Luminosity monitoring and search for an e^* through $e\gamma$ scattering at e^+e^- colliders

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(Received 2 August 1985)

At e^+e^- supercolliders such as the Stanford Linear Collider or CERN LEP, we suggest the use of $e\gamma$ scattering (where the photons are quasireal ones, generated by one of the $e^\pm$ beams and interacting with the other) for the monitoring of experimental luminosities. The same process may also be used for searching for an e^*, or determining a limit for its coupling constant, practically in the full mass range covered by such colliders. We discuss the experimental requirements and the results to be anticipated in that type of study.

At e^+e^- colliders of very high energy, it appears that the measurement of elastic e^+e^- scattering is not as well fit for monitoring the experimental luminosity as it is in storage rings of lower energy. This seems particularly obvious for CERN LEP and the Stanford Linear Collider (SLC), insofar as those machines will be used as Z generators. In a previous paper,[1] one of us proposed the use of a luminosity monitor based on the measurement of particle pairs of small invariant mass produced in $\gamma\gamma$ collisions. It must be kept in mind that such a monitor would require a specific low-momentum trigger.

Here we suggest a different method, based on $e\gamma$ scattering, where the photons are virtual ones generated by one of the $e^\pm$ beams and interacting with the other. The measurement of such a process was suggested many years ago[2,3] and was indeed performed at the low-energy storage ring ACO at Orsay.[4] Figure 1 shows the corresponding configuration. The electron used as photon generator may be assumed to escape detection (untagged or antitagged measurement), so that one observes a two-particle $(e^\pm\gamma)$ final state. That state, as we discuss later in the paper, tends to involve a large visible energy and to be kinematically overconstrained. The corresponding events should be easily selected in a clean way and should not require, *a priori*, a special trigger. Moreover, they should give rise, in a realistic setup, to counting rates large enough to allow their use for luminosity monitoring.

In the second part of this paper, we shall show that such a measurement should also provide one of the best ways of searching for an excited electron e^* or of determining a limit on the coupling constant of an $e^*e\gamma$ vertex, within a mass range extending almost to the full machine energy.

Obviously, similar possibilities also exist in an ep supercollider such as DESY HERA, with some differences. This will be discussed in the following paper.[5]

When they are observed within the apparatus, the two final-state particles $(e^\pm, \gamma)$ are well characterized (insofar as radiative corrections are neglected).

(i) The visible energy E_{vis} is always larger than the beam energy E.

(ii) The charge of the observed electron is correlated with the direction of the velocity $\boldsymbol{\beta}$ of the center of mass of the $e^\pm\gamma$ system in the laboratory frame; that direction can be immediately inferred from the $e\gamma$ acolinearity angle, whose observation is thus sufficient to determine, for each event, which beam has been involved in the scattering.

(iii) The kinematics is overconstrained: Calling W the invariant mass observed, E^γ the virtual photon's energy, and $s=4E^2$, one gets

$$x=\frac{E^\gamma}{E}=\frac{E_{\text{vis}}-E}{E}=\frac{W^2}{s}=\frac{1-\beta}{1+\beta} \tag{1}$$

with $\beta=|\boldsymbol{\beta}|=\sin(\theta^e+\theta^\gamma)/(\sin\theta^e+\sin\theta^\gamma)$, where θ^e and θ^γ are, in the laboratory frame, the emission angles of the observed electron and photon with respect to the direction of $\boldsymbol{\beta}$; that direction is determined by the fact that the total transverse momentum observed, with respect to it, is zero. From (1) one notices that β decreases as W or E_{vis} increases.

(iv) As the events considered are dominated by quasireal photons with $Q^2\simeq 0$, the spectator electron tends to be emitted close to the beam axis and to escape detection. Since $\boldsymbol{\beta}$ is practically parallel to the beam axis, the total transverse momentum observed with respect to that axis, as well as the acoplanarity angle, are close to zero.

