NATIONAL SCIENCE CENTRE
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UNIVERSITY OF WARSAW

SUSY $(g-2)_\mu$ with & without Neutralino Dark Matter

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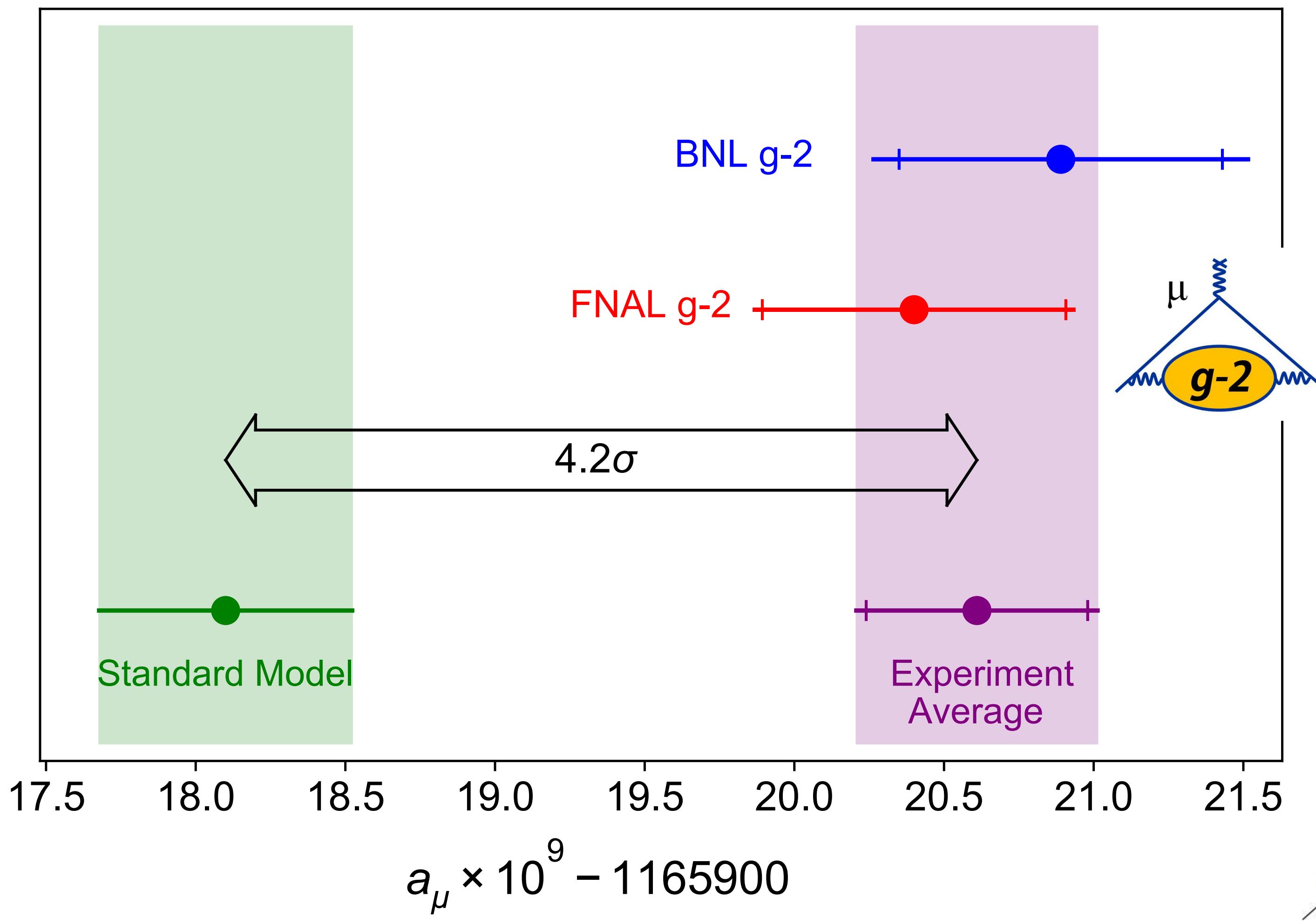
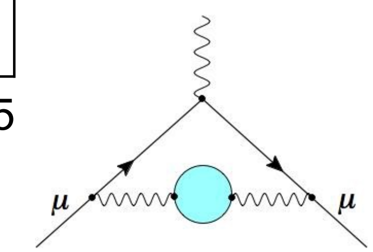
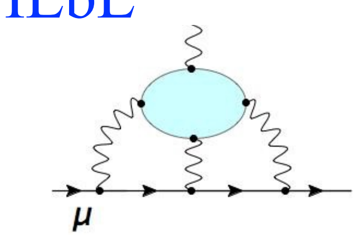
$(g - 2)_\mu$ anomaly

[Phys. Rev. LeS. 126 (2021) 14, 141801]





from HVP, HLbL



$$
\begin{array}{lcccccc}
 & & & \text{QED} & \text{HVP} & \text{EW} & \\
a_\mu^{\text{theo}} & = & 0.00 & 1165 & 91 & 810 & (43) \\
a_\mu^{\text{exp}} & = & 0.00 & 1165 & 92 & 061 & (41)
\end{array}
$$

stat err dominant

$$
a_\mu^{\text{exp}} - a_\mu^{\text{theo}} \simeq (25 \pm 6) \times 10^{-10} \simeq \Delta a_\mu^{\text{BSM}} \; ?
$$

Motivation

- There are many BSM scenarios that can explain the $(g\text{-}2)_\mu$ anomaly:

  Leptoquarks, Z', VLL, 2HDM, axion, ..

- Supersymmetry is particularly motivated since it offers:

  Coupling Unification, Radiative EWSB, Baryogenesis, DM, …

- There are many studies on SUSY g-2 already:

  [Athrona, Balazsa, Jacoba, Kotlarskic, Stockingerc, Stockinger-Kim]; [Chakraborti, Heinemeyer, Saha]; [Endo,Hamaguchi,Iwamoto,Kitahara]; [Cox, Han, Yanagida]; [Baum, Carena, Shah, Wagner]; [Badziak, KS]; [Hagiwara,Ma,Mukhopadhyay'18], …

- Most studies assume the neutralino is the Lightest SUSY Particle (LSP) and stable.

  Q: What happens if neutralino is unstable? (e.g. RPV, Gravitino LSP)

  A: DM constraints go away, but LHC constraints change. **How?**

$$\begin{array}{lcccccc} & & & \text{QED} & \text{HVP} & \text{EW} & \\ a_\mu^{\text{theo}} & = & 0.00 & 1165 & 91 & 810 & (43) \\ a_\mu^{\text{exp}} & = & 0.00 & 1165 & 92 & 061 & (41) \end{array}$$

- The deviation is size of the EW correction in SM:

$$a_\mu^{\text{exp}} - a_\mu^{\text{theo}} \simeq (25 \pm 6) \times 10^{-10} \sim \mathcal{O}\left(\Delta a_\mu^{\text{SM,EW}}\right)$$

- We need very light BSM particles **OR** enhancement from couplings

$$\Delta a_\mu^{\text{BSM}} \sim \Delta a^{\text{SM,EW}} \cdot \underbrace{\left(\frac{m_W^2}{m_{\text{BSM}}^2}\right) \cdot \text{coupling}}_{\mathcal{O}(1)}$$

Chiral (tanβ) enhancement in SUSY

- (g-2) operator requires chirality flip:

$$\vec{\mu} = g\left(\frac{e}{2m}\right)\vec{s}$$

$$a_\mu = \frac{(g-2)}{2} \equiv m_\mu \widetilde{a}_\mu$$

$$\mathscr{L}_{\text{eff}} \ni i\widetilde{a}_\mu \cdot \bar{\psi}_L \sigma^{\mu\nu} \psi_R F_{\mu\nu}$$

SM: $\widetilde{a}_\mu^{\text{SM}} \propto Y_\mu \langle H \rangle = m_\mu$

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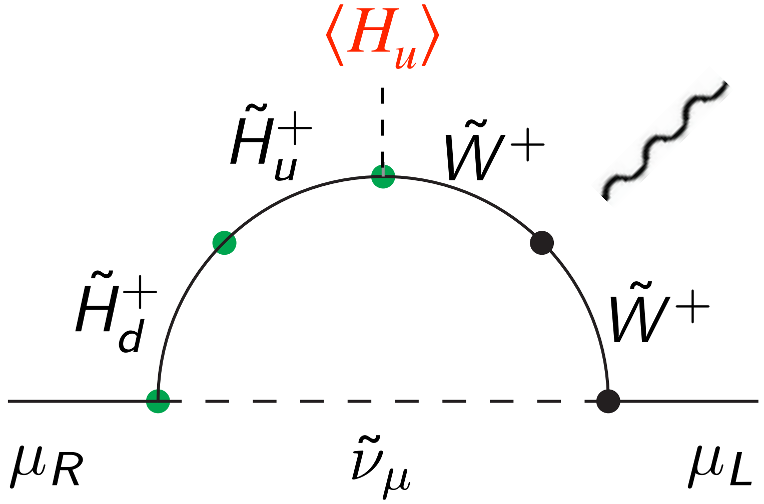
SM: $\tilde{a}_\mu^{\text{SM}} \propto Y_\mu \langle H \rangle = m_\mu$

SUSY: $\Delta\tilde{a}_\mu^{\text{SUSY}} \propto Y_\mu \langle H_u \rangle = m_\mu \cdot \tan\beta$

$$m_\mu = Y_\mu \langle H_d \rangle \qquad \tan\beta \equiv \frac{\langle H_u \rangle}{\langle H_d \rangle}$$



$$\langle H_u \rangle^2 + \langle H_d \rangle^2 = \langle H \rangle^2$$

$\uparrow$ $(246\,\text{GeV})^2$

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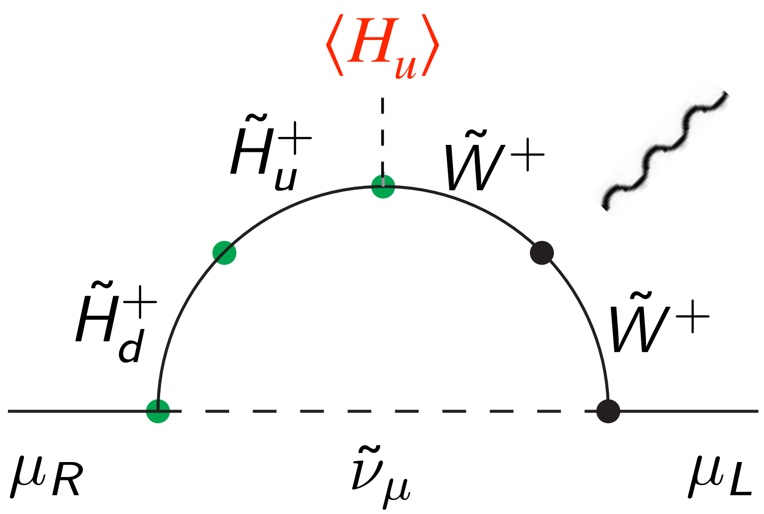


$$\langle H_u \rangle^2 + \langle H_d \rangle^2 = \langle H \rangle^2$$

$\uparrow$ $(246\,\text{GeV})^2$

$$\Delta a_\mu^{\text{BSM}} \sim \Delta a^{\text{SM,EW}} \cdot \left(\frac{m_W^2}{m_{\text{SUSY}}^2}\right) \cdot \tan\beta$$

$\tan\beta \in [5-60]$ ➡ $m_{\text{SUSY}} \in [200-600]\,\text{GeV}$

- Due to strong LHC constraints, we *decouple coloured SUSY particles* (they do not contribute to $(g-2)_\mu$ anyway).

- a_μ^{SUSY} depends on 5 mass parameters and $\tan\beta$:

M_1 : Bino mass

M_2 : Wino mass

μ : Higgsino mass

$$m_{\tilde{l}_R} \equiv \widetilde{m}^2_{\tilde{e}_R} = \widetilde{m}^2_{\tilde{\mu}_R} = \widetilde{m}^2_{\tilde{\tau}_R}$$

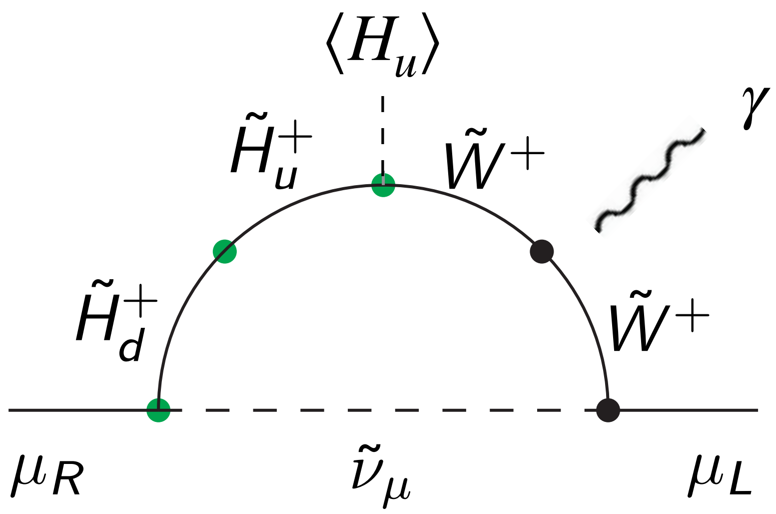
$$m_{\tilde{l}_L} \equiv \widetilde{m}_{\tilde{\nu}_e} = \widetilde{m}_{\tilde{\nu}_\mu} = \widetilde{m}_{\tilde{\nu}_\tau} = \widetilde{m}_{\tilde{e}_L} = \widetilde{m}_{\tilde{\mu}_L} = \widetilde{m}_{\tilde{\tau}_L}$$

$$\tan\beta \equiv \langle H_u \rangle / \langle H_d \rangle$$

no LFV due to universal soft masses: avoid strong constraint from $\mu \to e\,\gamma$

$$\Delta a_\mu^{\mathrm{SUSY}} = \Delta a_\mu^{\mathrm{WHL}} + \Delta a_\mu^{\mathrm{BHL}} + \Delta a_\mu^{\mathrm{BHR}} + \Delta a_\mu^{\mathrm{BLR}}$$

$$\Delta a_\mu^{\rm SUSY} = \Delta a_\mu^{\rm WHL} + \Delta a_\mu^{\rm BHL} + \Delta a_\mu^{\rm BHR} + \Delta a_\mu^{\rm BLR}$$



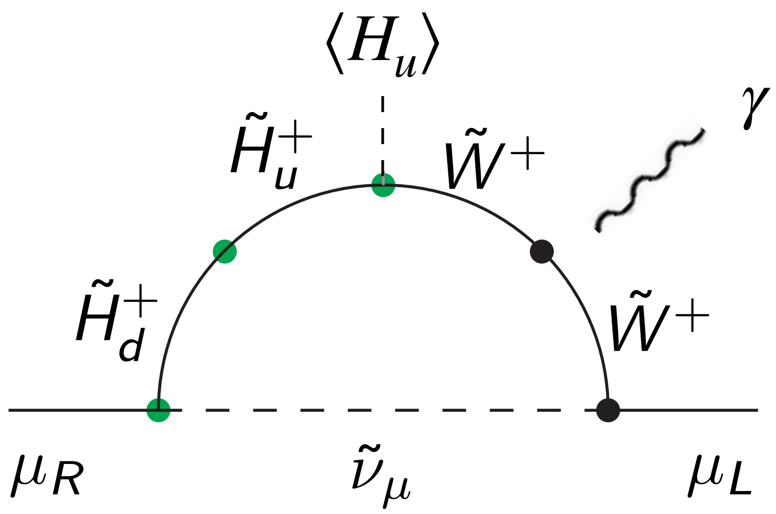
$$\Delta a_\mu^{\rm WHL}(M_2, \mu, m_{\tilde{l}_L}) = \frac{\alpha_W}{8\pi}\frac{m_\mu^2}{M_2\mu}\tan\beta \cdot f_{\rm WHL}(\{\mathbf{m}\})$$

M_1 : Bino ($\tilde{B}$) mass

M_2 : Wino ($\tilde{W}$) mass

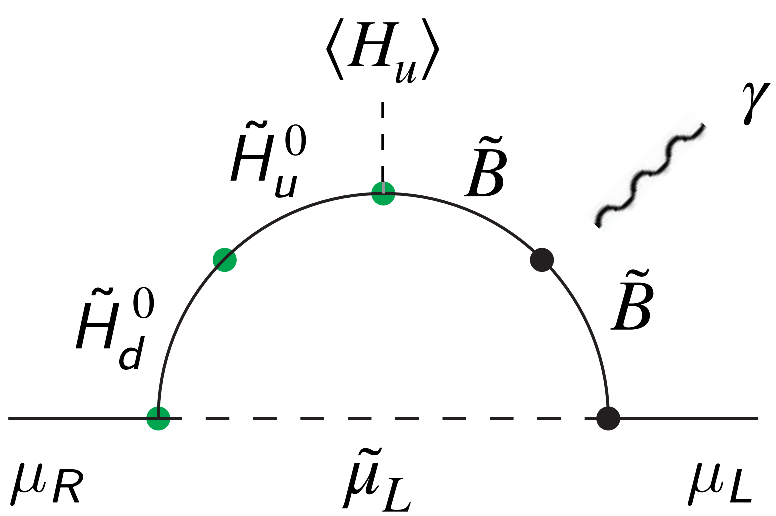
μ : Higgsino ($\tilde{H}_u, \tilde{H}_d$) mass

$$\Delta a_\mu^{\rm SUSY} = \Delta a_\mu^{\rm WHL} + \Delta a_\mu^{\rm BHL} + \Delta a_\mu^{\rm BHR} + \Delta a_\mu^{\rm BLR}$$



$$\Delta a_\mu^{\rm WHL}(M_2, \mu, m_{\tilde{l}_L}) = \frac{\alpha_W}{8\pi} \frac{m_\mu^2}{M_2 \mu} \tan\beta \cdot f_{\rm WHL}(\{\mathbf{m}\})$$

$$\Delta a_\mu^{\rm BHL}(M_1, \mu, m_{\tilde{l}_L}) = \frac{\alpha_Y}{8\pi} \frac{m_\mu^2}{M_1 \mu} \tan\beta \cdot f_{\rm BHL}(\{\mathbf{m}\})$$



