QCD Challenges in Nonleptonic Decays: SCET Factorization Successes & Open Questions

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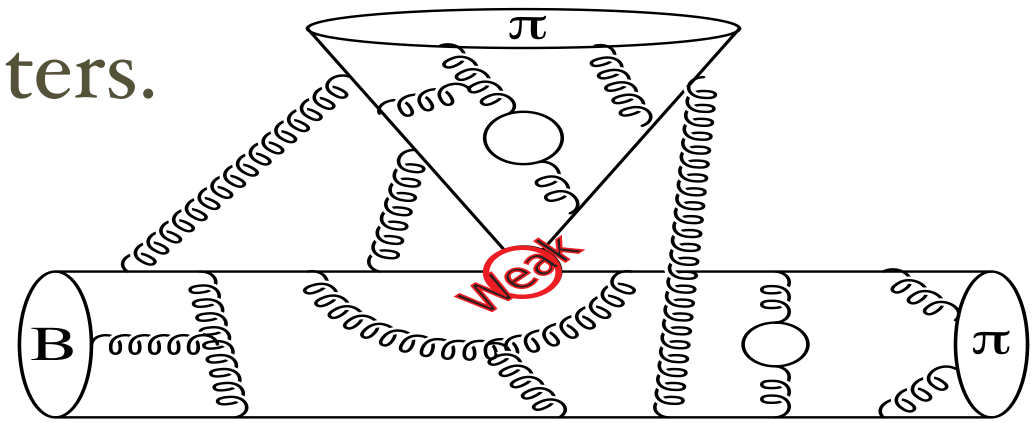
Flavour as a Window to New Physics at the LHC
CERN June 2008

Outline:

- Intro to Factorization
- Factorization vs. Data, successes
- Nonleptonic Predictions $B \to PP, \ B \to PV, \ B \to VV$
    - Global fits & uncertainties
    - Penguin-ology
    - Convolution Singularites (0 bin)
- Outlook

Ideally we would compute nonleptonic amplitudes exactly using the standard model Lagrangian. They would all be "related" by SM parameters. but...



... Hadronic Uncertainties ...

In practice relations between SM amplitudes are approximate, and are always based on expansions of $\mathcal{L}^{\rm SM}$

$$\text{Observable} = O^{(0)} + \epsilon\, O^{(1)} + \epsilon^2 O^{(2)} + \ldots$$

$$\epsilon \ll 1$$

Expansion — Parameter

- $m_W, m_t \gg m_b$ $\quad H_{\text{weak}} = \frac{G_F}{\sqrt{2}} \sum_i \lambda^i C_i(\mu) O_i(\mu)$ $\quad \epsilon^2 = \frac{m_b^2}{m_W^2} \sim 0.003$

- $\lambda^2 \ll 1$ $\quad V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \sim \begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}$ $\quad \epsilon^2 = \lambda^2 \sim 0.04$

- $\Lambda \gg m_{u,d}$ — SU(2) ie. isospin — $\epsilon = \frac{m_{u,d}}{\Lambda} \sim 0.02$

- $m_b \gg \Lambda$ — Heavy Quark Effective Theory — $\epsilon = \frac{\Lambda}{m_b} \sim 0.1$

- $E_\pi \gg \Lambda$ — Factorization for Nonleptonic decays (Soft Collinear Effective Theory) — $\epsilon = \frac{\Lambda}{E_\pi} \sim 0.2$

- $\Lambda \gg m_{s,d,u}$ — SU(3) or U-spin — $\epsilon = \frac{m_s}{\Lambda} \sim 0.3$

What precisely are we testing when we make measurements of β or γ with different methods?

- Using CKM unitarity of the standard model we can write:

$$A^{SM}(\bar{B} \to M_1 M_2) = S_1 + S_2 e^{-i\gamma}$$

where $S_{1,2}$ are complex, CP even, "hadronic amplitudes".

- Consider an arbitrary new physics contribution to this channel, and write:

$$A^{NP}(\bar{B} \to M_1 M_2) = N e^{i\phi} = N_1 + N_2 e^{-i\gamma}$$

$$\& \quad N e^{-i\phi} = N_1 + N_2 e^{i\gamma}$$

Botella & Silva

$N_{1,2}$ are complex and CP even.

eg. $\mathrm{Im} N_1 = \dfrac{\sin(\gamma+\phi)}{\sin(\gamma)} \mathrm{Im}(N)$

- Thus new physics in the decay simply shifts hadronic amplitudes:

$$S_1 \to S_1 + N_1 \quad , \quad S_2 \to S_2 + N_2$$

Measurements test relations between SM amplitudes S_i which may be violated by new physics.

More Expansion Parameters

More Relations

More tests for new physics

Larger SM uncertainties

Counting parameters

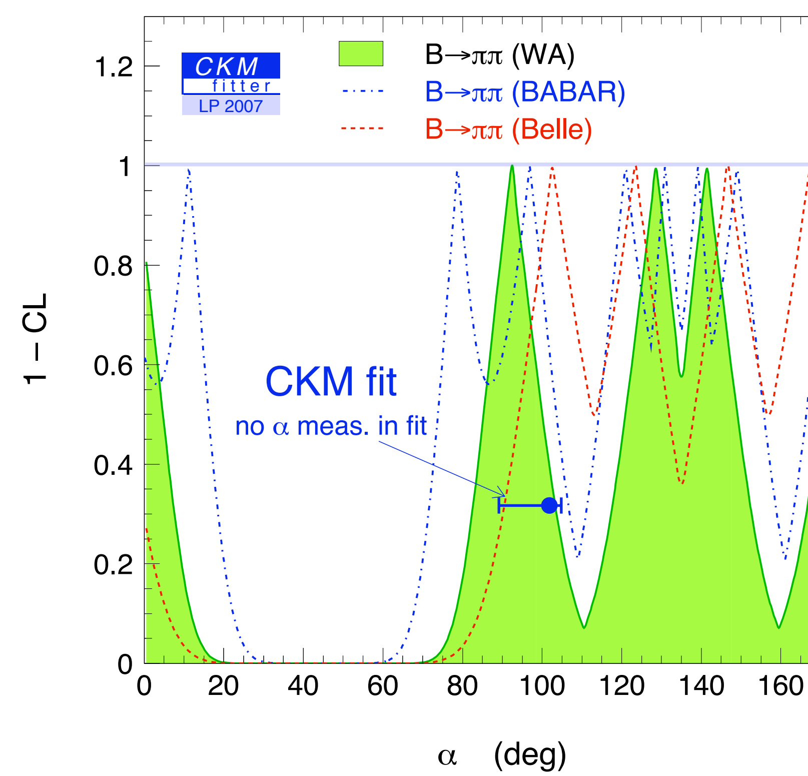
	no expn.	SU(2)	SU(3)	SCET +SU(2)	SCET +SU(3)
$B \to \pi\pi$	11	7/5	15/13	4	4
$B \to K\pi$	15	11		+5(6)	
$B \to K\bar{K}$	11	11	+4/0	+3(4)	+0

a/b remove small $O_{8,9}$

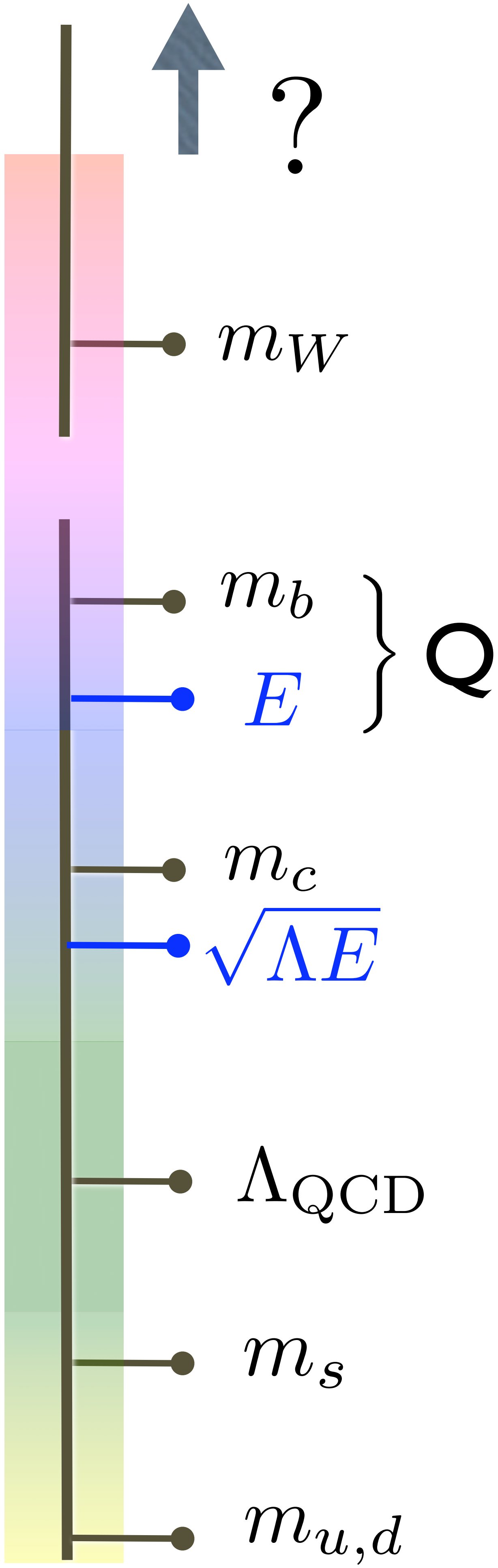
eg. Isospin Analysis

- tests small penguins in $B \to \pi^0\pi^-$, $B \to \rho^0\rho^-$
- can't see new physics in $I = 0$ amplitudes

Baek, Botella, London, Silva



so we don't want to stop here!



$\boxed{\text{Factorization at } m_b}$

$\mathrm{SCET_I}$

expansion in $\alpha_s(m_b) \simeq 0.22$

all that is used in BPRS approach

hard-scale

$\Downarrow$

intermediate-scale

$\Downarrow$

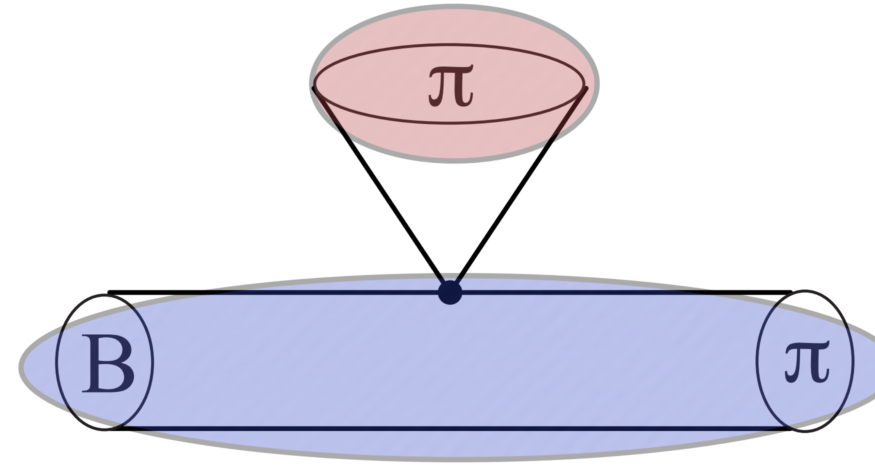
hadronic-scale

} treated as hadronic parameters

Recently $\mathcal{O}(\alpha_s(m_b))$ matching completed.

Beneke & Jager (tree & penguin)
Jain, Rothstein, I.S. (penguin)

Factorization at m_b



All the LO terms are factorized into two types of form factors

Nonleptonic $\quad B \to M_1 M_2$

$$A(B\to M_1M_2) = A^{c\bar{c}} + N\Big\{ f_{M_2}\,\zeta^{BM_1}\int du\, T_{2\zeta}(u)\,\phi^{M_2}(u) + f_{M_2}\int du\,dz\, T_{2J}(u,z)\,\zeta_J^{BM_1}(z)\,\phi^{M_2}(u) + (1\leftrightarrow 2)\Big\}$$

no endpoint singularities here

soft form factor

twist-2 distn.

hard form factor

twist-2 distn.

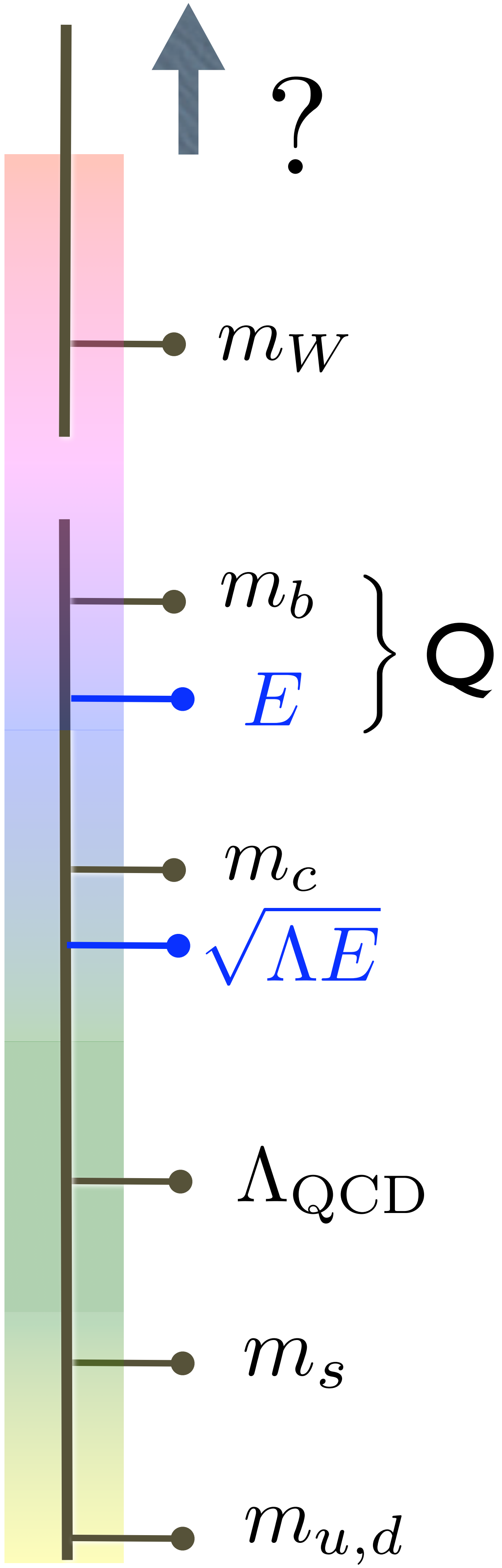
Form Factors

$B \to$ pseudoscalar: $f_+,\ f_0,\ f_T$
$B \to$ vector: $V,\ A_0,\ A_1,\ A_2,\ T_1,\ T_2,\ T_3$

Same form factors at large E

$$f(E) = \int dz\, T(z,E)\,\zeta_J^{BM}(z,E) + C(E)\,\zeta^{BM}(E)$$

$B \to \pi\ell\bar{\nu}$,
$B \to K^*\ell^+\ell^-$,
$B \to \rho\gamma$, ...



