Probing physics beyond the SM with K and B decays

Universität Zürich[UZH]

Kei Yamamoto
(University of Zurich/Hiroshima University)

HIROSHIMA

La Thuile 2019 - Les Rencontres de Physique de la Vallée d'Aoste

13th Mar 2019

collaborated with **Gino Isidori, Julie Pagès (University of Zurich)**

Work in progress

Motivation

B anomalies

Lepton flavor universality Violation (LFUV) in semi-leptonic **B** decays

$b \to c\tau\nu$

$$R_{D^{(*)}} = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$

~ 4σ excess over the SM

$b \to s\ell\ell$

$$R_{K^{(*)}} = \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)}$$

~ 3.8σ less over the SM

Motivation

Model independent consideration for B anomalies

- Anomalies are seen in only **semi-leptonic** (quark × lepton) operators
- Model independent analyses show that **left-handed** current current operators are favored
- Hierarchical NP is needed:

Large coupling for $R_{D^{(*)}}$ Small coupling for $R_{K^{(*)}}$

(Tree level in SM) $b \to c\ \ell_3 \nu_3 \gg b \to s\ \ell_2 \ell_2$ (Loop level in SM)

NP in **left-handed 3rd** generation
semi-leptonic operator

$$(\bar{Q}_L^3 \times Q_L^3)(\bar{L}_L^3 \times L_L^3)$$

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$\times \theta_L^c$ — $\times \theta_L^s \theta_L^\mu \theta_L^\mu$

NP in **left-handed** **3rd** generation **semi-leptonic** operator

$$(\bar{Q}_L^3 \times Q_L^3)(\bar{L}_L^3 \times L_L^3)$$

Generic framework where NP is coupled to 3rd gen. SM fermions, where light SM fermions are suppressed by small mixing angles $\theta^{1,2}_{L(R)}\ f^3_{L(R)} \to f^{1,2}_{L(R)}$ can realize B anomaly

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Kaon obs.

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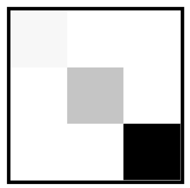
What can we learn from Kaon (semi-) leptonic decay?

Flavor Ansatz : U(2) symmetry

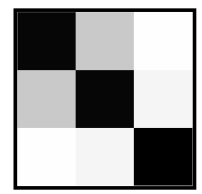
Barbieri, Isidori, Jones-Perez, Lodone, Straub [1105.2296]

The SM Yukawas respect an approximate U(2) symmetry

Mass matrix

$M_{u,d} \sim$ 

CKM

$V_{\text{CKM}} \sim$ 

$$\psi = (\psi_1, \psi_2, \psi_3)$$

$$U(2)_q \times U(2)_u \times U(2)_d$$

ex) up sector

Unbroken symmetry

$$Y_u = y_t \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$U(2)_q$

$U(2)_u$

After breaking

$$\left(\begin{array}{cc|c} \multicolumn{2}{c|}{\Delta} & V \\ \hline 0 & 0 & 1 \end{array}\right)$$

$|V| \sim |V_{ts}|$

$|\Delta| \sim y_c$

Diagonalize

Yukawa relation

$$\theta_R^s = \frac{m_s}{m_b}\theta_L^s \qquad \theta_R^\mu = \frac{m_\mu}{m_\tau}\theta_L^\mu$$

LFUV and LFV in Kaon + τ

Kaon decays (CC)	Data
$K^+ \to \pi^0\mu^+\nu_\mu$	$0.03352(33)$
$K^+ \to \pi^0 e^+\nu_e$	$0.0507(4)$
$K_L \to \pi^\pm\mu^\mp\nu_\mu$ $(K^0_{\mu 3})$	$0.2704(07)$
$K_L \to \pi^\pm e^\mp\nu_e$ (K^0_{e3})	$0.4055(11)$
$K_S \to \pi^\pm e^\mp\nu_e$	$(7.04 \pm 0.08) \times 10^{-4}$
$K^+ \to \mu^+\nu_\mu$	$0.6356(11)$
$K^+ \to e^+\nu_e$	$1.582(7) \times 10^{-5}$
$R^{e/\mu}$	$(2.488 \pm 0.009) \times 10^{-5}$

