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Bottom and charm quark production in two-photon collisions at LEP

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Abstract. Heavy b and c quark production in $\gamma\gamma$ collisions has been measured at LEP. We report here the cross sections measurement $\sigma(e^+e^- \to e^+e^- b\bar{b}X)$ and $\sigma(e^+e^- \to e^+e^- c\bar{c}X)$ made by DELPHI and L3 Collaboration. Inclusive $D^{*\pm}$ (J/ψ) has also been studied by L3 (DELPHI). The cross section for b production is found to exceed QCD predictions. The new DELPHI analysis using for the first time K-lepton double tagging in $\gamma\gamma$ physics confirms this excess.

1 Introduction

We report here a measurement of J/ψ production [1] in $\gamma\gamma$ collisions by the DELPHI collaboration. For the open heavy quark production the L3 collaboration measures the charm quark cross section [2] using the $D^{*\pm}$ meson for charm tagging. Concerning the $b\bar{b}$ pair production, we report here an upgrade on the cross section by L3 with the full LEP luminosity [3]. DELPHI presents a new analysis of this process [4]. As a première in two-photon physics, DELPHI made use of the K-lepton charge correlation, with kaons being identified with the RICH detector, in order to measure the charm cross section This allowed them to enhance the b and c signal.

2 J/ψ production

DELPHI has studied the inclusive J/ψ production [1] in photon-photon collisions. There are two independent leading processes in the J/ψ production. First, the J/ψ is producied by pomeron exchange or diffractive dissociation of the photon. At high J/ψ transverse momentum a resolved photon process including color octet contribution is the most probable hypothesis. DELPHI tagged 36 ± 7 J/ψ with muon pairs in LEP II data from 161 to 207 GeV for the integrated luminosity of 617 pb^{-1}. They extract the inclusive cross-section

$\sigma(J/\psi{+}X) = 53 \pm 9$ (stat) $\pm$ 17 (syst) pb. According to the PYTHIA 6.156 Monte Carlo prediction 0.74 ± 0.22 of the cross section originate from resolved processes. This production mechanism, where the 'resolved' gluon comes from a photon, provides a test of the gluon content of the photon [1].

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3 Open heavy quark production

The measurement of open heavy flavour production in photon-photon collisions provides a good test of perturbative QCD because the charm and beauty quark mass are large. This allows more reliable calculations. The next-to-leading order total cross section computation [5] [6] are available since 10 years.

3.1 Charm tagged by $D^{*\pm}$

Inclusive $D^{*\pm}$ production in photon-photon collisions have been studied by L3. This measurement [2] is performed with 683 pb^{-1} of LEP II data collected at centre-of-mass energies from 183 to 209 GeV. The event selection proceeds in two steps : first, hadronic final states from anti-tagged photon-photon collisions are selected, then $D^{*\pm}$ mesons are reconstructed in $D^0\pi$ channel. The D^0 candidates are searched in the $K^-\pi^+$, $K^-\pi^+\pi^0$ or $K^-\pi^+\pi^-\pi^+$ decay channels. In a visible kinematic region $1\ GeV < P_T < 12\ GeV$ and $|\eta| < 1.4$ they measure the $D^{*\pm}$ differential cross sections as a function of its transverse momentum and pseudorapidity. A comparison (see Fig. 1) with PYTHIA leading order and Frixione [6] next-to-leading order Monte Carlo shows a good agreement within the theoretical uncertainties. The visible $D^{*\pm}$ cross section is

$$\sigma^{e^+e^- \to\ e^+e^- D^{*\pm} X} = 71.2\ \pm\ 5.3\ (\text{stat})\ \pm\ 9.8\ (\text{syst})\ \text{pb} \quad (1)$$

From this the total charm cross section is obtained

$$\sigma^{e^+e^- \to e^+e^- c\bar{c}X} = 1.12 \pm 0.09\ (\text{stat})\ \pm\ 0.16\ (\text{syst})^{+0.54}_{-0.25}\ \text{nb}. \quad (2)$$

where the third uncertainty is that on the extrapolation from the visible phase space region to the full one. The measured cross section is in good agreement with their previous measurements based on lepton tag and the QCD expectations.

