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by

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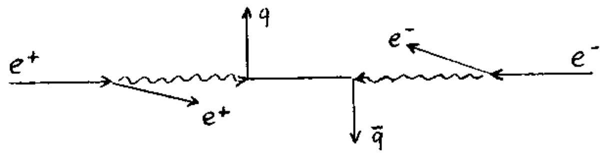
Abstract

The experiments JADE, PLUTO, and TASSO at the PETRA storage ring have searched for 2-jet-like processes in two-photon interactions. Events with a characteristic 2-jet topology have been observed and it is found that the point-like $\gamma\gamma \to q\bar{q}$ cross section is approached from above at large transverse momenta of the jets.

Motivation and Rates

The prime objective for studying two-photon-processes with high p_T constituents is to obtain information on the quark scattering process[1]



Its main characteristics are a normalized cross section of

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

if the first four quark flavours are included, and a differential cross section $d\sigma/dp_T^2$ roughly falling like p_T^{-4} where p_T can be either the transverse momentum of the produced quarks or their hadronic fragments. Since vector dominance processes fall off much more steeply, one expects the above hard scattering process to dominate at high p_T, but one has to keep in mind that also diffractive processes can develop a high p_T tail.

Rates for two-photon jets produced with transverse momenta above p_T^{min} have been calculated by various authors[2]. For an integrated luminosity of about 10^4 nb^{-1} (presently accumulated by the PETRA experiments) and p_T^{min} = 2 GeV, one expects roughly 600 produced two-photon $q\bar{q}$ events.

*) Invited talk given at the 4th International Colloquium on Photon-Photon Interactions, 6.-9.4.1981, Paris, France.

If a single tag condition is imposed (30-70 mrad) this number reduces to about 40 which will be further cut down by the trigger and software selection.

Inclusive Particle Distribution

By looking at the inclusive particle distribution one can get a first glimpse of the possible presence of the process $\gamma\gamma \to q\bar{q}$. The PLUTO collaboration has selected single and no tag data with a visible energy between 3 and 9 GeV[3] and plotted the inclusive charged particle p_T^2 distribution in Fig. 1. The pronounced tail resembles the $q\bar{q}$ scattering process (solid curve). For the TASSO experiment only single tag events[4] were selected and the $d\sigma/dp_T^2$ cross section is shown in Fig. 2. The initial steep fall-off is followed by a p_T^{-4} tail. In order to obtain an estimate of the high p_T tail of diffractive scattering, the π^+ momenta produced at 90° at the ISR are shown for comparison (dashed line). Above 2 GeV the excess and smaller slope of the two-photon data with respect to the ISR data are an indication for the presence of the process $\gamma\gamma \to q\bar{q}$. For both experiments the one-photon background has been subtracted and p_T is taken with respect to the beam axis. One may ask why doesn't one look for hadronic jets in two-photon production directly. Some clear examples of 2 jets pointing towards the same side as the tagged photon are shown for PLUTO, TASSO, and JADE in Figs. 3 to 5. However, before discussing the jet analysis I want to comment on background contributions from annihilation processes.

Background Considerations

Events with high p_T jets are associated with high invariant masses or high visible energies and therefore liable to be contaminated from annihilation processes. This contamination is considerably reduced by the tagging condition, but even in this case a radiated photon could hit the tagging counter. Fig. 6a shows the visible energy of the tagged events for the JADE experiment ($29.9 \le \sqrt{s} \le 36.7$ GeV; $\int L\,dt = 9730$ nb^{-1}). The events were required to have at least 4 tracks (charged or neutral) and the visible energy minus the energy component along the beam line had to exceed 3 GeV. Fig. 6b shows simulated annihilation events[5] where a radiated photon is heading towards one of the tagging counters. In the most pessimistic case (bad charged particle/photon discrimination), all "two-photon" events between 15 and 20 GeV are associated with annihilation processes and thus one obtains for the region from 3 to 15 GeV an upper limit of 2% for the annihilation background.

Another useful test is to look at the production angle of the hadronic system with respect to the beam axis. Fig. 7 shows a comparison of the data with a two-photon Monte-Carlo simulation to be described in the next section, both of which are very much peaked near the beam direction. The velocity β of the hadronic system along the beam line is defined as positive if it points to that side where the tagging is recorded. In Fig. 8 the data and the Monte-Carlo simulation display a fairly symmetric β distribution whereas annihilation events with a radiative photon faking the tag should have only negative β values. As a final check of the global properties of the two-photon system one can compare the radial momentum obtained from the tagged photon with that of the hadronic system (Fig. 9). As one can see, the radial momentum of the hadronic system is wider which is partly due to the second undetected photon being off the beam line and giving an additional contribution. Experimentally one can determine the transverse momentum of jets by either using the beam line or the movement of the CM system as reference axis. In the first case the transverse momentum gets modified by the overall radial momentum and in the second case one has the uncertainty of reference direction due to undetected or badly measured particles. However, the two differ significantly only for low p_T values.

Beam gas background is subtracted in the standard way by choosing control regions along the beam line away from the intersection point and its contribution is found to be of the order of 1%.

Jet Finding Methods and Monte-Carlo Simulation

I shall discuss two different jet finding methods. One is to group all particles into two classes C_1 and C_2 such that the momenta along two independent directions are maximized, forming a quantity called twoplicity:

$$T_2 = \underset{C_1,C_2}{\mathrm{Max}} \left\{ \frac{\left|\sum_{i\in C_1} \vec{p}_i\right| + \left|\sum_{i\in C_2} \vec{p}_i\right|}{\sum_{\mathrm{all}\ i} |p_i|} \right\}$$

By this method the one stray particle of the 2-jet event in Fig. 10 will be forced into one of the two classes. In order to avoid this and to account for more complicated cases a jet search method has been proposed[6] and an efficient algorithm has been set up[7] and checked against 30 GeV e^+e^- annihilation data. This search method allows for an arbitrary number of jets and proceeds via the following steps:

- Particles within 30° of each other are combined to form preclusters.
- Preclusters within 45° of each other are combined to form clusters.
- Clusters with an energy of at least 2 GeV and at least 2 particles (charged or neutral) are declared as jets.

If one uses the jet search method to find a class of 2-jet events in the two-photon CM system, one can compare the direction of the most energetic jet with the thrust axis, along which the longitudinal momentum is maximized (Fig. 11). Apart from the ambiguity inherent in the thrust determination, one can see from Fig. 11 that the two axes agree well within 10° for the JADE data.

Both methods define jets in a purely experimental way and it is the purpose of a detailed Monte-Carlo simulation to see how much the experimental findings resemble the leading order quark scattering process mentioned in the beginning. The Monte-Carlo calculation employs the two-photon Vermaseren generators[8] to produce in a QED-like fashion quark pairs which then turn into hadrons via the standard Field-Feynman fragmentation functions[9]. The fragmentation is checked in Fig. 12 by comparing - for the data and for the simulation - the transverse momenta of particles with respect to the jet axis. It turns out that not only this but many more distributions, obtained with the JADE data selection mentioned in the previous section, are well reproduced by the Monte-Carlo calculation. Even the twoplicity in Fig. 13 shows no difference; the solid line is obtained by $u\bar{u}$ production only and the dashed line shows how much smaller the contribution from $c\bar{c}$ production is.

Sofar the calculations have been normalized to the data and I shall be concerned about absolute predictions in the next section.

Results

The jet search method has been applied to the JADE data. In Fig. 14 the inclusive particle p_T distribution is plotted for all events, for 2-jet events and for only those 2-jet events with at least one of the jets having a p_T (w.r.t. to the CM direction of motion) which exceeds 2 GeV. One observes that the p_T distribution is getting flatter the more selective one is on the data, and the high p_T 2-jet class of events agrees best in shape with what is expected for the process $\gamma\gamma \to q\bar{q}$[10] (curve in Fig. 14).

