Impacts of recent LHCb results on NP models

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- Introduction
- The impact of $B_s \to \mu\mu$
- ϕ_s and CKM fits
- Future prospects (on CPV)

Introduction:

Key open questions in flavour physics (high-intensity frontier):

- *What determines the observed pattern of masses and mixing angles of quarks and leptons?*
- *Which are the sources of flavour symmetry breaking accessible at low energies?* [Is there anything else beside SM Yukawa couplings & neutrino mass matrix?]

↕

Key open questions in electroweak physics (high-energy frontier):

- *What determines the Fermi scale?*
- *Is there anything else beyond the SM Higgs at the TeV scale?*

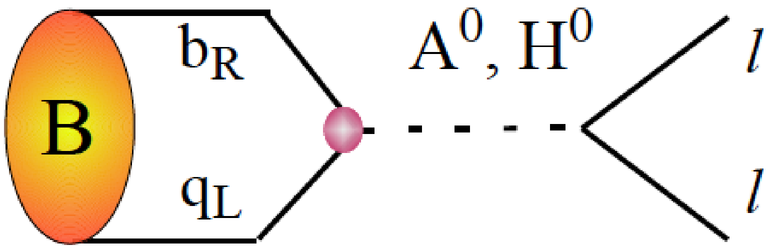
Introduction:

Even if we have not discovered (yet...) new phenomena, some significant progress has been achieved:

- On the flavour side, we have understood that large new sources of flavour symmetry breaking at the TeV scale are excluded. In my opinion, this points toward almost exact flavour symmetry + weakly interacting NP at the TeV (such as susy with some flavour symmetry).
- This picture is perfectly coherent with
    - e.w. precision tests
    - lack of large deviations from the SM at high-pT
- According to this picture, deviations from the SM are small, but by no means un-observables. The key tool to make progress is to push forward the precision in the most clean observables.

The impact of $B_s \to \mu\mu$

The set (*) of purely leptonic FCNC decays of $B_{s,d}$ mesons is the most sensitive probe on possible scalar-type FCNCs (naturally expected in any model with an extended Higgs sector).



E.g.: SUSY at large $\tan\beta$ with MFV

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

(*) *N.B.: there are 6 independent LF conserving channels + 6 LFV channels*

$$B(B_s \to \mu\mu)_{SM} = 3.2(2)\ 10^{-9}$$

$$B(B_d \to \mu\mu)_{SM} = 1.0(1)\ 10^{-10}$$

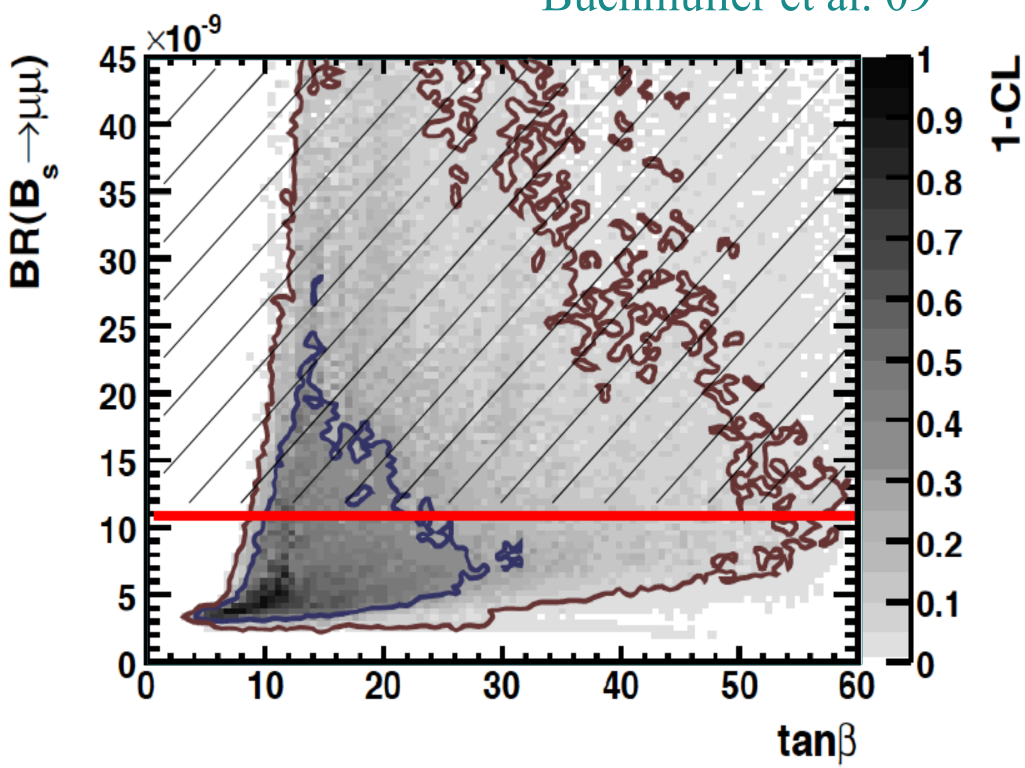
e channels suppressed by $(m_e/m_\mu)^2$

