Exclusive semileptonic B and Λ_b decays at large hadronic recoil

Alexander Khodjamirian

UNIVERSITÄT SIEGEN

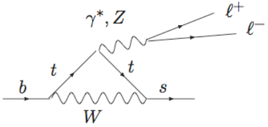
Workshop: Beautiful Mesons and Baryons on the Lattice,

ECT* Trento, 2-6 April 2012

Part 1: $B \to K\ell^+\ell^-$ at large hadronic recoil

$b \to s$ flavour-changing neutral currents (FCNC)

- $b \to s\ell^+\ell^-$, via virtual $t, Z, W \oplus$ New Physics?



$\Rightarrow$ effective local operators
$C(m_b) \otimes \{\bar{s}\, b\, \bar{\ell}\, \ell\}$

- experiment (LHCb) prefers exclusive channels,
  $B \to K\ell^+\ell^-$, $B \to K^*\ell^+\ell^-$, $B_s \to \phi\ell^+\ell^-$, ...
- the accuracy improving :
  recently, LHCb observed the zero in the FB asymmetry in $B \to K^*\ell^+\ell^-$
- can the theory provide a competetive accuracy?
  (in what follows: mainly $B \to K\ell^+\ell^-$ mode)

The anatomy of the effective Hamiltonian

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} C_i(\mu) O_i(\mu)\Big|_{\mu\sim m_b}$$

- local $b \to s\ell\ell$ operators:

  $O_{9(10)} = \frac{\alpha_{em}}{4\pi}[\bar{s}_L\gamma_\mu b_L]\ell\gamma^\mu(\gamma_5)\ell$, $C_9(m_b) \simeq 4.4$

  $C_{10}(m_b) \simeq= -4.7$,

- operators combined (nonlocally) with e.m. lepton-pair emission:

  $O_7 = -\frac{em_b}{8\pi^2}[\bar{s}\sigma_{\mu\nu}(1+\gamma_5)b]F^{\mu\nu}$, $C_7(m_b) \simeq -0.3$

  $O_1^{(c)} = [\bar{s}_L\gamma_\rho c_L][\bar{c}_L\gamma^\rho b_L]$, $C_1(m_b) \simeq 1.1$

  $O_2^{(c)} = [\bar{c}_L\gamma_\rho c_L][\bar{s}_L\gamma^\rho b_L]$, $C_2(m_b) \simeq -0.25$

  $O_{8g} = -\frac{m_b}{8\pi^2}\bar{s}\sigma_{\mu\nu}(1+\gamma_5)bG^{\mu\nu}$, $C_8(m_b) \simeq 0.2$

  O_{3-6} - quark-penguin operators , $C_{3,4,5,6} < 0.03$

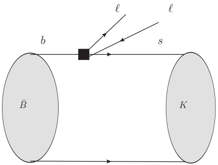
- neglected the $\sim V_{ub}V_{us}^*$ part

$B \to K\ell^+\ell^-$ decay in Standard Model

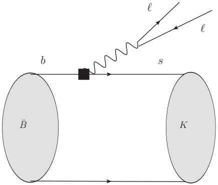
- the decay amplitude:

$$A(B \to K\ell^+\ell^-) = \langle K\ell^+\ell^- | H_{eff} \mid B\rangle$$
$$= -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_{i=1}^{10} C_i \langle K\ell^+\ell^-| \, O_i \, |B\rangle$$

- dominant contributions factorize: $\Rightarrow$ $B \to K$ form factors



$O_{9,10}$



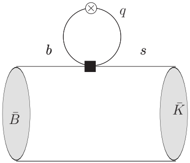
O_7

$$\langle K(p)|\bar{s}\gamma_\mu b|B(p+q)\rangle \Rightarrow f^+_{BK}(q^2), \;\; \langle K(p)|\bar{s}\sigma_{\mu\nu} b|B(p+q)\rangle \Rightarrow f^T_{BK}(q^2)$$

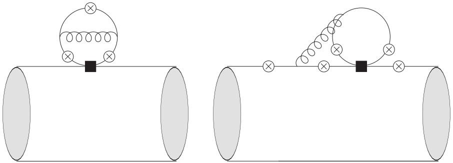
- additonal nonlocal contributions: combining O^c_{1-2}, O_{3-6}, O_{8g} with the emission of $\gamma^* \to \ell^+\ell^-$

