OBSERVATION OF HIGH-p_T JETS IN TWO-PHOTON INTERACTIONS

JADE Collaboration

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Events with a characteristic two-jet topology have been observed in two-photon interactions. The production cross section is found to be higher than the point-like $\gamma\gamma \to q\bar{q}$ cross section, which is approached only at transverse momenta larger than 3 GeV/c.

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Two-photon quark exchange scattering $\gamma\gamma \to q\bar{q}$ is of as fundamental importance as quark pair production in e^+e^- annihilation. This process [1] is expected to dominate at high four-momentum transfers which imply high two-photon invariant masses. Therefore, one has to look for a hard scattering process which is characterized in general by two non-back-to-back jets of high transverse momenta, since the two-photon system is normally moving with respect to the laboratory system. This letter reports on a jet analysis carried out on the data from the JADE detector [2] and discusses briefly the question of the quark charges which enter to the fourth power in the cross section.

In order to avoid a high background from e^+e^- annihilation, we restrict our analysis in this first stage to single tagging triggers having an electron shower recorded in one of two sets of lead glass counters, each of which has 92 elements and surrounds the beam pipe about 5 m away from the interaction point covering an approximate angular range from 34 to 75 mrad with respect to the beam line. In addition the trigger required that an energy of at least 1 GeV was deposited in the cylindrical lead glass array or at least two charged tracks registered in the central drift chambers [2].

The recorded events were further selected by demanding a tagging cluster of at least 4 GeV, a well defined vertex (of at least 2 charged tracks) within 8 cm of the nominal interaction point, and at least four particles (charged or neutral) in total. Charged tracks were accepted down to 20° and photon clusters down to 12° with respect to the beam line. Since the bulk of low-mass two-photon events is of no interest for this type of analysis, it was required further that the total visible energy E_{vis} (assuming all charged particles to be pions and all neutrals to be photons) exceeded the momentum component along the beam line $P_{vis,z}$ by 3 GeV. Events with a visible energy greater than 20 GeV were excluded. With these selection criteria and a total integrated luminosity of 9730 nb^{-1}, $(29.9 \leqslant \sqrt{s} \leqslant 36.7$ GeV) 538 events were found. The visible energy spectrum of these events is shown in fig. 1a. Even for tagged events a contamination from e^+e^- annihilation must be considered and in fig. 1b we show – scaled to the same luminosity – the energy spectrum of simulated annihilation events [‡1] with a radiated photon heading towards

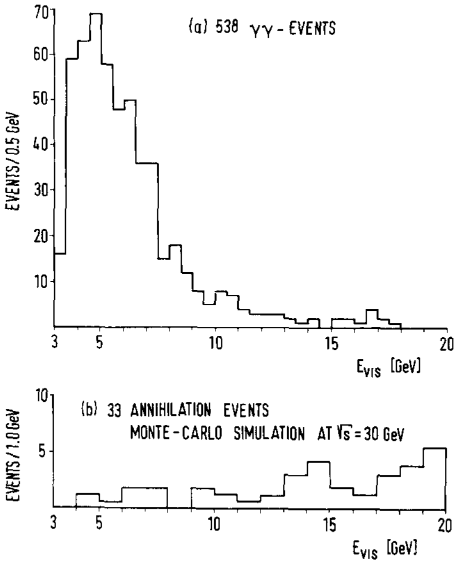

Fig. 1. Visible energy of (a) single tag multihadronic two-photon events (see text) and (b) Monte Carlo simulated annihilation events with a radiated photon heading towards one of the tagging counters.

one of the tagging counters. Since electrons and photons cannot be distinguished in the tagging counter all "two-photon" events between 15 and 20 GeV can be associated with annihilation processes. Normalizing the Monte Carlo distribution between 15 and 20 GeV to the actual number of observed events in this energy interval, one then obtains for the region from 3 to 10 GeV an annihilation background of 2% and from 10 to 15 GeV a background of about 20%.

The beam–gas background was subtracted in the standard way by choosing control regions along the beam line away from the interaction point, and its contribution was found to be of the order of 1%. The background from tau pair production is calculated to be about 1%.

In order to select events with a characteristic two-jet structure, a computer scan of the data was performed which resembles the visual grouping of tracks into narrow cones. Advantage was taken of the fact that a general jet search method [5] has been proposed and an efficient algorithm [6] set up and checked against e^+e^- annihilation Monte Carlo events at 13 and 30 GeV. This search method allows for an arbitrary number of jets and proceeds via the following steps:

– Particles within 30° of each other are combined

[‡1] Events were generated with the Lund Monte Carlo program [3] and radiative corrections were taken into account according to ref. [4].

to form preclusters. Single isolated particles are also regarded as preclusters.

