東京大学
THE UNIVERSITY OF TOKYO

KAVLI IPMU
東京大学 国際高等研究所 カブリ数物連携宇宙研究機構
KAVLI INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

Ipsita Saha

Kavli IPMU Postdoc Colloquium ‘ 2020

Status of EWkinos in view of muon (g-2), WIMP and collider searches

IPMU POSTDOC COLLOQUIUM – 06/11/2020

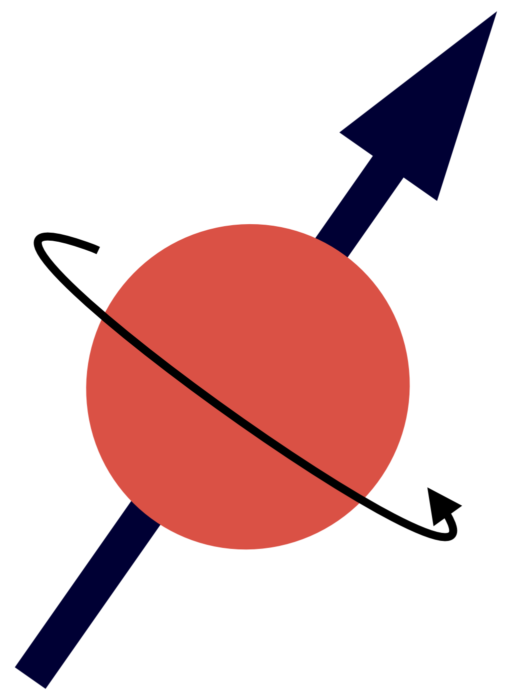
Post-Higgs Discovery Era

Some Intriguing Questions:

1. Only one Higgs? Nature of interaction? → Need more precision. HL-LHC, ILC.
2. Why no new physics at LHC? → Sensitivity!! Are we looking at right direction?
3. What is/are Dark Matter? → Experiments devoted to DM searches.
4. Other anomalies !! → Anomalous muon magnetic moment !!

Anomalous Muon Magnetic moment

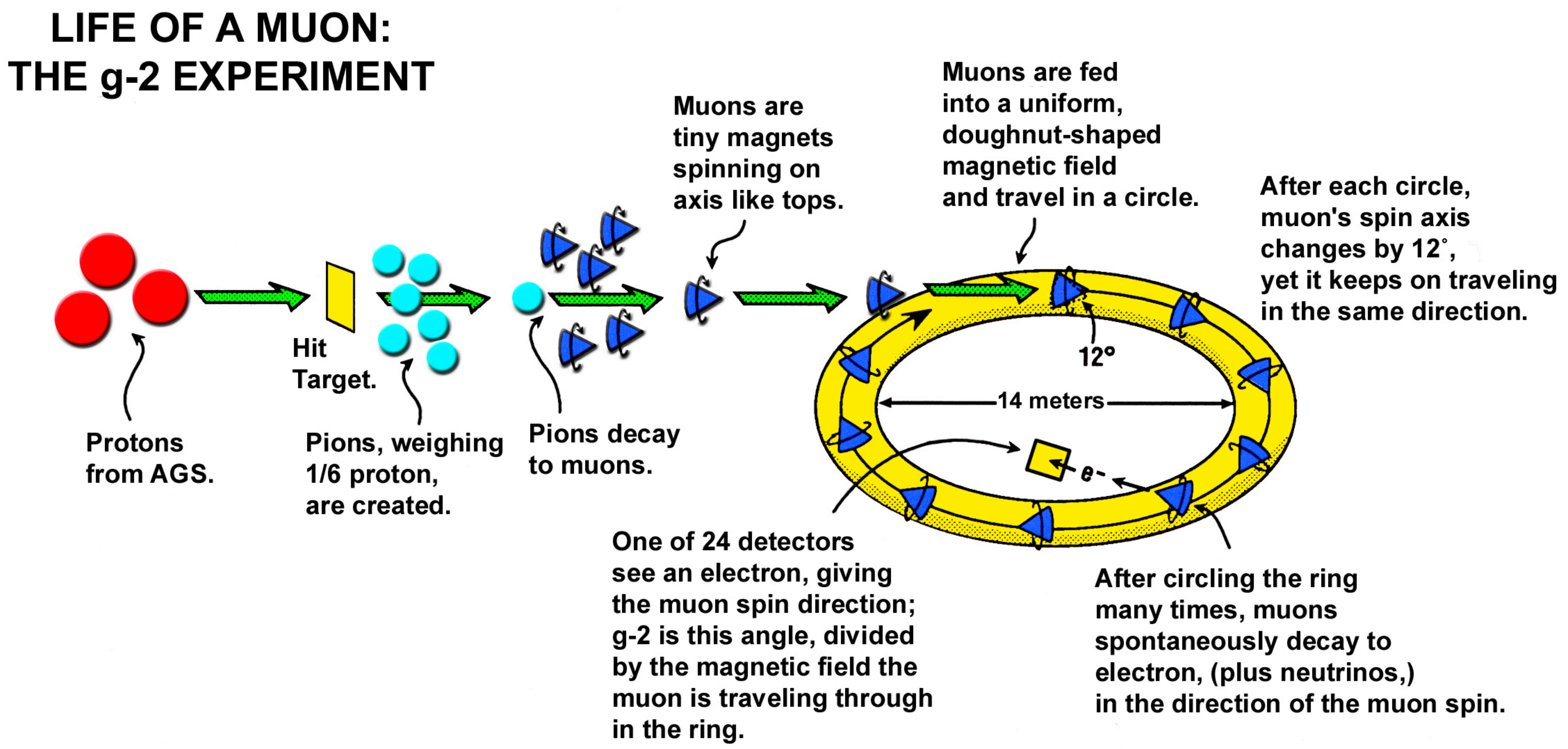
Magnetic moment of charged muon $\vec{\mu} = g\frac{e}{2m}\vec{S}$



Quantum loop effects: $\bar{u}(p')\left[\gamma^{\mu}F_1(q^2) + \frac{i}{2m_{\mu}}\sigma^{\mu\nu}q_{\nu}F_2(q^2)\right]u(p)A_{\mu}$

Anomalous magnetic moment $a_{\mu} \equiv \frac{g-2}{2} = F_2(0)$

Anomalous Muon Magnetic moment

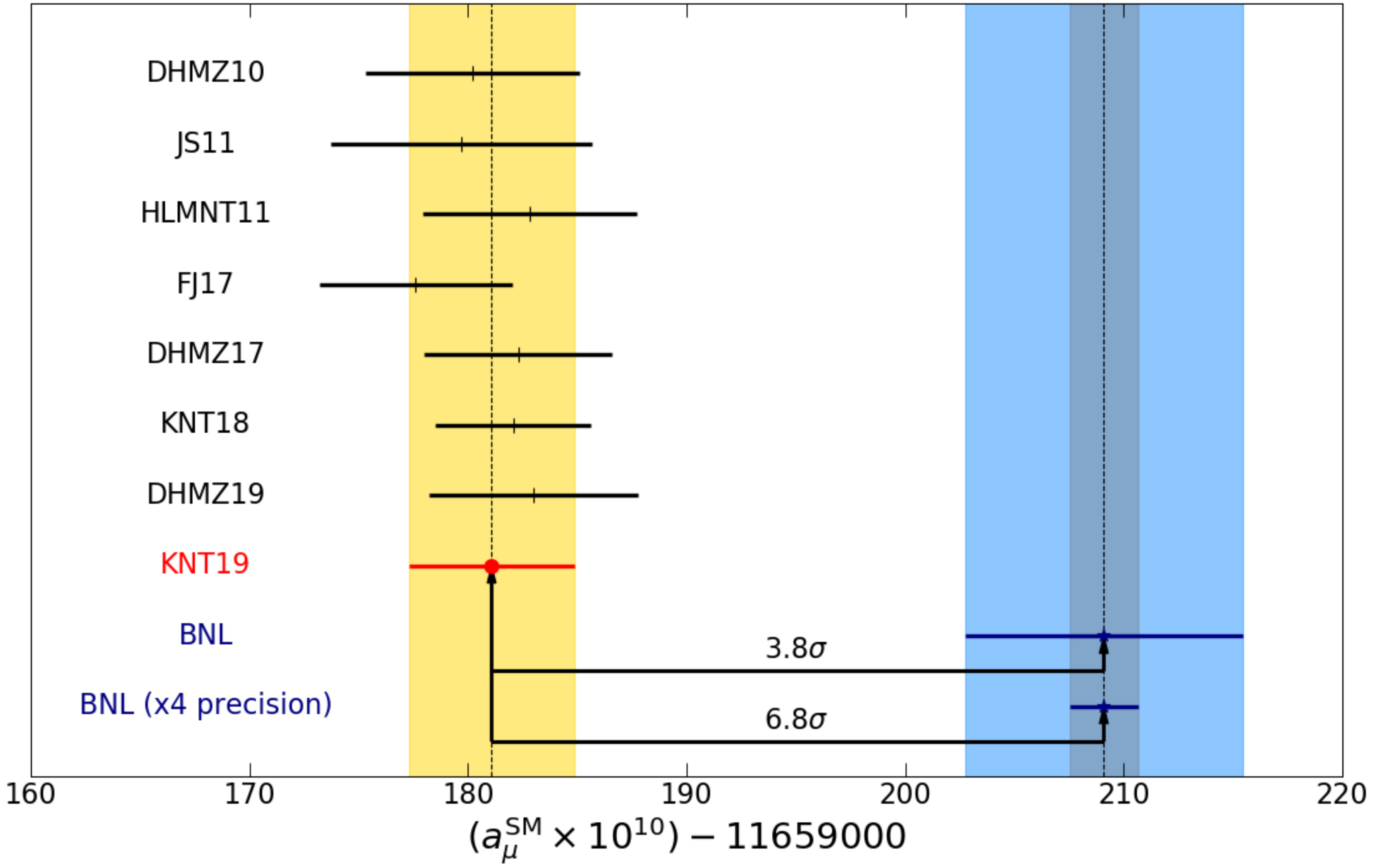


Picture taken from webpage of BNL experiment

Anomalous Muon Magnetic moment

The current experimental and theoretical (SM) results:

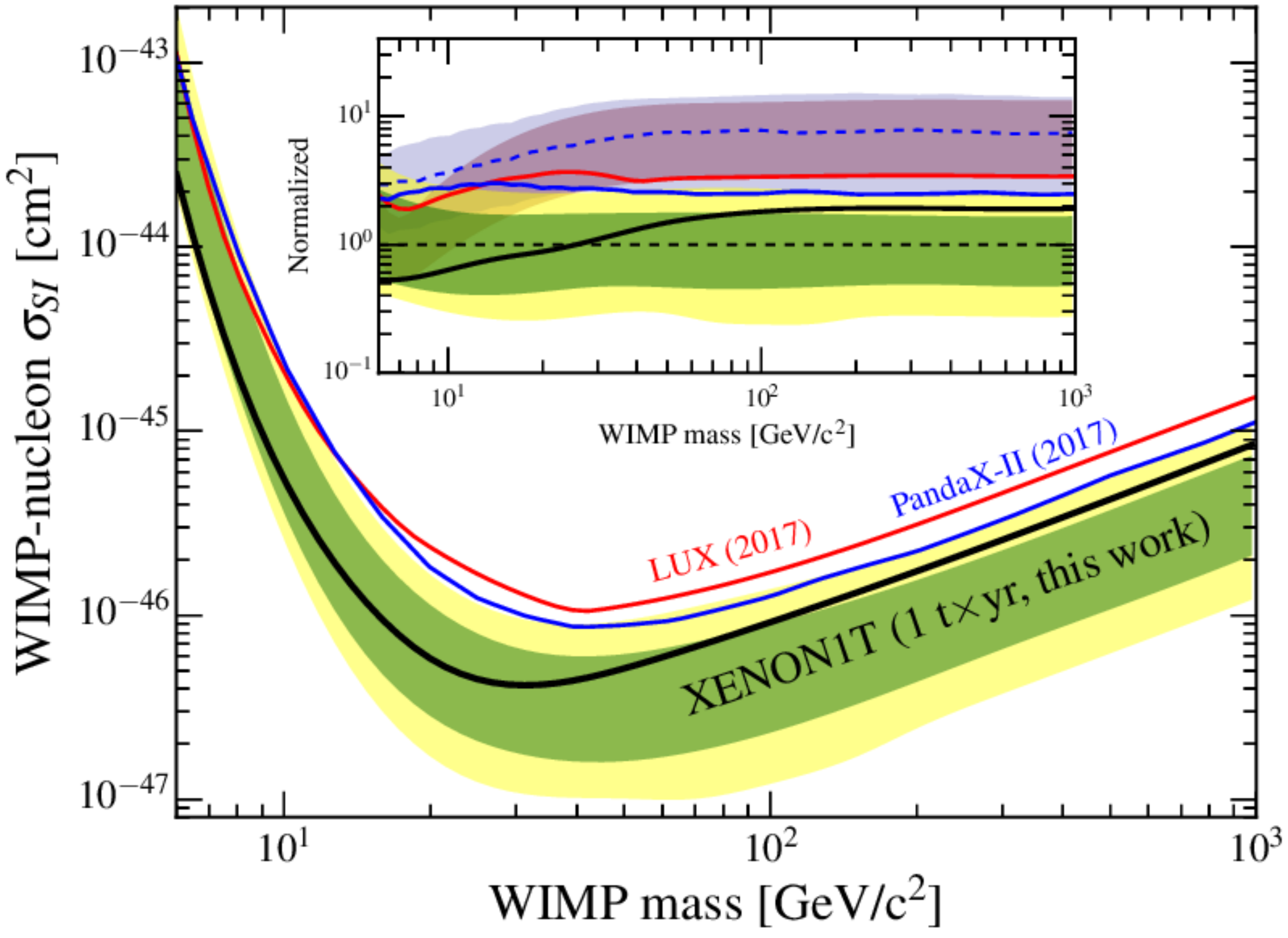
$$a_\mu^{exp} - a_\mu^{SM} = (28.02 \pm 7.37) \times 10^{-10}$$



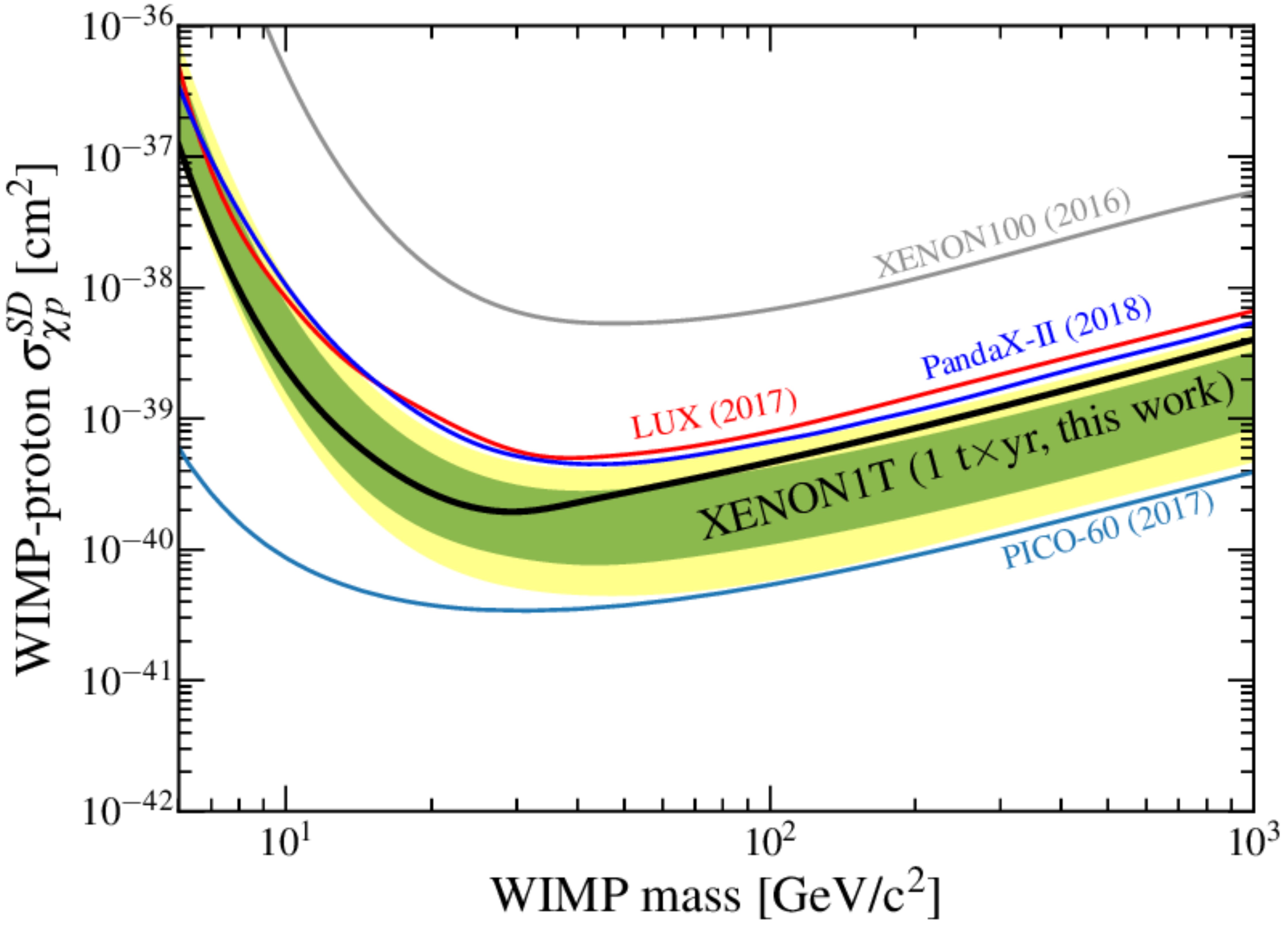
Latest SM world average - **Aoyama *et al* '20**

