Semiinclusive hadronic B decays using SCET

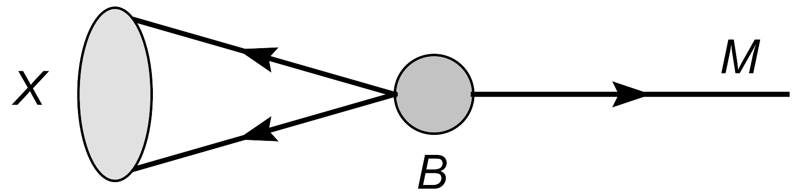
Jure Zupan

University of Ljubljana and Josef Stefan Institute

based on Chay, Leibovich, Kim, JZ, hep-ph/0607004 + unpubl.

Experimental info

- B decays to M and an inclusive jet X back-to-back



- endpoint region $p_X^2 \sim m_b \Lambda$
- for almost a decade only $Br(B \to \eta' X)$ BaBar 2004, CLEO 2003

$$Br(B \to \eta' X_s)|_{p_{\eta'} > 2.0\ \mathrm{GeV}} = (420 \pm 94) \cdot 10^{-6}$$

- summer 2006: BaBar first measurements of $B \to KX$ (using fully recon. B) BaBar 2006

$$Br(B^+/B^0 \to K^+ X)|_{p_K > 2.34\ \mathrm{GeV}} = (196^{+37+31}_{-34-30}) \cdot 10^{-6}$$

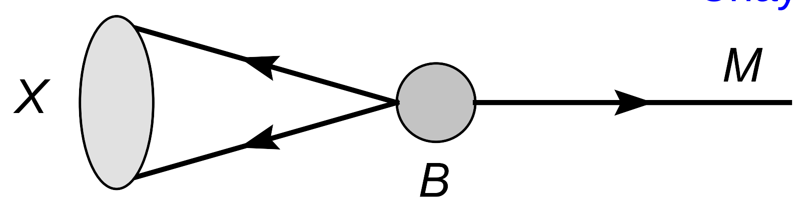
$$Br(B^+/B^0 \to K^0 X)|_{p_K > 2.34\ \mathrm{GeV}} = (154^{+55+55}_{-48-41}) \cdot 10^{-6}$$

Outline

- decays not involving isosinglets
  - factorization
  - charming penguins
- decays involving η, η'
- comparison with experiment

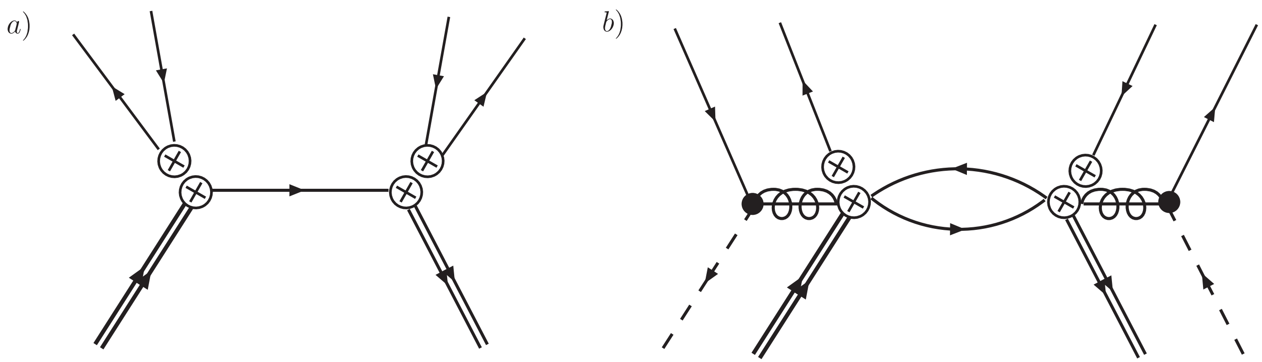
Motivation

Chay, Leibovich, Kim, JZ, 2006



- in the endpoint region factoriz. as in 2-body B decays
- these decays simpler than 2-body B decays
  - no dependence on ζ, ζ_J at LO in $1/m_b$
  - the same shape and jet function as in $B \to X_s \gamma$, even this cancels in A_{CP}
- can be used as probes of
  - factorization
  - $1/m_b$ expansion
  - nonpert. charming penguins

