Flavor changing matrix elements for Physics beyond the SM

Alessio Maiezza
University of L'Aquila

with *S. Bertolini, J. Eeg, F. Nesti*

Portoroz 2013

Contents

- Flavor changing operators in **NP**.

- **Left-Right model** as a paradigmatic example of NP

  - a brief review

  - Left-Right symmetry at low scale

- Hadronic matrix elements

  - Short Distance coefficients

  - Matrix elements of NP operators for K to two pions: estimations in the **Chiral Q. M.**

- Conclusions.

ΔS=1 processes

$L_Q = \Sigma_i C_i Q_i$ Flavor changing Lagrangian

$$
\begin{aligned}
Q_1^{LL} &= (\bar s_\alpha u_\beta)_L(\bar u_\beta d_\alpha)_L & Q_1^{RR} &= (\bar s_\alpha u_\beta)_R(\bar u_\beta d_\alpha)_R \\
Q_2^{LL} &= (\bar s u)_L(\bar u d)_L & Q_2^{RR} &= (\bar s u)_R(\bar u d)_R \\
Q_3 &= (\bar s d)_L(\bar q q)_L & Q_3' &= (\bar s d)_R(\bar q q)_R \\
Q_4 &= (\bar s_\alpha d_\beta)_L(\bar q_\beta q_\alpha)_L & Q_4' &= (\bar s_\alpha d_\beta)_R(\bar q_\beta q_\alpha)_R \\
Q_9 &= \tfrac{3}{2}(\bar s d)_L e_q(\bar q q)_L & Q_9' &= \tfrac{3}{2}(\bar s d)_R e_q(\bar q q)_R \\
Q_{10} &= \tfrac{3}{2}(\bar s_\alpha d_\beta)_L e_q(\bar q_\beta q_\alpha)_L & Q_{10}' &= \tfrac{3}{2}(\bar s_\alpha d_\beta)_R e_q(\bar q_\beta q_\alpha)_R
\end{aligned}
$$

$$
\begin{aligned}
Q_1^{RL} &= (\bar s_\alpha u_\beta)_R(\bar u_\beta d_\alpha)_L & Q_1^{LR} &= (\bar s_\alpha u_\beta)_L(\bar u_\beta d_\alpha)_R \\
Q_2^{RL} &= (\bar s u)_R(\bar u d)_L & Q_2^{LR} &= (\bar s u)_L(\bar u d)_R \\
Q_5 &= (\bar s d)_L(\bar q q)_R & Q_5' &= (\bar s d)_R(\bar q q)_L \\
Q_6 &= (\bar s_\alpha d_\beta)_L(\bar q_\beta q_\alpha)_R & Q_6' &= (\bar s_\alpha d_\beta)_R(\bar q_\beta q_\alpha)_L \\
Q_7 &= \tfrac{3}{2}(\bar s d)_L e_q(\bar q q)_R & Q_7' &= \tfrac{3}{2}(\bar s d)_R e_q(\bar q q)_L \\
Q_8 &= \tfrac{3}{2}(\bar s_\alpha d_\beta)_L e_q(\bar q_\beta q_\alpha)_R & Q_8' &= \tfrac{3}{2}(\bar s_\alpha d_\beta)_R e_q(\bar q_\beta q_\alpha)_L
\end{aligned}
$$

$$
\begin{aligned}
Q_g^L &= \frac{g_s m_s}{8\pi^2}\bar s \sigma_{\mu\nu} t^a G_a^{\mu\nu} L d & Q_g^R &= \frac{g_s m_s}{8\pi^2}\bar s \sigma_{\mu\nu} t^a G_a^{\mu\nu} R d \\
Q_\gamma^L &= \frac{e m_s}{8\pi^2}\bar s \sigma_{\mu\nu} F_a^{\mu\nu} L d & Q_\gamma^R &= \frac{e m_s}{8\pi^2}\bar s \sigma_{\mu\nu} F_a^{\mu\nu} R d\,.
\end{aligned}
$$

Standard plus nonstandard complete set of flavor changing operators, which are generated by SM +NP.
The set contains all possible chiral combinations.

