УДК 539.122

TWO-PHOTON COLLISIONS AT VERY LOW Q^2 FROM LEP2. FORTHCOMING RESULTS

***S.Almehed*[1]*, G.Jarlskog*[1]*, F.Kapusta*[2]*, U.Mjornmark*[1]*, A.Nygren*[1]*, I.Tyapkin, N.Zimin*[1]**

Experimental results that may soon be obtained in two-photon collisions at very low momentum transfer Q^2 at LEP2 are reviewed. A kinematical range is presented for both the forward and very forward detectors used to measure scattered electrons and positrons. A new acceptance, after this year's upgrade of the beam pipe at the position of the very forward detectors, is evaluated. The corresponding statistics are calculated for an integrated luminosity of 400 pb^{-1}, the total collected by the end of LEP2 operation according to current plans.

The investigation has been performed at the Laboratory of High Energies, JINR.

Двухфотонные столкновения на LEP2 при очень малых Q^2. Ожидаемые результаты

С.Алмехед и др.

Рассмотрены экспериментальные результаты, которые могут быть получены на LEP2 при изучении двухфотонных столкновений при очень малых моментах передачи Q^2. Представлены кинематические области для обоих калориметров, измеряющих очень малые и малые углы рассеянных электронов и позитронов. Принят во внимание новый аксептанс калориметра очень малых углов, полученный после модернизации вакуумной камеры в этом году. Оценка статистики сделана для полной светимости 400 пб$^{-1}$, которая должна быть набрана до окончания работы LEP2.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

1. Introduction

Studies of $\gamma\gamma$ collisions at very low momentum transfer Q^2 at LEP2 are attractive for many reasons (see, for example, [1]). First of all, it is worth pointing out that at present both theoretical and experimental knowledge is very poor in this range, and that previous measurements at LEP1 suffered from low statistics [2,3]. LEP2's increased integrated luminosity can help greatly in improving the information provided.

[1] Department of Physics, University of Lund, Sweden
[2] LPNHE, IN2P3-CNRS, Universités Paris VI et VII, France

There are at least three samples of $\gamma\gamma$ events that bring promise of interesting new results if they are studied: viz., depending on tagging conditions, a sample of single tagged events and two different samples for double tagged events. In all LEP experiments there are two ways of tagging the scattered electrons or positrons, either using the very forward calorimeters to detect polar angle of $\theta < 15$ mrad and thereby provide the measurements of very low momentum transfer squared Q^2, or using the forward calorimeters ($\theta > 30$mrad) to provide measurements of Q^2 in a region of higher transferred momenta.

For the single tag case [2], when only one of the scattered electrons or positrons is measured while the other goes into the beam pipe, higher statistics can help to further distinguish between the various parametrizations used to describe the quark and gluon densities inside the photon [4].

For the double tag case[3], when both the scattered leptons are detected in the very forward calorimeters, reliable measurements of the total $\gamma\gamma$ cross section in a range of high $\gamma\gamma$ centre-of-mass energies can be provided for the first time.

For the double tag case, when one scattered lepton is detected by the very forward calorimeters, giving the smaller measured momentum transfer P^2, while the second is detected by the forward calorimeter, giving the measured Q^2, the so-called virtual photon structure, i.e., the effect of nonzero virtuality of the tagged photon on the photon structure function [1] can then be studied.

Simplified theoretical concepts state that a total cross section of $\gamma\gamma$ interactions can be described by a sum of three components: a nonperturbative term describing a soft hadronic part by a Vector-meson Dominance Model (VDM), a perturbative term describing a point-like coupling of the photons to a quark-antiquark pair by the Quark Parton Model (QPM) and a term for the hard scattering of the partonic constituents of the photon, the so-called Resolved Photon Contribution (RPC). Either one (the single resolved case) or both photons (the double resolved case) may perturbatively fluctuate into $q\bar{q}$ pairs. In the single resolved case one parton from the photon subsequently interacts with another bare photon, while in the double resolved case one parton from each photon participates in a hard interaction thereby creating the high-p_T jets. The other partons create the so-called remnant jets which normally travel at low angles from the axis of $\gamma\gamma$ system (mainly into the beam pipe). These are the main ideas of the model, which is more complicated in reality. More detailed considerations can be found in [5]. For the single or double resolved perturbative part the lowest order diagrams are normally calculated with the different parametrizations used to describe parton density functions of the photon. These are available in PDFLIB[4]. There is a single free parameter p_T^{min}, the minimum transverse momentum of the outgoing partons, which has to be specified and used in order to separate the RPC from the nonperturbative contribution. These values of p_T^{min} were found for the parton density functions from the requirement to reproduce the visible experimental two-photon cross section at the Z^0 peak. Since the RPC was treated using leading order QCD factorization, a hard scattering subprocess gives the dominant scale p_T^2, taken also as tne factorization scale.

