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PARTICLE PRODUCTION AT HERA*

MYKHAILO LISOVYI

for the H1 and ZEUS collaborations

DESY, Notkestrasse 85, 22607 Hamburg, Germany

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Particle production has been studied in *ep* collisions with the H1 and ZEUS detectors at HERA. Charged particle spectra were measured in deep inelastic scattering. Predictions from Monte Carlo generators with different models of parton evolution were compared to the data. The production of the neutral strange hadrons $K^0_{\rm S}$ and Λ^0 was measured and was used to test various fragmentation models. Next-to-leading-order QCD calculations with fragmentation functions fitted to previous data as well as Monte Carlo generators were compared to the data. Spectroscopy of excited charm mesons with $L = 1$ was performed. In addition, fragmentation fractions of charm quarks hadronising into these states were extracted.

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1. Introduction

Various aspects of particle production have been studied in *ep* collisions at HERA. Transverse momentum spectra of charged particles were measured and were used to probe parton dynamics predicted by different models [1]. A measurement [2] of the scaled momentum distributions for $K^0_{\rm S}$ and Λ^0 hadrons[1] provides a stringent test of fragmentation models in the Monte Carlo generators and fragmentation functions (FF) fitted to other data. In addition, the $K^0_{\rm S}$ production was measured [3] at high photon virtuality, Q^2. The measurement allows the strangeness-suppression factor to be constrained. The production of excited charm mesons $D_1(2420)$ and $D^*_2(2460)$ was studied, improving a previous result from ZEUS. The measurements allow both perturbative and non-perturbative QCD effects to be tested.

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[1] Hereafter, the charge-conjugated modes are implied.

The kinematic variables used to describe ep scattering are the virtuality of the exchanged photon, Q^2, the Bjorken scaling variable, x, and the inelasticity y. The deep inelastic scattering (DIS) at HERA refers to the high-Q^2 region (in practice, $Q^2 > 1\,\mathrm{GeV}^2$).

2. Charged particle spectra

HERA experiments can access the small-x region, where one expects the parton dynamics to deviate from the DGLAP evolution. Earlier studies [5] suggested that transverse momentum spectra of charged particles should be more sensitive to the underlying parton dynamics than the inclusive structure-function F_2.

The recent measurement by H1 [1] was performed in the kinematic region $10^{-4} < x < 10^{-2}$ and $5 < Q^2 < 100\,\mathrm{GeV}^2$. The analysis was performed in the hadronic centre-of-mass frame (HCM), *i.e.* the virtual photon–proton rest frame. The charged particle densities as a function of pseudorapidity, η^*, and transverse momentum, p_{T}^*, in the HCM were defined as $(1/N)(dn/d\eta^*)$ and $(1/N)(dn/dp_{\mathrm{T}}^*)$, respectively. Here, dn is the number of charged particles with transverse momentum (pseudorapidity) in the dp_{T}^* ($d\eta^*$) bin, while N denotes the number of selected DIS events. The data are corrected to the number of stable charged particles including charged hyperions with mean proper lifetime $c\tau > 10\,\mathrm{mm}$. The integrated luminosity of the data used in the analysis was $88.6\,\mathrm{pb}^{-1}$.

At small transverse momenta, hadronisation is expected to contribute significantly to the charged particle densities, while the hard parton emissions are expected to play an important role in the high-p_{T}^* region [5]. Therefore, the measurement as a function of η^* was performed for $p_{\mathrm{T}}^* < 1\,\mathrm{GeV}$ and $1 < p_{\mathrm{T}}^* < 10\,\mathrm{GeV}$, to separate the regions predominantly affected by hadronisation and parton dynamics, respectively. Figure 1 shows a comparison of various tunes of hadronisation parameters in the RAPGAP Monte Carlo (MC) generator [6] to the measured charged particle spectra in the two bins in p_{T}^*. Significant sensitivity to the fragmentation tune is observed in the soft-p_{T}^* region, where the data prefer the ALEPH tune [7]. At large transverse momenta, all hadronisation tunes give similar results. Figure 2 shows a comparison of models with different approaches to QCD radiation to the measured charged particle spectra in the same bins in p_{T}^*. The charged particle density in the hard-p_{T}^* region exhibits a clear sensitivity to the modelling of QCD evolution in the parton-emission cascade. The colour-dipole model (CDM) used in the DJANGOH MC generator [8] provides the best description of the data in this region. In this model, the transverse momenta of the emitted partons are not ordered, producing a configuration similar to the BFKL parton evolution. DGLAP-based RAPGAP and Herwig++ [9] as well as CCFM-based Cascade [10, 11] MC generators fail to describe the measured charged particle density in the hard-p_T^* domain.

