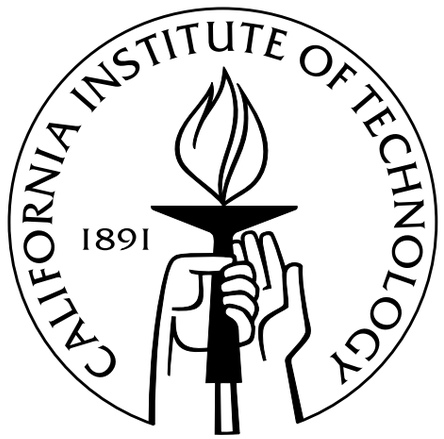
WIMP Dark Matter + SUSY

Clifford Cheung



Dark Matter in Southern California

Ingredients for a miracle (WIMP):

#1) Particle is neutral + stable.

#2) Particle couples to SM with weak scale annihilation cross-section.

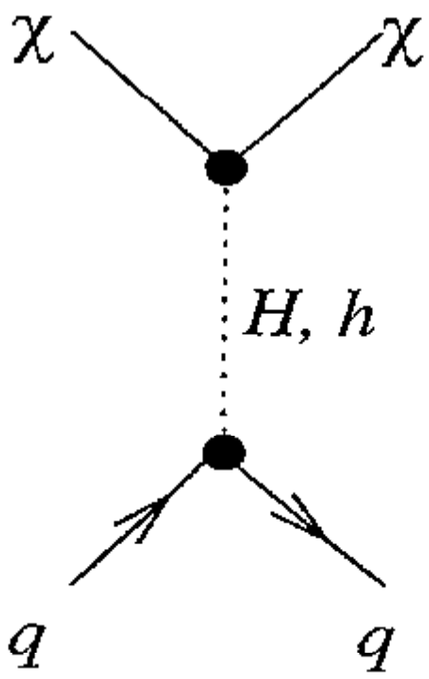
These are ubiquitous in models that address the hierarchy problem.

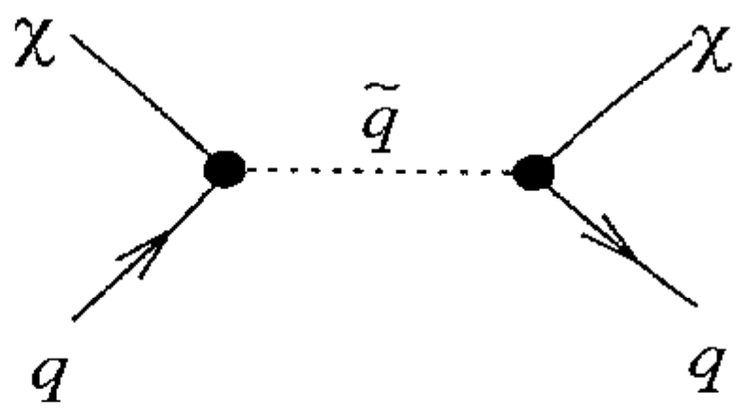
#1) Lots of examples of stabilizing symmetry!

theory	Z_2
Supersymmetry	R-parity
Extra Dimensions	KK-parity
Little Higgs	T-parity

Parities help with other exp'l constraints.

#2) Lots of weak scale masses + couplings!





Such couplings are mandatory to solve the hierarchy problem.

SUSY offers a "sandbox" for WIMP DM.

DM is among primary virtues of SUSY:

- dark matter
- hierarchy problem
- gauge coupling unification

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DM is among primary virtues of SUSY:

- dark matter
- hierarchy problem ?
- gauge coupling unification

DM probes offer a crucial experimental referendum on our motivations for SUSY.

What is the present status of neutralino DM and what is in its future?

Focus on neutralino DM that is an admixture of gauginos and Higgsinos:

$$\chi \sim (\tilde{b}, \tilde{w}, \tilde{h})$$

The parameter space is small, manageable:

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

Focus on neutralino DM that is an admixture of gauginos and Higgsinos:

$$\chi \sim (\tilde{b}, \tilde{w}, \tilde{h})$$

singlets, triplets, doublets

The parameter space is small, manageable:

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

simplifications

a) Ignore all scalars but light Higgs.

- resonant effects (Higgs funnels)
- scalar coannihilation (squark, etc)

b) Ignore all CP phases.

relic abundance

We allow for a range cosmology scenarios:

- thermal $\Omega_{\rm obs} = \Omega_\chi = \Omega_\chi^{\rm (th)}$
- non-thermal $\Omega_{\rm obs} = \Omega_\chi \neq \Omega_\chi^{\rm (th)}$
- sub-component $\Omega_{\rm obs} > \Omega_\chi = \Omega_\chi^{\rm (th)}$

relic abundance

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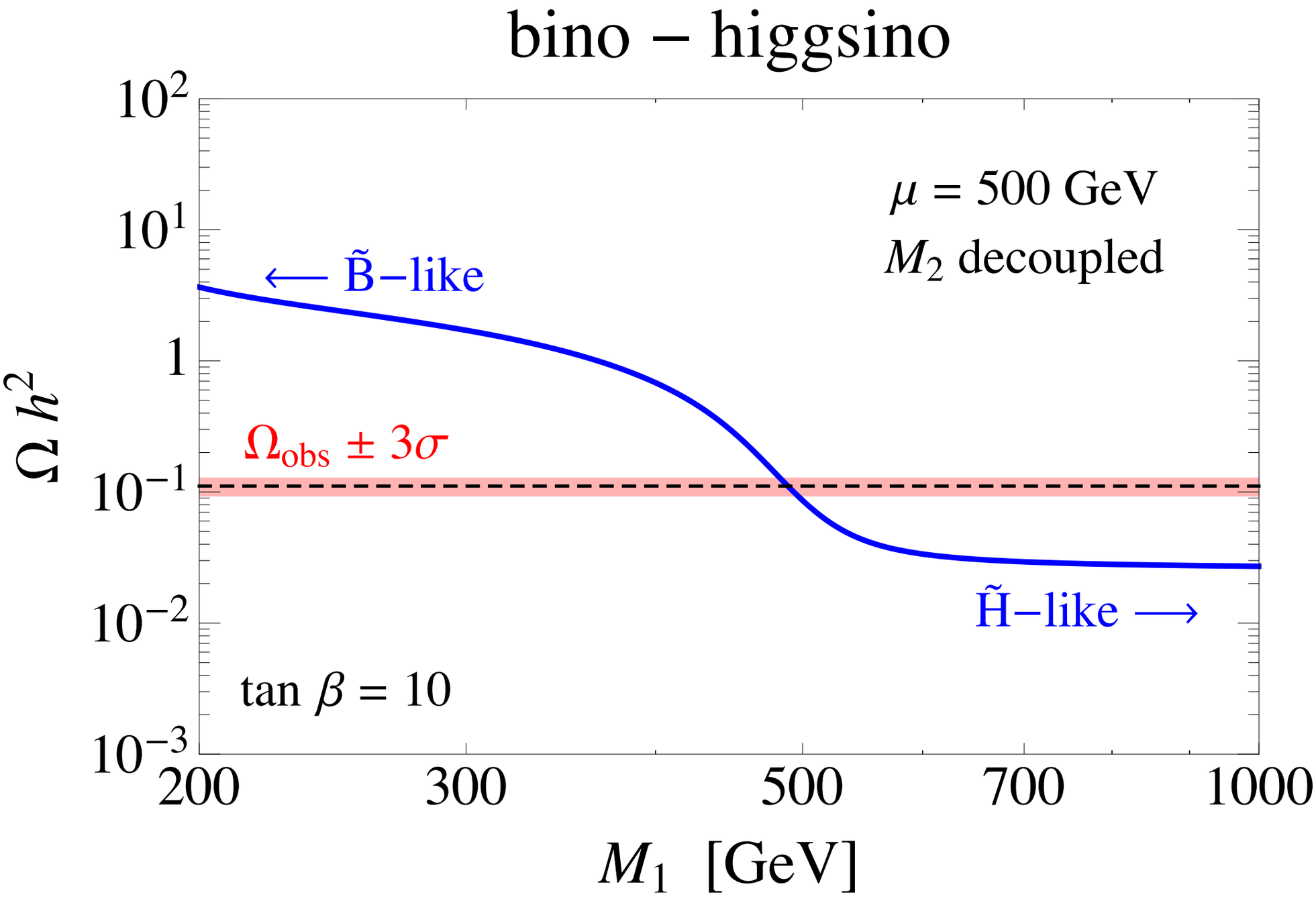
- sub-component $\Omega_{\rm obs} > \Omega_\chi = \Omega_\chi^{\rm (th)}$ } exp. limits weaker

"Well-tempering" is needed for correct relic abundance in many theories - including SUSY.



experiments

Consider present limits and future reach for direct detection / neutrinos experiments.

