Magnetic moment $(g-2)_\mu$ and new physics

Intensity Frontier Review, August 2010

Introduction

New $(g-2)$ experiment (and th. progress):

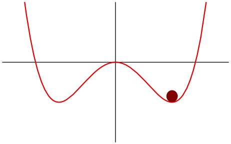
$$a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (255?? \pm 16 \pm 30) \times 10^{-11}$$

Outline

- Remarks on a_μ, new physics
- New physics contributions to a_μ in general
  - Benchmark for any new physics scenario
  - Timely, complementary constraints
- Examples within SUSY, Little Higgs, . . . :
  Parameter measurements, model discrimination

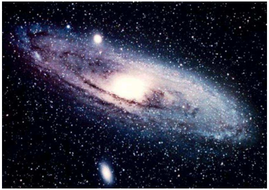
Why new physics?

Big questions…point to TeV scale new physics

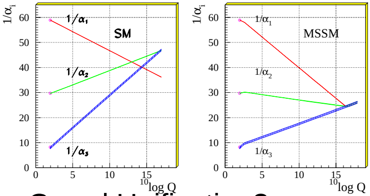


EWSB, Higgs, mass generation?

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



dark matter?

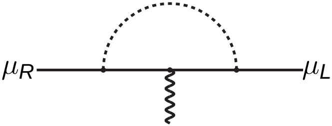


Grand Unification?

Tevatron, LHC: this decade = era of TeV-scale physics
→ discover signals for new physics
Quest: understand EWSB, understand new physics

Why is a_μ special?

$$\frac{a_\mu}{m_\mu}\,\bar{\mu}_L\,\sigma_{\mu\nu}\,\mu_R\,F^{\mu\nu}$$

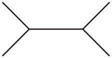


Beautifully simple "textbook" quantity

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

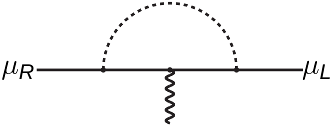
compare: $\begin{array}{l} b \longrightarrow s\gamma \\ \text{EDMs, } B \longrightarrow \tau\nu \\ \mu \longrightarrow e\gamma \end{array}$

EWPO

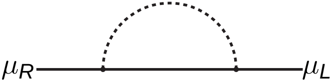


New physics contributions to a_μ

$g - 2$ = chirality-flipping interaction



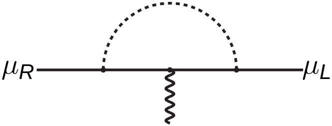
m_μ = chirality-flipping interaction as well



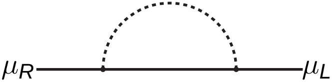
are the two related?

New physics contributions to a_μ

$g - 2$ = chirality-flipping interaction



m_μ = chirality-flipping interaction as well



are the two related?

New physics loop contributions to a_μ, m_μ related by chiral symmetry

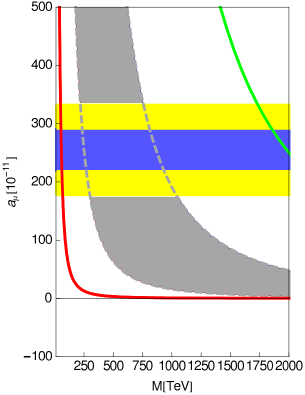
[Czarnecki, Marciano ’01]

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

Very different contributions to a_μ

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

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



$\mathcal{O}(1)$	radiative muon mass generation . . . [Czarnecki,Marciano '01]
$\mathcal{O}(\frac{\alpha}{4\pi}\ldots)$	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]
$\mathcal{O}(\frac{\alpha}{4\pi})$	Z', W', UED, Littlest Higgs (LHT). . .

a_μ and new physics

Different types of new physics lead to very different δa_μ(N.P.)

- SUSY, RS, ADD, . . . : strong parameter constraints
- Z', UED, LHT, . . . : ruled out if deviation confirmed

If new physics found at LHC:

- a_μ constitutes a benchmark for new physics models
- can sharply distinguish between different types of models
- timely, complementary constraints on models
  CP- and Flavour-conserving, chirality-flipping, loop-induced

a_μ and new physics

Different types of new physics lead to very different δa_μ(N.P.)

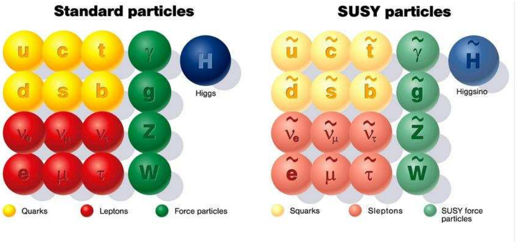
- SUSY, RS, ADD, . . . : strong parameter constraints
- Z', UED, LHT, . . . : ruled out if deviation confirmed

If new physics found at LHC:

- a_μ constitutes a benchmark for new physics models
- can sharply distinguish between different types of models
- timely, complementary constraints on models
  CP- and Flavour-conserving, chirality-flipping, loop-induced

Now illustrate general points with examples

SUSY and a_μ



$$a_\mu^{\mathrm{SUSY}} \approx 130 \times 10^{-11} \tan\beta \,\mathrm{sign}(\mu) \left(\frac{100\mathrm{GeV}}{M_{\mathrm{SUSY}}}\right)^2$$

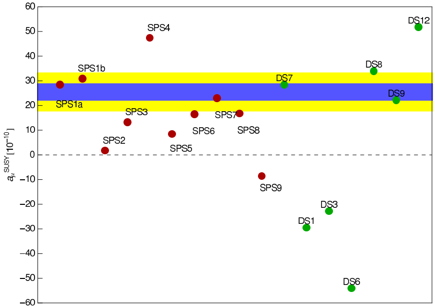
$\tan\beta = \frac{v_2}{v_1}$, $\mu = H_1$-H_2 transition — central for EWSB

If SUSY signals at LHC:

Need confirmation, precise SUSY parameter measurements

→ understand EWSB, . . .

