DEEP INELASTIC SCATTERING WITH LEADING BARYONS AT HERA

BENNO LIST
Deutsches Elektronen–Synchrotron DESY, F11, D–22603 Hamburg, Germany

for the ZEUS and H1 Collaborations

Using their forward neutron calorimeters and leading proton spectrometers, the ZEUS and H1 collaborations at HERA have explored leading baryon production in deep inelastic scattering to test predictions from pomeron and pion exchange models and of the soft color interaction model.

1 Introduction

Since the observation of rapidity gap events at HERA in 1992, and even before, there has been much interest in the direct observation of the leading protons which are produced in diffractive interactions. To this end, the ZEUS and H1 collaborations have installed leading (or forward) proton spectrometers. The additional measurement of forward scattered neutrons enhances further the possibility to test the properties of the exchange, e. g. in the case of meson exchange, therefore both collaborations have upgraded their detectors with forward neutron calorimeters.

Recently the model of soft color interactions (SCI) has been put forward [1], a version of which has been implemented in the Monte Carlo generator LEPTO 6.5 [2], which predicts production of forward going baryons without making use of a pomeron or meson exchange picture. This model has also been compared to the new data.

2 Kinematics

Deep inelastic scattering (DIS) is described in terms of the usual variables $Q^2 = -q^2$, Bjorken $x = Q^2/(2q \cdot p)$, inelasticity $y = (q \cdot p)/(k \cdot p)$, and the γp center–of–mass energy squared $W^2 = (q + p)^2$, where q, k, and p denote the four–vectors of the exchanged photon and the incoming positron and proton, respectively. When a leading baryon with momentum p' is produced, additional variables can be defined, namely the momentum transfer $t = (p - p')^2$ and the longitudinal momentum fraction of the scattered baryon $x_{\mathrm{L}} = p'_{\mathrm{z}}/p_{\mathrm{z}}$. If one thinks of the process as an exchange of a virtual object (pomeron or meson), it is useful to introduce the momentum fraction of this object with respect to the proton $\xi = q \cdot [p - p']/(q \cdot p) \approx 1 - x_{\mathrm{L}}$, and to define $\beta = Q^2/(2q \cdot [p - p']) = x/\xi$, the momentum fraction of the scattered parton out of the exchanged object.

3 Measurement of forward neutron production

Both collaborations, ZEUS and H1, have installed forward neutron calorimeters (FNC) approximately 106 m downstream of the interaction point that can detect forward going neutrons with emission angles $\lesssim 0.8\,\mathrm{mrad}$.

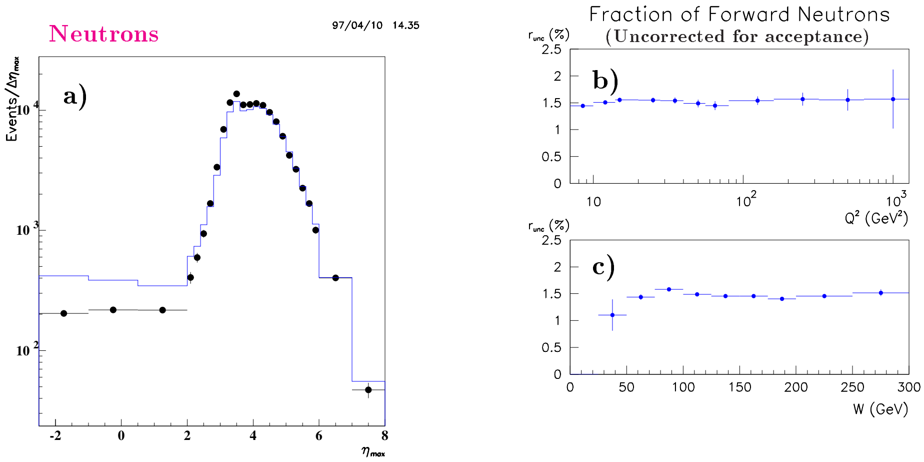

Figure 1: ZEUS results for DIS events with leading neutrons: a) η_{max}–Spectrum for events with leading neutrons (dots) and for all DIS events (histogram). b, c) Fraction of events with forward neutrons as function of Q^2 (b) and γp center–of–mass energy W (c).

Using data taken in 1995 ZEUS selected events with neutron energies above 400 GeV and a $|t| < 0.5\,\mathrm{GeV}^2$. These events were shown to contain less events with a rapidity gap (as indicated by a value of[a] $\eta_{\mathrm{max}} < 2$) than all DIS events (fig. 1a), showing that leading neutrons are not predominantly produced from diffractive proton dissociation, where a rapidity gap in the detector is expected, whereas pion exchange and SCI models predict almost no rapidity gaps [3].

