

So, is this “dark matter” in the room with us right now?



Interplay of Future Colliders and Dark Matter Direct Detection Experiments

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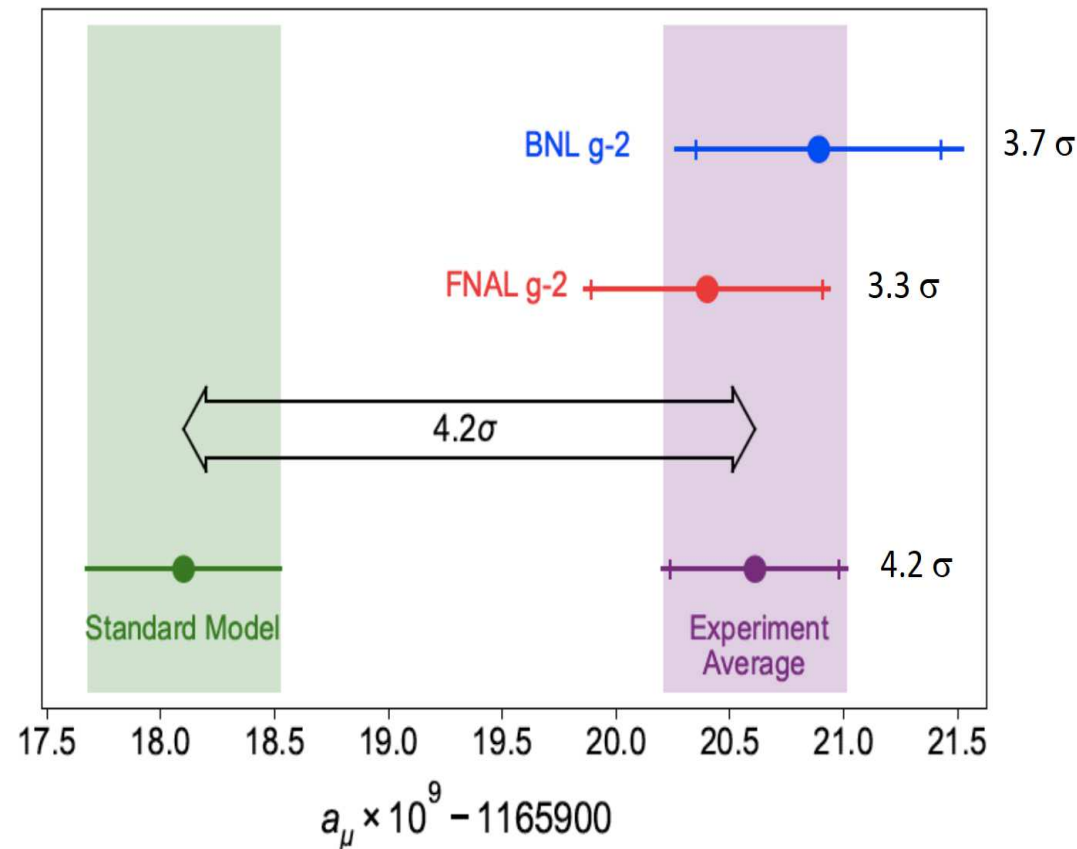
In collaboration with: *M. Chakraborti, I. Saha, C. Schappacher*

1. The main idea
2. Results for (nearly) all SUSY scenarios: Direct Detection prospects
3. Interplay with Future Colliders
4. The missing channel
5. Conclusions

1. The main idea

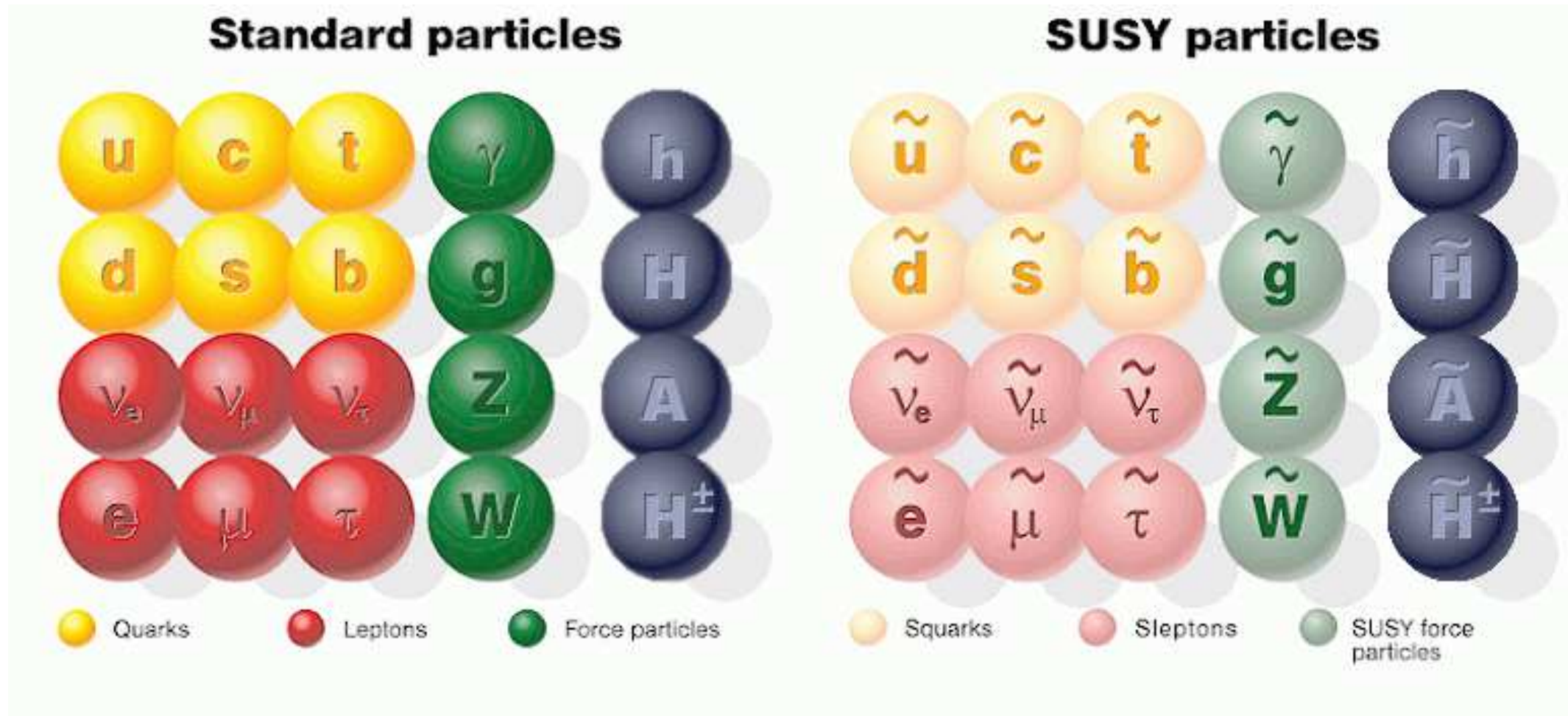
The anomalous magnetic moment of the muon: $a_\mu \equiv (g - 2)_\mu/2$

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



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

The MSSM



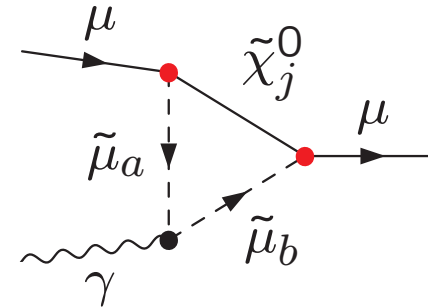
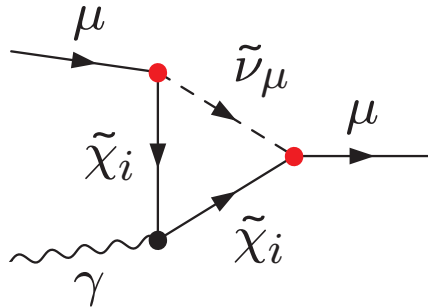
⇒ large uncolored / EW sector

charginos/neutralinos: $M_1, M_2, \mu, \tan \beta$

Sleptons: $M_{\tilde{l}_L}, M_{\tilde{l}_R}$ (for now equal for all 3 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:

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

$$\mu - \tilde{\chi}_j^0 - \tilde{\mu}_a : \sim m_\mu \tan \beta$$

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

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

The main 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 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: DD and Future Colliders

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

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

$\Rightarrow$ all results for $\Delta a_\mu^{\text{new}} (\equiv \Delta a_\mu)$

Dark Matter relic density: MicrOmegas

$$\begin{aligned} \Omega_{\text{CDM}} h^2 &= 0.120 \pm 0.001 \\ \text{or } \Omega_{\text{CDM}} h^2 &\leq 0.122 \end{aligned}$$

(as taken from [Planck '18])

Dark Matter direct detection: MicrOmegas

limit on spin independent scattering cross section (Xenon1T)

[Xenon collab. '18]

Results for (nearly) all SUSY scenarios

A) bino/wino DM with chargino co-annihilation ($M_1 \sim M_2 \lesssim \mu$)

relic DM density 100% fulfilled

$$\Rightarrow m_{(\text{N})\text{LSP}} \lesssim 650(700) \text{ GeV}$$

B/C) bino DM with slepton co-annihilation ($M_1 \lesssim M_2, \mu$)

relic DM density 100% fulfilled

$$\Rightarrow m_{(\text{N})\text{LSP}} \lesssim 650(700) \text{ GeV}$$

D) higgsino DM: $m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_2^0} \sim m_{\tilde{\chi}_1^\pm} \sim \mu$ ($\mu \lesssim M_1, M_2$)

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

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

E) wino DM: $m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_1^\pm} \sim M_2$ ($M_2 \lesssim M_1, \mu$)

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

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

$\Rightarrow$ predictions for future experiments?!

2. Prospects for Direct Detection Experiments



A) Bino/wino DM with chargino co-annihilation

Parameter scan:

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

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

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

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

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

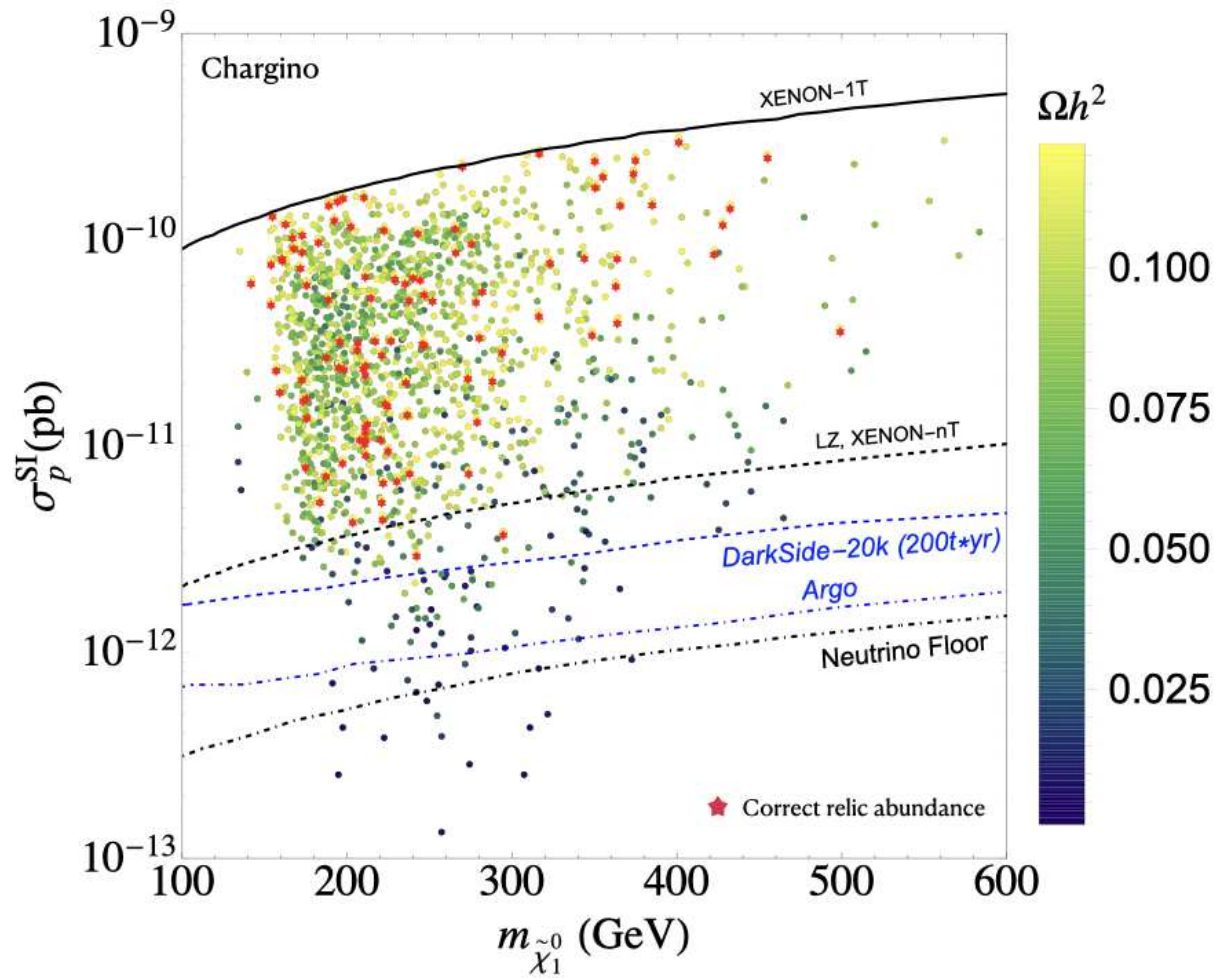
$$m_{\tilde{R}} = m_{\tilde{L}} .$$

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

relic DM density can be 100% fulfilled

$$\Rightarrow m_{(N)\text{LSP}} \lesssim 650(700) \text{ GeV}$$

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



⇒ large part covered by XENON-nT/LZ

⇒ but can go below even the neutrino floor

B/C) Bino DM with slepton co-annihilation

Parameter scan:

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

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

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

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

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

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

relic DM density can be 100% fulfilled

$$\Rightarrow m_{(N)\text{LSP}} \lesssim 650(700) \text{ GeV}$$

B/C) Bino DM with slepton co-annihilation

Parameter scan:

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

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

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

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

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

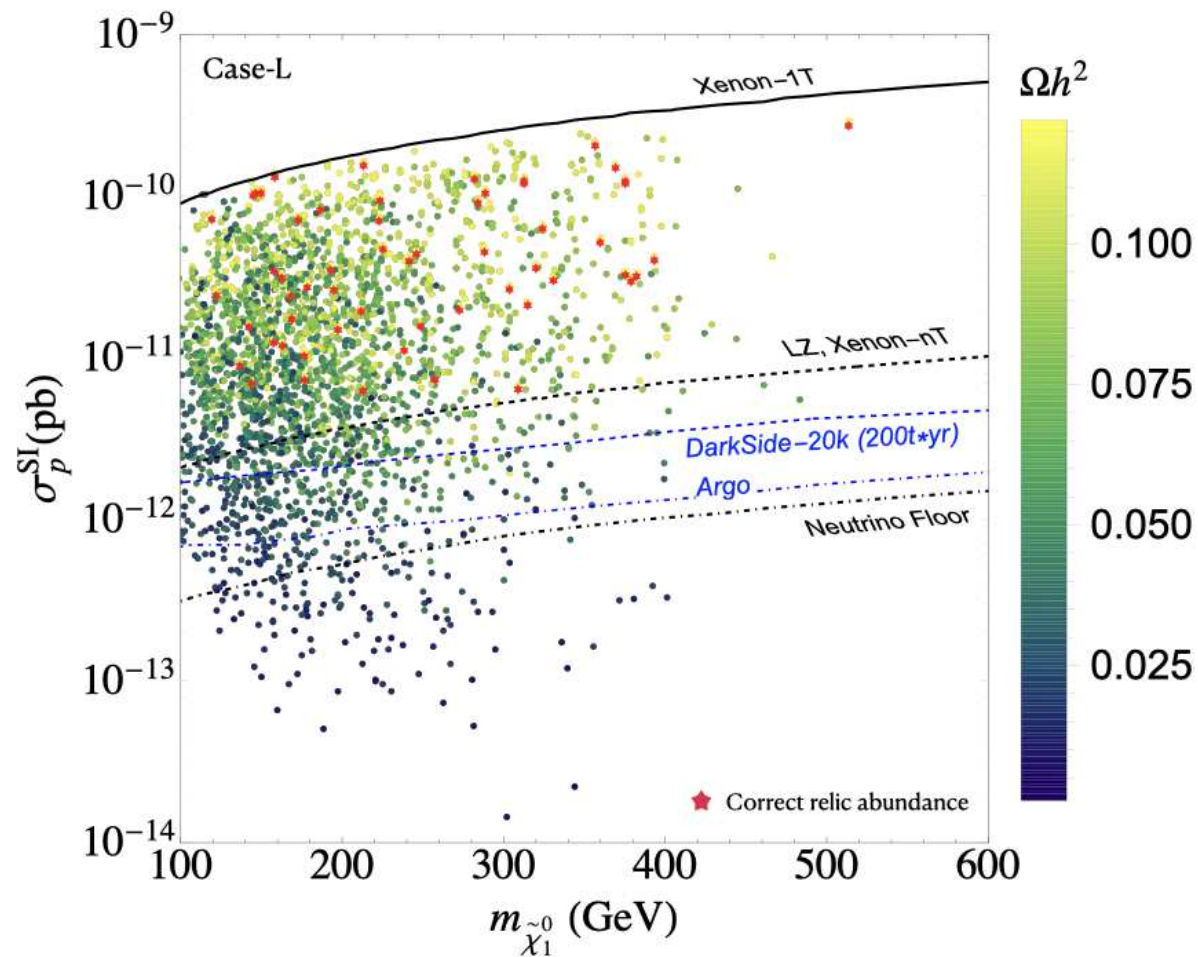
$$\text{Case-R: } M_1 \leq m_{\tilde{R}} \leq 1.2M_1, \quad M_1 \leq m_{\tilde{L}} \leq 10M_1 .$$

relic DM density can be 100% fulfilled

$$\Rightarrow m_{(\text{N})\text{LSP}} \lesssim 650(700) \text{ GeV}$$

$\Rightarrow$ funny that nobody ever complained here ...

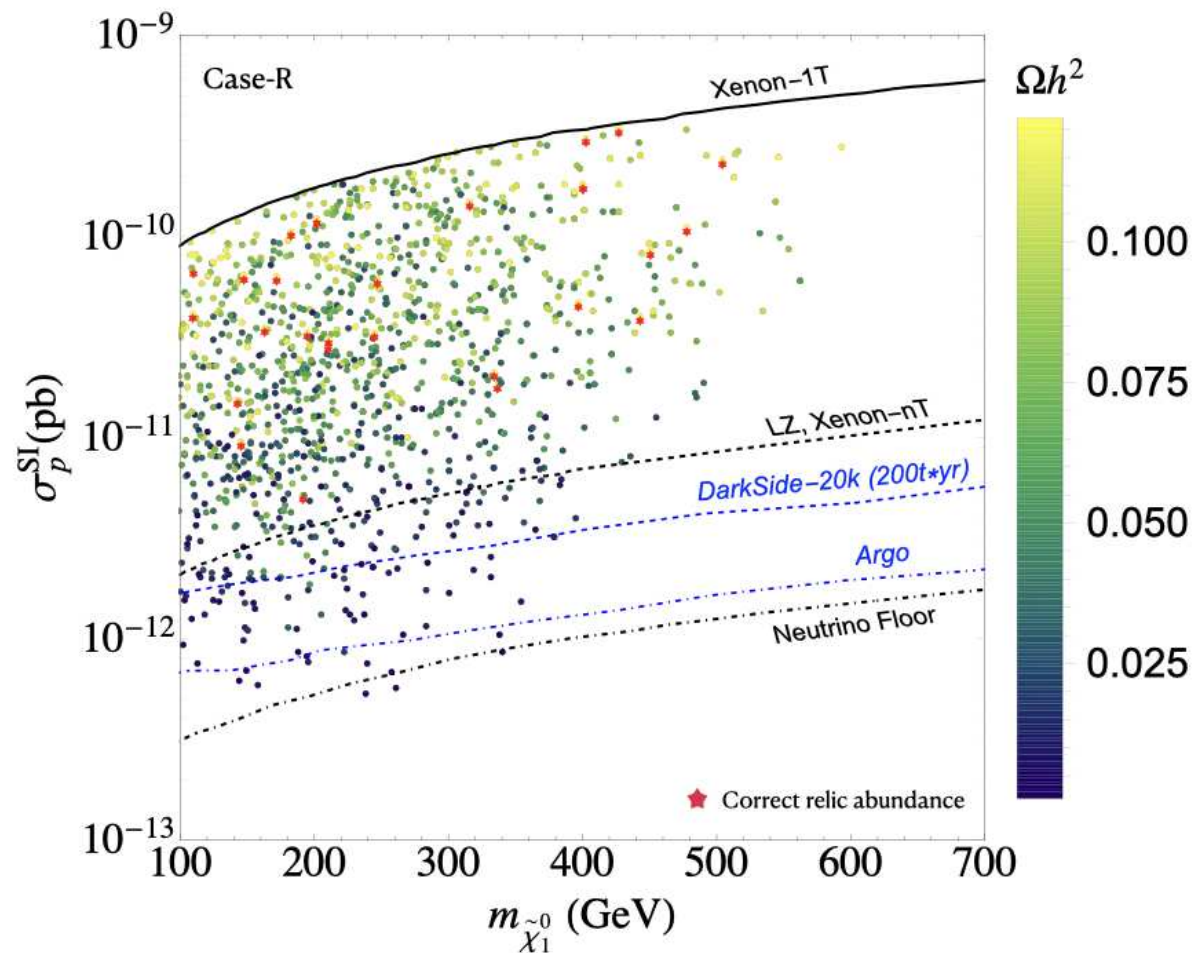
Case-L: results in the $m_{\tilde{\chi}_1^0} - \sigma_p^{\text{SI}}$ plane:



⇒ large part covered by XENON-nT/LZ

⇒ but can go below even the neutrino floor

Case-R: results in the $m_{\tilde{\chi}_1^0} - \sigma_p^{\text{SI}}$ plane:



⇒ large part covered by XENON-nT/LZ

⇒ but can go below even the neutrino floor

D) Higgsino DM

Parameter scan:

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

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

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

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

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

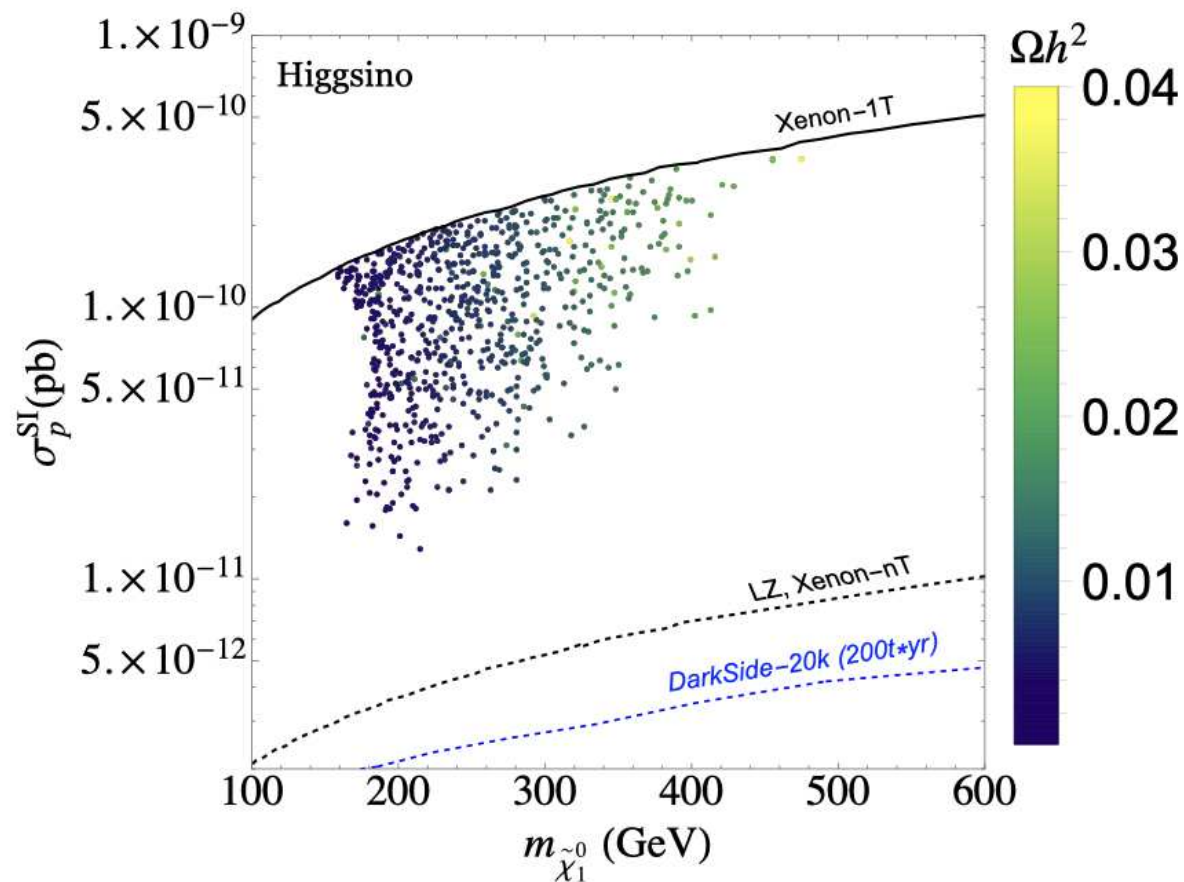
$$\Rightarrow m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_2^0} \sim m_{\tilde{\chi}_1^\pm} \sim \mu$$

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

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

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

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



⇒ everything covered by XENON-nT/LZ

⇒ Direct Detection experiments cover the full parameter space

E) Wino DM

Parameter scan:

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

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

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

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

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

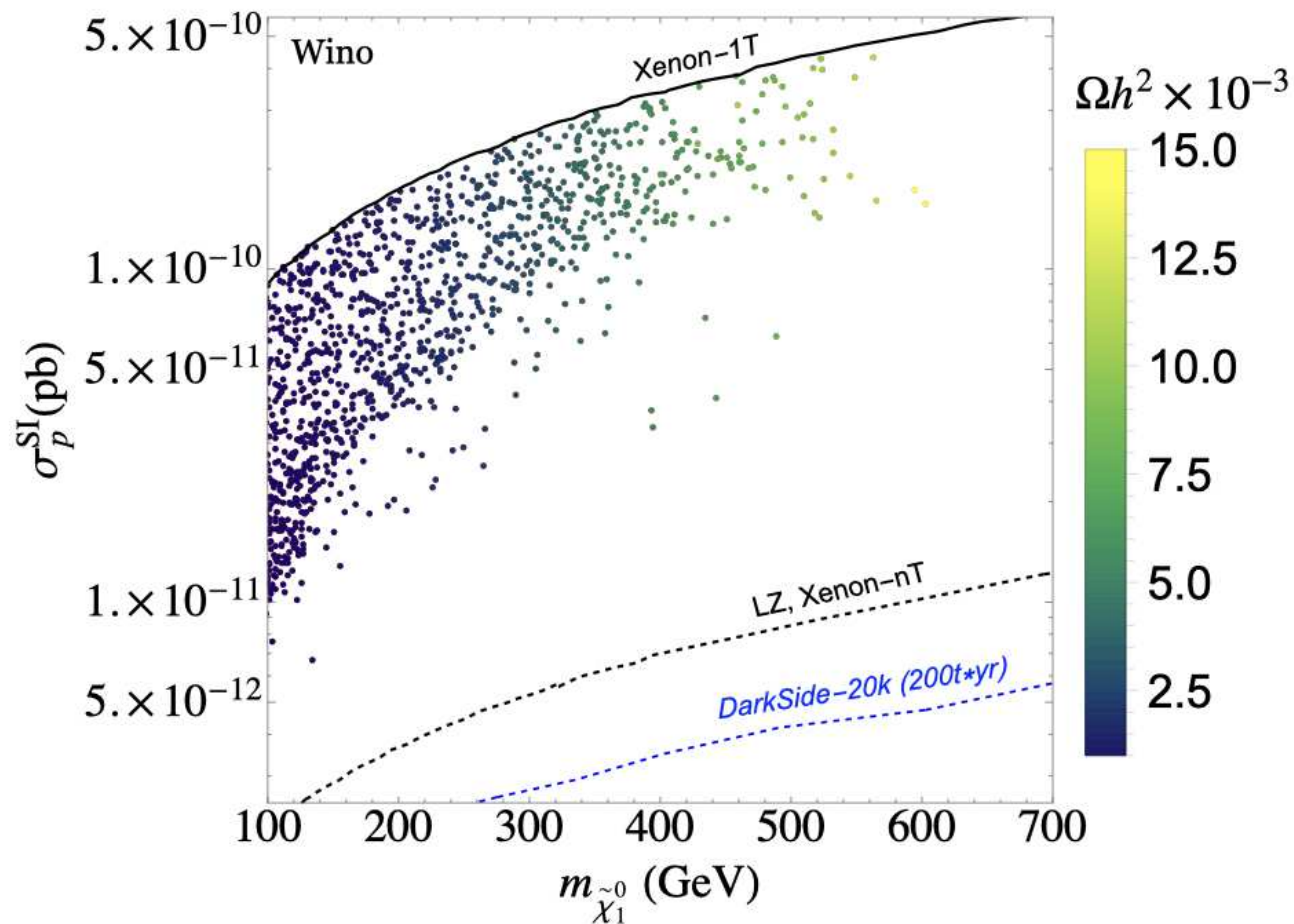
$$\Rightarrow m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_1^\pm} \sim M_2$$

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

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

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

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



⇒ everything covered by XENON-nT/LZ

⇒ Direct Detection experiments cover the full parameter space

3. Interplay with Future Colliders

Scenarios A/B/C:

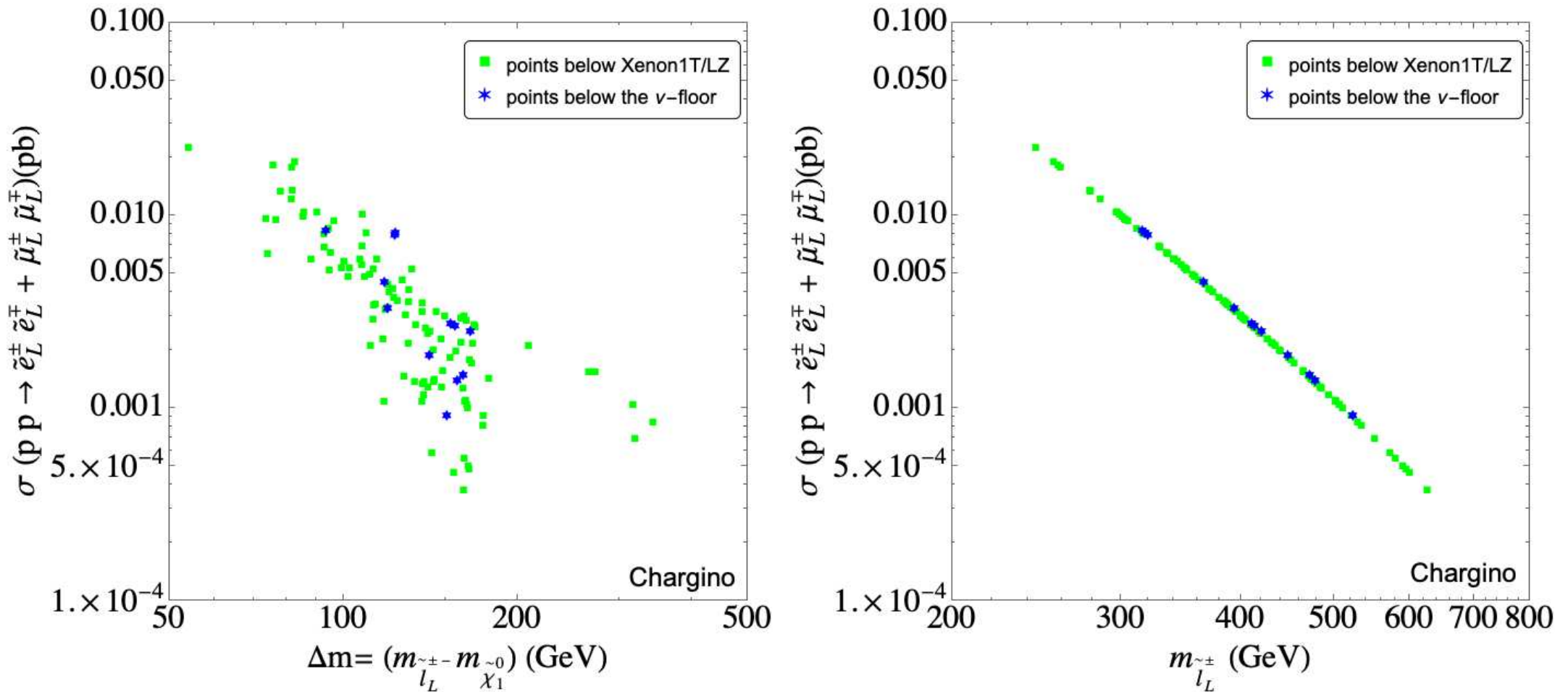
- ⇒ large part covered by XENON-nT/LZ
- ⇒ but can go below even the neutrino floor
- ⇒ (HL-)LHC has naturally problems because of compressed spectra
- ⇒ (HL-)LHC must go for heavier particles
- ⇒ compressed spectra “easy” for e^+e^- colliders
- ⇒ physics opportunities for ILC/CLIC?!

Scenarios D/E:

- ⇒ everything covered by XENON-nT/LZ
- ⇒ Direct Detection experiments cover the full parameter space
- ⇒ what can be learned at ILC/CLIC?

⇒ ILC and CLIC physics opportunities in the light of (HL-)LHC!

(HL-)LHC cross sections for $\tilde{\chi}_1^\pm$ -coannihilation (non-compressed):

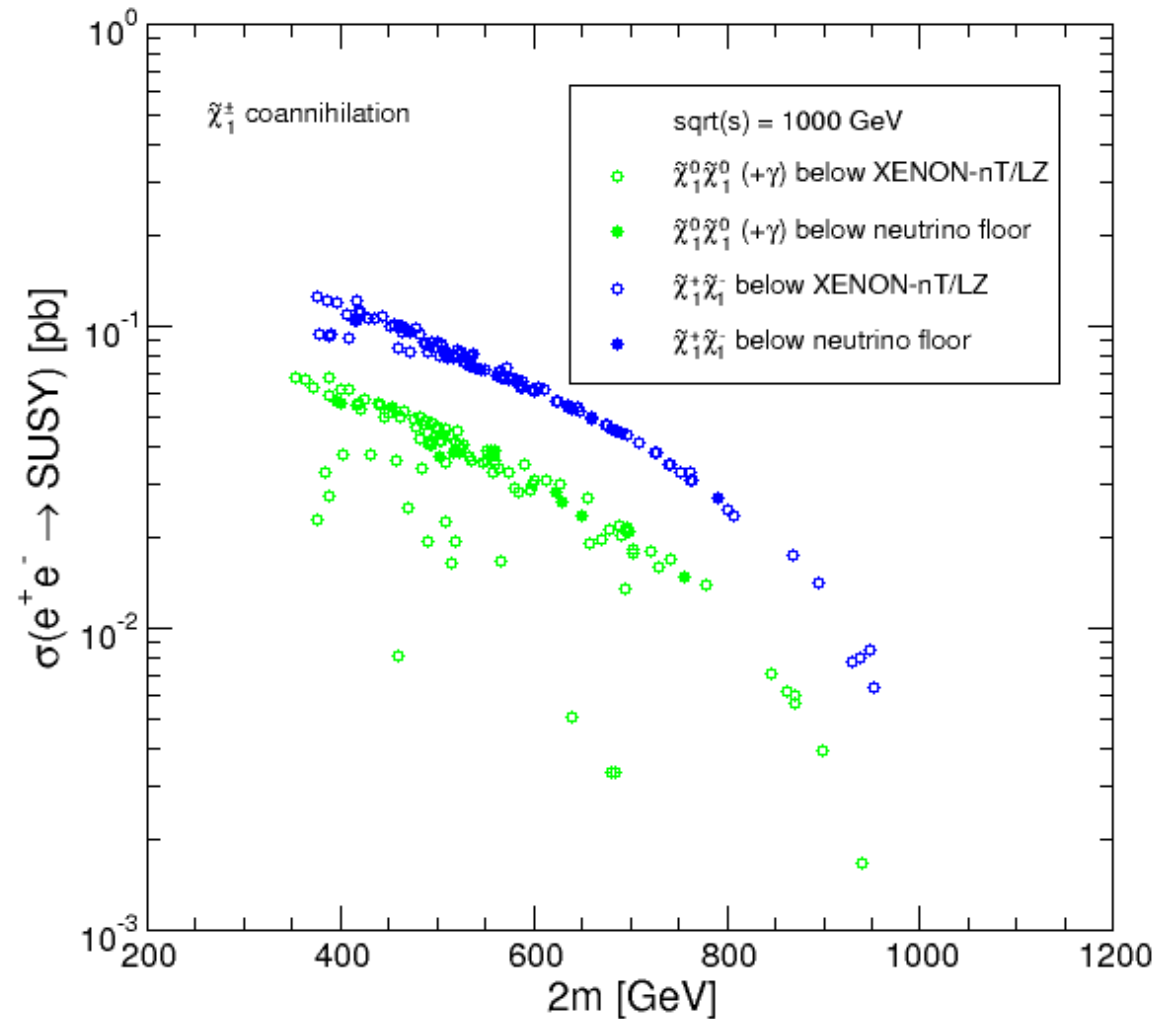


$\Rightarrow$ XS above 0.4 fb $\Rightarrow$ more than 1200 events

$\Rightarrow$ even better for "BNF" points: XS above 1 fb

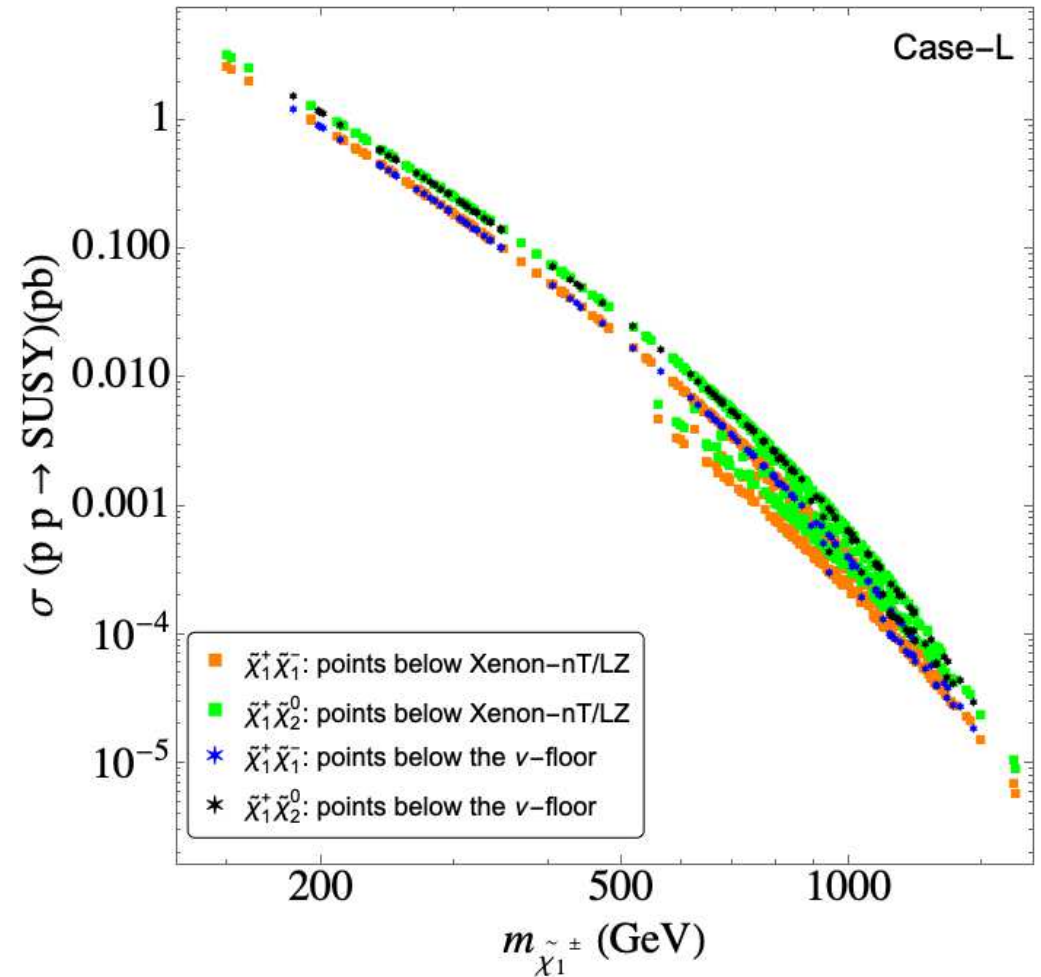
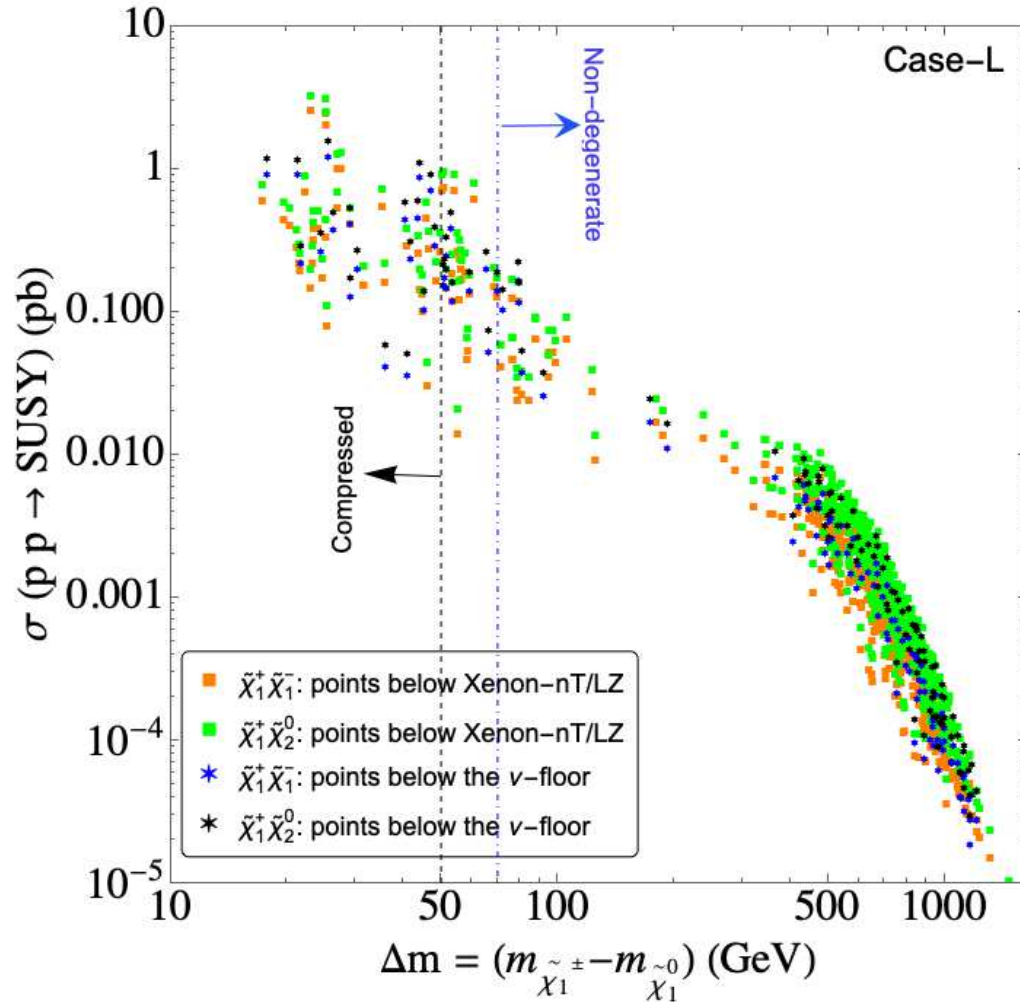
But: detailed (HL-)LHC analysis missing! (spectra not too compressed!)

