Probing new Physics in Electroweak penguin through B_d and B_s decays

Leonardo Vernazza

in collaboration with

Lars Hofer, Dominik Scherer

Based on arXiv:0910.2809 (Acta Phys.Polon. B3 (2010) 227-233) and arXiv:1011.6319

DISCRETE 2010 **Rome, December 10, 2010**

Outline

Motivations

- The purpose of this work is to analyse the possibility of having New Physics FCNC with the structure of electroweak penguins in hadronic B decays. (Buras, Fleischer, Recksiegel, Schwab,2004,2005,2006)

- This hypothesis has been motivated by discrepancies found in the $B \to \pi K$ decays. To date, the smoking gun is provided by (Gronau, Rosner, 1998; Baek, London, 2007; Fleischer, Recksiegel, Schwab, 2007)

$$\Delta A_{\rm CP} \equiv A_{\rm CP}(B^- \to \pi^0 K^-) - A_{\rm CP}(\bar{B}^0 \to \pi^+ K^-) \overset{\rm SM,QCDF}{=} 1.9^{+5.8}_{-4.8}\,\% \overset{\rm exp.}{=} (14.8 \pm 2.8)\%.$$

  which amounts to a 2.5σ discrepancy.

- The data on $B \to \pi K$ are still inconclusive. We provide an update analysis of these decays, and show that the B_s decays $\bar{B}_s \to \phi\rho^0$ and $\bar{B}_s \to \phi\pi^0$ are highly sensitive to New Physics in the electroweak penguin.

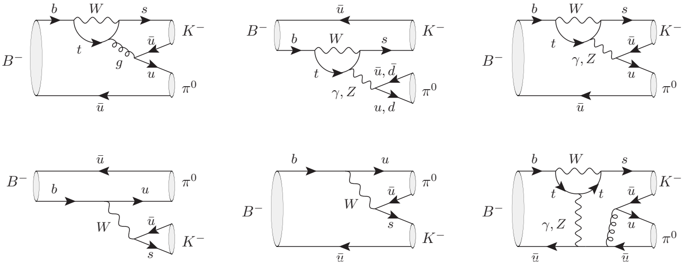
- We provide a quantitative analysis of these decays, and motivate their search in future flavour experiment.

$B \to \pi K$ decays

- The $B \to \pi K$ decay amplitudes can be parameterized as

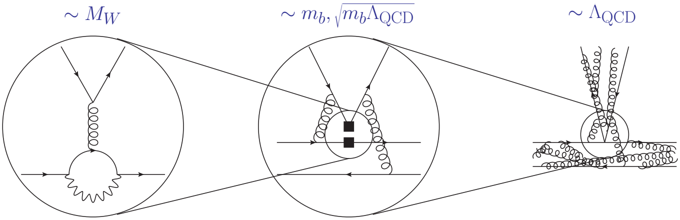
$$\begin{aligned}
\mathcal{A}(B^- \to \pi^- \bar{K}^0) &\simeq P\left(1 - \frac{1}{3} r^C_{\rm EW} + \frac{2}{3} r^A_{\rm EW}\right), \\
\sqrt{2}\,\mathcal{A}(B^- \to \pi^0 K^-) &\simeq P\left(1 + r_{\rm EW} + \frac{2}{3} r^C_{\rm EW} + \frac{2}{3} r^A_{\rm EW} - (r_{\rm T} + r_{\rm C}) e^{-i\gamma}\right), \\
\mathcal{A}(\bar{B}^0 \to \pi^+ K^-) &\simeq P\left(1 + \frac{2}{3} r^C_{\rm EW} - \frac{1}{3} r^A_{\rm EW} - r_{\rm T} e^{-i\gamma}\right), \\
\sqrt{2}\,\mathcal{A}(\bar{B}^0 \to \pi^0 \bar{K}^0) &\simeq -P\left(1 - r_{\rm EW} - \frac{1}{3} r^C_{\rm EW} - \frac{1}{3} r^A_{\rm EW} + r_{\rm C} e^{-i\gamma}\right).
\end{aligned}$$

- The diagrammatic representation reads e.g.



