# HADRON PRODUCTION IN $\gamma\gamma$ COLLISIONS AT $\sqrt{s}$= 130 -140 GeV

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The reaction $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^- hadrons$ is analysed using data taken by the L3 experiment at LEP during the 1995 high energy run. The events are compared with recent theoretical models which include non perturbative vector dominance effects as well as perturbative QED and QCD diagrams. The cross section $\sigma(\gamma\gamma \rightarrow hadrons)$ is measured in the interval $5 \leq W_{\gamma\gamma} \leq 75$ GeV .

## 1 Introduction

In November 1995 the LEP energy was raised to $\sqrt{s}$= 130, 136, 140 GeV , well above the Z resonance. At these energies the two-photon process $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^- hadrons$ is the main contribution to hadron production. A good understanding of $\gamma\gamma$ physics is therefore necessary not only because we are interested to study the complex nature of the photon, but also because we need to consider this interaction as a potential background for any other physics channel of interest.

An interacting photon provides a rich spectrum of processes. It can interact as a point-like particle (*direct component*) via a $q\bar{q}$ fluctuation, a pure QED process. Often a quantum fluctuation transforms the photon in a vector meson $\rho, \omega, \phi, ...$ (*VMD component*), opening up all the possibilities of an hadronic interaction (Regge poles, Pomeron exchange, etc.). In hard scattering the photon structure of the photon can be resolved (*anomalous component*) and quark and gluon content can be measured. The relative amounts of these components and their respective properties are not yet fully understood. Recently there has been an effort by Schuler and Sjöstrand [1] and by Engel and Ranft [2] to construct a model constrained by the knowledge accumulated from ep and pp scattering data. Both groups have provided a Monte Carlo generator which we can compare with the data. In PYTHIA [3] where both incoming photons are assumed to be on mass shell, we have complemented the code by generating the photon flux in the Equivalent Photon Approximation [4]. The model is then valid only for events with photon mass $Q^2 \simeq 0$. PHOJET [2] uses the exact $\gamma\gamma$ luminosity fonction ($\mathcal{L}_{\gamma\gamma}$) for transverse photons, it includes initial state radiation and the $\gamma^*\gamma^* \rightarrow hadrons$ cross section takes into account the photon virtuality.

In this study we analyse data, taken by the L3 detector, for an integrated luminosity of 4.98 $pb^{-1}$. The scattered electrons are not detected, thus the interacting photons have a small virtuality : $< Q^2 > \simeq 0.025$ GeV$^2$ . The visible cross sections and event shape of the data are compared to the predictions of the Monte Carlos. Preliminary results on total cross section $\sigma(\gamma\gamma \rightarrow hadrons)$ in the interval $5 \leq W_{\gamma\gamma} \leq 75$ GeV are given.

## 2 Event selection

In the reaction $e^+e^- \rightarrow e^+e^- hadrons$, most of the initial energy is taken by the scattered electrons ($e^\pm$); if $Q^2 \simeq 0$ their scattering angle is close to the beam and they go undetected. The hadron system is therefore concentrated at low masses and, for high values of $\sqrt{s}$, it is well separated from the $e^+e^-$annihilation processes. We have identified these events by the following criteria :

- We require at least four good tracks with transverse momentum greater than 100 MeV coming from the interaction vertex within 10 mm in the transverse plane. This selection excludes the dominant $e^+e^- \rightarrow e^+e^- leptons$ channels. With the additional condition that the total energy deposited in the electromagnetic calorimeter exceeds 500 MeV , it suppresses also beam-gas and beam-wall backgrounds.

- To exclude one boson annihilation events, we require that the energy in the electromagnetic calorimeter be smaller than 30 GeV and in the hadron calorimeter smaller than 20 GeV .

- We impose an anti-tag condition which exclude events with energy greater than 30 GeV in the luminosity monitor, or at the edges of the detector.

