Studies in non-leptonic B meson decays

Gilberto Tetlalmatzi-Xolocotzi

Based on: T. Huber and GTX, 2111.06418
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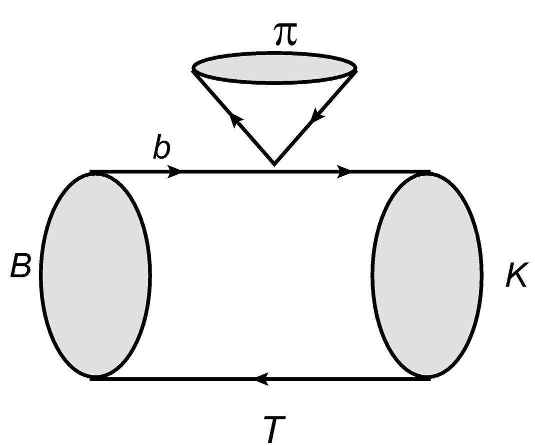
QCF Factorization of non-leptonic decays

A first principle technique to calculate transition amplitudes in non-leptonic decays is QCD-Factorization

Beneke et al: 9905312   *Beneke et al: 0308039*



Naive Factorization

$$\langle K\pi | Q | B \rangle \sim F_{B\to K} f_{\pi}$$

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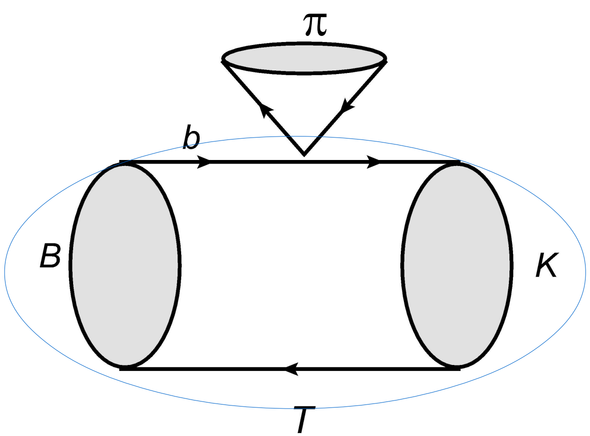

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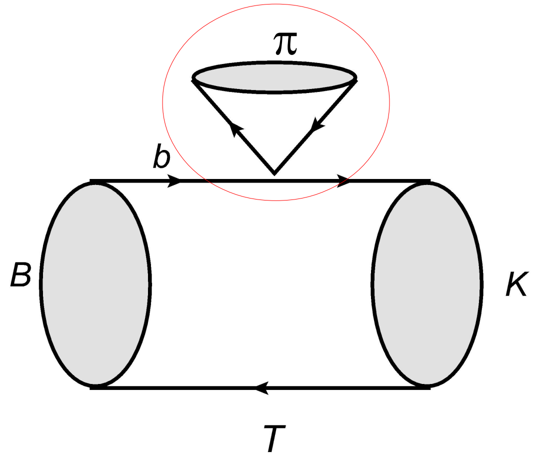


Naive Factorization

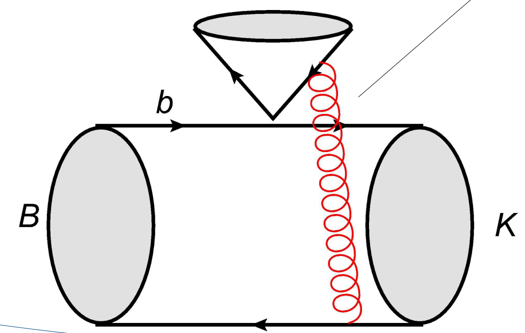
$$\langle K\pi | Q | B \rangle \sim F_{B\to K} f_{\pi}$$

QCF Factorization of non-leptonic decays

Naive factorization special case of

$$\langle M_1 M_2|\hat{Q}_i|B\rangle = \sum_j F_j^{B\to M_1}(0)\int_0^1 du T_{ij}^I(u)\Phi_{M_2}(u) + (M_1 \leftrightarrow M_2)$$

$$+ \int_0^1 d\xi du dv T_i^{II}(\xi,u,v)\Phi_B(\xi)\Phi_{M_1}(v)\Phi_{M_2}(u).$$



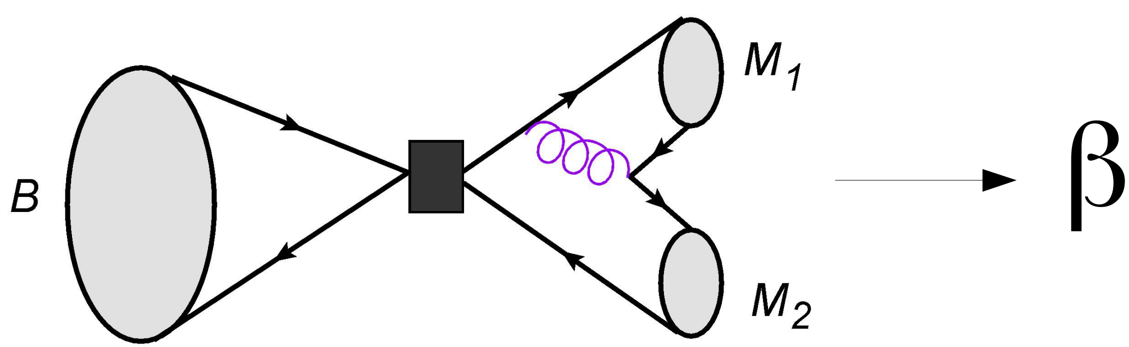
QCD-Factorization offers a systematic way to disentangle short from long distance physics considering $\Lambda_{QCD} \ll m_b$

QCF Factorization of non-leptonic decays

The transition amplitudes are expressed in terms of subamplitudes addressing different ''topologies''

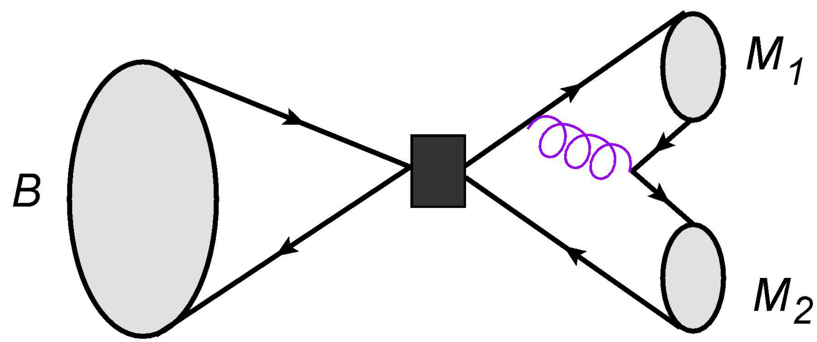
$$T(\bar{B}_d \to \bar{K}^{\,0} K^{\,0}) = A_{\bar{K}\;K}\,[\alpha_4^u - \frac{1}{2}\alpha_{4,EW}^u + \beta_3^u + \beta_4^u - \frac{1}{2}\beta_{3,EW}^u - \frac{1}{2}\beta_{4,EW}^u] + A_{K\;\bar{K}}\,[\beta_4^u - \frac{1}{2}\beta_{4,EW}^u]\,,$$

$$P(\bar{B}_d \to \bar{K}^{\,0} K^{\,0}) = A_{\bar{K}\;K}\,[\alpha_4^c - \frac{1}{2}\alpha_{4,EW}^c + \beta_3^c + \beta_4^c - \frac{1}{2}\beta_{3,EW}^c - \frac{1}{2}\beta_{4,EW}^c] + A_{K\;\bar{K}}\,[\beta_4^c - \frac{1}{2}\beta_{4,EW}^c]\,,$$



