CHARMLESS TWO-BODY B-MESON DECAYS IN QCD

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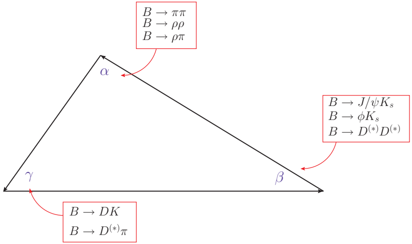
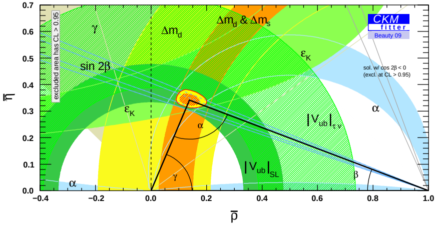
Outline

Introduction

- nonleptonic B-meson decays $\longrightarrow$ unique test of two fundamental phenomena in physics: CP-symmetry violation and flavour mixing
- today ($\mathcal{O}(10^8)$ $B\overline{B}$ pairs !) (Babar (SLAC), BELLE (KEK), CLEO-III (Cornell), CDF-II, D0 -II (Fermilab)) and future experiments (LHCb, ATLAS, CMS (CERN), SuperB) can extract parameters of B-meson decays with large precision
- CP violation in B-meson systems is confirmed today and strategies for testing flavour structure of SM (determined by the CKM mixing matrix) can be - for the first time - confronted with the precise experimental results

- nonleptonic B-meson decays into charmless particles $\longrightarrow$ test of "new physics"
- nonleptonic B-meson decays $\longrightarrow$ there is a need for precise calculation of QCD corrections in these processes

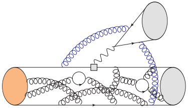




$$
\begin{aligned}
\alpha &= (92.0 \pm 3.4)^\circ && \text{UTfit} \\
&= \left(89.0^{+4.4}_{-4.2}\right)^\circ && \text{CKMfitter} \\
\beta &= (21.1 \pm 0.9)^\circ && \\
\gamma &= (74 \pm 11)^\circ && \text{UTfit} \\
&= \left(73^{+22}_{-25}\right)^\circ && \text{CKMfitter}
\end{aligned}
$$

$\delta|V_{cb}| \sim 2(\text{incl.}) - 7(\text{excl.})\%$

$\delta|V_{ub}| \sim 10\%$



$$\mathcal{H}_{weak} = \frac{G_F}{\sqrt{2}} \sum_{p=u,c} V_{pb} V_{pd}^* \left\{ C_1(\mu)\mathcal{O}_1^p + C_2(\mu)\mathcal{O}_2^p + \sum_{i=3,..,10} C_i(\mu)\mathcal{O}_i + C_{7\gamma}\mathcal{O}_{7\gamma} + C_{8g}\mathcal{O}_{8g} \right\}$$

$$|A|e^{i\delta} \sim \langle \overline{f}|\mathcal{H}_{weak}|\overline{B}\rangle = \sum_k \underbrace{C_k(\mu)}_{\text{pert. QCD}} \times \underbrace{\langle \overline{f}|\mathcal{O}_k(\mu)|\overline{B}\rangle}_{\text{non-pert. QCD}}$$

- ▷ how to calculate hadronic matrix elements ?
  multiple scale problem: M_W, m_b and $\Lambda_{\rm QCD}$

$$\mathcal{O} = (\overline{q_1}_i \Gamma_\mu q_{2i})\,(\overline{q_3}_j \Gamma^\mu b_j) \quad \rightarrow \quad \langle \overline{f}|\mathcal{O}|\overline{B}\rangle \text{ ?}$$

$$i.e. \ \langle \pi\pi|\mathcal{O}_1|B\rangle = \underbrace{\langle \pi|\overline{d}\Gamma_\mu u|0\rangle\langle \pi|\overline{u}\Gamma^\mu b|B\rangle}_{'naive'\ factorization} \left[1 + \mathcal{O}(\alpha_s) + \mathcal{O}(\Lambda_{QCD}/m_b)\right]$$

$$= i m_b^2 f_\pi f_{B\pi}^+(m_\pi^2)\left[1 + \mathcal{O}(\alpha_s) + \mathcal{O}(\Lambda_{QCD}/m_b)\right]$$

- ▷ how large are $O(\alpha_s)$ corrections ?
- ▷ how large are $O(\Lambda_{QCD}/m_b)$ corrections ?

