GUT inspired MSSM: dark matter and flavor before the LHC

Enrico Lunghi

Fermilab

based on:

E.L., O. Vives and W. Porod, Phys. Rev. D74:075003,2006

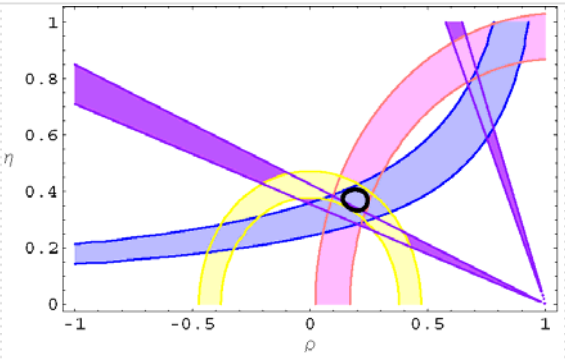
E.L., O. Vives and W. Porod, in preparation

Outline

- Hints for new physics?
- Minimal flavor violation
- Example: most general SUSY without extra flavor changing

Hints for new physics

- *dark matter*: ~80σ
- *muon g-2*: ~3σ
- *$b \to s\gamma$*: ~1σ
- tension between V_{ub}/V_{cb} and $(\sin 2\beta)_{cc}$: ~2σ
- CP asymmetries in $b \to sss$: ~2σ
- CP asymmetries in $B \to K\pi$: ~3.5σ



Realistic errors? (dark matter)

- Experimental result (WMAP data) is extremely accurate:

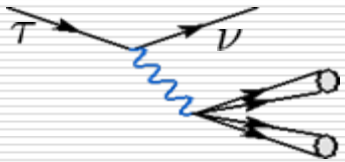
  $$\Omega h^2 = 0.1047^{+0.007}_{-0.0013}$$

- We use the program micrOMEGAs to implement the calculation of the relic neutralino density in SUSY models

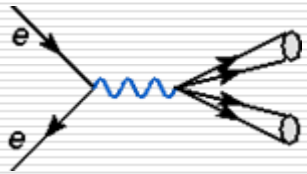
- Unfortunately the *theoretical situation is much cloudier*:
  - parametric errors (e.g. M_t) and uncertainties in the RGE running from the GUT to the EW scales (especially in the large $\tan\beta$ region) impact strongly the calculation of Ωh^2
  - moreover, points for which Ωh^2 is too small can always be "recovered" by some other dark matter candidate

Realistic errors? (g-2)

- Complete theoretical predictions are complicated by non-perturbative QCD effects:
  - *light by light scattering*
  - *hadronic contribution* → can be extracted by data on ee and τ data (the latter up to *isospin corr.*)



problematic



- Experimental and theoretical results read:

$$a_\mu^{\text{exp}} = 11\,659\,208\,(6) \times 10^{-10}$$
$$a_\mu^{\text{SM}}(ee) = 11\,659\,181\,(8) \times 10^{-10}$$
$$\Rightarrow \quad \boxed{\delta a_\mu = (27.6 \pm 8.1) \times 10^{-10}}$$

3.4σ effect

Realistic errors? ($B \to X_s\gamma$)

- The world average reads (E_γ>1.6 GeV):

  $$BR(B \to X_s\gamma)_{\text{WA}} = (3.55 \pm 0.24^{+0.09}_{-0.10} \pm 0.03) \times 10^{-4}$$

- The SM prediction includes NNLO effects (*caveat*)

- Becher and Neubert showed that the standard OPE is valid only for E_γ>1 GeV; in order to get a reliable prediction for a more realistic cut, effective theory techniques (SCET RGE) have to be used:

  $$BR(B \to X_s\gamma)_{E_\gamma > 1.6\text{GeV}} = 3.15 \times 10^{-4}$$ [normal OPE]

  $$BR(B \to X_s\gamma)_{E_\gamma > 1.6\text{GeV}} = 2.98 \times 10^{-4}$$ [SCET approach]

Sensitive observables

- $B_s \to \mu\mu$: in SUSY models, it scales as $(\tan\beta)^6$
  - the experimental bound and the SM theory predictions are:

    $BR(B_s \to \mu\mu)_{\text{exp}} < 10^{-7}$ at 90% C.L. [CDF&D0]

    $BR(B_s \to \mu\mu)_{\text{SM}} = (3.8 \pm 1.0) \times 10^{-9}$

- Δm_{B_s} : scales as $(\tan\beta)^4$
  - experiment vs SM:

    $\Delta M_{B_s} = (17.77 \pm 0.10 \pm 0.07)\ \text{ps}^{-1}$ [CDF]

    $$\Delta M_{B_s}^{SM} = \begin{cases} (20.5 \pm 3.1)\ \text{ps}^{-1} & \text{lattice only} \\ (18.4 \pm 2.2)\ \text{ps}^{-1} & \text{lattice + UTfit} \end{cases}$$

Sensitive observables

- $B \to \tau\nu_\tau$: tends to receive only negative contributions
  - experiment vs theory:

$$\mathrm{BR}(B \to \tau\nu_\tau)^{\mathrm{WA}} = (1.31 \pm 0.48) \times 10^{-4}$$

$$BR(B \to \tau\nu_\tau)^{SM} = \begin{cases} (1.53 \pm 0.38)10^{-4} & V_{ub} \text{ from PDG} \\ (1.10 \pm 0.24)10^{-4} & V_{ub} \text{ from UTfit} \end{cases}$$

- *Both Δm_{Bs} and $B \to \tau\nu$ are sensitive to the tension between V_{ub} and $\sin(2\beta)_{cc}$*

Why minimal flavor violation?

- The amazing agreement of most B-factories measurements with the SM predictions is a *powerful test of the CKM mechanism*

- We can have:
  - very heavy new physics with arbitrary FC couplings
  - *relatively light new particles with CKM-like couplings (MFV)*

- MFV: non trivial correlation between Tevatron/LHC results and low-energy data

- discovery at LHC ⟷ low energy data

MSSM with MFV

- R-parity
- Require GUT unification (universal gaugino masses)
- We adopt the definition of D'Ambrosio, Giudice, Isidori & Strumia. The only relevant information contained in the quark Yukawa's are the eigenvalues and the CKM matrix:
  $$Y_U = D_L\, V_{\mathrm{CKM}}^{\dagger}\, \lambda_u^{diag}\, U_R \ , \quad Y_D = D_L\, \lambda_d^{diag}\, D_R$$
  where the matrices U_R, D_L and D_R are unphysical
- This definition is *RGE invariant* and can be imposed in terms of an *exact additional flavor symmetry*

MSSM with MFV

- Structure of the soft-breaking terms:

$$
\begin{aligned}
M_Q^2 &= m_Q^2 \left(1 + b_1\, Y_U Y_U^\dagger + b_2\, Y_D Y_D^\dagger \right. \\
&\qquad \left. + b_3\, Y_D Y_D^\dagger\, Y_U Y_U^\dagger + b_4\, Y_U Y_U^\dagger\, Y_D Y_D^\dagger \right) \\
M_U^2 &= m_U^2\, (1 + b_5\, Y_U^\dagger Y_U) \\
M_D^2 &= m_D^2\, (1 + b_6\, Y_D^\dagger Y_D) \\
A_U &= a_U\, (1 + b_7\, Y_D Y_D^\dagger)\, Y_U \\
A_D &= a_D\, (1 + b_8\, Y_U Y_U^\dagger)\, Y_D
\end{aligned}
$$

- At this time we do not include new phases, but we could

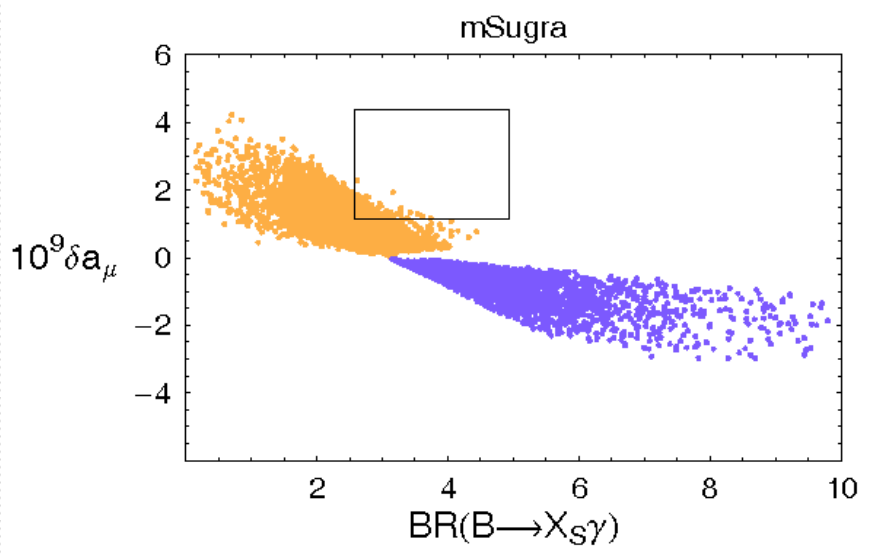
Tools of the game

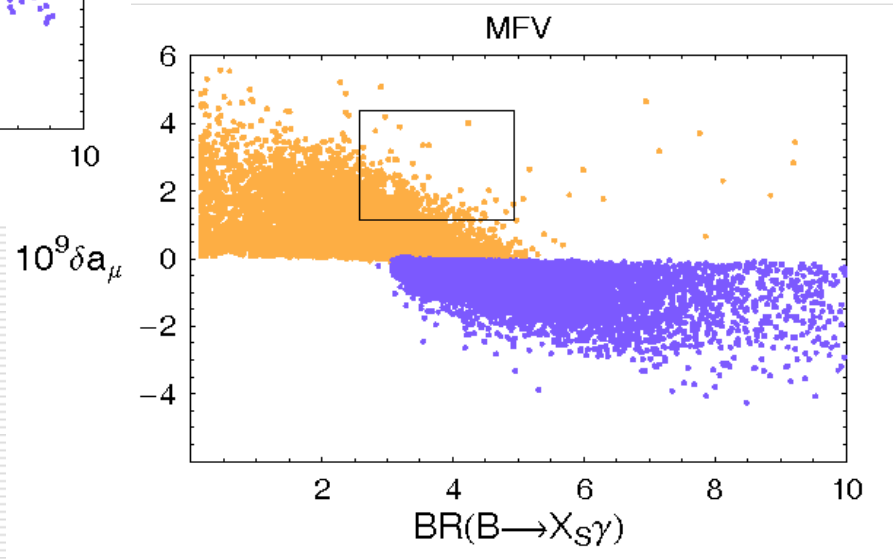
- We use Spheno *[Porod]* to run the 2-loop RGE's for the MSSM fully including generation mixing and large tan(β) resummation (almost public)

- Fix $|\mu|$ (at 2 loops) by requiring Radiative-EWSB

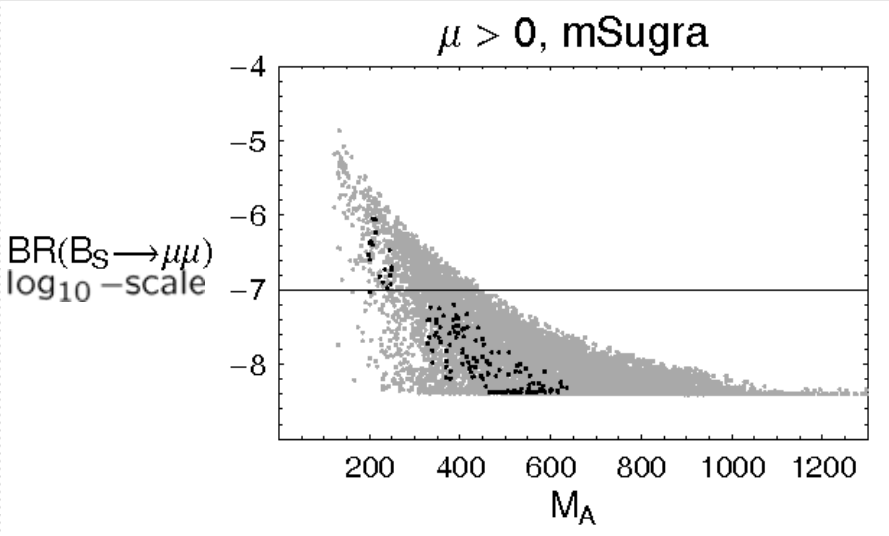
- At the low-scale we impose constraints from
  - direct searches
  - ρ-parameter
  - neutral LSP
  - dark matter (MicrOMEGAs)
  - perturbativity of the yukawas
  - $b \to s\,\gamma$
  - muon g-2
  - $B_s \to \mu\mu$
  - B_s mixing
  - $B \to \tau\,\nu$

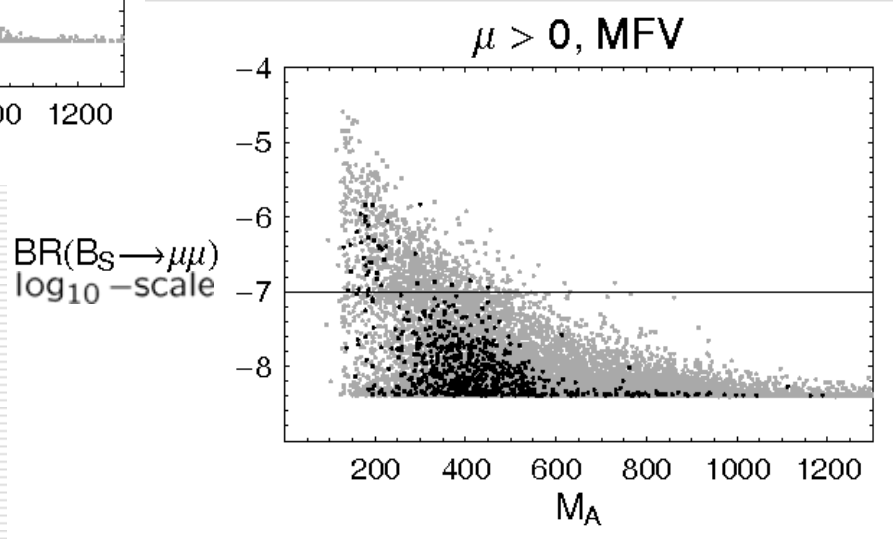
δa_μ vs $B \to X_s\gamma$



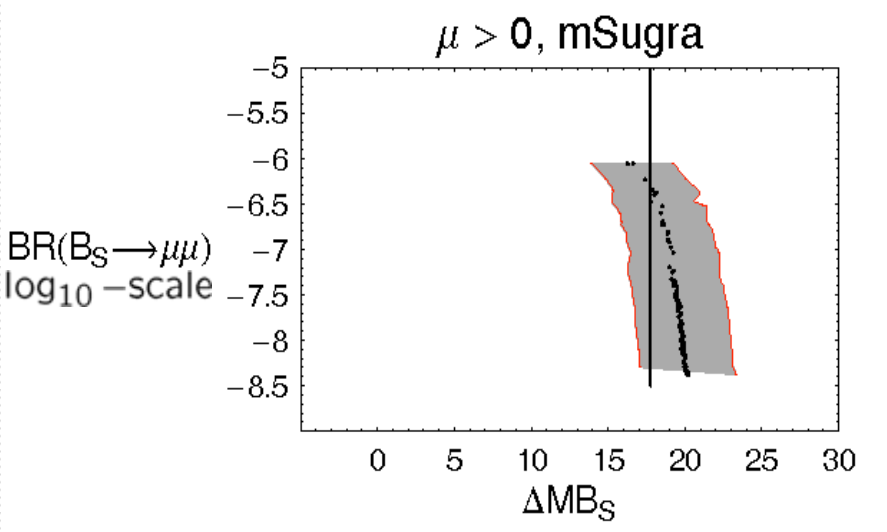


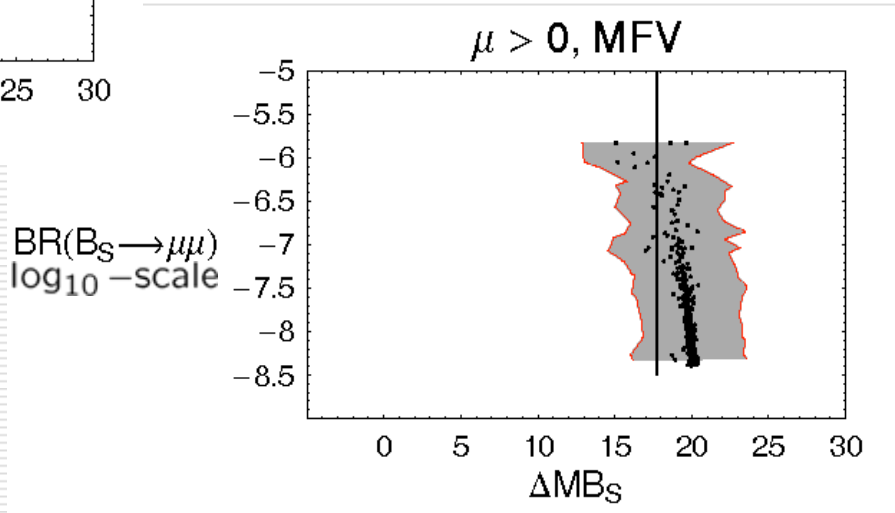
M_A vs $B_s \to \mu\mu$



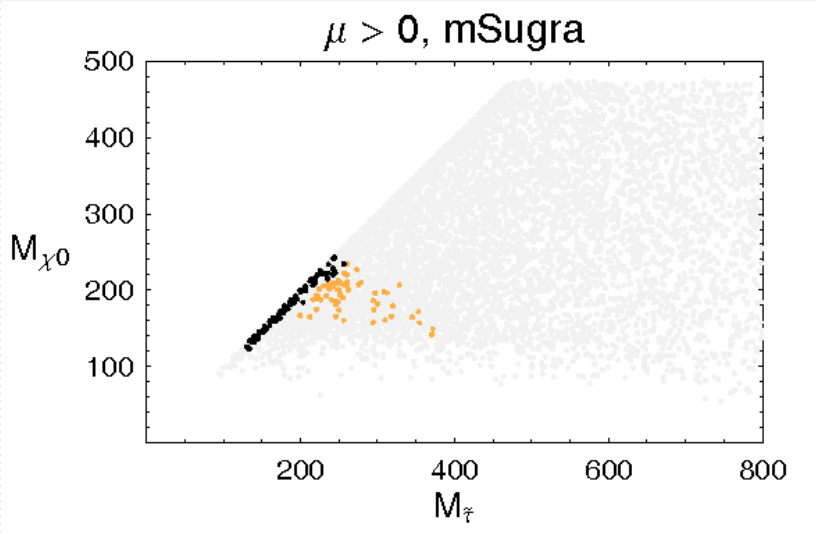


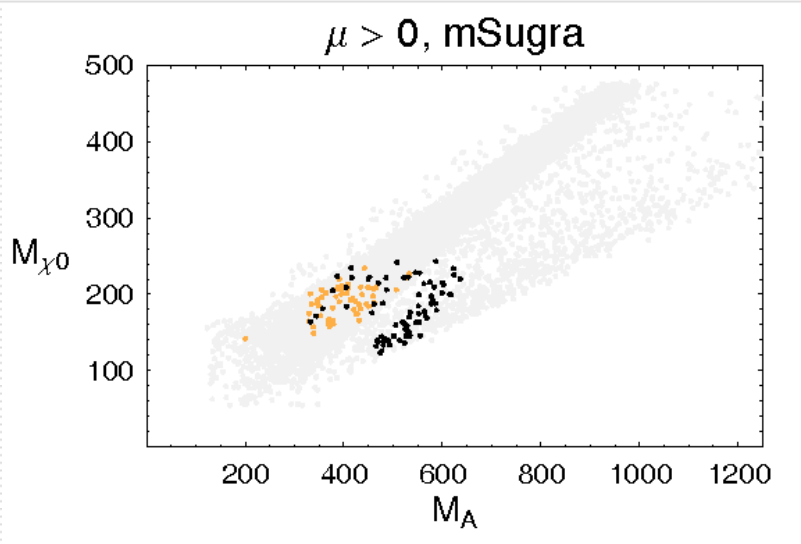
ΔM_{B_s} vs $B_s \to \mu\mu$





Dark matter scenarios: msugra



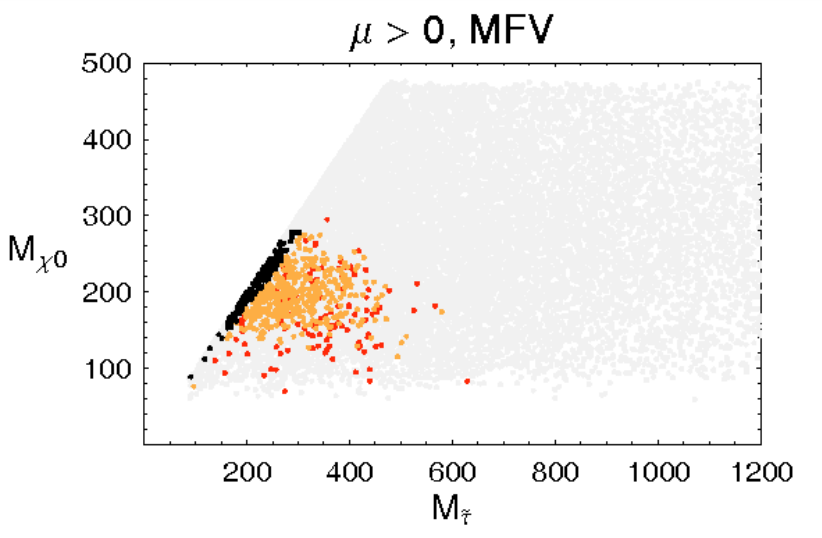


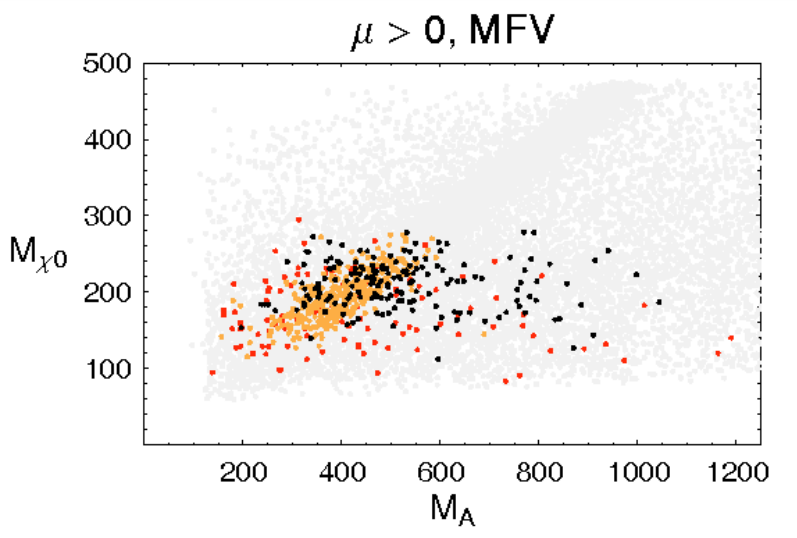
Black: stau coannihilation

orange: A-pole region

gray: excluded by low-energy data

Dark matter scenarios: MFV





Black: stau coannihilation

orange: A-pole region

red: higgsino “dominated” neutralino (>5%)

gray: excluded by low-energy data

Higgsino "domination"

- The neutralino mass matrix is:

$$M_{\tilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -g'v_d/2 & g'v_u \\ 0 & M_2 & gv_d/2 & -gv_u/2 \\ -g'v_d/2 & gv_d/2 & 0 & -\mu \\ g'v_u & -gv_u/2 & -\mu & 0 \end{pmatrix} \begin{matrix} \tilde{B} \\ \tilde{W}_3 \\ \tilde{H}_1^0 \\ \tilde{H}_2^0 \end{matrix}$$

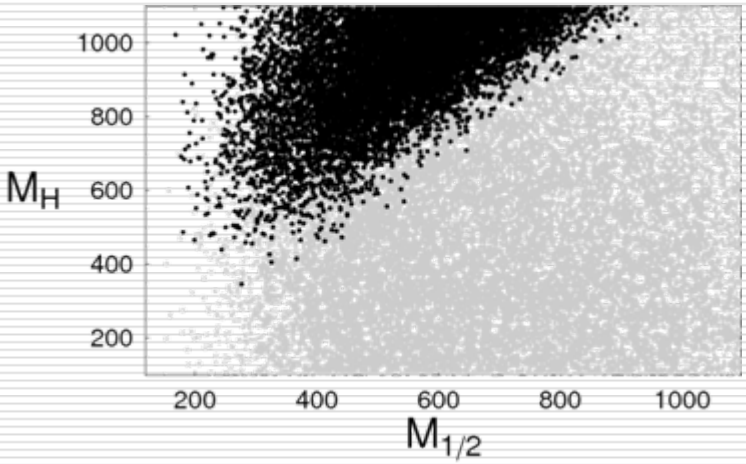
- The lightest neutralino is higgsino dominated if: $|\mu| < M_{1,2}$

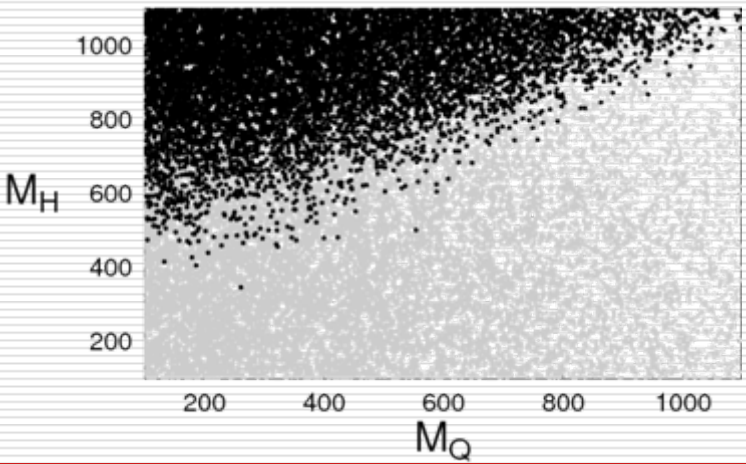
- In models with GU and REWSB we have:

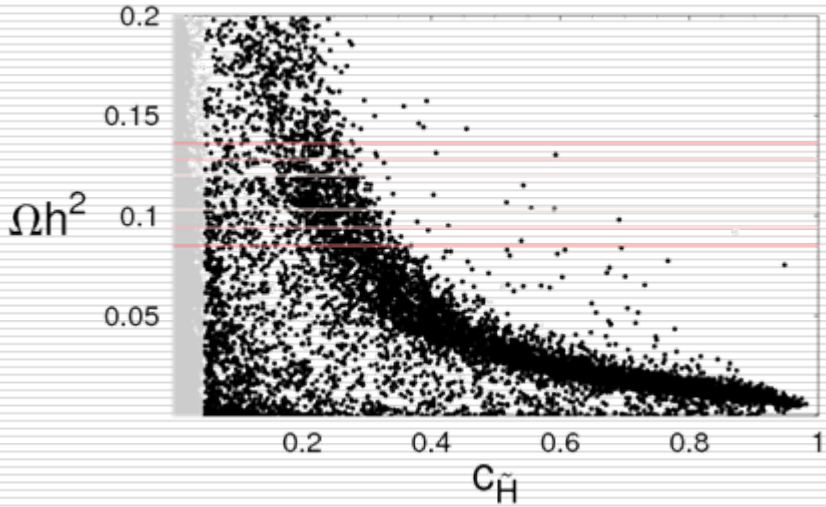
$$|\mu|^2 \sim +3\, M_{1/2}^2 + 0.75\, M_Q^2 - 0.63\, M_H^2 + \ldots$$

- So the LSP is higgsino dominated if $M_H \gg M_Q,\ M_{1/2}$

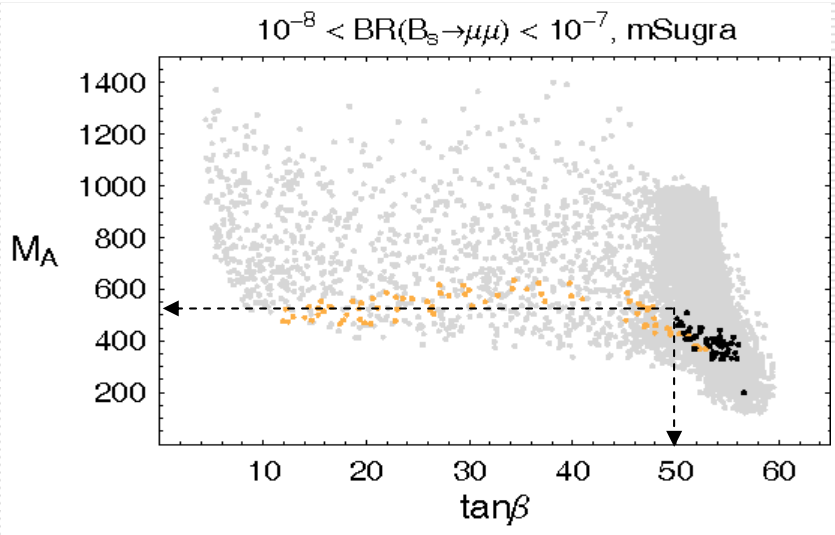
Higgsino “domination”

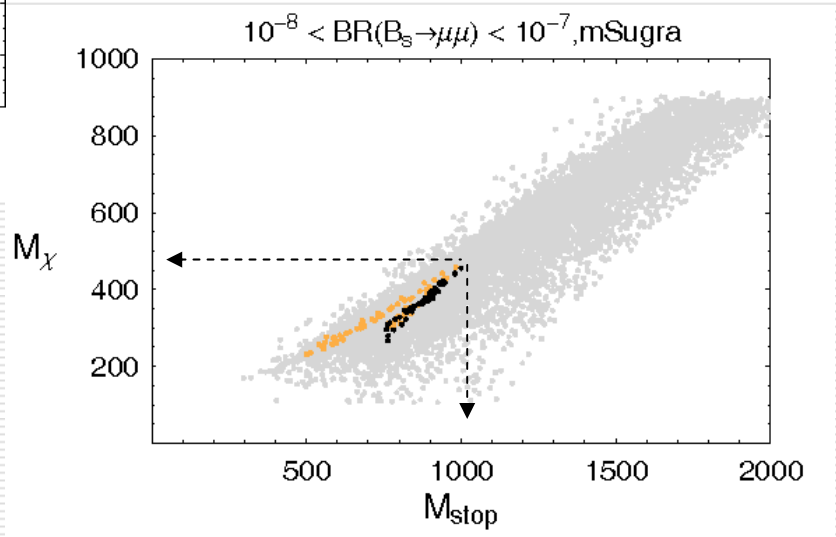






Large $B_s \to \mu\mu$ phenomenology

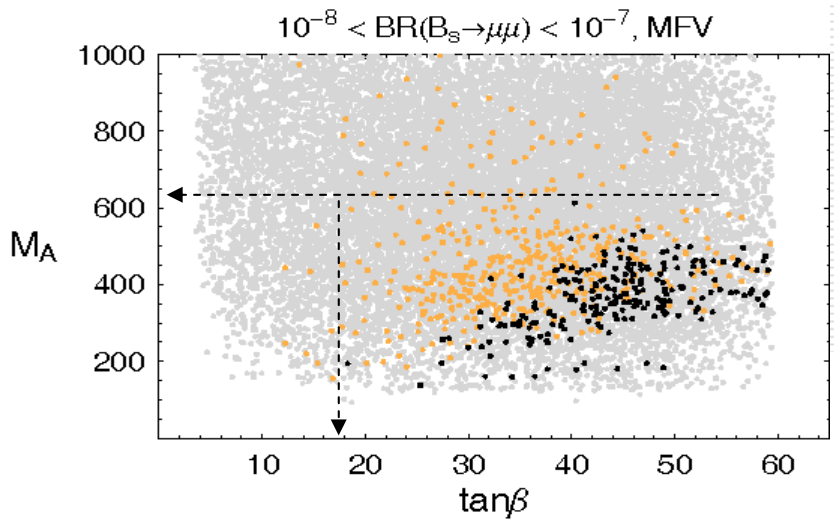


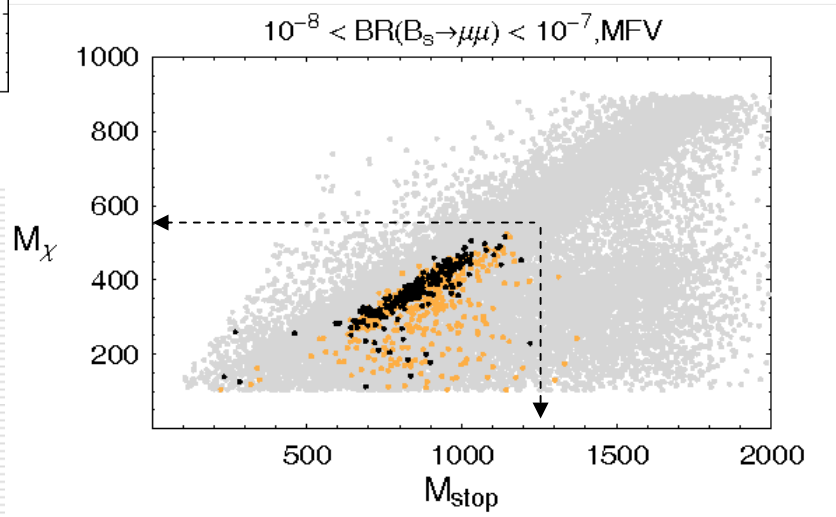


orange: all constraints imposed

black: $10^{-8} < BR(B_s \to \mu\mu) < 10^{-7}$

Large $B_s \to \mu\mu$ phenomenology



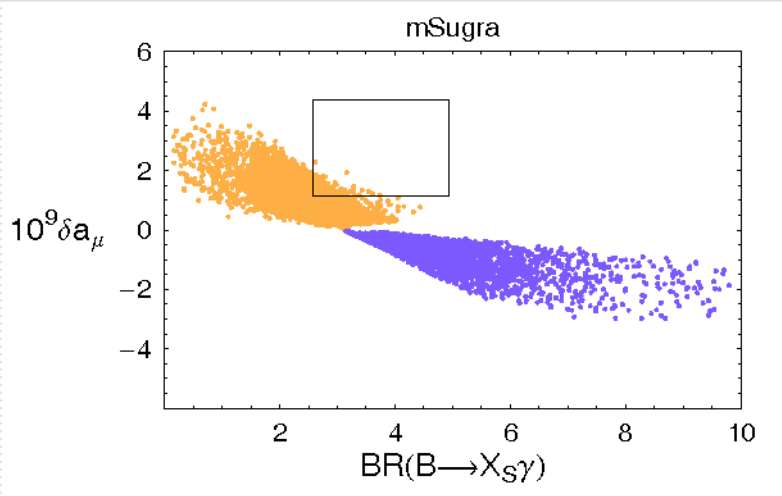


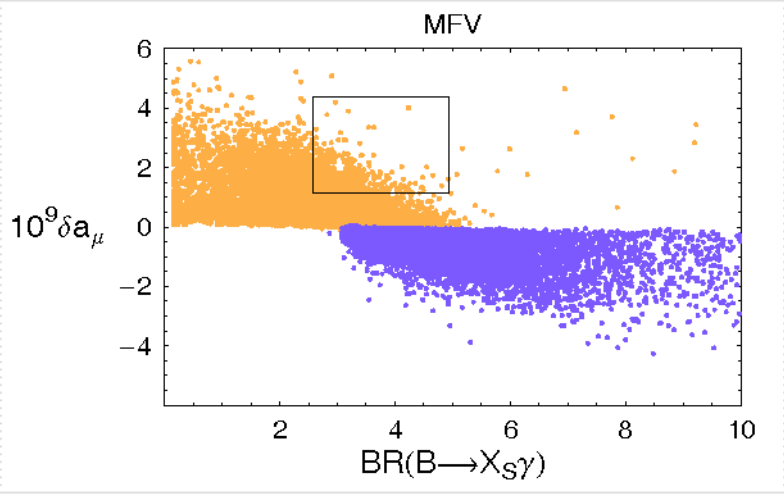
orange: all constraints imposed

black: $10^{-8} < BR(B_s \to \mu\mu) < 10^{-7}$

Summary

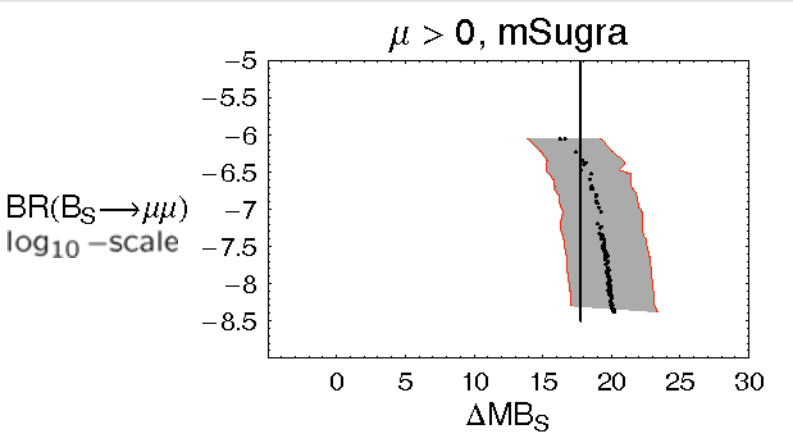
- Interplay between g-2, $b \to s\gamma$ and $B \to \tau\nu$

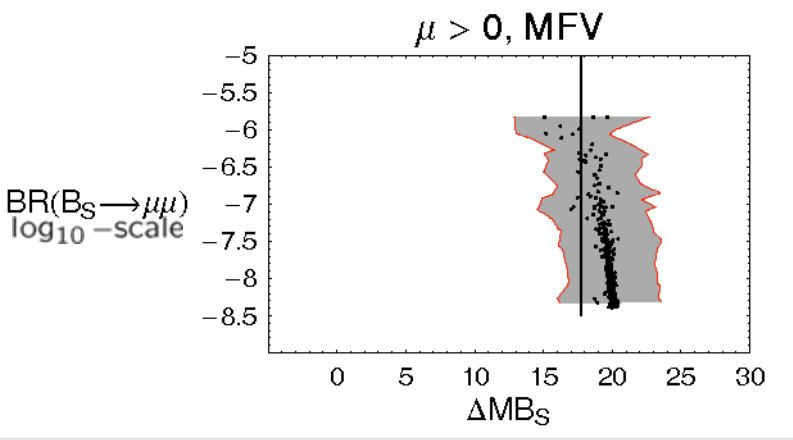




Summary

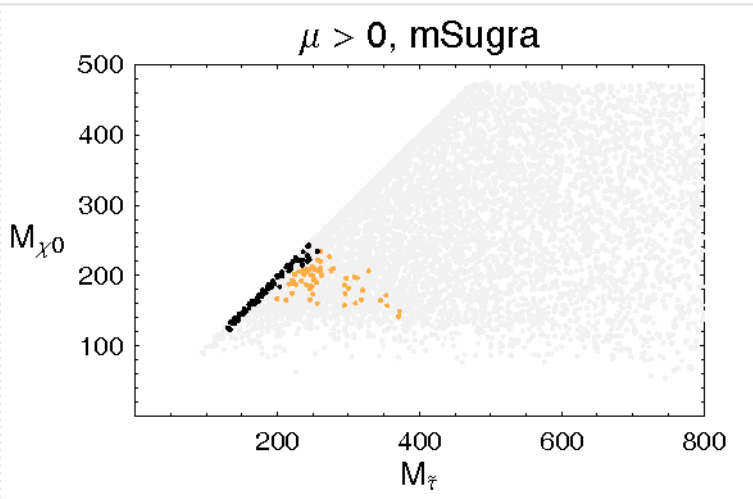
- Interplay between g-2, $b \to s\gamma$ and $B \to \tau\nu$
- Impact on $B_s \to \mu\mu$ and ΔM_{Bs}

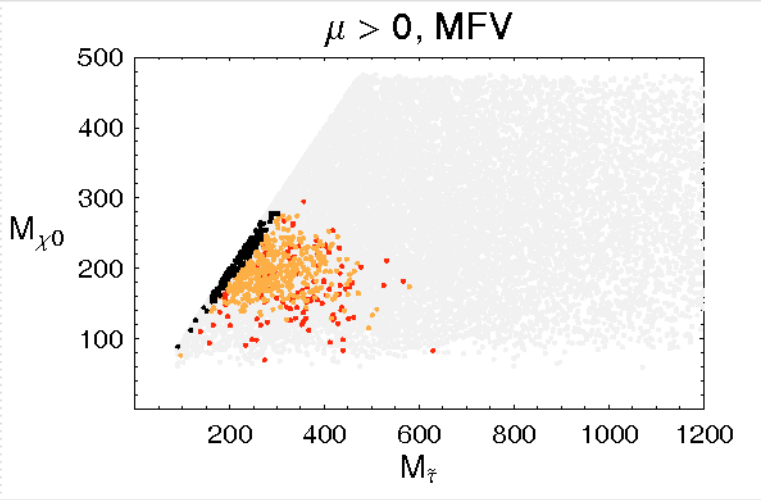


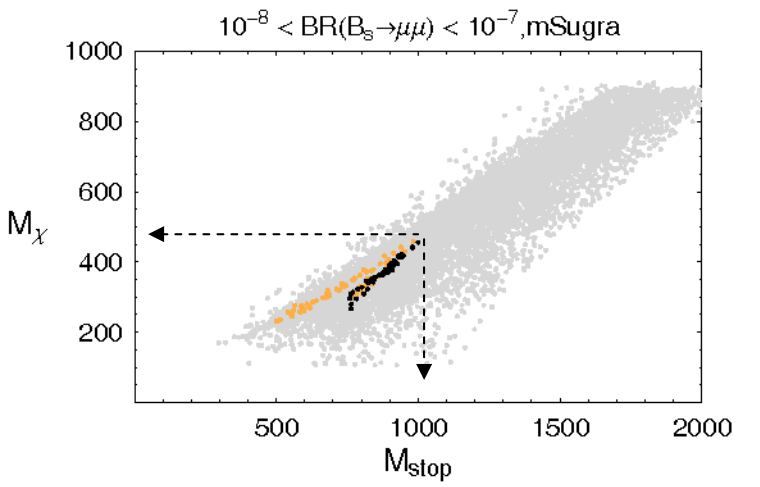
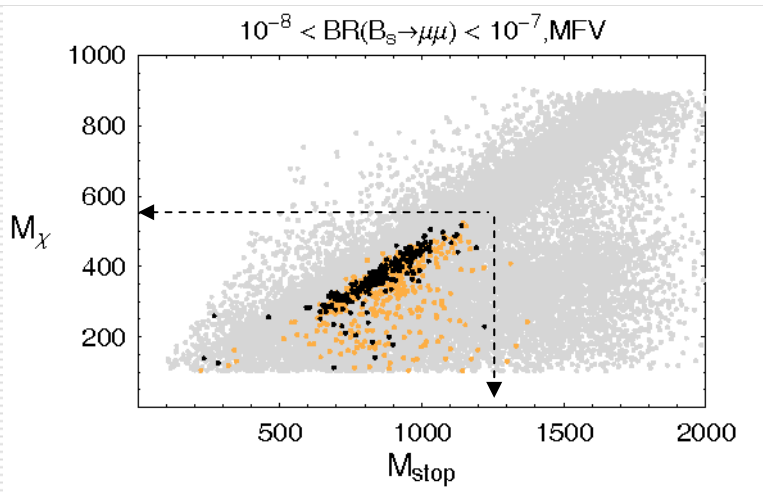


Summary

- Interplay between g-2, $b \to s\gamma$ and $B \to \tau\nu$
- Impact on $B_s \to \mu\mu$ and ΔM_{Bs}
- Dark matter scenarios (Higgsino domination)





Summary

- Interplay between g-2, $b \to s\gamma$ and $B \to \tau\nu$
- Impact on $B_s \to \mu\mu$ and ΔM_{Bs}
- Dark matter scenarios (Higgsino "domination")
- Large tan(β) phenomenology