A Study of the hadronic final state in single tagged $\gamma\gamma \to$ *hadrons*

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Abstract

The final state structure has been studied in single tagged $\gamma\gamma\to$ *hadrons* and compared to various models. The final state particles are found to lie at higher pseudorapidity relative to the tag than predicted by the models. This confirms the discrepancies recently observed by OPAL. Similar deviations are observed in the jet structure using a cone-based jet algorithm. A modified version of HERWIG is found to produce a better description of the data.

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1 Introduction

$e^+e^- \to e^+e^- + hadrons$, with one of the electrons observed (the 'tag'), can be described as the probing of a nearly real photon originating from the unobserved electron, by a highly virtual photon from the tagged electron. These tagged $\gamma\gamma$ processes have long been an area of study, but until recently the only Monte Carlos available were the Quark Parton Model and the Vector Meson Dominance model. More complete models have appeared which have tried a more coherent approach to describing the hadronic final state. However OPAL showed in [1] that the available models still do not correctly reproduce the energy flow of final state hadrons in events of this kind. The modelling of the final state is very important in, for example, the $F_2^\gamma(x, Q^2)$ analysis, and indeed the discrepancies reported by OPAL lead to a large error in their measurement.

In this paper ALEPH data are compared to a sum of Quark Parton Model and Vector Meson Dominance (QPM + VMD) Monte Carlos, to the HERWIG 5.9 [2] Monte Carlo (using the GRV [3] structure function) and to a modified version of HERWIG [4, 5] (again using GRV). All the Monte Carlo has been passed through the full ALEPH detector simulation. The jet structure of the accepted events is also examined using a cone-based algorithm.

This analysis is based on 102 pb^{-1} data taken with the ALEPH detector in the years 1992-1994. The ALEPH detector has been described in detail in [6]. A cluster (the 'tag') of more than 30 GeV energy was required in one of the forward luminosity calorimieters (LCAL) within the angular range 60mr $< \theta_{tag} <$ 155mr. The hadronic system was analysed using the ALEPH energy flow package [7] and the following selections made. The event must contain at least 3 charged tracks. No cluster of more than 15 GeV should be found in the half of the detector opposite the tag. The invariant mass of the hadronic system should be greater than 2.5 GeV/c^2. NLMB, the Normalised Longitudinal Momentum Balance must be greater than 0.5 where $NLMB = (p_z(total).p_z(tag))/(E_{beam}.|p_z(tag)|)$. No energy deposit in the hadron calorimeter should be within 11.5 degrees of the tag. The hadronic energy should be less than 50 GeV. A vertex must be reconstructed within 2.5 cm of the interaction point along the beam direction.

After correcting for the small trigger inefficiencies, this gave a data sample of 3333 events at an average Q^2 of 14.2 $(\mathrm{GeV}/c)^2$ (Q^2 is the negative four momentum squared of the 'probe' photon emitted by the tagged electron). The backgrounds remaining are small (see [8]). The only significant one (tagged $\gamma\gamma \to \tau\tau$) has been modelled using the Vermaseren generator [9] and added to the Monte Carlo predictions.

2 Monte Carlo Models

Figure 1 shows the four main diagrams which contribute to final state $\gamma\gamma \to hadrons$. Resolved processes have been identified in untagged analyses, but their presence in tagged events is less well established. The QPM + VMD model represents the data as a sum of fig. 1(a) and (b) only, ignoring the presence of the single and double resolved diagrams (c) and (d). The diagrams are modelled separately and added together without regard to any possible double counting. No attempt is made to smooth the transition from the low transverse momentum VMD process to the high transverse momentum QPM one.

HERWIG incorporates the single resolved case, fig. 1(c) as well as the digrams (a) and (b). To the extent that these are present at higher Q^2, HERWIG should provide a better description of the data (in particular at higher transverse momentum). It also attempts to smooth the transition from low transverse momentum to high transverse momentum processes.

