A dynamical approach to semi-inclusive B decays

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Abstract.
A dynamical approach to semi-inclusive decays based on an effective running coupling for the strong interactions is described.

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INTRODUCTION

Semi-leptonic and radiative semi-inclusive decays of heavy mesons are currently under intense investigation. Non perturbative physics seems to be more manageable in such decays, and there is hope for a reduction of theoretical assumptions and a more stringent comparison with experimental data. Several effective approaches to such decays are available. Most commonly, in order to calculate the decay rate, a series of operators is used, whose coefficients and matrix elements are weighted differently according to the theoretical assumptions. The matrix elements of the operators are not calculable within perturbation theory; the largest is the number of operators included in the calculation, the more accurate is the result. Another possible approach is based on an effective strong coupling, in turn based on perturbative threshold resumming and analyticity principles. [1, 2, 3, 4, 5, 6] In such approach, an effective strong coupling is introduced and used in the resummation soft–gluon formulas.

EFFECTIVE COUPLING

Long distance effects manifest themselves in perturbation theory in the form of series of large infrared logarithms, coming from “incomplete” cancellation of infrared divergencies in real and virtual diagrams in the threshold kinematical region. Such logarithms need to be resummed at all orders and resumming formulas are available within perturbation theory. Resumming requires integration over all possible kinematical domains, included low energy, order of $\Lambda_{QCD}$ ones; therefore, divergencies arise when the running coupling constant hits the Landau pole in the integrations. Several prescriptions can be used used in order to keep under control divergencies in the soft–gluon resumming formulas for the decay rates. An interesting possibility is to substitute an effective running coupling, with no Landau pole singularity, into the resumming formulas in place of the standard one. The non-physical Landau singularity can be removed by means of a
dispersion relation [5]

\[ \alpha(Q^2) = \frac{1}{2\pi i} \int_0^\infty \frac{ds}{s + Q^2} \text{Disc}_s \alpha(-s); \]  

(1)

\( Q \) is the hard scale of the process. At lowest order

\[ \tilde{\alpha}_{lo}(Q^2) = \frac{1}{\beta_0} \left[ \frac{1}{\log Q^2/\Lambda^2} - \frac{\Lambda^2}{Q^2 - \Lambda^2} \right]. \]  

(2)

Let us improve the effective coupling by adding the contributions of secondary emissions off the radiated gluons. The final effective coupling is given by the prescription

\[ \tilde{\alpha}(k^2_\perp) = \frac{i}{2\pi} \int_0^{k^2_\perp} ds \text{Disc}_s \frac{\tilde{\alpha}(-s)}{s}. \]  

(3)

If we neglect the \(-i\pi\) terms in the integral over the discontinuity — i.e. the absorptive effects — the cascade coupling exactly reduces to the ghost-less one:

\[ \tilde{\alpha}(k^2_\perp) \to \tilde{\alpha}(k^2_\perp). \]  

(4)

Let us notice that the dispersion relation (2) has automatically added a power term to the coupling. That leads to another assumption, that is that the effective coupling may have a role outside the perturbative contest where it has been introduced, by including long distance effects. The perturbative QCD formulas is extrapolated to a non-perturbative region by assuming that the relevant non-perturbative effects can be relegated into an effective coupling. By using an effective coupling to mimic also long distance effects, one can exploit the fact that resummation formulas have universal characteristics which do not depend on the single process. Of course, that implies that not all long distance effects can be accounted for. The description is assumed valid for bound state effects; they are due to the vibration of the \(b\) quark inside the \(B\) quark as a consequence of its interactions with light degrees of freedom (the so called Fermi motion). On the other side, other effects, like i.e. the \(K^*\) peak which appears in the radiative hadron mass distribution or the \(\pi\) and \(\rho\) peaks which appear in the semileptonic one, cannot be accurately predicted in this approach.

**COMPARISON WITH DATA**

Ultimately, the validity of the approach previously described relies on the comparison with the experimental data. The agreement is generally good [5]. F.i., in Fig. (1) and in Fig. (2) the invariant hadron mass distribution \(d\Gamma_r/dm_X\) and the photon energy spectrum \(d\Gamma_r/dt\) for the radiative decay \(B \to X_\gamma\) are compared, respectively, with experimental data given by the BaBar collaboration [7, 8]. There is good agreement also for the hadron spectrum in the semileptonic \(B \to X_u l \nu\) decay, as shown f.i. in Fig. (3), where data from Babar Collaboration are presented [9]. The electron spectrum in the semileptonic \(B \to X_u l \nu\) decay is affected by a large background coming from the decay...
FIGURE 1. $B \rightarrow X_c \gamma$ invariant hadron mass distribution compared with BaBar experimental points for $\alpha_S(m_Z) = 0.123$.

FIGURE 2. $B \rightarrow X_c \gamma$ photon spectrum from BaBar compared to the theoretical curve. The theoretical curve has been convoluted with a normal distribution with a standard deviation, $\sigma_\gamma$. Here $t \equiv 1 - \frac{2E_{\gamma}}{m_B}$. Dotted line (blue): $\alpha_S(m_Z) = 0.130$ and $\sigma_\gamma = 100$ MeV; continuous line (black): $\alpha_S(m_Z) = 0.129$ and $\sigma_\gamma = 200$ MeV.

$B \rightarrow X_c l \nu$. For the electron spectrum the agreement is not as good as in the previous cases, as can be seen in Fig. (4), where Belle data are shown [10]. However, before considering theory improvement, one has to investigate more sophisticated comparison with data, that are in principle possible; f.i., in this case, one could take into account more recent data for the charm background or a better analysis of the correlation of the systematics of the various bins.
FIGURE 3. invariant hadron mass distribution in semileptonic decays from BaBar for $\alpha_S(m_Z) = 0.119$.

FIGURE 4. electron spectrum in semileptonic decay from Belle for $\alpha_S(m_Z) = 0.135$.

REFERENCES

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