The nonlocal effects in $B \to K\ell^+\ell^-$

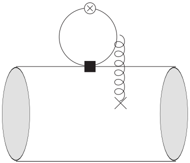
- 4-quark operators: $O^c_{1,2},\ O^q_{3-6}$ $(q = u, d, s, c, b)$



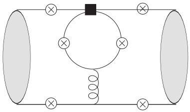
LO loop



NLO loops $\Rightarrow$ factorizable



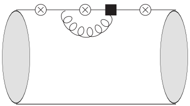
soft gluon emission



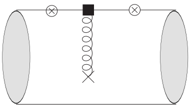
spectator scatt. $\Rightarrow$ nonfactoriz.

The nonlocal effects in $B \to K\ell^+\ell^-$

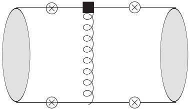
- gluon-penguin operator O_{8g}



factoriz. NLO

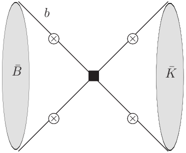


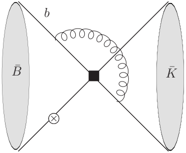
nonfact.: soft gluon



spectator scatt.

- weak annihilation: O^q_{3-6} $q = u, d$





Including nonlocal effects in the decay amplitude

- schematically:

$$A(B \to K\ell^+\ell^-) = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \Big[\sum_{i=7,9,10} C_i \otimes (\bar{\ell}\ell) \otimes f^i_{BK} + \sum_{i=1,2,3..6,8} C_i \otimes (\bar{\ell}\ell) \otimes \mathcal{H}^i_{BK} \Big]$$

- hadronic matrix elements of nonlocal contributions:

$$\mathcal{H}^i_{BK}(p,q) = \langle K(p)| \int d^4x\, e^{iq\cdot x} T\Big\{ j^{em}(x)\,, O^i(0) \Big\} |B(p+q)\rangle$$

- in LO reducible to form factors $\otimes$ loop factor (OPE)
- first estimates of NLO contributions to $B \to K^{(*)}\ell^+\ell^-$ in the QCD factorization scheme $(m_b \to \infty)$
  at small q^2 (large hadronic recoil)
  [Beneke, Feldmann, Seidel (2001)], ...

QCD calculation of $B \to K\ell^+\ell^-$

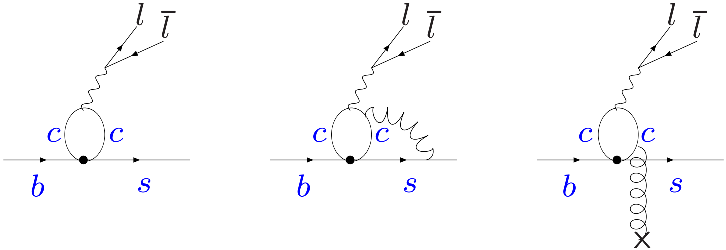
- $B \to K$ form factors:
  - lattice QCD,
  - light-cone QCD sum rules (LCSR)

  (the same accuracy as LCSR for $B \to \pi$ FF's including $m_s \neq 0$ effects)

- $\mathcal{H}^i_{BK}$, the size of nonfactorizable nonperturbative contributions? ("soft" gluons, vacuum quark-antiquark pairs)
- the dominant part : $\mathcal{H}^{1,2}_{BK}$ due to $O^c_{1,2}$ (charm loops)

Charm-loops in $B \to K\ell^+\ell^-$

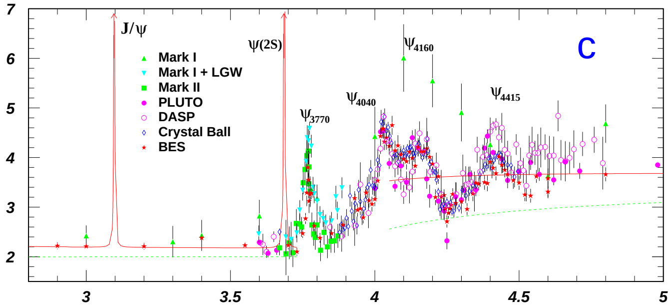
- Charm-loop effect: a combination of the $(\bar{s}c)(\bar{c}b)$ weak interaction ($O_{1,2}$) and e.m.interaction $(\bar{c}c)(\bar{\ell}\ell)$