ILC1000 cross sections for $\tilde{\chi}_1^\pm$ -coannihilation (compressed):



⇒ ILC1000 can cover everything!

(HL-)LHC cross sections for $\tilde{l}$ -coannihilation case-L (non-compressed):

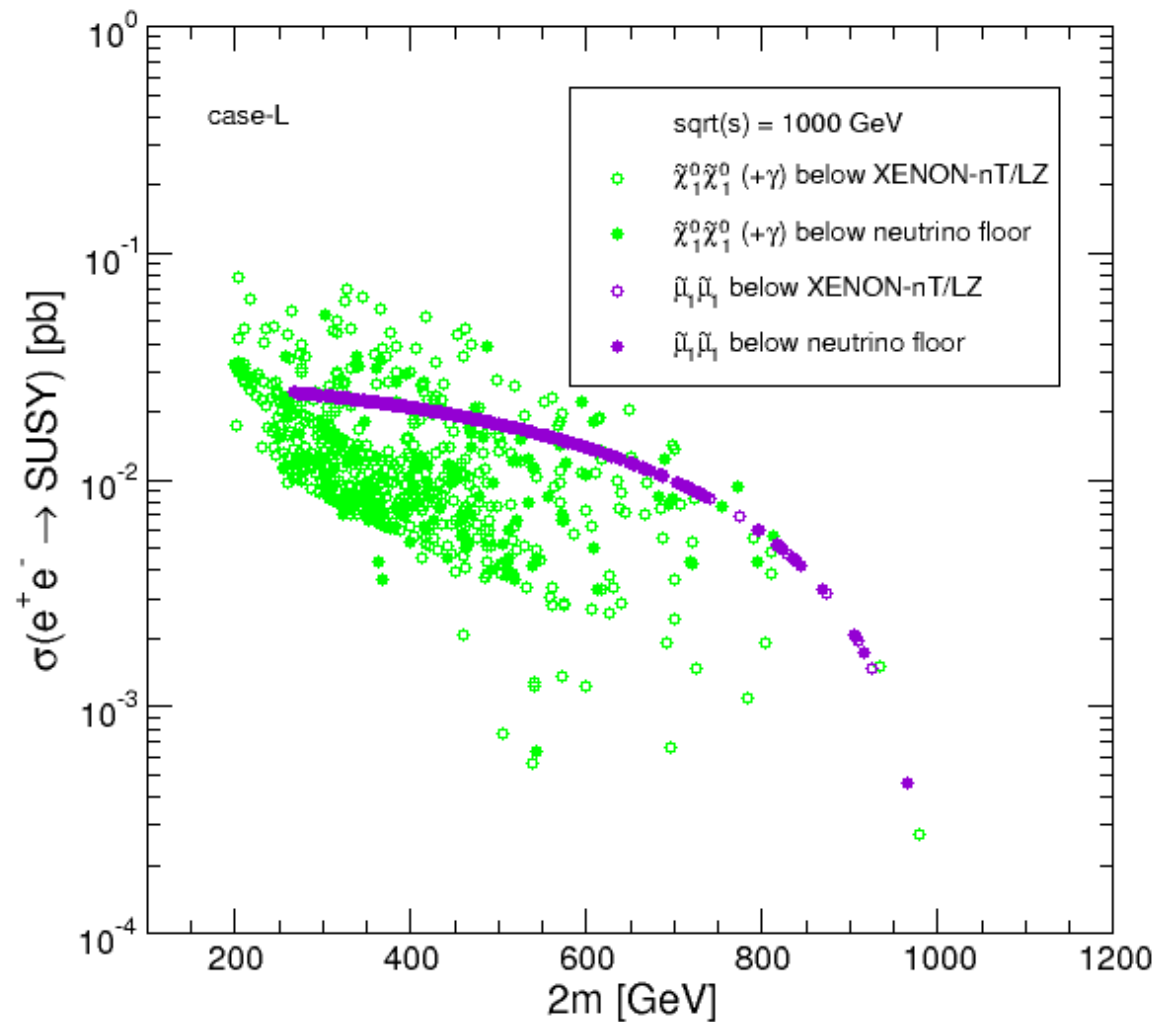


⇒ XS above 0.01 fb ⇒ more than 30 events

⇒ no improvement for “BNF” points!

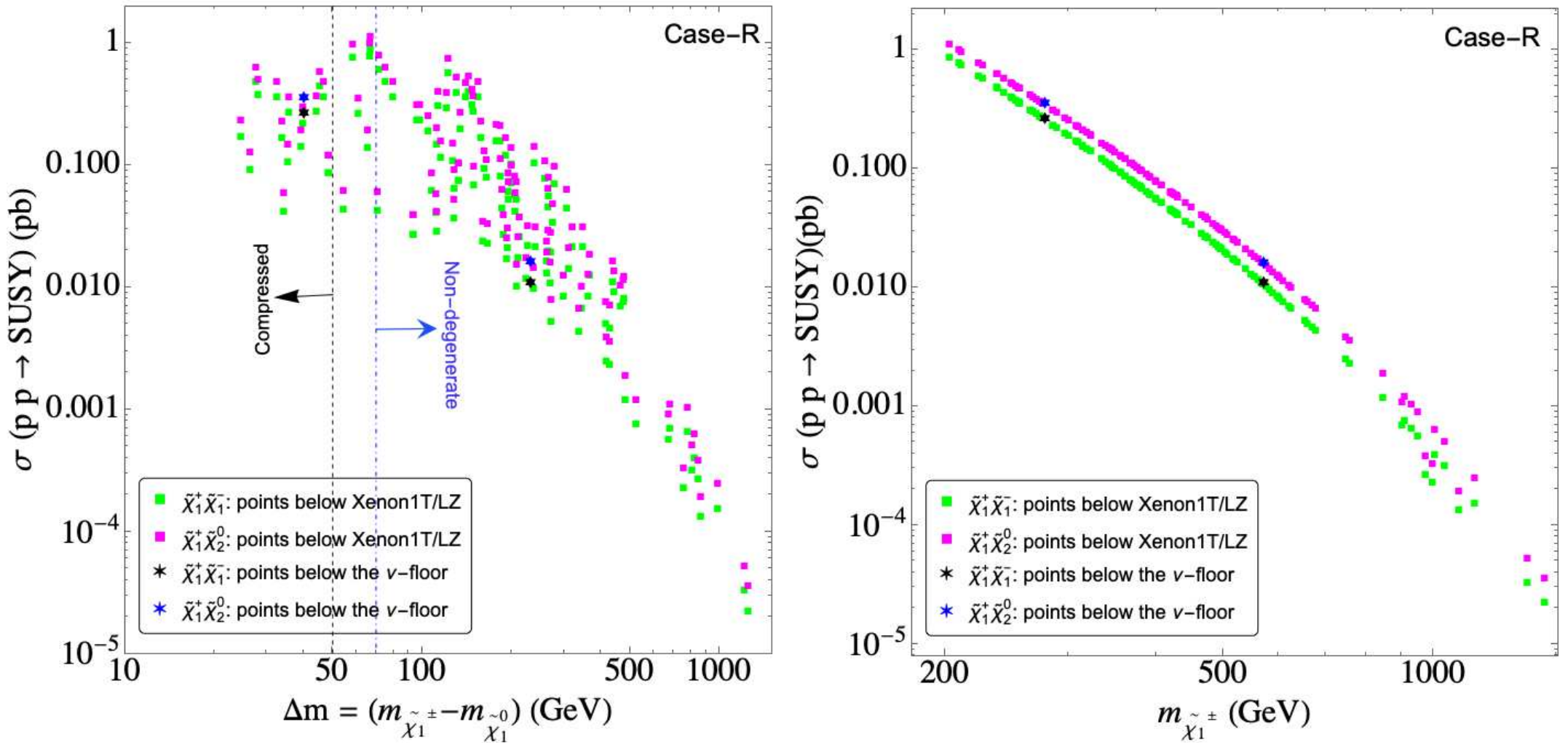
⇒ high-energy e^+e^- collider needed (CLIC3000)!

ILC1000 cross sections for $\tilde{l}$ -coannihilation case-L (compressed):



⇒ ILC1000 can cover everything!

(HL-)LHC cross sections for $\tilde{l}$ -coannihilation case-R (non-compressed):

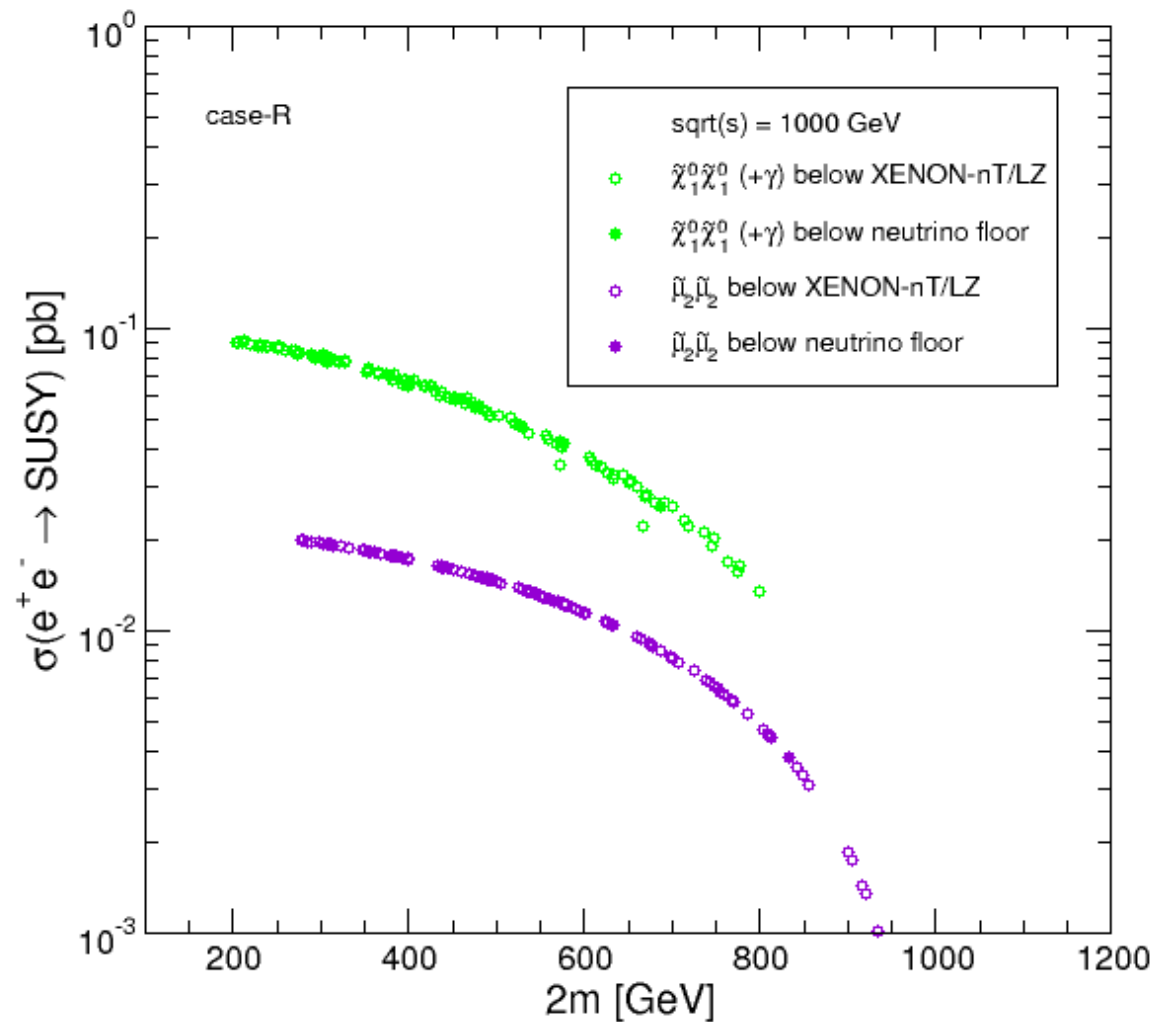


$\Rightarrow$ XS above 0.04 fb $\Rightarrow$ more than 120 events

$\Rightarrow$ very good for "BNF" points: XS above 10 fb

But: detailed (HL-)LHC analysis missing! (spectra can be compressed!)

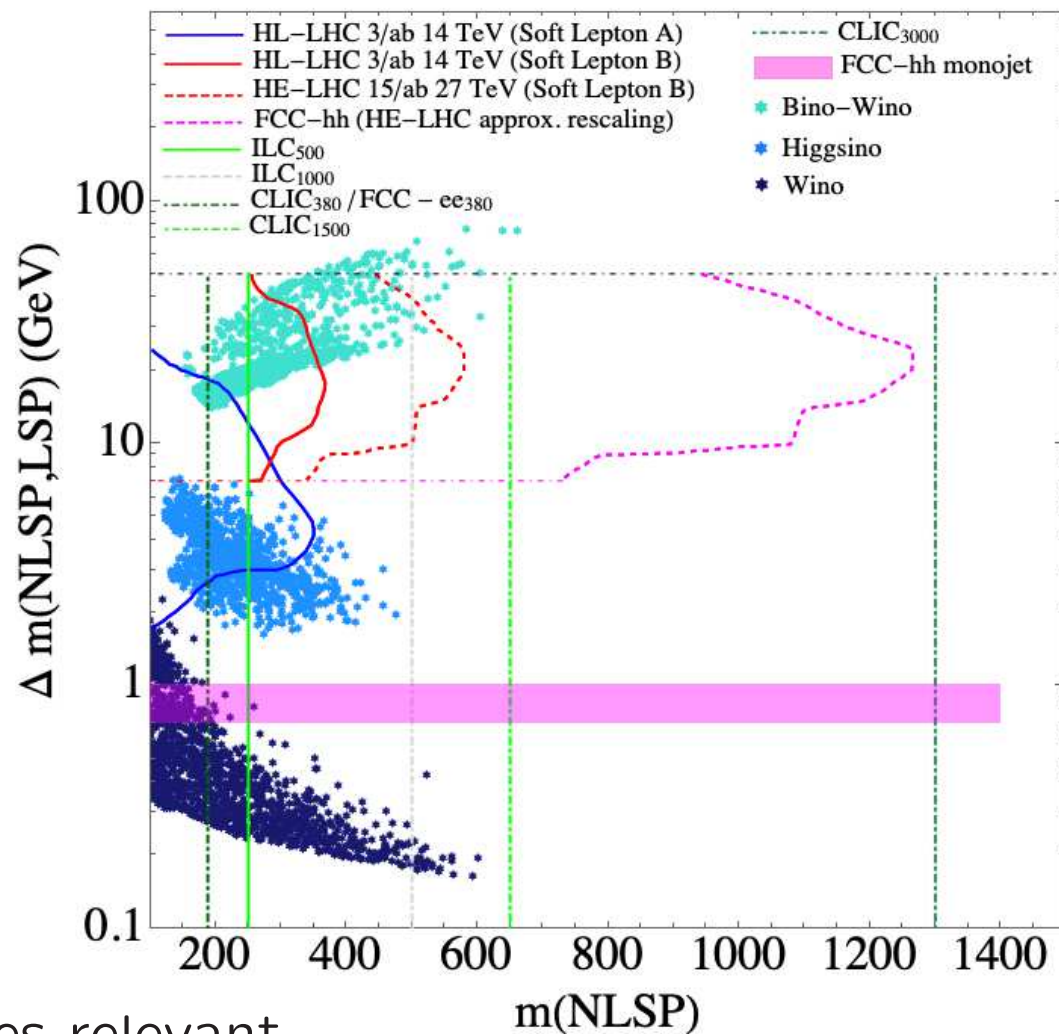
ILC1000 cross sections for $\tilde{l}$ -coannihilation case-R (compressed):



⇒ ILC1000 can cover everything!

Compressed spectra at current and future colliders

Higgsino, wino and bino/wino DM:



- current searches relevant
- HL-LHC searches can cover some part of the parameter space
- ILC/CLIC needed to cover these scenarios

4. The missing channel

B/C) Bino DM with slepton co-annihilation

Parameter scan:

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

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

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

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

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

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

relic DM density can be 100% fulfilled

$$\Rightarrow m_{(\text{N})\text{LSP}} \lesssim 650(700) \text{ GeV}$$

$\Rightarrow$ funny that nobody ever complained here ...

Potential problem:

Slepton co-annihilation directly linked to $(g - 2)_\mu$

⇒ slepton mass parameters chosen identical for all three generations

⇒ what happens if stau co-annihilation is chosen,
and no directly link to smuons contributing to $(g - 2)_\mu$ is made ??

Parameter scan for stau co-annihilation:

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

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

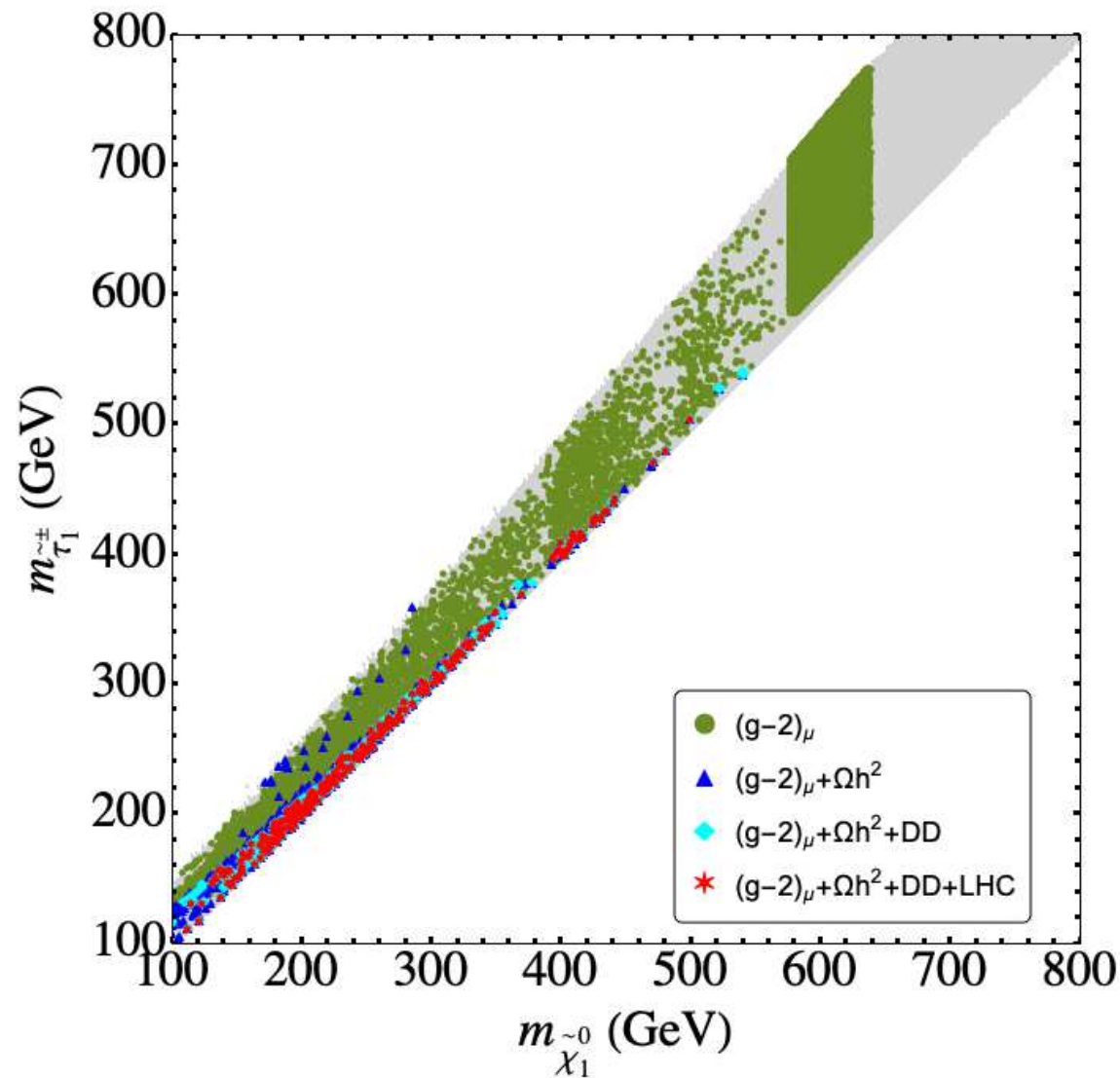
$$1.1M_1 \leq \mu \leq 10M_1 ,$$

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

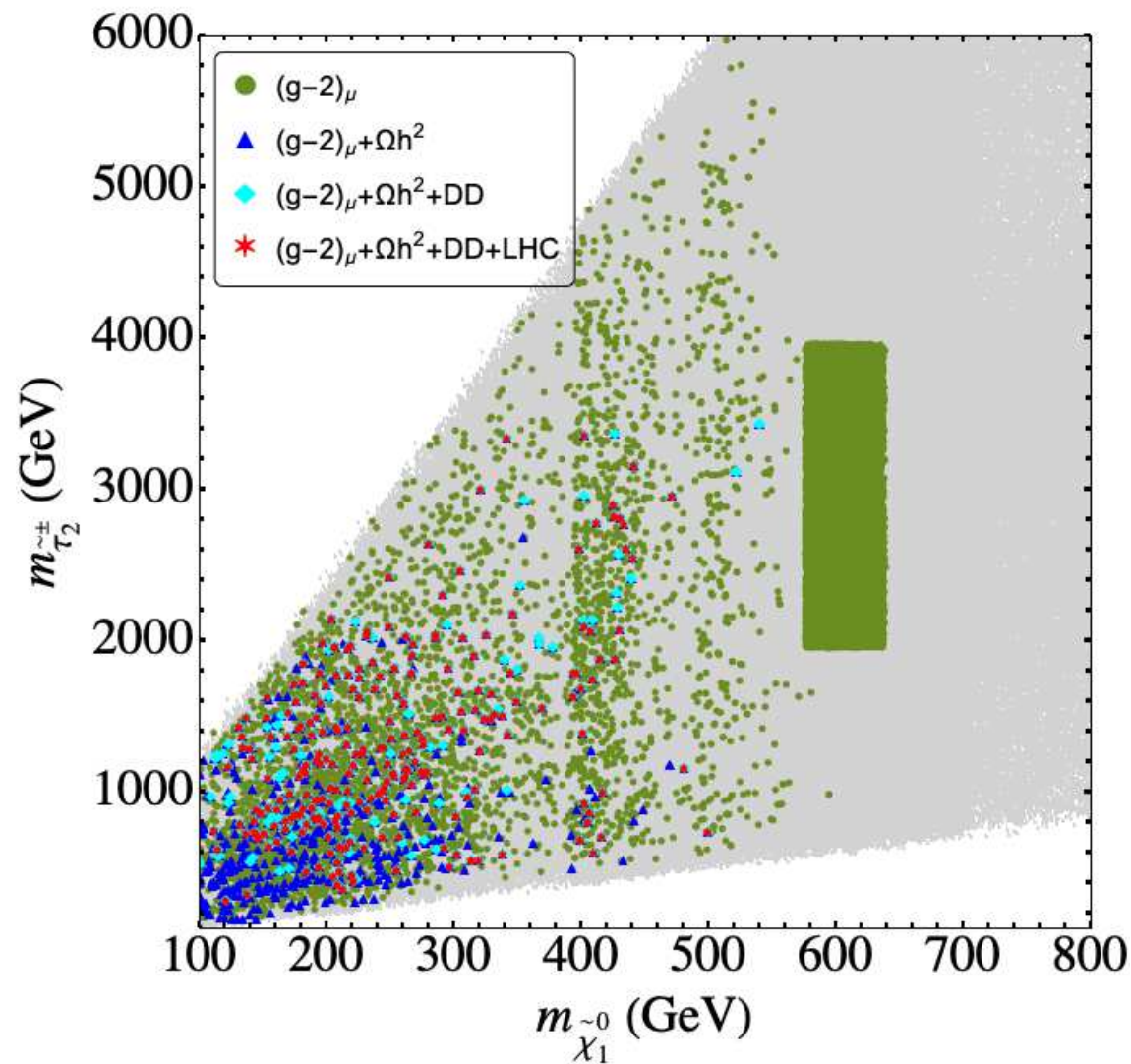
$$1.1M_1 \leq m_{\tilde{L}}, m_{\tilde{R}} \leq 10M_1 ,$$

$$\text{Case-L: } M_1 \leq m_{\tilde{\tau}_L} \leq 1.2M_1, \quad M_1 \leq m_{\tilde{\tau}_R} \leq 10M_1 ,$$