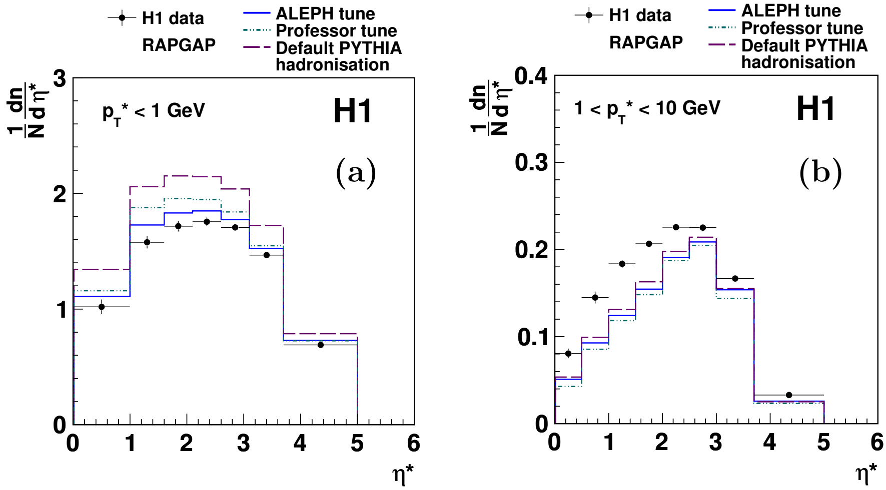

Fig. 1. Charged particle density as a function of η^* for (a) $p_T^* < 1\,\text{GeV}$ and (b) $1 < p_T^* < 10\,\text{GeV}$. Monte Carlo simulations with different sets of fragmentation parameters (lines) are compared to the data (dots).

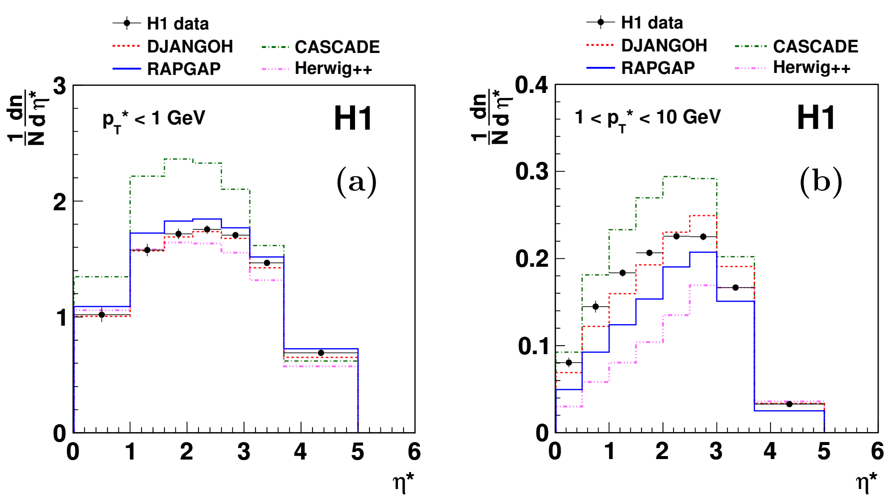

Fig. 2. Charged particle density as a function of η^* for (a) $p_T^* < 1\,\text{GeV}$ and (b) $1 < p_T^* < 10\,\text{GeV}$. Monte Carlo simulations with different modelling of parton showers (lines) are compared to the data (dots).

