Muon $g-2$ and other low-E observables

General thoughts and three a_μ-motivated BSM scenarios

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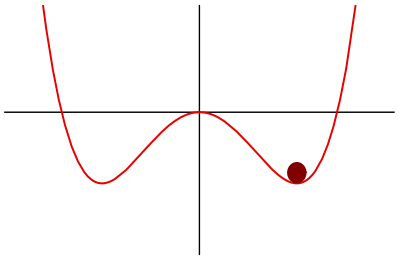
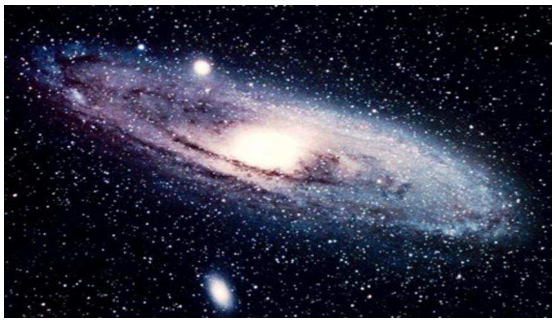
Why new physics?

Big questions. . . point to (TeV scale) new physics



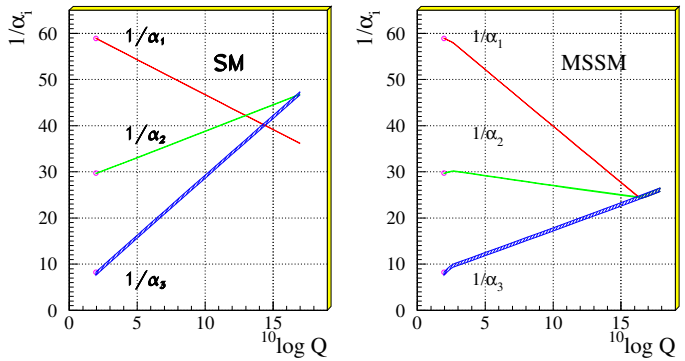
EWSB, Higgs, scalar particle?

hierarchy $M_{\rm Pl}/M_W$? Naturalness?



Dark Matter?

Baryon Asymmetry?



Grand Unification?
Flavor Structure?

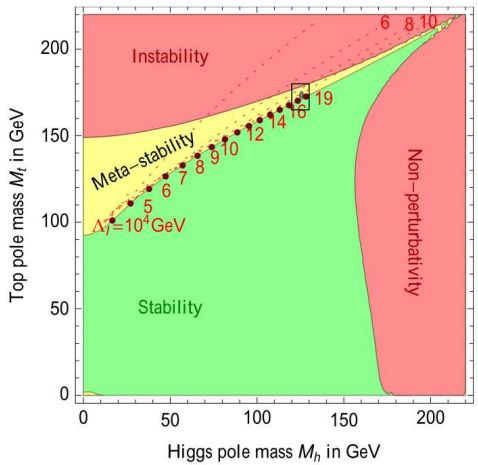
Neutrinos?

Supersymmetry? Extended Higgs sector? Extended Flavour sector?
Need complementary experiments to discover and scrutinize new physics

Lines of thought

Which direction? Oscillate between two strategies

- SUSY, Wimps, GUTs, etc: motivation still valid
  - $\Rightarrow$ keep exploring 'classic' BSM ideas
- BUT: maybe naturalness/Wimp-miracle/ gauge coupling unification misleading?
- Striking LHC result: vacuum stability: does nature prefer living on the knife-edge (some selection principle)?



  - $\Rightarrow$ Might focus on alternative, more minimal new physics [talks by Drewes, van der Bij...]

Lines of thought

There are some experimental hints!

