Gamma-Gamma Physics at LEP2; Experimental Possibilities*

DAVID J. MILLER

Physics and Astronomy, University College London,
Gower Street, London WC1E 6BT, U.K.

ABSTRACT

QCD tests and studies of heavy quark production and decay will be the most important parts of the $\gamma\gamma$ programme at LEP2. This discussion assesses the promise of a range of possible topics of study, comparing with what might be achieved at LEP1, TRISTAN or lower energy colliders.

Introduction

LEP2 must have approximately twice the energy of LEP1, but it must also collect significantly more integrated luminosity than LEP1 if it is to succeed in most of its physics programme - WW, W mass, Higgs, new particle searches. Gamma-gamma physics will benefit especially from the higher luminosity. The higher energy is also useful, especially for heavy quark production, but gamma-gamma physics does not demand the highest possible LEP2 energy. This discussion is largely based on the state of gamma-gamma physics as reported at the Cornell Lepton Photon Symposium[1], and in a 1992 working group report[2]. A more definitive review should be produced by the LEP2 working groups which start work this summer. Many of the points made in our studies[7,13,14,27,28] for the Aachen LEP200 workshop in 1986 are still valid.

1. Open Charm and Beauty

A recent QCD calculation[3] has predicted the rates for heavy quark production by gamma-gamma over the whole energy range from TRISTAN to LEP2. As well as the direct pointlike coupling to quarks, the calculation includes contributions from singly and doubly resolved photon-dissociation into gluons and quarks before the hard scatter (Figure 1). The predicted rates for charm-anticharm pairs are copious, and the rates for beauty pairs at LEP2 are significant (Table 1).

Table 1. Predicted[3] numbers of pairs of heavy quarks, before experimental cuts and tagging efficiencies.

Collider	Integrated Luminosity	Number of charm-anticharm	Number of beauty-antibeauty
TRISTAN	$150pb^{-1}$	$3x10^4$	75
LEP1	$100pb^{-1}$	$3x10^4$	100
LEP2	$500pb^{-1}$	$35x10^4$	1500

* Invited talk at "Two Photon Physics from DAΦNE to LEP200 and beyond", College de France, Paris, February 2-4 1994.

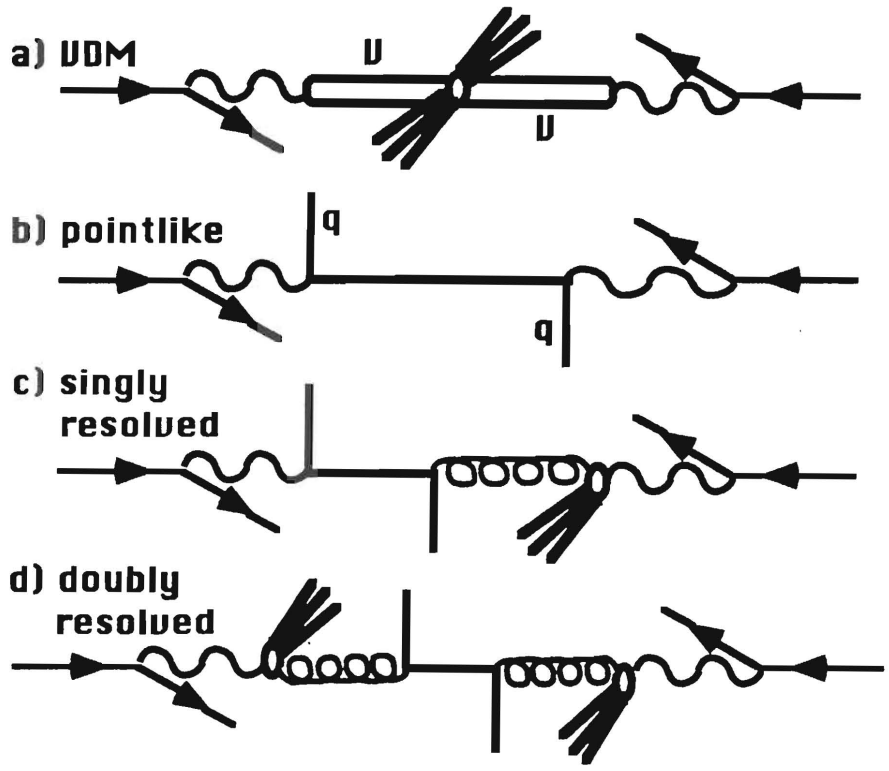

Figure 1. Contributions to $\gamma\gamma \rightarrow$ hadrons.