3. Strange particle production

3.1. Scaled momentum distributions for K^0_S and Λ^0 in DIS

The fragmentation process, through which coloured partons are bound in colourless hadrons, cannot be described in the framework of the perturbative QCD (pQCD). The most widely used approaches are the Lund string model [12] and the fragmentation functions (FFs). The former is used in Monte Carlo generators, while the latter are parametrisations that are fitted to data within the framework of leading-twist collinear QCD factorisation in a similar way as the parton density functions (PDFs) in the proton. The FFs for strange hadrons, such as K^0_S and Λ^0, are so far only poorly constrained.

A measurement of the scaled momentum distributions for neutral strange hadrons [2] was based on $330\,\mathrm{pb}^{-1}$ of data collected with the ZEUS detector. The analysis was done in the Breit frame, *i.e.* the frame in which

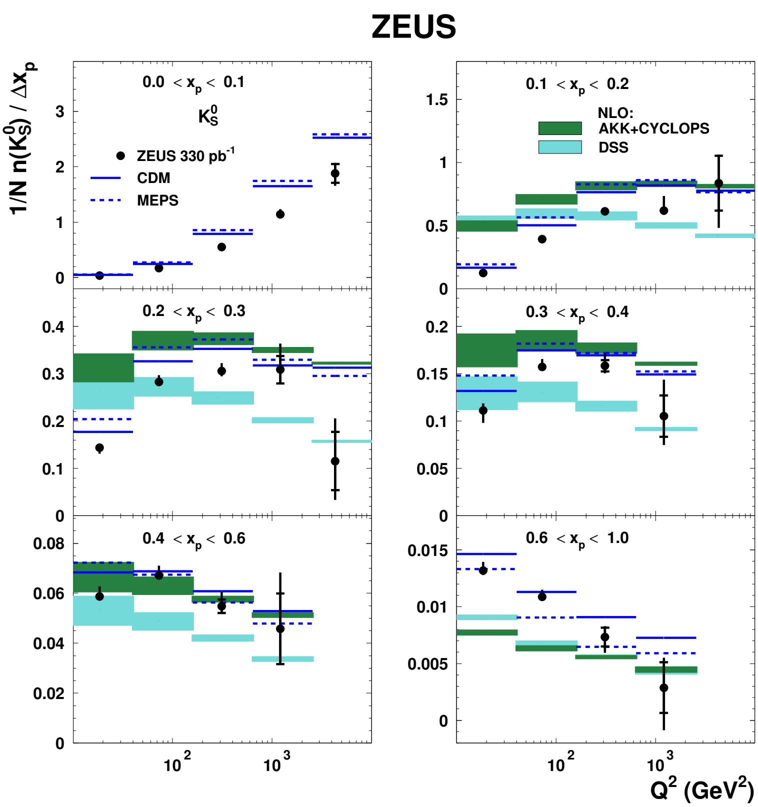

Fig. 3. The measured scaled momentum distributions for K^0_S and Λ^0 as a function of Q^2 in bins of x_P (dots). For comparison, the next-to-leading-order predictions (shaded bands) and MC simulations (lines) are also shown.

the exchanged virtual boson is purely space-like. The scaled momentum is defined as $x_P = 2P^{\rm Breit}/\sqrt{Q^2}$, where $P^{\rm Breit}$ is the strange-hadron momentum in the Breit frame. The kinematic region of the measurement was $10 < Q^2 < 40\,000\,{\rm GeV}^2$ and $10^{-3} < x < 0.75$.

The measured cross section as a function of Q^2 in bins of the scale momentum is shown in Fig. 3. The cross section was normalised to the DIS cross section in a given bin in Q^2. Clear scaling violation is observed in the data. Both next-to-leading-order QCD predictions fail to describe the data. Thus, the data presented in [2] will help to further constrain the FFs, in particular, at low x_P. Similar conclusions were drawn from the Λ^0 data.