Strategies for extracting matrix elements

- USE OF FLAVOUR (isospin, SU(3)) SYMMETRIES [Gronau, Rosner et. al]
  - matrix elements are extracted from the data
  - use of the symmetry breaking in decays constants and form factors

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$$\langle M_1 M_2 | \mathcal{O}_i | B \rangle = \int d\omega du dv \phi_B(\omega) T_H^i(\omega, u, v) \phi_{M_1}(u) \phi_{M_2}(v)$$

- factorization of matrix elements in the $m_b \to \infty$ limit - found to hold at NNLO level
- does not apply for $B \to light + D$ decays (colour-suppressed decays)
- $\mathcal{O}(\alpha_s)$ corrections are calculable - annihilation contributions and $\mathcal{O}(1/m_b)$ corrections cannot be calculated (divergent) - dominated by soft gluon exchange ?

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- PQCD APPROACH [Keum, Sanda, Li (2001)]

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  - the complete $\langle M_1 M_2|\mathcal{O}_i|B\rangle$ matrix element is calculated perturbatively;
  - long-range nonfactorizable contributions are suppressed by the Sudakov form factor (questionable)
  - problems with the factorization - appearance of the Glauber gluons $\longrightarrow$ modification of PQCD [Li, Mishima (2009)]

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- SCET(soft-collinear eff. theory) [Bauer, Fleming, Luke, Stewart (2001)]
  - for $B \to light + light$ decays; expansion in terms of collinear, soft, hard, etc. gluonic modes

- LIGHT-CONE SUM RULE METHOD [Khodjamirian (2001)]
  - both corrections $\mathcal{O}(\alpha_s)$ and $\mathcal{O}(\Lambda/m_b)$ are calculable

$$
\begin{aligned}
i.e. \quad \langle \pi\pi|\mathcal{O}_1|B\rangle &= \langle \pi|\bar{d}\Gamma_\mu u|0\rangle\langle \pi|\bar{u}\Gamma^\mu b|B\rangle \left[1 + O(\alpha_s) + O(\Lambda_{QCD}/m_b)\right] \\
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- all models give satisfactory overall description of BRs with some problems:
  - ▽ "charming penguin" (= 'long-distance charmed loops', '$D-\overline{D}$ rescattering') contributions [Ciuchini et al. (2001)]
    - long-distance large $O(\Lambda/m_b)$ contributions and large strong phases ?
  - ▽ annihilation could be large

$$X_A = (1+\rho_A e^{i\Phi_A})\log\frac{m_B}{\Lambda_h} \qquad\qquad \Lambda_h = 0.5\,\mathrm{GeV}$$

ρ_A i Φ_A parameters determined from exp. data on BR's and a_{CP}'s

  - ▽ penguin annihilation could be large - not addressed at all

Idea of sum rules

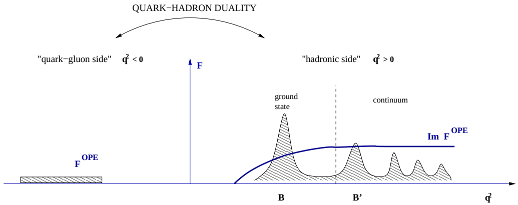
$$\boxed{F(q^2)^{hadr} = F(q^2)^{OPE}}$$

dispersion relation: a bridge between hadron spectral density AND calculation in the deep euclidean region:

$$\frac{\langle ground - state\ contrib.\rangle}{m_H^2 - q^2} + \int_{s_0^H}^{\infty} ds \frac{\rho_H(s)}{s - q^2} = \frac{1}{\pi} \int_0^{\infty} ds \frac{ImF(s)^{OPE}}{s - q^2}$$

