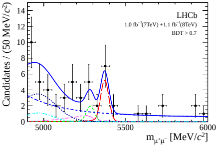
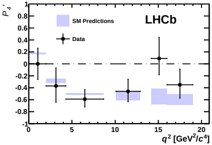
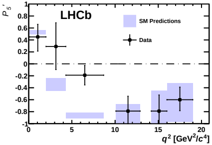
SUSY facing $b \to s\ell\ell$

Nazila Mahmoudi

LPC Clermont-Ferrand & CERN TH







Flavor of New Physics in b → s transitions

IHP Paris, June 2 - 3, 2014

B physics observables are essential in the search for new physics

B factories: important results in particular for inclusive $b \to s$ transitions

LHC:

- First observation of $B_s \to \mu^+\mu^-$
- Another important decay: $B \to K^*\mu^+\mu^-$

  $\to$ large variety of experimentally accessible observables using angular distributions

  $\to$ complementary information

  $\to$ issue of hadronic uncertainties in exclusive modes

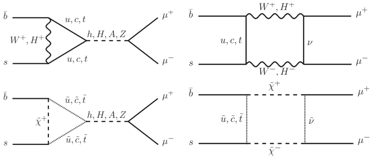
BR($B_s \to \mu^+\mu^-$)

Relevant operators:

$$O_{10} = \frac{e^2}{(4\pi)^2}(\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu\gamma_5\ell)$$

$$Q_1 = \frac{e^2}{16\pi^2}(\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\,\ell)$$

$$Q_2 = \frac{e^2}{16\pi^2}(\bar{s}_L^\alpha b_R^\alpha)(\bar{\ell}\gamma_5\ell)$$



$$\mathrm{BR}(B_s \to \mu^+\mu^-) = \frac{G_F^2\alpha^2}{64\pi^3} f_{B_s}^2 \tau_{B_s} m_{B_s}^3 |V_{tb}V_{ts}^*|^2 \sqrt{1 - \frac{4m_\mu^2}{m_{B_s}^2}}$$
$$\times \left\{ \left(1 - \frac{4m_\mu^2}{m_{B_s}^2}\right) \left|C_{Q_1} - C'_{Q_1}\right|^2 + \left|(C_{Q_2} - C'_{Q_2}) + 2\,(C_{10} - C'_{10})\frac{m_\mu}{m_{B_s}}\right|^2 \right\}$$

Largest contributions in SM from a Z penguin top loop (75%) and a W box diagram (24%)

First experimental evidence:

$$\mathrm{BR}(B_s \to \mu^+\mu^-) = (3.2^{+1.4}_{-1.2}(\mathrm{stat})^{+0.5}_{-0.3}(\mathrm{syst})) \times 10^{-9}$$

LHCb, Phys. Rev. Lett. 110 (2013) 021801

Combined LHCb/CMS result: $\mathrm{BR}(B_s \to \mu^+\mu^-) = (2.9 \pm 0.7) \times 10^{-9}$

CMS PAS BPH-13-007, LHCb-CONF-2013-012

→ Measurement consistent with the SM prediction!
→ Crucial to have a clear estimation of the uncertainties!

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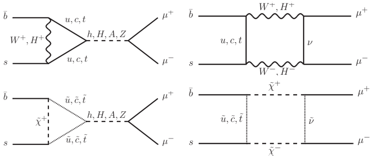

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In the large $\tan\beta$ region, the largest contribution to C_{Q_1} and C_{Q_2} comes from the chargino-stop loops:

$$C_{Q_1} \approx -C_{Q_2} \approx -\mu A_t \frac{\tan^3\beta}{(1+\epsilon_b \tan\beta)^2} \frac{m_t^2}{m_{\tilde{t}}^2} \frac{m_b m_\mu}{4\sin^2\theta_W M_W^2 M_A^2} f(x_{\tilde{t}\mu})$$

where

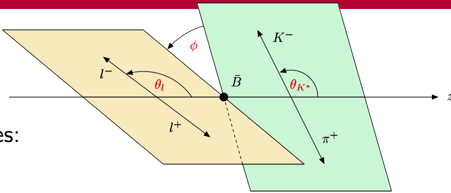
$x_{\tilde{t}\mu} = m_{\tilde{t}}^2/\mu^2$

$m_{\tilde{t}}$: geometric average of the two stop masses

$$f(x) = -\frac{x}{1-x} - \frac{x}{(1-x)^2}\ln x$$

Since $f(x) > 0$ the sign of C_{Q_1} is opposite to that of the μA_t term

Angular distributions



The full angular distribution of the decay $\bar{B}^0 \to \bar{K}^{*0} \ell^+ \ell^-$ ($\bar{K}^{*0} \to K^- \pi^+$) is completely described by four independent kinematic variables: q^2 (dilepton invariant mass squared), θ_ℓ, θ_{K^*}, ϕ

Differential decay distribution:

$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_\ell\, d\cos\theta_{K^*}\, d\phi} = \frac{9}{32\pi} J(q^2, \theta_\ell, \theta_{K^*}, \phi)$$

$J(q^2, \theta_\ell, \theta_{K^*}, \phi) = \sum_i J_i(q^2)\, f_i(\theta_\ell, \theta_{K^*}, \phi)$

