Muon $g-2$ and Lepton Flavour Violation in the MRSSM

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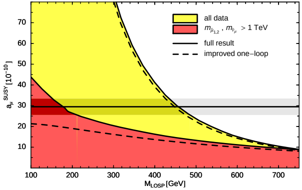
Motivation: low-energy lepton observable $g-2$

$(g-2)_\mu$: $a_\mu^{\text{Exp.}} - a_\mu^{\text{SM}} = (28.1 \pm 6.3^{\text{Exp.}} \pm 3.6^{\text{Th(KNT18)}}) \times 10^{-10}$

New experiment at Fermilab(E969): ~ 0.16 ppm

Question in preparation of new experiment:

- Which models predict what?
- Outcome: interesting scenarios, other experimental tests?



Standard MSSM

[DS '06]

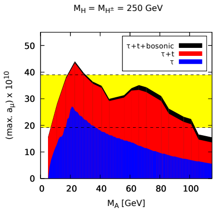
→ Dark Matter, LHC constraints, M_h

Heaviest SUSY

($\tan\beta \to \infty$)

[Bach,Park,DS,Stöckinger-Kim '15]

→ Higgs couplings, flavour, vacuum stability



Largest THDM

[Cherchiglia,DS,Stöckinger-Kim '17]

→ τ-physics, LHC-Higgs/Yukawa

Motivation: more low-energy lepton observables

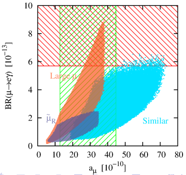
$(g-2)_\mu$: $a_\mu^{\text{Exp.}} - a_\mu^{\text{SM}} = (28.1 \pm 6.3^{\text{Exp.}} \pm 3.6^{\text{Th(KNT18)}}) \times 10^{-10}$
New experiment at Fermilab(E969): ~ 0.16 ppm

$\mu \to e\gamma$: $B_{\mu^+ \to e^+\gamma} = \frac{\Gamma(\mu \to e\gamma)}{\Gamma(\mu \to e\nu_\mu\bar{\nu}_e)} < 4.2 \times 10^{-13}$ (MEG 2016)
Future MEG-II: expect to improve sensitivity $\sim 5 \times 10^{-14}$

$\mu \to e$: $B_{\mu\text{Au} \to e\text{Au}} < 7 \times 10^{-13}$ (SINDRUM 2006)
Future COMET and Mu2E: expected 7.2×10^{-15}

Question:

- (Non-)correlations? Sensitivity to which models?



[Kersten,Park,DS,Velasco-Sevilla '14]

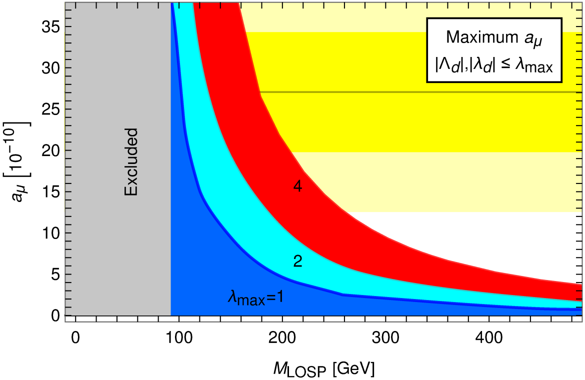
Motivation: Supersymmetry with R-symmetry

- Supersymmetry is one of the most attractive ideas for BSM
- It becomes even more attractive with R-symmetry [Kribs,Poppitz,Weiner]
- MRSSM is realization of SUSY distinct from MSSM
- Surprisingly rich and successful phenomenology [Diessner,Kalinowski, Kotlarski,DS'14-'19]

Question:

- What are the possible MRSSM contributions to a_μ?
- (Non-)correlations with LFV?