Weak annihilation contributions are non-factorizable

QCF Factorization decomposition



$\longrightarrow$ β

Weak annihilation contributions are non-factorizable ⇒ One of the main drawbacks of QCDF

These contributions are power suppressed Λ_{QCD}/m_b

To address this problem educated Ansatz are made

$$X_A = \left(1 + \rho_A e^{i\phi_A}\right) \ln \frac{m_B}{\Lambda_h}$$

$$0 < \rho_A < 1$$

$$\Lambda_h \approx \mathcal{O}(\Lambda_{QCD})$$

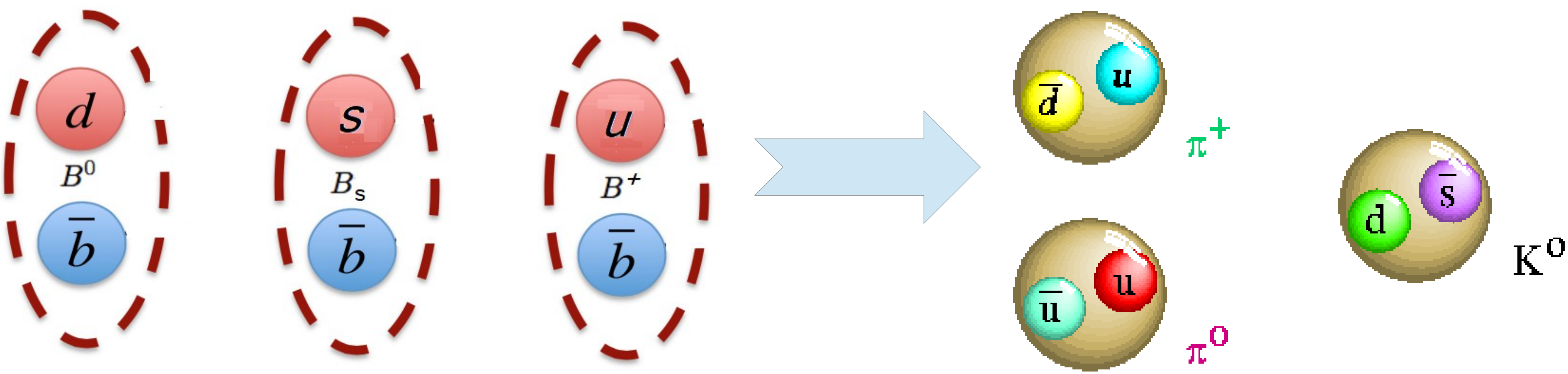
WHAT CAN WE LEARN ABOUT THE ANNIHILATION CONTRIBUTIONS FROM DATA?

WHAT IS THE SIZE OF THESE TERMS AS REQUIRED BY PHENOMENOLOGICAL OBSERVATIONS?

TO ADDRESS THESE QUESTIONS WE USE FLAVOUR SYMMETRIES TO PARAMETRIZE THE RELEVANT DECAYS

Non-leptonic B meson decays

We will concentrate in the case of B meson decaying into paira of light pseudoscalar mesons



$$B \to PP$$

The light pseudoscalar mesons are bound states of light quarks $[u, d, s]$ (SU(3) symmetry)

$$B = (B^+, B_d^0, B_s^0)$$

$$q_i \otimes \overline{q_j} \rightarrow 3 \otimes \overline{3} = 8 \oplus 1$$

$$i, j \in [u, d, s]$$

P

$$M = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta_q}{\sqrt{2}} + \frac{\eta'_q}{\sqrt{2}} & \pi^- & K^- \\ \pi^+ & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta_q}{\sqrt{2}} + \frac{\eta'_q}{\sqrt{2}} & \bar{K}^0 \\ K^+ & K^0 & \eta_s + \eta'_s \end{pmatrix}$$

Topological decomposition

$$\mathcal{T}^{TDA} = \underline{T}\ B_i(M)^i_j \bar{H}^{jl}_k (M)^k_l + \underline{C}\ B_i(M)^i_j \bar{H}^{lj}_k (M)^k_l + \underline{A}\ B_i \bar{H}^{il}_j (M)^j_k (M)^k_l$$
$$+\underline{E}\ B_i \bar{H}^{li}_j (M)^j_k (M)^k_l + \underline{T_{ES}} B_i \bar{H}^{ij}_l (M)^l_j (M)^k_k + \underline{T_{AS}} B_i \bar{H}^{ji}_l (M)^l_j (M)^k_k$$
$$+\underline{T_S} B_i (M)^i_j \bar{H}^{lj}_l (M)^k_k + \underline{T_{PA}} B_i \bar{H}^{li}_l (M)^j_k (M)^k_j + \underline{T_P} B_i (M)^i_j (M)^j_k \bar{H}^{lk}_l$$
$$+\underline{T_{SS}} B_i \bar{H}^{li}_l (M)^j_j (M)^k_k,$$

