$|V_{ub}|$ and $|V_{cb}|$ determinations in the presence of New Physics

Gilberto Tetlalmatzi-Xolocotzi

Based on:

R. Fleischer, R. Jaarsma and GTX: 2104.04023
Eur.Phys.J.C 81 (2021) 7, 658

R. Fleischer, R. Jaarsma and GTX: 1809.09051
Eur.Phys.J.C 78 (2018) 11, 911

CPPS, Theoretische Physik 1,
Universität Siegen

Center for Particle Physics Siegen

UNIVERSITÄT SIEGEN

Generalities

Effective Hamiltonian

$$\mathcal{H}_{\rm eff}^{q} = \frac{4G_{\rm F}}{\sqrt{2}} V_{qb} \left[\tilde{C}_{V_L}^{q,\ell} \mathcal{O}_{V_L}^{q,\ell} + \tilde{C}_{V_R}^{q,\ell} \mathcal{O}_{V_R}^{q,\ell} + \tilde{C}_{S}^{q,\ell} \mathcal{O}_{S}^{q,\ell} + \tilde{C}_{P}^{q,\ell} \mathcal{O}_{P}^{q,\ell} + \tilde{C}_{T}^{q,\ell} \mathcal{O}_{T}^{q,\ell} \right] + \text{h.c.},$$

Operator Basis

$$\mathcal{O}_{V_L}^{q,\ell} = (\bar{q}\gamma^\mu P_L b)(\bar{\ell}\gamma_\mu P_L \nu_\ell), \quad \mathcal{O}_{V_R}^{q,\ell} = (\bar{q}\gamma^\mu P_R b)(\bar{\ell}\gamma_\mu P_L \nu_\ell), \quad \mathcal{O}_{S}^{q,\ell} = \frac{1}{2}(\bar{q}b)(\bar{\ell} P_L \nu_\ell),$$

$$\mathcal{O}_{P}^{q,\ell} = \frac{1}{2}(\bar{q}\gamma_5 b)(\bar{\ell} P_L \nu_\ell), \quad \mathcal{O}_{T}^{q,\ell} = (\bar{q}\sigma^{\mu\nu} P_L b)(\bar{\ell}\sigma_{\mu\nu} P_L \nu_\ell),$$

Introduction of New Physics

$$\tilde{C}_a^{q,\ell} = C_a^{({\rm SM})q,\ell} + C_a^{q,\ell},$$

Generalities

Establish bounds on the NP Wilson Coefficients through
ratios of leptonic and semileptonic processes

$$\mathcal{B}(B_q^- \to \ell^- \bar{\nu}_\ell) \qquad \mathcal{B}(\bar{B} \to P \ell^- \bar{\nu}_\ell) \qquad \mathcal{B}(\bar{B} \to \tilde{V} \ell^- \bar{\nu}_\ell)$$

Work under the assumption of NP in all the fermionic generations.

Correlate NP in light generations according to

$$\text{Scenario 1:} \quad C_X^e = 0.1 C_X^\mu,$$
$$\text{Scenario 2:} \quad C_X^e = C_X^\mu,$$
$$\text{Scenario 3:} \quad C_X^e = 10 C_X^\mu.$$

where X=S, P, V, T

Generalities

RGE: 2011.02486

$$\begin{pmatrix} C^{q,\ell}_{V_L}(m_b) \\ C^{q}_{V_R}(m_b) \\ C^{q,\ell}_{S}(m_b) \\ C^{q,\ell}_{P}(m_b) \\ C^{q,\ell}_{T}(m_b) \end{pmatrix} \simeq \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1.71 & 0 & -0.27 \\ 0 & 0 & 0 & 1.71 & 0.27 \\ 0 & 0 & 0 & 0 & 0.84 \end{pmatrix} \begin{pmatrix} C^{q,\ell}_{V_L}(1\ \mathrm{TeV}) \\ C^{q}_{V_R}(1\ \mathrm{TeV}) \\ C^{q,\ell}_{S}(1\ \mathrm{TeV}) \\ C^{q,\ell}_{P}(1\ \mathrm{TeV}) \\ C^{q,\ell}_{T}(1\ \mathrm{TeV}). \end{pmatrix}$$

Strategy

1) Determine the NP regions using ratios of branching fractions where the CKM contributions cancel out.