$B \rightarrow \pi K$ decays

- From a theoretical point of view, these decays are a problem of multiple scales.



Starting from the weak Hamiltonian

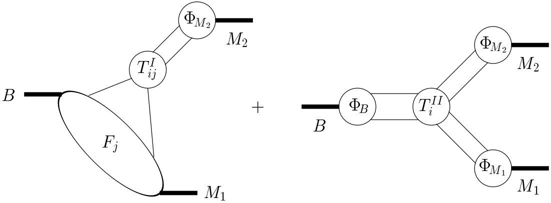
$$\mathcal{H}_{\rm eff} = \frac{G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p^{(s)} \left(C_1 Q_1^p + C_2 Q_2^p + \sum_{i=3}^{10} C_i Q_i + C_{7\gamma} Q_{7\gamma} + C_{8g} Q_{8g} \right) + \text{h.c.},$$

The amplitude reads

$$\mathcal{A}(B \to M_1 M_2) = \frac{G_F}{\sqrt{2}} \sum_i \lambda_i \, C_i(\mu) \, \langle M_1 M_2 | Q_i | B \rangle (\mu).$$

$B \to \pi K$ decays

- We use QCD factorization to evaluate the decay amplitudes. (Beneke, Buchalla, Neubert, Sachrajda 1999, 2000, 2001; Beneke, Neubert 2003)



$$\langle M_1 M_2 | Q_i | \bar{B} \rangle = \Big\{ F_{B\to M_1} \times \underbrace{T^I(\mu_h, \mu_s)}_{1+\alpha_s+\ldots} \star f_{M_2}\phi_{M_2}(\mu_s)$$

$$+ f_B\phi_B(\mu_s) \star \Big[\underbrace{T^{II}(\mu_h, \mu_I)}_{1+\ldots} \star \underbrace{J^{II}(\mu_I, \mu_s)}_{\alpha_s+\ldots} \Big] \star f_{M_1}\phi_{M_1}(\mu_s) \star f_{M_2}\phi_{M_2}(\mu_s) \Big\}$$

$B \to \pi K$ decays

- In the Standard Model $\Delta A_{\rm CP}$ reads

$$\Delta A_{\rm CP} \simeq -2\,{\rm Im}\,(r_{\rm C})\,\sin\gamma.$$

A large $\Delta A_{\rm CP}$ can be explained only through an enhanced colour-suppressed tree contribution, which would break QCD factorization.

- Though there are indications from $B \to \pi\pi$ decays that an enhancement of this topology has to be expected, (Beneke,Neubert, 2003; Bell, Volker, 2009) other data suggest that it is rather difficult to get such a large enhancement within the SM.

- A new electroweak amplitude of the same order of the SM one does the job quite naturally: set

$$r_{\rm EW} \to r_{\rm EW} + \tilde{r}_{\rm EW} e^{-i\delta}, \qquad r^{\rm C}_{\rm EW} \to r^{\rm C}_{\rm EW} + \tilde{r}^{\rm C}_{\rm EW} e^{-i\delta}, \qquad r^{\rm A}_{\rm EW} \to r^{\rm A}_{\rm EW} + \tilde{r}^{\rm A}_{\rm EW} e^{-i\delta},$$

and

$$\Delta A_{\rm CP} \simeq -2\,{\rm Im}\,(r_{\rm C})\,\sin\gamma + 2\,{\rm Im}\left(\tilde{r}_{\rm EW} + \tilde{r}^{\rm A}_{\rm EW}\right)\sin\delta.$$

$B \to \pi K$ decays

- There are a number of other observables, which can be constructed starting from the CP averaged branching ratio and CP asymmetries, which are sensitive to the electroweak penguin amplitude.

- The main problem which makes difficult to single out new physics in the electroweak penguin is that this amplitude appears always in combination with the colour-suppressed tree amplitude

$$r_{\mathrm{EW}} - r_{\mathrm{C}}\, e^{-i\gamma}.$$

- All these other observables do not show, to date, discrepancies larger than $1\,\sigma$.

