Penguin phenomenology

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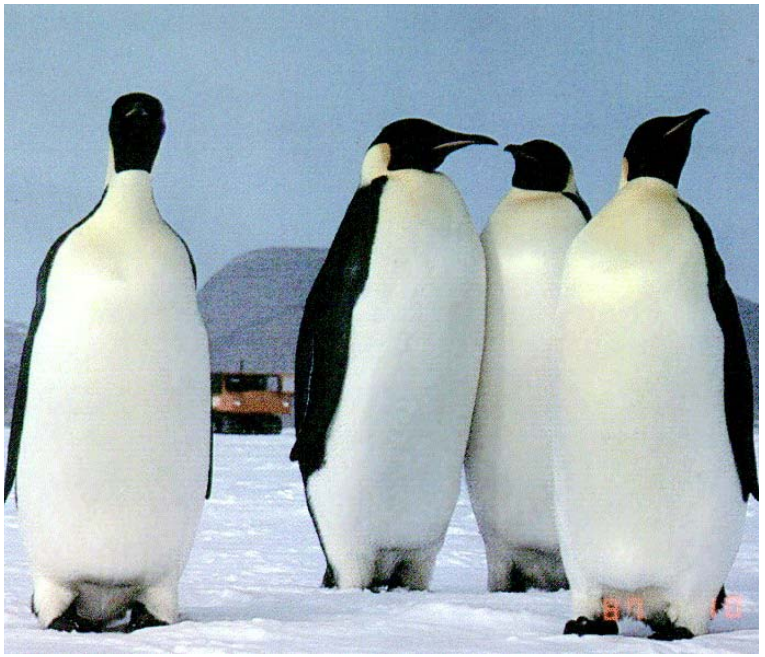
Question: Which penguin is fatter?

1. **Ordinary penguin**
2. **Chiral enhanced penguin**
3. **Annihilation penguin**
4. **Charming penguin**
5. **Electroweak penguin**
6. **Color suppressed Penguin**



Penguin over tree

- $B^0 \rightarrow K^+\pi^-$ and $B^0 \rightarrow \pi^+\pi^-$ are dominated by penguin (P) and tree (T) operators, respectively
- In leading power,
- $|P/T| \sim |f_K/f_\pi| * |V_{ts}/V_{ub}| * |a4/a1|$

  $=158/132 * 41.61/3.96 * 0.045/1.05 = 0.54$

Exp: $B(B^0 \rightarrow K^+\pi^-)/B(B^0 \rightarrow \pi^+\pi^-)=18.2/4.6 = 4$

Power Corrections

- **(V-A)(V+A) operator O_6 can be chirally enhanced when doing Fierz transformation in QCDF and pQCD.**
- **a_6 only slightly larger than a_4, QCDF needs very large chiral factor $m_0 = m_K^2/m_s$, ⇨ small m_s.**
- **pQCD has additional chiral enhanced annihilation penguin contribution O_6, does not need small m_s**
- **SCET/BPRS without a_6, needs very large charming penguin**

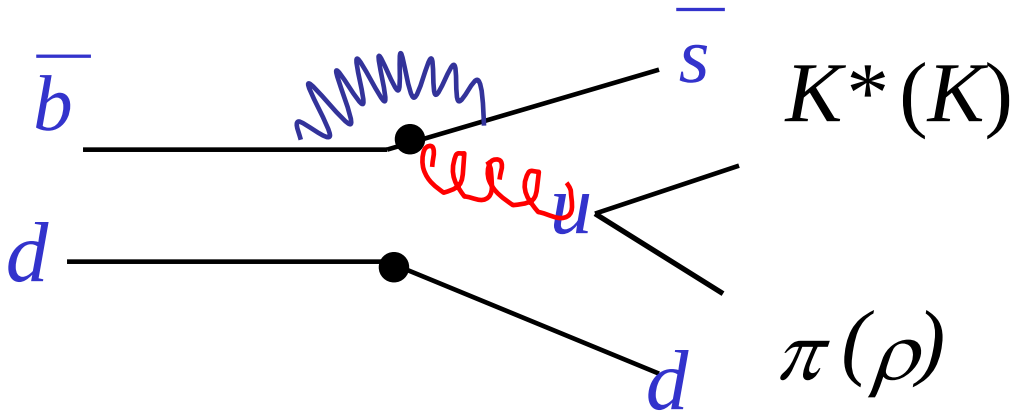
The dominant contribution

The biggest contribution for B→ π K in various approaches:

- Chiral enhanced penguin -- QCDF
- Chiral enhanced + annihilation penguin -- pQCD
- Charming penguin -- SCET

B→ VP decays

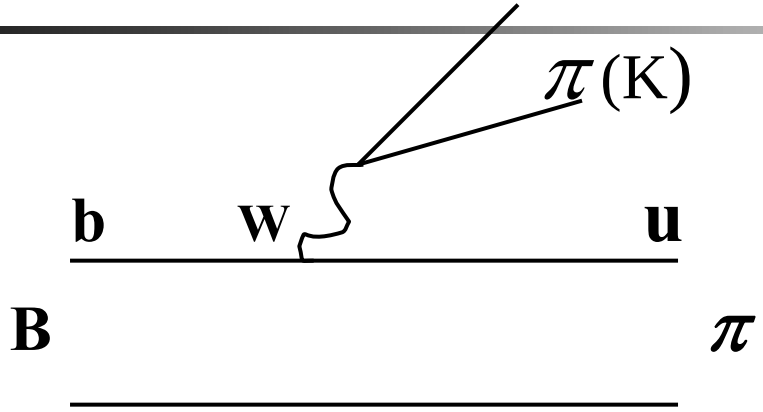
- Difficult for QCDF to get large enough BRs
- No chiral enhanced penguin for $B \to \pi K^*$
- Ordinary penguin canceled by chiral enhanced penguin (minus sign) for $B \to \rho K$



