Cross Section of Hadron Production in $\gamma\gamma$ Collisions at LEP

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Cross sections of $\gamma^*\gamma^*$ collisions are presented and diffractive contributions are studied. Interactions of quasi real and highly virtual photons are considered. The Regge parameterization of Donnachie and Landshoff describes the cross section behavior of quasi real processes whereas BFKL Pomeron calculations are not consistent with our data.

1. INTRODUCTION

We have analyzed the reaction $e^+e^- \rightarrow e^+e^-\gamma^*\gamma^* \rightarrow e^+e^-hadrons$ at high energies. Here most of the energy is taken by the scattered electrons and positrons. Many of the hadrons produced are not seen by the detector. Therefore in most of the events the measured effective mass W_{vis} is smaller than the total invariant mass of the two interacting photons $W_{\gamma\gamma}$. We have used the L3 luminosity detector to determine interactions of quasi real photons and interactions of highly virtual photons by selecting anti-tagged and double-tagged two-photon events (the scattered electron and positron are not detected or are detected in the luminosity monitors). The luminosity monitors cover a polar angle between 25 and 69 mrad on each side of the L3 detector.

2. EVENT SELECTION

The following conditions are used in this analysis to select events for two-photon interactions in the L3 detector:

- First level trigger condition:
  two charged tracks "back to back" (within $\pm 61^\circ$) with $p_t > 150$ MeV
- Quasi-real photons:
  - Scattered e^+e^- are strongly suppressed (antitagging), i.e. electromagnetic energy seen in the LUMI calorimeter < 50 GeV
  - At least 6 particles are detected (to eliminate the $e^+e^- \rightarrow e^+e^-leptons$ channels)
  - Total energy deposited in electromagnetic calorimeter > 500 MeV (suppress beam-gas and beam-wall background)
  - Total energy measured in the calorimeters < 50 GeV (exclude annihilation events)
- Virtual photons:
  - Scattered e^+e^- are detected (double-tagged), i.e. electromagnetic energy seen in the LUMI calorimeter > 40 GeV and polar angle of scattered e^+, e^- between 30 and 60 mrad
  - At least 3 tracks coming from the interaction vertex with $20^\circ < \theta < 160^\circ$ and $p_t > 100$ MeV
  - Total visible invariant mass of event $>$ 2 GeV

3. MONTE CARLO EVENT GENERATIONS

The following event generators have been used in our analysis [1]:

- Quasi-real $\gamma^*\gamma^*$ interactions:
  - Signal
    $e^+e^- \rightarrow e^+e^-hadrons$:
    PHOJET and PYTHIA

- Background
  $e^+e^- \to hadrons(\gamma)$: PYTHIA
  $e^+e^- \to ZZ(\gamma)$: PYTHIA
  $e^+e^- \to \tau^+\tau^-(\gamma)$: KORALZ
  $e^+e^- \to W^+W^-$: KORALW
  $e^+e^- \to e^+e^-\tau^+\tau^-$: DIAG36

- Virtual $\gamma^*\gamma^*$ collisions:

  - Signal
    $e^+e^- \to e^+e^- hadrons$ (183 GeV): PHOJET, TWOGAM
    $e^+e^- \to e^+e^- hadrons$ (189 GeV): PHOJET, JAMVG(Vermaseren)

  - Background
    $e^+e^- \to e^+e^- hadrons$(single tagged): PHOJET
    $e^+e^- \to e^+e^-\tau^+\tau^-$: JAMVG

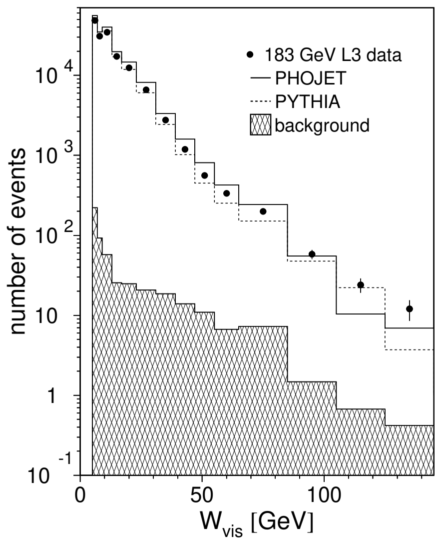

Figure 1. The measured visible mass at $\sqrt{s}$= 183 GeV compared to PHOJET and PYTHIA expectations.

