Low energy SUSY in light of current experiments

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Outline

1 SUSY confronted with LHC and dark matter

2 SUSY confronted with muon g-2

3 Can SUSY jointly explain muon g-2 and W-mass

4 Summary

1 SUSY confronted with LHC and dark matter

LHC

- LHC discovered a 125 GeV Higgs boson

  A great triumph of SUSY !

SUSY predicts 5 Higgs bosons

At tree level: $m_h < m_Z|\cos 2\beta| < m_Z$

At loop-level:

$$M_{\tilde{t}}^2 = \begin{pmatrix} M_{\tilde{Q}}^2 + m_Z^2\cos 2\beta(\frac{1}{2} - \frac{2}{3}s_W^2) + m_t^2 & m_t(A_t - \mu\cot\beta) \\ m_t(A_t - \mu\cot\beta) & M_{\tilde{U}}^2 + \frac{2}{3}m_Z^2\cos 2\beta s_W^2 + m_t^2 \end{pmatrix}$$

$$\equiv \begin{pmatrix} m_{\tilde{t}_L}^2 & m_t X_t \\ m_t X_t & m_{\tilde{t}_R}^2 \end{pmatrix}$$

$$m_{\tilde{t}_{1,2}}^2 = \frac{1}{2}\left(m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2\right) \mp \frac{1}{2}\sqrt{\left(m_{\tilde{t}_L}^2 - m_{\tilde{t}_R}^2\right)^2 + 4m_t^2 X_t^2}$$

$$M_S^2 \equiv \left(m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2\right)/2$$

$$m_h^2 \le m_Z^2 + \epsilon = m_Z^2 + \frac{3m_t^4}{2\pi^2 v^2}\left[\log\frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right]$$

$$\le 135\ GeV \quad (for\ M_S \le 2TeV)$$

LHC

- LHC discovered a 125 GeV Higgs boson

  A great triumph of SUSY !

  Require top squarks (colored sparticles) above TeV

- LHC direct search not seen any sparticles

  Push colored sparticles above TeV

LHC

- LHC discovered a 125 GeV Higgs boson

  A great triumph of SUSY !

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  Push colored sparticles above TeV

Consistent

DM

lightest neutralino $\tilde{\chi}_1^0$

- weak coupling $g \sim 0.5$
- massive $g \sim 500$ GeV

→ WIMP

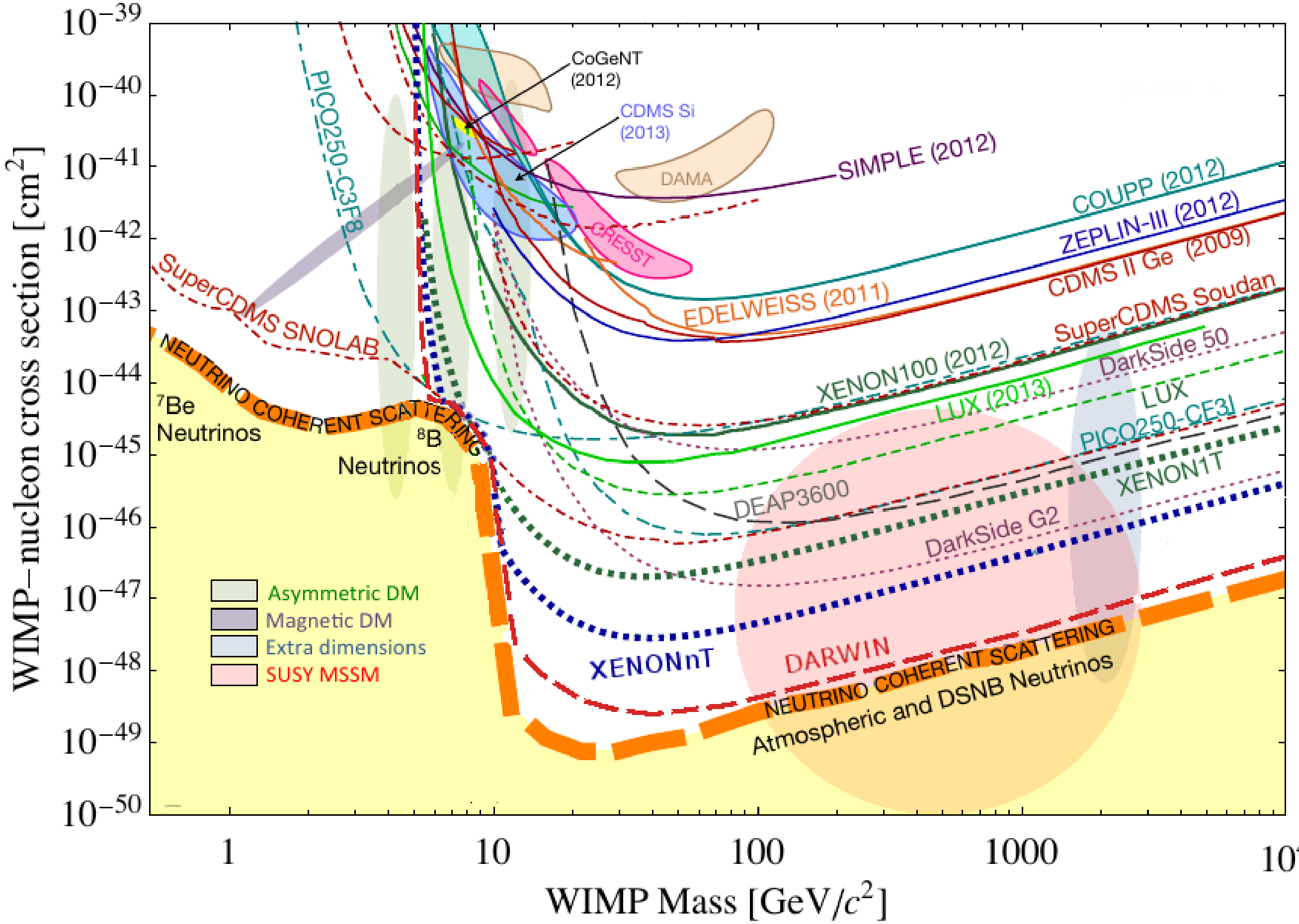
WIMP miracle for dark matter

$$\Omega_{DM} h^2 \equiv \frac{\rho_{DM}}{\rho_{\rm tot}} h^2 \simeq \frac{3 \times 10^{-27} {\rm cm}^3 {\rm s}^{-1}}{\langle \sigma v \rangle} \qquad 0.1199 \pm 0.0027$$

$$\langle \sigma v \rangle \sim \frac{g^4}{16\pi} \frac{1}{M^2} \simeq (6 \times 10^{-26} {\rm cm}^3\, {\rm s}^{-1}) \left(\frac{g}{0.5} \right)^4 \left(\frac{500\, {\rm GeV}}{M} \right)^2$$

