Detector calibration, luminosity monitoring, and search for an e^* at DESY HERA

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We propose $e\gamma$ scattering, where the photons are quasireal ones generated by the proton beam, to be used for electromagnetic calibration of the apparatus and for a normalization of experimental luminosities at DESY HERA. The same process may also be used for searching for an e^*, or determining a limit for its coupling constant, in particular, in the mass range of 100–200 GeV. We discuss experimental requirements and results to be anticipated.

In the previous paper,[1] henceforth called I, we have shown that it is possible to use $e\gamma$ scattering involving quasireal photons at e^+e^- colliders for experimental energy calibration and luminosity monitoring, as well as for investigating the hypothetical existence of an e^* in a given mass range. We mentioned that similar possibilities are provided by an *ep* collider. There are, however, some obvious differences.

(i) At the *ep* collider a factor of 2 is lost in the event yield, since only photons generated by the proton beam can be used for $e\gamma$ scattering.

(ii) In the equivalent-photon spectrum the electron mass, appearing in the argument of the logarithm, is to be replaced by the proton mass; it follows that the equivalent-photon flux is somewhat smaller (and consequently the event yield is further reduced) at the *ep* collider.

(iii) The proton differs from a pointlike Dirac particle, as regards its equivalent-photon spectrum, by the electric form factor, the anomalous-magnetic-moment contribution, and the inelastic contribution. However, it has been shown[2] that, for Q^2 not too large, those various contributions tend to cancel out when added together. It results that, in practice, we are allowed to use the equivalent-photon spectrum of a pointlike Dirac proton. In Ref. 2 we checked such an approximation for a typical QED process (photoproduction of lepton pairs), considering a wide range of the kinematic parameters (energy, invariant mass produced). It appeared to work, systematically, at the 10% level when applied to cross sections integrated over Q^2; it should actually work much better than that when, as is suggested here, one limits oneself to small Q^2 values ($<< W^2$).

(iv) In e^+e^- colliders with symmetric beams, one notices that (as far as radiative corrections may be neglected) the velocity $\boldsymbol{\beta}$ of the $e\gamma$ system in the laboratory frame is always peaked in the direction of the beam with the same charge as the electron observed; its absolute value decreases with W increasing. In an asymmetric *ep* machine such as DESY HERA ($E^e = 30$ GeV, $E^p = 830$ GeV) $\boldsymbol{\beta}$ will be peaked in the direction of the electron beam as long as the invariant $e\gamma$ mass observed, or the visible energy, stays lower than $2E^e = 60$ GeV, and in the direction of the proton beam for W (or E_{vis}) larger than that value; $|\boldsymbol{\beta}|$ decreases for $W < 60$ GeV, and increases above that value, with W increasing. The visible energy, at HERA, is always higher than $E^e = 30$ GeV.

(v) Here as well, the kinematics of the observed $e\gamma$ system is constrained. However, because of the energy asymmetry of the beams (and in principle also because of mass corrections, but one may neglect them in general), the exact kinematic relations are not quite as simple as for e^+e^- colliders; they actually involve the Q^2 of the virtual photon. Yet, since quasireal photons (with $Q^2 << W^2$) are strongly dominating, and thus the direction of $\boldsymbol{\beta}$ remains very close to the beam axis for the vast majority of events, simple correlations are again obtained for those events (see Fig. 1):

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

It results that a dominating contribution to the process considered can be selected by looking at coplanar $e\gamma$ events with a large visible energy. As in I a cutoff $E_{\text{vis}} \gtrsim E^e$ will

