Magnetic moment $(g-2)_\mu$ and new physics — complementarity between $(g-2)_\mu$ and collider physics

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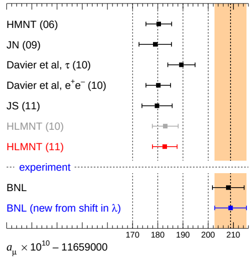
Outline

1. $a_\mu^{\mathrm{SM,Exp}}$ — how reliable is it?
2. New Physics contributions are very model-dependent
3. Constraints on new physics and complementarity
   - SUSY
   - Alternatives to SUSY

Current status: SM prediction



Full SM: $a_\mu \times 10^{10} - 11659000$

dR08:	$\ldots 178.5(5.1)$	(3.6σ)
JN09:	$\ldots 179.0(6.5)$	(3.2σ)
HLMNT09:	$\ldots 177.3(4.8)$	(4.0σ)
Detal09:	$\ldots 183.4(4.9)$	(3.2σ)
JS11:	$\ldots 179.7(6.0)$	(3.3σ)
HLMNT11:	$\ldots 182.8(4.9)$	(3.3σ)
BDDJ11:	$\ldots 175.4(5.3)$	(4.1σ)

Exp:

BNL06: $\ldots 208.9(6.3)$

errors:

exp $(5.4)_{\rm stat}(3.3)_{\rm syst}$

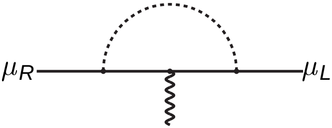
SM $(4.2)_{\rm vp,data}(2.6)_{\rm lbl,models}$

both will improve in future

Future experiments at Fermilab and JParc (N. Saito)

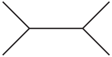
	BNL-E821	Fermilab	J-PARC
Muon momentum	3.09 GeV/c		0.3 GeV/c
gamma	29.3		3
Storage field	B=1.45 T		3.0 T
Focusing field	Electric quad		None
# of detected μ+ decays	5.0E9	1.8E11	1.5E12
# of detected μ- decays	3.6E9	-	-
Precision (stat)	0.46 ppm	0.1 ppm	0.1 ppm

New Physics: Why is a_μ special?



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

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



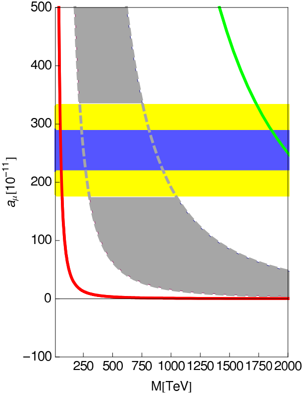
In the following:

- new physics contributions model-dependent
- constraints complementary to LHC, flavour physics, LC

Very different contributions to a_μ

$m_\mu \leftrightarrow a_\mu$relation: $\delta a_\mu(\mathrm{N.P.}) = \mathcal{O}(C)\left(\frac{m_\mu}{M}\right)^2, \quad C = \frac{\delta m_\mu(\mathrm{N.P.})}{m_\mu}$

classify new physics: C **very** model-dependent



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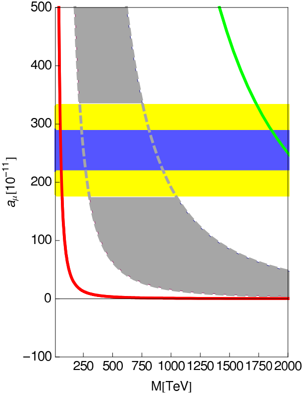

$\mathcal{O}(1)$	
$\mathcal{O}(\frac{\alpha}{4\pi}\ldots)$	
$\mathcal{O}(\frac{\alpha}{4\pi})$	Z', W', UED, Littlest Higgs (LHT)...

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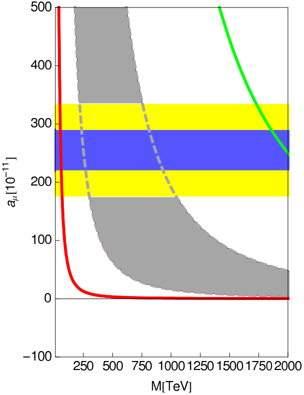

$\mathcal{O}(1)$	
$\mathcal{O}(\frac{\alpha}{4\pi}\ldots)$	supersymmetry ($\tan\beta$), unparticles [Cheung, Keung, Yuan '07] extra dim. (ADD/RS) (n_c)... [Davioudasl, Hewett, Rizzo '00] [Graesser,'00][Park et al '01][Kim et al '01]
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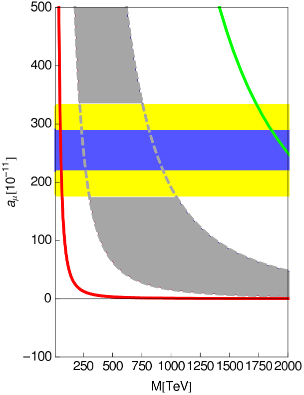

