Access to the NLO Gluon Distribution of the Photon

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Abstract: Inclusive differential rapidity cross sections of charged particles with large transverse momenta are sensitive to the parton content of the photon. We discuss the accuracy of a future measurement and the uncertainties of the different input distributions required for the next-to-leading order (NLO) QCD calculations.

1 Motivation and Method

The fluctuations of photons into quark–anti-quark pairs have been studied in deep inelastic electron–photon scattering ($e\gamma$ DIS) at e^+e^- colliders [1]. The subsequent radiation of gluons from the quark or anti-quark has been analyzed in resolved photon–proton scattering at the ep collider HERA. Here the first measurement of the gluon distribution in the photon was carried through using two-jet events and a leading order (LO) QCD analysis [2]. However, sizable error bars resulted from the uncertainties in the corrections of the underlying event energy effects.

In this contribution we suggest a measurement of the inclusive differential rapidity cross sections $d\sigma/d\eta$ of charged particles in γp scattering in the range $-1.5 < \eta < 2.5$. By comparison with a next-to-leading (NLO) QCD calculation, the gluon distribution of the photon can be extracted at NLO. The transverse momenta of these hadrons should be sufficiently large in order to a) minimize the influence of underlying event effects which cannot be calculated in NLO QCD, and b) have the scale in a regime where perturbative QCD calculations give reliable results.
On the other hand, p_t should not be much larger, since the sensitivity to the gluon component in the photon decreases with increasing p_t. Our choice of $p_t > 4$GeV satisfies both requirements.

The rapidity of the particles is to some extent correlated with the incoming fractional energy $x_\gamma = E_{parton}/E_\gamma$ of the parton from the photon side. In LO QCD, x_γ can be reconstructed from the two final state partons using $x_\gamma = p_t\left(e^{-\eta_1} + e^{-\eta_2}\right)/(2E_\gamma)$. Here we have predominantly one high–p_t particle per event with $p_t \approx 4$ GeV, carrying a rapidity η and reflecting the direction of one of the final state partons. With $\eta \propto \ln x_\gamma$, the rapidity distribution is sensitive to the parton distribution functions (PDF's) of the photon with a lower limit around $x_\gamma = 0.01$.

2 Measurement

The inclusive differential rapidity cross section for charged particles has been measured before [3]. Events were used where the scattered electron is tagged in the electron detector of the luminosity system. The statistical uncertainty from an integrated luminosity of 1 pb^{-1} was however too large at $p_t > 4$ GeV for a sufficiently precise measurement. A future measurement using 100 pb^{-1} will result in a statistical uncertainty of order 1%. The dominant systematic error is an overall uncertainty in the luminosity measurement which is currently of order $1-2\%$.

The rapidity interval of the previous measurements was $|\eta| < 1.5$. In future measurements it should be extended to the positive rapidity region as far as possible (forward trackers reach $\eta = 2.5$) to also cover the region of small x_γ.

In order to control the scaling violation, the differential cross section need to be measured in bins of p_t between $4 < p_t < 12$ GeV. $d\sigma/d\eta$ is expected to exhibit not only a decrease in the rate, but also a strong change in the shape of the distribution. The statistical error will be of order 5% in the highest anticipated bin $10 < p_t < 12$ GeV, which is still tolerable.

3 Prediction in NLO QCD

The NLO QCD calculation of the charged particle cross sections requires five ingredients. These are the splitting function $f_{\gamma/e}$, the PDF's for the photon and the proton ($f_{i/\gamma}$ and $f_{j/p}$), the fragmentation functions (FF's) $D_{h/k}$, and the hard scattering cross section $d\hat{\sigma}_{ij\to k}/d\eta$:

$$\frac{d\sigma^h}{d\eta} = \sum_{ijk=1}^{4} \int dy dx_\gamma dx_p dz\, f_{\gamma/e}(y, Q^2)\, f_{i/\gamma}(x_\gamma, M_i^2)\, f_{j/p}(x_p, M_i^2)\, \frac{d\hat{\sigma}_{ij\to k}}{d\eta}(\mu^2, M_i^2, M_h^2)\, D_{h/k}(z, M_h^2).$$

Here y denotes the scaled photon energy, x_p the fractional energy of the parton entering the hard scattering process from the proton side, z is the energy carried by the hadron relative to the energy of the scattered parton, Q^2 the virtuality of the photon, and μ, M_i, M_h the renormalization, factorization, and fragmentation scales. In the following the uncertainties in the different contributions are discussed. They are partly shown in Fig. 1:

$f_{\gamma/e}$: The Equivalent Photon Approximation for events where the scattered electron is measured at small scattering angles is precise to the percent level.

