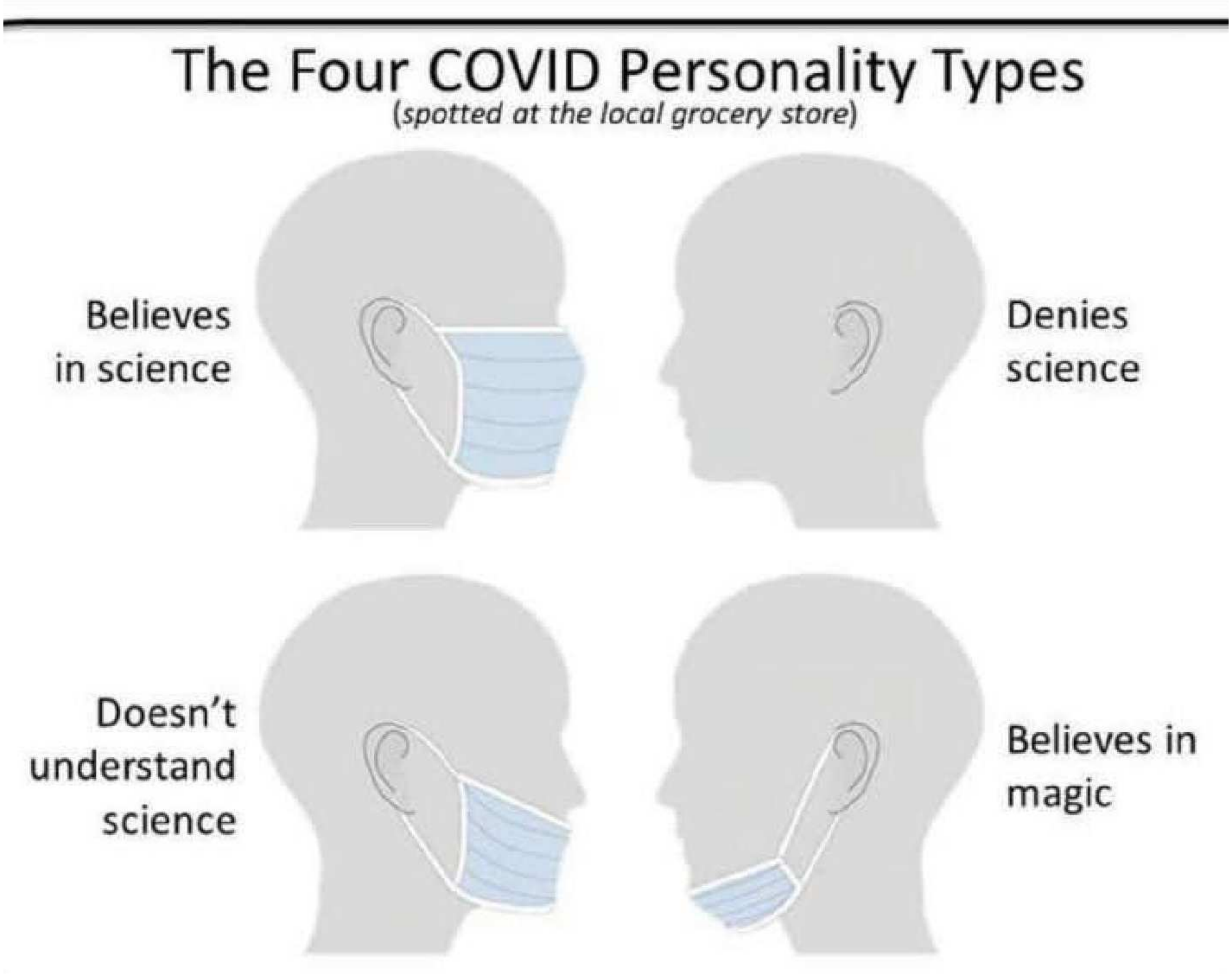

The Four COVID Personality Types
(spotted at the local grocery store)
Believes in science
Denies science
Doesn't understand science
Believes in magic

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

Sven Heinemeyer, IFT/IFCA (CSIC, Madrid/Santander)

DESY/virtual, 04/2021

1. The experimental situation

2. Excursion to the 2HDM

3. The real thing: the MSSM

4. Results for (nearly) all SUSY scenarios

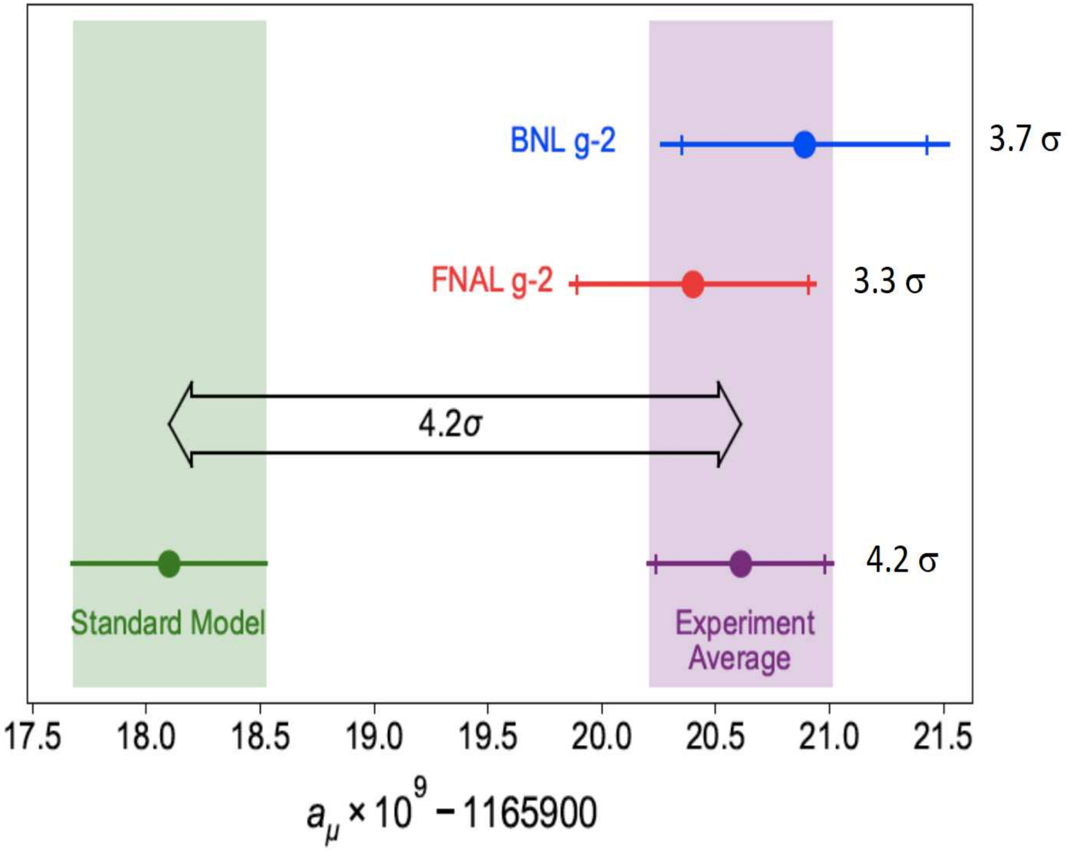
5. Predictions for future colliders

6. Conclusions

1. The experimental situation

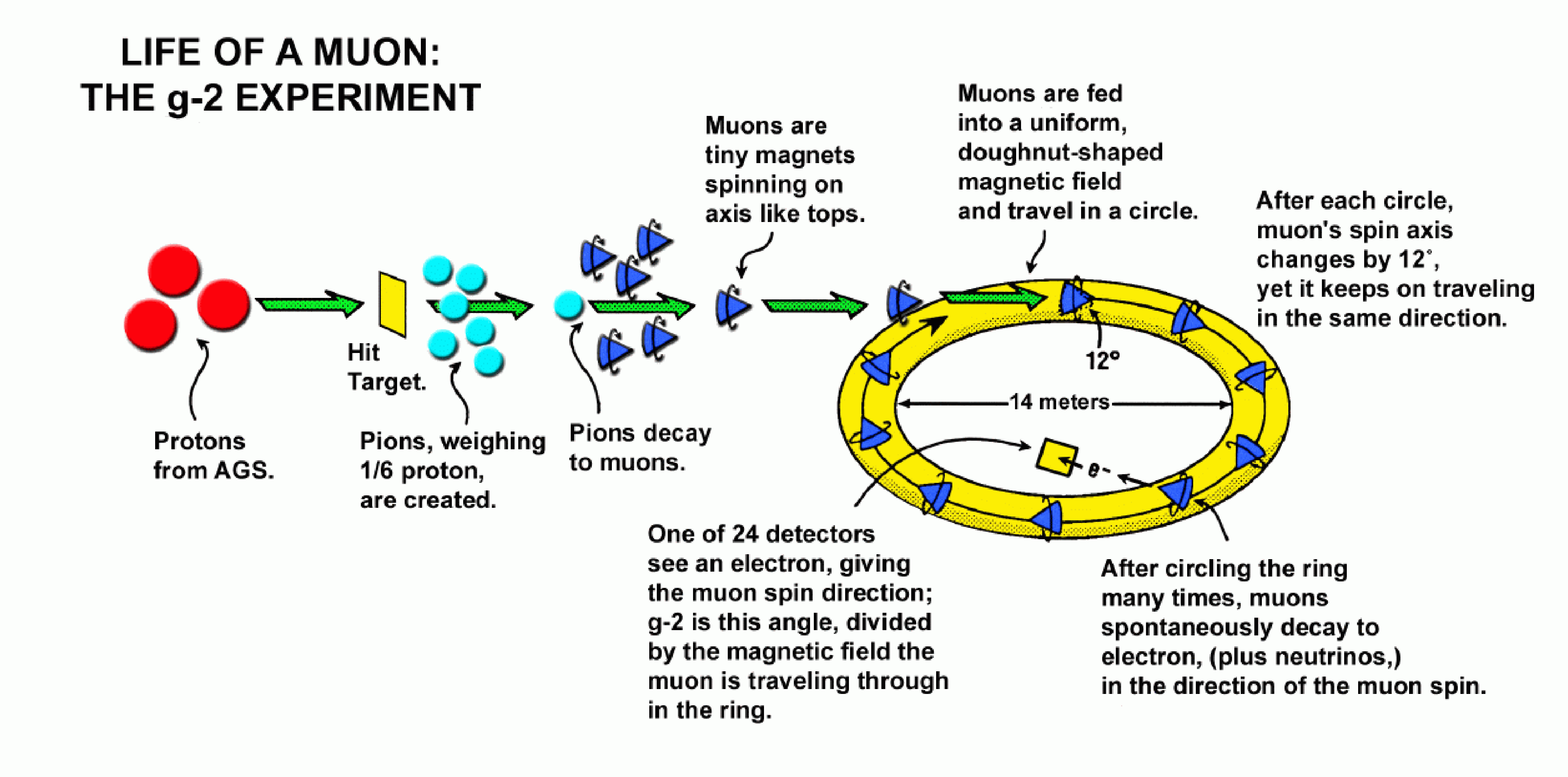
The anomalous magnetic moment of the muon: $a_\mu \equiv (g-2)_\mu/2$

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



$$a_\mu^{\rm exp} - a_\mu^{\rm theo,SM} \approx (25.1 \pm 5.9) \times 10^{-10} \quad : 4.2\,\sigma$$

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

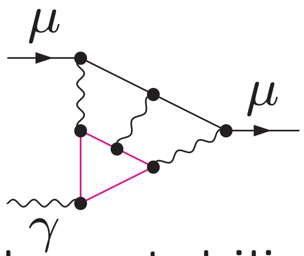


Coupling of muon to magnetic field : $\mu - \mu - \gamma$ coupling

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

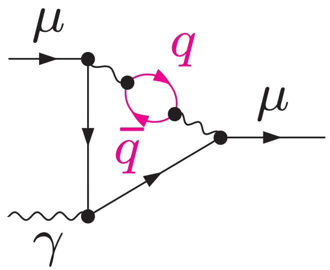
Theory of $(g-2)_\mu$:

– the light-by-light contribution:



2002: sign error discovered; since then stabilized
2021: confirmed by LQCD

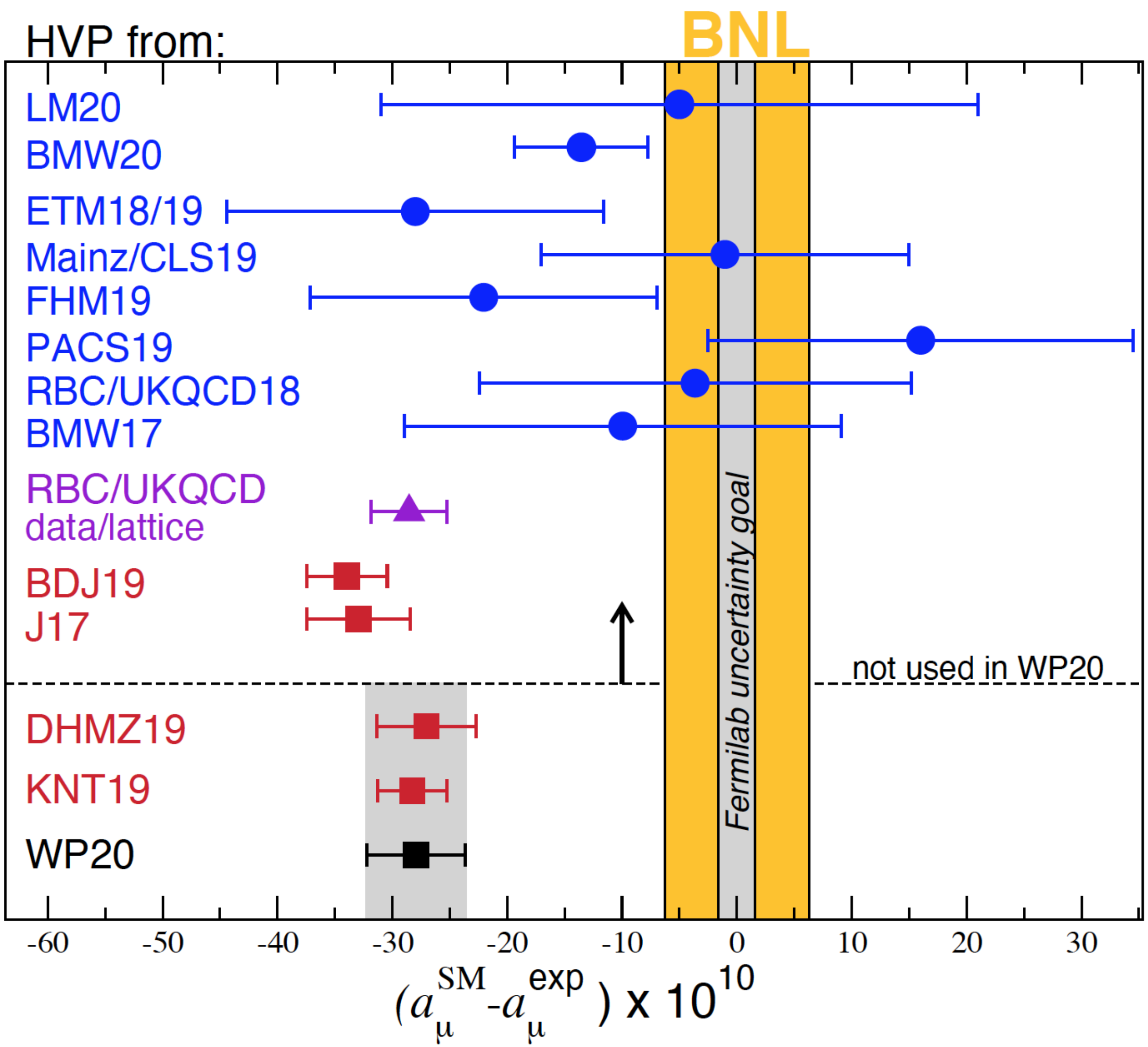
– the hadronic vacuum contribution:



'direct' e^+e^- data:
from CMD-II, SND, KLOE, BaBar (radiative return)
$\Rightarrow$ agree relarively well (also with old e^+e^- data)
$\Rightarrow$ tension with LQCD results

τ data:
tended to be closer to experimental result
inclusion of γ-ρ mixing: agreement with e^+e^- [F. Jegerlehner, R. Szafron '10]
$\Rightarrow$ still under discussion . . .