SU(3) Flavour $[u, d, s]$

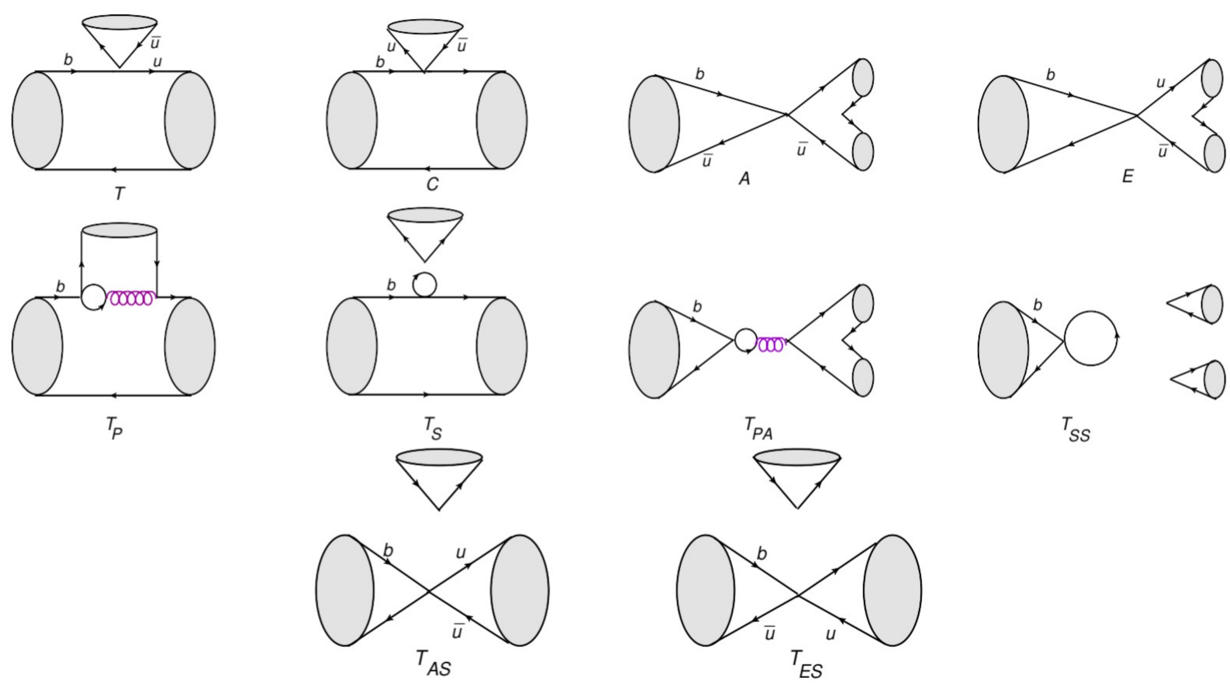
$$B = (B^+, B^0_d, B^0_s)$$

$$M = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta_q}{\sqrt{2}} + \frac{\eta'_q}{\sqrt{2}} & \pi^- & K^- \\ \pi^+ & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta_q}{\sqrt{2}} + \frac{\eta'_q}{\sqrt{2}} & \bar{K}^0 \\ K^+ & K^0 & \eta_s + \eta'_s \end{pmatrix}$$

$$\bar{H}^{12}_1 = \lambda^{(d)}_u, \quad \bar{H}^{13}_1 = \lambda^{(s)}_u,$$

Topological decomposition

$$
\begin{aligned}
\mathcal{T}^{TDA} = {} & \underline{T}\ B_i(M)^i_j \bar{H}^{jl}_k (M)^k_l + \underline{C}\ B_i(M)^i_j \bar{H}^{lj}_k (M)^k_l + \underline{A}\ B_i \bar{H}^{il}_j (M)^j_k (M)^k_l \\
& + \underline{E}\ B_i \bar{H}^{li}_j (M)^j_k (M)^k_l + \underline{T_{ES}} B_i \bar{H}^{ij}_l (M)^l_j (M)^k_k + \underline{T_{AS}} B_i \bar{H}^{ji}_l (M)^l_j (M)^k_k \\
& + \underline{T_S} B_i (M)^i_j \bar{H}^{lj}_l (M)^k_k + \underline{T_{PA}} B_i \bar{H}^{li}_l (M)^j_k (M)^k_j + \underline{T_P} B_i (M)^i_j (M)^j_k \bar{H}^{lk}_l \\
& + \underline{T_{SS}} B_i \bar{H}^{li}_l (M)^j_j (M)^k_k,
\end{aligned}
$$



SU(3)-Irreducible decomposition

$$\begin{aligned}\mathcal{T}^{IRA} = & \underline{A_3^T} B_i (\bar{H}_{\bar{3}})^i (M)_k^j (M)_j^k + \underline{C_3^T} B_i (M)_j^i (M)_k^j (\bar{H}_{\bar{3}})^k + \underline{B_3^T} B_i (\bar{H}_3)^i (M)_k^k (M)_j^j \\ & + \underline{D_3^T} B_i (M)_j^i (\bar{H}_{\bar{3}})^j (M)_k^k + \underline{A_6^T} B_i (H_6)_k^{ij} (M)_j^l (M)_l^k + \underline{C_6^T} B_i (M)_j^i (\bar{H}_6)_k^{jl} (M)_l^k \\ & + \underline{B_6^T} B_i (\bar{H}_6)_k^{ij} (M)_j^k (M)_l^l + \underline{A_{15}^T} B_i (\bar{H}_{\overline{15}})_k^{ij} (M)_j^l (M)_l^k + \underline{C_{15}^T} B_i (M)_j^i (\bar{H}_{\overline{15}})_l^{jk} (M)_k^l \\ & + \underline{B_{15}^T} B_i (\bar{H}_{\overline{15}})_k^{ij} (M)_j^k (M)_l^l .\end{aligned}$$

SU(3) Flavour $[u, d, s]$

$$B = (B^+, B_d^0, B_s^0)$$

$$M = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta_q}{\sqrt{2}} + \frac{\eta_q'}{\sqrt{2}} & \pi^- & K^- \\ \pi^+ & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta_q}{\sqrt{2}} + \frac{\eta_q'}{\sqrt{2}} & \bar{K}^0 \\ K^+ & K^0 & \eta_s + \eta_s' \end{pmatrix}$$

$$\bar{H}_1^{12} = \lambda_u^{(d)}, \quad \bar{H}_1^{13} = \lambda_u^{(s)},$$

Equivalence of the decompositions

$$\bar{H}^{ij}_k = \frac{1}{8}(H_{\overline{15}})^{ij}_k + \frac{1}{4}(H_6)^{ij}_k - \frac{1}{8}(H_{\overline{3}})^i\delta^j_k + \frac{3}{8}(H_{\overline{3}'})^j\delta^i_k$$

Topological to SU(3)

X.-G. He and W. Wang: 1803.04227

$$A_3^T = -\frac{A}{8} + \frac{3E}{8} + T_{PA}, \qquad B_3^T = T_{SS} + \frac{3T_{AS} - T_{ES}}{8},$$

$$C_3^T = \frac{1}{8}(3A - C - E + 3T) + T_P, \qquad D_3^T = T_S + \frac{1}{8}(3C - T_{AS} + 3T_{ES} - T)$$

$$A_6^T = \frac{1}{4}(A - E), \qquad B_6^T = \frac{1}{4}(T_{ES} - T_{AS}),$$

$$C_6^T = \frac{1}{4}(-C + T), \qquad A_{15}^T = \frac{A + E}{8},$$

$$B_{15}^T = \frac{T_{ES} + T_{AS}}{8}, \qquad C_{15}^T = \frac{C + T}{8},$$

SU(3) amplitudes from data

Perform a χ^2 fit $\chi^2 = \sum_i \left(\frac{\mathcal{O}_i^{\rm Theo} - \mathcal{O}_i^{\rm Exp}}{\sigma_i^{\rm Exp}} \right)^2$

10 Tree complex amplitudes

$$A_3^T\,,\ C_3^T\,,\ A_6^T\,,\ C_6^T\,,\ A_{15}^T\,,\ C_{15}^T\,,\ B_3^T\,,\ B_6^T\,,\ B_{15}^T\,,\ D_3^T$$

and 10 Penguin complex amplitudes (replace T for P above)

The combinations $C_6^T - A_6^T$ and $B_6^T + A_6^T$ always appear together (analogously for penguins)

Redefine

$$C_6^T - A_6^T \to C_6^T \qquad C_6^P - A_6^P \to C_6^P$$

$$B_6^T + A_6^T \to B_6^T \qquad B_6^P + A_6^P \to B_6^P$$

Absorb a global phase by taking C_3^P as a real parameter

35 parameters + θ_{FKS} = 36 parameters to fit.

