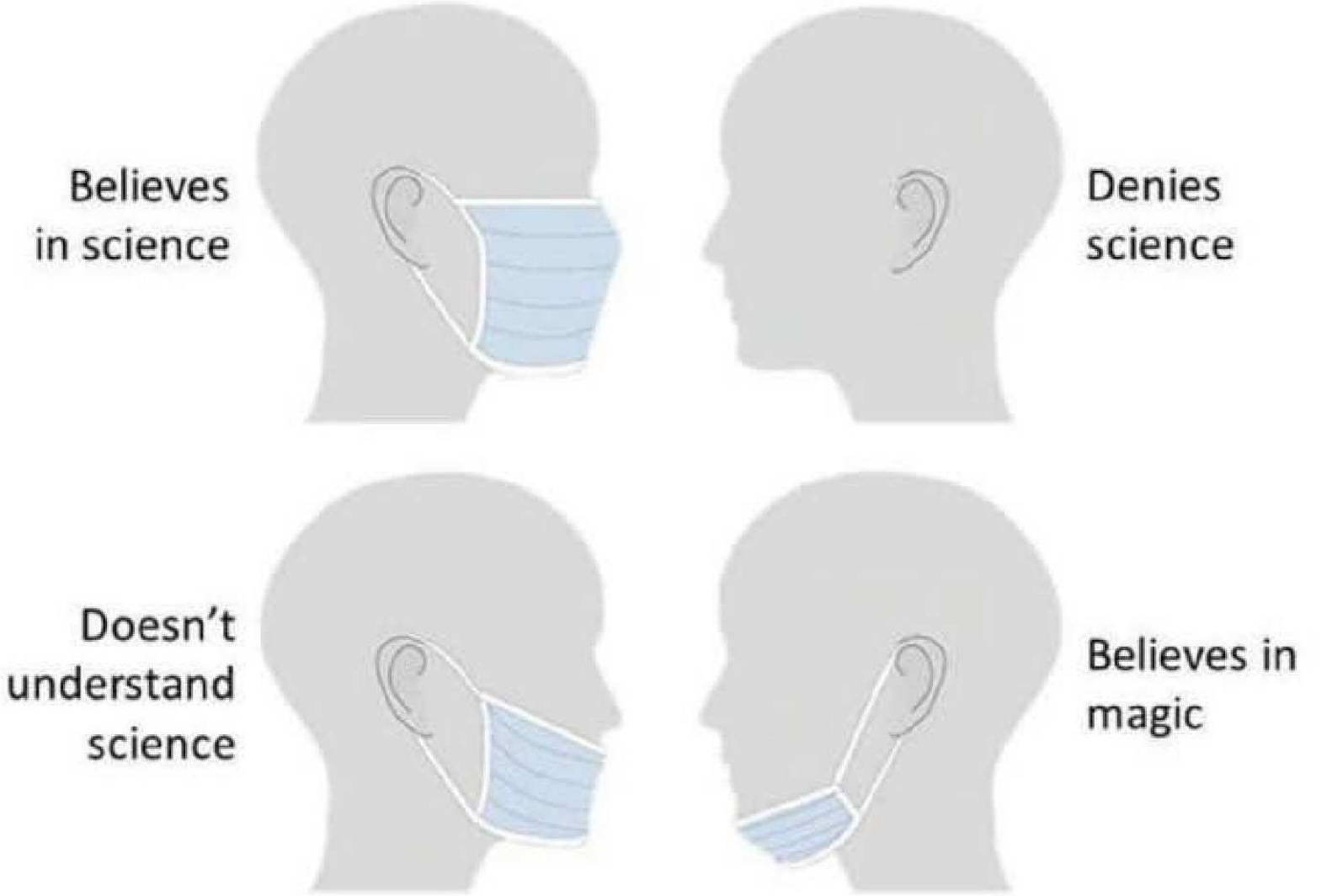
The Four COVID Personality Types

(*spotted at the local grocery store*)



Improved $(g-2)_\mu$ Measurements and SUSY

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Hong Kong/virtual, 01/2021

In collaboration with: *M. Chakraborti, I. Saha* [*arXiv:2006.15157, EPJC*]

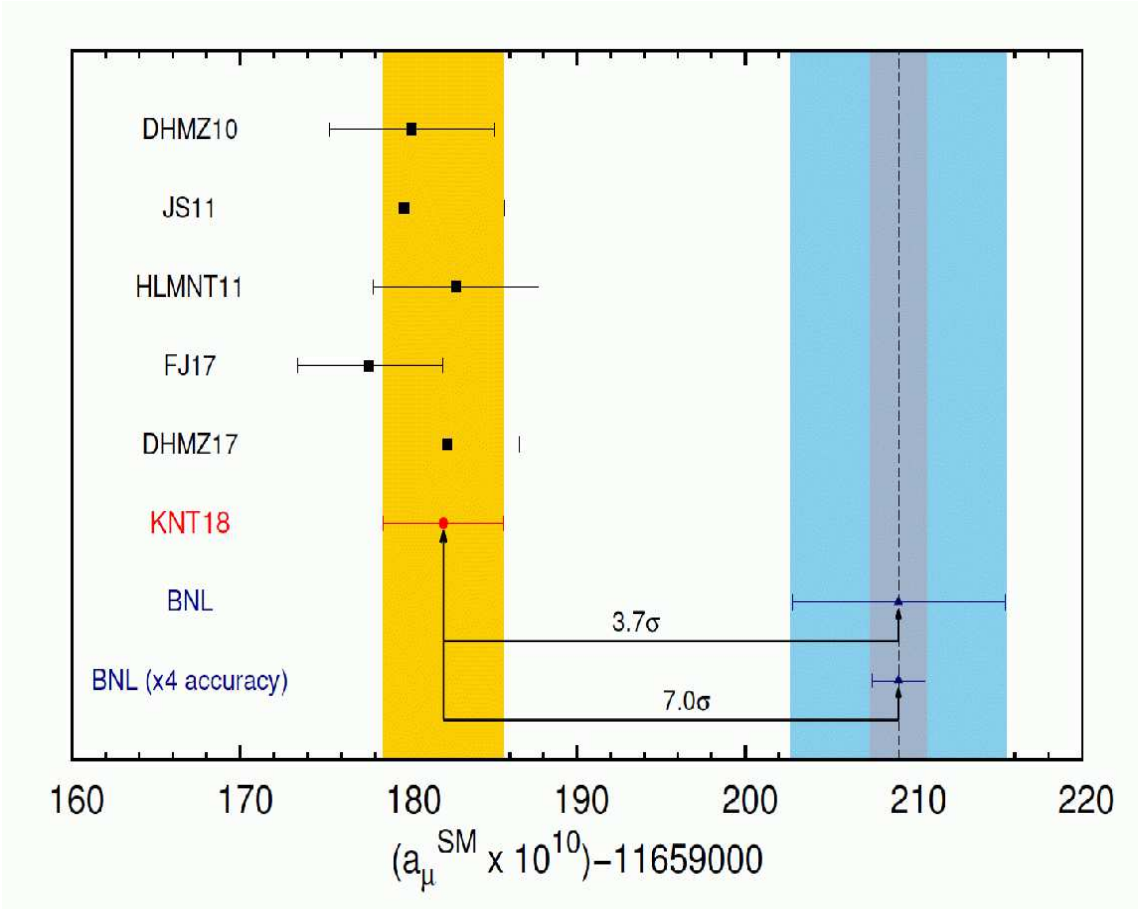
1. The general idea
2. Experimental constraints
3. Results for (nearly) all SUSY scenarios
4. Predictions for future colliders
5. Conclusions

1. The general idea

The anomalous magnetic moment of the muon: $a_\mu \equiv (g-2)_\mu/2$

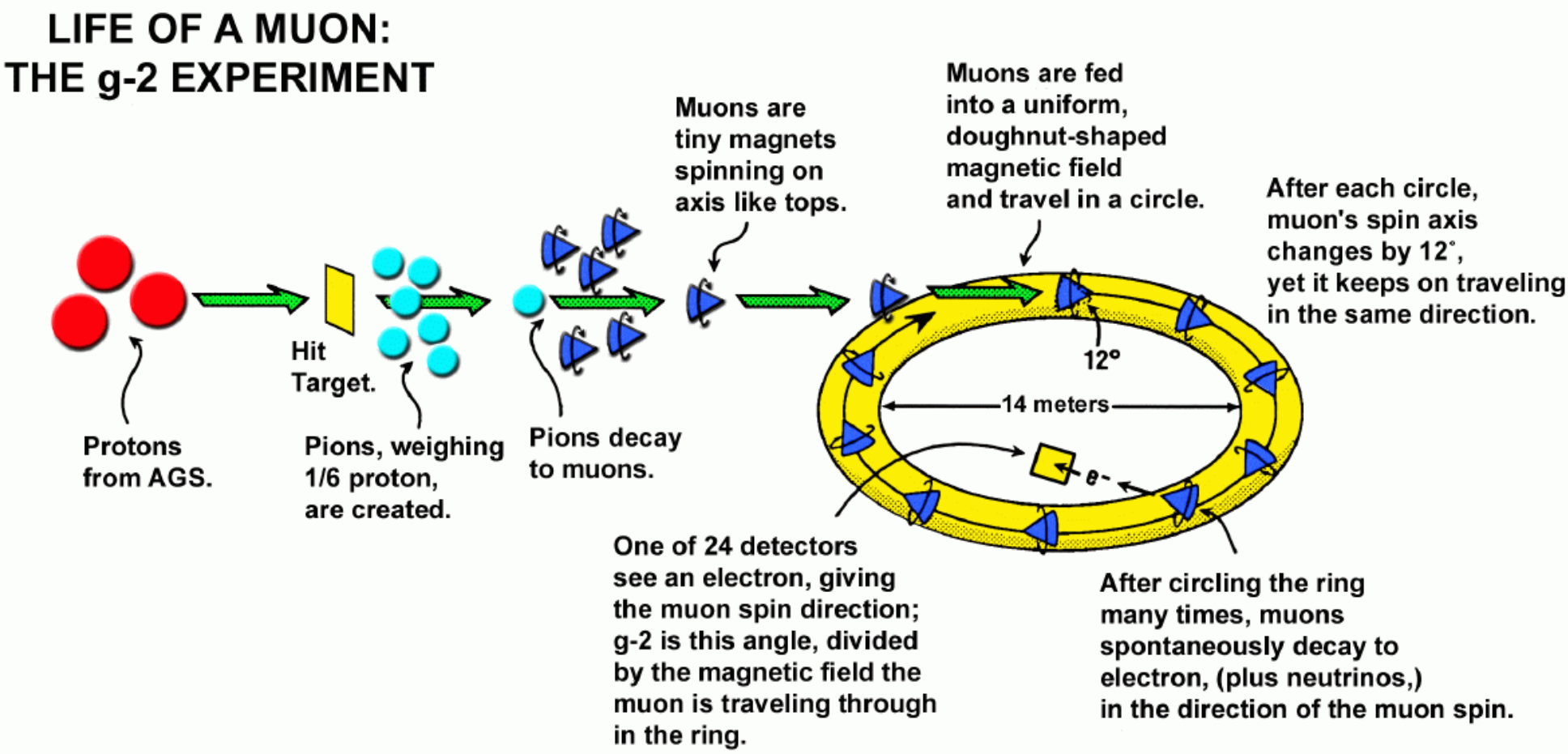
Overview about the current experimental and SM (theory) result:

[*A. Keshavarzia, D. Nomura, T. Teubner '18, '20*]



$$a_\mu^{\text{exp}} - a_\mu^{\text{theo,SM}} \approx (28.02 \pm 7.37) \times 10^{-10} \quad : 3.8\,\sigma$$

The $(g-2)_\mu$ experiment:

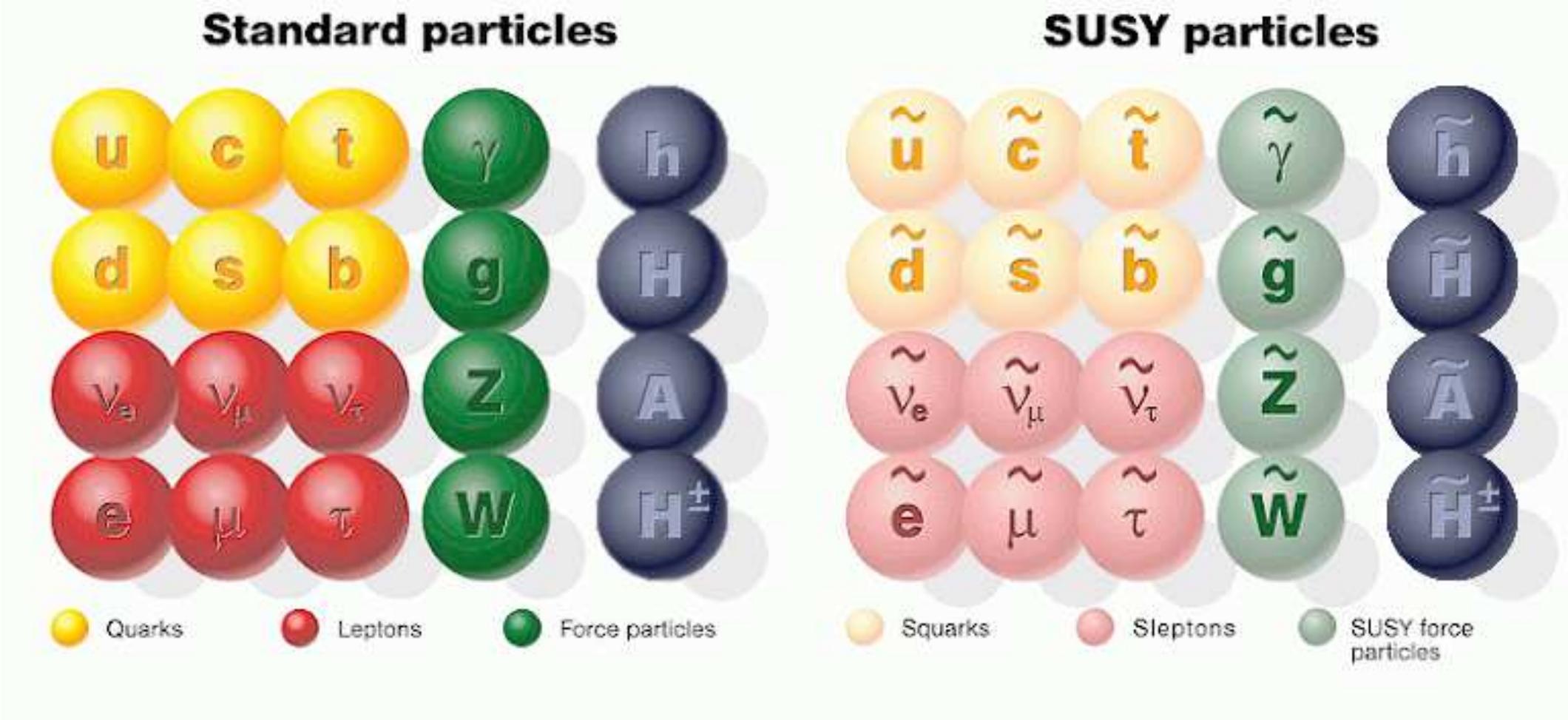


Coupling of muon to magnetic field : $\mu - \mu - \gamma$ coupling

$$\bar{u}(p')\left[\gamma^\mu F_1(q^2) + \frac{i}{2m_\mu}\sigma^{\mu\nu}q_\nu F_2(q^2)\right]u(p)A_\mu \qquad F_2(0) = a_\mu$$

The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles



⇒ large uncolored / EW sector

Neutralinos and charginos:

Higgsinos and electroweak gauginos mix

charged:

$$\tilde{W}^+, \tilde{h}_u^+ \to \tilde{\chi}_1^+, \tilde{\chi}_2^+, \qquad \tilde{W}^-, \tilde{h}_d^- \to \tilde{\chi}_1^-, \tilde{\chi}_2^-$$

Diagonalization of the mass matrix:

$$\mathbf{X} = \begin{pmatrix} M_2 & \sqrt{2}\sin\beta\, M_W \\ \sqrt{2}\cos\beta\, M_W & \mu \end{pmatrix},$$

$$\mathbf{M}_{\tilde{\chi}^-} = \mathbf{V}^* \mathbf{X}^\top \mathbf{U}^\dagger = \begin{pmatrix} m_{\tilde{\chi}_1^\pm} & 0 \\ 0 & m_{\tilde{\chi}_2^\pm} \end{pmatrix}$$

$\Rightarrow$ charginos: mass eigenstates

mass matrix given in terms of M_2, μ, $\tan\beta$

neutral:

$$\underbrace{\tilde{\gamma}, \tilde{Z}}, \tilde{h}_u^0, \tilde{h}_d^0 \to \tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$$
$$\tilde{W}^0, \tilde{B}^0$$

Diagonalization of mass matrix:

$$\mathbf{Y} = \begin{pmatrix} M_1 & 0 & -M_Z\, s_W \cos\beta & M_Z\, s_W \sin\beta \\ 0 & M_2 & M_Z\, c_W \cos\beta & -M_Z\, c_W \sin\beta \\ -M_Z\, s_W \cos\beta & M_Z\, c_W \cos\beta & 0 & -\mu \\ M_Z\, s_W \sin\beta & -M_Z\, c_W \sin\beta & -\mu & 0 \end{pmatrix},$$

$$\mathbf{M}_{\tilde{\chi}^0} = \mathbf{N}^* \mathbf{Y} \mathbf{N}^\dagger = \mathbf{diag}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\chi}_3^0}, m_{\tilde{\chi}_4^0})$$

$\Rightarrow$ neutralinos: mass eigenstates

mass matrix given in terms of M_1, M_2, μ, $\tan\beta$
$\Rightarrow$ only one additional parameter

$\Rightarrow$ MSSM predicts mass relations between neutralinos and charginos

Scalar lepton sector of the MSSM

Charged slepton mass matrices

$$\mathbf{M}^2_{\tilde{l}} = \begin{pmatrix} M^2_{\tilde{l}_L} + m^2_l + DT_{l_1} & m_l X_l \\ m_l X_l & M^2_{\tilde{l}_R} + m^2_l + DT_{l_2} \end{pmatrix} \xrightarrow{\theta_{\tilde{l}}} \begin{pmatrix} m^2_{\tilde{l}_1} & 0 \\ 0 & m^2_{\tilde{l}_2} \end{pmatrix}$$

with

$$X_l = A_l - \mu \tan\beta$$

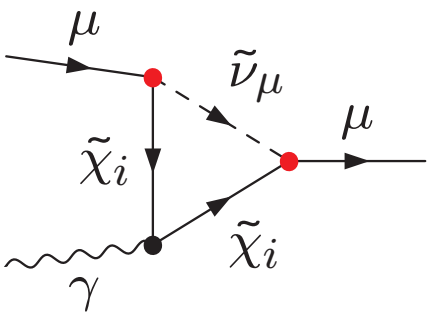
Sneutrino mass

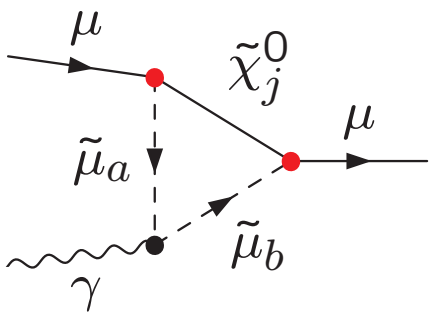
$$m^2_{\tilde{\nu}_l} = M^2_{\tilde{l}_L} + DT_\nu$$

Simplifying assumption: $M_{\tilde{l}_L}$ and $M_{\tilde{l}_R}$ identical for all three generations

SUSY can easily explain the deviation in a_μ:

Feynman diagrams for MSSM 1L corrections:





- Diagrams with chargino/sneutrino exchange
- Diagrams with neutralino/smuon exchange

Enhancement factor as compared to SM:

$$\mu - \tilde{\chi}_i^\pm - \tilde{\nu}_\mu \;:\; \sim m_\mu \tan\beta$$
$$\mu - \tilde{\chi}_j^0 - \tilde{\mu}_a \;:\; \sim m_\mu \tan\beta$$

SM, EW 1L: $\frac{\alpha}{\pi}\frac{m_\mu^2}{M_W^2}$

MSSM, 1L: $\frac{\alpha}{\pi}\frac{m_\mu^2}{M_{\text{SUSY}}^2} \times \tan\beta$

SUSY corrections at 1L:

$$a_\mu^{\text{SUSY,1L}} \approx 13 \times 10^{-10} \left(\frac{100\ \text{GeV}}{M_{\text{SUSY}}}\right)^2 \tan\beta\ \text{sign}(\mu)$$

$M_{\text{SUSY}}(= m_{\tilde{\mu}} = m_{\tilde{\nu}} = m_{\tilde{\chi}})$: generic SUSY mass scale

$$\begin{aligned} a_\mu^{\text{SUSY,1L}} &= (-100 \ldots + 100) \times 10^{-10} \\ a_\mu^{\text{exp}} - a_\mu^{\text{theo,SM}} &\approx (28 \pm 7.4) \times 10^{-10} \end{aligned}$$

$\Rightarrow$ SUSY could easily explain the "discrepancy"

$\Rightarrow$ a_μ can provide upper limits on the EW masses

(by requiering agreement at the 95% C.L.)

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$\Rightarrow$ SUSY could easily explain the "discrepancy"

$\Rightarrow$ a_μ can provide upper limits on the EW masses

(by requiering agreement at the 95% C.L.)

If SUSY exists, it should fix $(g-2)_\mu$!
$\Rightarrow$ there must be light EW SUSY particles!

