JET PRODUCTION IN $\gamma\gamma$ COLLISIONS*

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The production of two high $p_{\rm T}$ jets in the interactions of quasi-real photons is studied with DELPHI (LEP, CERN) data. The differential di-jet cross-section is measured as a function of mean jets momentum $\overline{p_{\rm T}}$ and is compared to the perturbative QCD calculations.

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1. Introduction

This paper presents the results of a study of di-jet events produced in two-photon collisions in the anti-tagged mode, where scattered electron and positron escape the setup. Large $p_{\rm T}$ processes involving quasi-real photons are sensitive to both, quark and gluon, components of the resolved photons. The analysis of the high $p_{\rm T}$ jet production complements the studies of deep-inelastic scattering of a quasi-real photon which probes the quark distributions. Considered together, they allow to determine the parton density function of the photon. The perturbative QCD scale of the hard interactions is provided by the jet transverse energy to be used in the calculations.

The data used for this analysis were collected by the DELPHI detector [1] at LEP at $\sqrt{s_{ee}}$ from 189 GeV to 209 GeV and an integrated e^+e^- luminosity of 550 pb^{-1}. The jets are reconstructed by the $k_\perp$-cluster algorithm [2] for the transverse momentum above 3 GeV/c and within the pseudo-rapidity range $|\eta| < 1$.

The data corrected for the detector effects are compared to the leading and next-to-leading order QCD calculations [3].

The DELPHI performance is described in detail in Ref. [1].

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The following criteria are applied to select the data sample:

— each event contains at least 5 charged particles *(multihadron events)*;

— invariant mass is below $35\,\mathrm{GeV}/c^2$. The total transverse momentum is below 30 GeV/c *(background suppression)*;

— there are no clusters in the luminosity monitor with energies greater than 25 GeV *(anti-tagging condition)*;

— pseudo-rapidity η of each jet must be in the range $-1 < \eta < 1$ and the jet transverse momentum p_T is above $3\,\mathrm{GeV}/c$ *(di-jet event selection)*;

— average transverse jet momentum $\overline{p_\mathrm{T}} > 4\,\mathrm{GeV}/c$ *(p_T asymmetry of jets)*. The cut is introduced for comparison with QCD calculations.

The above criteria select a data sample of *5147 events*.

The Monte Carlo leading order generator PYTHIA (version 6.205) [4] is used for the simulation of hadron production in $\gamma\gamma$ interactions. The soft underlying events are modeled through the multiple interactions (MIA) of several parton pairs interacting within the same event.

The main background process ($e^+e^- \to$ hadrons) is estimated to amount to (500 ± 5) events, using KK2f event generator (version 4.14) [6]. The contamination of τ pairs produced in the two-photon interactions is evaluated as (43 ± 3) events, using the BDKRC program [7]. The events with W, Z bosons contribute (38 ± 4) events. Additional sources will be discussed later.

The trigger efficiency is close to unity.

The $\gamma\gamma$ collisions exhibit a behavior typical of hadron–hadron interactions. In order to emphasize the invariance under boosts along the beam axis, the natural variables adopted for the jet analysis are the transverse momentum p_T, the azimuthal angle ϕ and the pseudo-rapidity $\eta = -\ln(\tan(\theta/2))$ of the particle.

The interaction of bare photons (the direct term) is described by the Born-box diagram within the quark–parton model (QPM). If one or both photons are resolved into a partonic structure, the process is termed single- or double-resolved, respectively. The relative contribution of different components depends on the kinematic regime.

Almost all hadrons produced in QPM-like event should belong to reconstructed jets, while events with resolved photons are accompanied by the remnant jet(s). The variables sensitive to such a difference are [8]:

$$x_\gamma^+ = \frac{\sum\limits_{\mathrm{jets}} (E_\mathrm{jet} + p_{z,\mathrm{jet}})}{\sum\limits_{\mathrm{part}} (E_\mathrm{part} + p_{z,\mathrm{part}})}, \qquad \text{and} \qquad x_\gamma^- = \frac{\sum\limits_{\mathrm{jets}} (E_\mathrm{jet} - p_{z,\mathrm{jet}})}{\sum\limits_{\mathrm{part}} (E_\mathrm{part} - p_{z,\mathrm{part}})}.$$

The entire (x_γ^+, x_γ^-) space can be split into four quadrants by x_γ equal to 0.85 with approximately equal statistics of the domains studied below.

The jet reconstruction $k_\perp$-cluster algorithm is implemented in the KTCLUS program [2].

Comparison of the data with the Monte Carlo simulation shown that the model does not describe the data in the parts of the $(x_\gamma^+ - x_\gamma^-)$ space where the contribution of the resolved processes is essential. The 3-parameters fit of the data is performed. The obtained parameters (scale factors for each model component) are $\alpha_{qpm} = (0.86 \pm 0.02), \alpha_{\mathrm{s-res}} = (1.49 \pm 0.09)$ and $\alpha_{\mathrm{d-res}} = (1.93 \pm 0.05)$. The Monte Carlo set consists of 33% QPM-like events, 23% single-resolved and 44% double-resolved events. The latter is subdivided into no-MIA (75%) and with-MIA (25%) contributions.

