Physics
OSAKA UNIVERSITY

Right-handed Current in the b→u Transition

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Introduction

Flavor structure in the quark sector

Standard Model:

Yukawa couplings ⇒ charged current

$$\mathcal{L}_{CC} = \frac{g}{\sqrt{2}} W_\mu^+ \, \bar{u}_L \gamma^\mu V_{\rm CKM} d_L + \rm h.\,c.$$

$$V_{\rm CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

New Physics:

Minimal Flavor Violation

No other flavor violation

Non-MFV

New source(s) of flavor violation

Hierarchy

$$V_{\rm CKM} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & \lambda^3 A(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & \lambda^2 A \\ \lambda^3 A(1-\rho-i\eta) & -\lambda^2 A & 1 \end{pmatrix}$$

$$= \begin{pmatrix} 0.97428 \pm 0.00015 & 0.2253 \pm 0.0007 & 0.00347^{+0.00016}_{-0.00012} \\ 0.2252 \pm 0.0007 & 0.97345^{+0.00015}_{-0.00016} & 0.0410^{+0.0011}_{-0.0007} \\ 0.00862^{+0.00026}_{-0.00020} & 0.0403^{+0.0011}_{-0.0007} & 0.999152^{+0.000030}_{-0.000045} \end{pmatrix}$$

V_{ub} the smallest element

may be affected by Non-MFV new physics

Right-handed current in b→u

Model-indep. effective Lagarangian of dim. 6

$$\mathcal{L}_6 = \frac{C}{\Lambda^2}\bar{u}_R\gamma^\mu b_R\,\tilde{\Phi}^\dagger iD_\mu\Phi + \mathrm{h.\,c.}$$

➡ Effective charged current interaction

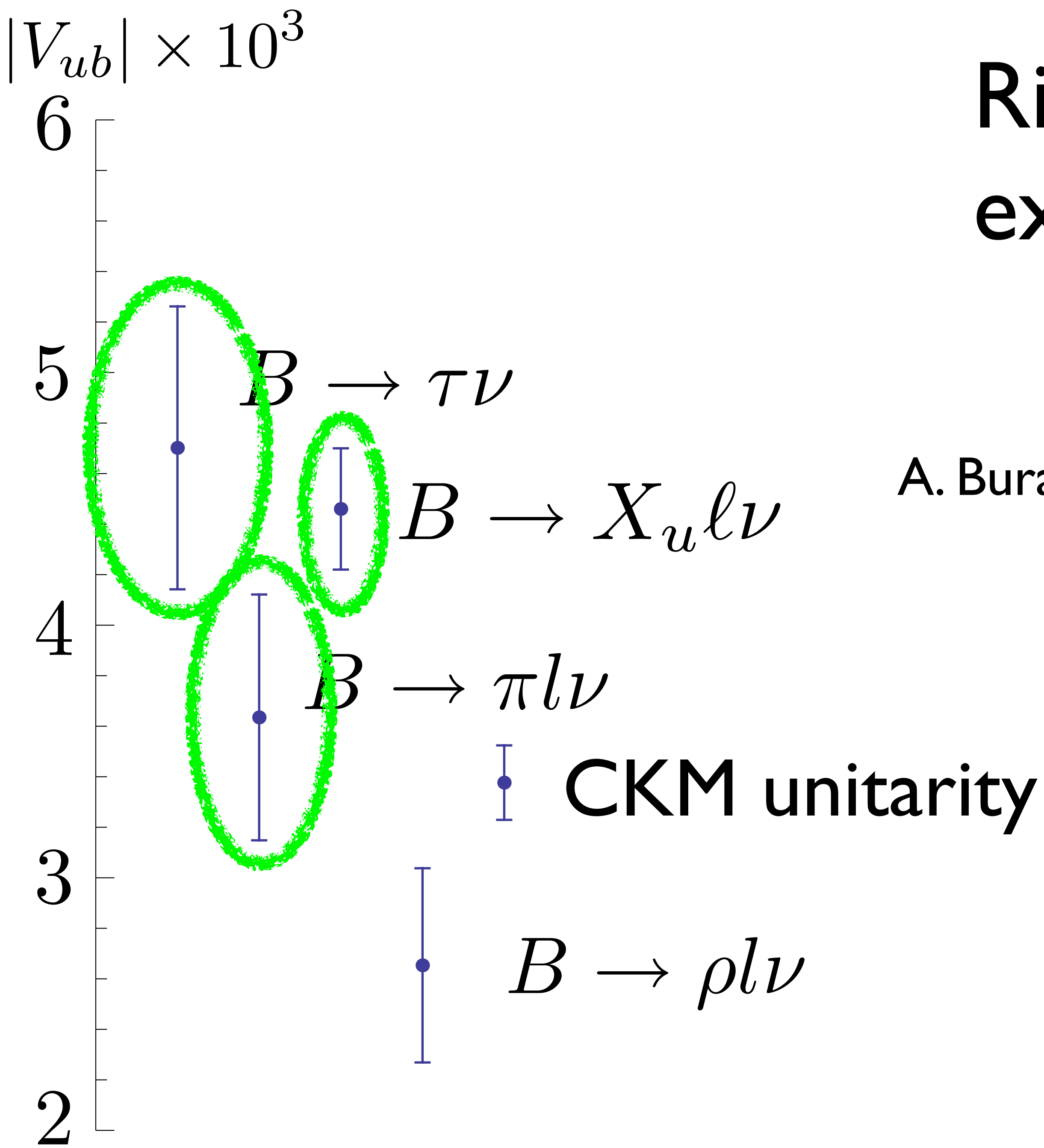
$$\mathcal{L}_{\rm cc}^{\rm eff} = -\frac{g}{\sqrt{2}}\left[V_{ub}^L\bar{u}_L\gamma^\mu b_L + V_{ub}^R\bar{u}_R\gamma^\mu b_R\right]W_\mu^+ + \mathrm{h.\,c.}$$

$$V_{ub}^R = C\frac{v^2}{2\Lambda^2} \sim 3\times 10^{-2}C\left(\frac{1\mathrm{TeV}}{\Lambda}\right)^2$$

$\sim \lambda^3$ possible

|Vub| Determinations

Present experimental status



Right-handed current explains the situation well.

C.-H. Chen, S.-H. Nam, PLB666,462,2008.
A. Crivellin, PRD81, 031301(R), 2010.
A. Buras, K. Gemmler, G. Ishidori, NPB843(2011),107.