DM

MSSM

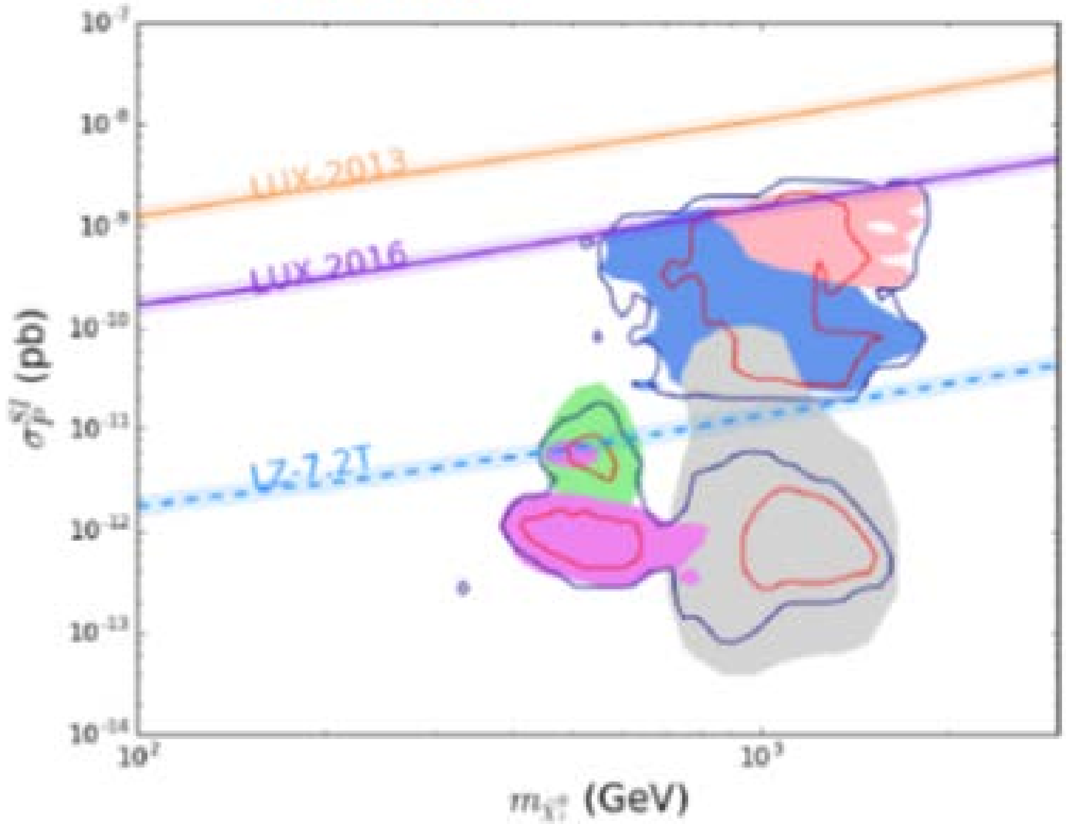


CoGeNT (2012)
CDMS Si (2013)
DAMA
CRESST
SIMPLE (2012)
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
EDELWEISS (2011)
SuperCDMS Soudan
DarkSide 50
XENON100 (2012)
LUX (2013)
LUX
PICO250-CF3I
PICO250-C3F8
XENON1T
DEAP3600
DarkSide G2
XENONnT
DARWIN
SuperCDMS SNOLAB
NEUTRINO COHERENT SCATTERING
7Be Neutrinos
8B Neutrinos
Atmospheric and DSNB Neutrinos
Asymmetric DM
Magnetic DM
Extra dimensions
SUSY MSSM
WIMP–nucleon cross section [cm2]
WIMP Mass [GeV/c2]

DM

Run-1 + Run-2
LUX-2016

1612.02296
Han, Hikasa, Wu, Yang, Zhang



CMSSM

mSUGRA

DM

SUSY neutralino as dark matter is ok !

- **Relic density is ok**
- **Direct detection limits satisfied**

2 SUSY confronted with muon g-2

Muon g-2 is a probe to new physics

$$\delta a_\ell \propto \frac{\alpha}{\pi} \frac{m_\ell^2}{M^2} \quad (M \gg m_\ell)$$

$$(m_\mu / m_e)^2 \simeq 4 \times 10^4$$

muon g-2 is a best probe to NP
(tau lepton is too short-lived)

$$\begin{aligned} \tau_e &= \infty \\ \tau_\mu &= 2.197 \times 10^{-6}\ \mathrm{s} \\ \tau_\tau &= 2.906 \times 10^{-13}\ \mathrm{s} \end{aligned}$$

