UNIVERSITY
of
GLASGOW

Department of Physics & Astronomy
Experimental Particle Physics Group
Kelvin Building, University of Glasgow,
Glasgow, G12 8QQ, Scotland
Telephone: +44 (0)141 339 8855 Fax: +44 (0)141 330 5881

GLAS-PPE/97–12
November 1997

The Hadronic Final States in Deep Inelastic $e\gamma$ Scattering at a Future e^+e^- Linear Collider

J. Jason Ward

Abstract

Energy flow distributions from tagged $\gamma\gamma$ events generated with HERWIG are presented for E_{beam} = 45.6 GeV (LEP1) and E_{beam} = 175 GeV (top-quark threshold at a future e^+e^- Linear Collider). They have very similar shapes regardless of the beam energy. Using the present knowledge of the LEP F_2^γ analyses, it is forseen that the understanding of the hadronic response of the forward region of the LC detector is vital to the development of the final state models in $\gamma\gamma$ Monte Carlos. Such models are relied upon to extract F_2^γ from the data, and hence understanding the forward region well may be crucial in the determination of whether or not a low-x rise exists in the photon structure function.

1 Introduction

As the centre–of–mass energy of an e^+e^- collider is increased, measurements of the photon structure function, F_2^γ, can be extended into two new kinematic regions. A preliminary study [1] has shown that a 500 GeV e^+e^- linear collider with a luminosity of 10 fb^{-1} per year provides sufficient hadronic gamma-gamma events with a tagged electron or positron to give good statistics at both high Q^2 (10^4 GeV^2) and low Bjorken-x ($0.001 < x < 0.1$). Events at high Q^2 would allow for the QCD test of the linear rise of F_2^γ with $\log Q^2$. The high statistics at small x presents the possibility of observing whether F_2^γ behaves in the same way as the proton structure function i.e. increasing as x decreases. It is also the region in which theoretical predictions of F_2^γ differ significantly. However, LEP measurements have since demonstrated that measuring F_2^γ at low-x is not trivial [2, 3] and requires a good knowledge of the hadronic response of the forward region detectors, in addition to having an electromagnetic calorimeter at small angles for tagging. This is also true of the future e^+e^- linear collider (LC) detector.

2 The F_2^γ Low-x Problem

The measurement of the low-x behaviour of F_2^γ is not trivial for the following reason. In the singly–tagged regime, the determination of x requires both the Q^2 of the probe photon (measured from the tag) and the invariant mass, W, of the hadronic final state (measured from the particles other than the tag). However, the visible invariant mass is less than the true invariant mass mainly due to losses in the beam pipe and poor hadronic acceptance in the forward regions. This results in increasing the reconstructed x ($x = Q^2/(Q^2 + W^2)$) and therefore the x distribution has to be corrected by an unfolding procedure to obtain F_2^γ. This unfolding heavily relies upon information, both before and after detector simulation, from the Monte Carlo that is used to model the tagged two–photon process. The critical point is that this Monte Carlo must correctly model the final state, so that the particle losses are properly accounted for. If an unfolding Monte Carlo has final state particles that are more forward–going than the ones in the data events, the unfolding procedure can falsely increase the result at small x (and correspondingly decrease it at high x) and even introduce a false low-x rise into a result. Clearly, the analysis of the hadronic final state is vital to the low-x analysis.

The energy flow of the final state relative to the tagged electron (or positron) has been introduced [2] and was used to demonstrate that the presently available tagged $\gamma\gamma$ Monte Carlos do not model the LEP data very well [3], even in the central acceptance. This results in uncertainties at low-x that are too large to be conclusive about the existence of a low-x rise.

3 The Hadronic Final State

The HERWIG [4] generator[1)] has been used for this generator level study to produce tagged $\gamma\gamma$ events corresponding to LEP1 and LC beam energies (45.6 and 175 GeV respectively). For each tagging region considered, every final state particle (other than the tag) has been entered into a histogram corresponding to its pseudorapidity ($\eta = -\ln\tan(\theta/2)$), where θ is the polar angle of the particle measured from the direction of the beam that has produced the target photon) using the particle energy as a weight. The resulting 'energy flow' distributions are shown in Figure 1, and are true energy distributions without the loss of energy due to acceptance effects.

[1)]Version 5.8d, IPROC=19000 (Deep Inelastic Scattering, all flavours, soft underlying event suppressed), F_2^γ =GRV Leading Order, Beamsstrahlung photon spectrum *not* incorporated.