HVP summary:



$\Rightarrow$ BMW20: difference to experimental data $\sim 1.5\,\sigma$

2. Excursion to the 2HDM

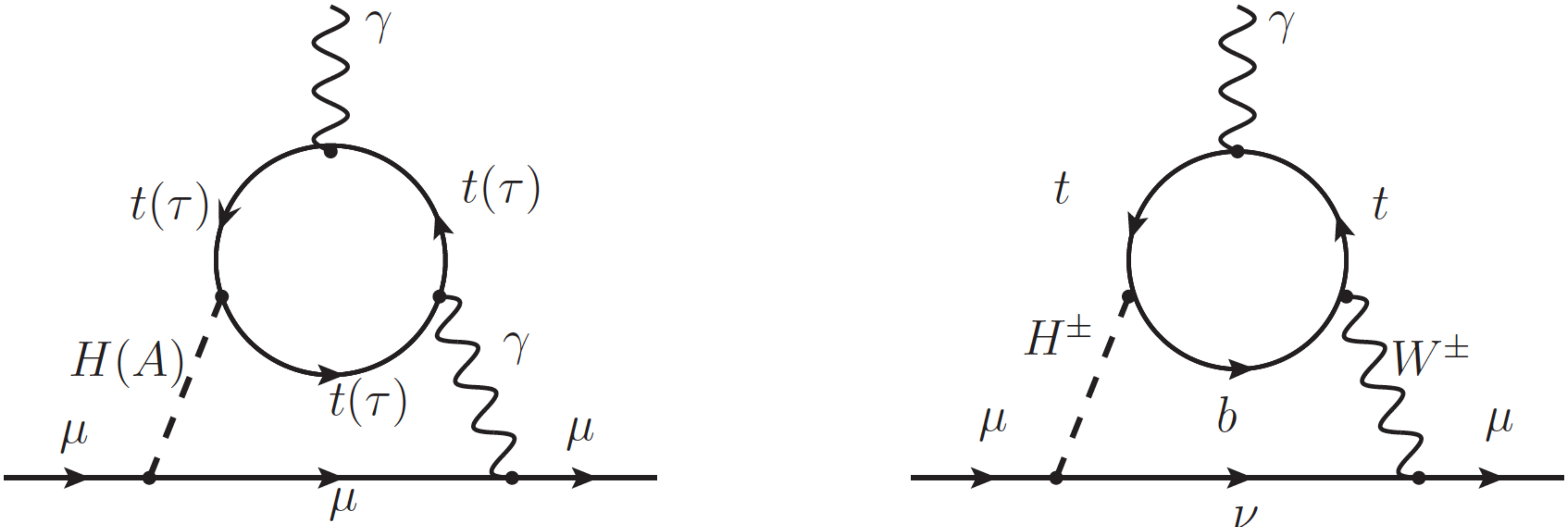
Extension of the Z_2 symmetry to fermions determines four types:

	u-type	d-type	leptons
type I	Φ_2	Φ_2	Φ_2
type II	Φ_2	Φ_1	Φ_1
type III (lepton-specific)	Φ_2	Φ_2	Φ_1
type IV (flipped)	Φ_2	Φ_1	Φ_2

Couplings to fermions:

	u-type (c_{Att})	d-type (c_{Abb})	leptons ($c_{A\tau\tau}$)
type I	$\cot\beta$	$\cot\beta$	$\cot\beta$
type II	$\cot\beta$	$\tan\beta$	$\tan\beta$
type III/X (lepton-specific)	$\cot\beta$	$\cot\beta$	$\tan\beta$
type IV/Y (flipped)	$\cot\beta$	$\tan\beta$	$\cot\beta$

Barr-Zee diagrams:

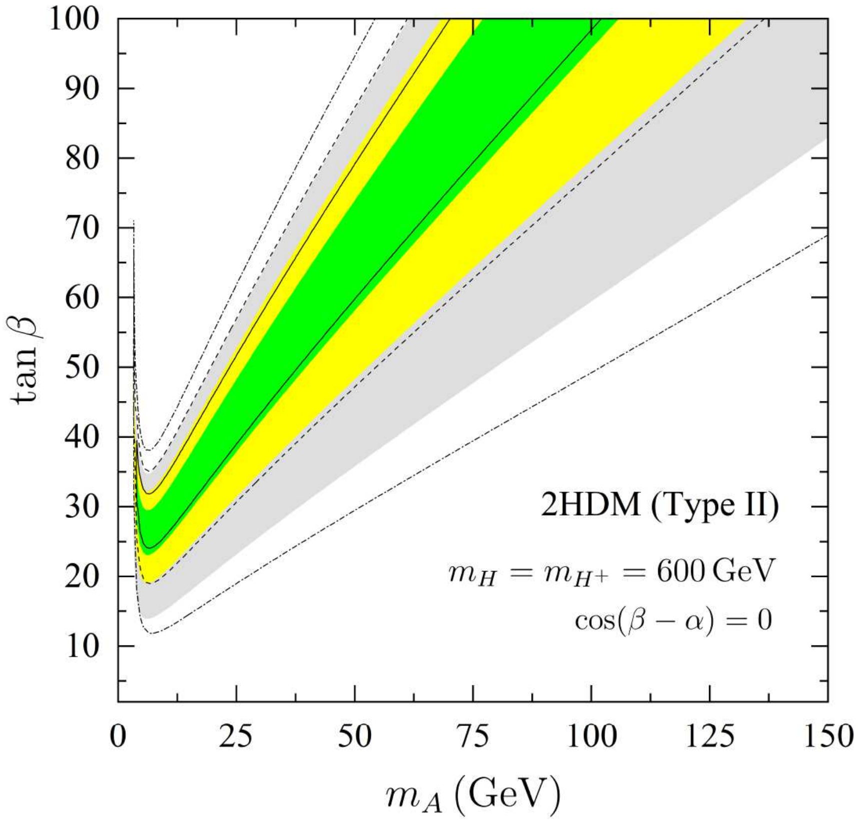


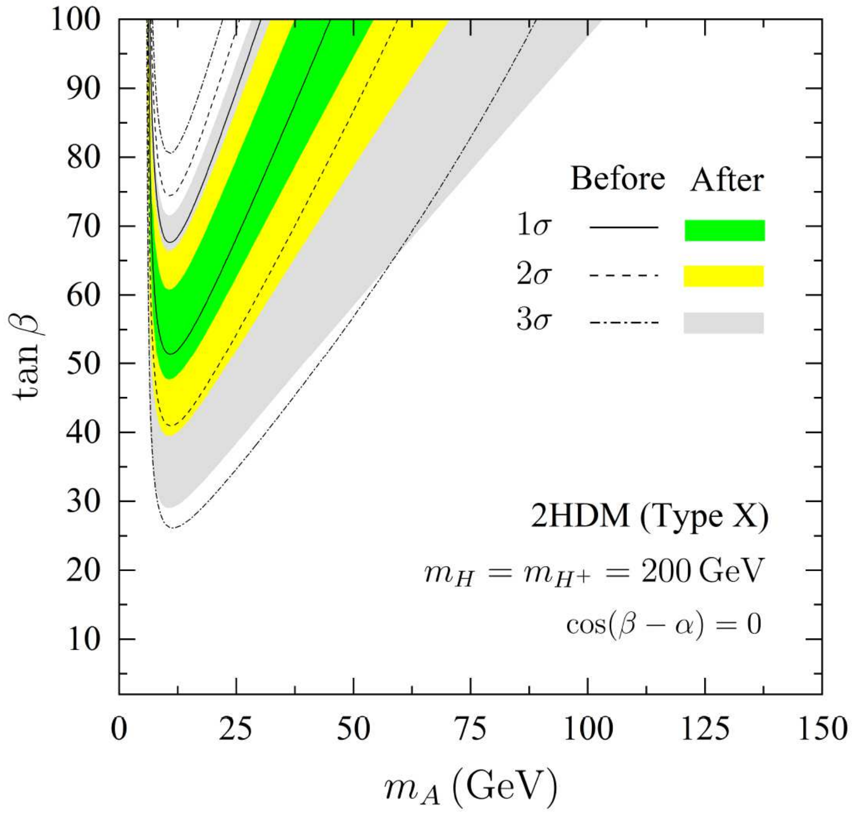
Known since long:

Light A at high $\tan\beta$ can explain the $(g-2)_\mu$ result

$\Rightarrow$ in type II and X: enhanced couplings to μ's

Updated 2HDM results: [P. Ferreira, B. Goncalvez, F. Joaquim, M. Sher '21]





Taking EWPO into account: $\Rightarrow M_{H^\pm} \lesssim 200$ GeV

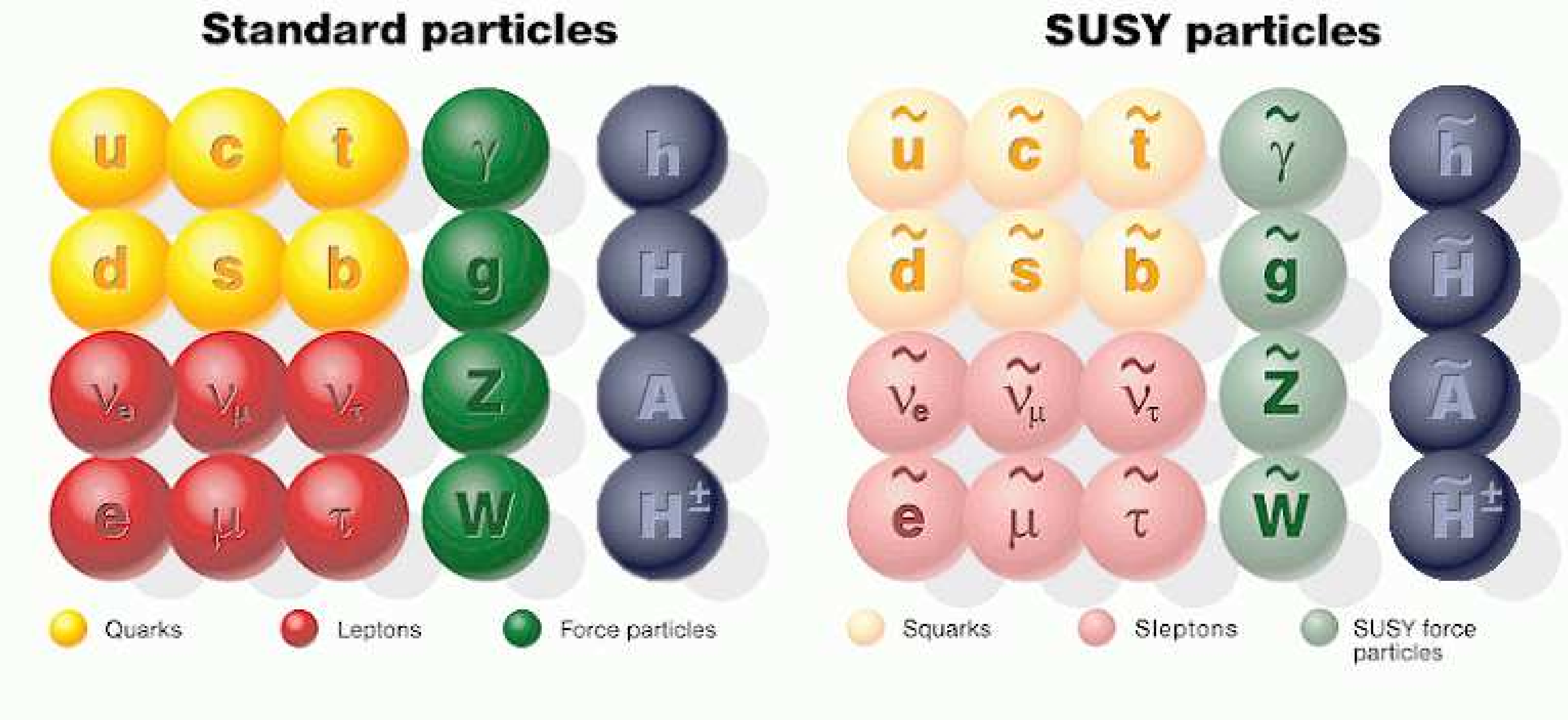
type II: problems with $b \to s\gamma$

$\Rightarrow$ only type X is in agreement with $(g-2)_\mu$, EWPO and flavor observables

$\Rightarrow$ opportunities for 2HDMS with light a_1??

The real thing: the MSSM

Superpartners for Standard Model particles



$\Rightarrow$ 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:

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

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

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

with

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

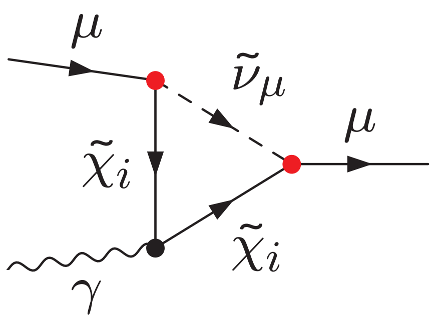
Sneutrino mass

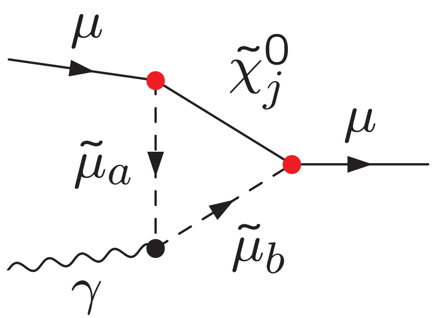
$$m^2_{\tilde{\nu}_l} = M^2_{\tilde{l}_L} + DT_\nu$$

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:

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

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:

[*M. Chakraborti, S.H., I. Saha '20, '21*]

- 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

LHC searches:

Decay via sleptons (3l)

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

Decay via sleptons (2l)

$$
\begin{aligned}
\tilde{\chi}_1^+ \tilde{\chi}_1^- &\to (\tilde{l}^+ \nu)(\tilde{l}^- \nu) \to 2l + \not{E}_T \ , \\
\tilde{\chi}_1^+ \tilde{\chi}_1^- &\to (l^+ \tilde{\nu})(l^- \tilde{\nu}) \to 2l + \not{E}_T
\end{aligned}
\tag{6}
$$

Decay via gauge bosons

$$
\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to (W \tilde{\chi}_1^0)(Z \tilde{\chi}_1^0) \to 3l + \not{E}_T \ , \tag{7a}
$$

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

$$
\tilde{\chi}_1^+ \tilde{\chi}_1^- \to (W^+ \tilde{\chi}_1^0)(W^- \tilde{\chi}_1^0) \to 2l + \not{E}_T \tag{8}
$$

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

⇒ all newly included into CheckMate *[M.C & I.S.]*

Exception: compressed spectra ⇒ direct application

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

$$\text{old: } \Delta a_\mu^{\text{old}} = (28.0 \pm 7.4) \times 10^{-10}$$
$$\text{new: } \Delta a_\mu^{\text{new}} = (25.1 \pm 5.9) \times 10^{-10}$$

$\Rightarrow$ some results for $\Delta a_\mu^{\text{new}} (\equiv \Delta a_\mu)$
some results only available for $\Delta a_\mu^{\text{old}}$

Note: $\Delta a_\mu^{\text{old}} - 2\,\sigma^{\text{old}} \approx \Delta a_\mu^{\text{new}} - 2\,\sigma^{\text{new}}$
$\Rightarrow$ upper limits on SUSY masses are not expected to change

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 $\Rightarrow$ updated with $\Delta a_\mu^{\text{new}}$

2. bino DM with slepton co-annihilation case-L
   $\Rightarrow$ full relic DM constraint $\Rightarrow$ updated with $\Delta a_\mu^{\text{new}}$

3. bino DM with slepton co-annihilation case-R
   $\Rightarrow$ full relic DM constraint $\Rightarrow$ updated with $\Delta a_\mu^{\text{new}}$

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 $\Rightarrow (g-2)_\mu$ not 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 $\Rightarrow (g-2)_\mu$ not ok
   $\Rightarrow$ relic DM upper bound

A) Bino/wino DM with chargino co-annihilation

[M. Chakraborti, S.H., I. Saha '20, '21]

Parameter scan:

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

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

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

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

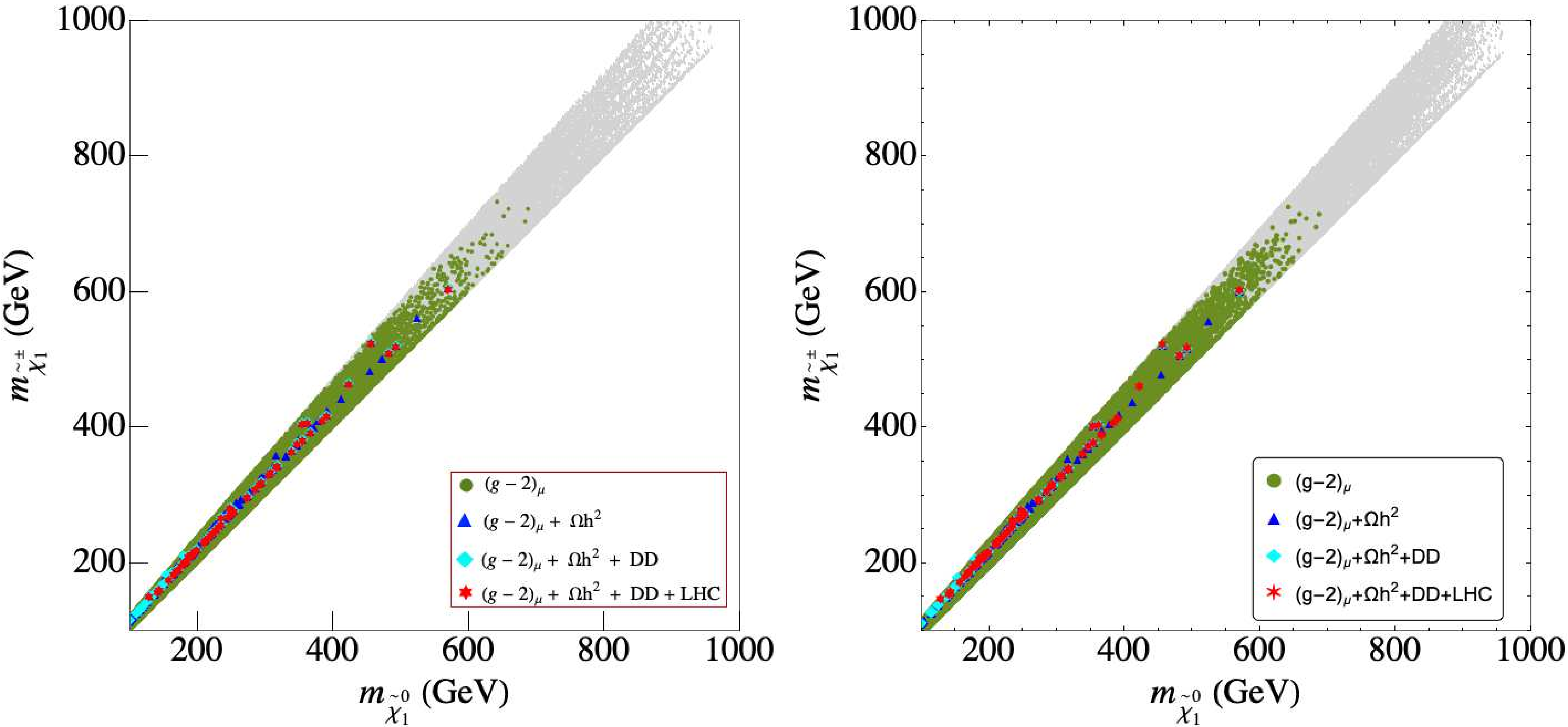
$$100 \text{ GeV} \leq m_{\tilde{L}} \leq 1 \text{ TeV},$$

