$(g-2)_\mu$ and physics beyond the SM

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Introduction

A 3σ deviation for $a_\mu^{\rm exp} - a_\mu^{\rm SM}$ has been established!

- Which types of physics beyond the SM could explain this?
- What is the impact of a_μ on physics beyond the SM?

Outline

1. Different types of new physics — the Czarnecki/Marciano bound
2. SUSY could explain the deviation
3. Examples for impact of a_μ on new physics
4. Conclusions

Outline

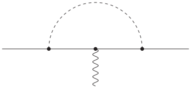
Relation a_μ–m_μ

In loops: new heavy particles, coupling to muons $\Rightarrow$

m_μ

$$\delta m_\mu \sim \frac{c^2}{16\pi^2}\, M$$

a_μ



$$\delta a_\mu \sim \frac{c^2}{16\pi^2}\frac{m_\mu}{M}$$

generally:

$$\frac{\delta m_\mu(\text{N.P.})}{m_\mu} = C \;\Leftrightarrow\; \delta a_\mu(\text{N.P.}) = \mathcal{O}(C)\left(\frac{m_\mu}{M}\right)^2$$

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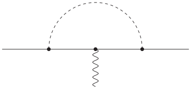

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Therefore, assuming $|\delta m_\mu / m_\mu| < 1$:

$$\delta a_\mu = C \left(\frac{m_\mu}{M}\right)^2, \qquad |C| < \mathcal{O}(1) \qquad \text{[Czarnecki, Marciano'01]}$$

Classification of new physics

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Allows classification of types of new physics:

$C = \mathcal{O}(\frac{\alpha}{4\pi})$, — Z', W', extra dim., ...

$C = \mathcal{O}(1)$, — radiative muon mass generation technicolor, ... [Czarnecki,Marciano '01]

$C = \mathcal{O}(\tan\beta\frac{\alpha}{4\pi})$, — supersymmetry

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contributions very small! $\delta a_\mu \sim 28 \times 10^{-10}$ for M<100GeV

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fits well! $\delta a_\mu \sim 28 \times 10^{-10}$ for M$\sim$300GeV, $\tan\beta \sim 10$

a_μ and new physics

- Different types of new physics can lead to very different contributions to a_μ
- a_μ is highly useful to discriminate between these different types of new physics

Outline

a_μ and SUSY

SUSY is a particularly promising scenario:
can nicely explain a_μ and is motivated in many other ways

Where does the $\tan\beta$-enhancement come from?
SUSY requires two Higgs doublets $H_{1,2}$:

$$\tan\beta = \frac{\langle H_2\rangle}{\langle H_1\rangle}, \qquad \mu = H_2 - H_1 \text{ transition}$$

- $\lambda_\mu \to \lambda_\mu^{\rm SM} \tan\beta$
- in a_μ this enhancement requires $H_2 - H_1$ transition

$\Rightarrow$ leading contributions $a_\mu^{\rm SUSY} \propto \frac{\alpha}{4\pi} \tan\beta \, \text{sign}(\mu) \, \frac{m_\mu^2}{M_{\rm SUSY}^2}$

SUSY prediction

- 1-loop and most 2-loop contributions known
- remaining theory uncertainty $\delta a_\mu^{\text{SUSY}} \approx 3 \times 10^{-10}$ [DS '06]

Approximate result:

$$a_\mu^{\text{SUSY}} \approx 12 \times 10^{-10} \tan\beta \, \text{sign}(\mu) \left(\frac{100\text{GeV}}{M_{\text{SUSY}}}\right)^2$$