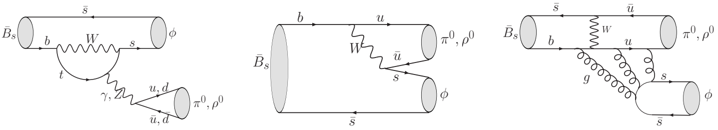
- An exception is given by the time dependent CP asymmetry

$$S_{\mathrm{CP}}(\bar{B}^0 \to \pi^0 \bar{K}^0) \simeq \sin 2\beta + 2\mathrm{Re}\,(r_{\mathrm{C}}) \cos 2\beta \sin\gamma - 2\mathrm{Re}(\tilde{r}_{\mathrm{EW}} + \tilde{r}^{C}_{\mathrm{EW}}) \cos 2\beta \sin\delta$$
$$\overset{\mathrm{SM,QCDF}}{=} \quad 0.80^{+0.06}_{-0.08} \quad \overset{\mathrm{exp}}{=} \quad 0.57^{+0.17}_{-0.17},$$

which also weakly support the hypothesis of New physics in the EW penguin. An enhanced colour-suppressed tree topology would drive S_{CP} to values larger than in the SM, in contrast to the observation (Fleischer, Jäger, Pirjol, Zupan, 2008)

$\bar{B}_s \to \phi\rho^0$ and $\bar{B}_s \to \phi\pi^0$ decays

- These decays have a very simple structure $0 \xrightarrow{\Delta I = 1} 0 \otimes 1 = 1$.



- Including a New Physics electroweak penguin contribution the amplitude reads

$$\sqrt{2}\, A(\bar{B}_s \to \phi M_2) = P_{\rm EW}^{M_2} \left(1 - r_{\rm C}^{M_2}\, e^{-i\gamma} + \tilde{r}_{\rm EW}^{M_2}\, e^{-i\delta}\right)$$

- In the SM, within QCDF one find

$$P_{\rm EW}^{\pi} = 17.0\, A_0^{B_s\to\phi}(0) \cdot 10^{-9}, \quad r_{\rm C}^{\pi} = -0.12i - 0.02 + \frac{0.01{\rm GeV}(1+X_H)}{A_0^{B_s\to\phi}(0)\lambda_{B_s}} = 0.41^{+0.37}_{-0.41} - 0.13^{+0.30}_{-0.30}\, i,$$

$$P_{\rm EW}^{\rho,0} = 26.2\, A_0^{B_s\to\phi}(0) \cdot 10^{-9}, \quad r_{\rm C}^{\rho,0} = -0.13i - 0.02 + \frac{0.01{\rm GeV}(1+X_H)}{A_0^{B_s\to\phi}(0)\lambda_{B_s}} = 0.39^{+0.35}_{-0.39} - 0.13^{+0.28}_{-0.29}\, i,$$

$$P_{\rm EW}^{\rho,-} = 6.6\, F_{-}^{B_s\to\phi}(0) \cdot 10^{-9}, \quad r_{\rm C}^{\rho,-} = 0.14i - 0.06 - \frac{0.02{\rm GeV}(1-X_H)}{F_{-}^{B_s\to\phi}(0)\lambda_{B_s}} = 0.21^{+0.49}_{-0.46} + 0.15^{+0.45}_{-0.45}\, i$$

$\bar{B}_s \to \phi\rho^0$ and $\bar{B}_s \to \phi\pi^0$ decays

- In the SM the branching ratio of these decays are rather small:

$$\mathrm{Br}(\bar{B}_s \to \phi\pi^0) = 1.6^{+1.1}_{-0.3} \cdot 10^{-7}, \qquad \mathrm{Br}(\bar{B}_s \to \phi\rho^0) = 4.4^{+2.7}_{-0.7} \cdot 10^{-7}.$$

- A New Physics amplitude of the same order as the SM one can easily enhance the B_s decays up to around an order of magnitude. This is more difficult to be obtained within an enhanced colour-suppressed tree amplitude.
- An enhancement of the colour-suppressed tree contribution would be a non-perturbative effect, which is not possible to correlate among decays into different final states like the *PP*, *PV*, *VV* decays.
- The hypothesis of New Physics in the electroweak penguin corresponds to a high-energy dynamical explanation, which is perturbatively calculable and therefore can be correlated among the different decays.

