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Structure Function Sensitivity of Leading Order Jet Cross Sections at HERA and the Measurement of the Gluon Distribution g^γ .

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Abstract

A study of large pr jet photoproduction is carried out for the ep collider HERA in Leading Order (LO) in QCD, with emphasis on the sensitivity of the cross sections to various structure function parametrisations. Updated estimates of various jet cross sections are made using the latest parametrisations of the parton distribution functions of both the proton and photon. In particular we re-examine in detail the possibility of using jet production at HERA as a means of directly measuring the quark, and in particular the gluon, distributions of the photon.

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1 Introduction

It is now well established that large pr jet production in colliding beam experiments provides important tests of perturbative QCD and can yield useful information on hadronic structure. This includes confirmation of the existence of gluons [1], measurement of the strong coupling α_s [2], and evidence for the gluon self coupling [3]. Large pr jet production has been observed in both hadron-hadron and e^+e^- collisions, but before HERA [4] had never been observed for ep collisions.

A significant proportion of the events at HERA involve the photoproduction of large pr jets from high energy collisions between protons and quasi-real photons emitted by the electron beam as shown schematically in fig.1. At HERA, energies in the γp centre-of-mass frame can be as high as 314 GeV, and hence it should be very effective for the production of high pr jets. This provides us with a unique opportunity to study these processes at energies which have never before been accessible, making it possible to test many aspects of perturbative QCD. In some of these processes the photon will interact via its quark and gluon structure: it may thus be possible to get information about the parton distributions in the photon. In particular the gluon distribution, by studying jet production. Although suffering from ambiguities in the precise experimental definition of a jet, large pr jet production has been, and is still, very important in experimental tests of perturbative QCD. This is mainly because the relatively large size of the cross section compared to that for producing single particles such as pions, for example, leads to many more detectable events. Also, and just as importantly, jets provide the most direct means known for studying the underlying short distance parton-parton interactions without the use of the generally poorly known parton fragmentation functions.

The possibility of using jet photoproduction at HERA to obtain information on the quark and particularly the gluon structure of the photon has been examined

before in leading order (LO) perturbative QCD in refs. [5-7]. These studies have suffered from a lack of reliable parametrisations for the parton distribution functions of the photon. Recently new fully regularised sets of parametrisations of these functions valid in LO QCD have become available [8,9,10]. The first sets, referred to as the LAC sets, have been obtained by using all the available data on the photon structure function in order to constrain the input, while the second (GS sets) have been obtained by using only some of the data, but in addition, an attempt has been made to constrain the gluon distribution by taking into account theoretical considerations pertaining to the sharing of momentum between the quarks and gluons in the photon. The third (GRV) set have been generated dynamically from low Q^2 with the use of only one free parameter, and are therefore different from the others which were obtained by fitting to data. It is well known that the gluon content of the photon is not constrained by the theory [11], and this problem is made worse by the poor quality of the available data on the photon structure function. The result is that there are generally considerable differences between the gluon distributions, g^* , of the different parametrisations, particularly in the small x region [11]. It is thus now possible to test the jet cross sections for sensitivity to this function. New sets of parametrisations of the parton distributions of the proton in LO QCD ([12-14]) have also become available recently, so it is now possible to completely update all estimates for jet cross sections at HERA, and so to re-examine the conclusions pertaining to the measurement of the q^* and g^* distributions.

As we mentioned above, most of the cross sections presented here have been examined before, but we believe that updated predictions taking into account the latest ideas pertaining to the separation of the resolved and direct components of the cross section, and using the latest parton distribution functions, will be useful. Furthermore, we examine for the first time the single jet inclusive cross section

integrated over a range of rapidities. The preliminary data at HERA are being taken over such a range [4] and thus theoretical calculations should reflect this.