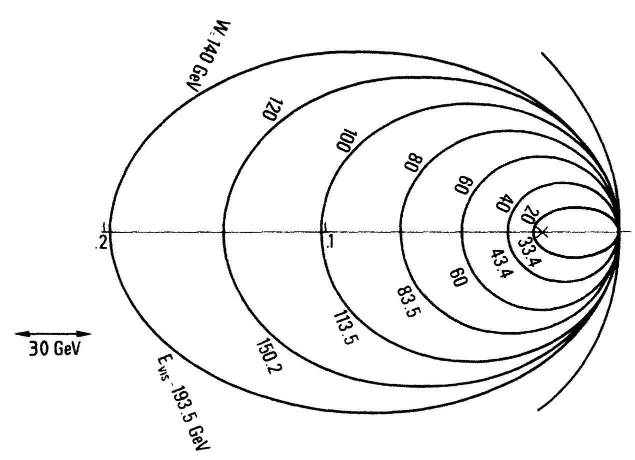

FIG. 1. Polar diagram describing the kinematics of the $e\gamma$ final state, assuming the velocity $\boldsymbol{\beta}$ of the Lorentz boost to be parallel to the beam axis. Each ellipse corresponds to a given value of $x \equiv E^\gamma/E^p$ (shown in the figure) or equivalently of the invariant mass W, of the visible energy or of $\beta = |\boldsymbol{\beta}|$. Energies (momenta) and angles are obtained by joining corresponding points (on the same ellipse, at the same distance from the symmetry axis, and on a different perpendicular to that axis) in the upper and lower parts of the diagram with the origin. Only the dynamically significant range ($x < 0.2$) is shown in this figure. Values of W and E_{vis} are given for all ellipses shown.

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eliminate most of the hard-photon tail of the radiative corrections (since here again $k = E^e - E_{vis} + E^\gamma$, where small values of E^γ strongly predominate); the remaining radiative correction will leave the kinematic correlations practically untouched. For the events thus selected, where $\boldsymbol{\beta}$ is essentially parallel to the beam axis, one can derive, for the purpose of electromagnetic calibration, the energies of the electron and photon observed from the measurement of their angles alone, using the relation

$$\frac{E'^e}{\sin\theta^\gamma} = \frac{E'^\gamma}{\sin\theta^e} = \frac{2E^e}{\sin\theta^e + \sin\theta^\gamma - \sin(\theta^e + \theta^\gamma)} .$$

A complete Monte Carlo simulation, including the remaining radiative correction by using formulas (2) and (3) of I, may then be performed. On the other hand, one may as well perform a straightforward analytic evaluation by means of formulas (4)–(6) of I. In the expression of Q_{min}, we must of course replace the electron mass by the proton mass; as for Q_{max}, it will be fixed by imposing an upper limit on $P \equiv |\sum \mathbf{p}_T|$ [since $Q = P/(1 - W^2/s)^{1/2}$]. Such an evaluation should involve, under standard conditions, an error of about 10%, mainly due to the neglect of radiative corrections.

Table I shows the cross-section values computed for various configurations corresponding to observing the electron and the photon within three detectors (forward, central, and backward). The yields thus predicted should be sufficient to allow an electromagnetic calibration of the backward and central detector,[3] and an off-line luminosity monitoring. Yet it should be emphasized that the largest contribution to those yields is provided by the backward detector. This is easily explained by the fact that high event rates are mainly obtained at low-W values, i.e., for $\boldsymbol{\beta}$ opposite to the proton beam direction (incidentally, we notice that here the neglect of hadronic masses, implicit in the formulas we used, is particularly well justified).

Assuming a backward detector to be available, the yields here shown may be considered basically sufficient, even if the trigger requires at least one particle observed in the central detector. However, obviously the luminosity monitoring would be better performed if the possibility of triggering on the backward detector alone were provided in addition. For the high visible energy (at least 30 GeV) and the specific configuration (two particles back to back in transverse view) here considered, such a triggering should be easily feasible. Notice that the use of a small-angle backward calorimeter would even allow one to perform an on-line luminosity monitoring, achieving yields of a few nanobarn.

In Fig. 2 we compare the visible-energy distribution [notice: $d\sigma/dE_{vis} = (2E^e/W)d\sigma/dW$], predicted for the process here considered, to the one computed for electron pair production in $\gamma\gamma$ interactions, assuming similar cuts in acceptance.[4] The use of the latter reaction has recently been proposed by Field[5] for calibrating the apparatus used at HERA, and by one of us (A.C.)[6] for luminosity monitoring. An important advantage of the virtual Compton process here discussed is obviously that it occurs at rather large visible energy (> 30 GeV), and that it does not require a special trigger. Actually, the tagging of quasireal photons by detection of the outgoing (elastically scattered) protons at 0° has been suggested by Field[7] in order to ensure a clean selection, as well as kinematic constraints, of $\gamma\gamma$ events. Let us remark that, in the procedure here proposed, such a tagging may be envisaged as well, but seems less necessary.

