Anomalous enhancement of $B \to K\eta'$ branching ratio

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Puzzle of large branching ratio of $B \to K\eta'$

❐ CLEO '97: observation of large branching ratio for $B \to K\eta'$

HFAG: Sept. 2007

$$Br(B^+ \to K^+\eta') = (70.2 \pm 2.5) \times 10^{-6}$$

c.f. similar penguin dominant processes:

$$Br(B^+ \to K^+\pi^0) = (12.9 \pm 0.6) \times 10^{-6}$$
$$Br(B^+ \to K^+\eta) = (2.7 \pm 0.3) \times 10^{-6}$$

❐ SU(3) relations: ratios of $B \to K[0^{-+}]$ branching ratios

Lipkin (PLB '97), Dighe, Gronau, Rosner (PRL '98)

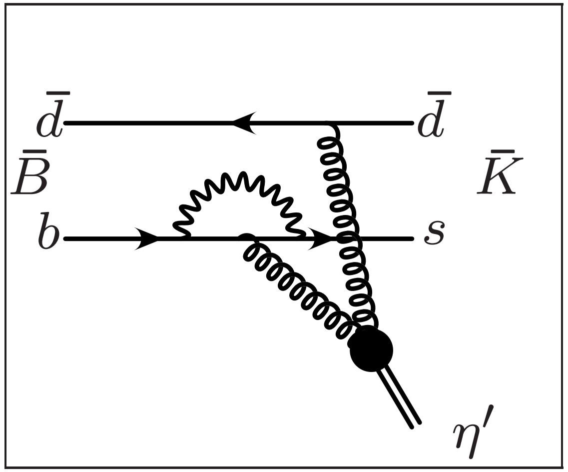
$$\boxed{\text{Br}(K\eta') : \text{Br}(K\eta) : \text{Br}(K\pi^0) = 3 : 0 : 1}$$

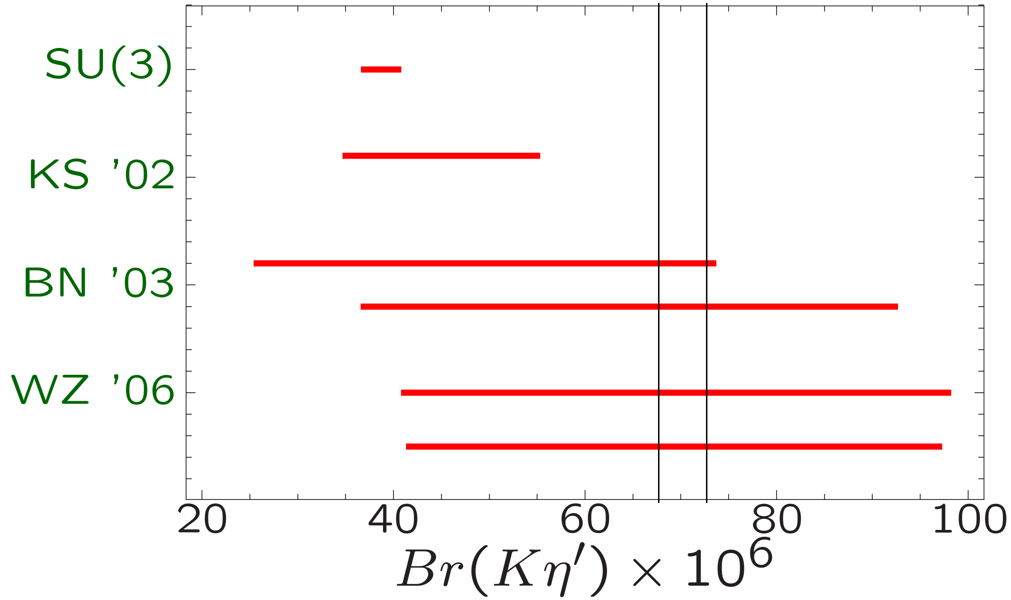
where $\theta = -19.5^\circ$ so that $\eta = (u\bar{u} + d\bar{d} - s\bar{s})/\sqrt{3}$, $\eta' = (u\bar{u} + d\bar{d} + 2s\bar{s})/\sqrt{6}$.