First answer/preview



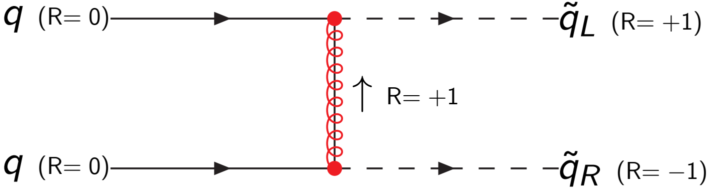
Result:

a_μ much smaller in MRSSM than in MSSM

Next questions/remainder of the talk:

- Why? Detailed influence of MRSSM parameters?
- Lepton flavour violation LFV — study!

Definition MRSSM [Kribs, Poppitz, Weiner]



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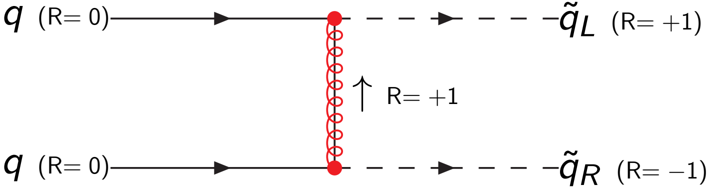
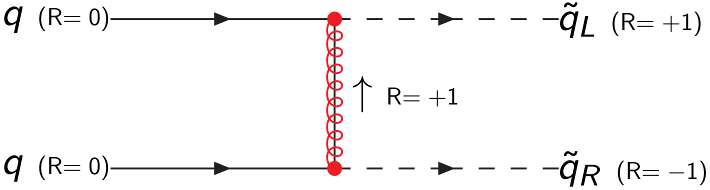


- MRSSM: beautiful alternative realization of SUSY
- R-symmetry: conserved U(1) R-charge (in superspace: $\theta \to e^{i\alpha}\theta$)
- no sfermion L/R mixing
- Dirac gauginos/Higgsinos, hence Dirac partner fields $\hat{R}_{u,d}$, $\hat{S}$, $\hat{T}$, $\hat{O}$

Definition MRSSM [Kribs, Poppitz, Weiner]



- Minimal: fewer parameters than MSSM (though more EW par.)

$$W_{\text{MRSSM}} = \ldots + \mu \hat{H}_u \hat{H}_d + \mu_u \hat{R}_u \hat{H}_u + \Lambda_u \hat{H}_u \hat{T} \hat{R}_u + y_u \hat{Q} \hat{H}_u \hat{U}$$

Phenomenological successes:

- natural protection from FCNC [Kribs, Poppitz, Weiner]
- smaller LHC cross section, lower masses possible [Diessner, Kalinowski, Kotlarski, DS '19]
- new Λ, λ-par. increase M_h but don't mess up EWPO precision [DKKS 14]
- dark matter possible, and light extra Higgs/sparticles [DKKS 15]

$g-2$: compare standard/R-symmetric SUSY

new Yukawa-like terms for Dirac partners $\hat{R}_{u,d}$, $\hat{T}$, $\hat{S}$

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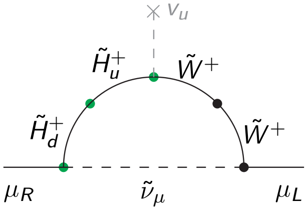
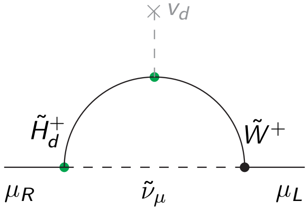
MSSM



$\longrightarrow$

MRSSM



MSSM $\propto \frac{v_u}{v_d} \tan\beta \sim 10 \ldots 50$

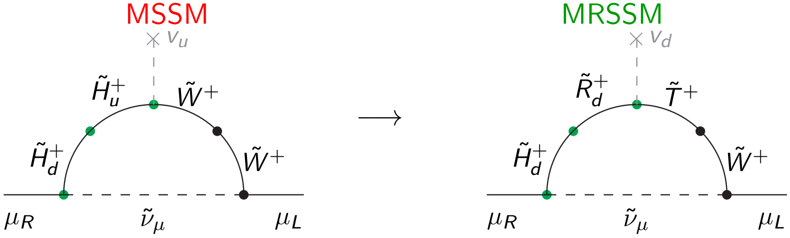
MRSSM $\propto \frac{\Lambda_d}{g_2} \sim 1 \ldots 5$

