QCD Challenges in Non-leptonic B Decays II

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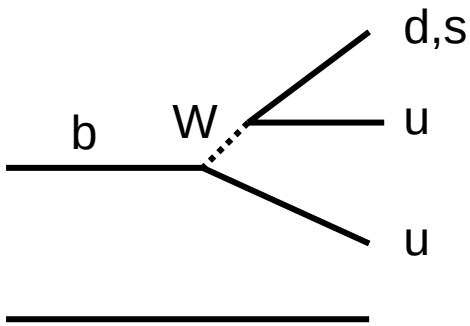
Can we calculate reliably

- Annihilation penguin
- Color-suppressed tree

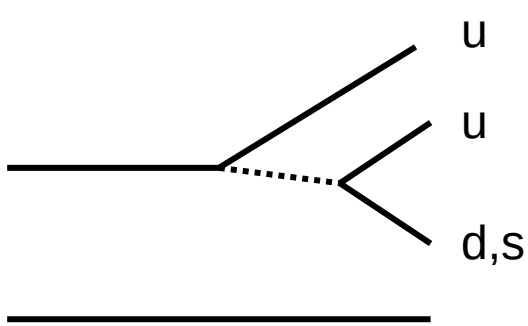
Discrepancies between theory and exp are new physics or not

- See Pierini's seminar (June 3)

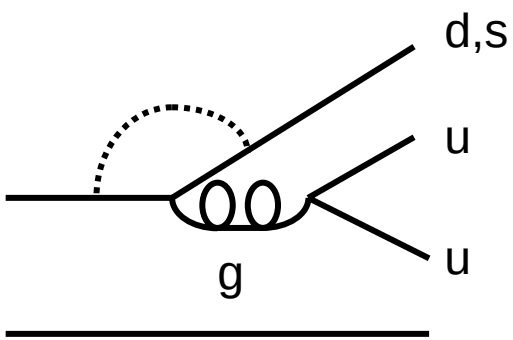
Quark amplitudes



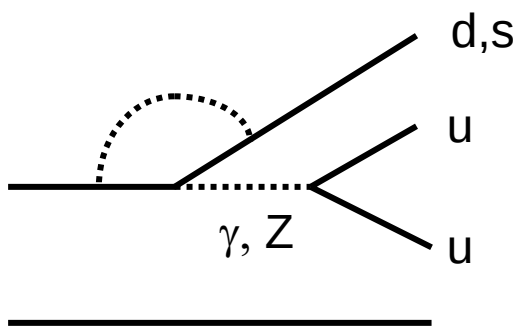
Color-allowed tree T



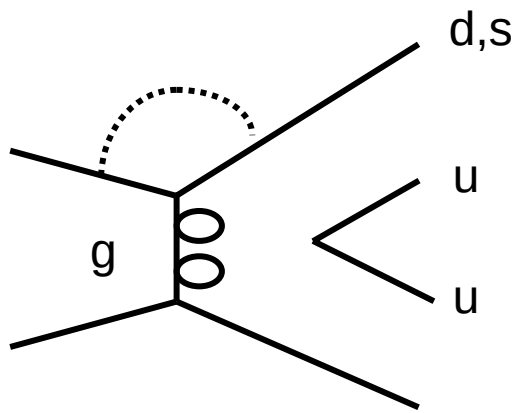
Color-suppressed tree C



QCD emission penguin Pe



EW penguin P_{ew}



QCD annihilation penguin Pa

Kπ parameterization

emission + annihilation

Weak phase

$$A(B^+ \to K^0\pi^+) = P' ,$$

$$A(B_d^0 \to K^+\pi^-) = -P'\left(1 + \frac{T'}{P'}e^{i\phi_3}\right) ,$$

$$\sqrt{2}A(B^+ \to K^+\pi^0) = -P'\left[1 + \frac{P'_{ew}}{P'} + \left(\frac{T'}{P'} + \frac{C'}{P'}\right)e^{i\phi_3}\right] ,$$

