# Measurement of Dijet Cross Sections With Leading Neutrons in Photoproduction at HERA [1]

Armen Bunyatyan

*Max-Planck-Institut für Kernphysik,*
*Saupfercheckweg 1, 69117 Heidelberg, Germany*
*and Yerevan Physics Institute, Armenia*
*E-mail: bunar@mail.desy.de*

Representing the H1 and ZEUS Collaborations

**Abstract.** An analysis is presented of dijets in photoproduction at the $ep$ collider HERA where a leading neutron with an energy $E_n > 400$ GeV and angle $\theta_n < 0.8$ mrad with respect to the proton direction is detected. The average photon-proton center-of-mass energy is about 200 GeV. Mechanism of leading neutron production is studied. The differential cross sections are measured as function of jet transverse energy and pseudorapidity, the fraction of the photon momenta entering the hard scattering, $x_\gamma$, and $x_\pi$, interpreted as the fraction of pion momenta in a model where the interaction proceeds via exchange of a pion. The Monte Carlo predictions based on standard photoproduction processes and those based on the one-pion-exchange model, using different parameterizations for the pion structure function, are compared to the measurements.

## INTRODUCTION

The H1 and ZEUS experiments at HERA have observed a class of events with highly energetic forward neutrons in the final state. While some leading neutron events may be explained by the hadronization of the quarks participating in the interaction, the exchange of a colour singlet particle (mainly $\pi^+$) is also expected to contribute to their production. If the one-pion-exchange process is dominant one may hope to extract the pion structure function from such measurements (see e.g. [1–3]).

The parton distributions of the pion in the region of $x \gtrsim 0.2$ have been measured by fixed target experiments. The analysis of leading neutron data in DIS at HERA [4,5] made possible for the first time a measurement of the pion structure function at small Bjorken-$x$ ($\sim 10^{-3} - 10^{-2}$). Further tests of the pion parton distributions can be provided by studies of the high $p_T$ jet production in hadronic interactions.

In this paper we report the recent results of H1 and ZEUS collaborations on the dijet production in photoproduction with leading neutrons [6,7]. Different predictions in the form of Monte Carlo simulations are compared to the measurements.

---

[1] Talk given at the International Conference PHOTON-2000, August 26–31, Ambleside, England

# RESULTS

For this analysis the H1 collaboration used the data from 1996-97 running period. The data sample corresponds to photon virtuality of $Q^2 < 0.01$ GeV$^2$ and $\gamma p$ centre-of-mass energies of $156 < W_{\gamma p} < 242$ GeV. The events were selected which contain two jets with a transverse energy $E_T^{jet} > 7$ GeV and pseudorapidity of $-1 < \eta^{jet} < 2$ reconstructed with a cone-type jet algorithm.

ZEUS collaboration use the data collected in 1995. The data sample corresponds to the kinematical range of $Q^2 < 1$ GeV$^2$ and $134 < W_{\gamma p} < 269$ GeV. The $k_T$-algorithm was used to select jets with $E_T^{jet} > 6$ GeV and $|\eta^{jet}| < 2$.

The subsamples of dijet events with leading neutrons were selected by requiring neutron with energy $E_n > 400$ GeV and scattered angle $\theta_n < 0.8$ mrad to be detected in the Forward Neutron Calorimeters (FNC) located in the HERA tunnel at about 107 m downstream of the $ep$ interaction point.

## Neutron energy spectrum

The energy distribution of leading neutrons is sensitive to the mechanism responsible for neutron production. Figure 1 shows the neutron energy distributions measured by Forward Neutron Calorimeters of H1 and ZEUS. Distributions are not corrected for detector inefficiency and acceptance.

