SOME ASPECTS OF CHARMLESS B DECAYS FROM QCD LCSR

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- charmless two-body B decays $\rightarrow$ search for CP violation
- extraction of $\gamma = arg(V_{ub}^*)$: $B \rightarrow \pi\pi$ and $B \rightarrow \pi K$ decays

  $\Rightarrow$ knowledge about hadronic matrix elements $\langle M_1 M_2 | H_{weak} | B \rangle$ is required

  MODELS FOR CALCULATING MATRIX ELEMENTS:

  - ▷ PQCD APPROACH (Keum, Sanda, Li (2001))
  - ▷ QCD FACTORIZATION APPROACH (Beneke, Buchalla, Neubert, Sachrajda (1999))
    - in the $m_b \rightarrow \infty$ limit, hadronic matrix elements for $B \rightarrow D + light$ and $B \rightarrow light + light$ decays factorize
    - leading nonfactorizable $O(\alpha_s)$ effects can be studied systematically
    - it does not apply for $B \rightarrow light + D$ decays

  $\Rightarrow$ what about nonfactorizable nonperturbative Λ_{QCD}/m_b corrections ?

  - ▷ LIGHT-CONE SUM RULE METHOD (Khodjamirian (2001))

- FACTORIZATION of the matrix elements ? :

$$\text{i.e. } \langle\pi\pi|\mathcal{O}_i|B\rangle = \langle\pi|\bar{d}\Gamma_\mu u|0\rangle\langle\pi|\bar{u}\Gamma^\mu b|B\rangle[1+O(\alpha_s)+O(\Lambda_{QCD}/m_b)]$$
$$= im_b^2 f_\pi F^+_{B\to\pi}(m_\pi^2)[1+O(\alpha_s)+O(\Lambda_{QCD}/m_b)]$$

- is it enough to keep only leading terms in $1/m_b$, i.e how large are $O(\Lambda_{QCD}/m_b)$ corrections ?

- large enhancement of penguin ("charming penguin") contributions ? (Ciuchini et al.) $\Leftrightarrow$ large $O(\Lambda/m_b)$ corrections ?
-large strong phases from penguin amplitudes ?

- ISOSPIN & SU(3) RELATIONS :

$$\text{i.e. } A(B^-\to\pi^-\overline{K}^0)+\sqrt{2}A(B^-\to\pi^0K^-)=\sqrt{2}\frac{V_{us}}{V_{ud}}A(B^-\to\pi^-\pi^0)(1+\Delta_{SU(3)})$$

- $\Delta_{SU(3)} = 5\%$ or 20%? $\quad (f_K/f_\pi, F_{B\to K}/F_{B\to\pi}, \delta(m_s)...)$

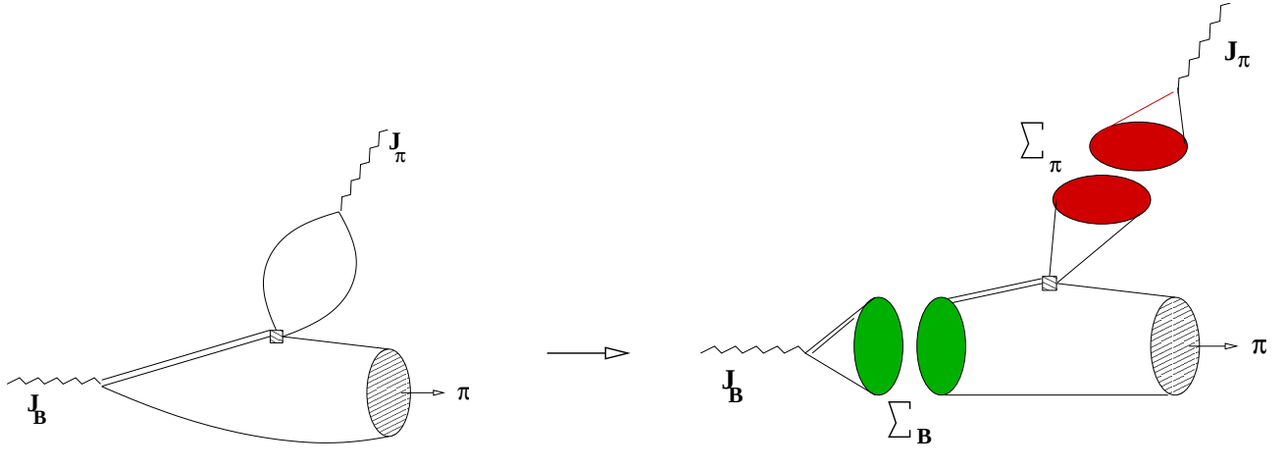
Khodjamirian, Mannel, Melcher - work in progess