↘ angular coefficients J_{1-9}

↘ functions of the spin amplitudes A_0, $A_\parallel$, $A_\perp$, A_t, and A_S

Spin amplitudes: functions of Wilson coefficients and form factors

Main operators:

$$O_9 = \frac{e^2}{(4\pi)^2}(\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu \ell), \quad O_{10} = \frac{e^2}{(4\pi)^2}(\bar{s}\gamma^\mu b_L)(\bar{\ell}\gamma_\mu\gamma_5 \ell)$$
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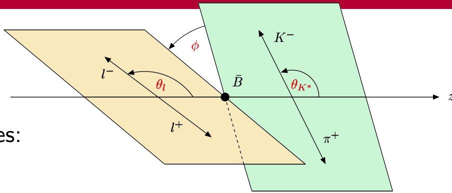
F. Kruger et al., Phys. Rev. D 61 (2000) 114028;
W. Altmannshofer et al., JHEP 0901 (2009) 019; U. Egede et al., JHEP 1010 (2010) 056

$B \to K^* \mu^+ \mu^-$ – Angular distributions

Angular distributions



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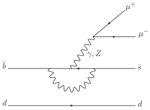
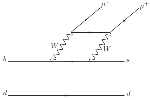




F. Kruger et al., Phys. Rev. D 61 (2000) 114028;

W. Altmannshofer et al., JHEP 0901 (2009) 019; U. Egede et al., JHEP 1010 (2010) 056

Dilepton invariant mass spectrum: $\frac{d\Gamma}{dq^2} = \frac{3}{4}\left(J_1 - \frac{J_2}{3}\right)$

Forward backward asymmetry:

$$A_{\rm FB}(q^2) \equiv \left[\int_{-1}^{0} - \int_{0}^{1}\right] d\cos\theta_l \, \frac{d^2\Gamma}{dq^2\, d\cos\theta_l} \Big/ \frac{d\Gamma}{dq^2} = \frac{3}{8} J_6 \Big/ \frac{d\Gamma}{dq^2}$$

Forward backward asymmetry zero-crossing: $q_0^2 \simeq -2 m_b m_B \frac{C_9^{\rm eff}(q_0^2)}{C_7} + O(\alpha_s, \Lambda/m_b)$

$\to$ fix the sign of C_9/C_7

Polarization fractions:

$$F_L(q^2) = \frac{|A_0|^2}{|A_0|^2 + |A_{||}|^2 + |A_\perp|^2}, \quad F_T(q^2) = 1 - F_L(q^2) = \frac{|A_\perp|^2 + |A_{||}|^2}{|A_0|^2 + |A_{||}|^2 + |A_\perp|^2}$$

Transverse asymmetries:

$$A_T^{(1)}(q^2) = \frac{-2\Re(A_{||} A_\perp^*)}{|A_\perp|^2 + |A_{||}|^2} \qquad A_T^{(2)}(q^2) = \frac{|A_\perp|^2 - |A_{||}|^2}{|A_\perp|^2 + |A_{||}|^2}$$

$$A_T^{(3)}(q^2) = \frac{|A_{0L} A_{||L}^* + A_{0R}^* A_{||R}|}{\sqrt{|A_0|^2 |A_\perp|^2}} \qquad A_T^{(4)}(q^2) = \frac{|A_{0L} A_{\perp L}^* - A_{0R}^* A_{\perp R}|}{|A_{0L} A_{||L}^* + A_{0R}^* A_{||R}|}$$

D. Becirevic, E. Schneider, Nucl. Phys. B854 (2012) 321

Low-q^2 region: $1\ \mathrm{GeV}^2 < q^2 < 6\ \mathrm{GeV}^2$

- method of QCD-improved Factorization (QCDF)
- Soft-Collinear Effective Theory (SCET)

Simplifications:

- heavy b-quark
- energetic K^* meson

These simplifications allow to design a set of **optimized** observables P_i and P_i'
$\to$ soft form factor dependence cancels out at leading order in α_s and Λ/m_b

High-q^2 region: $q^2 \gtrsim (14 - 15)\ \mathrm{GeV}^2$

- Local Operator Product Expantion applicable

Hadronic uncertainties well under control in the low-recoil region. But very small sensitivity to the Wilson coefficients in which potential NP contributions enter

Optimised: form factor uncertainties cancel at leading order

$$\langle P_1 \rangle_{\rm bin} = \frac{1}{2} \frac{\int_{\rm bin} dq^2 [J_3 + \bar{J}_3]}{\int_{\rm bin} dq^2 [J_{2s} + \bar{J}_{2s}]} \qquad \langle P_2 \rangle_{\rm bin} = \frac{1}{8} \frac{\int_{\rm bin} dq^2 [J_{6s} + \bar{J}_{6s}]}{\int_{\rm bin} dq^2 [J_{2s} + \bar{J}_{2s}]}$$

$$\langle P_4' \rangle_{\rm bin} = \frac{1}{\mathcal{N}'_{\rm bin}} \int_{\rm bin} dq^2 [J_4 + \bar{J}_4] \qquad \langle P_5' \rangle_{\rm bin} = \frac{1}{2\mathcal{N}'_{\rm bin}} \int_{\rm bin} dq^2 [J_5 + \bar{J}_5]$$

$$\langle P_6' \rangle_{\rm bin} = \frac{-1}{2\mathcal{N}'_{\rm bin}} \int_{\rm bin} dq^2 [J_7 + \bar{J}_7] \qquad \langle P_8' \rangle_{\rm bin} = \frac{-1}{\mathcal{N}'_{\rm bin}} \int_{\rm bin} dq^2 [J_8 + \bar{J}_8]$$

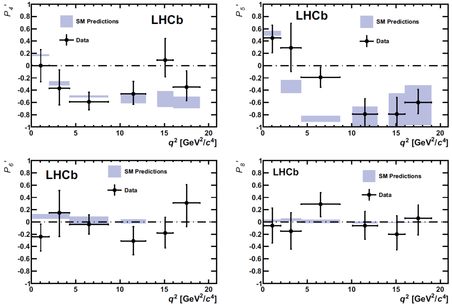
with

$$\mathcal{N}'_{\rm bin} = \sqrt{- \int_{\rm bin} dq^2 [J_{2s} + \bar{J}_{2s}] \int_{\rm bin} dq^2 [J_{2c} + \bar{J}_{2c}]}$$