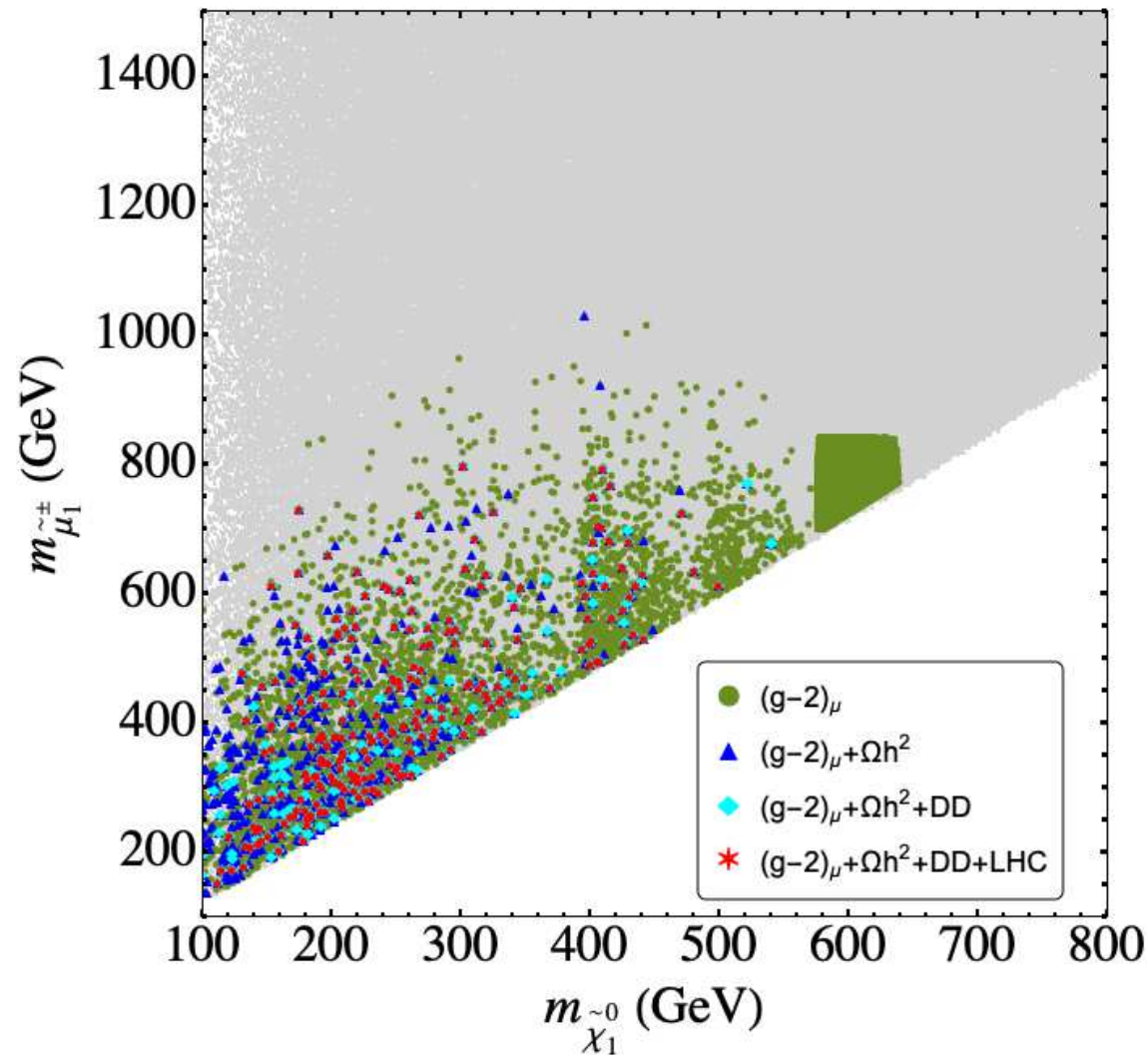
$$[\text{Case-R: } M_1 \leq m_{\tilde{\tau}_R} \leq 1.2M_1, \quad M_1 \leq m_{\tilde{\tau}_L} \leq 10M_1] .$$



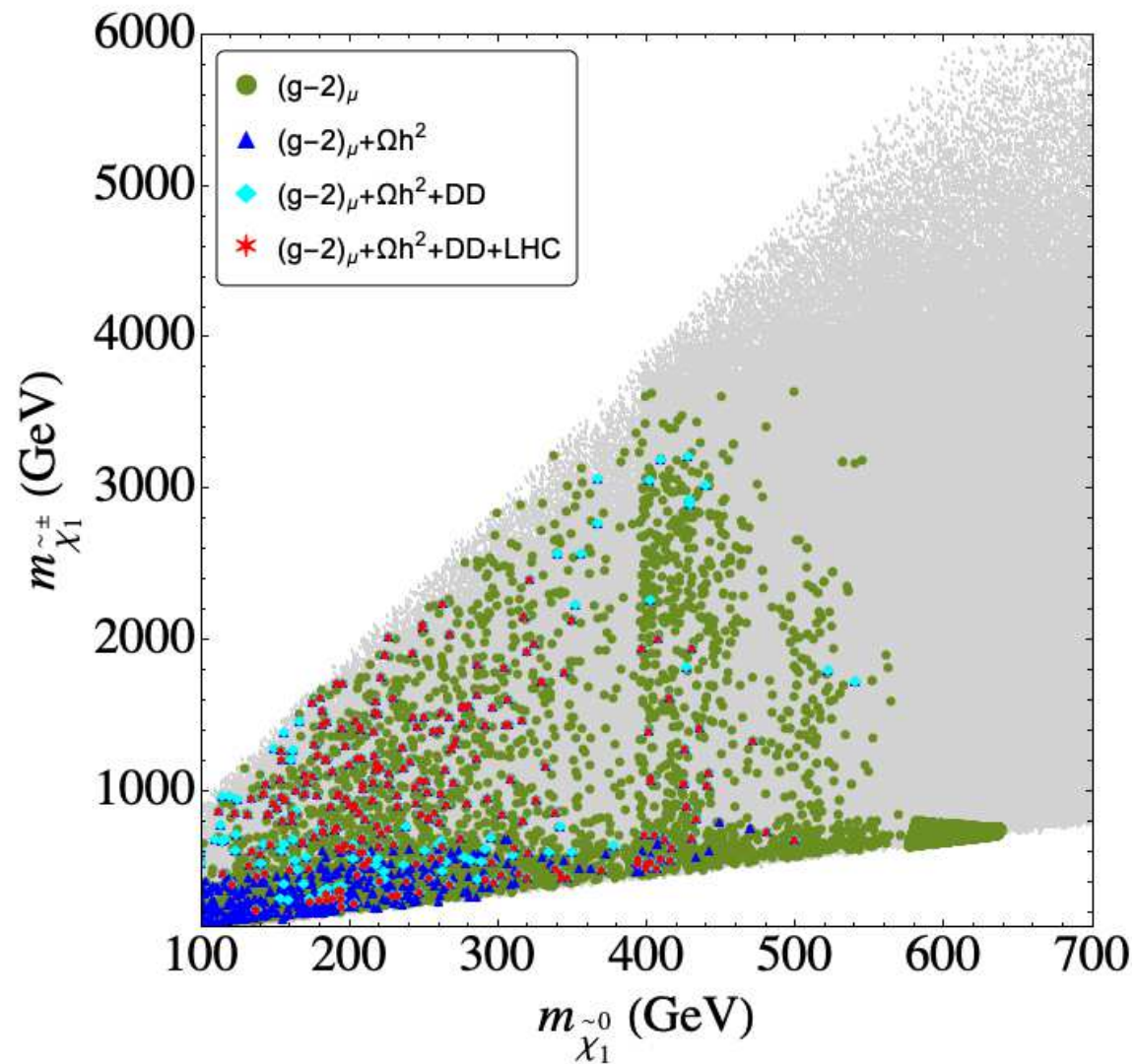
$\Rightarrow m_{(N)LSP} \lesssim 500 \text{ GeV}$



$\Rightarrow m_{\tilde{\tau}_2}$ nearly unconstrained

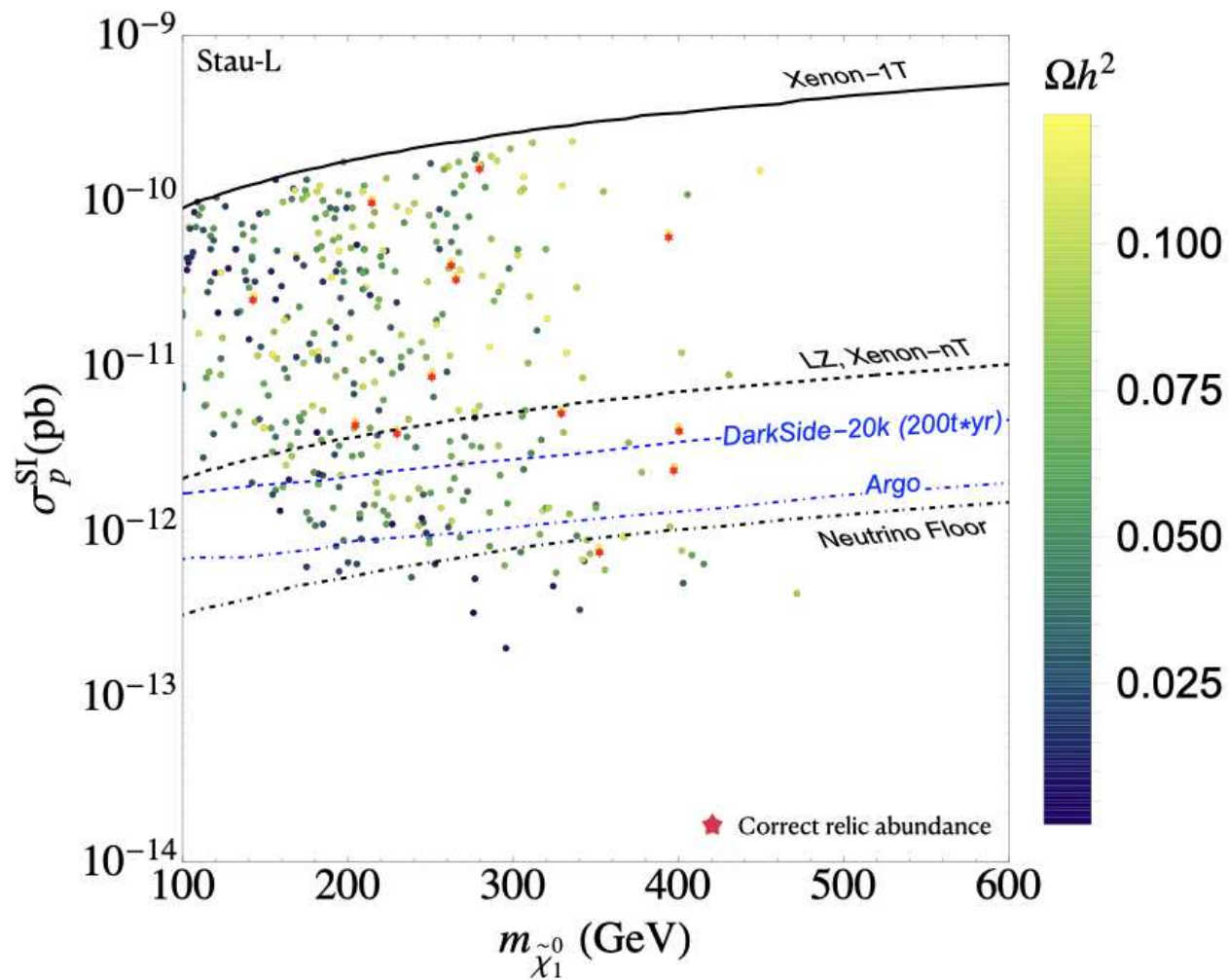


$\Rightarrow m_{\tilde{\mu}_1} \lesssim 800 \text{ GeV}$



$\Rightarrow m_{\tilde{\chi}_1^\pm}$ nearly unconstrained

Stau co-annihilation case-L: *[PRELIMINARY]* (no LHC limits applied yet)

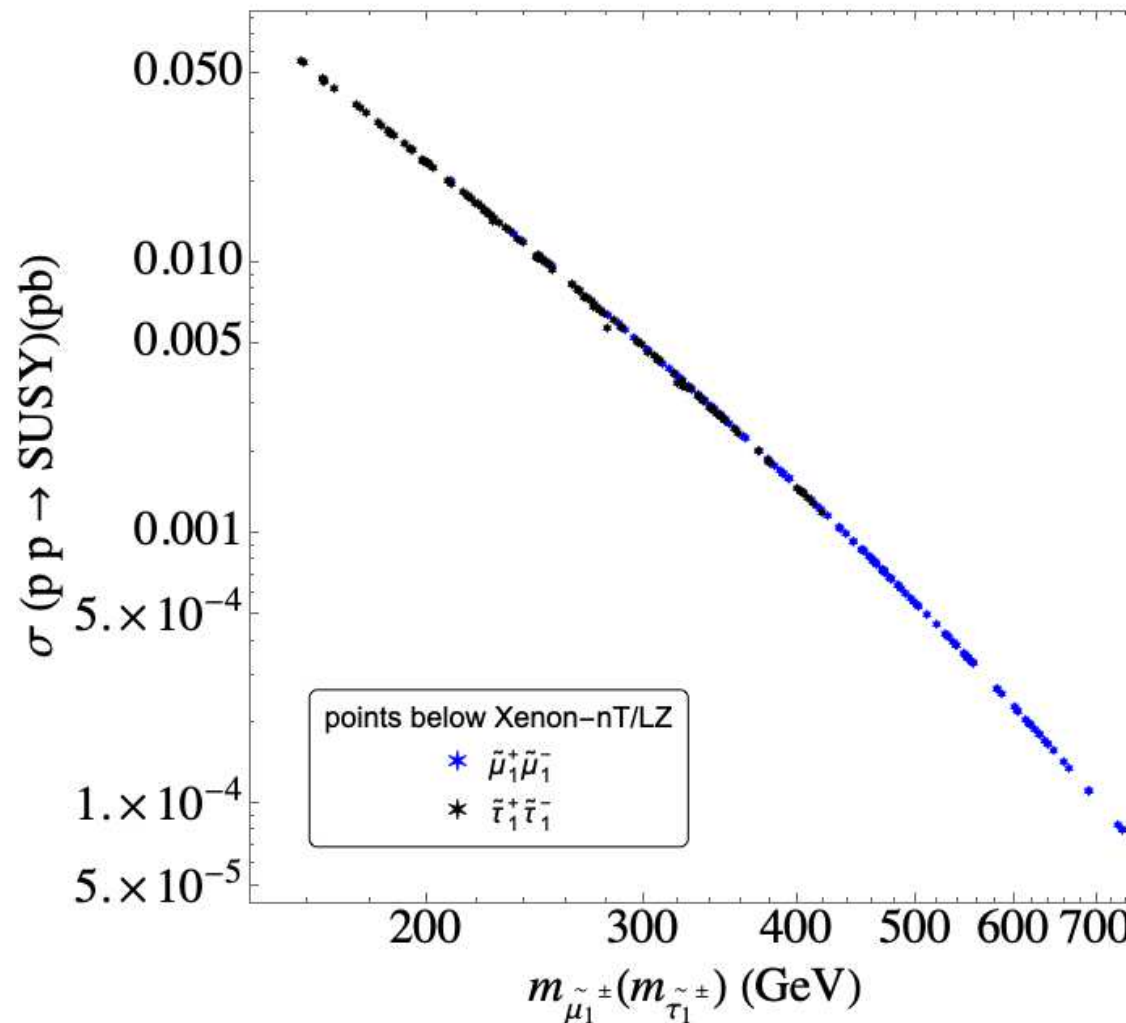


⇒ large part covered by XENON-nT/LZ

⇒ but can go below even the neutrino floor

Stau co-annihilation case-L: DD/HL-LHC complementarity: [PRELIMINARY]

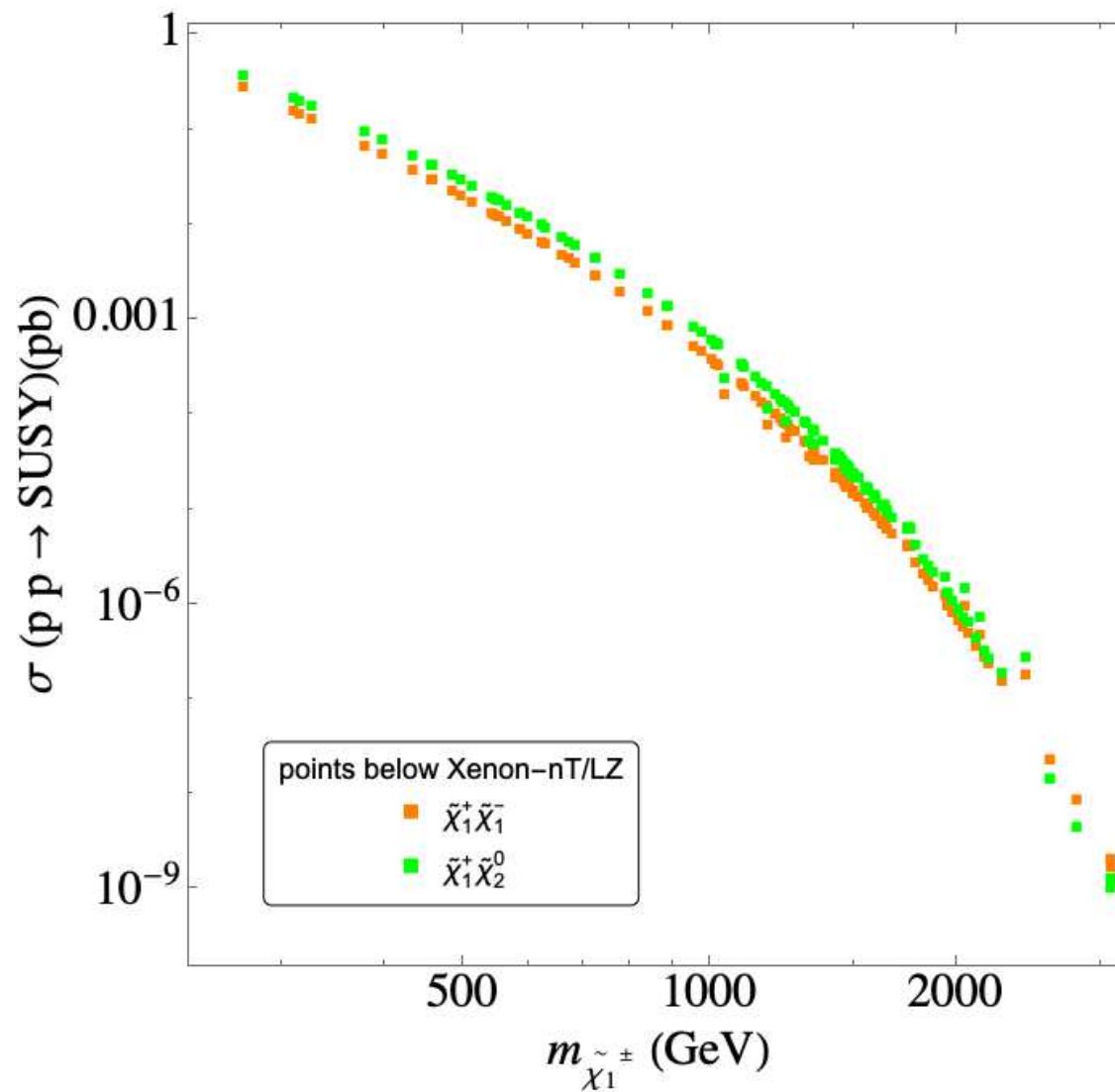
points below LZ limit: (no LHC limits applied yet)



$\Rightarrow$ in the kinematic reach, but compressed spectra! $\Rightarrow$ ILC/CLIC?

Stau co-annihilation case-L: DD/HL-LHC complementarity: [PRELIMINARY]

points below LZ limit: (no LHC limits applied yet)



⇒ too low cross sections at the HL-LHC ...