2) Extract the CKM element by substituting the NP contributions in a CKM-NP dependent observable.

$b \to u$ *transitions:* $|V_{ub}|$

$b \to c$ *transitions:* $|V_{cb}|$

$b \to c$ transitions

Determine NP regions through $|V_{cb}|$ independent quantities

$$\mathcal{R}(D) = \frac{\mathcal{B}(\bar{B} \to D\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D\ell'^-\bar{\nu}_{\ell'})}, \qquad \mathcal{R}(D^*) = \frac{\mathcal{B}(\bar{B} \to D^*\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^*\ell'^-\bar{\nu}_{\ell'})}$$

$$F_L(D^*) = \frac{\Gamma(B \to D_L^*\tau\bar{\nu}_\tau)}{\Gamma(B \to D^*\tau\bar{\nu}_\tau)} \qquad R_\mu^e(D^*) = \frac{\mathcal{B}(B^0 \to D^{*-}e^+\nu_e)}{\mathcal{B}(B^0 \to D^{*-}\mu^+\nu_\mu)}$$

$b \to c$ transitions

Experimental values

1909.12524

$$\mathcal{R}(D) = 0.340 \pm 0.030 \qquad \mathcal{R}(D^*) = 0.295 \pm 0.01$$

Belle: 1903.03102 *Belle: 1809.03290*

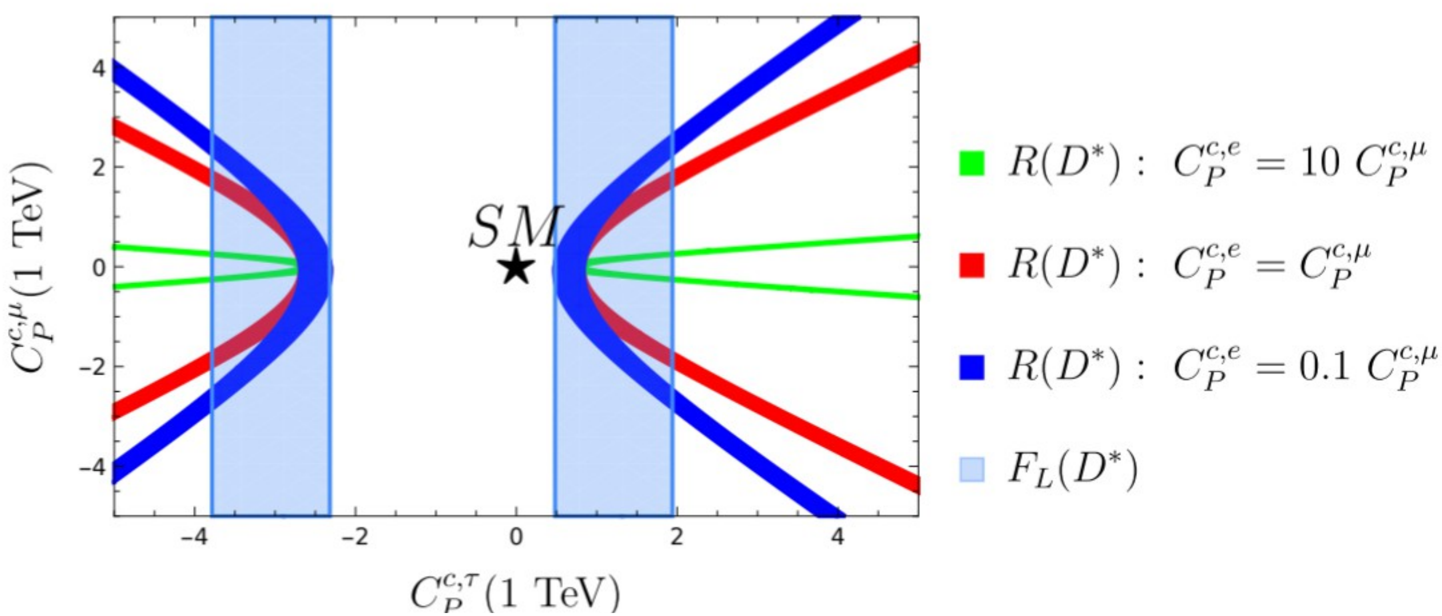
$$F_L(D^*) = 0.60 \pm 0.08 \pm 0.04 \qquad R^e_\mu(D^*) = 1.01 \pm 0.01 \pm 0.03$$

