Supersymmetric effects in rare semileptonic decays of K & B mesons

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Introduction

Flavour Changing Neutral Currents provide a powerful tool to search for physics beyond the Standard Model:

- No tree−level contributions & additional suppression due to the CKM hierarchy within the SM

- Possible non−decoupling effects $\Rightarrow$ sizable deviations from SM expectations even for $M_{new-physics} \gg M_W$

In the following I will concentrate on a specific class of FCNC transitions:

$$s \to d\, l^+ l^- \, (\nu\bar{\nu}) \qquad \& \qquad b \to s\, l^+ l^- \, (\nu\bar{\nu})$$

which have the following interesting features:

- Strong sensitivity to SUSY effects in models with non−universal soft−breaking terms

- Weak experimental constraints at present

- Precision tests possible in the near future by means of appropriate observables in rare K and B decays

Outline

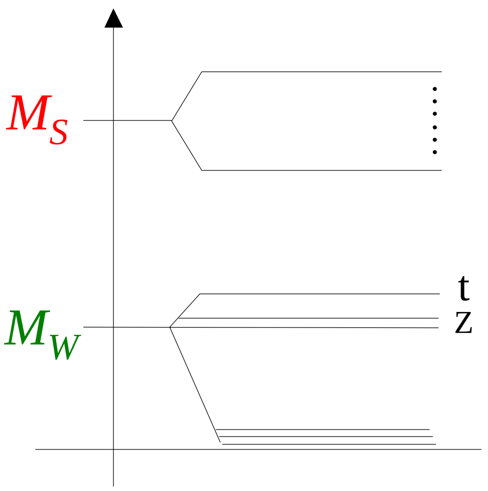
- The SUSY model
- SUSY contributions to $d_i \to d_j\, l^+ l^- (\nu\bar{\nu})$ transitions
  - generic dimension−6 operators
  - magnetic penguins
  - Z penguins
- $K \to \pi \nu\bar{\nu}$
- $K \to \pi e^+ e^-$
- Exclusive $b \to s$ decays
  - The lepton FB asymmetry in $B \to K^* \mu^+\mu^-$
- Conclusions

The SUSY model

- Minimal particle content below M_{GUT} :
  SM + 2nd Higgs doublet + SUSY partners

- Generic flavor structure & common scale ($M_S > M_W$)
  for the soft−breaking terms

- Natural link between soft−breaking trilinear terms &
  Yukawa couplings ($Y_{ij}^A = Y_{ij} A_{ij}$ with $A_{ij} \sim O(M_S)$)



vanishing mass in the limit
of unbroken $SU(2)_L$

$$M_{\tilde{\chi}} = \begin{pmatrix} M_{\tilde{W}} & 0 \\ 0 & M_{\tilde{H}} \end{pmatrix} \left[1 + O\left(M_W / M_S\right)\right]$$

$$M^2_{\tilde{Q}} = \underbrace{\begin{pmatrix} \tilde{M}^2_{LL} & 0 \\ 0 & \tilde{M}^2_{RR} \end{pmatrix}}_{O(M_S^2)} + \underbrace{\begin{pmatrix} 0 & \tilde{M}^2_{LR} \\ \tilde{M}^2_{RL} & 0 \end{pmatrix}}_{O(m_q M_S)}$$

$SU(2)_L$ −breaking terms
parametrically suppressed
by $O(M_W/M_S)$ in the
limit of large M_S

Similarly to the SM case, also within this generic SUSY model FCNC (with external quark fields) are generated only at the loop level

The new sources of flavor mixing can be parameterized by

$$\boxed{(\delta^Q_{AB})_{ij} = \frac{(\tilde{M}^2_Q)_{A_i B_j}}{\langle \tilde{M}^2_Q \rangle}}$$

$Q = U,D \quad A,B = L,R$
$i,j = 1,2,3$

Gabbiani *et al.* '96
Gabrielli *et al.* '95

Three substantially different type of couplings:

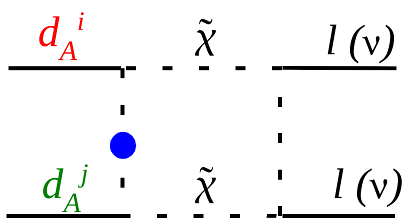
$(\delta^Q_{LL})_{ij}$ $\quad$ $(\delta^Q_{RR})_{ij}$	$(\delta^D_{LR})_{ij}$	$(\delta^U_{LR})_{ij}$
flavor mixing without $\cancel{SU(2)}_L$	flavor mixing with $\cancel{SU(2)}_L$	
scaling like a constant for $M_S \gg M_W$	scaling like m_q / M_S for $M_S \gg M_W$	
not related to the Yukawa's	suppressed by m_{d_i}	enhanced by m_t (j=3) but not allowed in gluino exchange for $d_i \to d_j$
dominant in box diagrams & generic dim.−6 operators	dominant in $d_i \to d_j$ magnetic penguins	dominant in $d_i \to d_j$ Z penguins