- In all models: need chirality flip $\rightsquigarrow$ VEV $\rightsquigarrow$ enhancements
- Perturbativity and EWPO constrain Λ_i, λ_i

$g-2$: compare standard/R-symmetric SUSY

new Yukawa-like terms for Dirac partners $\hat{R}_{u,d}$, $\hat{T}$, $\hat{S}$

$$W_{\text{MRSSM}} = \ldots + \mu \hat{H}_u \hat{H}_d + \mu_u \hat{R}_u \hat{H}_u + \Lambda_u \hat{H}_u \hat{T} \hat{R}_u + y_u \hat{Q} \hat{H}_u \hat{U}$$



MSSM $\propto \frac{v_u}{v_d} \tan\beta \sim 10\ldots50$ MRSSM $\propto \frac{\Lambda_d}{g_2} \sim 1\ldots5$

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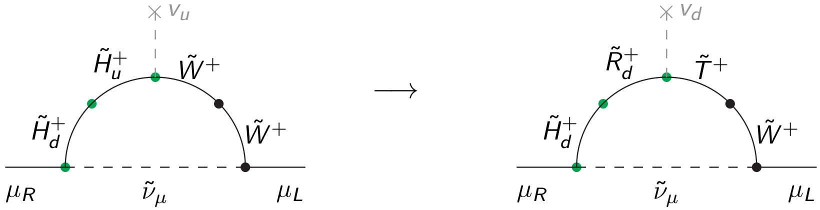
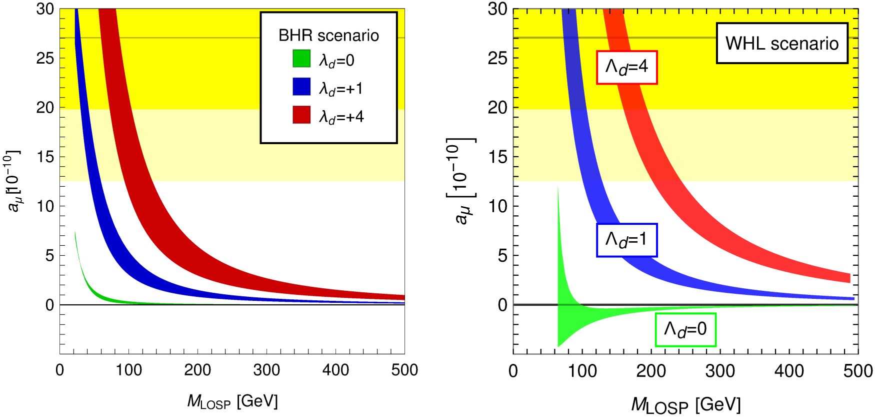
$g-2$: compare standard/R-symmetric SUSY



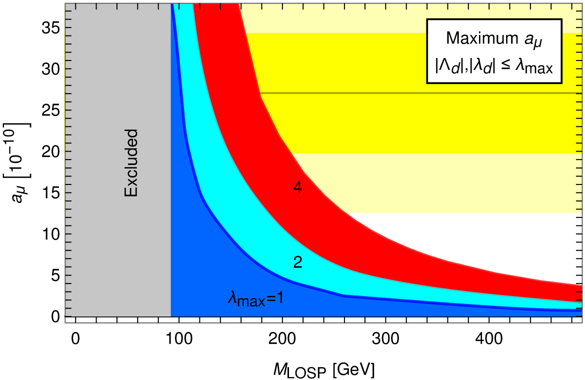
$$a_\mu^{\text{MSSM,WHL}} \approx \frac{g_2^2 \tan\beta}{16\pi^2}\,\frac{5}{12}\,\frac{m_\mu^2}{M_{\text{SUSY}}^2}, \qquad a_\mu^{\text{MI}\,(WHL/cn)} \approx \frac{g_2 \Lambda_d}{16\pi^2}\,\frac{5}{12}\,\frac{m_\mu^2}{M_{\text{SUSY}}^2} \tag{1}$$

similar for BHL, BHR,... (2)

