Penguin phenomenology

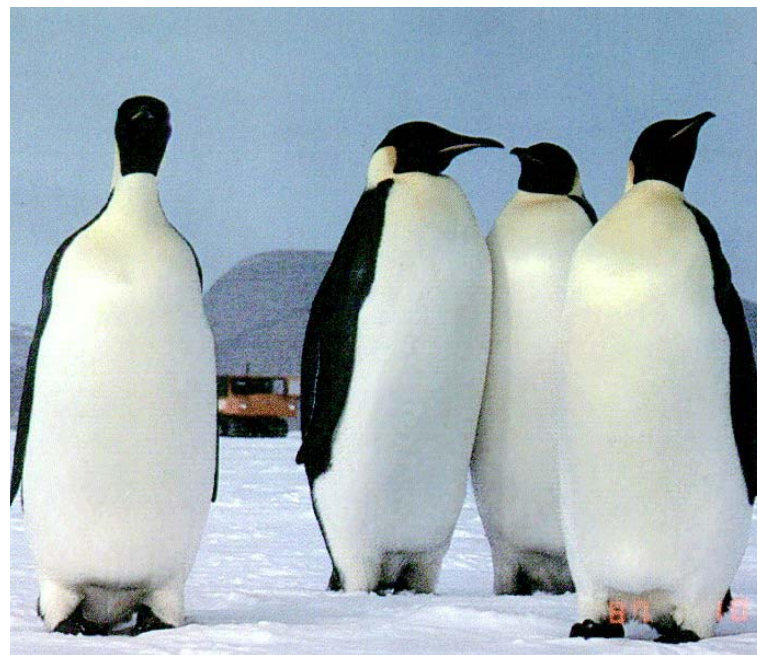## Cai-Dian Lu (呂才典)
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Question: Which penguin is fatter?

- **Ordinary penguin**
- **Chiral enhanced penguin**
- **Annihilation penguin**
- **Charming penguin**
- **Electroweak penguin**
- **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: $B(B^0 \rightarrow K^+ \pi^-)/B(B^0 \rightarrow \pi^+ \pi^-) = 18.2/4.6 = 4$

Penguin over tree

- **(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**

Charming penguins in SCET

- **has the same topology as chiral enhanced penguin**

- **Charming penguin appear always together with chiral enhanced penguin**

$$\overline{d}\,(\overline{s})$$

$$\overline{b}$$

$$\pi^{+}(K^{+})$$

$$c$$

$$u$$

$$\overline{u}$$

$$\pi^{-}$$
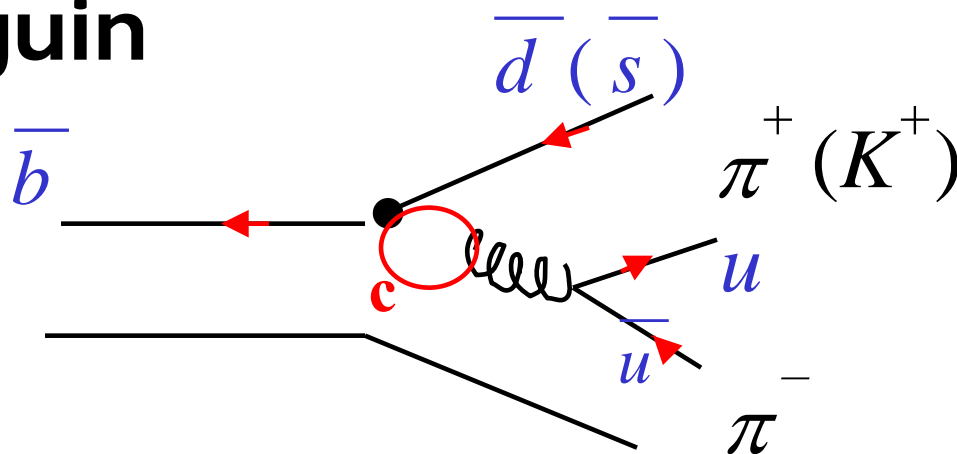
Importance of power corrections