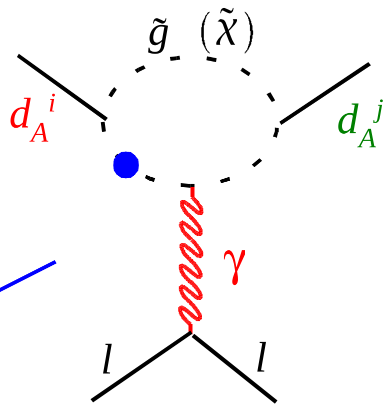
irrelevant for $d_i \to d_j\, l^+ l^- (\nu\nu)$

interesting for $d_i \to d_j\, l^+ l^- (\nu\nu)$

• SUSY contributions to $d_i \to d_j\, l^+ l^- (\nu\nu)$ transitions

A) Generic dim.−6 operators (box & γ−penguins)





$$(\bar{d}^i_A \gamma^\mu d^j_A) \times (\bar{l}_B \gamma_\mu l_B)$$

no helicity flip required

Dominant contr. to the Wilson coeff.:

$$\frac{(\delta^Q_{LL})_{ij}}{M_S^2} \quad \& \quad \frac{(\delta^Q_{RR})_{ij}}{M_S^2} \quad \longrightarrow \quad \sim \frac{1}{M_S^2}$$

LR insertions appear only at the 2nd order:

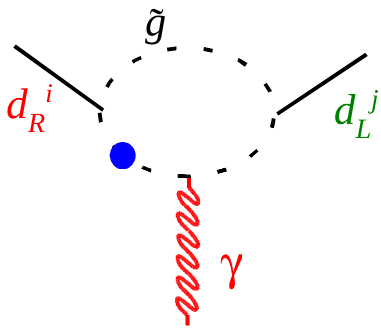
$$\frac{(\delta^U_{LR})_{i3}(\delta^U_{RL})_{3j}}{M_S^2}\ , \ \ldots \quad \longrightarrow \quad \sim \frac{m_t^2}{M_S^4}$$

All contributions are suppressed with respect to the corresponding SM ones after taking into account the $\Delta F=2$ bounds

Naïve dim. argument:

	SM	SUSY		
$\Delta F=2$	$\frac{\lambda_t^2}{M_W^2}(\bar{q}_i q_j)^2$	$\frac{\delta^2}{M_S^2}(\bar{q}_i q_j)^2$	$\longrightarrow$	$\delta \lesssim \lambda_t (M_S/M_W)$
$\Delta F=1$	$\frac{\lambda_t}{M_W^2}(\bar{q}_i q_j)(\bar{l}\, l)$	$\frac{\delta}{M_S^2}(\bar{q}_i q_j)(\bar{l}\, l)$		$\lesssim (M_W/M_S) \times$ "SM"

B) Magnetic penguins



$$\longrightarrow \quad \bar{d}^i_R \sigma_{\mu\nu} d^j_L F^{\mu\nu}$$

charged lepton pair

Dominant contr. to the Wilson coeff.: $\dfrac{(\delta^D_{RL})_{ij}}{M_S} \longrightarrow \sim \dfrac{m_i}{M_S^2}$

[subleading terms completely negligible: $\dfrac{(\delta^D_{RL})_{ii}(\delta^D_{LL})_{ij}}{M_S}$, $\dfrac{m_{d_i}(\delta^U_{LR})_{i3}(\delta^U_{RL})_{3j}}{M_S^2}$, ...]

This term escapes the $\Delta F=2$ bounds both in $b \to s$ & $s \to d$ transitions

$b \to s$: strong direct constraint from $b \to s\gamma$

$$2.0\times10^{-4} < B(B \to X_s \gamma) < 4.5\times10^{-4} \quad \Rightarrow \quad \left|(\delta^D_{LR})_{23}\right| \lesssim 10^{-2}$$

[CLEO 95% C.L.]

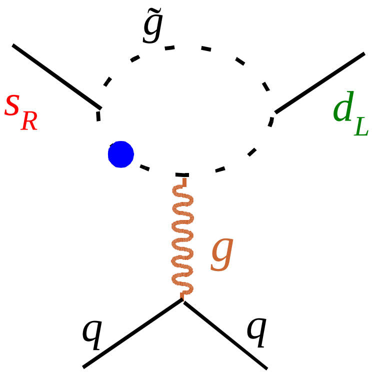
Natural scale: $(\delta^D_{LR})_{23} \lesssim \dfrac{m_b}{M_S} \simeq 10^{-2}\left(\dfrac{500\ GeV}{M_S}\right)$

Still room for a possible large $\not{CP}$ phase
(negligible within the SM)

Kagan & Neubert, '98

$\underline{s \to d}$: no significant constraints on $\left|(\delta^D_{LR})_{12}\right|$

Strong bound on $\Im(\delta^D_{LR})_{12}$ from the chromomagnetic contribution to $\Re(\varepsilon'/\varepsilon)$



