Non-leptonic B decays, discussion

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“Future Challenges in Non-Leptonic B Decays: Theory and Experiment”,
Mainz, January 14 - 18, 2019

Items

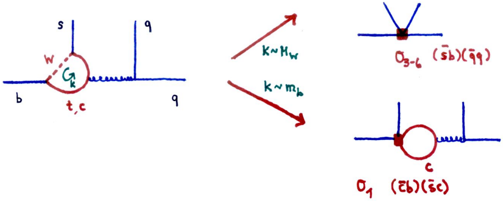
- Charm loops, duality & factorization
- Observations on PQCD
- Observations on FAT

I. Charm loops, duality & factorization

[BBNS, hep-ph/0411171, 0902.4446]

Penguins with charm

$b \to s$ transitions are dominated by loop diagrams. Among them a leading non-local contribution due to a charm-quark loop. Some controversy in the past about how well this can be calculated and about factorization as such.



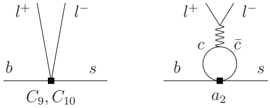
Two separate issues:

- Factorizes, but power corrections could be important [Ciuchini et al. '97; '01 – their fit to $B \to \pi K$ (0811.0341 [hep-ph]) seems to be consistent with power-suppressed deviations from factorization]
- No factorization in the heavy-quark limit [Bauer et al. '04; '05]
  Loss of predictivity for direct CP asymmetries and penguin modes. (final-state dependent phenomenological parameter)
  Non-factorization arises form the charm threshold region $k_g^2 = m_b^2 \bar{u} \approx 4m_c^2$. Large resonant effects well-known from $B \to X_s \ell\ell$. Why should charm loops in non-leptonic decays be different?

$B \to X_s \ell\ell$

Define "SD" as quark-level calculation including charm-loop, no resummations. Then

$$R_\psi \equiv \frac{\mathrm{B}(B \to X_s \psi \to X_s\, l^+ l^-)}{\mathrm{B}(B \to X_s\, l^+ l^-)_{\mathrm{SD}}} \approx 90$$



Parton-hadron duality violation!

Consider toy theory with Hamiltonian $\mathcal{H}_{\mathit{eff}} = \frac{G}{\sqrt{2}} \left[(\bar{l}_2 l_1)_{V-A}\, (\bar{c}c)_{V-A} - (\bar{l}_2 l_1)_{V-A}\, (\bar{t}t)_{V-A} \right]$

(drops inessential reconnections to b and s lines)

$$\frac{d\Gamma(l_1 \to l_2\, e^+ e^-)}{ds} = \frac{G^2 \alpha^2 m_1^5}{27\pi} \,(1-s)^2\,(1+2s)\left|\Pi(q^2)\right|^2$$

Resonance contribution:

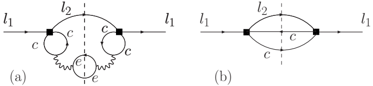
$$\Pi(q^2) = -\frac{f_\psi^2}{q^2 - M_\psi^2 + i M_\psi \Gamma_\psi}$$

$$\int_0^{m_1^2} dq^2\, \mathrm{Im}\,\Pi(q^2) \approx \pi f_\psi^2 \ll m_1^2 \qquad\qquad \int_0^{m_1^2} dq^2\, |\Pi(q^2)|^2 \approx \pi f_\psi^2 \times \frac{f_\psi^2}{M_\psi \Gamma_\psi}$$

Small contribution for averages of $\mathrm{Im}\,\Pi(q^2)$ and $\Pi(q^2)$, but (in principle arbitrarily large) enhancement by the small resonance width for averages of $|\Pi(q^2)|^2$.

No duality for $B \to X_s \ell\ell$

$\mathrm{Br}\,(l_1 \to l_2 e^+ e^-)$ is not a complete sum over cuts [compare the l_1 inclusive width]. Duality should not be expected!