Effects of the right-handed current

$B \to \tau\nu$ axial vector current only

$$|V_{ub}^{\rm exp}|^2 = |V_{ub}^L - V_{ub}^R|^2 = |V_{ub}^L|^2 \left[1 - 2{\rm Re}\left(\frac{V_{ub}^R}{V_{ub}^L}\right) + \left|\frac{V_{ub}^R}{V_{ub}^L}\right|^2\right]$$

$B \to \pi\ell\nu$ vector current only

$$|V_{ub}^{\rm exp}|^2 = |V_{ub}^L + V_{ub}^R|^2 = |V_{ub}^L|^2 \left[1 + 2{\rm Re}\left(\frac{V_{ub}^R}{V_{ub}^L}\right) + \left|\frac{V_{ub}^R}{V_{ub}^L}\right|^2\right]$$

$B \to X_u\ell\nu$ no interference $m_u \simeq 0$

$$|V_{ub}^{\rm exp}|^2 = |V_{ub}^L|^2 + |V_{ub}^R|^2 = |V_{ub}^L|^2 \left[1 + \left|\frac{V_{ub}^R}{V_{ub}^L}\right|^2\right]$$

$B \to \rho\ell\nu$ vector and axial vector

$$|V_{ub}^{\rm exp}|^2 = |V_{ub}^L|^2 \left[1 - 1.17\,{\rm Re}\left(\frac{V_{ub}^R}{V_{ub}^L}\right) + \left|\frac{V_{ub}^R}{V_{ub}^L}\right|^2\right]$$

LCSR

Ball, Zwicky

$|V_{ub}^L|$ from CKM unitarity

Assumptions:

Unitarity of V^L

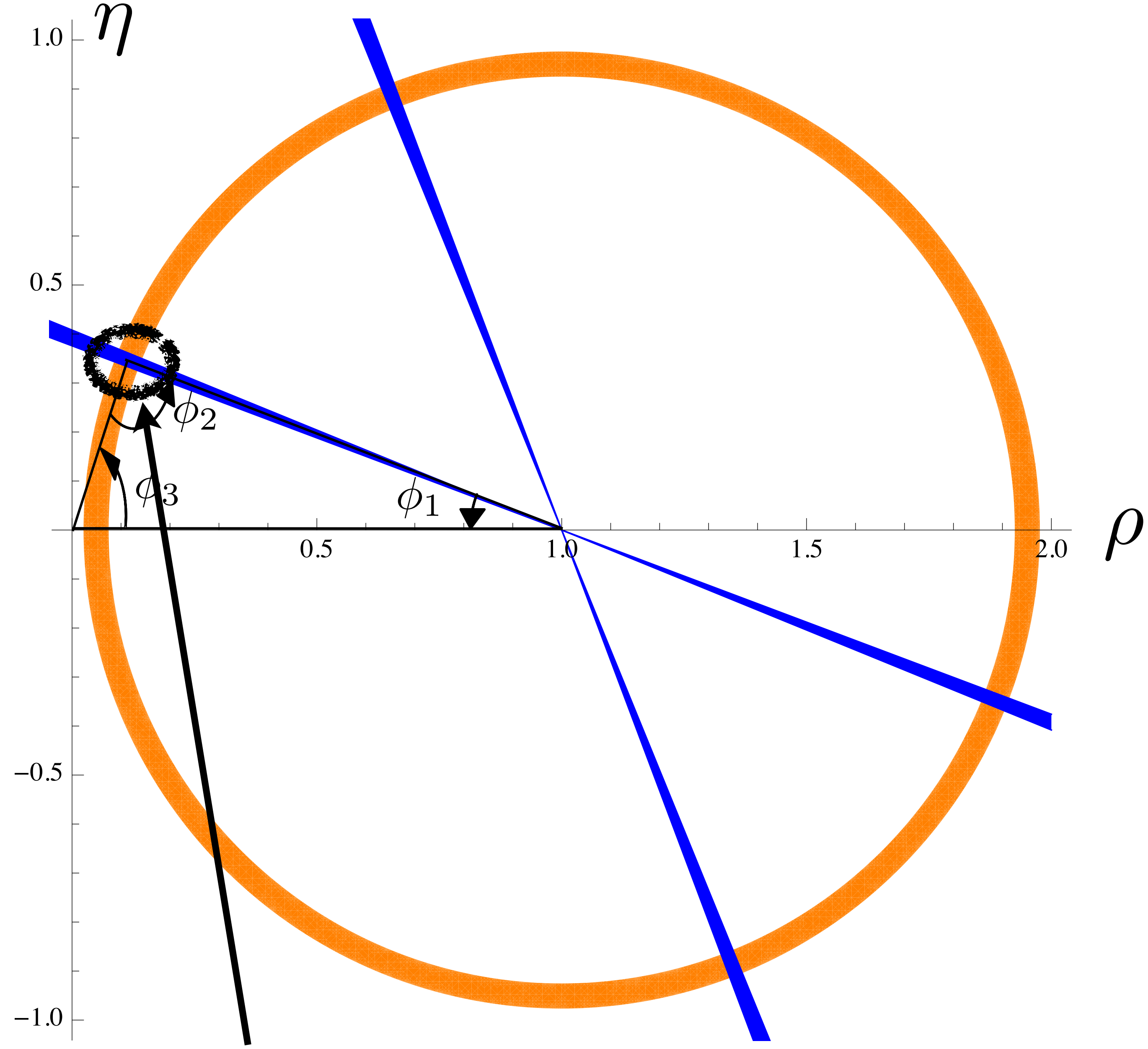
No new physics in

$B-\bar{B}$ mixing

$b \longrightarrow c\bar{c}s$

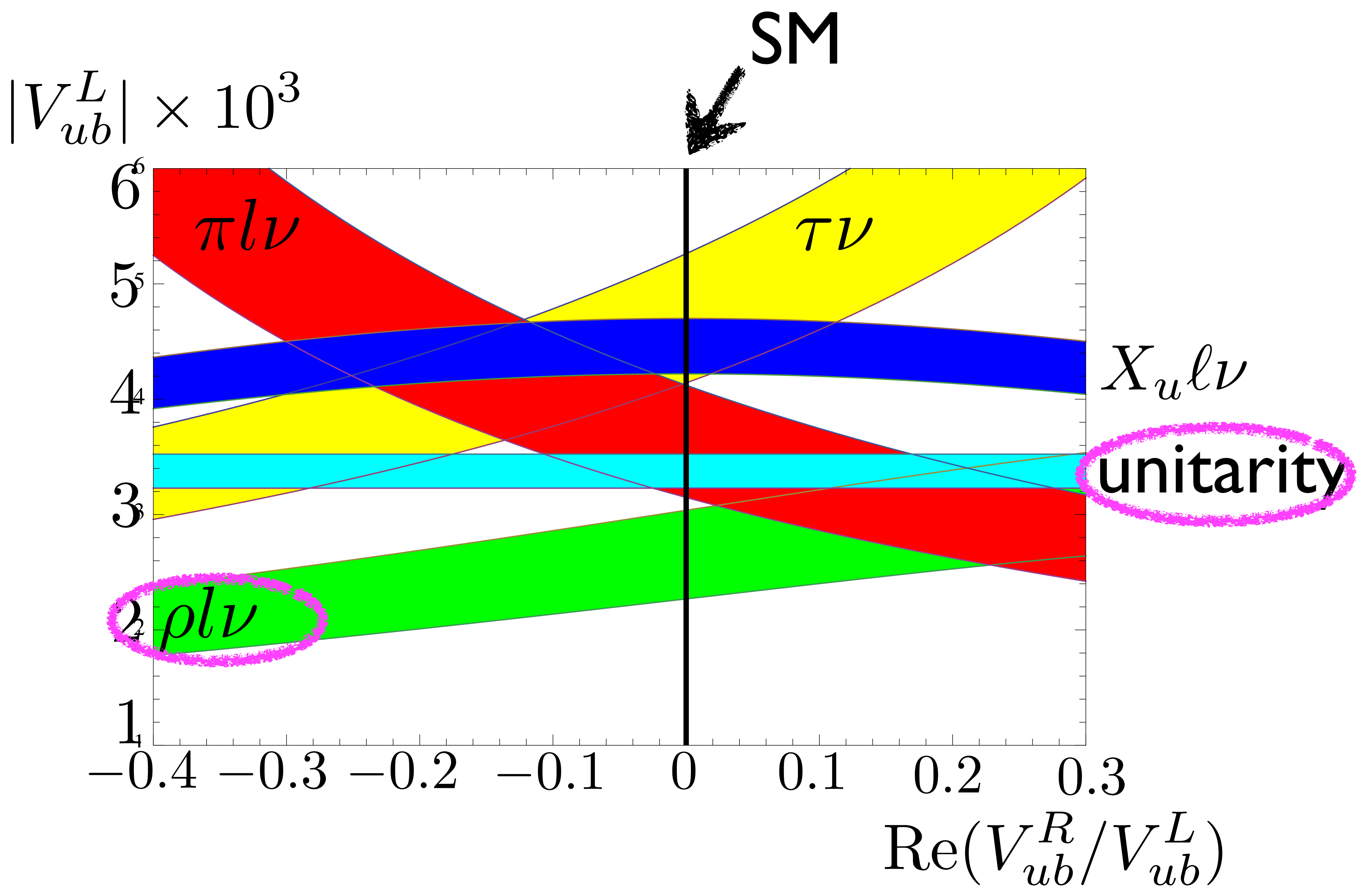
$$\frac{\Delta m(B_d)}{\Delta m(B_s)} = \xi^{-2}\lambda^2\{(1-\rho)^2+\eta^2\}$$

