Recent progress in B physics

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Outlines

- Introduction
- Theories: QCDF, PQCD, and SCET
- Phenomenology:
- B$\rightarrow$ $\pi\pi$, Kπ
- Mixing-induced $\not{CP}$ in b$\rightarrow$ s penguin
- B_s–$B_s$bar mixing
- B$\rightarrow$ VV polarizations
- Conclusion

Introduction

- B physics has entered the era of precision measurement.
- Both theoretical and experimental precisions are improved.
- Discrepancies are observed. Critical examination is necessary for revealing new physics signals.

Apology

- no inclusive B decays (Wu's talk at the previous meeting).
- No semileptonic B decays (Huang, Li, Qiao…)
- no B decays into charmonia (Chao…).
- No B decays into baryons (He, Li,…)
- no B_c decays (Du, Lu, Zhang, Li, Ma, Li…)
- no new physics in B decays (Xiao, Yang, Wu…)

Theories

QCD-improved Factorization

(Beneke, Buchalla, Neubert, Sachrajda)

Perturbative QCD

(Keum, Li, Sanda)

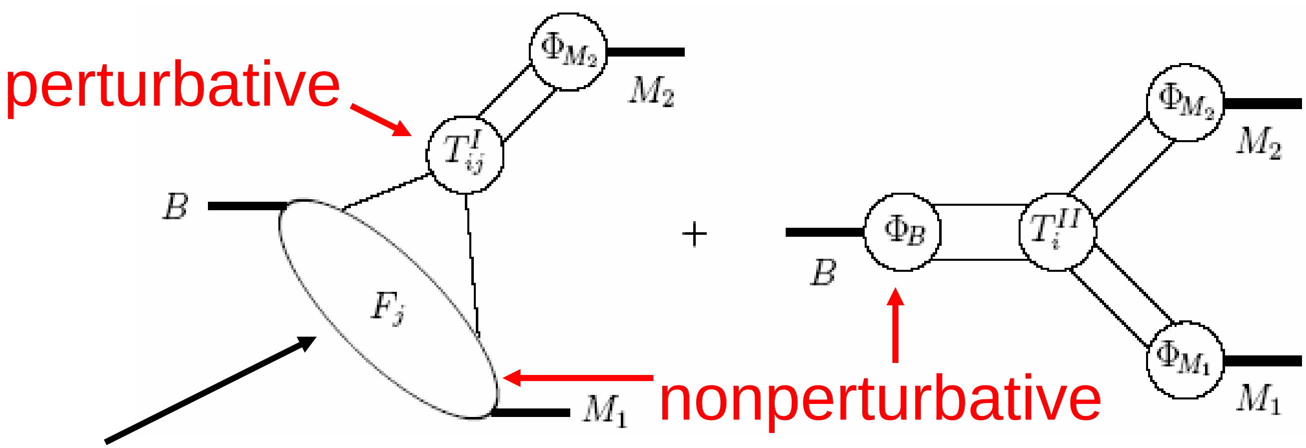
Soft-collinear Effective Theory

(Bauer, Pirjol, Rothstein, Stewart)

All assume large m_b

QCDF

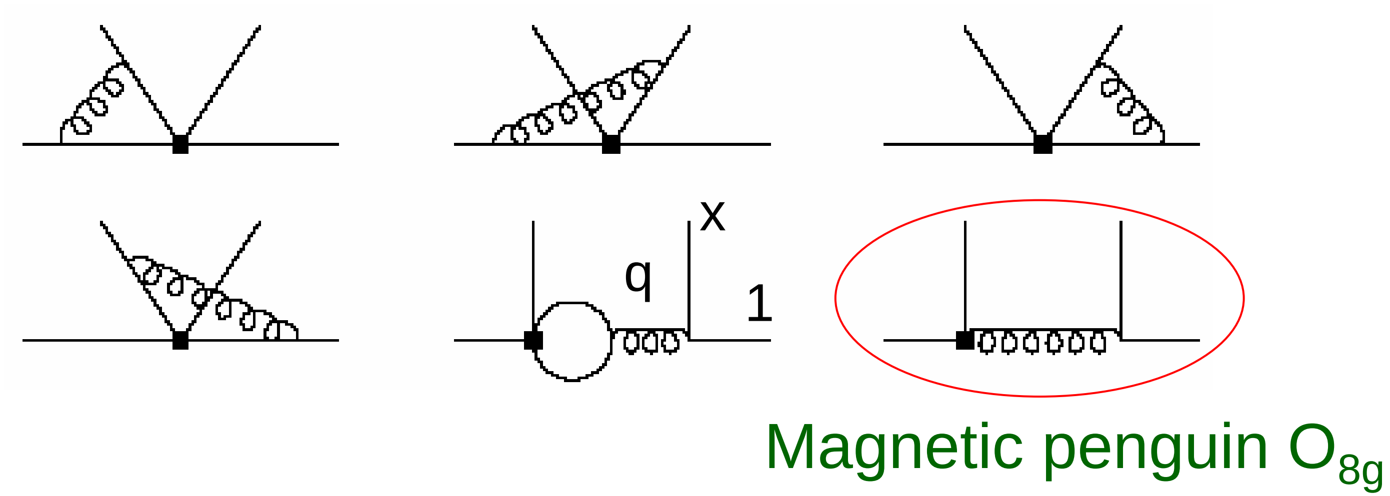
- Based on collinear factorization (Brodsky and Lepage 80).
- Compute correction to naïve factorization (NF), ie., the heavy-quark limit.



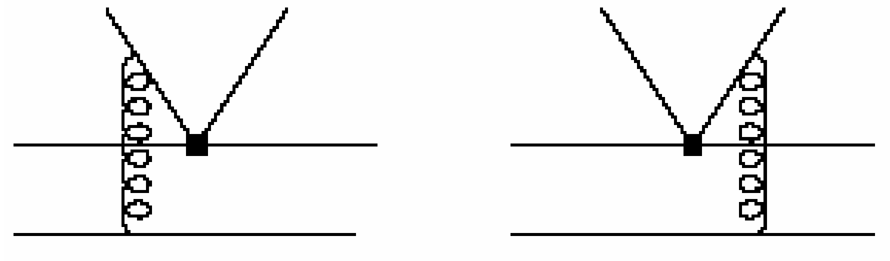
- Divergent like $\int_0^1 dx/x$ (end-point singularity) in collinear factorization

Factorization formula

- $A(B\to M_1M_2)=(T^I * F^{BM_1}+T^{II} * \phi_B * \phi_{M_1}) * \phi_{M_2}$
- T^I comes from vertex corrections, $O(\alpha_s)$

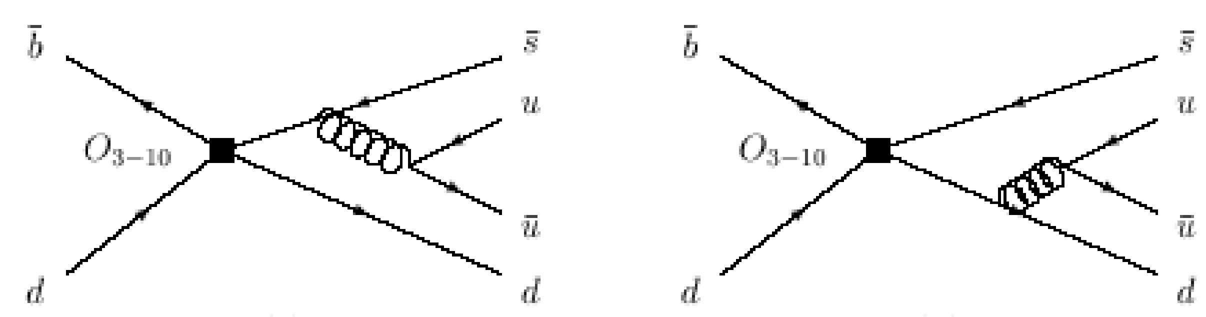


- T^{II} comes from spectator diagrams, $O(\alpha_s)$



End-point singularity

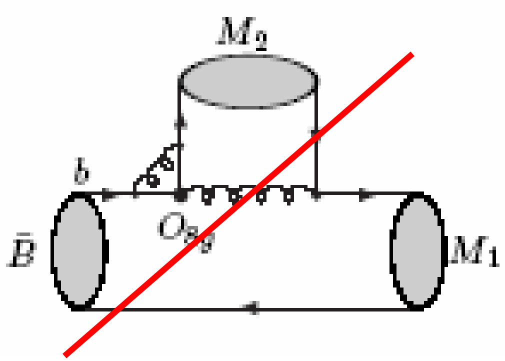
- Singularity appears at $O(1/m_b)$, twist-3 spectator and annihilation amplitudes, parameterized as $X=(1+\rho\, e^{i\phi})\ln(m_b/\Lambda)$

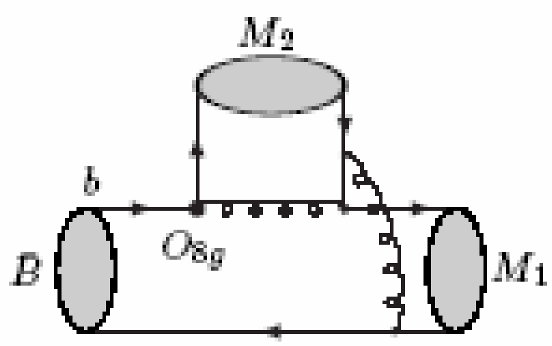


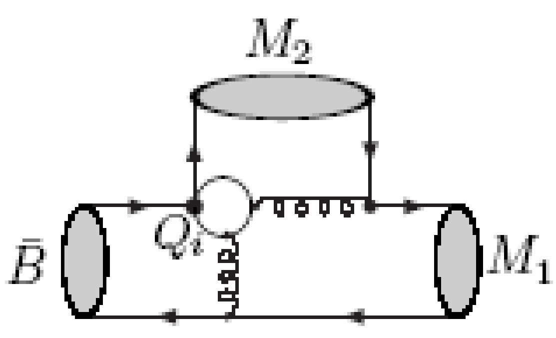
- For QCDF to be predictive, $O(1/m_b)$ corrections are better to be small $\approx$ FA.
- Data show important $O(1/m_b)$. Different free (ρ,ϕ) must be chosen for $B\to$ PP, PV, VP.

O(α_s^2) corrections

- $b \to d(s)g^*g^*$ (Li, Yang 05, 06)
- Enhance penguin and rates of penguin-dominated modes, such as $B \to \pi K$, but….
- Minor effects on tree-dominated modes, such as $B \to \pi\pi$.
- Incomplete O(α_s^2) for T^{II}.

