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PRODUCTION OF PROTONS IN PHOTOPRODUCTION AT HERA*

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A measurement of the inclusive cross-section for the photoproduction of protons in the central fragmentation region at HERA is presented. The measured cross-section is compared with the prediction of the PYTHIA MC model. The obtained value of the diquark suppression factor in the Lund string model is different from that obtained in e^+e^- data. The dependence of the cross-section as a function of the transverse mass M_{T} is shown to be similar for different hadrons produced in photoproduction at HERA.

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1. Introduction

Production of low momentum particles in the region away from the beam remnant is a key laboratory to study the non-perturbative effect of hadronisation, *i.e.* the process of conversion of the partonic final state into hadrons. The lack of understanding of this phenomenon leads to a huge variety of phenomenological models, each with a large number of free parameters. An example of such a model is the Lund string model [1] and its implementation in the JETSET Monte Carlo (MC) model [2]. Comparison of the predictions of this model with accurate data from the LEP experiments [3] allows some of the parameters to be precisely fixed. It is possible to test the universality of the fragmentation prescription in such models, by comparing the predictions of the MC, tuned with e^+e^- data, to the HERA data in photoproduction. In this paper we present a measurement [4] of centrally produced low momentum protons and compare the results with the

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predictions of the PYTHIA MC [2]. A common behaviour as a function of $M_{\rm T} = m + p_{\rm T}$ in the production cross-section for different hadrons of mass m and transverse momentum $p_{\rm T}$, produced in photoproduction, is also demonstrated.

2. Event selection

Experimental data for the analysis were collected with the H1 detector [5] during the 1996 running period, in which HERA collided 27.5 GeV positrons with 820 GeV protons. The data sample corresponds to an integrated luminosity of 6.0 pb^{-1}.

The photoproduction events are identified by a first level trigger which requires energy in the small angle electron tagger and the presence in the central tracking chamber of several well measured tracks which originate from the primary vertex. The former requirement restricts the kinematic region to $Q^2 < 0.01$ GeV^2 and $0.3 < y_e < 0.7$, where Q^2 is the virtuality of the exchanged photon and y_e is the inelasticity of the scattered positron. The average centre of mass energy of the γp system is 200 GeV.

Background events coming from the interaction of beam particles with the residual gas in the beam pipe (beam-gas events) are characterized by small or zero energy deposition in the direction opposite to the direction of the incoming beam particle. To suppress such background, only events with energy deposits greater than 2 GeV in both the forward region of the Liquid Argon Calorimeter and in the backward calorimeter SPACAL are accepted. Charged particles are measured in the H1 central tracker which covers the polar angle range of $22^\circ < \theta < 150^\circ$, where θ is defined with respect to the incoming proton direction. dE/dx, the measured specific ionization energy loss of the particle, is used to identify the protons in the region of high acceptance and resolution, $0.3 < p_{\rm T} < 0.55$ GeV and $-0.3 < y < 0.3$, where $p_{\rm T}$ is the transverse momentum relative to the beam-line and y is the rapidity of the particle.

The main source of the background is the production of secondary protons by particles from ep collision, interacting in the beam pipe and other material in front of the track chambers. In order to estimate the yield of such protons the distribution of closest approach (DCA) of the track to the primary vertex is analyzed. For background protons this distribution is flat, in contrast to the shape for protons and anti-protons from ep interaction, see Fig. 1. This background is subtracted on a statistical basis.

