Strangeness Production in DIS at HERA

Grażyna Nowak *
for the H1 Collaboration

Henryk Niewodniczański Institute of Nuclear Physics PAN
ul. Radzikowskiego 152, 31-342 Kraków, Poland
e-mail: grazyna.nowakifj.edu.pl

The production of neutral strange hadrons has been studied in deep inelastic ep processes at low Q^2 at HERA using events measured with the H1 detector. The production cross sections and ratios of the K_s^0, $\Lambda(\bar{\Lambda})$ and charged hadrons $h^\pm$ are measured as a function of DIS variables and of final state particle variables both in the laboratory and in the Breit frame. The measurement of the $\Lambda - \bar{\Lambda}$ asymmetry is found to be consistent with zero. The data are compared to predictions of leading order Monte Carlo models.

1 Introduction

In deep-inelastic scattering (DIS) particles with strangeness can be produced in the hard subprocesses directly from a strange quark s from the nucleon sea or from boson-gluon fusion processes. However, the largest contribution to strange quark production is due to the non-perturbative colour field fragmentation process. Precise knowledge about the suppression of strange quark-pair creation relative to lighter flavours is important for phenomenological models required for the description of quark fragmentation.

The presented studies [1, 2] are performed in the laboratory and in the Breit frame. For comparison theoretical predictions obtained from the DJANGOH program [3] either with the parton shower approach as implemented in LEPTO [4] (referred to as MEPS) or with the so-called color dipole model approach available within ARIADNE [5] (referred to as CDM [6]) are used. The hadronisation process is modelled according to the LUND string model as implemented in the JETSET [7] program. The strangeness suppression is described by the parameter λ_s defined as the ratio of the probabilities of producing an $(s\bar{s})$-pair to that of producing a $(u\bar{u})$- or $(d\bar{d})$-pair during the fragmentation process. For the description of strange baryon production two more parameters, λ_{qq} and λ_{sq}, describing the suppression of light diquark and strange diquark pair production are important. For model comparisons values $\lambda_{qq} = 0.108$ and $\lambda_{sq} = 0.690$ tuned to hadron production in e^+e^- collisions are taken [8].

2 Event and Hadron Selection

The data used in this analysis were taken in the 1999 and 2000 running periods, in which HERA collided 920 GeV protons with 27.6 GeV positrons, corresponding to an integrated luminosity of 49.9 pb^{-1}. The kinematic range is defined by the negative four-momentum transfer squared Q^2 and the inelasticity y: $2 < Q^2 < 100$ GeV^2, $0.1 < y < 0.6$. The K_s^0 meson and Λ baryon states[a] are measured by the kinematic reconstruction of their decays

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[a]Unless explicitly mentioned, a reference to a state implicitly includes the charge conjugate of that state.

$K_s^0 \to \pi^+\pi^-$ and $\Lambda \to p\pi^-$. The $\Lambda(\bar{\Lambda})$ are tagged by the electrical charge of the decay proton (antiproton). The transverse momentum and the pseudorapidity of the $K_s^0(\Lambda)$ particles are required to satisfy $0.5 < p_T < 3.5$ GeV and $|\eta| < 1.3$. The charged hadrons $h^\pm$ used for the ratio $R(K_s^0/h^\pm)$ are selected in the same kinematic region as the strange particles.

3 Results

Production cross sections and ratios of K_s^0, Λ and charged hadrons $h^\pm$ are measured differentially in the event variables Q^2 and Bjorken x and as a function of the particle variables p_T and η in the laboratory frame and of the variables x_p^{Breit} and p_T^{Breit} defined in the Breit frame. In the Breit frame the virtual space-like photon has momentum Q but no energy. The photon direction defines the negative z-axis with proton moving in the $+z$ direction. The current (target) hemisphere is defined by $p_z^{Breit} < 0$ ($p_z^{Breit} > 0$). Within the quark parton model (QPM) the struck quark only populates the current hemisphere which is less sensitive to non-perturbative contributions. The variable x_p^{Breit} is defined as equal to $2|\vec{p}|/Q$, where $\vec{p}$ is the momentum of the particle in the Breit frame.

3.1 K_s^0 Production Cross Sections

The measured differential cross sections of K_s^0 production as a function of x, p_T and η are shown in Fig. 1 and compared to the predictions of the LO Monte Carlos with two values of the strangeness suppression factor $\lambda_s = 0.3$ and $\lambda_s = 0.22$. The data are reasonable well described by the CDM model with $\lambda_s = 0.3$ while for the MEPS model a lower value of $\lambda_s = 0.22$ gives a better description. Both models have difficulties describing the low x region, the shape of the η distribution and the low p_T region.