τ channels enhanced by $(m_\tau/m_\mu)^2$

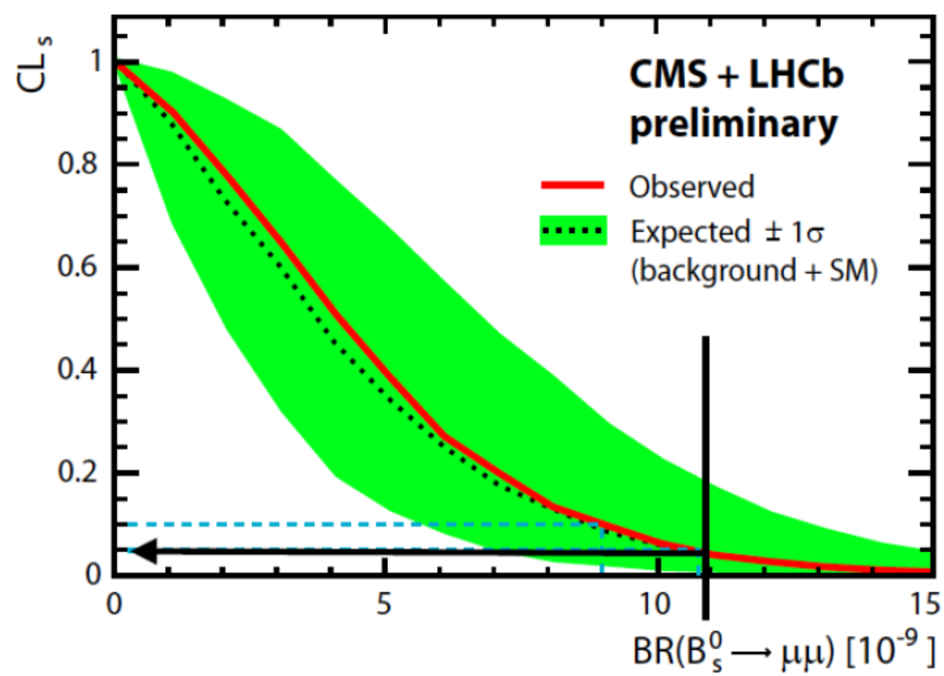
The impact of $B_s \to \mu\mu$

The recent LHCb+CMS bounds have excluded a significant portion of the available parameter space in various SUSY models, but there is still a lot to learn from more precise measurements.

Buchmuller et al. 09



G. Raven, LP '11



$< 11\times10^{-9}$ @ 95% CL

NHUM1 model
(CMSSM with non-univ. Higgs soft masses)

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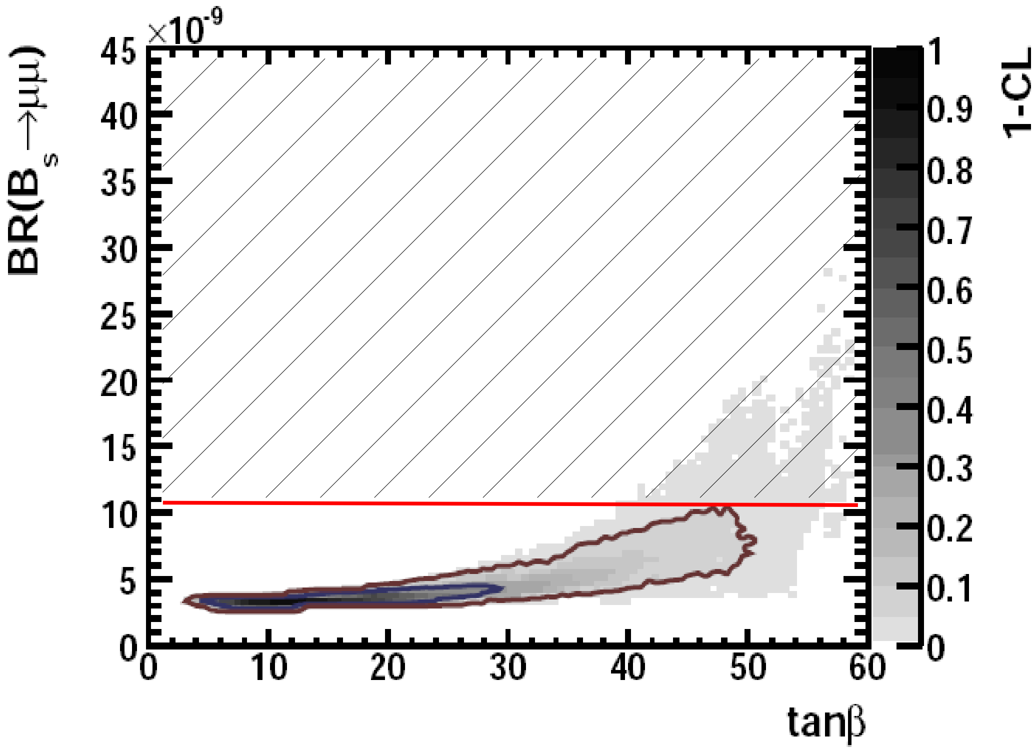
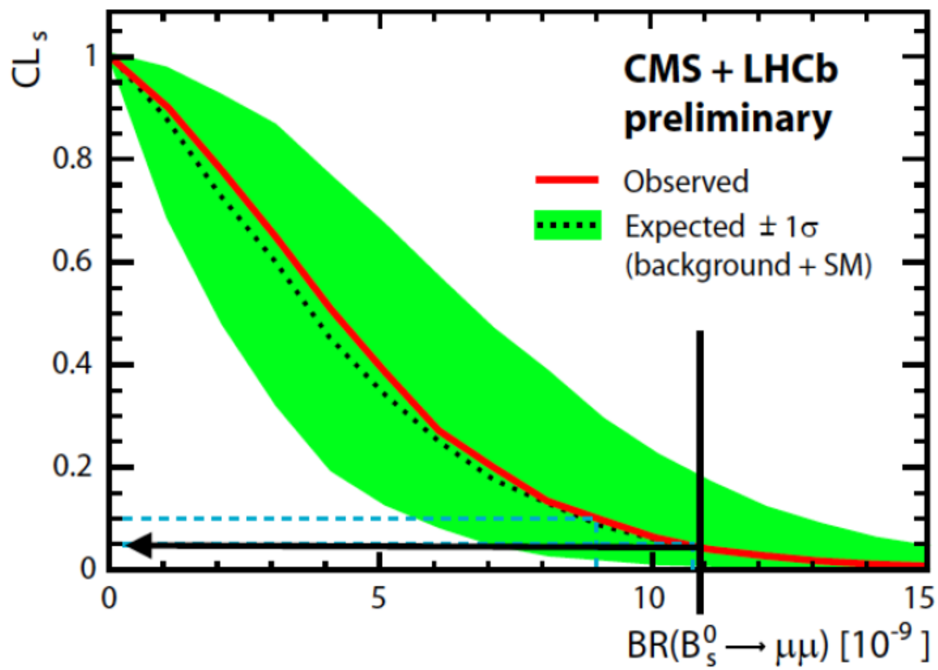


