CHARMLESS B DECAYS

Emi KOU
(LAL/IN2P3, Universite Paris-Sud XI)

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

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Outline

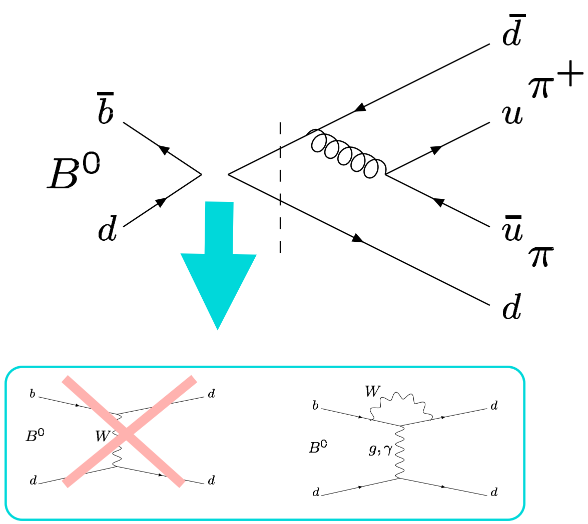
- Puzzle of $B \to \pi\pi, K\pi$
  - QCD based approaches: what did we learn?
  - Is annihilation large?
  - Large color-suppressed amplitude understandable?
- Puzzle of $B \to \eta' K$ branching ratio
  - An anomaly enhancement to density matrix

QCD based approaches and annihilation contribution

Importance of Annihilation Diagrams

E.K.'s talk at FPCP03 (Paris)

Keum, Li & Sanda, PLB504 ('01)



Annihilation diagrams had been neglected due to:

- α_s ~~suppressed~~ $\rightarrow$ **Not in pQCD**
- $\frac{1}{m_b}$ suppressed comparing to the emission diagrams.
- Angular momentum conservation forbids the $V-A$ currents ($O_{1\sim4}$) by a factor of m_π^2 (as $\pi \rightarrow e\bar{\nu}$).

However, $V+A$ currents ($O_{5,6}$) remain accompanied by the chiral enhancement factor $m_0^\pi = m_\pi^2/(m_u+m_d)$.

Furthermore, we found that:

☛ The large absorptive part arises from cuts on the intermediate state.

☛ The strong phase associated with $O_{5,6}$ annihilation diagrams is nearly 90° in $B \rightarrow \pi\pi$ as well as $B \rightarrow K\pi$.

QCD based approaches and annihilation contribution

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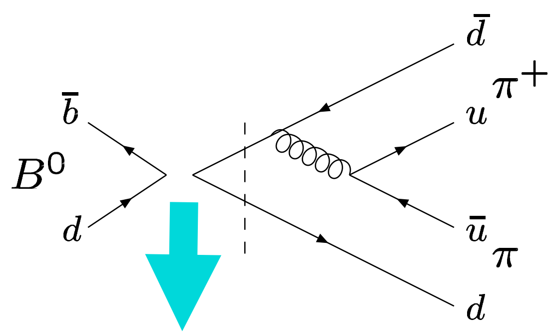

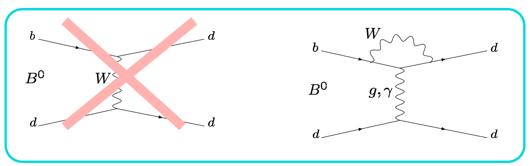

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✓QCD factorization:
Annihilation non-calculable but possibly large (para. ρ_A)

BBNS ('01), Beneke & Neubert ('03)

✓SCET:
Annihilation calculable but large and real (imaginary part from charm penguin)

Arnesen, Ligeti, Rothstein & Stewart ('06)