M_1 : Bino ($\tilde{B}$) mass

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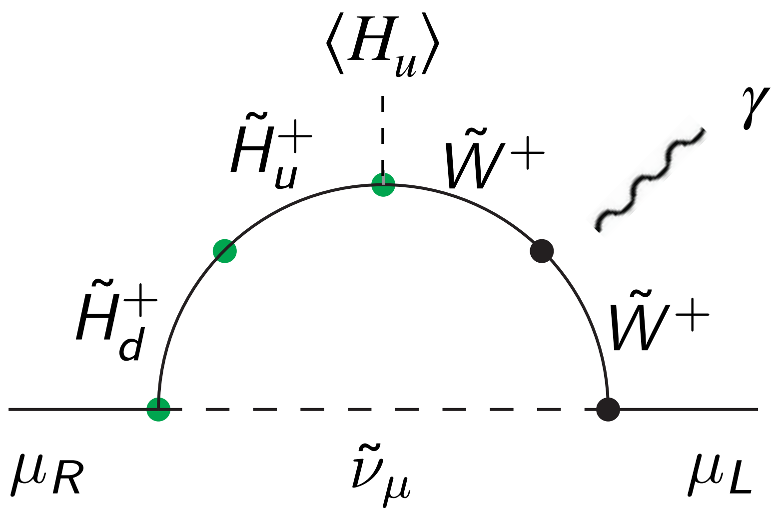

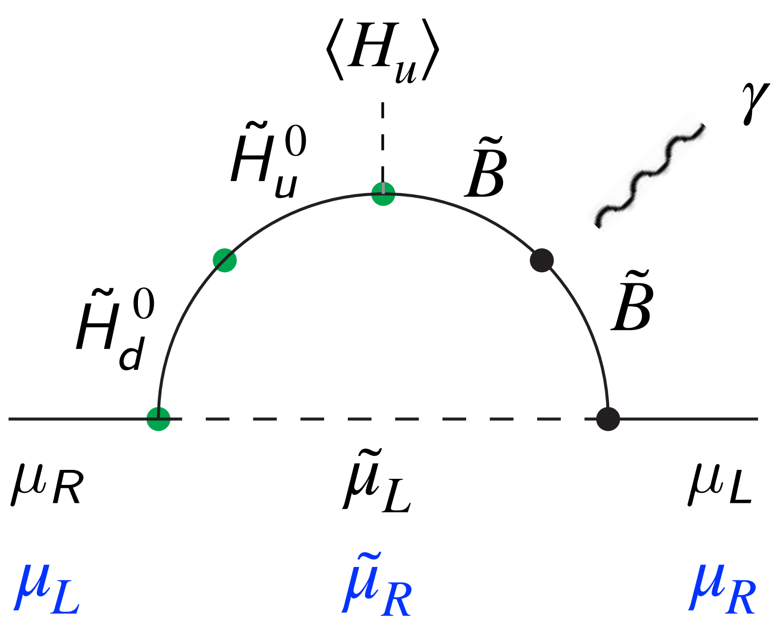

$$\Delta a_\mu^{\rm WHL}(M_2, \mu, m_{\tilde{l}_L}) = \frac{\alpha_W}{8\pi}\frac{m_\mu^2}{M_2\mu}\tan\beta \cdot f_{\rm WHL}(\{\mathbf{m}\})$$

$$\Delta a_\mu^{\rm BHL}(M_1, \mu, m_{\tilde{l}_L}) = \frac{\alpha_Y}{8\pi}\frac{m_\mu^2}{M_1\mu}\tan\beta \cdot f_{\rm BHL}(\{\mathbf{m}\})$$

$$\Delta a_\mu^{\rm BHR}(M_1, \mu, m_{\tilde{l}_R}) = -\frac{\alpha_Y}{8\pi}\frac{m_\mu^2}{M_1\mu}\tan\beta \cdot f_{\rm BHR}(\{\mathbf{m}\})$$

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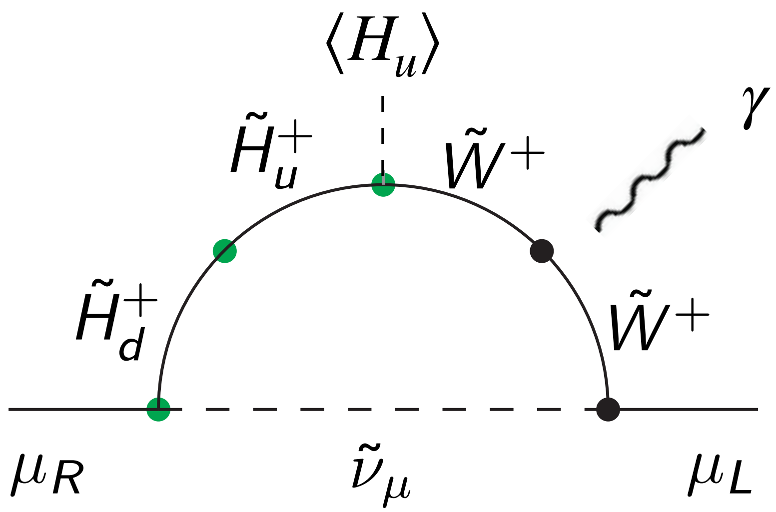
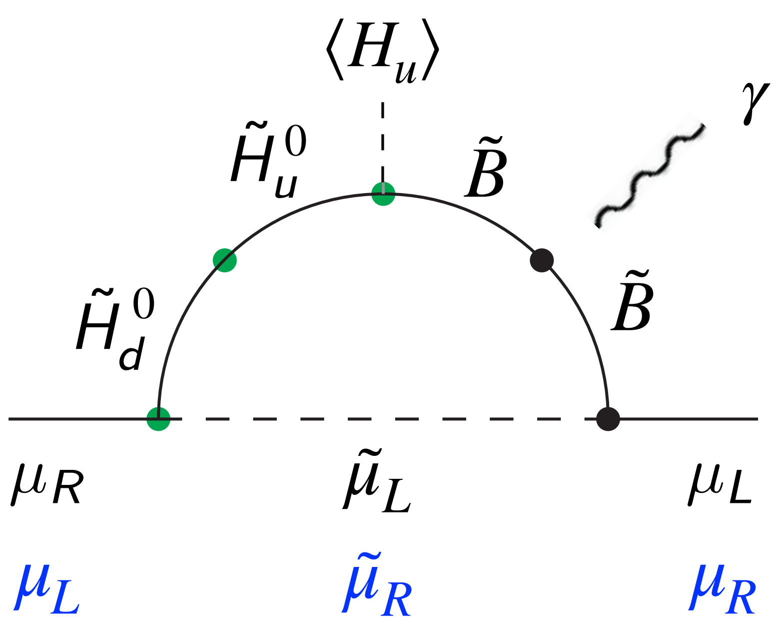


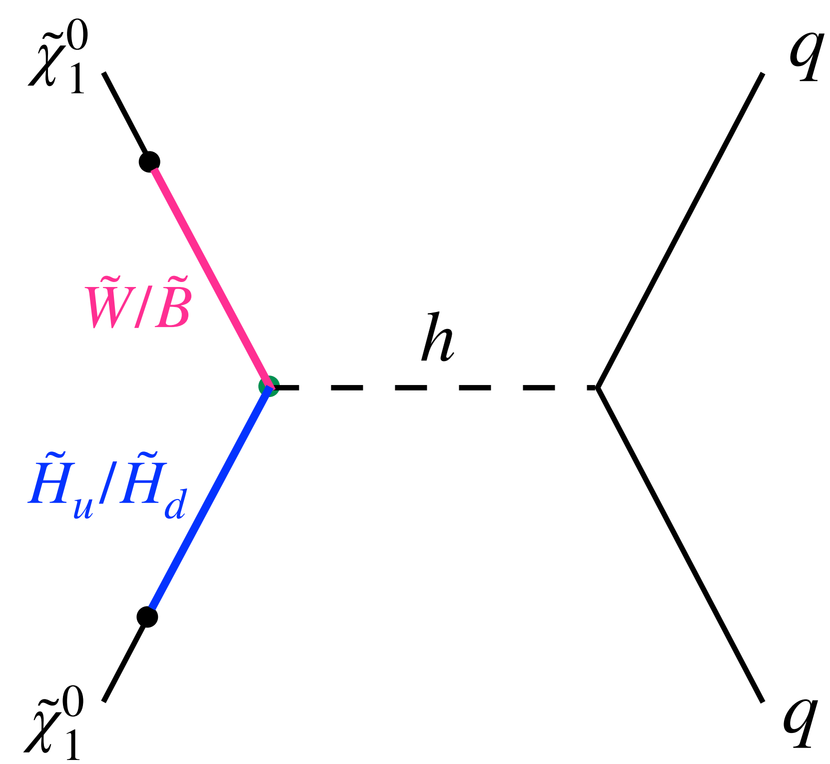
$$\Delta a_\mu^{\mathrm{WHL}}(M_2, \mu, m_{\tilde{l}_L}) = \frac{\alpha_W}{8\pi} \frac{m_\mu^2}{M_2 \mu} \tan\beta \cdot f_{\mathrm{WHL}}(\{\mathbf{m}\})$$

$$\Delta a_\mu^{\mathrm{BHL}}(M_1, \mu, m_{\tilde{l}_L}) = \frac{\alpha_Y}{8\pi} \frac{m_\mu^2}{M_1 \mu} \tan\beta \cdot f_{\mathrm{BHL}}(\{\mathbf{m}\})$$

$$\Delta a_\mu^{\mathrm{BHR}}(M_1, \mu, m_{\tilde{l}_R}) = -\frac{\alpha_Y}{8\pi} \frac{m_\mu^2}{M_1 \mu} \tan\beta \cdot f_{\mathrm{BHR}}(\{\mathbf{m}\})$$



Large gaugino-Higgsino mixing leads to a
large cross-section for DM Direct Detection:



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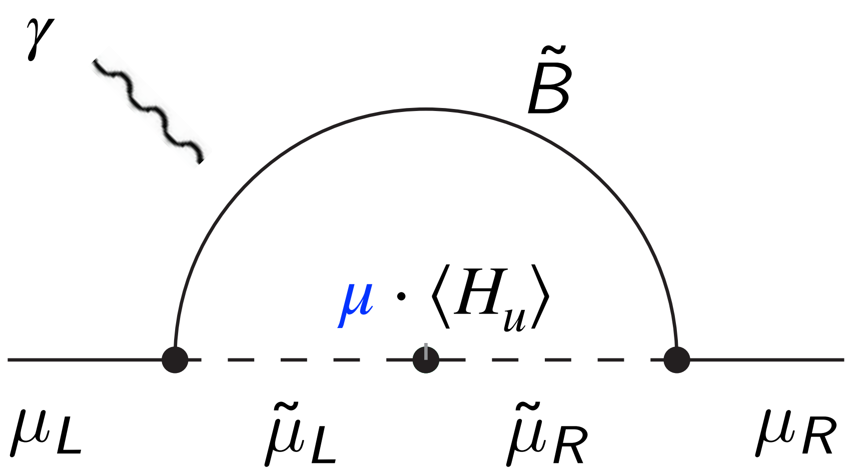
$$\Delta a_\mu^{\rm SUSY} = \Delta a_\mu^{\rm WHL} + \Delta a_\mu^{\rm BHL} + \Delta a_\mu^{\rm BHR} + \Delta a_\mu^{\rm BLR}$$



$$\Delta a_\mu^{\rm BLR}(M_1, m_{\tilde{l}_L}, m_{\tilde{l}_R}; \mu) = \frac{\alpha_Y}{4\pi} \frac{m_\mu^2 M_1 \mu}{m_{\mu_L}^2 m_{\mu_R}^2} \tan\beta \cdot f_{\rm BLR}(\{\mathbf{m}\})$$

↑ large μ needed

Constraints:

❖ Stau mass² becomes negative or too small!

$$(\tilde{\tau} \text{ mass matrix}) \sim \begin{pmatrix} m^2_{\tilde{\tau}_R} & Y_\tau \mu \langle H_u \rangle \\ Y_\tau \mu \langle H_u \rangle & m^2_{\tilde{\tau}_L} \end{pmatrix}$$

- charge breaking vacuum: $m^2_{\rm stau1} > 0$
- LEP bound: $m_{\rm stau1} > 90$ GeV
- stau LSP: $m_{\rm stau1} > m_{\rm neutralino1}$
- **Vacuum (meta-)stability:**

$$\left| m^2_{\tilde{\ell}_{LR}} \right| \leq \left[1.01 \times 10^2\,{\rm GeV} \sqrt{m_{\tilde{\ell}_L} m_{\tilde{\ell}_R}} + 1.01 \times 10^2\,{\rm GeV} (m_{\tilde{\ell}_L} + 1.03 m_{\tilde{\ell}_R}) - 2.27 \times 10^4\,{\rm GeV}^2 + \frac{2.97 \times 10^6\,{\rm GeV}^3}{m_{\tilde{\ell}_L} + m_{\tilde{\ell}_R}} - 1.14 \times 10^8\,{\rm GeV}^4 \left(\frac{1}{m^2_{\tilde{\ell}_L}} + \frac{0.983}{m^2_{\tilde{\ell}_R}} \right) \right]$$

[Kitahara, Yoshinaga 13]; [Endo, Hamaguchi, Kitahara, Yoshinaga 13]

❖ **Overproduction of Bino-like neutralinos** in the early universe: $\Omega_{\tilde{\chi}_1^0} < \Omega_{\rm DM}$

slepton-coannihilation needed ⇒ $m_{\rm slepton} \sim m_{\rm Bino}$

Summary of g-2 in MSSM

$$\Delta a_\mu^{\rm SUSY} = \Delta a_\mu^{\rm WHL} + \Delta a_\mu^{\rm BHL} + \Delta a_\mu^{\rm BHR} + \Delta a_\mu^{\rm BLR}$$

$\Delta a_\mu^{\rm WHL}(M_2, \mu, m_{\tilde{l}_L})$

$\Delta a_\mu^{\rm BHL}(M_1, \mu, m_{\tilde{l}_L})$

$\Delta a_\mu^{\rm BHR}(M_1, \mu, m_{\tilde{l}_R})$

Higgsino, one gaugino, one slepton all must be light:

⟹ subject to **LHC constraint**

gaugino-Higgsino mixing ⟹ **DM direct detection**

$\Delta a_\mu^{\rm BLR}(M_1, m_{\tilde{l}_L}, m_{\tilde{l}_R}; \mu)$

↑ large

Bino and both L and R sleptons must be light:

⟹ subject to **LHC constraint**

⟹ **Bino abundance** $\Omega_{\tilde{\chi}_1^0} < \Omega_{\rm DM}$

⟹ **Vacuum stability**

Unstable Neutralino (Gravitino, RPV)

$$\Delta a_\mu^{\rm SUSY} = \Delta a_\mu^{\rm WHL} + \Delta a_\mu^{\rm BHL} + \Delta a_\mu^{\rm BHR} + \Delta a_\mu^{\rm BLR}$$

$$\Delta a_\mu^{\rm WHL}(M_2, \mu, m_{\tilde{l}_L})$$

$$\Delta a_\mu^{\rm BHL}(M_1, \mu, m_{\tilde{l}_L})$$

$$\Delta a_\mu^{\rm BHR}(M_1, \mu, m_{\tilde{l}_R})$$

Higgsino, one gaugino, one slepton all must be light:

$\Longrightarrow$ subject to **LHC constraint** $\leftarrow$ **Modified**

gaugino-Higgsino mixing $\Longrightarrow$ ~~**DM direct detection**~~

$$\Delta a_\mu^{\rm BLR}(M_1, m_{\tilde{l}_L}, m_{\tilde{l}_R};\ \mu)$$

$\uparrow$ large

Bino and both L and R sleptons must be light:

$\Longrightarrow$ subject to **LHC constraint** $\leftarrow$ **Modified**

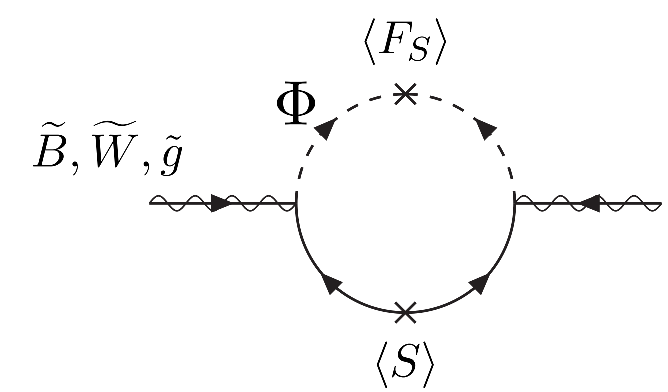
$\Longrightarrow$ ~~**Bino abundance** $\Omega_{\chi_1^0} < \Omega_{\rm DM}$~~