There will be two classes of contributions to the photoproduction of jets at HERA [6]: the direct contributions where the photon interacts directly with the partons in the proton through its electromagnetic interaction, and the resolved contributions where the photon interacts through its quark and gluon constituents. Examples are shown in figs. 2 and 3. It has been emphasized in many places that these two contributions are of the same order in the strong and electromagnetic coupling, and thus it cannot be decided a priori which one will be larger in any given kinematic region [6,7,15]. Thus the resolved contributions cannot be considered as merely small higher order corrections to the direct. To understand this, note that the direct *subprocesses* are $O(\alpha_{em}\alpha_s)$ and the resolved are $O(\alpha_s^2)$. The photon structure function is $O(\alpha_{em}/\alpha_s)$ hence the two processes are

$$O(\alpha_{em}\alpha_s) \odot O(1) = O(\alpha_{em}\alpha_s)$$

for the direct contribution and

$$O(\alpha_s^2) \odot O(\alpha_{em}/\alpha_s) = O(\alpha_{em}\alpha_s)$$

for the resolved. Another contributory factor to the importance of the resolved contributions is that the amplitudes for the relevant subprocesses have a $1/\hat{t}^2$ behavior from t -channel vector exchange which is more singular than the $1/\hat{t}$ behavior of the direct contributions from t -channel fermion exchange. Both processes are important for the study of QCD, but in order to study the distribution functions of the photon we need to identify regions where the resolved contributions are dominant.

In this paper we examine various jet cross sections at HERA calculated in the leading logarithm approximation using the latest parton distribution functions for both the photon and proton. We will examine the sensitivity of the cross sections to

parton distributions of both the photon and proton by using different parametrisations and comparing the results. Particular attention will be paid to the possibility of measuring the gluon distribution in the photon, g^γ . As we stressed before our knowledge of g^γ is very poor. In fact it is only recently [16] that the gluon component of the photon has been identified experimentally. It is thus essential to explore the possibility of obtaining such information at HERA.

There are many factors affecting the ability of experimenters at HERA to measure the resolved contribution to the jet photoproduction cross section. The most obvious is the relative sizes of the two contributions over the useful range of the HERA detectors. This factor should however, not be overly stressed since there are other methods at their disposal for separating the two contributions. For example, if the spectator jet from the photon can be observed then the direct contribution can, in principle, be eliminated[15]. Previous studies have suggested that the resolved contribution will dominate the cross section in the lower p_T and negative rapidity (proton direction) direction. Thus the ability to study the cross section in this region will affect the amount and quality of the information that will be obtainable on g^γ . Another factor, not often stressed, that will also affect the information obtainable on g^γ , is knowledge of the parton distributions of the proton. These are generally much better known than those for the photon, particularly the quark distributions, but if jet production from gluon-gluon scattering is the best process for measuring g^γ , then knowledge of g^p will be important.

The layout of this paper is as follows: in sect. 2 we discuss the status of leading log calculations of large p_T jet cross sections. In sect. 3 we look at the Equivalent Photon Approximation which will be used in all our calculations. Numerical results are presented in sect. 4 on the single jet inclusive cross section and in sect. 5 on the two jet cross section. In sect. 6 we summarise our results and present conclusions.

2 Jet Physics in Leading Order QCD

In perturbative QCD the interactions between hadrons at high energies are described in terms of interactions among the hadronic constituents, i.e. the quarks and gluons. When these scatter off each other they may produce quarks and gluons at high transverse momenta, but due to the confinement of colour we cannot detect these directly. Instead we detect a ‘spray’ or jet of hadrons leaving the reaction at high p_T . This is as close as we can get to actually seeing quarks and gluons, and so the production and detection of large p_T jets is very important in our search for tests of the theory. A study of the structure of these jets and their p_T and angular distributions can give valuable information about the underlying, short distance, parton-parton interactions. Jet studies are also useful in determining the strong coupling constant and the QCD scale Λ , and give important information about the parton distributions in the hadrons.

Most previous jet calculations have been performed in the leading log approximation, i.e., the subprocesses are calculated to $\mathcal{O}(\alpha_s^2)$ from the lowest order diagrams, the structure functions are evolved using the LO evolution equations, and each outgoing parton is associated with a jet. It is generally accepted that the theoretical error in such a calculation can be more than 50% [17], rendering the results of such calculations of semi-quantitative significance only. The major contributions to this error come from the sensitivity of the cross section to the choices of factorisation and renormalisation scales, the importance of higher order corrections and the use of unreliable parton distributions. Also, in LO, the jet cross sections do not depend on the jet definition used, a serious drawback when comparing results of calculation and experiments where there is a clear dependence on this definition. This level of accuracy has been acceptable in the past since it was within the range of experimental errors.

