Modelling non perturbative correction in inclusive B decays

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Based on: U. Aglietti, G. F. and G. Ricciardi

Phys. Rev. D74 (2006) 034004, [hep-ph/0507285].
Phys. Rev. D74 (2006) 034005, [hep-ph/0509095].
Phys. Rev. D74 (2006) 034006, [hep-ph/0509271].
Nucl. Phys. B 768 (2007) 85, [hep-ph/0608047].

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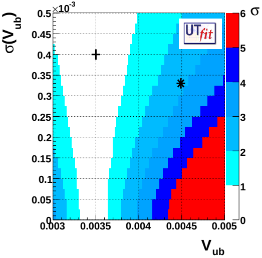

Inclusive decays involve large logarithmic perturbative corrections and non perturbative effects. Large theoretical uncertainties arise from the modelling these effects.

We propose a general model based on NNLL threshold resummation and on an effective QCD coupling which we have tested with precise LEP and SLD data. It reproduce with good accuracy the experimental data of the B-factories.

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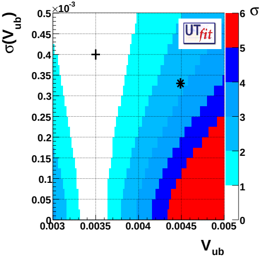

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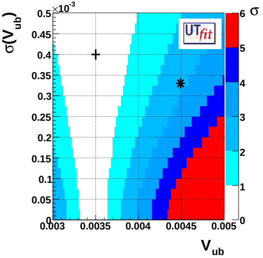

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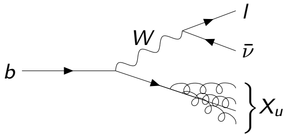
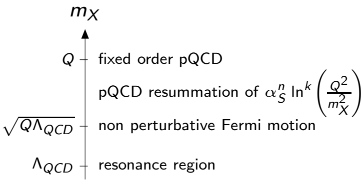
Outline

Inclusive B decays



Semileptonic charmless decay:
$B \to X_u + l + \bar{\nu}$



- Energy scales: $m_b \geq E_X \geq m_X$, $Q = E_X + \sqrt{E_X^2 - m_X^2}$
- B decays rates can be computed in a series in Λ_{QCD} and α_S using QCD factorization and the OPE ($m_X^2 \gg E_X \Lambda_{QCD} \gg \Lambda_{QCD}^2$).
- To avoid the ~ 50 times larger $B \to X_c l \nu$ background kinematic cuts are necessary: $m_X < m_D$, $E_l > (m_B^2 - m_D^2)/2m_B$, $q^2 > (m_B - m_D)^2$
- This means $m_X^2 \sim E_X \Lambda_{QCD} \gg \Lambda_{QCD}^2$. In this region the differential rates depends by non-perturbative shape functions .

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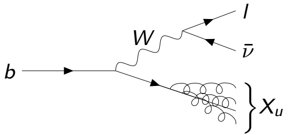

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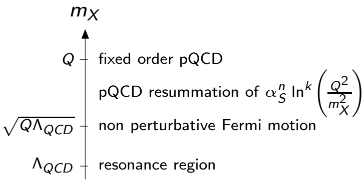

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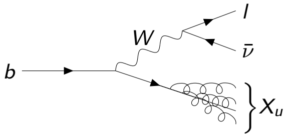

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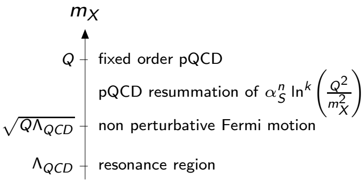

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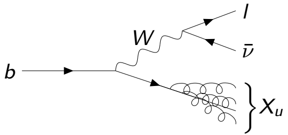

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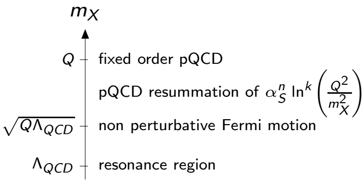

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Non-perturbative (f.i. from lattice QCD) calculation of the shape function do not exist: different models with free parameter to be extracted from the data of the radiative $B \to X_s \gamma$ decay have been proposed [Lange, Neubert, Paz ('05); Andersen, Gardi ('06); Bauer, Ligeti, Luke ('01)].

