$|V_{td}/V_{ts}|$ and γ from $B \to (\rho, \omega)\gamma / B \to K^*\gamma$

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Based on Ball/Zwicky, hep-ph/0603232 & Ball/Jones/Zwicky, hep-ph/0612081

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Theory Framework

- naive factorisation: $A(B \to V\gamma) = \langle V\gamma | H_{\rm eff} | B\rangle \propto T_1^{B\to V}(0)$
- QCD factorisation: Bosch/Buchalla 01

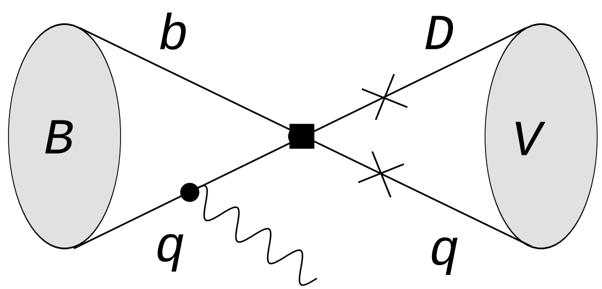
$$A(B \to V\gamma) \;=\; \sum_{i=1}^{8} \sum_{U=u,c} \lambda_U C_i \langle V\gamma | Q_i^U | B\rangle$$

$$\langle V\gamma | Q_i^U | B\rangle \;=\; \left[T_1^{B\to V}(0)\, T_i^I + \int_0^1 d\xi\, du\, T_i^{II}(\xi, u)\, \phi_B(\xi)\, \phi_{2;V}^{\perp}(u) \right] \cdot e$$

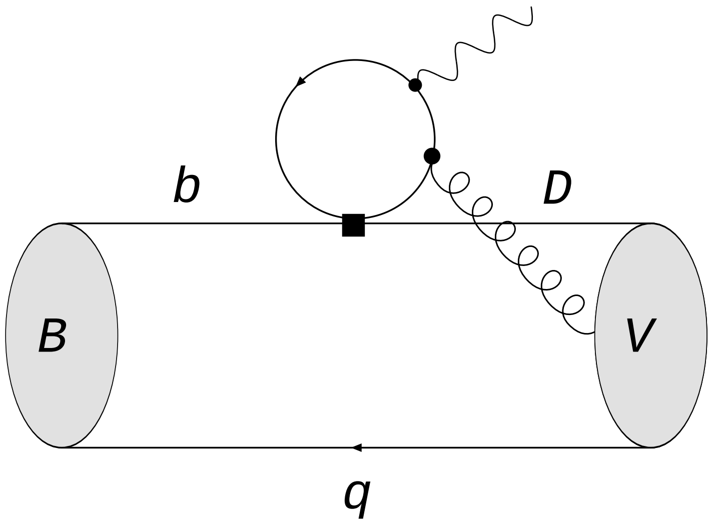
- λ_U: CKM factors
- $C_i, T_i^{I,II}$: perturbative QCD quantities
- $T_1, \phi_B, \phi_{2;V}^{\perp}$: non-perturbative QCD quantities
- QCD factorisation formula valid to leading order in $1/m_b$

Theory Framework

Contributions at $O(1/m_b)$:



(a)



(b)

- weak annihilation
- can be treated in QCDF
- relevant for $\mathcal{B}(B \to \rho\gamma)$ and isospin asymmetries
- long-distance photon emission, beyond QCDF, relevant for $\mathcal{B}(B^{\pm} \to \rho^{\pm}\gamma)$

- soft gluon emission
- beyond QCDF, new method developed by Ball/Jones/Zwicky
- relevant for $\mathcal{B}(B \to V\gamma)$ and time-dependent CP asymmetry

Form Factors

- state-of-the-art results from QCD sum rules on the light-cone:

$T_1^\rho(0)$	$T_1^\omega(0)$	$T_1^{K^*}(0)$
0.27 ± 0.04	0.25 ± 0.04	0.31 ± 0.04

- better accuracy for ratios:

$$\xi_\rho \equiv \frac{T_1^{K^*}}{T_1^\rho} = 1.17 \pm 0.09 \qquad \xi_\omega \equiv \frac{T_1^{K^*}}{T_1^\omega} = 1.30 \pm 0.10$$

