Study of lepton-pair and vector meson production in two-photon collisions using the L3 detector at LEP.

Excerpt of Ph.D. dissertation

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1 Introduction

In the framework of the classical electrodynamics light beams do not interact but traverse each other following the superposition principle, due to the linearity of the Maxwell equations. However, the situation is very different in quantum electrodynamics.

High energy photons fluctuate into fermion pairs, and these pairs could interact with the other photon, thus two-photon scattering is realized. While the cross section of this process is extremely small at low energies (for example in the optical region), the radiation field of high energy electron beams in e^+e^- storage rings contains energetic (virtual) photons. The bulk of these photons is radiated almost parallel to the beam line, thus electron beams can be regarded as an effective source of photon beams making possible the experimental realization of two-photon collisions.

Two-photon interactions have been studied experimentally and theoretically since several decades. With the advent of high-energy electron-positron colliders, which provide ideal environment for the experimental study of two-photon interactions – especially the LEP collider which could perform measurements in phase spaces not available in other laboratories – the study of a rich variety of possible two-photon reactions became available.

Two-photon reactions are dominant channels at LEP2. Charged lepton pair-production in two-photon collisions offers and efficient tool to test QED computations to order $\mathcal{O}(\alpha^4)$ over a wide kinematical range. These reactions are the $e^+e^- \to e^+e^-e^+e^-$, $e^+e^- \to e^+e^-\mu^+\mu^-$ and $e^+e^- \to e^+e^-\tau^+\tau^-$ processes. At the lowest order 36 Feynman diagrams for e^+e^- pairs and 12 diagrams for $\mu^+\mu^-$ and $\tau^+\tau^-$ pairs contribute to the process. With the study of e and μ pair production - because of their high cross section - not only a very precise QED measurement could be performed but they are of utmost importance for the understanding of the low energy behavior of the detector and for the study of several other 2-photon reactions. The τ pair production could give information about its electric and magnetic moment. As these cross sections factorize, using the concept of the two-photon luminosity function one can directly derive the $\gamma\gamma \to l^+l^-$ amplitudes, as well.

Mesons are strongly interacting particles having integer spin. All known mesons are believed to consist of a quark-antiquark pair – the so called valence quarks – plus a sea of virtual quark-antiquark pairs and virtual gluons. The vector mesons have odd parity and spin 1, where the quark and antiquark have parallel spin. Thus, vector mesons have the same quantum numbers as the photon ($J^{PC} = 1^{--}$). Such vector mesons are for example the ρ, ω, ϕ, J/Ψ particles.

Two-photon vector meson pair production has a long and interesting research history. Starting from the vector dominance model through the point-like photon-gluon coupling or the t-channel factorization approach , including the semi-hard approximations, the generalized Brodsky-Lepage model or the more recent color-dipole picture a lot of attempt have been made to describe and understand these processes. With the study of $\gamma\gamma \to \rho^0\rho^0$, $\gamma\gamma \to \pi^+\pi^-\pi^+\pi^-$ and $\gamma\gamma \to \pi^+\pi^-\pi^0\pi^0$ processes and with the observation of the poorly understood $\gamma\gamma \to f_2(1270)f_2(1270)$ reaction we can test and improve our knowledge. It also has been pointed out that the 2-photon J/Ψ production is a sensitive channel for the gluon content of the photon, thus it's observation reveals important information about the photon's gluon content.

2 Objectives

An important aim of the present experimental study was to extend our knowledge about the two-photon particle production mechanisms.

One of the important aims was the precise measurement of the cross section of charged lepton-pair production by two photons. This measurement was done for the first time ever at such energies.

A further aim was to study the production mechanisms of light vector mesons in two-photon collisions, in order to test varoius theoretical models, enrich and improve the set of measurements in this field.

An additional goal was the observation of inclusive J/Ψ production which was measured only by one single experiment so far, thus needs to be verified and cross checked by further measurements.

According to these motivations, in the thesis I present and discuss the experimental results of my analyses, the procedures followed in these studies, I summarize the theoretical models related to the channels in question, describe the used Monte Carlo programs, and I also give a description of the facilities used during this work including the L3 detector and the LHC Grid.

3 Applied methods

The study presented in the dissertation is based on the data recorded with the L3 detector at LEP in the 161-208 GeV e^+e^- center-of-mass energy range between the years 1996 and 2000. The collected data correspond to an integrated luminosity of $\approx$ 610 pb^{-1}. An important feature of two-photon collisions at LEP is that while the invariant mass of the e^+e^- system is unambiguously determined by the beam energy, the invariant mass of the two photon system ($W_{\gamma\gamma}$) is continuous. This fact makes possible to measure various quantities as the function of $W_{\gamma\gamma}$ for exclusive processes.