Need the matrix elements for K to pions.

(A.M.-Nesti-Bertolini-Eeg 2012)

A paradigmatic example of physics beyond SM: Left-Right Symmetric Model

Gauge group: $SU(2)_L \times SU(2)_R \times U(1)_{B-L} \Rightarrow SU(2)_L \times U(1)_Y$ (Pati-Salam '74, Mohapatra-Senjanovic '75)

The low scale minimal model $g_L = g_R$

with a further symmetry, or a generalized ***Parity***, between left and righ sector $L \leftrightarrow R$

Fermionic representations

$Q_L = \begin{pmatrix} u \\ d \end{pmatrix}_L$ $Q_R = \begin{pmatrix} u \\ d \end{pmatrix}_R$ $\Psi_L = \begin{pmatrix} \nu_l \\ l \end{pmatrix}_L$ $\Psi_R = \begin{pmatrix} \nu_l \\ l \end{pmatrix}_R$

gauge bosons

γ

$Z_L, W_L^{\pm}$

$Z_R, W_R^{\pm}$

Electric charge: $Q_{el} = T_{3L} + T_{3R} + \frac{B-L}{2}$

Quantum numbers: $Q_L \in (3,2,1,1/3)$ $Q_R \in (3,1,2,1/3)$ $\Psi_L \in (1,2,1,-1)$ $\Psi_R \in (1,1,2,-1)$

$$L_Y^{had.} = [\overline{Q}_{Li}(Y_{ij}\Phi + \widetilde{Y}_{ij}\widetilde{\Phi})Q_{Rj}] + h.c. \qquad \Phi \in (2_L, 2_R, 0)$$

$$\begin{aligned} M_u &= Y v_1 + \widetilde{Y} v_2 e^{-i\alpha} \\ M_d &= Y v_2 e^{i\alpha} + \widetilde{Y} v_1. \end{aligned}$$

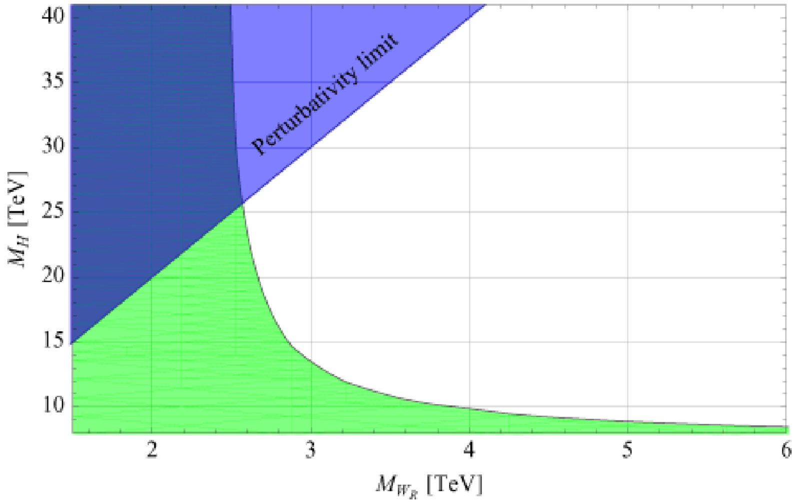
Bi-diagonalization produces left and right mixing matrices

$$L_{cc} = \frac{g}{2\sqrt{2}}\{[\bar{u}V_L\gamma^\mu(1-\gamma_5)d]W_{L\mu} + [\bar{u}V_R\gamma^\mu(1+\gamma_5)d]W_{R\mu}]\} + h.c.$$

Left-Right symmetry at low scale

-The LR model is a natural theory for **neutrino mass**. (Mohapatra-Senjanovic '80)

-Current strongest bound: from ΔM_K



Correlated plot between right gauge boson and heavy Higgs masses.

The lower bound on right-handed scale is 2.5-3 TeV.

