$B \to VV$ decays can be useful

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Flavour in the Era of the LHC, CERN, May 17, 2006

- A determination of α [γ]

  (MB, M. Gronau, J. Rohrer, M. Spranger, to appear in PLB, hep-ph/0604005)

- Enhanced electroweak penguin (electromagnetic dipole – $O_{7\gamma}^{\mp}$) contributions in decays to transversely polarized vector mesons

  (MB, J. Rohrer, D. Yang, PRL 96 (2006) 141801, hep-ph/0512258)

A determination of α $[\gamma]$

$B \longrightarrow \rho\rho$ is good, because P is small, and the longitudinal polarization amplitude dominates

$$\mathcal{A}_0(B^0 \longrightarrow \rho^+\rho^-) = T\,e^{i\gamma} + P\,e^{i\delta}$$

- three unknowns: $r \equiv \frac{P}{T}$, δ and α
  (T will not be needed, β is assumed to be known)
- two observables: S_L, C_L
- require one further constraint
  - Br$(B^0 \longrightarrow \rho^0\rho^0)$ $\quad\Rightarrow\quad$ bound on $|\Delta\alpha_{\rm eff}| < 11^\circ$ $\quad\Rightarrow\quad$ $\alpha = (96 \pm 13)^\circ$
  - Idea: Use instead longitudinal branching fraction Br$_L(B^+ \longrightarrow K^{*0}\rho^+)$

How is this related to $B \to \rho^+\rho^-$?

$$|\mathcal{A}_0(B^+ \to K^{*0}\rho^+)|^2_{\rm CP-av.} = \left(\frac{|V_{cs}|}{|V_{cd}|}\frac{f_{K^*}}{f_\rho}\right)^2 F P^2 = 21.4\, F P^2$$

with P from $\mathcal{A}_0(B^0 \to \rho^+\rho^-)$. This defines F. Roughly the ratio of longitudinal penguin amplitudes in $B^+ \to K^{*0}\rho^+$ to the one in $B^0 \to \rho^+\rho^-$.

Then the third observable is

$$\begin{aligned} \mathcal{R} &\equiv \left(\frac{|V_{cd}|}{|V_{cs}|}\frac{f_\rho}{f_{K^*}}\right)^2 \frac{\Gamma_L(B^+ \to K^{*0}\rho^+) + \Gamma_L(B^- \to \bar{K}^{*0}\rho^-)}{\Gamma_L(B^0 \to \rho^+\rho^-) + \Gamma_L(\bar{B}^0 \to \rho^+\rho^-)} \\ &= \frac{F r^2}{1 - 2r\cos\delta\cos(\beta+\alpha) + r^2} \\ &\stackrel{\rm exp.}{=} 0.0080 \pm 0.0023 \end{aligned}$$

But what is F?

$$\sqrt{F} = \frac{\hat{\alpha}_4^c - \frac{1}{2}\alpha_{4\mathrm{EW}}^c + \beta_{3,\mathrm{EW}}^c + \frac{V_{ub}V_{us}^*}{V_{cb}V_{cs}^*}\left[\,\ldots\,\right]_{|\rho K^*}}{\hat{\alpha}_4^c + \alpha_{4\mathrm{EW}}^c + 2\beta_4^c - \frac{1}{2}\beta_{3,\mathrm{EW}}^c + \frac{1}{2}\beta_{4,\mathrm{EW}|\rho\rho}^c} \overset{\text{if}\ldots}{=} 1$$

if

- Doubly CKM suppressed penguins [...] are neglected.
- Colour-suppressed electrowek penguin $\alpha_{4\mathrm{EW}}^c$ and EW penguin annihilation neglected.
- QCD penguin annihilation $2\beta_4^c$ neglected.
- SU(3) breaking in QCD penguin amplitude $\hat{\alpha}_4^c$ neglected

Standard assumptions in the SU(3) approach. Here want to be more conservative (because $\hat{\alpha}_4^c$ is smaller for VV, so other effects are relatively larger). Allow

$$0.3 \leq F \leq 1.5$$

i.e. factor 2.23 variation in the amplitude ratio.
N.B. In QCDF obtain $F = 0.65 \pm 0.36$ with -0.1 from electroweak penguin and -0.2 from QCD penguin annihilation.