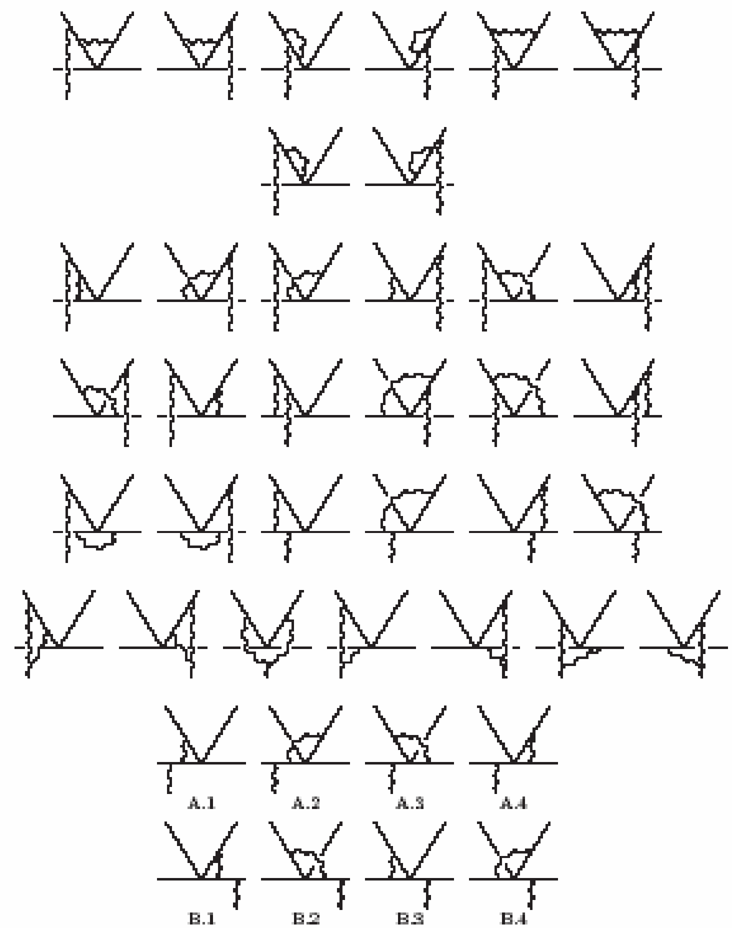






QCDF/SCET---complete $O(\alpha_s^2)$ T^{II}

- $T^{II}=H^{II}*J$ (see SCET)
- Motivated by $B\rightarrow\pi\pi$ data:
- $O(\alpha_s^2)$ for J, major effect (Beneke, Yang 05)
- $O(\alpha_s^2)$ for H^{II} (Beneke, Jager 05)
- $O(\alpha_s^2)$ for H^{II} of penguin amplitudes (BJ 06).
- Enhance color-suppressed tree, not QCD penguin

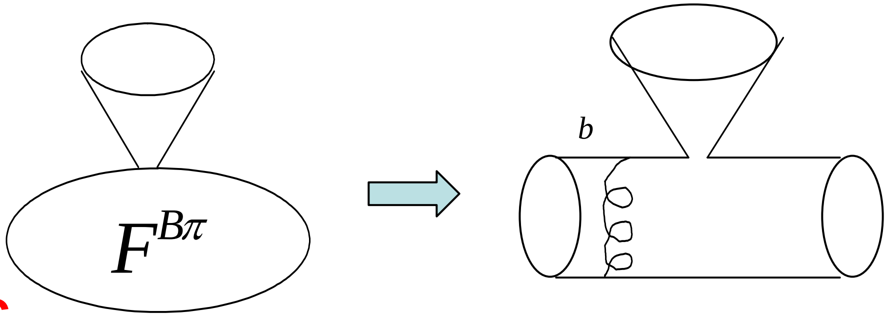


PQCD

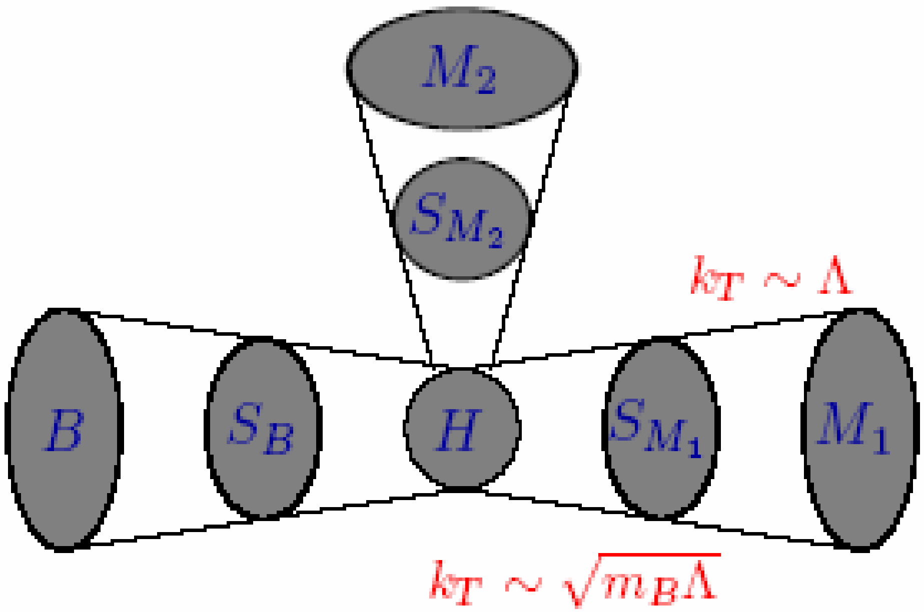
- End-point singularity means breakdown of collinear factorization
- Use more “conservative” k_T factorization (Li and Sterman 92)
- Parton k_T smear the singularity

$$\int_0^1 dx \frac{1}{x + k_T^2 / m_B^2}$$

- Same singularity in form factor is also smeared
- No free parameters



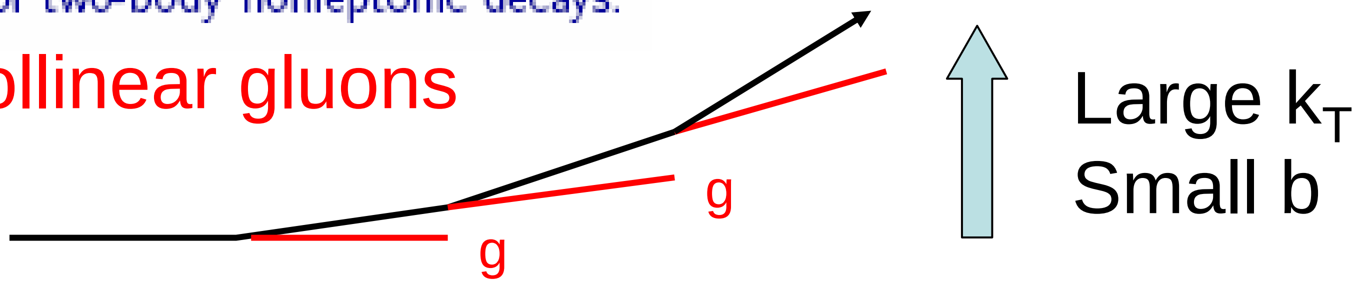
Factorization picture



PQCD picture for two-body nonleptonic decays.

Sudakov factors S, summation of $\alpha_s \ln^2(m_b/k_T)$ to all orders, describe parton distribution in k_T

Always collinear gluons

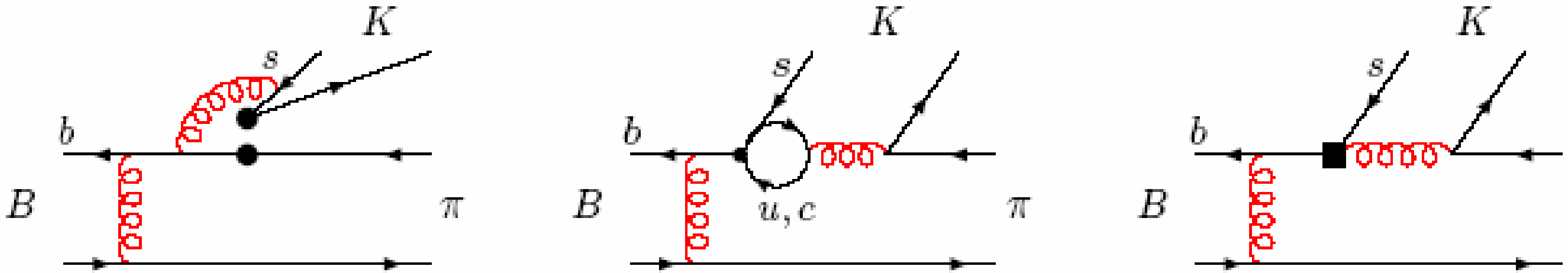


k_T accumulates after infinitely many gluon exchanges, similar to DGLAP evolution up to $k_T \sim Q$

$O(\alpha_s^2)$ corrections (Li, Mishima, Sanda 05)

- LO: all pieces at LO
- LO_{NLOWC}: NLO Wilson coefficients
- VC: vertex correction
- QL: quark loops
- MP: Magnetic penguin

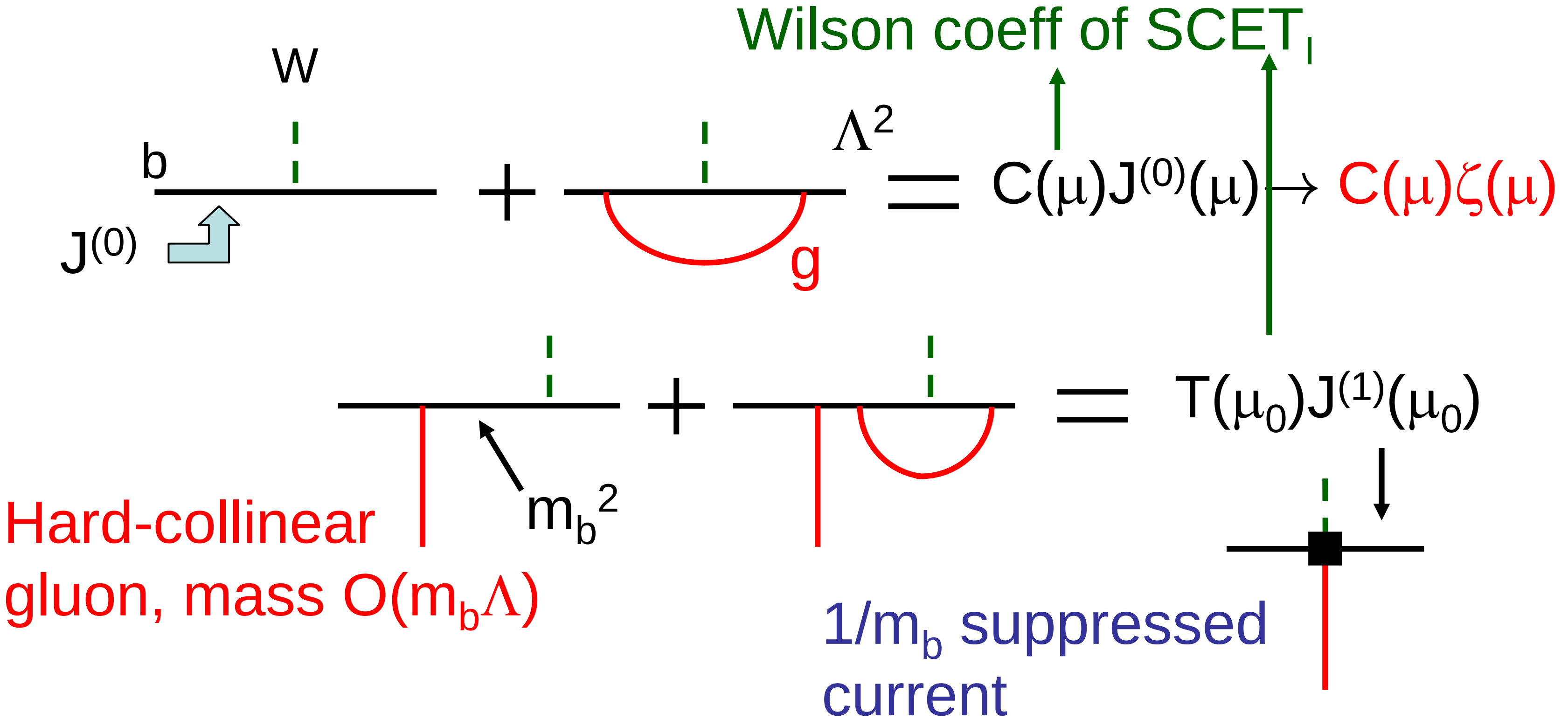
} decrease P by 10%



- Corrections to form factors are nontrivial (Ma, Wang 04; 06).