The visible effective mass ($W_{\mathrm{vis}}$) of the event is calculated from the four-momentum vectors of the tracks and of the clusters reconstructed in the calorimeters. All these particles are assumed to be pions, except for electromagnetic clusters with no corresponding track which are considered to be photons. We limit the analysis to events with $W_{\mathrm{vis}} \geq 5$ GeV . We select 6822 events. The background, due mainly to annihilation processes and two-photon tau production, is subtracted from the data, it varies from 0.5% at a mass of 5 GeV to 4% at a mass of 60 GeV .

## 3 Results

### *3.1 Monte-Carlo comparison*

We have generated samples of PHOJET [2] and PYTHIA [3] events with statistics three times larger than the data. The events were simulated in the L3 detector and passed through the same reconstruction program as the data.

There is a rather good agreement between the data and the two generators, for all the observed distributions : transverse momentum of the tracks, energy deposited in the calorimeters and angular distributions. The differences between the two generators and between the simulated events and the data are smaller than 30%. In fig 1 the $W_{vis}$ mass spectrum is compared to the generators expectations. In fig 2 the VMD, direct and anomalous contributions are shown as predicted by the PYTHIA generator. In the whole mass interval the main contribution is the vector dominance component.

### *3.2 $\sigma(\gamma\gamma)$ $\rightarrow$hadrons*

In order to calculate the $\gamma\gamma$ cross section we first obtain the $W_{\gamma\gamma}$ distribution from the $W_{vis}$ spectrum by using an unfolding matrix derived indipendently from the two generators.
By using the number of unfolded events N and the integrated luminosity ($\mathcal{L}_{ee}$) of 4.98 pb$^{-1}$we measure in each $W_{\gamma\gamma}$bin

$$d\,\sigma\,(e^+e^- \rightarrow e^+e^- hadrons) = \frac{N}{\mathcal{L}_{ee}\,\cdot\,\mathcal{A}} \qquad (1)$$

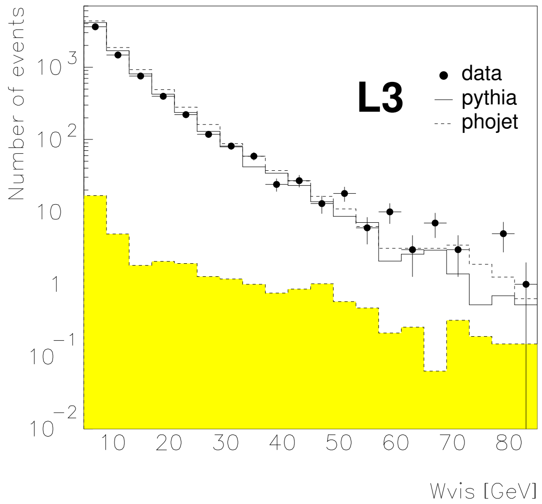


Figure 1: The measured visible mass compared with PYTHIA (continous line) and PHOJET (dashed line). The Monte Carlo events are normalized to the integrated luminosity of the data. Shaded is the sum of all backgrounds.

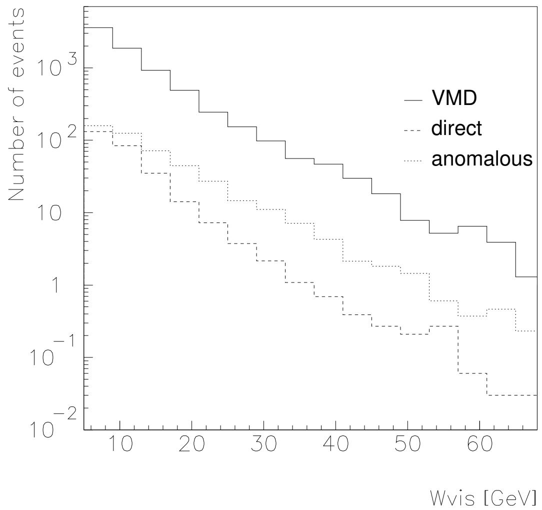


Figure 2: Mass dependence of different contributions as predicted by PYTHIA: VMD (continous line), direct (dashed line) and anomalous (dotted line). The Monte Carlo events are normalized to the integrated luminosity of the data.