Recent measurement of muon g-2

$$a_\mu^{\rm QED} = 116\,584\,718.9(1) \times 10^{-11}$$

$$a_\mu^{\rm EW} = 153.6(1.0) \times 10^{-11}$$

$$a_\mu^{\rm HVP,\,LO} = 6931(40) \times 10^{-11}$$

$$a_\mu^{\rm HVP,\,NLO} = -98.3(7) \times 10^{-11}$$

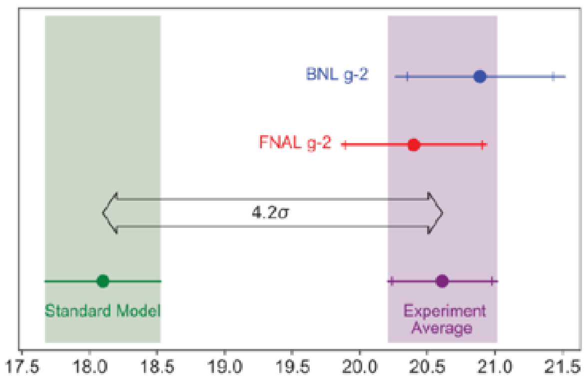
$$a_\mu^{\rm HVP,\,NNLO} = 12.4(1) \times 10^{-11}$$

$$a_\mu^{\rm HLBL} + a_\mu^{\rm HLBL,\,NLO} = 92(18) \times 10^{-11}$$

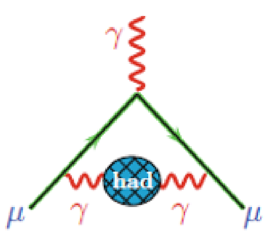
$$a_\mu^{\rm SM} = 116\,591\,810(43) \times 10^{-11}$$

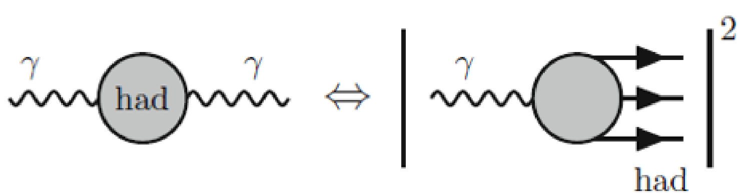
$$a_\mu^{\rm Exp} = 116\,592\,061(41) \times 10^{-11}$$

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



Theory uncertainty mainly from HVP





Recent measurement of muon g-2

Naturalness and the muon magnetic moment

2021年6月11日 上午9:50
40m
Zoom

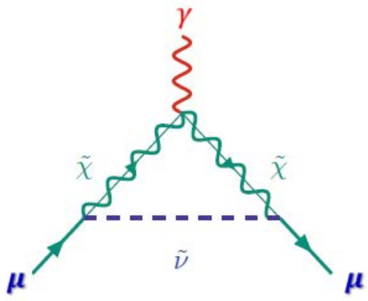
报告人

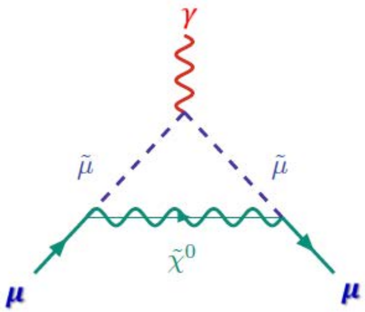
Nima Arkani-Hamed (IAS)

My Take

* ~10% chance it's new phys.
(Much more plausible than other anom.!)
* Lattice QCD groups should converge on ~ 1–2 year timescale
* ... But not easy to mess with disp. relation results!
* FNAL should reduce error bars by ~ ×4
* JPARC indep exp. by ~2025

SUSY can explain muon g-2, **but** not so easy





$$\delta a_\mu^{\rm SUSY} = 14 \tan\beta \left(\frac{100\ {\rm GeV}}{M_{\rm SUSY}} \right)^2 10^{-10}$$

See, e.g.,
Moroi, hep-ph/9512396

Require light slepton, light electroweakino

(uncolored sparticles are light)

MSSM:
g-2 is OK

2104.03262
Wang, Wu, Xiao, Yang, Zhang

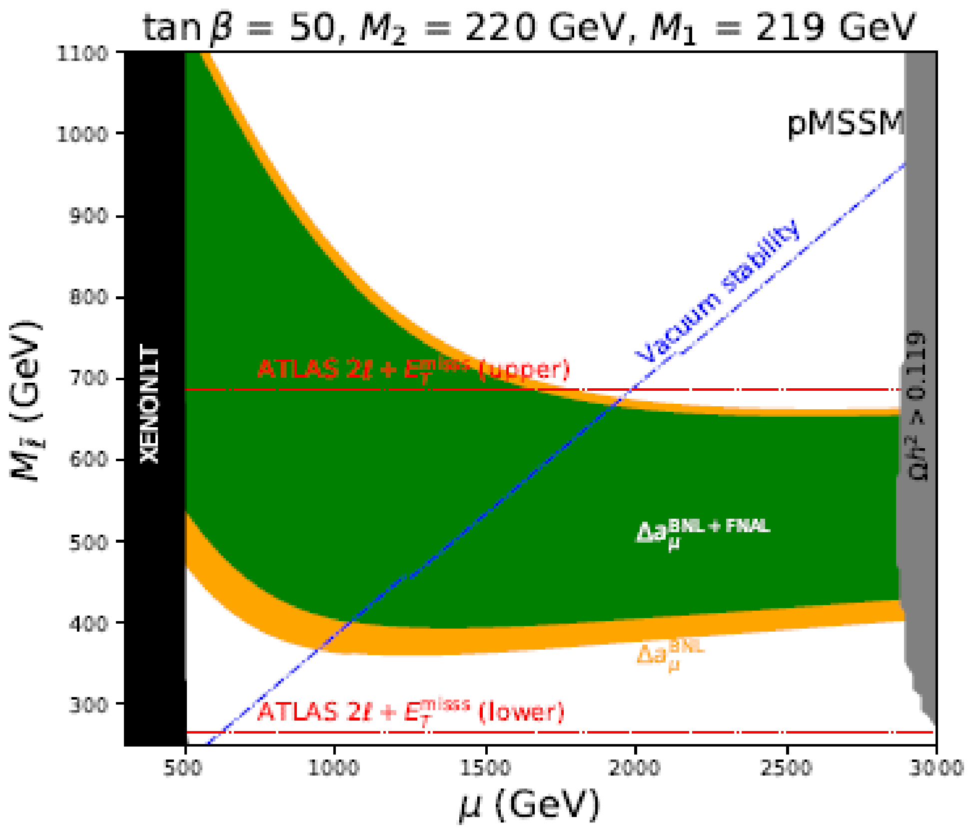


Figure 2. FNAL+BNL and BNL Δa_μ constraints for the BW scenario in the pMSSM. The orange and dark green regions can explain the BNL and the FNAL+BNL Δa_μ measurements at 2σ CL. The black region is excluded by Xenon-1T at 90% CL, while in the brown region the LSP is not bino-like neutralino. The areas between the two ATLAS $2\ell + E_T^{miss}$ limits (red dash lines) are excluded by 13 TeV LHC searches for slepton-pair production at 95% CL. The regions on the right of blue dash lines spoil stability of the electroweak vacuum.