QUARK-HADRON DUALITY (assumption !):

$$\rho_H(s)\theta(s - s_0^H) = \frac{1}{\pi} ImF(s)^{OPE}(s - s_0^h)$$



Light-cone sum rules

e.g. calculation of $B \to \pi$ form factor - from the correlator F_μ:

$$F_\mu = i \int d^4x e^{iqx} \langle \pi(p) | T\{\overline{u}\gamma_\mu b(x), m_b \overline{b} i\gamma_5 d(0)\} | 0 \rangle$$

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- $(p+q)^2 > 0 \to$ sum over hadronic states at large distances

$$\frac{2m_B^2 f_B f_{B\pi}^+(q^2)}{m_B^2 - (p+q)^2} + \textit{higher states}$$

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- $(p+q)^2 < 0 \to$ light-cone OPE - TWIST-expansion in terms of the light-cone wave functions

$$= \frac{1}{\pi} \int_{m_b}^{\infty} \frac{ds}{s-(p+q)^2} \mathrm{Im}_s F(q^2, s)$$

$$= \frac{1}{\pi} \int_{m_b}^{\infty} \frac{ds}{s-(p+q)^2} \sum_{n=twist} \int_0^1 du \mathrm{Im}_s T_H^{(n)} \phi_\pi^{(n)}$$

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- applying global quark-hadron duality (assumption!)

$$\textit{higher states} = \frac{1}{\pi}\int_{s_0^B}^{\infty} \frac{ds}{s-(p+q)^2} \sum_n \int_0^1 du\, \mathrm{Im}_s T_H^{(n)}(u, q^2, s; \mu_{\mathrm{IR}}) \Phi_\pi^{(n)}(u; \mu_{\mathrm{IR}})$$

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- 'enhancement' of ground state and suppression of higher states

  Borel transform: $\frac{1}{(s-(p+q)^2)^n} \overset{s=(p+q)^2}{\Rightarrow} \frac{1}{\Gamma(n)} \frac{1}{(M^2)^n} e^{-s/M^2}$ $\quad M =$ Borel parameter

Light-cone distribution amplitudes

- $\Phi_\pi^{(n)}$ - LIGHT-CONE DISTRIBUTION AMPLITUDE(DA) of twist n
  -leading term $\longrightarrow$ twist-2 DA ϕ_π:

$$\langle \pi(q)|\overline{u}(x)\gamma_\mu\gamma_5 d(0)|0\rangle_{x^2=0} = -iq_\mu \frac{f_\pi}{\sqrt{2}} \int_0^1 du e^{iuq\cdot x} \phi_\pi(u,\mu)$$

  u = fraction of the momentum carried by a constituent

- Gegenbauer polynomial expansion

$$\phi_{\pi,K}(u,\mu) = 6u(1-u)\left\{1 + \sum_{n=0}^{\infty} a_n^{\pi,K}(\mu) C_n^{3/2}(2u-1)\right\} \stackrel{\mu\to\infty}{=} 6u(1-u)$$

  - pion DA: $a_1^\pi(\mu) = 0$, $a_2^\pi(\mu) = 0.25 \pm 0.15$, $a_4^\pi(\mu) \simeq 0$ - exp/SR/lattice
  - kaon DA: $a_1^K(\mu) = 0.10 \pm 0.04 \longrightarrow$ SU(3)-breaking, $a_2^K(\mu)$, $a_4^K(\mu)$

- higher twists: two and three-particle DAs; related by Wandzura-Wilczek-type relations
- structure of pseudoscalar and vector DAs is know to twist-4 accuracy

