Measuring ϕ_s with $B_{d,s} \to VV$ Decays

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Introduction & Motivation

In SM: $\phi_s^{SM} = 2\beta_s = -2\lambda^2\eta \rightarrow$ Very small !!

- A measurement of $\phi_s \sim -10^\circ$ with 20% uncertainty would be a clear NP signal.

In NP: ϕ_s^{NP} can still be large and compatible with traditional bounds.

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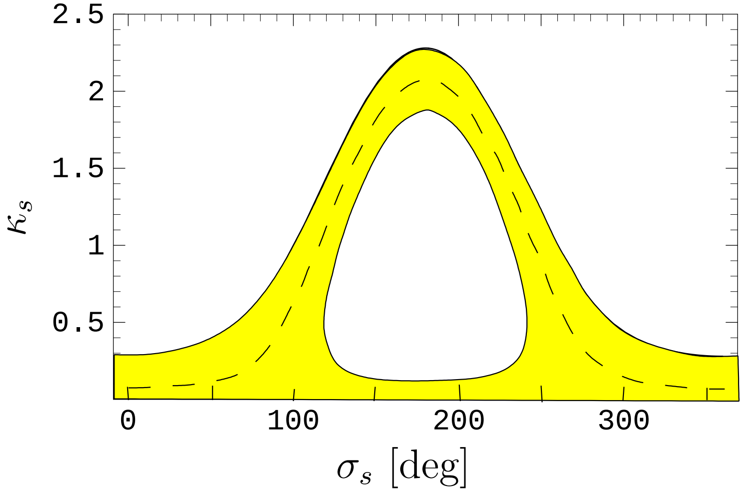
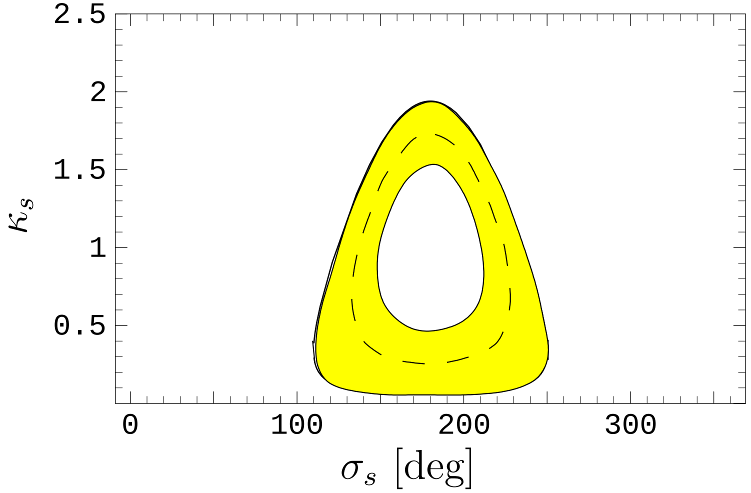
Example: Model independent bounds from ΔM_s *[Ball-Fleischer '06]*,





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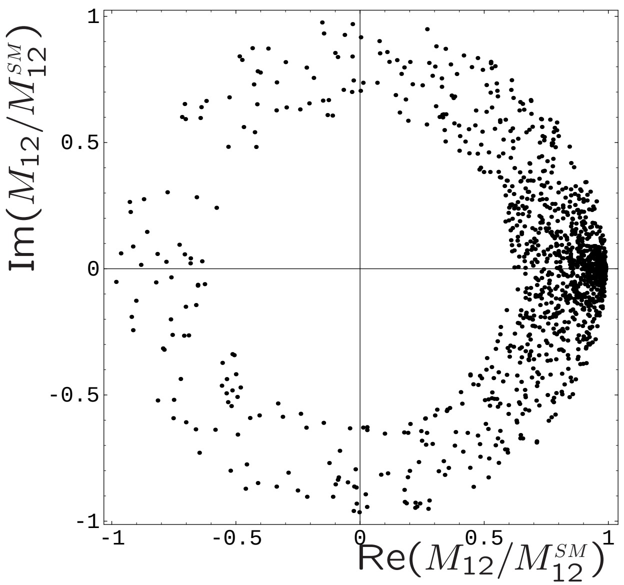
- A measurement of $\phi_s \sim -10^\circ$ with 20% uncertainty would be a clear NP signal.

<u>In NP:</u> ϕ_s^{NP} can still be large and compatible with traditional bounds.

Example: SUSY with general vertex mixing *a la Grossman-Neubert-Kagan '99*,



- Unconstrained mixing angles and squark masses $m_{\tilde{q}} \in (250, 1000)$GeV.

- Imposing bounds from $B \rightarrow X_s\gamma$, ΔM_s, $B \rightarrow \pi K$, etc. . .

Introduction & Motivation

Consistency checks:

- Extract ϕ_s from tree level decays: ϕ_s^{tree}
- Extract ϕ_s from penguin-mediated decays: ϕ_s^{peng}
- Compare: $2\beta_s$ vs. ϕ_s^{tree} vs. ϕ_s^{peng}

$\Rightarrow$ DISCOVER NP in Mixing and/or Decay

-Tree level determinations are quite clean $(B \to J/\Psi K_s,\ B \to J/\Psi\phi,\ \ldots)$

-Penguin determinations are affected by *hadronic uncertainties*:

Here is where the theoretical brainstorming begins. . .

What this talk is about

Problem: The phenomenology of hadronic B-decays is often obscure on the theoretical level because we don't fully understand QCD.

- The **Heavy Quark Limit** approach (QCDF) suffers from uncertainties due to $1/m_b$ suppressed contributions, and other non-factorizable contributions.
- Other approaches based on **Flavor Symmetries** cannot give precise results, due to bad data and poorly estimated SU(3) breaking.

To be able to extract conclusions from experiments, theory must be more precise and reliable.

Claim: The situation can be improved. I show some phenomenological applications of an approach based on a QCDF-inspired quantity: Δ.

Express $B_q - \bar{B}_q$ Mixing

$$|B(t)\rangle = c(t)\,|B^0\rangle + \bar{c}(t)\,|\bar{B}^0\rangle \quad + \text{decay}$$

$$i\,\partial_t \begin{pmatrix} c(t) \\ \bar{c}(t) \end{pmatrix} = \mathcal{H}_{eff} \begin{pmatrix} c(t) \\ \bar{c}(t) \end{pmatrix} \quad \rightsquigarrow \text{OSCILLATIONS}.$$

$$\mathcal{H}_{eff} = \mathbb{M} - \frac{i}{2}\,\Gamma = \begin{pmatrix} M_0 - \frac{i}{2}\Gamma_0 & M_{12} - \frac{i}{2}\Gamma_{12} \\ M_{12}^* + \frac{i}{2}\Gamma_{12}^* & M_0 - \frac{i}{2}\Gamma_0 \end{pmatrix}$$

hermitian

$$\Rightarrow \begin{cases} |B_L\rangle = \dfrac{1}{\sqrt{1+|q/p|^2}}\left(|B^0\rangle + \dfrac{q}{p}|\bar{B}^0\rangle\right) \\[2ex] |B_H\rangle = \dfrac{1}{\sqrt{1+|q/p|^2}}\left(|B^0\rangle - \dfrac{q}{p}|\bar{B}^0\rangle\right) \end{cases}$$

Express $B_q - \bar{B}_q$ Mixing

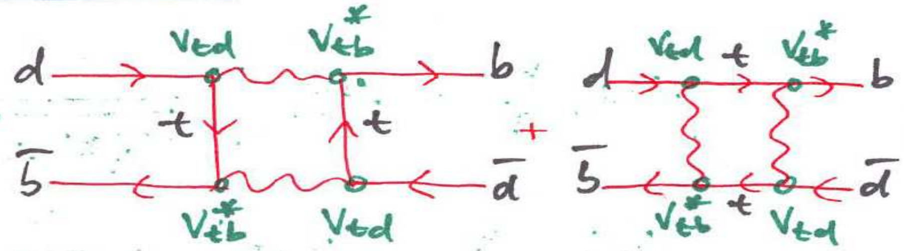
Define: $\frac{q}{p} = \left|\frac{q}{p}\right| \cdot e^{-i\phi_M}$ ← Mixing angle.

$$\frac{q}{p} = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - i/2\,\Gamma_{12}}} \simeq \sqrt{\frac{M_{12}^*}{M_{12}}} \Rightarrow \underline{\phi_M = \arg M_{12}}$$

(Although unphysical phases...)

$B_d - \bar{B}_d$ Mixing in SM:

$M_{12}^* \sim$



$\propto (V_{td}V_{tb}^*)^2$

Wolf. Param $\Rightarrow$ $\text{Arg}\, M_{12}^* = 2\arg(V_{td}V_{tb}^*) = 2\arg(V_{td}) = -2\beta$

$\Rightarrow$ $\underline{\phi_d^{SM} = 2\beta}$.

Express $B_q - \bar{B}_q$ Mixing

MEASURE ϕ_M : CP-Asymmetries

$$A_{CP}(t) \equiv \frac{\Gamma(B(t)\to f_{CP}) - \Gamma(\bar{B}(t)\to f_{CP})}{\Gamma(B(t)\to f_{CP}) + \Gamma(\bar{B}(t)\to f_{CP})} = \cdots\cdots =$$

$$= \frac{A_{dir}\cos(\Delta M t) + A_{mix}\sin(\Delta M t)}{\cosh(\Delta\Gamma t/2) - A_{\Delta\Gamma}\sinh(\Delta\Gamma t/2)}$$

- f_{CP} CP-eigenstate
- $|q/p| \simeq 1$.