$\Longrightarrow$ **Vacuum stability**

Gravitino LSP

- In the gauge-mediated SUSY breaking (GMSB) scenario, **light gravitino is motivated by naturalness**:

$$\delta m_h^2 \propto m_{SUSY}^2 \ln\left(\frac{\Lambda_{\rm mess}}{M_{\rm PL}}\right) \qquad m_{3/2} = \frac{4\pi}{\sqrt{3}\alpha_W} M_2 \frac{\Lambda_{\rm mess}}{M_{\rm PL}}$$



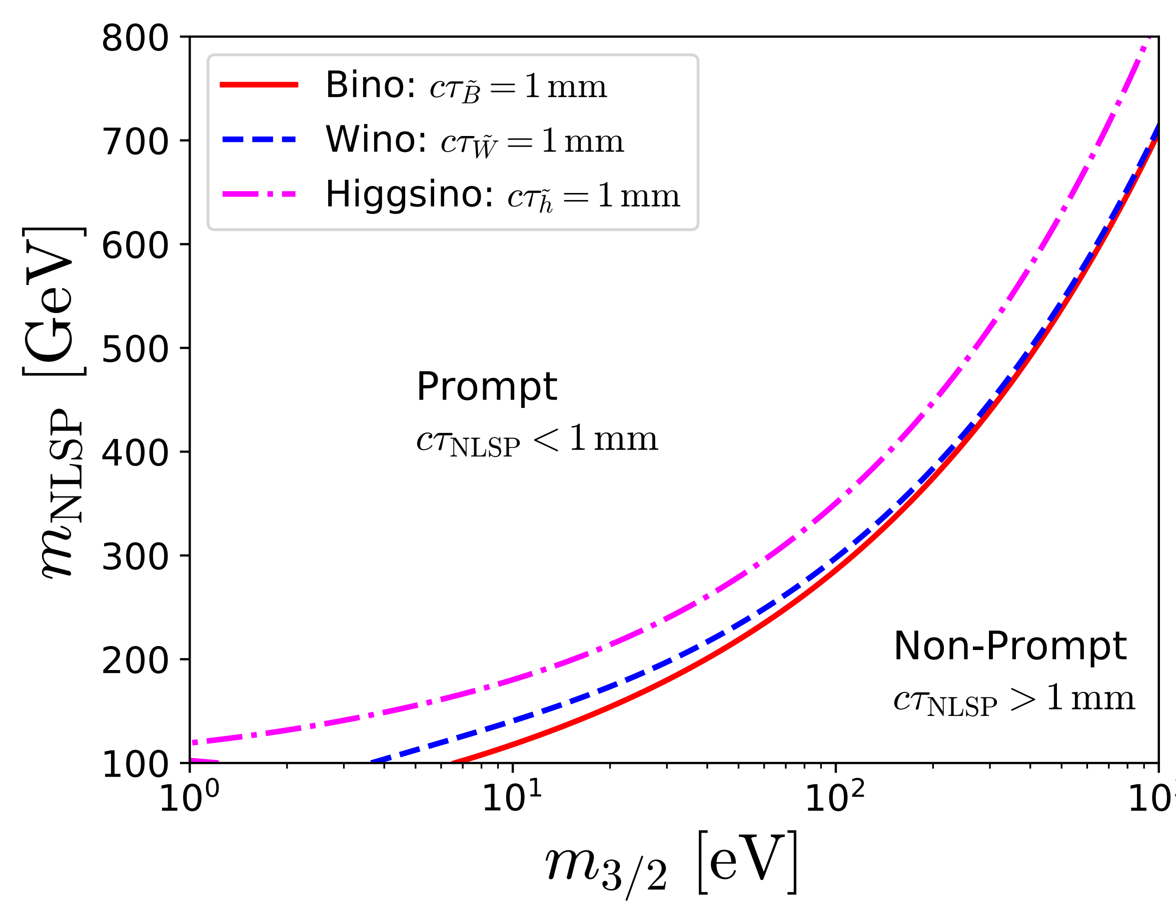
- The decay rate of the NSLP neutralino into the gravitino can be calculated. For light gravitinos (< 10-100 eV), the **neutralino decays are prompt**.

$$\Gamma(\tilde{\chi}_1^0 \to \tilde{G}\gamma) = \left|N_{11}c_W + N_{12}s_W\right|^2 \mathcal{A},$$

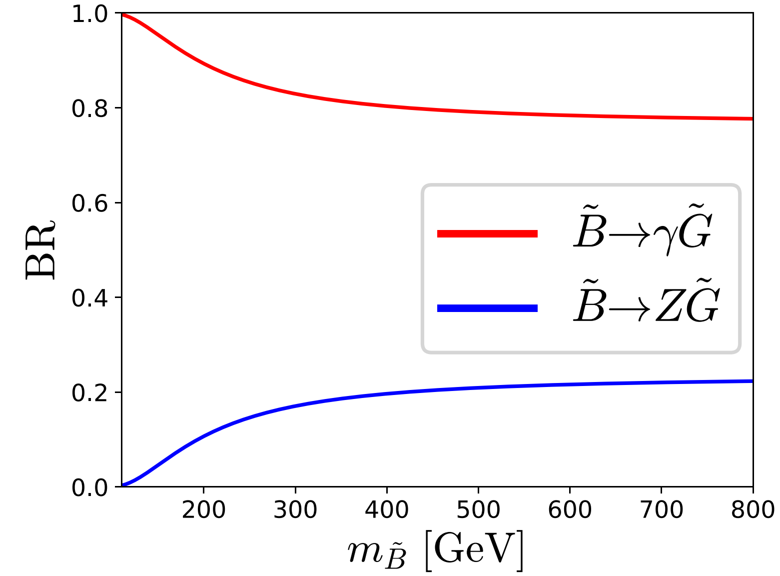
$$\Gamma(\tilde{\chi}_1^0 \to \tilde{G}Z) = \left(\left|N_{12}c_W - N_{11}s_W\right|^2 + \frac{1}{2}\left|N_{13}c_\beta - N_{14}s_\beta\right|^2\right)\left(1 - \frac{m_Z^2}{m_{\tilde{\chi}_1^0}^2}\right)^4 \mathcal{A},$$

$$\Gamma(\tilde{\chi}_1^0 \to \tilde{G}h) = \frac{1}{2}\left|N_{13}c_\beta + N_{14}s_\beta\right|^2\left(1 - \frac{m_h^2}{m_{\tilde{\chi}_1^0}^2}\right)^4 \mathcal{A},$$

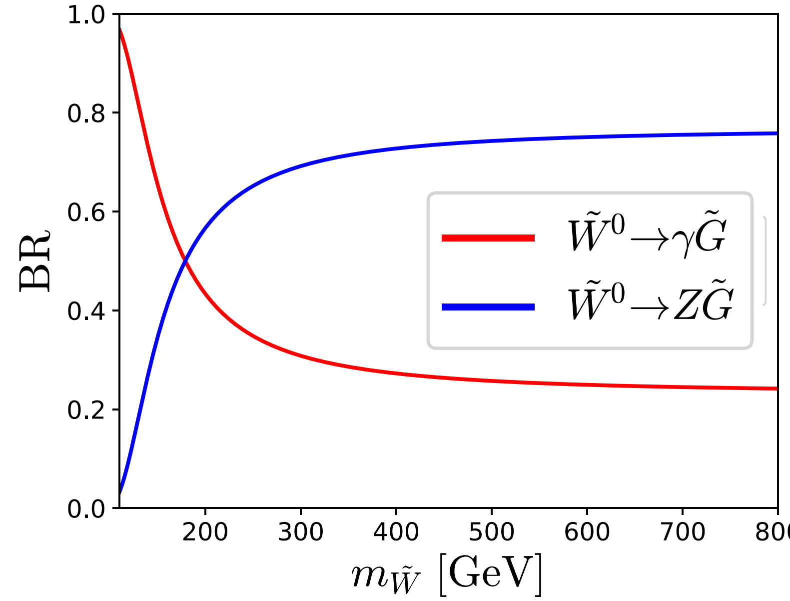
$$\mathcal{A} = \frac{m_{\tilde{\chi}_1^0}^5}{16\pi m_{3/2}^2 M_{\rm pl}^2} \sim \frac{1}{0.3\,{\rm mm}}\left(\frac{m_{\tilde{\chi}_1^0}}{100\,{\rm GeV}}\right)^5\left(\frac{m_{3/2}}{10\,{\rm eV}}\right)^{-2}$$



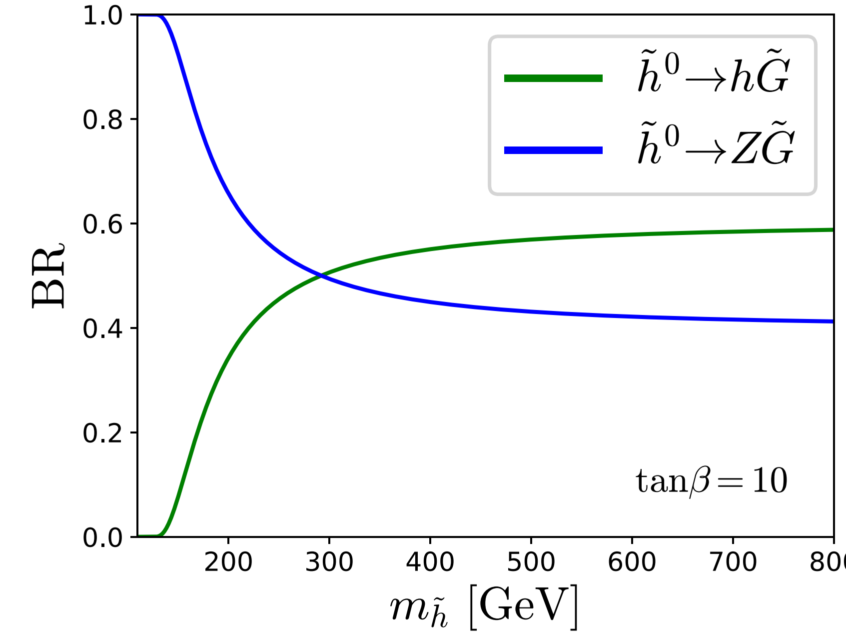
Bino-like

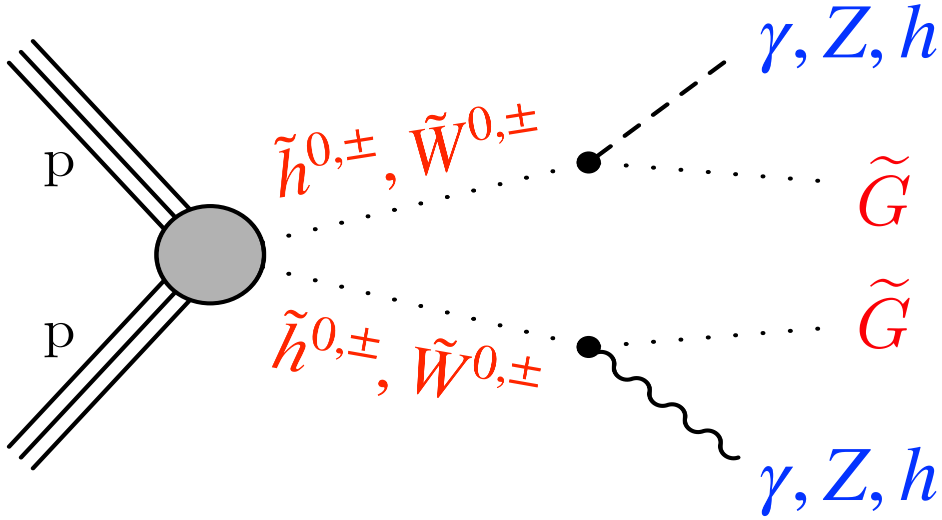


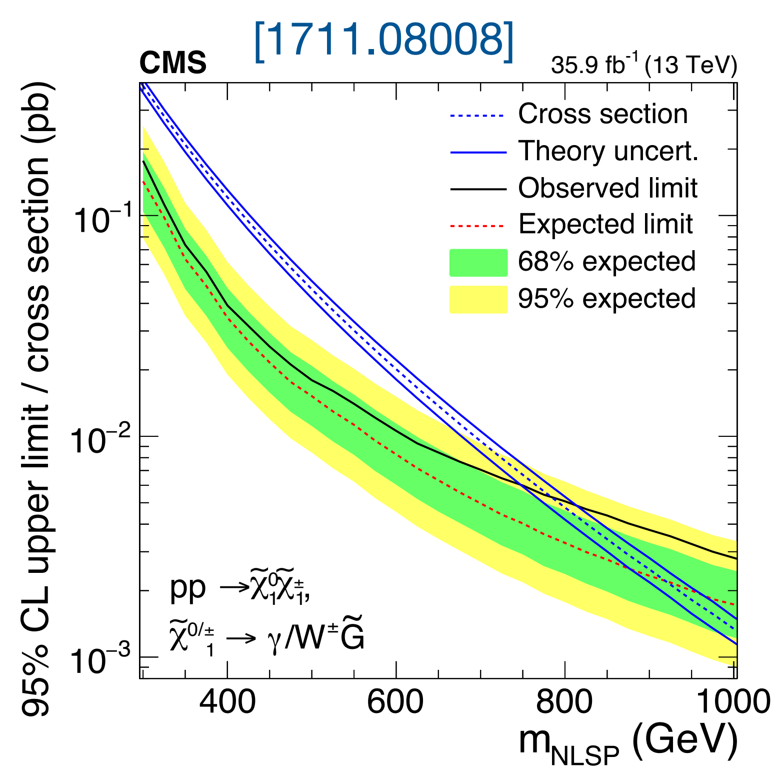
Wino-like

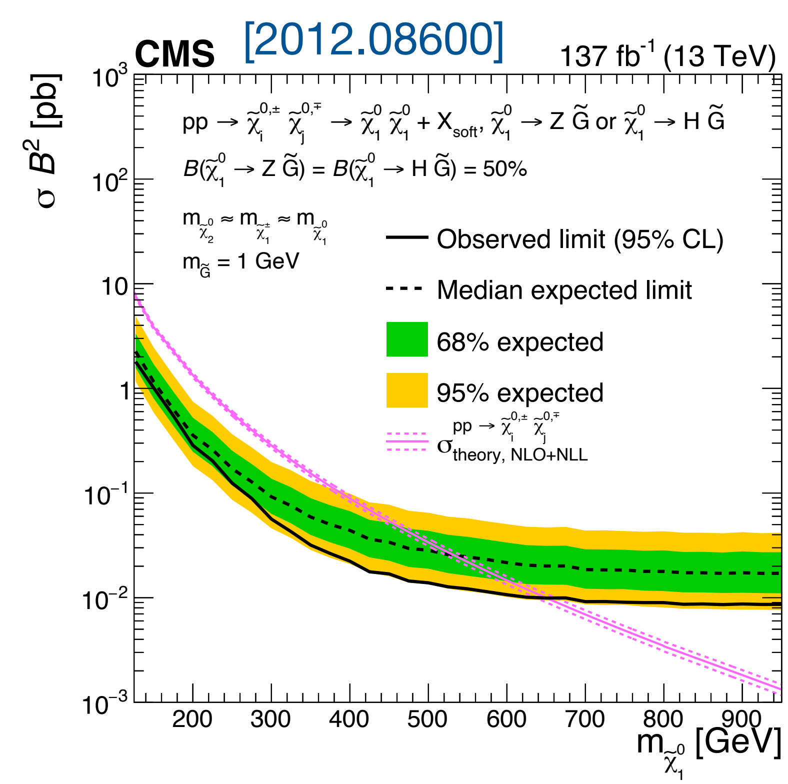


Higgsino-like









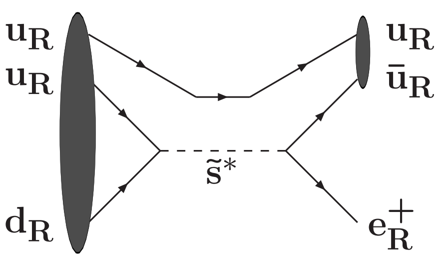
- Higgsino, Wino direct production excluded up to 700GeV
- SUSY g-2 requires Higgsino or Wino with m < 600 GeV

g-2 not compatible with LHC

R-Parity Violation; UDD

$$W_{\rm RPV} = \underbrace{\lambda''_{ijk} U_i^c D_j^c D_k^c}_{\not B} + \underbrace{\lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \kappa_i L_i H_u}_{\not L}$$

$p^+ \to \pi^0 e^+$



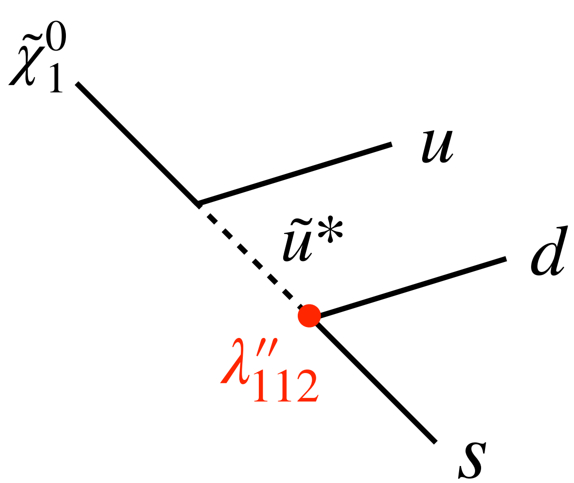
- Allowing both **B** and **L** violation leads to a rapid proton decay:
- We introduce only the **UDD** operator with: $\lambda''_{112} \neq 0$