In recent years experimental errors have been greatly reduced and hence the necessity for more accurate theoretical calculations. So, although LO calculations have been quite successful in describing the data, in the next decade the emphasis will be on more precise calculations with errors around the $\pm 10\%$ level. Next-to-leading order (NLO) calculations will go some way toward providing this level of accuracy since they are far less sensitive to the choice of renormalisation and factorisation scales, and recently more accurate NLO parton distributions have become available. Also, at this order, dependence of the cross section on the jet definition first appears. These precision calculations will be useful tests of the behavior of the QCD perturbation series and can provide evidence for new physics at high PT .

Regardless of the many drawbacks discussed here, jet cross sections calculated in LO have proved very valuable for comparing the predictions of QCD with experiment in cases where high accuracy is not a requirement. It is thus expected that LO QCD analyses, such as presented in this paper, of whether it will be possible to measure the parton structure of the photon at HERA by studying jet photoproduction will give reasonably reliable results. This is in spite of the fact that the predictions of rates for jet production may contain large normalisation uncertainties.

As calculations of single jet production at HERA in NLO QCD are now possible and have recently appeared [18-21], it may seem an inappropriate time to be updating LO results. However, as one of the most interesting aspects of such a calculation is the comparison with the LO results, it seems to us a necessary precursor to NLO calculations to have available the best possible LO results with the most recent structure functions and that is what we present here.

3 The Equivalent Photon Approximation

One of the problems that will be faced when attempts are made to extract information on the hadronic structure of the photon or proton from what are essentially electroproduction processes at HERA is the absence of a fixed center-of-mass energy of the γp system. This is unlike the situation in hadron-hadron colliders. At HERA there will be a spectrum of quasi-real photon energies in the initial state emitted by the electron beam. Some authors have attempted to evade this problem by estimating an average cms energy [22], but it is more realistic to estimate the spectrum of initial state energies by using the Equivalent Photon Approximation [23]. This is an important source of error in all photoproduction calculations at HERA, hence before any reliable estimates of cross sections can be made it must be demonstrated that the error from this source is under control. The Equivalent Photon Approximation (EPA), or Weizsacker-Williams Approximation as it is often known, is useful here because it relates the cross section for electroproduction to that for (quasi-real) photoproduction in a simple way. The cross section for the process ($eA \rightarrow B$) is related to the photoproduction cross section ($\gamma A \rightarrow B$) by the convolution

$$d\sigma_{eA \rightarrow B} = \int dx f_{\gamma/e}(x) d\sigma_{\gamma A \rightarrow B}. \quad (1)$$

The function $f_{\gamma/e}(x)$ is the probability that the electron will emit an almost on-shell photon with a fraction x of its momentum. This function, which is often called the electron structure function, is given in leading order for untagged electrons by

$$f_{\gamma/e}(x) = \frac{\alpha_{em}}{2\pi} \left[\frac{1 + (1-x)^2}{x} \right] \ln \frac{\bar{E}^2}{m_e^2}, \quad (2)$$

where m_e is the electron mass. $\bar{E}$ depends on the energy of the electron but its value is not well defined.

A choice for $\bar{E}$ is usually made for a process by first calculating a similar, but more easily calculable, electroproduction process exactly, and then calculating it

using the EPA. A comparison of the two is then made for various choices of $\bar{E}$. This has been done for two jet photoproduction in ref. [6]. We thus make the same choice for $\bar{E}$ as was done there.

4 Single Jet Production

In all our calculations we sum over four quark flavours in the hard scattering subprocess, and choose $Q^2 = p_T^2$ as our standard scale. We adopt the photon distributions of ref. [9], labelled as GS(1), and the proton distributions of ref. [12], labelled as MT(SL), as our standard parametrisations. The other photon distributions we will make use of are the GRV [10] and the LAC(1) [8] sets. For the proton we will also use the new parametrisation from ref. [13], labelled as O and the LO set from ref. [14], labelled GRV.

The inclusive cross section

$$\frac{d\sigma}{dp_T dy}, \quad (3)$$

where p_T and y are the transverse momentum and rapidity of the jet, is not expected to yield the detailed information available from a two jet cross section, and may thus be of less use for extracting information on the parton content of either the proton or photon. It will nevertheless still be useful, since it is more inclusive and should thus be larger, allowing easier measurement. In addition, it is this cross section that has been calculated in NLO QCD [18-21].