2.1 QPM + VMD

This is the same Monte Carlo as used in [10]. The QPM part comes from the Vermaseren generator [9]. This is a lowest order QED calculation of the process $e^+e^- \to e^+e^- + f\overline{f}$. It was used to produce events

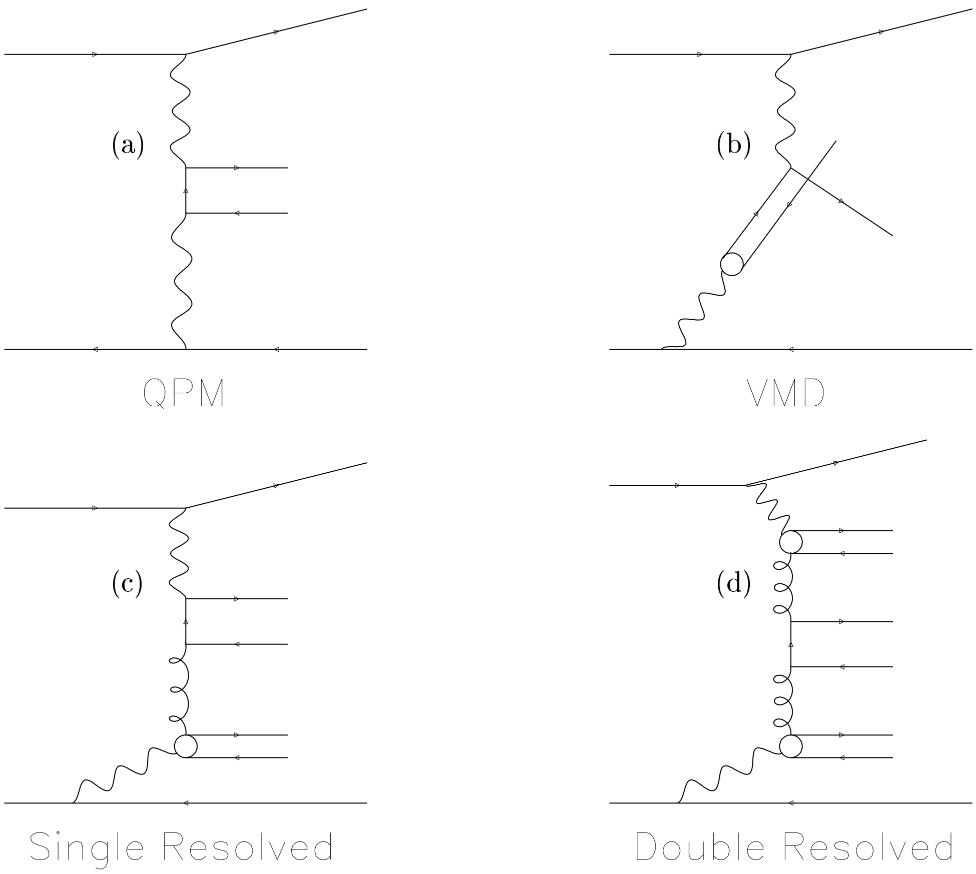

Figure 1: The diagrams involved in the process $\gamma\gamma \rightarrow hadrons$.

containing u,d or c quarks which were subsequently hadronised using the JETSET program [11].

In the VMD model the target photon is assumed to behave as a vector meson (ρ, ω... etc). The luminosity function of [12] was used in conjunction with a Generalised Vector Dominance Model form factor and an additional invariant mass (W) dependence, $\sigma(W) = A + B/W$ with $A = 110$ nb and $B = 1000$ nbGeV from [10]. Two quarks were produced with limited transverse momentum with respect to the $\gamma\gamma$ axis and fragmented by JETSET.

2.2 HERWIG

The generation process in HERWIG starts from a complete matrix element (ME) calculation of electron quark scattering where the electron is the source of the 'probe' photon. The quark is then both evolved 'forward' to produce the final state hadrons, and 'backward' towards the target photon. During the backwards evolution further partons can be produced or the quark can be coupled directly to the target photon in a QPM-like manner which stops the evolution. It is also possible for a ME coupling to a high transverse momentum parton to occur (which simulates the single resolved process). If the evolution reaches the HERWIG infra-red cut-off scale ($\sim$ 1GeV) then the target photon is replaced by a hadronic system, in keeping with the concepts of the Vector Dominance Model. This hadronic state is represented by a number of partons with their transverse momenta limited with respect to the initial target photon direction. In the standard HERWIG implementation a gaussian distribution is used to describe the limitation of transverse momentum. In the modified HERWIG studied here ("HERWIG+power law p_t") the gaussian distribution is replaced by a power law spectrum of the form $dk_T^2/(k_T^2 + k_0^2)$ (where k_0 is a constant - 0.66 GeV/c is used). This increases the average transverse momentum generated at the hadronic coupling and is motivated by the study of photon remnant jet properties from ZEUS [13], the value used for k_0 came from this paper.