However, turning now to the absolute normalization, one finds that the twoplicity method employed by TASSO and the jet search method used by JADE pick out more events from the measured data than are expected from the process $\gamma\gamma \to q\bar{q}$. The following table contains the relevant event numbers:

Experiment	expected $\gamma\gamma \to u\bar{u}$, $c\bar{c}$	observed events $\gamma\gamma \to \mu^+\mu^-$	$\gamma\gamma \to$ 2 jets with p_{T1} or $p_{T2} \geq 2$ GeV
JADE	20	18	42
TASSO	33		51

The transverse momenta p_T(JET) have been measured by TASSO with respect to the beam direction whereas the JADE results are quoted with the CM direction of motion as reference axis. Figs. 15 and 16 show the TASSO and JADE results as a function of p_T^2(JET) and x_T(JET) respectively. The curves are the absolute predictions. Whereas the excess of observed events shows up mainly in the low p_T bins for TASSO, this excess continues out to higher p_T values for the JADE data. The corresponding plot for the PLUTO data, which again includes single and no tag events, has been shown already at last year's Madison conference[3] and is included here for comparison.

Conclusions

2-jet-like events in two-photon processes have been clearly seen by the JADE, PLUTO, and TASSO experiments. The question is what is the source for the experimentally observed jets. The point-like $\gamma\gamma \to q\bar{q}$ cross section is apparently approached from above at large p_T values beyond 3 GeV. The excess of events may well be accounted for by the high p_T tail of diffractive effects which dominate at low p_T and also by processes like $\gamma q \to gq$ which may have a steeper p_T dependence than $\gamma\gamma \to q\bar{q}$. At which p_T value above 3 GeV the point-like $\gamma\gamma \to q\bar{q}$ limit will be reached has to be decided in the future when more events become available or the energy range of e^+e^- storage rings is extended.

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DISCUSSION

Q - WERMES — Maybe, I did not get your conclusion. Did you conclude that the jet events cannot be explained by a phase space model?

A - CORDS — If one looks at the sphericity distribution of the high p_T 2-jet events from JADE, one can see that it is incompatible with a phase space model. We also tried the jet search method on Monte Carlo events which simulate a high p_T tail for the particles and picked up only 6 events compared to 42 we observed.

Q - BERGER — I agree, that we see jets, i.e. clusters. But I am not sure, that they are originating from $\gamma\gamma \to q\bar{q}$. All hadronic Monte Carlos produce jet-like looking events.

A - D.C. — As you have seen from the numbers of the expected and observed jet-like events (e.g. in the JADE data), about 50% of these events cannot come from the process $\gamma\gamma \to q\bar{q}$.

Q - FIELD — Have you taken into account in your Monte Carlo the effect of higher order QCD subprocesses e.g. $\gamma q \to qg$, $q\bar{q} \to gg$ etc. leading to 2 observed high p_T jets, and giving the leading contribution at small values of x_T?

A - D.C. — No, but we shall do it in the future.

Q - KNIES — How many $\tau\bar{\tau}$ events do you expect to have in your acceptance?

A - D.C. — Less than one in JADE data.

C - BRODSKY —
1) In order to check the $\gamma\gamma \to q\bar{q}$ predictions and $R_{\gamma\gamma}$ predictions it is important to insure there are no forward hadrons or jets. Otherwise there are theoretical contributions from multijet and higher twist subprocesses.
2) The use of the Feynman-Field parametrization for the quark fragmentation which goes to a non-zero constant as $Z \to 1$ can severely bias single particle production for $\gamma\gamma \to$ high p_T hadrons. It should be emphasized that QCD is incompatible (in leading twist) with a non-zero $D_{\pi/q}(Z)$ at $Z = 1$ unless the pion is an elementary field.

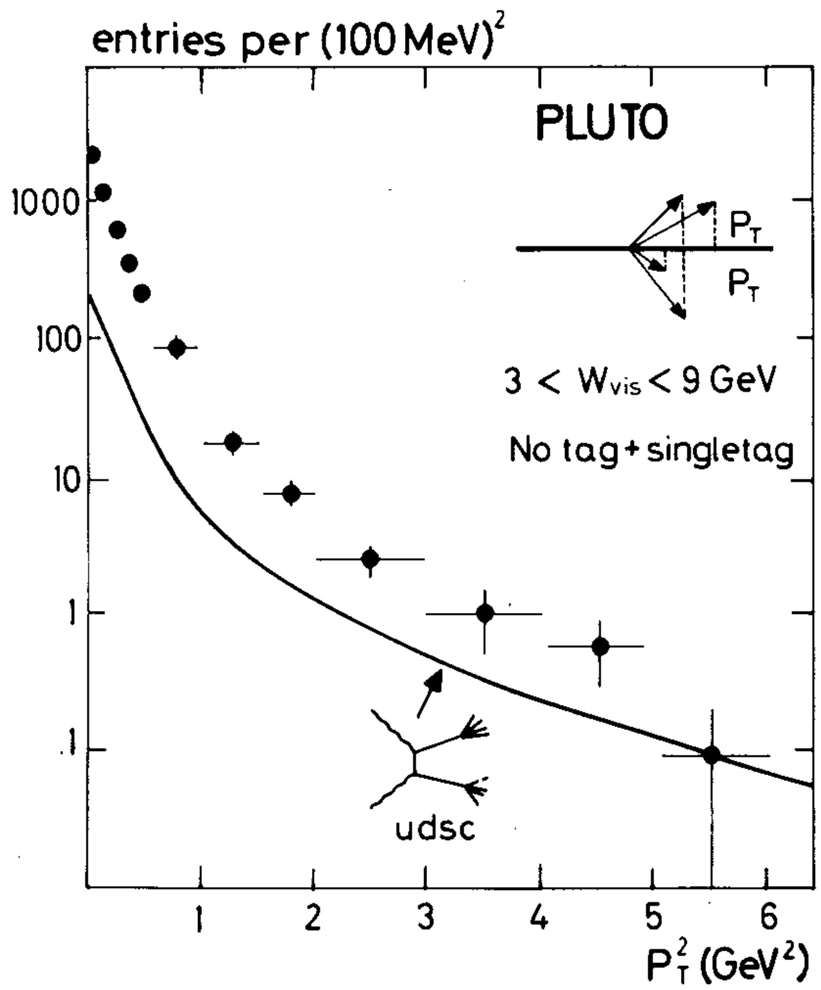


Fig. 1: Inclusive particle distribution of single and no tag data of the PLUTO experiment.