Kaon decays (NC)	
$K^+ \to \pi^+\nu\bar{\nu}$	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$ [1]
$K_L \to \pi^0\nu\bar{\nu}$	$< 3.0 \times 10^{-9}[90\%]$
$K_L \to \pi^0\mu^+\mu^-$	$< 3.8 \times 10^{-10}[90\%]$
$K_L \to \pi^0 e^+e^-$	$< 2.8 \times 10^{-10}[90\%]$
$K_S \to \pi^0\mu^+\mu^-$	$(2.9^{+1.5}_{-1.2}) \times 10^{-9}$
$K_S \to \pi^0 e^+e^-$	$(3.0^{+1.5}_{-1.2}) \times 10^{-9}$
$K^+ \to \pi^+\mu^+\mu^-$	$9.4(6) \times 10^{-8}$
$K^+ \to \pi^+ e^+e^-$	$3.00(9) \times 10^{-7}$
$K_L \to \mu^+\mu^-$	$(6.84 \pm 0.11) \times 10^{-9}$
$K_L \to e^+e^-$	$9^{+6}_{-4} \times 10^{-12}$
$K_S \to \mu^+\mu^-$	$< 8 \times 10^{-10}[90\%]$
$K_S \to e^+e^-$	$< 9 \times 10^{-9}[90\%]$
$K^+ \to \pi^+ e^-\mu^+$	$< 1.3 \times 10^{-11}[90\%]$
$K^+ \to \pi^+ e^+\mu^-$	$< 5.2 \times 10^{-10}[90\%]$
$K_L \to \mu^\mp e^\pm$	$< 4.7 \times 10^{-12}[90\%]$

- τ decays into Kaon are also produced in same type operators

τ decays (CC)	
$\tau \to K^-\nu_\tau$	$(6.96 \pm 0.10) \times 10^{-3}$
$\tau \to \pi^-\bar{K}^0\nu_\tau$	$(8.40 \pm 0.14) \times 10^{-3}$

τ decays (NC)	
$\tau \to K^-\pi^+e^-$	$3.7 \times 10^{-8}[90\%]$
$\tau \to K^+\pi^-e^-$	$3.1 \times 10^{-8}[90\%]$
$\tau \to K^-\pi^+\mu^-$	$8.6 \times 10^{-8}[90\%]$
$\tau \to K^+\pi^-\mu^-$	$4.5 \times 10^{-8}[90\%]$
$\tau \to K^0_S e^-$	$2.6 \times 10^{-8}[90\%]$
$\tau \to K^0_S \mu^-$	$2.3 \times 10^{-8}[90\%]$

Operators

Relevant operators can be categorized decay with or without π

$$K \to \ell\ell(\ell\nu, \nu\nu) \qquad P: \ (\bar{s}\gamma_5 d)(\bar{\ell}\gamma_5\ell), \quad A: \ (\bar{s}\gamma^{\ell}\gamma_5 d)(\bar{\ell}\gamma_{\ell}\gamma_5\ell)$$

$$K \to \pi\ell\ell(\pi\ell\nu, \pi\nu\nu) \qquad S: \ (\bar{s}d)(\bar{\ell}\ell), \quad V: \ (\bar{s}\gamma^{\mu}d)(\bar{\ell}\gamma_{\mu}\ell), \quad T: \ (\bar{s}\sigma^{\mu\nu}d)(\bar{\ell}\sigma_{\mu\nu}\ell)$$

$$\mathcal{L}_{\rm eff} = \frac{-2G_F}{\sqrt{2}} V_{us}^* \Big[\Big(\delta^{\alpha\beta} + [\epsilon^V_{\nu\ell}]^{\alpha\beta}\Big)(\bar{\nu}^\alpha_L \gamma_\mu e^\beta_L)(\bar{s}\gamma^\mu u) - \Big(\delta^{\alpha\beta} + [\epsilon^A_{\nu\ell}]^{\alpha\beta}\Big)(\bar{\nu}^\alpha_L \gamma_\mu e^\beta_L)(\bar{s}\gamma^\mu\gamma_5 u)$$
$$+ [\epsilon^S_{\nu\ell}]^{\alpha\beta}(\bar{\nu}^\alpha_L e^\beta_R)(\bar{s}u) + [\epsilon^P_{\nu\ell}]^{\alpha\beta}(\bar{\nu}^\alpha_L e^\beta_R)(\bar{s}\gamma_5 u) + 2[\epsilon^T_{\nu\ell}]^{\alpha\beta}(\bar{\nu}^\alpha_L \sigma^{\mu\nu} e^\beta_R)(\bar{s}_L\sigma_{\mu\nu}u_R)\Big] + (h.c.)$$