$\boxed{\text{Factorization at } \sqrt{E\Lambda}}$

$\mathrm{SCET_{II}}$

used in BBNS & pQCD approaches

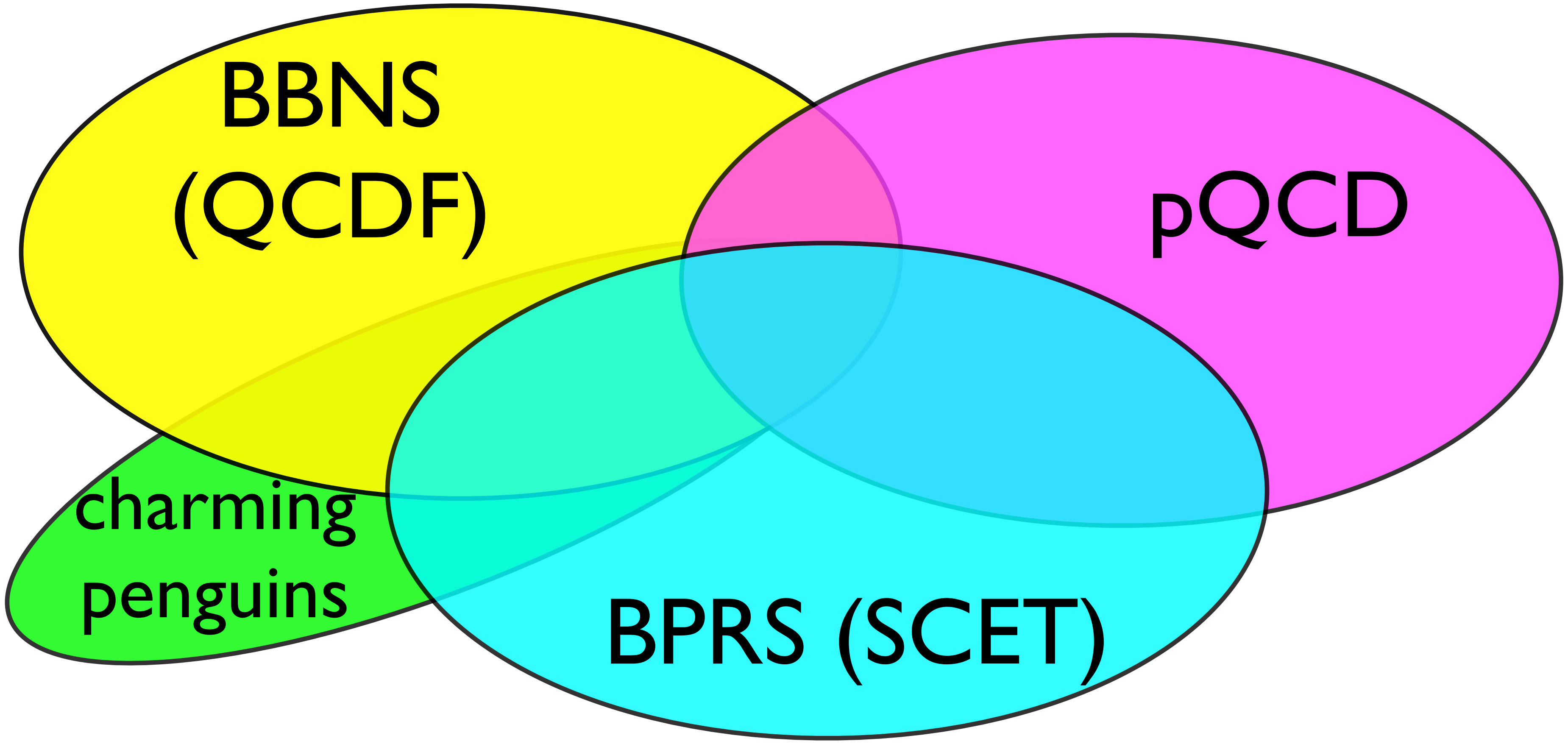
hard-scale

↓

intermediate-scale

↓

hadronic-scale } treated as hadronic parameters



Keum, Li, Sanda (pQCD);
Lu et al.;
Beneke,Buchalla,Neubert, Sachrajda,(BBNS);
Chay, Kim;
Bauer, Pirjol, Rothstein, I.S. (BPRS)
Ciuchini et al (charming penguin),

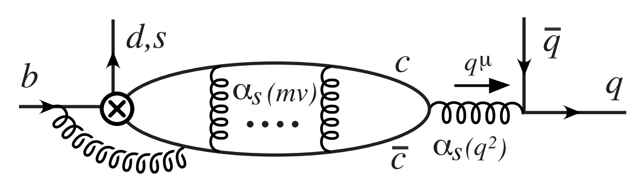
Key issues:

$$\underbrace{\alpha_s(Q^2)}\quad \underbrace{\alpha_s(E\Lambda)}$$
$$Q^2 \gg E\Lambda \gg \Lambda^2$$

- Treatment of perturbation theory at scales
- Treatment of $1/x^2$ endpoint singularities

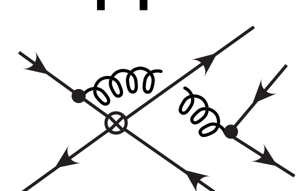
$$\int_0^1 dx \frac{\phi_\pi(x)}{x^2} \sim \int_0 \frac{dx}{x} = \infty$$

- Treatment of charm loops



threshold
NRQCD region

- Treatment of hadronic parameters appearing at LO in the expansion
- Treatment of annihilation



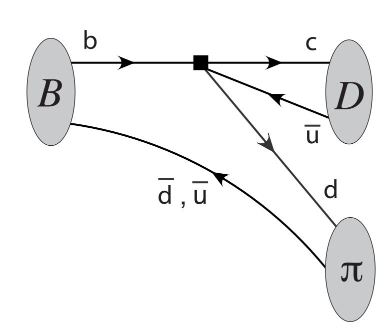
$$\sim \frac{\Lambda}{m_b}$$

Checking SCET Factorization (Successes)

$$\boxed{\bar{B}^0 \to D^0 M^0}$$

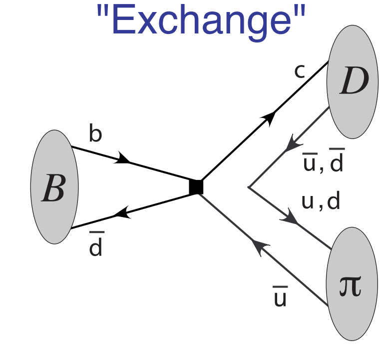
$\frac{\Lambda}{E_M}$ & $\frac{1}{N_c}$ suppressed

"Color suppressed"



$$A_{00}^{D^{(*)}\pi} = N_0^{(*)} \int dx\, dz\, dk_1^+ dk_2^+\, T^{(i)}(z)\, J^{(i)}(z,x,k_1^+,k_2^+)\, S^{(i)}(k_1^+,k_2^+)\, \phi_\pi(x) \;\; + A_{\rm long}^{D^{(*)}\pi}$$

"Exchange"



Mantry, Pirjol, I.S.
Blechman et al.

Predict

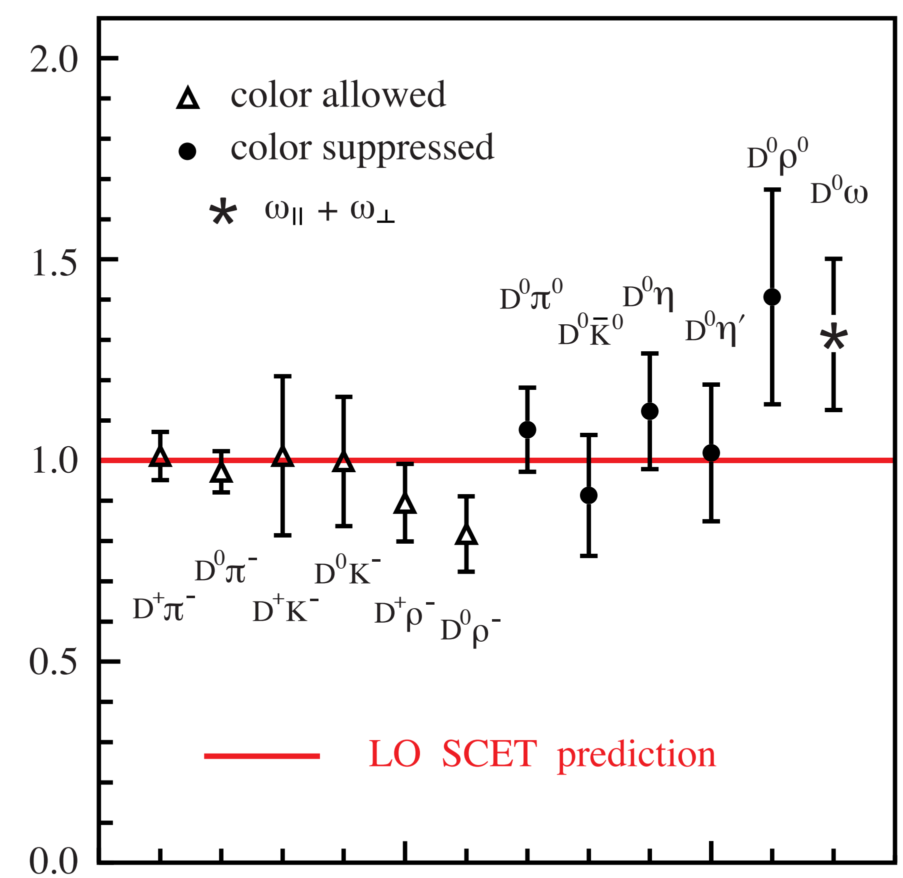
equal strong phases $\delta(DM) = \delta(D^*M)$

equal amplitudes $A(D^*M) = A(DM)$

Find

$$\delta(D\pi) = 30.4 \pm 4.8^\circ$$
$$\delta(D^*\pi) = 31.0 \pm 5.0^\circ$$

and $\rightarrow$ $\left|\frac{A(D^*M)}{A(D\,M)}\right|$



Without factorization

predictions spoiled by $\mathcal{O}\left(\frac{E_M}{m_c}\right) = \mathcal{O}(1)$ effects

$\boxed{B \to X_u e \bar{\nu}}$ in shape function region

Bigi et. al.; Neubert; Mannel, ...

$$m_b^2 \gg m_b \Lambda_{\rm QCD} \gg \Lambda_{\rm QCD}^2$$

$$d\Gamma = H(p^-, m_b) \int d\ell^+ J(p^-(p^+ - \ell^+)) S(\ell^+)$$

same scales as in nonleptonic factorization theorems and no sign of breakdown in power counting (eg. BLNP fits for Vub)

+ factorization for power corrections too in SCET

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eg. Model Independent predictions even at subleading order

K. Lee, arXiv:0802.0873

A weighted integral of the triple diff. rate can be taken to give the same leading + subleading shape functions as in $B \to X_s \gamma$ (using su3 for the 4-quark operator shape functions).

Thus, Vub can be extracted in a model independent way with corrections at $\mathcal{O}(\Lambda_{\rm QCD}^2/m_b^2)$ and $\mathcal{O}(m_s/m_b)$

In charmless nonleptonics:

I) small strong phase between color suppressed and tree amplitudes $\quad \mathrm{Im}\left(\frac{C}{T}\right) \sim \mathcal{O}\left(\alpha_s(m_b), \frac{\Lambda}{E_\pi}\right)$

$B \to \pi\pi$ Can use this to do isospin analysis without $C_{\pi^0\pi^0}$

Bauer et.al. (2008 updated)

$$\gamma^{\pi\pi} = 73.9^{\circ}{}^{+7.5}_{-10.3}\Big|_{\mathrm{exp}}\;{}^{+1.0}_{-2.5}\Big|_{\mathrm{thy}}$$ (expt. and theory errors)

there is a 2nd solution: $\gamma^{\pi\pi}_{\mathrm{2nd}} = 27.7^{\circ}{}^{+9.9}_{-7.3}\Big|_{\mathrm{exp}}\;{}^{+10}_{-4.5}\Big|_{\mathrm{thy}}$

$B \to \rho\rho$ same analysis applies

$$\gamma^{\rho\rho} = 77.5^{\circ}{}^{+7.4}_{-28}\Big|_{\mathrm{exp}}\;{}^{+1.0}_{-5.2}\Big|_{\mathrm{thy}} \qquad \gamma^{\rho\rho}_{\mathrm{2nd}} = 57.3^{\circ}{}^{+28}_{-7.5}\Big|_{\mathrm{exp}}\;{}^{+6.7}_{-4.1}\Big|_{\mathrm{thy}}$$ (overlaps)

1-σ from $\gamma^{\mathrm{CKMfit.}}_{\mathrm{global}} = 67.6^{\circ}{}^{+2.8^{\circ}}_{-4.5^{\circ}}$