Theoretical predictions: status

❒ Inclusion of an U(1) breaking: *anomaly diagram*

Atwood, Soni (PLB '97), E.K, Ahmady, Sugamoto (PRD '98)





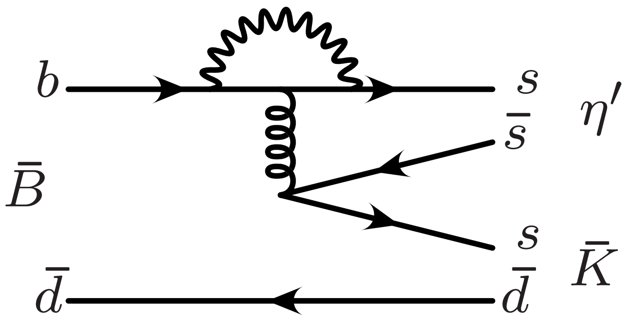
☞ Computations using the perturbative QCD techniques at large m_b limit have been attempted.

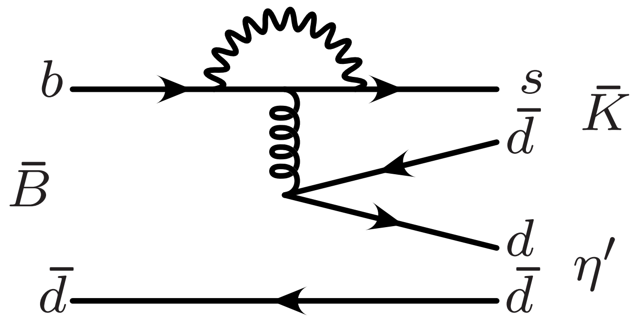
E.K. and Sanda (PLB '02), Beneke, Neubert (NPB '03), Williamson, Zupan (PRD '06)

☞ Large uncertainties could be reduced by the other observables, e.g. $\pi\eta', K^*\eta'$, etc.

see also Escribano, Matias, Virto ('07)

$B \to K\eta'$ and density matrix for η'





$$\propto C\langle K|\bar{b}\gamma_\mu\gamma_5 s|B\rangle\langle 0|\bar{s}\gamma^\mu\gamma_5 s|\eta'\rangle + \boxed{C'\langle K|\bar{b}\gamma_5 s|B\rangle\langle 0|\bar{s}\gamma_5 s|\eta'\rangle}$$

$$\propto C\langle \eta'|\bar{b}\gamma_\mu\gamma_5 s|B\rangle\langle 0|\bar{d}\gamma^\mu\gamma_5 s|K\rangle + \boxed{C'\langle \eta'|\bar{b}\gamma_5 s|B\rangle\langle 0|\bar{d}\gamma_5 s|K\rangle}$$

☞Density matrix $\langle 0|\bar{s}\gamma_5 s|\eta'\rangle$: this talk

☞Decay constant $\langle 0|\bar{s}\gamma_\mu\gamma_5 s|\eta'\rangle$: two mixing angle scheme

Kaiser, Leutwyler ('98), Feldman, Kroll, Stech (PRD '98)

☞ Form factor $\langle \eta'|\bar{s}\gamma_\mu\gamma_5 b|B\rangle$: QCD sum rule, lattice, experimental extraction.

Ball, Jones (JHEP '07), Pham ('07), Charng, Kurimoto, Li (PRD '06)

Anomaly contribution to the density matrix

❐ Example of the density matrix for K

$$\langle 0|\bar{d}\gamma_\mu\gamma_5 s|K\rangle = i f_K p_\mu$$

∂^μ and Eq. of motion

$$\downarrow$$

$$\langle 0|\bar{d}\gamma_5 s|K\rangle = \frac{m_K^2}{m_s + m_d} f_K$$

❐ Density matrix of $\eta - \eta'$:

Derivative of the singlet current leads to the anomaly term.

