Theoretical overview of Muon g-2

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Contents

- Recent progress and issue on SM prediction
- New physics interpretation — SUSY

SUSY, 2021.8.23

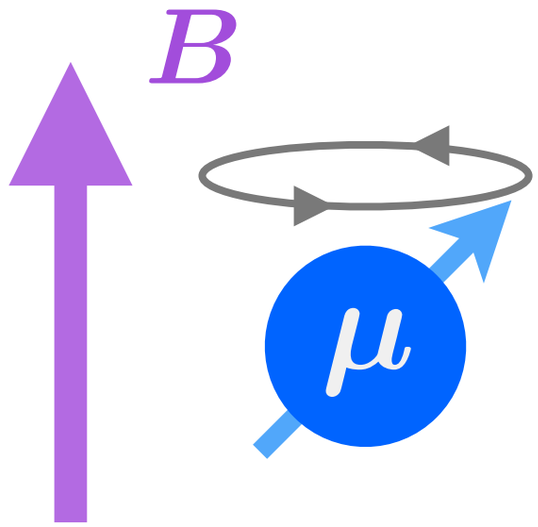
What is magnetic moment (g-factor)?

Magnetic interaction with spin

$$\mathcal{H} = -\vec{\mu} \cdot \vec{B}$$

Magnetic moment $\propto$ spin

$$\vec{\mu} = -g \frac{e}{2m} \vec{S}$$



Tree-level prediction

$$\mathcal{L} = \bar{\psi}(i\partial\!\!\!/ - m)\psi - \tfrac{1}{4}(F_{\mu\nu})^2 - e\bar{\psi}\gamma^\mu\psi A_\mu \longrightarrow g = 2$$

Radiative correction — "anomalous" magnetic moment, g-2

$$g \neq 2 \quad \Rightarrow \quad \boxed{a_\ell = \frac{g_\ell - 2}{2}}$$

First result from Fermilab

Fermilab (Run-1, ~ BNL E821) [2104.03281] → Talk by Liang Li

$$a_\mu^{\mathrm{FNAL}} = (11\,659\,204.0 \pm 5.1_{\mathrm{stat}} \pm 1.9_{\mathrm{sys}}) \times 10^{-10}$$

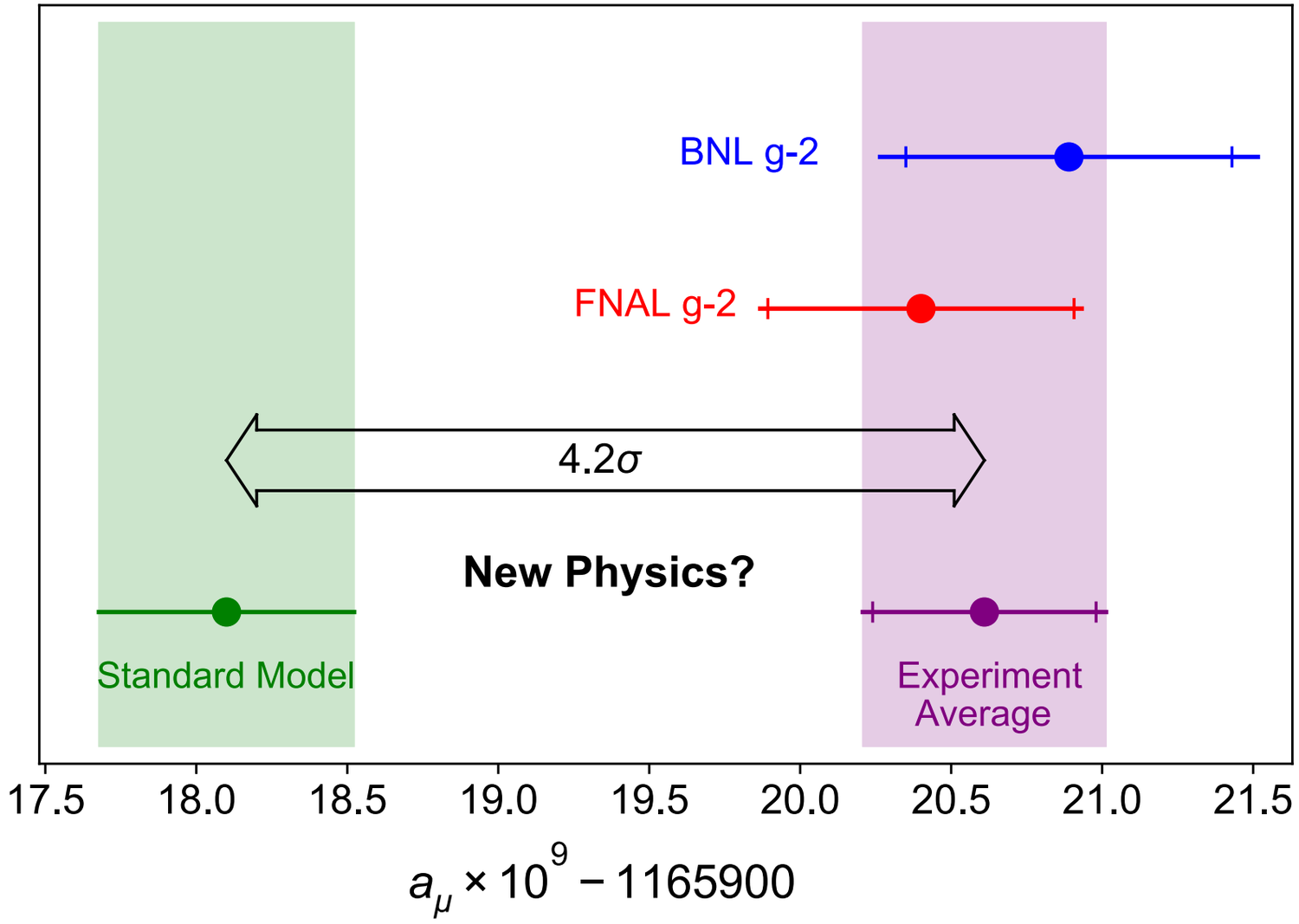
Confirmed BNL result: $a_\mu^{\mathrm{BNL}} = (11\,659\,208.9 \pm 5.4_{\mathrm{stat}} \pm 3.3_{\mathrm{sys}}) \times 10^{-10}$

$$a_\mu^{\mathrm{BNL+FNAL}} = (11\,659\,206.1 \pm 4.1) \times 10^{-10}$$

$$a_\mu^{\mathrm{BNL+FNAL}} - a_\mu^{\mathrm{SM}} = (25.1 \pm 5.9) \times 10^{-10}$$

4.2σ deviation

[2104.03281]



Today's talk

- Recent progress and issue on SM prediction
- New physics interpretation — SUSY

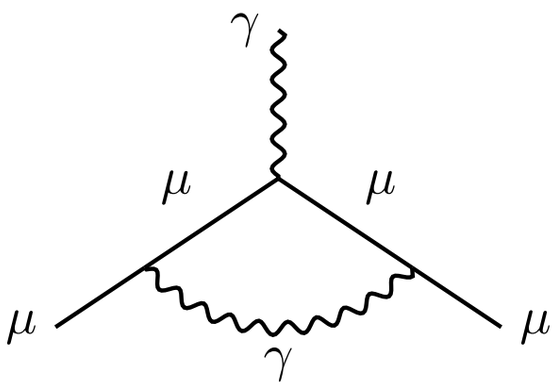
SM prediction

White paper (WP): new consensus of SM values [2006.04822]

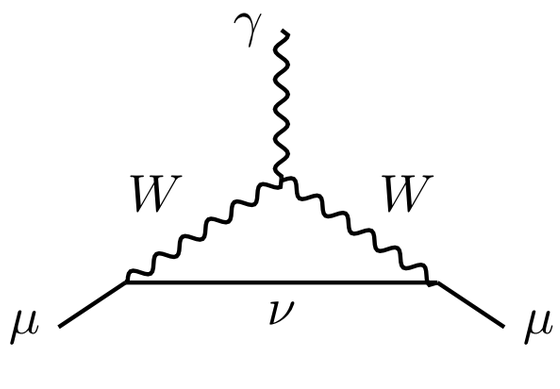
Contribution	Value $\times 10^{10}$	
QED	11 658 471.8931	± 0.0104
EW	15.36	± 0.10
HVP	684.5	± 4.0
HLbL	9.2	± 1.8
Total	11 659 181.0	± 4.3

Recent issue:

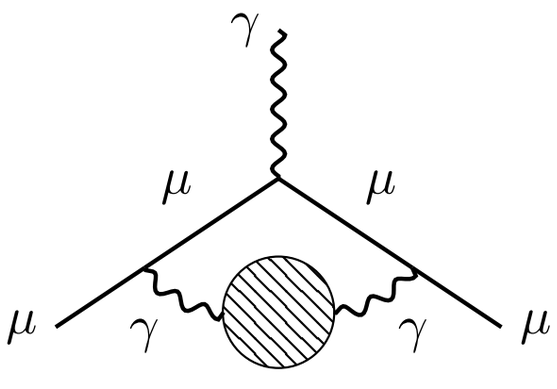
discrepancy between WP and new lattice result of HVP