- spin independent (SI) scattering:

  XENON, LUX

- spin dependent (SD) scattering:

  XENON, IceCube

SI

XENON100

LUX

SuperCDMS

XENON1T

0.1

0.01

10^{-43}

10^{-44}

10^{-45}

10^{-46}

10^{-47}

$\sigma_{p,n}$ [cm^2]

0

500

1000

1500

2000

m_χ [GeV]

$c_{h\chi\chi}$

SI

XENON100

LUX

SuperCDMS

XENON1T

0.1

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$\sigma_{p,n}$ [cm^2]

10^{-43}

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m_χ [GeV]

SD

XENON100

IceCube $t\bar{t}$

IceCube W^+W^-

XENON1T

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0.01

10^{-38}

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10^{-40}

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$\sigma_{p,n}$ [cm^2]

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m_χ [GeV]

$\sigma_{\chi\chi}$

SD

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0

500

1000

1500

2000

m_χ [GeV]

$\sigma_{Z\chi\chi}$

At zeroth order, XENON100 introduces tension for neutralino dark matter:

$$c_{h\chi\chi} \lesssim 0.1 \qquad \textbf{versus} \qquad g' \sim 0.35$$

$$g \sim 0.65$$

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Because contributions are of order the limit, cancellations will occur generically, e.g.

$$(2-1)^2 \ll (2+1)^2$$

how does DM hide?

- purity

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

$$\text{as } M_1, M_2, \mu \to \infty$$

- blind spots

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

$$\text{as } M_1, M_2, \mu = \text{finite}$$

purity

state	SI(h)	SI(Z)	SD(Z)
$\tilde{b}$	inert	inert	inert
$\tilde{w}$	no renorm. operator	no renorm. operator	no renorm. operator
$\tilde{h}_u, \tilde{h}_d$	no renorm. operator	present but inelastic	no renorm. operator

blind spots (SI)

Reinstate the Higgs boson:

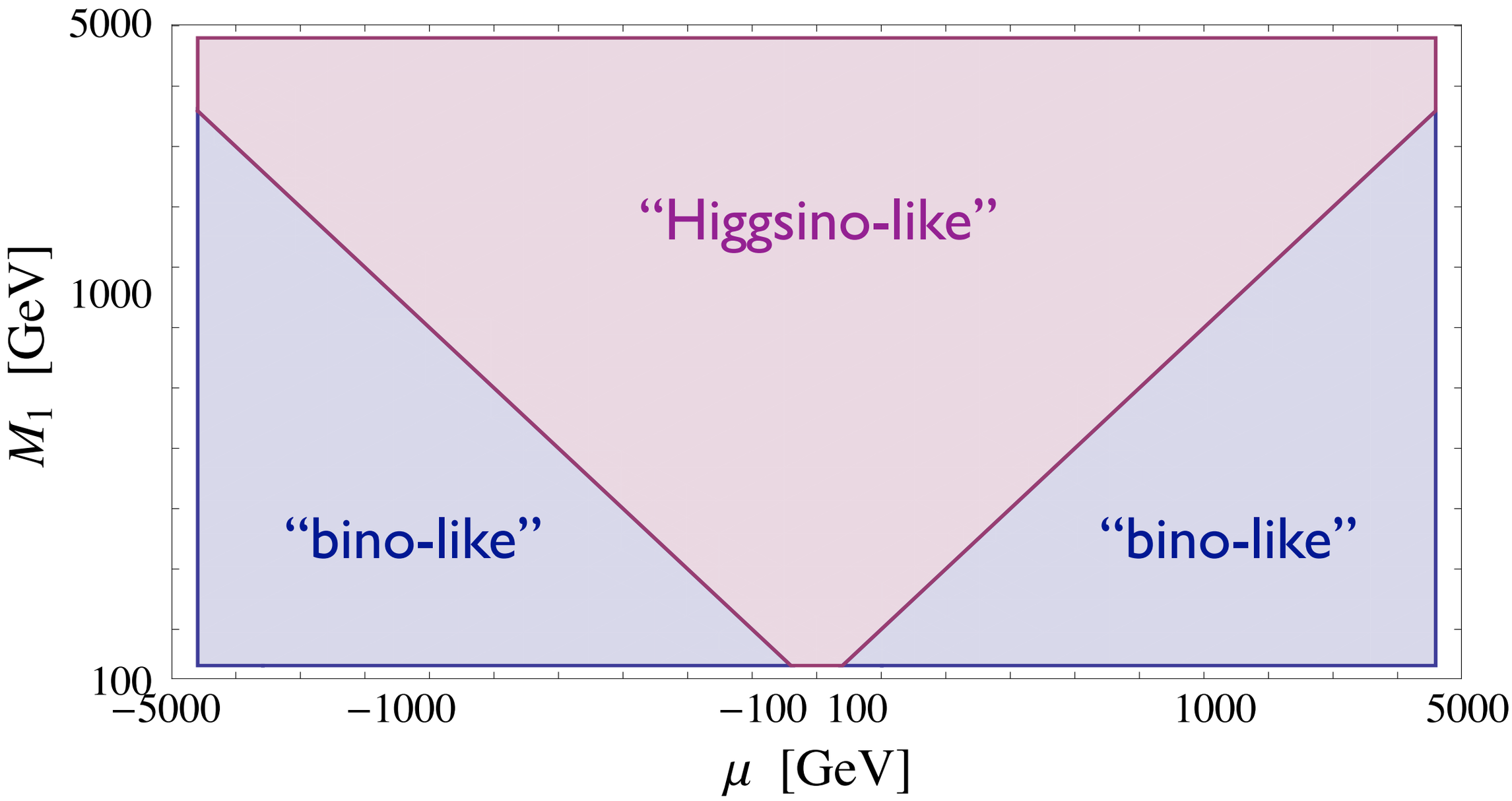
$$\begin{aligned}\mathcal{L}_{h\chi\chi} &= \frac{1}{2} m_\chi (v+h)\chi\chi \\ &= \frac{1}{2} m_\chi (v)\chi\chi + \frac{1}{2}\frac{\partial m_\chi(v)}{\partial v} h\chi\chi + \mathcal{O}(h^2),\end{aligned}$$

Higgs coupling cancellation at:

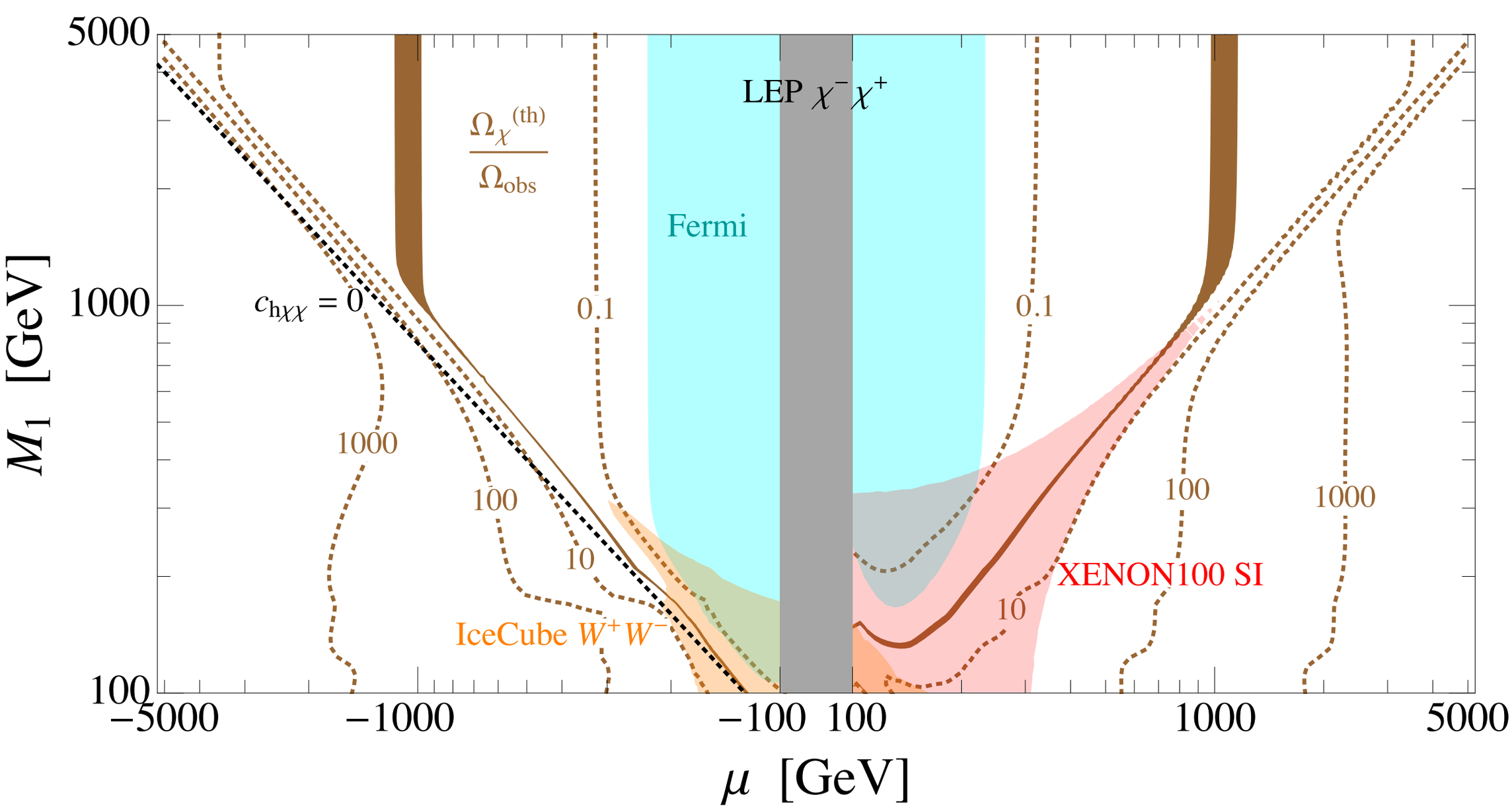
$$c_{h\chi\chi} = \frac{\partial m_\chi(v)}{\partial v} = 0$$

current

Take bino-Higgsino DM ($M_2 \to \infty$).