+ CP violating clean observables and other combinations

U. Egede et al., JHEP 0811 (2008) 032, JHEP 1010 (2010) 056
J. Matias et al., JHEP 1204 (2012) 104
S. Descotes-Genon et al., JHEP 1305 (2013) 137

First observation of new angular observables in $B \to K^* \mu^+ \mu^-$



LHCb collaboration, arXiv:1308.1707 [hep-ex]

3.7σ local discrepancy in one of the q^2 bins

(P_5', $4.3 < q^2 < 8.68$ GeV^2)

Possible explanations:

- Statistical fluctuations
- Underestimation of hadronic uncertainties
- New Physics!

S. Descotes-Genon, J. Matias, J. Virto, arXiv:1307.5683
W. Altmannshofer, D. M. Straub, arXiv:1308.1501
R. Gauld, F. Goertz, U. Haisch, arXiv:1308.1959, arXiv:1310.1082
F. Beaujean, C. Bobeth, D. van Dyk, arXiv:1310.2478
R.R. Horgan, Z. Liu, S. Meinel, M. Wingate, arXiv:1310.3887

Global analysis of the latest LHCb data under the hypothesis of

Minimal Flavour Violation

→ need for new flavour structure?

Relevant operators:

$$O_7,\ O_8,\ O_9,\ O_{10} \quad \text{and} \quad Q_{1-2} \propto (\bar{s} P_R b)(\bar{\mu} P_L \mu) \equiv O_0^l$$

NP manisfests itself in the shifts of the individual coefficients with respect to the SM values:

$$C_i(\mu) = C_i^{\rm SM}(\mu) + \delta C_i$$

→ Scans over the values of δC_7, δC_8, δC_9, δC_{10}, δC_0^l

→ Calculation of flavour observables

→ Comparison with experimental results

→ Constraints on the Wilson coefficients C_i

→ Prediction for other flavour observables

Observables

$\rightarrow$ Global fits of the $\Delta F = 1$ observables obtained by minimization of

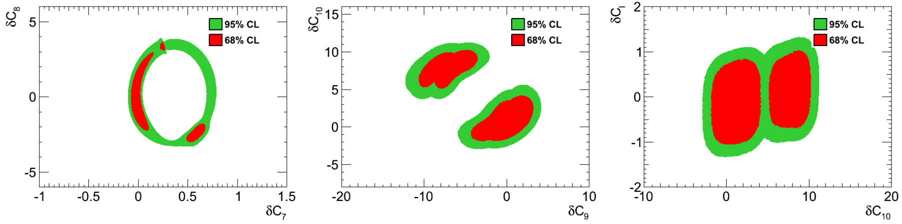
$$\chi^2 = \left(\vec{O}^{\rm th} - \vec{O}^{\rm exp}\right) \cdot \Sigma^{-1} \cdot \left(\vec{O}^{\rm th} - \vec{O}^{\rm exp}\right)$$

Σ^{-1} is the inverse correlation matrix.

Observables:

- $\mathrm{BR}(B \to X_s \gamma)$
- $\mathrm{BR}(B \to X_d \gamma)$
- $\Delta_0(B \to K^* \gamma)$
- $\mathrm{BR}^{\rm low}(B \to X_s \mu^+ \mu^-)$
- $\mathrm{BR}^{\rm high}(B \to X_s \mu^+ \mu^-)$
- $\mathrm{BR}(B_s \to \mu^+ \mu^-)$
- $\mathrm{BR}(B_d \to \mu^+ \mu^-)$
- $B \to K^* \mu^+ \mu^-$
  P_1, P_2, P_4', P_5', P_6', P_8', BR, F_L
  in 5 bins of q^2:
  [0.1,2], [2,4.3], [4.3,8.68], [14.18,16], [16,19] GeV^2

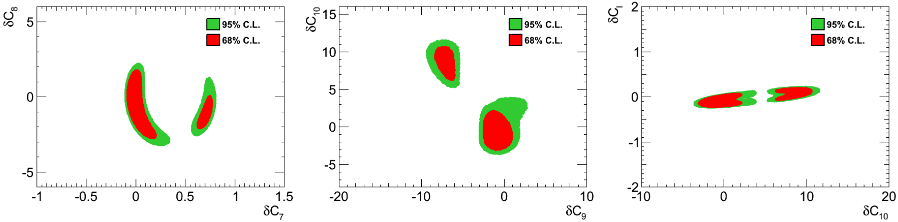
Before LHCb:



T. Hurth, FM, Nucl.Phys. B865 (2012) 461

- C_8 mostly constrained by $B \to X_{s,d}\gamma$
- C_7 constrained by the other observables as well
- $C_{9,10}$ constrained by $B \to X_s\mu^+\mu^-$ and $B \to K^*\mu^+\mu^-$
- C_l mostly constrained by $B_s \to \mu^+\mu^-$

With the latest LHCb results



T. Hurth, FM, JHEP 1404 (2014) 097

Strong impact from the new LHCb results on the fits!

