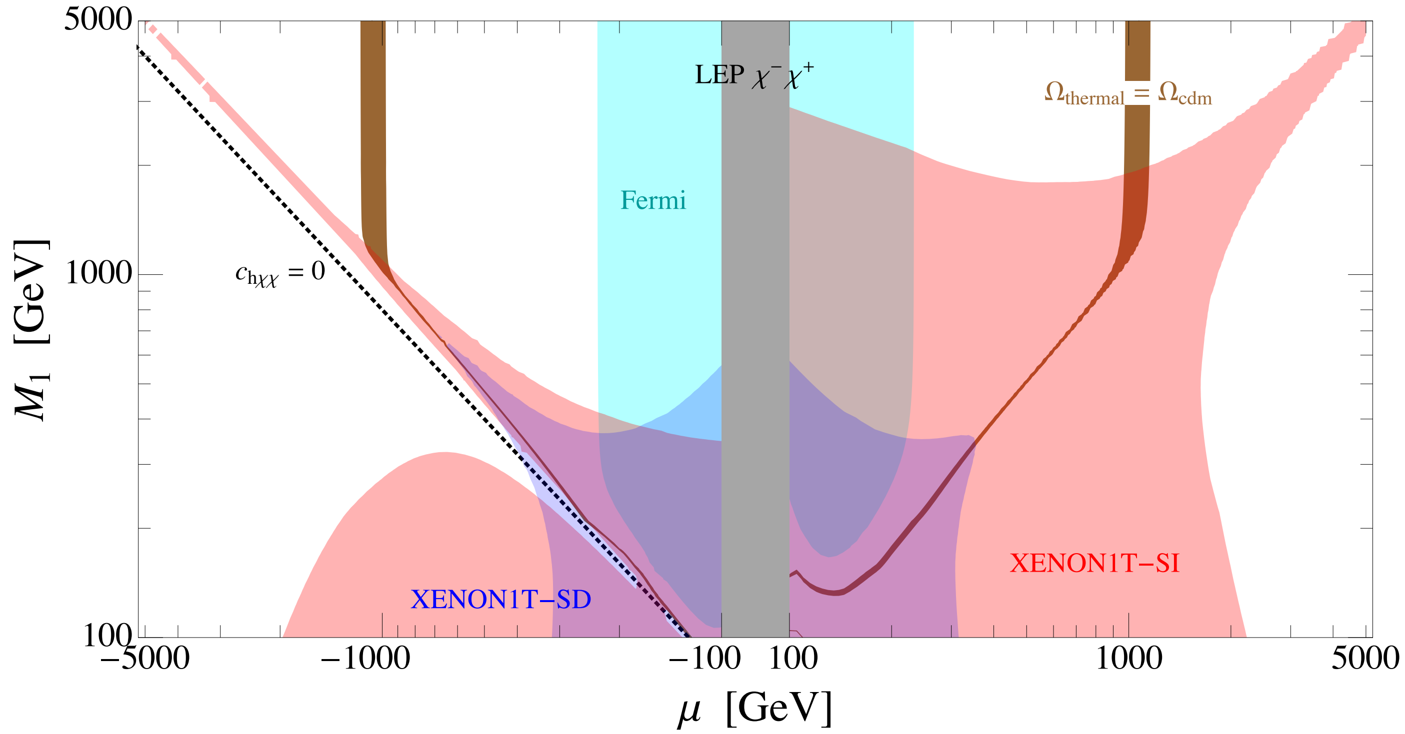


tan β = 20

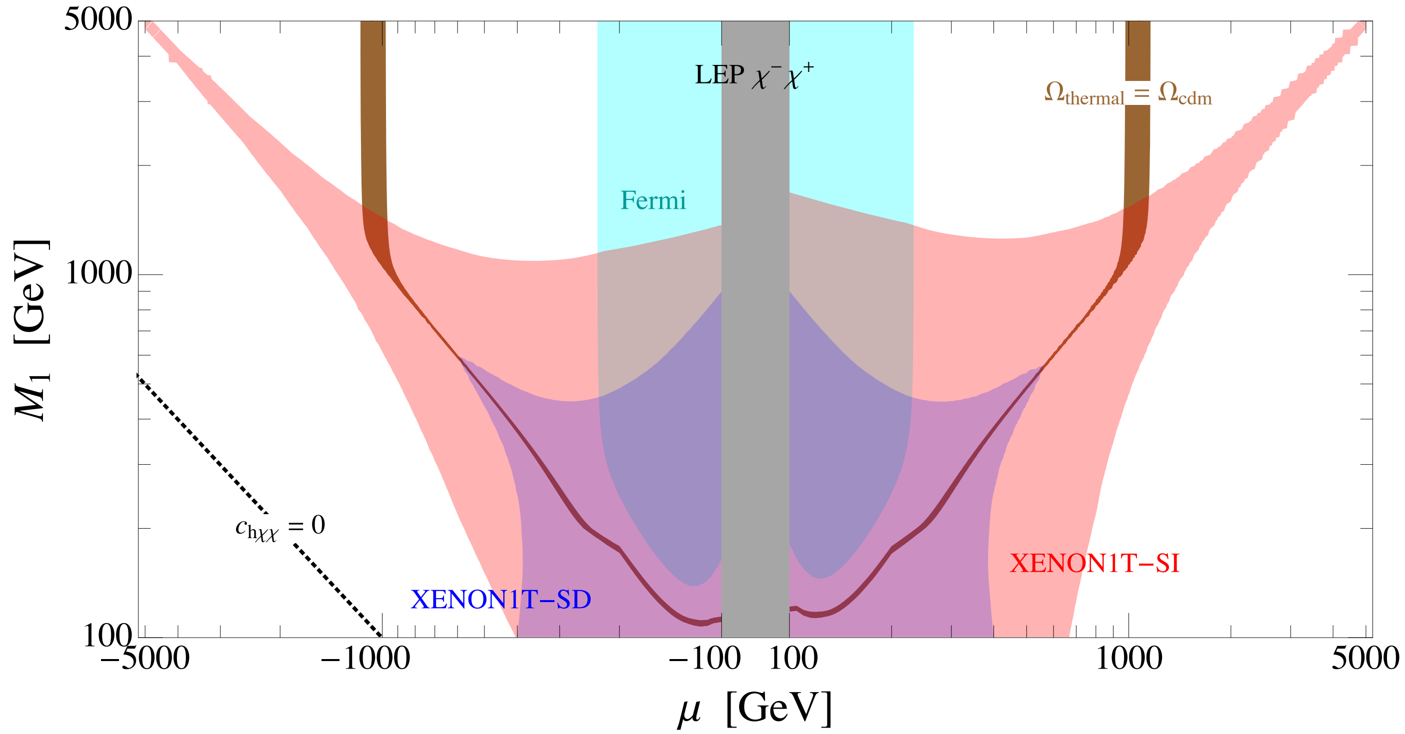


non-thermal

tan β = 2



tan β = 20



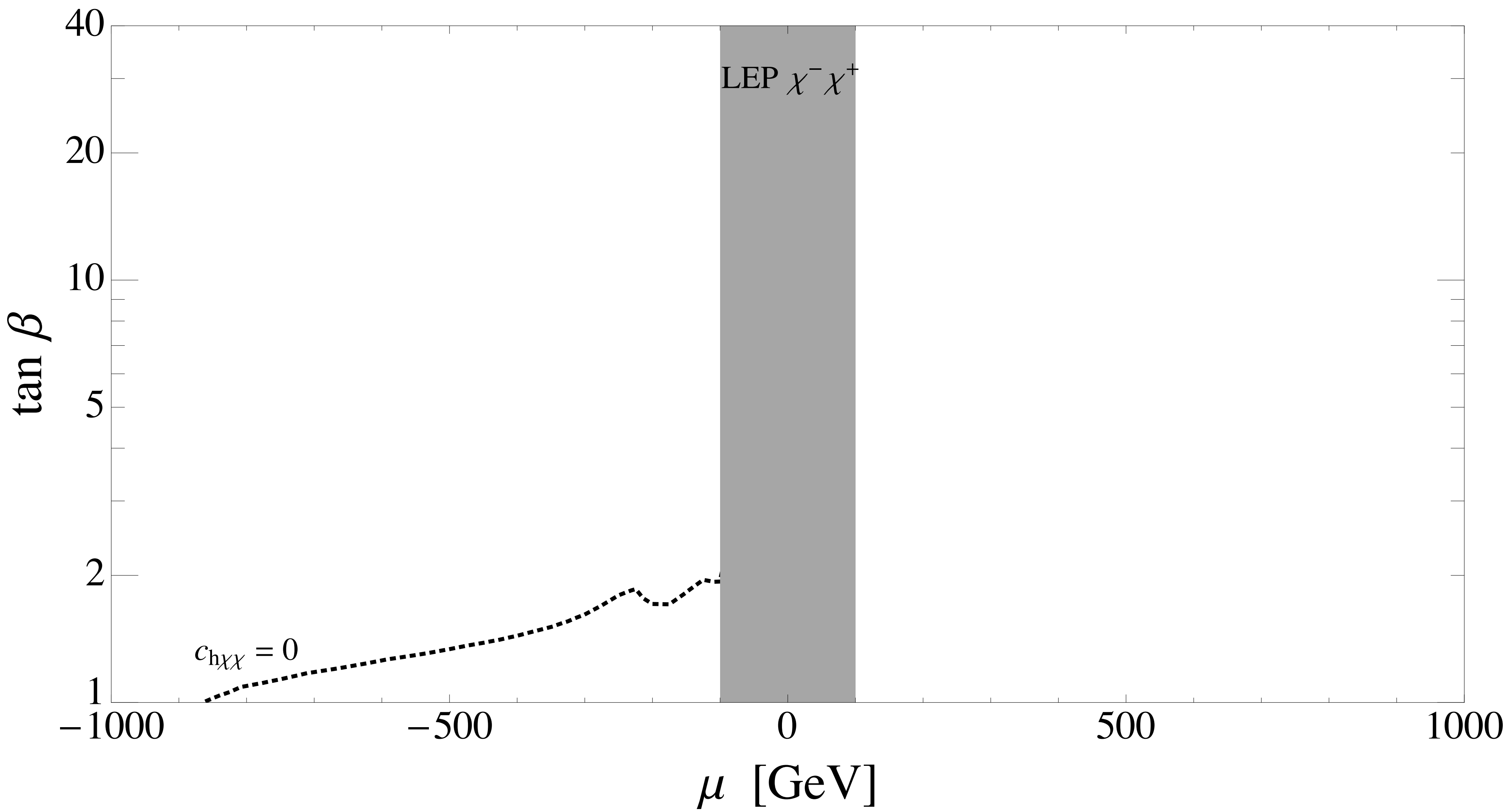
well-tempered

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

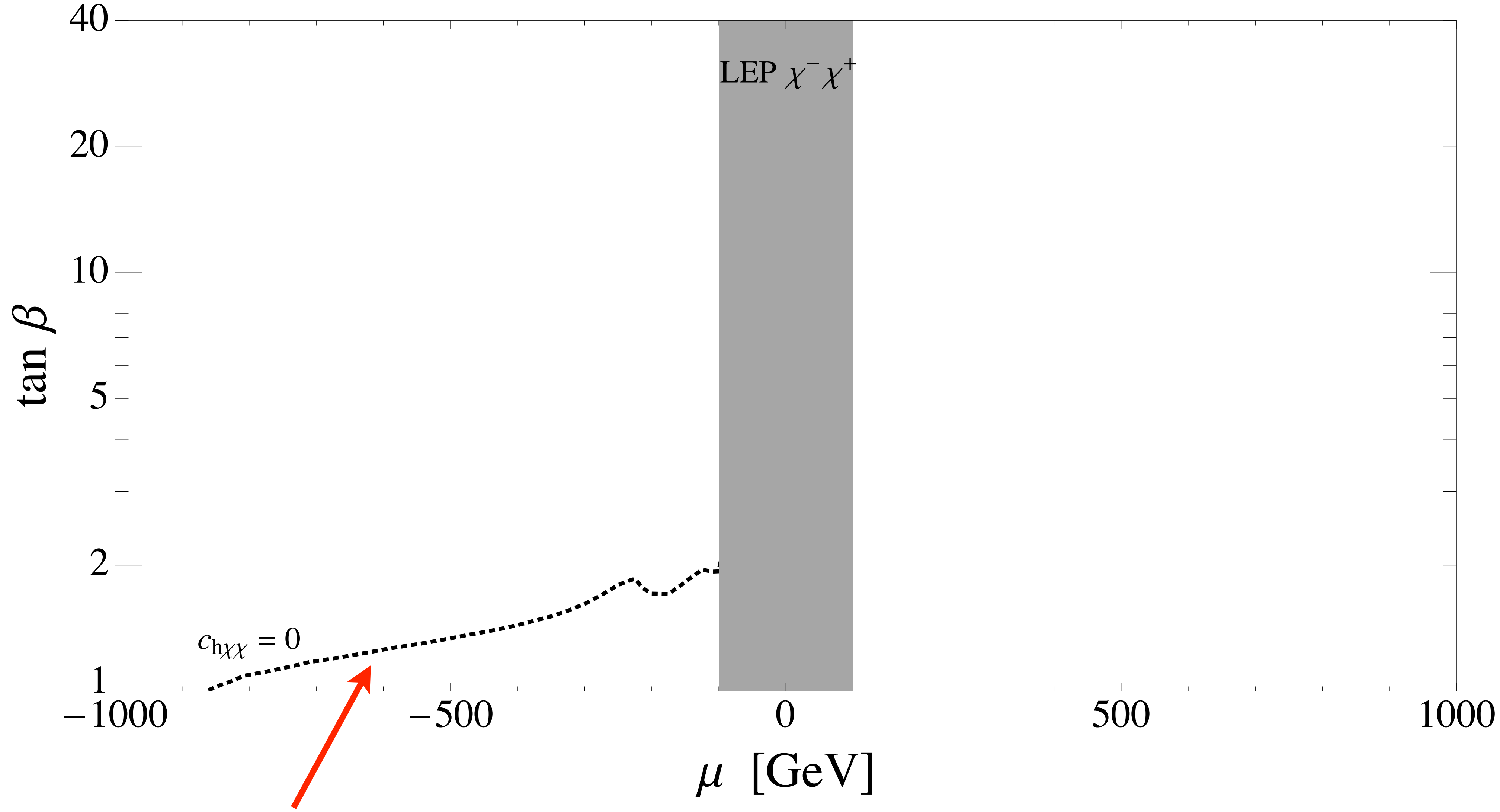
solve for:

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

well-tempered

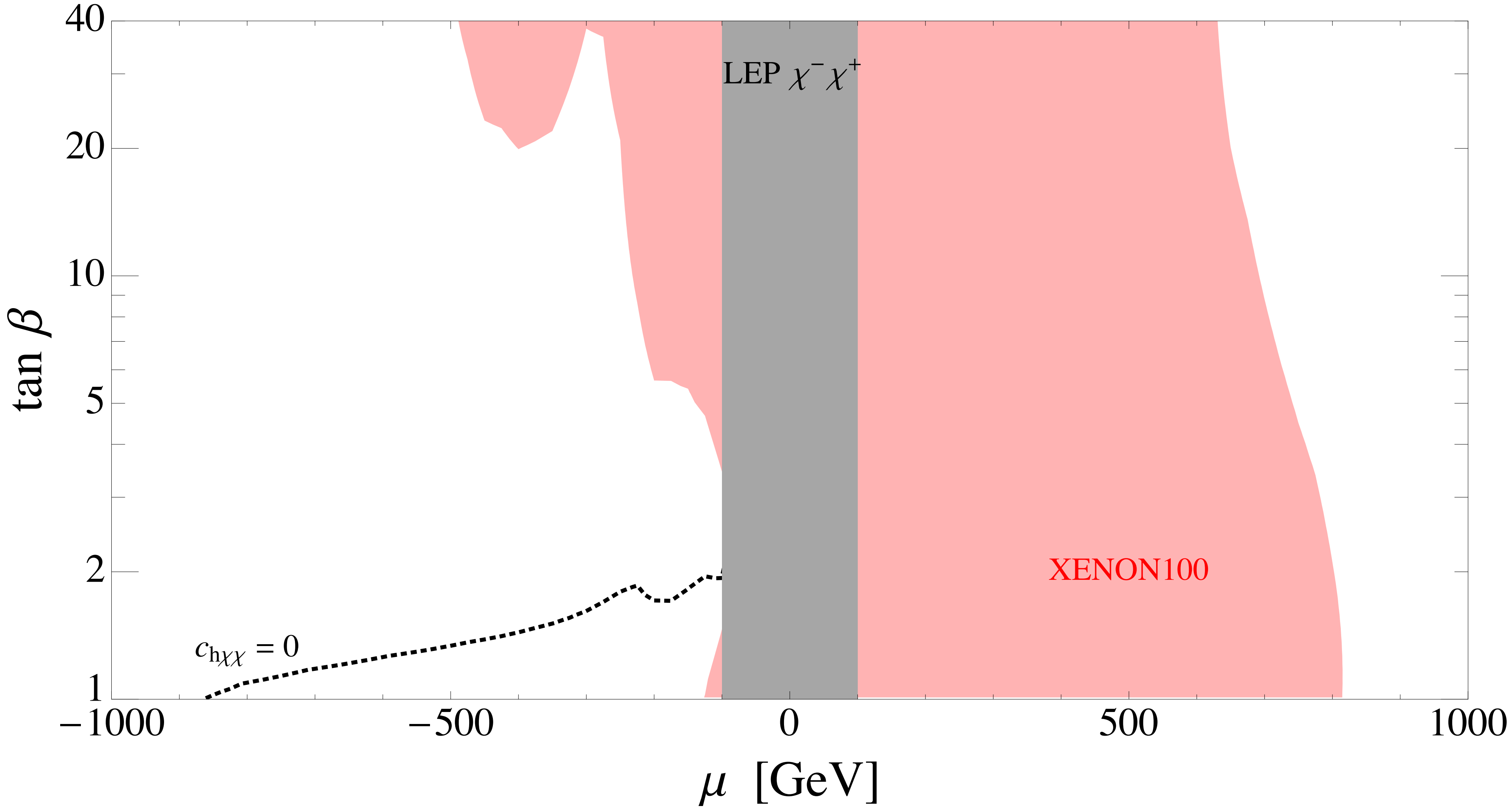


well-tempered

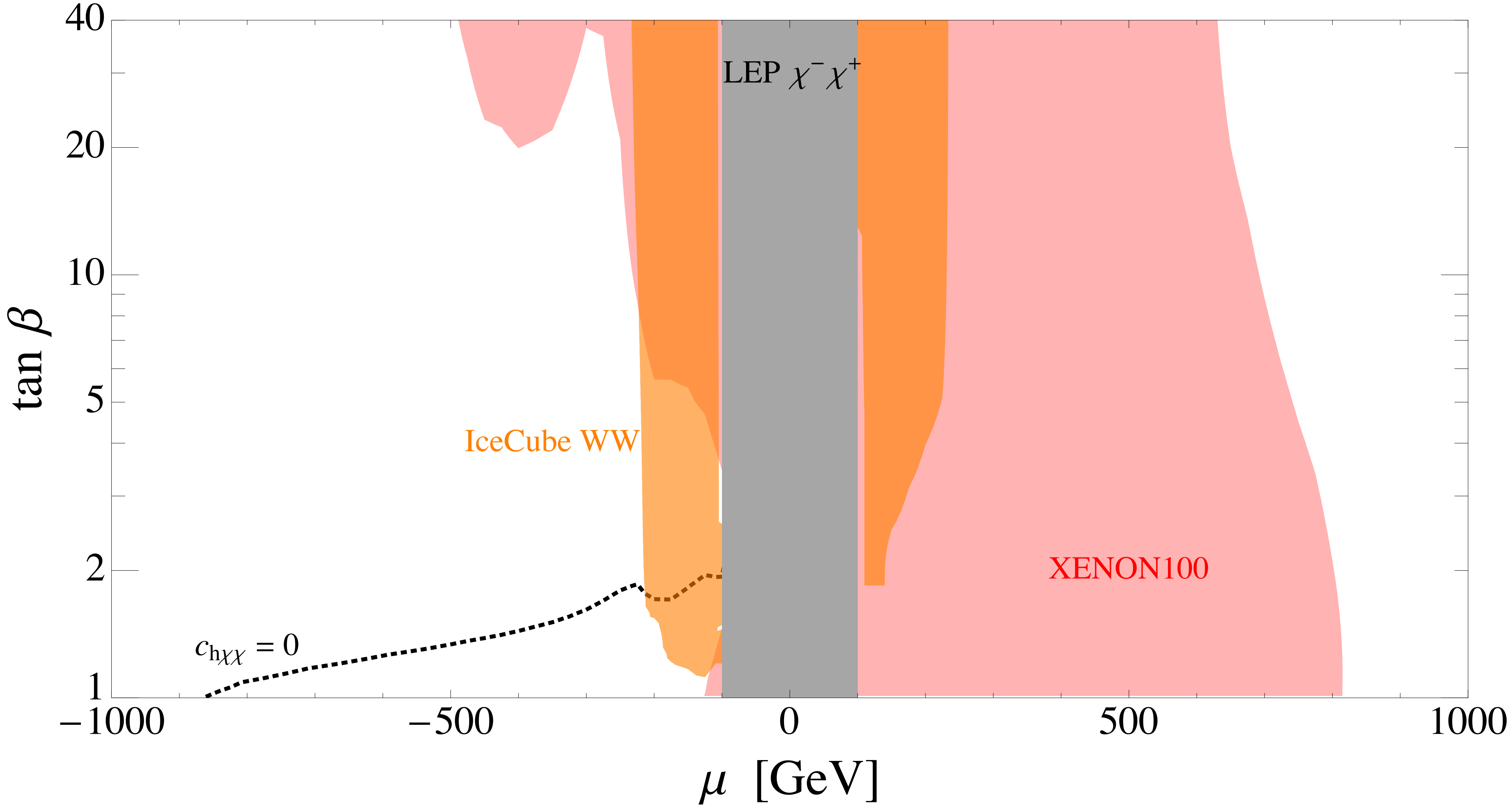


$M_1 + \sin 2\beta\, \mu = 0$

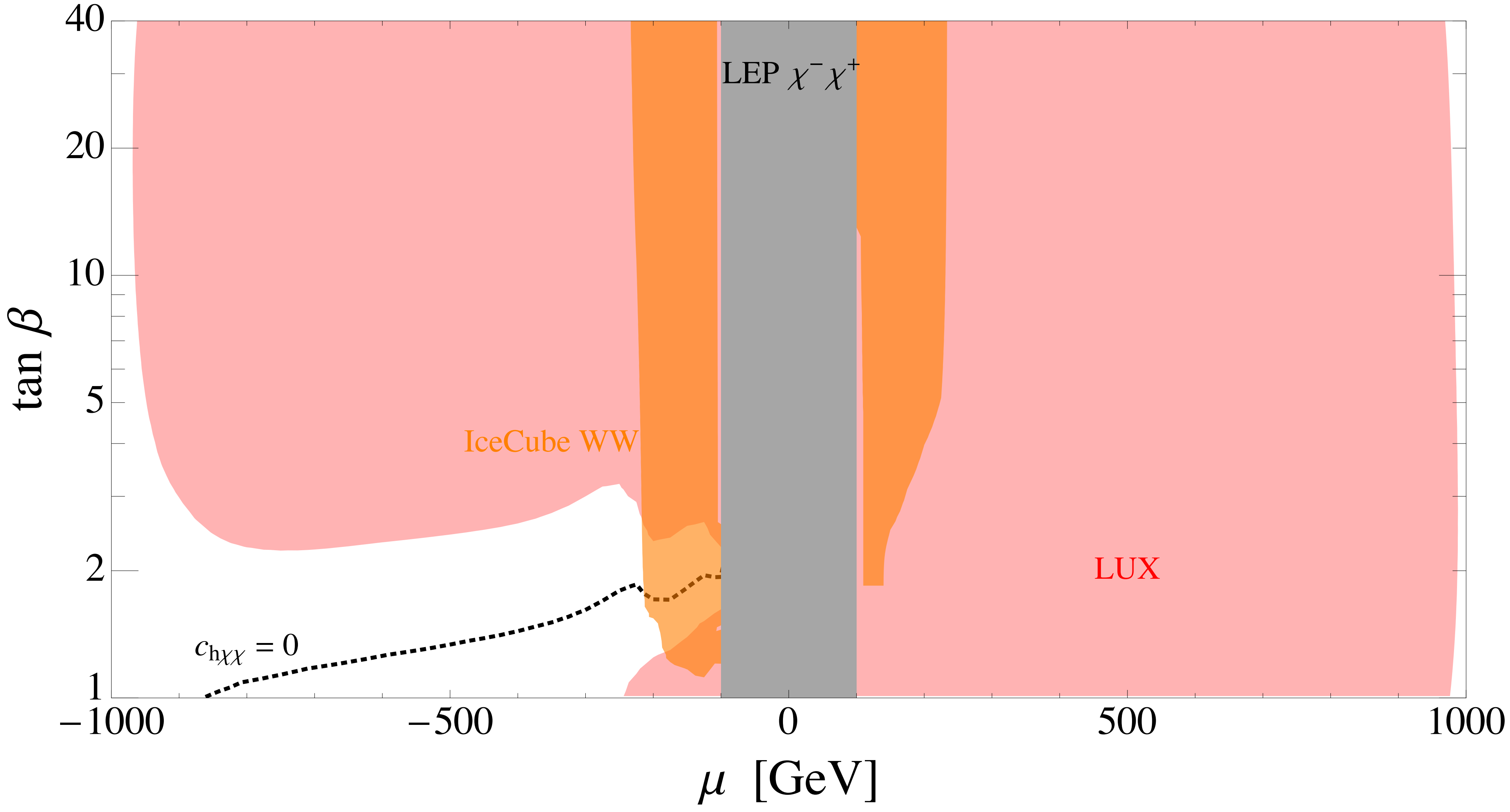
well-tempered



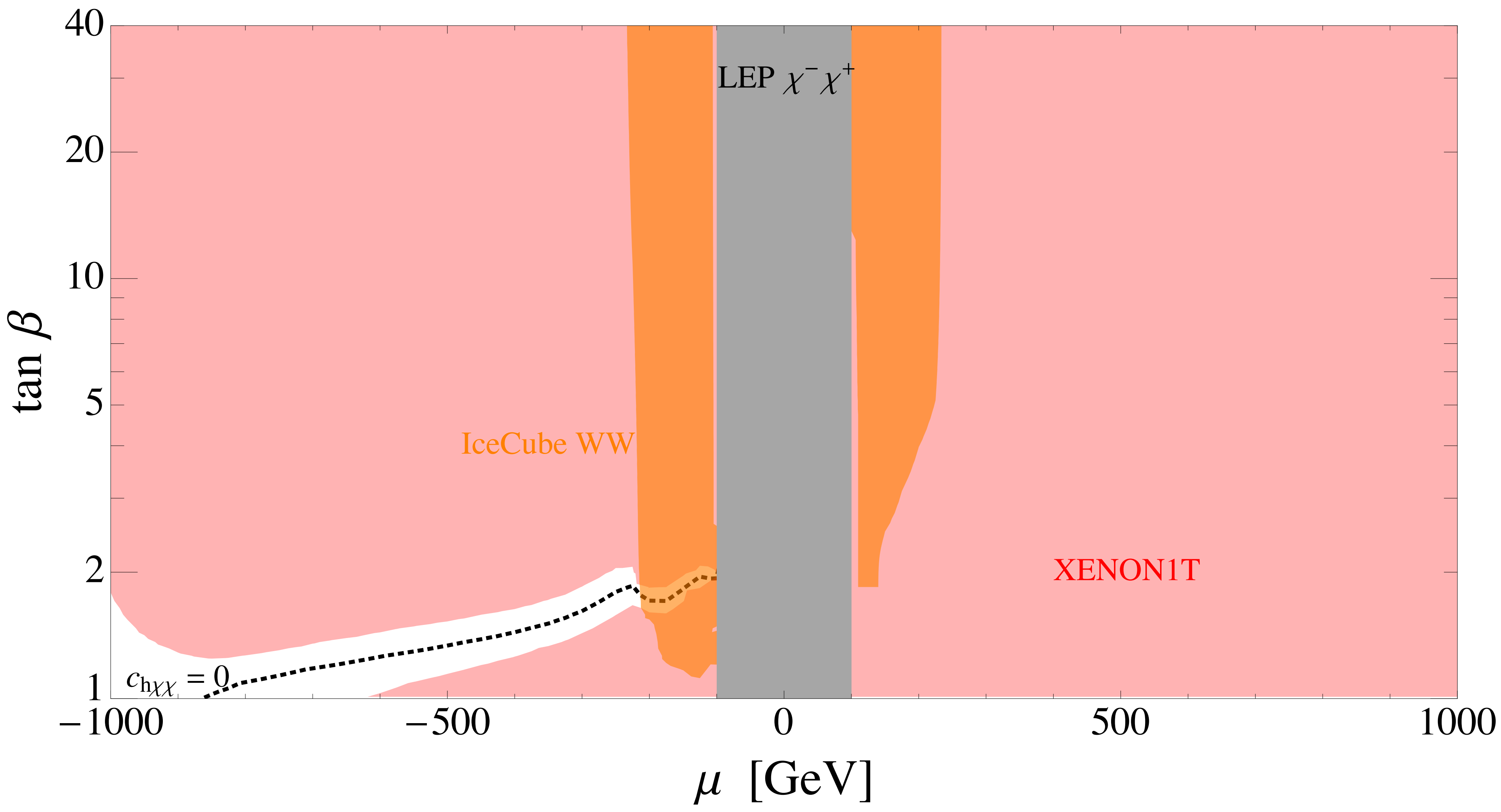
well-tempered



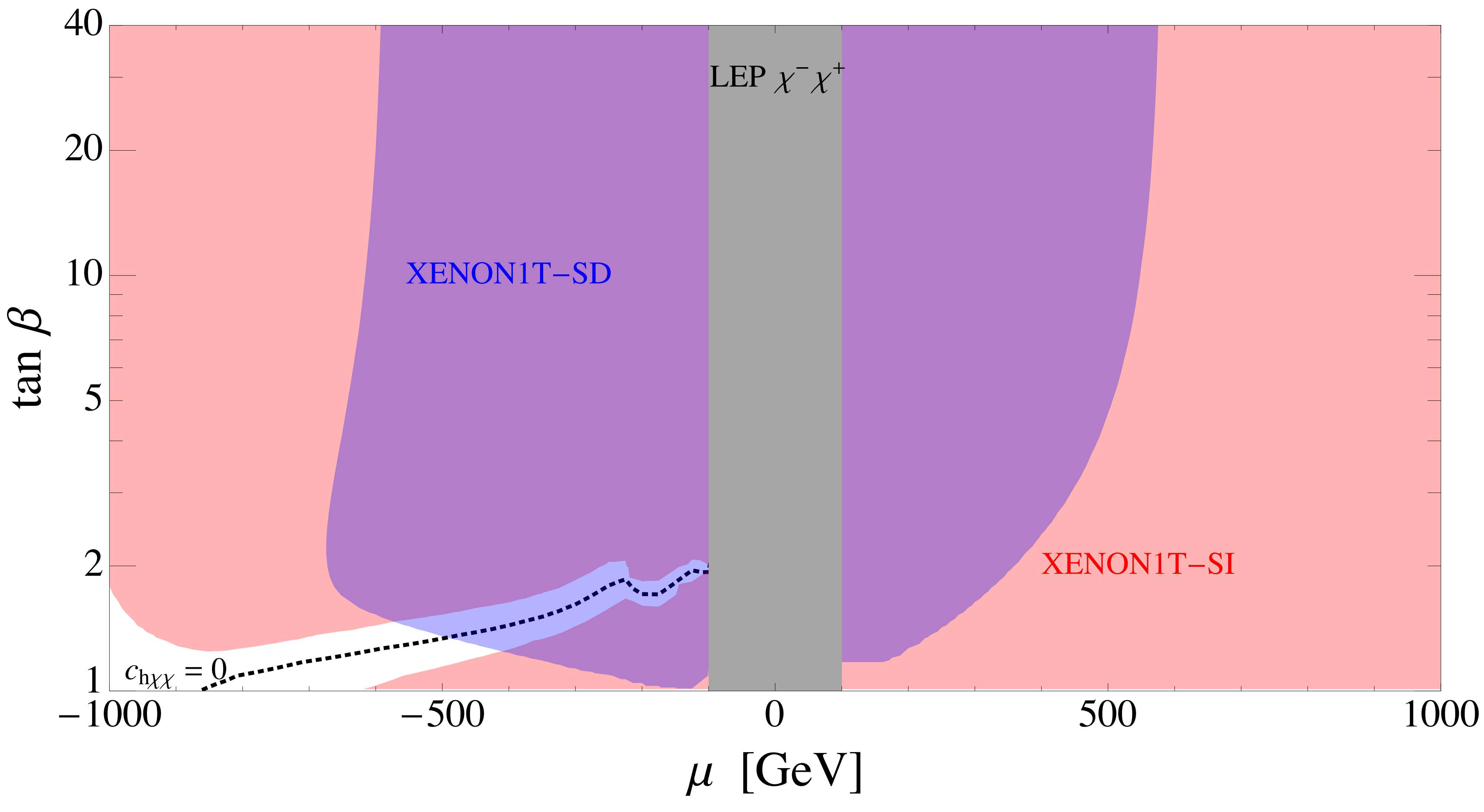
well-tempered



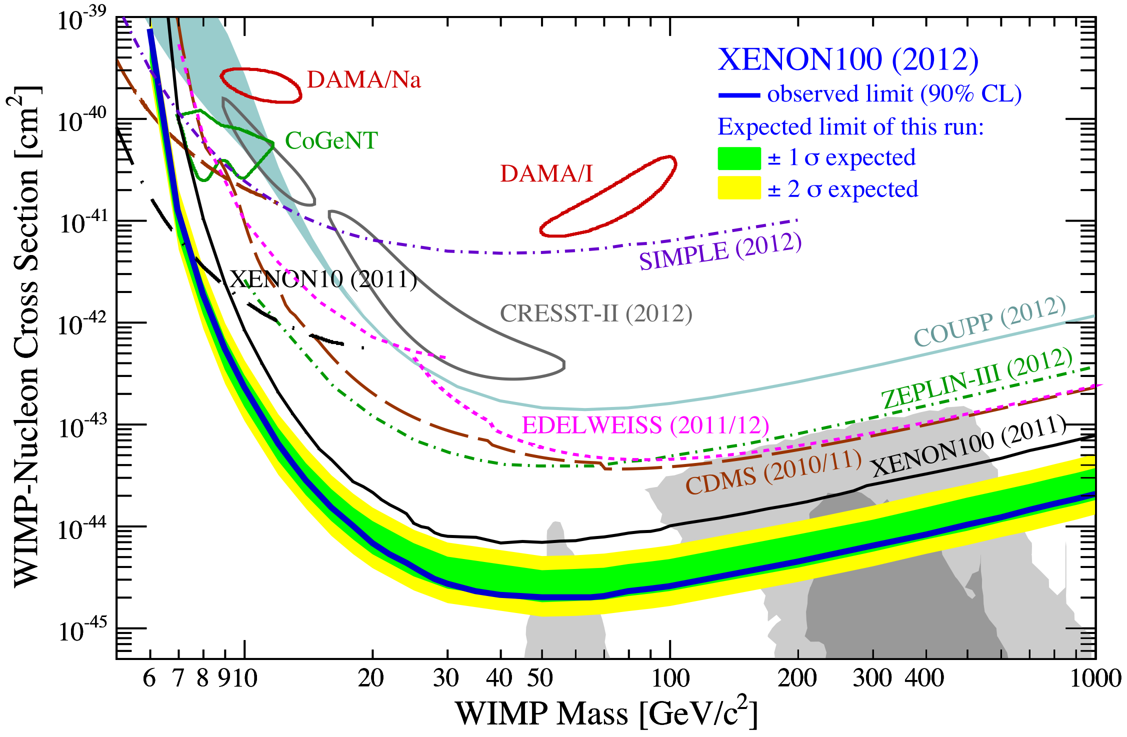
well-tempered



well-tempered

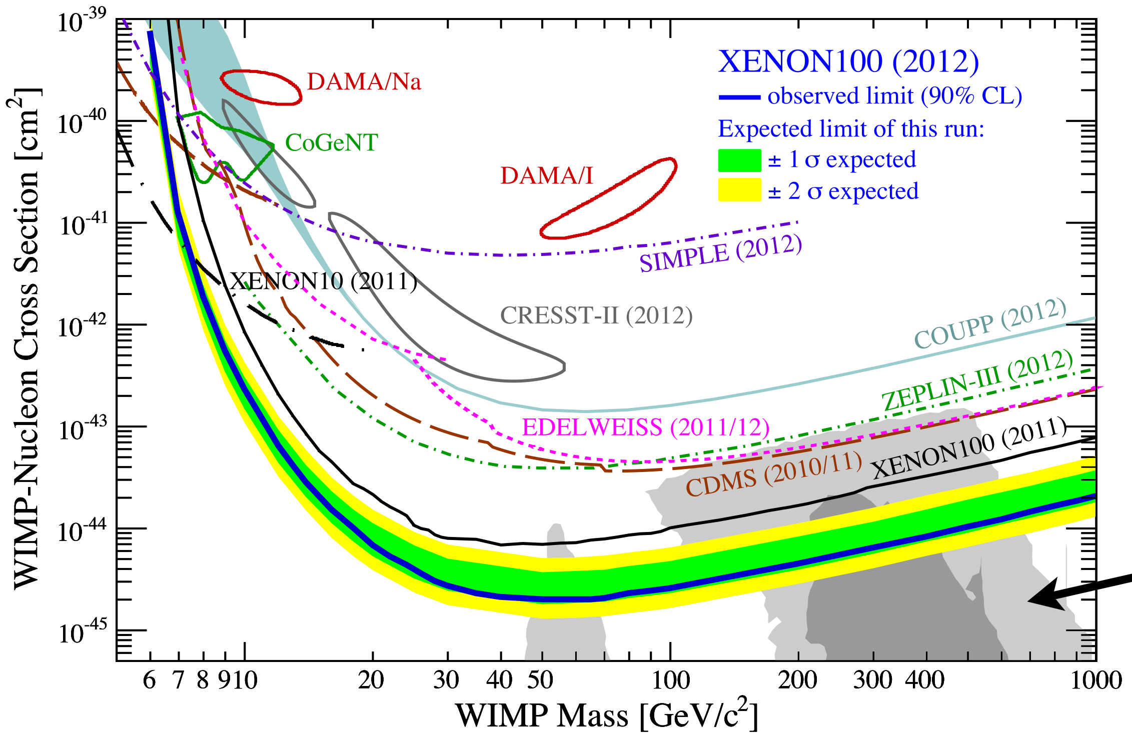


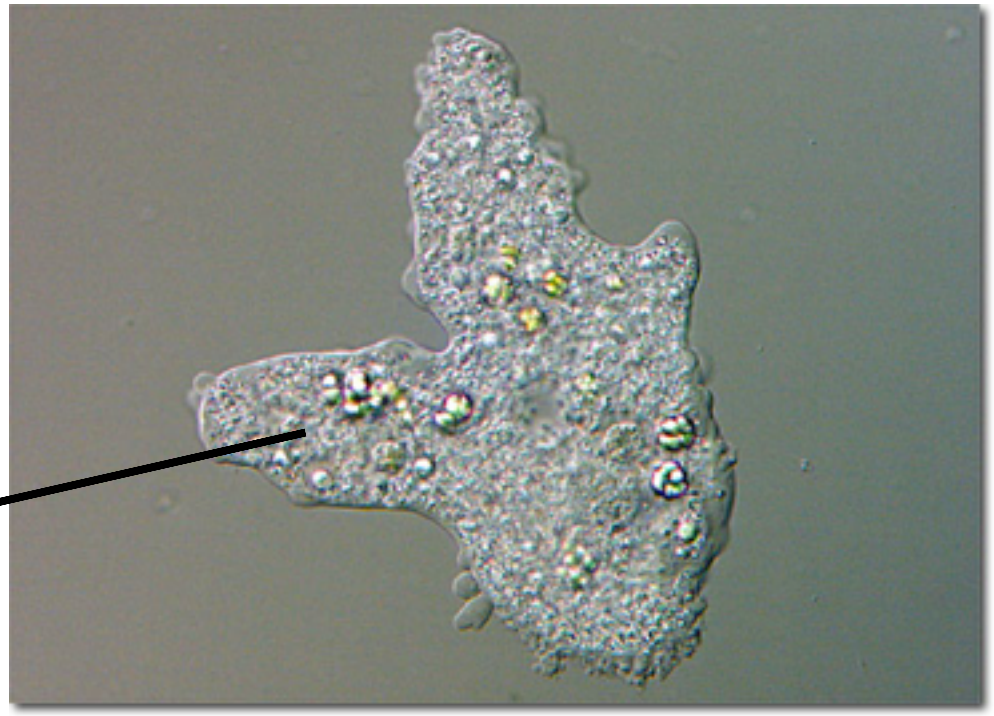
target



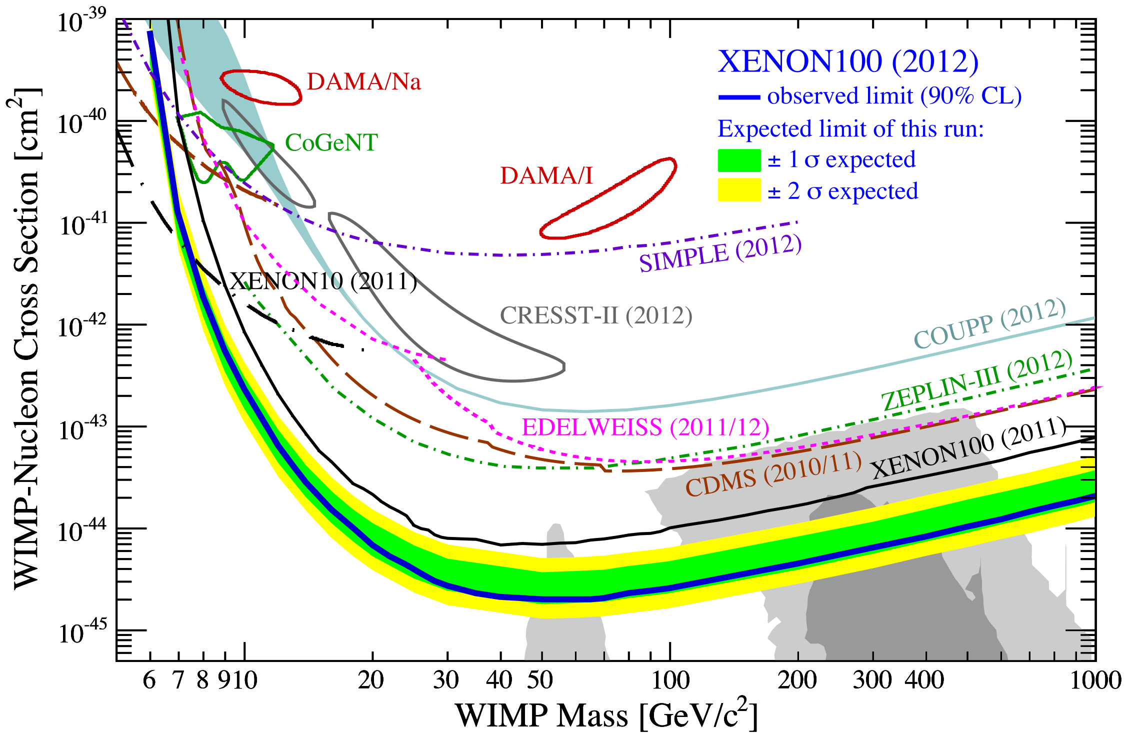
XENON100 (2012)
observed limit (90% CL)
Expected limit of this run:
± 1 σ expected
± 2 σ expected
DAMA/Na
CoGeNT
DAMA/I
SIMPLE (2012)
XENON10 (2011)
CRESST-II (2012)
COUPP (2012)
ZEPLIN-III (2012)
EDELWEISS (2011/12)
XENON100 (2011)
CDMS (2010/11)
WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]

target


XENON100 (2012)
observed limit (90% CL)
Expected limit of this run:
± 1 σ expected
± 2 σ expected
DAMA/Na
CoGeNT
DAMA/I
SIMPLE (2012)
XENON10 (2011)
CRESST-II (2012)
COUPP (2012)
ZEPLIN-III (2012)
EDELWEISS (2011/12)
CDMS (2010/11)
XENON100 (2011)
WIMP-Nucleon Cross Section [cm²]
WIMP Mass [GeV/c²]



target



XENON100 (2012)
observed limit (90% CL)
Expected limit of this run:
± 1 σ expected
± 2 σ expected
DAMA/Na
CoGeNT
DAMA/I
SIMPLE (2012)
XENON10 (2011)
CRESST-II (2012)
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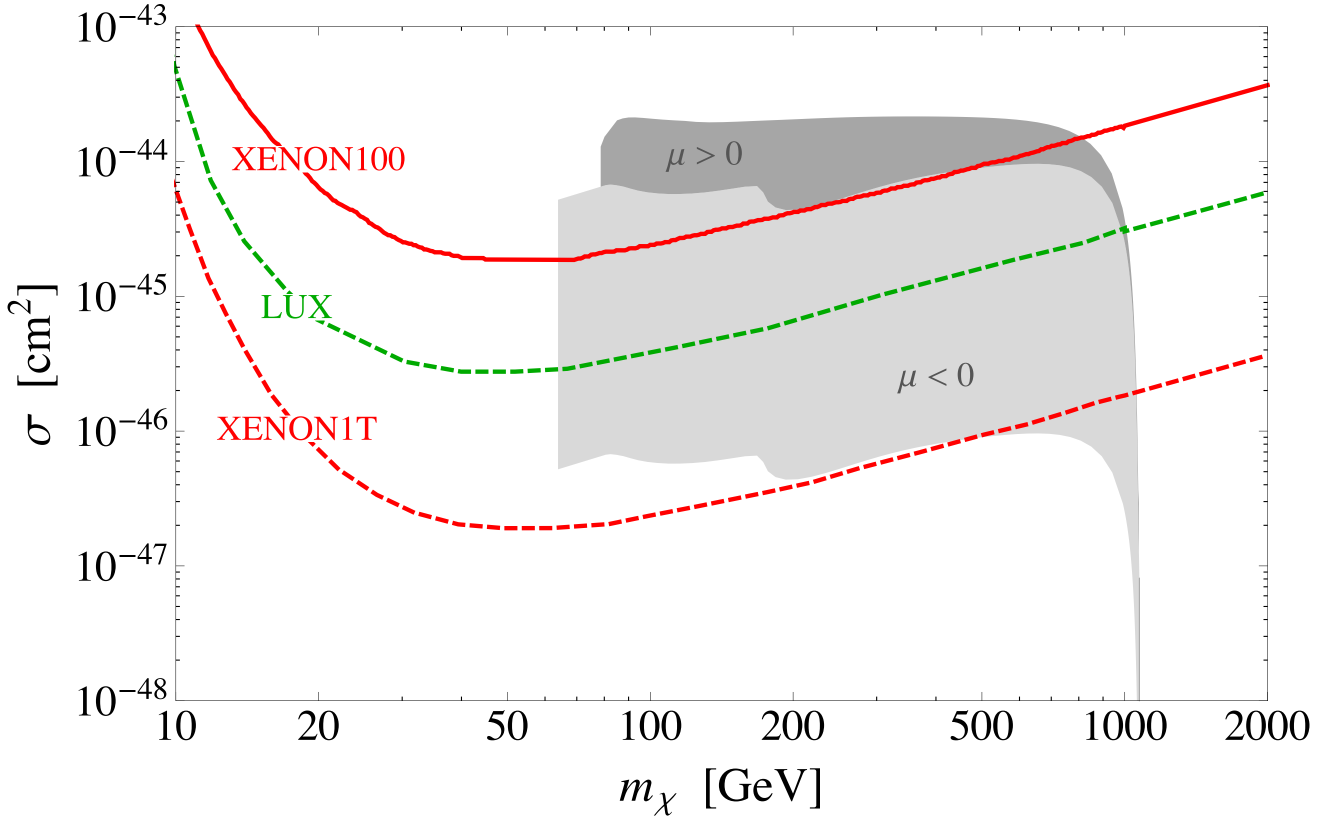
ZEPLIN-III (2012)
EDELWEISS (2011/12)
CDMS (2010/11)
XENON100 (2011)
WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]



XENON100
LUX
XENON1T
$\mu > 0$
$\mu < 0$
σ [cm^2]
m_χ [GeV]

bino-wino-(higgsino)