$$\sin 2\phi_1 = \sin 2\beta = \frac{2\eta(1-\rho)}{(1-\rho)^2+\eta^2}$$

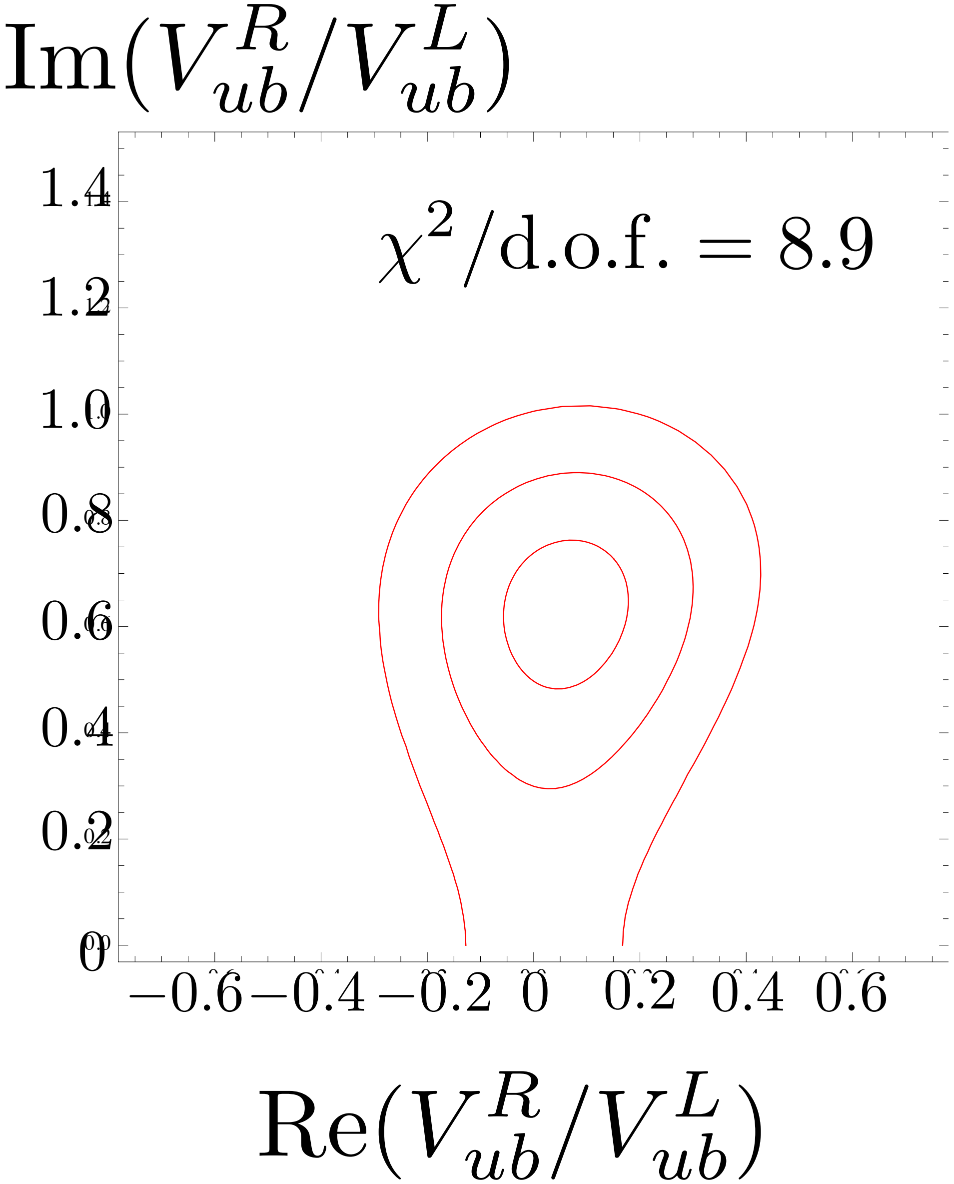


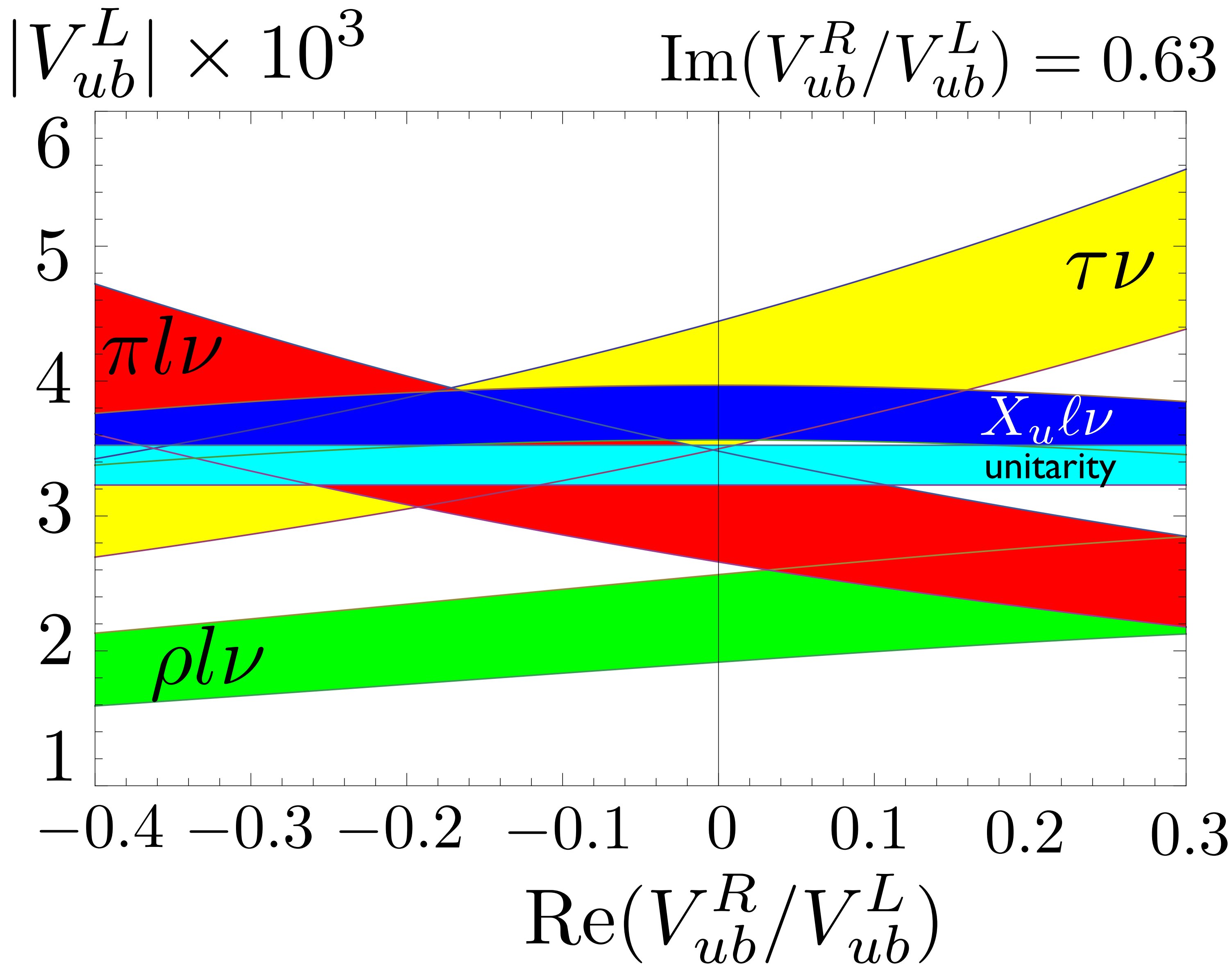
$$|V_{ub}^L| \simeq 3.4\times 10^{-3}$$
$$\arg V_{ub}^{L*} \simeq 72^\circ$$