Importance of power corrections

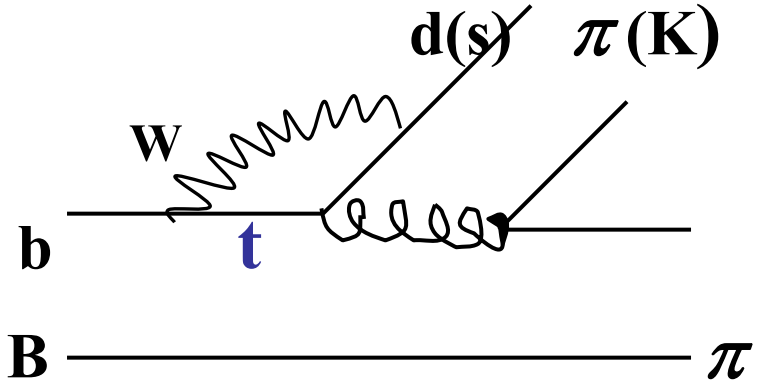
- **Most of the branching ratios agree well with experiments – leading power**
- **Difficult to distinguish between approaches**
- **but CP / polarization, suppressed channels require strong phase, sensitive to weak phase, power corrections will be different**

$B \to \pi\pi$, πK Have Two Kinds of Diagrams with different weak phase



O_1, O_2

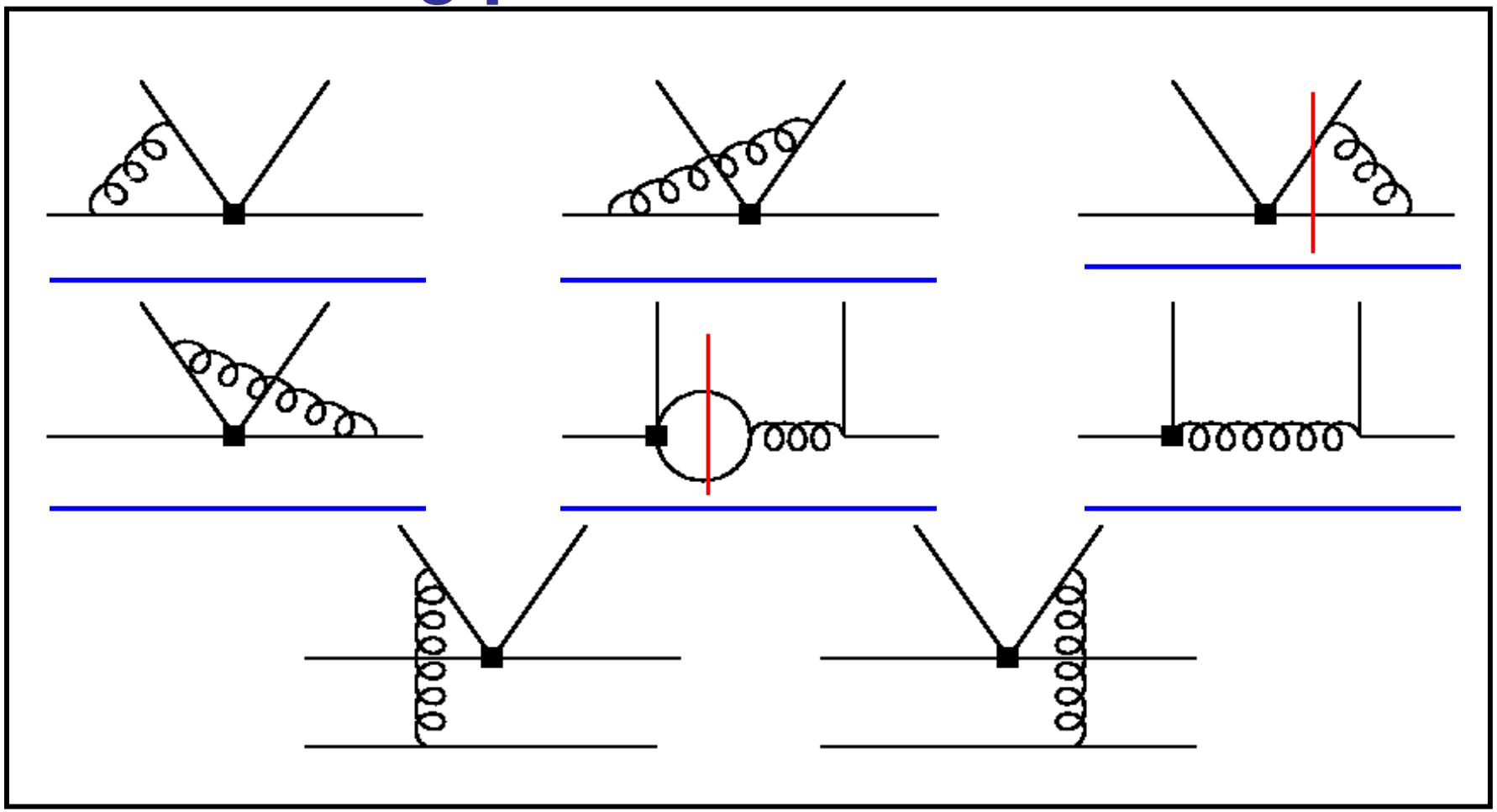
Tree $\propto V_{ub}V_{ud}^{*}$ (s)



