CERN, 3 Dec 2007

On the SUSY parameter space in light of B physics and EWPO

Gino Isidori

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- General considerations on the (quark) flavour observables
- The MFV-large tanβ scenario
- Some considerations on EWPO & the global CMSSM fit
- Conclusions / open questions

General considerations on the (quark) flavour observables

Two main roads

MFV ← → non -MFV

General considerations on the (quark) flavour observables

Two main roads

MFV

non -MFV

- Long list of useful observables (B and K physics: leptonic, radiative & non-leptonic channels)
- The absence of significant deviations from the SM in any of these, makes generic non-MFV scenarios highly contrived / fine-tuned
- In several realistic cases (MFV-GUT scenarios, new couplings only for the 3rd family, etc...) the most significant constraints are derived from Kaon physics (λ^5 suppression in the SM, because of $1 \leftrightarrow 3 \leftrightarrow 2$).

General considerations on the (quark) flavour observables

Two main roads

MFV → Small $\tan\beta$ [and small μ]; Large $\tan\beta$ [or moderate $\tan\beta$ + large μ]

non -MFV

- Most of the (present) flavour constraints naturally satisfied after imposing EWPO
- Only notable exception provided by $B \to X_s \gamma$

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Small $\tan\beta$

[and small μ]

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Large $\tan\beta$

[or moderate $\tan\beta$ + large μ]

- A few more <u>helicity suppressed observ.</u> play a key role: $B \to ll$, $B(K) \to l\nu$
- LR $\Delta F=2$ ops. in B(K) mixing might also be relevant in specific corners of the param. space)

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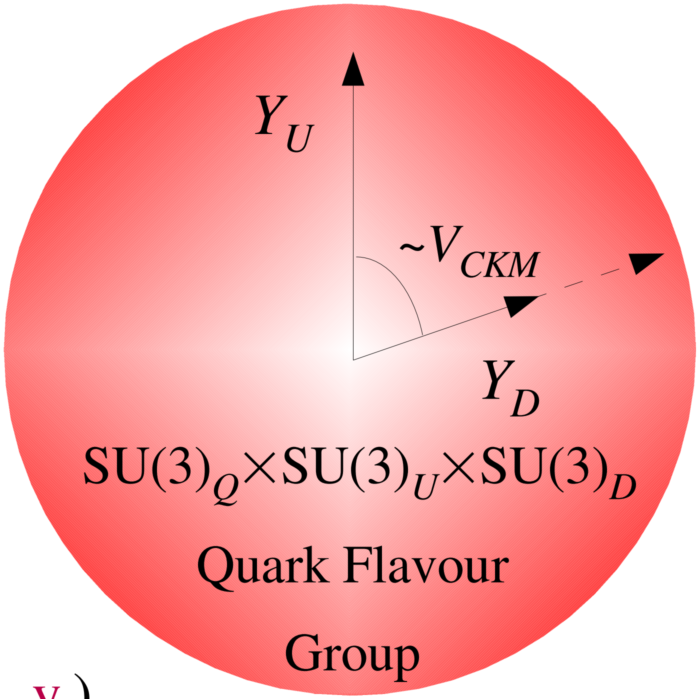
The MFV-large tanβ scenario

$$\mathscr{L}_{\text{q-Yukawa}} = \bar{Q}_L Y_D D_R H_D + \bar{Q}_L Y_U U_R H_U + \text{h.c.}$$



Y_D & Y_U are the only two irreducible breaking sources of $SU(3)_{Q_L} \times SU(3)_{U_R} \times SU(3)_{D_R}$

→ negligible non-standard effects in the standard CKM fits

$$Y_D = \text{diag}(y_d, y_s, y_b) \qquad Y_U = (V_{ckm})^{+} \times \text{diag}(y_u, y_c, y_t)$$

but we are free to change their overall normalization

$$y_u = m_u / \langle H_U \rangle \qquad y_d = m_d / \langle H_D \rangle = \tan\beta \, m_d / \langle H_U \rangle$$

→ sizable phenomenological consequences in helicity-supressed processes if $\tan\beta \gg 1$

N.B.: the *effective* Yukawa interaction of the MSSM can be very different with respect to the non-superymmetric Two-Higgs Doublet Model of type-II, even in the limit of light Higgses & heavy squarks

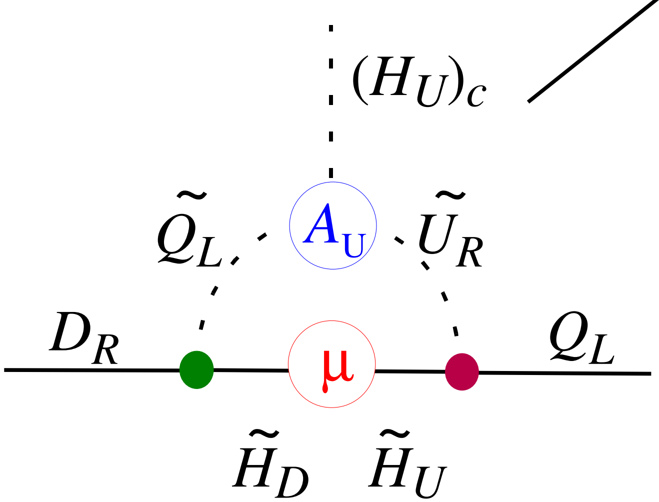
$$\mathscr{L}_{\rm tree} = \bar{Q}_L Y_D D_R H_D + \bar{Q}_L Y_U U_R H_U$$

invariant under $U(1)_{PQ}$ (each Higgs couples only to a specific right-handed field)

N.B.: the *effective* Yukawa interaction of the MSSM can be very different with respect to the non-superymmetric Two-Higgs Doublet Model of type-II, even in the limit of light Higgses & heavy squarks

$$\mathcal{L}_{\rm eff} = \bar{Q}_L Y_D D_R H_D + \bar{Q}_L Y_U U_R H_U + \epsilon_1 \bar{Q}_L Y_U Y_U^{+} Y_D D_R (H_U)_c + \ldots$$

...possible large $U(1)_{PQ}$ breaking induced by the μ term



Even if $\epsilon_i \sim (16\pi^2)^{-1}$ these loop corrections are a potential large destabilization of the tree-level Yukawa strucutre:

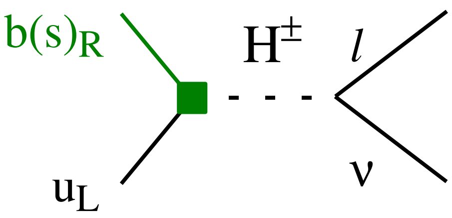
- $\epsilon_i \times \tan\beta \sim 1$
- dim-4 ops. non-decoupling effects

tanβ >>1 + large $U(1)_{PQ}$ breaking

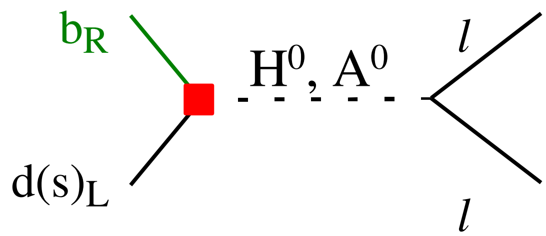
- sizable Higgs-mediated FCNC ampl. in the helicity suppressed B μμ
- sizable SUSY contributions to $(g-2)_\mu$

The flavour constraints at large $\tan\beta$

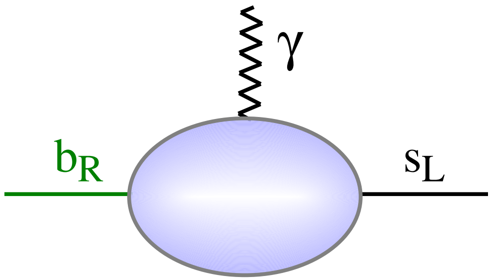
Three most interesting sets of observables:



$P^{\pm} \to l^{\pm}\nu$



$B_{s,d} \to l^{+} l^{-}$



$B \to X_s \gamma$

The flavour constraints at large tanβ

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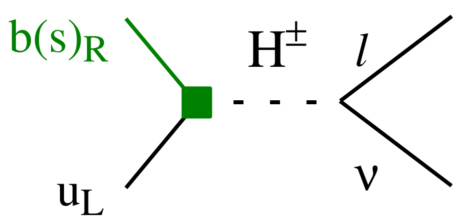

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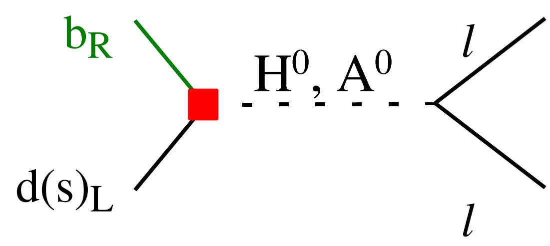
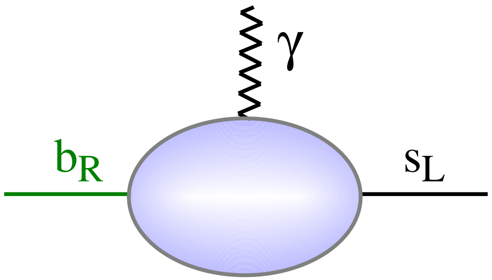


$B_{s,d} \to l^+ l^-$



$B \to X_s \gamma$

Simplest M_H & tanβ dependence [mild dependence on other parameters]

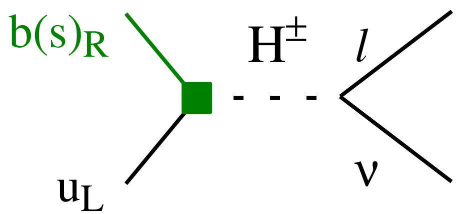
$$BR = BR_{SM} \times \left(1 - \frac{m_P^2 \tan\beta^2}{M_H^2 (1 + \epsilon_0 \tan\beta)} \right)^2$$

- $O(100\%)$–$O(10\%)$ in $B^{\pm} \to l^{\pm}\nu$
  [most likely $BR_{SUSY} < BR_{SM}$]
- $O(1\%)$–$O(0.1\%)$ in $K^{\pm} \to l^{\pm}\nu$
  [necessarily $BR_{SUSY} < BR_{SM}$]

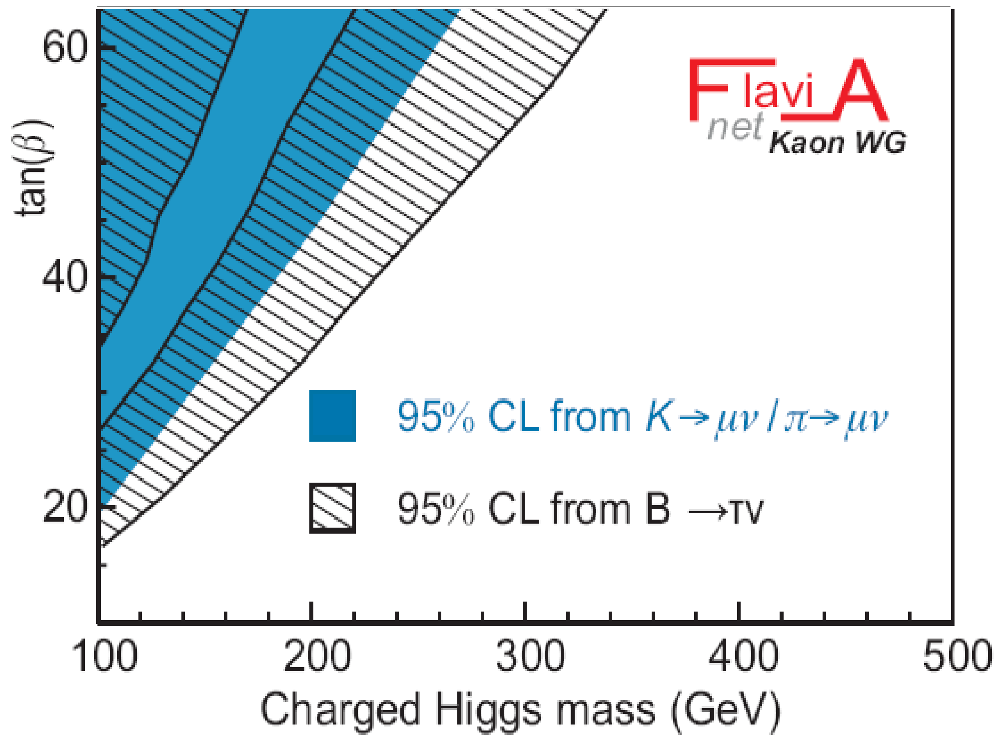
G. Hou, '93; Ackeroid, Recksiegel, '03

G.I. Paradisi '06

✯ *The flavour constraints at large tanβ*



$P^\pm \rightarrow l^\pm \nu$



$B(B \rightarrow \tau\nu) = (1.43 \pm 0.43)\ 10^{-4}$

$[B_{SM} \approx 1.2\times10^{-4}]$ [Babar+Belle '07]

$B(K \rightarrow \mu\nu(\gamma)) = (63.66 \quad 0.17)\%$ [KLOE]

+ f_K/f_π @ 0.7% [MILC/UKQCD '07]

+ V_{us} @ 0.5% [KLOE/NA48/KTeV + Theory]

Improving th. and exps. on $P \rightarrow l\,\nu$ can lead to very valuable infos on M_H & tanβ !