3.2. $K^0_{\rm S}$ production at high Q^2

$K^0_{\rm S}$ production cross sections were measured at high Q^2 with the H1 detector [3]. The results allow constraining the suppression of the $s\bar{s}$ pair production relative to the $u\bar{u}$ and $d\bar{d}$ pair production in fragmentation, which is parametrised in the MC simulations by the strangeness-suppression factor, $\lambda_{\rm s}$. The analysis was performed in the kinematic region $145 < Q^2 < 20\,000\,{\rm GeV}^2$, $0.2 < y < 0.6$, $p_{\rm T} > 0.3\,{\rm GeV}$ and $\eta < 1.5$.

The measured differential ratios of the $K^0_{\rm S}$ cross section to the charged particle production in the same phase space are shown in Fig. 4. The ratio is consistent with a constant in Q^2 and rise significantly with $p_{\rm T}$ owing to the mass effects. The measured distributions agree with the predictions based on $\lambda_{\rm s} = 0.286$.

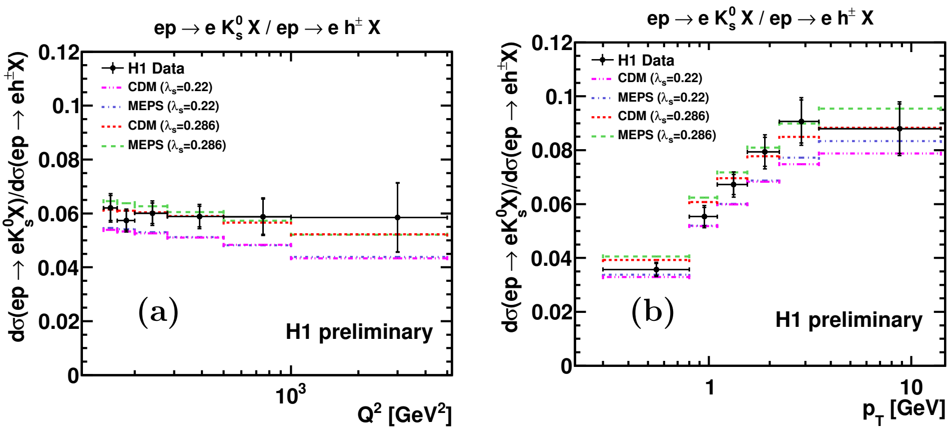

Fig. 4. The measured ratios of the $K^0_{\rm S}$ cross section to the charged particle production cross sections as a function of (a) Q^2 and (b) $p_{\rm T}$. The data (dots) are compared to different MC models with two values of $\lambda_{\rm s}$.

4. Excited D mesons

The ZEUS Collaboration has reported [4] a detailed study of the neutral and charged excited charm mesons $D_1^{\pm,0}(2420)$ and $D_2^{*\pm,0}(2460)$. For the neutral states, both the masses and the widths were measured, while for the charged states only the masses were determined. The results were found to be in agreement with earlier measurements. The measured D_1^0 helicity parameter was found to be in agreement with previous measurements and to allow an S- and D-wave mixing as well as a pure D-wave in the decay $D_1^0 \to D^{*+}\pi^-$. In addition, branching ratios and charm fragmentation fractions for the studied charm mesons were determined. The fragmentation fractions for the charged states were measured for the first time: $f(c \to D_1^+) = 4.6 \pm 1.8(\mathrm{stat.})^{+2.0}_{-0.3}(\mathrm{syst.})\%$, $f(c \to D_2^{*+}) = 3.2 \pm 0.8(\mathrm{stat.})^{+0.5}_{-0.2}(\mathrm{syst.})\%$.

5. Conclusions

Different aspects of particle production in ep collisions have been studied with the ZEUS and H1 detectors at HERA. The BFKL-like colour-dipole model of the parton evolution provides the best description of the transverse momentum spectra of charged particles at low Bjorken x. The K_S^0 and Λ^0 scaled momentum distributions provide additional constrains on the fragmentation functions, while strange-meson production at high Q^2 provides sensitivity to the strangeness-suppression factor, λ_s. Parameters of the neutral and charged orbitally-excited charm mesons were measured and were found to be in agreement with earlier measurements.

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