JETS AND PROMPT PHOTON PRODUCTION IN TWO-PHOTON COLLISIONS AT LEP*

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Di-jet and prompt photon production is studied in collisions of quasi-real photons radiated by the LEP beams at e^+e^- centre-of-mass energies $\sqrt{s_{ee}}$ from 183 to 209 GeV. The data have been taken with the OPAL and DELPHI detectors.

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1. Introduction

Two photon interactions studied at e^+e^- colliders traditionally provide information on the structure of the photon and tests of perturbative QCD. At e^+e^- colliders the photons are emitted by the beam electrons (positrons are also referred to as electrons). Most of the photons carry only a small negative squared four-momentum, Q^2, and can be considered quasi-real ($Q^2 \approx 0$). The electrons are scattered with very small polar angles and are generally not detected (tagged). Events where one scattered electrons is detected are deep inelastic scattering $e\gamma$ events which lead to the determination of structure functions, similar to the ones of nucleons.

Here events are selected where both electrons are untagged. Interactions of the photons can be modelled by assuming that each photon either interacts directly or fluctuates into hadronic components. At LO three processes contribute to di-jet production in photon–photon collisions: the direct process where two bare photons interact, the single-resolved process where a bare photon interacts with a parton (quark or gluon) of the other photon, and the double-resolved process where partons of both photons interact.

For the prompt photon production channel, the relevant diagrams are single resolved and double resolved contributions, with predicted total cross section of about 0.13 pb by PYTHIA [1].

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In both the di-jet and isolated prompt photon processes the resolved partonic structure of the photon is involved and can thus be measured. In particular the gluon density of the photon enters at the Born level, unlike in $e\gamma$ scattering where it enters via scaling violations. In practice the expected event rate in the prompt photon channel is too low, and this channel can only be used to check the pQCD prediction.

2. Di-jet production

OPAL has measured the production of di-jets in the collision of two quasi-real photons at $\sqrt{s_{ee}}$ from 189 to 209 GeV with a total integrated luminosity of 593 pb^{-1}. The jets are reconstructed using an inclusive $k_\perp$ clustering algorithm [2]. The two jets are used to estimate the fraction of the photon momentum participating in the hard interactions. The transverse energy of the jets provides a hard scale which allows such processes to be calculated in perturbative QCD. Fixed order calculations at next-to-leading order (NLO) in the strong coupling constant α_s for di-jet production are available and are compared to the data, providing tests of the theory.

Di-jet events in OPAL data [3] are selected by requiring at least two jets with $\eta_{\rm jet} < 2$ and a mean transverse energy $\bar{E}_{\rm T}^{\rm jet} > 4$ GeV. In addition $|E_{\rm T,1}^{\rm jet} - E_{\rm T,2}^{\rm jet}|/(E_{\rm T,1}^{\rm jet} + E_{\rm T,2}^{\rm jet}) < 1/4$ is required to prevent low $E_{\rm T}^{\rm jet}$ jets from entering the analysis. In events with more than two jets, only the two jets with the highest $E_{\rm T}^{\rm jet}$ values are taken. After applying all cuts 32860 di-jet events remain. The estimated background in this sample is about 5%.

In LO QCD a pair of variables, x_γ^+ and x_γ^-, can be defined which estimate the fraction of the photon's momentum participating in the hard scattering:

$$x_\gamma^+ \equiv \frac{\sum\limits_{\rm jets=1,2} (E^{\rm jet} + p_z^{\rm jet})}{\sum\limits_{\rm hfs} (E + p_z)} \quad \text{and} \quad x_\gamma^- \equiv \frac{\sum\limits_{\rm jets=1,2} (E^{\rm jet} - p_z^{\rm jet})}{\sum\limits_{\rm hfs} (E - p_z)}\,, \tag{1}$$

where p_z is the momentum component along the z axis of the detector and E is the energy of the jets or objects of the hadronic final state (hfs). At parton level for direct events the total energy is contained in the two jets, *i.e.* $x_\gamma^+ \sim 1$ and $x_\gamma^- \sim 1$, whereas for single-resolved events either x_γ^+ or x_γ^- and for double-resolved events both x_γ^+ and x_γ^-, are expected to be significantly smaller than 1.