- J/ψ resonance in $B \to X_s \ell\ell$

$$R_\psi \equiv \frac{\mathrm{B}(B \to X_s \psi \to X_s\, l^+ l^-)}{\mathrm{B}(B \to X_s\, l^+ l^-)_{\mathrm{SD}}} = \underbrace{\frac{512\pi^5 \kappa^2\, a_2^2\, (1-r)^2\, (1+2r)}{9(\langle |C_9|^2\rangle + |C_{10}|^2)} \times \frac{f_\psi^2}{m_b^2}}_{\approx\, 0.16} \times \underbrace{\frac{f_\psi^2}{M_\psi \Gamma_\psi}}_{560} \approx 90$$

In the heavy quark limit $m_b \gg \Lambda$, m_c/m_b fixed, this is $O(1)$, but enhanced:

$$R_\psi = \frac{512\pi^5 \kappa^2\, a_2^2\, (1-r)^2\, (1+2r)}{9(\langle |C_9|^2\rangle + |C_{10}|^2)} \times \frac{54}{5\pi(\pi^2-9)} \left(\frac{\alpha_s(m_c v)}{\alpha_s(M_\psi)}\right)^3 \times \frac{m_c^2}{m_b^2}$$

- ρ resonance in $B \to X_{s,d} \ell\ell$ – very small

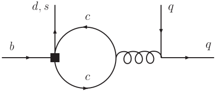
$$R_\rho \approx [10\text{–}50] \times \frac{f_\rho^2}{m_b^2} \times \underbrace{\frac{f_\rho^2}{M_\rho \Gamma_\rho}}_{0.38} \approx [0.007\text{–}0.036]$$

Comparison with $B \to \pi\pi\ (K\pi)$

Charm-loop contribution to the EW penguin amplitude

$$\Delta a_{10}^p = \frac{C_1 + NC_2}{N}\,\frac{\alpha}{9\pi}\left[-\frac{4}{3}\ln\frac{\mu}{m_b} + \frac{2}{3} - G_\pi(s_p)\right]$$

$$G_\pi(s) = \int_0^1 dx\,\phi_\pi(x)\left\{-\frac{2}{3}\ln s + \frac{8\pi^2}{3}\left[\Pi_q(\bar{x}m_b^2) - \Pi_q(0)\right]\right\}$$



The resonance contribution is

$$G_\pi^\psi = -\frac{8\pi^2 f_\psi^2}{m_b^2}\left[2r_\psi\,(1-r_\psi)\left(\ln\frac{1-r_\psi}{r_\psi} - i\pi\right) + 1 - 2r_\psi\right] \qquad (r_\psi = M_\psi^2/m_b^2)$$

Suppressed in the heavy quark limit and no width enhancement. The contribution from the threshold region is of order G_π^ψ:

$$\frac{A_{c\bar{c}}}{A_{\rm LO}} \sim \alpha_s(2m_c)\,f\left(\frac{2m_c}{m_b}\right) v \times \frac{4m_c^2 v^2}{m_b^2}$$

The last suppression factor is missing in [Bauer et al. '05] since in $\int_{r(1-v^2)}^{r(1+v^2)} du\, C_I^{\rm prod}(u)\ \ldots$ they set $C_I^{\rm prod}(u) \sim \delta(\bar{u} - 4m_c^2/m_b^2)$ rather than the correct $C_I^{\rm prod}(u) \sim 1$.

II. Observations on PQCD

PQCD [Keum, Li, Sanda (2000); Lü, Ukai, Zhang (2000)]

Main conceptual difference: $B \to M_1$ form factor ($\bar{\xi}\Gamma h_v$ SCET$_\mathrm{I}$ operator) assumed to factorize in LCDAs after self-consistent regularization of endpoint divergences by transverse-momentum-dependent Sudakov resummation

$$\begin{aligned}\langle M_1 M_2|Q_i|\bar{B}\rangle &= F^{BM_1}\, T_i^{\mathrm{I}} \star \Phi_{M_2} + \Phi_B \star [H_i^{\mathrm{II}} \star J^{\mathrm{II}}] \star \Phi_{M_1} \star \Phi_{M_2} \\ &\to \phi_B \star [T_i^{\mathrm{PQCD}} \star J^{\mathrm{PQCD}}] \star \phi_{M_1} \star \phi_{M_2} \\ &\to \phi_B \star [H_i] \star \phi_{M_1} \star \phi_{M_2}\end{aligned}$$

- Applied to *all* diagrams, spectator-scattering, weak annihilation, ...
  Scales not completely factorized, $1/m_b$ power counting of contributions never clarified.