The general idea:

- scan the relevant EW SUSY parameter space

- impose all relevant experimental constraints:
  - $(g-2)_\mu$
  - Dark Matter relic density
  - Dark Matter direct detection
  - LHC searches for EW particles

- Dark Matter relic density requires a mechanism to reduce the density in the early universe
  - bino/wino DM with chargino co-annihilation
  - bino/wino DM with slepton co-annihilation
  - higgsino DM
  - wino DM

- obtain lower and upper limits on the various EW particle masses

- evaluate the prospects for future searches

2. Experimental constraints

LHC searches:

Decay via sleptons (3l)

$$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to (\tilde{l}^{\pm}\nu)(\tilde{l}^{+}l^{-}) \to 3l + \not{E}_T \ ,$$
$$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to (l^{\pm}\tilde{\nu})(\tilde{l}^{+}l^{-}) \to 3l + \not{E}_T \qquad (5)$$

Decay via sleptons (2l)

$$\tilde{\chi}_1^{+}\tilde{\chi}_1^{-} \to (\tilde{l}^{+}\nu)(\tilde{l}^{-}\nu) \to 2l + \not{E}_T \ ,$$
$$\tilde{\chi}_1^{+}\tilde{\chi}_1^{-} \to (l^{+}\tilde{\nu})(l^{-}\tilde{\nu}) \to 2l + \not{E}_T \qquad (6)$$

Decay via gauge bosons

$$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to (W\tilde{\chi}_1^0)(Z\tilde{\chi}_1^0) \to 3l + \not{E}_T \ , \qquad (7a)$$
$$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to (W\tilde{\chi}_1^0)(Z\tilde{\chi}_1^0) \to 2l + \text{jets} + \not{E}_T \ , \qquad (7b)$$
$$\tilde{\chi}_1^{+}\tilde{\chi}_1^{-} \to (W^{+}\tilde{\chi}_1^0)(W^{-}\tilde{\chi}_1^0) \to 2l + \not{E}_T \qquad (8)$$

Decay via Higgs bosons

$$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to (W\tilde{\chi}_1^0)(h\tilde{\chi}_1^0) \to l + b\bar{b} + \not{E}_T \qquad (9)$$

$\tilde{l}$-pair production (2l)

$$\tilde{l}^+\tilde{l}^- \to (l^+\tilde{\chi}_1^0)(l^-\tilde{\chi}_1^0) \to 2l + \not{E}_T \qquad (10)$$

Compressed spectra

$$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to (W^*\tilde{\chi}_1^0)(Z^*\tilde{\chi}_1^0) \to 2l + \not{E}_T \ + \text{ISR}\ , \qquad (11)$$
$$\tilde{l}^+\tilde{l}^- \to (l^+\tilde{\chi}_1^0)(l^-\tilde{\chi}_1^0) \to 2l + \not{E}_T \ + \text{ISR} \qquad (12)$$

Searches involving Staus

$\Rightarrow$ all newly included into CheckMate [*M.C. & I.S.*]

Exception: compressed spectra $\Rightarrow$ direct application

$(g-2)_\mu$ constraint: (GM2Calc)

$$\Delta a_\mu = (28.02 \pm 7.37) \times 10^{-10}$$

Possible improvement in the very near future:

Inclusion of anticipated MUON G-2 Run 1 data

$$\Delta a_\mu^{\text{fut}} = (28.02 \pm 5.2) \times 10^{-10}$$

Dark Matter relic density: MicrOmegas

$$\Omega_{\text{CDM}} h^2 = 0.120 \pm 0.001$$
$$\text{or} \quad \Omega_{\text{CDM}} h^2 \leq 0.122$$

(as taken from [*Planck '18*])

Dark Matter direct detection: MicrOmegas

limit on spin independent scattering cross section (Xenon1T)

[*Xenon collab. '18*]

3. Results for (nearly) all SUSY scenarios

Possible scenarios:

1. bino/wino DM with chargino co-annihilation
   $\Rightarrow$ full relic DM constraint

2. bino/wino DM with slepton co-annihilation case-L
   $\Rightarrow$ full relic DM constraint

3. bino/wino DM with slepton co-annihilation case-R
   $\Rightarrow$ full relic DM constraint

4. higgsino DM: $m_{\tilde{\chi}_1^0} \approx m_{\tilde{\chi}_2^0} \approx m_{\tilde{\chi}_1^\pm}$
   full relic DM constraint $\Rightarrow m_{\tilde{\chi}_1^0} \sim 1$ TeV $\Rightarrow (g-2)_\mu$ no ok
   $\Rightarrow$ relic DM upper bound

5. wino DM: $m_{\tilde{\chi}_1^0} \approx m_{\tilde{\chi}_1^\pm}$
   full relic DM constraint $\Rightarrow m_{\tilde{\chi}_1^0} \sim 3$ TeV $\Rightarrow (g-2)_\mu$ no ok
   $\Rightarrow$ relic DM upper bound

A) Bino/wino DM with chargino co-annihilation

Parameter scan:

$$100 \text{ GeV} \leq M_1 \leq 1 \text{ TeV} ,$$

$$M_1 \leq M_2 \leq 1.1 M_1 ,$$

$$1.1 M_1 \leq \mu \leq 10 M_1,$$

$$5 \leq \tan\beta \leq 60,$$

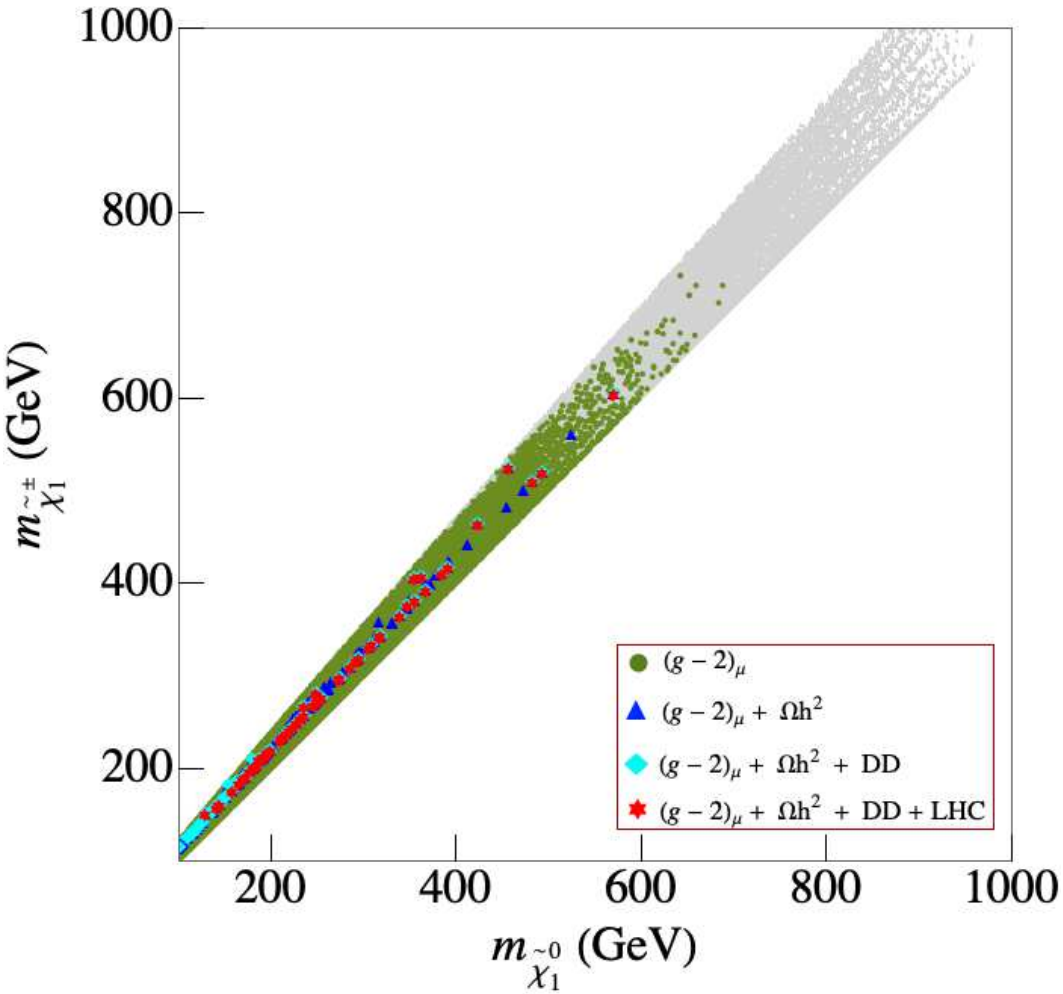
$$100 \text{ GeV} \leq m_{\tilde{L}} \leq 1 \text{ TeV},$$

$$m_{\tilde{R}} = m_{\tilde{L}} .$$

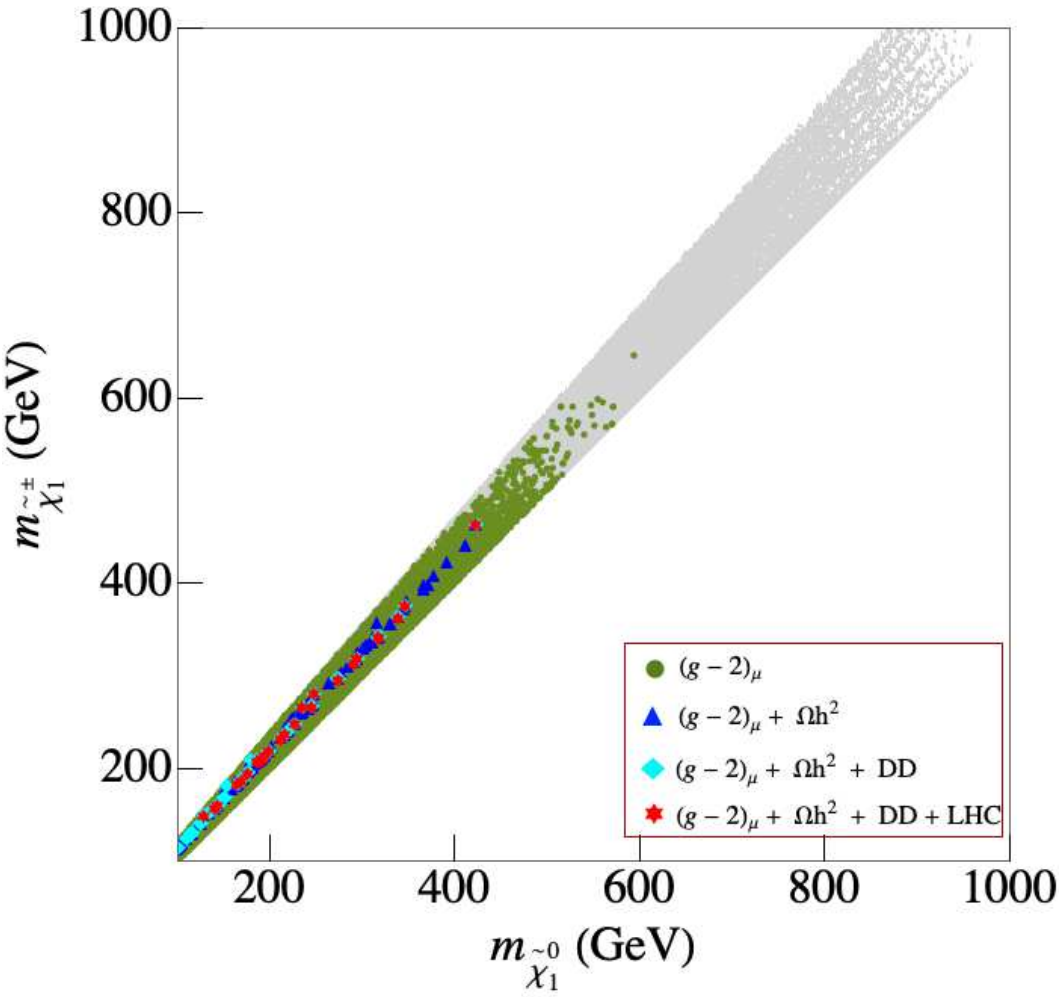
(latter condition only to make the analysis simpler, no relevant effect)

Results in the $m_{\tilde{\chi}_1^0}$-$m_{\tilde{\chi}_1^\pm}$ plane:

current $(g-2)_\mu$



future $(g-2)_\mu$

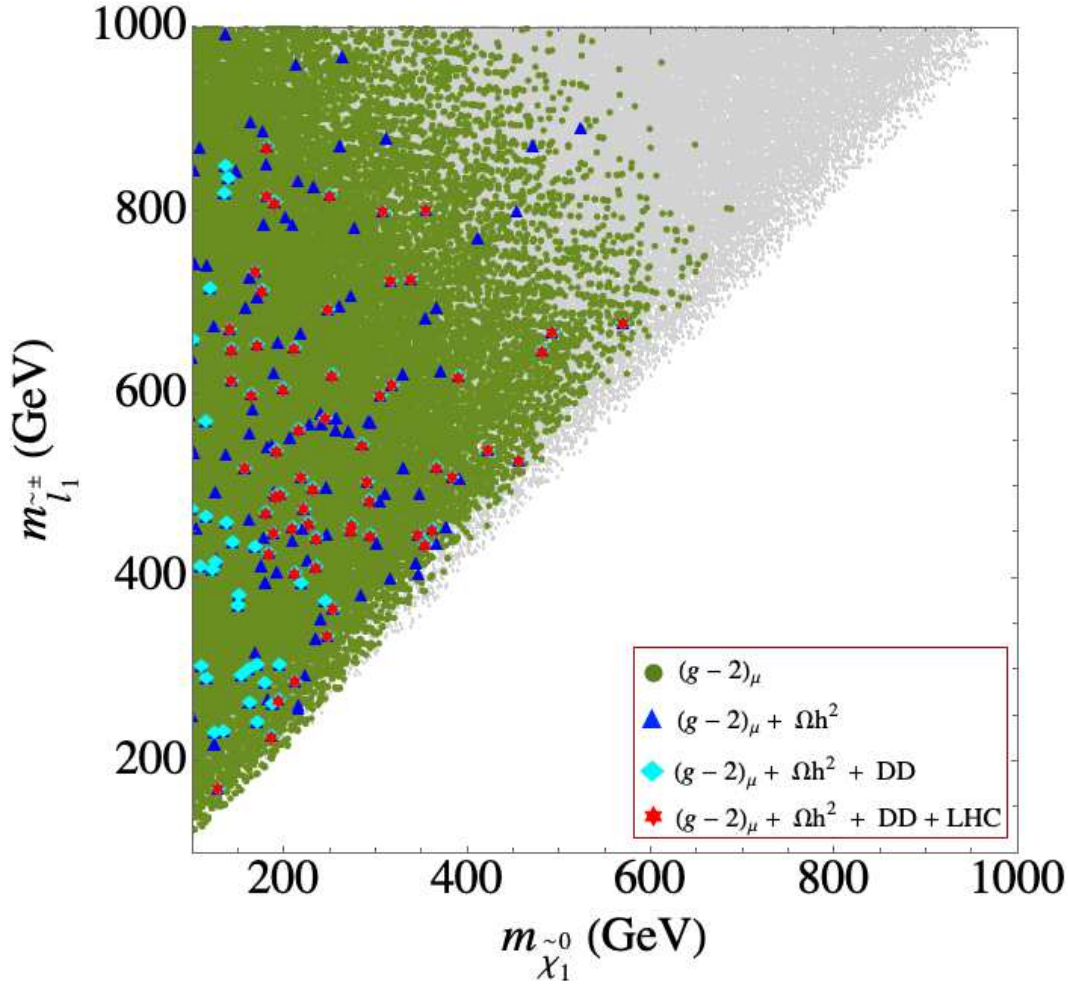


$\Rightarrow$ compressed spectrum as expected

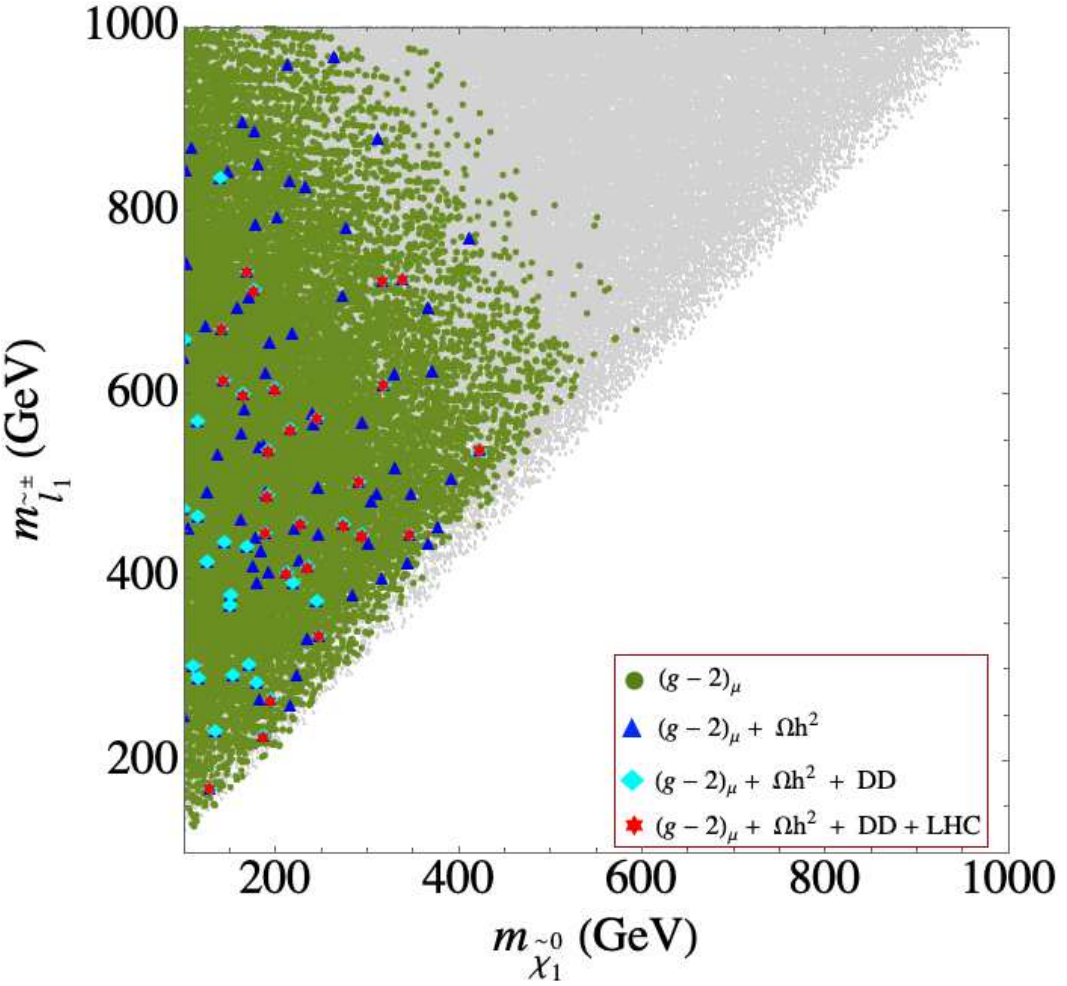
$\Rightarrow$ clear upper limits, $m_{\text{(N)LSP}} \lesssim 600(500)$ GeV

Results in the $m_{\tilde{\chi}_1^0}$-$m_{\tilde{l}_1}$ plane:

current $(g-2)_\mu$



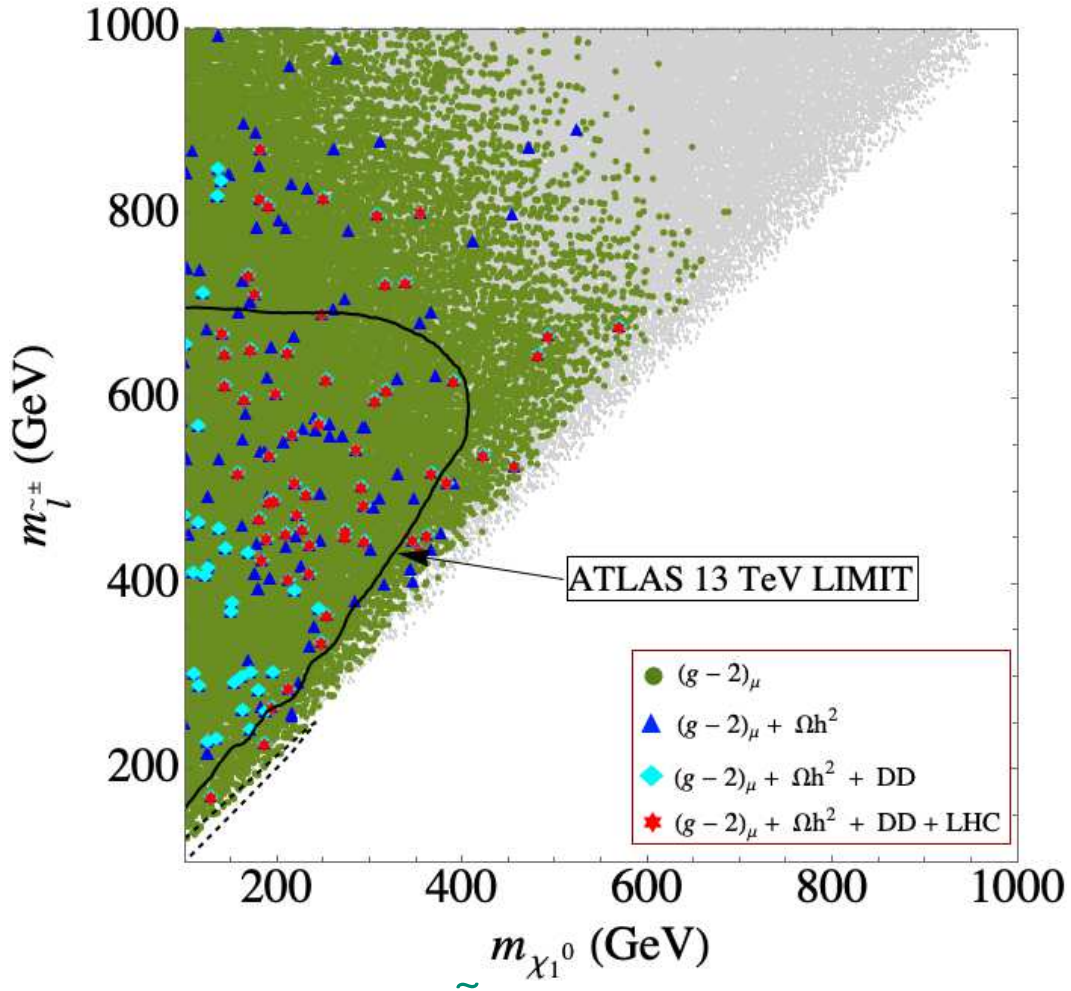
future $(g-2)_\mu$



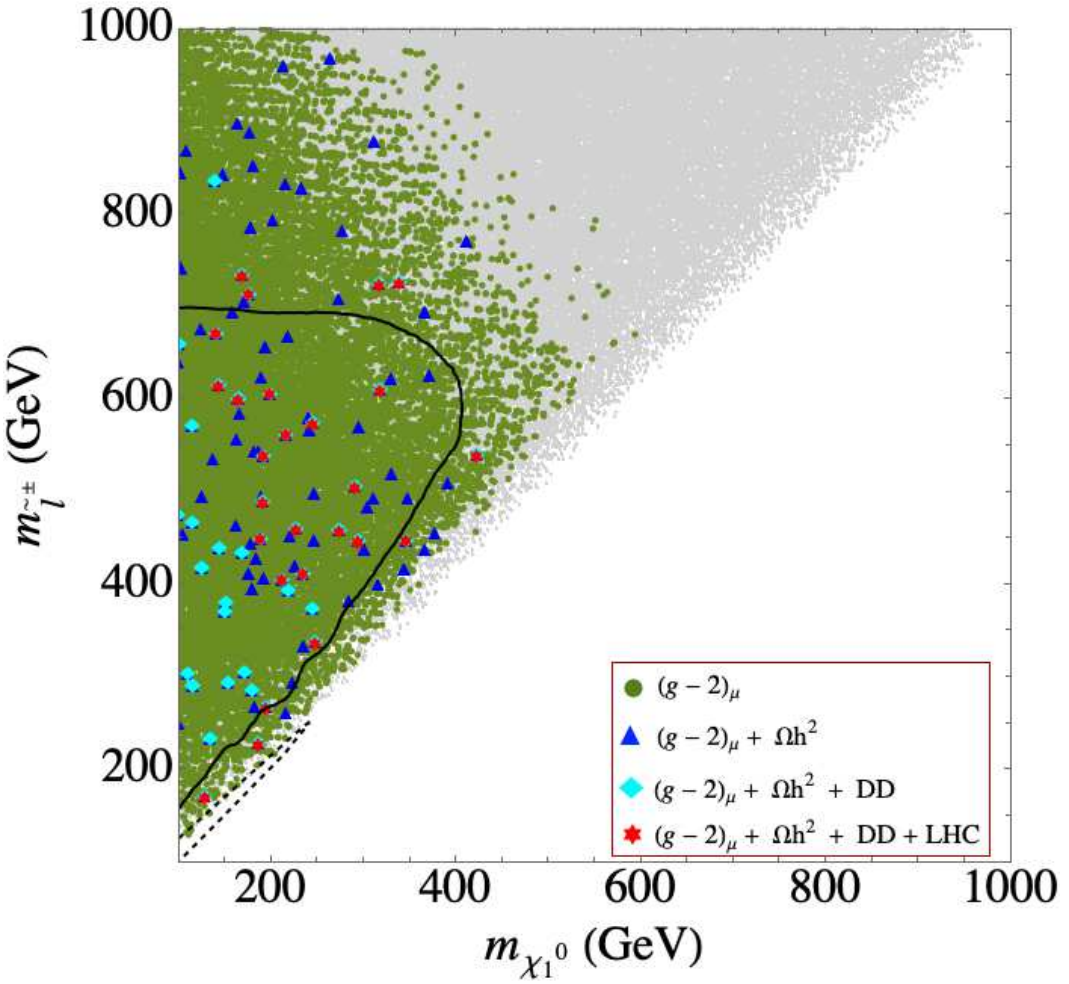
$\Rightarrow$ important: $\tilde{l}$-pair production searches (10)