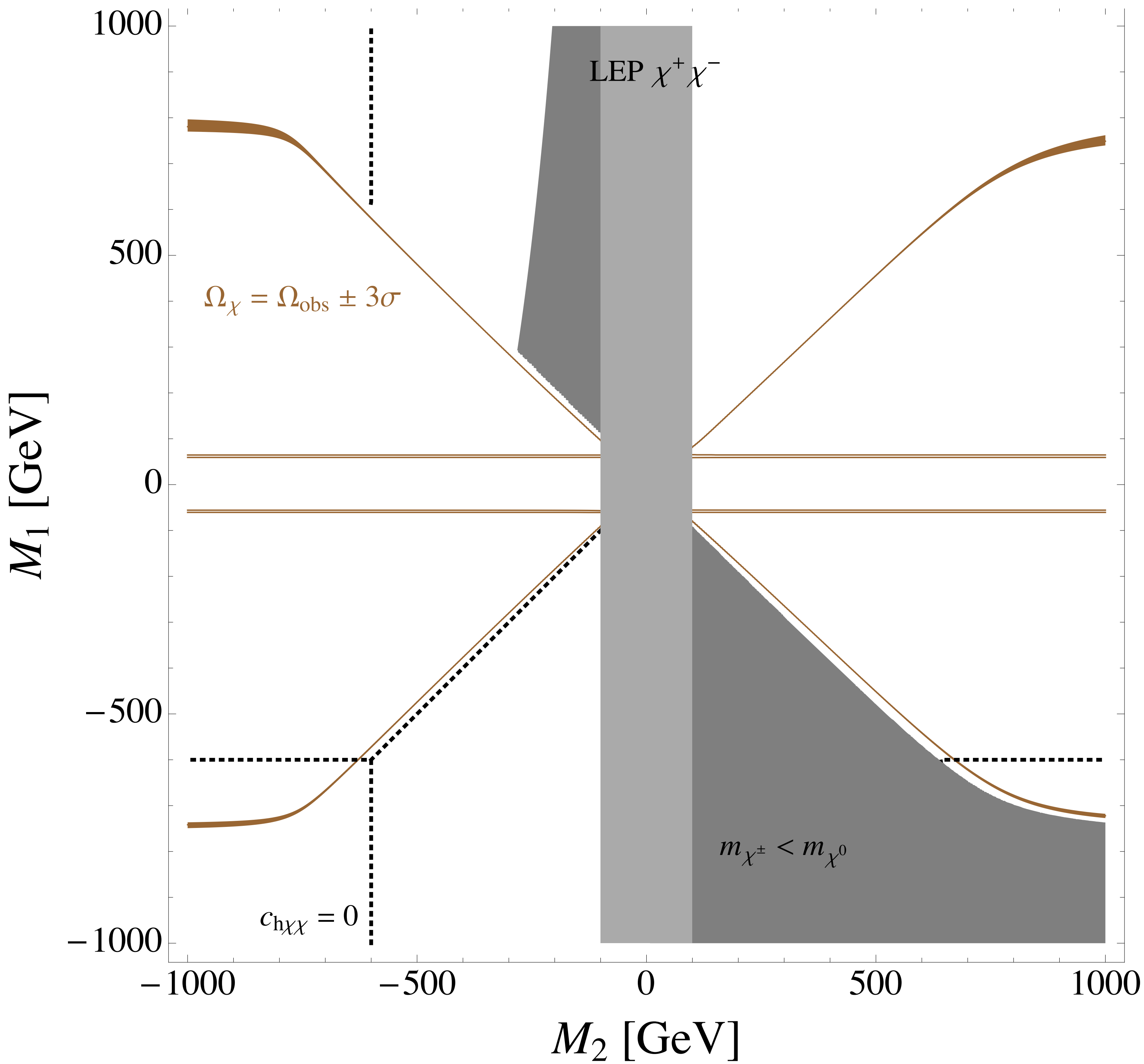
bino-wino-(higgsino)

$$\begin{pmatrix} M_1 & 0 & -\frac{g' \cos\beta}{\sqrt{2}} v & \frac{g' \sin\beta}{\sqrt{2}} v \\ 0 & M_2 & \frac{g \cos\beta}{\sqrt{2}} v & -\frac{g \sin\beta}{\sqrt{2}} v \\ -\frac{g' \cos\beta}{\sqrt{2}} v & \frac{g \cos\beta}{\sqrt{2}} v & 0 & -\mu \\ \frac{g' \sin\beta}{\sqrt{2}} v & -\frac{g \sin\beta}{\sqrt{2}} v & -\mu & 0 \end{pmatrix}$$