Main point: need $\mathcal{R}$ and F only to constrain the penguin contamination $r \neq 0$. But experimentally $\mathcal{R} \approx F r^2$ is small, so almost no effect on

$$S_L = \sin(2\alpha) + \mathcal{O}(r)$$

Hence, even a large theoretical uncertainty of F leads to a small error on α.

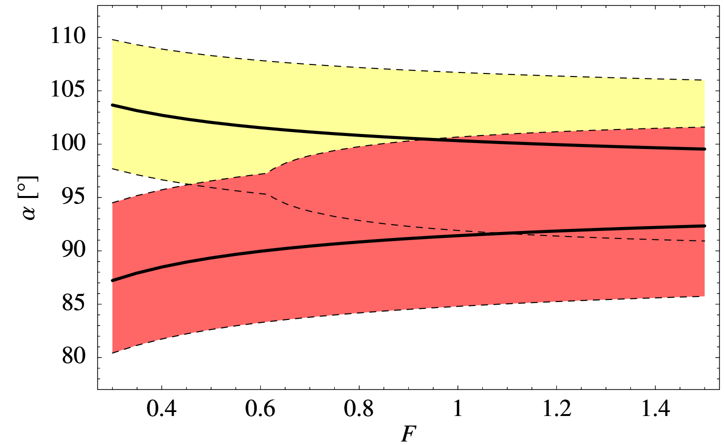
Input:
$C_{L,\rho\rho} = -0.03 \pm 0.17$
$S_{L,\rho\rho} = -0.21 \pm 0.22$
$\mathcal{R} = 0.0080 \pm 0.0023$

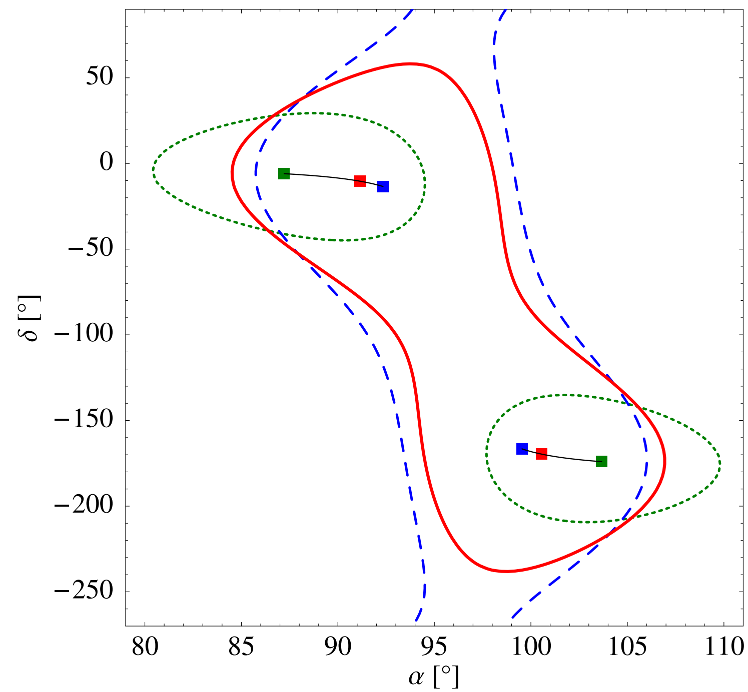
	$\alpha\ [^\circ]$	r	$\delta\ [^\circ]$
(1)	$91.2^{+9.1}_{-6.6}$	$0.098^{+0.014}_{-0.016}$	-10
(2)	$100.6^{+6.4}_{-8.3}$	$0.090^{+0.012}_{-0.013}$	-170
(3)	$175.3^{+7.2}_{-7.9}$	$0.102^{+0.017}_{-0.022}$	36
(4)	$172.9^{+6.4}_{-6.3}$	$0.088^{+0.018}_{-0.014}$	144