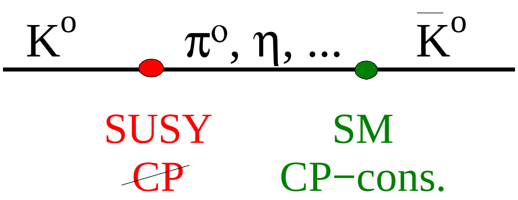
$$\left|\Im(\delta^D_{LR})_{12}\right| \lesssim 4\times 10^{-5}\left(\frac{M_S}{500\ \ GeV}\right)$$

assuming $\Re(\varepsilon'/\varepsilon)^{\rm cmo} < 3\times 10^{-3}$

Natural scale: $(\delta^D_{LR})_{12} \lesssim \dfrac{m_s}{M_S} \simeq 2\times 10^{-4}\left(\dfrac{500\ \ GeV}{M_S}\right)$

Sizable SUSY contributions to $\Re(\varepsilon'/\varepsilon)$ still possible

N.B.: if $\Im(\delta^D_{LR})_{12} \sim$ few$\times 10^{-5}$ we could also reproduce the exp. value of ε_K via a long−distance amplitude of the type $(\Delta S=1)_{\rm CPV}\times(\Delta S=1)_{\rm CPC}$



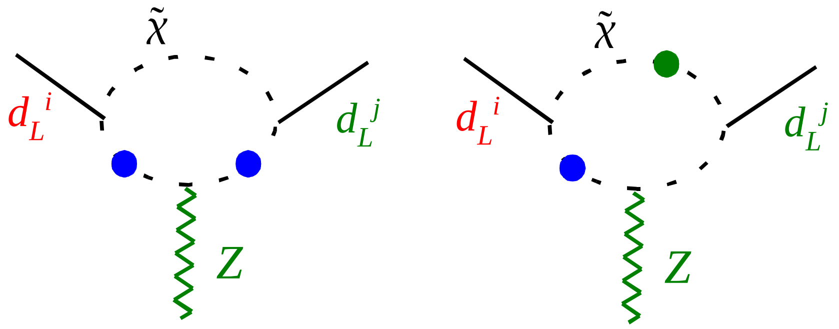
[$O(1)$ hadronic uncert.]

Fully supersymmetric ~~CP~~ in the kaon sector !

Clear observable consequences in rare K decays:

- $K_L \to \pi^0 e^+ e^-$ SUSY direct−~~CP~~ contribution similar to the SM one via the magnetic penguin: $BR \sim 10^{-12}$–10^{-11}
- $K_L \to \pi^0 \nu\nu$ No significant direct−~~CP~~ contribution: $BR < 10^{-14}$

C) Z penguins



$$\longrightarrow \quad \bar{d}^i_L \gamma_\mu d^j_L Z^\mu$$

$$\frac{Z^L_{ij}}{M_Z^2}(\bar{d}^i_L \gamma_\mu d^j_L) \times \begin{cases} \bar{l}\,\gamma^\mu \gamma_5 l & (v_Z^{(l)} \sim 0) \\ \bar{\nu}_L \gamma^\mu \nu_L \end{cases}$$

leading contribution by chargino up-type squarks loops
(double helicity-flip required)

$$Z^L_{ij} \sim \begin{cases} (\delta^U_{LR})_{i3}(\delta^U_{RL})_{3j} \\ \dfrac{m_t V^{CKM}_{i3}}{M_S}(\delta^U_{RL})_{3j} \end{cases} \longrightarrow \sim \frac{m_t^2}{M_S^2}$$

dominant for i=3 ($b \to s$)

Weak constraints from ΔS=2 & $(\Delta S=1)_{\text{mag.}}$ amplitudes

$$\left[\; (Z^L_{ij})_{SM} \sim \frac{m_t^2}{M_W^2} V_{i3} V^*_{3j} \; \right] \longrightarrow$$

$O(1)$ deviations from the SM are possible if:

$$\begin{matrix} \text{(i=2)} \; 0.1 \\ \text{(i=1)} \; 0.02 \end{matrix} \; \frac{m_t V_{i3}}{M_W} < (\delta^U_{LR})_{i3} < \frac{m_t}{M_S} \simeq 0.3 \left(\frac{500 \;\; GeV}{M_S} \right)$$

- A generic scenario with large non-standard FCNC amplitudes mediated by the Z exchange can be realized within SUSY
- This scenario is weakly constrained at present

$b \to s$:

$$B(B \to X_s l^+ l^-) < 4.2\times 10^{-5} \quad \Rightarrow \quad |Z^L_{bs}| \lesssim 0.15$$

[CLEO]

$$\left(|Z^L_{bs}|_{SM} \simeq 0.03 \quad \text{'t Hooft−Feynman} \right)$$

Slightly more stringent bound from $B \to K^* \mu^+\mu^-$: $|Z^L_{bs}| \lesssim 0.13$
subject, however, to larger th. uncertainties