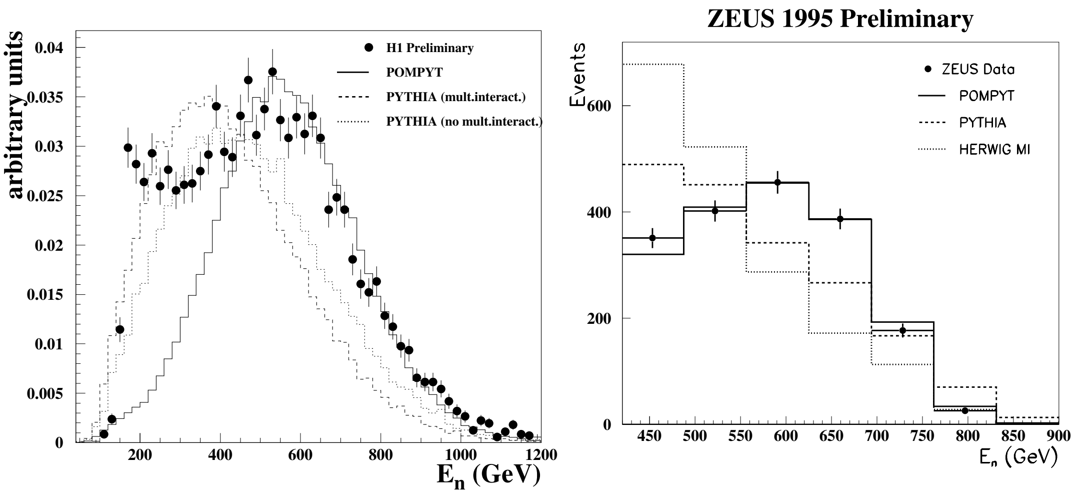


**FIGURE 1.** The uncorrected neutron energy spectrum for data and Monte Carlo simulations.

For comparison, the expectations from the different Monte Carlo simulations are shown which are normalized to allow for comparison of shapes. The POMPYT [8] Monte-Carlo predictions are based on the one-pion-exchange approach (using the light-cone pion flux from ref. [1]). In contrast, in the PYTHIA [9] and HERWIG [10] Monte-Carlo generators the neutrons are produced from the hadronization of proton remnant. In addition to the main hard parton scattering the PYTHIA and

HERWIG generators include the possibility for the additional (multiple) interactions between the remnant partons which were found necessary to describe the inclusive measurements of jet and energy flow.

The standard fragmentation models, both the Lund string model used by PYTHIA and the cluster fragmentation model used by HERWIG, fail to reproduce the neutron energy spectrum, predicting a distribution which is shifted towards lower energies. POMPYT, on the other hand, describes the energy spectrum well for $E_n \gtrsim 400$ GeV, thereby suggesting the necessity for a colour singlet component in the proton in the form of pion exchange and its explicit contribution to leading neutron production. A large tail at low $E_n$ in H1 data distribution compared to Monte Carlo is due to the background from neutral electromagnetic particles ($\pi^0, \gamma$) which are not present in the Monte Carlo simulations used for this analysis.

## Test of factorization

If the pion exchange is the dominant mechanism for production of leading neutrons, then the factorization of proton and lepton vertices is expected. Factorization can be tested by studying the ratios of jet cross sections for leading neutron events to inclusive jet cross section. Ratios have the advantage that the systematic effect are greatly reduced and that they provide a qualitative comparison of shapes of cross sections. Figure 2 shows the ratios as function of jet transverse energy $E_T^{jet}$ and variable $x_\gamma$, which is calculated from the jets energies and pseudorapidities ($x_\gamma = \Sigma E_T^{jet} e^{-\eta^{jet}} / 2E_\gamma$) and can be interpreted as a fractions of photon momentum carried by the partons entering the hard scattering subprocess. The contribution of leading neutron events is about 4% of the inclusive jet production and practically independent of $E_T^{jet}$ as expected from factorization. The strong increase of the ratio with $x_\gamma$ may be due to phase space effects– for leading neutron events the average

