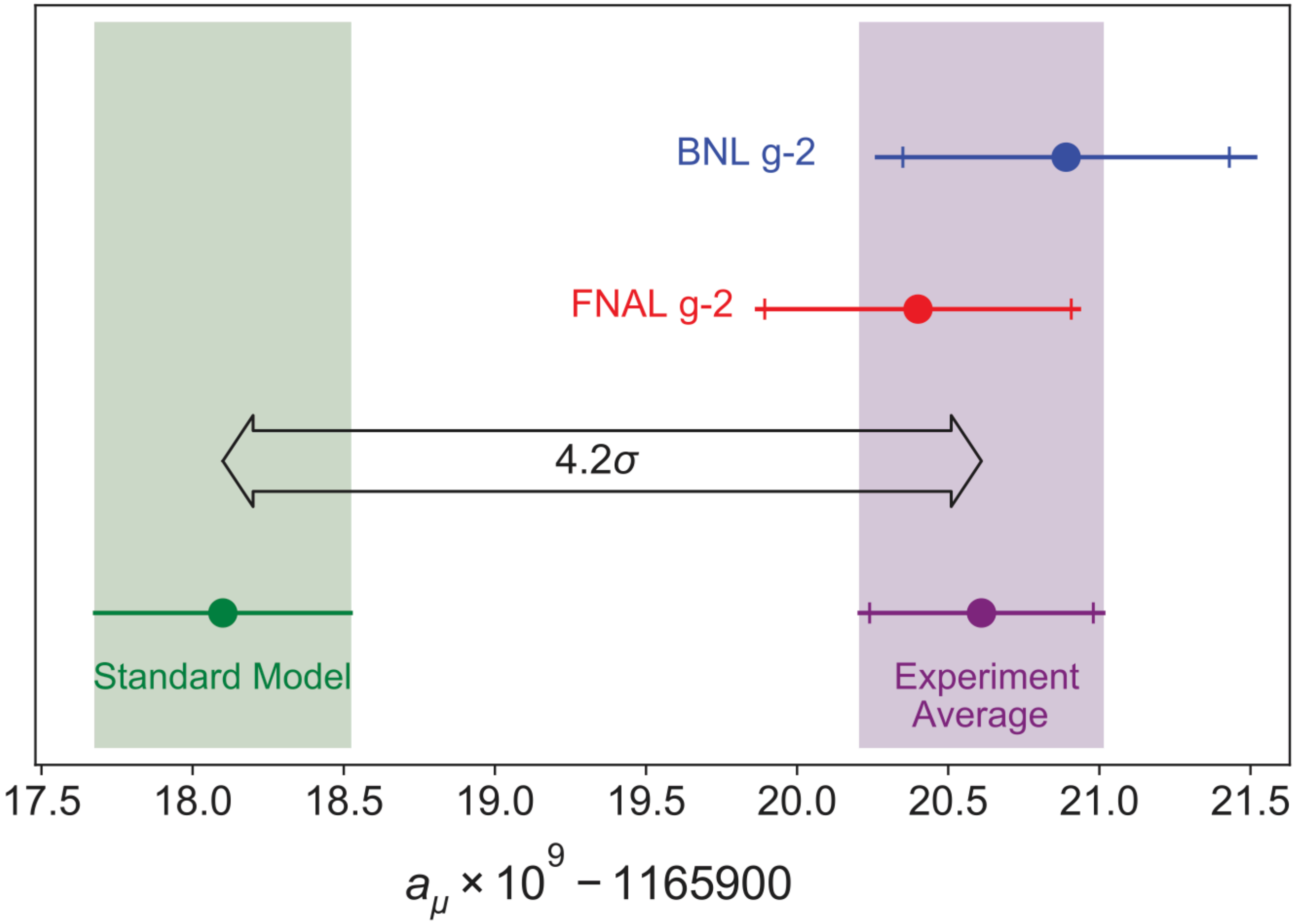
Implications of muon g-2 for SUSY

韩成成(中山大学)

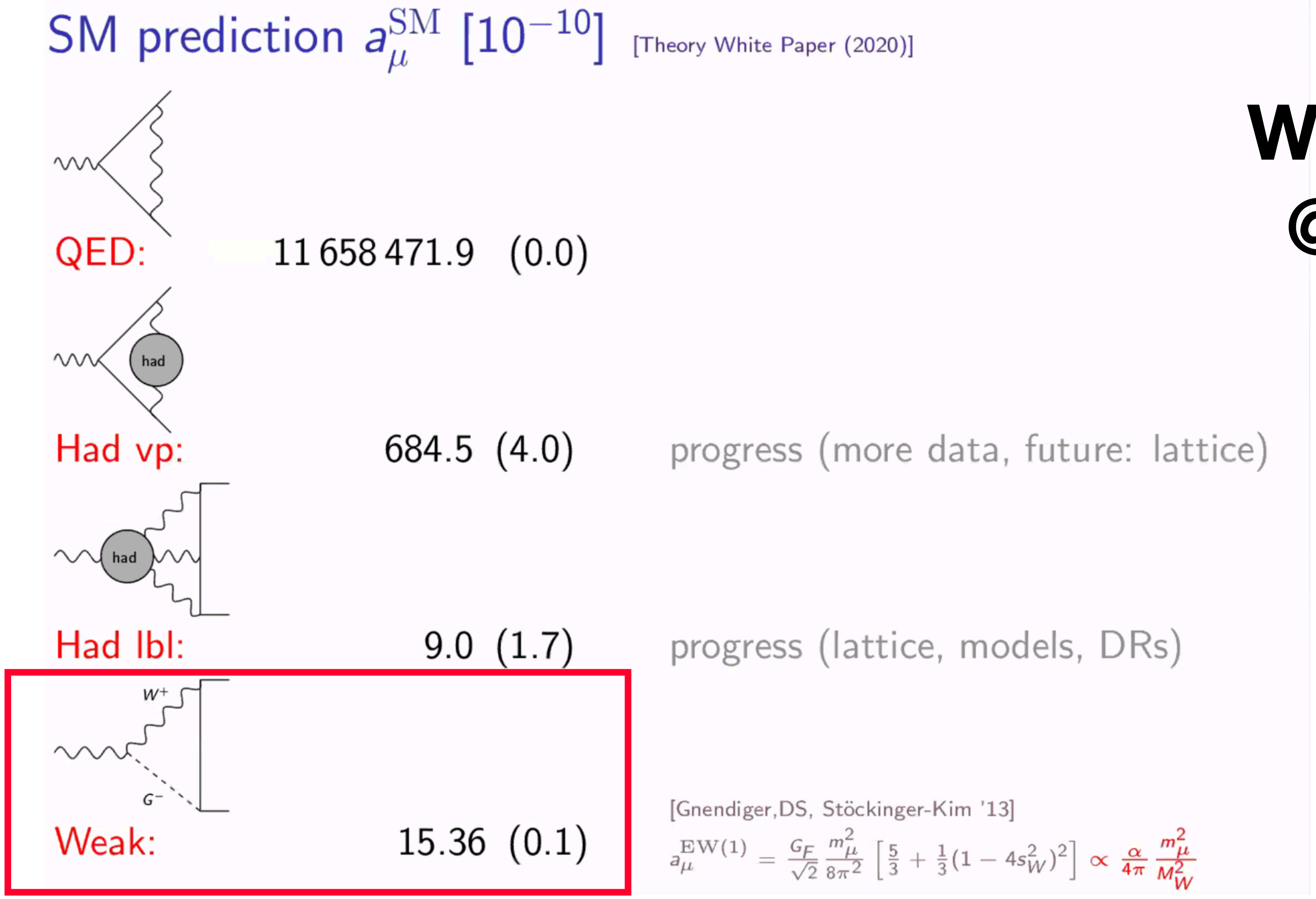
缪子g-2非正式研讨会
北京大学 2021.04.13

Muon g-2: observation and theory prediction



$$a_\mu(\text{Exp}) - a_\mu(\text{SM}) = (251 \pm 59) \times 10^{-11}$$

New physics at electroweak scale



SM prediction a_μ^{SM} $[10^{-10}]$ [Theory White Paper (2020)]

QED: 11 658 471.9 (0.0)

Had vp: 684.5 (4.0) progress (more data, future: lattice)

Had lbl: 9.0 (1.7) progress (lattice, models, DRs)

Weak: 15.36 (0.1)

[Gnendiger,DS, Stöckinger-Kim '13]

$$a_\mu^{\mathrm{EW}(1)} = \frac{G_F}{\sqrt{2}} \frac{m_\mu^2}{8\pi^2} \left[\frac{5}{3} + \frac{1}{3}(1 - 4s_W^2)^2\right] \propto \frac{\alpha}{4\pi} \frac{m_\mu^2}{M_W^2}$$

Why new particle mass @electroweak scale?