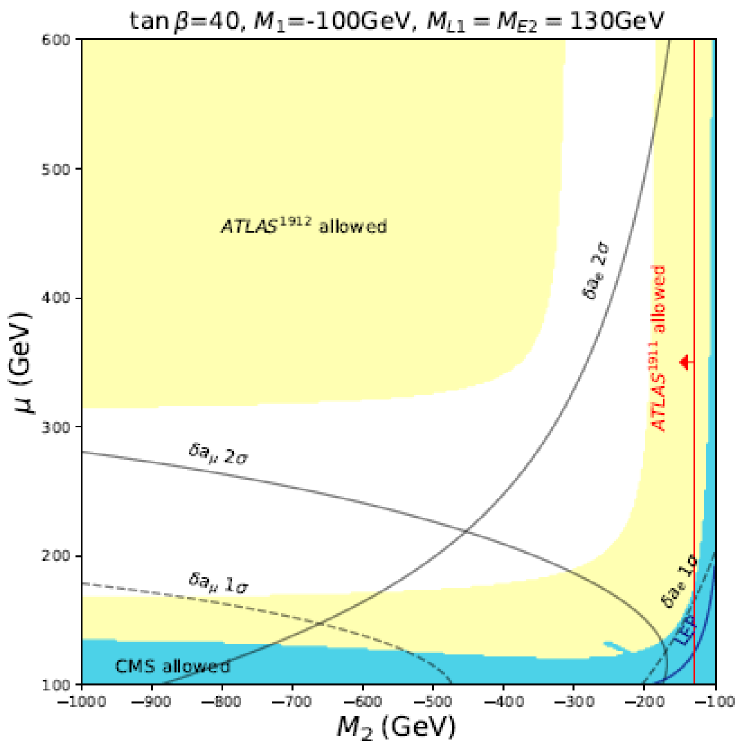
MSSM： muon g-2 and electron g-2 simultaneously OK !

$$\Delta a_e^{\mathrm{Exp-SM}} = a_e^{\mathrm{Exp}} - a_e^{\mathrm{SM}}(\mathrm{Cs}) = (-8.8 \pm 3.6) \times 10^{-13}$$

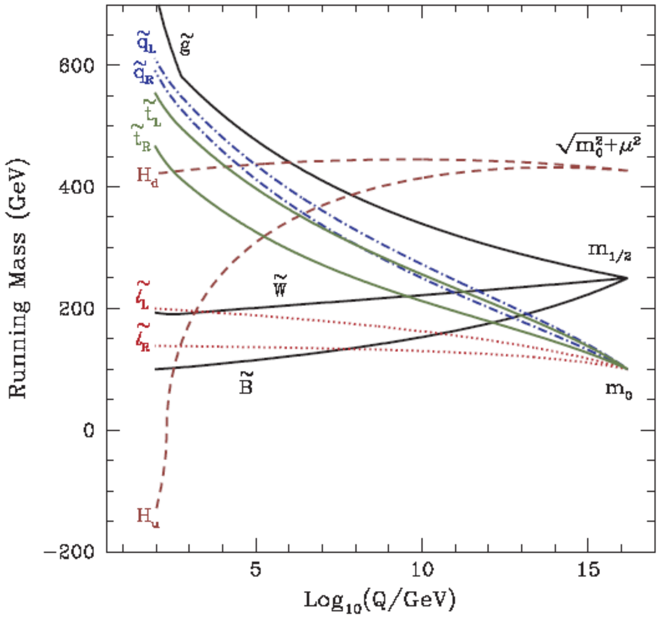
2107.04962

Li, Xiao, Yang

from measurement of fine-structure constant using ^{133}Cs atoms at Berkeley is 2.4σ below SM prediction



CMSSM/mSUGRA, GMSB, AMSB： g-2 not OK



125 GeV Higgs → heavy top squarks

→ m_0 is large

→ heavy sleptons

→ cannot explain g-2

GMSB/AMSB： g-2 not OK

See, e.g.,
Baer, Barger, Mustafayev, 1202.4038

To give a 125 GeV Higgs, SUSY particles are above 10 TeV

→ g-2 cannot be explained

GMSB/AMSB： g-2 not OK

Extend GMSB:

For example,

See, e.g.,
Kang, Li, Liu, Tong, Yang, 1203.2336

A Heavy SM-like Higgs and a Light Stop from Yukawa-Deflected Gauge Mediation

$$W_1 = \lambda_u S \bar{\Phi}_L H_u + \lambda_d \bar{S} \Phi_L H_d,$$

can have large A_t, giving 125 GeV Higgs without very heavy stops

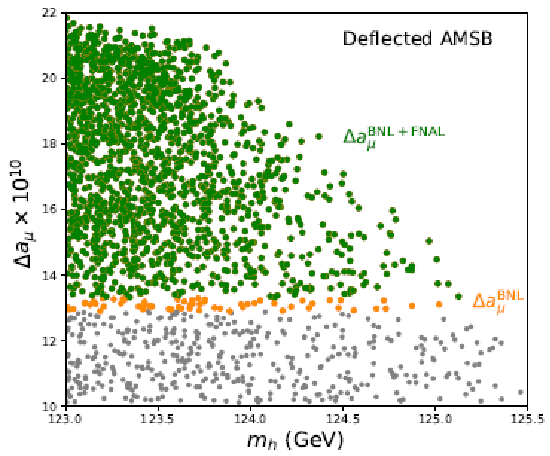
→ *g-2* can be explained

GMSB/AMSB： g-2 not OK

Extend AMSB:

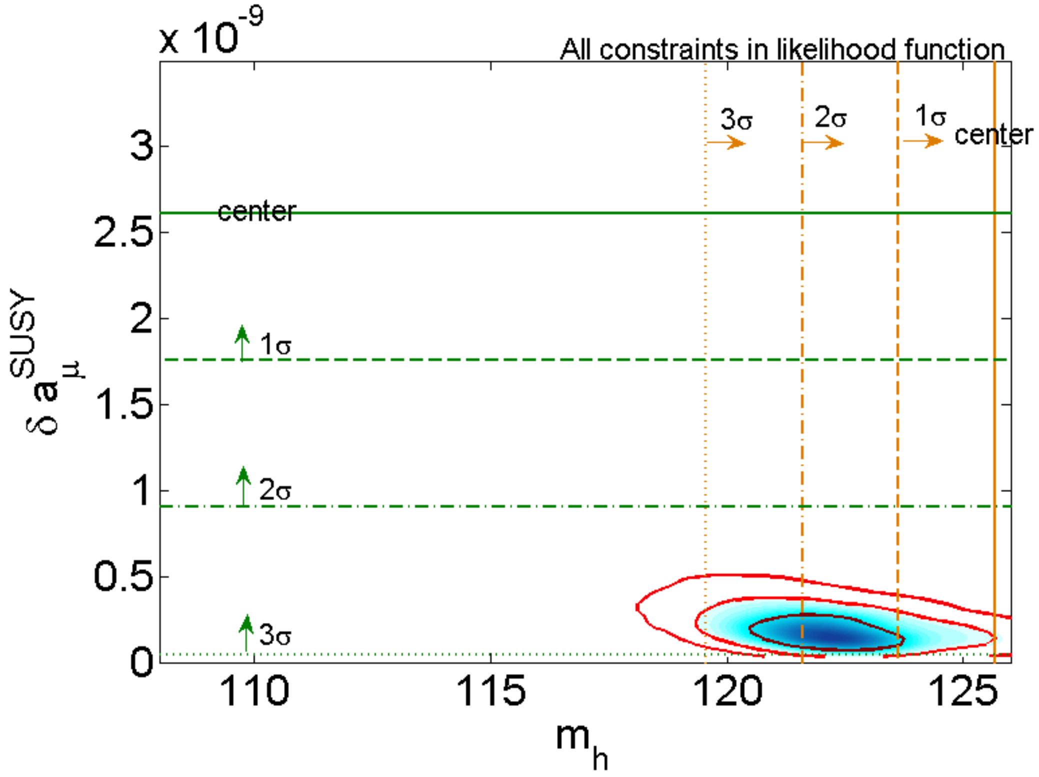
For example, Wang, Wang, Yang, Zhang, 1505.02785

Heavy colored SUSY partners from deflected anomaly mediation



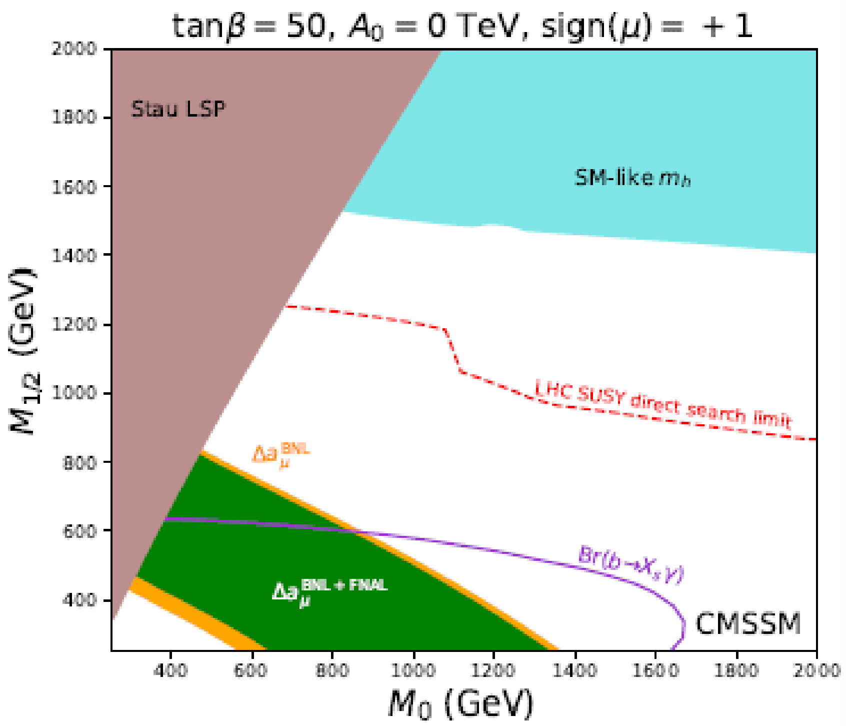
→ *g-2* can be explained

CMSSM/mSUGRA： g-2 not OK



Han, Hikasa, Wu, Yang, Zhang, 1612.02296

CMSSM/mSUGRA： g-2 not OK



Wang, Wu, Xiao, Yang, Zhang,
2104.03262

CMSSM/mSUGRA：g-2 not OK

Extend CMSSM/mSUGRA:

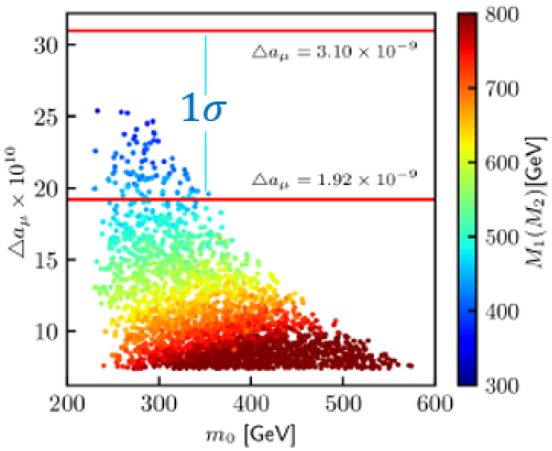
For example,

Reconcile muon g-2 anomaly with LHC data in SUGRA with generalized gravity mediation

