

Very forward production and Feynman scaling of photons and neutrons at HERA

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Measurements of very forward neutron and photon production in deep-inelastic ep scattering at HERA as a function of Feynman- x are presented. The data are taken with the H1 detector in the years 2006 and 2007 and correspond to an integrated luminosity of $126 pb^{-1}$. The analysis covers the range of negative four momentum transfer squared at the positron vertex $6 < Q^2 < 100 GeV^2$, inelasticity $0.05 < y < 0.6$ and the center-of-mass energy of the virtual photon-proton system $70 < W < 250 GeV$. The dependence of the cross sections on W is investigated. Predictions from DIS models and from models of the hadronic interactions of high energy Cosmic Rays are compared to the measurements.

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1. Introduction

Measurements of particle production at very small angles with respect to the proton beam direction (forward direction) in ep collision are important for the understanding of proton fragmentation. Measurements of forward particle also provide important constraints for modeling of high energy air showers and thereby are very valuable for the understanding of high energy cosmic ray data.

New results from the H1 Experiment on very forward photon and neutron production in deep-inelastic positron-proton scattering (DIS) are reported [1]. The photons and neutrons are measured in the Forward Neutron Calorimeter (FNC) [2, 3], which was installed at 106 m from the ep interaction point at a polar angle 0° with respect to the proton beam direction at the interaction point. The acceptance of the FNC is defined by the aperture of the HERA beam-line magnets and is limited to scattering angles of $\theta < 0.8$ mrad or pseudorapidity $\eta > 7.9$.

2. Forward Photon and Neutron Spectra in DIS

Differential cross sections normalised to the inclusive DIS cross sections are measured for forward photons and neutrons as a function of the Feynman- x variable $x_F = p_{||}^*/p_{||max}^*$ for three W ranges: $70 < W_1 < 130$ GeV, $130 < W_2 < 190$ GeV and $190 < W_3 < 250$ GeV. The measurements are shown in Figures 1 - 6 together with the Monte Carlo (MC) model predictions.

The DJANGO program [4] is used to generate inclusive DIS events. Higher order QCD effects are simulated using leading log parton showers as implemented in LEPTO [5], or using the Color Dipole Model (CDM) as implemented in ARIADNE [6]. In addition the RAPGAP [7] pion-exchange model is used to describe the high x_F part of forward neutron spectra. The data are also compared with Cosmic Ray (CR) hadronic interaction models commonly used for the simulation of CR air shower cascades: EPOS [8], QGSJET 01 [9] [10], QGSJET II [11] [12] and SIBYLL [13] [14].

In Figure 1 the cross sections measured for the most energetic photons with pseudorapidity $\eta > 7.9$ is shown as a function of Feynman- x variable for three W region compared to DJANGO (upper row) and CR (lower row) models. Both MC models, LEPTO and CDM, significantly overestimate the rate of forward photons by $\sim 70\%$. The shape of the LEPTO prediction is close to the data, while CDM exhibits a harder x_F behaviour. The CR models are closer to data in absolute values, but are also higher by $\sim 30 - 50\%$. These properties are well visible in the MC/Data ratios depicted in Figure 2. The best description of the forward photon measurements is provided by QGSJET model. In Figure 3 the W_2/W_1 and W_3/W_1 ratios of the x_F spectrum are shown for DJANGO (upper row) and CR (lower row) models. The ratio for the data is consistent with unity within errors and being independent of x_F , supporting the validity of Feynman scaling. The ratios for the standard DIS models (LEPTO and CDM) are slightly larger, and the ratios for CR models are lower than unity.

The results of the x_F measurements of forward neutron production are presented in Figure 4. In the upper row a comparison of the data and the CDM, RAPGAP- π (pion-exchange) and the combination of these models is shown. The ‘combined’ model describes the data well. The comparison of the data with the CR hadronic interaction models depicted in lower row of Figure

4. In the Figure 5 MC to Data Ratios is given for combination of CDM and RAPGAP- π model and in the lower row for CR models. One can say the EPOS gives the best description of the data. In Figure 6 the W_2/W_1 and W_3/W_1 ratios of the x_F spectra are presented for Combined (upper row) and the CR (lower row) models. The ratio for the data is consistent with unity and independent of x_F within errors, supporting the validity of Feynman scaling. The combined model deviates from unity but does not depend on x_F while most of the CR models show a dependence with x_F indicating the x_F scaling is broken in these models.

