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Measurement of Inclusive Cross-Sections of the Photoproduction of Protons at HERA.

H1 Collaboration

Abstract

The inclusive cross-sections for the photoproduction of protons as a function of transverse momentum and rapidity are measured with the H1 detector at the ep collider HERA. The analysis is performed for scattering processes in a kinematic region restricted to inelasticities $0.3 < y_e < 0.7$ and virtuality of the exchanged photon $Q^2 < 0.01\mathrm{GeV}^2$. The measurements are compared to expectations from QCD-based models as a means of investigating the sensitivity of baryon production in hadronisation to the properties of the QCD perturbative vacuum.

1 Introduction

Measurements by the H1 and ZEUS Collaborations of the hadronic final state at the ep collider HERA have proven important in probing QCD dynamics and have provided information on the partonic nature of the proton and the photon[1]. This paper continues a series of studies which are designed to produce a picture of the ep induced hadronic final state that is as complete as is experimentally possible. Measurements are presented of the kinematic properties of low transverse momentum protons[1] inclusively photoproduced in electron-proton interactions. The aim of this study is to investigate, using QCD-based models, baryonic production mechanisms and assess the environmental independence of these processes.

Within the framework of traditional QCD-based ep scattering models, baryons are produced in the ep-induced hadronic final state through the conservation of the baryon number of the incoming proton and a soft hadronisation mechanism in which the partonic final state is converted to hadrons. This is achieved by hadronising a series of colour strings[2] stretched between colour triplet charges in the partonic final state. This leads to the vacuum production of quark, anti-quark $(q, \bar{q})$ and diquark, anti-diquark $(qq, \bar{q}\bar{q})$ pairs which eventually form bound states of mesons and baryons. However, this approach may not be valid in gluon-dominated processes at HERA which give rise to configurations of octet colour charges. The hadronisation of such fields would be characterised by a lower baryon rate than in fields between triplet charges[3].

Such a test of this aspect of non-perturbative QCD modelling can be made by comparing ep measurements with string model calculations, with free parameters determined from hadronic final state measurements in e^+e^- collisions. This prescription described well earlier measurements of the production characteristics of K_s^0 and Λ particles in ep interactions[4, 5] albeit with limited statistical precision. This paper presents complementary measurements of protons in the previously uncovered fragmentation-dominated low momentum region and uses a data-set five times as great as used in the earlier work.

2 Event Selection and Detector Description

Experimental data for this analysis were collected with the H1 detector[7] during the 1996 running period, in which HERA collided 27.5 GeV positrons with 820 GeV protons. The data sample used corresponds to an integrated luminosity of 6.0 pb^{-1}.

Photoproduction events are characterised by the presence of the scattered electron in the low angle electron tagger. This restricts the kinematic region over which this study is made 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 electron.

The scattered electrons are identified by a first level trigger which requires energy in the electron tagger and the presence of several tracks in the central tracking chamber which originate from the primary vertex.

[1]The term proton is used generically in this paper to also refer to an anti-proton unless stated otherwise or when used in the context of the colliding beams.

In order to perform the analysis in a region of high trigger acceptance, an additional requirement is made that there are at least five tracks in the central tracking chamber following full event reconstruction.

To suppress beam-gas background events, both the summed hadronic energy in the forward region of the Liquid Argon calorimeter and the total electromagnetic energy in the backward detector, the SPACAL, are required to be greater than 2 GeV.

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. The specific ionisation energy loss of the particles, dE/dx, is also measured and this is used to identify the protons in this study in the high acceptance and resolution region of $0.3 < p_T < 0.55$ GeV and $-0.3 < y < 0.3$, where p_T is the transverse momentum relative to the beam-line and y is the rapidity of the particle.

3 QCD based models

QCD-based calculations are confronted with the data via the PYTHIA model[6], employing the GRV-LO proton and photon parton densities[9]. This scheme uses leading order (LO) QCD matrix elements to describe the hard scattering processes and parton shower algorithms to produce initial and final state parton radiation. Multiple soft and hard parton interactions are also simulated.

The PHOJET1.06a[10] model of photoproduction is also used in this analysis. This also uses leading order QCD matrix elements with matched parton showers and a phenomenological description of soft photoproduction processes.

The Lund string model, as implemented in JETSET 7.4[6], performs the hadronisation step for both of the above models.

The production of diquarks within the Lund string model is regulated by several parameters, the most important of which in the context of this work being the diquark suppression factor `PARJ(1)` which determines the probability of producing a $(qq, \bar{q}q)$ pair relative to a $(q, \bar{q})$ pair in the colour field. Results from e^+e^- collisions at LEP favour a value of approximately 0.1[11].