Wang, Wang, Yang, 1504.00505

Wang, Wang, Yang, Zhu, 1808.10851

Gluino-SUGRA scenarios in light of FNAL muon g-2

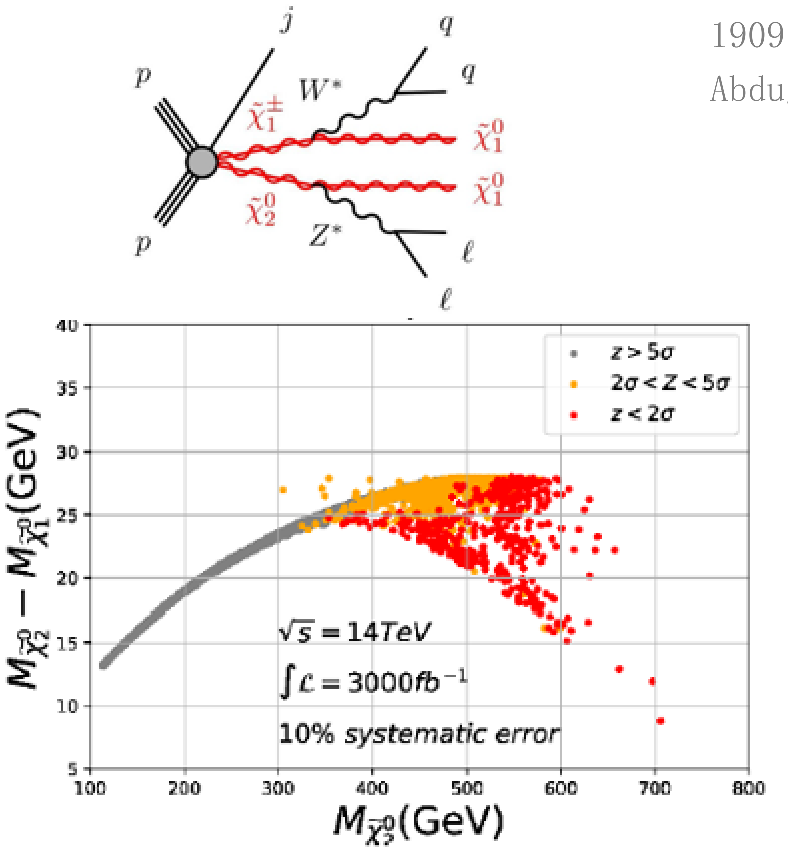


Akula, Nath, 1304.5526

Li, Liu, Wang, Yang, Zhang, 2106.04466

Implication for MSSM search at LHC

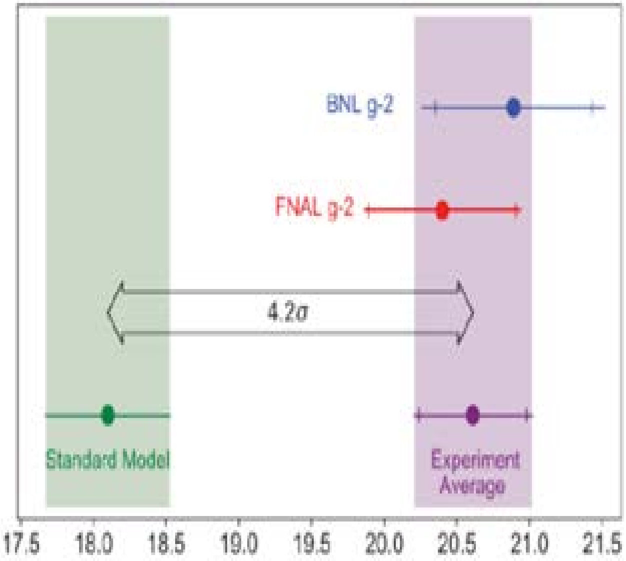
1909.07792
Abdughani, Hikasa, Wu, Yang, Zhao



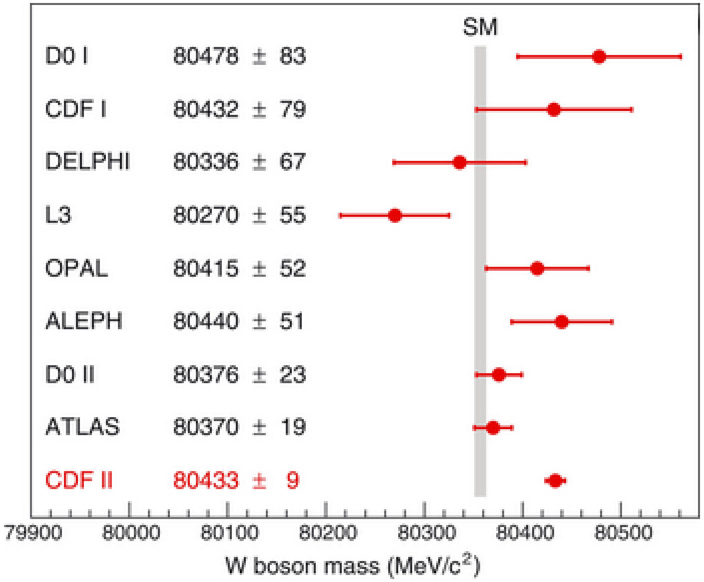
3 Can SUSY jointly explain muon g-2 and W-mass ?

