Muon *g*-2 and Dark Matter in the MSSM

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arXiv:1805.02802

Muon g-2

- Long standing discrepancy in the g-2 of the muon:

$$a_\mu^{\mathrm{exp}} = 11\ 659\ 209.1\ (5.4)\ (3.3) \times 10^{-10}$$

[E821]

$$a_\mu^{\mathrm{SM}} = (11\ 659\ 182.04 \pm 3.56) \times 10^{-10}$$

[Keshavarzi et. al. arXiv:1802.02995]

$$\Delta a_\mu = (27.06 \pm 7.26) \times 10^{-10} \longrightarrow 3.7\sigma$$

(discrepancy of order EW contributions)

- Factor of 4 improvement in precision expected with new experiments at Fermilab and J-PARC

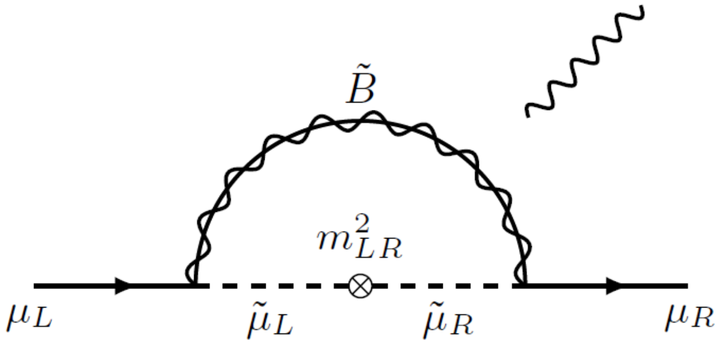
g-2 in the MSSM

- One-loop contributions from chargino-sneutrino and smuon-neutralino loops

Assuming degenerate spectrum:

$$|a_\mu^{\mathrm{SUSY}}| \approx 1.3 \times 10^{-9} \left(\frac{100\,\mathrm{GeV}}{M_{\mathrm{SUSY}}}\right)^2 \tan\beta$$

⟶ Need relatively light EW superpartners



- Bino-smuon contribution enhanced by L-R smuon mixing $\propto \mu \tan\beta$

- Leading 2-loop effects reduce by ~10%

Dark Matter in the MSSM

With R-parity, neutralino LSP provides a natural DM candidate

But… generic 'well-tempered' neutralino strongly constrained by direct detection

- Possible ways out:
  - "Blind-spot" regions
  - Z/h/A funnel regions
  - h/H destructive interference

- Other possibilities are (almost) pure $\widetilde{H}$ or pure $\widetilde{W}$
  but masses required for thermal relic density too large for g-2

⟶ Strong bounds from direct detection motivate a *bino-like* LSP!

Bino-like LSP ⟶ co-annihilation

- Bino-like DM generally over abundant
  ⟶ co-annihilations can be used to obtain correct relic abundance

- LHC already suggests squarks, gluino need to be relatively heavy.
  ⟶ assume they play no role for DM

Leaves two scenarios to consider:

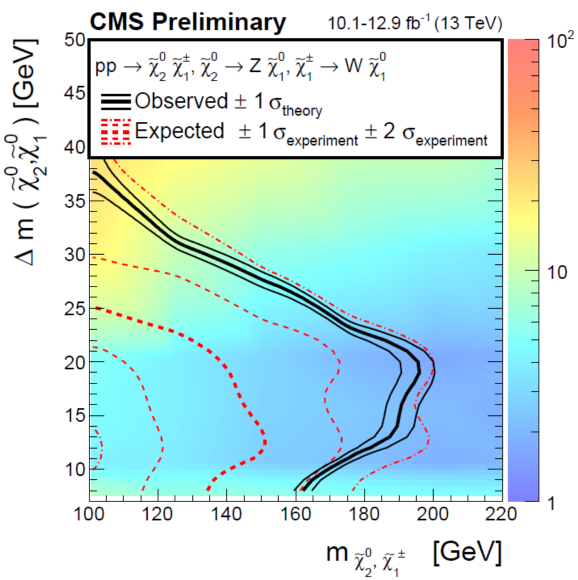
➢ $\tilde{B} - \widetilde{W}$ co-annihilation