Charged electron pairs are seen in the detector as two curved tracks in the TEC (Time Expansion Chamber) [1] and two associated bumps in the electromagnetic calorimeter. Intermediate energy electrons (over few GeV) could be unambiguously identified by their shower shape in the electromagnetic calorimeter, however very low energy electrons require new methods for their identification. I developed a neural network based low energy electron identification method for the analysis of this channel and used it successfully during my inclusive J/Ψ studies. The μ particles – after leaving a track in the TEC – are passing through the detector leaving only some hits in the

[1] The TEC is a special Time Projection Chamber modified in order to achive higer precision, located in the central part of the L3 detector and plays very important role in particle track and vertex reconstruction.

muon chambers. In order to exclude the cosmic muon background we had to use the scintillator's time-of-flight information and accept events only in a very narrow time window around the nominal collision time. The number of misidentified background events originating from other processes is negligible in case of lepton pair production.

While charged pions are identified by their showers in the electromagnetic and hadronic calorimeters and their dE/dx properties measured in the TEC, neutral pions are reconstructed from two well isolated photon bumps in the electromagnetic calorimeter. Vector mesons are reconstructed from their pion and electron decay products. In general the limiting factors in the accuracy of the vector meson production analyses are the theoretical uncertanities, the combinatorical background and the very low cross sections.

All the data were compared to high statistics Monte Carlo data samples, but in addition, for a better understanding of the ρ^0 pair production I applied the semi-hard framework for this process and calculated the $\gamma\gamma \rightarrow \rho^0\rho^0$ cross section in the very phase space this measurement has been performed. This allowed a direct comparison of my results to theoretical predictions. A significant discrepancy has been found between the measured and calculated quantities.

Ensuring the quality of the data to be analyzed various filters have been applied to exclude the data registered in a time period with malfunctioning subdetectors. During the analysis mainly the inner part of the L3 detector was used, except for the μ pair production study when the scintillators and the muon chambers played a main role. Apart from the "usual" event selection and reconstruction procedure, we had to deal with and fix several other probelm like inefficiency correction due to the erroneous TEC trigger simulation, cosmic muon background, low-energy detector recalibration and low energy particle identification issues.

Altough the amount of data analyzed is almost negligible compared to the data of the forthcoming large experiments it was still computationally demanding, therefore I used the EGEE Grid computing facility for my analysis, in the development of which I was heavily involved and played a leading role. I was also the coordinator and a main developer of the middleware configuration software, which is now installed on $\approx$ 60.000 computer distributed among $\approx$ 250 computer center located on 5 continents.

All our results are discussed, interpreted and compared to theoretical predictions.

4 Excerpts

The results of this dissertation can be organized in the following points:

1. **Cross section measurement of two-photon charged lepton pair production.** I measured the cross section of the $e^+e^- \rightarrow e^+e^-e^+e^-$ and $e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ processes at various e^+e^- center-of-mass energies (161-208 GeV). Using the concept of the two-photon luminosity function I extracted the $\gamma\gamma \rightarrow e^+e^-$ and the $\gamma\gamma \rightarrow \mu^+\mu^-$ cross sections, as the function of the two-photon invariant mass, $W_{\gamma\gamma}$. The results are in very good agreement with the $\mathcal{O}(\alpha^4)$ QED calculations and are of utmost importance for the understanding of the low energy behavior of the detector and for the study of other 2-photon processes. This measurement has been performed for the very first time at such energies. Publications: [4,5,6]

2. **Study of $\pi^+\pi^-\pi^+\pi^-$ final states of two-photon collisions.** The $\gamma\gamma \rightarrow \pi^+\pi^-\pi^+\pi^-$ reaction was studied, it's cross section measured and the importance of the various contributing processes assesed. Based on the relatively high statistics data sample, I measured the diffractive cross section of the exclusive ρ^0 pair production by two quasi real photon ($\gamma\gamma \rightarrow \rho^0\rho^0$). A very important parameter of diffractive processes the t dependence of the cross section, was determined. I also calculated its cross section using the semi-hard framework in the same phase space the measurement was performed. We observed a discrepancy between the calculated results and the measured cross section.

This questions the usability of the semi-hard framework in our energy range. Publications: [3]

3. **Study of the** $\pi^+\pi^-\pi^0\pi^0$ **final state of two-photon collisions.** The $\gamma\gamma \rightarrow \pi^+\pi^-\pi^0\pi^0$ reaction was studied, and various properties of the process determined. The results are compared to theoretical predictions. Publications: [1,2]

4. **Observation of the elusive** $\gamma\gamma \rightarrow f_2(1270)f_2(1270)$ **process** This process is hardly explained by the theoretical works currently available, thus every new information including it's existence and visible cross section is of high interest. Publications: [1,3]

5. **Observation of two-photon inclusive** J/Ψ **production and measurement of the cross section** A very delicate low energy particle identification method had to be developed for the success of this analysis. The observation of the $\gamma\gamma \rightarrow J/\Psi X$ process has only been done by one single experiment before. I measured it's cross section detecting it through the leptonic decay of the J/Ψ particle. The results were compared to theoretical predictions. Publications: [8]

5 References

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