Leading Neutron Production in Deep Inelastic Scattering at HERA

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Abstract. Events with a high energy neutron produced at small angles with respect to the proton beam direction have been observed by the H1 experiment at HERA. The observed energy and $|t|$ distributions of final-state neutrons with energy $E_n \geq 400$ GeV are in good agreement with the predictions of Monte Carlo models based on pion exchange, and with those based on string fragmentation. In the kinematic range $5 \leq Q^2 \leq 100$ GeV^2 and $0.05 \leq y \leq 0.7$, the fraction of $e-p$ collisions which contain a neutron with $E_n \geq 400$ GeV and $|t| < 0.5$ GeV^2 is $(7.8^{+3.0}_{-2.0})\%$. The fraction of DIS events which contain a neutron with $E_n \geq 100$ GeV is independent of Q^2 and x_{BJ}, and is consistent with having the same multiplicity distribution as does the fully inclusive DIS sample.

The H1 experiment at HERA used a new forward neutron calorimeter (FNC) during 1996 to obtain $ep \rightarrow e'nX$ data [1]. Semi-inclusive neutron production in deep inelastic scattering (DIS) is of theoretical interest because virtual pion exchange is believed to be a dominant production mechanism at small momentum transfers with $|t| \ll 1$ GeV^2 [2]. An alternative process, where neutrons are predominantly produced as a result of the hadronization of the proton remnant is also possible. In this paper, we compare our leading neutron data with two different Monte Carlo models in order to test these hypotheses.

The H1 forward neutron calorimeter is situated in the HERA tunnel at a distance of 107 m away from the nominal interaction region. It is a modified version of the SPACAL calorimeter developed by the LAA project at CERN [3,4]. The calorimeter consists of interleaved layers of lead and 2 m long scintillating fibers. The calorimeter is 9.5 interaction-lengths deep ($\lambda_I \approx 21$ cm) and is laterally segmented into 75 hexagonal towers. Each tower is defined by coupling 1141 scintillating fibers to a common photomultiplier located at the rear of the detector. Two planes of hodoscopes situated in front of the FNC are used to veto charged particles. A schematic diagram of the FNC and a detailed

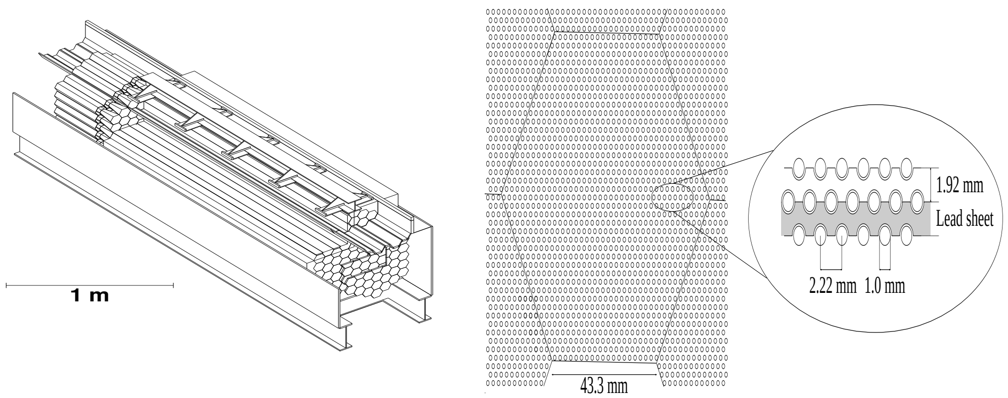

FIGURE 1. Configuration of the H1 forward neutron calorimeter and a detailed view of the lead/scintillating fiber matrix.

view of the lead/scintillating fiber matrix is shown in Fig. 1.

Lepto 6.5 [5] is a Monte Carlo program which uses soft color interactions and an implementation of the string fragmentation model to produce final-state neutrons. In the Pompyt 2.6 Monte Carlo [6], neutrons are produced using a Regge based model of virtual pion exchange. Fig. 2 shows that at the generator level, without any detector resolution or acceptance effects, these Monte Carlo programs give very different predictions for the shape of the neutron energy spectra. The Monte Carlo predictions have approximately the same order of magnitude though in the high energy region with $E_n \geq 600 - 800$ GeV.