(A.M.-Nemevsek-Nesti-Senjanovic,2010)

-The NP contribution to **neutrinoless double-beta decay**

$$A^{N.P.} \propto \frac{G_F^2 M_W^4}{M_{W_R}^5}$$

(Tello-Nemevsek-Nesti-Senjanovic '11)

fits well with Heidelberg Moscow claim, for the right-handed scale in the range of TeV

(Klapdor et al. '01-06)

Effective approach to CP-violation

Motivated by this hint of a **NP** in the LHC reach, it is important to evaluate the new hadronic matrix elements for **ΔS=1 processes** (which lead to potentially stringent constraints).

We approach the problem through a effective theory: the **Chiral Quark Model**.
(Note: lattice evaluation is difficult, first results expected this year) (Soni et al.)

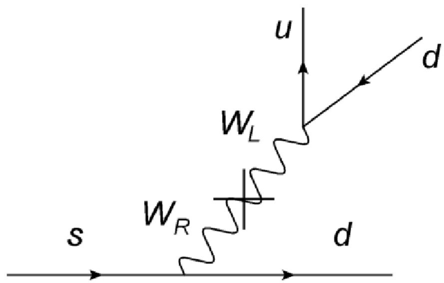
We start from the relevant NP operators and their S.D. coefficients.

The most important operators, generated by NP

Current-Current

$$Q_1^{RL} = (\bar{s}_\alpha u_\beta)_R(\bar{u}_\beta d_\alpha)_L \qquad Q_1^{LR} = (\bar{s}_\alpha u_\beta)_L(\bar{u}_\beta d_\alpha)_R \qquad Q_1^{RR} = (\bar{s}_\alpha u_\beta)_R(\bar{u}_\beta d_\alpha)_R$$

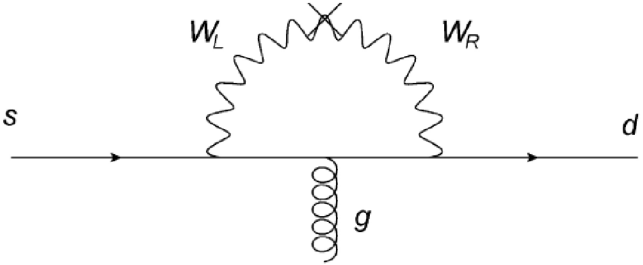
$$Q_2^{RL} = (\bar{s}u)_R(\bar{u}d)_L \qquad Q_2^{LR} = (\bar{s}u)_L(\bar{u}d)_R \qquad Q_2^{RR} = (\bar{s}u)_R(\bar{u}d)_R$$



RR analogous to the LL ones, which are generated by SM.

Chromomagnetic operators

$$Q_g^L = \frac{g_s m_s}{8\pi^2}\bar{s}\sigma_{\mu\nu}t^a G_a^{\mu\nu} L d \qquad Q_g^R = \frac{g_s m_s}{8\pi^2}\bar{s}\sigma_{\mu\nu}t^a G_a^{\mu\nu} R d$$



Short-Distance coefficients

-Chromagnetic operators

In the LR model the S.D. chromomagnetic coefficients are enhanced with respect to the SM by internal quark mass into the loop. The coefficient is

$$C_g^{LR} = \zeta \, \Sigma_i m_i \lambda_i^{LR} F_2^{LR}(x_i) \quad \Longleftrightarrow \quad C_g^{SM} = m_s \Sigma_i \lambda_i^{LL} F_2^{LL}(x_i)$$

Enhancement

$$C_g^{LR} / C_g^{SM} \approx 2 \times 10^5 \zeta \approx 200$$

$$\zeta \propto (M_{W_L} / M_{W_R})^2$$

-Current-current operators

The coefficient of Q_2^{LR} is **not loop suppressed**

$$C_2^{LR} = \zeta \lambda_u^{LR}$$

Note that Q_1^{LR} is not generated at S.D. It is produced during the running to low scale (0.8 GeV).

