Leading Neutron Production at ZEUS

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ZEUS results on leading neutron production in ep scattering are presented. Production in deep inelastic scattering and photoproduction are compared, giving indications of absorption. The data are compared to Monte Carlo, meson exchange and absorption models.

1 Introduction

Events with a neutron carrying a large fraction of the proton energy have been observed in ep scattering at HERA [1]. The dynamical mechanisms for their production are not completely understood. They may be the result of hadronization of the proton remnant, conserving baryon number in the final state. Exchange of virtual isovector mesons is also expected to contribute, predominantly the exchange of low mass π^+ mesons [2]. In this picture the proton fluctuates into a virtual n-π^+ state. The virtual π^+ scatters with the projectile lepton, leaving the fast forward neutron in the final state. Depending on the virtuality of the exchanged photon, which is a measure of how pointlike the photon is, the neutron may also rescatter with it and migrate to a region outside of the detector acceptance, leading to a depletion of neutrons in some kinematic regions [3].

The ZEUS experiment at HERA had a forward neutron calorimeter (FNC) in the proton beam direction. It measured the fraction of the beam energy carried by the neutron, x_L, and the transverse momentum transferred to the neutron, p_T. HERA machine elements along the neutron flight path limited neutron scattering angles to $\theta_n < 0.75$ mrad, restricting measurement to the kinematic region $p_T^2 < 0.476 x_L^2$ GeV^{-2}. Here we report results on leading neutron production, in both photoproduction, where the photon virtuality Q^2 is nearly zero, and in deep inelastic scattering (DIS), where Q^2 is greater than a few GeV^2. Comparisons are made to Monte Carlo models, one of which incorporate the pion exchange mechanism. Comparisons are also made to models of pion exchange incorporating rescattering, and a model including exchanges of additional mesons.

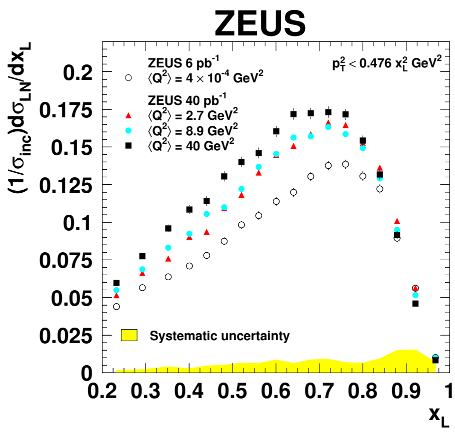

Figure 1: Neutron x_L distributions for photoproduction and three Q^2 bins of DIS.

2 Results

Leading neutron x_L distributions for photoproduction and three Q^2 bins of DIS are shown in Fig. 1. The distributions are normalized by σ_{inc}, the inclusive cross section without the neutron requirement. The distributions all rise from lowest x_L due to the increase in p_T^2 space, reach a maximum near $x_L = 0.7$, and fall to zero at the kinematic limit $x_L = 1$. There is a clear increase of the relative neutron yield with Q^2. This is consistent with absorption models, where at lower Q^2 the larger photon size can result in rescattering of the neutron, where the neutron can migrate to a region outside of the detector acceptance and is lost.

For further studies the full Q^2 range of the DIS sample is taken together. The ratio of the photoproduction x_L distribution to that of the full DIS sample is shown in Fig. 2. The depletion of neutrons in the photoproduction sample increases with decreasing x_L. In pion exchange models the size of the virtual n-π^+ system is smaller at lower x_L, with increased probability of rescattering. Thus the depletion of neutrons in photoproduction is consistent with pion exchange models including absorption.

The p_T^2 distributions of neutrons in photoproduction and DIS are shown for several x_L bins in Fig. 3. They are normalized to unity at $p_T^2 = 0$. The lines are fits to exponentials in p_T^2, which give a good description of the data. The photoproduction distributions are steeper in the range $0.6 < x_L < 0.9$, with relatively fewer neutrons at high p_T^2. This is qualitatively consistent with absorption, where rescattering is more likely for the small n-π^+ separations corresponding to higher p_T^2.

