HEAVY FLAVOUR PRODUCTION IN TWO-PHOTON INTERACTIONS

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Measurements of charm and bottom quarks production in two-photon collisions at LEP are presented. The cross section of b production is in excess of the QCD prediction by a factor of three.

1 Introduction

The production of heavy quarks in two-photon collisions consists mainly of charm quarks. Because of their smaller electric charge and larger mass, the production of b-quarks is expected to be suppressed by more than two orders of magnitude relative to the production of charm quarks. The resolved photon cross section is dominated by the photon-gluon fusion diagram $\gamma g \rightarrow c\bar{c}, b\bar{b}$. At LEP energies, the direct and resolved processes, shown in Figure 1, are predicted to give comparable contributions to the cross section [1]. Measurements of charm production in two-photon collisions were done at LEP by ALEPH[2], DELPHI[3], L3[4,5] and OPAL[6] collaborations. Beauty production has been measured by L3[5] for the first time in gamma-gamma collisions. Preliminary result on beauty production from OPAL collaboration has been presented at PHOTON2000 conference.

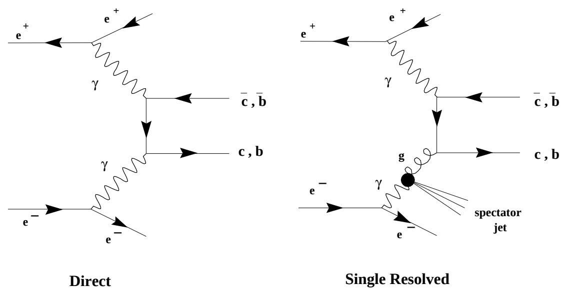

Figure 1. Diagrams contributing to charm and beauty production in $\gamma\gamma$ collisions at LEP.

2 Charm Production

Charm particles in the final state were identified by the reconstruction of charged D^* meson decays by ALEPH, DELPHI, L3 and OPAL. Both, charm and beauty quarks were identified by the L3 collaboration using tagging by electrons and muons from semileptonic charm and beauty decays.

The total inclusive charm cross sections are plotted in Figure 2 together with previous measurements. The data are compared to the theory predictions of Ref.[1]. The dashed line corresponds to the direct process, NLO QCD calculation, while the solid line shows the QCD prediction for the sum of the direct and the resolved processes calculated to NLO accuracy. The prediction for open charm is calculated using a charm mass of either 1.3 GeV or 1.7 GeV and the open charm threshold energy is set to 3.8 GeV. The theory prediction for the resolved process is calculated with the GRV parton density function [7]. The renormalization and factorization scales are chosen to be the heavy quark mass. The direct process $\gamma\gamma \to c\bar{c}$ is insufficient to describe the data, even if real and virtual gluon corrections are included. The data therefore require a significant gluon content in the photon.

The cross section of charm production with a D^* tag is in agreement with the lepton tag measurement.

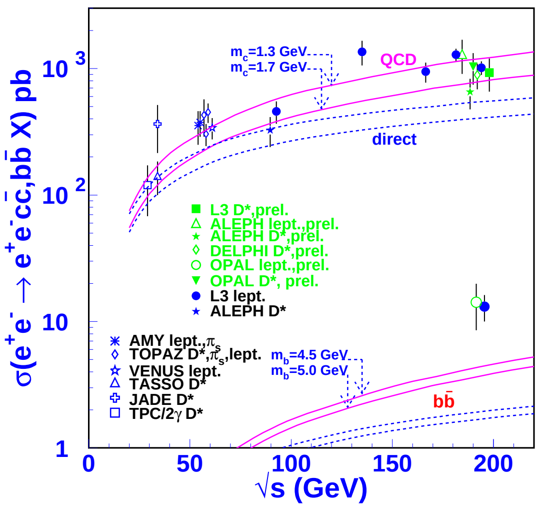

Figure 2. The open charm and beauty production cross section in two-photon collisions. The dashed line corresponds to the direct process contribution and the solid line represents the NLO QCD prediction for the sum of the direct and resolved processes.