There are two surprising features in the three results from TRISTAN on open charm production which were reported at Cornell[1,4,5,6]. The first is the very small number of events seen. Despite integrated luminosities of about 150pb^{-1}, TOPAZ[4] had only 20 events tagged by D*. VENUS had 23 D* events[5] and between 70 and 80 identified[6] by seeing an electron in the hadronic shower. The second surprise was that, when they had been corrected for detection efficiency, all three samples were *bigger* than had been expected from the QCD calculation[3]. When such a small fraction of the expected number of events is recognised there is some scope for errors in modelling the production process - especially the degree of longitudinal boost and the detection of identified final states close to the edge of the angular acceptance. It would therefore be premature, from these data, to conclude that the QCD model is inadequate. The urgent next step is to repeat the analysis at LEP1, where each experiment now has about 100 pb^{-1} on disc, with significant increases expected in 1994 and 1995. At LEP2 the resolved processes are predicted to overtake the pointlike production, so a measurement of the increase of the charm rate will be a further check of the model. One would hope to see a worthwhile fraction of the 1500 beauty events, but they may prove even harder to tag than charm - unless the lengthened microvertex detectors come to the rescue (something for the LEP2 working groups to check).

2. Charmonium

Erné's Discovery Plot[7] (Figure 2) predicts 900 reconstructed η_c events from 1 fb^{-1} of integrated luminosity at LEP2. It is interesting to compare this with what L3 has just