$\gamma^{\mathrm{UTfit.}}_{\mathrm{global}} = 66.7^{\circ} \pm 6.4^{\circ}$

from Jan.08

2) Relations between semileptonic & nonleptonic

nonleptonic $B \longrightarrow \pi\pi$

- $$|V_{ub}|\zeta^{B\pi} = \frac{N_{\pi^0\pi^-}}{C_1^2 - C_2^2}\left[(C_1+C_2)t_c^{\pi\pi} - C_2 + \frac{4(C_1+C_2)t_c^{\pi\pi} - 3C_1 - C_2}{\langle x^{-1}\rangle_{\phi_\pi}}\right]\left[1+\mathcal{O}\Big(\alpha_s(m_b), \frac{\Lambda}{E}\Big)\right]$$
- $$|V_{ub}|\zeta_J^{B\pi} = \frac{N_{\pi^0\pi^-}}{C_1^2 - C_2^2}\left[\frac{-4(C_1+C_2)t_c^{\pi\pi} + 3C_1 + C_2}{\langle x^{-1}\rangle_{\phi_\pi}}\right]\left[1+\mathcal{O}\Big(\alpha_s(m_b), \frac{\Lambda}{E}\Big)\right]$$

from Jain et.al.

$$N_{\pi^0\pi^-} = \left[\frac{64\pi}{m_B^3 f_\pi^2}\frac{Br(B^- \to \pi^0\pi^-)}{\tau_{B^-}|V_{ud}|^2 G_F^2}\right]^{1/2} \qquad B_{\pi\pi} = \sqrt{1 - C^2_{\pi^+\pi^-} - S^2_{\pi^+\pi^-}}$$

$$t_c^{\pi\pi} = \left[\frac{Br(B^- \to \pi^+\pi^-)\tau_{B^-}}{Br(B^- \to \pi^0\pi^-)\tau_{B^0}}\frac{(1+B_{\pi\pi}\cos 2\beta + S_{\pi^+\pi^-}\sin 2\beta)}{4\sin^2\gamma}\right]^{1/2} = \frac{|T_{\pi\pi}|}{|T_{\pi\pi}+C_{\pi\pi}|}$$

semileptonic $B \longrightarrow \pi\ell\bar{\nu}$

- $$f_+(0) = (\zeta^{B\pi} + \zeta_J^{B\pi})\left[1+\mathcal{O}\Big(\alpha_s(m_b), \frac{\Lambda}{E}\Big)\right]$$
- $$\delta \equiv 1 - \frac{(m_B^2 - m_\pi^2)}{f_+(0)}\left(\frac{df_+}{dq^2}\bigg|_{q^2=0} - \frac{df_0}{dq^2}\bigg|_{q^2=0}\right) = \frac{2\zeta_J^{B\pi}}{\zeta_J^{B\pi} + \zeta^{B\pi}}\left[1+\mathcal{O}\Big(\alpha_s(m_b), \frac{\Lambda}{E}\Big)\right]$$

shape parameter Hill

δ from expt. + lattice has large uncertainty currently

Nonleptonic data gives:

form factors of similar size with small expt. uncertainties

$$\delta \approx 1$$

$$f_+(0) = \left(0.19 \pm 0.01\big|_{\rm exp} \pm 0.05\big|_{\rm thy}\right)\left(\frac{3.8\times 10^{-3}}{|V_{ub}|}\right)$$

Semileptonic data (with dispersion fit & lattice) gives:

Arnesen et.al. (2008 update)

$$f_+^{\rm FNAL}(0) = 0.23 \pm 0.03 \qquad f_+^{\rm HPQCD}(0) = 0.25 \pm 0.03$$

At Super B

- we should use precision semileptonic data to determine hadronic parameters

  from $B \to \{\pi, \rho, \eta, \omega, \eta'\}\ell\bar{\nu}$ spectra

- plus get help from the Lattice, particularly for form factors that are difficult/impossible to measure

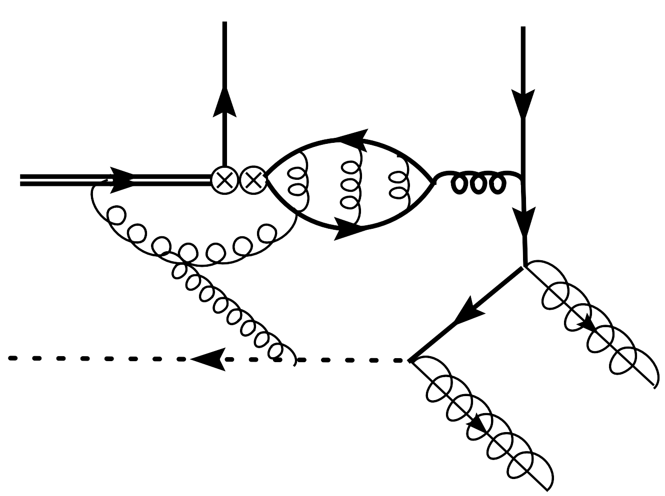
Counting parameters

Global Fit

	no expn.	SU(2)	SU(3)	SCET +SU(2)	SCET +SU(3)
$B \to \pi\pi$	11	7/5	15/13	4	4
$B \to K\pi$	15	11		+5(6)	
$B \to K\bar{K}$	11	11	+4/0	+3(4)	+0

Extension to isosinglets

$\pi\eta, \eta\eta, K\eta', \ldots$



Williamson & Zupan

$+4$

(2 solutions)

Predictions (4 param. fit)

$\gamma = 59^\circ$

Branching Fraction
Direct CP Asymmetry

Mode	Exp	Theory
$\bar{B}^0 \to \pi^-\pi^+$	5.0 ± 0.4	$5.4 \pm 1.3 \pm 1.4 \pm 0.4$
	0.37 ± 0.23 [a]	$0.20 \pm 0.17 \pm 0.19 \pm 0.05$
$\bar{B}^0 \to \pi^0\pi^0$	1.45 ± 0.52 [b]	$0.84 \pm 0.29 \pm 0.30 \pm 0.19$
	0.28 ± 0.40	$-0.58 \pm 0.39 \pm 0.39 \pm 0.13$
$B^- \to \pi^0\pi^-$	5.5 ± 0.6	$5.2 \pm 1.6 \pm 2.1 \pm 0.6$
	0.01 ± 0.06	< 0.04
$B^- \to K^0K^-$	1.2 ± 0.3	$1.1 \pm 0.4 \pm 1.4 \pm 0.03$
	$-$	$-$
$\bar{B}^0 \to K^0\bar{K}^0$	0.96 ± 0.25	$1.0 \pm 0.4 \pm 1.4 \pm 0.03$
	$-$	$-$
$\bar{B}^0 \to \pi^0\bar{K}^0$	11.5 ± 1.0	$9.4 \pm 3.6 \pm 0.2 \pm 0.3$
	0.02 ± 0.13	$0.05 \pm 0.04 \pm 0.04 \pm 0.01$
$\bar{B}^0 \to K^-\pi^+$	18.9 ± 0.7	$20.1 \pm 7.4 \pm 1.3 \pm 0.6$
	-0.115 ± 0.018	$-0.06 \pm 0.05 \pm 0.06 \pm 0.02$
$B^- \to K^-\pi^0$	12.1 ± 0.8	$11.3 \pm 4.1 \pm 1.0 \pm 0.3$
	0.04 ± 0.04	$-0.11 \pm 0.09 \pm 0.11 \pm 0.02$
$B^- \to \bar{K}^0\pi^-$	24.1 ± 1.8 [c]	$20.8 \pm 7.9 \pm 0.6 \pm 0.7$
	-0.02 ± 0.05 [d]	< 0.05

errors: su3, 1/mb, fit

Predictions (4 param. fit)

$\gamma = 59^o$

Branching Fraction
Direct CP Asymmetry

Mode	Exp.	Theory I	Theory II
$B^- \to \pi^-\eta$	4.3 ± 0.5 $(S = 1.3)$	$4.9 \pm 1.7 \pm 1.0 \pm 0.5$	$5.0 \pm 1.7 \pm 1.2 \pm 0.4$
	-0.11 ± 0.08	$0.05 \pm 0.19 \pm 0.21 \pm 0.05$	$0.37 \pm 0.19 \pm 0.21 \pm 0.05$
$B^- \to \pi^-\eta'$	2.53 ± 0.79 $(S = 1.5)$	$2.4 \pm 1.2 \pm 0.2 \pm 0.4$	$2.8 \pm 1.2 \pm 0.3 \pm 0.3$
	0.14 ± 0.15	$0.21 \pm 0.12 \pm 0.10 \pm 0.14$	$0.02 \pm 0.10 \pm 0.04 \pm 0.15$
$\bar{B}^0 \to \pi^0\eta$	–	$0.88 \pm 0.54 \pm 0.06 \pm 0.42$	$0.68 \pm 0.46 \pm 0.03 \pm 0.41$
	–	$0.03 \pm 0.10 \pm 0.12 \pm 0.05$	$-0.07 \pm 0.16 \pm 0.04 \pm 0.90$
$\bar{B}^0 \to \pi^0\eta'$	–	$2.3 \pm 0.8 \pm 0.3 \pm 2.7$	$1.3 \pm 0.5 \pm 0.1 \pm 0.3$
	–	$-0.24 \pm 0.10 \pm 0.19 \pm 0.24$	–
$\bar{B}^0 \to \eta\eta$	–	$0.69 \pm 0.38 \pm 0.13 \pm 0.58$	$1.0 \pm 0.4 \pm 0.3 \pm 1.4$
	–	$-0.09 \pm 0.24 \pm 0.21 \pm 0.04$	$0.48 \pm 0.22 \pm 0.20 \pm 0.13$
$\bar{B}^0 \to \eta\eta'$	–	$1.0 \pm 0.5 \pm 0.1 \pm 1.5$	$2.2 \pm 0.7 \pm 0.6 \pm 5.4$
	–	–	$0.70 \pm 0.13 \pm 0.20 \pm 0.04$
$\bar{B}^0 \to \eta'\eta'$	–	$0.57 \pm 0.23 \pm 0.03 \pm 0.69$	$1.2 \pm 0.4 \pm 0.3 \pm 3.7$
	–	–	$0.60 \pm 0.11 \pm 0.22 \pm 0.29$
$\bar{B}^0 \to \bar{K}^0\eta'$	63.2 ± 4.9 $(S = 1.5)$	$63.2 \pm 24.7 \pm 4.2 \pm 8.1$	$62.2 \pm 23.7 \pm 5.5 \pm 7.2$
	0.07 ± 0.10 $(S = 1.5)$	$0.011 \pm 0.006 \pm 0.012 \pm 0.002$	$-0.027 \pm 0.007 \pm 0.008 \pm 0.005$
$\bar{B}^0 \to \bar{K}^0\eta$	< 1.9	$2.4 \pm 4.4 \pm 0.2 \pm 0.3$	$2.3 \pm 4.4 \pm 0.2 \pm 0.5$
	–	$0.21 \pm 0.20 \pm 0.04 \pm 0.03$	$-0.18 \pm 0.22 \pm 0.06 \pm 0.04$
$B^- \to K^-\eta'$	69.4 ± 2.7	$69.5 \pm 27.0 \pm 4.3 \pm 7.7$	$69.3 \pm 26.0 \pm 7.1 \pm 6.3$
	0.031 ± 0.021	$-0.010 \pm 0.006 \pm 0.007 \pm 0.005$	$0.007 \pm 0.005 \pm 0.002 \pm 0.009$
$B^- \to K^-\eta$	2.5 ± 0.3	$2.7 \pm 4.8 \pm 0.4 \pm 0.3$	$2.3 \pm 4.5 \pm 0.4 \pm 0.3$
	-0.33 ± 0.17 $(S = 1.4)$	$0.33 \pm 0.30 \pm 0.07 \pm 0.03$	$-0.33 \pm 0.39 \pm 0.10 \pm 0.04$

errors: su3, 1/mb, fit

Predictions (4 param. fit)