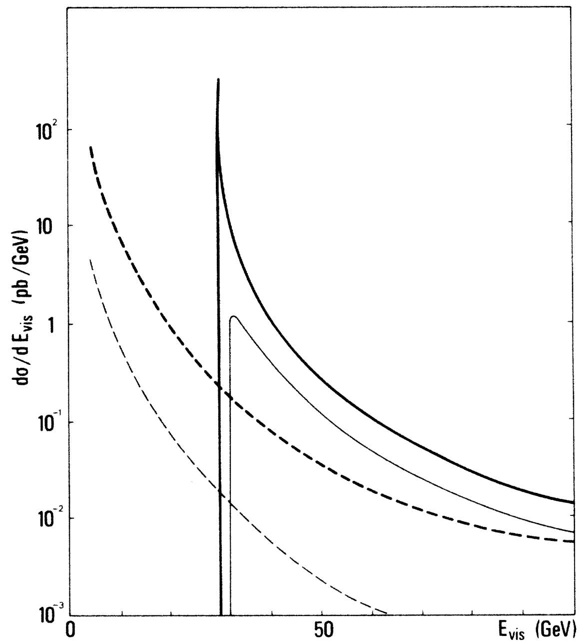

FIG. 2. Visible-energy spectrum predicted for $e\gamma \to e\gamma$ (solid curve) and $\gamma\gamma \to e^+e^-$ (dashed curve) under similar conditions at HERA. Thick curve: $8° < \theta^e, \theta^\gamma < 172°$ (full acceptance of the apparatus). Thin curve: $30° < \theta^e, \theta^\gamma < 150°$ (acceptance limited to the central detector). Here, and in the predictions shown in Fig. 3, Q_{max} has been fixed by setting $P = |\sum \mathbf{p}_T| < \inf$ (2 GeV; 0.05W).

As in I we shall finally consider the search for a hypothetical e^*, and the determination of a limit for the coupling constant characterizing an $e^*e\gamma$ vertex. Figure 3(a) shows $d\sigma/dW$ (for the standard Compton process) and σ^*/λ^2 [for an e^* effect; see formulas (7) and (8) of I] computed for CERN LEP or the Stanford Linear Collider (SLC) and for HERA[8] under similar conditions, i.e., assuming only a central detector to be used. One notices, as could actually be inferred from remarks (i)–(iii) in the beginning of this paper, that, in the W range where HERA overlaps with LEP or SLC, a somewhat (roughly 4 times) higher luminosity would be needed for HERA to compete with the latter machines in the search for an e^* or the determination of λ_0. As for the low-mass range below that covered by LEP or SLC, it is obvious (see Fig. 3 of I) that DESY PETRA and SLAC PEP are much better fit than HERA for such an experiment.

TABLE I. Distribution of electron and photon prongs in the three detectors (backward, 150°–172°; central, 30°–150°; forward, 8°–30°), predicted for a measurement of the $e\gamma$ final state at HERA (figures are given in pb).

Photon \ Electron	Backward	Central	Forward	Total
Backward	130	49	2	181
Central	18	10	0.4	28
Forward	1	0.1	0.0	1
Total	149	59	2	210

