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Deep Inelastic eγ Scattering, with Beamsstrahlung

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DEEP INELASTIC $e\gamma$ SCATTERING, WITH BEAMSSTRAHLUNG.*

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1. Introduction

A 500 GeV linear collider with a luminosity of 10fb^{-1} per year will permit measurements to be made of the structure of the photon in two new kinematic regions. This preliminary study shows that there will be sufficient hadronic events with an observed scattered electron or positron at large Q^2 to allow accurate measurement of the F_2 structure function to be made up to the region of Q^2=10^4 GeV^2, a classic test of perturbative QCD. And the hard spectrum of target photons, especially real beamsstrahlung photons, will give good statistics for the first time at very low values of Bjorken-x, down to below x=0.01 where nothing is known of the photon's structure but where semi-hard effects may be expected. A "generic" linear collider detector will be perfectly adequate for the large-Q^2 study but a specially hardened small-angle tagger must be added to give access to the low x region.

2. Calculation of rates.

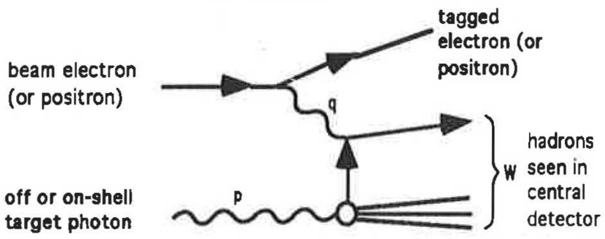

Figure 1. Definition of variables in deep inelastic electron-photon scattering.

W is the invariant mass of the hadronic system.

$Q^2 = -q^2$, the four-momentum transfer squared from the tagged electron; or, for low values of the transverse momentum $p_{T tag}$ of the tagged electron, $Q^2 \approx p^2_{T tag}$.

$$x = \frac{Q^2}{Q^2 + W^2} = \frac{Q^2}{2p.q} \qquad (1)$$

Event rates have been calculated as a function of x and Q^2 using Chen's analytic expressions[1] for the electron and photon fluxes, incorporating the effects of the radiation of virtual bremsstrahlung photons and the production of real beamsstrahlung photons for two alternative designs of a linear collider with $\sqrt{s} = 500GeV$; the 1991 versions[2] of the TESLA design - BEAM 1 - and of the Palmer G design -BEAM 2. The $e\gamma$ cross-section was obtained from an all-order QCD parameterisation[3] of the F_2 structure function of the target photon.

3. The large Q^2 region.

Figure 2 shows the number of events as a function of Q^2, integrated over x, assuming 10 fb^{-1} of integrated luminosity with each of the two linear collider beams, together with the number of events expected[4] from 500 pb^{-1} at LEP200. Both linear colliders give a worthwhile number of events with a mean Q^2 of 10^4 GeV^2, with twice the

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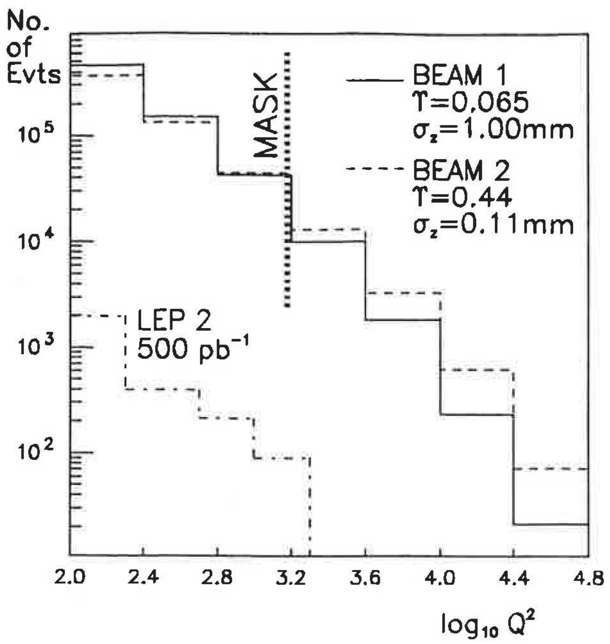

Figure 2. Expected numbers of events with $10 fb^{-1}$ at a linear collider for two different beam designs; compared with the total numbers expected from LEP2.

rate from BEAM 2, whose higher flux of beamsstrahlung photons has most effect at the highest values of Q^2. (This is an underestimate of the difference between the two linac designs over any running period because higher beamsstrahlung is also normally associated with higher luminosity.)