In Figure 3 the DELPHI [3], L3 [8] and OPAL [6] measurements of the differential cross section $d\sigma/dP_T^{D^*}$ are compared to NLO QCD calculations [11], based on a massive matrix elements. In this scheme the charm quark is not considered to be one of the active flavours inside the photon. The Glück-Reya-Schienbein (GRS) [9] parton density parametrization of the photon is used in the calculation. The renormalization scale, $\mu_{\rm R}$, and the factorization scale of the photon structure function, $\mu_{\rm F}$, have been taken as $\mu_{\rm R} = \mu_{\rm F}/2 = {\rm m_T} = \sqrt{p_T^2 + m_c^2}$ with charm quark mass value $m_c = 1.5$GeV. The calculations have been also done using different renormalization scales separately for the direct and single-resolved contributions and different charm quark masses to estimate the theory prediction uncertainty. The measurements are in agreement with NLO QCD calculation within rather big theory prediction uncertainty.

The L3 collaboration measured the cross sections $\sigma({\rm e^+e^-} \to {\rm e^+e^-c\bar{c}X})$ and $\sigma(\gamma\gamma \to {\rm c\bar{c}X})$ in the interval 5 GeV $\leq W_{\gamma\gamma} \leq$ 70 GeV[10]. Figure 4 shows the $\sigma(\gamma\gamma \to {\rm c\bar{c}X})$ as function of $W_{\gamma\gamma}$ at $\sqrt{s} = 189 - 202$ GeV with NLO QCD calculations [11]. In the calculations the charm mass, $m_{\rm c}$, is fixed to 1.2 GeV, the renormalization and factorization scales are set to $m_{\rm c}$ and $2m_{\rm c}$, respectively, the QCD parameter $\Lambda_5^{\rm QCD}$ is set at 227.5 MeV, and the GRS-HO [9] photon parton density function is used. Using this set of input parameters, the NLO QCD predictions reproduce well the energy dependence and the normalization. The calculation with $m_{\rm c} = 1.5$ GeV results in about 50% lower cross section values, except the first point, where it is lower by 25%. A change in the renormalization scale from $m_{\rm c}$ to $2m_{\rm c}$ decreases the QCD prediction by

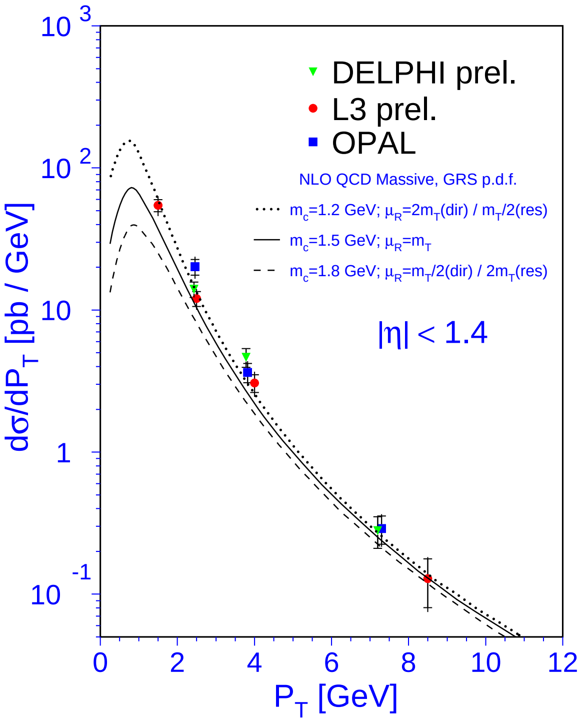

Figure 3. The differential D^* production cross section ${\rm d}\sigma/dP_T^{D^*}$ compared to the NLO QCD calculations [11].