- Due to the different hard scale between the radiative and the semileptonic decay, non-universal long distance effects are present even at the perturbative level [Aglietti, G.F. & Ricciardi ('06)].
- Universality of the shape function is violated at Λ_{QCD}/m_b level, these corrections cannot be extracted from the data.
- Experimental data do not permit an accurate extraction of the shape function.

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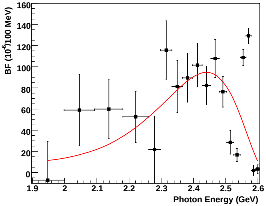

Threshold resummation

In the Mellin space the threshold resummed form factor reads [Sterman ('87), Catani & Trentadue ('89)]:

$$\ln \sigma_N = \int_0^1 dy \frac{(1-y)^{N-1}-1}{y} \left\{ \int_{Q^2y^2}^{Q^2y} \frac{dk_\perp^2}{k_\perp^2} A[\alpha_S(k_\perp^2)] + B[\alpha_S(Q^2y)] + D[\alpha_S(Q^2y^2)] \right\}$$

$$\text{where} \quad A(\alpha_S) = \sum_{n=1}^{\infty} A_n\, \alpha_S^n, \quad B(\alpha_S) = \sum_{n=1}^{\infty} B_n\, \alpha_S^n, \quad D(\alpha_S) = \sum_{n=1}^{\infty} D_n\, \alpha_S^n \;.$$

When $y = \frac{m_X^2}{Q^2} \to 0$ this formula involves $\alpha_S(k_\perp^2)$ evaluated at the Landau pole: it is necessary a prescription, f.i. the Minimal Prescription [Catani, Mangano, Nason & Trentadue ('96)].

Our approach is different, we treat the unphysical Landau pole from the very beginning using the analytic QCD coupling [Aglietti, Ricciardi ('04)].

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Analytic QCD coupling

Analytic QCD coupling: same discontinuity of the standard coupling along the cut but analytic elsewhere in the complex plane [Shirkov & Solovtsov ('97)]:

$$\bar{\alpha}_S^{lo}(Q^2) = \frac{1}{\beta_0}\left[\frac{1}{\ln Q^2/\Lambda^2_{QCD}} - \frac{\Lambda^2_{QCD}}{Q^2-\Lambda^2_{QCD}}\right] \quad , \quad LO \quad space-like$$

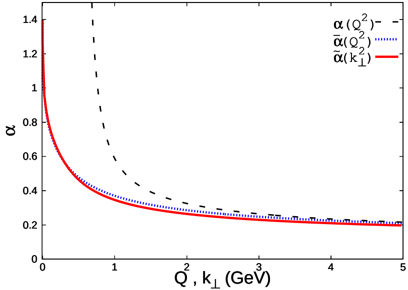

Figure 1: Time-like, space-like analytic and standard QCD couplings.

Phenomenological Analysis

b-quark fragmentation: $e^+e^- \to Z^0 \to B + X, \qquad x_b = \frac{2E_b}{m_Z}$

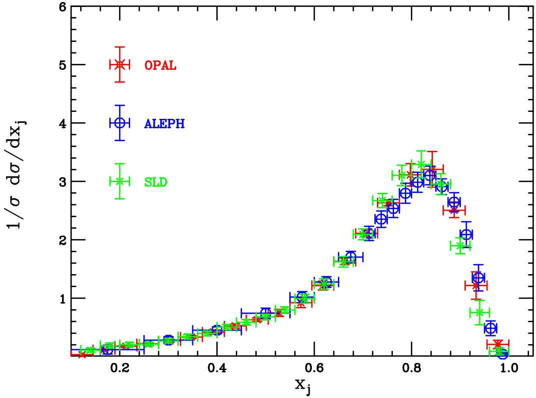

Figure 2: *B*-hadron spectrum in e^+e^- annihilation at Z^0 peak: prevision of the model compared with experimental data [Aleph ('01), Delphi ('02), SLD ('00)].