- dark matter, strong CP, B-anomalies, $(g-2)_\mu$
  - $\Rightarrow$ light new particles ($<$1 GeV)? (unrelated to naturalness etc?)
  - $\Rightarrow$ or heavy new particles?
- need complementary low-E experiments! Might discover light or heavy BSM
  - $g-2$ (main focus here)
  - EDMs ($\leftrightarrow$ CPV, baryon asymmetry)
  - LFV ($\leftrightarrow$ flavor symmetries, neutrino mass generation)
  - B-, K-physics, τ-physics ($\leftrightarrow$ flavor)

Overview on $g-2$

Now: $a_\mu^{\rm exp} - a_\mu^{\rm SM} = (28.1 \pm 6.3^{\rm Exp} \pm 3.6^{\rm Th(KNT17)}) \times 10^{-10}$

Soon: $a_\mu^{\rm exp} - a_\mu^{\rm SM} = (30?? \pm 1.6^{\rm Exp} \pm 3.4^{\rm Th}??) \times 10^{-10}$

Electron (recent): $a_e^{\rm Exp} - a_e^{\rm SM} = (-8.8 \pm 3.6) \times 10^{-13}$

Fermilab

+

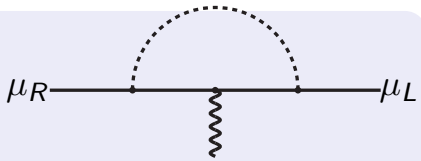
planned

J-Parc

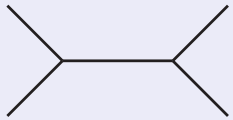
a_μ experiments

Complementarity: $g-2$, EDMs, LFV

CP- and Flavor-conserving, chirality-flipping, loop-induced



compare: EDMs, $b \to s\gamma$, $B \to \tau\nu$, $\mu \to e\gamma$ EWPO



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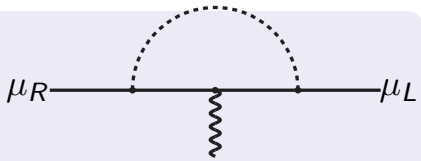

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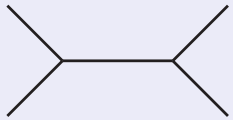
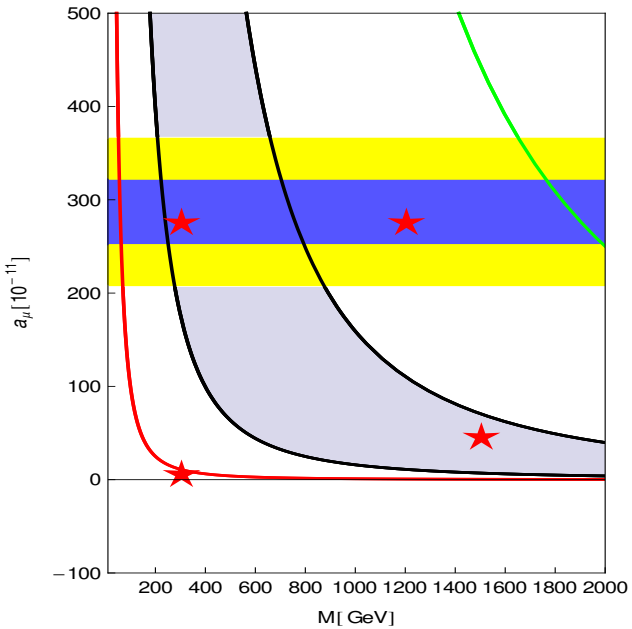


- Mass reach $\begin{cases} \text{EDMs, Flavor (large } \phi_{\rm CP}, \theta_{\rm FCNC}\text{):} & > 1000 \text{ TeV} \\ (g-2)_\mu\text{:} & < 2 \text{ TeV} \end{cases}$



$$a_\mu^{\rm BSM} = \mathcal{O}\left(\frac{m_\mu^2}{M_{\rm BSM}^2}\right) \times \underbrace{\frac{\delta m_\mu^{\rm BSM}}{m_\mu}}_{\downarrow}$$

~ 1 (radiative muon mass)

$\sim \alpha$ (1-loop [SUSY])

$\sim \alpha^2$ (2-loop [THDM])

a_μ in the 2-Higgs doublet model?