- **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
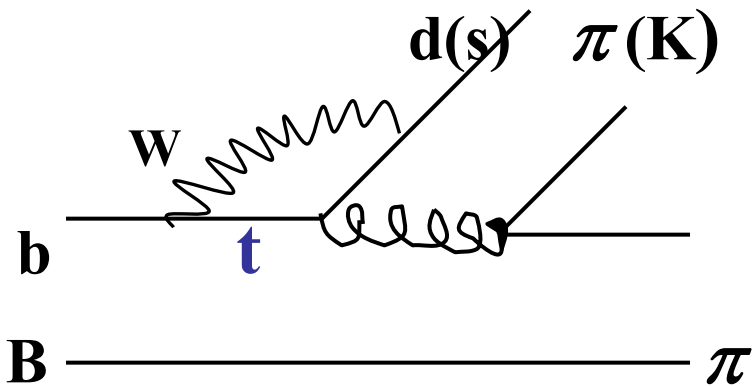
$B \rightarrow \pi\pi, \pi K$ Have Two Kinds of Diagrams with different weak phase

π (K)

b   W   u

B π

O_1, O_2

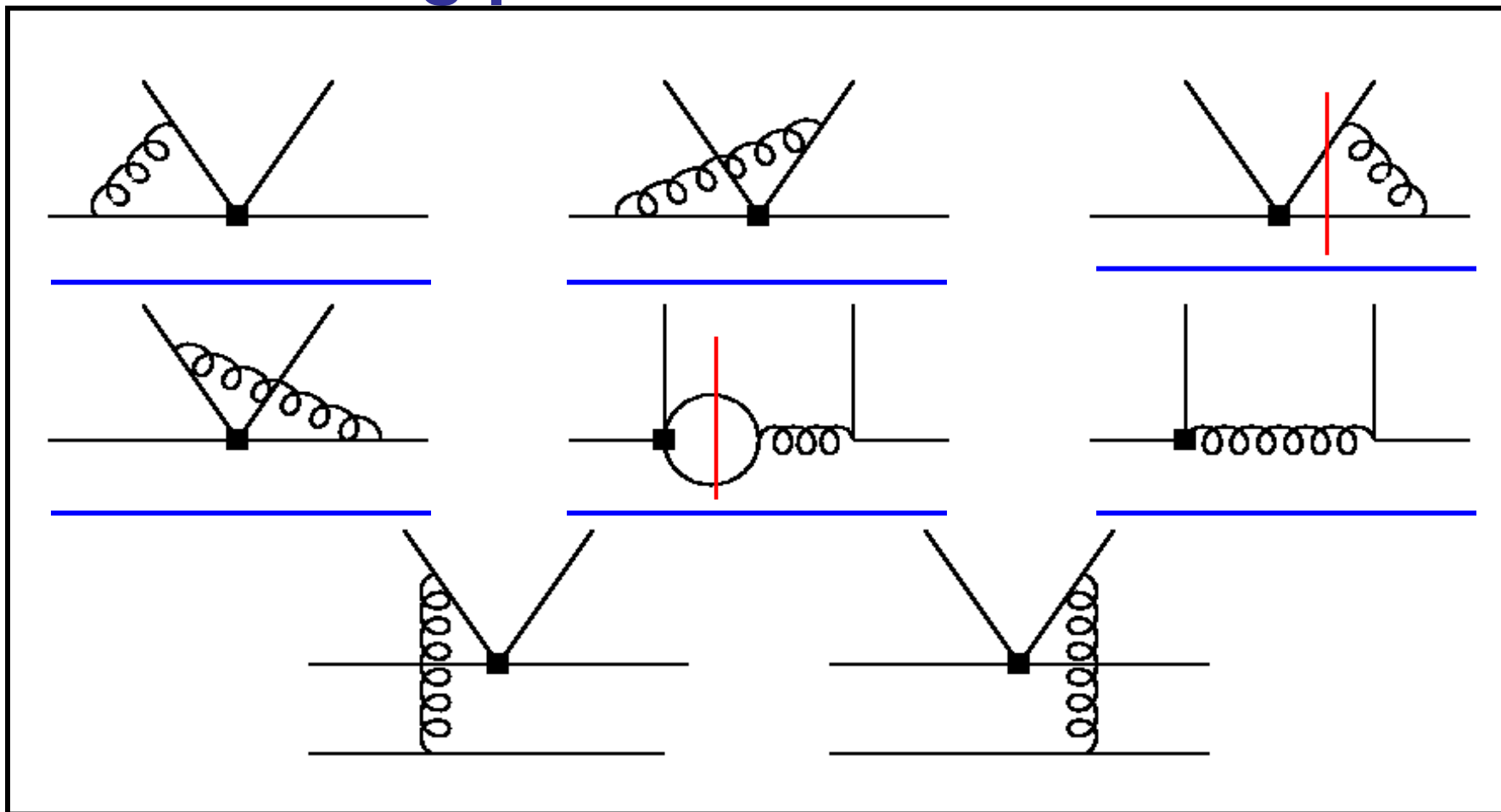Tree $\propto$ $V_{ub}V_{ud}*_{(s)}$

d(s) π (K)