A. Keshavarzia, D. Nomura, T. Teubner '19

WIMP Status



Spin-independent



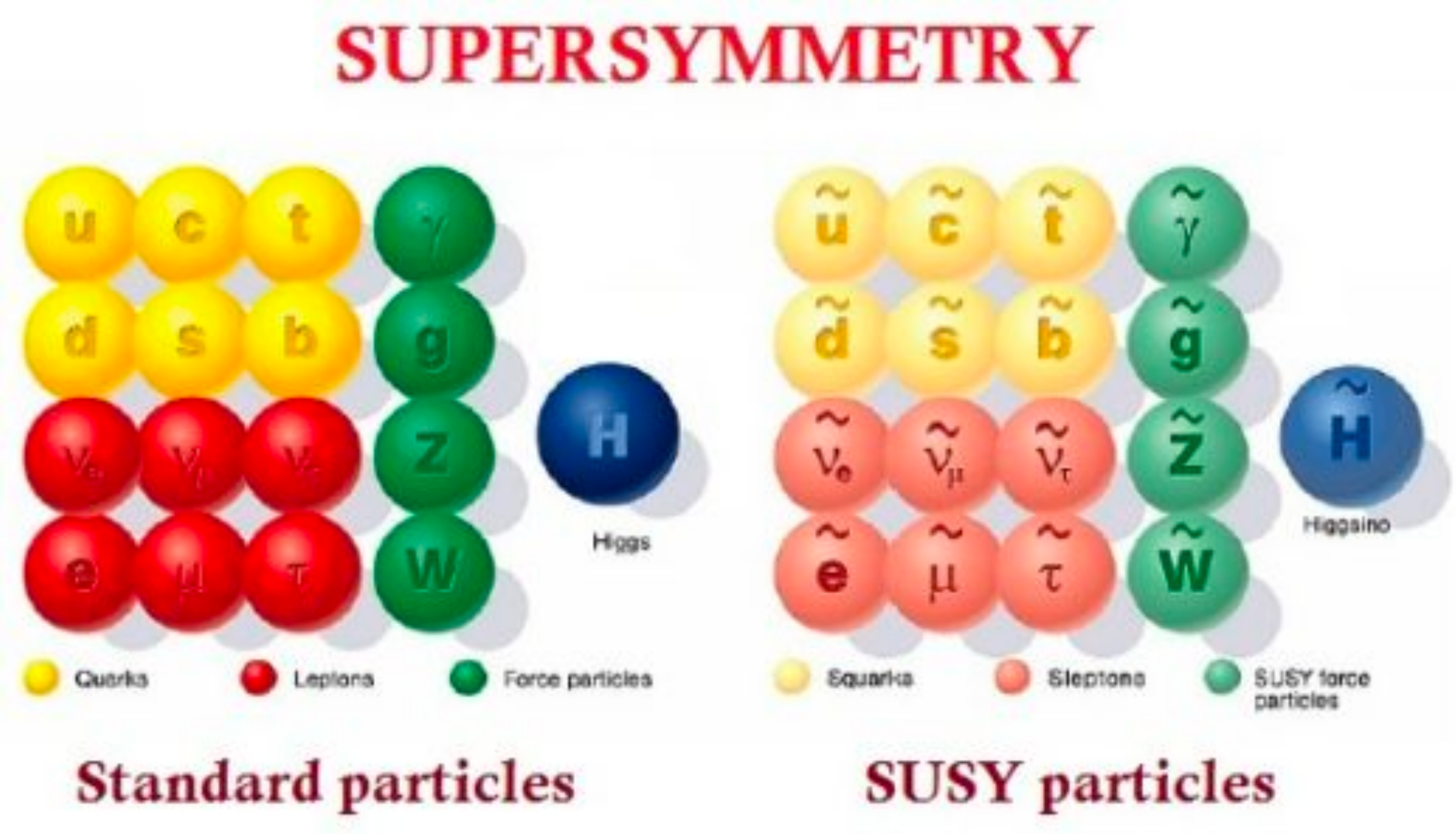
Spin-dependent

Minimal supersymmetric standard model

- Large uncolored EW Sector may be the hiding key to new physics!

- Modest production cross-section, mass bounds from LHC rather weak.

- Compelling evidence may come from Dark Matter experiments, $(g-2)_\mu$ etc..



MSSM Superpotential

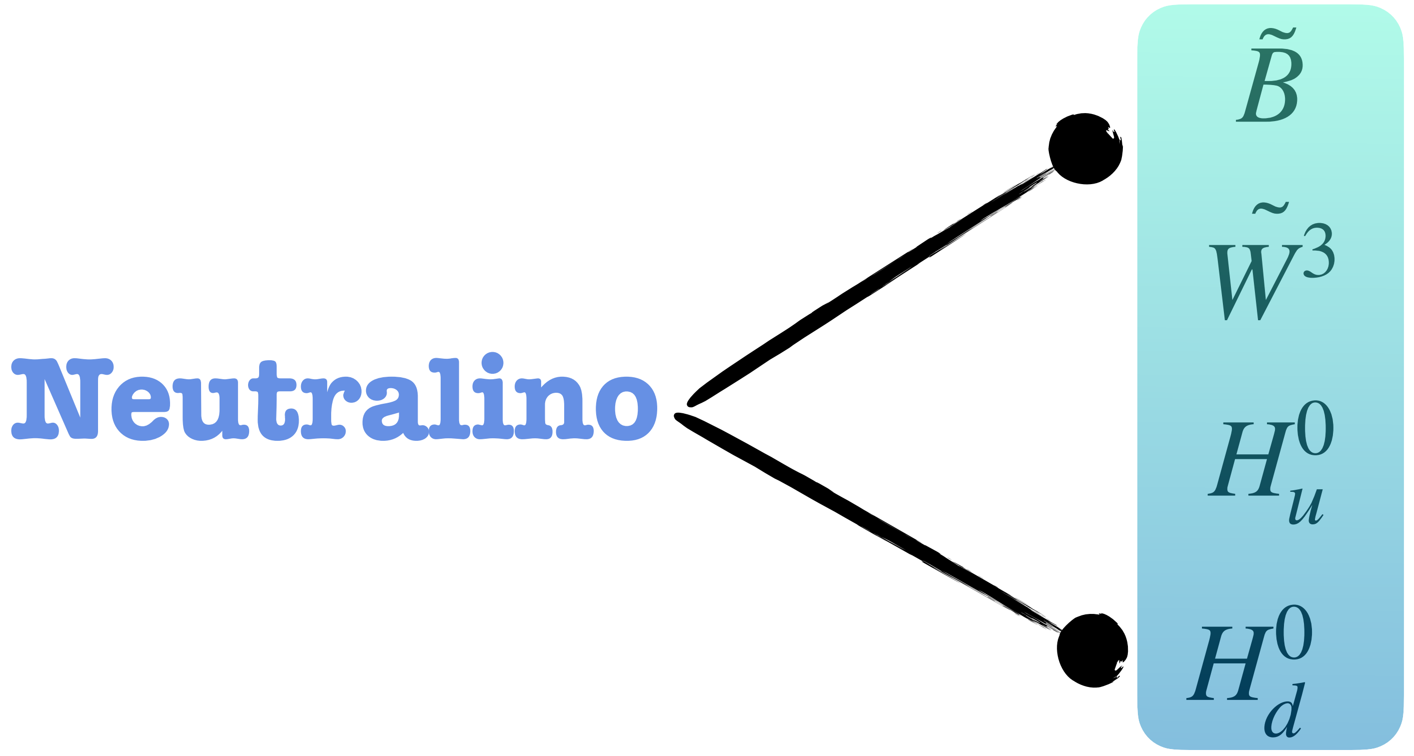
$$W_{\text{MSSM}} = \bar{u} Y_u Q H_u - \bar{d} Y_d Q H_d - \bar{e} Y_e L H_d + \mu H_u H_d$$

Soft Breaking Terms

$$\begin{aligned}\mathscr{L}_{\text{soft}}^{\text{MSSM}} = &-\frac{1}{2}\left(M_3 \tilde{g}\tilde{g} + M_2 \tilde{W}\tilde{W} + M_1 \tilde{B}\tilde{B} + c.c\right) \\ &-\left(\tilde{\bar{u}}\, \mathbf{a_u}\, \tilde{Q} H_u - \tilde{\bar{d}}\, \mathbf{a_d}\, \tilde{Q} H_d - \tilde{\bar{e}}\, \mathbf{a_e}\, \tilde{L} H_d + c.c\right) \\ &-\tilde{Q}^\dagger \mathbf{m_Q^2} \tilde{Q} - \tilde{L}^\dagger \mathbf{m_L^2} \tilde{L} - \tilde{\bar{u}}\, \mathbf{m_{\bar{u}}^2}\, \tilde{\bar{u}}^\dagger - \tilde{\bar{d}}\, \mathbf{m_{\bar{d}}^2}\, \tilde{\bar{d}}^\dagger - \tilde{\bar{e}}\, \mathbf{m_{\bar{e}}^2}\, \tilde{\bar{e}}^\dagger \\ &- m_{H_u}^2 H_u^* H_u - m_{H_d}^2 H_d^* H_d - \left(b H_u H_d + c.c\right)\end{aligned}$$

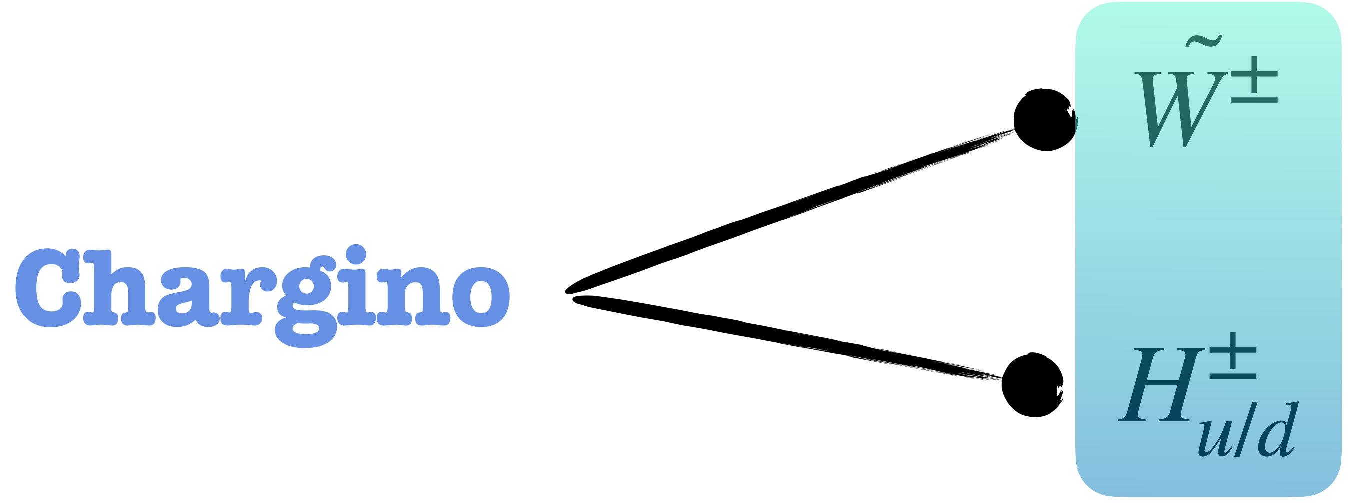
EW Gauginos

Masses and mixing are determined by U(1) and SU(2) gaugino masses M_1, M_2 and Higgs mass parameter μ.



<u>Neutralino Mass Matrix</u>

$$M_N = \begin{pmatrix} M_1 & 0 & -M_Z\, c_\beta\, s_W & M_Z\, s_\beta\, s_W \\ 0 & M_2 & M_Z\, c_\beta\, cW & -M_Z\, s_\beta\, cW \\ -M_Z\, c_\beta\, s_W & M_Z\, c_\beta\, c_W & 0 & -\mu \\ M_Z\, s_\beta\, s_W & -M_Z\, s_\beta\, c_W & -\mu & 0 \end{pmatrix}$$



<u>Chargino Mass Matrix</u>

$$M_C = \begin{pmatrix} M_2 & \sqrt{2} M_W c_\beta \\ \sqrt{2} M_W s_\beta & \mu \end{pmatrix}$$

LSP in RPC

DM

Four Parameters → $M_1, M_2, \mu, \tan\beta$

Sleptons

Slepton Mass Matrix

$$M_{\tilde{L}}^2 = \begin{pmatrix} m_l^2 + m_{LL}^2 & m_l X_l \\ m_l X_l & m_l^2 + m_{RR}^2 \end{pmatrix}$$

$$m_{LL}^2 = m_{\tilde{L}}^2 + (I_l^{3L} - Q_f s_w^2) M_z^2 \cos 2\beta$$

$$m_{RR}^2 = m_{\tilde{R}}^2 + Q_f s_w^2 M_z^2 \cos 2\beta$$

$$X_l = A_l - \mu (\tan\beta)^{2 I_l^{3L}}$$

Parameters → $M_1, M_2, \mu, \tan\beta, m_{\tilde{L}}, m_{\tilde{R}}$

Muon (g-2)

- Currently large discrepancy from the SM $> (3\sigma). a_\mu^{exp} - a_\mu^{SM} = (28.02 \pm 7.37) \times 10^{-10}$

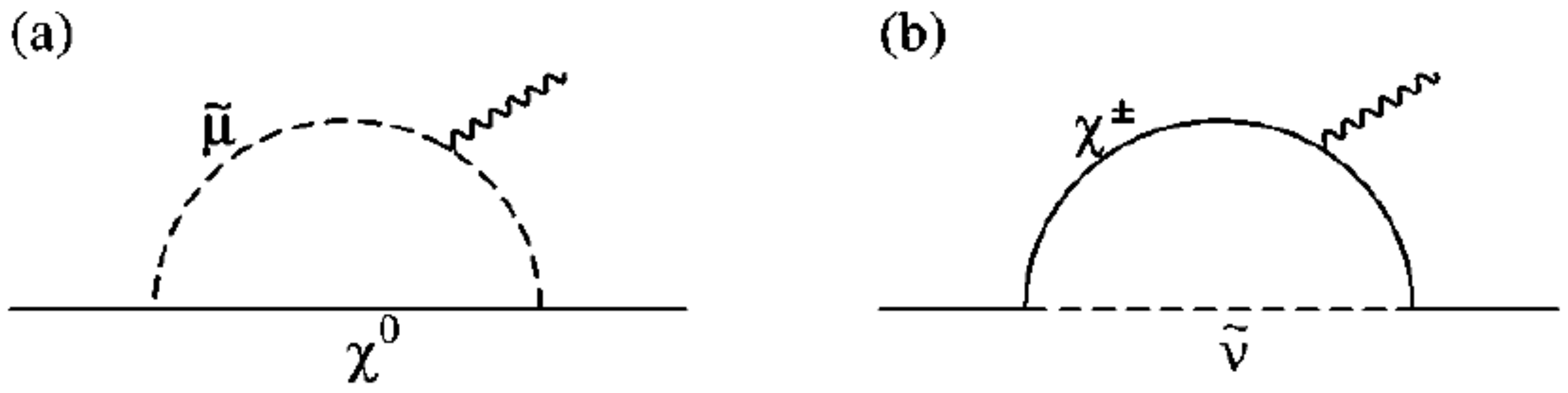
Kashavarzi, Nomura, Teubner '19

- Assuming upcoming Fermilab Run-I result to have the same central value and same exp uncertainty, combined data corresponds to $> 5\sigma$ discrepancy.
$a_\mu^{exp} - a_\mu^{SM} = (28.02 \pm 5.2) \times 10^{-10}$

- New "World average" appeared
→ modest impact on our analysis

Aoyama *et al* '20

SUSY contributions @ 1L from Chargino-Sneutrino and Smuon-Neutralino loop



Enhancement factor ~ $\tan\beta$.

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

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

Upper limit on EW masses at 95% C.L from a_μ

K.Hagiwara, K.Ma, S. Mukhopadhyaya '17, T. Yanagida, W.Yu, N.Yokozaki '16, '20,

S. AbdusSalam et. al '11, E. Bagnashi et. al '15, P. Cox, C. Han, T. Yanagida '18, '19, M.Endo, K. Hamaguchi, S. Iwamoto, T. Kitahara '20

Other Constraints

Proper recasting is important.

Direct Searches at LHC

- LHC searches restricted to **simplified models**

  → sparticles except those relevant to the signal are taken to be decoupled.

- $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ are taken to be mass-degenerate and purely wino. $\tilde{\chi}_1^0$ is assumed to be purely bino.

- All three generations of sleptons and sneutrinos are assumed mass degenerate. In MSSM:

  $$m_{\tilde{\nu}}^2 = m_{\tilde{l}}^2 + \frac{1}{2} m_Z^2 cos2\beta$$

- Heavier gauginos $\tilde{\chi}_3^0, \tilde{\chi}_4^0, \tilde{\chi}_2^{\pm}$ assumed to be decoupled.

- No sensitivity to parameters like $\tan\beta$.

