Jet (and heavy flavour) production in hard photon-photon collisions

Valery P. Andreev[1]

Department of Physics and Astronomy,
202 Nicholson Hall,
Louisiana State University,
Baton Rouge, LA 70803, USA
E-mails: Valeri.Andreev@cern.ch

Abstract

The results on the production of jets, charged hadrons and K_S^0 mesons in the collisions of quasi-real photons by the OPAL collaboration at LEP are presented. We present also recent results on production of charm (by the L3 and OPAL) and beauty (by L3) in $\gamma\gamma$ collisions. Hadronic final states containing charm and beauty particles were identified by detecting electrons or muons from their semi-leptonic decays. Charm particles in the final state were also identified by the reconstruction of charged D^* meson decays. The cross section of beauty production in $\gamma\gamma$ collisions has been measured for the first time. The measurements are in a reasonable agreement with QCD calculations.

1. Introduction

A quasi-real photon interacts as a hadron due to quantum fluctuations into vector mesons or into quark-antiquark pairs. The $\gamma\gamma$ cross section is composed by a "soft (VDM)" interaction, which can be described by hadronic phenomenology, like the Regge poles, a point like two-photon reaction, $\gamma\gamma \rightarrow q\bar{q}$, which is exactly calculable in QED (direct component) and a "hard component" (resolved or anomalous or QCD component) which implies the knowledge of the quark and gluon density in the photon. The "hard component" of two-photon interactions can be accessed in measurements of high-p_t single particle and jet production, and in heavy flavour production. A hard physical scale is given then by p_t or by c(b)-quark mass. The LEP e^+e^- collider is an ideal place to study two photon physics. The background from the high energy annihilation events is normally low.

2. Jet and single particle production

Di-jet production, the production of charged hadrons and K_S^0 mesons in the collisions of quasi-real photons has been measured by the OPAL collaboration at LEP[1]. The data were taken at e^+e^- centre-of-mass energies of 161 and 172 GeV with the total integrated luminosity of $\mathcal{L} = 20$ pb^{-1}. The jets were reconstructed using a cone jet finding algorithm in the kinematic range $E_T^{jet} > 3$ GeV and $|\eta^{jet}| < 2$. The differential cross sections as a function of the transverse energy and the pseudorapidity have been compared to the leading order Monte Carlo generators of PYTHIA and PHOJET and to perturbative next-to-leading order (NLO) QCD calculations. The inclusive two-jet cross section is shown in Figure 1a as a function of E_T^{jet}. The distribution is compared to a NLO QCD calculation[2]. The renormalisation and factorisation scales have been chosen to be equal to E_T^{jet}. The measured cross sections are in good agreement with NLO QCD calculations except for the first bin were the NLO calculations are not reliable. The inclusive two-jet cross section is dominated by the resolved processes in the low E_T^{jet} region, at high E_T^{jet} the direct process contribution is the largest. The Monte Carlo models PYTHIA and PHOJET describe the transverse energy flow around the jets reasonably well. Figure 1b shows the inclusive p_T distribution for the charged hadrons measured in $\gamma\gamma$ interactions by OPAL and compared to the p_T distribution measured in γp and hp ($h = \pi, K$) interactions by WA69. There is an evidence for hard photon interactions (direct process contribution) in addition to the hadronic photon interactions. A clear deviation is seen at large p_T from the

† on leave from Petersburg Nuclear Physics Institute.

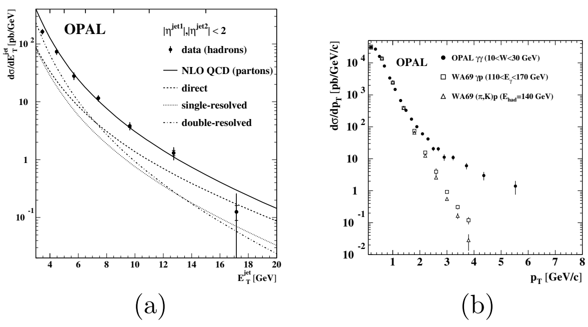


Figure 1. (a) The inclusive two-jet cross section as a function of E_T^{jet} compared with the NLO QCD calculations [2], (b) the charge hadron p_T distribution measured in $\gamma\gamma$ interactions is compared to the p_T distribution measured in γp and hp ($h = \pi, K$) interactions.

exponential fall-off expected for purely hadronic interactions. The transverse momentum and pseudorapidity distributions of the K_S^0 mesons are well reproduced by the NLO calculations, but they are significantly underestimated by the Monte Carlo models PYTHIA and PHOJET.