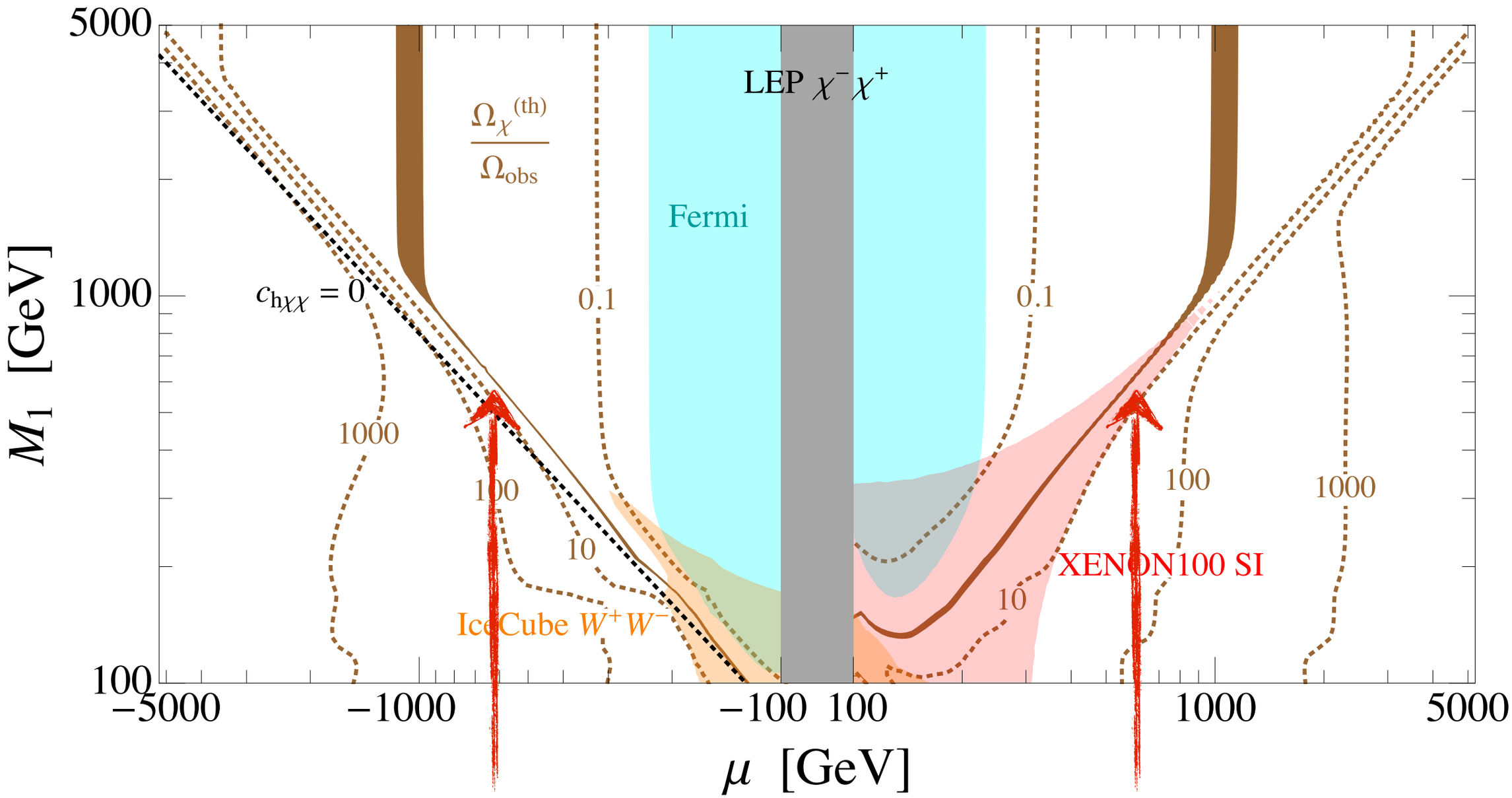


current


tan $\beta = 2$
5000
1000
100
M_1 [GeV]
$\frac{\Omega_\chi^{(\mathrm{th})}}{\Omega_{\mathrm{obs}}}$
LEP $\chi^-\chi^+$
Fermi
$c_{h\chi\chi} = 0$
0.1
0.1
1000
100
10
100
1000
10
IceCube W^+W^-
XENON100 SI
−5000
−1000
−100
100
1000
5000
μ [GeV]