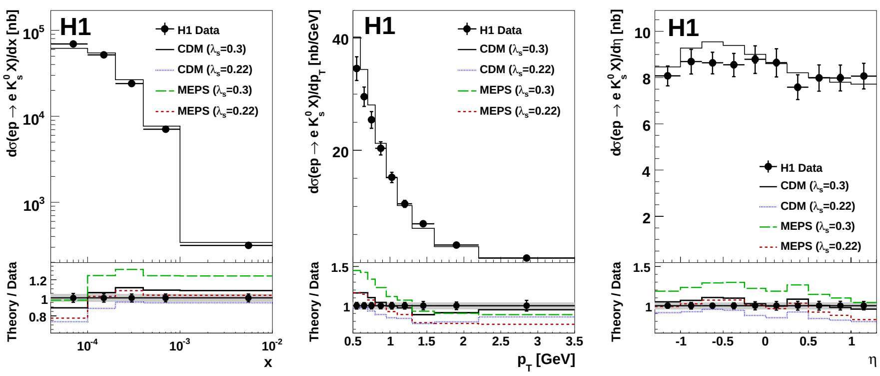

Figure 1: The differential production cross sections for K_s^0 mesons in the laboratory frame as a function of the Bjorken variable x, the K_s^0 transverse momentum p_T and the K_s^0 pseudorapidity η. The inner (outer) error bars show the statistical (total) errors. On the bottom of each figure, the “Theory/Data” ratios are shown for different LO Monte Carlo predictions (see text). For comparison, the data points are put to one and only uncorrelated errors are shown; the correlated systematic errors are indicated by the grey band.

The cross sections measured as a function of x_p^{Breit} and p_T^{Breit} both in the target and current region are in general described by both the MEPS and CDM model predictions.

However, in the current hemisphere, as presented in Fig. 2 the sensitivity to λ_s is reduced with respect to the target region or the laboratory frame. This is due to both large errors and an increased contribution of strangeness produced in hard sub-processes in comparison to the target hemisphere.

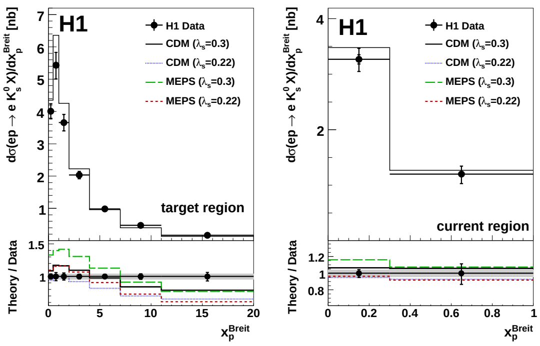

Figure 2: The differential K_s^0 production cross sections in the Breit frame as a function of K_s^0 momentum fraction x_p^{Breit} in the current (right) and target (left) hemisphere. More details in the caption of Fig. 1.

3.2 Λ Production Cross Sections

The measured differential cross sections of Λ production as a function of x, p_T and η are shown in Fig. 3 and compared to the predictions of LO Monte Carlos with two values of the strangeness suppression factor $\lambda_s = 0.3$ and $\lambda_s = 0.22$. In contrast to K_s^0 production the Λ distributions are well described by both CDM and MEPS models with the same value of $\lambda_s = 0.3$. However, the difficulties in describing the low x region, the shape of η and low p_T region remain as in the K_s^0 case. It should be noted that Λ production depends not only on λ_s parameter but also on parameters describing diquark and strange diquark suppression during fragmentation which were not varied in the simulations. In the Breit frame a similar behaviour of the measured cross sections as for K_s^0 data is observed.

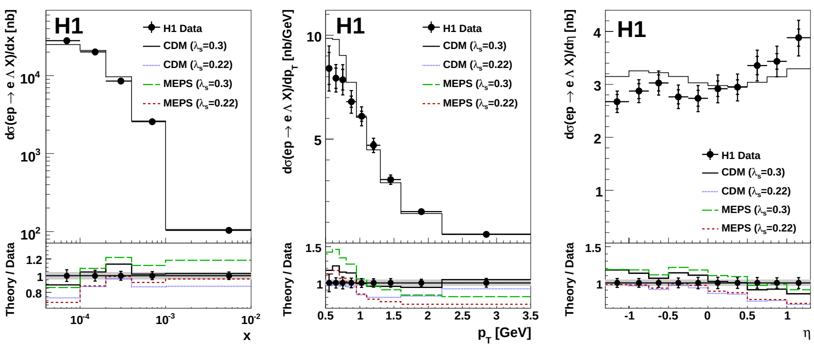

Figure 3: The differential production cross sections for Λ baryons in the laboratory frame as a function of the Bjorken variable x, Λ transverse momentum p_T and Λ pseudorapidity η.

A measurement of the asymmetry in the production of Λ with respect to $\bar{\Lambda}$ allows to test if the baryon number of the initial state proton is transferred to the strange particles in the final state. The measured asymmetry both in the laboratory and in the Breit frame is found to be consistent with zero thus not supporting the hypothesis of baryon number transfer.

3.3 Ratios of Production Cross Sections

Different aspects of strangeness production within the fragmentation models can be tested by studying the ratios of production rates of Λ to K_s^0 and of K_s^0 to charged hadrons $h^{\pm}$ as some model dependencies are expected to cancel.