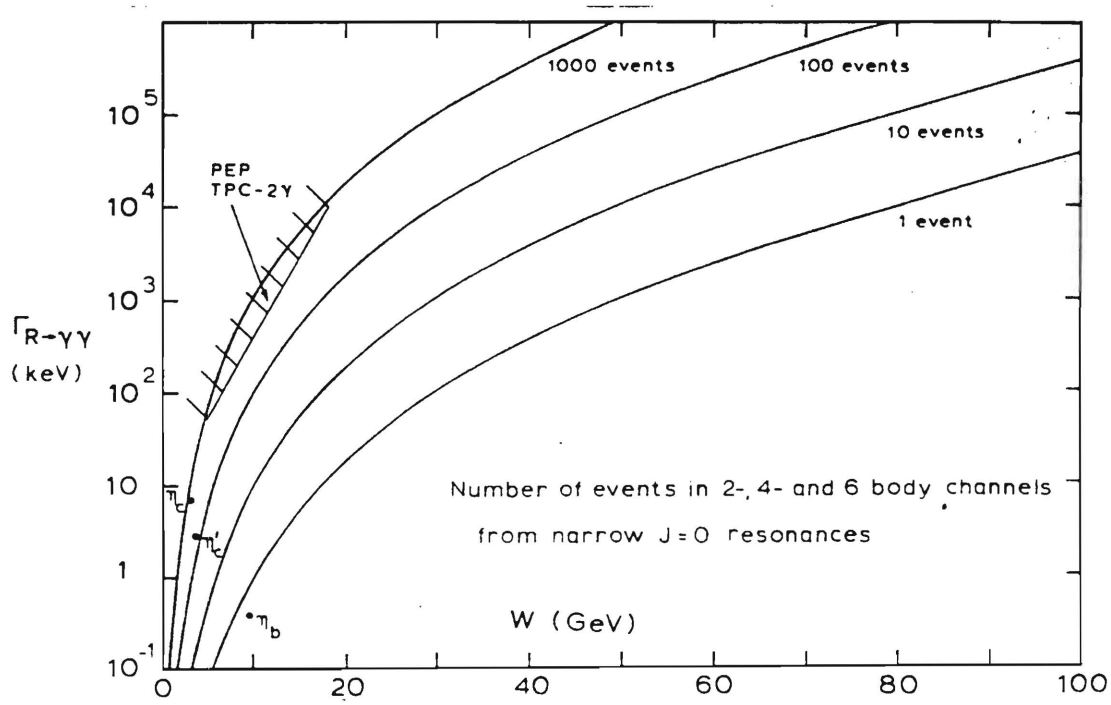

Figure 2. Erné's Discovery Plot[7] for narrow J = 0 resonances decaying into heavy-quark pairs in the sum of exclusive 2, 4 and 6 body decays, with 1 fb^{-1} of running at LEP200. The event-rates shown on the curves include an estimate of the acceptance. W is the $\gamma\gamma$ invariant mass. $\Gamma_{R\to\gamma\gamma}$ is the $\gamma\gamma$ partial width for resonance R, mass W.

reported[8]. In going from Erné's LEP2 prediction to L3 we have to multiply his 900 events by the following three factors:-

x 35/1000 for integrated luminosity,
x 1/2.3, cross section ratio LEP1/LEP2 for open charm from Drees et al[3],
x 1.2, for the reduced LEP1 loss due to the boost along the beam (also from Erné[7]).

This gives 16 η_c events expected; and L3 sees 17 above background. The prediction could not be better - so we can be confident that each experiment at LEP2 will reconstruct 450 $\gamma\gamma \to \eta_c$ if it gets 500 pb^{-1}, giving accurate measurements of the partial width. Figure 2 also suggests that there will be worthwhile numbers of η_c', and one should also see some χ_c events. These $\gamma\gamma$ partial widths tell us about the quality of perturbation theory calculations using the non-relativistic quark model[9]. In the simplest picture they should be determined by $\alpha_s(m_c)$, α and the wavefunction squared (or its derivatives) at the origin.

3. Bottomonium

The Discovery Plot (Figure 2) predicts fewer than 1 reconstructed η_b event in 1 fb^{-1} at LEP2, and the L3 η_c result means we can believe its predictions. The big reduction in rate compared with η_c comes from three inescapable effects: a smaller $\gamma\gamma$ partial width, reduced $\gamma\gamma$ luminosity at the heavier mass and a smaller fraction of reconstructable final states. There is therefore little prospect of measuring the $\gamma\gamma$ partial width of bottomonium states at LEP2. It was suggested[9] that an η_b peak might be seen inclusively by measuring the missing mass recoiling against two tagged

electrons in gamma-gamma, but it has been shown[10] that none of the LEP experiments has good enough energy measurement in the forward tagging detectors to resolve a peak at 10 GeV/c^2 to better than 1.5 GeV/c^2, which would be unlikely to give a recognisable signal above the expected continuum background. The only hope for gamma-gamma production of bottomonium would be to build a Low Energy Compton Collider[11], in which backscattered laser beams from two linear electron colliders, each with about 20 GeV, could be optimised for high luminosity in the region of $W_{\gamma\gamma}$=10 GeV/c^2.

4. Photon Structure Functions.

LEP2 has two important jobs to do with F_2^γ, measuring it properly for the first time in two regions; at large Q^2 and at low x. (It would also be desirable to measure the longitudinal structure function F_l [12] but there are considerable problems due to statistics, as explained at Aachen[13], and also due to low-momentum background electrons from LEP.)