Buchalla, Hiller & G.I. '00

No siginficant constraints on $\Im(Z^L_{bs})$

$s \to d$:

$$B(K^+ \to \pi^+ \nu\nu) = \left(1.5^{+3.4}_{-1.2}\right)\times 10^{-5} \qquad \left(|Z^L_{sd}|_{SM} \simeq 3\times 10^{-4} \right)$$

[BNL−E787]

$$\begin{cases} |Z^L_{sd}| < 18\times 10^{-4} & \text{neglecting the SM contr.} \\ \Re\left(Z^L_{sd}\right) = -\left(2.7^{+7.9}_{5.6}\right)\times 10^{-4} & \text{assuming positive interference with the SM} \end{cases}$$

$$-10^{-3} < \Re(\varepsilon'/\varepsilon)_Z < 2\times 10^{-3} \qquad \left(\Im(Z^L_{sd})_{SM} \simeq 1\times 10^{-4} \right)$$

$(+ B_8 \gtrsim 0.6)$

$$-8\times 10^{-4} \lesssim \Im(Z^L_{ds}) \lesssim 4\times 10^{-4}$$

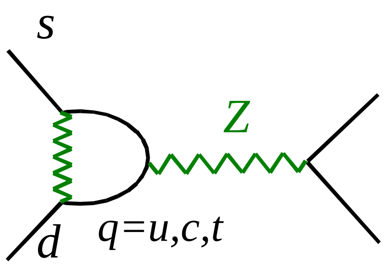
⇒ Large room for sizable non−standard contributions ⇐

$K \to \pi \nu\nu$

Golden modes for precision tests of the $s \to d$ FCNC transition

Key features within the SM:

A) *hard−GIM* mechanism $\Rightarrow$ short−distance dominance



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$$\Rightarrow \quad A_q \sim m_q^2 \underbrace{V_{qs}^* V_{qd}}_{\lambda_t} \sim \begin{cases} \Lambda_{QCD}^2 \lambda & (u) \\ m_c^2 \lambda + i\, m_c^2 \lambda^5 & (c) \\ m_t^2 \lambda^5 + i\, m_t^2 \lambda^5 & (t) \end{cases}$$

$$\boxed{\mathcal{H}_{eff} = \frac{G_F \alpha}{2\sqrt{2}\pi s_W^2} \sum_l \left[\lambda_c X_c^{(l)} + \lambda_t X_t \right] (\bar{s} d)_{V-A} (\bar{\nu}_l \nu_l)_{V-A}}$$

Inami & Lim, ’81 (LO)

Buchalla & Buras, ’93−’94
Misiak & Urban, ’99 (NLO)

B) Hadronic matrix element ($\langle \pi | (\bar{s}d)_{V-A} | K \rangle$) extracted from $K \to \pi l \nu$ with good acuracy

Marciano & Parsa, ’96

C) The $\bar{\nu}_l \nu_l$ state produced by $\mathcal{H}_{eff}$ is a *CP* eigenstate

$\longrightarrow$ $K_L \to \underline{\pi^0 \bar{\nu}\nu}$ provides an excellent probe of the CKM mechanism for $\cancel{CP}$

$CP \; | \pi^0 \bar{\nu}\nu \rangle = + \, | \pi^0 \bar{\nu}\nu \rangle$

Littenberg, ’89

Theoretical uncertainties of $BR(K \to \pi \nu\nu)$ within the SM:

$K_L \to \pi^0 \nu\nu$

- Charm contribution to the direct−CP−violating amplitude suppressed by $\sim (m_c/m_t)^2$
- Indirect $\cancel{CP}$ suppressed by $\epsilon_K (\tau_L/\tau_S)^{1/2} \sim 10^{-2}$
- $BR_{CPC}/BR_{CPV} \sim 10^{-4}$ (CPC strongly suppressed by phase space due to $|\nu\nu\rangle_{(J=2)}$)

Buchalla & G.I, '98

$$BR(K_L)^{(SM)} = \underline{4.30\times 10^{-10}} \left(\frac{\overline{m}_t(m_t)}{170\ GeV}\right)^{2.3} \left[\frac{\Im(V^*_{ts} V_{td})}{\lambda^5}\right]^2$$

$$= (3.1 \pm 1.3) \times 10^{-11}$$

th. error ~ 1 % !

$K^+ \to \pi^+ \nu\nu$

- QCD corrections to the charm contribution: $\delta(BR) < 10\ \%$

Buchalla & Buras, '97

- Genuine long−ditance effects induced by light−quark loops: $\delta(BR) \sim 1\%$