Model independent analysis

- We proceed first with a model independent analysis. Given the electroweak penguin operators

$$Q_7 = (\bar{s}_\alpha b_\alpha)_{V-A} \sum_q \tfrac{3}{2} e_q (\bar{q}_\beta q_\beta)_{V+A}, \qquad Q_8 = (\bar{s}_\alpha b_\beta)_{V-A} \sum_q \tfrac{3}{2} e_q (\bar{q}_\beta q_\alpha)_{V+A},$$

$$Q_9 = (\bar{s}_\alpha b_\alpha)_{V-A} \sum_q \tfrac{3}{2} e_q (\bar{q}_\beta q_\beta)_{V-A}, \qquad Q_{10} = (\bar{s}_\alpha b_\beta)_{V-A} \sum_q \tfrac{3}{2} e_q (\bar{q}_\beta q_\alpha)_{V-A},$$

we parameterize the New Physics contribution as

$$C_{7,9}^{(\prime)\mathrm{NP}}(m_W) = C_9^{\mathrm{LO}}(m_W)\, q_{7,9}^{(\prime)}, \qquad q_{7,9}^{(\prime)} = |q_{7,9}^{(\prime)}| e^{i\phi_{7,9}^{(\prime)}}.$$

Model independent analysis

- The purpose is to individuate which New Physics fit best the current experimental data. We do this by performing a χ^2-fit of the $B \to \pi K$ data with

$$\chi^2 = \sum_j \begin{cases} \frac{(x_{j\,\text{theo}} - \sigma_{j\,\text{theo, inf}} - x_{j\,\text{exp}})^2}{\sigma^2_{j\,\text{exp}}} & \text{if } x_{j\,\text{exp}} < (x_{j\,\text{theo}} - \sigma_{j\,\text{theo, inf}}), \\ \frac{(x_{j\,\text{exp}} - (x_{j\,\text{theo}} + \sigma_{j\,\text{theo, sup}}))^2}{\sigma^2_{j\,\text{exp}}} & \text{if } x_{j\,\text{exp}} > (x_{j\,\text{theo}} + \sigma_{j\,\text{theo, sup}}), \\ 0 & \text{otherwise,} \end{cases}$$

(Rfit scheme), (Hocker, Lacker, Laplace,Diberder, 2001) and alternatively a $2\,\sigma$ constraint test as follows:

$$\text{Point}[\text{q}^{(\prime)}_{7,9}\ \text{space}] = \begin{cases} \text{allowed} & \text{if } \begin{cases} (x_{\text{theo}} + \sigma_{\text{theo, sup}}) > (x_{\text{exp}} - 2\sigma_{\text{exp, inf}}) \\ \text{and } (x_{\text{theo}} - \sigma_{\text{theo, inf}}) < (x_{\text{exp}} + 2\sigma_{\text{exp, sup}}), \end{cases} \\ \text{excluded} & \text{otherwise.} \end{cases}$$

Model independent analysis

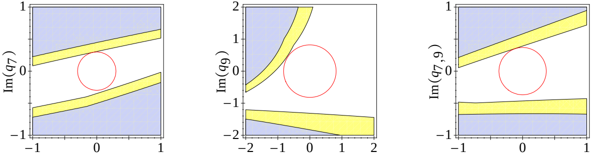
- The new amplitudes reads

$$\sum_{i=7,9,7',9'} \tilde{r}_{\mathrm{EW},\,i}\, e^{-i\delta_i} = (q_7 - q_7') \left[(-0.12)^{+0.04}_{-0.05} + (-0.02)^{+0.07}_{-0.02}\, i \right] + (q_9 - q_9') \left[0.12^{+0.05}_{-0.04} + 0.02^{+0.02}_{-0.07}\, i \right],$$