The rates for singly tagged deep-inelastic electron-photon scattering at large Q^2 were calculated by Cordier and Zerwas for the 1986 LEP200 workshop[14], and have recently been confirmed[15]. The Cordier-Zerwas estimate of the precision on the measured F_2 structure function was optimistic because they made no allowance for errors in unfolding the true x_{Bj} distribution from the measured distribution. Experience with the OPAL data shows[16] that a reliable unfolded result can be obtained with about 500 tagged events in a Q^2 bin. There are just over 500 events in the OPAL bin with $8<Q^2<30$ GeV^2, giving[17,1] the unfolded value of $\frac{1}{\alpha}\int_{0.3}^{0.8} F_2^\gamma(x,Q^2)dx = 0.447 \pm 0.045$ at $<Q^2>= 14.7 GeV^2$. At LEP2, with 500 pb^{-1}, Cordier and Zerwas expect 500 events in a bin with $<Q^2> \approx 450 GeV^2$, where the expected logQ^2 growth will give a value for $\frac{1}{\alpha}\int_{0.3}^{0.8} F_2^\gamma(x,Q^2)dx$ of 0.66 ± 0.07 - if the fractional error is the same as given by OPAL. (This is pessimistic. The hadrons from events at high Q^2 are better contained so unfolding will be easier than in the current OPAL sample.) The errors on the low Q^2 bins will shrink substantially at LEP2, so the logarithmic rise predicted by QCD[18,19] will be established to better than three standard deviations; one of the classic tests of the theory. It may even be possible to make a measurement of α_s .

HERA's results[20,21] on F_2^{proton} have shown a distinct rise with falling x, for x<0.01 with $10 < Q^2 < 40$. Most QCD models or parametrisations of F_2^γ predict a similar rise - in some cases[22] beginning very early, at x = 0.1. The LEP1 OPAL results[16] show no sign of such early-rising There is no prospect of pushing the measurement into the region below $x_{min} = 0.01$ until the LEP2 data are available. This follows from simple kinematics $\left(x = \frac{Q^2}{Q^2 + W_{\gamma\gamma}^2} \right)$, and the softness of the Weiszäcker-Williams luminosity spectrum which only gives events with $W\gamma\gamma < E_{beam}$. At LEP2 the value of E_{beam} will be doubled, so x_{min} will be reduced to 1/4 of its LEP1 value - enough to establish whether the photon has the kind of rise which HERA observes for the proton; which may be due to BFKL[23] gluon condensation effects at very small x.

5. Low Mass Resonances

There is a great deal to be done before the meson spectrum can be properly understood. Gamma-gamma studies will play an important part, but mostly at lower energy machines with higher integrated luminosities than LEP will ever achieve. The DAΦNE programme is discussed elsewhere in these proceedings. The region of masses between 1 and 2.5 GeV/c^2 will be most accessible at CLEOII or a beauty factory[1]. Important constraints on the total cross-section should come from the beautiful zero-angle double tagging spectrometer[24] of the KEDR experiment on the VEP4M collider at Novosibirsk, where recent tests have confirmed a mass resolution of 10 to 20 MeV/c^2. A Low Energy Compton Collider[11] could be optimised to have an effective luminosity in the $\gamma\gamma$ resonance region which would be competitive with a beauty factory, with the added advantages of much smaller longitudinal boosts for the final state particles and the possibility of controlling and varying the helicities of the incoming photons. Erné[7] shows how at LEP these low mass states are highly boosted along the beam direction, making them hard to reconstruct and offsetting the increase of cross section with energy. There may however be some channels, especially all-neutral final states, where L3 and perhaps OPAL will have an advantage over other detectors because of their good hermetic electromagnetic calorimetry.

6. Higher Twist Exclusive Pairs

CLEO II's high integrated luminosity (1.3 fb^{-1} by summer 1993) is already paying dividends[1] in the study of $\gamma\gamma \rightarrow p\bar{p}$ [25] and $\gamma\gamma \rightarrow \pi\pi$ [26]. In the mass region between 2 and 3.5 GeV/c^2 they see the behaviour predicted by models with a perturbative hard scattering followed by coalescence of the partons into a pair of hadrons according to partonic wave-functions. Erné[7] showed that 1 fb^{-1} at PEP would have given about the same number of useful events as 1 fb^{-1} at LEP2 in the mass region below 10 GeV/c^2. The lower energy of CESR means that CLEO II has not yet quite reached the predicted PEP or LEP2 numbers[27] for 1 fb^{-1}, but the expected integrated luminosities at CESR and the beauty factories over the next decade will surely swamp any contribution that 500 pb^{-1} at LEP2 would make to these studies. (The two-body higher twist channels are another field in which a Low Energy Compton Collider[11] would be competitive with the beauty factories.)