3 Energy Flow

Figure 2(a) shows the energy flow of the final state particles (excluding the tag) as a function of the pseudorapidty (η). η is defined as $\eta = -ln[tan(\theta/2)]$ where θ is the angle with respect to the beam pipe (the tag being in the negative η direction). In this distribution each particle is weighted by it's energy and the whole plot is then divided by the total number of events to give an energy flow per event.

Neither the QPM + VMD or standard HERWIG 5.9 adequately reproduce the peak at positive η (the direction away from the tag). The peak at negative η mostly contains hadrons coming from the parton directly connected to the high Q^2 photon, whereas the peak at positive η mostly comes from the parton attached to the target photon (this is shown in [5]). An increase in the transverse momentum of partons produced at the target photon vertex is expected to result in a larger peak at positive η. The HERWIG + power law p_t model, with larger transverse momentum generated at this vertex, does indeed represent the data better in this region.

Figure 2(b) shows the transverse energy out of the tag-beam plane (E_t^{out}). This plot is expected to be directly related to the transverse momentum generated in the $\gamma\gamma$ interaction. Again neither HERWIG 5.9 or QPM + VMD fits the data well. HERWIG + power law p_t is better at modelling the region of large E_t^{out}.

4 Cone jets

At hadron colliders a number of factors, including the longitudinal boost of the final state, and the presence of target remnants and underlying events has led to a preference for so called 'cone' jet-finding algorithms, in preference to the 'JADE' type algorithms more commonly used in e^+e^- annihiliation physics. As similar arguments apply to $\gamma\gamma$ physics a cone jet-finding algorithm [14] has been adopted for this study.

An $\eta - \phi$ metric (R) was used. A track was in the cone jet if $R < 1$ where,

$$R = \sqrt{(\eta_{track} - \eta_{cone})^2 + (\phi_{track} - \phi_{cone})^2}.$$

η_{cone} was defined as the E_t-weighted average of the individual η_{track},

$$\eta_{cone} = \frac{1}{E_t^{cone}} \sum_{tracks \in R<1} E_t^{track} \eta_{track},$$

where E_t^{cone} is the sum of the E_t^{track}. ϕ_{cone} is similarily defined.

A good cone jet had the following properties at the jet-finding level:-

- $E_{jet} > 2.0$ GeV.
- $N_{particles}$ in jet ≥ 2.

In addition, for the following plots, the jet was required to lie within $|cos\theta| < 0.8$ i.e. to be in the central region of the detector.

A plot of the number of jets found in each event is shown in figure 3. There are more events generally in the data than in any of the Monte Carlos, which might indicate that we prefer a higher structure

(a)

(b)