4. QUASI-REAL $\gamma^*\gamma^*$ INTERACTIONS

L3 has collected an integrated luminosity of 51.35 pb^{-1} at $\sqrt{s}$= 183 GeV. In the analysis only events with $W_{\rm vis} \geq 5$ GeV are used. A comparison with Monte Carlo predictions shows a satisfactory agreement (Fig. 1). To get the true hadron mass $W_{\gamma\gamma}$ from W_{vis} the data are compared with the Monte Carlo prediction (unfolding procedure) [2]. Then the number of events is corrected for efficiency and acceptance of the detector. The result depends strongly on the Monte Carlo generator used and can be the source for rather large systematic errors. To get an estimate of this uncertainty we have used the two generators PHOJET and PYTHIA. Beside this further sources of systematic errors are trigger rejection, calorimeter energy scale factors, and the cut on the number of particles in the event selection. A comparison with the Regge model using the Donnachie Landshoff parameterization $\sigma_{\rm tot} = A\, s^{\epsilon} + B\, s^{-\eta}$ is shown in Fig. 2 and 3. The errors given herein are the combined statistical and systematic errors (without the uncertainty from the Monte Carlo model predictions). The fit with A, B, ϵ free and $\eta = 0.4678$ yields:
$\epsilon = 0.158 \pm 0.006$ (stat.) $\pm$ 0.028 (sys.) (PHOJET corrected data)
$\epsilon = 0.143 \pm 0.005$ (stat.) $\pm$ 0.025 (sys.) (PYTHIA corrected data)
This has to be compared with the value from the world average for hardonic cross section of $\epsilon = 0.095 \pm 0.002$ which is lower but still consistent.

4.1. The process $\gamma\gamma \to \rho^0\rho^0$

We have selected events of the reaction $e^+e^- \to e^+e^-\pi^+\pi^-\pi^+\pi^-$. The $\gamma\gamma \to 4\pi$ cross section is estimated by correcting the data for acceptance and efficiency and using the Low formula [3] for the luminosity function. Requiring that the $\pi^+\pi^-$ mass is in the ρ^0 mass range and correcting for combinatorial background we have calculated the $\gamma\gamma \to \rho^0\rho^0$ cross section for $W_{\gamma\gamma} > 3$ GeV (236 events). The results are shown in Fig. 4 and compared with the measurements of the TPC/2γ Collaboration [4].

5. VIRTUAL $\gamma^*\gamma^*$ INTERACTIONS

In this analysis double-tag events $e^+e^- \to e^+e^- hadrons$ at $\sqrt{s}$= 91 GeV, 183 GeV, and 189 GeV are selected. The corresponding integrated luminosities are 140 pb^{-1}, 52 pb^{-1}, and 176 pb^{-1}.

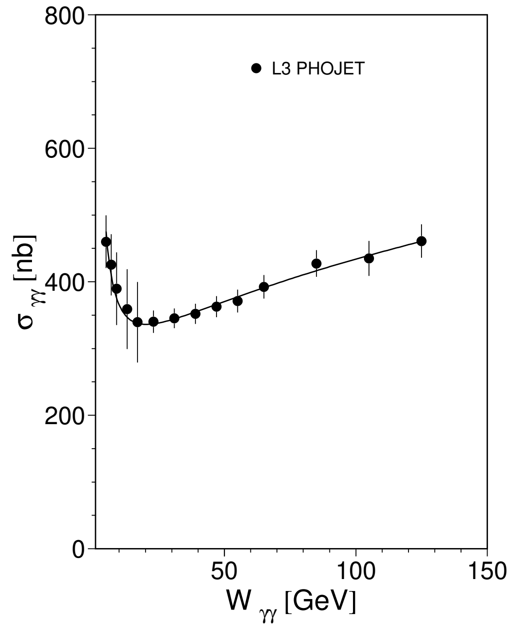

Figure 2. Total cross section for $\gamma\gamma \to$ *hadrons* obtained with PHOJET.