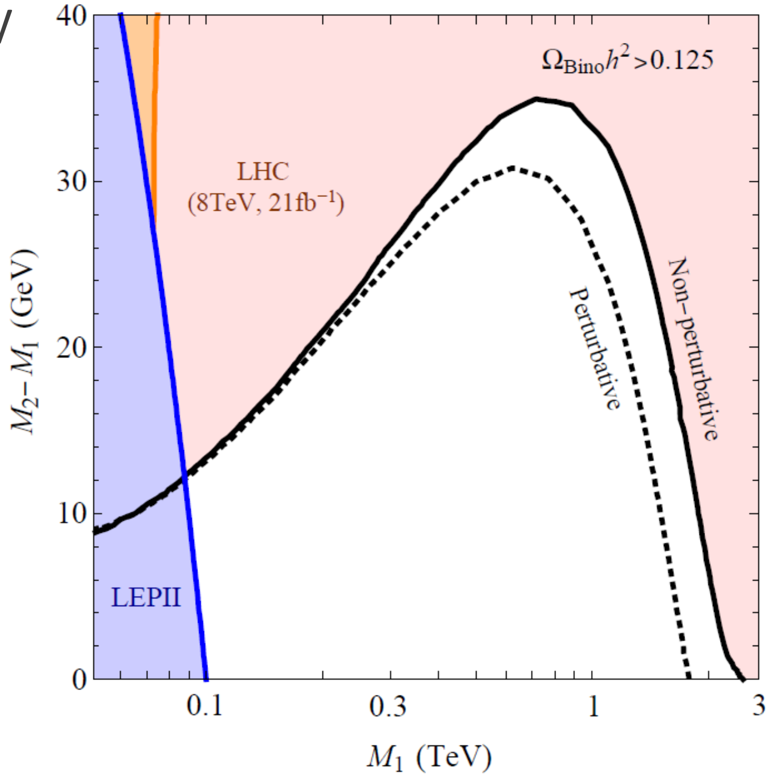
➢ $\tilde{B} - \tilde{l}$ co-annihilation

$\tilde{B} - \tilde{W}$ co-annihilation

- Requires small mass-splitting $O(10)$ GeV
- Avoids DM direct/indirect detection

[Harigaya et. al. arXiv:1403.0715]