JMY, Y. Zhang, arXiv: 2204.04202

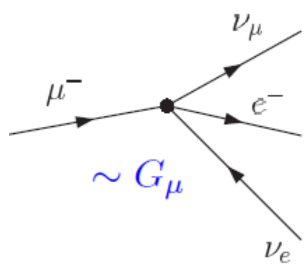
muon g-2



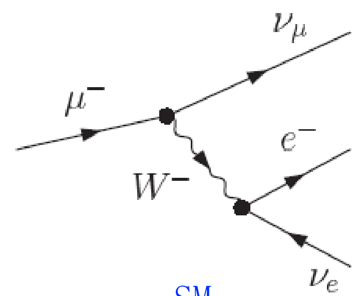
W-mass



W-mass：



Fermi model



SM

$$M_W^2\left(1-\frac{M_W^2}{M_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_\mu}(1+\Delta r)$$

$\Updownarrow$

loop corrections

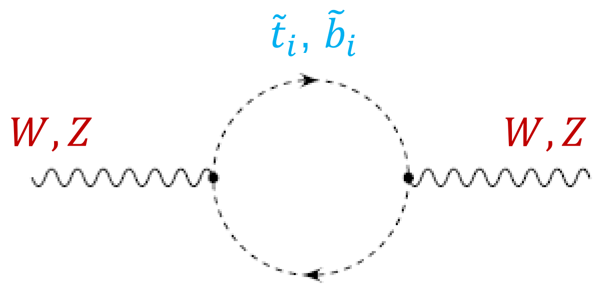
$$\Delta r = \Delta\alpha - \frac{\cos^2\theta_W}{\sin^2\theta_W}\Delta\rho + \cdots$$

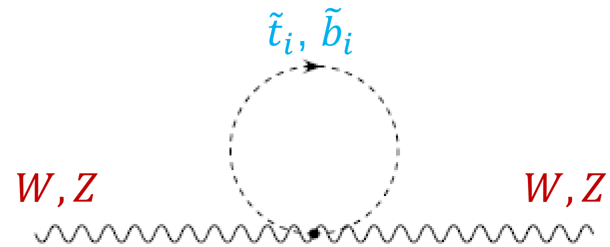
$$\delta M_W \simeq \frac{M_W}{2}\frac{\cos^2\theta_W}{\cos^2\theta_W - \sin^2\theta_W}\Delta\rho \qquad \Delta\rho = \frac{\Sigma^Z(0)}{M_Z^2} - \frac{\Sigma^W(0)}{M_W^2}$$

S. Heinemeyer, W. Hollik, G. Weiglein,
hep-ph/0412214

W-mass：

$$\delta M_W \simeq \frac{M_W}{2} \frac{\cos^2\theta_W}{\cos^2\theta_W - \sin^2\theta_W} \Delta\rho \qquad \Delta\rho = \frac{\Sigma^Z(0)}{M_Z^2} - \frac{\Sigma^W(0)}{M_W^2}$$