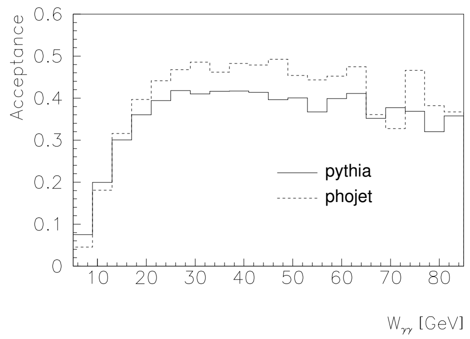


Figure 3: Total acceptance and efficiency of this analysis as function of the two-photon mass,calculated by the two generators PYTHIA and PHOJET

The acceptance $\mathcal{A}$ (fig 3) is defined as the ratio between reconstructed and generated events in each $W_{\gamma\gamma}$interval. It includes the effects of the missing particles escaping detection and the inefficiencies of the detector, of the trigger and of the analysis. We extract the $\gamma\gamma \to hadrons$ cross section using the photon flux $\mathcal{L}_{\gamma\gamma}$ [4]

$$d\sigma(e^+e^- \to e^+e^- hadrons) = d^5\mathcal{L}_{\gamma\gamma}(\alpha_i) \times \sigma(\gamma\gamma \to \text{hadrons}) \quad (2)$$

We take into account the photon virtuality by inserting a $\rho$ form factor :

$$\sigma(\gamma^*\gamma^* \to hadrons) = \sigma(W, Q_1^2, Q_2^2) = F^2(Q_1^2)F^2(Q_2^2)\sigma(W, 0., 0.) \quad (3)$$

$$F(Q^2) = \frac{m_\rho^2}{m_\rho^2 + Q^2} \quad (4)$$

For each $W_{\gamma\gamma}$bin we perform a numerical integration of $\mathcal{L}_{\gamma\gamma} \times F(Q^2)$ over the unmeasured kinematical variables $\alpha_i$ of the scattered electrons. In fig 4 we plot the results. The main contributions to the errors come from the differences between PYTHIA and PHOJET and from the uncertainties due to the unfolding method. The uncertainties due to the analysis cuts are also taken into account, they are dominated by the cut on the minimum number of tracks.

The total hadronic cross sections, for any reaction A+B →X, show a characteristic fall-off at low

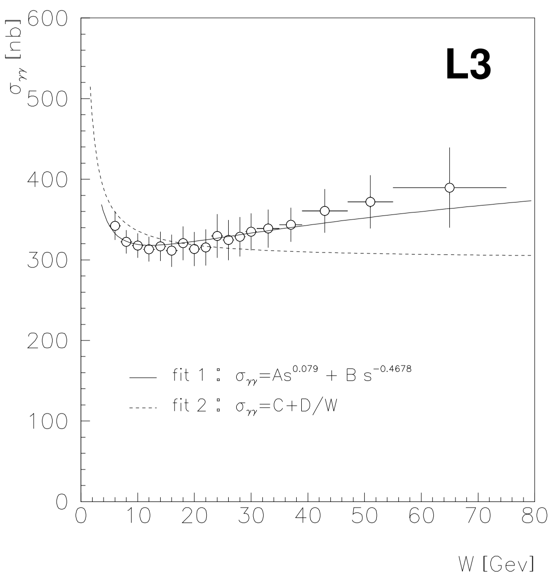


Figure 4: Total cross section $\gamma\gamma \to hadrons$ measured in L3 at 130-140 GeV $e^+e^-$center-of-mass energy. The curves are two Regge-pole inspired models fitted to the data.