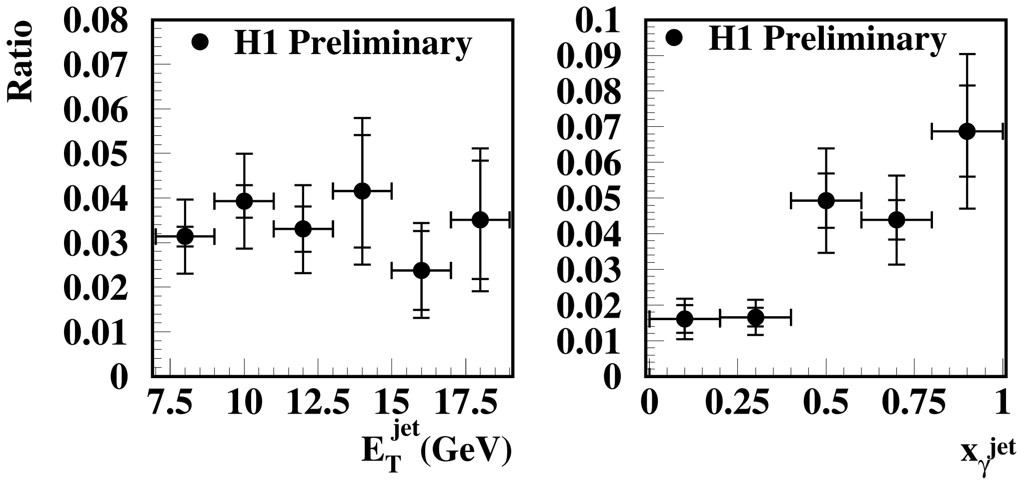


**FIGURE 2.** The ratios of the cross sections of dijet photoproduction with leading neutrons to inclusive dijet photoproduction.

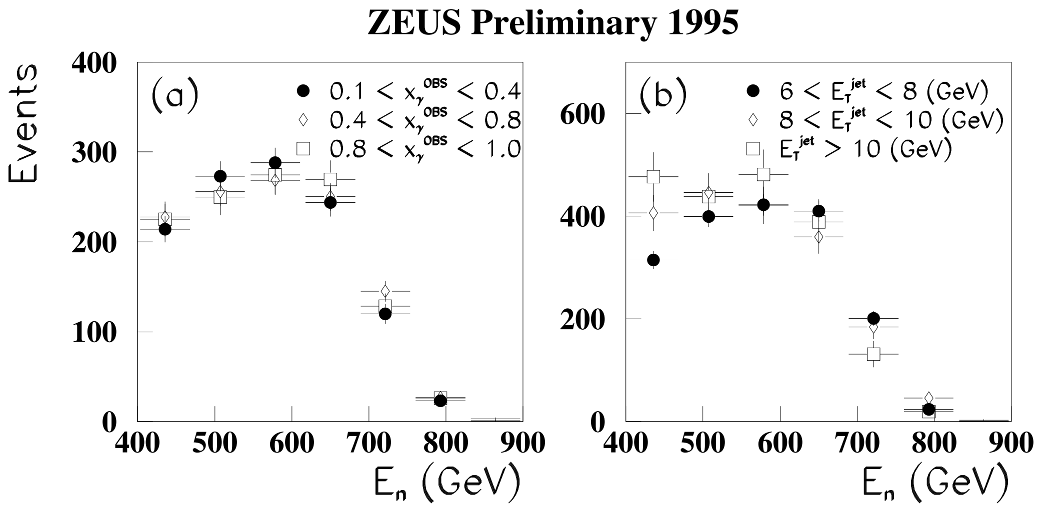


**FIGURE 3.** The uncorrected neutron energy spectrum for different ranges of $(a)$ $x_\gamma$ and $(b)$ $E_T^{jet}$.

total energy available for jet production is smaller than in inclusive sample because significant part of proton beam energy is taken away by the neutron.

To further test the factorization properties of the dijet cross section, the neutron energy spectra are studied for different values of $x_\gamma$ and $E_T^{jet}$. The shape of the observed neutron energy spectrum is approximately independent of $x_\gamma$ and $E_T^{jet}$, as seen in Figure 3. The results of these studies are consistent with factorization of the proton and lepton vertices and the one-pion-exchange.

## Dijet cross sections

The dijet cross sections for events with leading neutrons ($E_n > 400$ GeV and $\theta_n < 0.8$ mrad) have been measured differentially in the jet transverse energy and pseudorapidity, $E_T^{jet}$ and $\eta^{jet}$, and the fractional momenta of the photon $x_\gamma$ and the pion $x_\pi$ carried by the partons involved in the hard scattering ($x_\pi = \Sigma E_T^{jet} e^{\eta^{jet}}/2(E_p^0 - E_n)$, where $E_p^0$ is the proton beam energy).