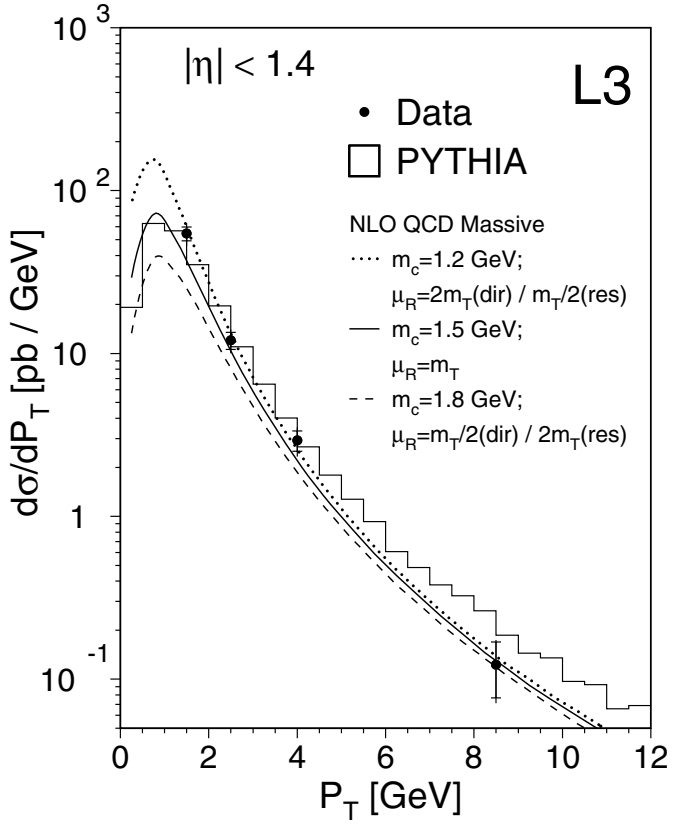

Fig. 1. The differential cross section $d\sigma/dP_T$ for inclusive $D^{*\pm}$ production

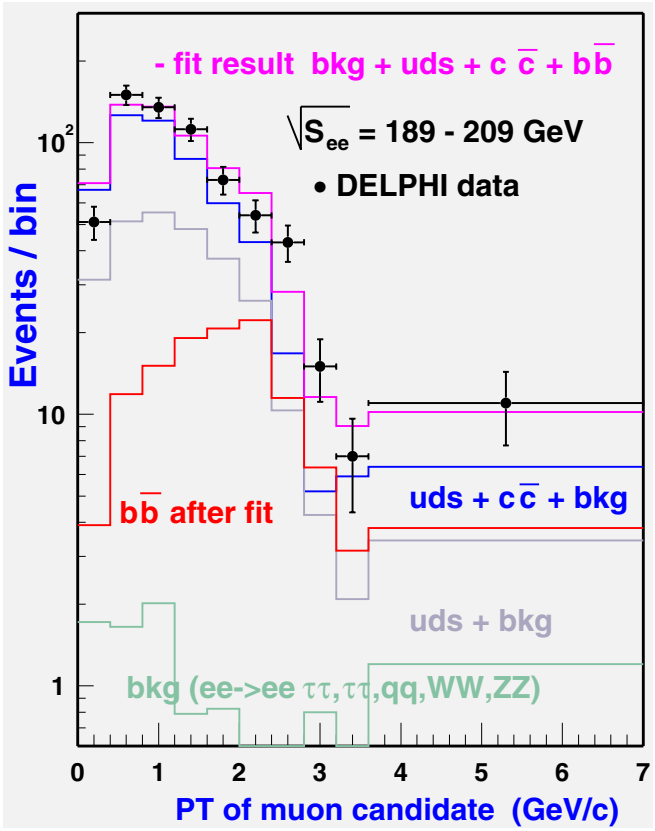

Fig. 2. Transverse momentum spectrum of inclusive muons together with the various production components

3.2 Beauty and Charm tagged lepton

The strategy for open beauty event selection is the same for both DELPHI and L3. It proceeds in three steps : selection of antitagged two-photon events, identify a lepton as a semi-leptonic charm and beauty decays and reconstructs jets in order to compute the sensitive variable ie the lepton transverse momentum (p_T) with respect to the jet axis.

