

Questions in Two Photon Physics at LEP2; including data Monte-Carlo comparison ‡.

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Abstract. A partisan review of some of the most important $\gamma\gamma$ channels accessible at LEP 2, with special stress on the measurement of the photon structure function F_2^γ and on associated problems with Monte Carlo modelling.

1. Introduction

There is a long agenda of possible $\gamma\gamma$ topics for LEP2 to study. This talk dwells most upon the measurement of F_2^γ , with brief visits to some of the rest. I apologise in advance for OPAL-centricity.

2. Extracting $F_2^\gamma(x, Q^2)$

Figure 1 shows the Feynman graph from which the interesting variables are defined. The tagged lepton is either an electron or a positron, detected in the forward or endcap detectors with a scattering angle θ_t and energy E_t .

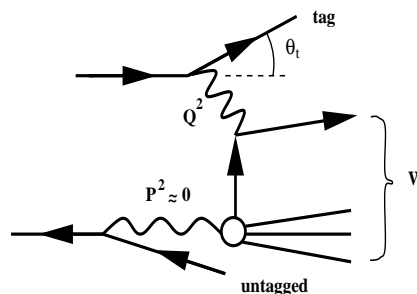


Figure 1. Variables in electron-photon DIS.

$$\frac{d^2\sigma_{e\gamma\rightarrow eX}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} [(1 + (1-y)^2)F_2^\gamma(x, Q^2) - y^2 F_L^\gamma(x, Q^2)]$$

$$Q^2 = -q^2 \simeq 2E_b E_t (1 - \cos\theta_t)$$

$$y = 1 - (E_t/E_b)\cos^2(\theta_t/2)$$

$$x = \frac{Q^2}{Q^2 + P^2 + W^2} \simeq \frac{Q^2}{Q^2 + W^2}$$

where q is the four-momentum of the off-shell probe photon and E_b is the beam energy. Note that

- It is very difficult to measure F_L because the rate is lower at high y where this term is most significant, and there are serious backgrounds generated by beam-associated low energy electrons – at least in OPAL and DELPHI. (For $y \gg 0.5$, $E_t \ll 0.5$, yet most tagged studies require $E_t > 0.7E_b$.) There is a suggestion that ALEPH may be able to do it [1] but it is hard to be hopeful. Nothing has changed since the 1986 Aachen green book [2].

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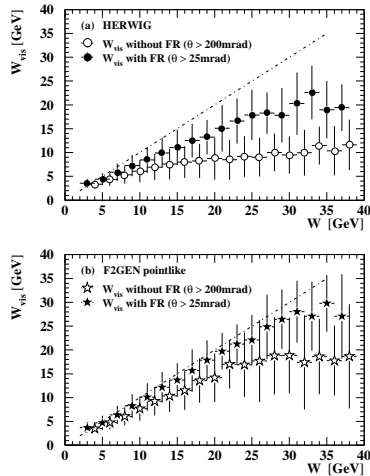


Figure 2. $W - W_{\text{vis}}$ correlation [3] for various Monte Carlo models with and without the included simulation of the OPAL forward region (FR) between $25 < \theta < 200$ mrad.

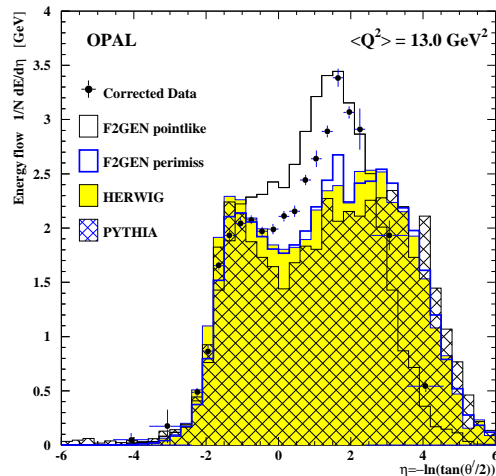


Figure 3. Hadronic energy flow per event as a function of pseudorapidity; data [4] compared with various Monte Carlo models. The tag is always at negative η and is not shown.

- The double tagged rate is low with existing luminometers, but all of the experiments are now taking their very small angle taggers more seriously so we should soon see measurements of P^2 dependence from 0 to $\simeq 0.5$ GeV^2 .
- In singly tagged studies for F_2^γ real progress has been made, but there are practical problems, mainly because the mass W of the $\gamma\gamma$ system is hard to measure (a completely a different situation from HERA where the target proton has a known momentum). These problems will be the main focus of my talk.