$\gamma = 59^o$

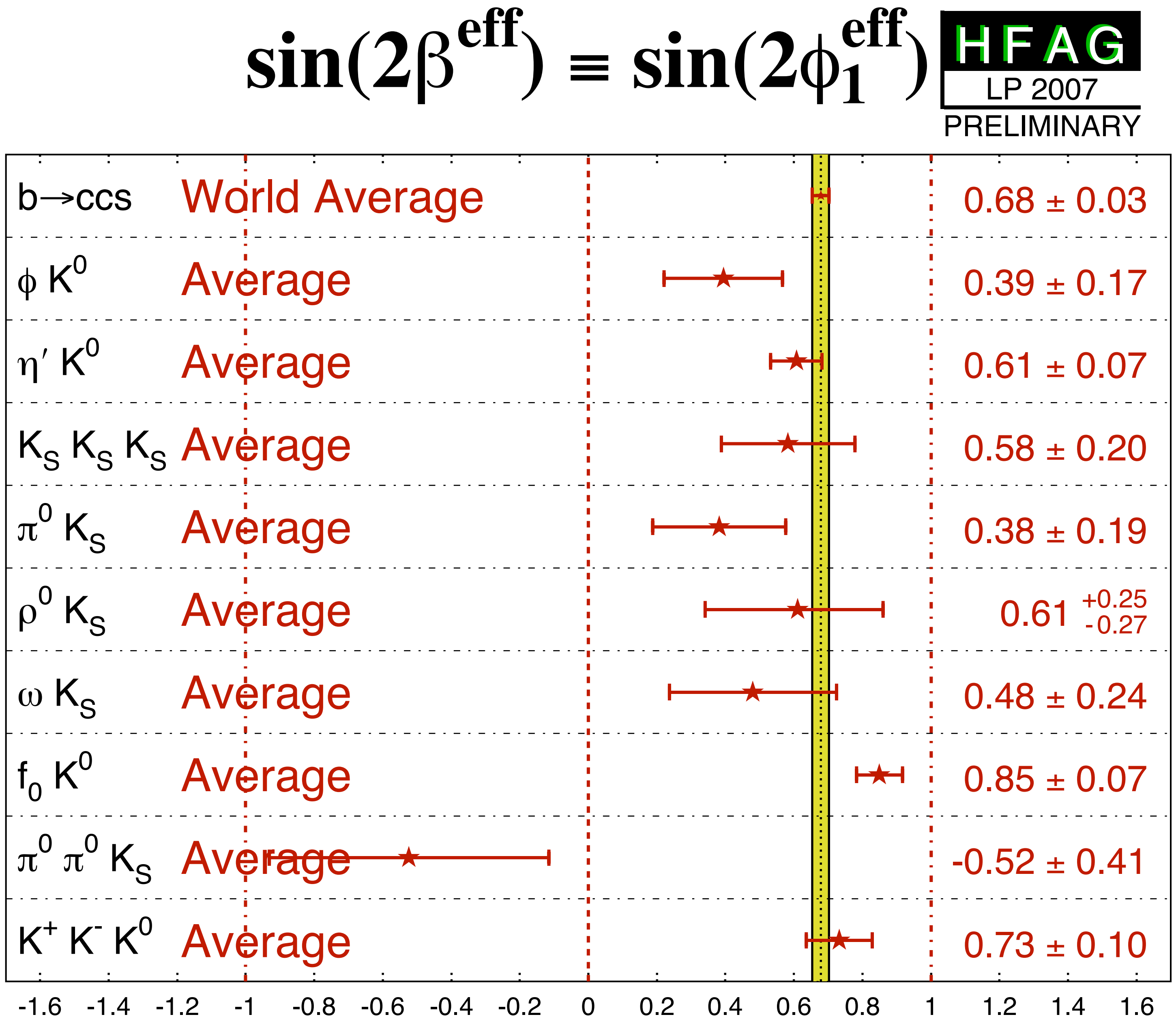
Branching Fraction
Direct CP Asymmetry

Mode	Exp.	Theory I	Theory II
$\bar{B}^0 \to \pi^0\eta$	$-$	$-0.90 \pm 0.08 \pm 0.03 \pm 0.22$	$-0.67 \pm 0.14 \pm 0.03 \pm 0.81$
$\bar{B}^0 \to \pi^0\eta'$	$-$	$-0.96 \pm 0.03 \pm 0.05 \pm 0.11$	$-0.60 \pm 0.08 \pm 0.08 \pm 1.30$
$\bar{B}^0 \to \eta\eta$	$-$	$-0.98 \pm 0.06 \pm 0.03 \pm 0.09$	$-0.78 \pm 0.19 \pm 0.12 \pm 0.22$
$\bar{B}^0 \to \eta\eta'$	$-$	$-0.82 \pm 0.02 \pm 0.04 \pm 0.77$	$-0.71 \pm 0.14 \pm 0.19 \pm 0.29$
$\bar{B}^0 \to \eta'\eta'$	$-$	$-0.59 \pm 0.05 \pm 0.08 \pm 1.10$	$-0.78 \pm 0.09 \pm 0.19 \pm 0.23$
$\bar{B}^0 \to K_S\eta'$	0.50 ± 0.13 $(S = 1.4)$	$0.706 \pm 0.005 \pm 0.006 \pm 0.003$	$0.715 \pm 0.005 \pm 0.008 \pm 0.002$
$\bar{B}^0 \to K_S\eta$	$-$	$0.69 \pm 0.15 \pm 0.05 \pm 0.01$	$0.79 \pm 0.14 \pm 0.04 \pm 0.01$

Mode	Exp	Theory I	Theory II
$\bar{B}_s^0 \to \pi^- K^+$	$< 2.2 f_d/f_s{}^a$	$4.9 \pm 1.2 \pm 1.3 \pm 0.3$	
	$-$	$0.20 \pm 0.17 \pm 0.19 \pm 0.05$	
$\bar{B}_s^0 \to \pi^0 K^0$	$-$	$0.76 \pm 0.26 \pm 0.27 \pm 0.17$	
	$-$	$-0.58 \pm 0.39 \pm 0.39 \pm 0.13$	
$\bar{B}_s^0 \to \eta K^0$	$-$	$0.80 \pm 0.48 \pm 0.29 \pm 0.18$	$0.59 \pm 0.34 \pm 0.24 \pm 0.15$
	$-$	$-0.56 \pm 0.46 \pm 0.14 \pm 0.06$	$0.61 \pm 0.59 \pm 0.12 \pm 0.08$
$\bar{B}_s^0 \to \eta' K^0$	$-$	$4.5 \pm 1.5 \pm 0.4 \pm 0.5$	$3.9 \pm 1.3 \pm 0.5 \pm 0.4$
	$-$	$-0.14 \pm 0.07 \pm 0.16 \pm 0.02$	$0.37 \pm 0.08 \pm 0.14 \pm 0.04$
$\bar{B}_s^0 \to K^- K^+$	$(9.5 \pm 2.0) f_d/f_s{}^a$	$18.2 \pm 6.7 \pm 1.1 \pm 0.5$	
	$-$	$-0.06 \pm 0.05 \pm 0.06 \pm 0.02$	
$\bar{B}_s^0 \to K^0 \bar{K}^0$	$-$	$17.7 \pm 6.6 \pm 0.5 \pm 0.6$	
	$-$	< 0.1	
$\bar{B}_s^0 \to \eta\pi^0$	$-$	$0.014 \pm 0.004 \pm 0.005 \pm 0.004$	$0.016 \pm 0.007 \pm 0.005 \pm 0.006$
	$-$	$-$	$-$
$\bar{B}_s^0 \to \eta'\pi^0$	$-$	$0.006 \pm 0.003 \pm 0.002^{+0.064}_{-0.006}$	$0.038 \pm 0.013 \pm 0.016^{+0.260}_{-0.036}$
	$-$	$-$	$-$
$\bar{B}_s^0 \to \eta\eta$	$-$	$7.1 \pm 6.4 \pm 0.2 \pm 0.8$	$6.4 \pm 6.3 \pm 0.1 \pm 0.7$
	$-$	$0.079 \pm 0.049 \pm 0.027 \pm 0.015$	$-0.011 \pm 0.050 \pm 0.039 \pm 0.010$
$\bar{B}_s^0 \to \eta\eta'$	$-$	$24.0 \pm 13.6 \pm 1.4 \pm 2.7$	$23.8 \pm 13.2 \pm 1.6 \pm 2.9$
	$-$	$0.0004 \pm 0.0014 \pm 0.0039 \pm 0.0043$	$0.023 \pm 0.009 \pm 0.008 \pm 0.076$
$\bar{B}_s^0 \to \eta'\eta'$	$-$	$44.3 \pm 19.7 \pm 2.3 \pm 17.1$	$49.4 \pm 20.6 \pm 8.4 \pm 16.2$
	$-$	$0.009 \pm 0.004 \pm 0.006 \pm 0.019$	$-0.037 \pm 0.010 \pm 0.012 \pm 0.056$

$b \longrightarrow c\bar{c}s$ vs. $b \longrightarrow q\bar{q}s$

Theory Uncertainty (from factorization)



Beneke	Buchalla, Hiller Nir, Raz	Zupan, Williamson
$+0.02^{+0.01}_{-0.01}$	$+0.02$	
$+0.01^{+0.01}_{-0.01}$	$+0.01^{+0.01}_{-0.02}$	-0.01 ± 0.02
$+0.07^{+0.05}_{-0.04}$	$+0.06^{+0.04}_{-0.03}$	$+0.07 \pm 0.03$
$+0.13^{+0.08}_{-0.08}$	$+0.19^{+0.06}_{-0.14}$	

- Constructive interference of penguins give a large $Br(B \to \eta' K^0)$ (to agree with data), and simultaneously a small uncertainty above
- Determination of hadronic parameters dominates factorization uncertainties

Counting parameters VP, VV modes

	no expn.	SU(2)	SU(3)	SCET +SU(2)	SCET +SU(3)
$B \to \pi\pi$	11	$7/5$	$15/13$	4	4
$B \to K\pi$	15	11		$+5(6)$	
$B \to K\bar{K}$	11	11	$+4/0$	$+3(4)$	$+0$

PP, PV with isosinglets

Wang, Wang, Yang, Lu (arXiv:0801.3123)

$\pi\eta, \eta\eta, K\eta', \ldots$ $\quad +4$

$\rho\pi, \omega\pi, K^*K, \rho\eta, \ldots$ $\quad +8$

Global Fit (2 solutions)

Branching Ratios

Wang et.al.

Channel	Exp.	QCDF	PQCD	This work 1	This work 2
$B^- \to \rho^-\pi^0$	$10.9^{+1.4}_{-1.5}$	$14.0^{+6.5+5.1+1.0+0.8}_{-5.5-4.3-0.6-0.7}$	6-9	$8.8^{+0.2+1.0}_{-0.1-1.0}$	$11.0^{+0.6+1.0}_{-0.6-0.9}$
$B^- \to \rho^0\pi^-$	$8.7^{+1.0}_{-1.1}$	$11.9^{+6.3+3.6+2.5+1.3}_{-5.0-3.1-1.2-1.1}$	$10.4^{+3.3}_{-3.4} \pm 2.1$	$10.8^{+0.7+1.0}_{-0.7-0.9}$	$7.9^{+0.1+0.8}_{-0.0-0.8}$
$B^- \to \omega\pi^-$	6.9 ± 0.5	$8.8^{+4.4+2.6+1.8+0.8}_{-3.5-2.2-0.9-0.9}$	$11.3^{+3.3}_{-2.9} \pm 1.4$	$6.7^{+0.4+0.7}_{-0.3-0.6}$	$8.6^{+0.4+0.8}_{-0.3-0.8}$
$B^- \to K^{*0}K^-$	< 1.1	$0.30^{+0.11+0.12+0.09+0.57}_{-0.09-0.10-0.09-0.19}$	$0.31^{+0.12}_{-0.08}$	$0.48^{+0.25+0.09}_{-0.20-0.08}$	$0.51^{+0.18+0.07}_{-0.15-0.06}$
$B^- \to K^{*-}K^0$		$0.30^{+0.08+0.41+0.08+0.58}_{-0.07-0.18-0.07-0.17}$	$1.83^{+0.68}_{-0.47}$	$0.54^{+0.26+0.10}_{-0.21-0.08}$	$0.51^{+0.21+0.08}_{-0.17-0.07}$
$B^- \to \phi\pi^-$	< 0.24	≈ 0.005		≈ 0.003	0.003
$\left.\begin{matrix}\bar{B}^0 \to \rho^-\pi^+ \\ \bar{B}^0 \to \rho^+\pi^-\end{matrix}\right\}$	24.0 ± 2.5	$36.5^{+18.2+10.3+2.0+3.9}_{-14.7-\ 8.6-3.5-2.9}$	18-45	$13.1^{+0.6+1.2}_{-0.5-1.2}$	$16.8^{+0.5+1.6}_{-0.4-1.5}$
$B^0/\bar{B}^0 \to \rho^+\pi^-$			24-34	$12.5^{+1.9+1.2}_{-1.7-1.1}$	$16.0^{+1.6+1.5}_{-1.5-1.4}$
$B^0/\bar{B}^0 \to \rho^-\pi^+$			24-34	$13.8^{+1.9+1.3}_{-1.8-1.2}$	$17.7^{+1.6+1.6}_{-1.7-1.5}$
$\bar{B}^0 \to \rho^+\pi^{-\,a}$	8.9 ± 2.5	$15.4^{+8.0+5.5+0.7+1.9}_{-6.4-4.7-1.3-1.3}$		$5.7^{+0.5+0.5}_{-0.5-0.5}$	$6.7^{+0.2+0.7}_{-0.1-0.7}$
$\bar{B}^0 \to \rho^-\pi^{+\,a}$	13.9 ± 2.7	$21.2^{+10.3+8.7+1.3+2.0}_{-\ 8.4-7.2-2.3-1.6}$		$7.4^{+0.2+0.8}_{-0.1-0.8}$	$10.1^{+0.4+0.9}_{-0.4-0.9}$
$\bar{B}^0 \to \rho^0\pi^0$	$1.8^{+0.6}_{-0.5}$	$0.4^{+0.2+0.2+0.9+0.5}_{-0.2-0.1-0.3-0.3}$	0.07-0.11	$2.6^{+0.2+0.2}_{-0.1-0.2}$	$1.4^{+0.1+0.1}_{-0.1-0.1}$
$\bar{B}^0 \to \omega\pi^0$	< 1.2	$0.01^{+0.00+0.02+0.02+0.03}_{-0.00-0.00-0.00-0.00}$	0.10-0.28	$0.003^{+0.047+0.000}_{-0.000-0.000}$	$0.025^{+0.036+0.002}_{-0.004-0.002}$
$\bar{B}^0 \to K^{*0}\bar{K}^0$		$0.26^{+0.08+0.10+0.08+0.46}_{-0.07-0.09-0.08-0.15}$		$0.45^{+0.24+0.09}_{-0.19-0.07}$	$0.47^{+0.17+0.06}_{-0.14-0.05}$
$\bar{B}^0 \to \bar{K}^{*0}K^0$	< 1.9	$0.29^{+0.10+0.39+0.08+0.60}_{-0.09-0.17-0.07-0.17}$		$0.51^{+0.24+0.09}_{-0.20-0.08}$	$0.48^{+0.20+0.07}_{-0.16-0.06}$
$\left.\begin{matrix}\bar{B}^0 \to K^{*0}\bar{K}^0 \\ \bar{B}^0 \to \bar{K}^{*0}K^0\end{matrix}\right\}$			≈ 1.96	$0.96^{+0.34+0.18}_{-0.27-0.15}$	$0.95^{+0.26+0.14}_{-0.22-0.12}$
$B^0/\bar{B}^0 \to K^{*0}\bar{K}^0$				$0.96^{+0.34+0.18}_{-0.27-0.15}$	$0.95^{+0.26+0.14}_{-0.22-0.12}$
$B^0/\bar{B}^0 \to \bar{K}^{*0}K^0$				$0.96^{+0.34+0.18}_{-0.27-0.15}$	$0.95^{+0.26+0.14}_{-0.22-0.12}$
$\bar{B}^0 \to \phi\pi^0$	< 0.28	≈ 0.002		0.002	0.001
$B^- \to \rho^-\eta$	5.4 ± 1.2	$9.4^{+4.6+3.6+0.7+0.7}_{-3.7-3.0-0.4-0.7}$	$8.5^{+3.0+0.8+0.4+1.2\ b}_{-2.1-0.7-0.4-0.2}$	$3.9^{+2.0+0.4}_{-1.7-0.4}$	$3.0^{+1.8+0.3}_{-1.5-0.3}$
$B^- \to \rho^-\eta'$	$9.1^{+3.7}_{-2.8}$	$6.3^{+3.1+2.4+0.5+0.5}_{-2.5-2.0-0.3-0.5}$	$8.7^{+3.0+0.7+0.5+1.1\ b}_{-2.2-0.9-0.7-0.3}$	$0.37^{+2.51+0.08}_{-0.22-0.07}$	$0.36^{+2.59+0.06}_{-0.18-0.05}$
$\bar{B}^0 \to \rho^0\eta$	< 1.5	$0.03^{+0.02+0.16+0.02+0.05}_{-0.01-0.10-0.01-0.02}$	$0.024^{+0.012+0.004+0.002+0.102\ b}_{-0.007-0.002-0.002-0.005}$	$0.03^{+0.18+0.00}_{-0.02-0.00}$	$0.17^{+0.36+0.02}_{-0.16-0.02}$
$\bar{B}^0 \to \rho^0\eta'$	< 1.3	$0.01^{+0.01+0.11+0.02+0.03}_{-0.00-0.06-0.00-0.01}$	$0.061^{+0.030+0.004+0.003+0.114\ b}_{-0.018-0.003-0.003-0.009}$	$0.37^{+2.37+0.04}_{-0.11-0.05}$	$1.3^{+3.8+0.1}_{-1.1-0.1}$
$\bar{B}^0 \to \omega\eta$	< 1.9	$0.31^{+0.14+0.16+0.35+0.22}_{-0.12-0.11-0.14-0.16}$	$0.27^{+0.11}_{-0.10}$	$0.98^{+0.69+0.10}_{-0.51-0.10}$	$1.3^{+0.8+0.1}_{-0.6-0.1}$
$\bar{B}^0 \to \omega\eta'$	< 2.2	$0.20^{+0.10+0.15+0.25+0.15}_{-0.08-0.05-0.10-0.11}$	$0.075^{+0.037}_{-0.033}$	$0.20^{+1.46+0.04}_{-0.09-0.03}$	$3.1^{+4.8+0.3}_{-2.6-0.3}$
$\bar{B}^0 \to \phi\eta$	< 0.6	≈ 0.001	$0.0063^{+0.0033}_{-0.0019}$	0.0004	0.0008
$\bar{B}^0 \to \phi\eta'$	< 0.5	≈ 0.001	$0.0073^{+0.0035}_{-0.0026}$	0.0001	0.0007