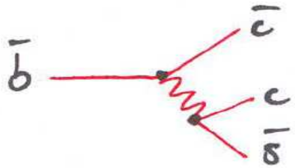
Convention-independent quantity: $\lambda_f \equiv \frac{q}{p} \cdot \frac{\bar{A}_f}{A_f}$

$\bar{A}_f$: $\bar{B} \to f$

A_f: $B \to f$

$$A_{mix} = -\frac{2\,\mathrm{Im}\,\lambda_f}{1 + |\lambda_f|}$$

$$\boxed{B_d \to J/\psi\, K_S^0}$$



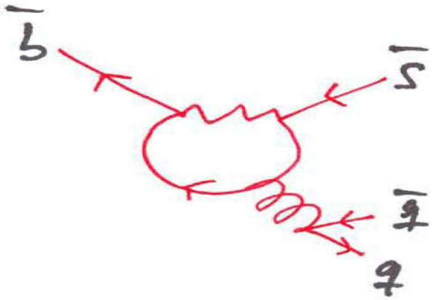
Dominated by single amplitude

$\Rightarrow \bar{A}_f / A_f \simeq \eta_f = -1$

$$\Rightarrow \boxed{A_{mix}(B_d \to J/\psi K_S) \simeq -\sin\phi_d}$$

ϕ_M from $b \to s$ penguins

Penguin - Mediated $b \to s$ decays



$$\boxed{A = T\,\lambda_u^{(s)*} + P\,\lambda_c^{(s)*}} \quad \text{(SM)}$$

$$\lambda_u^{(s)*} \equiv V_{ub}^* V_{us} \; ; \qquad \left|\frac{\lambda_u^{(s)}}{\lambda_c^{(s)}}\right| \simeq 0.022 \; !!$$

$$\lambda_c^{(s)*} \equiv V_{cb}^* V_{cs}$$

CKM suppressed !

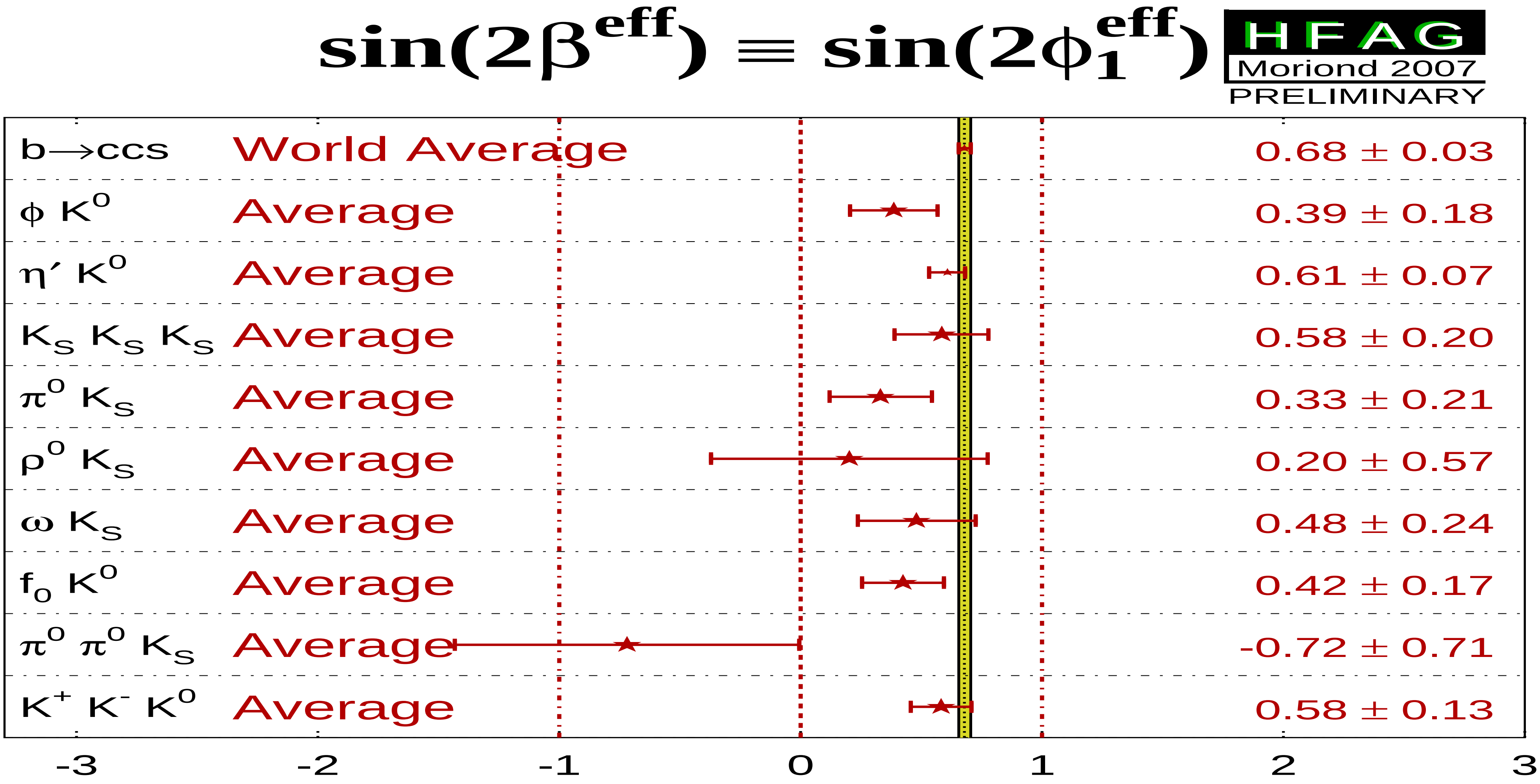
Example: $B_d \to \phi K_S$

$$-A_{mix}(B_d \to \phi K_S) = \sin 2\beta + \underbrace{2\left|\frac{\lambda_u^{(s)}}{\lambda_c^{(s)}}\right| \mathrm{Re}\left(\frac{T}{P}\right) \sin\gamma \cos 2\beta}_{\equiv\, \Delta S \text{ (small?)}} + \ldots$$

$$\simeq \sin 2\beta \quad \text{as long as} \quad T \not\gg P \; !!$$

$\Rightarrow$ MUST CONTROL HADRONIC PARS. T & P.

$\sin 2\beta$ from $b \to s$ penguins



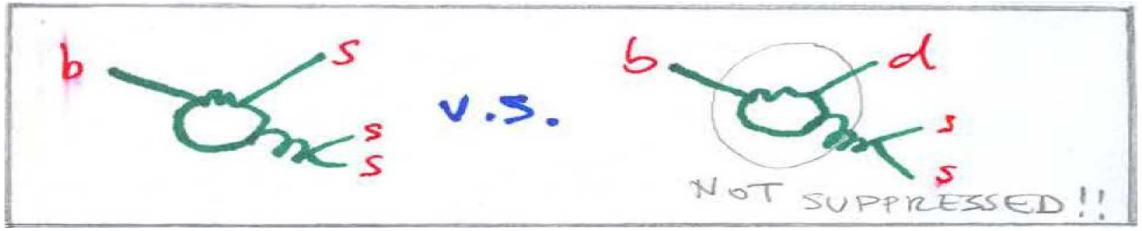
$\sin 2\beta$ from $b \to s$ penguins

- Grossman-Isidori-Worah '98 ; Grossman-Ligeti-Nir-Quinn '03

  SU(3) + Non-cancellation assumption $\Rightarrow$

$$\Delta S_{\phi K_s} < \sqrt{2}\lambda \left(\sqrt{\frac{BR(B^+ \to \phi\pi^+)}{BR(B \to \phi K_s)}} + \sqrt{\frac{BR(B^+ \to K^* K^+)}{BR(B \to \phi K_s)}} \right) + \mathcal{O}(\lambda^2)$$