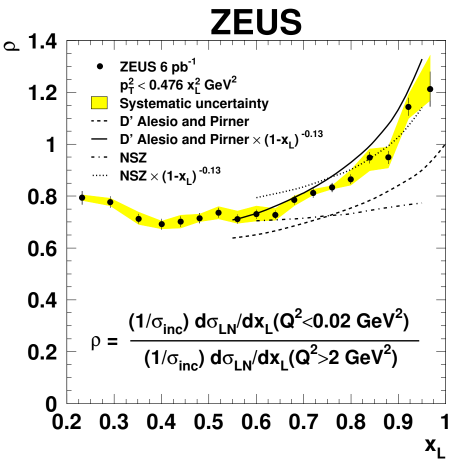

Figure 2: Ratio of neutron x_L distributions in photoproduction and DIS.

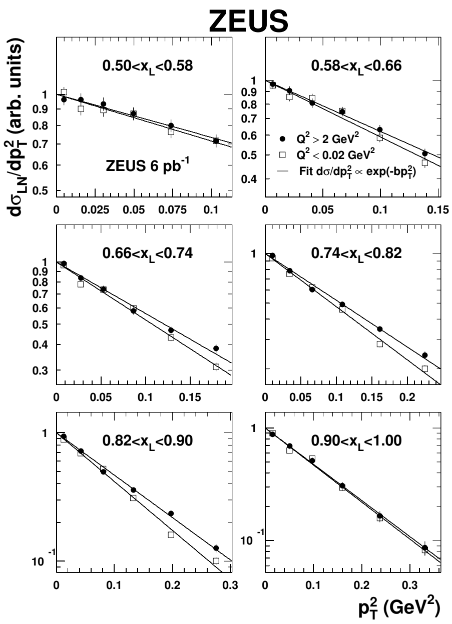

Figure 3: Neutron p_T^2 distributions for photoproduction and DIS, normalized to unity at $p_T^2 = 0$.

3 Comparison to models

The normalized neutron distributions in DIS were fit to the form

$$\frac{1}{\sigma_{\text{inc}}} \frac{d\sigma_{\text{LN}}}{dx_L dp_T^2} = a e^{-bp_T^2}.$$

Figure 4 shows the x_L distributions for $\theta_n < 0.75$ mrad and the intercepts a and slopes b as a function of x_L. Also on the plots are the expectations of the LEPTO [4] and RAPGAP [5] Monte Carlo models. Both were run in the configuration where neutron were produced from the fragmentation of the proton remnant [6]. LEPTO was also run implementing soft color interactions [**?**]; RAPGAP was also run including neutron production via pion exchange. Both models with only fragmentation of the proton remnant do not describe the data. They predict too few neutrons, peaked at lower x_L than the data. They do not have the broad plateau in intercepts a that the data exhibit for medium values of x_L, and they predict slopes b smaller than and without the steep x_L dependence of the data. LEPTO including soft color interactions gives an x_L distribution which better describes the peak in the data and has a slight enhancement of a at medium x_L value. RAPGAP with pion exchange gives a good description of the shapes of all distributions, although it predicts more neutrons with larger intercepts and slopes than the data.

The ratio of x_L distributions photoproduction over DIS in Fig. 2 also shows the predictions of two models of absorption [3]. The model of D' Alesio and Pirner describes the shape of the data, with increasing absorption at decreasing values of x_L, but it predicts a lower value of the ratio than the data. γp interactions have a power law dependence on the photon-proton center-of-mass energy, $\sigma \propto W^{\lambda}$, with different values of λ for DIS and photoproduction. Assuming that $\gamma\pi$ interactions have the same dependence, and recalling that $W_{\gamma\pi} = \sqrt{1-x_L}W_{\gamma p}$, the ratio of photoproduction and DIS cross sections is proportional to $(1-x_L)^{\Delta\lambda}$. After correcting the absorption factor of D' Alesio and Pirner for this differing W dependence the model give a good description of the data.