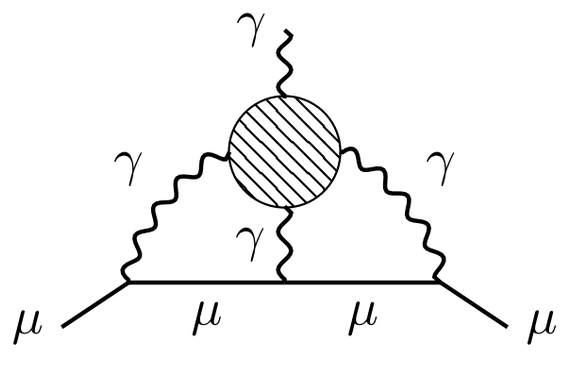
QED



EW



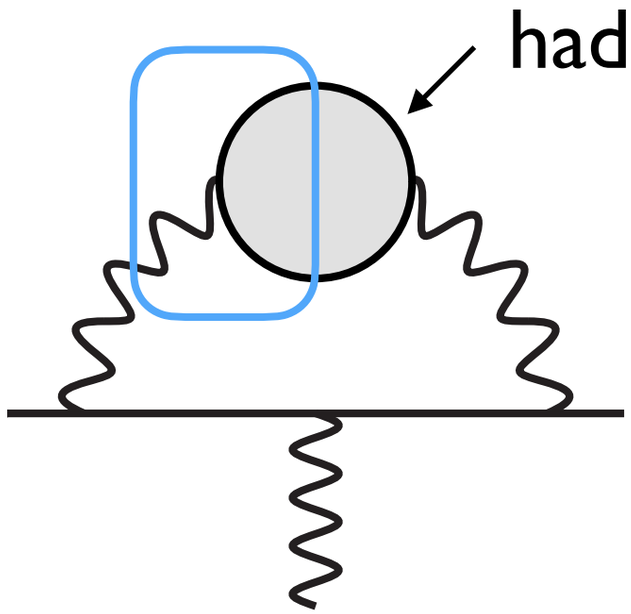
Hadronic VP



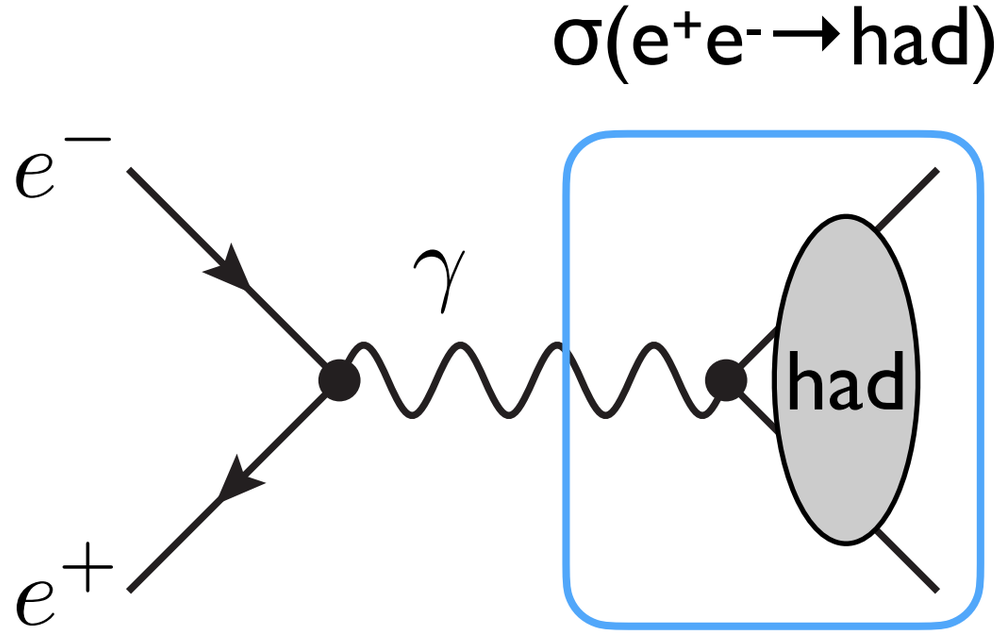
Hadronic LbL

Hadronic vacuum polarization

Traditionally determined by hadronic cross section



Gauge sym.
Analyticity
Unitarity



"R-ratio" approach: $a_\mu^{\mathrm{HVP,LO}} = \frac{\alpha^2}{3\pi^2}\int_{m_\pi^2}^{\infty}\frac{ds}{s}K(s)R(s)$

known experimental data

Lattice calculation of HVP

→ Talk by Luchang Jin

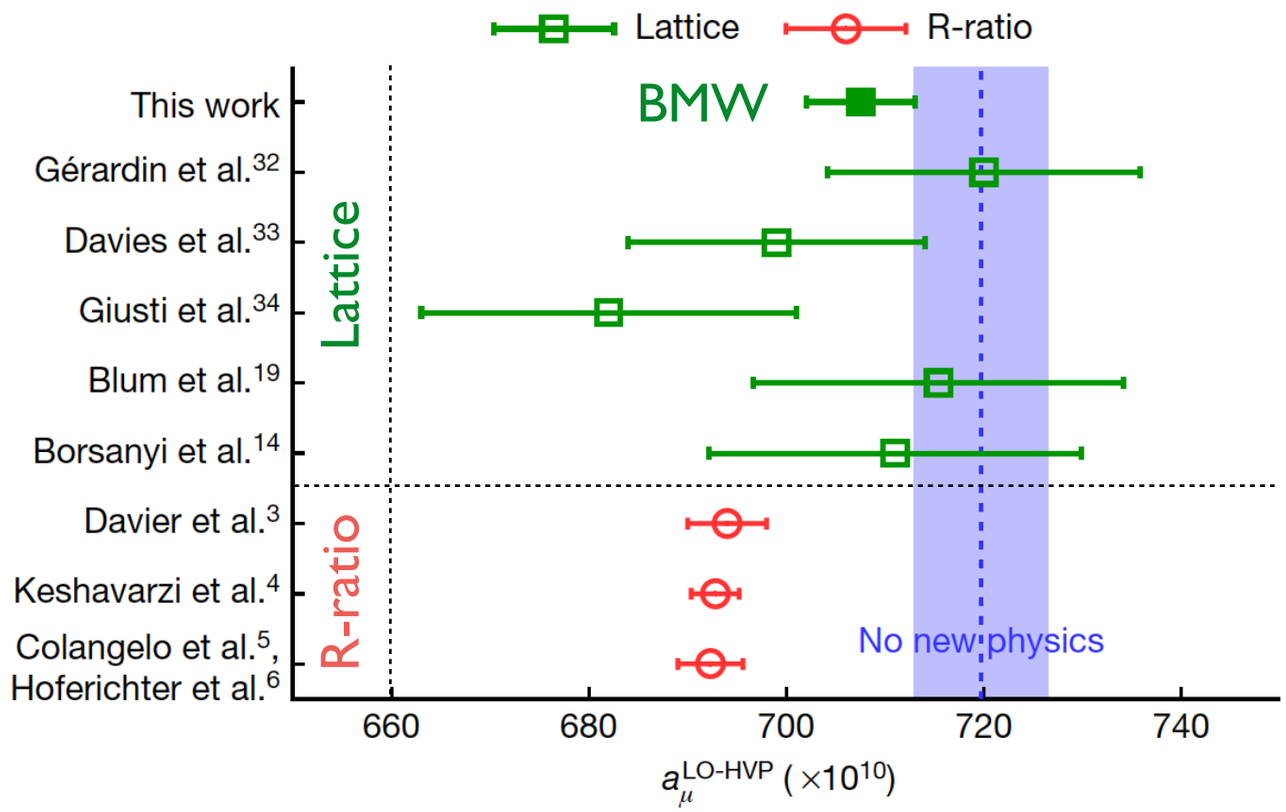
BMW collaboration [2002.12347]

No tension w/. Fermilab g-2

But, ~2.1σ away from R-ratio

Deviation is not resolved yet

Need independent lattice



Deficits in R-ratio approach?

EW precision observables limit such a possibility (via $\Delta\alpha_{\text{had}}^{(5)}$)