We conclude that the dominant contribution to the process considered can be selected by looking at coplanar and/or antitagged $e\gamma$ events with a well-defined charge and large visible energy. Obviously, radiative corrections affect the cross section, as well as the distributions of various parameters and the above-shown kinematic correlations. Actually, the only significant contribution to those corrections proceeds from radiation by the incident electron participating in the Compton process. Such a correction can be taken account of in the calculation by introducing a loss of that initial electron's energy according to a probability law given by[6]

$$dP(k)=\eta k^{\eta-1}\left(1-k+\frac{k^2}{2}\right)dk \tag{2}$$

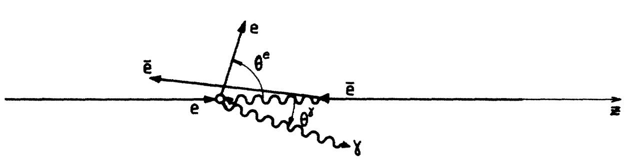

FIG. 1. Schematic representation of the process $ee\to ee\gamma$, involving Compton scattering of quasireal photons.

with

$$\eta = \frac{2\alpha}{\pi}\left(\ln\frac{2E}{m_e} - \frac{1}{2}\right) . \tag{3}$$

Notice that the hard-photon tail of the spectrum can be eliminated to a large extent by imposing a lower limit on the visible energy, i.e., $E_{\text{vis}} \gtrsim E$ (since one has $k = E - E_{\text{vis}} + E^{\gamma}$, where small values of E^{γ} are strongly favored). In that case the radiative corrections still modify the absolute rates and spectra, but leave the kinematic correlations practically untouched. Then a rather simple Monte Carlo simulation, including all constraints (in particular regarding E_{vis}), using the factorization of the equivalent-photon spectrum with the real Compton scattering cross section, and taking account of the remaining radiative correction, should be accurate at the 1% level. Indeed, as has been shown by various authors for different high-energy electromagnetic processes,[7] the equivalent-photon approximation usually works at the 10% level when applied to cross sections integrated over Q^2 (the photon's four-momentum squared), and is much better than that when one limits oneself to small Q^2 values ($\ll W^2$).

Let us notice, on the other hand, that for the bulk of events selected the full kinematics can be derived from measuring the angles alone, which generally leads to a better resolution than using the measured energies. One is thus provided with a method for electromagnetic calibration of the apparatus.

Neglecting radiative corrections, a straightforward evaluation can be performed analytically. We have checked that, with respect to the above-described simulation and within a realistic experimental acceptance, such an evaluation involves an error of less than 10%, mainly due to the neglect of radiative corrections. It proceeds as follows:

$$\frac{d\sigma}{dW} = \frac{\alpha^3}{W^3} n(s,W)\left[(u_1 - u_0)\left(1 - \frac{u_1 + u_0}{2}\right) + 4\ln\frac{1-u_0}{1-u_1}\right] , \tag{4}$$

with

$$n(s,W) = \frac{s^2 + (s-W^2)^2}{s^2}\ln\frac{Q_{\max}}{Q_{\min}} - \frac{s-W^2}{s} \tag{5}$$

and

$$u_0 = \sup\left(\frac{u^e_{\min} - \beta}{1-\beta u^e_{\min}}, \frac{\beta - u^e_{\max}}{1-\beta u^{\gamma}_{\max}}\right) ,$$
$$u_1 = \inf\left(\frac{u^e_{\max} - \beta}{1-\beta u^e_{\max}}, \frac{\beta - u^{\gamma}_{\min}}{1-\beta u^{\gamma}_{\min}}\right) , \tag{6}$$

where $u^e = \cos\theta^e$, $u^{\gamma} = \cos\theta^{\gamma}$, their maxima and minima being defined by the experimental acceptance cuts. Notice that

$$Q_{\min} = m_e W^2 / [s(s-W^2)]^{1/2} ,$$

while $Q_{\max}$ is determined by the experimental limitation due to antitagging and/or coplanarity.

Accounting for the symmetry between the incoming electrons, and assuming the detection to be symmetric in space and charge, a factor of 2 is to be included in the computation.

Table I shows the cross sections expected, within an acceptance assumed to be realistic, for various trigger configurations. We remark that, when the trigger implies at least one prong in the central detector, the corresponding counting rates should be large enough for deriving a luminosity monitor. However, a better efficiency would be achieved by triggering as well on the end caps alone; since such a triggering involves either a high-energy electron or a high-energy photon (actually both, on opposite sides of the beam axis), it should certainly be feasible.