Pure CMSSM

G. Raven, LP '11



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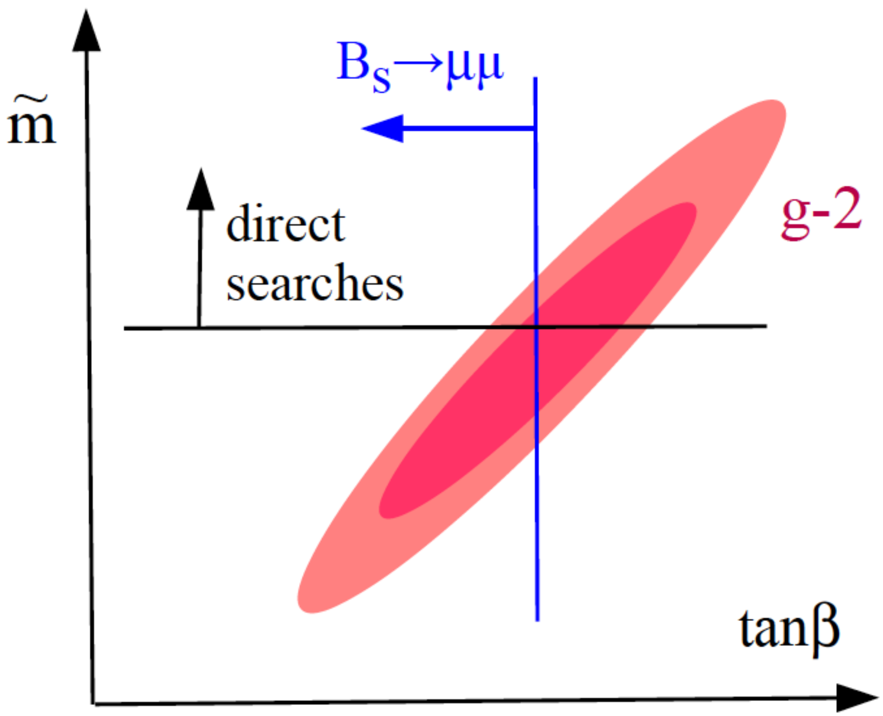


The interplay of $B_s \to \mu\mu$ with g-2 and the direct searches is one of the main problem of the MSSM with (almost) degenerate sfermion masses.

ϕ_s and CKM fits

Despite the overall success of the standard picture...

...there are still a few "*anomalies*" that is worth to *investigate* in more detail.

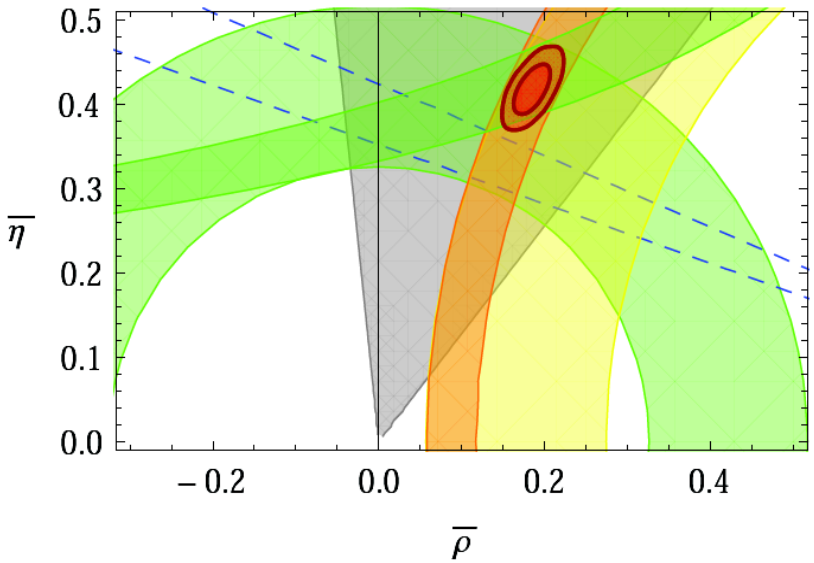
Most interesting case (in my opinion):