$f_{i/\gamma}$: (Fig.1a) The quark distributions in the photon $f_{q/\gamma}$ have been measured in $e\gamma$ DIS with an accuracy of $\approx 30\%$ in the relevant kinematic region [1]. With the upcoming measurements at the LEP2 collider the precision in $f_{q/\gamma}$ will improve to the level of a few percent [4]. The gluon distribution in the photon $f_{g/\gamma}$ has so far the largest uncertainty and is expected to contribute up to 50% to the cross section.

$f_{j/p}$: (Fig.1b) The uncertainties in the PDF's of the proton currently contribute $< 10\%$ to the uncertainty in the cross section calculation. This error will be reduced with new HERA data and analysis.

$d\hat{\sigma}/d\eta$: (Fig.1c) The NLO QCD parton cross sections have been calculated for direct and resolved photoproduction processes [6]. The dependence of the calculation on the renormalization, factorization and fragmentation scales has been studied in multiples ξ of the hadron transverse momenta p_t. With the requirement $p_t > 4$ GeV the scale dependence of the calculation does not show a point of minimal sensitivity. We employ the method of fastest apparant convergence, which yields a scale of $\xi = 1/\sqrt{2}$. Variations of this scale choice between $0.5 < \xi < 1$ result in an overall shift of the cross section, but not in a sizeable change of its shape.

$D_{h/k}$: (Fig.1d) The quark FF's $D_{h/q}$ have been determined from e^+e^- data with an accuracy of a few percent [7]. The gluon FF $D_{h/g}$ currently has a relatively large uncertainty. The gluon FF is expected to increase by about 45%, when $\mathcal{O}(\alpha_S^2)$ corrections to the cross section are included in the analysis [8]. With new LEP data on the longitudinal polarized cross sections, the uncertainty in $D_{h/g}$ will be reduced to below 10%.

Therefore, in 1997 the expected uncertainty in the theoretical calculation – apart from the gluon contribution of the photon $f_{g/\gamma}$ – is expected to be at the level of 10%. Comparisons of precise cross section measurements with the NLO calculations will then allow the extraction of $f_{g/\gamma}$ for a fixed choice of the scale.

4 Summary

A measurement of the inclusive rapidity cross section for charged particles with $p_t > 4$ GeV will have an accuracy of order few percent using an integrated luminosity of 100 pb^{-1}. The uncertainty of a corresponding NLO QCD calculation due to the input PDF's (except for the gluon in the photon) and the FF's is expected to be at the level of 10% in 1997. The comparison between the measurement and the calculation at a fixed scale will then allow the extraction of the NLO gluon distribution in the photon with a precision of order 10%.

