Rare decays in the SM and MSSM

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FCNC decays of Kaons and B-mesons to be discussed:

- $K_L^0 \to \pi^0 \nu\bar{\nu}$
- $K^+ \to \pi^+ \nu\bar{\nu}$
- $\bar{B} \to X_s \gamma$
- $\bar{B} \to X_s l^+ l^-$
- $B_s^0 \to \mu^+ \mu^-$

Common property:

relatively small hadronic uncertainties

Common framework:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm QCD \times QED} + \mathcal{L}_{\rm weak}$$

$$\mathcal{L}_{\rm weak} \sim \sum_i C_i(\mu) Q_i$$

Fields in the effective theory: b-quark and lighter particles.

Information on electroweak-scale physics is encoded in the values of $C_i(\mu)$.

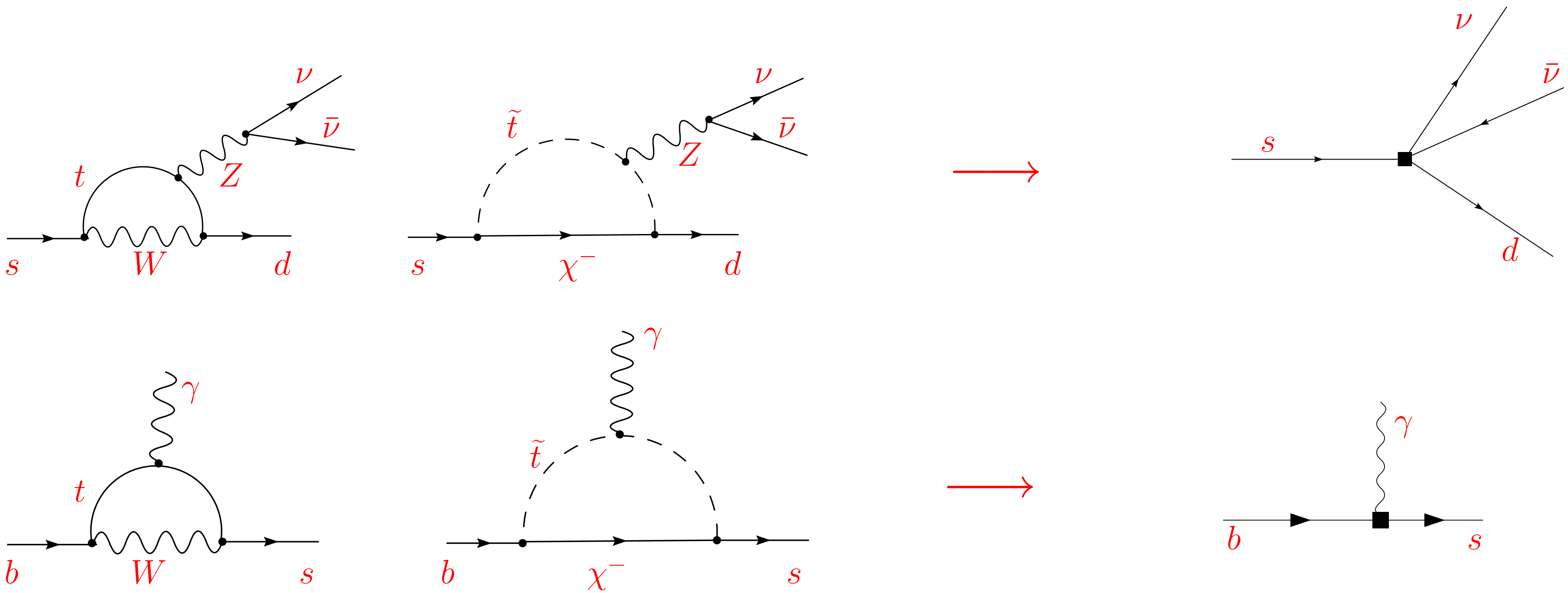
Three steps of the calculation:

- **Matching**: **Finding the Wilson coefficients $C_i(\mu_0)$, $\mu_0 \sim M_W$.**
- **Mixing**: **Calculating anomalous dimensions and evolving $C_i(\mu)$ down to low μ.**
- **Matrix elements**: **Evaluating physical amplitudes at low μ.**

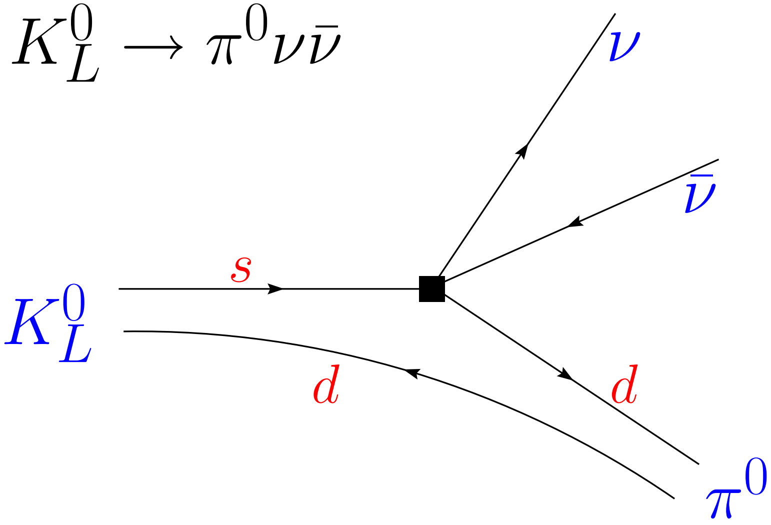
CP-violation in B-physics $\longrightarrow$ G. Hiller
Lepton flavour violation $\longrightarrow$ A. Brignole
} **Plenary talks on Saturday**

Information on electroweak-scale physics is encoded in the values of $C_i(\mu)$.

For instance:



The decay $K_L^0 \to \pi^0 \nu\bar{\nu}$



Dominated by direct CP-violation: both π^0 and S-wave $\nu\bar{\nu}$ are CP-odd.

Non-perturbative matrix element known precisely from the measured $K^+ \to \pi^0 e \overline{\nu_e}$ decay rate.

$$\mathcal{B}(K_L^0 \to \pi^0 \nu\bar{\nu})_{\rm SM} = (2.12 \pm 0.03) \times 10^{-10} \frac{1}{\lambda^5} {\rm Im}(K_{ts}^* K_{td}) \; X\left(\frac{m_t^2}{M_W^2}\right) = (3.0 \pm 0.6) \times 10^{-11}$$

Direct 90% C.L. bound from KTeV (2000):	5.9×10^{-7}
Preliminary direct 90% C.L. bound from E391a @ KEK (June 2005):	2.86×10^{-7}
Indirect 90% C.L. bound from the $K^+ \to \pi^+ \nu\bar{\nu}$ measurements:	1.4×10^{-9}

Future:

J-PARC (Tokai, 2009+): ~ 100 **events at the SM level**
KOPIO (BNL, ?): 40-60 **events at the SM level**

The decay $K^+ \to \pi^+ \nu \bar{\nu}$

Experiment AGS E787 @ BNL: $\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu}) = 14.7^{+13.0}_{-8.9} \times 10^{-11}$

(3 events)

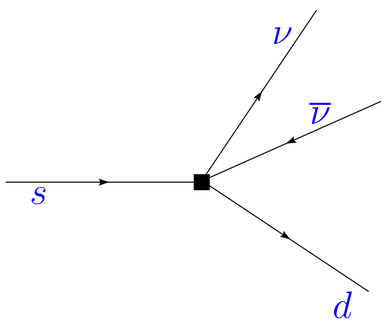
Future:

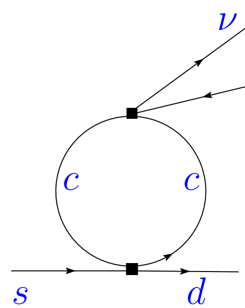
(i) J-PARC (Tokai, 2009+)
(ii) proposal for CERN SPS

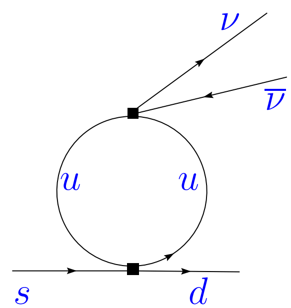
} $\mathcal{O}(100)$ **events at the SM level**

$$\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu})_{\rm SM} = (8.3 \pm 1.2) \times 10^{-11}$$

Three types of contributions to the CP-conserving $s \to d \nu \bar{\nu}$ transition:







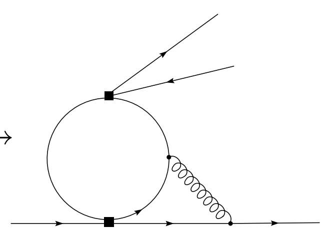
$\mathcal{O}(\lambda^5)$

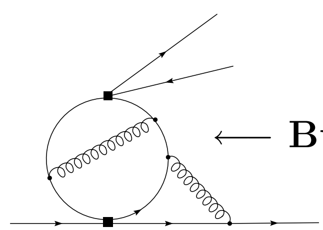
dominant

$$\mathcal{O}\left(\lambda\, m_c^2/M_W^2\right)_{\rm SD} + \mathcal{O}\left(\lambda\, \Lambda_{\rm QCD}^2/M_W^2\right)_{\rm LD}$$

need for $\alpha_s(m_c)^n$ χ**PT** $\Rightarrow$ **small**

Buchalla, Buras $\longrightarrow$
(1994)





$\longleftarrow$ **Buras, Gorbahn, Haisch, Nierste**
(in progress)

The decay $\mathcal{B}(\bar{B} \to X_s \gamma)$

Exp. average (HFAG, hep-ex/0505100)
(Includes CLEO, BELLE and BABAR but not ALEPH)

$$\mathcal{B}(\bar{B} \to X_s\gamma)^{\mathrm{exp}}_{E_\gamma > \frac{m_b}{20}} = \left(3.39\ {}^{+0.30}_{-0.27}\right) \times 10^{-4}$$

$$\Rightarrow \quad \mathcal{B}(\bar{B} \to X_s\gamma)^{\mathrm{exp}}_{E_\gamma > 1.8\mathrm{GeV}} = \left(3.23\ {}^{+0.29}_{-0.26}\right) \times 10^{-4}$$

SM predictions:

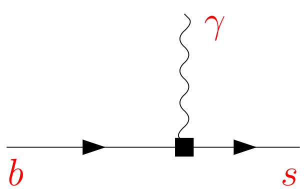
P. Gambino, MM, hep-ph/0104034
A.J. Buras *et al.*, hep-ph/0203135

$$\mathcal{B}(\bar{B} \to X_s\gamma)^{\mathrm{SM}}_{E_\gamma > 1.8\mathrm{GeV}} = (3.53 \pm 0.29) \times 10^{-4}$$

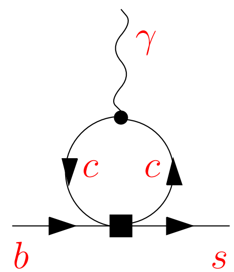
M. Neubert, hep-ph/0408179:

$$\mathcal{B}(\bar{B} \to X_s\gamma)^{\mathrm{SM}}_{E_\gamma > 1.8\mathrm{GeV}} = \left(3.38\ {}^{+0.31}_{-0.42}\ {}^{+0.32}_{-0.30}\right) \times 10^{-4}$$

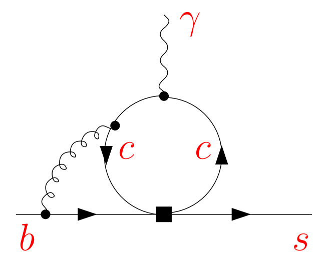
Sample contributions:



pert. **dominant**
non-pert. $\mathcal{O}(\Lambda^2/m_b^2)$
(known)



pert. 0
non-pert. $\mathcal{O}(\Lambda^2/m_c^2)$
(known)



pert. $\mathcal{O}(\alpha_s(m_b))$
non-pert. $\mathcal{O}(\alpha_s(m_b)\ \Lambda/m_b)$
(unknown)

Main source of perturbative uncertainty ($\sim 6\%$): scheme-dependence of m_c at $\mathcal{O}(\alpha_s(m_b))$.

$\Rightarrow$ **NNLO QCD calculation necessary.**

Resummation of large logarithms $\left(\alpha_s \ln \frac{M_W^2}{m_b^2}\right)^n$ in the $b \to s\gamma$ amplitude.

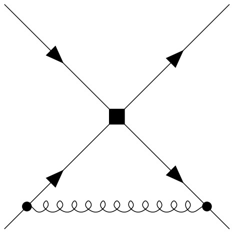
RGE for the Wilson coefficients:

$$\mu \frac{d}{d\mu} C_j(\mu) = C_i(\mu) \gamma_{ij}(\mu)$$

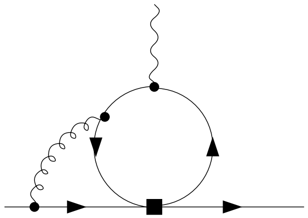
The anomalous dimension matrix γ_{ij} is found from the effective theory renormalization constants, e.g.:

Z_{22} Z_{27} Z_{87}

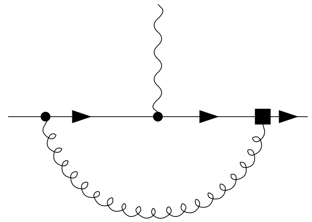
LO



[Gaillard, Lee, 1974]
[Altarelli, Maiani, 1974]

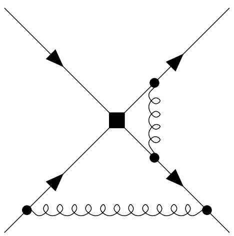


[Grinstein *et al.*, 1990]

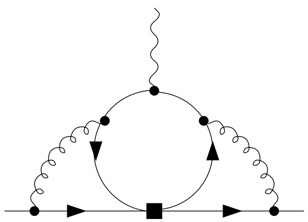


[Shifman *et al.*, 1978]
[Grigjanis *et al.*, 1988]

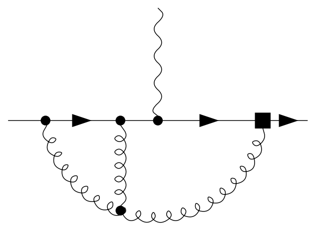
NLO



[Altarelli *et al.*, 1981]
[Buras, Weisz, 1990]

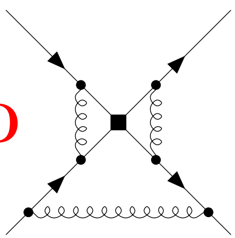


[Chetyrkin *et al.*, 1997]

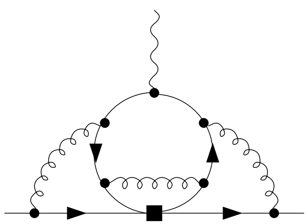


[MM, Münz, 1995]

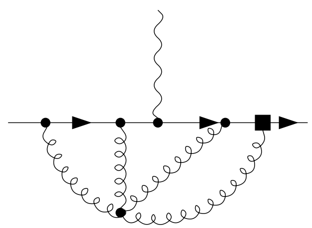
NNLO



[Gorbahn, Haisch, 2004]



in progress:
Czakon *et al.*

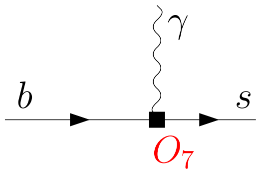


[Gorbahn, Haisch, MM, 2005]
[hep-ph/0504194]

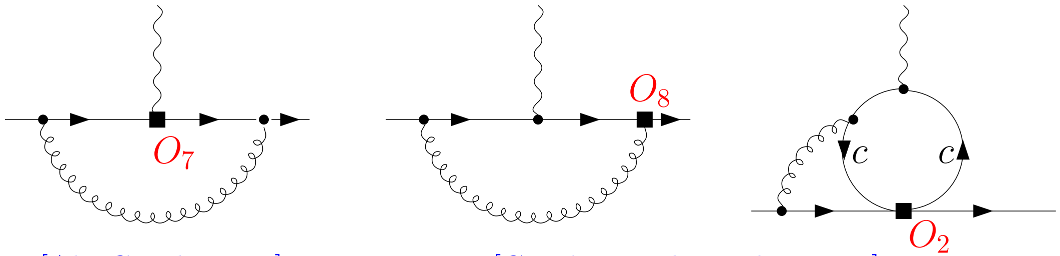
The $b \to s\gamma$ matrix elements

Perturbative on-shell amplitudes:

LO



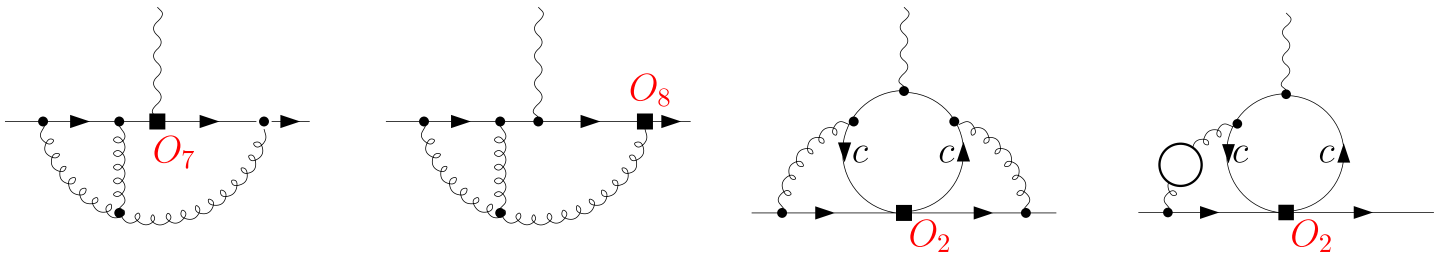
NLO



[Ali, Greub, 1991]

[Greub, Hurth, Wyler, 1996]

NNLO



[Blokland *et al.*, 2005]

in progress: Asatrian, Greub, Hurth

[Bieri, Greub, Steinhauser, 2003]

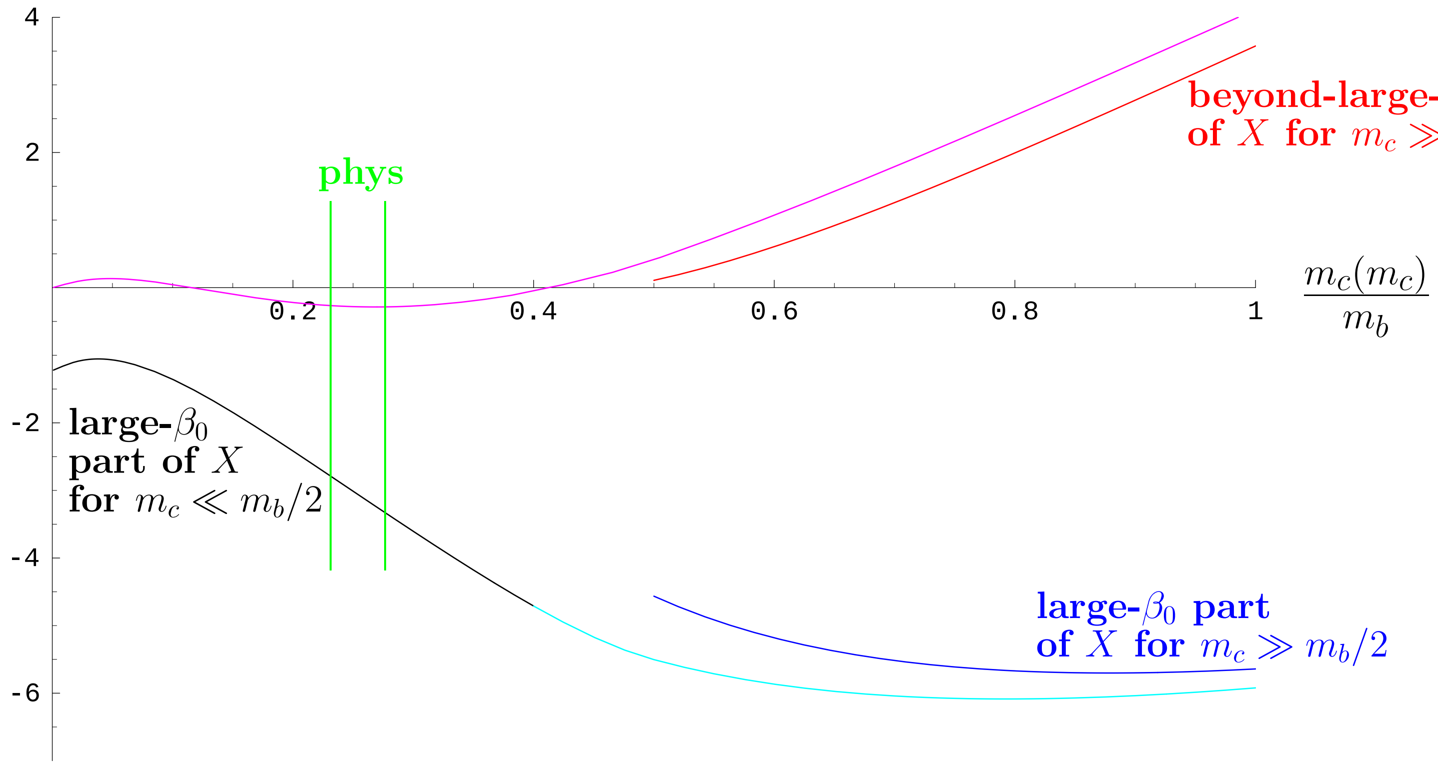
($\Rightarrow$ large-β_0 approximation)

Progress for the beyond-large-β_0 part of 3-loop matrix elements:

M. Steinhauser, MM: **Finding the behaviour for $m_c \gg m_b/2$:** **const + logs of m_c/m_b (done).**

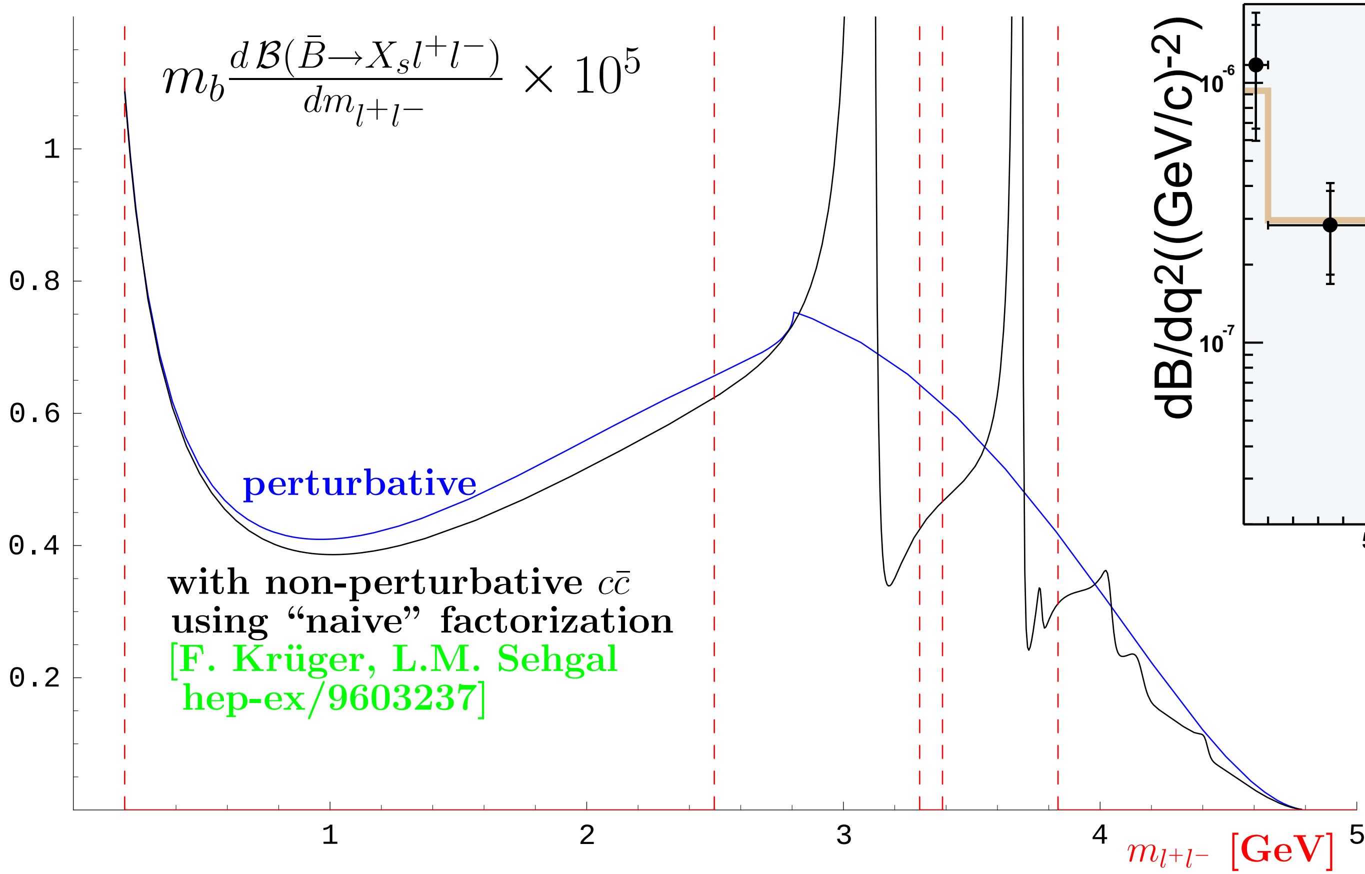
Next: Interpolation to assumed approximate zero at $m_c = 0$.

