Quest for new physics with ratio of CKM elements

(Based on : A. Bansal, N. Mahajan, D.M., JHEP 03 (2022) 130)

Dayanand Mishra (dayanand@prl.res.in)

Motivation

(1) $|V_{ub}|_{incl} - |V_{ub}|_{excl} \sim 3.5\sigma$ and $|V_{cb}|_{incl} - |V_{cb}|_{excl} \sim 3\sigma$ [1] (Masked with hadronic uncertainties) $\Longrightarrow$ No unambiguous New Physics

(2) Curious observation: $R_V = \frac{|V_{ub}|}{|V_{cb}|}$ as constructed using measurements of $|V_{ub}|$ and $|V_{cb}|$ obtained from PDG; $R_V|_{excl} - R_V|_{incl} \sim 1\sigma$

Introduction

- Explicit values of inclusive and exclusive $R_V\left(=\frac{|V_{ub}|}{|V_{cb}|}\right)$:

$$R_V\Big|^{\text{high } q^2}_{excl} = 0.094 \pm 0.005 \qquad R_V\Big|^{\text{high } q^2}_{incl} = 0.101 \pm 0.007$$

- Before considering phenomenology, let's ask about theoretical uncertainties, particularly
  - (1) Soft photon QED effects,
  - (2) Dependence on choice of form factors

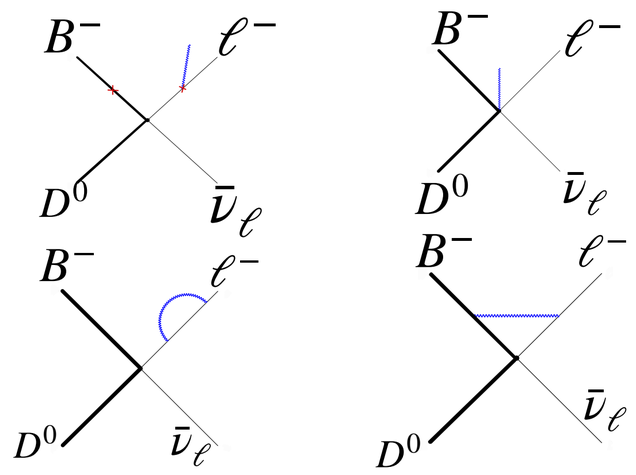
1. Soft photon QED effects

- Gauge invariant matrix element :

$$\mathscr{M} = e\epsilon_\alpha(k)\Big[\mathscr{M}_0\left(-\frac{p_B^\alpha}{p_B.k} + \frac{p_\ell^\alpha}{2p_\ell.k}\right) + \bar{u}(p_\ell)\frac{\gamma^\alpha\gamma_\mu k^\mu}{2p_B.k}\Gamma_\mu\nu(p_\nu)\mathscr{H}^\mu - (f_+ - f_-)\bar{u}(p_\ell)\left(\frac{p_B^\alpha}{p_B.k}\gamma_\mu k^\mu - \gamma^\alpha\right)(1-\gamma^5)\nu(p_\nu)\Big]$$

Contact term

Blue : Eikonal (or soft) part, Magenta : Non-eikonal part



- Differential decay width :

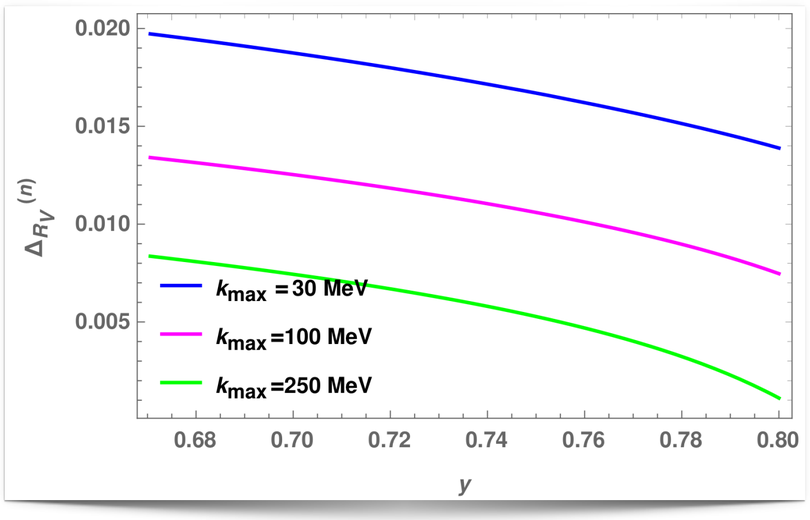
$$\frac{d^2\Gamma_\ell^{\text{QED}}}{dydz} = \frac{d^2\Gamma_0}{dydz}\left(1+\Delta_\ell^{QED}\right)$$