$$\sum_{i=7,9,7',9'} \tilde{r}^{\mathrm{C}}_{\mathrm{EW},\,i}\, e^{-i\delta_i} = (q_7 - q_7') \left[0.10^{+0.03}_{-0.02} + 0.01^{+0.01}_{-0.06}\, i \right] + (q_9 - q_9') \left[0.04^{+0.02}_{-0.03} + (-0.005)^{+0.016}_{-0.026}\, i \right],$$

$$\sum_{i=7,9,7',9'} \tilde{r}^{\mathrm{A}}_{\mathrm{EW},\,i}\, e^{-i\delta_i} = (q_7 - q_7') \left[0.03^{+0.04}_{-0.07} + (-0.06)^{+0.12}_{-0.01}\, i \right] + (q_9 - q_9') \left[0.007^{+0.003}_{-0.010} + (-0.006)^{+0.012}_{-0.003}\, i \right].$$

- In particular for ΔA_{CP} one finds e.g.



Model independent analysis

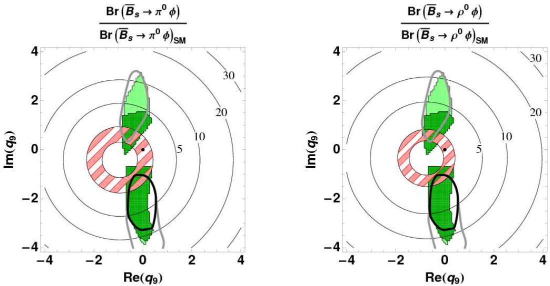
- In case of the B_s decays one finds

$$\sum_{i=7,9,7',9'} \tilde{r}^{\pi}_{\mathrm{EW},\,i}\, e^{-i\delta_i} = -0.9\,(q_7 + q_7' - q_9 - q_9')\,,$$

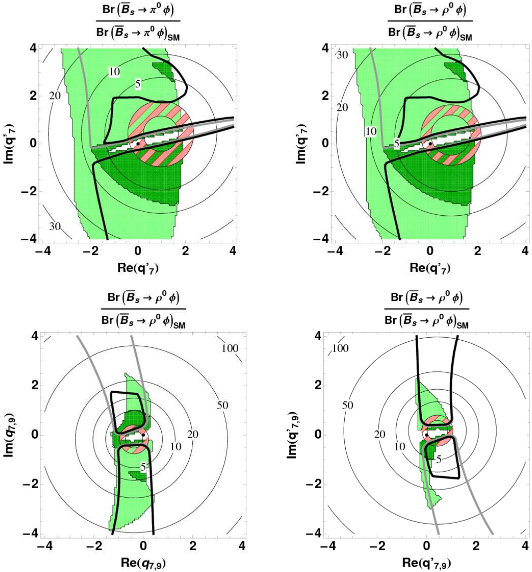
$$\sum_{i=7,9,7',9'} \tilde{r}^{\rho,0}_{\mathrm{EW},\,i}\, e^{-i\delta_i} = 0.9\,(q_7 - q_7' + q_9 - q_9')\,,$$

$$\sum_{i=7,9,7',9'} \tilde{r}^{\rho,-}_{\mathrm{EW},\,i}\, e^{-i\delta_i} = -0.6\,(q_7 + q_9)\,,$$

$$\sum_{i=7,9,7',9'} \tilde{r}^{\rho,+}_{\mathrm{EW},\,i}\, e^{-i\delta_i} = 0.6\,(q_7' + q_9') \times P^{\rho,-}_{\mathrm{EW}} / P^{\rho,+}_{\mathrm{EW}}\,,$$

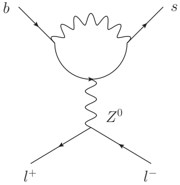


Model independent analysis



Model dependent analysis

- In realistic New Physics models one has additional constraints from additional flavour processes