3. Fraction of DIS events with forward photons and neutrons

The measurement of forward photons and neutrons allows a test of the limiting fragmentation hypothesis, which implies that forward particle production is insensitive to W . To investigate this prediction, the ratio of the forward photon and neutron production cross section to the inclusive DIS cross section is measured as a function of W and compared with the standard DIS and the CR models in Figure 7.

Within the uncertainties measured fraction of DIS events with photons and neutrons is independent from W , in agreement with the hypothesis of limiting fragmentation. LEPTO and CDM indicate a significant differences in normalization compared to data, but independence of W for photons. The CR models indicate a large spread of their predictions and some W dependencies for both, the photon and the neutron yields. For forward neutrons the combination of the standard DIS and pion exchange models describe the data well, but shows some W dependencies.

4. Summary

The production of forward photons and neutrons has been studied in deep inelastic positron-proton scattering in the kinematic range $6 < Q^2 < 100 \text{ GeV}^2$, $0.05 < y < 0.6$ and in the pseudorapidity range of photons and neutrons $\eta > 7.9$ in laboratory frame. The Monte Carlo models overestimate the production rate of photons. While LEPTO describes the shapes well, CDM predicts a harder x_F spectrum. The CR models considered are closer to the data in normalisation. For forward neutrons none of the models describes the data well. The combination of standard fragmentation and the pion-exchange models describes the measured x_F neutron spectra well.

The measurements support the limiting fragmentation hypothesis and are consistent with Feynman scaling. The present measurements provides further insight into the proton fragmentation process and can be used for models tuning.

References

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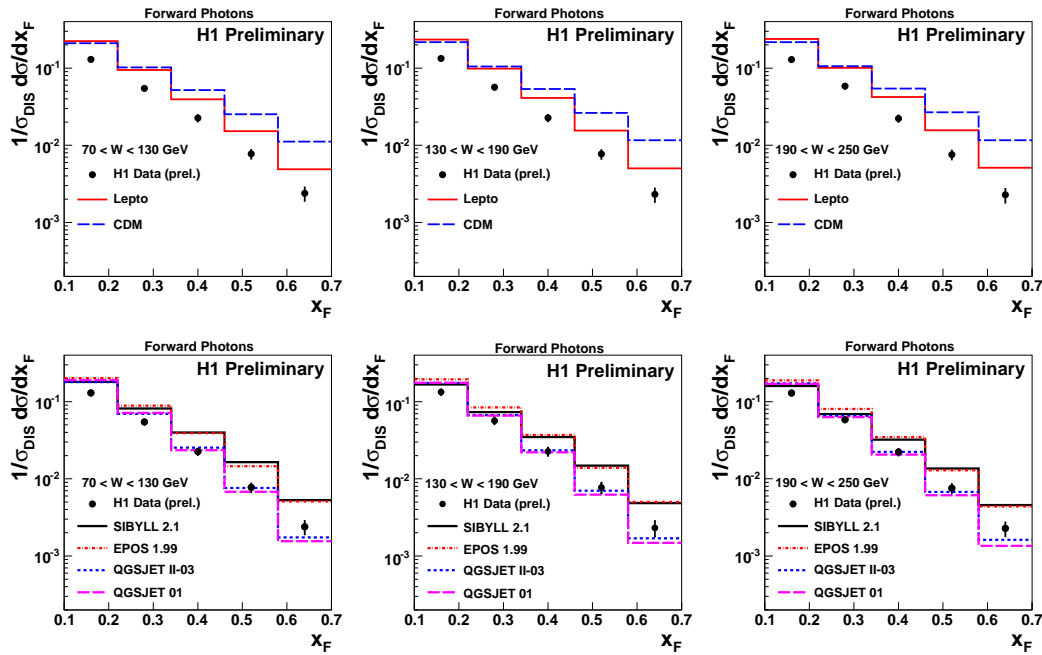


Figure 1: Normalized cross sections for forward photon production as a function of x_F compared to predictions of the LEPTO and CDM MC models (upper row), and Cosmic Ray hadronic interaction models (lower row) for three W ranges.