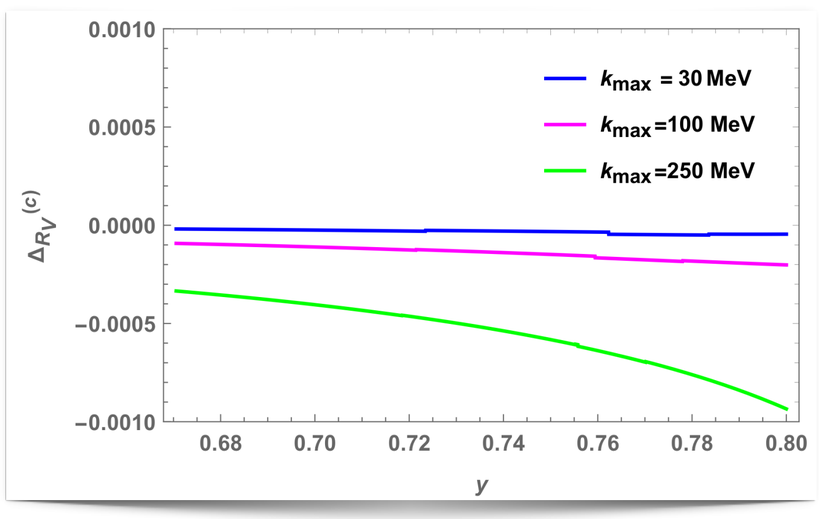
$$\left(y = \frac{2p_B\cdot p_\ell}{m_B^2}, z = \frac{2p_B\cdot p_P}{m_B^2}\right)$$

- QED corrected Observable:

$$\Delta_{R_V} = \frac{R_V(\text{with QED})}{R_V(\text{without QED})} - 1$$

Little effect:
$\Delta_{R_V} \sim$ 0.3%
($k_{max} = 250$ MeV)





Negligible correction

Radiative corrections to R_V (c(n)=charged (neutral) B) for different thresholds on photon energy, k_{max} for (a) $B^0 \to P^+(=D,\pi)\mu^-\bar{\nu}_\mu$ and (b) $B^- \to P^0(=D,\pi)\mu^-\bar{\nu}_\mu$

2. Dependence on choice of form factors

	$(f_{B\to\pi}^{(I)}; f_{B\to D}^{(I)})$	$(f_{B\to\pi}^{(II)}; f_{B\to D}^{(I)})$	$(f_{B\to\pi}^{(I)}; f_{B\to D}^{(II)})$	$(f_{B\to\pi}^{(II)}; f_{B\to D}^{(II)})$
R_V	0.091	0.093	0.091	0.093

The ratio R_V determined with the choice $f_{B\to\pi}^{(A)}$ and $f_{B\to D}^{(A)}$ for the corresponding form factors.

(I) : form factors obtained from HQET[2] and LCSR[3]

(II) : form factors obtained from lattice[4]

- R_V : robust against soft photon corrections and choice of form factors $\Longrightarrow$ Theoretically Clean observable

Phenomenological importance

- Example: Consider new physics (NP) using right handed currents in quark sector

$$H_{\text{NP}} = \frac{4G_F}{\sqrt{2}}V_{qb}c_R^q(\bar{\ell}\gamma_\mu P_L\nu)\left(\bar{q}\gamma_\mu P_R b\right).$$

- $R_V|_{excl} \equiv R_V|_{incl} \Longrightarrow$ relates coefficients of NP in u quark sector with those in c quark.
- $|V_{ub}|$ and $|V_{cb}|$ puzzles are not independent. Could be related even in model independent approach

Summary and Conclusions

- QED radiative corrections: sensitive to maximum energy k_{max}
- R_V gets negligible corrections due to the soft photon QED effects.
- R_V is affected very mildly by the choice of form factors in chosen q^2 range.
- $|V_{ub}|$ and $|V_{cb}|$ puzzles treat the NP couplings independently. The equality of inclusive and exclusive R_V relates two type of couplings in a model independent approach.

We thus propose R_V as a powerful probe of SM and beyond, both experimentally and theoretically.

References

[1] PDG (Prog. Theor. Exp. Phys.., 083C01 (2022)).

[2] Ligeti et.al., (PRD 95 (2017) 11, 115008).

[3] Khodjamirian et.al., (PRD 83 (2011) 094031).

[4] FLAG Review (EPJC, 82 (2022) 10, 869).