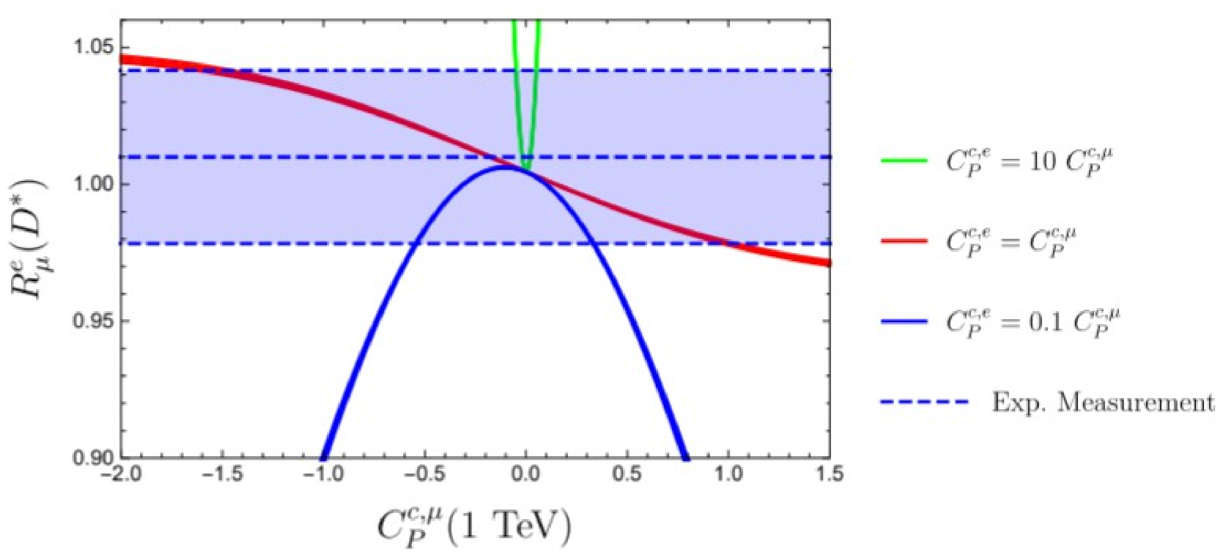
Theory values: 2104.04023
1703.05330

$$\mathcal{R}(D)|_{\rm SM} = 0.300 \pm 0.006, \qquad \mathcal{R}(D^*)|_{\rm SM} = 0.253 \pm 0.005$$

$$F_L(D^*)|_{\rm SM} = 0.458 \pm 0.004 \qquad R^e_\mu(D^*)|_{\rm SM} = 1.0045(1)$$

$b \to c$ transitions: pseudoscalar





$b \to c$ transitions: pseudoscalar

Results after applying all the constraints

Scenario	$C_P^{c,\mu}(1\ \mathrm{TeV})$		$C_P^{c,\tau}(1\ \mathrm{TeV})$	
	$\mathcal{R}(D^*)$ and $F_L(D^*)$	$R_\mu^e(D^*)$	$\mathcal{R}(D^*)$ and $F_L(D^*)$	$\mathcal{R}(D^*)$, $F_L(D^*)$ and $R_\mu^e(D^*)$
$C_P^{c,e} = 10 C_P^{c,\mu}$	$[-0.27, 0.27]$ $[-0.27, 0.27]$	$[-0.05, 0.05]$	$[-3.78, -2.32]$ $[0.48, 1.94]$	$[-2.76, -2.32]$ $[0.48, 0.90]$
$C_P^{c,e} = C_P^{c,\mu}$	$[-2.0, 1.90]$ $[-2.00, 1.89]$	$[-1.46, 1.04]$	$[-3.78, -2.32]$ $[0.48, 1.94]$	$[-3.52, -2.32]$ $[0.48, 1.66]$
$C_P^{c,e} = 0.1 C_P^{c,\mu}$	$[-2.86, 2.65]$ $[-2.84, 2.64]$	$[-0.55, 0.34]$	$[-3.78, -2.32]$ $[0.48, 1.94]$	$[-2.73, -2.32]$ $[0.48, 0.89]$