The measurements of the ratio of the differential cross sections for Λ baryons and K_s^0 mesons in the laboratory frame as a function of Q^2 and η are shown in Fig. 4. The CDM model describes the data at low Q^2 but systematic deviations are seen at high Q^2. Also the shape of the η dependence of the ratio can not be described by the model. The MEPS predictions lie below the data.

In the Breit frame, both models (CDM, MEPS) predictions describe reasonably the p_T^{Breit} and x_p^{Breit} spectra, both in the target and current hemispheres.

As expected, the model predictions for the ratios of two strange particles show no dependence on λ_s.

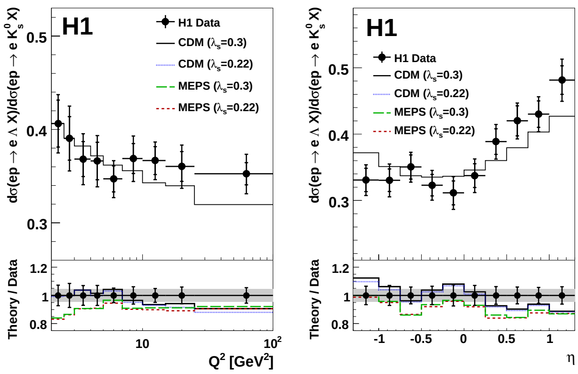

Figure 4: The ratio of the differential production cross sections for baryons and mesons in the laboratory frame as a function of the photon virtuality Q^2, and the pseudorapidity η of the final state particles. More details in the caption of Fig. 1.

The sensitivity of the data to λ_s can be enhanced by studying a ratio of strange mesons to charged hadrons. The ratio should not depend on the modelling of the partonic final states, in particular on the choice of the proton structure function. The ratio as a function of Q^2, p_T and η is shown in Fig. 5 together with the CDM and MEPS model predictions each given for two values of λ_s =0.3 and λ_s =0.22. The shapes of the ratios are reasonably well decribed by both models. However, there is a difference in the normalisation between the two models. The MEPS model with a value of λ_s =0.22 describes the data reasonably well over the full phase space. The CDM predictions with λ_s =0.3 describes the data better at low Q^2, whereas at high Q^2 a value of λ_s =0.22 is preferred. The same behaviour was observed by ZEUS [9]. Both models have difficulties to describe the data at large positive η values and the shape of p_T distribution.

4 Conclusions

Differential cross sections for the production of K_s^0 mesons, Λ baryons and their ratio as well as the ratio of K_s^0 to charged hadrons $h^{\pm}$ are measured as a function of various kinematic variables, both in the laboratory frame and in the Breit frame. The measurement is performed in the visible kinematic range defined by $2 < Q^2 < 100$ GeV^2, 0.1< y <0.6,

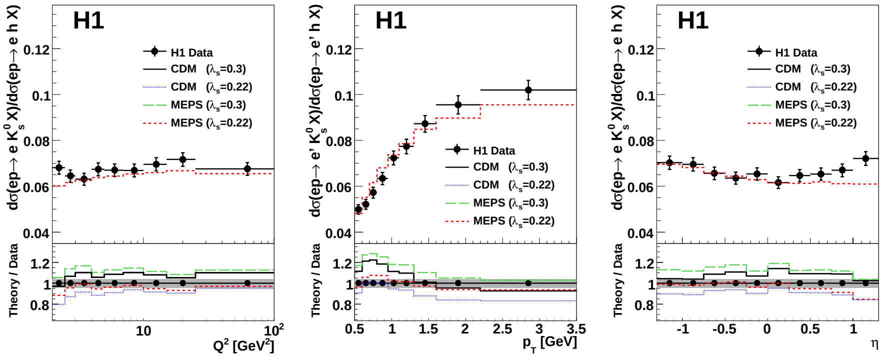

Figure 5: The ratio of the differential production cross sections for K_s^0 mesons and charged hadrons in the laboratory frame as a function of the Bjorken x, the transverse momentum p_T and the pseudorapidity η of the final state particles. More details in the caption of Fig. 1.

0.5< $p_T(K_s^0, \Lambda, h^{\pm})$ <3.5 GeV and $|\eta(K_s^0, \Lambda, h^{\pm})|$ <1.3. The results are compared with predictions of Monte Carlo programs, based on leading order matrix elements with parton shower simulations. The overall features of the various differential distributions are reproduced by CDM predictions with the strangeness suppression factor $\lambda_s = 0.3$. However, no single combination of model and λ_s describes the distributions over the full measured region, in particular in the low p_T, low x and large positive η region. The measured cross sections in the Breit frame are reasonably described by both CDM and MEPS predictions.

The ratio of cross sections for Λ baryons to K_s^0 mesons is well decribed by the CDM predictions with $\lambda_s = 0.3$, whereas for the ratio of cross sections for K_s^0 mesons to charged hadrons the MEPS predictions with a lower value of $\lambda_s = 0.22$ are in better agreement with the data.

The measured asymmetry in the production of Λ relative to $\bar{\Lambda}$ baryons in the laboratory and in the Breit frame is compatible with zero, thus not supporting the hypothesis of baryon number transfer.

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