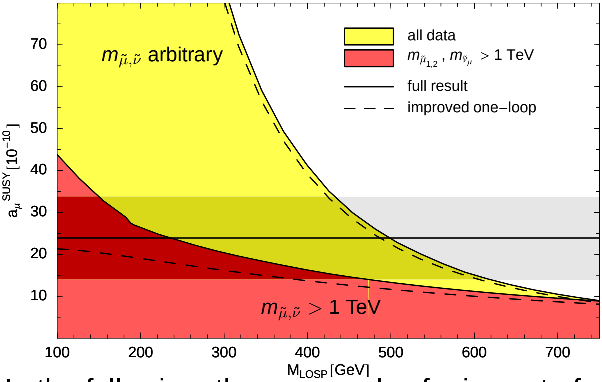
e.g. $a_\mu^{\text{SUSY}} = 24 \times 10^{-10}$ for

$$\begin{array}{ll} \tan\beta = 2, & M_{\text{SUSY}} = 100\text{ GeV} \\ \tan\beta = 50, & M_{\text{SUSY}} = 500\text{ GeV} \end{array} \quad (\mu > 0)$$

$\Rightarrow$ SUSY could easily be the origin of the observed deviation!

Numerical results

Summary: scan for $\tan\beta = 50$, all parameters < 3 TeV [DS '06]



- SUSY with $M_{\mathrm{SUSY}} = 200\ldots600$GeV fits well
- large parameter regions already excluded

In the following: three examples for impact of a_μ on new physics

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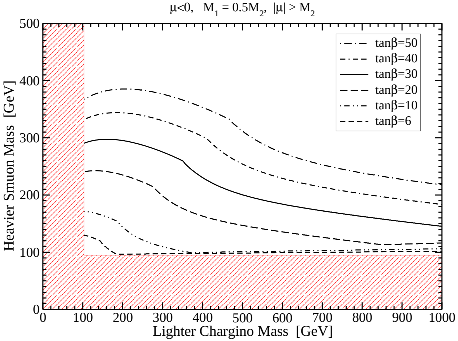
"Superconservative approach"



[Martin, Wells '02]

"superconservative": general MSSM, require $a_\mu^{\rm SUSY}$ within 5σ band

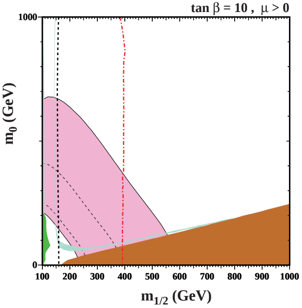
$\Rightarrow$ region under the curves is excluded by a_μ and nothing else

a_μ provides indispensable information that cannot be obtained from other observables!

Constrained MSSM scans

Constrained MSSM (only 4 parameters)
(gravity-mediated susy-breaking)

Experimentally constrained by a_μ,
$b \to s\gamma$, dark matter, EWPO, ...



[Ellis, Olive, Sandick '06]

Comprehensive CMSSM scan [Roszkowski et al] (similar scans by [Allanach et al, Ellis et al]):

$\Rightarrow$ not easy to accomodate all current observations in CMSSM
$\Rightarrow$ more precise determinations could seriously challenge CMSSM!

a_μ plus other observables have the potential to rule out CMSSM even before LHC-data!

Yukawa Unification

Yukawa Unification [G.G. Ross, M. Serna '07]

requires particular running of $m_b \leftrightarrow \delta m_\mu \leftrightarrow a_\mu$

in model considered by Ross, Serna:

$$\frac{\mu M_3}{m_{\tilde{b}}^2} \sim -0.5, \quad \text{while } a_\mu \text{ requires } \mu M_2 > 0$$

$\Rightarrow M_3 < 0, M_{1,2} > 0? \Rightarrow$ anomaly-mediated SUSY breaking?

a_μ can provide hints even on ultra-high energy physics, such as Grand Unification and the mechanism of susy-breaking/mediation

Outline

Conclusions

- a_μ provides one of the strongest indications for new physics at/below the TeV-scale
- a_μ useful to discriminate between different types of new physics
  - susy with $\tan\beta > 10$, sign(μ)=+, $M_{\rm susy} \sim 200\ldots600$GeV fits very well
  - strong constraints on susy and other types of new physics
- a_μ is independent from and complementary to collider data
- More precise determination very important and promising!