No dependence on ζ, ζ_J at LO in $1/m_b$



- topologies with spectator going in M are down $1/m_b^2$
- LO contribution (in SCET$_{\mathrm{I}}$, $\lambda = \Lambda/m_b$)

$$\int dx_i T\mathcal{O}_i(x_1)\mathcal{O}_j^\dagger(x_2) \sim \underbrace{(\lambda^3)^2}_{\mathcal{O}_{i,j}} \underbrace{\frac{1}{(\lambda)^2}}_{dx_{1,2}} = \lambda^4$$

- spectator interaction

$$\int dx_i T\mathcal{O}_{1i}(x_1)\mathcal{L}_{sc}(x_3)\mathcal{O}_{1j}^\dagger(x_2)\mathcal{L}_{sc}(x_4) \sim \underbrace{(\lambda^3\sqrt{\lambda})^2}_{\mathcal{O}_{1i,1j}} \underbrace{\frac{1}{(\lambda)^2}}_{dx_{1,2}} \underbrace{\frac{1}{(\lambda^2)^2}}_{dx_{3,4}} \underbrace{(\lambda^{5/2})^2}_{\mathcal{L}_{sc}} = \lambda^4\lambda^2$$

Factorization for nonisosinglets

Chay, Leibovich, Kim, JZ, 2006

- the weak operators have the form

$$\mathcal{O}_i = \left[\overline{q'}_n \bar{\not n} P_L Y_n^\dagger b_v\right] \left[\overline{q'}_{\bar n} \not n P_{L,R} q''_{\bar n}\right]_u \sim J_C \times J_H$$

- no soft gluon exchanges at LO

$$\langle MX|\mathcal{O}_i|B\rangle \to \langle M|J_C|0\rangle\langle X|J_H|M\rangle$$

- the decay width from

$$\begin{aligned}\mathcal{S}(E_M,\mu_0) &\propto \ \mathrm{Im}\ \ i\int d^4z\, e^{-ip_M\cdot z}\langle B|\mathrm{T}J_H^\dagger(z)J_H(0)|B\rangle \\ &\propto \int dl_+\ f(l_+)\mathrm{Im}J_P\Big(m_b - 2E_M + l_+ + i\epsilon\Big)\end{aligned}$$