5. Conclusinos

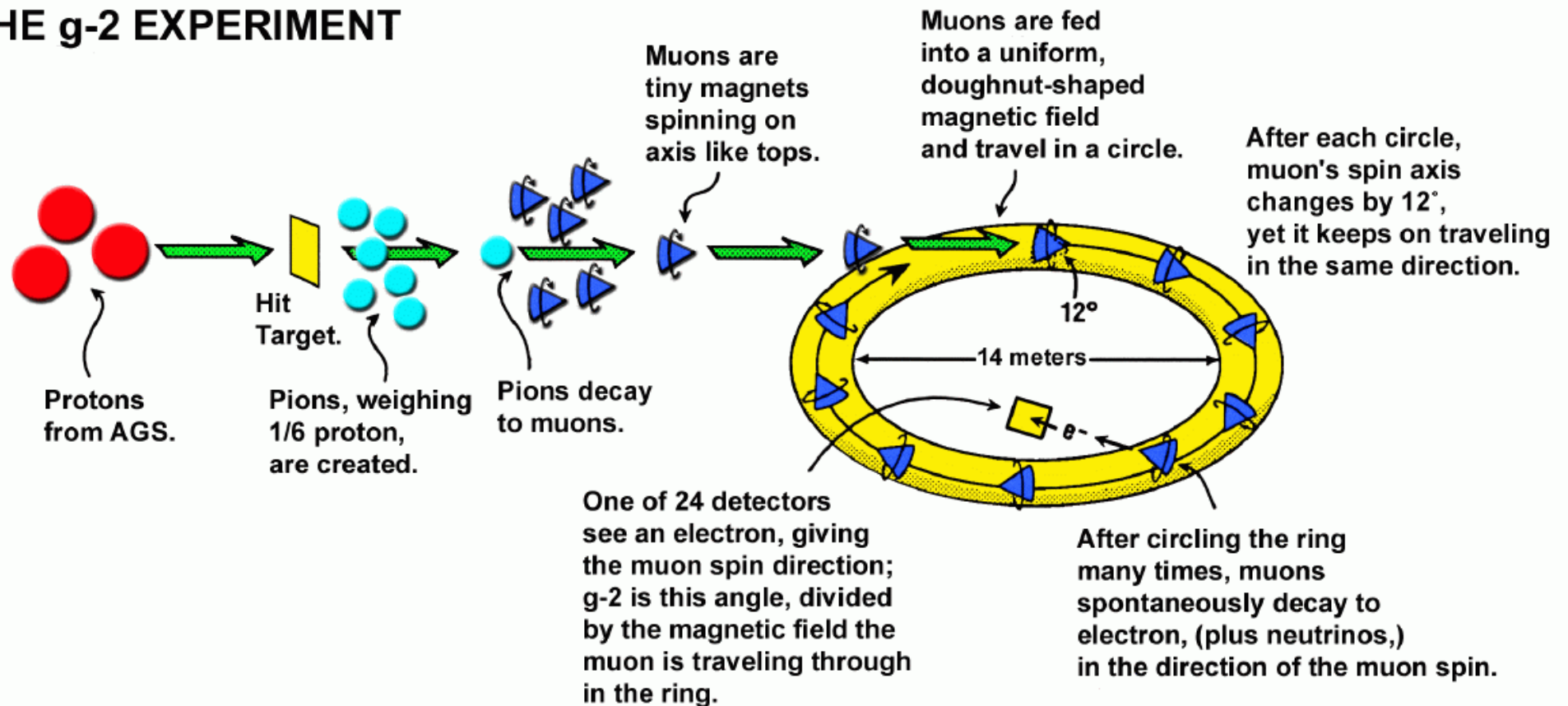
- new $(g - 2)_\mu$ result confirms old result and deviation from the SM
 $(g - 2)_\mu$ is real $\Rightarrow$ (relatively) light EW particles $\Rightarrow$ focus on MSSM
- $\Rightarrow$ scan the EW sector of the MSSM with all constraints:
 $(g - 2)_\mu$, DM relic density, DM DD, LHC EW searches
 $\Rightarrow$ upper limits on EW masses $\Rightarrow$ evaluate prospects for DD/FCs
- A) bino/wino DM with chargino coann. (DM full): $m_{(N)\text{LSP}} \lesssim 650(700)$ GeV
B/C) bino DM with slepton coann. (DM full): $m_{(N)\text{LSP}} \lesssim 650(700)$ GeV
D) higgsino eDM $m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_2^0} \sim m_{\tilde{\chi}_1^\pm} \sim \mu$ (DM u.l.): $m_{(N)\text{LSP}} \lesssim 500$ GeV
E) wino DM $m_{\tilde{\chi}_1^0} \sim m_{\tilde{\chi}_1^\pm} \sim \tilde{M}_2$ (DM u.l.): $m_{(N)\text{LSP}} \lesssim 600$ GeV
B'/C') bino DM with stau coann. (DM full): $m_{(N)\text{LSP}} \lesssim 500$ GeV
- Direct Detection prospects:
 - bino/wino DM with $\tilde{\chi}_1^\pm$ -coann., bino DM with $\tilde{l}$ -coann.:
allowed points go below XENON-nT/LZ and even neutrino floor
 - higgsino/wino DM: DD experiments cover everything
- Interplay with FCs: DM $\Leftrightarrow$ compressed spectra $\Rightarrow pp :- (, e^+e^- :-)$
below X-nT/LZ: HL-LHC: $\sigma \gtrsim 0.1 - 0.04$ fb $\Rightarrow$ prospects unclear
ILC1000: can cover everything easily



Further Questions?

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

LIFE OF A MUON: THE g-2 EXPERIMENT

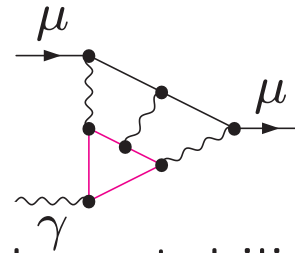


Coupling of **muon** to **magnetic field** : $\mu - \mu - \gamma$ coupling

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

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

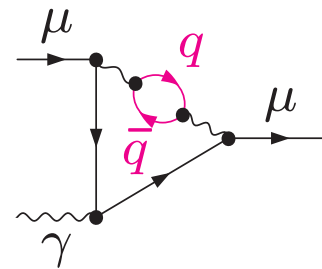
- the **light-by-light** contribution:



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 relatively well (also with old e^+e^- data)

$\Rightarrow$ **tension with LQCD results**

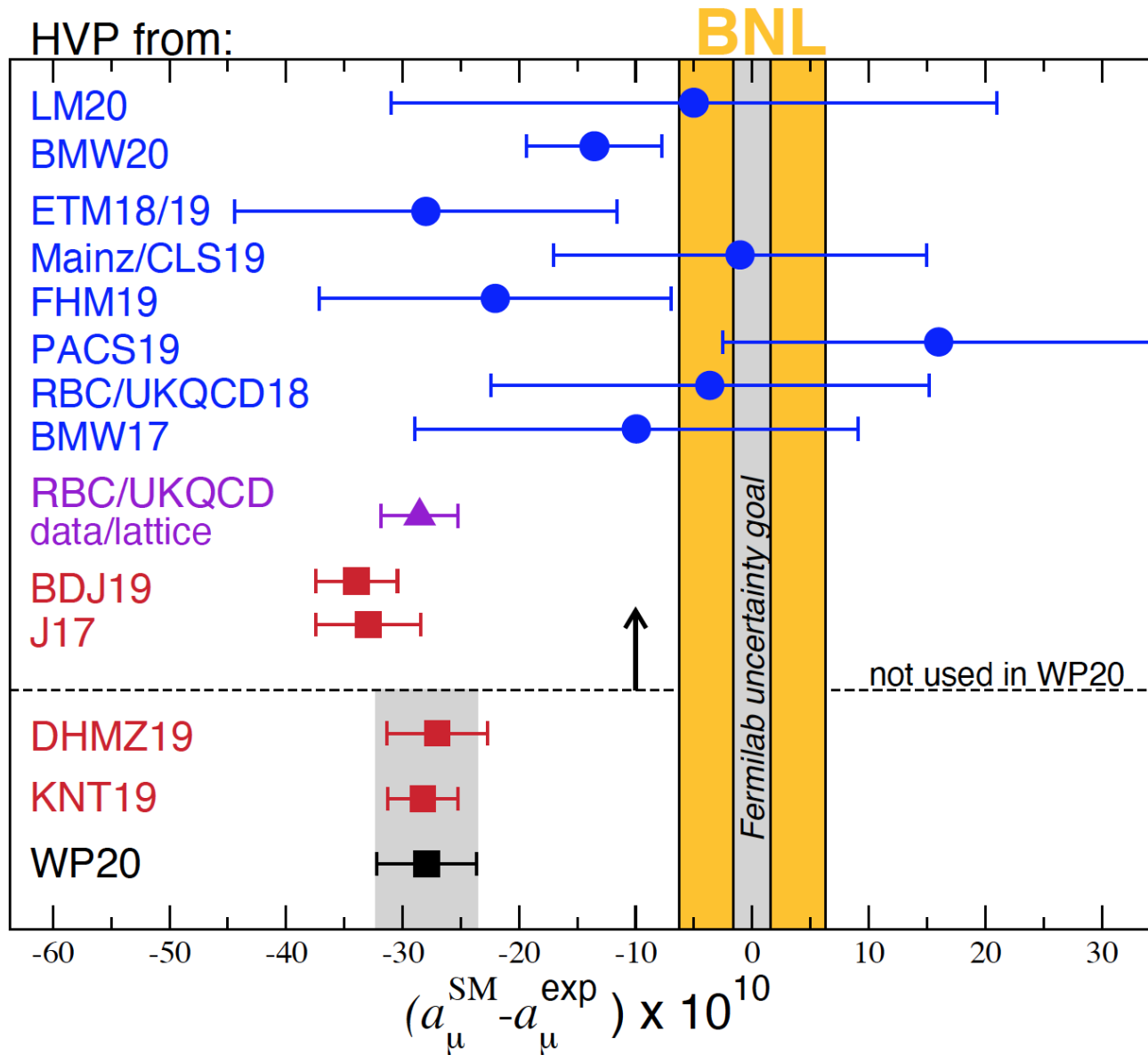
τ data:

tended to be closer to experimental result

inclusion of γ - ρ mixing: agreement with e^+e^- [F. Jegerlehner, R. Szafron '10]

$\Rightarrow$ **not used anymore**

HVP summary:



⇒ BMW20: difference to experimental data $\sim 1.5 \sigma$

LHC searches: (as given for Simplified Model Spectra (SMS))

Decay via sleptons (3I)

$$\begin{aligned}\tilde{\chi}_1^\pm \tilde{\chi}_2^0 &\rightarrow (\tilde{l}^\pm \nu)(\tilde{l}^+ l^-) \rightarrow 3l + \cancel{E}_T , \\ \tilde{\chi}_1^\pm \tilde{\chi}_2^0 &\rightarrow (l^\pm \tilde{\nu})(\tilde{l}^+ l^-) \rightarrow 3l + \cancel{E}_T\end{aligned}\quad (5)$$

Decay via sleptons (2I)

$$\begin{aligned}\tilde{\chi}_1^+ \tilde{\chi}_1^- &\rightarrow (\tilde{l}^+ \nu)(\tilde{l}^- \nu) \rightarrow 2l + \cancel{E}_T , \\ \tilde{\chi}_1^+ \tilde{\chi}_1^- &\rightarrow (l^+ \tilde{\nu})(l^- \tilde{\nu}) \rightarrow 2l + \cancel{E}_T\end{aligned}\quad (6)$$

Decay via gauge bosons

$$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow (W \tilde{\chi}_1^0)(Z \tilde{\chi}_1^0) \rightarrow 3l + \cancel{E}_T , \quad (7a)$$

$$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow (W \tilde{\chi}_1^0)(Z \tilde{\chi}_1^0) \rightarrow 2l + \text{jets} + \cancel{E}_T , \quad (7b)$$

$$\tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow (W^+ \tilde{\chi}_1^0)(W^- \tilde{\chi}_1^0) \rightarrow 2l + \cancel{E}_T \quad (8)$$

Decay via Higgs bosons

$$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow (W \tilde{\chi}_1^0)(h \tilde{\chi}_1^0) \rightarrow l + b\bar{b} + \cancel{E}_T \quad (9)$$

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

$$\tilde{l}^+ \tilde{l}^- \rightarrow (l^+ \tilde{\chi}_1^0)(l^- \tilde{\chi}_1^0) \rightarrow 2l + \cancel{E}_T \quad (10)$$

Compressed spectra

$$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow (W^* \tilde{\chi}_1^0)(Z^* \tilde{\chi}_1^0) \rightarrow 2l + \cancel{E}_T + \text{ISR} , \quad (11)$$

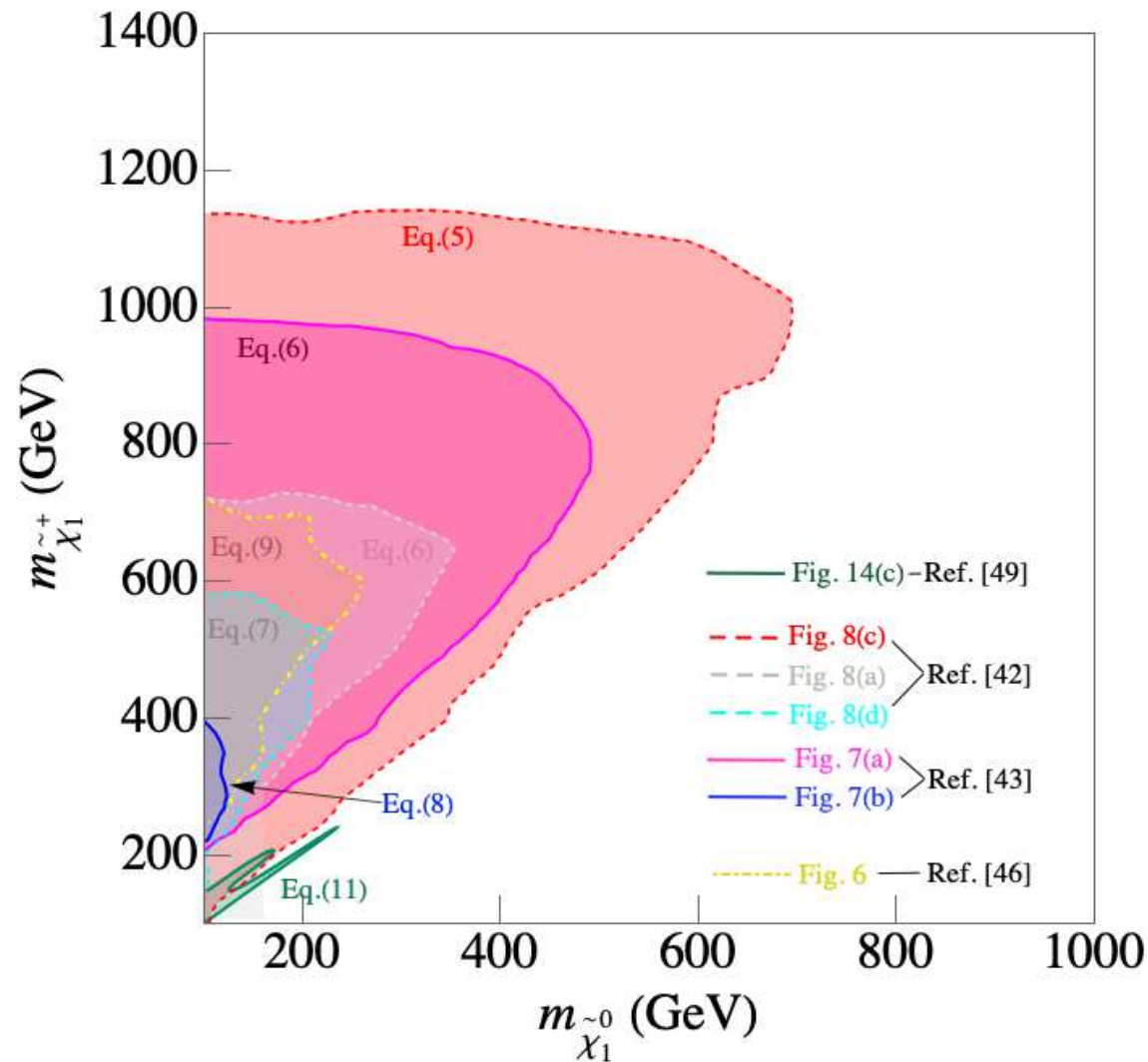
$$\tilde{l}^+ \tilde{l}^- \rightarrow (l^+ \tilde{\chi}_1^0)(l^- \tilde{\chi}_1^0) \rightarrow 2l + \cancel{E}_T + \text{ISR} \quad (12)$$

Searches involving Staus

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

Exception: compressed spectra $\Rightarrow$ direct application

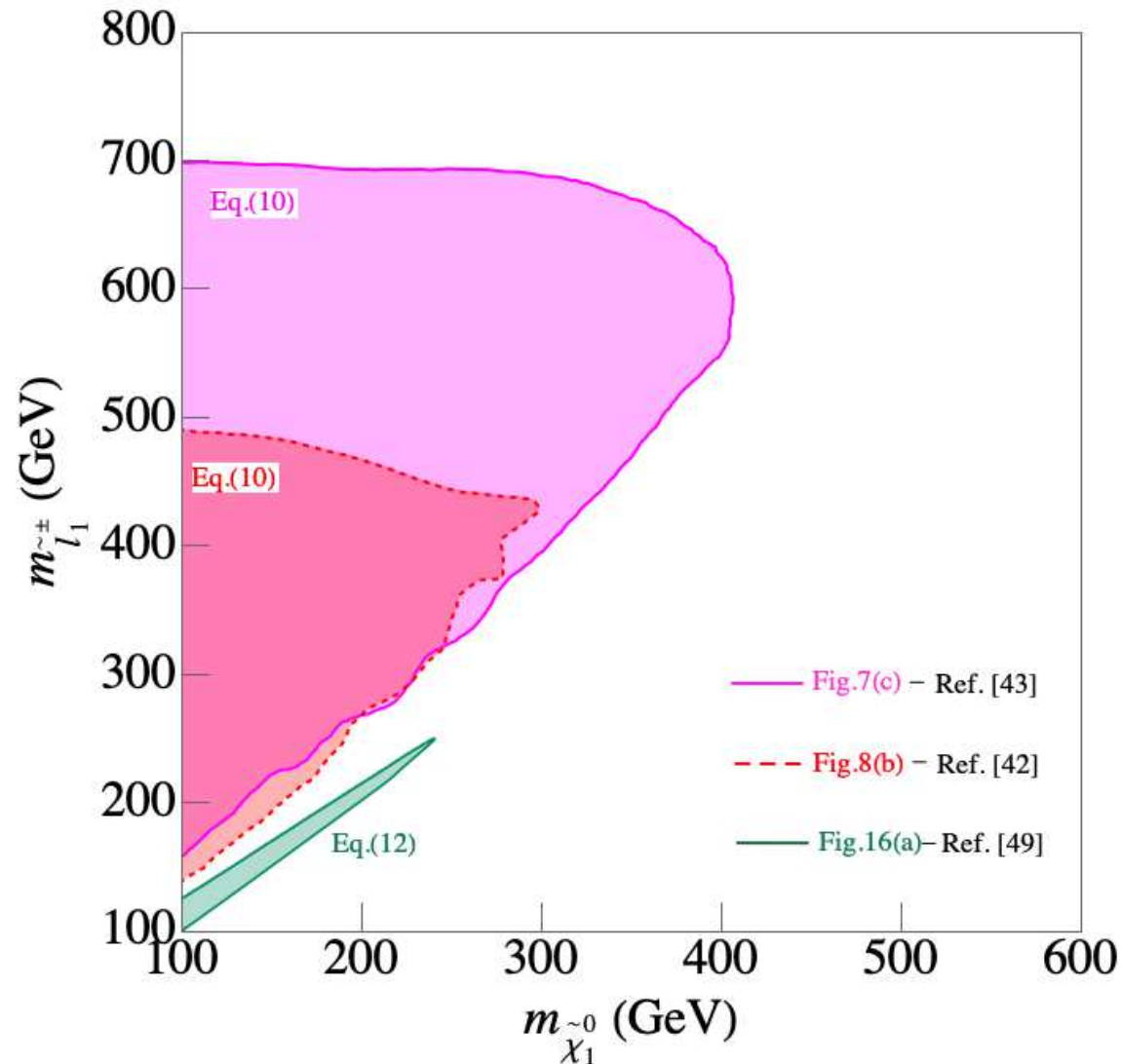
LHC exclusion bounds (I) (as given for Simplified Model Spectra (SMS))



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

Exception: compressed spectra ⇒ direct application

LHC exclusion bounds (II) (as given for Simplified Model Spectra (SMS))



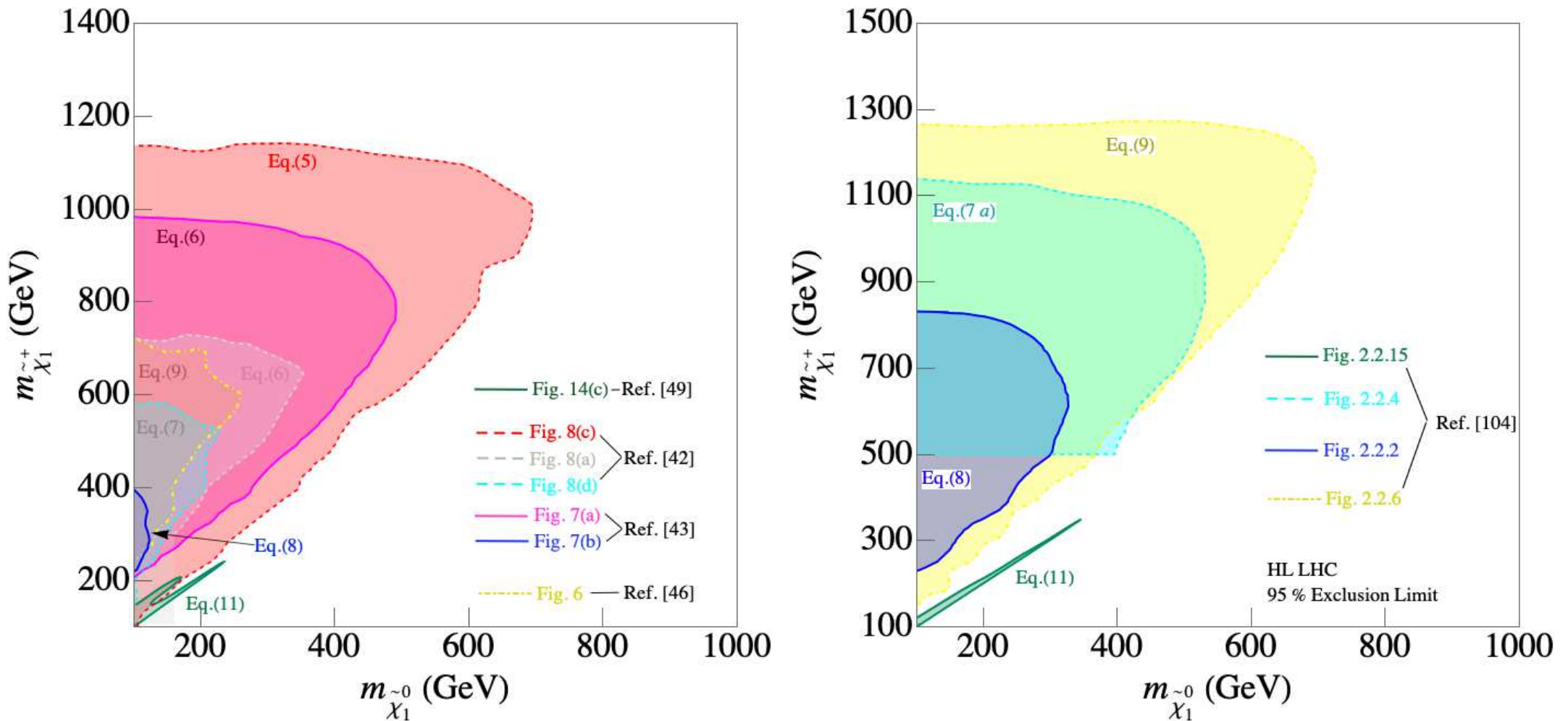
⇒ all newly included into CheckMate [M.C & I.S.]