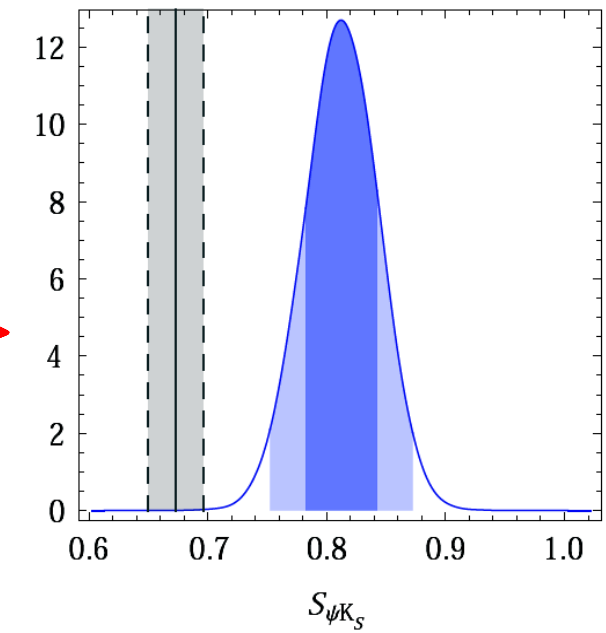
the ε_K - $\sin(2\beta)$ tension in the CKM fit

The ε_K - sin(2β) tension in the CKM fit:

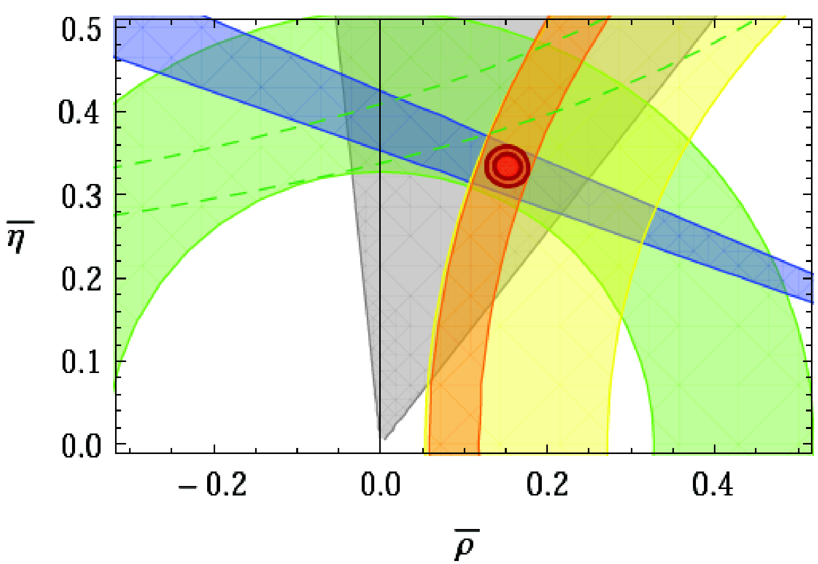
Barbieri *et al.* '11

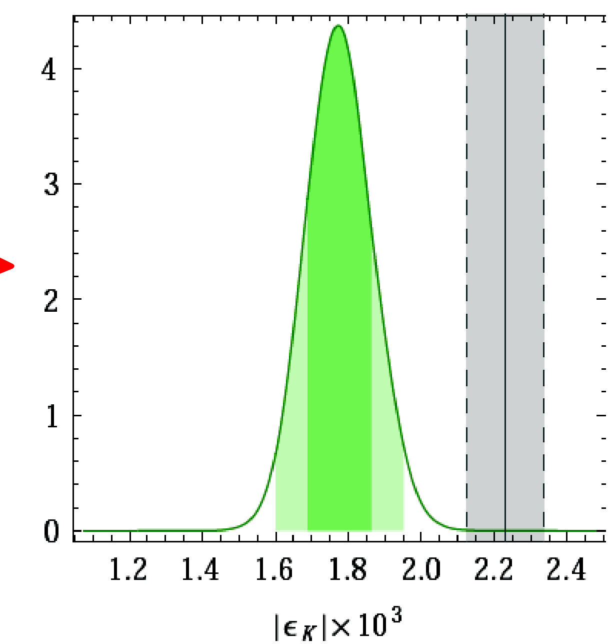
I. SM fit, no $S_{\Psi K}$





II. SM, no ε_K





Similar results by CKMfitter & UTfit

This "anomaly" fits well with a well-motivated attempt to go beyond MFV:

MFV virtue

Naturally small effects in FCNC observables

MFV main open problems

No explanation for small CPV flavor-conserving observables (edms)

No explanation for *Y* hierarchies (masses and mixing angles)

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No explanation for *Y* hierarchies (masses and mixing angles)

A solutions of both these problems is obtained in the so-called "effective susy" framework:

Susy + horizontal U(2) flavor symmetry acting on the first two generations only, such that $\tilde{m}_1 = \tilde{m}_2 \gg \tilde{m}_3$

Dimopulos, Giudice, '95
Cohen, Kaplan, Nelson '96

Dine, Leigh, Kagan, '93
Pomarol, Tommasini, '96
Barbieri, Dvali, Hall, '96
Barbieri, Hall, Romanino, 97

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Naturally small effects in FCNC observables

Effective susy with a U(2) flavour symmetry

Naturally small CPV flavor-conserving observables (edms)

Partial explanation for *Y* hierarchies ($|V_{td}/V_{ts}| = \vartheta_d = (m_d/m_s)^{1/2}$, ...)