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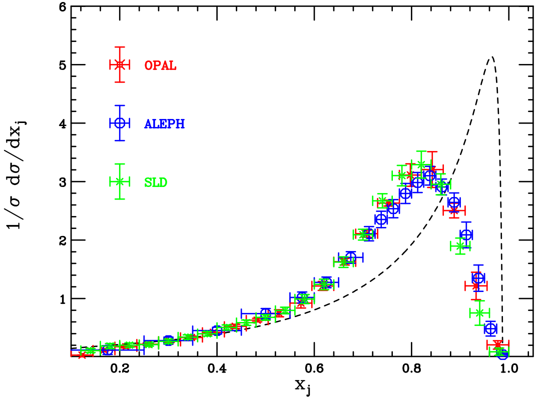

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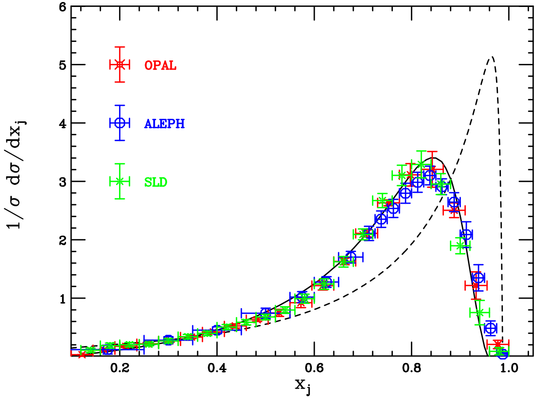

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Radiative decay: hadron mass and photon energy distribition

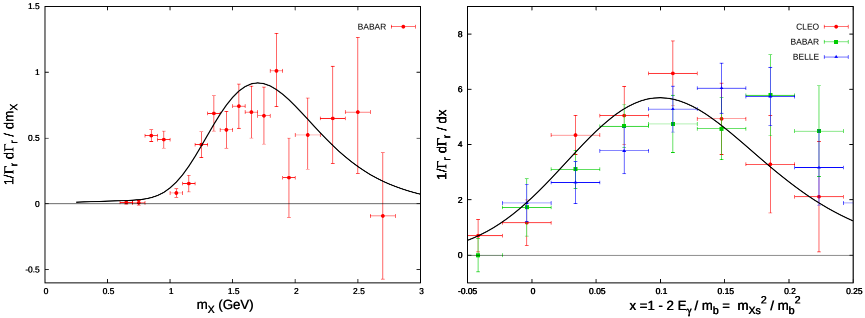

Figure 3: Invariant hadron mass distribution in the radiative decay: prevision of the model compared with the experimental data [BaBar ('05)].The K^* peak cannot clearly be accounted for in a perturbative QCD framework.
Photon energy spectrum in the radiative decay: prevision of the model compared with data [Cleo ('01), BaBar ('05), Belle ('05)]

Semileptonic decay: hadron mass distribution

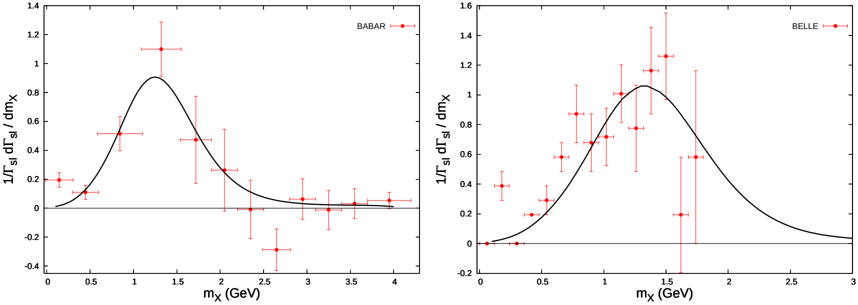

Figure 4: Invariant hadron mass distribution in the semileptonic decay: prevision of the model compared with the experimental [Belle ('04), BaBar ('05)]. Note the π and the ρ peaks at small hadron masses.