$\mathrm{Im}(V_{ub}^R/V_{ub}^L) = 0$ case



$\mathrm{Im}(V_{ub}^R/V_{ub}^L) \neq 0$ case

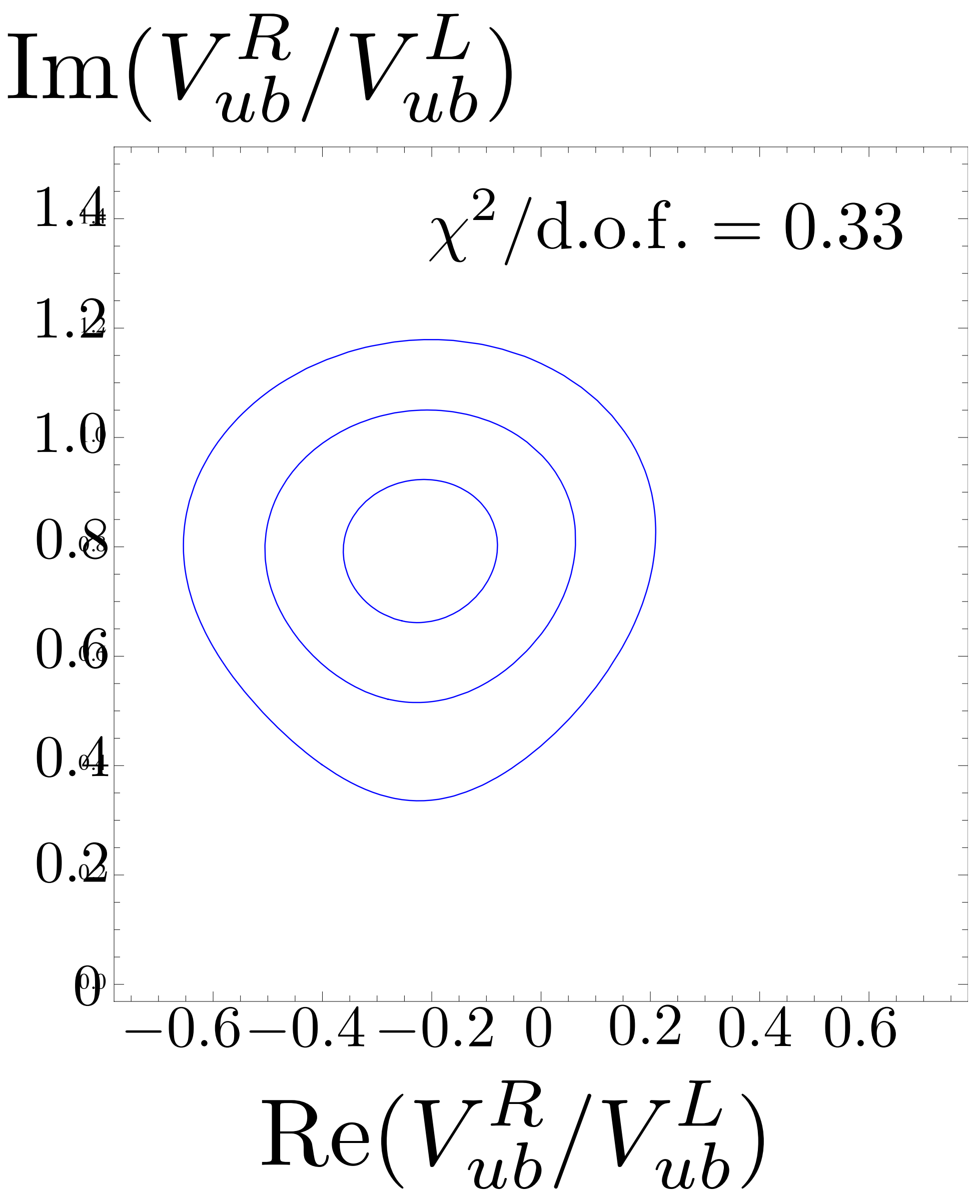


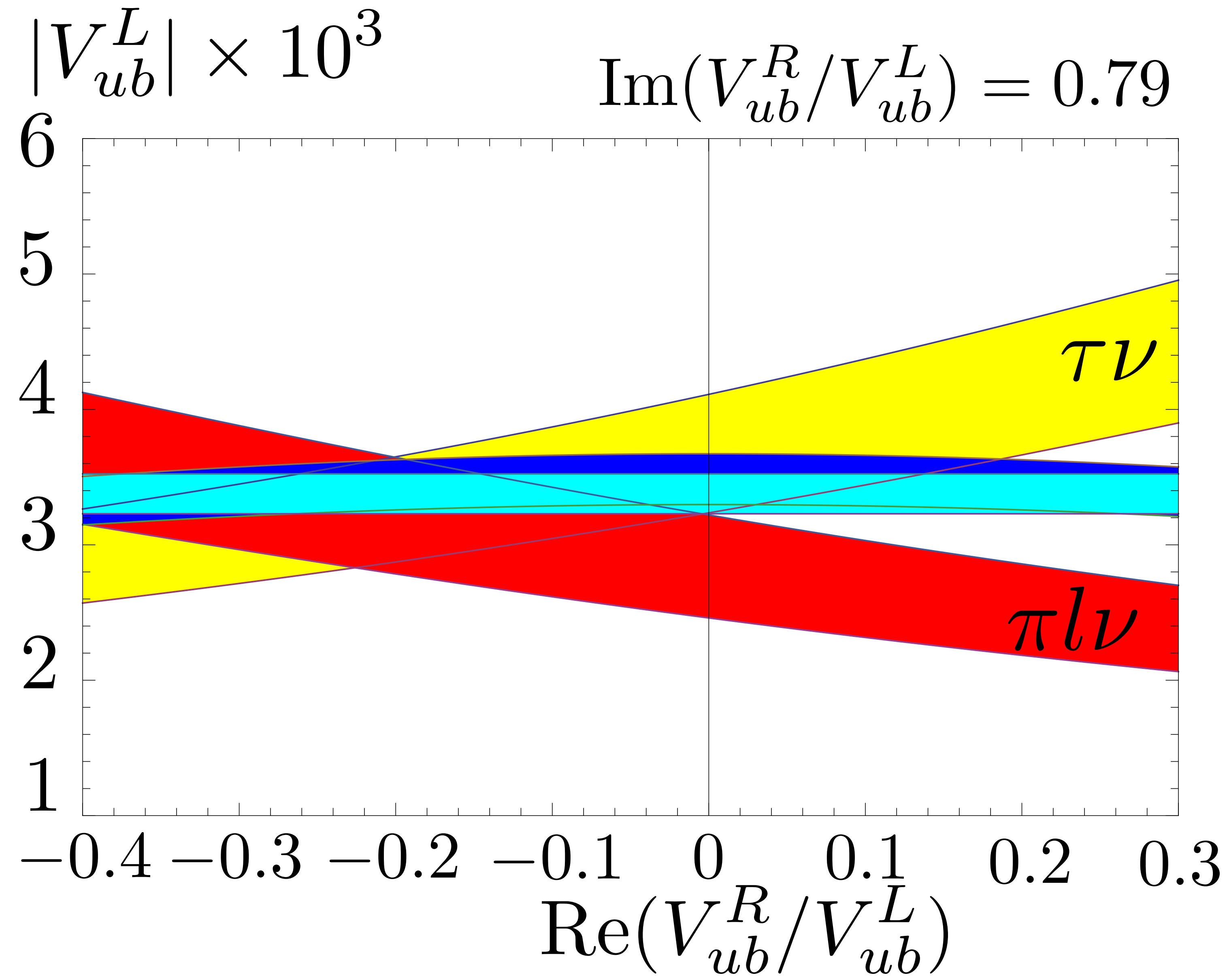


$B \to \rho \ell \nu$ difficult to explain by V_{ub}^R

form factor? (LCSR)

