Short-distance QCD corrections to $K\bar{K}$ mixing in Left-Right Models

[Bernard, Descotes-Genon, LVS - arXiv:1512.00543 [hep-ph]]

Luiz Vale Silva

LPT/IPN/Université Paris-Sud & CNRS
in collaboration with V. Bernard (IPN) and S. Descotes-Genon (LPT)
Rencontre de Physique des Particules, Annecy

January 26th, 2016

Introduction

- Many possible extensions to SM...

Introduction

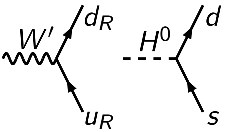
- Many possible extensions to SM...
- Left-Right Models (LRM): explain the chiral nature of the SM from the breakdown of a higher-scale parity-sym. th.

$$\begin{array}{c} SU(2)_L \times SU(2)_R \times U(1) \\ \downarrow \mu_R \\ SU(2)_L \times U(1)_Y \end{array}$$

Introduction

- Many possible extensions to SM...
- Left-Right Models (LRM): explain the chiral nature of the SM from the breakdown of a higher-scale parity-sym. th.
- Manifestations: **weak right-handed currents** (W'), **new scalar degrees of freedom** (H^0 , $H^\pm$, ...), etc.

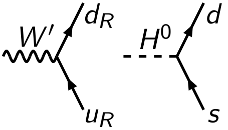
$$\begin{array}{c} SU(2)_L \times SU(2)_R \times U(1) \\ \downarrow \mu_R \\ SU(2)_L \times U(1)_Y \end{array}$$



Introduction

- Many possible extensions to SM...
- Left-Right Models (LRM): explain the chiral nature of the SM from the breakdown of a higher-scale parity-sym. th.
- Manifestations: **weak right-handed currents** (W'), **new scalar degrees of freedom** (H^0 , $H^{\pm}$, ...), etc.
- Direct searches, EW precision tests, flavor observables,... test their viability and structure

$$\begin{array}{c} SU(2)_L \times SU(2)_R \times U(1) \\ \downarrow \mu_R \\ SU(2)_L \times U(1)_Y \end{array}$$

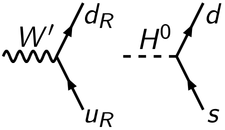


$$M_{W'}, M_H \propto \mu_R$$
$$\mu_R \gtrsim 1\ \text{TeV}$$

Introduction

- Many possible extensions to SM...
- Left-Right Models (LRM): explain the chiral nature of the SM from the breakdown of a higher-scale parity-sym. th.
- Manifestations: **weak right-handed currents** (W'), **new scalar degrees of freedom** (H^0 , $H^\pm$, ...), etc.
- Direct searches, EW precision tests, flavor observables,... test their viability and structure
- In particular, LRM are strongly constrained by $K\bar{K}$ mixing observables

$$\begin{array}{c} SU(2)_L \times SU(2)_R \times U(1) \\ \downarrow \mu_R \\ SU(2)_L \times U(1)_Y \end{array}$$



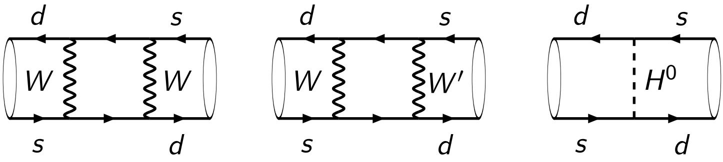
$$M_{W'}, M_H \propto \mu_R$$
$$\mu_R \gtrsim 1 \text{ TeV}$$

$K\bar{K}$ mixing

- Accurate measurements: ex. $\frac{\delta|\varepsilon_K|_{exp}}{|\varepsilon_K|_{exp}} \sim 0.5$ % [PDG14]
- Good theo. control in SM: ex. $\frac{\delta|\varepsilon_K|_{\rm SM}}{|\varepsilon_K|_{\rm SM}} \sim 20$ % [CKMfitter15]
- LRM: introduce potentially large effects