Well-known for many years, the VDM and QPM models are widely used to describe the experimental data at any beam energies and any Q^2 range . The relatively new RPC model has been tested at KEK, HERA and LEP1 (see, for example, the last Workshop Photon'97 [6]) in the region of low Q^2 ($< 2(\text{GeV/c}^2)^2$), and quite recently it was extended into a higher Q^2 region [7].

It is also important to mention, that depending on the tagging conditions, which in fact simply define the Q^2 region, the relative contributions from different models may vary widely.

Thus it is really important to get an estimate for the statistics for all of the cases mentioned above.

2. Kinematical Range and Luminosity

During the 1997-1998 year shutdown period all LEP experiments were equipped with a smaller beam pipe at the position of their very forward calorimeters, which are normally used for luminosity measurements as well. Initially the upgrade was proposed by the DELPHI experiment [8] in order to increase acceptance for the Very Small Angle Tagger (VSAT) and thus to improve the statistics available for two-photon studies. The following consideration has therefore been made for the DELPHI set-up. The principle of the upgrade was very simple: namely, to decrease the radius of the LEP beam pipe in the horizontal direction. The upgrade was simpler still because the DELPHI VSAT itself had previously been fitted with instruments designed to accommodate the larger acceptance.

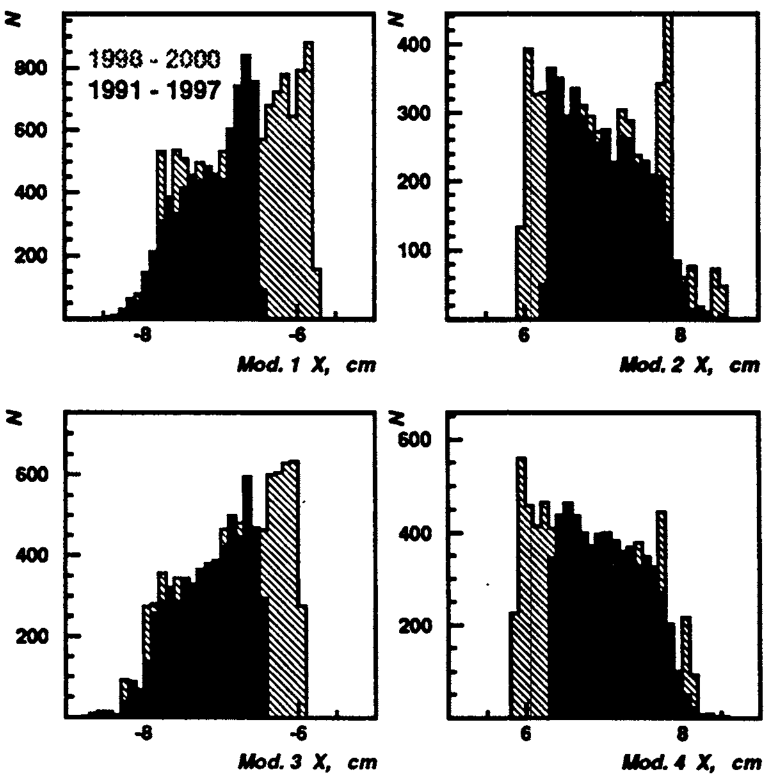

Fig. 1. New and old acceptance of all four modules of the DELPHI VSAT detector. An arbitrary vertical scale is used to show only the profit from the active detector area increased in x-coordinate direction