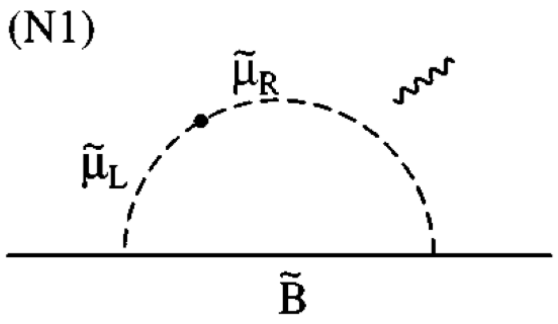
At hand

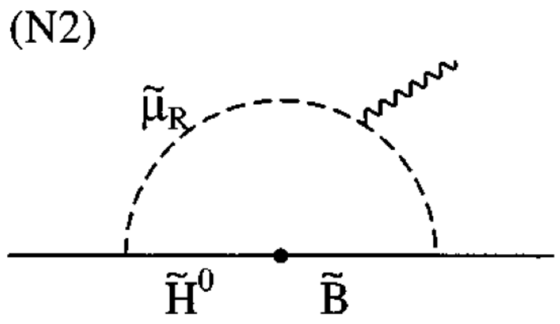
- **Naturalness problem**
- **WIMP dark matter**

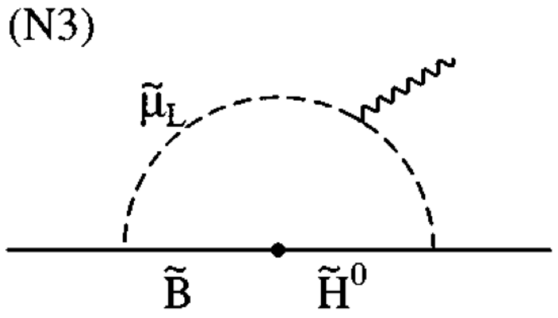
SUSY incorporate two, providing an attractive solution

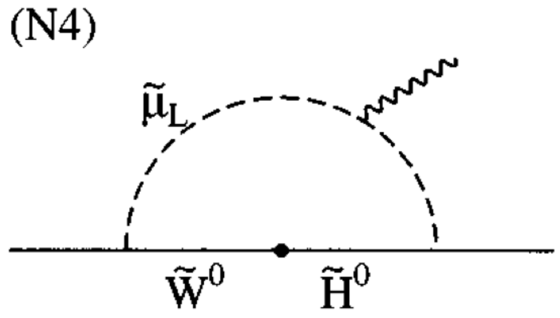
SUSY contribution to g-2

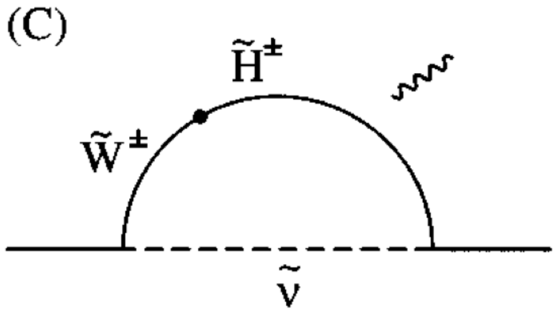
$$a_\mu(\mathrm{BLR}) \simeq \frac{\alpha_Y}{4\pi}\frac{m_\mu^2 M_1\mu}{m_{\tilde\mu_L}^2 m_{\tilde\mu_R}^2}\tan\beta\cdot f_N\left(\frac{m_{\tilde\mu_R}^2}{M_1^2},\frac{m_{\tilde\mu_R}^2}{M_1^2}\right)$$











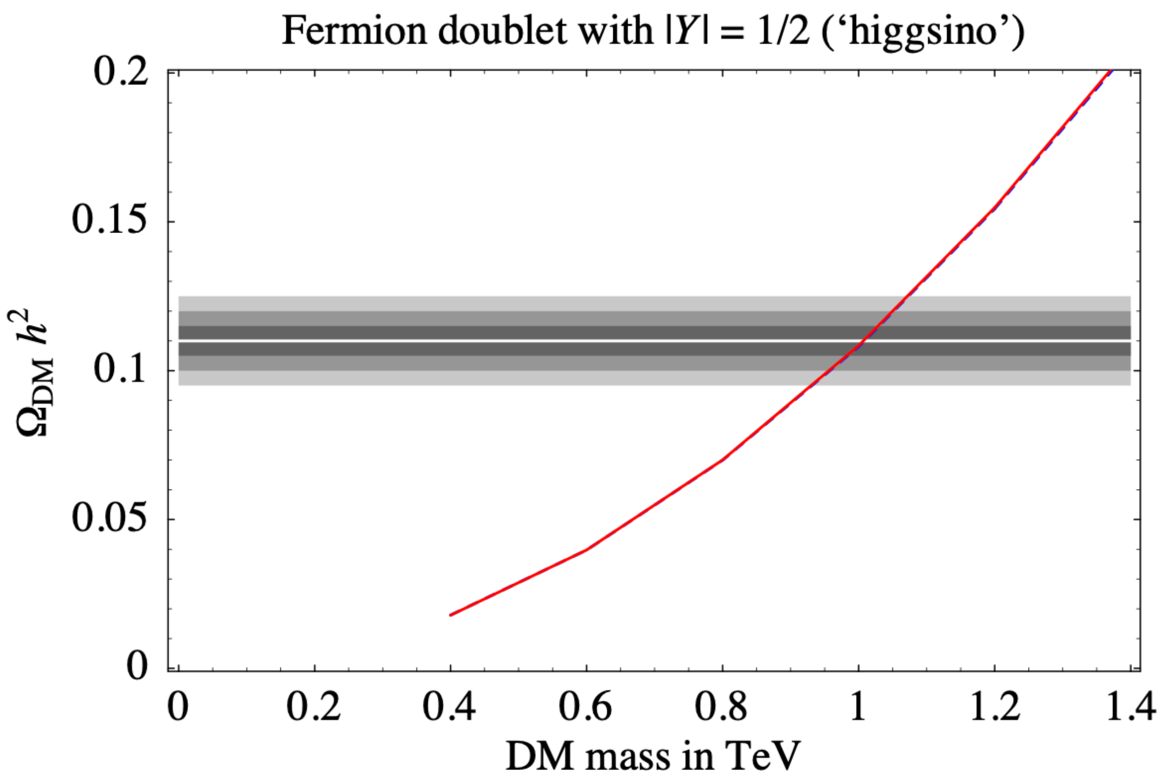
$$a_\mu(\mathrm{WHL2}) \simeq \frac{\alpha_2}{4\pi}\frac{m_\mu^2}{M_2\mu}\tan\beta\cdot f_C\left(\frac{M_2^2}{m_{\tilde\nu_\mu}^2},\frac{\mu^2}{m_{\tilde\nu_\mu}^2}\right)$$

SUSY dark matter

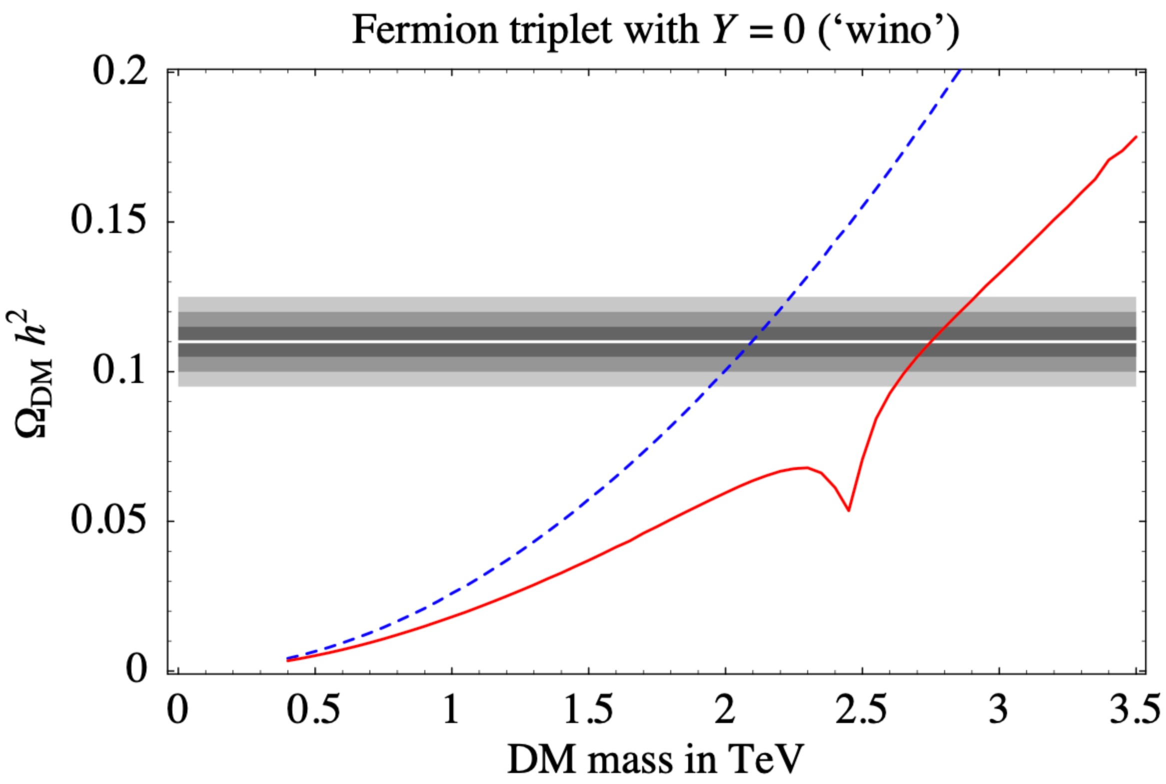
SUSY dark matter: mixing of bino, higgsino, wino