Heavy-to-light form factors

- $B \to \pi$ form factors [analogously for $B_{(s)} \to K$]:

$$\langle \pi^+(p)|\bar{u}\gamma_\mu b|\bar{B}_d(p+q)\rangle = 2f^+_{B\pi}(q^2)p_\mu + \left[f^+_{B\pi}(q^2) + f^-_{B\pi}(q^2)\right] q_\mu \, ,$$

$$\langle \pi^+(p)|\bar{u}\sigma_{\mu\nu}q^\nu b|\bar{B}_d(p+q)\rangle = \left[q^2(2p_\mu + q_\mu) - (m_B^2 - m_\pi^2)q_\mu\right] \frac{if^T_{B\pi}(q^2)}{m_B + m_\pi} \, ,$$

$$0 \leq q^2 \leq (m_B - m_\pi)^2 \sim 24\,\mathrm{GeV}^2$$

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$$i \int d^4x\, e^{iq\cdot x} \langle \pi^+(p)| T\left\{\bar{u}(x)\Gamma_\mu b(x), m_b \bar{b}(0) i\gamma_5 d(0)\right\} |0\rangle$$

$$= \begin{cases} F(q^2,(p+q)^2)p_\mu + \widetilde{F}(q^2,(p+q)^2)q_\mu \,, & \Gamma_\mu = \gamma_\mu \\ F^T(q^2,(p+q)^2)\left[p_\mu q^2 - q_\mu (qp)\right] , & \Gamma_\mu = -i\sigma_{\mu\nu}q^\nu \end{cases}$$

$$F(q^2,(p+q)^2) \sim f^+_{B\pi}(q^2)\,, \quad \widetilde{F}(q^2,(p+q)^2) \sim f^+_{B\pi}(q^2) + f^-_{B\pi}(q^2)$$

$$F^T(q^2,(p+q)^2) \sim f^T_{B\pi}(q^2)$$

$$f^0_{B\pi}(q^2) = f^+_{B\pi}(q^2) + \frac{q^2}{m_B^2 - m_\pi^2} f^-_{B\pi}(q^2)$$

Update of $B \to$ *light* form factors

$B \longrightarrow \pi$: [G. Duplančić, A. Khodjamirian, Th. Mannel, B.M., N. Offen (2008)]
$B_{(s)} \longrightarrow K$: [G. Duplančić, B.M.(2008)]

$$\begin{aligned} f^+_{B\pi}(q^2) &= \frac{e^{m_B^2/M^2}}{2m_B f_B}\frac{f_\pi}{\pi}\int_{m_b^2}^{s_0^B} ds e^{-s/M^2}\int_0^1 du \sum_n \mathrm{Im}_s T^{(n)}(q^2,s,u)\Phi_\pi^{(n)}(u) \\ &= \text{twist2}[1 + \underbrace{O(\alpha_s)}_{\text{Ball et al, Khodj. et al 97}}] + \text{twist3}[1 + \underbrace{O(\alpha_s)}_{\text{Ball,Zwicky 01}}] + \text{twist4}[1] \end{aligned}$$

- we use $\overline{\mathrm{MS}}$ mass

$$\overline{m}_b(\overline{m}_b) = 4.164 \pm 0.025\,\mathrm{GeV}$$

[(J. Kühn, M. Steinhauser, C. Sturm (2007)]

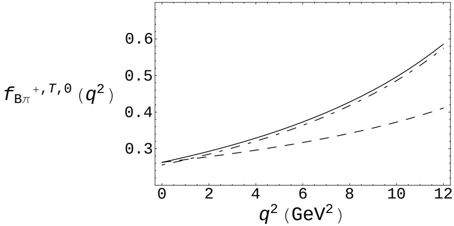
- we use f_B determined in $\overline{\mathrm{MS}}$ sheme

$$f_B = 210 \pm 19\,\mathrm{MeV}$$

[M. Jamin, B. Lange (2001)]

- s_0^B and M are fixed from LCSR result by fitting m_B with high precision
- for $B_{(s)} \to K$ with mass corrections a new, numerical method is used

