Light-Cone Sum Rules: from semileptonic to nonleptonic *B* decays

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□ QCD Light-Cone Sum Rules

- the general outline of the method:

vacuum-to-hadron correlator of currents in the spacelike region

$\swarrow$ $\searrow$

light-cone OPE = hadronic dispersion relation

quark-hadron duality

$\swarrow$

sum rule for hadronic transition amplitude

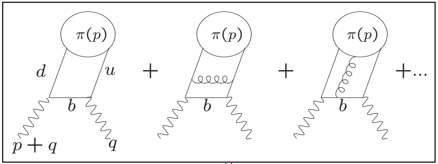
- applications to $B \to h$ semileptonic form factors

$$F_a^{B\to h}(q^2) = \langle h(p)|\bar{q}\,\Gamma_a b|B(p+q)\rangle \qquad q = u, d, s, c,$$

- valid at $q^2 \ll (m_B - m_h)^2$ (large recoil of h)

□ LCSR for $B \to \pi$ form factor

Method 1: with pion distribution amplitudes (DAs)



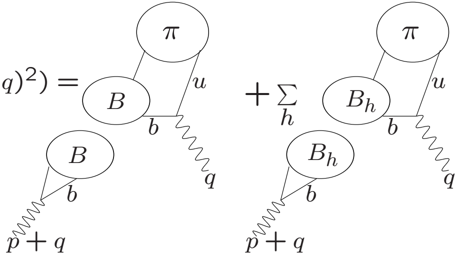
$\Leftarrow$ vacuum-to-pion correlator

at $(p+q)^2, q^2 \ll m_b^2$

OPE in terms of pion DAs

$\Downarrow$

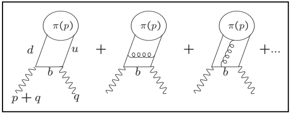
hadronic dispersion relation } $F(q^2,(p+q)^2) =$



$f_B f^+_{B\pi}(q^2)$ $\qquad$ $\sum_{B_h} \to duality\ (s_0^B)$

□ OPE calculation

- the correlation function $q^2 \ll m_b^2$



$$[F(q^2,(p+q)^2)]_{OPE} =$$

$$= \sum_{t=2,3,4,..} \int_0^1 \mathcal{D}u \; T^{(t)}(\alpha_s, m_b, m_q; q^2, (p+q)^2, u, \mu)\, \varphi_\pi^{(t)}(u,\mu)$$

$$\Uparrow \qquad\qquad\qquad \Uparrow$$

{diagrams with b-propagator} $\otimes$ {pion Distribution Amplitudes}

- pion DA's, polynomial expansion:

$$\varphi_\pi^{(t)}(u,\mu) = f_\pi^{(t)}(\mu)\{C_0(u) + \sum_{n=1} a_n^{(t)}(\mu) C_n(u)\}$$

- accuracy of OPE
  - precision of the input: m_b, m_q, α_s, $f_\pi^{(t)}(\mu_0)$, $a_n^{(t)}(\mu_0)$
  - truncation level: $O(\alpha_s)$, $t \leq 6$, $n \leq 4$
  - variable scales: μ, $(p+q)^2 \to M^2 \sim m_b \chi$, $m_b \gg \chi \gg \Lambda_{QCD}$

□ Hadronic dispersion relation

$$[F(q^2,(p+q)^2)]_{OPE} = \frac{m_B^2 f_B f^+_{B\pi}(q^2)}{m_B^2-(p+q)^2} + \int\limits_{(m_{B^*}+m_\pi)^2}^{\infty} ds\, \frac{\rho_h(s)}{s-(p+q)^2}$$

$\Uparrow$

- quark-hadron "semilocal" duality

$$\int\limits_{(m_{B^*}+m_\pi)^2}^{\infty} ds\, \frac{\rho_h(s)}{s-(p+q)^2} = \int\limits_{s_0^B}^{\infty} ds\, \frac{[\text{Im} F(q^2,s)]_{OPE}}{s-(p+q)^2}$$

- accuracy:
    - f_B calculated from 2-point QCD SR
    - variable scale: $(p+q)^2 \to M^2 \sim m_b\chi \to$ optimal interval of M^2
    - duality approximation, s_0^B (determined by calculating m_B^2)

□ Form factors from LCSRs with light hadron DAs

- $B \to \pi$: gradual improvements of OPE

  [V.Belyaev, A.K., R.Rückl (1993)]; [V.Belyaev, V.M.Braun, A.K., R.Rückl (1995)]