$$\mathcal{B}(\bar{B} \to X_s \gamma) = \mathcal{B}_0 \left\{ 1 + \frac{\alpha_s}{\pi} F\left(\frac{m_c(m_c)}{m_b}\right) + \left(\frac{\alpha_s(m_b)}{\pi}\right)^2 \left[\mathbf{X}\left(\frac{\mathbf{m_c}}{\mathbf{m_b}}\right) + (\text{other}) \right] \right\}$$

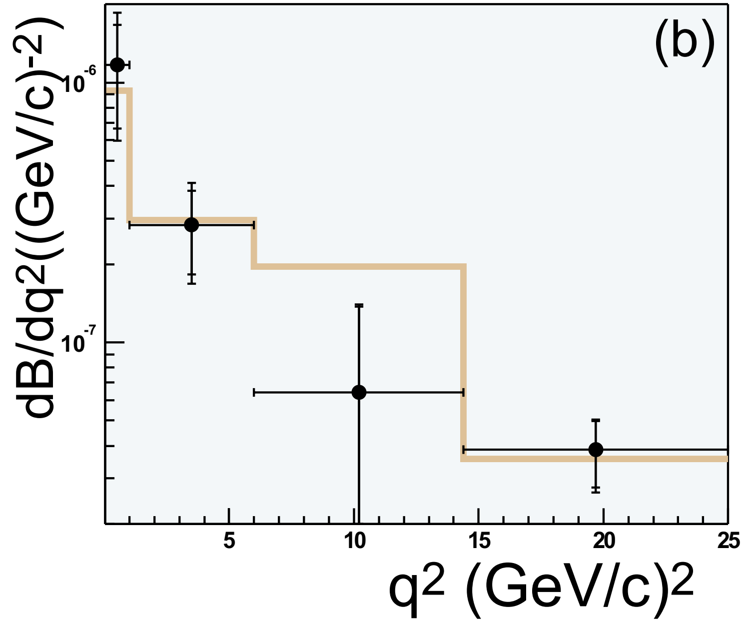


In the long run: full calculation for $0 < m_c < m_b/2$ [M. Czakon, ...].

The decay $\bar{B} \to X_s l^+ l^-$.



BELLE, hep-ex/0408119



Range of q^2	BELLE hep-ex/0503044	BABAR hep-ex/0404006	weighted average	SM
(a)	$4.11 \pm 0.83\ ^{+0.85}_{-0.81}$	$5.6 \pm 1.5 \pm 0.6 \pm 1.1$	4.5 ± 1.0	4.4 ± 0.7
(b)	$1.493 \pm 0.504\ ^{+0.411}_{-0.321}$	$1.8 \pm 0.7 \pm 0.5$	1.60 ± 0.52	1.57 ± 0.16

$\mathcal{B}(\bar{B} \to X_s l^+ l^-)\ [10^{-6}]$ **for two different ranges of the dilepton invariant mass squared: (a)** $(2m_\mu)^2 < q^2 < (m_B - m_K)^2$ **and (b)** $1\,\mathrm{GeV}^2 < q^2 < 6\,\mathrm{GeV}^2$.

The SM branching ratios for $B^0_{s(d)} \to l^+ l^-$:

$$\mathrm{BR}(B_q^0 \to l^+ l^-) = \frac{\tau(B^0)}{\pi} M_{B_q^0} \left(\frac{G_F \alpha_{\rm em} \hat{F}_{B_q} \mathbf{m_l}}{4\pi \sin^2\theta_W} \right)^2 \sqrt{1 - \frac{4 m_l^2}{M_{B_q^0}^2}} \; \left| K_{tq}^* K_{tb} \, Y(x_t) \right|^2$$

Mode	SM expectation (leading EW)	Experimental bound (90% CL)
$B_s \to \tau^+\tau^-$	$(7.7 \pm 2.1) \times 10^{-7}$	$\sim 5\%$ **from LEP? hep-ph/9607473**
$B_s \to \mu^+\mu^-$	$(3.7 \pm 1.0) \times 10^{-9}$	1.5×10^{-7} **CDF, talk by C.-J. Lin yesterday**
		4.1×10^{-7} **D0, hep-ex/0410039**
$B_s \to e^+e^-$	$(8.6 \pm 2.4) \times 10^{-14}$	5.4×10^{-5} **PDG 2002**
$B_d \to \tau^+\tau^-$	$(2.2 \pm 0.7) \times 10^{-8}$	$\sim 1.5\%$ **from LEP? hep-ph/9607473**
		New bound from BaBar expected this week
$B_d \to \mu^+\mu^-$	$(1.04 \pm 0.34) \times 10^{-10}$	3.8×10^{-8} **CDF, talk by C.-J. Lin yesterday**
		8.3×10^{-8} **BaBar, hep-ex/0408096**
		11.1×10^{-8} **D0 @ 95% C.L., talk by T. Kamon**
		16×10^{-8} **Belle, hep-ex/0309069**
$B_d \to e^+e^-$	$(2.4 \pm 0.8) \times 10^{-15}$	6.1×10^{-8} **BaBar, hep-ex/0408096**
		1.9×10^{-7} **Belle, hep-ex/0309069**

Generic amplitude of any FCNC process in the SM:

$$\mathcal{A}(\text{process})_{\rm SM} = \sum_{i=0}^{7} B^i \, \eta^i_{\rm QCD} \, K^i_{\rm CKM} \; F_i^{\rm SM}\left(\frac{m_t^2}{M_W^2}\right) + \left(\begin{array}{c}\text{small}\\ \text{corrections}\end{array}\right)$$

A phenomenological definition of Minimal Flavour Violation (MFV):

$$\mathcal{A}(\text{process})_{\rm MFV} = \sum_{i=0}^{7} B^i \, \eta^i_{\rm QCD} \, K^i_{\rm CKM} \; F_i(v) + \left(\begin{array}{c}\text{small}\\ \text{corrections}\end{array}\right).$$

v **stands for the parameters of the MFV model.**

$B_i \, \eta^i_{\rm QCD} \, K^i_{\rm CKM}$ **are the same as in the SM, though process-dependent.**

$F_0 \equiv 1$.

The MSSM is a MFV model in this sense, provided:

- **Flavour violation in the squark mixing matrices gives small effects,**
- $(\tilde{u}, \tilde{c})$ **and** $(\tilde{d}, \tilde{s}, \tilde{b})$ **are either approximately degenerate or heavy,**
- $\tan\beta$ **is not too large.**

The CMSSM with $\tan\beta \ll 50$ satisfies these constraints.

"Phenomenological" MFV $\leftrightarrow$ **[Buras, Gambino, Gorbahn, Jäger, Silvestrini, hep-ph/0007085].**