Case of higgsino, wino dark matter

M. Cirelli, A. Strumia, M. Tamburini, arXiv 0706.4071


Fermion doublet with $|Y| = 1/2$ ('higgsino')

~1 TeV

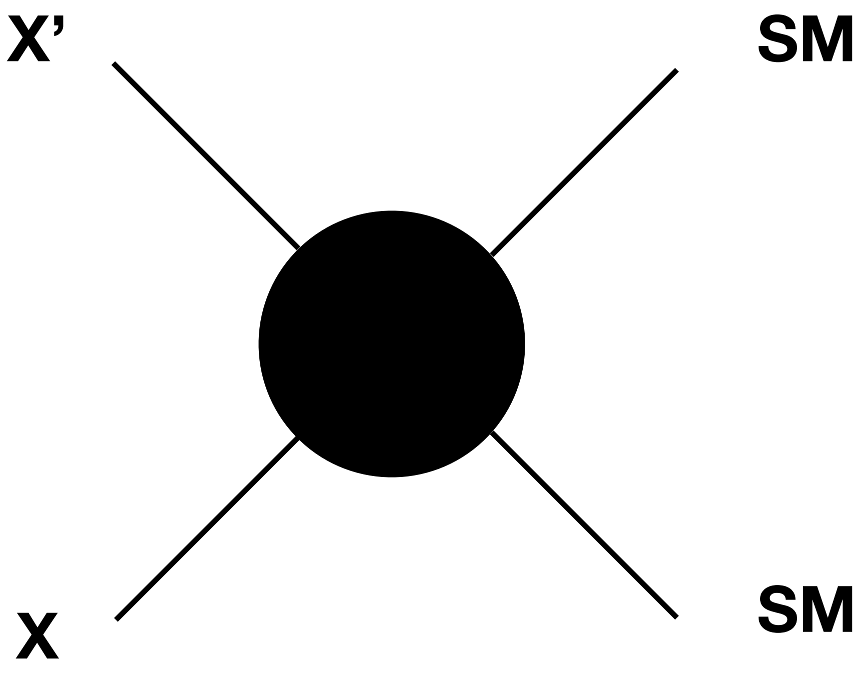

Fermion triplet with $Y = 0$ ('wino')

~3 TeV

Only bino-like LSP, but over-abundance

Co-annihilaiton!

SUSY dark matter: co-annihilation



$$\frac{dn}{dt} = -3Hn - \langle \sigma_{eff} v \rangle [n^2 - (n^{eq})^2]$$

$$\Delta_i = (m_i - m_1)/m_1, x = m_1/T$$

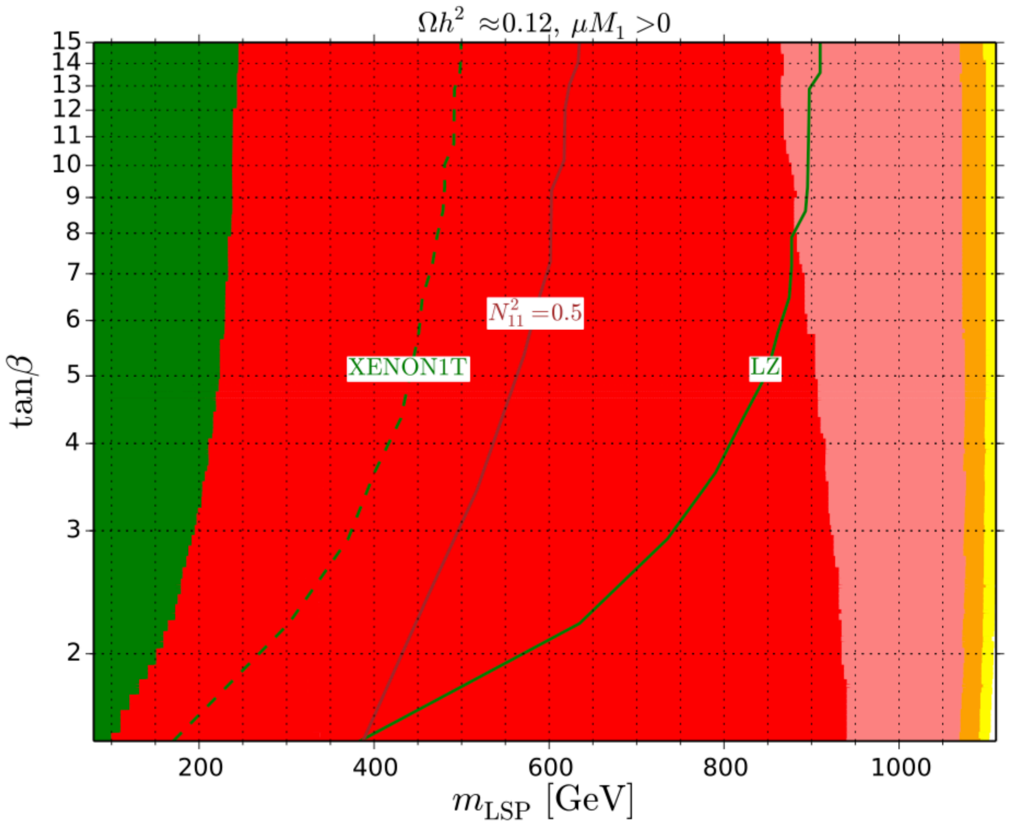
$$\langle \sigma_{eff} v \rangle = \sum_{i,j=1}^{N} \langle \sigma_{ij} v \rangle r_i r_j = \sum_{i,j=1}^{N} \langle \sigma_{ij} v \rangle \frac{g_i g_j}{g_{eff}^2} (1+\Delta_i)^{3/2} (1+\Delta_j)^{3/2} e^{-x(\Delta_i + \Delta_j)}$$