- Constraint from K0-K0bar mixing can easily be satisfied:

$$|\lambda''_{112}\lambda''_{123}| \lesssim 2.8 \times 10^{-2} \left(\frac{m_{\tilde{s}_R, \tilde{u}_R}}{1\,\mathrm{TeV}}\right)$$
$$|\lambda''_{112}\lambda''_{113}| \lesssim 1.2 \times 10^{-1} \left(\frac{m_{\tilde{d}_R, \tilde{u}_R}}{1\,\mathrm{TeV}}\right)$$

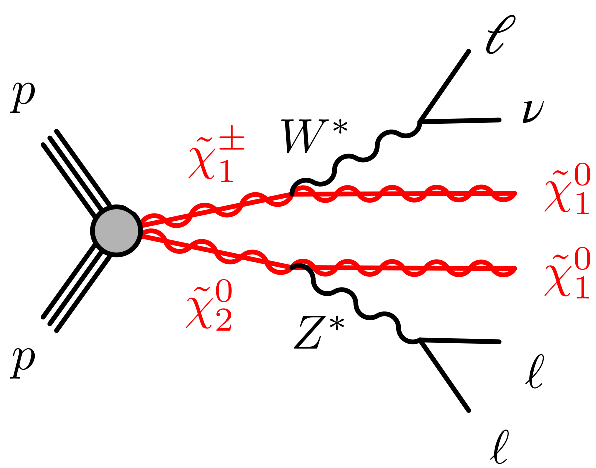
[1810.08228]

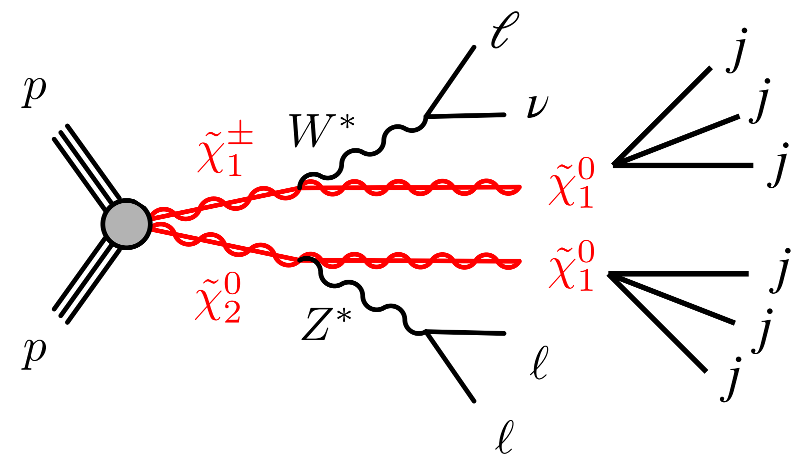
- **LHC signature is the most challenging:**
  no leptons, no b-jets in the neutralino decay



R-Parity Violation; UDD

neutralino LSP

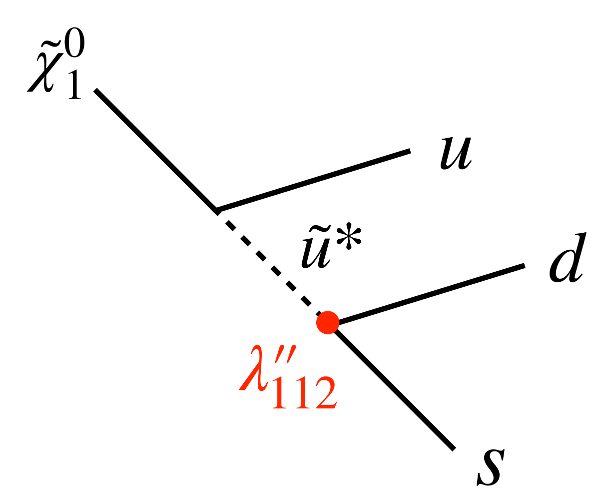




RPV (UDD-type)

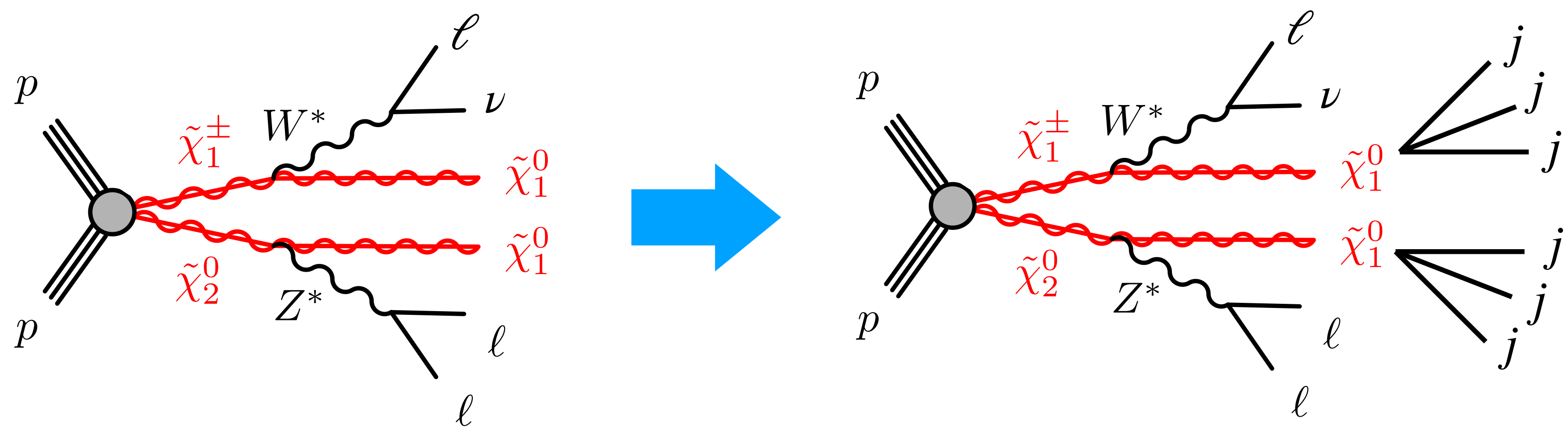
No missing energy, but multi-jet

- LHC signature is the most challenging:
  no leptons, no b-jets in the neutralino decay



R-Parity Violation; UDD

neutralino LSP

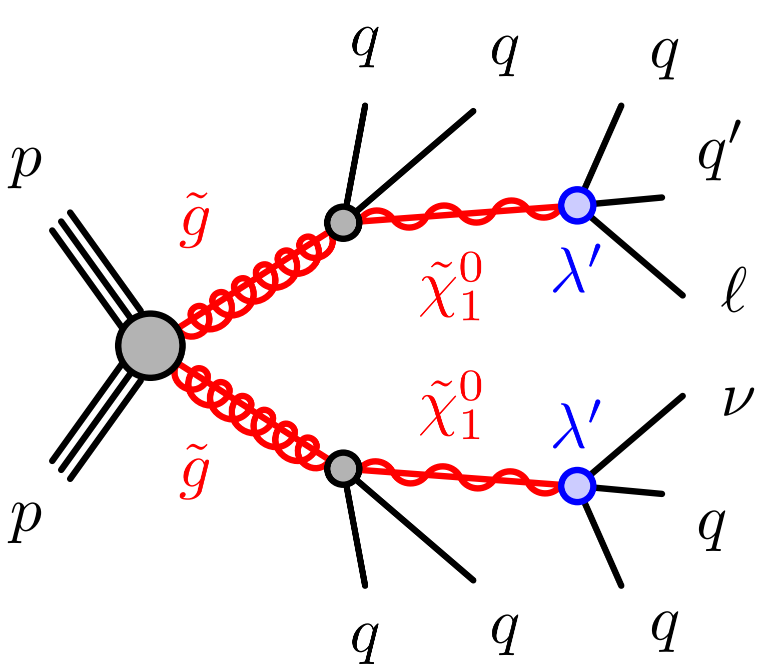


RPV (UDD-type)

No missing energy, but multi-jet

- There exist ATLAS and CMS analyses sensitive to such final states:

ATLAS [2106.09609]



CMS [1709.05406]

Bin	Final state	Definition
1	2 SS leptons	0 jets, $M_T > 100$ GeV and $p_T^{miss} > 140$ GeV
2	2 SS leptons	1 jet , $M_T < 100$ GeV, $p_T^{\ell\ell} < 100$ GeV and $p_T^{miss} > 200$ GeV
3	3 light leptons	$M_T > 120$ GeV and $p_T^{miss} > 200$ GeV
4	3 light leptons	$p_T^{miss} > 250$ GeV
5	2 light leptons and 1 tau	$M_{T2}(\ell_1, \tau) > 50$ GeV and $p_T^{miss} > 200$ GeV
6	1 light lepton and 2 taus	$M_{T2}(\ell, \tau_1) > 50$ GeV and $p_T^{miss} > 200$ GeV
7	1 light lepton and 2 taus	$p_T^{miss} > 75$ GeV
8	more than 3 leptons	$p_T^{miss} > 200$ GeV

Analysis Framework

SUSY g-2: 1-loop + leading 2-loop GM2Calc [Eur.Phys.J. C76 (2016) no.2, 62]

Neutralino abundance, Direct Detection: MicrOMEGAs [2003.08621]

Decay of SUSY particles: SUSY-HIT [hep-ph/0609292]

LHC constraints:

- **MSSM:** Fastlim/SModelS-like approach with HEP-DATA info
- **Gravitino LSP:** Pythia 8 + CheckMATE 2 [1907.09874], [1611.09856]
- **RPV (UDD-type):** Pythia 8 + CheckMATE 2 [1907.09874], [1611.09856]

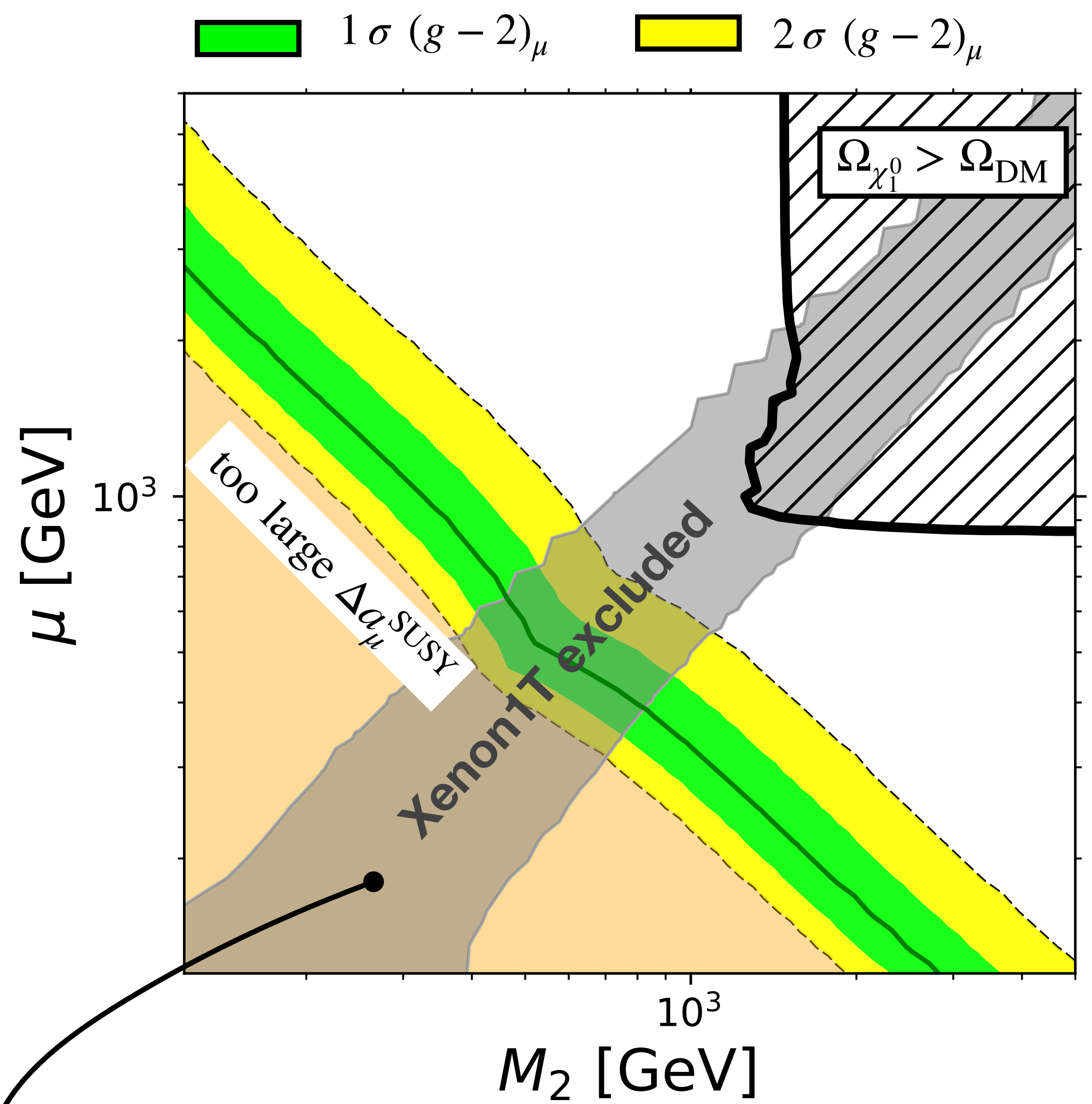
All results are preliminary

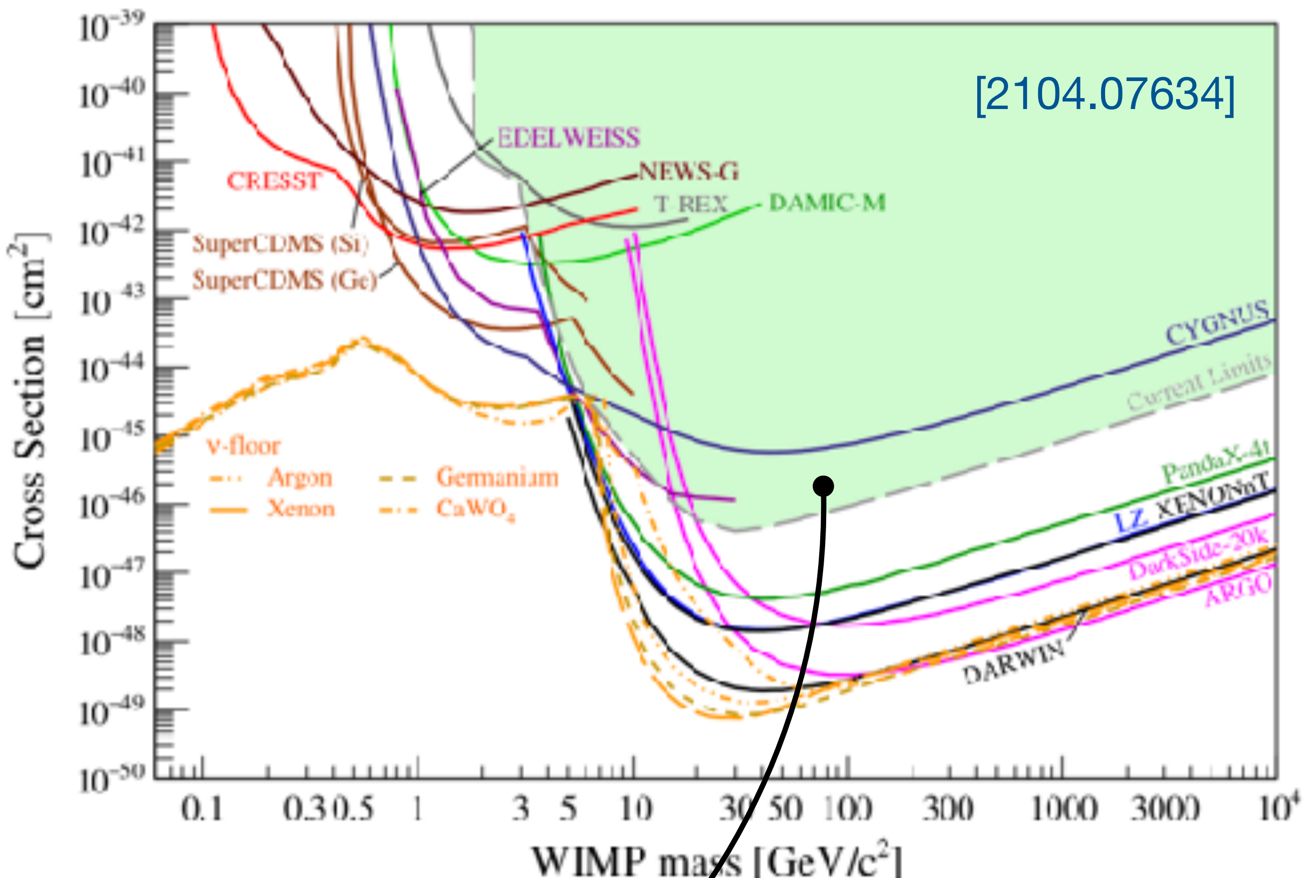
Name	E/TeV	$\mathcal{L}/\text{fb}^{-1}$	discription
atlas_1604_01306	13	3.2	Monophoton
atlas_1605_09318	13	3.3	3 b-jets + 0-1 lepton + MET
atlas_1609_01599	13	36	Monophoton
atlas_1704_03848	13	36	Monophoton
atlas_conf_2015_082	13	3.2	2 leptons (Z) + jets + MET
atlas_conf_2016_013	13	3.2	1 lepton + jets (4 tops, VVL quarks)
atlas_conf_2016_050	13	13.3	1 lepton + (b) jets + MET
atlas_conf_2016_054	13	13.3	1 lepton + (b) jets + MET
atlas_conf_2016_076	13	13.3	2 lepton + jets + MET
atlas_conf_2016_096	13	13.3	Multi-lepton + MET
atlas_conf_2017_060	13	36	Monojet
atlas_conf_2016_066	13	13.3	Photons, jets and MET
atlas_1712_08119	13	36	soft leptons (compressed EWKinos)
atlas_1712_02332	13	36	squarks and gluinos, 0 lepton, 2-6 jets
atlas_1709_04183	13	36	Jets + MET (stops)
atlas_1802_03158	13	36	search for GMSB with photons
atlas_1708_07875	13	36	EWKino search with taus and MET
atlas_1706_03731	13	36	Multilepton + Jets + MET (RPC and RPV)
atlas_1908_08215	13	36	2 leptons + MET (EWKinos)
atlas_1909_08457	13	139	SS lepton + MET (squark, gluino)
atlas_conf_2019_040	13	139	Jets + MET (squark, gluino)
atlas_conf_2019_020	13	139	3 leptons (EWKino)
atlas_1803_02762	13	36	2 or 3 leptons (EWKino)
atlas_conf_2018_041	13	80	Multi-b-jets (stops, sbottoms)
atlas_2101_01629	13	139	1 lepton + jets + MET
atlas_conf_2020_048	13	139	Monojet
atlas_2004_14060	13	139	$t\bar{t}$ + MET
atlas_1908_03122	13	139	Higgs bosons + b-jets + MET
atlas_2103_11684	13	139	4 or more leptons (RPV, GMSB)
atlas_2106_09609	13	139	Multijets + leptons (RPV)