- strategy for predicting branching ratios:

$$\overline{\mathcal{B}}(B \to V\gamma)\Big|_{\rm th} = \left[\frac{\overline{\mathcal{B}}(B \to V\gamma)}{\overline{\mathcal{B}}(B \to K^*\gamma)}\right]_{{\rm th},\, \boxed{\xi_V}} \overline{\mathcal{B}}(B \to K^*\gamma)\Big|_{\rm exp}$$

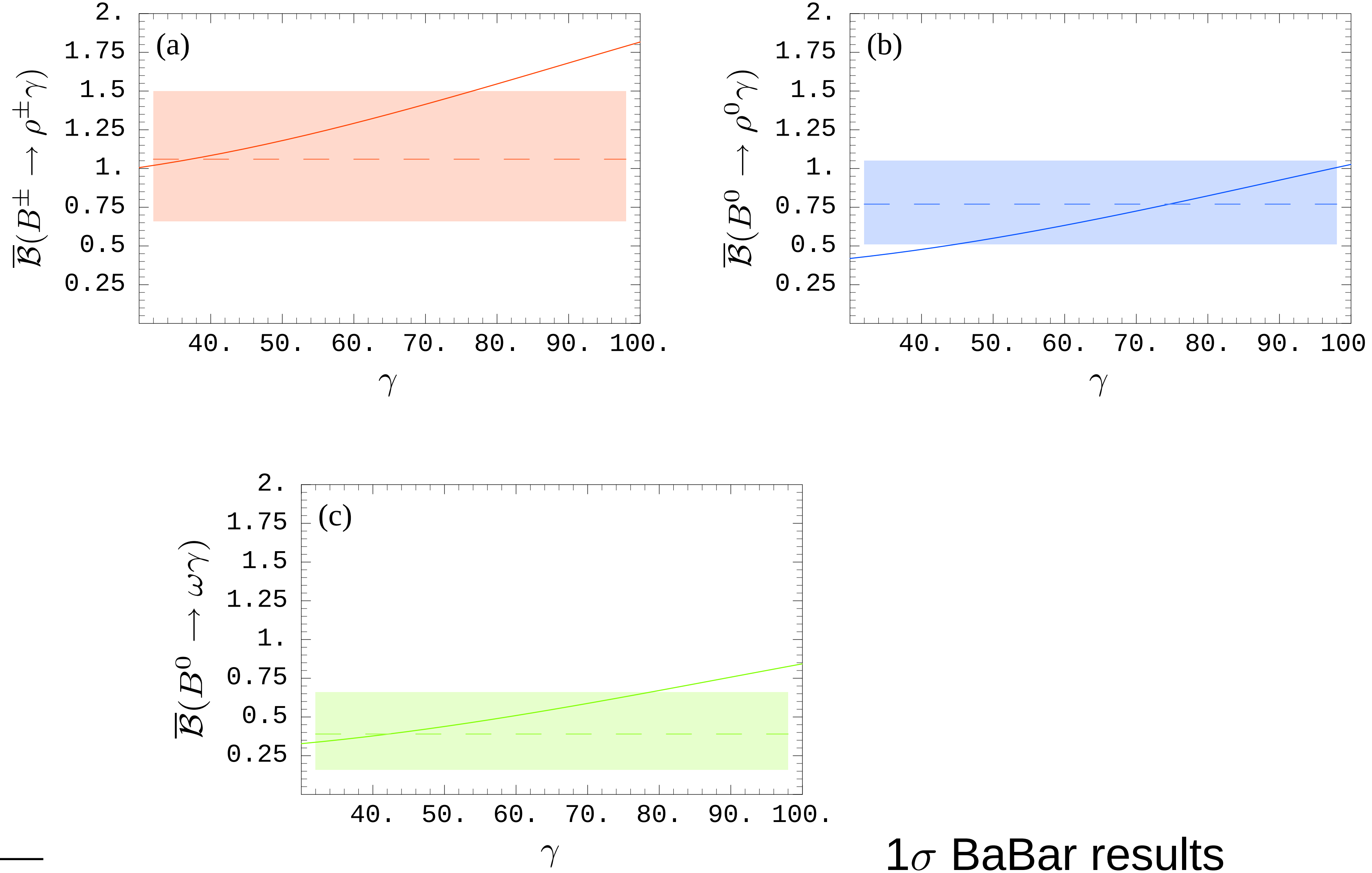
Branching Ratios (CP-averaged)