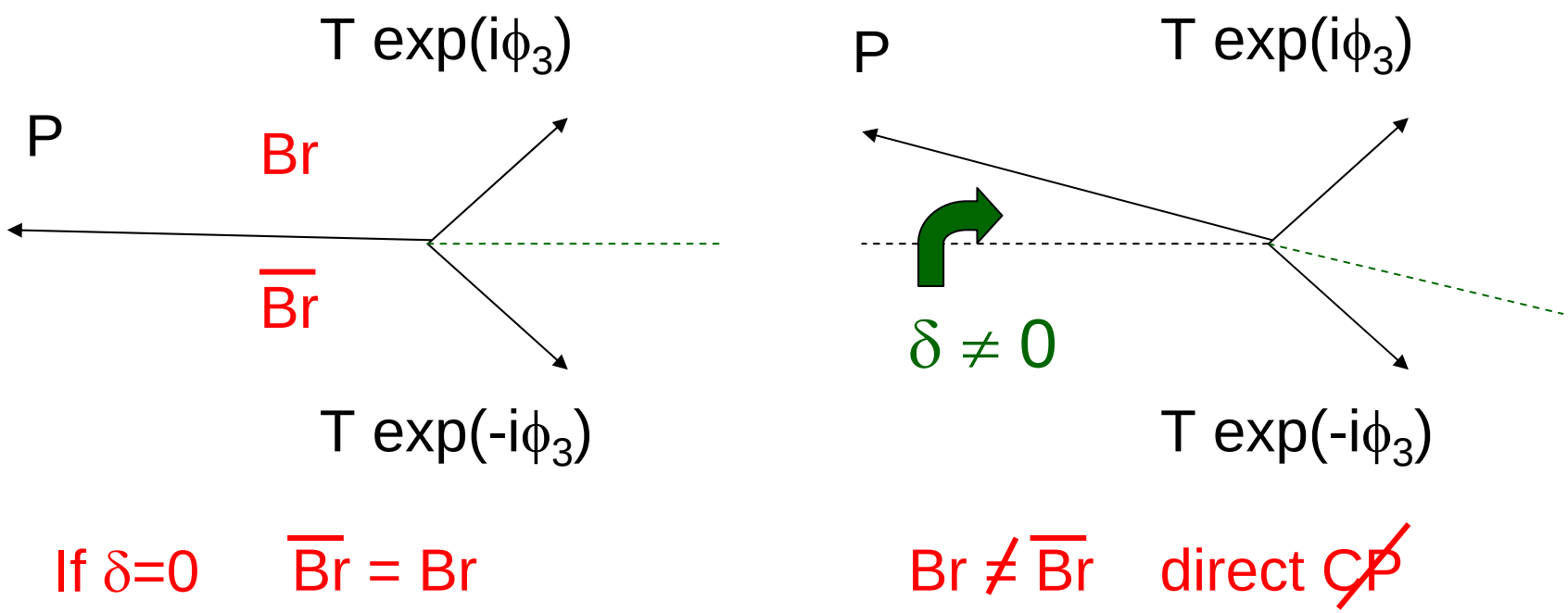
$$\sqrt{2}A(B_d^0 \to K^0\pi^0) = P'\left(1 - \frac{P'_{ew}}{P'} - \frac{C'}{P'}e^{i\phi_3}\right) ,$$

$$\frac{T'}{P'} \sim \lambda , \quad \frac{P'_{ew}}{P'} \sim \lambda , \quad \frac{C'}{P'} \sim \lambda^2$$

$(C_2/C_4)(V_{us}V_{ub}/V_{ts}V_{tb}) \sim (1/\lambda^2)(\lambda^5/\lambda^2) \sim \lambda$

$K^+\pi^-$ direct CP asymmetry

- Data $A_{CP}(K^+\pi^-) \approx$ -0.1 imply strong phase between P relative to T, $\delta \sim 15^o$.



