New results on the total cross section and on charmonium formation in two-photon collisions at LEP

Silvia Costantini[1]

[1] DESY-Zeuthen, Platanenallee 6, D-15738 Zeuthen, Germany
Present address: CERN-EP, CH-1211, Geneva 23

E-mail: `Silvia.Costantini@cern.ch`

Abstract

We present new results obtained by L3 and OPAL in the measurement of the total cross section $\gamma\gamma \to hadrons$. The production of the resonances η_c and χ_{c2} is also discussed.

1. The two-photon total cross section

The process $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^- hadrons$ is the largest source of hadron production at LEPII. In this reaction most of the initial energy is taken by the scattered electrons and positrons, which often go undetected at angles close to the beam-pipe. In this case the events are classified as non-tagged and the two photons are referred to as quasi-real. The hadron system has typically a low mass compared to the center-of-mass energy $\sqrt{s}$.

The total hadronic cross section for quasi-real photons has been measured by L3 [1] and OPAL [2] for center-of-mass energies up to 189 GeV. The cross section $\sigma(\gamma\gamma \to hadrons)$ has been derived for values of the two-photon mass $W_{\gamma\gamma}$ between 5 GeV and 145 GeV. Due to the Lorentz boost of the $\gamma\gamma$ system and to the detector acceptance, the measured effective hadronic mass W_{vis} is smaller than $W_{\gamma\gamma}$. For this reason, unfolding procedures are used to extract the true hadronic mass $W_{\gamma\gamma}$ from the observed distribution of the visible effective mass [1, 2].

The cross section measurements of L3 show a steep decrease in the region of low center-of-mass energies. Both experiments measure a slow rise at high energies. For values of $W_{\gamma\gamma}$ greater than 10-20 GeV, the data are well reproduced by models which include QCD effects, as shown in Fig. 1. The data are compared with the prediciton by Schuler and Sjöstrand [3], by the dual parton model of Engel and Ranft [4] and by the minijet model of Godbole and Pancheri [5].

The cross section can be described by a Regge parametrisation of the form [6]:

$$\sigma_{\gamma\gamma} = As^{\varepsilon} + Bs^{-\eta}\ ,\ \ s = W^2_{\gamma\gamma}, \tag{1}$$

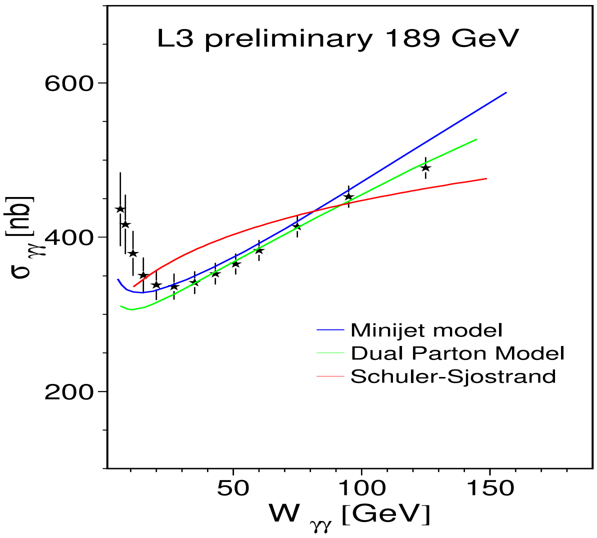

Figure 1. The measured cross section $\sigma(\gamma\gamma \to hadrons)$ as a function of $W_{\gamma\gamma}$. The L3 data are compared with theoretical predictions (see text).

where the first term represents pomeron exchange and the second reggeon exchange. The exponents are assumed to be universal and the coefficients A and B are process and Q^2 dependent. If photons behave predominantly as hadrons, Eq. 1 may also be valid for the two-photon total hadronic cross section. Fig. 2 shows two different fits to the L3 data, the first one with A, B and ε as free parameters (light gray line) and the second one (black line) with ε fixed to the universal value of 0.095 ± 0.002 [7]. In both cases η is fixed to the universal value of 0.34 ± 0.02. The $\sigma_{\gamma\gamma}$ energy