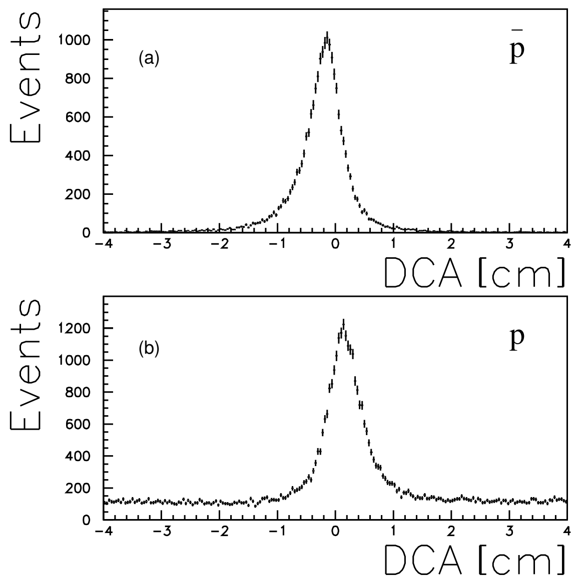

Fig. 1. DCA distribution for (a) identified anti-protons and (b) identified protons.

3. Results

The measurement is made in the laboratory frame of reference and is presented as an average cross-section $E\frac{d^3\sigma}{d^3p}$ for photoproduction of protons and anti-protons, *i.e.* as half the sum of the corresponding proton and anti-proton cross-sections. Here E and p are the proton[1] energy and momentum, respectively. This cross section is shown as a function of the proton transverse momentum p_{T} and rapidity y in Fig. 2. The errors are the quadratic sum of the statistical and systematic uncertainties. The systematic component is dominant. Using the MC simulation, the resulting cross-sections are corrected for the acceptance cuts discussed in the previous section (cuts on the energy in forward and backward part of the H1 calorimeters and on the number of tracks coming from the primary vertex).

The measured cross-section is compared with the PYTHIA MC model [2] prediction, including the GRV-LO proton and photon parton densities [6]. In this model Leading Order (LO) QCD matrix elements are used to describe the hard scattering processes, while parton shower algorithms produce initial and final state parton radiation. Multiple soft and hard parton interactions are also simulated. For the hadronisation step the Lund string model [1], as implemented in JETSET 7.4 [2], was utilized.

[1] Henceforth proton is used to designate both proton and anti-proton.

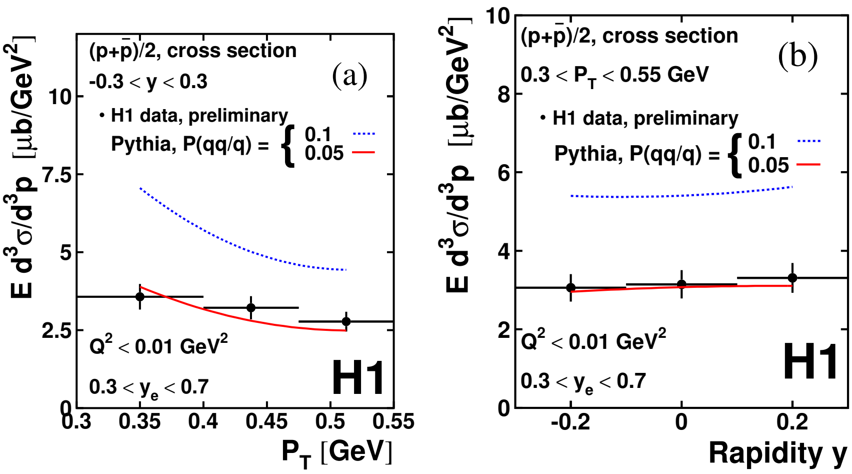

Fig. 2. The measured photoproduction cross-section $E\frac{d^3\sigma}{d^3p}$ as a function of (a) transverse momentum p_{T} and (b) rapidity y, in the region of $0.3 < p_{\mathrm{T}} < 0.55$ GeV and $-0.3 < y < 0.3$. The cross-section represents half of the sum of protons and anti-protons inclusively produced. The prediction of the PYTHIA model is shown with two different values of the diquark suppression factor, 0.1 (upper curve) and 0.05 (lower curve).

The yield of baryons produced during the hadronisation in the Lund string model is proportional to the amount of diquark states created in the color field. Thus the most important parameter of this model related to the production of protons is the diquark suppression factor which determines the probability of producing a $(qq, \bar{q}\bar{q})$ pair relative to the $(q, \bar{q})$ pair in the color field. Results from e^+e^- collisions at LEP favor a value of approximately 0.1 [3] for this parameter.