✓QCD sum-rule:
Annihilation calculable but small

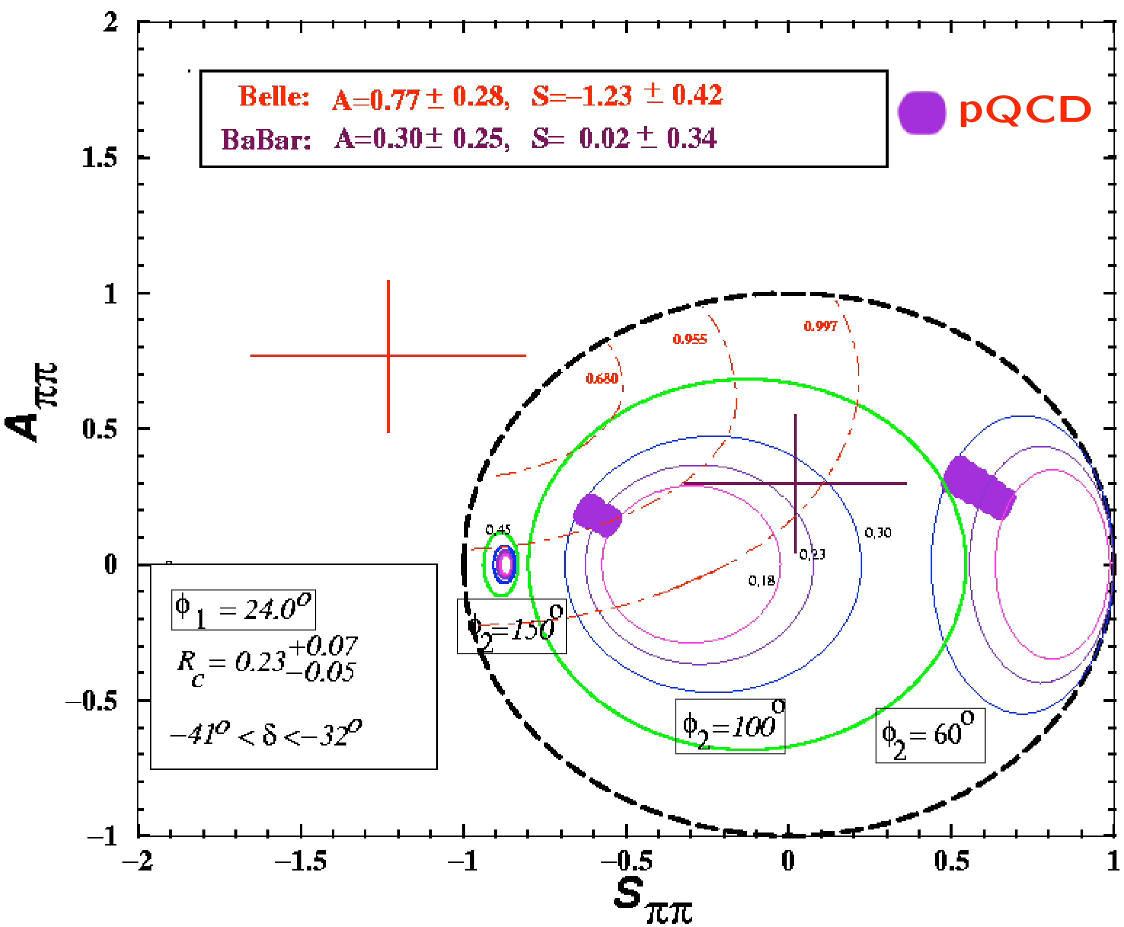
Khodjamirian Mannel, Melcher, Melic ('05)

Attempts to predict CPV with annihilation phase...

CP Violation in $B \to \pi^+\pi^-$

Keum & Sanda, PRD68 ('03)

E.K.'s talk at FPCP03 (Paris)



Thanks to Y.Y. Keum for the figure!

$$A_{CP} = \frac{\Gamma(\overline{B}^0 \to \pi^+\pi^-) - \Gamma(B^0 \to \pi^+\pi^-)}{\Gamma(\overline{B}^0 \to \pi^+\pi^-) + \Gamma(B^0 \to \pi^+\pi^-)} = S_{\pi\pi} \sin \Delta M_B \Delta t + A_{\pi\pi} \cos \Delta M_B \Delta t$$