– Preclusters within 45° of each other are combined to form clusters. Single isolated preclusters are also regarded as clusters.

– Assuming all charged particles to be pions and all neutrals to be photons, clusters with an energy of at least 2 GeV and with at least 2 particles (charged or neutral) are defined to be jets.

The search for jets was performed in the laboratory frame and also in the centre of mass system of the measured charged particles and photons, and it was found that our final results did not depend on the reference system. Here we shall only present the jet analysis performed in the centre of mass system. Out of the original data sample 119, 104, and 9 events are assigned as one-jet, two-jet, and more than two-jet topologies, respectively. The two-jet events, being of prime interest for our discussion, contain on the average 85% of the visible energy in the jets. For this sample of two-jet events we now require that at least one of the jets has a transverse momentum p_T(JET) exceeding 2 GeV/c and obtain 46 events. Of these 46 events 2 have a visible energy above 15 GeV and are therefore discarded. Applying our annihilation background analysis with these more stringent cuts, we expect 2 more background events below 15 GeV. Therefore one ends up with 42 high-p_T two-jet events after background subtraction.

The inclusive particle spectra are shown in fig. 2 as a function of the transverse particle momenta p_T with respect to the centre of mass direction of motion: (a) for all selected events, (b) for two-jet events selected as described above, and (c) for only those two-jet events with at least one of the jets having a p_T(JET) which exceeds 2 GeV/c. One observes that the p_T distribution becomes flatter as more selections are applied to the data. The high-p_T two-jet class of events agrees best in shape with what is expected [7] for $\gamma\gamma \to q\bar{q}$ when in addition to the QED type process, a standard fragmentation of the quarks is taken into account. The curve [7] in fig. 2 is normalized to the high-p_T two-jet events and depicts the expected approximate x_T^{-4} dependence where $x_T = p_T/E_{beam}$.

This definition of jets is purely experimental and it was the purpose of a detailed Monte Carlo simulation to see how well the experimental findings resembled the leading order quark scattering mentioned above. The Monte Carlo calculation employed a two-photon

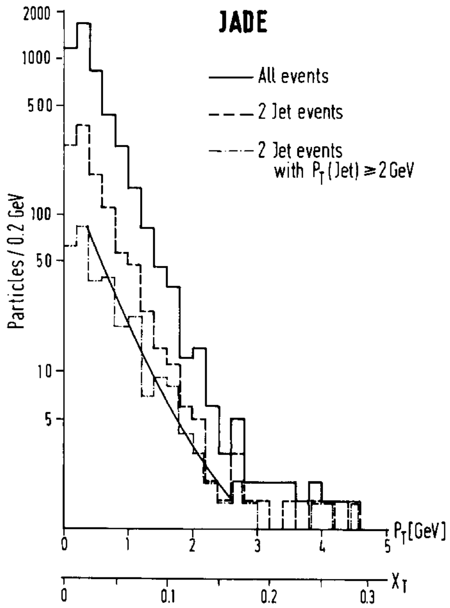

Fig. 2. Inclusive particle distribution for multihadronic two-photon events compared with the expected approximate x_T^{-4} dependence (curve) given in ref. [7, fig. 4]. $x_T = p_T/E_{beam}$ is taken with respect to the centre of mass direction of motion.

event generator [8] to produce in a QED-like fashion quark pairs (with a mass of 300 MeV for u, d, s and of 1.5 GeV for c) which then turn into hadrons via the standard Field–Feynman fragmentation mechanism [9] [‡2]. In an attempt to observe differences between these model calculations and the unselected data sample, we found that the model described the shape of most experimental distributions of the original 538 events surprisingly well, for example the charged and neutral multiplicity and the two-photon invariant mass spectrum. An exception is the inclusive particle p_T distribution which came out too flat and only fitted the high-p_T two-jet events, as we have already discussed above. This comparison reinforces our procedure to select high-p_T events which is equivalent to selecting events with low sphericity in the event centre of mass frame. Whereas the average sphericity of the unselected

[‡2] The constant in the fragmentation function has been chosen a = 0.77 for u, d, s, quarks and a = 0 for the c quark. The transverse momentum within a jet is limited by $\sqrt{2}\,\sigma(p_T)$ = 350 MeV. Sea quark contributions are u : d : s = 2 : 2 : 1 and the vector to pseudo-vector part is 1 : 1.

data sample is 0.34, it drops to about half that value, i.e. 0.16, for the selected high-p_T two-jet events.