Thus the usual technique like the K case does not work.

$$\partial^\mu(\bar{s}\gamma_\mu\gamma_5 s) = 2im_s\bar{s}\gamma_5 s + \frac{\alpha_s}{4\pi}G^a_{\mu\nu}\tilde{G}^{\mu\nu}_a$$

Estimate of density matrix

❒ FKS scheme: see also Beneke, Neubert (NPB '03)

$$\begin{pmatrix} \eta \\ \eta' \end{pmatrix} = \begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} (u\bar{u}+d\bar{d})/\sqrt{2} \\ s\bar{s} \end{pmatrix} : \quad \phi = \theta - \theta_I + \frac{\pi}{2}$$

$$\langle 0|\bar{s}\gamma_\mu\gamma_5 s|\eta^{(\prime)}\rangle = i f^s_{\eta^{(\prime)}} p_\mu$$

$$f^q_\eta = f_q \cos\phi, \quad f^s_\eta = -f_s \sin\phi$$

$$f^q_{\eta'} = f_q \sin\phi, \quad f^s_{\eta'} = f_s \cos\phi$$

$\Rightarrow$

$$2m_s\langle 0|\bar{s}\gamma_5 s|\eta^{(\prime)}\rangle = i h^s_{\eta^{(\prime)}}$$

$$h^q_\eta = h_q \cos\phi, \quad h^s_\eta = -h_s \sin\phi$$

$$h^q_{\eta'} = h_q \sin\phi, \quad h^s_{\eta'} = h_s \cos\phi$$

❒ Effective Lagrangian at large N_c (this talk)

E.K. and Gerard (PRL '07)

$$\begin{aligned}\mathcal{L} \;=\;& \frac{f^2}{8}\langle \partial_\mu U \partial^\mu U^\dagger \rangle + \frac{m_0^2}{4N_c}\frac{f^2}{8}\langle \ln U - \ln U^\dagger \rangle^2 + \frac{f^2}{8} r \langle m U^\dagger + U m \rangle \\ &+ \frac{f^2}{8}\left[-\frac{r}{\Lambda^2}\langle m \partial^2 U^\dagger \rangle + \frac{r^2}{2\Lambda_1^2}\langle m U^\dagger m U^\dagger \rangle + \frac{r}{2\Lambda_2^2}\langle m U^\dagger \partial_\mu U \partial^\mu U^\dagger \rangle \right] + h.c.\end{aligned}$$

Parameters are fitted using $\eta - \eta'$ masses, J/ψ radiative decays and π, K masses and decay constants.

Numerical result

$$\zeta \equiv \frac{\langle 0|\bar{s}\gamma_5 s|\eta\rangle}{\langle 0|\bar{d}\gamma_5 s|K\rangle} / \sin\phi, \qquad \zeta' \equiv \frac{\langle 0|\bar{s}\gamma_5 s|\eta'\rangle}{\langle 0|\bar{d}\gamma_5 s|K\rangle} / \cos\phi$$

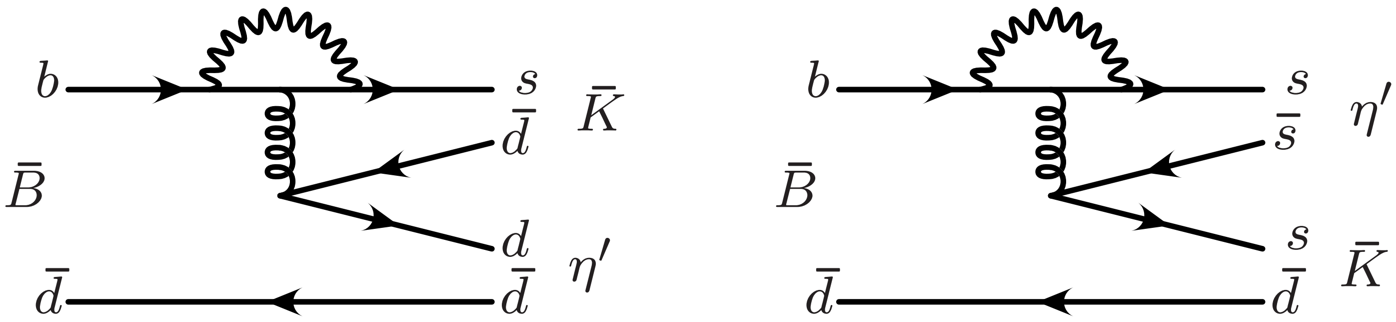
	our result	SU(3)	AG	BN
ζ	1.29 ± 0.19	1	1.38	1.34
ζ'	1.72 ± 0.26	1	1.12	1.07

AG: Ali, Greub (PRD '98), BN: Beneke, Neubert (NPB '03)

☞ We find 50-70 % of increase in the η' density matrix comparing to the previously obtained values.