$b \to c$ transitions: pseudoscalar

Determination of $|V_{cb}|$

To extract the CKM element we consider

$$\langle \mathcal{B}(\bar{B} \to D^* \tau^- \bar{\nu}_\tau) \rangle$$

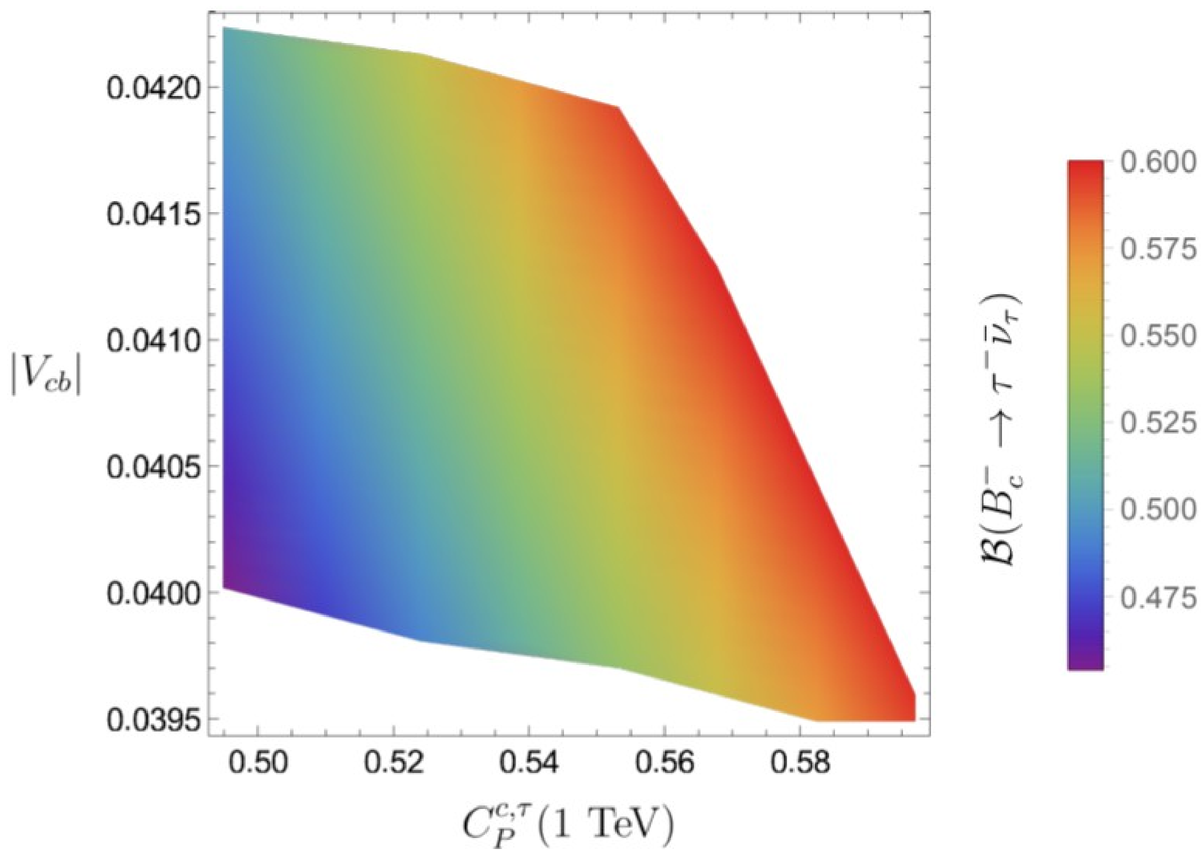
In particular we use the experimental result