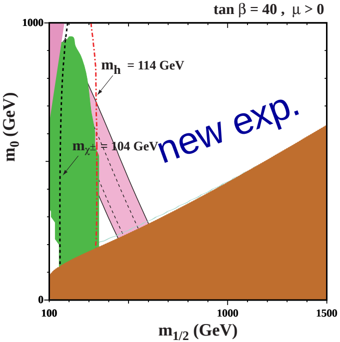
a_μ central complement for SUSY parameter analyses



SPS benchmark points

LHC Inverse Problem (300fb^{-1})

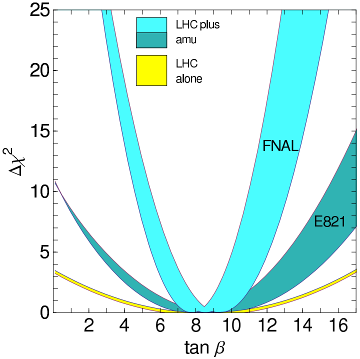
can't be distinguished at LHC [Sfitter: Adam, Kneur, Lafaye, Plehn, Rauch, Zerwas '10]



Constrained MSSM [Ellis, Olive, et al, update K. Olive]

- a_μ sharply distinguishes SUSY models
- breaks LHC degeneracies
- central, complementary in global analyses of SUSY parameters

a_μ central complement for SUSY parameter analyses



$\tan\beta = \frac{v_2}{v_1}$

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

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

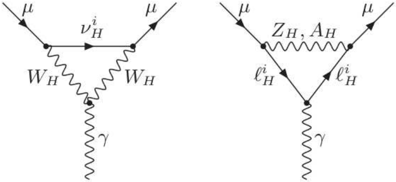
$$(t_\beta)^{a_\mu} = (t_\beta)^{\text{LHC,masses}} = (t_\beta)^{H} = (t_\beta)^{b}?$$

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 $\frac{\alpha}{4\pi}\left(\frac{m_\mu}{M}\right)^2$

≈10 TeV
strong dyn.

↓

≈1 TeV
states $W_H, l_H \ldots$

↓

≈250 GeV
SM, Higgs

$$a_\mu^{\rm LHT} < 12 \times 10^{-11}$$

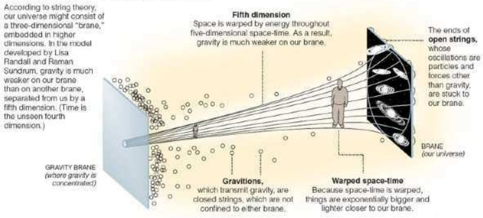
[Blanke, Buras, et al '07]

Clear-cut prediction, sharp distinction from SUSY possible

Other examples

Randall-Sundrum models

Island Universes in Warped Space-Time



According to string theory, our universe might consist of a three-dimensional "brane," embedded in higher dimensions. In the model developed by Lisa Randall and Raman Sundrum, gravity is much weaker on our brane than on another brane, separated from us by a fifth dimension. (Time is the unseen fourth dimension.)

Fifth dimension Space is warped by energy throughout five-dimensional space-time. As a result, gravity is much weaker on our brane.

The ends of **open strings,** whose oscillations are particles and forces other than gravity, are stuck to our brane.

Gravitions, which transmit gravity, are closed strings, which are not confined to either brane.

Warped space-time Because space-time is warped, things are exponentially bigger and lighter closer to our brane.

Complementarity: LHC

- lowest KK-modes
- masses

a_μ from KK-loops

- higher modes, details
- e.g. $C_{\text{Grav}} \propto M^2$, $C_{\text{H}} \sim 1$

What if the LHC does not find new physics — "Dark force"? [Pospelov, Ritz. . .]

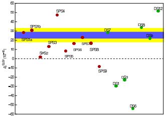
- very light new vector boson
- very weak coupling
- motivated e.g. by dark matter, not by EWSB

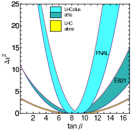
$C \propto 10^{-8}$, $M < 1\text{GeV}$

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

Conclusions

- Big questions of TeV-scale (EWSB) motivate radically new ideas
- Understanding TeV-scale phenomena discovered at the LHC/Tevatron requires input from complementary experiments
- $a_\mu^{\text{N.P.}}$ very model-dependent, typically $\mathcal{O}(\pm 10 \dots 500) \times 10^{-11}$
  - Benchmark for new physics scenario, unique
- New measurement of a_μ will
  - sharply distinguish models, even with similar LHC signatures
  - exclude some models, pin down important details of others
  - break degeneracies
    measure central parameters