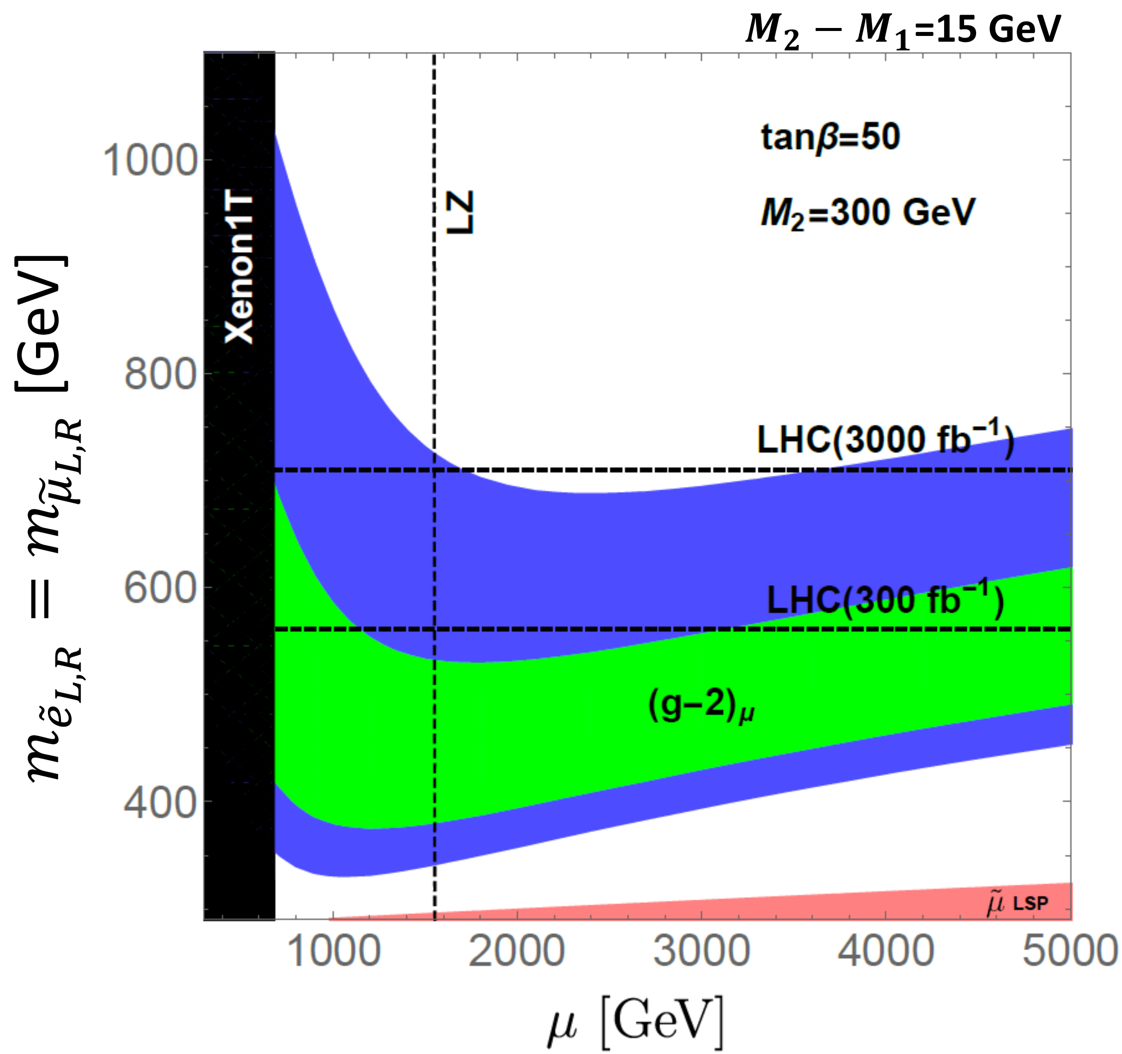


- Dedicated LHC searches for this kind of spectrum, but bounds are weak

$$m_{\tilde{\chi}_2^0/\tilde{\chi}_1^\pm} > 195\,\text{GeV for } \Delta m = 20\,\text{GeV}$$

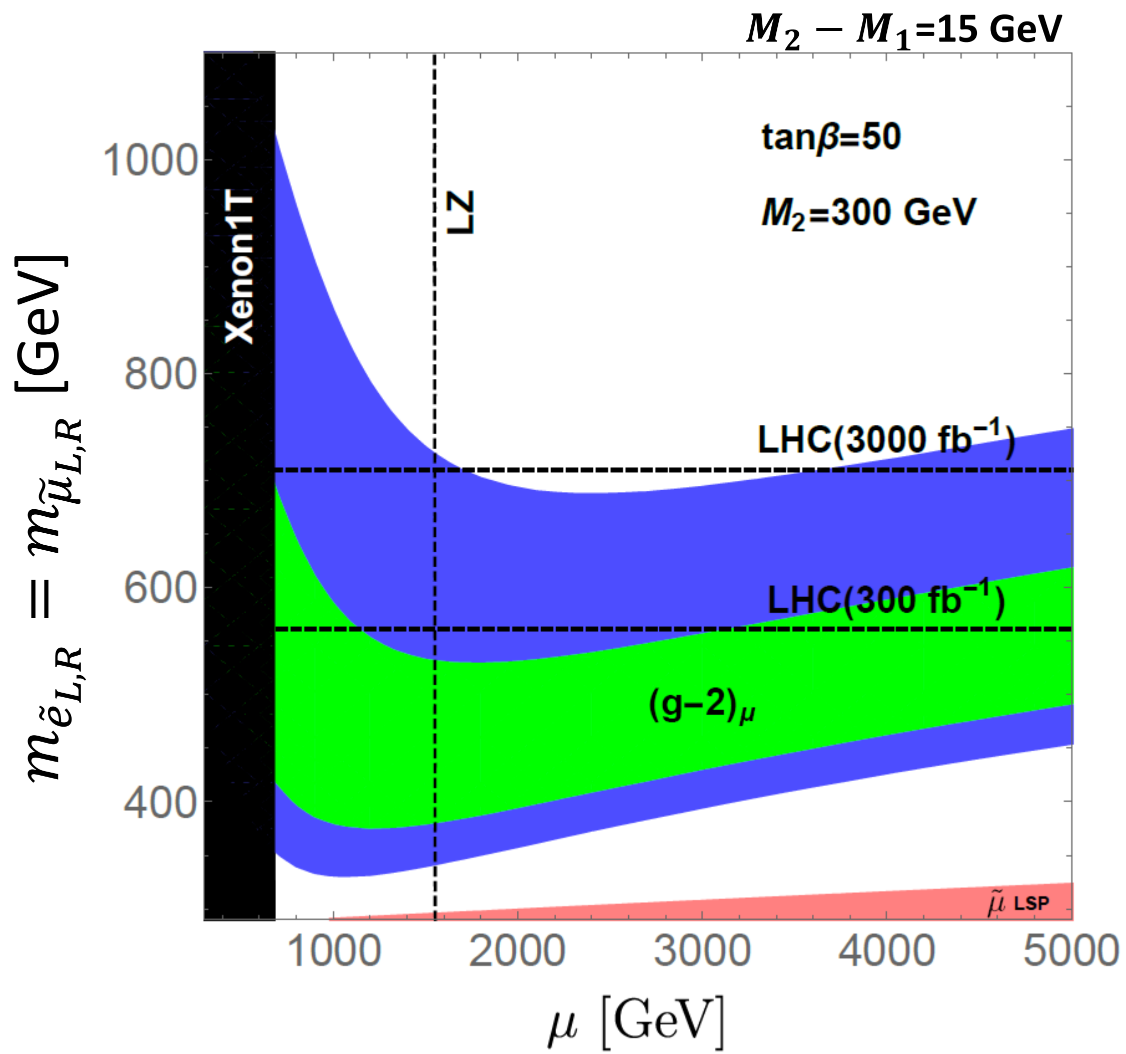
(also indirect probes at HL-LHC, ILC)