The flavour constraints at large $\tan\beta$

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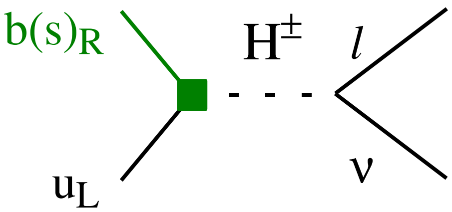
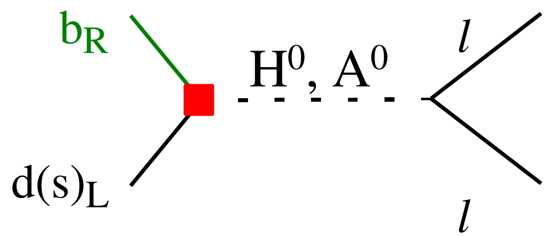


$P^{\pm} \to l^{\pm}\nu$



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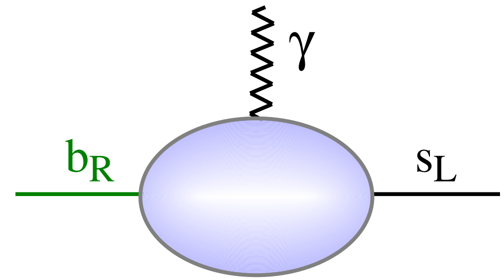
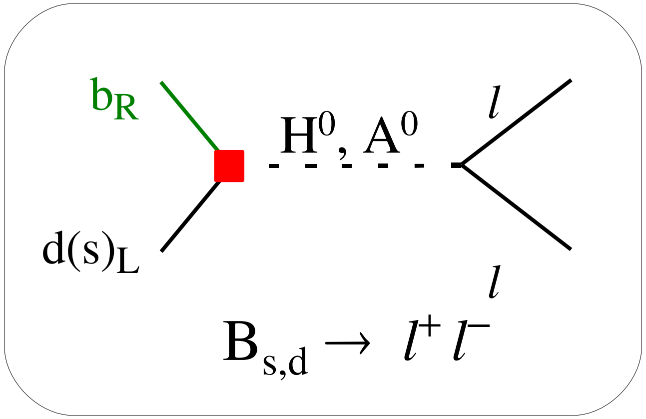


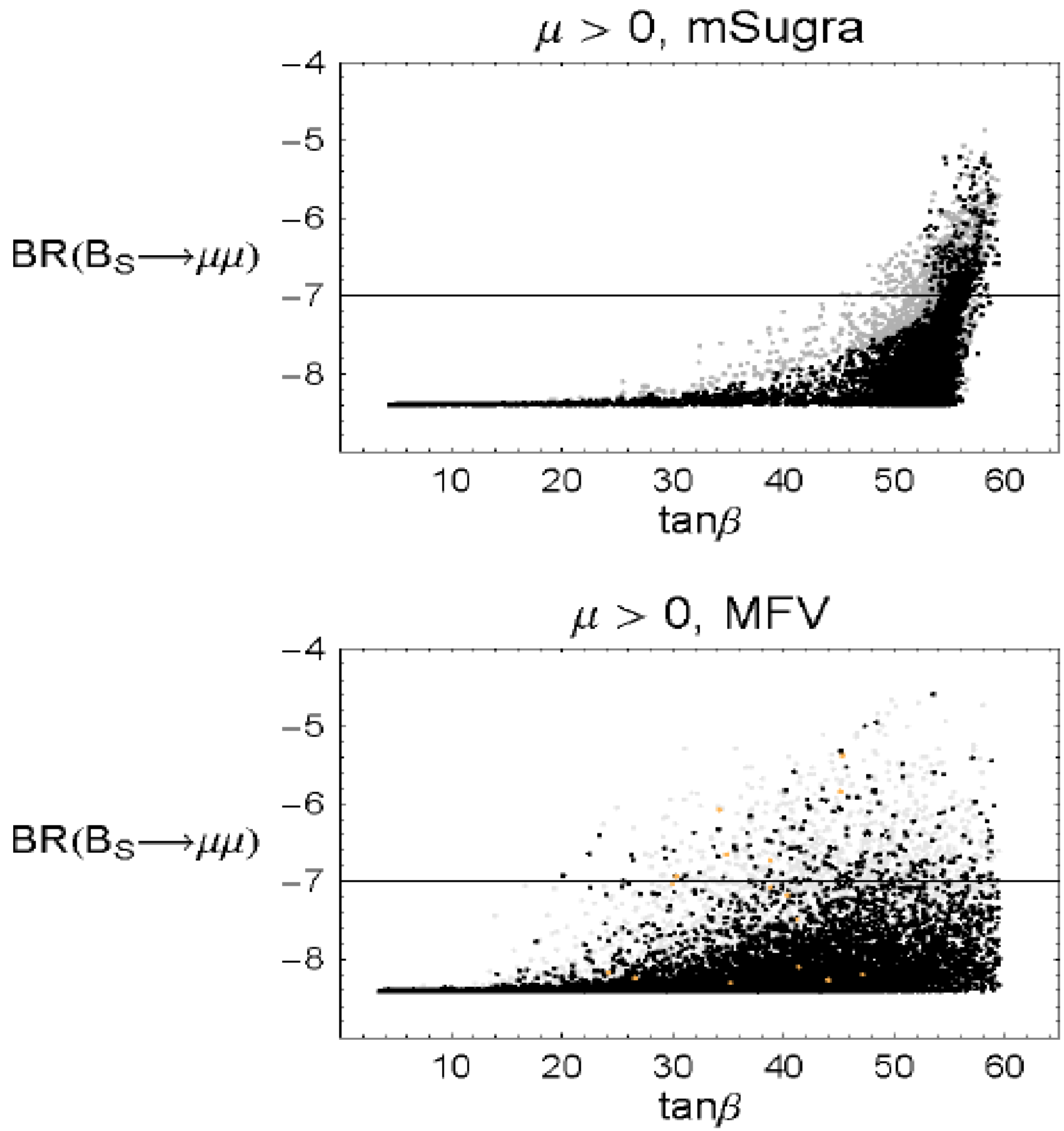
$B \to X_s\,\gamma$

Crucial dependence on μ and A_U [in addition to M_H & $\tan\beta$]

$$A(B\to ll)_H \sim \frac{m_b\, m_l}{M_A^{\,2}}\,\frac{\mu\, A_U}{\tilde{M}_q^{\,2}}\,\tan^3\beta$$

Possible large enhancement over the SM
but size (and magnitude) of the effect can change
substantially in different SUSY-breaking scenarios





$B(B_s \to \mu\mu) < 5.8 \times 10^{-8}$ (95%CL)