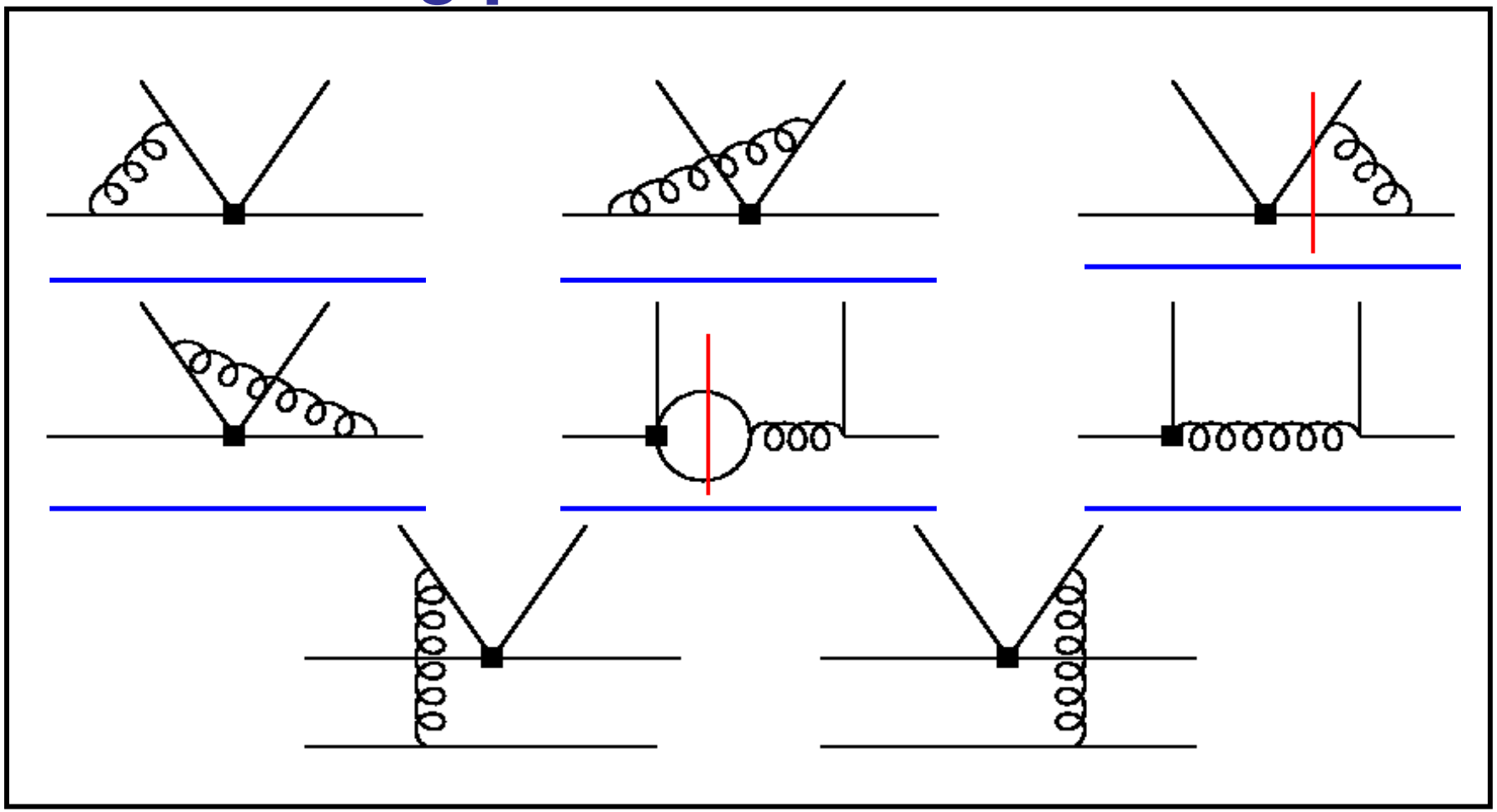
O_3, O_4, O_5, O_6

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

QCD corrections are at α_s order, strong phase too small

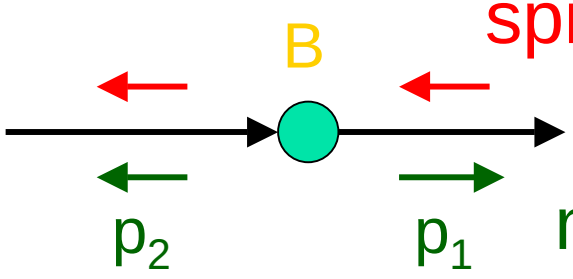


QCD corrections are at α_s order, strong phase too small



Wrong sign for direct CP in $B^0 \rightarrow K^+ \pi^-$

annihilation penguin can provide a large strong phase



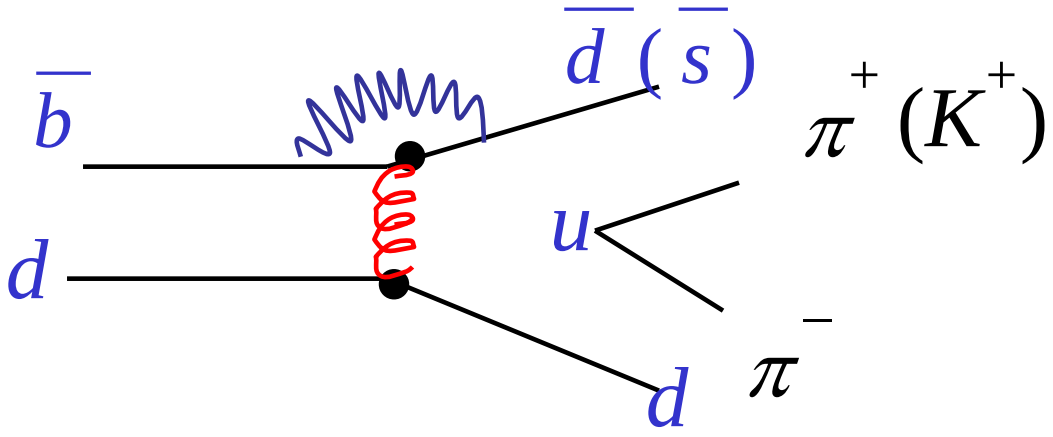
Like $B \to e\ \nu_e$

pseudo-scalar B requires spins in opposite directions, namely, helicity conservation

Annihilation suppression ~ $1/m_B$ ~ 10%

No suppression for O_6

- Space-like penguin (annihilation)
- Become (s-p)(s+p) operator after Fiertz transformation **Chirally enhanced**
- No suppression, contribution **"big"** (20-30%)