current

$\tan\beta = 2$

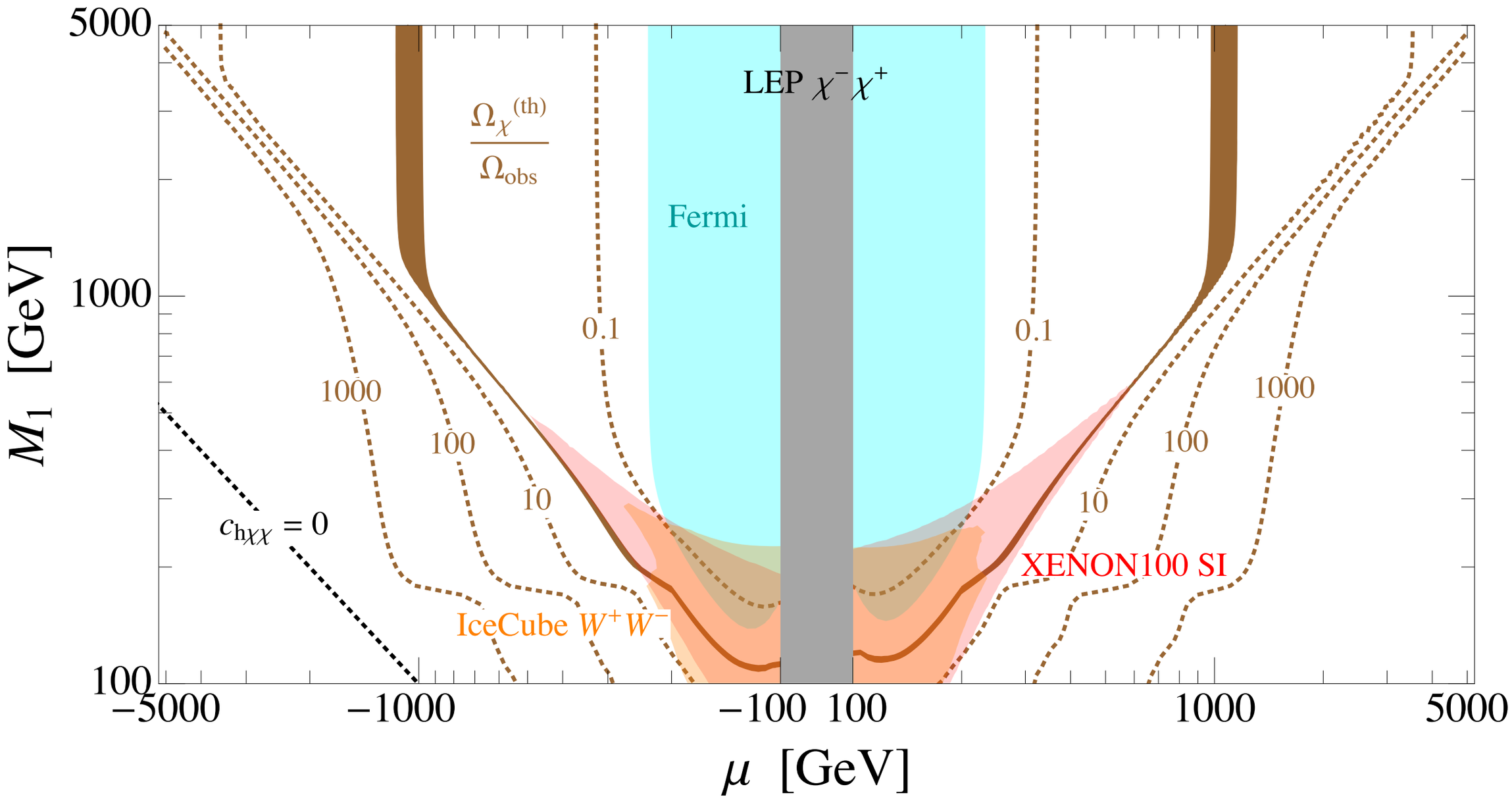


well-tempered neutralino allowed

well-tempered neutralino excluded

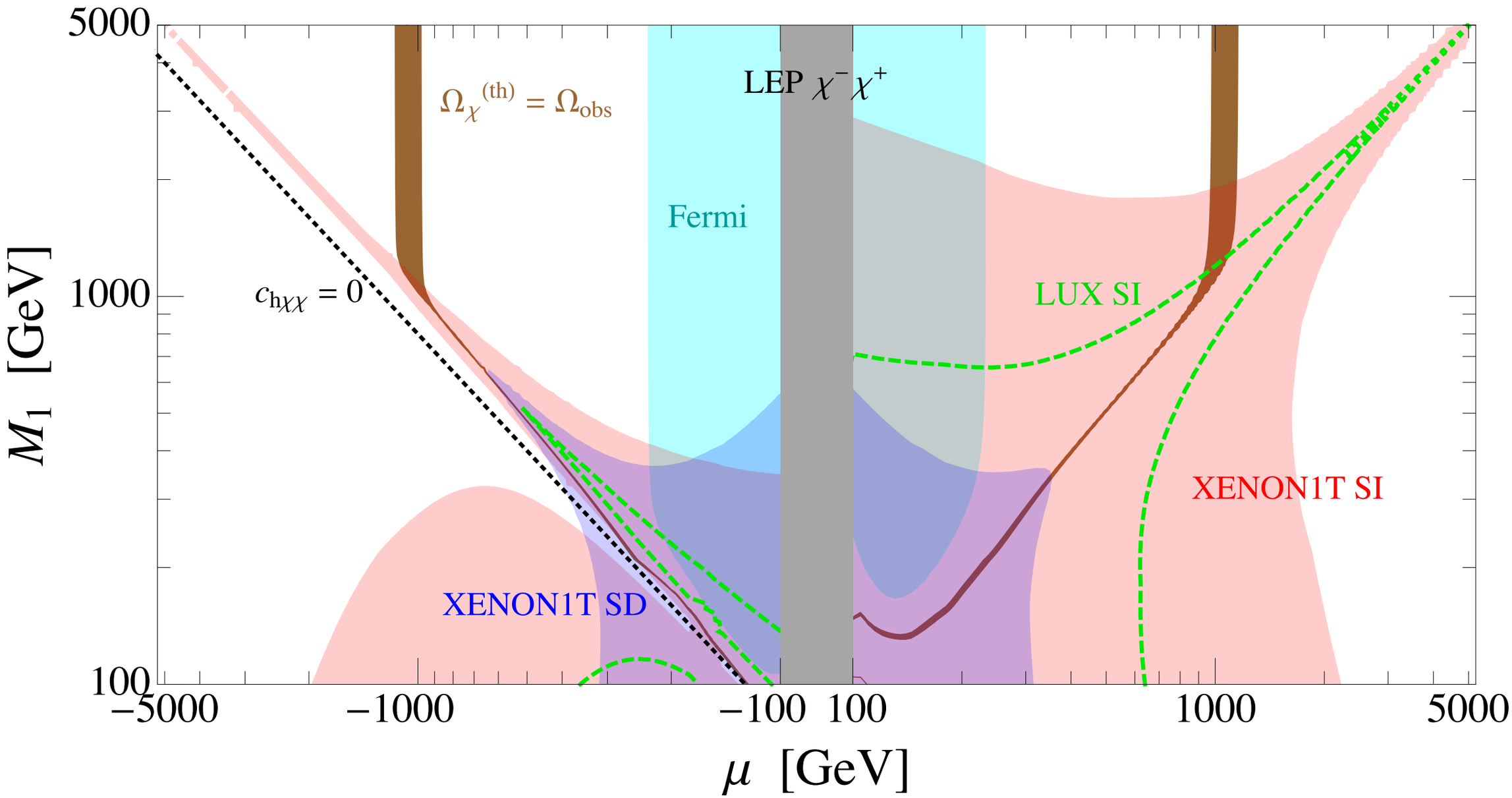
current

$\tan\beta = 20$

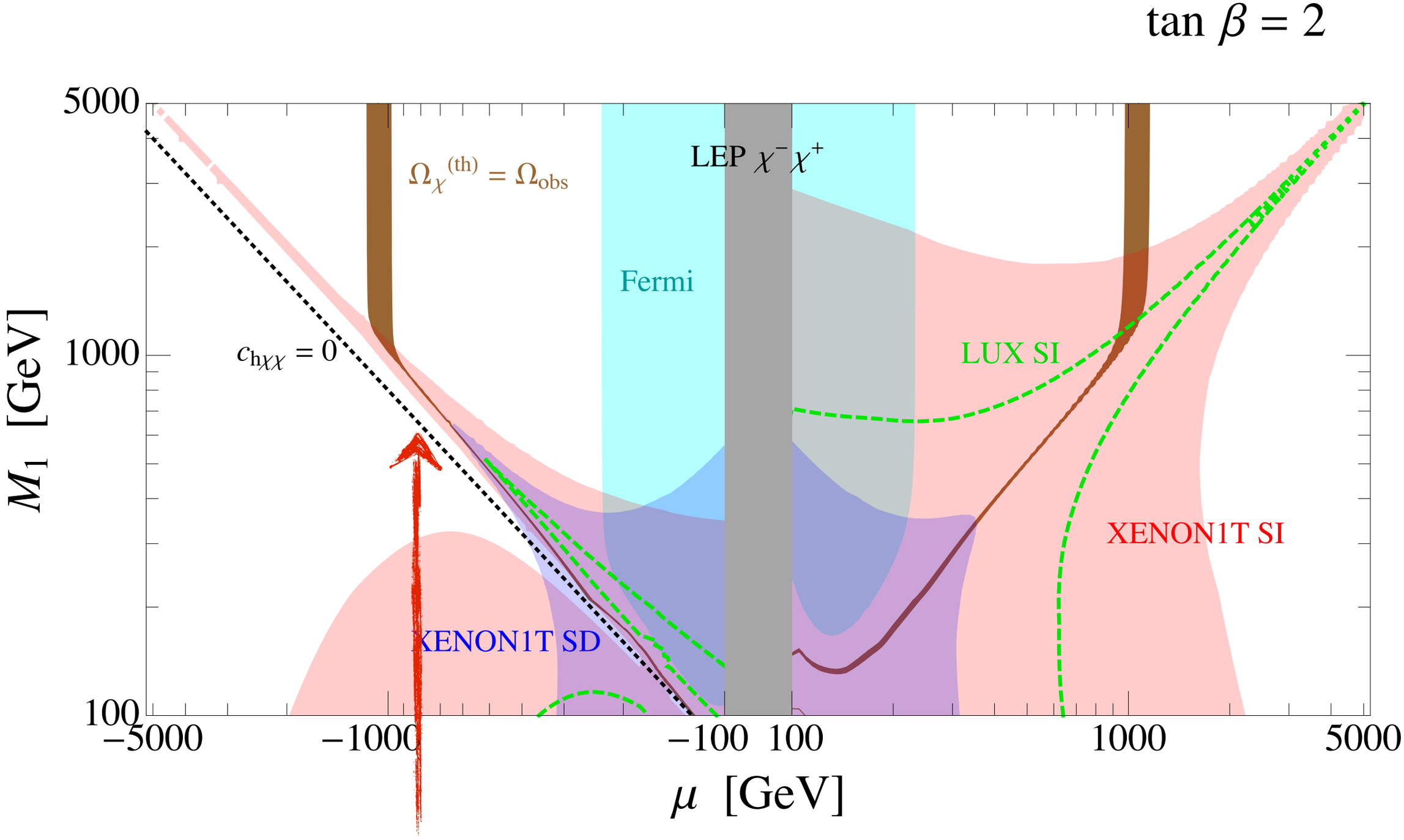