Results for a_μ in the MRSSM: WHL and BHR



Results for a_μ in the MRSSM: general

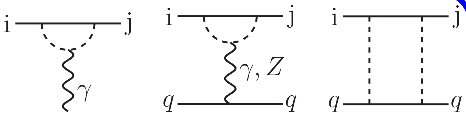


Result:
a_μ much smaller in MRSSM than in MSSM

Reason and details:

- no $\tan\beta$ enhancement, only enhancement by Λ_d, λ_d
- Large a_μ at most if several SUSY particles below 200 GeV and $\Lambda_i \ll g_2$

a_μ vs LFV observables

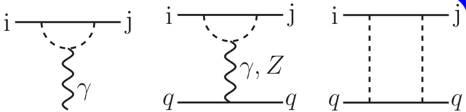


$A^{ji}_{1\,[q^2\gamma^\mu]}$ $\quad A^{\bar{e}\mu}_1,\ A^{\bar{e}\mu}_2$ $\quad A_{\text{box}}$

$A^{ji}_{2\,[\sigma^{\mu\nu}q_\nu]}$ $\quad A_Z,$

$$(g-2)_\mu \propto A_2^{\bar{\mu}\mu}$$
$$\mu \to e\gamma \propto A_2^{\bar{e}\mu}$$
$$\mu \to e \propto A_1^{\bar{e}\mu}, A_2^{\bar{e}\mu}, A_Z, A_{\text{box}}$$

a_μ vs LFV observables



$A^{ji}_{1\,[q^2\gamma^\mu]}$ $A^{\bar{e}\mu}_1,\ A^{\bar{e}\mu}_2$ A_{box}

$A^{ji}_{2\,[\sigma^{\mu\nu}q_\nu]}$ $A_Z,$

$$(g-2)_\mu \propto A_2^{\bar{\mu}\mu}$$
$$\mu \to e\gamma \propto A_2^{\bar{e}\mu}$$
$$\mu \to e \propto A_1^{\bar{e}\mu}, A_2^{\bar{e}\mu}, A_Z, A_{\text{box}}$$

Expect:

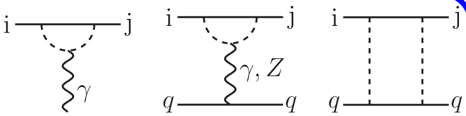
1. a_μ and $\mu \to e\gamma$ always correlated
2. correlation with $\mu \to e$ conversion if dipole A_2 dominates (large a_μ)
3. this is usually not the case $\rightsquigarrow$ interesting non-correlation

a_μ vs LFV observables

LFV in MRSSM: flavour-transitions in slepton sector $\mathcal{L} = \ldots - (m^2_{\tilde{l}})_{12} \tilde{l}_1^\dagger \tilde{l}_2$

LFV $\propto$ dimensionless parameters $\delta^L_{12} \equiv \frac{(m^2_{\tilde{l}})_{12}}{m_{\tilde{l},11} m_{\tilde{l},22}}$, $\delta^R_{12} \equiv \frac{(m^2_{\tilde{e}})_{12}}{m_{\tilde{e},11} m_{\tilde{e},22}}$

- otherwise $(g-2)_\mu$ and $\mu \to e\gamma$ depend on same parameters
- $\mu \to e$ in addition: Z-couplings to Higgsinos and sleptons; squarks



