

# Leading Baryons and $\sigma_{\text{tot}}(\gamma p)$ 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  $\pi^+$  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:  $\sigma_{ep \rightarrow enX} = f_{\pi/p}(x_L, t) \cdot \sigma_{e\pi \rightarrow eX}$ . 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.  $\sigma_{e\pi \rightarrow eX}$  is the cross section for electroproduction on the pion.

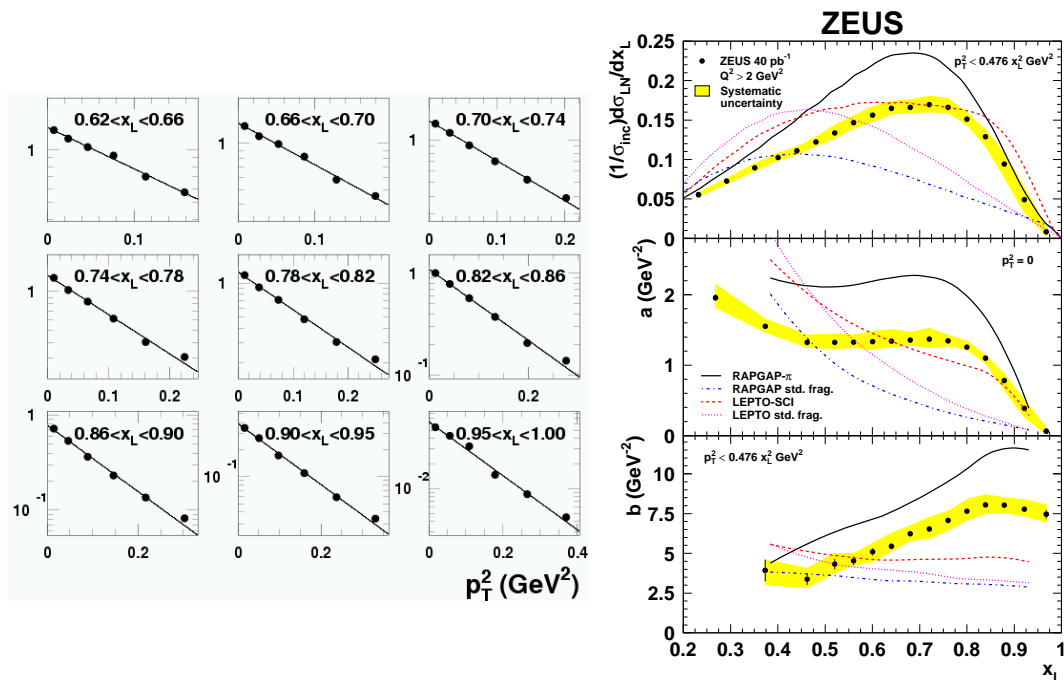


Figure 1: Left: LN  $p_T^2$  distributions in bins of  $x_L$  in the range  $p_T^2 < 0.476 x_L^2 \text{ GeV}^2$ , where  $p_T$  is the LN transverse momentum. The lines are the result of exponential fits. Right: LN  $x_L$ , intercept and slope distributions compared to models. Results are from the ZEUS 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  $(1/\sigma_{\text{inc}})d^2\sigma/dx_L dp_T^2 \propto a(x_L)\exp(-b(x_L)p_T^2)$  fully characterizes the two dimensional distribution. Here  $\sigma_{\text{inc}}$  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 RAGGAP and LEPTO and the LEPTO model with soft color interactions do not describe the data. The RAGGAP 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.