$$\Rightarrow \boxed{|\Delta S^{\mathrm{SU(3)}}_{\phi K_s}| < 0.18}$$



- Beneke '05

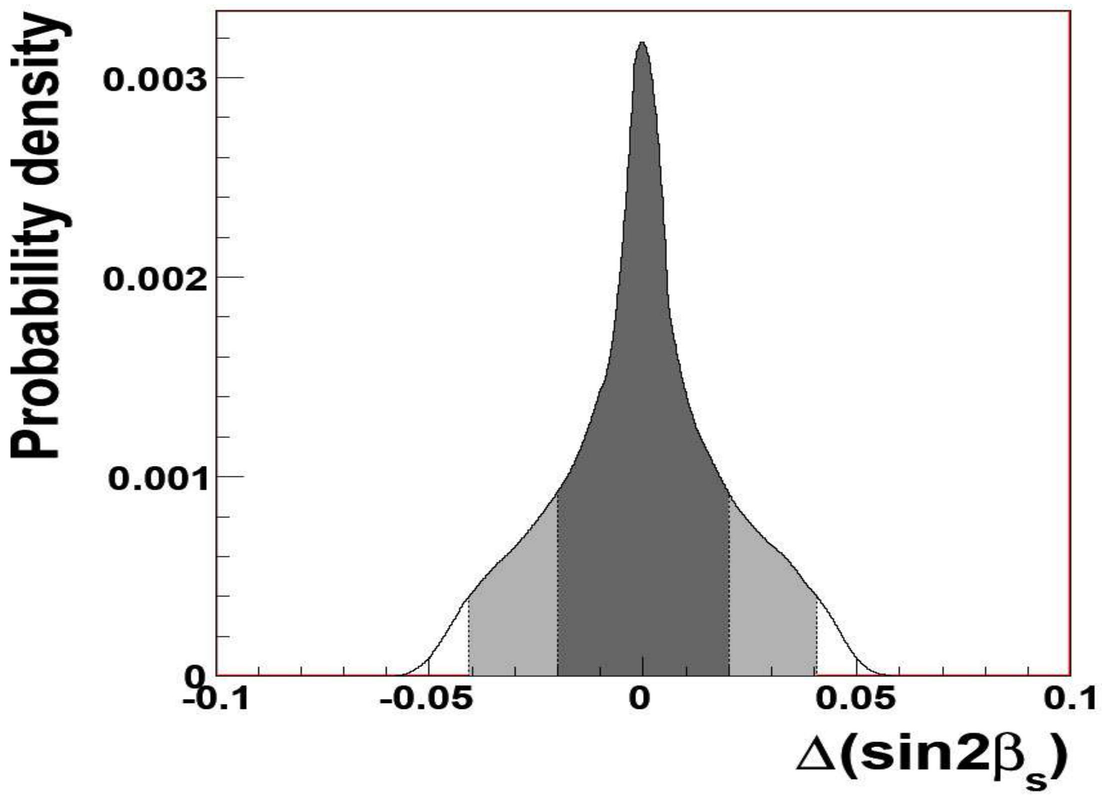
  QCD-Factorization $\Rightarrow$ $\boxed{0.01 < \Delta S^{\mathrm{QCDF}}_{\phi K_s} < 0.05}$

- EXPERIMENT: $\underline{\Delta S^{\mathrm{exp}}_{\phi K_s} = -0.29 \pm 0.18}$

$\sin 2\beta_s$ from $B_s \to K^* K^*$

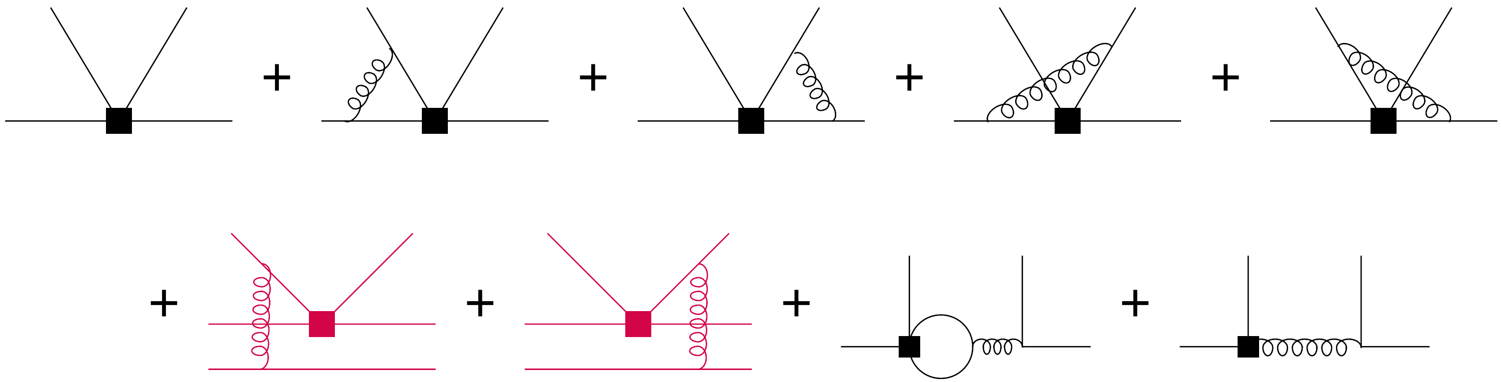
- Ciuchini, Pierini, Silvestrini '07

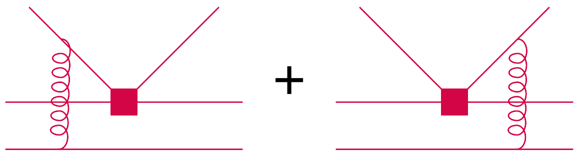
channel	BR	S	C
$B_s \to K^{*0}\bar{K}^{*0}$	$(11.8 \pm 0.6)10^{-6}$	-0.07 ± 0.02	0.01 ± 0.02
$B_d \to K^{*0}\bar{K}^{*0}$	$(5.00 \pm 0.25)10^{-7}$	-0.12 ± 0.02	0.13 ± 0.02



B decays in QCDF: α-coefficients

$\alpha_i^p(M_1 M_2) =$



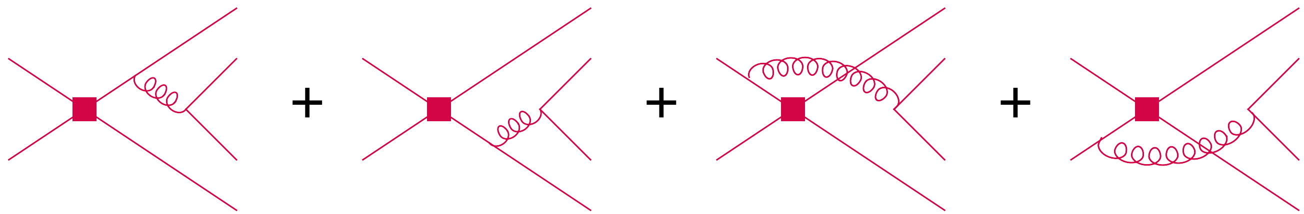


$$\supset \int_0^1 \frac{dy}{\bar{y}} \Phi_{m_1}(y) = \Phi_{m_1}(1) X_H^{M_1} + \text{finite}$$

$X_H^{M_1} \longrightarrow$ Model dependence

B decays in QCDF: β-coefficients

$\beta_i^p(M_1 M_2) \quad =$



$$\supset \int_0^1 \frac{dx\,dy}{\bar{x}y} \Phi_{m_2}(x)\Phi_{m_1}(y)$$

– Divergent subtractions: $\displaystyle \int_0^1 \frac{dy}{y} \to X_A^{M_1}, \quad \int_0^1 dy \frac{\ln y}{y} \to -\frac{1}{2}(X_A^{M_1})^2$

$X_A^{M_1},\ X_A^{M_2} \longrightarrow$ Model dependence

Δ: A solid quantity in QCDF

- Consider the following quantity:

$$\boxed{\Delta \equiv T - P}$$

$\longrightarrow$ I.R. divergencies X_A, X_H CANCEL in Δ

- For $B_q \to K^* \bar{K}^*$:

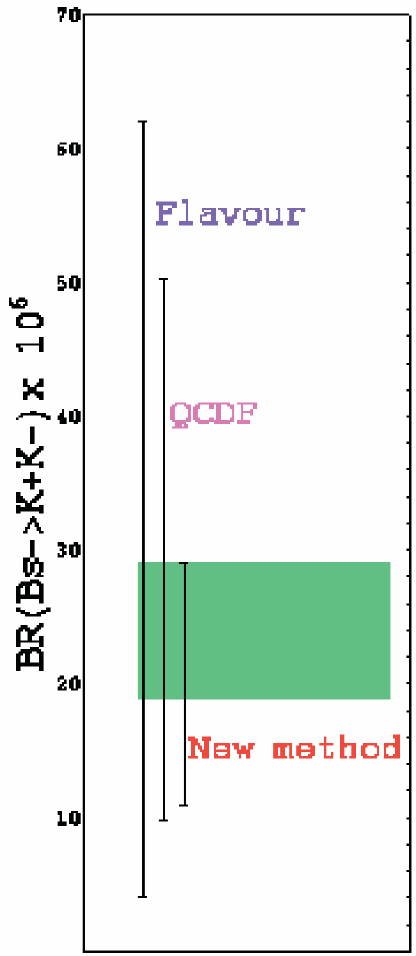
$$\left\{ \begin{array}{lcl} |\Delta^d_{K^*K^*}| & = & A^{d,0}_{K^*K^*} \frac{C_F \alpha_s}{4\pi N_c} C_1 \, |\bar{G}_{K^*}(s_c) - \bar{G}_{K^*}(0)| \\ |\Delta^s_{K^*K^*}| & = & A^{s,0}_{K^*K^*} \frac{C_F \alpha_s}{4\pi N_c} C_1 \, |\bar{G}_{K^*}(s_c) - \bar{G}_{K^*}(0)| \end{array} \right.$$

- Including QCDF input uncertainties:

$$|\Delta^d_{K^*K^*}| = (1.85 \pm 0.79) \times 10^{-7} \text{ GeV}$$
$$|\Delta^s_{K^*K^*}| = (1.62 \pm 0.69) \times 10^{-7} \text{ GeV}$$

An application to $B \to KK$

- Our method was used to predict BR's and Asymmetries in $B_s \to K^+K^-$ and $B_s \to K^0\bar{K}^0$.
  (Descotes-Genon, Matias, Virto, *Phys.Rev.Lett* **97** 061801 (2006))
  The outcome was quite promising.
- SU(3) methods suffer from large experimental uncertainties and cannot estimate SU(3)-breaking.
- QCDF has trouble with chirally enhanced $1/m_b$ suppressed contributions, which have to be modelled and introduce huge uncertainties.