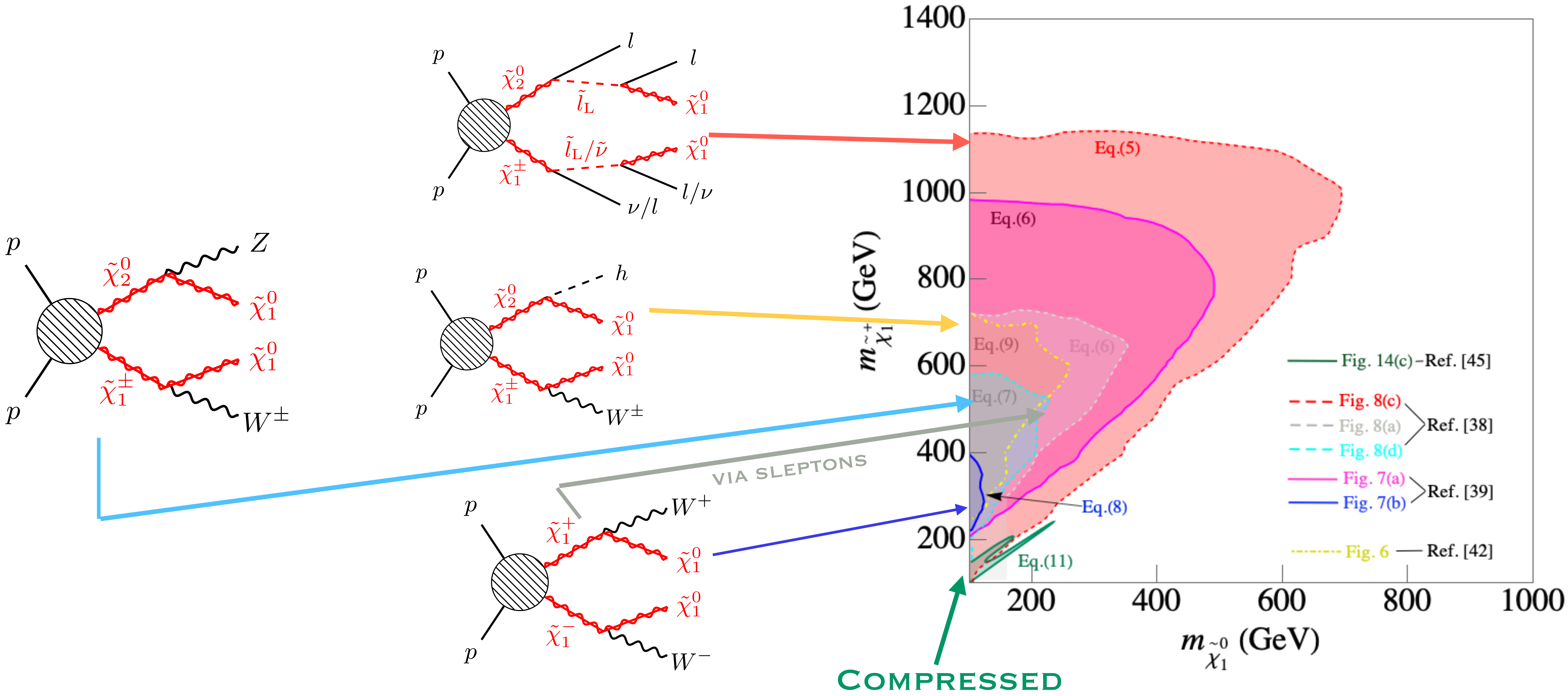
Indirect Constraints

- Relic abundance from PLANCK $\Omega_h^2 = 0.120 \pm 0.001$.

- Spin independent direct detection data from XENON1T.

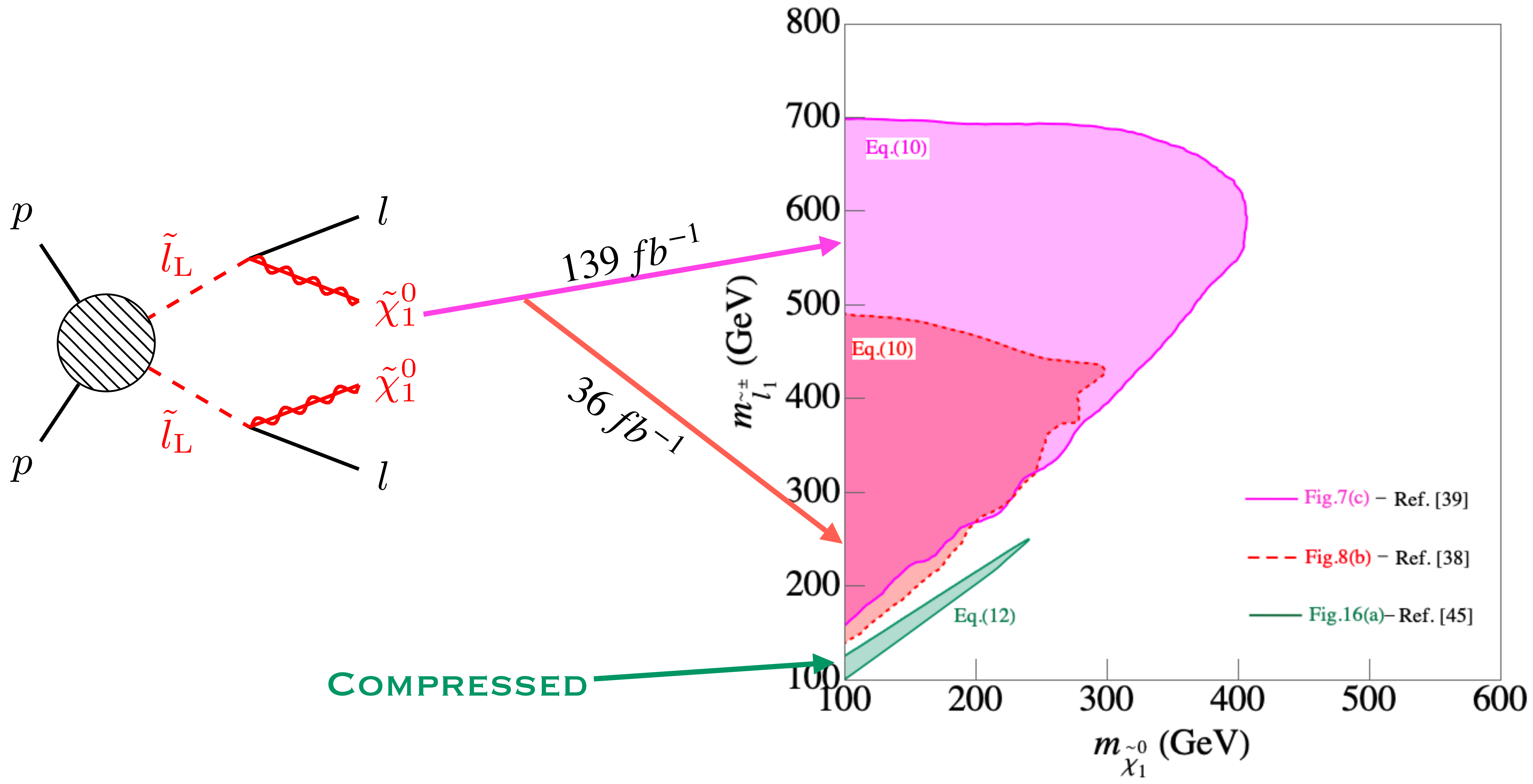
- Indirect detection constraints of dark matter.

Current searches at the LHC



Proper recasting is important. → CheckMATE

Current searches at the LHC

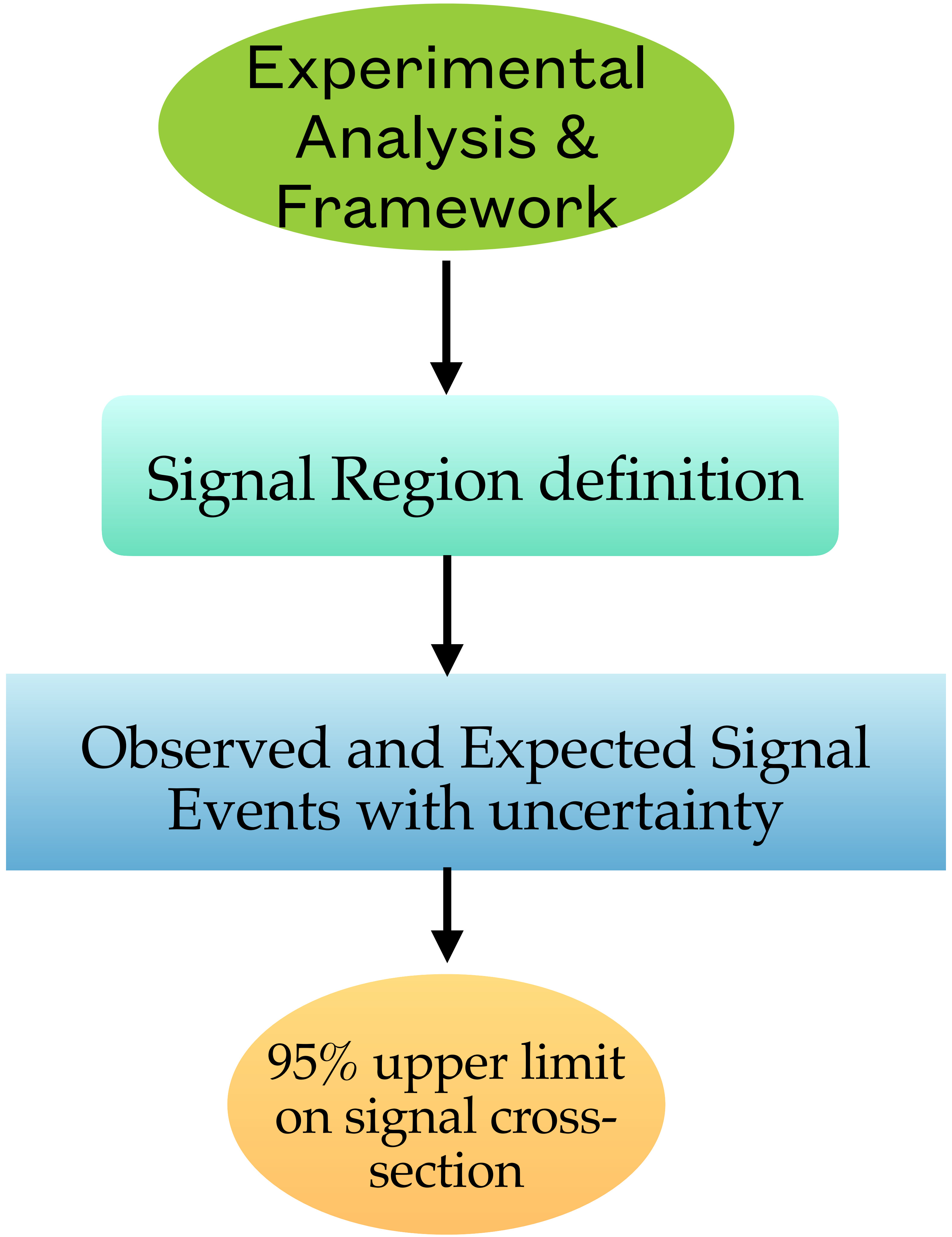


Proper recasting is important. → CheckMATE

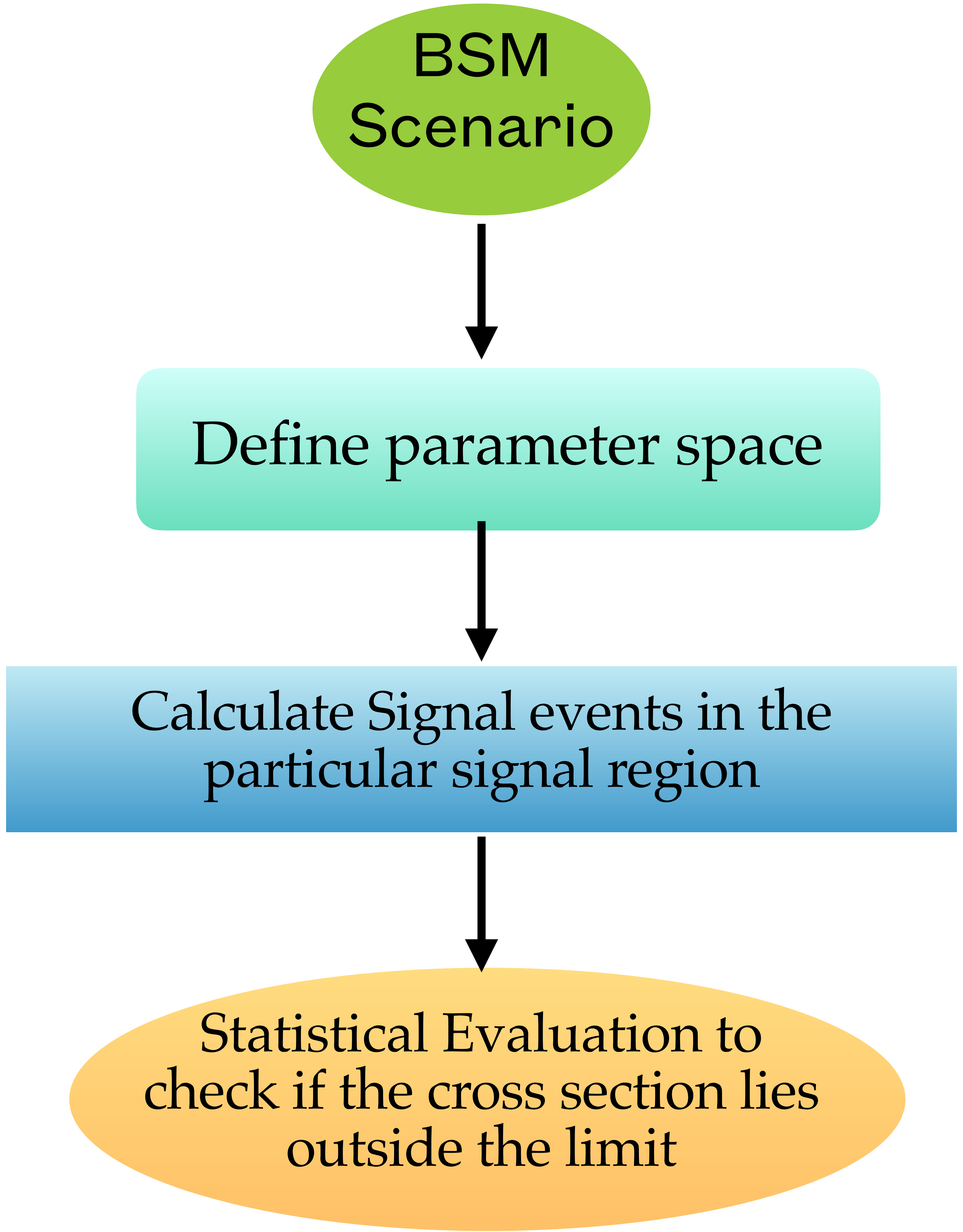
CheckMATE in brief

J. S. Kim, D. Schmeier, J. Tattersall and K. Rolbiecki, *Comput. Phys. Commun.* **196** (2015), 535-562 [arXiv:1503.01123 [hep-ph]].

M. Drees, H. Dreiner, D. Schmeier, J. Tattersall and J. S. Kim, *Comput. Phys. Commun.* **187** (2015), 227-265 [arXiv:1312.2591 [hep-ph]].



Input for Implementation of new analysis



Model parameter test

ut. Phys. Commun. **196**

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CHECKMATE

M. Chakraborti, S.Heinemeyer, IS :EPJC 80 (2020) 10, 984

M. Chakraborti, S.Heinemeyer, IS : Ongoing

CheckMATE (**Check M**odels **At T**erascale **E**nergies) is a program package which accepts simulated event files in many formats for any given model. The program then determines whether the model is excluded or not at 95% C.L. by comparing to many recent experimental analyses. Furthermore the program can calculate confidence limits and provide detailed information about signal regions of interest. It is simple to use and the program structure allows for easy extensions to upcoming LHC results in the future.

Current Members: Manimala Chakraborti, Nishita Desai, Florian Domingo, Jong Soo Kim, Krzysztof Rolbiecki, Roberto Ruiz de Austri, Ipsita Saha, Liangliang Shang, Mangesh Sonawane, Zeren Simon Wang, Yuanfang Yue

Former Members: Daniel Dercks, Manuel Drees, Herbert Dreiner, Frederic Ponzca, Jamie Tattersall, Thorsten Weber

Code References

CheckMATE is built upon the tools and hard work of many people. If CheckMATE is used in your publication it is *important* that all of the following citations are included,

Delphes 3: JHEP 1402 (2014) 057
FastJet: Eur.Phys.J. C72 (2012) 1896
Phys.Lett. B641 (2006) 57-61
Anti-kt jet algorithm: JHEP 0804 (2008) 063
CLs prescription: J.Phys. G28 (2002) 2693-2704

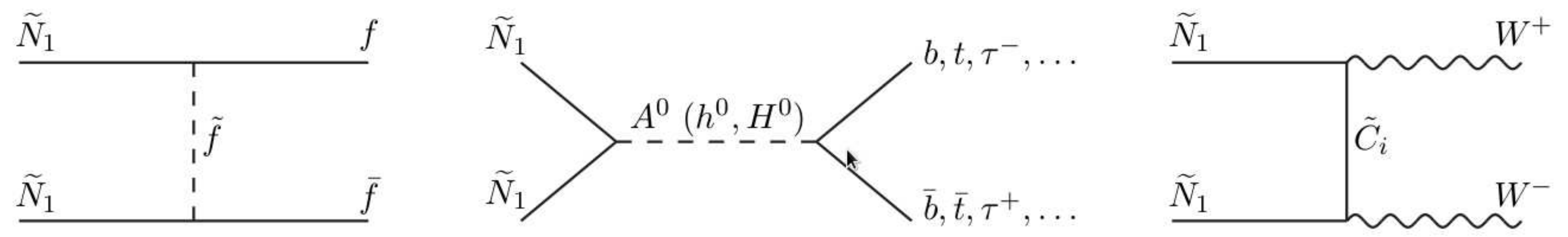
For analyses that use the MT2 family of kinematical discriminants,
Oxbridge Kinetics Library: www.hep.phy.cam.ac.uk/~lester/mt2/
Phys.Lett. B463 (1999) 99-103
J.Phys. G29 (2003) 2343-2363
Cheng and Han algorithm: JHEP 0812 (2008) 063
MT2bl: JHEP 1207 (2012) 110

For analyses that use the MCT family of kinematical discriminants,
MctLib: mctlib.hepforge.org
MCT: JHEP 0804 (2008) 034