Impact on the SU(3) relation

$$\left.\frac{A(B\to K\eta^{(\prime)})}{A(B\to K\pi^0)}\right|_{C'} = \frac{\langle K|\bar{b}\gamma_5 s|B\rangle}{\langle \pi|\bar{b}\gamma_5 d|B\rangle}\left[\frac{\langle \eta^{(\prime)}|\bar{b}\gamma_5 d|B\rangle}{\langle K|\bar{b}\gamma_5 s|B\rangle} + \underbrace{\frac{\langle 0|\bar{s}\gamma_5 s|\eta^{(\prime)}\rangle}{\langle 0|\bar{d}\gamma_5 s|K\rangle}}_{\propto \zeta^{(\prime)}}\right].$$



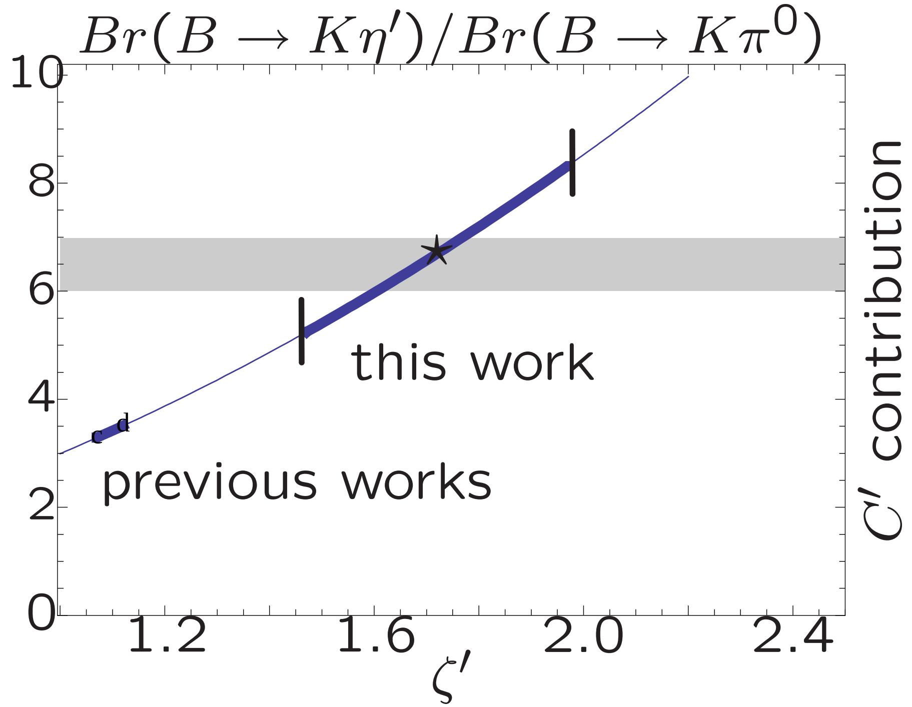
$$\frac{A(B\to K\eta)}{A(B\to K\pi^0)} \simeq -[\cos\phi - \zeta\sqrt{2}\sin\phi] \overset{\theta=-19.5^\circ}{=} -\sqrt{\frac{2}{3}}[1-\zeta]$$

$$\frac{A(B\to K\eta')}{A(B\to K\pi^0)} \simeq -[\sin\phi + \zeta'\sqrt{2}\cos\phi] \overset{\theta=-19.5^\circ}{=} -\sqrt{\frac{1}{3}}[1+2\zeta']$$

At SU(3) limit, $\zeta^{(\prime)} = 1$.

Impact on $B \to K\eta'$

☞ Our result has to be implemented in the perturbative QCD computations but meanwhile, we find around 70 % of increase in the dominant C' contribution.



Conclusions

- We emphasised that the puzzle of the large branching ratio for $B \to K\eta'$ has not been fully understood yet.

- We computed the density matrix for $\eta - \eta'$ using the effective Lagrangian at large N_c limit.

- We found over 50 % of increase in the density matrix for η' comparing to the previous works, which would enhance the existing theoretical predictions for the $B \to K\eta'$ branching ratio.