Calculable in pQCD approach

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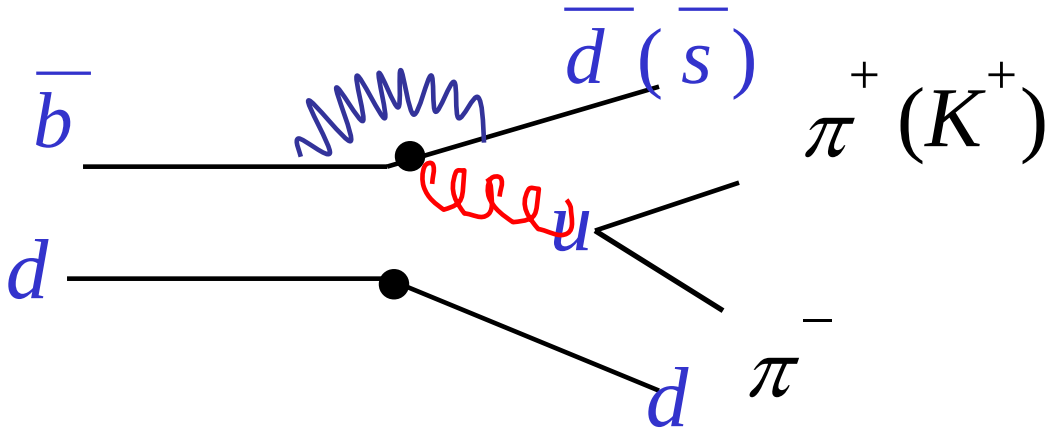
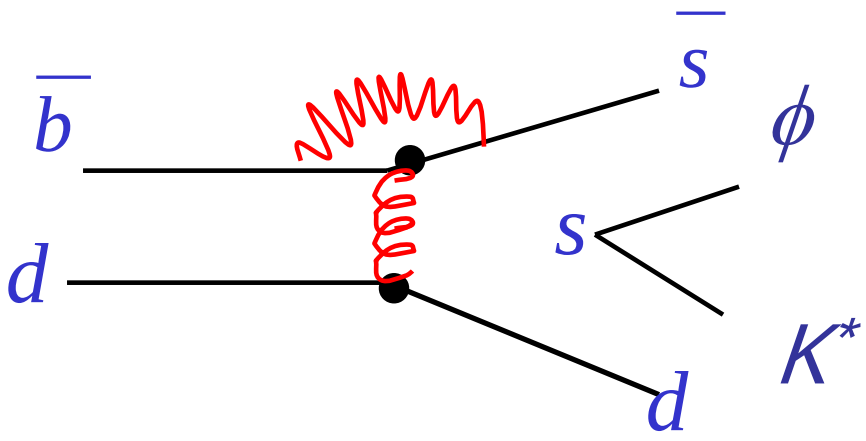


Calculable in pQCD approach

Large transverse component in $B \to \phi K^*$ decays

Annihilation can enhance transverse contribution: $R_L = 59\%$ (exp:50%)

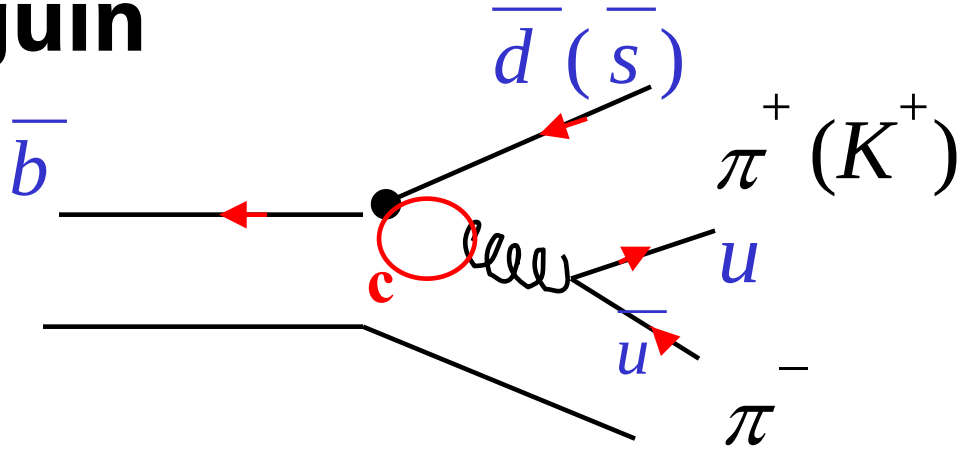
and also right ratio of $R_=$, $R_\perp$ and right strong phase $\phi_=$, $\phi_\perp$



H-n Li, **Phys. Lett. B622, 68, 2005**

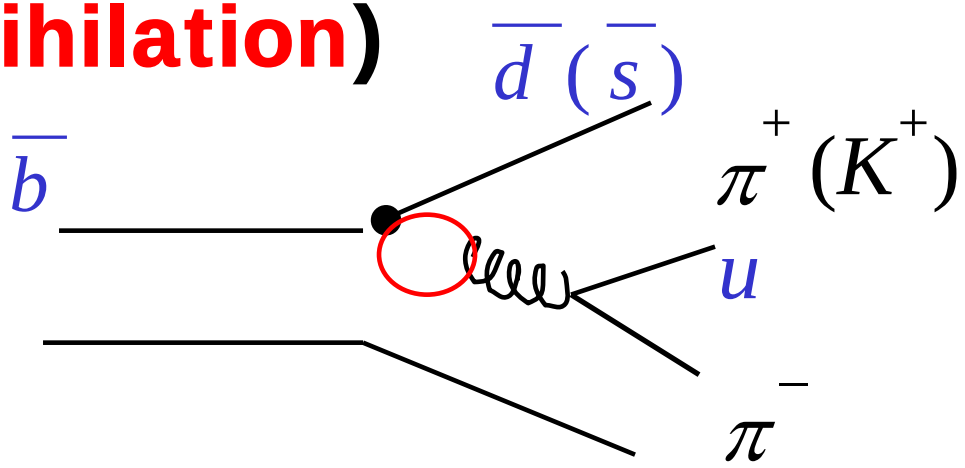
Charming penguins in SCET

- **has the same topology as chiral enhanced penguin**
- **Charming penguin appear always together with chiral enhanced penguin**



Charming penguins in SCET

- **Play the similar role as annihilation penguin, but not calculable**
- **Charming penguin appear always together with space like penguin (annihilation)**