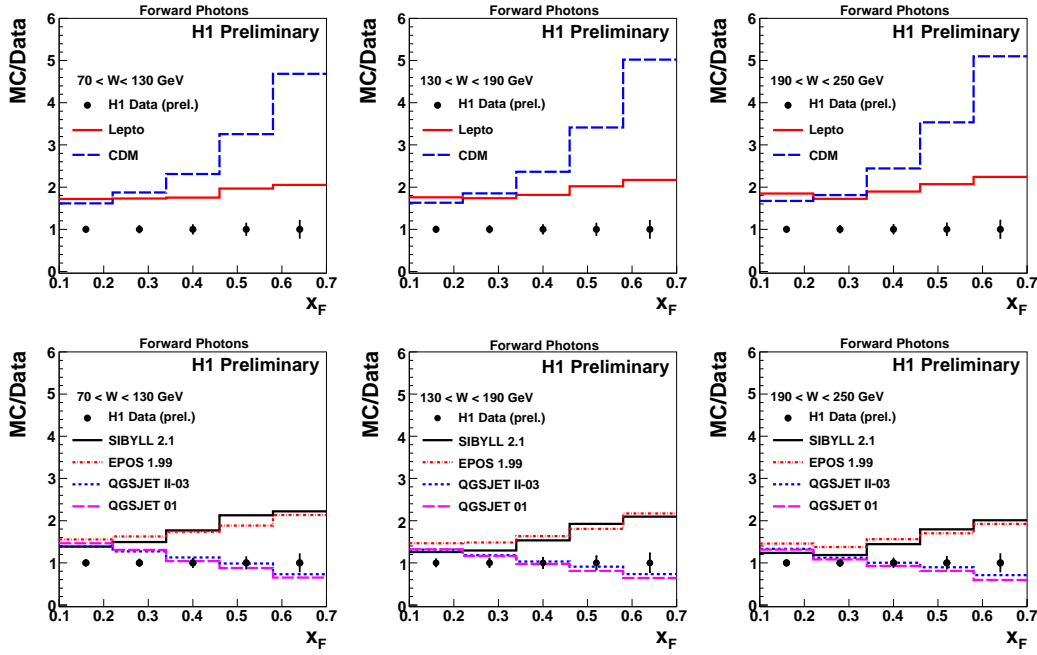


Figure 2: The ratios of MC predictions to the data as a function of x_F compared to predictions of the LEPTO and CDM MC models (upper row), and Cosmic Ray hadronic interaction models (lower row) for three W ranges.

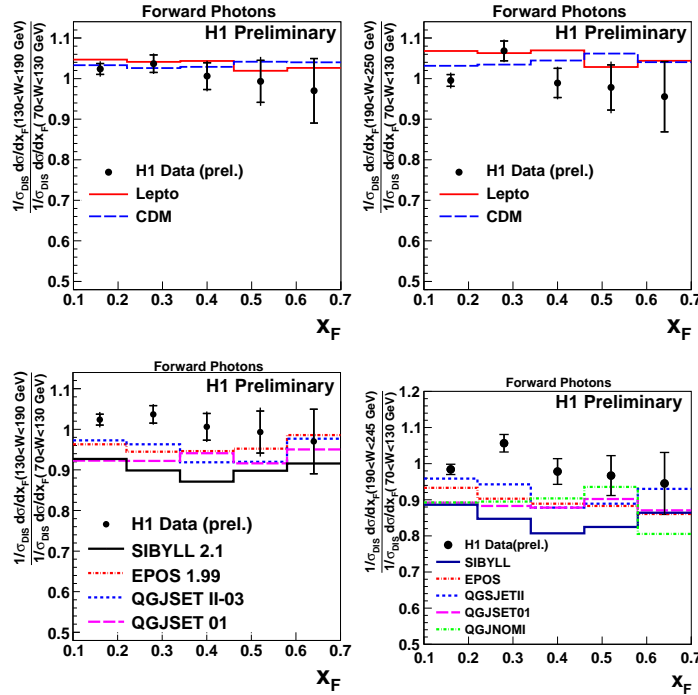


Figure 3: The Photons W_2/W_1 and W_3/W_1 x_F spectra ratios for LEPTO and CDM MC models (upper row), and Cosmic Ray hadronic interaction models (lower row).