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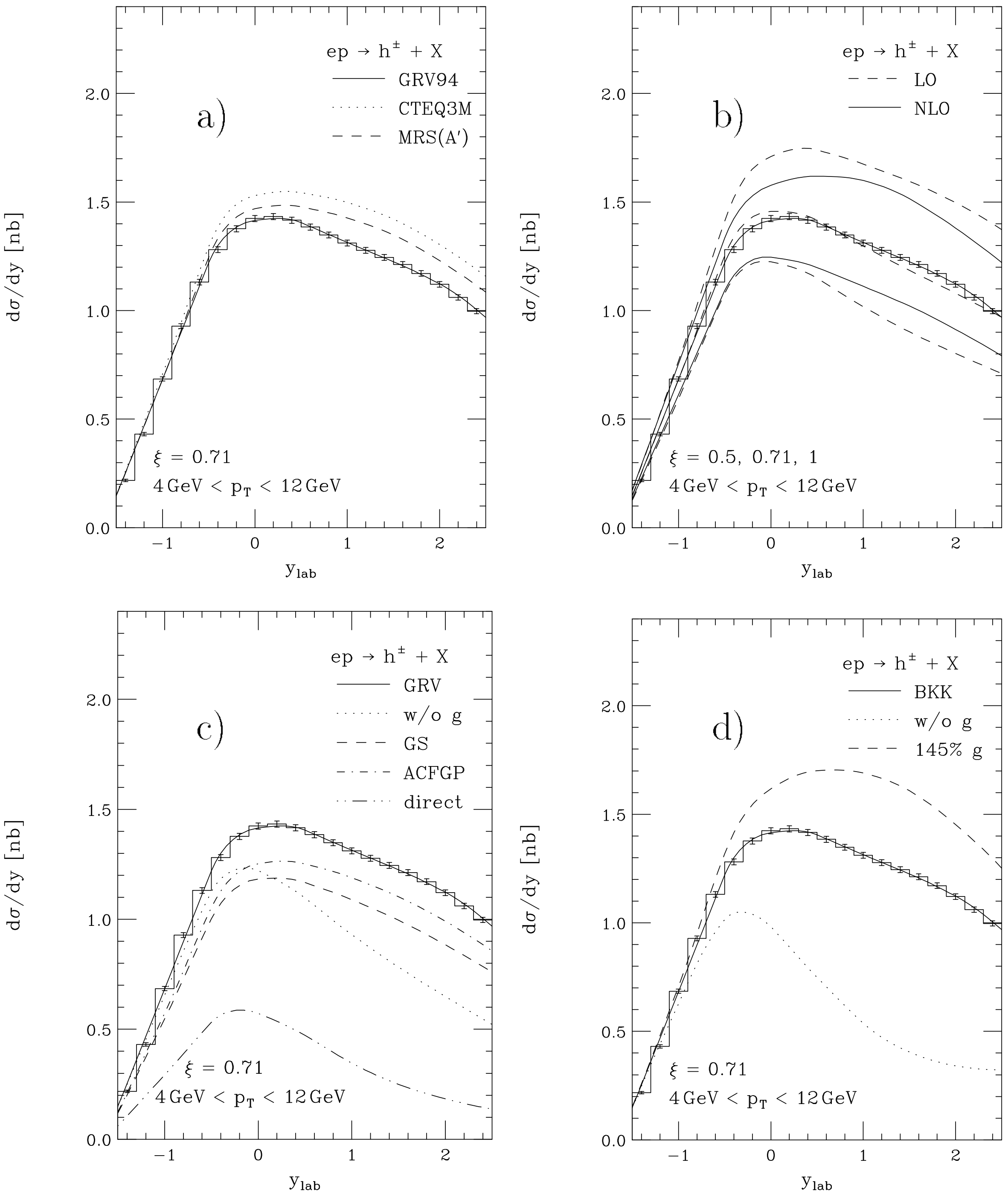

Figure 1: The inclusive differential rapidity cross section for charged particles with $4 < p_t < 12$ GeV, $-1.5 < \eta < 2.5$ is shown for events with photon energy $0.3 < y < 0.7$ and virtualities $Q^2 < 0.01$ GeV^2. The symbols represent a possible measurement with statistical errors corresponding to an integrated luminosity of 100 pb^{-1}.

a) $f_{i/p}$: the full (dotted) [dashed] curve gives the NLO QCD calculations using the proton PDF of GRV [11] (CTEQ3M [12]) [MRS(A′) [13]].

b) The scale dependence of a LO (dashed) and NLO (full) QCD calculation is shown as function of $\xi = \mu/p_t$.

c) $f_{i/\gamma}$: the full (dashed) [dot-dashed] curve gives the NLO QCD calculations using the photon PDF's of GRV [5] (GS [9]) [ACFGP [10]]. The double-dot-dashed curve is the direct γ component, the dotted curve shows the contribution resulting from the direct γ and the quark distribution of the photon (using GRV).

d) $D_{h/k}$: contribution of the quark FF $D_{h/q}$ (dotted) and total (quark+gluon) FF (full) are shown [7]. The dashed curve corresponds to a 45% rise in $D_{h/g}$, as expected for an updated analysis.