Semileptonic decay: electron energy distribution

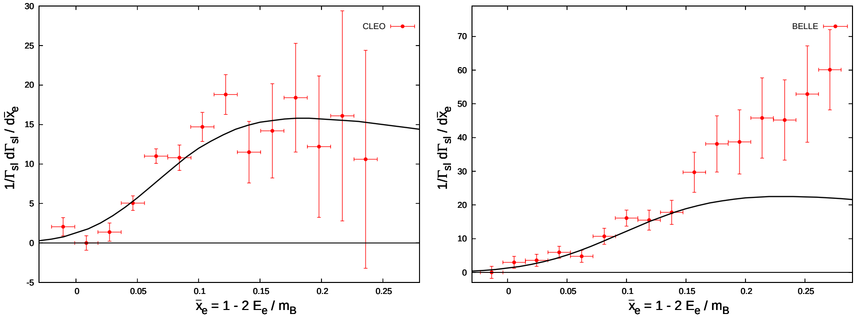

Figure 5: Inclusive charmless electron spectrum in the semileptonic decay: prevision of the model compared with data [Cleo ('01) and Belle ('04)]. To include the Doppler effect, we have convoluted our spectrum with a Gaussian distribution with $\sigma \sim 100$ MeV. Our model predicts a maximum around the energy $E_e = 2$ GeV, below which data are not available.

Semileptonic decay: electron energy distribution

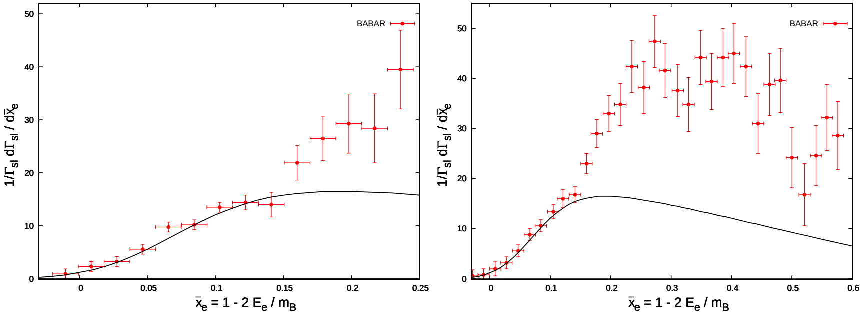

Figure 6: Inclusive charmless electron spectrum in the semileptonic decay: prevision of the model compared with data [Babar ('05)]. To include the Doppler effect, we have convoluted our spectrum with a Gaussian distribution with $\sigma \sim 100$ MeV. We do not known whether the discrepancy is related to a deficiency of our model or to an under-estimate charm background.

Extraction of $\alpha_S(m_Z)$ and V_{ub} from the data

$$b \to s\,\gamma$$

$$\alpha_S(m_Z) = 0.117 \pm 0.004 \qquad (E_\gamma :\ CLEO,\ \sigma_\gamma = 150\ MeV)$$

$$\alpha_S(m_Z) = 0.129 \pm 0.005 \qquad (E_\gamma :\ BABAR,\ \sigma_\gamma = 200\ MeV)$$

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$$\alpha_S(m_Z) = 0.1176 \pm 0.0020 \qquad (PDG06)$$

Conclusions

- Heavy flavour physics in the threshold region is plagued by large logarithmic perturbative corrections and non perturbative effects : all order resummation and a model for non perturbative physics is mandatory.
- Through the analytic QCD coupling and NNLL threshold resummation we have developed a model that describes with good accuracy the measured spectra without introducing any ad hoc non-perturbative component.
- We have found a remarkable disagreement with the electron spectrum in the semileptonic charmless decay (BaBar and Belle). We suppose a possible underestimate of the charm background.
- The extracted values for $\alpha_S(m_Z)$ are in agreement with the PDG avarage, the extraction of $|V_{ub}|$ from the data using our model is in progress.

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