Lu & Wise, '94

$$BR(K^+)^{(SM)} = (8.3 \pm 3.2) \times 10^{-11}$$

Buchalla & Buras, '99

error dominated at present by the poor knowledg of V_{td}

	SM	A	B	C	Exp.
		SUSY scenarios			
	SM	A	B	C	Exp.
$B(K^+ \to \pi^+\nu\nu)\times 10^{-10}$	0.8 ± 0.3	$\leqslant BR_{\mathrm{SM}}$	$\leqslant 2.1$	$\leqslant 2.7$	$1.5\,^{+3.5}_{-1.3}$ (BNL−E787)
$B(K_L \to \pi^0\nu\nu)\times 10^{-10}$	0.3 ± 0.1	$\leqslant BR_{\mathrm{SM}}$	$\leqslant 1.7$	$\leqslant 4.0$	$< 5.9\times 10^3$ (KTeV)
$B(K_L \to \pi^0 e^+e^-)^{\mathrm{CP}}_{\mathrm{dir}}\times 10^{-11}$	0.5 ± 0.2	$\leqslant 1.8$	$\leqslant 3.0$	$\leqslant 10$	< 56 (KTeV)

A) $(\delta^D_{LR})_{12} \neq 0 \Rightarrow \varepsilon'/\varepsilon,\ \varepsilon$ (*chromomag. peng.*)

B) $(\delta^U_{LR})_{j3} \neq 0 \Rightarrow \varepsilon'/\varepsilon$ (*Z peng.*), ε (*RGE*)

C) = A) + B) + non−standard CKM

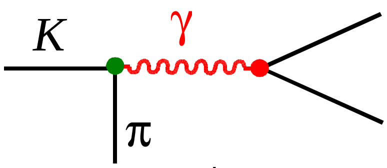
Buras, Colangelo, G.I,
Romanino & Silvestrini ’00

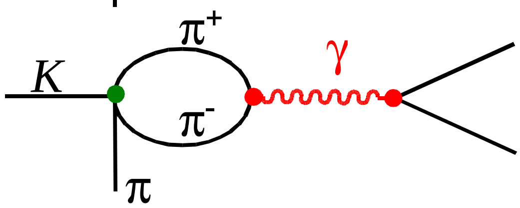
• $K \to \pi\, l^+ l^-$

Two very different scenarios:

A) $K^\pm \to \pi^\pm l^+ l^-$, $K_S \to \pi^0 l^+ l^-$

dominated by the long−distance contribution to the single−photon exchange amplitude





$B(K^+ \to \pi^+ e^+ e^-) = (2.94 \pm 0.14) \times 10^{-7}$

$B(K^+ \to \pi^+ \mu^+ \mu^-) = (9.22 \pm 0.77) \times 10^{-8}$

BNL−E865 ’99

$\left(B(K^+ \to \pi^+ e^+ e^-)_{SD} \sim 10^{-11} \right)$

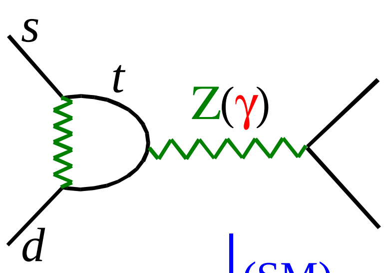
$K_S \to \pi^0 l^+ l^-$ decays not observed yet

B) $K_L \to \pi^0 l^+ l^-$

single−photon exchange forbidden in the limit of *CP* invariance

interference

1. Direct *CPV* amplitude



+ *box*

(SM)

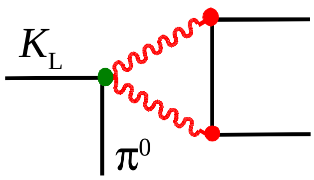
$B(K_L \to \pi^0 e^+ e^-)_{CPV-dir} \sim 5 \times 10^{-12}$

Buras *et al.* ’94

2. Indirect *CPV* amplitude

$B(K_L \to \pi^0 e^+ e^-)_{CPV-mix} \simeq 3 \times 10^{-3} \times B(K_S \to \pi^0 e^+ e^-)$

3. *CP*−conserving amplitude



strong constr. thanks to the new results on $K_L \to \pi^0 \gamma\gamma$ @ small $m_{\gamma\gamma}$

[KTeV, NA48 ’99]

$B(K_L \to \pi^0 e^+ e^-)_{CPC} \lesssim 2 \times 10^{-12}$

Very interesting interplay of short− & long−distance dynamics !

General structure of the $K \to \pi \gamma^* \to \pi l^+ l^-$ amplitude:

$$\boxed{A(K^i(k) \to \pi^i(p) l^+ l^-) \;=\; \frac{e^2 W_i(z)}{(4\pi)^2 m_K^2}(k+p)^\mu\, \bar{u}_l \gamma_\mu v_l}$$

$$i\int d^4x\, e^{iqx} \langle \pi^i(p) | T\{ J^\mu_{e.m.}(x) L_W(0) \} | K^i(k) \rangle = \frac{W_i(z)}{(4\pi)^2 m_K^2}\left[q^2 (k+p)^\mu - (m_K^2 - m_\pi^2) q^\mu \right]$$

Properties of $W_i(z)$: $\left(z = q^2/m_K^2 = (p_{l^+} + p_{l^-})^2 / m_K^2 \right)$

- $W_i(0)$ = const. (non singular for $q^2 \to 0$)
- There are two distinct form factors, W_+ & W_0, not related by chiral symmetry