SU(3) amplitudes from data

Best fit point (modulus in GeV^3)

$\lvert A_3^T\rvert = 0.029,$	$\delta_{A_3^T} = -3.083,$	$\lvert C_3^T\rvert = 0.258,$	$\delta_{C_3^T} = -0.105,$
$\lvert C_6^T\rvert = 0.235,$	$\delta_{C_6^T} = -0.079,$	$\lvert A_{15}^T\rvert = 0.029,$	$\delta_{A_{15}^T} = -3.083,$
$\lvert C_{15}^T\rvert = 0.151,$	$\delta_{C_{15}^T} = 0.061,$	$\lvert B_3^T\rvert = 0.034,$	$\delta_{B_3^T} = 3.087$
$\lvert B_6^T\rvert = 0.033,$	$\delta_{B_6^T} = -0.286,$	$\lvert B_{15}^T\rvert = 0.008,$	$\delta_{B_{15}^T} = -1.892$
$\lvert D_3^T\rvert = 0.055,$	$\delta_{D_3^T} = 2.942,$		

$\lvert A_3^P\rvert = 0.014,$	$\delta_{A_3^P} = -1.328,$	$\lvert C_6^P\rvert = 0.145,$	$\delta_{C_6^P} = -2.881,$
$\lvert A_{15}^P\rvert = 0.003,$	$\delta_{A_{15}^P} = 2.234,$	$\lvert C_{15}^P\rvert = 0.003,$	$\delta_{C_{15}^P} = -0.608,$
$\lvert B_3^P\rvert = 0.043,$	$\delta_{B_3^P} = 2.367,$	$\lvert B_6^P\rvert = 0.099,$	$\delta_{B_6^P} = 0.353,$
$\lvert B_{15}^P\rvert = 0.031,$	$\delta_{B_{15}^P} = -0.690,$	$\lvert D_3^P\rvert = 0.030,$	$\delta_{D_3^P} = 0.477,$
$\lvert C_3^P\rvert = 0.008,$	$\theta_{FKS} = 0.628.$		

Annihilation amplitudes below 10%.

$$\chi^2/d.o.f. = 0.851$$

QCF Factorization decomposition

$$\mathcal{A}^{\mathrm{QCDF}} = i\frac{G_F}{\sqrt{2}}\sum_{p=u,c} A_{M_1M_2}\Big\{BM_1\left(\alpha_1\delta_{pu}\hat{U} + \alpha_4^p\hat{I} + \alpha_{4,EW}^p\hat{Q}\right)M_2\,\Lambda_p$$

$$+\,BM_1\Lambda_p\cdot\mathrm{Tr}\left[\left(\alpha_2\delta_{pu}\hat{U} + \alpha_3^p\hat{I} + \alpha_{3,EW}^p\,\hat{Q}\right)M_2\right]$$

$$+\,B\left(\beta_2\delta_{pu}\hat{U} + \beta_3^p\hat{I} + \beta_{3,EW}^p\,\hat{Q}\right)M_1M_2\Lambda_p$$

$$+\,B\Lambda_p\cdot\mathrm{Tr}\left[\left(\beta_1\delta_{pu}\hat{U} + \beta_4^p\hat{I} + b_{4,EW}^p\,\hat{Q}\right)M_1M_2\right]$$

$$+\,B\left(\beta_{S2}\delta_{pu}\hat{U} + \beta_{S3}^p\hat{I} + \beta_{S3,EW}^p\,\hat{Q}\right)M_1\Lambda_p\cdot\mathrm{Tr}M_2$$

$$+\,B\Lambda_p\cdot\mathrm{Tr}\left[\left(\beta_{S1}\delta_{pu}\hat{U} + \beta_{S4}^p\hat{I} + b_{S4,EW}^p\hat{Q}\right)M_1\right]\cdot\mathrm{Tr}M_2\Big\}$$

$$\Lambda_p = \begin{pmatrix} 0 \\ \lambda_p^{(d)} \\ \lambda_p^{(s)} \end{pmatrix}, \qquad \hat{U} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix},$$

$$\hat{Q} = \frac{3}{2}Q = \begin{pmatrix} 1 & 0 & 0 \\ 0 & -\frac{1}{2} & 0 \\ 0 & 0 & -\frac{1}{2} \end{pmatrix}, \qquad \hat{I} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix},$$

$$A_{M_1M_2} = M_B^2\,F_0^{B\to M_1}(0)\,f_{M_2}$$

Beneke et al: 0308039

QCF Factorization-Topological Equivalence

We consider the following results

$$\alpha_3^u = \alpha_3^c = \alpha_3, \quad \alpha_{3,EW}^u = \alpha_{3,EW}^c = \alpha_{3,EW}, \quad \beta_i^u = \beta_i^c = \beta_i, \quad b_i^u = b_i^c = b_i$$

$$|\alpha_{4,EW}^c - \alpha_{4,EW}^u| < 10^{-3} \qquad |\alpha_4^c - \alpha_4^u| \sim 2\%$$

NLO

NNLO

Bell, Beneke, Huber, Li:2002.03262

QCDF to topological transformation rules

$$T = A_{M_1M_2}\alpha_1, \quad C = A_{M_1M_2}\alpha_2, \quad E = A_{M_1M_2}\beta_1,$$

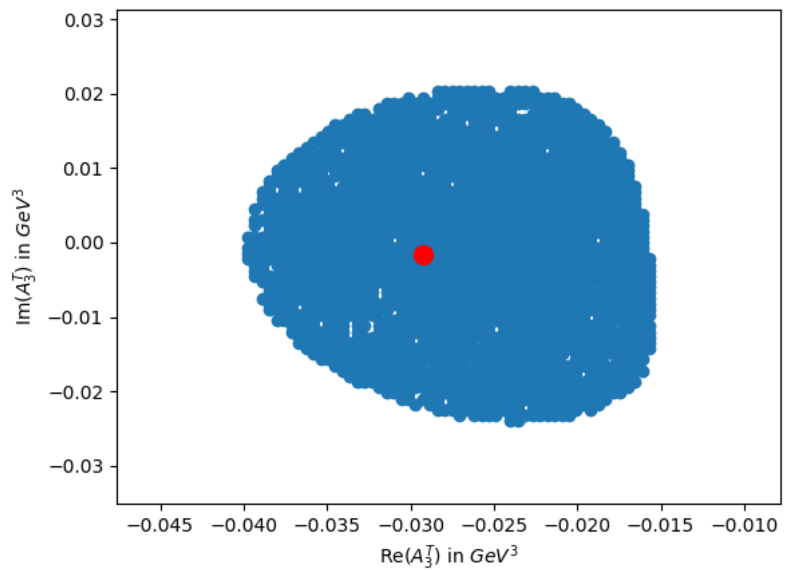
$$A = A_{M_1M_2}\beta_2, \quad T_{AS} = A_{M_1M_2}\beta_{S1}, \quad T_{ES} = A_{M_1M_2}\beta_{S2},$$