- parameters

$$M_1,\ M_2,\ \mu,\ \tan\beta$$

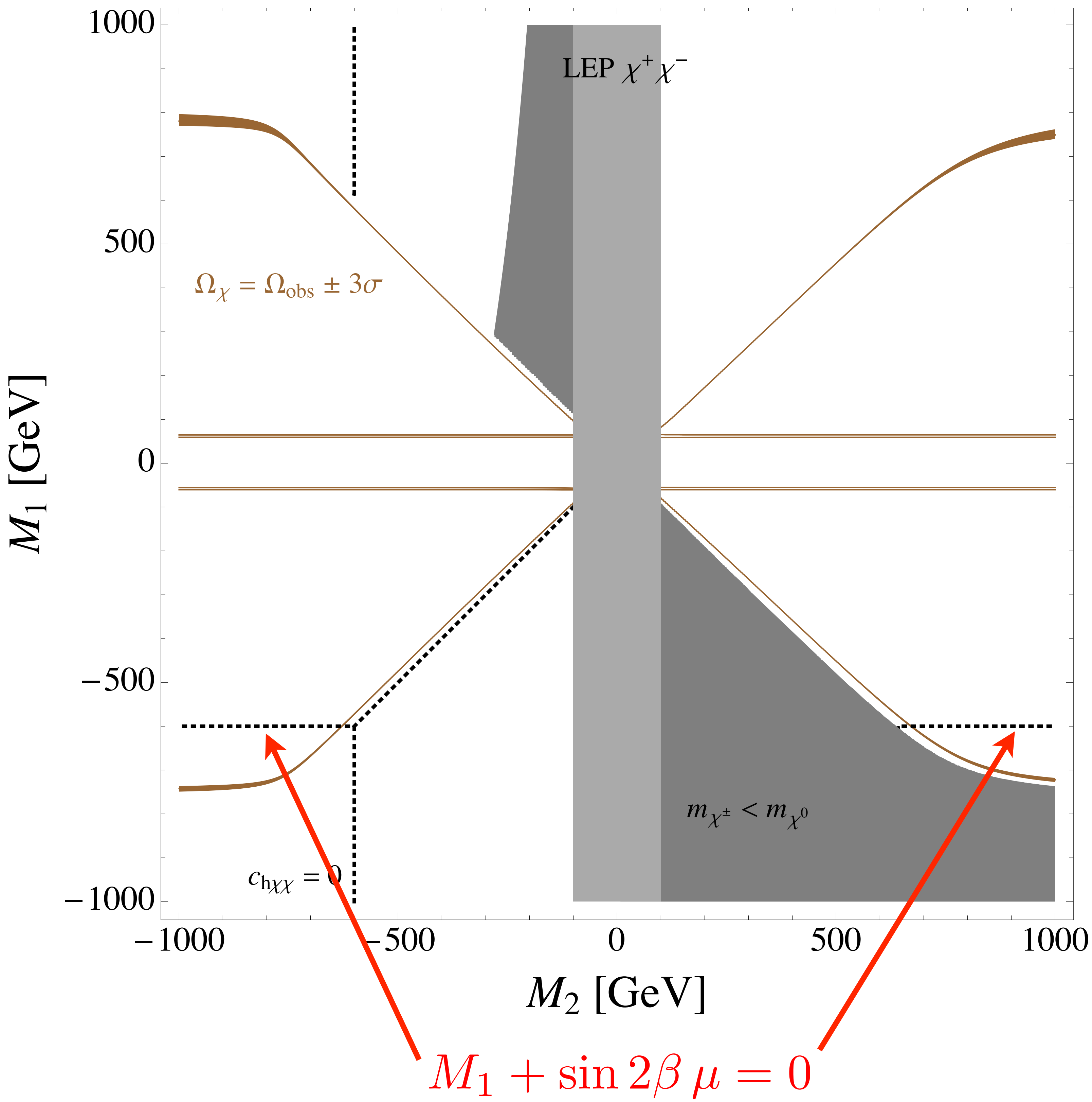
non-thermal



$\tan\beta = 2$

$\mu = 750$ GeV

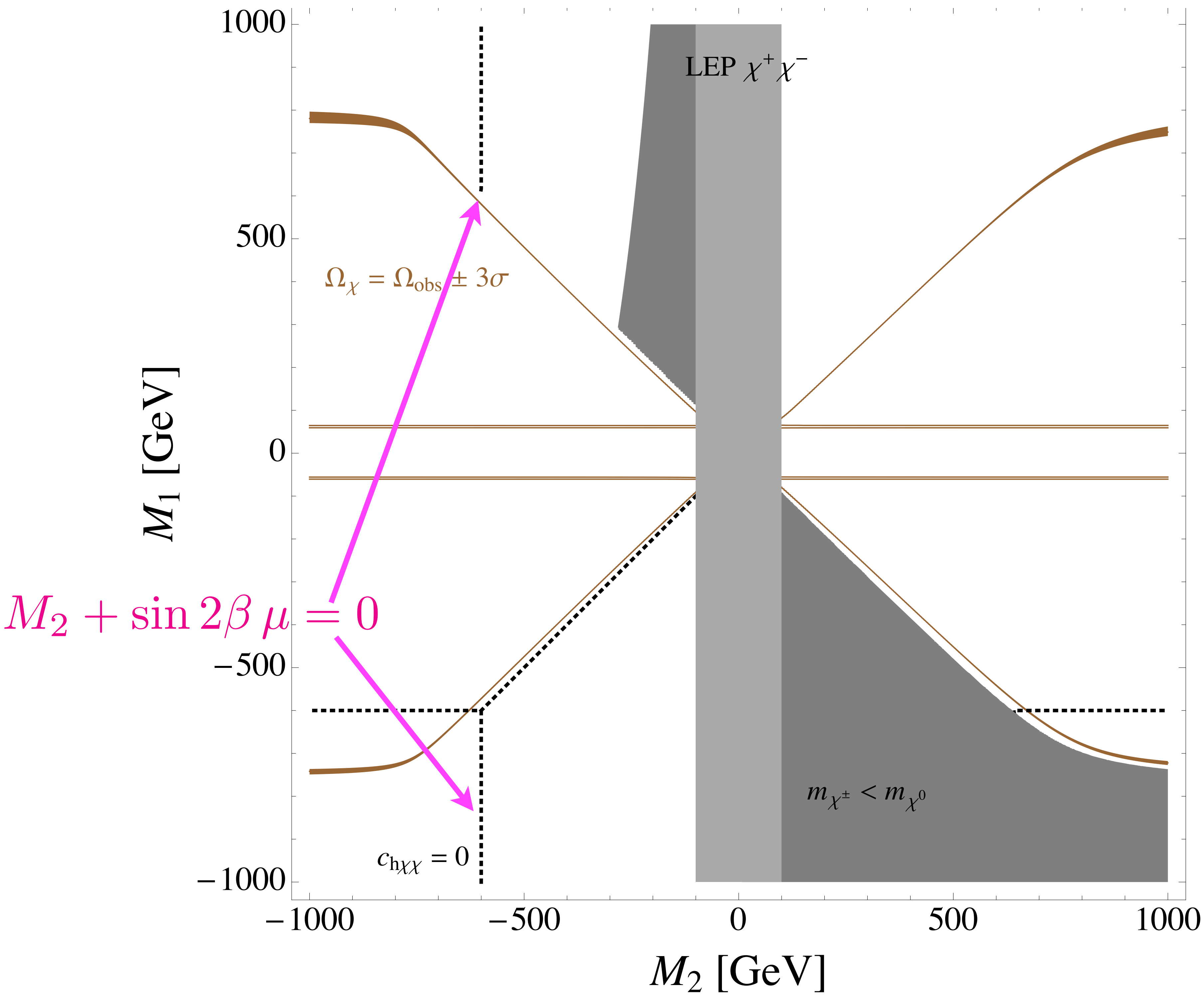
non-thermal



$$\tan\beta = 2$$

$$\mu = 750\ \mathrm{GeV}$$

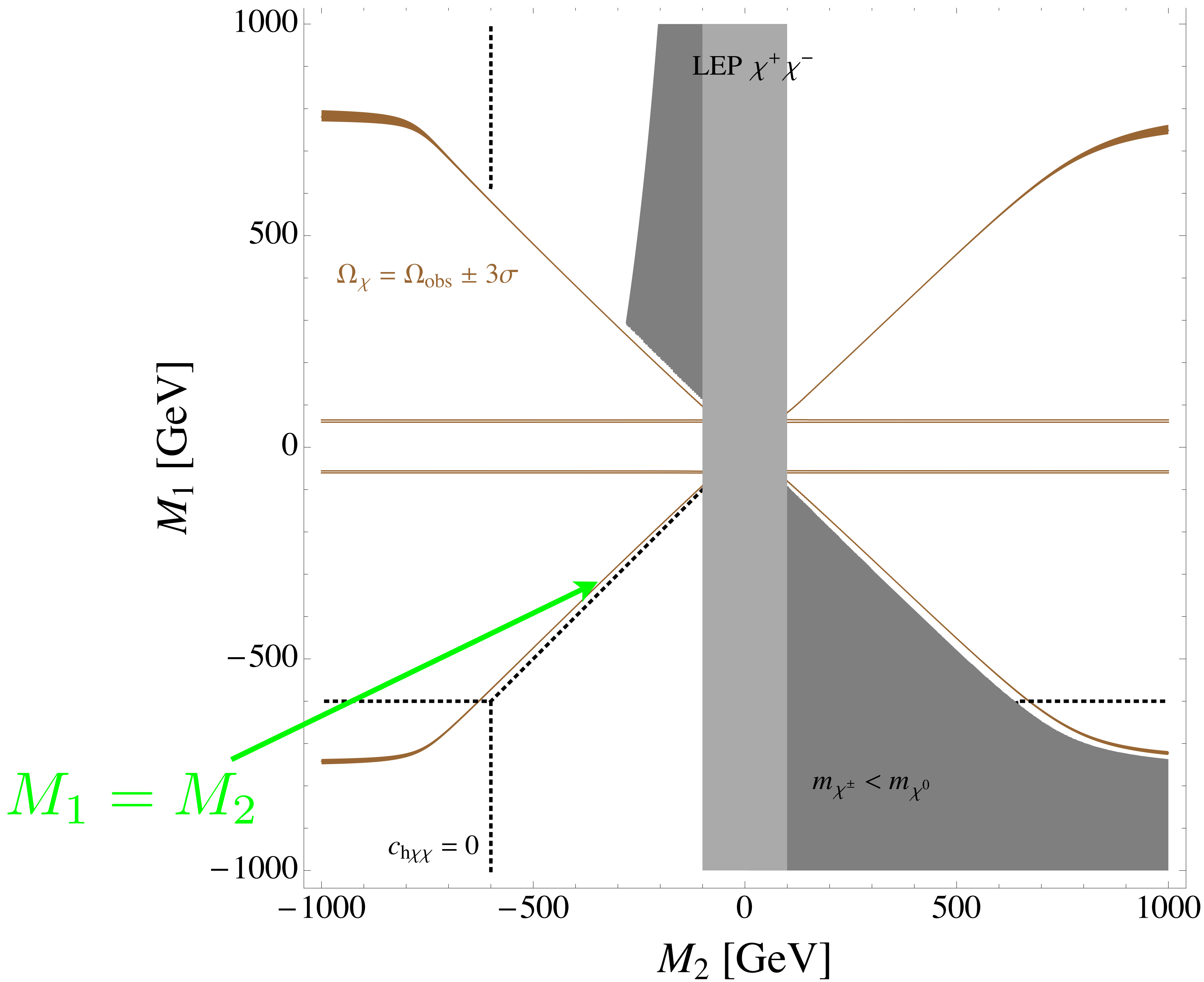
non-thermal



$$\tan\beta = 2$$

$$\mu = 750 \text{ GeV}$$

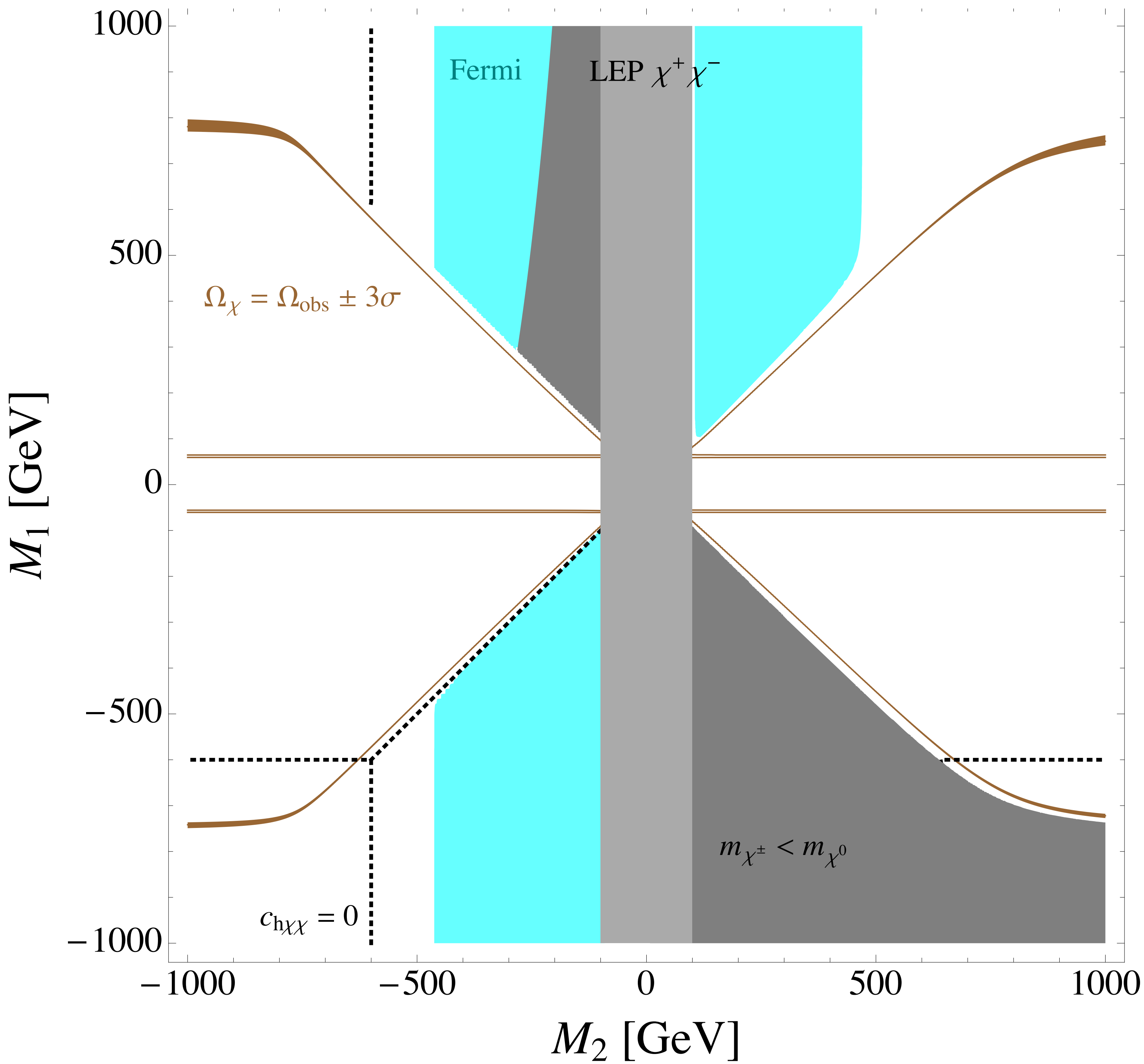
non-thermal



$\tan\beta = 2$

$\mu = 750$ GeV

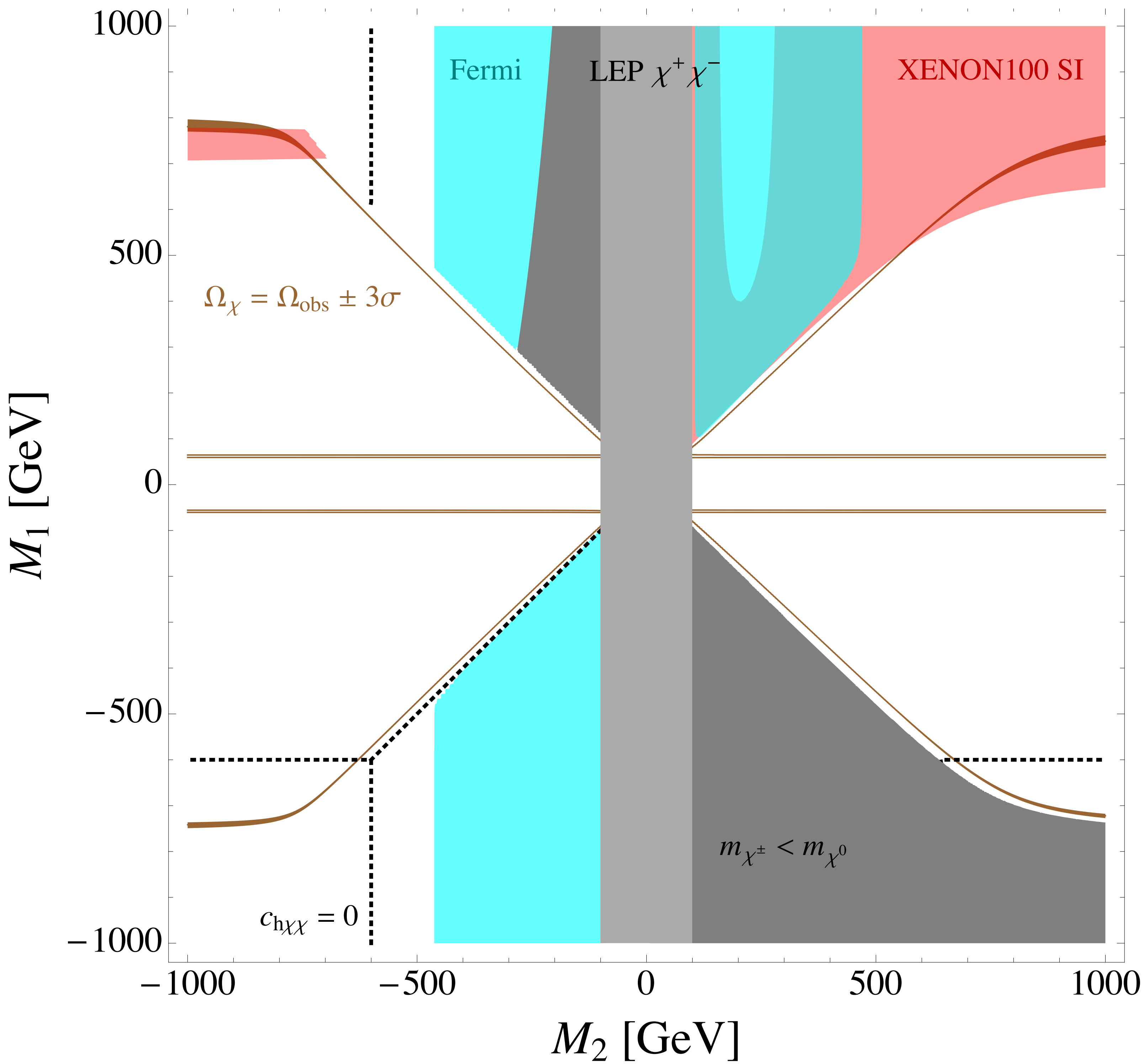
non-thermal



$\tan\beta = 2$

$\mu = 750$ GeV

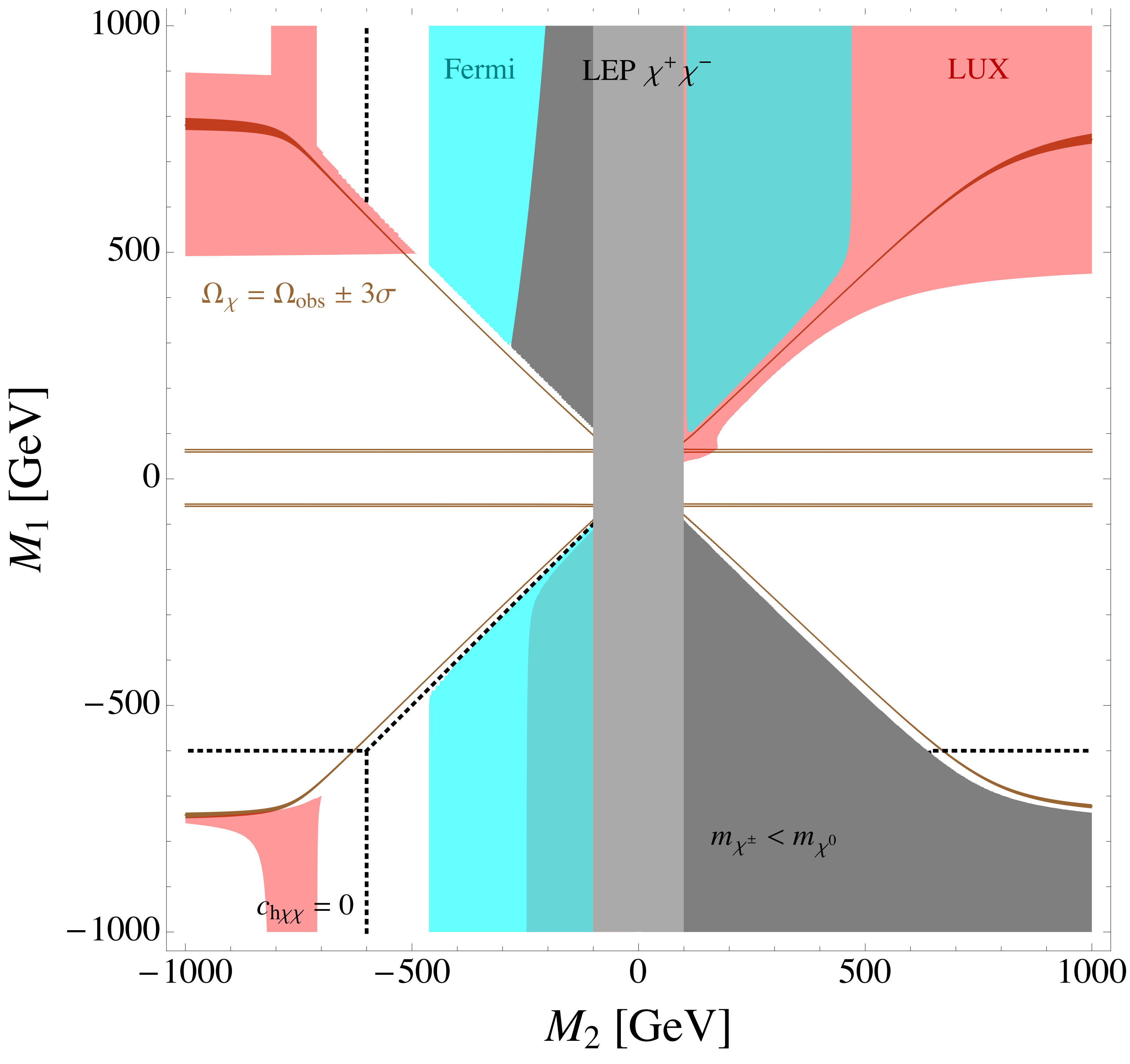
non-thermal



$$\tan\beta = 2$$

$$\mu = 750\ \mathrm{GeV}$$

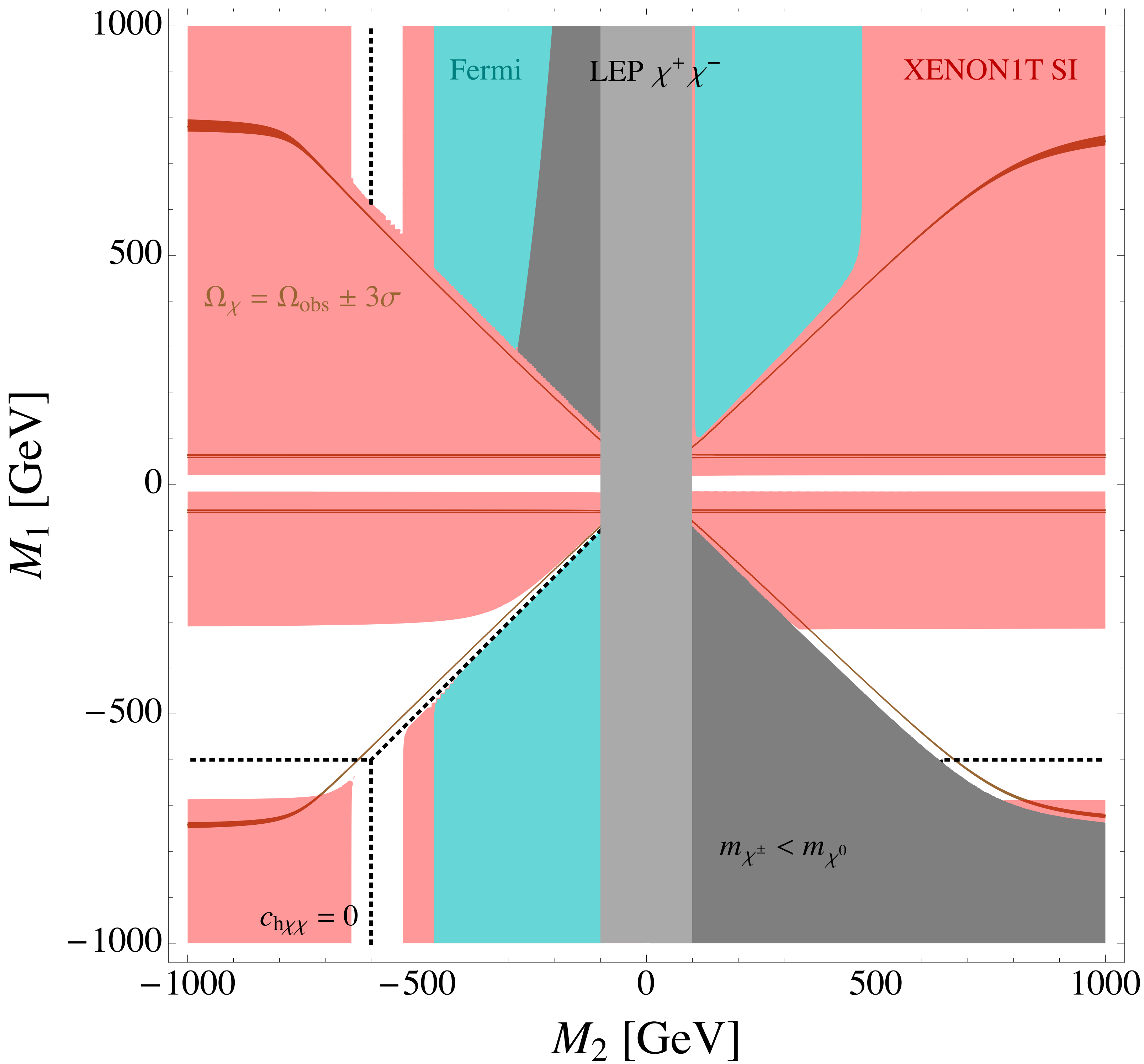
non-thermal



$\tan\beta = 2$

$\mu = 750$ GeV

non-thermal



$$\tan\beta = 2$$

$$\mu = 750 \text{ GeV}$$

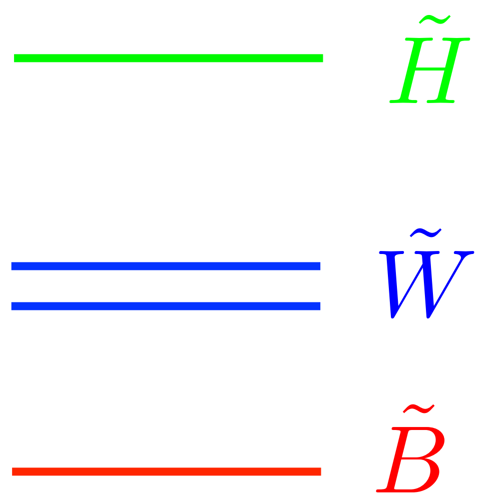
well-tempered

$$\Omega\ (M_1, M_2, \mu, \tan\beta) = \Omega_{DM}$$

solve for:

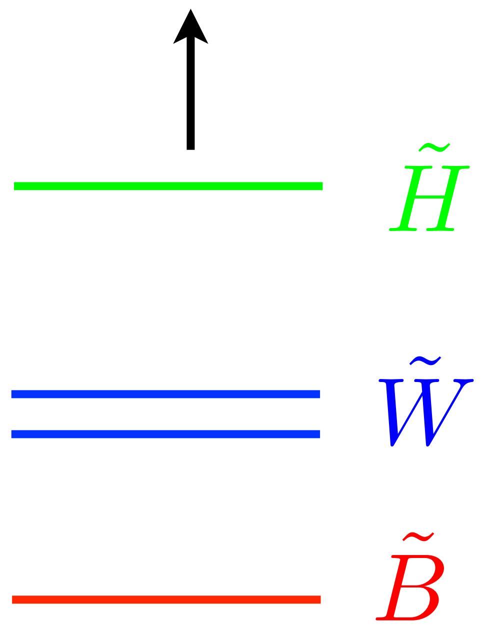
$$M_1\,(M_2, \mu, \tan\beta)$$

bino/wino coannihilation



$$\begin{pmatrix} M_1 & 0 & -\frac{g'\cos\beta}{\sqrt{2}}v & \frac{g'\sin\beta}{\sqrt{2}}v \\ 0 & M_2 & \frac{g\cos\beta}{\sqrt{2}}v & -\frac{g\sin\beta}{\sqrt{2}}v \\ -\frac{g'\cos\beta}{\sqrt{2}}v & \frac{g\cos\beta}{\sqrt{2}}v & 0 & -\mu \\ \frac{g'\sin\beta}{\sqrt{2}}v & -\frac{g\sin\beta}{\sqrt{2}}v & -\mu & 0 \end{pmatrix}$$

