TWO PHOTON PHYSICS AT A HIGH ENERGY LINEAR COLLIDER : PHYSICS ISSUES

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An e^+e^- linear collider is an excellent source of colliding photons - both real and virtual. Combinations of real and virtual photons produced actively by laser backscattering or passively by tagging the scattered e^+ and/or e^- lead to a diverse collection of physics topics. Studies of the physics related to the structure of real and virtual photons and to the dynamics of QCD along with detector implications for calorimetry in the forward region are reported here.

1 Introduction

Collisions involving two photons dominate the $e^+e^- \to e^+e^- + hadrons$ cross section. For untagged processes, vector meson production dominates the cross section (characterized by $Q^2 \simeq 0$ for both photons). As Q^2 increases, parton production increases, and by tagging one photon ($Q_1^2 \gg Q_2^2 \simeq 0$), deep inelastic scattering of an e^+ or e^- on a photon target is observed. If both photons are tagged ($Q_1^2, Q_2^2 \gg 0$), collisions between two virtual photons occur, allowing pQCD dynamics to be observed in a very clean environment. The detector requirements for these processes are characterized by 1) small angle e^+e^- scattering and 2) hadronic activity over the entire angular region.

2 $\gamma^*\gamma^*$ Scattering

By colliding two virtual photons, it is possible to study the dynamics of QCD - this process should provide the cleanest laboratory to study BFKL effects.[1] Virtual photons are tagged in e^+e^- collisions by detecting both the scattered e^+ and e^- in a fine-grained electromagnetic calorimeter located around the outgoing beam pipe at very small angles. Hadronic activity observed in the central detector signals the interaction of the two virtual photons. The combination of a small virtual photon production cross section and a judicious choice of analysis cuts almost eliminates backgrounds to the BFKL signal.

2.1 Kinematics of Doubly Tagged Events

The following equations define some kinematic variables and the form of the $\gamma^*\gamma^*$ cross section for doubly tagged events :

$$Q_{1,2}^2 = 2E_{beam}E_{1,2}(1-\cos\theta_{1,2}) \approx E_{beam}E_{1,2}\theta_{1,2}^2 \quad (1)$$

$$y_{1,2} = 1-(E_{1,2}/E_{beam}) * \cos^2(\theta_{1,2}/2) \qquad \hat{s} = W_{\gamma^*\gamma^*}^2 \approx sy_1y_2 \quad (2)$$

The four-momentum transfer, Q^2, and the energy transfer y, of each virtual photon as well as the total (squared) energy of the $\gamma^*\gamma^*$ system, $W^2_{\gamma^*\gamma^*}$, are all determined from the detected energy and angle of the scattered e^+ and e^-.

$$\sigma_{\gamma^*\gamma^*} = \frac{\sigma_0}{\sqrt{Q_1^2 Q_2^2 Y}} * (\frac{s}{s_0})^{\alpha_P - 1} \approx \frac{\sigma_0}{\sqrt{Q_1^2 Q_2^2 Y}} * (\frac{\hat{s}}{\sqrt{Q_1^2 Q_2^2}})^{\alpha_P - 1} \tag{3}$$

$$\sigma_0 = const \qquad Y = \ln(\frac{s}{s_0}) \qquad s_0 = \sqrt{Q_1^2 Q_2^2 / y_1 y_2} \tag{4}$$

The total cross section depends on the kinematic variables as well as on the parameter, Y, which is the rapidity interval between the two virtual photons, and on the (BFKL) Pomeron intercept. To enhance BFKL effects, the ratio Q_1^2/Q_2^2 must be ~ 1. This requirement reduces the QCD background from standard DGLAP (Q^2) evolution between the two virtual photons. At a $\sqrt{s} = 500\ GeV$ e^+e^- linear collider, requiring $0.9 < Q_1^2/Q_2^2 < 1.1$ reduces the QCD background by a factor of ~ 14 according to Monte Carlo studies.

The PYTHIA monte carlo program, modified to generate virtual photon scattering, was used to study the kinematics of tagged virtual photons.[2] While this program does not include BFKL effects, it does produce what would be the (QCD) background. Figure 1 shows the average Q^2 versus the reach in Y for an e^+e^- linear collider (LC) at $\sqrt{s} = 500\ GeV$ compared to LEP2 at 189 GeV. The interesting region is at high Y where the (DGLAP) backgrounds are small. Note that at the LC, the minimum Q^2 is larger than at LEP2 due to the increased beam energies at the same minimum scattering angle.