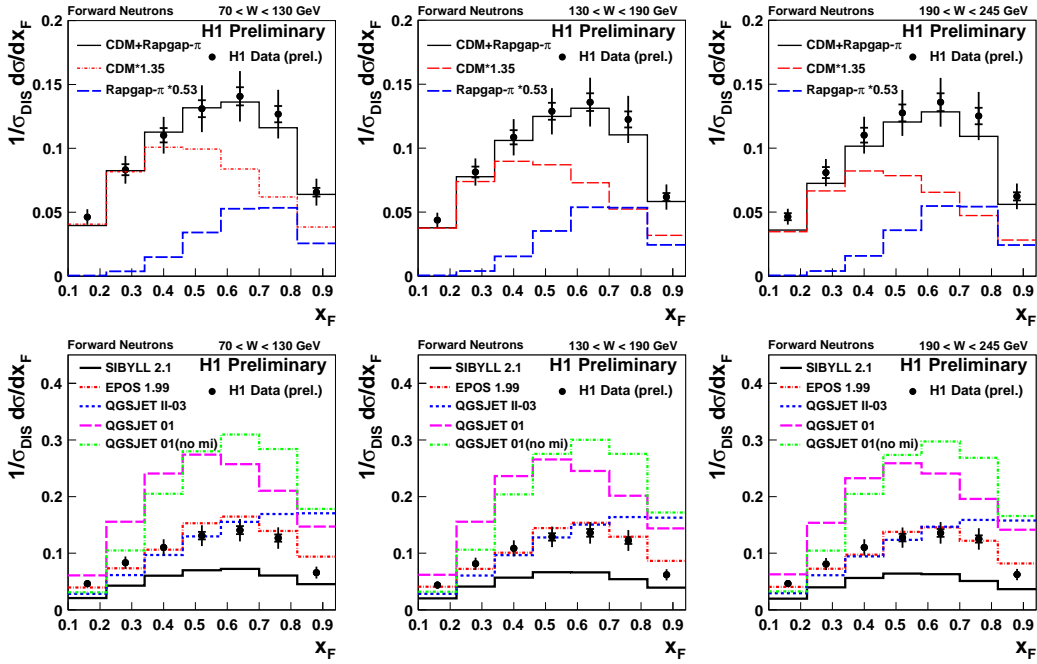


Figure 4: Normalized cross sections for forward neutron production as a function of x_F compared to CDM, the RAPGAP pion-exchange model and their combination using scaling factors (upper row), and Cosmic Ray hadronic interaction models (lower row) for three W ranges.