future

$\tan\beta = 2$

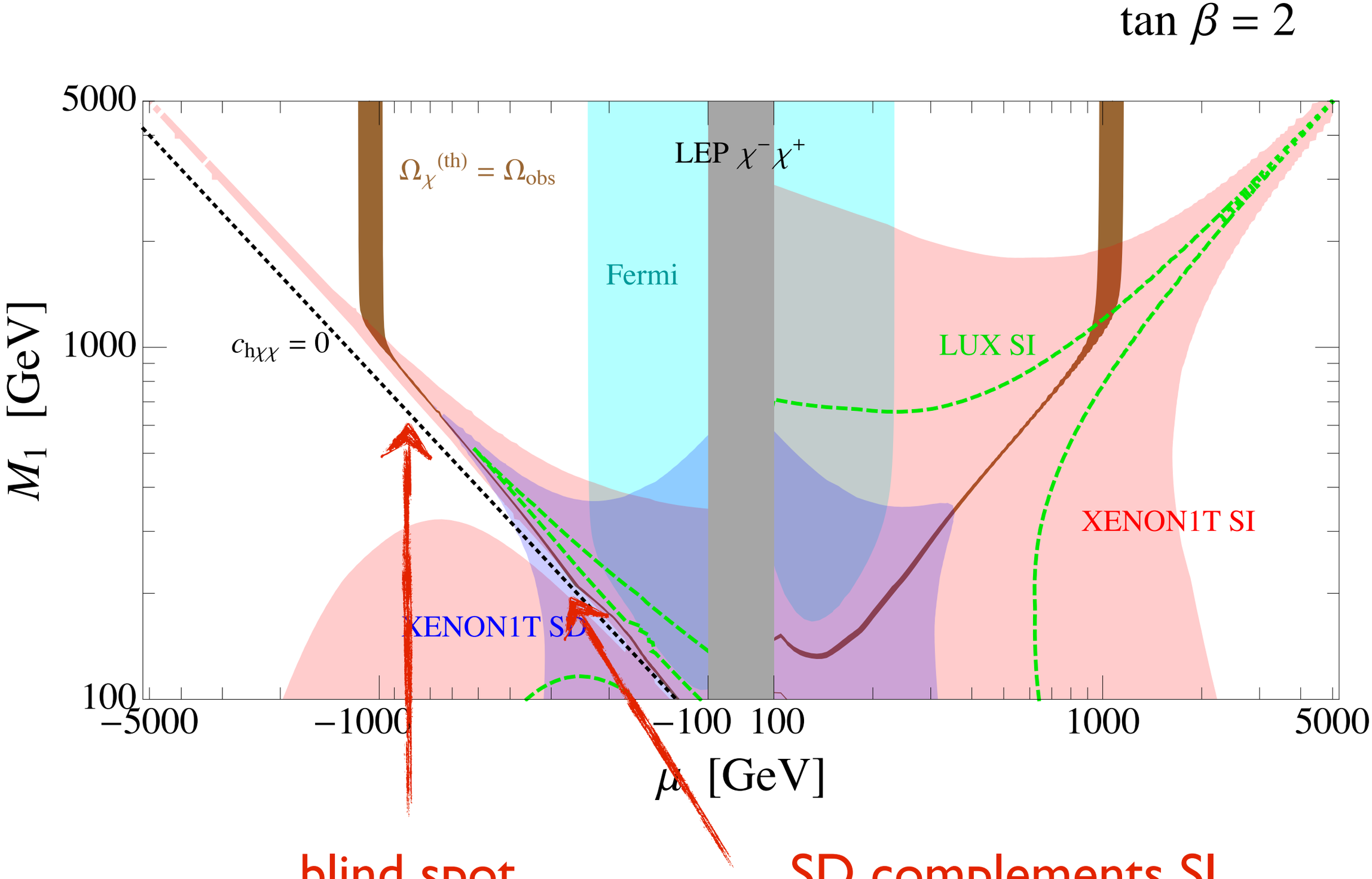


future



blind spot

future

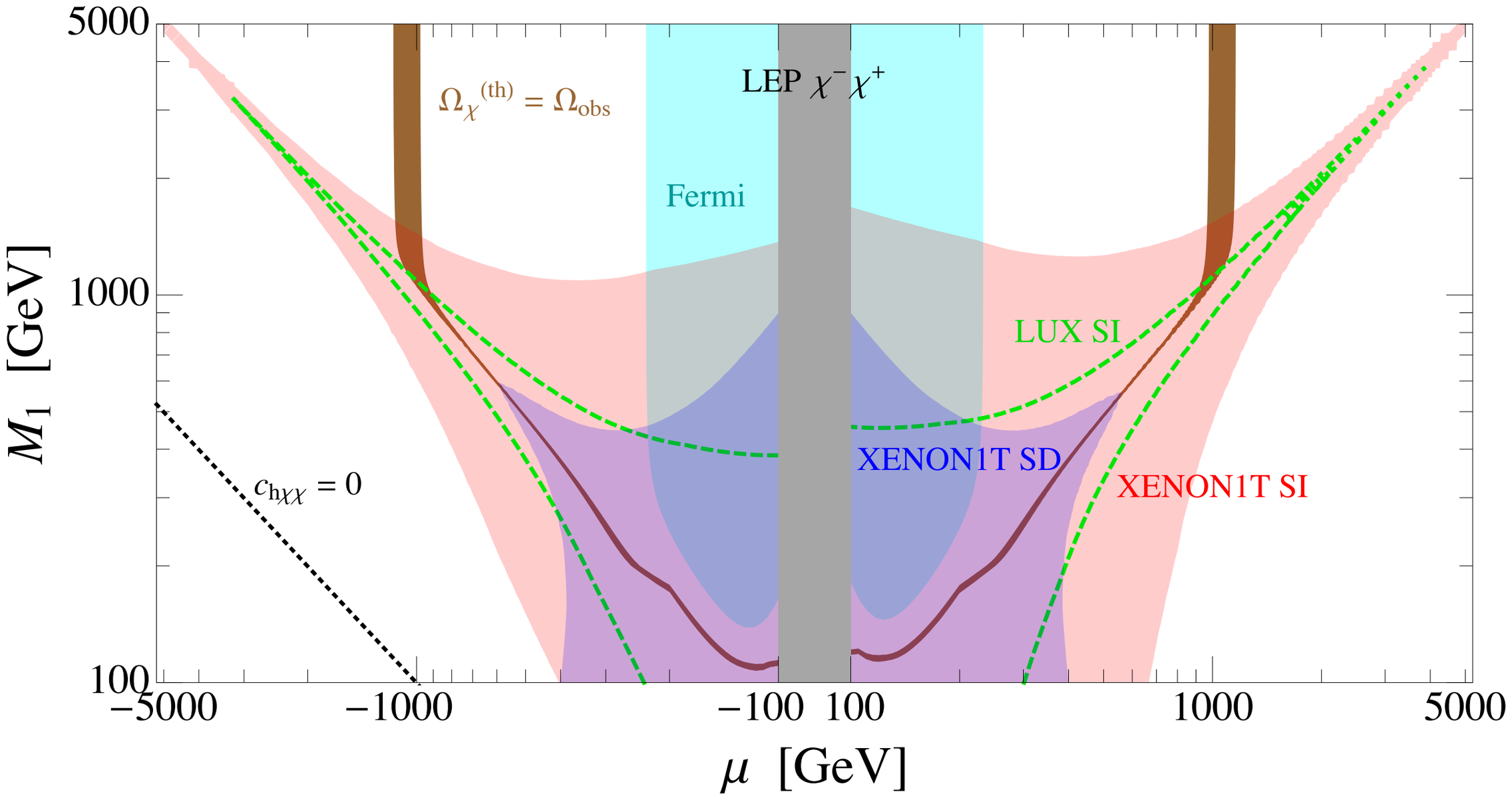


blind spot

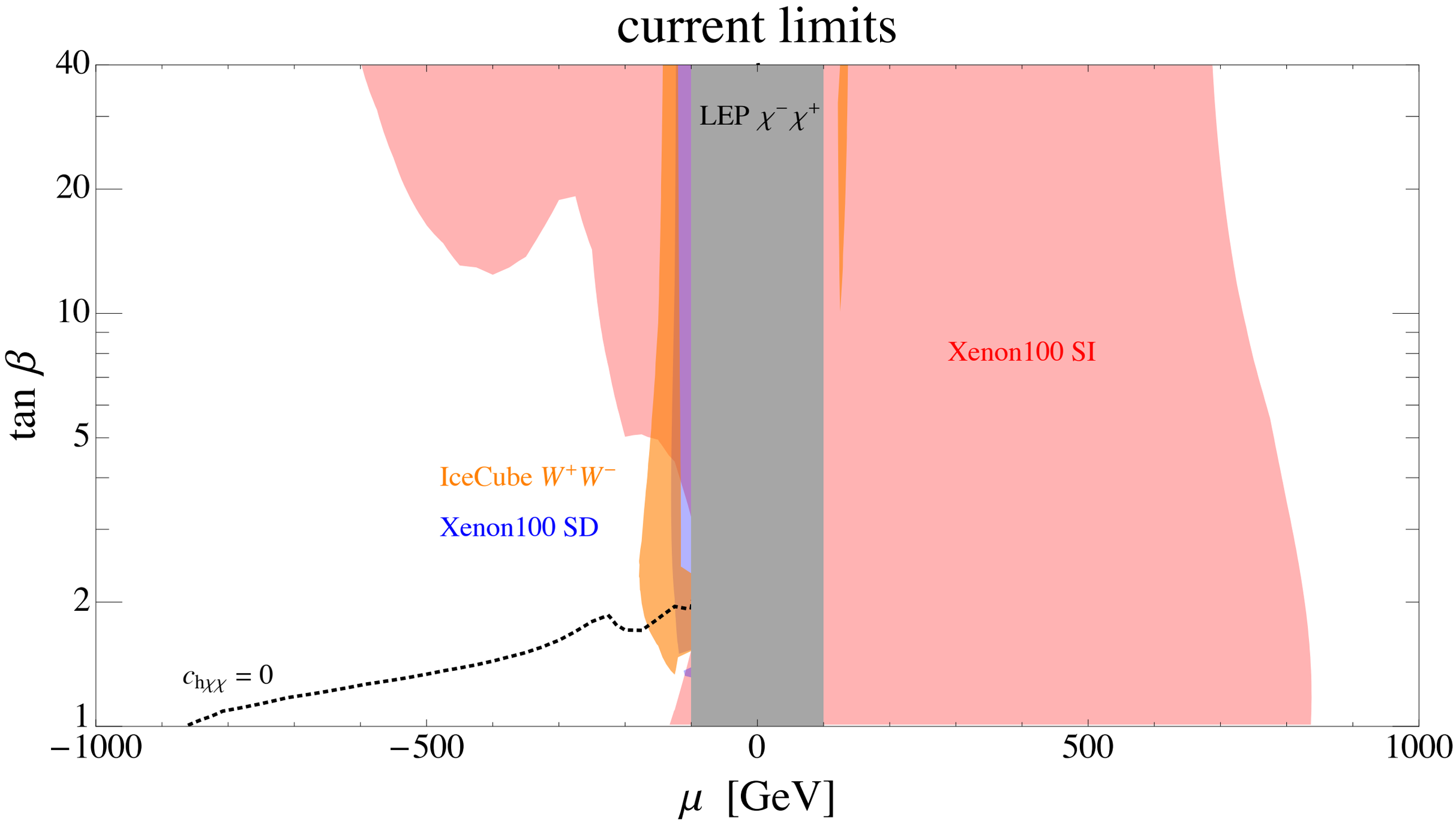
SD complements SI

future

$\tan\beta = 20$