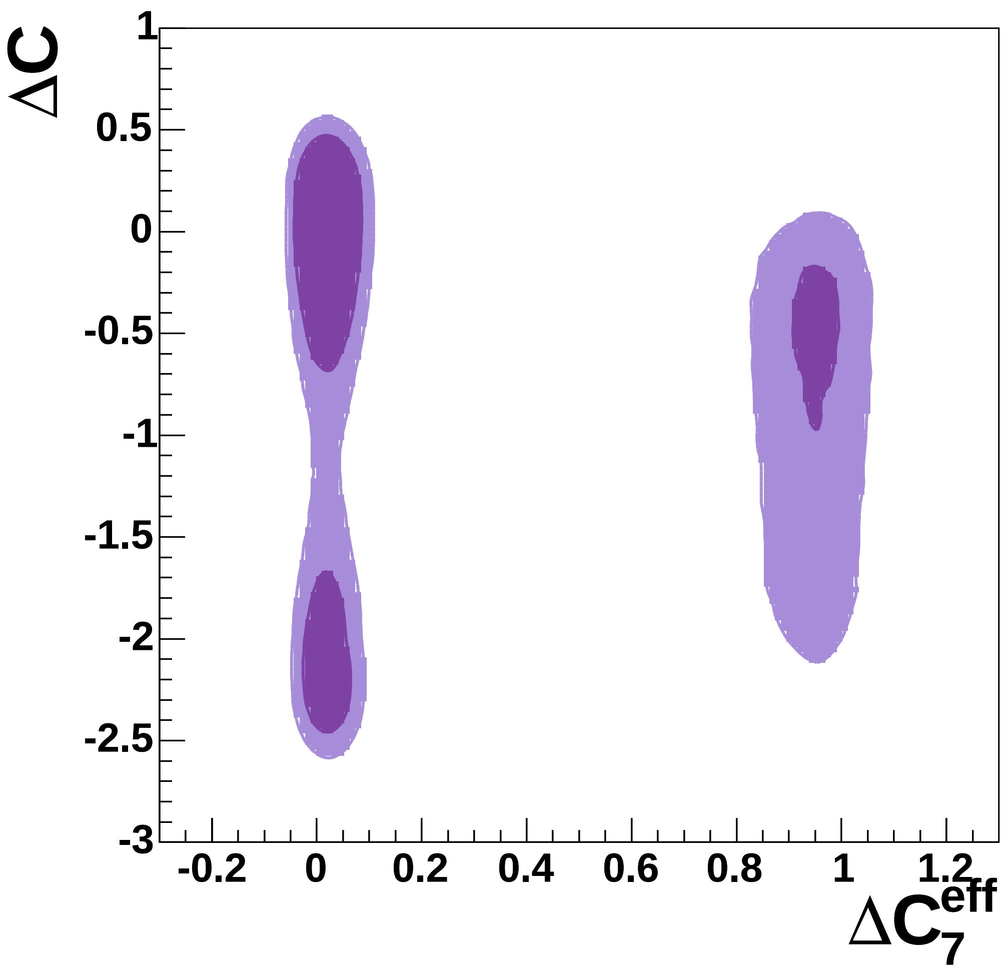
"Theoretical" MFV $\leftrightarrow$ **[D'Ambrosio, Giudice, Isidori, Strumia, hep-ph/0207036].**
(large $\tan\beta$ **included)**

$$\mathcal{A}(\text{process})_{\text{MFV}} = \sum_{i=0}^{8} B^i\, \eta^i_{\text{QCD}}\, K^i_{\text{CKM}}\, F_i(v) + \left(\begin{array}{c}\text{small}\\ \text{corrections}\end{array}\right)$$

Operator	**Function**
$(\bar{q}q')_{V-A}(\bar{q}q')_{V-A}$	$S(v)$
$(\bar{q}q')_{V-A}(\bar{\nu}\nu)_{V-A}$	$X(v)$
$(\bar{q}q')_{V-A}(\bar{l}l)_{V-A}$	$Y(v)$
$(\bar{q}q')_{V-A}(\bar{l}l)_{V}$	$Z(v)$
$(\bar{q}'T^a q'')_{V-A}\Sigma_q(\bar{q}T^a q)_V$	$E(v)$
$(\bar{q}\ \sigma\cdot F\ q')$	$D'(v)$
$(\bar{q}\ \sigma\cdot G\ q')$	$E'(v)$

Processes	**Functions**
$K \to \pi\nu\bar{\nu}$, $\bar{B} \to X_s\nu\bar{\nu}$	$X(v)$
$\bar{B} \to X_s\gamma$	$D'(v)$, $E'(v)$, $E(v)$
$\bar{B} \to X_s l^+l^-$	$Y(v)$, $Z(v)$, $D'(v)$, $E'(v)$, $E(v)$
$B^0 \to l^+l^-$, $K_L \to \mu^+\mu^-$	$Y(v)$
$K^0\overline{K}^0$, $B^0\overline{B}^0$ mixing	$S(v)$
$K_L \to \pi^0 l^+l^-$	$Y(v)$, $Z(v)$, $E(v)$, $S(v)$
Nonlept. $\Delta B = 1$, $\Delta S = 1$, ϵ'	$X(v)$, $Y(v)$, $Z(v)$, $E(v)$, $E'(v)$

Constraints on the MFV functions from $K^+ \to \pi^+ \nu\bar{\nu}$, $\bar{B} \to X_s\gamma$ and $\bar{B} \to X_s l^+ l^-$. [hep-ph/0505110; Bobeth, Bona, Buras, Ewerth, Pierini, Silvestrini, Weiler]



Assumptions:

1) $X(v) - X^{\text{SM}} \equiv \Delta C$
$Y(v) - X(v) = Y^{\text{SM}} - X^{\text{SM}}$
$Z(v) - X(v) \simeq \pm 4(Z^{\text{SM}} - X^{\text{SM}})$
Coefficients at the quark-lepton and quark-neutrino operators are modified along the Z-penguin direction.

2) $D'(v)$ and $E'(v)$ are traded for $C_7^{\text{eff}} \sim \sqrt{\mathcal{B}(b \to s\gamma)}$.

3) $E(v) = E^{\text{SM}}$

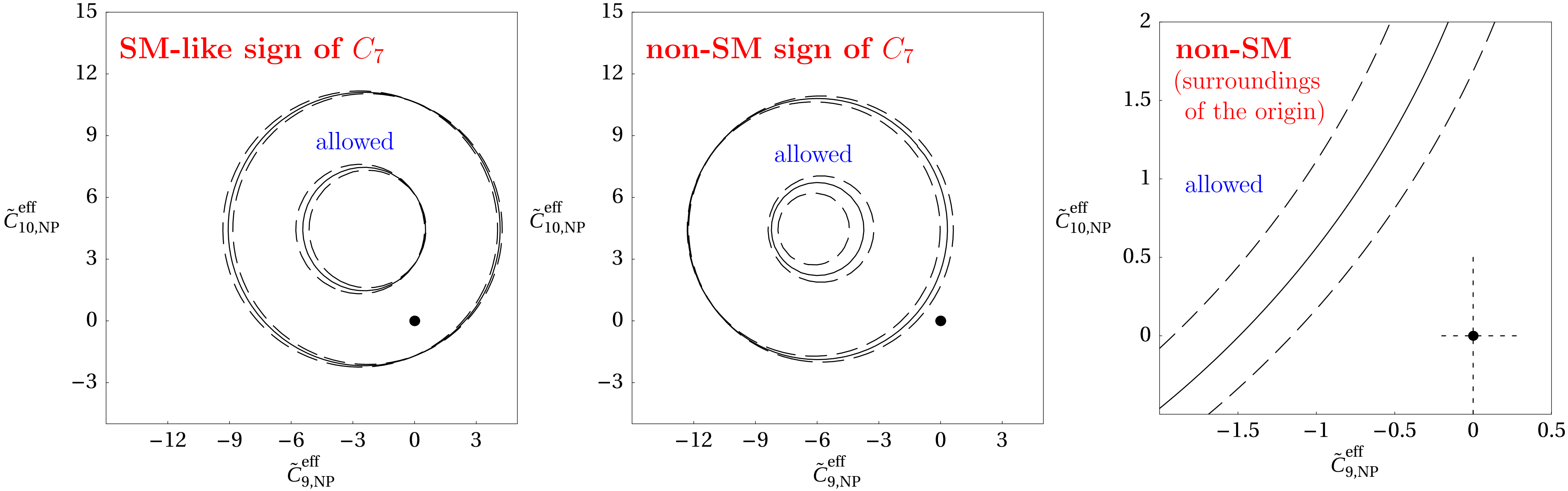
$\Rightarrow$ No more than factor-of-two enhancements possible in $B^0_{s,d} \to \mu^+\mu^-$.

By the way: $\Delta S = 0.29 \pm 0.44$
[Talk by A. Stocchi yesterday]

In the MFV MSSM, only the SM-like region (around (0,0)) is accessible. Points where the sign of the $b \to s\gamma$ amplitude gets reversed are either excluded experimentally or require too large effects in Y and Z.

Model-independent constraints from $\bar{B} \to X_s l^+ l^-$ and $\bar{B} \to X_s \gamma$ on extra contributions to $C_9 = Y/\sin^2\theta_W - 4Z$ and $C_{10} = -Y/\sin^2\theta_W$ at 90% C.L.

[hep-ph/0410155, Gambino, Haisch, MM]



The three lines correspond to three different values of $\mathcal{B}(\bar{B} \to X_s\gamma) \times 10^4$: the experimental central value and borders of the 90% C.L. domain for this branching ratio.