Four VSAT modules are situated in the horizontal plane at ≅ 7.7 m from the interaction point, behind the superconducting quadrupole magnets which produce the final focus. These magnets deflect the scattered electrons and positrons from the direction of the beam pipe, and thus permit measurements at very small polar angles. At the modules there is a small elliptical section of the beam pipe providing a thin window in front of the calorimeters. The instrumented area of the VSAT modules is not large, being only 5 cm high and 3 cm wide for the x-position measurements. The active area used was previously even smaller, i.e., 2 cm in the x direction, because for the outer range in x of the modules there was a dead zone due to a flange located in the beam pipe about 70 cm in front of the detectors. The upgraded beam pipe is made with a ≅ 0.5 cm smaller radius in the x direction, and the VSAT modules have been moved closer to the beam line. Thus we can benefit greatly from the increase in cross sections and the active detector area was also enlarged. The upgrade has now been also adopted by all the LEP experiments.

Rates of occupancy of the VSAT modules obtained from this year's preliminary analysis are shown in Fig.1 together with results from previous years. Here the benefit of the upgrade can clearly be seen. As expected, the tails of the distributions behave similarly at high x, thereby confirming that all (hardware and software) modifications were properly carried out.

As shown in [8], the increase in cross sections, because smaller polar angles can now be detected, should increase statistics by a factor ≅ 2 for double tagged events and by a factor ≅ 1.5 for single tagged events. These factors are used in estimate of the final statistics. The kinematical coverage of the very forward and the forward detectors shown in Fig.2 provides the answer to questions concerning the upper and the lower limits of the Q^2 scale, and also shows how far the measurements can explore the regions of low Bjorken-x, where the main theoretical interest lies. For the very forward detectors (the DELPHI VSAT), the statistics are concentrated below 1 GeV^2 and peak at around 0.2 GeV^2, while for the forward detectors (the DELPHI STIC) they go up to ≅ 100 GeV^2. The range of invariant masses W from 5 GeV to 80 GeV can be reasonably measured with high enough statistics, so results can be obtained in the regions

- $10^{-4} < x < 2 \cdot 10^{-2}$ for the VSAT and
- $2 \cdot 10^{-3} < x < 0.8$ for the STIC.

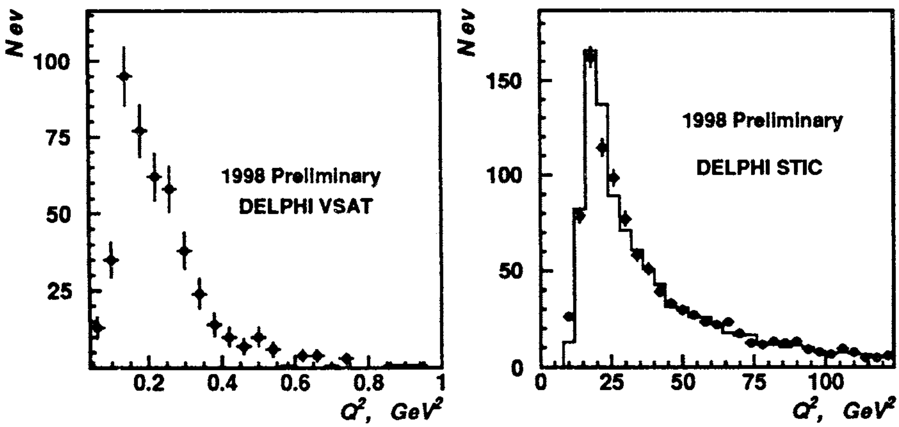

Fig. 2. Momentum transfer distributions measured by the DELPHI VSAT and STIC detectors. An arbitrary vertical scale is used to show the relative statistics for different ranges

1998 was a very successful year for LEP with a record integrated luminosity of $\cong 200\,\mathrm{pb}^{-1}$. For next two years, however, the prime stress will be on maximum attainable beam energies. According to current plans, a luminosity of $\cong 200\,\mathrm{pb}^{-1}$ is expected to be collected by the end of LEP2 running. Thus, a total integrated luminosity of $\cong 400\,\mathrm{pb}^{-1}$ will have been used for the statistics estimations.