Non-trivial (challenging) to reconcile

→ Talk by Andreas Crivellin

Status of tensions

Prospect

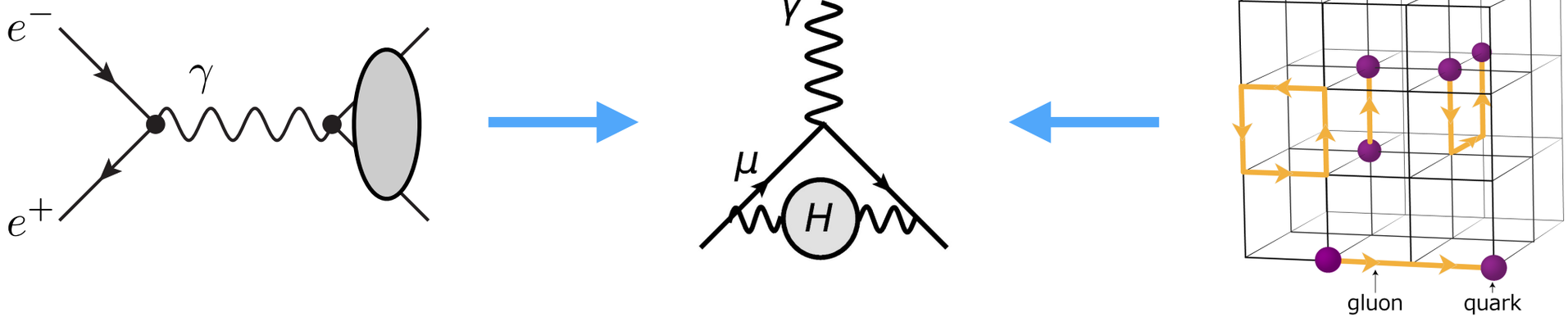
Fermilab Muon g-2 → Fermilab J-PARC

4.2σ

no tension

~2.1σ

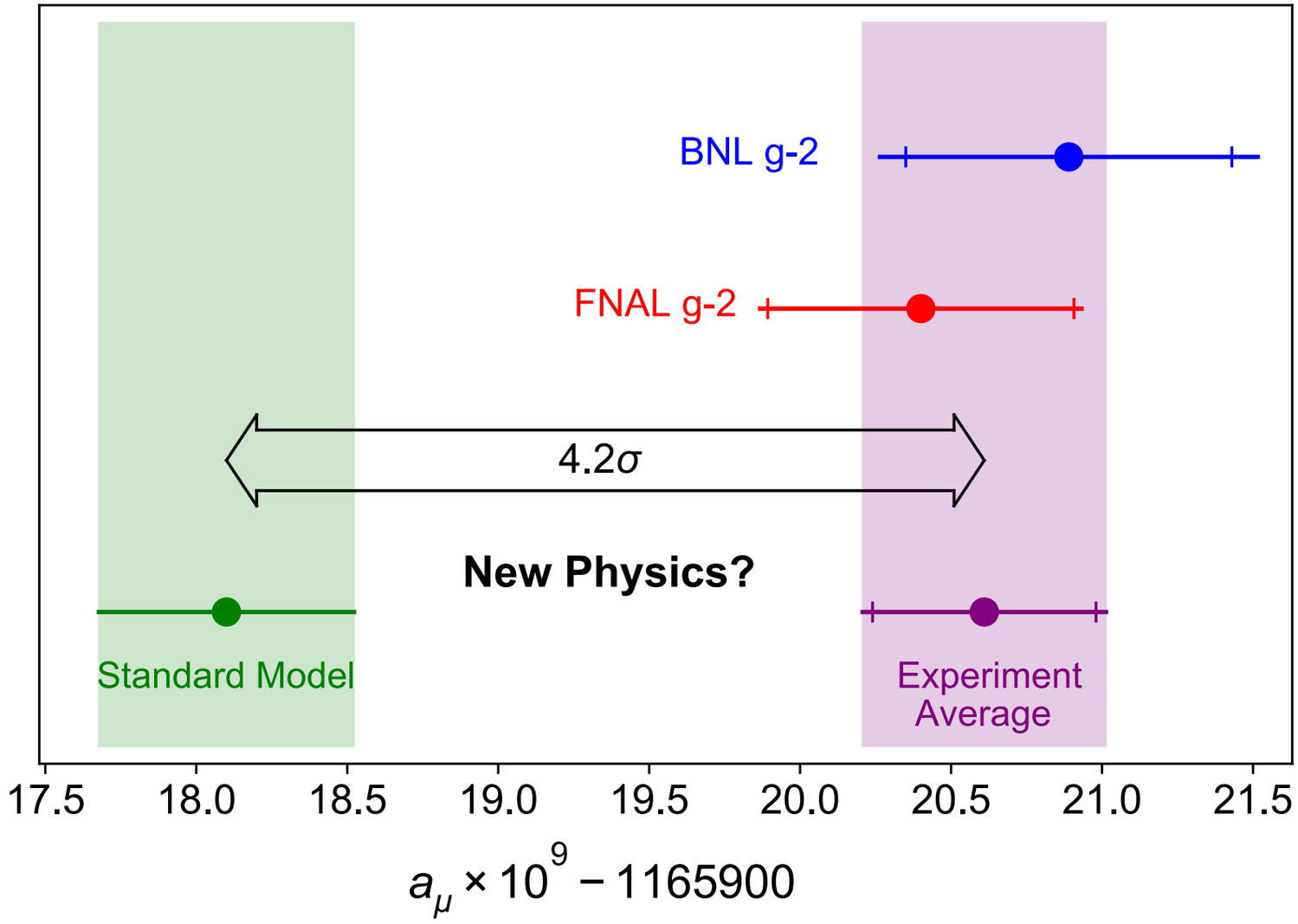
SM w/. R-ratio (WP) ⟷ SM w/. BMW lattice



→ Belle II, BES-III, CMD-3, MUonE, …

→ Independent analysis

[2104.03281]



Today's talk

- Recent progress and issue on SM prediction
- New physics interpretation — SUSY

New physics interpretation

SM based on white paper

$$a_\mu^{\mathrm{BNL+FNAL}} - a_\mu^{\mathrm{SM}} = (25.1 \pm 5.9) \times 10^{-10}$$

4.2σ deviation

Deviation is larger than electroweak contribution

$$a_\mu^{\mathrm{EW}} \simeq 15.4 \times 10^{-10}$$

No new particles have been discovered in EW scale

Need mechanism to enhance contribution to muon g-2

Light particle or enhancement

Many models have been proposed

$$a_\mu^{\rm new} \sim \frac{g^2_{\rm new}}{16\pi^2}\frac{m^2_\mu}{m^2_{\rm new}}$$

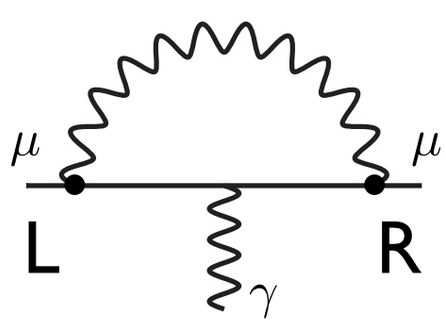
Light particle = tiny interactions

scalar extension, vector extension, axion-like particle, …

Heavy particle = enhancement mechanism

SUSY, Leptoquark, vectorlike fermion, …

Relation with B-anomalies, DM, etc, …



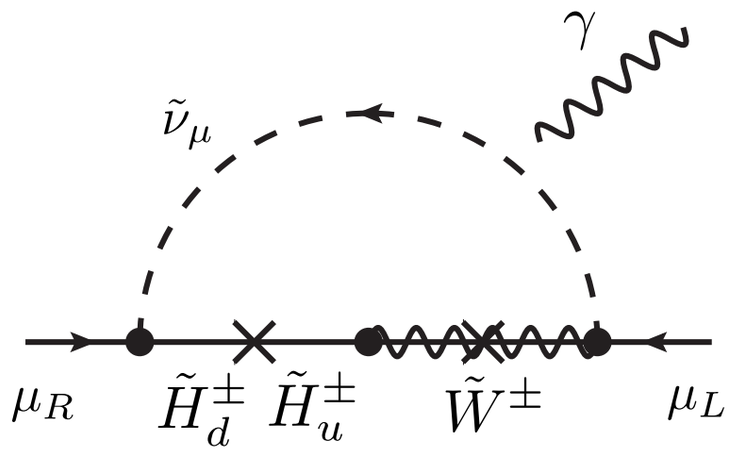
→ Talks by Arcadi, Bagnaschi, Crivellin, Ghosh, Ibrahim, Iyer, Jacob, Jesus, Khasianevich, Lopez-Ibanez, Saha, Singirala, Steudtner, Suzuki, Tabet, Villamizr, Fei Wang, Fang Xu, Fangrong Xu, Di Zhang, Jingya Zhu

Essence of SUSY interpretation

Smuon (SUSY partner of muon)

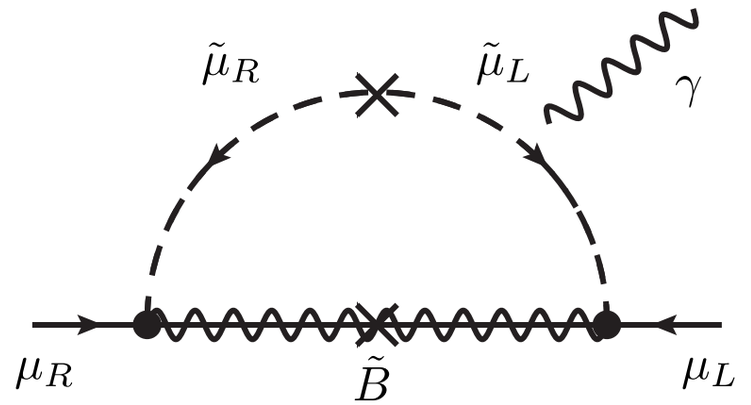
Neutralino, Chargino

(SUSY partner of B, W, H bosons)

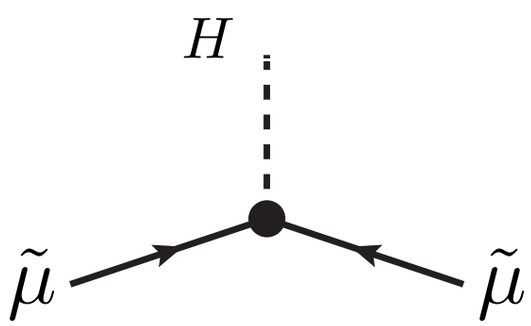


$$a_\mu^{(\mathrm{SUSY})} \sim \frac{g_{\mathrm{EW}}^2}{16\pi^2}\frac{m_\mu^2}{m_{\mathrm{SUSY}}^2}\tan\beta$$

large



cf. $\tan\beta \equiv \langle H_u\rangle/\langle H_d\rangle \sim 10$



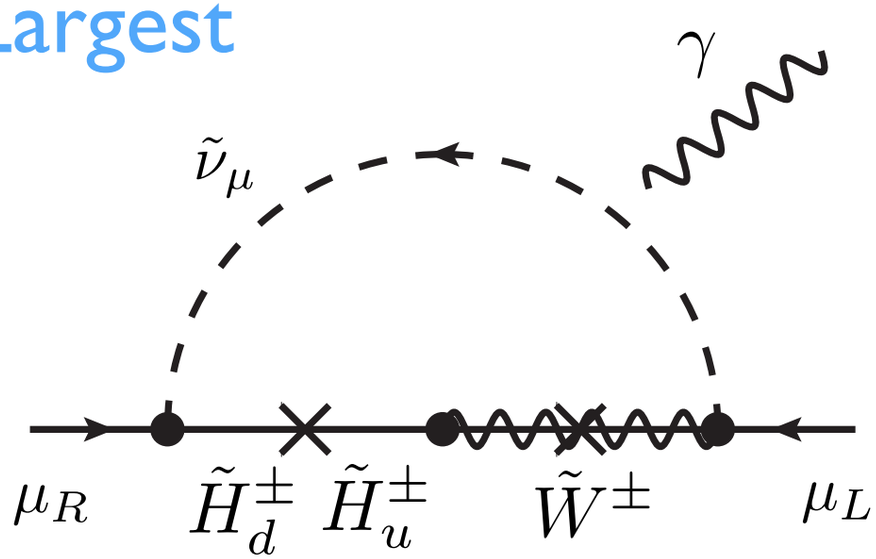
$$Y_\mu^{(\mathrm{SUSY})} \simeq Y_\mu^{(\mathrm{SM})}\tan\beta$$