Tree and Penguin Contributions

$$A = \lambda_u^{(D)*}\, T \;+\; \lambda_c^{(D)*}\, P\,, \qquad \bar{A} = \lambda_u^{(D)}\, T \;+\; \lambda_c^{(D)}\, P$$

Tree and Penguin Contributions

$$A = \lambda_u^{(D)*}\ T\ +\ \lambda_c^{(D)*}\ P\ , \qquad \bar{A} = \lambda_u^{(D)}\ T\ +\ \lambda_c^{(D)}\ P$$

$$\Big\downarrow\ T = P - \Delta$$

$$|A|^2 = |\lambda_c^{(D)*} + \lambda_u^{(D)*}|^2 \left| P + \frac{\lambda_u^{(D)*}}{\lambda_c^{(D)*} + \lambda_u^{(D)*}} \Delta \right|^2 , \qquad |\bar{A}|^2 = |\lambda_c^{(D)} + \lambda_u^{(D)}|^2 \left| P + \frac{\lambda_u^{(D)}}{\lambda_c^{(D)} + \lambda_u^{(D)}} \Delta \right|^2$$

Tree and Penguin Contributions

$$|A|^2 = |\lambda_c^{(D)*} + \lambda_u^{(D)*}|^2 \left| P + \frac{\lambda_u^{(D)*}}{\lambda_c^{(D)*} + \lambda_u^{(D)*}} \Delta \right|^2 , \quad |\bar{A}|^2 = |\lambda_c^{(D)} + \lambda_u^{(D)}|^2 \left| P + \frac{\lambda_u^{(D)}}{\lambda_c^{(D)} + \lambda_u^{(D)}} \Delta \right|^2$$

– But the amplitudes $|A|^2$, $|\bar{A}|^2$ are related to observables:

$$|A|^2 = BR\,(1 + \mathcal{A}_{\mathrm{dir}})/g_{PS} , \qquad |\bar{A}|^2 = BR\,(1 - \mathcal{A}_{\mathrm{dir}})/g_{PS}$$

$\star$ $g_{PS} \longrightarrow$ phase-space factor:

$$\begin{aligned} g_{PS}(B_d) &\simeq 8.8 \times 10^9 \text{ GeV}^{-2} \\ g_{PS}(B_s) &\simeq 8.2 \times 10^9 \text{ GeV}^{-2} \end{aligned}$$

Tree and Penguin Contributions

$$\frac{BR\,(1+\mathcal{A}_{\rm dir})/g_{PS}}{|\lambda_c^{(D)}+\lambda_u^{(D)}|^2} = \left| P + \frac{\lambda_u^{(D)*}}{\lambda_c^{(D)*}+\lambda_u^{(D)*}}\triangle \right|^2 , \qquad \frac{BR\,(1-\mathcal{A}_{\rm dir})/g_{PS}}{|\lambda_c^{(D)}+\lambda_u^{(D)}|^2} = \left| P + \frac{\lambda_u^{(D)}}{\lambda_c^{(D)}+\lambda_u^{(D)}}\triangle \right|^2$$

Tree and Penguin Contributions

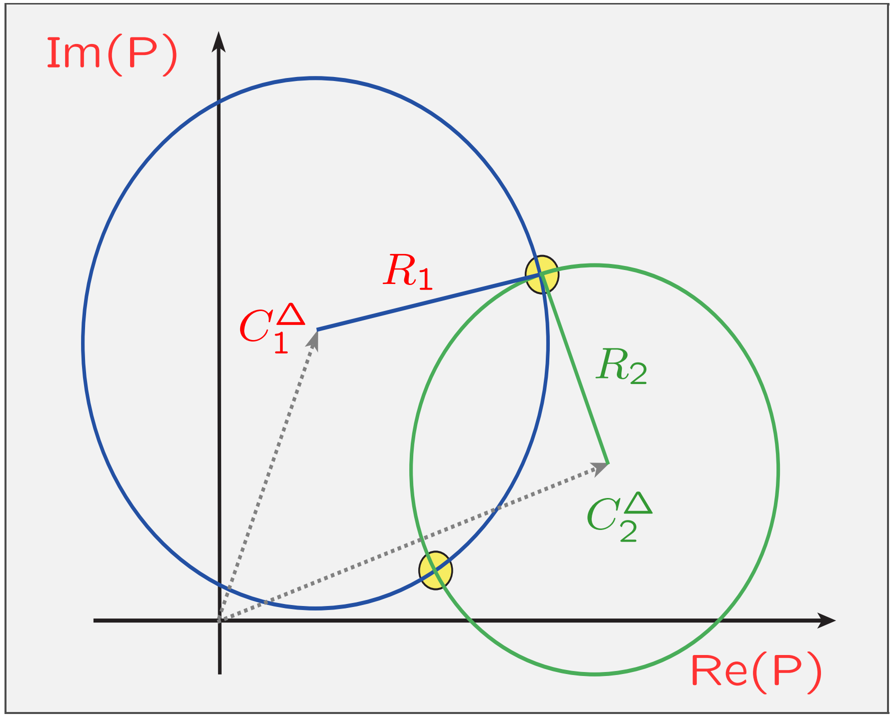
$$\underbrace{\frac{BR\,(1+\mathcal{A}_{\rm dir})/g_{PS}}{|\lambda_c^{(D)}+\lambda_u^{(D)}|^2}}_{R_1^2} = \left|P + \underbrace{\frac{\lambda_u^{(D)*}}{\lambda_c^{(D)*}+\lambda_u^{(D)*}}\triangle}_{-C_1^{\triangle}}\right|^2 , \quad \underbrace{\frac{BR\,(1-\mathcal{A}_{\rm dir})/g_{PS}}{|\lambda_c^{(D)}+\lambda_u^{(D)}|^2}}_{R_2^2} = \left|P + \underbrace{\frac{\lambda_u^{(D)}}{\lambda_c^{(D)}+\lambda_u^{(D)}}\triangle}_{-C_2^{\triangle}}\right|^2$$

$$R_1^2 = \left|P - C_1^{\triangle}\right|^2 , \quad R_2^2 = \left|P - C_2^{\triangle}\right|^2$$

- $R_i \longrightarrow$ depend on DATA and CKM's
- $C_i^{\triangle} \longrightarrow$ depend on $\triangle$ and CKM's

Tree and Penguin Contributions

$$R_1^2 = \left|P - C_1^{\Delta}\right|^2 , \quad R_2^2 = \left|P - C_2^{\Delta}\right|^2$$



–**Consistency Condition:**

$$|R_1 - R_2| \leq |C_1^{\Delta} - C_2^{\Delta}| \leq |R_1 + R_2|$$

Which translates into:

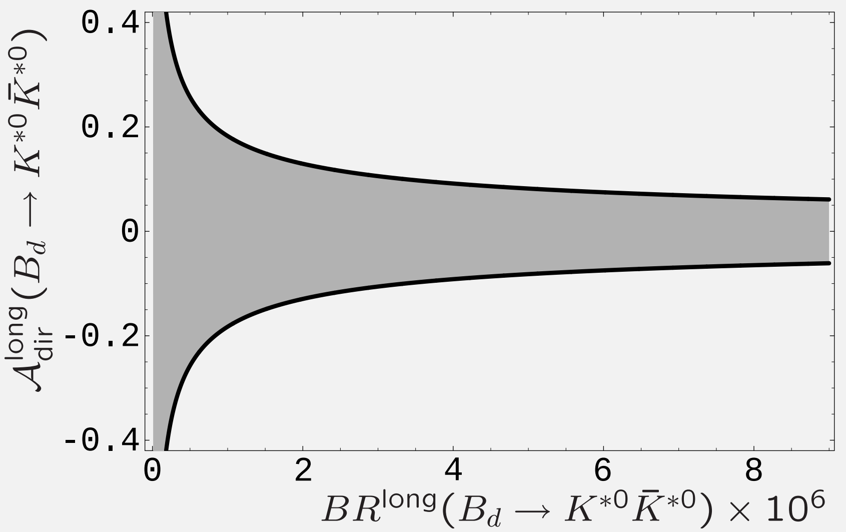
$$\boxed{|\mathcal{A}_{\mathrm{dir}}| \leq \sqrt{\frac{\mathcal{R}_D^2 \Delta^2}{2\widetilde{BR}}\left(2 - \frac{\mathcal{R}_D^2 \Delta^2}{2\widetilde{BR}}\right)}}$$

$$\left(\widetilde{BR} \equiv BR/g_{PS} \,; \quad \mathcal{R}_D \sim \text{CKM's}\right)$$

Tree and Penguin Contributions

$$R_1^2 = \left|P - C_1^{\Delta}\right|^2 , \quad R_2^2 = \left|P - C_2^{\Delta}\right|^2$$