$\mathrm{Im}(V_{ub}^R/V_{ub}^L) \neq 0$ without $B \to \rho\ell\nu$

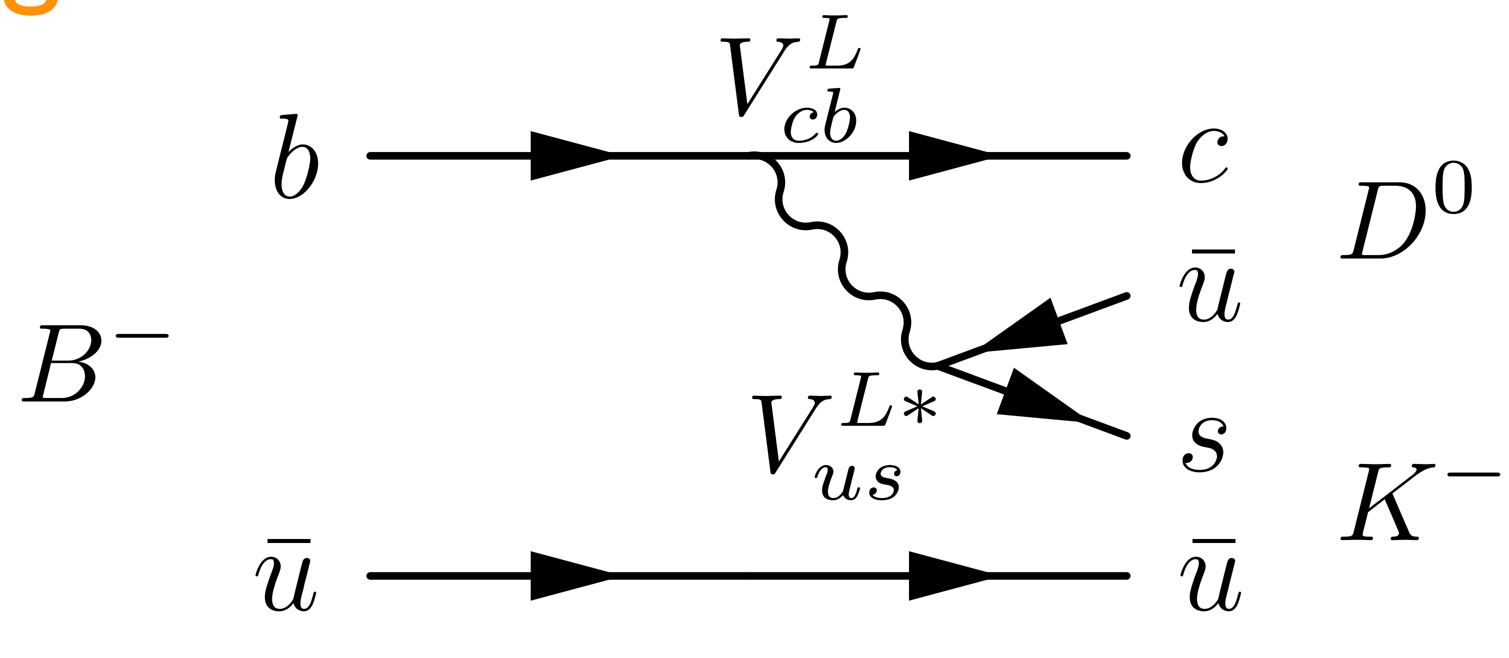




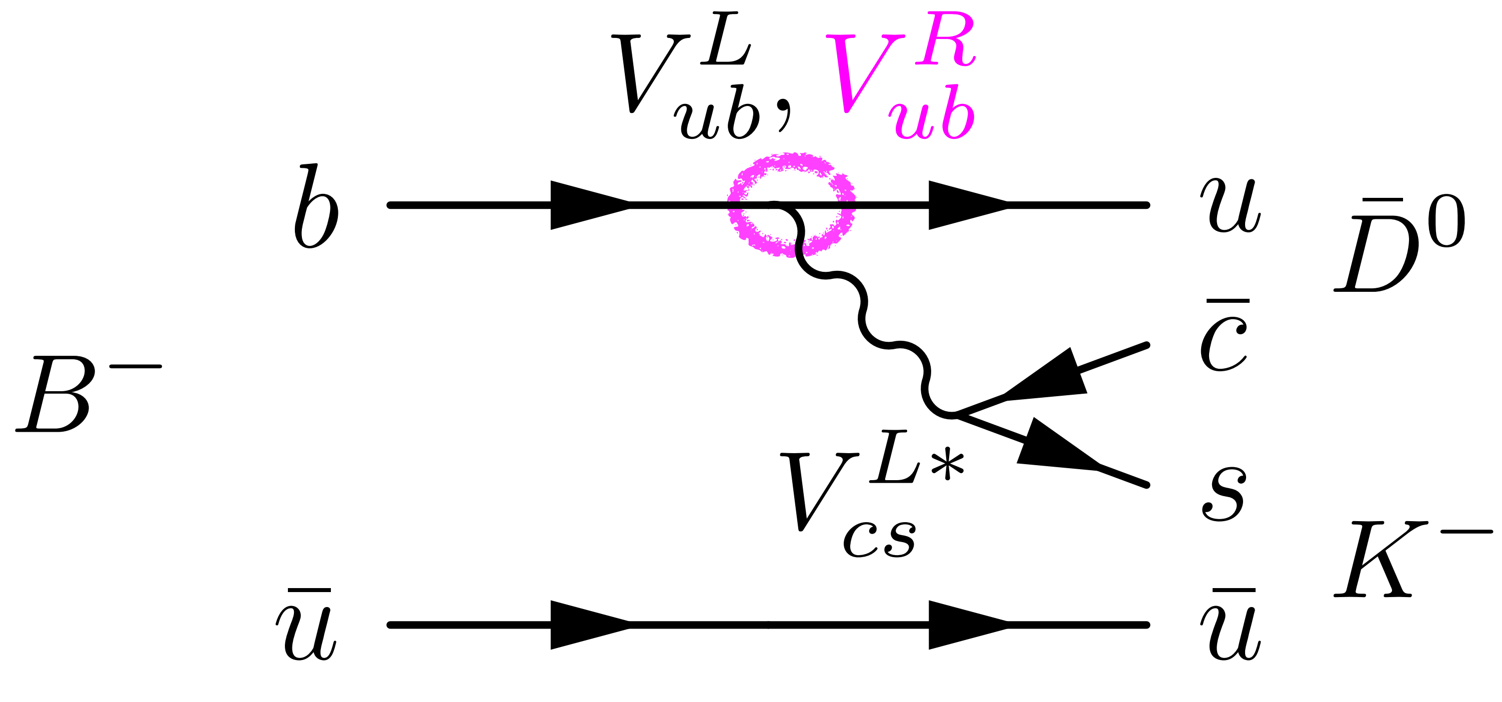
V_{ub}^R works well.

Effect on B→DK

Diagrams



V_{cb}^L
b
c
D^0
$\bar{u}$
B^-
V_{us}^{L*}
s
K^-
$\bar{u}$
$\bar{u}$



V_{ub}^L, V_{ub}^R
b
u
$\bar{D}^0$
$\bar{c}$
B^-
V_{cs}^{L*}
s
K^-
$\bar{u}$
$\bar{u}$

Amplitudes

$$A(B^- \to D^0 K^-) = a \quad (a > 0)$$

$$A(B^- \to \bar{D}^0 K^-) = a_- e^{-i\phi} e^{i\delta}$$

$$= a_L e^{-i\phi_L} e^{i\delta_L} + a_R e^{-i\phi_R} e^{i\delta_R}$$

$$\phi_L = \arg V_{ub}^{L*} \qquad \phi_R = \arg V_{ub}^{R*}$$

$$A(B^+ \to \bar{D}^0 K^+) = a$$