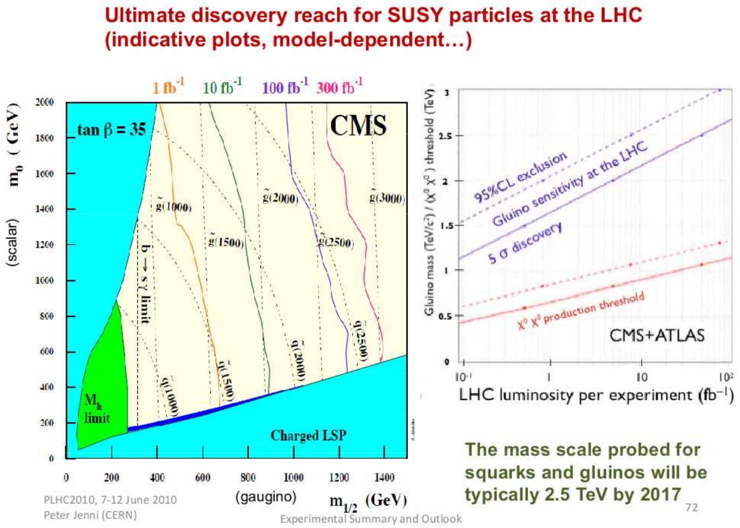


> a_μ will provide critical input and sharp constraints and will be timely complement of LHC in understanding TeV-scale physics

Outline

1. Introduction
2. New physics contributions to a_μ in general
3. a_μ, parameter measurements and model discrimination
4. Conclusions
5. Backup on LHC, fits, tan β
6. Backup on complementarity to flavour-changing processes
7. Backup other models
8. Backup on SUSY

SUSY Discovery at LHC, LHC Conference 2010



Ultimate discovery reach for SUSY particles at the LHC (indicative plots, model-dependent…)

The mass scale probed for squarks and gluinos will be typically 2.5 TeV by 2017

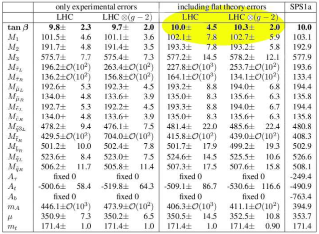
PLHC2010, 7-12 June 2010
Peter Jenni (CERN)

Experimental Summary and Outlook

72

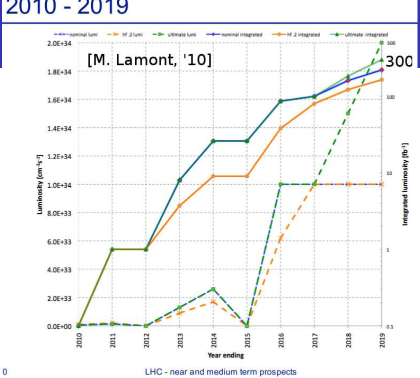
However, reach for $(\chi, \tilde{\mu})$ worse, and more model-dependent

Sfitter SUSY fits



	only experimental errors		including flat theory errors		SPS1a
	LHC	LHC $\otimes(g-2)$	LHC	LHC $\otimes(g-2)$	
$\tan\beta$	**9.8± 2.3**	**9.7± 2.0**	**10.0± 4.5**	**10.3± 2.0**	**10.0**
M_1	101.5± 4.6	101.1± 3.6	102.1± 7.8	102.7± 5.9	103.1
M_2	191.7± 4.8	191.4± 3.5	193.3± 7.8	193.2± 5.8	192.9
M_3	575.7± 7.7	575.4± 7.3	577.2± 14.5	578.2± 12.1	577.9
$M_{\tilde{\tau}_L}$	196.2$\pm\mathcal{O}(10^2)$	263.4$\pm\mathcal{O}(10^2)$	227.8$\pm\mathcal{O}(10^3)$	253.7$\pm\mathcal{O}(10^2)$	193.6
$M_{\tilde{\tau}_R}$	136.2$\pm\mathcal{O}(10^2)$	156.8$\pm\mathcal{O}(10^2)$	164.1$\pm\mathcal{O}(10^3)$	134.1$\pm\mathcal{O}(10^2)$	133.4
$M_{\tilde{\mu}_L}$	192.6± 5.3	192.3± 4.5	193.2± 8.8	194.0± 6.8	194.4
$M_{\tilde{\mu}_R}$	134.0± 4.8	133.6± 3.9	135.0± 8.3	135.6± 6.3	135.8
$M_{\tilde{e}_L}$	192.7± 5.3	192.2± 4.5	193.3± 8.8	194.0± 6.7	194.4
$M_{\tilde{e}_R}$	134.0± 4.8	133.6± 3.9	135.0± 8.3	135.6± 6.3	135.8
$M_{\tilde{q}3_L}$	478.2± 9.4	476.1± 7.5	481.4± 22.0	485.6± 22.4	480.8
$M_{\tilde{t}_R}$	429.5$\pm\mathcal{O}(10^2)$	704.0$\pm\mathcal{O}(10^2)$	415.8$\pm\mathcal{O}(10^2)$	439.0$\pm\mathcal{O}(10^2)$	408.3
$M_{\tilde{b}_R}$	501.2± 10.0	502.4± 7.8	501.7± 17.9	499.2± 19.3	502.9
$M_{\tilde{q}_L}$	523.6± 8.4	523.0± 7.5	524.6± 14.5	525.5± 10.6	526.6
$M_{\tilde{q}_R}$	506.2± 11.7	505.8± 11.4	507.3± 17.5	507.6± 15.8	508.1
A_τ	fixed 0	fixed 0	fixed 0	fixed 0	-249.4
A_t	-500.6± 58.4	-519.8± 64.3	-509.1± 86.7	-530.6± 116.6	-490.9
A_b	fixed 0	fixed 0	fixed 0	fixed 0	-763.4
m_A	446.1$\pm\mathcal{O}(10^3)$	473.9$\pm\mathcal{O}(10^2)$	406.3$\pm\mathcal{O}(10^3)$	411.1$\pm\mathcal{O}(10^2)$	394.9
μ	350.9± 7.3	350.2± 6.5	350.5± 14.5	352.5± 10.8	353.7
m_t	171.4± 1.0	171.4± 1.0	171.4± 1.0	171.4± 0.90	171.4

Table 1: Result for the general MSSM parameter determination at the LHC in SPS1a. The left part neglects all theory errors, the right one assumes flat theory errors. In all cases a set of 20 kinematic endpoints and the top-quark and lightest Higgs–mass measurements have been used. In the third and fifth column we include the current measurement of $(g-2)$. All masses are given in GeV.