Our photons come from a very soft, spread-out spectrum. We are forced to measure the visible mass W_{vis} of the hadronic tracks and clusters. This is an efficient measurement in the barrel region ($\theta > 300$ mrad) but the efficiency and accuracy both fall off in the endcaps and luminometers. The two standard QCD Monte Carlos, HERWIG [5] and PYTHIA [6], both show a serious loss of correlation [7] between the generated and the visible values at large W (e.g. section (a) of figure 2, where the open circles represent a measurement using only the barrel detectors). This lack of correlation at large W corresponds to very poor reconstruction of x in the interesting region where HERA sees rising values of the proton structure function as x decreases [8, 9]. There is great theoretical interest in knowing if the photon has a similar behaviour to the proton at low x because of its hadron-like character, or whether the photon's direct coupling to quark pairs makes a visible difference. At first sight the HERWIG and PYTHIA predictions suggest that these measurements might be impossible at LEP.

But there is hope. Making use of the sampled hadronic energy in the endcaps and luminometers, the observed energy flows seen in figure 3 are by no means as strongly

forward as HERWIG or PYTHIA would suggest. In fact, the experimental points have some of the character of the extreme-case Monte Carlo sample from the purely pointlike F2GEN generator [10]. And note from section (b) of figure 2 that using this pointlike F2GEN sample with hadronic energy from the forward region detectors almost completely restores the correlation between W_{visible} and true W . HERWIG and PYTHIA are clearly not yet fully suitable to be used as unfolding Monte Carlo programmes for the extraction of F_2^γ . They must have something missing, possibly in the way they treat hard sub-processes like photon-gluon fusion. Interestingly, the PHOJET [11] Monte Carlo shows signs of lying closer to the OPAL data, in a still unpublished study with $1.5 < Q^2 < 6 \text{ GeV}^2$, but the present version of PHOJET is not properly set up for virtual photons.

The working group must look at what needs to be done to produce a Monte Carlo generator that is suitable for unfolding. This generator should be driven by physics from outside the $\gamma\gamma$ field but must match all aspects of the $\gamma\gamma$ data. The group is also in a position to study the effects of the particular unfolding package that is used to go from the observed x distribution to the true distribution. There are now two unfolding packages in use, based on very different statistical methods, and the new ALEPH results use both of them: SVD [12] and RUN [13]. My impression is that they agree reasonably well when the statistics are good.

The question list for the group is probably longer than the answer list will be:

- How can the QCD Monte Carlo programmes be improved?
- What will the remaining systematics then be?
- Can we ever see if there is a low x rise in the structure function like that observed for the proton at HERA?
- How should the charm threshold be treated: can realistic and consistent kinematics and phase-space be used in the Monte Carlo models; should QCD evolution be included, or just the Quark parton Model; what value should be taken for the effective charm mass?
- Will we be able to fit for $\Lambda_{\overline{MS}}$ from the high Q^2 evolution?
- Will double tags work?

3. Inclusive studies

Ever since $\gamma\gamma$ physics started at PEP and PETRA there have been attempts to test the predictions of QCD by studying jets at high p_T , mostly with untagged events. And every experiment has developed its own tools, its own set of variables and its own cuts [14]. Now OPAL has introduced an analysis [15] based very closely on what is done in photoproduction at HERA, and there is some hope that the other LEP experiments will follow suit. They use a development of the x_γ variable which is an estimator of the fraction of the target photon's momentum carried by the hard parton which produces identified jets with high E_T ,

$$x_\gamma^\pm = \frac{\sum_{jets} E_j \pm p_{z,j}}{\sum_{hadrons} E_i \pm p_{z,i}}$$

where $p_{z,i}$ is the momentum of the i th hadron projected along the beam direction. The \pm ambiguity arises because the untagged initial state is intrinsically symmetric, unlike the situation in ep , and either photon may be the target. Three main categories of events with high E_T jets are expected: direct, singly resolved or doubly resolved – as

shown in Figure 4 [16]. Using the PYTHIA Monte Carlo, OPAL shows that the direct sample should be very cleanly separated from the resolved samples by requiring both x_γ^+ and x_γ^- to be greater than 0.8. They confirm this separation in the experimental data for two jet events with $E_T > 3$ GeV by computing an effective parton scattering angle θ^* in the dijet C. of M. and showing that the “direct” ($x_\gamma^\pm > 0.8$) sample has the expected rather flat distribution, while the “resolved” sample (x_γ^+ or x_γ^- less than 0.8) is much more forward-backward peaked, as predicted on a parton level by lowest order QCD (and as seen in analyses of photoproduction at HERA [17]). This is a new field which has opened up at LEP 2 where the background in the untagged channel from $Z^0 \rightarrow \text{hadrons}$ is greatly reduced compare with LEP 1.