W

b   t

B π
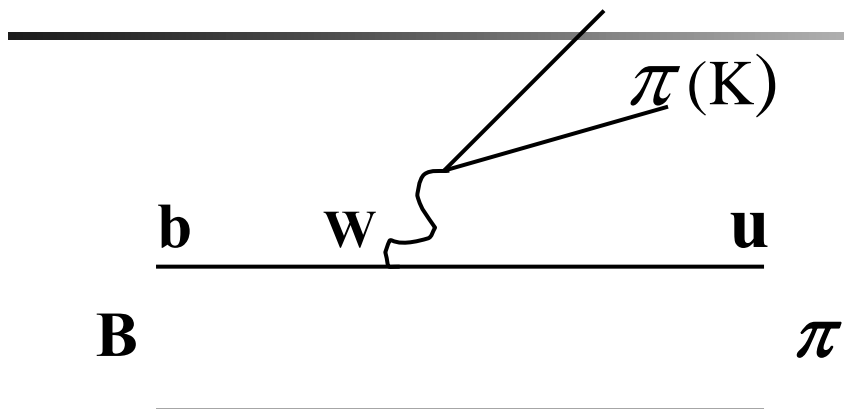
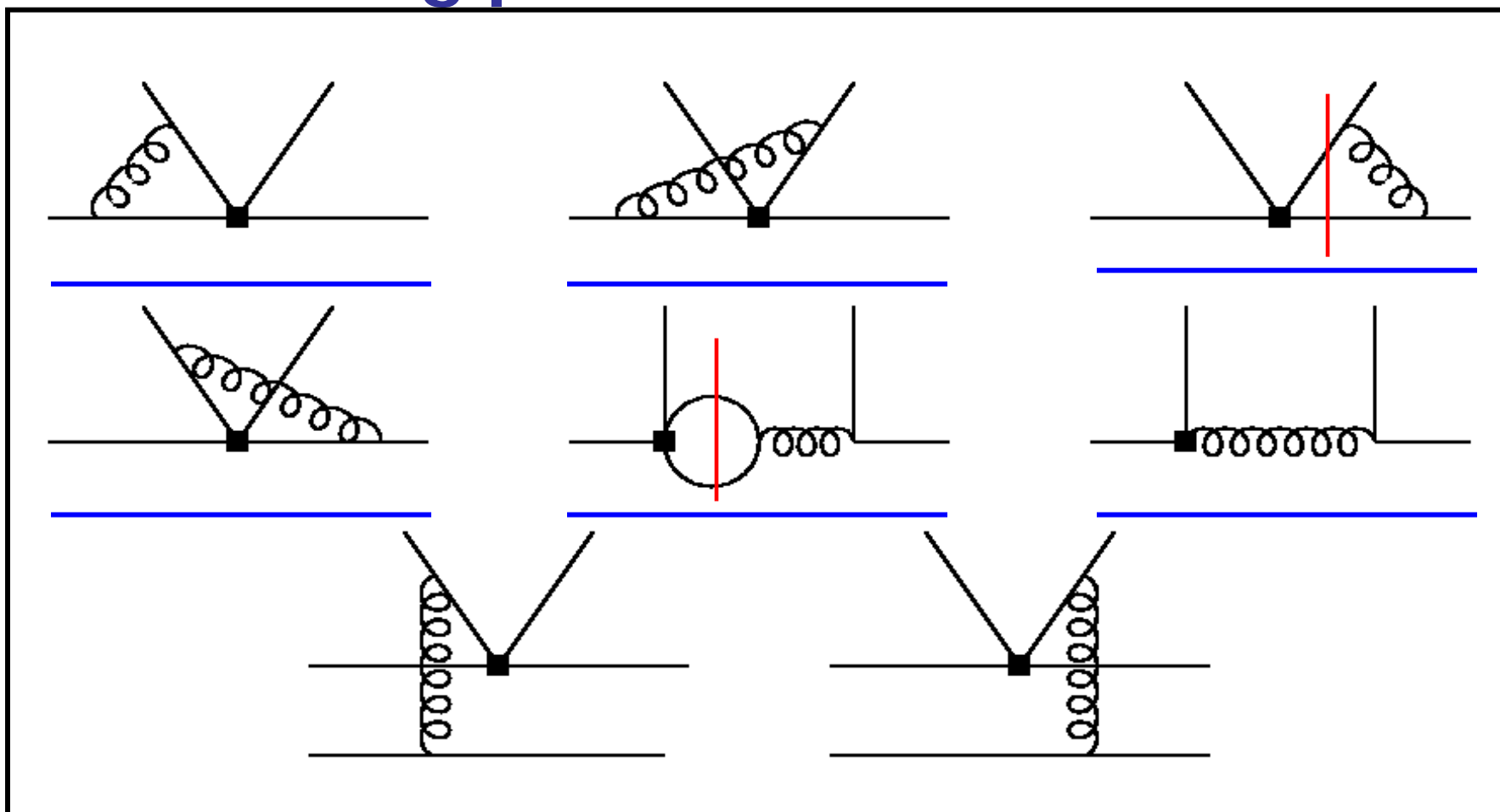O_3, O_4, O_5, O_6