enhancement of chirality flip

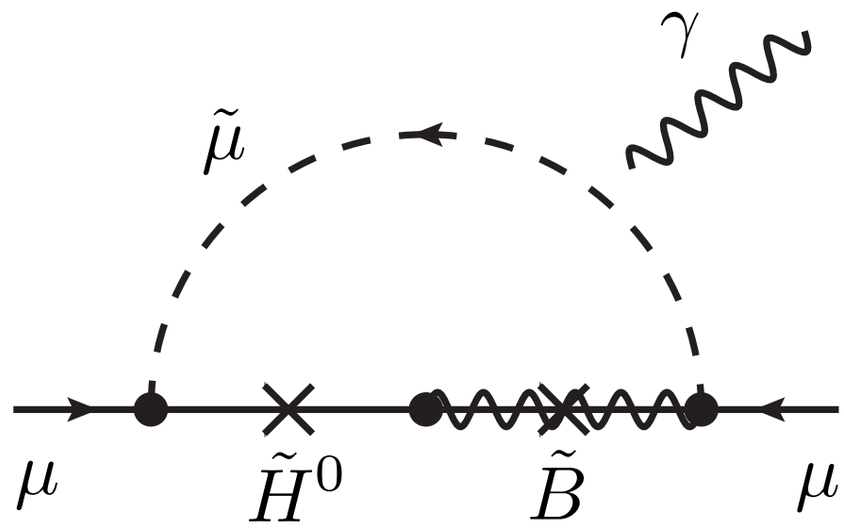
Three SUSY scenarios

Light Wino/Higgsino

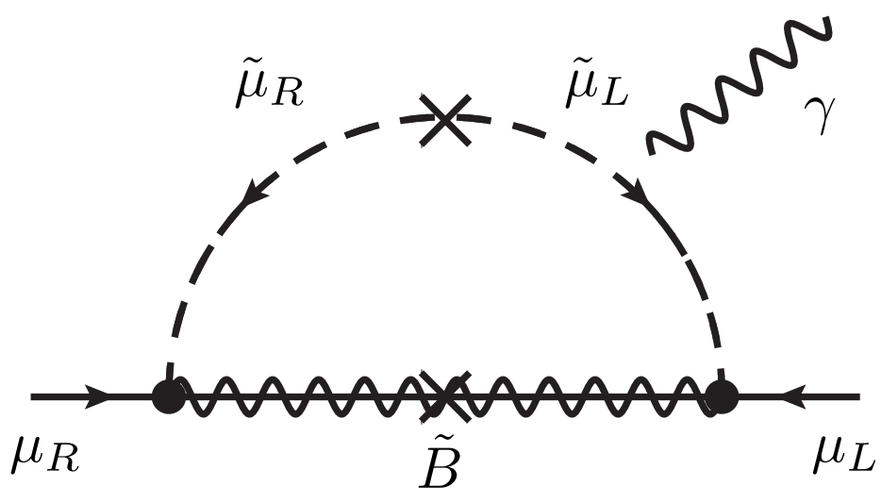
Largest



Light Bino/Higgsino



Pure Bino



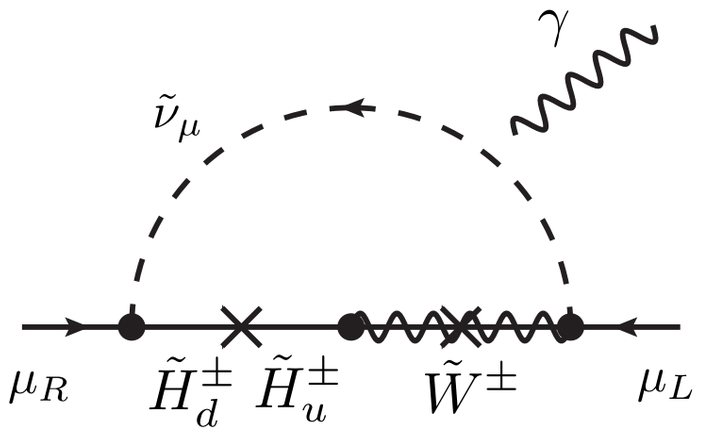
Light Wino/Higgsino scenario

Light left-handed smuon, Wino, Higgsino + Bino (LSP)