Fig. 3 shows the observed neutron energy and $|t|$ distributions for DIS events

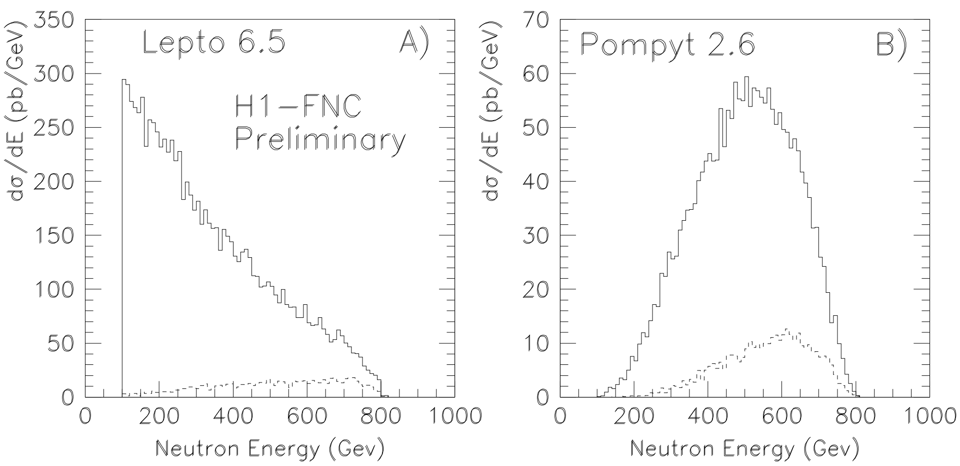

FIGURE 2. The solid curves show the generator level predictions from the Lepto and Pompyt Monte Carlo programs for the energy spectra of neutrons with $E_n > 100$ GeV. The dashed curves show the predictions after the FNC geometrical acceptance. The GRV leading order parton distributions for the pion were used to calculate the Pompyt Monte Carlo predictions.

in the kinematic range $5 \le Q^2 \le 100$ GeV^2 and $0.05 \le y \le 0.7$. The solid points are data and the histograms show the predictions of the Lepto and Pompyt Monte Carlo programs after simulating the FNC geometrical acceptance and energy resolution. A Gaussian neutron energy resolution of 25% is used in these simulations. Both Monte Carlo programs give a good description of neutrons with $E_n \ge 400$ GeV and $|t| \le 1$ GeV^2. The data shown in Fig. 3 corresponds to an integrated luminosity of 1.98 pb^{-1} which is approximately 25% of the total 1996 data sample.

The fraction of DIS events with a neutron with $E_n \ge 100$ GeV is measured to be (36^{+14}_{-9})%. This value is determined by correcting the fraction of observed events ((2.6 ± 0.4)%) for the FNC acceptance and resolution ((7.8 ± 2.0)%), and for the neutron detection efficiency of the calorimeter ((93 ± 5)%). The geometrical acceptance of the FNC was calculated using the Lepto Monte Carlo and depends upon the apertures of the beam line magnets. Its effect on the observed energy spectrum is shown in Fig. 2A. The neutron detection efficiency is less than 100% because of accidental coincidences in our veto hodoscopes which mostly originate from the back-scattering of charged particles produced during the hadronic shower. This inefficiency was estimated