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

QCD corrections are at α_s order, strong phase too small

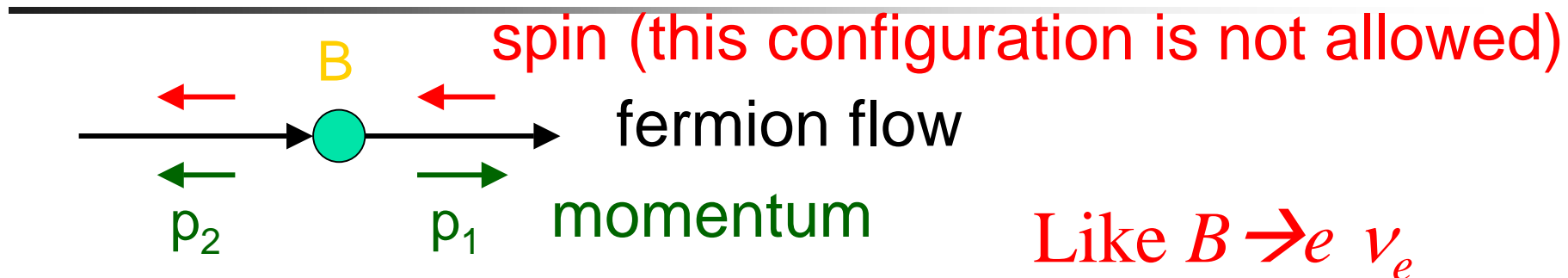# QCD corrections are at α_s order, strong phase too small

Wrong sign for direct CP

annihilation penguin can provide a large strong phase

spin (this configuration is not allowed)