7. Minijets and Inclusive distributions.

QCD makes predictions for the differential cross-sections as a function of jet and single hadron[28] transverse momenta, with significant contributions from the four diagrams shown in Figure 1. Recent results from TRISTAN and LEP1 - as reviewed at Cornell[1] - agree quite well with the prediction that the resolved components of the photon must be included in addition to vector-dominance and the pointlike coupling. There has been some controversy[29] about how rapidly the cross-sections will rise with energy, and whether they will grow sufficiently to give a serious background of hadronic events at a high-energy Next Linear Collider. HERA results on photoproduction[30] have already suggested that the rise will be less rapid than was first predicted, but it is important for LEP2 to check this. Studies of $\gamma\gamma$ to jets have been essentially exploratory so far, but the extra energy and luminosity at LEP2 should make it possible to set up hard quantitative tests of QCD models.

8. Jet Structure in Tagged Events.

At low Q^2 it is expected that gamma gamma to hadrons will have a strong peripheral component due to vector meson dominance, as well as the singly and doubly resolved parts represented in Figure 1. As Q^2 increases the pointlike coupling should take over, giving much larger transverse momenta to the jets and changing the multiplicity distribution. DELPHI[31] reported a first study of the transverse momenta in final states tagged at very small angles, $< Q^2 >= 0.06 GeV^2$, finding that the same kind of model works for these events as for the untagged sample. LEP2 will allow us to investigate a wide range of Q^2 with good statistical accuracy - though the detectors always loose events in the forward region so the Monte Carlo simulation will play an important part in the results.

9. Conclusions

Gamma-gamma physics at LEP2 will be a much more significant part of the programme than it has been at LEP1. Two important questions in QCD will be answered: does the structure function F_2^γ grow linearly with $\log Q^2$; and does it grow like F_2^{proton} at small x_{Bj} ? A new measurement of α_s may be possible. There are clear predictions to be tested of the rates for inclusive production of charm and beauty particles. The $\gamma\gamma$ partial width of η_c will be well measured and there should be useful numbers of χ_c events, but $\gamma\gamma$ to bottomonium will not be accessible. The study of inclusive particle production and jet distributions will progress from its current phase - confirming the need for resolved hadronic components of the photon - to proper quantitative tests of QCD models. But for light quark resonances, and other strong interaction dynamics at $\gamma\gamma$ invariant masses less than about 4 GeV/c, LEP2 will only compete in a very limited way with DAΦNE, CESR and the beauty factories (or a Low Energy Compton Collider[11]).

References

1. Miller D.J., "Gamma-Gamma Topics, and a look at Mesonic Goo", *in proceedings of the Lepton Photon Symposium, Cornell University, August 1993*, ed. P. Drell, AAP Conference Proceedings.

2. Miller D.J., "Gamma-gamma collisions at LEP II", *Memorandum to LEP Committee, CERN, November 1992*, on behalf of a working group of 24 Physicists.

3. Drees M, Kraemer M., Zerwas P., Zunft J.; *Phys. Lett.* **B277**(1992)215; *Phys. Lett.* **B306**(1993)371.

4. Enomoto R. *et al* (the TOPAZ collaboration), KEK 93-107 and KEK 93-215.

5. Uehara S. *et al* (the VENUS collaboration), KEK 93-142.

6. Uehara S. *et al* (the VENUS collaboration), private communication.

7. Erné F.C., "Resonance Excitation in $\gamma\gamma$-collisions at LEP200", *proceedings of the ECFA workshop on LEP200,* **Aachen 1986**, eds Böhm and Hoogland, CERN 87-08, Vol I, p211.

8. Adriani O. *et al* (the L3 collaboration) CERN PPE 93-173

9. Sens J.C., NIKHEF; private communication, including a missing mass plot from doubly-tagged events in TPC/2γ at PEP with significant numbers of events in a falling continuum at around 10 GeV/c^2.