$SCET_I$

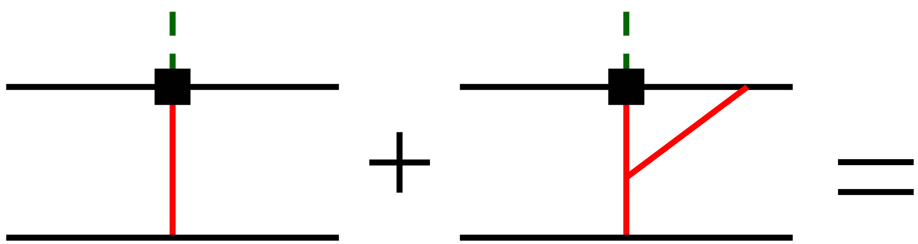
- Two scales in B decays: $m_b\Lambda$ and m_b^2
- Full theory$\to$ $SCET_I$: integrate out the lines off-shell by m_b^2

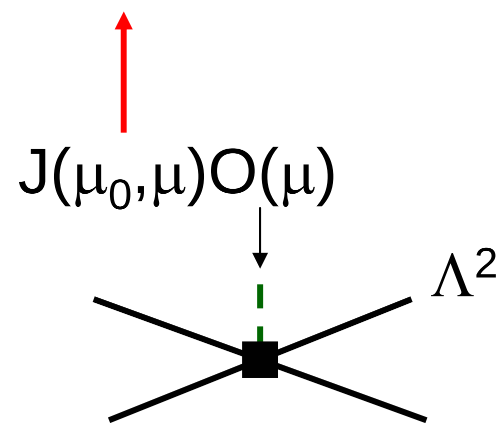


$\mathrm{SCET}_{\mathrm{II}}$

- $\mathrm{SCET}_{\mathrm{I}} \to \mathrm{SCET}_{\mathrm{II}}$: integrate out the lines off-shell by $m_b\Lambda$

Jet=Wilson coeff of $\mathrm{SCET}_{\mathrm{II}}$





$\to T(\mu_0)J(\mu_0,\mu)\phi_M(\mu)\phi_B(\mu)$

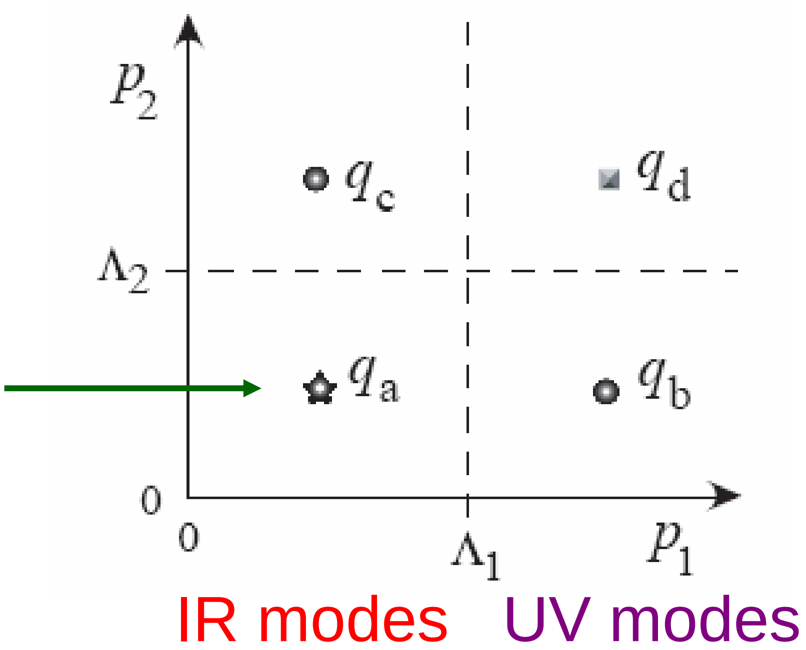
- Compared to QCDF, $T^{\mathrm{II}} \to T(\mu_0)J(\mu_0,\mu)$
- Framework for $O(\alpha_s^2)$ QCDF/SCET.

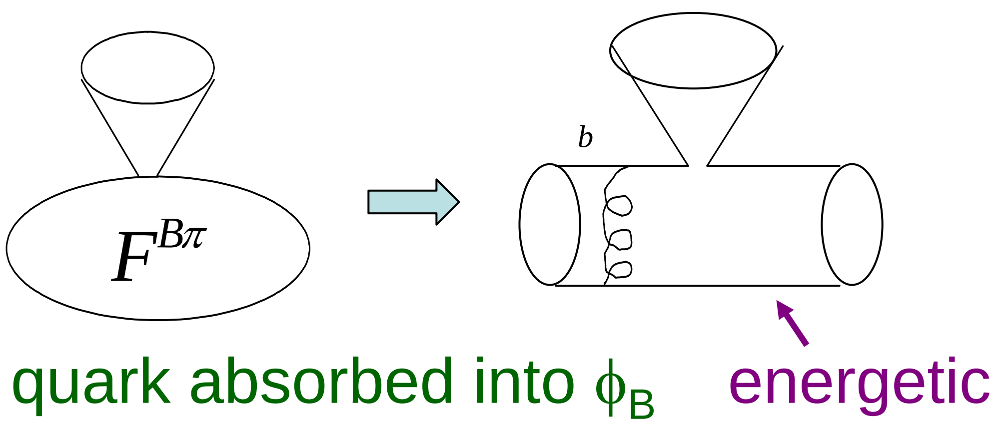
BPRS's SCET

- Do not attempt to calculate matrix elements in SCET, but treat them as free parameters determined by data (Bauer, Pirjol, Rothstein, Stewart 04).
- Even introduce arbitrary charming penguins in order to input strong phases.
- BPRS's SCET is not very different from amplitude parameterization using SU(3).
- Intensive application by Williamson, Zupan 06.

Zero-bin subtraction (Manohar, Stewart 06)

- Effective theory with more than two momenta, IR modes are doubly counted.
- P_1=0 bin should be removed
- Form factor is factorizable
- Merge with PQCD





Higher-power corrections are not yet explored!

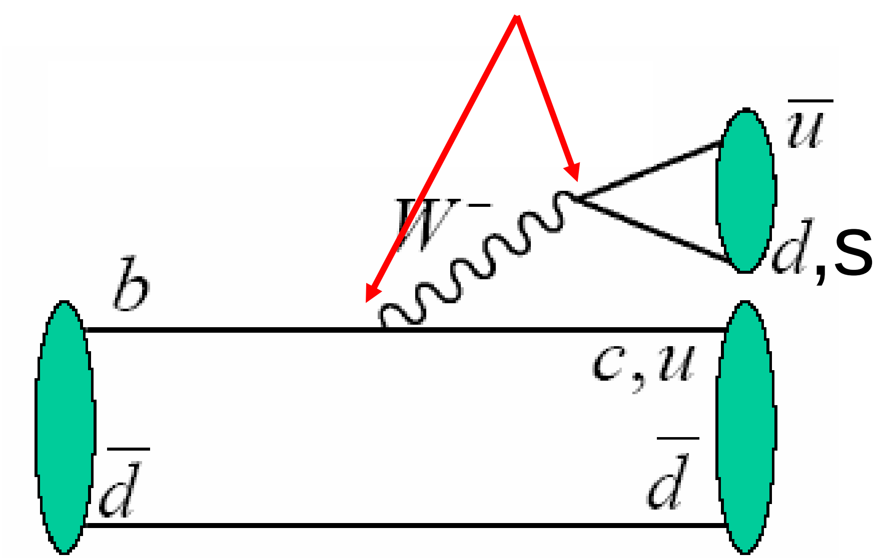
A much more difficult job

Phenomenology

$B \to \pi\pi$, $K\pi$

Naïve power counting

- Estimate order of magnitude of B decay amplitudes in power of the Wolfenstein parameter $\lambda \sim 0.22$
- It is not a power counting from any rigorous theory
- Amplitude$\sim$ (CKM) (Wilson coefficient)



Induced by $O_2 = (\bar{s}u)(\bar{u}b)$

$\propto C_2$

- CKM matrix elements

$|\rho - i\eta| \approx 0.4$

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$$= \begin{pmatrix} O(1) & O(\lambda) & O(\lambda^4) \\ O(\lambda) & O(1) & O(\lambda^2) \\ O(\lambda^3) & O(\lambda^2) & O(1) \end{pmatrix},$$

- Wilson coefficients

$a_1 = C_2 + C_1/N_c$

$a_2 = C_1 + C_2/N_c$

$O(1) : a_1 ,$

$O(\lambda) : a_2 , 1/N_c$

$O(\lambda^2) : C_4 , C_6 , a_4 , a_6$

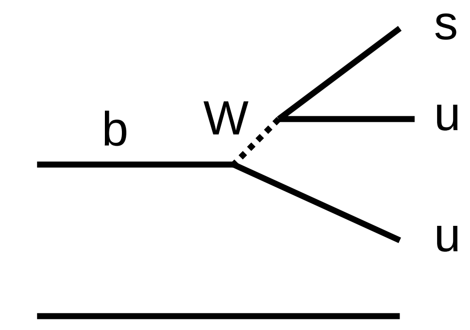
$O(\lambda^3) : C_3 , C_5 , C_9 , a_3 , a_5 , a_9$

$O(\lambda^4) : C_{10} ,$

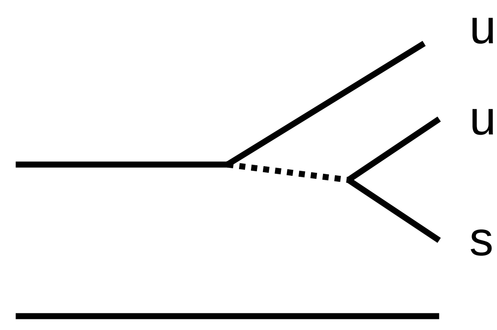
$O(\lambda^5) : C_7 , C_8 , a_7 , a_8 , a_{10}$