Constrained MSSM

CMSSM:

- MSSM with GUT scale universality assumptions
  $\rightarrow$ 4 parameters + 1 sign
- Useful for benchmarking, model discrimination,...
- However the mass patterns could be more complicated

General MSSM

Phenomenological MSSM (pMSSM):

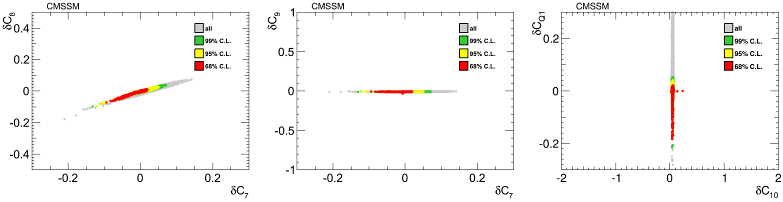
- The most general CP/R parity-conserving MSSM
- Minimal Flavour Violation at the TeV scale
- The first two sfermion generations are degenerate
- The three trilinear couplings are general for the 3 generations

$\rightarrow$ 19 free parameters

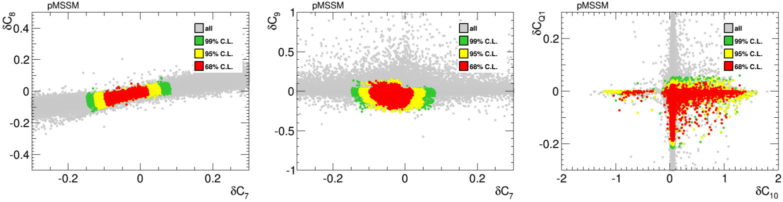
10 sfermion masses, 3 gaugino masses, 3 trilinear couplings, 3 Higgs/Higgsino

A. Djouadi et al., hep-ph/9901246

CMSSM:

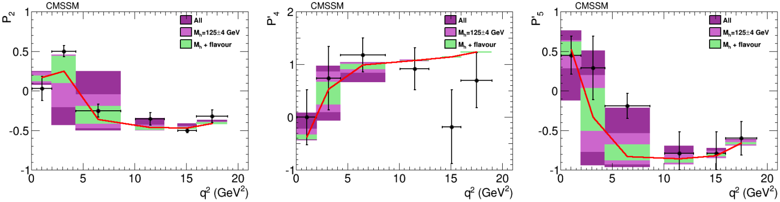


pMSSM

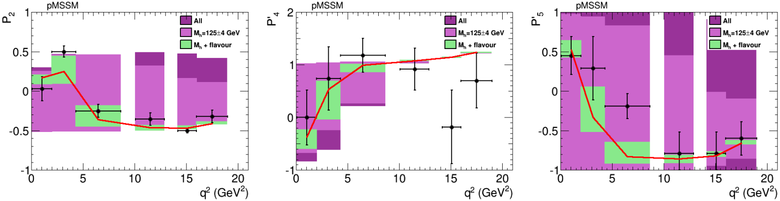


FM, S. Neshatpour, J. Virto, arXiv:1401.2145

CMSSM:



pMSSM



FM, S. Neshatpour, J. Virto, arXiv:1401.2145

Red lines: SM predictions

CMSSM with m_0 and $m_{1/2}$ varied, $\mu > 0$, $A_0 = -2\, m_0$ and $\tan\beta$ fixed:

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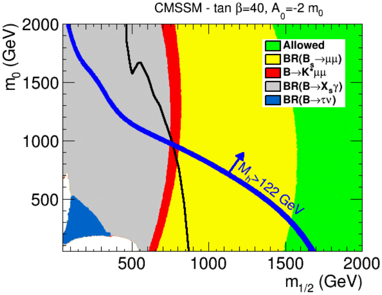

FM, S. Neshatpour, J. Virto, arXiv:1401.2145

Black line: ATLAS exclusion limit with 20.3 fb^{-1} data

Blue line: Higgs mass exclusion limit ($M_h = 122$ GeV)

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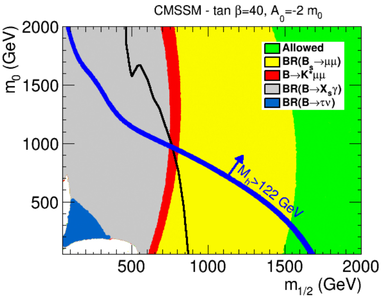

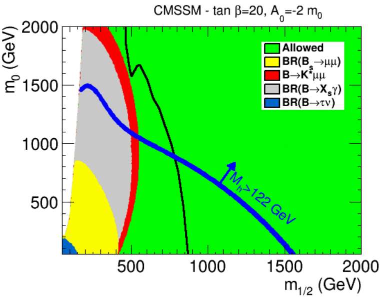

FM, S. Neshatpour, J. Virto, arXiv:1401.2145

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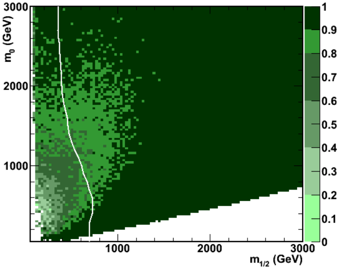
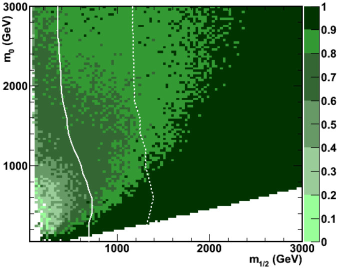
CMSSM with all parameters varied:

Fraction of CMSSM points compatible with BR($B_s \to \mu^+\mu^-$)

Current constraints



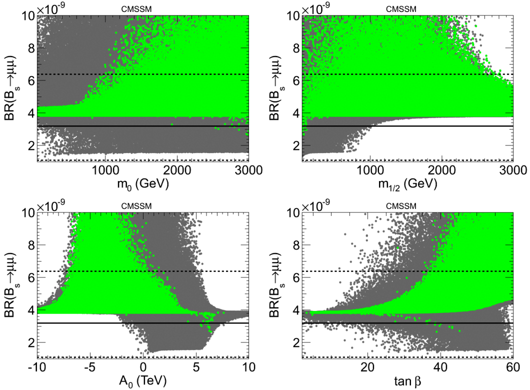
Ultimate constraints



A. Arbey, M. Battaglia, FM, D. Martinez Santos, Phys.Rev. D87 (2013) 035026

Continuous line: ATLAS SUSY searches at 8 TeV with 5.8 fb^{-1} of data
Dotted line: reach estimated at 14 TeV with 300 fb^{-1}