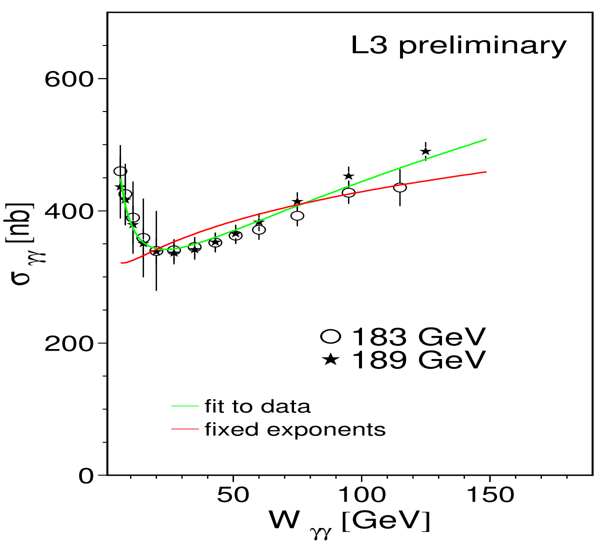

Figure 2. Fits to to $\sigma_{\gamma\gamma}$ with the L3 data, as a function of $W_{\gamma\gamma}$, with ε as a free parameter (light gray line) and with ε fixed to the universal value of 0.095 ± 0.002 (black line).

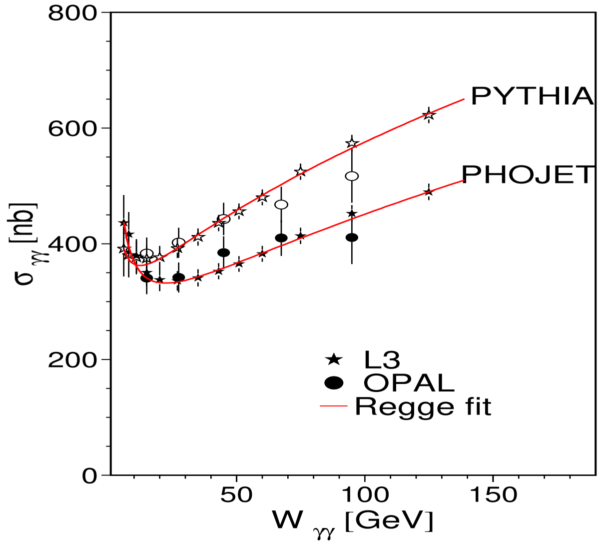

Figure 3. Regge fits to $\sigma_{\gamma\gamma}$ with the L3 data, with ε as a free parameter, using the data unfolded with PYTHIA (empty stars) or PHOJET (full stars). The corresponding measurements by OPAL are included as empty circles (data unfolded with PYTHIA) or full circles (data unfolded with PHOJET).

dependence is better reproduced by a fit with ε as a free parameter. In particular L3 obtains: $\varepsilon = 0.222 \pm 0.019$ in the interval $W_{\gamma\gamma} = 5 - 145$ GeV, with the data unfolded with PHOJET [4]. In the range $W_{\gamma\gamma} = 39 - 145$ GeV ε is found equal to 0.136 ± 0.008 [1]. Those measurements indicate a faster rise of $\sigma_{\gamma\gamma}$ with respect to pp or γp interactions. When PYTHIA [8] is used for unfolding the data a similar behaviour is found. It has to be noticed that PYTHIA and PHOJET differ by about 20% in the absolute normalization.

OPAL finds no evidence of a second pomeron [2] and obtains: $\varepsilon = 0.101 \pm 0.003^{+0.025}_{-0.020}$. In this case the results obtained by unfolding the data with PYTHIA and PHOJET are averaged. Using only PHOJET, OPAL measures a two-photon cross section lower by 5%-10%.