Also the ratio of events with a leading neutron to all DIS events was evaluated as function of Q^2 (fig. 1b) and W (fig. 1c), and found to be constant within errors. The total fraction of DIS events with a leading neutron of $E_{\mathrm{n}} > 400\,\mathrm{GeV}$ and $|t| < 0.5\,\mathrm{GeV}^2$ has been measured by ZEUS [4] to be $9.1^{+3.6}_{-5.7}\,\%$.

The H1 collaboration has performed a similar analysis from 1996 data with an integrated luminosity of $\int \mathcal{L}dt = 1.98\,\mathrm{pb}^{-1}$. For DIS events within $5\,\mathrm{GeV}^2 < \mathrm{Q}^2 < 100\,\mathrm{GeV}^2$ and $0.05 < y < 0.7$, the ratio of events with a leading neutron of energy $E_{\mathrm{n}} > 100\,\mathrm{GeV}$ and $|t| < 0.5\,\mathrm{GeV}^2$ to all DIS events

[a] η_{max} is the pseudorapidity $\eta = -\ln\tan\theta/2$ of the most forward (in the proton beam direction) significant energy deposit found in the detector.

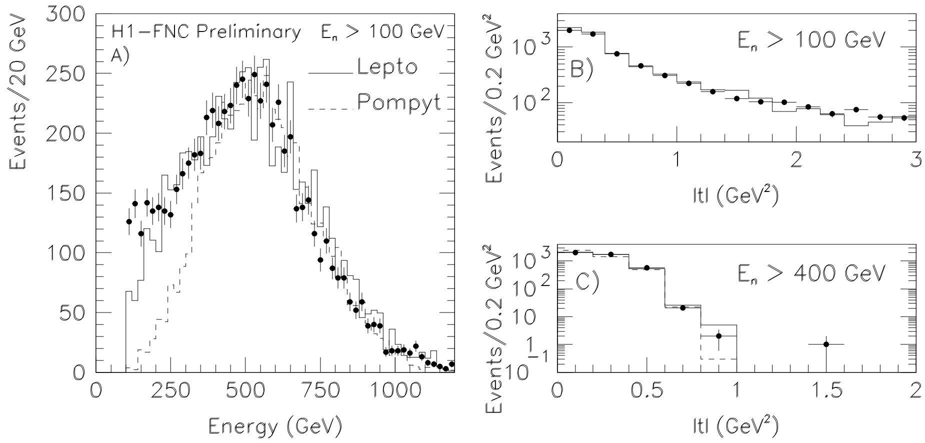

Figure 2: Uncorrected energy (A) and t (B, C) spectra for events with leading neutrons measured by H1. Dots denote data, the solid and dashed line indicate the predictions from LEPTO 6.5 and POMPYT, respectively. The Monte Carlo predictions are normalized to the data, only the shapes are to be compared.

was measured as function of Q^2, x, and the number of charged tracks (as proposed by Frankfurt et al. [5]), and found to be constant within errors [6].

The shape of the energy and $|t|$ spectra, uncorrected for acceptance and resolution effects (fig. 2), were also compared to Monte Carlo models, namely LEPTO 6.5 [2], which is a universal DIS generator including soft color interactions, and POMPYT [7], which implements a pion exchange model. For energies above 400 GeV both models fit the data, below that only the LEPTO model reproduces the observed spectrum, indicating the energy region where conventional fragmentation becomes important.

4 Leading protons in DIS

The ZEUS leading proton spectrometer (LPS) has been operated since 1993. It consists of 6 stations located between 24 and 90 m downstream of the interaction point and employs silicon strip detectors in movable plunger vessels ("Roman pots") to measure the trajectories of protons scattered at small angle.

4.1 Dependency of the t slope on x_{L}

The LPS was used to measure the $|t|$ spectra of leading protons as function of x_{L}. The data for this analysis were taken in 1994, they correspond to an integrated luminosity of $900\,\mathrm{nb}^{-1}$; about 3500 events were used.