$$\Delta/m \ll 1$$

SUSY dark matter: co-annihilation

M. Badziak, M. Olechowski, P. Szczerbiak, arXiv1701.05869

X'= higgsino

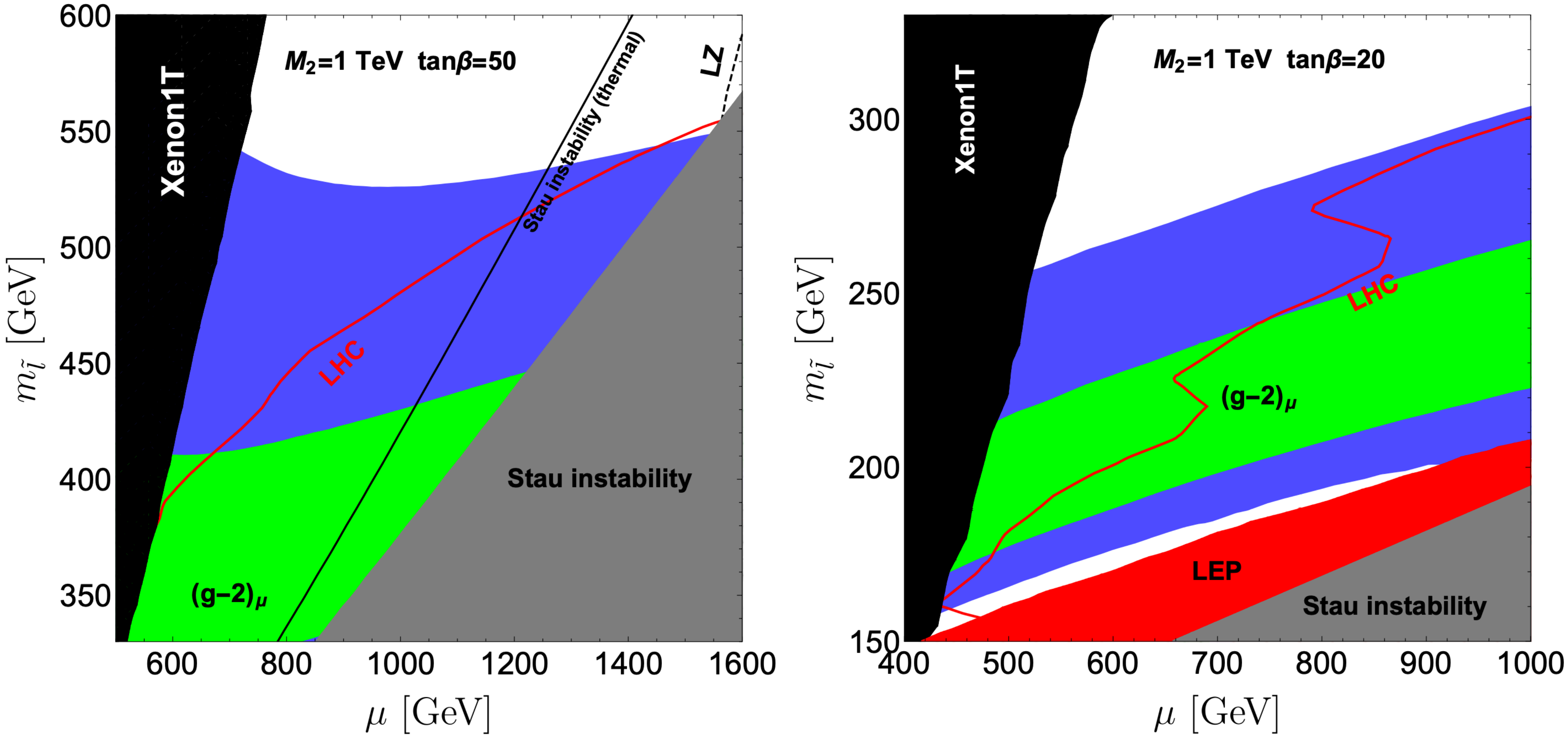


Leaving two interesting possibilities

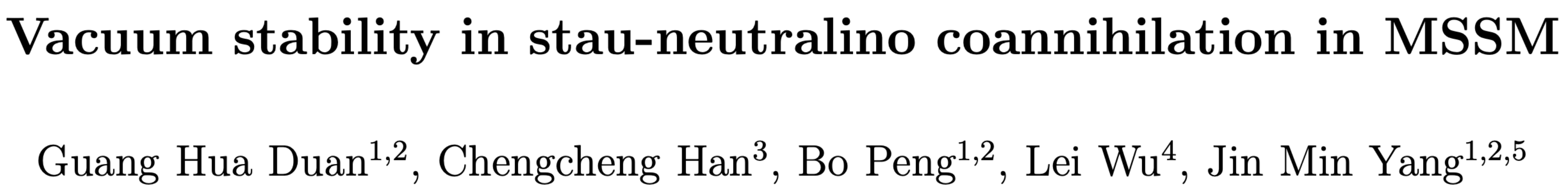
X'= slepton or X'= wino

Case I: stau co-annihilation

P. Cox, CH, T.T. Yanagida, arXiv: 2104.03290



Strong limit from LHC and stau instability!



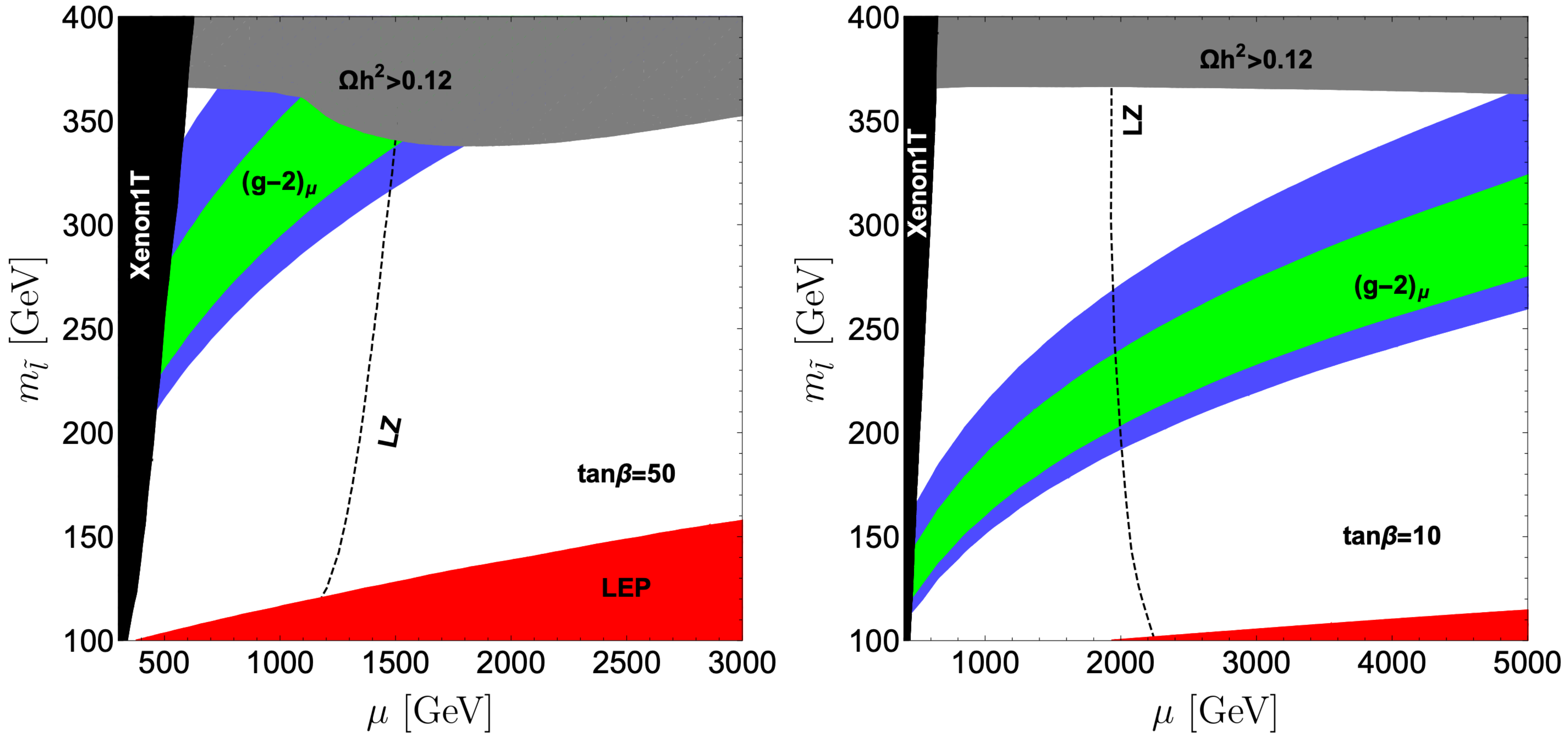
Vacuum stability in stau-neutralino coannihilation in MSSM

Guang Hua Duan[1,2], Chengcheng Han[3], Bo Peng[1,2], Lei Wu[4], Jin Min Yang[1,2,5]

arXiv:1809.10061

Case II: slepton co-annihilation(heavy stau)