Branching Ratios

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Channel	Exp.	QCDF	PQCD	This work 1	This work 2
$B^- \to K^{*-}\pi^0$	6.9 ± 2.3	$3.3^{+1.1+1.0+0.6+4.4}_{-1.0-0.9-0.6-1.4}$	$4.3^{+5.0}_{-2.2}$	$4.1^{+2.2+0.8}_{-1.7-0.7}$	$6.5^{+1.9+0.7}_{-1.6-0.7}$
$B^- \to \bar{K}^{*0}\pi^-$	10.7 ± 0.8	$3.6^{+0.4+1.5+1.2+7.7}_{-0.3-1.4-1.2-2.3}$	$6.0^{+2.8}_{-1.5}$	$8.5^{+4.6+1.7}_{-3.6-1.4}$	$9.9^{+3.4+1.3}_{-2.9-1.1}$
$B^- \to \rho^0 K^-$	$4.25^{+0.55}_{-0.56}$	$2.6^{+0.9+3.1+0.8+4.3}_{-0.9-1.4-0.6-1.2}$	$5.1^{+4.1}_{-2.8}$	$6.6^{+2.7+1.0}_{-2.2-0.9}$	$4.7^{+1.8+0.7}_{-1.5-0.6}$
$B^- \to \rho^- \bar{K}^0$	$8.0^{+1.5}_{-1.4}$	$5.8^{+0.6+7.0+1.5+10.3}_{-0.6-3.3-1.3-\ 3.2}$	$8.7^{+6.8}_{-4.4}$	$9.3^{+4.7+1.7}_{-3.7-1.4}$	$10.0^{+4.0+1.5}_{-3.3-1.3}$
$B^- \to \omega K^-$	6.7 ± 0.5	$3.5^{+1.0+3.3+1.4+4.7}_{-1.0-1.6-0.9-1.6}$	$10.6^{+10.4}_{-5.8}$	$5.1^{+2.4+0.9}_{-1.9-0.8}$	$5.9^{+2.1+0.8}_{-1.7-0.7}$
$B^- \to \phi K^-$	8.30 ± 0.65	$4.5^{+0.5+1.8+1.9+11.8}_{-0.4-1.7-2.1-\ 3.3}$	$7.8^{+5.9}_{-1.8}$	$9.7^{+4.9+1.8}_{-3.9-1.5}$	$8.5^{+3.2+1.2}_{-2.7-1.0}$
$\bar{B}^0 \to \bar{K}^{*0}\pi^0$	$0.0^{+1.3}_{-0.1}$	$0.7^{+0.1+0.5+0.3+2.6}_{-0.1-0.4-0.3-0.5}$	$2.0^{+1.2}_{-0.6}$	$4.6^{+2.3+0.9}_{-1.8-0.7}$	$3.6^{+1.4+0.5}_{-1.2-0.4}$
$\bar{B}^0 \to \bar{K}^{*-}\pi^+$	9.8 ± 1.1	$3.3^{+1.4+1.3+0.8+6.2}_{-1.1-1.2-0.8-1.6}$	$6.0^{+6.8}_{-2.6}$	$8.3^{+4.3+1.6}_{-3.4-1.3}$	$9.5^{+3.2+1.2}_{-2.7-1.1}$
$\bar{B}^0 \to \rho^0 \bar{K}^0$	$5.4^{+0.9}_{-1.0}$	$4.6^{+0.5+4.0+0.7+6.1}_{-0.5-2.1-0.7-2.1}$	$4.8^{+4.3}_{-2.3}$	$3.5^{+2.0+0.7}_{-1.5-0.6}$	$5.8^{+2.1+0.8}_{-1.8-0.7}$
$\bar{B}^0 \to \rho^+ K^-$	$15.3^{+3.7}_{-3.5}$	$7.4^{+1.8+7.1+1.2+10.7}_{-1.9-3.6-1.1-\ 3.5}$	$8.8^{+6.8}_{-4.5}$	$9.8^{+4.5+1.7}_{-3.7-1.4}$	$10.2^{+3.8+1.5}_{-3.2-1.2}$
$\bar{B}^0 \to \omega \bar{K}^0$	5.0 ± 0.6	$2.3^{+0.3+2.8+1.3+4.3}_{-0.3-1.3-0.8-1.3}$	$9.8^{+8.6}_{-4.9}$	$4.1^{+2.1+0.8}_{-1.7-0.6}$	$4.9^{+1.9+0.7}_{-1.6-0.6}$
$\bar{B}^0 \to \phi \bar{K}^0$	$8.3^{+1.2}_{-1.0}$	$4.1^{+0.4+1.7+1.8+10.6}_{-0.4-1.6-1.9-\ 3.0}$	$7.3^{+5.9}_{-1.8}$	$9.1^{+4.5+1.7}_{-3.6-1.4}$	$8.0^{+2.9+1.1}_{-2.5-0.9}$
$B^- \to K^{*-}\eta$	19.3 ± 1.6	$10.8^{+1.9+8.1+1.8+16.5}_{-1.7-4.4-1.3-\ 5.5}$	$22.13^{+0.26}_{-0.27}$	$17.9^{+5.4+3.5}_{-5.3-2.9}$	$18.6^{+4.5+2.6}_{-4.6-2.2}$
$B^- \to K^{*-}\eta'$	$4.9^{+2.1}_{-1.9}$	$5.1^{+0.9+7.5+2.1+6.7}_{-1.0-3.8-3.0-3.3}$	6.38 ± 0.26	$4.4^{+6.5+0.9}_{-3.8-0.8}$	$4.1^{+4.9+0.7}_{-3.3-0.6}$
$\bar{B}^0 \to \bar{K}^{*0}\eta$	15.9 ± 1.0	$10.7^{+1.1+7.8+1.4+16.2}_{-1.0-4.3-1.2-\ 5.5}$	$22.31^{+0.28}_{-0.29}$	$16.6^{+5.1+3.2}_{-5.0-2.7}$	$16.5^{+4.1+2.3}_{-4.2-2.0}$
$\bar{B}^0 \to \bar{K}^{*0}\eta'$	3.8 ± 1.2	$3.9^{+0.4+6.6+1.8+6.2}_{-0.4-3.3-2.5-2.9}$	$3.35^{+0.29}_{-0.27}$	$4.1^{+6.1+0.9}_{-3.6-0.7}$	$3.8^{+4.8+0.6}_{-3.3-0.5}$

Branching Ratios

Wang et.al.

Channel	Exp.	QCDF	PQCD	This work 1	This work 2
$B^- \to K^{*-}\pi^0$	6.9 ± 2.3	$3.3^{+1.1+1.0+0.6+4.4}_{-1.0-0.9-0.6-1.4}$	$4.3^{+5.0}_{-2.2}$	$4.1^{+2.2+0.8}_{-1.7-0.7}$	$6.5^{+1.9+0.7}_{-1.6-0.7}$
$B^- \to \bar{K}^{*0}\pi^-$	10.7 ± 0.8	$3.6^{+0.4+1.5+1.2+7.7}_{-0.3-1.4-1.2-2.3}$	$6.0^{+2.8}_{-1.5}$	$8.5^{+4.6+1.7}_{-3.6-1.4}$	$9.9^{+3.4+1.3}_{-2.9-1.1}$
$B^- \to \rho^0 K^-$	$4.25^{+0.55}_{-0.56}$	$2.6^{+0.9+3.1+0.8+4.3}_{-0.9-1.4-0.6-1.2}$	$5.1^{+4.1}_{-2.8}$	$6.6^{+2.7+1.0}_{-2.2-0.9}$	$4.7^{+1.8+0.7}_{-1.5-0.6}$
$B^- \to \rho^- \bar{K}^0$	$8.0^{+1.5}_{-1.4}$	$5.8^{+0.6+7.0+1.5+10.3}_{-0.6-3.3-1.3-3.2}$	$8.7^{+6.8}_{-4.4}$	$9.3^{+4.7+1.7}_{-3.7-1.4}$	$10.0^{+4.0+1.5}_{-3.3-1.3}$
$B^- \to \omega K^-$	6.7 ± 0.5	$3.5^{+1.0+3.3+1.4+4.7}_{-1.0-1.6-0.9-1.6}$	$10.6^{+10.4}_{-5.8}$	$5.1^{+2.4+0.9}_{-1.9-0.8}$	$5.9^{+2.1+0.8}_{-1.7-0.7}$
$B^- \to \phi K^-$	8.30 ± 0.65	$4.5^{+0.5+1.8+1.9+11.8}_{-0.4-1.7-2.1-3.3}$	$7.8^{+5.9}_{-1.8}$	$9.7^{+4.9+1.8}_{-3.9-1.5}$	$8.5^{+3.2+1.2}_{-2.7-1.0}$
$\bar{B}^0 \to \bar{K}^{*0}\pi^0$	$0.0^{+1.3}_{-0.1}$	$0.7^{+0.1+0.5+0.3+2.6}_{-0.1-0.4-0.3-0.5}$	$2.0^{+1.2}_{-0.6}$	$4.6^{+2.3+0.9}_{-1.8-0.7}$	$3.6^{+1.4+0.5}_{-1.2-0.4}$
$\bar{B}^0 \to \bar{K}^{*-}\pi^+$	9.8 ± 1.1	$3.3^{+1.4+1.3+0.8+6.2}_{-1.1-1.2-0.8-1.6}$	$6.0^{+6.8}_{-2.6}$	$8.3^{+4.3+1.6}_{-3.4-1.3}$	$9.5^{+3.2+1.2}_{-2.7-1.1}$
$\bar{B}^0 \to \rho^0 \bar{K}^0$	$5.4^{+0.9}_{-1.0}$	$4.6^{+0.5+4.0+0.7+6.1}_{-0.5-2.1-0.7-2.1}$	$4.8^{+4.3}_{-2.3}$	$3.5^{+2.0+0.7}_{-1.5-0.6}$	$5.8^{+2.1+0.8}_{-1.8-0.7}$
$\bar{B}^0 \to \rho^+ K^-$	$15.3^{+3.7}_{-3.5}$	$7.4^{+1.8+7.1+1.2+10.7}_{-1.9-3.6-1.1-3.5}$	$8.8^{+6.8}_{-4.5}$	$9.8^{+4.5+1.7}_{-3.7-1.4}$	$10.2^{+3.8+1.5}_{-3.2-1.2}$
$\bar{B}^0 \to \omega \bar{K}^0$	5.0 ± 0.6	$2.3^{+0.3+2.8+1.3+4.3}_{-0.3-1.3-0.8-1.3}$	$9.8^{+8.6}_{-4.9}$	$4.1^{+2.1+0.8}_{-1.7-0.6}$	$4.9^{+1.9+0.7}_{-1.6-0.6}$
$\bar{B}^0 \to \phi \bar{K}^0$	$8.3^{+1.2}_{-1.0}$	$4.1^{+0.4+1.7+1.8+10.6}_{-0.4-1.6-1.9-3.0}$	$7.3^{+5.9}_{-1.8}$	$9.1^{+4.5+1.7}_{-3.6-1.4}$	$8.0^{+2.9+1.1}_{-2.5-0.9}$
$B^- \to K^{*-}\eta$	19.3 ± 1.6	$10.8^{+1.9+8.1+1.8+16.5}_{-1.7-4.4-1.3-5.5}$	$22.13^{+0.26}_{-0.27}$	$17.9^{+5.4+3.5}_{-5.3-2.9}$	$18.6^{+4.5+2.6}_{-4.6-2.2}$
$B^- \to K^{*-}\eta'$	$4.9^{+2.1}_{-1.9}$	$5.1^{+0.9+7.5+2.1+6.7}_{-1.0-3.8-3.0-3.3}$	6.38 ± 0.26	$4.4^{+6.5+0.9}_{-3.8-0.8}$	$4.1^{+4.9+0.7}_{-3.3-0.6}$
$\bar{B}^0 \to \bar{K}^{*0}\eta$	15.9 ± 1.0	$10.7^{+1.1+7.8+1.4+16.2}_{-1.0-4.3-1.2-5.5}$	$22.31^{+0.28}_{-0.29}$	$16.6^{+5.1+3.2}_{-5.0-2.7}$	$16.5^{+4.1+2.3}_{-4.2-2.0}$
$\bar{B}^0 \to \bar{K}^{*0}\eta'$	3.8 ± 1.2	$3.9^{+0.4+6.6+1.8+6.2}_{-0.4-3.3-2.5-2.9}$	$3.35^{+0.29}_{-0.27}$	$4.1^{+6.1+0.9}_{-3.6-0.7}$	$3.8^{+4.8+0.6}_{-3.3-0.5}$