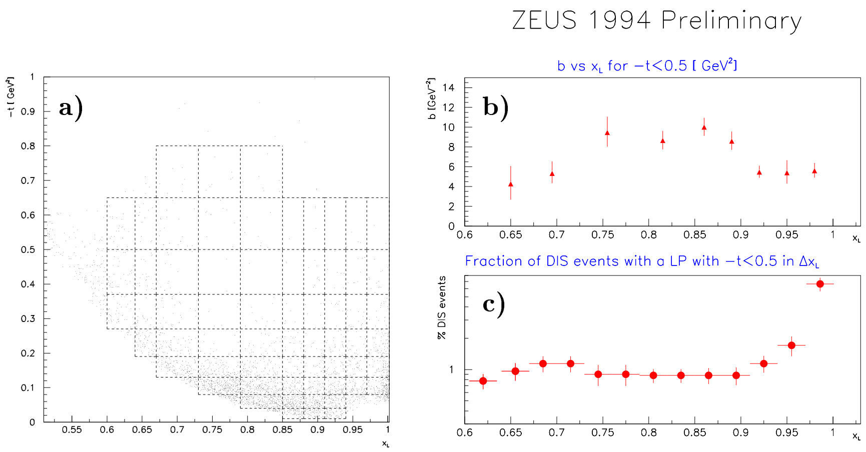

Figure 3: ZEUS measurement of leading proton production in DIS. a) Binning of events in the (x_{L}, t)–plane. b) Slope parameter b and c) fraction of DIS events with a leading proton of $|t| < 0.5\,\mathrm{GeV}^2$ as a function of x_{L}.

The events with leading protons were binned in x_{L} and t (fig. 3a), and the t distribution was fitted with a single exponential $\exp(bt)$. The b values resulting from fits to data at $|t| < 0.5\,\mathrm{GeV}^2$ are shown in fig. 3b. The slope parameter b shows a striking x_{L}-dependence: From a value of $6\,\mathrm{GeV}^{-2}$ in the diffractive region at $x_{\mathrm{L}} \approx 1$ it rises to values around $9\,\mathrm{GeV}^{-2}$ in the region $0.75 < x_{\mathrm{L}} < 0.9$, and falls to a value around $3\,\mathrm{GeV}^{-2}$ towards lower x_{L}-values.

Both, the soft color interaction model and diffractive models, are able to describe the slope in the diffractive region, but fail to reproduce the rise to $9\,\mathrm{GeV}^{-2}$ at lower values of x_{L}. A π^0 exchange model, however, describes the b slope well in the region $0.75 < x_{\mathrm{L}} < 0.9$, where pion exchange is expected [8] to dominate forward proton production. The variation of b is expected in pomeron/meson exchange pictures, because pion exchange is known to have a steeper t dependence than diffraction. In the SCI such a change is not as easily understood.

Also the fraction of DIS events with a leading proton of $|t| < 0.5\,\mathrm{GeV}^2$ in a given x_{L} bin was evaluated (fig. 3c). For $x_{\mathrm{L}} > 0.98$ this fraction is close to 10 %, in accordance with the observation that around 10 % of all DIS events are of diffractive origin. For $0.6 < x_{\mathrm{L}} < 0.9$ this fraction is constant and at a level of 1 % in each 0.03 interval of x_{L}. The ratio, integrated over $0.6 < x_{\mathrm{L}} < 0.92$, was found to be about 8 %, independent of Q^2, W and track multiplicity [3]. The fraction of events with a rapidity gap in the main detector was found to be small and independent of x_{L}.

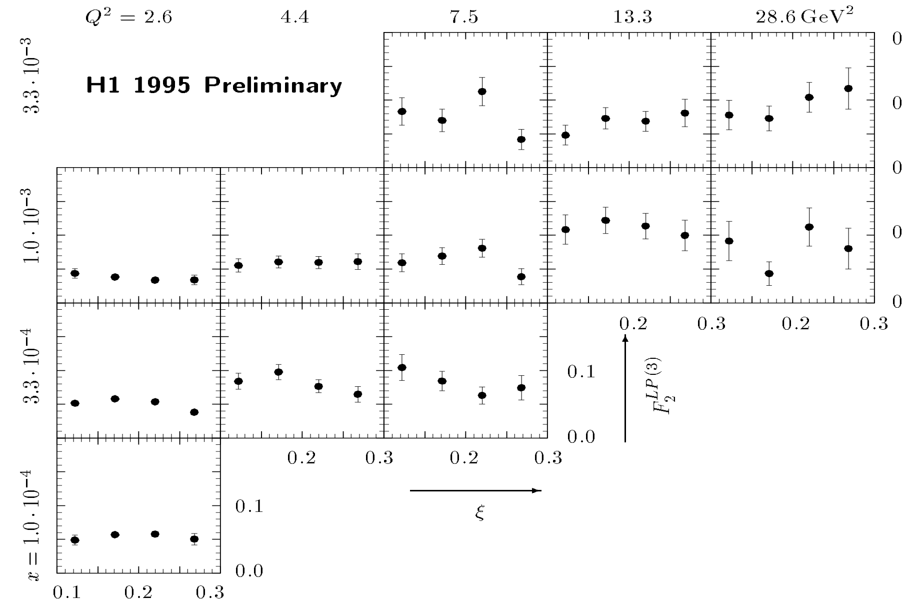

Figure 4: $F_2^{LP\,(3)}\,(x,\,Q^2,\,\xi)$ in bins of x and Q^2 as function of ξ.