Results in the $m_{\tilde{\chi}_1^0}$-$m_{\tilde{l}_1}$ plane:

current $(g-2)_\mu$



future $(g-2)_\mu$



$\Rightarrow$ important: $\tilde{l}$-pair production searches (10)

$\Rightarrow$ naive application of LHC bounds fails

B/C) Bino/wino DM with slepton co-annihilation

Parameter scan:

$$100 \text{ GeV} \leq M_1 \leq 1 \text{ TeV} ,$$

$$M_1 \leq M_2 \leq 10 M_1 ,$$

$$1.1 M_1 \leq \mu \leq 10 M_1,$$

$$5 \leq \tan\beta \leq 60,$$

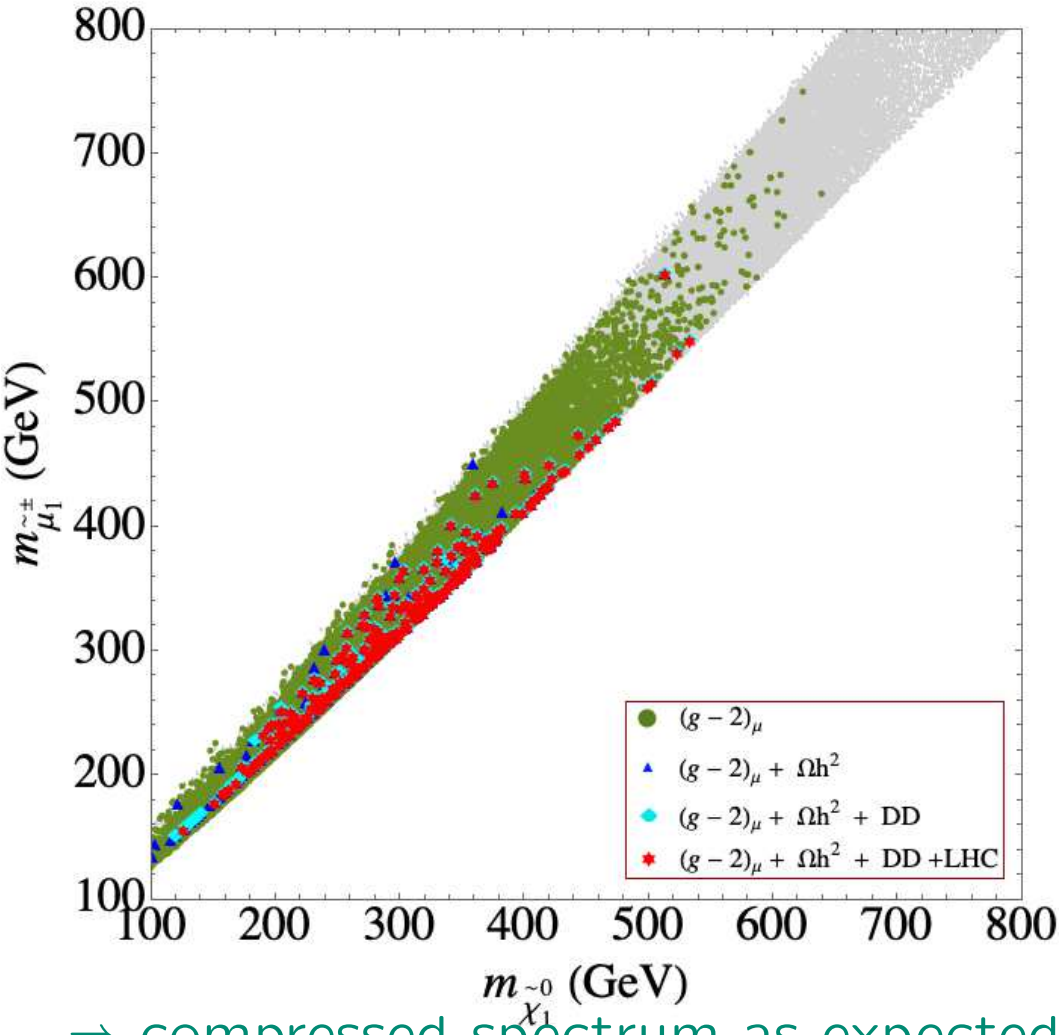
Case-L: $M_1 \leq m_{\tilde{L}} \leq 1.2 M_1,$ $M_1 \leq m_{\tilde{R}} \leq 10 M_1.$

Case-R: $M_1 \leq m_{\tilde{R}} \leq 1.2 M_1,$ $M_1 \leq m_{\tilde{L}} \leq 10 M_1.$

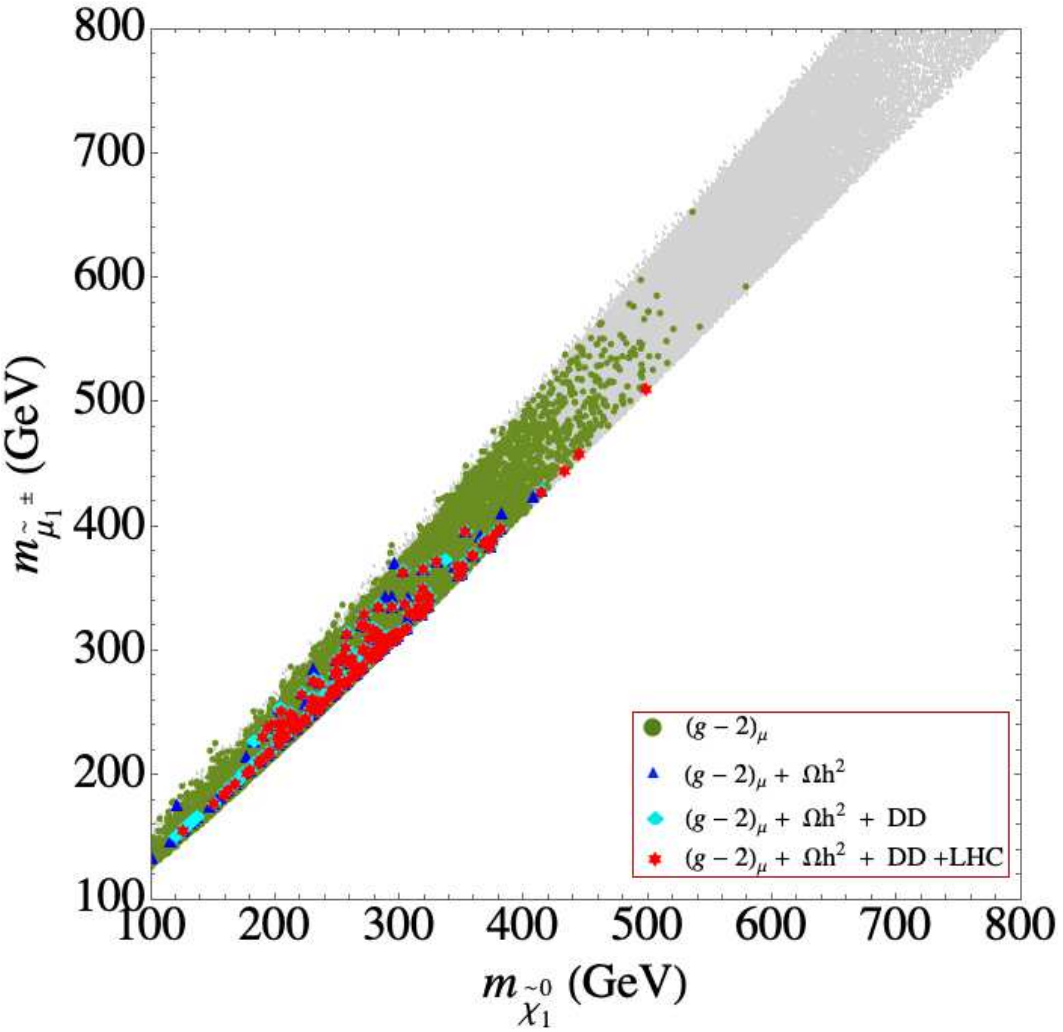
$\Rightarrow$ here focus on Case-L

Results in the $m_{\tilde{\chi}_1^0}$-$m_{\tilde{l}_1}$ plane:

current $(g-2)_\mu$



future $(g-2)_\mu$

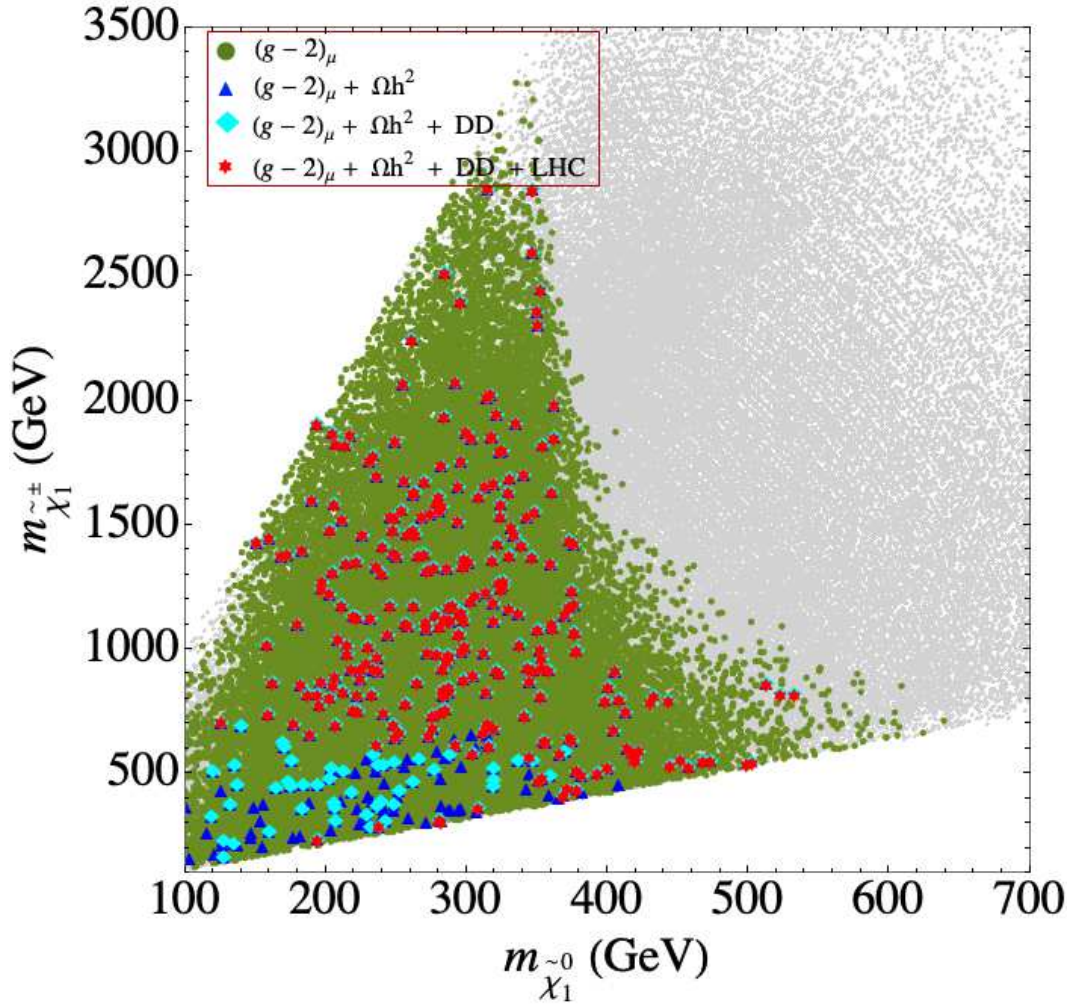


$\Rightarrow$ compressed spectrum as expected

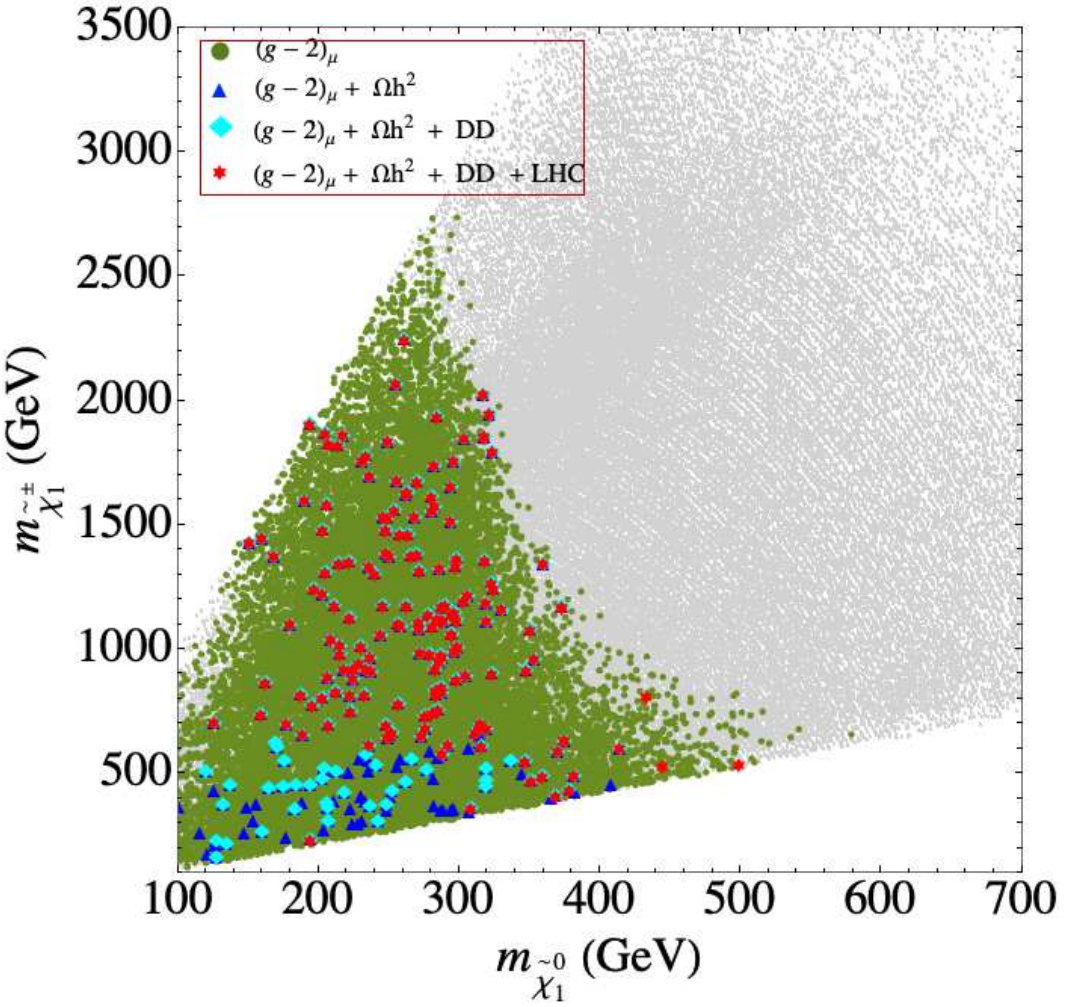
$\Rightarrow$ clear upper limits, $m_{\text{(N)LSP}} \lesssim 550(500)$ GeV

Results in the $m_{\tilde{\chi}_1^0}$-$m_{\tilde{\chi}_1^\pm}$ plane:

current $(g-2)_\mu$



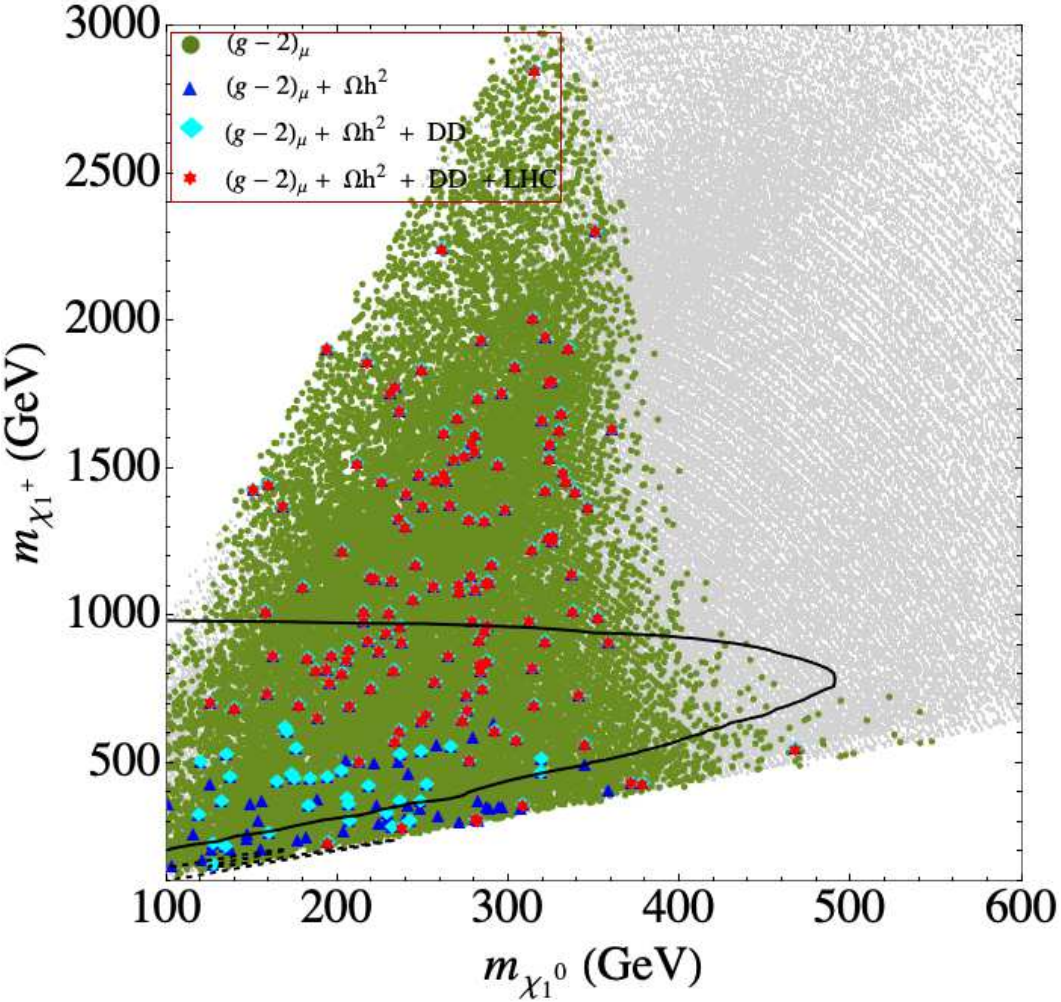
future $(g-2)_\mu$



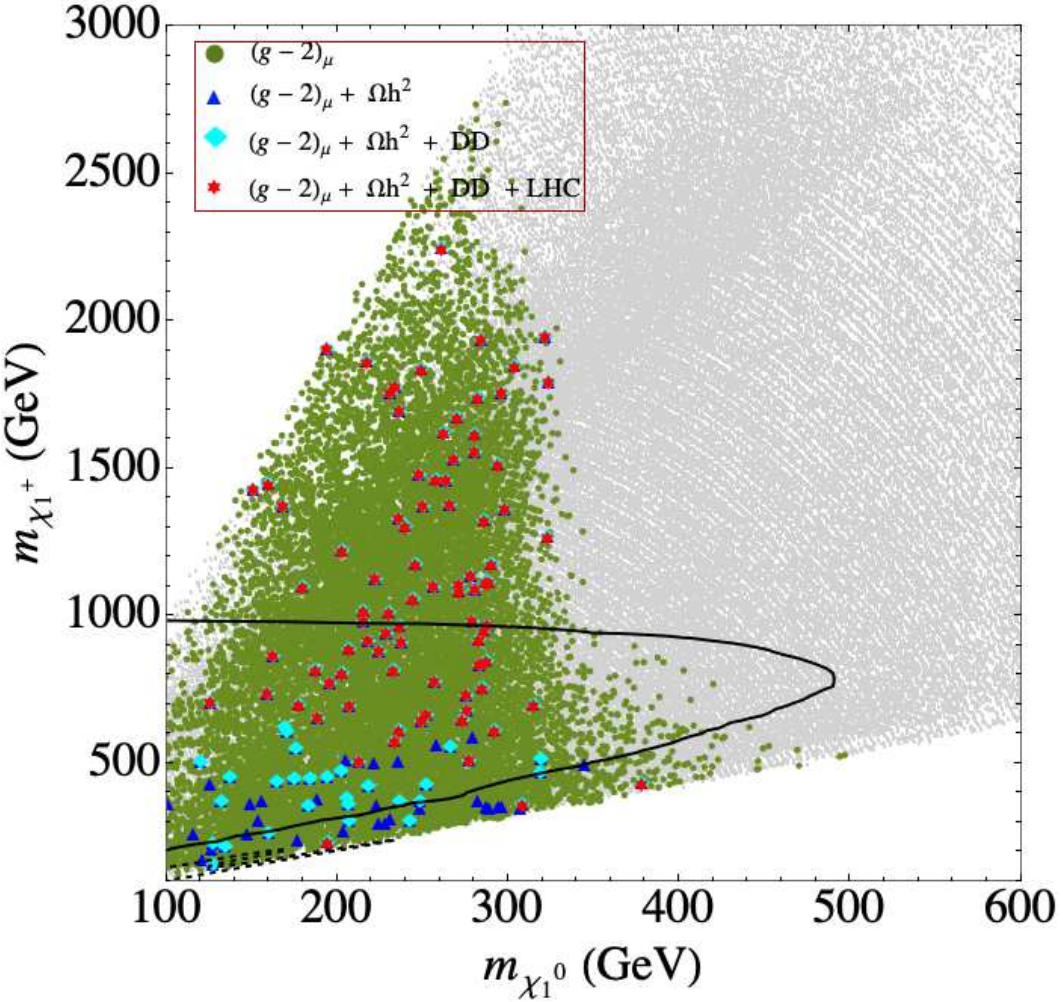
$\Rightarrow$ important: $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production searches (5)

Results in the $m_{\tilde{\chi}_1^0}$-$m_{\tilde{l}_1}$ plane:

current $(g-2)_\mu$



future $(g-2)_\mu$



$\Rightarrow$ important: $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production searches (5)