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

(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:

old $(g-2)_\mu$ new $(g-2)_\mu$

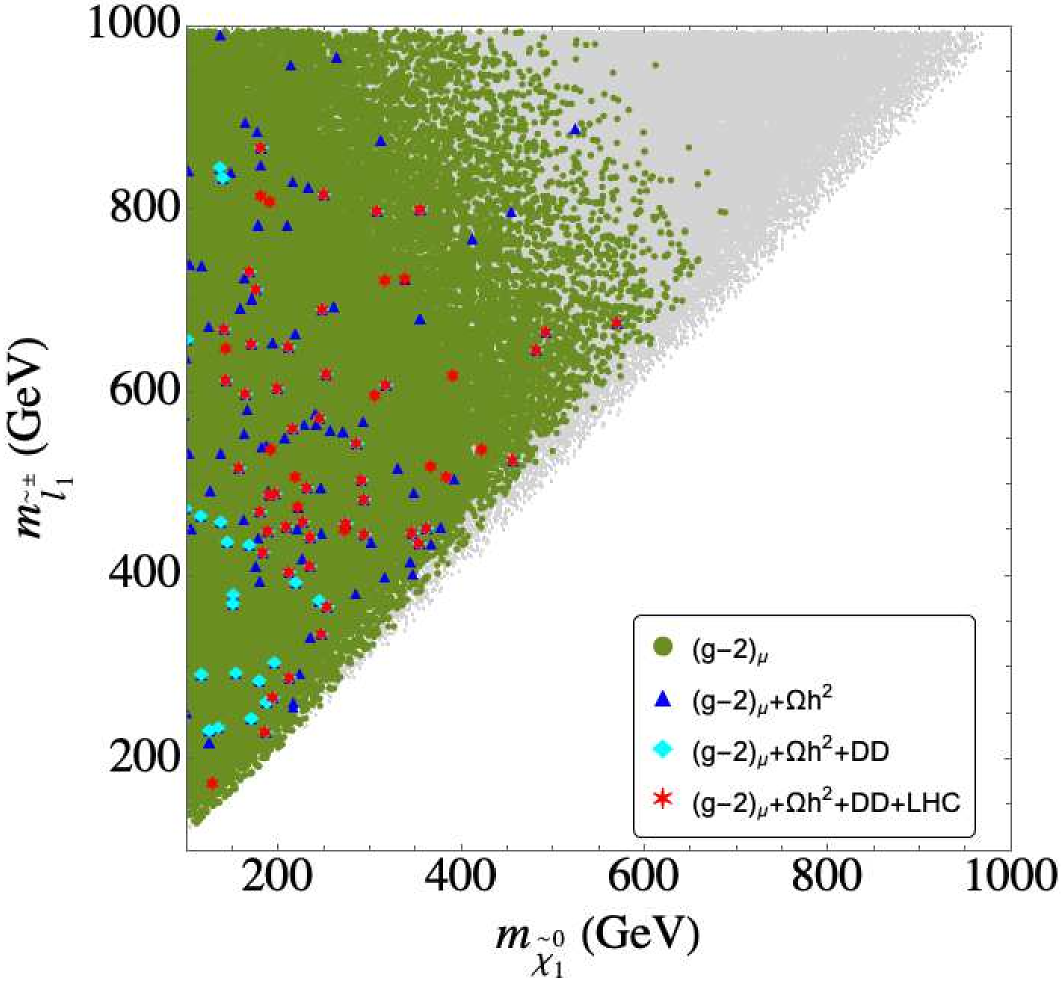


$\Rightarrow$ compressed spectrum as expected

$\Rightarrow$ clear upper limits, $m_{\text{(N)LSP}} \lesssim 600(650)$ GeV confirmed

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

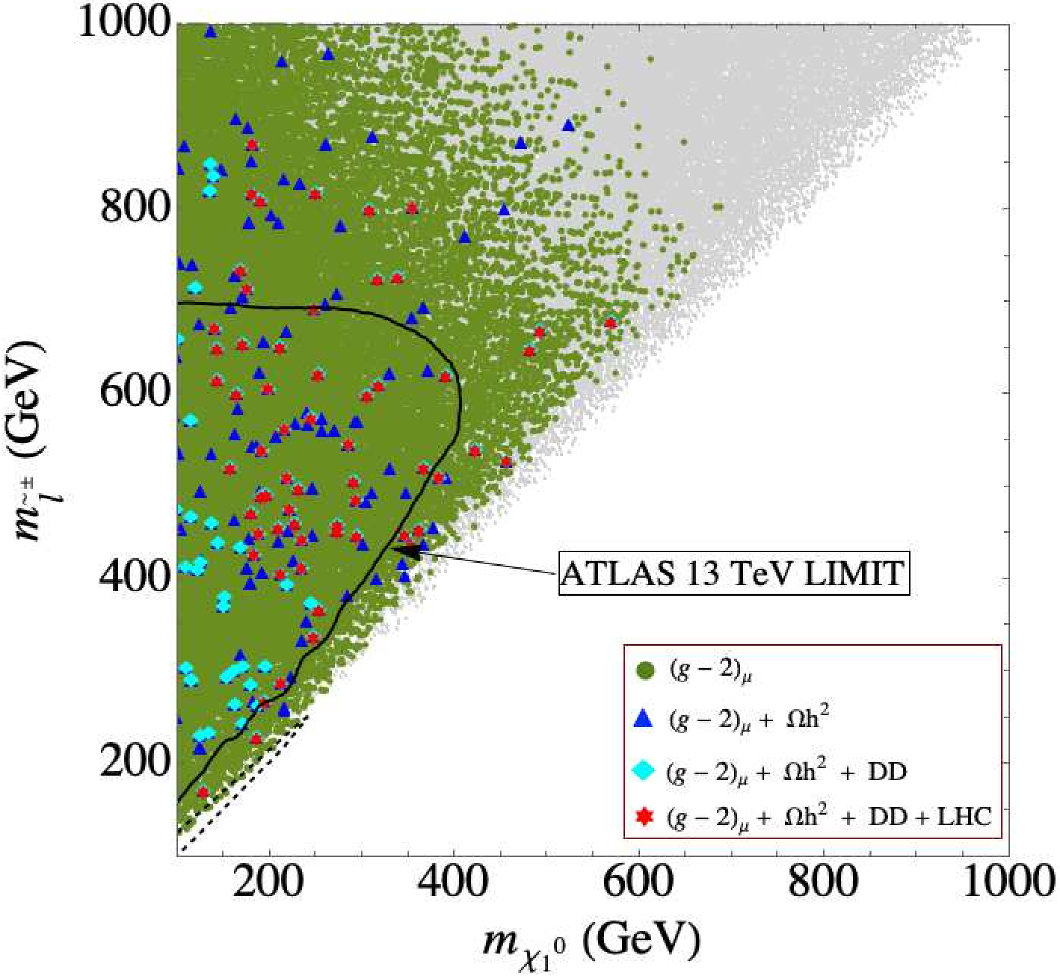
new $(g-2)_\mu$



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

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

old $(g-2)_\mu$



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

$\Rightarrow$ naive application of LHC bounds fails

B/C) Bino DM with slepton co-annihilation

[*M. Chakraborti, S.H., I. Saha '20, '21*]

Parameter scan:

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

$$M_1 \le M_2 \le 10 M_1\ ,$$

$$1.1 M_1 \le \mu \le 10 M_1,$$

$$5 \le \tan\beta \le 60,$$

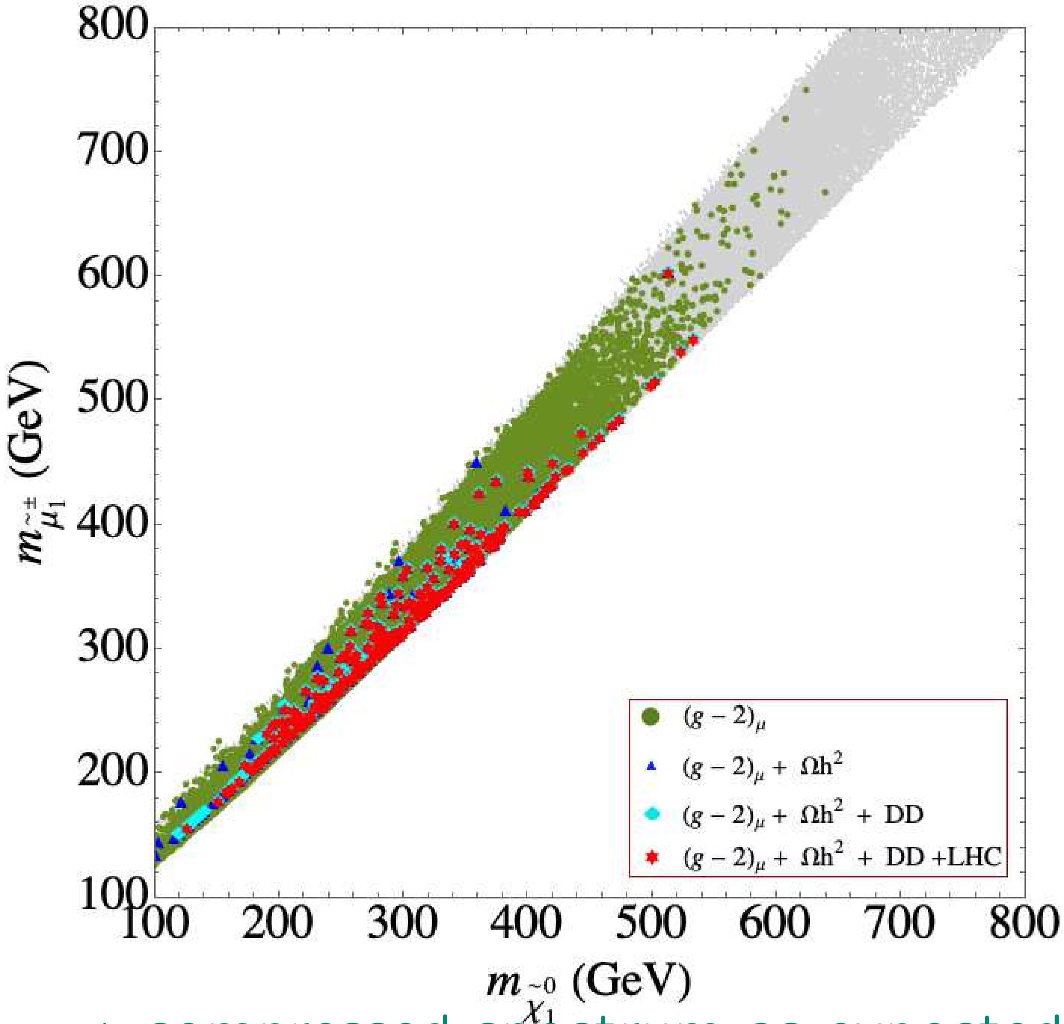
Case-L: $M_1 \le m_{\tilde{L}} \le 1.2 M_1, \quad M_1 \le m_{\tilde{R}} \le 10 M_1.$

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

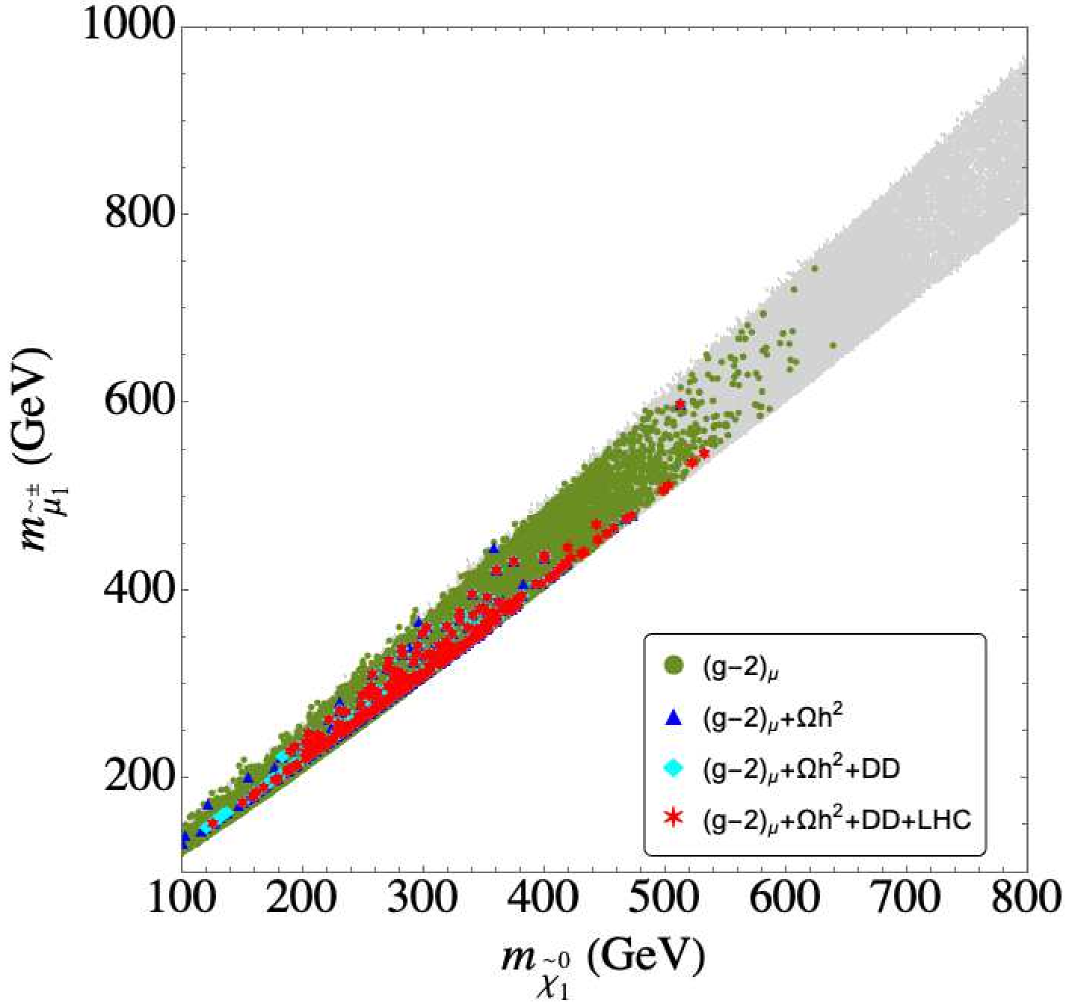
$\Rightarrow$ here focus on Case-L

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

old $(g-2)_\mu$



new $(g-2)_\mu$

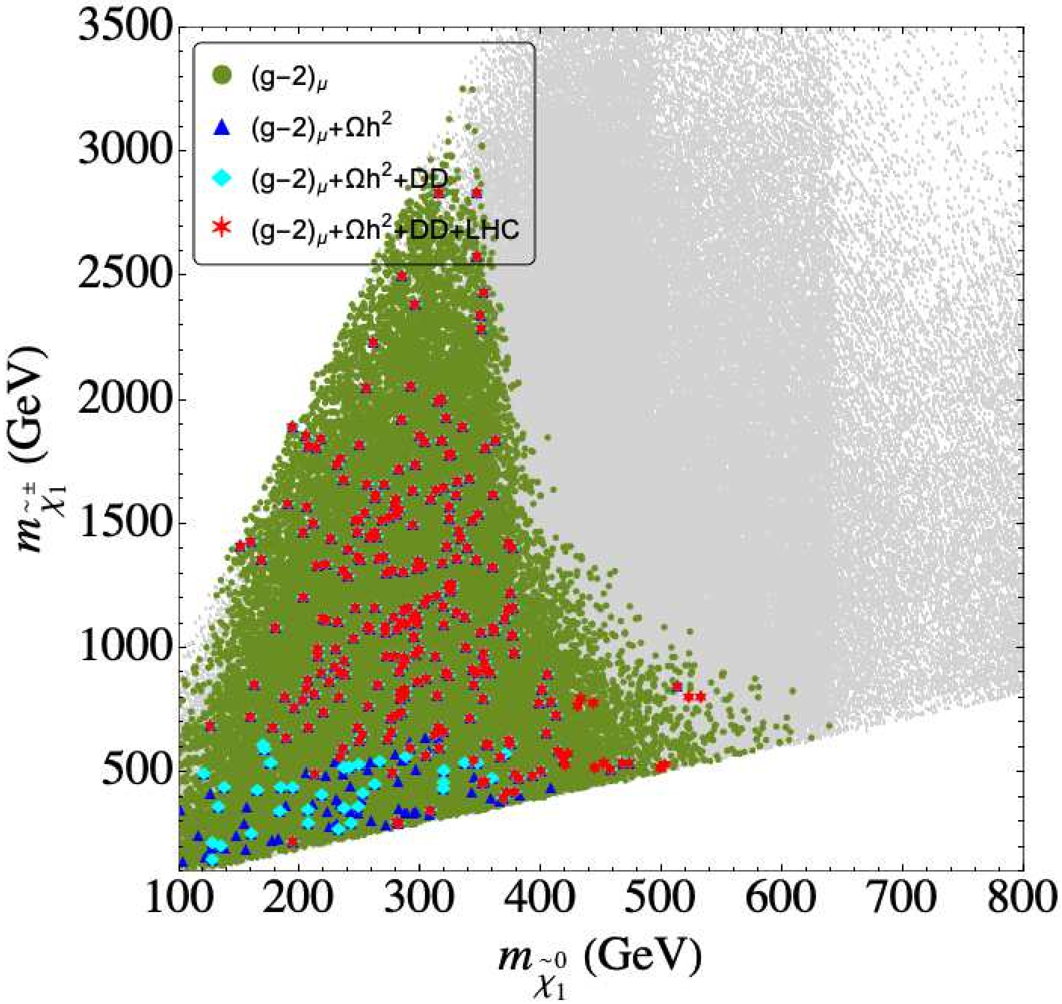


$\Rightarrow$ compressed spectrum as expected

$\Rightarrow$ clear upper limits, $m_{\text{(N)LSP}} \lesssim 550(600)$ GeV confirmed