$[B_{SM} \sim 3\times10^{-9}]$

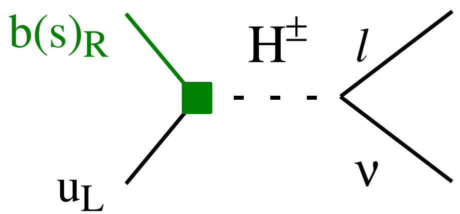
non-official CDF+D0 combined limit [EPS '07]

Significant constraint
but a good fraction of the
parameter sapce is still allowed

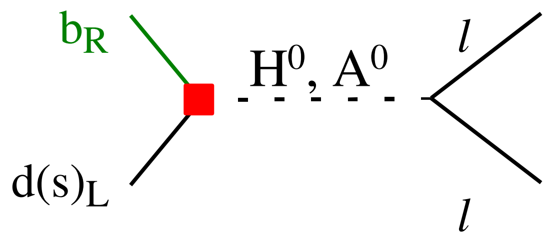
Lunghi, Porod, Vives '06

✭ The flavour constraints at large tanβ

Three most interesting sets of observables:



$P^{\pm} \to l^{\pm} \nu$



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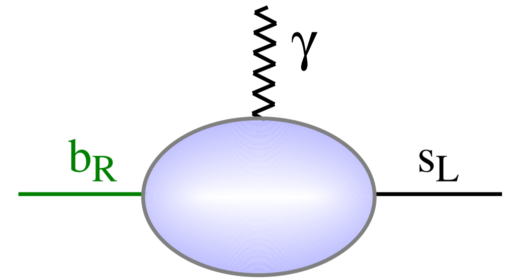
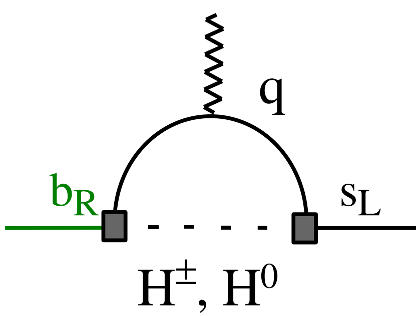
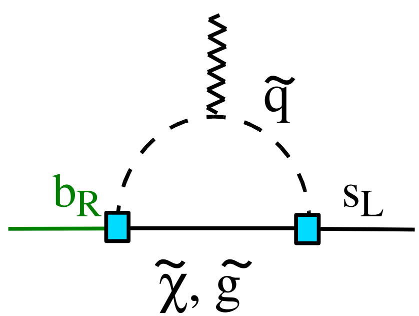


$B \to X_s \gamma$

Most complicated observable with several, naturally competitive, contributions:



- positive
- decreasing with tanβ



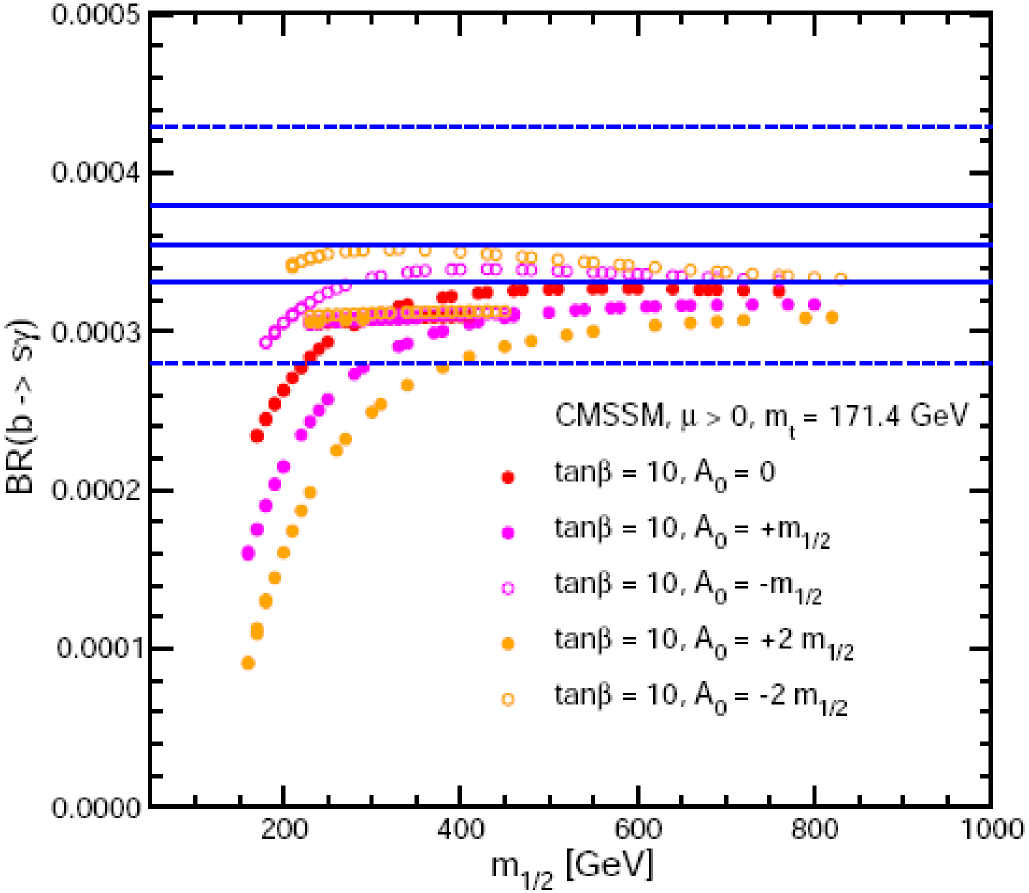
- sign ~ sgn(μ,A)
- increasing with tanβ

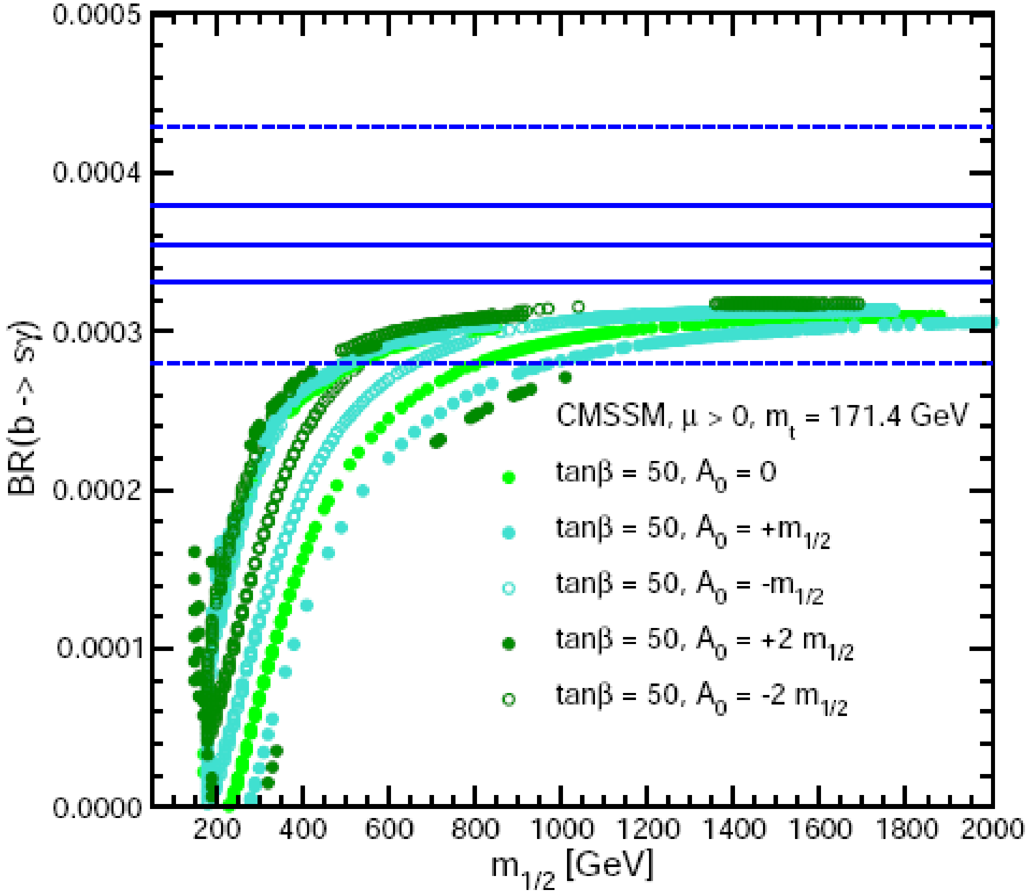
One of the most significant constraint of the MSSM (even at small tanβ)

$B(B \to X_s\gamma)^{exp} = (3.55 \pm 0.26)\ 10^{-4}$ [HFAG '06]

$B(B \to X_s\gamma)^{SM} = (3.15 \pm 0.23)\ 10^{-4}$ [Misiak et al. '06]

E.g.: The $B \to X_s\gamma$ constraint in the CMSSM, after imposing Dark-matter conditions



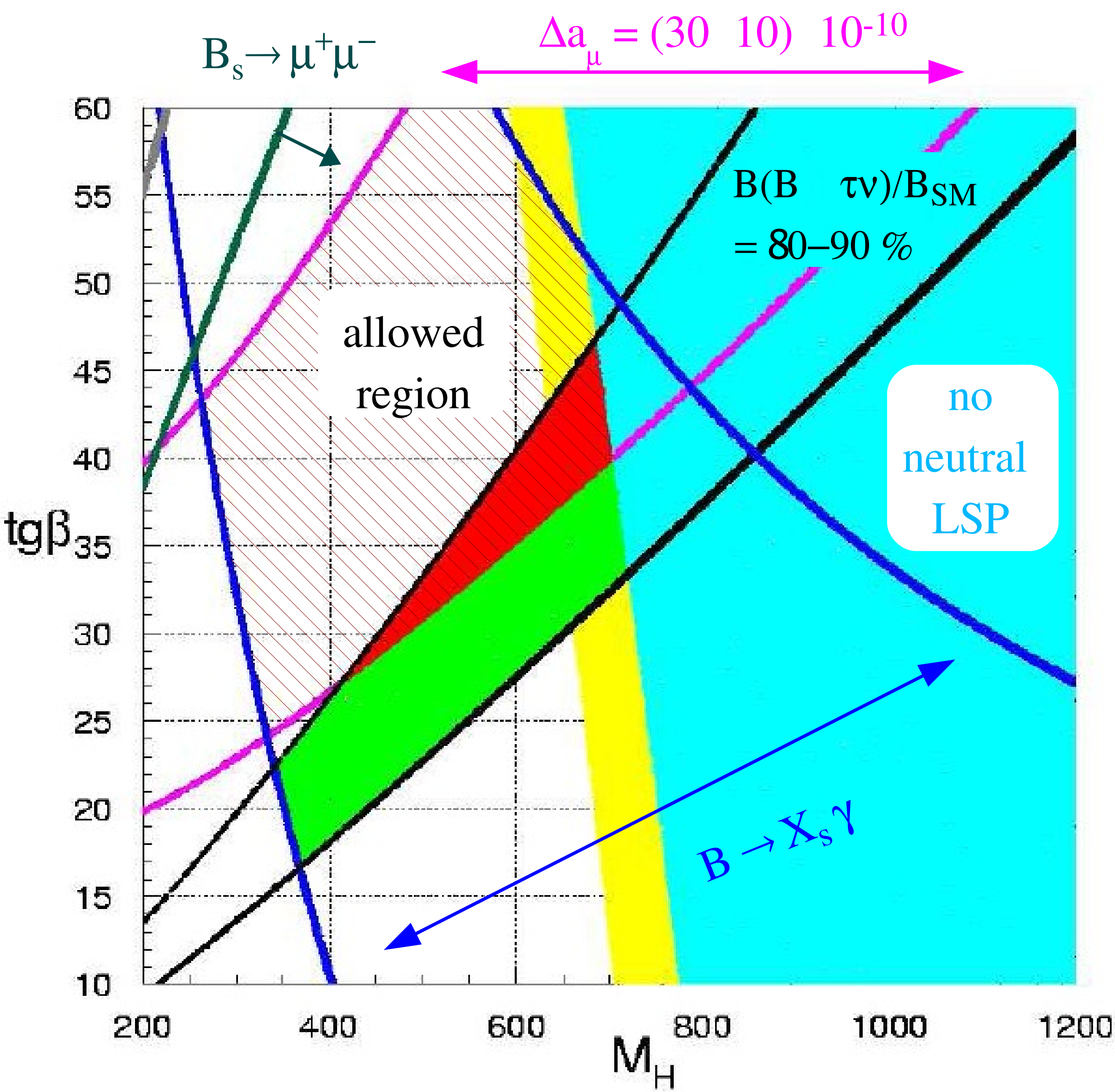


Ellis et al. '07

E.g.: combined constraints in a general MFV-MSSM assuming heavy squarks:

Flavour physics
+ $(g\text{-}2)_\mu$
+ dark matter
(A-funnel region)

M_{sq} = 1.5 TeV M_{sl} = 0.5 TeV
A_u = -1.0 TeV μ = 0.5 TeV

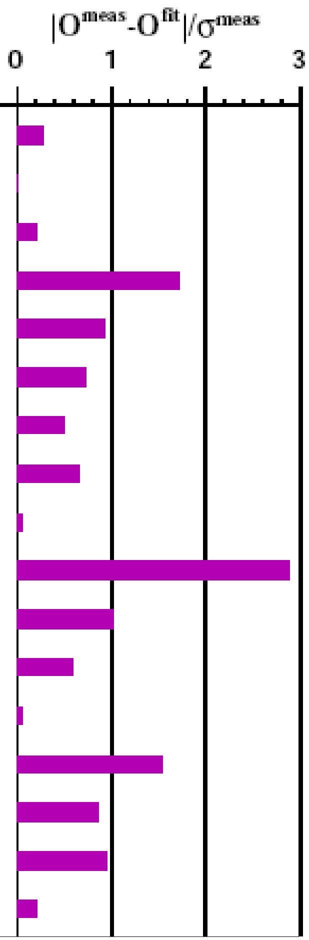


G.I., Mescia, Paradisi, Temes, '07

Some considerations on EWPO & the global CMSSM fit

Pulls of the EWPO within the SM:

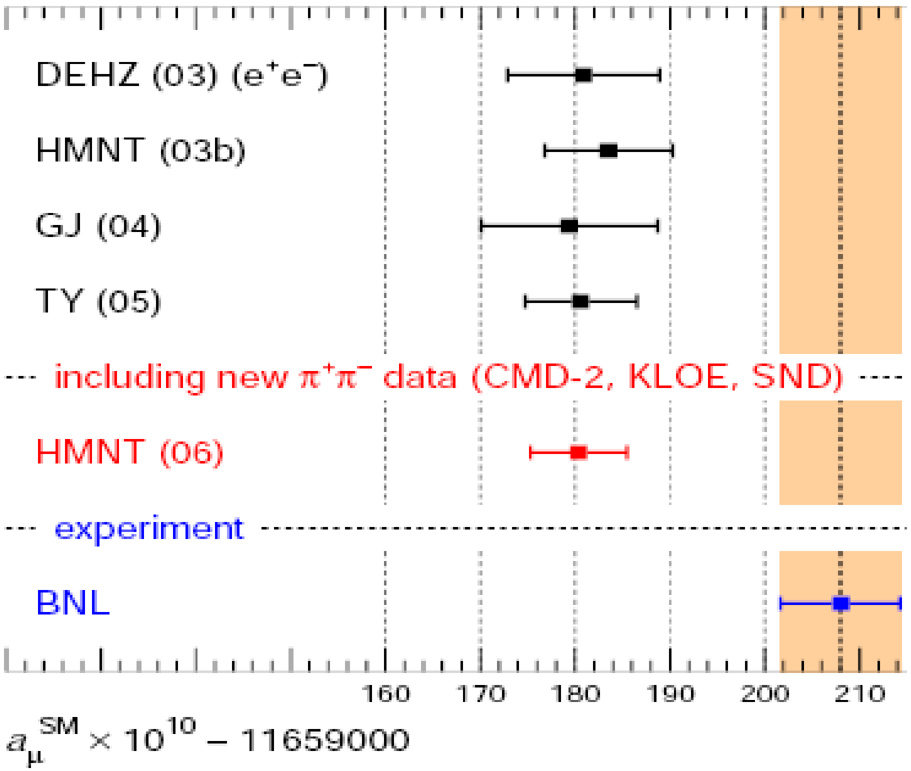
Variable	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957
σ^0_{had} [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21586
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.374
m_t [GeV]	170.9 ± 1.8	171.3

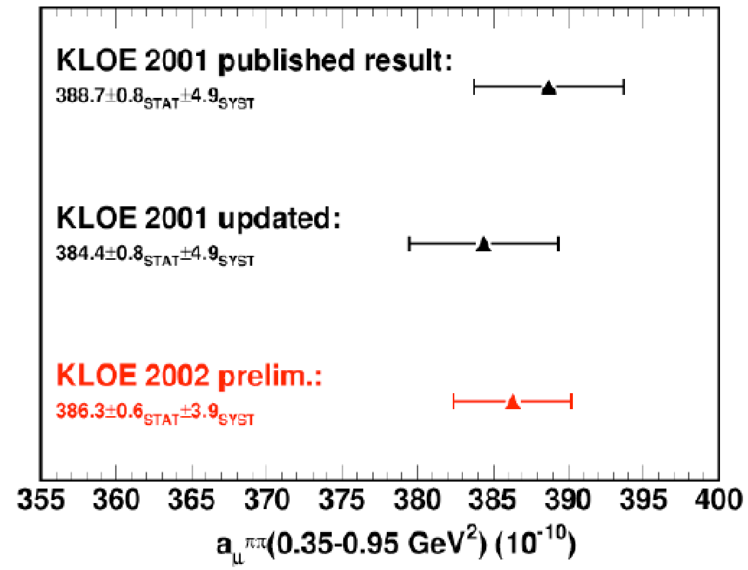


Main implications in constraining the MSSM parameter space:

- Mainly exclusion bounds (e.g.: not possible to improve A_b^{FB} except in very contrived scenarios)
- Notable exception provided by: $(g-2)_\mu$
- Only mild improv. expected in the near future (m_t, M_W)

On the anomalous magnetic moment of the muon:





$$\Delta a_\mu^{exp} = a_\mu^{exp} - a_\mu^{SM} = (29 \pm 9) 10^{-10}$$

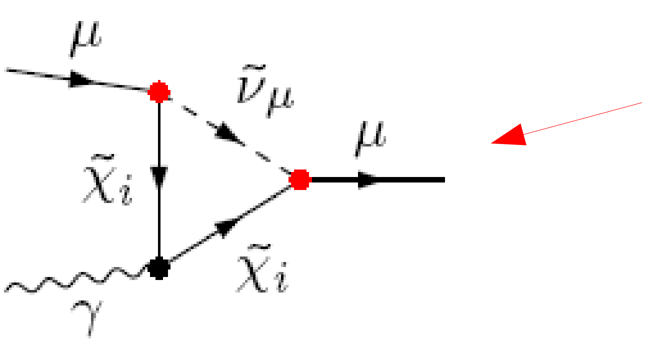
- In the last few years the result for a_μ^{SM} has become more reliable and the size of the discrepancy has (slightly) increased
- The discrepancy is large compared to $a_\mu^{light\text{-}light}$
- The discrepancy is large compared to $a_\mu^{ew\text{-}SM}$ ($a_\mu^{ew\text{-}SM} \sim 15 \times 10^{-10}$)

On the anomalous magnetic moment of the muon:

$$\Delta a_\mu^{exp} = a_\mu^{exp} - a_\mu^{SM} = (29 \pm 9)10^{-10}$$

The anomalous magnetic moment is an helicity suppressed observeble ($a_\mu^{SM} \propto m_\mu$) and SUSYwith moderate/large tanβ provides a natural mechanism to explain this discrepancy:

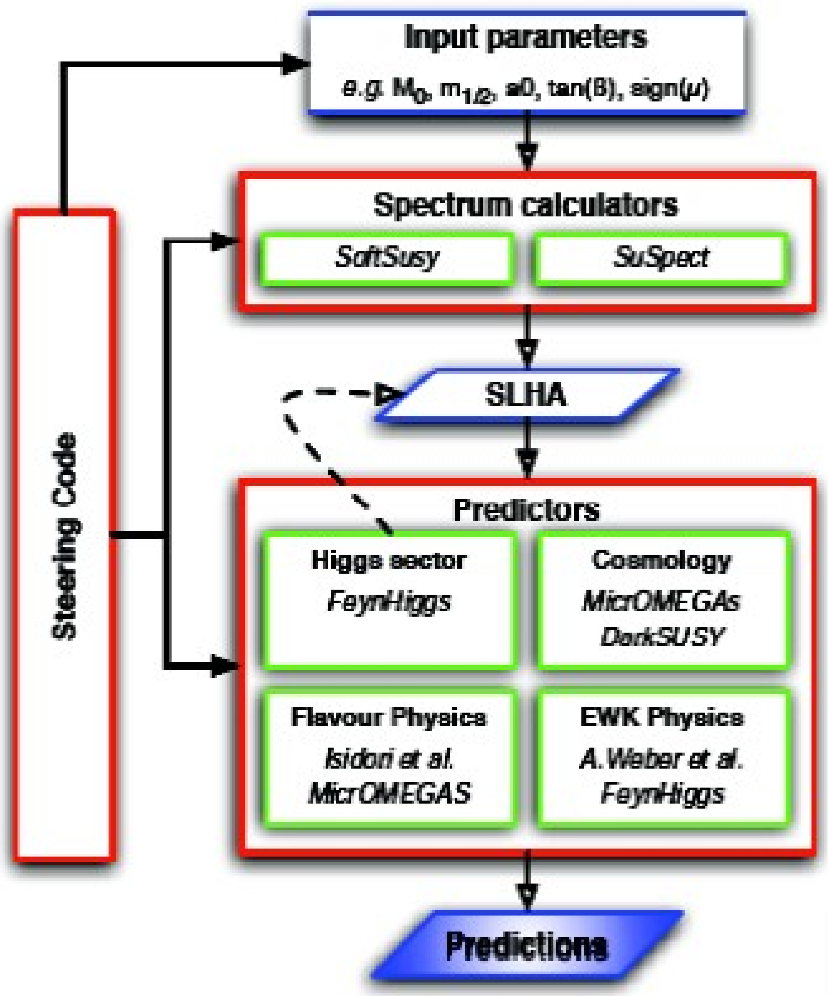
$$\Delta a_\mu^{SUSY} \sim \tan\beta \times (m_W/M_{SUSY})^2 \times (a_\mu^{ew\text{-}SM}) \times \mathrm{sgn}(\mu)$$



Couplings proportional to the muon Yukawa and not to its mass !!

The global fit in the CMSSM:

At the CERN workshop *"Flavour Physics in the LHC era"* we started a th. + exp. collaboration aimed to develop a common tool (*master-code*) able to combine all the available indirect constraints on the MSSM (EWPO, flavour physics, dark-matter), and produce in output global probability distributions for the parameter space of the model.



More about this in the talks by
F. Ronga & S. Heinemeyer

Given the limited number of positive constraints, we started from the global analysis of a simplified scenario (much simpler than the general MSSM with MFV): the CMSSM (also known as mSUGRA):

Scenario characterized by 4 free parameter
[after imposing e.w. symmetry breaking]:

GUT param.

