УДК 539.12...164

STUDY OF MULTIHADRON PRODUCTION IN TWO-PHOTON COLLISIONS AT LEP1 AND LEP2

***S.Almehed*[1], *G.Jarlskog*[1], *P.Jonsson*[1], *F.Kapusta*[2], *I.A.Tyapkin*[3], *N.I.Zimin*[1,3], *A.I.Zinchenko*[3]**

Results of an experimental study of the reaction $e^+e^- \to e^+e^-$ + hadrons are presented. The data have been obtained by the DELPHI detector at LEP1 and LEP2. Together with Monte Carlo predictions they illustrate the evolution of the two-photon process under antitag conditions. Double-tag events with both scattered e^+ and e^- measured by the DELPHI VSAT detector were observed for the first time at LEP1. The total $\gamma\gamma$ hadronic cross section is estimated for the $\gamma\gamma$ centre of mass energy up to 35 GeV.

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

Изучение множественного рождения адронов в двухфотонных взаимодействиях на ЛЭП1 и ЛЭП2

С.Алмехед, Г.Ярлског, П.Йонссон, Ф.Капуста, И.А.Тяпкин, Н.И.Зимин, А.И.Зинченко

Представлены результаты исследования реакции $e^+e^- \to e^+e^-$ + адроны. Экспериментальные данные были получены установкой ДЕЛФИ на коллайдере ЛЭП1 и ЛЭП2. Вместе с результатами, полученными при математическом моделировании, они показывают эволюцию двухфотонного процесса при условиях антимечения электронов. Впервые на ЛЭП1 наблюдались события с двойным мечением, в которых рассеянные e^- и e^+ регистрировались в детекторе мечения под очень малыми углами. Приведена оценка полного сечения реакции $\gamma\gamma \to$ адроны для энергий $\gamma\gamma$-системы до 35 ГэВ.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

1. Introduction

Multihadron production in $\gamma\gamma$ reaction has been studied in many previous experiments, more recently at KEK [1] and LEP [2,3]. According to these studies a correct leading order description of the experimental data has to combine three components: a soft interaction term described by the generalized Vector meson Dominance Model (VDM), a perturbative term described by the Quark Parton Model (QPM) with a direct quark exchange, and a term

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

for the hard scattering of the partonic constituents of the photon, the so-called Resolved Photon Contribution (QCD—RPC).

All these models were realized in the TWOGAM generator which describes DELPHI data satisfactorily for both the antitag and single tag cases. The QPM and VDM events were generated with the same parameters as in previous DELPHI analyses [3]. The QCD—RPC was treated using leading order QCD factorization: a hard scattering subprocess gives the dominant scale p_t^2, taken also as the factorization scale. Since such subprocesses are considered as perturbative, a single free parameter, $p_t^{\min}$, the transverse momentum of the outgoing partons has to be specified and used in order to separate the RPC from the nonperturbative contribution. These valuies of $p_t^{\min}$ were found for parton density functions from the requirement to reproduce the visible experimental two-photon cross section at the Z^0 peak. The Gordon–Storrow (GS2 with $p_t^{\min}(\mathrm{GS2}) = 1.88 \pm 0.020$ GeV/c) and Glück–Reya–Vogt (GRV with $p_t^{\min}(\mathrm{GRV}) = 1.58 \pm 0.018$ GeV/c) parametrizations of the parton density functions have been shown to reproduce data better and were chosen for simulation. The generated events were processed by the full detector simulation program and then subjected to the same selection procedure as the experimental data. A description of the DELPHI detector together with the basic criteria used to select $\gamma\gamma$ hadronic events can be found in Refs. 3,4.

2. Antitag Visible Cross Section Behaviour

The experimental data analysed were collected during 1995 and 1996 LEP runs. They correspond to integrated luminosities of 29.4 pb^{-1}, 5.8 pb^{-1}, and 7.9 pb^{-1} for centre-of-mass energies of $\simeq 91$, $\simeq 135$, and $\simeq 172$ GeV, respectively. The configuration of the DELPHI detector was quite stable during that period providing a good opportunity to look at the evolution of the $\gamma\gamma$ process at different energies.

In order to select two-photon hadronic events at least four charged particles in the event with an energy below 20 GeV are required together with invariant mass of the hadronic system in the range 4—30 $\mathrm{GeV/c}^2$ and total transverse momentum of the event below 3 GeV/c. These criteria suppress the Z^0 decay background at the peak, the background from $\tau\tau$ pairs and beam-gas interactions and remove the $\gamma\gamma$ resonance energy region. To validate trigger conditions the total energy of the charged particles greater than 3 GeV was also required together with the momentum of the most energetic particle greater than 1 GeV/c. In order to use a neutral component of the hadronic system and hence to provide better rejection of the background and increase sensitivity to the parton distribution function behaviour all calorimetric information was included in the analysis.