WHL (MSSM)

$$m_{\tilde{l}_L} = \min(M_2, \mu) + 20\,\mathrm{GeV}$$

$$\tan\beta = 50, \quad M_1 = m_{\tilde{l}_R} = 10\,\mathrm{TeV}$$

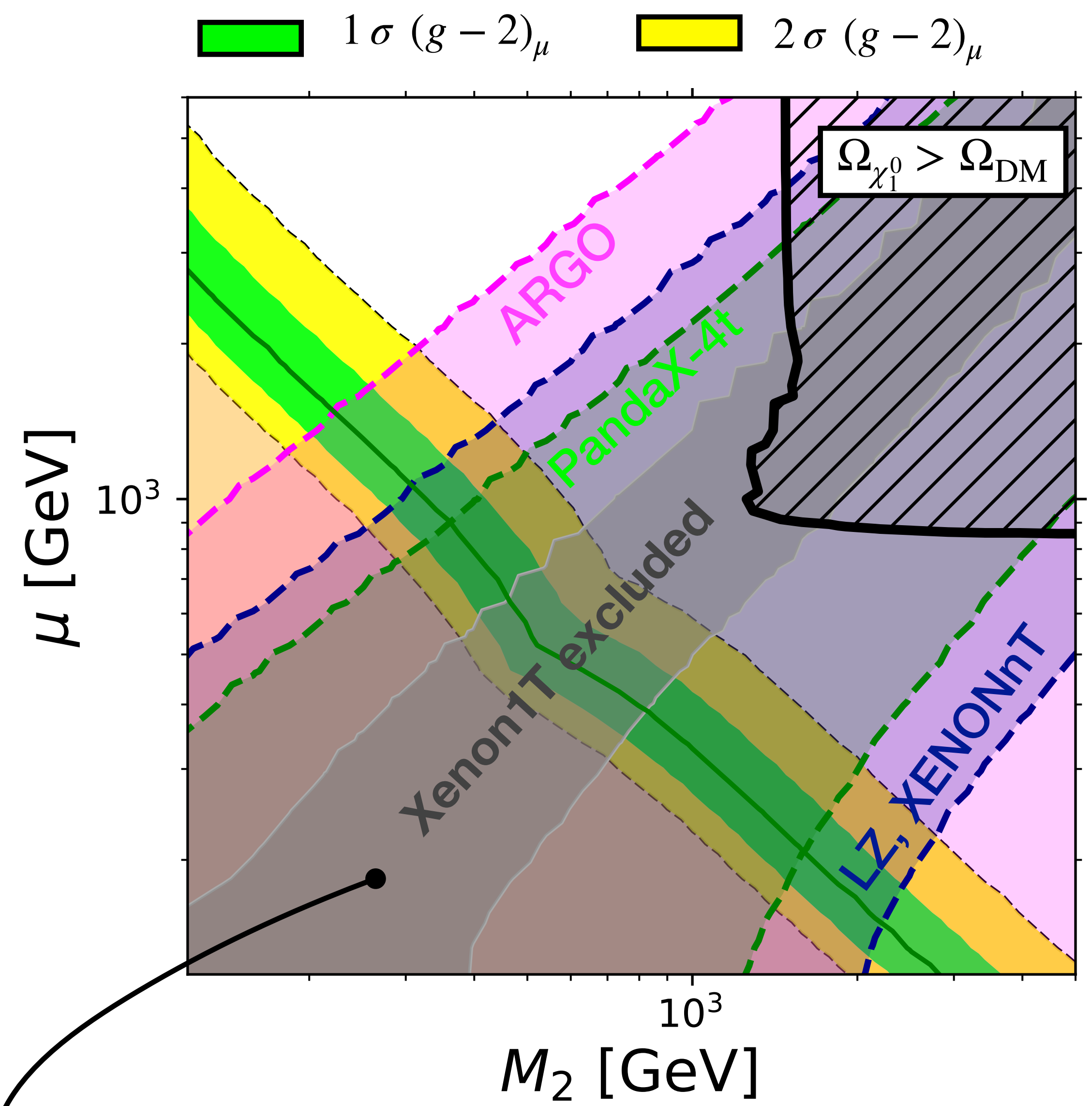


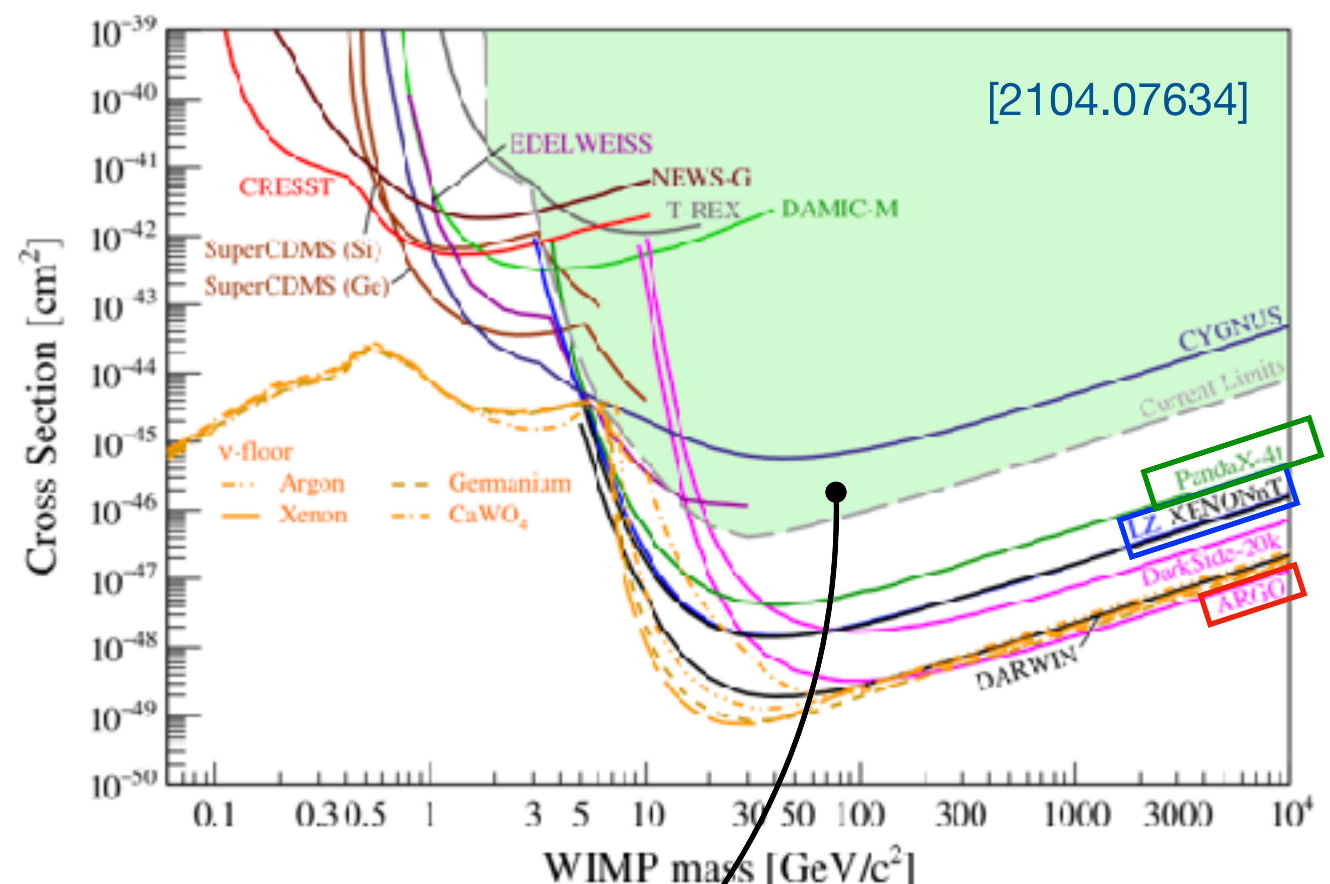


$$\sigma^{\mathrm{SI}}_{\chi N\to\chi N}(m_{\tilde{\chi}_1^0}) \cdot \frac{\Omega_{\tilde{\chi}_1^0}}{\Omega_{\mathrm{DM}}} > \sigma^{\mathrm{SI}}_{\mathrm{Xenon1T}}(m_{\mathrm{DM}})$$

WHL (MSSM, future DM-DD)

$$m_{\tilde{l}_L} = \min(M_2, \mu) + 20\,\mathrm{GeV}$$
$$\tan\beta = 50, \quad M_1 = m_{\tilde{l}_R} = 10\,\mathrm{TeV}$$

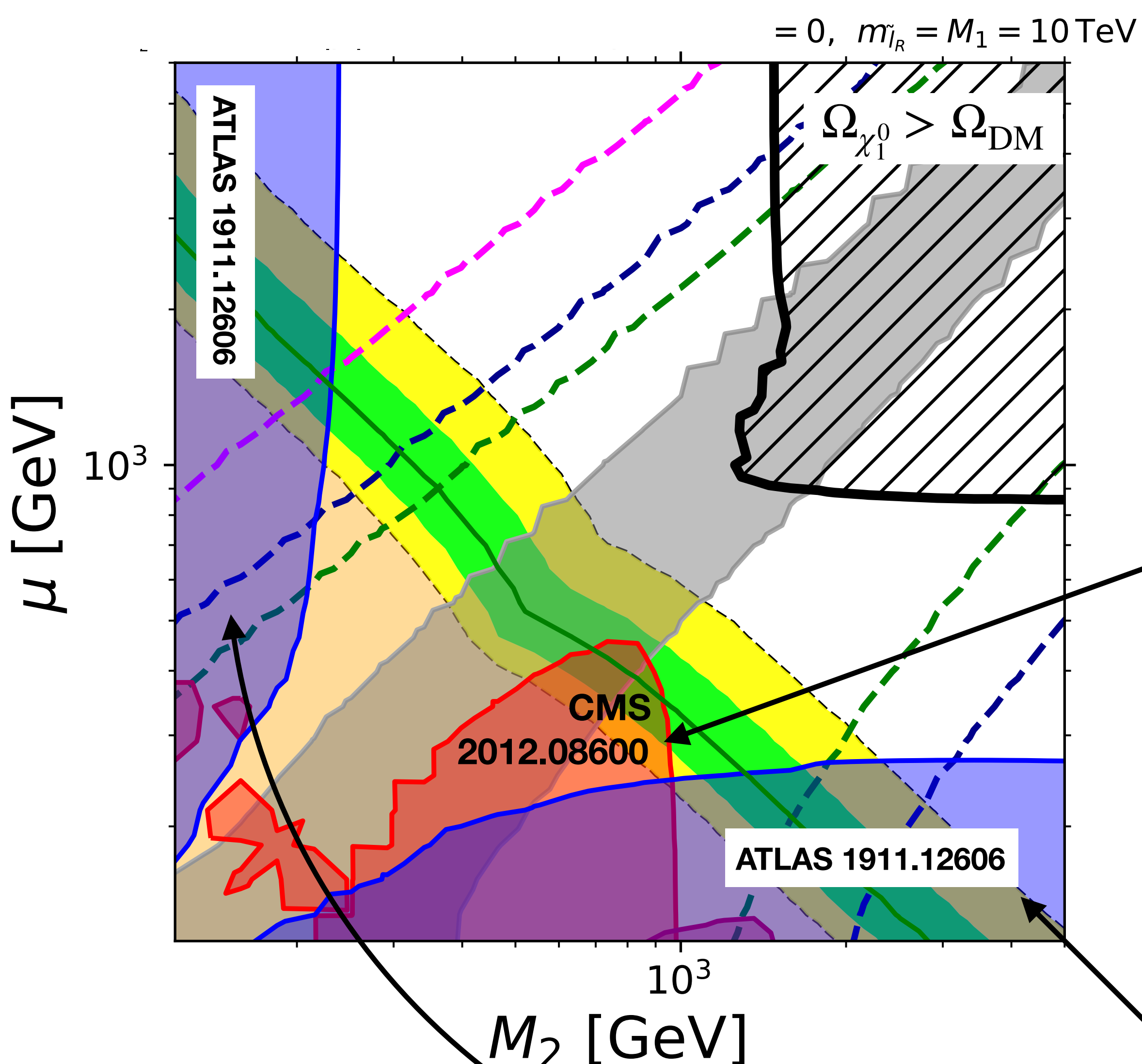


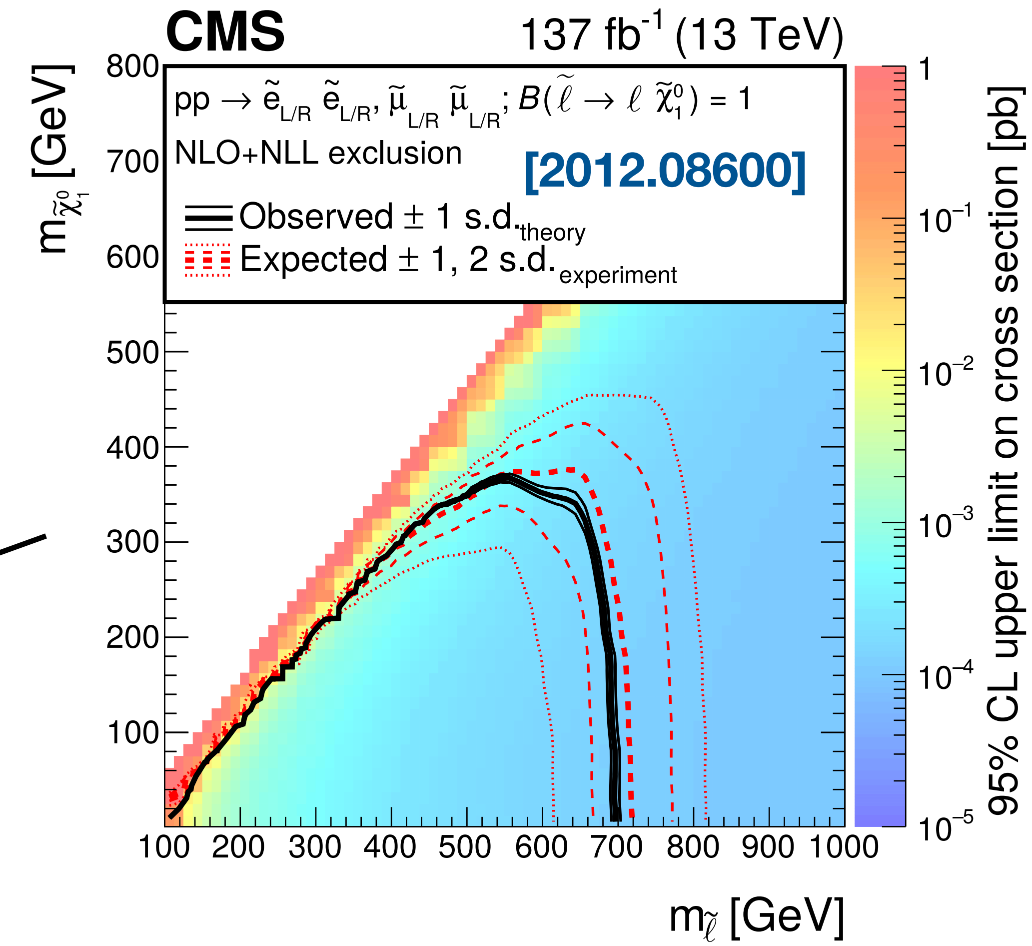


$$\sigma^{\rm SI}_{\chi N\to\chi N}(m_{\tilde{\chi}_1^0}) \cdot \frac{\Omega_{\tilde{\chi}_1^0}}{\Omega_{\rm DM}} > \sigma^{\rm SI}_{\rm Xenon1T}(m_{\rm DM})$$