- similar u, d, s, b-quark loops: suppressed by Wilson coeffs. (quark-penguin operators O_{3-6}) or by CKM (u-loops from $O^u_{1,2}$)

Charm loop turns charmonium

- at $q^2 \to m^2_{J/\psi}$, $\bar{c}c$ loop becomes a hadronic state:
  e.g., $B \to K\ell^+\ell^-$ = { $B \to J/\psi K \otimes J/\psi \to \ell^+\ell^-$}
- heavier ψ-levels (charmonia with $J^P = 1^-$) at $q^2 = m^2_\psi$,
  $\bar{c}c$ states with the masses up to $m_B - m_K^{(*)} \simeq 4.8\text{GeV}(\simeq 4.4\text{GeV})$
- spectrum of ψ states as seen in $e^+e^- \to$ *hadrons*



[PDG, V.V. Ezhela et al. hep-ph/0312114]

The $B \to \psi K^{(*)}$ amplitudes

- naive factorization fails in $B \to \psi K^{(*)}$, $(\psi = J/\psi, \psi(2S))$,

  $A(B \to \psi K) \sim \frac{G_F}{\sqrt{2}} V_{cb} V^*_{cs} (c_1(\mu) + c_2(\mu)/3) f_\psi f^+_{BK}(q^2 = m^2_\psi)$

  yields $\Gamma(B \to \psi K) \ll exp.$
- indicating large nonfactorizable contribuitons

  (which should effectively remove the μ-dependence)
- QCD factorization should not (and does not) work in these decays, due to heavy-mass final states

How to account for the charm-loop effect?

- $\bar{c}c$ loops $\oplus$ ψ resonances - a double counting !!
- the experimentalists (BABAR,Belle,CDF,LHCb):
  subtract the "bins" of J/ψ and $\psi(2S)$ from the
  q^2-distribution data in $B \to K^{(*)}\ell^+\ell^-$
- the effect of intermediate/virtual $\bar{c}c$ states remains at
  $q^2 \ll m^2_{J/\psi}$ (nonperturbative at $q^2 \sim 4m_c^2$)
- Can we use the { loop $\oplus$ corrections } ansatz in the small
  $q^2 \ll 4m_c^2$ region (large hadron recoil) ?
- soft-gluon emission from c-quark loop
  from OPE on the light-cone

  [A.K., Th. Mannel, A. Pivovarov and Yu-M. Wang, 1006.4945 [hep-ph]]

Charm-loop in $B \to K\ell^+\ell^-$ at $q^2 \ll 4m_c^2$

- the hadronic matrix element:

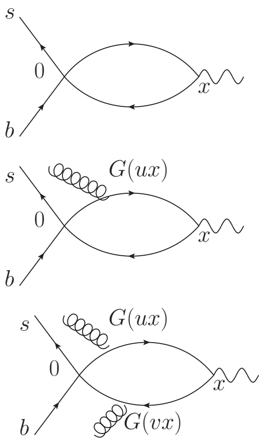
$$\mathcal{H}^{\mu}_{BK}(p,q) = i\langle K(p)| \int d^4x\, e^{iq\cdot x}\, T\Big\{\bar{c}(x)\gamma^{\mu}c(x)\,,$$

$$\Big[C_1[\bar{s}_L(0)\gamma_{\rho}c_L(0)\bar{c}_L(0)\gamma^{\rho}b_L(0)] + C_2 ...\Big]\Big\}|B(p+q)\rangle$$

- at $q^2 \ll 4m_c^2$, contracting c-quark fields in propagators: $\langle c(0)\bar{c}(x)\rangle$ and $\langle c(x)\bar{c}(x)\rangle$, including gluon emission:

Expansion near the light-cone

- at $q^2 \ll 4m_c^2$, the dominant region: $\langle x^2 \rangle \sim 1/(2m_c - \sqrt{q^2})^2$
- T- product of $\bar{c}c$-operators can be expanded near the light-cone $x^2 \sim 0$, diagrammatically:



the simple loop

(unit operator LO $\oplus$ NLO)

one-gluon emission

(non-local, $x \neq 0$)

$(\bar{s}(0)G(x)b(0))$

two-gluon emission

.....