$(F = 0.9)$

Lower figure:
$\chi^2 = 1$ contours for $F = 0.3, 0.9, 1.5$.
Including $F = 0.9 \pm 0.6$ gives (assuming $|\delta| < \pi/2$)

$$\alpha = [91.2^{+9.1}_{-6.6}\ (\text{exp})^{+1.2}_{-3.9}\ (\text{th})]^\circ$$





- ⋆ In good agreement with the global fit:

$$(91^{+9}_{-8})^\circ \quad \text{vs.} \quad (97 \pm 5)^\circ \text{ global}$$

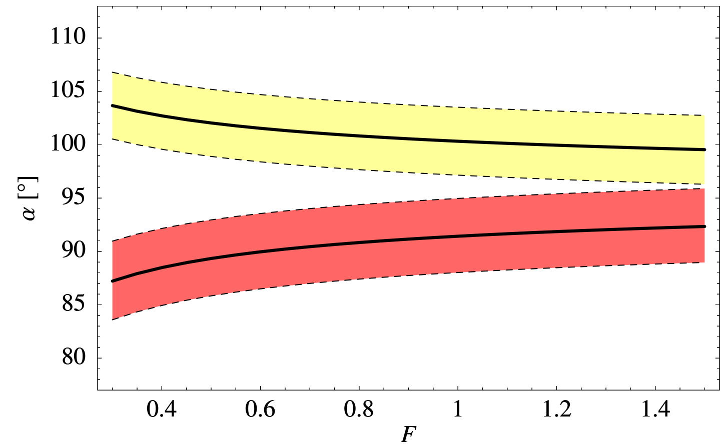
- ⋆ Accurate measurement of C_L isolates one of the two solutions near 90°. Phase assumption can be relaxed.

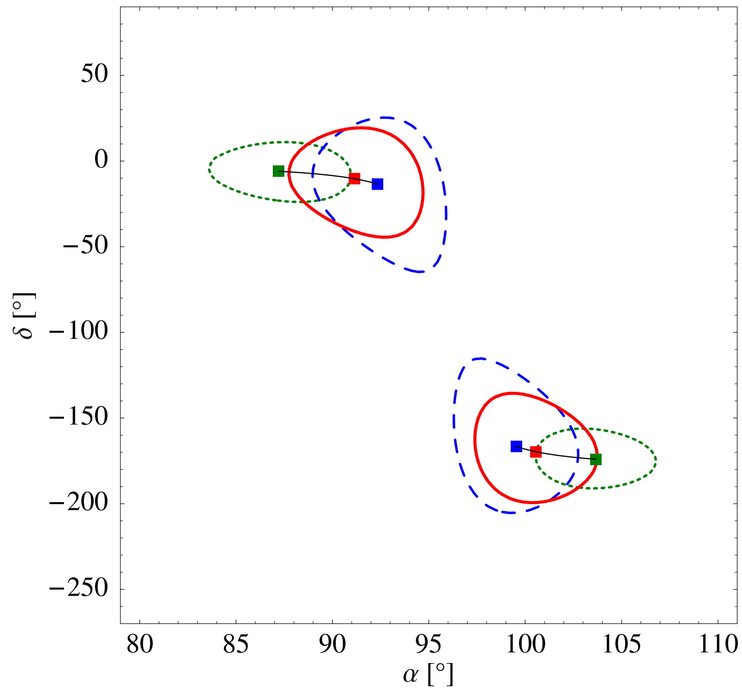
- ⋆ Imagine exp. error on $C_{L,\rho\rho}$, $S_{L,\rho\rho}$ decreases by factor of 2. Then (see right figures)

$$\alpha = [91.2 \pm 3.5\ (\text{exp})^{+1.2}_{-3.9}\ (\text{th})]^\circ$$

(projection to the future)

competitive with global fit.