CP Asymmetries

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Channel	Exp.	QCDF	PQCD	This work 1	This work 2
$B^- \to \rho^-\pi^0$	2 ± 11	$-4.0^{+1.2+1.8+0.4+17.5}_{-1.2-2.2-0.4-17.7}$	0-20	$8.3^{+17.8+0.8}_{-18.9-0.8}$	$5.4^{+9.7+0.4}_{-10.0-0.5}$
$B^- \to \rho^0\pi^-$	-7^{+12}_{-13}	$4.1^{+1.3+2.2+0.6+19.0}_{-0.9-2.0-0.7-18.8}$	-20-0	$-5.7^{+13.0+0.5}_{-12.8-0.4}$	$-8.4^{+15.6+0.8}_{-14.5-0.8}$
$B^- \to \omega\pi^-$	-4 ± 6	$-1.8^{+0.5+2.7+0.8+2.1}_{-0.5-3.3-0.7-2.2}$	~ 0	$-5.0^{+19.7+0.5}_{-19.3-0.5}$	$-5.8^{+13.7+0.5}_{-12.9-0.6}$
$B^- \to K^{*0}K^-$	...	$-23.5^{+6.9+7.8+5.5+25.2}_{-5.7-9.0-6.5-36.8}$	$-20 \pm 5 \pm 2$	$-0.8^{+5.8+0.1}_{-5.6-0.1}$	$-0.4^{+4.1+0.0}_{-4.1-0.0}$
$B^- \to K^{*-}K^0$	...	$-13.4^{+3.7+7.8+4.2+27.4}_{-3.0-3.5-4.7-36.7}$	-49^{+7+7}_{-3-7}	$-1.3^{+2.6+0.1}_{-2.4-0.1}$	$-1.1^{+1.7+0.1}_{-1.6-0.1}$
$\bar{B}^0 \to \rho^+\pi^-$	-53 ± 30	$0.6^{+0.2+1.3+0.1+11.5}_{-0.1-1.6-0.1-11.7}$		$-8.6^{+17.4+0.8}_{-17.0-0.6}$	$-11.0^{+17.4+1.0}_{-15.3-1.1}$
$\bar{B}^0 \to \rho^-\pi^+$	-15 ± 8	$-1.5^{+0.4+1.2+0.2+8.5}_{-0.4-1.3-0.3-8.4}$		$2.6^{+19.1+0.3}_{-19.7-0.2}$	$0.9^{+10.0+0.1}_{-10.1-0.1}$
$\bar{B}^0 \to \rho^0\pi^0$	-30 ± 38	$-15.7^{+4.8+12.3+11.0+19.8}_{-4.7-14.0-12.9-25.8}$	-75-0	$5.5^{+20.8+0.5}_{-21.8-0.5}$	$9.7^{+21.5+0.9}_{-22.5-0.9}$
$\bar{B}^0 \to \omega\pi^0$	...	...	-20-75	$-58.4^{+150.1+4.2}_{-0.0-4.1}$	$-72.9^{+179.1+4.7}_{-32.9-4.8}$
$\bar{B}^0 \to K^{*0}\bar{K}^0$	...	$-26.7^{+7.4+7.2+5.7+10.9}_{-5.7-9.0-6.9-13.4}$		$-0.8^{+5.8+0.1}_{-5.6-0.1}$	$-0.4^{+4.1+0.0}_{-4.1-0.0}$
$\bar{B}^0 \to \bar{K}^{*0}K^0$	...	$-13.1^{+3.8+5.4+4.5+5.8}_{-3.0-2.9-5.2-7.4}$		$-1.3^{+2.6+0.1}_{-2.4-0.1}$	$-1.1^{+1.7+0.1}_{-1.6-0.1}$
$B^- \to \rho^-\eta$	1 ± 16	$-2.4^{+0.7+6.3+0.4+0.2}_{-0.7-6.3-0.4-0.2}$	$-13^{+1.2+2}_{-0.5-14}$	$-11.7^{+22.0+1.1}_{-21.0-1.2}$	$9.1^{+17.7+0.9}_{-17.3-0.9}$
$B^- \to \rho^-\eta'$	-4 ± 28	$4.1^{+1.2+7.9+0.5+7.0}_{-1.1-6.9-0.8-7.0}$	$-18^{+3.0+1}_{-1.6-14}$	$-18.0^{+65.9+2.6}_{-44.1-2.9}$	$6.6^{+66.6+0.8}_{-119.9-0.9}$
$\bar{B}^0 \to \rho^0\eta$	...	...	$-13^{+1.2+2}_{-0.5-14}$	$-76.0^{+189.5+2.9}_{-33.3-4.5}$	$-28.2^{+55.0+2.4}_{-76.6-2.6}$
$\bar{B}^0 \to \rho^0\eta'$	...	...	$-18^{+3.0+1}_{-1.6-14}$	$-59.5^{+112.2+3.4}_{-40.1-4.2}$	$-57.5^{+68.6+4.4}_{-16.1-4.6}$
$\bar{B}^0 \to \omega\eta$	...	$-33.4^{+10.0+65.3+20.9+19.2}_{-9.5-55.8-21.4-20.8}$	$-69.1^{+15.1}_{-13.4}$	$-16.1^{+30.2+1.5}_{-28.7-1.6}$	$9.5^{+18.3+0.9}_{-18.0-0.9}$
$\bar{B}^0 \to \omega\eta'$	...	$0.2^{+0.1+53.0+11.6+19.2}_{-0.1-76.5-11.5-20.1}$	$13.9^{+4.1}_{-3.5}$	$-55.4^{+104.1+4.9}_{-37.0-5.5}$	$35.6^{+38.9+2.9}_{-19.7-3.0}$

CP Asymmetries

Wang et.al.

Channel	Exp.	QCDF	PQCD	This work 1	This work 2
$B^- \to K^{*-}\pi^0$	4 ± 29	$8.7^{+2.1+5.0+2.9+41.7}_{-2.6-4.3-3.4-44.2}$	-32^{+21}_{-28}	$-4.0^{+29.2+0.5}_{-27.8-0.5}$	$-1.1^{+11.8+0.1}_{-11.8-0.1}$
$B^- \to \bar{K}^{*0}\pi^-$	-8.5 ± 5.7	$1.6^{+0.4+0.6+0.5+2.5}_{-0.5-0.5-0.4-1.0}$	-1^{+1}_{-0}	0	0
$B^- \to \rho^0 K^-$	31^{+11}_{-10}	$-13.6^{+4.5+6.9+3.7+62.7}_{-5.7-4.4-3.1-55.4}$	71^{+25}_{-35}	$8.0^{+15.4+0.6}_{-16.1-0.6}$	$14.3^{+20.8+1.1}_{-22.5-1.4}$
$B^- \to \rho^- \bar{K}^0$	-12 ± 17	$0.3^{+0.1+0.3+0.2+1.6}_{-0.1-0.4-0.1-1.3}$	1 ± 1	0	0
$B^- \to \omega K^-$	2 ± 5	$-7.8^{+2.6+5.9+2.4+39.8}_{-3.0-3.6-1.9-38.0}$	32^{+15}_{-17}	$10.1^{+18.5+1.0}_{-20.5-0.9}$	$11.1^{+16.8+0.8}_{-17.3-1.0}$
$B^- \to \phi K^-$	3.4 ± 4.4	$1.6^{+0.4+0.6+0.5+3.0}_{-0.5-0.5-0.3-1.2}$	1^{+0}_{-1}	0	0
$\bar{B}^0 \to \bar{K}^{*0}\pi^0$	$\cdots$	$-12.8^{+4.0+4.7+2.7+31.7}_{-3.2-7.0-4.0-35.3}$	-11^{+7}_{-5}	$1.1^{+8.0+0.1}_{-8.3-0.1}$	$0.4^{+4.8+0.0}_{-4.8-0.0}$
$\bar{B}^0 \to \bar{K}^{*-}\pi^+$	-5 ± 14	$2.1^{+0.6+8.2+5.1+62.5}_{-0.7-7.9-5.8-64.2}$	-60^{+32}_{-19}	$-2.5^{+18.5+0.3}_{-17.8-0.3}$	$-1.0^{+11.4+0.1}_{-11.4-0.1}$
$\bar{B}^0 \to \rho^0 \bar{K}^0$	$-2 \pm 27 \pm 8 \pm 6$	$7.5^{+1.7+2.3+0.7+8.8}_{-2.1-2.0-0.4-8.7}$	7^{+8}_{-5}	$-5.9^{+11.9+0.7}_{-10.1-0.8}$	$-3.1^{+4.9+0.2}_{-4.8-0.2}$
$\bar{B}^0 \to \rho^+ K^-$	22 ± 23	$-3.8^{+1.3+4.4+1.9+34.5}_{-1.4-2.7-1.6-32.7}$	64^{+24}_{-30}	$6.0^{+11.1+0.6}_{-12.1-0.6}$	$8.7^{+13.1+0.6}_{-13.6-0.8}$
$\bar{B}^0 \to \omega \bar{K}^0$	21 ± 19	$-8.1^{+2.5+3.0+1.7+11.8}_{-2.0-3.3-1.4-12.9}$	-3^{+2}_{-3}	$4.7^{+8.4+0.5}_{-9.5-0.5}$	$3.4^{+5.2+0.3}_{-5.4-0.3}$
$\bar{B}^0 \to \phi \bar{K}^0$	1 ± 12	$1.7^{+0.4+0.6+0.5+1.4}_{-0.5-0.5-0.3-0.8}$	3^{+1}_{-2}	0	0
$B^- \to K^{*-}\eta$	2 ± 6	$3.5^{+0.9+1.9+0.8+20.7}_{-0.9-2.7-0.8-20.5}$	$-24.57^{+0.72}_{-0.27}$	$-0.9^{+5.3+0.1}_{-5.5-0.1}$	$-4.6^{+3.4+0.3}_{-3.4-0.3}$
$B^- \to K^{*-}\eta'$	30^{+33}_{-37}	$-14.2^{+4.7+\ 8.5+\ 4.9+27.5}_{-4.2-13.8-14.6-26.1}$	$4.60^{+1.16}_{-1.32}$	$2.6^{+29.1+0.3}_{-20.9-0.3}$	$-0.7^{+36.4+0.1}_{-34.5-0.1}$
$\bar{B}^0 \to \bar{K}^{*0}\eta$	19 ± 5	$3.8^{+0.9+1.1+0.2+3.8}_{-1.1-0.8-0.2-3.5}$	0.57 ± 0.011	$-0.4^{+2.3+0.0}_{-2.4-0.0}$	$-1.6^{+1.1+0.1}_{-1.1-0.1}$
$\bar{B}^0 \to \bar{K}^{*0}\eta'$	-8 ± 25	$-5.5^{+1.6+3.1+1.8+6.2}_{-1.3-5.1-5.9-7.0}$	-1.30 ± 0.08	$10.2^{+8.7+1.3}_{-10.3-1.3}$	$-9.8^{+4.5+0.9}_{-6.4-0.9}$

B_s Decays

Branching Ratios

Wang et.al.