- the same $\mathcal{S}(E_M,\mu_0)$ also in $B\to X_s\gamma$

The decay width

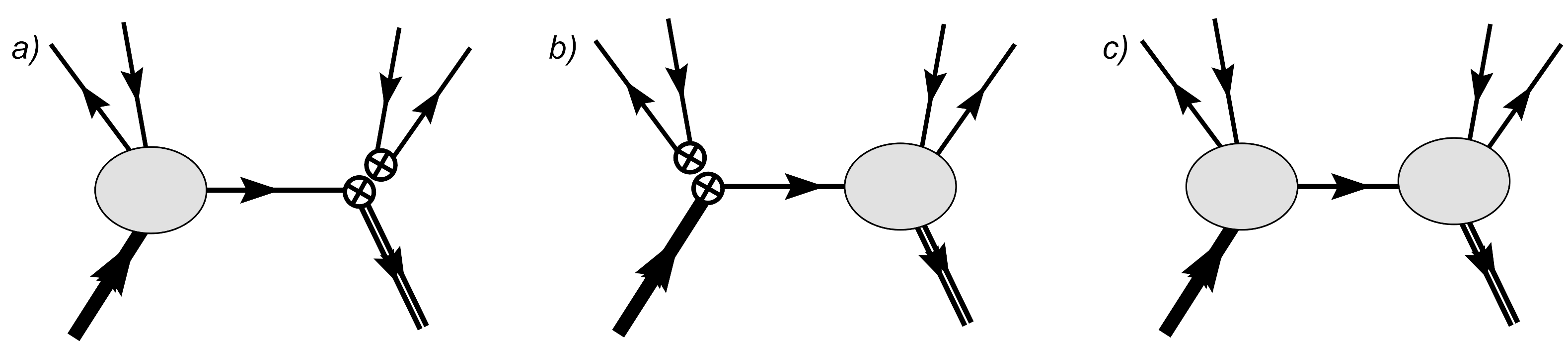
- normalizing to $B \to X_s \gamma$

$$\frac{d\Gamma(\bar{B} \to MX)/dE_M}{d\Gamma(\bar{B} \to X_s\gamma)/dE_\gamma}\bigg|_{E_M=E_\gamma} \propto \frac{\left|h_M^{(q)}\right|^2 + 2\mathcal{R}e\left[c_{cc}\lambda_c^{(q)} f_M p_{cc}^M \left(h_M^{(q)}\right)^*\right] + \left|c_{cc}\lambda_c^{(q)}\right|^2 f_M^2 \mathcal{P}_{cc}^M}{|\lambda_t^{(s)} C_\gamma (c_9^{\text{eff}} + 1/2 c_{12}^{\text{eff}})|^2}$$

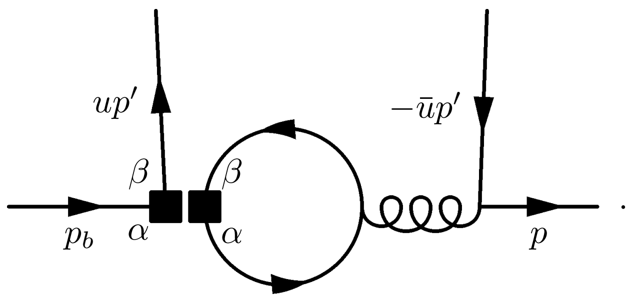
- $h_M^{(q)}$: the hard kernels convoluted with LCDA

$$h_M^{(q)} = f_M \phi_M(u) \otimes \left(\lambda_u^{(q)} T_{M,u}^{(q)}(u) + \lambda_c^{(q)} T_{M,c}^{(q)}(u)\right)$$

- $p_{cc}^M, \mathcal{P}_{cc}^M$: nonpert. charming penguin parameters



Factor. for charming penguins



- work in the limit $m_b, m_c \to \infty$, m_c/m_b fixed
- charm quark pair annihilation:

$$\mathcal{O}_{c\bar{c}n\bar{n}} \sim (\overline{q}_n \gamma^\mu T^a q_{\overline{n}}) \, (\overline{c}_{-v_{\bar{c}c}} Y_{\overline{n}} \gamma_\mu T^a Y_n^\dagger c_{v_{\bar{c}c}})$$

- weak operator

$$\mathcal{O}_{qbc\bar{c}} \sim \left[(\overline{q}_{\overline{n}})_\beta \gamma^\nu P_L (Y_n^\dagger b_v)_\alpha\right] \left[(\overline{c}_{v_{\bar{c}c}} Y_n^\dagger)_\alpha \gamma_\nu P_L (Y_{\overline{n}}^\dagger c_{-v_{\bar{c}c}})_\beta\right]$$

- using factorization of $\overline{n}$ and n degrees of freedom

$$\langle MX|\mathrm{T}\mathcal{O}_{c\bar{c}n\overline{n}}\mathcal{O}_{qbc\bar{c}}|B\rangle \to \langle X|\mathcal{Q}_{c\bar{c}}|B\rangle \times \phi_M(u) H(u, E_M)\big|_{\bar{u}=\frac{2m_c^2}{m_b E_M}}$$

- $\mathcal{Q}_{c\bar{c}}$ nonlocal oper. of q_n and soft fields

Contribution to the decay width

- using optical theorem from

$$\mathcal{I}m\langle B|\mathrm{T}J_H^\dagger(z)\mathcal{Q}_{c\bar{c}}(0)|B\rangle \to \mathcal{F}_{c\bar{c}}$$

- single charming penguin insert. at LO in $1/m_c$ gives

$$\frac{d\Gamma c\bar{c}(B\to MX)}{dE_M} \propto \alpha_s(2m_c)f_M\phi_M\Big(1-\frac{2m_c^2}{m_bE_M}\Big)\times \\ \times\,\mathrm{Re}\Big[h_M^{(q)*}(m_b)\lambda_c^{(q)}\mathcal{F}_{c\bar{c}}(E_M)\Big]$$

- integrating out $q_n \Rightarrow J_P$, further factorization

$$\mathcal{F}_{c\bar{c}} \propto f_{c\bar{c}}(l_+)\otimes_{l_+}\mathrm{Im}J_P(l_+ + i\epsilon)$$