Quark amplitudes

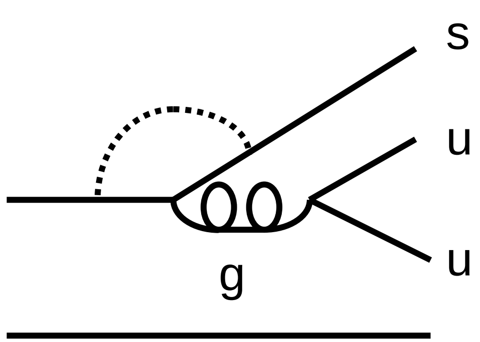
most recent work by Wu, Zhou, Zhuang



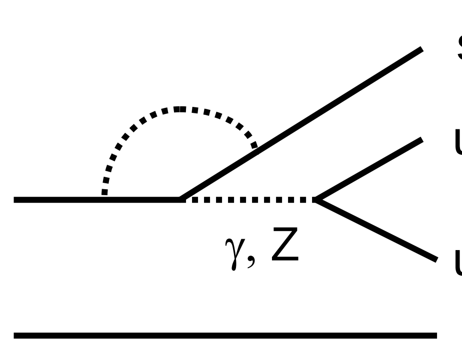
Color-allowed tree T



Color-suppressed tree C



QCD penguin P



Electroweak penguin P_{ew}

$\pi\pi$ parameterization

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

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

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

$\lambda \approx 0.2$ $\frac{P}{T} \sim \lambda\,, \quad \frac{C}{T} \sim \lambda\,, \quad \frac{P_{ew}}{T} \sim \lambda^2\,.$ Tree-dominant

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

$B\to \pi\pi$ puzzle

- P, C, and P_{ew} in $\pi^0\pi^0$ are all subleading.
- We should have $Br(\pi^0\pi^0)\approx O(\lambda^2)Br(\pi^+\pi^-)$
- Data show $Br(\pi^0\pi^0)\approx O(\lambda)Br(\pi^+\pi^-)$

$$B(B0 \to \pi+\pi-) = (5.2 \pm 0.2)\times 10^{-6}$$

$$B(B+ \to \pi+\pi 0) = (5.7 \pm 0.4)\times 10^{-6}$$

$$B(B0 \to \pi 0 \pi 0) = (1.3 \pm 0.2)\times 10^{-6}$$

← reduced from 1.5×10^{-6}

- Large P and/or C---motivates $O(\alpha_s^2)$ QCDF/SCET. It remains as a puzzle, because $B(\rho^0\rho^0)=(1.16 \pm 0.46)\times 10^{-6}$ (Li, Mishima 06).

Kπ parameterization

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

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

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

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

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

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

Direct $\not{CP}$ in $B \to K\pi$

- $K^+\pi^-$ and $K^+\pi^0$ differ by subleading amplitudes, $P_{ew}/P \sim C/T \sim \lambda$.
  Their $\not{CP}$ are expected to be similar.

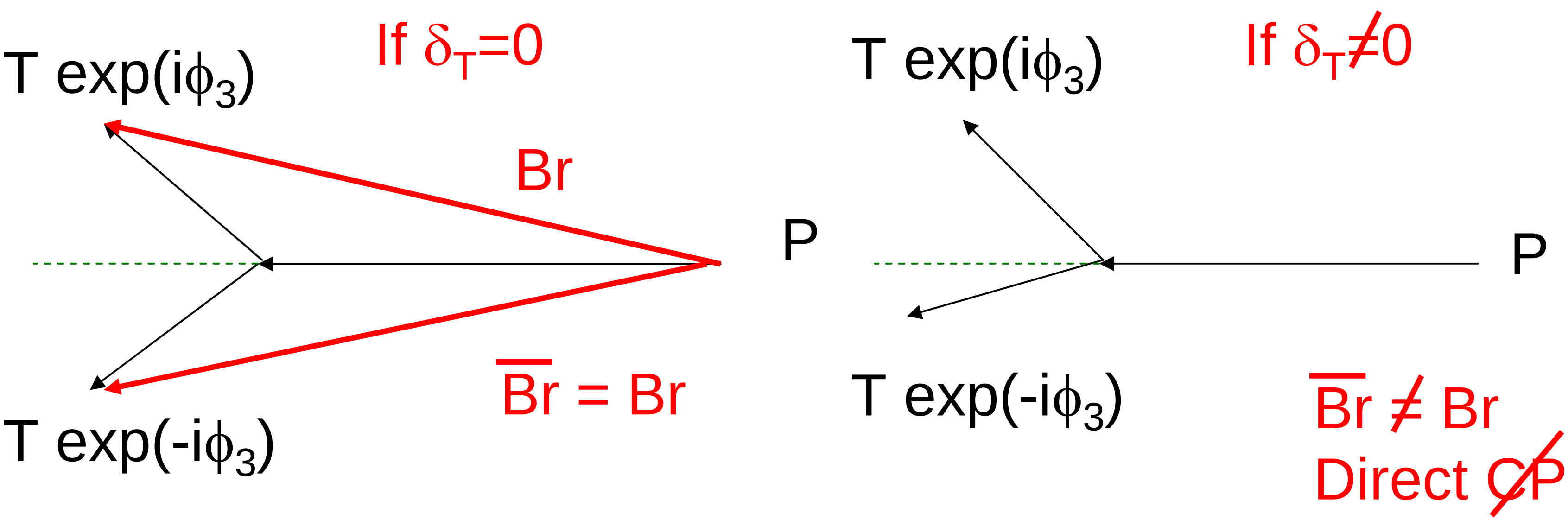
$$A^0_{CP} = \frac{\mathrm{Br}(\bar{B}^0_d \to K^-\pi^+) - \mathrm{Br}(B^0_d \to K^+\pi^-)}{\mathrm{Br}(\bar{B}^0_d \to K^-\pi^+) + \mathrm{Br}(B^0_d \to K^+\pi^-)},$$

$$A'^c_{CP} = \frac{\mathrm{Br}(B^- \to K^-\pi^0) - \mathrm{Br}(B^+ \to K^+\pi^0)}{\mathrm{Br}(B^- \to K^-\pi^0) + \mathrm{Br}(B^+ \to K^+\pi^0)},$$

- Their data differ by more than 3σ!
- $A_{CP}(K^+\pi^-) = -(9.3 \pm 1.5)\%$
- $A_{CP}(K^+\pi^0) = (4.7 \pm 2.6)\%$, large P_{ew} or C?
- $b \to sg^*g^*$, FSI can not resolve the puzzle.

Large strong phase

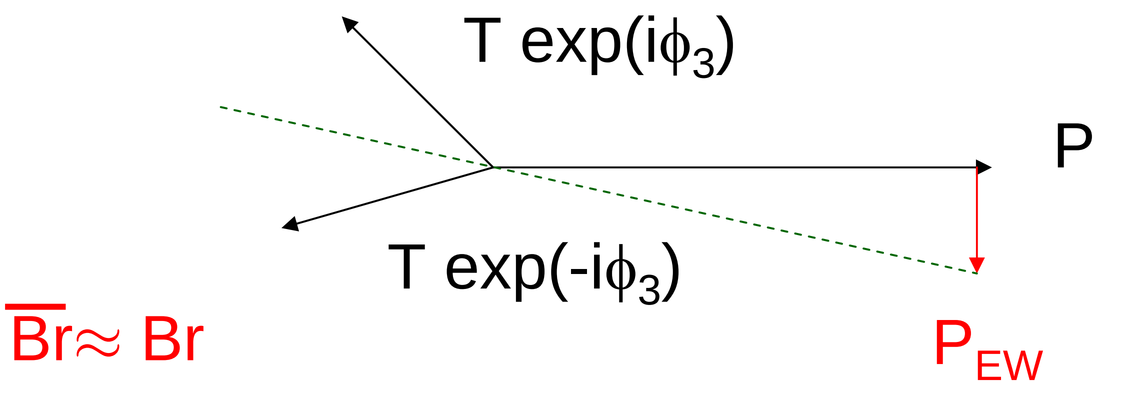
- $A_{CP}(K^+\pi^-) \approx -0.115$ implies sizable $\delta_T \sim 15^o$ between T and P (Keum, Li, Sanda 00)



Explanation 1

- How to understand the small $A_{CP}(K^+\pi^0)$?
- Large P_{EW} to rotate P (Buras et al.; Yoshikawa; Gronau and Rosner; Ciuchini et al., Kundu and Nandi, Wu and Zhou)
- Also motivated by old large $B(K^0\pi^0)$ data

$\Rightarrow$ new physics?

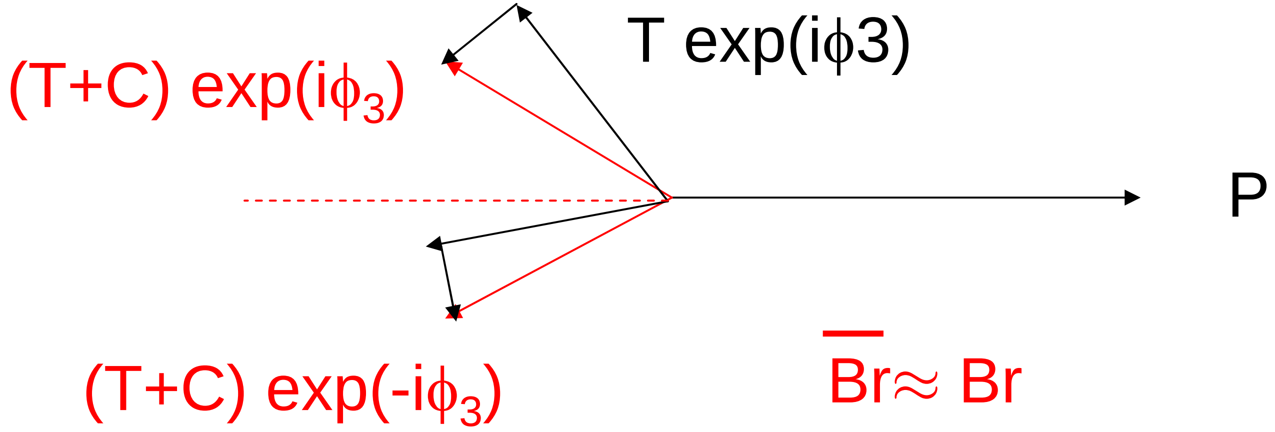


Explanation 2

- Large C to rotate T (Charng and Li; He and McKellar)

  $\Rightarrow$ mechanism missed in naïve power counting?

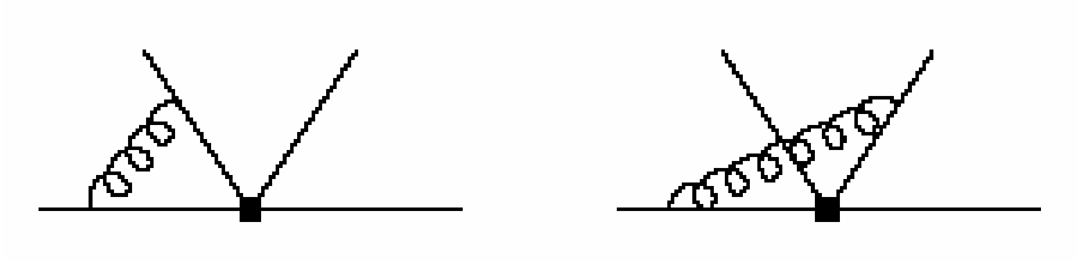
- C is subleading by itself. Try NLO PQCD.