In fig.4a we show the rapidity distribution of the resolved and direct contributions at two values of p_T . The main feature of the curves is the domination of the backward (negative) rapidity region (which we define to be the proton direction) by the resolved contributions, with the direct contributions dominating the forward (positive) rapidity region or electron direction. At low p_T ($\leq 8 \text{ GeV}$) the resolved contribution dominates the entire allowed rapidity range. This property of the dis-

tributions should make it possible to separate the two contributions, allowing each to be studied separately. This is partly due to the different energies of the two beams and partly to the different beam types. At HERA the collisions will be between a 30 GeV electron and an 820 GeV proton beam. The partons from the electron have lower energies than the real photons from the electron and therefore deposit less energy in the reaction. Thus, although both the jets from the resolved and direct contributions are boosted in the direction in which the more energetic proton is travelling, those produced when the photon interacts directly are less affected. Since the photon deposits all its energy in the reaction when it interacts directly, it produces very high energy jets more effectively in this mode which explains why the direct contribution dominates at higher p_T [15]. This is seen more clearly in fig.4b where the p_T distribution is plotted at $y = -2$: the direct contribution competes with the resolved at very large p_T only.

In fig.5 we show a breakdown of the resolved contribution into its constituent gg , gq and qq initial states at $p_T = 5 \text{ GeV}$. The gg initial state dominates in the rapidity region $-4 \leq y \leq 0$, but falls very steeply with increasing p_T due to the steeply falling gluon distributions in both the photon and proton. It is negligible for $p_T \simeq 10 \text{ GeV}$ as we will also see in the case of the two jet cross section. If jets with $p_T \leq 8 \text{ GeV}$ can be detected at HERA in this rapidity region it be possible to measure g^* directly using this process. Otherwise it will only be possible to obtain indirect information on it by studying the resolved contribution as a whole in as low a region of p_T as possible so that the contribution from g^* is significant. It is also useful to note that in this region the contribution from initial gq scattering is dominated by those processes which involve a gluon from the photon. Thus the cross section is dominated by processes involving g^* in this region. Measuring g^* using a combination of initial gg and gq scattering will of course require accurate knowledge

of the quark and gluon distributions of the proton which will have to come from another source, hopefully, proton structure function measurements at HERA. We can thus conclude that the single jet inclusive cross section will yield some useful information on the parton content of the photon, and may even be useful for directly measuring its gluon content in a restricted kinematic range.

In fig.6a we present the resolved and direct contributions to the cross section integrated over the rapidity range $-3 \leq y \leq 1$. It is obvious that the resolved contribution is very much larger than the direct for the range of p_T shown. This is seen very clearly in fig.6b which also shows how the ratio of resolved to direct depends on the choice of photon distribution used. The GRV and GS(I) distributions give similar predictions while the LAC(I) parametrisation is significantly larger at lower p_T . A potential problem is illustrated in fig.6c where we show sensitivity to the choice of proton distributions. The GRV and MT(SL) distributions give similar results to within 25% but the O parametrisation gives significantly different results.

As mentioned in the introduction, an additional source of error in the calculations is the choice of scale for the reaction, chosen as $Q^2 = p_T^2$ above. For example, if we choose $Q^2 = \frac{1}{4}p_T^2$, the resolved contribution increases by up to 40% and the direct by only 30%, thereby slightly changing the relationship between the two.

5 Two Jet Cross Sections

5.1 Rapidity, Mass and Angular Distributions

The cross section for the production of two jet systems is very useful for detailed tests of QCD since it allows the study of the angular distribution of the underlying parton-parton scattering. It has been suggested that the measurement of the dijet cross section at HERA should provide more detailed information about the parton distributions in the proton and photon than will the inclusive cross section, since

in this case the kinematic variables of two jets can be constrained simultaneously [7]. It has also been pointed out that a study of the variation of the cross section with the scattering angle in the parton system, θ^* , as the dijet mass, M , increases, should give a signal for the presence of the resolved contribution. The reason for this is that the direct contribution, which will dominate at large M , is expected to be dominated by the process $\gamma q \rightarrow gq$ which proceeds via s and u channel fermion exchange. The variation with θ^* of this contribution is

$$\frac{d\hat{\sigma}}{d\cos\theta^*} \propto \frac{1}{\sin^2 \frac{\theta^*}{2}}. \quad (4)$$