Charming penguin parameters

- at LO in $1/m_c$, $\alpha_s(2m_c)$

$$p_{cc}^M \propto \mathcal{F}_{cc}\ \ \phi_M\Big(1-\frac{2m_c^2}{E_M m_b}\Big), \qquad \mathcal{P}_{cc}^M \propto \bar{\mathcal{F}}_{cc}\ \ \Big[\phi_M\Big(1-\frac{2m_c^2}{E_M m_b}\Big)\Big]^2$$

- parameters $\mathcal{F}_{cc}$ and $\bar{\mathcal{F}}_{cc}$ are universal
- dependence on M fixed through ϕ_M
- $\mathcal{F}_{cc}$ can carry strong phase
- nonperturb. charming penguins for all $B \to XM$ described by 3 real parameters
  - in the limit $m_c \to \infty$
  - E_M dependence neglected (subleading effect)
- in principle can also treat p_{cc}^M, $\mathcal{P}_{cc}^M$ as free params.

$B \to \eta' X, \eta X$ decays

- $\eta - \eta'$ mixing $\Rightarrow$ FKS scheme

$$\eta = \eta_q \cos\varphi - \eta_s \sin\varphi, \quad \eta' = \eta_q \sin\varphi + \eta_s \cos\varphi$$

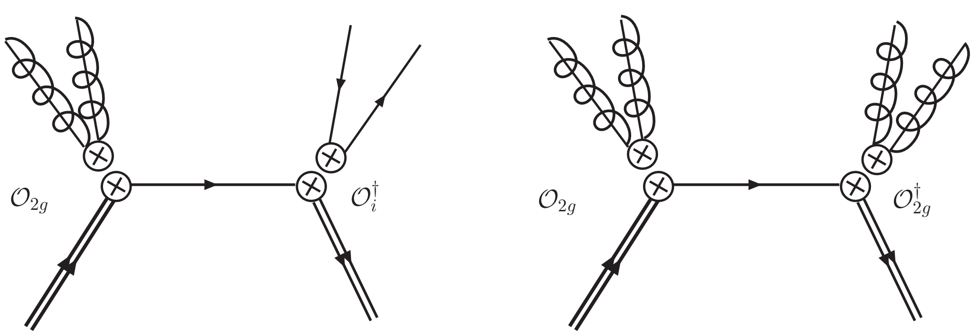
  with $\varphi = (39.3 \pm 1.0)^\circ$

- gluonic content of $\eta^{(\prime)}$
  - two new operators at LO

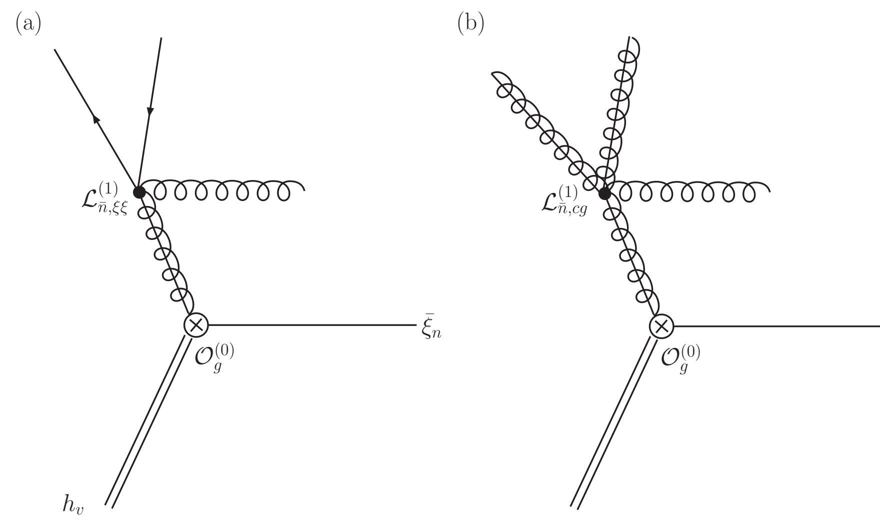
$$\mathcal{O}_{1g} = m_b [\bar{q}_n Y_n^\dagger Y_{\bar{n}} \, \bar{n}\!\!\!/ P_L \, \mathcal{B}\!\!\!/_{\bar{n}}^{\perp} Y_{\bar{n}}^\dagger b_v],$$

$$\mathcal{O}_{2g} = m_b [\bar{q}_n \, \bar{n}\!\!\!/ P_L Y_n^\dagger b_v] \mathrm{Tr}[\mathcal{B}_{\bar{n}}^{\perp\mu} \mathcal{B}_{\bar{n}}^{\perp\nu}]_u i\epsilon_{\perp\mu\nu},$$