  [A.K., R.Rückl, S.Weinzierl, O.I.Yakovlev (1997)]; [E.Bagan,P.Ball, V.M. Braun (1997)]

  [P.Ball, R.Zwicky (2004)]; [G.Duplancic, A.K., T.Mannel, B.Melic, N.Offen (2008)]

  [A.K., T.Mannel, N.Offen, Y.M. Wang (2011)]

  [A. Bharucha (2012)], [A.Rusov (2016)]

- $D \to \pi, K$: byproduct of $B \to \pi$ LCSR [A.K., C.Klein, T.Mannel, N.Offen, (2009)]

- $B \to K$, $B_s \to K$: $SU(3)$ breaking: $m_s \neq 0$, in kaon DAs, $f_{B_s} \neq f_B$

  the latest update in [A.K., A.Rusov (2017)]

- $B_{(s)} \to \rho, \omega, K^*, \phi$: with (zero-width) ρ, K^* DAs

  [P.Ball, R. Zwicky (2004)], [A.Bharucha, D.Straub, R.Zwicky (2015)]

- $\Lambda_b \to p$: with nucleon DAs, no NLO corrections yet

  [AK, Th.Mannel, Ch. Klein, Y.-M. Wang (2011)]

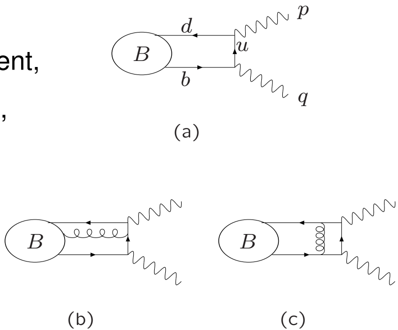
□ LCSR for $B \to \pi$ form factor

Method 2: with B-meson distribution amplitudes (DAs)

[A.K., N. Offen, Th. Mannel (2006)]

"SCET sum rules", [F. De Fazio, Th. Feldmann, T.Hurth (2006)]

- vacuum-to-B-correlator:
  the pion interpolated by a current,
- OPE in terms of B-meson DA's,
  defined in HQET,
- dispersion relation
  in the pion channel
- valid at small q^2
- easy to replace the pion
  by any other hadronic state



□ *B*-meson DAs

- definition of two-particle DA in HQET:

$$\langle 0|\bar{q}_{2\alpha}(x)[x,0]h_{v\beta}(0)|\bar{B}_v\rangle$$
$$= -\frac{if_B m_B}{4}\int_0^\infty d\omega e^{-i\omega v\cdot x}\left[(1+\not{v})\left\{\phi_+^B(\omega) - \frac{\phi_+^B(\omega)-\phi_-^B(\omega)}{2v\cdot x}\not{x}\right\}\gamma_5\right]_{\beta\alpha}$$

$\oplus$ higher twists

- key input parameter: the inverse moment

$$\frac{1}{\lambda_B(\mu)} = \int_0^\infty d\omega \frac{\phi_+^B(\omega,\mu)}{\omega}$$

- possible to extract λ_B from $B \to \gamma\ell\nu_\ell$ using QCDF$\oplus$LCSR

  [M.Beneke, V.M. Braun, Y.Ji, Y.B. Wei (2018)]

- current limit from Belle measurement (2018): $\lambda_B > 240$ MeV
- QCD sum rules in HQET: $\lambda_B(1\ \text{GeV}) = 460 \pm 110$ MeV

  [V.Braun, D.Ivanov, G.Korchemsky (2004)]

- higher twists DAs recently worked out [V. Braun, Y. Ji and A. Manashov (2017)]

□ Uses of LCSRs with HQET DA's

- $B \to h$ form factors:
  - $B \to \pi, K, K^*, \rho$ [A.K., T.Mannel, N.Offen (2007)]
  - $B \to D, D^*$ [S.Faller,A.K., C.Klein,T.Mannel (2009)]
  - NLO corrections to $B \to \pi$ FFs [Y-M. Wang, Y-L.Shen (2015)
  - higher twists in OPE, $B \to \pi, K$ [C-D.Lü,Y.L. Shen,Y-M. Wang,Y-B. Wei (2018)]
  - all $B \to \pi, K, D, \rho, K^*, D^*$ form factors [N.Gubernari, A.Kokulu, D. van Dyk, (2018)
- Heavy baryon form factors:
  - $\Lambda_b \to \Lambda$ [T.Feldmann, M. Yip (2012)]

□ Which LCSR method is better?