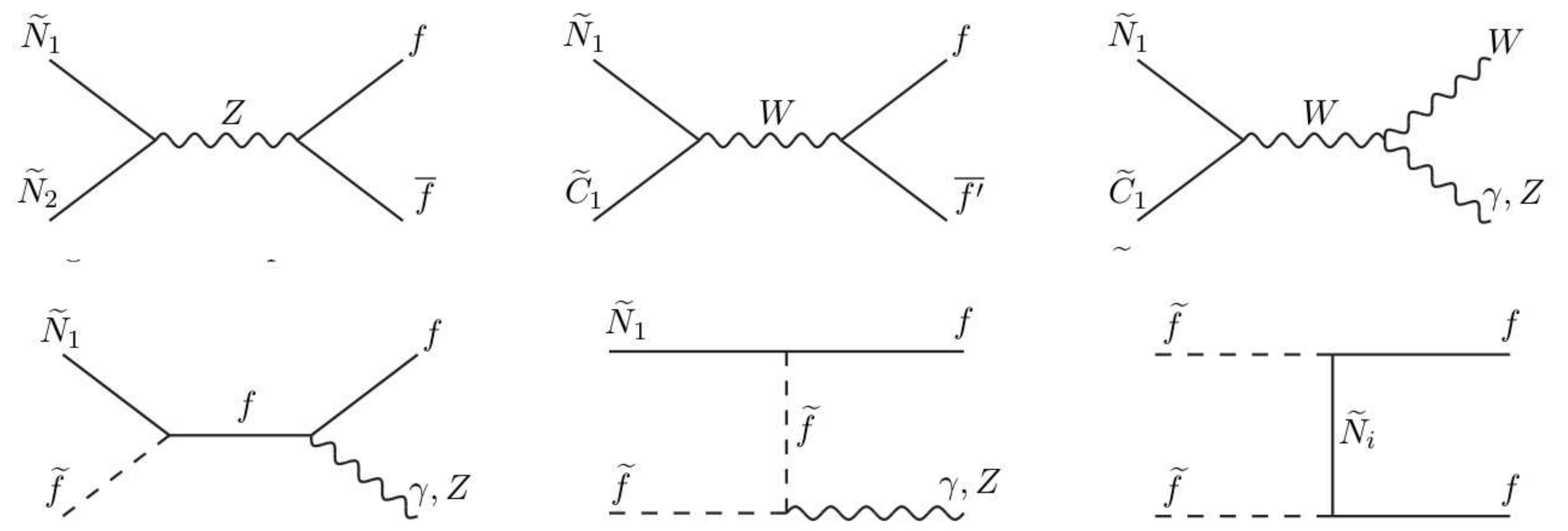
DM CONSTRAINTS

Relic Density

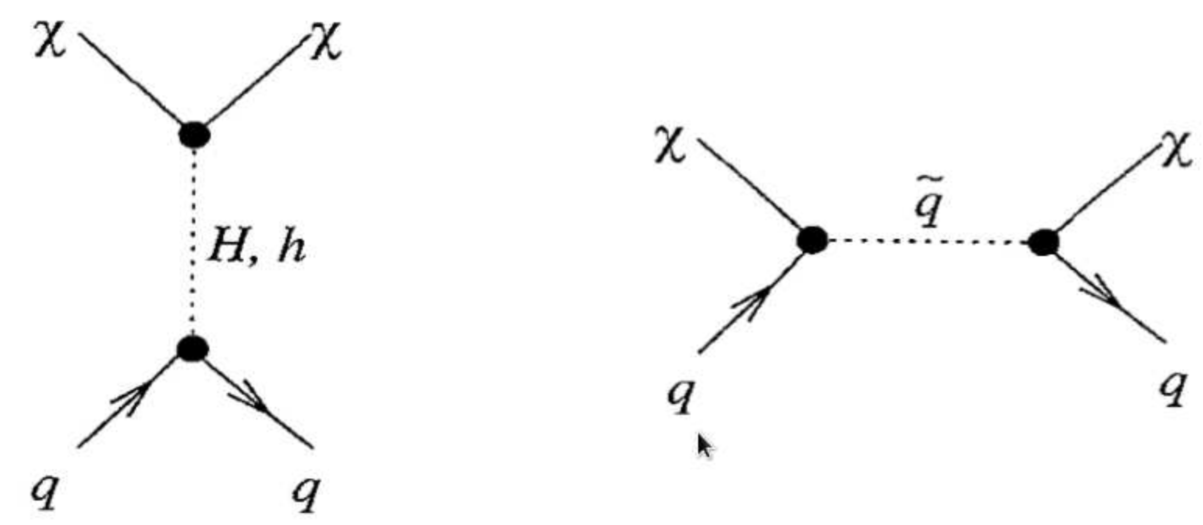
Some annihilation channels that could give right relic density :



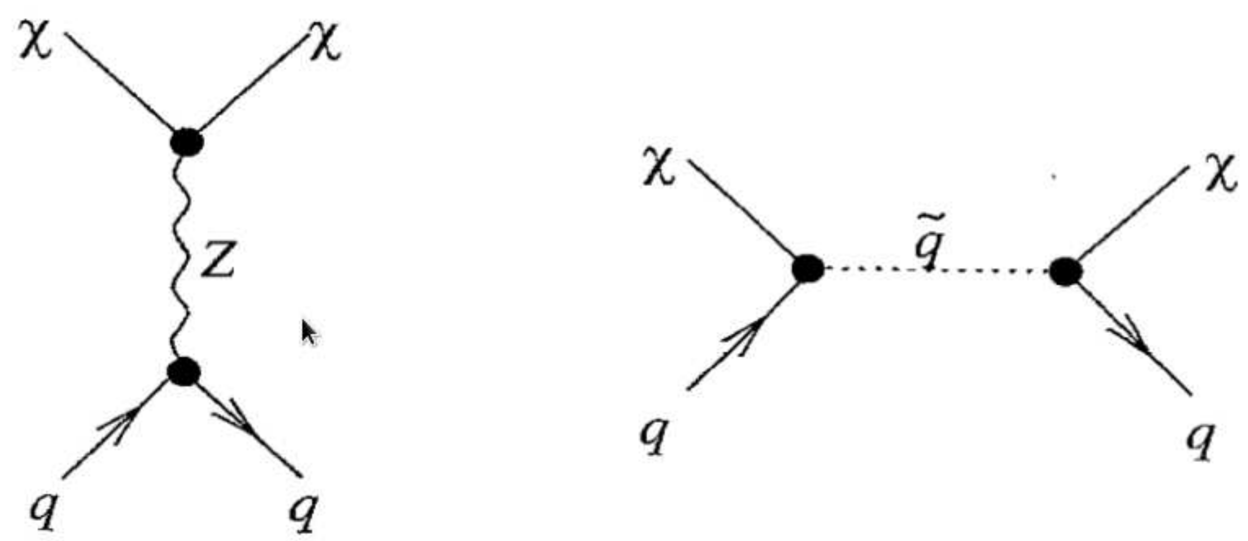
There can be coannihilations with sparticles of slightly heavier masses:



Direct Detection



Diagrams contributing to SI interactions



Diagrams contributing to SD interactions

A well-tempered bino-wino or bino-higgsino LSP is favorable for chargino co-annihilation while a bino dominated LSP will work for slepton co-annihilation.

Parameter Scanning

Chargino co-annihilation region:

$$100 \text{ GeV} \leq M_1 \leq 1 \text{ TeV} , \quad M_1 \leq M_2 \leq 1.1 M_1 ,$$
$$1.1 M_1 \leq \mu \leq 10 M_1, \quad 5 \leq \tan\beta \leq 60,$$
$$100 \text{ GeV} \leq m_{\tilde{l}_L} \leq 1 \text{ TeV}, \quad m_{\tilde{l}_R} = m_{\tilde{l}_L} .$$

Slepton co-annihilation region:

Case-L: SU(2) doublet

$$100 \text{ GeV} \leq M_1 \leq 1 \text{ TeV} , \quad M_1 \leq M_2 \leq 10 M_1 ,$$
$$1.1 M_1 \leq \mu \leq 10 M_1, \quad 5 \leq \tan\beta \leq 60,$$
$$M_1 \text{ GeV} \leq m_{\tilde{l}_L} \leq 1.2 M_1, \quad M_1 \leq m_{\tilde{l}_R} \leq 10 M_1 .$$

Case-R: SU(2) singlet

$$100 \text{ GeV} \leq M_1 \leq 1 \text{ TeV} , \quad M_1 \leq M_2 \leq 10 M_1 ,$$
$$1.1 M_1 \leq \mu \leq 10 M_1, \quad 5 \leq \tan\beta \leq 60,$$
$$M_1 \text{ GeV} \leq m_{\tilde{l}_R} \leq 1.2 M_1, \quad M_1 \leq m_{\tilde{l}_L} \leq 10 M_1 .$$

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Packages used → SuSpect, SUSYHIT, GM2Calc, micrOMEGAs, CheckMATE etc.

Chargino Co-annihilation

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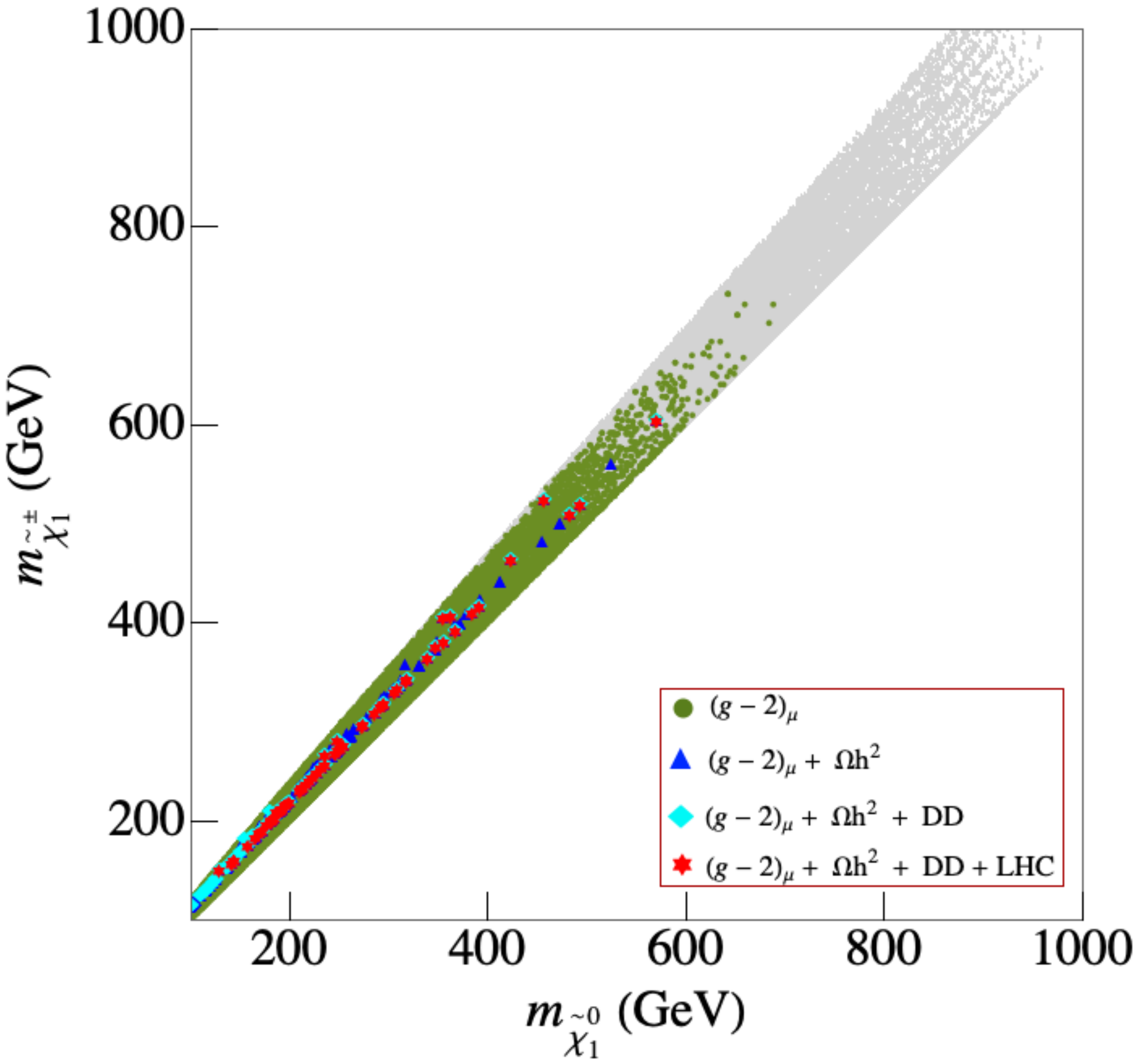
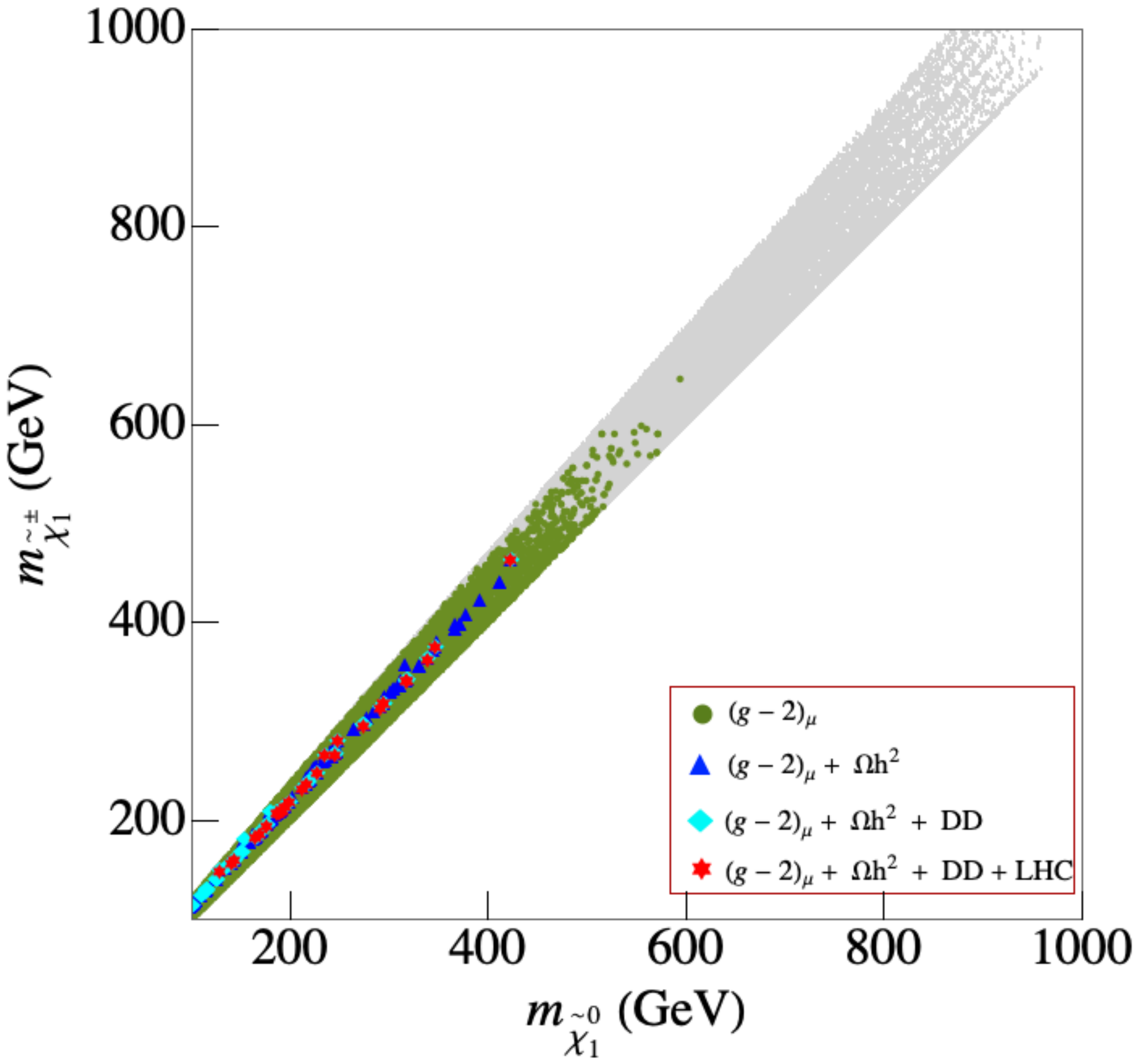
Current $(g-2)_\mu$ limit



Anticipated future $(g-2)_\mu$ limit



Upper and lower bounds from $(g-2)_\mu$ and LHC searches (compressed spectrum)