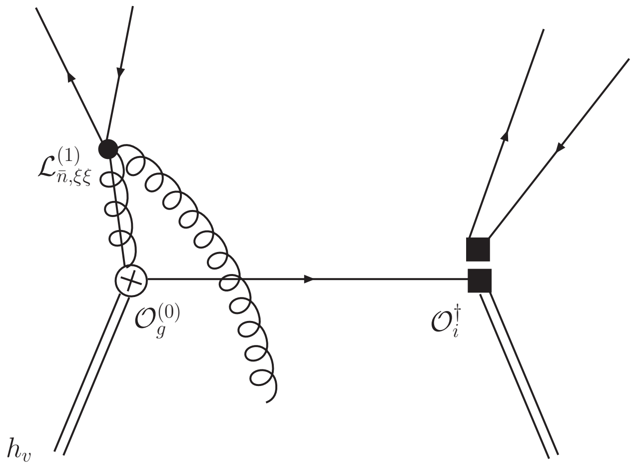
  - $\mathcal{O}_{2g}$ insertions $\Rightarrow \phi_M \to \bar{\Phi}_M^g$



  - $\mathcal{O}_{1g}$ insertions



$\mathcal{O}_{1g}$ insertion



- focusing only on this T product

$$\mathcal{G}_{\xi\xi} = \langle MX| i \int d^4x T\{\mathcal{O}_{1g}, \mathcal{L}^{(1)}_{\xi\xi}(x)\}|B\rangle$$

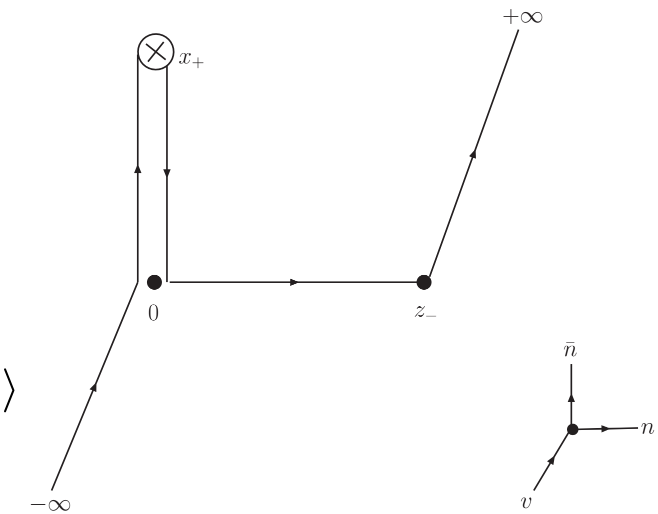
- integrating out hard-collinear gluon $\Rightarrow$ new jet function J_1
- in general J_1 depends on u and k_- so

$$\mathcal{G}_{\xi\xi} = -\frac{g^2}{2}\int du f_M \phi_M(u) \int \frac{dk_- dx_+}{4\pi} e^{-ik_- x_+/2}\Big(\frac{1}{u}J_1(u,k_-) - \frac{1}{\bar{u}}J_1(\bar{u},-k_-)^*\Big)$$
$$\langle X|[\bar{q}_n Y_n^\dagger Y_{\bar{n}}(0)\,\bar{n}\!\!\!/ g\, \mathcal{A}\!\!\!/^\perp_{us}(x_+) P_R Y_{\bar{n}}^\dagger b_v(0)|B\rangle$$

with $g\mathcal{A}^{\perp,\mu}_{us} = \big[Y_{\bar{n}}^\dagger i D^{\perp\mu}_{us} Y_{\bar{n}}\big]$

- at tree level $J_1(u,k_-)$ only function of $k_- \Rightarrow$ integrations over u and k_- factor

