Leading Baryons and $\sigma_{\mathrm{tot}}(\gamma p)$ at HERA

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Leading baryon measurements from the H1 and ZEUS collaborations are reported and compared to production models. A new study of the energy dependence of the photon-proton total cross section is also reported.

1. Leading baryons

Events with a baryon carrying a large fraction of the proton beam energy have been observed in ep scattering at HERA [1, 2]. The dynamical mechanisms for their production are not completely understood. They may be the result of hadronization of the proton remnant, leaving a baryon in the final state. Exchange of virtual particles is also expected to contribute. In this picture, the target proton fluctuates into a virtual meson-baryon state. The virtual meson scatters with the projectile lepton, leaving the fast forward baryon in the final state. Leading neutron (LN) production occurs through the exchange of isovector particles, notably the π^+ meson. For leading proton (LP) production isoscalar exchange also contributes, including diffraction mediated by Pomeron exchange. In the exchange picture, the cross section for some process in ep scattering with e.g. LN production factorizes: $\sigma_{ep\to enX} = f_{\pi/p}(x_L, t) \cdot \sigma_{e\pi\to eX}$. Here $f_{\pi/p}$ is the flux of virtual pions in the proton, $x_L = E_n/E_p$ is the fraction of the proton beam energy carried by the neutron, and t is the virtuality of the exchanged pion. $\sigma_{e\pi\to eX}$ is the cross section for electroproduction on the pion.

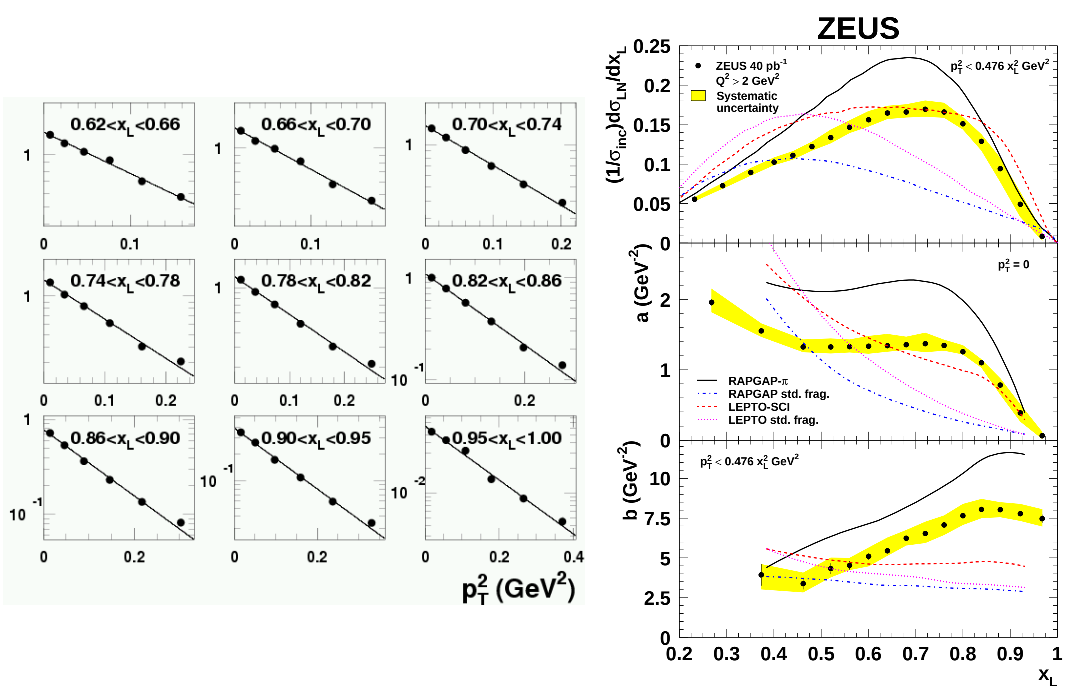

Figure 1: Left: LN p_T^2 distributions in bins of x_L in the range $p_T^2 < 0.476\, x_L^2$ GeV^2, where p_T is the LN transverse momentum. The lines are the result of exponential fits. Right: LN x_L, intercept and slope distributions compared to models. Results are from the ZEUS collaboration [2].