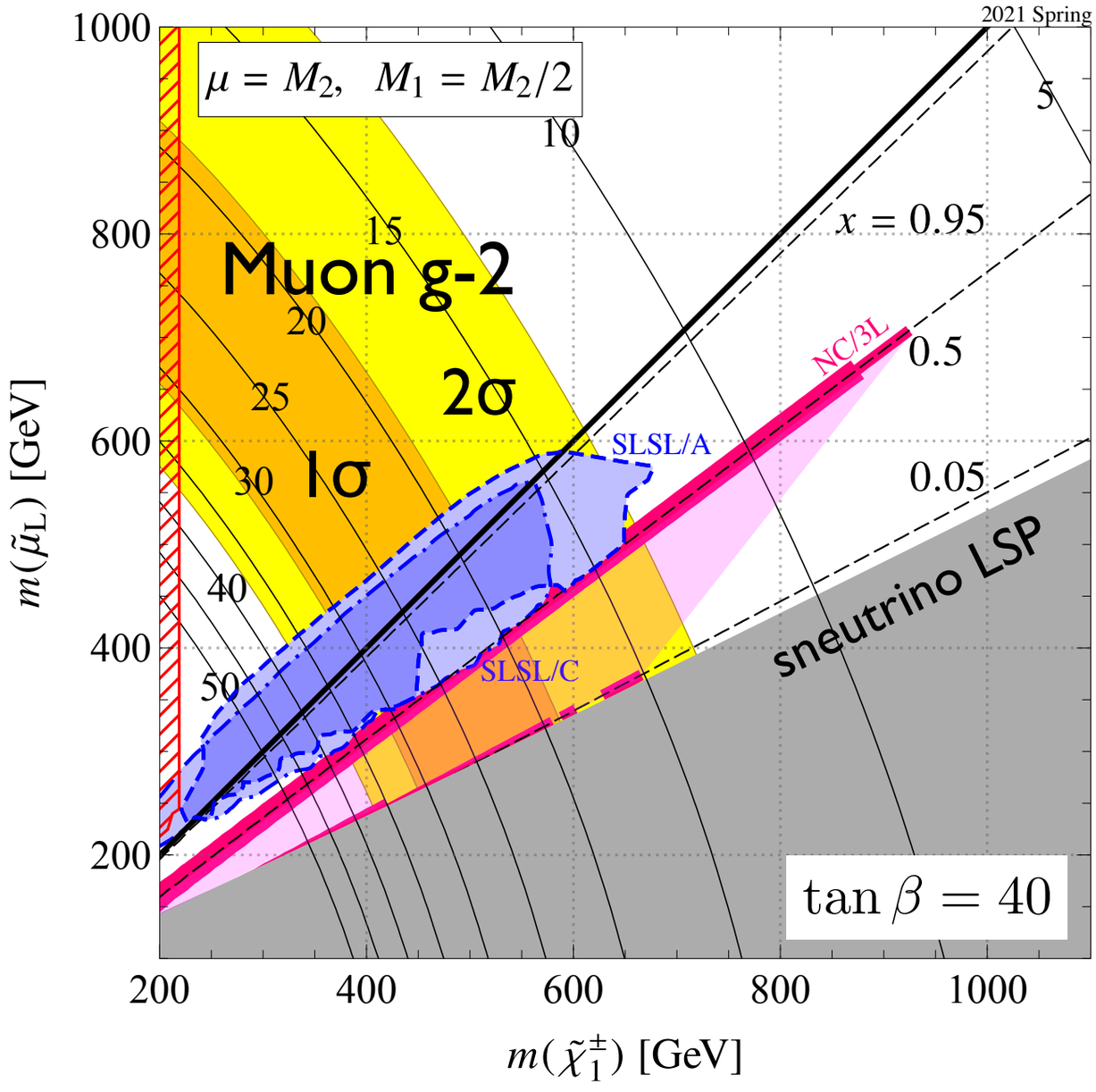
Large tanβ

g-2 favors ~100-1000GeV

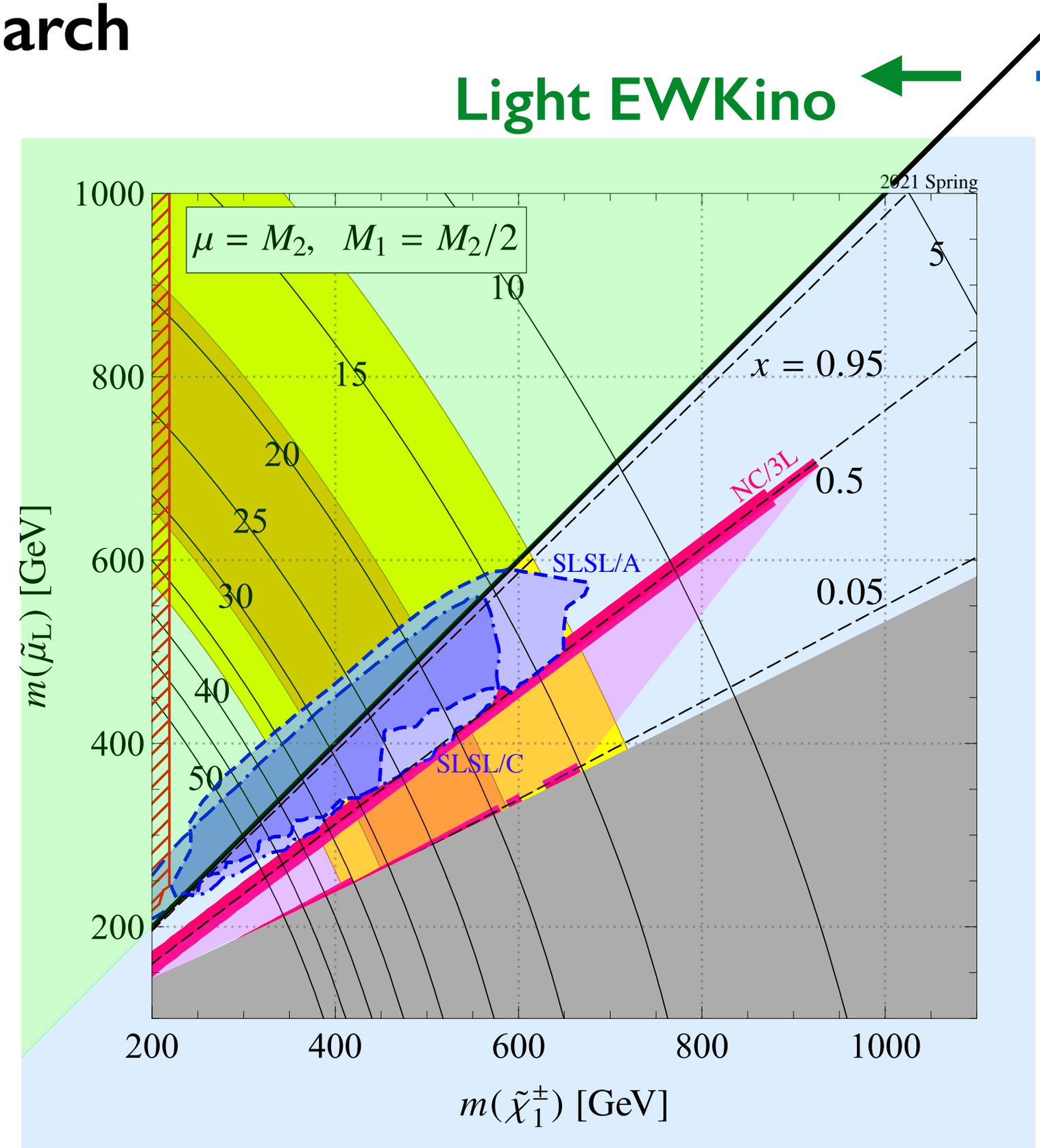
→ **LHC experiment**



ME, Hamaguchi, Iwamoto, Kitahara



LHC search

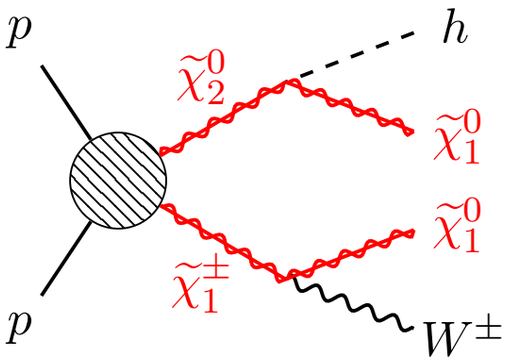


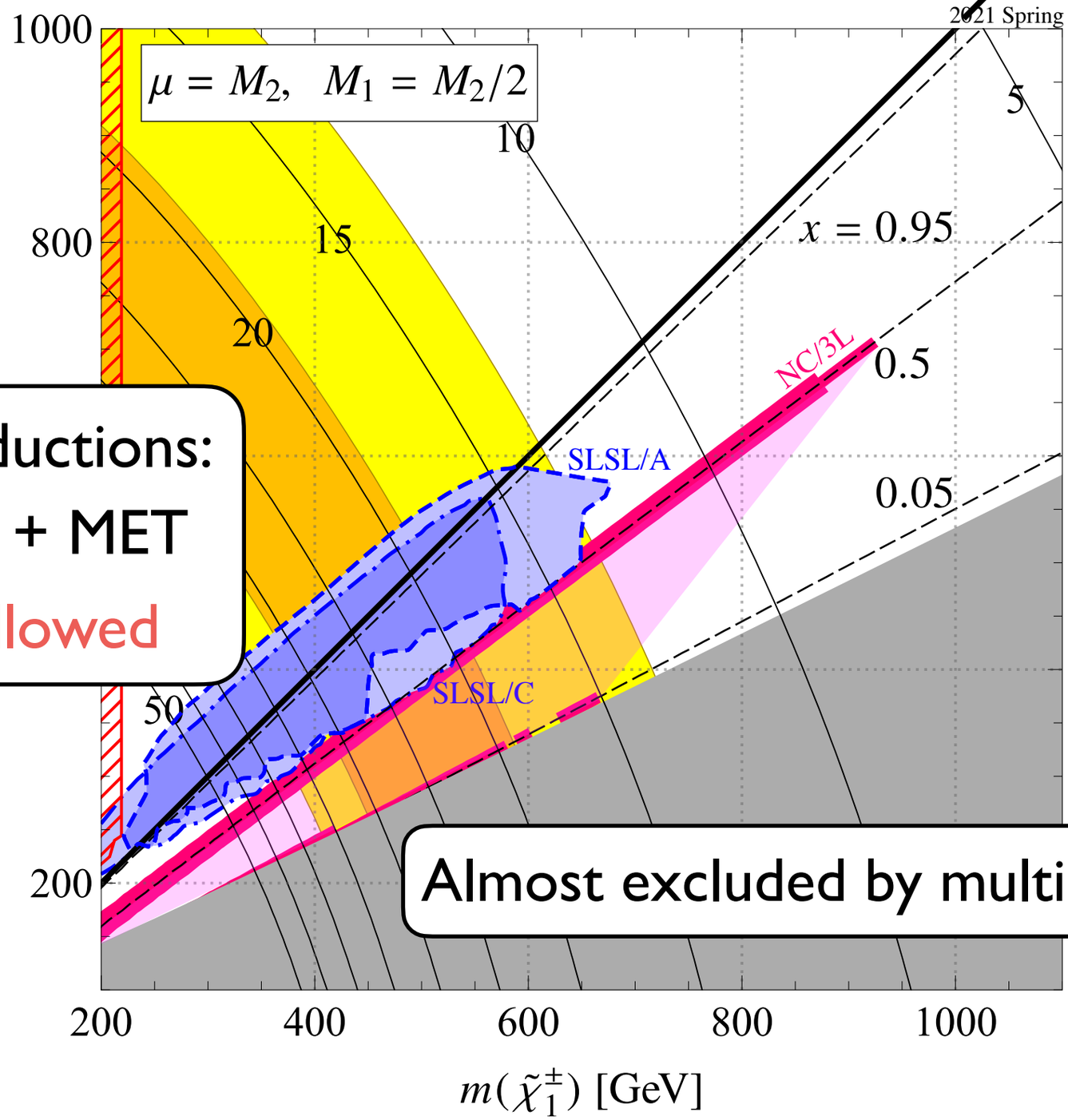
ME,Hamaguchi,Iwamoto,Kitahara

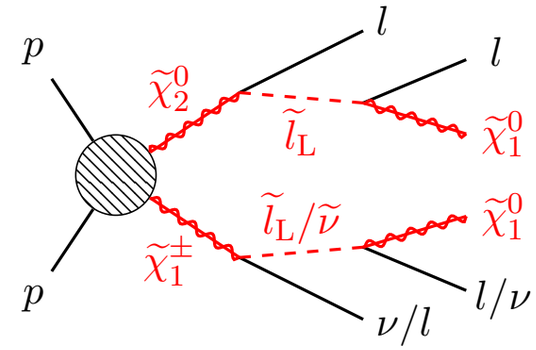
LHC search

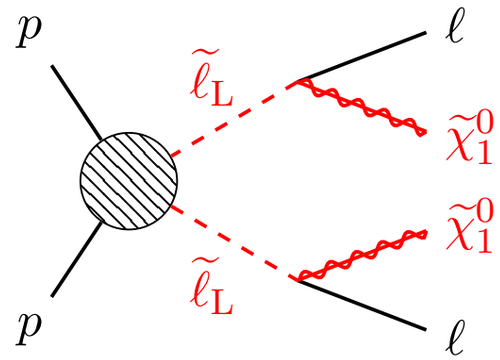
Light EWKino

Light slepton









SM boson productions:
ZW, HW, WW + MET

Still widely allowed

Almost excluded by multi-lepton channels

$$x = \frac{m_{\tilde{\mu}_\mathrm{L}} - m_{\tilde{\chi}_1^0}}{m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0}}$$

ME, Hamaguchi, Iwamoto, Kitahara

Why is it so weak?