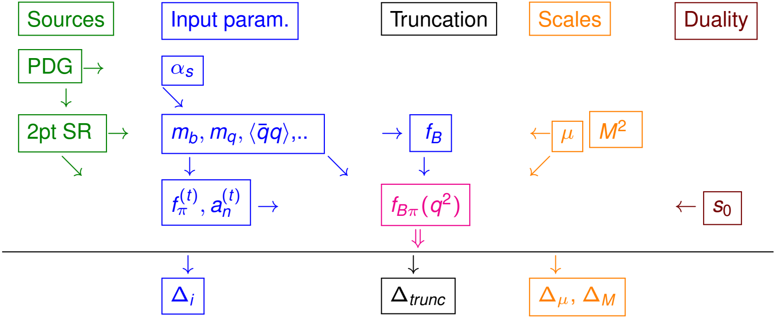
taking $B \to \pi$ form factor $f^+(q^2)$ as a sample

LCSR	method 1 (pion DAs)	method 2 (B DAs)
input for DAs exp. data	sufficient for π DAs pion FFs	λ_B,$\lambda_{H,E}$ uncertainty $B \to \ell \nu_\ell \gamma$
OPE twist expansion α_s expansion	$\leq$ tw 6 (N)NLO tw 2, NLO tw3	$\leq$ tw 6 NLO tw 2
disp.relation/duality	s_0^B	s_0^π

- the method 1 needs a set of DAs for every light hadron
the method 2 more flexible (changing the current),
- B_s form factors not available in method 2, need λ_{B_s}

☐ Counting the uncertainties in LCSR

- a “traditional” way



⇒ total uncertainty estimate: (conservative, correlations neglected)

$$\Delta f_{B\pi}(q^2) = \sqrt{\sum_i \Delta_i^2 + \Delta_{trunc}^2 + \Delta_\mu^2 + \Delta_M^2}$$

- more advanced: statistical (Bayesian) analysis,

[I.S.Imsong, A.K., T. Mannel and D. van Dyk, (2015)]

[N.Gubernari, A.Kokulu, D. van Dyk, (2018)]

Some results

- purely LCSR prediction (method 1)

$$\Delta\zeta_{B\pi}\,(0, 12\mathrm{GeV}^2) = \frac{1}{|V_{ub}|^2}\int\limits_0^{12\,\mathrm{GeV}^2} dq^2 \frac{d\Gamma}{dq^2}(B\to\pi\ell\nu_\ell)$$

$$\equiv \frac{G_F^2}{24\pi^3}\int\limits_0^{12\,\mathrm{GeV}^2} dq^2 p_\pi^3 |f_{B\pi}^+(q^2)|^2 = (5.25^{+0.68}_{-0.54})\,\mathrm{ps}^{-1}\,,$$

[I. S.Imsong, A.K., T. Mannel and D. van Dyk, (2015)]

$$\Delta\zeta_{B_sK}\,(0, 12\,\mathrm{GeV}^2) = 6.92^{+1.09}_{-0.90}\ \mathrm{ps}^{-1}$$

[A.K., A.Rusov, (2015)]

- no parametrization/extrapolation involved

Comparison

- comparing with the results of LCSRs:

form factor	Method 1 [Ref]	Method 2 [Ref]
$f_+^{B\pi}(0)$	0.258 ± 0.031 [BZ05]	0.25 ± 0.05 [KMO07]
	0.31 ± 0.02 [IKMvD14]	0.281 ± 0.038 [WS15]
	0.301 ± 0.023 [KR18]	0.21 ± 0.07 [GKvD18]
$f_+^{BK}(0)$	0.331 ± 0.041 [BZ05]	0.31 ± 0.04 [KMO07]
	0.395 ± 0.033 [KR18]	0.27 ± 0.08 [GKvD18]

- comparison with lattice QCD - the issue of z-expansion
  e.g., the Fermilab-MILC (2018) $B_s \to K$ form factor extrapolated to $q^2 = 0$ deviates from both LCSR and HPQCD

- comparing the slope of the calculated form factor with experiment provides a nontrivial check of a QCD method