Exception: compressed spectra ⇒ direct application

LHC exclusion bounds vs. HL-LHC exclusion bounds

not all channels available

[YR18]

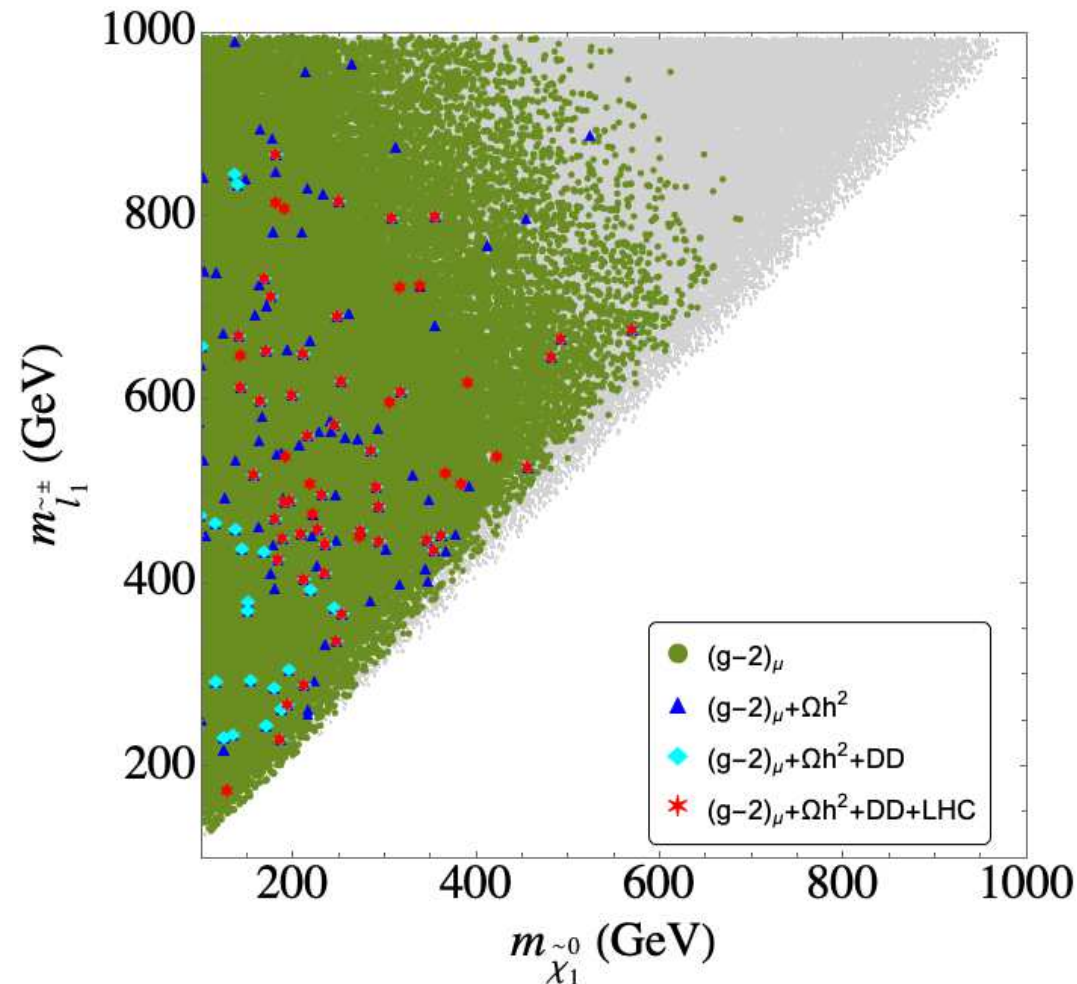


⇒ exclusion reach can be important

⇒ no CheckMate inclusion available ...

Example I: $\tilde{\chi}_1^\pm$ -coannihilation: $m_{\tilde{\chi}_1^0} - m_{\tilde{l}_1}$ plane:

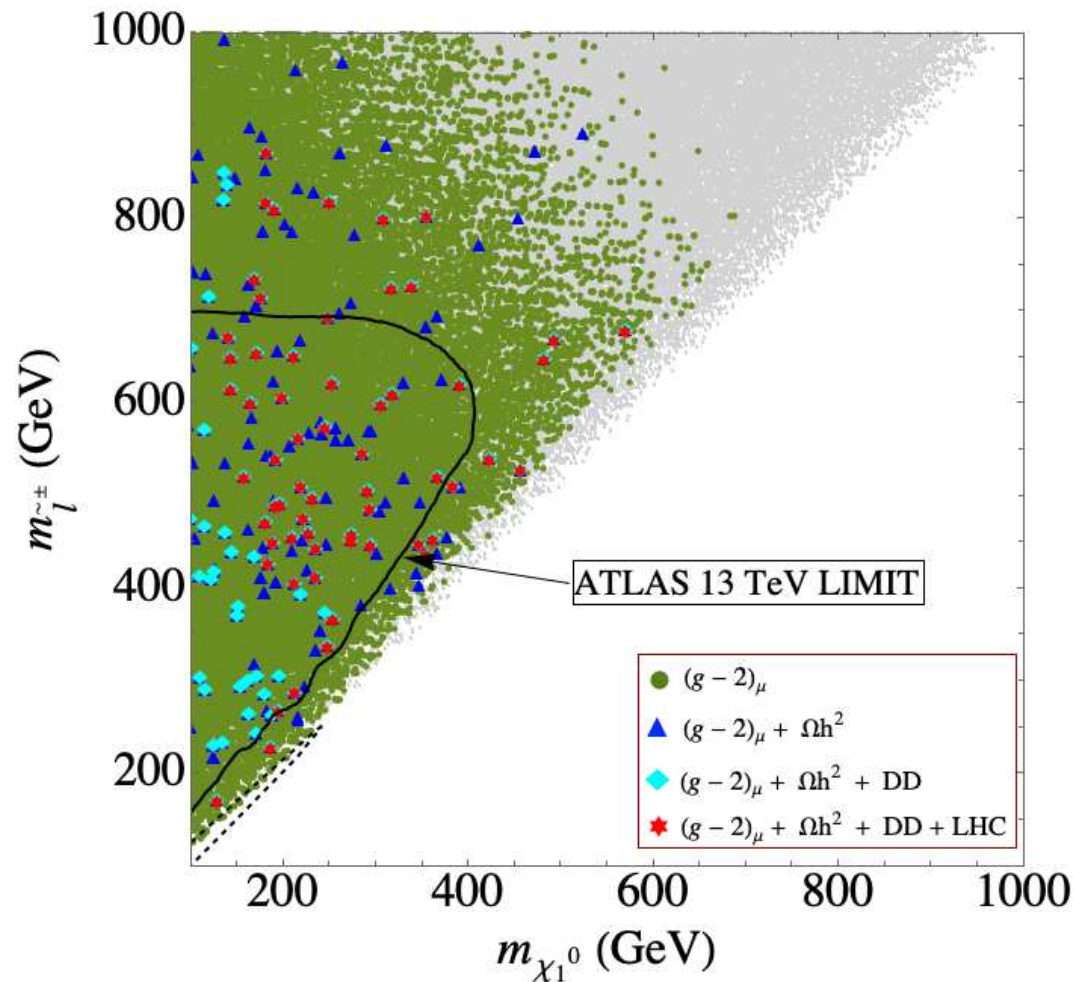
new $(g-2)_\mu$



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

Example I: $\tilde{\chi}_1^\pm$ -coannihilation: $m_{\tilde{\chi}_1^0} - m_{\tilde{l}_1}$ plane:

old $(g - 2)_\mu$

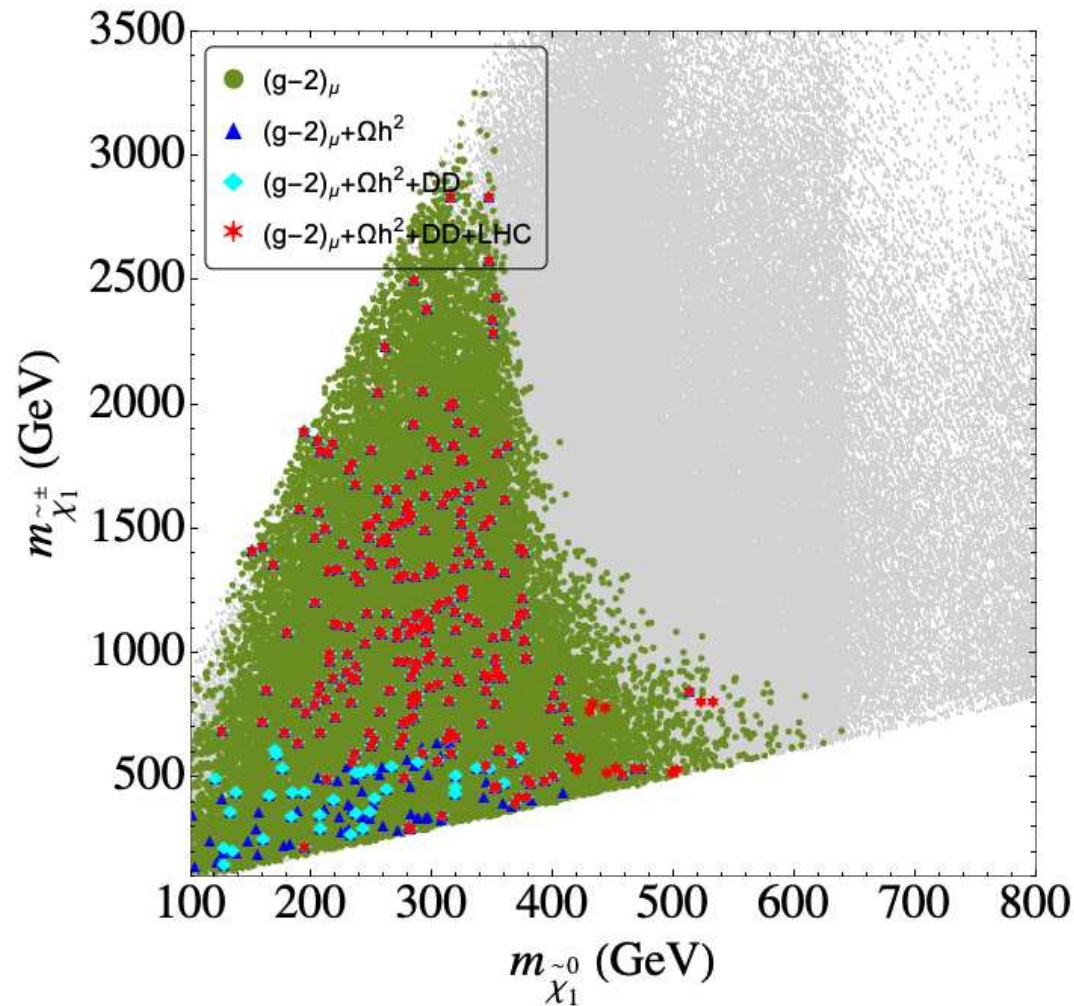


⇒ important: $\tilde{l}$ -pair production searches (10)

⇒ naive application of LHC bounds fails

Example II: $\tilde{l}$ -coannihilation: $m_{\tilde{\chi}_1^0} - m_{\tilde{\chi}_1^\pm}$ plane:

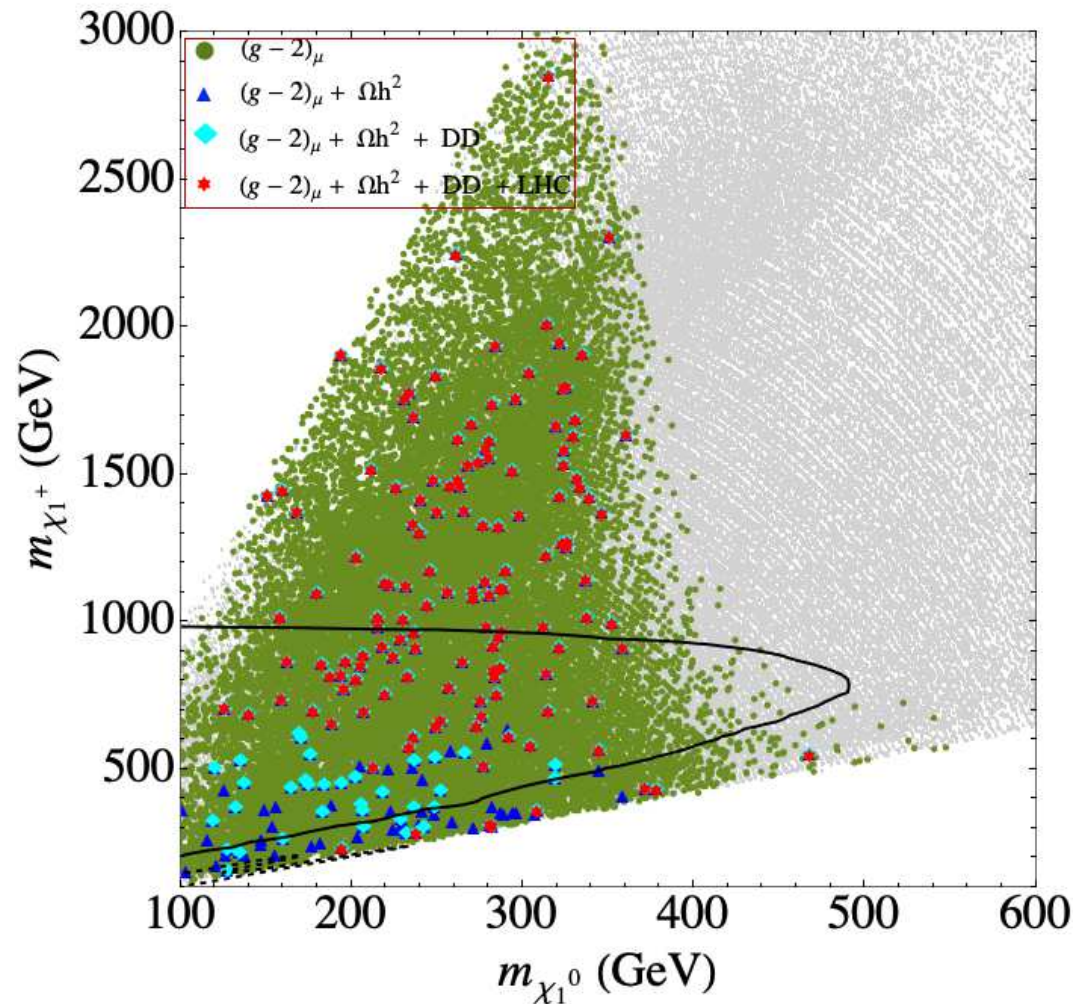
new $(g-2)_\mu$



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

Example II: $\tilde{l}$ -coannihilation: $m_{\tilde{\chi}_1^0} - m_{\tilde{\chi}_1^\pm}$ plane:

old $(g - 2)_\mu$

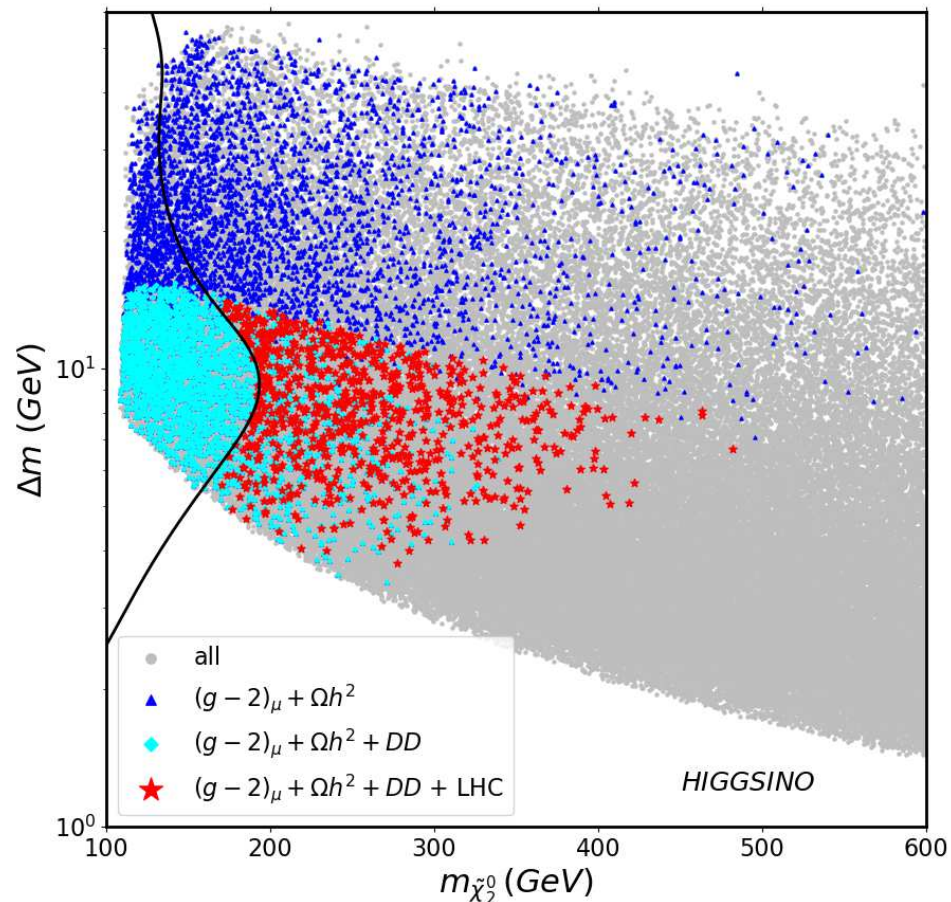


⇒ important: $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production searches (5)

⇒ naive application of LHC bounds fails

Example III: higgsino DM: $m_{\tilde{\chi}_2^0} - \Delta m$ plane:

old $(g - 2)_\mu$

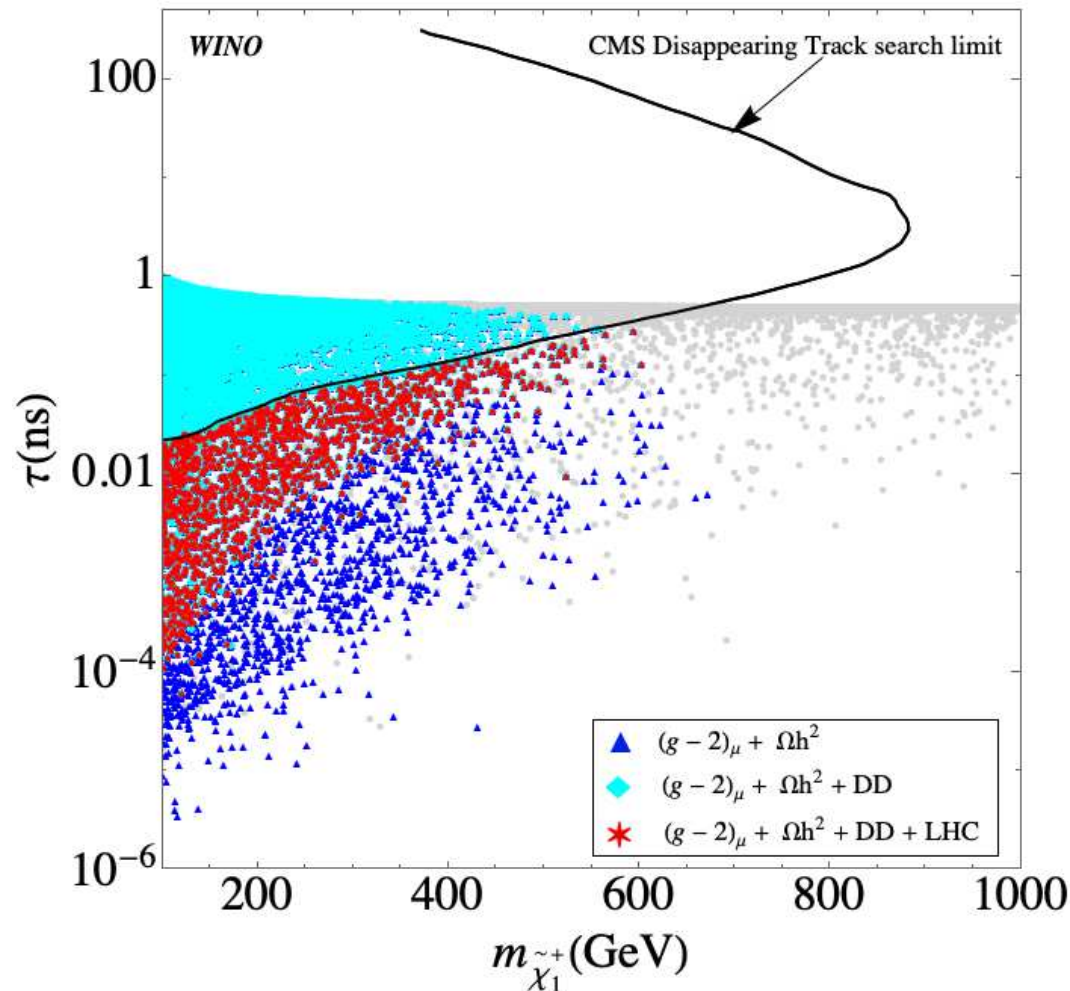


⇒ important: compressed spectra searches (11)