B

fermion flow

p_2 p_1 momentum

Like $B \rightarrow e \ \nu_e$

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**
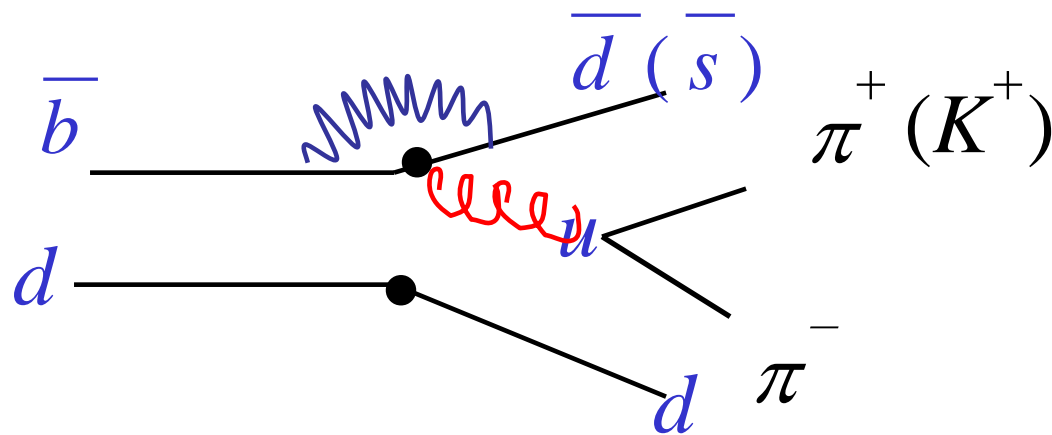- **No suppression, contribution "big" (20-30%)**
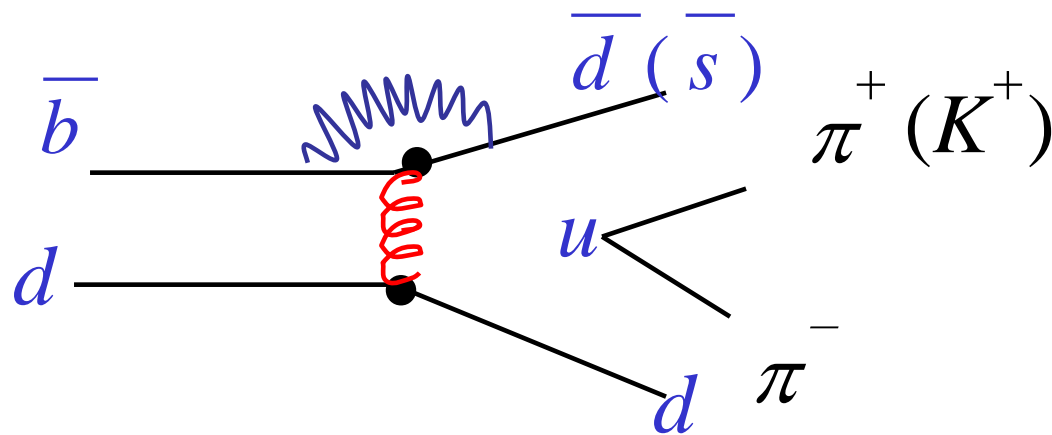
Calculable in pQCD approach

No suppression for O_6

- **Space-like penguin (annihilation)**
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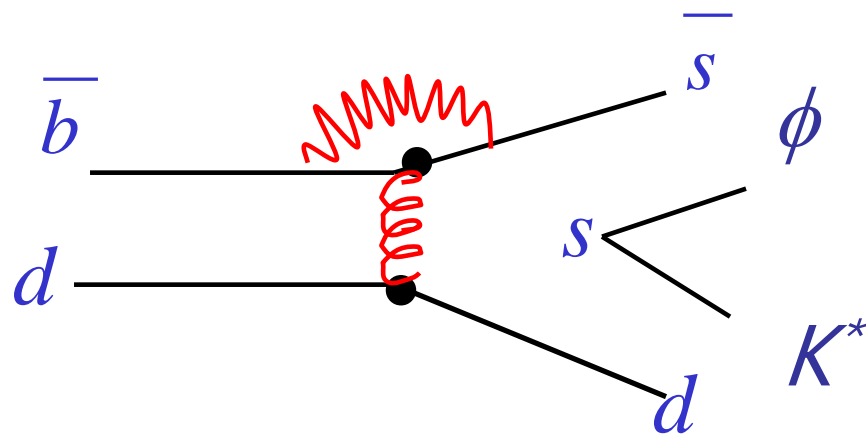- **No suppression, contribution "big" (20-30%)**

Calculable in pQCD approach

Large transverse component in B→φK* 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**

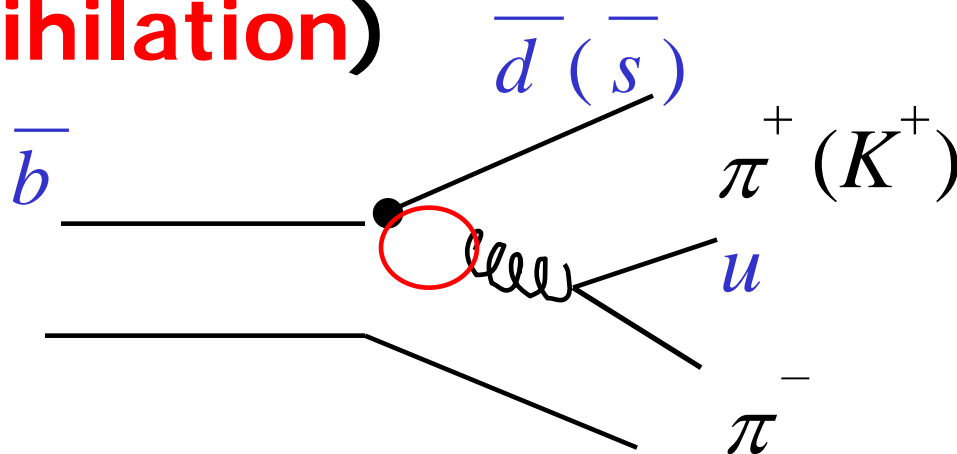# Charming penguins in SCET

- **Play the similar role at SCET, but not calculable**

- **Charming penguin appear always together with space like penguin (annihilation)**

