Chiral CKM mixing

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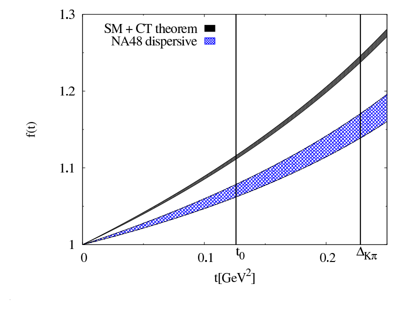
V. Bernard, M.O., E. Passemar, J.Stern, Phys. Lett. B 638 (2006) 480
V. Bernard, M.O., E. Passemar, J.Stern, in preparation

Introduction

- Precise prediction in the SM for scalar $K\pi$ form factor at the CT point
- Direct experimental measurement (dispersive representation): test of the SM!
- First direct measurement (NA48, PLB '07,hep-ph/0703002): 5σ deviation with SM prediction
- Is there a direct coupling of right-handed quarks to W? (see talks by E. Passemar and J. Stern)



- Right-handed quarks currents in different new physics scenarios ("not-quite decoupling" effective theory, left-right symmetric, extra dimensions, . . .)
- What are the consequences for quark mixing?

Chiral CKM mixing

- Effective quark charged current interaction (universal non-standard effects) including coupling of right-handed quarks to W

$$W^+_\mu \left((1+\delta)\, \bar{U}_L\, \gamma^\mu\, V^L\, D_L \;+\; \epsilon\, \bar{U}_R\, \gamma^\mu\, V^R\, D_R \right) + h.c.$$

- V^L and V^R: two a priori independent unitary mixing matrices (origin: diagonalisation of the mass matrix)
  $\longrightarrow$ $n(n-1)$ angles and $n(n+1)$ phases for n families
  (side remark: this induces CP-violating effects for example in K_{l4} decays)
- Effective couplings $(\mathcal{V}, \mathcal{A})$:

$$\bar{U}\, \underbrace{\left((1+\delta)V^L + \epsilon\, V^R\right)}_{\mathcal{V}_{eff}} \gamma_\mu D - \bar{U}\, \underbrace{\left((1+\delta)V^L - \epsilon\, V^R\right)}_{-\mathcal{A}_{eff}} \gamma_\mu \gamma_5 D$$

- If $\epsilon \neq 0$ (coupling of right-handed quarks to W) then $\mathcal{V}_{eff} \neq -\mathcal{A}_{eff}$

Non-standard parameters in the light quark sector

- Focus on the light-quark sector (u, d, s):
  - RHCs in the (non)-strange sector: $\epsilon_{ns} = \epsilon \, \mathrm{Re}\left(\frac{V^R_{ud}}{V^L_{ud}}\right) \qquad \epsilon_s = \epsilon \, \mathrm{Re}\left(\frac{V^R_{us}}{V^L_{us}}\right)$
  - Unitarity (suppose V^L_{ub} negligible) $\longrightarrow$ $|V^L_{ud}|^2 + |V^L_{us}|^2 = 1$
  - Modification of the left-handed couplings: δ
- Determination of EW couplings $\leftrightarrow$ knowledge of QCD parameters!
- Example: extraction of F_π from $\pi \to \mu\nu$

$$\Gamma(\pi_{l2}) \sim |F_\pi \mathcal{A}^{ud}_{eff}|^2 = |F_\pi|^2 |\mathcal{V}^{ud}_{eff}|^2 \frac{|\mathcal{A}^{ud}_{eff}|^2}{|\mathcal{V}^{ud}_{eff}|^2} = F^2_\pi |\mathcal{V}^{ud}_{eff}|^2 (1 - 4\epsilon_{ns})$$

$\longrightarrow$ this process does not probe directly $\quad i\sqrt{2} F_{\pi^+} q_\mu = \langle 0 | \bar{u}\gamma_\mu\gamma_5 d | \pi^+(q)\rangle$
but rather $F_\pi\,(1 - 2\epsilon_{ns}) \equiv \hat{F}_\pi$

How to extract QCD/EW parameter?

- Starting point: determination of $|\mathcal{V}_{eff}^{ud}| \equiv \cos\hat{\theta}$ in nuclear beta decays
- Assuming SM weak interactions:

$$|\mathcal{V}_{eff}^{ud}| \equiv |V_{\mathrm{CKM}}^{ud}| = 0.97377(26) \quad \Rightarrow \quad |V_{\mathrm{CKM}}^{us}| = 0.2275(11)$$

$\longrightarrow$ form factors and decay constants can be measured precisely in semileptonic decays

Denote quantities extracted assuming SM with a hat:

$$\hat{F}_\pi = 0.09242(26)\ \mathrm{GeV}, \quad \hat{F}_K/\hat{F}_\pi = 1.182(7), \quad \hat{f}_+^{K^0\pi^-}(0) = 0.951(5)$$

- Relation between QCD and EW parameters, e.g.

$$F_\pi = \hat{F}_\pi\,(1 + 2\,\epsilon_{ns})$$

$$\left(\frac{F_{K^+}}{F_{\pi^+}}\right)^2 = \left(\frac{\hat{F}_{K^+}}{\hat{F}_{\pi^+}}\right)^2 \frac{1+2\,(\epsilon_s-\epsilon_{ns})}{1+\frac{2}{\sin^2\hat{\theta}}(\delta+\epsilon_{ns})}$$

$$|f_+^{K^0\pi^-}(0)|^2 = (\hat{f}_+^{K^0\pi^-}(0))^2\,\frac{1-2(\epsilon_s-\epsilon_{ns})}{1+\frac{2}{\sin^2\hat{\theta}}(\delta+\epsilon_{ns})}$$

Unitarity for the extracted mixing matrix elements?