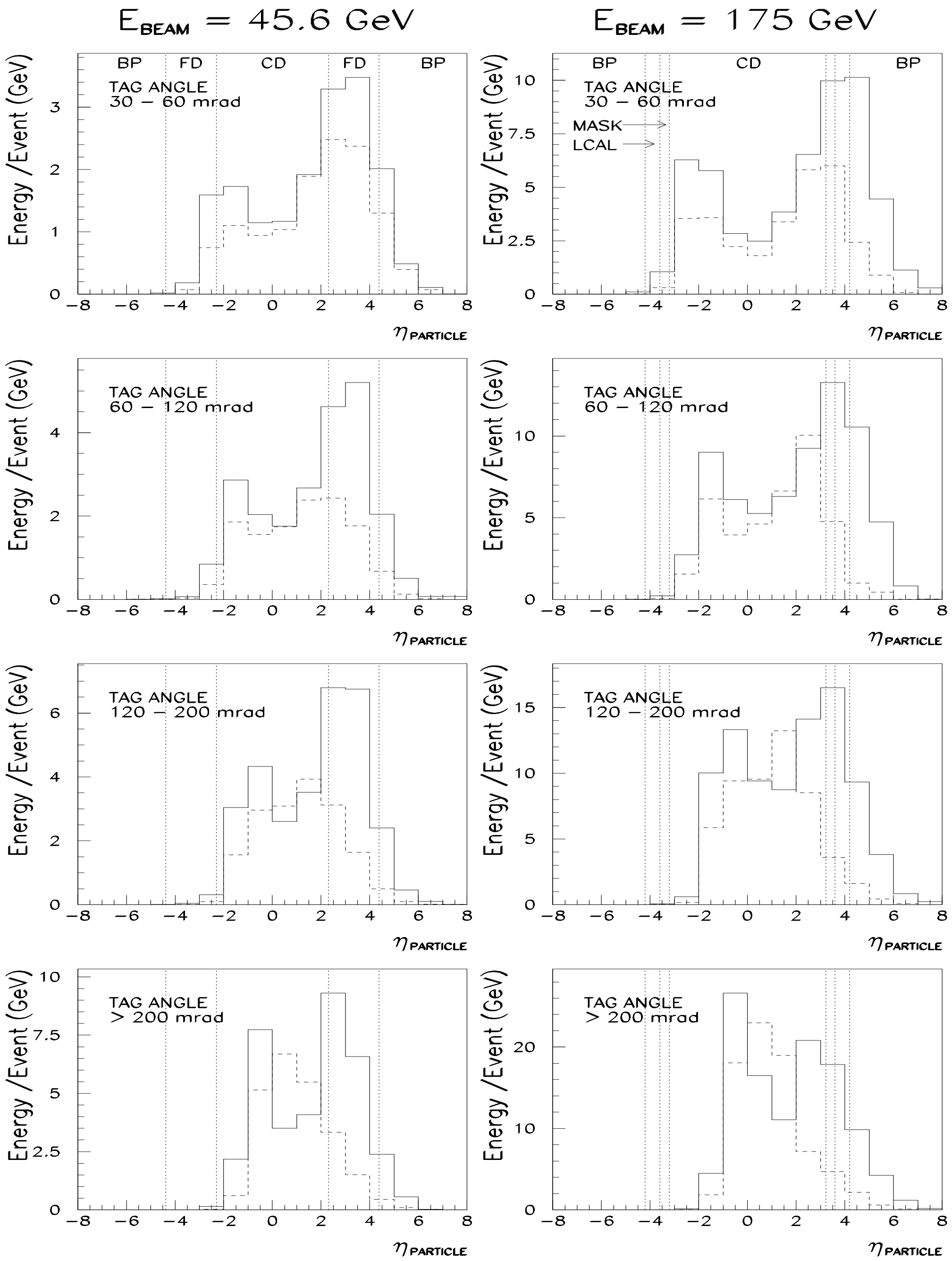

Figure 1: The $\gamma^*\gamma$ final state energy flow per event for $x < 0.1$ (solid line) and $x > 0.1$ (dashed line) events, as a function of pseudorapidity η and the range of the tagging angle. The tagged electron is always at negative pseudorapidity and is not shown. The different regions in rapidity denote the central detector (CD), forward detector (FD) and beampipe (BP). For the LC detector, the arrowheads to the MASK and LCAL terminate in the regions of the tungsten mask and forward luminosity monitor inside the mask, and correspond to the TESLA configuration. The pictures on the left refer to LEP1 ($E_{beam} = 45.6$ GeV) and on the right refer to the LC ($E_{beam} = 175$ GeV).

The histograms are energy flows *per event* corresponding to $x < 0.1$ events (solid line) and $x > 0.1$ events (dashed line). The following cuts were made: $W_{generated} > 5$ GeV (above charm threshold); $E_{tag} > 0.75 \quad E_{beam}$ (N.B. changes with beam energy); $\theta_{tag} > 30$ mrad. The cross–sections after the cuts are shown in Table 1.