If $\delta=0$ $\overline{Br} = Br$

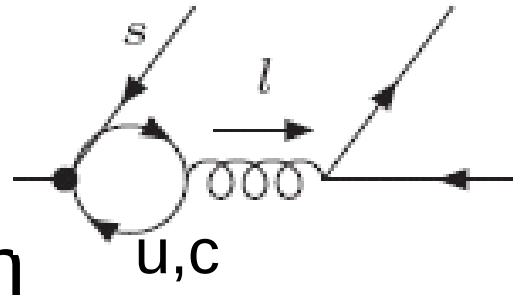
$Br \neq \overline{Br}$ direct CP

Sources of strong phase

- Perturbative sources

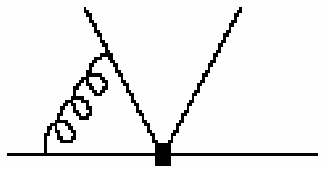
  BSS mechanism: too small

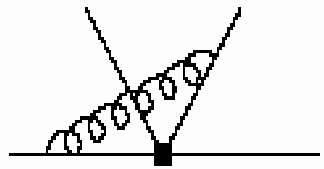
  Vertex corrections: wrong sign



- Source under debate

  Annihilation penguin





  Can be calculated reliably?

  Can generate sufficient strong phase?

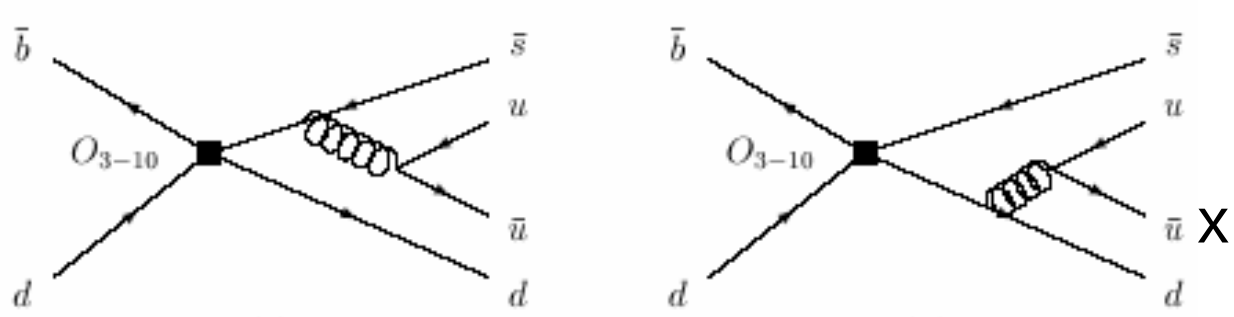
- Nonperturbative sources (not commented)

  Charming penguin

  Final-state interaction

Nonperturbative in QCDF

- Collinear factorization of annihilation penguin gives end-point singularity.



x

$$\int_0^1 dx \frac{\phi^P(x)}{x} = \int_0^1 \frac{dx}{x}$$

two-parton twist-3 DA

- Parameterized as $X_A=(1+\rho\, e^{i\phi})\ln(m_b/\Lambda)$
- Fit data by tuning ϕ

Real in SCETo (Manohar, Stewart 06)

- x=0 is removed in zero-bin subtraction

$$\int_0^1 dx_1 \frac{\phi_\pi(x_1,\mu) - x_1\phi_\pi'(0,\mu)}{(x_1)^2} + \phi_\pi'(0,\mu)\ \ln\left(\frac{\bar{n}\cdot p_\pi}{\mu^-}\right)$$