Well motivated beyond flavor physics...
(hierarchy problem + non-observation of SUSY so far)

...not efficient as MFV in FCNC observables
(too large flavor-violating effects in the RH sector)

- Fine-tuning in the kaon system (ε_K & ε')
- Sizable non-standard CPV phases in $\Delta B=1$ obs.

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Effective susy with a U(2) flavour symmetry

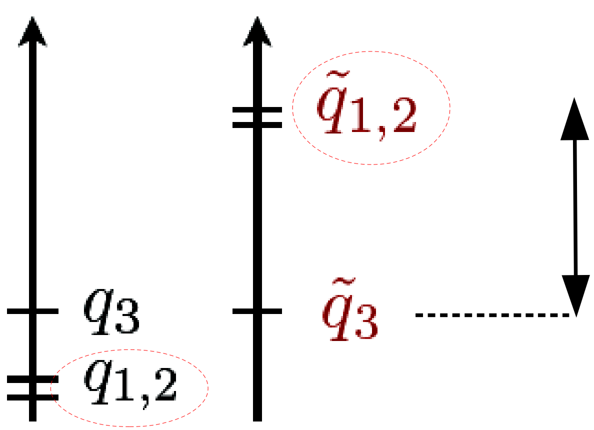
Naturally small effects in FCNC observables

Naturally small CPV flavor-conserving observables (edms)

Partial explanation for *Y* hierarchies

Effective susy with a U(2)^3 = $U(2)_{Q_L} \times U(2)_{U_R} \times U(2)_{D_R}$ flavor symmetry

Barbieri, G.I., Jones-Perez, Lodone, Straub, '11



Large mass gap (several TeV) not controlled by flavor symmetries (as opposite to MFV) and fine-tuning considerations

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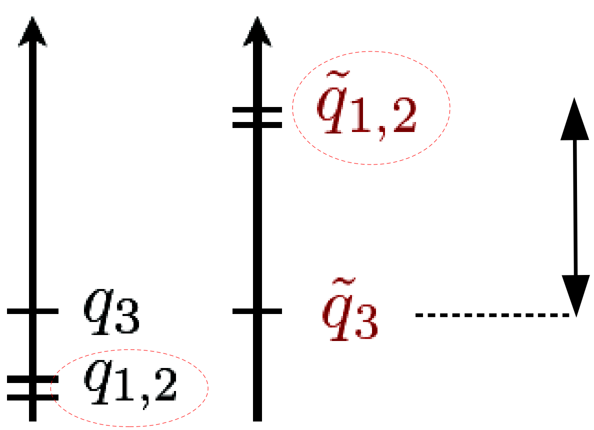
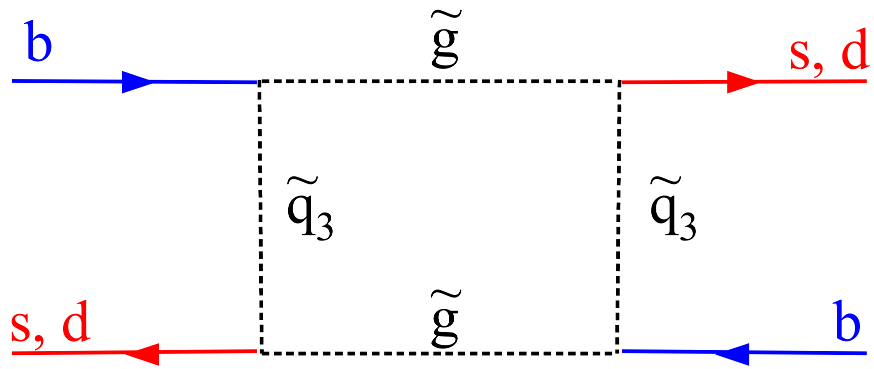


Exact symmetry is a good approximation to the SM quark spectrum ($m_u=m_d= m_s=m_c=0$, $V_{CKM}=1$)

=> we only need <u>small breaking terms</u>

Effective susy with U(2)^3

The leading and most clean deviations from the SM are expected in meson-anti-meson mixing, from gluino-box diagrams:



- Correction to K^0 mixing aligned in phase with the SM amplitude, with definite sign (constructive interference)
- New CPV appearing in $B_{s,d}$ mixing (in a universal way)

Equivalent to non-linear MFV
(Feldmann, Mannel, '08; Kagan *et al*. '09)

⬇

Solution of the "ε_K - sin(2β) tension" + clean predictions for the LHC

Effective susy with $U(2)^3$

Two clean predictions for the LHC:

I. Small non standard CPV in B_s mixing

$$S_{\psi K}^{U(2)} = 0.12 \pm 0.05$$

$$\left[\ S_{\psi K}^{SM} = 0.041 \pm 0.01\ \right]$$

↓

Interesting challenge for LHCb !!