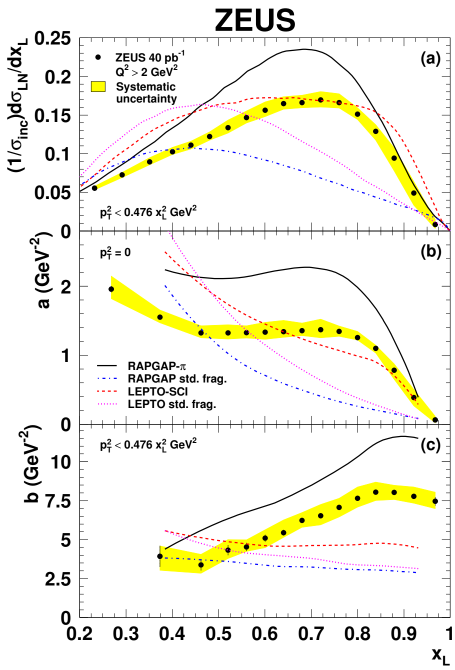

Figure 4: Leading neutron x_L distributions and intercepts and slope for DIS, compared to Monte Carlo models.

Figure 5 shows the slopes b for DIS, and the difference between slopes in photoproduction and DIS, Δb. Also shown are the predictions of a model of pion exchange incorporating neutron absorption and migration [8], and a model including in addition exchanges of ρ and a_2 mesons [9]. The model with only pion exchange predicts too high a value of the slopes, but does predicts the correct magnitude of Δb. The model including also ρ and a_2 exchanges gives a good description of the slopes, including the turnover at highest x_L. It also gives a fair prediction of the value of Δb.

4 Summary

Leading neutron energy and p_T distributions were measured in DIS and photoproduction. A decrease in neutron yield from high Q^2 DIS to very low Q^2 is indicative of absorption. Monte Carlo models incorporating only fragmentation of the proton remnant fail to describe the data. A pion exchange model gives a fair description of the energy distribution of neutron in DIS, but predicts too steep p_T^2 distributions. Addition of neutron absorption to the model describes the suppression seen in photoproduction. Adding further exchanges of ρ and a_2 mesons gives a good description also of the p_T^2 distributions.

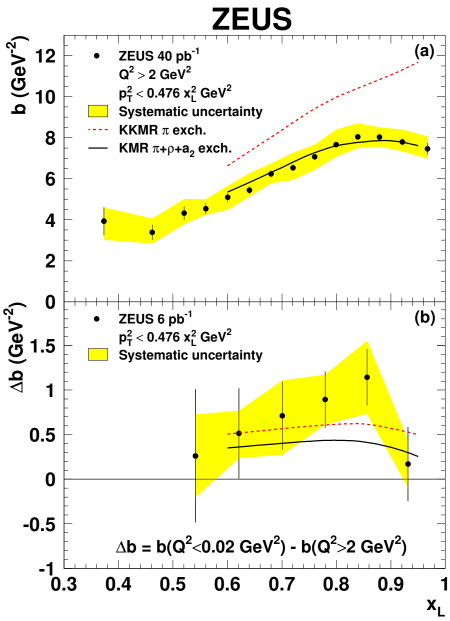

Figure 5: Neutron p_T^2 slopes in DIS (top) and difference in slopes between photoproduction and DIS (bottom). The dashed curve is a model of pion exchange including absorption; the solid curve is the model with the addition of ρ and a_2 meson exchange.

References

[1] ZEUS Coll., S. Chekanov *et al.*, Nucl. Phys. **B776** 1 (2007), and references therein.

[2] M. Bishari, Phys. Lett. **B38** 510 (1972).

[3] N.N. Nikolaev, J. Speth and B.G. Zakharov, Preprint KFA-IKP(TH)-1997-17 (hep-ph/9708290), KFA-IKP (1997);
U. D'Alesio and H.J. Pirner, Eur. Phys. J. **A7** 109 (2000).

[4] G. Ingelman, A. Edin and J. Rathsman, Comp. Phys. Comm. **101** 108 (1997).

[5] H. Jung, Comp. Phys. Comm. **86** 147 (1995).

[6] T. Sjöstrand and M. Bengtsson, Comp. Phys. Comm. **43** 367 (1987).

[7] A. Edin, G. Ingelman and J. Rathsman, Phys. Lett. **B366** 371 (1996).

[8] A.B. Kaidalov *et al.*, Eur. Phys. J. **C47** 385 (2006).

[9] V.A. Khoze, A.D. Martin and M.G. Ryskin, Preprint IPPP-06-36, DCPT-06-72 (hep-ph/0606213) 2006.

[10] Slides:
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