□ Semileptonic transitions to unstable mesons

- practical problem: to assess "nonresonant" background in $B \to \pi\pi\ell\nu_\ell$ or $B \to K\pi\ell\ell$
- in the theory language:
  - define $B \to \pi\pi$ form factors, e.g.,:

$$\langle\pi^+(k_1)\pi^0(k_2)|\bar{u}\gamma^\mu(1-\gamma_5)b|\bar{B}^0(p)\rangle = -F_\perp(q^2,k^2,\zeta)\,\frac{4}{\sqrt{k^2\lambda_B}}\,i\epsilon^{\mu\alpha\beta\gamma}\,q_\alpha\,k_{1\beta}\,k_{2\gamma} + ...$$

$$(2\zeta-1) = (1-4m_\pi^2/k^2)^{1/2}cos\theta_\pi\,,\ \text{in dipion c.m.}$$

  - expand in partial waves, isolate dipion P-wave $F_\perp(q^2,k^2,\zeta) \Rightarrow F_\perp^{(\ell=1)}(q^2,k^2)$
  - hadronic dispersion relation in dipion invariant mass

□ Dispersion relation for the $B \to \pi\pi$ vector FF

- three-resonance ansatz:

$$\frac{\sqrt{3}F_\perp^{(\ell=1)}(q^2,k^2)}{\sqrt{k^2}\sqrt{\lambda_B}} = \frac{g_{\rho\pi\pi}}{m_\rho^2 - k^2 - im_\rho\Gamma_\rho(k^2)}\,\frac{V^{B\to\rho}(q^2)}{m_B+m_\rho}$$
$$+\frac{g_{\rho'\pi\pi}}{m_{\rho'}^2 - k^2 - im_{\rho'}\Gamma_{\rho'}(k^2)}\,\frac{V^{B\to\rho'}(q^2)}{m_B+m_{\rho'}}+$$
$$+\frac{g_{\rho''\pi\pi}}{m_{\rho''}^2 - k^2 - im_{\rho''}\Gamma_{\rho''}(k^2)}\,\frac{V^{B\to\rho''}(q^2)}{m_B+m_{\rho''}}+\ldots$$

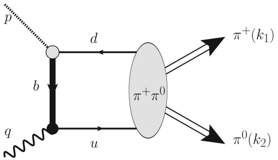
- inspired by the timelike pion e.m. form factor in $e^+e^- \to \pi^+\pi^-$ or in $\tau \to \pi^-\pi^0\nu_\tau$: modelled at $\sqrt{k^2} \lesssim 1.5$ GeV to a sum of ρ,$\rho'(1450)$, $\rho''(1750)$
- calculate $B \to \pi\pi$ or $B \to K\pi$ form factors with QCD methods $\rho, \rho', \ldots$ or K^*,... have to be "embedded" in this calculation
- model-dependence of the input is unavoidable

□ LCSRs for $B \to \pi\pi$ form factors: Method 1

[Ch. Hambrock, AK, Nucl. Phys. B (2016); 1511.02509 [hep-ph]]

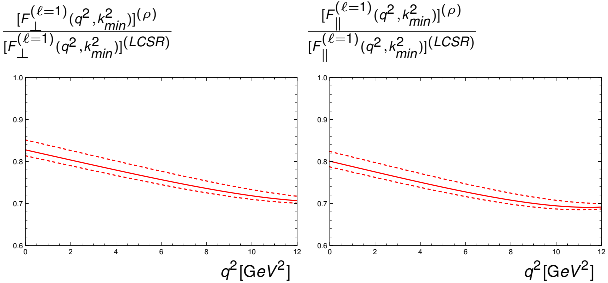
- applicable for dipion with a small invariant mass and large recoil:
  $k^2 \lesssim 1$ GeV^2, $0 \leq q^2 \leq$ 12-14 GeV^2.
- nonperturbative input: dipion distribution amplitudes (DAs)
- vacuum $\to$ on-shell dipion hadronic matrix elements of nonlocal $\bar{u}(x)d(0)$ operators

  FSI including the ρ-meson "embedded" in DAs



- considered only $\bar{B}^0 \to \pi^+\pi^0\ell^-\nu_\ell$,
  isospin 1, $L = 1, 3, , ..$
- only LO, twist-2 approximation for dipion DAs available
- quark-hadron duality in the B-channel, $\Rightarrow$ effective threshold s_0^B,