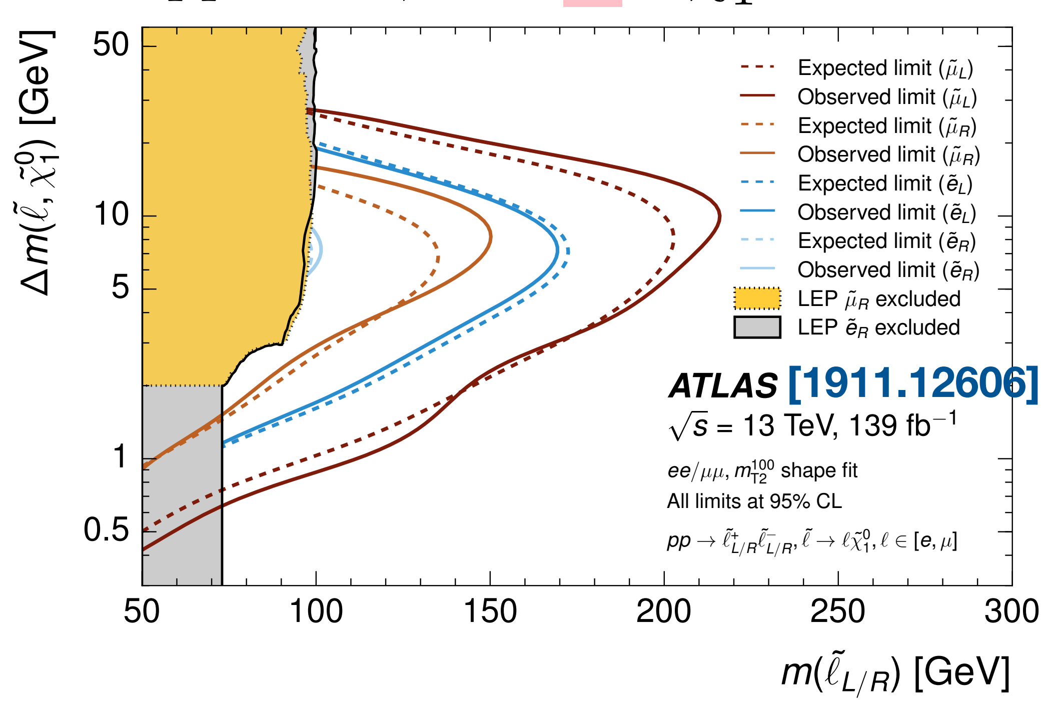
WHL (MSSM, LHC)

$$pp \to \widetilde{W}\widetilde{W},\ \ \widetilde{W}^{0,\pm} \to \ell + (\tilde{\ell}, \tilde{\nu})$$





$$pp \to \tilde{\ell}\tilde{\ell},\ \ \tilde{\ell} \to \ell + \tilde{\chi}_1^0$$



$$m_{\tilde{l}_L} = \min(M_2, \mu) + 20\,\text{GeV}$$

$$\tan\beta = 50,\ \ M_1 = m_{\tilde{l}_R} = 10\,\text{TeV}$$

WHL (RPV UDD)

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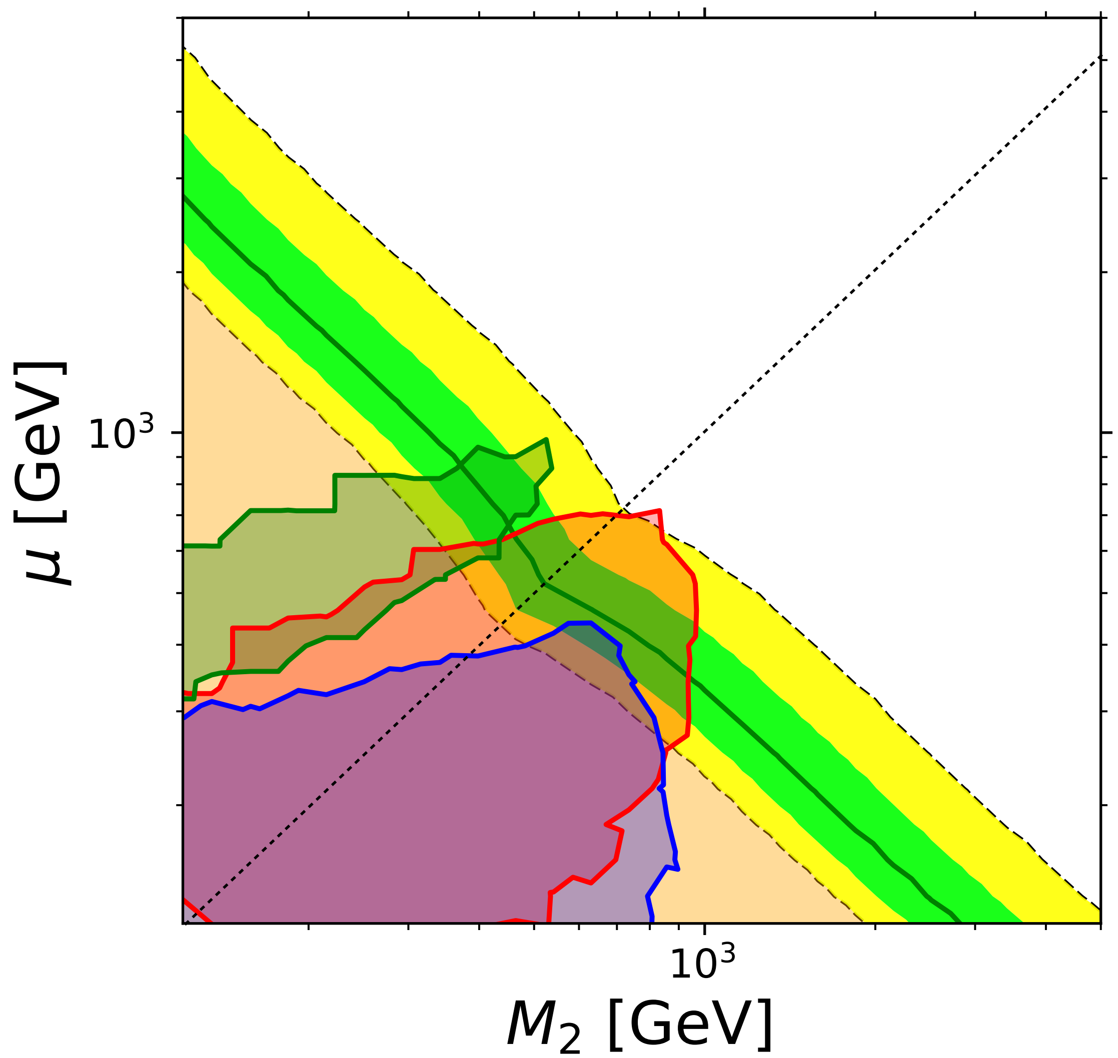
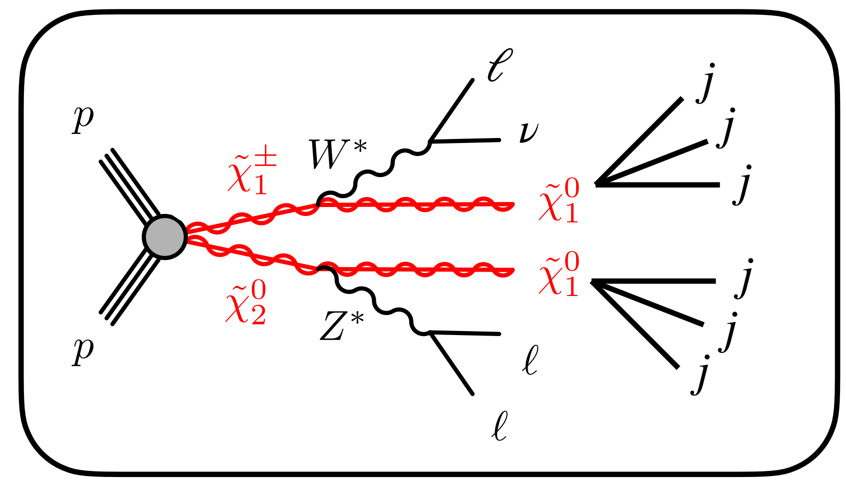
$$\tan\beta = 50, \quad M_1 = m_{\tilde{l}_R} = 10\,\mathrm{TeV}$$

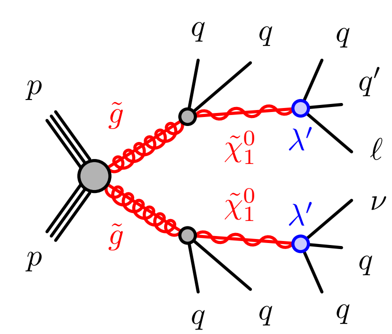


$$pp \to W^{\pm}W^{0,\mp}, \quad \tilde{h}^{0,\pm}\tilde{h}^{0,\mp}$$



soft lepton + multi-jet final state

More g-2 region available due to absence of DM constraints



RPV ATLAS13 139/fb [2106.09609]

Multi & SS-leptons CMS13 36/fb [1709.05406]

Multijet ATLAS13 139/fb [2106.09609]

Bin	Final state	Definition
1	2 SS leptons	0 jets, $M_T > 100\,\mathrm{GeV}$ and $p_T^{miss} > 140\,\mathrm{GeV}$
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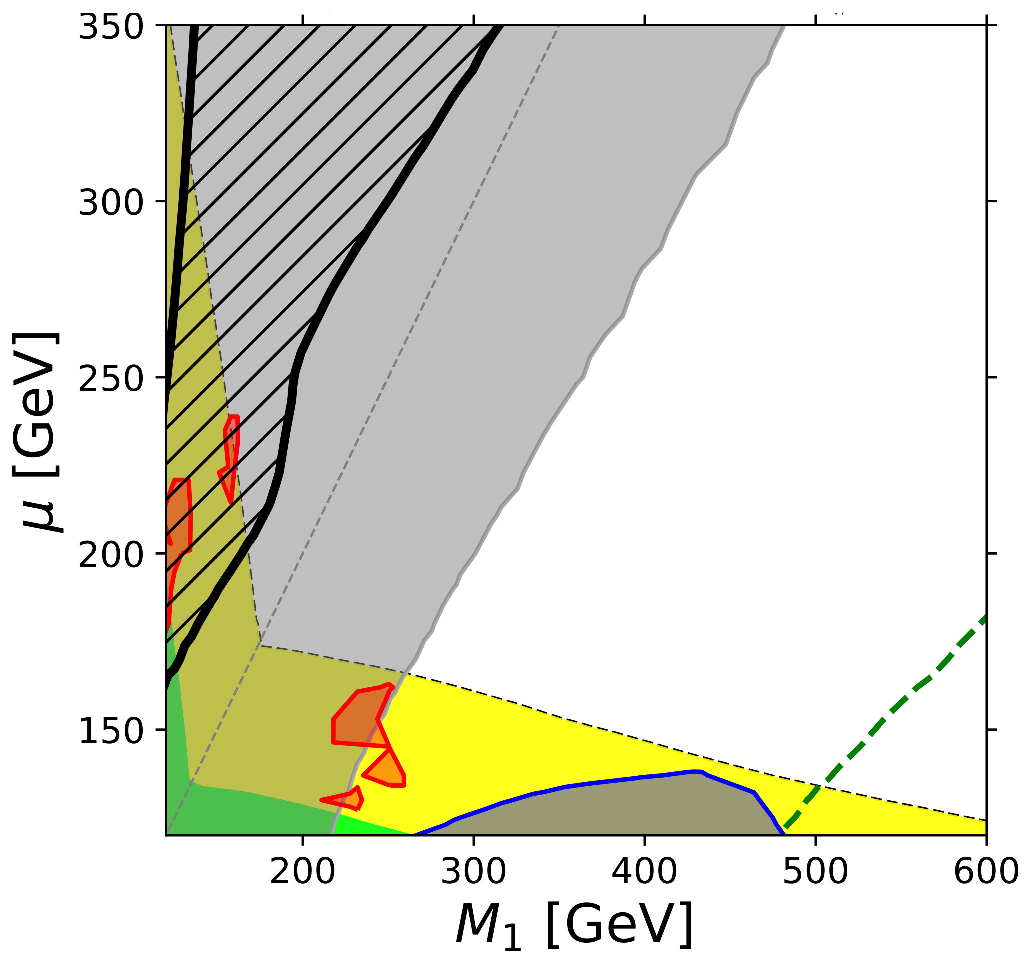
7	1 light lepton and 2 taus	$p_T^{miss} > 75\,\mathrm{GeV}$
8	more than 3 leptons	$p_T^{miss} > 200\,\mathrm{GeV}$

MSSM

BHL

$m_{\tilde{l}_L} = \min(M_1, \mu) + 20\,\text{GeV}$

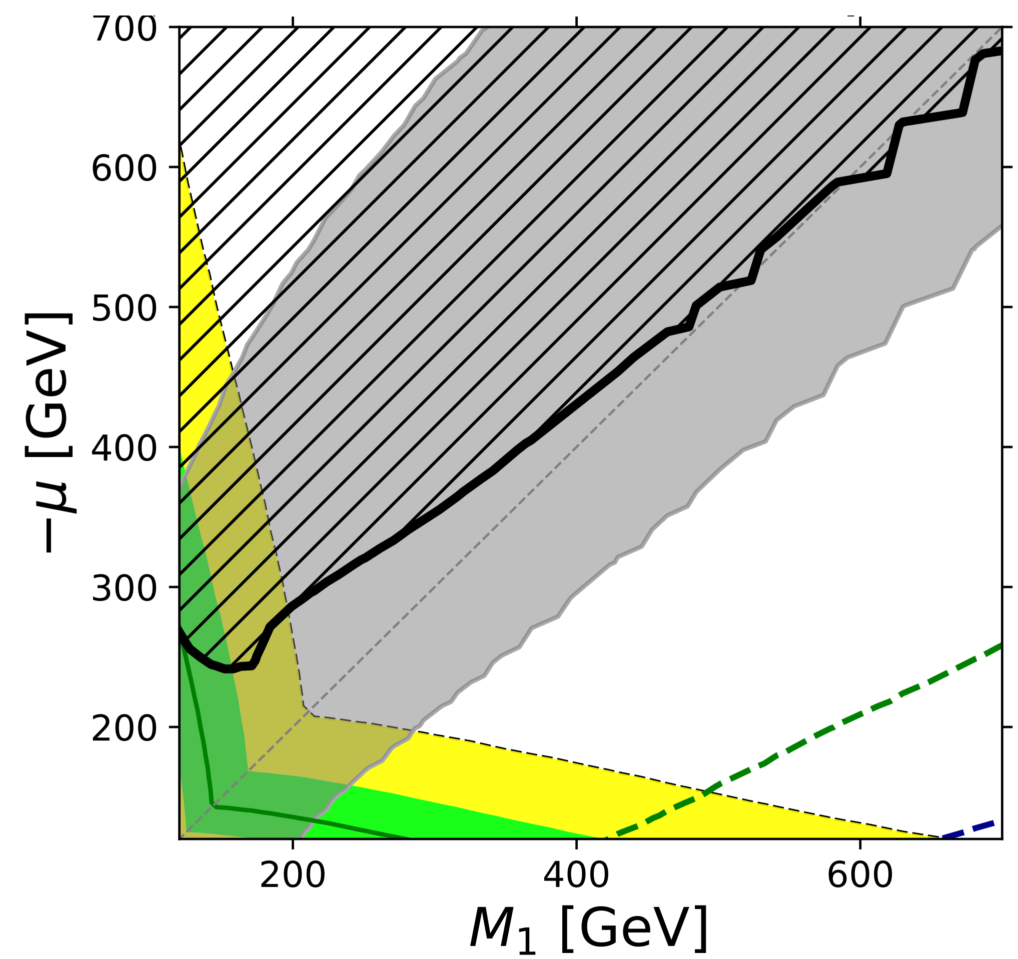
$\tan\beta = 50, \quad M_2 = m_{\tilde{l}_R} = 10\,\text{TeV}$