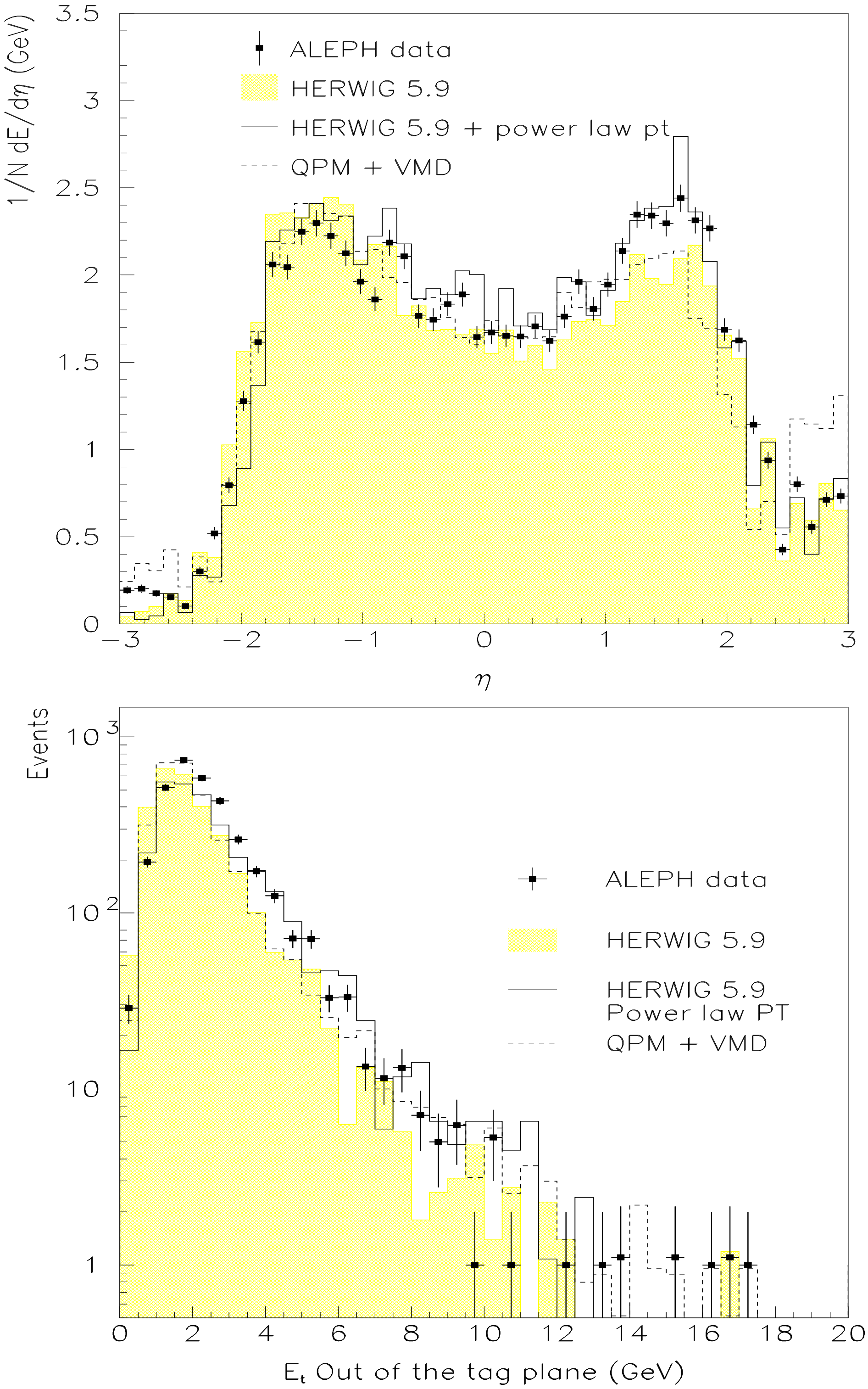

Figure 2: (a) The energy flow in η in tagged $\gamma\gamma$ events compared to various Monte Carlos. (b) The total energy sum out of the plane of the tag and the beam.

function than GRV. As the HERWIG model contains the single resolved process in addition to the QPM and VMD processes, it might be expected to produce a greater number of two jet events than the QPM+VMD model. Figure 3 shows that on the contrary the HERWIG model produces fewer two jet events than the QPM+VMD model.

Although both direct (i.e. QPM), single, and double resolved processes can produce a topology including two large angle jets, the characteristics of the event are expected to differ due to the presence of respectively 0,1 and 2 target remants in the event. In order to search for evidence of these different processes the variable $E_2^{non-jet}$ was constructed. This is defined as the energy of all the particles in the event not contained in jets for events where two large angle jets have been found. A small value of $E_2^{non-jet}$ would indicate a direct event whereas a large value suggests the presence of photon remnants.

Figure 4 shows $E_2^{non-jet}$ for the data and models. It can be seen that HERWIG 5.9 does not describe the data at low values which indicates that the missing two jet events are QPM like. In contrast the QPM+VMD model does not describe the region of high $E_2^{non-jet}$ events, which is to be expected as this model does not contain resolved processes. Neither of the models can be brought into agreement with the data by a simple renormalization. HERWIG + power law p_t provides a better description of this variable.