□ Numerical estimates



Relative contribution of ρ-meson to the $B \to \pi^+\pi^0$ P-wave form factors

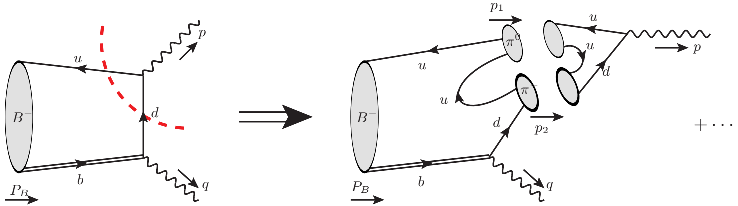
$F_\perp^{(\ell=1)}(q^2, k^2_{min})$ (left panel) and $F_\parallel^{(\ell=1)}(q^2, k^2_{min})$ (right panel) from LCSRs.

Dashed lines - the uncertainty due to the variation of the Borel parameter.

□ LCSRs for $B \to \pi\pi$ FFs: Method 2

[S.Cheng, AK, J.Virto (2017)]

- LCSRs with B-meson DA and $\bar{u}\gamma_\mu d$ interpolating current

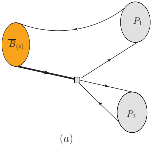


- insert a dispersion.relation for $B \to 2\pi$ form factors and a (dispersion rel. $\oplus$ experiment) parametrization for F_π
- not a direct calculation, given the ansatz of the $B \to 2\pi$ form factors, these sum rules provide normalization parameters

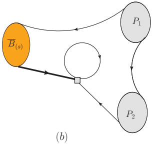
□ Charmless $B \to P_1 P_2$ decays

see also the talks by M.Jung and by M. Beneke at this workshop

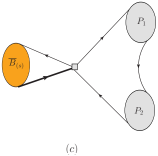
- anatomy of $B \to P_1 P_2$ decays: distinguishing hadronic matrix elements with four topologies



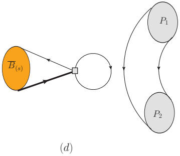
Emission



Penguin



Annihilation



Penguin Annihilation

$B = B_{u,d,s}$, $P = \pi, K$, no isosinglets $\Rightarrow$ no disconnected topolgies

□ Structure of decay amplitudes

$$\mathcal{A}(\bar{B} \to P_1 P_2) = \langle P_1 P_2 | \mathcal{H}_{eff} | \bar{B} \rangle \,,$$

- each hadronic matrix element of a given O_i in $\mathcal{H}_{eff}$ expanded in contributions with different topologies (quark flow diagrams)

$$\begin{aligned} \mathcal{A}(\bar{B} \to P_1 P_2) &= \frac{G_F}{\sqrt{2}} \sum_{p=u,c} \lambda_p^{(D)} \Bigg\{ \sum_T \Bigg[\sum_{i=1,2} c_i \langle P_1 P_2 | O_i^{p(D)} | \bar{B} \rangle_T \\ &+ \sum_{i=3,4,..,10,7\gamma,8g} c_i \langle P_1 P_2 | O_i^{(D)} | \bar{B} \rangle_T \Bigg] \Bigg\} \,, \end{aligned}$$

$\lambda_p^{(D)} = V_{pb} V_{pD}^*$, $D = s, d$, T=E, P, A, PA

- this decomposition is meaningful for all approaches where the valence quark structure of mesons is essential (such as QCDF)

Structure of nonleptonic decay amplitudes

- factorizable approximation d

$$\langle P_1 P_2|O_1^{u(D)}|\bar{B}\rangle_E \simeq \langle P_1 P_2|O_1^{u(D)}|\bar{B}\rangle_{E,fact}$$
$$= i(m^2_{B_{(s)}} - m^2_{P_1}) f^0_{BP_1}(m^2_{P_2}) f_{P_2} \equiv \mathcal{A}_{BP_1P_2}/(G_F/\sqrt{2}),$$

- introducing ratios of topological matrix elements to the factorizable piece

$$r_{E(\bar{B}P1P2)} \equiv \frac{\langle P_1 P_2|\widetilde{O}_1^{u,(D)}|\bar{B}\rangle_E}{\langle P_1 P_2|O_1^{u,(D)}|\bar{B}\rangle_{E,fact}}.$$

$$r_{Pp(\bar{B}P_1P_2)} \equiv \frac{\langle P_1 P_2|\widetilde{O}_2^{p,(D)}|\bar{B}\rangle_P}{\langle P_1 P_2|O_1^{u,(D)}|\bar{B}\rangle_{E,fact}} \quad (p = u, c).$$