$B \to \pi$ from factors



- *Form factors $f^+_{B\pi}(q^2)$ (solid line), $f^0_{B\pi}(q^2)$ (dashed line) and $f^T_{B\pi}(q^2)$ (dash-dotted line) for $\mu = 3.0$ GeV, $s_0^B = 35.75\,\mathrm{GeV}^2$, $M_s^2 = 18\,\mathrm{GeV}^2$ and $q^2_{max} = 12\,\mathrm{GeV}^2$*

$$f^+_{B\pi}(0) = 0.263\ {}^{+0.004}_{-0.005}\Big|_{M,\overline{M}}\ {}^{+0.009}_{-0.004}\Big|_{\mu} \pm 0.02\Big|_{shape}\ {}^{+0.03}_{-0.02}\Big|_{\mu_\pi} \pm 0.001\Big|_{m_b}$$

$$f^+_{B\pi}(0) = f^0_{B\pi}(0) = 0.26^{+0.04}_{-0.03}$$
$$f^T_{B\pi}(0) = 0.255 \pm 0.035$$

Recent determinations of V_{ub} from $B \to \pi l \nu_l$

- lattice QCD - form factors are extracted for high values of q^2
- LCSR - form factors are extracted for low values of q^2, $0 < q^2 < 12 - 14$ GeV
- different parametrisations of form factors in the whole q^2 region:
  Becirevic-Kaidalov; Ball-Zwicky, conformal mapping method, etc.

[C. Bourrely, I. Caprini, L. Lellouch, 0807.2722; A. Bharucha, Th. Feldmann, M. Wick, 1004.324]

- V_{ub} is extracted from the P.Ball's fit [P. Ball (2007)] of $|V_{ub} f^+_{B\pi}|$ to BaBar data on $B \to \pi l \nu_l$

$$|V_{ub}| f^+_{B\pi}(0) = \left(9.1 \pm 0.6\big|_{shape} \pm 0.3\big|_{BR} \right) \times 10^{-4}$$

[ref.]	$f^+_{B\pi}(q^2)$ calculation	$f^+_{B\pi}(q^2)$ input	$\lvert V_{ub}\rvert \times 10^3$
FNAL - MILC '08	lattice	-	3.38±0.35
HPQCD '07	lattice	-	3.55±0.25±0.50
Flynn, Nieves '07	-	lattice ⊕ LCSR	$3.47 \pm 0.29 \pm 0.03$
Bourrely, Caprini, Lellouch '08	-	lattice ⊕ LCSR	3.54 ± 0.24
Ball, Zwicky '04	LCSR	-	$3.5 \pm 0.4 \pm 0.1$
our work '08	**LCSR**	-	$\mathbf{3.5 \pm 0.4 \pm 0.2 \pm 0.1}$

$B_{(s)} \to K$ from factors

- various SU(3)-breaking effects are included: f_K/f_π, $\langle \bar{s}s \rangle$, hadronic parameters,...
- SU(3)-breaking effects in $\Phi_K^{(n)}$ DAs are included

[Ball,Braun,Lenz (2006)]

- m_K^2 effects included; problems with m_s-corrections at NLO - negligible
- instead of the analytical extraction of imag. parts of LCSR amplitudes $\to$ the method of direct integration in a complex plane is used

- $B \to K$ form factors

$$f_{BK}^+(0) = f_{BK}^0(0) = 0.36^{+0.05}_{-0.04}$$
$$f_{BK}^T(0) = 0.38 \pm 0.05$$

- $B_s \to K$ form factors

$$f_{B_sK}^+(0) = f_{B_sK}^0(0) = 0.30^{+0.04}_{-0.03}$$
$$f_{B_sK}^T(0) = 0.30 \pm 0.05$$

- predicted SU(3) breaking:

$$\frac{f^+_{BK}(0)}{f^+_{B\pi}(0)} = 1.38^{+0.11}_{-0.10} \qquad \frac{f^+_{B_sK}(0)}{f^+_{B\pi}(0)} = 1.15^{+0.17}_{-0.09}$$

$$\frac{f^T_{BK}(0)}{f^T_{B\pi}(0)} = 1.49^{+0.18}_{-0.06} \qquad \frac{f^T_{B_sK}(0)}{f^T_{B\pi}(0)} = 1.17^{+0.15}_{-0.11}$$