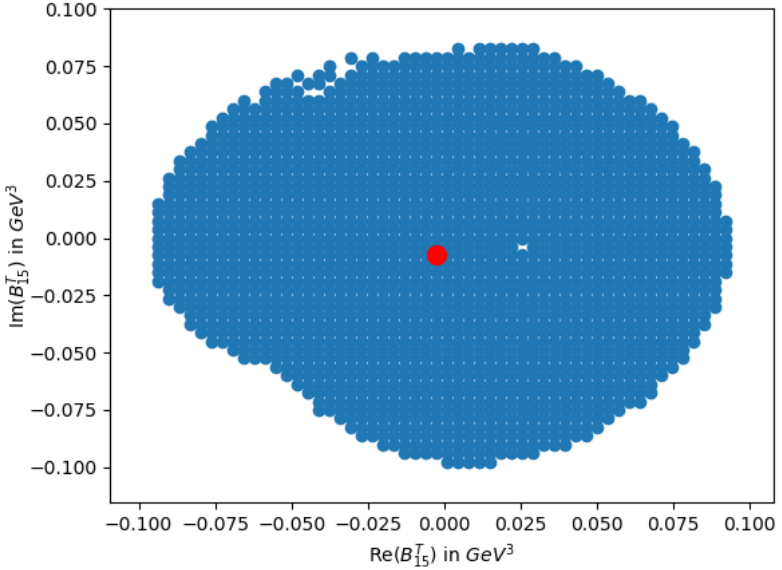
$$S = -A_{M_1M_2}\left[\alpha_3 + \beta_{S3} - \frac{\alpha_{3,EW}}{2} - \frac{\beta_{S3,EW}}{2}\right],$$

$$P = -A_{M_1M_2}\left[\alpha_4^c + \beta_3 - \frac{\alpha_{4,EW}^c}{2} - \frac{\beta_{3,EW}}{2}\right],$$

$$A_{M_1M_2} = (1.25 \pm 0.17)\ \mathrm{GeV}^3$$

SU(3) Confidence Regions





The real and imaginary components of the weak annihilation amplitudes as allowed by data can be between 4% and 30%.

Optimized Observables

Another way to deal with the power corrections is to construct optimized observables

Use a ratio involving as initial state B_s (numerator) vs B_d (denominator) to benefit from flavour symmetry

$$L_{K^*\bar{K}^*} = \rho(m_{K^{*0}}, m_{K^{*0}}) \frac{\mathcal{B}(\bar{B}_s \to K^{*0}\bar{K}^{*0})}{\mathcal{B}(\bar{B}_d \to K^{*0}\bar{K}^{*0})} \frac{f_L^{B_s}}{f_L^{B_d}} = \frac{|A_0^s|^2 + |\bar{A}_0^s|^2}{|A_0^d|^2 + |\bar{A}_0^d|^2}$$

since the final states are vector states only the longitudinal amplitude is free from infrared divergences at LO.

S. Descotes, J. Matias, et al [2011.07867]

A Biswas, S. Descotes, J. Matias, GTX et al [2301.10542]

$f_L^{B_s}, f_L^{B_d}$ Longitudinal polarization fractions

$\rho(m_{K^{*0}}, m_{K^{*0}})$ Phase space function

Optimized Observables

$$L_{K^*\bar{K}^*} = \frac{|A_0^s|^2 + |\bar{A}_0^s|^2}{|A_0^d|^2 + |\bar{A}_0^d|^2} = \kappa \left|\frac{P_s}{P_d}\right|^2 \left[\frac{1 + |\alpha^s|^2 \left|\frac{\Delta_s}{P_s}\right|^2 + 2\mathrm{Re}\left(\frac{\Delta_s}{P_s}\right)\mathrm{Re}(\alpha^s)}{1 + |\alpha^d|^2 \left|\frac{\Delta_d}{P_d}\right|^2 + 2\mathrm{Re}\left(\frac{\Delta_d}{P_d}\right)\mathrm{Re}(\alpha^d)}\right]$$

$$\kappa = \left|\frac{\lambda_u^s + \lambda_c^s}{\lambda_u^s + \lambda_c^s}\right|^2 = 22.91^{+0.48}_{-0.47},$$

$$\alpha^d = \frac{\lambda_u^d}{\lambda_u^d + \lambda_c^d} = -0.0135^{+0.0123}_{-0.0124} + 0.4176^{+0.0123}_{-0.0124} i,$$

$$\alpha^s = \frac{\lambda_u^s}{\lambda_u^s + \lambda_c^s} = 0.0086^{+0.0004}_{-0.0004} - 0.0182^{+0.0006}_{-0.0006} i.$$

S. Descotes, J. Matias, et al [2011.07867]

SU(3)	Naive factorization	QCD factorization
$\left\lvert\frac{P_s}{P_d}\right\rvert = 1 \pm 0.3$	$\left\lvert\frac{P_s}{P_d}\right\rvert = 0.91^{+0.20}_{-0.17}$	$\left\lvert\frac{P_s}{P_d}\right\rvert = 0.92^{+0.20}_{-0.18}$