	σ_{cuts} (pb)			
	$E_{beam} = 45.6$ GeV		$E_{beam} = 175$ GeV	
θ_{tag} (mrad)	$x < 0.1$	$x > 0.1$	$x < 0.1$	$x > 0.1$
30–60	75.29	9.99	23.92	10.85
60–120	13.87	18.39	3.67	3.71
120–200	1.15	6.10	0.43	0.77
> 200	0.11	2.48	0.08	0.26

Table 1: Cross–sections for each beam energy and tagging region after the cuts described in the text. Note that requiring a minimum invariant mass reduces the cross section in the $\theta_{tag} = 30 - 60$ mrad range at $E_{beam} = 45.6$ GeV.

The shapes of the energy flow distributions are quite similar for the different beam energies considered. This is an important observation as it means that the progress and conclusions of the LEP studies of F_2^γ, especially at low-x, are almost directly applicable to the LC analysis. It is already known that HERWIG generates the final state particles more forwardly than the LEP data [2, 5], but nevertheless the distributions are a reasonably good approximation to those those expected at the LC (assuming Beamsstrahlung does not alter these energy flow distributions too much).

If the shapes are so similar under a change of beam energy, then those seen at beam energies of 45.6 GeV and 175 GeV indicate what those at higher beam energies might be like.

There are two vital components to a low-x F_2^γ measurement at the LC. The first is having the small angle tagger (LCAL) to measure the low angle tags, and hence the low-x events. This also maintains tagging continuity in Q^2 from LEP to the LC [6]. The second is to constrain the final state models of the $\gamma\gamma$ Monte Carlos with the data. To do this, one must understand the hadronic response of the whole detector very well, especially the mask (if it is to be instrumented) and the LCAL. This would provide vital *sampling* of the energy flow in the forward region opposite to the tag (approximately $3 < \eta < 4$). One need only look at the lower θ_{tag} ($30 < \theta_{tag} < 120$) regions, where the low-x cross–section is higher, to see the importance of at least sampling the final state at small angles, because this is where the largest differences are seen between low-x ($x < 0.1$) and high-x ($x > 0.1$) events. Looking at the photon structure problem at low-x another way, one is likely to see in the final state the signature of a low-x rise, due to the process that would be responsible for it, before ever unfolding to extract F_2^γ - once again it is the knowledge of the hadronic response of the detector that is important.

As the tagging angle increases the situation becomes easier because the final state is more well contained in the central detector (the p_T of the final state is higher in order to balance the higher p_T of the tag). This is reflected by the energy flow distributions moving more towards the central detector (CD) as θ_{tag} increases. In this tag region the measurement of F_2^γ is therefore less model dependent, so the study of the evolution of F_2^γ at high Q^2 is still an achievable goal.

4 Conclusions

A critical aspect of measuring F_2^γ is to ensure that the Monte Carlos used for the unfolding procedure correctly model the final state. Energy flow distributions from tagged $\gamma\gamma$ events have very similar shapes regardless of the beam energy in e^+e^- collisions. Using this fact, and the present knowledge of the LEP F_2^γ analyses, it is forseen that the understanding of the hadronic response of the forward region of the LC detector is vital to the development of the final state models in $\gamma\gamma$ Monte Carlos. This could be especially important in the determination of whether or not a low-x rise exists in the photon structure function.

5 Acknowledgements

It is a pleasure to thank David Miller of University College London, who supported this work and presented it on my behalf, Mike Seymour for his valuable help with the HERWIG generator and David Saxon for his helpful comments on this text.

References

[1] B. W. Kennedy *et al.*, "Deep Inelastic eγ Scattering with Beamsstrahlung", in *e^+e^- Collisions at 500 GeV: The Physics Potential, Part C*, Workshops at Munich, Annecy, Hamburg, 1992-1993, ed. P. M. Zerwas, DESY 93-123C (1993), p521.

[2] J. J. Ward, "A Study of Photon Structure with Special Attention to the Low-x Region", Ph.D. Thesis, University College London (1996), unpublished.

[3] OPAL Collaboration, K. Ackerstaff *et al.*, CERN-PPE/97-103.

[4] M. H. Seymour, *Proceedings of the Workshop on Two–Photon Physics at LEP and HERA*, Lund, May 26–28 1994, eds. G. Jarlskog and L. Jönsson, Lund University 1994, p215; LU-TP-94/11 (1994).

[5] OPAL Collaboration, K. Ackerstaff *et al.*, Z. Phys. **C74** 1997 33.

[6] D. J. Miller and A. Vogt, "Kinematical coverage for determining the photon structure function F_2^γ ", in *e^+e^- Collisions at TeV energies: The Physics Potential, Part D*, Workshops at Annecy, Gran–Sasso, Hamburg, 1995, ed. P. M. Zerwas, DESY 96-123D (1996), p473.

[7] OPAL Collaboration, K. Ackerstaff *et al.*, CERN-PPE/97-087.