- analogously r_A and r_{PA}, the PA not calculable
  $\oplus$ special operator-specific ratios, such as

$$R^{(6)}_{A(\bar{B}P_1P_2)} \equiv \frac{\langle P_1 P_2|O_6^{(D)}|\bar{B}\rangle_A}{\langle P_1 P_2|O_1^{u,(D)}|\bar{B}\rangle_{E,fact}},$$

- decomposition in terms of c_i and r_T and $\mathcal{A}_{BP_1P_2}$

Sample of a new decomposition

[M.Jung, AK,B.Melic, work in progress]

$$
\begin{aligned}
&\mathcal{A}(B^- \to \pi^- \bar{K}^0)/A_{\pi K} = \\
&\lambda_u^{(s)} \left\{ \left[2c_1 - \frac{1}{3}\frac{\alpha_{em}}{\alpha_s}(c_1 + 3c_2) \right] r_{Pu} + 2c_2 r_A \right\} + \lambda_c^{(s)} \left\{ \left[2c_1 - \frac{1}{3}\frac{\alpha_{em}}{\alpha_s}(c_1 + 3c_2) \right] r_{Pc} \right\} \\
&+ \left(\lambda_u^{(s)} + \lambda_c^{(s)} \right) \left\{ \frac{c_3}{3} + c_4 - \frac{5}{9}\frac{\alpha_s C_F}{2\pi}(c_4 + c_6) + r_\chi^{(\pi\pi)} \left[\frac{c_5}{3} + c_6 - \frac{1}{2}\left(\frac{c_7}{3} + c_8 \right) \right] - \frac{c_9}{6} - \frac{c_{10}}{2} \right. \\
&\qquad + (2c_3 - c_9) r_E + (2c_5 - c_7) r_{E6} + 2\left[c_3 + 3(c_4 + c_6) \right] r_{Pu} + 2(c_4 + c_6) r_{Pc} \\
&\qquad + 2(c_3 + c_4 + c_6) r_{Pb} + \left(-\frac{3}{4}\frac{\alpha_{em}}{\alpha_s} c_{7\gamma} + c_{8g}^{eff} \right) r_{P8g} + 2(c_3 + c_9) r_A \\
&\qquad \left. + \left(\frac{c_5}{3} + c_6 + \frac{c_7}{3} + c_8 \right) R_A^{(6)} + 2(c_5 + c_7) r_A^{(6)} \right\}, \qquad \text{(C1)}
\end{aligned}
$$

- effectively, a splitting of α_i and β_i parameters from [M. Beneke, M. Neubert (2003)]
- certain advantages: can vary c_i independently of r_T, apply different versions of $SU(3)_{fl}$ for r_T etc.

□ Light-cone sum rule for $B \to PP$ amplitudes

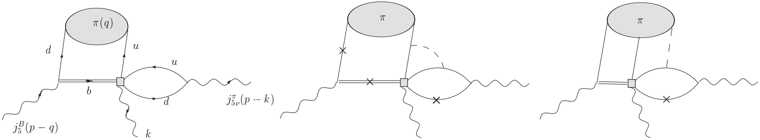
- Can we generalize the LCSR approach to obtain $\langle P_1 P_2 | O_i | B \rangle_T$?
  two hadrons in the final state, strong FSI - a challenge
- the method suggested for $B \to \pi\pi$: [A. K., Nucl. Phys. B **605** (2001) 558]
- advantage of $B \to \pi\pi$ channel:
  the invariant mass of the 2π final state: $(p_\pi^1 + p_\pi^2)^2 = m_B^2$
  timelike, but asymptotically large:
  $m_B, m_b \gg \Lambda_{QCD}, m_\pi$
- Choice of the correlation function:

$$F_\alpha^{(O_i)}(p,q,k) = -\int d^4x\, e^{-i(p-q)x} \int d^4y\, e^{i(p-k)y} \langle 0| T\left\{ j^\pi_{\alpha 5}(y) O_i(0) j_5^{(B)}(x) \right\} |\pi^-(q)\rangle,$$

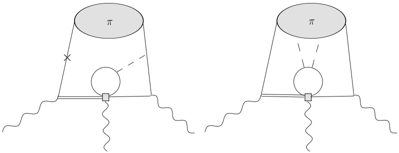
O_i-effective operator, $j_{\alpha 5}^{(\pi)} = \bar{u}\gamma_\alpha\gamma_5 d$ and $j_5^{(B)} = im_b \bar{b}\gamma_5 d$
interpolate π and B

k - auxiliary (unphysical) 4-momentum,
$P^2 = (p-q-k)^2 < 0$, $|(p-k)^2|, |(p-q)^2|, |P^2| \gg \Lambda_{QCD}^2$