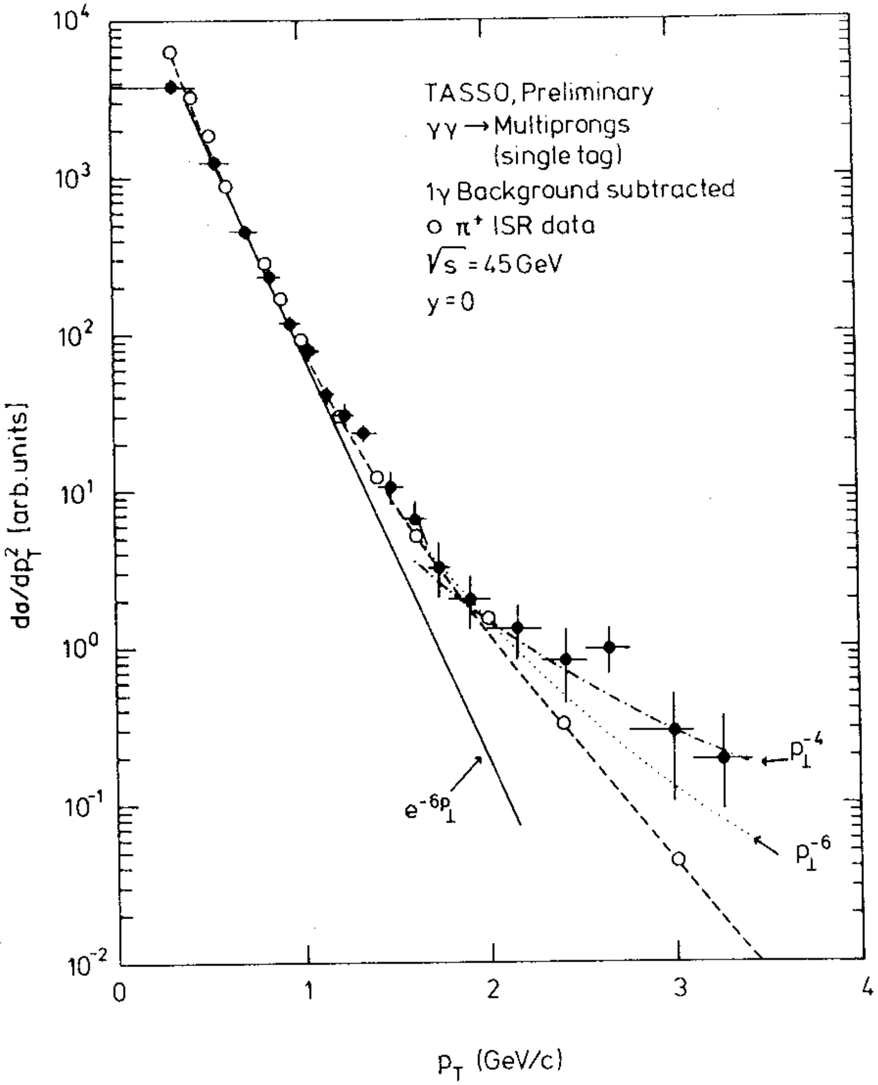


Fig. 2: Inclusive particle distribution of single tag data of the TASSO experiment and a comparison with ISR data (dashed line).

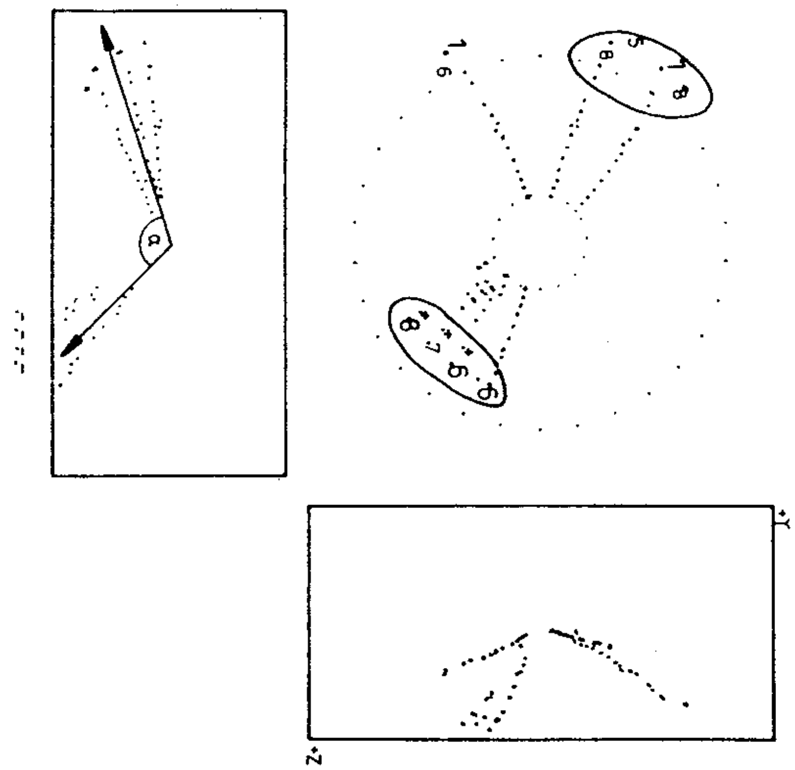


Fig. 3: 2-jet event of PLUTO.

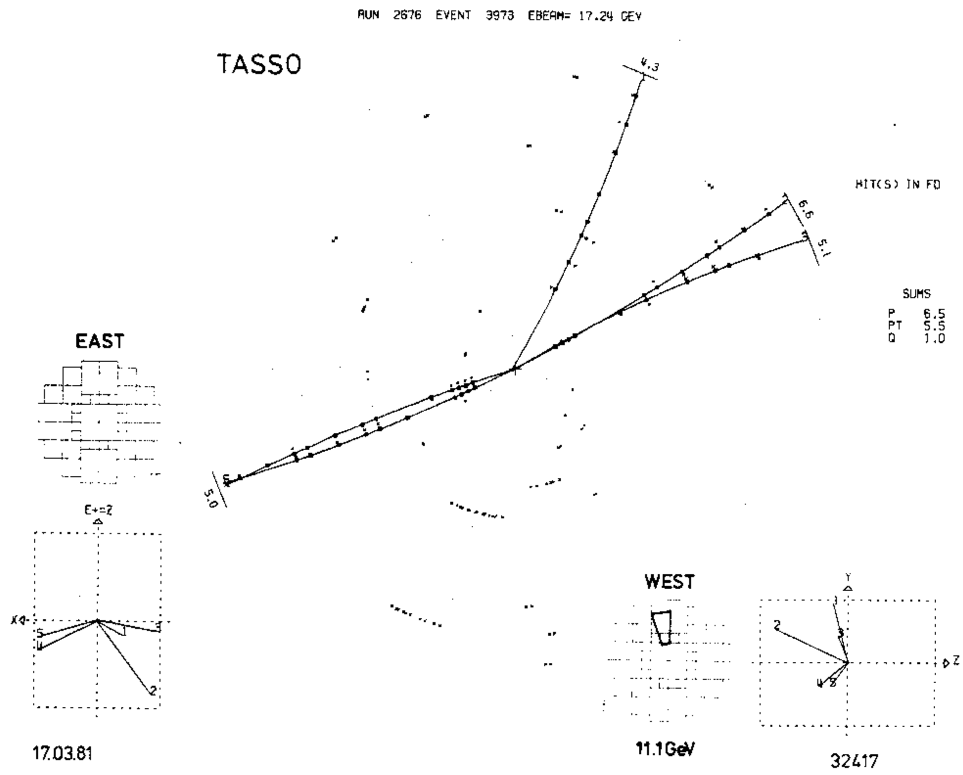
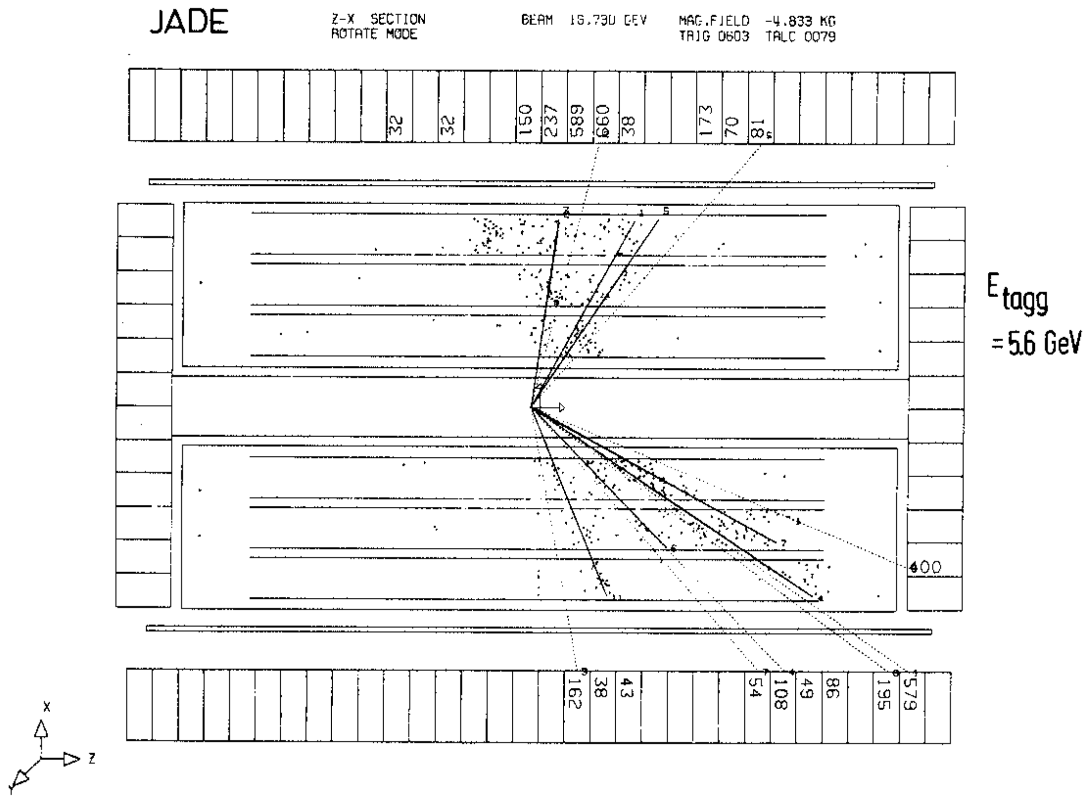