The PYTHIA MC model with the e^+e^--derived value of 0.1 overshoots the data (Fig. 2), although it provides a fair description of the shape of the spectra. With the parameter value 0.05 both the shape and yield are well described. This could indicate the absence of universality of baryon production within this model approach. More detailed studies of the production of different hadrons over a wider range a phase space than covered in this work are required in order to further understand this phenomenon.

4. Other identified particles

The present measurement of the inclusive proton cross-section adds a new point to the series of measurements on inclusive hadron production in photoproduction at HERA. Previous data on the production of long-lived low mass hadrons $\pi^{\pm}$ [7, 8], K^0, Λ^0 [9] and the charmed mesons D^{*+}

and D_s [10, 11] are available. In the following we compare these cross-sections with the present new measurement of protons. For this comparison we convert the published data points to differential cross-sections $E\frac{d^3\sigma}{d^3p}$, correcting for the flux of the photons [12] where ep cross-sections are given. The pion data are recalculated from the measured charged particle spectra taking into account a 17% admixture of charged kaons and protons to these spectra. In the comparison for different hadrons the cross-sections are given for one isospin projection and are corrected for the spin.

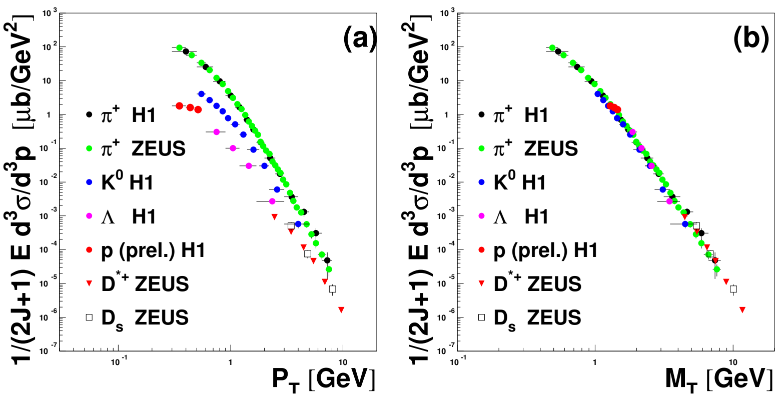

Fig. 3. Photoproduction cross section $E\frac{d^3\sigma}{d^3p}$ for different hadrons as a function of (a) transverse momentum $p_{\rm T}$ and (b) transverse mass $M_{\rm T}$ $(= m+p_{\rm T})$, in the central rapidity region as measured in the laboratory frame of reference. The cross-sections are given for one isospin and corrected for the spin.

In Fig. 3(a) these cross-sections are plotted as a function of the transverse momentum $p_{\rm T}$. The individual particle cross-section clearly depends strongly on the specific hadron mass. It was shown in lepton–hadron [7] and hadron–hadron [13] collisions that the $p_{\rm T}$-dependence of the hadron cross-sections is well described by a power-law behavior $A(p_0 + p_{\rm T})^{-n}$. In e^+e^- collisions, on the other hand, the production rates of hadrons are determined only by the particle spins, isospins and masses [14]. We replot in Fig. 3(b) our cross-section data as a function of the modified transverse mass $M_{\rm T}$ $(= m+p_{\rm T}$, where m is the particle mass). The data show that the cross-sections for different hadrons produced in the photoproduction regime at HERA have similar behaviour as a function of this variable.

In summary, we have presented a measurement of the production of protons in photoproduction at HERA, performed in the central rapidity region and at low proton momentum. The PYTHIA MC model only describes the normalisation of the cross section if the model parameter (diquark suppression factor) is a factor of 2 smaller than the value obtained from e^+e^-

collisions. The cross-sections for different hadrons produced in photoproduction at 200 GeV are shown to have similar behaviour as a function of $m + p_{\mathrm{T}}$.

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