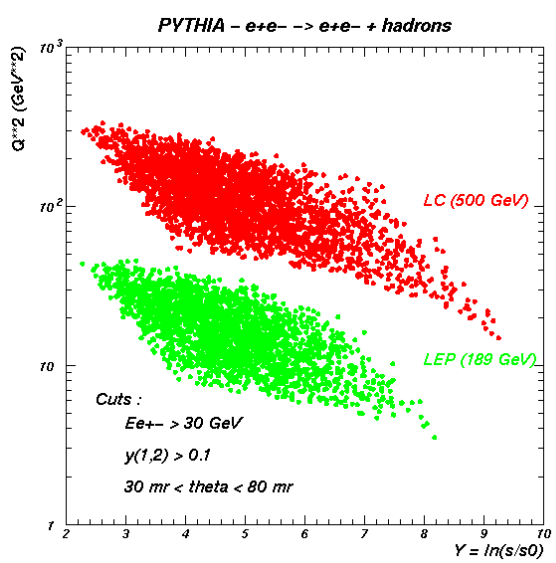

Figure 1: Q^2 vs Y for LC (500 GeV) and LEP2 (189 GeV).

2.2 Detector Options at Small Angles

Virtual photons with Q^2 between 10 and 100 GeV^2 require tagging calorimeters within 100 mr of the beam line. For some current LC designs, this means that the tagging calorimeters must be located inside the conical tungsten shields designed to protect the central detector from large beam-related backgrounds. For the NLC, two scenarios are being considered - aggressive masking, where the mask is located between 30 and 55 mr;

and conservative masking, where the mask is located between 80 and 110 mr. For this study, tagging was done in the range $30 - 80\ mr$. For the conservative masking scenario, this means that the calorimeter is completely inside the mask, while for the aggressive masking scenario, the inner part of the calorimeter is assumed to be instrumentation of the mask itself. The resolution of the (electromagnetic) calorimeter in the conservative scenario was taken to be $15\%/\sqrt{E} \oplus 1\%$. In the instrumented mask, the resolution was assumed to be slightly worse.

Figure 2 summarizes $\gamma^*\gamma^*$ kinematic reconstruction performance, showing reconstructed versus true values plotted for the aggressive (blue, under) and conservative (red, over) masking scenarios. The top left plot shows the Q^2 reconstruction. More important than the energy resolution is angular segmentation, which was assumed to be 0.5 cm in the radial direction for both scenarios. The top right plot shows the y (energy transfer) reconstruction. The worse resolution of the instrumented mask can be seen at low y for the aggressive scenario. The bottom left plot shows the reconstructed $W_{\gamma^*\gamma^*}$. W_{vis}, from observed hadrons down to 30 mr, is also shown, illustrating the difficulty of this measurement from hadrons. The bottom right plot shows the reconstructed Y (rapidity interval between the virtual photons).

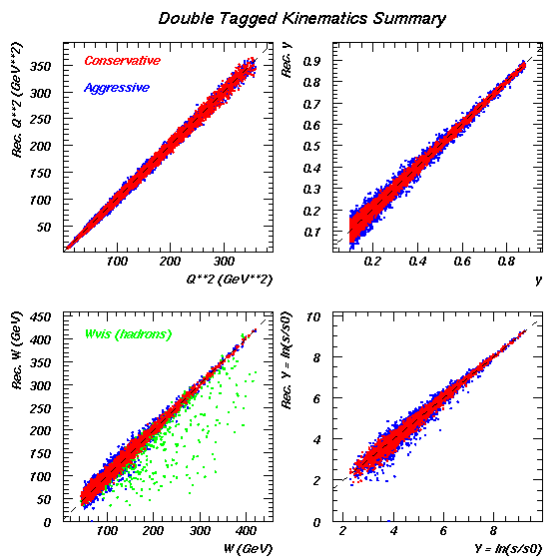

Figure 2: Reconstructed versus true $\gamma^*\gamma^*$ kinematics.

3 $\gamma^*\gamma$ Scattering

Events in which a single virtual photon is tagged can be characterized as $e\gamma$ deep inelastic scattering (DIS). At the LC, it is possible to observe $e\gamma$ DIS and thus measure the structure function of the photon, $F_2^\gamma(x, Q^2)$, at values of x an order of magnitude lower than are presently accessible. However, the challenge will be to reconstruct x from observed hadrons at these low values.

3.1 Kinematics of Singly Tagged Events

The following equations define the kinematic variables for $e\gamma$ deep inelastic scattering :

$$Q^2 = 2E_{beam}E_{tag}(1 - \cos\theta_{tag}) \approx E_{beam}E_{tag}\theta_{tag}^2 \tag{5}$$

$$p^2 = 2E_{beam}E_{untagged}(1 - \cos\theta_{untagged}) \approx 0 \tag{6}$$

Q^2 is determined from the tagged virtual photon and p^2 (not measured) is assumed to be ≈ 0.

$$y = 1 - (E_{tag}/E_{beam}) * \cos^2(\theta_{tag}/2) \qquad x = \frac{Q^2}{Q^2 + W^2 + P^2} \tag{7}$$

The energy transfer, y, is determined from the tagged virtual photon, but x must be calculated after measuring $W_{\gamma^*\gamma}$ from visible hadrons. The differential cross section is given by :

$$\frac{d\sigma_{\gamma^*\gamma}}{dxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}[(1 + (1-y)^2)F_2^\gamma(x, Q^2) - y^2 F_L^\gamma(x, Q^2)] \tag{8}$$

F_2^γ can be extracted in regions where $y^2 F_L^\gamma$ is small.