Electroweak penguins and transverse polarization

$B \to VV$ has three helicity amplitudes $\mathcal{A}_0$, $\mathcal{A}_-$, $\mathcal{A}_+$
Naive expectation ($\bar{B}$ decay)

$$\mathcal{A}_0 : \mathcal{A}_- : \mathcal{A}_+ = 1 : \frac{\Lambda}{m_b} : \left(\frac{\Lambda}{m_b}\right)^2$$

due to

- V-A interactions
- large m_b/Λ

$\Rightarrow$ probe helicity structure of flavour-violating interactions

Experimentally

$$\mathcal{A}_0 \gg \mathcal{A}_- \gg \mathcal{A}_+ \qquad \text{tree decays}$$

$$\mathcal{A}_0 \approx \mathcal{A}_- \gg \mathcal{A}_+ \qquad \text{penguin decays}$$

Theoretical status

- Hierarchy

$$\mathcal{A}_0 : \mathcal{A}_- : \mathcal{A}_+ = 1 : \frac{\Lambda}{m_b} : \left(\frac{\Lambda}{m_b}\right)^2$$

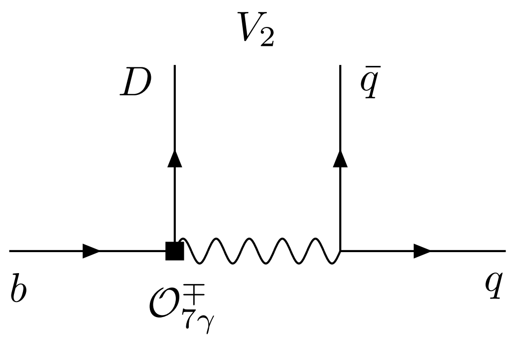
parametrically confirmed in QCD factorization.

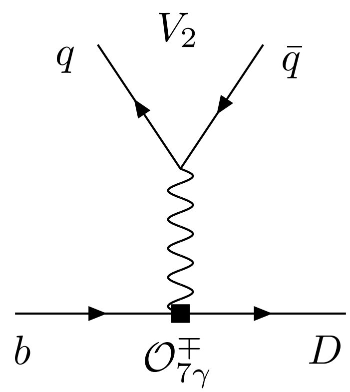
- Not numerically. $P_-/P_0 \sim 1$ is possible due to weak annihilation [Kagan]. Large transverse polarization in penguin decays is attributed to this effect.

- Parametric hierarchy not true for electromagnetic interactions [MB, Rohrer, Yang]. Instead

$$\mathcal{A}_0 : \mathcal{A}_- : \mathcal{A}_+ = 1 : \frac{m_b}{\Lambda} : 1$$

Enhancement of transverse polarization by $(m_b/\Lambda)^2$.





- left: γ always off-shell, $q^2 \sim m_b^2$

- right: γ nearly on-shell, $q^2 = m_{V_2}^2 \sim \Lambda^2$
  - ⋆ V_2 longitudinal $\Rightarrow$ photon propagator is cancelled $\Rightarrow$ effective local four-quark interaction
  - ⋆ for V_2 transverse no cancellation $\Rightarrow$ local $b \longrightarrow D\gamma$ transition followed by long-distance $\gamma \longrightarrow V_2$ transition $\Rightarrow$ enhanced by large photon propagator

  New operator in SCET$_{\rm I}$ (leading in heavy quark power counting, same as in $B \to V\gamma$)

$$\left[\bar{\xi} W \gamma_{\perp\mu}(1 \mp \gamma_5) h_v\right](0) \left[W_\gamma^\dagger i D_{\gamma\perp}^\mu W_\gamma\right](0),$$

Consider electromagnetic dipole operators including both chiralities

$$Q_{7\gamma}^{\mp} = -\frac{e\bar{m}_b}{8\pi^2}\,\bar{D}\sigma_{\mu\nu}(1 \pm \gamma_5)F^{\mu\nu}b,$$