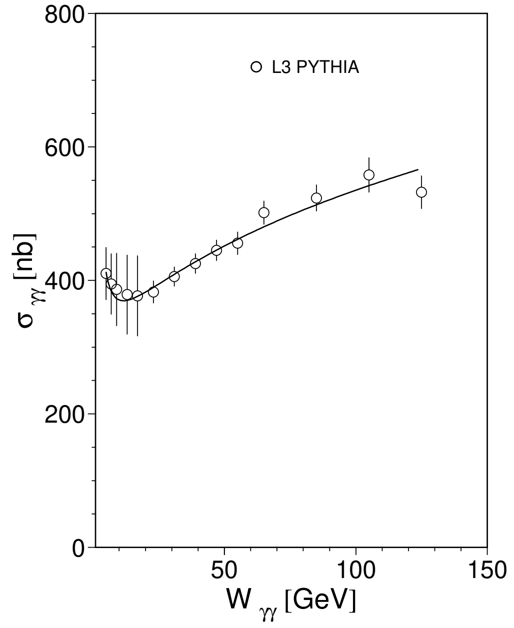

Figure 3. Total cross section for $\gamma\gamma \to$ *hadrons* obtained with PYTHIA.

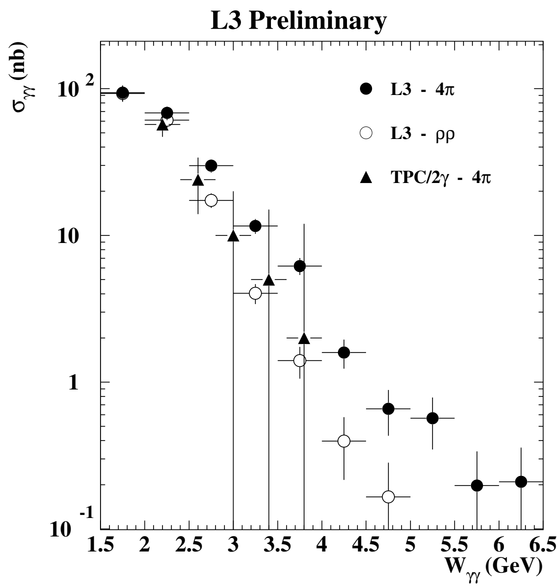

Figure 4. Total cross section for $\gamma\gamma \to 4\pi$ and $\gamma\gamma \to \rho^0\rho^0$ including results from [4].

The virtuality of the photons is in the range 1.2 GeV^2 < Q$^2_{1,2}$ < 9 GeV^2 at $\sqrt{s} \simeq$ 91 GeV and 2.5 GeV^2 < Q$^2_{1,2}$ < 38 GeV^2 at $\sqrt{s} \simeq$ 183, 189 GeV. $W_{\gamma\gamma}$ is calculated using the measurement of the tagged outgoing e^+, e^-. From the cross section $\sigma_{e^+e^-}$ the two-photon cross section $\sigma_{\gamma^*\gamma^*}$ is extracted taking into account only the transverse photon luminosity function [5,6] .