3. Charm production

At high energies, the direct and resolved photon processes are predicted to give comparable contributions to the charm and beauty production cross section [3]. The single-resolved photon cross section is dominated by the photon-gluon fusion diagram $\gamma g \to c\bar{c}, b\bar{b}$. The production rate of the c- and b-quarks in two-photon collisions depends on the mass of the c- and b-quark and on the gluon density in the photon.

In this paper we present recent results on the measurement of charm production by the L3 and OPAL collaborations at LEP[5]. The measurements of $\sigma(\mathrm{e^+e^-} \to \mathrm{e^+e^-c\bar{c}X})$ cross section , inclusive D^* production cross section as well as differential D^* cross sections in p_t and pseudorapidity have been performed. Charm quarks have been tagged by electrons and muons from their semi-leptonic decays by the L3. Electrons are selected with momentum greater than 0.6 GeV/c, muons with momentum greater than 2.0 GeV/c. The data collected by L3 in the period of 1994 through 1997 at $\sqrt{\mathrm{s}} =$ 91-183 GeV have been analyzed for an integrated luminosity of $\mathcal{L} = 165$ pb^{-1} [4]. Preliminary result at $\sqrt{\mathrm{s}} =$ 189 GeV corresponds to $\mathcal{L} = 176$ pb^{-1}. The preliminary L3 result on charm production at $\sqrt{s} = 189$ GeV is $\sigma(e^+e^- \to e^+e^-c\bar{c}X) = 1378\mathrm{pb} \pm 55(\mathrm{st}) \pm 134(\mathrm{sys})$.

The charmed vector mesons $D^*(2010)^+$ are identified by the small energy released in D^* decay, applying the mass difference technique[6]. The D^{*+} mesons are reconstructed in their decay to $D^0\pi^+$ with the D^0 observed in the two decay modes $K^-\pi^+$ (L3, OPAL), $K^-\pi^+\pi^0$ (L3) and $K^-\pi^+\pi^-\pi^+$ (OPAL). Differential D^* production cross sections as functions of the $D^{*\pm}$ transverse momentum $\mathrm{p_T^{D^*}}$ and pseudorapidity η^{D^*} are presented in Figure 2 in the kinematic region 1 GeV $< \mathrm{p_T^{D^*}} <$ 5 GeV, $|\eta^{\mathrm{D}^*}| <$ 1.4 (L3),and 2 GeV $< \mathrm{p_T^{D^*}} <$ 12 GeV, $|\eta^{\mathrm{D}^*}| < 1.5$ (OPAL). The observed number of D* mesons is 149 for the L3 ($\mathcal{L} = 176$ pb^{-1}) and 139 for the OPAL ($\mathcal{L} = 220$ pb^{-1}). The differential cross sections

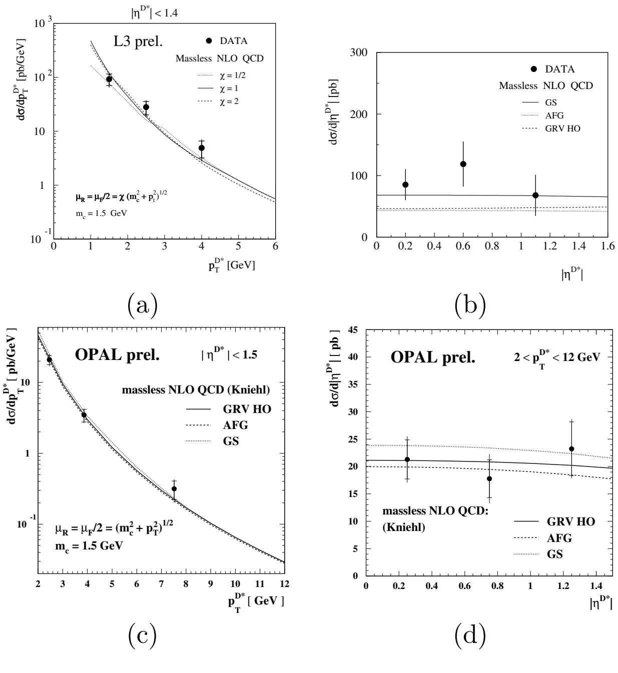


Figure 2. The differential cross section of D^* production as a function of the transverse momentum, ((a) for L3 and (c) for OPAL), and as a function of the pseudorapidity ((b) for L3 and on (d) for OPAL).

are compared to next-to-leading order perturbative QCD computations, based on a massless approach in calculating the parton level cross sections [7]. There is a reasonable agreement between the data and the calculations. The OPAL data for the kinematic variable $\mathrm{p_T^{D^*}/W_{vis}}$ have been fitted in order to determine fractions of direct and single-resolved processes. The fit yields $(52 \pm 10)\%$ events in the data are direct and $(48 \pm 10)\%$ are single-resolved which translates into the direct process contribution to the total cross section to be $(392 \pm$

117) pb and the single-resolved contribution to be (553 ± 184) pb.