Chiral Quark Model approach

-The Lagrangian at the meson level

integrating out the quark

$$L_Q = \Sigma_i C_i Q_i \rightarrow L_{\chi PT} = \sum_{i,j} = G_j(Q_i) L^{\chi}$$

Linear combination of meson operators

-By means of a **quark-meson interaction**

$$L = -m(\bar{q}_R \Sigma q_L + \bar{q}_L \Sigma^{\dagger} q_R)$$

(Manohar, Georgi, '84, Gasser,Leutwyler,'84, Weinberg,2010)

Any process amplitude is evaluated through quark loops.

-By matching the result of loops with the transition resulting from chiral Lagrangian, one finds the coefficients:

$$G_j(Q_i)$$

-In the end, with the completely determinated chiral Lagrangian, one can compute the chiral loops.

The results are in terms of three parameters: fitted to reproduce the ΔI=1/2 rule:

(Bertolini, Eeg, Fabbrichesi, Lashin, '98)

allowed to a good theoretical estimation of epsilon' in the SM.

(Antonelli, Bertolini, Eeg, Fabbrichesi, Lashin, '96-2001)

Chiral Lagrangians

Chromagnetic operators

The chiral Lagrangians as functions of **meson octet** (and flavor projectors)

$$L_L^{(4)} = G_8^L Tr[\Sigma^\dagger \lambda_2^3 D_\mu \Sigma^\dagger D^\mu \Sigma] \qquad L_R^{(4)} = G_8^R Tr[\Sigma \lambda_2^3 D_\mu \Sigma D^\mu \Sigma^\dagger]$$

(Bertolini-Eeg-Fabbrichesi, '95)
(A.M.-Nesti-Bertolini-Eeg 2012)

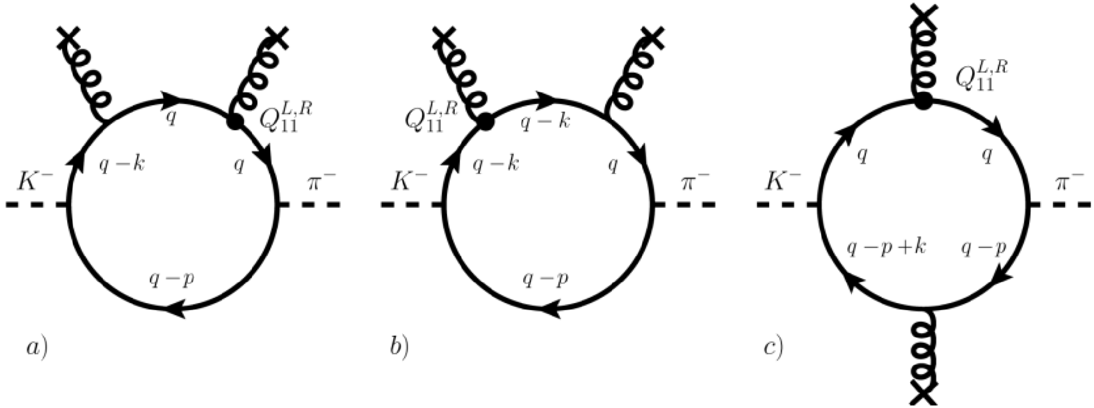
Current-current operators

$$\begin{aligned}
L &= G_0(Q_{1,2}^{LR}) Tr[\lambda_1^3 \Sigma^\dagger \lambda_2^1 \Sigma] + \\
&+ G_m(Q_{1,2}^{LR})(Tr[\lambda_1^3 \Sigma^\dagger \lambda_2^1 \Sigma \mathcal{M} \Sigma] + Tr[\lambda_2^1 \Sigma \lambda_1^3 \Sigma^\dagger \mathcal{M} \Sigma^\dagger]) \\
&+ G_{LR}^a(Q_{1,2}^{LR}) Tr[\lambda_2^3 D^\mu \Sigma] Tr[\lambda_1^1 D_\mu \Sigma^\dagger] + \\
&+ G_{LR}^b(Q_{1,2}^{LR}) Tr[\lambda_1^3 \Sigma^\dagger D^\mu \Sigma] Tr[\lambda_2^1 \Sigma D_\mu \Sigma^\dagger] + \\
&+ G_{LR}^c(Q_{1,2}^{LR}) \{Tr[\lambda_2^3 \Sigma] Tr[\lambda_1^1 D_\mu \Sigma^\dagger D^\mu \Sigma \Sigma^\dagger] + Tr[\lambda_2^3 D_\mu \Sigma D^\mu \Sigma^\dagger \Sigma] Tr[\lambda_1^1 \Sigma^\dagger]\}
\end{aligned}$$