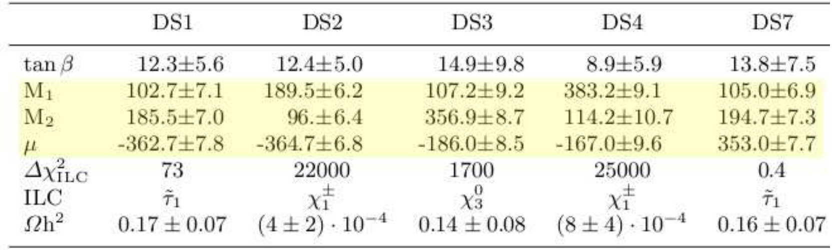


2010 - 2019

0

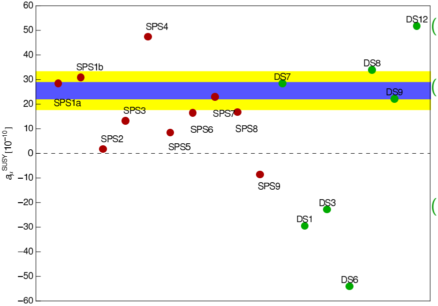
LHC - near and medium term prospects

Fits need 300fb^{-1} ($\sim$10 years running)



	DS1	DS2	DS3	DS4	DS7
$\tan\beta$	12.3±5.6	12.4±5.0	14.9±9.8	8.9±5.9	13.8±7.5
M_1	102.7±7.1	189.5±6.2	107.2±9.2	383.2±9.1	105.0±6.9
M_2	185.5±7.0	96.±6.4	356.9±8.7	114.2±10.7	194.7±7.3
μ	-362.7±7.8	-364.7±6.8	-186.0±8.5	-167.0±9.6	353.0±7.7
$\Delta\chi^2_{\mathrm{ILC}}$	73	22000	1700	25000	0.4
ILC	$\tilde{\tau}_1$	$\chi_1^\pm$	χ_3^0	$\chi_1^\pm$	$\tilde{\tau}_1$
Ωh^2	0.17 ± 0.07	$(4 \pm 2) \cdot 10^{-4}$	0.14 ± 0.08	$(8 \pm 4) \cdot 10^{-4}$	0.16 ± 0.07

Sfitter SUSY fits



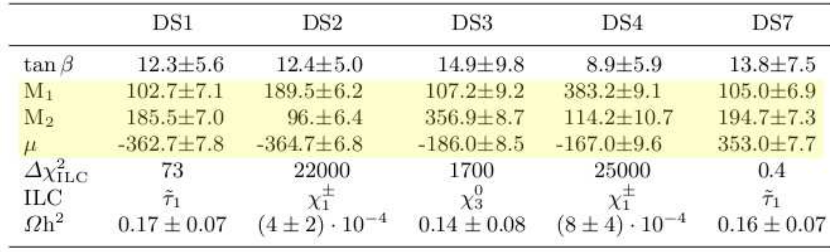
$(\mu|M_1|M_2)$

(83|368|136)

(352|99|192)

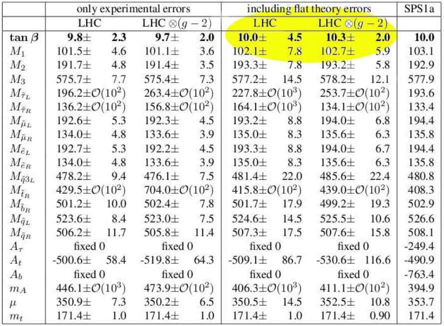
(−184|101|354)

DS1–12 can't be distinguished at LHC (300fb^{-1}) if SPS1a realized [Sfitter: Adam, Kneur, Lafaye, Plehn, Rauch, Zerwas '10]



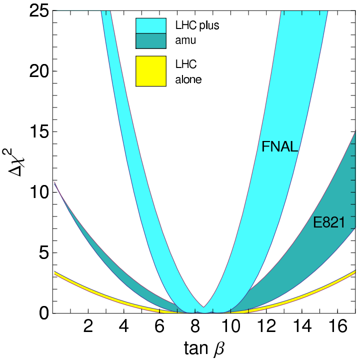
	DS1	DS2	DS3	DS4	DS7
$\tan\beta$	12.3±5.6	12.4±5.0	14.9±9.8	8.9±5.9	13.8±7.5
M_1	102.7±7.1	189.5±6.2	107.2±9.2	383.2±9.1	105.0±6.9
M_2	185.5±7.0	96.±6.4	356.9±8.7	114.2±10.7	194.7±7.3
μ	-362.7±7.8	-364.7±6.8	-186.0±8.5	-167.0±9.6	353.0±7.7
$\Delta\chi^2_{\rm ILC}$	73	22000	1700	25000	0.4
ILC	$\tilde\tau_1$	$\chi_1^\pm$	χ_3^0	$\chi_1^\pm$	$\tilde\tau_1$
Ωh^2	0.17 ± 0.07	$(4 \pm 2) \cdot 10^{-4}$	0.14 ± 0.08	$(8 \pm 4) \cdot 10^{-4}$	0.16 ± 0.07