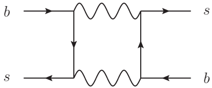
From semileptonic decays:

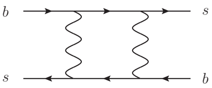
$$R_{e^+e^-}(q^2) \equiv \frac{\frac{d}{dq^2}\Gamma(b\to s\,e^+e^-)}{\Gamma(b\to c\,e\bar{\nu})},$$

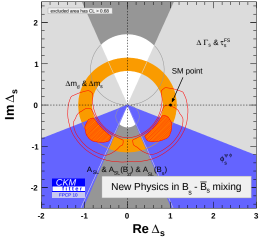
$$R_{e^+e^-}|_{[1,6]} \equiv \int_{1\mathrm{GeV}^2}^{6\mathrm{GeV}^2} R_{e^+e^-}(q^2)dq^2 \overset{\exp}{=} (1.60\pm 0.51)\cdot 10^{-6},$$

$$\int_{q^2>14\mathrm{GeV}^2} A_{\mathrm{FB}}(q^2) < 0.$$

- From ΔM_s:







$$\Delta M_s = 2|M_{12}^{B_s}| \overset{\text{exp.}}{=} (17.77\pm 0.12)\,\mathrm{ps}^{-1}; \qquad \Delta_s \equiv \frac{M_{12}^{B_s}}{M_{12}^{B_s,\mathrm{SM}}} = |\Delta_s|e^{i\phi_s},$$

Modified Z^0 penguin

- We parameterize the flavour-changing coupling as

$$\mathcal{L}_Z^{eff} = -\frac{g}{4\cos\theta_W}\sum_{I\neq J}\bar{d}_I\left[\kappa_L^{IJ}\gamma^\mu(1-\gamma_5)+\kappa_R^{IJ}\gamma^\mu(1+\gamma_5)\right]d_J Z_\mu,$$

and we focus on the $s\bar{b}Z^0$ coupling. We obtain

$$\delta C_3 = \frac{1}{6}\frac{\kappa_L^{sb}}{\lambda_t^{(s)}}, \qquad C_5' = \frac{1}{6}\frac{\kappa_R^{sb}}{\lambda_t^{(s)}},$$

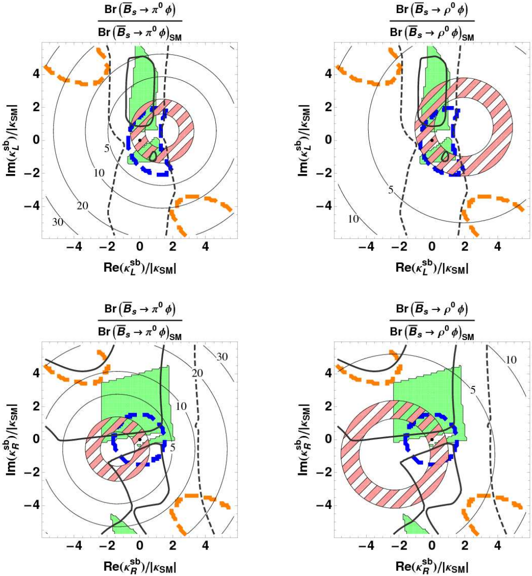
$$\delta C_7 = \frac{2}{3}\frac{\kappa_L^{sb}}{\lambda_t^{(s)}}\sin^2\theta_W, \qquad C_7' = -\frac{2}{3}\frac{\kappa_R^{sb}}{\lambda_t^{(s)}}\cos^2\theta_W,$$

$$\delta C_9 = -\frac{2}{3}\frac{\kappa_L^{sb}}{\lambda_t^{(s)}}\cos^2\theta_W, \qquad C_9' = \frac{2}{3}\frac{\kappa_R^{sb}}{\lambda_t^{(s)}}\sin^2\theta_W.$$

In the SM

$$|\kappa_{L,R}^{sb}| \sim |\kappa_{\rm SM}| \equiv \frac{\alpha}{\pi\sin^2\theta_W}\lambda_t^{(s)}\,C_0(x_{tW}) \sim 0.00035.$$