Today's talk $+R_{D^{(*)}}$

	Obs.	Operator	
CC($\nu\ell$)	$K \to \pi\ell\nu$	$(\bar{\nu}^\alpha\gamma_\mu P_L e^\beta)(\bar{d}^i\gamma^\mu u^j)$	$[\epsilon^V_{\nu\ell}]^{\alpha\beta}$
	$\tau \to K\pi\nu$	$(\bar{\nu}^\alpha P_R e^\beta)(\bar{d}^i u^j)$	$[\epsilon^S_{\nu\ell}]^{\alpha\beta}$
		$(\bar{\nu}_{Lp}\sigma^{\mu\nu}e_{Rr})(\bar{d}_{Ls}\sigma_{\mu\nu}u_{Rt})$	$[\epsilon^T_{\nu\ell}]^{\alpha\beta}$
	$K \to \ell\nu$	$(\bar{\nu}^\alpha\gamma_\mu P_L e^\beta)(\bar{d}^i\gamma^\mu\gamma_5 u^j)$	$[\epsilon^A_{\nu\ell}]^{\alpha\beta}$
	$\tau \to K\nu$	$(\bar{\nu}^\alpha P_R e^\beta)(\bar{d}^i\gamma_5 u^j)$	$[\epsilon^P_{\nu\ell}]^{\alpha\beta}$
NC($\nu\nu$)	$K \to \pi\nu\nu$	$(\bar{\nu}^\alpha\gamma_\mu P_L \nu^\beta)(\bar{d}^i\gamma^\mu d^j)$	$[\epsilon^V_{\nu\nu}]^{\alpha\beta}$
	$(K \to \nu\nu)$	$(\bar{\nu}^\alpha\gamma_\mu P_L \nu^\beta)(\bar{d}^i\gamma^\mu\gamma_5 d^j)$	$[\epsilon^A_{\nu\nu}]^{\alpha\beta}$

※ NC modes : work in progress

NC($\ell\ell$)	$K \to \pi\ell\ell$	$(\bar{e}^\alpha\gamma_\mu P_L e^\beta)(\bar{d}^i\gamma^\mu d^j)$	$[\epsilon^{L,V}_{\ell\ell}]^{\alpha\beta}$
	$\tau \to K\pi\ell$	$(\bar{e}^\alpha\gamma_\mu P_R e^\beta)(\bar{d}^i\gamma^\mu d^j)$	$[\epsilon^{R,V}_{\ell\ell}]^{\alpha\beta}$
		$(\bar{e}^\alpha P_R e^\beta)(\bar{d}^i d^j)$	$[\epsilon^S_{\ell\ell}]^{\alpha\beta} =$
		$(\bar{e}^\alpha_L\sigma^{\mu\nu}e^\beta_R)(\bar{d}_{Ls}\sigma_{\mu\nu}d_{Rt})$	$[\epsilon^T_{\ell\ell}]^{\alpha\beta} =$
	$K \to \ell\ell$	$(\bar{e}^\alpha\gamma_\mu P_L e^\beta)(\bar{d}^i\gamma^\mu\gamma_5 d^j)$	$[\epsilon^{L,A}_{\ell\ell}]^{\alpha\beta}$
	$\tau \to K\ell$	$(\bar{e}^\alpha\gamma_\mu P_R e^\beta)(\bar{d}^i\gamma^\mu\gamma_5 d^j)$	$[\epsilon^{R,A}_{\ell\ell}]^{\alpha\beta}$
		$(\bar{e}^\alpha P_R e^\beta)(\bar{d}^i\gamma_5 d^j)$	$[\epsilon^P_{\ell\ell}]^{\alpha\beta} =$

K_{ell2} ($K \to l\nu$) & $\tau \to K\nu$

Constrain for NP contribution for axial $[\epsilon^{A}_{\nu\ell}]^{\ell\ell}$ and p-scalar $[\epsilon^{P}_{\nu\ell}]^{\ell\ell}$ coefficients

$\delta_{K\ell}$: EM correction

$$\Gamma(K^+ \to \ell^+\nu_\ell) = \frac{G_F^2 f_K^2 M_K m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{M_K^2}\right)^2 |V_{uq}|^2 \left|1 + [\epsilon^{A}_{\nu\ell}]^{\ell\ell} - \frac{M_K^2}{(m_u + m_s)m_\ell}[\epsilon^{P}_{\nu\ell}]^{\ell\ell}\right|^2 (1 + \delta_{K\ell})$$

chiral enhancement factor

Take LU ratio $R_{e/\mu} \equiv \mathcal{B}(K_{e2})/\mathcal{B}(K_{\mu 2})$
where most theoretical uncertainties are canceled, and normalized to SM