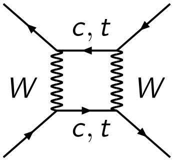
  (a) loop diagrams, including W' and $H^{\pm}$ exchanges

  (b) tree-level diagrams, heavy neutral Higgs(es) H^0



SM contribution to $K\bar{K}$ mixing

$$\mathcal{H}_{\text{eff}}^{\text{SM}} = G_F^2 \sum_{i=c,t} \sum_{j=c,t} V_{is}^L V_{id}^{L*} V_{js}^L V_{jd}^{L*} S(x_i, x_j) \, \bar{\eta}_{ij} \, Q_V + h.c., \quad \text{(after GIM)}$$



V^L = CKM matrix

$\bar{\eta}_{ij}$ short-range QCD corrections (w/o QCD, $\bar{\eta}_{ij} = \delta_{ij}$)

$Q_V = \bar{s}\gamma^\mu P_L d \cdot \bar{s}\gamma_\mu P_L d$ (due to weak LH currents)

$S(x_i, x_j)$ loop-function ($x_i = m_i^2/M_W^2$)

Loop-functions (Inami-Lim): sensitive to the internal d.o.f.

i, j	t, t	c, t	c, c
$S(x_i, x_j)$	x_t	x_c, and (large) $\log(x_c)$	x_c

Short-distance QCD corrections

Many scales in $\langle \mathcal{H}_{\rm eff}^{\rm SM} \rangle$: $\mathbf{m_c}, \mathbf{m_t}, \mathbf{M_W}$, and the scale $\mu_{\rm had} = \mu_{\rm low}$ where $\langle K | Q | \bar{K} \rangle$ is calculated on the Lattice

Factorization long/short dist.:

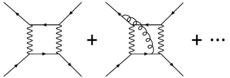
$$\mathcal{H} = C(\mu) \cdot Q(\mu)$$

$C(\mu_{\rm high})$ at high energies

$\langle Q(\mu_{\rm low}) \rangle$ at low energies

$\xrightarrow{\rm RGE}$

$$C(\mu_{\rm low}) = \bar{\eta} C(\mu_{\rm high})$$



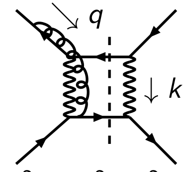
- $\bar{\eta} = 1 + \mathcal{O}(\alpha_s)$ collects the QCD effect of $\mu_{\rm high} \to \mu_{\rm low}$
- Large $\alpha_s \cdot \log((\mathbf{m_c}/\mathbf{M_W})^2)$ resummed to all orders by RGE, schematically: $\bar{\eta} = 1 + \Sigma_n (\alpha_s \cdot \log)^n + \ldots$
- $\bar{\eta}$ very $\neq$ from 1, impacting pheno. constraints [Buras et al, Nierste et al]

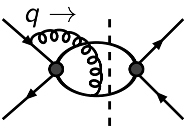
Two methods to compute $\bar{\eta}$:

- "Method of Regions" (MR): main QCD effects [Shifman et al, Vysotskii]
- EFT: build effect. th. valid at lower energies [Gilman, Wise]

“Method of Regions” (MR)

Resum large $\alpha_s \cdot \log$ to compute $\bar{\eta}$ in an **approximated** way