One further way of looking at these two jet events is by using the two variables

$$x_\gamma = \frac{\sum_{jets}(E + p_z)}{\sum_{hadrons}(E + p_z)}$$

and

$$x_{tag} = \frac{\sum_{jets}(E - p_z)}{\sum_{hadrons}(E - p_z)}$$

where the tag is in the negative p_z direction. QPM-like events where all of the energy is in (or near) the two jets will have both x_γ and x_{tag} values near 1. Single resolved processes (which should have two high transverse momentum jets and one jet away from the tag) should have a low value of x_γ, but a high value of x_{tag}. Double resolved processes, with one beam-pipe jet in each direction, should have both low x_γ and low x_{tag}. The x_γ distribution is shown in figure 5(a). There is certainly a tail at low values of x_γ which is not well represented by the simple QPM + VMD sum. Standard HERWIG, on the other hand, matches this tail well, but the peak near $x_\gamma = 1$ is not well reproduced, indicating again that more direct events are required in the model. Neither model can be simply renormalized to fit the data. HERWIG + power law p_t successfully represents the region $x_\gamma > 0.8$ without destroying the agreement at lower values.

The x_{tag} distribution in figure 5(b) does not show an appreciable excess at low values in the data. This indicates that double resolved processes are not present to a large extent in the data at this Q^2.

5 Conclusions

The ALEPH data confirms recent problems reported by OPAL in modelling the hadronic final state in tagged $\gamma\gamma \rightarrow hadrons$. Changing the transverse momentum produced in the HERWIG generator improved the agreement with the data in some problematic areas. Further work might well produce a model which describes the data well and can thus be relied upon for use in analyses where the $\gamma\gamma$ background is large. However the *ad hoc* nature of the new model studied here is of concern for analyses such as structure function measurements.

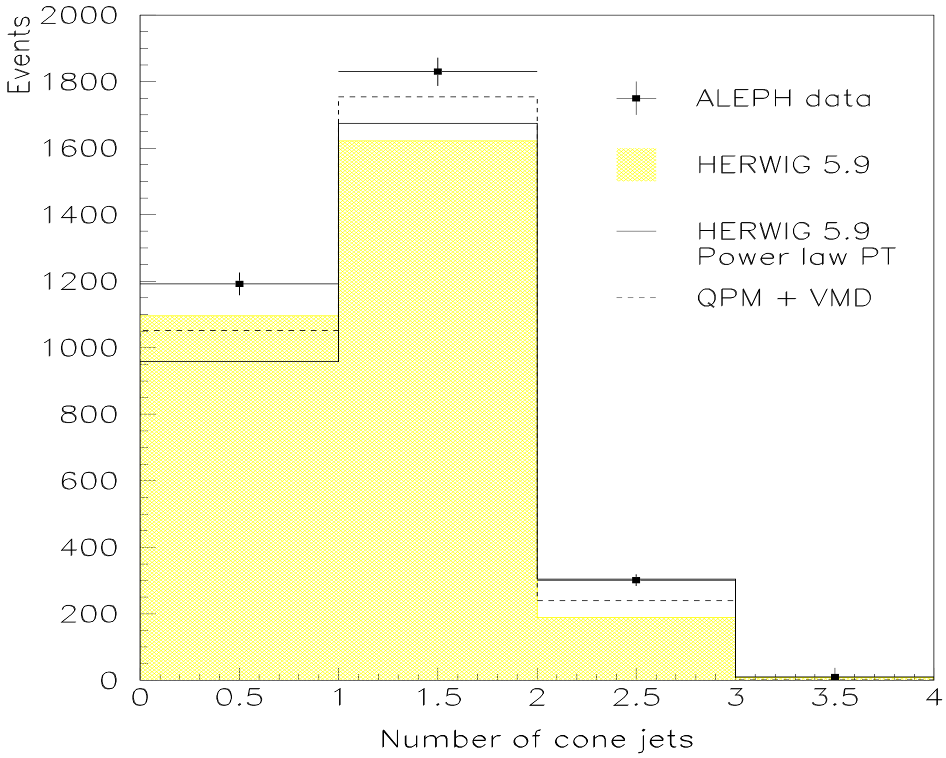

Figure 3: The number of good cone jets found per event.