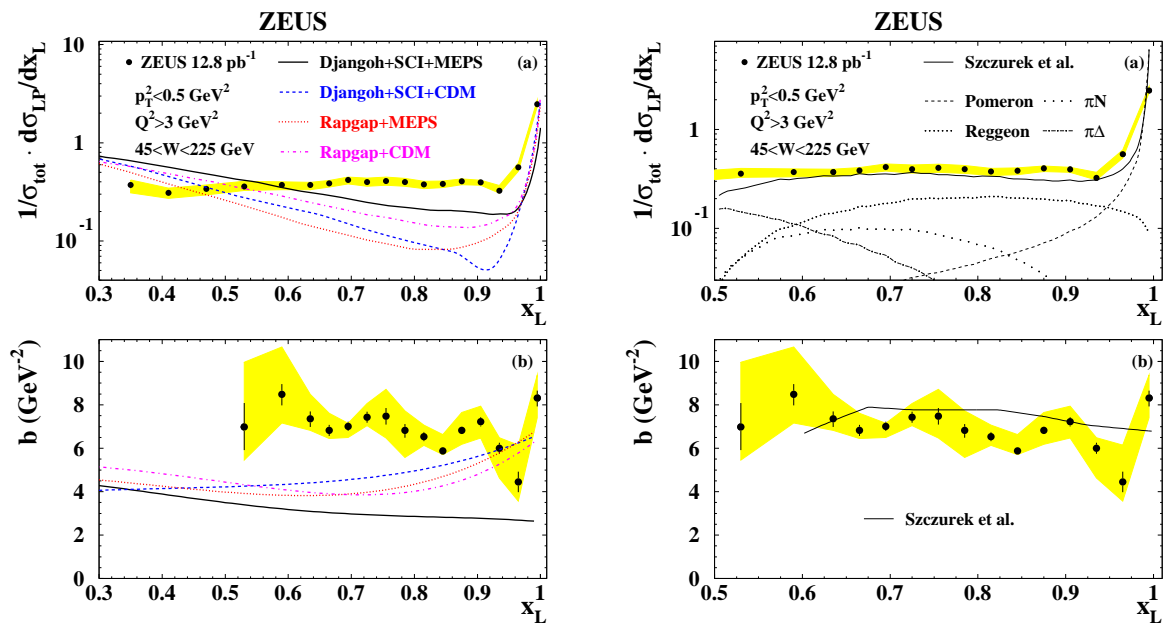


Figure 2: Left: LP  $x_L$  distribution and exponential slopes compared to standard fragmentation models. Right: LP  $x_L$  distribution and exponential slopes compared to a model incorporating isoscalar and isovector exchanges. Results are from the ZEUS collaboration [2].

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 DJANGO and RAGGAP 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  $Q^2$ .

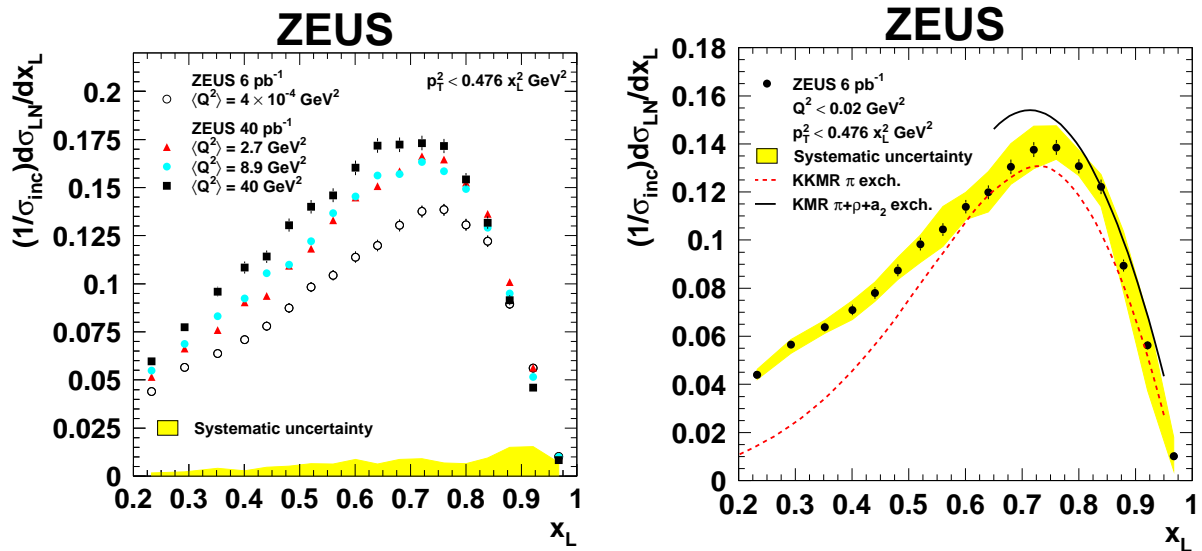


Figure 3: Left: LN  $x_L$  distributions for photoproduction and three bins of  $Q^2$  in DIS. Right: LN  $x_L$  distributions for photoproduction compared to exchange models including absorptive effects. Results are from the ZEUS collaboration [2].