Modes	QCDF	PQCD	This work 1	This work 2
$\bar{B}_s^0 \to K^+K^{*-}$	$4.1^{+1.7+1.5+1.0+9.2}_{-1.5-1.3-0.9-2.3}$	$6.0^{+1.7+1.7+0.7}_{-1.5-1.2-0.3}$	$8.3^{+4.3+1.6}_{-3.4-1.3}$	$9.5^{+3.2+1.2}_{-2.7-1.1}$
$\bar{B}_s^0 \to K^{*+}K^-$	$5.5^{+1.3+5.0+0.8+14.2}_{-1.4-2.6-0.7-\ 3.6}$	$4.7^{+1.1+2.5+0.0}_{-0.8-1.4-0.0}$	$9.8^{+4.6+1.7}_{-3.7-1.4}$	$10.3^{+3.8+1.5}_{-3.2-1.2}$
$\bar{B}_s^0 \to K^0\overline{K}^{*0}$	$3.9^{+0.4+1.5+1.3+10.4}_{-0.4-1.4-1.4-\ 2.8}$	$7.3^{+2.5+2.1+0.0}_{-1.7-1.3-0.0}$	$7.9^{+4.3+1.6}_{-3.4-1.3}$	$9.3^{+3.2+1.2}_{-2.7-1.0}$
$\bar{B}_s^0 \to K^{*0}\overline{K}^0$	$4.2^{+0.4+4.6+1.1+13.2}_{-0.4-2.2-0.9-\ 3.2}$	$4.3^{+0.7+2.2+0.0}_{-0.7-1.4-0.0}$	$8.7^{+4.4+1.6}_{-3.5-1.3}$	$9.3^{+3.7+1.4}_{-3.1-1.2}$
$B_s^0/\bar{B}_s^0 \to K^+K^{*-}$			$17.3^{+6.5+3.2}_{-5.1-2.7}$	$18.8^{+5.1+2.5}_{-4.5-2.2}$
$B_s^0/\bar{B}_s^0 \to K^{*+}K^-$			$18.8^{+6.8+3.3}_{-5.4-2.8}$	$20.8^{+5.3+2.7}_{-4.7-2.3}$
$\left.\begin{array}{l}\bar{B}_s^0 \to K^{*+}K^- \\ \bar{B}_s^0 \to K^{*-}K^+\end{array}\right\}$			$18.1^{+6.3+3.3}_{-5.0-2.7}$	$19.8^{+4.9+2.6}_{-4.2-2.2}$
$B_s^0/\bar{B}_s^0 \to K^0\overline{K}^{*0}$			$16.6^{+6.1+3.2}_{-4.8-2.7}$	$18.6^{+4.9+2.6}_{-4.1-2.2}$
$B_s^0/\bar{B}_s^0 \to K^{*0}\overline{K}^0$			$16.6^{+6.1+3.2}_{-4.8-2.7}$	$18.6^{+4.9+2.6}_{-4.1-2.2}$
$\left.\begin{array}{l}\bar{B}_s^0 \to K^{*0}\bar{K}^0 \\ \bar{B}_s^0 \to \bar{K}^{*0}K^0\end{array}\right\}$			$16.6^{+6.1+3.2}_{-4.8-2.7}$	$18.6^{+4.9+2.6}_{-4.1-2.2}$
$\bar{B}_s^0 \to \pi^0\phi$	$0.12^{+0.03+0.04+0.01+0.02}_{-0.02-0.04-0.01-0.01}$	$0.16^{+0.06+0.02+0.00}_{-0.05-0.02-0.00}$	$0.07^{+0.00+0.01}_{-0.00-0.01}$	$0.09^{+0.00+0.01}_{-0.00-0.01}$
$\bar{B}_s^0 \to \pi^-K^{*+}$	$8.7^{+4.6+3.5+0.7+0.8}_{-3.7-2.9-1.0-0.7}$	$7.6^{+2.9+0.4+0.5}_{-2.2-0.5-0.3}$	$5.8^{+0.5+0.5}_{-0.5-0.5}$	$6.8^{+0.2+0.7}_{-0.1-0.7}$
$\bar{B}_s^0 \to \pi^0K^{*0}$	$0.25^{+0.08+0.10+0.32+0.30}_{-0.08-0.06-0.14-0.14}$	$0.07^{+0.02+0.04+0.01}_{-0.01-0.02-0.01}$	$0.90^{+0.07+0.10}_{-0.00-0.11}$	$0.99^{+0.16+0.10}_{-0.15-0.08}$
$\bar{B}_s^0 \to \rho^-K^+$	$24.5^{+11.9+9.2+1.8+1.6}_{-9.7-7.8-3.0-1.6}$	$17.8^{+7.7+1.3+1.1}_{-5.6-1.6-0.9}$	$7.4^{+0.2+0.8}_{-0.1-0.8}$	$10.1^{+0.4+0.9}_{-0.4-0.9}$
$\bar{B}_s^0 \to \rho^0K^0$	$0.61^{+0.33+0.21+1.06+0.56}_{-0.26-0.15-0.38-0.36}$	$0.08^{+0.02+0.07+0.01}_{-0.02-0.03-0.00}$	$2.1^{+0.2+0.2}_{-0.2-0.2}$	$0.79^{+0.02+0.08}_{-0.00-0.09}$
$\bar{B}_s^0 \to K^0\omega$	$0.51^{+0.20+0.15+0.68+0.40}_{-0.18-0.11-0.23-0.25}$	$0.15^{+0.05+0.07+0.02}_{-0.04-0.03-0.01}$	$0.94^{+0.05+0.10}_{-0.00-0.11}$	$1.3^{+0.1+0.1}_{-0.1-0.1}$
$\bar{B}_s^0 \to K^0\phi$	$0.27^{+0.09+0.28+0.09+0.67}_{-0.08-0.14-0.06-0.18}$	$0.16^{+0.04+0.09+0.02}_{-0.03-0.04-0.01}$	$0.44^{+0.23+0.08}_{-0.18-0.07}$	$0.54^{+0.21+0.08}_{-0.17-0.07}$
$\bar{B}_s^0 \to \rho^0\eta$	$0.17^{+0.03+0.07+0.02+0.02}_{-0.03-0.06-0.02-0.01}$	$0.06^{+0.03+0.01+0.00}_{-0.02-0.01-0.00}$	$0.08^{+0.04+0.01}_{-0.03-0.01}$	$0.06^{+0.03+0.00}_{-0.02-0.00}$
$\bar{B}_s^0 \to \rho^0\eta'$	$0.25^{+0.06+0.10+0.02+0.02}_{-0.05-0.08-0.02-0.02}$	$0.13^{+0.06+0.02+0.00}_{-0.04-0.02-0.01}$	$0.003^{+0.089+0.000}_{-0.000-0.000}$	$0.15^{+0.24+0.02}_{-0.12-0.01}$
$\bar{B}_s^0 \to \omega\eta$	$0.012^{+0.005+0.010+0.028+0.025}_{-0.004-0.003-0.006-0.006}$	$0.04^{+0.03+0.05+0.00}_{-0.01-0.02-0.00}$	$0.04^{+0.04+0.00}_{-0.02-0.00}$	$0.007^{+0.010+0.001}_{-0.002-0.001}$
$\bar{B}_s^0 \to \omega\eta'$	$0.024^{+0.011+0.028+0.077+0.042}_{-0.009-0.006-0.010-0.015}$	$0.44^{+0.18+0.15+0.00}_{-0.13-0.14-0.01}$	$0.002^{+0.108+0.000}_{-0.000-0.000}$	$0.22^{+0.35+0.02}_{-0.18-0.02}$
$\bar{B}_s^0 \to \phi\eta$	$0.12^{+0.02+0.95+0.54+0.32}_{-0.02-0.14-0.12-0.13}$	$3.6^{+1.5+0.8+0.0}_{-1.0-0.6-0.0}$	$0.40^{+1.40+0.08}_{-0.51-0.07}$	$1.2^{+2.1+0.2}_{-1.2-0.2}$
$\bar{B}_s^0 \to \phi\eta'$	$0.05^{+0.01+1.10+0.18+0.40}_{-0.01-0.17-0.08-0.04}$	$0.19^{+0.06+0.19+0.00}_{-0.01-0.13-0.00}$	$7.7^{+7.8+1.6}_{-5.5-1.3}$	$4.2^{+5.2+0.7}_{-3.5-0.6}$
$\bar{B}_s^0 \to K^{*0}\eta$	$0.26^{+0.15+0.49+0.15+0.57}_{-0.13-0.22-0.05-0.15}$	$0.17^{+0.04+0.10+0.03}_{-0.04-0.06-0.01}$	$1.7^{+0.3+0.2}_{-0.3-0.1}$	$0.55^{+0.13+0.07}_{-0.12-0.07}$
$\bar{B}_s^0 \to K^{*0}\eta'$	$0.28^{+0.04+0.46+0.23+0.29}_{-0.04-0.24-0.10-0.15}$	$0.09^{+0.02+0.03+0.01}_{-0.02-0.02-0.01}$	$0.66^{+0.34+0.12}_{-0.26-0.11}$	$0.77^{+0.33+0.09}_{-0.30-0.08}$

$\mathrm{B} \to K\pi$

There is an interesting correlation in the CP-asymmetries:
(BBNS or BPRS or Williamson et.al. or Pierini et.al.)

LO: $\mathrm{A}_{K^+\pi^0} < A_{K^+\pi^-}$

$\sim 1.5 - 2.5\sigma$ deviation
(with theory error estimate from
hadronic parameters and power corr.)

HFAG'08

$$\mathrm{A}_{K^+\pi^-} = -0.097 \pm 0.012$$
$$\mathrm{A}_{K^+\pi^0} = 0.050 \pm 0.025$$

The usual "largest" power corrections that people include (chiral enhanced annihilation, chiral enhanced amplitudes, charming penguins) do not explain this, since they contribute equally to both amplitudes.

Sizeable power corrections can shift things towards the data, but an explicit power suppressed amplitude with a suitably large numerical coefficient (in SCET) has not yet been derived.

Br are reproduced IF penguin is reproduced

Penguin ology

$$A(B \to M_1 M_2) = T^{M_1 M_2} V_{ub} V_{uf}^* + P^{M_1 M_2} V_{cb} V_{cf}^*$$

How well can we reproduce the experimentally observed penguin amplitudes?

Penguin Phenomenology

Beneke, Jager; Jain et.al.

theory: $\alpha_s \equiv \alpha_s(m_b)$

$$\hat{P}_0 \sim \left(C_{3,4}+\frac{\alpha_s(m_b)C_{1,2,8g}}{\pi}\right)\zeta^{BM}\phi^{M'} + \left(C_{3,4}+\frac{\alpha_s(m_b)C_{1,2,8g}}{\pi}\right)\zeta_J^{BM}\phi^{M'}$$

LO

$$+ C_{1,2}\,\alpha_s(2m_c)v\hat{A}_{c\bar{c}}^{BMM'}$$

Non.Pert. Charm Penguin

Ciuchini et al, Colangelo et al

$$+\left(C_{5,6}+\frac{\alpha_s(m_b)C_{1,2,8g}}{\pi}\right)\left[\frac{\mu_{M'}}{m_b}\zeta^{BM}\phi_{pp}^{M'} + \frac{\mu_{M'}}{m_b}\zeta_J^{BM}\phi_{pp}^{M'}\right] + \left(C_{3,4}+\frac{\alpha_s(m_b)C_{1,2,8g}}{\pi}\right)\frac{\mu_M}{m_b}\zeta_\chi^{BM}\phi^{M'}$$

Chiral Enh. terms

BBNS

$$\hat{P}_{\pi\pi}^{\zeta_J} + \hat{P}_{\pi\pi}^{\chi\zeta_J}\Big|_{C_{3-10}} \sim f_\pi\zeta_J^{B\pi}\left(28+215\frac{\mu_\pi}{3m_B}\right)$$

$$\int dx\,\frac{\phi_\pi^{pp}(x)}{x(1-x)} \sim 6$$

$$+\frac{\alpha_s(m_b)}{m_b}\left(C_{3,4}f_B\phi^M\phi^{M'} + C_{5,6}f_B\phi_B^+\phi^{3M}\phi^{M'}\right)$$

$$+C_{5,6}\frac{\alpha_s(m_b)\mu_M}{m_b^2}f_B\phi_{pp}^M\phi^{M'},$$

Arnesen et al.

$$+\ldots$$

singular

$$\int_0 \frac{dx}{x} = ?$$

Annihilation terms

Keum, Li, Sanda

$$+P^{\mathrm{new-physics}}$$

Jain et.al. (BPRS)

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	$\hat{P}^{\rm LO}\times 10^4$	$\hat{P}^{\chi}\times 10^4$	$\hat{P}^{\rm ann}\times 10^4$	$\hat{P}^{\rm total}\times 10^4$	$\hat{P}^{\rm expt}_{\rm ispin}\times 10^4$ $(\gamma=59^\circ)$	$\hat{P}^{\rm expt}_{\rm ispin}\times 10^4$ $(\gamma=74^\circ)$	$\hat{P}^{\rm expt}_{\rm TF}\times 10^4$ $(\gamma=59^\circ$-$74^\circ)$
$B\to\pi\pi$	(8.10 ± 0.63) $+i(1.61\pm0.21)$	(10.2 ± 2.9) $+i(1.10\pm0.39)$	-1.31 ± 5.08	(16.9 ± 5.9) $+i(2.71\pm0.45)$	(18 ± 9) $-i(29\pm6)$	(44 ± 6) $-i(29\pm6)$	
$B\to K\pi$	(9.34 ± 1.00) $+i(2.08\pm0.25)$	(13.8 ± 3.9) $+i(1.49\pm0.57)$	0.46 ± 8.03	(23.6 ± 9.0) $+i(3.57\pm0.62)$			$\pm(48\pm4\pm10)$ $-i(22\pm7\pm4)$
$B\to\rho\rho$	$22.4^{+3.7}_{-2.3}$ $+i\,5.68^{+2.45}_{-1.07}$	— —	$0.87^{+0.67}_{-0.29}$	$23.3^{+3.7}_{-2.4}$ $+i\,5.68^{+2.45}_{-1.07}$	$-(29\pm26)$ $-i(8\pm18)$	(38 ± 23) $-i(8\pm18)$	

phase relative to $T^{M_1^+ M_2^-}$

All terms above have SMALL imaginary parts

Possible Imaginary contributions:

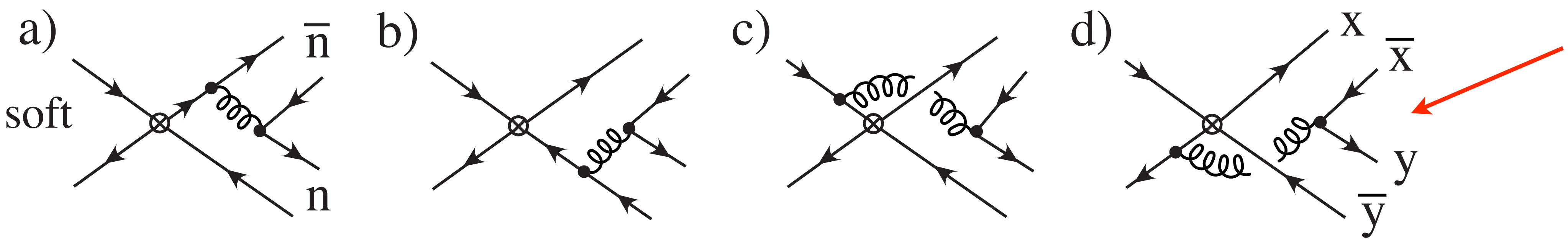
- new physics without long-distance penguins?
  very unlikely. A large imaginary part requires that the new physics have a large strong phase

$$\boxed{|Im(N_{1,2})| \leq \frac{|\mathrm{Im}(N)|}{\sin\gamma}} \qquad N e^{-i\phi} = N_1 + N_2 e^{i\gamma}$$

- complex annihilation

- complex charm penguins

Does Annihilation produce the Imaginary term?