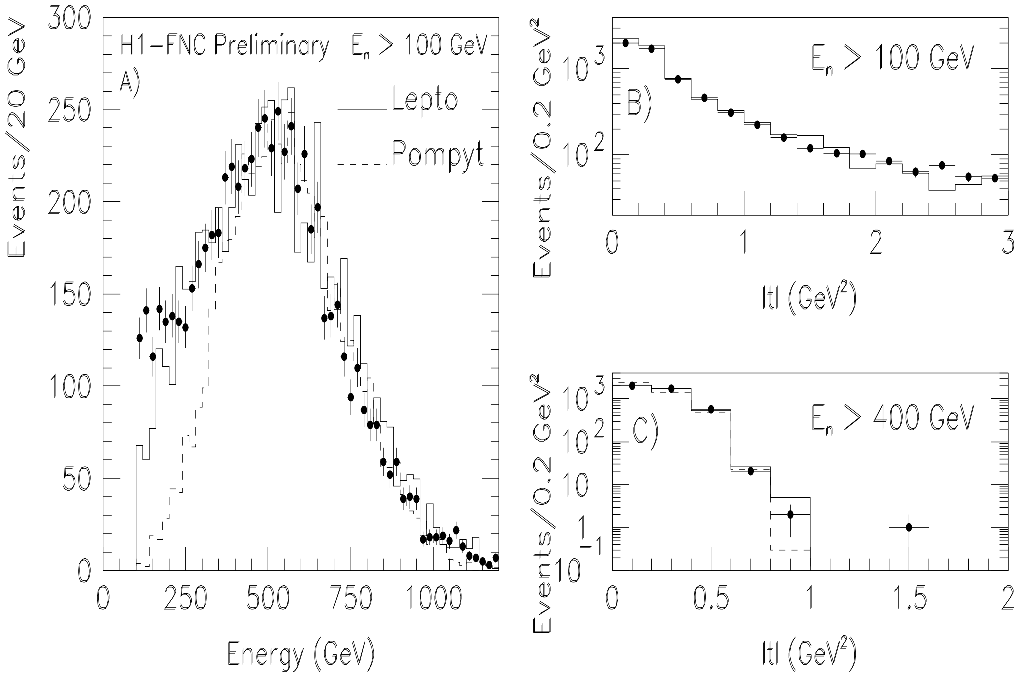

FIGURE 3. The observed neutron energy and $|t|$ distributions compared to the predictions of the Lepto and Pompyt Monte Carlo models. The Pompyt predictions shown in A) and C) are normalized to the number of events observed in the data with $E_n \ge 400$ GeV.

by measuring the rate of signals in our hodoscope planes as a function of the radial distance away from the neutron impact position. The Lepto Monte Carlo predicts that 36% of DIS events contain a neutron with $E_n \geq 100$ GeV which is in agreement with our result.

The ZEUS Collaboration has reported that $(9.1^{+3.6}_{-5.7})$% of DIS events have a neutron with $E_n > 400$ GeV and $|t| < 0.5$ GeV^2 [7]. Applying the same criteria, we obtain consistent results equal to $(8.3^{+3.2}_{-2.1})$% or $(7.3^{+2.8}_{-1.8})$% depending upon whether we use Lepto or Pompyt to correct for the FNC acceptance.

Fig. 4 shows the observed ratio of events with a neutron with $E_n \geq 100$ GeV relative to all DIS events as a function of Q^2, x_{BJ}, and the number of charged tracks reconstructed in the H1 central detector. Within the statistical errors, the distributions in these variables for events with a high energy neutron are the same as those for the fully inclusive DIS sample.

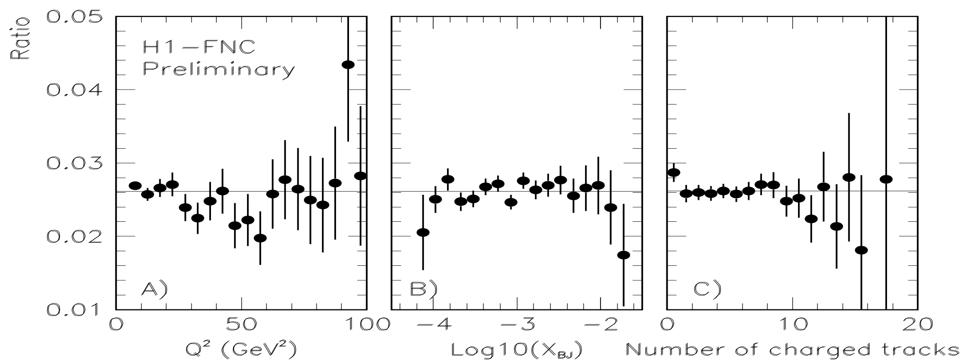

FIGURE 4. The observed ratio of events with a neutron with $E_n \geq 100$ GeV relative to all DIS events as a function of Q^2, x_{BJ}, and the number of charged tracks reconstructed in the H1 central detector.

The preliminary results presented in this paper show that the Lepto and Pompyt Monte Carlo models both give a good description of high energy neutrons with $E_n \geq 400$ GeV. The fraction of DIS events which contain a neutron with $E_n \geq 400$ GeV is approximately 8%. The fraction of DIS events containing a neutron with $E_n \geq 100$ GeV does not depend upon Q^2 or x_{BJ}.

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