The dot at the origin indicates the SM case for $C_{9,10}$. The SM values have been assumed for E and E'. New physics there would have little effect provided one accepts the bound $\mathcal{B}(b \to \text{charmless})_{NP}$ = 3.7% @ 95% C.L. [DELPHI, PLB 426 (1998) 193].

In the rightmost plot, the maximal MFV MSSM ranges for $C_{9,\rm NP}$ and $C_{10,\rm NP}$ are indicated by the dashed cross. They were obtained in hep-ph/0112300 by A. Ali, E. Lunghi, C. Greub and G. Hiller who scanned over the following parameter ranges:

$$2.3 < \tan\beta < 50, \qquad 0 < M_2 < 1~\text{TeV}, \qquad -1~\text{TeV} < \mu < 1~\text{TeV},$$

$$78.6~\text{GeV} < M_{H^\pm} < 1~\text{TeV}, \qquad 90~\text{GeV} < M_{\tilde{t}_{1,2}} < 1~\text{TeV},$$

$$-\tfrac{\pi}{2} < \theta_{\tilde{t}} < \tfrac{\pi}{2}, \qquad M_{\tilde{\nu}} \geq 50~\text{GeV}.$$

One step beyond the phenomenological MFV: Large $\tan\beta$.

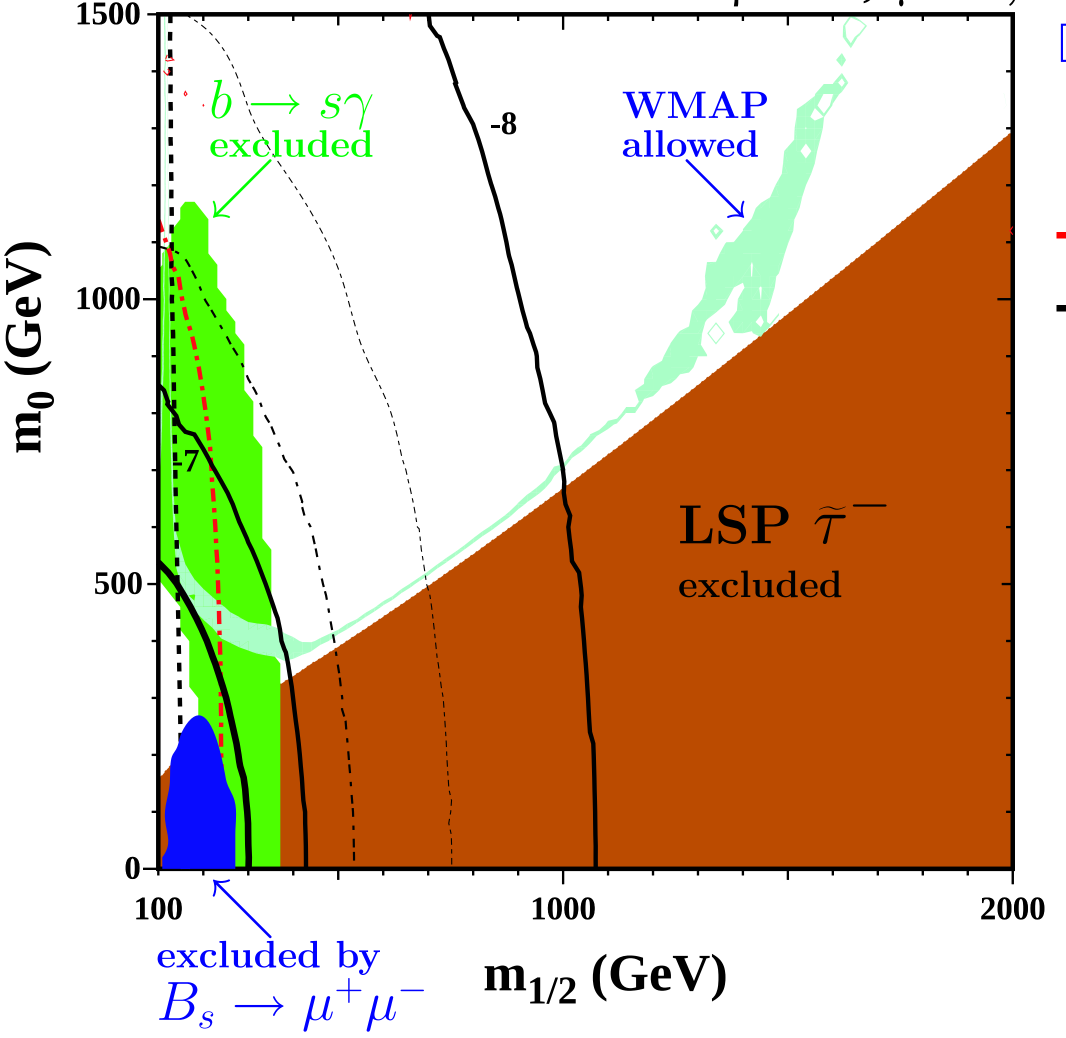
In the SM, the operators $(\bar{s}_L b_R)(\bar{l}l)$ and $(\bar{s}_L b_R)(\bar{l}\gamma_5 l)$ are negligible even for $B_s \to \mu^+\mu^-$.

In the MSSM, their coefficients receive contributions that are proportional to $\tan^3\beta$.

$\Rightarrow$ Already the current bounds on $B_s \to \mu^+\mu^-$ constrain the MSSM with large $\tan\beta$.

The CMSSM case:

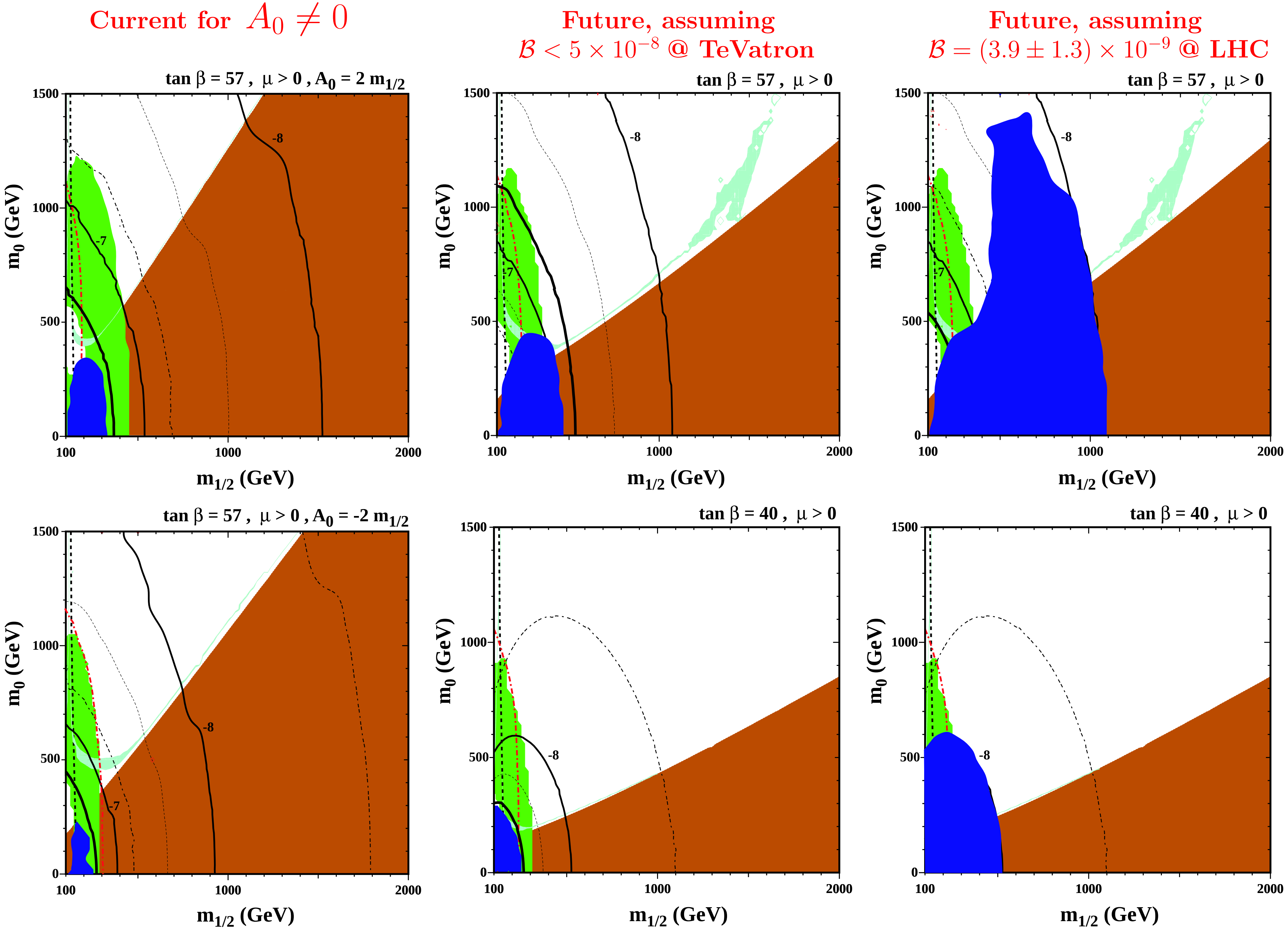
tan β = 57 , μ > 0 , $A_0 = 0$



[hep-ph/0504196; Ellis, Olive, Spanos]

m_{h^0} exclusion bound.