P. Cox, CH, T.T. Yanagida, arXiv: 2104.03290

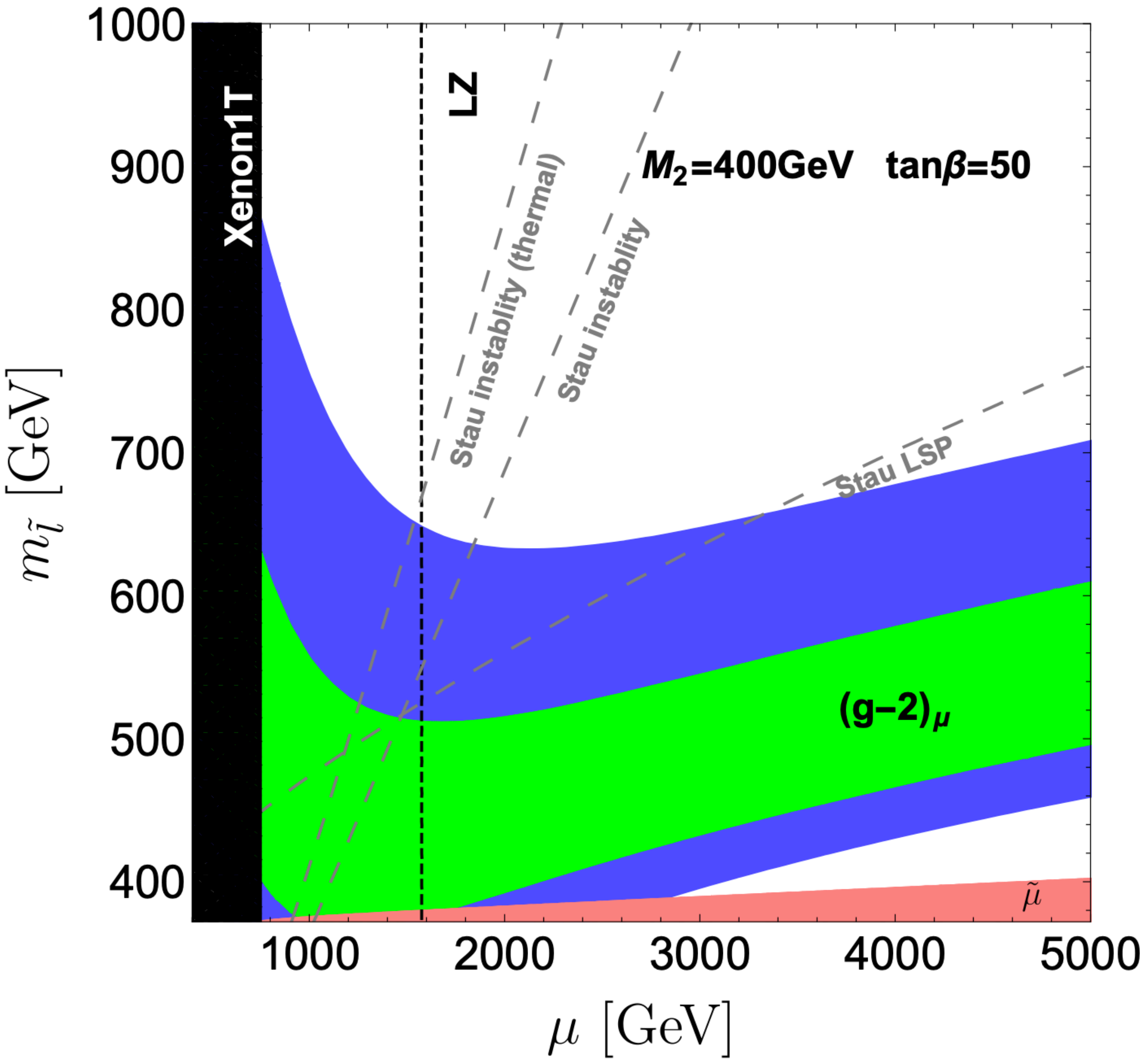


Escape all the constraints, upper limit on the slepton mass!

Good target for lepton collider!

Case III: wino-bino co-annihilation

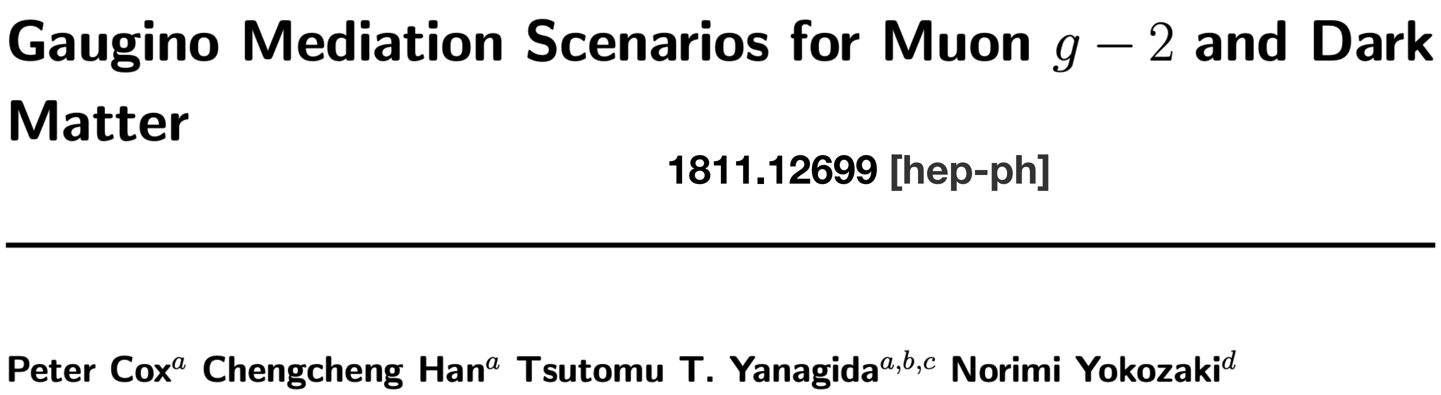
P. Cox, CH, T.T. Yanagida, arXiv: 2104.03290



Future LHC could probe !