In contrast, the resolved processes proceed via t -channel vector exchange and have the usual

$$\frac{d\hat{\sigma}}{d\cos\theta^*} \propto \frac{1}{\sin^4 \frac{\theta^*}{2}} \quad (5)$$

behaviour. Thus, as M increases and the proportion of the direct contribution increases relative to the resolved, a flattening in the angular distribution is expected. We will also be interested in identifying those regions of θ^* , M or Y (the rapidity of the dijet system)

$$Y = \frac{y_1 + y_2}{2} \quad (6)$$

where it will be possible to separate the two contributions.

In fig.7a we show the rapidity distribution of the direct and resolved contributions at dijet masses of 20 and 100 GeV for $\cos\theta^* = 0$, where the cross section is defined by

$$\frac{d\sigma}{dM^2 d\cos\theta^* dY}. \quad (7)$$

At negative rapidities and for lower dijet masses the resolved contribution is dominant. This contribution is largest in the region $-3 \leq Y \leq -1.5$. At $Y = -2$ and for dijet mass $M = 20$ GeV we expect 2.5×10^4 events per year for an integrated luminosity of 100pb^{-1} per year. Fig.7b shows the cross section plotted against dijet

mass for $Y = -2$ and $\cos \theta^* = 0$. The resolved component is 16 times as large as the direct at $M = 10 \text{ GeV}$ and dominates out to $M \approx 70 \text{ GeV}$ where it is still twice as large. At low M the gg initial state is the largest, and should thus be measurable for $M \leq 45 \text{ GeV}$ (fig 7c).

How do the different gluon distributions in the various parametrisations of the parton distributions of the photon and proton affect the contribution of scattering from the gg initial state? To answer this question we calculated the rapidity and dijet mass distributions of the gg initial state contribution for the various parametrisations of the photon and proton. In fig.8a-d we display the results relative to that of the GS(1) and MT(SL) parametrisations for the photon and proton respectively.

At fixed M , the value of x_γ at which g^γ , the gluon distribution of the photon, is probed decreases in the negative Y direction. The LAC(1) result shows the large gluon distribution at small x , resulting in a cross section that is 3 times as large as that given by GS(1). As before the GRV parametrisation gives similar results to that of the GS(1).

In the dijet mass distributions (fig.8b), larger M corresponds to both higher x_γ and higher Q^2 . The differences between the various parametrisations clearly become less at higher Q^2 and higher x . Again the LAC(1) parametrisations give the most significantly different results. The conclusion that can be drawn from all this is that the gluon contribution to the resolved component of the dijet cross section should be measurable at HERA in the low M region. The differences between the predictions of the LAC and GS/GRV parametrisations are significant, hence measurement should easily discriminate between them.

Figs.8c and 8d shows the effect on the gg initial state of using the different proton structure function parametrisations. In fig.8c larger Y corresponds to smaller x_p . The results indicate that the parametrisations of the gluon distribution of the proton

differ by a surprising amount, particularly at large x . This is confirmed in fig.8d, where it also appears that the differences are more pronounced at higher Q^2 . The second conclusion is more uncertain since large M also corresponds to larger x at fixed Y .

In figs.9a-c we plot the cross sections vs $\cos \theta^*$ for $Y = -1$ and various values of M , normalised to their respective values at $\cos \theta^* = 0$. Fig.9c exhibits the predicted flattening as M increases. This confirms that the change of shape in the angular distribution as M varies tells us something about the relative importance of the direct and resolved components. We note that to get any significant change in the shape of the distribution as M increases, it is necessary to look at the more central rapidity region, $-1 \leq Y \leq 1$. The reason for this becomes clear if we note that for a change in shape the relative proportions of resolved and direct contributions to the cross section must change over a range of M for which the cross section is still measurable. If Y is large and negative then the direct contribution will be too small over this range of M to cause any significant change of shape. Similarly if Y is too large and positive the direct contribution will dominate the cross section even at low M with the same result. There is no significant change of shape in the distributions for different photon or proton structure functions, hence this effect cannot be used to measure the photon structure function.