10% and 30% at low and high $W_{\gamma\gamma}$ respectively. The measured charm cross section is also compared with the total cross section of hadron production in two-photon collisions [12], scaled by an arbitrary factor 1/20.

A steeper rise with energy is observed as compared to hadron-hadron cross sections and to $\sigma(\gamma\gamma \rightarrow hadrons)$. The fit of the form $\sigma_{\rm tot} = A\,s^{\epsilon} + B\,s^{-\eta}$, with fixed value of $\eta = -0.358$ [13] gives for the Pomeron slope $\epsilon = 0.40 \pm 0.08(\text{stat})$. The fitted value of ϵ is higher than the universal value for the total hadron-hadron cross sections $\epsilon = 0.093 \pm 0.002$ [13].

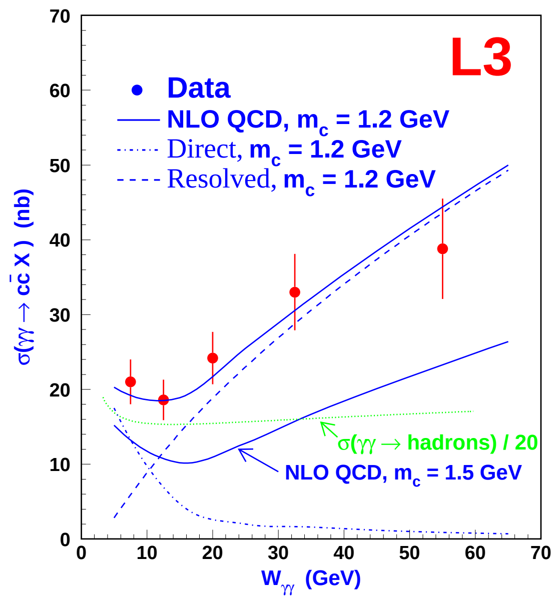

Figure 4. Cross section $\sigma(\gamma\gamma \rightarrow c\bar{c})$ versus $W_{\gamma\gamma}$ by L3. The dotted curve is the total cross section $\sigma(\gamma\gamma \rightarrow hadrons)$ measured by L3 [12] scaled by an arbitrary factor 1/20. The continuous line is the NLO QCD prediction, while the dashed-dotted and dashed curves show the expectation from the direct and resolved process respectively.

3 Beauty Production

Leptons from b semi-leptonic decays are more energetic than from charm semi-leptonic decays and non-charm two-photon processes. To select $b\bar{b}$ events L3 apply cuts on the lepton momentum and transverse momentum with respect to the closest jet defined by excluding the lepton from the jet. After all cuts are applied 137 electron and 269 muon candidates remain. The beauty purity is 42 % and 52 %, respectively. The beauty selection efficiency is 1.25 % for the electron and 2.2 % for the muon tag. The beauty production cross section in $\gamma\gamma$ collisions has been measured by L3 to be $\sigma^{ee\rightarrow eebbX} = 13.1 \pm 2.0$ (st) ± 2.4 (sys) pb. The preliminary result by OPAL using muon tag is $\sigma^{ee\rightarrow eebbX} = 14.2 \pm 2.5$ (st) ± 5.0 (sys) pb [14]. The measured b cross sections lie above QCD prediction, Figure 2. The prediction for open beauty is calculated for a b quark mass of 4.5 GeV or 5.0 GeV and the open beauty threshold energy is set to 10.6 GeV. For $\langle\sqrt{s}\rangle = 194$ GeV and a b quark mass of 4.5 GeV, this cross section is 4.4 pb. The $b\bar{b}$ cross section is measured in $\gamma\gamma$ collisions for the first time and is a factor of 3 and about 4 statistical uncertainty standard deviations higher than expected.

This is particularly interesting as measurements of beauty production in $p\bar{p}$ collisions by CDF [15] and DØ [16] as well as in ep collisions by H1 [17] and ZEUS [18] have been found to be a factor ∼2–3 higher than NLO QCD predictions.

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