Only a few hundred events are needed at circular e^+e^- colliders[5] for a measurement of $F_2(x,Q^2)$ in a given Q^2 bin, with an unfolding[6] to correct for unseen and badly measured hadrons in the event-by-event measurement of W. At the linear collider there will also have to be an unfolding of the effects of beamsstrahlung on the apparent value of Q^2 since it can no longer be assumed that the initial electron has the full beam energy. A measurement of the luminosity spectrum[7] will be needed as input to this. Conservatively, if we assume that 1000 events at the linear collider will give as good a measurement of F_2 as 200 events at LEP200, then the linear collider will do as well at Q^2= 10^4 GeV^2 as LEP200 at Q^2= 300 GeV^2. The balance between increased gluon radiation and the change of the coupling constant in QCD ensures a linear rise of F_2 with $\log Q^2$ which can be looked for with definitive precision at the linear collider. Figure 3 shows, for instance, how far the QCD prediction separates from that of a model[8] with a fixed coupling.

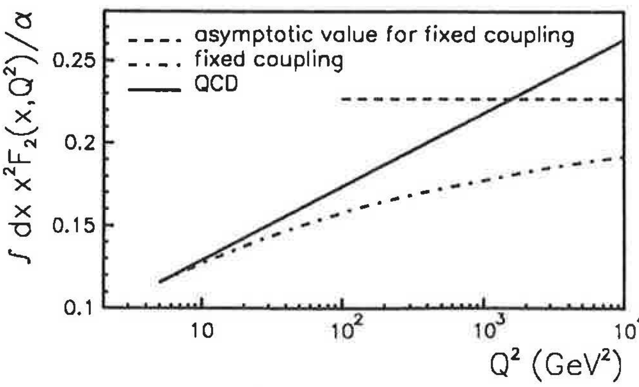

Figure 3. Comparison[4] of the evolution of the QCD photon structure function with a theory in which the coupling is frozen.

4. The low x region.

Recent results[9] show that the proton structure function F_2 rises rapidly as x falls below 0.01, supporting the perturbative QCD prediction that soft (small x) gluons prefer to radiate even softer gluons. This region of QCD, often referred to as semi-hard, is of great theoretical interest[10], and its study requires that the hard scale Q^2 satisfies $\Lambda^2_{QCD} << Q^2 << W^2$. To extend the study of semi-hard physics to gamma-gamma reactions equation (1) requires us, therefore, to go to very low x values. Existing experiments have no events at very low x in the deep inelastic region ($Q^2 \geq 5GeV^2$), due to the softness of the bremsstrahlung photon spectrum and the low

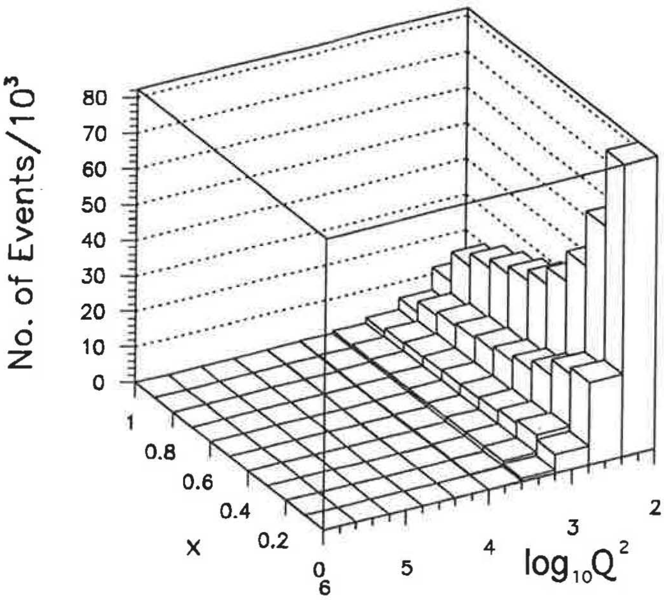

Figure 4. Number of events versus x and logQ^2 for BEAM 2.