$B \to \pi\pi$ FROM LCSR:

$$F_\nu^{(\mathcal{O})}(p,q,k) = \int d^4x e^{-i(p-q)x} \int d^4y e^{i(p-k)y} \langle 0|T\{j_{\nu,5}^{(\pi)}(y)\mathcal{O}(0)j_5^{(B)}(x)\}|\pi(q)\rangle$$

- interpolating currents for a pion and a B meson:

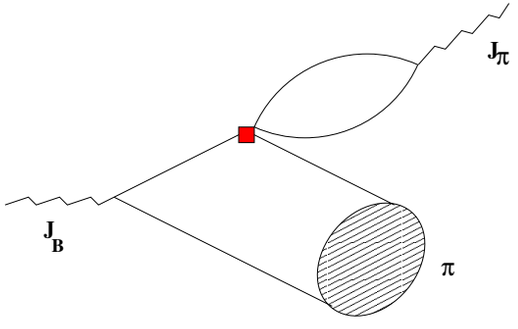
$$j_{\nu,5}^{(\pi)} = \bar{u}\gamma_\nu\gamma_5 d \qquad j_{\nu,5}^{(B)} = m_b \bar{b} i\gamma_5 d$$



quark-hadron duality $\to \langle\pi\pi|\mathcal{O}|B\rangle$

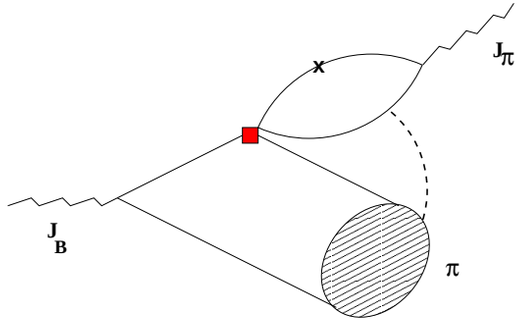
▷ LEADING CONTRIBUTION $\Rightarrow$ factorizable amplitude

$$\langle \pi^- \pi^+ | \mathcal{O}_1 | B \rangle_E \simeq i m_B^2 \, f_\pi \, (F^+_{B\to\pi}(0))_{LCSR}$$



- $O(\alpha_s)$ corrections :
  - calculated in QCD factorization
  - in LCSR model - two-loop effects

Q1: NONFACTORIZABLE $O(\Lambda/m_b)$ corrections from
$\mathcal{O}_2 \sim 2\,\tilde{\mathcal{O}}_1 = (\bar{d}\Gamma_\mu \frac{\lambda^a}{2} u)(\bar{u}\Gamma^\mu \frac{\lambda^a}{2} b)$

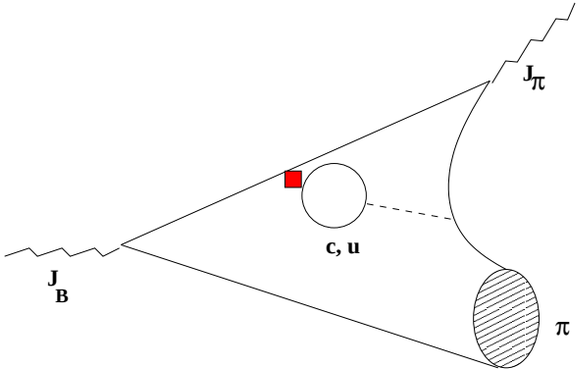


A1: $O(\Lambda/m_b)$ corrections are small, but they are of the same order as $O(\alpha_s)$ corrections calculated in QCD factorization