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

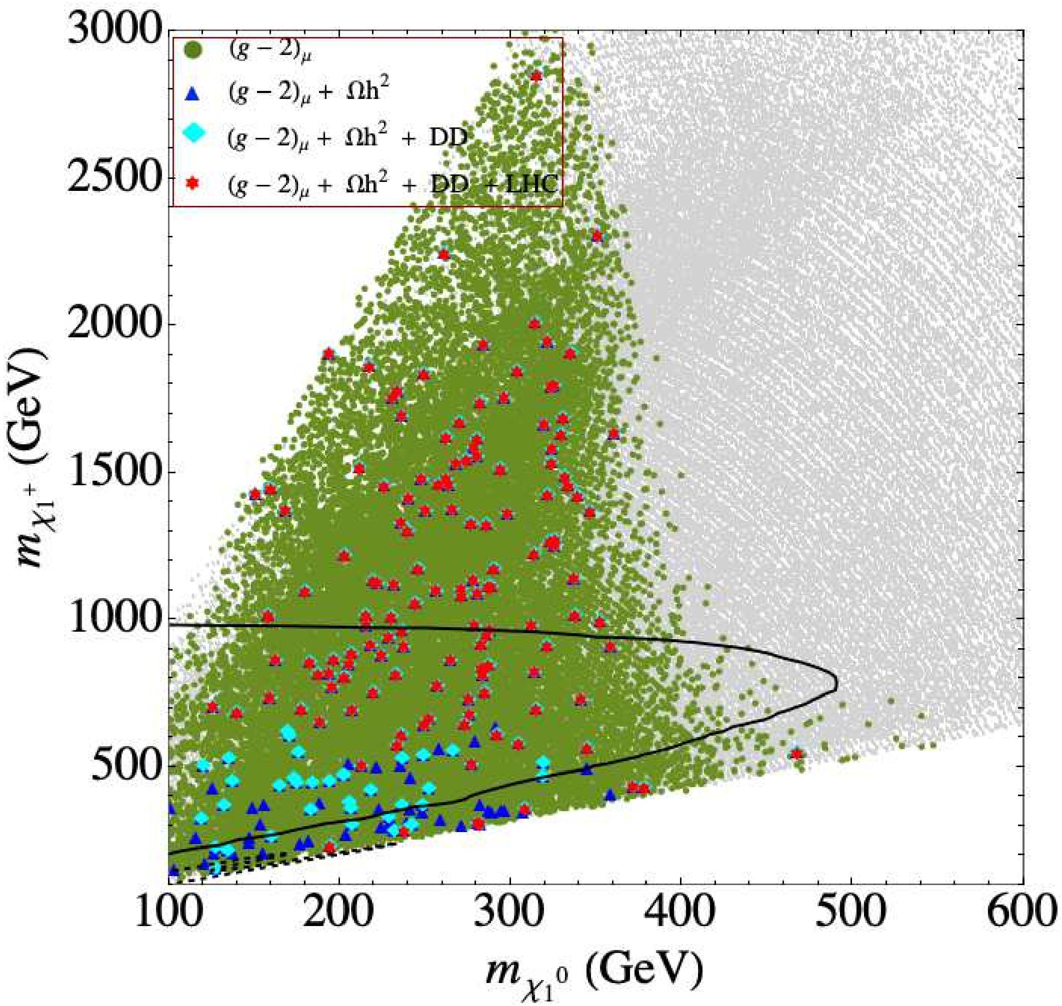
new $(g-2)_\mu$



$\Rightarrow$ 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:

old $(g-2)_\mu$



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

⇒ naive application of LHC bounds fails

D) Higgsino DM

[*M. Chakraborti, S.H., I. Saha '21*]

Parameter scan:

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

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

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

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

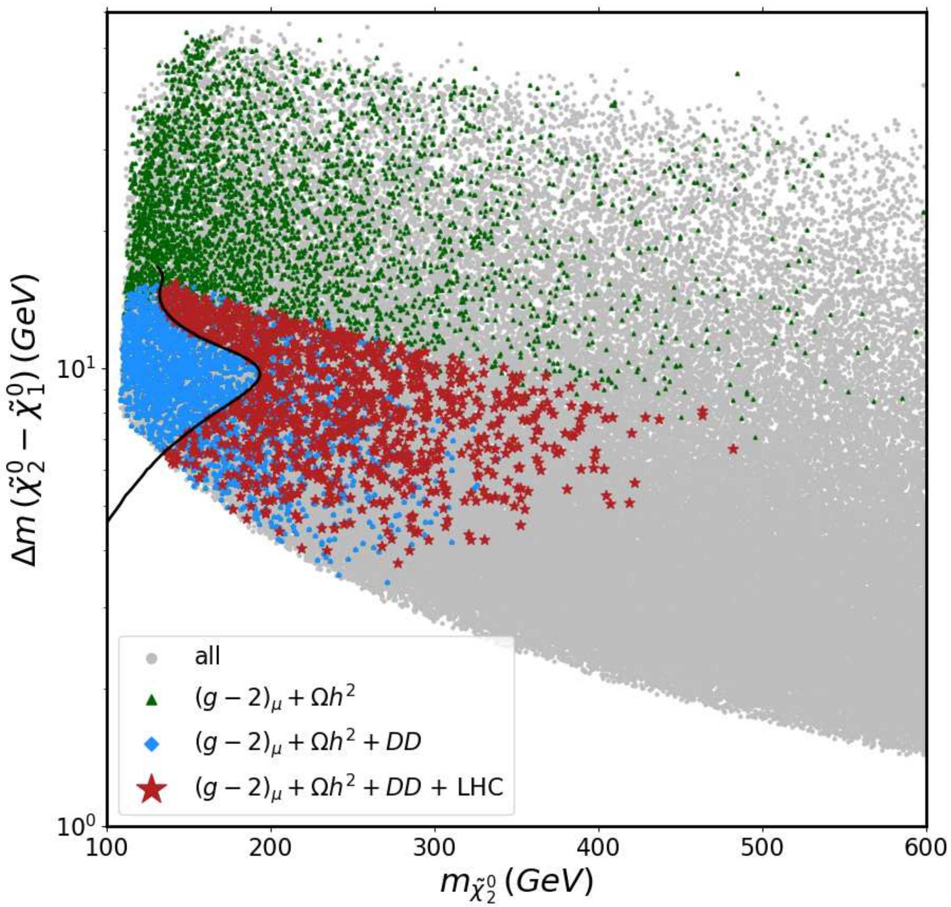
$$100 \text{ GeV} \leq m_{\tilde{L}}, m_{\tilde{R}} \leq 2 \text{ TeV},$$

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

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:

old $(g-2)_\mu$

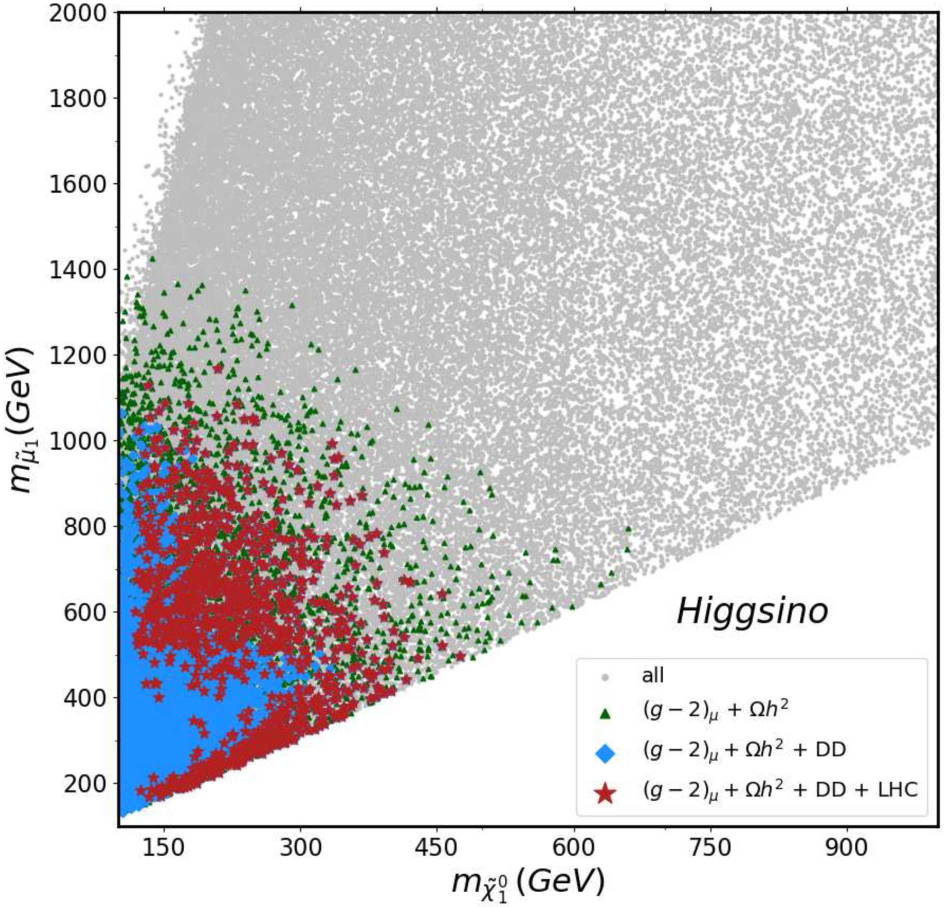


⇒ important: compressed spectra searches (11)

⇒ right where the model prediction sits ⇒ very powerful

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

old $(g-2)_\mu$



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

E) Wino DM

[M. Chakraborti, S.H., I. Saha '20, '21]

Parameter scan:

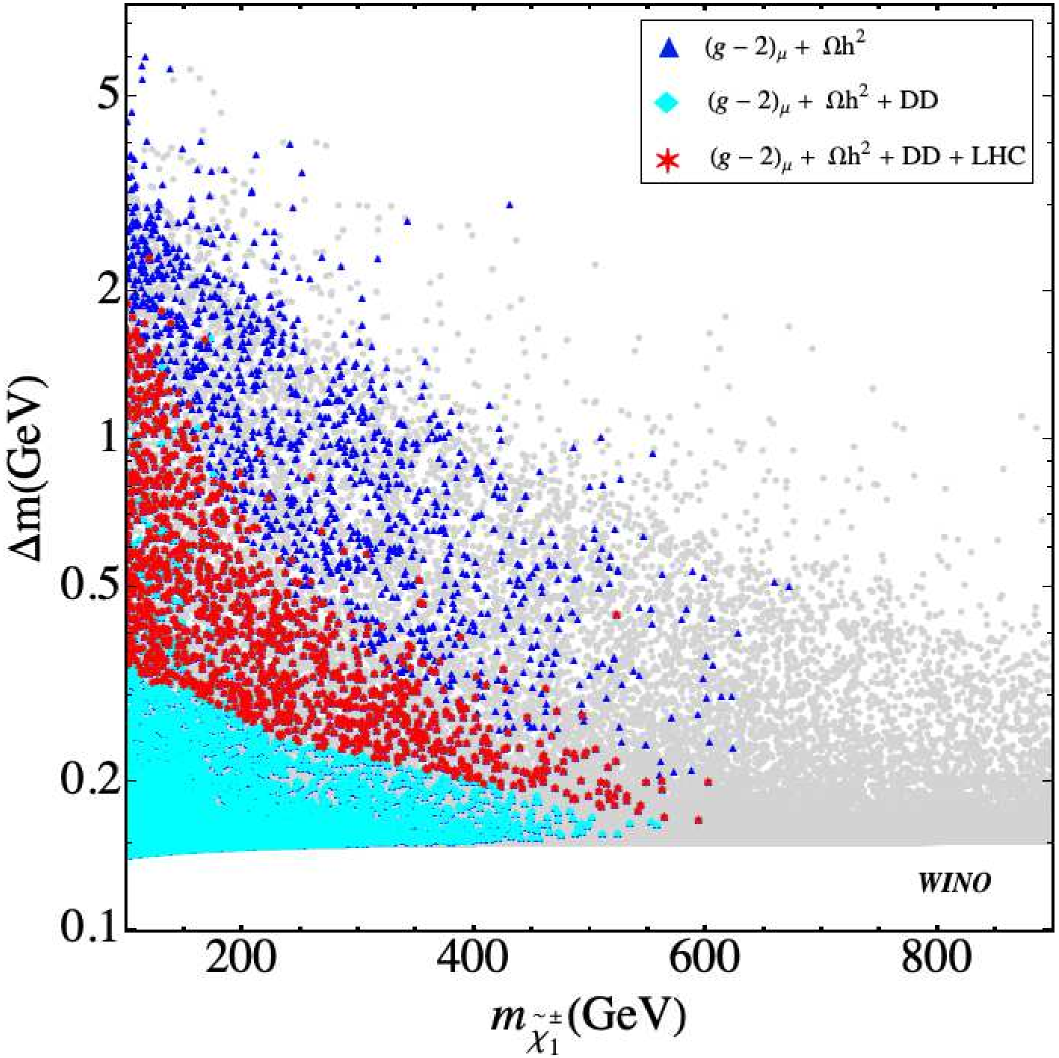
$$100 \text{ GeV} \le M_2 \le 1.5 \text{ TeV} ,$$
$$1.1 M_2 \le M_1 \le 10 M_2 ,$$
$$1.1 M_2 \le \mu \le 10 M_2 ,$$
$$5 \le \tan\beta \le 60,$$
$$100 \text{ GeV} \le m_{\tilde{L}}, m_{\tilde{R}} \le 2 \text{ TeV},$$

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

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:

old $(g-2)_\mu$

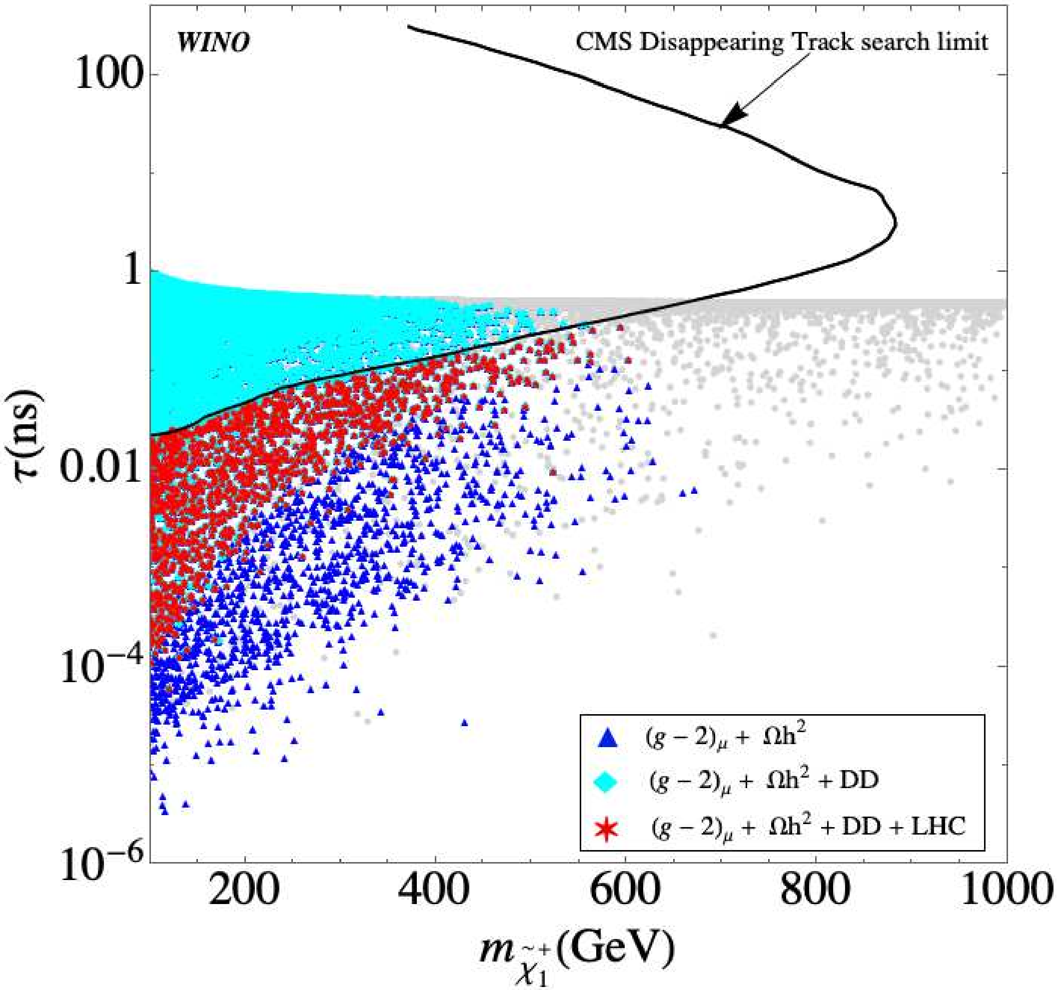


$\Rightarrow$ important: disappearing track limit $\Rightarrow m_{\text{(N)LSP}} \lesssim 600$ GeV