  → we cannot predict $B(K_S \to \pi^0 l^+ l^-)$ using $K^+ \to \pi^+ l^+ l^-$ data

- General decomposition:

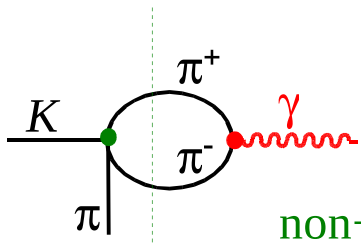
$$W_i(z) = G_F M_K^2 W_i^{pol}(z) + W_i^{\pi\pi}(z)$$

$a_i + b_i z + \ldots$

$a_i \neq 0$ @ $O(p^4)$

$b_i \neq 0$ @ $O(p^6)$

normalization such that $a_i \sim O(1)$



non−analytic term

$W^{\pi\pi}(z)$ from $A(K \to 3\pi)^{(2)}$

Ecker, Pich & de Rafael, '91

$W^{\pi\pi}(z)$ from $A(K \to 3\pi)^{(\exp)}$

D'Ambrosio, Ecker, G.I. & Portolés, '98

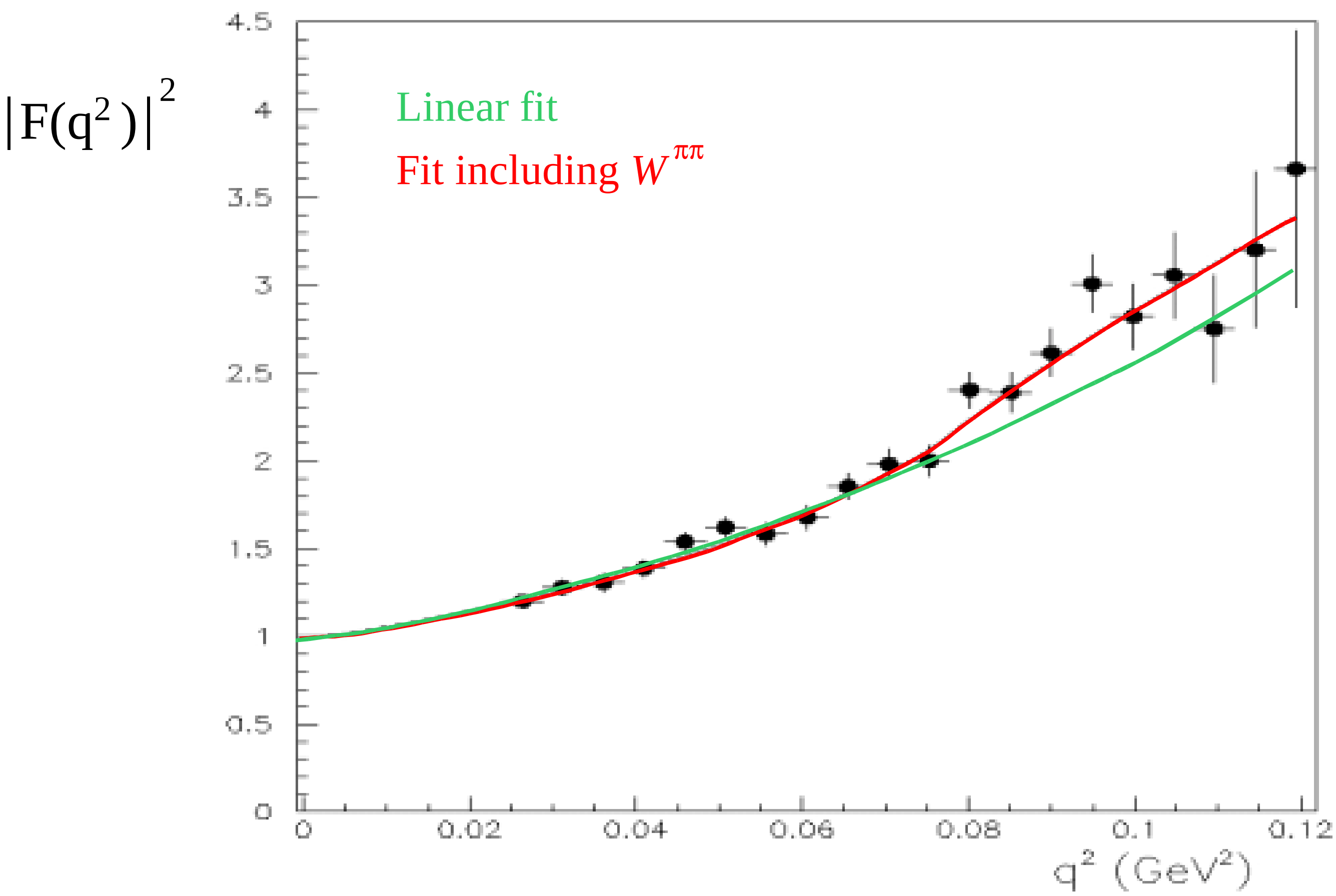
Recent high−statistic result on $K^+ \to \pi^+ e^+ e^-$ from BNL−E865:

(~ 10^4 events)

Linear Fit $\Rightarrow$ $\chi^2/N_{\rm dof} = 22.9/18$

Fit incuding $W^{\pi\pi}$ $\Rightarrow$ $\chi^2/N_{\rm dof} = 13.3/18$ $a_+ = -0.59 \pm 0.01$

$b_+ = -0.65 \pm 0.04$



- Clear evidence of $W^{\pi\pi}$ $\Rightarrow$ successful prediction of Ch. Dynamics
- $O(p^6)$ effects are very important (b/a larger than naïve estimate)

  $\Rightarrow$ Can we explain it within VMD models ?