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  $\rho$  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.

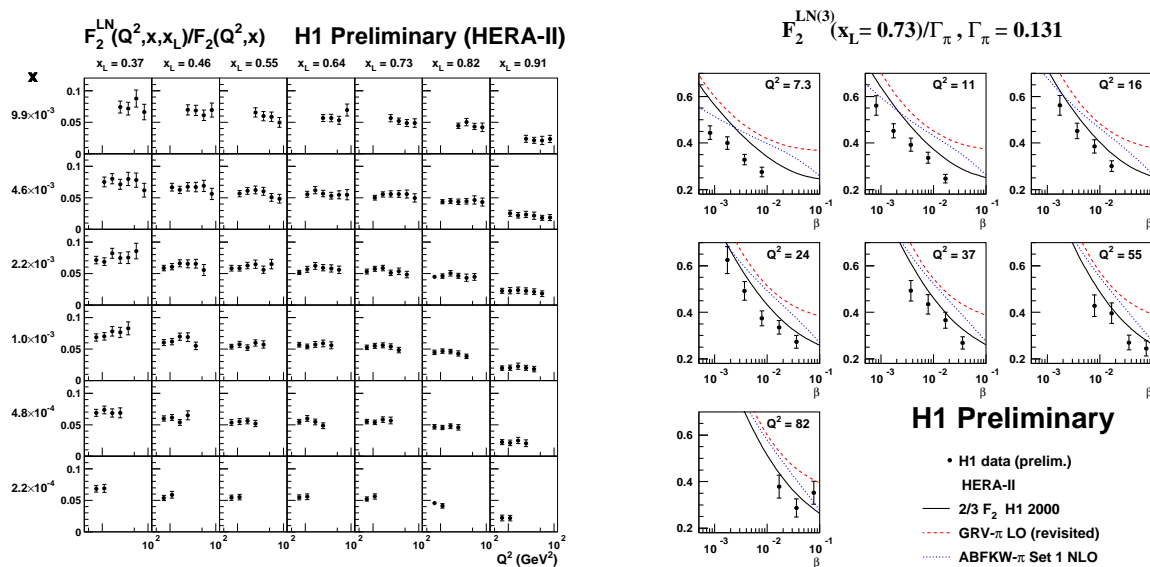


Figure 4: Left: Ratio of semi-inclusive LN to inclusive structure functions as a function of  $Q^2$  in bins of  $x$  and  $x_L$ . Right: Extracted pion structure function as a function of  $\beta = x/(1-x_L)$  in bins of  $Q^2$ . The curves are the proton structure function scaled by  $2/3$  and two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

### 1.3. Pion structure function $F_2^\pi$

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  $F_2^\pi$ . 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  $\beta$ , 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:  $\sigma_{\text{tot}} = A \cdot W^{2\epsilon} + B \cdot W^{-2\eta}$  [9], where  $W$  is the hadron-hadron center-of-mass energy. The term with power  $2\epsilon$  is from Pomeron exchange and is expected to be universal for all hadron-hadron reactions. This has been studied at HERA in the  $\gamma p$  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  $\epsilon$ .

At the end of HERA running the proton beam energy was lowered to half of its nominal value. ZEUS took data for  $\gamma p$  total cross section measurements at both energies, identifying photoproduction events with a positron tagger. At these high values of  $W$  the term with power  $2\eta$  can be neglected, and  $\epsilon$  can be extracted from the ratio of  $\sigma_{\text{tot}}(\gamma p)$  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.

## References

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