4.2 Measurement of $F_2^{LP\,(3)}$

The H1 forward proton spectrometer (FPS) in its 1995 configuration comprises two Roman pot stations 81 and 90 m downstream the interaction point, instrumented with scintillating fiber hodoscopes. Its acceptance extends over the range $0.5 < x_{\mathrm{L}} < 0.93$ and $\theta \lesssim 0.3\,\mathrm{mrad}$.

The H1 collaboration used data taken in 1995, corresponding to an integrated luminosity of $1.44\,\mathrm{pb}^{-1}$, to measure the semi–inclusive cross section for the DIS process $ep \to e'p'X$ with a leading proton of transverse momentum [b] $p_\perp < 200\,\mathrm{MeV}$. A triple differential cross section in terms of x, Q^2, and ξ was measured and parametrized by a structure function termed $F_2^{LP\,(3)}$:

$$\frac{\mathrm{d}^3\sigma}{\mathrm{d}x\,\mathrm{d}Q^2\,\mathrm{d}\xi} = \frac{4\pi\alpha^2}{x\,Q^4}\left(1 - y + \frac{y^2}{2}\right) F_2^{LP\,(3)}(x,\,Q^2,\,\xi). \tag{1}$$

This structure function was measured [9] in 12 $(x,\,Q^2)$–bins in the kinematic region $6 \cdot 10^{-5} < x < 6 \cdot 10^{-3}$ and $2\,\mathrm{GeV}^2 < \mathrm{Q}^2 < 50\,\mathrm{GeV}^2$ and in 4 ξ–bins for $0.098 < \xi < 0.244$. The result of the measurement is shown in figure 4.

[b] t is linked to $p_\perp$ by $t = -(\xi^2 m_{\mathrm{p}}^2 + p_\perp^2)/(1-\xi)$, where m_{p} is the proton mass.

In pion exchange models, $F_2^{LP\,(3)}$ is expected to factorize into a pion flux factor that depends only on ξ, and the pion structure function $F_2^{\pi}\,(\beta,\,Q^2)$. It has been shown that a factorization ansatz of the form

$$F_2^{LP\,(3)}\,(\beta,\,Q^2,\,\xi) = r\,(\xi)\cdot(a\cdot\beta^b + c\cdot\beta^d\cdot\log Q^2), \tag{2}$$

where $r\,(\xi)$ is a normalization factor for each ξ bin, is indeed able to describe the data. In a soft color interaction model, however, β may not be the relevant scaling variable, but there may be a universal proton spectrum, independent of x and Q^2. To test this, a second fit was performed, where β in equation (2) was replaced by x, which gave an equally good description of the data. Therefore at the present level of precision of the data one cannot distinguish between both factorization hypotheses.

5 Summary and Conclusions

By upgrading their detectors with forward proton spectrometers and forward neutron calorimeters, the H1 and ZEUS collaborations have been able to explore the production of leading baryons at high energies and small scattering angles in DIS processes. The data show no dependence of the measured spectra or particle yields on x, Q^2, W, or the charged multiplicity in the central detector. Some aspects of the data are well described by pomeron– or pion–exchange models, but a comprehensive description in this framework has not yet been obtained. The same conclusion applies to the soft color interaction model.

References

1. W. Buchmüller and A. Hebecker, *Phys. Lett.* B **355**, 573 (1995).
   A. Edin, G. Ingelman, and J. Rathsman, *Phys. Lett.* B **366**, 371 (1996).
2. G. Ingelman *et al.*, *Comp. Phys. Comm.* **101**, 108 (1997).
3. N. Cartiglia, *Talk at DIS97, Chicago.* **hep–ph/9706416**.
4. ZEUS Collaboration, M. Derrick *et al.*, *Phys. Lett.* B **384**, 388 (1996).
5. L. Frankfurt *et al.*, *Phys. Lett.* B **405**, 367 (1997).
6. D. M. Jansen, *Talk at DIS97, Chicago.*
7. P. Bruni *et al.*, POMPYT version 2.6. *Unpublished program manual.*
8. H. Holtmann *et al.*, *Phys. Lett.* B **338**, 363 (1996).
   W. Koepf *et al.*, *Phys. Rev.* D **53**, 2586 (1996).
   B. Kopeliovich, B. Povh, and I. Potashnikova, *Z. Phys.* C **73**, 125 (1996).
   M. Przybycień, A. Szczurek, and G. Ingelman, *Z. Phys.* C **74**, 509 (1997).
9. B. List, *Talk at DIS97, Chicago,* and *PhD thesis, Univ. Hamburg, 1997.*