II. Relatively "light" gluinos and 3rd generation squarks

$$m_{\tilde{g}},\ m_{\tilde{q}_3} < 1.0,\ \ 1.5\ \text{TeV}$$

Compatible with present ATLAS & CMS data, within their near-future reach

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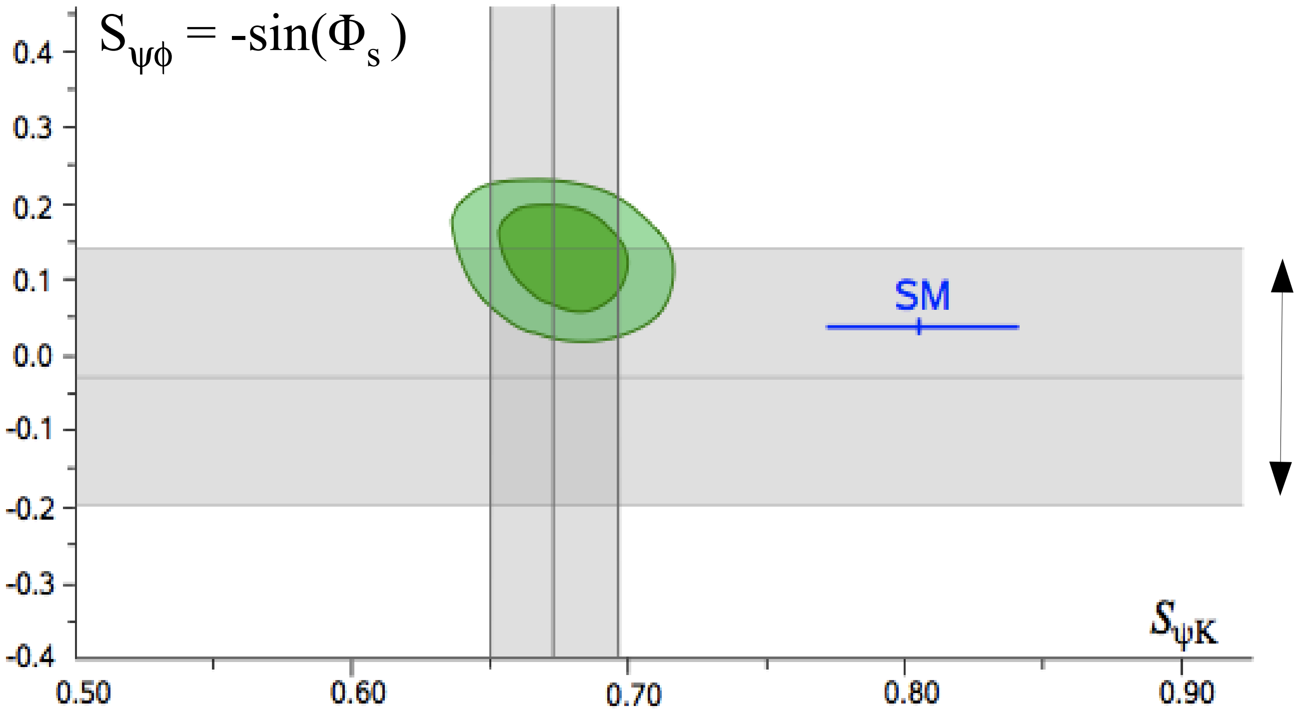

1σ, prelim. LHCb result (LP2011)

$-\Phi_s^{exp} = -0.03 \pm 0.16 \pm 0.07$

Not easy to distinguish form the SM, but not impossible...

N.B.: the LHCb result has already allowed us to rule out the wide (and interesting) class of models where $\Delta\Phi_s \gg \Delta\Phi_d$

I. Small non standard CPV in B_s mixing

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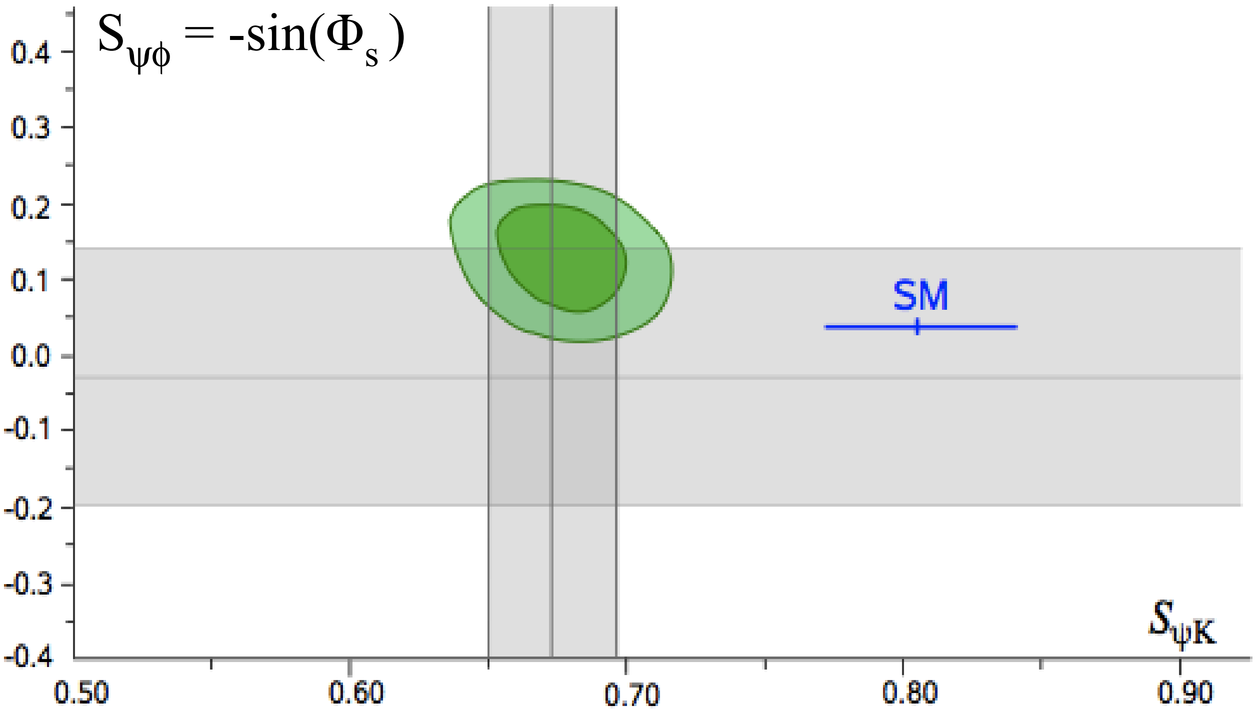