The experimental two-jet cross section may now be compared with the absolute prediction for the $\gamma\gamma \to q\bar{q}$ process. Including the first four quark flavours u, d, s, c one obtains:

$$R_{\gamma\gamma} = \frac{\sigma(e^+e^- \to \gamma\gamma \to q\bar{q})}{\sigma(e^+e^- \to \gamma\gamma \to \mu^+\mu^-)} = 3 \sum_{i=u,d,s,c} Q_i^4 = \tfrac{34}{27}$$

and the Monte Carlo simulation leads to an expected number of 20 two-jet events with at least one p_T(JET) exceeding 2 GeV/c. Since $R_{\gamma\gamma}$ is close to one, we expect roughly the same number of muon pairs. In fact, 18 $\gamma\gamma \to \mu^+\mu^-$ events were observed which were selected under identical kinematic conditions. However, the actually observed number of high-p_T two-jet events was 42 and therefore twice as high as expected. The transverse momentum dependence of the two-jet event cross section is shown in fig. 3 as a function of x_T(JET) = p_T(JET)/E_{beam} and compared to the curve expected for $\gamma\gamma \to q\bar{q}$. It appears that the point-like $\gamma\gamma \to q\bar{q}$ cross section is approached from above ‡3. Whereas the measurement and the prediction differ by a factor of nearly 4 at p_T(JET) of 2 GeV/c, this difference drops down to a factor of about 1.5 for p_T(JET) values above 3 GeV/c. The excess of events may possibly be accounted for by the high-p_T tail of diffractive events which dominate at low p_T and also by processes [1,7] like $\gamma q \to gq$ or $\gamma g \to q\bar{q}$ which may have a steeper p_T dependence than $\gamma\gamma \to q\bar{q}$.

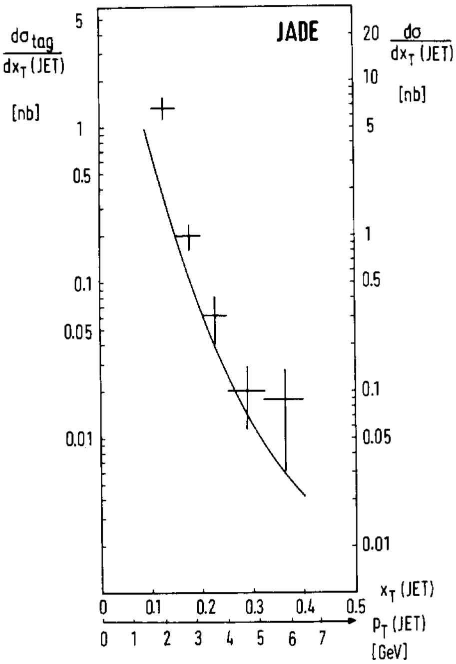

Fig. 3. Transverse momentum distribution of jets for single tag data compared with absolute predictions for fractional charged quarks (curve). x_T(JET) = p_T(JET)/E_{beam} is taken with respect to the centre of mass direction of motion. The cross section is given for the JADE tagging condition on the left-hand scale and integrated over all electron angles and energies on the right-hand scale.

The measured invariant mass of the observed high-p_T two-jet events range from 5 to 15 GeV. Because of this high mass the c quark was included in the charge counting for the quark coupling which also determines the normalization in fig. 3. The above calculations assumed standard fractional charged quarks. If, however, one follows the conjecture [11] of integer charged quarks, then the curve in fig. 3 has to move up by a factor of 2.65, and the data points beyond p_T(JET) of 3 GeV/c would fall below this curve by nearly a factor of two. Even with our limited number of events this conjecture seems to be ruled out. Another point of interest is that within the scheme of integer charged quarks the prediction should increase by an additional factor of 1.8 when the colour threshold is crossed. This threshold effect is not expected for fractional charged quarks, and for integer charged quarks it is certainly excluded in the energy range of our two-photon two-jet events.

In conclusion, we observe that the high-p_T two-jet cross section in two-photon interactions approaches the theoretical point-like $\gamma\gamma \to q\bar{q}$ cross section from above and that the scheme of integer charged quarks is excluded from this process by four standard deviations. More data would be needed to decide at which p_T(JET) value above 3 GeV/c the point-like $\gamma\gamma \to q\bar{q}$ limit is reached.

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‡3 A similar analysis is in progress for the PLUTO and TASSO experiments [10].

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