(A.M.-Nesti-Bertolini, to appear)

Chromomagnetic operator, reevaluation of the matrix element

The χQM approach to chromomagnetic operators. (Bertolini-Eeg-Fabbrichesi, '95)



the matching with chiral Lagrangian leads to the amplitude :

$$\langle (2\pi)_I | (-i) H_{\Delta S=1} | K^0 \rangle = \frac{G_F m_\pi^2}{6 m f^3} \left\langle \frac{\alpha}{\pi} GG \right\rangle \frac{m_s (C_g^L - C_g^R)}{16\pi^2}$$

Nonperturbative contribution proportional to gluon condensate.

(A.M.-Nesti-Bertolini-Eeg 2012)

Evaluation of LR current-current matrix elements

-Determined coefficients: MSbar scheme (and, in this example, in the 't Hooft Veltman gamma_five scheme)

$$G_0(Q1) = -2\langle\bar{q}q\rangle^2 \qquad G_m(Q1) = -2f^2\langle\bar{q}q\rangle$$

$$G_a^{LR}(Q1) = 2\frac{f^2\langle\bar{q}q\rangle}{m} \qquad G_b^{LR}(Q1) = -\frac{f^4}{3}$$

$$G_c^{LR}(Q1) = -\frac{f^2\langle\bar{q}q\rangle\epsilon}{m} \qquad \text{with} \qquad \epsilon = \frac{2m^3N_cf^2}{\langle\bar{q}q\rangle\Lambda^2}$$

-Amplitudes: considering the leading bosonization plus chiral loops corrections

$$A_{00} = \frac{\sqrt{2}\left(\left(m_k^2 + m_\pi^2\right)G_a^{\mathrm{LR}} - 3m_\pi^2 G_c^{\mathrm{LR}} + 2m_sG_m + 2G_0\right)}{f^3} + \text{chiral loops}$$

$$A_{+-} = \frac{\sqrt{2}\left(m_k^2G_a^{\mathrm{LR}} + (m_k^2 - m_\pi^2)G_b^{\mathrm{LR}} + \left(m_k^2 - 3m_\pi^2\right)G_c^{\mathrm{LR}} + m_sG_m + G_0\right)}{f^3} + \text{chiral loops}$$

B parameters for LR current-current operators

We give the results in the standard form, i.e. parameterizing the amplitude as

$$B_i^{(0,2)} \equiv \frac{\mathrm{Re}\langle Q_i \rangle_{0,2}^{\mathrm{model}}}{\langle Q_i \rangle_{0,2}^{\mathrm{VSA}}} \qquad \langle Q_i \rangle_{0,2} \equiv \langle (\pi\pi)_{(I=0,2)} | Q_i | K^0 \rangle$$

where VSA is the Vacuum Saturation Approximation.

B parameters (HV scheme)

$$B_0(Q_1^{LR}) = 2.26^{+0.79}_{-0.46}$$
$$B_2(Q_1^{LR}) = 1.01^{+0.25}_{-0.29}$$
$$B_0(Q_2^{LR}) = 2.20^{+0.75}_{-0.44}$$
$$B_2(Q_2^{LR}) = 1.01^{+0.30}_{-0.32}$$

(A.M.-Nesti-Bertolini , to appear)

-Very small dependence on the scheme.

-The errors are evaluated varying all input parameters. We use the fitted values, see: (Bertolini, Eeg, Fabbrichesi, Lashin, '98)

Note that the RL B are equal to the LR ones.