1σ, prelim. LHCb result (LP2011)

$-\Phi_s^{exp} = -0.03 \pm 0.16 \pm 0.07$

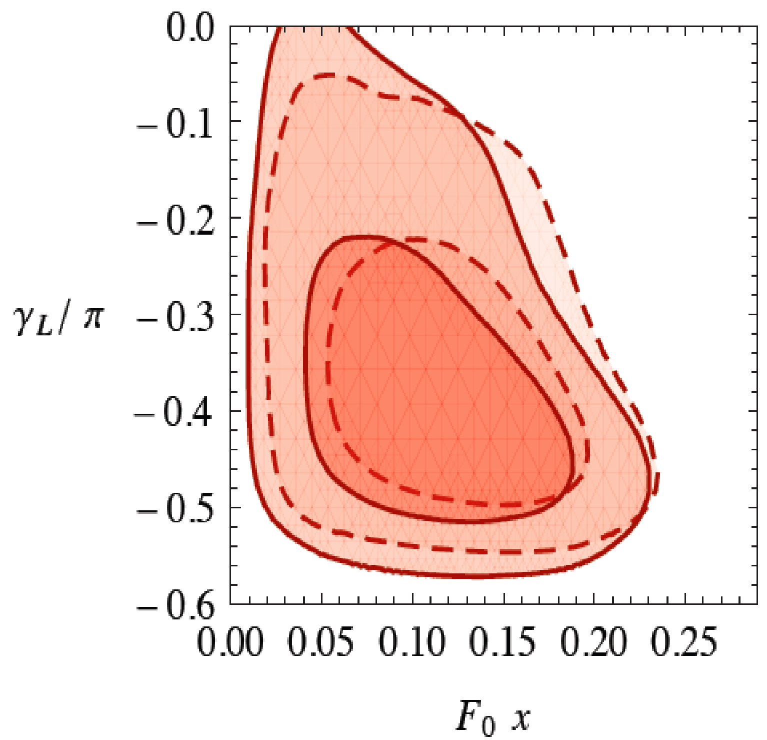
Representative example of the type of non-standard effects we should search for in the more "conservative" NP models (or the models which naturally survives the recent LHC bounds

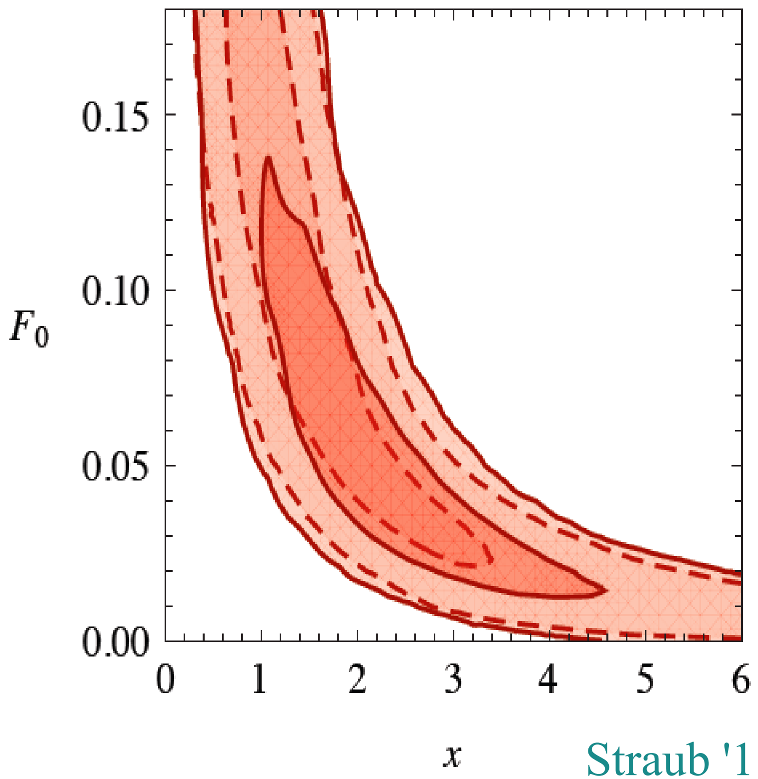
N.B.: also in the $U(2)^3$ framework the recent LHCb measurement has some impact (although quite limited at present) on the parameter space of the model.

$$\varepsilon_K = \varepsilon_K^{\mathrm{SM(tt)}} \times \left(1 + x^2 F_0\right) + \varepsilon_K^{\mathrm{SM(tc+cc)}},$$

$$S_{\psi K_S} = \sin\left(2\beta + \arg\left(1 + xF_0 e^{2i\gamma_L}\right)\right), \qquad \Delta M_d = \Delta M_d^{\mathrm{SM}} \times \left|1 + xF_0 e^{2i\gamma_L}\right|,$$

$$S_{\psi\phi} = \sin\left(2|\beta_s| - \arg\left(1 + xF_0 e^{2i\gamma_L}\right)\right), \qquad \Delta M_d/\Delta M_s = \Delta M_d^{\mathrm{SM}}/\Delta M_s^{\mathrm{SM}},$$





$$x = \frac{s_L^2 c_d^2}{|V_{ts}^2|} = O(1)$$

$$F_0 = F_0(m_{\tilde{b}_L}, m_{\tilde{g}})$$

Straub '11

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$$S_{\psi\phi} = \sin\left(2|\beta_s| - \arg\left(1 + xF_0 e^{2i\gamma_L}\right)\right), \qquad \Delta M_d/\Delta M_s = \Delta M_d^{\rm SM}/\Delta M_s^{\rm SM},$$