Contributes to the electroweak penguin amplitudes

$$P_{\mp}^{\rm EW}(V_1V_2) = C_7 + C_9 + \frac{1}{N_c}(C_8 + C_{10}) \mp \underbrace{\frac{2\alpha_{\rm em}}{3\pi} C_{7\gamma,\rm eff}^{\mp} R_{\mp} \frac{m_B\bar{m}_b}{m_{V_2}^2}}_{\text{dipole operator contribution}} + \ldots$$

with R_- a form factor ratio that equals 1 in the heavy-quark limit and $R_+ \sim m_b/\Lambda$.

Compare leading QCD penguin to EW penguin amplitude (in some units)

$$P_-(\rho K^*) \approx -1 \qquad\qquad P_-^{\rm EW}(\rho K^*) \approx -0.3 + 0.7 \text{ [new]}$$

A very large effect.

For positive helicity $\quad 0.7 \to 0.7 \times (10-20) \times \dfrac{C_{7\gamma}^{+}}{C_{7\gamma,\rm eff}^{-}}$

The $B \to \rho K^*$ system

$$\begin{aligned}
\mathcal{A}_h(\rho^- \bar{K}^{*0}) &= P_h \\
\sqrt{2}\,\mathcal{A}_h(\rho^0 K^{*-}) &= [P_h + P_h^{EW}] + e^{-i\gamma}\,[T_h + C_h] \\
\mathcal{A}_h(\rho^+ K^{*-}) &= P_h + e^{-i\gamma}\,T_h \\
-\sqrt{2}\,\mathcal{A}_h(\rho^0 \bar{K}^{*0}) &= [P_h - P_h^{EW}] + e^{-i\gamma}\,[-C_h],
\end{aligned}$$

T_h, C_h CKM suppressed.

Consider CP-averaged negative helicity decay rate ratio ($p_h^{EW} = P_h^{EW}/P_h$)

$$R \equiv \frac{\bar{\Gamma}_-(\rho^0 \bar{K}^{*-})}{\bar{\Gamma}_-(\rho^0 \bar{K}^{*0})} = \left|\frac{1 + p_-^{EW}}{1 - p_-^{EW}}\right|^2 + \Delta = \begin{cases} 3.0 \pm 0.7 & \\ 0.6 \pm 0.1 & \text{without dipole operator} \end{cases}$$

(Fit P_- to data, use QCDF for the other amplitudes)

Available data (HFAG values 12/05 – not updated):

	$\text{Br}_{\text{Av}}/10^{-6}$	A_{CP}	f_L
$\rho^-\bar{K}^{*0}$	10.6 ± 1.9	-0.14 ± 0.43	0.66 ± 0.07
$\rho^0 K^{*-}$	$10.6^{+3.8}_{-3.5}$	$0.20^{+0.32}_{-0.29}$	$0.96^{+0.06}_{-0.15}$

$$\mathcal{F} \equiv \frac{f_-(\rho^0\bar{K}^{*-})}{f_-(\rho^-\bar{K}^{*0})} \overset{\text{exp.}}{=} 0.12^{+0.44}_{-0.11} \qquad \mathcal{F} \overset{\text{th.}}{=} \begin{cases} 0.4 \pm 0.1 & \\ 0.8 \pm 0.1 & \text{without dipole operator} \end{cases}$$

Detecting physics beyond the Standard Model

- ⋆ New Physics could enhance $Q^+_{7\gamma}$ through new flavour-changing neutral currents
- ⋆ $Q^+_{7\gamma}$ contribution to $\bar{\mathcal{A}}_+$ is suppressed only by $C^+_{7\gamma}/C^-_{7\gamma}$, while other contributions have additional Λ/m_b suppression $\Rightarrow$ Sensitivity to $C^+_{7\gamma} \approx 0.1$ may be possible.
- ⋆ An alternative to studies of photon polarization in $B \to K^\star\gamma$. Here the ρ meson (decay) acts as the polarization analyzer.