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

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

old $(g-2)_\mu$

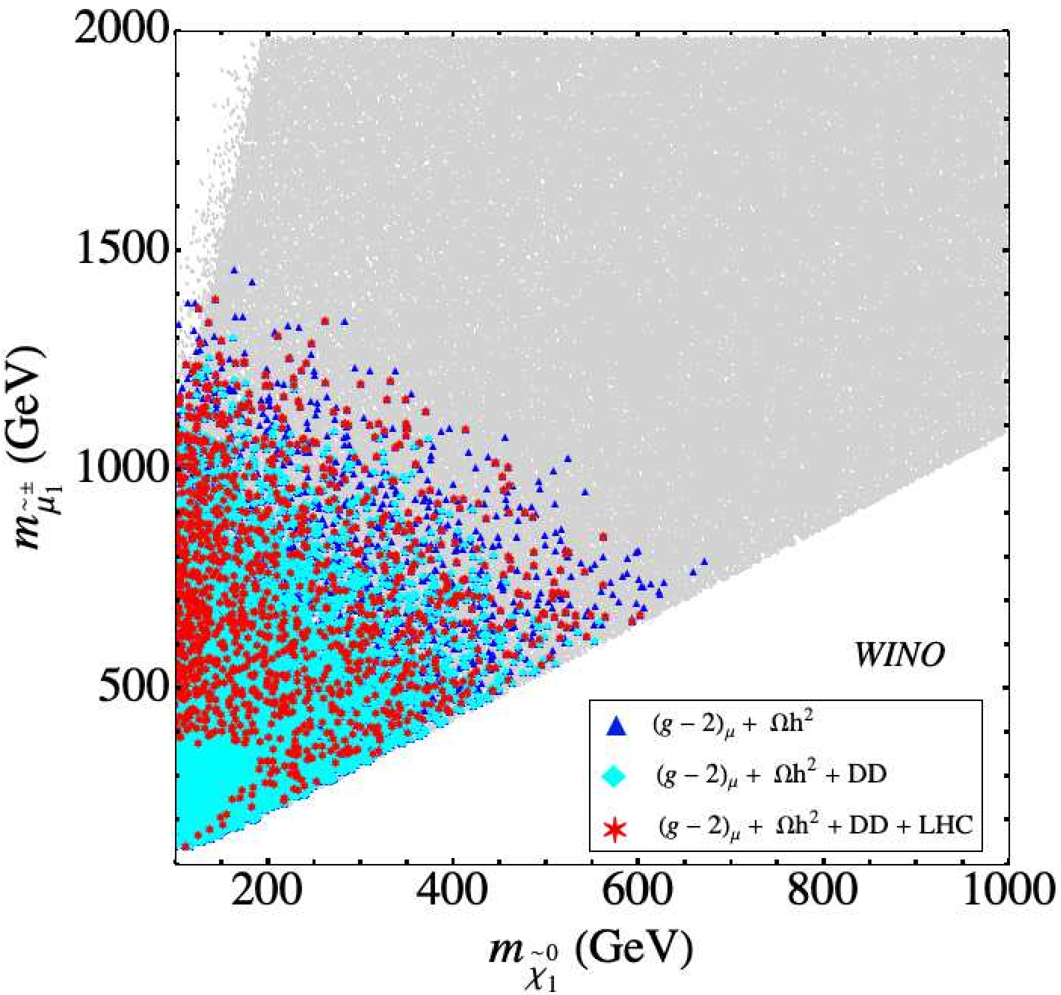


⇒ important: disappearing track limit ⇒ $m_{\text{(N)LSP}} \lesssim 600$ GeV

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

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

old $(g-2)_\mu$



$\Rightarrow m_{\tilde{l}_1} \lesssim$ 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(650) GeV for new (and old) $(g-2)_\mu$

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

relic DM density 100% fulfilled

$\Rightarrow m_{\text{(N)LSP}} \lesssim$ 550(600) GeV for new (and old) $(g-2)_\mu$

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 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 GeV

$\Rightarrow$ predictions for future colliders?!

4. Predictions for future colliders

– HL-LHC direct search projections

– HL-LHC searches for compressed spectra $\Leftarrow$ focus

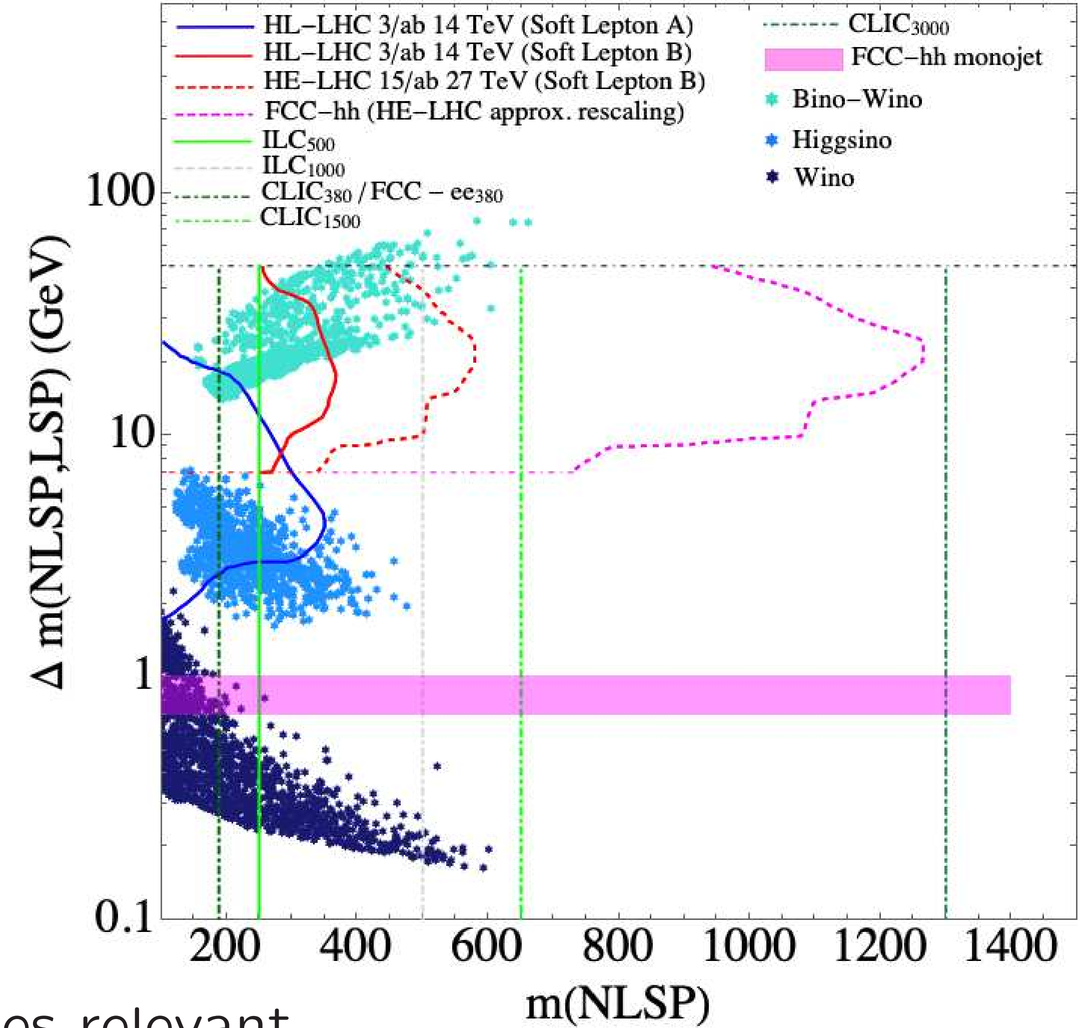
– future collider prospects for compressed spectra $\Leftarrow$ focus

– direct production at e^+e^- colliders $\Leftarrow$ focus

– . . .

Compressed spectra at current and future colliders

Higgsino, wino and bino/wino DM:



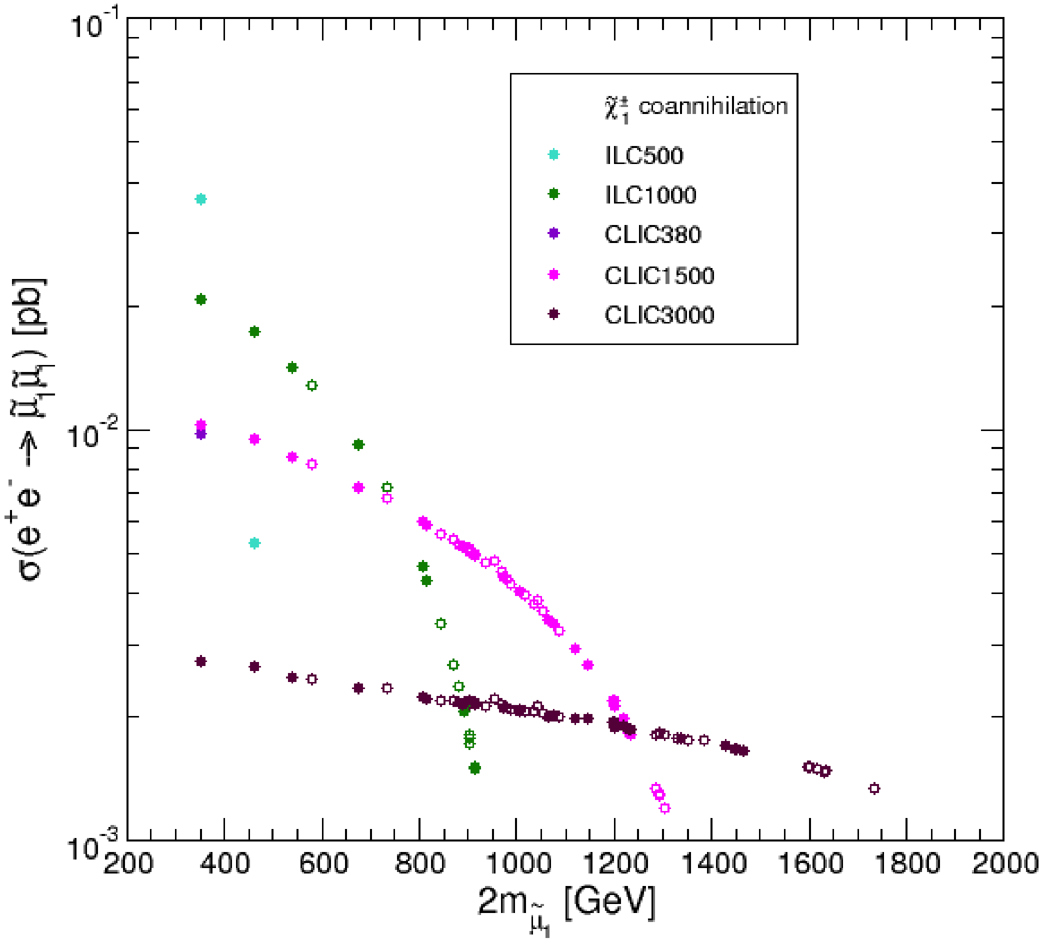
– current searches relevant

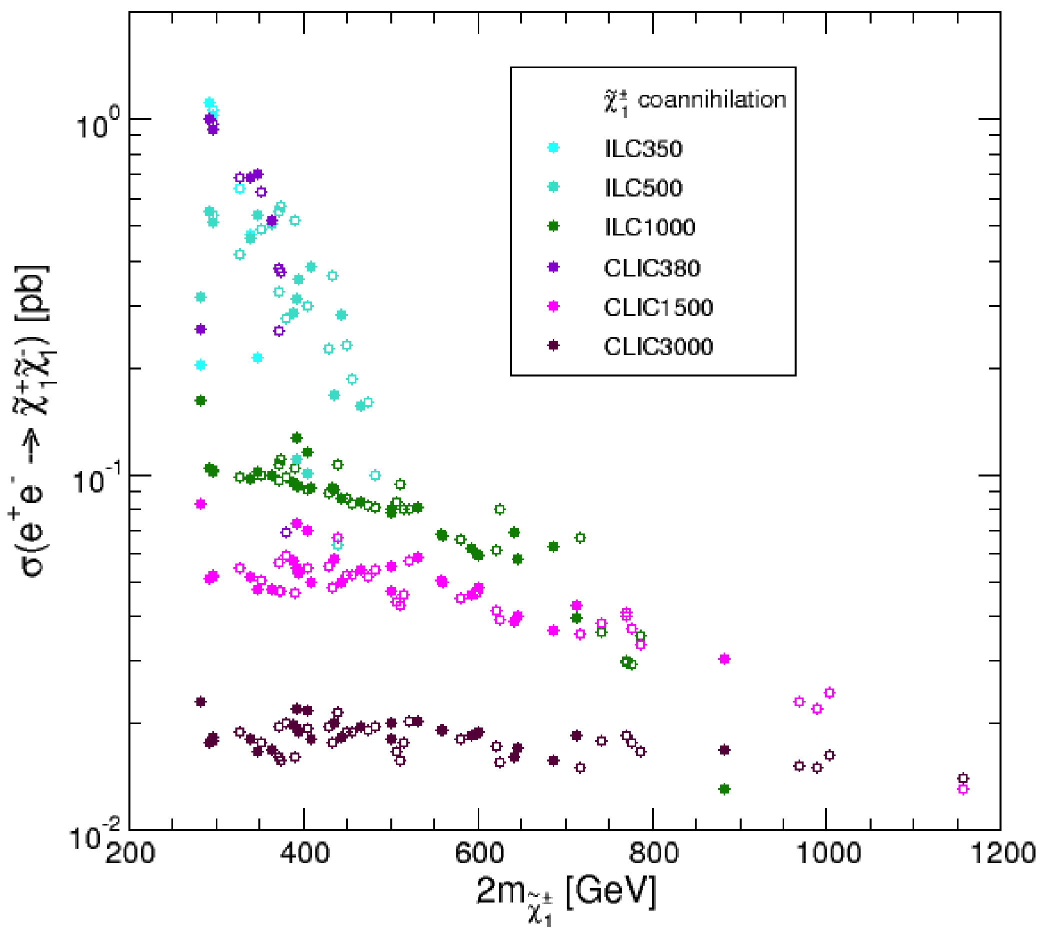
– HL-LHC searches very powerful

– ILC/CLIC needed to cover these scenario

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

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



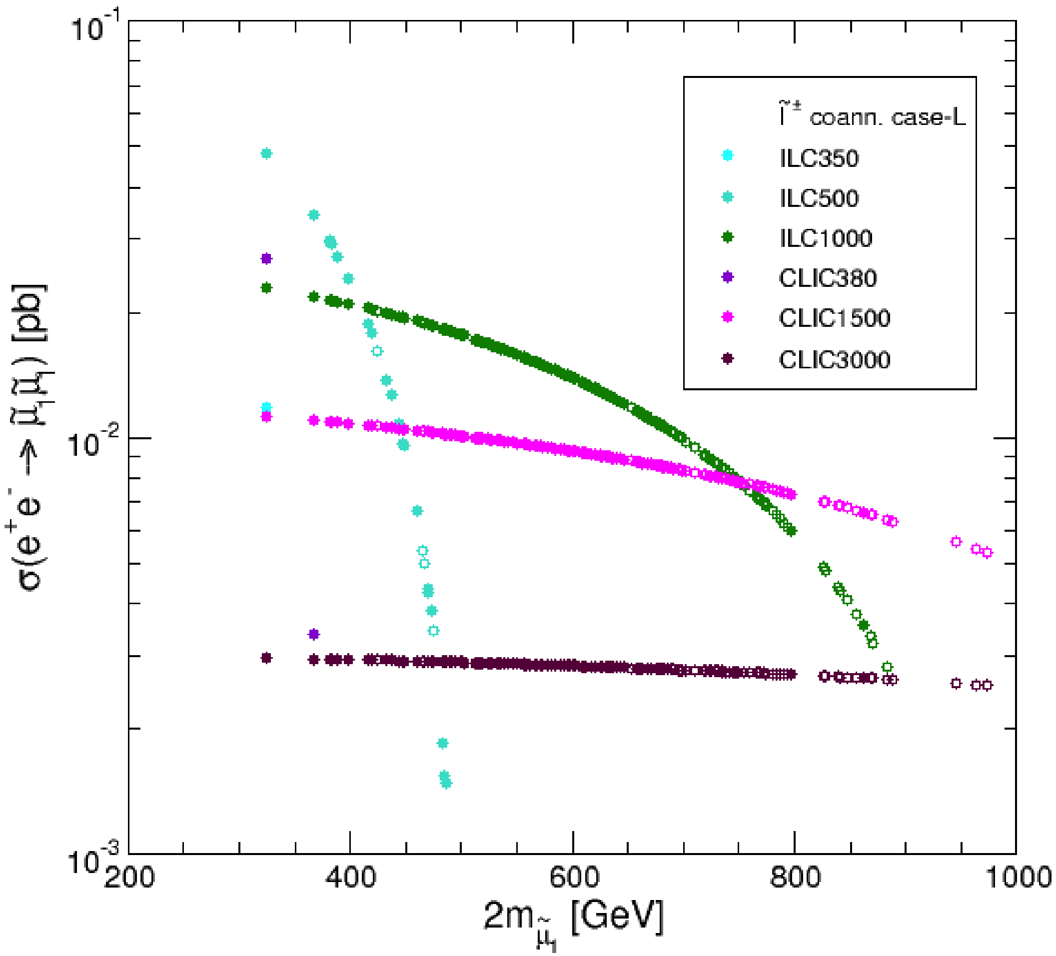


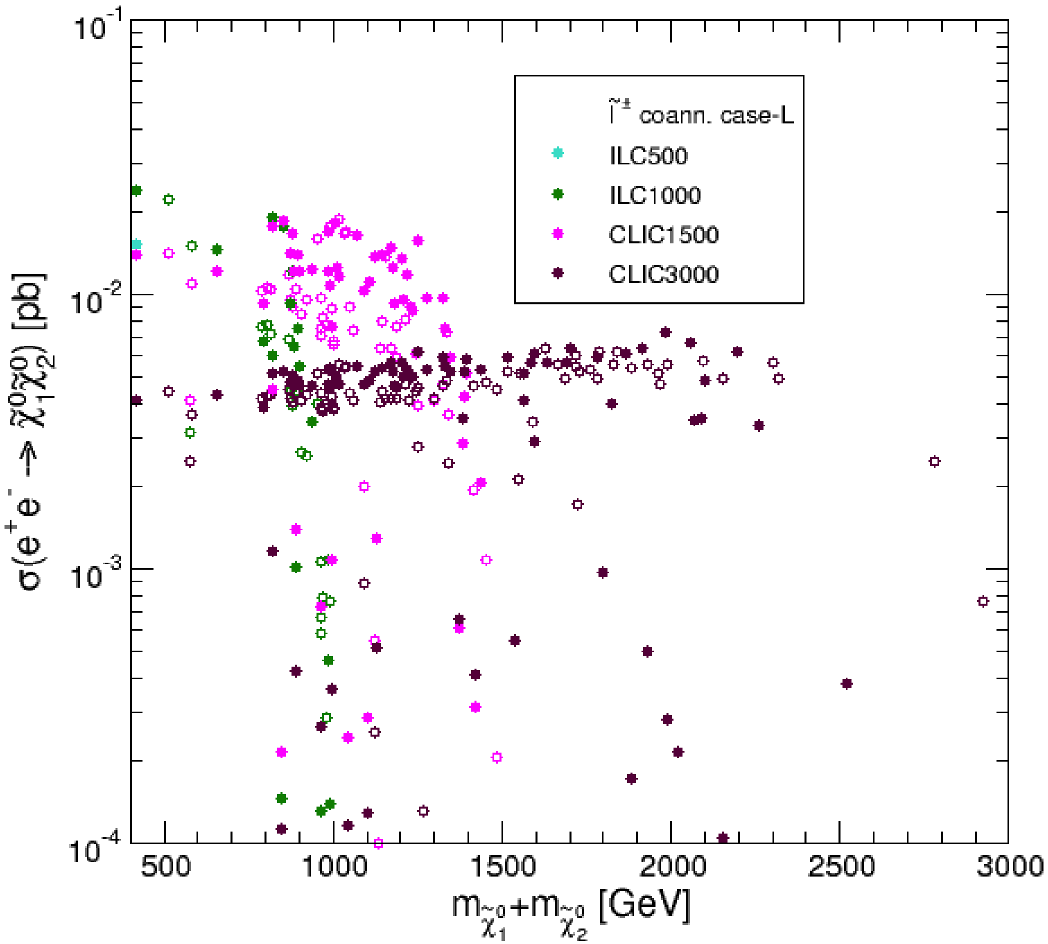
$\Rightarrow$ ILC has good prospects (particularly for $\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$)