Indications for SUSY models

SUSY universal masses at high energy scale

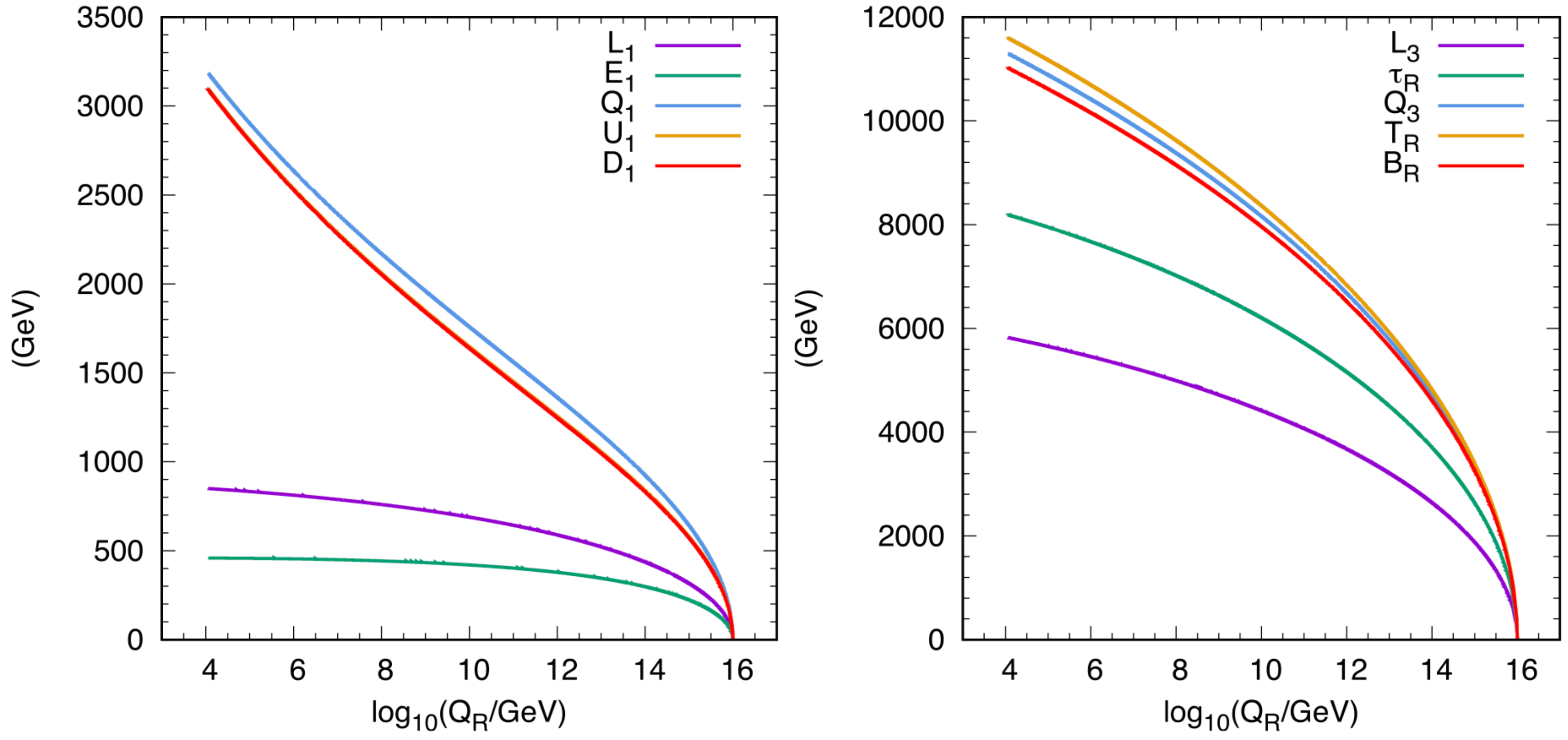


Gaugino Mediation Scenarios for Muon $g-2$ and Dark Matter

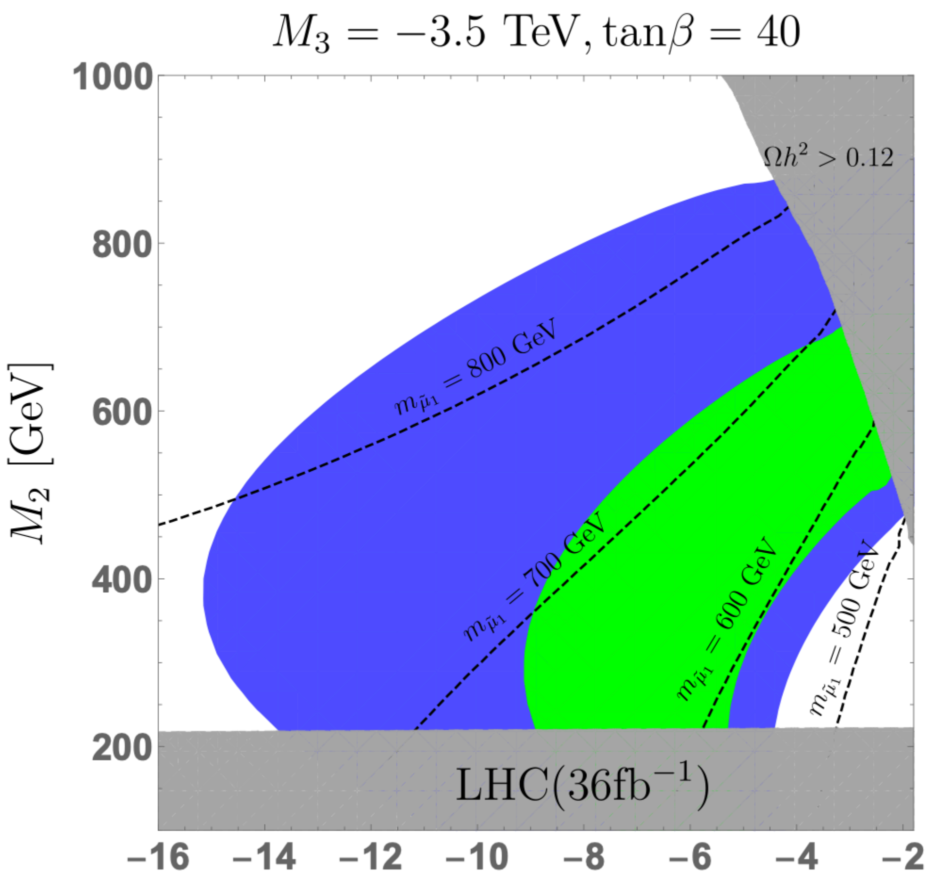
1811.12699 [hep-ph]

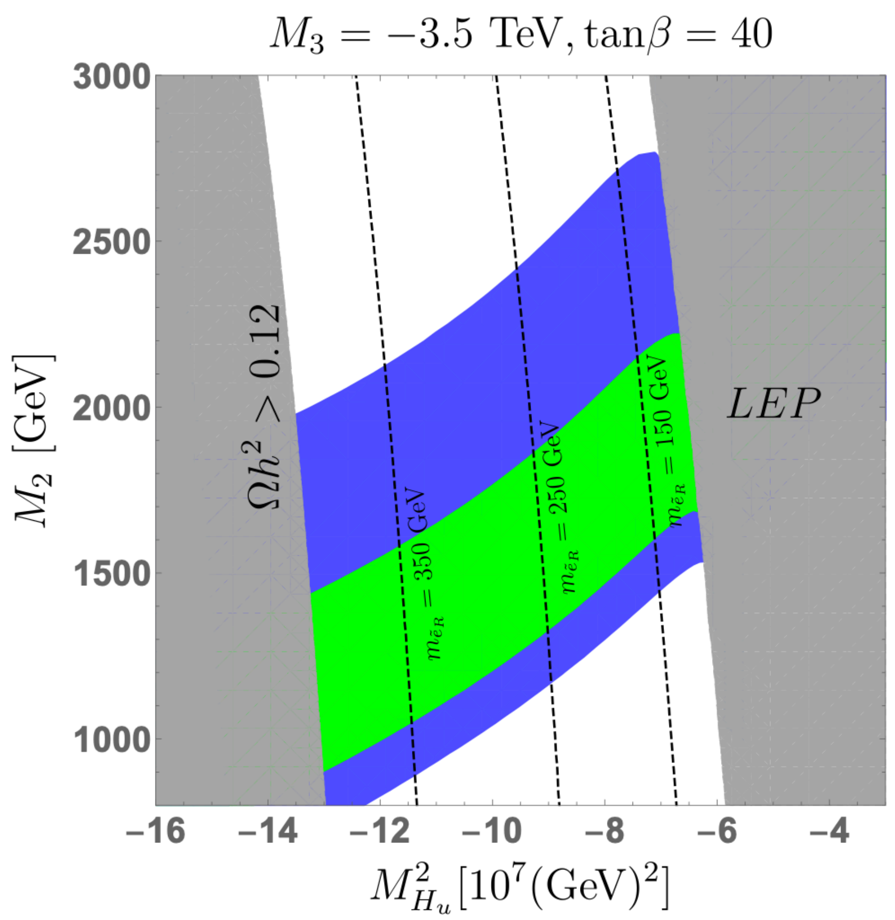
Peter Cox^a **Chengcheng Han**^{a} **Tsutomu T. Yanagida**^{a,b,c} **Norimi Yokozaki**^{d}

Large third generation sfermions from RGE, gaugino+ Higgs mediation model



Benchmark for two cases





	BP1 $(\tilde{B}-\tilde{W})$	BP2 $(\tilde{B}-\tilde{l})$
$M_1(M_{\mathrm{GUT}})$	810.4	473.5
$M_2(M_{\mathrm{GUT}})$	400	1500
$M_3(M_{\mathrm{GUT}})$	-3500	-3500
$m^2_{H_u} = m^2_{H_d}(M_{\mathrm{GUT}})$	$-6.0 \times 10^8\ \mathrm{GeV}^2$	$-9.0 \times 10^7\ \mathrm{GeV}^2$
$\tan\beta$	40	40
$m_{\tilde{g}}$	7230	7100
$m_{\tilde{q}}$	5800	6000
$m_{\tilde{t}_1}, m_{\tilde{t}_2}$	11600, 11700	6680, 6770
$m_{\tilde{e}_L}, m_{\tilde{e}_R}$	704, 653	961, 246
$m_{\tilde{\mu}_L}, m_{\tilde{\mu}_R}$	742, 733	968, 296
$m_{\tilde{\tau}_1}, m_{\tilde{\tau}_2}$	5500, 7780	2410, 3200
$m_{\tilde{\nu}_e}, m_{\tilde{\nu}_\mu}, m_{\tilde{\nu}_\tau}$	700, 738, 5500	958, 965, 2430
$m_{\tilde{\chi}^0_1}$	395	241
$m_{\tilde{\chi}^\pm_1} \simeq m_{\tilde{\chi}^0_2}$	422	1360
$m_{\tilde{\chi}^\pm_2} \simeq m_{\tilde{\chi}^0_{3,4}}$	20800	8540
$m_A \simeq m_{H^0} \simeq M_{H^\pm}$	6560	2170
m_h	124.9	124.8
Δa_μ	2.64×10^{-9}	2.87×10^{-9}
$\Omega_{DM} h^2$	0.1195	0.1188

LFV violation?

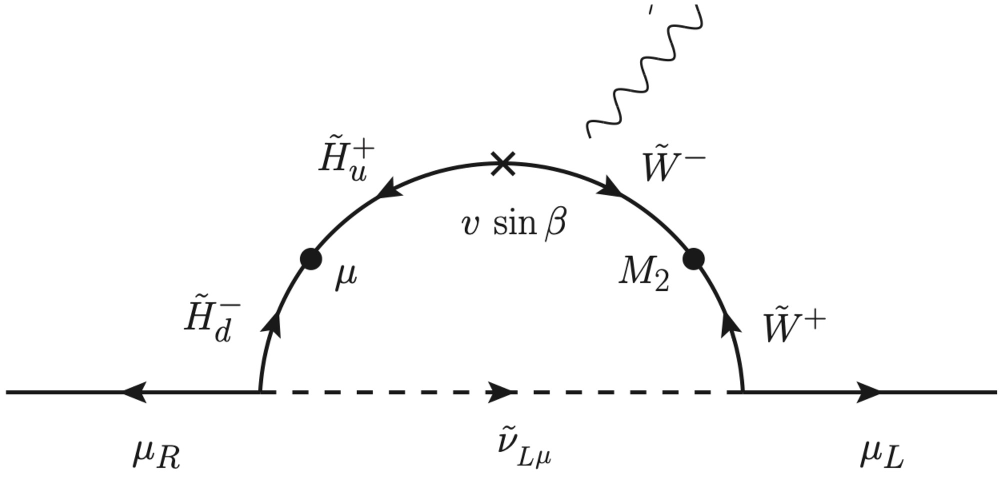
LFV and (g-2) in non-universal SUSY models with light higgsinos