Notice that, using a (possibly available) Bhabha luminometer at very small angle, the rate of $e\gamma$ events (a few nanobarns) measured with such a device would allow one, as well, to apply the virtual Compton process for on-line monitoring.

A possible cause for a deviation from the standard expectation for $e\gamma$ scattering may be the production and decay of a heavy excited electron, e^*.[8] Thus the measurement here suggested provides a possibility of investigating the existence of such a particle, or setting a limit to the strength of its coupling constant. Obviously, this is not the only way of performing such an investigation;[9] however, it is the only one based on a two-body final-state measurement involving a possible e^* whose mass may extend to the full machine energy.

Here as well, one may perform a Monte Carlo simulation; on the other hand, an analytic evaluation is again straightforward. From a conventional expression of the $e^*e\gamma$ interaction (assuming the e^* to be a spin-$\frac{1}{2}$ particle)[10]

$$L_{\text{int}} = \frac{\lambda_e}{2m^*}\bar{\psi}_{e^*}\sigma_{\mu\nu}\psi_e F^{\mu\nu} + \text{H.c.} , \tag{7}$$

one gets the corresponding integrated cross section

$$\sigma^* = \frac{2\pi\alpha^2\lambda^2}{m^{*2}} n(s,m^*)(u_1 - u_0) , \tag{8}$$

where $n(s,m^*)$ is derived from (5), and u_0, u_1 are given by (6). Again a factor of 2 is to be included whenever the detection is symmetric in space and charge, assuming of course the e^* to appear at the same mass and to be coupled in the same way, in both charge states.

Here the angular distribution of the outgoing electrons/photons in the $e\gamma$ c.m. frame is isotropic,[11] in obvious contrast with the standard Compton effect favoring backward scattering. Therefore, we may increase the relative importance of an e^* effect, with respect to the standard process,

TABLE I. Distribution of prongs in the detectors, predicted for LEP or SLC (50 GeV per beam). (Central detector: 30°–150°. End caps: 8°–30°, 150°–172°. Full acceptance: 8°–172°).

	(pb)
Two prongs in the central detector	11
One prong (electron) in the central detector	71
One prong (photon) in the central detector	26
At least one prong in the central detector	108
Two prongs in opposite end caps	2
Two prongs in the same end cap	182
Two prongs in the end caps	184
Two prongs in the full acceptance of the apparatus	292

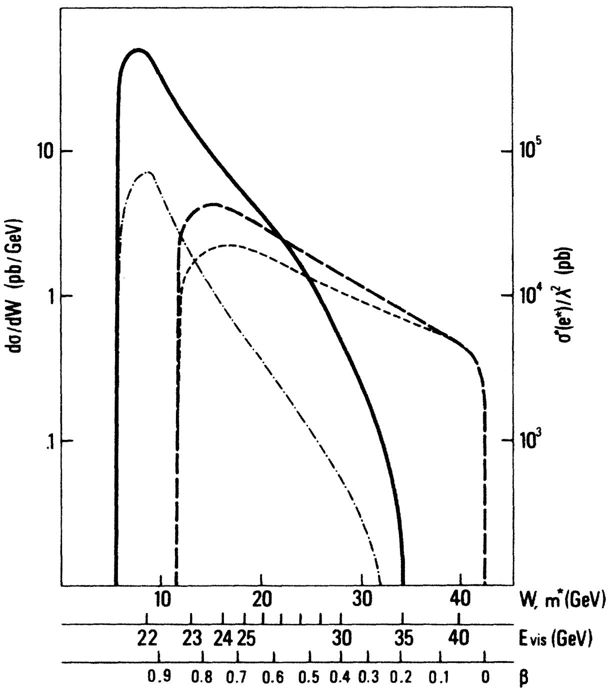

FIG. 2. Invariant-mass spectrum predicted for the standard Compton effect, and cross section divided by λ^2 of a possible e^* effect (as a function of its mass), at PETRA (21 GeV per beam), for configuration 1, defined by the electron seen in the central detector (30°–150°) and the photon in the end caps (8°–30°, 150°–172°); and for configuration 2, defined by both the electron and the photon seen in the central detector (30°–150°). Solid curve, $d\sigma/dW$, configuration 1; long-dashed line, $d\sigma/dW$, configuration 2; dash-dotted line: $\lambda^{-2}\sigma^*$, configuration 1; short-dashed line: $\lambda^{-2}\sigma^*$, configuration 2. Here, and in the predictions of Fig. 3, $Q_{\max}$ is fixed by setting $P \equiv |\sum \mathbf{p}_T| < 0.1W$ [note that $Q = P/(1-W^2/s)^{1/2}$].