5.1. Test of the BFKL Pomeron

For highly virtual two-photon interactions with Q$^2_1 \approx$ Q$^2_2$ the BFKL diagram is expected to be dominant compared to the also contributing processes from the Quark Parton Model and the one-gluon exchange (Fig. 5). In leading order approximation the BFKL Pomeron exchange [7] cross section can be written as $\sigma_{\gamma^*\gamma^*} = \sigma_0(\frac{s}{s_0})^{\alpha_P - 1}$. To compare this prediction with the data we have chosen the cross section dependence on
$Y = \ln(\frac{s}{s_0}) \approx \ln(\frac{W^2_{\gamma^*\gamma^*}}{\sqrt{Q_1^2 Q_2^2}})$, $2 \leq$ Y ≤ 6.
In Fig. 6 we show the data fitted with α_P as free parameter. Also the the expected contribution from one-gluon exchange is shown. Our fit re-

sults are:
$\alpha_P - 1 = 0.28 \pm 0.05$ at $\sqrt{s} \approx$ 91 GeV,
$\alpha_P - 1 = 0.40 \pm 0.07$ at $\sqrt{s} \approx$ 183 GeV.
$\alpha_P - 1 = 0.29 \pm 0.03$ at $\sqrt{s} \approx$ 189 GeV.
These values disagree with the expected value from the BFKL model in LLA of $\alpha_P - 1 \approx 0.53$. A new calculation with NLO corrections yields a value of $\alpha_P - 1 \approx 0.16$ [8], significantly lower than our results.

6. CONCLUSIONS

Data are presented for both quasi real two-photon interactions and highly virtual two-photon processes. Existing models can not describe our data very well. The Regge model parameter fitted with our data for quasi real two-photon intersections show a larger ϵ than the world average for hadronic cross sections. The BFKL Pomeron intercept fitted using highly virtual two-photon interactions depend only slightly on the virtuality of the photons and lies significantly below the LO prediction and above the NLO one. For the exclusive reaction $\gamma\gamma \to 4\pi$ a good agreement with older measurements is obtained.

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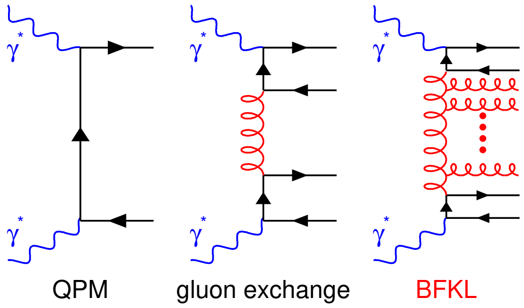

Figure 5. Diagrams for contributing processes.

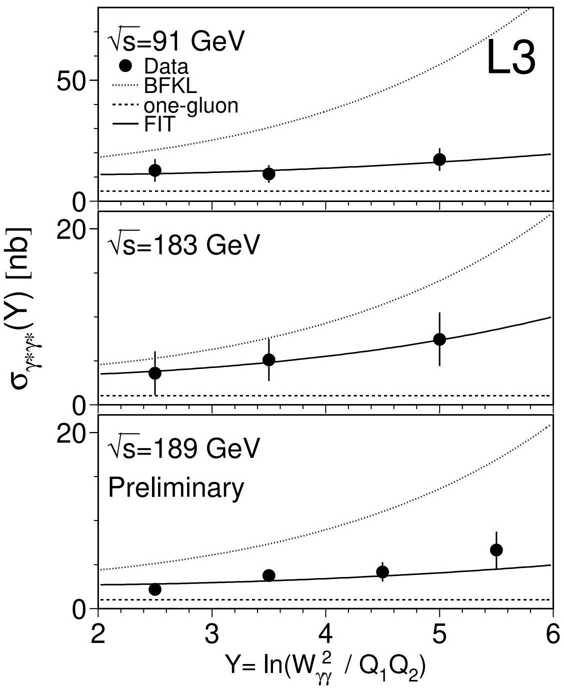

Figure 6. $\sigma_{\gamma^*\gamma^*}$ as function of Y, after subtraction of QPM contribution. The combined statistical and systematic errors are shown.