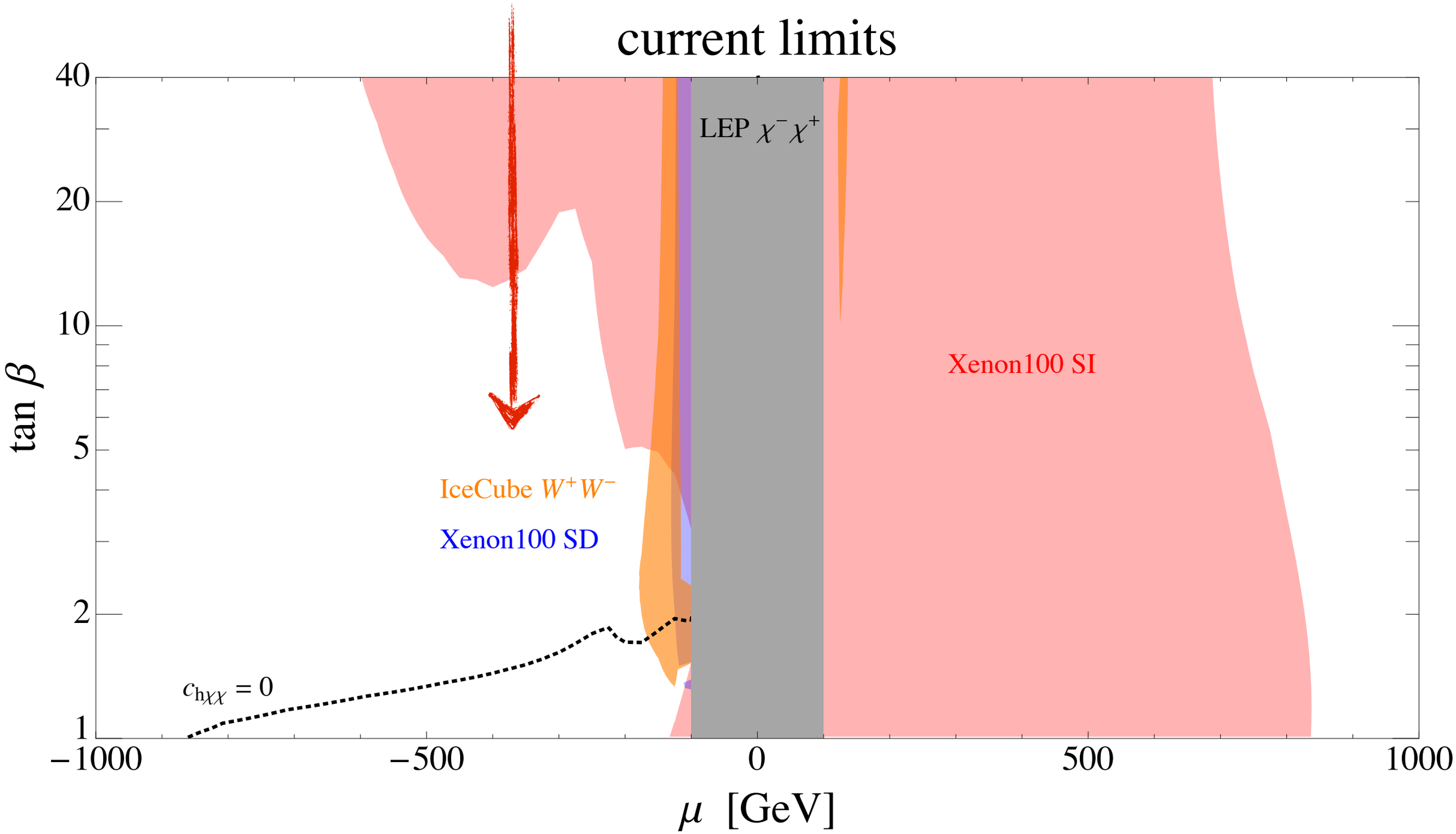


current

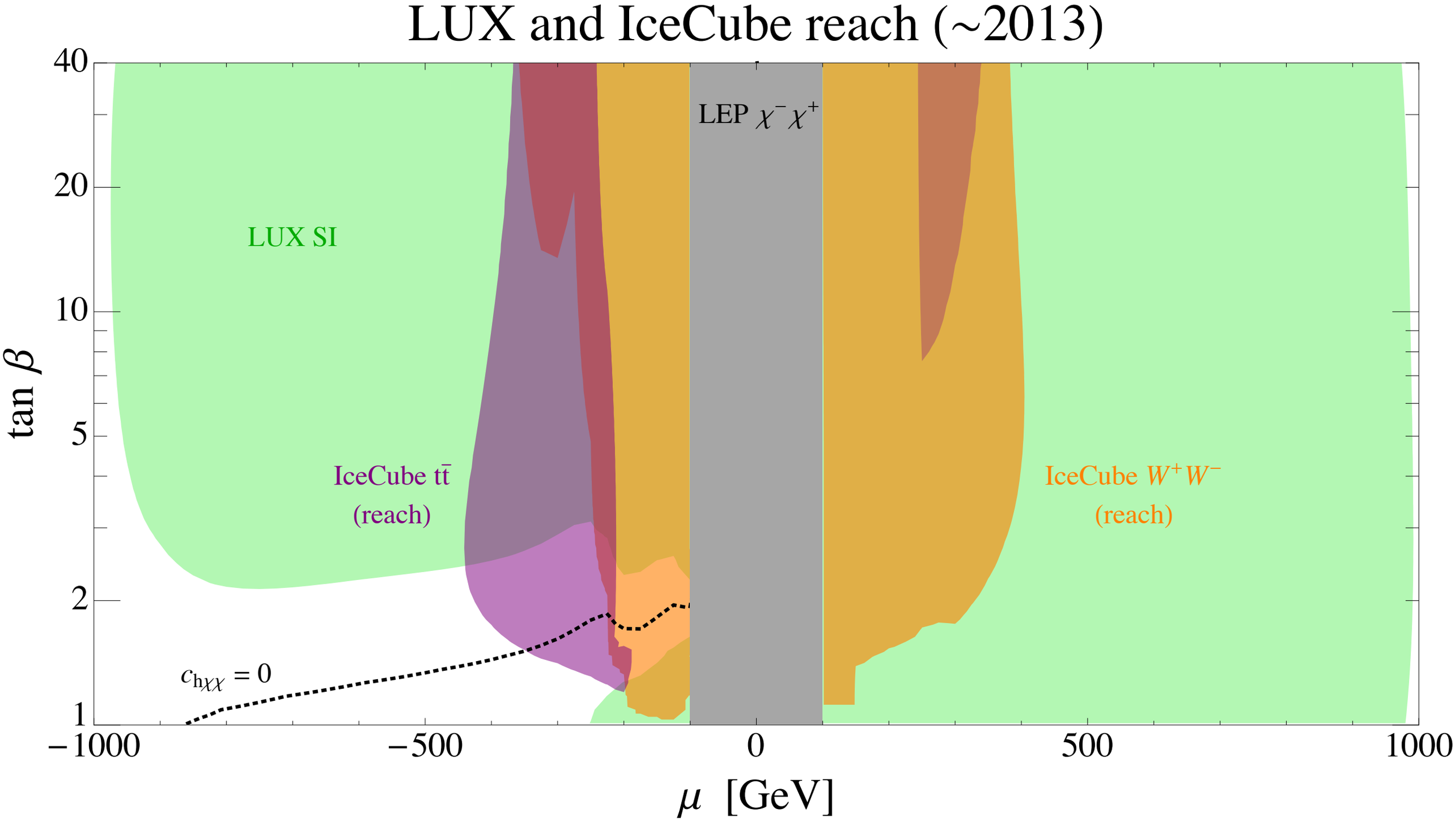

current limits
LEP $\chi^-\chi^+$
Xenon100 SI
IceCube W^+W^-
Xenon100 SD
$c_{h\chi\chi} = 0$
tan β
μ [GeV]
40
20
10
5
2
1
−1000
−500
0
500
1000