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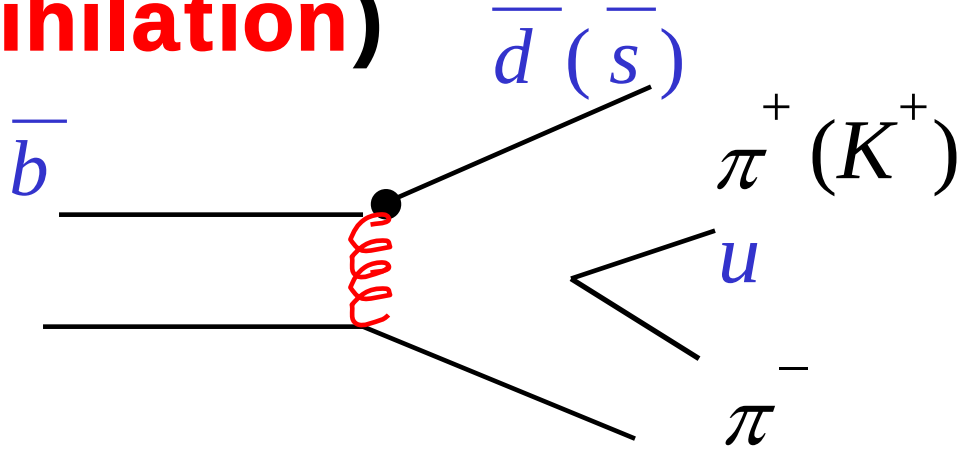


SCET

- χ^2 **Fit from experiments requires a large charming penguin, it even become the most important contribution in** $B \to K\pi$ **decays**
- **It is essential to provide a right strong phase for direct CP asymmetry, and large transverse polarization in B→ VV**

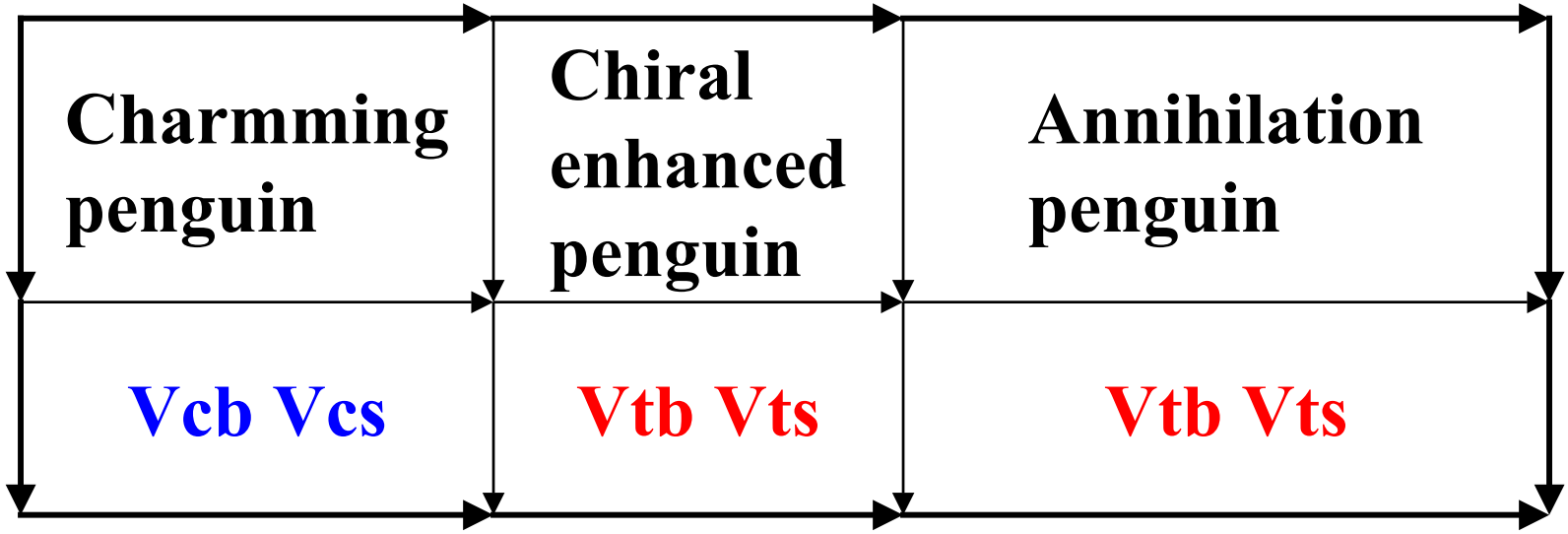
Williamson, Zupan, Phys.Rev.D74:014003,2006,

Wang[2],Yang,Lu, arXiv:0801.3123

Comparison

	Charmming penguin	Chiral enhanced penguin	Annihilation penguin
BBNS/ QCDF	Perturbative, small	Big	nonperturbative model parameters, large phases
pQCD	Perturbative, small	Big	Big, perturbative large phases
BPRS/ SCET	Big, non-perturbative fit parameter	Not known	perturbative

Comparison



CKM phase slightly different

B→ Kπ puzzle

- $K^+\pi^-$ and $K^+\pi^0$ differ by subleading amplitudes P_{ew} and C. Their CP are expected to be similar.
- Their data differ by 5σ! A puzzle!

$$A_{CP}(K^+\pi^-) = (-9.7 \pm 1.2)\%$$

$$A_{CP}(K^+\pi^0) = (5.0 \pm 2.5)\%$$

Amplitude parametrization

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

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

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

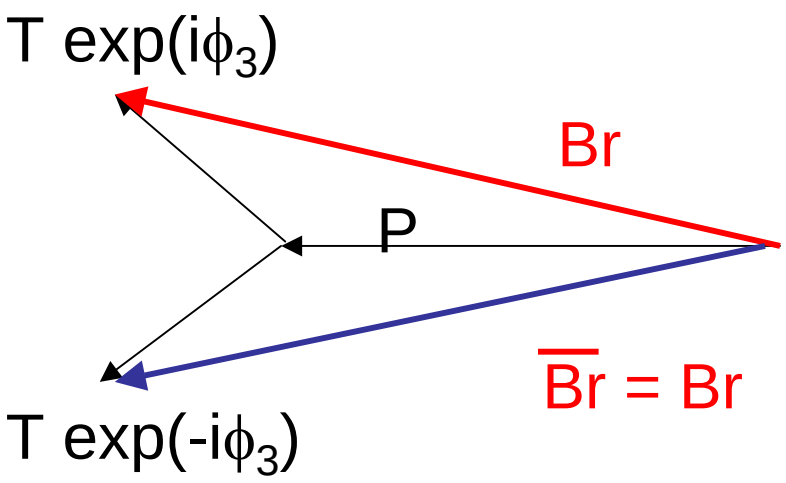
$$\sqrt{2}A(B_d^0 \to K^0\pi^0) = P'\left(1 - \frac{P'_{ew}}{P'} - \frac{C'}{P'}e^{i\phi_3}\right) ,$$