1.1. Leading baryon production and models

The left side of Fig. 1 shows the LN p_T^2 distributions in bins of x_L. They are well described by exponentials; thus the parameterization $(1/\sigma_{\rm inc})d^2\sigma/dx_L dp_T^2 \propto a(x_L)\exp(-b(x_L)p_T^2)$ fully characterizes the two dimensional distribution. Here $\sigma_{\rm inc}$ is the inclusive cross section without an LN requirement. The right side of Fig. 1 shows the LN x_L, intercept a and slope b distributions compared to several models. The standard fragmentation models implemented in RAPGAP and LEPTO and the LEPTO model with soft color interactions do not describe the data. The RAPGAP model mixing standard fragmentation and pion exchange gives a better description of the shape of the x_L distribution, and also predicts the rise of the slopes with x_L, although both with too high values.

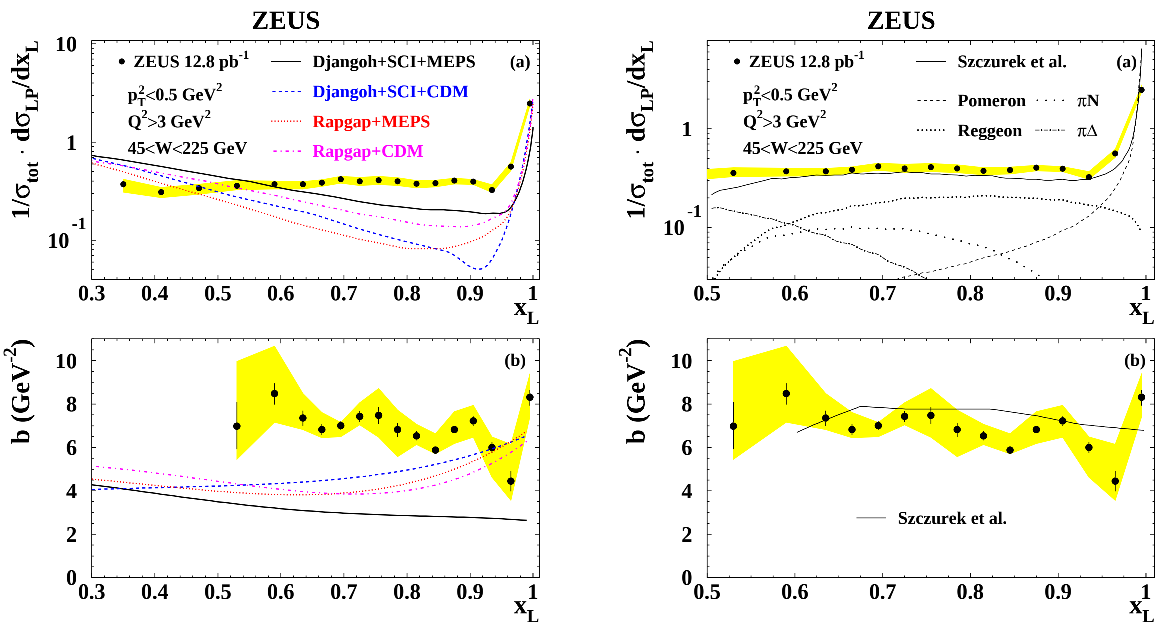

Figure 2: Left: LP x_L distribution and exponential slopes compared to standard fragmentation models. Right: LP x_L distribution and exponential slopes compared to a model incorporating isoscalar and isovector exchanges. Results are from the ZEUS collaboration [2].

If LP production proceeded only through isovector exchange, as LN production must, there should be half as many LP as LN. The data (not shown) instead have approximately twice as many LP as LN. Thus, exchanges of particles with isospins such as isoscalars must be invoked for LP production. The left side of Fig. 2 shows a comparison of the LP x_L distributions and p_T^2 exponential slopes b to the DJANGOH and RAPGAP Monte Carlo models incorporating standard fragmentation or soft color interactions, none of which describe the data. The right side of Fig. 2 shows a comparison to a model including exchange of both isovector and isoscalar particles, including the Pomeron for diffraction [3]. These exchanges combine to give a good description of the the x_L distribution and slopes.

1.2. Absorption of leading neutrons

The evidence for particle exchange in leading baryon production motivates further investigation of the model. One refinement of the simple picture described in the introduction is absorption, or rescattering [4]. In this process, the virtual baryon also scatters with the projectile lepton. The baryon may migrate to lower x_L or higher p_T such that it is outside of the detector acceptance, resulting in a relative depletion of observed forward baryons. The probability of this should increase with the size of the exchanged photon. The size of the photon is inversely related to its virtuality Q^2, so the amount of absorption should increase with decreasing Q^2.