⇒ right where the model prediction sits ⇒ very powerful

Example IV: wino DM: $m_{\tilde{\chi}_1^\pm} - \tau_{\tilde{\chi}_1^\pm}$ plane:

old $(g-2)_\mu$



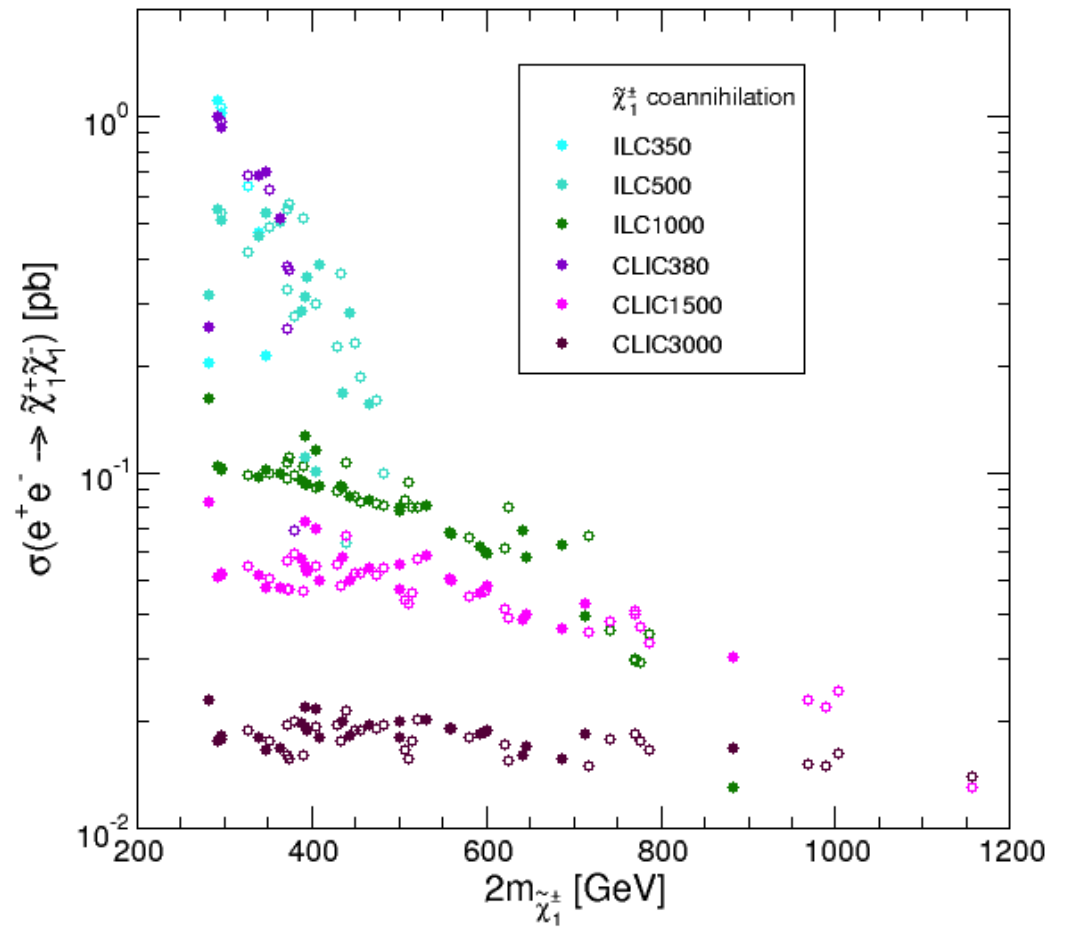
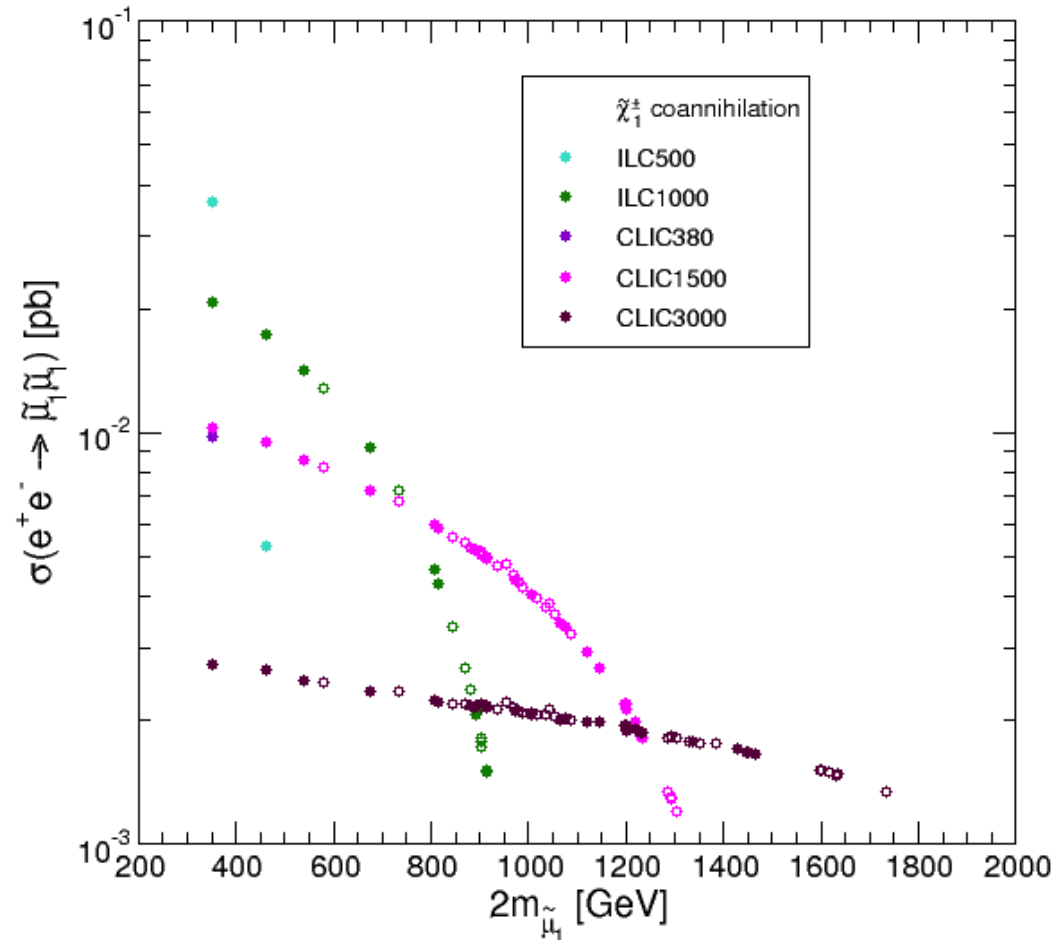
⇒ important: disappearing track limit ⇒ $m_{(\text{N})\text{LSP}} \lesssim 600 \text{ GeV}$

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

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

wino/bino DM with chargino co-ann.

(open/full: "old" $(g-2)_\mu$)



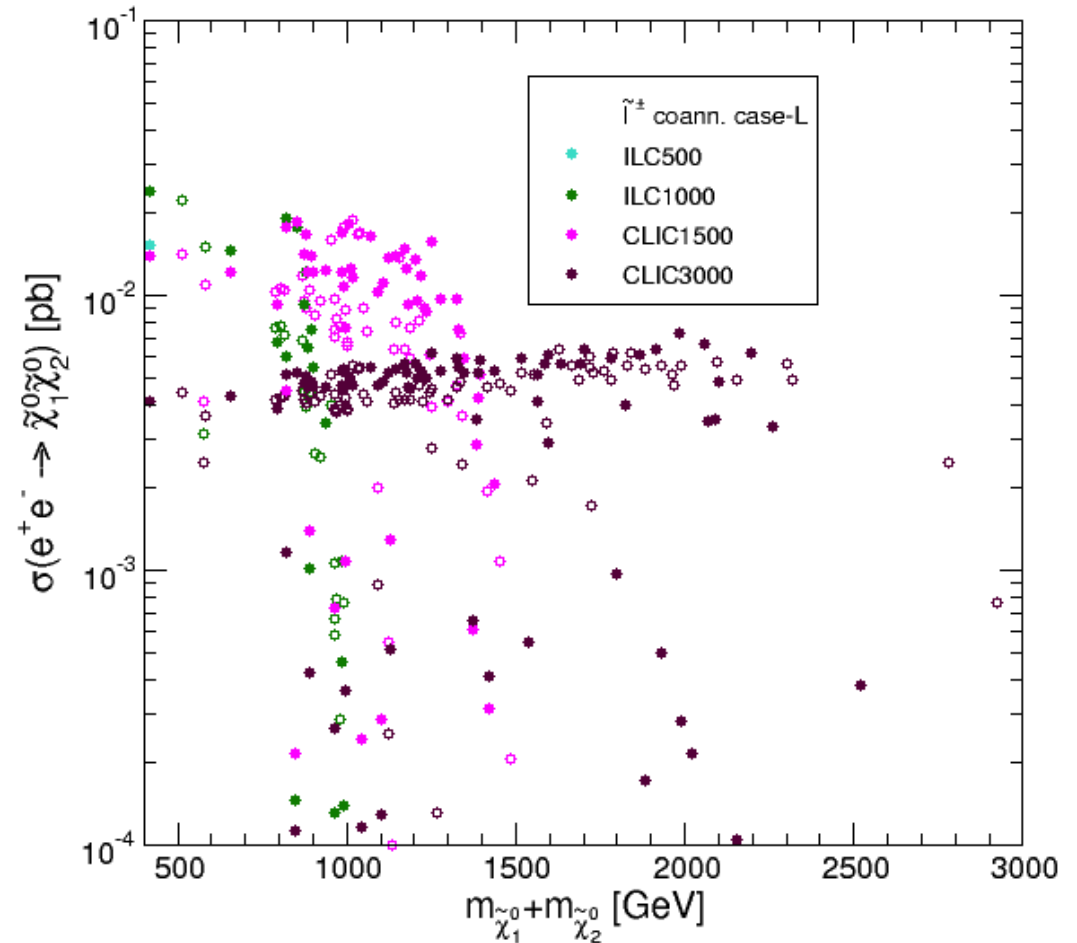
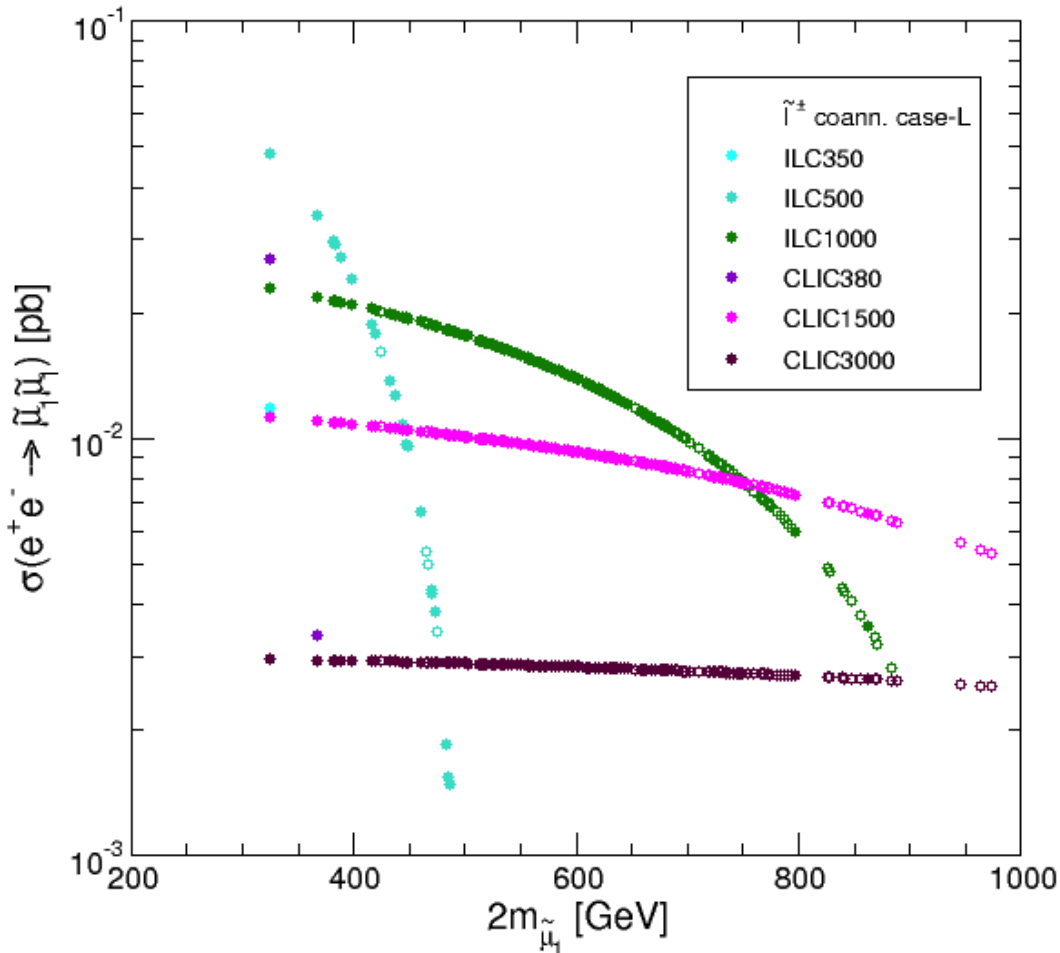
$\Rightarrow$ ILC has good prospects (particularly for $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$)

$\Rightarrow$ CLIC can cover everything

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

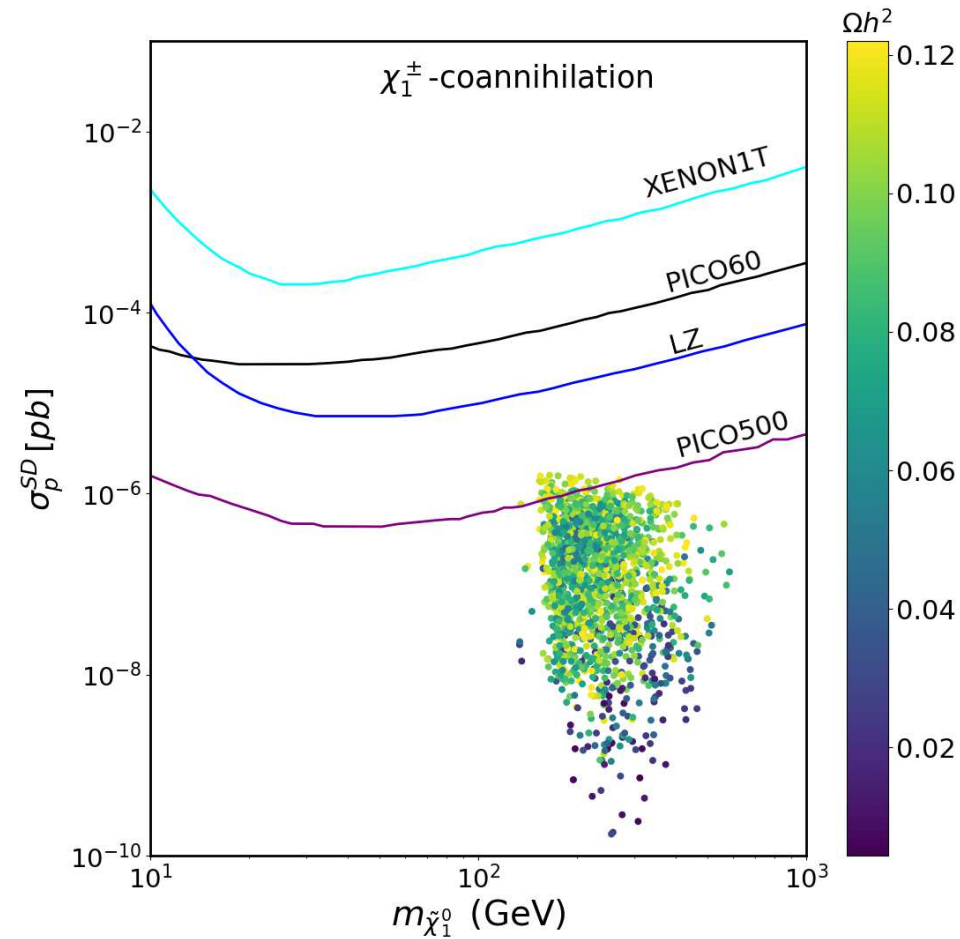
bino DM with slepton co-ann.

(open/full: "old" $(g-2)_\mu$)



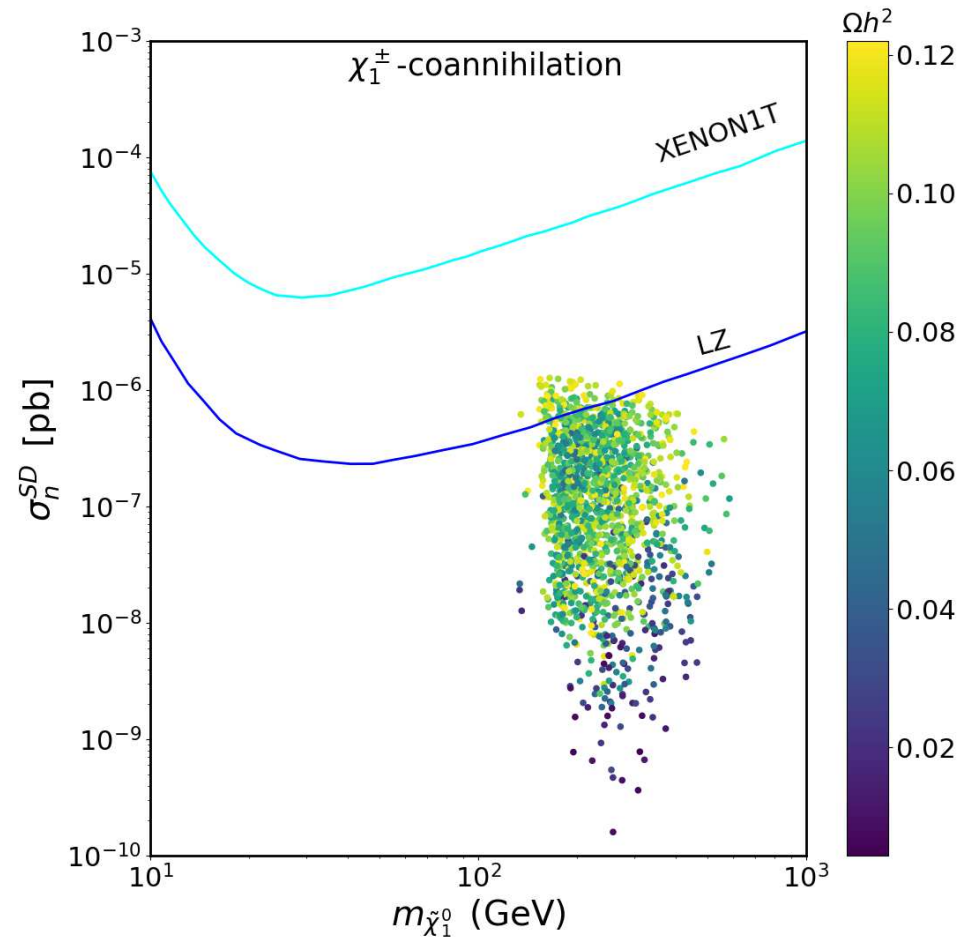
$\Rightarrow$ ILC can nearly covers full smuon channel (but not $\tilde{\chi}_1^0 \tilde{\chi}_2^0$)

$\Rightarrow$ CLIC can cover everything



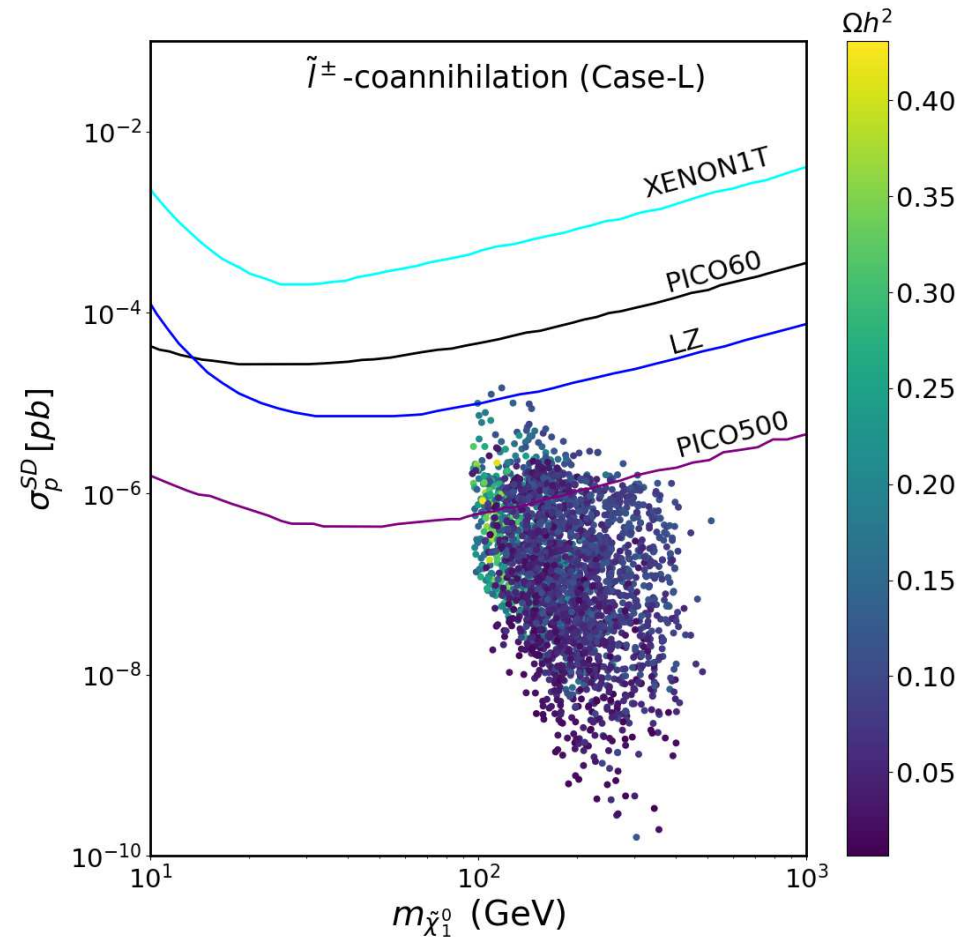
⇒ SD DD experiments have to do better ...