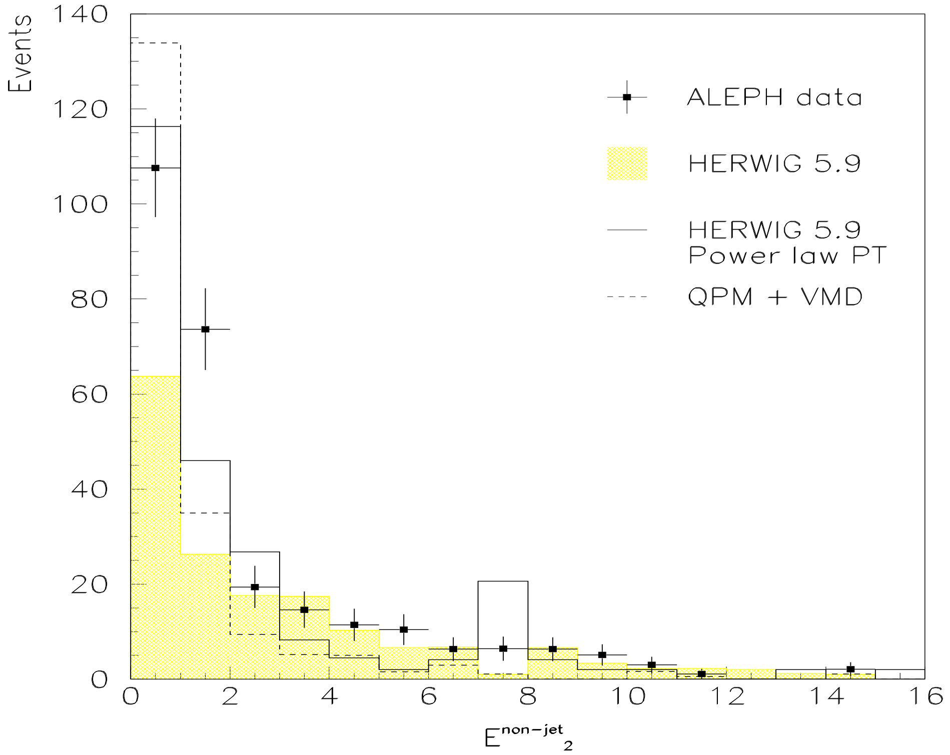

Figure 4: For two jet events: the energy of the hadrons that are not assigned to the jets.