Application: CP-violation in LR minimal model

Collecting our result in the **epsilon-prime** definition, we find the correlated bound between the LR mixing parameter and CP phases :

$$|\zeta(\alpha-\theta_c-\theta_d)|<1.7\times10^{-4}$$

$$\zeta \propto (M_{W_L}/M_{W_R})^2$$

(A.M.-Nesti-Bertolini-Eeg 2012)

Note that none bound comes for right-handed scale by epsilon-prime, this thanks to the freedom of CP phases. (A.M.-Nemevsek-Nesti-Senjanovic,2010).
Otherwise a very large bound turns out!

Conclusions

• New Physics induces flavor changing operators that are relevant for **ΔS=1 processes**.

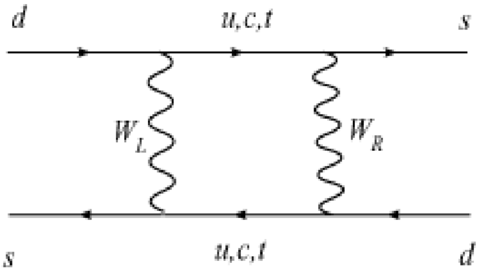
• An interesting example is the **Left-Right model** which has still a low bound on the right handed scale.

• We have calculated in the **Chiral Quark Model** the hadronix matrix elements which are generated by generic Physics beyond the SM.

• In the end we have applied our result in LR minimal model to find a constraint on CP phases from the epsilon-prime limit.

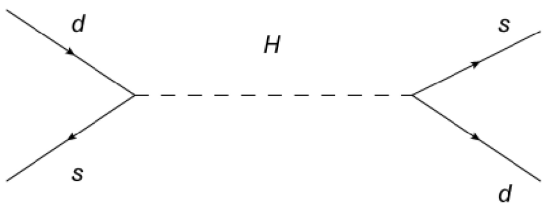
Thank you

Left-Right model provide New Physics for meson oscillations



New Box diagram from charged gauge interactions. V_L and V_R entering.

(Beall- Bander –Soni '82, Ecker-Grimus '85)



$$L \propto \bar{d}_L V_L^+ m_u V_R d_R H$$

Neutral Heavy Higgs lavor Changing at Tree level.

Same V_L and V_R structure.

(G. Senjanovic, P. Senjanovic '80)

V_R plays an important role in determining the LR contribution to flavor violations. If right CKM matrix were free no bound emerges.

(Langacker-Sankar '89)

The choice of Left-Right symmetry is not univocal

$$\mathcal{P}: \begin{cases} Q_L \leftrightarrow Q_R \\ \Phi \to \Phi^\dagger \end{cases} \qquad \mathcal{C}: \begin{cases} Q_L \leftrightarrow (Q_R)^c \\ \Phi \to \Phi^T \end{cases}$$

Which lead respectively to

$$V_R \simeq S_u V_L S_d$$

(A.M.-Nemevsek-Nesti-Senjanovic)

