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Heavy Flavour Production in Two-Photon Collisions

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Abstract. We review the production of charm and bottom quarks in two-photon collisions at e^+e^- colliders. The next-to-leading order QCD predictions for total cross sections and differential distributions are compared with recent experimental results.

1. Introduction

The production of charm and bottom quarks in two-photon collisions at high-energy e^+e^- colliders provides new possibilities to study the dynamics of heavy quark production and complements the extensive analyses that have been carried out at fixed-target experiments and at other colliders [1]. In two-photon collisions, each of the photons can behave as either a point-like or a hadronic particle. Consequently, one distinguishes in such collisions direct- (both photons are point-like), single resolved- (one photon is point-like, the other hadron-like), and double resolved (both photons are hadron-like) production channels. The resolved channels require the use of parton densities in the photon, whereas the production via the direct channel is free of such phenomenological inputs.

The mass of the heavy quark, $m_Q \gg \Lambda_{\text{QCD}}$, sets the hard scale for the perturbative calculation at small transverse momentum. It is thus possible to define an all-order infrared-safe cross section for open heavy flavour production. The heavy quark mass also ensures that the separation into direct and resolved production channels is unambiguous at next-to-leading order (NLO). Beyond NLO, however, the different channels mix and the distinction between the direct and resolved contributions becomes non-physical and scheme-dependent.

2. Results

Total cross sections and various distributions for inclusive charm and bottom quark production in two-photon collisions at e^+e^- colliders have been calculated in [2],

including NLO QCD corrections for the leading subprocesses.‡ At low energies, in the PETRA/PEP/TRISTAN range, the direct production mechanism by far dominates the total cross section. At LEP2 energies, the resolved- γ contribution becomes sizeable, up to about 50% of the total cross section, depending in detail on the choice for the parton densities in the photon. The cross sections for charmed particle production are large, giving a total of roughly 200000 events for an integrated luminosity of $\int \mathcal{L} = 200 \text{ pb}^{-1}$ at LEP2; b quark production is suppressed by more than two orders of magnitude, a consequence of the smaller bottom electric charge and the phase space reduction by the larger b mass. The inclusion of QCD corrections is important, increasing the cross section by about 30%.

In Figure 1 we compare the NLO predictions for the total charm and bottom cross section with experimental data [4,5] from PETRA energies up to LEP2 energies. The theoretical predictions appear under control, the uncertainty due to variation of the heavy quark mass and the renormalization and factorization scale being approximately $\pm 40\%$, as indicated in the figure. The overall agreement between the experimental charm data and the QCD predictions is good, provided higher-order corrections and resolved-photon contributions are included in the theory. The experimental and theoretical errors, however, do not allow to discriminate between different recent sets of photonic parton distributions [7]. More data are needed before any conclusions on two-photon production of bottom quarks can be drawn.

More detailed comparisons between QCD predictions and experimental data can be performed by using fully differential NLO Monte Carlo programs [8], which have recently been constructed. In these codes, all final-state kinematical quantities are available on an event-by-event basis, and it is thus possible to calculate more exclusive observables at NLO and to include heavy-quark-to-heavy-meson fragmentation functions.

The OPAL and L3 collaborations have presented [5] new data for D^* production in two-photon collisions, at (mostly) $\sqrt{s_{e^+e^-}} = 189 \text{ GeV}$. Besides the total cross section $\sigma_{\gamma\gamma}^{D^*}$, both experiments have measured the differential rate with respect to the D^* transverse momentum, $d\sigma_{\gamma\gamma}^{D^*}/dp_T^{D^*}$, and pseudorapidity $d\sigma_{\gamma\gamma}^{D^*}/d\eta^{D^*}$. In Figure 2 we compare our predictions for the D^* transverse momentum distribution with the OPAL and L3 measurements. Three different theoretical curves are shown, where the charm quark mass and the renormalization scale are varied as indicated in the figure. The shape of the distribution is described well by NLO theory, while there is a small discrepancy in absolute normalization, in particular for the L3 data, when central values for the theoretical input parameters are adopted. A definite statement, however, will only be possible after the statistical errors affecting the measurements have decreased. For both experiments, the pseudorapidity distribution is observed to be essentially flat in the central region, in accordance with the theoretical expectations [2,8].