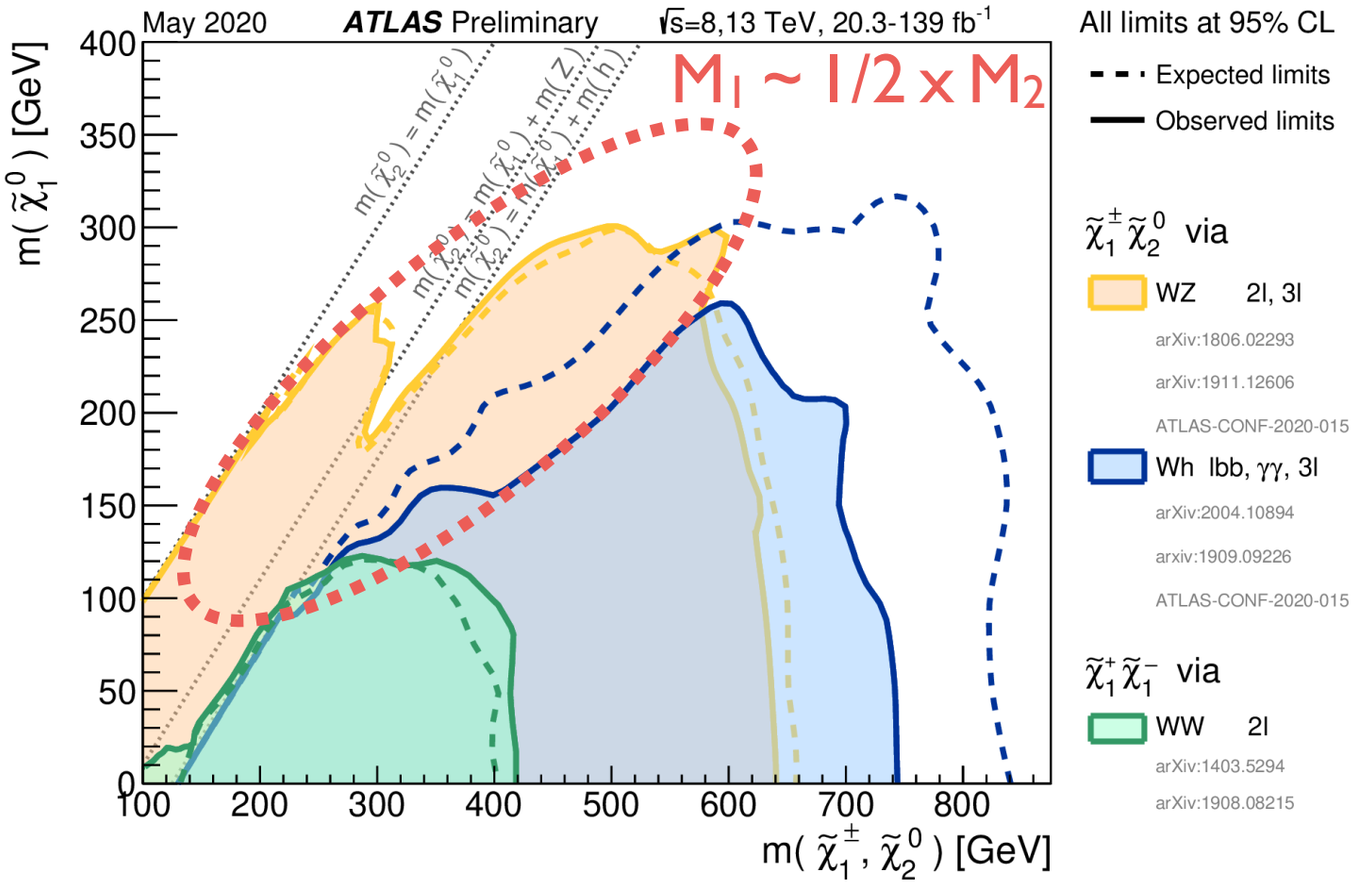
Setup: $M_1 \sim 1/2 \times M_2$

Seem to be covered by WZ

However, $\mathcal{B}(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z) \simeq 1$

is NOT realistic

(No $\widetilde{W}$-$\widetilde{B}$-Z int. in SUSY)



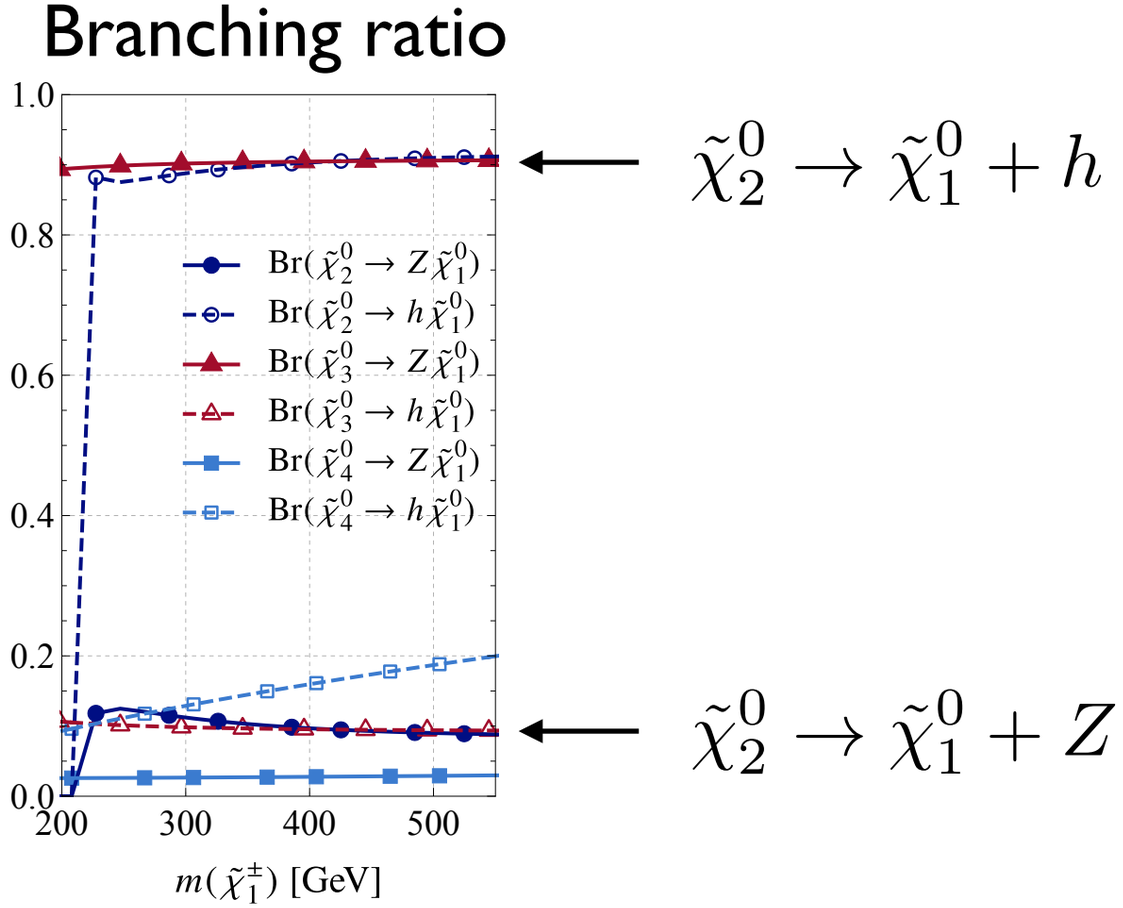
Need $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to Wh + \not{E}_T$