3. Difficulties in the Analysis

Though the analysis appears to be well understood, there are several complications. In order to obtain reliable results for all possible Q^2 regions, an accurate reconstruction of the energy and the polar angle of the tagged particle is needed. Therefore, many corrections have to be specified and then applied. The most important ones for energy reconstruction are new calibration constants and in particular, new leakage corrections due to the higher energy in comparison with LEP1.

On the other hand, the quality of the energy measurements can be checked for each LEP fill, or even for each run, by using Bhabha events. Moreover, the new acceptance means there are more statistics available. The reconstruction of the initial polar angle θ is based on a determination of the energy and the position of the tagged particle, which is traced backwards in an iterative procedure from the detector through the superconducting quadrupole and the solenoid magnetic fields to the interaction point. For the position reconstruction accurate geometrical survey measurements of the position of the VSAT modules in relation to each other at the beginning and the end of the data taking year are essential. Clearly, the angle reconstruction procedure is very sensitive to the LEP beam parameters, which sometimes vary even within a fill. Thus, to define the angle in the event vertex as precisely as possible, the beam spot position, the angles between the beams and the parameters of the superconducting quadrupoles all have to be known and taken into account for each data taking fill or even run. High background is usually a serious problem for the analysis. Surprisingly enough, however, in our case the presence of abundant background (off-momentum electrons for single tagged events and Bhabha events for double tagged events) helps improve the angular reconstruction. Most of the off-momentum electrons are concentrated in the horizontal plane and enter the two VSAT modules on the outer side of the LEP ring. By studying their sharply peaked impact point distribution, the y coordinates of the outer modules can be aligned with respect to the beam axis. By using the strict collinearity of the Bhabha events, the y coordinates of the inner modules can also be aligned. Of course, very careful study of the Bhabha events is needed to do so. In turn, effective rejection of the background also depends on how accurately the θ angle is reconstructed and how well the LEP beam parameters are defined. The results of a simple rejection of background at LEP1 energies[2] are shown in Fig.3. Now, with better understanding of the background, it can be rejected more efficiently, albeit in a more complicated and labour-intensive way.

Nevertheless, it is beyond doubt that the background in the final analysis can be rejected as efficiently as it was for LEP1 double tagged data (Fig.4).

4. Statistics Estimates

As mentioned above, the total integrated luminosity collected at LEP2 after the upgrade of the very forward calorimeters is expected to be $\cong 400\,\mathrm{pb}^{-1}$. This number is used hereunder to estimate the available statistics for all of the topics.

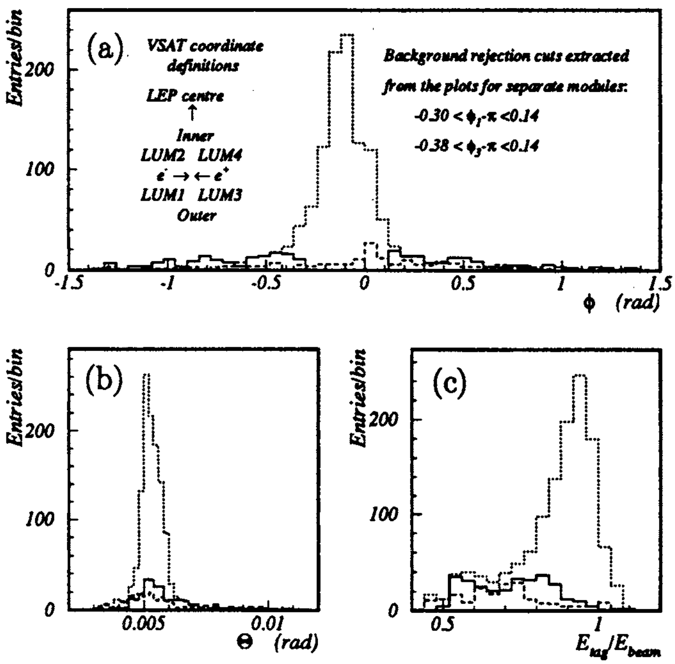

Fig. 3. VSAT off-momentum electron background distributions, found from a random coincidence between well measured Z^0 events and high energy signals in one outer of four VSAT modules (denoted LUM1 to LUM4 in the inset): (a) ϕ and (b) Θ-distributions, (c) E_{tag}/E_{beam}. The dashed lines show the background behaviour in the inner modules 2 and 4; and the dotted lines, in the modules 1 and 3 (outside of the LEP ring) before rejection. Solid lines show the remaining background after applying cuts on ϕ to the outer modules as indicated in (a)