- SU(3) and U-spin relations in factorization models for $B_{(s)} \to K\pi, KK$ amplitudes:

$$\xi = \frac{f_K}{f_\pi}\frac{f^+_{B\pi}(m_K^2)}{f^+_{B_sK}(m_\pi^2)}\frac{m_B^2 - m_\pi^2}{m_{B_s}^2 - m_K^2} = 1.01^{+0.07}_{-0.15}$$

[Chiang,Gronau,Rosner (2008)]

but

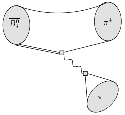
$$\frac{A_{fact}(B_s \to K^+K^-)}{A_{fact}(B_d \to \pi^+\pi^-)} = \frac{f_K}{f_\pi}\frac{f^+_{B_sK}(m_K^2)}{f^+_{B\pi}(m_\pi^2)}\frac{m_{B_s}^2 - m_K^2}{m_B^2 - m_\pi^2} = 1.41^{+0.20}_{-0.11} \; !$$

[Gronau (2008)]

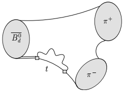
Charmless B-decays: $B \to \pi\pi$, $B_{(s)} \to \pi K, KK$

- there are very accurate measurements for such decays
- these decays are very important for determination of the direct CP violation
- factorization does not agree with the experiment

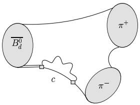
- contribution from different TOPOLOGIES is important:



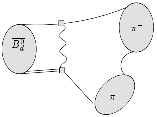
(a) emission



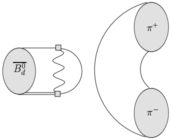
(b) penguin



(c) charming penguin

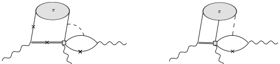


(d) annihilation



(e) penguin annihilation

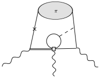
▷ EMISSION TOPOLOGY - nonfactorizable $O(\Lambda/m_b)$ corrections from $\tilde{\mathcal{O}}_1 = (\bar{d}\Gamma_\mu \frac{\lambda^a}{2} u)(\bar{u}\Gamma^\mu \frac{\lambda^a}{2} b)$ [Khodjamirian (2001)]



$$r_E^{(\pi\pi)} = \left[\left(1.8^{+0.5}_{-0.7}\right) \times 10^{-2} \right]_{\mathrm{soft}} + \left[\left(1.3^{+5.6}_{-5.2}\right) + i \left(-4.7^{+1.1}_{-0.3}\right) \right]_{\mathrm{hard}\,QCDF} \times 10^{-2}$$

$$r_E^{(\pi\pi,6)} = [(-2.7 \pm 0.4) \times 10^{-2}]_{\mathrm{hard}\,QCDF}$$

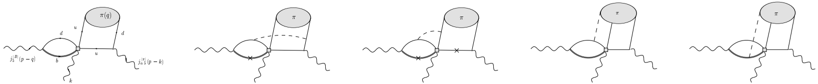
▷ PENGUIN CONTRIBUTIONS: [Khodjamirian, Mannel, BM (2003), Khodjamirian, Mannel, Urban (2002)]



$$r_{P_q}^{(\pi\pi)} = \left[0.11^{+0.02}_{-0.36} + i\left(1.1^{+0.2}_{-0.1}\right)\right] \times 10^{-2} \qquad r_{P_c}^{(\pi\pi)} = \left[-0.18^{+0.06}_{-0.68} + i\left(-0.80^{+0.17}_{-0.08}\right)\right] \times 10^{-2}$$

$$r_{P_b}^{(\pi\pi)} = \left(0.93^{+0.09}_{-0.65}\right) \times 10^{-2} \qquad r_{8g}^{(\pi\pi)} = -\left(3.8^{+1.3}_{-0.4}\right) \times 10^{-2}$$

▷ ANNIHILATION: [Khodjamirian, Mannel, Melcher, BM (2005)]



$$r_A^{(\pi\pi)} = \left[-0.67^{+0.47}_{-0.87} + i\left(3.6^{+0.5}_{-1.1}\right)\right] \times 10^{-3} \qquad R_A^{(\pi\pi,6)} = -\frac{2 f_B F_\pi^S(m_B^2)}{m_b f_\pi f_{B\pi}^+(0)} = 0.23^{+0.05}_{-0.08} \qquad r_A^{(\pi\pi,(5,6))} \simeq 0$$