for $m_{\chi_1^0} \sim m_{\chi_2^0}, m_{\chi_1^{\pm}}$

Similar for other gaugino spectra

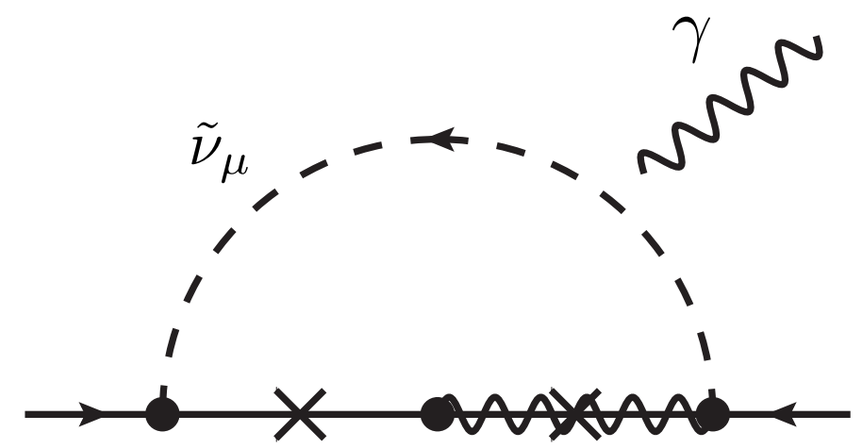
e.g., for fixed M_1 = 100GeV,

because Br is not close to unity

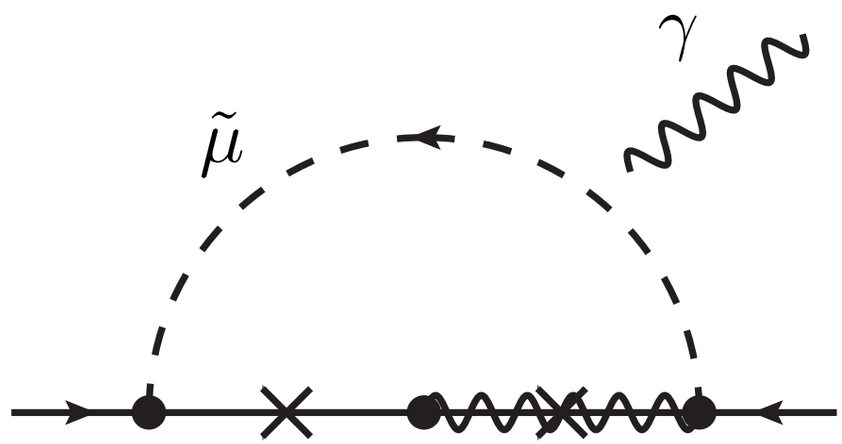


Three SUSY scenarios

Light Wino/Higgsino

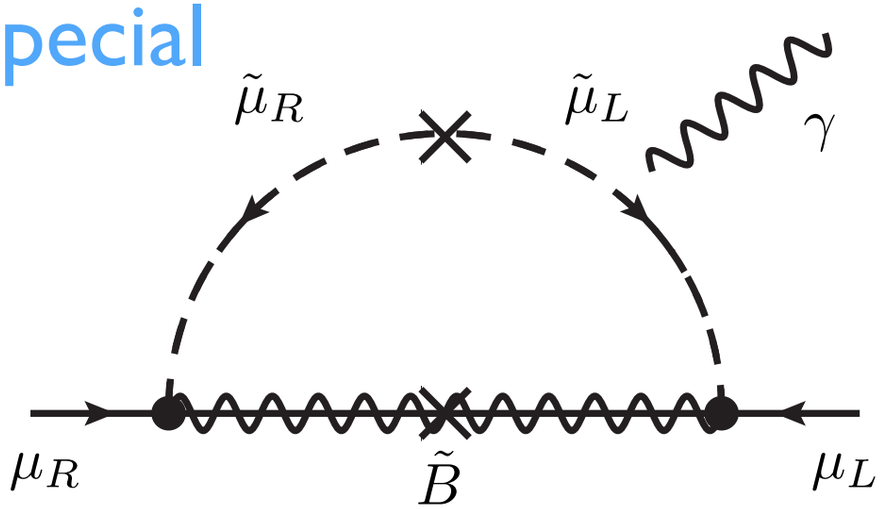


Light Bino/Higgsino



Pure Bino

Special

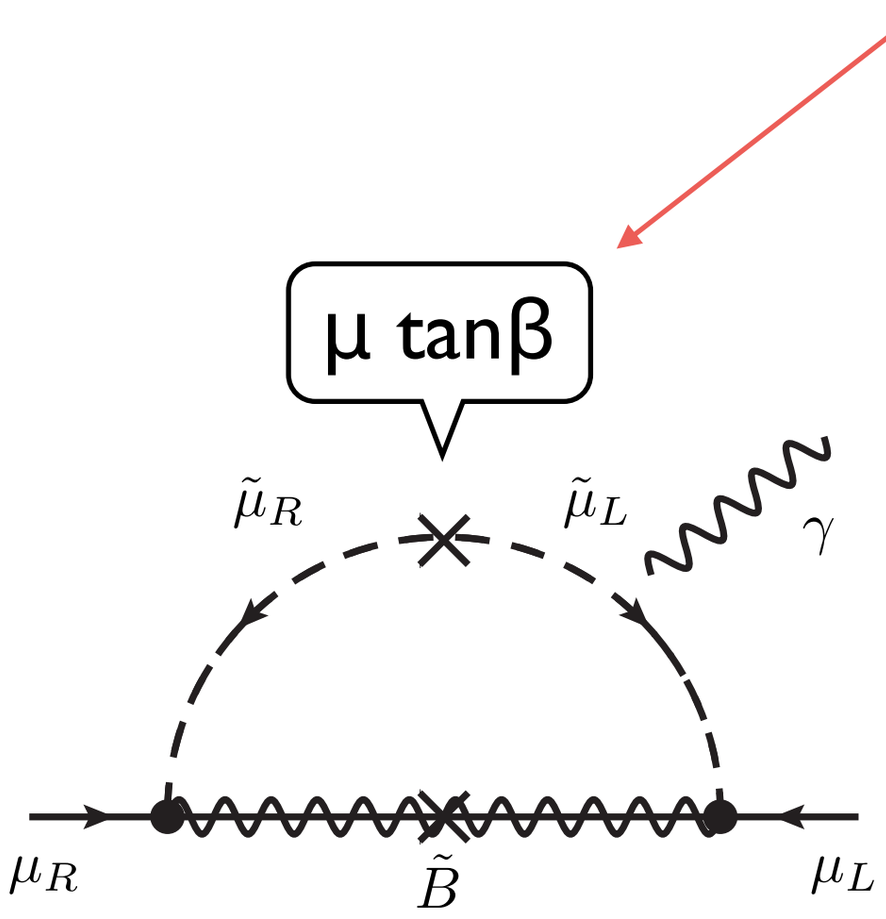


Pure Bino scenario

Light Bino (neutralino), light left- and right-handed smuons

Enhanced by smuon "chirality" flip — large μ tanβ

μ: Higgsino mass, smuon LR mixing



No Higgsinos in loop

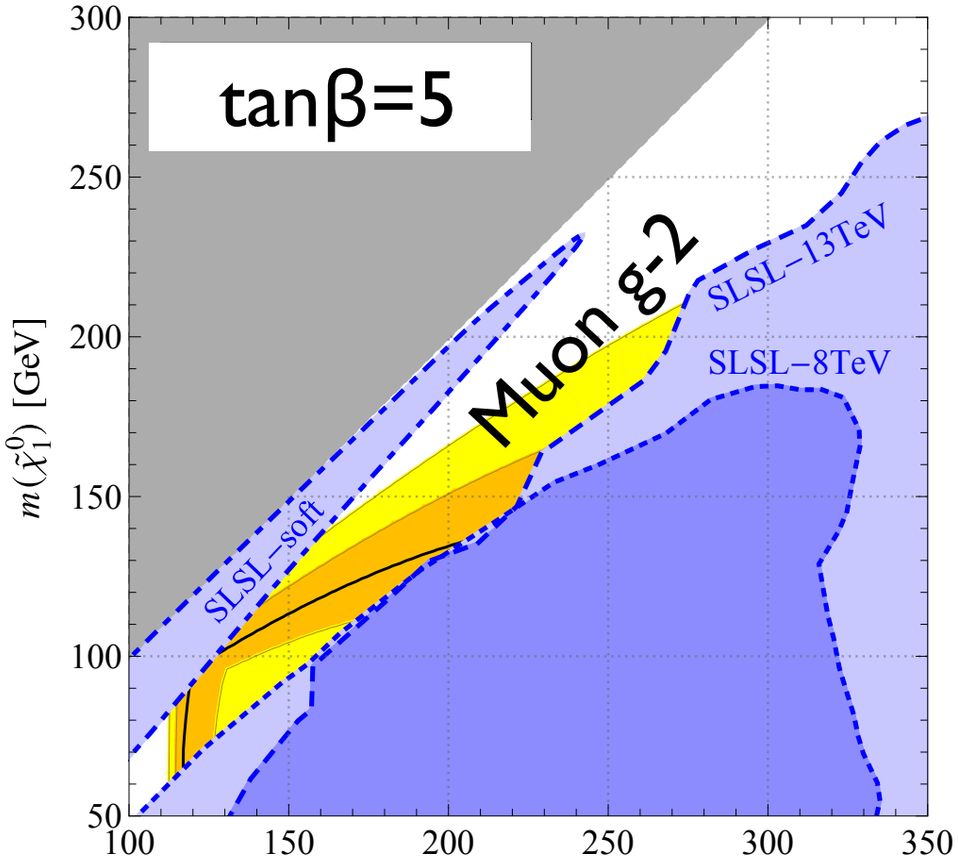
Status

μ is maximized under constraints

Smaller tanβ (~5-10) is favored

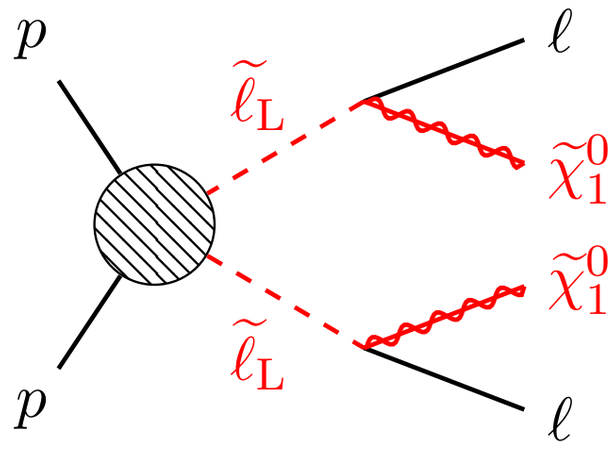
(Destructive contribution to g-2

is suppressed by larger μ)

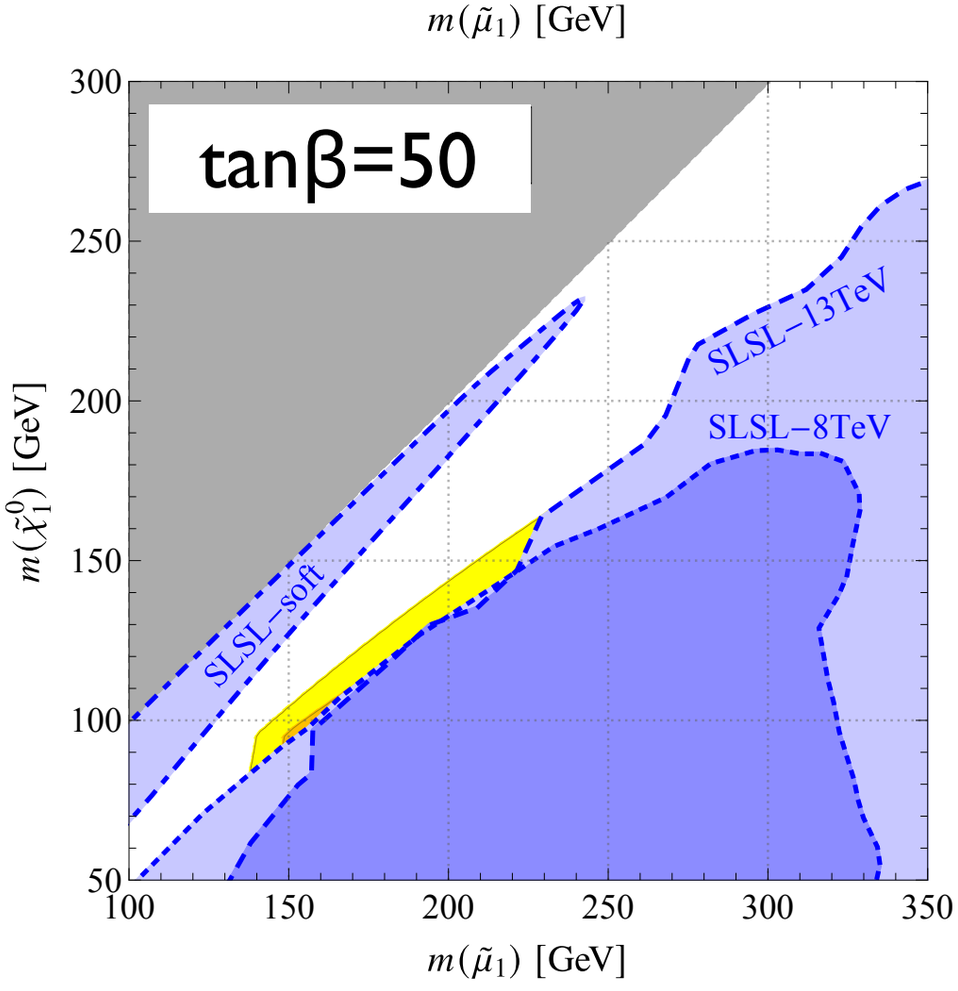


Still allowed by LHC constraints:

SLSL (-soft) : lepton pair



(+jet)