$$A(B^+ \to D^0 K^+) = a_+ e^{i\phi} e^{i\delta}$$

$$= a_L e^{i\phi_L} e^{i\delta_L} + a_R e^{i\phi_R} e^{i\delta_R}$$

Interference: $D^0,\ \bar{D}^0 \to X$

GLW, ADS, Dalitz plot

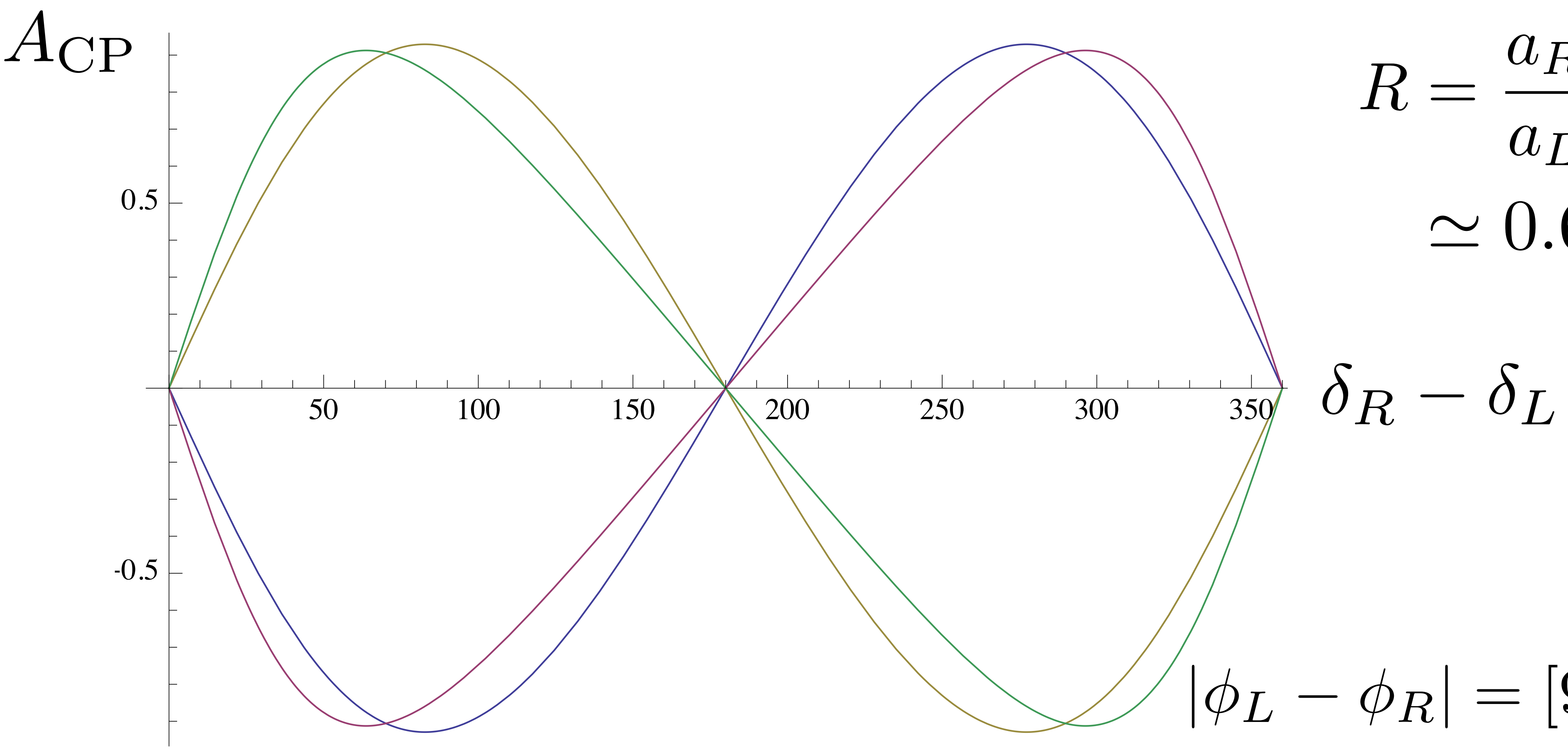
→ $a, a_\pm, \phi, \delta$

SM $\phi = \phi_L = \phi_3 = \gamma$

Flavor specific direct CP violation

$$A_{\rm CP} = \frac{\Gamma(B^- \to \bar{D}^0 K^-) - \Gamma(B^+ \to D^0 K^+)}{\Gamma(B^- \to \bar{D}^0 K^-) + \Gamma(B^+ \to D^0 K^+)}$$

$$= \frac{2R\sin(\phi_R - \phi_L)\sin(\delta_R - \delta_L)}{1 + 2R\cos(\phi_R - \phi_L)\cos(\delta_R - \delta_L) + R^2}$$



$$R = \frac{a_R}{a_L} = \left|\frac{V_{ub}^R}{V_{ub}^L}\right| h$$
$$\simeq 0.66$$