DELPHI collects data with LEP center-of-mass energies from 189 GeV to 209 GeV. The luminosity sample is 463 pb^{-1}. The luminosity weighted average e^+e^- center-of-mass energy is approximately $\sqrt{s_{ee}} = 198$ GeV. We show the DELPHI p_T-distribution of candidate muons in Fig. 2 where the corresponding distributions from b and c quark have well separated shapes. The visible b contribution is fitted by minimizing the binned χ^2. DELPHI fits only one variable : the beauty contribution number in their sample. The number of annihilation background events is estimated from Monte Carlo. The charm contribution is fixed by the LEP average charm cross section and the number of light quarks (u,d,s) is estimated from a special dedicated data sample. The result is

$$\sigma^{e^+e^-\to\ e^+e^-b\bar{b}X} = 14.9 \pm 3.3\ (\text{stat}) \pm 3.4\ (\text{syst})\ \text{pb} \quad (3)$$

L3 collaboration upgrate their previous measurement with 627 pb^{-1} for the same energie range as DEPLHI. they use both muons and electrons. With their lepton candidate p_T-distribution they fit 3 variables simultaneiously, the number of beauty events, the number of charm events and the number of light quarks in their sample. The muon and electrons tag results are consistent:

$$\sigma^{e^+e^-\to\ e^+e^-b\bar{b}X}_{muons} = 13.0 \pm 2.3\ (\text{stat}) \pm 2.3\ (\text{syst})\ \text{pb}$$

$$\sigma^{e^+e^-\to\ e^+e^-b\bar{b}X}_{electrons} = 12.6 \pm 2.4\ (\text{stat}) \pm 2.3\ (\text{syst})\ \text{pb}$$

so they combine the results

$$\sigma^{e^+e^-\to\ e^+e^-b\bar{b}X}_{combined} = 12.8 \pm 1.7\ (\text{stat}) \pm 2.3\ (\text{syst})\ \text{pb} \quad (4)$$

and this is in agreement with their previous measurement. As a subproduct of the control test of the charm sample they give the charm cross section

$$\sigma^{e^+e^-\to\ e^+e^-c\bar{c}X}_{combined} = 998 \pm 117\ (\text{stat})\ \text{pb} \quad (5)$$

3.3 K-lepton correlations

The DELPHI analysis uses the charge correlation between kaon and lepton arising from the semileptonic decay of heavy quarks. It is a useful tool to increase the purity of b and c events. Extracting cross sections in particular provides a check on the internal consistency of the measurement in case of b quark production.

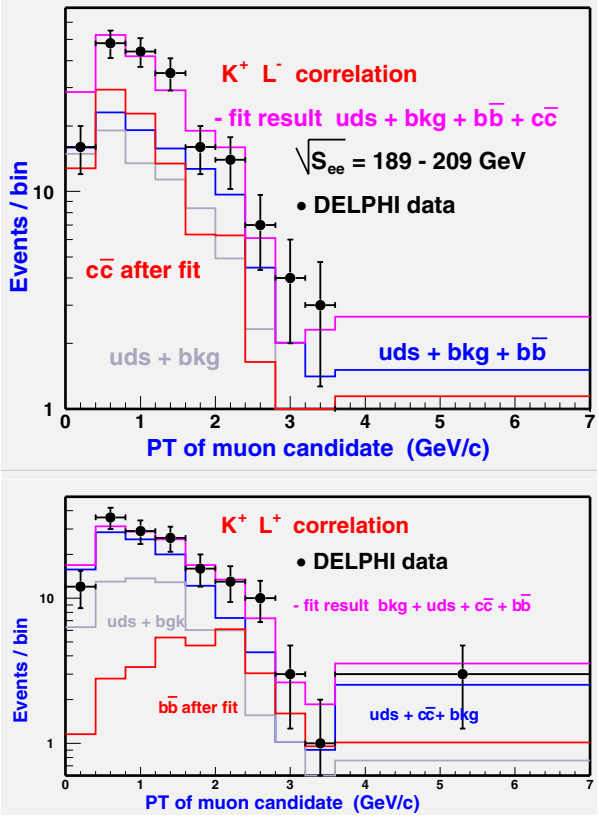

Fig. 3. Inclusive muons transverse momentum with K-lepton tagging showing all rescaled components