$\Rightarrow$ naive application of LHC bounds fails

D) Higgsino DM

[*PRELIMINARY*]

Parameter scan:

$$100 \text{ GeV} \leq \mu \leq 1.2 \text{ TeV} ,$$

$$1.1\mu \leq M_1 \leq 10\mu ,$$

$$1.1 M_2 \leq \mu \leq 10\mu ,$$

$$5 \leq \tan\beta \leq 60,$$

$$100 \text{ GeV} \leq m_{\tilde{L}}, m_{\tilde{R}} \leq 2 \text{ TeV},$$

$\Rightarrow m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_2^0} \sim m_{\tilde{\chi}_1^\pm} \sim \mu$

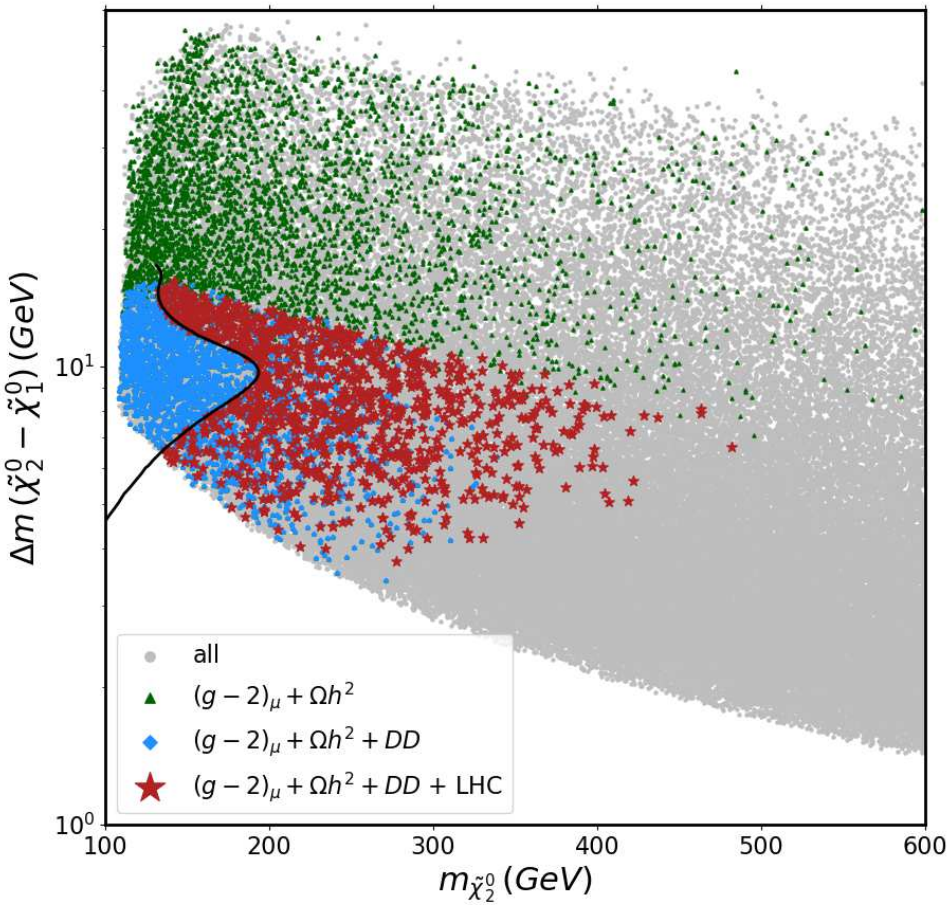
Full DM relic density reached only for $m_{\tilde{\chi}_1^0} \sim 1$ TeV

$\Rightarrow$ incompatible with $(g-2)_\mu$

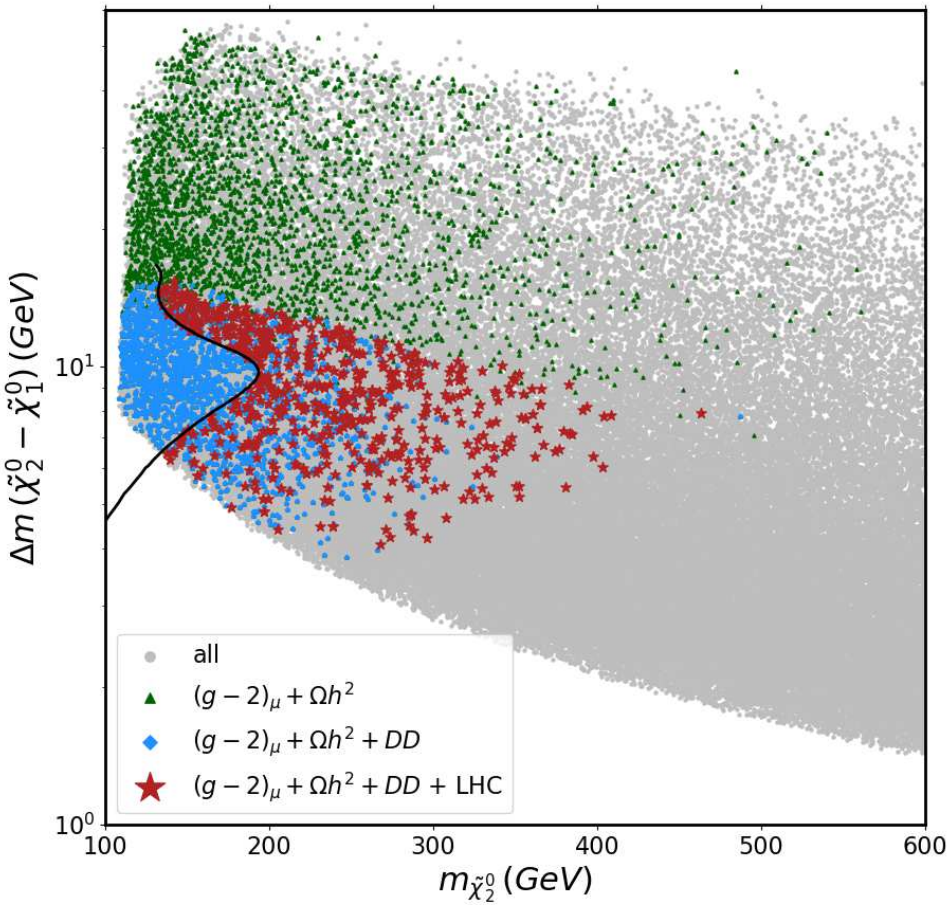
Results in the $m_{\tilde{\chi}_2^0}$-Δm plane:

[*PRELIMINARY*]

current $(g-2)_\mu$



future $(g-2)_\mu$



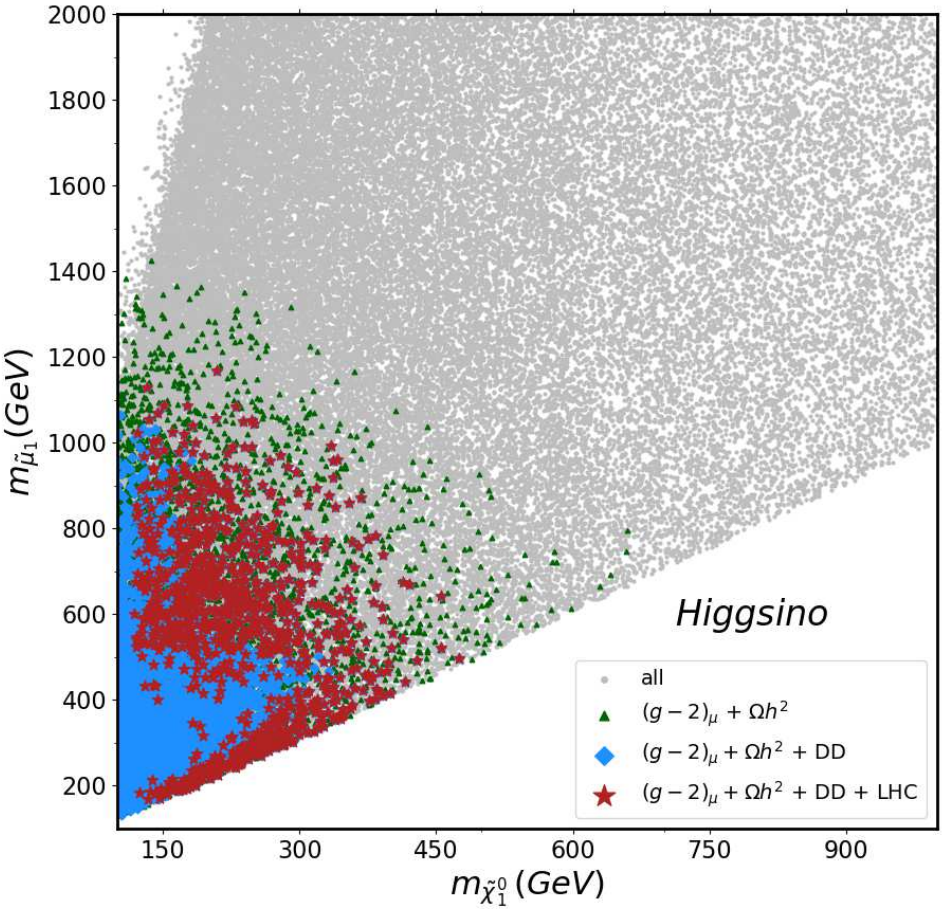
$\Rightarrow$ important: compressed spectra searches (11)

$\Rightarrow$ right where the model prediction sits $\Rightarrow$ very powerful

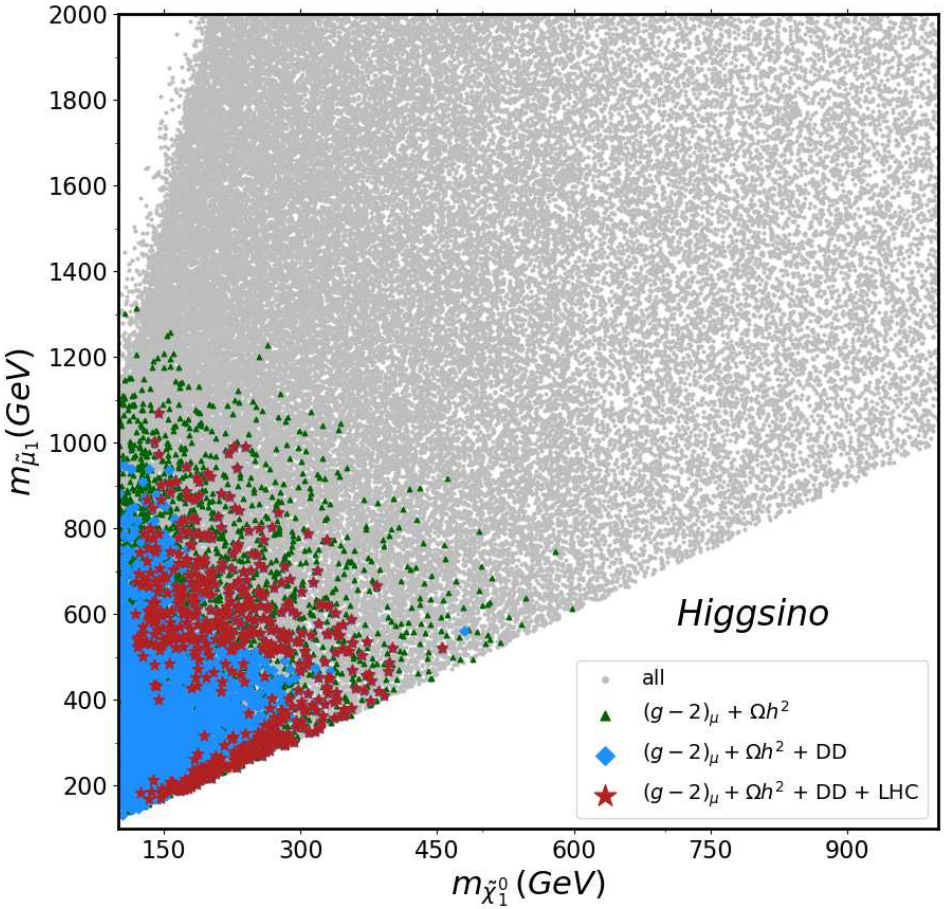
Results in the $m_{\tilde{\chi}_1^0}$-$m_{\tilde{l}_1}$ plane:

[*PRELIMINARY*]

current $(g-2)_\mu$



future $(g-2)_\mu$



$\Rightarrow$ upper limit on slepton masses: $m_{\tilde{l}_1} \lesssim 1.1$ TeV

E) Wino DM

[PRELIMINARY]

Parameter scan:

$$100 \text{ GeV} \leq M_2 \leq 1.5 \text{ TeV} ,$$

$$1.1 M_2 \leq M_1 \leq 10 M_2 ,$$

$$1.1 M_2 \leq \mu \leq 10 M_2 ,$$

$$5 \leq \tan\beta \leq 60,$$

$$100 \text{ GeV} \leq m_{\tilde{L}}, m_{\tilde{R}} \leq 2 \text{ TeV},$$

$\Rightarrow m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_1^\pm} \sim M_2$

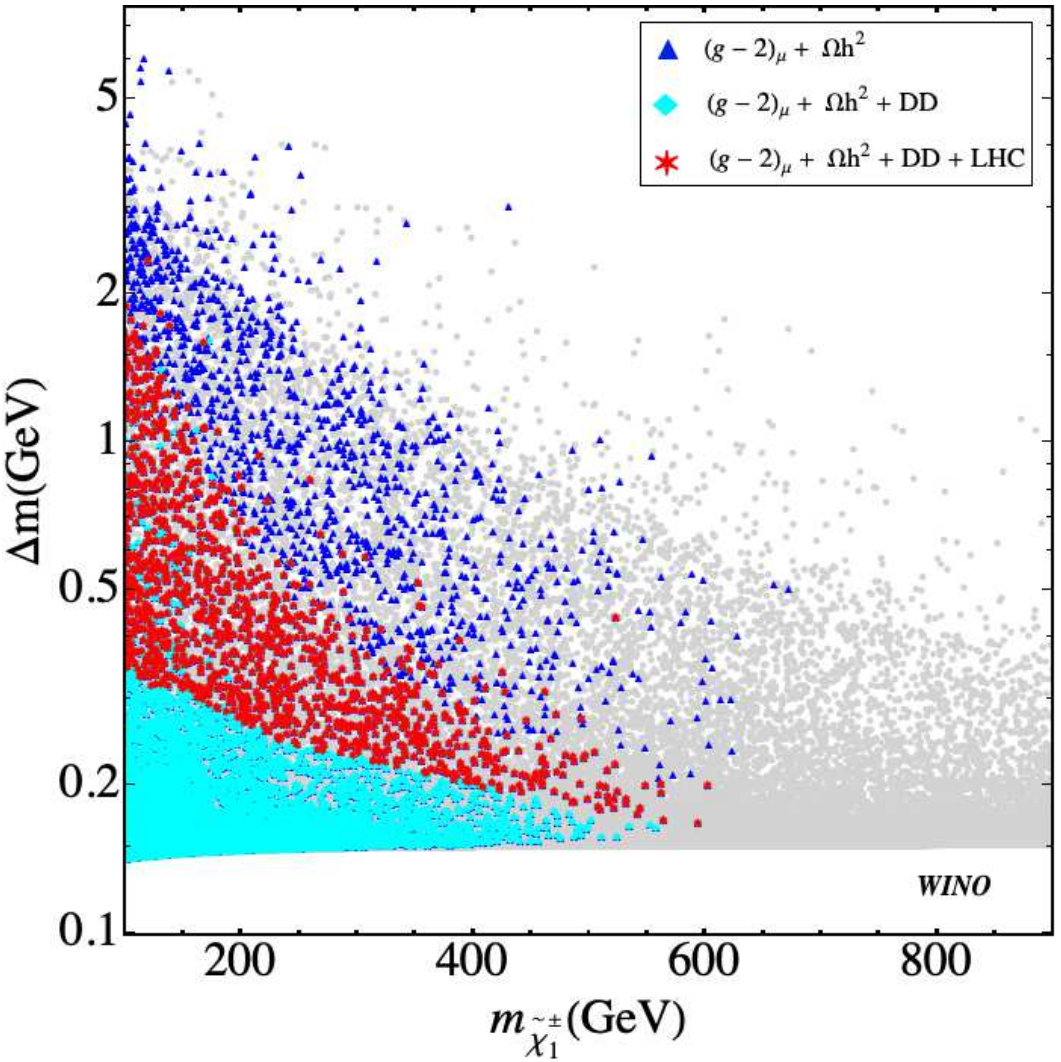
Full DM relic density reached only for $m_{\tilde{\chi}_1^0} \sim 3$ TeV

$\Rightarrow$ incompatible with $(g-2)_\mu$

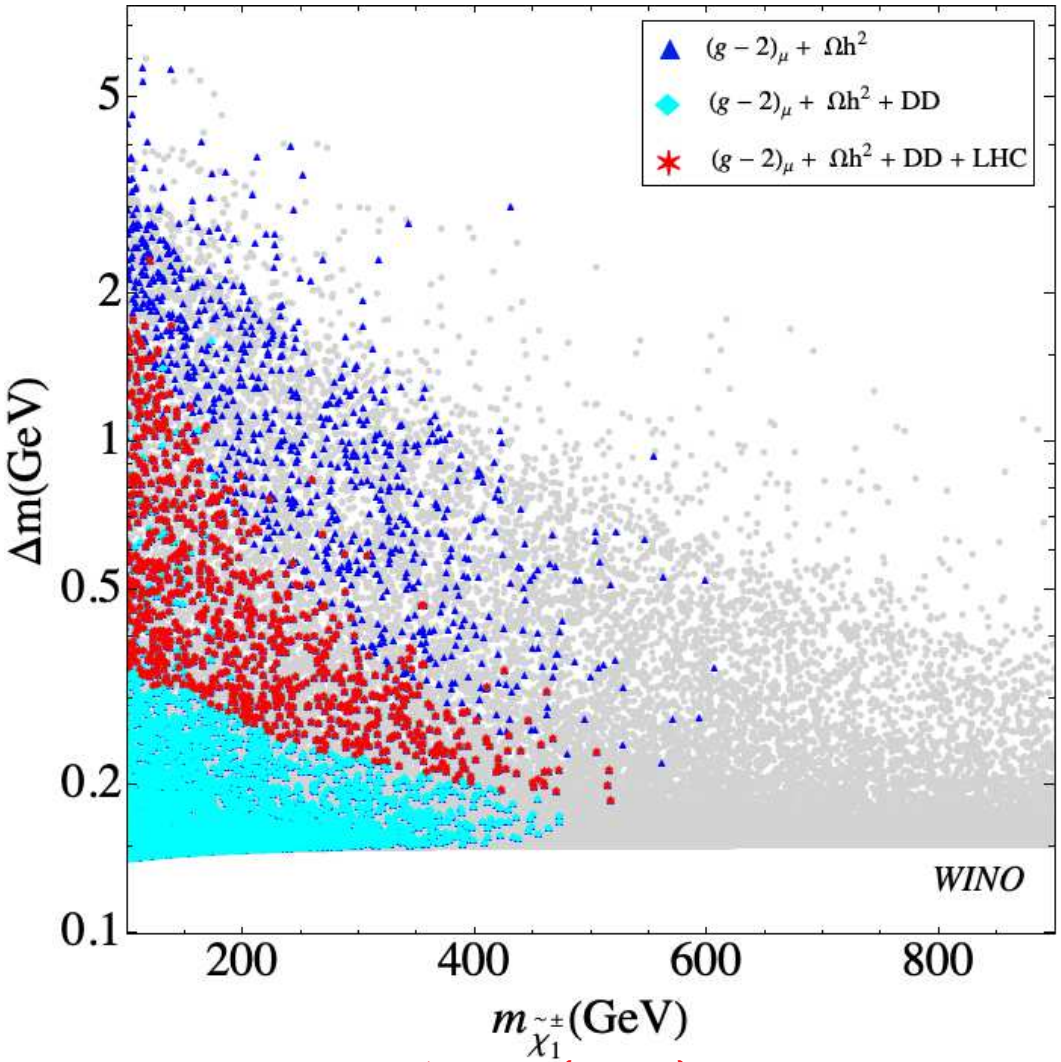
Results in the $m_{\tilde{\chi}_1^\pm}$-Δm plane:

[*PRELIMINARY*]

current $(g-2)_\mu$



future $(g-2)_\mu$



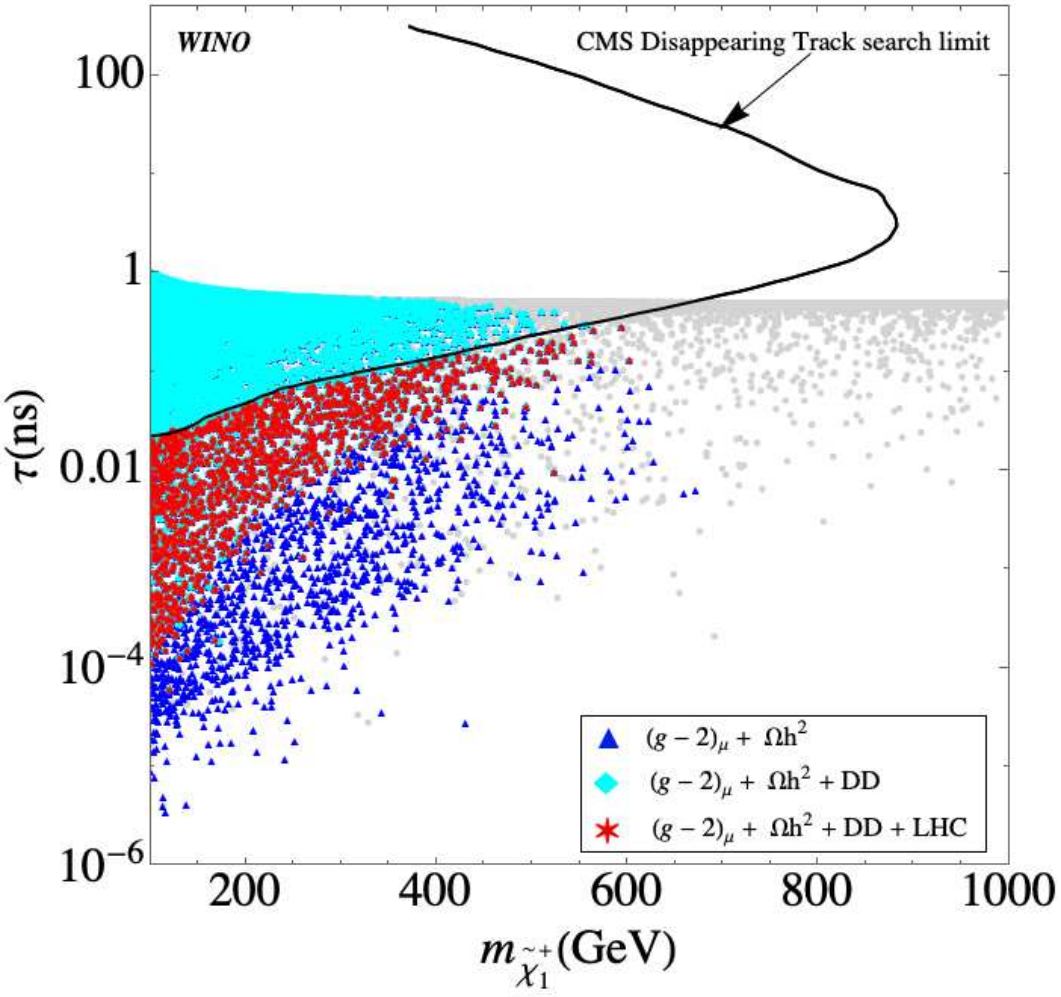
⇒ important: disappearing track limit ⇒ $m_{\text{(N)LSP}} \lesssim 600(500)$ GeV