- Annihilation becomes factorizable

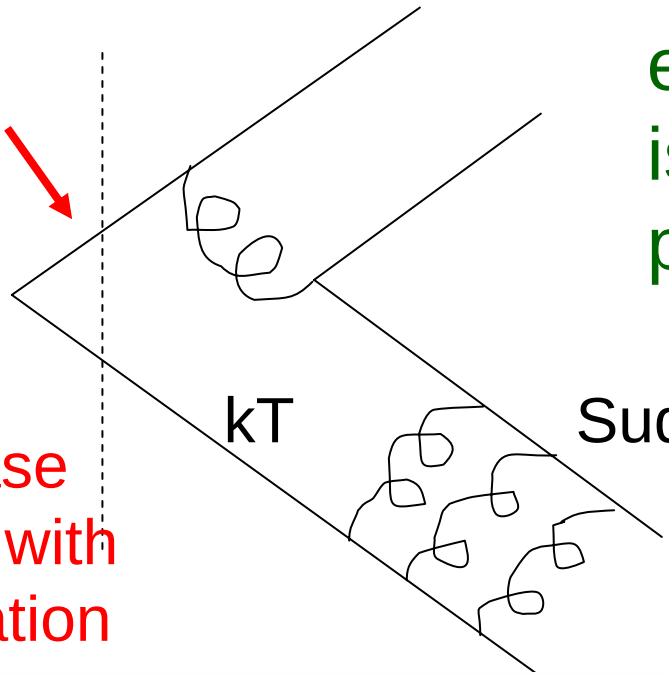
$$A^{(1)}_{Lann}(\bar{B}\to M_1M_2) = \frac{G_F f_B f_{M_1} f_{M_2}}{\sqrt{2}} \int_0^1 dx\, dy\, H(x,y)\, \phi^{M_1}(y)\phi^{M_2}(x)$$

$$\text{H(x,y)} \propto F(x,y) = \left[\frac{1}{\bar{x}^2 y} - \frac{1}{y(x\bar{y}-1)}\right]_\oslash$$

- Internal particles are on shell only at the endpoints, where zero-bin subtraction applies ⇨ real annihilation in SCET

Complex in PQCD

internal line goes on-shell



end-point singularity is regularized by parton kT

strong phase consistent with data indication

$$\frac{1}{xm_B^2 - k_T^2 + i\epsilon} = \frac{P}{xm_B^2 - k_T^2} - i\pi\delta(xm_B^2 - k_T^2).$$

Internal particles are on shell away from endpoints

⇨ complex annihilation in PQCD

$\pi\pi$ parameterization

$$\sqrt{2}A(B^+ \to \pi^+\pi^0) = -T\left[1 + \frac{C}{T} + \frac{P_{ew}}{T}e^{i\phi_2}\right] ,$$

$$A(B_d^0 \to \pi^+\pi^-) = -T\left(1 + \frac{P}{T}e^{i\phi_2}\right) ,$$

$$\sqrt{2}A(B_d^0 \to \pi^0\pi^0) = T\left[\left(\frac{P}{T} - \frac{P_{ew}}{T}\right)e^{i\phi_2} - \frac{C}{T}\right] ,$$

Weak phase

$$\frac{P}{T} \sim \lambda , \quad \boxed{\frac{C}{T} \sim \lambda}, \quad \frac{P_{ew}}{T} \sim \lambda^2 .$$

$(C_4/C_2)(V_{td}V_{tb}/V_{ud}V_{ub}) \sim (\lambda^2/1)(\lambda^3/\lambda^4) \sim \lambda$