$\chi^\pm$ exclusion bound.



Current for $A_0 \neq 0$
Future, assuming $\mathcal{B} < 5 \times 10^{-8}$ @ TeVatron
Future, assuming $\mathcal{B} = (3.9 \pm 1.3) \times 10^{-9}$ @ LHC
tan β = 57 , μ > 0 , A0 = 2 m1/2
tan β = 57 , μ > 0
tan β = 57 , μ > 0
tan β = 57 , μ > 0 , A0 = -2 m1/2
tan β = 40 , μ > 0
tan β = 40 , μ > 0
m0 (GeV)
m1/2 (GeV)
-7
-8

The generic MSSM case.

The down-squark mass matrix in the SCKM basis

$$\mathcal{M}_d^2 = \begin{pmatrix} m^2_{d,LL} + F_{d,LL} + D_{d,LL} & m^2_{d,LR} + F_{d,LR} \\ \left(m^2_{d,LR} + F_{d,LR}\right)^\dagger & m^2_{d,RR} + F_{d,RR} + D_{d,RR} \end{pmatrix},$$

$m_{d,XY}$ – **soft masses,** $F_{d,XY} \sim$ **(quark masses and** μ**),** $D_{d,XY} \sim M_Z.$

The mass insertions:

$$\left(\delta^d_{XY}\right)_{ij} = \frac{\left(m^2_{d,XY}\right)_{ij}}{\sqrt{\left(m^2_{d,XX}\right)_{ii}\left(m^2_{d,YY}\right)_{jj}}}, \qquad \left(\delta^d_{XY}\right)_{ij} = \left(\delta^d_{YX}\right)^\star_{ji}.$$

The up-squark mass insertions δ^u_{XY} **are analogously defined.**

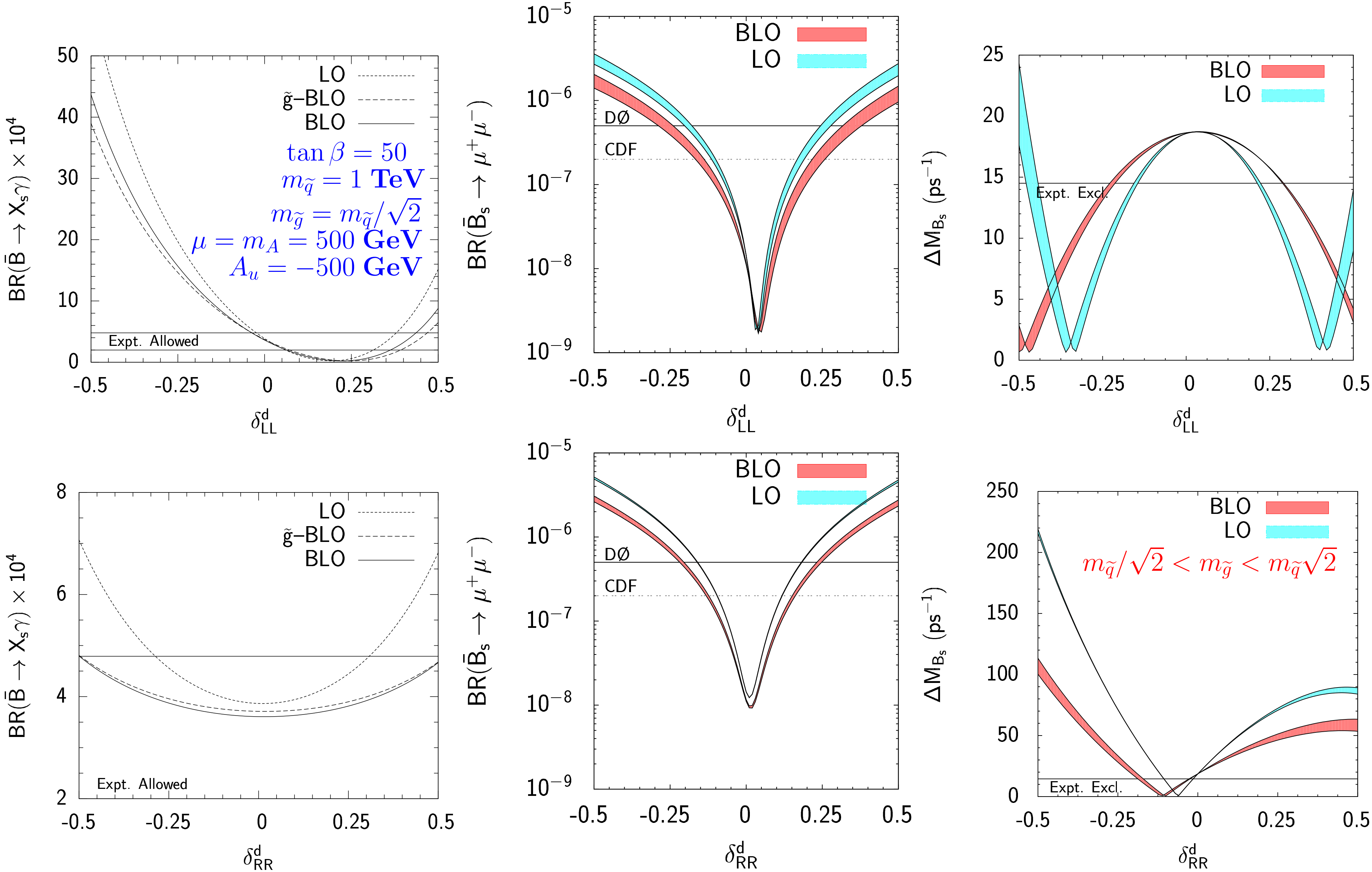
The FCNC processes provide constraints on $\delta^{u,d}_{XY}$.

For instance, $\bar{B} \to X_s\gamma$**,** $B^0_s \to \mu^+\mu^-$ **and** $B^0_s\bar{B}^0_s$ **mixing constrain** $\left(\delta^{u,d}_{XY}\right)_{23}$**.**

Remember: $|K_{ts}| \simeq 0.04$**.**

Bounds on $(\delta^d_{LL})_{23} \equiv \delta^d_{LL}$ and $(\delta^d_{RR})_{23} \equiv \delta^d_{RR}$ from