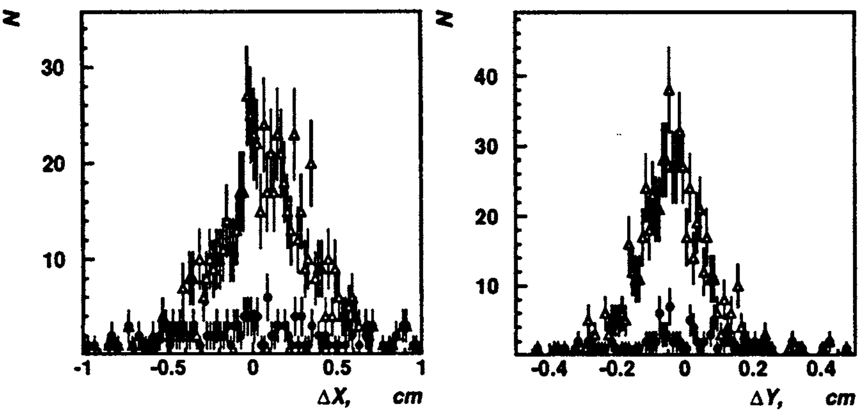

Fig. 4. VSAT double tagged events. Triangles are before rejection and points are after rejection of the background from the Bhabha events

4.1. VSAT Single Tagged Events. Of particular interest to an analysis of single tagged events is the rather large contribution [2] to the total $\gamma\gamma$ cross section from RPC. This is indeed the case where there is a hope of finding the best parametrizations of parton density function in the photon. As mentioned above, an extensive compilation of existing parametrizations is available in [4].

By comparing data obtained with higher statistics at LEP2 with the three-component model predictions a distinction may possibly be drawn between the Gordon–Storrow (GS), Gluck–Reya–Vogt (GRV), Levy–Abramowicz–Charchula (LAC1) and Schuler and Sjöstrand (SAS) parametrizations [9].

The published results from DELPHI at LEP1 are used to estimate the statistics. Around 500 events were obtained for an integrated luminosity of $\cong$ 30pb^{-1}. Taking into account the factor of $\cong$ 1.5 after the VSAT upgrade, $\cong$ 10.5K events are expected to be available for the final analysis.

4.2. VSAT-VSAT Double Tagged Events. The double tag mode is attractive because both the hadronic invariant mass produced and the absolute momentum transfers squared for both photons can be directly measured, as in small angle approximation the invariant mass is reconstructed from the energy measurements of the tagged particles. This means that there is little need to apply the unfolding procedure to extract the total $\gamma\gamma$ cross section, which may now be measured in a wide region that was previously inaccessible.

The previous analysis of LEP1 data suffered from very low statistics. Only 43 events survived after all selection criteria had been applied to pick out $\gamma\gamma$ events and reject Bhabha background. To illustrate this both the tagged energy and the invariant mass distribution of the hadronic system are shown in Fig. 5, where the level of agreement between data and simulation can be seen. The limited statistics mean that not much information can be extracted despite good agreement between data and simulation.

At LEP2 energies the accuracy of the invariant mass reconstruction improves. With the factor $\cong$ 2 after the VSAT upgrade taken into account, $\cong$ 350 events available for the final analysis of DELPHI data may be expected. A similar number of events should be recorded by the other LEP experiments.