A development of this analysis will be to study the jet structure in tagged events and to see how it varies as a function of the Q^2 of the probe photon. It is not obvious what the equivalent variable should be in this case to E_T in the untagged case, since the transverse energy in tagged events contains the hadronic recoil against the tag. It has been suggested that it might be possible to use normal jet-finding algorithms in the C. of M. system of the visible hadrons, but we know that missed forward energy will always make this a poor approximation to the true hadronic rest frame. Another possibility is to use the distribution of the $E_{t,out}$ variable (see figure 1 of [18]) instead of E_T . A preliminary study by Rooke [19] has found a much larger signal in OPAL for two jet events than the predictions of HERWIG or PYTHIA.

One of the worst measured quantities in $\gamma\gamma$ physics is the total cross section $\sigma_{\gamma\gamma}$ for $W < 5$ GeV. L3 [20] is now producing LEP2 results at higher W , up to $\simeq 70$ GeV. We should all try to match them. Here again, the big problem will be in correcting believably for the lost hadrons going into the forward region and even down the beampipe – a significant number of diffractive events at high W may give no signal at all in our detectors. L3 may not yet have understood the full extent of this problem (but see “Utopia”, below).

4. Resonances

There is no doubt that we should continue to study charmonium resonances at LEP2. L3 has already had some success at LEP1 with η_c [21] and with χ_c [22]. It is hard work because there are lots of decay modes, but adding many channels together can give respectable peaks. Hundreds of events should be collected in the end for each of the charmonium resonances, enough to give worthwhile measurements of their $\gamma\gamma$ partial widths.

It is not so clear how far we should pursue the study of non-charmonium resonances in the 1 to 2 GeV region. Close and colleagues [23] have an important list of glueball

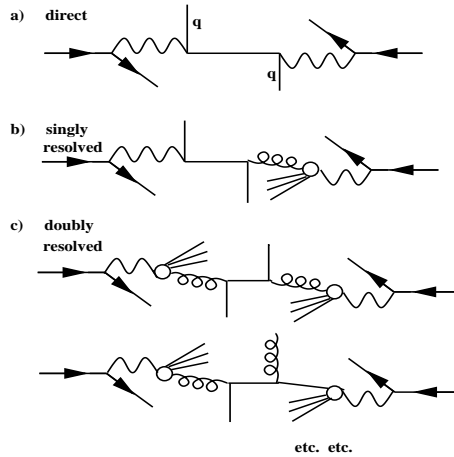


Figure 4. Feynman graphs for direct and resolved processes.

and hybrid candidates whose “stickiness” S has to be checked, where for resonance R ,

$$S = \frac{\Gamma(J/\psi \rightarrow \gamma R)/\text{phasespace}}{\Gamma_{\gamma\gamma}^R/\text{phasespace}}.$$

($S \simeq 1$ for the $f_2^0(1270)$, a clear $q\bar{q}$ state which is prominent in $\gamma\gamma \rightarrow \pi^+\pi^-$, but $S \simeq 25$ for $\eta(1440)$, a well known glueball candidate which is barely visible in $\gamma\gamma$). The integrated luminosity at LEP 2 is never expected to exceed 500pb^{-1} , whereas Cleo II already has in excess of 3fb^{-1} and the new beauty factories BaBar and Belle should each get more than 10fb^{-1} . Beauty factories have almost as large a production cross section for low mass resonances as LEP, and the final states are easier to measure because they are not so strongly boosted along the beam direction. LEP triggers are also heavily biased against low transverse momentum tracks and low multiplicities. Nevertheless, L3 is beginning to get into resonance studies. It will be hard for the working group to judge how much should be done on resonances at LEP 2 because no one can tell how much effort will eventually be available for $\gamma\gamma$ resonance studies at the beauty factories. [Note added later. In my judgement, the only two $\gamma\gamma \rightarrow$ resonance results at Photon '97 which had real physics impact both came from Cleo II, with large statistics [24, 25]. On one of the two topics (Q^2 dependence of η' production) there was also an L3 paper [26] which did not add much at this stage, though with the full LEP 2 statistics it will eventually give a useful check].