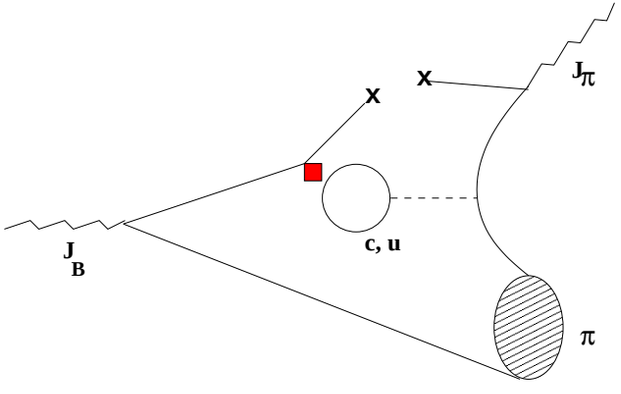
Q2 : NONFACTORIZABLE $O(\Lambda/m_b)$ CONTRIBUTIONS FROM PENGUIN LOOPS

(Khodjamirian, Mannel, Melić)

"hard contributions":

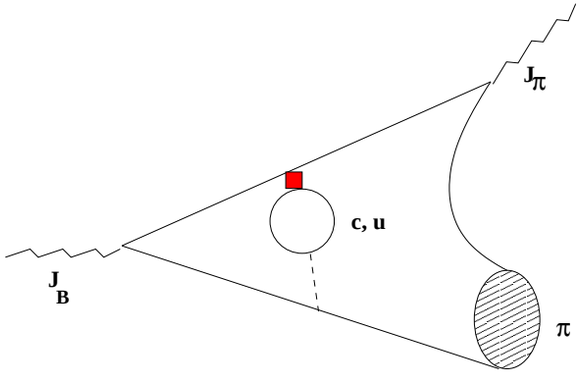


$\mathcal{O}(\alpha_s)$



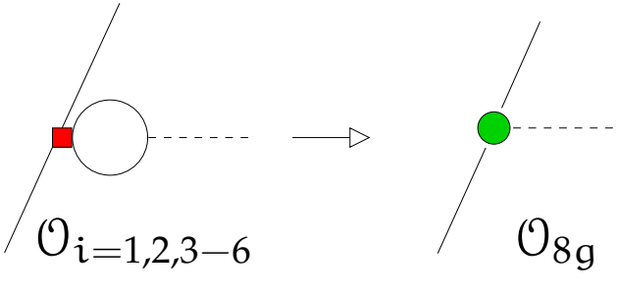
$\mathcal{O}(\alpha_s\, r_\chi)$

$$r_\chi = \frac{2m_\pi^2}{m_b(m_u+m_d)}$$

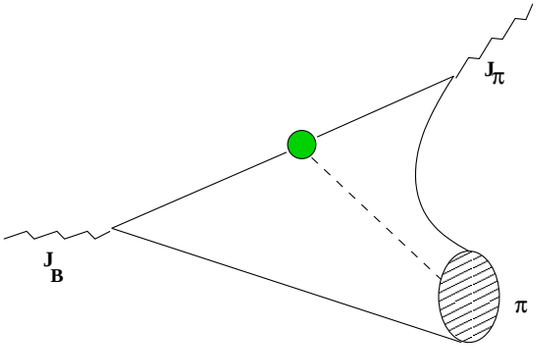


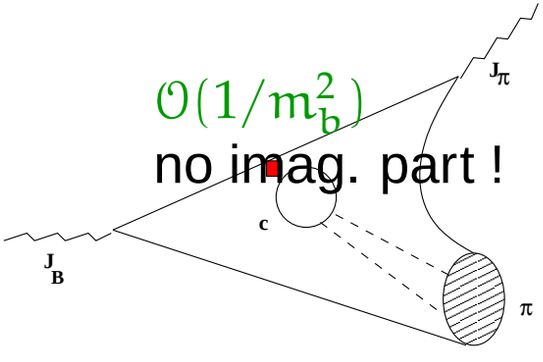
$\mathcal{O}(\alpha_s/m_b)$

no imag. part !

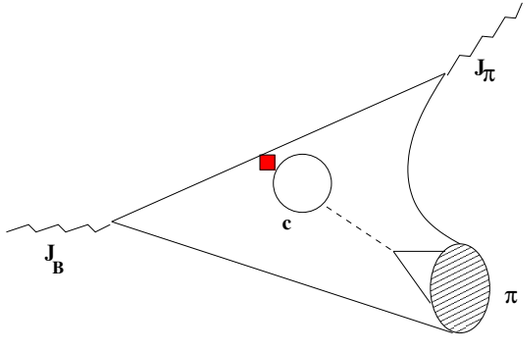


"soft contributions"