Differential cross sections are shown in Fig. 1. The left plot in Fig. 1 shows the differential di-jet cross section as a function of the mean transverse energy $\bar{E}_{\rm T}^{\rm jet}$ of the di-jet system for the full x_γ-range, for either x_γ^+ or x_γ^-<1 (dominated by single resolved processes), or $x_\gamma^\pm$<1 (dominated by double resolved processes). The prediction of perturbative QCD in NLO [4] using the GRV-G HO [5] parton densities is compared to the data after hadronisation corrections have been applied to the calculation. The calculation is in good agreement with the data, except for being too low at small $\bar{E}_{\mathrm{T}}^{\mathrm{jet}}$ for $x_\gamma^\pm<1$. The NLO calculations do not contain effects from underlying event such as *e.g.* multiple parton interactions (MIA). The three plots on the right hand side of Fig. 1 show the differential cross section as a function of x_γ for the three regions in x_γ^+-x_γ^--space described above. The shaded histogram on the bottom of each of the three plots indicates the contribution of MIA to the cross section as obtained from the PYTHIA [1] MC generator. It is evident especially for $x_\gamma^\pm<1$ that the MIA contribution is of about the same size as the discrepancy between the measurement and the NLO prediction. Furthermore it is interesting to observe that there is almost no MIA contribution to the cross section if either x_γ^+ or x_γ^- is required to be less than 0.75, while the sensitivity to the photon structure at small x_γ is retained. Hence this region will allow to test different assumptions of the gluon distribution in the photon.

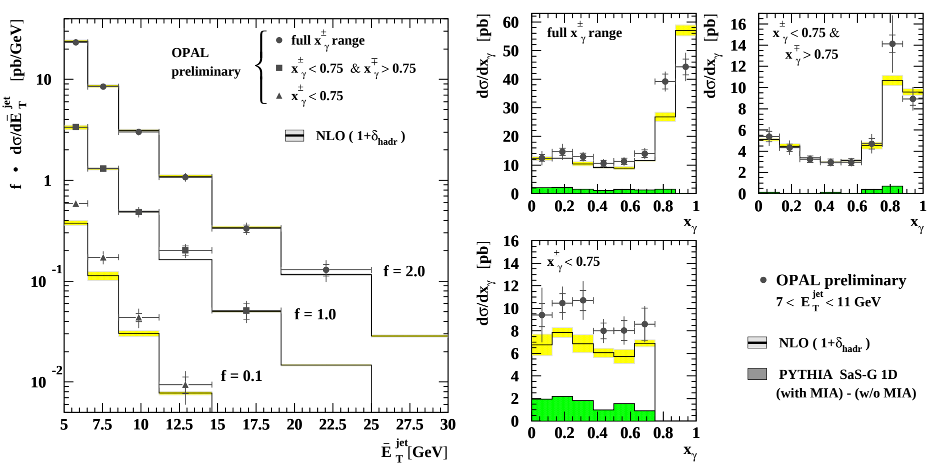

Fig. 1. Differential jet cross sections as measured by OPAL

DELPHI [6] has analysed 220 pb^{-1} of data taken at $\sqrt{s_{ee}}$=192–202 GeV using a cone algorithm with $R = 1$ to define the jets. The first preliminary results of the di-jet cross sections as a function of the jet transverse energy and the jet pseudorapidity are found to be consistent with a previous measurement by OPAL.