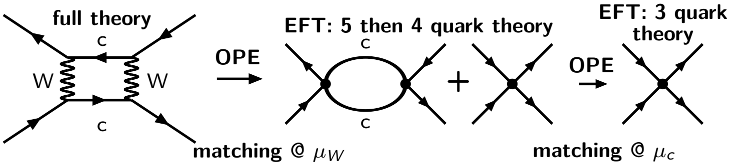


- Fix k of box
- Identify range of q providing large $\alpha_s \cdot \log$
- Over this range, product of two $|\Delta S| = 1$ ops. of anom. dim. (AD) γ
- Resum large $\alpha_s \cdot \log$ to all orders w/ RGE $\left(\frac{\alpha_s(M_W^2)}{\alpha_s(k^2)}\right)^\gamma \overset{\mathrm{LO}}{=} \left[\sum_{n=0}^{\infty}\left(\beta_0 \frac{\alpha_s(k^2)}{4\pi} \log\left(\frac{k^2}{M_W^2}\right)\right)^n\right]^\gamma$
- Finally, integrate over the relevant range k

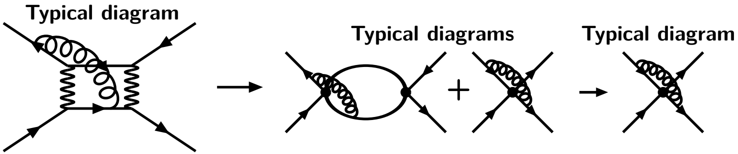
Initially designed to the Leading Log for SM [Shifman et al, Vysotskii]
Considered for the LRM @ LL [Frere, Bigi, Grimus, Ecker, Maiezza et al]
Extension to the NLL investigated [Bernard, Descotes-Genon, LVS]

EFT method

energy scales $<$ masses of a set of degrees of freedom



$$\mathrm{RGE}: \quad d(C_1, C_2, \ldots)/d\log(\mu) = \gamma^{\mathrm{T}} \cdot (C_1, C_2, \ldots) \Rightarrow C_i(\mu_{\mathrm{low}})$$



- Large nb. of 2-loop diagrams for matchings and AD
- In $D = 4 - \epsilon$ dim., need to include extra (evanescent) ops.

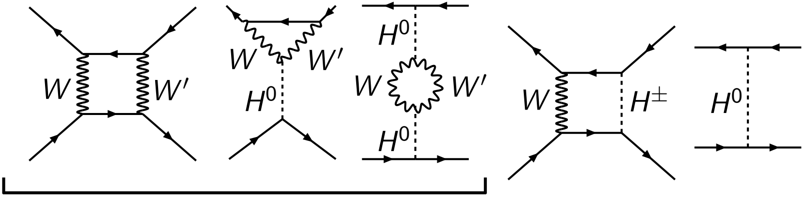
Comparison MR and EFT for SM

SM	η_{tt}	η_{ct}
Leading Log	$(\alpha_s \cdot \log(x_c))^n$	$\log(x_c) \cdot (\alpha_s \cdot \log(x_c))^n$
Next-to-LL	$\alpha_s \cdot (\alpha_s \cdot \log(x_c))^n$	$(\alpha_s \cdot \log(x_c))^n$
MR (LL, NLL)	$0.598 + 0.028 = 0.626$	$0.345 - 0.011 = 0.334$
EFT (LL, NLL)	$0.612 - 0.038 = 0.574$	$0.368 + 0.099 = 0.467$

For η_{cc}: same expressions MR and EFT
(EFT values [Buras et al])

- Generally, MR values are at good agreement w/ EFT
- 30 % agreement of MR w/ EFT @ NLL when large logarithms are present in the loop-function (Inami-Lim)

LRM corrections to $K\bar{K}$ mixing



gauge inv. set [Basecq et al, Soni et al] $\Rightarrow$ S^{LR}

$$\beta\, G_F^2 \frac{g_R^2}{g_L^2} \sum_{i=c,t} \sum_{j=c,t} V_{is}^L\, V_{id}^{R*}\, V_{js}^R\, V_{jd}^{L*}\, S^{LR}(x_i, x_j, \beta, \omega)\, \bar{\eta}_{ij}^{LR}\, Q_2^{LR} + h.c.,$$