The resulting effective operators

- LO reduced to simple $\bar{c}c$ -loop,
  no difference between local and LC,

$$\mathcal{O}_\mu(q) = (q_\mu q_\rho - q^2 g_{\mu\rho})\frac{9}{32\pi^2}\, g(m_c^2, q^2)\bar{s}_L\gamma^\rho b_L\,.$$

- gluon emission: use c-quark propagator near the light-cone in the external gluon field [I. Balitsky, V. Braun (1999)]
- define LC kinematics ($n_\pm$) in the rest-frame of B,
  $q \simeq (m_b/2)n_+$
- one-gluon emission yields a new nonlocal operator:

$$\widetilde{\mathcal{O}}_\mu(q) = \int d\omega\, I_{\mu\rho\alpha\beta}(q, m_c, \omega)\bar{s}_L\gamma^\rho\delta[\omega - \frac{(in_+\mathcal{D})}{2}]\widetilde{G}_{\alpha\beta}b_L\ ,$$

Hadronic matrix elements for the charm-loop effect

- the LO: factorized $\bar{c}c$ loop

$$\Big[\mathcal{H}^{\mu}_{BK}(p,q)\Big]_{fact} = \left(\frac{C_1}{3} + C_2\right)\langle K(p)|\mathcal{O}^{\mu}(q)|B(p+q)\rangle\,,$$

- reduced to $f^{+}_{BK}(q^2)$ form factors, ($\otimes$ loop function)
- The gluon emission yields:

$$\Big[\mathcal{H}^{\mu}_{BK}(p,q)\Big]_{nonfact} = 2C_1\langle K(p)|\widetilde{\mathcal{O}}^{\mu}(q)|B(p+q)\rangle\,.$$

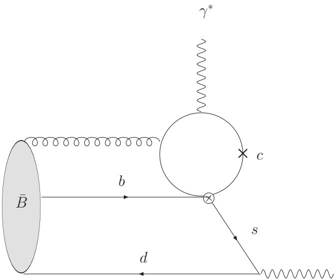
- new hadronic matrix element ($\otimes$ coeff.function)

$$\langle K(p)|\bar{s}_L\gamma^{\rho}\delta[\omega - \frac{(in_+\mathcal{D})}{2}]\widetilde{G}_{\alpha\beta}b_L|B(p+q)\rangle\,,$$

LCSR for the soft-gluon hadronic matrix element

- the correlation function:

$\mathcal{F}^{(B\to K)}_{\nu\mu}(p,q) = i\int d^4y e^{ip\cdot y}$
$\langle 0|T\{j^K_\nu(y)\widetilde{\mathcal{O}}_\mu(q)\}|B(p+q)\rangle\,,$



- hadronic dispersion relation in the kaon channel

$$\mathcal{F}^{(B\to K)}_{\nu\mu}(p,q) = \frac{if_K p_\nu}{m_K^2 - p^2}\langle K(p)|\widetilde{\mathcal{O}}^\mu(q)|B(p+q)\rangle + \int_{s_h}^\infty ds\,\frac{\tilde{\rho}_{\mu\nu}(s,q^2)}{s-p^2}$$

- B meson DA's used as nonperturbative input

Nonlocal effects in $B \to K\ell^+\ell^-$ in terms of ΔC_9

- the Wilson coefficient $C_9(\mu = m_b) \simeq 4.4$, a process-dependent correction to be added:

$$\Delta C_9^{BK}(q^2) \sim \frac{\sum_i \mathcal{H}^i_{BK}(q^2)}{f^+_{BK}(q^2)}$$

- previously we investigated only the role of c-loop soft nonfact. effect vs LO and found $\Delta C_9^{BK(\bar{c}c, LO\oplus nf)}(q^2 = 0) \sim 0.2$

Nonlocal effects in $B \to K\ell^+\ell^-$ in terms of ΔC_9

[A.K., Th.Mannel, Y.M. Wang, work in progress]