The visible cross section (Fig.1) for the events meeting the selection criteria was calculated for each LEP energy point. A simulation was used to check the visible $\gamma\gamma$ cross section due to Z^0 background. The visible Z^0 background corresponds to $\sigma_Z^{MC} = 92.9 \pm 5.7$ pb (averaged over points around the peak) and only 2.5 ± 0.5 pb at $\simeq 135$ GeV. The cross section of the beam-gas background was estimated to be below 1 pb for all

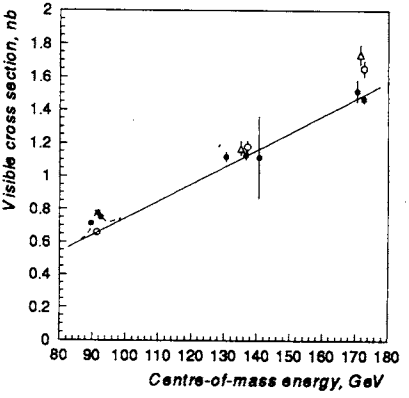

Fig.1. Visible cross section of the process $e^+e^- \to e^+e^- +$ + *hadrons* for antitag events. Points are experimental results, white circles — simulation with GS2 parton density function, white triangles — the same with GRV parametrization. Also shown is the result of the fit by the combination of Cahn's formula and a linear term (dashed line). The solid line shows the linear term alone expressed as $\sigma_{\gamma\gamma} = \sigma^Z_{\gamma\gamma} + d\sigma/dE \times (E_{\text{cms}} - 91.25)$, where $\sigma^Z_{\gamma\gamma} = 658.6 \pm$ ± 7.6 pb, $d\sigma/dE = 10.3 \pm 0.2$ pb/GeV and E_{cms} is the centre-of-mass energy in GeV

samples using events originated far from the interaction point. The remaining background contribution was found to be negligible. After bin-by-bin subtraction of the background the visible $\gamma\gamma$ cross section at the Z^0 peak was found to be $\sigma^{\text{exp}}_{\gamma\gamma} = 658.6 \pm 7.6$ pb, which is in agreement with our previous studies [3]. The experimental values are well fitted by the combination of a linear term and Cahn's formula [5], describing the shape of the Z^0 peak. The errors of the simulated points come from the uncertainty of $p_t^{\min}$ determinations and

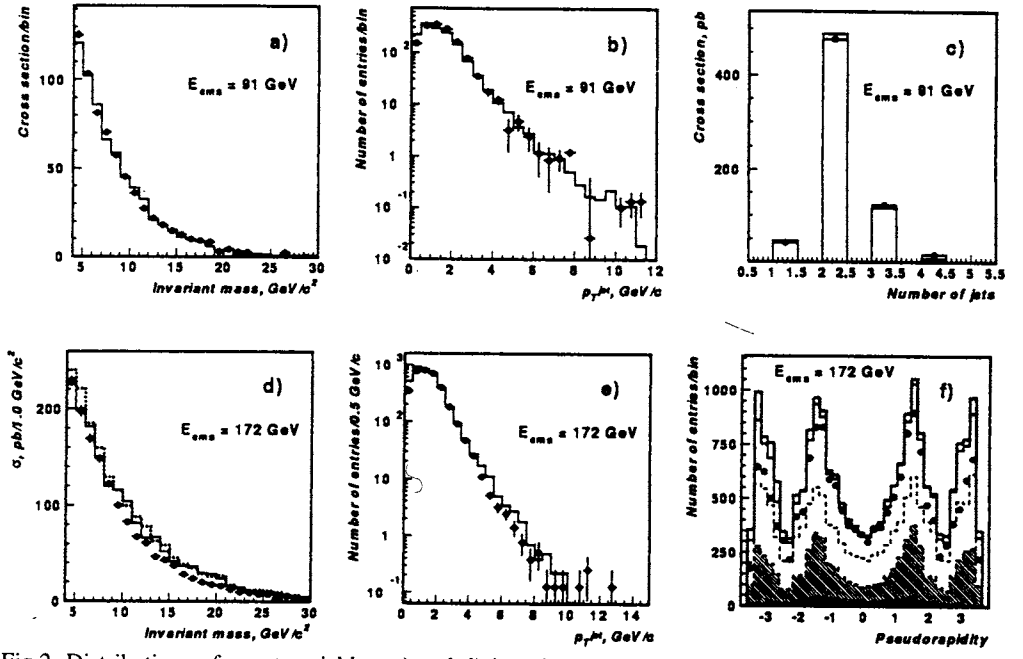

Fig.2. Distributions of event variables: a) and d) invariant mass, b) and e) transverse momentum of jets c) number of reconstructed jets, f) energy flow. Points are data, solid and dotted lines are the full VDM + QPM + RPC predictions with GS2 and GRV parton density functions, respectively, dashed line is QCD—RPC contribution for GS2, hatched histogram is VDM part, double hatched — QPM part

statistical errors of the simulated samples. Systematic errors relevant for comparing different parton density parametrizations are highly correlated and move the points in the same direction. Estimation of errors affecting the level of agreement of the simulated and experimental samples is much more complicated. It was found that the main disagreement comes from the events with a low energy of charged particles and a low fraction of transverse energy, where detector effects (tracking and trigger efficiencies, calorimeter thresholds) are very important and hard to simulate. These effects are under ongoing studies.