$\tilde{B} - \widetilde{W}$ co-annihilation



Significant regions of parameter space can be probed at (HL)-LHC

$\tilde{B} - \widetilde{W}$ co-annihilation

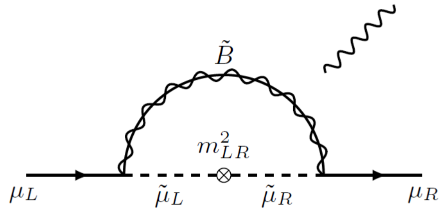


What about large $\mu \tan\beta$?

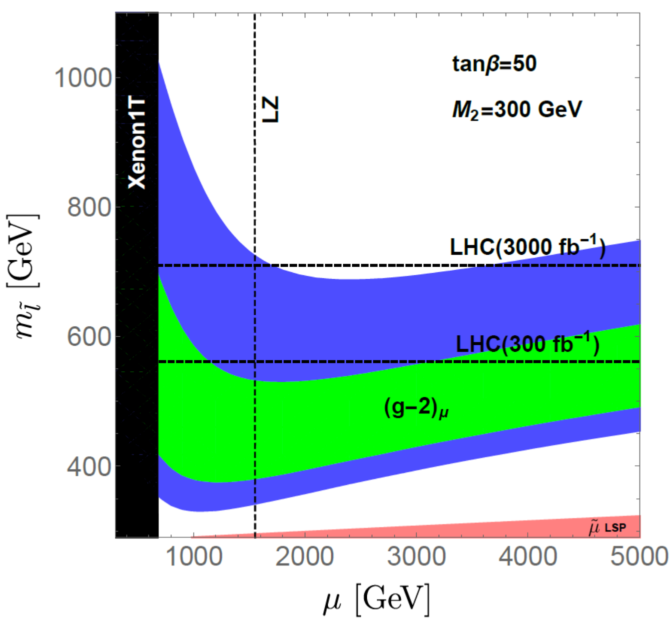
Significant regions of parameter space can be probed at (HL)-LHC

Large $\mu \tan \beta$

- Bino-smuon contribution to *g-2* proportional to $\mu \tan \beta$
- In principle, can explain *g-2* with very large smuon masses!
  (eventually saturates when higher order effects included)



- But, large L-R slepton mixing leads to problems with EW vacuum stability:



Upper bound on smuon mass:

[Endo et. al. arXiv:1309.3065]

Mass spectrum	Smuon	Vacuum
$m_{\tilde{e}} = m_{\tilde{\mu}} = m_{\tilde{\tau}}$	$< 330/460$ GeV	$\tilde{\tau}$
$m_{\tilde{e}} = m_{\tilde{\mu}} < m_{\tilde{\tau}}$	$< 1.4/1.9$ TeV	$\tilde{\tau}$ or $\tilde{\mu}$