Chargino Co-annihilation

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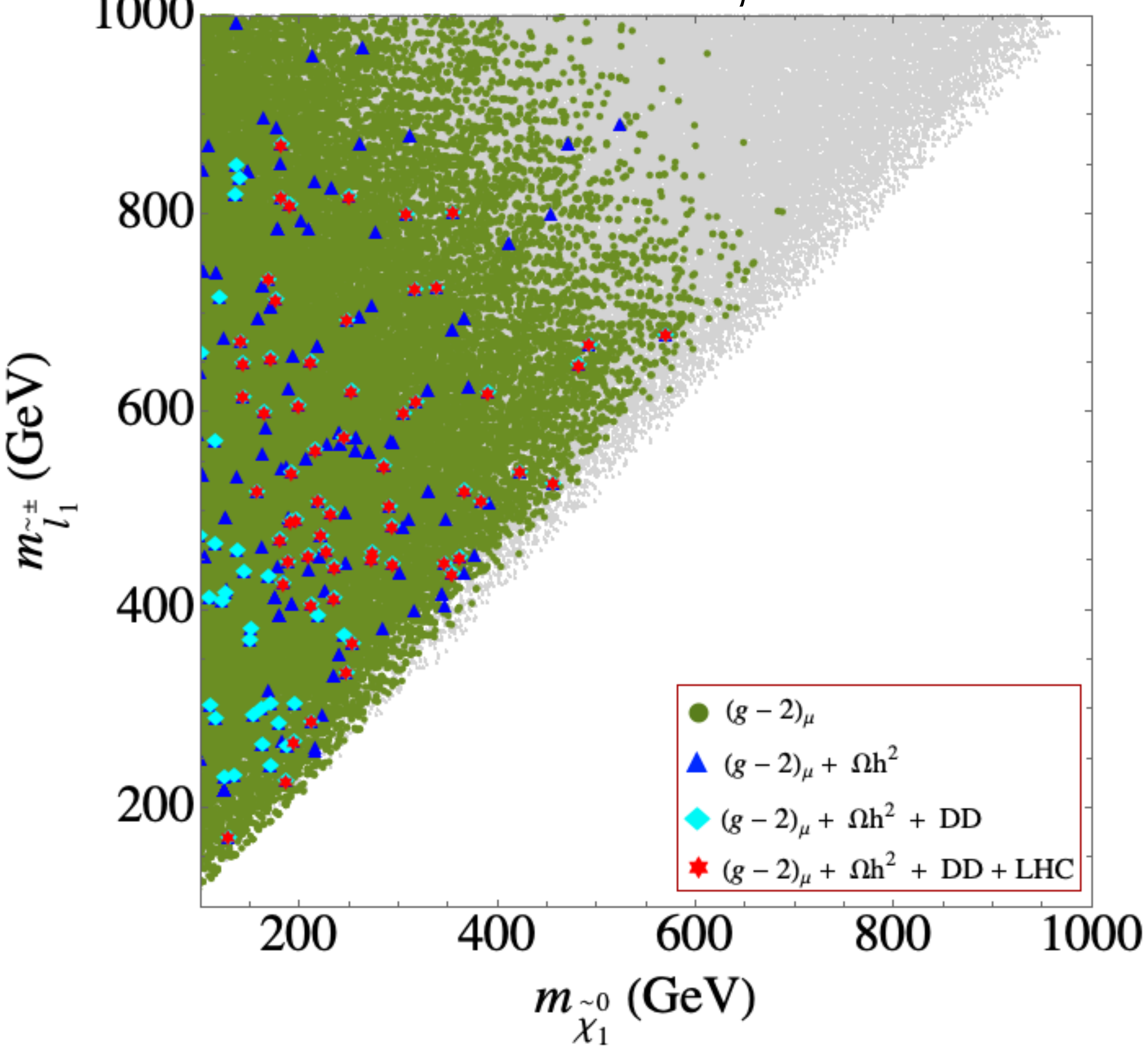
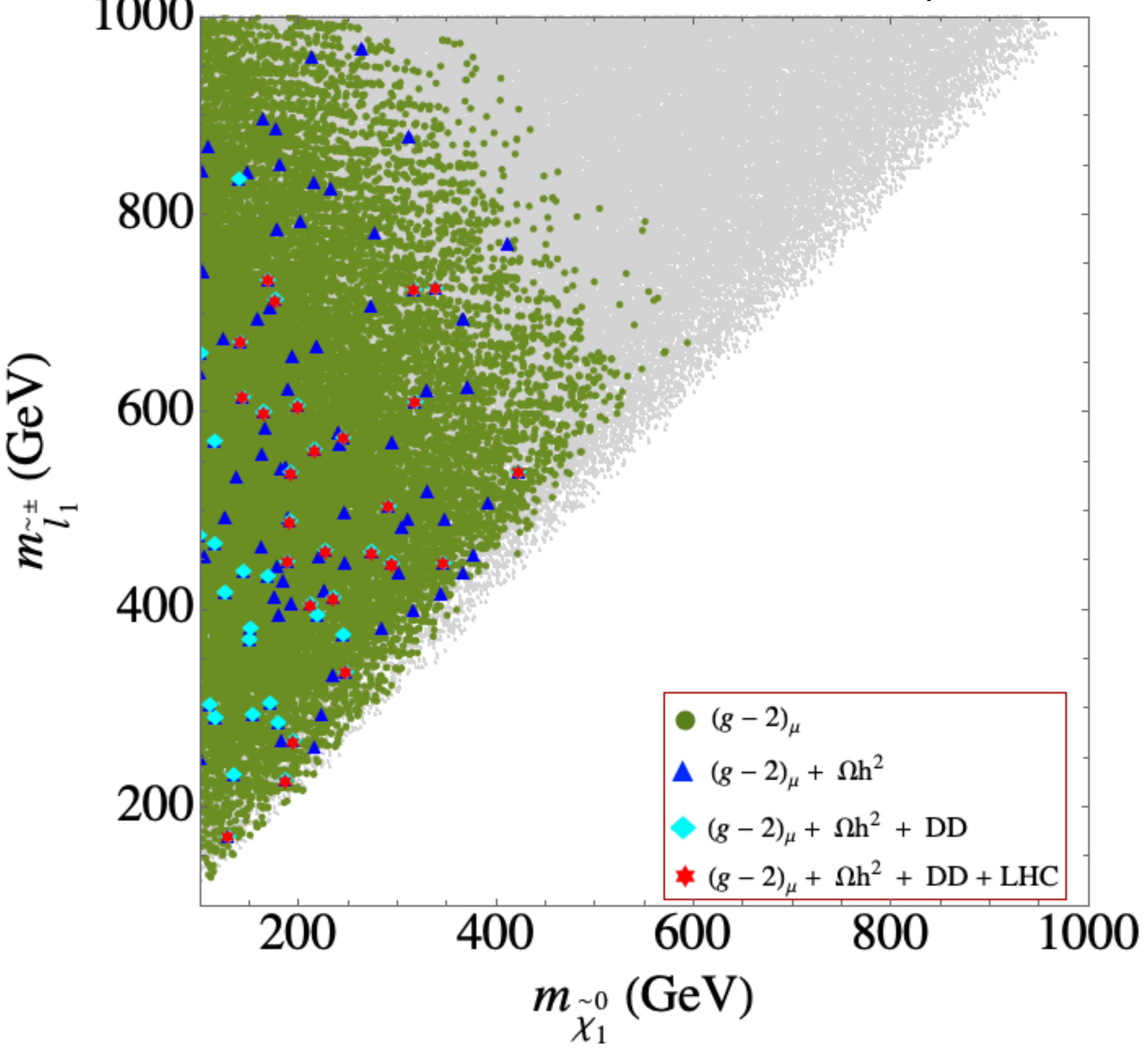
Current $(g-2)_\mu$ limit



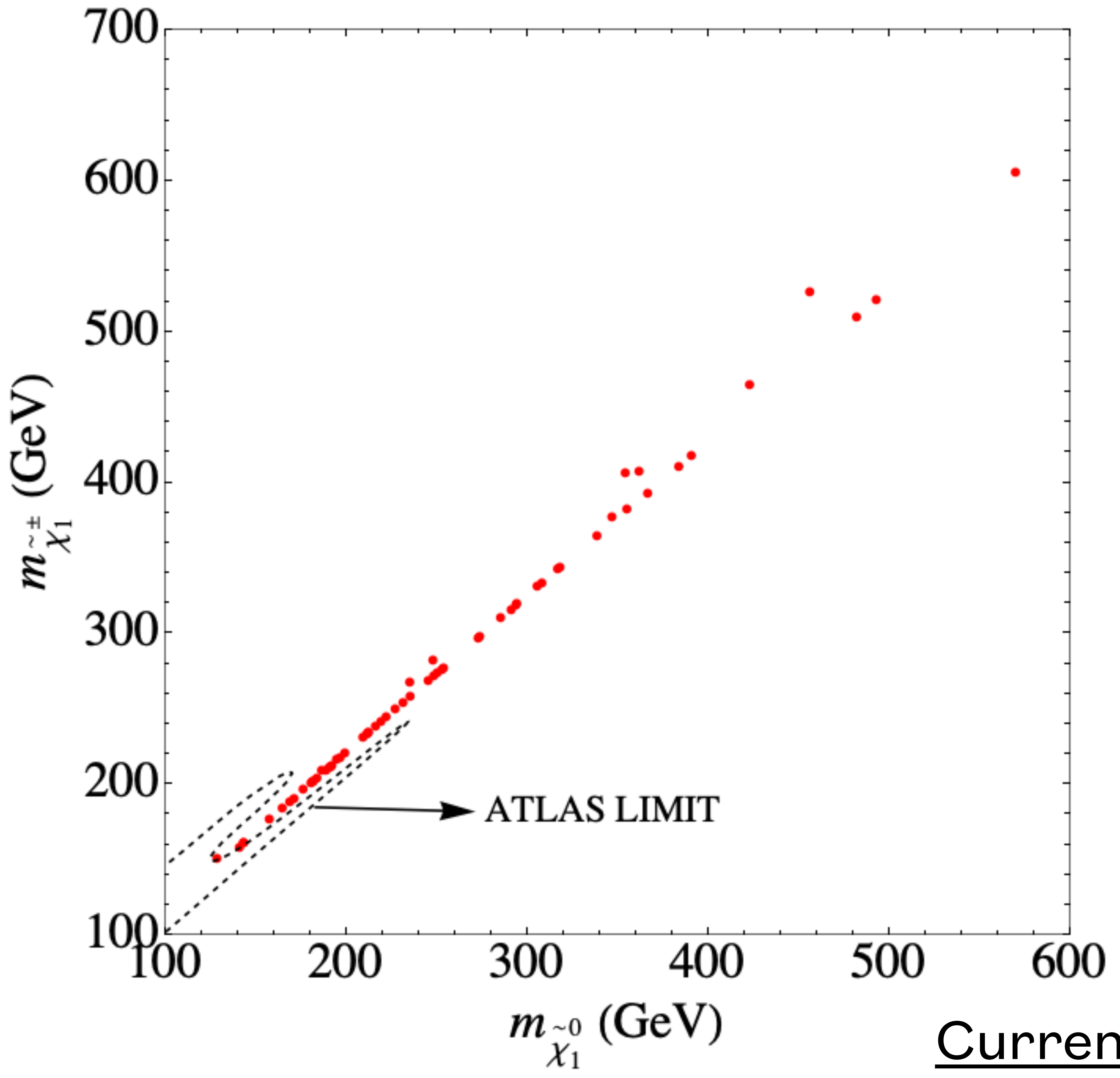
Anticipated future $(g-2)_\mu$ limit

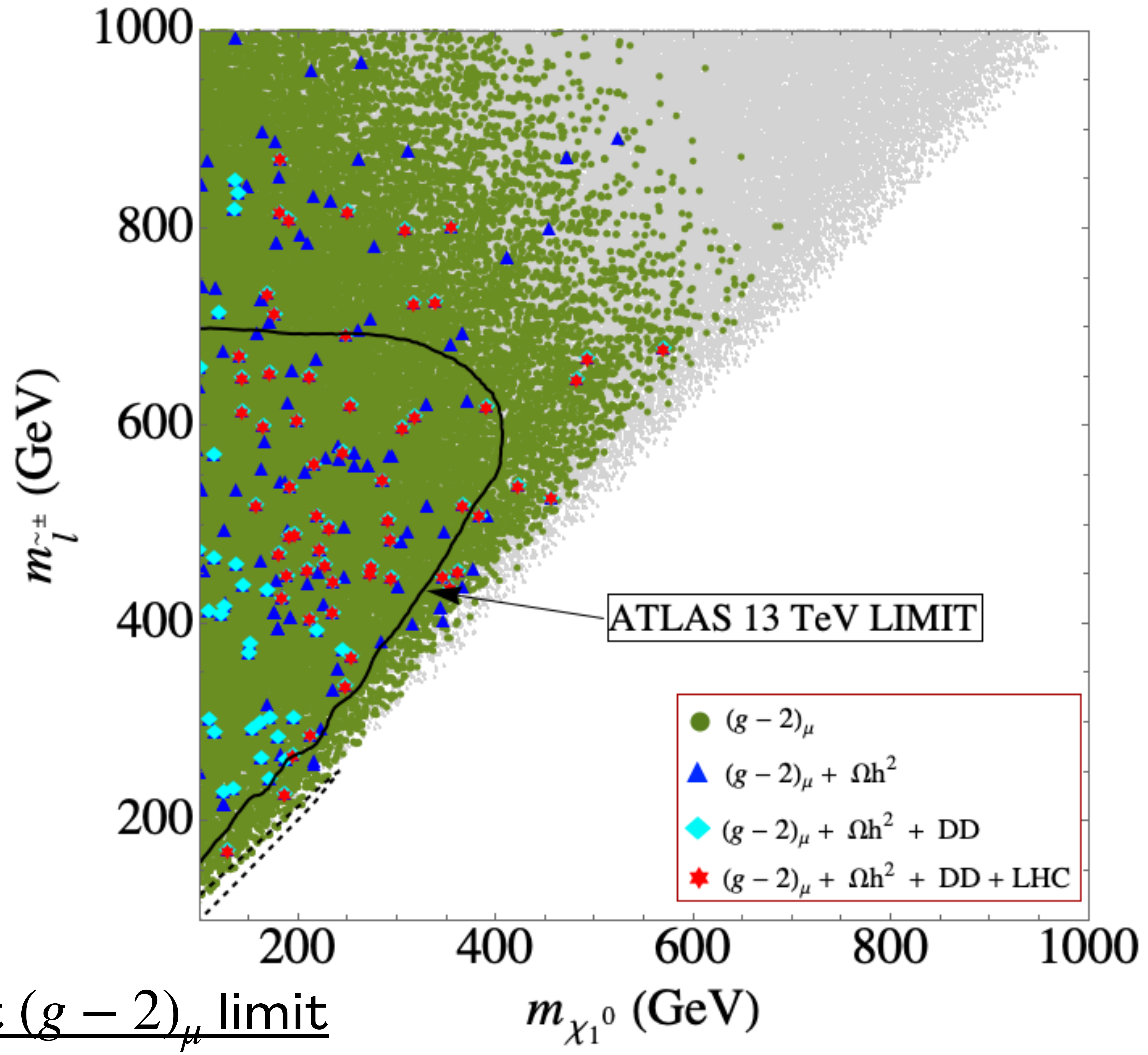


Slepton-pair production→($2l$+missingE_T) provides important search channel.

Right-sleptons are significantly heavy, Considerable BR for $\tilde{e}_L(\tilde{\mu}_L) \to \tilde{\chi}_1^\pm \nu_e(\nu_\mu)$ → Less no. of signal leptons.