▷ CHARMED PENGUINS and ANNIHILATION effects in $B \to \pi\pi$ are found to be small

---

for $|V_{ub}| = (3.57 \pm 0.26) \cdot 10^{-3}$ and $\gamma = (67.6 \pm 10)^\circ$ we get:

$$BR(B^+ \to \pi^+\pi^0) = \left(4.8^{+1.8+0.9}_{-1.5-0.8}\right) \times 10^{-6} \qquad exp : (5.59 \pm 0.4) \times 10^{-6}$$

$$BR(B^0 \to \pi^+\pi^-) = \left(7.2^{+2.3+1.2}_{-1.9-1.2}\right) \times 10^{-6} \qquad exp : (5.16 \pm 0.22) \times 10^{-6}$$

$$BR(B^0 \to \pi^0\pi^0) = \left(0.36^{+0.24+0.07}_{-0.12-0.07}\right) \times 10^{-6} \qquad exp : (1.55 \pm 0.19) \times 10^{-6}$$

CP asymmetry:

	$a_{CP}^{dir}(B^+ \to \pi^+\pi^0)$	$a_{CP}^{dir}(B^0 \to \pi^+\pi^-)$	$a_{CP}^{dir}(B^0 \to \pi^0\pi^0)$
Average	0.06 ± 0.05	0.25 ± 0.10(BaBar) 0.55 ± 0.10(Belle)	0.43 ± 0.25
our work	0	$-0.07 \pm 0.01 \pm 0.01$	$0.84^{+0.29+0.08}_{-0.19-0.08}$

▷ general isospin decomposition of $B \to \pi\pi$ amplitude:

$$\begin{aligned} A(B^- \to \pi^-\pi^0) = & \quad \langle \pi^-\pi^0 | H_{\rm eff} | B^- \rangle & = \frac{3}{\sqrt{2}} A_2 \\ A(\bar{B}^0 \to \pi^+\pi^-) = & \quad \langle \pi^+\pi^- | H_{\rm eff} | \bar{B}^0 \rangle & = A_2 + A_0 \\ A(\bar{B}^0 \to \pi^0\pi^0) = & \quad \langle \pi^0\pi^0 | H_{\rm eff} | \bar{B}^0 \rangle & = 2A_2 - A_0 \end{aligned}$$

$$\frac{|A_0|}{|A_2|}_{exp} = 1.33 \pm 0.31$$

- 'naive' test: naive factorization (i.e. without 'penguins' and annihilation)

$$\frac{A_0}{A_2} = \frac{5}{4}\left(\frac{C_1(\mu) - C_2(\mu)/5}{C_1(\mu) + C_2(\mu)}\right) = \begin{cases} 1.92\,, \mu = m_b/2 \\ 1.68\,, \mu = m_b \\ 1.25\,, \mu = M_W \end{cases}$$

- $B^- \to \pi^-\pi^0$ prediction in agreement with the experiment
⇒ A_2 amplitude can be relatively well calculated in the naive factorization
- predictions for B^0 decays are in a drastical disagreement with the experiment
⇒ in A_0 amplitude we are missing proper treatment of nonemission topologies (penguin and/or annihilation diagrams) and final state effects

- models cannot reproduce some observed branching ratios and CP asymmetries for $B \to \pi\pi$ and $B_{(s)} \to K\pi$ decays
- $B \to \pi\pi$:
  - problem with $BR(\pi^0\pi^0)$ and with the negative sign of $a_{\rm CP}(\pi^+\pi^-)$
- "$B \to \pi K$" puzzle:

  th: $a_{CP}(\overline{B}^0 \to K^-\pi^+) \simeq a_{CP}(B^- \to K^-\pi^0)$
  exp: $a_{CP}(\overline{B}^0 \to K^-\pi^+) \simeq -2\, a_{CP}(B^- \to K^-\pi^0)$

  solution: large C/T with a large negative phase (i.e. large EW penguins; large long-distance FSI, like charmed penguins...)
  - not supported by any of the model
- $B \to KK$:
  - all BRs and almost all $a_{\rm CP}$ are measured; even the BR of the annihilation dominated $B \to K^-K^+$ decay
- $B_s \to PP$:
  - $BR(B_s \to KK))$ and $BR(B_s \to \pi^-K^+)$ are measured

