Fragmentation Functions and Rapidity Spectra in the Breit Frame at H1

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Recent work in the scaling violations of the fragmentation function and the rapidity spectra are discussed using data taken from the H1 experiment in 1996.

1. INTRODUCTION

This paper presents results of charged track spectra in deep inelastic positron-proton scattering. The kinematic variables considered are the invariant four-momentum transfer squared of the virtual photon, Q^2, and the Bjorken scaling variable $x_{\rm Bj}$.

The study of QCD phenomena in the HERA laboratory reference frame can be complicated by the fact that most of the transverse momentum associated with the hadronic final state comes from the recoil against the scattered lepton. Additionally it can be difficult to isolate hadronic fragments related to the scattered quark (current system) from those related to the proton-target remnant.

A particularly suitable frame of reference in which to study the current system with minimal contamination from target fragmentation effects is the Breit Frame [1].

In the naive quark-parton model (QPM), the purely space-like virtual photon has longitudinal momentum $-Q$ and collides elastically and head-on with a quark of longitudinal momentum $Q/2$. The struck quark is back-scattered with an equal but opposite momentum, while the proton remnant, which has a very large momentum relative to the scattered quark since $x_{\rm Bj} << 1$, fragments in the opposite hemisphere. Particles emerging from the interaction are assigned to the current region if they have negative longitudinal momenta or to the target region if they have positive longitudinal momenta.

Unlike the hadronic center of mass system, the Breit frame is not a rest frame.

2. SCALING VIOLATIONS OF THE FRAGMENTATION FUNCTION IN THE CURRENT REGION

One of the simplest distributions that is sensitive to gluon radiation is the inclusive scaled momentum distribution. The scaled momentum variable x_p is a measure of the fraction of the initial parton momentum $(Q/2)$ that is taken by the final state charged hadron in the QPM.

The fragmentation function is an event-normalised charged track density and characterises the complete process of perturbative parton shower development and non-perturbative hadronisation. It is a “soft” function in the sense that there is a small probability to observe any final state hadron with a large share of the initial parton momentum. As the available energy for fragmentation increases the function becomes “softer”.

The processes that give rise to these scaling violations also lead to similar violations of the structure function F_2 giving an indirect determination of the proton gluon density [2].

In Fig. 1, the fragmentation function is plotted in intervals of the scaled momentum variable, x_p, as a function of the invariant four-momentum transfer, Q. The function shows a strong rise at small x_p with increasing energy which becomes flatter in the large x_p region.

Predictions based on next-to-leading order (NLO) QCD calculations [3] that use Λ dependent parton distribution functions together with Λ dependent parameterisations of e^+e^- fragmentation functions are available. They are shown for $\Lambda_{\overline{\rm MS}} = 350$ MeV (dotted lines).

2.1. Power Corrections

The fragmentation function parameterisations are done in a region of phase space where the mass of the final state particle can be neglected. Therefore, the NLO calculations are only valid in the region where

$$x_p > \frac{2m_T}{Q}\frac{1}{\sqrt{1-(\tanh(y_{\min}))^2}} \tag{1}$$

where m_T is the transverse mass $\mathcal{O}(500\ \mathrm{MeV})$ and $y_{\min}$ is the minimum rapidity between the struck parton and the hadron ~ 1.0 unit.

However, outside of this region mass effects strongly suppress the available phase space for fragmentation, as can be seen clearly in the small (x_p, Q) region of Fig. 1 where the calculation overestimates the data by as much as two orders of magnitude.

To extend the region of applicability, these effects may be taken into account by means of a "power-correction" ansatz [4] of the form

$$F = \left(1 + \left(\frac{\mu}{p_h}\right)^2\right)^{-1}. \tag{2}$$

Here, p_h is the momentum of the final state hadron and μ is a free parameter that sets the hadronic mass scale. When the momentum of the final state fragmented particle is large compared to μ, its mass may be neglected and F approaches unity. However, if the momentum of the particle is small compared to μ, mass effects strongly suppress phase space and $F \to 0$. Therefore, F may be interpreted as a phase space limitation factor which grows in the limit of small momenta (small x_p).

The solid lines in Fig. 1 show the result of applying this correction ($\mu = 330$ MeV) to the NLO calculation. The agreement with the H1 ep data over the available phase space is remarkable.

Theoretical activity in this exciting new field continues to gain momentum [5].

3. RAPIDITY DISTRIBUTIONS

Charged track spectra have been investigated in both the current and target regions of the Breit frame. A recent publication presented preliminary rapidity distributions for ep scattering over a range of particle transverse momentum [6]. In Fig. 2, the spectra are shown at two Q^2 intervals for charged tracks with transverse momenta above 1 GeV.