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

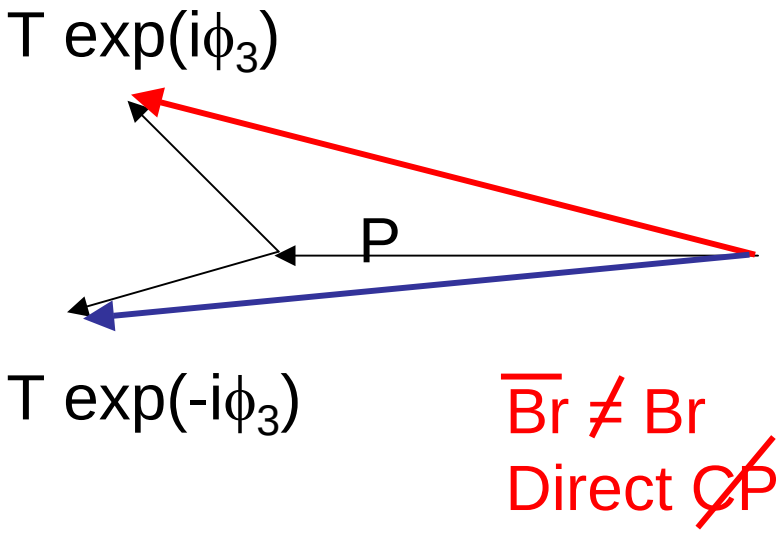
$(C_2/C_4)(V_{us}V_{ub}/V_{ts}V_{tb}) \sim (1/\lambda^2)(\lambda^5/\lambda^2) \sim \lambda$

Direct CP violation

If $\delta_T=0$



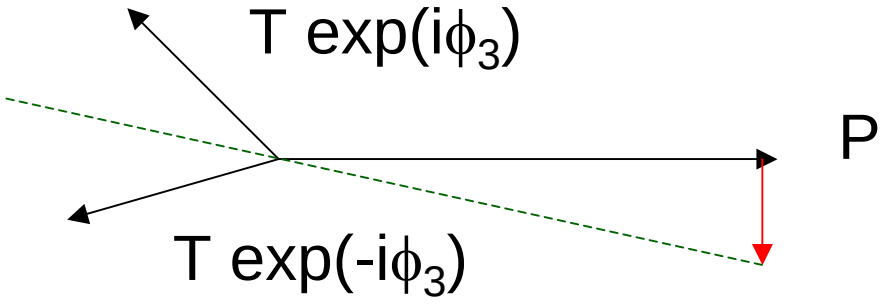
If $\delta_T\neq 0$



Direct CP $A_{CP} \propto \sin\delta \sin\phi$

1 of Explanations

- **Large $K^+\pi^-$ CP implies large δ_T**
- **Large P_{EW} to cancel its effect (Buras et al.; Yoshikawa) in $K^+\pi^0$ new physics?**

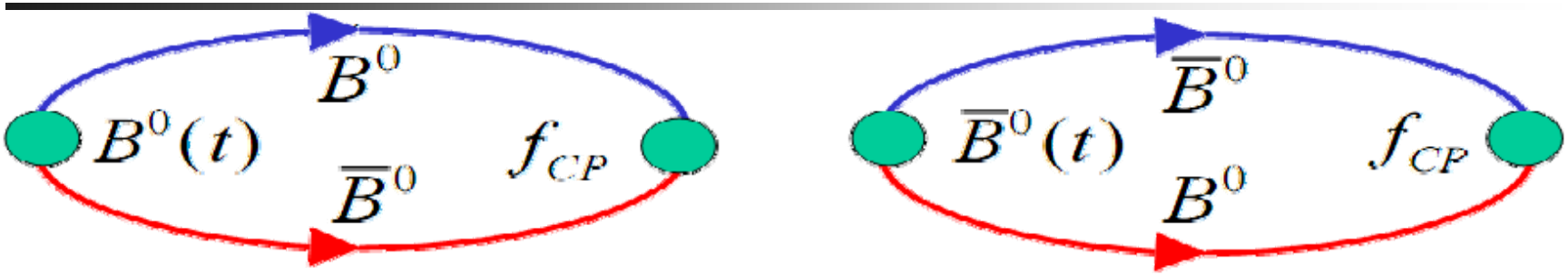


SM electroweak penguin does not help, need new physics

Mixing Induced CP

- $B \rightarrow \pi^+\pi^-$, ϕK, $\eta' K$, KKK …
- Dominant by the B-B bar mixing
- Most of the approaches give similar results
- Even with final state interactions
- Because characterized by weak phase

Mixing induced CP violation



$$\Gamma(B^0(t) \to f) = \frac{1}{2}|A_f|^2 e^{-\Gamma t}\left\{(1+|\lambda|^2) + (1-|\lambda|^2)\cos\Delta mt - 2\mathrm{Im}\lambda \sin\Delta mt\right\}$$

$$\Gamma(\bar{B}^0(t) \to f) = \frac{1}{2}|A_f|^2 e^{-\Gamma t}\left\{(1+|\lambda|^2) - (1-|\lambda|^2)\cos\Delta mt + 2\mathrm{Im}\lambda \sin\Delta mt\right\}$$

$$\mathcal{A}_{CP}(t) = \frac{\Gamma(B^0(t) \to f) - \Gamma(\bar{B}^0(t) \to f)}{\Gamma(B^0(t) \to f) + \Gamma(\bar{B}^0(t) \to f)} = \frac{|\lambda|^2 - 1}{|\lambda|^2 + 1}\cos\Delta mt + \frac{2\mathrm{Im}\lambda}{|\lambda|^2 + 1}\sin\Delta mt$$