Constraint on $B_d \to K^{*0}\bar{K}^{*0}$



–**Consistency Condition:**

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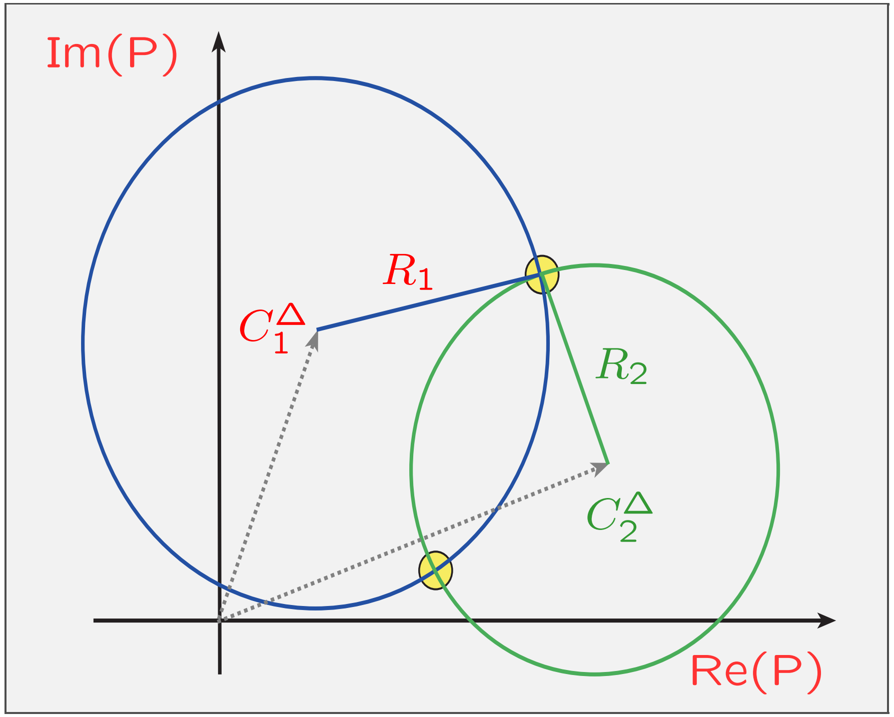
$$\left(\widetilde{BR} \equiv BR/g_{PS}\ ; \quad \mathcal{R}_D \sim \text{CKM's}\right)$$

Tree and Penguin Contributions

$$R_1^2 = \left|P - C_1^{\Delta}\right|^2 \ , \quad R_2^2 = \left|P - C_2^{\Delta}\right|^2$$



–Hadronic Parameters:

$$\mathbf{Re}[P] = -c_1^{(D)}\,\Delta \pm \sqrt{-\mathrm{Im}[P]^2 - \left(\frac{c_0^{(D)}\Delta}{c_2^{(D)}}\right)^2 + \frac{\widetilde{BR}}{c_2^{(D)}}}$$

$$\mathbf{Im}[P] = \frac{\widetilde{BR}\,\mathcal{A}_{\mathrm{dir}}}{2c_0^{(D)}\Delta}$$

$$T = P + \Delta$$

$$\left(\widetilde{BR} \equiv BR/g_{PS}\ ; \quad c_i^{(D)} \sim \text{CKM's}\right)$$

Tree and Penguin Contributions

SUMMARY

- Amplitudes: $A_{SM}(B_q \to M_1 M_2) = \lambda_u^{(D)*}\, T + \lambda_c^{(D)*}\, P$

- IR-safe quantity: $\Delta \equiv T - P$

- Consistency condition: $|\mathcal{A}_{\rm dir}| \leq \sqrt{\frac{\mathcal{R}_D^2 \Delta^2}{2\widetilde{BR}}\left(2 - \frac{\mathcal{R}_D^2 \Delta^2}{2\widetilde{BR}}\right)}$

- Hadronic Parameters:

$$\mathrm{Re}[P] = -c_1^{(D)}\, \Delta \pm \sqrt{-\mathrm{Im}[P]^2 - \left(\frac{c_0^{(D)} \Delta}{c_2^{(D)}}\right)^2 + \frac{\widetilde{BR}}{c_2^{(D)}}} \qquad ; \qquad T = P + \Delta$$

$$\mathrm{Im}[P] = \frac{\widetilde{BR}\, \mathcal{A}_{\rm dir}}{2 c_0^{(D)} \Delta}$$

$\sin 2\beta$ from $B \to \phi K_s$

$$\Delta S_{\phi K_s} = 2\left|\frac{\lambda_u^{(s)}}{\lambda_c^{(s)}}\right| Re\left(\frac{T_{\phi K_s}}{P_{\phi K_s}}\right) \sin\gamma \cos 2\beta \lesssim 0.044\, Re\left(\frac{T_{\phi K_s}}{P_{\phi K_s}}\right)$$

- FROM $BR(B \to \phi K_s) + \Delta_{\phi K_s} \rightsquigarrow \underline{T_{\phi K_s}, P_{\phi K_s}}$

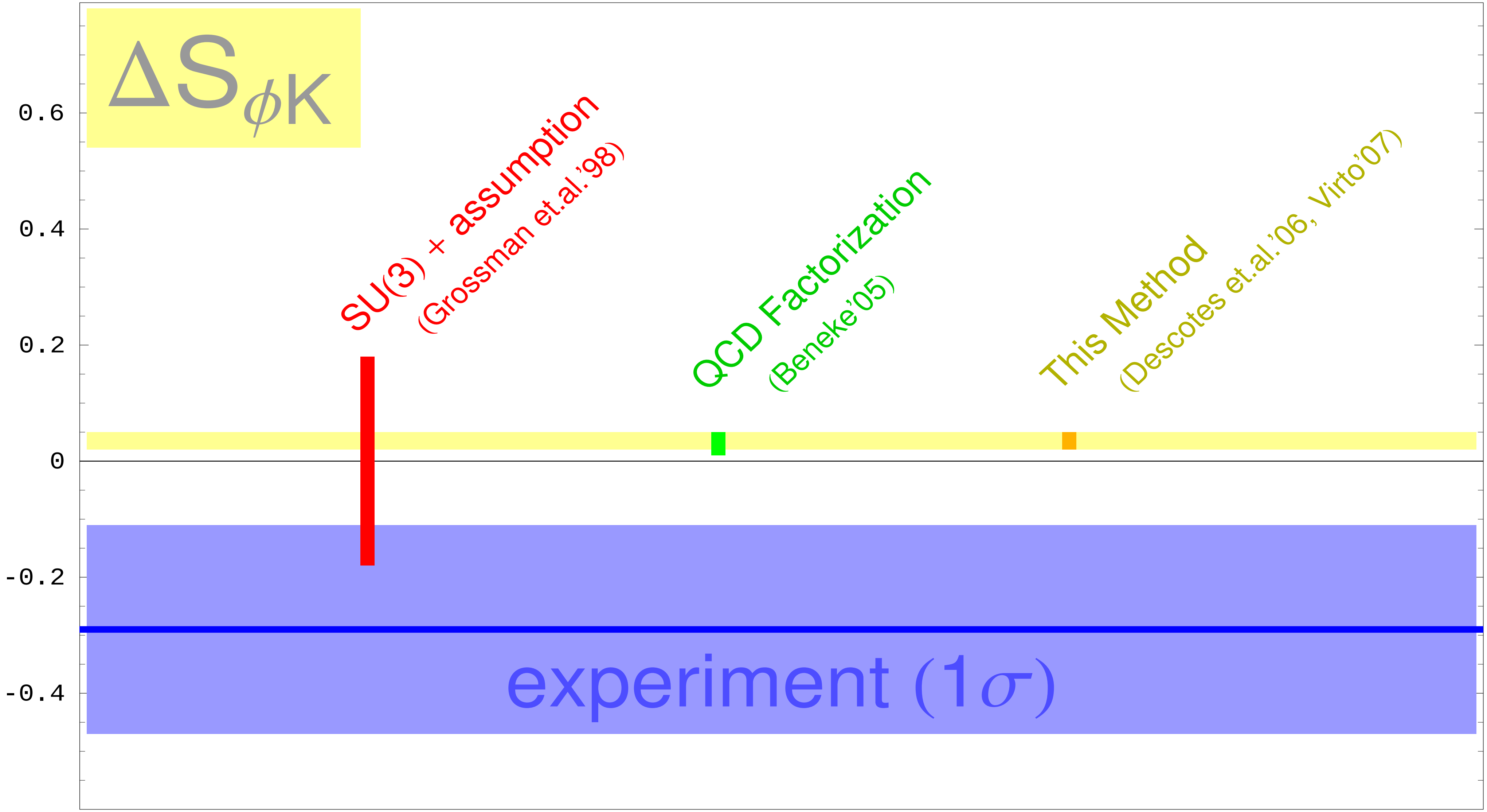
We get:

$$\boxed{\begin{aligned} Re\left(\frac{T}{P}\right) &\lesssim 1 + \left(-0.011 + \sqrt{-3.62 \cdot 10^{-4} + 612\, \widetilde{BR}/\Delta^2}\right)^{-1} \\ Re\left(\frac{T}{P}\right) &\gtrsim 1 + \left(-0.11 - \sqrt{-3.62 \cdot 10^{-4} + 612\, \widetilde{BR}/\Delta^2}\right)^{-1} \end{aligned}}$$

- $BR(B \to \phi K_s) = 8.3^{+1.2}_{-1.0} \cdot 10^{-6}$
- $\Delta_{\phi K_s} = (2.29 \pm 0.67) \cdot 10^{-7}\ GeV$