$$S_{\pi\pi} = \frac{2Im(\lambda_{\pi\pi})}{|\lambda_{\pi\pi}|^2 + 1}$$

$$A_{\pi\pi} = \frac{|\lambda_{\pi\pi}|^2 - 1}{|\lambda_{\pi\pi}|^2 + 1}$$

✔ $R_c = |P/T|$

0.18 0.23 0.30

✔ $\delta = \delta_P - \delta_T$

0 π

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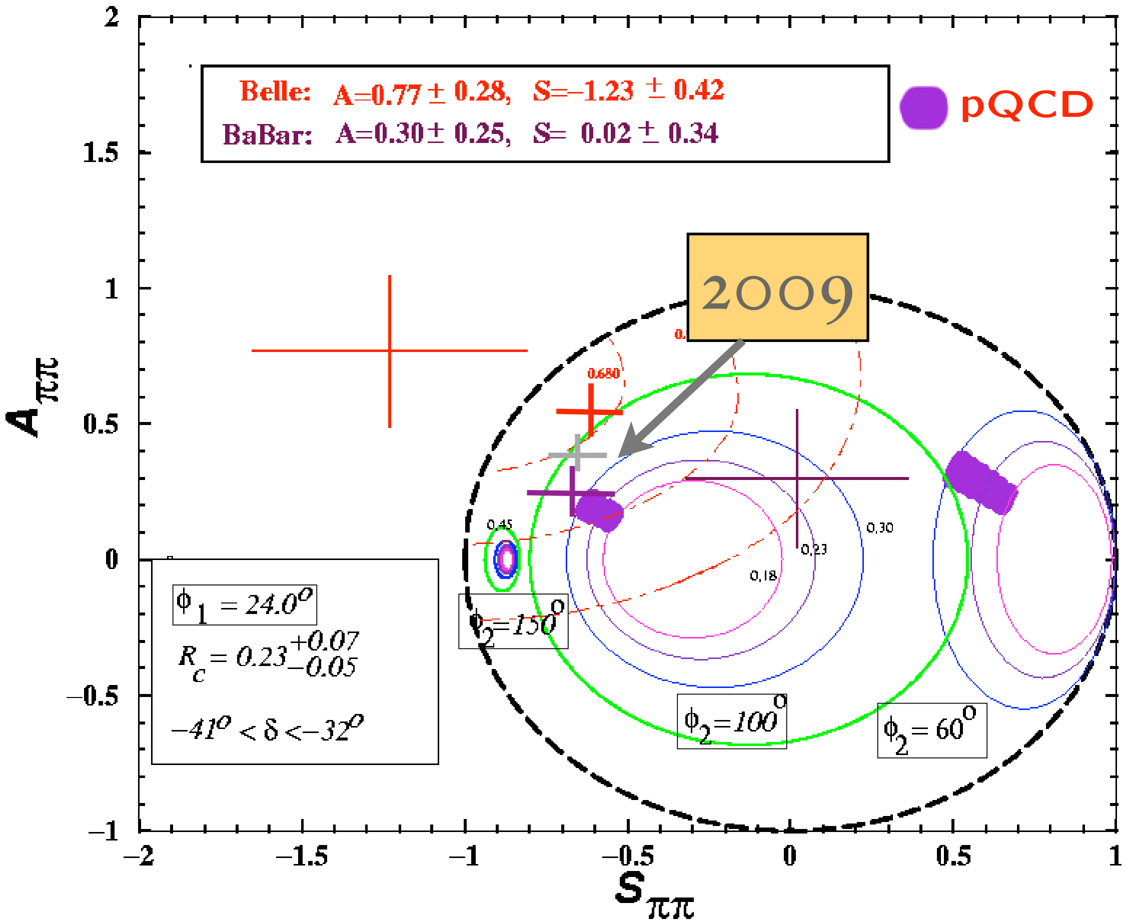

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✔ $R_c = |P/T|$

○ 0.18 ○ 0.23 ○ 0.30

✔ $\delta = \delta_P - \delta_T$

✓ This was our LO result. More refined result available now...

More hints of large annihilation

- In most of the decay channels, annihilation is difficult to separate from the other topologies, however,
  - In PQCD/QCDF, some of $B \to PV$ modes seem to require a large annihilation (e.g. $Br(B \to \phi K)$). *Mishima ('02), Beneke & Neubert ('03)*
  - A large penguin annihilation provides an interesting solution to the $B \to VV$ polarization problem. *Kagan ('04), Beneke & Rohre, Yang ('07)*

- Is there any role in the pure annihilation processes?
  - $Br(B^0 \to K^+K^- / B_s \to \pi^+\pi^-)$:

    PQCD/QCDF predict very small branching ratio: $\mathcal{O}(10^{-8})$.
    The current experimental bound is: $(0.15^{+0.11}_{-0.10}) \times 10^{-6}$
    An observation will have a huge impact! *Chen & Li ('00), Beneke & Neubert ('03), Lu, Shen, Wang ('05)*

  - Note: pure annihilation is seen (though different regime) in:

    $B^0 \to D_s^- K^+, \ D_s \to \pi\rho/\pi\omega$ *Fajfer, Prapotnik, Singer & Zupan ('03), Gronau & Rosner ('09)*

More recent progresses

- Many refinements in the theoretical predictions have been made by including the higher order corrections.