- preliminary results including nonlocal effects due to

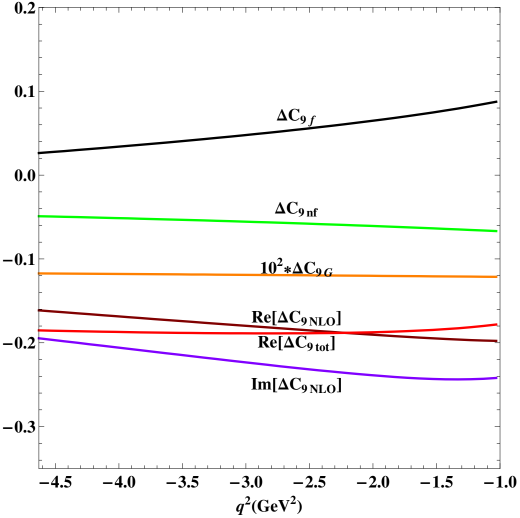
  - $O^c_{1,2}$ LO and soft nonfact.
  - O_{3-6} LO and soft nonfact.
  - O_8 soft nonfact. (new LCSR estimate)
  - $O^c_{1,2}$ NLO two-loop factorizable contributions

  using diagrams from *[Asatrian,Greub,Walker(2002)]* ,
  - $O^c_{1,2}$ NLO spectator contributions

  [Beneke, Feldmann, Seidel (2001)], ...

- we use OPE results at negative q^2 having in mind the presence of light-quark loops

Nonlocal effects for $B \to K\ell^+\ell^-$ in spacelike region



preliminary

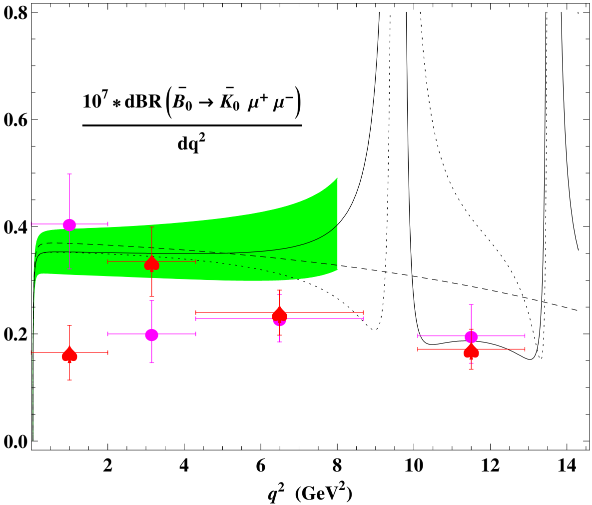
Accessing the timelike q^2 region ?

- analyticity of the hadronic matrix element in q^2,
  $\oplus$ unitarity $\Rightarrow$ hadronic dispersion relation:

$$\mathcal{H}^{(B\to K)}(q^2) = \mathcal{H}^{(B\to K)}(0) + q^2\Big[\sum_{\psi=J/\psi,\psi(2S),..} \frac{f_\psi A_{B\psi K}}{m_\psi^2(m_\psi^2 - q^2 - i m_\psi \Gamma_\psi^{tot})} + \int_{4m_D^2}^{\infty} ds \frac{\rho(s)}{s(s-q^2-i\epsilon)}\Big]$$

- the residues $|A_{B\psi K}|$ and $|f_\psi|$ determined by $BR(B\to\psi K)$, $BR(\psi\to\ell^+\ell^-)$
- FSI phase attributed to $A(B\to\psi K)$, (Im part in $(p+q)^2$)
- a certain ansatz (z-parameterization) used for the integral
- dispersion relation fitted to the calculated $\mathcal{H}^{(B\to K)}$ at $q^2<0$

The width of $B \to K\ell\ell$ *[preliminary]*

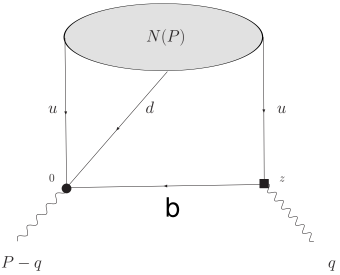


- exp. data on $B \to K\ell\ell$, [Belle '09 (violet), CDF'11(red)]
- solid (green shaded-theor. uncertainties) and dotted - two different ansaetze for dispersion relation; dashed - without nonlocal effects