Fig. 4: 2-jet event of TASSO



Fi. 5: 2-jet event of JADE. Full lines are charged particles and dotted lines are photons.

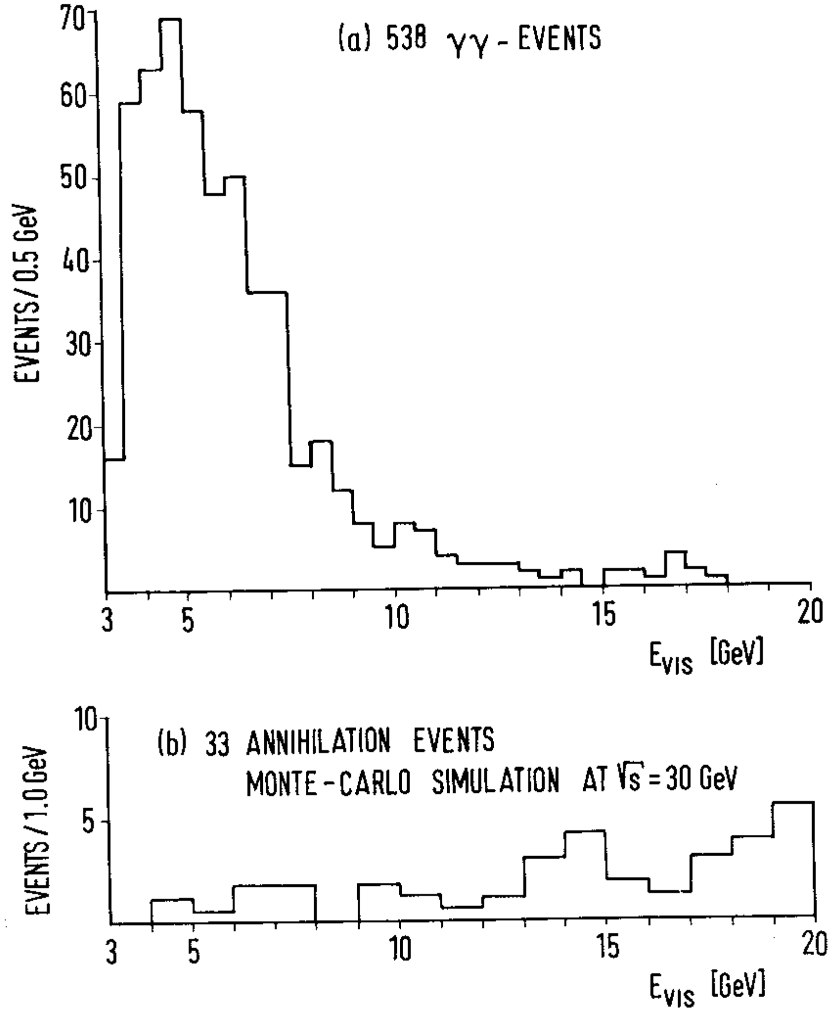


Fig. 6: Visible energy of (a) multihadronic two-photon events from JADE and (b) Monte-Carlo simulated annihilation events with a radiated photon heading towards one of the tagging counters.

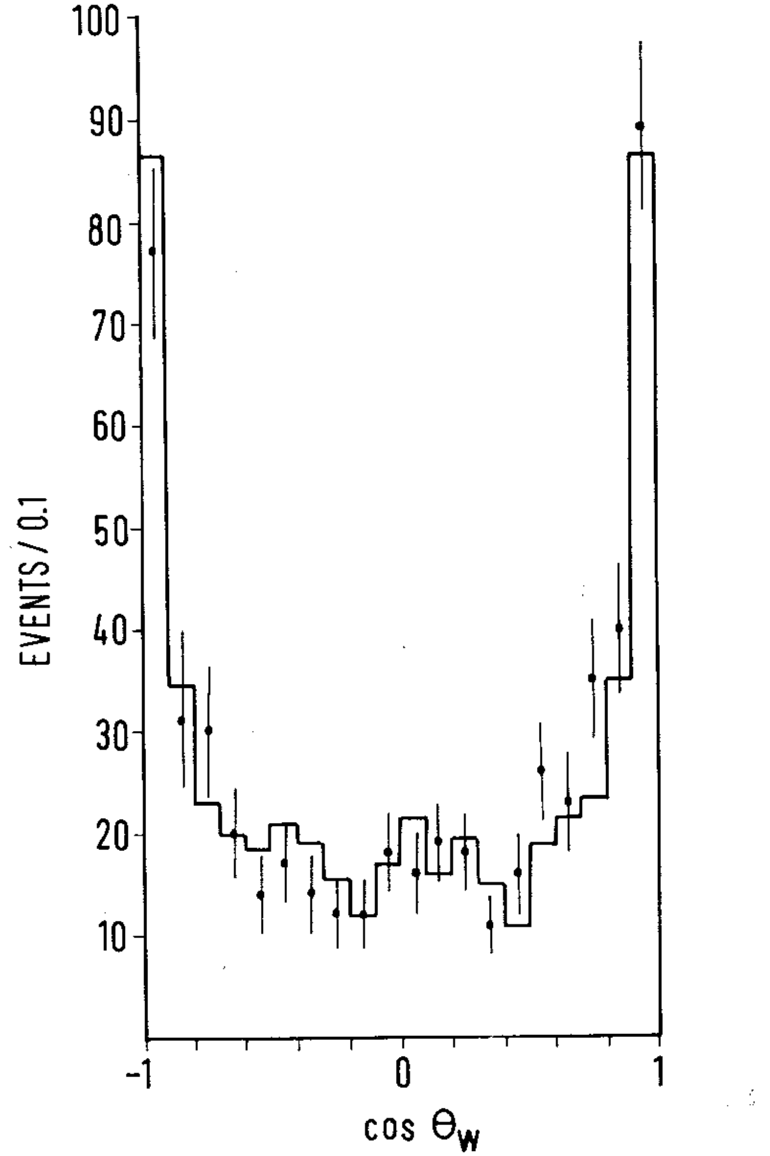


Fig. 7: Angular distribution of the direction of motion of the hadronic system w.r.t. the beam line for JADE data (points) and Monte-Carlo simulation (histogram).