$\mathcal{O}(1)$	radiative muon mass generation ... [Czarnecki,Marciano '01] [Crivellin, Girrbach, Nierste '11][Dobrescu, Fox '10]
$\mathcal{O}(\frac{\alpha}{4\pi}\ldots)$	supersymmetry ($\tan\beta$), unparticles [Cheung, Keung, Yuan '07] extra dim. (ADD/RS) (n_c)... [Davioudasl, Hewett, Rizzo '00] [Graesser,'00][Park et al '01][Kim et al '01]
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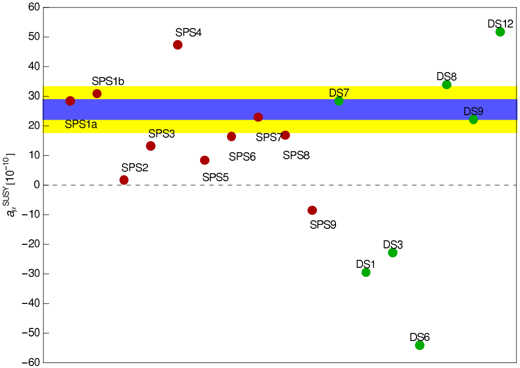
a_μ central complement for SUSY parameter analyses

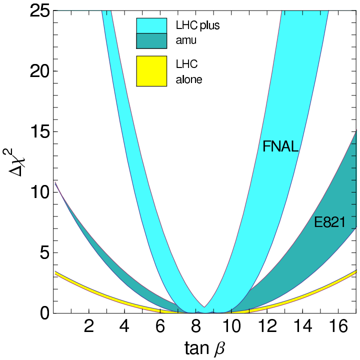


SPS benchmark points

LHC Inverse Problem (300fb^{-1})
can't be distinguished at LHC
[Sfitter: Adam, Kneur, Lafaye, Plehn, Rauch, Zerwas '10]

- a_μ sharply distinguishes SUSY models
- breaks LHC degeneracies (before Linear Collider!)

a_μ central complement for SUSY parameter analyses



[Hertzog, Miller, de Rafael, Roberts, DS '07]

$\tan\beta = \frac{v_2}{v_1}$
central for understanding EWSB

LHC: $(\tan\beta)^{\text{LHC,masses}} = 10 \pm 4.5$ bad
[Sfitter: Lafaye, Plehn, Rauch, Zerwas '08, assume SPS1a]

a_μ improves $\tan\beta$ considerably
Also complementary to LC!

vision: test universality of $\tan\beta$, like for $\cos\theta_W = \frac{M_W}{M_Z}$ in the SM:

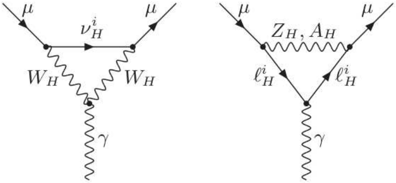
$$(t_\beta)^{a_\mu} = (t_\beta)^{\text{masses}} = (t_\beta)^H = (t_\beta)^b?$$

Littlest Higgs (with T-parity)

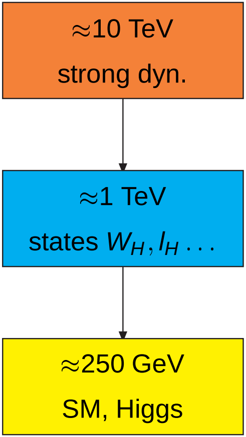
[Georgi; Arkani-Hamed,Cohen,Georgi]
Concrete LHT model: [Cheng, Low '03]
[Hubisz, Meade, Noble, Perelstein '06]

Bosonic SUSY

- partner states, same spin
- cancel quadratic div.s
- T-parity⇒lightest partner stable



no enhancement of $\frac{\alpha}{4\pi}\left(\frac{m_\mu}{M}\right)^2$



$$a_\mu^{\mathrm{LHT}} < 1.2 \times 10^{-10}$$

[Blanke, Buras, et al '07]

Clear-cut prediction, sharp distinction from SUSY possible

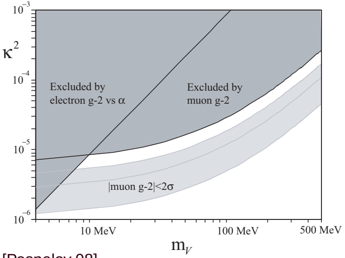
What if the LHC does not find new physics —

"Dark force"? [Pospelov, Ritz. . .]

$C \propto 10^{-8}$, $M < 1$GeV

- a_μ can be large
- could be "seen" by a_μ-exp.

- very light new vector boson
- very weak coupling
- motivated e.g. by dark matter, not by EWSB



[Pospelov 08]

Flavour-dependent Z'?