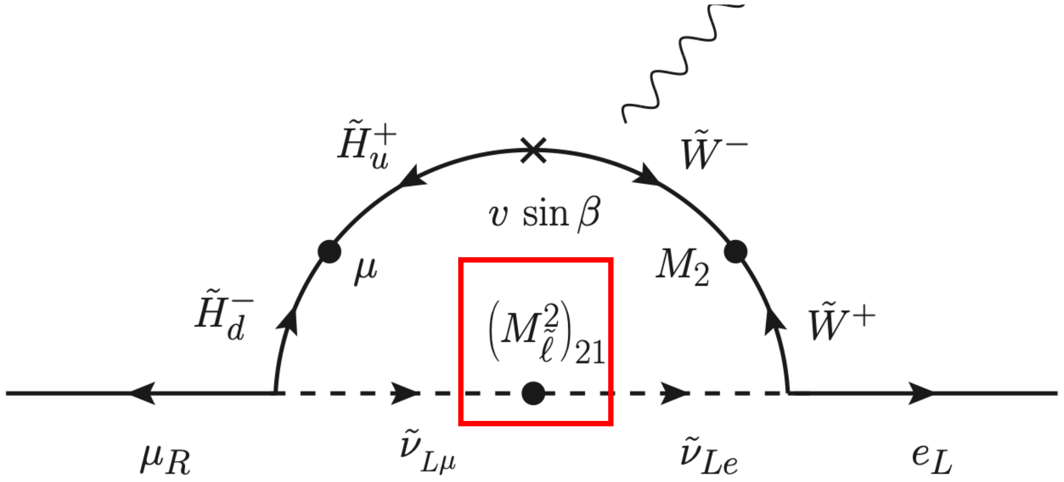
2003.06187[hep-ph]

C. Han[1], M.L. López-Ibáñez[†2], A. Melis[‡3], O. Vives[‡4], L. Wu[⋆5], J.M. Yang[†, §6]

$$W = W_{\rm MSSM} + \nu_R^{cT}\, Y_\nu\, \ell_L \cdot H_u + \frac{1}{2}\, \nu_R^{cT}\, M_R\, \nu_R^c$$

$$\left(M^2_{\tilde\ell}\right)_{i\neq j} \simeq -\frac{2\, m_0^2 + m_{H_u}^2 + A_0^2}{16\,\pi^2} \sum_k Y^*_{\nu,ki} Y_{\nu,kj} \log\left(\frac{m^2_{\rm GUT}}{m^2_{N_k}}\right)$$





LFV Process	**Current Limit**	**Future Limit**
BR($\mu \to e\gamma$)	4.2×10^{-13} (`MEG at PSI`[51])	6×10^{-14} (`MEG II` [52])

LFV violation?

我们考虑了两种情形：

A general Georgi-Jarslkog factor

$$\text{Small Mixing (CKM-like): } Y_\nu^{\rm ckm} = \boxed{\mathrm{k_{GJ}}}\,\mathrm{Y_u}.$$

$$\text{Large Mixing (PMNS-like): } Y_\nu^{\rm pmns} = \boxed{\mathrm{k_{GJ}}}\,\mathrm{Y_u^{diag}\,V_{pmns}^T}$$

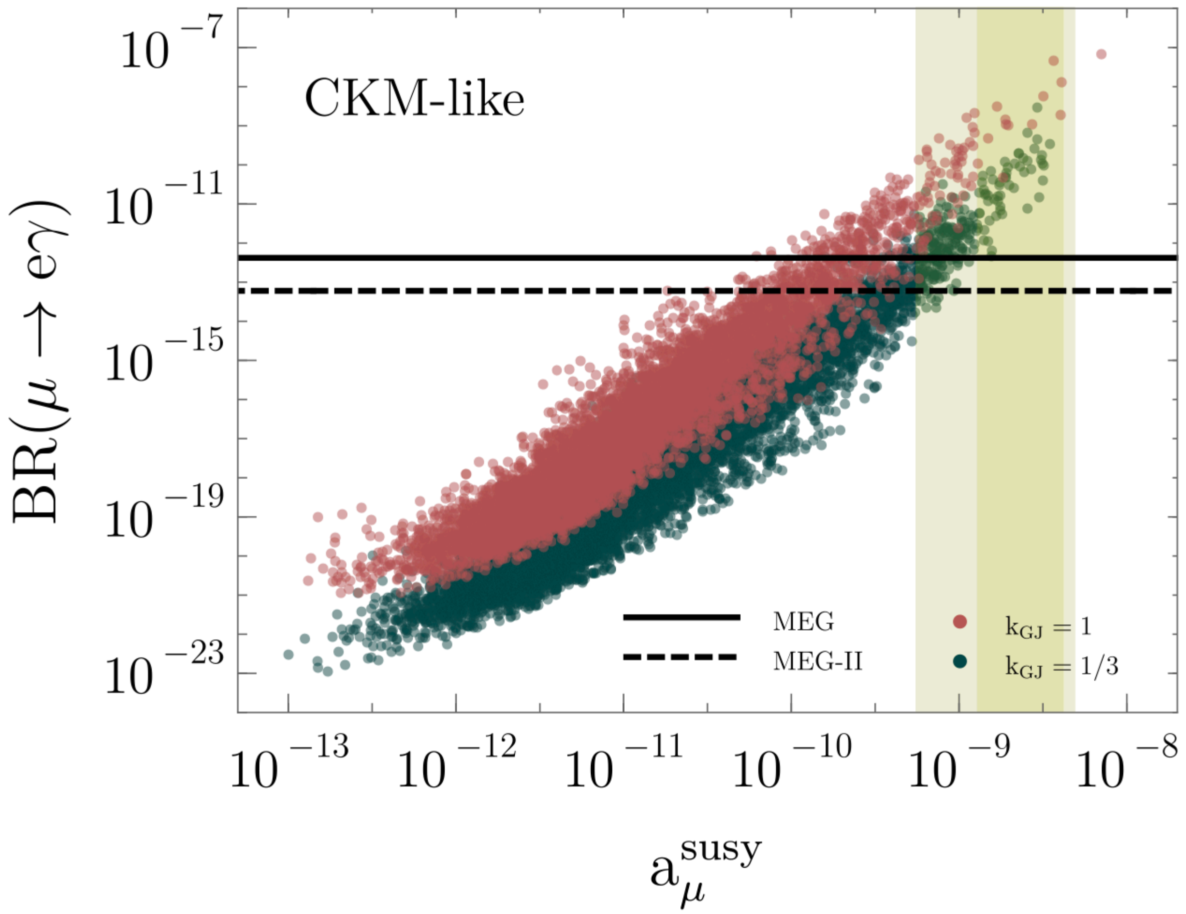
As a typical example, for SO(10)

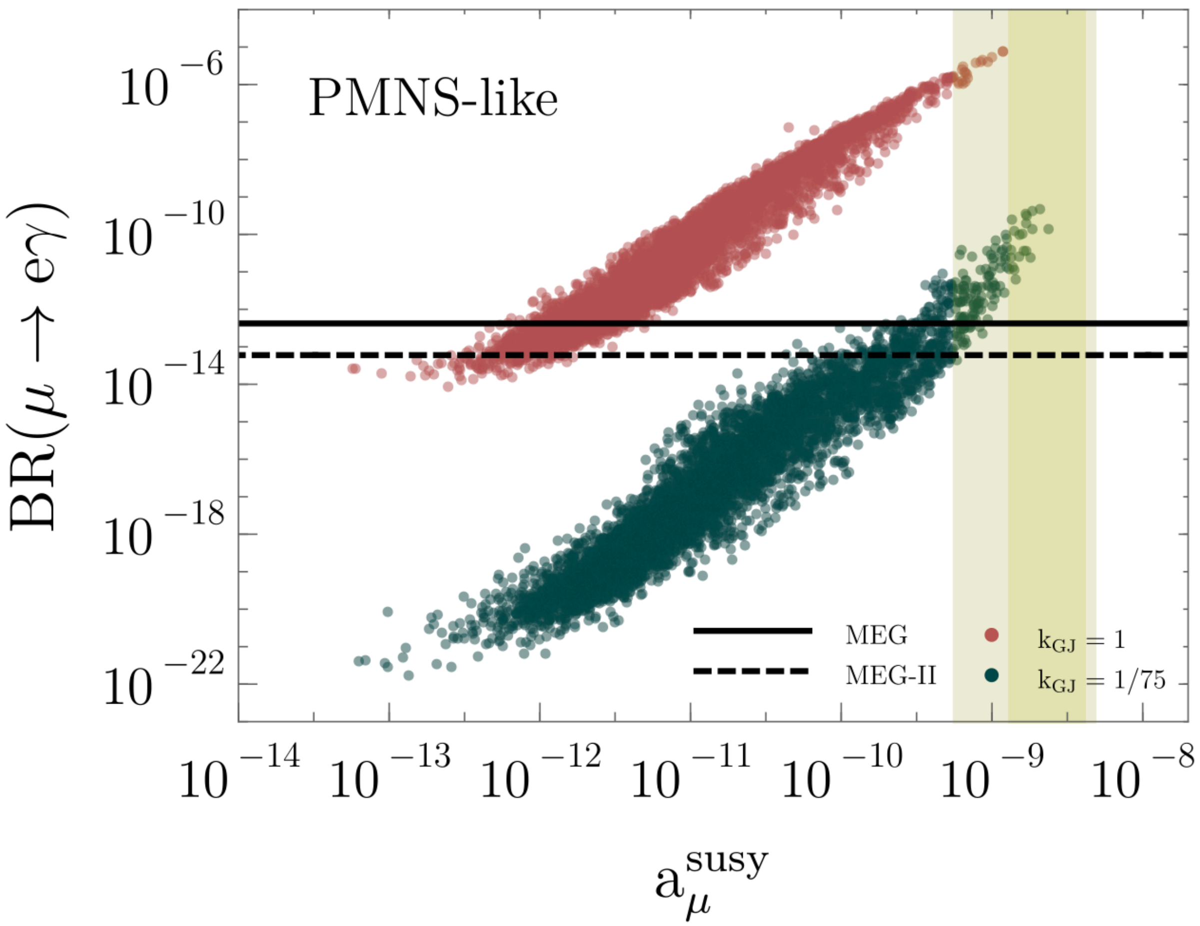
$$16_f(q_L, u_R, d_R, L, \boxed{\nu_R}) \quad 10(H_1, H_2)$$