‡ The effects of summing large logarithms $\log(p_T/m_Q)$ at $p_T \gg m_Q$ have been studied in [3] at NLO.

3. Summary

Total and differential heavy-quark production rates in two-photon collisions at e^+e^- colliders have been studied including NLO QCD corrections. Compared with charm and bottom production in hadron–hadron or photon–hadron collisions, the two-photon cross section appears to be under better theoretical control, mainly because of the dominance of the direct channel, where QCD uncertainties are smaller than in the case of the resolved contributions. The overall agreement between the total cross section measurements and the QCD predictions is good, provided higher-order corrections and resolved-photon contributions are included in the theory. We also find good agreement for the shape of the differential distributions. The absolute normalization of the data in the experimentally visible region is, however, slightly underestimated by NLO theory when central values for the input parameters are adopted. A special tuning of the input parameters is needed to improve the agreement, a pattern already known from other types of collider experiments. When the statistical significance of the measurements will be increased, heavy quark production in two-photon collisions will be a valuable tool in testing the underlying production dynamics.

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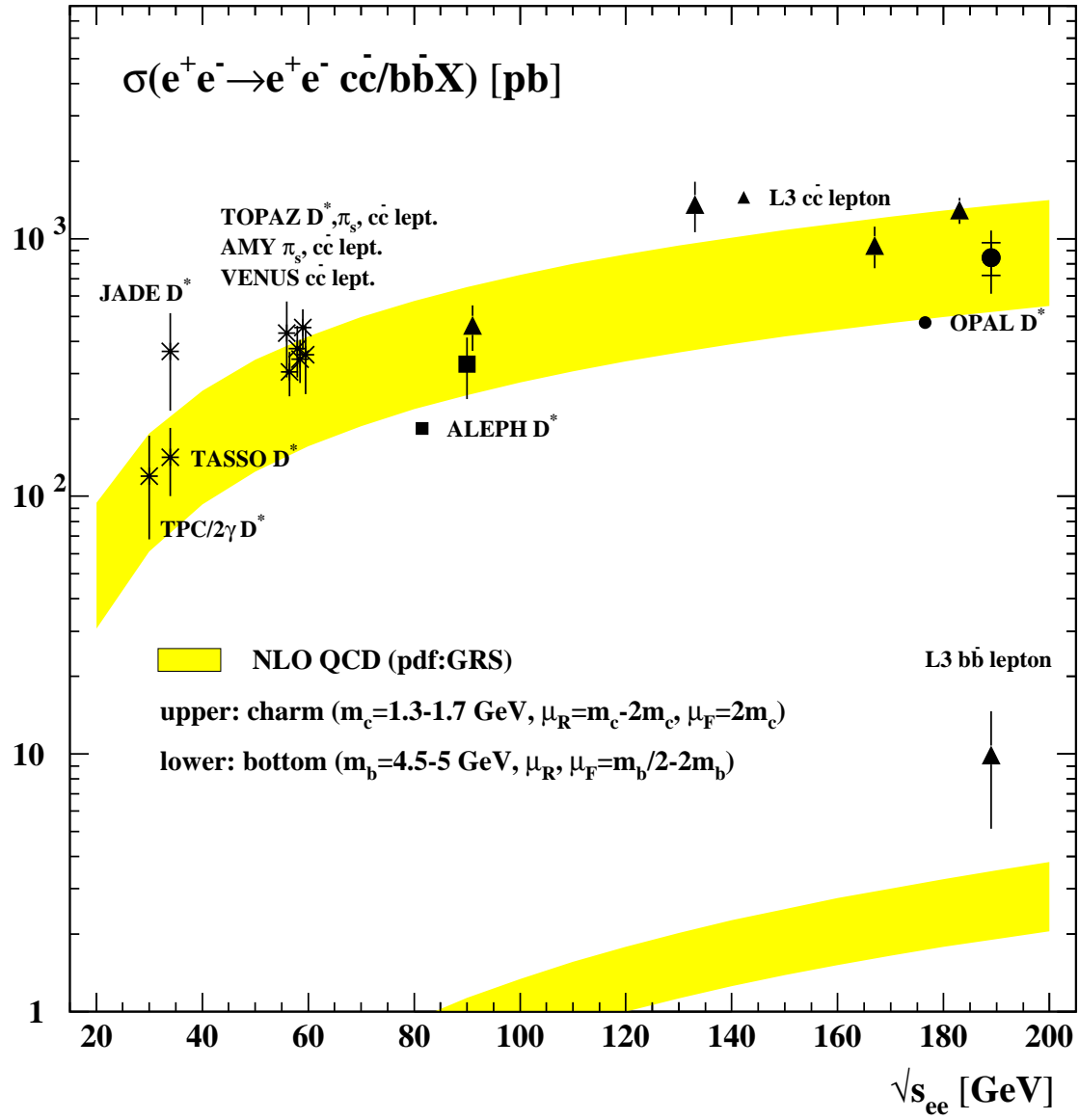