Sfitter SUSY fits



	only experimental errors		including flat theory errors		SPS1a
	LHC	LHC $\otimes(g-2)$	LHC	LHC $\otimes(g-2)$	
$\tan\beta$	**9.8± 2.3**	**9.7± 2.0**	**10.0± 4.5**	**10.3± 2.0**	**10.0**
M_1	101.5± 4.6	101.1± 3.6	102.1± 7.8	102.7± 5.9	103.1
M_2	191.7± 4.8	191.4± 3.5	193.3± 7.8	193.2± 5.8	192.9
M_3	575.7± 7.7	575.4± 7.3	577.2± 14.5	578.2± 12.1	577.9
$M_{\tilde{\tau}_L}$	196.2±$\mathcal{O}(10^2)$	263.4±$\mathcal{O}(10^2)$	227.8±$\mathcal{O}(10^3)$	253.7±$\mathcal{O}(10^2)$	193.6
$M_{\tilde{\tau}_R}$	136.2±$\mathcal{O}(10^2)$	156.8±$\mathcal{O}(10^2)$	164.1±$\mathcal{O}(10^3)$	134.1±$\mathcal{O}(10^2)$	133.4
$M_{\tilde{\mu}_L}$	192.6± 5.3	192.3± 4.5	193.2± 8.8	194.0± 6.8	194.4
$M_{\tilde{\mu}_R}$	134.0± 4.8	133.6± 3.9	135.0± 8.3	135.6± 6.3	135.8
$M_{\tilde{e}_L}$	192.7± 5.3	192.2± 4.5	193.3± 8.8	194.0± 6.7	194.4
$M_{\tilde{e}_R}$	134.0± 4.8	133.6± 3.9	135.0± 8.3	135.6± 6.3	135.8
$M_{\tilde{q}3_L}$	478.2± 9.4	476.1± 7.5	481.4± 22.0	485.6± 22.4	480.8
$M_{\tilde{t}_R}$	429.5±$\mathcal{O}(10^2)$	704.0±$\mathcal{O}(10^2)$	415.8±$\mathcal{O}(10^2)$	439.0±$\mathcal{O}(10^2)$	408.3
$M_{\tilde{b}_R}$	501.2± 10.0	502.4± 7.8	501.7± 17.9	499.2± 19.3	502.9
$M_{\tilde{q}_L}$	523.6± 8.4	523.0± 7.5	524.6± 14.5	525.5± 10.6	526.6
$M_{\tilde{q}_R}$	506.2± 11.7	505.8± 11.4	507.3± 17.5	507.6± 15.8	508.1
A_τ	fixed 0	fixed 0	fixed 0	fixed 0	-249.4
A_t	-500.6± 58.4	-519.8± 64.3	-509.1± 86.7	-530.6± 116.6	-490.9
A_b	fixed 0	fixed 0	fixed 0	fixed 0	-763.4
m_A	446.1±$\mathcal{O}(10^3)$	473.9±$\mathcal{O}(10^2)$	406.3±$\mathcal{O}(10^3)$	411.1±$\mathcal{O}(10^2)$	394.9
μ	350.9± 7.3	350.2± 6.5	350.5± 14.5	352.5± 10.8	353.7
m_t	171.4± 1.0	171.4± 1.0	171.4± 1.0	171.4± 0.90	171.4

Table 1: Result for the general MSSM parameter determination at the LHC in SPS1a. The left part neglects all theory errors, the right one assumes flat theory errors. In all cases a set of 20 kinematic endpoints and the top-quark and lightest Higgs–mass measurements have been used. In the third and fifth column we include the current measurement of $(g-2)$. All masses are given in GeV.

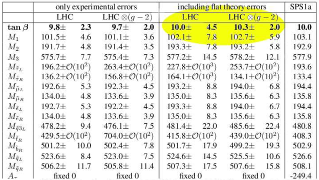


Importance: tan β, μ are central parameters in EWSB

$$\mu^2 + M_{H_u}^2 = B\mu \cot\beta + \frac{1}{2} M_Z^2 \cos 2\beta$$

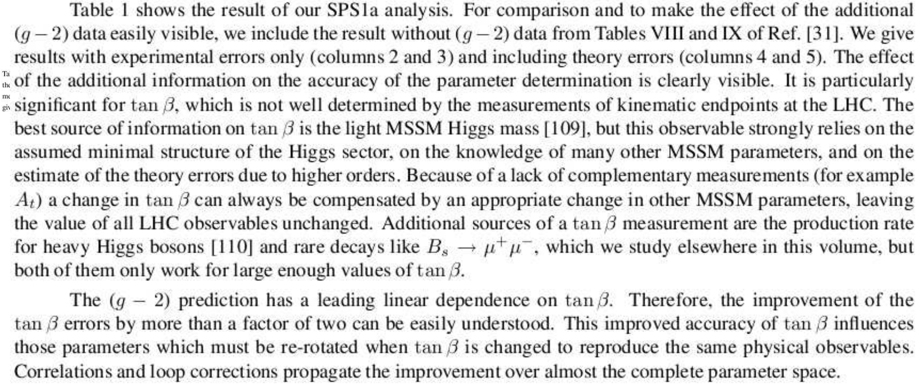
$$\mu^2 + M_{H_d}^2 = B\mu \tan\beta - \frac{1}{2} M_Z^2 \cos 2\beta$$

tan β determinations from Les Houches 2007 Report, M.M. Nojiri, T. Plehn, G. Polesello