BHR

$m_{\tilde{l}_R} = \min(M_1, |\mu|) + 20\,\text{GeV}$

$\tan\beta = 50, \quad M_2 = m_{\tilde{l}_L} = 10\,\text{TeV}$



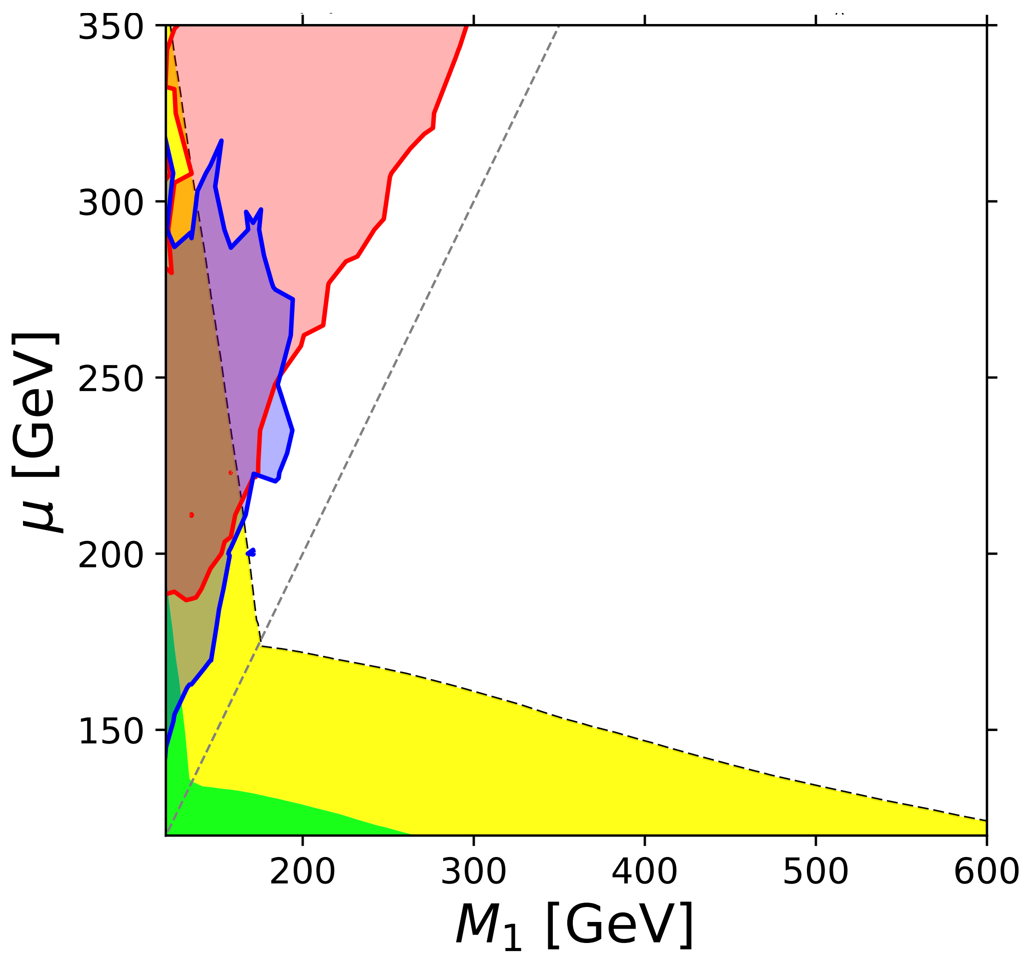
- Large regions are excluded by $\Omega_\chi > \Omega_{DM}$ and DM-DD.
- Future DM-DD experiments will explore the entire region
- LHC limits very weak

RPV

BHL

$$m_{\tilde{l}_L} = \min(M_1, \mu) + 20\,\text{GeV}$$

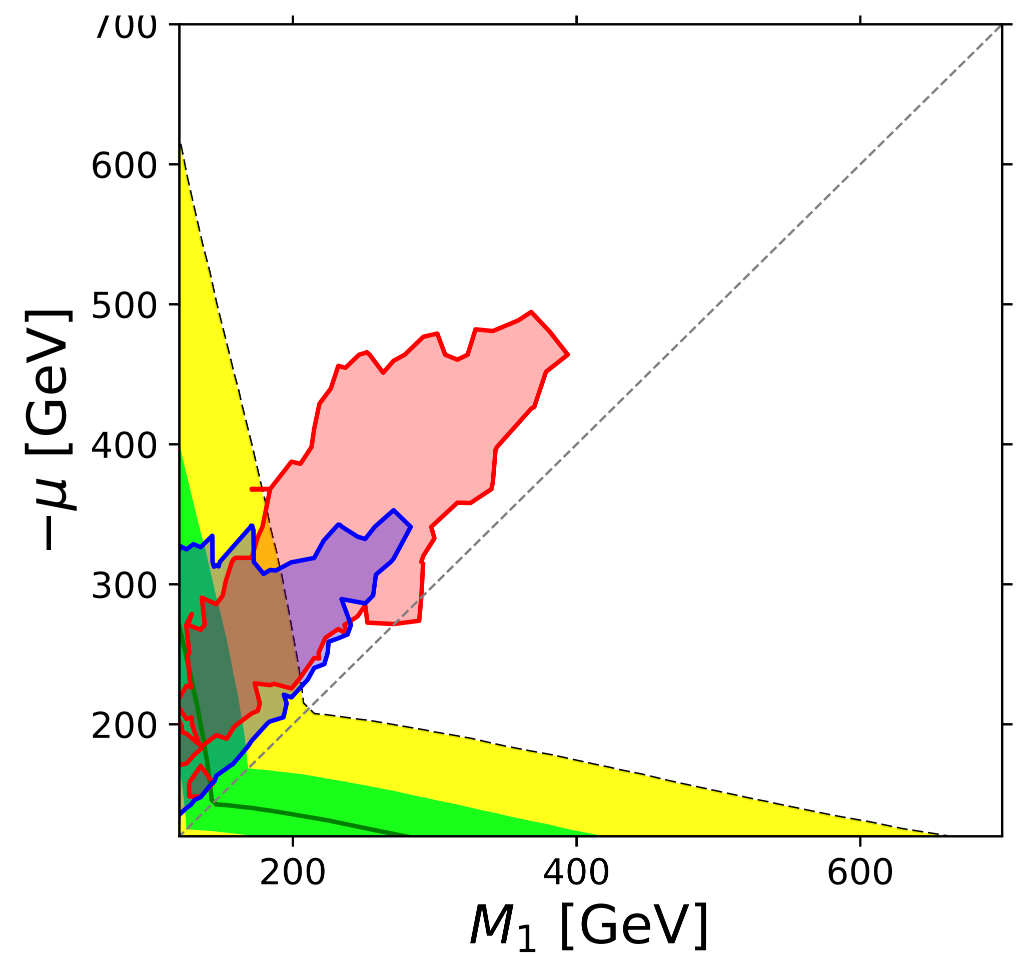
$$\tan\beta = 50, \quad M_2 = m_{\tilde{l}_R} = 10\,\text{TeV}$$



BHR

$$m_{\tilde{l}_R} = \min(M_1, |\mu|) + 20\,\text{GeV}$$

$$\tan\beta = 50, \quad M_2 = m_{\tilde{l}_L} = 10\,\text{TeV}$$

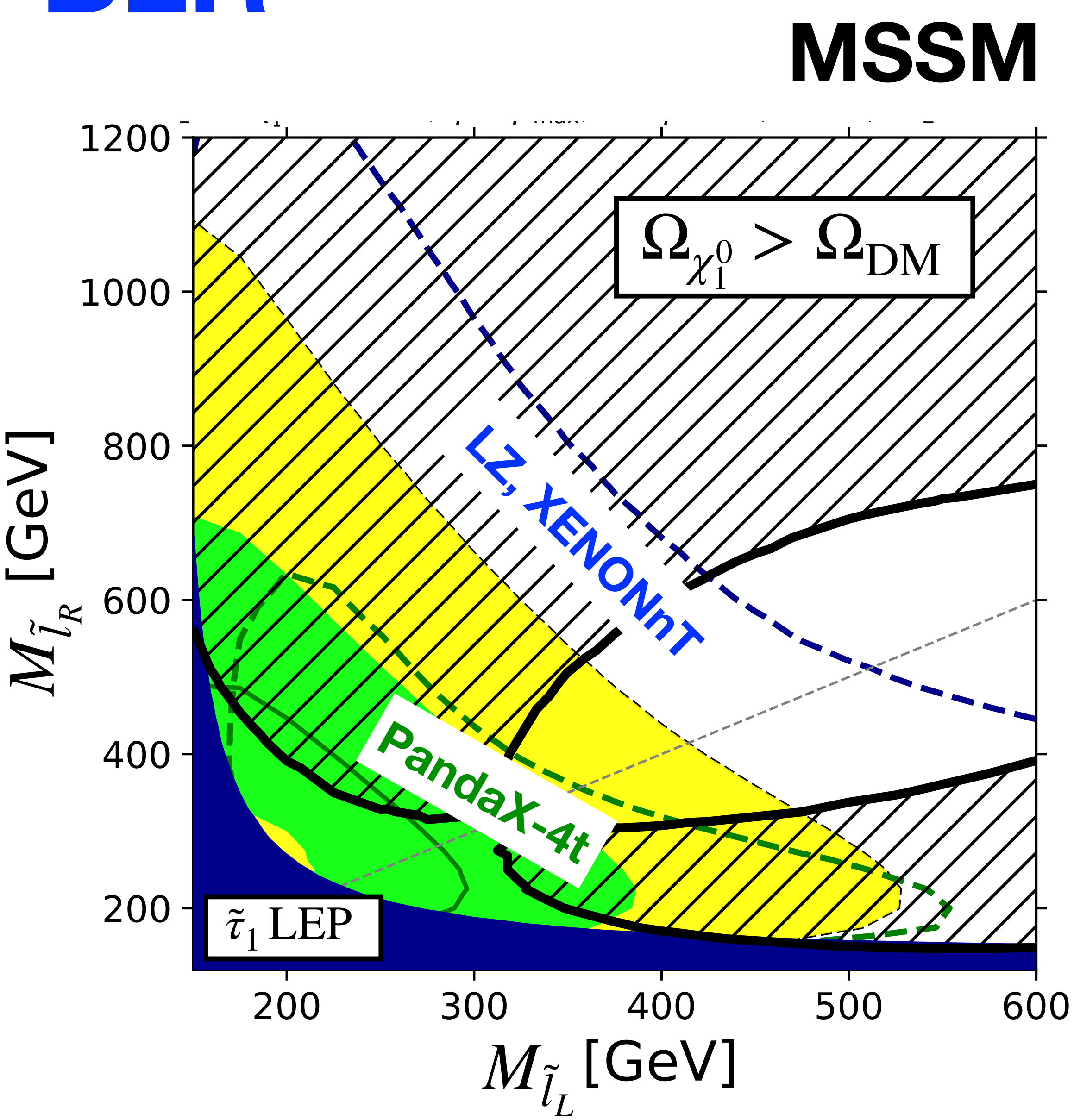


RPV ATLAS13 139/fb [2106.09609]

Multi & SS-leptons CMS13 36/fb [1709.05406]

- **Stronger LHC limits**
- **More g-2 region available**

BLR



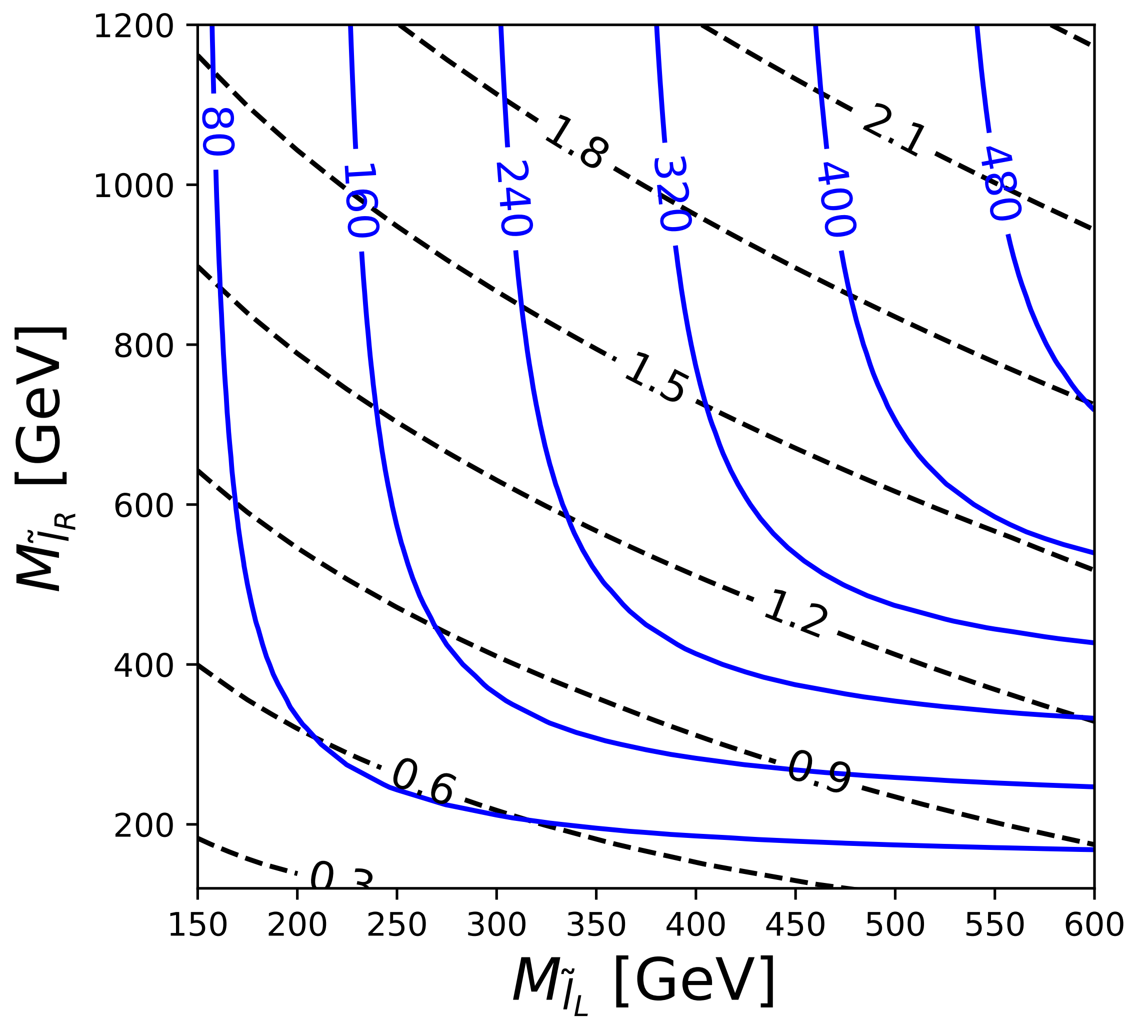
$M_1 = m_{\tilde{\tau}_1} - 20\,\mathrm{GeV}$, $M_2 = 10\,\mathrm{TeV}$