10. Ward J.J., University College London, private communication.

11. Bauer D., Borden D., Miller D.J., Spencer J., "The Use of a Prototype Next Linear Collider for $\gamma\gamma$ and eγ Collisions", **SLAC-PUB-5816**, June 1992.

12. Laenen E., Riemersma S., Smith J., Van Neerven W.L.; "Complete next to leading order QCD corrections to the photon structure functions $F_2^\gamma(x,Q^2)$ and $F_l^\gamma(x,Q^2)$" Institute Lorentz, Leiden, preprint INLO-PUB-13/93.

13. Miller D.J.; in "Gamma-gamma Physics; Convenor's Review", **Aachen 1986**, ibid., Vol I, p202.

14. Cordier A., Zerwas P.M., "The Photon Structure Function at Large Q^2", **Aachen 1986**, ibid, Vol I, p242.

15. Kennedy B.W., "Deep inelastic eγ scattering at a Linear Collider" These proceedings. Miller D.J., Kennedy B.W., Ward J.J. and Forshaw J.R., "Deep inelastic eγ scattering, with Beamsstrahlung", *Proceedings of the Workshop on Physics and Experiments at Linear Colliders*, **Waikoloa, Hawaii, 26-30 April 1993**, ed. Harris, Olsen, Pakvasa and Tata, World Scientific, Singapore 1993, Vol II p577.

16. Ward J.J., "Unfolding of the Photon Structure Function F_2^γ with special Attention to the low-x Region", these proceedings.

17. Akers R. *et al* (the OPAL collaboration), *Z. Phys.* **C61**(1994)199-208. (Thanks to B.W.Kennedy for calculations from the published data.)

18. Witten E. *Nucl. Phys.* **B120**(1977)189.

19. Peterson C., Walsh T.F., Zerwas P.M., *Nucl. Phys.* **B229**(1983)301.

20. Abe I. *et al* (the H1 collaboration) DESY 93-117

21. Derrick M. *et al*(the ZEUS collaboration) DESY 93-110

22. Abramowicz H., Charchula K. and Levy A., *Phys. Lett.* **B269** (1991) 458.

23. Balitskij Ya. Ya., Lipatov L.N., *Sov. J. Nucl. Phys.* **29** (1978) 822; SJNCA
and Kuraev E.A., Lipatov L.N., Fadin V.S., *Phys. Lett.* **60B** (1975) 50.

24. Aulchenko V.M. et al, "Detector KEDR tagging system for Two-Photon Physics" Novosibirsk preprint 91-49; and Bondar A. (Novosibirsk) private communication.

25. Artuso M. *et al* (CLEOII collaboration) "Measurement of the Cross-Section for $\gamma\gamma \rightarrow p\bar{p}$", contributed paper No. 271 to the Cornell Lepton-Photon Symposium, August 1993.

26. Acosta D. (for the CLEOII collaboration), private communication; also thesis, University of California San Diego 1993.

27. Brodsky S.J., Erné F.C., Damgaard P.H., Zerwas P.M., "Two Photon Exclusive Meson Production at Large Angles", **Aachen 1986**, ibid, Vol I, p222.

28. Aurenche P., Baier R., Douiri A., Fontannaz M., Schiff D., "High P_T Inclusive Hadron Spectrum at LEP 200", **Aachen 1986**, ibid, Vol I, p232.

29. Drees M., "Jet production in two-photon collisions at present and future e^+e^- colliders", **Waikoloa, Hawaii, 26-30 April 1993,** ibid.
Forshaw J.R. and Storrow J., "The minijet contribution to the total e^+e^- cross-section at linear colliders", **Waikoloa, Hawaii, 26-30 April 1993,** ibid.

30. Ahmed T. *et al* (the H1 collaboration) *Phys. Lett.* **B299** (1993) 374-384.
Derrick M. *et al* (the ZEUS collaboration) DESY 94-032.

31. Bjarne J. *et al*(the DELPHI collaboration), Cornell Lepton-Photon Symposium 1993, contributed paper No. 26.