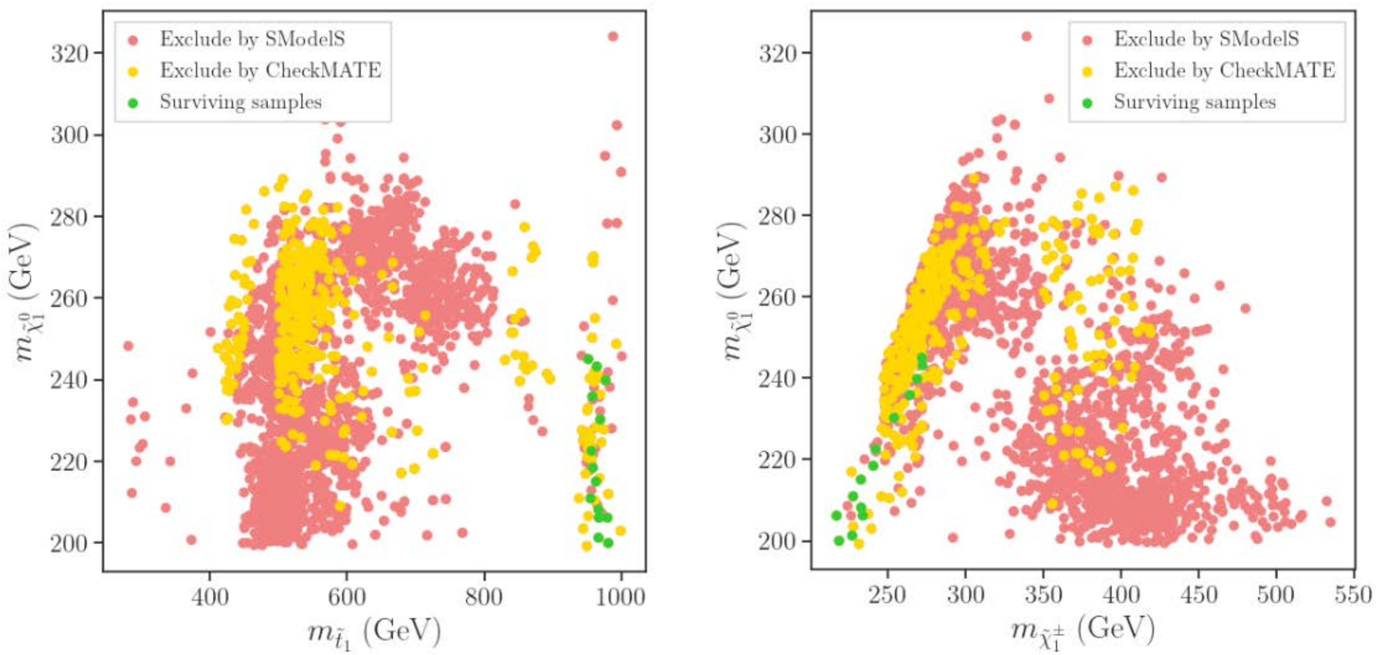




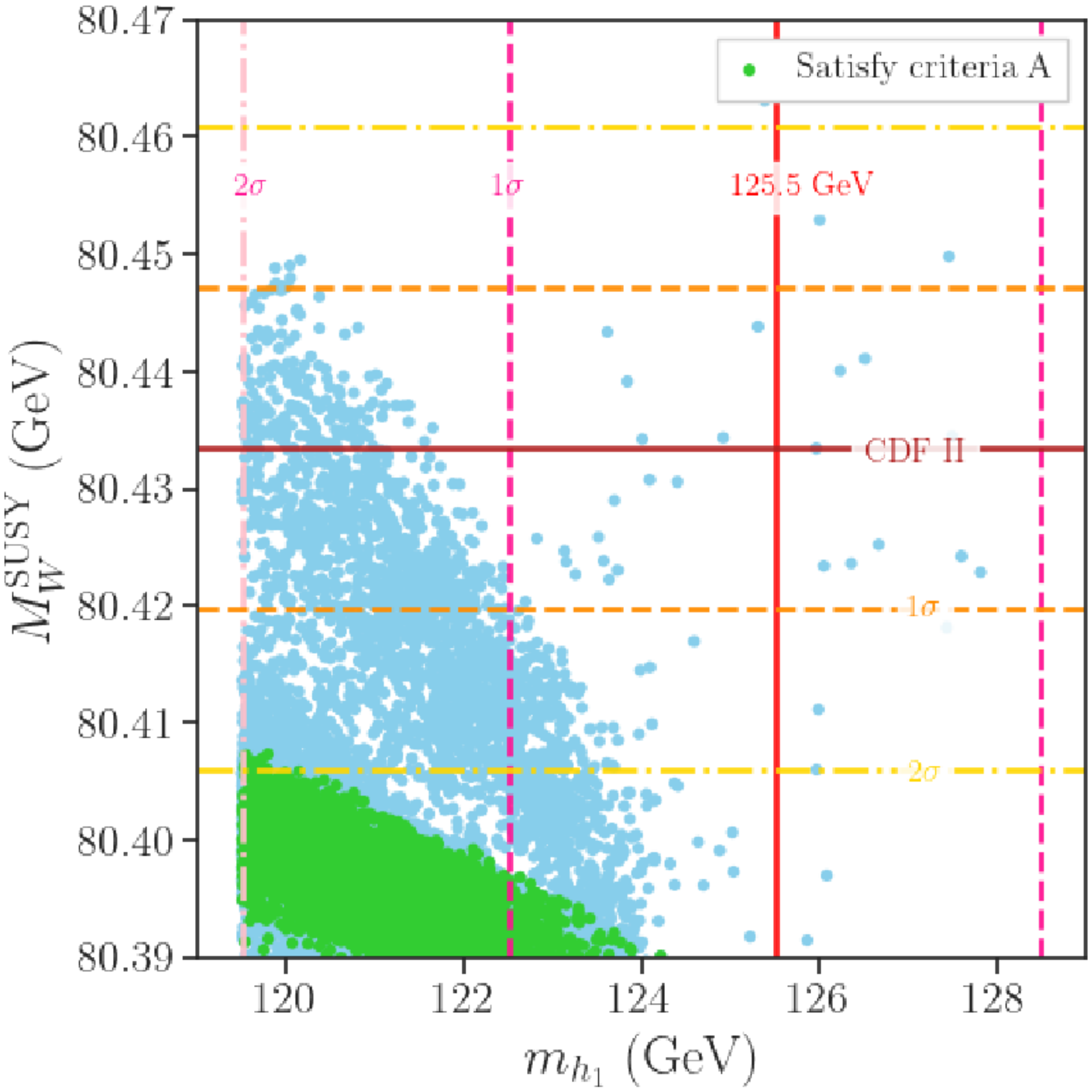
$$\begin{aligned}\Delta\rho_0^{\text{SUSY}} = \frac{3G_F}{8\sqrt{2}\pi^2}[&-\sin^2\theta_{\tilde{t}}\cos^2\theta_{\tilde{t}} F_0(m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2) - \sin^2\theta_{\tilde{b}}\cos^2\theta_{\tilde{b}} F_0(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2) \\ &+ \cos^2\theta_{\tilde{t}}\cos^2\theta_{\tilde{b}} F_0(m_{\tilde{t}_1}^2, m_{\tilde{b}_1}^2) + \cos^2\theta_{\tilde{t}}\cos^2\theta_{\tilde{b}} F_0(m_{\tilde{t}_1}^2, m_{\tilde{b}_2}^2) \\ &+ \sin^2\theta_{\tilde{t}}\cos^2\theta_{\tilde{b}} F_0(m_{\tilde{t}_2}^2, m_{\tilde{b}_1}^2) + \sin^2\theta_{\tilde{t}}\cos^2\theta_{\tilde{b}} F_0(m_{\tilde{t}_2}^2, m_{\tilde{b}_2}^2)]\end{aligned}$$

JMY, Y. Zhang, arXiv: 2204.04202

- In the parameter space allowed by current experimental constraints from colliders and dark matter detections, MSSM can simultaneously explain both measurements at 2σ level.
- The favored parameter space, characterized by a compressed spectrum between (bino, wino, stau), with top-squark around 1 TeV.



JMY, Y. Zhang, arXiv: 2204.04202



4 Summary

SUSY Status (in light of current experiments)

- Fancy models:

GMSB/AMSB:	can give 125 GeV Higgs, but with very heavy stop (fine-tuning)
CMSSM/mSUGRA:	can give 125 GeV Higgs; but cannot explain muon g-2

- Low energy effective models:

MSSM: NMSSM:	can fit all data well, but suffer from little fine-tuning

- Weird-smart models:

Split-SUSY:	no problem (give up naturalness)
Stealth SUSY:	no problem (can always escape detections)
Compressed SUSY:	no problem (can escape detection at LHC)

4 Summary

SUSY Status (in light of current experiments)

Then, what is the problem of SUSY ?

- LHC direct search not seen any sparticles

  Push colored sparticles above TeV (stop mass M_{SUSY} > TeV)

- Quadratic divergence cancel, log divergence still exist

$$\Delta m_H^2 \sim (M_{SUSY}^2 - M_{SM}^2)\frac{\lambda_f^2}{16\pi^2}\ln\left(\frac{\Lambda}{M_{SUSY}}\right)$$

little fine-tuning problem

$$m_H^2 = m_0^2 - \Delta m_H^2$$

125 GeV bare

SUSY is natural if $M_{SUSY} \sim \mathcal{O}(1)$ TeV

4 Summary

- SUSY confronted with LHC: ok
- SUSY confronted with DM: ok
- Can SUSY explain muon g-2 and W-mass ?

CMSSM, mSUGRA, GMSB, AMSB: need to be extended

MSSM: ok

- light electroweakinos
- light sleptons
- light stop

Most hopefully accessible at LHC

Thanks for your attention !