[Cherchiglia,DS,Stöckinger-Kim '17]

- 2-Higgs doublet model with light A_0, large couplings to τ (and top)

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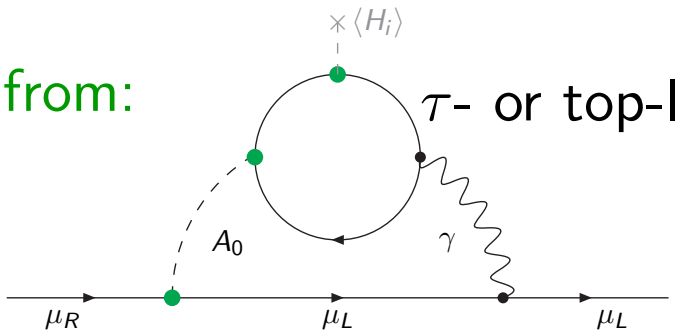
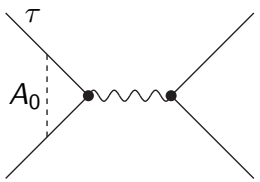
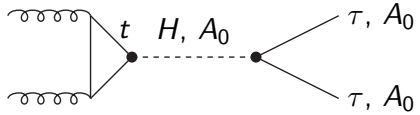
a_μ from:

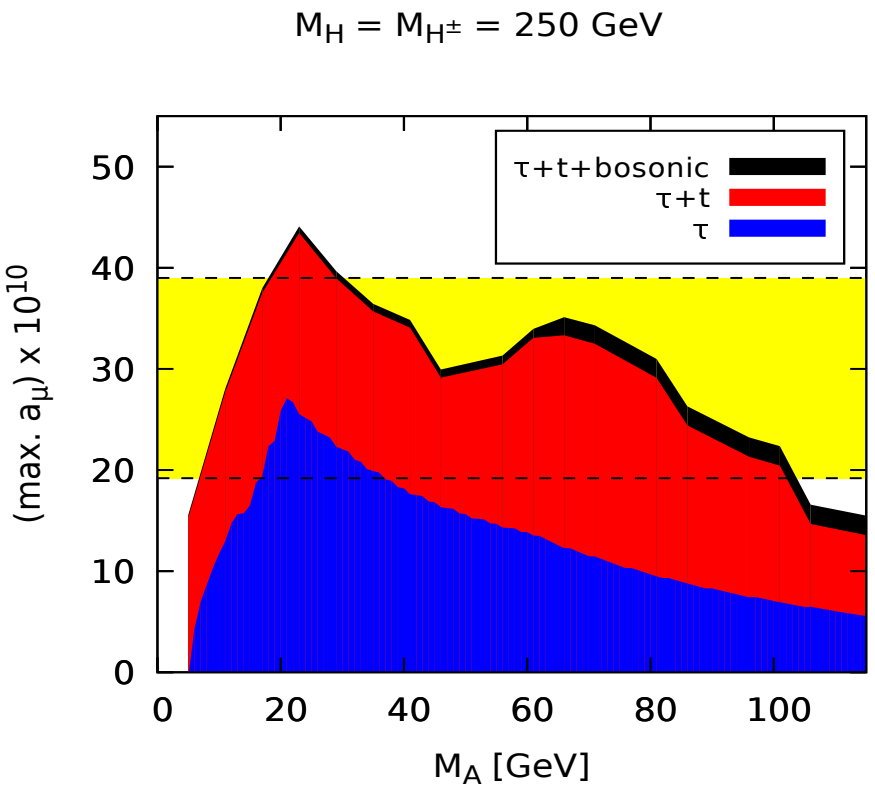


τ- or top-loop

Constraints:







$\Rightarrow$ can explain a_μ but testable by many observables: $Z \to \tau\tau$, τ- and b-decays, LHC $gg \to A, H \to \tau\tau$, future ILC?

a_μ in R-symmetric SUSY?