Part 2: $\Lambda_b \to p$ form factors from LCSR

[A.K., Ch.Klein, Th.Mannel, Y.-M. Wang arXiV:1108.2971]

The LCSR method



- vacuum-to-nucleon correlation function:

$$\Pi_{\mu(5)}(P,q) = i\int d^4z\, e^{iq\cdot z}\langle 0|T\left\{\eta_{\Lambda_b}(0), \bar{b}(z)\gamma_\mu(\gamma_5)u(z)\right\}|N(P)\rangle\,.$$

- $q^2 \ll m_b^2$, $(P-q)^2 \ll m_b^2$, $P^2 = m_N^2$,
- Λ_b interpolating 3-quark current, we use

$$\eta_{\Lambda_b}^{(\mathcal{P})} = (u\,C\,\gamma_5\,d)\,b,\;\; \eta_{\Lambda_b}^{(\mathcal{A})} = (u\,C\,\gamma_5\gamma_\lambda\,d)\,\gamma^\lambda\,b\,.$$

Nucleon Distribution Amplitudes (DA's)

[V.Braun, A.Lenz et al (2000-2009)],

- definition, schematically ($z^2 \sim 0$):

$$\langle 0|\epsilon^{ijk} u^i_\alpha(0) u^j_\beta(z) d^k_\gamma(0)|N(P)\rangle = \sum_t \mathcal{S}^t_{\alpha\beta\gamma}$$

$$\times \int dx_1 dx_2 dx_3 \delta(1 - \sum_{i=1}^{3} x_i) e^{-ix_2 P\cdot z} F_t(x_i, \mu)\,,$$

- twist expansion: 27 DA's of twist 3,4,5,6
- coefficients and normalization parameters determined from 2-point sum rules
- proton e.m. form factors were calculated from LCSR

Accessing the $\Lambda_b \to p$ form factors

- hadronic dispersion relation, schematically

$$\Pi_{\mu(5)}(P,q) = \frac{\langle 0|\eta_{\Lambda_b}|\Lambda_b\rangle\langle\Lambda_b|\bar{b}\gamma_\mu(\gamma_5)u|N\rangle}{m_{\Lambda_b}^2-(P-q)^2}$$

$$+\frac{\langle 0|\eta_{\Lambda_b}|\Lambda_b^*\rangle\langle\Lambda_b^*|\bar{b}\gamma_\mu(\gamma_5)u|N\rangle}{m_{\Lambda_b^*}^2-(P-q)^2} + \int\limits_{s_0^h}^{\infty} ds\,\frac{\rho_{\mu(5)}(s,q^2)}{s-(P-q)^2}$$

- 6 form factors, standard definitions (cf nucleon β decay):

$$\langle\Lambda_b(P-q)|\bar{b}\,\gamma_\mu\,u|N(P)\rangle = \bar{u}_{\Lambda_b}(P-q)\left\{f_1(q^2)\,\gamma_\mu + i\,\frac{f_2(q^2)}{m_{\Lambda_b}}\,\sigma_{\mu\nu}q^\nu + \frac{f_3(q^2)}{m_{\Lambda_b}}\,q_\mu\right\}u_N(P)\,,$$

$$0\le q^2\le(m_{\Lambda_b}^2-m_N^2)\,,\quad \gamma_\mu\to\gamma_\mu\gamma_5\,,\ f_i(q^2)\to g_i(q^2)$$

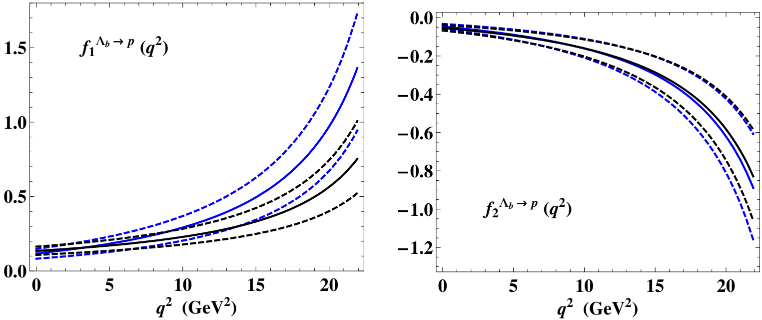
- decay constant of Λ_b from two-point sum rules