Chargino Co-annihilation



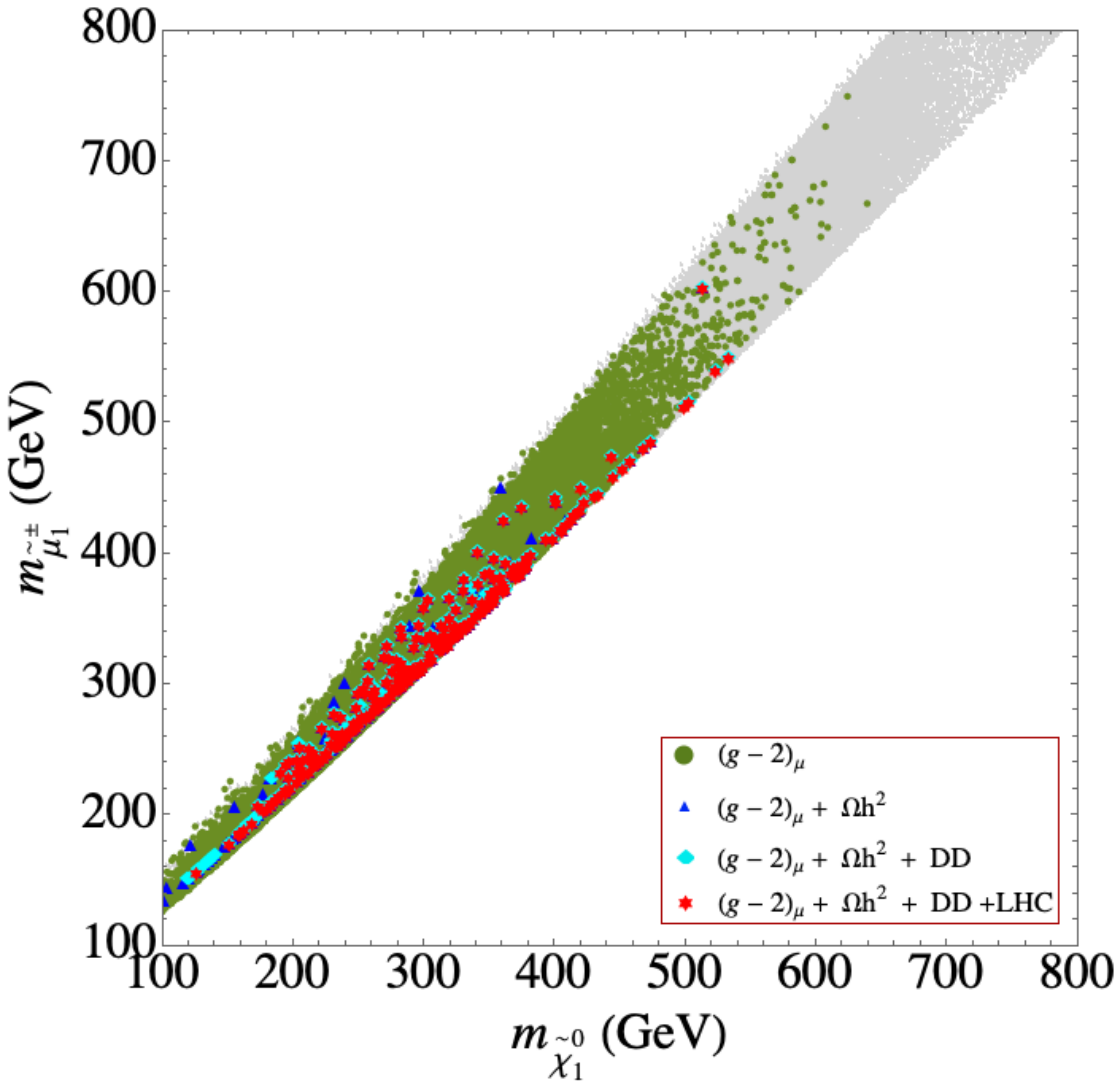


Current $(g-2)_\mu$ limit

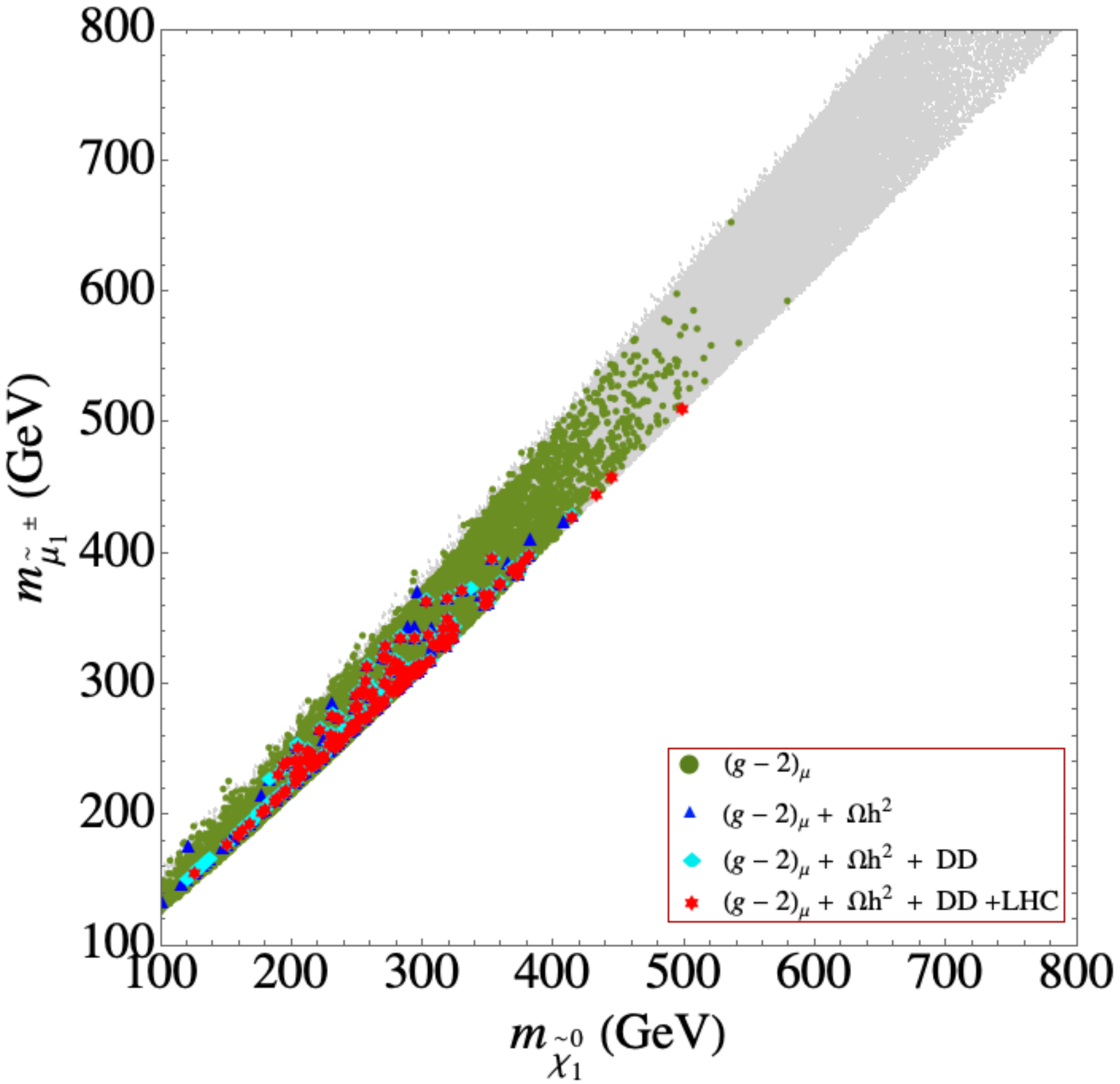
Right-sleptons are significantly heavy, Considerable BR for $\tilde{e}_L(\tilde{\mu}_L) \rightarrow \tilde{\chi}_1^{\pm}\nu_e(\nu_\mu)$ → Less no. of signal leptons.

Slepton Co-annihilation: Case-L

Current $(g-2)_\mu$ limit



Anticipated future $(g-2)_\mu$ limit



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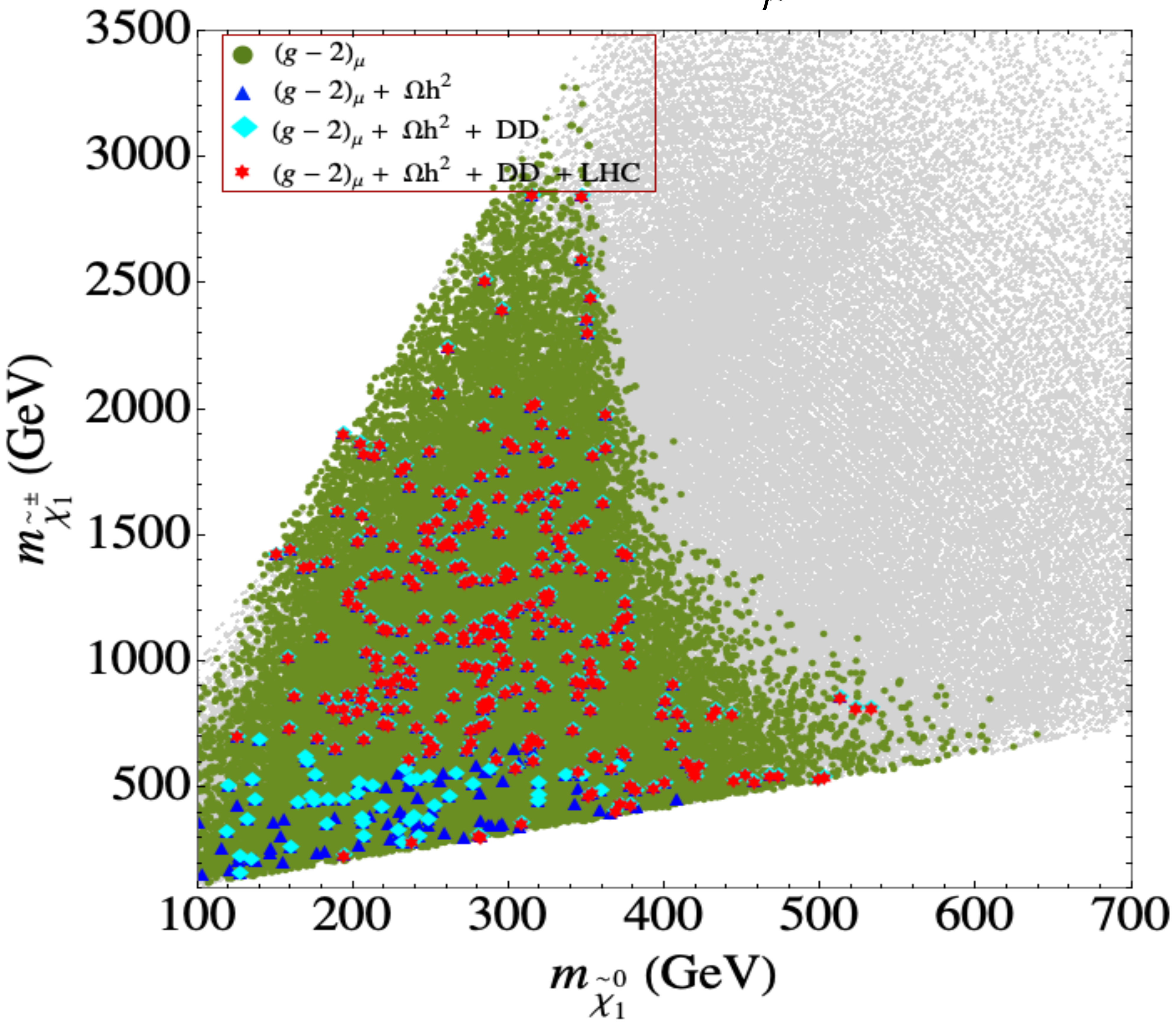
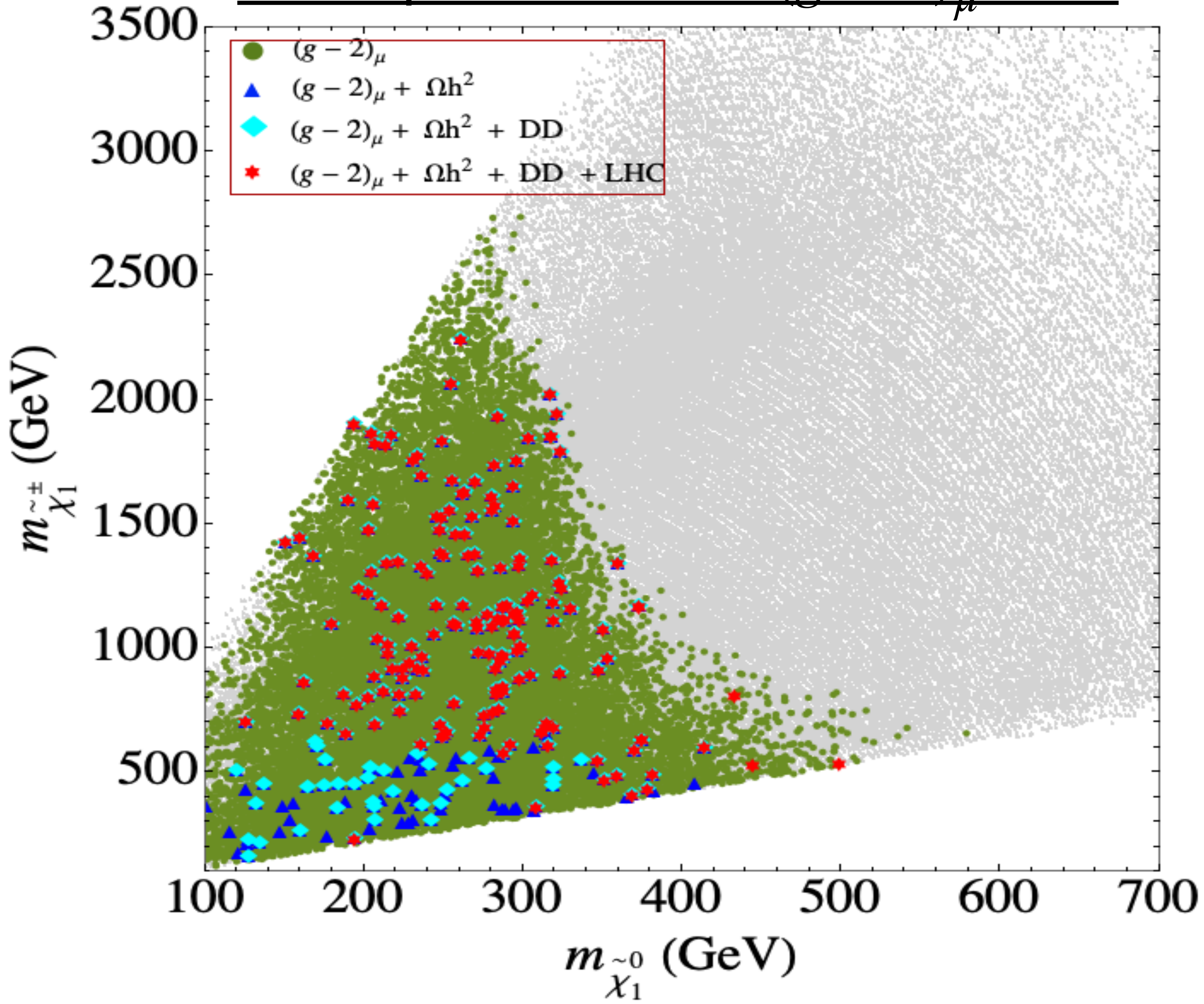
The left-sleptons and sneutrinos are close in mass to the LSP → stau not far away

Slepton Co-annihilation: Case-L

Current $(g-2)_\mu$ limit



Anticipated future $(g-2)_\mu$ limit

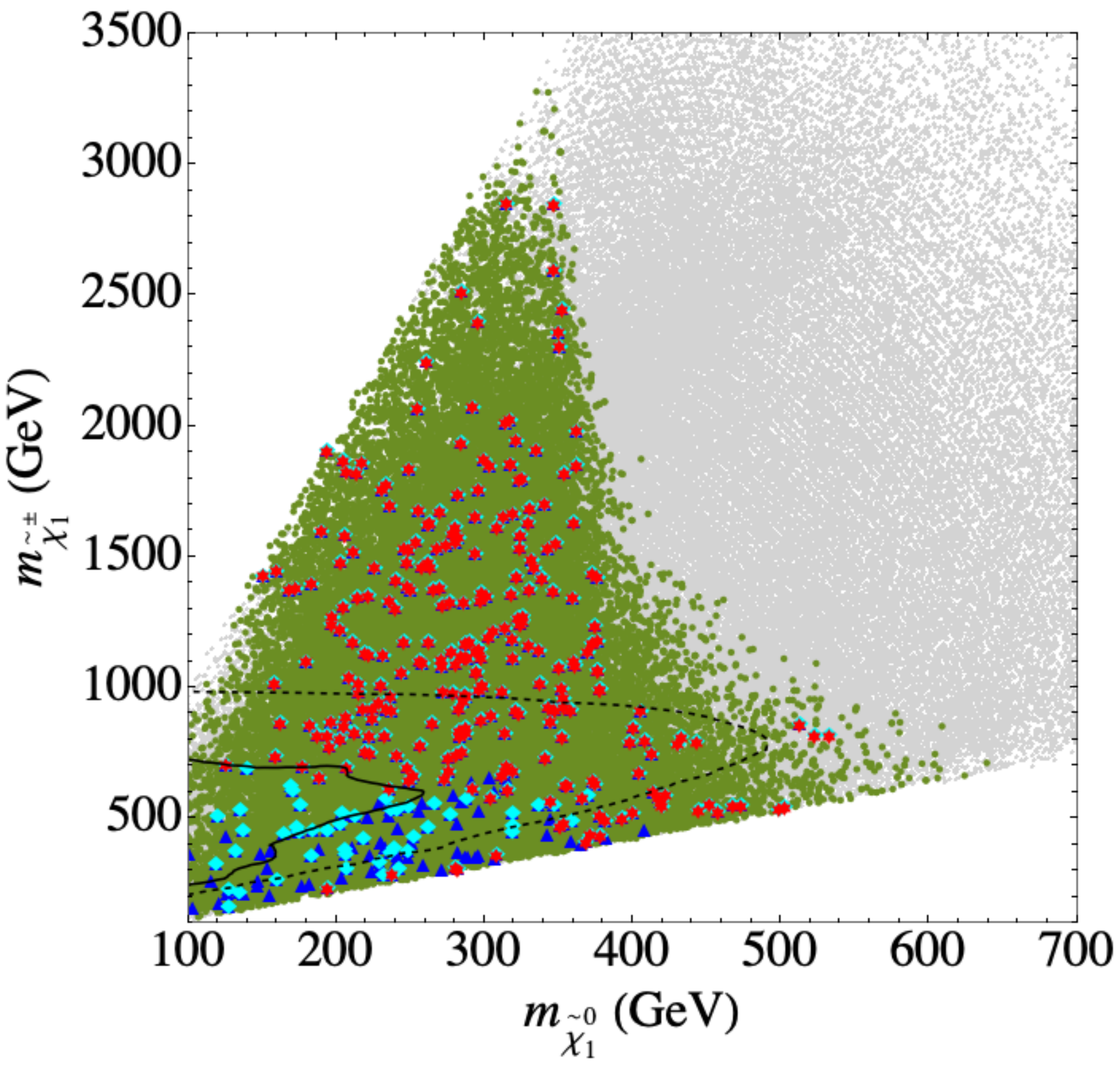


Reduced limit attributed by significant $\mathrm{BR}(\tilde{\chi}_1^\pm \to \tilde{\tau}_1 \nu_\tau)$ and $\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau)$, $\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\nu}\nu)$