The flatness of the direct contribution at small angles can be helpful in separating the resolved and direct components. Fig.10 shows that for small angles of the dijet system the resolved contribution will dominate more of the rapidity range even for larger dijet masses. It also shows that, by varying M , the ratio of direct to resolved processes can be varied significantly. At $Y = -2$, $\cos \theta^* = 0.8$ and $M = 30 \text{ GeV}$ the total resolved contribution is 27 times that of the direct. It is also helpful that for large $\cos \theta^*$ the cross section is larger and can be measured more easily.

A study of the dijet cross section at HERA provides the possibility of directly measuring the photon structure function. The freedom to choose three parameters, the dijet mass, angle and rapidity, enables us to identify regions where the resolved or direct component dominates by a factor of 25 or more, thereby effectively isolating either. The major source of uncertainty in the calculation is again due to the choice of scales. It may also be that limitations of the HERA detectors will mean that the cross section may not be measurable in some interesting angular or energy regions. Further studies taking into consideration any limitations in the detectors would be necessary to determine this. Despite these limitations, we believe that the dijet cross section will provide some useful tests of perturbative QCD at HERA.

5.2 p_T Distribution of the Two Jet Cross Section

According to Drees and Godbole [6] it will be easy to use two jet production at HERA to measure the quark distributions in the photon. They predicted that the resolved component will dominate the direct for $p_T \leq 40 \text{ GeV}$. In this section we re-examine their conclusions using the new parametrisations of the photon and proton distribution functions.

In fig. 11a we show the p_T distributions of the resolved and direct contributions and their sum. At $p_T = 40 \text{ GeV}$ we can expect 250 events/year from both direct and resolved contributions, assuming as usual an integrated luminosity of 100pb^{-1} . This indicates that the cross section will be measurable there, but only 100 events/year will be from the resolved component, so it will be difficult to isolate it at this p_T . At $p_T = 10 \text{ GeV}$, on the other hand, we predict 0.6×10^6 events/year totally, 0.5×10^6 of which will be from the resolved component. This is seen more clearly in fig.12a where we plot the ratio of the resolved to direct component vs p_T for various parametrisations of the photon structure function.

All the parametrisations suggest that the resolved only dominates the direct for $p_T \leq 25 - 30 \text{ GeV}$. The differences between the parametrisations are more pronounced at low p_T where the gluon contribution is most significant. The LAC parametrisations give larger ratios than the GS and GRV parametrisations. In fig.11b we show the p_T distribution for the resolved component broken down into the various initial states. It is clear that the gg initial state does not dominate even at low p_T , unlike the single jet cross section. Hence the two jet cross section will not be useful for measuring g^* , but it will enable the quark distributions of the photon to be measured at HERA for $p_T \leq 25 \text{ GeV}$.

In fig.12b we plot the p_T distribution of the ratio of the resolved to the direct contribution and it is apparent that this ratio is sensitive to the proton structure function parametrisation used. The O parametrisation gives results which are up to 45% larger than that predicted by the the MT(SL) parametrisation.

We conclude that it will be possible to measure the quark distributions in the photon at HERA by studying the two jet cross section in the region $p_T \leq 25 \text{ GeV}$ if the proton structure function is known. The gluon structure of the photon will only be measurable if jets with $p_T \leq 5 \text{ GeV}$ can be detected. Our results indicate that the resolved contribution will only dominate the cross section for $p_T \leq 25 - 30 \text{ GeV}$ as opposed to $p_T \leq 40 \text{ GeV}$ as predicted by Drees and Godbole [6]. We have confirmed that this is due to the structure functions used by those authors by reproducing their results.