$$\overline{b} \qquad \overline{d}\,(\overline{s}) \qquad \pi^{+}\,(K^{+})$$

$$u$$

$$\pi^{-}$$

SCET

- χ^2 **Fit** from experiments requires **a large charming penguin**, it even become the **most important** contribution in $B \rightarrow K\pi$ decays

- It is essential to provide a **right strong phase** for direct CP asymmetry

**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

Charmming penguin	Chiral enhanced penguin	Annihilation penguin
Vcb Vcs	**Vtb Vts**	**Vtb Vts**
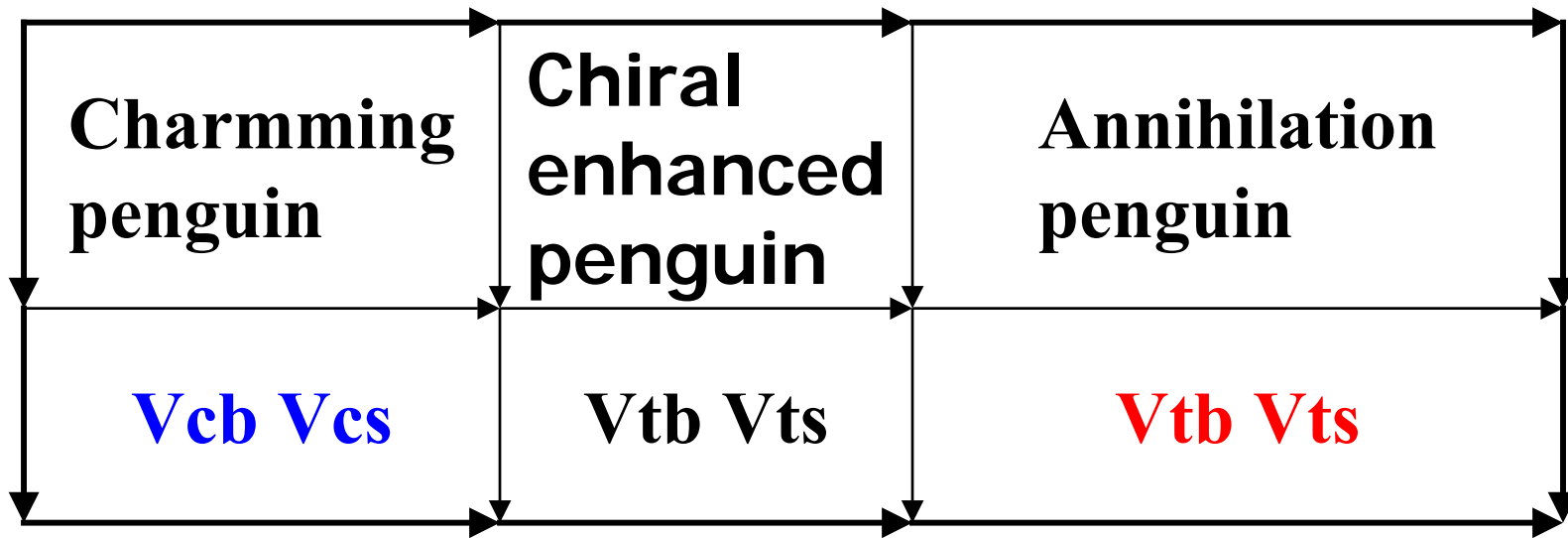
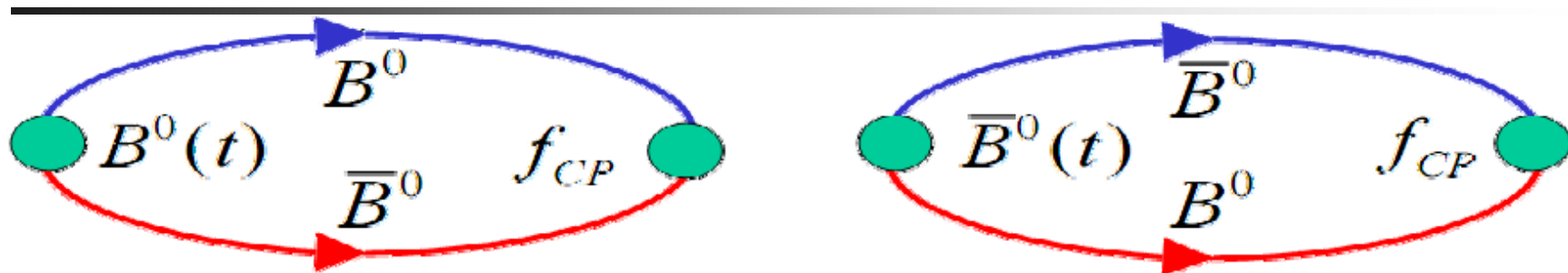**CKM phase slightly different**