$$\Delta R_{e/\mu} \equiv \frac{R_{e/\mu}}{R^{\rm SM}_{e/\mu}} - 1$$

K_{ell2} (K→lν) & τ→Kν

$$R_{e/\mu} \equiv \mathcal{B}(K_{e2})/\mathcal{B}(K_{\mu 2})$$

$$\frac{R_{e/\mu}}{R^{\rm SM}_{e/\mu}} = 1 + 2([\epsilon^A_{\nu\ell}]^{ee} - [\epsilon^A_{\nu\ell}]^{\mu\mu}) - 2\frac{m_K^2}{m_u + m_s}\left(\frac{[\epsilon^P_{\nu\ell}]^{ee}}{m_e} - \frac{[\epsilon^P_{\nu\ell}]^{\mu\mu}}{m_\mu}\right) + \mathcal{O}(\epsilon^2)$$

$$\frac{R^{\rm exp}_{e/\mu}}{R^{\rm SM}_{e/\mu}} = \frac{\mathcal{B}(K^- \to e^-\bar\nu_e)^{\rm exp}/\mathcal{B}(K^- \to e^-\bar\nu_e)^{\rm SM}}{\mathcal{B}(K^- \to \mu^-\bar\nu_\mu)^{\rm exp}/\mathcal{B}(K^- \to \mu^-\bar\nu_\mu)^{\rm SM}} = 1.00444 \pm 0.00366$$

SM Cirigliano and Rosell, [0707.3439]

$$\Delta R_{e/\mu} = 2\left[([\epsilon^A_{\nu\ell}]^{ee} - [\epsilon^A_{\nu\ell}]^{\mu\mu}) - \frac{M_K^2}{m_u + m_s}\left(\frac{[\epsilon^P_{\nu\ell}]^{ee}}{m_e} - \frac{[\epsilon^P_{\nu\ell}]^{\mu\mu}}{m_\mu}\right)\right]$$

$$= (4.44 \pm 3.66) \times 10^{-3}$$

NP room in e/μ ratio at O(10^-3) level is still allowed

$$R_{\mu/\tau} = \mathcal{B}(K^+ \to \mu^+\nu_\mu)/\mathcal{B}(\tau^+ \to K^+\bar\nu_\tau)$$

$$\frac{R^{\rm exp}_{\mu/\tau}}{R^{\rm SM}_{\mu/\tau}} = \frac{\mathcal{B}(K^- \to \mu^-\bar\nu_\mu)^{\rm exp}/\mathcal{B}(K^- \to \mu^-\bar\nu_\mu)^{\rm SM}}{\mathcal{B}(\tau^- \to K^-\nu_\tau)^{\rm exp}/\mathcal{B}(\tau^- \to K^-\nu_\tau)^{\rm SM}} = 1.0285 \pm 0.0151$$

SM Pich [1310.7922]

$$\Delta R_{\mu/\tau} = 2\left[([\epsilon^A_{\nu\ell}]^{\mu\mu} - [\epsilon^A_{\nu\ell}]^{\tau\tau}) - \frac{m_K^2}{m_u + m_s}\left(\frac{[\epsilon^P_{\nu\ell}]^{\mu\mu}}{m_\mu} - \frac{[\epsilon^P_{\nu\ell}]^{\tau\tau}}{m_\tau}\right)\right]$$

$$= (28.5 \pm 15.1) \times 10^{-3}$$

※ Interestingly, present data exhibits a small tension with the SM prediction

K_{ell3} ($K\to\pi l\nu$) & $\tau\to K\pi\nu$

Relevant coefficients: $[\epsilon^V_{\nu\ell}]^{\ell\ell}$ ~~$[\epsilon^S_{\nu\ell}]^{\ell\ell}$~~ ~~$[\epsilon^T_{\nu\ell}]^{\ell\ell}$~~

Consider only vector one

More general analysis including NP effects on ε^S and ε^T, see ex.
González-Alonso et al[1605.07114,1809.01161,,]
Rendon,Roig,Sanchez[1902.08143]

and see Gonzalez-Alonso's talk on Thus.