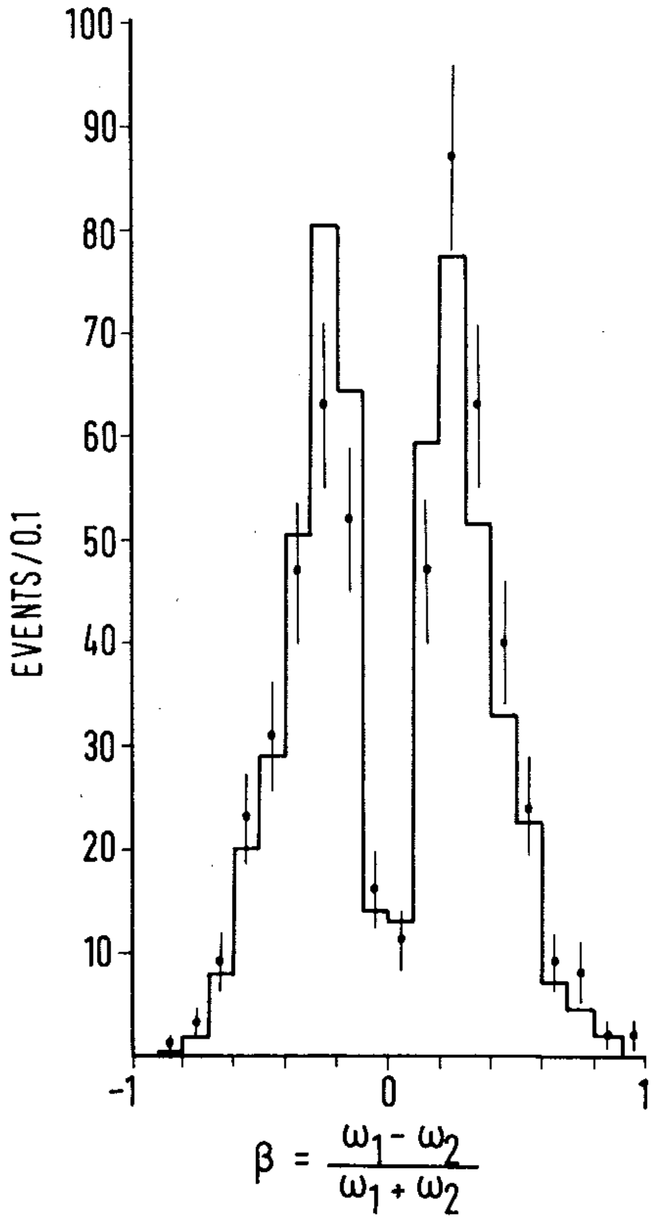


Fig. 8: Velocity of hadronic system towards (positive β) or away from (negative β) the recorded tagging for JADE data (points) and Monte-Carlo simulation (histogram). ω_1 and ω_2 are the photon energies obtained from the measured hadronic energy and momentum.

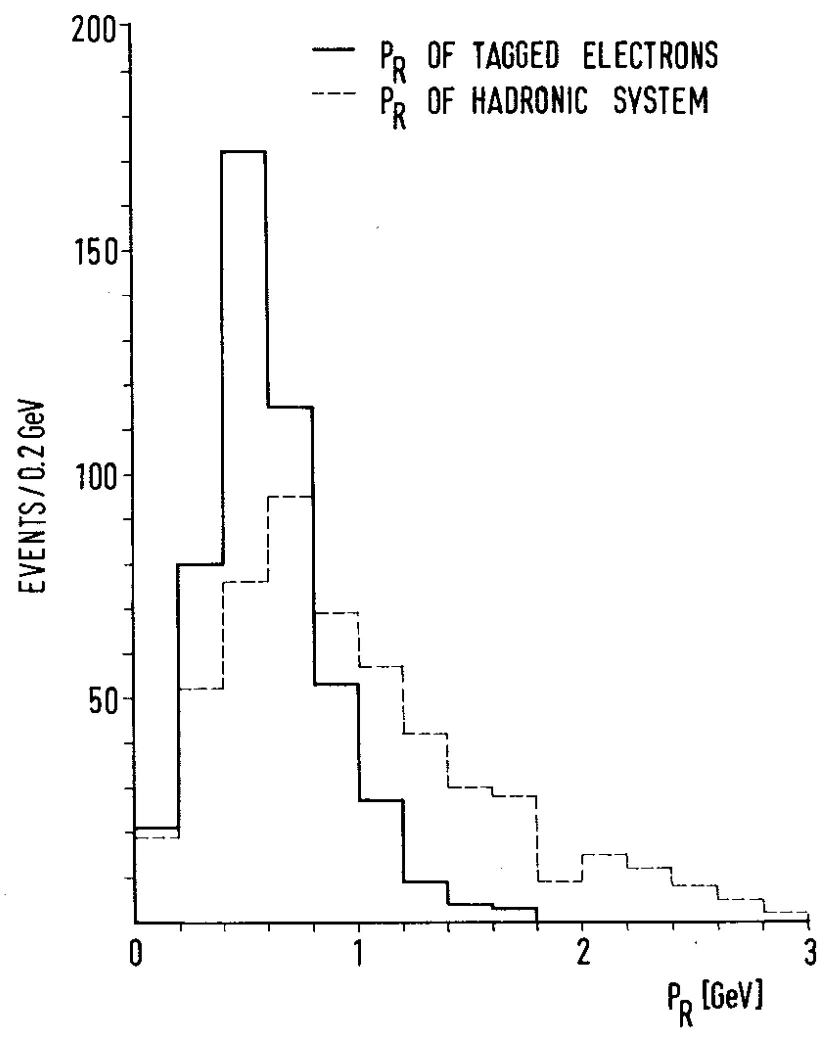


Fig. 9: Radial momenta obtained from the tagged electron and from the measured hadronic system for JADE.

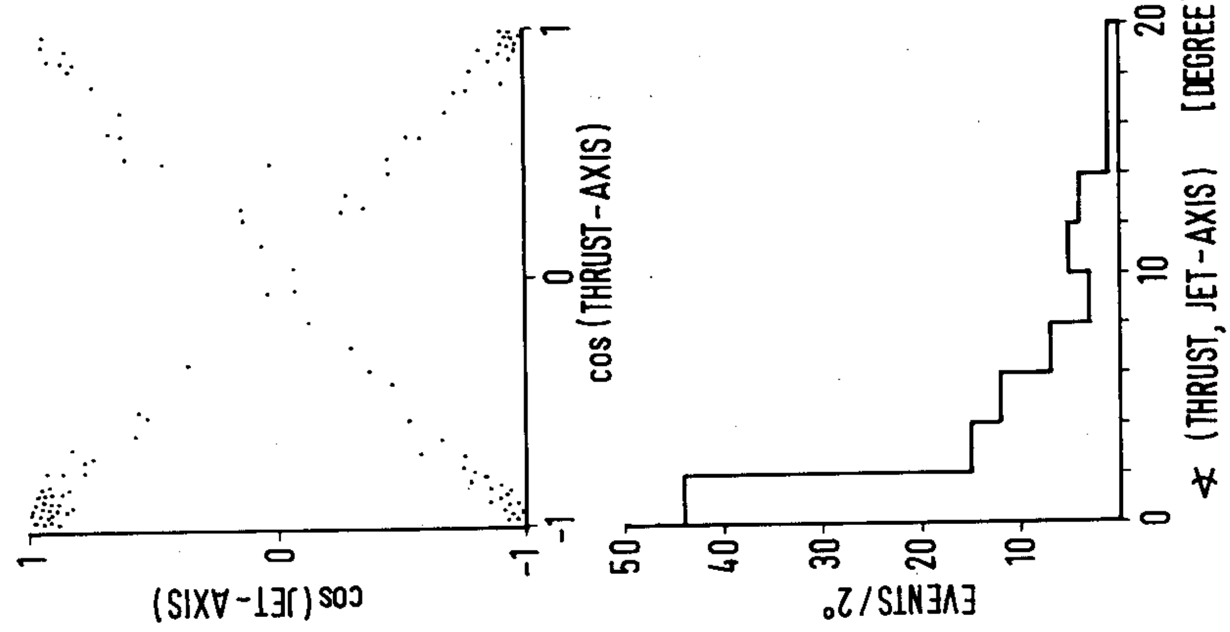


Fig.11: Comparison of jet axis (see text) and thrust axis for multi-hadronic $\gamma\gamma$ events of JADE. The angles of the axes are taken w.r.t. the CM direction of motion.