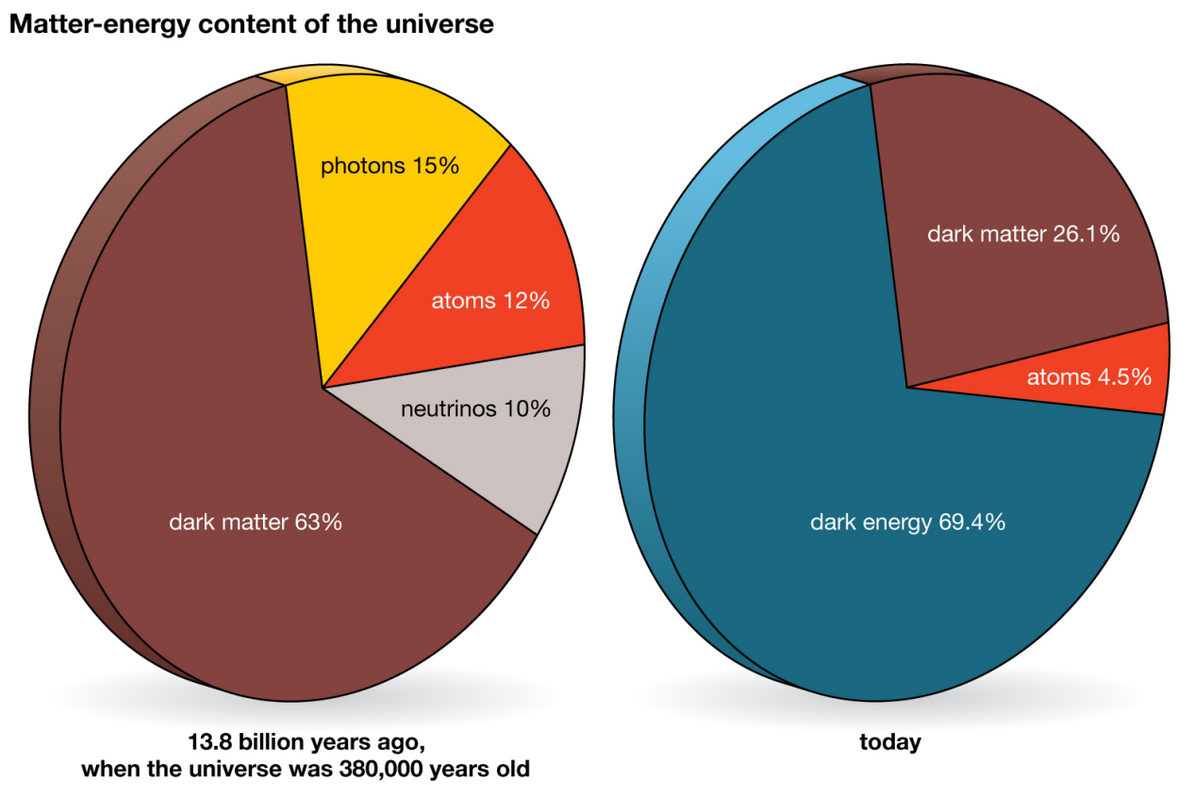


ME,Hamaguchi,Iwamoto,Kitahara

Big Picture

SUSY motivations

- naturalness
- dark matter candidate
- grand unified theory
- muon g-2, …

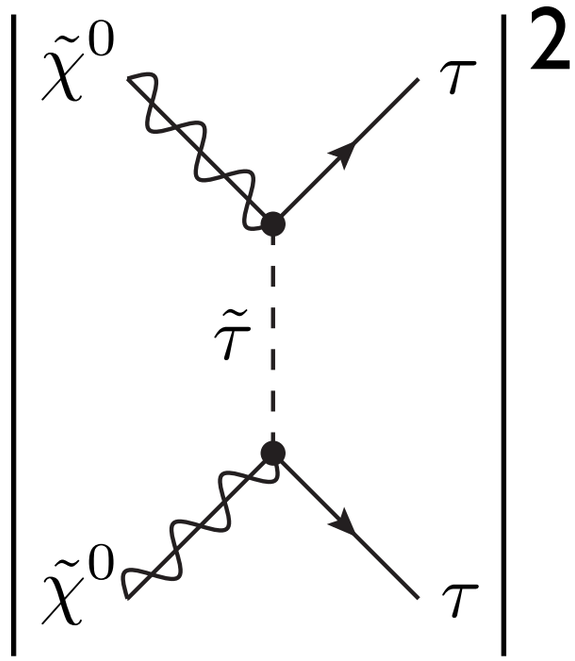


(snapshot observed by CMB)

DM thermal relic abundance

Bino is a well-known WIMP DM candidate

Thermal relic abundance : $\Omega_{\rm DM} \propto \langle \sigma_{\rm ann} v \rangle^{-1}$

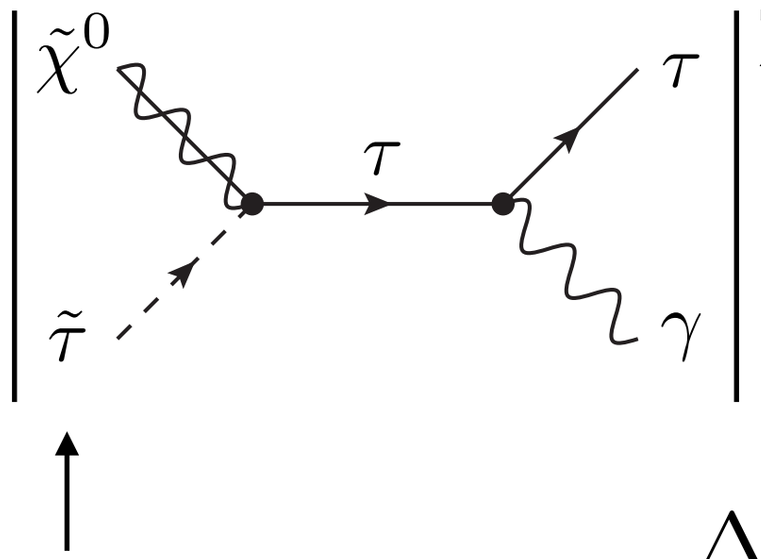


pure Bino

$\Omega_\chi > \Omega_{\rm DM}$

+

"stau coannihilation"



thermal

$e^{-\Delta/kT}$

$\Delta = m_{\tilde{\tau}} - m_{\tilde{\chi}}$

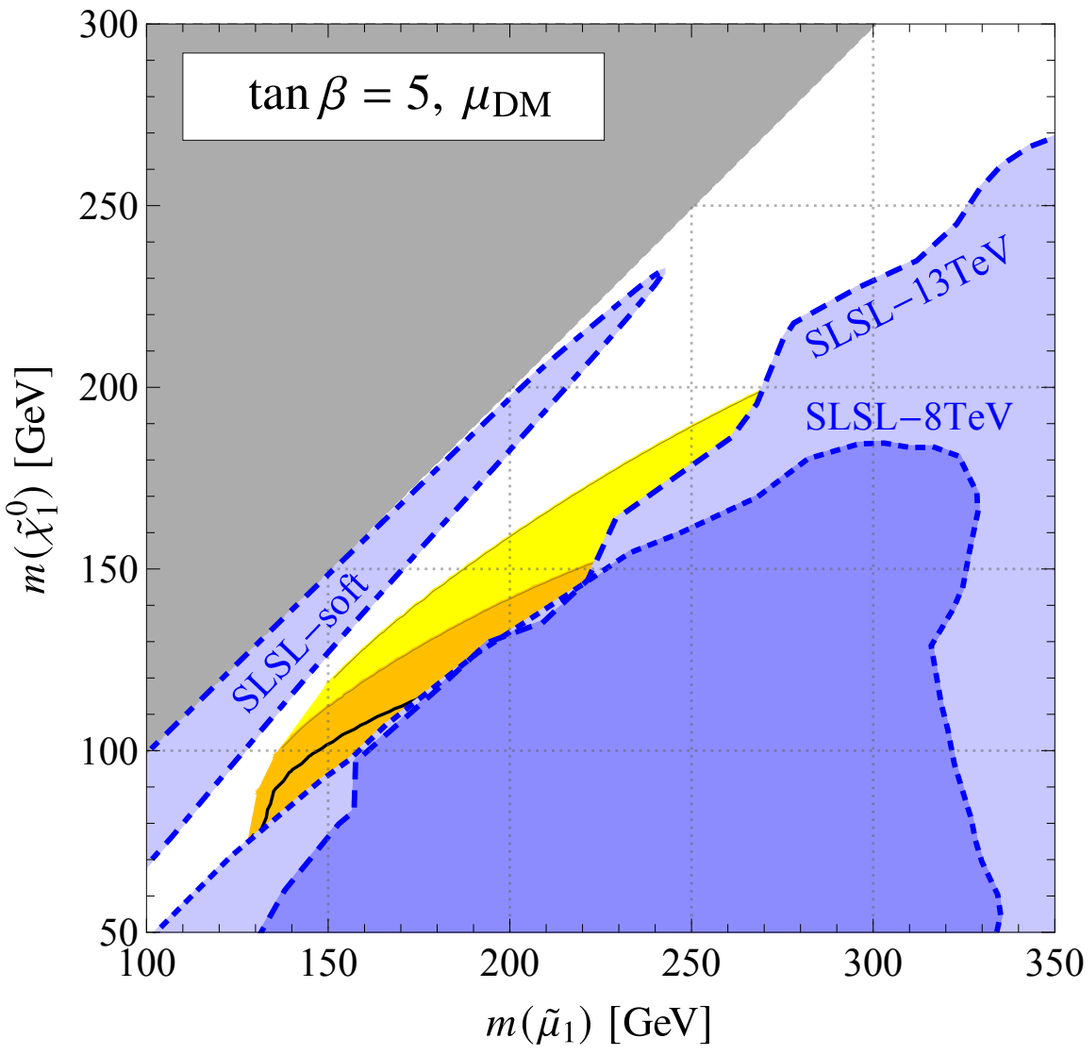
Degeneracy is favored

Muon g-2 and dark matter

μ is determined by DM relic abundance

Wide g-2 regions can be covered by DM direct detection exp.

e.g., XENONnT, PandaX-4T, …



ME, Hamaguchi, Iwamoto, Kitahara

Summary

Fermilab confirmed muon g-2 result — 4.2σ deviation

White paper has been published, but an issue on HVP was raised

Many new physics models have been proposed

→ short talks

SUSY is a major target, and expected to be checked in near future