$\overline{\mathcal{B}} \times 10^6$	QCDF	+ WA	+ soft gluons	th. error
$B^- \to \rho^- \gamma$	1.05	1.11	1.16	± 0.26
$B^0 \to \rho^0 \gamma$	0.49	0.53	0.55	± 0.13
$B^0 \to \omega \gamma$	0.40	0.42	0.44	± 0.10
$B^- \to K^{*-} \gamma$	39.7	38.3	39.4	only exp. error
$B^0 \to K^{*0} \gamma$	37.1	39.9	41.0	only exp. error
$B_s^0 \to \bar{K}^{*0} \gamma$	1.12	1.23	1.26	± 0.31
$B_s^0 \to \phi \gamma$	34.6	38.3	39.4	± 11.9

BaBar: HFAG:

$B^- \to \rho^- \gamma$	$B^0 \to \rho^0 \gamma$	$B^0 \to \omega \gamma$	$B^- \to K^{*-} \gamma$	$B^0 \to K^{*0} \gamma$
1.10 ± 0.38	0.79 ± 0.23	< 0.78	40.3 ± 2.6	40.1 ± 2.0

Theory Predictions for $B \to (\rho, \omega)\gamma$



1σ BaBar results

$|V_{td}/V_{ts}|$

$$\frac{\overline{\mathcal{B}}(B \to (\rho,\omega)\gamma)}{\overline{\mathcal{B}}(B \to K^*\gamma)} \equiv R_{\rho/\omega} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m_\rho^2/m_B^2}{1 - m_{K^*}^2/m_B^2}\right)^3 \frac{1}{\xi_\rho^2}\,[1 + \Delta R]$$

BaBar 06: $R_{\rho/\omega} = 0.030 \pm 0.006$, Belle 05: 0.032 ± 0.008

Ball/Zwicky 06: $\xi_\rho = 1.17 \pm 0.09$

Ali/Lunghi/Parkhomenko 04: $\Delta R = 0.1 \pm 0.1$

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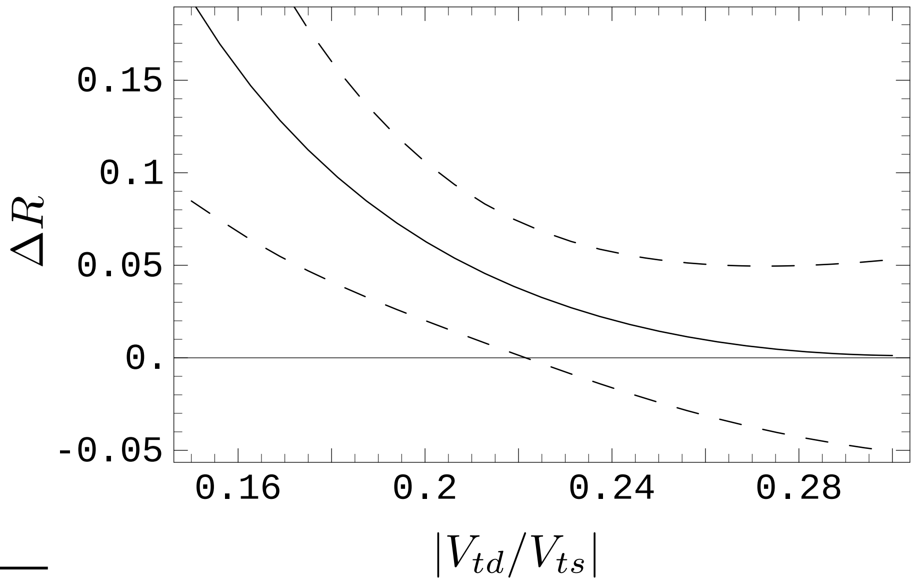

ΔR depends on $|V_{td}/V_{ts}|$!