$$y16_f16_f10 \longrightarrow k_{\rm GJ} = 1$$

If the mass from different presentation of Higgs, KGJ could vary for different generations

LFV violation?





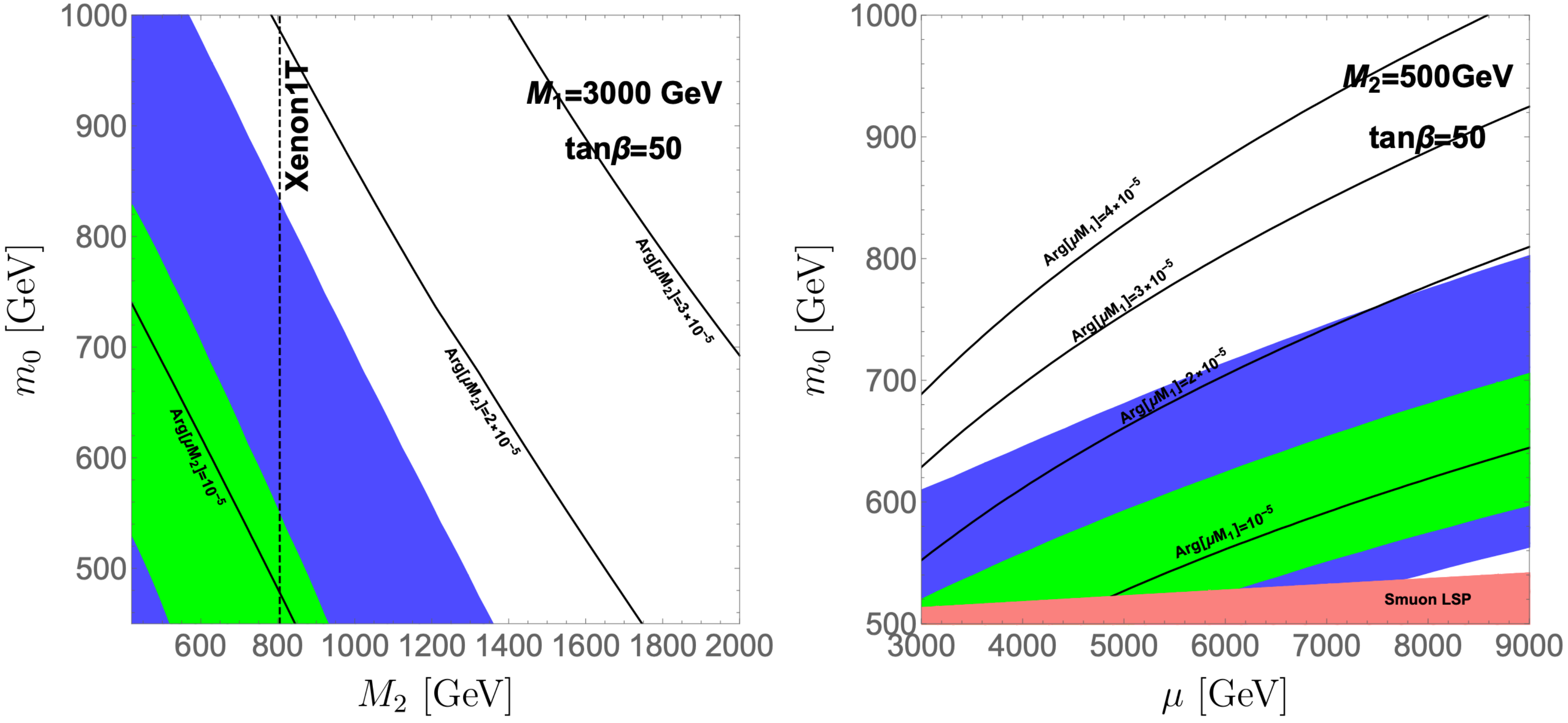
$k_{\rm GJ}=1$ 情形基本不存在两者共存的区间

需要比较小的KGJ系数，对大统一模型的构建提出挑战

SUSY weak CP problem?

Muon $g-2$ and CP violation in MSSM

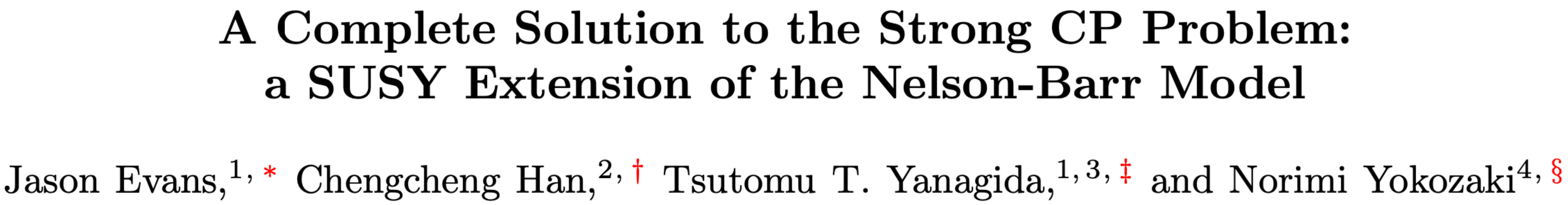
Chengcheng Han[1] 2104.03292(hep-ph)



Arg[mu M1] or Arg[mu M2] < O(2-3) *10^-5

1. SUSY is generally CP violated, but with a 10^-5 fine-tuning(comparing with the fine-tuning in strong CP 10^-10)
2. CP is conserved in SUSY sector, or CP is a symmetry of nature(same solution with strong CP problem)!

Solve all the CP problems at the same time!



A Complete Solution to the Strong CP Problem: a SUSY Extension of the Nelson-Barr Model

Jason Evans,[1, *] Chengcheng Han,[2, †] Tsutomu T. Yanagida,[1, 3, ‡] and Norimi Yokozaki[4, §]

2002.04204 [hep-ph]

More details in the paper!

Thanks for waiting to the end!

Back up

Stau co-annihilation

$$
\begin{aligned}
V = {} & m_\phi^2\phi^2 + \left(m_{\tilde L}^2 + \frac{g_2^2 - g_Y^2}{4} v_u^2\right)\tilde L^2 + \left(m_{\tilde\tau_R}^2 + \frac{g_Y^2}{2} v_u^2\right)\tilde\tau_R^2 - 2 y_\tau \mu v_u \tilde L \tilde\tau_R \\
& - 2 y_\tau \mu \phi \tilde L \tilde\tau_R + \frac{g_2^2 - g_Y^2}{2} v_u \phi \tilde L^2 + g_Y^2 v_u \phi \tilde\tau_R^2 + \frac{m_\phi^2}{v_u}\phi^3 + \cdots ,
\end{aligned}
$$

$$
\mathcal{M}_{\tilde\tau}^2 = \begin{pmatrix} m_{\tilde L}^2 + (\frac{1}{2} - s_W^2) m_Z^2 & \mu y_\tau v_u \\ \mu y_\tau v_u & m_{\tilde\tau_R}^2 + s_W^2 m_Z^2 \end{pmatrix}
$$