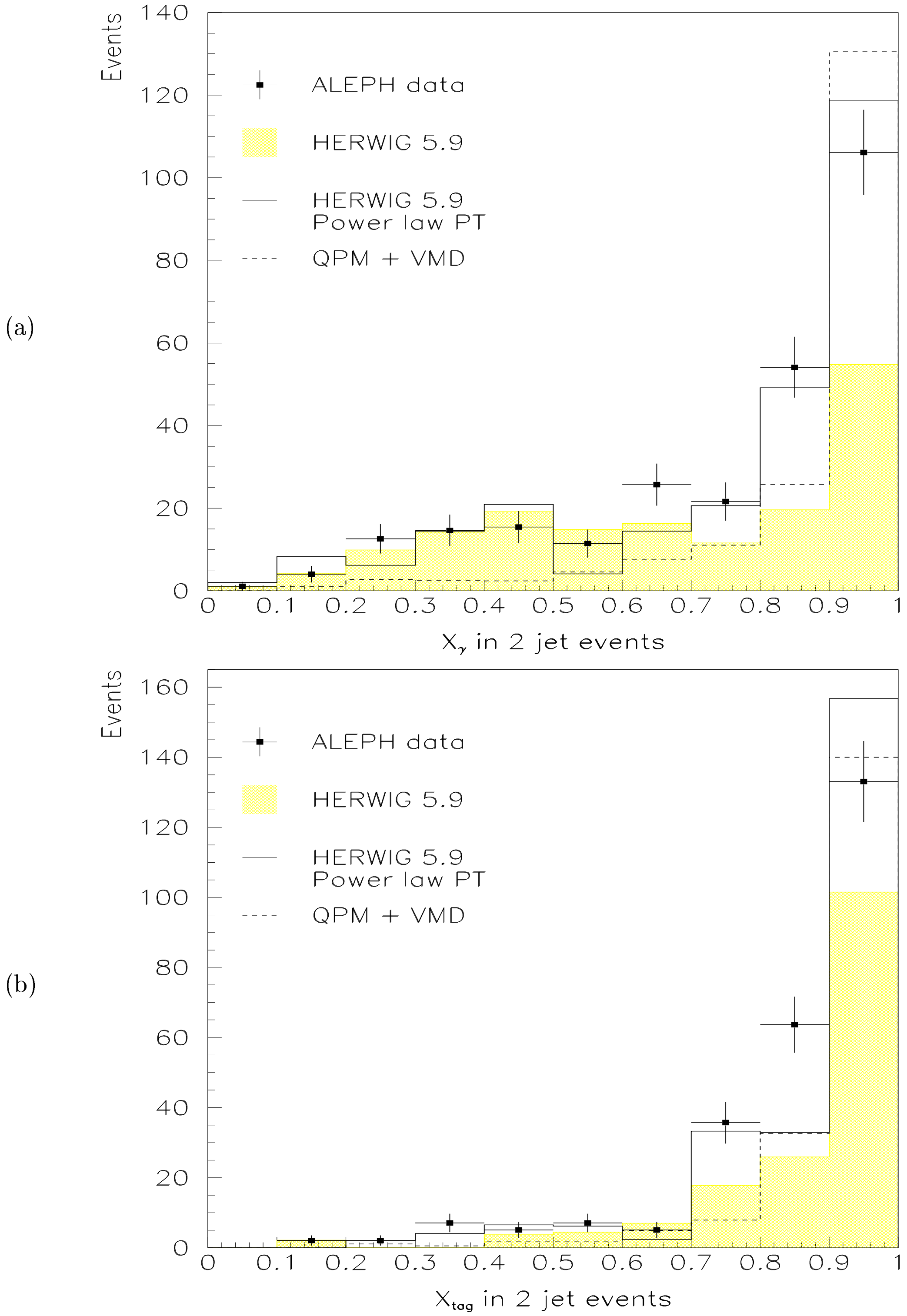

Figure 5: For two jet events: (a) x_γ - the tail in the data indicate the presence of some single resolved events, and (b) x_{tag} - double resolved events, if present in numbers would appear at low values.

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References

[1] K. Ackerstaff et al., OPAL Collab., Z. Phys. **C74** (1997) 33.

[2] G. Marchesini et al., Computer Phys. Commun. **67** (1992) 465.

[3] M. Glück, E. Reya and A. Vogt, Phys. Rev. **D46** (1992) 1973.

[4] M.H. Seymour, personal communication.

[5] S. Cartwright et al., Proc. of the Oxford workshop on LEP2 phyics (in preparation).

[6] D. Decamp et al., ALEPH collab. Nucl. Instr. Meth. **A294** (1990) 121.

[7] D. Decamp et al., ALEPH collab., Phys. Lett. **B246** (1990) 306.

[8] G. Crawford, University of Lancaster Thesis, RAL-TH-97-005.
A. Finch, Proc. of the Photon 97 Workshop, to be published.

[9] J.A.M. Vermaseren, Proc. of the IV International Workshop on Gamma Gamma interactions, *eds* G. Cochard and P. Kessler (1980).

[10] D. Buskulic et al., ALEPH collab., Phys. Lett. **313** (1993) 509.

[11] T. Sjöstrand, Computer Phys. Commun. **82** (1994) 74.

[12] J.H. Field, Nucl. Phys. **B168** (1980) 477, and erratum, NP **B176** (1980) 545.

[13] M. Derrick et al., Zeus Collaboration, Phys. Lett. **B354** (1995) 163.

[14] W. Newton, ALEPH note, ALEPH 96-094.