5. The biggest exclusive cross-sections at LEP; $\gamma\gamma \rightarrow$ vector meson pairs.

Figure 5 shows that the cross section for $\gamma p \rightarrow \rho p$ at HERA remains at about 1/12 of the total γp cross section from about 10 GeV to the highest visible energy. The same kind of behaviour is to be expected for the equivalent “elastic” channel $\gamma\gamma \rightarrow \rho^0\rho^0$. No one has ever measured this channel for $\rho\rho$ masses beyond about 2.5 GeV because the process becomes almost totally diffractive and the pions from high energy ρ^0 decays go strongly forward. These events must be coming at a rate of 1 every 20 seconds or so, but it is a real challenge to the LEP experiments to devise triggers which will identify them, together with related channels like $\rho\omega$, $\rho\phi$ and the semi-inclusive diffractive channels with a ρ plus a low mass forward jet. There will be good old-fashioned soft strong interaction physics to be done with such data. But there is even more interest in the semi-hard processes where one or both of the vector mesons is a J/ψ . Notice that

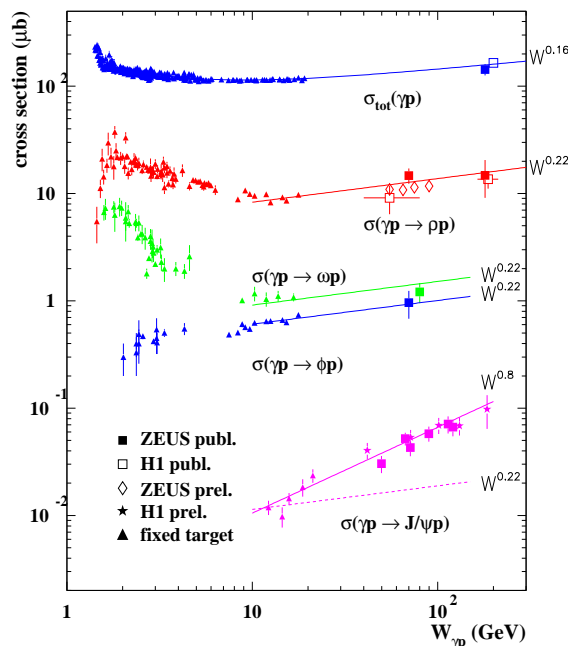


Figure 5. The γp total cross section and the cross sections for photoproduction of single vector-mesons, including recent HERA data.

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the $\gamma p \rightarrow J/\psi p$ cross section rises in Figure 5 much more rapidly than the total cross section. QCD has predictions to make about such processes [27], and the final state will be much more triggerable and measurable than $\rho\rho$ if it contains a $J/\psi \rightarrow l^+l^-$ decay. The $\gamma\gamma \rightarrow J/\psi\rho$ channel is well worth further study.

6. Utopia

A flight of fancy: *if* LEP runs to the year 2000, *if* we had an extra £2M to spend and *if* we could find 6 strong uncommitted groups to work flat out for four years. *Then* let us build a 0° double-tag spectrometer in an unused LEP straight section. We would use the Novosibirsk technique [28], with a simple central detector and magnetic bends close to the mini-beta quadrupoles so that the momenta of the two tagged electrons can be measured with very high precision by a series of small position sensitive detectors placed along the outgoing beamlines. Each detector sees the image of the collision point formed by electrons scattered close to 0° in a small range of momenta and angles, focussed by the quadrupole and dispersed by the bending magnet. The simplest such set-up would measure the total cross section with small errors up to $W_{\gamma\gamma} \simeq 100$ GeV. Adding better large-angle taggers would give $F_2^\gamma(x, Q^2)$ without the current uncertainties in unfolding x . More elaborate forward hadron tracking would allow $\gamma\gamma \rightarrow \rho\rho$ to be done properly. It would be a coherent programme and not too expensive, but somehow I do not see it happening.

7. Conclusions and Acknowledgements

This review is meant to be provocative rather than even-handed, and to start the working group off with a list of issues to discuss. It is a good time to have a UK workshop session on the problems of $\gamma\gamma$ physics at LEP because a significant number of the most active protagonists are based in this country.

The organisers of the workshop are to be congratulated on putting together a very sound programme of work to be done in many fields of LEP 2 physics. I look forward to IOP 1/2 day meetings over the next few years in which the LEP 2 experimental results are reported and discussed.

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