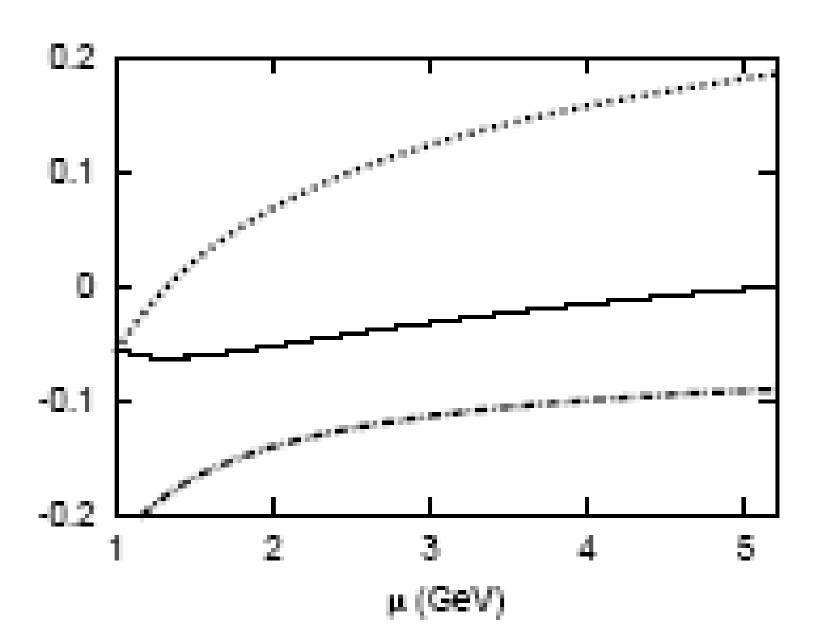


$\overline{Br} \approx Br$

Vertex correction

- Vertex correction enhances $C \propto a_2$, and makes it almost imaginary.





Without vertex correction

Re, with vertex correction

Im, with vertex correction
Is negative. It rotates T!

Hadronic uncertainty

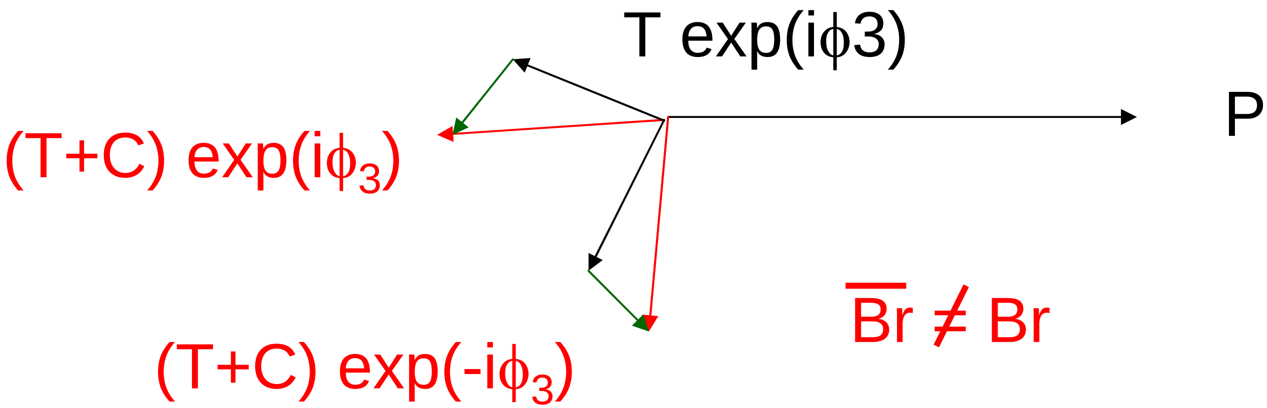
PQCD results

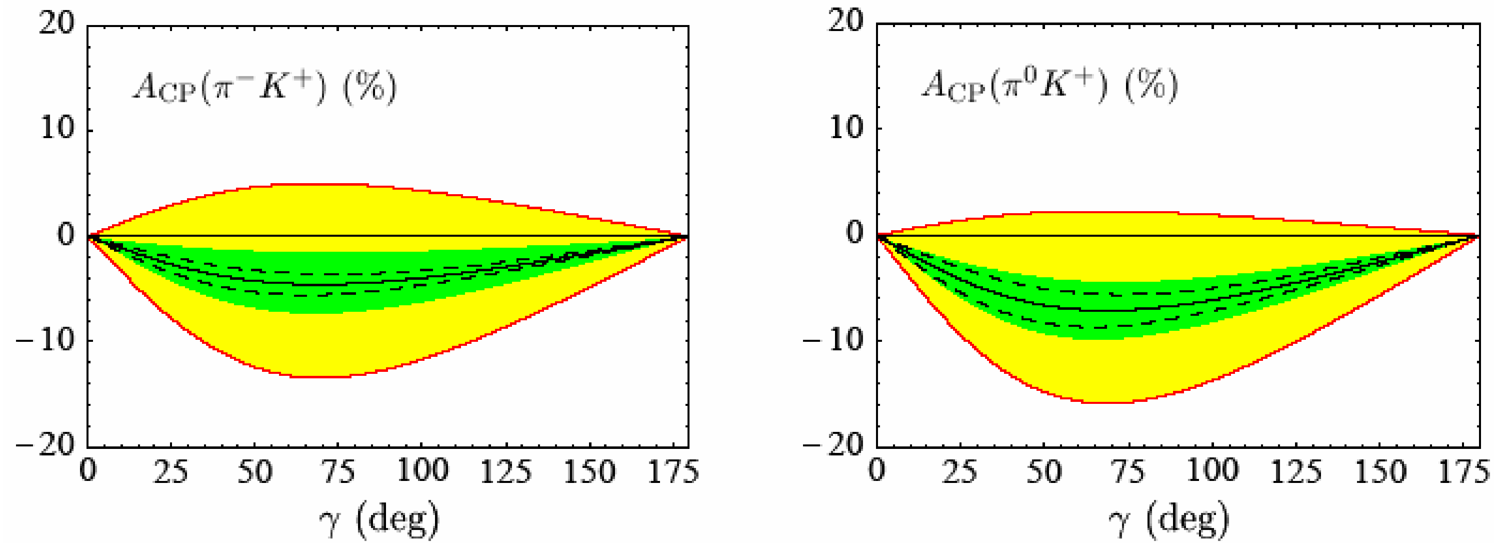
Mode	Data [1]	LO	LO_{NLOWC}	+VC	+QL	+MP	+NLO
$B^{\pm} \to \pi^{\pm} K^{0}$	24.1 ± 1.3	17.3	32.9	31.6	34.9	24.5	$24.9^{+13.9\,(+13.2)}_{-\,8.2\,(-\,8.2)}$
$B^{\pm} \to \pi^{0} K^{\pm}$	12.1 ± 0.8	10.4	18.7	17.7	19.7	14.2	$14.2^{+10.2\,(+\,7.1)}_{-\,5.8\,(-\,4.3)}$
$B^{0} \to \pi^{\mp} K^{\pm}$	18.9 ± 0.7	14.3	28.0	26.9	29.7	20.7	$21.1^{+15.7\,(+11.1)}_{-\,8.4\,(-\,6.6)}$
$B^{0} \to \pi^{0} K^{0}$	11.5 ± 1.0	5.7	12.2	11.9	13.0	8.8	$9.2^{+\,5.6\,(+\,5.1)}_{-\,3.3\,(-\,3.0)}$
$B^{0} \to \pi^{\mp} \pi^{\pm}$	5.0 ± 0.4	7.1	6.8	6.6	6.9	6.7	$6.6^{+\,6.7\,(+\,2.7)}_{-\,3.8\,(-\,1.8)}$
$B^{\pm} \to \pi^{\pm} \pi^{0}$	5.5 ± 0.6	3.5	4.2	4.1	4.2	4.2	$4.1^{+\,3.5\,(+\,1.7)}_{-\,2.0\,(-\,1.2)}$
$B^{0} \to \pi^{0} \pi^{0}$	1.45 ± 0.29	0.12	0.28	0.37	0.29	0.21	$0.30^{+0.49\,(+0.12)}_{-0.21\,(-0.09)}$

Mode	Data [1]	LO	LO_{NLOWC}	+VC	+QL	+MP	+NLO
$B^{\pm} \to \pi^{\pm} K^{0}$	-0.02 ± 0.04	-0.01	-0.01	-0.01	0.00	-0.01	$0.00 \pm 0.00\,(\pm 0.00)$
$B^{\pm} \to \pi^{0} K^{\pm}$	0.04 ± 0.04	-0.08	-0.06	-0.01	-0.05	-0.08	$-0.01^{+0.03\,(+0.03)}_{-0.05\,(-0.05)}$
$B^{0} \to \pi^{\mp} K^{\pm}$	-0.115 ± 0.018	-0.12	-0.08	-0.09	-0.06	-0.10	$-0.09^{+0.06\,(+0.04)}_{-0.08\,(-0.06)}$
$B^{0} \to \pi^{0} K^{0}$	—	-0.02	0.00	-0.07	0.00	0.00	$-0.07^{+0.03\,(+0.01)}_{-0.03\,(-0.01)}$
$B^{0} \to \pi^{\mp} \pi^{\pm}$	0.37 ± 0.10	0.14	0.19	0.21	0.16	0.20	$0.18^{+0.20\,(+0.07)}_{-0.12\,(-0.06)}$
$B^{\pm} \to \pi^{\pm} \pi^{0}$	0.01 ± 0.06	0.00	0.00	0.00	0.00	0.00	$0.00 \pm 0.00\,(\pm 0.00)$
$B^{0} \to \pi^{0} \pi^{0}$	$0.28^{+0.40}_{-0.39}$	-0.04	-0.34	0.65	-0.41	-0.43	$0.63^{+0.35\,(+0.09)}_{-0.34\,(-0.15)}$

QCDF

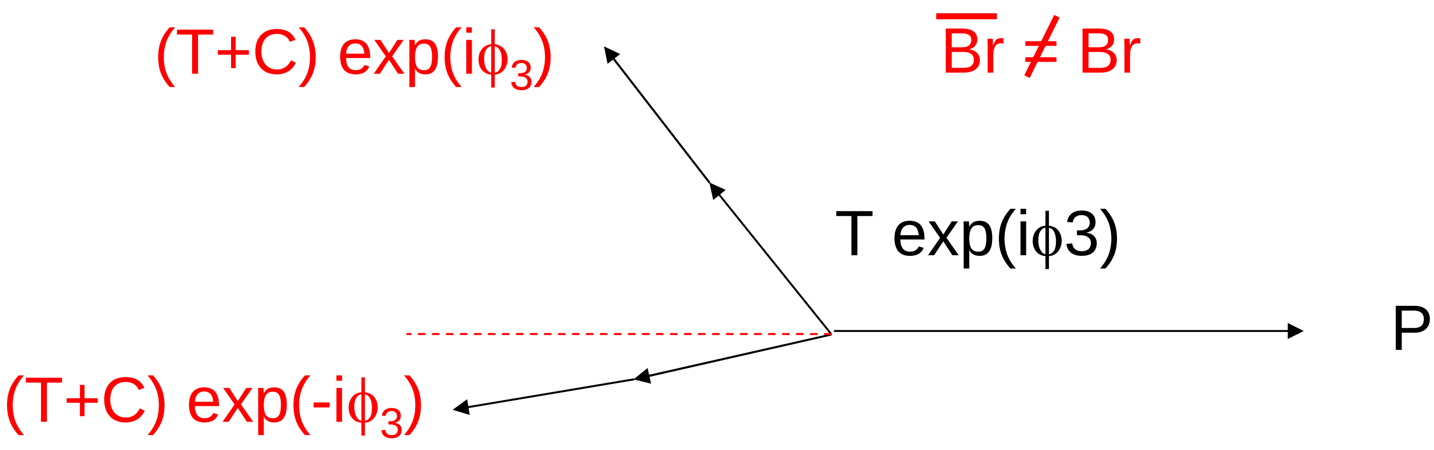
δ_T has a wrong sign in QCDF. C makes the situation worse.