$B_{(s)} \to PP(P = \pi, K)$ decays in LCSR

[M. Jung, A. Khodjamirian, BM, in preparation]

- we plan to use CKMfitter with the LCSR input (decay constants, form factors, different contributions and topologies) to perform the fit to $B_{(s)} \to PP(P = \pi, K)$ decays
- we use different scenarios, trying to minimize the input, and to obtain all BRs and CP asymmetries simultaneously
- penguin annihilation contribution - extracted from the measured annihilation dominated decays
- we want to give predictions for B_s decays
- we plan to also to test charmed two-body decay, $D \to \pi K, KK$ decays

VERY PRELIMINARY RESULTS (CONSIDERATIONS):

- just LCSR input:
  - $BR(\pi\pi)$ are reproduced within the ranges, even $BR(\pi^0\pi^0)$
  - $a_{\rm CP}(\pi^0\pi^0)$ is completely undetermined
  - $a_{\rm CP}(\pi^+\pi^-) = [-0.14, -0.01]2\sigma$ is still too small and negative
- one of the scenarios - extraction of the emisson topology contribution from the data:
  - there is a problem with the twist-3 part of the hard-spectator contribution there (in both, QCDF and LCSR)
  - however, the emission part r_E can be extracted from the data (the absolute value):

$$|1 + \frac{3}{2} r_E| = \frac{3}{2\pi^2} \frac{BR(B^- \to \pi^- \pi^0)}{BR(\overline{B}^0 \to \pi^+ l^- \nu_l)} \frac{\tau_{B^0}}{\tau_{B^\pm}} \frac{\int_0^{(m_B-m_\pi)^2} dq^2 \{(E_\pi^2 - m_\pi^2)^{3/2} (f_{B\pi}^+(0)/f_{B\pi}(0))^2\}}{|V_{ud}|^2 (C_1(\mu)+C_2(\mu))^2 f_\pi^2 m_B^3}$$
$$= 1.28 \pm 0.12_{\rm stat} \pm 0.10_{\rm syst}$$

  - a) just the extracted r_E
  - b) we allow for an additional strong phase $r_E e^{i\delta}$

  - no relevant improvements concerning $B \to \pi\pi$ decays

$BR(K\pi)$ - due to the uncertain normalization factor, the predicted ranges for BRs are large;

this can be fixed by fixing one of the BRs, $BR(B^- \to \pi^- \overline{K}^0)$; then BRs agree well with the experiment

- $a_{\rm CP}(\pi^0 K^-) = [-0.12, 0.41] 2\sigma$ and $a_{\rm CP}(\pi^+ K^-) = [0.00, 0.20] 2\sigma$ cannot accomodate the data

- in a scenario b), with an additional phase (large imag. part ≥ 0.2 is needed), one cures the sign-problem of $a_{\rm CP}(\pi^+ K^-) = [-0.22, 0.48] 2\sigma$, however we are left with the problem of the relatively large exp. value for $a_{\rm CP}(\pi^+ K^-)$ and large ranges of predicted CP-asymmetries

- it has to be examined in more constrained scenarios (with more exp. input)

- ▷ isospin decomposition of amplitudes with a phase
  - a relative phase is introduced which is varied in a full range
  - unfortunately, this does not solve the "$B \to \pi K$" puzzle, since asymmetries flip the sign simultaneously

CONCLUSION:

- ▷ we still have unsatisfactory theoretical understanding of nonfactorizable effects in nonleptonic B-meson decays, which prevents us from identifying 'new physics' effects in these decays (yet)