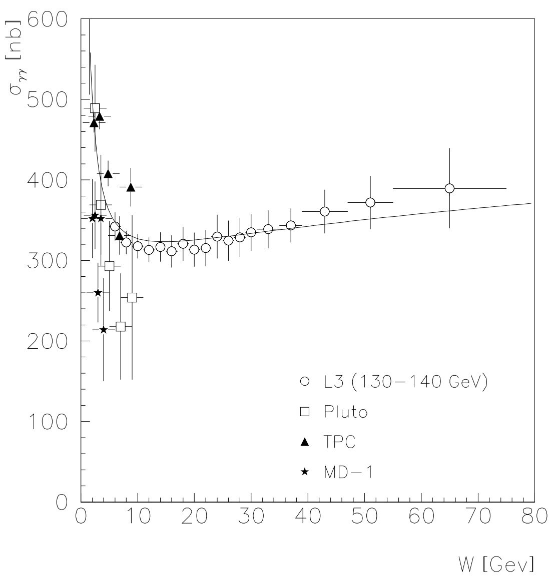


Figure 5: Total cross section $\gamma\gamma \to hadrons$ as measured by various experiments . The Donnachie-Landshoff function is fitted and superimposed to the data.

energies and a slow rise at higher energies. This behaviour can be parametrised by the form [5],

$$\sigma_{\gamma\gamma} = A\, s^{0.079} + B\, s^{-0.4678} \tag{5}$$

The powers of $s$ are universal [6]. Within the Regge theory the first term corresponds to pomeron exchange and gives the asymptotic rise of the cross-section. The second term parametrises the rapid decrease of the cross-sections at low energies due to reggeon exchange. The coefficients A and B are process and $Q^2$ dependent. We fit them to our data and we obtain

$$A = 183 \pm 6nb \quad B = 481 \pm 92nb$$
$$\chi^2/d.o.f. = 0.12$$

To gain sensitivity on the reggeon parameter we also include the results of previous experiments [7]. A common fit gives

$$A = 181 \pm 4nb \quad B = 575 \pm 25nb$$
$$\chi^2/d.o.f. = 2.7$$

Although the compatibility between the experiments is not very good (fig 5), the parameters of the fit are consistent with the one obtained by fitting only our data. We also fit the data with a critical-pomeron parametrisation [8] which assumes a constant value for the cross sections at high energies

$$\sigma_{\gamma\gamma} = C + \frac{D}{W} \tag{6}$$

Also here the reggeon parameter D is mainly defined by the low energy data : $D = 350 \pm 29nb$ and the constant is the same if we fit our data only or if we include all data : $C = 301 \pm 6nb$ . This fit (fig 4) , doesn't reproduce the increase of the cross section at higher energies observed in our data ($\chi^2/d.o.f. = 1.3$).

## 4 Conclusions

In the first high energy run of the LEP collider we obtained 6822 events of the untagged two-photon interaction $e^+e^- \rightarrow e^+e^- hadrons$ with visible mass greater than 5 GeV.

The detailed features of the events: angular distributions, energy deposited in the calorimeters, visible mass and missing momentum are rather well described by the recent generators PYTHIA [3] and PHOJET [2]. The PHOJET model describes well also the tagged events with high $Q^2$, the study of these data is in progress. We have measured the cross section $\sigma(e^+e^- \rightarrow e^+e^- hadrons)$ at beam energies of 130-140 GeV for a mean photon virtuality $< Q^2 >= 0.025 GeV^2$. This cross section is dominated by soft $\gamma\gamma$ interactions. The cross section $\sigma(\gamma\gamma \rightarrow hadrons)$ is extracted in the mass interval $5 \leq W_{\gamma\gamma} \leq 75$ GeV . The energy dependence of the measurement is well represented by the universal Regge parametrization of Donnachie and Landshoff.


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