□ OPE diagrams



Emission topology [A. K., Nucl. Phys. B **605** (2001) 558]

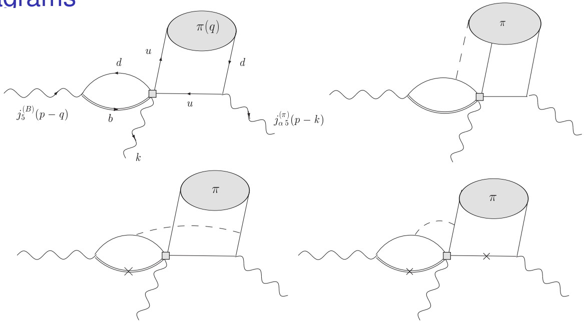


Penguin topology [AK,B.Melic, T. Mannel (2005)]

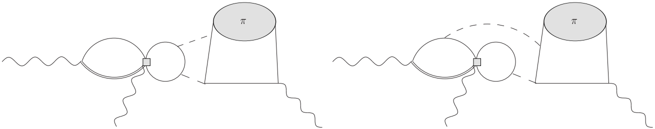
- - - - gluon lines;

gluonic penguin diags not shown explicitly

□ OPE diagrams

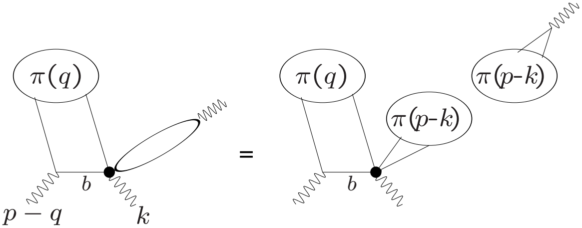


Annihilaton topology [AK,B.Melic, M.Melcher, T. Mannel (2005)]



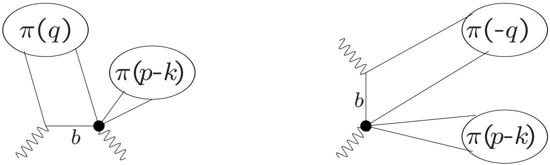
Penguin Annihilaton topology

□ Derivation of LCSR: step 1



- Dispersion relation $\oplus$ duality in the pion channel

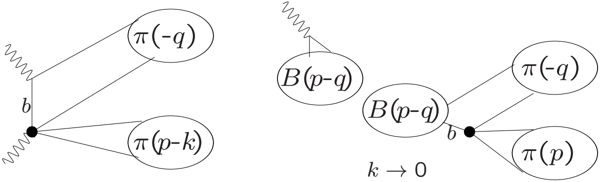
□ Derivation of LCSR: step 2



$P^2 = (p-q-k)^2 < 0 \qquad \Rightarrow \qquad P^2 = m_B^2$

- Analytic continuation;
  (e.g., spacelike $\to$ timelike transition in the π form factor)
- Im-part $\simeq$ FSI phase!

□ Derivation of LCSR: step 3



- Dispersion relation in the B channel $\oplus$ duality
- Calculation done at finite m_b:
  - r_E- only the $\sim 1/m_b$ soft gluon part accessible in LCSR ;

    (hard part demands quasi-three-loop diagrams)
  - r_P, r_A finite, develop a phase
  - $m_b \to \infty$ reproduces QCDF results;

    annihilation contribution$\sim 1/m_b$ suppressed and diverges

Numerical estimates for the ratios r_T

- inputs for the factorizable parts

f_B	207^{+17}_{-9} MeV [10]	f_{B_s}	242^{+17}_{-12} MeV [10]
Form factors [11, 12]			
$f^+_{B\pi}(0)$	0.301 ± 0.023	$f^+_{BK}(0)$ $f^+_{B_sK}(0)$	0.395 ± 0.033 0.336 ± 0.023

- Penguin topology contributions (partially extended to $B \to PP$)