Mixing Induced CP

- $B \rightarrow \pi^+\pi^-, \phi K, \eta'K, KKK \ldots$
- **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

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

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

$$\mathcal{A}_{CP}(t) = \frac{\Gamma(B^0(t) \to f) - \Gamma(\bar{B}^0(t) \to f)}{\Gamma(B^0(t) \to f) + \Gamma(\bar{B}^0(t) \to f)}$$

$$= \frac{|\lambda|^2 - 1}{|\lambda|^2 + 1}\cos\Delta mt + \frac{2\mathrm{Im}\lambda}{|\lambda|^2 + 1}\sin\Delta mt$$
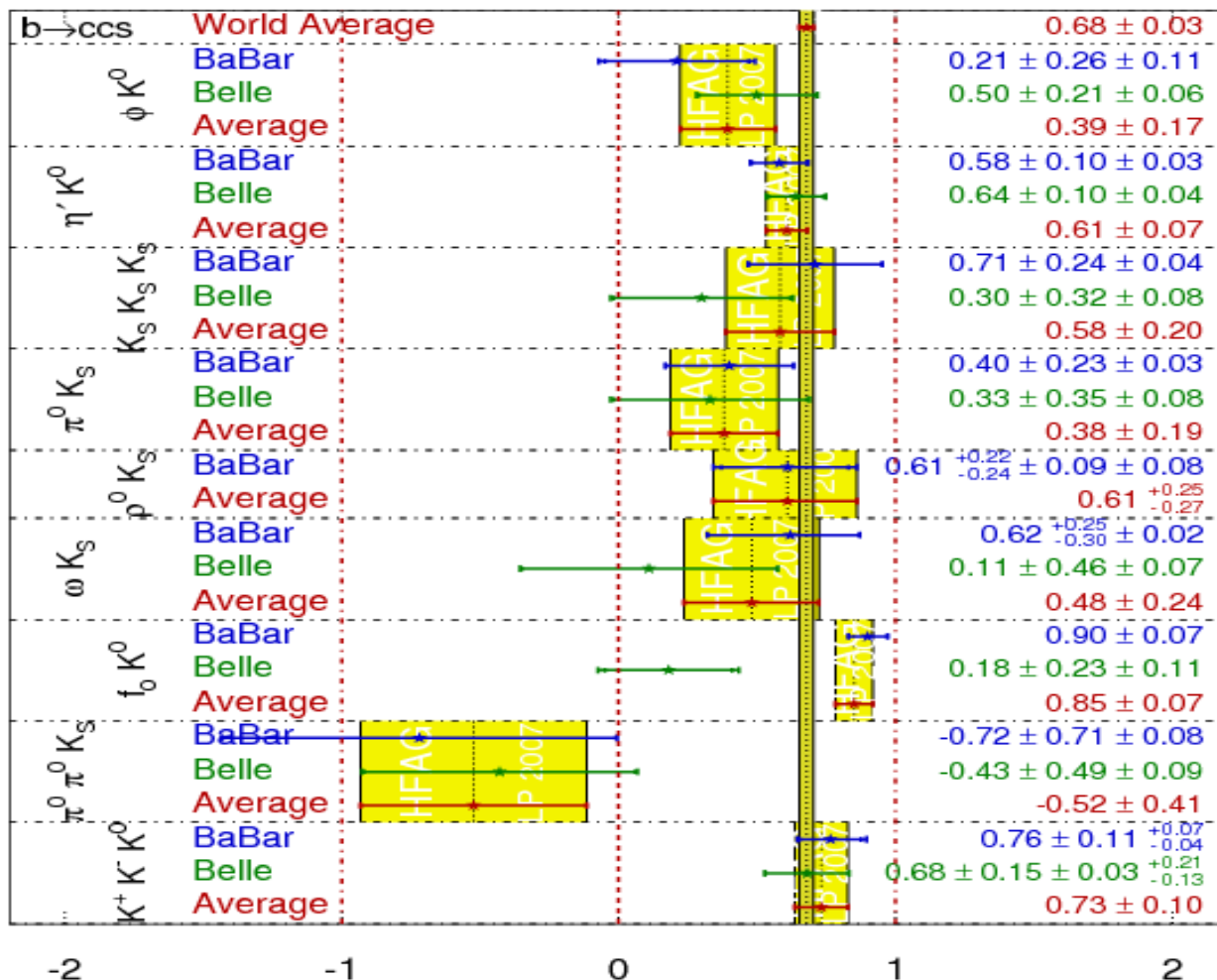
$$\lambda = \frac{q}{p}\frac{\bar{A}}{A}. = e^{-2i\beta}e^{-2i\delta}$$