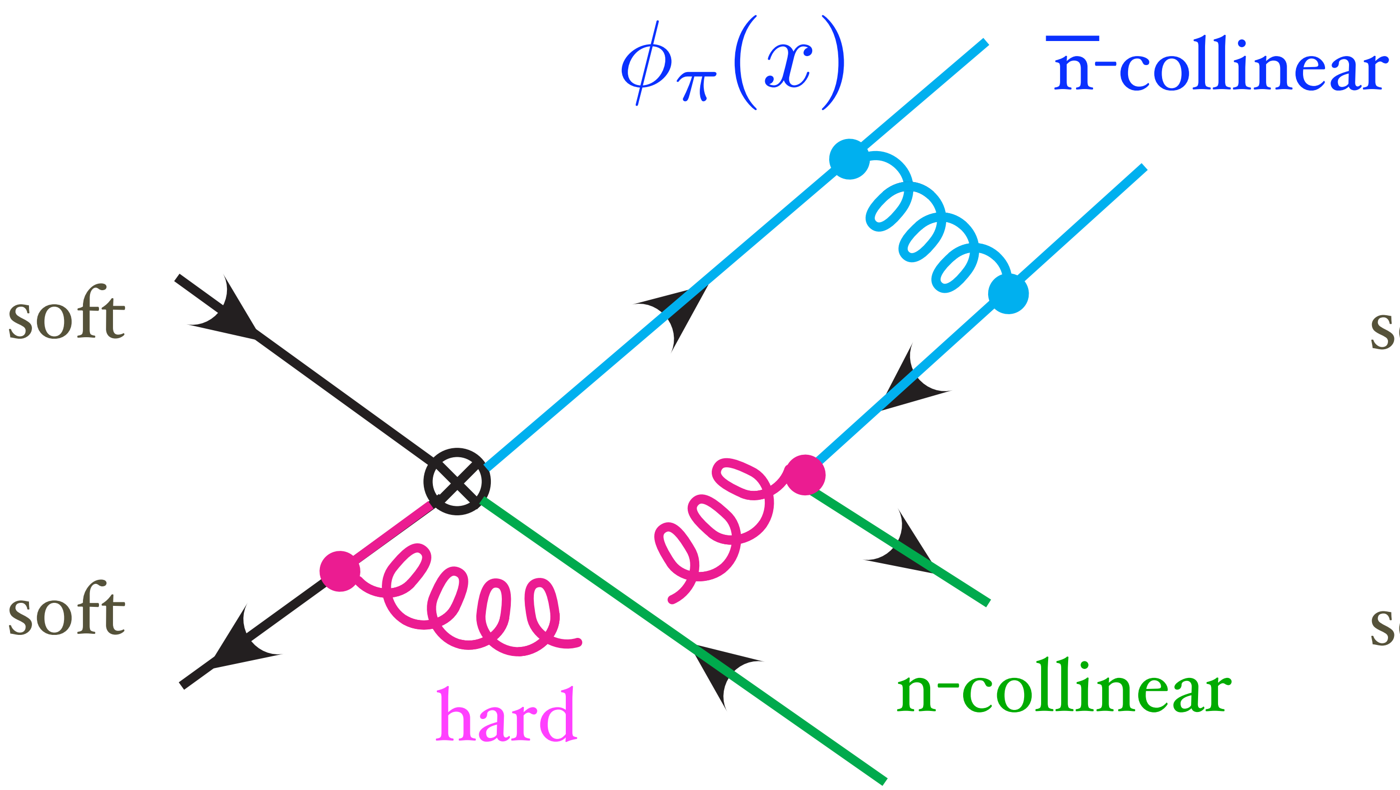
singular

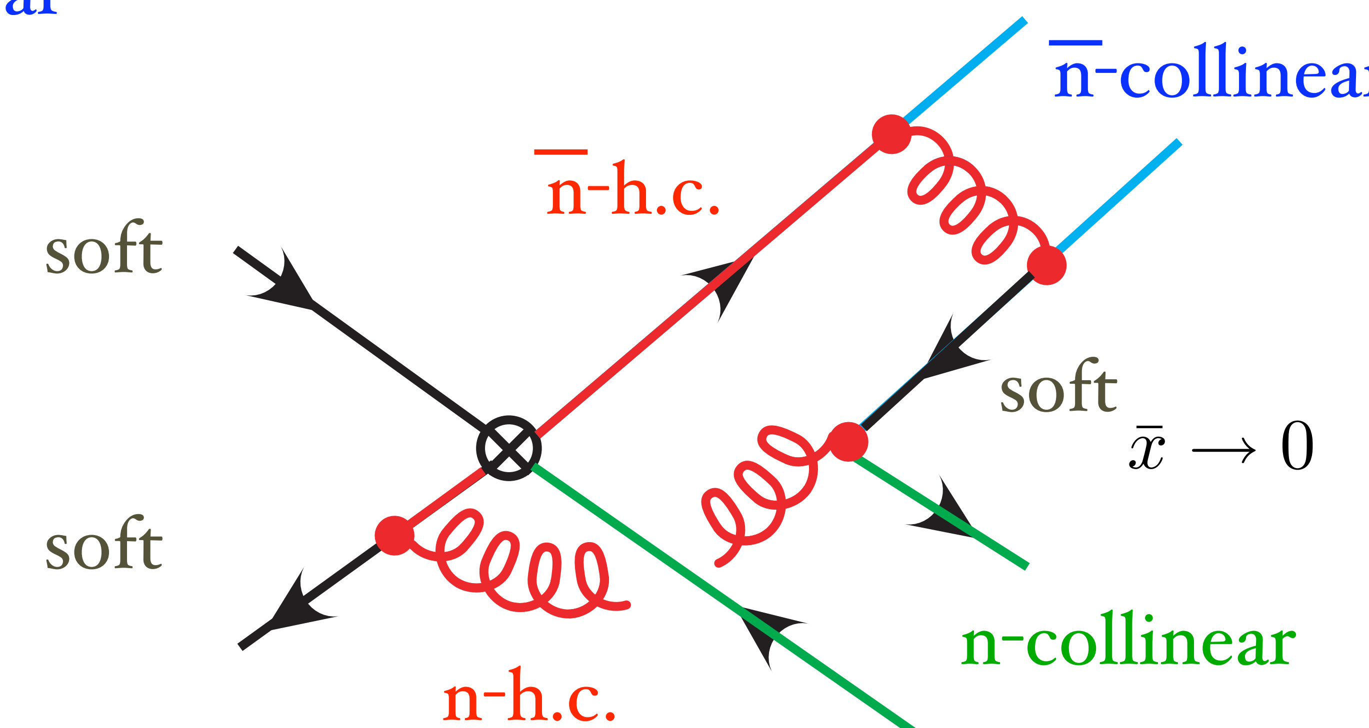
$\bar{x} \to 0$

$$\int_0^1 dx\, \frac{\phi_\pi(x)}{\bar{x}^2}$$

This singularity has to do with a potential double counting in SCET

Arnesen et.al.





Same QCD topology appears twice.

In SCET there must be a cutoff to distinguish these two terms

(& dim.reg. alone does not suffice)

SCET $_{\text{II}}$

Rapidity Fact. in SCET distinguishes the collinear and soft d.o.f.

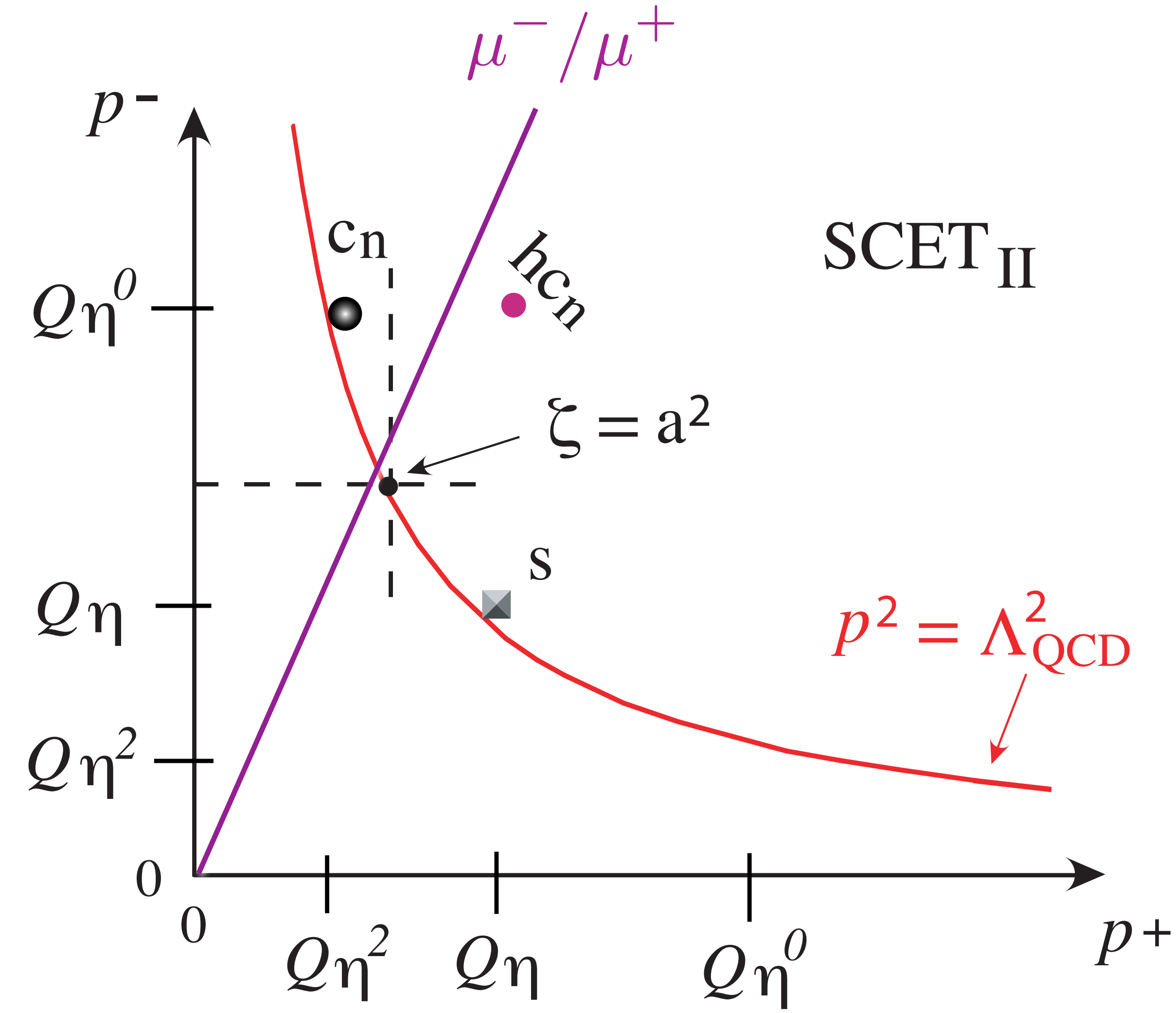
Manohar & I.S.

Can use cutoff or dim.reg. type regulators

get $\quad \phi(x,\mu,p^-/a)$

$\qquad \phi(x,\mu,p^-/\mu^-)$

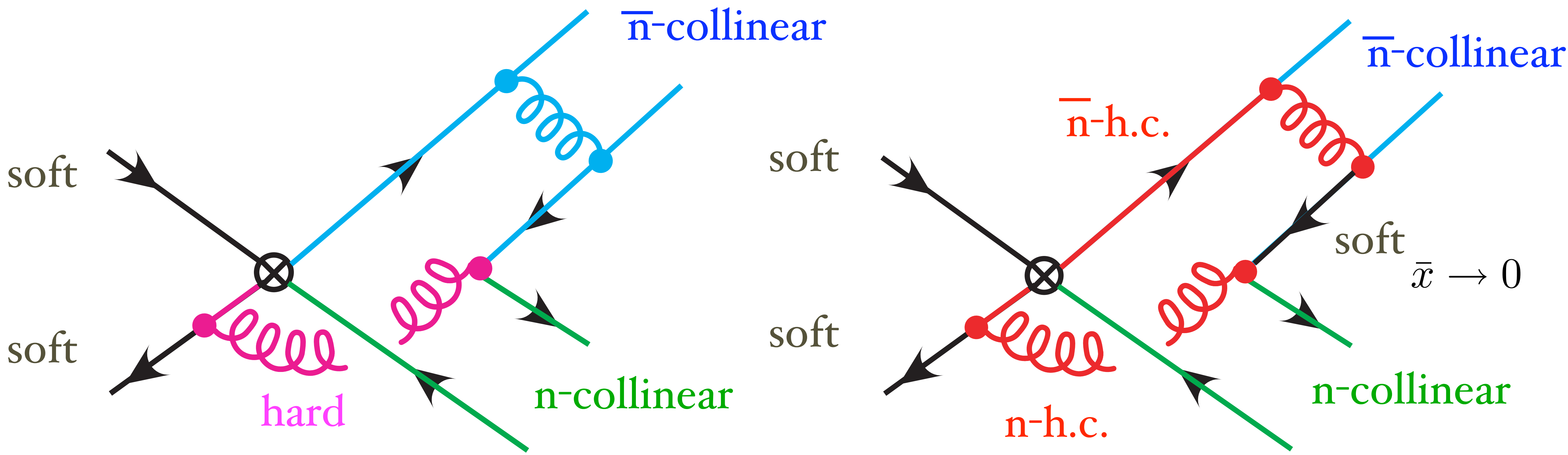
nonpert. functions



zero-bin subtraction

$$\sum_{p_1\neq 0}\int dp_1^r\; F(p_1) = \int dp_1\Big[F(p_1) - F_{\text{subt}}(p_1)\Big]$$

removes support of collinear integrand in soft region and visa-versa



This hard scattering term is real.

This soft rescattering term is complex.

Naive counting:

$$\sim \alpha_s(m_b)\frac{\Lambda}{m_b}$$

$$\sim \alpha_s^2(\sqrt{m\Lambda})\frac{\Lambda}{m_b}$$

conclude: “Annihilation is real”

Proper: the two graphs are factored at a high scale where all alphas' are equal. To determine the dominance one needs an RGE (which has not been derived for these rapidity cutoff amplitudes).

Path to finding New Physics in the presence of Hadronic Parameters/Expansions (best we can do?)

I) use as much form factor information from semileptonic decays as possible (synergy is like $B \to X_s \gamma$ with $B \to X_u e \bar{\nu}$)

II) use global fits which combine Factorization and SU(3) to look for interesting channels with large deviations

III) use Factorization and SU(2) for individual channels, to obtain more precise predictions (at the expense of additional fit parameters)

IV) use SU(3) fits as a cross-check on the hadronic uncertainties (supplementing II and III)

V) include THEORY uncertainty when discussing any deviations (power corrections, model parameters, etc.)

VI) build a new-physics model that correlates and explains the deviations in several channels

The End