NP effects in ε^S is well below the present exp. and th. errors

FlaviaNet Kaon WG[0801.1817]

$$R_{\pi e/\pi\mu} = \mathcal{B}(K_{e3})/\mathcal{B}(K_{\mu3})$$

$$\frac{R_{\pi e/\pi\mu}}{R^{\rm SM}_{\pi e/\pi\mu}} = 1 + 2\left([\epsilon^V_{\nu\ell}]^{ee} - [\epsilon^V_{\nu\ell}]^{\mu\mu}\right) + \mathcal{O}(\epsilon^2)$$

$$\frac{R^{\rm exp}_{\pi e/\pi\mu}}{R^{\rm SM}_{\pi e/\pi\mu}} = \frac{\mathcal{B}(K_L\to\pi^- e^+\nu_e)^{\rm exp}}{\mathcal{B}(K_L\to\pi^-\mu^+\nu_\mu)^{\rm exp}}\frac{I(K^0_{\mu3})}{I(K^0_{e3})}\left(1+2(\delta^{K^0\mu}_{\rm EM} - \delta^{K^0 e}_{\rm EM})\right)$$
$$= 1.00008 \pm 0.00473$$

$I(K)$: phase space integral
$\delta_{\rm EM}$: EM correction
FlaviaNet Kaon WG [0801.1817]

$$\Delta R_{\pi e/\pi\mu} = 2\left([\epsilon^V_{\nu\ell}]^{ee} - [\epsilon^V_{\nu\ell}]^{\mu\mu}\right)$$
$$= (0.08 \pm 4.73)\times 10^{-3}$$

K_{ell3} ($K\to\pi l\nu$) & $\tau\to K\pi\nu$

$$R_{\pi\ell/\pi\tau} = \mathcal{B}(K \to \pi\ell\bar{\nu}_\ell)/\mathcal{B}(\tau \to \pi\bar{K}\nu_\tau)$$

$$\frac{R_{\pi\ell/\pi\tau}}{R^{\mathrm{SM}}_{\pi\ell/\pi\tau}} = 1 + 2\left([\epsilon^V_{\nu\ell}]^{\ell\ell} - [\epsilon^V_{\nu\ell}]^{\tau\tau}\right) + \mathcal{O}(\epsilon^2)$$

$$\frac{R^{\mathrm{exp}}_{\pi e/\pi\tau}}{R^{\mathrm{SM}}_{\pi e/\pi\tau}} = \frac{\mathcal{B}(K^0 \to \pi e\bar{\nu}_e)^{\mathrm{exp}}/\mathcal{B}(K^0 \to \pi e\bar{\nu}_e)^{\mathrm{SM}}}{\mathcal{B}(\tau^- \to \bar{K}^0\pi^-\nu_\tau)^{\mathrm{exp}}/\mathcal{B}(\tau^- \to \bar{K}^0\pi^-\nu_\tau)^{\mathrm{SM}}}$$
$$= 1.0198 \pm 0.0394$$

Antonellia, Ciriglianob,Lusianic Passemarb [1304.8134]

$$\Delta R_{\pi\ell/\pi\tau} = 2\Big([\epsilon^V_{\nu\ell}]^{\ell\ell} - [\epsilon^V_{\nu\ell}]^{\tau\tau}\Big)$$
$$= (19.8 \pm 39.4) \times 10^{-3}$$

Constraints

			constraints	relevant coefficients
K_{ell3}	e vs μ	$\Delta R_{\pi e/\pi\mu}$	$(0.08 \pm 4.73) \times 10^{-3}$	$2\Big[[\epsilon^V_{\nu\ell}]^{ee} - [\epsilon^V_{\nu\ell}]^{\mu\mu}\Big]$
	μ vs τ	$\Delta R_{\pi\mu/\pi\tau}$	$(19.8 \pm 39.4) \times 10^{-3}$	$2\Big[[\epsilon^V_{\nu\ell}]^{\mu\mu} - [\epsilon^V_{\nu\ell}]^{\tau\tau}\Big]$
K_{ell2}	e vs μ	$\Delta R_{e/\mu}$	$(4.44 \pm 3.66) \times 10^{-3}$	$2\Big[[\epsilon^A_{\nu\ell}]^{ee} - [\epsilon^A_{\nu\ell}]^{\mu\mu} - \frac{m_K^2}{(m_u+m_s)m_\mu}\Big(\frac{m_\mu}{m_e}[\epsilon^P_{\nu\ell}]^{ee} - [\epsilon^P_{\nu\ell}]^{\mu\mu}\Big)\Big]$
	μ vs τ	$\Delta R_{\mu/\tau}$	$(28.5 \pm 15.1) \times 10^{-3}$	$2\Big[[\epsilon^A_{\nu\ell}]^{\mu\mu} - [\epsilon^A_{\nu\ell}]^{\tau\tau} - \frac{m_K^2}{(m_u+m_s)m_\tau}\Big(\frac{m_\tau}{m_\mu}[\epsilon^P_{\nu\ell}]^{\mu\mu} - [\epsilon^P_{\nu\ell}]^{\tau\tau}\Big)\Big]$