($3l$ + missingET)exclusion limit weakens

Slepton Co-annihilation: Case-L

Current $(g-2)_\mu$ limit

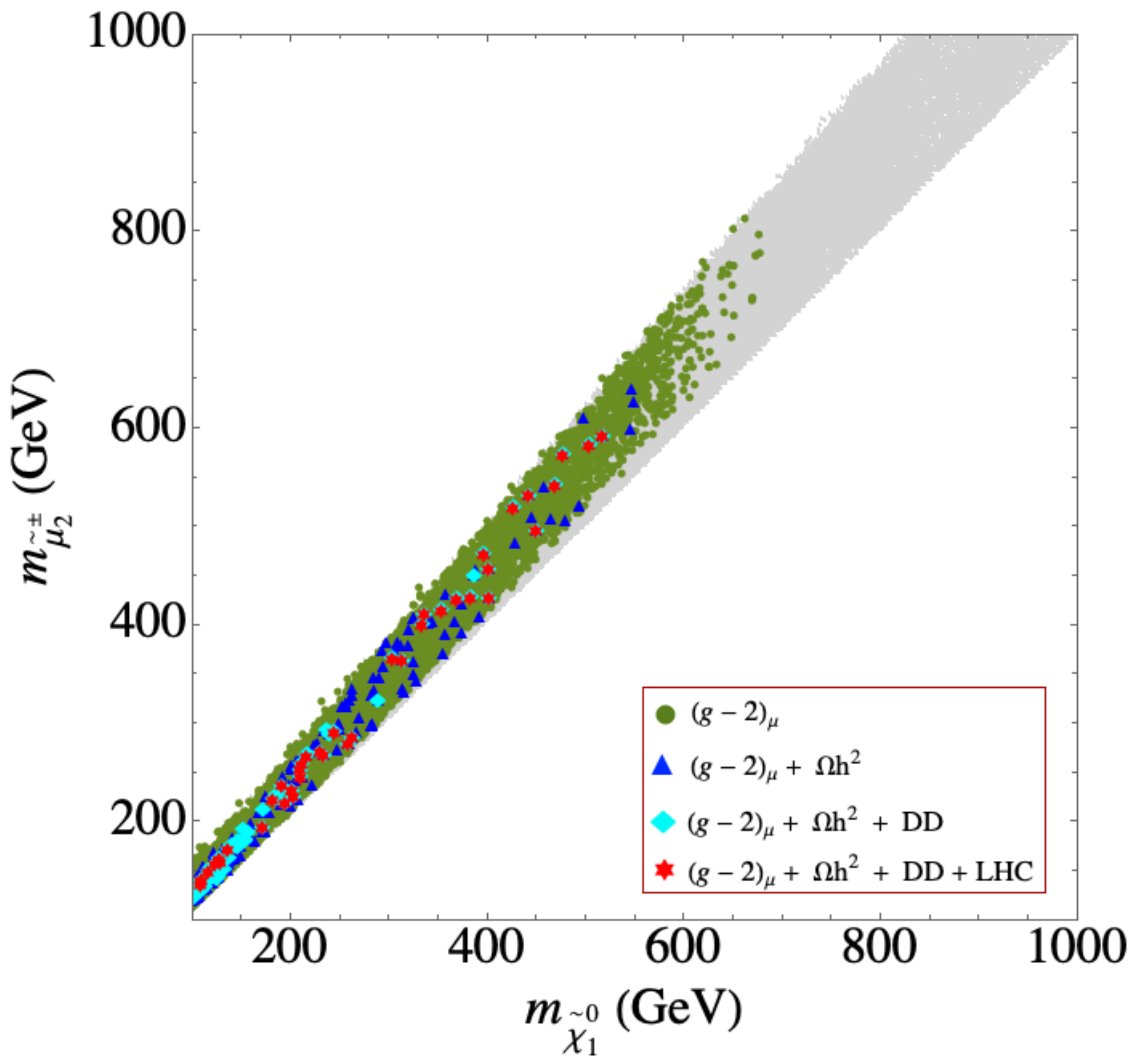


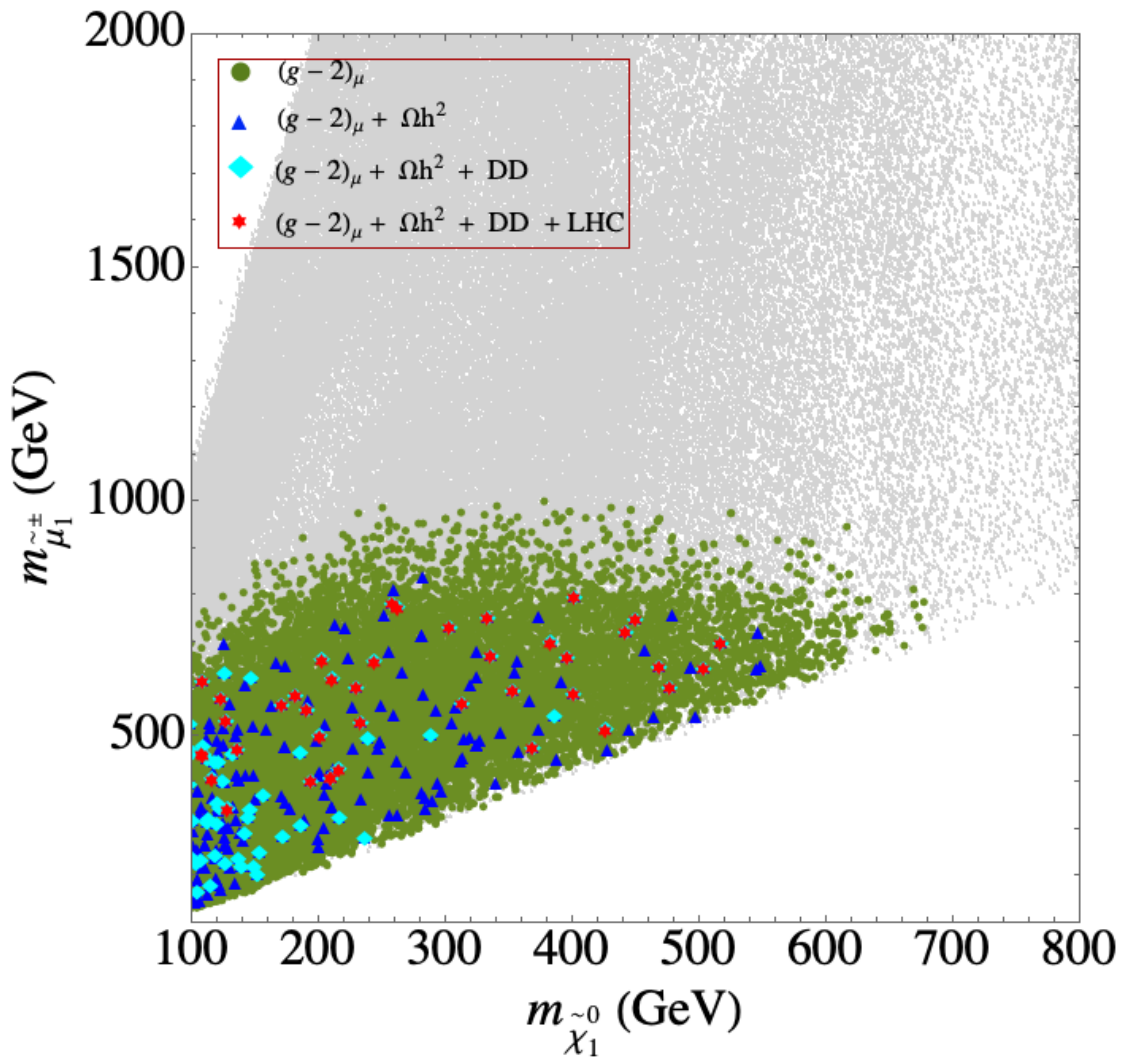
Reduced limit attributed by significant $\mathrm{BR}(\tilde{\chi}_1^\pm \to \tilde{\tau}_1 \nu_\tau)$ and $\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau)$, $\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\nu}\nu)$

($3l$ + missingET)exclusion limit weakens

Slepton Co-annihilation: Case-R

Current $(g-2)_\mu$ limit

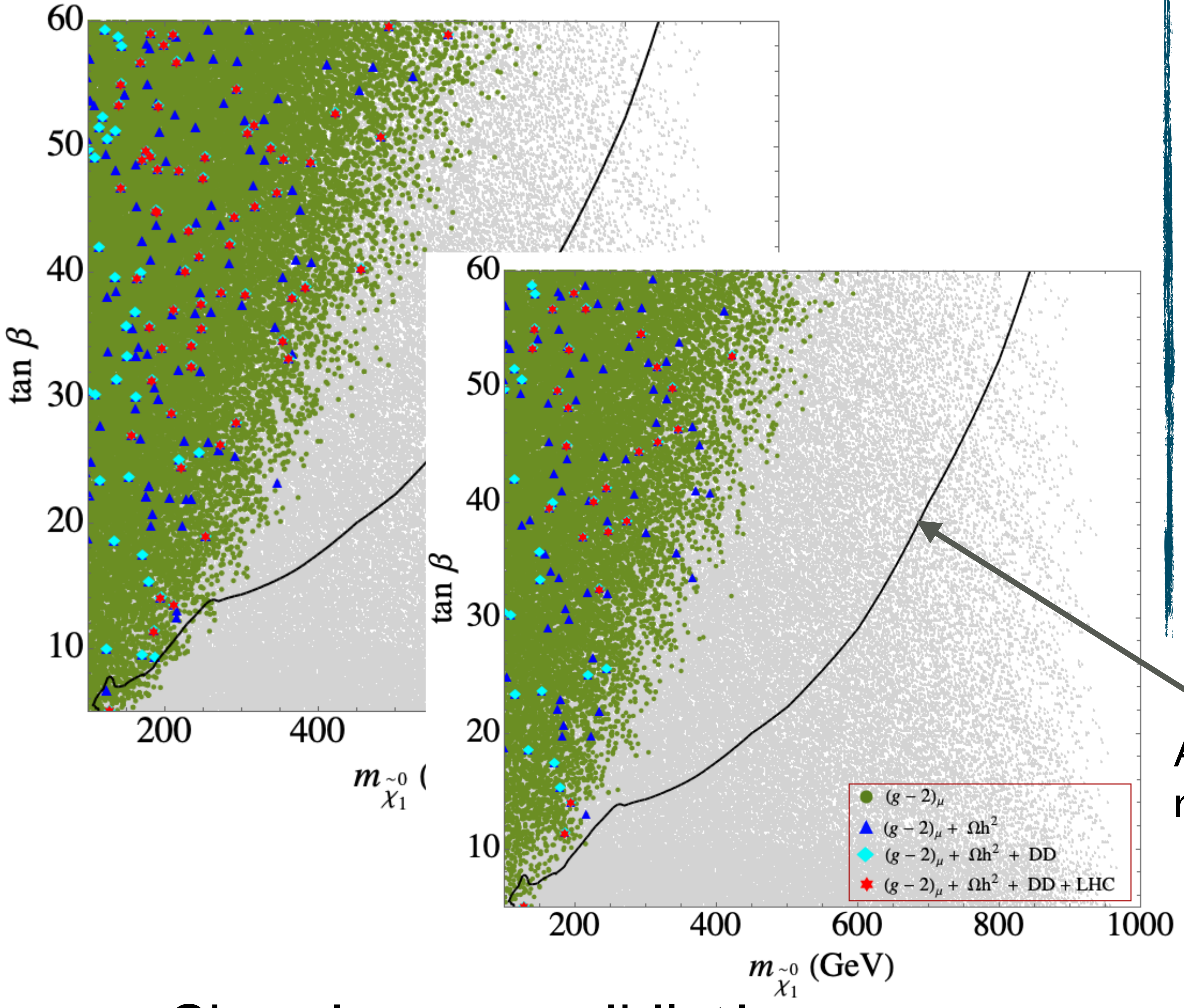




Right-sleptons are close in mass to LSP. Get stringent constraint from LHC.

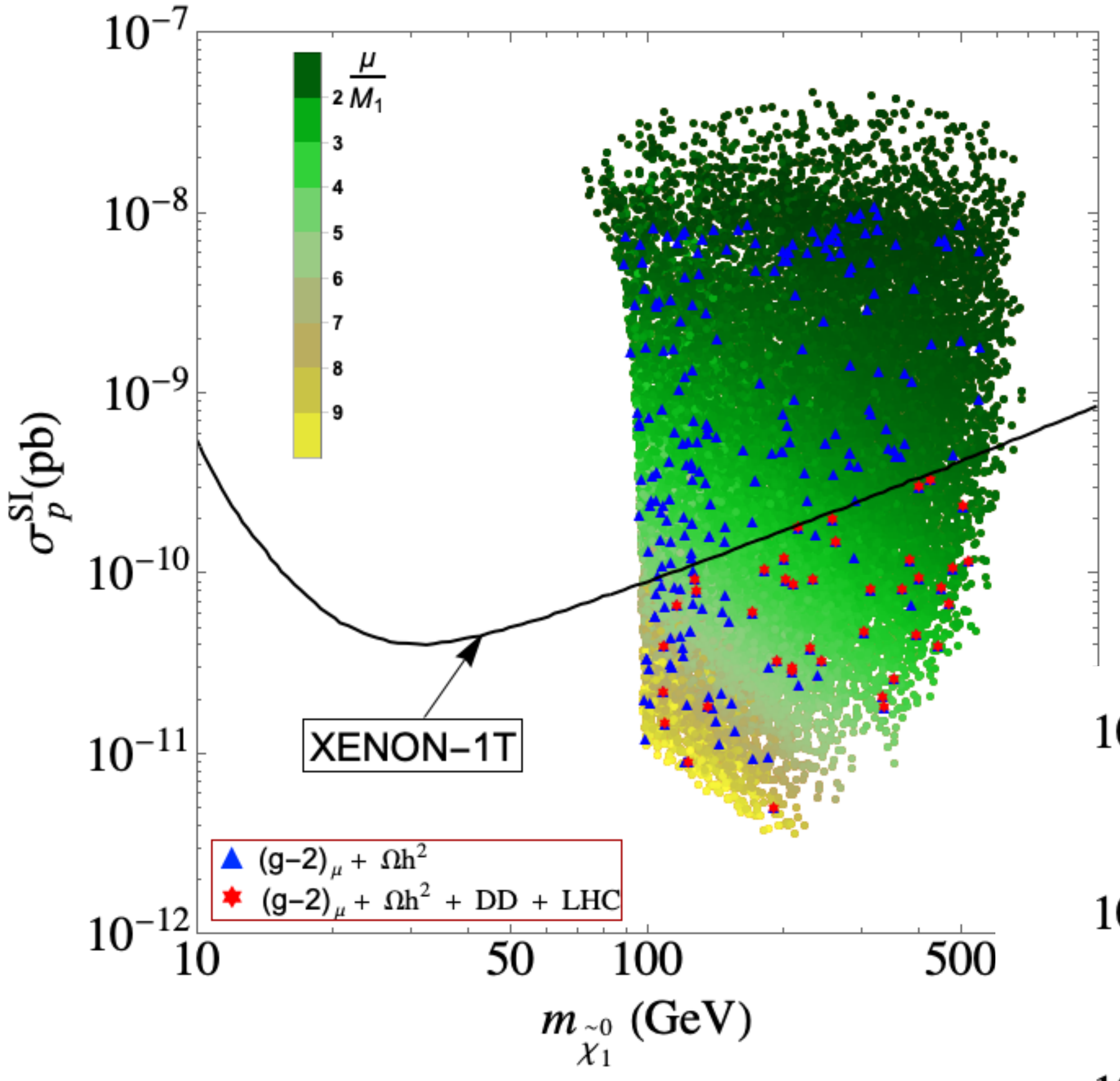
Left-sleptons can not be too heavy to have relevant contribution to $(g-2)_\mu$.

Further Comments

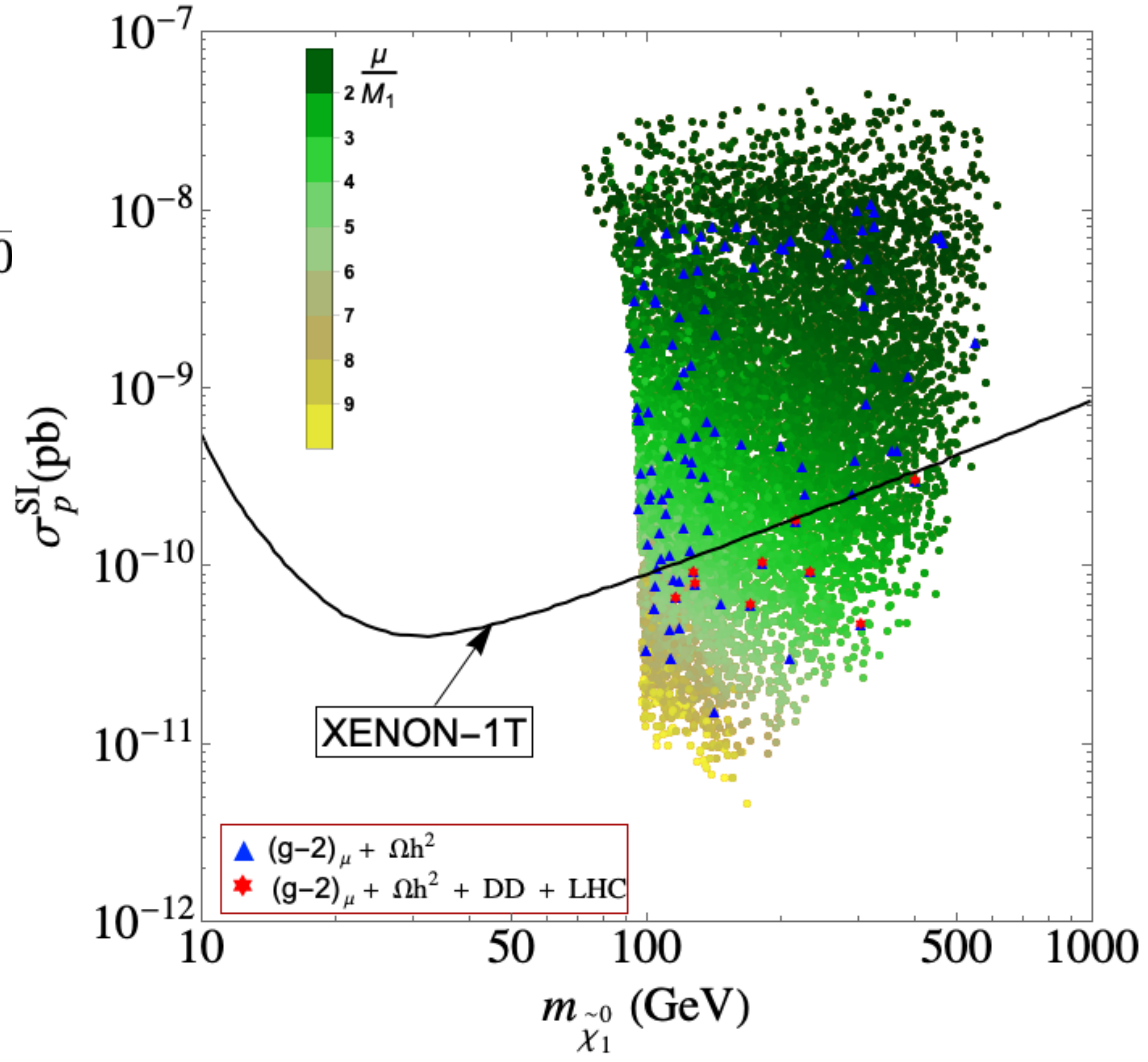


A-pole annihilation restricted

Chargino co-annihilation



Slepton Co-annihilation
Case-R



Larger $\tan\beta$ can easily satisfy $(g-2)_\mu$.

Tension between DD and $(g-2)_\mu$.

Lowest and highest LSP : chargino coannihilation

Lowest LSP in Current (g-2) → C1

Highest LSP in Current (g-2) → C2

Highest LSP in Future (g-2) → C3

Sample points	C1	C2	C3
M_1	133	579	430
M_2	144	583	444
μ	1329	1081	1024
$\tan\beta$	5.1	59	52.7
$m_{\tilde{l}_L} = m_{\tilde{l}_R}$	170	678	540
$m_{\tilde{\chi}_1^0}$	129	570	423
$m_{\tilde{\chi}_2^0}$	150	605	464
$m_{\tilde{\chi}_3^0}$	1338	1087	1032
$m_{\tilde{\chi}_4^0} \sim m_{\tilde{\chi}_2^\pm}$	1341	1093	1036
$m_{\tilde{\chi}_1^\pm}$	150	605	464
$m_{\tilde{e}_1,\tilde{\mu}_1}$	176	680	542
$m_{\tilde{e}_2,\tilde{\mu}_2}$	176	680	541
$m_{\tilde{\tau}_1}$	140	582	437
$m_{\tilde{\tau}_2}$	205	765	629
$m_{\tilde{\nu}}$	159	675	536
$\Omega_{\tilde{\chi}} h^2$	0.118	0.121	0.118
$a_\mu^{\rm SUSY} \times 10^{10}$	21.1	15.6	20.14
$\sigma_p^{\rm SI} \times 10^{10}$	0.39	2.3	1.12

Sample points	C1	C2	C3
$\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau)$	100	100	100
$\mathrm{BR}(\tilde{\chi}_1^\pm \to \tilde{\tau}_1 \nu_\tau)$	100	100	100
$\mathrm{BR}(\tilde{e}_1 \to \tilde{\chi}_1^0 e$	20	14	16.4
$\to \tilde{\chi}_2^0 e$	28	30	28.9
$\to \tilde{\chi}_1^\pm \nu_e)$	52	55	54.6
$\mathrm{BR}(\tilde{e}_2 \to \tilde{\chi}_1^0 e$	99.9	99.7	99.9
$\to \tilde{\chi}_2^0 e)$	0.1	0.3	0.1

BR in %

Searches for τ rich final states will be beneficial for further study.