- Two questions: 1) theory of k_t resummation, 2) does it work for $m_b = 5\,\mathrm{GeV}$?
  [Descotes-Genon, Sachrajda, hep-ph/0109260]

- Phases from (resummed) tree diagrams in the endpoint region

$$\frac{1}{x\bar{y}m_b^2 - k_\perp^2 + i\epsilon}$$

If $k_\perp^2 \sim m_b\Lambda$, the effect is part of the perturbative loop function. If $k_\perp^2 \sim \Lambda^2$, it can't be computed. Need to argue that resummation forces self-consistently $m_b\Lambda \gg k_\perp^2 \gg \Lambda^2$.

NLO computations in PQCD and Glauber singularities (1/2)

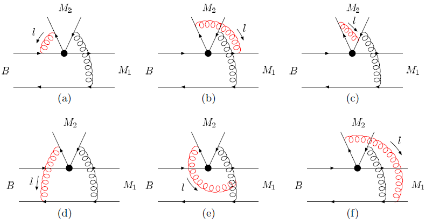
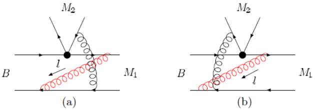


FIG. 2: NLO diagrams for Fig. 1(a) that are relevant to the factorization of the M_2 meson wave function. Figures 2(d)-2(f) contribute to the Glauber divergences.



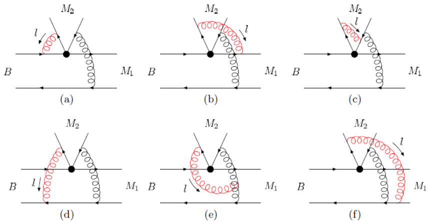
[Li, Mishima, (2009) and 1407.7647]

- Glauber scaling $n_+ l, n_- l \ll l_\perp$.
- Glauber often subsumed in soft by contour deformation.
  Glauber effects in SCET [Rothstein, Stewart (2016)]. Do not expect Glauber singularities here?
- Here Glauber supposed to result in non-factorization whenever there is an integral

$$\int_{-a}^{b} \frac{d(n_- l)}{n_- l + i\epsilon}$$

which contains $n_- l = 0$.

NLO computations in PQCD and Glauber singularities (2/2)



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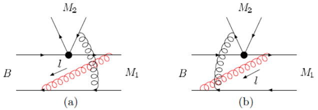


[Li, Mishima, (2009) and 1407.7647]

- Same graphs appear in the calculation of spectator scattering [MB, Yang (2005), MB, Jäger (2005)]. The IR singularities could be consistently factorized into B-meson and light-meson LCDAs as predicted by the QCD factorization formula.
- Glauber divs noted for (d)-(f) when l is M_2-collinear. However, these diagrams are all power-suppressed, except for one term in (e), which is Glauber-free.

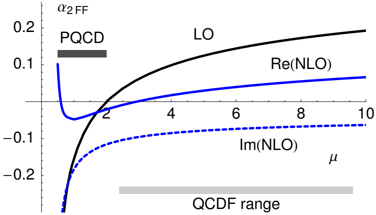
⇒ Effectively a parameterization of an arbitrary power-suppressed contribution to the colour-suppressed tree amplitude.

- Also for penguin diagrams, ...?

Phenomenology

- Weak effective Lagrangian Wilson coefficients evolved to low scale. But their running stops at $\mathcal{O}(m_b)$ and is replaced by factorized SCET_I running.

$$a_{2\text{FF}}(\mu) = C_2 + \frac{C_1}{N_c} + \underbrace{\frac{\alpha_s C_F}{4\pi}\frac{C_1}{N_c}\left[12\ln\frac{m_b}{\mu} - \frac{37}{2} - 3i\pi\right]}_{\text{NLO correction (asymptotic LCDA)}}$$



- Assumptions on and form of B meson LCDA
- Scale variations and theory parameter uncertainties not realistically estimated, sometimes determined from fit to data.
- Too low scales of α_s etc. Not in the regime where PT is reliable.