SCET

- C/T is real in leading SCET, and large from the $\pi\pi$ data.
- C can not reduce $A_{CP}(K^+\pi^0)$ (hep-ph/0510241).



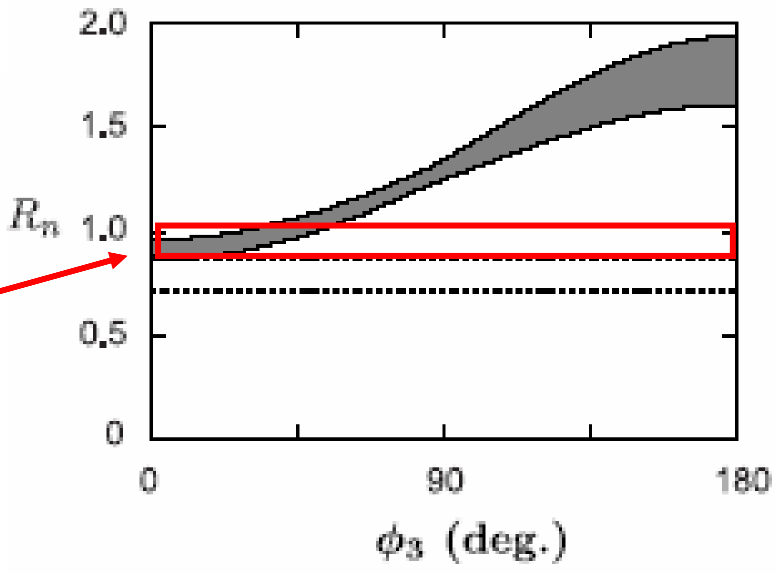
Large P_{ew}?

- $A_{CP}(K^+\pi^-)$ is insensitive to NLO. NLO could modify C, and thus $A_{CP}(K^+\pi^0)$. C remains subleading, and branching ratios do not change much.
- Predicted $B(\pi^0 K^0)$ is smaller than old data.

PQCD (05)

$$R_n = \frac{1}{2}\frac{B(B^0 \to \pi^\mp K^\pm)}{B(B^0 \to \pi^0 K^0)} = 0.79 \pm 0.08$$

- New data soften the need for large P_{ew}



Mixing-induced ~~CP~~ in b$\to$ s

Calculation of the time-dependent CP asymmetry

$$A_{f_{CP}}(t) = \frac{\left|\langle f_{CP}|H|\overline{B}^0(t)\rangle\right|^2 - \left|\langle f_{CP}|H|B^0(t)\rangle\right|^2}{\left|\langle f_{CP}|H|\overline{B}^0(t)\rangle\right|^2 + \left|\langle f_{CP}|H|B^0(t)\rangle\right|^2}$$

$$= \frac{\Gamma\left(\overline{B}^0(t) \to f_{CP}\right) - \Gamma\left(B^0(t) \to f_{CP}\right)}{\Gamma\left(\overline{B}^0(t) \to f_{CP}\right) + \Gamma\left(B^0(t) \to f_{CP}\right)}$$

$$A_{f_{CP}}(t) = S \cdot \sin(\Delta m \cdot t) - C \cdot \cos(\Delta m \cdot t)$$

$$S = \frac{2 \cdot \mathrm{Im}(\lambda)}{1 + |\lambda|^2} \qquad C = \frac{1 - |\lambda|^2}{1 + |\lambda|^2}$$

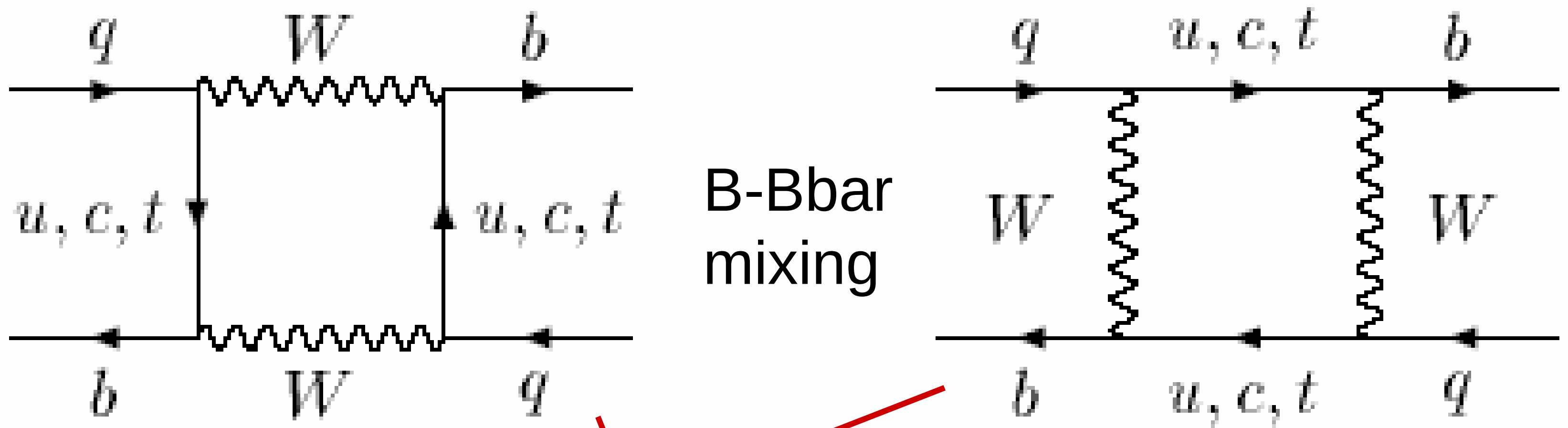
1 decay amplitude:

$$|\lambda| = 1 \quad \Rightarrow \quad S = \mathrm{Im}(\lambda), \quad C = 0$$

$$A_{f_{CP}}(t) = \mathrm{Im}(\lambda) \cdot \sin(\Delta m \cdot t)$$

Δm: Mass difference of two B eigenstates

Calculating λ



$$B^0 \to J/\psi K_S^0 \quad \lambda = (-1) \cdot \frac{V_{tb}^* V_{td}}{V_{tb} V_{td}^*} \cdot \frac{V_{cs}^* V_{cb}}{V_{cs} V_{cb}^*} \cdot \frac{V_{cd}^* V_{cs}}{V_{cd} V_{cs}^*} \quad \mathrm{Im}(\lambda) = \sin(2\beta)$$

$$(b \to c\bar{c}s) \times (K^0 \to K_S^0)$$

decay

K-Kbar mixing

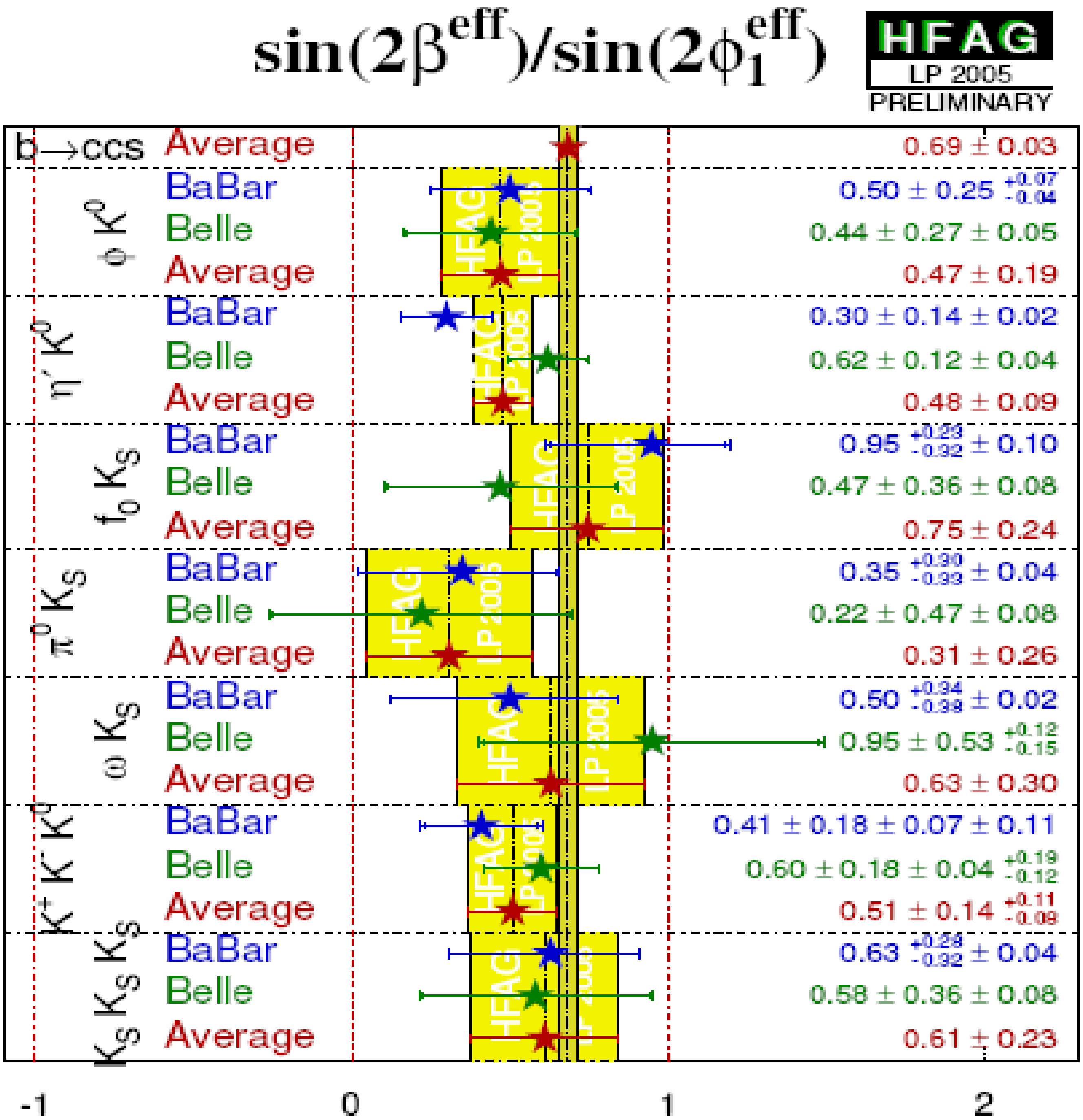
$\sin 2\phi_1/\sin 2\beta$

- 1 decay amplitude, $\lambda_{f_{CP}}=\exp(-2i\phi_1)$
- Measure $S_{f_{CP}} \propto \mathrm{Im}\lambda_{f_{CP}} \Rightarrow$ measure $\sin(2\phi_1)$
- Either pure-tree or pure-penguin modes serve the purpose
- Tree-dominant $B \to J/\psi\, K_S$, penguin pollution:

  $P/T \sim (C_4/C_2)(V_{us}V_{ub}/V_{cs}V_{cb}) \sim \lambda^4 \sim 0.2\%$
- Penguin-dominant $b \to s$, tree pollution:

$$\lambda_{\pi^0 K_S} = -e^{-2i\phi_1}\frac{P' - P'_{ew} - C'e^{-i\phi_3}}{P' - P'_{ew} - C'e^{i\phi_3}}\,.$$

$C'/P' \sim \lambda^2 \sim 5\%$



Penguin-dominated

$\Delta S \equiv$ "$\sin 2\phi_1'' - \sin 2\phi_1$

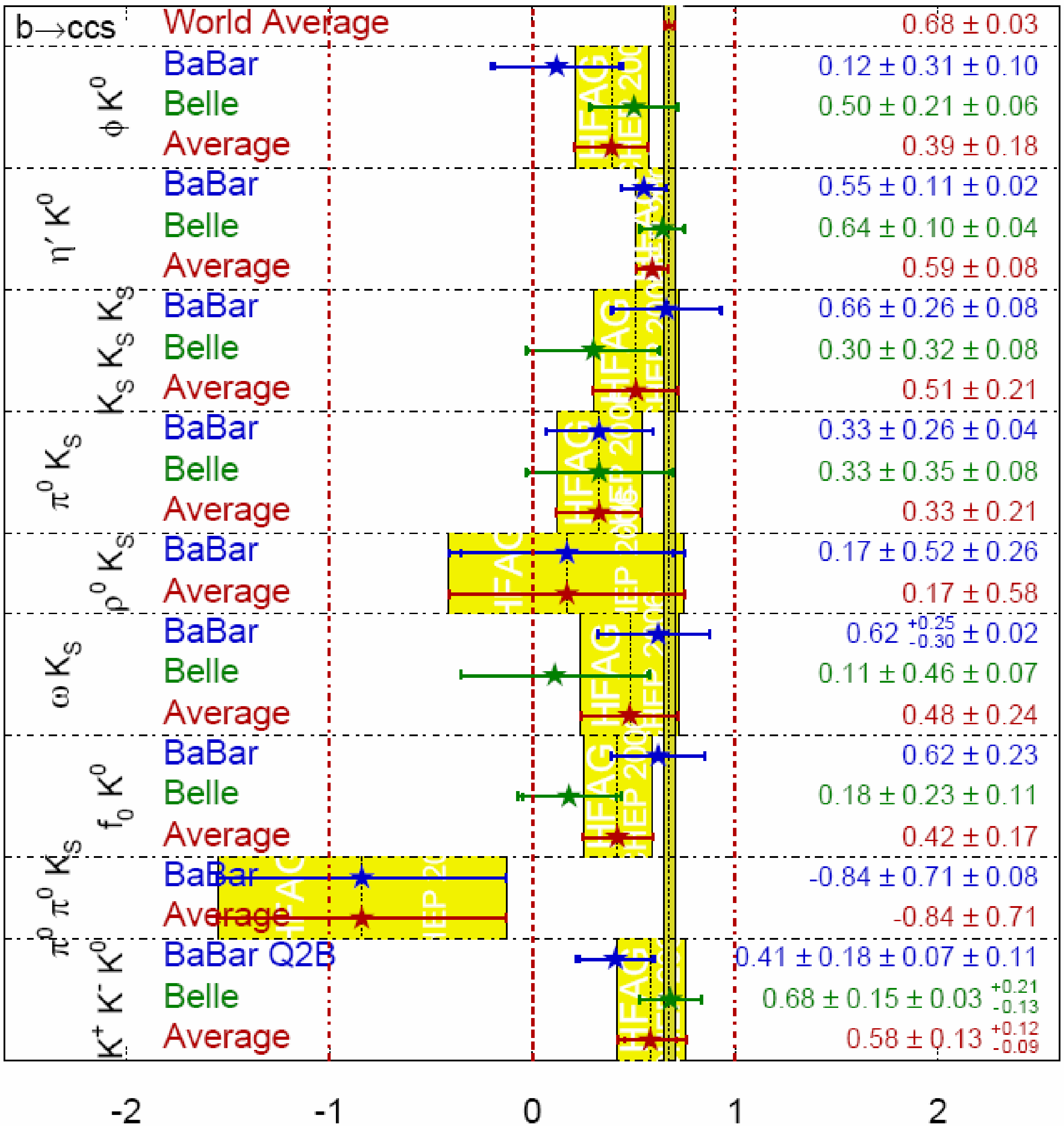
Tree-dominated

$\Delta S \neq 0$ by about 1σ

A puzzle?

$\sin(2\beta^{eff}) \equiv \sin(2\phi_1^{eff})$

HFAG
ICHEP 2006
PRELIMINARY



ΔS puzzle is still there

Recent theoretical calculation of ΔS

	QCDF+FSI Cheng-Chua-Soni	QCDF Beneke	QCDF Buchalla-Hiller-Nir-Raz	SCET Williamson-Zupan	PQCD Li, Mishima
$\Delta S(\phi K_s)$	$0.03^{+0.01}_{-0.04}$	0.02 ± 0.01	0.02		$0.03^{+0.01}_{-0.01}$
$\Delta S(\eta' K_s)$	$0.00^{+0.00}_{-0.04}$	0.01 ± 0.01	$0.01^{+0.01}_{-0.02}$	-0.019 ± 0.008 -0.010 ± 0.010	
$\Delta S(\pi^0 K_s)$	$0.04^{+0.02}_{-0.03}$	$0.07^{+0.05}_{-0.04}$	$0.06^{+0.04}_{-0.03}$	0.077 ± 0.030	$0.05^{+0.02}_{-0.03}$

$\Delta S \propto \cos\delta_C$, large C but $\delta_C \approx 90^o$ in NLO PQCD

All approaches gave consistent results, and small uncertainty. Tree pollution remains small even with NLO. Promising new physics signal, if data persist.

B_s–$B_s$bar mixing

Δm_d and Δm_s: constraints in the (ρ-η) plane

$$\Delta m_s = \frac{G_F^2}{6\pi^2} m_{B_s} m_W^2 \eta_B S_0(x_t) f_{B_s}^2 B_s \left| V_{ts} V_{tb}^* \right|^2$$

Very weak dependence on ρ and η

The point is:

$$f_{B_s}^2 B_s = \frac{f_{B_s}^2 B_s}{f_{B_d}^2 B_d} f_{B_d}^2 B_d = \xi^2 f_{B_d}^2 B_d$$

ξ: SU(3)-breaking corrections

Measurement of Δm_s reduces the uncertainties on $f^2_{B_d} B_d$ since ξ is better known from Lattice QCD

$$\sigma_{\text{rel}}\left(f_{B_{d/s}}^2 B_{d/s}\right) = 36\% \quad \rightarrow \quad \sigma_{\text{rel}}\left(\xi^2 = f_{B_s}^2 B_s / f_{B_d}^2 B_d\right) = 10\%$$

➔Leads to improvement of the constraint from Δm_d measurement on $|V_{td}V^*_{tb}|^2$

$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_{B_d} m_W^2 \eta_B S_0(x_t) f_{B_d}^2 B_d \left| V_{td} V_{tb}^* \right|^2 \propto A^2 \lambda^6 \left[(1-\bar{\rho})^2 + \bar{\eta}^2 \right]$$

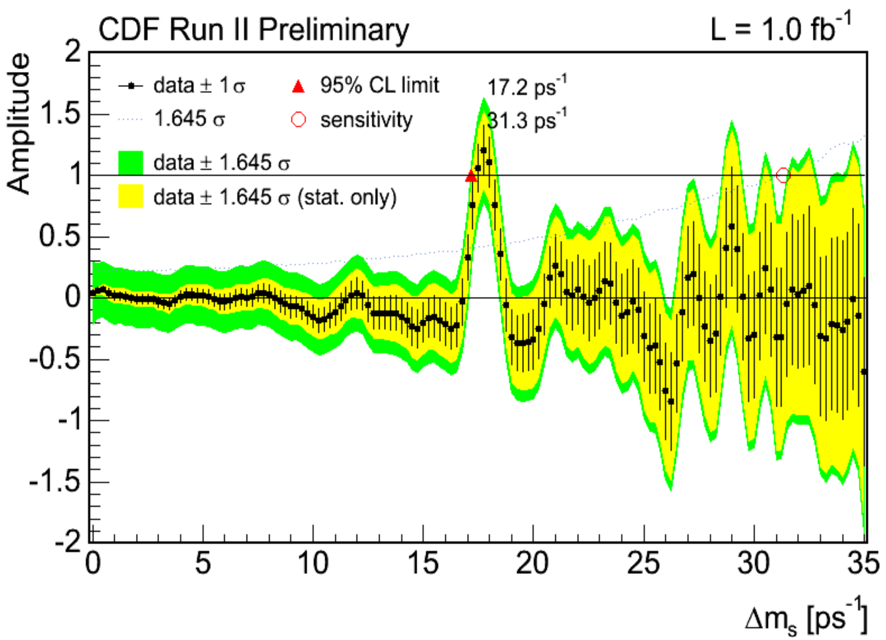
Δm_s

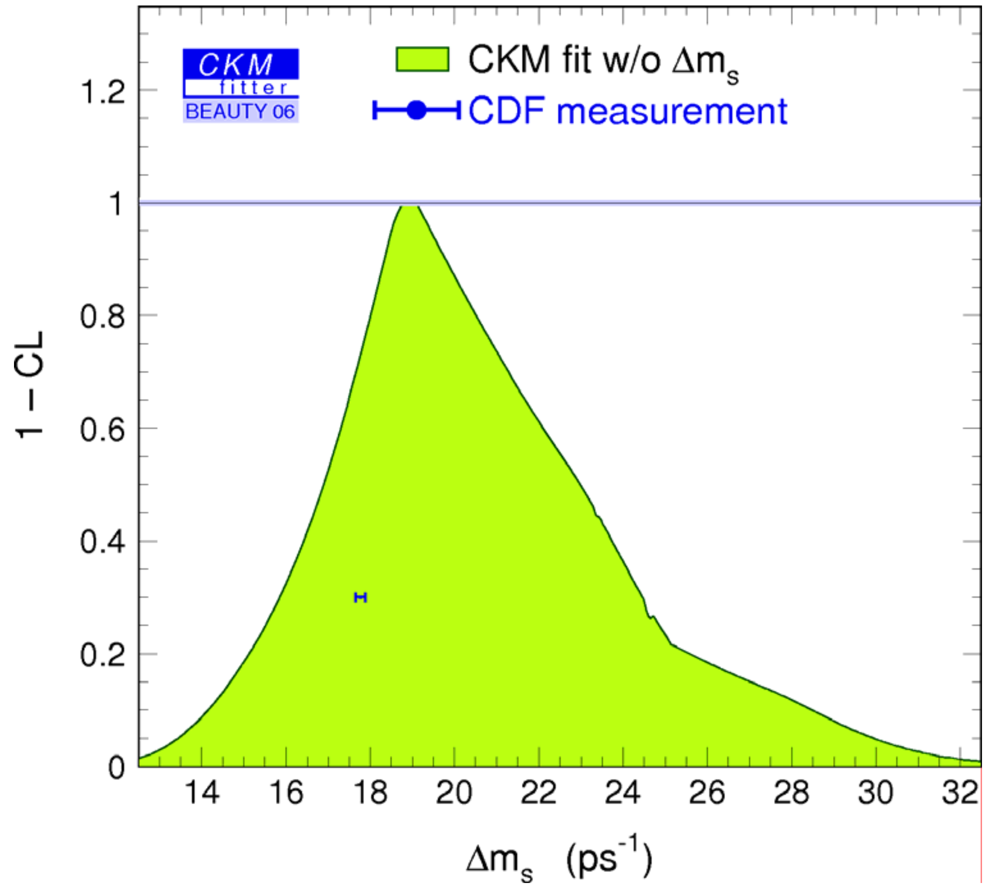
hep-ex/0603029

$17 < \Delta m_s < 21\ ps^{-1}$ @90 C.L.