$\Rightarrow$ CLIC can cover evertything

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

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





$\Rightarrow$ ILC can nearly covers full smuon channel (but not $\tilde{\chi}^0_1\tilde{\chi}^0_2$)

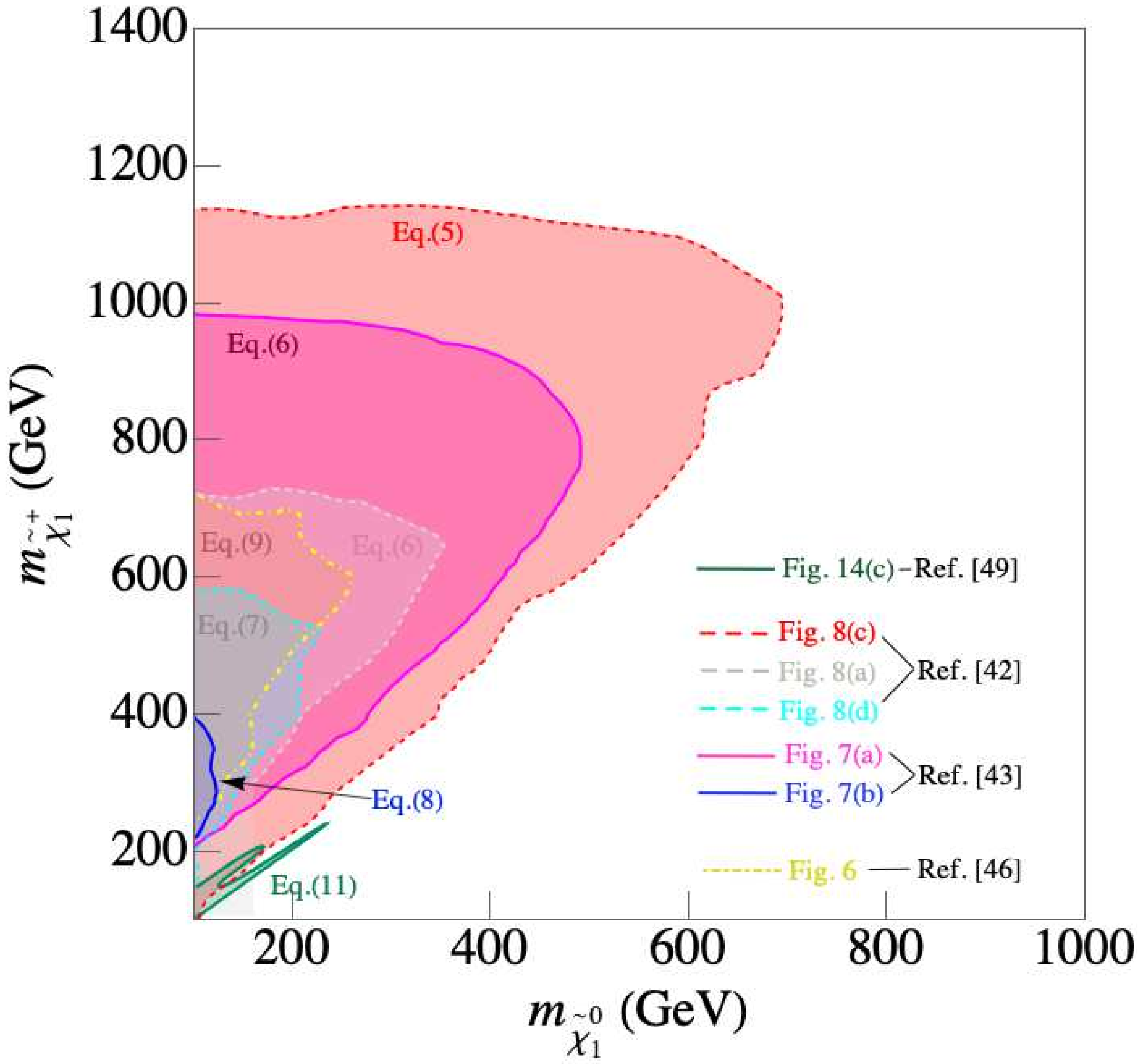
$\Rightarrow$ CLIC can cover evertything

5. Conclusinos

- new $(g-2)_\mu$ result confirms old result and deviation from the SM
  $(g-2)_\mu$ is real $\Rightarrow$ light EW particles
- 2HDM: only type X can be in agreement with $(g-2)_\mu$, EWPO, flavor
- MSSM general idea:
  – scan the EW sector of the MSSM with all constraints:
  $(g-2)_\mu$, DM relic density, DM DD, LHC EW searches
  – upper limits on EW masses $\Rightarrow$ evaluate future prospects
- LHC searches included via CheckMate [*M.C, I.S*] $\Rightarrow$ crucial!
- A) bino/wino DM with chargino coann. (DM full)
  B/C) bino 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 confirmed
- Prospects for future colliders
  – compressed spectra: good HL-LHC prospects, but ILC/CLIC needed
  – direct production at e^+e^- colliders: ILC good, CLIC excellent

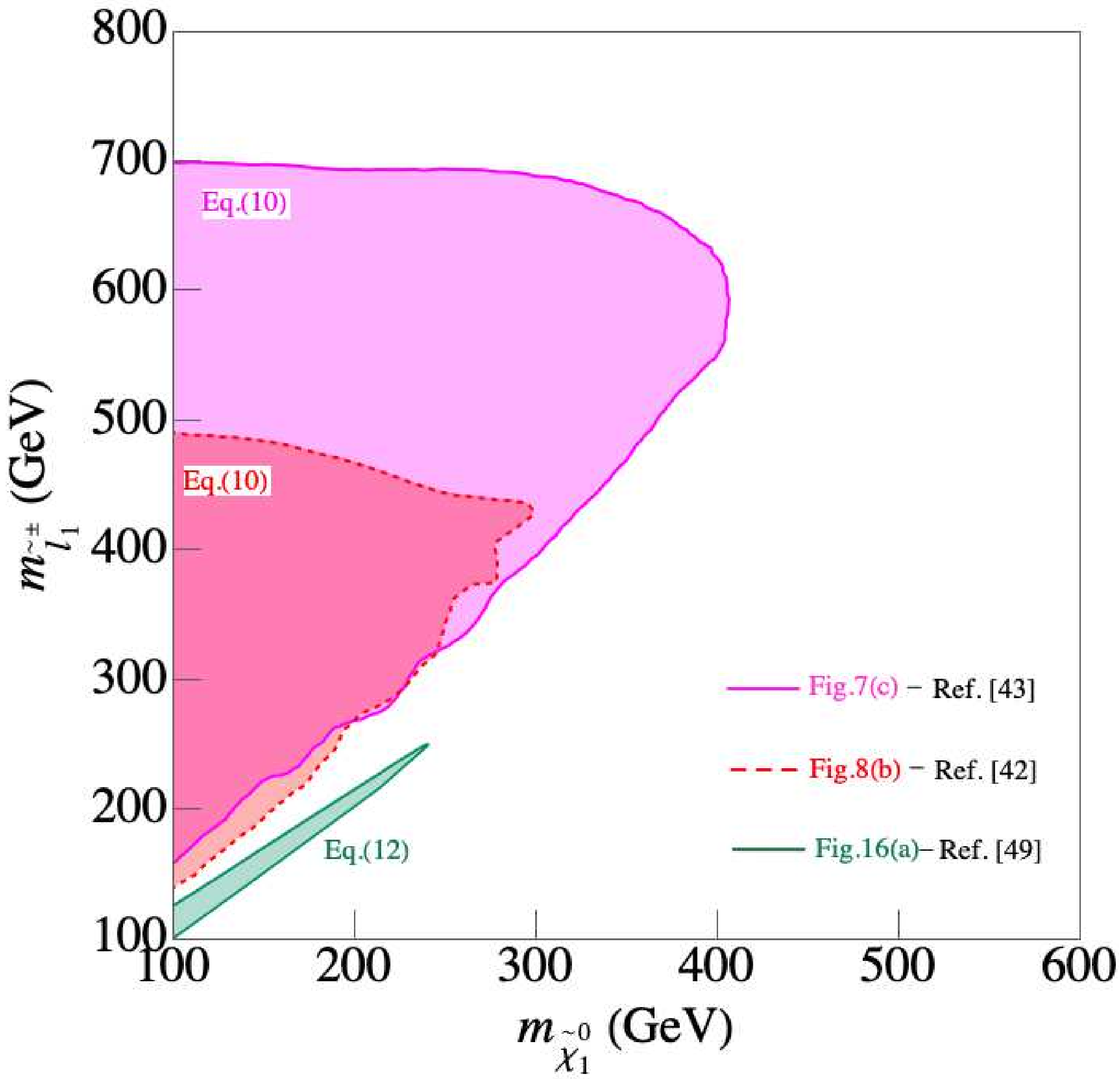

Further Questions?

LHC exclusion bounds (I)



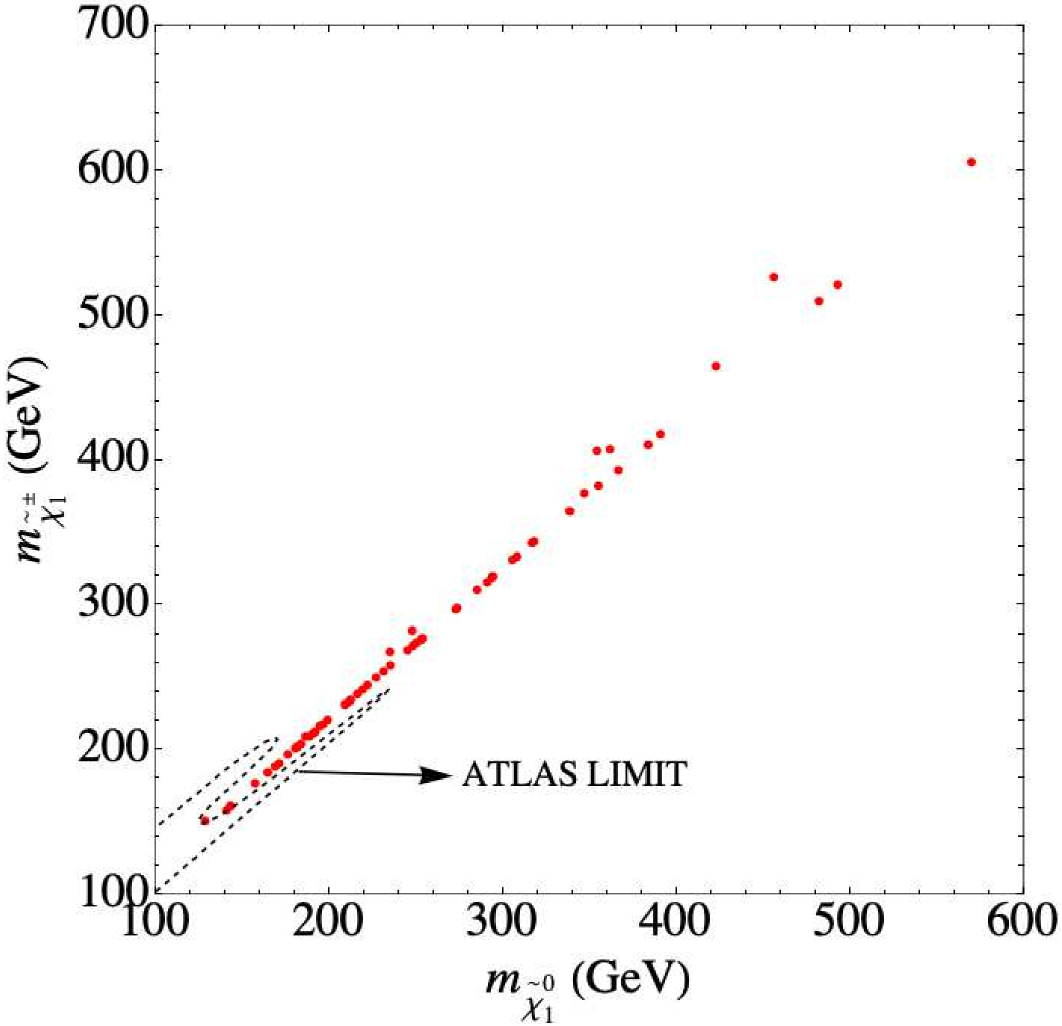
⇒ crucial to take latest bounds into account

LHC exclusion bounds (II)



$\Rightarrow$ crucial to take latest bounds into account

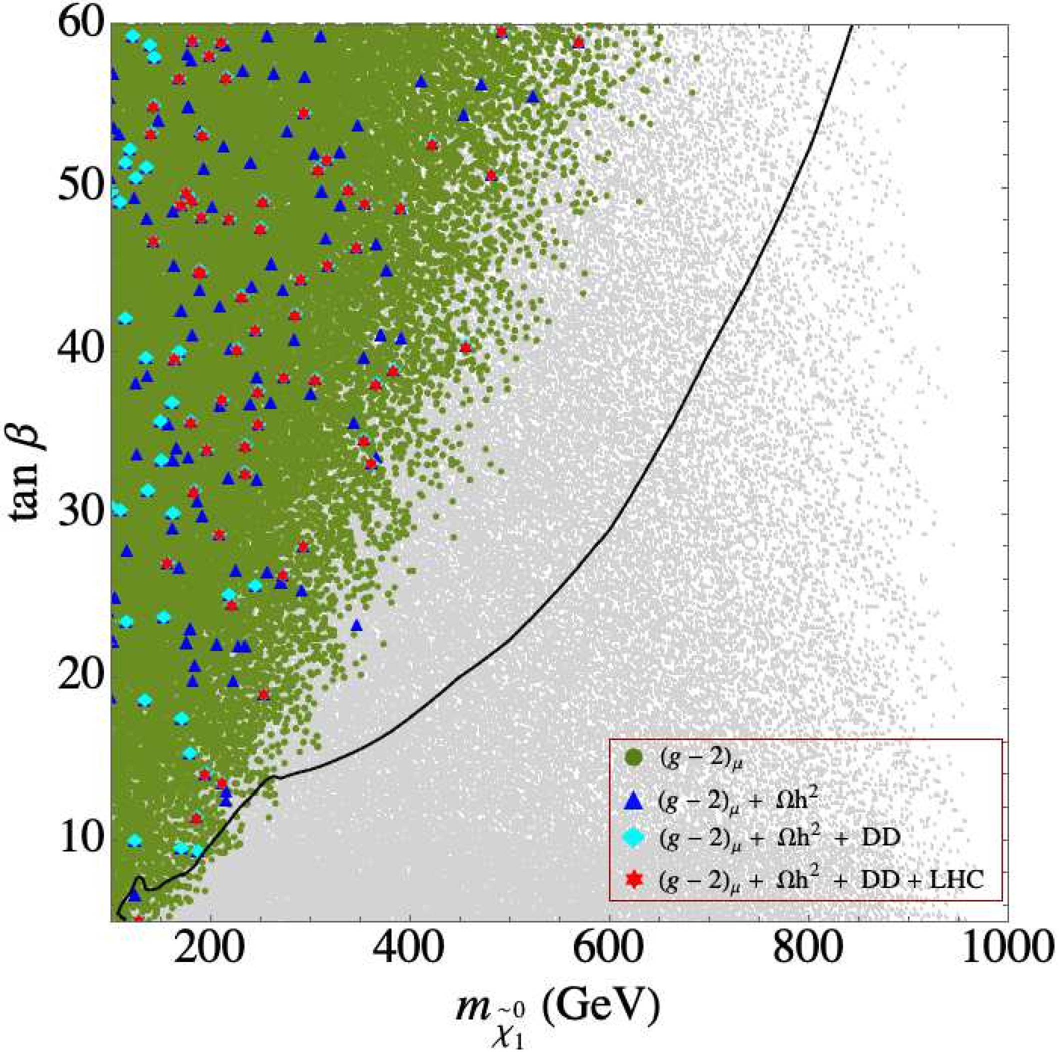
$\tilde{\chi}_1^{\pm}$ co-ann.: comparison with the compressed spectra searches:



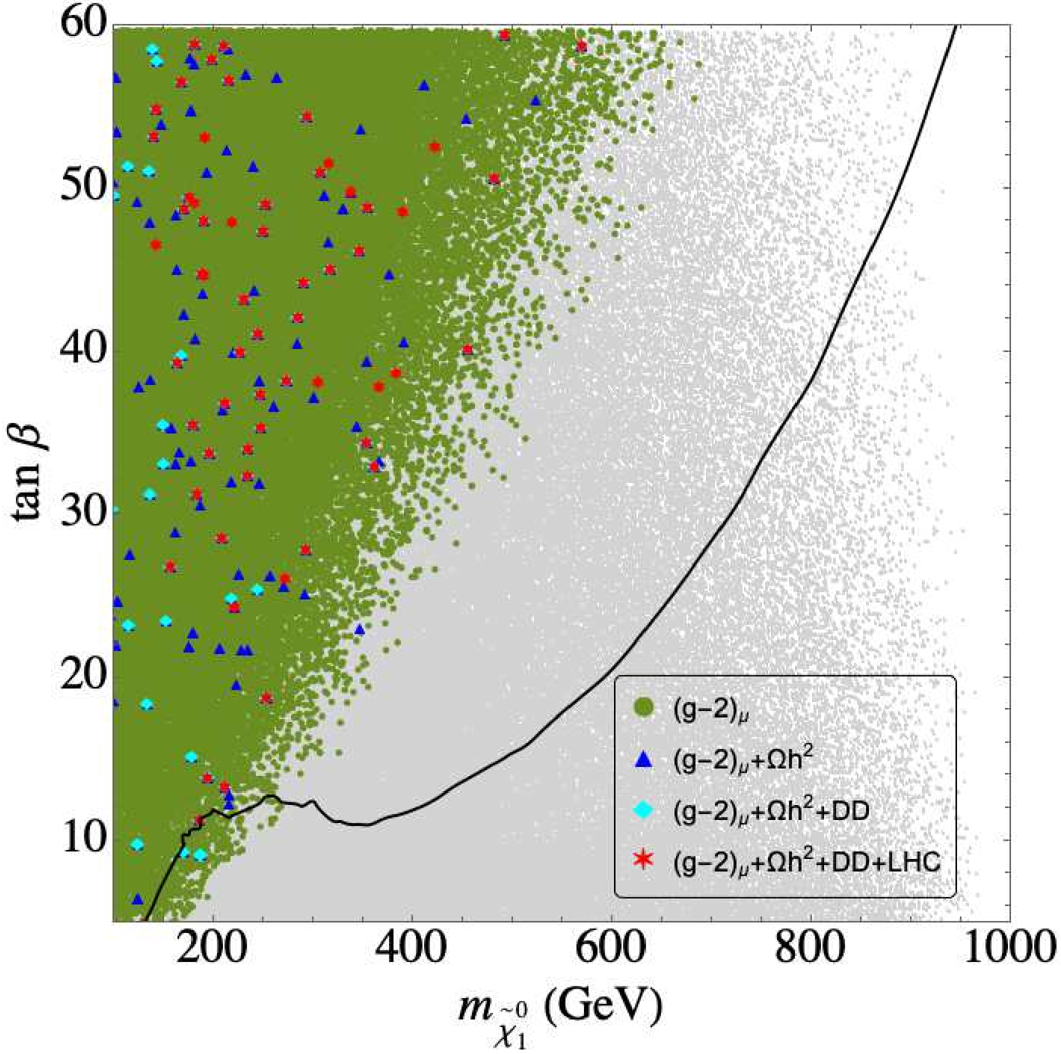
$\Rightarrow$ compressed spectrum avoids current bounds!