$A^{ji}_{1\,[q^2\gamma^\mu]}$ $A^{\bar{e}\mu}_1$, $A^{\bar{e}\mu}_2$ A_{box}

$A^{ji}_{2\,[\sigma^{\mu\nu} q_\nu]}$ A_Z,

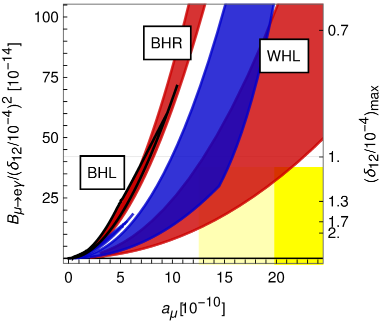
$(g-2)_\mu \propto A^{\bar{\mu}\mu}_2$

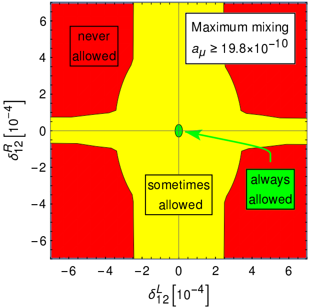
$\mu \to e\gamma \propto A^{\bar{e}\mu}_2$

$\mu \to e \propto A^{\bar{e}\mu}_1, A^{\bar{e}\mu}_2, A_Z, A_{\text{box}}$

Results for $\mu \to e\gamma$ in the MRSSM [Kotlarski,DS,Stöckinger-Kim]

$a_\mu \propto A_2^{\bar{\mu}\mu L} + A_2^{\bar{\mu}\mu R}$ $\qquad B_{\mu\to e\gamma} \propto |A_{2\text{red}}^{\bar{e}\mu L}|^2 \times |\delta_{12}^L|^2 + |A_{2\text{red}}^{\bar{e}\mu R}|^2 \times |\delta_{12}^R|^2$





Expected: a_μ and $\mu \to e\gamma$ correlated
Result: True $\rightsquigarrow$ distinctive patterns

Apply: max. δ's assuming exptl. limits $\rightsquigarrow$ tight!

Results for $\mu \to e$: details (sample scenario BHR)

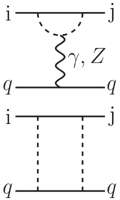
$$R(N) \equiv \frac{B_{\mu N \to eN}}{B_{\mu \to e\gamma}} \propto \frac{|A_2, A_1, A_Z, A_{\text{box}}|^2}{|A_2|^2}$$

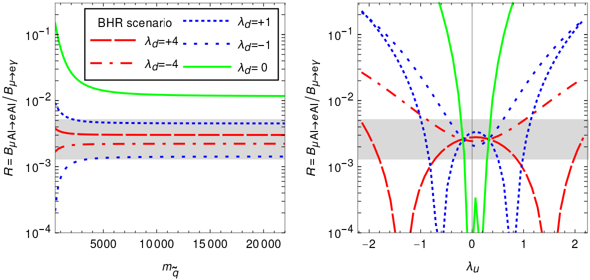
(dependence on the δ's essentially drops out)

$$R^{\text{only } A_2}(Al) = 0.0026$$

Especially for A_2 dominance: perfect correlation [Kitano, Koike, Okada, 2002]

Results for $\mu \to e$: details (sample scenario BHR)





Expected: correlation if dipole A_2 dominates

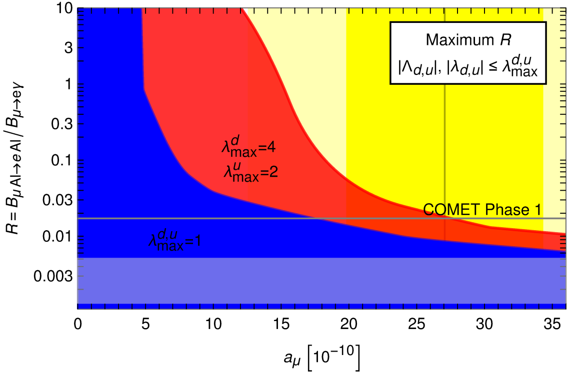
- $\mu \to e\gamma$ MEG limit determines the max. possible $\mu \to e$ rate

Result: often impact of form factors A_1, A_Z, A_{box} $\rightsquigarrow$ non-correlation

- Large $\lambda_u \to A_Z$ dominance (Z-Higgsino coupling $\sim v_u \lambda_u$)