Flat scans over the CMSSM parameters with $\mu > 0$



Solid line: central value of the BR($B_s \to \mu^+\mu^-$) measurement

Dashed lines: 2σ experimental deviations

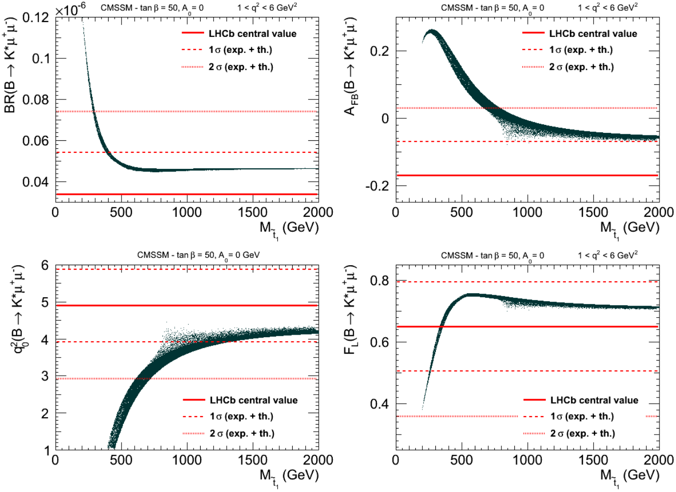
Gray points: all valid points

Green points: points in agreement with the Higgs mass constraint

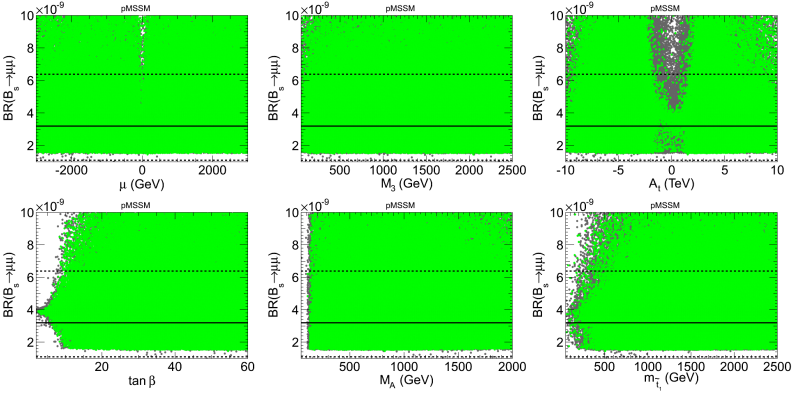
A. Arbey, M. Battaglia, FM, D. Martinez Santos, Phys.Rev. D87 (2013) 035026

BR($B_s \to \mu^+\mu^-$) smaller than SM and the Higgs mass constraint cannot be satisfied simultaneously!!

$B \to K^* \mu^+ \mu^-$ in the low q^2 region: CMSSM - $\tan\beta = 50$



A_{FB} in the low q^2 region is especially interesting!



A. Arbey, M. Battaglia, FM, D. Martinez Santos, Phys.Rev. D87 (2013) 035026

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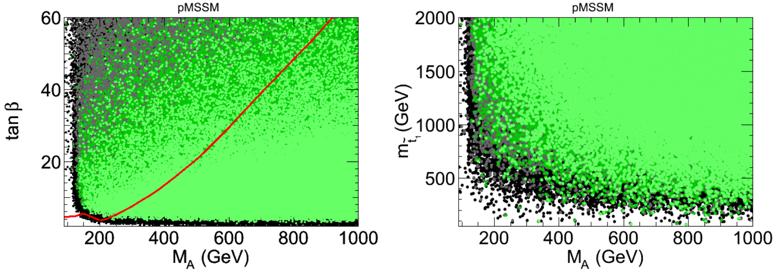
Gray points: all valid points
Green points: points in agreement with the Higgs mass constraint



A. Arbey, M. Battaglia, FM, D. Martinez Santos, Phys.Rev. D87 (2013) 035026

Black points: all the valid pMSSM points

Gray points: $123 < M_h < 129$ GeV

Dark green points: in agreement with the latest BR($B_s \to \mu^+\mu^-$)

Light green points: in agreement with the ultimate LHCb BR($B_s \to \mu^+\mu^-$) measurement

Red line: excluded at 95% C.L. by the latest CMS $A/H \to \tau^+\tau^-$ searches

- $B \to K^* \mu^+ \mu^-$ offers multiple sensitive observables
- Latest LHCb results for the optimised observables have a very important impact on the global fits
- No need for any new flavour structure with the current measurements
- Important constraints from both $B_s \to \mu^+ \mu^-$ and $B \to K^* \mu^+ \mu^-$ decays in the MSSM
- MSSM still provides solutions in global agreement with all the available data for $b \to s\ell\ell$ transitions