	$(\bar{B}\pi K)$	$(\bar{B}_{(s)}KK)$	$(\bar{B}\pi\pi)$	$(\bar{B}K\bar{K})$	$(\bar{B}_{(s)}\pi K)$
r_{Pu}			$[0.11^{+0.02}_{-0.36} + i(1.1^{+0.2}_{-0.1})](*)$		
r_{Pc}	$-0.16 - i0.79$	$-0.18 - i0.68$	$-0.18 - i0.90$ $[-(0.18^{+0.68}_{-0.06}) - i(0.80^{+0.08}_{-0.17})](*)$	$-0.16 - i0.67$	$-0.20 - i0.$
r_{P8g}	-2.9	-2.8	-3.5± $-(3.8^{+1.3}_{-0.4})(*)$	-2.8	-3.5
r_{Pb}			$(0.93^{+0.09}_{-0.65})(*)$		

- Annihilation contributions

$$r_{A(\bar{B}\pi\pi)} = [-(0.67^{+0.87}_{-0.47} + i(3.6^{+0.5}_{-1.1})] \times 10^{-3}\,, \quad R^6_{A(\bar{B}\pi\pi)} = 0.23^{+0.05}_{-0.08}\,,$$

extending LCSR results to all $B \to P_1 P_2$

very preliminary!

[M.Jung, AK,B.Melic, work in progress]

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Decay mode	BR-exp (in 10^{-6})	$A_{CP} = -C_{CP}$	BR-th	A_{CP}-th
$\Delta S = -1$				
$B^- \to \pi^0 K^-$	12.7 ± 0.6	0.040 ± 0.021	13.74	0.050
$B^- \to \pi^- \bar{K}^0$	23.3 ± 0.8	-0.017 ± 0.016	24.56	-0.012
$\bar{B}^0 \to \pi^+ K^-$	20.0 ± 0.6	-0.082 ± 0.006	20.10	0.057
$\bar{B}^0 \to \pi^0 \bar{K}^0$	10.1 ± 0.5	-0.01 ± 0.10	8.87	-0.021
$\bar{B}_s \to K^+ K^-$	24.4 ± 2.0	-0.24 ± 0.06	23.38	-0.015
$\bar{B}_s \to K^0 \bar{K}^0$	20 ± 6	n.a.	26.82	-0.014
$\bar{B}_s \to \pi^+ \pi^-$	0.67 ± 0.08	n.a.	0.60	0.004
$\bar{B}_s \to \pi^0 \pi^0$	n.a.	n.a.	0.30	0.004
$\Delta S = 0$				
$B^- \to \pi^0 \pi^-$	5.41 ± 0.36	0.026 ± 0.039	6.3	-0.0003
$\bar{B}^0 \to \pi^+ \pi^-$	5.23 ± 0.22	0.275 ± 0.041	10.86	0.02
$\bar{B}^0 \to \pi^0 \pi^0$	1.62 ± 0.19	0.34 ± 0.22	0.57	0.385
$B^- \to K^0 K^-$	1.29 ± 0.14	-0.09 ± 0.10	1.85	0.27
$\bar{B}^0 \to K^+ K^-$	0.082 ± 0.016	n.a.	0.061	-0.089
$\bar{B}^0 \to K^0 \bar{K}^0$	1.23 ± 0.16	0.06 ± 0.26	1.59	0.31
$\bar{B}_s \to \pi^- K^+$	5.4 ± 0.6	0.26 ± 0.04	13.9	-0.076
$\bar{B}_s \to \pi^0 K^0$	n.a.	n.a.	0.39	0.43

Table 4: The $B_{(s)} \to P_1 P_2$ modes preliminary results vs experimental data. The measured $B^- \to \pi^0 \pi^-$ and $\bar{B}_s \to K^+ K^-$ are used to adjust r_E and r_{PA}, respectively.

Concluding remarks

- LCSRs: a set of QCD-based tools (methods 1,2) to calculate B form factors and estimate simplest nonleptonic amplitudes
- advantages: finite b-quark mass, access to soft-gluon effects and to power corrections
- wish list (experiment):
  - more accurate measuruments of pion and kaon form factors,
  - $B \to \gamma \ell \nu_\ell$
  - slope of $B \to \pi \ell \nu_\ell$, $B_s \to K \ell \nu_\ell$
  - to complete the observables in $B \to PP$
- wish list (theory):
  - B-meson DA, updated QCD SR estimates λ_B, $\lambda_{E,H}$, λ_{B_s} and other parameters
  - dipon and dikaon DAs
  - a method 2 for nonleptonic amplitudes?
  - B_c form factors

.... let us discuss now ...