Li & Mishima ('06, '07), Bekene, Jager ('05)

- Still a few puzzling phenomena...

- Large $B^0 \to \pi^0\pi^0$ branching ratio:

  Exp: $Br = (1.55 \pm 0.19) \times 10^{-6}$ Theo: $Br = (0.1 \sim 0.8) \times 10^{-6}$

  A very large color-suppressed amplitude (C) is required!

- K pi puzzle:

$$\mathcal{A}^{\rm CP}_{K^-\pi^+} = -0.098^{+0.012}_{-0.011}, \ \mathcal{A}^{\rm CP}_{K^-\pi^0} = 0.050 \pm 0.025$$

Different from branching ratio K pi (Rc/Rn) puzzle (in 2003), solution can be *either* large electroweak penguin *or* large color-suppressed amplitude

e.g. see Baek, Chiang, Gronau, London, Rosner ('09), Li & Mishima ('09)

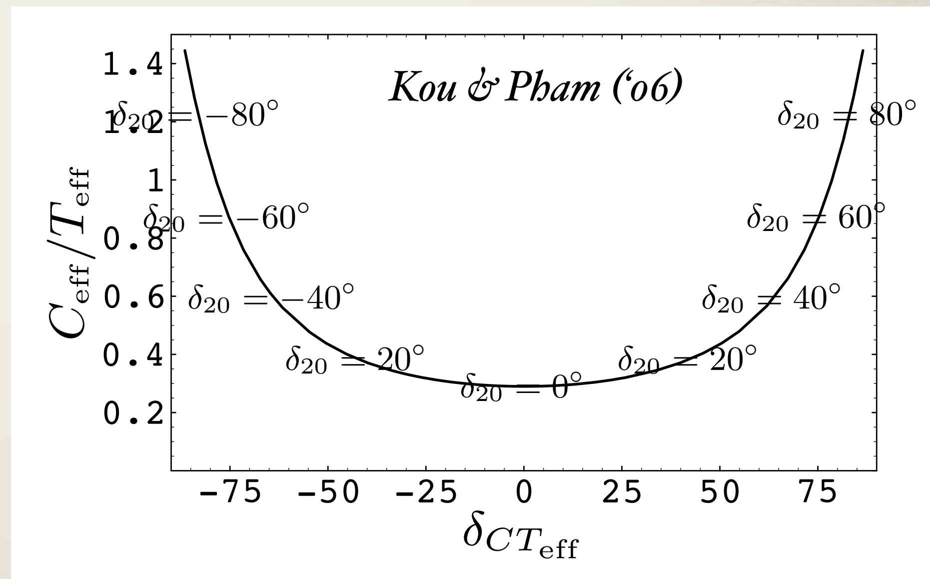
How to increase color-suppressed amplitude?

- QCD based approaches:
  - PQCD: uncanceled soft divergence (soft factor introduced)

    Li & Mishima ('09)
  - QCDF: large spectator-scattering (or decrease $\lambda_B \simeq 200$ MeV)

    Beneke and Jager ('05)
- Final State Interaction:
  - The re-scattering $\pi^+\pi^- \to \pi^0\pi^0$ can enhance effectively the color-suppressed amplitude, when there is a phase difference between $I = 0, 1$
  - Large enhancement on C through $\rho^+\rho^- \to \pi^0\pi^0$?!