Figure 4 shows the measured cross sections together with Monte-Carlo predictions. The POMPYT and RAPGAP [11] Monte-Carlo models which are based on one-pion-exchange describe the cross sections well both in shapes and absolute values. PYTHIA which includes multiple interactions fails to describe the cross sections for leading neutrons although this model describes the inclusive jet measurements. The PYTHIA without multiple interactions is able to describe the cross sections, however since it failed to describe the neutron energy spectrum, the agreement in absolute values of cross section is to large extent accidental.

In the framework of the one-pion-exchange model in POMPYT, the sensitivity of the measurement to different choices for the pion structure function [12] is presented in Figure 5. It is clear that the present level of systematic uncertainty in the measurement means that no preference for any of the pion structure function

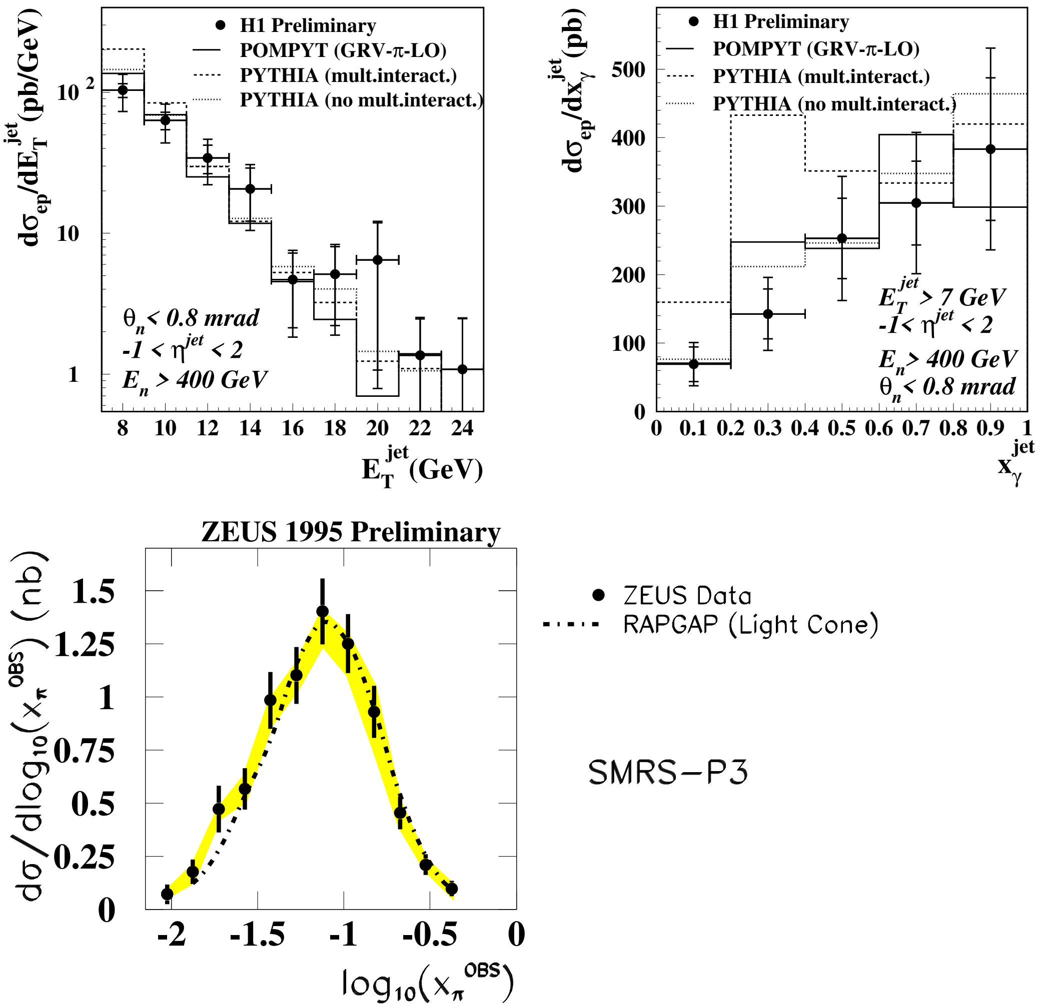


**FIGURE 4.** Dijet differential cross sections for events with leading neutrons $E_n > 400$ GeV and $\theta_n < 0.8$ mrad. The Monte-Carlo predictions are compared to the measurements.

parameterizations can yet be given.

## SUMMARY

The photoproduction of dijets is studied in events containing an energetic forward neutron in the final state.