⇒ allowed parameter space squeezed by DD limits and disapp. tracks

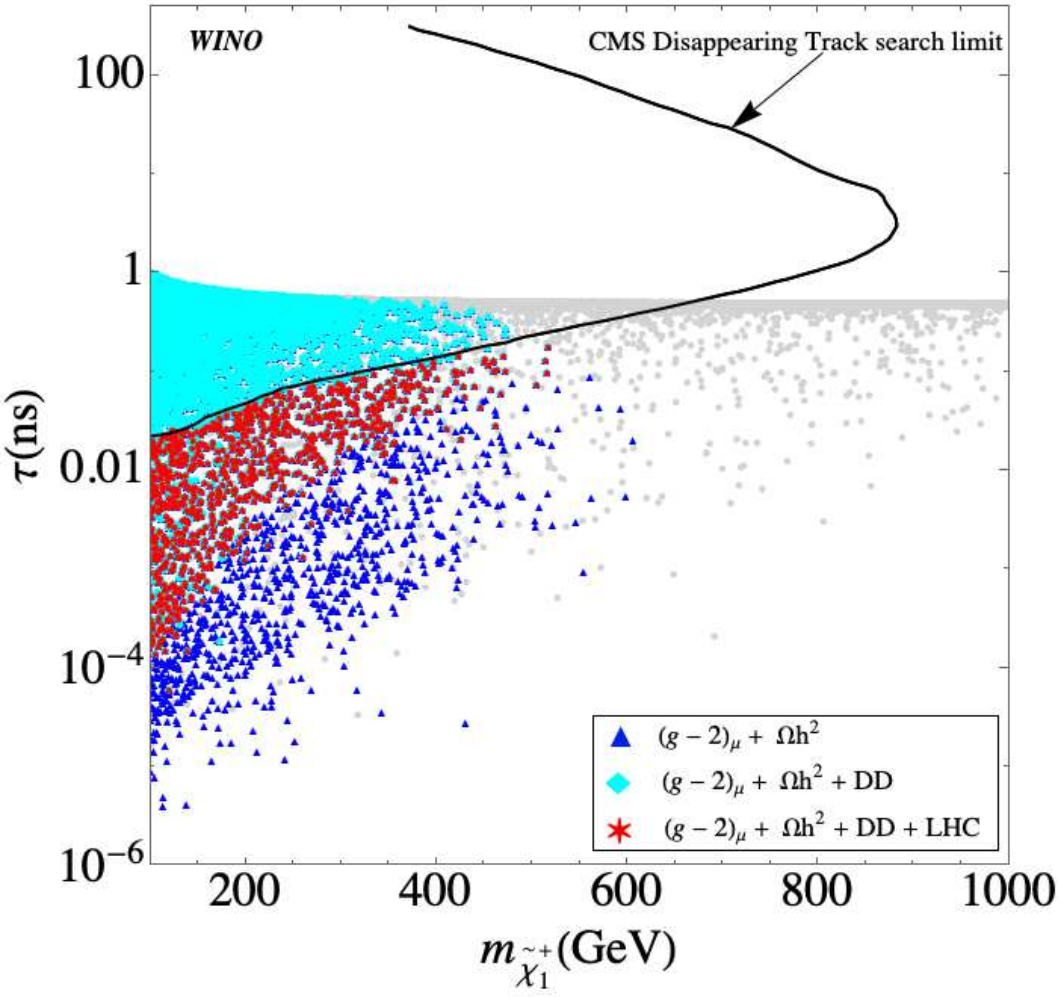
Results in the $m_{\tilde{\chi}_1^\pm}$-$\tau_{\tilde{\chi}_1^\pm}$ plane:

[*PRELIMINARY*]

current $(g-2)_\mu$



future $(g-2)_\mu$



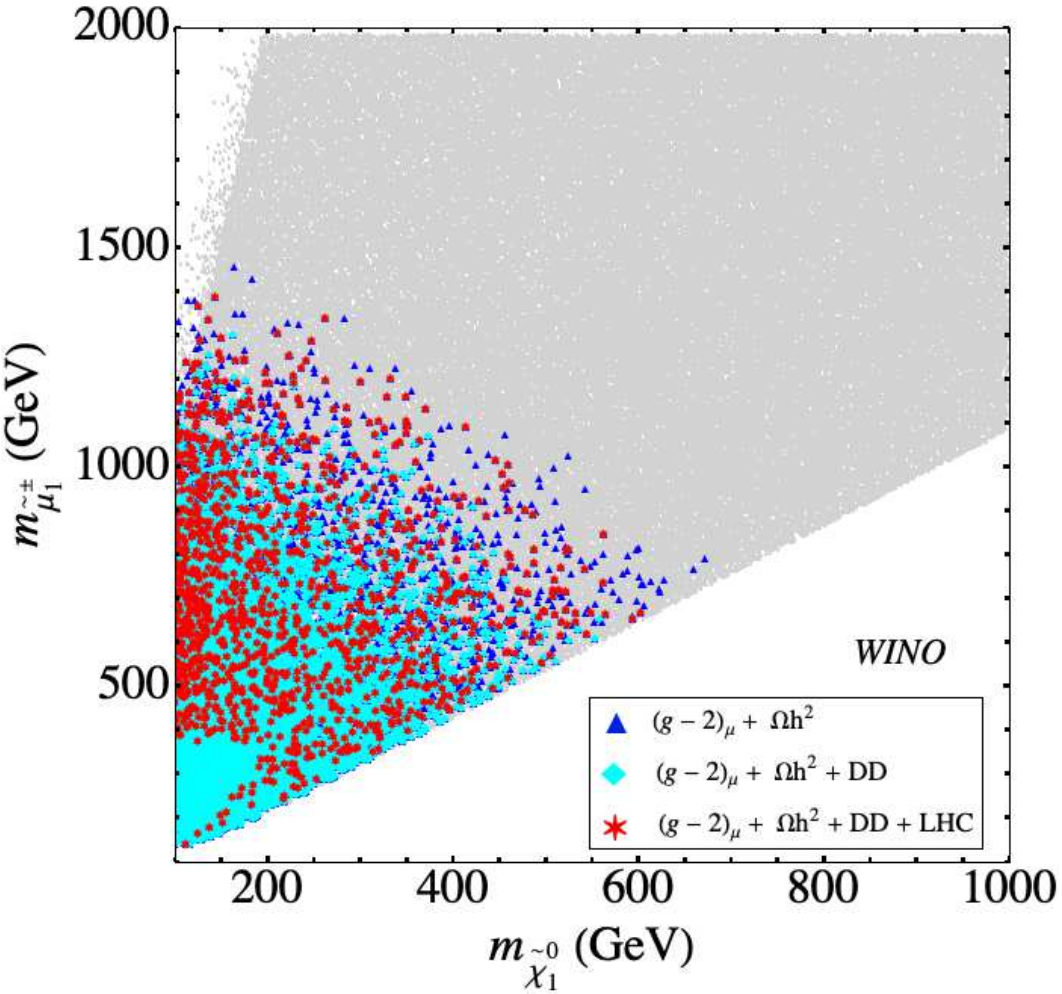
$\Rightarrow$ important: disappearing track limit $\Rightarrow m_{\text{(N)LSP}} \lesssim 600(500)$ GeV

$\Rightarrow$ allowed parameter space squeezed by DD limits and disapp. tracks

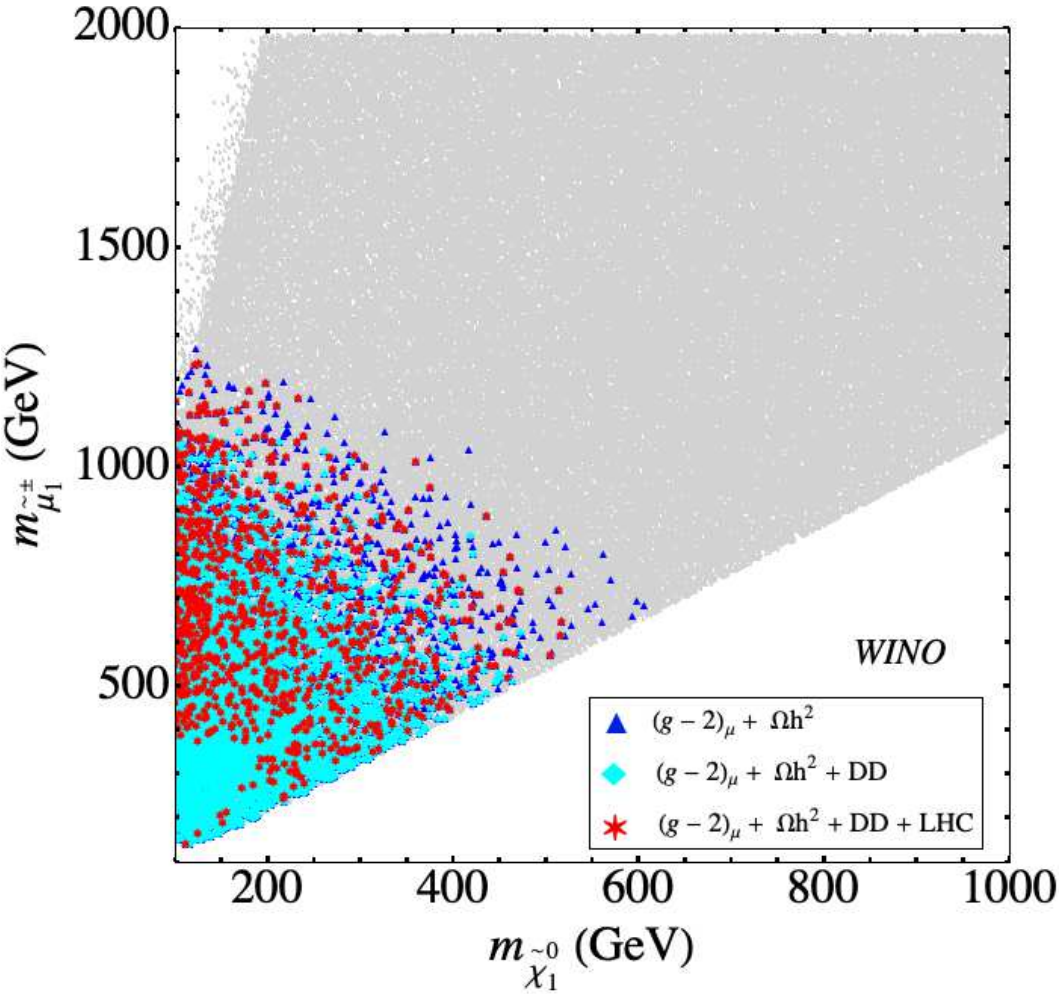
Results in the $m_{\tilde{\chi}_1^0}$-$m_{\tilde{l}_1}$ plane:

[*PRELIMINARY*]

current $(g-2)_\mu$



future $(g-2)_\mu$



$\Rightarrow m_{\tilde{l}_1} \lesssim 1400(1200)$ GeV

Mini summary

A) bino/wino DM with chargino co-annihilation

relic DM density 100% fulfilled

$\Rightarrow m_{\text{(N)LSP}} \lesssim 600(500)$ GeV for current (future) $(g-2)_\mu$ precision

B/C) bino/wino DM with slepton co-annihilation

relic DM density 100% fulfilled

$\Rightarrow m_{\text{(N)LSP}} \lesssim 550(500)$ GeV

D) higgsino DM: $m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_2^0} \sim m_{\tilde{\chi}_1^\pm} \sim \mu$

relic DM density as upper limit (otherwise $m_{\tilde{\chi}_1^0} \sim 1$ TeV)

$\Rightarrow m_{\text{(N)LSP}} \lesssim 500(450)$ GeV

E) wino DM: $m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_1^\pm} \sim M_2$

relic DM density as upper limit (otherwise $m_{\tilde{\chi}_1^0} \sim 3$ TeV)

$\Rightarrow m_{\text{(N)LSP}} \lesssim 600(500)$ GeV

$\Rightarrow$ predictions for future colliders?!

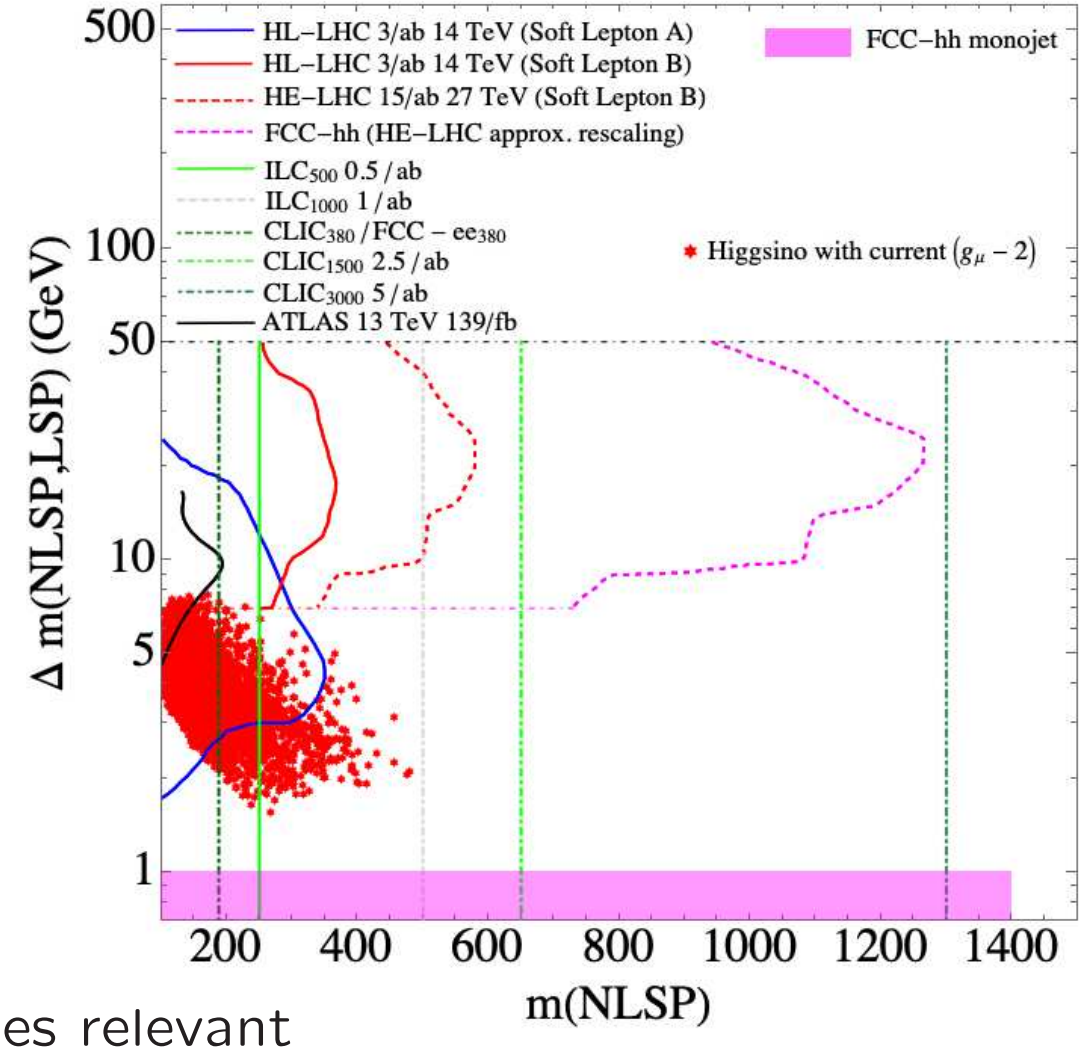
4. Predictions for future colliders

- HL-LHC direct search projections
- HL-LHC searches for compressed spectra ⇐ focus
- future collider prospects for compressed spectra ⇐ focus
- direct production at e^+e^- colliders
- ...

⇒ more in the back-up

Compressed spectra at current and future colliders [PRELIMIMARY]

Higgsino DM:

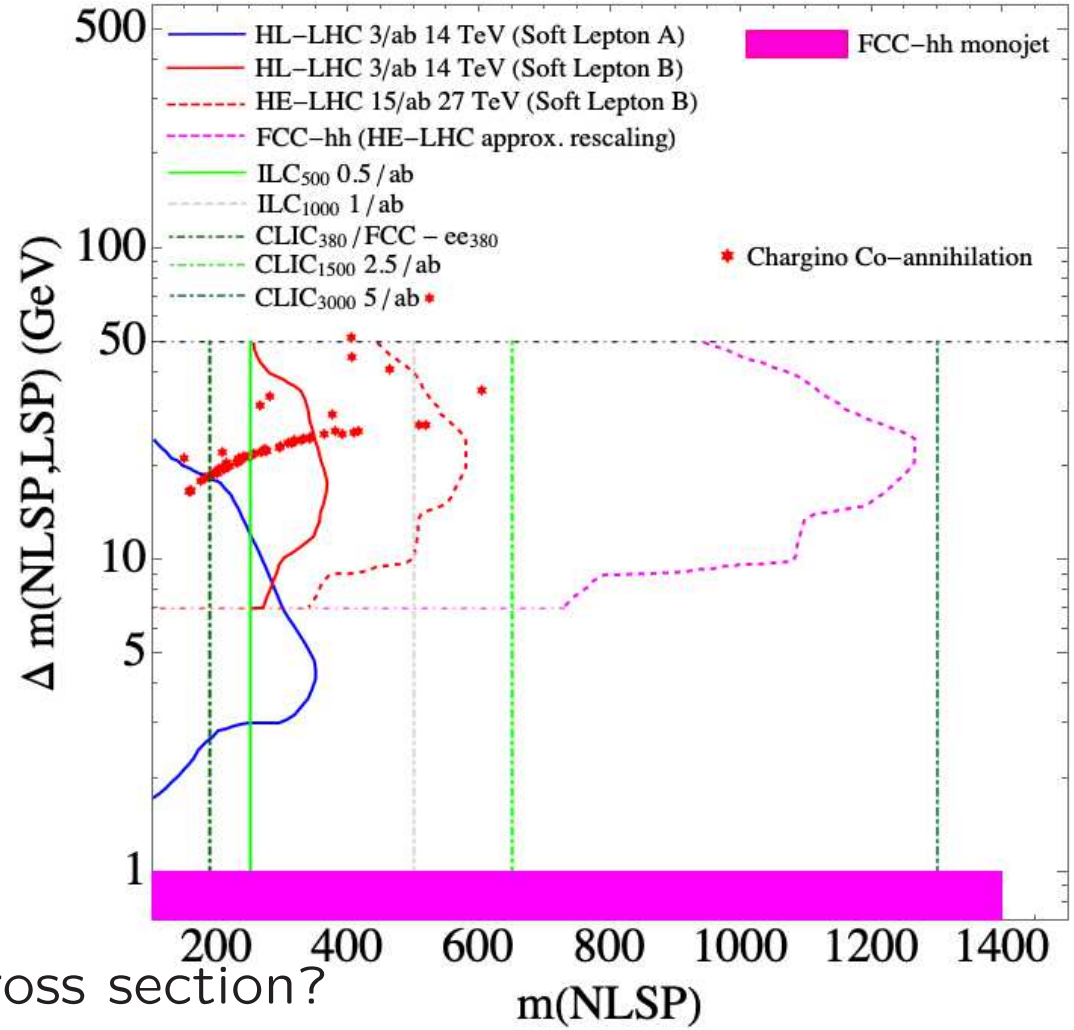


- current searches relevant
- HL-LHC searches very powerful
- ILC/CLIC needed to cover this scenario

Compressed spectra at current and future colliders [*PRELIMIMARY*]

wino/bino DM with chargino co-annihilation

⇒ available ONLY for higgsino LSP ⇒ naive inclusion into the plot:



– scaling with cross section?

– possible problems?

– experimental projections for bino/wino/higgsino LSP?!