If the same generator is used, the measurements of $\sigma_{\gamma\gamma}$ by L3 and OPAL are compatible, as shown in Fig. 3. Both experiments show a clear rising behaviour as a function of $W_{\gamma\gamma}$, which is independent of the generator used. The uncertainty on the absolute value is about 20%, due to the difference in the absolute normalization of the two Monte Carlo models.

2. η_c and χ_{c2} formation

At e^+e^- colliders, resonance formation in two-photon interactions is studied via the process $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^- R$, where the resonance R must have positive charge conjugation. The total production cross section is proportional to the two-photon cross section $\sigma_{\gamma\gamma\to R}$ through the two-photon luminosity function described by QED [9]:

$$\sigma(e^+e^- \to e^+e^- R) = \int d\mathcal{L}_{\gamma\gamma}(W^2_{\gamma\gamma}) \;\; \sigma_{\gamma\gamma\to R}, \quad (2)$$

with the Breit-Wigner cross section:

$$\sigma_{\gamma\gamma\to R}(W^2_{\gamma\gamma}, q_1^2, q_2^2) = 8\pi\,(2J_R+1)\,\Gamma_{\gamma\gamma}(R) \quad (3)$$
$$F^2(q_1^2,q_2^2)\,\frac{\Gamma_R}{(W^2_{\gamma\gamma}-M_R^2)^2+M_R^2\Gamma_R^2}.$$

The resonance R is characterised by its mass M_R, total spin J_R, total width Γ_R and two-photon width $\Gamma_{\gamma\gamma}(R)$. The two-photon width and the transition form factor $F^2(q_1^2, q_2^2)$ are the two parameters to be measured. In case of quasi-real photons, the form factor is normalised to unity, so that the total cross section is linearly proportional to the two-photon width, which is left as the only unknown parameter.

L3 has measured the two-photon width of the $\eta_c(2980)$ using the data collected at 91 GeV and 183 GeV [10], with integrated luminosities of 140 pb^{-1}and 52 pb^{-1}, respectively. Since the η_c does not have a dominant decay mode, nine different channels have been analysed, with branching ratios

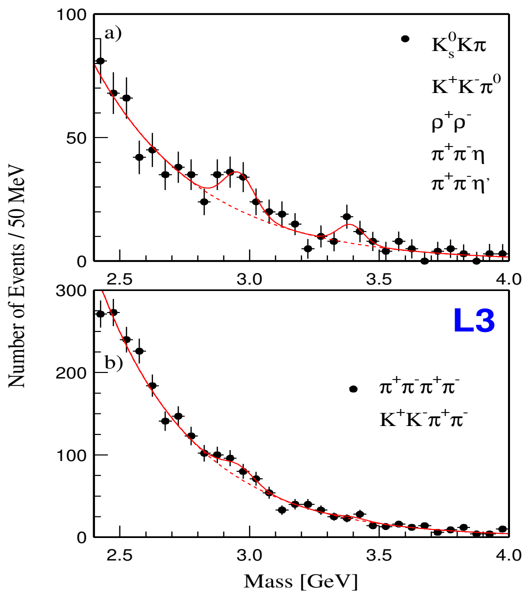

Figure 4. The mass distribution of the selected non-tagged events for the listed decay modes. The solid lines show fits to the data with an exponential background and Gaussians for the η_c and χ_{c0} signals.

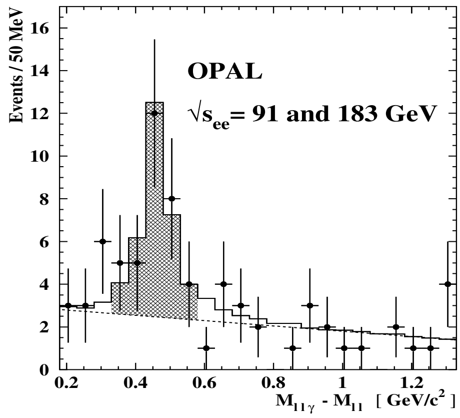

Figure 5. Difference between the $\ell\ell\gamma$ and $\ell\ell$ invariant masses. The dashed line shows the fit to the sidebands of the signal with a linear function. The hatched histogram represents the invariant mass region between 330 MeV and 580 MeV.