Tendency of exp.data against theory

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

HFAG
LP 2007
PRELIMINARY

CD Lu

ΔS calculated from QCDF,pQCD,SCET

ΔS	QCDF	pQCD	SCET	exp
φKs	0.02	0.02	0.00	−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' Ks	0.01		−0.02, −0.02	−0.07 ±0.07
π Ks	0.07	0.05	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**
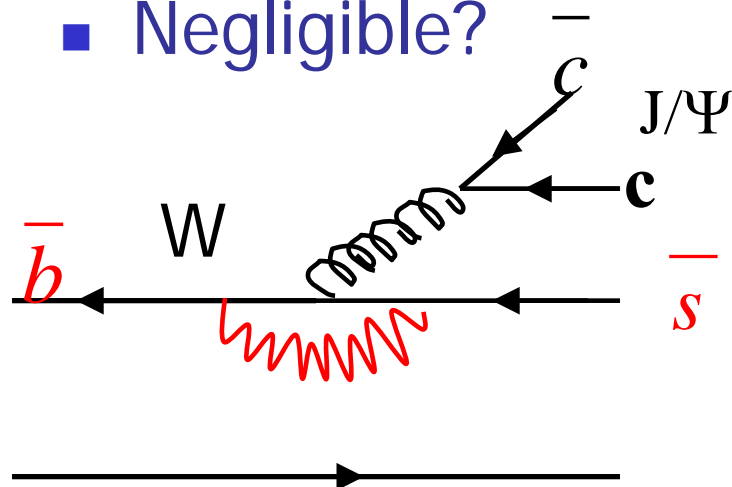
Color suppressed penguin

- Color suppressed tree
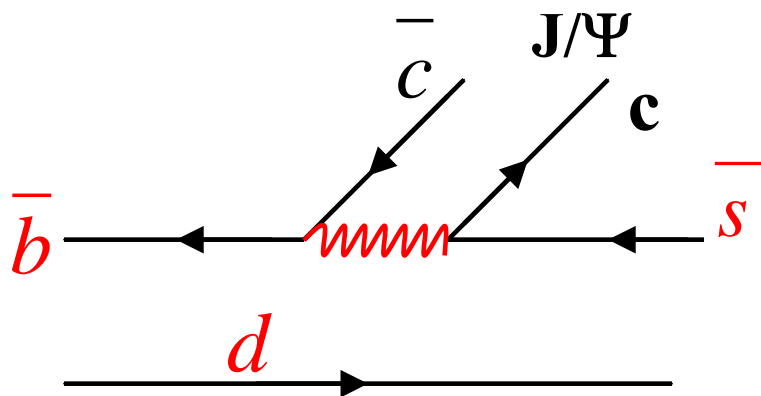
- Color suppressed penguin

- Negligible?

- $V_{cb} \ V_{cs}$

- $V_{tb} \ V_{ts}$

- **nrQCD predict large color octet contribution for J/Ψ production.**

- **The color suppressed penguin is a kind of color octet contribution.**

- **If it is "big", we have sin 2β_{eff} for B $\rightarrow$ J/Ψ Ks,**

- **Δs will change sign**

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, counting rules consistent with pQCD, but need more parameters**

- **NLO, $1/m_B$ corrections not yet fully studied, important for certain channels**

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**

Thank you!