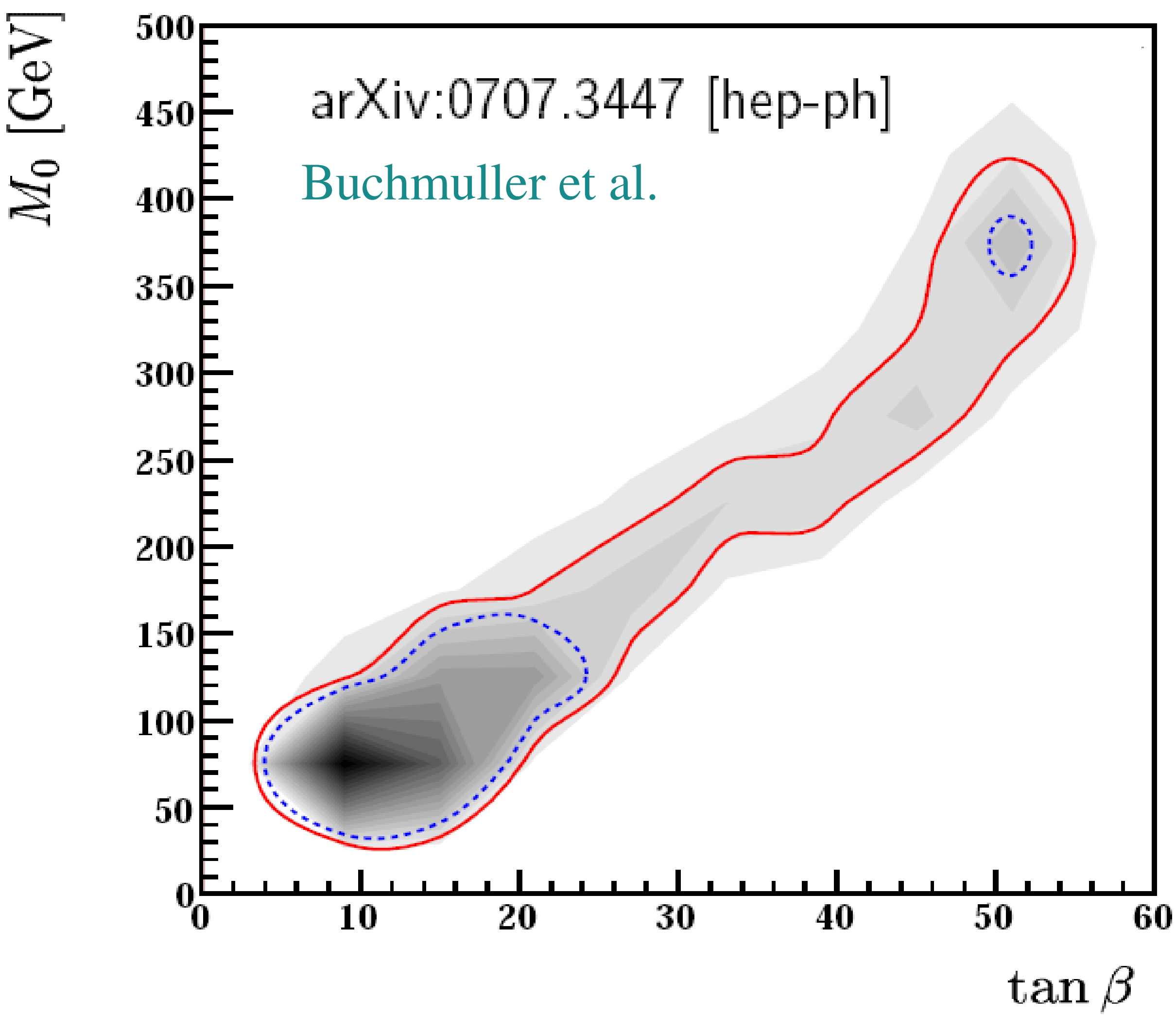
M_0 = univ. soft scalar mass

$M_{1/2}$ = univ. soft gaugino mass

A_0 = univ. soft trilinear term

μ, B ⟷ $\tan\beta + \mathrm{sgn}(\mu)$

- Multi-parameter χ^2 fit
- fitting for all CMSSM parameters: M_0, $M_{1/2}$, A_0, $\tan\beta$;
- including relevant SM uncertainties (*e.g.* m_{top});



- overall preferred minimum at low $\tan\beta$, low squark mass;
- less preferred region at high $\tan\beta$, higher squark mass;
- consistent with previous studies.

Key role played by $(g\text{-}2)_\mu$, Ω_{CDM} & $B \to X_s \gamma$

CMSSM

Variable	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
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A_l(SLD)	0.1513 ± 0.0021	0.1479	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.398 ± 0.025	80.382	
m_t [GeV]	170.9 ± 1.8	170.8	
$R(b\to s\gamma)$	1.13 ± 0.12	1.12	
$B_s\to\mu\mu$ [$\times 10^{-8}$]	< 8.00	0.33	N/A (upper limit)
Δa_μ [$\times 10^{-9}$]	2.95 ± 0.87	2.95	
Ωh^2	0.113 ± 0.009	0.113	

SM

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m_t [GeV]	170.9 ± 1.8	171.3	

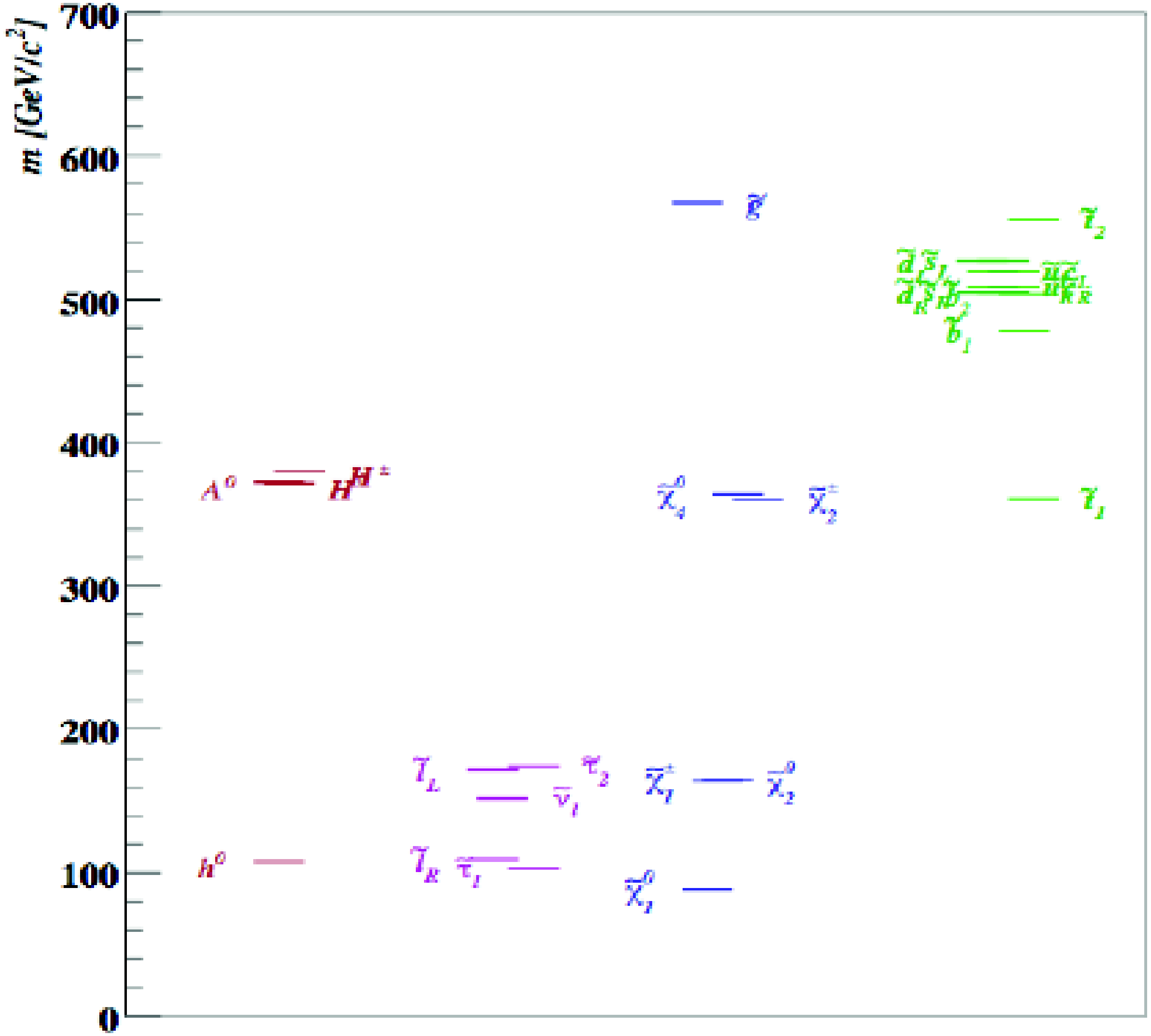
Probabilities from the χ^2 analysis: 24% (CMSSM) 12% (SM) (same number of d.o.f)

Conclusions / open issues

- The MSSM is not in bad shape (even within its most constrained form, it gives a good fit to present data and solves various phenomenological problems of the SM)
- A few low-energy obs. play a key role in determining the allowed parm. space (and will continue to be very relevant also in the LHC era)

- How solid are the conclusions on the MSSM parameter space if we abandon the simple CMSSM scenario? Can we hope to perform a global analysis in the general MFV-MSSM?
- Are there natural non-MFV reference scenarios for which it is worth to perform global fits?
- Are there MSSM-RGE codes which consistently take into account also the flavour off-diagonal entries when computing low-energy sfermion mass matrices?

“best CMSSM Fit”



M0	M12	A0	tb
49.2	232.3	-122.4	6.9

Ma=372 GeV; mu=336 GeV; mh=111 GeV