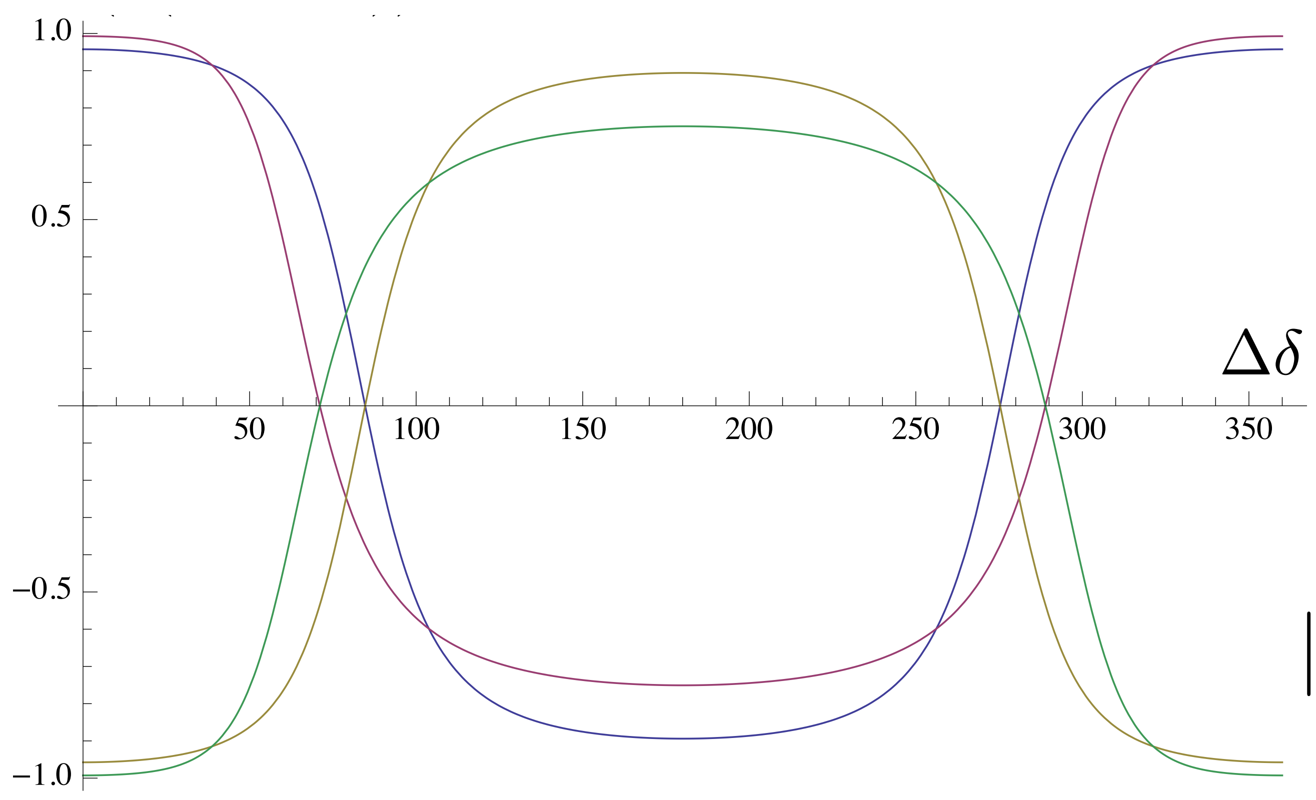
$$|\phi_L - \phi_R| = [95^\circ, 115^\circ]$$

Discrepancy in $\phi_3\,(\gamma)$ measurement

$$\phi - \phi_L = (\theta_+ - \theta_-)/2 \qquad \tan\theta_\pm = \frac{R\sin(\delta_R - \delta_L \pm (\phi_R - \phi_L))}{1 + R\cos(\delta_R - \delta_L \pm (\phi_R - \phi_L))}$$

$$= R\cos(\delta_R - \delta_L)\sin(\phi_R - \phi_L) + O(R^2)$$

$\sin 2(\phi - \phi_L)$



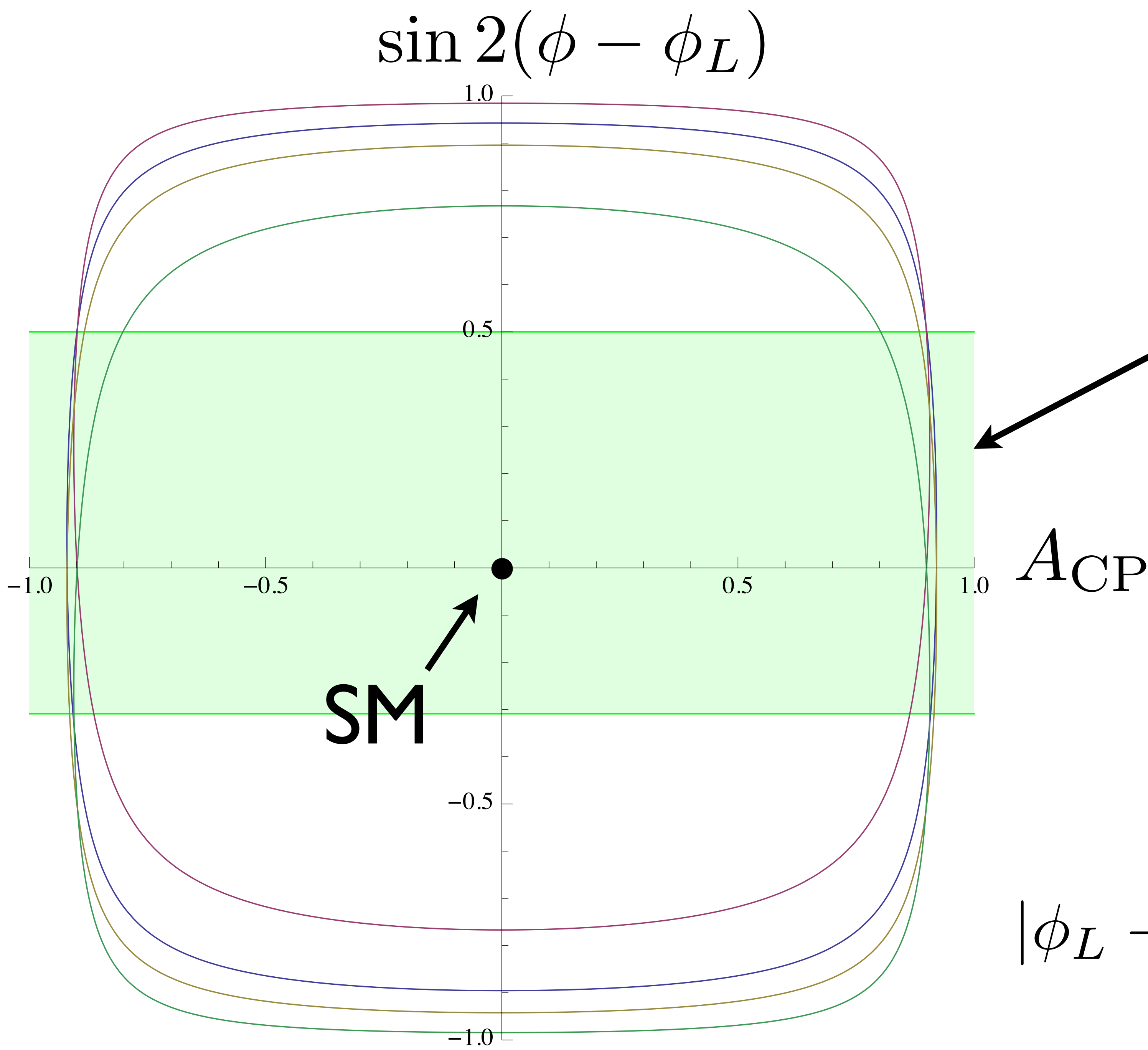
$\delta_R - \delta_L$

$$|\phi_L - \phi_R| = [95^\circ, 115^\circ]$$

Combination

$$A_{\rm CP}^2 + \sin^2 2(\phi - \phi_L) = 4R^2 \sin^2(\phi_R - \phi_L) + \cdots$$