	only experimental errors		including flat theory errors		SPS1a
	LHC	LHC $\otimes(g-2)$	LHC	LHC $\otimes(g-2)$	
tan β	**9.8± 2.3**	**9.7± 2.0**	**10.0± 4.5**	**10.3± 2.0**	**10.0**
M_1	101.5± 4.6	101.1± 3.6	102.1± 7.8	102.7± 5.9	103.1
M_2	191.7± 4.8	191.4± 3.5	193.3± 7.8	193.2± 5.8	192.9
M_3	575.7± 7.7	575.4± 7.3	577.2± 14.5	578.2± 12.1	577.9
$M_{\tilde{\tau}_L}$	$196.2\pm\mathcal{O}(10^2)$	$263.4\pm\mathcal{O}(10^2)$	$227.8\pm\mathcal{O}(10^3)$	$253.7\pm\mathcal{O}(10^2)$	193.6
$M_{\tilde{\tau}_R}$	$136.2\pm\mathcal{O}(10^2)$	$156.8\pm\mathcal{O}(10^2)$	$164.1\pm\mathcal{O}(10^3)$	$134.1\pm\mathcal{O}(10^2)$	133.4
$M_{\tilde{\mu}_L}$	192.6± 5.3	192.3± 4.5	193.2± 8.8	194.0± 6.8	194.4
$M_{\tilde{\mu}_R}$	134.0± 4.8	133.6± 3.9	135.0± 8.3	135.6± 6.3	135.8
$M_{\tilde{e}_L}$	192.7± 5.3	192.2± 4.5	193.3± 8.8	194.0± 6.7	194.4
$M_{\tilde{e}_R}$	134.0± 4.8	133.6± 3.9	135.0± 8.3	135.6± 6.3	135.8
$M_{\tilde{q}3_L}$	478.2± 9.4	476.1± 7.5	481.4± 22.0	485.6± 22.4	480.8
$M_{\tilde{t}_R}$	$429.5\pm\mathcal{O}(10^2)$	$704.0\pm\mathcal{O}(10^2)$	$415.8\pm\mathcal{O}(10^2)$	$439.0\pm\mathcal{O}(10^2)$	408.3
$M_{\tilde{b}_R}$	501.2± 10.0	502.4± 7.8	501.7± 17.9	499.2± 19.3	502.9
$M_{\tilde{q}_L}$	523.6± 8.4	523.0± 7.5	524.6± 14.5	525.5± 10.6	526.6
$M_{\tilde{q}_R}$	506.2± 11.7	505.8± 11.4	507.3± 17.5	507.6± 15.8	508.1
A	fixed 0	fixed 0	fixed 0	fixed 0	-249.4

From Les Houches 2007 Report,
M.M. Nojiri, T. Plehn, G. Polesello



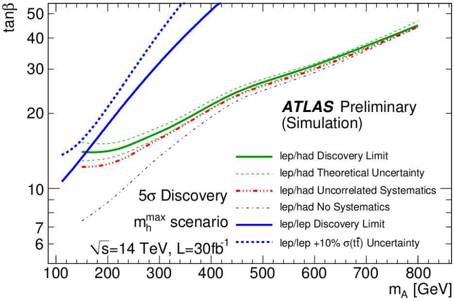
Ta
the
me
giv

Table 1 shows the result of our SPS1a analysis. For comparison and to make the effect of the additional $(g-2)$ data easily visible, we include the result without $(g-2)$ data from Tables VIII and IX of Ref. [31]. We give results with experimental errors only (columns 2 and 3) and including theory errors (columns 4 and 5). The effect of the additional information on the accuracy of the parameter determination is clearly visible. It is particularly significant for $\tan\beta$, which is not well determined by the measurements of kinematic endpoints at the LHC. The best source of information on $\tan\beta$ is the light MSSM Higgs mass [109], but this observable strongly relies on the assumed minimal structure of the Higgs sector, on the knowledge of many other MSSM parameters, and on the estimate of the theory errors due to higher orders. Because of a lack of complementary measurements (for example A_t) a change in $\tan\beta$ can always be compensated by an appropriate change in other MSSM parameters, leaving the value of all LHC observables unchanged. Additional sources of a $\tan\beta$ measurement are the production rate for heavy Higgs bosons [110] and rare decays like $B_s \to \mu^+\mu^-$, which we study elsewhere in this volume, but both of them only work for large enough values of $\tan\beta$.

The $(g-2)$ prediction has a leading linear dependence on $\tan\beta$. Therefore, the improvement of the $\tan\beta$ errors by more than a factor of two can be easily understood. This improved accuracy of $\tan\beta$ influences those parameters which must be re-rotated when $\tan\beta$ is changed to reproduce the same physical observables. Correlations and loop corrections propagate the improvement over almost the complete parameter space.

tan β determinations from Les Houches 2007 Report, M.M. Nojiri, T. Plehn, G. Polesello

- a_μ linear, requires χ, $\tilde{\mu}$ masses
- lightest Higgs mass M_h: depends on minimality of Higgs sector, many other SUSY parameters (A_t!)



[ATL-Phys-pub-2010-011]

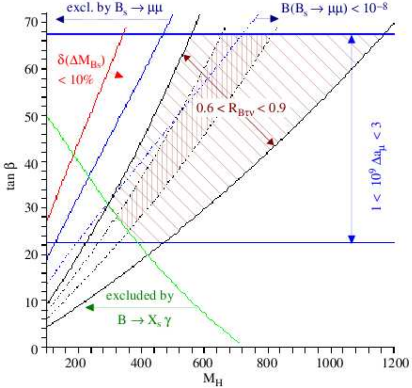
- production rate of heavy Higgs bosons: only if heavy Higgs can be discovered, cross section measured! Then $\mathcal{O}(10\%)$ possible.
- $B_s \to \mu\mu \propto \tan^6\beta/M_A^4$: problems
  (1) non-perturbative theory uncertainty $\mathcal{O}(30\%)$,
  (2) requires precise M_A! Can hope to obtain $\mathcal{O}(10\ldots20\%)$ for $\tan\beta > 30$.
- Note, heavy Higgses difficult unless tan β large

Complementarity to $B \to \tau\nu$, $B_S \to \mu\mu$

How sensitive to NP are observables?