Backup

Observable	Experiment	SM prediction
$\mathrm{BR}(B \to X_s\gamma)$	$(3.43 \pm 0.21 \pm 0.07) \times 10^{-4}$	$(3.09 \pm 0.24) \times 10^{-4}$
$\Delta_0(B \to K^*\gamma)$	$(5.2 \pm 2.6) \times 10^{-2}$ **??** ± 0.09	$(7.9 \pm 3.9) \times 10^{-2}$
$\mathrm{BR}(B \to X_d\gamma)$	$(1.41 \pm 0.57) \times 10^{-5}$	$(1.49 \pm 0.30) \times 10^{-5}$
$\mathrm{BR}(B_s \to \mu^+\mu^-)$	$(2.9 \pm 0.7) \times 10^{-9}$	$(3.49 \pm 0.38) \times 10^{-9}$
$\mathrm{BR}(B_d \to \mu^+\mu^-)$	$(3.6 \pm 1.6) \times 10^{-10}$	$(1.07 \pm 0.27) \times 10^{-10}$
$\mathrm{BR}(B \to X_s\mu^+\mu^-)_{q^2\in[1,6]\mathrm{GeV}^2}$	$(1.60 \pm 0.68) \times 10^{-6}$	$(1.73 \pm 0.16) \times 10^{-6}$
$\mathrm{BR}(B \to X_s\mu^+\mu^-)_{q^2>14.4\mathrm{GeV}^2}$	$(4.18 \pm 1.35) \times 10^{-7}$	$(2.20 \pm 0.44) \times 10^{-7}$
$\langle dBR/dq^2(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[0.1,2]\mathrm{GeV}^2}$	$(0.60 \pm 0.06 \pm 0.05 \pm 0.04 \pm 0.05) \times 10^{-7}$	$(0.70 \pm 0.81) \times 10^{-7}$
$\langle F_L(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[0.1,2]\mathrm{GeV}^2}$	$0.37 \pm 0.10 \pm 0.04$	0.32 ± 0.20
$\langle P_1(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[0.1,2]\mathrm{GeV}^2}$	$-0.19 \pm 0.40 \pm 0.02$	-0.01 ± 0.04
$\langle P_2(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[0.1,2]\mathrm{GeV}^2}$	$0.03 \pm 0.15 \pm 0.01$	0.17 ± 0.02
$\langle P_4'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[0.1,2]\mathrm{GeV}^2}$	$0.00 \pm 0.52 \pm 0.06$	-0.37 ± 0.03
$\langle P_5'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[0.1,2]\mathrm{GeV}^2}$	$0.45 \pm 0.22 \pm 0.09$	0.52 ± 0.04
$\langle P_6'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[0.1,2]\mathrm{GeV}^2}$	$0.24 \pm 0.22 \pm 0.05$	-0.05 ± 0.04
$\langle P_8'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[0.1,2]\mathrm{GeV}^2}$	$-0.12 \pm 0.56 \pm 0.04$	0.02 ± 0.04
$\langle dBR/dq^2(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[2,4.3]\mathrm{GeV}^2}$	$(0.30 \pm 0.03 \pm 0.03 \pm 0.02 \pm 0.02) \times 10^{-7}$	$(0.35 \pm 0.29) \times 10^{-7}$
$\langle F_L(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[2,4.3]\mathrm{GeV}^2}$	$0.74 \pm 0.10 \pm 0.03$	0.76 ± 0.20
$\langle P_1(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[2,4.3]\mathrm{GeV}^2}$	$-0.29 \pm 0.65 \pm 0.03$	-0.05 ± 0.05
$\langle P_2(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[2,4.3]\mathrm{GeV}^2}$	$0.50 \pm 0.08 \pm 0.02$	0.25 ± 0.09
$\langle P_4'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[2,4.3]\mathrm{GeV}^2}$	$0.74 \pm 0.58 \pm 0.16$	0.54 ± 0.07
$\langle P_5'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[2,4.3]\mathrm{GeV}^2}$	$0.29 \pm 0.39 \pm 0.07$	-0.33 ± 0.11
$\langle P_6'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[2,4.3]\mathrm{GeV}^2}$	$-0.15 \pm 0.38 \pm 0.05$	-0.06 ± 0.06
$\langle P_8'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[2,4.3]\mathrm{GeV}^2}$	$-0.3 \pm 0.58 \pm 0.14$	0.04 ± 0.05
$\langle dBR/dq^2(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[4.3,8.68]\mathrm{GeV}^2}$	$(0.49 \pm 0.04 \pm 0.04 \pm 0.03 \pm 0.04) \times 10^{-7}$	$(0.48 \pm 0.53) \times 10^{-7}$
$\langle F_L(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[4.3,8.68]\mathrm{GeV}^2}$	$0.57 \pm 0.07 \pm 0.03$	0.63 ± 0.14
$\langle P_1(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[4.3,8.68]\mathrm{GeV}^2}$	$0.36 \pm 0.31 \pm 0.03$	-0.11 ± 0.06
$\langle P_2(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[4.3,8.68]\mathrm{GeV}^2}$	$-0.25 \pm 0.08 \pm 0.02$	-0.36 ± 0.05
$\langle P_4'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[4.3,8.68]\mathrm{GeV}^2}$	$1.18 \pm 0.30 \pm 0.10$	0.99 ± 0.03
$\langle P_5'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[4.3,8.68]\mathrm{GeV}^2}$	$-0.19 \pm 0.16 \pm 0.03$	-0.83 ± 0.05
$\langle P_6'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[4.3,8.68]\mathrm{GeV}^2}$	$0.04 \pm 0.15 \pm 0.05$	-0.02 ± 0.06
$\langle P_8'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[4.3,8.68]\mathrm{GeV}^2}$	$0.58 \pm 0.38 \pm 0.06$	0.02 ± 0.06
$\langle dBR/dq^2(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[14.18,16]\mathrm{GeV}^2}$	$(0.56 \pm 0.06 \pm 0.04 \pm 0.04 \pm 0.05) \times 10^{-7}$	$(0.67 \pm 1.17) \times 10^{-7}$
$\langle F_L(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[14.18,16]\mathrm{GeV}^2}$	$0.33 \pm 0.08 \pm 0.03$	0.39 ± 0.24
$\langle P_1(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[14.18,16]\mathrm{GeV}^2}$	$0.07 \pm 0.28 \pm 0.02$	-0.32 ± 0.70
$\langle P_2(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[14.18,16]\mathrm{GeV}^2}$	$-0.50 \pm 0.03 \pm 0.01$	-0.47 ± 0.14
$\langle P_4'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[14.18,16]\mathrm{GeV}^2}$	$-0.18 \pm 0.70 \pm 0.08$	1.15 ± 0.33
$\langle P_5'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[14.18,16]\mathrm{GeV}^2}$	$-0.79 \pm 0.20 \pm 0.18$	-0.82 ± 0.36
$\langle P_6'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[14.18,16]\mathrm{GeV}^2}$	$0.18 \pm 0.25 \pm 0.03$	0.00 ± 0.00
$\langle P_8'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[14.18,16]\mathrm{GeV}^2}$	$-0.40 \pm 0.60 \pm 0.06$	0.00 ± 0.01
$\langle dBR/dq^2(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[16,19]\mathrm{GeV}^2}$	$(0.41 \pm 0.04 \pm 0.04 \pm 0.03 \pm 0.03) \times 10^{-7}$	$(0.43 \pm 0.78) \times 10^{-7}$
$\langle F_L(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[16,19]\mathrm{GeV}^2}$	$0.38 \pm 0.09 \pm 0.03$	0.36 ± 0.13
$\langle P_1(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[16,19]\mathrm{GeV}^2}$	$-0.71 \pm 0.35 \pm 0.06$	-0.55 ± 0.59
$\langle P_2(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[16,19]\mathrm{GeV}^2}$	$-0.32 \pm 0.08 \pm 0.01$	-0.41 ± 0.15
$\langle P_4'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[16,19]\mathrm{GeV}^2}$	$0.70 \pm 0.52 \pm 0.06$	1.24 ± 0.25
$\langle P_5'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[16,19]\mathrm{GeV}^2}$	$-0.60 \pm 0.19 \pm 0.09$	-0.66 ± 0.37
$\langle P_6'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[16,19]\mathrm{GeV}^2}$	$-0.31 \pm 0.38 \pm 0.10$	0.00 ± 0.00
$\langle P_8'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[16,19]\mathrm{GeV}^2}$	$0.12 \pm 0.54 \pm 0.04$	0.00 ± 0.04
$\langle dBR/dq^2(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[1,6]\mathrm{GeV}^2}$	$(0.34 \pm 0.03 \pm 0.04 \pm 0.02 \pm 0.03) \times 10^{-7}$	$(0.38 \pm 0.33) \times 10^{-7}$
$\langle F_L(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[1,6]\mathrm{GeV}^2}$	$0.65 \pm 0.08 \pm 0.03$	0.70 ± 0.21
$\langle P_1(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[1,6]\mathrm{GeV}^2}$	$0.15 \pm 0.41 \pm 0.03$	-0.06 ± 0.04
$\langle P_2(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[1,6]\mathrm{GeV}^2}$	$0.33 \pm 0.12 \pm 0.02$	0.10 ± 0.08
$\langle P_4'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[1,6]\mathrm{GeV}^2}$	$0.58 \pm 0.36 \pm 0.06$	0.53 ± 0.07
$\langle P_5'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[1,6]\mathrm{GeV}^2}$	$0.21 \pm 0.21 \pm 0.03$	-0.34 ± 0.10
$\langle P_6'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[1,6]\mathrm{GeV}^2}$	$0.18 \pm 0.21 \pm 0.03$	-0.05 ± 0.05
$\langle P_8'(B \to K^*\mu^+\mu^-)\rangle_{q^2\in[1,6]\mathrm{GeV}^2}$	$0.46 \pm 0.38 \pm 0.04$	0.03 ± 0.04