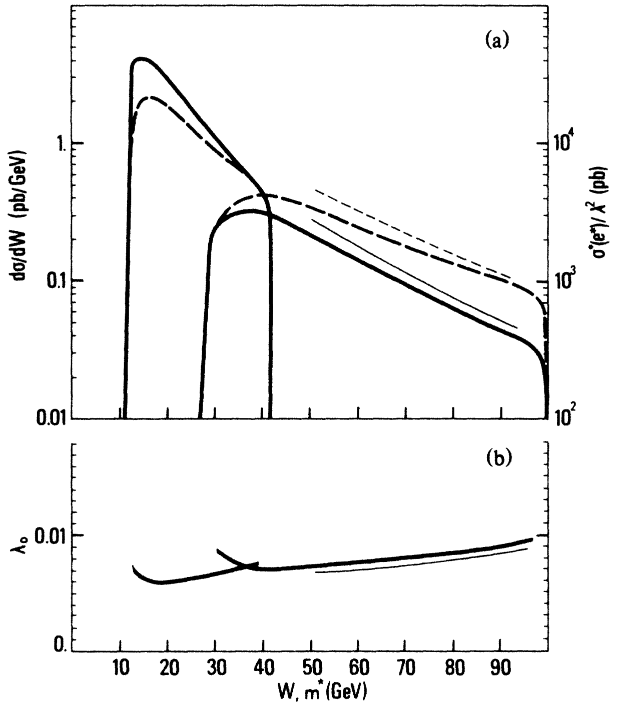

FIG. 3. (a) Solid thick line (dashed thick line), $d\sigma/dW$ (σ^*/λ^2) in configuration 2 (see caption of Fig. 2), at PETRA (21 GeV) and LEP or SLC (50 GeV). Solid thin line or dashed thin line, $d\sigma/dW$ or σ^*/λ^2 in configuration 3, defined by the electron seen in the full acceptance range (8°–172°) and the photon in the central detector (30°–150°), at LEP or SLC for $W > 50$ GeV. (b) Lower limit of λ that can be expected to be reached with realistic assumptions and requirements (see the text). Solid thick line: in configuration 2, at PETRA and LEP or SLC. Solid thin line: in configuration 3, at LEP or SLC for $W > 50$ GeV.

by rejecting events with the photon seen in the end caps.[12] Figure 2 shows, as an example, $d\sigma/dW$ (for the standard process) and σ^*/λ^2 (for an e^* effect, as a function of the latter's mass) expected at DESY PETRA (21 GeV per beam) when the electron is detected within the central detector, and the photon within either the central detector or the end caps. Figure 3(a) shows the same invariant-mass spectrum, or cross section, predicted both for PETRA (21 GeV) and for LEP or SLC (50 GeV), assuming both the electron and the photon to be measured in the central detector. Figure 3(b) shows, for the latter configuration, the experimental limit λ_0 of λ that can be reached, assuming an integrated luminosity $\mathcal{L}(e^+e^-) = 25$ pb^{-1} and a mass resolution $\Delta W = 1$ GeV, while requiring the yield of an e^* effect to increase the counting rate by at least two standard deviations with respect to the QED Compton effect, and to involve at least two events by itself.[13] Notice that, as long as the requirement of two standard deviations implies more than two e^* events, one has $\lambda_0 \sim (\Delta W/\mathcal{L})^{1/4}$; i.e., λ_0 remains quite insensitive to variations of either parameter, or ΔW.