Different experimental distributions were produced and compared with a simulation (Fig.2). It can be seen that the Monte Carlo predicts good agreement at $\simeq 91$ GeV and slightly exceeds data at $\simeq 172$ GeV. The increasing activity in the forward direction comes mainly from the QCD—RPC processes (Fig.2f) and is more pronounced for the GRV parton density parametrization.

3. Double Tagged Events

The full statistics collected at LEP1 with the corresponding integrated luminosity of 101 pb^{-1} is used in the analysis. Four electromagnetic luminometers, the so-called Very Small Angle Taggers (VSAT) [6], are used for energy and angle reconstruction for both scattered e^+ and e^-. They are placed symmetrically $\simeq 7.7$ m downstream of the DELPHI interaction point behind the superconducting quadrupoles at $\simeq 60$ mm from the beam line covering polar angles θ between $4 \div 15$ mrad. Despite the low angles measured the visible cross section for double-tag events is small due to the acceptance of modules (3 cm in X and 5 cm in Y directions). Moreover, the reconstruction of θ and ϕ angles is quite sensitive to LEP beam parameters, many run-time corrections should be defined and then applied (incident angles of beams for each fill, beam spot position for each run). When all corrections were applied the energy resolution was found to be $\simeq 7$ %, accuracy of angle reconstruction $\sigma_\theta = 0.6$ mrad and $\sigma_\phi = 9°$. Due to a high cross section of Bhabha scattering for diagonal modules, it is important to have sufficient rejection of a background to avoid random coincidence with no-tag events measured by DELPHI. The following cuts were applied for this purpose: the difference in X and Y coordinates measured for both scattered leptons $\leq 2 \times \sigma$ of the corresponding narrow distributions found for Bhabha events (due to their specific kinematics) for each fill, the energy measured in each module $\leq 0.7 \times E_{\text{beam}}$. Together with the requirement for the total event energy measured ≤ 115 GeV, 99 % of Bhabha events are rejected with only 1 % for double tagged events. Outer modules are also populated by off-momentum electrons located narrowly around the horizontal plane. This fact can be used for a relative alignment of these modules and thus, with the use of collinearity of Bhabha events, for a relative alignment of inner modules as well. To eliminate possible background from leptonic $\gamma\gamma$ production for the hadronic part of event $3 \leq N_{\text{Charged}} \leq 15$, energy of the charged particles below 12 GeV and total energy of the hadronic system below 20 GeV are required. The procedure described above is used for a full simulation of double tagged events. Only GS2 parametrization is used for the QCD—RPC part. The VSAT part of the events was treated by special programs used for luminosity studies.