The contribution of events with this leading neutron is about 4% of the inclusive dijet production and independent on the jet transverse energy. The neutron energy spectrum is also independent of jet $E_T$ and $x_\gamma$. These results are consistent with the factorization of proton and lepton vertices and the one-pion-exchange interpretation.

Models which do not include pion exchange fail to describe the neutron energy

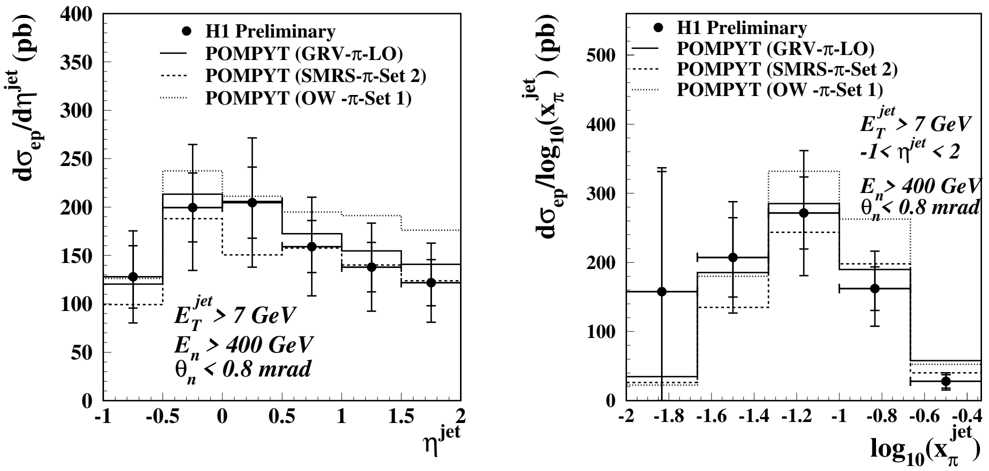


**FIGURE 5.** Dijet differential cross sections for events with leading neutrons $E_n > 400$ GeV and $\theta_n < 0.8$ mrad. The POMPYT Monte Carlo predictions using different parameterizations for the parton distributions in the pion are compared to the measurements.

spectrum. Models which include pion exchange describe the neutron energy spectrum well, thereby suggesting the need for a colour singlet component of proton structure in the form of pion exchange and leading neutron production. These models also reproduce the observed jet production differential cross sections. Within the present experimental uncertainties of this measurement, it is not yet possible to discriminate between different parameterizations for the pion structure function.

## REFERENCES


1. H. Holtmann et al., *Phys.Lett.* **B338**, 363 (1994).
2. B. Kopeliovich, B. Povh and I. Potashnikova, *Z. Phys.* **C73**, 125 (1996).
3. M. Przybycień, A. Szczurek and G. Ingelman, *Z. Phys.* **C74**, 509 (1997).
4. H1 Collaboration, *Eur. Phys.J.* **C6**, 587 (1999).
5. ZEUS Collaboration, *Energetic neutron production in $e^+p$ collisions at HERA*, Paper 441, XXXth ICHEP Conference, Osaka, 2000.
6. H1 Collaboration, *Measurement of dijet cross sections with leading neutrons in photoproduction at HERA*, Paper 959, XXXth ICHEP Conference, Osaka, 2000.
7. ZEUS Collaboration, *Measurement of dijet cross sections with leading neutron in photoproduction at HERA*, Paper 432, XXXth ICHEP Conference, Osaka, 2000.
8. P.Bruni, G. Ingelman, *Proceedings of the Europhysics Conference, Marseille, France, July 1993, p.595*; see also http://www3.tsl.uu.se/thep/pompyt
9. T. Sjöstrand, *Comp. Phys. Comm.* **82**, 74 (1994).
10. G. Marchesini et al., *Comp. Phys. Comm.* **67**, 465 (1992).
11. H. Jung, *Comp. Phys. Comm.* **86**, 147 (1995).
12. M. Glück, E. Reya and A. Vogt, *Z. Phys.* **C53**, 651 (1992);
    J.F. Owens, *Phys.Rev.* **D30**, 943 (1984);
    P.J. Sutton et al., *Phys.Rev.* **D45**, 2349 (1992).