Where V^R is the RH analogous of the CKM matrix,

$$\beta = \left(\frac{M_W}{M_{W'}}\right)^2, \; \omega = \left(\frac{M_{W'}}{M_H}\right)^2, \; Q_2^{LR} = \bar{s}P_L d \cdot \bar{s}P_R d \text{ (weak RH curr.)}$$

i, j	t, t	c, t	c, c
$S^{LR}(x_i, x_j, \beta, \omega)$	x_t, β, ω	x_c, x_t, β, ω	x_c, β, ω, (large) $\log(x_c)$

Results for MR

Same overall strategy compared to the SM, but

- Other high scales, $M_{W'}, M_H$
- More diagrams to consider
- Different operators (w/ known anom. dim.)

LRM	$\bar{\eta}_{tt}^{LR}$	$\bar{\eta}_{ct}^{LR}$	$\bar{\eta}_{cc}^{LR}$
LL	$(\alpha_s \cdot \log(x_c))^n$	$(\alpha_s \cdot \log(x_c))^n$	$\log(x_c) \cdot (\alpha_s \cdot \log(x_c))^n$
NLL	$\alpha_s \cdot (\alpha_s \cdot \log(x_c))^n$	$\alpha_s \cdot (\alpha_s \cdot \log(x_c))^n$	$(\alpha_s \cdot \log(x_c))^n$
MR (NLL)	5.9 ± 2.0	2.74 ± 0.87	1.35 ± 0.44

$$(M_{W'} = 1 \text{ TeV}, \; M_{W'}^2/M_H^2 = 0.1, \; \mu_{\text{had}} = 1 \text{ GeV})$$

- We add a conservative 30 % error inspired in the comparison MR/EFT in the SM
- Loop-function for cc includes a $\log(x_c)$: we do not expect in this case a good result (cf. SM for η_{ct})

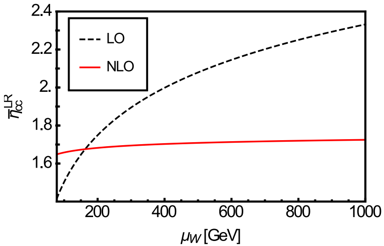
Results for EFT: $\bar{\eta}_{cc}^{\mathrm{LR}}$

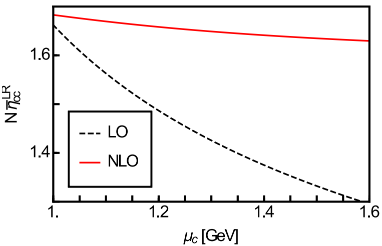
NLL for full th., and 5-, 4-, 3-th. matchings and anom. dims.:

$$LL : 1.41 \to NLL : 1.65$$
$$\bar{\eta}_{cc}^{\mathrm{LR}} = 1.65 \pm 0.33$$
$$(\text{cf. } \bar{\eta}_{cc}^{\mathrm{LR}}|_{MR} = 1.35 \pm 0.44)$$

Important checks:

- Weak dependence on renormalization scales
- Independence on QCD gauge and IR reg. parameters
- Independence on particular choice of the op. basis [Nierste et al]





Conclusions

- Kaon meson-mixing provides valuable information to probe the structure of LRM: scales,...
- Short-distance corrections from QCD for reliable bounds
- In the SM, two methods in the literature

  MR: simplified method, easy when AD already known

  EFT: more formal method, requiring two-loop computations
- They are employed in the LRM [Bernard, Descotes-Genon, LVS]

$$
\begin{aligned}
\bar{\eta}_{tt}^{\mathrm{LR}} &= 5.9 \pm 2.0 && (MR) \\
\bar{\eta}_{ct}^{\mathrm{LR}} &= 2.74 \pm 0.87 && (MR) \\
\bar{\eta}_{cc}^{\mathrm{LR}} &= 1.65 \pm 0.33 && (EFT)
\end{aligned}
$$

Next: perform a pheno. analysis of LRM w/ doublets based on meson mixing and other constraints