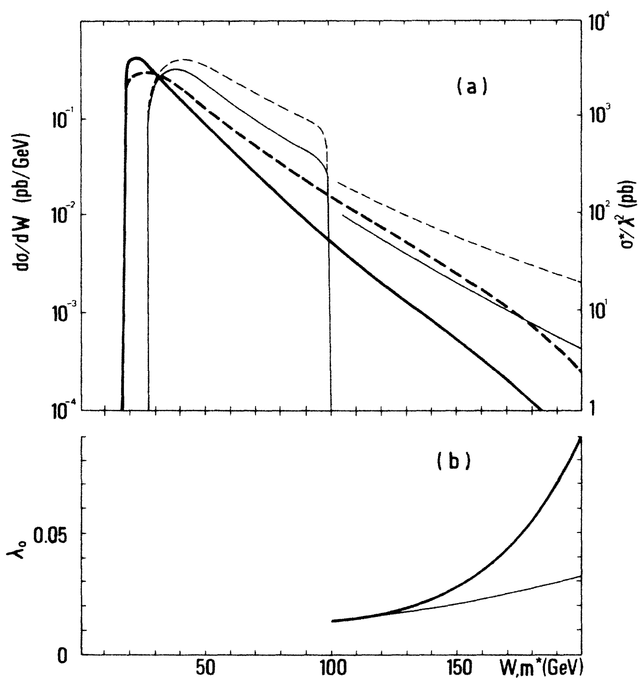

FIG. 3. (a) Predictions for $d\sigma/dW$ (solid curve) and σ^*/λ^2 (dashed curve) at LEP or SLC (50 GeV per beam) and at HERA. Thin curve, at left: LEP or SLC, $30° < \theta^e, \theta^\gamma < 150°$ (central detector). Thick curve: HERA $30° < \theta^e, \theta^\gamma < 150°$ (central detector). Thin curve, at right: HERA, $8° < \theta^e, \theta^\gamma < 150$ (central + forward detectors). (b) Lower limit of λ that can be expected to be reached with realistic assumptions ($L = 100$ pb, $\Delta W = 1$ GeV) and requirements (see the text) at HERA, in the range $W = 100$–200 GeV. Thick curve: $30° < \theta^e, \theta^\gamma < 150°$ (central detector). Thin curve: $8° < \theta^e, \theta^\gamma < 150°$ (central + forward detectors).

At $W > 100$ GeV, where we shall assume HERA to be the only machine available,[9] values predicted for both σ^*/λ^2 and $d\sigma/dW$ are small, and rapidly decrease when W is increased. Since any evidence for an e^* particle should imply a statistically significant excess of e^* events with respect to the standard prediction for $e\gamma$ scattering, and, on the other hand, an absolute number of at least two such events, evidence of that kind would require relatively large values of λ and/or of the integrated luminosity under the conditions assumed.

The yield of an e^* effect, if its exists, can obviously be increased by extending the angular acceptance, i.e., accounting for the direction of the Lorentz boost at large W, essentially by using the forward detector in addition to the central one. Therefore, we also show in Fig. 3(a) the values predicted for σ^*/λ^2 and $d\sigma/dW$ at $W > 100$ GeV and $8° < \theta^e$, $\theta^\gamma < 150°$. In Fig. 3(b) we compare the limit found for λ, with and without the forward detector, in the mass range thus considered, assuming an integrated luminosity of 100 pb^{-1} and a resolution $\Delta W = 1$ GeV.

Let us add a few remarks regarding our choice of angular acceptance in an experiment aimed at looking for a high-mass excited electron at HERA.

(i) While we have shown above that a backward detector would be very useful for calibration and luminosity monitoring, such a detector is unimportant for e^* search.

(ii) It seems that at HERA the acceptance of the forward detector is foreseen to extend down to angles smaller than 8°. However, because of kinematics (and as we checked numerically), there is no significant effect on the value obtained for λ_0 when we take a lower limit of, for instance, 3° instead of 8°, for the angular acceptance.

(iii) In principle, because of the specific dynamics of Compton scattering, the ratio $\sigma^*/(d\sigma/dW)$ might be improved by rejecting events where the outgoing electron is seen in the forward detector. Indeed, at HERA for $W > 100$ GeV (in contrast with what we expect for LEP or SLC), the electrons, scattered through the standard process, will tend to be more peaked than the photons in the direction of the beam axis. In practice, however, since anyway the standard Compton process provides an extremely small yield at $W > 100$ GeV, rejection of the forward-scattered electrons would not result in any improvement regarding λ_0 (actually that value would even become somewhat worse), as long as realistic luminosities are anticipated.

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[1] A. Courau and P. Kessler, preceding paper, Phys. Rev. D **33**, 2024 1986).

[2] C. Carimalo, P. Kessler, and J. Parisi, Phys. Rev. D **14**, 1819 (1976).

[3] Notice that, once the central detector has been calibrated through this process, calibration of the forward detector can, in principle, be performed by using other reactions, such as electroproduction of jets.

[4] The analytic calculation of that spectrum has been performed by using (with slight modifications due to the asymmetry in beam energy at HERA) the method defined by A. Courau, Phys. Rev. D **29**, 24 (1984).

[5] J. H. Field (private communication).

[6] A. Courau, Phys. Lett. **151B**, 469 (1985).

[7] J. H. Field, in *Proceedings of the Fifth International Workshop on Photon-Photon Collisions, Aachen, 1983*, edited by Ch. Berger, (Lecture Notes in Physics, Vol. 191) (Springer, Berlin, 1983), p. 270.

[8] Predictions for e^* production at LEP (with $\sqrt{s} = 200$ GeV) and HERA were also recently given by K. Hagiwara, D. Zeppenfeld, and S. Komamiya, Z. Phys. C **29**, 115 (1985). Such predictions were also provided for an ep collider of higher energy ($E^e = 15$–200 GeV, $E^p = 20$ TeV) by J. A. Bagger and H. E. Peskin, Phys. Rev. D **31**, 2211 (1985).

[9] In this discussion we are not considering later stages of the LEP project, where the beam energy might be increased far beyond 50 GeV.