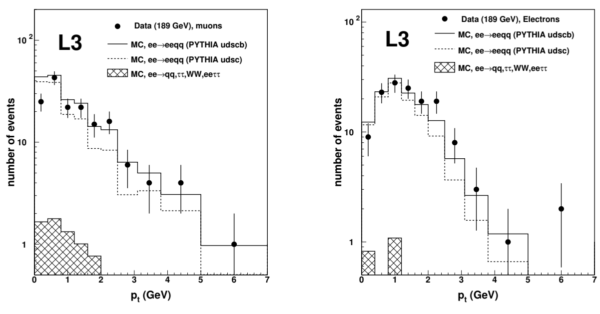
The total inclusive charm cross sections are plotted in Figure 4 together with previous measurements. The data are compared to the theory predictions of Ref.[3]. The dashed line corresponds to the direct process, NLO QCD calculation, while the solid line shows the QCD prediction for the sum of the direct and the resolved processes calculated to NLO accuracy ($m_c =$ 1.3 GeV and $m_b =$ 5.0 GeV). The cross section increases with energy as expected by QCD predictions. The cross section of charm production with a D^* tag is in agreement with the lepton tag measurement.

4. Beauty production

The events with b-quarks have been selected by the L3 applying cuts on the lepton momentum and transverse momentum p_t with respect to the closest jet. The jets are reconstructed by the JADE algorithm with cut $y = 0.1$. The lepton is excluded from the jet. Figure 3 shows an electron and muon transverse momentum with respect to the closest jet. The solid histogram is the contribution from all flavours including b, while the dashed histogram is the PYTHIA prediction for uds quarks plus charm. The charm fraction in the PYTHIA Monte Carlo has been scaled to the measured charm cross section. The cuts are defined by minimizing the statistical error on the cross section measurement. The lepton momentum must be greater than 2 GeV for electrons and 2.5 GeV for muons, the transverse momentum p_t greater than 1 GeV and 1.5 GeV for electrons and muons, respectively. The observed number of events is 96 for the electron tag and 49 for the muon tag. The beauty purities (selection efficiencies) are 28% (1.6%) and 34% (0.9%) for electron and muon samples, respectively. One can see from the Figure 3 that the beauty purity increases with the transverse momentum. The preliminary beauty production cross section in $\gamma\gamma$ collisions has been measured to be

$$\sigma^{ee \to eebbX} = 9.9 \pm 2.9 \text{ (stat) } \pm 3.8 \text{ (syst) pb}$$

The results plotted in Figure 4 lie somewhat above QCD predictions.



(a) (b)

Figure 3. (a) Muon and (b) electron p_t with respect to the closest jet.

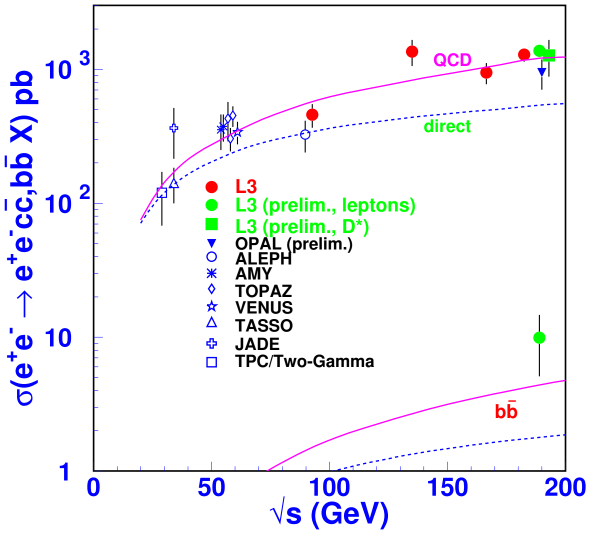


Figure 4. Charm and beauty production cross section

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