    Kaidalov & Vysotsky ('07)

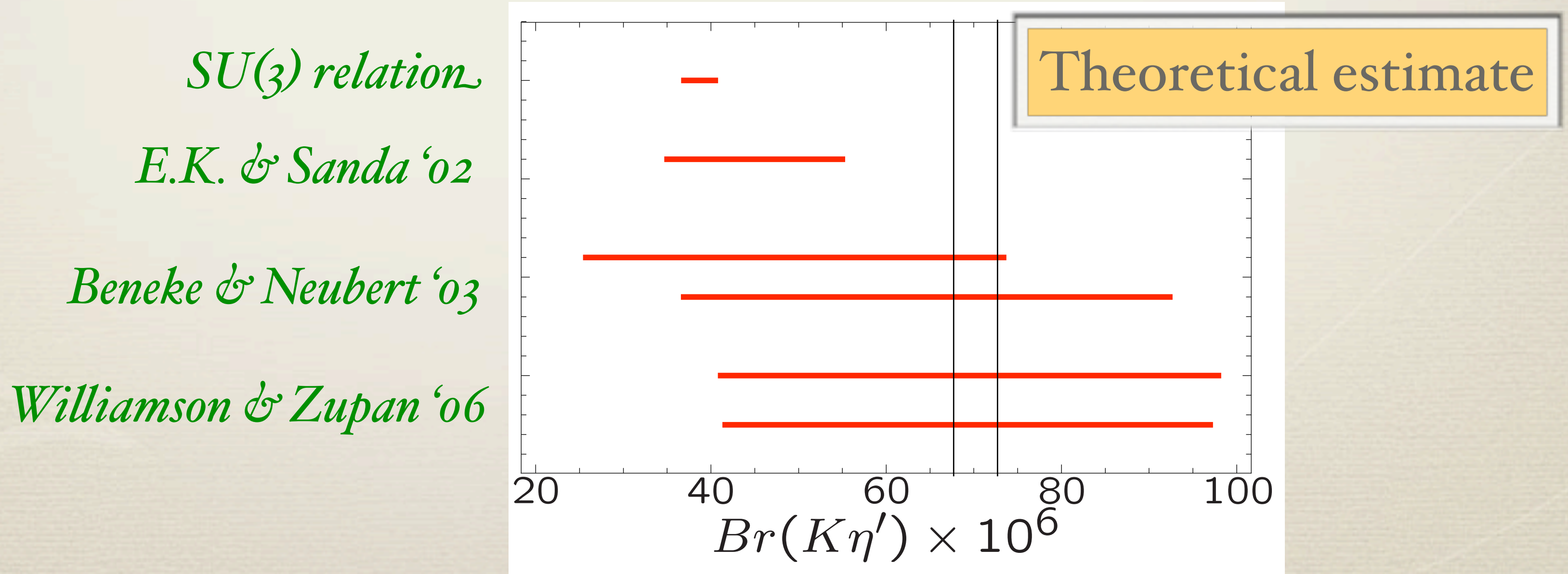


$$C_{\rm eff}e^{i\delta_{\rm eff}} = [-(2T - C)e^{i\delta_0} + 2(T + C)e^{i\delta_2}]/3$$

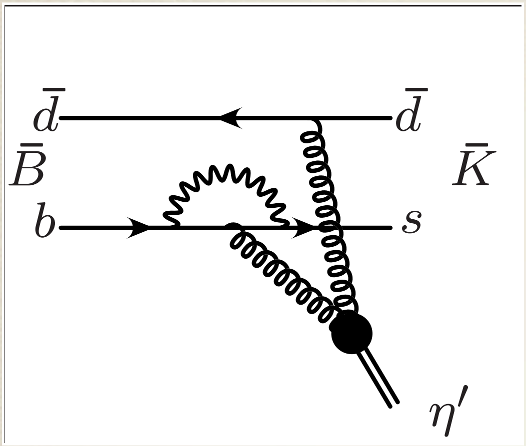
Puzzle of $B \to K\eta'$

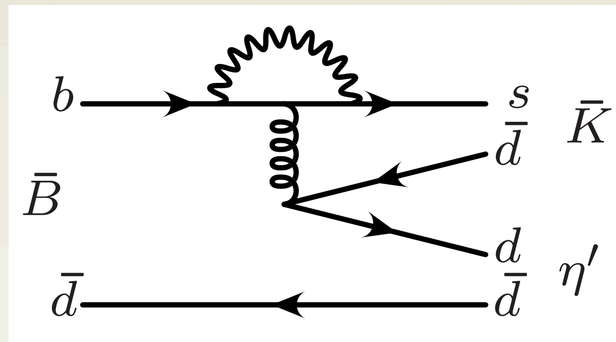
- A puzzle since CLEO's measurement in '97
  $Br(K^+\eta') = (70.2 \pm 2.5) \times 10^{-6}, \; Br(K^+\eta') = (64.9 \pm 3.1) \times 10^{-6}$
- It is very large comparing to
  $Br(K^+\pi^0) = (12.9 \pm 0.6) \times 10^{-6}, \; Br(K^+\eta) = (2.7 \pm 0.3) \times 10^{-6}$
- SU(3) relation derived ($\theta = -19.5^\circ$):