$$\langle \mathcal{B}(\bar{B} \to D^* \tau^- \bar{\nu}_\tau) \rangle = (1.62 \pm 0.08) \times 10^{-2}$$

together with the constraint

$$\mathcal{B}(B_c \to \tau^- \bar{\nu}_\tau) < 0.60$$

$b \to c$ transitions: pseudoscalar



$b \to c$ transitions: pseudoscalar

Scenario	$\lvert V_{cb} \rvert$		$C_P^{c,\mu}(1\ \mathrm{TeV})$	$C_P^{c,\tau}(1\ \mathrm{TeV})$
	$\mathcal{R}(D^*)$, $F_L(D^*)$, $R^e_\mu(D^*)$			
	without $\mathcal{B}(B_c \to \tau^- \bar{\nu}_\tau)$	with $\mathcal{B}(B_c \to \tau^- \bar{\nu}_\tau)$		
$C_P^{c,e} = 10 C_P^{c,\mu}$	$[0.032, 0.042]$	$[0.039, 0.042]$	$[-0.05, 0.05]$	$[0.49, 0.60]$
$C_P^{c,e} = C_P^{c,\mu}$	$[0.032, 0.042]$	$[0.039, 0.042]$	$[-0.51, 0.41]$	$[0.49, 0.60]$
$C_P^{c,e} = 0.1 C_P^{c,\mu}$	$[0.034, 0.042]$	$[0.039, 0.042]$	$[-0.55, 0.34]$	$[0.49, 0.60]$

Exclusive value from HFLAV Collaboration:1909.12524

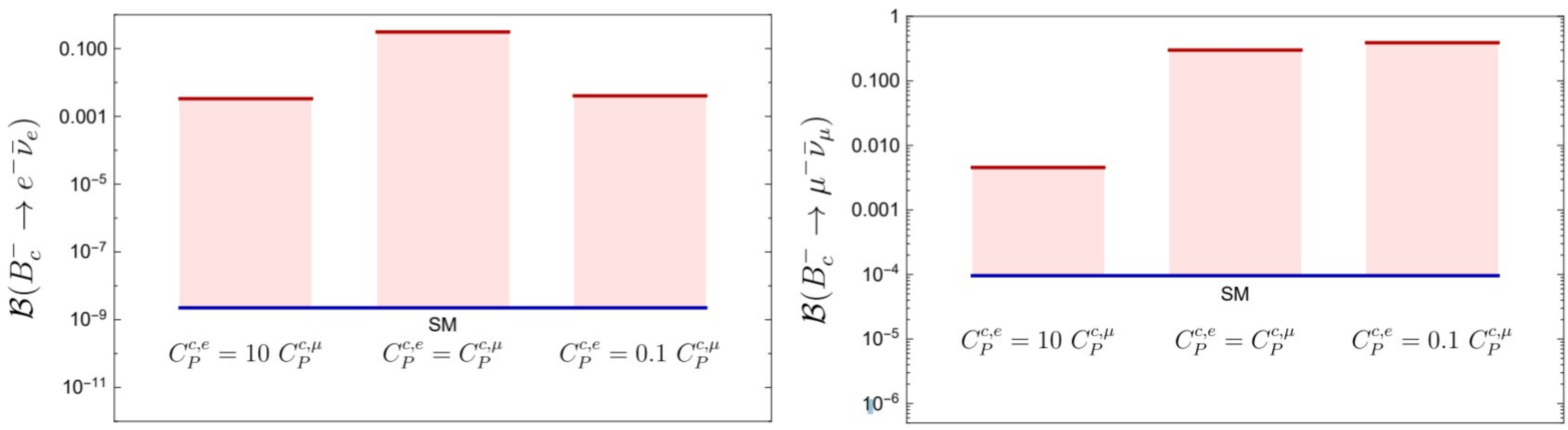
$\lvert V_{cb} \rvert$=0.03958+/-0.00117