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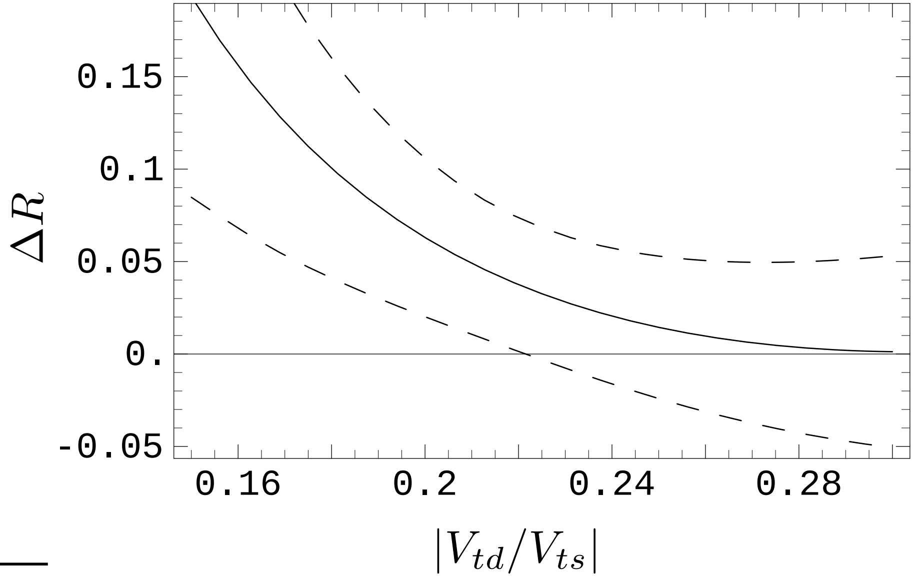


ΔR depends on $|V_{td}/V_{ts}|$!

Why?

ΔR

Theory expression in terms of QCD and CKM parameters:

$$1+\Delta R \;=\; \left|\frac{a^c_{7L}(\rho)}{a^c_{7L}(K^*)}\right|^2 \Bigg(1+\mathrm{Re}\,(\delta a_\pm+\delta a_0)\left[\frac{R_b^2-R_b\cos\gamma}{1-2R_b\cos\gamma+R_b^2}\right]$$

$$+\frac{1}{2}\left(|\delta a_\pm|^2+|\delta a_0|^2\right)\left\{\frac{R_b^2}{1-2R_b\cos\gamma+R_b^2}\right\}\Bigg)$$

R_b, γ, λ and $|V_{td}/V_{ts}|$ are not independent of each other!

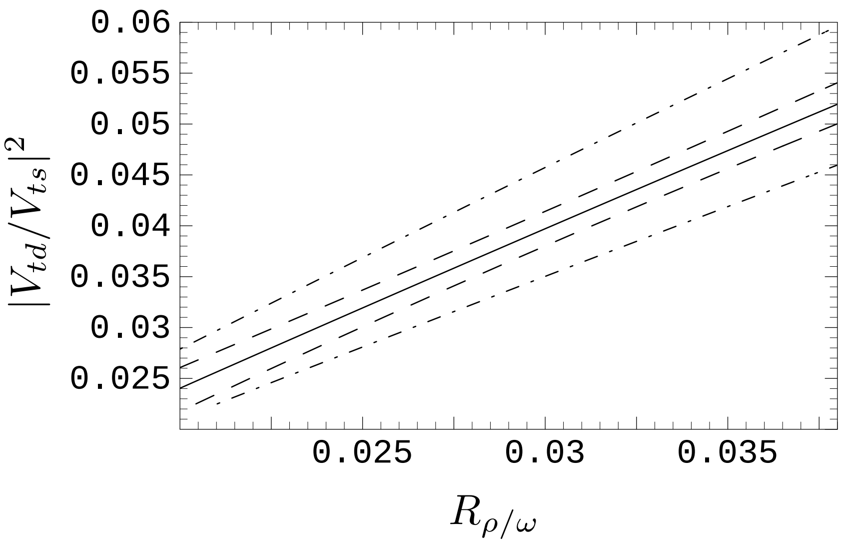
$$\left|\frac{V_{td}}{V_{ts}}\right| = \lambda\sqrt{1-2R_b\cos\gamma+R_b^2}$$