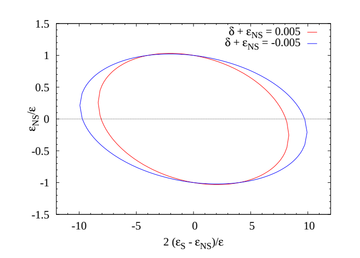
- $\mathcal{V}_{eff}$ does not need to be unitary!
- Deviation from unitarity for the first row:

$$|\mathcal{V}_{eff}^{ud}|^2 + |\mathcal{V}_{eff}^{us}|^2 = 1 + 2\,(\delta + \epsilon_{ns}) + 2\,(\epsilon_s - \epsilon_{ns})\,\sin^2\hat{\theta}$$

- Deviation can be positive or negative
- "Apparent" deviation can be very small
- V_L and V_R are separately unitary:

$$|\epsilon_{ns}|^2\,|V_L^{ud}|^2 + |\epsilon_s|^2\,|V_L^{us}|^2 \leq \epsilon^2$$

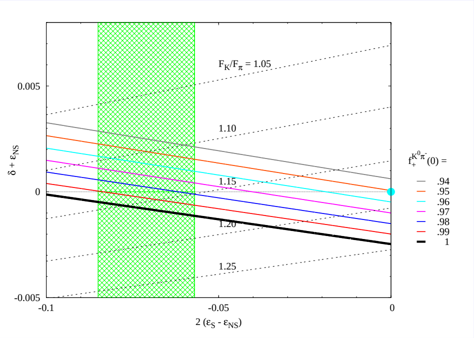
- This implies: $|\epsilon_{ns}| \lesssim \epsilon$ and $|\epsilon_s| \lesssim 4.5\epsilon$



Relation between EW parameters and $F_K/F_\pi, f_+(0)$

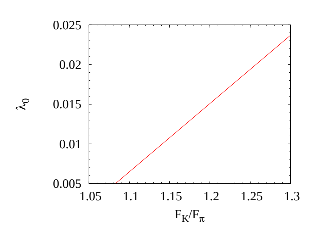
- Implications for F_K/F_π and $f_+(0)$?
  Take EW parameters + values of $\hat{F}_{K^+}/\hat{F}_{\pi^+}, \hat{f}_+^{K^0\pi^-}(0)$
- Shaded region: determination of $2(\epsilon_s - \epsilon_{ns})$ from NA48 data
  (PLB'07,hep-ph/0703002)

- For given $f_+(0)$
  $\longrightarrow$ upper bound on F_K/F_π:
  $f_+(0) < 1 \longrightarrow F_{K^+}/F_{\pi^+} < 1.190$
- With lattice result
  $f_+(0) = 0.9680(16)$
  $\longrightarrow F_{K^+}/F_{\pi^+} = 1.14(2)$
- Supposing "unitarity"
  $(|\mathcal{V}_{eff}^{ud}|^2 + \mathcal{V}_{eff}^{us}|^2 = 1)$
  $\longrightarrow F_{K^+}/F_{\pi^+} = 1.095(19)$



Is this coherent with the χPT prediction for λ_0?

- The χPT prediction for the slope of the scalar $K\pi$ form factor depends on F_K/F_π
- Take as illustration the result at $\mathcal{O}(p^4)$ for λ^0 (Gasser&Leutwyler '85)
- Some examples:
  - NA48 (PLB '07,hep-ph/0703002): $\lambda_0 = 0.0095(14)$ consistent with $F_K/F_\pi = 1.135(16)$
  - KTeV (PRD '04): $\lambda_0 = 0.0128(18)$ consistent with $F_K/F_\pi = 1.174(21)$
  - KLOE (preliminary, Moriond '07): $\lambda_0 = 0.0156(26)$ consistent with $F_K/F_\pi = 1.206(30)$



- In all cases χPT prediction for λ_0 consistent with data if EW parameters (RHCs) taken into account to extract proper value of F_K/F_π

Summary

- Assuming SM weak interactions, QCD form factors and decay constants determined precisely in semileptonic decays (starting with $|\mathcal{V}_{eff}^{ud}| = 0.97377(26)$)

$$\hat{F}_\pi = 0.09242(26)\ \mathrm{GeV}, \quad \hat{F}_K/\hat{F}_\pi = 1.182(7), \quad \hat{f}_+^{K^0\pi^-}(0) = 0.951(5)$$

- If there is a direct coupling of right-handed quarks to W two independent quark mixing matrices exist $(V_L, V_R) \longrightarrow \mathcal{V}_{eff} \neq -\mathcal{A}_{eff}$
- Determination of QCD and EW parameters correlated!
- Example: value of F_K/F_π

$$\left(\frac{F_{K^+}}{F_{\pi^+}}\right)^2 = \left(\frac{\hat{F}_{K^+}}{\hat{F}_{\pi^+}}\right)^2 \frac{1+2\,(\epsilon_s - \epsilon_{ns})}{1+\frac{2}{\sin^2\hat{\theta}}(\delta+\epsilon_{ns})}$$

- All (KLOE, KTeV, NA48) data for scalar $K\pi$ form factor slope in agreement with χPT prediction (dependence on F_K/F_π)
- Deviation from “unitarity” of $|\mathcal{V}_{eff}^{ud}|^2 + |\mathcal{V}_{eff}^{us}|^2$ constrains EW parameters
- Matching with χPT at two loops allows to determine $\mathcal{O}(p^6)$ LECs for $f_+(0)$