ranging from 0.5% to 2.0%. As shown in Fig. 4, two peaks are observed at $M_{\eta_c} = 2.974 \pm 0.018$ GeV and $M_{\chi_{c0}} = 3.400 \pm 0.019$ GeV. The resulting two-photon width of the η_c is: $\Gamma_{\gamma\gamma}(\eta_c) = 6.9 \pm 1.7$ (stat.) $\pm$ 0.8 (syst.) $\pm$ 2.0 (BR) keV, where the last error is due to the uncertainty on the branching ratio of $J/\psi \to \eta_c\gamma$. This result is in agreement with the world average [7]: $\Gamma_{\gamma\gamma}(\eta_c) = 7.5^{+1.6}_{-1,4}$ keV. The two-photon width of the χ_{c0} has not been measured, because its branching ratios are unknown.

The two-photon formation of the resonance χ_{c2} has been studied by L3 [11] and OPAL [12] with the data collected at 91 GeV and 183 GeV. The decay channel considered is $\chi_{c2} \to J/\psi\gamma \to \ell^+\ell^-\gamma$, with $\ell = e, \mu$, corresponding to a total branching ratio of 1.6%. As shown in Fig. 5, a clear peak is seen around $M_{\chi_{c2}} - M_{J/\psi} = 459$ MeV. The measured two-photon width is: $\Gamma_{\gamma\gamma}(\chi_{c2}) = 1.02 \pm 0.40$ (stat.) $\pm$ 0.15 (syst.) $\pm$ 0.09 (BR) keV (L3) and $\Gamma_{\gamma\gamma}(\chi_{c2}) = 1.76 \pm 0.47$ (stat.) $\pm$ 0.37 (syst.) $\pm$ 0.15 (BR) keV (OPAL). The combined value of all two-photon measurements: $\Gamma_{\gamma\gamma}(\chi_{c2}) = 1.23 \pm 0.23 \pm 0.11$ (BR) keV, is three standard deviations higher than the $p\bar{p}$ measurement of E835 [13]: $\Gamma_{\gamma\gamma}(\chi_{c2}) = 0.31 \pm 0.05 \pm 0.04$ keV.

Acknowledgements

I would like to thank Maria Kienzle-Focacci for useful discussions.

References

[1] L3 Collab., Acciarri M *et al.*, 1997 *Phys. Lett.* B **408** 450; L3 Collab., Acciarri M *et al.*, 1999, L3 Note 2400 submitted to this conference.
[2] OPAL Collab., Abbiendi G *et al.*, CERN-EP/99-076 submitted to this conference.
[3] Schuler G A and Sjöstrand T 1993 *Phys. Lett.* B **8** 343; Schuler G A and Sjöstrand T 1997 *Z. Phys.* C **73** 677;
[4] Engel R 1995 *Z. Phys.* C **66** 203; Engel R and Ranft J 1996 *Phys. Rev.* D **54** 4246.
[5] Godbole R M and Pancheri G 1999 hep-ph/9903331.
[6] Donnachie A and Landshoff P V 1992 *Phys. Lett.* B **296** 227.
[7] Review of Particle Physics 1998 *Eur. Phys. J.* C **3** 205.
[8] Sjöstrand T 1994 *Comp. Phys. Comm.* **82** 74.
[9] Budnev V M *et al.*(1974) *Phys. Rep.* **15** 181.
[10] L3 Collab., Acciarri M *et al.*, 1999 *Phys. Lett.* B **461** 155.
[11] L3 Collab., Acciarri M *et al.*, 1999 *Phys. Lett.* B **453** 73.
[12] OPAL Collab., Abbiendi G *et al.*, 1998 *Phys. Lett.* B **439** 197.
[13] E835 Collab. 1999, talk by M. Stancari at Photon99, Freiburg im Breisgau, Germany.