Target Proton Properties in Deep Inelastic Scattering at HERA

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Abstract: Leading protons with longitudinal momentum significantly below the proton beam energy are a powerful tool to study the transition of partons to observable hadrons. Some distributions of leading-proton properties are studied which will allow to learn more about this transition process.

Introduction

The fragmentation and hadronisation of partons to observable particles is not calculable in perturbative QCD. Monte Carlo models, which simulate deep inelastic ep scattering events (DIS), first generate the hard scattering process based on perturbative QCD calculations. Then the fragmentation and hadronisation of the colored partons to observable hadrons is modeled differently. Most of the global properties of final state particles are described successfully by the following models: ARIADNE (using the Color Dipole Model and string fragmentation), HERWIG (using parton showers and cluster fragmentation) and LEPTO (using parton showers and string fragmentation). The test of these models in all possible regions of phase space is an important test of our knowledge of nature.

The ZEUS detector has a powerful leading proton spectrometer (LPS). It allows to detect final-state protons, which move with high momentum p_z along the proton beam line. Monte Carlo generators for DIS processes produce such a leading proton in 50-60% of the events. Some of them have about the beam momentum, i.e. $x_l = p_z/820$ GeV ≈ 1. They are attributed to diffractive scattering processes, where a colorless object, a pomeron, is exchanged between the proton and the virtual photon. The initial state proton does not break up in this case.

A bulk of events have lower x_l: $0.05 \lesssim x_l \lesssim 0.95$. These protons are an excellent tool to study the hadronisation process because they likely have exchanged a colored object with the incoming virtual photon. Thus the proton was left in a colored state (the proton remnant) for a very short time. The way the proton remnant hadronises to a real proton again is not well understood and is modeled differently by the various models. The color forces acting in this process may be studied with high accuracy because these final-state leading protons are not the result of a long fragmentation and hadronisation chain as the rest of the hadrons in the event.

Standard Monte Carlo predictions

The predicted x_l distributions of the LEPTO, HERWIG and ARIADNE Monte Carlo generators [1] are shown in Fig. 1. They differ in shape, offering a handle to investigate the color forces involved by comparing the measured distributions to the different models. Events with a detected good LPS track from the HERWIG sample are indicated by the dashed-dotted line (scaled by an arbitrary factor). The acceptance of the LPS detector is limited to x_l values above ~ 0.5.

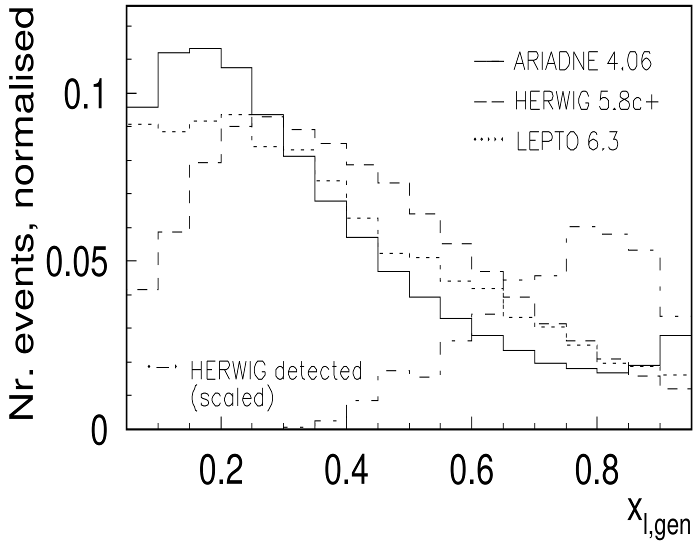

Figure 1: *Generated and detected x_l spectrum from various Monte Carlo Models*

Q^2-dependence of the rapidity distribution of leading protons

The rapidity difference Δy between the incoming and outgoing proton can be used to study the color forces. In DIS Monte Carlo models the initial state QCD radiation decreases the rapidity of the outgoing proton. The Δy distribution is thus shifted to higher values with increasing Q^2. The shift is about 0.25 units when Q^2 changes from 10 to 100 GeV^2. Kopeliovich and Nemchik developed a model [2] to describe QCD effects for partons moving through hadronic matter. Their model leads to a Q^2-dependent retarding force $\kappa = \frac{8}{9\pi} \cdot Q^2 \cdot \alpha_s(Q^2)$ between the colored objects. In [3] the retarding force is related to the rapidity difference of leading particles in pp-collisions so that the differential particle rate $dN/dy = N_o \exp^{-\Delta y/\Delta y_o}$ depends on this force: $\Delta y_o \sim \kappa$. Assuming that in ep-collisions the retarding force between the parton emitted from the proton and the proton remnant is Q^2-dependent as in [2], one finds $\Delta y_o = 2.3 \cdot Q^2/\ln(Q/\Lambda)^2$ (with $\Lambda \approx 0.3$ GeV). This Q^2-dependent retarding force leads to a change of the slope of the Δy distribution with changing Q^2 in contrast to a shift of Δy in the standard DIS models. The slope is expected to change by $\sim$20% when Q^2 rises from 10 to 100 GeV^2. In [3] the slope of the Δy distribution is related to the lifetime of the colored object, i.e. of the proton remnant in our case.