3. Prompt photon production

A measurement is presented of the inclusive production of isolated prompt photons in photon–photon collisions using OPAL data [7], $\gamma\gamma \to \gamma X$, where X denotes the hadronic final state produced in addition to the photon. In these processes a quark or a gluon from the hadronic state participates in the hard interaction, $\gamma q \to \gamma q$, $gq \to \gamma q$, and $qqbar \to \gamma g$. The inclusive production cross section for isolated prompt photons is expected to be about two orders of magnitude smaller than for di-jet production in a similar kinematic range (transverse energy $E_{\mathrm{T}} > 3$ GeV, pseudorapidity $|\eta| < 1$). Hadronisation uncertainties, however, are much smaller than in the case of jet production allowing a complementary study of the hadronic structure of photon interactions. All data are used from the years 1997–2000, giving a data sample of approximately 650 pb^{-1}.

The measurement of prompt photon production is restricted to isolated photons to suppress backgrounds from neutral particle decays into photons and from photons radiated by Final State Quarks (FSR) predominantly close to the direction of the quark momentum. Photons are selected with $|\eta_\gamma| < 1$ and $p_{\mathrm{T}} > 3$ GeV/c. After a series of cuts, including an isolation criterion [8] on the photon, 130 events are left. The composition of single and double resolved events is made with two techniques, one based on photon-jet events which allow to reconstruct x_γ and another which uses all events and is based on the photon transverse momentum x_{T}. This composition needs to be known since the efficiencies for both processes are different. Both methods give a similar result of about 50% single and double resolved contributions in the selected phase space.

The result is the cross section is

$$\sigma(|\eta_\gamma| < 1, p_{\mathrm{T}} > 3\mathrm{GeV}/c) = 0.26 \pm 0.04 \pm 0.03\,\mathrm{pb}\,. \tag{2}$$

The measured cross section is 1.85 times higher than the PYTHIA prediction.

Differential cross sections are compared to recent NLO calculations [9] in Fig. 2. The theoretical uncertainty is about 10%. Note that in present experimental analysis the final state radiation is not included in the data shown. Including this contribution as in the theoretical calculations would increase the data points by about 5-10%.

4. Summary

New results on di-jets and prompt photon data production in photon–photon collisions using 1997 (1998) to 2000 data from LEP have been presented.

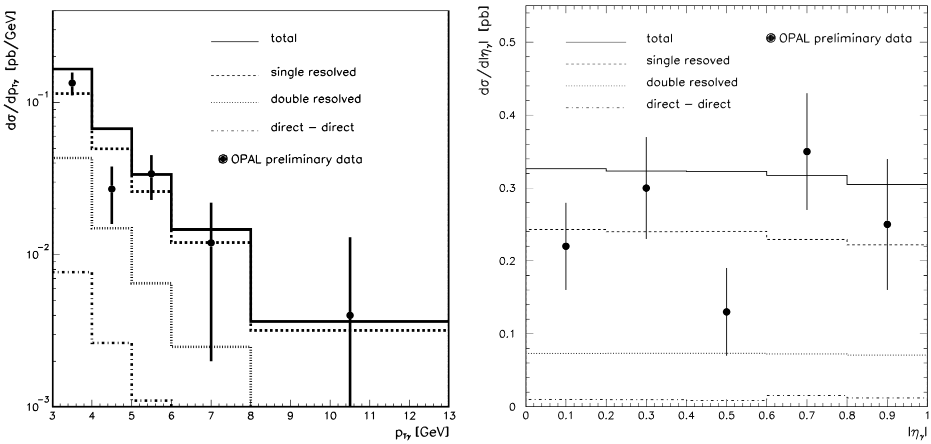

Fig. 2. Comparison of the NLO calculations of [9] with OPAL prompt photon data for p_{T} and η.

Di-jets show sensitivity to the gluon distribution. When selecting a sample dominated by single resolved events the multiple interaction effects can be largely reduced. Hence these measurements can be used to measure the gluon density in the photon. NLO calculations agree well with the data

The prompt photon signal is small as expected. PYTHIA predicts a cross section which is 1.85 smaller than the one observed. The NLO calculations agree reasonably well with the data.

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