5. Conclusinos

- General idea:
  - $(g-2)_\mu$ is real $\Rightarrow$ light EW particles
  - scan the EW sector of the MSSM
    with all constraints taken into account: $(g-2)_\mu$ (today and future),
    DM relic density, DM direct detection, LHC EW searches
  - upper limits on EW masses $\Rightarrow$ evaluate future prospects

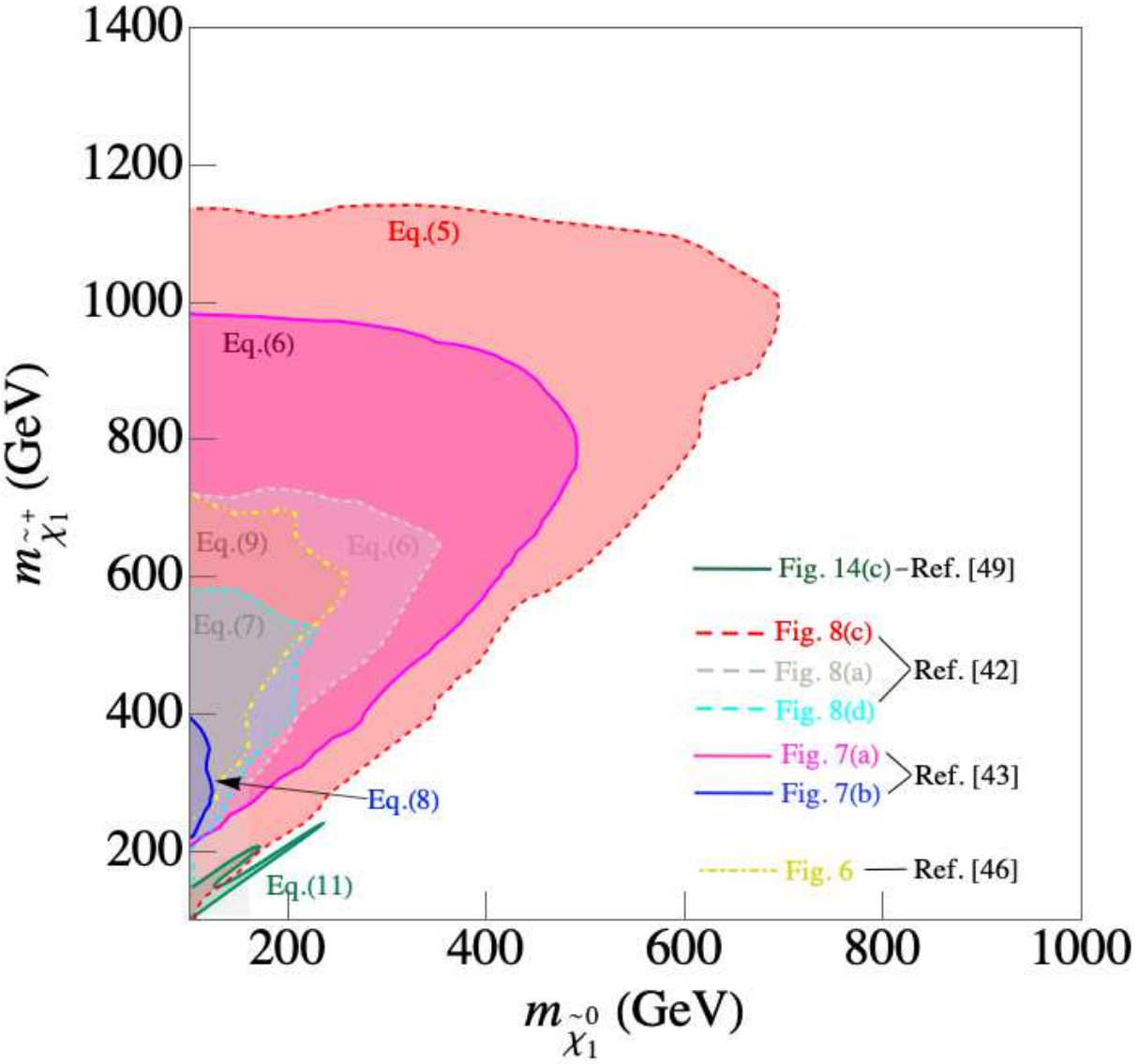
- LHC searches included via CheckMate
  $\Rightarrow$ many searches had to be included by M.C, I.S.
  $\Rightarrow$ crucial for correct application

- A) bino/wino DM with chargino coann. (DM full)
  B/C) bino/wino DM with slepton coann. (DM full)
  D) higgsino eDM $m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_2^0} \sim m_{\tilde{\chi}_1^\pm} \sim \mu$ (DM upper limit)
  E) wino DM $m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_1^\pm} \sim M_2$ (DM upper limit)
  $\Rightarrow$ clear upper limits, $m_{\text{(N)LSP}} \lesssim 600$ GeV

- Prospects for future colliders
  - compressed spectra (higgsino): good prospects, but ILC/CLIC needed
  - direct production at e^+e^- colliders: ILC good, CLIC excellent

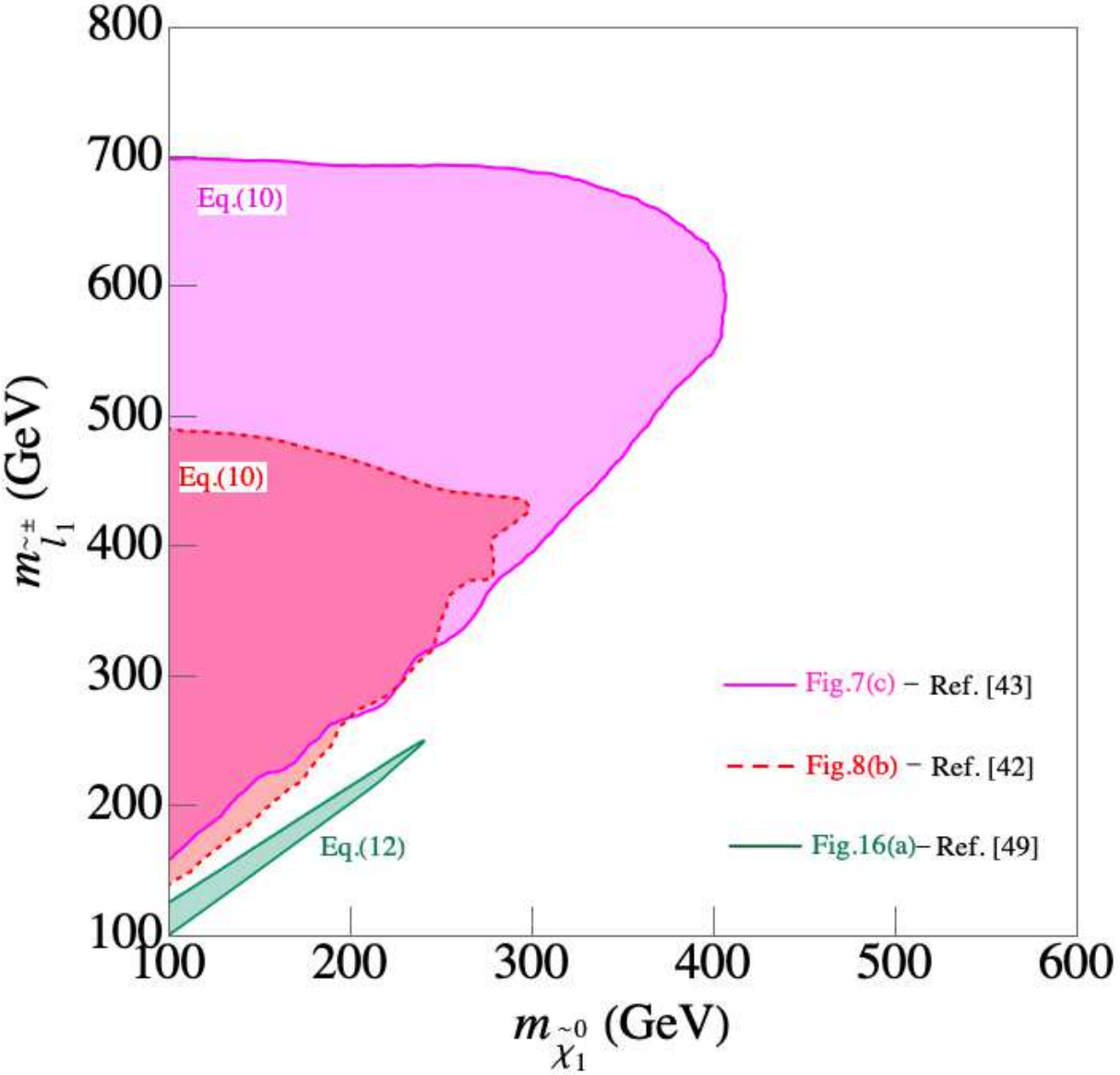
Further Questions?

LHC exclusion bounds (I)



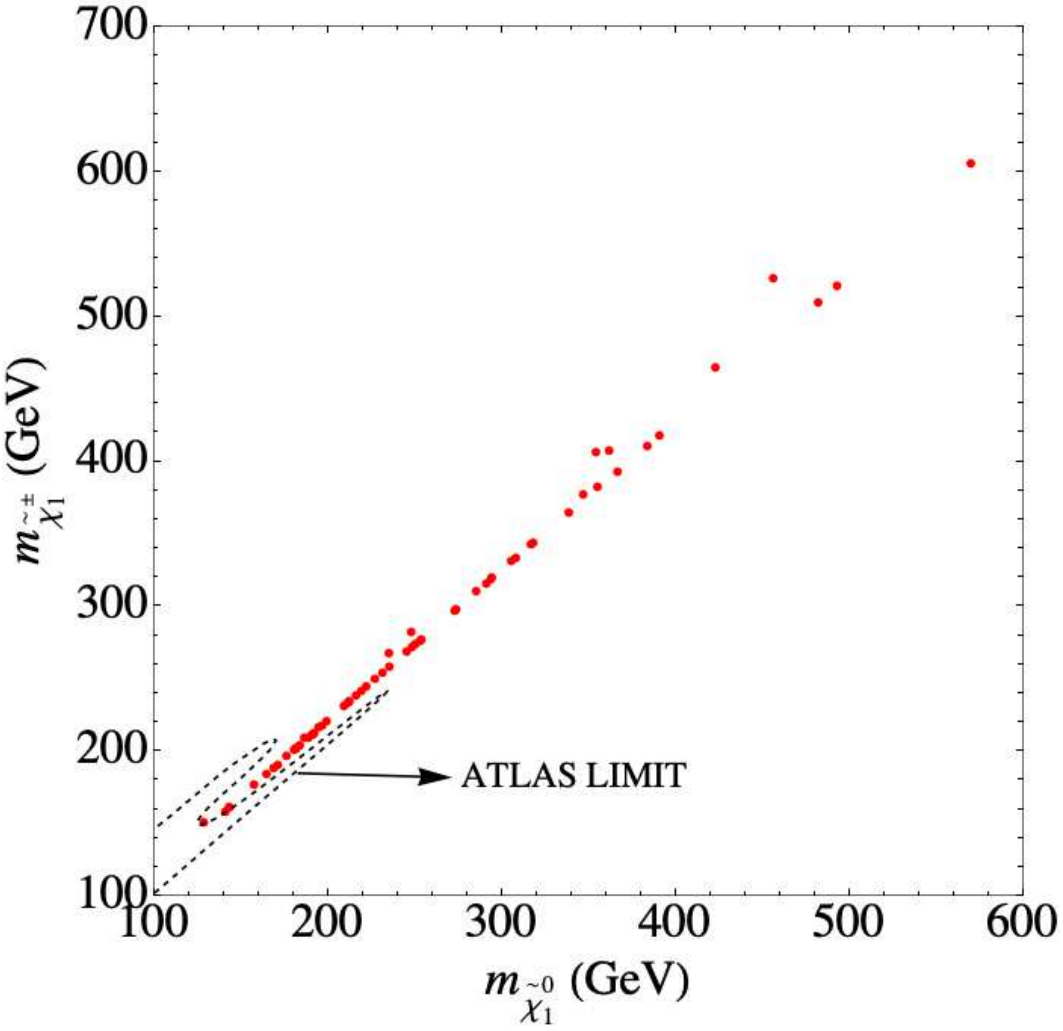
$\Rightarrow$ crucial to take latest bounds into account

LHC exclusion bounds (II)



$\Rightarrow$ crucial to take latest bounds into account

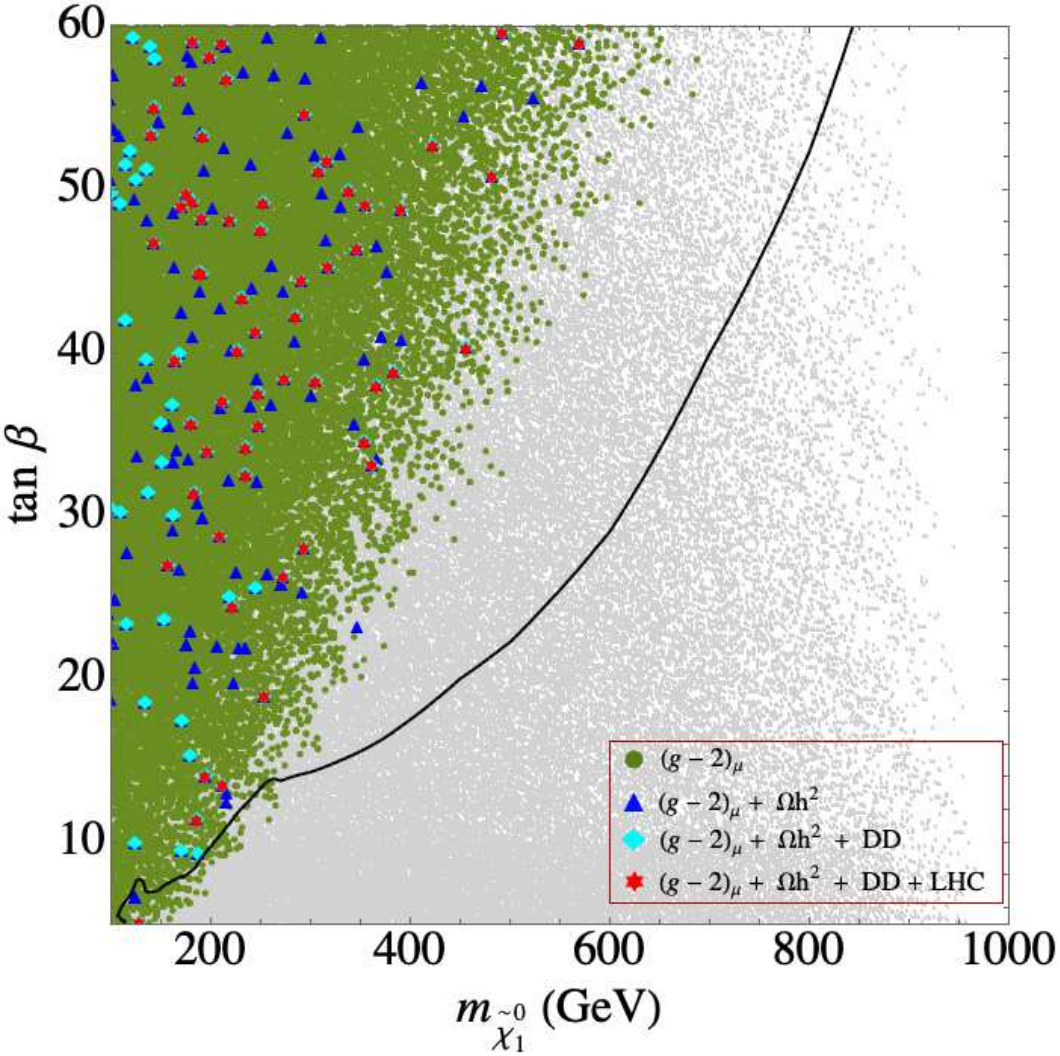
$\tilde{\chi}_1^{\pm}$ co-ann.: comparison with the compressed spectra searches:



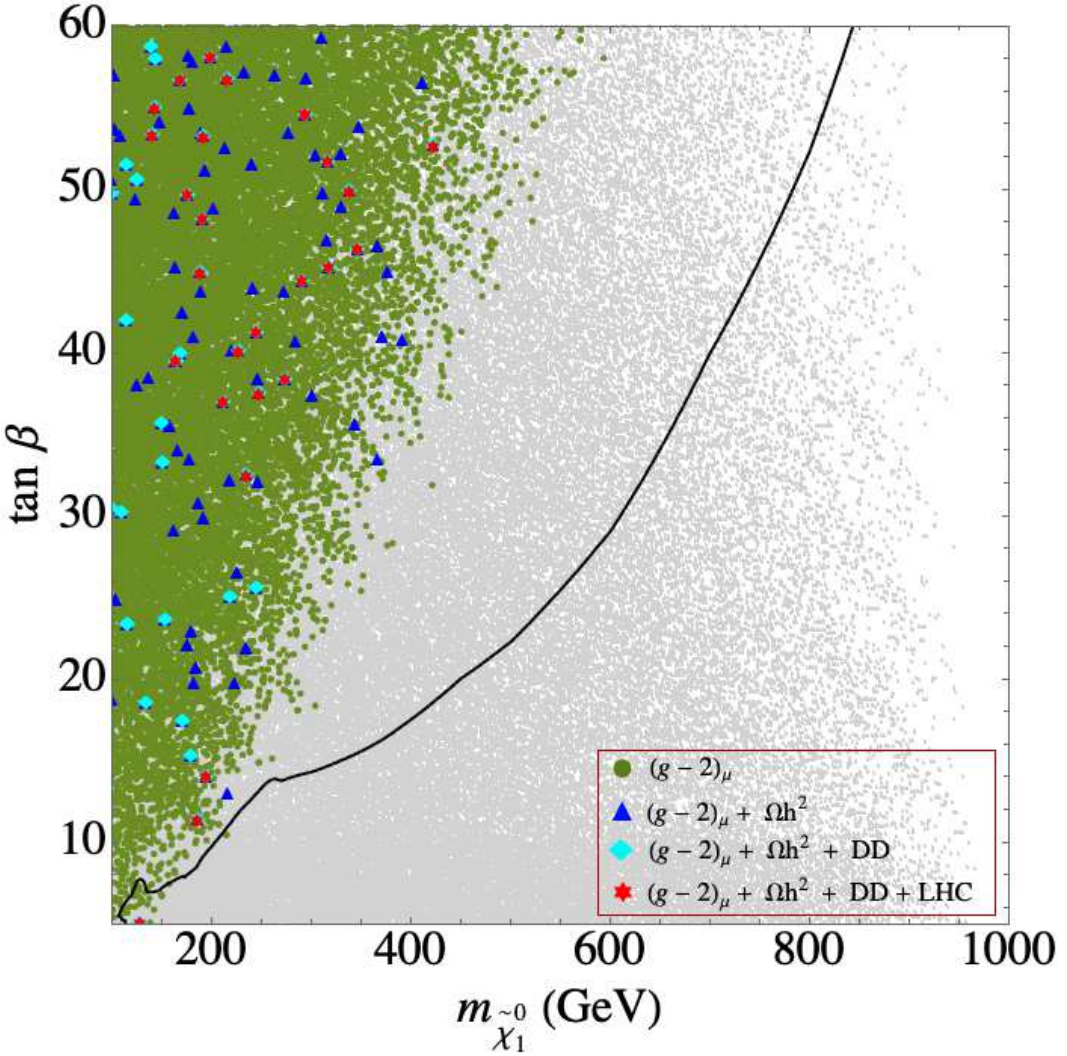
$\Rightarrow$ compressed spectrum avoids current bounds!

$\tilde{\chi}_1^\pm$ co-annihilation: results in the $m_{\tilde{\chi}_1^0}$-$\tan\beta$ plane:

current $(g-2)_\mu$



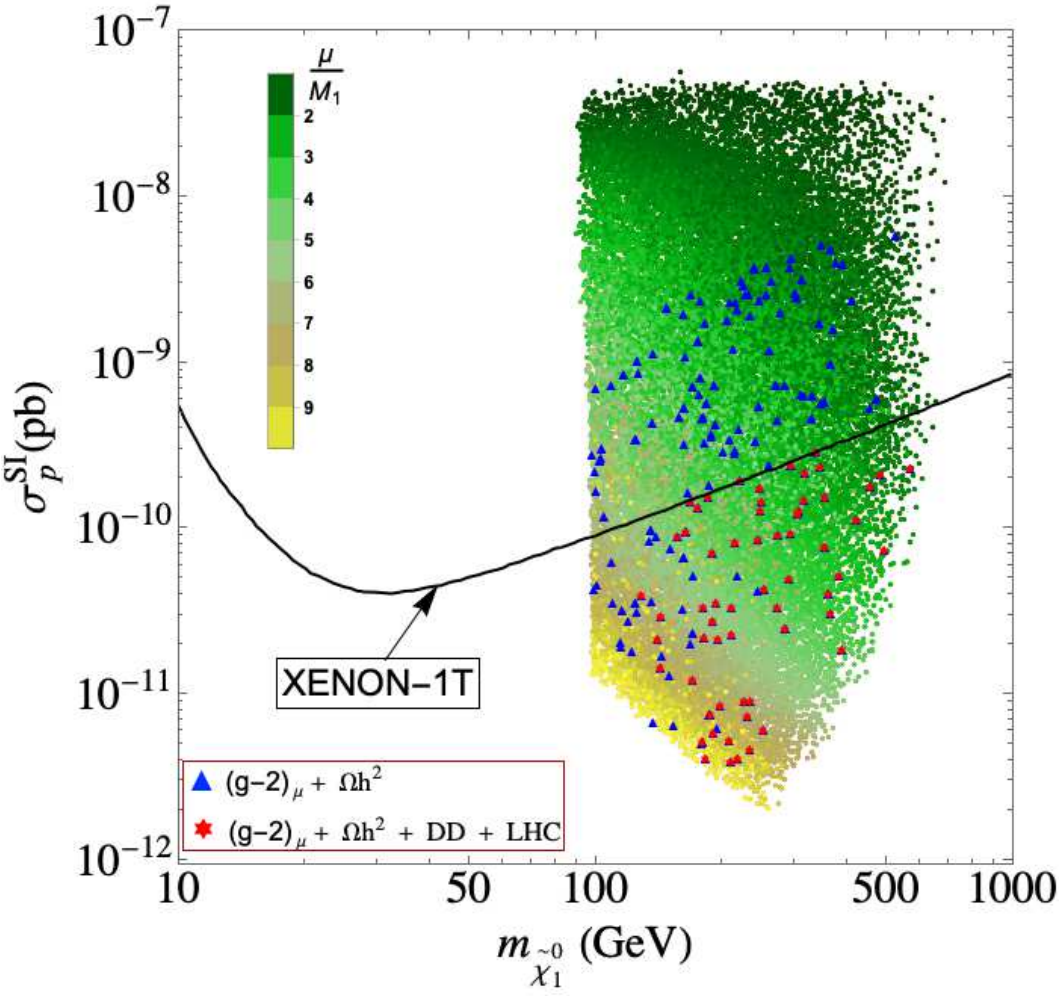
future $(g-2)_\mu$



black contour: (simplified) application of $H/A \to \tau^+\tau^-$

$\Rightarrow$ A-pole annihilation effectively excluded

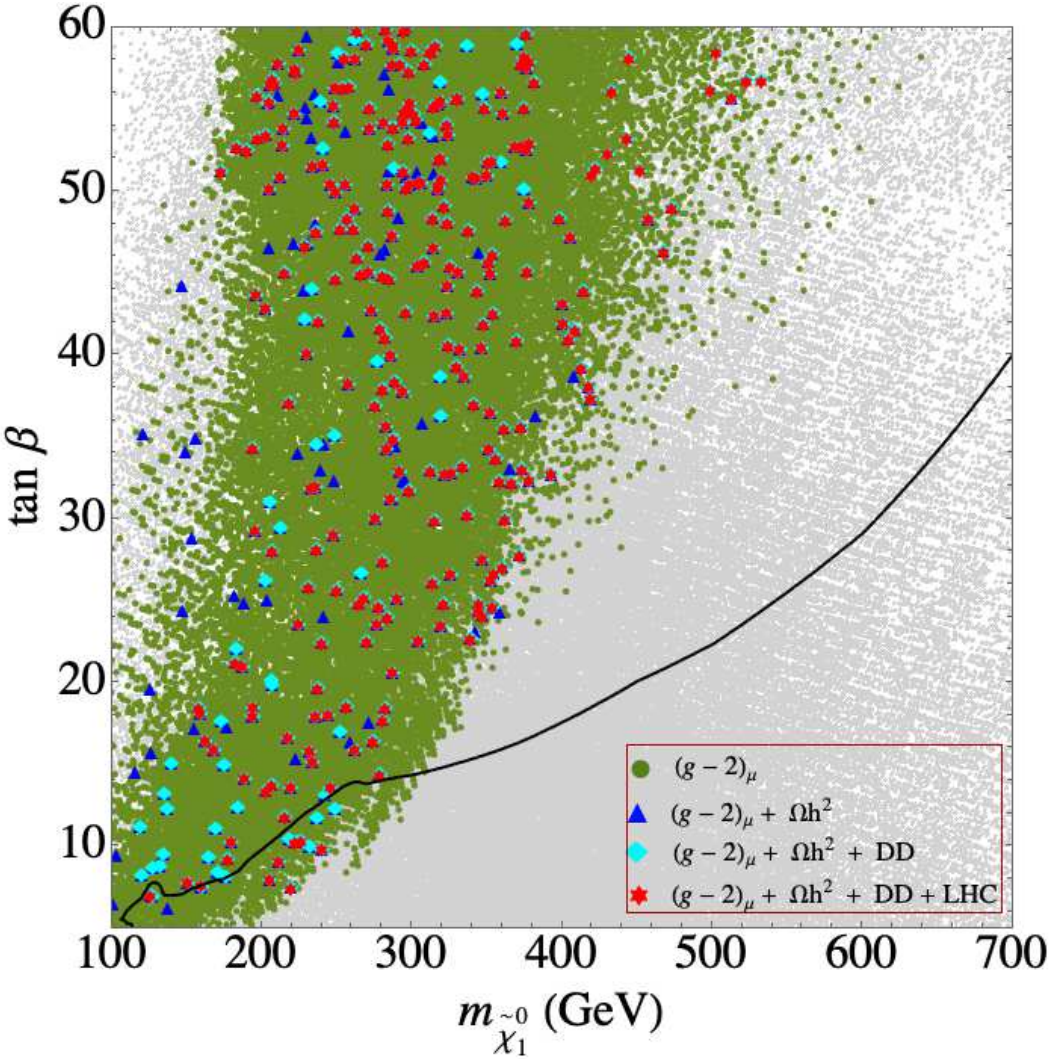
$\tilde{\chi}_1^\pm$ co-annihilation: results in the $m_{\tilde{\chi}_1^0}$-$\sigma_p^{\rm SI}$ plane:



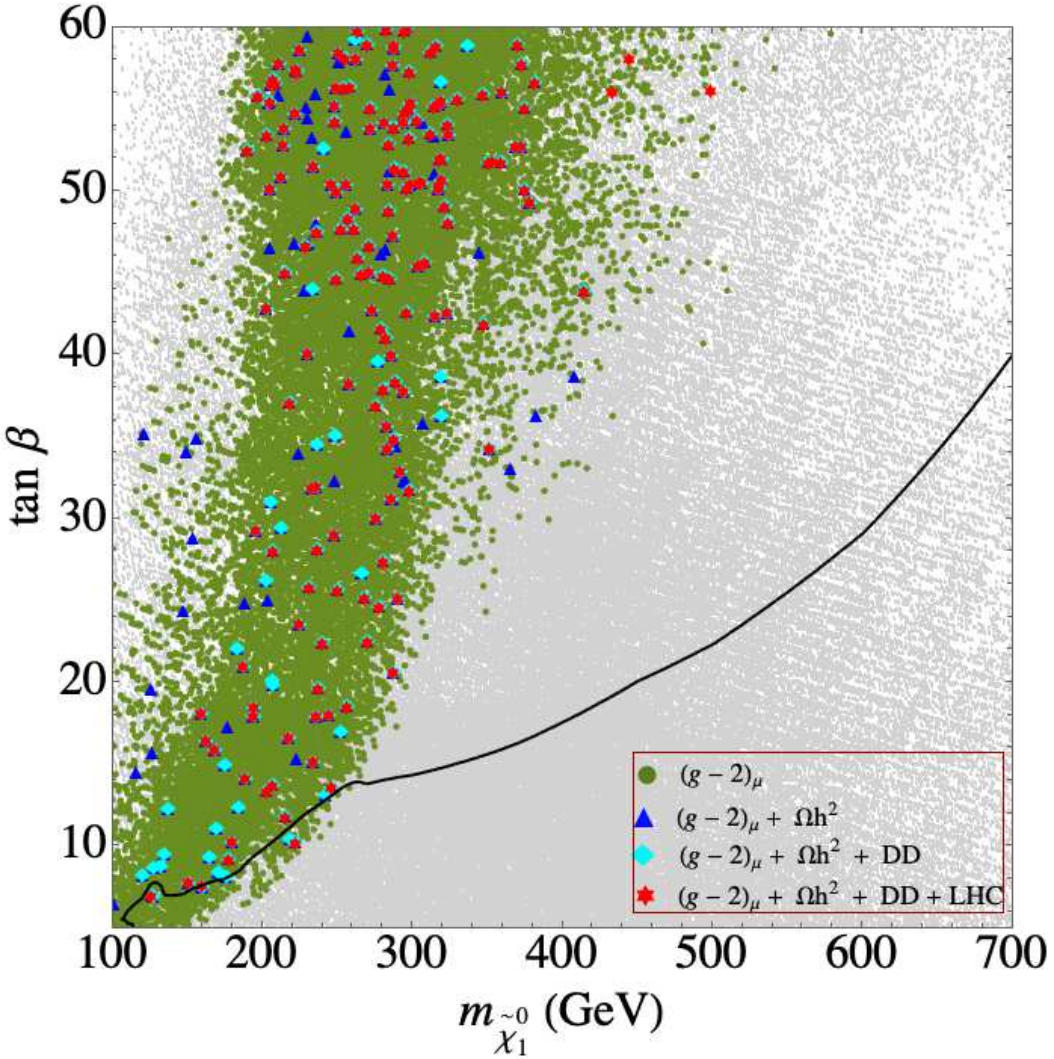
$\Rightarrow$ larger μ values favored

Slepton coann.: results in the $m_{\tilde{\chi}_1^0}$-$\tan\beta$ plane:

current $(g-2)_\mu$



future $(g-2)_\mu$

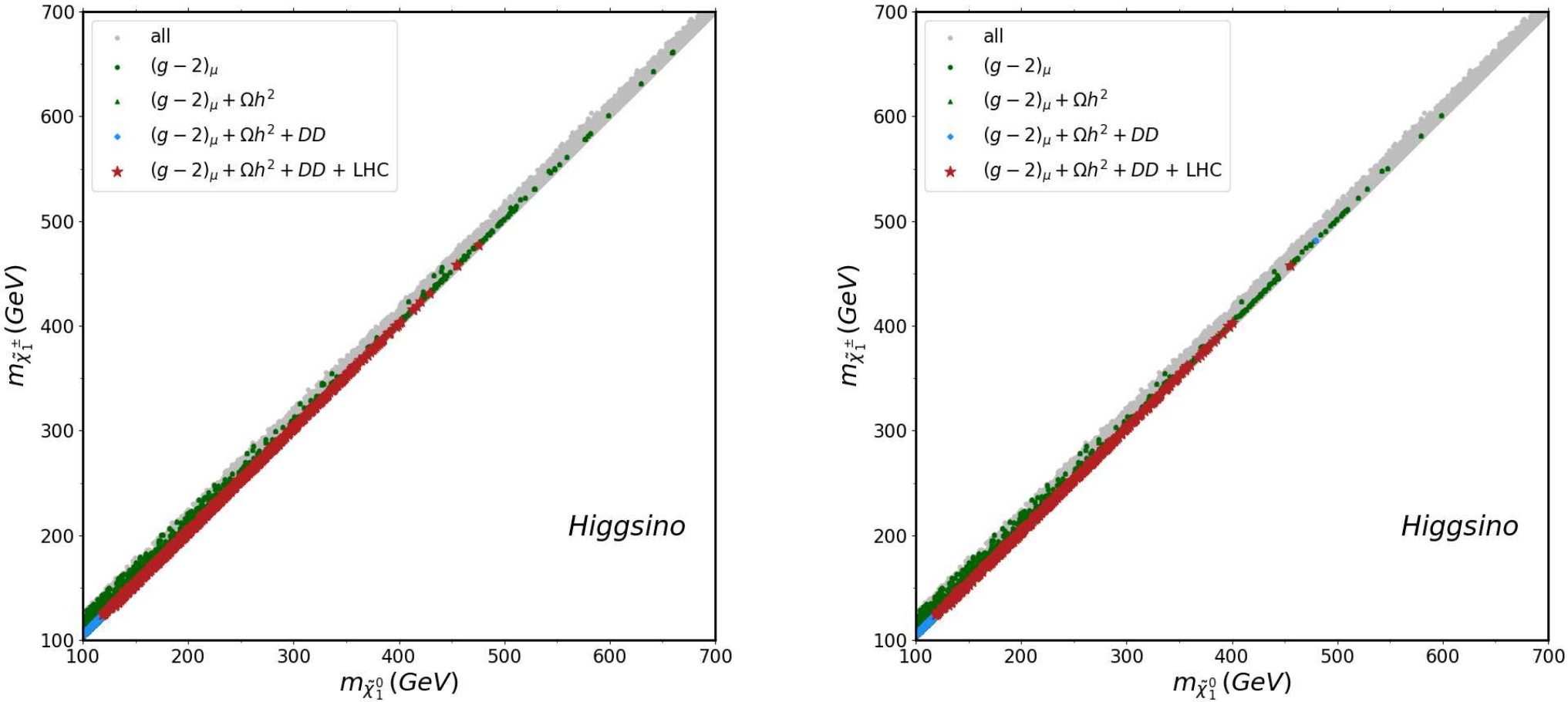


black contour: (simplified) application of $H/A \to \tau^+\tau^-$

$\Rightarrow$ A-pole annihilation largely excluded

Higgsino DM: results in the $m_{\tilde{\chi}_1^0}$-$m_{\tilde{\chi}_1^\pm}$ plane: [*PRELIMINARY*]

current $(g-2)_\mu$ future $(g-2)_\mu$

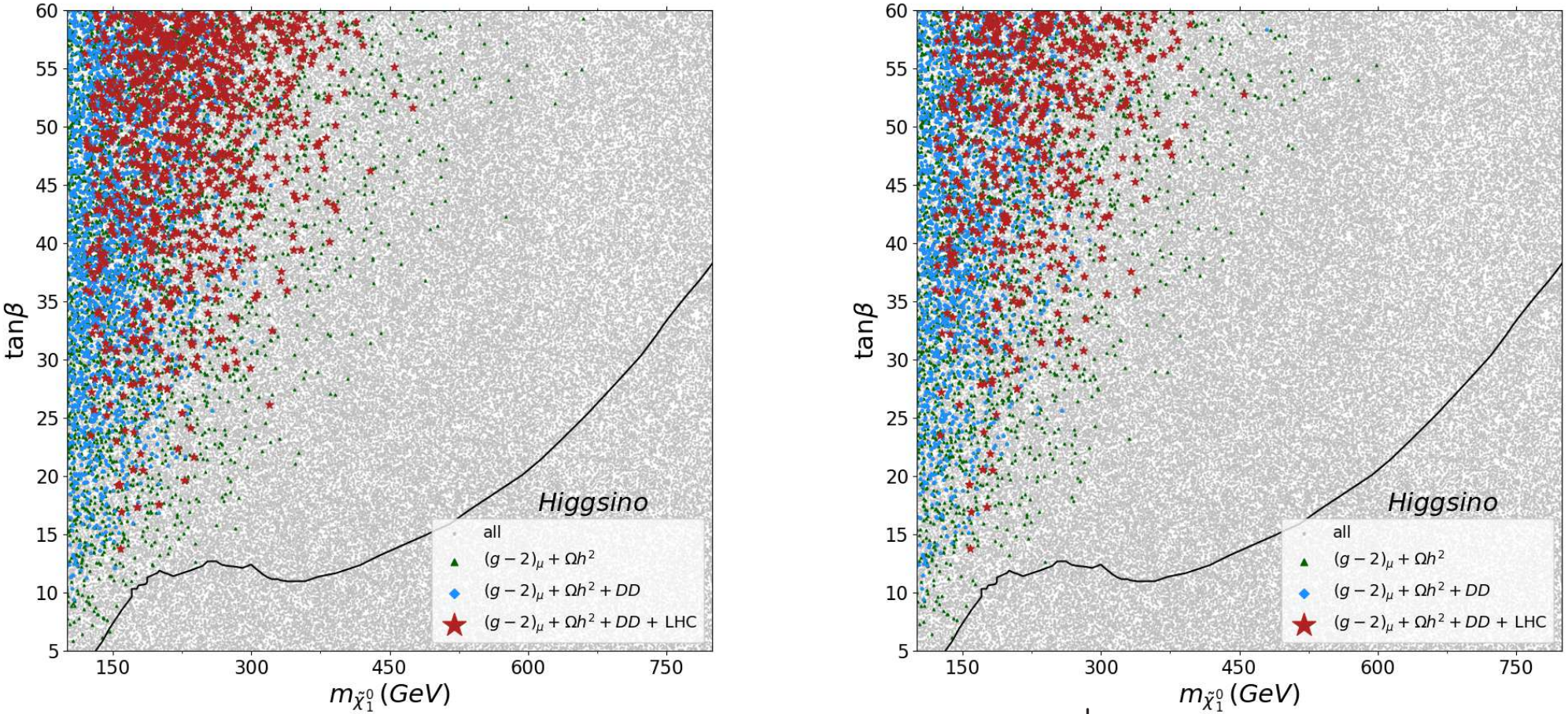


$\Rightarrow$ important: compressed spectra searches (11)

$\Rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to (W^* \tilde{\chi}_1^0)(Z^* \tilde{\chi}_1^0) \to 2l + \not{E}_T$ + ISR $\Rightarrow m_{\text{(N)LSP}} \lesssim 500(450)$ GeV

Higgsino DM: results in the $m_{\tilde{\chi}_1^0}$-tan β plane: [*PRELIMINARY*]

current $(g-2)_\mu$ future $(g-2)_\mu$

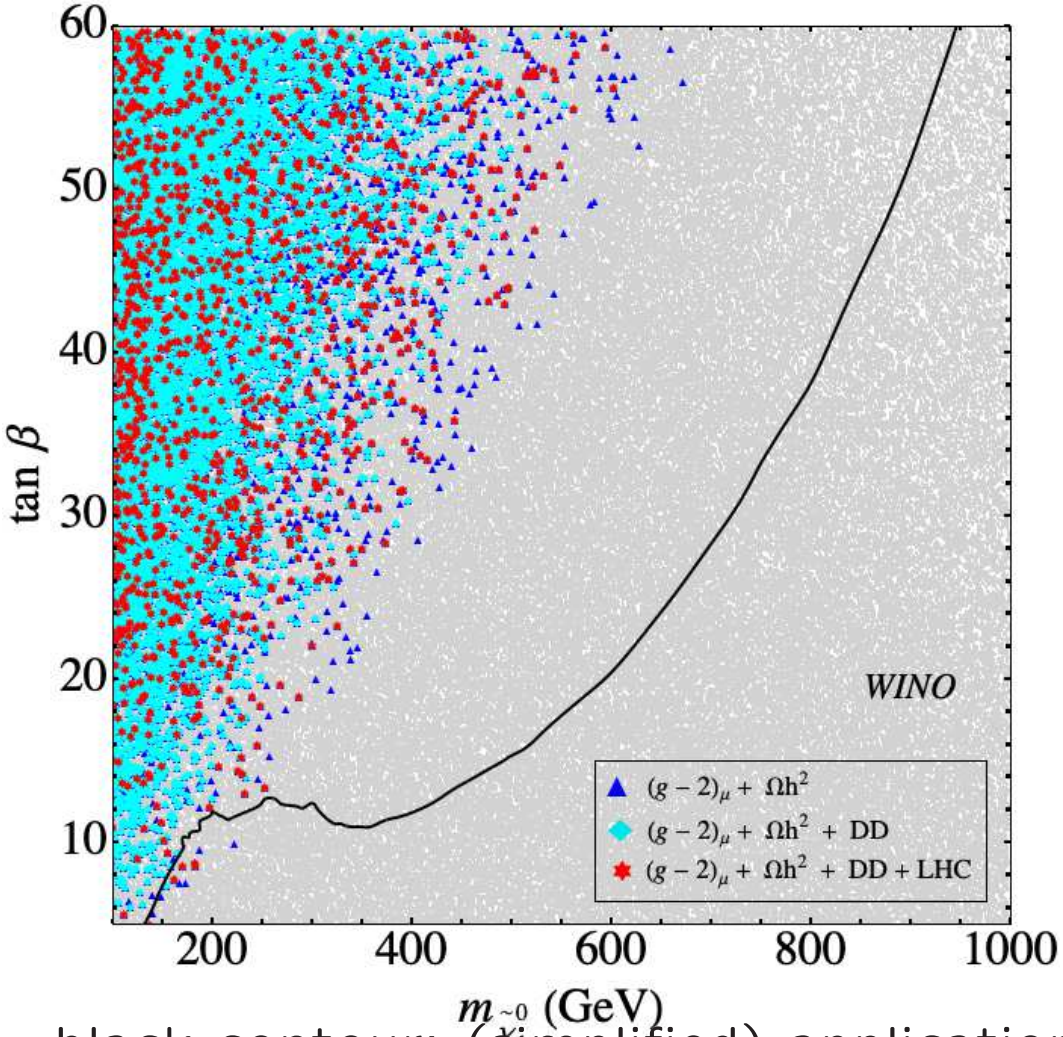


black contour: (simplified) application of $H/A \to \tau^+\tau^-$

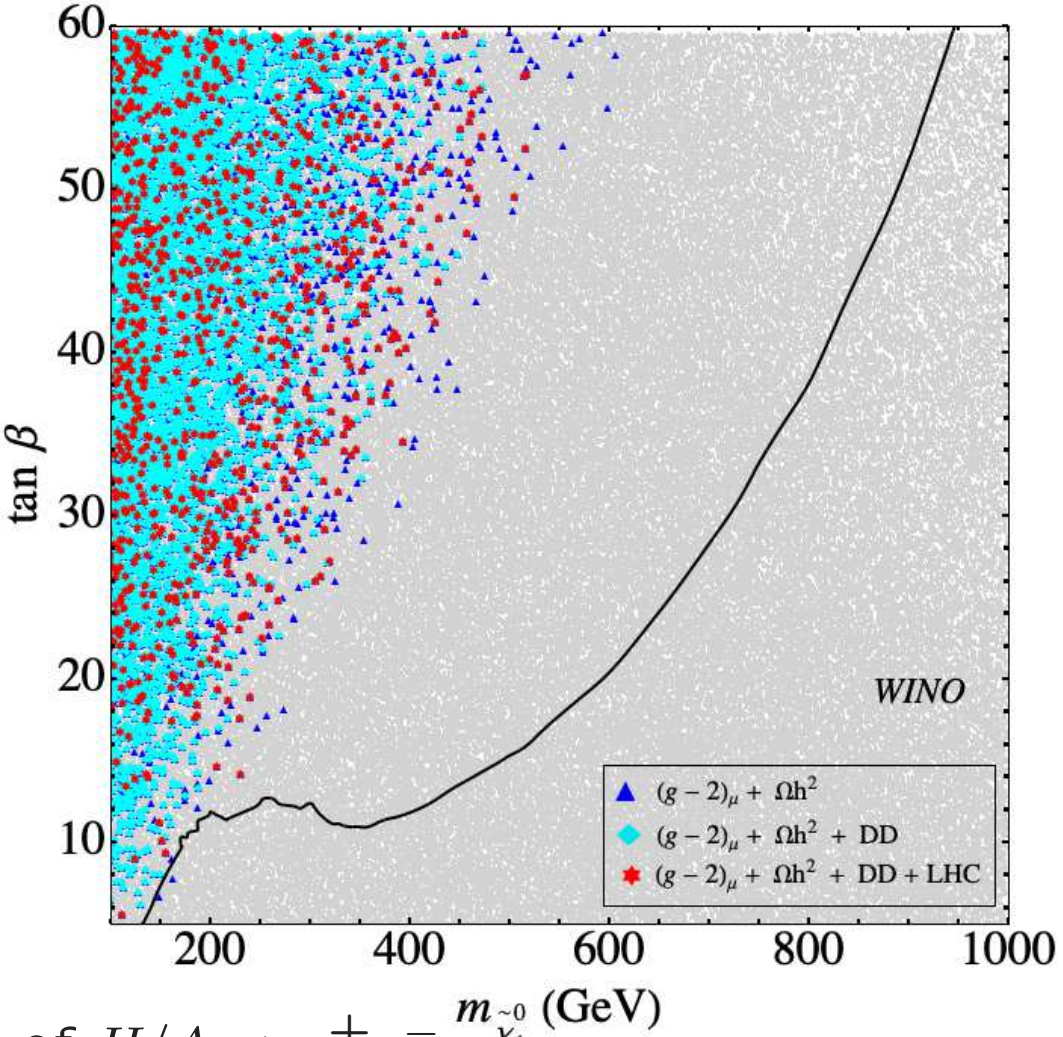
$\Rightarrow$ A-pole annihilation fully excluded

Wino DM: results in the $m_{\tilde{\chi}_1^0}$-tan β plane: [*PRELIMINARY*]

current $(g-2)_\mu$



future $(g-2)_\mu$



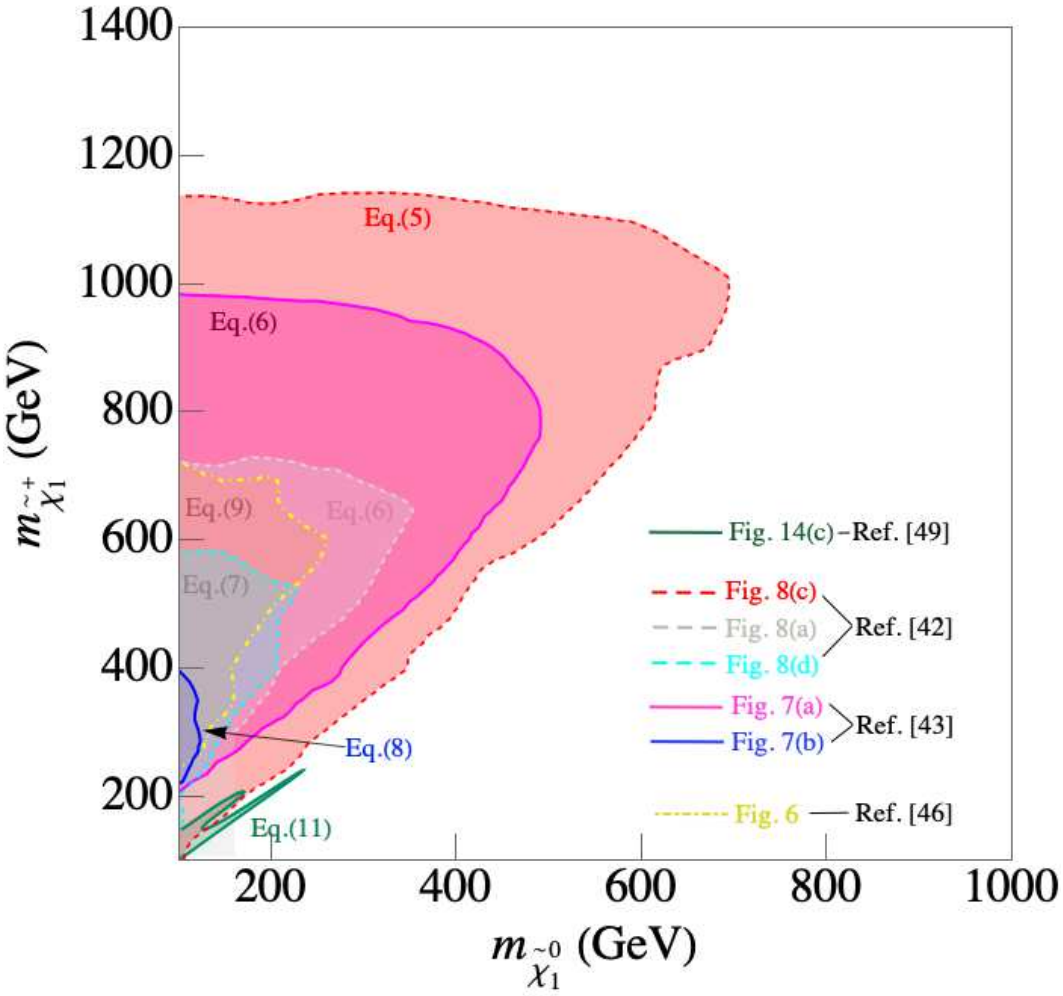
black contour: (simplified) application of $H/A \to \tau^+\tau^-$