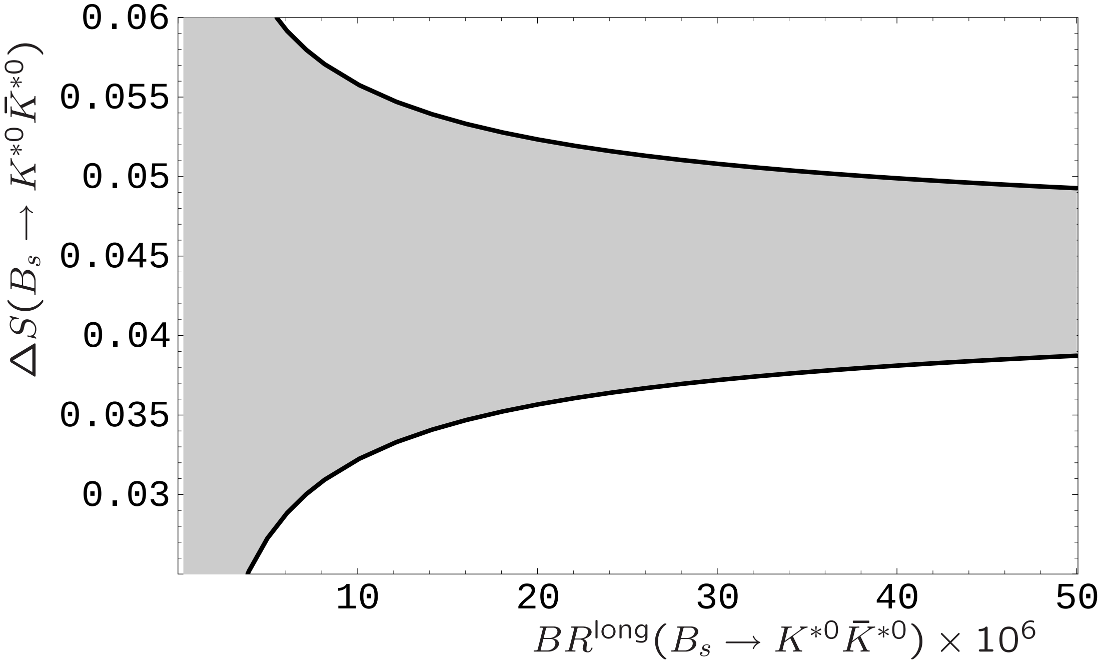
$\Rightarrow$ $\boxed{0.03 < \Delta S_{\phi K_s} < 0.06}$

$\sin 2\beta$ from $B \to \phi K_s$



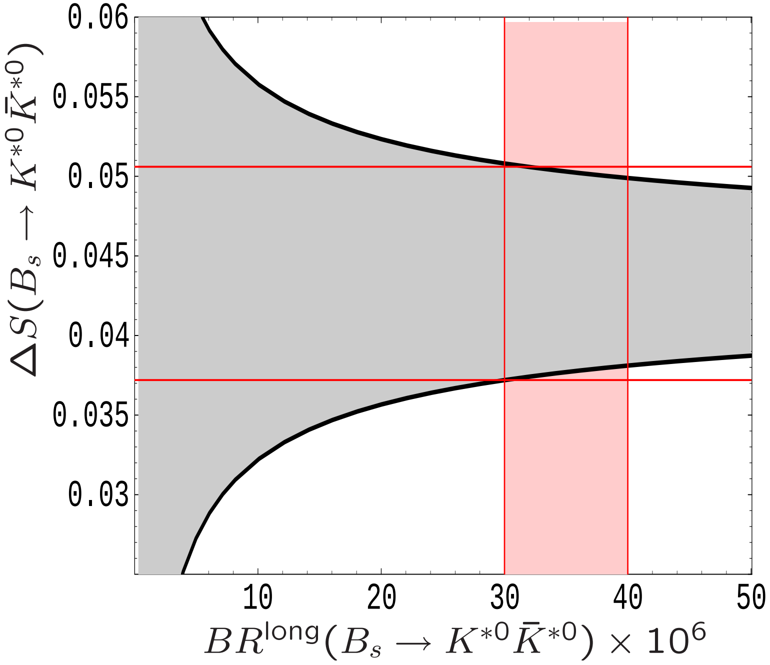
ϕ_s from $B_s \to VV$ (Strategy I)

$$\mathcal{A}_{\text{mix}}^{\text{long}}(B_s \to K^{*0}\bar{K}^{*0}) \simeq \sin\phi_s + \underbrace{2\left|\frac{\lambda_u^{(s)}}{\lambda_c^{(s)}}\right| \text{Re}\left(\frac{T^s_{K^*K^*}}{P^s_{K^*K^*}}\right)\sin\gamma\cos\phi_s}_{\Delta S(B_s \to K^{*0}\bar{K}^{*0})} + \cdots$$



ϕ_s from $B_s \to VV$ (St.I)

$$\mathcal{A}^{\text{long}}_{\text{mix}}(B_s \to K^{*0}\bar{K}^{*0}) \simeq \sin\phi_s \underbrace{+\, 2\left|\frac{\lambda_u^{(s)}}{\lambda_c^{(s)}}\right| \text{Re}\left(\frac{T^s_{K^*K^*}}{P^s_{K^*K^*}}\right)\sin\gamma\cos\phi_s}_{\Delta S(B_s \to K^{*0}\bar{K}^{*0})} + \cdots$$



Example:

For $\quad BR^{\text{long}}(B_s \to K^{*0}\bar{K}^{*0}) \sim (30-40) \times 10^{-6}$

Then

$$\boxed{\left(\mathcal{A}^{\text{long}}_{\text{mix}} - \mathbf{0.051}\right) < \sin\phi_s < \left(\mathcal{A}^{\text{long}}_{\text{mix}} - \mathbf{0.037}\right)}$$

Other angles from data & Δ (St.II)

In the case of a B_d meson decaying through a $b \to D$ process $(D = d, s)$:

$$\sin^2 \alpha = \frac{\widetilde{BR}}{2|\lambda_u^{(D)}|^2|\Delta|^2}\left(1 - \sqrt{1 - (\mathcal{A}_{\text{dir}})^2 - (\mathcal{A}_{\text{mix}})^2}\right)$$

$$\sin^2 \beta = \frac{\widetilde{BR}}{2|\lambda_c^{(D)}|^2|\Delta|^2}\left(1 - \sqrt{1 - (\mathcal{A}_{\text{dir}})^2 - (\mathcal{A}_{\text{mix}})^2}\right)$$

In the case of a B_s meson decaying through a $b \to D$ process $(D = d, s)$:

$$\sin^2 \frac{\phi_s}{2} = \frac{\widetilde{BR}}{2|\lambda_c^{(D)}|^2|\Delta|^2}\left(1 - \sqrt{1 - (\mathcal{A}_{\text{dir}})^2 - (\mathcal{A}_{\text{mix}})^2}\right)$$

$$\sin^2 \left(\frac{\phi_s}{2} + \gamma\right) = \frac{\widetilde{BR}}{2|\lambda_u^{(D)}|^2|\Delta|^2}\left(1 - \sqrt{1 - (\mathcal{A}_{\text{dir}})^2 - (\mathcal{A}_{\text{mix}})^2}\right)$$

Other angles from data & Δ (St.II)

Even better: Measure the time-dependent "untagged" rate

$$\Gamma^{\rm long}(B_s(t) \to VV) + \Gamma^{\rm long}(\overline{B_s}(t) \to VV) \;\propto\; R_{\rm H} e^{-\Gamma_{\rm H}^{(s)} t} + R_{\rm L} e^{-\Gamma_{\rm L}^{(s)} t}$$

Which allows to extract $\mathcal{A}_{\Delta\Gamma}^{\rm long}$:

$$\mathcal{A}_{\Delta\Gamma}^{\rm long}(B_s \to VV) = \frac{R_{\rm H} - R_{\rm L}}{R_{\rm H} + R_{\rm L}}$$

$$\boxed{\sin^2 \frac{\phi_s}{2} = \frac{\widetilde{BR}\,(1 - \mathcal{A}_{\Delta\Gamma}^{\rm long})}{2|\lambda_c^{(D)}|^2 |\Delta|^2} \quad ; \quad \sin^2\left(\frac{\phi_s}{2} + \gamma\right) = \frac{\widetilde{BR}\,(1 - \mathcal{A}_{\Delta\Gamma}^{\rm long})}{2|\lambda_u^{(D)}|^2 |\Delta|^2}}$$

$B_s \to K^* \bar{K}^*$ observables (St.III)

- Assume no NP in $B_d \to K^{*0} \bar{K}^{*0}$.
- Extract $P^d_{K^*K^*}$, $T^d_{K^*K^*}$ from $BR^{d,\,\text{long}}_{K*K*}$, $A^{d,\,\text{long}}_{dir,\,K*K*}$ and Δ^d_{K*K*}.
- Relate $B_s \to K^{*0} \bar{K}^{*0}$ to $B_d \to K^{*0} \bar{K}^{*0}$ by U-spin:

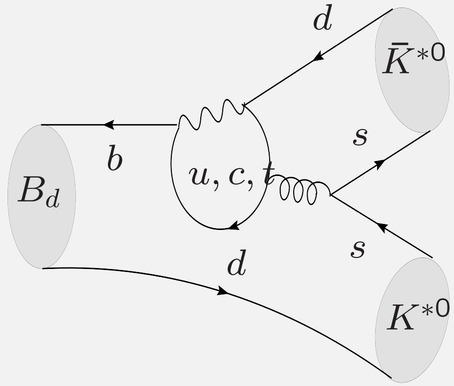
$$P^s_{K^*K^*} = f\, P^d_{K^*K^*}(1 + \delta^P_{K^*K^*})$$

$$T^s_{K^*K^*} = f\, T^d_{K^*K^*}(1 + \delta^T_{K^*K^*})$$

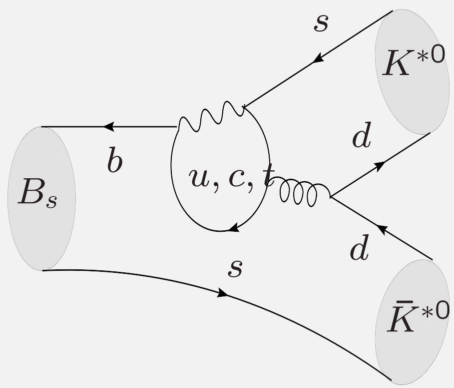
Factorizable SU$\cancel{(}$3) : (lattice) $f = \frac{m^2_{B_s} A_0^{B_s \to K^*}}{m^2_B A_0^{B \to K^*}} = 0.88 \pm 0.19$

Non-Factorizable SU$\cancel{(}$3) : (QCDF) $|\delta^P_{K^*K^*}| \leq 0.12$, $|\delta^T_{K^*K^*}| \leq 0.15$

- Compute observables for $B_s \to K^{*0} \bar{K}^{*0}$ as a function of ϕ_s.

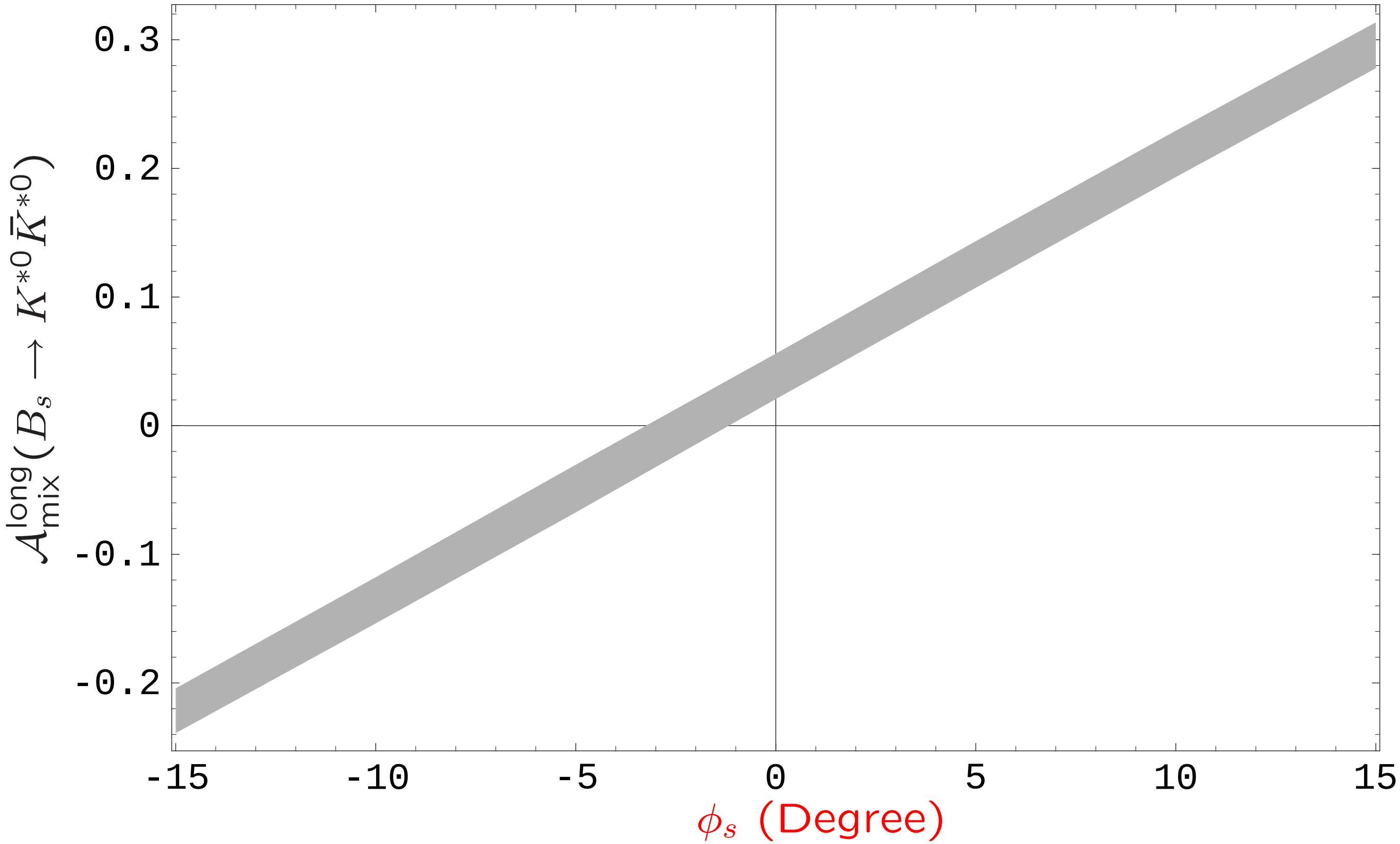


$B_d \to K^{*0} \bar{K}^{*0}$

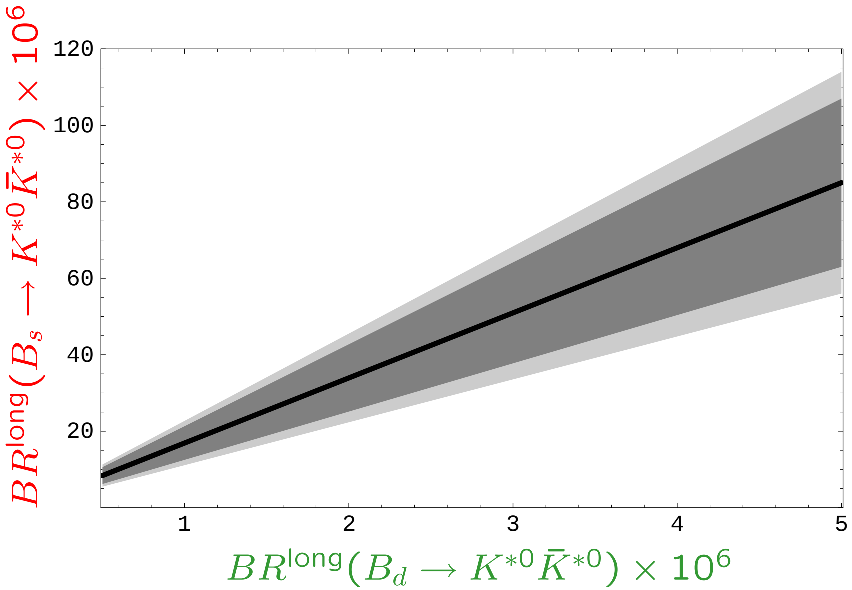


$B_s \to K^{*0} \bar{K}^{*0}$

$B_s \to K^* \bar{K}^*$ observables (St.III)



$B_s \to K^*\bar{K}^*$ observables (St.III)



–Central values

–Input uncertainties

–Error from f

Results within SM, obtained taking

$$\gamma = 62 \pm 6$$

$$\phi_s = -2^\circ$$

$$\left(\frac{BR^{\text{long}}(B_s \to K^{*0}\bar{K}^{*0})}{BR^{\text{long}}(B_d \to K^{*0}\bar{K}^{*0})}\right)_{SM} = 17 \pm 6$$

$$\mathcal{A}^{\text{long}}_{\text{dir}}(B_s \to K^{*0}\bar{K}^{*0})_{SM} = 0.000 \pm 0.014$$

$$\mathcal{A}^{\text{long}}_{\text{mix}}(B_s \to K^{*0}\bar{K}^{*0})_{SM} = 0.004 \pm 0.018$$

Comparison between the Strategies

	Strategy 1	Strategy 2	Strategy 3
Inputs	$BR^{\mathrm{long}}(B_s \to K^{*0}\bar{K}^{*0})$ $\mathcal{A}^{\mathrm{long}}_{\mathrm{mix}}(B_s \to K^{*0}\bar{K}^{*0})$ $\Delta^s_{K^*K^*}$, γ	$BR^{\mathrm{long}}(B_s \to K^{*0}\bar{K}^{*0})$ $\mathcal{A}^{\mathrm{long}}_{\mathrm{dir}}(B_s \to K^{*0}\bar{K}^{*0})$ $\mathcal{A}^{\mathrm{long}}_{\mathrm{mix}}(B_s \to K^{*0}\bar{K}^{*0})$ $\Delta^s_{K^*K^*}$	$BR^{\mathrm{long}}(B_d \to K^{*0}\bar{K}^{*0})$ $\mathcal{A}^{\mathrm{long}}_{\mathrm{mix}}(B_s \to K^{*0}\bar{K}^{*0})$ $\Delta^d_{K^*K^*}$, δ_T, δ_P, γ
Outputs	ϕ_s	$\lvert\sin\phi_s\rvert$, γ	$BR^{\mathrm{long}}(B_s \to K^{*0}\bar{K}^{*0})_{SM}$ $\mathcal{A}^{\mathrm{long}}_{\mathrm{dir}}(B_s \to K^{*0}\bar{K}^{*0})_{SM}$ ϕ_s
Advantages	Applies also to $B_s \to \phi K^{*0}$ and $B_s \to \phi\phi$	Applies also to $B_s \to \phi K^{*0}$ and $B_s \to \phi\phi$	It can be easily generalized to include New Physics in the decay and mixing.
Limitations	It assumes no New Physics in $b \to s$ decay.	It assumes no New Physics in $b \to s$ decay.	Does not apply to $B_s \to \phi K^{*0}$ or $B_s \to \phi\phi$ because $\delta_{T,P}$ are big.