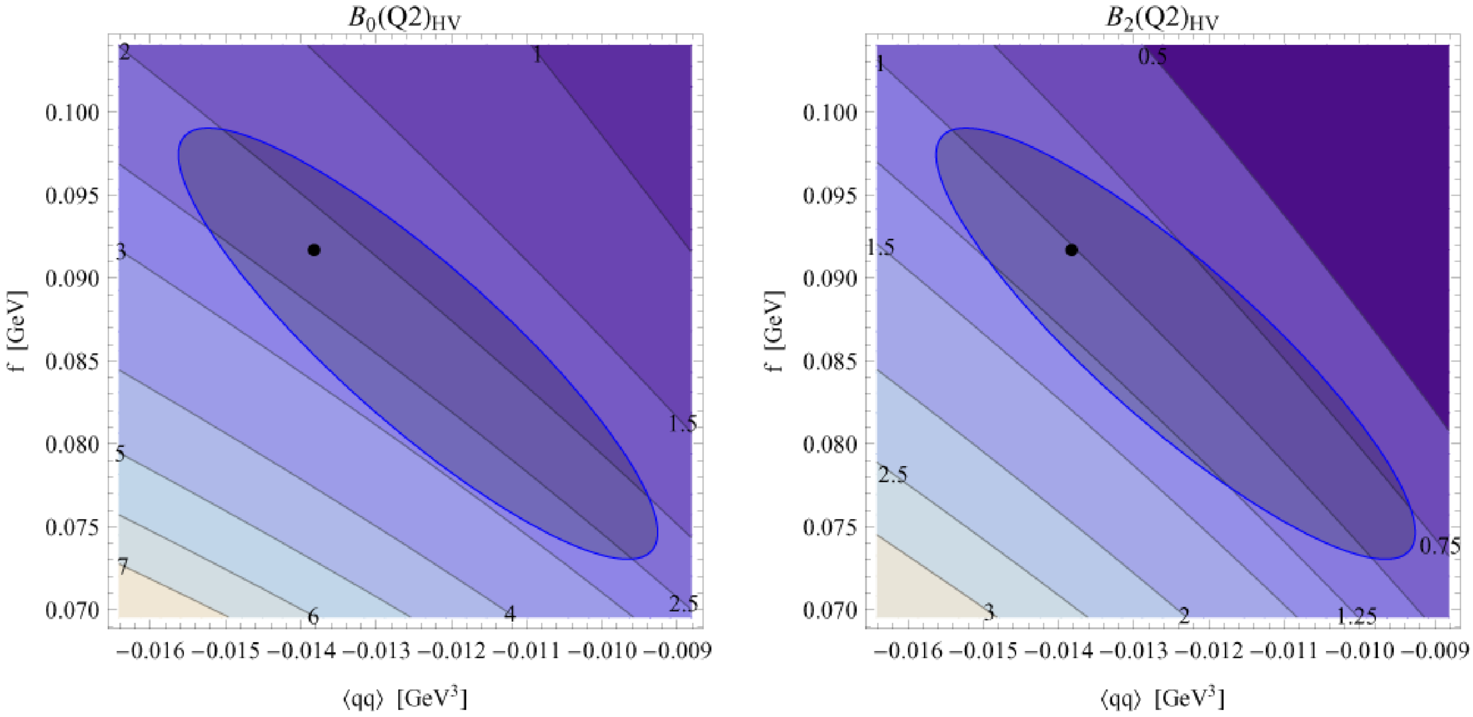
or

$$V_R = S_u V_L^* S_d$$

with $S_{u,d}$ diagonal matricies of up and down phases.

- In the "P" case the phases S are fixed of order 1/100.
- In the "C" case the phases are free parameters. Better in view of CP-violation.
- The second case is more interesting also inSO(10) GUT scenario. L-R symmetry is a gauge trasformation in the form of charge conjugation, since the fermions and its charge conjugated reside in the same representation **16**F.

Correlation between renormalized decay constant and quark condensate



Input parameters

<qq>= quark condensate

m= constituent mass

<GG>= Gluon condensate

They are a priori free parameters which are determinated by fitting the $\Delta I = 1/2$ rule for kaon decays.

(Bertolini, Eeg, Fabbrichesi, Lashin, ‘98)

Regualarization divergences

$$f^2 = \frac{m^2 Nc}{4\pi^2} \left(\frac{\mu^2}{m^2} \right)^{\epsilon} \Gamma(\epsilon)$$

$$\langle \bar{q} q \rangle = \frac{m^3 Nc}{4\pi^2} \left(\frac{\mu^2}{m^2} \right)^{\epsilon} \Gamma(-1 + \epsilon)$$

(Antonelli, Bertolini, Eeg, Fabbrichesi, Lashin, '96)

Epsilon-Prime definition

$$\epsilon' = \frac{i}{\sqrt{2}}\,\omega\left(\frac{\mathrm{Im}A_2}{\mathrm{Re}A_2} - \frac{\mathrm{Im}A_0}{\mathrm{Re}A_0}\right)\frac{q}{p}\,e^{i(\delta_2-\delta_0)}$$

$0{,}2 = Isospin$

$\omega = A_2 / A_0 \cong 22$

$q / p \cong 1$