$\mu = \mu_{max}$, $\tan\beta = 50$

maximum allowed by vacuum (meta-)stability

$\Delta a_\mu^{BLR}(M_1, m_{\tilde{l}_L}, m_{\tilde{l}_R}; \mu)$

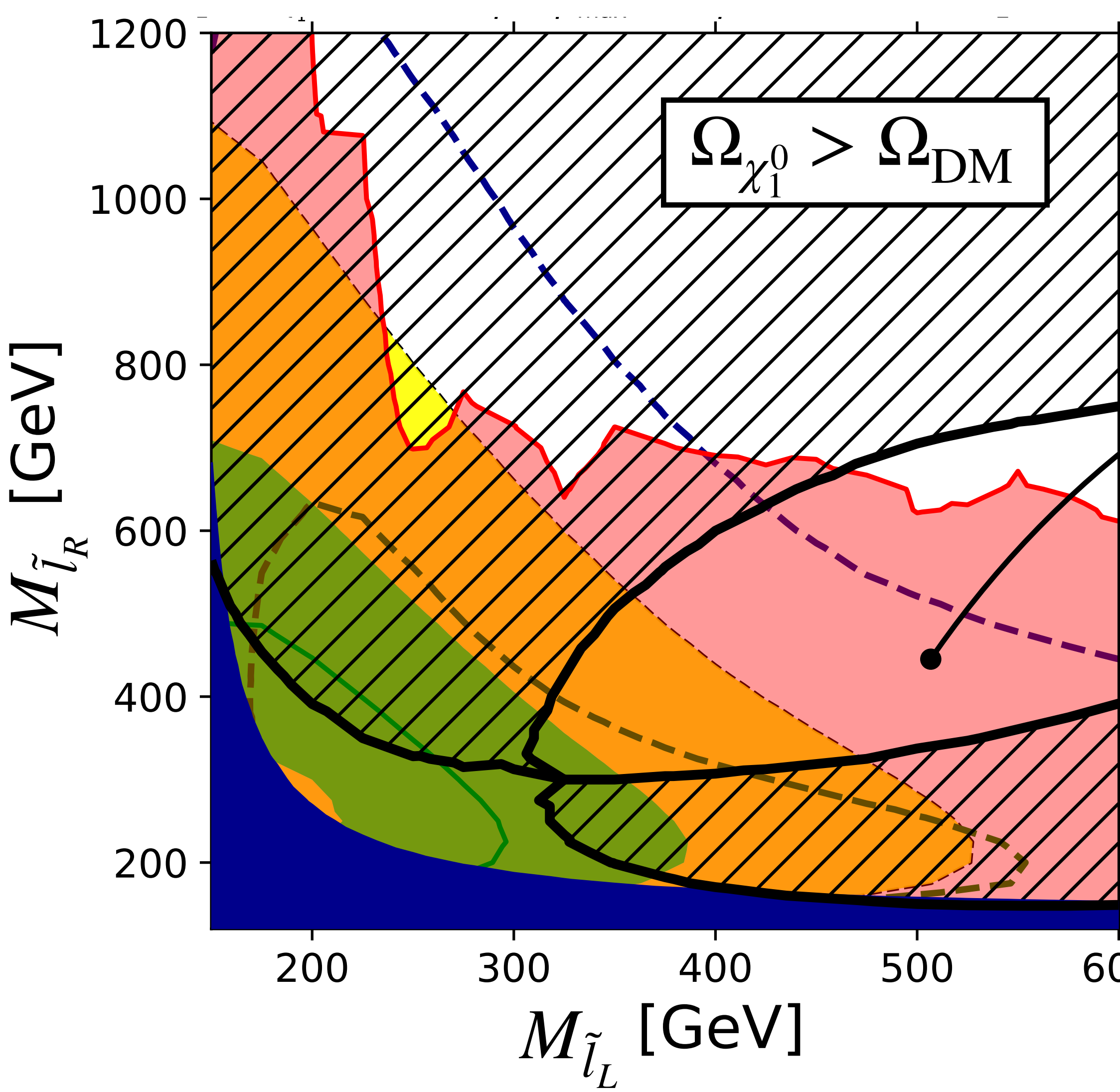
μ /TeV, M_1 /GeV

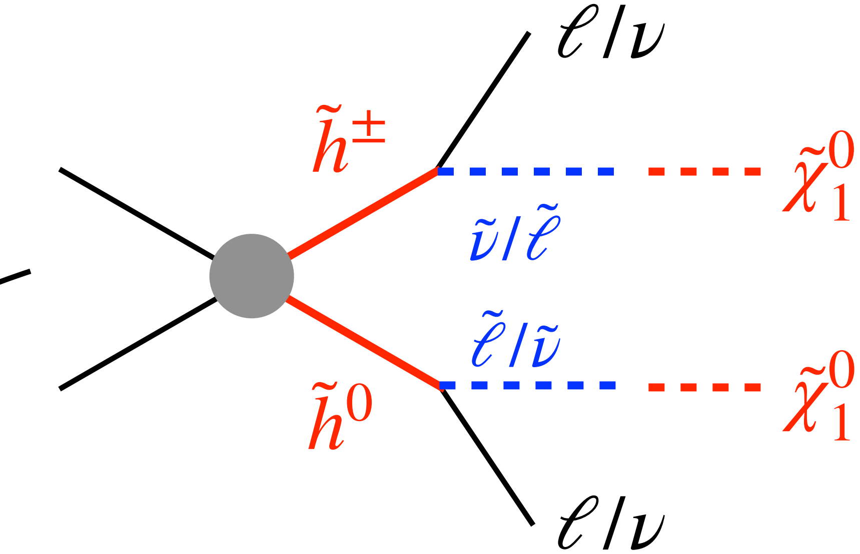


BLR

$$\Delta a_\mu^{\rm BLR}(M_1, m_{\tilde{l}_L}, m_{\tilde{l}_R}; \mu)$$

MSSM





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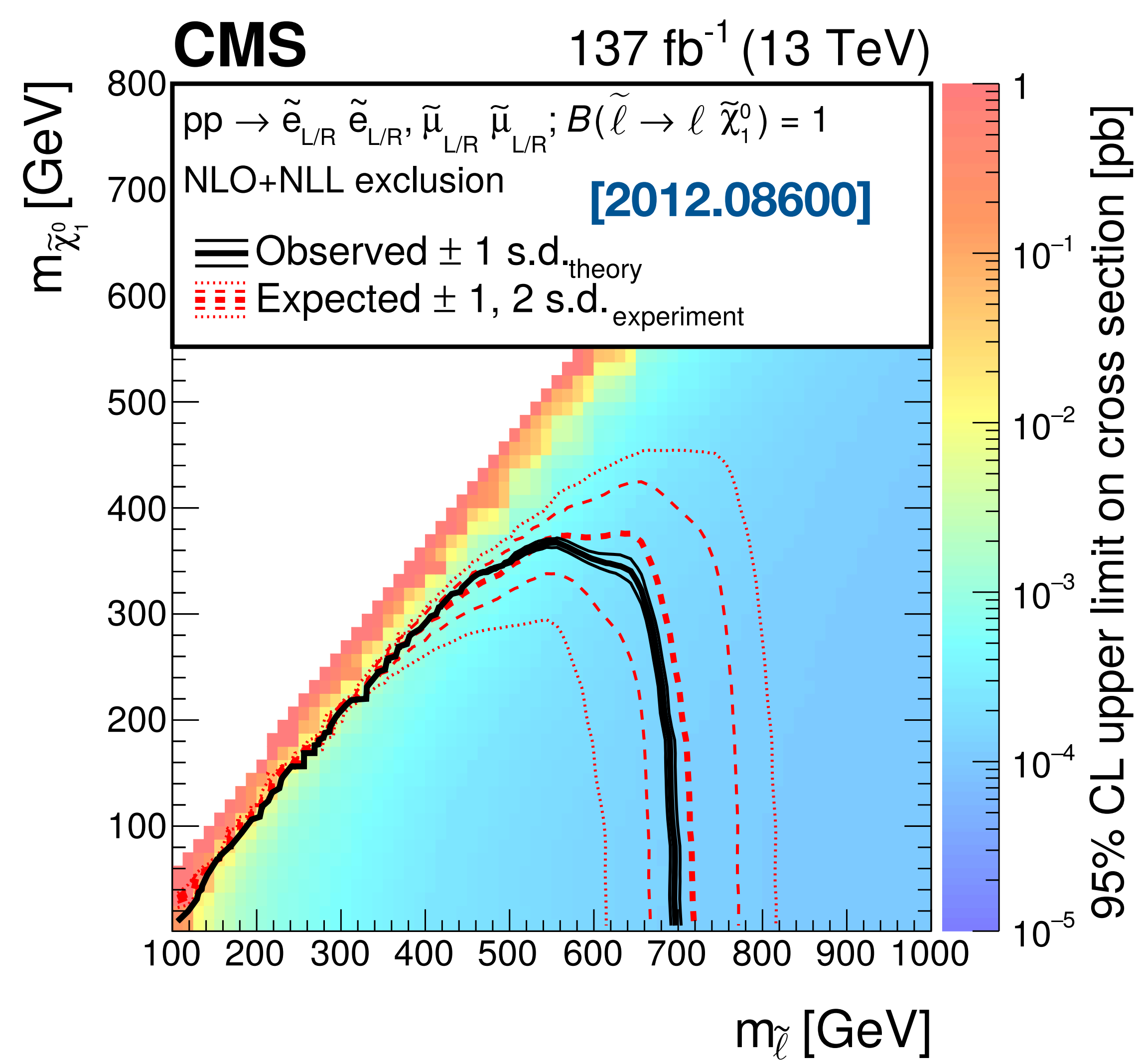
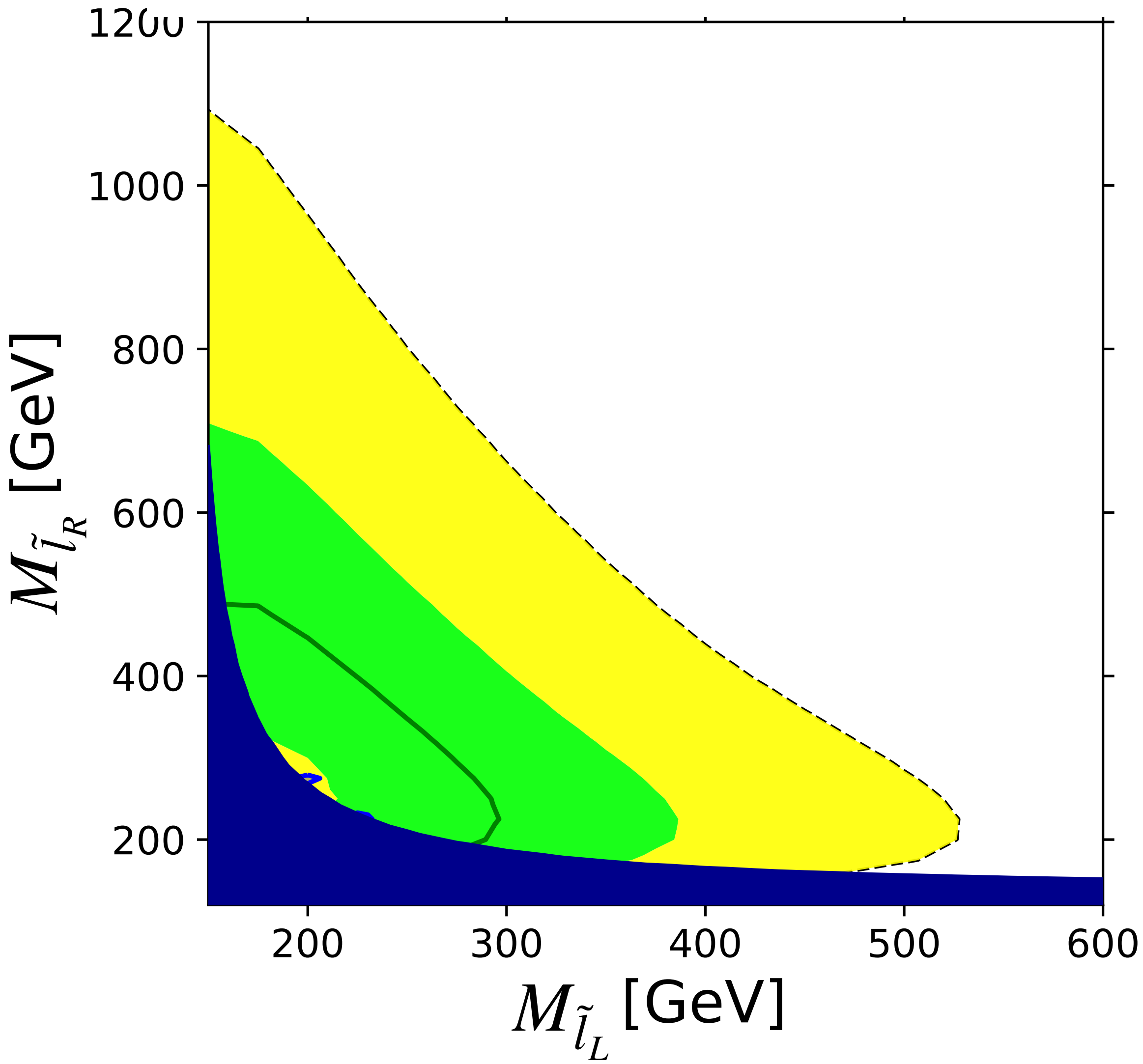
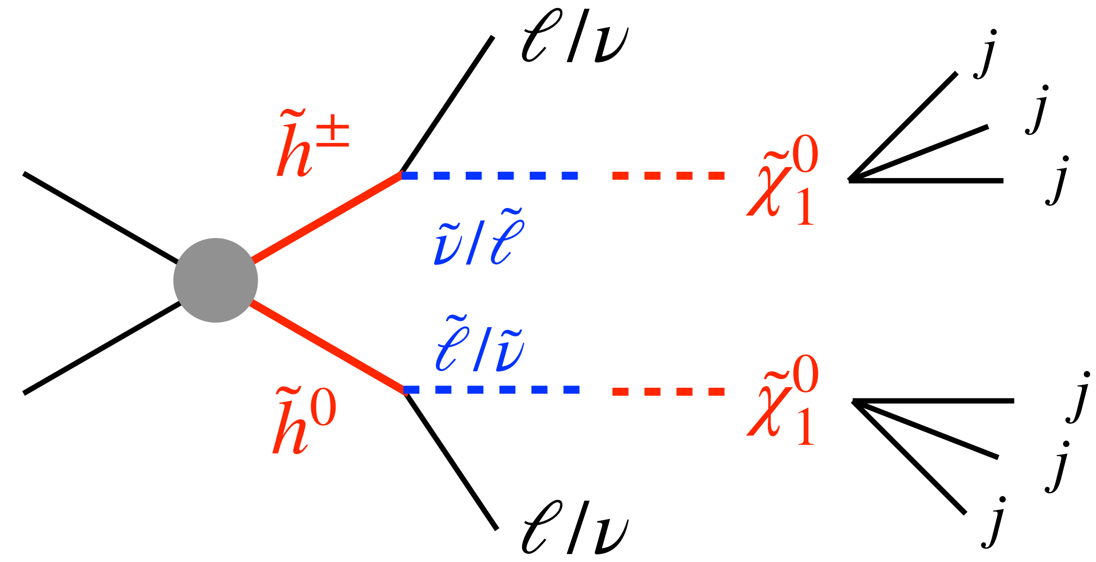


BLR

$$\Delta a_\mu^{\text{BLR}}(M_1, m_{\tilde{l}_L}, m_{\tilde{l}_R}; \mu)$$

RPV





No g-2 region is constrained by LHC

$M_1 = m_{\tilde{\tau}_1} - 20\,\text{GeV},\quad M_2 = 10\,\text{TeV}$

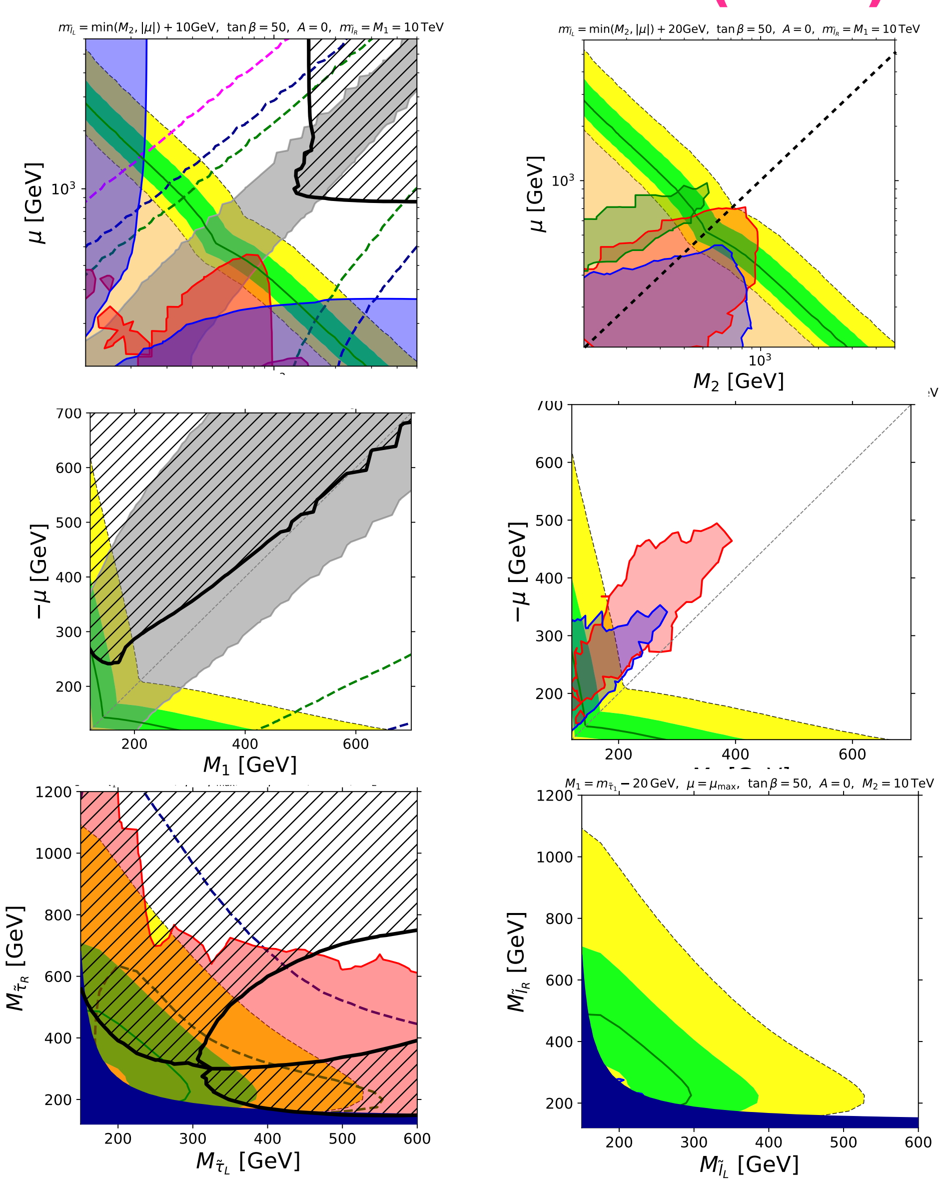
$\mu = \mu_{\text{max}},\quad \tan\beta = 50$

maximum allowed by vacuum (meta-)stability

Conclusion

- We studied the SUSY parameter space favoured by the muon g-2 anomaly.
- Phenomenological constraints depend on whether or not neutralino-1 is stable:

MSSM | **RPV (UDD)**



Stable (**MSSM**):

- Dark Matter:
  Overproduction, Direct Detection
  → future DM-DD cover the entire 2-sigma region
- LHC constraints: **Lepton + MET**

Unstable:

- **No dark matter constraints:**
- LHC constraints:
  Gravitino → **excluded by boson + MET**
  (what if stau is NLSP?)

  RPV (UDD) → **more g-2 regions available**

Norway grants

NATIONAL SCIENCE CENTRE
POLAND

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Understanding the Early Universe:
interplay of theory and collider experiments

Joint research project between the University of Warsaw & University of Bergen