$$\lambda = \frac{q}{p}\frac{\bar{A}}{A}. \quad = e^{-2i\beta}e^{-2i\delta}$$

Tendency of exp.data against theory

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

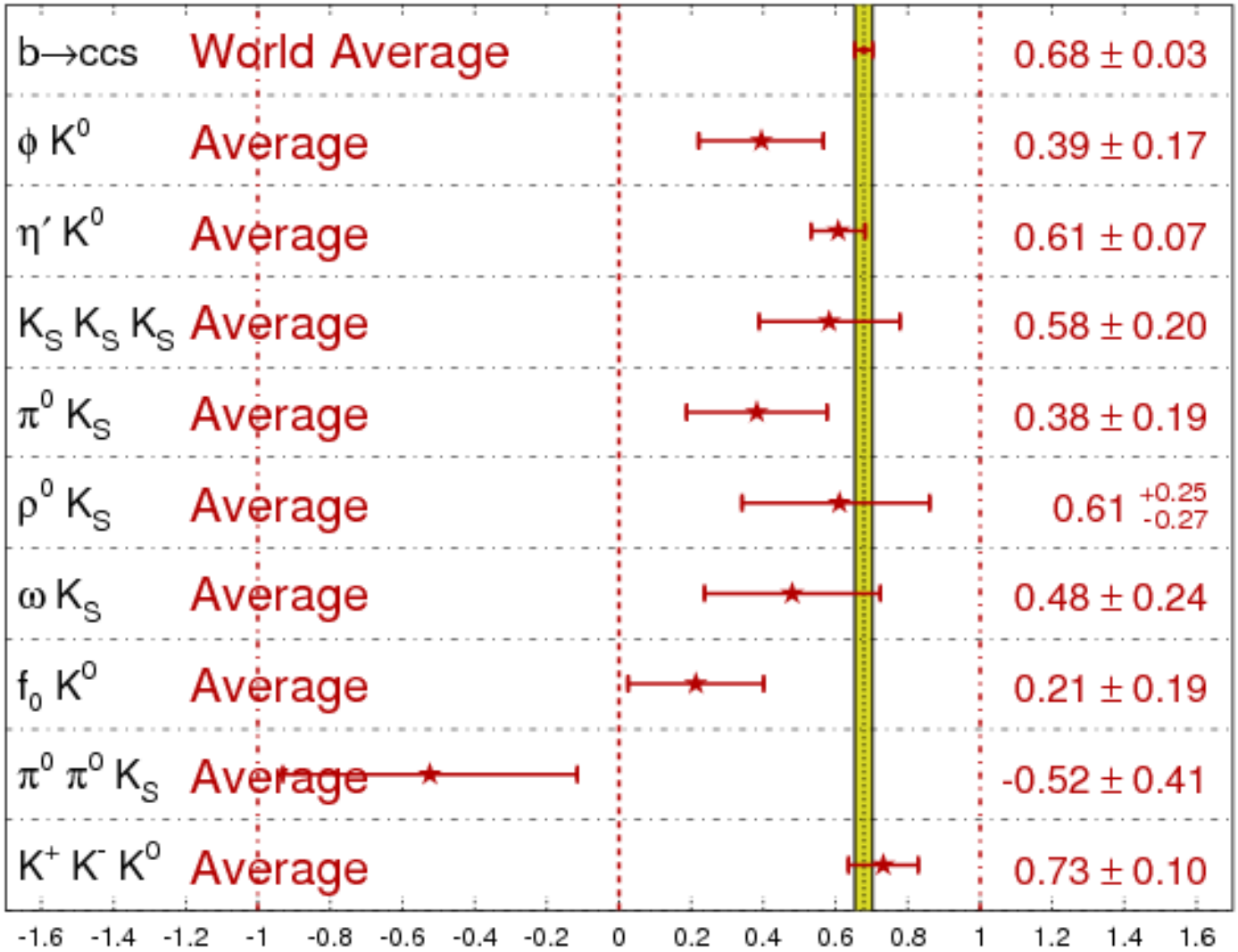
HFAG
LP 2007
PRELIMINARY

theory :

ΔS(SM) is Positive

Exp:

negative



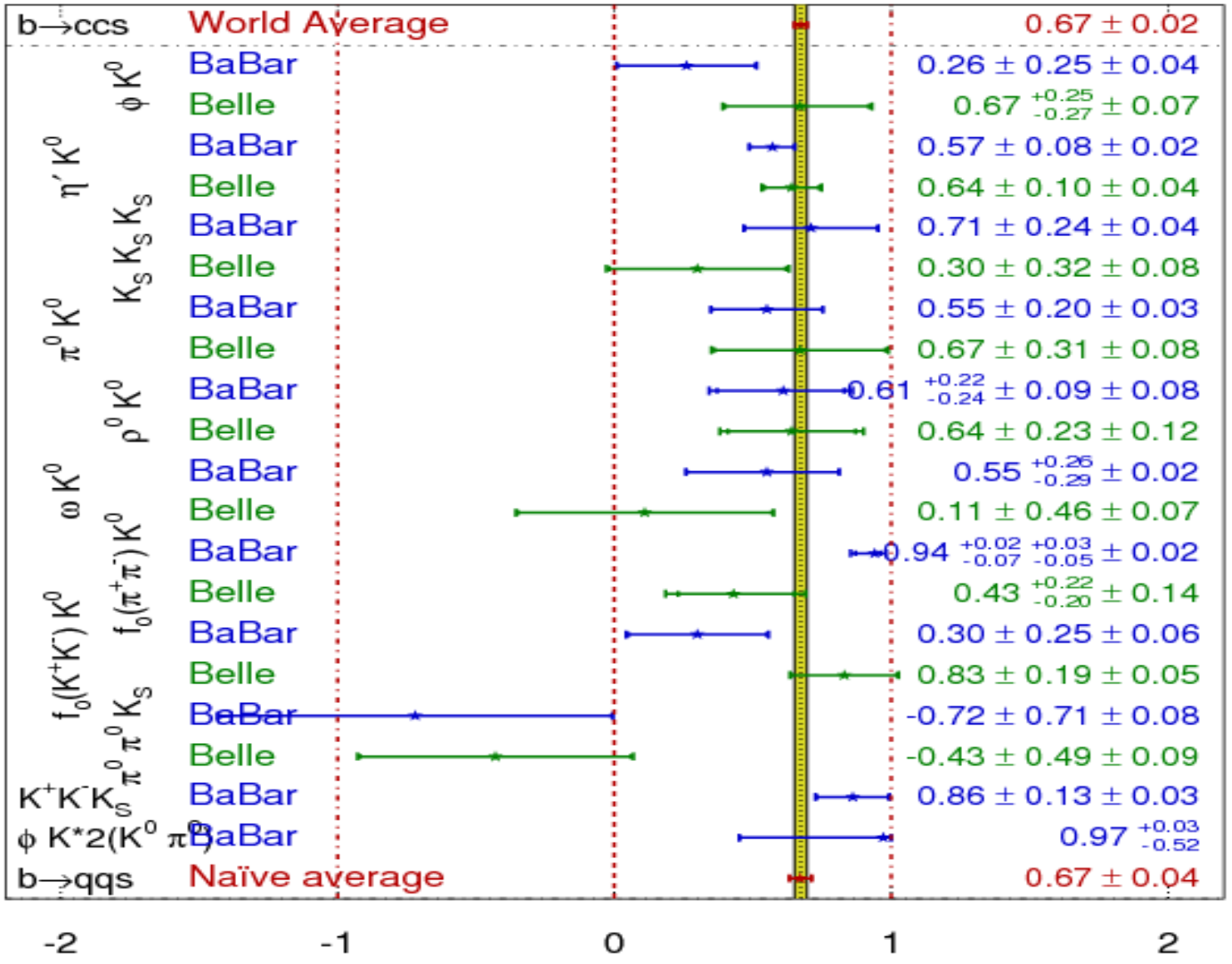
Tendency of exp.data against theory

theory :

ΔS(SM) is Positive

Exp:

(ICHEP08 Paoti Chang)



ΔS calculated from QCDF,pQCD,SCET

ΔS	QCDF	pQCD	SCET	exp
ϕK^0	0.02	0.02	0.003, 0.003	-0.29 ±0.17
ω Ks	0.13	0.15	-0.19, 0.11	-0.20 ±0.24
ρ Ks	-0.08	-0.19	0.16, -0.13	-0.07 ±0.26
η Ks	0.10		-0.03, 0.07	-
η‘ K^0	0.01		-0.02, -0.02	-0.07 ±0.07
π Ks	0.07	0.05	0.08, 0.08	-0.30 ±0.19

- QCDF: Beneke [results consistent with Cheng-CKC-Soni]
- pQCD: Mishima-Li
- SCET: Williamson-Zupan and Wang[2],Yang,Lu, arXiv:0801.3123

ΔS calculated from QCDF,pQCD,SCET

ΔS	QCDF	pQCD	SCET	Babar	Belle
ϕK^0	0.02	0.02	0.003, 0.003	-0.41	0.00
ω Ks	0.13	0.15	-0.19, 0.11	-0.12	-0.56
ρ Ks	-0.08	-0.19	0.16, -0.13	-0.06	-0.03
η Ks	0.10		-0.03, 0.07	-	
η‘ K^0	0.01		-0.02, -0.02	-0.10	–0.03
π Ks	0.07	0.05	0.08, 0.08	-0.12	0.00

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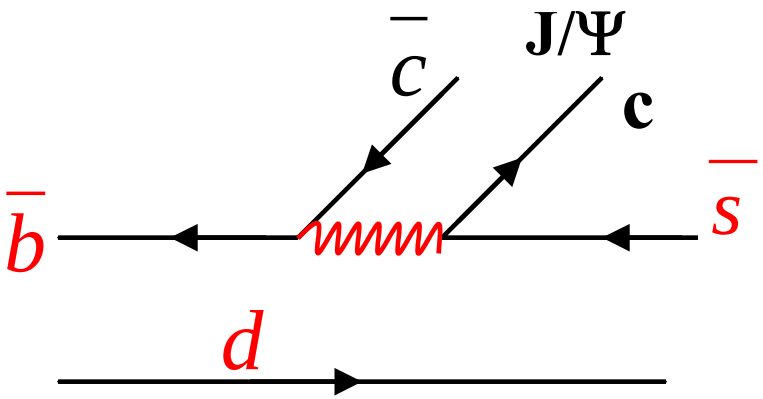
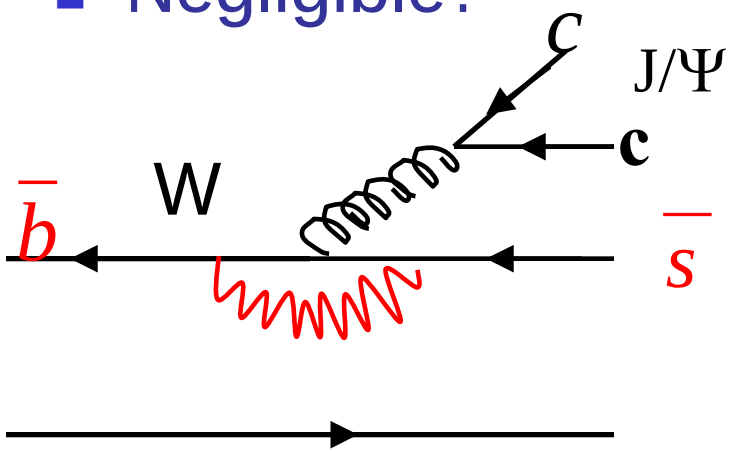
Color suppressed penguin

- Color suppressed tree



- V_{cb} V_{cs}

- Color suppressed penguin/ EW penguin
- Negligible?



- V_{tb} V_{ts}

- **nrQCD predict large color octet contribution for J/Ψ production.**
- **The color suppressed penguin is a kind of color octet contribution.**
- **If it were "big", we would have sin $2\beta_{eff}$ for B → J/Ψ Ks,**
- **Δs will change sign**

Summary / Comment

- The direct CP measurements need a large contribution from annihilation penguin (or charming penguin), with large strong phase
- The large BRs of B→ VP modes also need such annihilation penguin
- Similar in the polarization of B→ VV modes
- Only pQCD approach can predict its size by calculation

Summary / Comment

- **Factorization approaches are systematic tools, sometimes have to be used for data fitting (Scenario 1,2,3,4 in QCDF, charming penguin in SCET)**
- **SCET is encouraging, with consistent counting rules, but need more parameters**
- **The $1/m_B$ power corrections are much more important than the NLO α_s corrections**

Thank you!