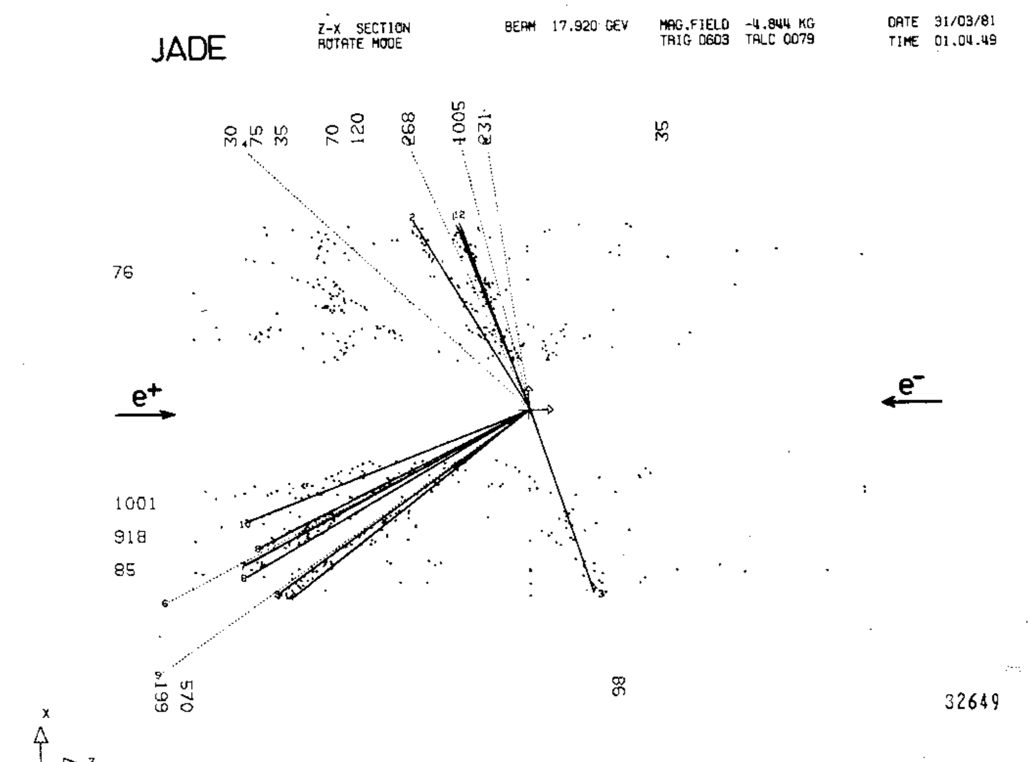


Fig.10: 2-jet event from JADE. Full lines are charged particles and dotted lines are photons.

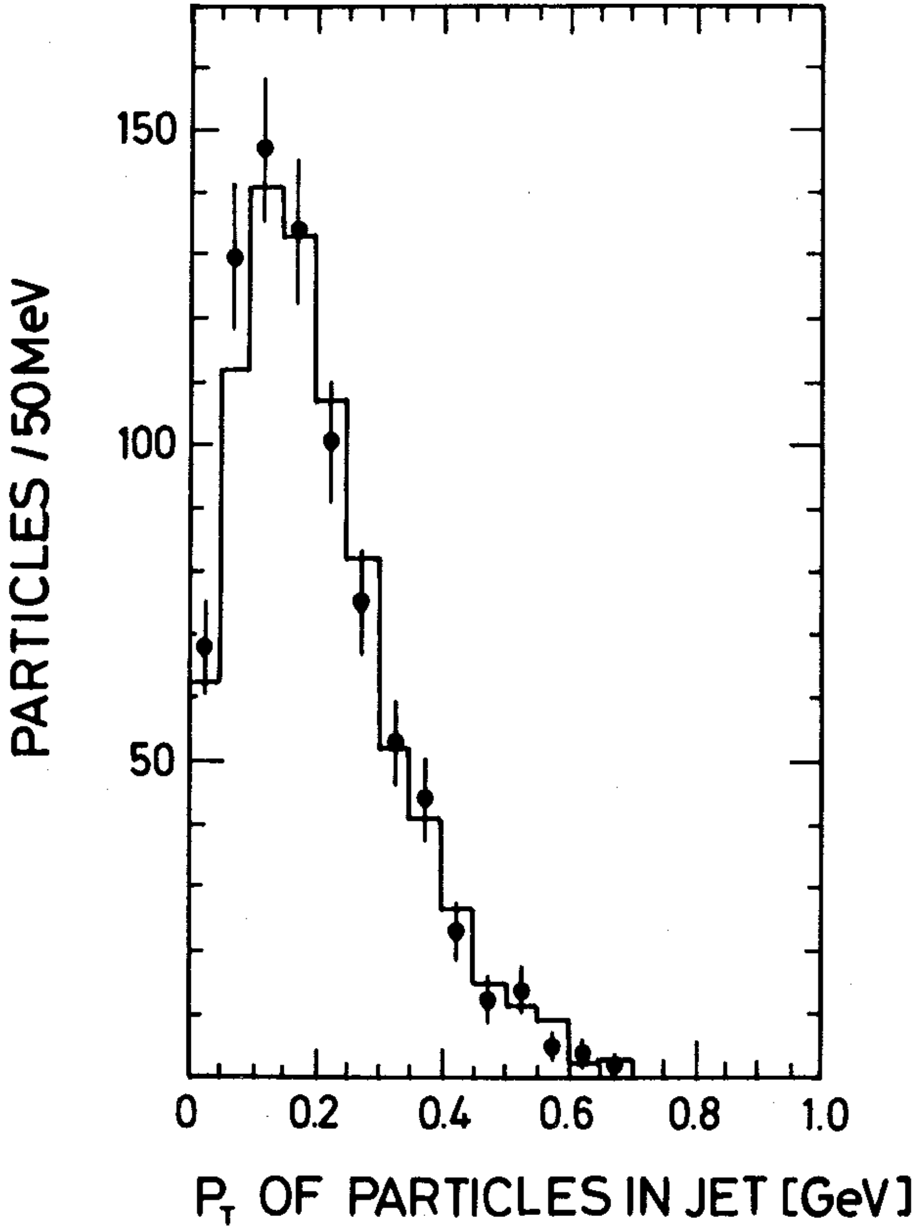


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Fig.12: Transverse momentum of particles w.r.t. the jet axis for JADE data (points) and Monte-Carlo simulation (histogram).