g-2 @ 1σ, 2σ

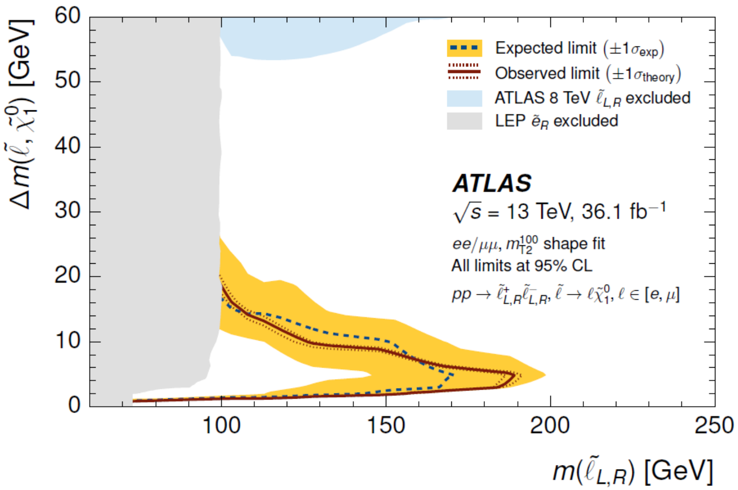
$\tilde{B} - \tilde{l}$ co-annihilation

- Often expect $\tilde{\tau}$ to be NLSP, but $\tilde{\tau}$ instability highly constrains parameter space for g-2
  ⟶ I will focus on co-annihilation with $1^{st}/2^{nd}$ generation sleptons

- Requires even smaller mass-splitting $\lesssim 10$ GeV

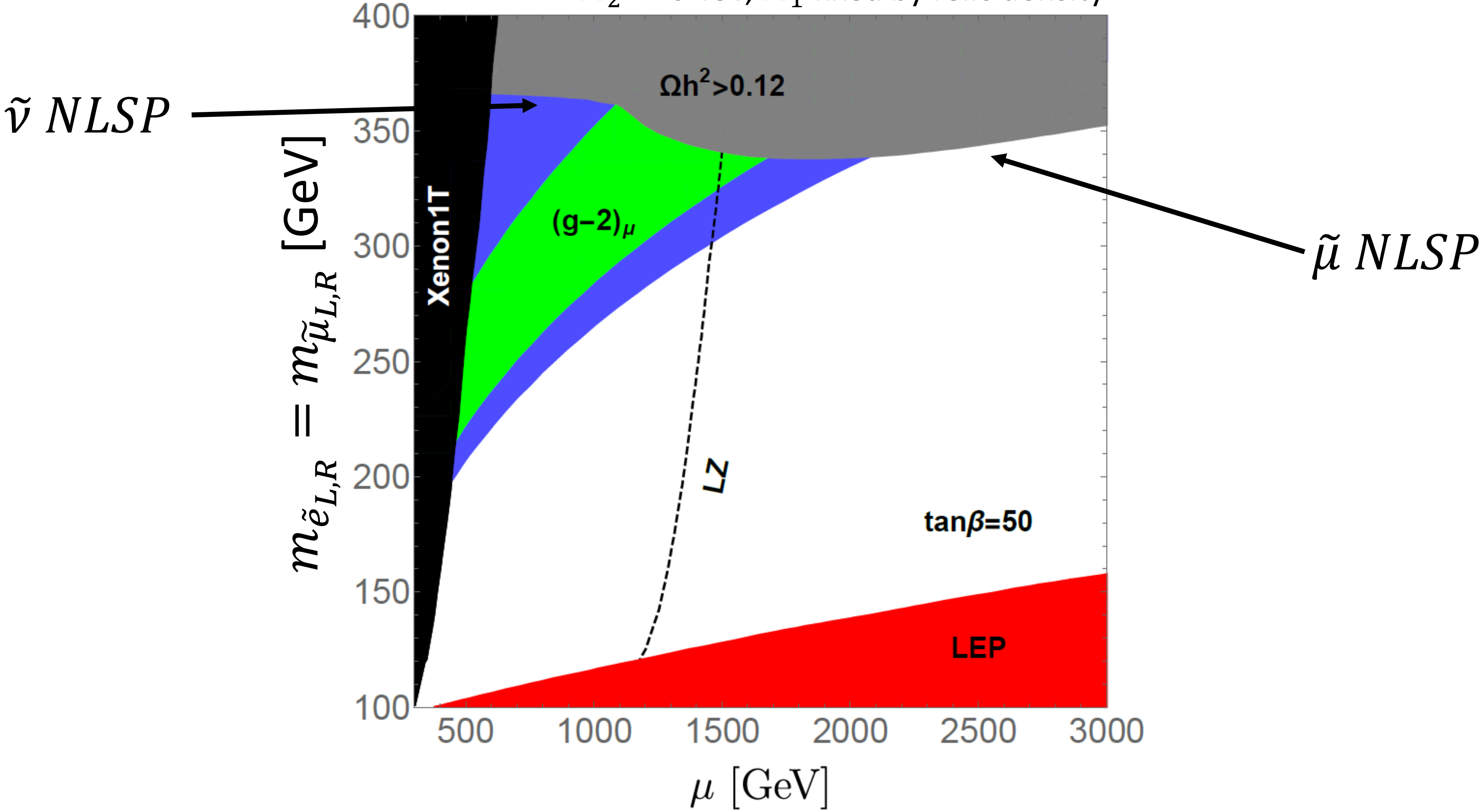
- Very challenging spectrum to test at the LHC