current

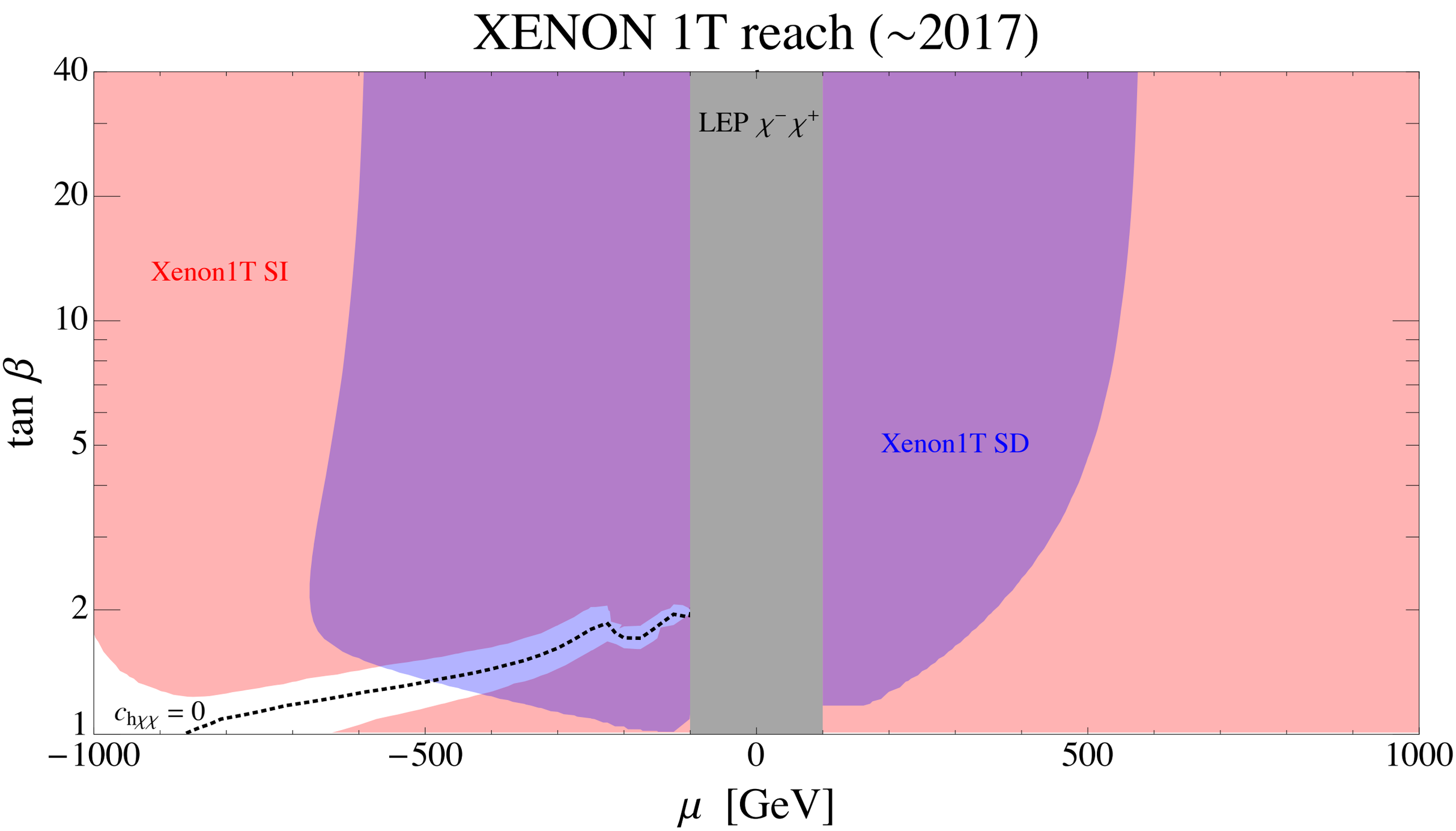
well-tempered neutralino
is alive and well



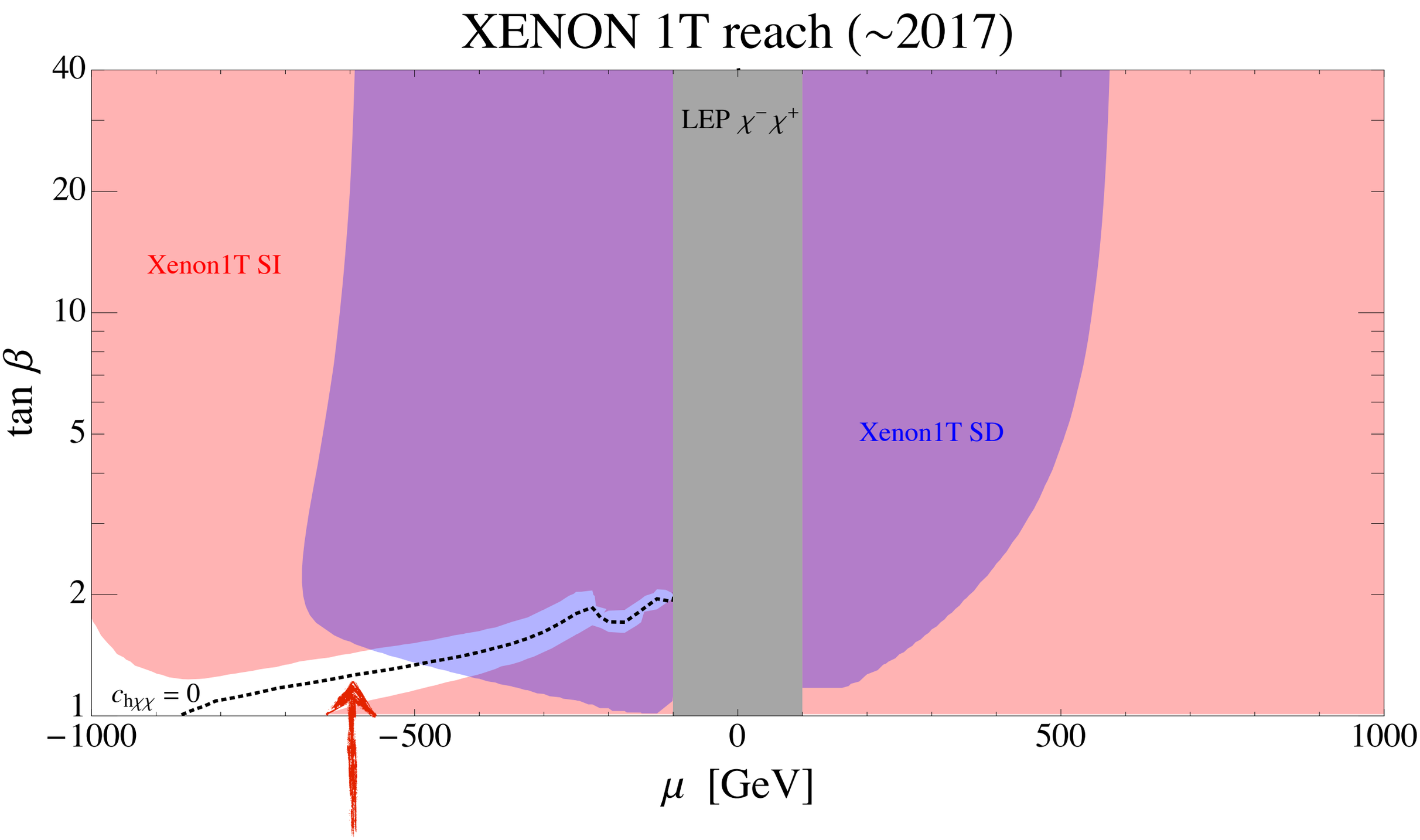
2013


LUX and IceCube reach (~2013)
LUX SI
LEP $\chi^-\chi^+$
IceCube $t\bar{t}$
(reach)
IceCube W^+W^-
(reach)
$c_{h\chi\chi} = 0$
tan β
μ [GeV]
40
20
10
5
2
1
−1000
−500
0
500
1000

2017


XENON 1T reach (~2017)
LEP $\chi^- \chi^+$
Xenon1T SI
Xenon1T SD
$c_{h\chi\chi} = 0$
tan β
μ [GeV]
40
20
10
5
2
1
−1000
−500
0
500
1000

2017



soon, nothing left but blind spot

Are there any theory motivated blind spots?

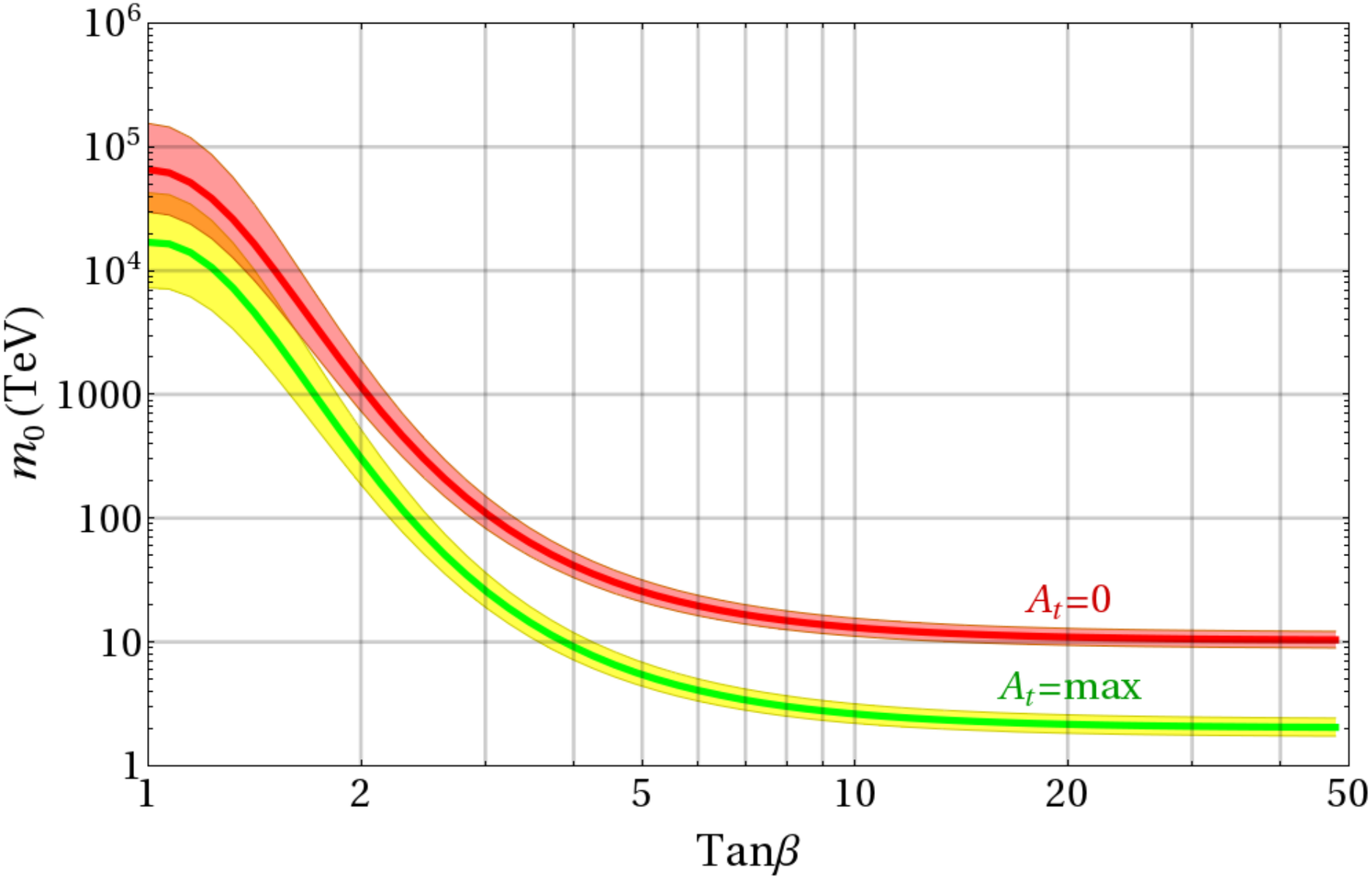
Higgsino DM at tan beta ~ 1 hard to probe.