[Isidori, Paradisi '06]:

"The observables $B \to \tau\nu$, $B_S \to \mu\mu$ and a_μ can be considered as the most promising low-energy probes of the MSSM scenario with heavy squarks and large $\tan\beta$."

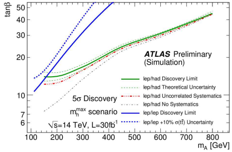


Minimal Flavour Violation

$\mu = 1$TeV, $A_t = -1$TeV, $M_{\tilde{q}} = 1$TeV, $M_{\tilde{l}} = .5$TeV, $M_2 = 300$GeV

Which aspects of NP are determined by observables?

- a_μ: $\propto \tan\beta$, no flavour-parameters
- $B_u \to \tau\nu$: **tree**-level ($H^\pm$) $\sim \tan^2\beta/M^2_{H^\pm}$
- $B_s \to \mu\mu$: loop-induced, $\propto \tan^6\beta/M^4_A$
- b-decays sensitive to non-MFV-parameters!

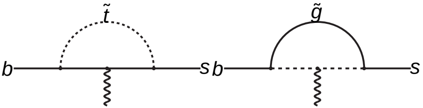


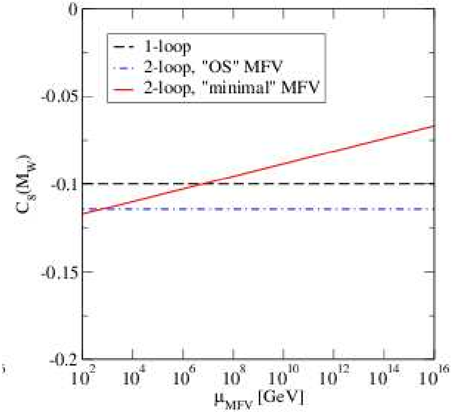
- Recall, heavy Higgses difficult at LHC

Use complementarity (assume masses known (LHC)):

- $a_\mu \to t_\beta$, b-decays $\to t_\beta/M_{H,A}$/SUSY-flavour structure
- If MFV is assumed/established: use of b-decays:
  if $M_{A,H}$ known$\to$alternative $\tan\beta$-measurement
  if not, use t_β from $a_\mu \to$ infer $M_{H,A}$
- Note: $(t_\beta)^{a_\mu}$: Higgsino-coupling, $(t_\beta)^b$: Higgs-coupling
  Crucial test of SUSY!

Impact of small non-MFV on $b \to s\gamma$



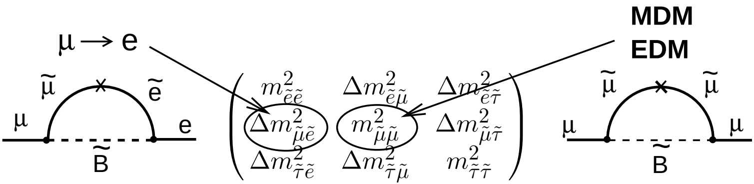


[Degrassi,Gambino,Slavich '06]

Illustration: dependence on small non-MFV parameters

- Minimal Flavour Violation at which scale?
- loops induce FCNC (=non-MFV) Gluino-couplings
- $b \to s\gamma$-prediction depends on μ_{MFV}!
- similar if there are generic non-MFV contributions

Complementarity to CLFV



- different sensitivities
- a_μ from $\tilde{B}$-diagram could be sensitive to multiple FC-insertions:

$$\Delta m^2_{\tilde{\mu}\tilde{\tau}L} \times \Delta m^2_{\tilde{\tau}\tilde{\mu}R}$$

- only possibility for large FC-effects in a_μ: $\Delta m^2_{\tilde{\mu}\tilde{\tau}L}$ **and** $\Delta m^2_{\tilde{\mu}\tilde{\tau}R}$ both large.

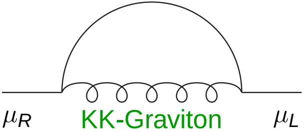
- However $\tilde{B}$-diagram anyway suppressed, a_μ dominated by chargino exchange
- Hence: even if $\Delta m^2 \approx 0.2 m^2$, only 10% correction to a_μ

[Moroi '95]

- a_μ clean probe of flavour-diagonal parameters

$g-2$ and Randall-Sundrum models

Gravity propagates in extra dimension



each KK-Graviton contributes equally, weakly, **no decoupling**

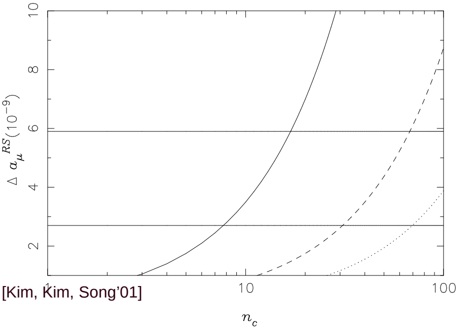
theory breaks down at scale $\sim \Lambda_\pi$, n_c KK-gravitons up to that scale

$$\rightarrow a_\mu^{\mathrm{RS}} \sim \frac{5n_c}{16\pi^2}\frac{m_\mu^2}{\Lambda_\pi^2}$$

potential enhancement $\propto n_c = \mathcal{O}(1 \ldots 100 \sim 1/\text{coupling})$