- For realistic mass-splitting, best limits still from LEP



$\tilde{B} - \tilde{l}$ co-annihilation

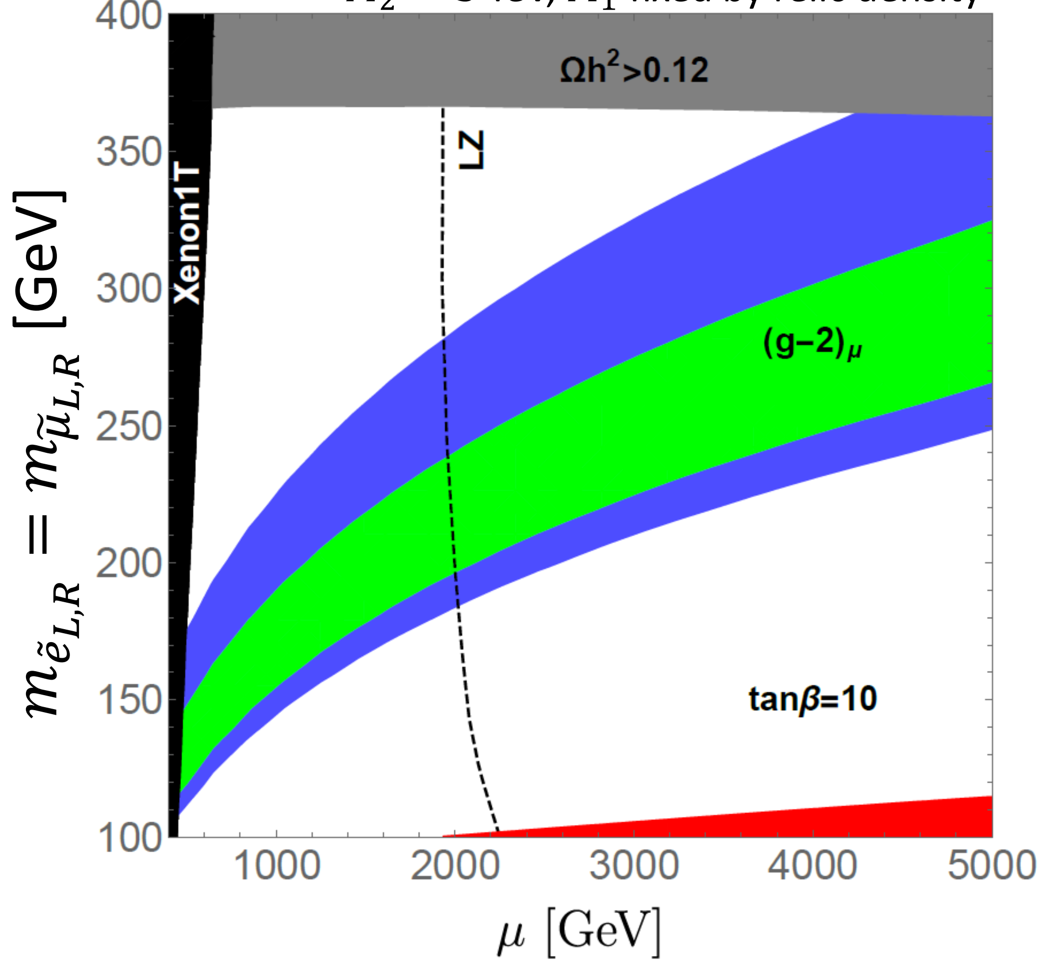
$M_2 = 3$ TeV, M_1 fixed by relic density



Most of the parameter space can be probed by direct detection (for large $\tan\beta$)

$\tilde{B} - \tilde{l}$ co-annihilation

$M_2 = 3$ TeV, M_1 fixed by relic density



Requires slepton masses $\lesssim 350$ GeV

⟶ potentially within reach of a future lepton collider

High-scale models?

- So far, only focused on low-energy MSSM…
- Are there high-scale models that can realise the required spectra?

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- Are there high-scale models that can realise the required spectra?