- SI scattering is in blind spot.
- SD scattering is in blind spot.

Higgsino DM at tan beta ~ 1 is motivated.

- natural theories (lambda SUSY)
- unnatural theories (split SUSY)

Low tan beta preferred by theory (gaugino/ scalar hierarchy) and experiment (flavor).



Arvanitaki et al. [1210.0555]

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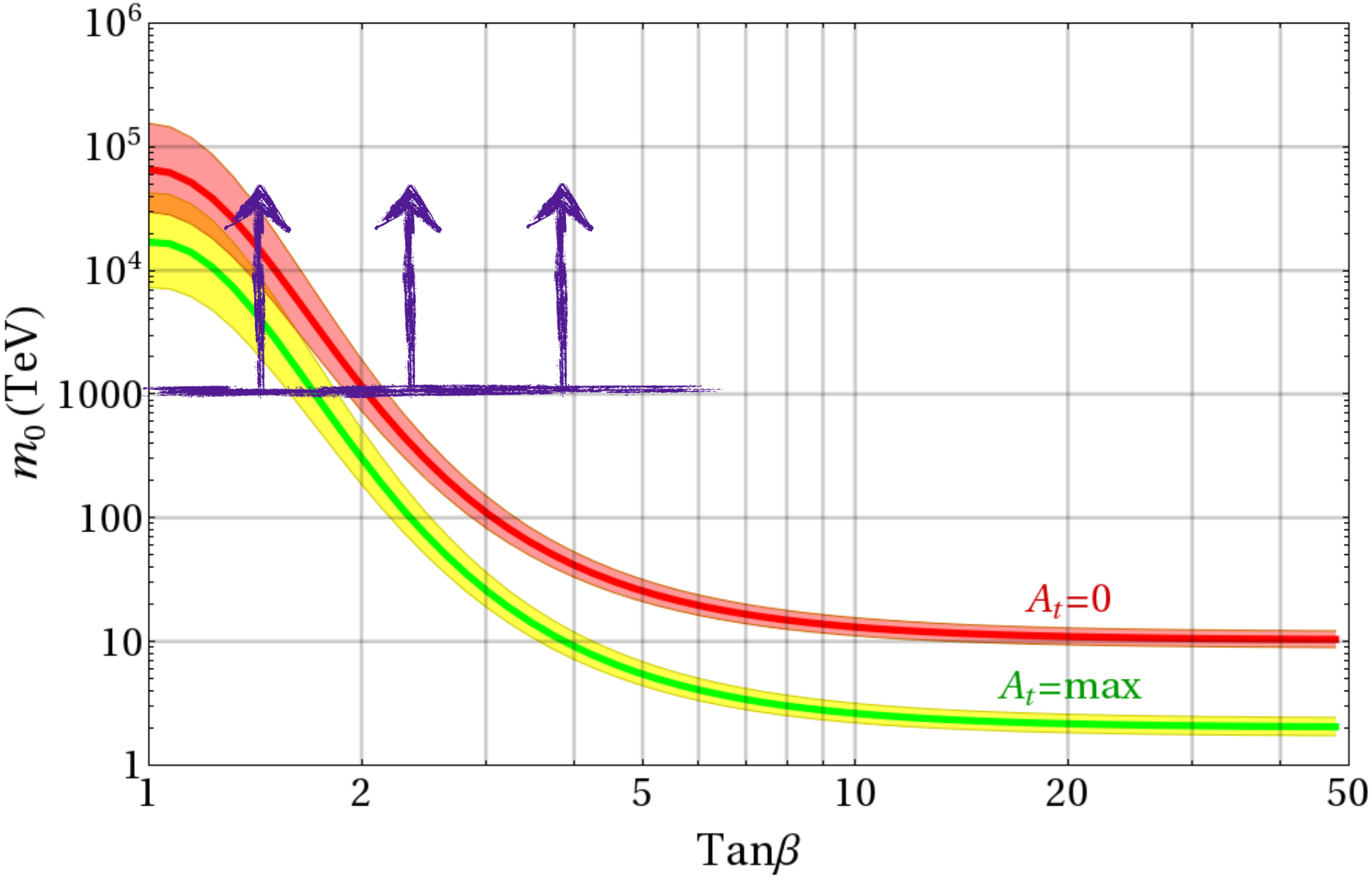
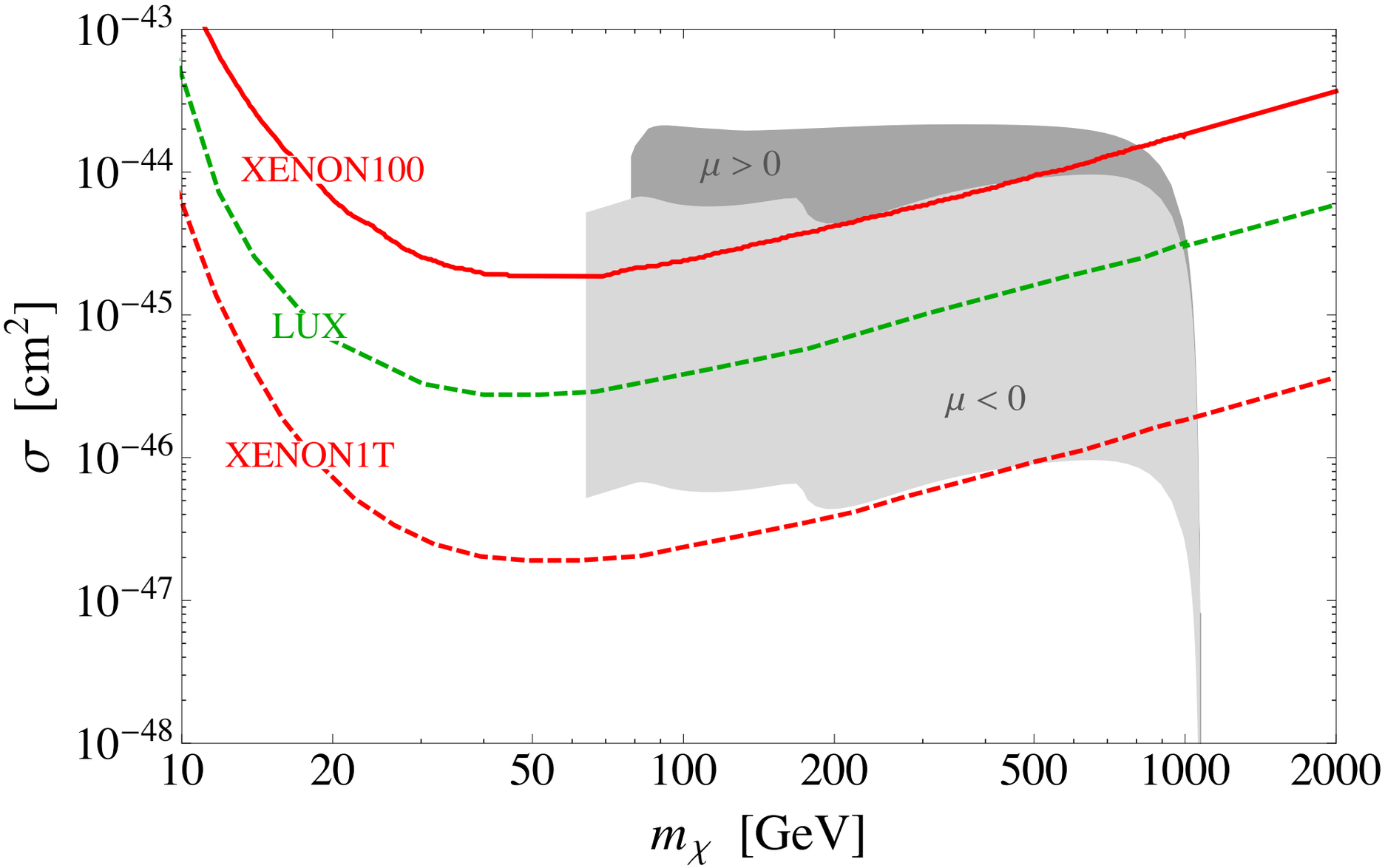


Arvanitaki et al. [1210.0555]

XENON100 has just cut into the Higgs scattering region of thermal neutralino DM!



thanks!