LCSR in detail

- specific problems for baryon QCD sum rules
  - the contributions of Λ_b^* , ($J^P = 1/2^-$ state,
  $m_{\Lambda_b^*} - m_{\Lambda_b} \sim 200 - 300$ MeV
  we used linear combinations of kinematical structures in the correlation function to eliminate Λ_b^*
  - baryon interpolating current: multiple choice
  we used pseudoscalar and axial currents
- replace b by c in LCSR $\Rightarrow \Lambda_c \to N$ form factors
  (used to calculate strong couplings)
- inputs:
  finite m_b , a few universal parameters of nucleon DA's ,
  two-point sum rules for η_{Λ_b} currents:

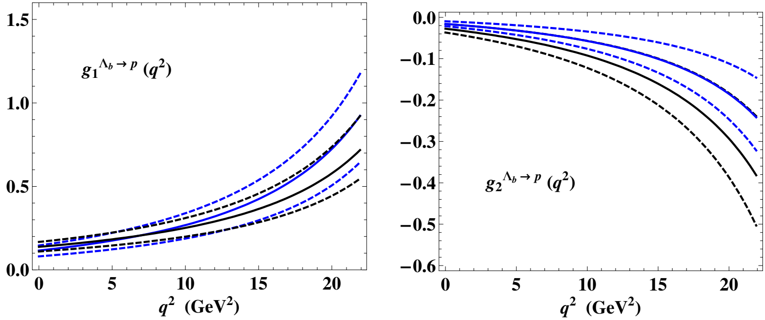
$$\lambda_{\Lambda_b}^{(\mathcal{A})} = 1.27^{+0.35}_{-0.34} \times 10^{-2} \text{ GeV}^2 , \quad \lambda_{\Lambda_b}^{(\mathcal{P})} = 1.09^{+0.31}_{-0.30} \times 10^{-2} \text{ GeV}^2 ,$$

Numerical results for the $\Lambda_b \to p$ vector form factors



- $q^2 \leq 11$ GeV^2 direct calculation from LCSR, at larger q^2 z-parameterization and extrapolation
- reasonable agreement between sum rules with different baryon currents

Numerical results for the axial-vector $\Lambda_b \to p$ form factors

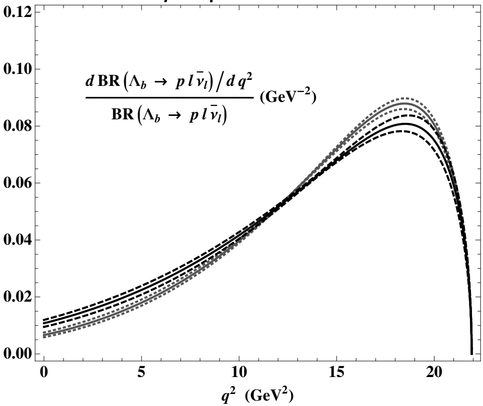


The width of $\Lambda_b \to p\ell\nu_\ell$ decay

- can be used to extract $|V_{ub}|$

$$\frac{d\Gamma}{dq^2}(\Lambda_b \to pl\nu_l) = \frac{G_F^2 m_{\Lambda_b}^3}{192\pi^3}|V_{ub}|^2\left\{k_1(q^2, m_{\Lambda_b}, m_N)|f_1(q^2)|^2 + ...\right\}$$

- normalized q^2-spectrum



The width of $\Lambda_b \to p\ell\nu_\ell$ decay

- partially integrated width: pure prediction of LCSR

$$\Delta\zeta(0, q^2_{max}) = \frac{1}{|V_{ub}|^2} \int_0^{q^2_{max}} dq^2 \, \frac{d\Gamma}{dq^2}(\Lambda_b \to p l \nu_l)$$
$$= 5.5^{+2.5}_{-2.0}\ \mathrm{ps}^{-1} \left(= 5.6^{+3.2}_{-2.9}\ \mathrm{ps}^{-1} \right)$$

  for axial-vector (pseudoscalar) interpolating current of Λ_b
- improvements in the future possible: nucleon DA parameters, α_s corrections