Results for correlation $\frac{\mu\to e}{\mu\to e\gamma}$ in the MRSSM

Expected: correlation if dipole A_2 dominates **Result:** $\Leftrightarrow$ large a_μ



[Kotlarski,DS,Stöckinger-Kim '19]

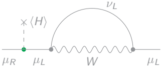
If a_μ large $\Rightarrow$
narrow param. space
$m_{\text{LOSP}} <\sim 200$ GeV, $\Lambda_i \gg g_i$

$\Rightarrow$ correlation
$\overset{\text{MEG}}{\Rightarrow}$ $\mu \to e$ small

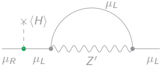
If $\mu \to e$ observed $\Rightarrow$
a_μ must be small

Typical behaviour: $\sim$ chirality flip ($\rightsquigarrow$ Higgs!) and masses

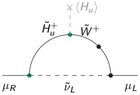
- EWSM: $\alpha \frac{m_\mu^2}{M_W^2}$



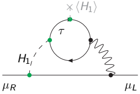
- Z', A': $\alpha' \frac{m_\mu^2}{M_{Z'}^2}$



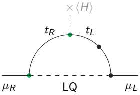
- SUSY: $\alpha \frac{m_\mu^2 \tan\beta}{M_{\text{SUSY}}^2}$



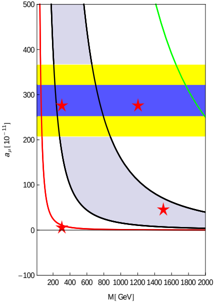
- 2HDM: $\alpha^2 \tan^2\beta \frac{m_\mu^2}{M_H^2}$



- LQ: $g_L g_R \frac{m_\mu m_t}{M_{\text{LQ}}^2}$



- rad. m_μ $\sim \frac{m_\mu^2}{M_{\text{NP}}^2}$



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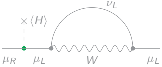
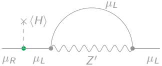


- Z', A': $\alpha' \frac{m_\mu^2}{M_{Z'}^2}$

  No chiral enhancement



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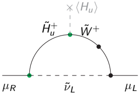

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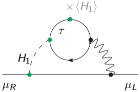

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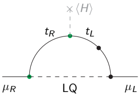

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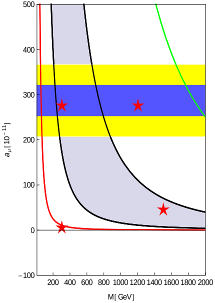

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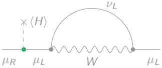

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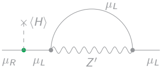

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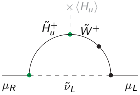
  Well-motivated. "Fits like a glove"



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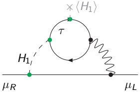

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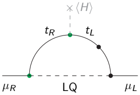

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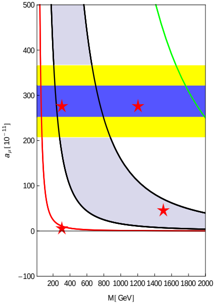

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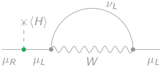

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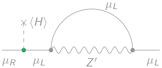
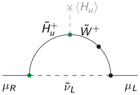
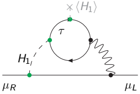


- SUSY: $\alpha \frac{m_\mu^2 \tan\beta}{M_{\text{SUSY}}^2}$

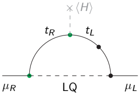


- 2HDM: $\alpha^2 \tan^2\beta \frac{m_\mu^2}{M_H^2}$

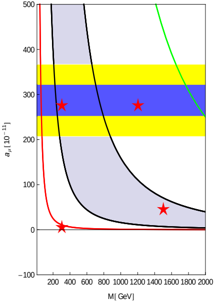
  Well motivated; typically very small



- LQ: $g_L g_R \frac{m_\mu m_t}{M_{\text{LQ}}^2}$

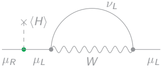


- rad. m_μ $\sim \frac{m_\mu^2}{M_{\text{NP}}^2}$

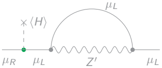


Typical behaviour: $\sim$ chirality flip ($\rightsquigarrow$ Higgs!) and masses

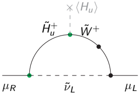
- EWSM: $\alpha \frac{m_\mu^2}{M_W^2}$



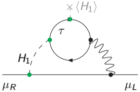
- Z', A': $\alpha' \frac{m_\mu^2}{M_{Z'}^2}$