  Yes, but only at a qualitative level: experimental info on $K_S \to \pi^0 e^+ e^-$ are needed for a deeper understanding

D'Ambrosio *et al.* '98

Neutral modes:

I) $B(K_S \to \pi^0 e^+ e^-) \simeq 5\times 10^{-9}\,|a_S|$

(small sensitivity to b_S, pion−loop term negligible)

($a_S \sim O(1)$ by dim. analysis)

Values of $B(K_S \to \pi^0 e^+ e^-) \sim 10^{-8}$ cannot be excluded a priori: this possibility is even predicted within some VMD scenarios given the recent results on a_+ & b_+

$\longrightarrow$ interesting prospect for NA48 (& KLOE)

II) $B(K_L \to \pi^0 e^+ e^-) = B(K_L \to \pi^0 e^+ e^-)_{CPV} + B(K_L \to \pi^0 e^+ e^-)_{CPC}$

interference of short − & long−distance components

$$\left[15.3\, a_S^2 - 6.8\, a_S \frac{\Im(V_{ts}^* V_{td})}{10^{-4}} + 2.8 \left(\frac{\Im(V_{ts}^* V_{td})}{10^{-4}} \right)^2 \right] \times 10^{-12}$$

lepton pair in $J=2$

different Dalitz−Plot distribution

$\lesssim 2\times 10^{-12}$

Assuming no sizable New Physics effects in $K_L \to \pi^0 e^+ e^-$:

$B(K_L \to \pi^0 e^+ e^-) < 5.6\times 10^{-12}$ (KTeV '99)

$\longrightarrow$ $|a_S| < 6.0$ $\longrightarrow$ $B(K_S \to \pi^0 e^+ e^-) < 1.9\times 10^{-7}$

recently superseeded by the direct bound:

$B(K_S \to \pi^0 e^+ e^-) < 1.6\times 10^{-7}$ (NA48 '00)

(still ~ 1 order of magnitude far from th. expectations)

Exclusive $b \to s$ decays

Even if no sizable new physics effecs are found in $b \to s\gamma$, we can still hope to observe large deviations from the SM in FCNC transitions of the type $b \to s\, l^+ l^-$ $(\nu\nu)$

Inclusive measurements could be used for precision tests ($B \to X_s \nu\nu$ = golden mode) but are very challenging from the exp. point of view

Exclusive measurements could be used in the short term to detect possible large effects:

decay mode	BR_{SM}	BR_{max}	BR_{exp}
$B \to K^* \nu\nu$	$\approx 1.3\times 10^{-5}$	$\lesssim 10^{-4}$	$< 7.7\times 10^{-4}$ LEP
$B \to K \nu\nu$	$\approx 4\times 10^{-6}$	$\lesssim 3\times 10^{-5}$	$< 7.7\times 10^{-4}$ LEP
$B \to K \mu^+\mu^-$	$\approx 6\times 10^{-7}$	$\lesssim 2\times 10^{-6}$	$< 5.2\times 10^{-6}$ CDF
$B_s \to \mu^+\mu^-$	$\approx 3\times 10^{-9}$	$\lesssim 3\times 10^{-8}$	$< 2.6\times 10^{-6}$ CDF

Enhancements up to ~ 10 possible in the modes where the single−photon exchange amplitude is forbidden

Buchalla, Hiller & G.I. ’00

The lepton FB asymmetry in $B \to K^* \mu^+ \mu^-$

An excellent probe of non−standard effects in Z^L_{bs} , including a possible $\not{CP}$ phase, is provided by the forward−back asymmetry of the emitted leptons in $B \to K^* l^+ l^-$:

$$A^{(B)}_{FB}(s) = \frac{1}{d\Gamma(B \to K^* \mu^+ \mu^-)/ds} \int d\cos\vartheta \frac{d^2\Gamma(B \to K^* \mu^+ \mu^-)}{ds\, d\cos\vartheta} sgn(\cos\vartheta)$$

ϑ = angle between μ^+ & B momenta in the dilepton c.o.m. frame

$s = (p_{\mu^+} + p_{\mu^-})^2 / m_B^2$

$\boxed{A^{(B)}_{FB}(s) \neq 0}$ $\longleftrightarrow$ interference between Vector and Axial−vector couplings to the lepton pair

$$\left.\begin{array}{l} Q_7 \sim (\bar{s}_L \sigma_{\mu\nu} b_L) F^{\mu\nu} \\ Q_9 \sim (\bar{s}_L \gamma^\mu b_L)(\bar{l} \gamma_\mu l) \end{array}\right]$$ Vector coupling (~ insensitive to Z^L_{bs})