4 Results

The measurements are made in the laboratory frame of reference and are presented as the average cross-sections $E\frac{d^3\sigma}{d^3p}$ for the photoproduction of protons and antiprotons, that is, half the sum of the proton and anti-proton cross sections. Here E and p are the proton energy and momentum, respectively. This cross-section is shown as a function of the particle transverse momentum p_T and rapidity y , in figures 1 and 2, respectively. The errors shown are the quadratic sum of the statistical and systematic uncertainties. The systematic component is dominant. Furthermore, the systematic uncertainies are highly correlated.

Neither of the corrected distributions in figures 1 and 2 displays a large variation over the kinematic range studied, although the data suggest a slow fall-off towards higher transverse momentum values.

The predictions of the QCD-based model PYTHIA are presented using diquark suppression factors of 0.1 and 0.05. The model over-estimates the data with the e^+e^--derived value of 0.1 although it provides a fair description the shape of the spectra. However, a description of both shape and yield is provided if a diquark suppression value of 0.05 is used.

This could signal an absence of the fragmentation universality of baryon production within the currently used theoretical framework. However, more studies are required of different baryon species over a wider range of phase space range then covered in this work in order to investigate this.

There are several major sources of systematic uncertainty in these measurements.

- The uncertainty on the acceptance calculations arising from the forward and backward energy cuts and the cut on the observed multiplicity of charged tracks was determined using Monte Carlo simulations of the H1 detector response to different samples of PYTHIA and PHOJET-generated events, and was found to be about 8%.
- The correction due to the inefficiencies in the first level triggering of photoproduction events containing a proton was determined to an accuracy of 5%.
- The correction due to the acceptance of the low angle electron tagger also gives rise to a systematic error of 5%.

Corrections to the proton yield arising from nuclear interactions of inclusively produced hadrons with the material of the detector and beam pipe are evaluated from an analysis of the distributions of the impact parameters of candidate protons and anti-protons. The uncertainty on this background removal procedure accounts for a systematic error on the proton yields of less than 2%.

5 Summary

First measurements are presented of the cross-section of protons inclusively produced in the range $0.3 < p_T < 0.55$ GeV and $-0.3 < y < 0.3$ in photoproduction processes confined to the kinematic region $Q^2 < 0.01$ GeV^2 and $0.3 < y_e < 0.7$.

The particle cross-sections fall off slowly with increasing transverse momentum while they show very little dependence on rapidity.

The QCD-based model PYTHIA was confronted with the data and found to give a good description of the data if a value of the diquark suppression factor of approximately 0.05 was used.

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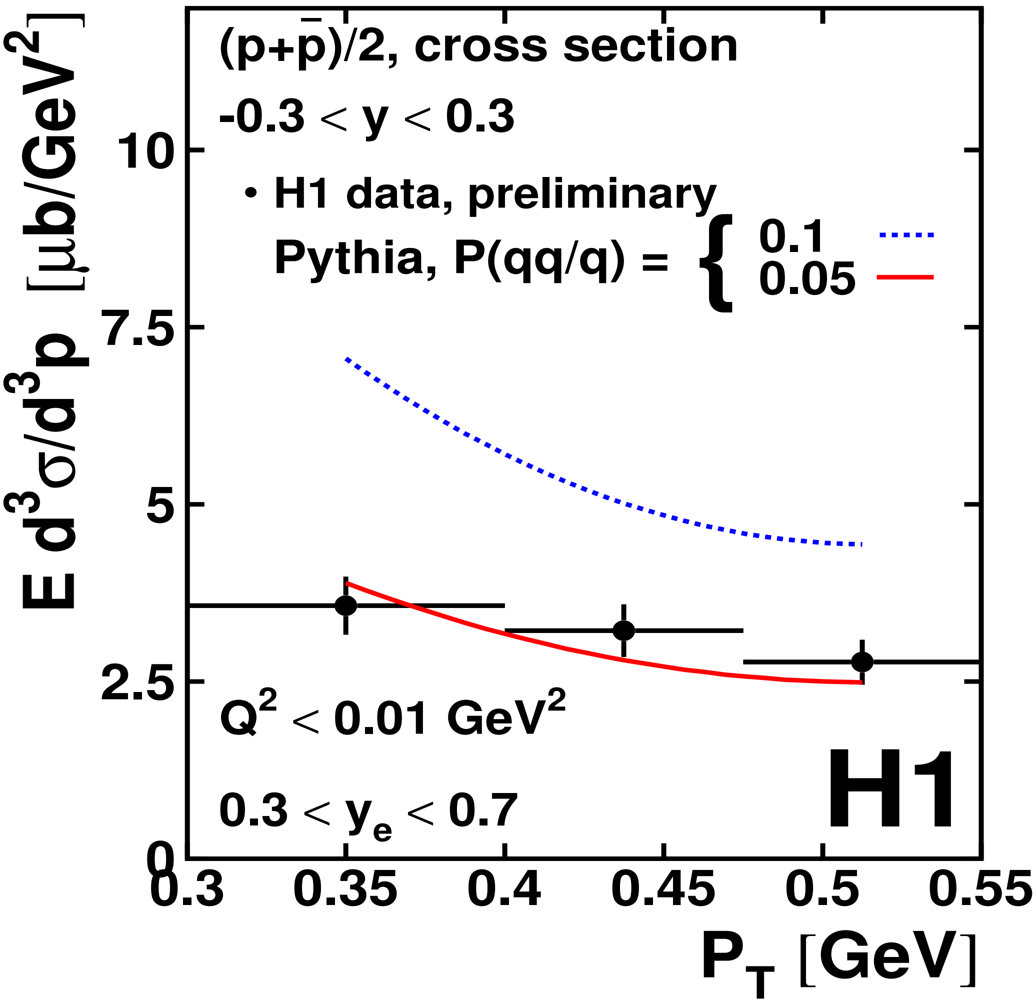