$b \to c$ transitions: pseudoscalar

Predictions on leptonic decays

$$\mathcal{B}(B_q^- \to \ell^-\bar{\nu}_\ell)|_{\rm SM} = \frac{G_F^2}{8\pi}|V_{qb}|^2 M_{B_q} m_\ell^2 \left(1 - \frac{m_\ell^2}{M_{B_q}^2}\right)^2 f_{B_q}^2 \tau_{B_q}$$

$$\mathcal{B}(B_q^- \to \ell^-\bar{\nu}_\ell) = \mathcal{B}(B_q^- \to \ell^-\bar{\nu}_\ell)|_{\rm SM}\left|1 + C_{V_L}^{q,\ell} - C_{V_R}^q + \frac{M_{B_q}^2}{m_\ell(m_b+m_q)}C_P^{q,\ell}\right|^2$$



$b \to c$ transitions: vector(left handed)

Scenario	$C_{V_L}^{c,\mu}(1\ \text{TeV})$	$C_{V_L}^{c,\tau}(1\ \text{TeV})$
	$R_\mu^e(D^*)$	$\mathcal{R}(D^*)$, $\mathcal{R}(D)$ and $R_\mu^e(D^*)$
$C_{V_L}^{c,e} = 10C_{V_L}^{c,\mu}$	$[-0.183, -0.181]$ $[-0.001, 0.002]$	$[-1.913, -1.857] \cup [-0.143, -0.087]$ $[-2.120, -2.045] \cup [0.045, 0.120]$
$C_{V_L}^{c,e} = 0.1C_{V_L}^{c,\mu}$	$[-1.828, -1.805]$ $[-0.020, 0.015]$	$[-1.911, -1.855] \cup [-0.144, -0.089]$ $[-2.116, -2.042] \cup [0.042, 0.116]$

CKM $|V_{cb}|$ results: $0.038<|V_{cb}|<0.043$

	Predictions		
Scenario	$\mathcal{B}(B_c \to e^-\bar{\nu}_e)$	$\mathcal{B}(B_c \to \mu^-\bar{\nu}_\mu)$	$\mathcal{B}(B_c \to \tau^-\bar{\nu}_\tau)$
$C_{V_L}^{c,e} = 10C_{V_L}^{c,\mu}$	$[1.91 \times 10^{-9}, 2.36 \times 10^{-9}]$	$[8.39 \times 10^{-5}, 1.10 \times 10^{-4}]$	$[0.026, 0.029]$
$C_{V_L}^{c,e} = 0.1C_{V_L}^{c,\mu}$	$[1.96 \times 10^{-9}, 2.36 \times 10^{-9}]$	$[8.08 \times 10^{-5}, 1.10 \times 10^{-4}]$	$[0.026, 0.029]$

$b \to u$ transitions

Different possibilities to construct $|V_{ub}|$ independent quantities

$$\mathcal{R}^{\ell}_{\langle e,\mu\rangle;\rho\ [q^2\leq 12]\ \mathrm{GeV}^2} \equiv \mathcal{B}(B^- \to \ell^- \bar{\nu}_\ell)/\left\langle \mathcal{B}(\bar{B} \to \rho \ell'^- \bar{\nu}_{\ell'})\right\rangle_{[\ell'=\ e,\mu],\ q^2\leq 12\ \mathrm{GeV}^2},$$

$$\mathcal{R}^{\ell}_{\langle e,\mu\rangle;\pi} \equiv \mathcal{B}(B^- \to \ell^- \bar{\nu}_\ell)/\left\langle \mathcal{B}(\bar{B} \to \pi \ell'^- \bar{\nu}_{\ell'})\right\rangle_{[\ell'=\ e,\mu]},$$

$$\mathcal{R}^{\langle e,\mu\rangle;\rho\ [q^2\leq 12]\ \mathrm{GeV}^2}_{\langle e,\mu\rangle;\pi} \equiv \left\langle \mathcal{B}(\bar{B} \to \rho \ell'^- \bar{\nu}_{\ell'})\right\rangle_{[\ell'=\ e,\mu],\ q^2\leq 12\ \mathrm{GeV}^2} / \left\langle \mathcal{B}(\bar{B} \to \pi \ell'^- \bar{\nu}_{\ell'})\right\rangle_{[\ell'=e,\mu]}$$