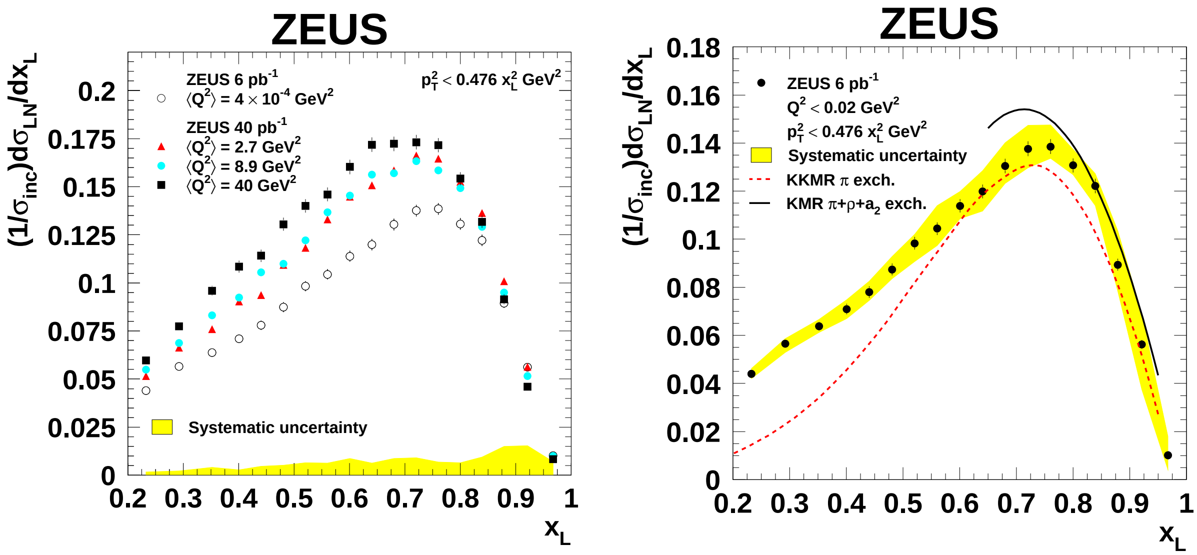

Figure 3: Left: LN x_L distributions for photoproduction and three bins of Q^2 in DIS. Right: LN x_L distributions for photoproduction compared to exchange models including absorptive effects. Results are from the ZEUS collaboration [2].

The left side of Fig. 3 shows the LN x_L spectra for photoproduction and for three bins of increasing Q^2. The yield of LN increases monotonically with Q^2, in agreement with the expectation of the decrease of loss through absorption as Q^2 rises. The right side of Fig. 3 shows the photoproduction data with two predictions from models of meson exchange with absorption [5]. The dashed curve model incorporates pion exchange with absorption, accounting also for the migration in x_L and p_T of the neutron. The solid curve model include the same effects, adding also exchange of ρ and a_2 mesons. Both models give a good description of the large depletion of LN in photoproduction relative to DIS seen in the left side of the figure.

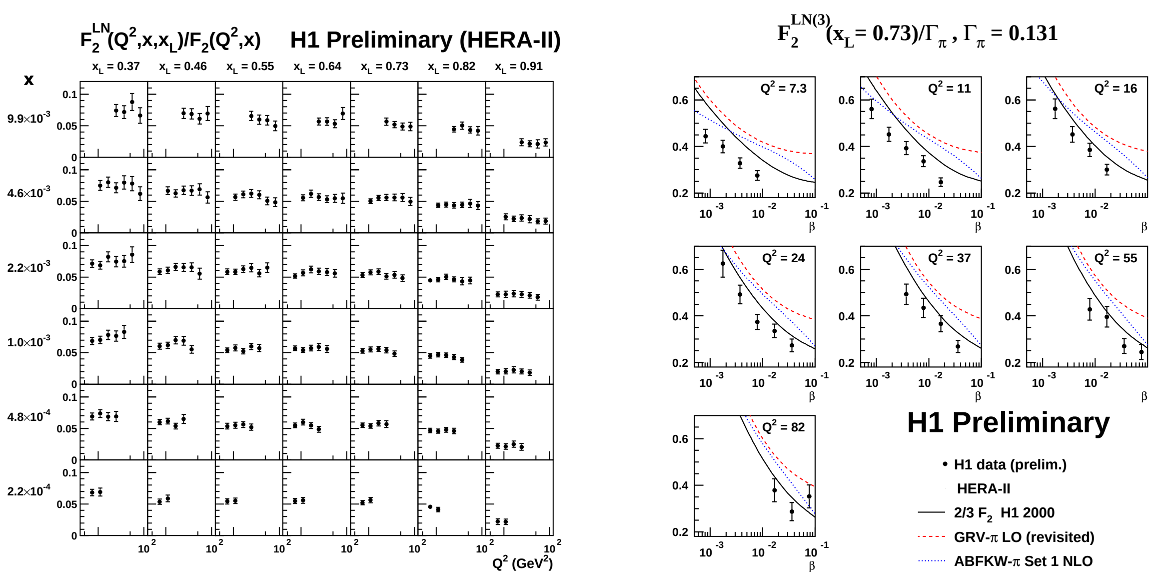

Figure 4: Left: Ratio of semi-inclusive LN to inclusive structure functions as a function of Q^2 in bins of x and x_L. Right: Extracted pion structure function as a function of $\beta = x/(1 - x_L)$ in bins of Q^2. The curves are the proton structure function scaled by 2/3 and two parameterizations based on Drell-Yan and direct photon production data. Results are from the H1 collaboration [1].

1.3. Pion structure function F_2^π

Analogous to the inclusive proton structure function $F_2(Q^2,x)$, one can define an LN tagged semi-inclusive structure function $F_2^{LN(3)}(Q^2,x,x_L)$, including also the dependence on x_L. Here x is the Bjorken scaling variable. The left side of Fig. 4 shows the ratios F_2^{LN}/F_2 as a function of Q^2 in bins of x and x_L. Here F_2^{LN} are the measured values from LN production in DIS and the values of F_2 are obtained from the H1-2000 parameterization [6]. For fixed x_L the ratios are almost flat for all (x,Q^2) implying that F_2^{LN} and F_2 have a similar (x,Q^2) behavior. This result suggests the validity of factorization, i.e. independence of the photon and the proton vertices.

The factorization relation can be rewritten replacing the cross sections by F_2^{LN} and F_2^π. Using the measurement of $F_2^{LN(3)}$ for $0.68 < x_L < 0.77$, and the integral over t of the pion flux factor at the center of this x_L range, $\Gamma_\pi = \int f_{\pi/p}\,dt = 0.131$, one can extract the pion structure function as $F_2^\pi = F_2^{LN(3)}/\Gamma_\pi$. The right side of Fig. 4 shows $F_2^{LN(3)}/\Gamma_\pi$ as a function of $\beta = x/(1-x_L)$ for fixed values of Q^2. The results are consistent with a previous ZEUS measurement [7]. The data are compared to predictions of parameterizations of the pion structure function [8], and to the H1-2000 parameterization of the proton structure function [6] multiplied by the factor 2/3 according to naive expectation based on the number of valence quarks in the pion and proton respectively. The distributions show a steep rise with decreasing β, in accordance with the pion and the proton structure function parameterizations. The scaled proton structure function gives the best description of the data.

2. Energy dependence of the photon-proton total cross section

The energy dependences of hadronic total cross sections can be described simply as the sum of two powers: $\sigma_{\rm tot} = A\cdot W^{2\epsilon} + B\cdot W^{-2\eta}$ [9], where W is the hadron-hadron center-of-mass energy. The term with power 2ϵ is from Pomeron exchange and is expected to be universal for all hadron-hadron reactions. This has been studied at HERA in the γp total cross section, where the photon fluctuates into a virtual hadron. Previous HERA measurements had only one cross section measurement at high W, and required results from lower W fixed-target experiments to extract ϵ.

At the end of HERA running the proton beam energy was lowered to half of its nominal value. ZEUS took data for γp total cross section measurements at both energies, identifying photoproduction events with a positron tagger. At these high values of W the term with power 2η can be neglected, and ϵ can be extracted from the ratio of $\sigma_{\rm tot}(\gamma p)$ at two energies. By making the measurement with the same apparatus, many acceptances and systematic effects in the ratio cancel. The value extracted from the preliminary ZEUS measurement is $\epsilon = 0.070 \pm 0.055$, consistent with the value $\epsilon = 0.0808$ extracted from low-energy data [9]. The error on the ZEUS value will be reduced, leading to an independent measurement of the high energy dependence of hadronic total cross sections with one apparatus.

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