Modified Z^0 penguin



An additional $U(1)'$

- We parameterize the flavour-changing coupling as

$$\mathcal{L}_{Z'}^{eff} = -\frac{g_{U(1)'}}{2\sqrt{2}} \sum_{IJ} \bar{d}_I \left[\zeta_L^{IJ} \gamma^\mu (1-\gamma_5) + \zeta_R^{IJ} \gamma^\mu (1+\gamma_5)\right] d_J Z'_\mu .$$

Introducing $\xi \equiv \frac{g^2_{U(1)'}}{g^2} \frac{M_W^2}{M_{Z'}^2}$ we obtain

$$\begin{aligned}
\delta C_3 &= -\frac{\zeta_L^{sb}}{\lambda_t^{(s)}} \zeta_L^q \, \xi \,, & C'_3 &= -\frac{1}{3} \frac{\zeta_R^{sb}}{\lambda_t^{(s)}} \left(\zeta_R^u + 2\zeta_R^d\right) \xi \,, \\
\delta C_5 &= -\frac{1}{3} \frac{\zeta_L^{sb}}{\lambda_t^{(s)}} \left(\zeta_R^u + 2\zeta_L^d\right) \xi \,, & C'_5 &= -\frac{\zeta_R^{sb}}{\lambda_t^{(s)}} \zeta_L^q \, \xi \,, \\
\delta C_7 &= -\frac{2}{3} \frac{\zeta_L^{sb}}{\lambda_t^{(s)}} \left(\zeta_R^u - \zeta_R^d\right) \xi \,, & C'_7 &= 0 \,, \\
\delta C_9 &= 0 \,, & C'_9 &= -\frac{2}{3} \frac{\zeta_R^{sb}}{\lambda_t^{(s)}} \left(\zeta_R^u - \zeta_R^d\right) \xi \,.
\end{aligned}$$

We focus on the couplings contributing to electroweak penguin operators.

An additional $U(1)'$

- Rescale $\widetilde{\zeta}^{sb}_{L,R} \equiv \xi \zeta^{sb}_{L,R}$. Then

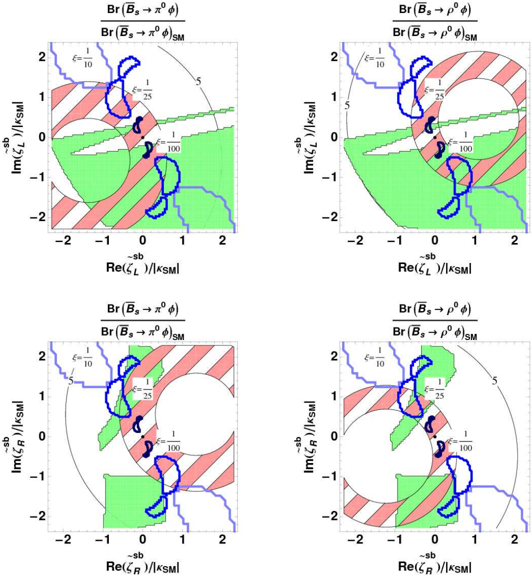
$$\delta C_7 = -\frac{2}{3}\,\frac{\widetilde{\zeta}^{sb}_L}{\lambda_t^{(s)}}\,, \qquad C_9' = -\frac{2}{3}\,\frac{\widetilde{\zeta}^{sb}_R}{\lambda_t^{(s)}}\,,$$