Flat scans over the 19 parameters:

Parameter	Range (in GeV)
$\tan\beta$	[1, 60]
M_A	[50, 2000]
M_1	[-2500, 2500]
M_2	[-2500, 2500]
M_3	[50, 2500]
$A_d = A_s = A_b$	[-10000, 10000]
$A_u = A_c = A_t$	[-10000, 10000]
$A_e = A_\mu = A_\tau$	[-10000, 10000]
μ	[-3000, 3000]
$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	[50, 2500]
$M_{\tilde{e}_R} = M_{\tilde{\mu}_R}$	[50, 2500]
$M_{\tilde{\tau}_L}$	[50, 2500]
$M_{\tilde{\tau}_R}$	[50, 2500]
$M_{\tilde{q}_{1L}} = M_{\tilde{q}_{2L}}$	[50, 2500]
$M_{\tilde{q}_{3L}}$	[50, 2500]
$M_{\tilde{u}_R} = M_{\tilde{c}_R}$	[50, 2500]
$M_{\tilde{t}_R}$	[50, 2500]
$M_{\tilde{d}_R} = M_{\tilde{s}_R}$	[50, 2500]
$M_{\tilde{b}_R}$	[50, 2500]

~100M points generated with Softsusy

Flavour constraints with SuperIso

Theory prediction: CP-averaged quantities, effect of $B_s - \bar{B}_s$ oscillations disregarded
Experimental measurement: untagged branching fraction