- feels all KK-gravitons
- very sensitive to UV-completion of theory

$g-2$ and Randall-Sundrum models



[Kim, Kim, Song'01]

Complementarity: LHC

- lowest KK-gravitons
- determines model parameters

a_μ tells us what the cutoff is

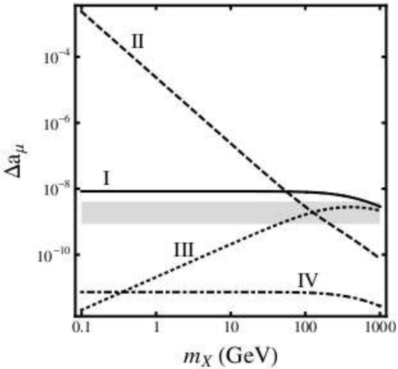
- hint to full 5-dim dynamics
- guides model building of full theory

potential enhancement $\propto n_c = \mathcal{O}(1\ldots 100 \sim 1/\text{coupling})$

- feels all KK-gravitons
- very sensitive to UV-completion of theory

Alternative models

- Hidden sector coupling to muon [McKeen '09]



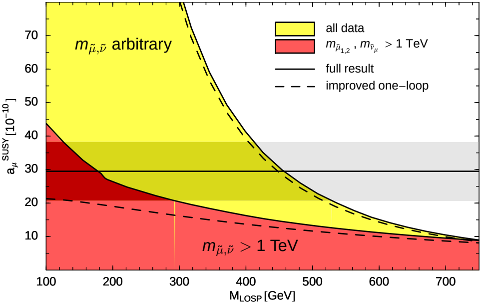
$$\mathcal{L}_{\rm int} = \lambda_L X \bar{Y}_R \mu_L + \dots$$
$$\lambda_L = 0.1$$

- Dark matter⇒a_μ, leptogenesis, neutrino masses simultaneously

  [Hambye,Kannike,Ma,Raidal '06]

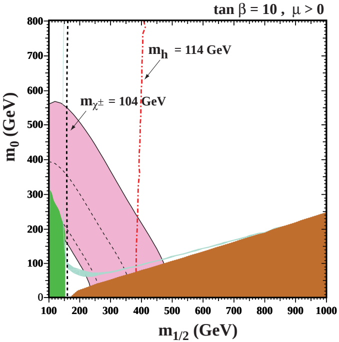
  (C very large, $M \sim$ 1TeV possible)

Numerical results



General MSSM 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



Constrained MSSM [Ellis, Olive, et al, update K. Olive]

Complementary constraints:

a_μ, dark matter, $b \to s\gamma$

$g-2$ and SUSY

$$a_\mu^{\mathrm{SUSY}} \approx 130 \times 10^{-11} \tan\beta \, \mathrm{sign}(\mu) \left(\frac{100\mathrm{GeV}}{M_{\mathrm{SUSY}}}\right)^2$$

Why enhanced? $g-2$ = chirality-flipping interaction

- In SUSY, chirality-flips governed by λ_μ and $m_\mu = \lambda_\mu \langle H_1 \rangle$
- two Higgs doublets: $\tan\beta = \frac{\langle H_2 \rangle}{\langle H_1 \rangle}$, $\mu = H_2 - H_1$ transition

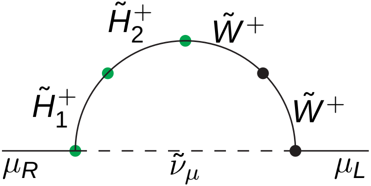
$\Rightarrow$ all terms $\propto \lambda_\mu$ but two options:

$$\propto \lambda_\mu \langle H_1 \rangle \quad = m_\mu$$

$$\propto \lambda_\mu \, \mu \langle H_2 \rangle = m_\mu \; \mu \; \tan\beta$$

$g-2$ and SUSY

$$a_\mu^{\rm SUSY} \approx 130 \times 10^{-11} \tan\beta \, \mathrm{sign}(\mu) \left(\frac{100\mathrm{GeV}}{M_{\rm SUSY}}\right)^2$$



$\propto \lambda_\mu \, \mu \langle H_2 \rangle = m_\mu \, \mu \, \tan\beta$

where $\lambda_\mu \langle H_1 \rangle = m_\mu$

potential enhancement $\propto \lambda_\mu \propto \tan\beta = 1 \ldots 50$ (and $\propto$sign(μ))

- sensitive to muon mass generation mechanism
- structure of Higgs sector

SUSY without prejudice - compare observables

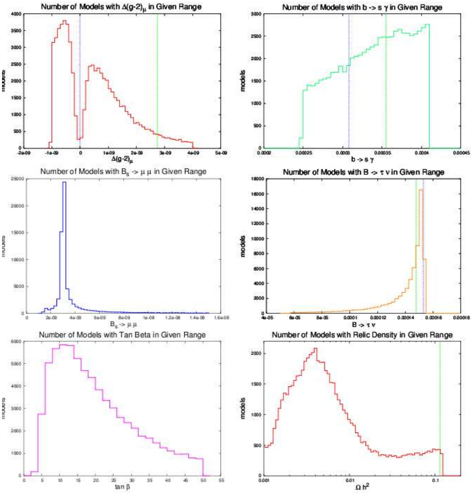


Figure 10: Distributions of predictions for several observables as well as tan β for our model sample subject to the constraints discussed in the text. The blue and green dashed lines show the SM predictions as well as the current central values obtained by experiment, respectively.

- a_μ
- $b \rightarrow s\gamma$
- dark matter

have highest selective power and are complementary: