Observation of Deep Inelastic ep Scattering with a Leading Baryon

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Deep inelastic scattering events with a leading baryon have been detected by the H1 experiment at HERA using a forward proton spectrometer and a forward neutron calorimeter. The semi–inclusive cross sections have been measured for events with a high–energy proton with $580 \leq E' \leq 740$ GeV, and for events with an energetic neutron with $E' \geq 160$ GeV. A model of leading baryon production, which consists of pion, reggeon and pomeron exchanges, gives a good description of the data in the region $E'/E_p \geq 0.6$ and can be used to constrain the pion structure function.

1 Introduction

The observation of rapidity gap events at HERA triggered much interest in measuring directly leading baryons produced in deep inelastic scattering (DIS). In addition to diffraction one also expects meson fluctuations within the proton to contribute to the total DIS cross section and to the production of leading protons and neutrons [1,2,3]. Because of its small mass the most prominent candidate for such a fluctuation is the pion. The pion exchange model of leading baryon production is implemented in the POMPYT 2.6 Monte Carlo [4].

A different approach to describe the production of leading baryons is the soft colour interaction model which is implemented in the LEPTO 6.5 Monte Carlo program [5]. In this model the colour topology of the final state is modified by an exchange of soft gluons leading to a colour separation between the current and target fragmentation regions.

The kinematics of the semi–inclusive production of baryons in DIS can be described by four independent variables: Q^2 and Bjorken x and in addition the transverse momentum p_T of the leading baryon and $z \equiv 1 - (q \cdot (p - p'))/(q \cdot p)$, where p' is the four vector of the outgoing forward baryon. If the leading baryon is produced exclusively at the proton vertex, $z = 1 - x_{\mathbb{P}}$. In this paper we make the approximation $z = E'/E_p$ which is the fractional energy of the leading baryon with respect to the energy of the incoming proton.

H1 uses a forward proton spectrometer (FPS, since 1995) [6] and a forward neutron calorimeter (FNC, upgraded version since 1996) [7] to detect leading baryons.

2 Measurement of the Semi–Inclusive Structure Functions $F_2^{LB(3)}$

The semi–inclusive cross sections $\sigma\,(ep \rightarrow e'NX$, with $N = p'$ or $n)$ for DIS events with a high–energy proton with $0.7 \leq z \leq 0.9$ and for events with an energetic neutron with $0.2 \leq z \leq 1$ have been measured in the kinematic region $2 \leq Q^2 \leq 50$ GeV^2, $0.00006 \leq x \leq 0.0060$ and $p_T \leq 200$ MeV/c. The data used for this analysis were collected during 1995 and 1996 using the HERA accelerator at DESY where 27.6 GeV positrons collide with 820 GeV protons.

We present our results in terms of semi–inclusive structure functions $F_2^{LB(3)}$ (where LB stands for either leading proton (LP) or neutron (LN)), which are defined in close analogy to the inclusive structure function:

$$\frac{\mathrm{d}^3\sigma(ep \rightarrow e'NX)}{\mathrm{d}x\,\mathrm{d}Q^2\,\mathrm{d}z} = \frac{4\pi\alpha^2}{x\,Q^4}(1 - y + \frac{y^2}{2})F_2^{LB(3)}(x, Q^2, z)\ .$$

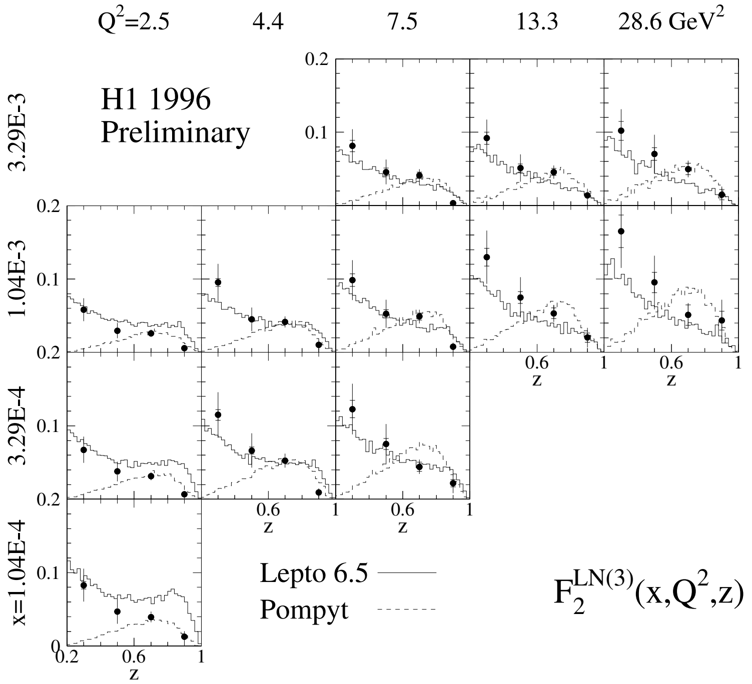

Figure 1: The semi–inclusive structure function $F_2^{LN(3)}$, for neutrons with $p_T \leq 200$ MeV/c

The results for $F_2^{LP(3)}$, which are based on a luminosity of $\mathcal{L} = 1.44\,\mathrm{pb}^{-1}$ taken in 1995, have already been shown at previous conferences [8]. The measurement of $F_2^{LN(3)}$ has been made on the basis of $\mathcal{L} = 3.38\,\mathrm{pb}^{-1}$ of 1996 data and the results are shown in Figure 1. They are compared to the predictions of the LEPTO and POMPYT Monte Carlo models [4,5].

The LEPTO Monte Carlo model describes the general shape of the neutron data over the entire z range but there are indications of a failure to reproduce the rise of the semi–inclusive structure functions as a function of Q^2 which is also observed for the proton data [8]. The POMPYT Monte Carlo simulation, which uses the GRV-LO parametrisation of the pion structure function, gives a good description of the high energy neutron data with $z \geq 0.6$. It reproduces the rise in $F_2^{LN(3)}$ as a function of Q^2. However it undershoots the data for $z < 0.6$, where π^+ exchange is not the dominant production mechanism.

3 Comparison to a Regge Model of Baryon Production

Figure 2 shows an examplary comparison between the leading baryon structure functions for $z \geq 0.6$ and our model of baryon production for particular values of x and Q^2. Similar results are obtained for the other x and Q^2 bins. The model consists of pion, reggeon (f, ω) and pomeron exchanges, with the contribution of each exchange determined by the particle flux $f_{\mathcal{P}/p}(z, p_T)$ and its structure function $F_2^{\mathcal{P}}(\beta, Q^2)$. For leading baryon production with $p_T \leq 200$ MeV/c we therefore have:

$$F_2^{LB(3)}(\beta, Q^2, z) = \sum_{\mathcal{P}} \left\{ \int_{\mathrm{p_T=0\ MeV/c}}^{\mathrm{p_T=200\ MeV/c}} \mathrm{d}p_T \; f_{\mathcal{P}/p}(z, p_T) \right\} \cdot F_2^{\mathcal{P}}(\beta, Q^2) \; ,$$

where $\mathcal{P}$ denotes the pion, reggeon and pomeron. The different flux factors have been determined using hadron–hadron data [2,9,10]. We neglect any contribution of isospin-1 reggeon exchange (ρ,a), which could lead to neutron production, and also do not consider possible interference terms. The structure functions for the exchanged particles are basically unknown in the low β region and one has to rely on theoretical models. For the pion structure function F_2^{π} we took the leading order parametrisation by Glück, Reya and Vogt (GRV) [11]. For the reggeon and pomeron structure function we assume $F_2^{\mathrm{I\!R}} = F_2^{\pi}$ and $F_2^{\mathrm{I\!P}} = 0.22 F_2^{\mathrm{I\!R}}$ following the discussion in reference [9].

Figure 2 shows that the measured cross–section for leading neutrons can be described with the prediction for π^+ exchange alone whereas for the proton data, reggeon exchange contributes approximately 2/3 of the cross–section. In the measured z range, $F_2^{LP(3)}$ is not sensitive to diffraction ($\mathrm{I\!P}$ exchange) which dominates at $z \approx 1$. Not shown in the figure is the contribution of π^0 exchange to the rate of leading protons which is exactly half of the π^+ contribution.

The model gives a good description of the neutron and proton data with $z \geq 0.6$. Since for these values of z the rate of leading neutron production can be described entirely by π^+ exchange, the data can be used to constrain the structure function of the pion. The comparison of the measured $F_2^{LN(3)}$ and the POMPYT prediction in Figure 1 shows that the GRV-LO parametrisation of the pion structure function is consistent with the data.

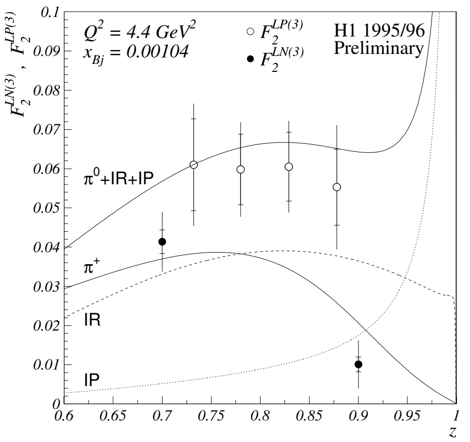

Figure 2: $F_2^{LN(3)}$ and $F_2^{LP(3)}$ data with $z \geq 0.6$ compared to our Regge model of baryon production which includes pion, reggeon and pomeron exchanges. The different contributions are labeled.

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