⇒ no indirect detection limits ...



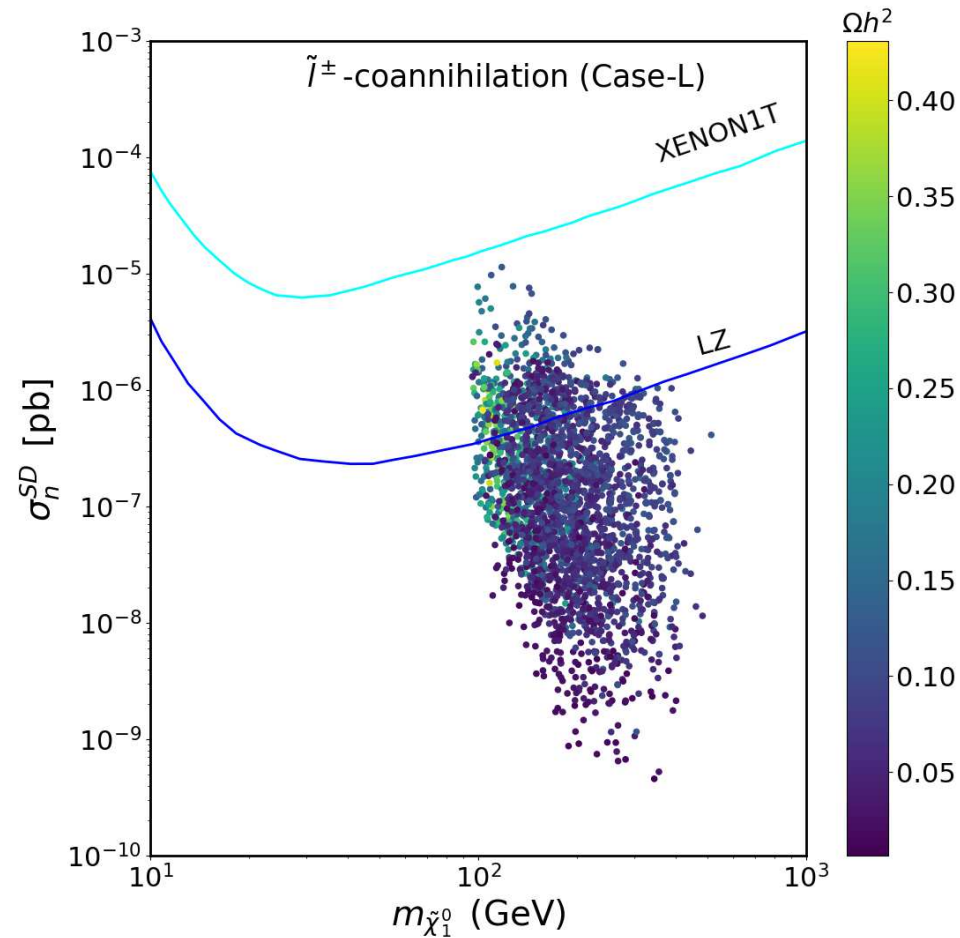
⇒ SD DD experiments have to do better ...

⇒ only LZ limits ...



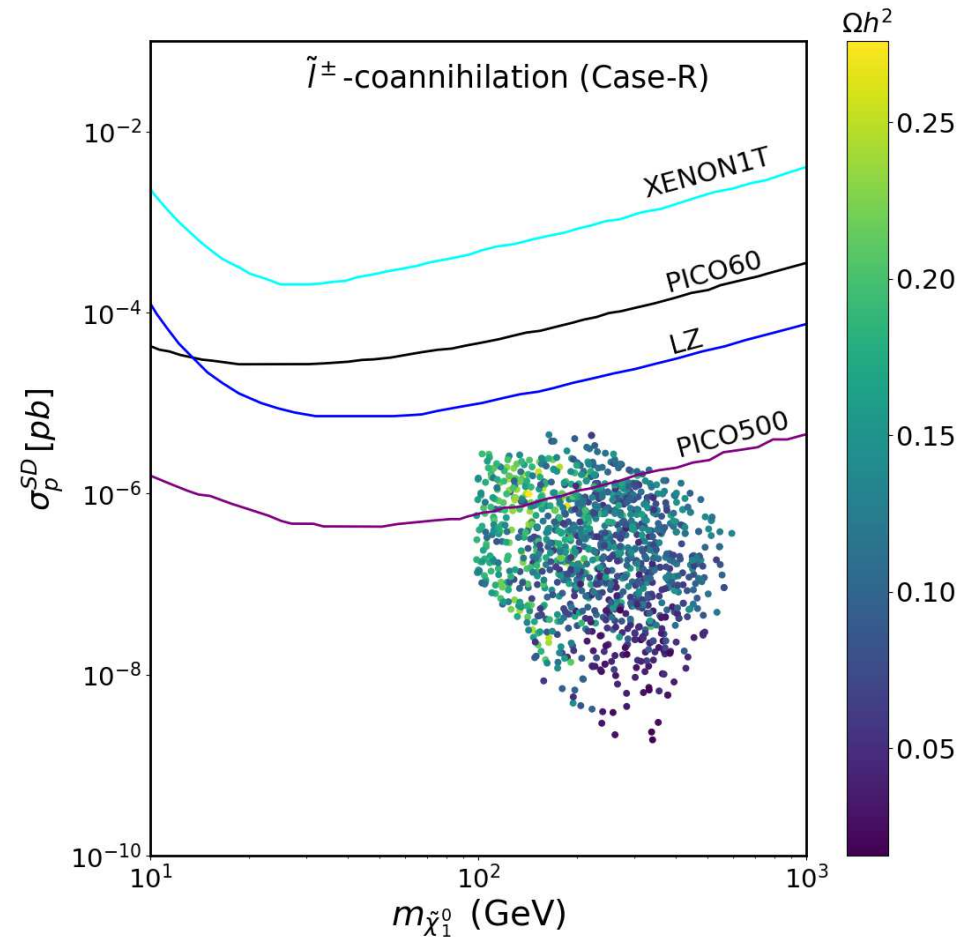
⇒ SD DD experiments have to do better . . .

⇒ no indirect detection limits . . .



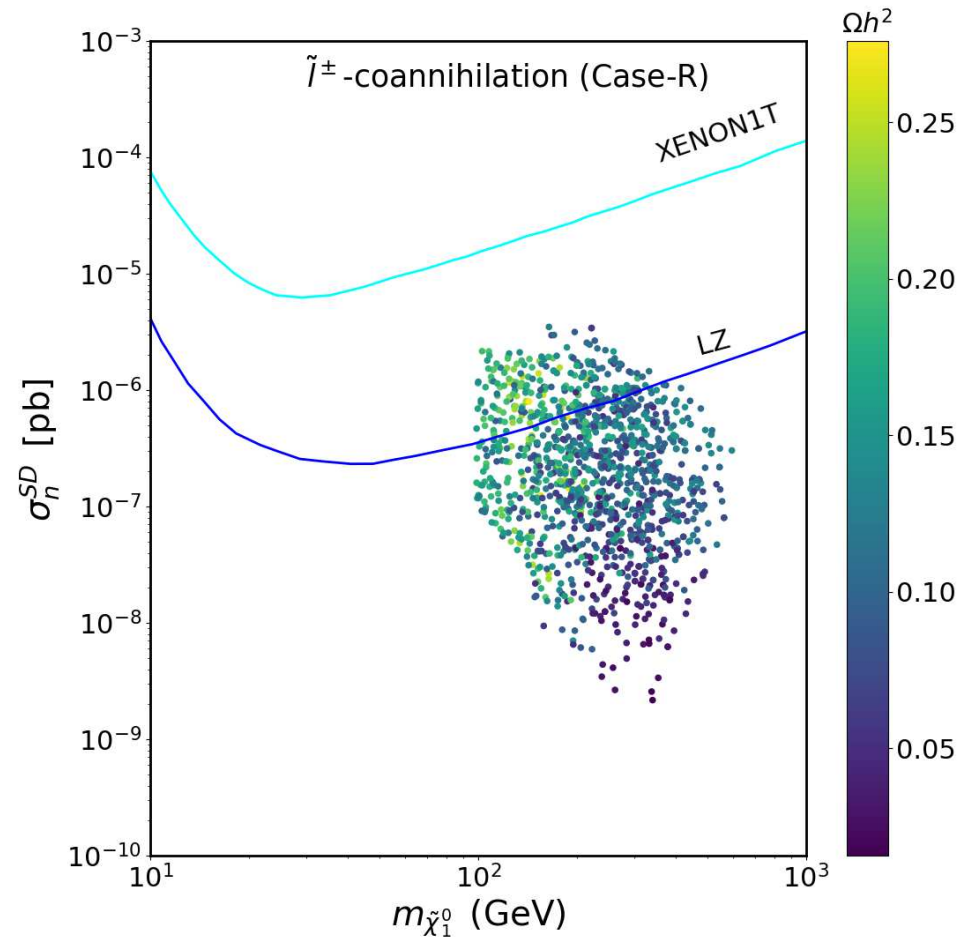
⇒ SD DD experiments have to do better ...

⇒ only LZ limits ...



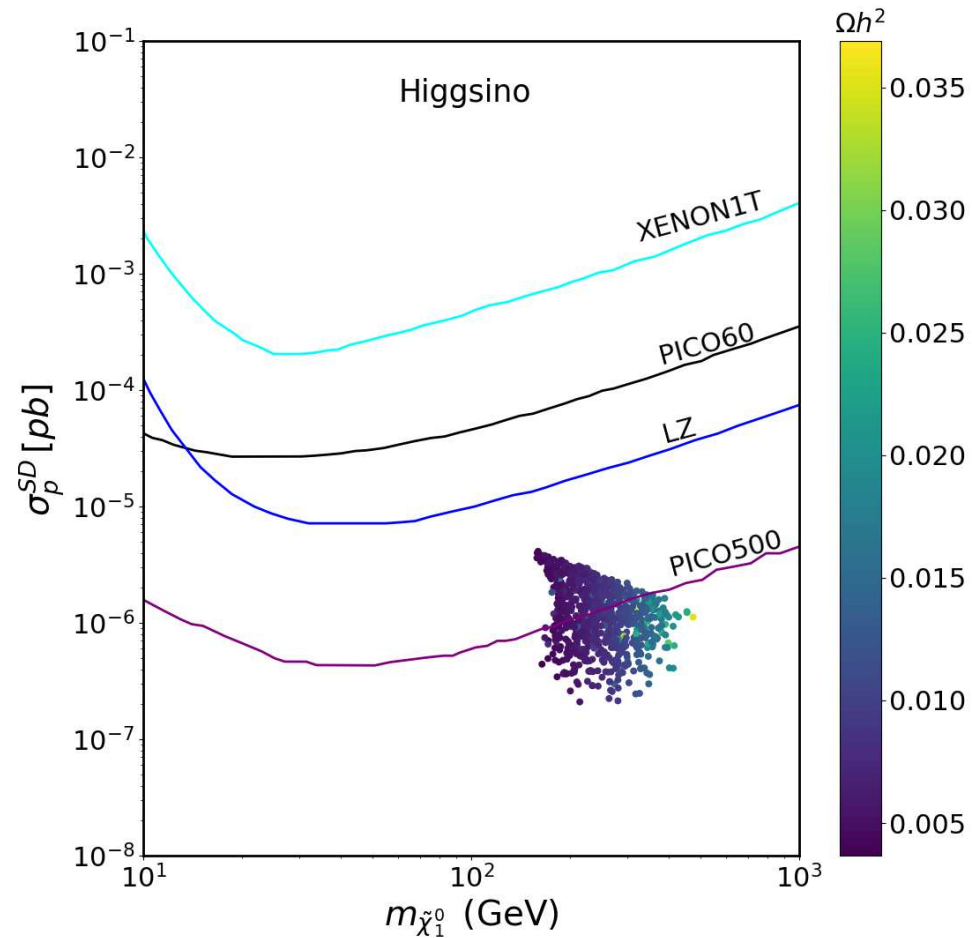
⇒ SD DD experiments have to do better . . .

⇒ no indirect detection limits . . .



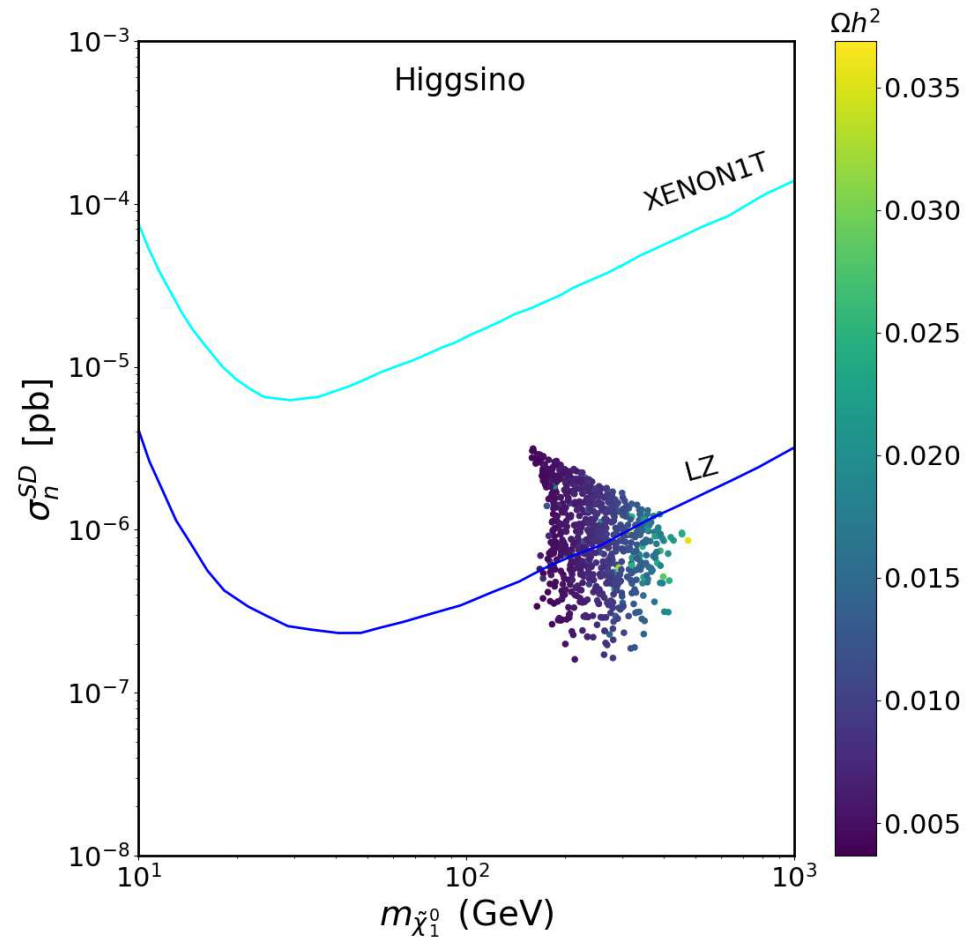
⇒ SD DD experiments have to do better ...

⇒ only LZ limits ...



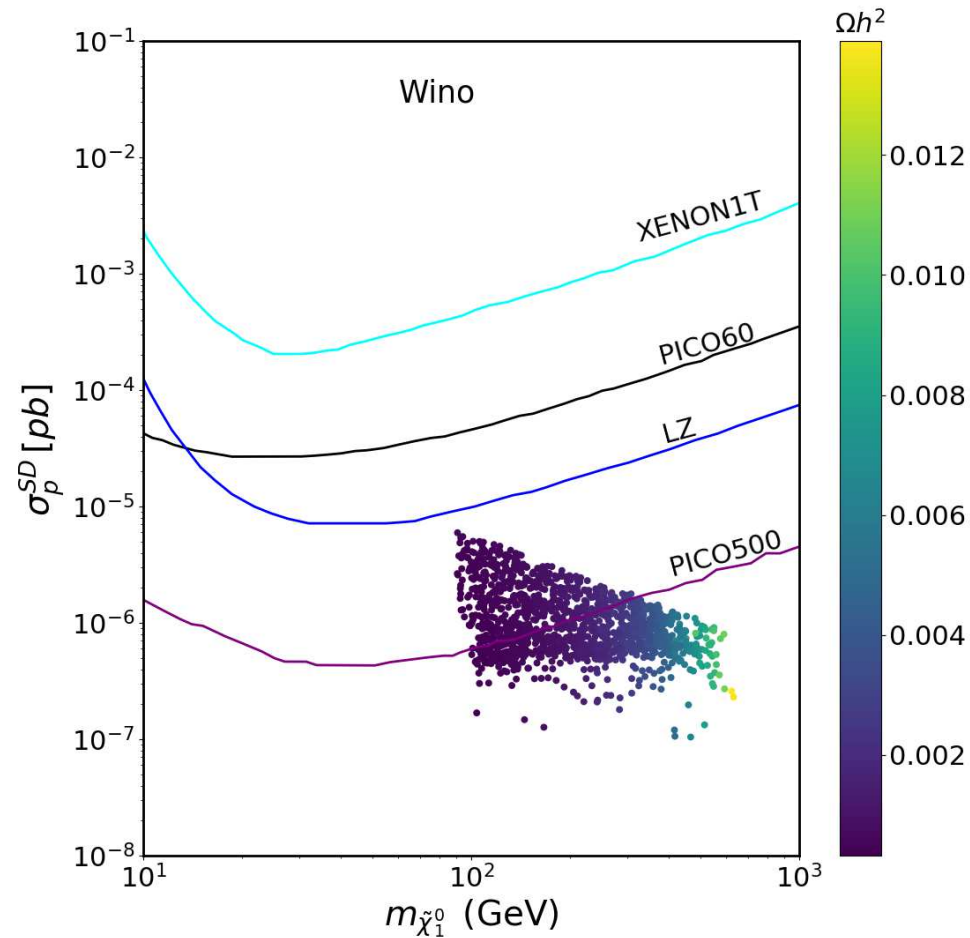
⇒ looks better, but SI experiments clearly win ...

⇒ no indirect detection limits ...



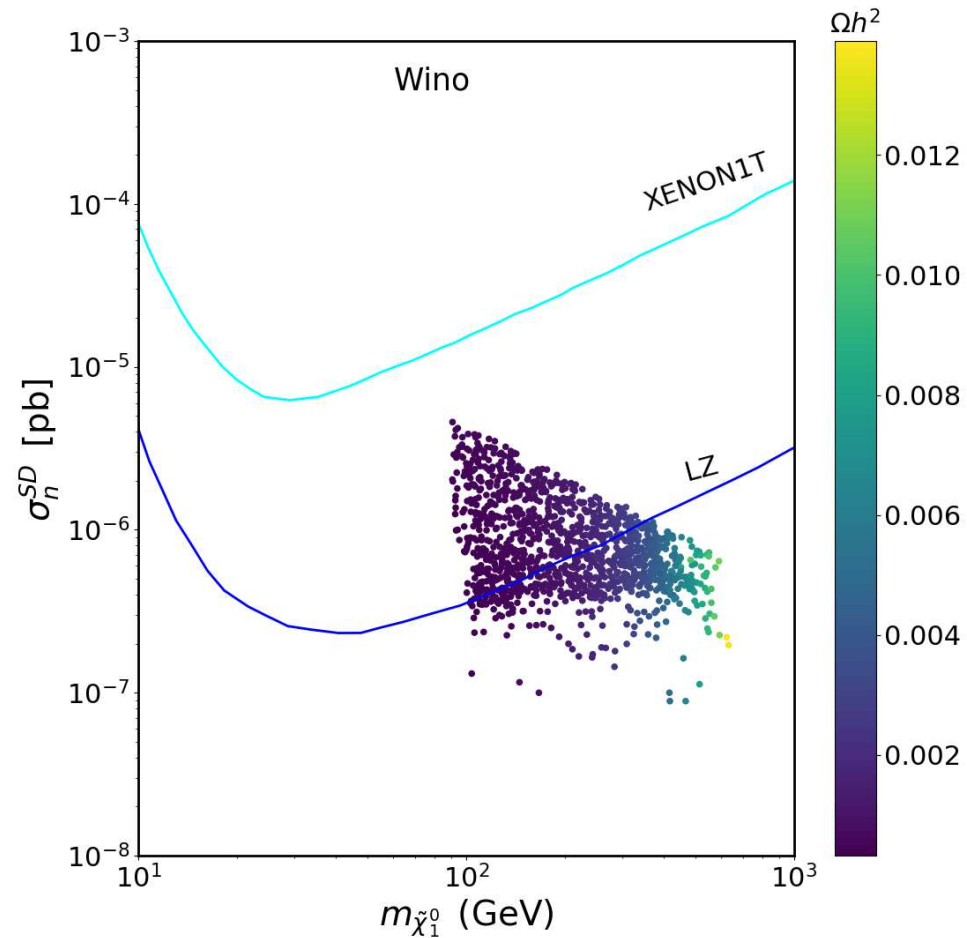
⇒ looks better, but SI experiments clearly win ... ??

⇒ only LZ limits ... maybe there are chances?



⇒ looks better, but SI experiments clearly win ...

⇒ no indirect detection limits ...



⇒ looks better, but SI experiments clearly win ... ??

⇒ only LZ limits ... maybe there are chances?