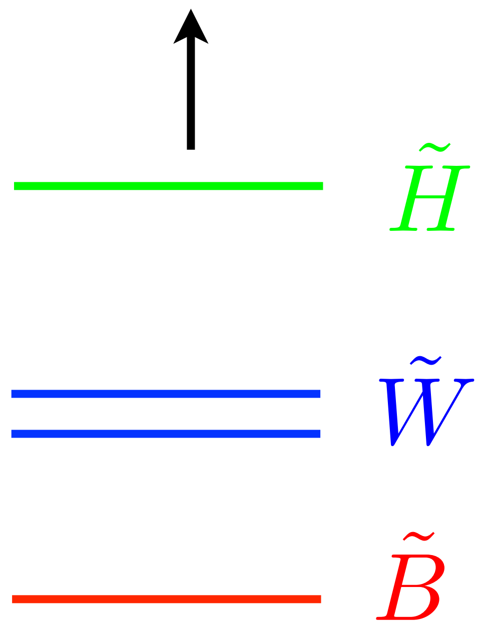
bino/wino coannihilation



$$\begin{pmatrix} M_1 & 0 & -\frac{g' \cos\beta}{\sqrt{2}}v & \frac{g' \sin\beta}{\sqrt{2}}v \\ 0 & M_2 & \frac{g \cos\beta}{\sqrt{2}}v & -\frac{g \sin\beta}{\sqrt{2}}v \\ -\frac{g' \cos\beta}{\sqrt{2}}v & \frac{g \cos\beta}{\sqrt{2}}v & 0 & -\mu \\ \frac{g' \sin\beta}{\sqrt{2}}v & -\frac{g \sin\beta}{\sqrt{2}}v & -\mu & 0 \end{pmatrix}$$

how heavy can the higgsino be?

bino/wino coannihilation



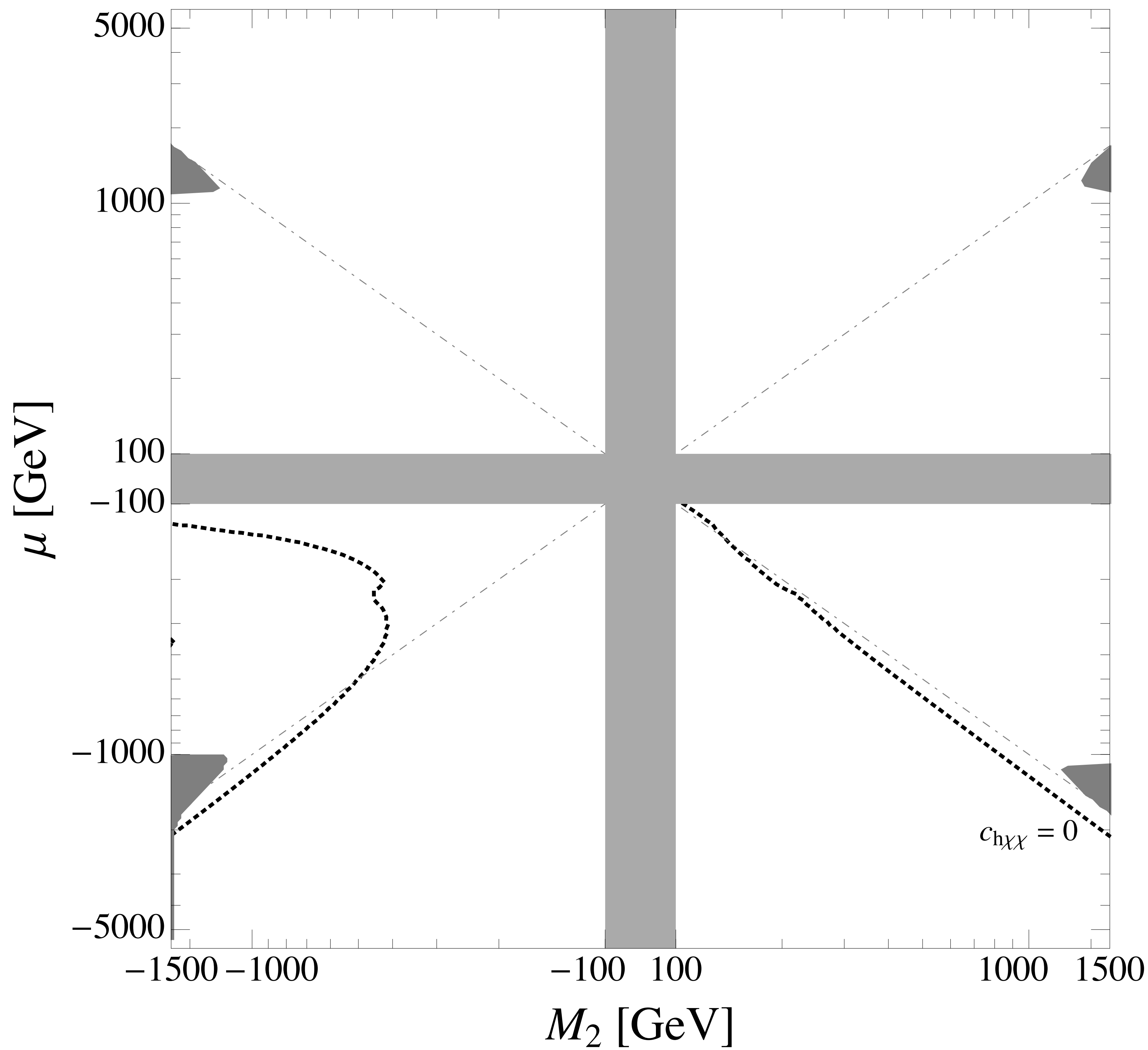
$$\begin{pmatrix} M_1 & 0 & -\frac{g' \cos\beta}{\sqrt{2}} v & \frac{g' \sin\beta}{\sqrt{2}} v \\ 0 & M_2 & \frac{g \cos\beta}{\sqrt{2}} v & -\frac{g \sin\beta}{\sqrt{2}} v \\ -\frac{g' \cos\beta}{\sqrt{2}} v & \frac{g \cos\beta}{\sqrt{2}} v & 0 & -\mu \\ \frac{g' \sin\beta}{\sqrt{2}} v & -\frac{g \sin\beta}{\sqrt{2}} v & -\mu & 0 \end{pmatrix}$$

how heavy can the higgsino be?

coannihilation:

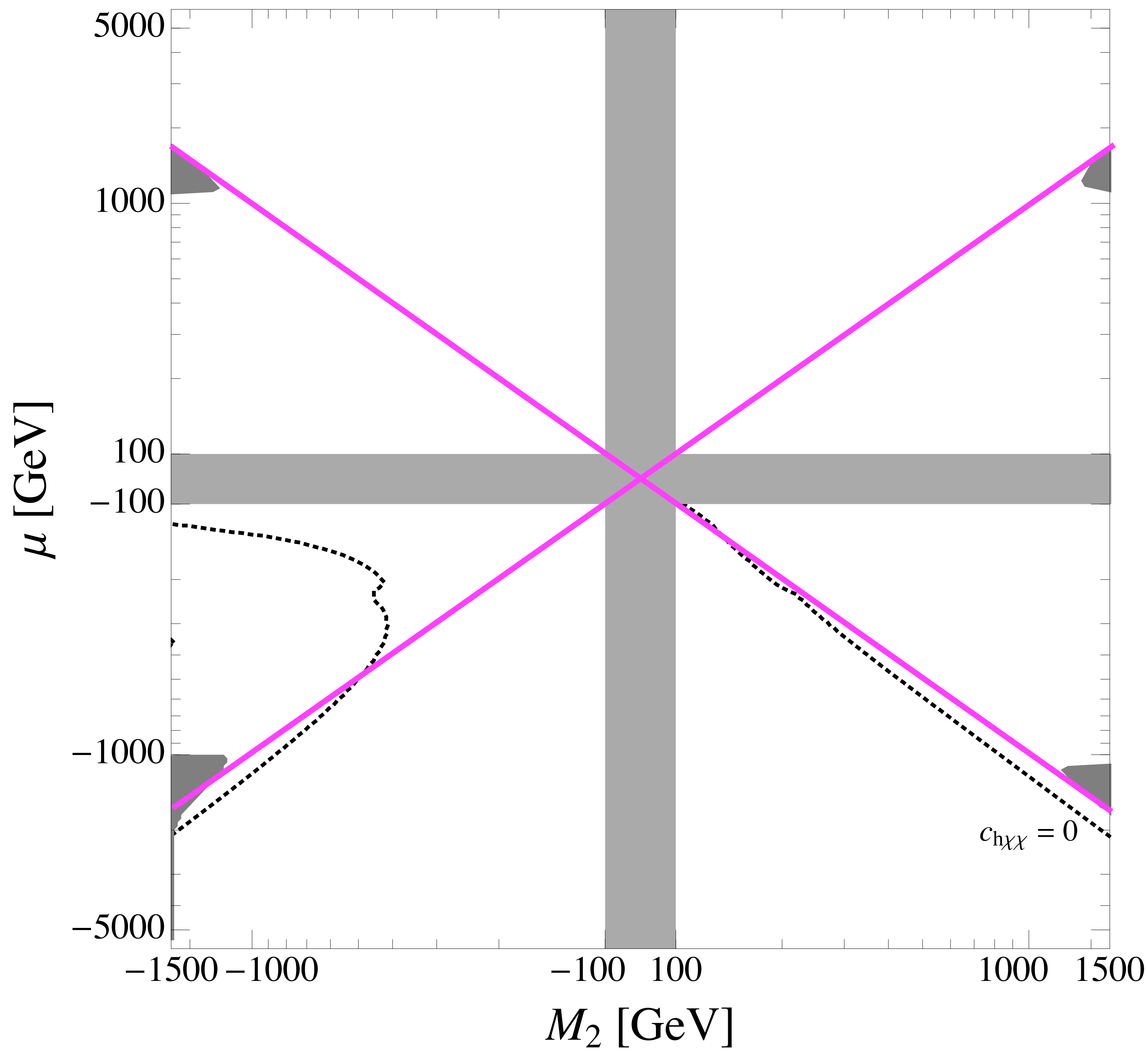
$$\langle \sigma_{eff}\, v \rangle = \frac{\Sigma_{i,j}\, w_i w_j\ \langle \sigma_{ij} v \rangle}{\left(\Sigma_i\, w_i\right)^2} \qquad w_i = \left(\frac{m_i}{m_1}\right)^{3/2} e^{-x\left(\frac{m_i}{m_1}-1\right)}$$