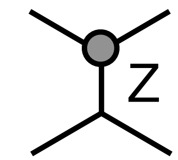
LEFT operators

Low energy effective theory (LEFT) operators are gauge-invariant operators below EW scale

Jenkins, Manohar, Stoffer [1709.04486]

$$\mathcal{L}_{\rm LEFT} = -\frac{4G_F}{\sqrt{2}}\sum_i \mathcal{C}_i \mathcal{O}_i$$

Produced from $(H^\dagger i \overleftrightarrow{D}^I_\mu H)(\bar q_p \tau^I \gamma^\mu q_r)$ in SMEFT and not produce LFUV



	Obs.	Operator	LEFT WC
CC($\nu\ell$)	$K\to\pi\ell\nu$, $\tau\to K\pi\nu$	$(\bar\nu^\alpha\gamma_\mu P_L e^\beta)(\bar s\gamma^\mu u)$	$[\epsilon^V_{\nu\ell}]^{\alpha\beta} = \frac{2}{V^*_{us}}\left([\mathcal{C}^{V,LL}_{\nu edu}]_{\alpha\beta21} + [\mathcal{C}^{V,LR}_{\nu edu}]_{\alpha\beta21}\right)$, h.c.
	$K\to\ell\nu$	$(\bar\nu^\alpha\gamma_\mu P_L e^\beta)(\bar s\gamma^\mu\gamma_5 u)$	$[\epsilon^A_{\nu\ell}]^{\alpha\beta} = \frac{2}{V^*_{us}}\left(-[\mathcal{C}^{V,LL}_{\nu edu}]_{\alpha\beta21} + [\mathcal{C}^{V,LR}_{\nu edu}]_{\alpha\beta21}\right)$, h.c.
	$\tau\to K\nu$	$(\bar\nu^\alpha P_R e^\beta)(\bar s\gamma_5 u)$	$[\epsilon^P_{\nu\ell}]^{\alpha\beta} = \frac{2}{V^*_{us}}\left(-[\mathcal{C}^{S,RL}_{\nu edu}]_{\alpha\beta21} + [\mathcal{C}^{S,RR}_{\nu edu}]_{\alpha\beta21}\right)$, h.c.

Operator with right handed light quark can be assumed to be suppressed under U(2)

Relevant LEFT ope.

$$[\mathcal{O}^{V,LL}_{\nu edu}]_{\alpha\beta ij} = (\bar\nu^\alpha_L\gamma_\mu e^\beta_L)(\bar d^i_L\gamma_\mu u^j_L)$$

$$[\mathcal{O}^{S,RL}_{\nu edu}]_{\alpha\beta ij} = (\bar\nu^\alpha_L e^\beta_R)(\bar d^i_R u^j_L)$$

$K\to\pi\mu\nu$

vector only

$K\to\ell\nu$

combination of vector and scalar

Scaling

U(2) symmetry + NP couple to 3rd gene.

- Assume generic framework where NP is coupled to 3rd gen. SM fermions, while light SM fermions are suppressed by small mixing angles

Light SM fermion is produced by following **Scaling**

$$\theta^{1,2}_{L(R)}\ f^{3}_{L(R)} \to f^{1,2}_{L(R)}$$

favored by B ano

$$C_V(\bar{Q}^3_L\gamma^\mu\sigma^a Q^3_L)(\bar{L}^3_L\gamma^\mu\sigma^a L^3_L)$$

$$[\mathcal{C}^{V,LL}_{\nu edu}]_{\ell\ell 21} \sim 2C_V\ (\theta^\mu_L)^2\theta^s_L\theta^u_L$$

$$C_S(\bar{Q}^3_R Q^3_L)(\bar{L}^3_L L^3_R)$$

$$[\mathcal{C}^{S,RL}_{\nu edu}]_{\ell\ell 21} \sim C_S\ \theta^\mu_L\theta^\mu_R\theta^s_R\theta^u_L$$

Yukawa relation

$$\theta^s_R = \frac{m_s}{m_b}\theta^s_L \qquad \theta^\mu_R = \frac{m_\mu}{m_\tau}\theta^\mu_L$$

$$\sim C_S\ \frac{m_\mu}{m_\tau}\frac{m_s}{m_b}\theta^\mu_L\theta^\mu_L\theta^s_L\theta^u_L$$

Yukawa suppression $\sim 10^{-3}$

Results 1&2

$K_{\ell 2}$ vs. $K_{\ell 3}$ → Scalar vs Vector

$$\frac{\Delta R_{e/\mu}}{\Delta R_{\pi e/\pi\mu}} \overset{\text{Yukawa relation}}{\approx} -1 + 0.015\frac{C_S}{C_V} \lesssim 1$$

Chiral enhancement < Yukawa suppression

Constraint on C_V is $\mathcal{O}(10^{-2})$ tighter than C_S

Flavor ratio → constraint on θ_L^{μ}

$$\frac{\Delta R_{\pi e/\pi\mu}}{\Delta R_{\pi\mu/\pi\tau}} = \frac{(\theta_L^{\mu})^2}{1-(\theta_L^{\mu})^2} \lesssim 0.1 \qquad \frac{\Delta R_{e/\mu}}{\Delta R_{\mu/\tau}} \overset{\text{Yukawa relation}}{\approx} \frac{(\theta_L^{\mu})^2}{1-(\theta_L^{\mu})^2} \lesssim 0.2$$

$\frac{\Delta R_{\pi e/\pi\mu}}{\Delta R_{\pi\mu/\pi\tau}}$ gives stronger constraint than $\frac{\Delta R_{e/\mu}}{\Delta R_{\mu/\tau}}$ as

$$(\theta_L^{\mu})^2 \lesssim \mathcal{O}(10^{-1})$$

The bound is given independently from C_V and C_S

$R_{D^{(*)}}$

~ 20% of SM effect is needed to realize 1σ data

$$\Delta R_D \approx 0.2$$

	R_D	R_{D^*}
SM	$0.299(3)$	$0.258(5)$
Data	$0.407(46)$	$0.306(15)$

Vector contribution can explain $R_{D^{(*)}}$ anomaly

$$\Delta R_D \approx \frac{2}{V_{cb}} [\mathcal{C}^{\mathrm{V,LL}}_{\nu e d u}]_{\tau\tau 32}$$

$$[\mathcal{C}^{V,LL}_{\nu e d u}]_{\tau\tau 32} \sim 2 C_V \; \theta^{c}_{L}$$

Result 3

R_D vs $K_{\ell 3}$ → constraint on $|\theta_L^s \theta_L^u|$

$$\frac{\Delta R_{\pi e/\pi\mu}}{\Delta R_D} = -\frac{2V_{cb}}{V_{us}}(\theta_L^\mu)^2 \frac{\theta_L^s \theta_L^u}{\theta_L^c} \quad \lesssim 2\times 10^{-2}$$

$$\rightarrow \quad |\theta_L^\mu|^2 |\theta_L^s \theta_L^u| \ \lesssim\ 7\times 10^{-2}\ \theta_L^c \left(\frac{0.2}{\Delta R_D}\right)$$

$$|\theta_L^\mu|^2 |\theta_L^s \theta_L^u| \ \lesssim\ \mathcal{O}(10^{-3}) \quad (\theta_L^c \sim V_{cb})$$

in MFV $\theta_L^s \theta_L^u \sim V_{ts} V_{ub} = 1.4 \times 10^{-4}$

$K \to \pi\nu\nu$

	$K^+ \to \pi^+ \nu\bar{\nu}$	$K_L \to \pi^0 \nu\bar{\nu}$
SM	$(9.11 \pm 0.72) \times 10^{-11}$	$(3.00 \pm 0.30) \times 10^{-11}$
Data	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$	$< 3.0 \times 10^{-9} [90\%]$

$$\frac{\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})}{\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})\big|_{SM}} = \frac{2}{3} + \frac{1}{3}\left| 1 - \frac{[\mathcal{C}_{\nu d}^{\mathrm{V,LL}}]_{\tau\tau 21}}{\alpha/(2\pi)\, V_{ts}^* V_{td}\, C_{sd,\tau}^{\mathrm{SM,eff}}} \right|^2$$

NP in ντ (3rd)

SM@1-loop

→ Large NP effect

$$[\mathcal{C}_{\nu d}^{V,LL}]_{\tau\tau 21} \sim -C_V \;\theta_L^s \theta_L^d$$

※ EW singlet operator set to zero

$$\left| \frac{2}{V_{ts}^* V_{td}} \theta_L^s \theta_L^d C_V \right| \lesssim 0.1$$

Result 4

R_D vs $K \to \pi\nu\bar{\nu}$ → constraint on $|\theta_L^s \theta_L^d|$

$$\frac{\Delta R_{K^+\to\pi^+\nu\nu}}{\Delta R_D} = \frac{V_{cb}}{V_{ts}^* V_{td}} \frac{\theta_L^s \theta_L^d}{2\theta_L^c} \lesssim 0.5$$

$$\to \quad |\theta_L^s \theta_L^d| \lesssim 8 \times 10^{-3} \theta_L^c \left(\frac{0.2}{\Delta R_D}\right)$$

$$|\theta_L^s \theta_L^d| \lesssim \mathcal{O}(10^{-4}) \qquad (\theta_L^c \sim V_{cb})$$