- MRSSM: alternative realization of SUSY with: U(1) R-symmetry, $N = 2$ SUSY gauge sectors, Dirac gauginos, protection from FCNC

  [Kribs, Poppitz, Weiner]

- successful phenomenology (Higgs, dark matter, LHC bounds, EWPO)

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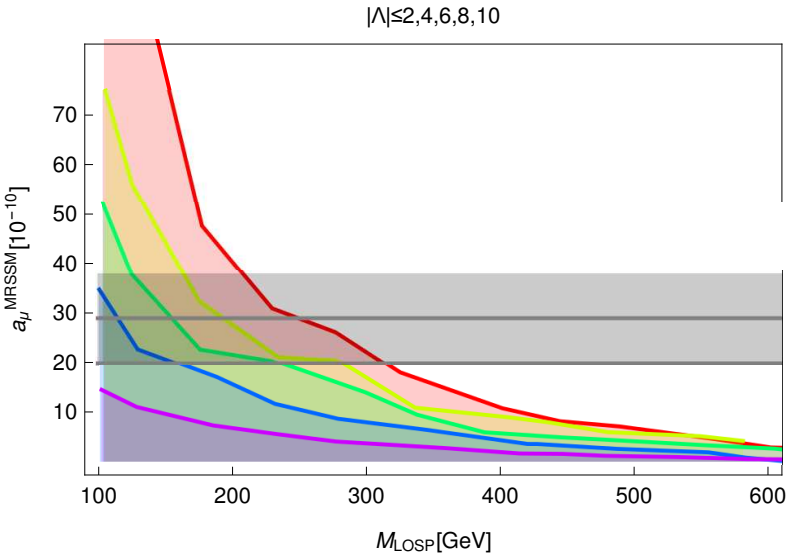
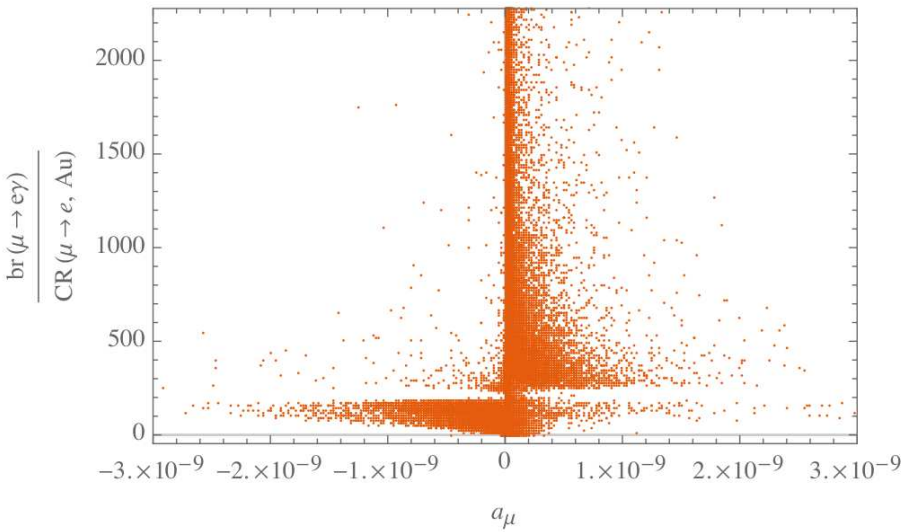
- a_μ NOT $\tan\beta$-enhanced! Small unless m_{SUSY} very small



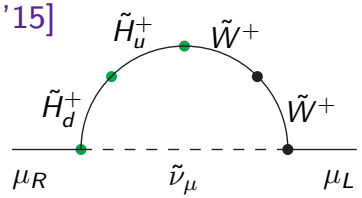


[Kotlarski,Park,DS,Stöckinger-Kim]

$\Rightarrow$ testable by LHC/ILC and possibly large effects in $\mu \to e$ conversion (weak correlation!)

a_μ and radiative muon mass: MSSM for $\tan\beta \to \infty$

[Bach,JH Park,DS,Stöckinger-Kim, '15]



Idea: $v_d = 0 \rightsquigarrow m_\mu^{\text{tree}} = y_\mu v_d = 0$

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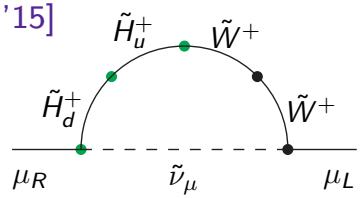