Yet another possibility to hide new physics at colliders

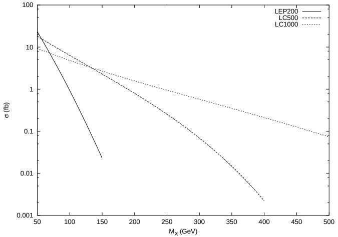
Gauged $L_\mu - L_\tau$ [Ma,Roy,Roy '02][Heeck,Rodejohann '11]

- flavour-dependent Z'
- hidden at LEP, even for $g' = 1$, $M_{Z'} = 200$ GeV
- reach for $g' = 1$:
  - LHC (10fb^{-1}): 130GeV
  - LHC (100fb^{-1}): 350GeV

    [Heeck,Rodejohann '11]
  - LC (0.5TeV): 300GeV

$C \sim C_{SM,weak}$, $M_{Z'} \sim M_Z$

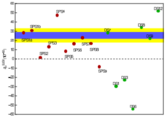
- explains a_μ for $M_{Z'}/g' \approx 200$ GeV

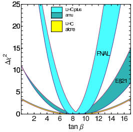


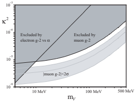
[Ma,Roy,Roy '01]

Summary

- $a_\mu^{\text{Exp}} - a_\mu^{\text{SM}} \approx (25 \pm 8) \times 10^{-10}$ — future promising!
- $a_\mu^{\text{N.P.}}$ very model-dependent, typically $\mathcal{O}(\pm 1 \ldots 50) \times 10^{-10}$
  - break degeneracies
  - parameter sensitivity complementary to LHC/LC
  - sensitive to models hard to detect at colliders







Mass reach:

SUSY($t_\beta \leq 50$)+a_μ: $m_{\tilde{\mu},\chi} \leq 600\text{GeV}$

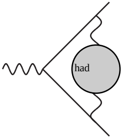
rad.mass gen.+a_μ: $M_{\text{NP}} \leq 2\text{TeV}$

Tension:

a_μ	LHC bounds
finetuning	$m_h = 125$ GeV

Current status: SM prediction

Hadronic vacuum polarization contributions: $(692.3(4.2)\times 10^{-10})$



$\leftrightarrow e^+e^- \to \gamma^* \to$hadrons

- consensus on methods — final result/error depends on exp data
- alternative: τ-data ($\tau \to \nu + W^* \to \nu+$hadrons)
- recent years: convergence of theoretical determinations

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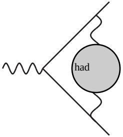


$\leftrightarrow e^+e^- \rightarrow \gamma^* \rightarrow$hadrons

Recent progress:

- new exp data (CMD2, SND, KLOE, B-factories)

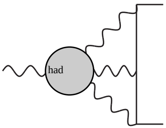
  $\Rightarrow$ significantly more precise and reliable!
- reconciled with τ-based results

  $\rightarrow$ confirmation of e^+e^--based evaluations

[Davier et al '10][Jegerlehner, Szafron '11][Benayoun + Jegerlehner '11]

Current status: SM prediction

Hadronic light-by-light contributions
Cannot be computed from first principles — Error difficult to assess!



[Bijnens, Prades '07]	10.0 ± 4.0
[Melnikov, Vainshtein '03]	13.6 ± 2.5
[Jegerlehner '08]	11.4 ± 3.8
[Jegerlehner, Nyffeler '09]	11.6 ± 4.0
[Prades, Vainshtein, de Rafael '08]	10.5 ± 2.6

- "Glasgow" consensus: combine methods, inflate errors
- Promising new approaches: **lattice**, Dyson-Schwinger

$a_\mu(\pi, \eta, \ldots)$	114	(13)
a_μ(pseudovectors)	15	(10)
a_μ(scalars)	-7	(7)
a_μ(dressed π-loop)	-19	(19)

- $1/N_C$-expansion: all terms LO, except last term NLO
- error estimates: based on comparing different evaluations and enlarging error (reason for adding errors in quadrature, although in original calculations error were added linearly), e.g. $a_\mu(\pi, \eta, \ldots) = 85(13)_{\mathrm{BPP}}, 114(10)_{\mathrm{MV}} \rightarrow 114(13)_{\mathrm{PdRV}}$ (splitting of contributions is model-dependent)

Discussion: reconcile LHC bounds with a_μ

a_μ vs LHC-bounds on squarks/gluinos

- Even within the CMSSM: heavy masses + large $\tan\beta$
- Beyond the CMSSM:
  - sleptons lighter than squarks
  - compressed SUSY, a_μ from subleading contributions, ...

a_μ vs $m_h = 125$ GeV

- still possible in CMSSM, e.g.
  $m_{1/2} = 1800, m_0 = 1080, A_0 = 860, t_\beta = 48$ [Buchmüller et al]
- beyond CMSSM, see above

The tension is increasing

a_μ	LHC bounds
finetuning	$m_h = 125$ GeV

- prefer low/high SUSY masses, difficult to reconcile (and with dark matter, b-physics)
- increasingly interesting to pin down a_μ more precisely!
- Challenge: is there a possibility to reconcile everything in SUSY (non-MSSM?)