energy of the colliders. Experiments with circular colliders only find significant numbers of tagged events with $W \leq \alpha E_{beam}$, where $\alpha \approx 0.3$. From (1), if the lowest accessible angle for tagging scattered electrons is $\theta \approx .04 radians$, then $Q_{\min}{}^2 \approx p_{Ttag}^2 \approx (\theta E_{beam})^2$ and the minimum accessible x is

$$x_{\min} \approx \left(\frac{\theta^2}{\theta^2+\alpha^2}\right) \approx 0.02 \qquad (2)$$

To get more events at very low x it is necessary to increase the available range of W at fixed Q^2. With beamsstrahlung at the linear collider the energies of the target photons can be much harder than for Weiszäcker-Williams bremsstrahlung photons, giving $\alpha \approx 0.7$ and $x_{\min} \approx 0.003$. What is more, beamsstrahlung causes the event rate to peak in the lowest bin of x (see figure 4) so that 80,000 events could be expected with $x \leq 0.1$ and $100 < Q^2 \leq 250 GeV^2$, assuming we can tag down to 40 milliradians. This would open a quite new window on the structure of the photon, far from any possibility of complications from Vector Meson Dominance. But will it be possible to tag down to small angles ?

5. Small-angle Taggers.

As well as beamsstrahlung, another side-effect of the intensity and small spot size in the next linear collider will be a very high rate of soft e^+e^- pair production at the interaction point. These particles will spiral along field lines and hit the surfaces of the first quadrupoles, generating intense soft photon radiation which will need to be kept out of the detectors by thick conical tungsten masks at about 10 degrees to the forward direction. If we can only tag electrons in the region outside the masks we can only study deep inelastic scattering at very large Q^2 (> 10^3 GeV^2, see line on Figure 2). To tag down to 40mr will require special detectors inside the tungsten masks, hardened against intense electromagnetic radiation, but with sufficiently fine resolution and fast online pattern-recognition to pick out the cores of high energy electron showers from the soft background.

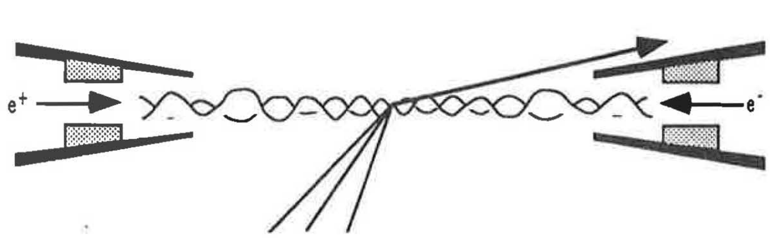

Figure 5. Tungsten masks shield the central detectors from backscatter. The arrow is a tagged electron going into the endcap detector outside the mask. Shaded boxes are hardened calorimeters for tagging down to smaller angles.

6. Conclusions

We have shown that event-rates at a future linear collider will be sufficient to extend the knowledge of the QCD properties of gamma-gamma scattering into two important new regions. The rates in both of these regions will be enhanced by the presence of hard beamsstrahlung[11] photons. At very large values of Q^2 a classic and definitive test can be made of the QCD prediction that the structure function rises linearly with $\log Q^2$, and at low values of Bjorken x we can search for possible semi-hard behaviour. Most suggested designs for a general purpose collider detector will be adequate for the first study but the expected soft electromagnetic backgrounds close to the beam direction mean that special tagging detectors will be needed to measure events at low x.

7. References

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