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$$a_\mu^{\text{SUSY}} = y_\mu \times \text{loop}$$

$$m_\mu^{\text{pole}} = \underbrace{y_\mu v_d}_{\text{usual approx.}} + \underbrace{y_\mu \times \text{loop}}_{\text{now important}}$$

$$a_\mu^{\text{SUSY}} \longrightarrow \frac{\text{loop}}{\text{loop}}$$

New features for $\tan\beta \to \infty$:

- a_μ = ratio of loops — no loop suppression! $a_\mu^{\text{SUSY}} \sim \frac{m_\mu^2}{M_{\text{SUSY}}^2}$
- many details cancel in ratio — important: mass ratios

a_μ and radiative muon mass: MSSM for $\tan\beta \to \infty$

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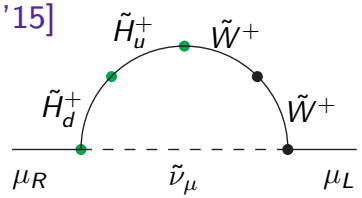

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Results:

$$a_\mu(\text{equal masses}) \approx -70 \times 10^{-10}\,(1/M_{\text{SUSY}}[\text{TeV}])^2$$

$$a_\mu(\mu \text{ or } m_L \to \infty) \approx +36 \times 10^{-10}\,(1/M_{\text{SUSY}}[\text{TeV}])^2$$

Can explain a_μ even if $M_{\text{LSP}} > 1$ TeV, large mass hierarchies needed
Experimental tests: B-physics, Higgs-physics/couplings, τ-physics

Radiative muon/electron mass fits well to a_μ and a_e!

Take seriously:

$$a_\mu^{\text{Exp-SM}} \approx 30 \times 10^{-10}$$
$$a_e^{\text{Exp-SM}} = -8.8(3.6) \times 10^{-13}$$

Radiative m_e, m_μ, $\tan\beta \to \infty$:

$$M_{\text{SUSY}} = \ldots = m_{\tilde{e}_R} = 500 \text{ GeV}$$

$$\Rightarrow \quad a_e = -7 \times 10^{-13}$$

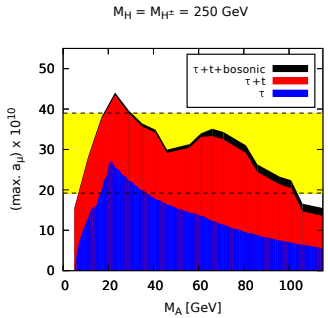
$$m_{\tilde{\mu}_R} = (7 \ldots 10) \times M_{\text{SUSY}}$$

$$\Rightarrow \quad a_\mu \sim 30 \times 10^{-10}$$

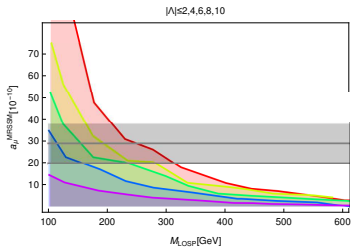
$\tan\beta \to \infty$: perfect fit to a_μ and a_e!

Conclusions

- Should we stop taking seriously naturalness, Wimp-miracle. . . ?
- a_μ, B-anom., baryon-asymmetry $\Rightarrow$ low-E experiments important
  - a_μ, LFV, B-/K-physics, τ-physics, EDM, a_e
  - a_μ: Intriguing hint
  - sensitive to light or heavy new physics



- 2HDM and a_μ: light A_0, large τ, t Yukawas
  - LHC, B-physics, τ-decays, light A_0 searches!



- R-symmetric SUSY MRSSM and a_μ
  - small a_μ, interplay $a_\mu/\mu \to e\gamma/\mu \to e$
  - light sparticles $\rightsquigarrow$ ILC

- Radiative m_μ, MSSM $\tan\beta \to \infty$
  - explain a_μ for TeV-scale sparticles (even fits a_e)
  - need very high-E collider, precise Higgs-coupling measurements