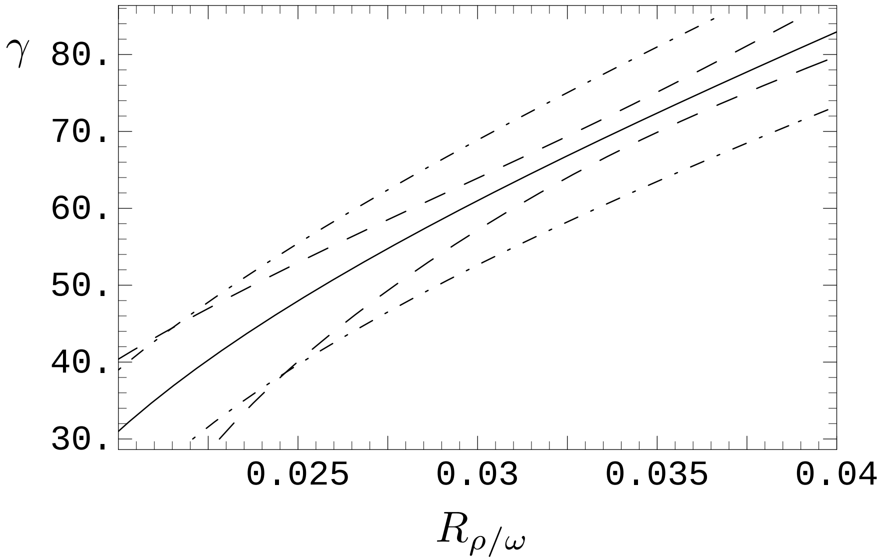
Once λ, R_b and γ are fixed, $|V_{td}/V_{ts}|$ is also completely fixed.

ΔR

Solution: use independent set of CKM parameters:

$\lambda,\ R_b,\ |V_{td}/V_{ts}|$ or $\lambda,\ R_b,\ \gamma$





Recall $R_b = \left(1 - \frac{\lambda^2}{2}\right)\frac{1}{\lambda}\left|\frac{V_{ub}}{V_{cb}}\right|.$

ΔR

Solution: use independent set of CKM parameters:

λ, R_b, $|V_{td}/V_{ts}|$ or λ, R_b, γ

$R_{\rho/\omega}$	$\lvert V_{td}/V_{ts}\rvert$	Δ_{ξ_ρ}	$\Delta_{\text{other th}}$	γ	Δ_{ξ_ρ}	$\Delta_{\text{other th}}$
0.026	0.183	± 0.012	± 0.007	50.8	${}^{+7.5}_{-8.2}$	± 5.8
0.028	0.191	${}^{+0.012}_{-0.013}$	± 0.006	56.0	${}^{+7.7}_{-8.3}$	± 4.7
0.030	0.199	± 0.013	± 0.006	61.0	${}^{+7.9}_{-8.4}$	± 4.0
0.032	0.207	${}^{+0.013}_{-0.014}$	± 0.006	65.7	${}^{+8.1}_{-8.5}$	± 3.6
0.034	0.214	± 0.014	± 0.006	70.2	${}^{+8.4}_{-8.8}$	± 3.5

Theory errors!

Isospin Asymmetry

Experimental $R_{\rho/\omega}$ uses

$$\overline{\Gamma}(B^\pm \to \rho^\pm\gamma) \equiv 2\overline{\Gamma}(B^0 \to \rho^0\gamma) \equiv 2\overline{\Gamma}(B^0 \to \omega\gamma)$$

Is it justified?