5.3 The Triple Differential Cross Section

This cross section is related to the dijet cross section calculated above, but permits different control over the kinematic variables of the two jets. We include it because it is a simpler cross section to measure experimentally, since we will always require

that the two jets have equal rapidities, $y_1 = y_2 (= Y)$. This makes it a special case of the dijet cross section. In other words we are looking only at those events that are symmetrical in rapidity. The two cross sections are related by

$$\frac{d\sigma}{dy_1 dy_2 dp_T^2} = 2 \frac{d\sigma}{dM^2 d\cos\theta^* dY} \quad (8)$$

In figs. 13 and 14a-b we show the rapidity distributions at $p_T = 5 \text{ GeV}$ and $y_1 = y_2$ for different parametrisations of the photon structure function and we use the MT(S) proton distributions in each case. At $p_T = 5 \text{ GeV}$, as expected, the resolved contribution dominates most of the rapidity range, except at large positive rapidities. It will be possible to directly measure the gluon distribution of the photon by looking at the rapidity range $-3 \leq Y \leq 0$ at low p_T , since contributions involving a gluon from the photon clearly dominate the cross section in this region. At $p_T = 25 \text{ GeV}$ the direct contribution dominates most of the allowed rapidity range, and it would be almost impossible to study the individual initial states of the resolved contribution since they will be small, although the total resolved component is still larger in the far negative rapidity region.

A close examination of the rapidity distributions in fig.14 highlights the similarities and differences between the three parametrisations. All the distributions are similar in shape for the qg initial state. The LAC(I) parametrisation gives a different shaped distribution when compared to the others. There is a sharp peak at large negative rapidity in the qg initial state, and the gg initial state is sharply peaked in the rapidity range $-3 \leq Y \leq -1$. Both can be traced to the large gluon distribution at low x in LAC(I).

The effect of varying the proton distributions is shown in figure 14c and 14d. The GS(I) photon is used in each case, so these should be compared to figure 13. The differences between the results obtained using the GRV and MT(SL) parametrisations are less pronounced than that obtained using the O parametrisation, although

they should be certainly large enough to detect in an experiment. These results show, unfortunately, that the differences between the various proton structure function parametrisations are certainly larger than those between the GS(I) and GRV photon structure function parametrisations. This means that it is necessary to first remove this uncertainty before useful information on the photon distributions can be reliably extracted from the data. Fortunately this is currently being done at HERA, where preliminary data appear to favour the GRV proton parametrisation [24].

6 Summary and Conclusions

In this paper we have examined the possibility of using jet photoproduction at HERA to measure the quark and gluon distributions of the photon. We have used all the latest parametrisations of the parton distribution functions of the photon to check the cross sections for sensitivity to g^* . If we are to measure g^* using jet photoproduction at HERA we must know the parton distributions of the proton, so we have examined the cross sections for sensitivity to three different parametrisations of the parton distributions functions of the proton.

Our main conclusion is that all the jet cross sections we have examined could be used in some kinematic region at HERA to get information about the parton distributions of the photon. The problem of directly measuring g^* is more difficult since it requires a measurement of the cross section in the lower p_T region. For this the dijet cross section and the equivalent triple differential cross section offer the best possibilities. The ability to vary the relative importance of the resolved and direct contributions by varying M is particularly useful here. The conclusion of Drees and Godbole [6] that the resolved contribution to the two jet cross section will be measurable for $p_T \leq 40 \text{ GeV}$ appears to be an overly optimistic estimate.

Our results indicate that $p_T \leq 25 \text{ GeV}$ is more realistic.

The differences between the predictions for the various jet cross sections at HERA that are made using the different parametrisations of the photon structure functions are, in general, large enough for experimental measurement to discriminate between them, except in the case of the GRV and GS(l) parametrisations in the larger x region. This is particularly true for the contributions involving a gluon from the photon, but it is also true in the regions where the quark distributions of the photon are probed at small x . This last result is expected since the gluon distribution significantly affects the evolved quark distributions at small x only [9,11]. Unfortunately the differences between the predictions of the proton structure function parametrisations used are in many regions larger than those for the photon structure functions. This suggests that if LO parametrisations of the proton structure are to be used in the analysis of jet production at HERA it will first be necessary to tie down the proton distributions better than is currently the case. High Q^2 studies at HERA will presumably achieve this.