Theoretical and Experimental values

Final Experimental result $L^{\rm exp}_{K^*\bar{K}^*} = 4.43 \pm 0.92$

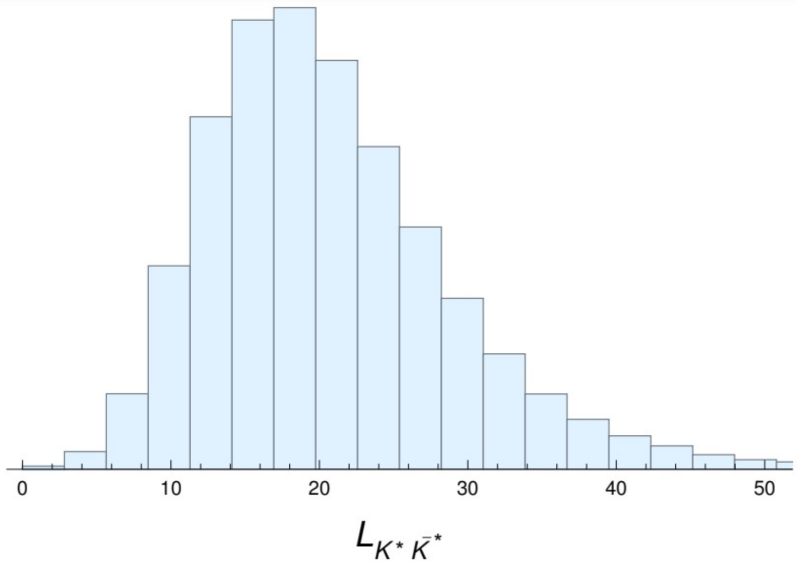
Theory

SU(3) $L_{K^*\bar{K}^*} = 23^{+16}_{-12}$ 1.9σ

Naive factorization $L_{K^*\bar{K}^*} = 19.2^{+9.3}_{-6.5}$ 3.0σ

QCD factorization $L^{\rm SM}_{K^*\bar{K}^*} = 19.53^{+9.14}_{-6.64}$ 2.6σ

Montecarlo distribution obtained from varying the nuisance parameters



2.6 σ discrepancy between theory and experiment

Alternative Observables

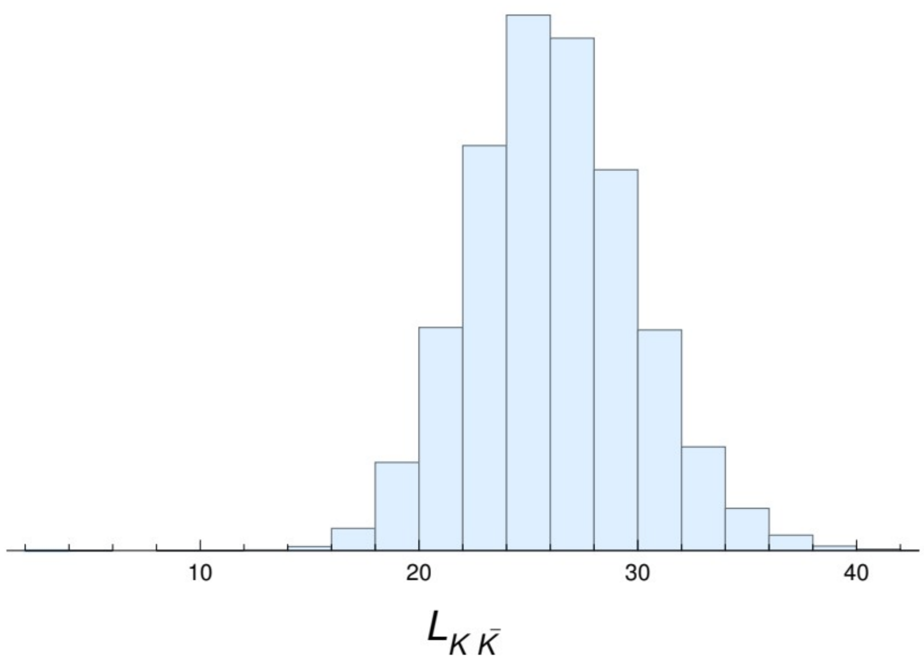
Proceed in an analogous way to define

$$L_{K\bar{K}} = \rho(m_{K^0}, m_{K^0}) \frac{\mathcal{B}(\bar{B}_s \to K^0\bar{K}^0)}{\mathcal{B}(\bar{B}_d \to K^0\bar{K}^0)} = \frac{|A^s|^2 + |\bar{A}^s|^2}{|A^d|^2 + |\bar{A}^d|^2},$$

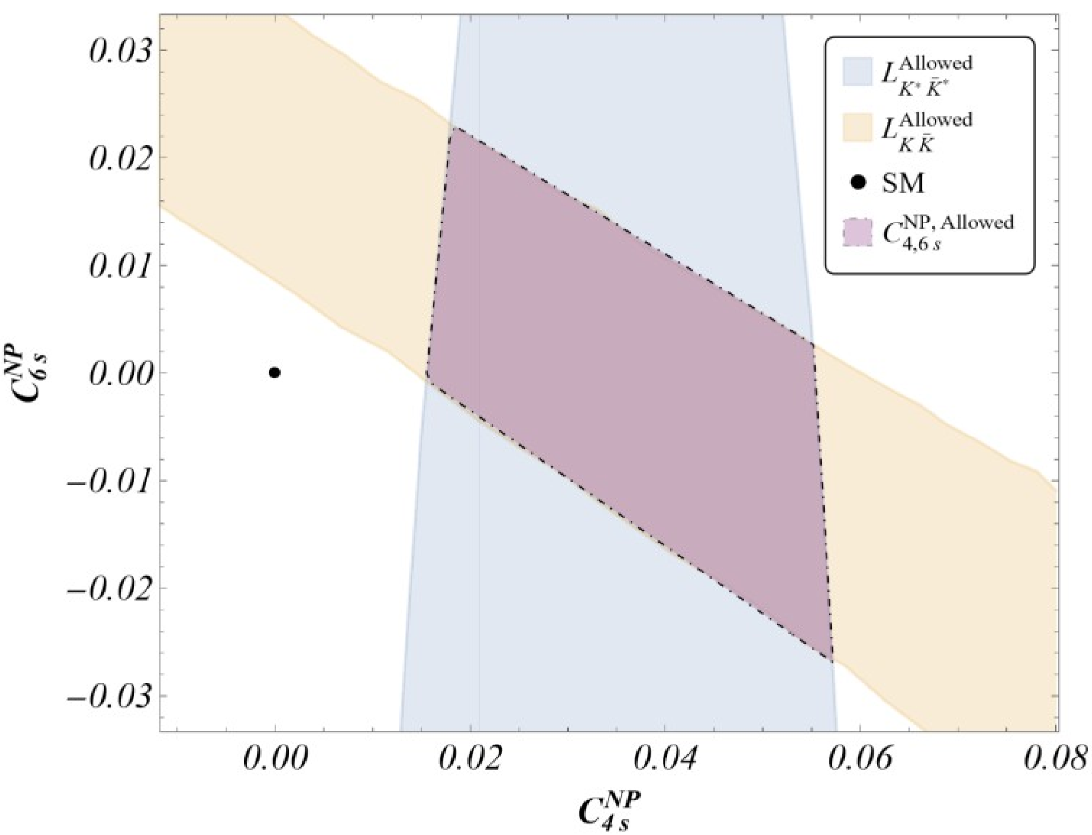
Experimental result $L_{K\bar{K}}^{\exp} = 14.58 \pm 3.37$

QCD factorization $L_{K\bar{K}}^{\rm SM} = 26.00^{+3.88}_{-3.59}$

2.4 σ discrepancy



Explaining the tensions via NP



Solutions for C_{4s}^{NP} and C_{6s}^{NP} combined

Notice that C_{6s}^{NP} requires $C_{4s}^{NP} \neq 0$

Summary and Outlook

- Power corrections are a major source of uncertainty in our determinations for non-leptonic B meson decays.
- By fitting to data we have determined bounds for different QCDF amplitudes.
- The real and imaginary components of the weak annihilation amplitudes as allowed by data can be between 4% and 30%.
- Another way of dealing to reduce our sensitivity towards these effects is by using optimized observables based on ratios of squared amplitudes.