N.B.: beside the particularly clean pattern of deviations from the SM in DF=2 observables, some (more model-dependent) effect is expected also in CP-violating DF=1 observables (e.g. $B_s \to \varphi\varphi$, T-odd correlations in $B \to K^*\mu\mu$, ...)

Future prospects on CPV (a personal perspective)

We should aim a significant step forward in clarifying the room for NP in CP-violating $\Delta F=2$ amplitudes

Operator	Bounds on Λ (TeV)		Bounds on c_{ij} ($\Lambda = 1$ TeV)		Observables
	Re	Im	Re	Im	
$(\bar{s}_L\gamma^\mu d_L)^2$	9.8×10^2	1.6×10^4	9.0×10^{-7}	3.4×10^{-9}	$\Delta m_K;\ \varepsilon_K$
$(\bar{s}_R d_L)(\bar{s}_L d_R)$	1.8×10^4	3.2×10^5	6.9×10^{-9}	2.6×10^{-11}	$\Delta m_K;\ \varepsilon_K$
$(\bar{c}_L\gamma^\mu u_L)^2$	1.2×10^3	2.9×10^3	5.6×10^{-7}	1.0×10^{-7}	$\Delta m_D;\ \|q/p\|, \phi_D$
$(\bar{c}_R u_L)(\bar{c}_L u_R)$	6.2×10^3	1.5×10^4	5.7×10^{-8}	1.1×10^{-8}	$\Delta m_D;\ \|q/p\|, \phi_D$
$(\bar{b}_L\gamma^\mu d_L)^2$	5.1×10^2	9.3×10^2	3.3×10^{-6}	1.0×10^{-6}	$\Delta m_{B_d};\ S_{B_d\to\psi K}$
$(\bar{b}_R d_L)(\bar{b}_L d_R)$	1.9×10^3	3.6×10^3	5.6×10^{-7}	1.7×10^{-7}	$\Delta m_{B_d};\ S_{B_d\to\psi K}$
$(\bar{b}_L\gamma^\mu s_L)^2$	1.1×10^2	1.1×10^2	7.6×10^{-5}	7.6×10^{-5}	Δm_{B_s}
$(\bar{b}_R s_L)(\bar{b}_L s_R)$	3.7×10^2	3.7×10^2	1.3×10^{-5}	1.3×10^{-5}	Δm_{B_s}

G.I, Nir, Perez '10

$$\mathscr{L}_{\rm eff} = \mathscr{L}_{\rm SM} + \frac{c_{ij}}{\Lambda^2} O_{ij}^{(6)}$$

Future prospects on CPV (a personal perspective)

List of key problems/set-of-observables (related to CPV):

- γ from tree ($B \to DK$, ...)
- $|V_{ub}|$ from exclusive semilept. B decays

↔ Key ingredients to predict ε_K & ϕ_d in the SM (*for which we have good measurements but "poor" predictions*)

- CPV in B_s mixing

- CPV in D mixing

Future prospects on CPV (a personal perspective)

List of key problems/set-of-observables (related to CPV):

- γ from tree ($B \to DK$, ...) → well-known golden channel for LHCb (little to add...)
- $|V_{ub}|$ from exclusive semilept. B decays → Can LHCb say something ?

(maybe $B_s \to K^+\mu\nu$ better than $B_d \to \pi^+\mu\nu$?)

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- CPV in B_s mixing → Add more (clean) channels for ϕ_s

Potentially promising: $\psi + (KK)_{\text{non-res}}$, $D_s^+ D_s^-$

No valence up's, large BRs, (with only charged tracks)

$BR(D_s^+ D_s^-) \sim 1\%$

$BR(D_s \to K\pi\pi) \sim 5\%$

- CPV in D mixing

Future prospects on CPV (a personal perspective)

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  Potentially promising: $\psi + (KK)_{non\text{-}res}$, $D_s^+ D_s^-$

  (maybe also $D_s^* D_s$ or $\phi\psi(\psi \to ee, \text{hadr.})$?)

  even larger BR than $D_s^+ D_s^-$ but no CP eigenstate and γ's from $D_s^* \to D_s \gamma$

- CPV in D mixing

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- CPV in B_s mixing
  - → Add more (clean) channels for ϕ_s
    Potentially promising: $\psi + (KK)_{non\text{-}res}$, $D_s^+ D_s^-$
    (maybe also $D_s^* D_s$ or $\phi\psi(\psi \to ee, \text{hadr.})$?)
  - → Control the penguin pollution in all modes via auxiliary channels (*see next talk*)
- CPV in D mixing

Conclusions

The recent results of LHCb have already had a quite significant impact on our knowledge about flavour physics.

Don't be discouraged by the (so far) negative results concerning NP searches: there are still very good reasons to believe that

- NP is just around the corner !
- LHCb has good chances to determine its flavour structure !

You just need to push forward the precision in the most clean observables.