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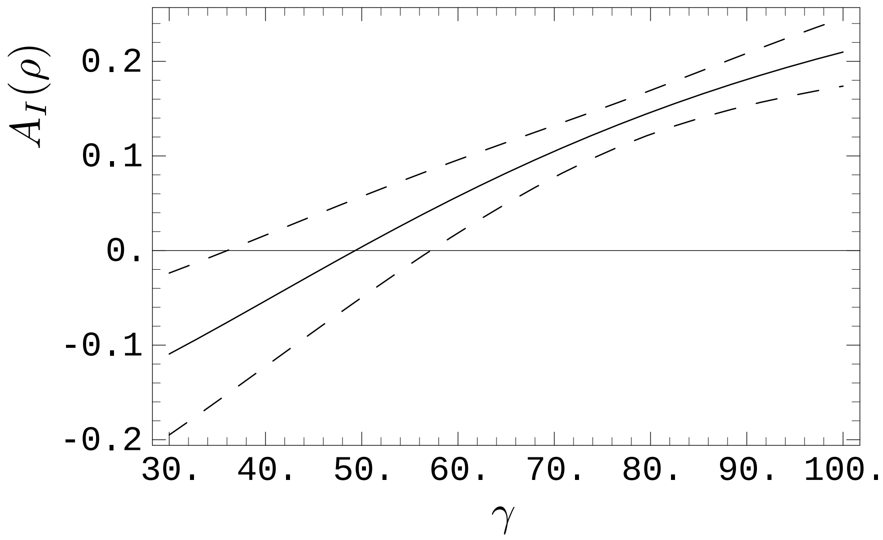

Define isospin asymmetry

$$A_I(\rho) = \frac{2\overline{\Gamma}(\bar{B}^0 \to \rho^0\gamma)}{\overline{\Gamma}(\bar{B}^\pm \to \rho^\pm\gamma)} - 1$$

- strongly dependent on γ
- near 0 for $\gamma \approx 55^\circ$

Isospin Asymmetry

Experimental $R_{\rho/\omega}$ uses

$$\overline{\Gamma}(B^\pm \to \rho^\pm\gamma) \equiv 2\overline{\Gamma}(B^0 \to \rho^0\gamma) \equiv 2\overline{\Gamma}(B^0 \to \omega\gamma)$$

Is it justified?

$$A_I(\rho,\omega) = \frac{\overline{\Gamma}(B^0 \to \omega^0\gamma)}{\overline{\Gamma}(B^0 \to \rho^0\gamma)} - 1 = -0.20 \pm 0.09(\mathrm{th})$$

- driven by difference in form factors
- driven, in turn, by difference in decay constants from $(\rho^0,\omega) \to e^+e^-$: EM isospin-breaking effect

May be wise to drop ω from experimental average. . . (as done by BaBar. . .)

Results

From 2006 BaBar data:

$$\left|\frac{V_{td}}{V_{ts}}\right| = 0.199^{+0.022}_{-0.025}(\text{exp}) \pm 0.014(\text{th}) \leftrightarrow \gamma = (61.0^{+13.5}_{-16.0}(\text{exp})^{+8.9}_{-9.3}(\text{th}))^\circ$$

- $|V_{td}/V_{ts}|$ depends on $\cos\gamma$
- discrete ambiguity $\gamma \leftrightarrow -\gamma$

- CP asymmetry in $B \to D^{(*)}K^{(*)}$ depends on $\sin^2\gamma$
- discrete ambiguity $\gamma \leftrightarrow \gamma + \pi$

Remove discrete ambiguity! $\gamma < 180^\circ$ is favoured!

Summary

- new contributions to $B \to V\gamma$ beyond QCDF:
  - soft-gluon emission from quark loops
  - long-distance photon emission
- updated input parameters (ratios of form factors ξ_V with reduced theoretical uncertainty)
- determination of $|V_{td}/V_{ts}|$ or, equivalently, γ
- $|V_{td}/V_{ts}| \leftrightarrow \cos\gamma$, $B \to D^{(*)}K^{(*)} \leftrightarrow \sin^2\gamma$:

remove discrete ambiguity!

- also new/updated results for CP asymmetry $S(V\gamma)$ and isospin asymmetry in $B \to K^*\gamma$: all very sensitive to new physics!