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

old $(g-2)_\mu$



new $(g-2)_\mu$

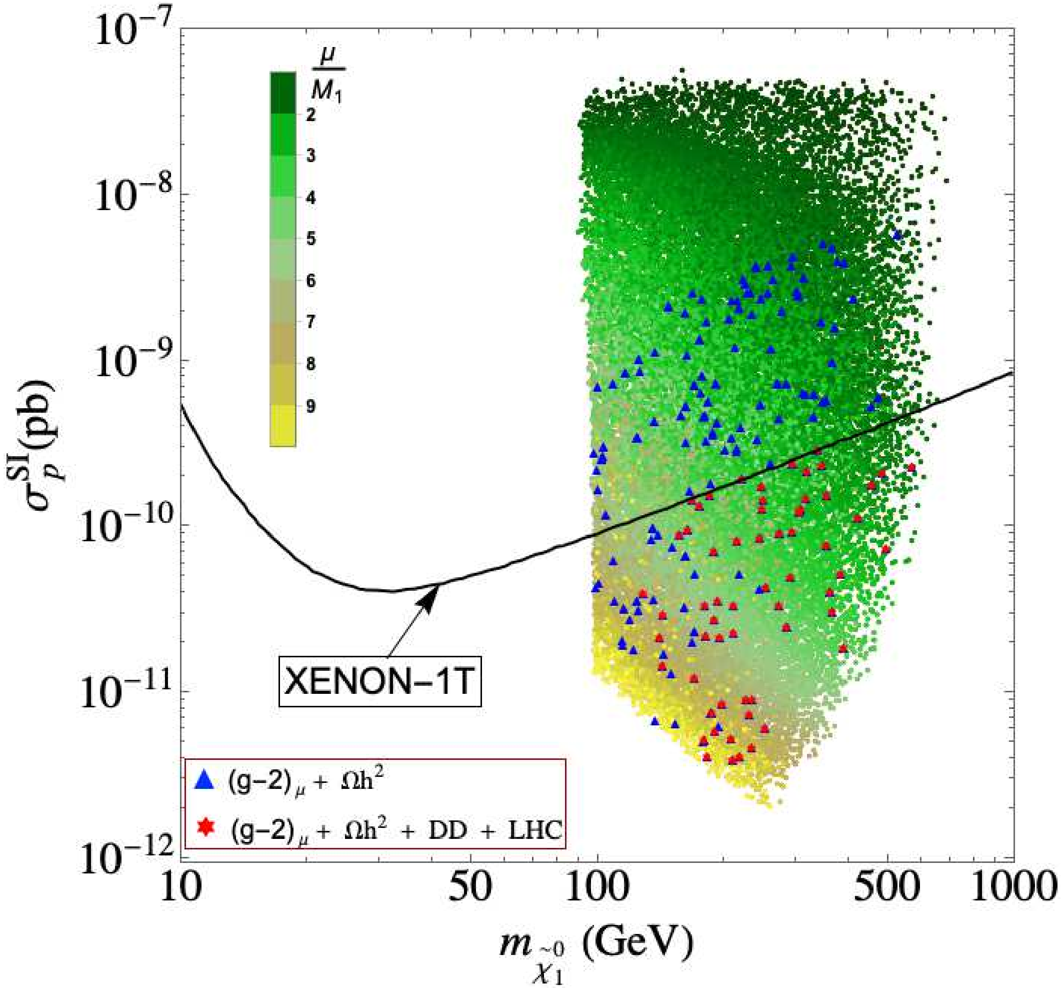


black contour: (simplified) application of $H/A \to \tau^+\tau^-$

$\Rightarrow$ A-pole annihilation effectively excluded

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

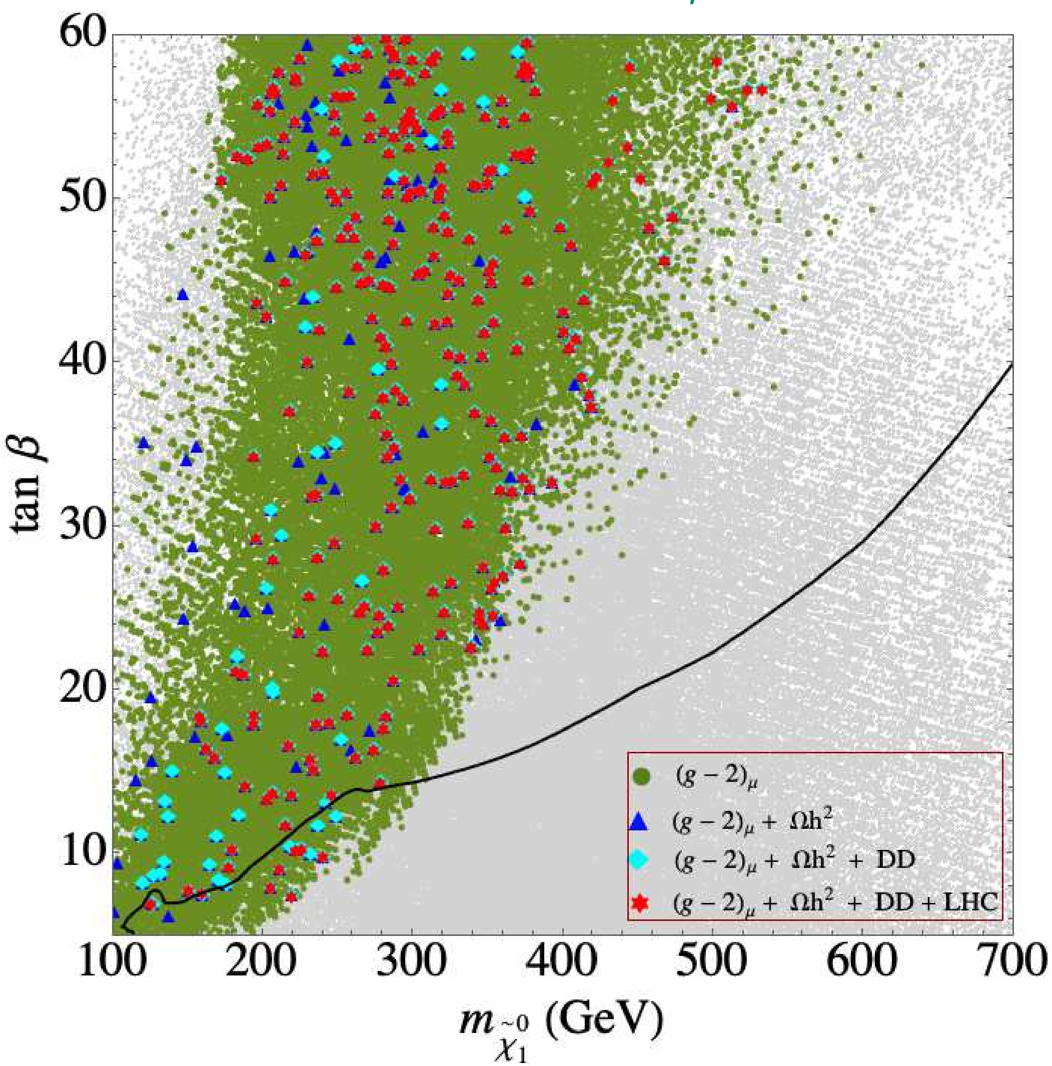
old $(g-2)_\mu$



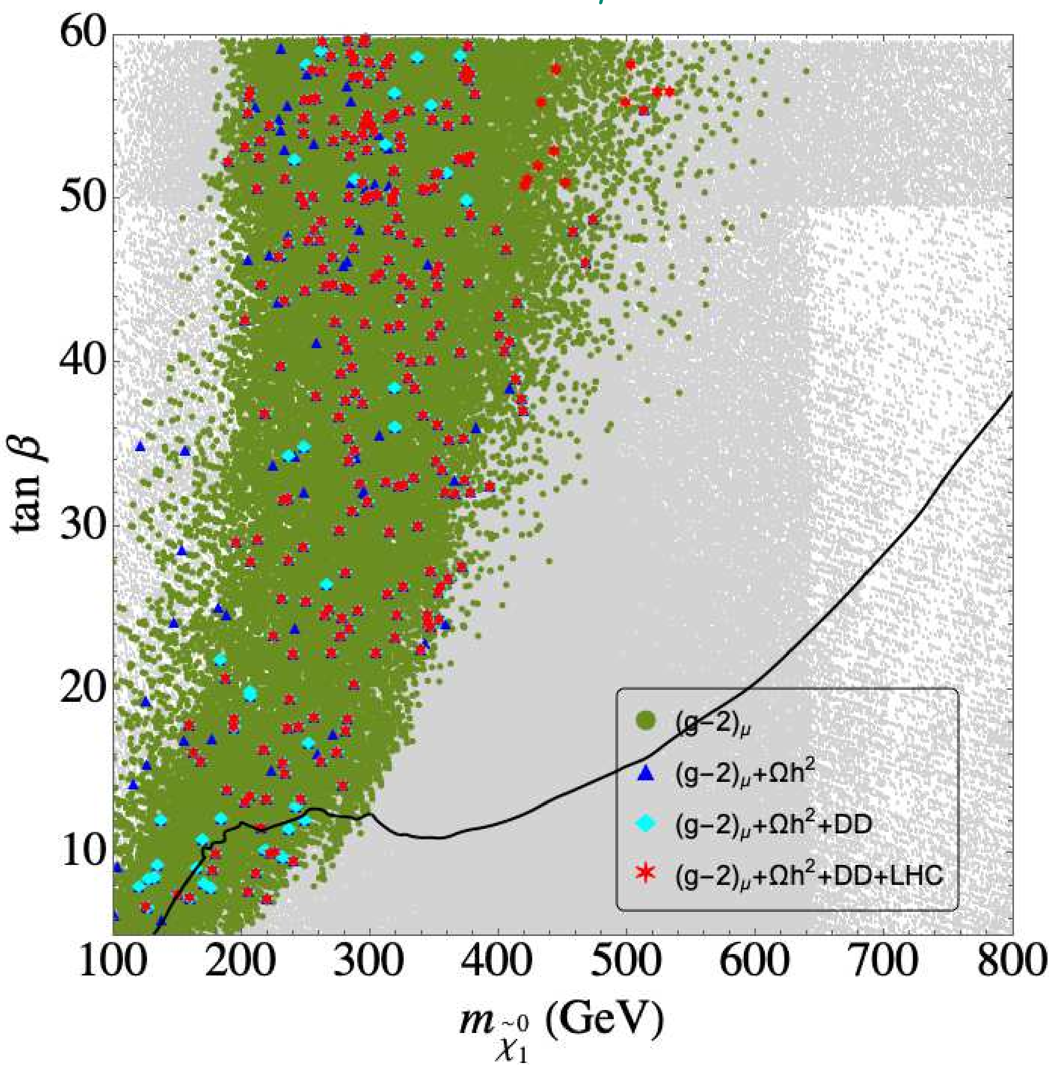
$\Rightarrow$ larger μ values favored

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

old $(g-2)_\mu$



new $(g-2)_\mu$

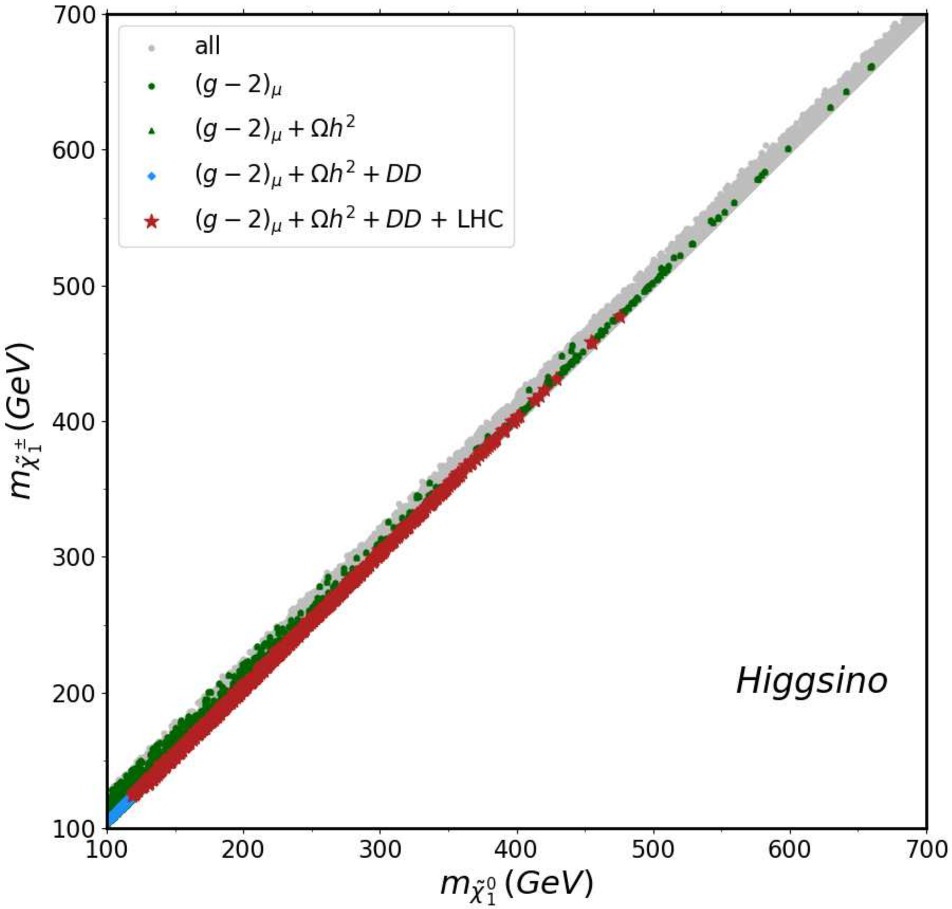


black contour: (simplified) application of $H/A \to \tau^+\tau^-$

$\Rightarrow$ A-pole annihilation largely excluded

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

old $(g-2)_\mu$

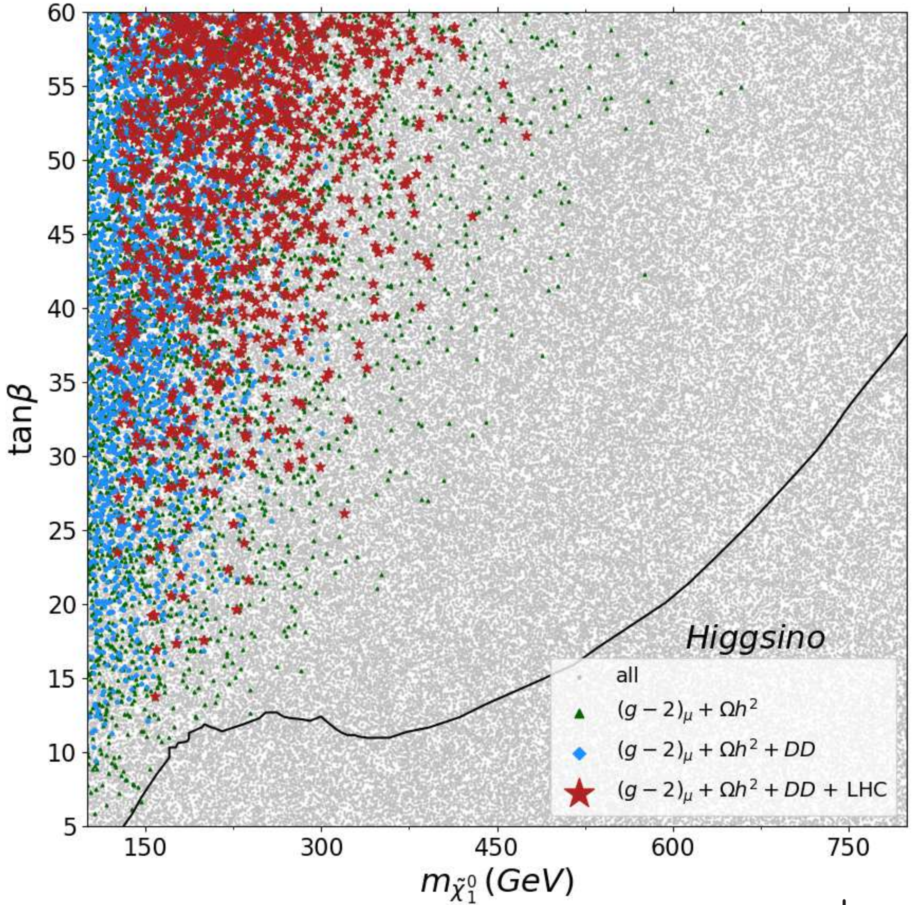


$\Rightarrow$ important: compressed spectra searches (11)

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

Higgsino DM: results in the $m_{\tilde{\chi}_1^0}$-$\tan\beta$ plane:

old $(g-2)_\mu$

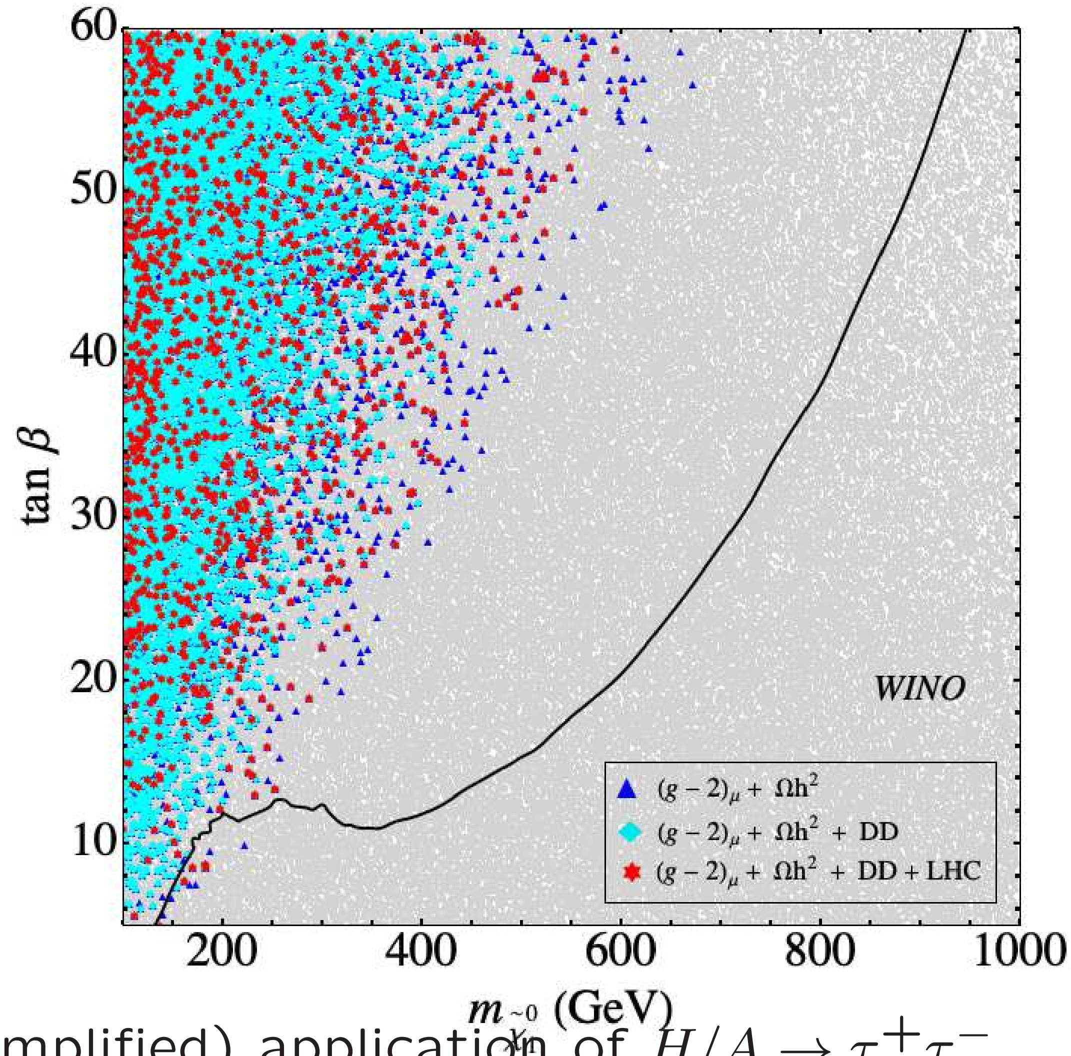


black contour: (simplified) application of $H/A \to \tau^+\tau^-$

$\Rightarrow$ A-pole annihilation fully excluded

Wino DM: results in the $m_{\tilde{\chi}_1^0}$-$\tan\beta$ plane:

old $(g-2)_\mu$

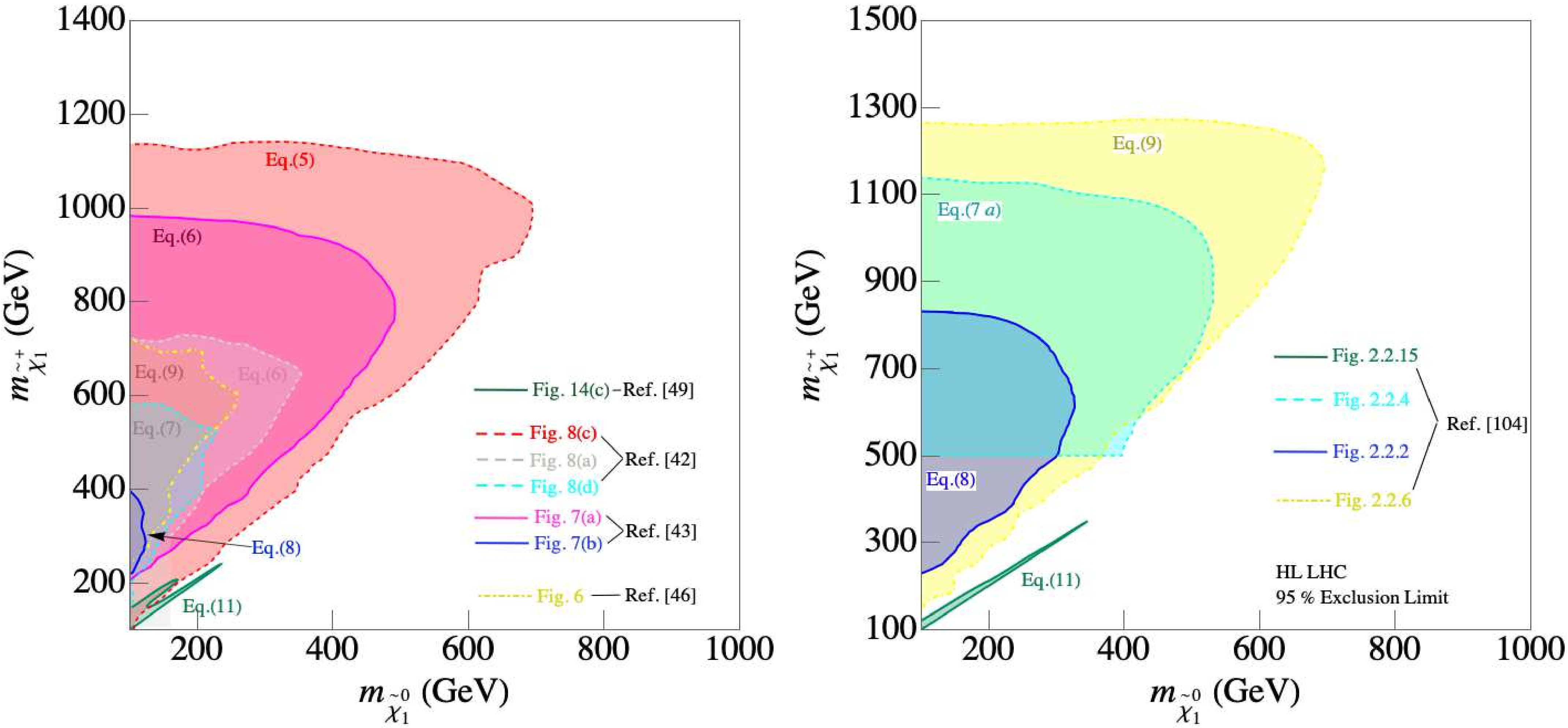


black contour: (simplified) application of $H/A \to \tau^+\tau^-$

$\Rightarrow$ A-pole annihilation largely excluded

LHC exclusion bounds vs. HL-LHC exclusion bounds

not all channels available [*YR18*]

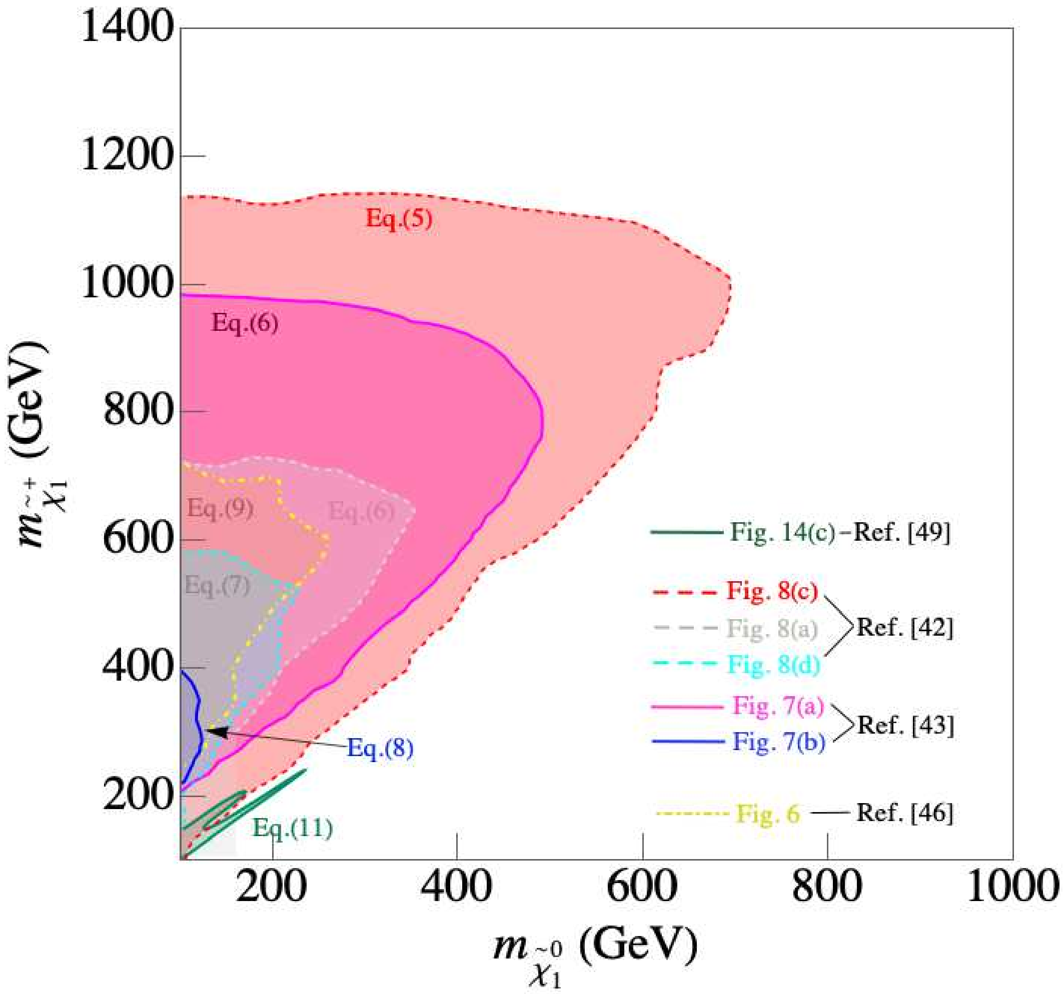


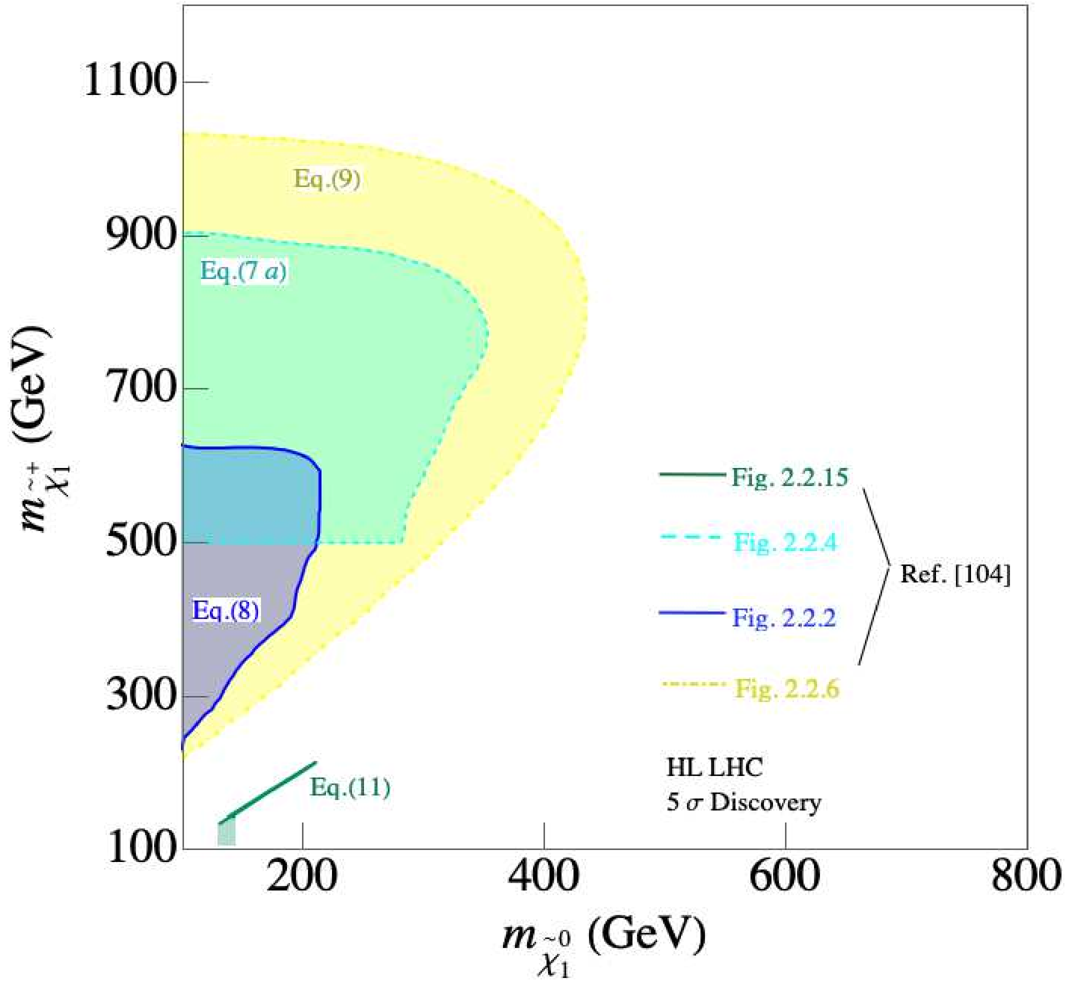
⇒ exclusion reach can be important

⇒ 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 . . .