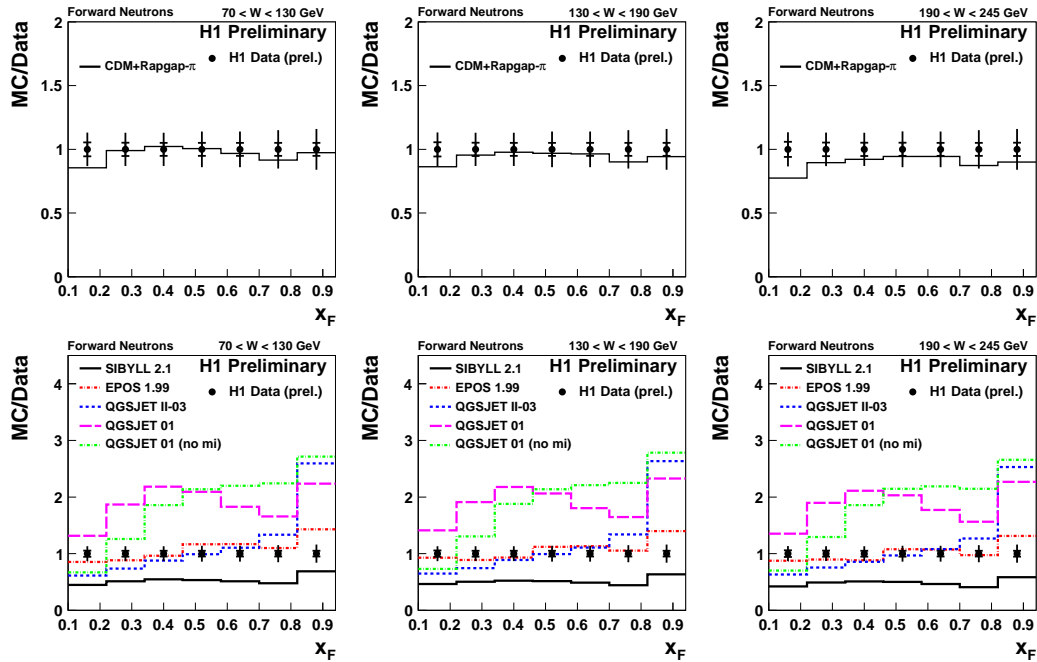


Figure 5: The ratios of MC predictions to the data as a function of x_F compared to predictions of the Combined(CDM+RAPGAP) models (upper row), and Cosmic Ray hadronic interaction models (lower row) for three W ranges.

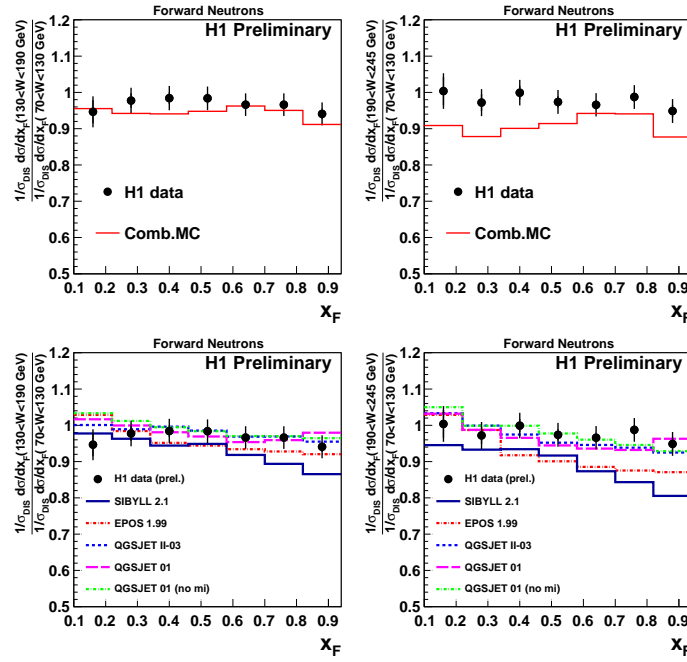


Figure 6: The Neutrons W_2/W_1 and W_3/W_1 x_F spectra ratios for Combined CDM and RAPGAP pion-exchange models (upper row), and Cosmic Ray hadronic interaction models (lower row).

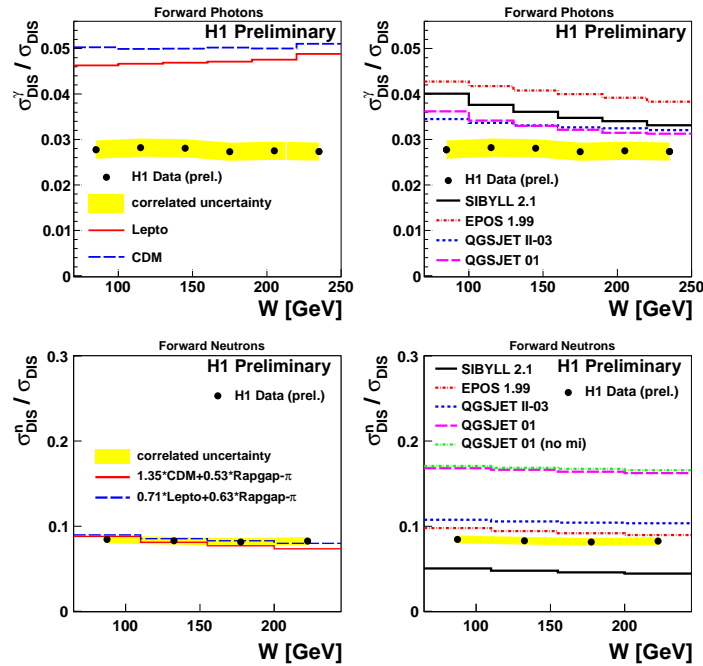


Figure 7: Fraction of DIS events with forward photons and neutrons as a function of W . Upper (lower) row shows the distributions for the forward photons(neutrons). The MC models are compared to the measurements.