It results that at PETRA (or at SLAC PEP) where σ^* tends to be relatively high (so that the "two-events" requirement should be relatively easy to meet) for a given value of λ, a somewhat lower integrated luminosity and/or acceptance may be used without notably increasing the limit λ_0 that one should be able to obtain. On the other hand, using LEP or SLC for investigating higher masses (involving considerably smaller predictions for σ^*/λ^2), it would be important to increase the integrated luminosity, if possible, and also to extend the angular acceptance by including electrons scattered at smaller angles, i.e., detecting them in the end caps in addition to the central detector, while detection of the photons should remain confined to the latter (see our discussion in the previous paragraph). Results predicted for LEP and SLC for such an extended configuration at W (or m^*) larger than 50 GeV are also shown in Figs. 3(a) and 3(b) (assuming the same requirements as defined above for the determination of λ_0).

To finish, let us mention that measurements of the type here suggested[14] are being performed by one of us (A.C.) and collaborators at PEP (DELCO Collaboration), and as well by the CELLO Collaboration at PETRA.

We wish to thank N. Arteaga-Romero, C. Carimalo, and F. Le Diberder for useful discussions.

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[2]SLAC Proposal No. SP-4, 1971 (unpublished); J. D. Bjorken, in *Proceedings of the Fourth Hawaii Topical Conference on Particle Physics, Honolulu, 1971* (University of Hawaii, Honolulu, 1972), p. 185.

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[6]E. Etim, G. Pancheri, and B. Touschek, Nuovo Cimento **51B**, 276 (1967); G. Pancheri, *ibid.* **60A**, 321 (1969).

[7]See, for instance, C. J. Brown and D. H. Lyth, Nucl. Phys. **B53**, 323 (1973); **B73**, 417 (1974); R. Bhattacharya, J. Smith, and G. Grammer, Jr., Phys. Rev. D **15**, 3267 (1977); C. Carimalo, P. Kessler, and J. Parisi, *ibid.* **20**, 1057 (1979).

[8]Such a deviation should not affect our previous considerations concerning the luminosity monitoring, since a possible excited electron should be expected to appear as a local peak and to leave the integrated mass spectrum practically unmodified.

[9]In particular $e^{\pm}\gamma$ mass spectra were investigated, looking for an e^*, in three-particle final states resulting from the reaction $e^+e^- \rightarrow e^+e^-\gamma$, by JADE Collaboration, W. Bartel *et al.*, Z. Phys. C **19**, 197 (1983).

[10]That form of the $e^*e\gamma$ coupling, which is the only one satisfying *C*, *P*, and *T* separately, was first given by F. E. Low, Phys. Rev. Lett. **14**, 238 (1965).

[11]Using the more general, parity-violating, form

$$L_{\text{int}} = (e/2m^*)\bar{\psi}_{e^*}\sigma_{\mu\nu}(a - ib\gamma_5)\psi_e F^{\mu\nu} + \text{H.c.}$$

discussed by F. M. Renard [Phys. Lett. **116B**, 264 (1982)], the angular distribution of the e^* decay products, instead of being flat, would become

$$d\sigma^*/d(\cos\theta) = 1 + \{[2\,\text{Im}(ab^*)]^2/(|a|^2 + |b^2|)^2\}\cos\theta \ ,$$

where θ is the $e\gamma$ c.m. scattering angle (in the most interesting case, $|a| = |b|$, with a purely real and b purely imaginary as required by *CP* invariance, it would become $\sim 1 + \cos\theta$). One would thus get a forward peak, i.e., the contrast with QED Compton scattering would be even sharper.

[12]In principle, one should exclude photons seen in the end cap located close to the direction of the beam of same charge as the observed $e^{\pm}$ particles. Moreover, especially in the predominating low-W (large-β) range, the Lorentz boost anyway tends to preclude the occurrence of any prongs in the opposite end cap.

[13]We may safely assume that the yields of the two processes are purely additive (neglecting their interference), since their overlap in phase space is minimal.

[14]Similar suggestions were made as well by other authors: F. M. Renard, Z. Phys. C **14**, 209 (1982); K. Hagiwara, D. Zeppenfeld, and S. Komamiya, *ibid.* **29**, 115 (1985); P. M. Zerwas (private communication).