$b \to u$ transitions

Experimental results
leptonic

$$\mathcal{B}(B^- \to \mu^- \bar{\nu}_\mu) = (5.3 \pm 2.2) \times 10^{-7}$$

$$\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau) = (1.09 \pm 0.24) \times 10^{-4}$$

$$\mathcal{B}(B^- \to e^- \bar{\nu}_e) < 9.8 \times 10^{-7} \, (90\% \text{ C.L.})$$

Belle: 1911.03186 *PDG* *Belle:0611045*

$b \to u$ transitions

Experimental results semileptonic

$$\langle \mathcal{B}(\bar{B} \to \pi \ell'^- \bar{\nu}_{\ell'}) \rangle_{[\ell' = e,\mu]} = (1.53 \pm 0.04) \times 10^{-4}$$ *PDG*

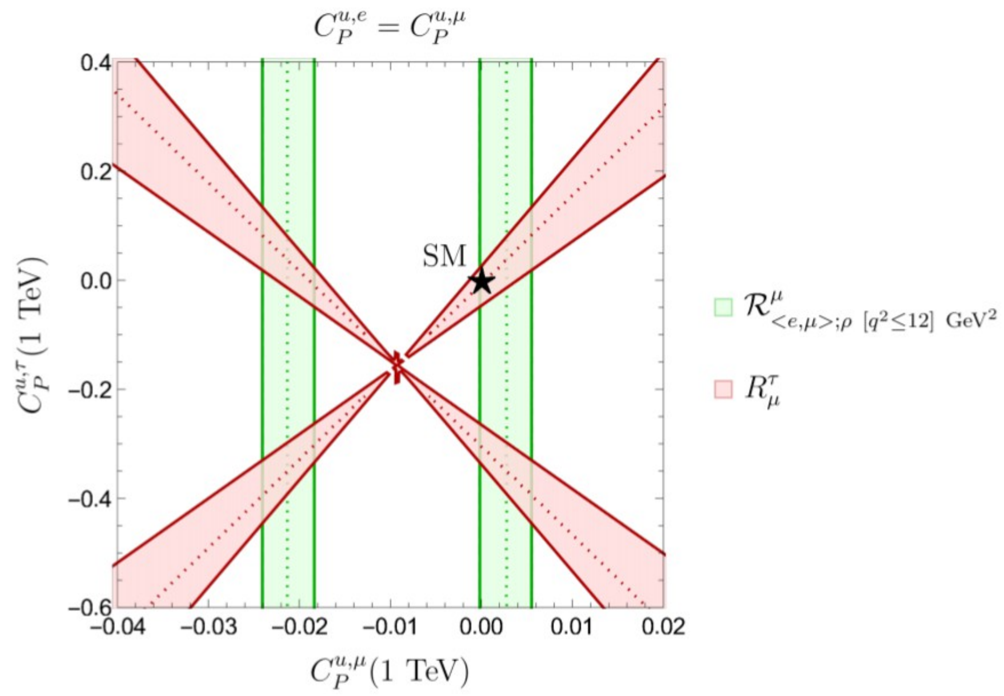
$$\mathcal{B}(\bar{B}^0 \to \pi^+ \tau^- \bar{\nu}_\tau) < 2.5 \times 10^{-4} \, (90\% \text{ C.L.})$$ *Belle: 1509.06521*

$$\langle \mathcal{B}(\bar{B} \to \rho \ell'^- \bar{\nu}_{\ell'}) \rangle_{[\ell' = e,\mu],\ q^2 \leq 12 \text{ GeV}^2} = (1.98 \pm 0.12) \times 10^{-4}.$$