well-tempered



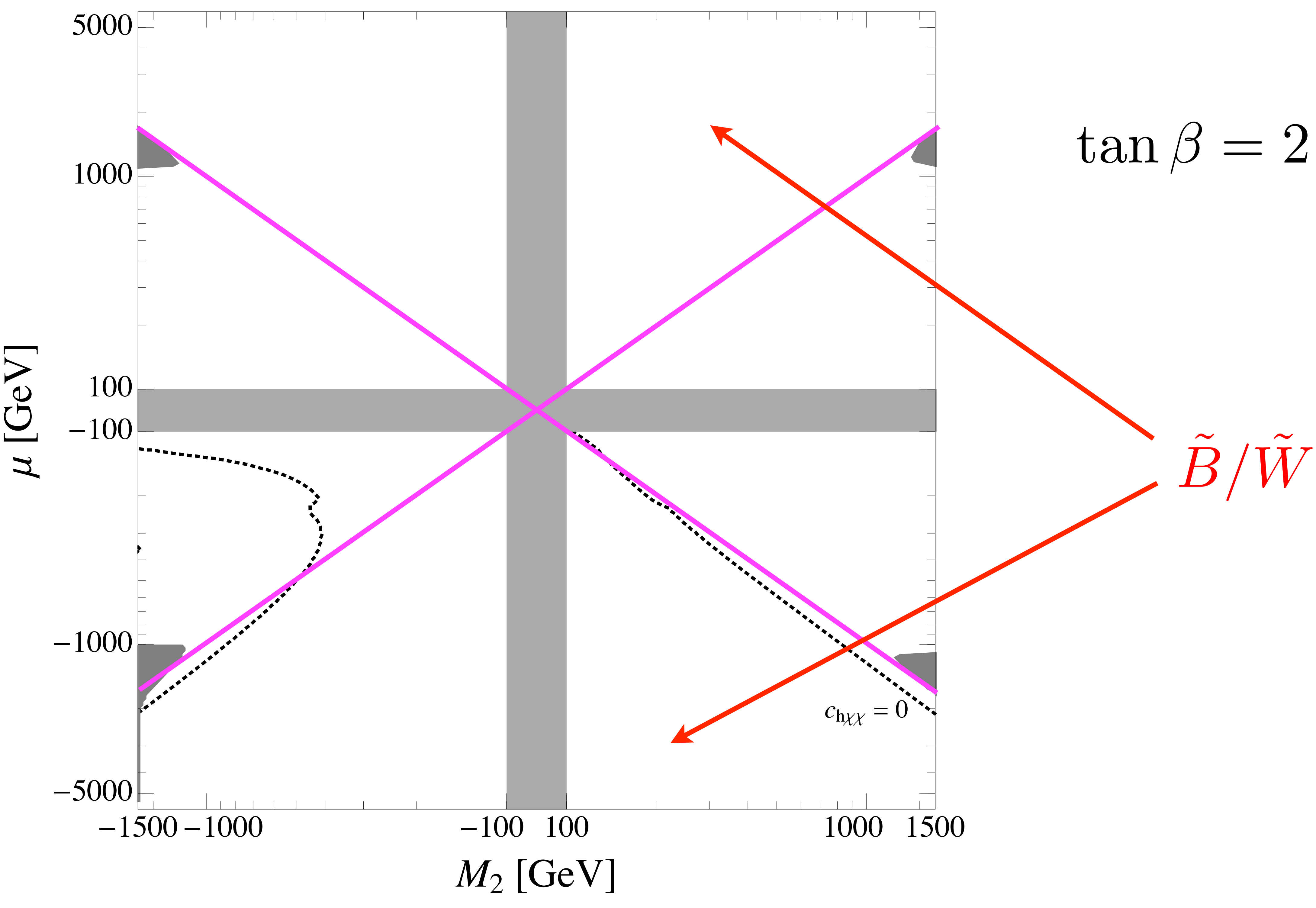
$$\tan\beta = 2$$

well-tempered

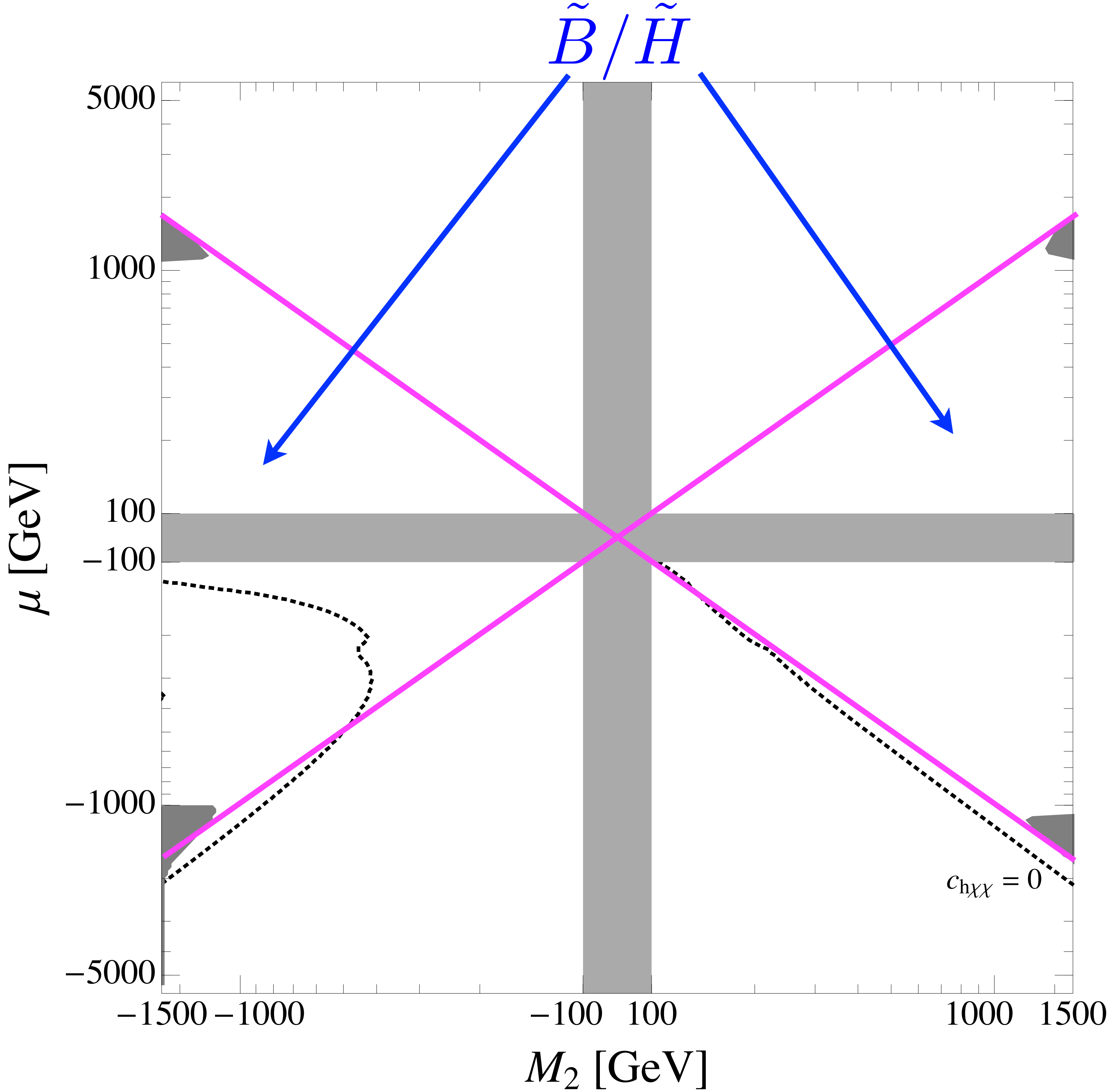


$$\tan\beta = 2$$

well-tempered

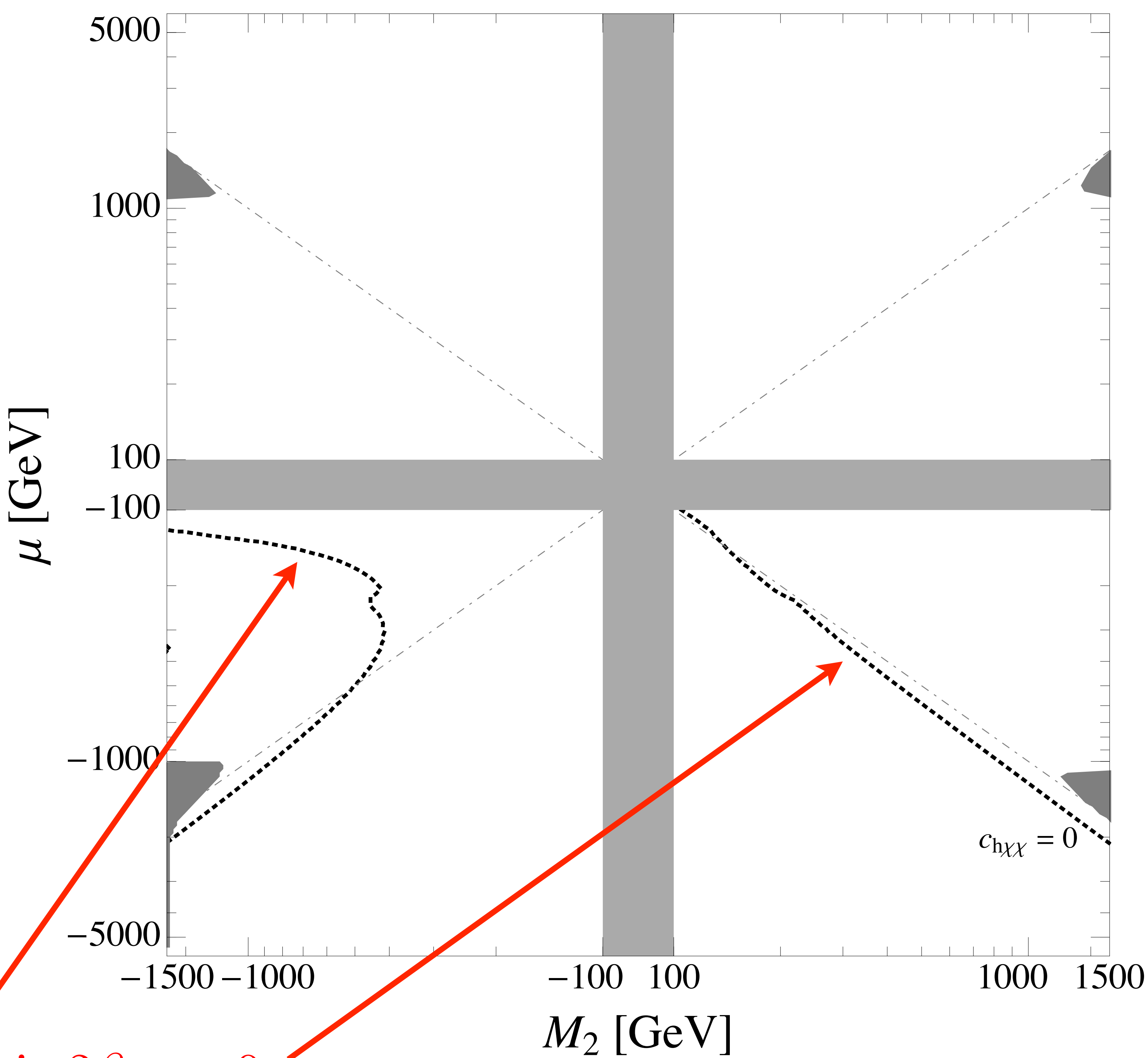


well-tempered



$\tan\beta = 2$

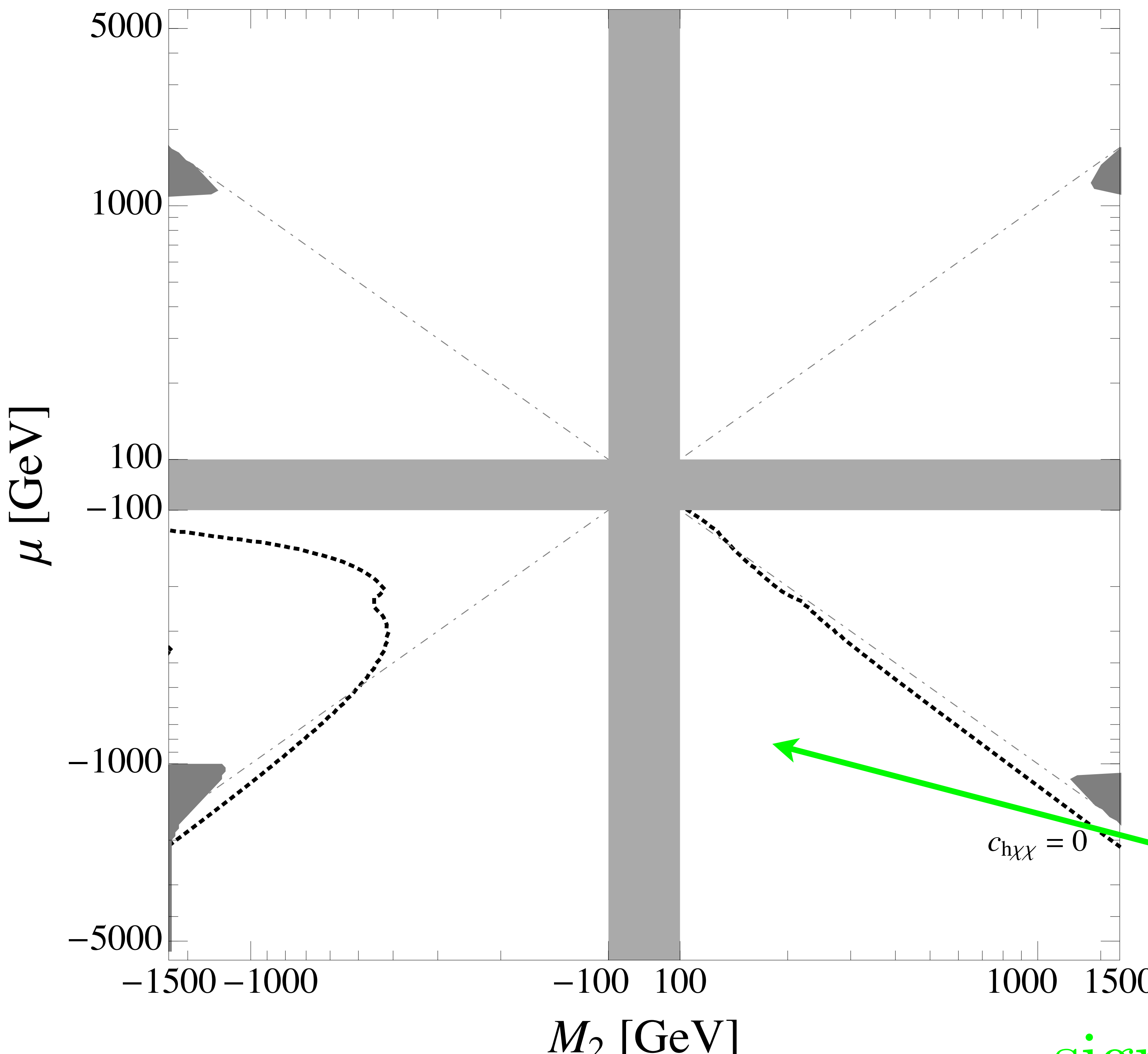
well-tempered



$\tan\beta = 2$

$M_1 + \sin 2\beta\,\mu = 0$

well-tempered

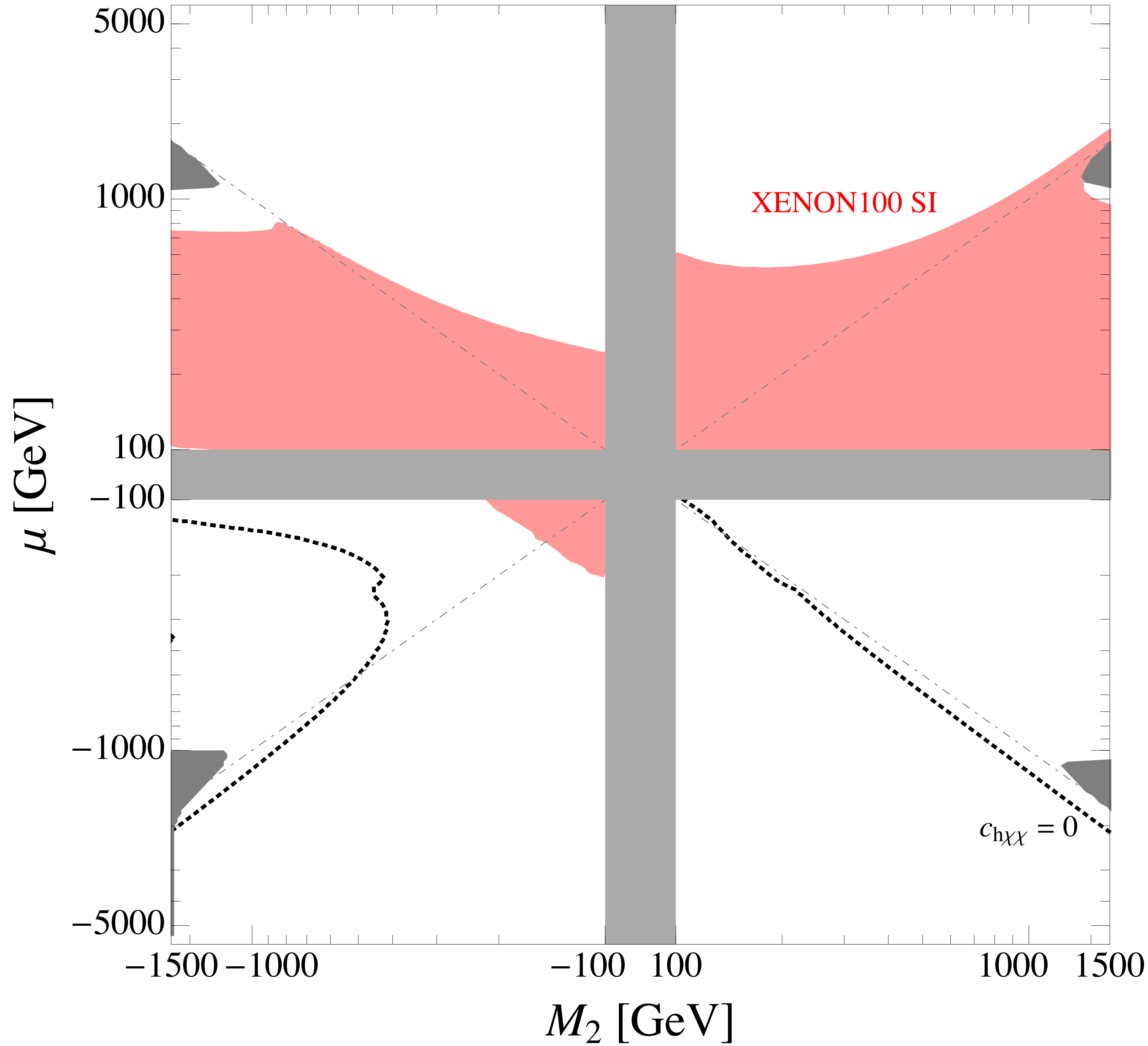


$\tan\beta = 2$

$M_1 \approx M_2$

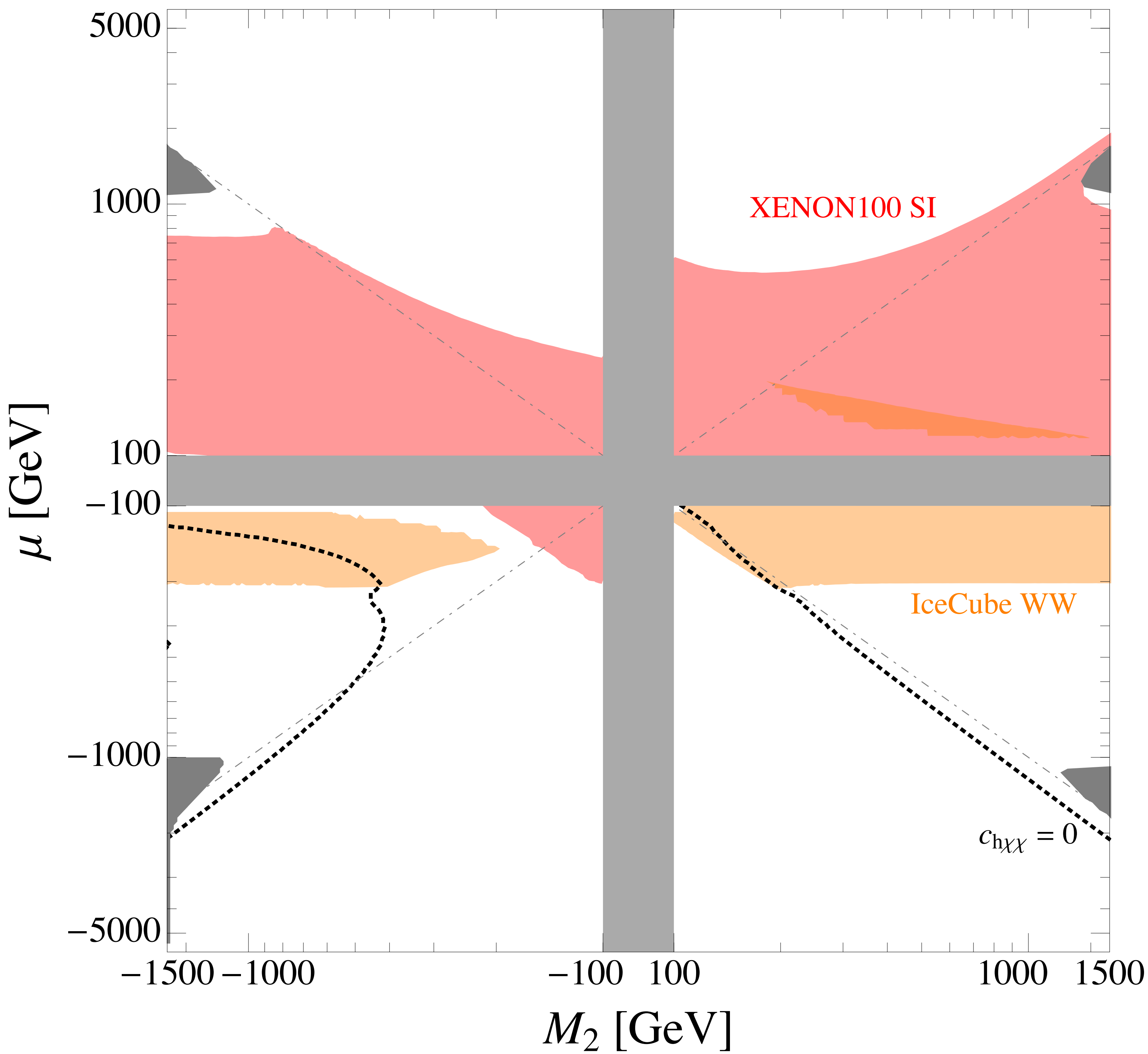
$\mathrm{sign}(\mu) = -\mathrm{sign}(M_{1,2})$