Conclusions

- with LC OPE and LCSR the effects of four-quark and penguin operators in $b \to s\ell^+\ell^-$ exclusive decays can be systematically accounted including soft-gluon effects in the region $q^2 <$few GeV^2,
- $B \to K\ell^+\ell^-$ allows for more accurate treatment than $B \to K^*\ell^+\ell^-, K^*\gamma$ both in FF's and nonlocal effects
- are (or will be) the $\mathcal{H}^i_{BK}$ amplitudes accessible on the lattice ?
- Λ_b form factors can be calculated from LCSR

both topics will be discussed further
in the talk by Thorsten Feldmann

BACKUP SLIDES

The hierarchy of contributions in LC OPE

after integrating over x and taking hadronic matrix element

- each extra gluon brings one power of $\sim \frac{\Lambda_{QCD}^2}{4m_c^2-q^2}$ suppression
- perturbative gluon corrections are α_s suppressed
- reexpanding the one-gluon nonlocal operator near $x = 0$ in derivatives of $G_{\mu\nu}(0)$:

$$\text{term with } k\text{-th derivative} \Rightarrow \sum_{k=0}^{\infty} \frac{(q\Lambda_{QCD})^k}{(4m_c^2 - q^2)^{k+1}}$$

$q \sim m_b/2$ and $m_b\Lambda_{QCD} \sim m_c^2$.

the OPE near the light-cone works, but not the local OPE

The local OPE limit

- $\omega \to 0$ in the nonlocal operator, no derivatives of $G_{\mu\nu}$

$$\widetilde{\mathcal{O}}_\mu^{(0)}(q) = I_{\mu\rho\alpha\beta}(q)\bar{s}_L\gamma^\rho \widetilde{G}_{\alpha\beta} b_L \ ,$$

$$I_{\mu\rho\alpha\beta}(q, m_c) = (q_\mu q_\alpha g_{\rho\beta} + q_\rho q_\alpha g_{\mu\beta} - q^2 g_{\mu\alpha} g_{\rho\beta}) \times \frac{1}{16\pi^2}\int_0^1 dt\ \frac{t(1-t)}{m_c^2 - q^2 t(1-t)}$$

At $q^2 = 0$, the quark-gluon operator obtained
in $B \to X_s\gamma$ in *[M.Voloshin (1997)]*
in $B \to K^*\gamma$ *[A.K.,G. Stoll,R. Rueckl,D. Wyler(1997)]*

- the neccesity of resummation was discussed before
[Z. Ligeti, L. Randall and M.B. Wise,(1997);
A.K. Grant, A.G. Morgan, S. Nussinov and R.D. Peccei (1997);
J. W. Chen, G. Rupak and M. J. Savage,(1997);
G. Buchalla, G. Isidori and S.J. Rey (1997)]

Charm-loop effect for $B \to K^* \ell^+ \ell^-$

- factorizable part determined by the three $B \to K^*$ form factors $V^{BK*}(q^2)$, $A_1^{BK^*}(q^2)$, $A_2^{BK^*}(q^2)$,
- three kinematical structures for the nonfactorizable part:

$$\Delta C_9^{(\bar{c}c, B\to K^*, V)}(q^2) = (C_1 + 3C_2)\, g(m_c^2, q^2) \\ -2C_1 \frac{32\pi^2}{3} \frac{(m_B + m_{K^*})\widetilde{A}_V(q^2)}{q^2 V^{BK^*}(q^2)} \, ,$$

- nonfactorizable part enhances the effect, $1/q^2$ factor

$\Delta C_9^{(\bar{c}c, B\to K^*, V)}(1.0\text{GeV}^2) = 0.7^{+0.6}_{-0.4}$
$\Delta C_9^{(\bar{c}c, B\to K^*, A_1)}(1.0\text{GeV}^2) = 0.8^{+0.6}_{-0.4}$
$\Delta C_9^{(\bar{c}c, B\to K^*, A_2)}(1.0\text{GeV}^2) = 1.1^{+1.1}_{-0.7}$