Belle: 1306.2781

$b \to u$ transitions

Example Pseudoscalar Operator



$b \to u$ transitions

Example Pseudoscalar Operator

Scenario: $C_P^{u,e} = C_P^{u,\mu}$			
Region	$C_P^{u,\mu}(1\ \text{TeV})$	$C_P^{u,\tau}(1\ \text{TeV})$	$\|V_{ub}\|$
1	$[-0.0001, 0.0055]$	$[-0.05, 0.13]$	$[0.0030, 0.0037]$
2	$[-0.0001, 0.0055]$	$[-0.44, -0.27]$	$[0.0030, 0.0037]$
3*	$[-0.024, -0.018]$	$[-0.44, -0.27]$	$[0.0030, 0.0037]$
4*	$[-0.024, -0.018]$	$[-0.05, 0.13]$	$[0.0030, 0.0037]$

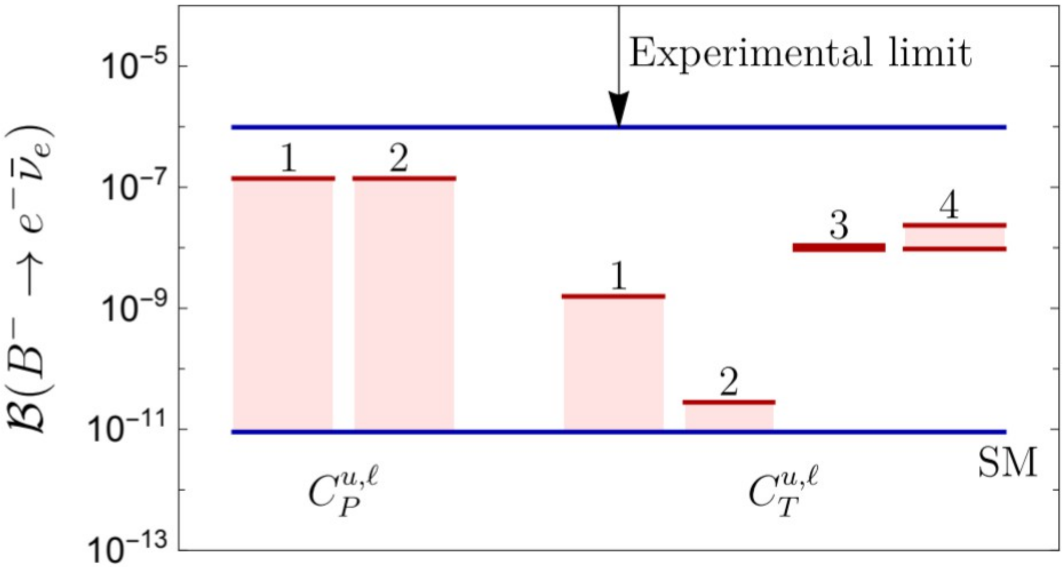
Exclusive value from HFLAV Collaboration:1909.12524

$|V_{ub}|$=0.00367+/-0.00015

$b \to u$ transitions

Predictions

Scenario: $C_P^{u,e} = C_P^{u,\mu}$		
Region	$\mathcal{B}(B^- \to e^- \bar{\nu}_e)$	$\mathcal{B}(\bar{B} \to \rho \tau^- \bar{\nu}_\tau)_{q^2 \leq 12\ \mathrm{GeV}^2}$
1	$[0, 1.4 \times 10^{-7}]$	$[5.2 \times 10^{-5}, 1.2 \times 10^{-4}]$
2	$[0, 1.4 \times 10^{-7}]$	$[4.3 \times 10^{-5}, 9.3 \times 10^{-5}]$



Final Remarks

- *We have presented a simple strategy to extract the CKM elements $|V_{ub}|$ and $|V_{cb}|$ in the presence of NP contributions.*

- *To illustrate our approach we have assumed the presence of NP in all the generations of fermions.*

- .*Our studies took into account different Lorenz structures finding values for $|V_{cb}|$ consistent with the exclusive determinations.*

- *The presence of pseudoscalar mediators leads to potential enhancements in the branching fractions of not yet measured leptonic decays.*