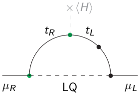
- SUSY: $\alpha \frac{m_\mu^2 \tan\beta}{M_{\text{SUSY}}^2}$



- 2HDM: $\alpha^2 \tan^2\beta \frac{m_\mu^2}{M_H^2}$



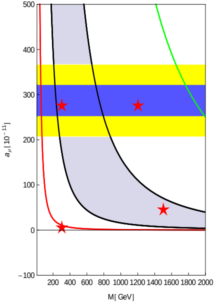
- LQ: $g_L g_R \frac{m_\mu m_t}{M_{\text{LQ}}^2}$



Also possible, although difficult: B-physics.

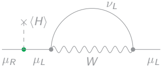
Beware: $\Delta m_\mu / m_\mu \sim g_L g_R m_t / m_\mu$ restricts couplings

- rad. m_μ $\sim \frac{m_\mu^2}{M_{\text{NP}}^2}$

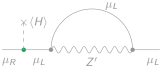


Typical behaviour: $\sim$ chirality flip ($\rightsquigarrow$ Higgs!) and masses

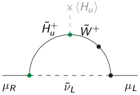
- EWSM: $\alpha \frac{m_\mu^2}{M_W^2}$



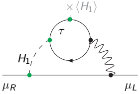
- Z', A': $\alpha' \frac{m_\mu^2}{M_{Z'}^2}$



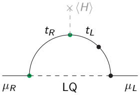
- SUSY: $\alpha \frac{m_\mu^2 \tan\beta}{M_{\text{SUSY}}^2}$

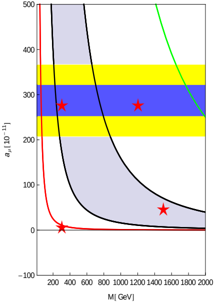


- 2HDM: $\alpha^2 \tan^2\beta \frac{m_\mu^2}{M_H^2}$



- LQ: $g_L g_R \frac{m_\mu m_t}{M_{\text{LQ}}^2}$



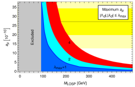


- rad. m_μ $\sim \frac{m_\mu^2}{M_{\text{NP}}^2}$

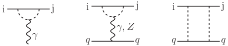
Theoretical maximum. Need $M_{\text{NP}} <\sim 2$ TeV

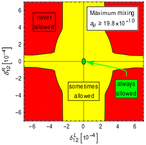
Conclusions

- R-symmetric SUSY challenges usual views on SUSY!
  - very different from standard SUSY, no MSSM limit
  - phenomenologically rich, viable for smaller M_{SUSY}
  - Interplay a_μ / $\mu \to e\gamma$ / $\mu \to e$

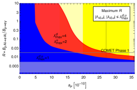


- MSSM: a_μ large and LFV correlation pattern
- MRSSM: a_μ small, not $\propto \tan\beta$

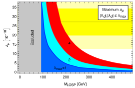




- Suppose a_μ large and MEG-limit ($\mu \to e\gamma$) met
  - need very small/compressed M_{SUSY}, $\Lambda_i \gg g_i$
  - LFV-parameters δ_{12} very small $\rightsquigarrow$ non-generic!
  - Upper limit on $\mu \to e$ $\rightsquigarrow$ No COMET signal possible!



- If a_μ small
  - Larger/non-compressed masses possible
  - COMET signal possible! Enhancements $\propto \Lambda_u \ldots$



- a_μ is hint for BSM — MSSM and MRSSM are viable and motivated
  - New a_μ and LFV measurements could distinguish!