The modeling of the double-resolved events includes the so-called multiple parton interactions (MIA) — it is assumed that different pairwise interactions may take place during one $\gamma\gamma$ collision. It has been shown that the inclusion of the MIA part improves the description of the data [9]. The MIA contribution becomes the background when the hard process alone does not provide two jets passing via the selection criteria but being combined with MIA initiated particles it provides. The background coming from the MIA contribution is estimated as (131 ± 7) events, using the PYTHIA generator running in the mode with MIA switched off.

The theoretical predictions have to be transformed from the parton level (so-called "hadronization corrections") since Monte Carlo partons are considered in the leading-order and are not identical to the NLO partons in the theoretical calculations. The corrections have been calculated using the PYTHIA program. The distribution of the mean transverse momentum of the jets $\overline{p_{\mathrm{T}}}$ obtained with $k_\perp$-cluster algorithm at the parton level, is divided by the distribution obtained after hadronization.

Transformation of the data from the level of the detected particles to the hadrons produced in $\gamma\gamma$ interactions is made in order to take the detector acceptance into account. The bin-by-bin corrections are used.

One more source of the background (so-called "non2-to-2 jets" background) should be taken into account. Some event, being a non-two-jet event at the level of the produced particles, is reconstructed as a two-jet event because undetected particles change the event topology. This kind of the background is estimated as (893 ± 13) events.

The data are corrected on the acceptance and the hadronization, and the total di-jet cross-section is measured as (17.1 ± 0.3) pb. The model expectations are (20.2 ± 0.1) pb and (17.8 ± 0.1) pb for the calculations which have been carried out in the leading and next-to-leading order [3], respectively. The differential cross-section is shown in Fig. 1 together with the predictions mentioned above.

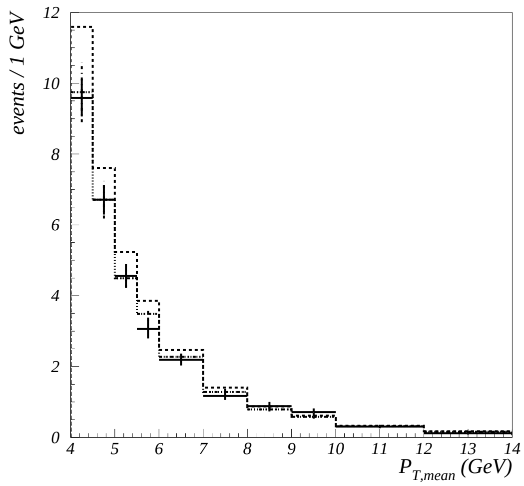

Fig. 1. Cross-section of di-jet production in quasi-real $\gamma\gamma$ interactions. Histograms show the leading (dotted) and next-to-leading (dashed) order calculations [3].

2. Conclusion

The production of two high p_{T} jets in the interactions of quasi-real photons is studied with the DELPHI data taken at LEP2 at the integrated e^+e^- luminosity of $550\,\mathrm{pb}^{-1}$. The jets reconstructed by the $k_\perp$-cluster algorithm are defined within the pseudo-rapidity range of $-1 < \eta < 1$ and at the jet transverse momentum p_{T} — above $3\,\mathrm{GeV}/c$. The total and differential di-jet cross-sections are measured for the mean jet momentum $\overline{p_{\mathrm{T}}}$ from $4\,\mathrm{GeV}/c$ to $14\,\mathrm{GeV}/c$. The total cross-section agrees with the next-to-leading order perturbative QCD calculation within the experimental uncertainties, at the same time it is 18% below the calculation carried out in the leading order. The measured differential di-jet cross-section is also found in good agreement with NLO QCD predictions.

REFERENCES

[1] DELPHI Collab., P. Abreu *et al.*, *Nucl. Instrum. Methods* **A378**, 57 (1996).
[2] M. Seymour, `http://hepwww.rl.ac.uk/theory/seymour/ktclus`
[3] M. Klasen, G. Kramer, *Phys. Lett.* **B366**, 385 (1996); M. Klasen, private communication.
[4] T. Sjöstrand, *Comput. Phys. Commun.* **82**, 74 (1994).
[5] H. Plothow-Besch, *Int. J. Mod. Phys.* **A10**, 2901 (1995).
[6] S. Jadach, B. Ward, Z. Was, *Comput. Phys. Commun.* **130**, 260 (2000).
[7] F. Berends *et. al., Comput. Phys. Commun.* **40**, 271 (1986); **40**, 285 (1986); **40**, 309 (1986).
[8] L. Lönnblad, M. Seymour (conveners), *Physics at LEP2*, Ed. G. Altarelli, T. Sjöstrand and F. Zwirner, CERN 96-01 (1996), volume 2, 204.
[9] H1 Collab., S. Aid *et al., Z. Phys.* **C70**, 17 (1996).