Indications of large C

$B(\pi^0\pi^0) = (1.31 \pm 0.21) \times 10^{-6}$

greater than PQCD, QCDF predictions

$A_{CP}(K^+\pi^0) = 0.050 \pm 0.025$

much different from $A_{CP}(K^+\pi^-) = -0.097 \pm 0.012$

need large imaginary C to change
strong phase between tree and penguin

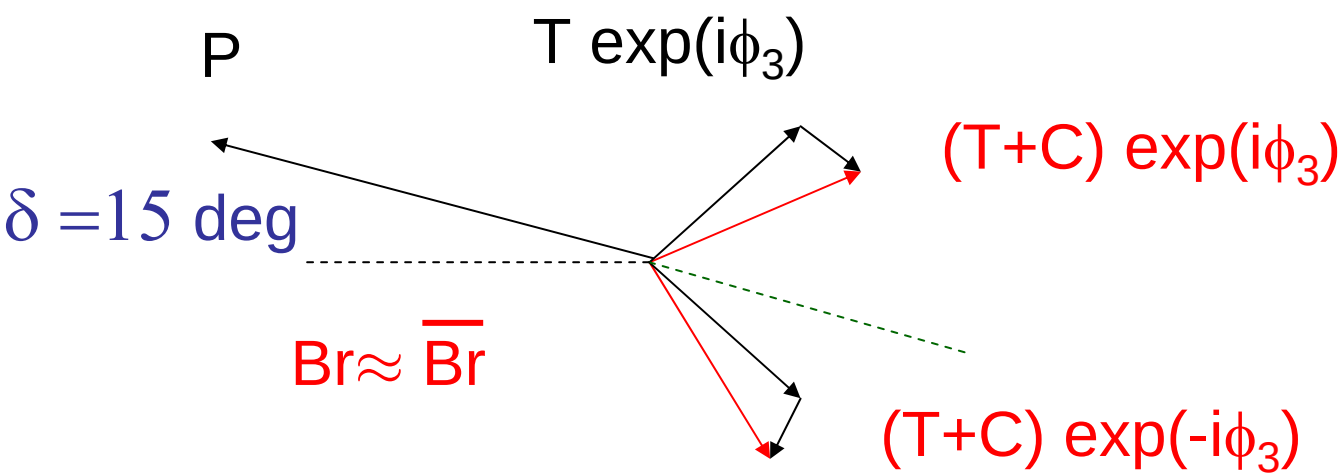
$S(K_S\pi^0) = 0.38 \pm 0.19$

smaller than $S(c\bar{c}s) = 0.681 \pm 0.025$

need large tree pollution from C

Puzzle is…

- PQCD, QCDF predictions |C/T| ~ 0.2-0.5, O(λ), are constrained by $B(\rho^0\rho^0) = (0.68 \pm 0.27) \times 10^{-6}$
- $A_{CP}(K^+\pi^0)$ implies large $\delta_{C/T}$, i.e., large $\delta_{C/P}$



- Then $\Delta S(K_S\pi^0) \propto \cos\delta_{C/P} \to 0$

Predictions for ΔS

ΔS	*QCDF*	*pQCD*	*SCET*	ΔS *Expt*
ϕK_S	$0.02^{+0.01}_{-0.01}$	$0.020^{+0.005}_{-0.008}$		-0.29 ± 0.17
ωK_S	$0.13^{+0.08}_{-0.08}$	$0.153^{+0.03}_{-0.07}$		-0.20 ± 0.24
$\rho^0 K_S$	$-0.08^{+0.08}_{-0.12}$	$-0.187^{+0.10}_{-0.06}$		$-0.07^{+0.25}_{-0.27}$
ηK_S	$0.10^{+0.11}_{-0.07}$	–	-0.034 ± 0.165 0.070 ± 0.143	–
$\eta' K_S$	$0.01^{+0.01}_{-0.01}$	–	-0.019 ± 0.008 -0.010 ± 0.010	-0.07 ± 0.08
$\pi^0 K_S$	$0.07^{+0.05}_{-0.04}$	$0.053^{+0.02}_{-0.03}$	0.077 ± 0.030	-0.30 ± 0.19

QCDF: Beneke [see also Cheng, Chua, Soni]

PQCD: Li, Mishima

SCET: Williamson, Zupan (two solutions)

Summary

- Annihilation penguin is a theoretical issue related to predictive power of an approach.
- It is a challenge if predictive power is the goal.
- Opposite conclusions between SCETo and PQCD arise from different treatments of subleading contributions.
- Color-suppressed tree is a real challenge.
- Consistent understanding of C in all modes is difficult in SM.

New physics?

- If data persist, may require exotic EW penguin, i.e., new physics (NP).

$$\Delta\mathcal{A}_{K\pi^0} = 2r_{\rm EW}\sin\delta_{\rm EW}\sin\phi_{\rm EW},$$
$$\Delta\mathcal{S}_{K_S\pi^0} = -2r_{\rm EW}\cos 2\phi_1\cos\delta_{\rm EW}\sin\phi_{\rm EW},$$

r_{EW}=NP P_{EW}/P

- P_{EW} is anti-parallel to T+C from isospin symmetry. Its strong phase relative to full P, $\delta_{EW} < 90^\circ$
- NP phase $\phi_{EW} < 90^\circ$ improves both.