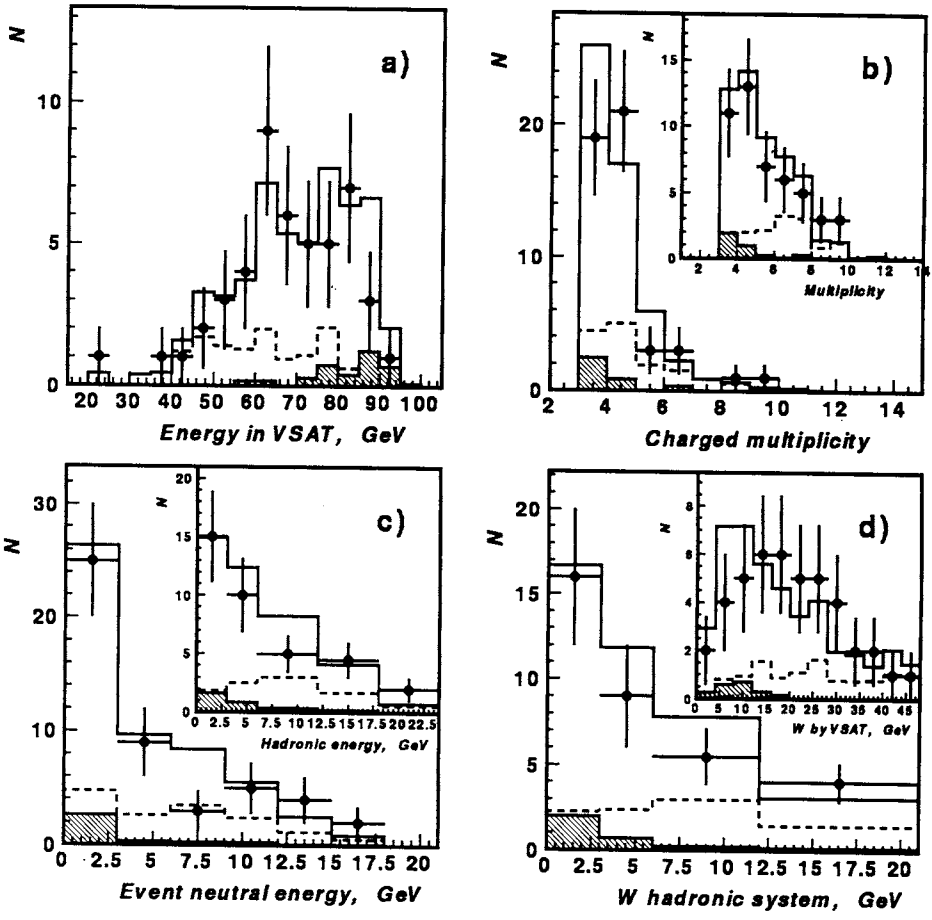

Fig.3. Double-tag events: a) energy of scattered e^+ and e^-, b) event multiplicity, c) energy of hadronic system, d) invariant mass reconstructed. Points are data, solid lines are the full VDM+QPM+RPC predictions, dotted lines are the QPM+RPC and hatched histogram — QPM part

After applying all the selection criteria only 43 events are left. Different distributions obtained for such events are shown in Fig.3. Reasonable agreement can be seen between data and simulation predictions both for the VSAT measurements (Fig.3a) and hadronic component of events shown in Fig.3b—3d. There is an indication that an unfolding procedure should be adopted for a better reconstruction of invariant mass from the scattered leptons measured by VSAT (upper part of Fig.3d). It is clear that due to the very low Q^2 range covered the main contribution comes from the VDM part, while the QCD—RPC gives $\simeq 22$ % and the QPM only 5 %. Taking these fractions into account it becomes possible to estimate the total ef-

Table. Effective total $\gamma\gamma$ hadronic cross section

$\sqrt{s}$, GeV	Number of events	Total $\sigma_{\mathrm{Tot}}^{\gamma\gamma}$, nb
25	16	356 ± 90
35	10	325 ± 105

fective $\gamma\gamma$ hadronic cross section from these components implemented in the TWOGAM generator. For the points combined in the range of $\gamma\gamma$ invariant mass 20—30 GeV and 30—48 GeV results are shown in the Table, with only statistical errors presented.

4. Conclusions

We have studied hadronic events produced in two-photon collisions at centre-of-mass energies $\sqrt{s} \simeq 91$, 135 and 172 GeV. The visible cross section of the process $e^+e^- \to e^+e^- + hadrons$ with the antitag condition as a function of e^+e^- centre-of-mass energy is well described by the linear function. Different experimental distributions can be reproduced by the simulation with reasonable accuracy and can be used to evaluate the role of the two-photon process as a background for some physics analyses. At higher energies some indication of the increased simulated activity is observed in the forward direction due to QCD—RPC processes which is higher for the GRV parton density parametrization.

Preliminary results have been obtained for double tagged events at LEP1 energies. Reasonable agreement with Monte Carlo predictions was shown for such events with very low measured Q^2. The effective total $\gamma\gamma$ cross section is estimated for $\gamma\gamma$ centre-of-mass energy up to 35 GeV.

The forthcoming higher energy LEP runs will contribute to a better understanding of two-photon phenomena.

References

1. AMY Coll., Tanaka R. et al. — Phys. Lett., 1992, v.B277, p.215;
   TOPAZ Coll., Enomoto R. et al. — KEK-93-107, KEK-93-215.
2. ALEPH Coll., Buskulic D. et al. — Phys. Lett., 1993, v.B313, p.509;
   OPAL Coll., Akers R. et al. — Z. Phys. C, 1994, v.61, p.119;
   L3 Coll., Adriani O. et al. — Phys. Lett., 1993, v.B318, p.575.
3. DELPHI Coll., Abreu P. et al. —Z. Phys. C, 1994, v.62, p.357.
4. DELPHI Coll., Abreu P. et al. —Nucl. Instr. Meth., 1996, v.A378, p.57.
5. Cahn R.N. — Phys. Rev., 1987, v.D36, p.2666.
6. DELPHI Coll., Abreu P. et al. —Phys. Lett., 1995, v.B342, p.402.

Received on October 21, 1997.