Figure 3 is a comparison of the Q^2 versus x regions of the LC and LEP2 using the same tagging cuts as shown in Figure 1 for the tagged virtual photon. Additionally, it was required that the unmeasured e^+ or e^- be inside a 30 mr cone around the beampipe. Note that for fixed Q^2, the x reach of the LC is at least an order of magnitude lower than LEP2.

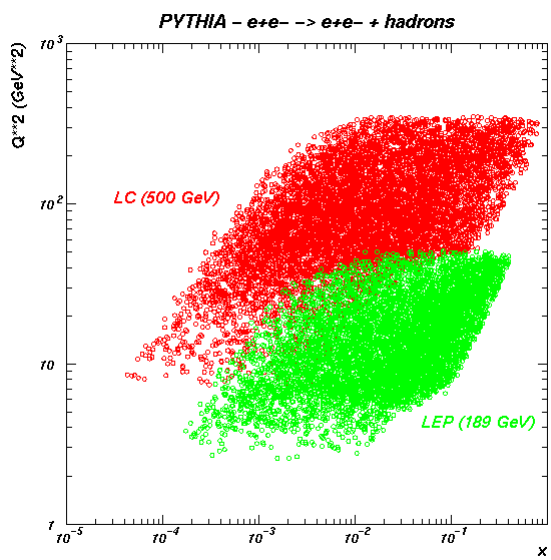

Figure 3: Q^2 vs x for LC (500 GeV) and LEP2 (189 GeV).

3.2 W_{vis} from Hadrons and x Reconstruction

For singly tagged interactions, $W_{\gamma^*\gamma}$ can not be determined solely from tagging parameters and must be measured from the produced hadrons (W_{vis}) and corrected with Monte Carlo (MC) models in order to reconstruct x. Depending on the choice of MC model, W_{vis} can be different from $W_{\gamma^*\gamma}$ by as much as 50 %. Even worse than the size of the correction itself is that various MC models yield different size corrections, leading to large systematic uncertainties in x.

Figure 4 shows x reconstructed from the measured W_{vis} (assuming hadron energy and angle are measured down to 30 mr), comparing results from the two masking scenarios to true x. The top left plot shows the shift from low x to high x which results from using the uncorrected W_{vis} (crosses) compared to the true x

(solid line). The top right plot further illustrates this point as a function of x. The bottom plots have been made after using the PYTHIA MC model to correct W_{vis}.

The differences, both between W_{vis} and $W_{\gamma^*\gamma}$ and between different MC models, lead to large corrections and large systematic uncertainties especially in the (most interesting) large $W_{\gamma^*\gamma}$ (low x) region. It is important to improve both the W_{vis} measurement and the MC models in order to determine, e.g., Will a steep rise in F_2^γ at low x be seen as observed in F_2^p at HERA? [3]

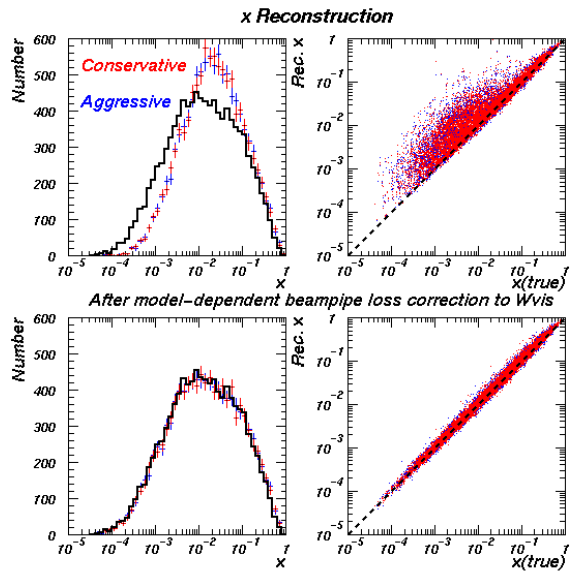

Figure 4: x reconstruction before and after correction to W_{vis}.

4 Conclusions

At the LC, the main physics advantages in the $\gamma^*\gamma^*$ cross section come from a larger $\sqrt{s}$ than is current at LEP2. Larger $\sqrt{s} \rightarrow$ larger Y, which can be realized if the Q^2 tag is low enough. On the other hand, if Q^2 is larger at the LC, the background is reduced due to the more pointlike γ^*. Good kinematic reconstruction of the relevant parameters is obtained with standard electromagnetic calorimetry. However, the effects of beam-related backgrounds have not been included in these studies.

For single tags, the main physics advantage at the LC comes from the larger $W_{\gamma^*\gamma} \rightarrow$ lower x, yielding a measurement of $F_2^\gamma(x, Q^2)$ an order of magnitude lower in x than current results. However, this depends on the ability to detect and measure hadrons at very small angles and on having MC models which describe the data. The ultimate measurement will be limited by the size of systematic uncertainties on the corrected W.

References

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