hep-ex/0609040

Δm_s : 17.77±0.10(stat.) ± 0.07 (syst.) ps^{-1}

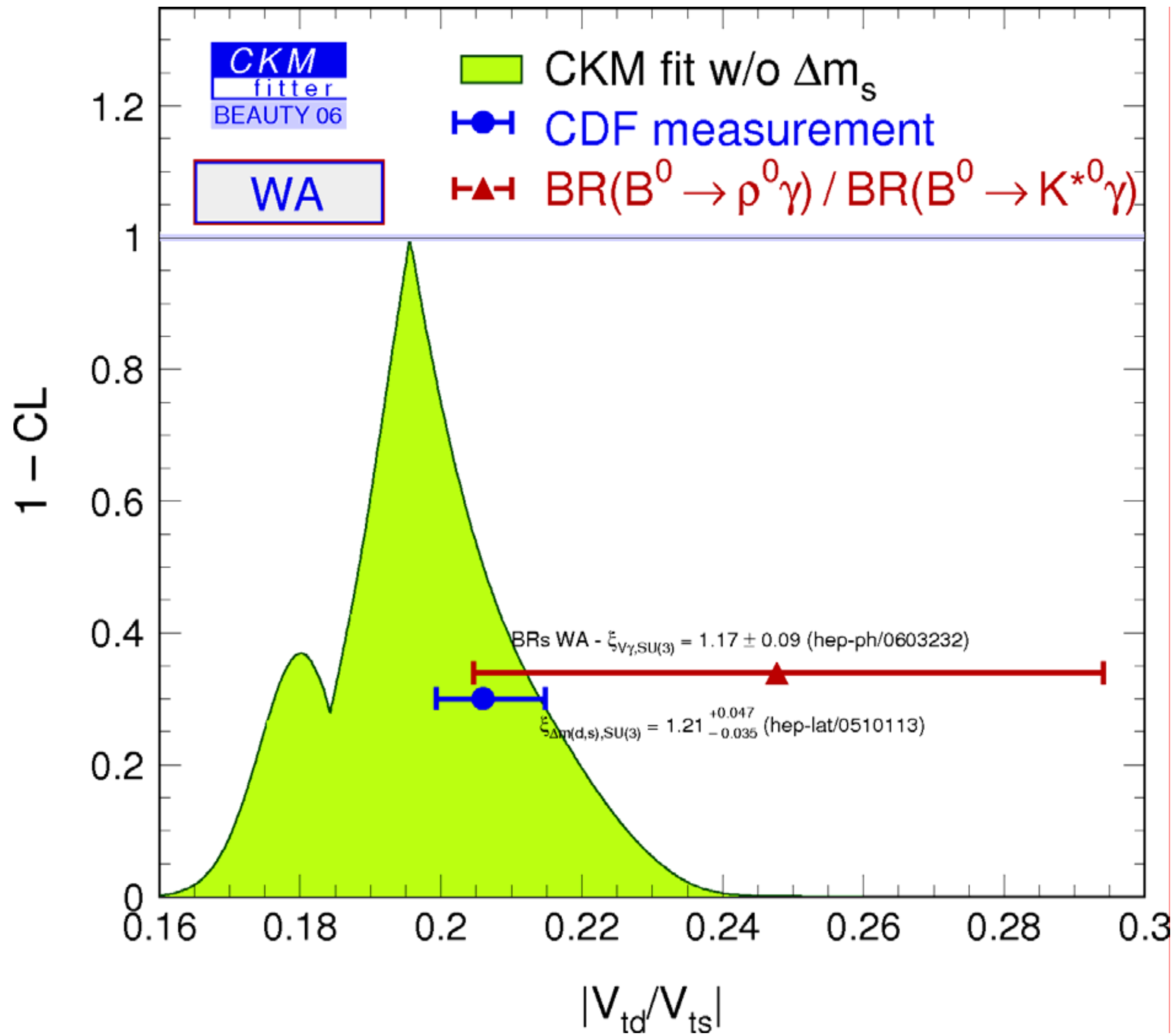




The signal has a significance of 5.4σ

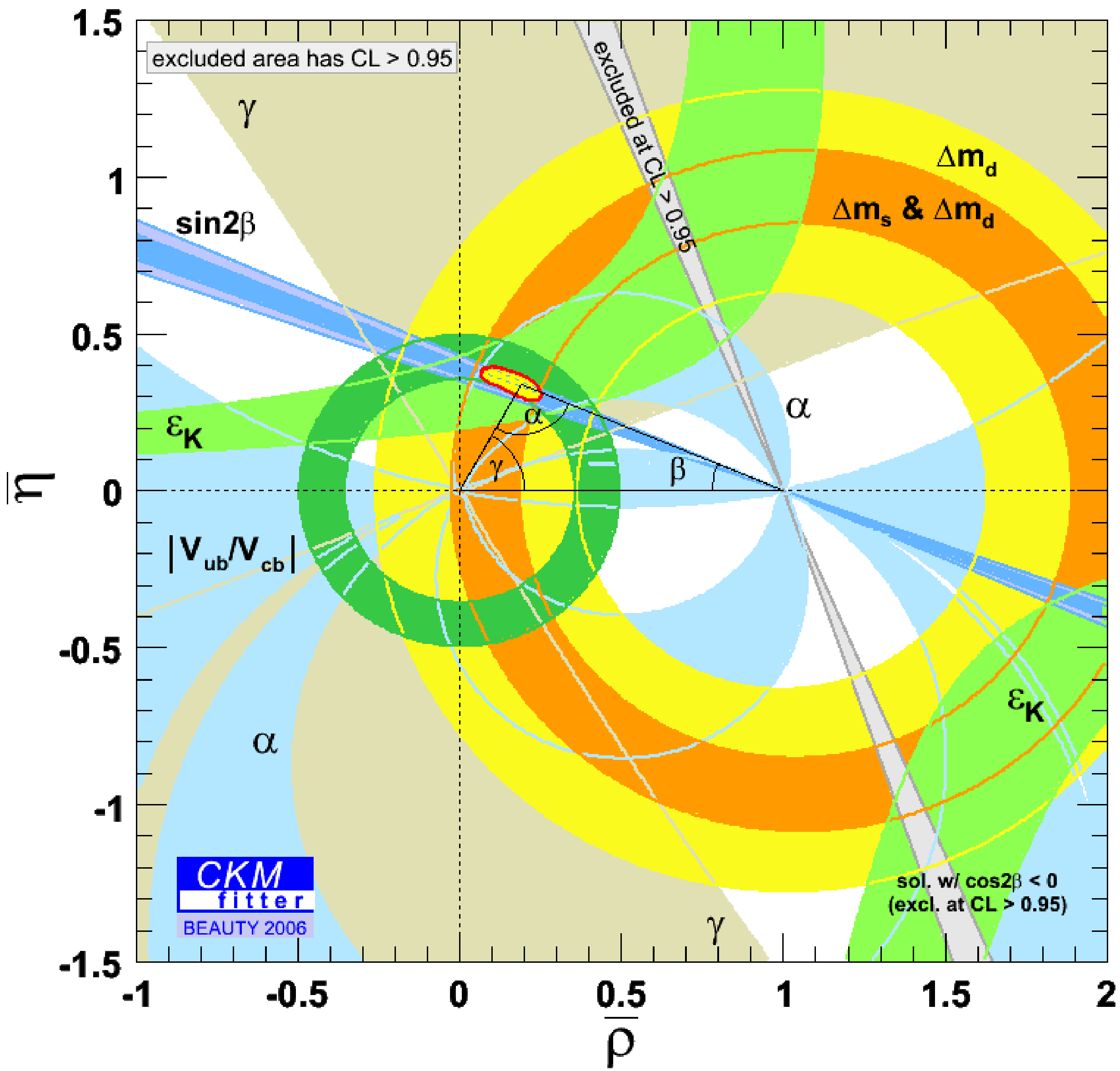
Constraint on $|V_{td}/V_{ts}|$

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{Bd}}{m_{Bs}} \xi_{\Delta m}^{-2} \frac{|V_{td}|^2}{|V_{ts}|^2}$$



➔ First strong indication that B_s-B_s mixing is probably SM-like.

Putting it all together



Inputs:

$\left|\frac{V_{ub}}{V_{cb}}\right|$

Δm_d

Δm_s

$B \to \tau\nu$

$|\varepsilon_K|$

$\sin 2\beta$

α

γ

LHCb physics

- It is time to calculate B_s decays
- Yu, Li, Lu 05, 06
- Xiao, Chen, Guo 06; Xiao, Liu, Wang 06
- Wu, Zhong, Zuo 06
- …

Polarization in B→ VV

- Many works from Lu's group using PQCD

Decay	Branching ratio theory	Branching ratio exp.	polarization fraction $R_L(\%)$ theory	polarization fraction $R_L(\%)$ exp.	$R_\parallel(\%)$	$R_\perp(\%)$
$B^0 \to \rho^- K^{*+}$	10-13	≤ 24	$71-78$		12	10
$B^+ \to \rho^+ K^{*0}$	13-17	10.5 ± 1.8	$76-82$	66 ± 7	13	10
$B^+ \to \rho^0 K^{*+}$	6-9	$10.6^{+3.8}_{-3.5}$	$78-85$	$96^{+4}_{-15} \pm 4$	11	11
$B^+ \to \omega K^{*+}$	5-8	< 7.4	$73-81$		19	9
$B^0 \to \rho^+ \rho^-$	$35 \pm 5 \pm 4$	30 ± 6	94	96^{+4}_{-7}	3	3
$B^+ \to \rho^+ \rho^0$	$17 \pm 2 \pm 1$	$26.4^{+6.1}_{-6.4}$	94	99 ± 5	4	2
$B^+ \to \rho^+ \omega$	$19 \pm 2 \pm 1$	$12.6^{+4.1}_{-3.8}$	97	88^{+12}_{-15}	1.5	1.5
$B^0 \to \rho^0 \rho^0$	$0.9 \pm 0.1 \pm 0.1$	< 1.1	60	-	22	18
$B^0 \to \rho^0 \omega$	$1.9 \pm 0.2 \pm 0.2$	< 3.3	87	-	6.5	6.5
$B^0 \to \omega \omega$	$1.2 \pm 0.2 \pm 0.2$	< 19	82	-	9	9

Conclusion

- Great progress in theoretical and experimental studies of B physics has been made.
- Discrepancies have appeared, but are not significant enough for new physics discovery.
- Continuous effort is required.