Acknowledgements

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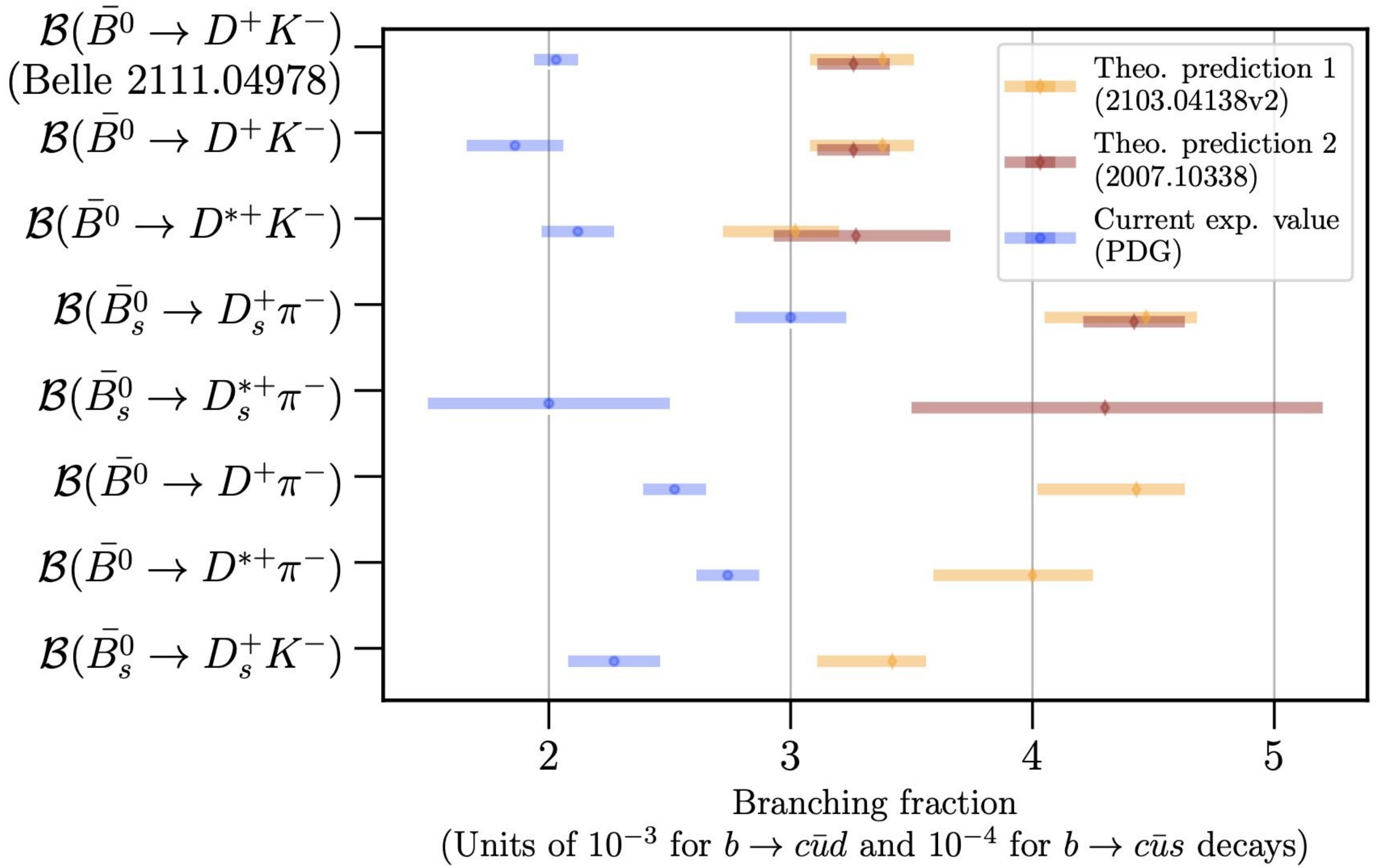
Anomalies in $B \to D\,K$ *and* $B \to D\,\pi$



The state of the art experimental and theory determinations are in strong statistical tension (up to 7 to 9 standard deviations).

Decay Amplitudes Parameterizations

Consider the process $B \to PP$

where P is a charmless pseudoscalar meson

The physical amplitude can be decomposed as

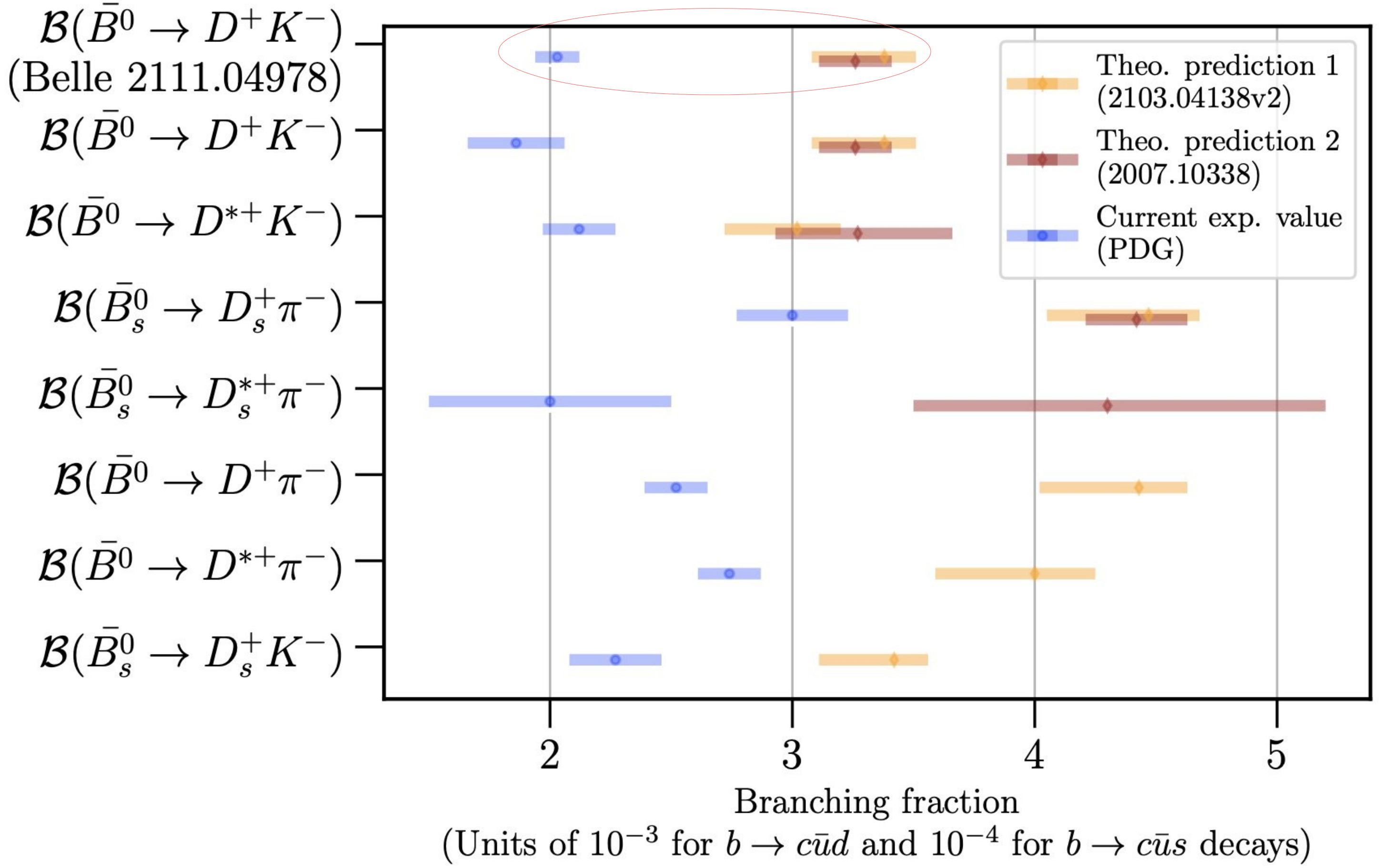
$$\mathcal{A}^{TDA} = i\frac{G_F}{\sqrt{2}}\left[\mathcal{T}^{TDA} + \mathcal{P}^{TDA}\right]$$