no strong phase



current ϕ_3 data

$$\phi - \phi_L = [-9^\circ, 15^\circ]$$

$$|\phi_L - \phi_R| = [95^\circ, 115^\circ]$$

Summary

- V_{ub}^R works well for |Vub| determinations by $B \to X_u \ell \nu,\ B \to \pi \ell \nu,\ B \to \tau \nu$, and unitarity.

  $B \to \rho \ell \nu$ does not match with this scheme.

- V_{ub}^R appears in B→DK as:

  New direct CP violation in $B^- \to \bar{D}^0 K^-$

  and/or

  Discrepancy in $\phi_3\ (\gamma)$ measurement

Backup

Input parameters

$B \to \tau\nu$

$\mathrm{Br} = (1.64 \pm 0.34) \times 10^{-4}$ HFAG 2010

$f_B = 205(12)\,\mathrm{MeV}$ Tantalo 2011

$B \to X_u \ell\nu$

$|V_{ub}^{\mathrm{exp}}| = (4.46 \pm 0.16^{+0.18}_{-0.17}) \times 10^{-3}$ HFAG 2009

$B \to \pi\ell\nu$

$|V_{ub}^{\mathrm{exp}}| = (3.63 \pm 0.12^{+0.59}_{-0.40}) \times 10^{-3}$ BABAR 2011

$B \to \rho\ell\nu$

$|V_{ub}^{\mathrm{exp}}| = (2.65 \pm 0.38) \times 10^{-3}$ BABAR 2011

$B-\bar{B}$ mixing

$\Delta m(B_d) = 0.507 \pm 0.004\,\mathrm{ps}^{-1}$ HFAG 2010

$\Delta m(B_s) = 17.77 \pm 0.10 \pm 0.07\,\mathrm{ps}^{-1}$ HFAG 2010

$\xi = 1.258(25)(21)$ HPQCD 2009

CPV in $B \to J/\psi K_S, \cdots$

$\phi_1 = \beta = 21.4^\circ \pm 0.8^\circ$

$\sin 2\phi_1 = \sin 2\beta = 0.68 \pm 0.02$

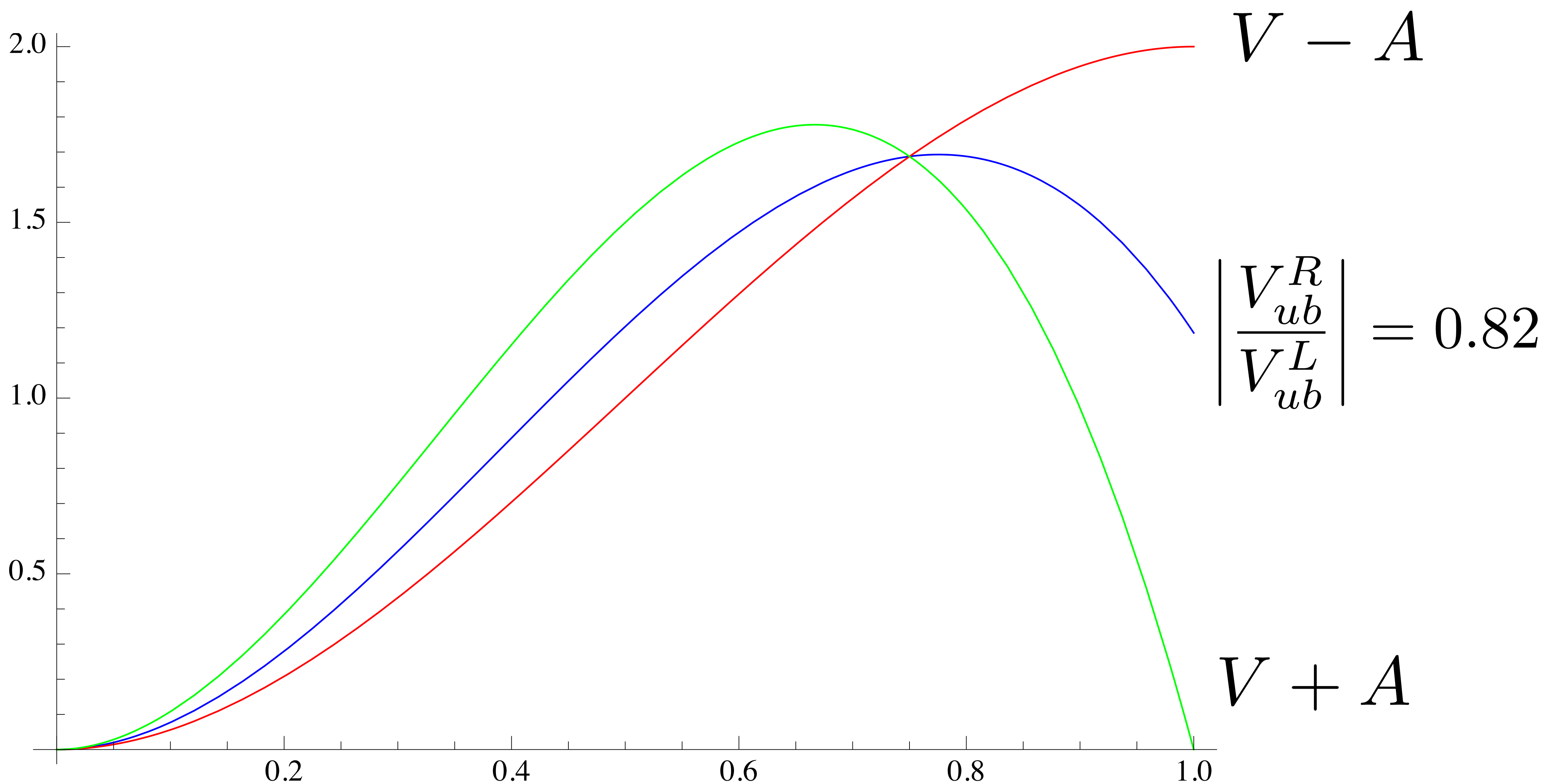
HFAG 2011

$\phi_3(B \to DK)$

$\phi_3 = \gamma = 74^\circ \pm 11^\circ$ UTfit 2010

Distribution in $B \to X_u \ell \nu$

$$\frac{1}{\Gamma}\frac{d\Gamma}{dy}$$



$$y = \frac{2E_\ell}{m_B}$$