In case of the B_s-$\bar{B}_s$ mixing one finds

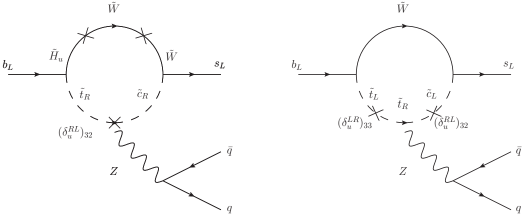
$$\delta C_1^{\mathrm{VLL}} = \frac{4\pi^2\sqrt{2}}{G_F M_W^2}\left(\frac{\widetilde{\zeta}^{sb}_L}{\lambda_t^{(s)}}\right)^2 \frac{1}{\xi}, \qquad C_1^{\mathrm{VRR}} = \frac{4\pi^2\sqrt{2}}{G_F M_W^2}\left(\frac{\widetilde{\zeta}^{sb}_R}{\lambda_t^{(s)}}\right)^2 \frac{1}{\xi},$$

$$C_1^{\mathrm{LR}} = \frac{8\pi^2\sqrt{2}}{G_F M_W^2}\left(\frac{\widetilde{\zeta}^{sb}_L}{\lambda_t^{(s)}}\right)\left(\frac{\widetilde{\zeta}^{sb}_R}{\lambda_t^{(s)}}\right)\frac{1}{\xi}\,.$$

An additional $U(1)'$



Minimal Supersymmetric Standard Model



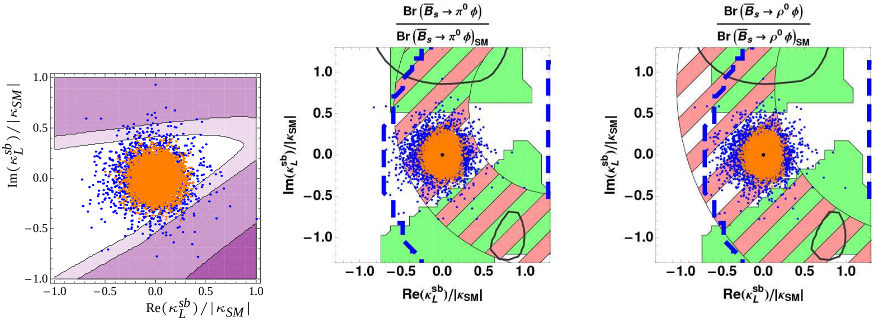
- The model is in practice equivalent to a modified Z^0 penguin scenario, with (MIA)

$$\kappa_L = V_{tb}V_{cs}^* \frac{\alpha_{EM}}{\pi \sin\theta_W^2} (\delta^u_{LR})_{32} \left(\frac{m_t A_t}{8\tilde{m}_0^2} f_1(x_2) - \frac{m_t M_2}{4\tilde{m}_0^2} f_2(x_\mu, x_2) \right) \sim 10^{-4} \div 10^{-5} (\delta^u_{LR})_{32}.$$

- We performed a calculation with full diagonalization of the squark mixing matrix.
  - physical squark and chargino masses $\geq$ 100 GeV,
  - $\mathrm{Br}(\bar{B} \to X_s\gamma)$ compatible with data at the 2σ level,
  - chargino contribution $|C_{7\gamma}^{\chi}| \leq |C_{7\gamma}^{\mathrm{SM}}| \approx 0.22$.

  A scan of the allowed parameters space show that no large contributions can be obtained, in contrast to other results in literature. (Huitu,Khalil,2009; Khalil, Masiero, Murayama, 2009); (See however Imbeault, Baek, London,2008).

Minimal Supersymmetric Standard Model



Summary

- We analysed the effects of having a new electroweak penguin amplitude in the $\bar{B}_s \to \phi\rho^0$ and $\bar{B}_s \to \phi\pi^0$ decays.
- The hypothesis is motivated by the discrepancy found in the $B \to \pi K$ decays $A_{\rm CP}(B^- \to \pi^0 K^-) - A_{\rm CP}(\bar{B}^0 \to \pi^+ K^-)$.
- We performed a correlated analysis of the $B \to \pi K$ and the $\bar{B}_s \to \phi\rho^0$ and $\bar{B}_s \to \phi\pi^0$ decays, in model independent as well as model dependent scenarios.
- The model independent analysis shows that the branching ratios of the B_s decays can be enhanced up to an order of magnitude, without violating constraints from other non-leptonic decays.
- The model dependent analysis shows that when additional constraints from other flavour processes are available, the possible enhancement are reduced and clear distinction from an hadronic effect cannot be made easily.