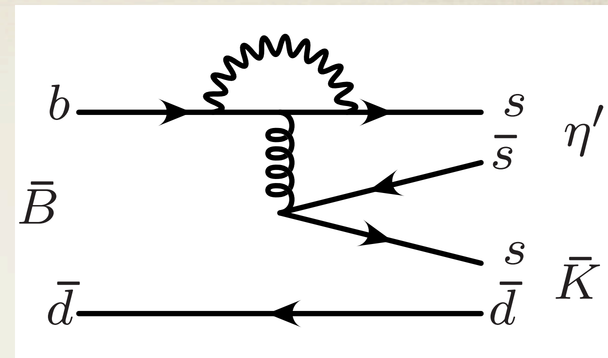
$$Br(K\eta') : Br(K\eta) : Br(K\pi^0) = 3 : 0 : 1$$



Theoretical investigations...







- Anomaly diagram specific for $B \to K\ '$

Gronau & Rosner '97 , Atwood & Soni '97

- Theoretical estimate still has a large error.

- Estimate of $B \to \eta'$ form factor essential.

$$\langle \eta' | \bar{b}\gamma_\mu\gamma_5 b | B \rangle$$

Ball, Jones '07, Pham '07, Charng, Kurimoto, Li '06

- Estimate of η' decay constant and density matrix essential.

$$\langle 0 | \bar{s}\gamma_\mu\gamma_5 s | \eta' \rangle$$

Kaiser, Leutwyler '98, Feldman, Kroll, Stech '98

$$\langle 0 | \bar{s}\gamma_5 s | \eta\ \rangle$$

Gerard, E.K. '07

Decay constant and density matrix from effective theory

- Effective Lagrangian at large Nc (NLO)

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

➡ $\eta - \eta'$ and K/pi masses, mixing, K/pi decay constants fix all the input parameters (we find mixing angle as $\theta_p \simeq -22^\circ$).

$$f_K/f_\pi - 1 = (m_K^2 - m_\pi^2)\left(\frac{1}{\Lambda_0^2} + \frac{1}{2\Lambda_2^2}\right) \quad M_K^2 = m_K^2 \left[1 + m_K^2 \left(\frac{2}{\Lambda_1^2} - \frac{1}{2\Lambda_2^2} \right) \right]$$

➡ Using these parameters, we can predict $\eta - \eta'$ decay constants and density matrix.

➡ Decay constant prediction coincides with the FKS values.

$$\langle 0 | \bar{s}\gamma_5 s | \eta^{(\prime)} \rangle, \ \langle 0 | \bar{u}\gamma_5 u | \eta^{(\prime)} \rangle$$

Kaiser, Leutwyler '98, Feldman, Kroll, Stech '98

Decay constant and density matrix from effective theory

- Density matrix of K:

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

$$\downarrow \quad \boxed{\partial^\mu \text{ and Eq. of motion}}$$

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

- Density matrix of

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

Decay constant and density matrix from effective theory

- Our numerical result:

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

$$\phi = \theta - \theta_I + \pi/2$$

	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

Gerard, E.K. PRL '07

Ali & Greub ('98)

Beneke & Neubert ('03)

- The SU(3) relation is modified as:

$$A(K\eta') : A(K\eta) : A(K\pi^0) = -\sqrt{\frac{1}{3}}[1 + 2\zeta'] : -\sqrt{\frac{2}{3}}[1 - \zeta] : 1$$

✓ Interpretation in terms of the distribution function, in progress

Conclusions

- Several puzzles exist in charmless B decays. Confrontation of the theoretical predictions to the experimental data continue.
- QCD based approaches (PQCD, QCDF, SCET, QCDSR, ChPTH ...) play important roles to distinguish new physics and hadronic uncertainties.