$\mathcal{O}_{1g}$ insertion II



- working at tree level
- a new shape function

$$\int dl_+ e^{il_+ z_-/2} \int dr_- e^{ir_- x_+/2} f_g(l_+, r_-) =$$

$$\langle \bar{B}_v | \bar{b}_v Y_n(z_-) Y_n^\dagger Y_{\bar{n}}(0) \not{\bar{n}} g \not{\mathcal{A}}_{us}^\perp(x_+) P_R Y_{\bar{n}}^\dagger b_v(0) | B_v \rangle$$

- from it a new $\tilde{\mathcal{S}}$ func.

$$\tilde{\mathcal{S}}_g(E_M, \mu_0) \propto \int dl_+ dr_- \mathcal{I}m \big[J_P(l_+ + m_b - 2E_M + i\epsilon) f_g(l_+, r_-) J_1(r_-)|_{\text{tree}} \big]$$

- decay width at LO in $\alpha_s(\sqrt{\Lambda m_b})$

$$\Big(\frac{d\Gamma}{dE_M}\Big)_g \propto \tilde{\mathcal{S}}_g(E_M, \mu_0) 2\mathcal{R}e \big[(f_M \phi_M \otimes \lambda_p^{(q)} T_{M,p}^{(q)})^* (\lambda_t^{(q)} \mathcal{C}_{1g} \frac{g^2}{2} f_M \phi_M \otimes (\frac{1}{u} + \frac{1}{\bar{u}})) \big]$$

- similarly for two $\mathcal{O}_{1g}$ insertions

Comparison with data

- at present not enough data to determine nonpert. charming peng. parameters
- comparing purely pert. predictions with experiment

$$\frac{\Gamma(B^+/B^0 \to K^+ X)}{\Gamma(B \to X_s \gamma)} = \begin{cases} 1.13 \pm 0.30 \pm ? & \text{Exp.} \\ 0.17 \pm 0.09 \pm 0.06 & \text{Th.} \end{cases}$$

$$\frac{\Gamma(B^+/B^0 \to K^0 X)}{\Gamma(B \to X_s \gamma)} = \begin{cases} 0.89 \pm 0.42 \pm ? & \text{Exp.} \\ 0.20 \pm 0.11 \pm 0.06 & \text{Th.} \end{cases}$$

- hint of nonpert. charm. peng. or large $1/m_b$?

Comparison with data II

- other way of presenting
  - extract p_{cc}^K with assumption $|p_{cc}^K|^2 \sim \mathcal{P}_{cc}^K$
  - this still depends on phase of p_{cc}^K
  - vary this phase

$$\left|\frac{\lambda_c^{(s)} f_K p_{cc}^K}{h_K^{(s)}}\right| = \begin{cases} 2.2 \pm 1.1 & : K^+ X \\ 2.0 \pm 1.5 & : K^0 X. \end{cases}$$

Phenomenology of $\to \eta' X_s$

- perturb. prediction without $\mathcal{O}_{1g}$ much smaller than exp.
- two formal limits are instructive
  - dominating charming penguins

$$\frac{Br(B^-\to\eta X^-_{s\bar u})}{Br(B^-\to\eta' X^-_{s\bar u})} = \big(\tan\phi\big)^2 = 0.67$$

    contrary to $B \to \eta^{(\prime)} K$ no large hierarchy in this limit
  - $\mathcal{O}_{2g}$ contributions dominate then at LO in $\alpha_s(\sqrt{\Lambda m_b})$

$$\frac{Br(B^-\to\eta X^-_{s\bar u})}{Br(B^-\to\eta' X^-_{s\bar u})} = \frac{\left|(\cos\phi f_{\eta_q}\phi_{\eta_q} - \sin\phi f_{\eta_s}\phi_{\eta_s})\otimes\left(\frac{1}{u}+\frac{1}{\bar u}\right)\right|^2}{\left|(\cos\phi f_{\eta_q}\phi_{\eta_q} + \sin\phi f_{\eta_s}\phi_{\eta_s})\otimes\left(\frac{1}{u}+\frac{1}{\bar u}\right)\right|^2}$$

    depending on LCDA this $\sim 10^{-4} - \sim 10^{-2}$
- important to have a measurement of $B \to \eta X_s$ decays

Conclusions

- LO analysis of all $B \to XM$ modes has been presented
- a disagreement between measured $B \to KX$ rates and the LO perturbative predictions?