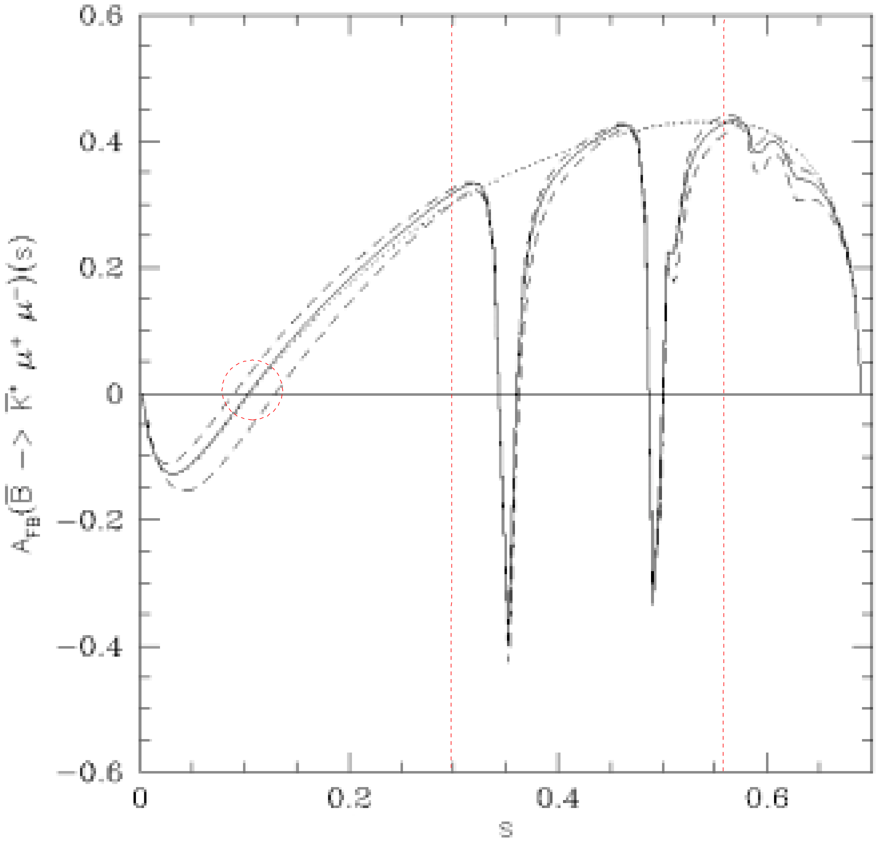
$Q_{10} \sim (\bar{s}_L \gamma^\mu b_L)(\bar{l} \gamma_\mu \gamma_5 l)$ Axial coupling (strongly sensitive to Z^L_{bs})

$$A^{(\bar{B})}_{FB}(s) \propto \Re\left[C^*_{10} \left(s C^{eff}_9(s) + r(s) C_7 \right) \right]$$

Direct access to the relative phases of the Wilson Coefficients

$\not{CP}$ phase (beyond the SM)

absorptive (CP−cons.) phase due to intermediate $c\bar{c}$ states



$A_{FB}(s)$ within the SM for the $\bar{B} = |b\bar{d}\rangle$ mode

Properties of $A_{FB}(s)$ independent from the detailed structure of the hadronic form factors:

- $A_{FB}(s_0) = 0$ for $s_0 \sim C_7/C_9$
  (unaffected by new physics in Z_{bs})

Burdman '98

- $\overset{(\bar{B})}{A}_{FB}(s) < 0$ for $s < s_0$ within the SM
- $\overset{(B)}{A}_{FB}(s) = - \overset{(\bar{B})}{A}_{FB}(s)$ in absence of $\cancel{CP}$

Buchalla,
Hiller & G.I. '00

clear tests of possible new physics effects in Z_{bs}

N.B.: several wrong statements in the literature about the sign of $A_{FB}(s)$!

Conclusions

- FCNC transitions of the type $d_i \to d_j\ l^+l^-\ (\nu\nu)$ have a great potential in probing non−standard flavour dynamics

  $\Rightarrow$ $\cancel{\text{flavour}} \oplus \cancel{SU(2)_L}$

- Sizable rate enhancements of $K^+ \to \pi^+\nu\bar{\nu}$ and/or $B \to (K^*,K)+(l^+l^-,\nu\bar{\nu})$ cannot be excluded yet and could be realized within specific SUSY scenarios with non−universal soft−breaking terms

- The largest deviations from the SM can be expected in the sector of CP violation, where precision tests are possible (*hopefully in the near future !*) by means of $K_L \to \pi^0\nu\bar{\nu}$, $K_L \to \pi^0 e^+e^-$ and $A_{FB}(B \to K^*\mu^+\mu^-)$