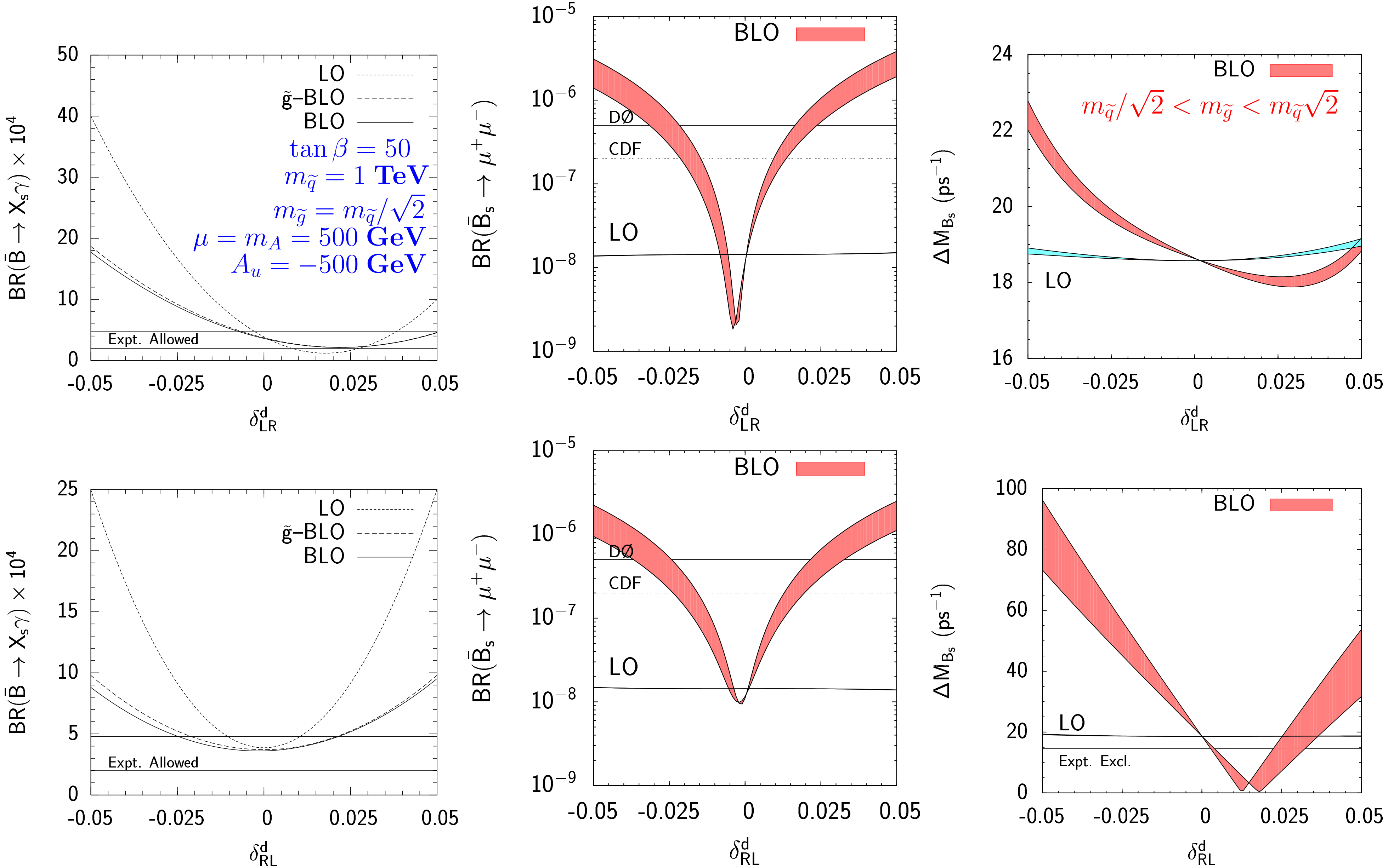
$\bar{B} \to X_s \gamma$ | $B^0_s \to \mu^+ \mu^-$ | $B^0_s \bar{B}^0_s$ **mixing.**



[hep-ph/0506146; Foster, Okumura, Roszkowski]

Bounds on $(\delta^d_{LR})_{23} \equiv \delta^d_{LR}$ and $(\delta^d_{RL})_{23} \equiv \delta^d_{RL}$ from

$\bar{B} \to X_s \gamma$ | $B^0_s \to \mu^+\mu^-$ | $B^0_s \bar{B}^0_s$ **mixing.**



[hep-ph/0506146; Foster, Okumura, Roszkowski]

Summary

- **So far, the measured branching ratios of the B-meson and Kaon FCNC decays are in perfect agreement with the SM expectations.**
  Possible exception: purely hadronic two-body decays $\longrightarrow$ talk of G. Hiller.

- **Ongoing calculations of higher-order perturbative corrections in the SM should improve the constraining power of such rare decays.**

- **Any future observation of large enhancements in these processes would exclude the phenomenological MFV.**

- **In the MFV MSSM (also with large $\tan\beta$), the sign of the $b \to s\gamma$ amplitude must be the same as in the SM.**

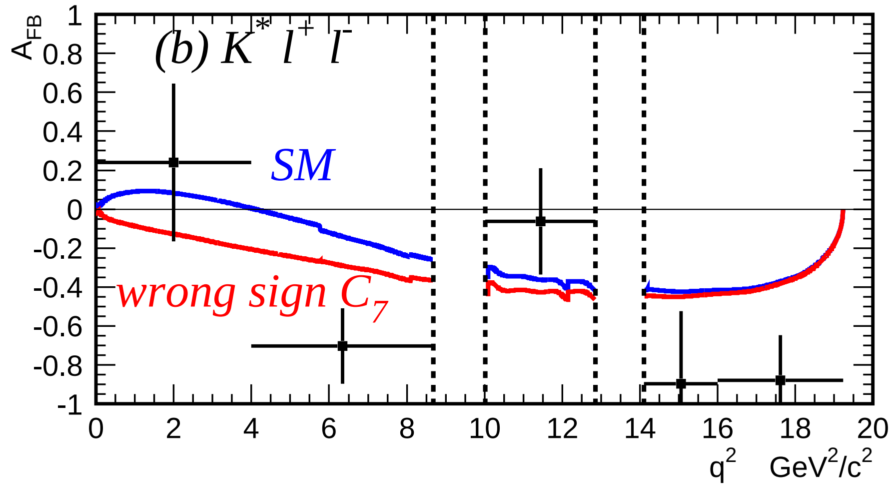
- **Large enhancements of $B_s^0 \to \mu^+\mu^-$ are still possible for large $\tan\beta$, even in the CMSSM. If this decay was observed with the SM rate at the LHC, it would exclude a sizeable region in the large-$\tan\beta$ CMSSM parameter space.**

- **Mass insertions in the general MSSM are strongly constrained by the existing data. However, many of them can still remain larger than the corresponding CKM factors.**

Backup

BELLE, hep-ex/0410006:

The first measurement of forward-backward asymmetry as a function of q^2 in $B \to K^* l^+ l^-$. Within the limited statistical precision, the measured asymmetry is consistent with both the SM and the wrong sign $C_7^{\rm eff}$ case.



P. Gambino, U. Haisch, MM, hep-ph/0410155:

The sign of $C_7^{\rm eff}$ can be determined using the published BELLE and BABAR measurements of the inclusive branching ratio:

Range of q^2	experimental average	SM	$C_7^{\rm eff} \to -C_7^{\rm eff}$
(a)	4.5 ± 1.0	4.4 ± 0.7	8.8 ± 1.0
(b)	1.60 ± 0.51	1.57 ± 0.16	3.30 ± 0.25

$\mathcal{B}(\bar{B} \to X_s l^+ l^-)\ [10^{-6}]$ **for two different ranges of the dilepton invariant mass squared: (a)** $(2m_\mu)^2 < q^2 < (m_B - m_K)^2$ **and (b)** $1\,{\rm GeV}^2 < q^2 < 6\,{\rm GeV}^2$.

$\Rightarrow$ The non-SM sign of $C_7^{\rm eff}$ is excluded at 3σ.

Table 3. from [hep-ph/0505110; Bobeth, Bona, Buras, Ewerth, Pierini, Silvestrini, Weiler]

Branching Ratios	**MFV (95%)**	**SM (68%)**	**SM (95%)**	**exp**
$Br(K^+ \to \pi^+ \nu\bar{\nu}) \times 10^{11}$	< 11.9	8.3 ± 1.2	$[6.1, 10.9]$	$(14.7^{+13.0}_{-8.9})$
$Br(K_L \to \pi^0 \nu\bar{\nu}) \times 10^{11}$	< 4.59	3.08 ± 0.56	$[2.03, 4.26]$	$< 5.9 \cdot 10^4$
$Br(K_L \to \mu^+\mu^-)_{\rm SD} \times 10^9$	< 1.36	0.87 ± 0.13	$[0.63, 1.15]$	-
$Br(B \to X_s \nu\bar{\nu}) \times 10^5$	< 5.17	3.66 ± 0.21	$[3.25, 4.09]$	< 64
$Br(B \to X_d \nu\bar{\nu}) \times 10^6$	< 2.17	1.50 ± 0.19	$[1.12, 1.91]$	-
$Br(B_s \to \mu^+\mu^-) \times 10^9$	< 7.42	3.67 ± 1.01	$[1.91, 5.91]$	$< 2.7 \cdot 10^2$
$Br(B_d \to \mu^+\mu^-) \times 10^{10}$	< 2.20	1.04 ± 0.34	$[0.47, 1.81]$	$< 1.5 \cdot 10^3$

Upper bounds for rare decays in MFV models at 95% probability, the corresponding values in the SM (using inputs from the UUT analysis) and the available experimental information.