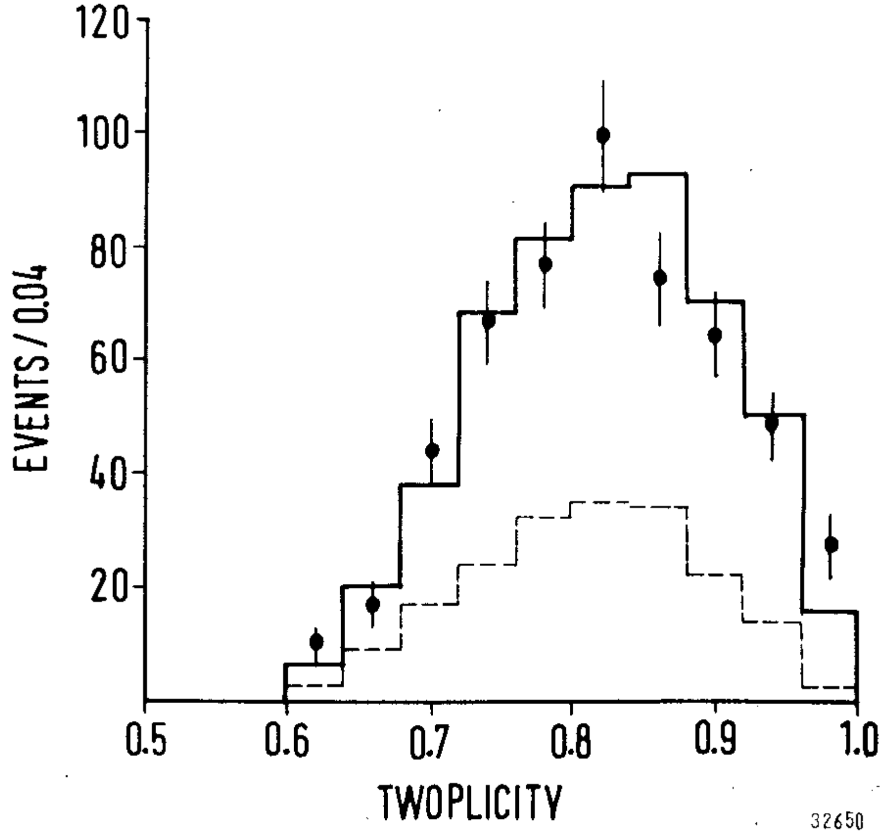

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Fig.13: Monte-Carlo simulation of $\gamma\gamma \to u\bar{u}$ (full line) and of $\gamma\gamma \pm c\bar{c}$ (dashed line) compared to the JADE data (points). $\gamma\gamma \to u\bar{u}$ has been normalized to the data.

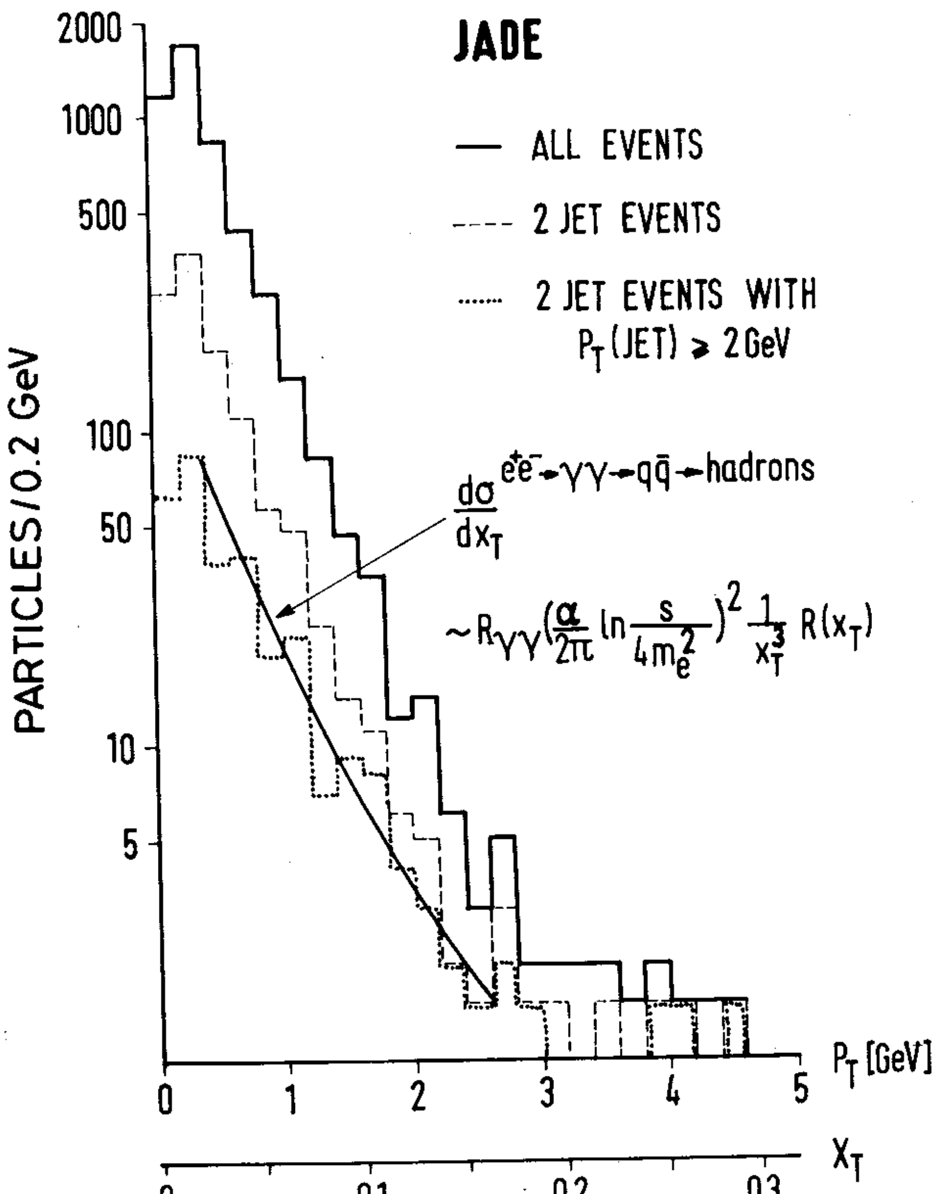

Fig.14: Inclusive particle distribution for multihadronic $\gamma\gamma$ events of JADE compared with the expected slope for $d\sigma/dx_T$ where $x_T = p_T/E_{BEAM}$ (see ref. 10, Fig. 4).