The proton remnant is located at large positive rapidity where, $Y = \frac{1}{2}\ln((E+p_z)/(E-p_z))$. The origin of the Breit frame is located at $Y = 0$ and the current region extends in the negative Y direction. It can be seen clearly that at low energy, the spectra are peaked in the target region. As the available energy for fragmentation increases, the spectra shift toward the current region peaking at the origin.

In the naive QPM, the transverse momentum of the hadronic final state arising from the scattering of a massless parton is due largely to hadronisation effects and is small, typically $<< 1.0$ GeV.

If the scattering parton is massive with an invariant mass squared, $m^2 >> 0$, then it may branch via gluon bremsstrahlung e.g, QCD Compton. Viewed in this frame, the topology of the event depends on the size of the quark-gluon invariant mass relative to the four-momentum transfer of the exchanged photon. For $m/Q \approx 1$ the quark-gluon system is at rest and back-to-back. Approximately half of the hadronic fragments related to the initial struck parton are scattered into the current hemisphere while the other half are scattered into the target hemisphere. For $m/Q >> 1$, both the quark and gluon are boosted forward into the target hemisphere giving a large observed p_T in this region. The current region is completely devoid of hadronic fragments (empty). For $m/Q << 1$, both the quark and gluon are boosted backward into the current region giving large p_T in this region. With increasing Q, events with $m/Q >> 1$ become less significant.

The mean transverse energy flow [7] measured in the hadronic centre-of-mass system exhibits a similar shift with increasing photon virtuality.

4. CONCLUSIONS

Charged particle distributions have been studied in both the current and target regions of the Breit frame. A power correction ansatz, needed to describe phase space limitation effects, modify NLO QCD calculations and provide a good description of the data.

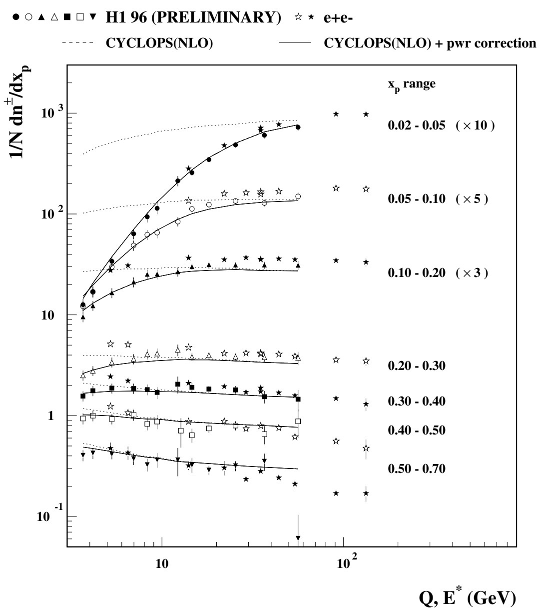

Figure 1. The fragmentation functions are plotted for different intervals of x_p as a function of Q^2 and compared with e^+e^- data at equivalent centre-of-mass energies, E^*. Note that the data for the three smallest intervals of x_p are scaled by factors of 10, 5 and 3 for clarity. The dotted/solid lines show the predictions of the CYCLOPS NLO with/without a power correction ansatz to describe phase space limitations due to non-perturbative effects.

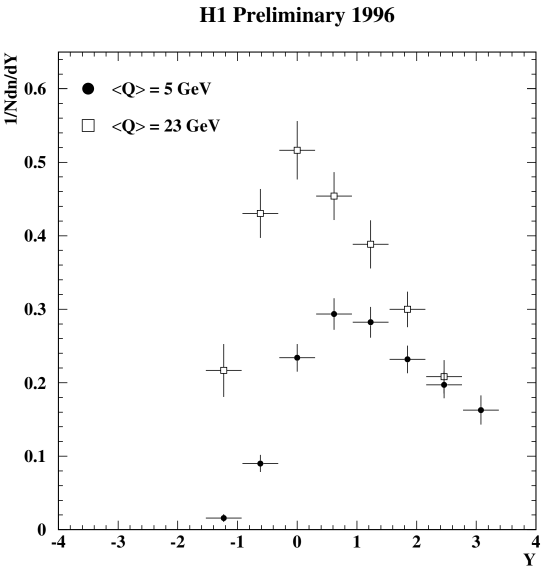

Figure 2. Preliminary 1996 rapidity distributions in the Breit frame of reference for two Q^2 intervals at high p_T.

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