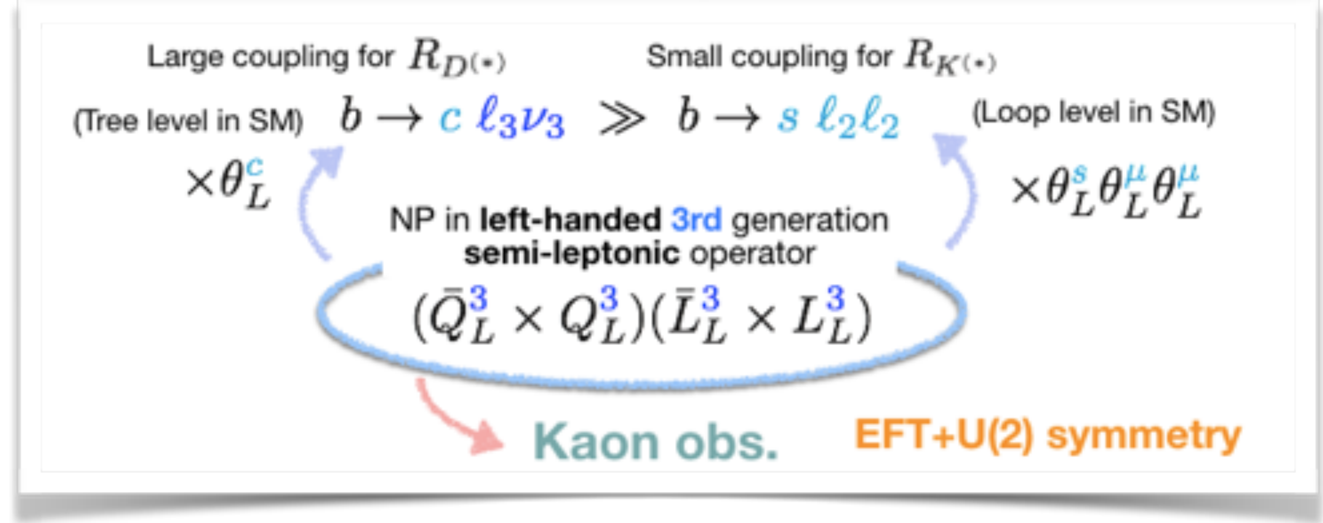
in MFV $\theta_L^s \theta_L^d \sim V_{ts} V_{td} = 3 \times 10^{-4}$

※ Bound from neutral mode $K_L \to \pi^0 \nu\bar{\nu}$ gives ~10 times weaker than the one from K+

Bordone, Buttazzo, Isidori Monnard [1705.10729]

Summary

In light of current **B** anomalies, we investigate **Kaon** (semi-)leptonic decay in **EFT+U(2),** where NP is coupled to 3rd gen. SM fermions, while light ones are suppressed by small mixing angles



We found

- Constraint on C_V is $\mathcal{O}(10^{-2})$ smaller than C_S
- $\frac{\Delta R_{\pi e/\pi\mu}}{\Delta R_{\pi\mu/\pi\tau}}$ gives stronger constraint than $\frac{\Delta R_{e/\mu}}{\Delta R_{\mu/\tau}}$ as $(\theta_L^\mu)^2 \lesssim \mathcal{O}(10^{-1})$
- R_D vs $K_{\ell 3}$

  $|\theta_L^\mu|^2 |\theta_L^s \theta_L^u| \lesssim \mathcal{O}(10^{-3})$ (in MFV $\theta_L^s \theta_L^u \sim V_{ts} V_{ub} = 1.4 \times 10^{-4}$)
- R_D vs $K \to \pi\nu\bar{\nu}$

  $|\theta_L^s \theta_L^d| \lesssim \mathcal{O}(10^{-4})$ (in MFV $\theta_L^s \theta_L^d \sim V_{ts} V_{td} = 3 \times 10^{-4}$)

Updated exp. result for $K^+ \to \pi^+ \nu\bar{\nu}$ / $K_{\ell 3}$ / $\tau \to K\pi\nu$ will have impact on EFT + U(2)

Stay tuned for other modes ($K \to \ell\ell,\ K \to \pi\ell\nu,,,$)