well-tempered



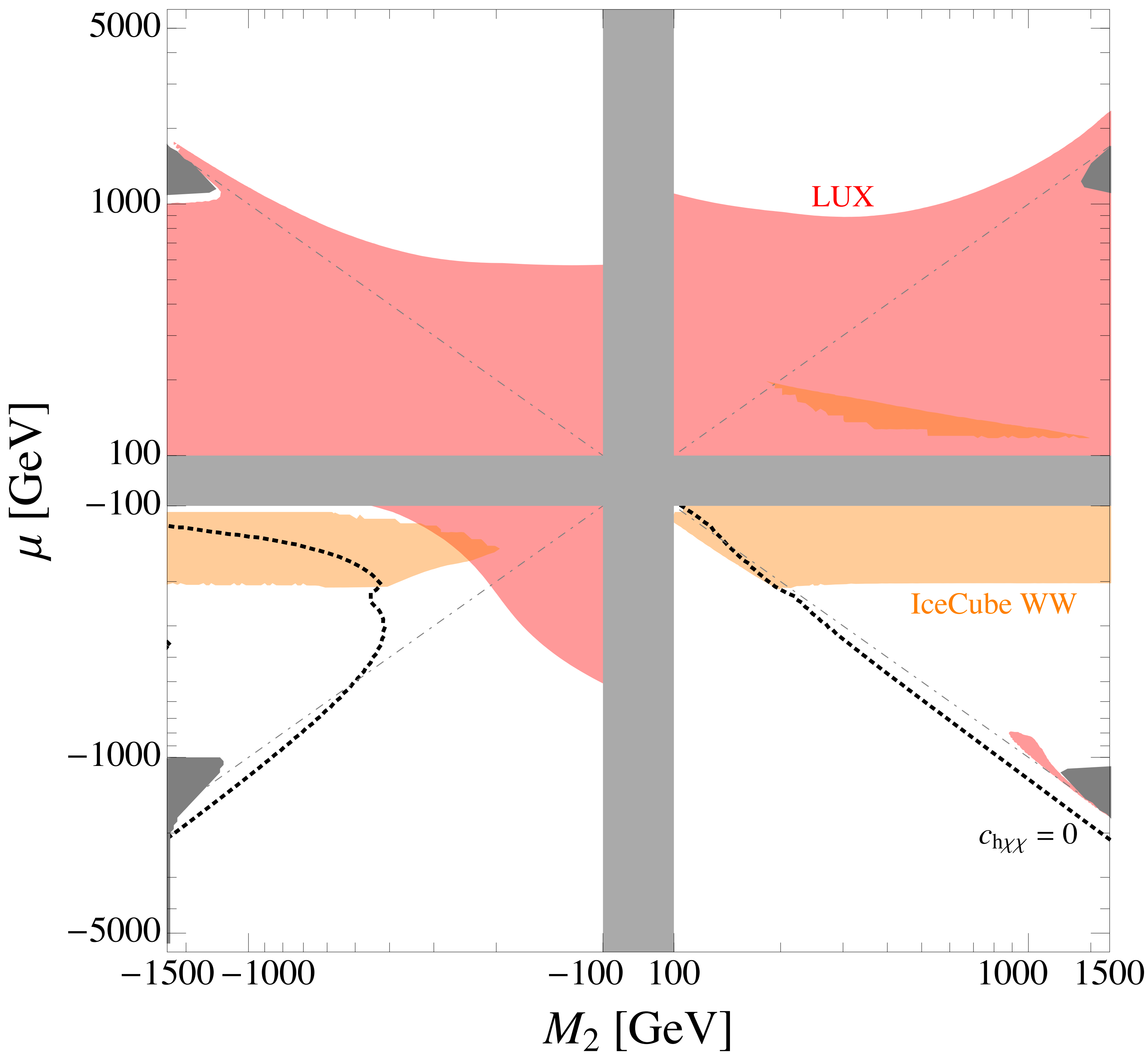
$$\tan\beta = 2$$

well-tempered



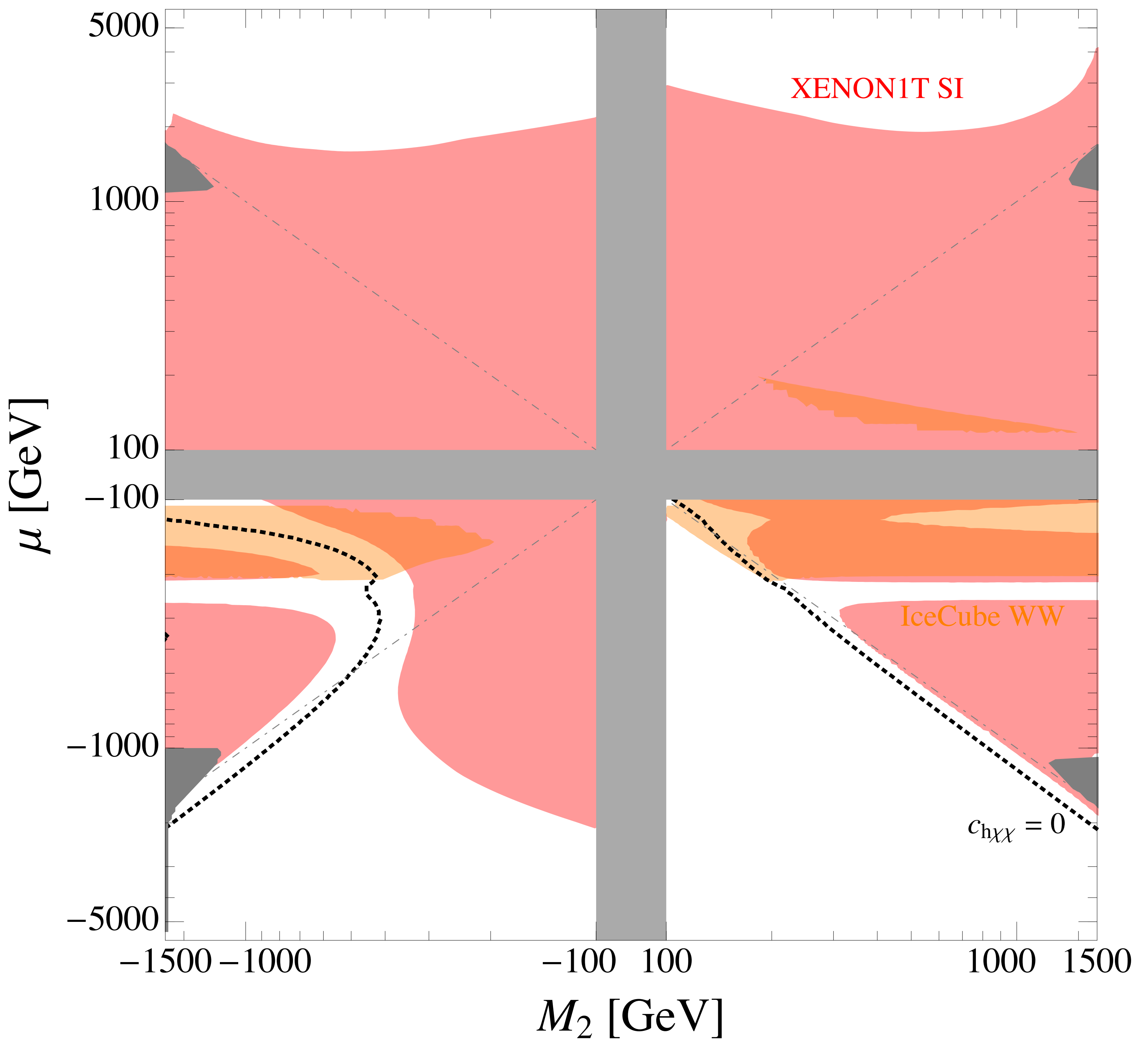
$\tan\beta = 2$

well-tempered



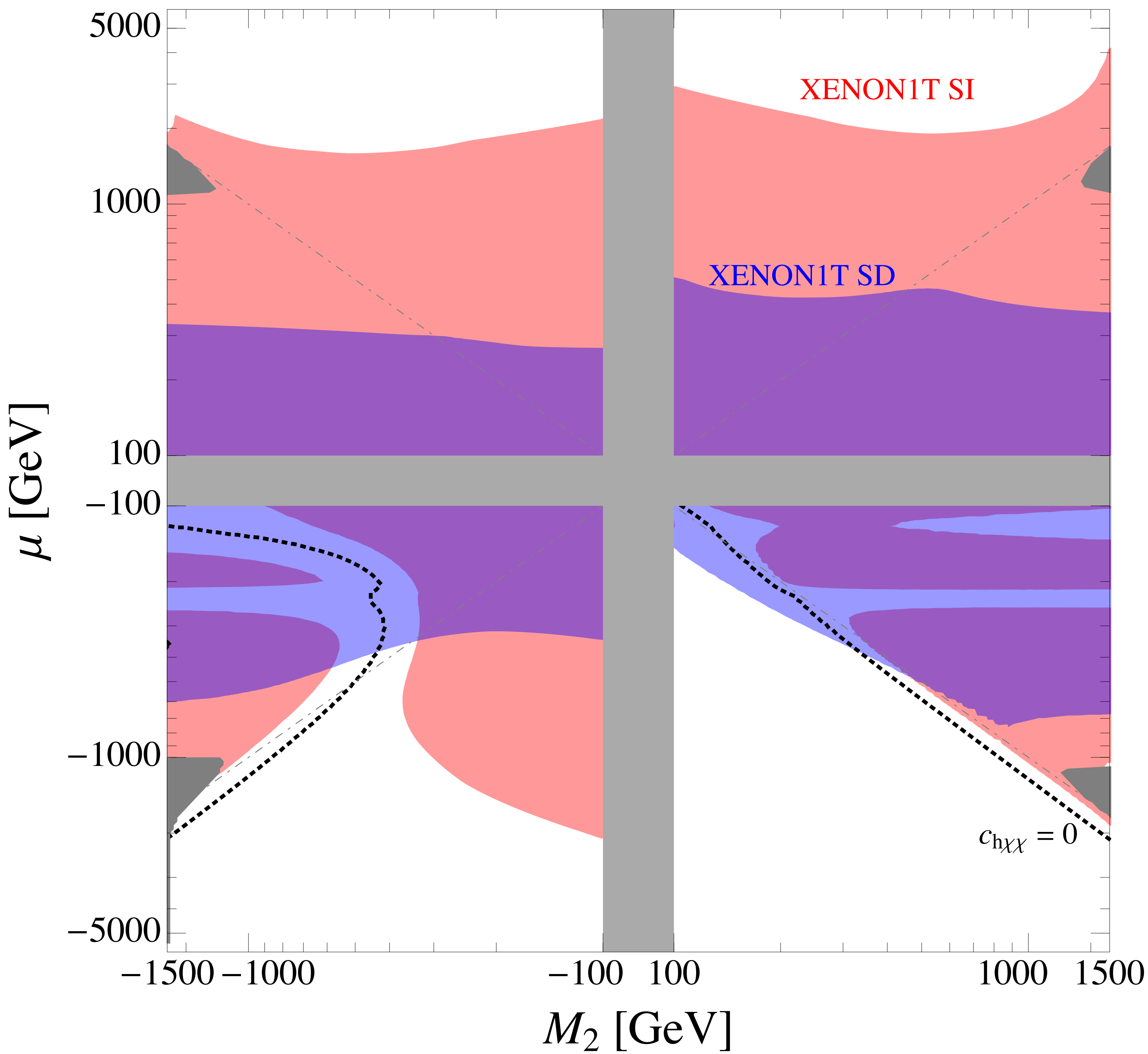
$\tan\beta = 2$

well-tempered



$\tan\beta = 2$

well-tempered

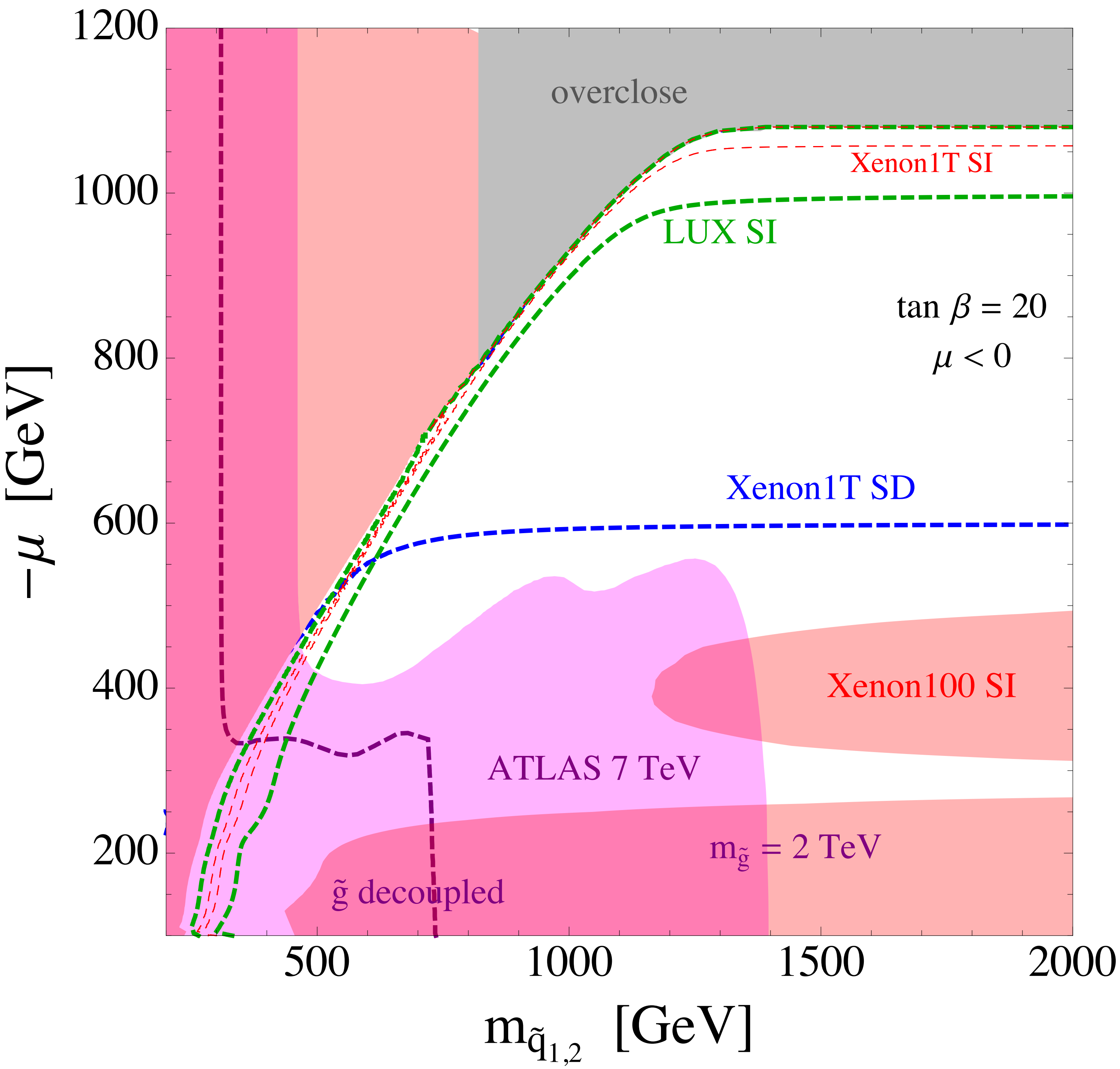


$\tan\beta = 2$

take away points

- direct detection is finally probing neutralino DM
- large parameter space remains
- blindspots with small spin-independent cross-section evade Xenon1T

backup



1200
1000
800
600
400
200
500
1000
1500
2000
−μ [GeV]
m$_{\tilde{q}_{1,2}}$ [GeV]
overclose
Xenon1T SI
LUX SI
tan β = 20
μ < 0
Xenon1T SD
Xenon100 SI
ATLAS 7 TeV
m$_{\tilde{g}}$ = 2 TeV
g̃ decoupled