Figure 1. Comparison of NLO QCD predictions [2] and experimental results [4,5] for the total charm and bottom cross section as a function of the e^+e^- collider energy. GRS photonic parton densities [10].

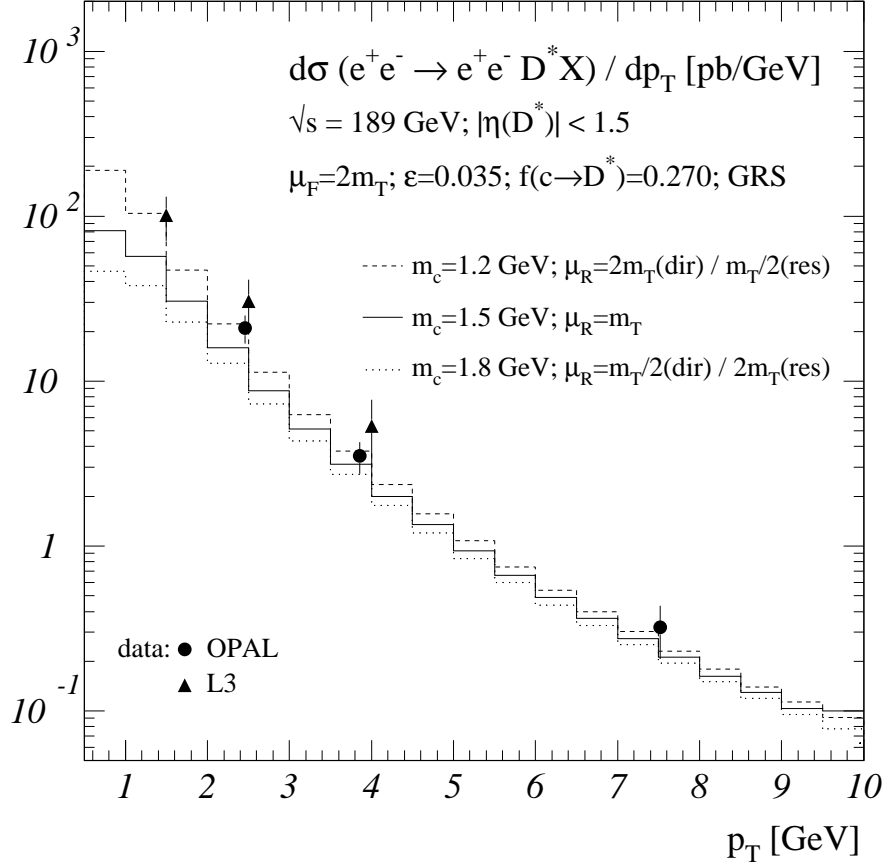


Figure 2. Comparison between the NLO QCD prediction [8] and the OPAL/L3 data [5] for the D^* transverse momentum distribution. The Peterson *et al.* fragmentation function [9] with $\epsilon = 0.035$ has been adopted and the probability for a charm quark to fragment into a D^* meson is set to $f(c \rightarrow D^*) = 0.270$. GRS photonic parton densities [10]. The L3 data [5] have been reanalyzed using an anti-tag condition for the scattered electrons [6]. In order to allow a common display of the OPAL and L3 data sets, we have scaled the L3 data to account for the different pseudorapidity range and electron anti-tag condition; numerically, the effect is $\lesssim 10\%$ and negligible on the scale of the Figure.