To Summarize...

- ⋆ An approach based on the QCDF-inspired quantity Δ improves precision of Flavor Symmetries and reliability of QCDF:
  - $B_s \to KK$ modes
  - B_d mixing: $\sin 2\beta$

..... *Waiting for measurements of* $A_{\text{mix}}(B_s \to K^+K^-)$,

and improved results for $A_{\text{mix}}(B_d \to \phi K_s)$ .....

- ⋆ $B_s - \bar{B}_s$ mixing: The hope for a clear NP signal in flavor physics.

- ⋆ Longitudinal observables in penguin-mediated $B_s \to VV$ decays allow for nice ways of extracting ϕ_s.

.....*Wating for measurements of* $A^{\text{long}}_{\text{mix}}(B_s \to VV)$ *and* $BR^{\text{long}}(B_{d,s} \to VV)$,

with $VV = K^*K^*, \phi K^*, \phi\phi$ .....

Back up

$B \to VV$: Polarization Amplitudes

$$
\begin{aligned}
A(B \to V_1 V_2) &= \left[\frac{4 m_1 m_2}{m_B^4}(\epsilon_1^* \cdot p_B)(\epsilon_2^* \cdot p_B)\right] A_0 \\
&+ \left[\frac{1}{2}(\epsilon_1^* \cdot \epsilon_2^*) - \frac{(p_B \cdot \epsilon_1^*)(p_B \cdot \epsilon_2^*)}{m_B^2} - \frac{i\epsilon_{\mu\nu\rho\sigma}\epsilon_1^{*\mu}\epsilon_2^{*\nu}p_1^\rho p_2^\sigma}{2 p_1 \cdot p_2}\right] A_+ \\
&+ \left[\frac{1}{2}(\epsilon_1^* \cdot \epsilon_2^*) - \frac{(p_B \cdot \epsilon_1^*)(p_B \cdot \epsilon_2^*)}{m_B^2} + \frac{i\epsilon_{\mu\nu\rho\sigma}\epsilon_1^{*\mu}\epsilon_2^{*\nu}p_1^\rho p_2^\sigma}{2 p_1 \cdot p_2}\right] A_-
\end{aligned}
$$

Transversity basis: $A_{\parallel,\perp} = (A_+ \pm A_-)\sqrt{2}$

Polarization fractions: $f_{0,\perp,\parallel} \equiv \dfrac{|A_{0,\perp,\parallel}|^2}{|A_0|^2 + |A_\perp|^2 + |A_\parallel|^2}$

$B \to VV$: Transverse Polarizations

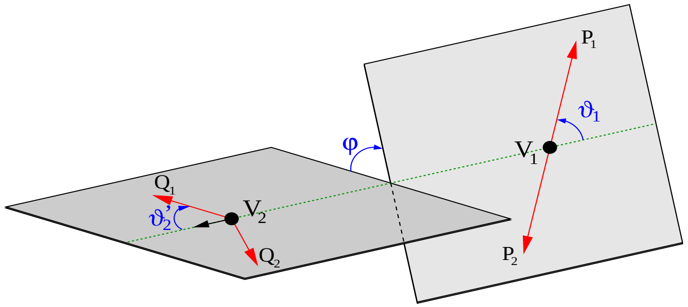
- In naive factorization: $1 - f_0 = \mathcal{O}(1/m_b^2)$, $\frac{f_\perp}{f_\parallel} = 1 + \mathcal{O}(1/m_b^2)$
- $B \to \rho\rho$ $\surd$ $\begin{cases} f_0 = 0.941^{+0.034}_{-0.040} \pm 0.030 & -\text{Belle} \\ f_0 = 0.977 \pm 0.024^{+0.015}_{-0.013} & -\text{BaBar} \end{cases}$
- $B \to \phi K^{*0}$ $\times$ $\begin{cases} f_0 = 0.45 \pm 0.05 \pm 0.02 & -\text{Belle} \\ f_0 = 0.506 \pm 0.040 \pm 0.015 & -\text{BaBar} \end{cases}$
- Transverse amplitudes don't factorize at leading order
  $\Rightarrow$ $B \to VV$ decays are more problematic theoretically
- On the other hand there are some experimental advantages:
  Larger BR's and charged decay products.

$B \to VV$: Longitudinal Observables

$$\frac{d^3\Gamma}{\Gamma d\cos\theta_1 d\cos\theta_2 d\phi} = \frac{9}{8\pi}\frac{1}{|A_0|^2+|A_\parallel|^2+|A_\perp|^2} \times \Big[|A_0|^2\cos^2\theta_1\cos^2\theta_2 + |A_\parallel|^2\frac{1}{2}\sin^2\theta_1\sin^2\theta_2\cos^2\phi$$

$$+|A_\perp|^2\frac{1}{2}\sin^2\theta_1\sin^2\theta_2\sin^2\phi + \mathrm{Re}[A_0^* A_\parallel]\frac{1}{2\sqrt{2}}\sin 2\theta_1\sin 2\theta_2\cos\phi$$

$$+\mathrm{Im}[A_0^* A_\perp]\frac{-1}{2\sqrt{2}}\sin 2\theta_1\sin 2\theta_2\sin\phi + \mathrm{Im}[A_\parallel^* A_\perp]\frac{-1}{2}\sin^2\theta_1\sin^2\theta_2\sin 2\phi\Big]$$



- $$\Gamma^{\text{long}} \equiv \int \frac{d^3\Gamma}{d\cos\theta_1 d\cos\theta_2 d\phi}\left(\frac{5}{2}\cos\theta_1^2 - \frac{1}{2}\right) d\cos\theta_1 d\cos\theta_2 d\phi = g_{PS}|A_0|^2/\tau_B$$

- $$\Gamma^{\text{long}} \equiv \int_{-1}^{1} d\cos\theta_1 \int_T d\cos\theta_2 \int_0^{2\pi} d\phi \frac{d^3\Gamma}{d\cos\theta_1 d\cos\theta_2 d\phi} = g_{PS}|A_0|^2/\tau_B$$

with $$\int_T d\cos\theta_2 = \left(\frac{11}{9}\int_0^{\pi/3} - \frac{5}{9}\int_{\pi/3}^{2\pi/3} + \frac{11}{9}\int_{2\pi/3}^{\pi}\right)(-\sin\theta_2)d\theta_2$$

$B \to VV$: Longitudinal Observables

- Angular analysis:

$$BR^{\text{long}} = \frac{\tau_B}{2}\left(\Gamma^{\text{long}}(B_q^0 \to f) + \Gamma^{\text{long}}(\bar{B}_q^0 \to f)\right) = g_{PS}\frac{|A_0|^2 + |\bar{A}_0|^2}{2}$$

$$\mathcal{A}_{\text{dir}}^{\text{long}} \equiv \frac{\Gamma^{\text{long}}(B_q^0 \to f) - \Gamma^{\text{long}}(\bar{B}_q^0 \to \bar{f})}{\Gamma^{\text{long}}(B_q^0 \to f) + \Gamma^{\text{long}}(\bar{B}_q^0 \to \bar{f})} = \frac{|A_0|^2 - |\bar{A}_0|^2}{|A_0|^2 + |\bar{A}_0|^2}$$

- Time-dependent analysis:

$$\mathcal{A}_{\text{CP}}(t) \equiv \frac{\Gamma^{\text{long}}(B_q^0(t) \to f) - \Gamma^{\text{long}}(\bar{B}_q^0(t) \to \bar{f})}{\Gamma^{\text{long}}(B_q^0(t) \to f) + \Gamma^{\text{long}}(\bar{B}_q^0(t) \to \bar{f})} = \frac{\mathcal{A}_{\text{dir}}^{\text{long}} \cos(\Delta M t) + \mathcal{A}_{\text{mix}}^{\text{long}} \sin(\Delta M t)}{\cosh(\Delta\Gamma t/2) - \mathcal{A}_{\Delta\Gamma}^{\text{long}} \sinh(\Delta\Gamma t/2)}$$

$$\mathcal{A}_{\text{mix}}^{\text{long}} \equiv -2\eta_f \frac{\text{Im}(e^{-i\phi_M} A_0^* \bar{A}_0)}{|A_0|^2 + |\bar{A}_0|^2} \quad ; \quad \mathcal{A}_{\Delta\Gamma}^{\text{long}} \equiv -2\eta_f \frac{\text{Re}(e^{-i\phi_M} A_0^* \bar{A}_0)}{|A_0|^2 + |\bar{A}_0|^2}$$

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