Lowest and highest LSP : Slepton coannihilation

Sample points	L1	L2	L3	Sample points	L1	L2	L3
M_1	131	541	508	$\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{l}_1 l$	32	32.4	28
M_2	838	793	515	$\to \tilde{\tau}_1 \tau$	17	18.4	17.4
μ	720	1365	1012	$\to \tilde{\nu} \nu$	34.5	49.2	54.6
$\tan\beta$	6.95	56.7	56	$\to \tilde{\chi}_1^0 h$	13	-	-
$m_{\tilde{l}_L}$	149	548	509	$\to \tilde{\chi}_1^0 Z)$	3.43	-	-
$m_{\tilde{l}_R}$	1172	1278	2349				
$m_{\tilde{\chi}_1^0}$	126	533	499				
$m_{\tilde{\chi}_2^0}$	706	816	535				
$m_{\tilde{\chi}_3^0}$	731	1369	1019				
$m_{\tilde{\chi}_4^0} \sim m_{\tilde{\chi}_2^\pm}$	889	1374	1025	$\mathrm{BR}(\tilde{\chi}_1^\pm \to \tilde{\nu}_{l_1} l$	32	33.2	39.4
$m_{\tilde{\chi}_1^\pm}$	706	816	535	$\to \tilde{\nu}_{\tau_1} \tau$	17	17	20.4
$m_{\tilde{e}_1,\tilde{\mu}_1}$	155	549	511	$\to \tilde{l}_1 \nu_l$	23.2	31.8	25.2
$m_{\tilde{e}_2,\tilde{\mu}_2}$	1173	1279	2349	$\to \tilde{\tau}_1 \nu_\tau$	11.7	17.7	15
$m_{\tilde{\tau}_1}$	155	534	509	$\to W \tilde{\chi}_1^0)$	16	-	-
$m_{\tilde{\tau}_2}$	1173	1286	2350				
$m_{\tilde{\nu}}$	135	544	505				
$\Omega_{\tilde{\chi}} h^2$	0.119	0.121	0.12	$\mathrm{BR}(\tilde{e}_1 \to \tilde{\chi}_1^0 e)$	100	100	100
$a_\mu^{\mathrm{SUSY}} \times 10^{10}$	19.7	14.06	21.1	$\mathrm{BR}(\tilde{e}_2 \to \tilde{\chi}_1^0 e$	100	100	99.2
$\sigma_p^{\mathrm{SI}} \times 10^{10}$	0.8	0.46	2.13	$\to \tilde{\chi}_2^0 e)$	-	-	0.5

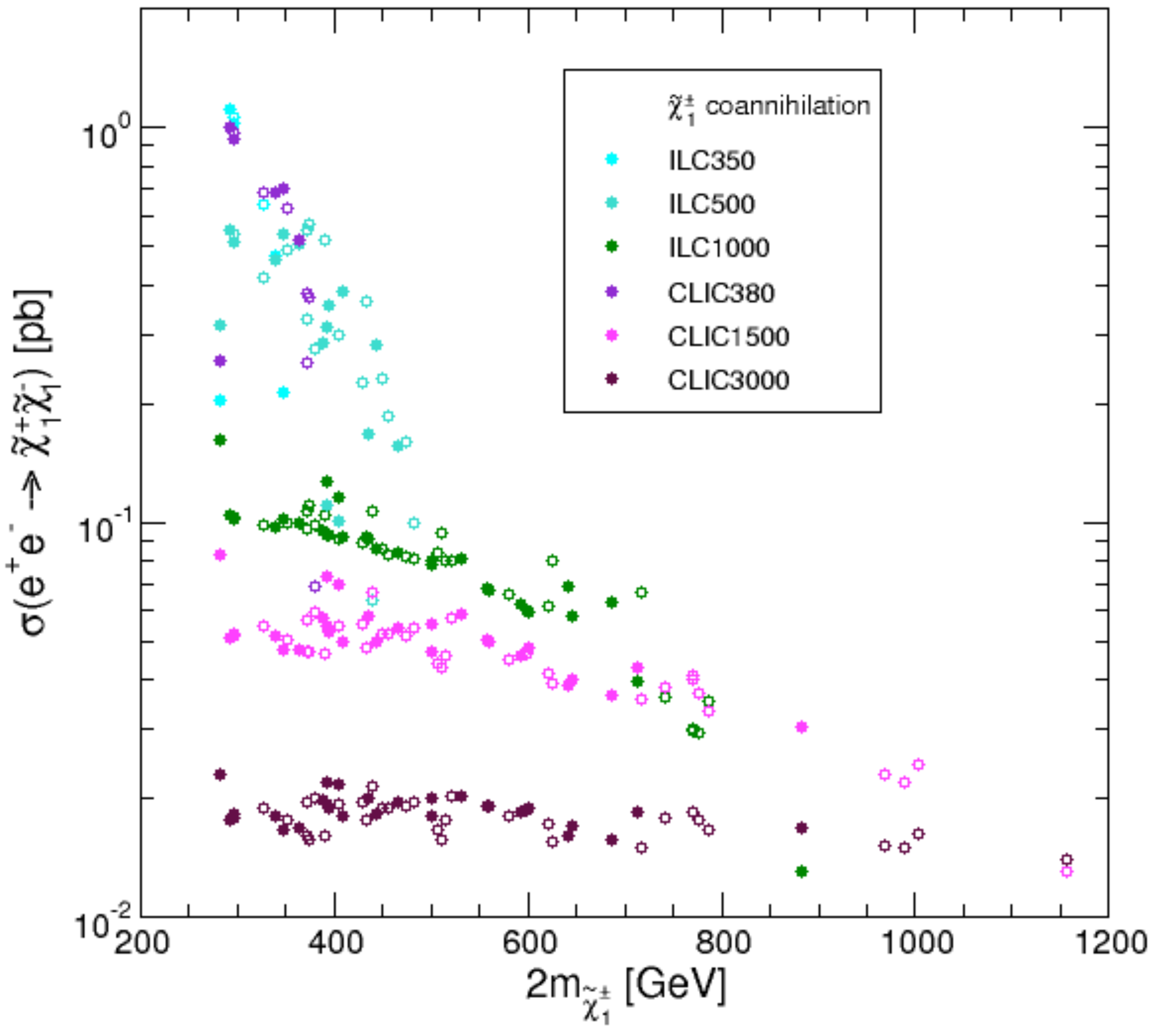
Case-L

Sample points	R1	R2	R3	Sample points	R1	R2	R3
M_1	111	525	408	$\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{l}_2 l$	0.72	-	2.4
M_2	352	662	429	$\to \tilde{\tau}_2 \tau$	93.7	96.8	97.6
μ	812	1091	822	$\to \tilde{\chi}_1^0 h$	4.5	2.92	-
$\tan\beta$	20.5	58.5	59	$\to \tilde{\chi}_1^0 Z)$	0.99	-	-
$m_{\tilde{l}_L}$	458	695	794				
$m_{\tilde{l}_R}$	128	591	425				
$m_{\tilde{\chi}_1^0}$	109	518	402				
$m_{\tilde{\chi}_2^0}$	367	685	448	$\mathrm{BR}(\tilde{\chi}_1^\pm \to \tilde{l}_1 \nu_l$	-	-	-
$m_{\tilde{\chi}_3^0}$	823	1098	830	$\to \tilde{\tau}_2 \nu_\tau$	94.3	97	100
$m_{\tilde{\chi}_4^0} \sim m_{\tilde{\chi}_2^\pm}$	828	1105	838	$\to W \tilde{\chi}_1^0)$	5.7	2.8	-
$m_{\tilde{\chi}_1^\pm}$	367	685	448				
$m_{\tilde{e}_1,\tilde{\mu}_1}$	460	696	795				
$m_{\tilde{e}_2,\tilde{\mu}_2}$	136	592	428	$\mathrm{BR}(\tilde{e}_1 \to \tilde{\chi}_1^0 e)$	42	95	9.2
$m_{\tilde{\tau}_2}$	119	526	406	$\to \tilde{\chi}_2^0 e$	19.6	1.7	32
$m_{\tilde{\tau}_1}$	464	747	807	$\to \tilde{\chi}_1^\pm \nu_e)$	38.3	3.2	58.7
$m_{\tilde{\nu}}$	453	692	792				
$\Omega_{\tilde{\chi}} h^2$	0.121	0.121	0.121				
$a_\mu^{\mathrm{SUSY}} \times 10^{10}$	17.5	14.8	17.8	$\mathrm{BR}(\tilde{e}_2 \to \tilde{\chi}_1^0 e)$	100	100	100
$\sigma_p^{\mathrm{SI}} \times 10^{10}$	0.23	1.2	3.1				

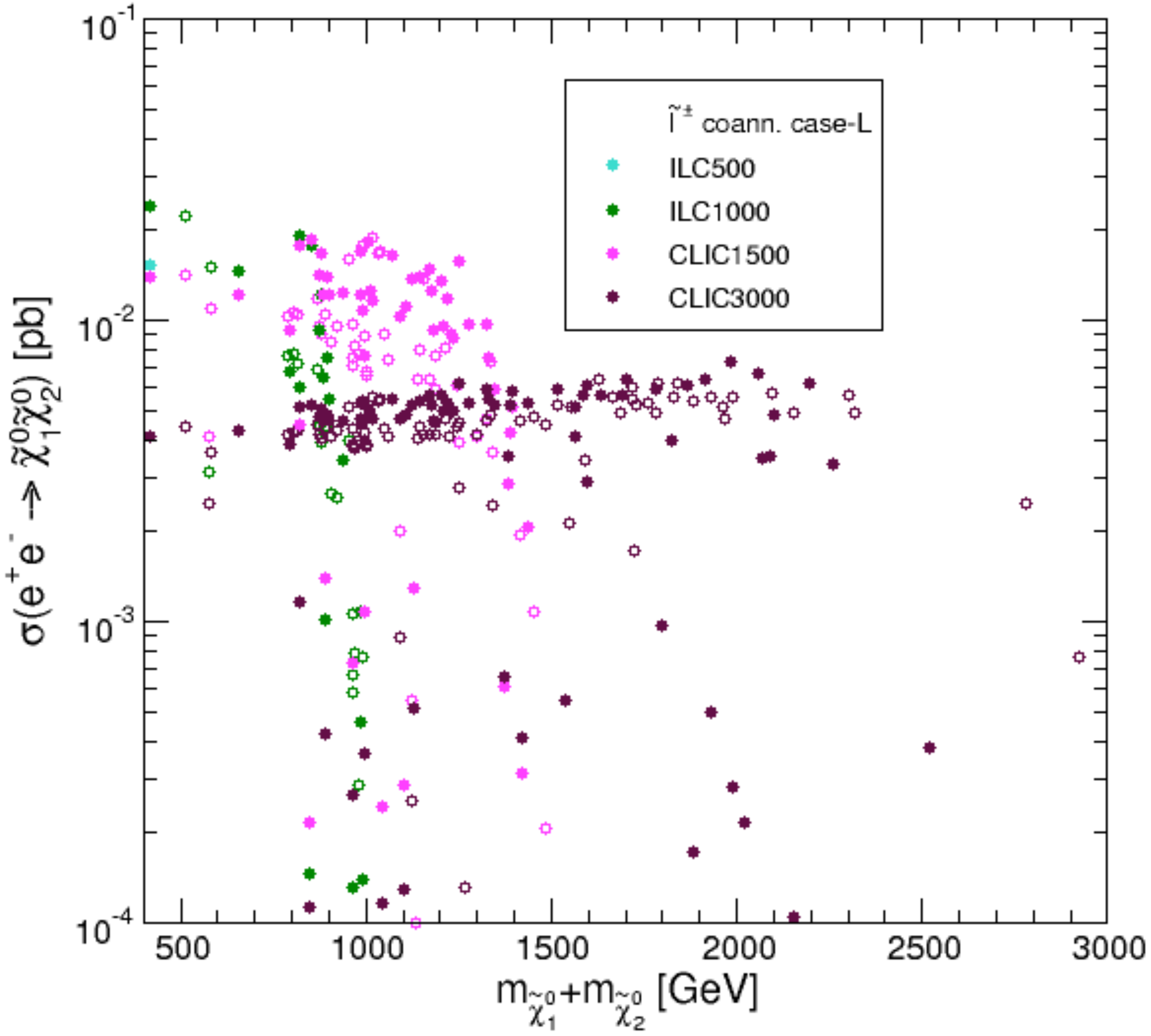
Case-R

Lowest & Highest LSP mass in current (g-2) : L1, L2 (R1,R2)   Highest LSP mass in Future (g-2) : L3 (R3)

Target for future collider : ILC/CLIC



Chargino coannihilation



Slepton coannihilation : Case L

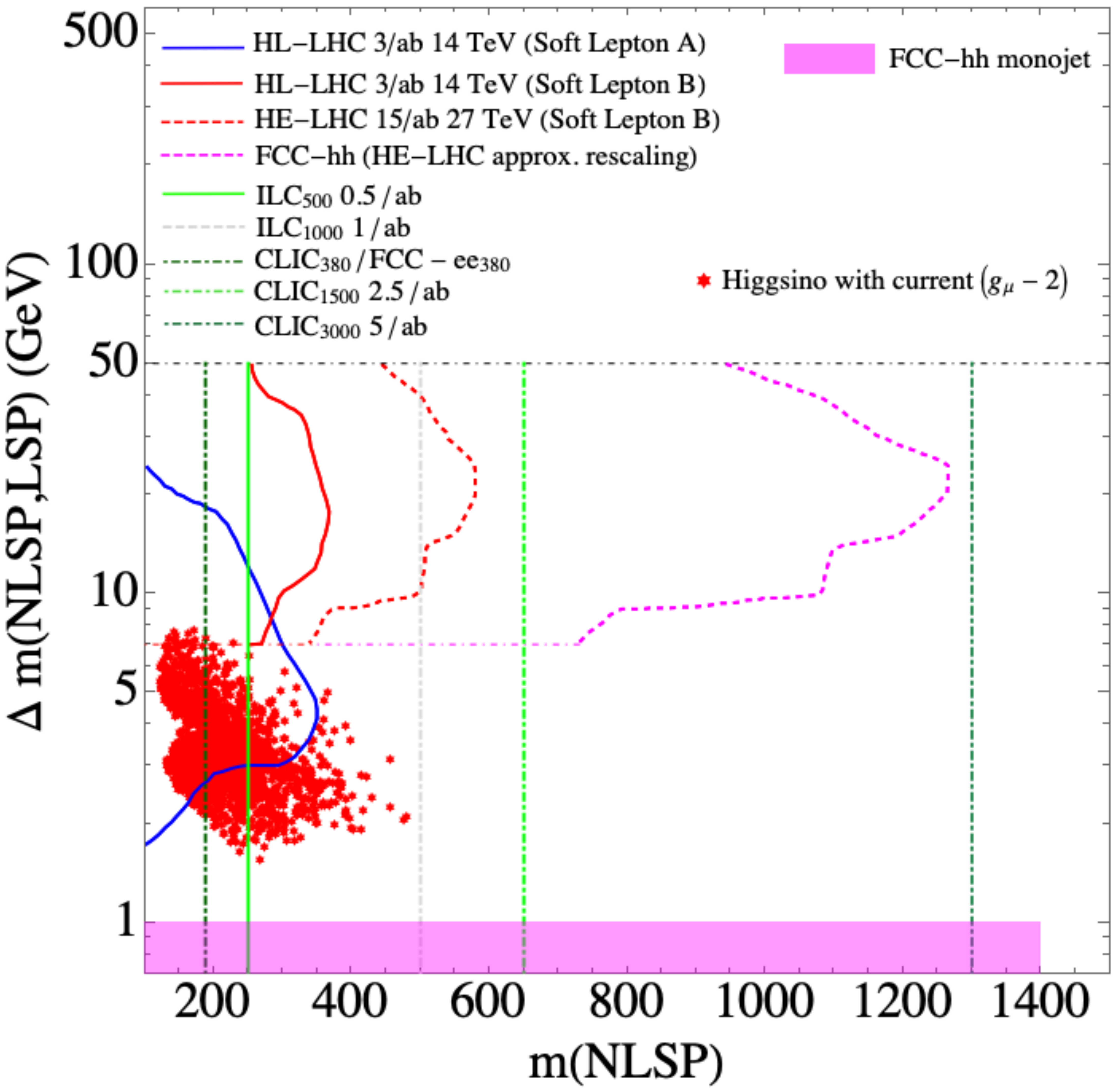
Other possibilities

HIGGSINO LSP Scenario (PRELIMINARY)

M. Chakraborti, S.Heinemeyer, IS : Ongoing

Much Compressed Spectrum.

$\Omega_h^2 < \Omega_{Planck}$. ILC/CLIC needed to cover this scenario.



Ref: H. Fukuda, N. Nagata, H. Oide, H. Otono and S. Shirai *Phys.Rev.Lett.* 124 (2020) 10, 101801

Future bounds from HL-LHC Yellow Report.

Conclusions

- Direct LHC bounds still have ample room for sub-TeV EW SUSY particles.
- It is possible to constrain the EW MSSM with the help of indirect constraints along with the direct collider limits.
- DM and muon (g-2) constraint put effective upper limit on EW SUSY masses while LHC limits restrict the mass ranges from below.
- LHC exclusion bound strongly depends on EW gaugino composition. Proper recasting of ATLAS/CMS analysis relaxes the existing bound.
- Searches for τ rich final states will be beneficial for further study. Compressed Spectrum searches needed to be more sensitive.
- Future colliders, HL-LHC, ILC/CLIC also have significant prospect for detection.
- We await the new experiments results on muon (g-2) from Fermilab, J-PARC.
  STAY TUNED!!!

THANK YOU!