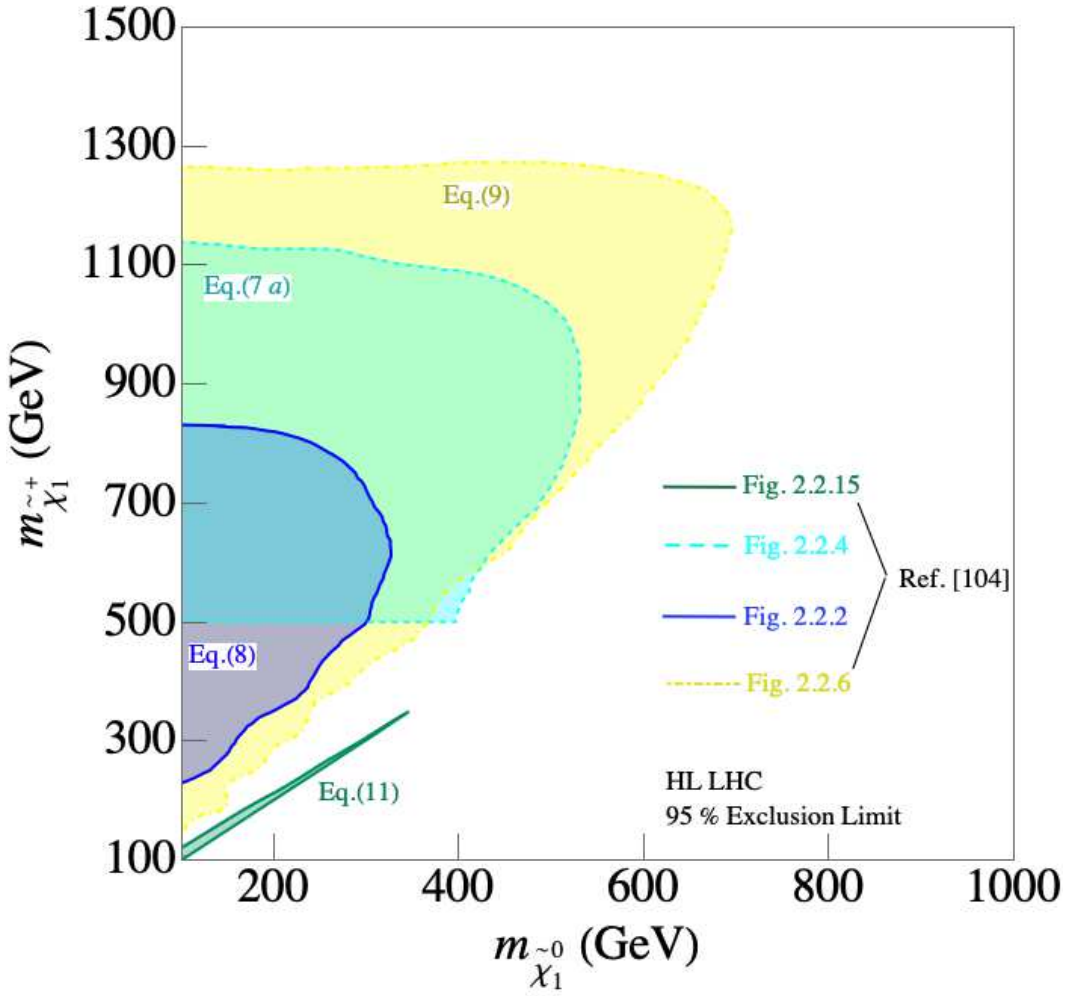
$\Rightarrow$ A-pole annihilation largely excluded

LHC exclusion bounds vs. HL-LHC exclusion bounds

not all channels available

[YR18]



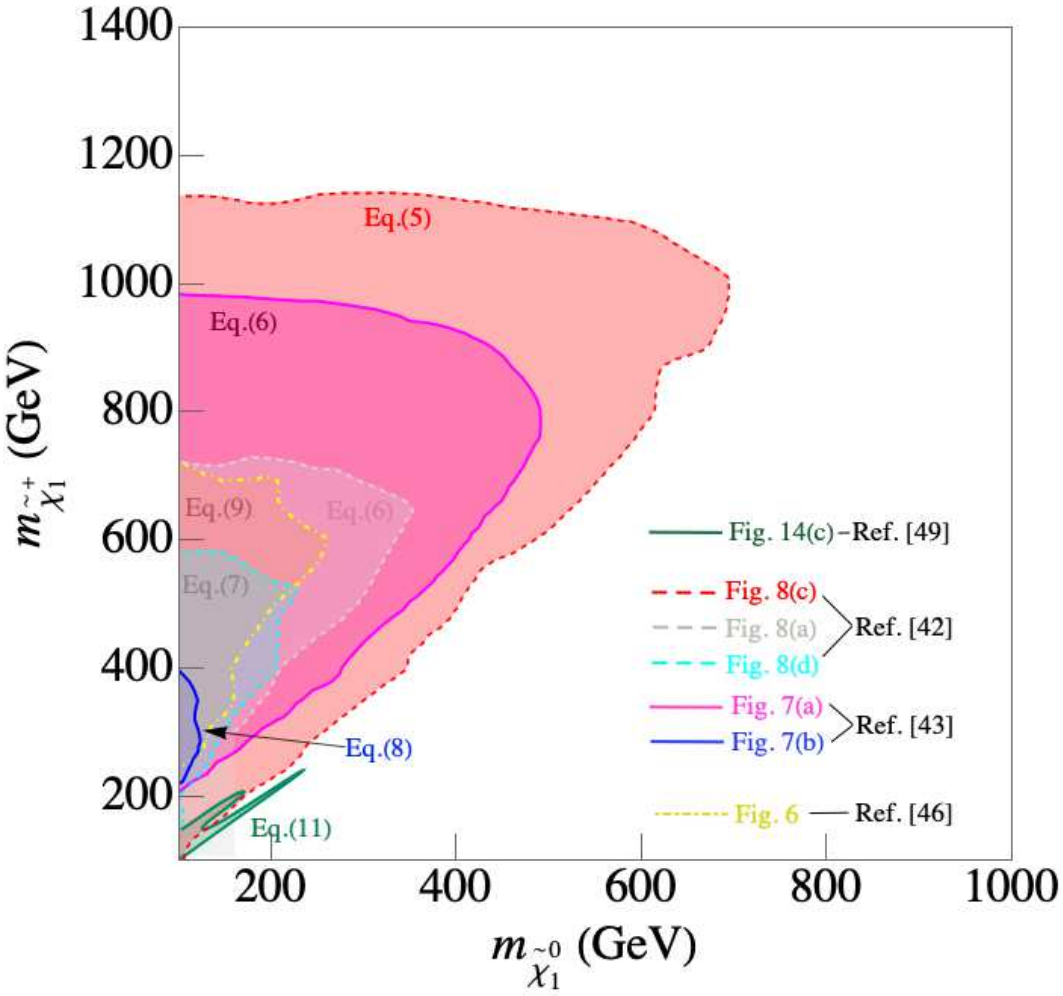


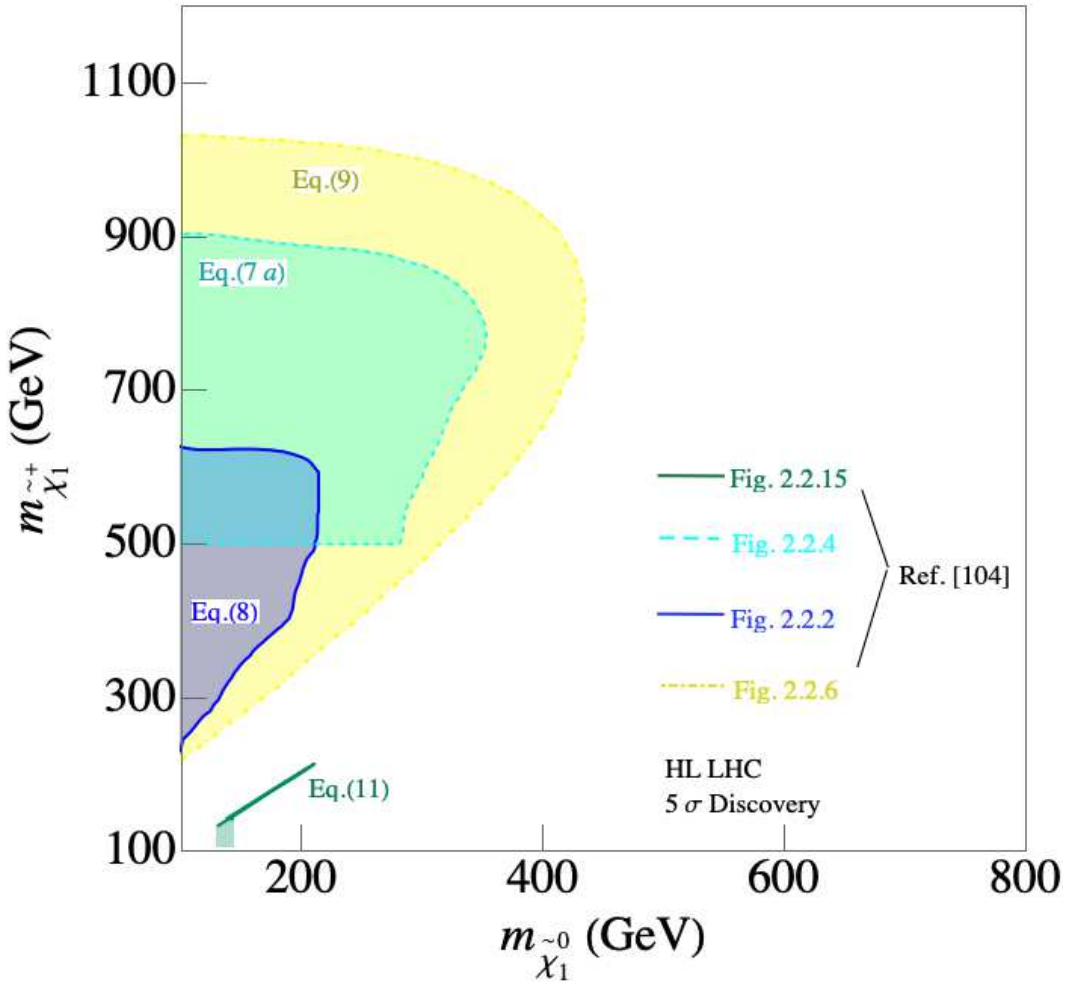
⇒ exclusion reach can be important

⇒ no CheckMate inclusion available . . .

LHC exclusion bounds vs. HL-LHC discovery bounds

not all channels available [YR18]



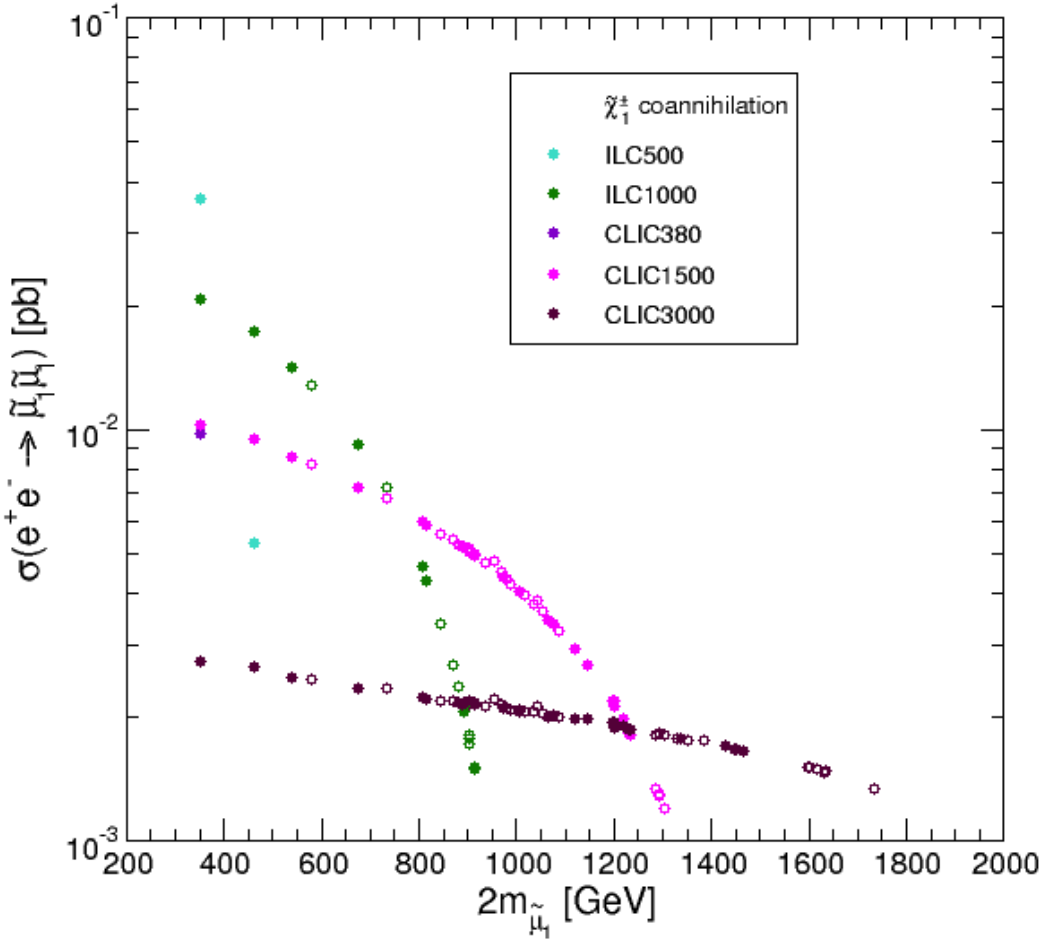


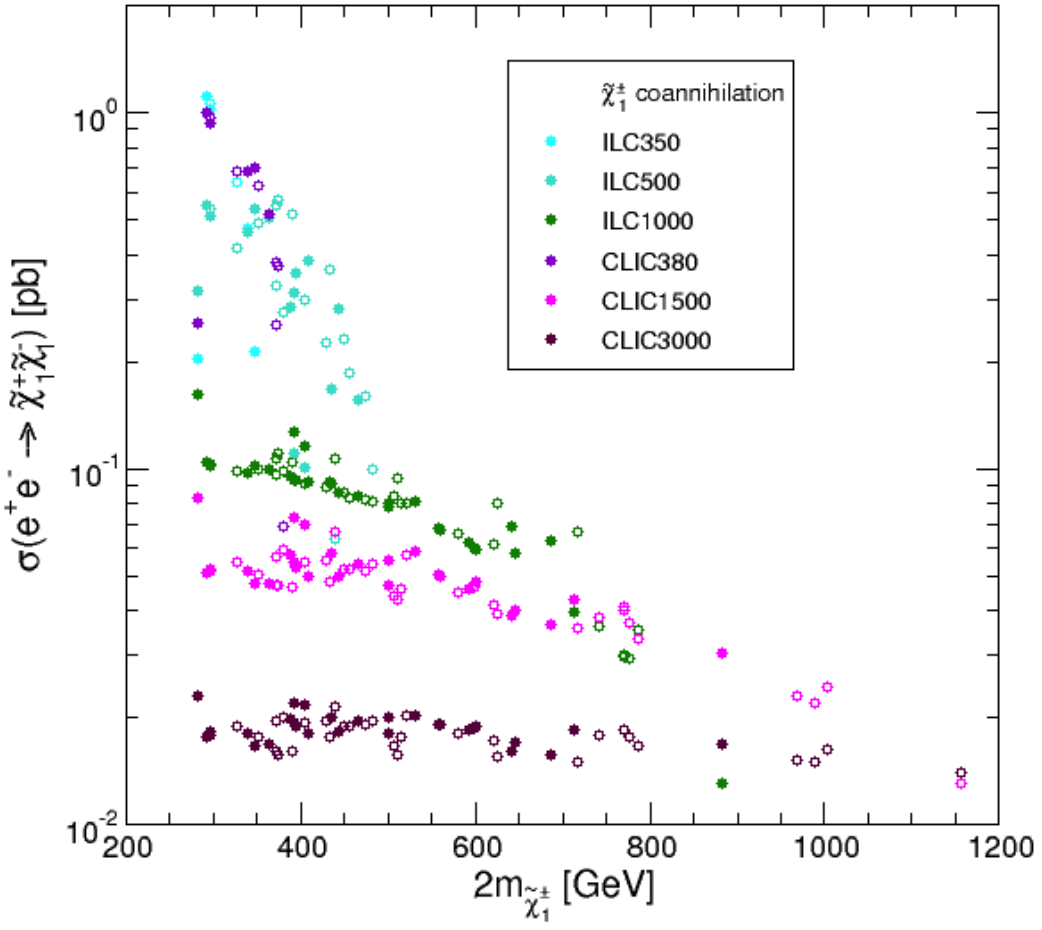
⇒ discovery reach larger than current exclusion

⇒ no CheckMate inclusion available . . .

Direct production at e^+e^- colliders (ILC/CLIC)

wino/bino DM with chargino co-ann. (open/full: current/future $(g-2)_\mu$)



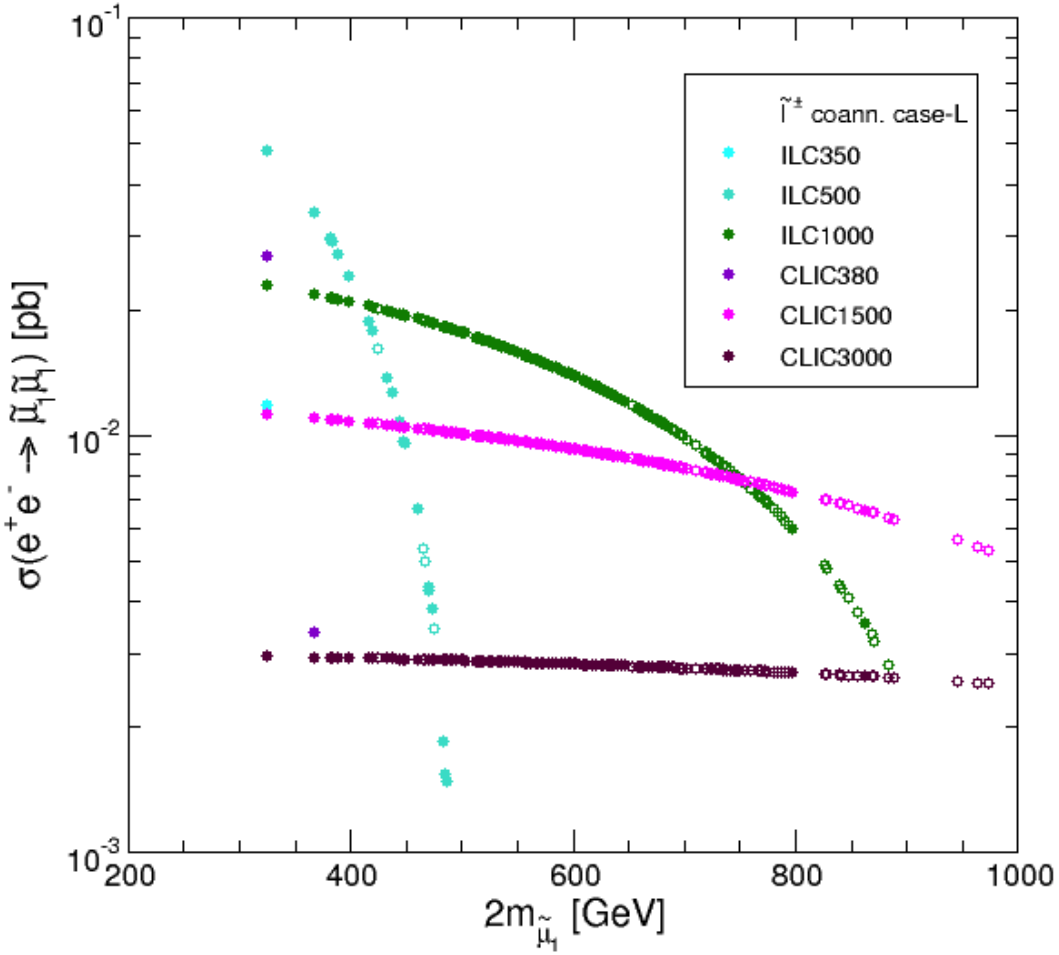


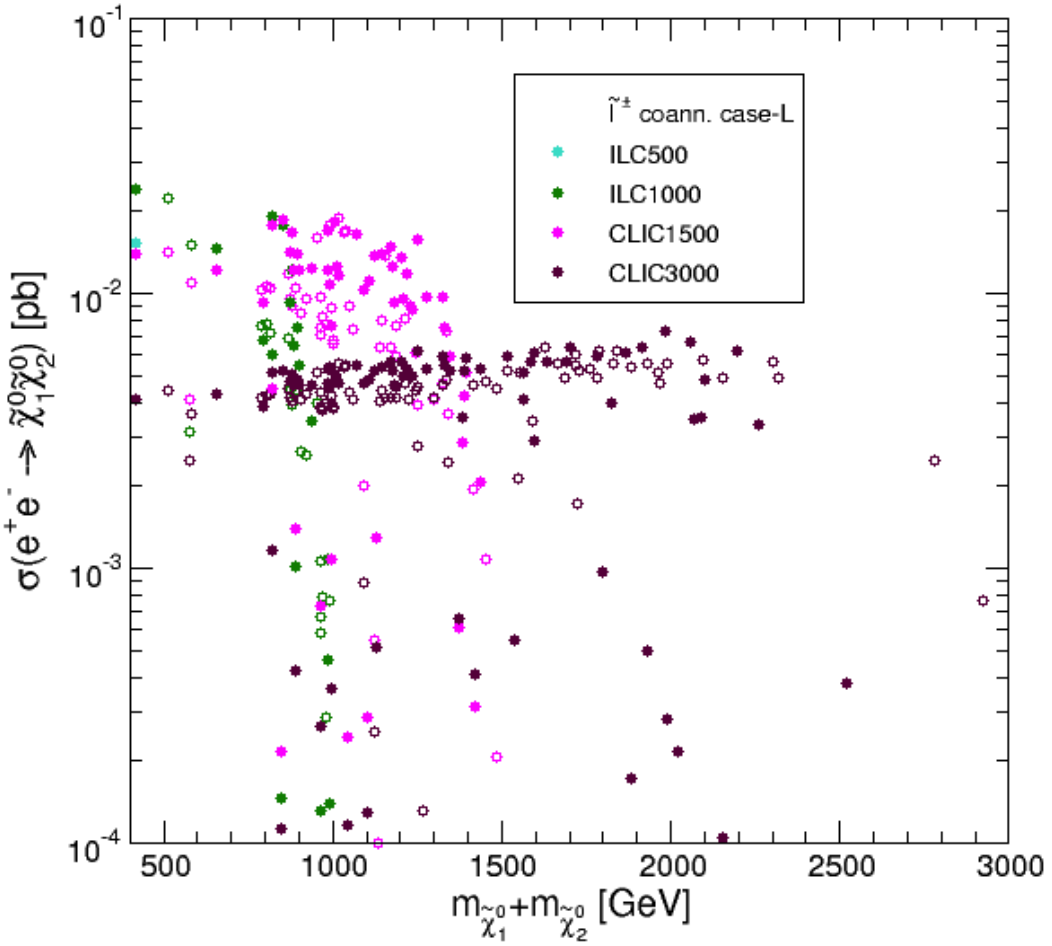
$\Rightarrow$ ILC has some prospects

$\Rightarrow$ CLIC can cover evertything

Direct production at e^+e^- colliders (ILC/CLIC)

wino/bino DM with slepton co-ann. (open/full: current/future $(g-2)_\mu$)





$\Rightarrow$ ILC can cover full "future" smuon channel

$\Rightarrow$ CLIC can cover evertything