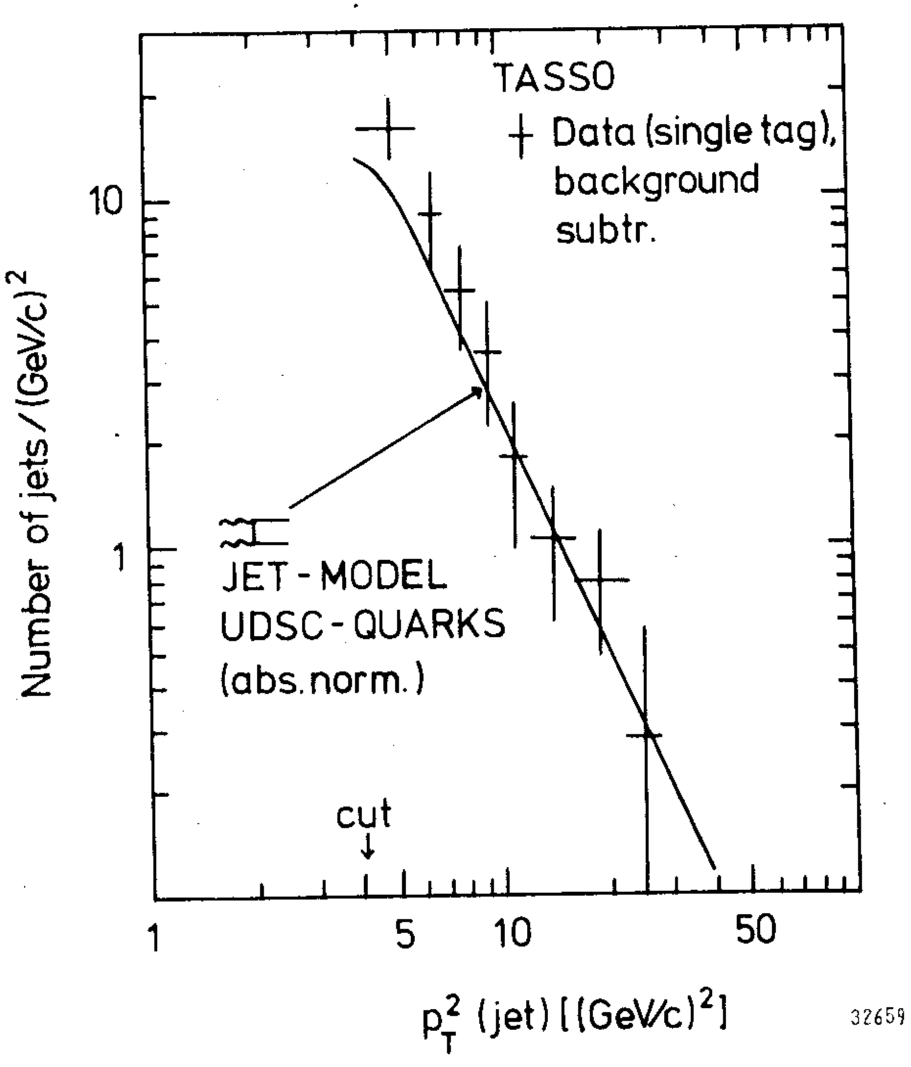

Fig.15: Transverse momentum distribution of jets for single tag data of TASSO.

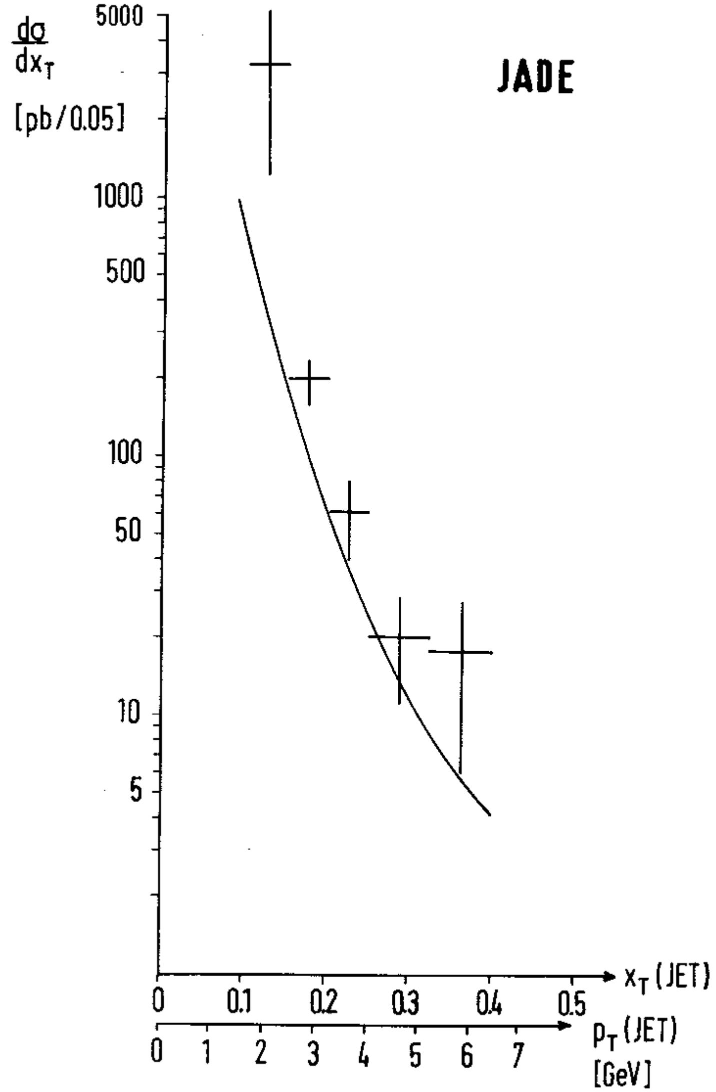

Fig.16: Transverse momentum distribution of jets for single tag data of JADE compared with absolute prediction (curve). $x_T(\text{JET}) = p_T(\text{JET})/E_{BEAM}$.

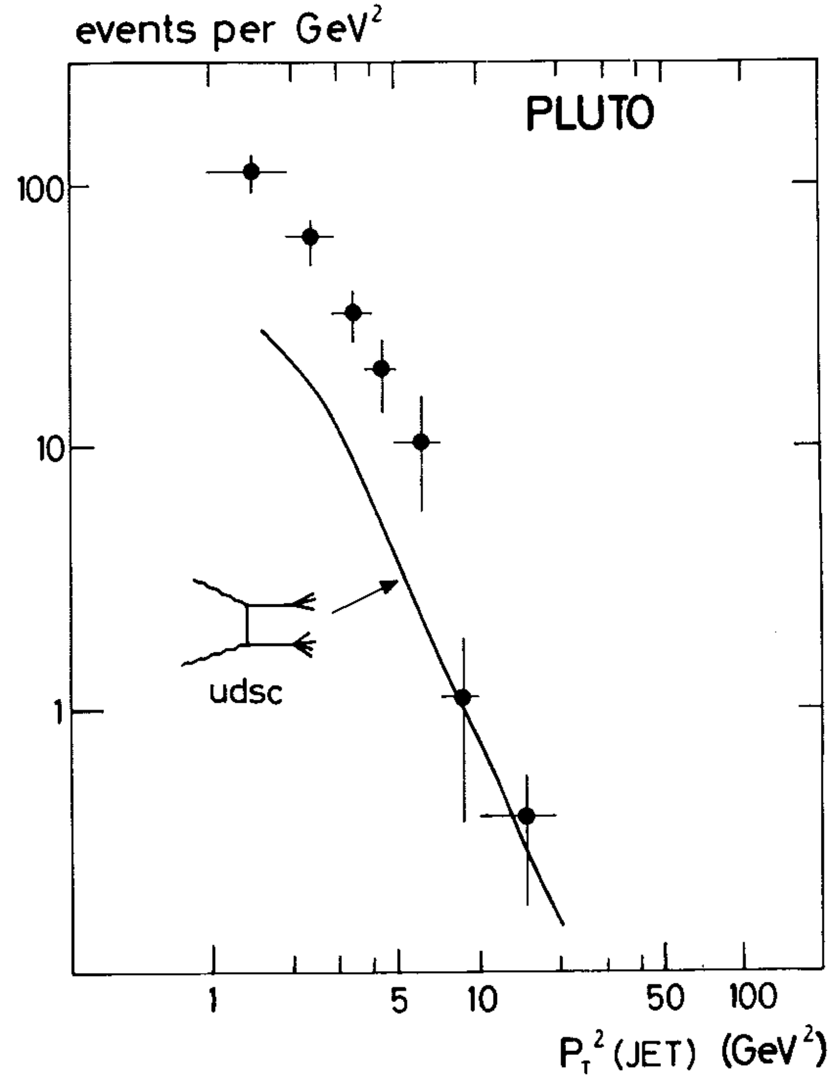

Fig.17: Transverse momentum distribution of jets for single and no tag data of PLUTO.