An example: *non-universal gaugino mediation*

At GUT scale: $M_1, M_2, M_3, \tan\beta, \text{sgn}(\mu)$

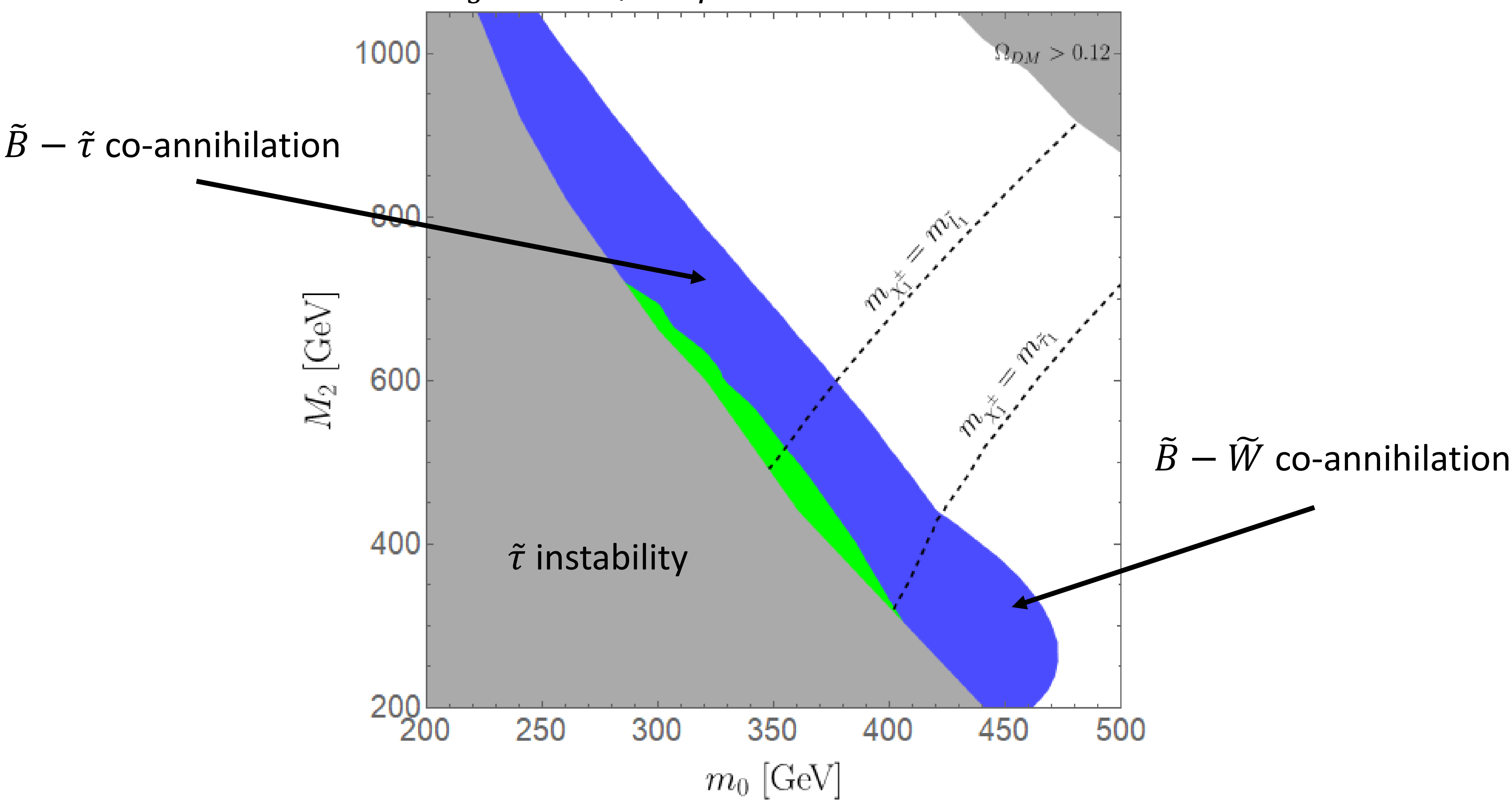
But, issues with tachyonic slepton masses…

⟶ Introduce additional universal scalar soft mass m_0
(proxy for effects of B-L gaugino mediation?)