$\mathcal{T}^{TDA} \to \lambda_u^{(q)}$, $\mathcal{P}^{TDA} \to \lambda_t^{(q)}$

$$\lambda_p^{(q)} = V_{pb}V_{pq}^{*} \qquad \lambda_u^{(q)} \qquad \lambda_t^{(q)} \qquad q = d, s$$

$$\lambda_u^{(q)} + \lambda_c^{(q)} + \lambda_t^{(q)} = 0$$

Anomalies in $B \to D\,K$ *and* $B \to D\,\pi$



These processes are particularly clean from theory uncertainties that affect most of the hadronic decays (annihilation)

SU(3) amplitudes from data

The physical amplitudes can be expressed as linear combinations of the SU(3) sub-amplitudes

Channel	A_3^T	C_3^T	A_6^T	C_6^T	A_{15}^T	C_{15}^T	B_3^T	B_6^T	B_{15}^T	D_3^T
$B^- \to \pi^0\pi^-$	0	0	0	0	0	$4\sqrt{2}$	0	0	0	0
$B^- \to K^0K^-$	0	1	1	-1	3	-1	0	0	0	0
$B^0 \to \pi^+\pi^-$	2	1	-1	1	1	3	0	0	0	0
$B^0 \to \pi^0\pi^0$	2	1	-1	1	1	-5	0	0	0	0
$B^0 \to K^+K^-$	2	0	0	0	2	0	0	0	0	0
$B^0 \to K^0\bar{K}^0$	2	1	1	-1	-3	-1	0	0	0	0
$B_s \to \pi^0K^0$	0	$-\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	$-\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	$\frac{5}{\sqrt{2}}$	0	0	0	0
$B_s \to \pi^-K^+$	0	1	-1	1	-1	3	0	0	0	0
$B^- \to \pi^0K^-$	0	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	$-\frac{1}{\sqrt{2}}$	$\frac{3}{\sqrt{2}}$	$\frac{7}{\sqrt{2}}$	0	0	0	0
$B^- \to \pi^-K^0$	0	1	1	-1	3	-1	0	0	0	0
$B^0 \to \pi^+K^-$	0	1	-1	1	-1	3	0	0	0	0
$B^0 \to \pi^0K^0$	0	$-\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	$-\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	$\frac{5}{\sqrt{2}}$	0	0	0	0
$B_s \to \pi^+\pi^-$	2	0	0	0	2	0	0	0	0	0
$B_s \to \pi^0\pi^0$	2	0	0	0	2	0	0	0	0	0
$B_s \to K^+K^-$	2	1	-1	1	1	3	0	0	0	0
$B_s \to K^0\bar{K}^0$	2	1	1	-1	-3	-1	0	0	0	0

SU(3) amplitudes from data

Include η contributions in the Feldmann–Kroll–Stech scheme

θ_{FKS} mixing angle *T. Feldmann et al: 9802409*

Channel	A_3^T	C_{3T}^T	A_6^T	C_6^T	A_{15}^T	C_{15}^T	B_3^T	B_6^T	B_{15}^T	D_3^T
$B^- \to \eta_q \pi^-$	0	$\sqrt{2}$	$\sqrt{2}$	0	$3\sqrt{2}$	$2\sqrt{2}$	0	$\sqrt{2}$	$3\sqrt{2}$	$\sqrt{2}$
$B^- \to \eta_s \pi^-$	0	0	0	1	0	-1	0	1	3	1
$B^0 \to \eta_q \pi^0$	0	-1	-1	0	5	2	0	-1	5	-1
$B^0 \to \eta_s \pi^0$	0	0	0	$-\frac{1}{\sqrt{2}}$	0	$\frac{1}{\sqrt{2}}$	0	$-\frac{1}{\sqrt{2}}$	$\frac{5}{\sqrt{2}}$	$-\frac{1}{\sqrt{2}}$
$B_s \to \eta_q K^0$	0	$\frac{1}{\sqrt{2}}$	$-\frac{1}{\sqrt{2}}$	$-\frac{1}{\sqrt{2}}$	$-\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	0	$-\sqrt{2}$	$-\sqrt{2}$	$\sqrt{2}$
$B_s \to \eta_s K^0$	0	1	-1	0	-1	-2	0	-1	-1	1
$B^- \to \eta_q K^-$	0	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	$\frac{3}{\sqrt{2}}$	$\frac{5}{\sqrt{2}}$	0	$\sqrt{2}$	$3\sqrt{2}$	$\sqrt{2}$
$B^- \to \eta_s K^-$	0	1	1	0	3	-2	0	1	3	1
$B^0 \to \eta_q K^0$	0	$\frac{1}{\sqrt{2}}$	$-\frac{1}{\sqrt{2}}$	$-\frac{1}{\sqrt{2}}$	$-\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$	0	$-\sqrt{2}$	$-\sqrt{2}$	$\sqrt{2}$
$B^0 \to \eta_s K^0$	0	1	-1	0	-1	-2	0	-1	-1	1
$B_s \to \eta_q \pi^0$	0	0	-2	0	4	0	0	-2	4	0
$B_s \to \eta_s \pi^0$	0	0	0	$-\sqrt{2}$	0	$2\sqrt{2}$	0	$-\sqrt{2}$	$2\sqrt{2}$	0
$B^0 \to \eta_q \eta_q$	1	$\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	2	-1	1	1
$B^0 \to \eta_q \eta_s$	0	0	0	$\frac{1}{\sqrt{2}}$	0	$-\frac{1}{\sqrt{2}}$	$2\sqrt{2}$	$\frac{1}{\sqrt{2}}$	$-\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}$
$B^0 \to \eta_s \eta_s$	1	0	1	0	-1	0	1	1	-1	0
$B_s \to \eta_q \eta_q$	1	0	0	0	1	0	2	0	2	0
$B_s \to \eta_q \eta_s$	0	0	0	0	0	$\sqrt{2}$	$2\sqrt{2}$	0	$-\sqrt{2}$	$\sqrt{2}$
$B_s \to \eta_s \eta_s$	1	1	0	0	-2	-2	1	0	-2	1