Figure 2a shows the generated Δy distribution for HERWIG events at Q^2 of 10 and 100 GeV^2. The slope of the distribution as shown in logarithmic scale does not change much. In Fig. 2b the Δy distributions for HERWIG and LEPTO events at $Q^2 = 10$ GeV^2 are shown as default. The events are then weighted with a factor corresponding to the retarding force at $Q^2 = 100$ GeV^2. The change of the slope is obvious. The acceptance of the LPS is limited to Δy values below ~ 1, i.e. the exponential fall off, from which the lifetime of the proton remnant would be measurable, is not accessible. However, the study of the Δy distribution in the threshold region will give new information on the Q^2-dependence of the color forces.

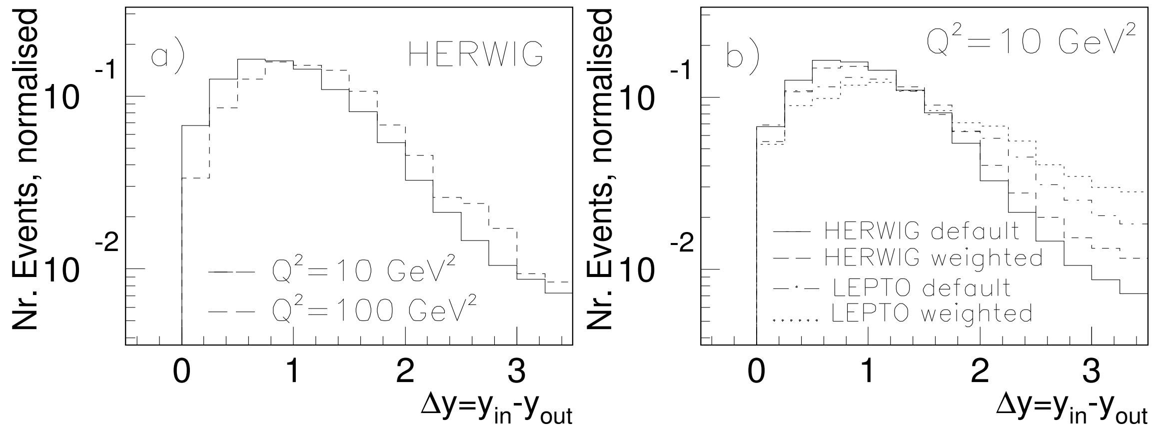

Figure 2: Q^2 *dependence of the* Δy *distribution of leading protons, see text for details*

Background sources
Events with π^o or ρ^o exchange can result in leading protons too. Contributions of those events have to be subtracted because they are usually not generated in the standard DIS Monte Carlo programs. Figure 3 shows the shapes of generated leading-proton distributions (normalised arbitrarily) of various processes. The EPSOFT-DD sample [4] corresponds to double dissociative events. Background from misidentified π^+ from DIS events is expected to be small. Leading protons from HERWIG -representing the signal- are shown for comparison too.

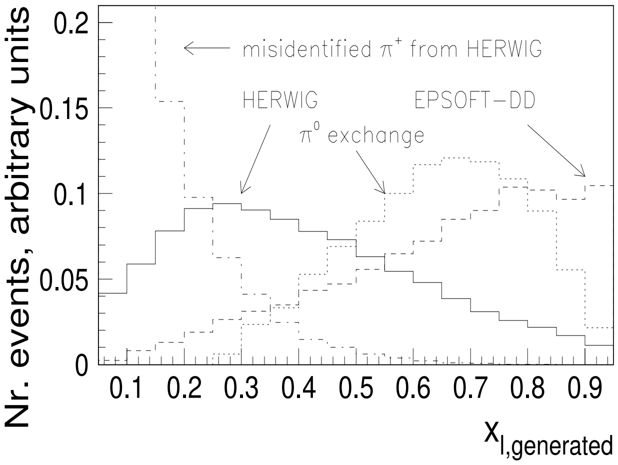

Figure 3: $x_{l,gen}$ *distributions of leading particles from several sources*

Summary
Leading protons are a powerful tool to study hadron formation. The statistics taken with the ZEUS detector from 1994–1996 will give some 10 k events with a good LPS track. This will allow to distinguish between the predictions for the leading-proton properties of various Monte Carlo models and thus improve our understanding of fragmentation and hadronisation. The background from non-DIS events needs to be well understood for this purpose.

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