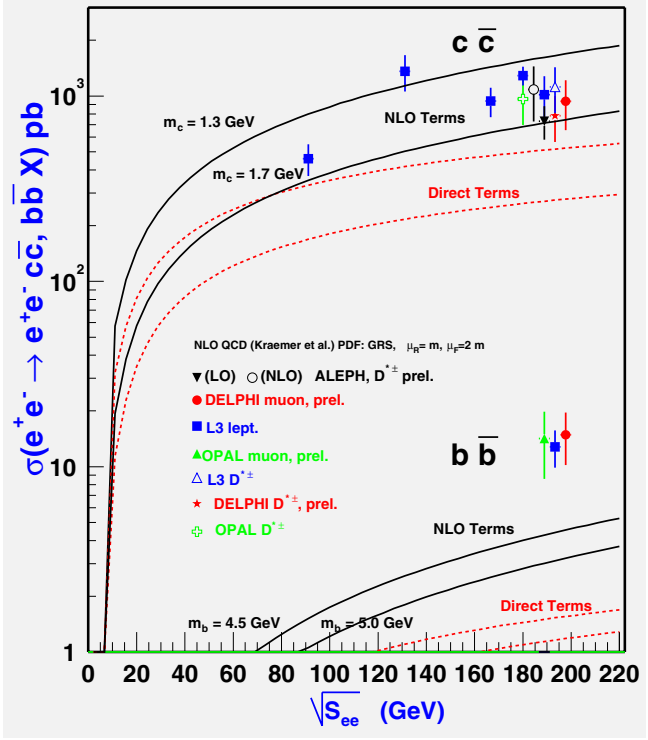

Fig. 4. LEP results

The muon p_T-distribution was again used. In addition, a kaon had to be identified in the jet using the specific ionisation dE/dx measured in the TPC detectors and the Cherenkov radiation detected in the barrel and forward RICH. In order to obtain the charm cross section from the $K^{\pm}\ell^{\mp}$ sample (see Fig. 3) DELPHI fits the number of charm events. The other parameters are fixed. In particuliar the number of beauty events is given by their previous measurement. The result is

$$\sigma^{e^+e^-\to\, e^+e^- c\bar{c}X} = 937 \pm 191\ (\text{stat}) \pm 206\ (\text{syst})\ \text{pb}. \quad (6)$$

Using the charge correlation between $K^{\pm}$ and $\ell^{\pm}$ (see Fig. 3) DELPHI fits the beauty contribution, all other parameters are fixed, in particuliar the charm contribution is always given by charm cross section LEP average. The beauty cross section is then

$$\sigma^{e^+e^-\to\, e^+e^- b\bar{b}X} = 11.4\ \pm\ 4.5\ (\text{stat})\ \ \text{pb} \qquad (7)$$

which is quite compatible with the previous DELPHI results.

3.4 Discussion

The measurement of the cross section of beauty and charm quarks in two photon collisions at LEP2 average center of mass energy of 198 GeV has been performed. The results beetween Collaborations show a good agreement. All the LEP experiments published and preliminary results on the total e^+e^- cross section for b and c production in $\gamma\gamma$ collisions are shown in Fig. 4. They are compared to the Drees, Krämer, Zunft and Zerwas NLO QCD calculation [5].For the charm production a significant gluon content in the photon is required by the data [3], [4]. DELPHI extracted b cross section confirms the L3 and OPAL [7] beauty excess. The L3 best precise measurement shows a factor 3 higher than expected [3].

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