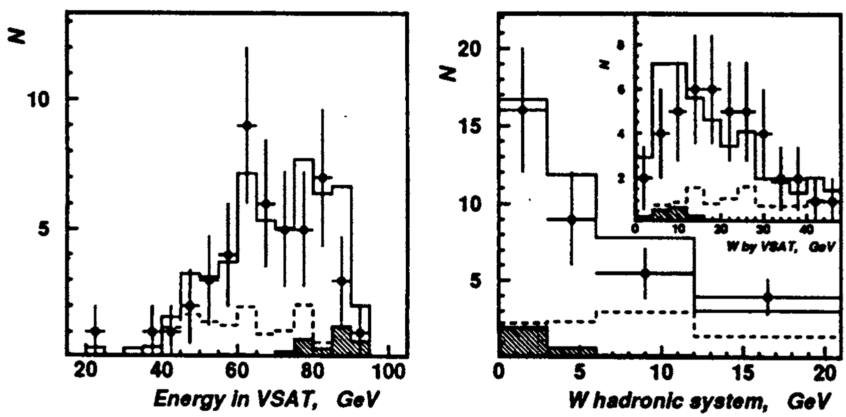

Fig. 5. DELPHI LEP1 double tag events. VSAT-tagged energy and invariant mass reconstructed. Points are data, solid lines are the full VDM+QPM+RPC predictions, dotted lines are the QPM+RPC and hatched histogram – QPM part

4.3. VSAT-STIC Double Tagged Events. Since the rate of double tagged events in the main forward calorimeters is very low, because of the relatively high $\theta > 30$ mrad, the double tagged results expected to come from events with one tag in the main forward calorimeter (the STIC for DELPHI) and the other tag in the very forward ones (the VSATJ or DELPHI) are more promising. To a certain extent the effects of the target photon nonzero virtuality, $P^2 \neq 0$, on the photon structure function $F_2^{\gamma}(x,Q^2;P^2)$ can be studied only with this sample. Such studies are attractive mainly for two reasons: our present state of experimental knowledge is very poor, and because of the rise in the LEP beam energy the nonperturbative hadronic contribution (VDM) is expected to be suppressed with increasing P^2, allowing for a perturbative prediction of the photon structure function. More details can be found in [1]. There are still no results available from the LEP experiments. A two-photon generator TWOGAM, which was successfully tested in previous DELPHI studies, is used to estimate the number of events in this case. Taking into account the factor $\cong 1.5$ after the VSAT upgrade, $\cong 200$ events are expected to be available for the analysis. Since the forward and the very forward calorimeters have different acceptances for the other LEP experiments, the number of events can differ by several times from one experiment to the next.

5. Summary

Due to its high energy and increased integrated luminosity, LEP2 provides a unique opportunity to study the topics described above, with good prospects for obtaining new interesting results. Though the analysis technique is very laborious, the procedure is well understood and clear. A fairly large number of events is expected for the single tagged events detected by the very forward calorimeters. Unfortunately however, this is not true for either of the double tagged event samples, for which the statistics available are very limited, so that a combined effort by all the LEP experiments is needed if we want to obtain reliable results.

References

1. Aurenche P. et al. – Physics at LEP2, eds. G. Altarelli, T. Sjöstrand and F. Zwimer, CERN 96-01, 1956, 291.
2. DELPHI Coll., Abreu P. et al. – Phys. Lett., 1995, v. B342, p.402.
3. DELPHI Coil., Zimin N. – Proc. Photon '97, Egmond aan Zee, eds. A. Buijs and F.Erne., World Scientific, Singapore, 1997, p.74.
4. Plothow-Besch H. – Comput. Phys. Commun., 1993, v.75, p.396.
5. Schuler G., Sjöstrand T. – Nuclear Physics, 1993, v.B407, p.539.
6. Proc. Photon '97, Egmond aan Zee, eds. A. Buijs and F. Erne., World Scientific, Singapore, 1997.
7. DELPHI Coil., Tyapkin I. – Proc. of 28th International Conference on High Energy Physics, Warsaw, Poland, World Scientific, Singapore, 1996, p.729.
8. Almehed S. et al. – JINR Rapid Commun., 1997, 3[83]-97, p.47.
9. Gordon L., Storrow J. – Z. Phys., 1992, v.C56, p.307;
   Glück M., Reya E., Vogt A. – Phys. Rev., 1992, v.D46, p.973.
   Abramowicz H., Charchula K., Levy A. – Phys. Lett., 1991, v.B269, p.458.
   Schuler G., Sjöstrand G. – Phys., 1995, v.C68, p.607.

Received on December 22, 1998.