Figure 1: The measured cross-section $E\frac{d^3\sigma}{d^3p}$ as a function of transverse momentum, p_T, for rapidity values in the range $-0.3 < y < 0.3$. The cross-section represents half of the sum of protons and anti-protons inclusively produced in photoproduction interactions. Calculations of the PYTHIA model are shown with different values of the diquark suppression factor of 0.1 (upper curve) and 0.05 (lower curve).

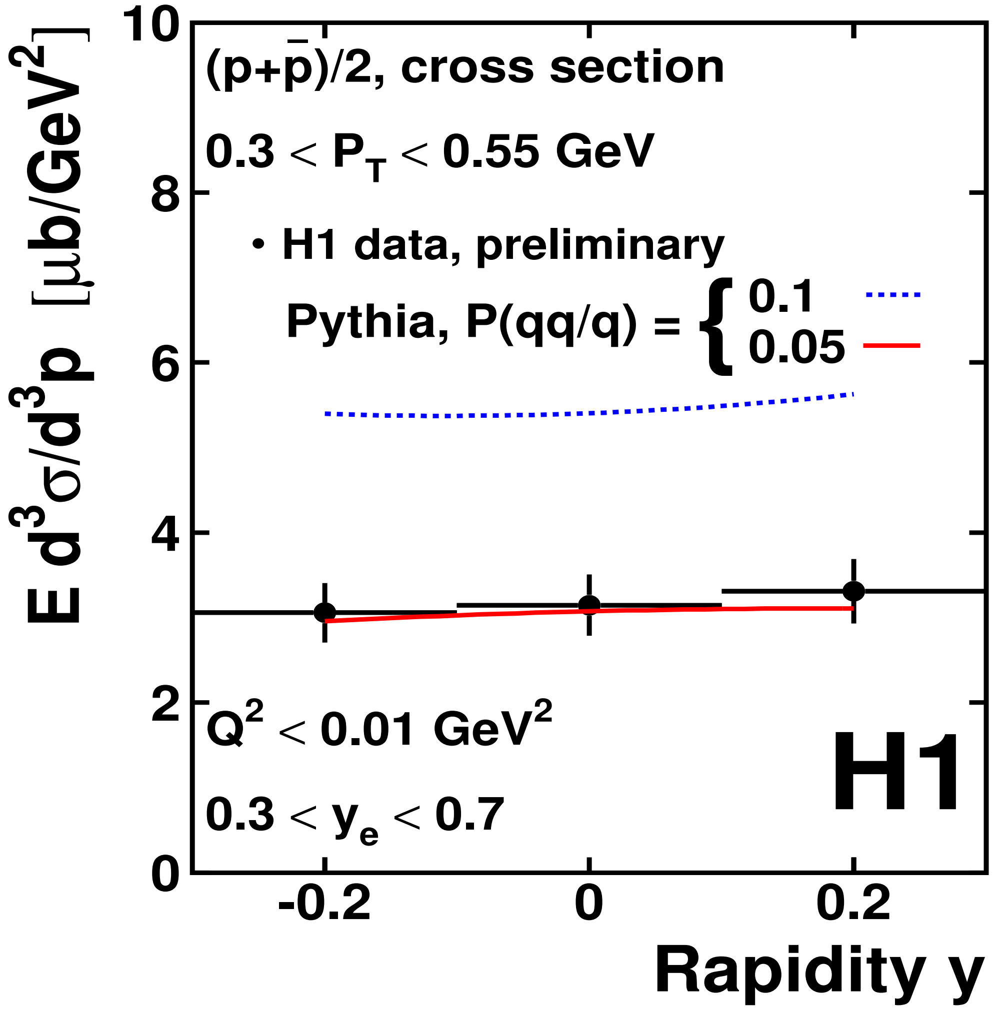

Figure 2: The measured cross-section $E\frac{d^3\sigma}{d^3p}$ as a function of rapidity, y, for values of transverse momentum in the range $0.3 < p_T < 0.55$ GeV. The cross-section represents half of the sum of protons and anti-protons inclusively produced in photoproduction interactions. Calculations of the PYTHIA model are shown with different values of the diquark suppression factor of 0.1 (upper curve) and 0.05 (lower curve).