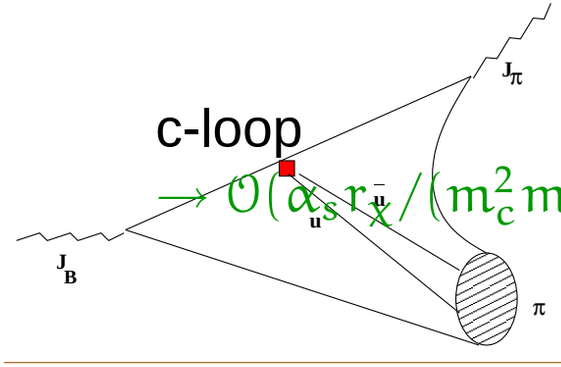




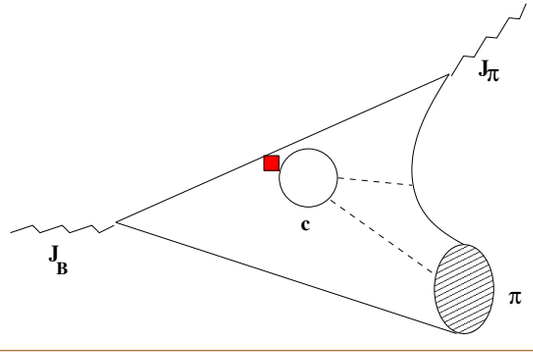
$\mathcal{O}(1/m_b^2)$
no imag. part !



$\longrightarrow \mathcal{O}(\alpha_s r_\chi)$
no imag. part !



c-loop
$\rightarrow \mathcal{O}(\alpha_s r_\chi^{\bar{u}}/(m_c^2 m_b^2))$



$\mathcal{O}(\alpha_s/m_b^2)$

▷ how large are penguin-loop corrections and strong phases produced by the penguins at finite m_b ?
A2: $\Rightarrow$ IMPLICATIONS TO a_{CP}^{dir} :

$$\mathcal{A}(\overline{B}^0 \to \pi^+\pi^-) = A_{fact}\left[V_{ub}V_{ud}^* \underbrace{\equiv T_0 + P^u}_{T} + V_{cb}V_{cd}^* \underbrace{\equiv P^c}_{P} + \underbrace{EW + A}_{\text{neglected}}\right]$$

$$A_{fact} = i\frac{G_F}{\sqrt{2}} m_B^2 f_\pi F^+_{B\to\pi}$$

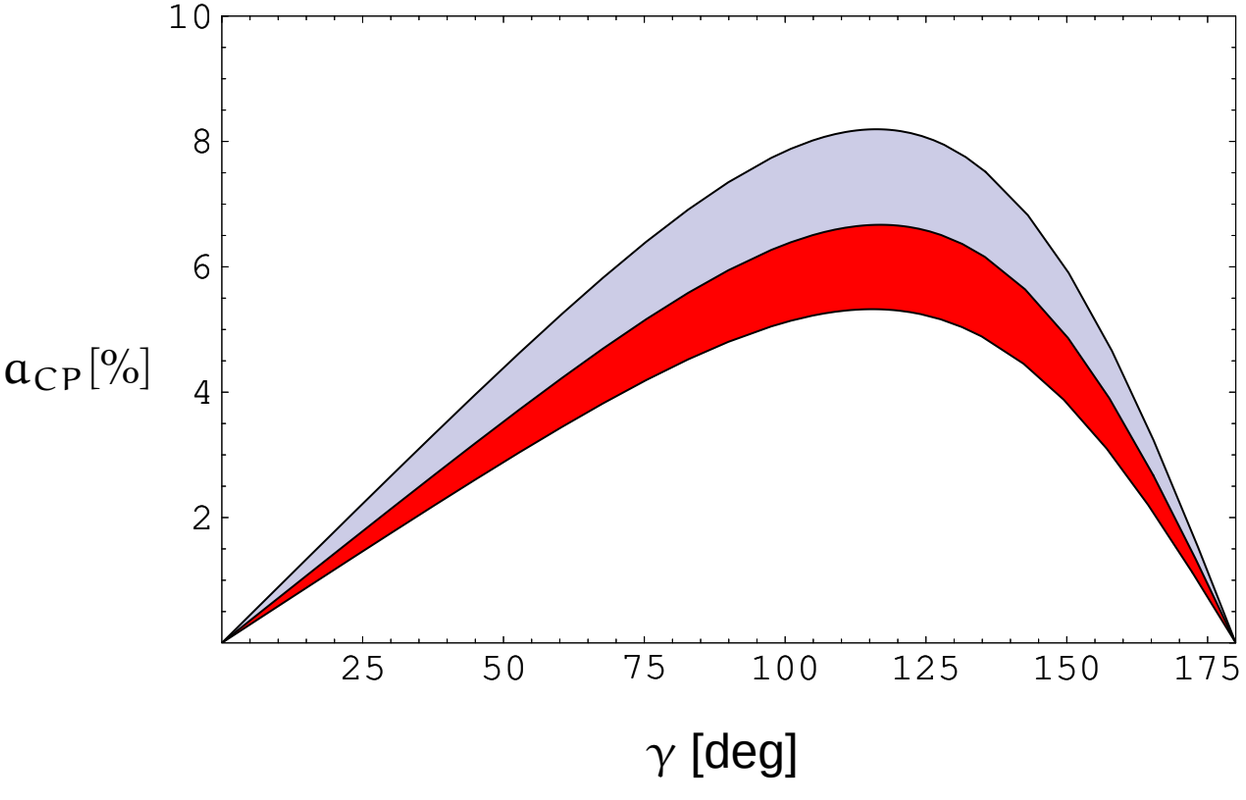
$\to$ we can neglect hard $O(\alpha_s)$ corrections to T and P - small with small strong phases $\Rightarrow$ strong δ phases are generated mainly by the penguin-loop contributions:

$$\mathcal{A}(\overline{B}^0 \to \pi^+\pi^-) \sim e^{-i\gamma} - \frac{1}{R_b}\frac{|P|}{|T|} e^{i(\delta_{P^c_{loop}} - \delta_{P^u_{loop}})} \qquad R_b = \frac{|V_{ud}V_{ub}|}{|V_{cd}V_{cb}|}$$

$$= e^{-i\gamma} - |R|\, e^{i(\delta_{P^c_{loop}} - \delta_{P^u_{loop}})}$$

$$a_{CP}^{dir} = \frac{-2|R|\sin\gamma\sin(\delta_{P^c_{loop}} - \delta_{P^u_{loop}})}{1 - 2|R|\cos\gamma + |R|^2}$$

$$R \equiv -\frac{1}{R_b}\frac{P}{T}$$



upper curve: $m_b \to \infty$ result
red region $\to$ LSCR result

no additional uncert. included
(annihilation ? , $\delta(V_{ub}/V_{cb})$)

violet region: $\to 1/m_b$ corrections !

$$(|R|\, e^{i\delta})\big|_{\substack{m_b\to\infty \\ \mu = m_b/2}} = 0.24\, e^{i(9.1^\circ)}$$

$$(|R|\, e^{i\delta})\big|_{\substack{LCSR \\ \mu = m_b/2}} = 0.25\, e^{i(5.9^\circ)}$$

LCSR PROVIDE AN EFFICENT METHOD FOR CALCULATING NONFACTORIZABLE CORRECTIONS IN (CHARMLESS) B DECAYS:

- A1: NONFACTORIZABLE $\mathrm{O}(\Lambda/m_b)$ CORRECTIONS IN THE EMISSION TOPOLOGY ARE SMALL
  - CAVEAT:
    IN COLOR-SUPPRESSED B DECAYS NONFACTOR. CORRECTIONS ARE LARGE !
    - LCSR calculation for $\mathrm{B} \to \mathrm{J}/\psi\mathrm{K}$ decay (Melić (2003))
    - BELLE and CLEO (2002) on $\overline{\mathrm{B}}^0 \to \mathrm{D}^{(*)0}\pi^0$
- A2: NONFACTORIZABLE $\mathrm{O}(\Lambda/m_b)$ CORRECTIONS IN THE PENGUIN TOPOLOGY ARE SMALL:
  - both real and imaginary parts $\Rightarrow$ SMALL STRONG PHASES
  - BUT ACCUMULATE TO A NOTICABLE EFFECT IN a_{CP}^{dir} ! (numerically smaller than in the $m_b \to \infty$ limit)

- Q3: SU(3) BREAKING EFFECTS ($B \to K\pi$) ?
  A3: work in progress
- Q4: ANNIHILATION EFFECTS ?
  A4: future work ??????