Non-universal gaugino mediation

[PC, Han, Yanagida, Yokozaki, preliminary]

$M_3 = 4$ TeV, $\tan\beta$=15



Non-universal gaugino mediation

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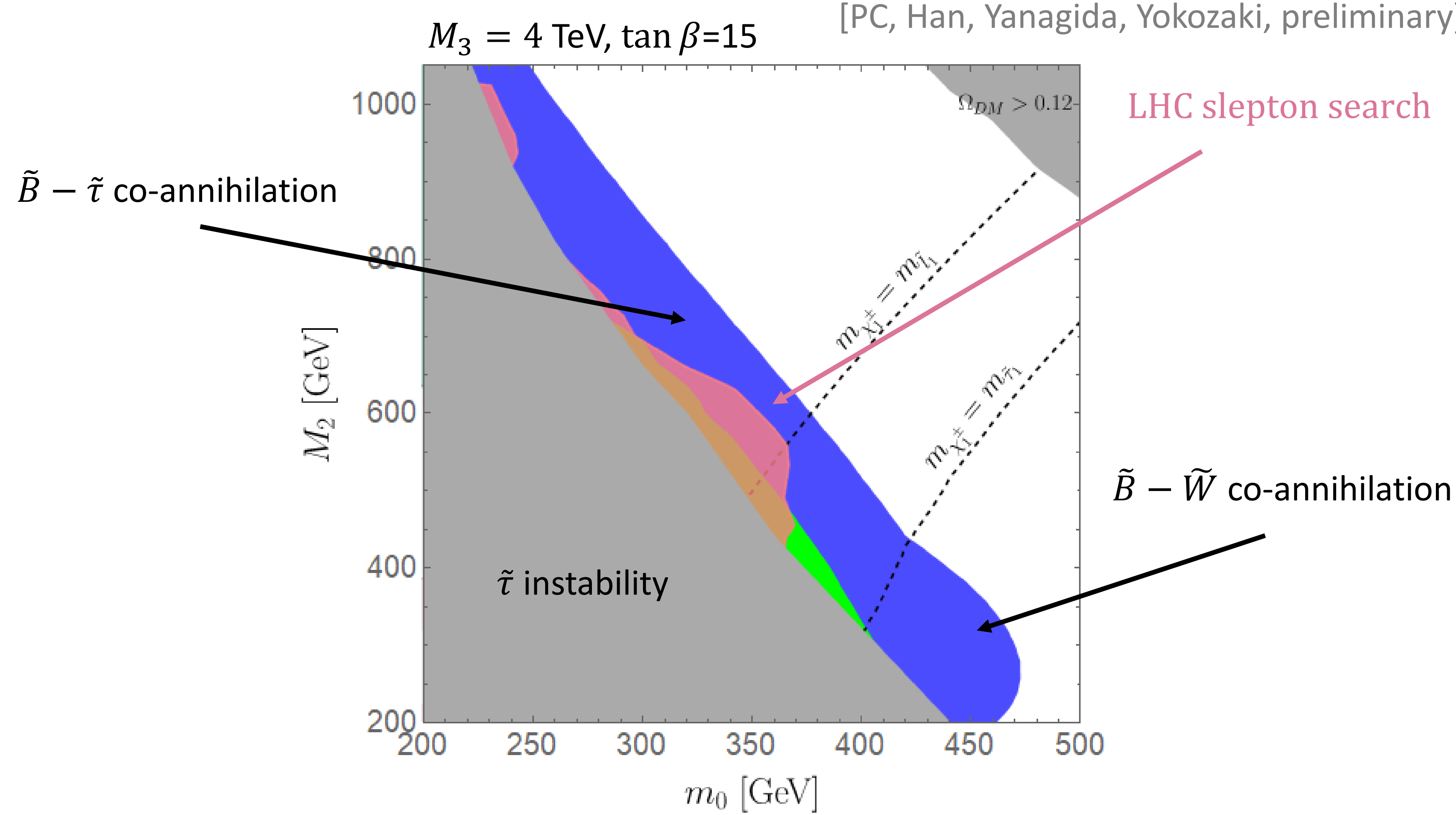

Better to consider scenarios that split the 3rd gen. sleptons ⟶ Higgs mediation?

Summary

- SUSY remains a well-motivated framework and can simultaneously account for the DM density and observed discrepancy in the muon *g-2*
- Strong direct detection constraints motivate a bino-like LSP, with relic density obtained via co-annihilations
- $\tilde{B} - \widetilde{W}$: much of the parameter space can be probed at (HL)-LHC, but in extreme case sleptons as heavy as 1.4 TeV
- $\tilde{B} - \tilde{l}$: significant regions will be probed by direct detection; relic density requires light sleptons $\lesssim 350$ GeV, potentially within reach of a future linear collider
- Necessary spectrum can be obtained in high-scale models, but ideally want to split 3rd generation sfermions $\longrightarrow$ further model building