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Figure Captions

- [1] Schematic representation of a jet photoproduction process at HERA.
- [2] Examples of direct contributions to jet photoproduction processes at HERA: (a) the $\gamma q \rightarrow gq$ subprocess (gluon Compton scattering) and (b) the $\gamma g \rightarrow q\bar{q}$ subprocess (photon-gluon fusion).
- [3] Example of a resolved contribution to jet photoproduction processes at HERA. The suffices i, j, k and l refer to all types of parton.
- [4] (a) Rapidity distributions of the single jet inclusive cross section at two values of p_T and (b) the p_T distribution at $y = -2$.
Legend: (---) direct; (—) resolved;
(————) sum of resolved and direct.
- [5] Rapidity distribution of the single jet inclusive cross section at low p_T showing the different initial state contributions. Legend: (—) gg ; (---) qg ; (----) qq ; (-----) direct.
- [6] (a) Resolved (broken line) and direct (dashed line) contributions to the single jet inclusive cross section at HERA for standard (see text) parameters and structure functions, integrated over the rapidity range $-3 \leq y \leq 1$. (b) Ratio of resolved to direct contributions to the cross section as defined in (a) for various parametrisations of the photon structure function. Legend: dashed line (---) LAC(1)[8]; broken line (—) GS(1)[9]; Full line (————) GRV[10].
- (c) ratio of the cross section defined in (a), as predicted by the various parametrisations of the proton structure function to the MT(SL)

prediction vs p_T . Legend: (—————) GRV/MT(SL)(resolved);
(— — — —) O/MT(SL)(resolved).

[7] (a) Rapidity distribution of the dijet cross section (eq. 7) for two values of the dijet mass showing direct (- - - -) and resolved (— — — —) contributions and their sum (—————).

(b) Dijet mass distribution at $Y = -2$. Legend as in (a).

(c) Initial state contributions to the dijet cross section.
Legend: (— — — —) gg; (————) qq; (—————) sum.
qq; (- - - - -) direct.

All curves correspond to $\cos \theta^* = 0$.

[8] Structure function parametrisation dependence of the gg initial state contribution to the dijet cross section (eq. 7). Cross section ratios shown.

(a) Rapidity distribution at $M = 20 \text{ GeV}$. Legend: (- - - - -) LAC(I)/GS(I); (—————) GRV/GS(I).

(b) Mass distribution at $Y = -2$. Legend: as in (a).

(c) Rapidity distribution at $M = 20 \text{ GeV}$. Legend: (—————) GRV/MT(SL); (- - - - -) O/MT(SL).

(d) Mass distribution at $Y = -2$. Legend: as in (c).

[9] Variation with the dijet mass M of the angular distributions of the (a) direct, (b) resolved contributions and (c) the sum of resolved and direct contributions to the dijet cross section at $Y = -1$. All normalised to their respective values at $\cos \theta^* = 0$. Legend: (—————) $M=20\text{GeV}$; (— — — —) $M=80\text{GeV}$; (- - - - -) $M=120\text{GeV}$.

[10] Variation of the ratio of resolved to direct contributions to the dijet cross section with dijet mass M (labelled) at $Y = -2$.

[11] p_T distribution of the two jet cross section (a) showing direct (dashed line - - - -), resolved (broken line — — — —) and the sum of direct and resolved contributions (full line ————).

(b) same as (a) showing initial state contributions. Legend: (— — — —) gg; (————) qq; (————) sum.

[12] (a) Dependence of the ratio of resolved to direct contributions to the two jet cross section on the photon distribution functions. Legend: (- - - - -) LAC(I); (— — — —) GS(I); (—————) GRV.

(b) same as (a) for different proton distributions. Legend: (—————) MT(SL); (- - - - -) GRV; (— — — —) O.

[13] Triple differential cross section

$$\frac{d\sigma}{dy_1 dy_2 d p_T^2}$$

measured in nb/GeV^2 plotted vs rapidity $y_1 = y_2 = Y$ of the two final state jets for the GS(I) parametrisation of the photon distribution functions and the MT(SL) proton distribution functions at $p_T = 5 \text{ GeV}$, and showing various initial state contributions. Legend: (—————) total(upper); (— — — —) gg; (————) qq; (—————) qq(lower); (- - - - -) direct.

[14] (a) and (b) same as fig. 13 for the GRV and LAC(I) parametrisations of the photon distributions respectively, and (c) and (d) same as fig. 13 but for the GRV and O parametrisations of the proton distributions respectively.

Fig.1

(a)

(b)

Fig.2

Fig.3

Fig.4

Fig.5

Fig.6

Fig.7

Fig.8

Fig.9

Fig.10

Fig.12

Fig.11

Fig.13

Fig.14