K. De Bruyn et al., Phys. Rev. D86, 014027; Phys. Rev. Lett. 109, 041801 (2012)

$$\mathrm{BR}(B_s \to \mu^+\mu^-)_{\mathrm{untag}} = \left(\frac{1 + \mathcal{A}_{\Delta\Gamma}\, y_s}{1 - y_s^2}\right) \mathrm{BR}(B_s \to \mu^+\mu^-)$$

with

$$y_s \equiv \frac{1}{2}\tau_{B_s}\Delta\Gamma_s = 0.088 \pm 0.014$$

$$\mathcal{A}_{\Delta\Gamma} = \frac{|P|^2\cos(2\varphi_P) - |S|^2\cos(2\varphi_S)}{|P|^2 + |S|^2}$$

S and P are related to the Wilson coefficients by:

$$S = \sqrt{1 - 4\frac{m_\mu^2}{M_{B_s}^2}}\,\frac{M_{B_s}^2}{2m_\mu}\,\frac{1}{m_b + m_s}\,\frac{C_{Q_1} - C'_{Q_1}}{C_{10}^{SM}}\;, \qquad P = \frac{C_{10}}{C_{10}^{SM}} + \frac{M_{B_s}^2}{2m_\mu}\,\frac{1}{m_b + m_s}\,\frac{C_{Q_2} - C'_{Q_1}}{C_{10}^{SM}}$$

$$\varphi_S = \arg(S)\;, \qquad \varphi_P = \arg(P)$$

The SM expectation for this corrected branching fraction is:

$$\mathrm{BR}(B_s \to \mu^+\mu^-)_{\mathrm{untag}} = (3.87 \pm 0.46) \times 10^{-9}$$

Main source of uncertainty: f_{B_s}

- ETMC-11: $\mathbf{232 \pm 10}$ MeV
- HPQCD-12: $\mathbf{227 \pm 10}$ MeV
  HPQCD NR-09: 231 ± 15 MeV
  HPQCD HISQ-11: 225 ± 4 MeV
- Fermilab-MILC-11: $\mathbf{242 \pm 9.5}$ MeV

Our choice: 234 ± 10 MeV

With the most up-to-date input parameters (PDG), in particular $\tau_{B_s} = 1.497$ ps:

SM prediction: $\mathrm{BR}(B_s \to \mu^+\mu^-) = (3.53 \pm 0.38) \times 10^{-9}$

FM, S. Neshatpour, J. Orloff, JHEP 1208 (2012) 092

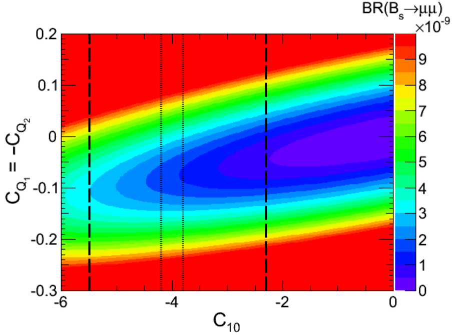
Most important sources of uncertainties:

	f_{B_s}	EW cor.	scales	τ_{B_s}	V_{ts}	top mass	Overall
Uncertainty	8%	2%	2%	2%	5%	1.3%	$\sim$ **10%**

Using $f_{B_s} = 227$ MeV and $\tau_{B_s} = 1.466$ ps, one gets: $\mathrm{BR}(B_s \to \mu^+\mu^-) = 3.25 \times 10^{-9}$

A. Buras et al. Eur.Phys.J. C72 (2012) 2172

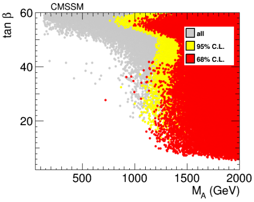
Constraints on pMSSM

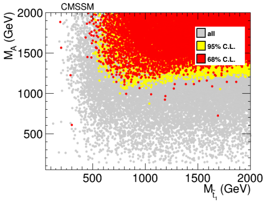


A. Arbey, M. Battaglia, FM, D. Martinez Santos, Phys.Rev. D87 (2013) 035026

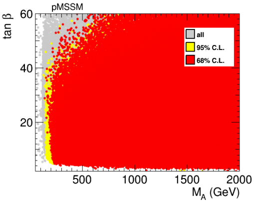
Dotted vertical lines: delimit the range of C_{10} in the CMSSM
Dashed lines: delimit the range of C_{10} in the pMSSM.

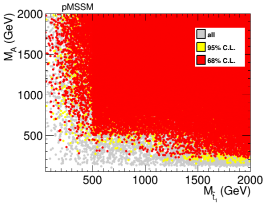
CMSSM:





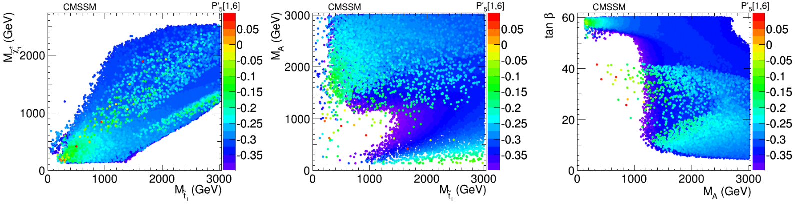
pMSSM



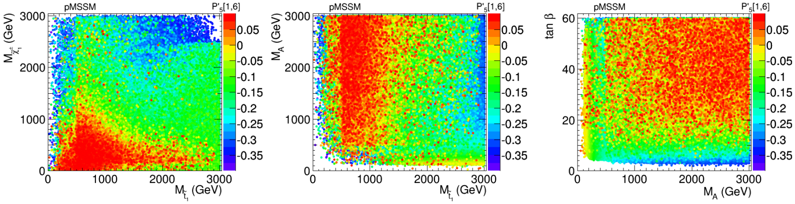


FM, S. Neshatpour, J. Virto, arXiv:1401.2145

CMSSM:



pMSSM



FM, S. Neshatpour, J. Virto, arXiv:1401.2145